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IPCC Address (1989) [1]

Stack:	Row:	Section:	Shelf:	Position:
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(Lange/Cawley)
February 4, 1989
11:15 A.M.
[IPCC.DOC]

PRESIDENTIAL ADDRESS: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
GEORGETOWN UNIVERSITY
MONDAY, FEBRUARY 5, 1990
10:15 A.M.

Thank you, Dr. Bolin [Bo-leen]. Professor Obasi. Dr. Tolba. Delegates of the World Meteorological Organization, and the United Nations Environment Program. Let me commend **all** of you, for coming together to examine an issue of such great importance. The recommendations this distinguished organization makes ^{can} ~~will~~ have a profound effect on the world's environmental and economic policy.

By being here today, I hope to underscore concern -- my country's, and my own -- about environmental stewardship; and to reaffirm our commitment to finding responsible solutions. It is both an honor and a pleasure to be the first American President to speak to this organization, as its work takes shape.

difficult yet a critical moment
You are called upon to develop recommendations which strike ~~an~~ international bargain: a convergence between global ^{a bargain} environmental policy, and global economic policy, where **both** perspectives benefit -- and **neither** is compromised.

as experts
You understand that economic growth and environmental integrity are **not** contradictory priorities. One reinforces and complements the other. Each ^{a partner} ~~enables and empowers the other.~~

A sound environment is the basis for the continuity and quality of human life and enterprise. ^{clearly the path} ~~And~~ strong economies allow

nations to fulfill the obligations of environmental stewardship.

Where there is economic strength, such ^{protection} ~~stewardship~~ is possible.

But where there is poverty, ^{the competition for resources gets tougher} it all too often fails to coalesce ~~consensus~~.

^{all these} For ~~that~~ reason, I sincerely believe we must do everything in our power to promote global cooperation ⁱ ~~for~~ environmental protection **and** economic growth; For intelligent management of our natural resources and efficient use of our industrial capacity; And above all, for **sustainable** and **environmentally sensitive** development -- around the world.

The United States is strongly committed to the I.P.C.C. process of international cooperation on global climate change.

We consider it vital, that the community of nations be drawn together -- in an ^{orderly, disciplined} ~~ordered~~, rational way -- to ^{renew celebration of our global environment} ~~assess~~ the potential for climate change, and develop ^{future} ~~appropriate~~ ^{to} ~~valid~~, ^{effective} ~~reasonable responses~~ ^{programs}.

The state of the science; the social and economic impacts; ^{appropriate} ~~right~~ response strategies -- All are crucial components to a global resolution. **The stakes here are very high; the consequences, very significant.**

Last week, in my State of the Union address, I spoke of stewardship: because I believe it's something we owe ourselves, our children and their children.

^{In our} Thus the United States remains committed to aggressive and thoughtful action on environmental issues. In our domestic programs. ^{In} Our work to forge international agreements. Our

assistance to developing and East Bloc nations. And here, by chairing the Response Strategies Working Group.

I have just submitted a budget to our Congress for fiscal 1991. It includes over \$2 billion in new spending to protect the environment. And, ^{understanding} ~~with direct application to the issues at hand~~ ^{supporting our commitment to your efforts here} here, I am pleased to note that funding for the U.S. Global Change Research Program will increase by nearly 60 percent, to over \$1 billion ^{dollars.}

That commitment, by far the largest by any nation ever, will ^{allow her sister agencies and my international partners} allow NASA to move forward with ~~its~~ ^{the} "Mission to Planet Earth," ^{that program} ~~together with our international partners, and~~ will initiate the U.S. Earth Observing System, in cooperation with Europe and Japan, to advance the state of knowledge about the planet we share.

^{Furthermore} The United States ^{is not waiting for the results of this research} ~~has~~ ^{We have} already taken many steps in our country that bring **major benefits in their own right.** Steps that make sense on their own merits in terms of ^{responsibility} ~~prudence~~ and efficiency, which help reduce emissions of carbon dioxide and ^{CFCS} ~~other gases~~ ^{pollutants} ~~now building up in~~ ^{entering} the atmosphere. **Let me outline them very briefly:**

We want to increase the **efficiency** of our energy use, and thus reduce total emissions. ^{TP} ~~So we're~~ ^{We are} pursuing new **technology development.** ^{that will}

We're crafting a revised **Clean Air Act** with incentives for industry to find creative, market-driven solutions to enhance air quality.

We've launched a major **reforestation initiative** to plant a **billion** trees a year on private land across America.

And we're working out a comprehensive review and revision of our **National Energy Strategy**, with initiatives to increase energy efficiency and the use of renewable sources. These initiatives, *are part of the heart of a \$336 million Dept. of Energy program and* already underway, ~~will cost our Department of Energy \$336 million over the next six years, but~~ are expected to produce energy savings through the year 2000 of over **\$30 billion** -- while achieving significant pollution reduction. Quite a return on investment.

We're also working through diplomatic channels with our colleagues in other countries, and through innovative measures like debt-for-nature swaps, to do more than simply reduce global deforestation. **We hope to reverse it** -- not unilaterally, but by working with our international neighbors.

The **economics** of our response strategies to climate change are getting intensive study in America. We are developing real data on the costs of various ~~response~~ strategies, assessing new measures, and encouraging other nations to follow suit. And we look forward to sharing this knowledge and technical support with our international colleagues.

As we work to create **policy** *and agreements on action* on CFCs, CO2 and other *effective approaches* emissions, we want to encourage the most innovative *responses*. Wherever possible, we believe that market mechanisms should be applied -- and that *our* policy *ies* must be consistent with economic growth and free market principles in **all** countries. Our

development efforts and our dialogue can help us reach effective and acceptable solutions.

Last December at Malta, in my meeting with President Gorbachev, I proposed that the United States offer a venue for the first negotiating session for a framework convention, once the I.P.C.C. completes its work. I reiterate that invitation here, and look forward to your cooperation in that agenda.

~~But~~ ^{But} much remains to be done. Many questions remain to be answered. ^{ful} We have a responsibility to ourselves and the generations to come to do it right. We all know that human activities are changing the atmosphere in unexpected and unprecedented ways. But we must develop solutions that can fulfill our stewardship responsibilities **and** maintain our capacity to extend a beneficial quality of life to those who have not yet seen the benefits of their emerging economies.

We acknowledge a broad spectrum of views on these issues, but our respect for a diversity of perspective ^s does not diminish our recognition of our obligation -- or soften our will to produce policies that **work**.

So the United States continues ^{its efforts} ~~to work~~ to improve our understanding of climate change -- to seek hard data and new ways to improve the science, and determine how best to meet these challenges. Where politics and opinion have ^{outpaced} ~~moved~~ faster than ^{technology} ~~science~~ the science, we are accelerating our support of the ~~science~~ to bridge that gap.

Therefore, this spring, the United States will host a White House conference on science and economic research on the environment -- convening top officials from a representative group of nations, to bring together the three essential disciplines: science, economics, and ecology. They will share their knowledge, assumptions, and state-of-the-art research models, to outline our understanding and help focus our efforts. I look forward to participating in this seminar, and to learning from its deliberations.

Our goal continues to be matching policy^{commensurate} to emerging scientific knowledge -- and a reconciling of environmental protection to the continued benefits of economic development. And as Secretary Baker observed a year ago, **whatever** global solutions to climate change are considered, they should be as specific and as cost-effective as they can possibly be.

If we hope to promote environmental protection **and** economic growth around the world, it will be important ^{not to work in conflict but with} to work with, not ^{will} ~~against~~ our industrial sector. That ^s means moving beyond the ^{practice} tradition of command, control, and compliance -- toward a new kind of environmental cooperation -- and toward an emphasis on pollution **prevention**, rather than mere mitigation and litigation.

Many of our industries, in fact, are already providing crucial research and solutions. And a few are already ahead of us.

One corporation, for example, started an in-house program called Pollution Prevention Pays, that has saved the company well

over half a **billion** dollars since 1975 -- and prevented 112,000 tons of air pollutants, 15,000 tons of water pollutants, and almost 400,000 tons of sludge and solid waste from being released into the environment. ~~And~~ ^{they} they've done it by rewarding employees for coming up with the ideas. ^{They}

Where developing nations are concerned, some ^{argue} suggest we'll have to abandon ^{the} free-market principles ^{of} that allowed ~~the~~ ^{prosperous economies} the industrial world to prosper. In fact, we think it's all the more crucial, in the developing countries, to harness the ^{incentives of the} free enterprise system in the **service** of the environment.

I believe we should make use of what we know. We know that the future of the earth **cannot** be compromised. We bear a sacred trust in our tenancy here -- and a covenant with those most precious to us: our children, and theirs. We also know of the efficiency of economic incentive -- and that free markets yield the most creative solutions. We must now apply the wisdom of ^{the} ~~the~~ ^{that} market, in ^{the power of these forces} **defense** of the environment we ^{cherish} ~~share~~.

Working together, with good faith and earnest dialogue, I believe we can reconcile economic ^{vitality} ~~growth~~ with environmental protection. Let me commend you on your outstanding work -- and wish you all deliberate speed in your efforts to address a very difficult, but very important, human concern.

Thank you -- and God bless you.

WATKINS/CARD

Lange/Cawley)

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the United Nations Environment Program. Let me commend all of

you, for *coming together to examine* an issue of such great importance. The

recommendations this distinguished organization makes will have a

profound effect on the world's environmental and economic policy.

By being here today, I hope to underscore concern-- my

country's, and my own *responsible* about environmental stewardship; and to

reaffirm our commitment to finding solutions. It is both an

honor and a pleasure to be the first American President to speak

to this organization, as its work takes shape, and the right response

You are called upon to *to develop recommendations which* strike an *necessary* unprecedented international

bargain: a convergence between global environmental policy, and

global economic policy, where both *perspectives* sides benefit-- and neither

is compromised. actions we take now *understand, deep inside,*

You understand that economic growth and environmental

integrity are not contradictory priorities. One reinforces and

complements the other. *Each* enables and empowers the other.

A sound environment is the basis for the continuity and grandchildren

quality of human life and enterprise. And strong economies allow

nations to fulfill the obligations of environmental stewardship.

Where there is economic strength, such stewardship is ~~considered~~ ^{possible} ~~often a~~ ^{possibility}. But where there is poverty, it is ~~too often a~~ ^{all too often a} ~~luxury~~ ^{consensus} ~~of our~~ ^{of our} ~~industrial and natural resources~~ ^{industrial and natural resources}. Above all, for sustainable ~~development~~ ^{sensitive} -- around the world.

The United States is strongly committed to the I.P.C.C. process of international cooperation on global climate change. We consider it vital that the community of nations be drawn together -- in an ordered, rational way -- to assess the ~~potential for climate change~~ ^{valid}, and develop appropriate, ~~reasoned~~ ^{reasoned} responses.

The state of the science; the social and economic impacts; and the right response strategies -- all are crucial components to a global resolution. The stakes here are very high, ~~very significant~~ ^{the consequences}. With every word, with every decision made, we're also making a commitment that is profoundly personal. I think all of us understand, deep inside, how the actions we take now speak to the future.

Last week, in my State of the Union address, I ~~talked~~ ^{spoke} of stewardship: because I believe it's something we owe ourselves, our children and ~~grandchildren~~ ^{their}. Because the earth we stand upon is only borrowed, never owned.

Thus
 So the United States remains committed to aggressive and thoughtful action on environmental issues. In our domestic programs. Our work to forge international agreements. Our assistance to developing and East Bloc nations. And here, by *Chairing* leading the Response Strategies Working Group.

have submitted
 I just ~~proposed~~ a budget to our Congress for fiscal 1991. *over* It includes *with* \$2 billion in new spending to protect the environment. *And with direct application to the issues at hand here, I am pleased to note that* Funding for the U.S. Global Change Research Program will increase by nearly 60 percent, to over \$1 billion.

commitment, by far the largest by any nation ever,
 That will allow NASA to move forward with its "Mission to Planet Earth," together with our international partners, *And we will* And we will initiate the U.S. Earth Observing System, in cooperation with Europe and Japan, to advance the state of knowledge about the planet we share.

The United States has
 We've already taken many steps in our country that bring major benefits in their own right. Steps that make sense on *in terms of prudence and efficiency which* their own merits, ~~and that will~~ also help reduce emissions of carbon dioxide and other gases now building up in the atmosphere.

Let me outline them very briefly:

We want to increase the efficiency of our energy use, and thus reduce total emissions. So we're pursuing new technology development. *TP* We're *crafting* creating a revised Clean Air Act with incentives for industry to find creative, market-driven *to enhance our quality* solutions. We've launched a major reforestation initiative to plant a billion trees a year on private land across America. *TP* And we're working out a comprehensive review and revision of our

energy efficiency and the use of renewable sources. completes its work.

These initiatives, already underway, will cost our Department of Energy \$336 million over the next six years, but ~~are expected~~ ^{will} produce energy savings through the year 2000 of over \$32 billion -- while achieving significant pollution reduction. Quite a return on investment.

We're also working through diplomatic channels with our colleagues in other countries, and through innovative measures like debt-for-nature swaps, to do more than simply reduce global deforestation. We hope to reverse it -- not unilaterally, but by working with our international neighbors.

The economics of our response strategies to climate change are getting intensive study in America. We are developing real data on the costs of various response strategies, assessing new measures, and encouraging other nations to follow suit. And we look forward to sharing ^{this knowledge and} technical support with our international colleagues.

As we work to create policy on CFC's, CO2 and other emissions, we want to encourage the most innovative responses. Wherever possible, we believe that market mechanisms should be applied -- and that policy must be consistent with economic growth and free market principles in all countries. ^{Our development efforts and} Dialogue can help us reach effective and acceptable solutions. ^{three essential disciplines}

^{Last December at Manila,} That is why, in my meeting with President Gorbachev, I proposed that the United States offer a venue for the first

the G.P.C.C. negotiating session for a framework convention, once the I.P.C.C. and a co-

completes its work. I reiterate that invitation here and look forward to your cooperation in that agenda. *participating in this seminar*

But much remains to be done. Many questions remain to be answered. We have a responsibility to ourselves and the generations to come to do it right. We all know that human activities are changing the atmosphere in unexpected and unprecedented ways. *But we are not*

yet prepared -- academically, or otherwise -- to draw *fulfill on the* conclusions. *standing responsibilities and maintain our capacity*

to extend a beneficent quality of life to those who have not yet seen the *benefits of these* Those who question the likelihood of climate change if the *underlying*

world continues on its current path represent one distinct *are at one end of the spectrum.*

minority. *P* We acknowledge a broad spectrum of views on these issues but our *respect for a*

threat to mankind represent another. *we are at the other.* And many scientists are *diversity of perspectives does not diminish our recognition of our obligation to protect our*

uncomfortable claiming [with absolute certainty] that global *will to protect*

climate change can now be detected -- or predicted. *In some quarters, politics or emotion may be outstripping science.* *and driving policy.*

So the United States continues to work to improve our understanding of climate change -- to seek hard data and new ways

to improve the science. *and further determine how best to meet those* *challenges*

confidence, policy makers can't use. And what policy makers need

to make decisions, *And* science doesn't yet conclusively know. *which are*

Where politics and opinion have moved faster than the science we need *accelerating our* *support of the* *needed to* *bridge the* *gaps.*

the United States will host a White House *conference* *A* Seminar on Science and

Economic Research on the Environment -- convening top officials

from a representative group of nations, to bring together the

three essential disciplines: science, economics, and ecology.

They will share their knowledge, assumptions, and state-of-the-art research models, to outline the gaps in our understanding and

** The things policy-makers need to make sound decisions.*

and help focus on efforts

forward to chart a course toward a common understanding. I look forward to participating in this seminar, and to learning from its deliberations, we've done it by pouring ~~into~~ the environment. And

While some suggest we should make significant policy now, on the chance that real climate change becomes certain, others point to the opposite edge of that sword: that any meaningful preemptive policies would bring only the certainty of prohibitive expense; conflict with Third World development; and declining standards of living, worldwide.

Our goal continues to be a matching
I believe we can do better. We must seek a reasoned middle ground, that matches policy to emerging scientific knowledge -- and reconciles environmental protection to economic development.

And as Secretary Baker observed a year ago, whatever global solutions to climate change are considered, they should be as specific and as cost-effective as they can possibly be.

If we hope to promote environmental protection and economic growth around the world, it will be important to work with, not *our industrial sector's* against *industry*. That *will* mean moving beyond the tradition of command, control, and compliance -- toward a new kind of environmental cooperation -- and toward an emphasis on pollution prevention, rather than mere mitigation and litigation.

four Many industries, in fact, are already providing crucial research and solutions. And a few are already ahead of us.

One corporation, for example, started an in-house program called Pollution Prevention Pays, that has saved the company well over half a billion dollars since 1975 -- and prevented 112,000

tons of air pollutants, 15,000 tons of water pollutants, and almost 400,000 tons of sludge and solid waste from being released into the environment. And they've done it by rewarding employees for coming up with the ideas.

Where developing nations are concerned, some suggest we'll have to abandon the ~~laissez-faire~~ free-market principles that allowed the industrial world to prosper. In fact, we think it's all the more crucial, in the developing countries, to harness the free enterprise system in the service of the environment.

To the extent we can accelerate the advancement of these nations, ~~it will take less energy for them to produce wealth~~ ^{we can help them use} ~~modern industrial countries~~ ^{have shown themselves demonstrate that} energy use per unit of G.N.P. has declined over time -- steadily, and dramatically. ^{as we have}

So we look forward to working with the developing nations: Applying the power of the marketplace, considering technology transfer, and encouraging industry to work with them. That will allow developing nations to grow more quickly and easily -- and may help them avoid making the environmental mistakes we older nations have made.

I believe we should make use of what we know. We know that the future of the earth cannot be compromised. We bear a sacred trust in our tenancy here -- and a covenant with those most precious to us: our children, and theirs. We also know of the efficiency of economic incentive -- and that free markets yield the most creative solutions. We must now apply the wisdom of the market, in defense of the environment we share.

[You know, I recently heard from a national champion bass fisherman in America, that just downstream on the Potomac river here in Washington -- right across from Mount Vernon -- the bass fishing is as good as it is anywhere in the country. I take that as reason for optimism. Not too long ago, that river was considered a serious environmental problem. Now the story it tells, is that we are capable, not merely of halting damage done, but reversing it.]

Working together, with good faith and earnest dialogue, I believe we can reconcile economic growth with environmental protection. Let me commend you on your outstanding work -- and wish you all deliberate speed in your efforts to address a very difficult, but very important, human concern.

Thank you -- and God bless you.

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Chris Winston
or
Mark Langl

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(Lange/Cawley)
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1:45 P.M.
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As experts, you understand that economic growth and environmental integrity are **not** contradictory priorities. One reinforces and complements the other. Each, a partner. Both are crucial.

A sound environment is the basis for the continuity and quality of human life and enterprise. Clearly, strong economies allow nations to fulfill the obligations of environmental stewardship. ^{With that} ~~Where there is economic~~ strength, such protection is possible. But where there is poverty, the competition for resources gets tougher. Stewardship suffers.

For all of these reasons, I sincerely believe we must do everything in our power to promote global cooperation: For environmental protection **and** economic growth. For intelligent management of our natural resources **and** efficient use of our industrial capacity. And above all, for **sustainable** and **environmentally sensitive** development -- around the world.

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So we are renewing the ethic of stewardship in our domestic programs. In our work to forge international agreements. In our assistance to developing and East Bloc nations. And here, by chairing the Response Strategies Working Group.

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That commitment, by far the largest ever made by any nation, will allow NASA, her sister agencies, and our international partners to move forward with the "Mission to Planet Earth." That program will initiate the U.S. Earth Observing System, in cooperation with Europe and Japan, to advance the state of knowledge about the planet we share. ✓ (?)

Furthermore, even as we wait for the benefits of this research, the United States has already taken many steps in our country that bring both **economic and environmental benefits**. Steps that make sense on their own merits in terms of responsibility and efficiency, which help reduce emissions of CFC's, carbon dioxide, and other pollutants now entering the atmosphere. **Let me outline them very briefly:**

We are pursuing new **technology development** that will

increase the **efficiency** of our energy use, and thus reduce total emissions.

We're crafting a revised **Clean Air Act** with incentives for *private sector* ~~industry~~ to find creative, market-driven solutions to enhance air quality.

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As we work to create **policy** and agreements on action, we

want to encourage the most creative, effective approaches. Wherever possible, we believe that market mechanisms should be applied -- and that our policies must be consistent with ~~economic~~ growth and free market principles in **all** countries. Our development efforts and our dialogue can help us reach effective and acceptable solutions.

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We acknowledge a broad spectrum of views on these issues, but our respect for a diversity of perspective does not diminish our recognition of our obligation -- or soften our will to produce policies that **work**.

So the United States continues its efforts to improve our understanding of climate change -- to seek hard data, ~~and~~ ^{accurate models,} and new ways to improve the science, and determine how best to meet these challenges. Where politics and opinion have outpaced the science, we are accelerating our support of the technology to



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If we hope to promote environmental protection and ~~economic~~ growth around the world, it will be important not to work in conflict, but with our industrial sectors. That will mean moving beyond the practice of command, control, and compliance -- toward a new kind of environmental cooperation -- and toward an emphasis on pollution **prevention**, rather than mere mitigation and litigation. Many of our industries, in fact, are already providing crucial research and solutions.

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called Pollution Prevention Pays, that has saved the company well over half a **billion** dollars since 1975 -- and prevented 112,000 tons of air pollutants, 15,000 tons of water pollutants, and almost 400,000 tons of sludge and solid waste from being released into the environment. They've done it by rewarding employees for coming up with the ideas. And they have clearly demonstrated the benefits of doing it right.

Where developing nations are concerned, some argue we'll have to abandon the free-market principles of prosperous economies. In fact, we think it's all the more crucial, in the developing countries, to harness incentives of the free enterprise system, in the **service** of the environment. \\\

I believe we should make use of what we know. We know that the future of the earth ~~cannot~~ ^{must not} be compromised. We bear a sacred trust in our tenancy here -- and a covenant with those most precious to us: our children, and theirs. We also know of the efficiency of ~~economic~~ ^{well informed} incentive -- and that ^{well informed} free markets yield the most creative solutions. We must now apply the wisdom of that ~~market~~ ^{system}, the power of those forces, in **defense** of the environment we cherish.

Working together, with good faith and earnest dialogue, I believe we can reconcile ~~economic~~ ^{international} vitality with environmental protection. Let me commend you on your outstanding work -- and wish you all deliberate speed in your efforts to address a very difficult, but very important, human concern.

Thank you -- and God bless you.

(Lange/Cawley)
February 4, 1989
3:45 P.M.
[IPCC.DOC]

PRESIDENTIAL ADDRESS: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
GEORGETOWN UNIVERSITY
MONDAY, FEBRUARY 5, 1990
10:15 A.M.

Thank you, Dr. Bolin [Bo-leen]. Professor Obasi. Dr. Tolba. Delegates of the World Meteorological Organization, and the United Nations Environment Program. Let me commend **all** of you, for coming together to examine an issue of such great importance. The recommendations this distinguished organization makes can have a profound effect on the world's environmental and economic policy.

By being here today, I hope to underscore concern -- my country's, and my own -- about environmental stewardship; and to reaffirm our commitment to finding responsible solutions. It is both an honor and a pleasure to be the first American President to speak to this organization, as its work takes shape.

You are called upon to develop recommendations which strike a difficult yet critical international bargain: a convergence between global environmental policy, and global economic policy. A bargain where **both** perspectives benefit -- and **neither** is compromised.

As experts, you understand that economic growth and environmental integrity ~~are~~ ^{need} ~~not~~ ^{be} contradictory priorities. One reinforces and complements the other. Each, a partner. Both are crucial. ✓✓

A sound environment is the basis for the continuity and quality of human life and enterprise. Clearly, strong economies allow nations to fulfill the obligations of environmental stewardship. Where there is economic strength, such protection is possible. But where there is poverty, the competition for resources gets tougher. Stewardship suffers.

For all of these reasons, I sincerely believe we must do everything in our power to promote global cooperation: For environmental protection **and** economic growth. For intelligent management of our natural resources **and** efficient use of our industrial capacity. [And ~~above all~~,] for **sustainable** and **environmentally sensitive** development -- around the world. ✓

The United States is strongly committed to the I.P.C.C. process of international cooperation on global climate change. We consider it vital, that the community of nations be drawn together -- in an orderly, disciplined, rational way -- to review the history of our global environment, to assess the potential for future climate change, and to develop effective programs.

The state of the science; the social and economic impacts; and the appropriate strategies -- all are crucial components to a global resolution. **The stakes here are very high; the consequences, very significant.**

The United States remains committed to aggressive and thoughtful action on environmental issues. Last week, in my State of the Union address, I spoke of stewardship: because I

believe it's something we owe ourselves, our children and their children.

So we are renewing the ethic of stewardship in our domestic programs. In our work to forge international agreements. In our assistance to developing and East Bloc nations. And here, by chairing the Response Strategies Working Group.

I have just submitted a budget to our Congress for fiscal 1991. It includes over \$2 billion in new spending to protect the environment. And, underscoring our commitment to your efforts, I am pleased to note that funding for the U.S. Global Change Research Program will increase by nearly 60 percent, to over one billion dollars.

That commitment, by far the largest ever made by any nation, reflects our determination to **improve our understanding of the science** of climate change.

We are working with our neighbors around the world to enhance global monitoring and data management, improve analysis, **reduce the uncertainty of predictive models, and conduct regular reassessments of the state of the science.**

Our program allows NASA, her sister agencies, and all our international partners, to move forward with the "Mission to Planet Earth." That will initiate the U.S. Earth Observing System, in cooperation with Europe and Japan, to advance the state of knowledge about the planet we share.

Furthermore, even as we wait for the benefits of this research, the United States has already taken many steps in our country that bring both **economic and environmental benefits**. Steps that make sense on their own merits in terms of responsibility and efficiency, which help reduce emissions of CFC's, carbon dioxide, and other pollutants now entering the atmosphere. **Let me outline them very briefly:**

We are pursuing new **technology development** that will increase the **efficiency** of our energy use, and thus reduce total emissions.

We're crafting a revised **Clean Air Act** with incentives for our private sector to find creative, market-driven solutions to enhance air quality.

We've launched a major **reforestation initiative** to plant a **billion** trees a year on private land across America.

And we're working out a comprehensive review and revision of our **National Energy Strategy**, with initiatives to increase energy efficiency and the use of renewable sources. These efforts, already underway, are the heart of a \$336 million Department of Energy program, and are expected to produce energy savings through the year 2000 of over \$30 **billion** -- while achieving significant pollution reduction. Quite a return on investment.

We're also working through diplomatic channels with our colleagues in other countries, and through innovative measures like debt-for-nature swaps, to do more than simply reduce global

deforestation. We hope to reverse it -- not unilaterally, but by working with our international neighbors.

The **economics** of our response strategies to climate change are getting intensive study in America. We are developing real data on the costs of various strategies, assessing new measures, and encouraging other nations to follow suit. And we look forward to sharing this knowledge and technical support with our international colleagues.

As we work to create **policy** and agreements on action, we want to encourage the most creative, effective approaches. Wherever possible, we believe that market mechanisms should be applied -- and that our policies must be consistent with economic growth and free market principles in **all** countries. Our development efforts and our dialogue can help us reach effective and acceptable solutions.

Last December at Malta, in my meeting with President Gorbachev, I proposed that the United States offer a venue for the first negotiating session for a framework convention, once the I.P.C.C. completes its work. I reiterate that invitation here, and look forward to your cooperation in that agenda.

We all know that human activities are changing the atmosphere in unexpected and unprecedented ways. Much remains to be done. Many questions remain to be answered. Together, we have a responsibility to ourselves and the generations to come, to fulfill our stewardship obligations. But that responsibility demands that we do it right.

We acknowledge a broad spectrum of views on these issues, but our respect for a diversity of perspective does not diminish our recognition of our obligation -- or soften our will to produce policies that **work**. Some may be tempted to exploit legitimate concerns for political positioning. Our responsibility is to maintain the quality of our approach, our commitment to sound science, and an open mind to policy options.

So the United States will continue its efforts to improve our understanding of climate change -- to seek hard data, accurate models, and new ways to improve the science -- and determine how best to meet these challenges. Where politics and opinion have outpaced the science, we are accelerating our support of the technology to bridge that gap. And we are committed to coming together periodically, for international assessments of where we stand.

Therefore, this spring, the United States will host a White House conference on science and economic research on the environment -- convening top officials from a representative group of nations, to bring together the three essential disciplines: science, economics, and ecology. They will share their knowledge, assumptions, and state-of-the-art research models, to outline our understanding and help focus our efforts. I look forward to participating in this seminar, and to learning from its deliberations.

Our goal continues to be matching policy commitments to emerging scientific knowledge -- and a reconciling of

environmental protection to the continued benefits of economic development. And as Secretary Baker observed a year ago, **whatever** global solutions to climate change are considered, they should be as specific and as cost-effective as they can possibly be.

If we hope to promote environmental protection **and** economic growth around the world, it will be important not to work in conflict, but with our industrial sectors. That will mean moving beyond the practice of command, control, and compliance -- toward a new kind of environmental cooperation -- and toward an emphasis on pollution **prevention**, rather than mere mitigation and litigation. Many of our industries, in fact, are already providing crucial research and solutions.

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Climate sensitivity due to increased CO₂: experiments with a coupled atmosphere and ocean general circulation model*

Warren M Washington and Gerald A Meehl

National Center for Atmospheric Research** Boulder, CO 80307-3000, USA

Abstract. A version of the National Center for Atmospheric Research community climate model — a global, spectral (R15) general circulation model — is coupled to a coarse-grid (5° latitude–longitude, four-layer) ocean general circulation model to study the response of the climate system to increases of atmospheric carbon dioxide (CO₂). Three simulations are run: one with an instantaneous doubling of atmospheric CO₂ (from 330 to 660 ppm), another with the CO₂ concentration starting at 330 ppm and increasing linearly at a rate of 1% per year, and a third with CO₂ held constant at 330 ppm. Results at the end of 30 years of simulation indicate a globally averaged surface air temperature increase of 1.6°C for the instantaneous doubling case and 0.7°C for the transient forcing case. Inherent characteristics of the coarse-grid ocean model [low sea-surface temperatures (SSTs) in the tropics and higher-than-observed SSTs and reduced sea-ice extent at higher latitudes] produce lower sensitivity in this model after 30 years than in earlier simulations with the same atmosphere coupled to a 50-m, slab-ocean mixed layer. Within the limitations of the simulated meridional overturning, the thermohaline circulation weakens in the coupled model with doubled CO₂ as the high-latitude ocean-surface layer warms and freshens and westerly wind stress is decreased. In the transient forcing case with slowly increasing CO₂ (30% increase after 30 years), the zonal mean warming of the ocean is most evident in the surface layer near 30°–50° S. Geographical plots of surface air temperature

change in the transient case show patterns of regional climate anomalies that differ from those in the instantaneous CO₂ doubling case, particularly in the North Atlantic and northern European regions. This suggests that differences in CO₂ forcing in the climate system are important in CO₂ response in regard to time-dependent climate anomaly regimes. This confirms earlier studies with simple climate models that instantaneous CO₂ doubling simulations may not be analogous in all respects to simulations with slowly increasing CO₂.

Introduction

Because of potential significant changes, computer simulation of the effects on the earth's climate of increased carbon-dioxide (CO₂) concentrations has been an active area of research. Since the mid-1970s, more realistic and complex general circulation models (GCMs) of the climate system have been dedicated to this type of research. The Department of Energy (DOE)/Carbon-Dioxide Research Division, Office of Basic Energy Sciences, has issued State-of-the-Art (SOA) volumes on the status of this research in the climate community (see MacCracken and Luther 1985, in particular). These SOA volumes complement the earlier, less-detailed reviews (National Research Council 1982) of scientific knowledge of climate change resulting from CO₂. The present paper discusses experiments with a fully coupled atmosphere and ocean dynamical model developed at the National Center for Atmospheric Research (NCAR). This is the latest in a series of ocean models coupled, essentially, to the same atmospheric model.

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** The National Center for Atmospheric Research is sponsored by the National Science Foundation

Offprint requests to: WM Washington

Most early simulations of coupled atmosphere-ocean models included a simple ocean component, such as a basic energy-balance ocean (sometimes referred to as a swamp model), which had no seasonal heat storage and no vertical or horizontal heat transport (e.g., Manabe and Wetherald 1975; Washington and Meehl 1983, 1986). Although this type of model allowed for the fact that the ocean is a saturated surface interacting with the atmosphere, it is still far from the real ocean. A second type of simple coupled atmosphere-ocean model has a shallow, constant, mixed-layer thickness of ≈ 50 m and takes into account seasonal heat storage, but not horizontal or vertical heat transport (e.g., Manabe and Stouffer 1980; Washington and Meehl 1984). Hansen et al. (1984, 1988) and Wilson and Mitchell (1987) have used models that, in addition to the mixed-layer ocean, prescribe seasonal horizontal ocean heat transport obtained from a model simulation with observed ocean temperature. This specified horizontal transport does not allow for feedbacks with changes in ocean temperature or sea ice. In their SOA review paper discussing model intercomparisons of several different ocean formulations with increased concentration of CO₂, Schlesinger and Mitchell (1985, 1987) found that the general pattern of zonally averaged changes was similar, but the geographical patterns were quite different.

The NCAR model coupled to the simple mixed-layer ocean formulation has been studied in the context of (1) effect of limitations of the simple mixed layer on the computed sea-surface temperatures (SSTs) and surface-energy balance (Meehl and Washington 1985), (2) changes of blocking events and persistent height anomalies (Bates and Meehl 1986), (3) changes of tropical circulation in the model (Meehl and Washington 1986), (4) ice-albedo feedback sensitivity (Dickinson et al. 1987), (5) tropical-midlatitude interactions (Meehl 1988), and (6) soil-moisture sensitivity (Meehl and Washington 1988).

Interactive atmosphere and ocean models with a dynamical component are limited because of the requirement for lengthy computer runs, even with coarse resolution. CO₂ experiments with ocean general circulation models (OGCMs) of this type have been conducted by Bryan et al. (1982), Bryan and Spelman (1985), and Bryan et al. (1988), using a Geophysical Fluid Dynamics Laboratory (GFDL) model with idealized geographical domain (a sector of the globe), and by Schlesinger et al. (1985) and Schlesinger and Jiang (1988), using an Oregon State University

model with a realistic geographical domain. In both studies, a step-function increase of CO₂ was used to investigate the transient response of the system. The GFDL coupled models built upon the previous work of Manabe (1969) and Bryan (1969).

This paper describes CO₂ experiments with model versions having current concentration ($1 \times \text{CO}_2$), double the concentration ($2 \times \text{CO}_2$), and a gradually increasing concentration of CO₂ (transient). These experiments use the same atmospheric (Washington and Meehl 1983, 1984) and dynamical ocean models described by Semtner (1974, 1987) and Meehl et al. (1982). Brief descriptions of the atmospheric and oceanic models are given in Sections 2 and 3; sea ice is included in the ocean description. Section 4 explains coupling of the atmospheric and oceanic models and describes the experiments. Examples of the comparison of the simulations with the observed atmosphere, ocean, and sea-ice distributions are given in Section 5. Section 6 discusses the differences between a control simulation with current and instantaneous doubling of CO₂ concentrations; zonal and geographical distributions are also shown. Section 7 describes a separate experiment with a gradually increasing (1% per year) concentration of CO₂. This experiment allows an estimate of the so-called transient response of the climate system to a gradual increase in CO₂ concentration. [Note the discussion by Schneider and Thompson (1981) showing differences between sudden and gradual increases of CO₂.] The conclusions in Section 8 are in terms of the simulation compared to the observed and the differences caused by a doubling of CO₂. Plans for improvements of the various aspects of the coupled model are also discussed. The Appendix describes a coupled climate-sensitivity experiment with decreased wind stress, another experiment with decreased horizontal diffusion, and a third with a shallowed second layer. All experiments show a sensitivity that causes large changes in the simulated tropical ocean-surface temperature.

Description of atmospheric model

In a schematic diagram of the components of the coupled ocean-atmosphere-sea-ice model (Fig. 1), atmospheric and oceanic levels are shown at the left with the physical processes at the middle and right. The atmospheric component of the interactive climate model is a version of the NCAR Community Climate Model (CCM) (Bourke et al.

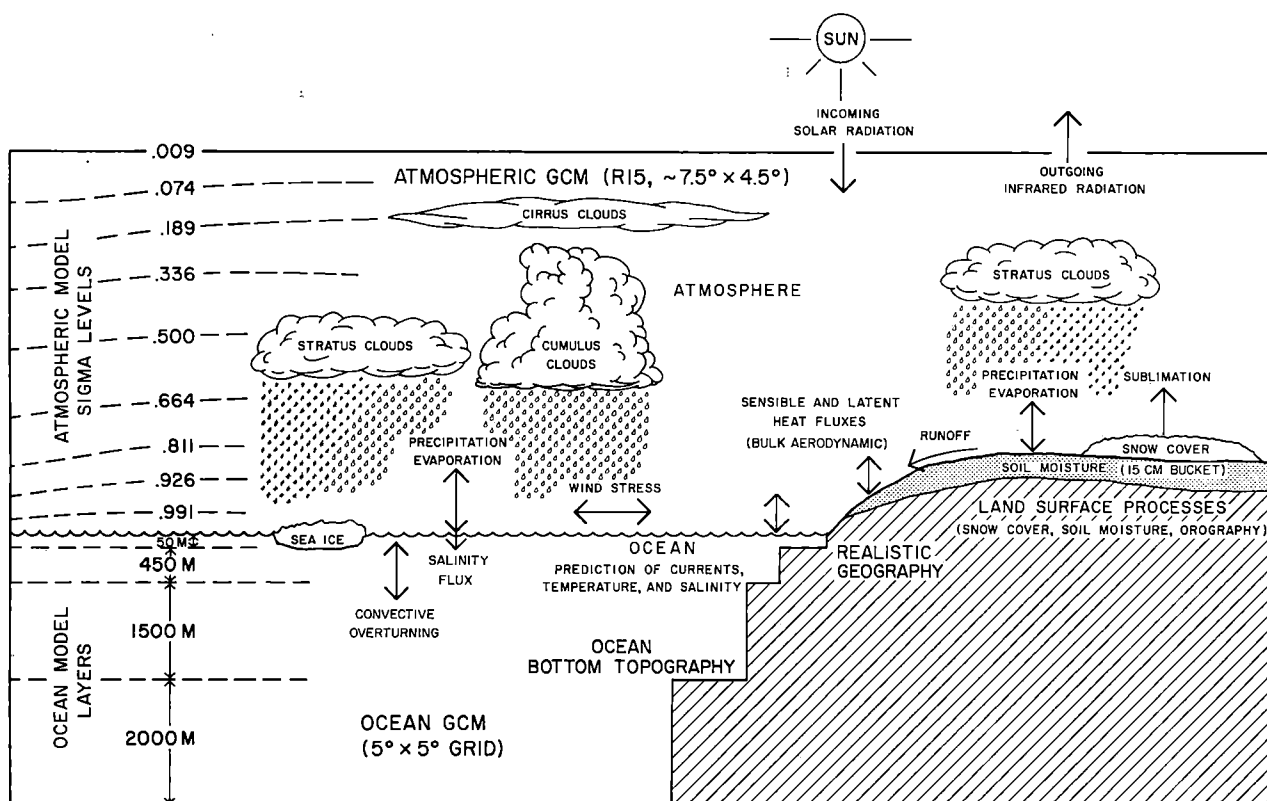


Fig. 1. Schematic of vertical-layer structure of coupled atmosphere/ocean model. Various physical processes and their interactions are depicted

1977; McAvaney et al. 1978; Pitcher et al. 1983). The physical parameterizations in the model, except for radiation, are from GFDL models (Manabe et al. 1965). The atmospheric part of the model uses a sigma vertical coordinate system with nine levels and the spectral transform method for computing horizontal nonlinear transport terms with a truncation wave number of rhomboidal 15, which yields a resolution between poles of approximately 4.5° in latitude. The longitudinal grid has 48 points and thus a 7.5° resolution, the time step is 40 min, and the radiation-cloudiness scheme is as described by Ramanathan et al. (1983). The cirrus formulation assumes that upper-layer clouds have emissivity of unity and are perfect blackbodies independent of liquid-water or ice-equivalent content. The blackbody assumption of the simulation of temperature and associated wind structure has been explored by Ramanathan et al. (1983, see section entitled "Variable Black Cirrus"). The blackbody assumption is applied because of the uncertain effect of cloud-emissivity feedback on the CO₂ question, especially for thin clouds. This precludes the possibility of cloud-emissivity climate feedbacks. The sur-

face-hydrology cycle uses model-derived rates of precipitation, evaporation, and sublimation to simulate the changes of soil moisture and snow cover following Washington and Williamson (1977), whose treatment is similar to that described by Manabe (1969). The methods of parameterization for surface albedos are described by Washington and Meehl (1984).

Description of ocean and sea-ice models

The OGCM uses primitive equations for a hydrostatic, Boussinesq ocean with a rigid lid and follows a numerical method developed by Bryan (1969). Coriolis terms in the horizontal equation of motion are treated semi-implicitly. The horizontal finite-difference scheme is second-order, energy-conserving, and has a second-order, leap-frog, time-differencing approximation (Semtner 1974, 1987). In the Arctic Ocean only, forecast variables are smoothed longitudinally to avoid a computational restriction on the time step because of the small geographical distances in the longitudinal direction. The large-scale bottom to-

Table 1. World ocean model characteristics

1) Vertical coordinate	Depth
2) Horizontal domain	Global (latitude and longitude)
3) Horizontal resolution	5°
4) Horizontal approximation of derivatives	Second-order
5) Vertical resolution	$\Delta z_1 = 50$ m, $\Delta z_2 = 450$ m, $\Delta z_3 = 1500$ m, $\Delta z_4 = 2000$ m
6) Time step	$\Delta t = 1800$ s
7) Topography	Included
8) Convective adjustment	Included
9) Salinity flux at surface	Included
10) Computed sea ice	Included

pography has been included (Bryan 1969; Washington et al. 1980). If adjacent vertical layers become statically unstable, then convective adjustment is invoked, thus returning the respective layers to a stable state by uniformly mixing temperature and salinity in the two layers. Table 1 summarizes the major characteristics of the OGCM.

Small-scale features, such as mid-ocean eddies, and concentrated aspects of the western boundary currents, such as the Gulf Stream, are not resolved by the 5° latitude-longitude horizontal grid. Details of how they contribute to horizontal and vertical transports of heat and momentum in nature are not well known because of limited observations; they can be crudely parameterized with large eddy diffusivities (e.g., Semtner and Mintz 1977; Cox 1985). The vertical eddy diffusivity for heat is generally $10^{-4} \text{ m}^2 \text{ s}^{-1}$. However, like Philander and Seigel's (1985) method, the vertical eddy diffusivity at the base of the top layer for momentum is $10^{-3} \text{ m}^2 \text{ s}^{-1}$, except at the equator where it is $2 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$; elsewhere in the model it is $10^{-4} \text{ m}^2 \text{ s}^{-1}$. The horizontal momentum diffusivity is $1 \times 10^6 \text{ m}^2 \text{ s}^{-1}$ and the horizontal sensible-heat diffusivity is $4 \times 10^4 \text{ m}^2 \text{ s}^{-1} \times \cos(\phi)^2$. The $\cos(\phi)^2$ factor is an ad hoc attempt to decrease diffusion near the polar regions. These values were chosen to give smooth predicted fields with the coarse 5°-grid spacing, even though they may seem to overestimate substantially the effects of subgrid-scale processes. One of the shortcomings of ocean models with coarse resolution is that the advective processes, especially horizontal, are too weak and features such as the Gulf Stream are therefore poorly represented. The Appendix shows model sensitivity

to a decrease in the horizontal diffusivity for heat. In such a coarse-grid model, the earth's continents and ocean are crudely represented due to the 5° × 5° resolution. For example, the Mediterranean and Hudson Bay are "lakes" not connected to the Atlantic Ocean, precluding direct interaction. Sensitivities of this ocean model to parameter variations have been documented by Meehl et al. (1982).

The initial formation of sea ice depends upon ocean surface temperature such that if the ocean temperature becomes equal to the approximate freezing point for sea water (271.2° K), sea ice forms. The amount of growth and melting of sea ice depends upon the energy balance at the top of sea ice and the heat conduction through sea ice, following the parameterization of the zero-layer model described by Semtner (1976). The heat flux from ocean to sea ice is computed by assuming upward heat diffusion where the temperature at the base of the sea ice is at the freezing point of sea ice and the temperature of sea water under sea ice is the top layer of the ocean model. Such a simple sea-ice model does not allow for heat storage within the ice or detailed processes involving brine formation.

The heat flux to the bottom of sea ice is approximated by simple heat diffusion assuming a temperature gradient between the middle of the first ocean layer and the freezing temperature at the base of the sea ice. The ocean vertical thermal eddy diffusivity directly beneath sea ice is $0.01 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ because vertical mixing is thought to be substantially less there. The effects of salinity changes from sea-ice freezing or thawing are not included, and there is no contribution to salinity change by river runoff.

Method of coupling atmosphere-ocean-sea-ice models and description of experiments

Our strategy in coupling the atmospheric GCM to the OGCM is entirely different from that used in an earlier study (Washington et al. 1980). In the study described here, atmospheric and oceanic models are coupled synchronously rather than asynchronously. Asynchronous coupling does not accurately allow for the time evolution of interaction between oceans and atmosphere, especially seasonal changes. For the present synchronous scheme, the atmospheric model provides wind stress (at the bottom layer of the model, i.e., $\sigma = 0.991$), precipitation minus evaporation, and the sum of the surface-energy balance to the

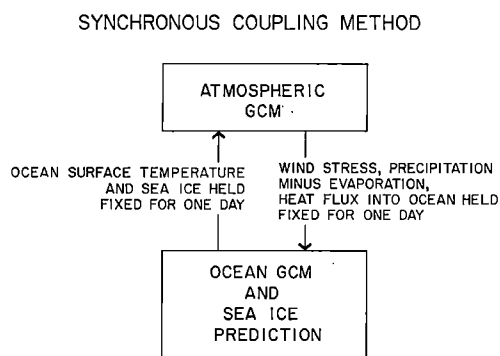


Fig. 2. Schematic of synchronous coupling method for atmospheric and oceanic sea-ice models

ocean. In turn, the ocean model provides surface-temperature and sea-ice data to the atmospheric model (interactions are shown schematically in Fig. 2). The atmospheric and oceanic models are each run for 1 day. The atmospheric model uses 40-min time steps (36 iterations per day), and the oceanic model uses 30-min time steps (48 iterations per day). Typically, ocean models use much longer time steps, usually with steady or smoothly varying wind stress. The computed wind stress from the lowest atmospheric model layer occasionally gave large local values for relatively short time periods which, when applied to a 50-m top ocean layer, caused large local and episodic acceleration in the top layer of the ocean. This led to local instabilities in the current systems of the top layer of the ocean. Observations of large transient wind-stress forcing indicate that the surface layers of the ocean undergo increased vertical mixing and generation of surface waves rather than having all the momentum applied as a boundary force to move the upper ocean laterally. The precise amount of momentum going into each of these mechanisms is dependent upon a wide range of conditions. An improved parameterization of vertical diffusivity in the ocean is needed to describe this process properly. In the meantime, the Appendix describes a sensitivity experiment with the effects of decreased wind stress.

The method of carrying out coupled simulations for $1 \times \text{CO}_2$, $2 \times \text{CO}_2$, and a slowly increasing CO₂ (or transient forcing) experiment is shown schematically in Fig. 3. The ocean model started from the end of the uncoupled model experiment with observed atmospheric forcing (≈ 50 years), where the first year was forced by a Newtonian-type observed, zonally averaged temperature and salinity distribution (Meehl et al. 1982). This artificial forcing decreased the time (≈ 1

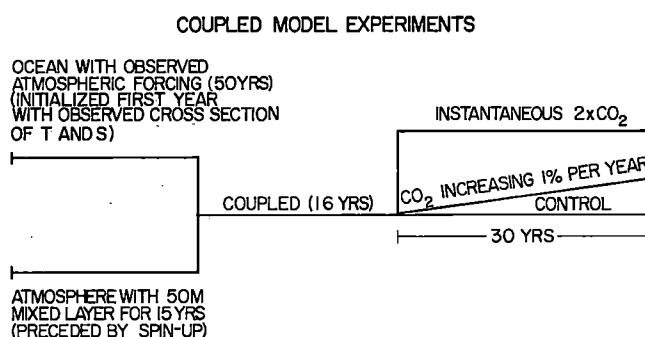


Fig. 3. Description of running of the coupled experiments. At the left, the atmospheric and oceanic models were run separately and then coupled for 16 years. At the right, the control ($1 \times \text{CO}_2$) was extended for 30 years, and an instantaneous $2 \times \text{CO}_2$ experiment and a transient CO₂ experiment (with CO₂ increasing 1% per year) were run for 30 years

year) required to bring the overall zonal temperature and salinity patterns to roughly that of the observed. The atmospheric part of the coupled model began from the 15th year of the climate simulation by Washington and Meehl (1984), in which a 50-m, simple, mixed-layer ocean was used. The coupled model system was then run for 16 years with several changes in ocean diffusion parameters. The model was run for an additional 30 years for the $1 \times \text{CO}_2$, $2 \times \text{CO}_2$, and transient experiments. Obviously, the overall system cannot be in complete equilibrium, but the top parts of the ocean model appear to change little from year to year. Figure 4 shows time-evolution graphs of globally averaged ocean-surface temperature and ocean surface temperature differences from the coupled model with $1 \times \text{CO}_2$, $2 \times \text{CO}_2$, and transient forcing (slowly increasing) CO₂ experiments. The globally averaged ocean temperature in the top model layer with $1 \times \text{CO}_2$ exhibits a very slow cooling trend or drift ($\sim 0.02^\circ \text{C}$ per year), while the $2 \times \text{CO}_2$ experiment shows little trend. This trend, as will be shown later, is substantially smaller than the increased CO₂ warming signal. The transient experiment shows less cooling than the $1 \times \text{CO}_2$ experiment and a small warming by year 30. In the $2 \times \text{CO}_2$ experiment, the upper part of the ocean warms quickly and then shows a smaller secular change at the 15- to 30-year range. The globally averaged SST difference between the $2 \times \text{CO}_2$ and $1 \times \text{CO}_2$ experiments is about 1.2°C and 1.6°C for globally averaged surface air temperature at 30 years, which is larger than the value found at 20–25 years by Bryan et al. (1982) and Schlesinger et al. (1985). The transient experiment shows a much smaller difference of about 0.7°C after 30 years for surface air temperature increase

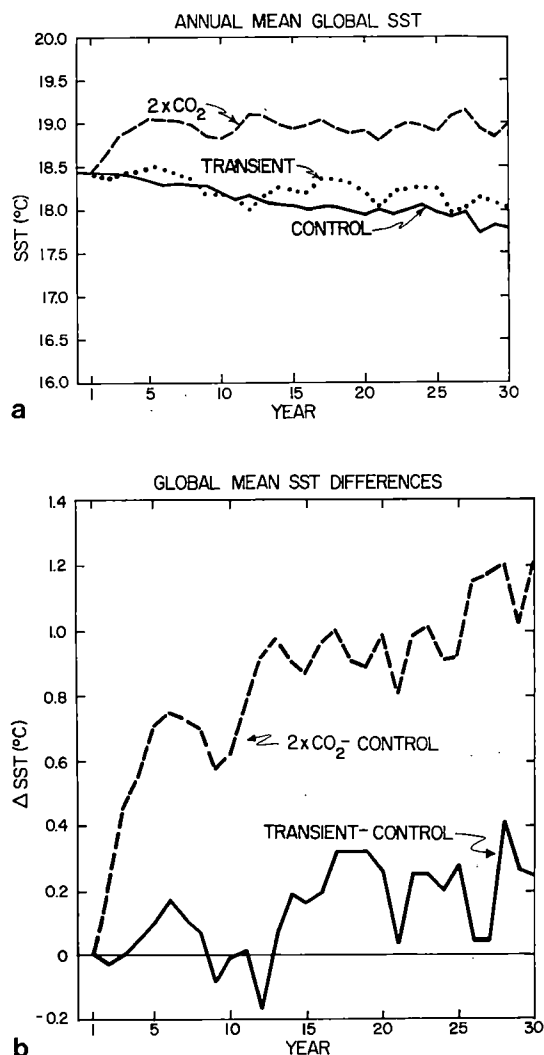


Fig. 4. a Time evolution of globally averaged ocean surface temperature ($^{\circ}\text{C}$) for $1 \times \text{CO}_2$, $2 \times \text{CO}_2$, and transient CO_2 experiments; b time evolution of ocean surface temperature differences from part (a) ($^{\circ}\text{C}$)

and about $0.3^{\circ}\text{--}0.4^{\circ}\text{C}$ for globally averaged SST differences.

The pattern of climate drift in the ocean for the three cases is similar, with small-amplitude changes occurring in the surface layer, cooling in the second layer (less than 0.05°C per year), a warming of the third layer (less than 0.03°C per year), and a slight warming of the bottom layer (less than 0.005°C per year). Most of the climate drift is removed by subtracting cases averaged over the same time period. Although the pattern of climate drift is similar in the three cases, small-amplitude changes in the drift of the surface layer affect the globally averaged SST numbers in Fig. 4. Slight flux differences due to increased CO₂ result in a near-zero globally averaged drift of the

surface layer in the $2 \times \text{CO}_2$ case compared to the transient and control cases. However, the magnitude of the drift is smaller than the size of the CO₂ signals. A number of these questions dealing with equilibrium and transient forcing of the coupled atmosphere-ocean system have been explored with simpler models (e.g., Schneider and Thompson 1981; Thompson and Schneider 1982).

Simulation of observed climate

Atmosphere

Confidence in a model as a useful indicator of climate sensitivity is measured in part by how well it simulates present climate. By simulating the change of seasons, which involves a larger signal than most climate sensitivity experiments, one can assess the effect of external forcing on the simulated climate system. In atmospheric simulations with specified observed ocean-surface temperatures, the climate simulated by such a model has a strong surface-boundary constraint on the atmosphere. Coupled models involving mutual interactions between atmosphere and ocean have no specified lower boundary constraint and thus are more prone to drift to a climate different from the observed than are constrained climate models.

Most coupled model simulations yield ocean-surface temperatures with substantial errors. Contributions to some of these errors are known because of the inherent limitations of some of the formulations in the atmosphere and ocean models, but some of the causes are not evident because of the complexities and uncertainties in modeling the climate system (e.g., cloudiness-radiation, surface transfers of sensible heat, momentum, salinity, and moisture). In spite of these uncertainties, it is still possible to simulate many basic aspects of the climate system. Figure 5 shows the latitude vs. pressure distribution of zonally averaged temperature from the coupled model compared to the observed data of Newell et al. (1972) for December-January-February (DJF) and June-July-August (JJA). These figures can be compared with the atmospheric simulation with the simple mixed-layer ocean model (50 m) reported by Washington and Meehl (1984, Fig. 3, p. 9479). A comparison of the results from the mixed-layer ocean model provides more insight into the role of ocean dynamics in determining model climate since the atmospheric model is the same. The temperatures in the present OGCM experiment near the surface in the tropics are cooler

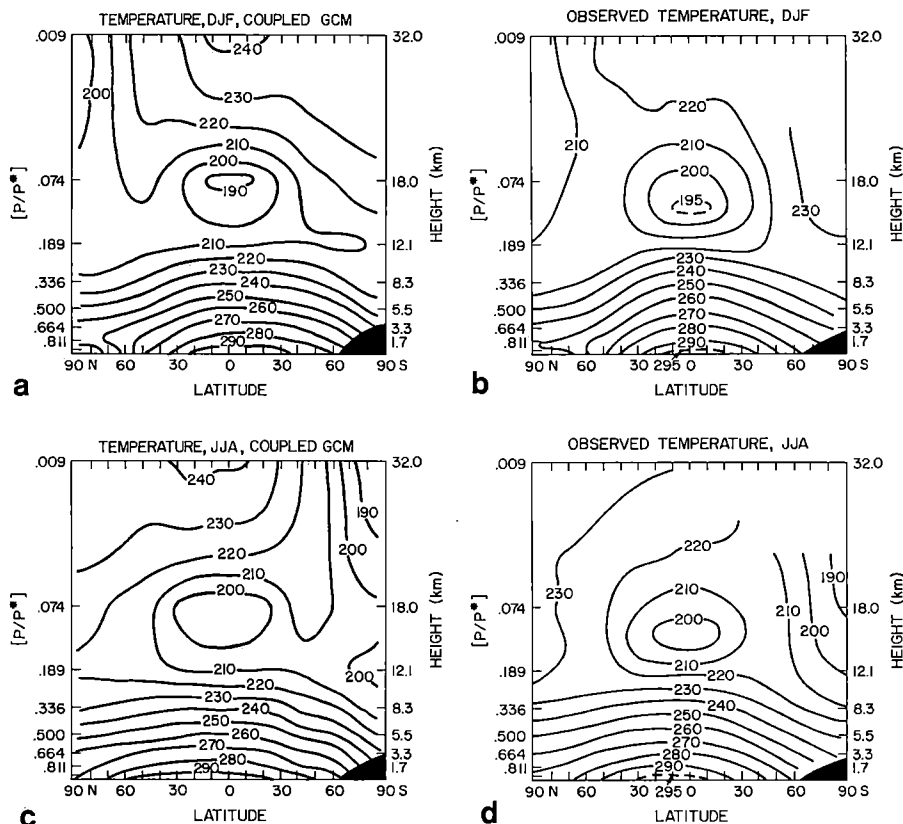


Fig. 5 a-d. Zonal mean temperatures as a function of latitude and height (K). Computed values are 3-month seasonal averages taken over the last 5 years of control case. Observed values are long-term, 3-month seasonal means from Newell et al. (1972); a computed, DJF; b observed, DJF; c computed, JJA; d observed, JJA

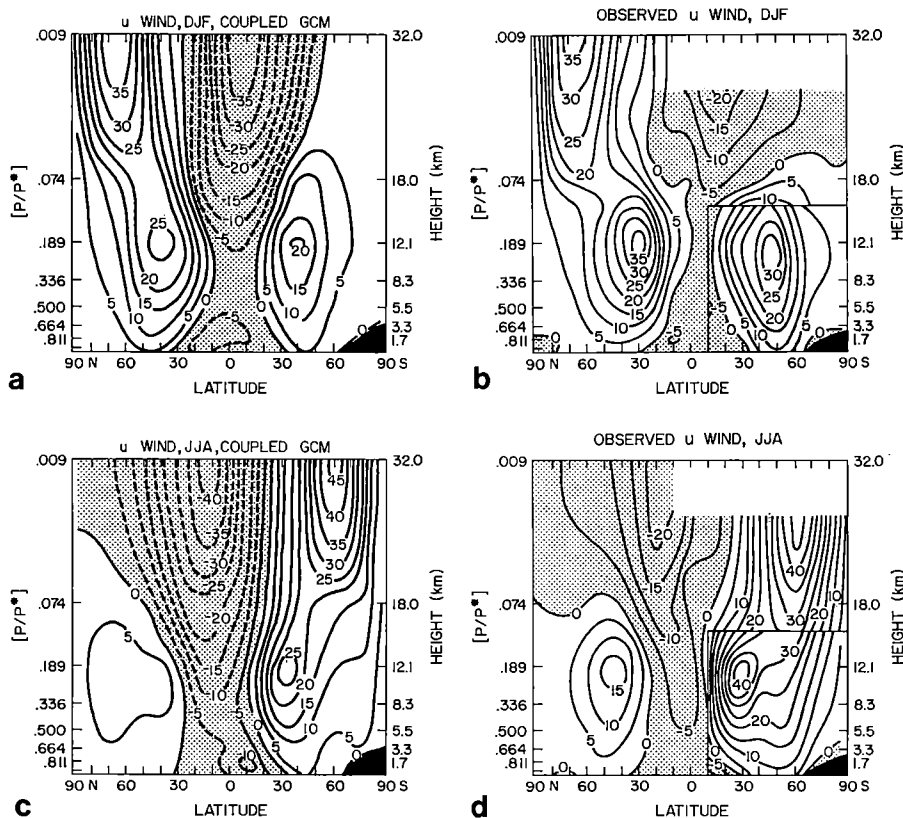


Fig. 6 a-d. Mean zonal (east-west) wind component u as a function of latitude and height (m s^{-1}). Computed values are compiled as in Fig. 5. Observed SH tropospheric values are geostrophic winds for January (b) and July (d), from van Loon et al. (1971). All other observed values are 3-month seasonal means from station data (Newell et al. 1972); a computed, DJF; b observed, DJF (SH, January); c computed, JJA; d observed, JJA (SH, July)

by up to 5° K in the zonal average than the observed in the tropics; but in the higher-latitude Southern Hemisphere (SH), ocean temperatures are substantially warmer than the observed in both seasons. The OGCM yields cooler tropical and subtropical ocean temperatures than the mixed-layer ocean version because of equatorial upwelling and poleward heat transport which are absent in the mixed-layer model. Other aspects of tropospheric and stratospheric simulations are similar with both types of ocean models, with one important exception — there is less overall tropospheric latitudinal temperature gradient in the present model. Because the temperature gradient can be related to the vertical wind shear through the thermal wind relationship, the zonal wind field is significantly affected.

Figure 6 shows the zonally averaged zonal wind component as a function of latitude and pressure for DJF and JJA. During DJF, some features in the simulation with the OGCM are closer to the observed of Newell et al. (1972) and van Loon et al. (1971) than to the model with the mixed-layer ocean (Washington and Meehl 1984, Fig. 4, p. 9480). In the DJF simulation, there is a continuous distribution of easterlies throughout the midtroposphere with the OGCM. As sug-

gested from the previous figure of zonally averaged temperatures, the midlatitude westerly jet streams are weaker, which is consistent with the warmer-than-observed high-latitude temperature distribution. The simulation with the OGCM yields 25 m s⁻¹ and 20 m s⁻¹ DJF maxima, respectively, for the Northern and Southern Hemispheres versus 40 m s⁻¹ and 30 m s⁻¹ with the mixed-layer ocean version. The present JJA simulation shows, respectively, 5 and 25 m s⁻¹ jet maxima versus the 15 and 40 m s⁻¹ maxima found with the mixed-layer ocean model. This is indicative of the weaker zonal temperature gradient with the OGCM. As discussed in more detail later, the OGCM has less sea ice than observed and much less than the simulation with the mixed layer. The latter had an overabundance of sea ice in both hemispheres, partially as a result of the lack of poleward ocean heat transport.

The latitude-height distribution of moisture is shown in Fig. 7. This figure can be compared with the distribution in the mixed-layer ocean version (Fig. 10 on p. 9487 of Washington and Meehl 1984). The observed is from Oort (1983). A striking difference is the much smaller amount of moisture in the tropics where the maximum in DJF is 13 g kg⁻¹ versus 17 g kg⁻¹ for the ob-

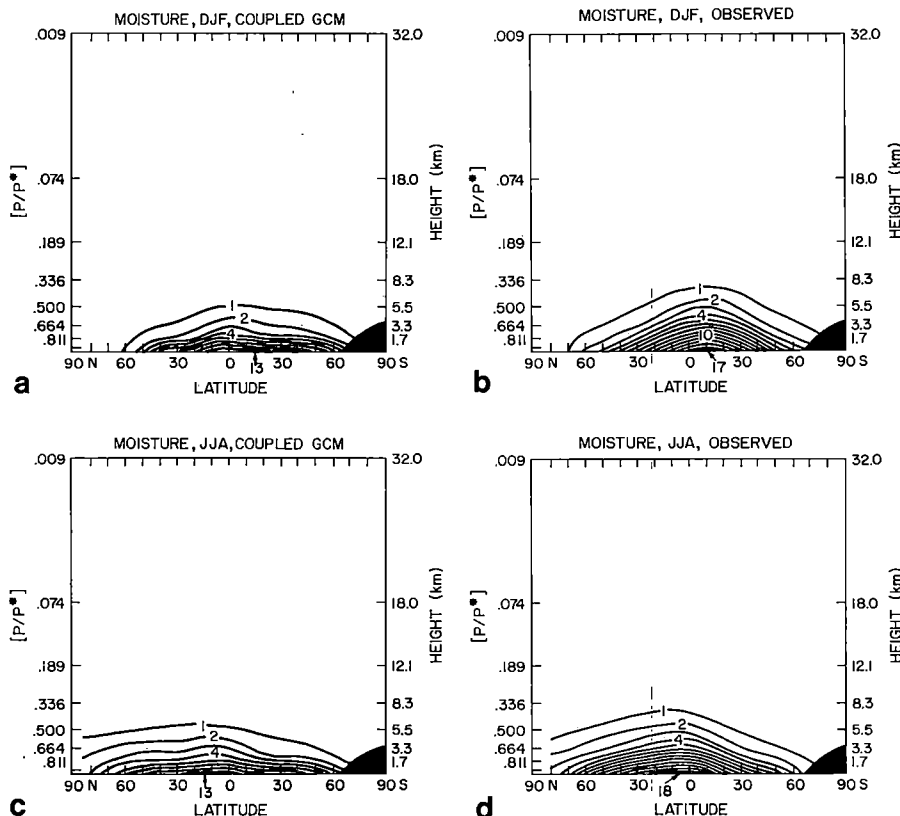


Fig. 7a-d. Specific humidity (g kg⁻¹). Computed values are compiled as in Fig. 5. Observed values are after Oort (1983); a computed, DJF; b observed, DJF; c computed, JJA; d observed, JJA

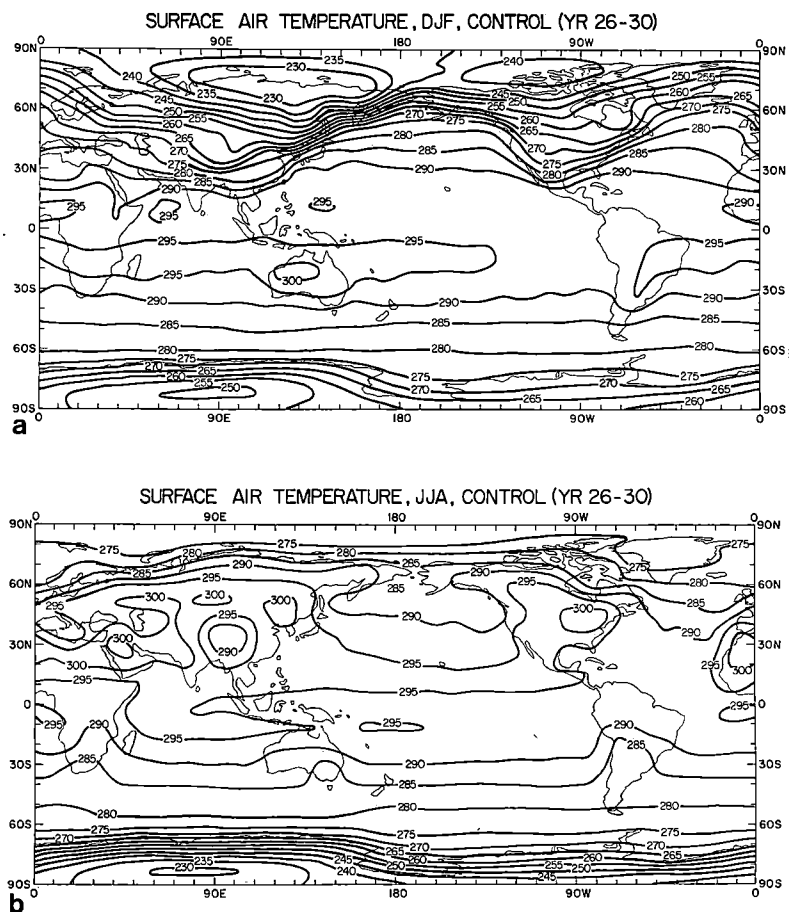


Fig. 8a, b. Geographical distribution of surface air temperature ($\sigma=0.991$) and sea ice. Computed values are compiled as in Fig. 5. Observed values of surface air temperature are shown by Washington and Meehl (1984); a computed, DJF; b computed, JJA

served. Presumably, this is largely a result of the colder-than-observed ocean temperatures. A similar difference is found in JJA. Also, the computed distributions are more uniform with latitude, indicating a smaller zonal temperature gradient and warmer polar regions. This water-vapor feedback has been extensively discussed by Ramanathan (1981) and others in simple radiative-convective models.

The geographical distribution of the surface air temperature ($\sigma=0.991$) for DJF and JJA is shown in Fig. 8 and can be compared to observed values in Washington and Meehl (1984). The Northern Hemisphere (NH) winter shows more northward-shifted zonal temperature gradients with the OGCM than the experiment with the mixed-layer ocean (Washington and Meehl 1984, Fig. 5, pp. 9481-9482) in the Atlantic and Pacific Ocean regions. Temperatures are substantially warmer over the North Atlantic and near the edge of Antarctica. Over the tropical ocean, surface temperatures in the present model are more than 5° K too cold in places. The continental temperatures over North America, Asia, and Africa are

quite similar in the two simulations. The simulation of less-than-observed sea-ice distribution (shaded on Fig. 10) in the OGCM results in substantially warmer-than-observed surface air temperatures in the SH.

The distribution of precipitation is shown in Fig. 9. Again, we compare these with mixed-layer results (Washington and Meehl 1984, Fig. 6, pp. 9483-9484), and the observed values from Jaeger (1976). The midlatitude DJF distributions between the two model versions are quite similar; for example, in the northern Pacific and Atlantic Oceans, the pattern of 2-6 mm day⁻¹ agrees well with the observed. However, in the tropical Pacific, the OGCM gives much smaller amounts of precipitation and a weak Intertropical Convergence Zone (ITCZ). This is associated with colder-than-observed ocean temperature, as shown later, compared to the higher-than-observed tropical Pacific SSTs and precipitation in the mixed-layer model. The other tropical precipitation maxima in the coupled model occur over the relatively warmer land surfaces of South America and Africa and are higher than observed. The JJA val-

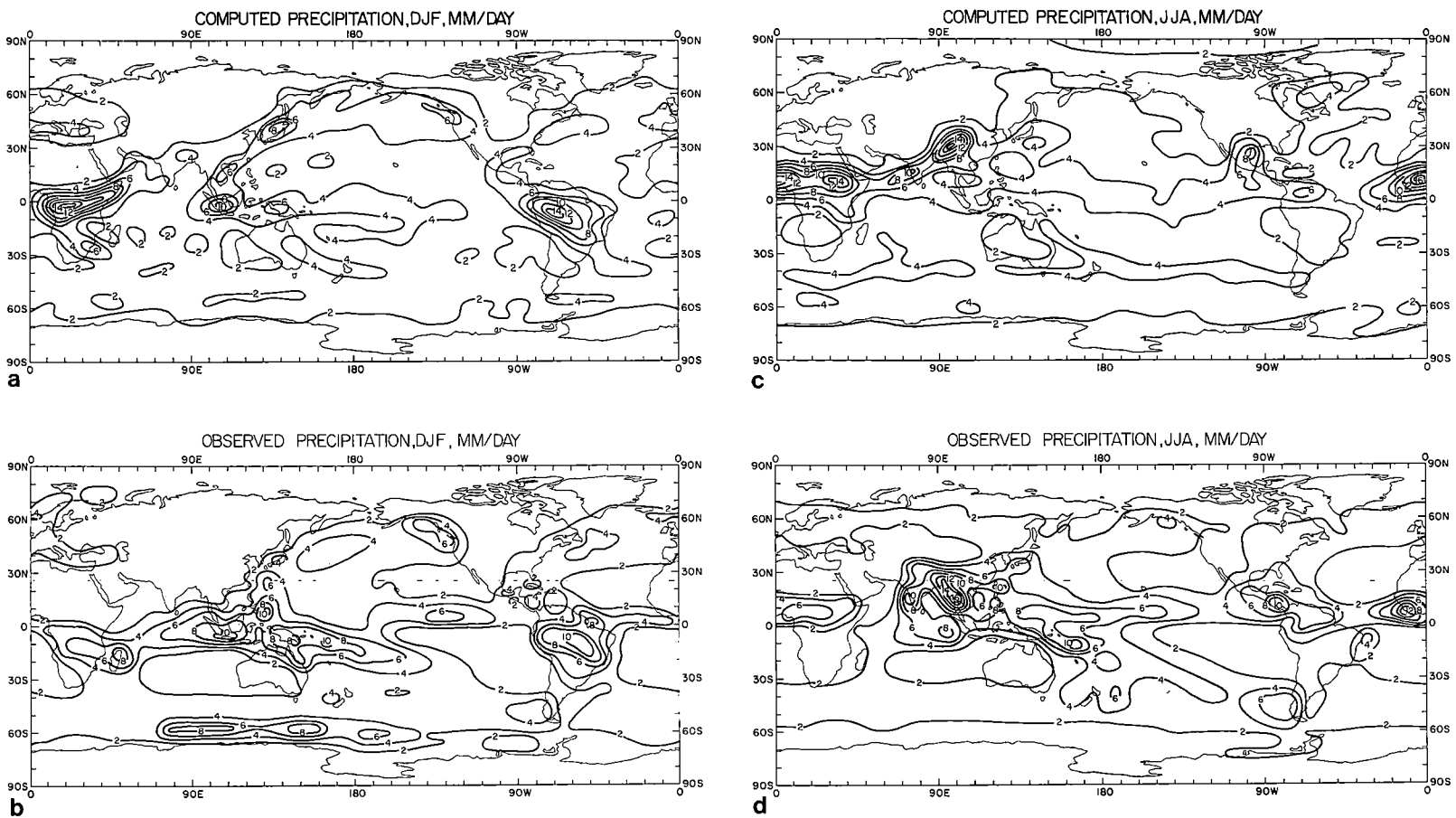


Fig. 9a-d. Geographical distribution of precipitation rate (mm d⁻¹). Computed values are compiled as in Fig. 5. Observed values are from Jaeger (1976) for DJF and JJA; **a** computed, DJF; **b** observed, DJF; **c** computed, JJA; **d** observed, JJA

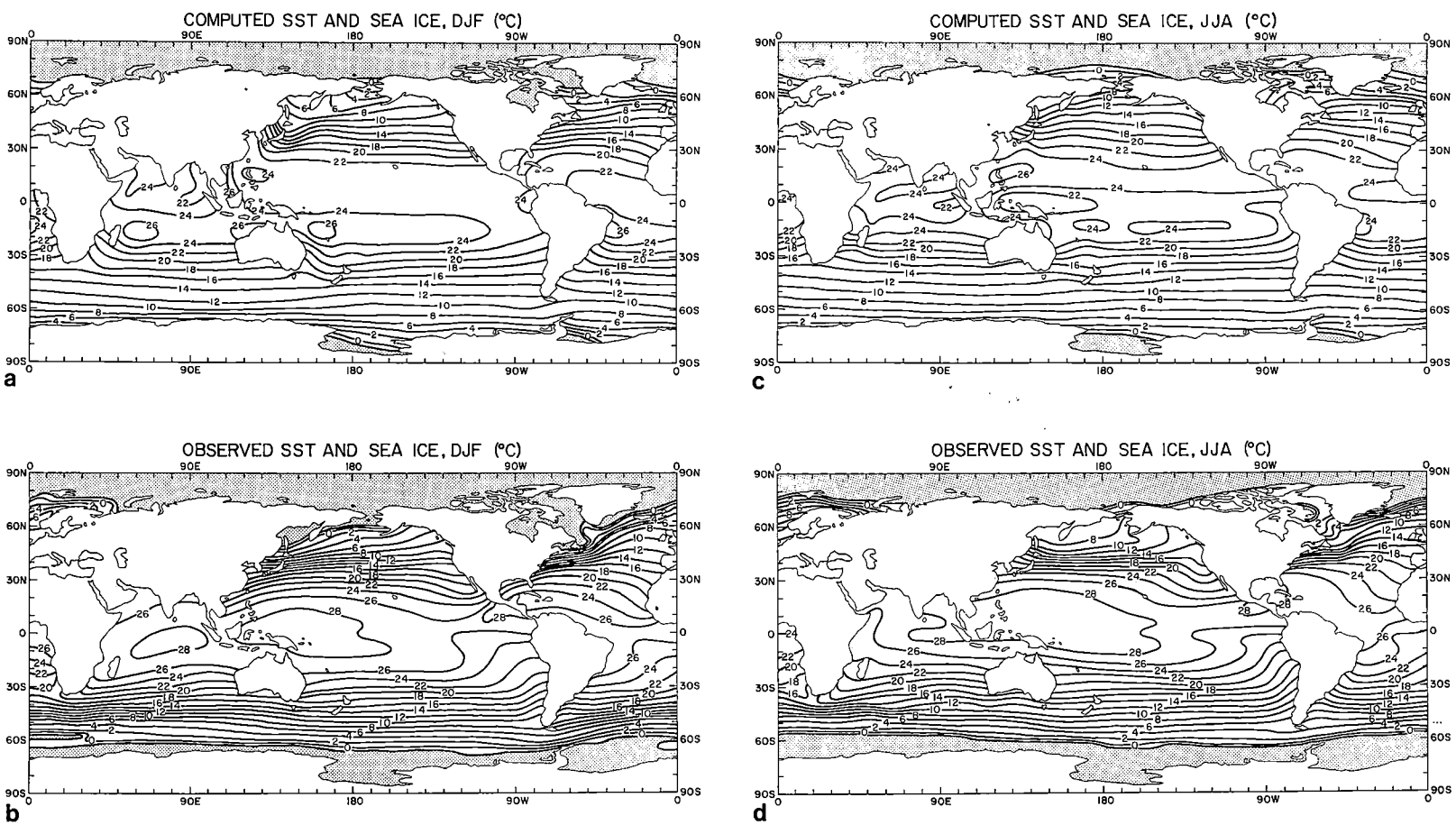


Fig. 10. **a** Computed and **b** observed ocean surface temperature ($^{\circ}\text{C}$) and sea-ice limits for DJF; **c** and **d** same as **a** and **b**, except for JJA. Observed values are from Alexander and Mobley (1976). Stippling indicates extent of sea ice

ues show a pattern similar to the observed with maxima somewhat greater than observed, particularly in the African monsoon region. Again, because of colder-than-observed ocean temperatures in the vicinity of Indonesia, the precipitation in this region is too low. The tropical Indian-Asian monsoon precipitation maxima occur mainly over land areas, avoiding the cool ocean surface.

Ocean and sea ice

The geographical distributions of ocean-surface temperature and sea ice are shown in Fig. 10 for DJF and JJA. The observed are from Alexander and Mobley (1976). The overall tropical temperatures are too low (1° – 3° K), and the western Pacific warm pool is not simulated by the coupled model. Some factors contributing to the excessively low temperatures in this region will be addressed in the Appendix, where additional experiments are described, with reduced wind stress applied to the ocean, decreased subgrid-scale lateral

diffusion, and a shallower second layer in the ocean. All of these additional experiments yield warmer ocean-surface temperatures in the tropics.

The tongue of cooler water in Fig. 10 off the west coast of South America and the warm water off the east coast of South America are crudely simulated in the OGCM. These features are not simulated in the experiment with the mixed-layer model because of lack of ocean dynamics. The SH midlatitude ocean temperatures are much too high in both seasons, resulting in very little sea ice around Antarctica, even in winter. An error of the ocean model is that the dynamical mechanisms and horizontal heat diffusion are transporting too much heat into the higher southern latitudes, whereas SSTs and sea ice in the NH are closer to the observed distributions, presumably because the Arctic Ocean is somewhat isolated from the northern Pacific and Atlantic Oceans. Washington and Meehl (1984) noted that the simple, mixed-layer ocean model simulated excessive sea ice partially due to the lack of ocean dynamics.

The temperatures in the vicinity of the Antarc-

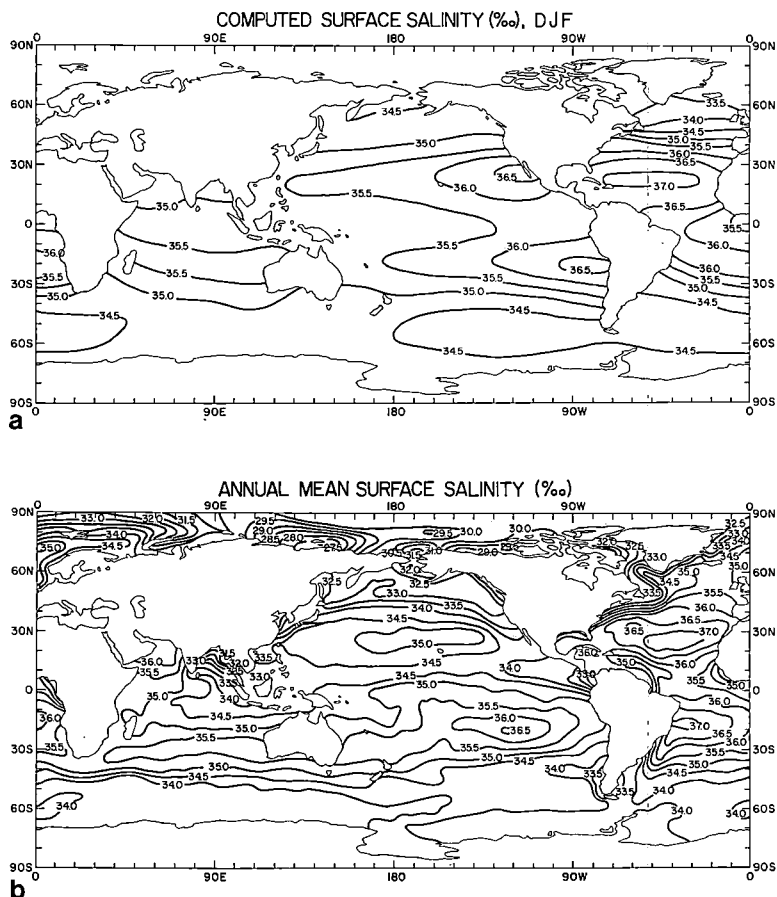


Fig. 11a, b. Geographical distribution of (a) computed (DJF) and (b) observed annual surface salinity (‰) (Levitus 1982). Computed JJA patterns are qualitatively similar

tic circumpolar current are much too warm and there is little concentration of the gradient. The same can be said for the Gulf Stream and Kuroshio Current systems. This pattern of weaker-than-observed currents occurs often in coarse-grid calculations that have horizontal resolutions of the order of 5° latitude and longitude [see examples of simulations with observed atmospheric forcing, e.g., Meehl et al. (1982) and Han (1984)]. The underestimation of sea ice and the lack of seasonal variability were also noted in a similar coupled simulation by Gates et al. (1985). The role of poleward ocean heat transport will be discussed later.

The geographical surface-salinity distribution for DJF from the model can be compared qualitatively with annual mean observations from Levitus (1982) in Fig. 11. Northern winter is shown from the model for later reference in discussions of the thermohaline circulation in that season. The observed distributions of salinity are determined from the precipitation, evaporation, and river runoff into oceans, as well as the internal dynamics of the ocean circulation. In the coupled model, river runoff is not taken into account. Thus, there is no fresh-water input into the oceans from the land areas. In spite of the simplifications and limitations of the model, some of the major features are simulated. This can be explained partly by the fact that salinity fluxes at the top of the ocean contribute little to the total salt content of the oceans. Over the time scale of these experiments, the salinity distribution is still heavily influenced by the initial distribution. The subtropical maxima of salinity in the North Pacific and North Atlantic are simulated, including the maxima of 37‰ in the North Atlantic. The Antarctic circumpolar and Arctic Ocean minima are also reproduced. The NH and SH Pacific salinity maxima associated with the semipermanent, high-pressure cells in the coupled model are too close to the west coasts of the continents, partially due to the weaker-than-observed upwelling of low-salinity sub-surface water there. Also, coarse-resolution OGCMs such as this one have difficulty upwelling lower-salinity water near the midlatitude eastern continental boundaries.

Figure 12 shows the latitude–depth distribution of the zonally averaged temperature for DJF from the model. Small seasonal changes are seen in JJA (not shown), but similar features can be compared to the observed annual mean values from Levitus (1982). The general pattern of the isotherms is simulated, but the permanent thermocline in the model is not as intense as the ob-

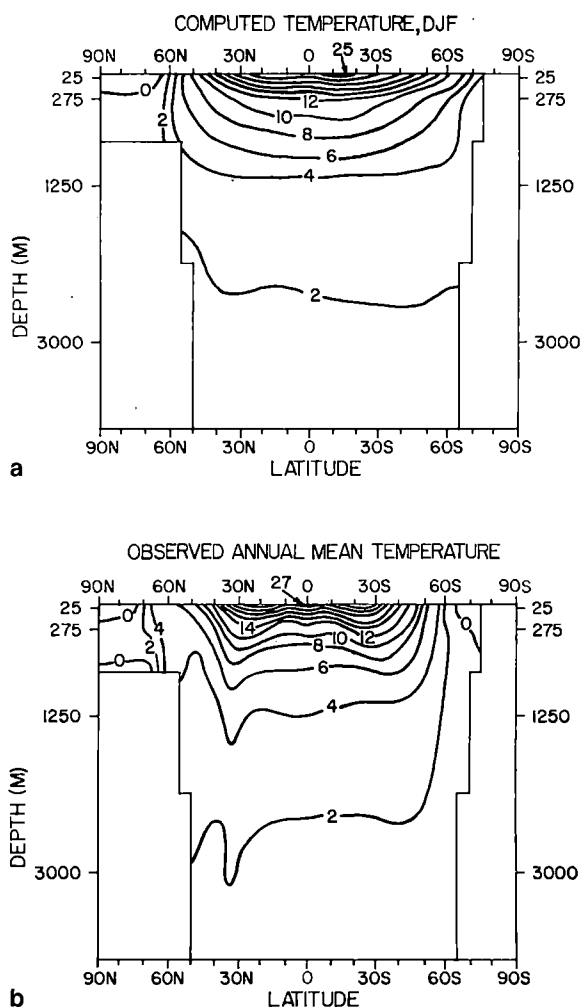


Fig. 12a, b. Zonally averaged (a) computed temperature (DJF, °C) and (b) observed annual mean temperature (Levitus 1982, °C). Contours every 2° C. Computed JJA patterns are qualitatively similar

served. As discussed earlier, the coarse vertical resolution in the model contributes to this discrepancy. Tropical surface temperatures are too low, and the model temperatures near Antarctica at the surface are about 4° C too high. The latitude–depth distribution of salinity (Fig. 13) shows the distinctive subtropical surface maxima mentioned earlier and the higher-latitude minima of less dense water. The model fails to show the deep penetration of saline water near 30°–40° N or the tongue of less saline water near 50° S. It is unclear how much of this error is from the initial distribution of salinity or model physics. More information on penetration of surface waters is given in Section 6 where the meridional streamfunction of both the global and North Atlantic sections is shown.

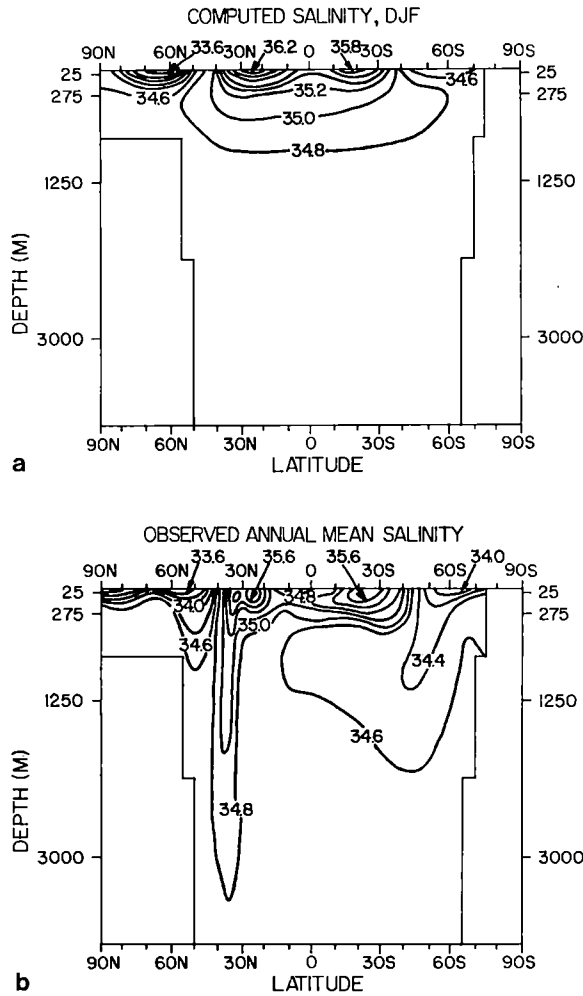


Fig. 13 a, b. Zonally averaged (a) computed salinity (‰) for DJF and (b) observed annual mean salinity (‰) (Levitus 1982). Computed JJA patterns are qualitatively similar

The ocean-heat transport can be divided into three components (Bryan and Lewis 1979; Meehl et al. 1982; Spelman and Manabe 1984): (1) the meridional component, which is overturning in the latitude-depth plane $\overline{VT}$, where the overbar indicates zonal average; (2) the gyre component $\overline{V'T'}$, where the prime represents deviation from the zonal average such that warmer water $T' > 0$ and north poleward flow $V' > 0$ yield $\overline{V'T'} > 0$ (thus, flow along the latitude-longitude horizontal plane, such as in the midlatitude gyres in which the Gulf and Kuroshio Currents are imbedded) and results in poleward heat transport; and (3) subgrid-scale lateral diffusion that transports heat in the model to account for subgrid-scale processes.

Figure 14 compares the total and component parts of ocean-heat transport with observed latitudinal estimates by Oort and Vonder Haar (1976),

Trenberth (1979), Hastenrath (1980), and Carissimo et al. (1985). The computed estimates with the OGCM are larger than those found in GFDL studies by Spelman and Manabe (1984) with a coupled model and by Bryan and Lewis with an ocean model with observed atmospheric forcing. Meehl et al. (1982) found that this same OGCM with specified atmospheric forcing produced heat

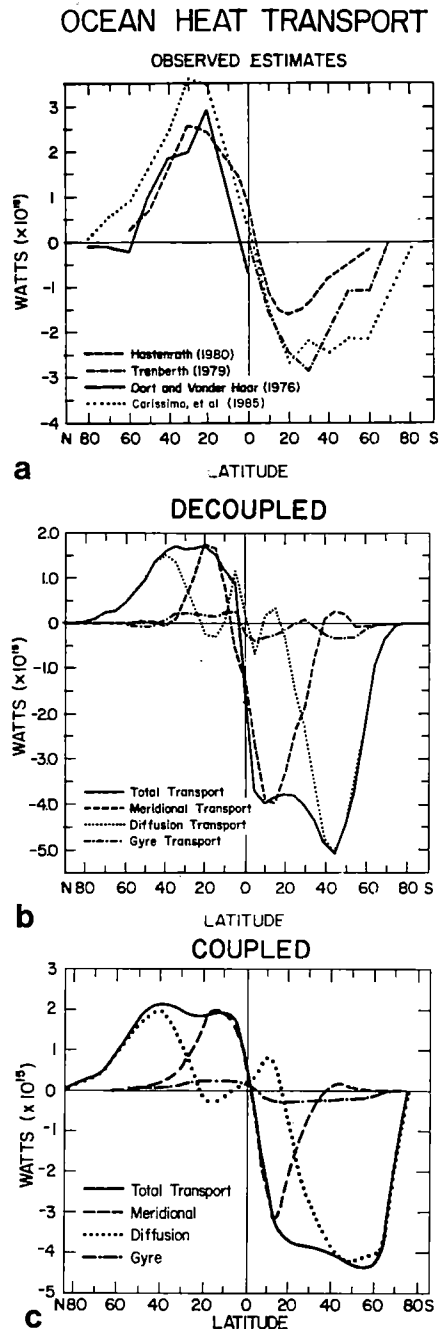


Fig. 14 a-c. Annual mean zonally averaged ocean heat transport for observed (a), decoupled experiment (b) (Meehl et al. 1982), and coupled experiment (c). Units are watts $\times 10^{15}$

transports dependent upon the strength of the wind stress. A more recent observational study by Hsiung (1985) with the surface-energy flux method yielded smaller values of heat transport than the earlier estimates. Another method sometimes used to estimate this flux is to calculate the ocean transport as a residual (Hartmann et al. 1986) from the atmosphere with a knowledge of the atmospheric heat transport. With all of the uncertainties and because direct global measurements are not yet feasible, it is difficult to estimate the true poleward ocean heat fluxes to within factors of at least two. In any case, the model transports in Fig. 14 show that most of the flux is accomplished by meridional overturning in the midlatitudes and tropics. The diffusion transport is very large in the middle and high latitudes, particularly in the Southern Hemisphere in the region of strong zonal temperature gradients. A smaller horizontal diffusivity for heat would have resulted in more heat transport by the meridional and gyre transports (Meehl et al. 1982) such that the total transport remains approximately the same [see Cox (1985) for discussion of such compensations when the resolution is changed]. Typically, with increased ocean resolution, the lateral diffusion heat transport decreases and the gyre component becomes larger. Remarkably, ocean heat transport in the coupled experiment shows the same characteristics as the specified atmospheric forcing case from Meehl et al. (1982), but the meridional transport is smaller. The diffusion component is also smaller, partly a result of less horizontal temperature gradient in the coupled experiment compared to the decoupled experiment.

The annual cycle of heat transport is shown in Fig. 15. To better understand this quantity, we also show an observed estimate for the NH (Oort and Vonder Haar 1976) (a), along with that computed from a decoupled ocean model with specified atmospheric forcing (including the full annual cycle of wind-stress forcing) (b), and another with one annual harmonic of wind-stress forcing (c) and the coupled experiment (d). The role of the second harmonic of wind stress in the tropics is discussed by Meehl et al. (1982). The coupled model yields a pattern qualitatively similar to that of the decoupled model forced with one annual harmonic of wind stress. These deficiencies are mostly found in the decoupled model. Since the semiannual variation of ocean heat transport is not well simulated in the coupled model, atmospheric forcing from the coupled system must be partially responsible.

OCEAN HEAT TRANSPORT

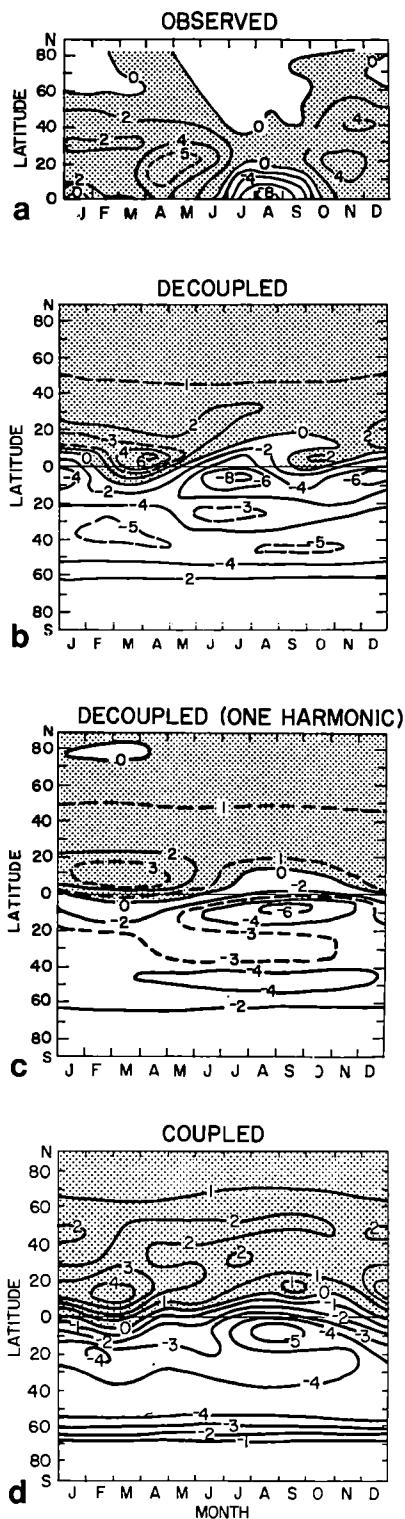


Fig. 15a-d. Annual cycle of total ocean heat transport (northward is positive, units are watts $\times 10^{15}$); a observed estimate for NH (Oort and Vonder Haar 1976); b computed for decoupled experiment; c computed for decoupled experiment with one harmonic; d computed for coupled experiment. Frames (b) and (c) are from Meehl et al. (1982)

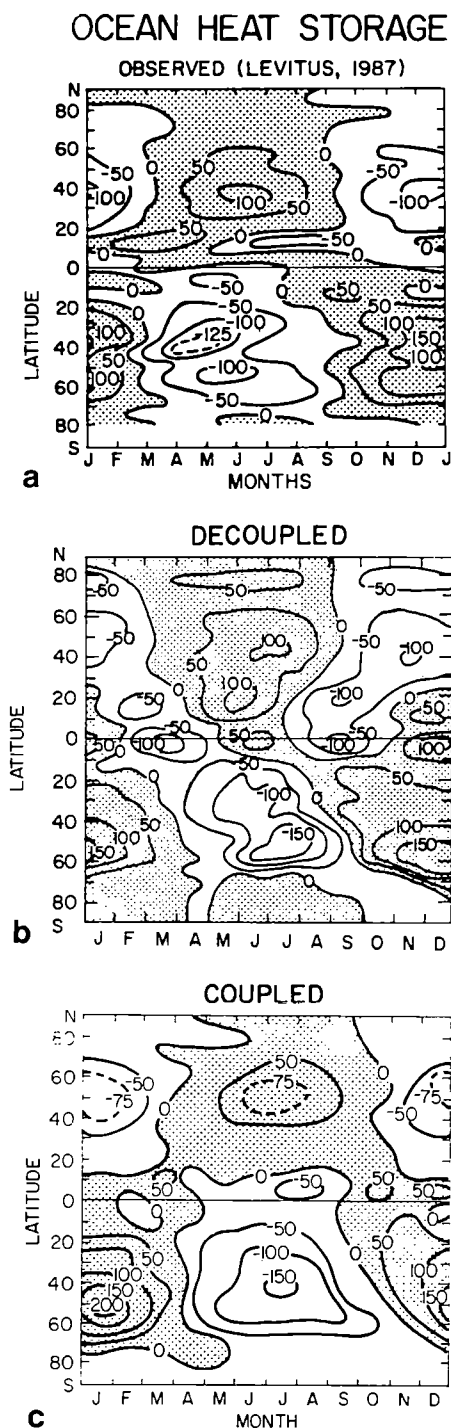


Fig. 16a-c. Annual cycle of rate of heat storage (W m^{-2}); a observed (Levitus 1987), b decoupled experiment (Meehl et al. 1982), c coupled experiment. Computed and observed are zonal averages over entire latitude strips; stippling designates ocean heating

Another important ocean quantity to examine is the annual cycle of ocean heat storage. The computation of the observed heat storage is discussed by Oort and Vonder Haar (1976), Meehl

(1984) and, more recently for the NH and SH, by Levitus (1987). This quantity is somewhat difficult to compute since it requires knowledge of the surface energy balance as well as changes in the local ocean heat content. The observed summer and winter midlatitude maxima and minima are about 100 W m^{-2} (Fig. 16). The decoupled and coupled experiments show qualitatively the same pattern with heat loss in winter and heat gain in summer, and slightly smaller amplitude of the annual cycle in the NH with somewhat larger amplitude in the SH. There is also a phase shift such that the seasonal extremes occur about 1 month later in the annual cycle in the ocean model compared to the observed estimates. It is not clear if the differences are significant, but for a reasonable climate simulation it is important that the model pattern resemble the observed.

Simulation of climate change due to instantaneous doubling of CO₂

Zonal distribution

To assess the changes in the climate system as a result of an instantaneous doubling of CO₂, 5-year averages from years 26 to 30 are computed for the $2\times\text{CO}_2$ and control cases. Figure 17 shows latitude-depth of zonal mean differences, $2\times\text{CO}_2$ minus control, for temperature (a) and salinity (b) for DJF. Similar patterns are evident in JJA (not shown). In Fig. 17a, the warming has penetrated into the third model layer (midpoint of 1250 m). The greatest warming is concentrated near the surface with maxima of about $+1.7^\circ\text{C}$ near 60°N and $+1.3^\circ\text{C}$ around 50°S . Similar maxima at these latitudes were noted in the coupled model simulation of Schlesinger and Jiang (1988). Minima of warming in the ocean are present in the tropics and high latitudes of each hemisphere, which contrast with the earlier ocean mixed-layer model results (Washington and Meehl 1984). Reasons for the differences will be explored later.

The zonal mean salinity differences (Fig. 17b) also show biggest changes in the surface layer of the ocean. Relative decreases of salinity occur in the midlatitudes of each hemisphere with greatest freshening (about 0.4‰) near 60°N . Salinity increases occur in the subtropics of each hemisphere with a slight decrease of zonal mean salinity near the equator. These changes in salinity are indicative of alterations of precipitation minus evaporation as well as changes of vertical mixing

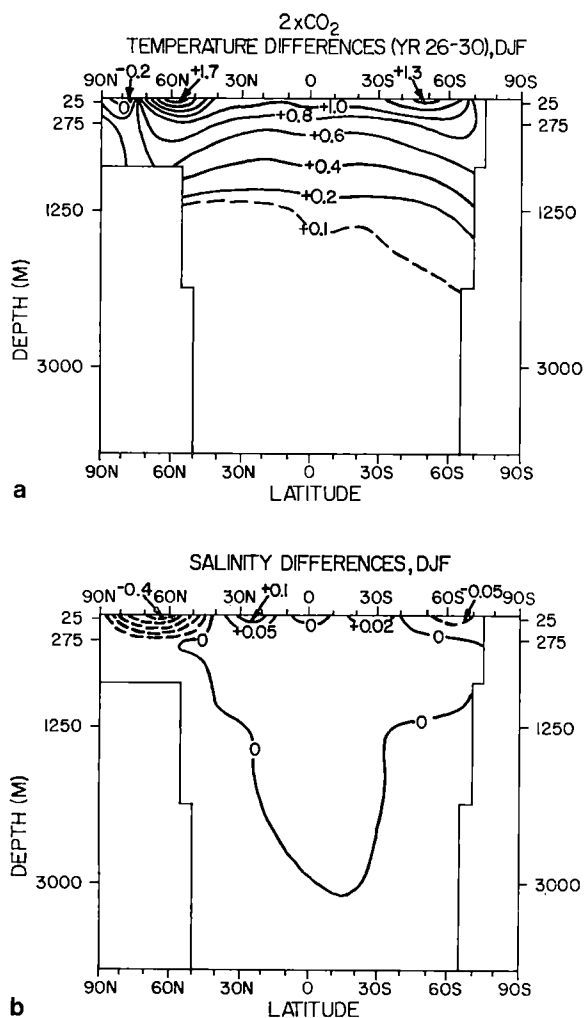


Fig. 17 a, b. Zonally averaged (a) ocean temperature ($^{\circ}\text{C}$) and (b) salinity differences (‰) between $2\times\text{CO}_2$ and $1\times\text{CO}_2$ (DJF) experiments for years 26-30

(discussed later). Warmer SSTs (Fig. 17a) that occur as a result of CO₂ doubling produce increased evaporation at most latitudes. Therefore, salinity changes roughly to correspond to differential alterations of precipitation. Increases of precipitation correspond to areas of decreases of salinity, and vice versa for relative decreases of precipitation. The fact that we neglect river runoff represents about a 10% error in the fresh-water addition to the oceans; the remaining 90% comes from local precipitation (Knauss 1978).

The associated zonal mean temperature changes in the atmosphere for years 26-30 are shown in Fig. 18. In the NH, reduction of sea ice (discussed in more detail in Fig. 32) is associated with a maximum warming during DJF of $+5.0^{\circ}\text{C}$ at the surface near 75°N . Such large surface warming at this time of year occurs as a conse-

quence of the ice-albedo feedback noted in previous studies. The signature of this feedback process is most readily apparent during winter. Increased absorption of solar radiation at the surface during summer (due to the reduction of sea ice) limits the equatorward expansion of sea ice during winter and is manifested by large relative surface temperature differences (e.g., Washington and Meehl 1984). Similar ice-albedo effects are not evident in the SH in Fig. 18 because of the near absence of sea ice around Antarctica (Fig. 10). The pattern of atmospheric temperature change in the vertical is similar to previous GCM results in that the increased CO₂ causes a warming throughout most of the troposphere and a cooling in the stratosphere.

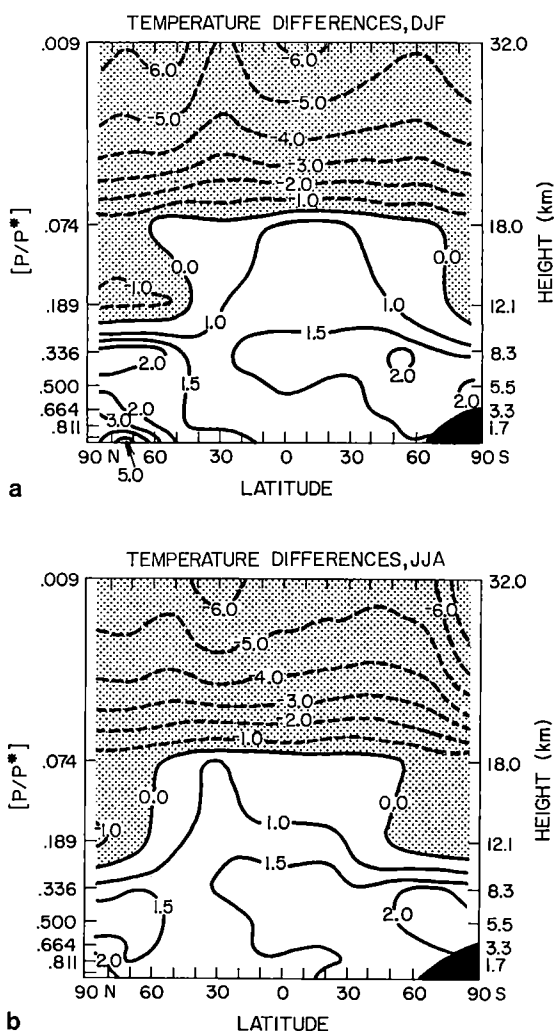


Fig. 18 a, b. Zonal mean atmospheric temperature differences ($^{\circ}\text{C}$) $2\times\text{CO}_2$ minus control ($1\times\text{CO}_2$), years 26-30. DJF (a), JJA (b)

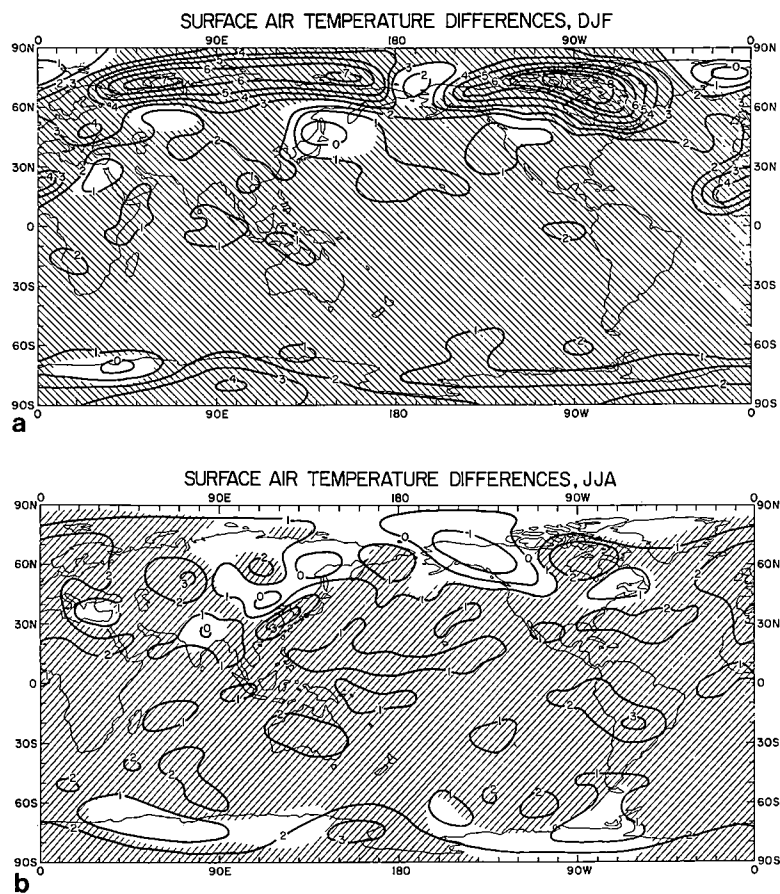


Fig. 19 a, b. Geographical distribution of surface air temperature differences ($^{\circ}\text{C}$, $\sigma=0.991$), $2 \times \text{CO}_2$ minus control ($1 \times \text{CO}_2$); a DJF, b JJA. Differences are 3-month averages taken over last 5 years of the experiment. Cross-hatching indicates differences significant at 5% level or greater

Geographical distribution

To examine the geographical patterns of surface air temperature change, difference maps, $2 \times \text{CO}_2$ minus control from the lowest model level ($\sigma=0.991$), are shown in Fig. 19 for DJF and JJA. Hatching indicates areas where the differences are significant at the 5% level, as computed from the first-moment test variate described by Chervin (1981) and used by Washington and Meehl (1984). The large warming in areas of sea-ice reduction alluded to in Fig. 18a for the zonal mean plots is statistically significant during DJF in Fig. 19a. Areas of significant warming are not as uniform over the NH during JJA in Fig. 19b. In the northern midlatitudes, warming at the surface greater than 2°C occurs near Hudson Bay and in east-central Asia and Europe. Warming in the SH is smaller in magnitude but geographically more uniform with most areas experiencing significant surface air temperature increases of about 1° – 2°C . Areas of cooling are present but are not statistically significant.

SST differences corresponding to the surface air temperature differences in Fig. 19 are shown

in Fig. 20. SSTs in most regions have warmed by about 1.0° – 1.5°C . Warming of 2.5° – 3.0°C in both seasons is evident in the north Atlantic, and there are positive differences of 2.0°C in the eastern equatorial Pacific during DJF and JJA.

It was mentioned that this model at 30 years produces less warming from increased CO₂ than the previous version coupled to the simple mixed-layer ocean. The lower tropical SSTs (Fig. 10) are associated with reduced atmospheric moisture (Fig. 7). The warmer high-latitude SSTs result in less-extensive sea ice (Fig. 10). Both factors contribute to a reduction of feedbacks that have been identified in previous studies as important in magnifying model sensitivity. For example, Washington and Meehl (1983) used the same atmospheric model coupled to a simple energy balance or swamp model which produced cooler SSTs in the tropics (see their Fig. 3). This contributed to reduced atmospheric moisture amounts (Washington and Meehl 1984, their Fig. 23a) and a reduced sensitivity compared to their subsequent mixed-layer ocean formulation (Washington and Meehl 1984). The latter formulation simulated SSTs warmer than observed (Meehl and Washing-

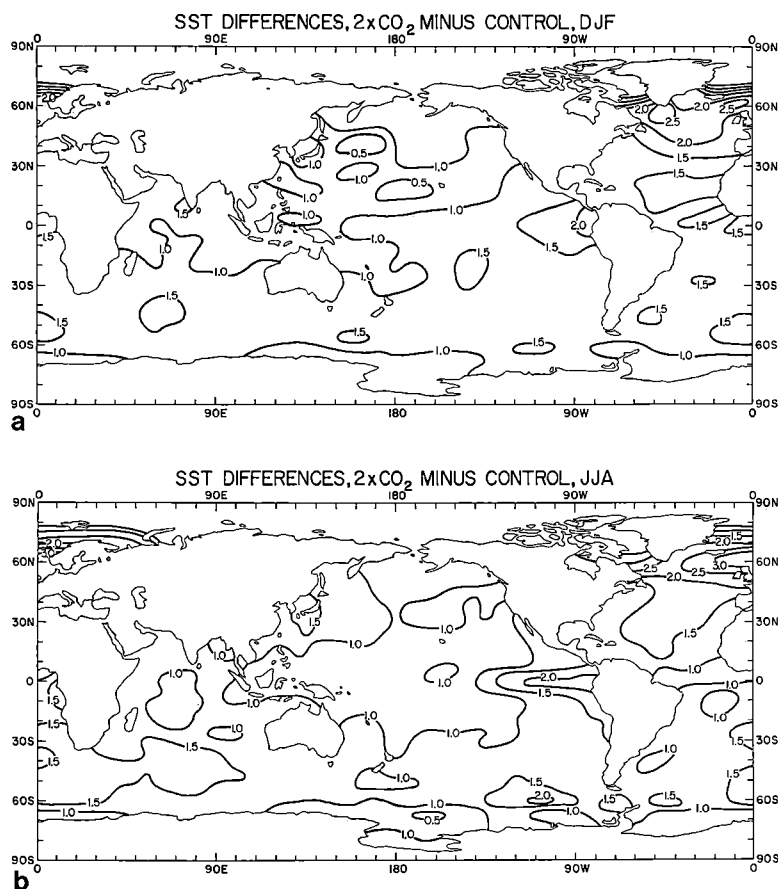


Fig. 20 a, b. Geographical distribution of SST differences ($^{\circ}\text{C}$, $\sigma=0.991$), $2 \times \text{CO}_2$ minus control ($1 \times \text{CO}_2$); a DJF, b JJA. Differences are 3-month averages taken over last 5 years of experiment

ton 1985) with greater amounts of tropical atmospheric moisture throughout the troposphere (their Fig. 10). This is partially due to the nonlinear Clausius-Clapyron relationship that links temperature and saturation vapor pressure which, in turn, is related to evaporation such that higher SSTs are associated with much greater evaporation. As a consequence, there is an increase in convection as well as a large fractional increase in atmospheric moisture in the upper troposphere associated with the enhancement of warming with height. For cooler tropical SSTs, a given increase in SST will result in smaller increases of evaporation and proportionately less CO₂ warming. For the swamp model, a doubling of CO₂ produced increases of low-level atmospheric moisture in the tropics of about 0.75 g kg^{-1} (Washington and Meehl 1984, their Fig. 23b) and a global warming of 1.3°C . The mixed-layer model warmed 3.5°C for the same CO₂ increase and raised the amounts of low-level atmospheric moisture in the tropics by about 2.0 g kg^{-1} (Washington and Meehl 1984, their Fig. 11).

The ice-albedo feedback is also important in

that the more extensive the sea ice, the greater the sensitivity (Washington and Meehl 1986). Estimates show that the ice-albedo feedback alone (in the mixed-layer model with overextensive sea ice) contributed more than 1°C of the 3.5°C global warming in that model (Dickinson et al. 1987).

From these studies and others, a model with high tropical SSTs and overextensive sea ice could be more sensitive than a model with low tropical SSTs and reduced sea-ice extent. Such is the case with the present model after 30 years of simulation. The large areas of surface warming noted in the previous mixed-layer model associated with sea-ice changes are present with much smaller amplitudes in northern winter (where sea ice is less extensive than in the mixed-layer model) and absent in the SH (Figs. 18 and 19). The anomalously cool tropical SSTs in the present model (Fig. 10) are associated with reduced amounts of atmospheric moisture in the control case compared to observations (Fig. 7) and smaller-amplitude increases in atmospheric moisture in the tropics when CO₂ is doubled (Fig. 21). The maximum values of low-level moisture increase in

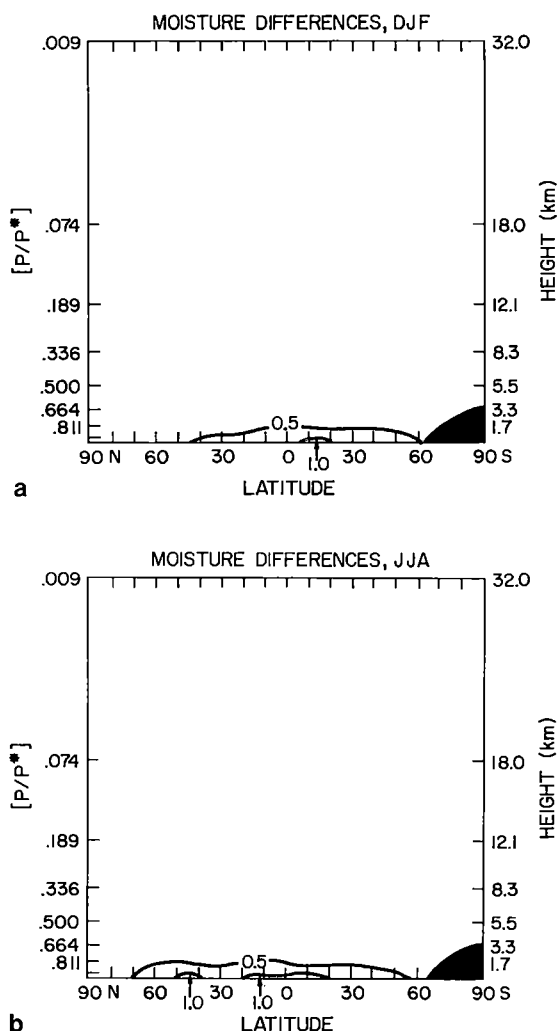


Fig. 21 a, b. Computed specific humidity differences (g kg^{-1}), $2 \times \text{CO}_2$ minus control ($1 \times \text{CO}_2$); DJF (a), JJA (b)

the present model are near 1.0 g kg^{-1} compared to twice that number for the mixed-layer ocean model.

Geographical patterns of soil-moisture change are shown in Fig. 22 for the two extreme seasons. Areas of soil-moisture decrease are stippled, and significance at the 5% level is hatched. Similar to previous experiments with the mixed-layer model (Washington and Meehl 1984; Meehl and Washington 1988), the continents are relatively dry in the present control case. For the doubled CO₂ case, many NH midlatitude continental areas experience soil-moisture increases during winter, but the pattern in summer is not as uniform. Soil moisture decreases in JJA over Europe and parts of Asia and North America, but increases are also evident. In particular, the increase over Alaska and northern Canada during JJA, in the mixed-

layer model associated with a soil-moisture-cloud-precipitation feedback (Meehl and Washington 1988), is also simulated by the present model in Fig. 22b. Thus, the soil-moisture change in these experiments is quite similar to that found in earlier versions of this atmospheric model.

To identify circulation changes in the ocean, it is useful first to examine the changes in wind-stress forcing. Figure 23 shows zonally averaged wind stress over the ocean for the control and $2 \times \text{CO}_2$ cases during DJF. Also plotted are the observed estimates for DJF from Hellerman and Rosenstein (1983). For reference, Meehl (1989) compares surface winds from several of the NCAR coupled model versions with observations. Model wind stresses for the present coupled model are still too weak, particularly in the midlatitude westerlies. This is a reflection of the general reduction of the equator-to-pole temperature gradient due to the limitations of the simulated ocean model SSTs. The pattern of easterlies in the tropics and westerlies at midlatitudes is reproduced in both model cases, however. When CO₂ is doubled, there is a noticeable reduction of westerly wind stress of about 0.03 N m^{-2} in the northern midlatitudes. This amounts to a decrease of about 20%–50% of the westerly wind-stress maximum in the northern winter. The SH westerly maximum at 40° S is also reduced at this time of year in the $2 \times \text{CO}_2$ case. The tropics show very small changes of zonal mean wind stress, even though there are interesting regional changes. For example, the warming of SSTs in the eastern tropical Pacific (Fig. 20) is associated with a local weakening of the easterlies there (not shown).

To understand how the zonal mean mass circulation in the ocean is affected by a doubling of CO₂, the meridional mass transport streamfunction is computed to represent the meridional overturning in the ocean. It follows the formulation of Bryan (1986) and can be written

$$\Phi = \int_z^0 \int_{\lambda_W}^{\lambda_E} v a \cos \phi d\lambda,$$

where Φ is the meridional mass transport streamfunction, z is the depth, λ_E and λ_W are limits on the ocean basin's east and west boundaries, a is the radius of the earth, ϕ is latitude, and v is the meridional component of the ocean current. The global meridional overturning from the control run during DJF is shown in Fig. 24a. Negative values indicate counterclockwise circulation. Near the surface are shallow wind-driven cells,

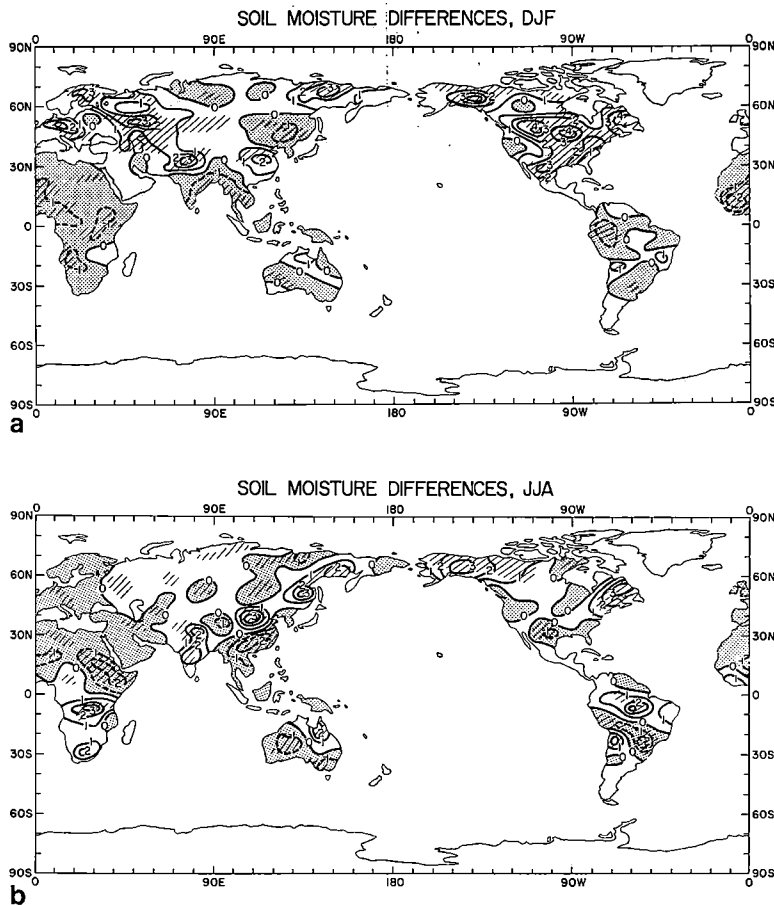


Fig. 22 a, b. Soil-moisture differences (cm), $2 \times \text{CO}_2$ -minus control, for 5-year averages from coupled model. *Stippling* shows decrease of soil moisture in $2 \times \text{CO}_2$ experiment. *Hatching* indicates differences significant at 5% level or greater. **a** DJF, **b** JJA

with deeper overturning indicating sinking near 40°–50° latitude below the wind-driven surface cells in both hemispheres. Bryan and Lewis (1979) show an ocean simulation of the meridional over-

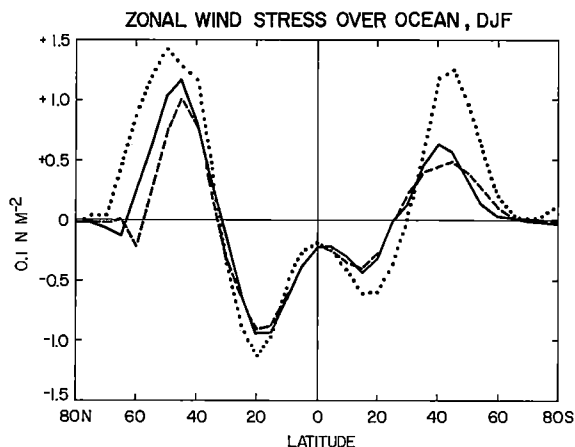


Fig. 23. Zonally averaged zonal wind stress over ocean (DJF, 0.1 N m^{-2}) for control, $2 \times \text{CO}_2$, and observed (Hellerman and Rosenstein 1983). *Solid line* control (year 26–30); *broken line* $2 \times \text{CO}_2$ (year 26–30); *dotted line* observed (Hellerman and Rosenstein 1983)

turning with a coarse-grid ocean model that is forced with observed atmospheric data. They found shallow, wind-driven cells near the surface with surface convergence and sinking near 30° N and 30° S. They also show sinking in the deeper ocean in the midlatitudes of both hemispheres, with strong sinking at high latitudes of the Southern Hemisphere. The deeper-layer circulations are partly driven by temperature and salinity differences. A weak upward circulation from great depths is indicated near 60° S. In a sector ocean-atmosphere model described by Bryan et al. (1988), this type of deep meridional overturning is much stronger and appears to minimize warming at high southern latitudes.

Pairs of tropical cells occur in opposition throughout the depth of the ocean and appear to be driven by continuity considerations between the four model layers and to vary seasonally with the wind forcing. Similar cells in the tropics have been noted in other model studies and may also be due to the inertial instability of cross-equatorial flow (Bryan 1986).

Since there are no strictly observed measures of meridional streamfunction and various ocean

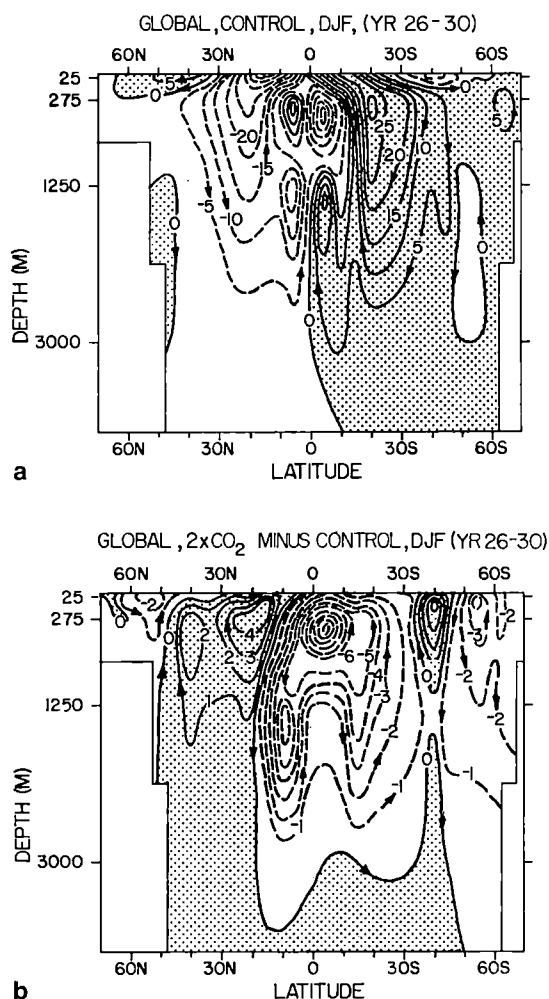


Fig. 24 a, b. Zonally averaged meridional overturning streamfunction (DJF) for years 26-30; a control, b $2 \times \text{CO}_2$ minus control. Positive values indicate clockwise circulation. Units are Sverdrups ($10^6 \text{ m}^3 \text{ s}^{-1}$)

models at different resolutions give different results, it is difficult to quantify the errors in the present model. Based on high-resolution ocean model calculations (e.g., Cox 1975; Semtner and Chervin 1988), the present model does not adequately represent the high-latitude sinking in the Northern Hemisphere. Representation of the Southern Hemisphere is even more ambiguous. For the present coarse-grid coupled model, the following discussion is only a qualitative indication of what may occur in the real ocean.

The difference of meridional streamfunction, $2 \times \text{CO}_2$ minus control for DJF, is shown in Fig. 24b. Positive values indicate anomalous clockwise circulation for the $2 \times \text{CO}_2$ case. Consistent with the reduction of the westerly wind stress in Fig. 23, the shallow, wind-driven midlatitude cells weaken in both hemispheres. The deep-ocean

midlatitude cells also weaken in both hemispheres. In particular, sinking weakens markedly near 50° N in the deep ocean with a doubling of CO_2 . This is associated with the warming and freshening of the surface layer noted in Fig. 17.

A similar plot of meridional streamfunction is shown in Fig. 25 for the Atlantic Ocean. Values are omitted south of about 30° S , where the Atlantic is not bounded by a finite basin. In the control case (Fig. 25a), the shallow, wind-driven cells are present near the surface as in Fig. 24. The thermohaline circulation is qualitatively represented with sinking in the deep ocean in the north and flow at depth crossing the equator into the SH. As mentioned earlier, however, this can only be a qualitative representation of the real circulation since the sinking in the North Atlantic is located south of

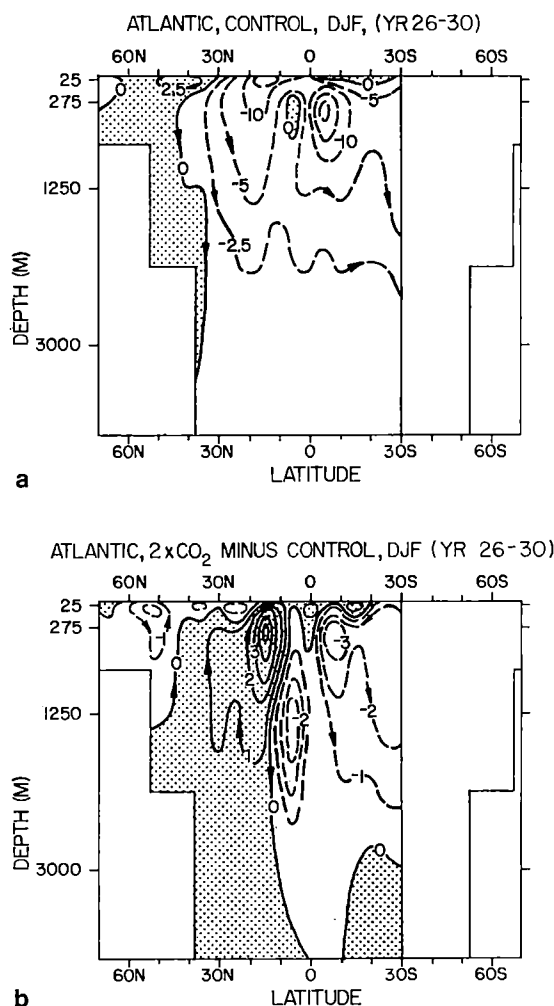


Fig. 25 a, b. Zonal averages for Atlantic meridional overturning streamfunction (DJF) for years 26-30; a control, b $2 \times \text{CO}_2$ minus control. Units are Sverdrups ($10^6 \text{ m}^3 \text{ s}^{-1}$). Positive values indicate clockwise circulation (not shown south of 30° S because basin not defined)

its likely observed location. A contributing factor appears to be the lack of northward penetration of warm saline waters from the North Atlantic Current in the model. This plays an important role in meridional overturning in the Atlantic (Manabe and Stouffer 1988). When CO₂ is doubled (Fig. 25b), the sinking in the north is weakened in association with the warming and freshening (and stabilization) of the upper ocean noted earlier and a weakening of the wind-driven circulation with the reduction of wind stress (Fig. 23).

Such a rapid response of the ocean (order of tens of years) with effects to great depths has been noted in previous modeling studies that reproduced altered buoyancy in the ocean. Bryan and Spelman (1985) documented a partial collapse of the ocean thermohaline circulation with a quadrupling of CO₂ after 25 years of simulation in a coupled ocean-atmosphere sector model. This was associated with warming and freshening of the upper ocean due to the increase of CO₂. Bryan (1986) documented changes of the thermohaline circulation in a basin ocean model associated with alterations of the salinity forcing at the surface. With a small surface salinity perturbation (a decrease of 1‰), a collapse of the thermohaline circulation was fairly rapid (order of 50 years). The response was much slower for an increased salinity anomaly. The present results from a coupled global ocean-atmosphere model with realistic geography and bottom topography support these earlier results obtained with simpler models. The models indicate that warming and freshening of the high-latitude surface layer cause stabilization of the ocean and weakening of the thermohaline circulation with effects to great depths on relatively short time scales (tens of years). In this coupled process, a change in the atmosphere (a doubling of CO₂) causes alterations of precipitation and evaporation which, in turn, stabilize the ocean by warming and freshening the surface layer and thus weakening the thermohaline circulation. In addition, the weakening of the westerlies in the model with increased CO₂ (Fig. 23) is associated with decreased overturning between the first and second layers of the model (not shown). Because of the halocline at high latitudes, less high-salinity water from the second layer is brought to the surface, thus also contributing to a stabilization of the ocean. A more realistic simulation of deep overturning at the high northern latitudes of the Atlantic would likely be even more sensitive to this process than the present model with sinking simulated farther south.

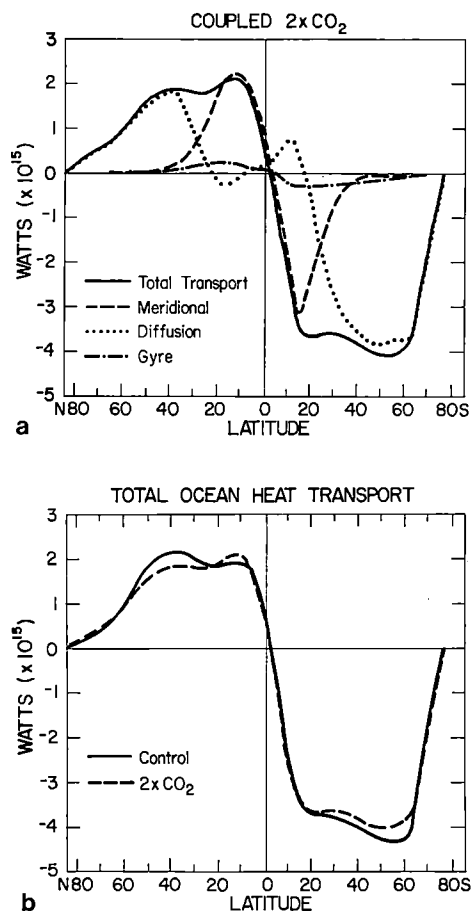


Fig. 26a, b. Annual mean ocean heat transport for (a) $2 \times \text{CO}_2$ case and (b) total annual mean ocean heat transport for control (from Fig. 14c) and $2 \times \text{CO}_2$ (from Fig. 26a)

Figure 26 depicts the annual mean components of horizontal ocean heat transport for the $2 \times \text{CO}_2$ case, and total heat transport for the control case and the case with an instantaneous doubling of CO₂. Transport decreases at midlatitudes, mainly due to a decrease in diffusion (Fig. 26a) associated with the slackening of the oceanic temperature gradient (Fig. 17a). A small increase of poleward transport near 10° S is associated with somewhat stronger meridional circulation in the second model layer (Fig. 24b).

The annual cycle of zonal mean heat transport and storage for the $2 \times \text{CO}_2$ case is shown in Fig. 27. The pattern of heat transport is similar to the control case (comparing Fig. 27a with Fig. 15d), with changes in amplitude reflected in the annual mean plot in Fig. 26. Heat-gain maxima are roughly the same in the two cases comparing Fig. 27b with Fig. 16c, but the seasonal heat-loss minima are reduced by about 10% (NH) to 30% (SH). This results in a net heat gain by the ocean in the $2 \times \text{CO}_2$ case.

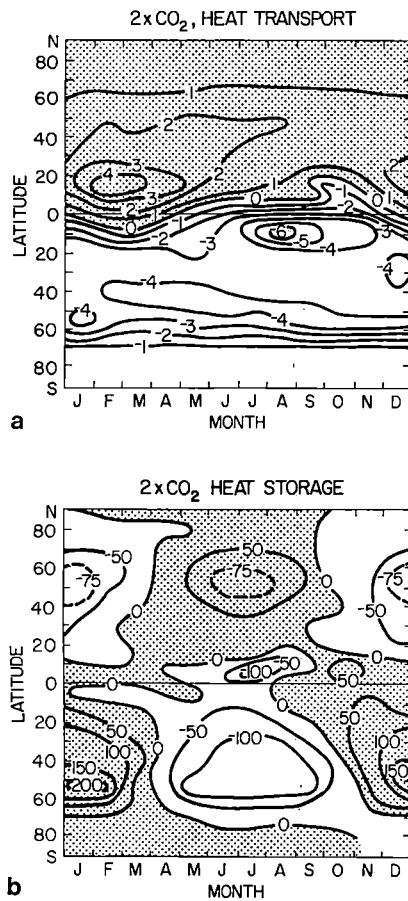


Fig. 27. a Annual cycle of zonal mean ocean heat transport ($\text{watts} \times 10^{15}$) and b ocean heat storage rate (W m^{-2}) for the $2\times\text{CO}_2$ case

An exception to this pattern is found in the equatorial tropics. The heat-gain maxima are reduced and the heat-loss minima, particularly in June and July, are greater in the $2\times\text{CO}_2$ case (comparing Fig. 16c with Fig. 27b). This goes along with the increase in poleward heat transport in the annual mean at 10°N (Fig. 26) for $2\times\text{CO}_2$. In the annual cycle of heat transport (Fig. 27a), an increase of poleward heat transport near 10°S in July and August is evident, along with an increase near 10°N . A similar pattern of change in heat transport and storage has been noted by Philander and Hurlin (1988) in a simulation of the 1982–1983 El Niño event. As tropical SSTs increase, they observed that net downward heat flux decreases as latent heat flux increases from the warmer water. When the excess heat from the equatorial tropics is transported poleward (increasing ocean heat transport), the net heat storage decreases since there is a deficit of net heat flux across the ocean surface to replenish the loss from the stronger poleward ocean heat transport.

A similar set of interactions occurs in the present coupled model.

Transient forcing response and time evolution

Zonal distribution

Even though an instantaneous doubling of CO₂ provides the climate system with a large uniform forcing in time, it is of interest to compare the more realistic effects of a gradual increase of CO₂ with the instantaneous CO₂ doubling case to determine if the latter can be used as an analogue of the former. Figure 28 shows zonal mean ocean temperature differences for 5-year periods in two experiments. Figure 28a is an average of years 6–10 ($2\times\text{CO}_2$ minus control), and Fig. 28b is an av-

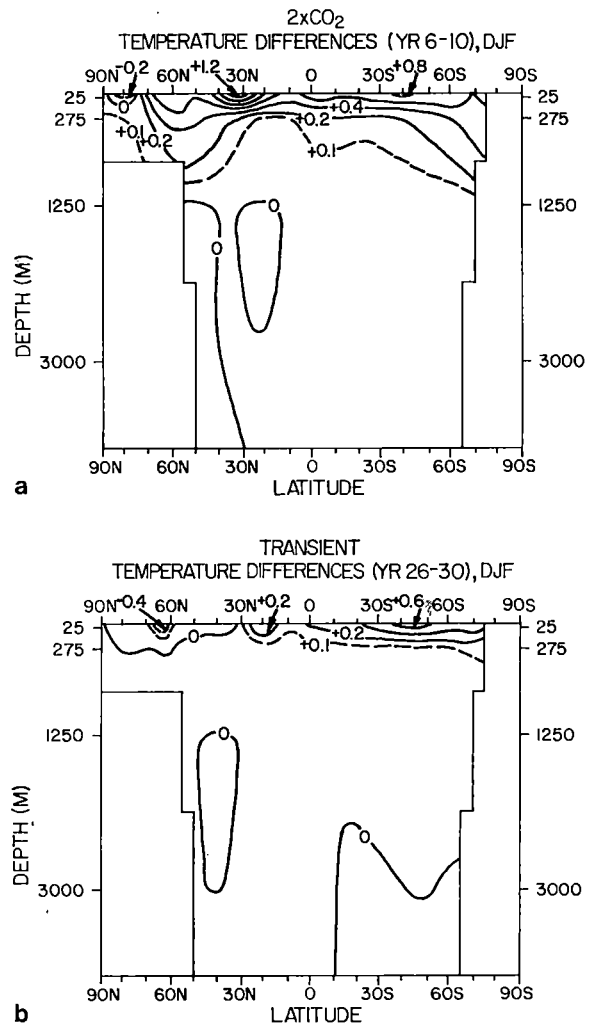


Fig. 28a, b. Zonally averaged ocean temperature differences ($^\circ\text{C}$); a $2\times\text{CO}_2$ minus control years 6–10 (DJF), b transient minus control years 26–30 (DJF)

erage of years 26–30 (transient minus control). The CO₂ amount in part (a) was doubled instantaneously at the beginning of year 1 to 660 ppm. In part (b), the CO₂ was increased gradually 30% over the 30-year period to 429 ppm. The averages for years 6–10 of the instantaneous doubling case are taken after the initial large increase of globally averaged temperature noted in Fig. 4. The results in Fig. 28a can be compared to the averages 20 years later in that same experiment (i.e., Fig. 17a). DJF is shown because it is the season that exhibited the largest signal of surface air temperature change in the instantaneous CO₂ doubling experiment (Fig. 19). The results for this earlier period in Fig. 28a show most of the warming confined to the top two layers of the ocean, with greatest temperature increases at the surface near 30° N and 40° S and minima of surface warming at high latitudes of each hemisphere. This pattern is similar in a number of respects to that of Fig. 17a for the later period averaged over years 26–30. A relative minimum of warming occurs in the tropics and at high latitudes in both periods, but the magnitude of the warming is larger in the later period and the temperature changes penetrate into the third layer. Also, the latitude of maximum warming in the ocean surface layer shifts from approximately 30°–40° latitude in both hemispheres in the early period to approximately 60° N and 50° S in the later period. Changes in salinity in the early period (not shown) are nearly identical to those in the later period (Fig. 17b). This indicates that the alterations of the climate occur rapidly, that precipitation, evaporation, and vertical overturning due to wind-stress changes affect the salinity, and that the pattern remains fairly constant in time. Temperatures, on the other hand, appear to warm in the subtropics first and then, as feedbacks with sea ice and stabilization (discussed above) occur, the warming at the surface increases in the midlatitudes.

The temperature changes for years 26–30 in the transient experiment are understandably smaller compared to the CO₂ doubling case because the CO₂ amount has increased by only 30%. Most of the changes are confined to the surface layer with maxima of warming near 45° S and 20° N. For this time period, however, there is no uniform warming at all latitudes in the surface layer. North of about 30° N there is cooling in the zonal mean with a maximum of negative temperature difference near 65° N. In both periods of the instantaneous CO₂ doubling case, warming was at a minimum at high latitudes of both hemispheres with even slight zonal mean cooling at high north-

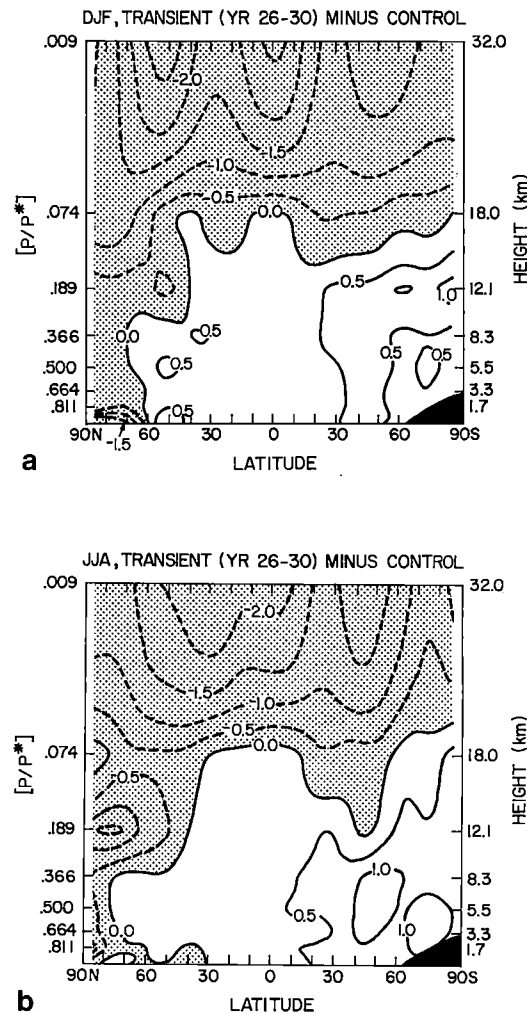


Fig. 29a, b. Zonally averaged atmospheric temperature of transient minus control for years 26–30 (°C); DJF (a), JJA (b)

ern latitudes. The cooling in the transient case is more extensive than in the earlier instantaneous doubling case, as discussed later.

Figure 29 shows the zonal mean temperature differences, transient (years 26–30) minus control, for the atmosphere in DJF and JJA. The pattern for the instantaneous doubling case (Fig. 18) is similar, with warming at most latitudes in the troposphere and cooling in the stratosphere. But the cooling in the zonal mean temperatures of the ocean surface layer poleward of 30° N is reflected as a cooling in the zonal mean through the depth of the troposphere at high northern latitudes in both seasons. Near 60°–80° N, where the largest warming in the lower atmosphere was seen in Fig. 18a during DJF, a net zonal mean cooling is evident in Fig. 29a for the transient case. Reasons for these differences are discussed below.

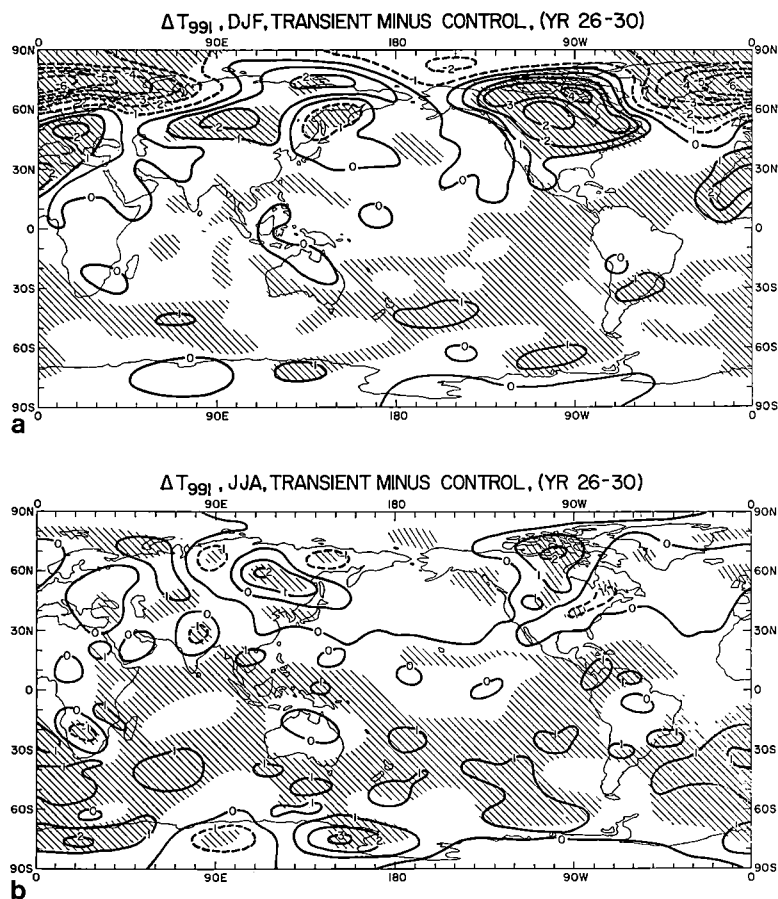


Fig. 30 a, b. Geographical distribution of surface air temperature differences ($^{\circ}\text{C}$, $\sigma=0.991$), transient minus control years 26–30; **a** DJF, **b** JJA. Differences significant at 5% significance level are *hatched*

Geographical distribution

Geographical plots of surface air temperature difference (from the lowest model level at $\sigma=0.991$), transient (years 26–30) minus control, for DJF and JJA are shown in Fig. 30. These plots can be compared to similar maps from the instantaneous doubling case in Fig. 19. Statistical significance at the 5% level is indicated by cross-hatching as before. In the NH, significant warming is present over North America, Europe, central Asia, and northwest Africa. A large area of significant cooling appears over the North Atlantic and extends north of Europe into the Arctic. During northern summer (Fig. 30b), the magnitude of the temperature differences in the NH decreases with significant areas of warming over eastern Asia and northern North America. In the SH year-round, large areas of small-amplitude (near 1°C) statistically significant warming occur, particularly over the southern oceans. This was noted in the zonal mean ocean temperatures in Fig. 28.

In a comparison of the results from the transient experiment in Fig. 30 with those from the in-

stantaneous doubling case in Fig. 19, there is clearly more noise in the differences of the transient case (much less area of statistical significance). Agreement is mainly in the SH, where significant warming of the order of 1°C covers much of the southern oceans in both cases. Over the NH mid- and high latitudes, however, interesting differences exist between the two cases. The area of cooling from about 65°W to 80°E between about 60° and 80°N in the transient forcing case is much larger than the corresponding small area of negative temperature difference just east of Greenland in Fig. 19a for the instantaneous doubling case.

The patterns of change for SSTs in the transient case (not shown) reflect the surface air temperature differences in Fig. 30 with cooling of up to 1°C in the North Atlantic near 60°N and cooler SSTs (about 1°C) off the northeast Asian coast. In the SH, SSTs are higher by about 0.5° – 1.0°C . Surface salinity changes for this same case (not shown) indicate a pattern similar to that shown for the instantaneous doubling case, except that the magnitude of the changes is reduced

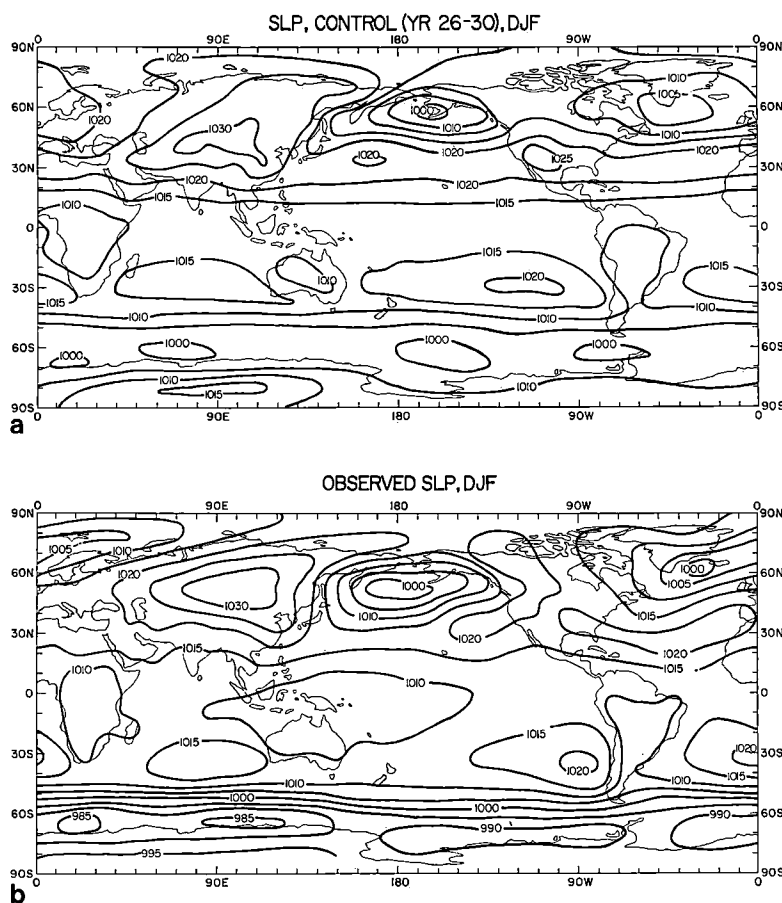


Fig. 31a, b. SLP (mbar) for (a) the control case averaged over years 26–30, and (b) observed values from Crutcher and Meserve (1970, Northern Hemisphere) and Taljaard et al. (1969, Southern Hemisphere)

by about one-half or less. In the North Atlantic, the salinity in the transient case is reduced by about 0.1‰.

To determine the differences in climate change between the instantaneous doubling and transient cases, it is necessary to examine the effects of changes in atmospheric circulation between the two cases for this period. Figure 31 shows the mean sea-level pressure (SLP) for the control case DJF, averaged over years 26–30, and the long-term mean observed SLP for DJF. In the NH, the intensity and position of the Aleutian and Icelandic lows and high pressure over Asia and North America are well simulated. The Aleutian low in the model is shifted somewhat north and east over the ice-free Bering Sea which is ice-covered in the observations (Fig. 10). The Icelandic low in the model is located south and west of its position in the observations. In the model, warmer SSTs are located here. In the observations, the Gulf Stream and North Atlantic Current advect warm water farther north and east, and the Icelandic low is positioned accordingly.

The distribution of sea ice in the NH during winter is shown in Fig. 32. The extent of sea ice

observed during January averaged over the period 1973–1976 is shown in Fig. 32c from Parkinson et al. (1987). The limits of sea ice in the model for DJF (defined as the extent of average ice thickness more than 0.01 m deep) are shown for the $2 \times \text{CO}_2$ case compared to the control (Fig. 32a) and for the transient case compared to the control (Fig. 32b). The position of the 0.50-m ice-depth line is also shown. In a comparison of the control-case distributions with the observed, the lack of penetration of warm water into the North Atlantic in the model (associated with a weaker-than-observed Gulf Stream and North Atlantic current) results in sea ice covering the ocean from Greenland to Norway in the model. The warmer-than-observed SSTs in the North Pacific (Fig. 10) are associated with a sea-ice limit in the model located in the Bering Strait instead of farther south, as in the observations. The implications of these sea-ice distributions on the SLP field were previously mentioned in relation to Fig. 31.

When CO₂ is doubled, reductions of sea ice occur almost everywhere (Fig. 32a), as indicated by a retreat of both the 0.01-m and 0.50-m contours. Near the ice margin, a mean reduction of

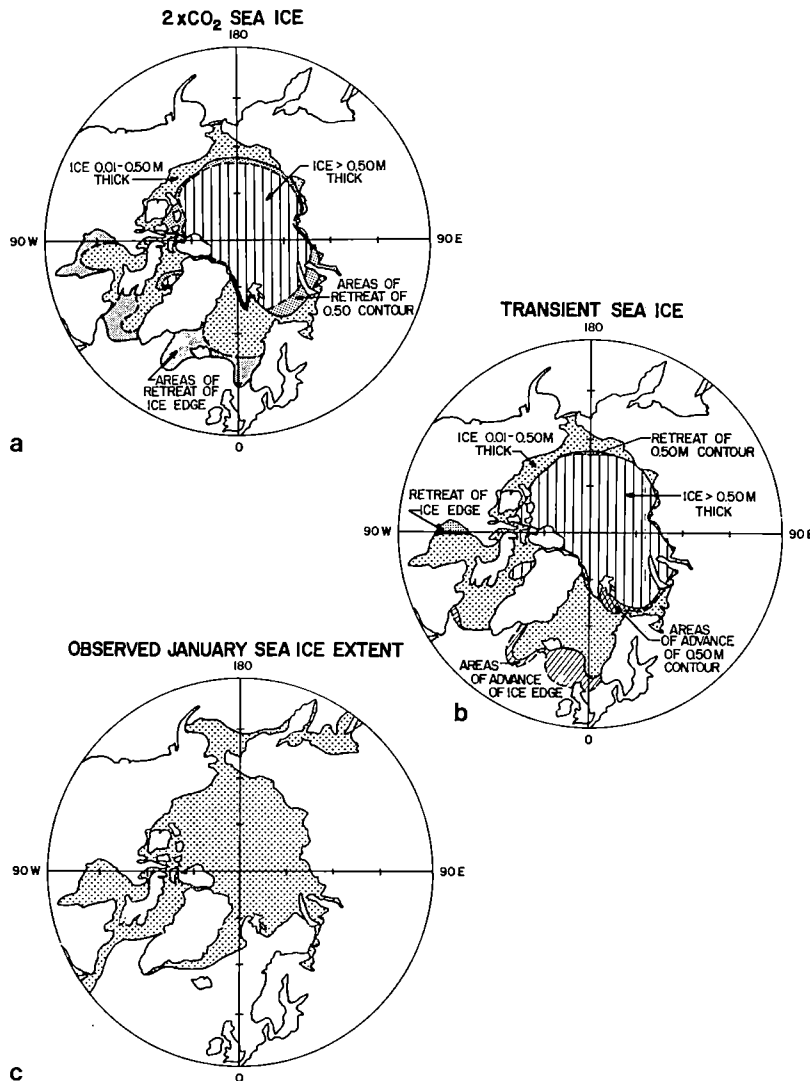


Fig. 32 a-c. Sea-ice distribution for (a) $2 \times \text{CO}_2$ case compared to control case (DJF), (b) transient case compared to control case (DJF), and c observed sea-ice limits for January from Parkinson et al. (1987) averaged over 1973-1976. In a and b solid contours indicate control case; dashed contours indicate increased CO₂ cases

ice thickness is represented by periods of open water alternating with periods of ice-covered water. Therefore, the frequency of ice-free ocean areas increases and is evidenced by a decrease of seasonal mean ice thickness. In the transient case, the largest areas of sea-ice decrease from the warmer climate occur mainly in Hudson Bay and are associated with the warmer continent (Fig. 30a). In the North Atlantic, the sea-ice limit advances in association with the colder temperatures there (Fig. 30a).

SLP differences (Fig. 33) indicate how the atmospheric circulation is affected in the model experiments. For the $2 \times \text{CO}_2$ case (Fig. 33a), the warmer continents in the NH are associated with lower SLP (negative differences). Large centers of positive differences are located near northeastern Greenland and over the North Atlantic. These are associated with a weakening and northwestward

shift of the Icelandic low. The low weakens in the mean (implying fewer and less intense storms) due to the general warming of the North American continent and reduction of baroclinity in this region. The center of the low shifts northwestward over the more frequent ice-free ocean areas (ice-covered in the control case) of Hudson Bay and the Labrador Sea southeast of Baffin Island. In the North Pacific, the Aleutian low shifts northwestward as the sea ice is reduced north of the Bering Strait. This is manifested by positive SLP in the Gulf of Alaska and negative differences over the northwest Pacific. A similar decrease of SLP with an imposed ice-line retreat in these regions was noted by Herman and Johnson (1978). Lower SLP is located north of most of Russia associated with the reduction of mean sea-ice thickness (and associated increase in episodes of open water) in those regions. Depending on the

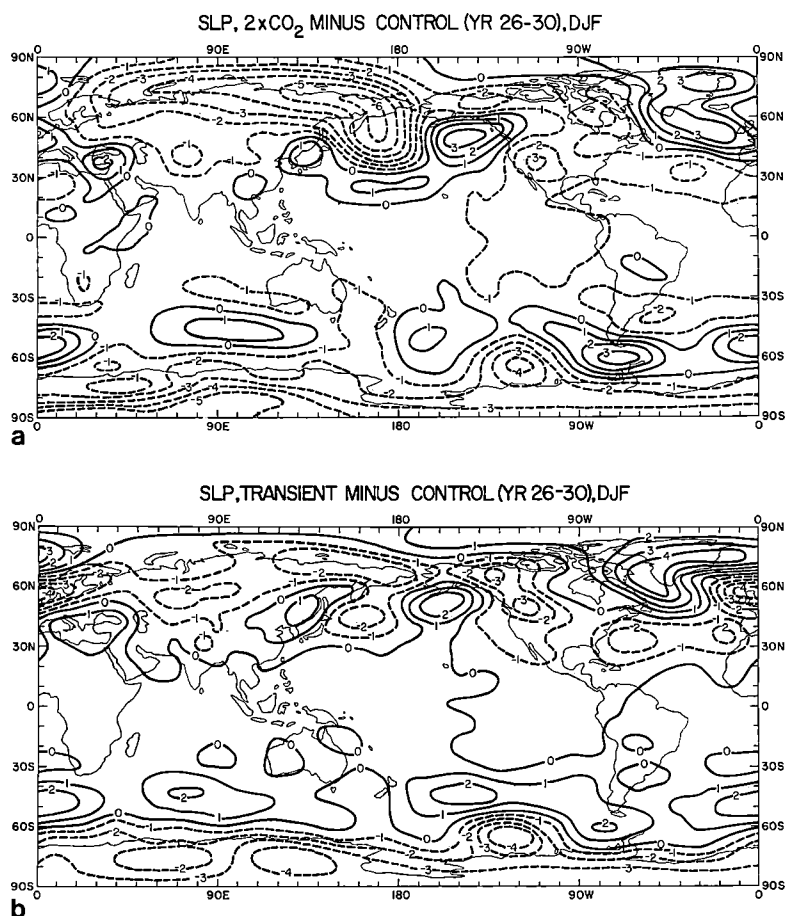


Fig. 33 a, b. SLP differences (mb), DJF, for (a) $2 \times \text{CO}_2$ minus control, years 26–30, and (b) transient minus control, years 26–30. Solid contours indicate positive SLP differences. Dashed contours are negative differences

model and associated circulation regimes, decreases in sea ice often are associated with lower SLP [shown for the Southern Hemisphere, for example, by Mitchell and Hills (1986)].

In the SH, the warming of the oceans increases baroclinity at the surface (Fig. 17a), and the circumpolar trough intensifies slightly and moves south as evidenced by positive SLP differences near 45° S and negative differences near 65° S. Although the effect of an increase in baroclinity has been documented in the atmospheric model by Meehl and Albrecht (1988), the effect in the present model involves fairly shallow changes near the surface. Since the amount of sea ice is negligible around Antarctica (Fig. 10), there is no ice-albedo feedback at those latitudes. If sea ice existed there in the present coupled model, it could have the same effect as noted in the mixed-layer model of Washington and Meehl (1984) in that a decrease of baroclinity would occur. That would have the opposite effect on the circumpolar trough.

As the centers of action, denoted by the SLP field, are affected by the change of CO₂, advec-

tion of air at the surface in the model is altered accordingly. This contributes to the surface air temperature differences (Fig. 19). In this figure, surface air temperature values increase almost everywhere except northeast of Greenland and north of Japan during DJF. The anomalous geostrophic flow implied by the SLP differences in Fig. 33a (and substantiated by changes in the surface wind field, not shown) indicates an increase of northerly component flow from polar latitudes northeast of Greenland and greater northwesterly flow off the Asian continent north of Japan. Colder air advected from these regions results in the decrease in surface air temperature (and SSTs) in the $2 \times \text{CO}_2$ case.

For the transient case (Fig. 33b), the pattern of SLP differences is similar to the $2 \times \text{CO}_2$ case (Fig. 33a). A notable difference is in the North Atlantic. The weakening of the Icelandic low with the warming of the continent and decrease in baroclinity is reflected by positive SLP differences near Greenland as in the $2 \times \text{CO}_2$ case. A center of negative SLP difference is located near England. In the $2 \times \text{CO}_2$ case, this area was dominated by

higher SLP. This subtle difference has implications for the coupled climate system in this region and critically affects the climate-change signal over a wide region during this period of the transient forcing case.

In the instantaneous doubling case, the large constant CO₂ warming signal causes rapid changes to the climate system (time scale of less than 5 years; see Figs. 4, 17, and 28). Sea-ice reduction and associated atmospheric circulation changes happen quickly and most of the surface layer of the ocean in the model responds to these large-amplitude changes in forcing. During the first year after the instantaneous doubling of CO₂, the pattern of changes in years 26–30 is already established (not shown). This includes a rapid warming of the ocean surface layer and model troposphere and a uniform reduction of sea ice at all longitudes.

In the transient case, the changes in forcing are much slower and the climate system has a chance to evolve gradually. The pattern of changes is similar (comparing Fig. 33a with 33b), but the time evolution allows more adjustment by the ocean to the gradual changes in atmospheric circulation. This is the case with the North Atlantic in the model. As the Icelandic low weakens, sea ice does not retreat as fast as in the 2×CO₂ case (Fig. 32 and noted above). Therefore, the center of the Icelandic low does not shift as quickly northwestward, and substantial northerly wind-stress anomalies set up in the North Atlantic (Fig. 34). This flow brings colder air southward.

In the 2×CO₂ case, the ocean is in closer equilibrium with the air above it in the North Atlantic. The difference in surface heat flux for the DJF season, years 26–30, averaged over an area from 45° N to 65° N and 45° E to 65° E between the 2×CO₂ case and the control shows a net loss from the ocean of only 1.9 W m⁻². In the transient case compared to the control for the same season and averaging period, the ocean is losing 21.2 W m⁻² to the colder air above it in this same area of the North Atlantic. Consequently, in the transient case the ocean surface cools along with the surface air temperature (Fig. 30a) and sea ice expands southward accordingly (Fig. 32). This process actually increases baroclinity between the North Atlantic and the European continent, more storms form there, and the result is anomalously low SLP near England (Fig. 33b). As these storms move across northern Europe, cold air is advected from the north, resulting in cooler surface air temperatures across most of Scandinavia and northern Russia in the transient case (Fig. 30a). This pattern of surface air temperature change for this period in the transient forcing case is noticeably different from that described for the instantaneous CO₂ doubling case (Fig. 19). These differences in the patterns of climate change appear to be the result of feedbacks among the atmosphere, ocean, and sea ice that are affected by the rate of change of the external forcing (i.e., instantaneous doubling versus a gradual increase of CO₂) as well as the CO₂ amount. These different patterns are indicative of time-dependent climate anomaly

SURFACE WIND STRESS VECTOR DIFFERENCES TRANSIENT MINUS CONTROL (YR 26-30)

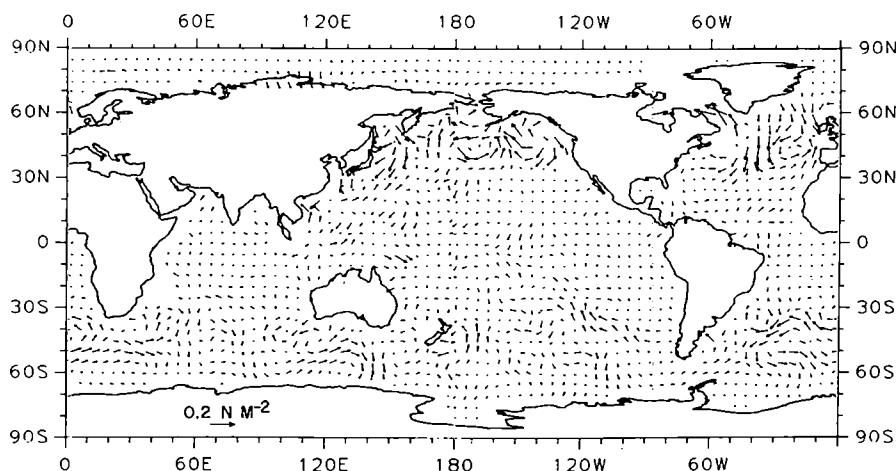


Fig. 34. Wind-stress vector differences, transient minus control, years 26–30

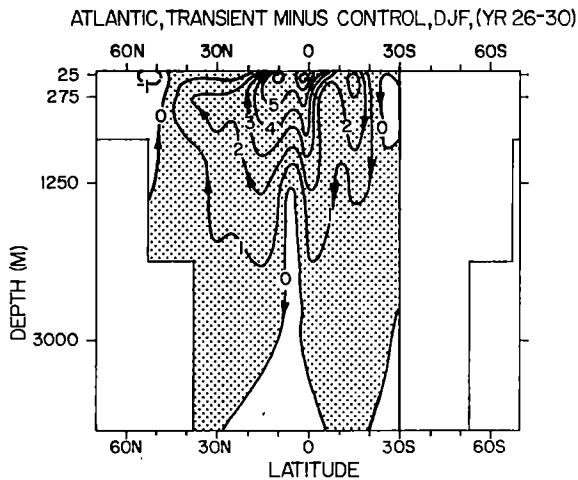


Fig. 35. Zonally averaged Atlantic meridional overturning streamfunction, transient minus control (DJF) for years 26-30. Units are Sverdrups ($10^6 \text{ m}^3 \text{ s}^{-1}$)

regimes in the transient forcing case. This suggests that there may not be one single CO₂-forced atmospheric circulation pattern at high latitudes that would remain constant with time and merely grow in amplitude.

A somewhat analogous situation has been observed in the real atmosphere in association with the North Atlantic Oscillation. Rogers and van Loon (1979) show that a deeper Icelandic low is often associated with colder temperatures in southeastern Iceland and more extensive ice cover in the North Atlantic. However, in the model the southward-shifted storm track brings cold temperatures to Scandinavia and northern Russia as well. Rogers (1989) notes a similar regime in the Arctic observed in recent years similar to that in the transient forcing case, suggesting that analogue regimes may exist in the real coupled climate system.

Near Japan, similar processes are taking place in the $2 \times \text{CO}_2$ and transient cases to produce cooler temperatures. The weakening and westward shift of the Aleutian low result in anomalous northerly component flow at the surface (Fig. 34) and lower surface air temperatures and SSTs in this region.

The salinity changes in the transient case resemble the $2 \times \text{CO}_2$ case in the North Atlantic in that both are manifested by a decrease in salinity. This is associated with a weakening of the mean

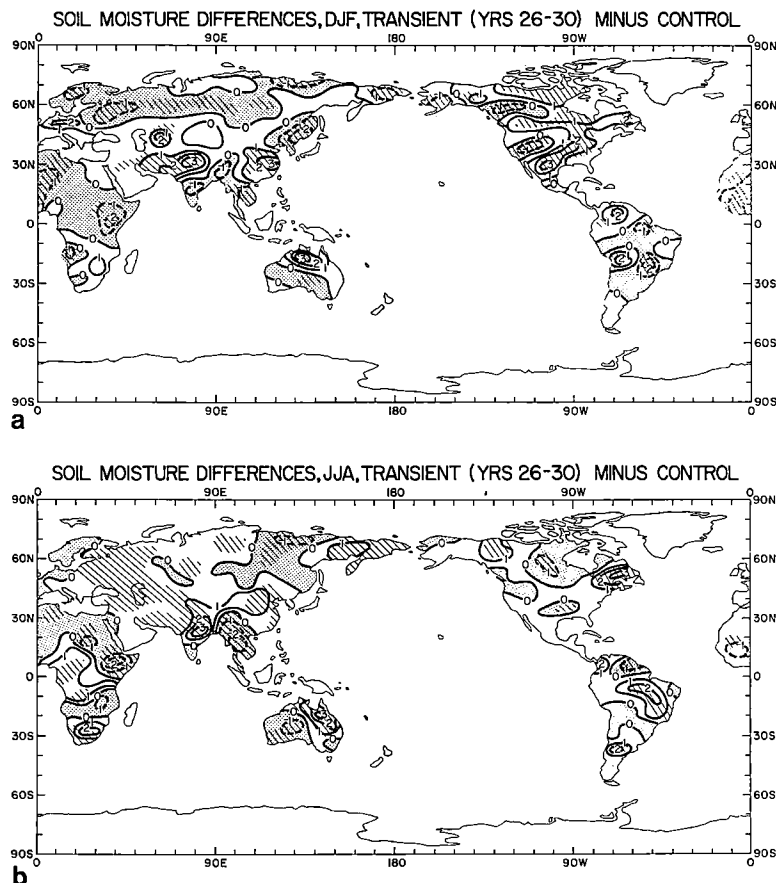


Fig. 36a, b. Soil moisture differences (cm), transient minus control, for 5-year averages for coupled model (years 26-30). Stippling shows decrease of soil moisture in $2 \times \text{CO}_2$ experiment. Hatching indicates differences significant at 5% level or greater. a DJF; b JJA

southwesterly wind stress in this region in the model, Ekman divergence at the surface decreases, and upward vertical motion in the ocean is reduced (not shown). As discussed previously, since a strong halocline exists in the ocean model at these latitudes (Fig. 13a), the mixing between the first and second layers is also reduced, thus contributing to a decrease in surface salinity in both cases at those latitudes. This effect, along with the anomalous northerly flow at the surface (associated with the northerly wind-stress vector differences shown in Fig. 34), results in a weakening of the meridional overturning in the Atlantic in the transient case (Fig. 35) in spite of the lower SSTs there. However, as discussed in the instantaneous CO₂ doubling case, aspects of the meridional ocean circulation not well simulated by the model may be important in the transient forcing case. Determination of the importance of these factors awaits a better coupled model.

The changes in atmospheric circulation in the transient case are reflected in the differences in soil moisture (Fig. 36). During DJF (Fig. 36a), the relatively colder air temperatures over Scandinavia and northern Russia are associated with increased snow cover that does not melt during that season (and therefore does not add to the soil-moisture reserve). This is reflected in the negative soil-moisture differences in that region during winter. When this snow melts later in the year, it adds to the soil-moisture reserve and soil moisture increases during JJA in that area (Fig. 36b). Similar to the $2 \times \text{CO}_2$ case (Fig. 22), much of North America experiences an increase in soil moisture during winter and decreases during summer in the transient case. Both cases are similar in that many areas of Africa show net decreases in soil moisture for most of the year.

Conclusions

As part of a continuing series of experiments with a hierarchy of ocean formulations coupled to the same atmospheric model, a coarse-grid (5° latitude-longitude grid, four layers in the vertical) OGCM is coupled to a global, spectral (R15) GCM of the atmosphere. Three experiments are performed with this model. The first is a control run with the present amount of CO₂ (330 ppm), the second instantaneously doubles the CO₂ (to 660 ppm), and a third gradually increases CO₂ at a linear rate of 1% per year. All three are run for 30 years, and 5-year averages at the end of this period (years 26–30) are computed. In addition,

other periods in the evolution of the experiments are studied to assess the time evolution of the climate-change signals.

Globally averaged surface temperatures for the instantaneous CO₂ doubling case show a fairly rapid rise in the first 5 years followed by very slight increases after that. The control case shows a gradual global cooling over the 30-year period (about 0.02°C per year). The globally averaged surface temperatures for the transient case (with slowly increasing CO₂) separate from the control-case temperatures over the 30-year period. At the end of 30 years, the globally averaged surface air temperature increase for the instantaneous CO₂ doubling case is 1.6°C , while the same quantity for the transient forcing case (with CO₂ increasing to 30% over the 30-year period to 429 ppm) is 0.7°C .

The climate drift in the ocean in all three cases is similar, with small-amplitude changes in the surface layer, a cooling of the second layer (less than 0.05°C per year), a warming of the third layer (less than 0.03°C per year), and slight warming of the bottom layer (less than 0.005°C per year). Much of this climate drift is caused by the large thermal inertia of the ocean layers which are coupled by diffusion and advective processes. By subtracting perturbed cases and the control case, a part of the climate drift is essentially removed. The magnitude of the climate drift is much less than the CO₂ climate-change signals. Therefore, the effects of nonlinearities in the system that could alter the climate change due to climate drift in the model are reduced. In addition, the time scale of the climate drift in the model is much longer than the time scales of the response of the system to changes of CO₂. If much longer time scales were considered (greater than 100 years, for example) or if it was desirable to run the coupled model to some type of equilibrium over hundreds of years, the climate drift in the ocean would become a major factor. The climate change studied here over a 30-year period is analogous to the time scale of climate change in the real climate system due to rapid increases of CO₂ (on the order of 50–100 years). The CO₂ signal in the real world is superimposed over various "climate drifts" in the system as a result of many factors other than CO₂ changes, most of which are not understood. Some of these secular trends may be due to the natural oscillation of the climate system unrelated to changes in the external forcing. The goals here are to identify basic feedbacks and mechanisms in the coupled system and to study the nature of the CO₂ signal superimposed over

some very long time-scale climate drift in the model.

In spite of the inherent limitations of the ocean model and errors in the simulated SSTs, the coupled system simulates many features of the present climate system. The zonal mean patterns of temperatures and winds in the atmosphere are reproduced, as are zonal mean temperatures, salinities, and heat transport and storage in the ocean. Important errors involve the tendency of the ocean model to produce tropical SSTs that are too cold and high-latitude temperatures that are too warm. The latter characteristic results in reduced sea-ice extent in the Bering Sea and an almost total absence of sea ice around Antarctica. Various sensitivity experiments are performed (Appendix) to determine first-order effects on simulated SSTs of the magnitude of wind-stress forcing (reduced wind stress results in less equatorial upwelling and warmer tropical SSTs); the depth of the second layer (a shallower second layer remains warmer so that when equatorial upwelling occurs, warmer water is brought to the surface and SSTs are higher; the shallower second layer at extratropical latitudes is cooler, which results in cooler SSTs at those latitudes following similar reasoning); and the effects of a decrease of horizontal heat diffusion (less heat is diffused out of the low and midlatitudes which results in warmer tropical SSTs and cooler high-latitude SSTs).

Such inherent limitations of the coupled model produce lower sensitivity to increased CO₂ after 30 years of integration compared to an earlier experiment with the same atmospheric model coupled to a 50-m slab-ocean mixed layer (Washington and Meehl 1984). In that model, tropical SSTs were too warm, high-latitude SSTs were too cold and, as a consequence, overextensive sea ice formed. The combination of warm tropical SSTs and greater-than-observed sea-ice extent caused that model to be very sensitive to a CO₂-induced warming (3.5°C globally averaged surface air temperature change for a doubling of CO₂). Conversely, the present model has lower-than-observed tropical SSTs, reduced sea-ice extent, and a sensitivity of 1.6°C after 30 years of integration. This number is closer to a previous experiment with this atmospheric model coupled to a simple energy balance or swamp model which also had colder-than-observed tropical SSTs. This suggests that the sensitivity of the real climate system to a doubling of CO₂ is probably somewhere between the two sets of experiments.

For the instantaneous CO₂ doubling case, pat-

terns of temperature change in the atmosphere are similar (with reduced magnitude) to those of the earlier experiment with the 50-m slab ocean. Temperatures in the troposphere warm, the stratosphere cools, and regions of greatest surface air temperature change occur where sea ice has retreated. Changes in soil moisture are also similar on a continental scale with mostly increases over the northern continents during winter and areas of significant increase and decrease during summer.

In the ocean, most of the warming is confined to the upper 1250 m with greatest warming in the surface layer near 60° N and 50° S. Salinity amounts decrease at high latitudes of each hemisphere (corresponding to increases in precipitation, and weakened westerly wind stress and reduced overturning) and increase in the subtropics. The warming and freshening of the high-latitude ocean surface layer stabilize the ocean and weaken the thermohaline circulation, thus affecting circulation to great depths in the ocean.

Some changes of climate in the transient experiment are similar to those in the instantaneous CO₂ doubling experiment. The greatest changes to ocean temperatures take place in the ocean surface layer, most of the troposphere warms while the stratosphere cools, and large areas of significant warming at the surface occur over the southern oceans. However, there are a number of interesting differences as well. Areas of significant cooling in the NH appear to be related to time-dependent regimes of climate anomalies involving the atmosphere-ocean-sea-ice system as a function of the gradually increasing CO₂ forcing. Some elements of these same patterns appear in the instantaneous CO₂ doubling experiment, but are different in that experiment because of the large uniform CO₂ forcing. This confirms earlier studies with simple models showing that patterns of climate change from an instantaneous CO₂ doubling experiment may not be accurate analogues to signals during the gradual evolution of a slowly increasing CO₂ amount (Schneider and Thompson 1981; Thompson and Schneider 1982). Patterns of climate change early in an instantaneous CO₂ doubling case also may not be appropriate analogues because of the rapid response of the climate system to a large constant forcing such as a doubling of CO₂. Thus, time-dependent climate regimes may be important in the evolution of a slowly increasing CO₂ climate, and a search for CO₂ climate change in the real climate system should not rely totally on patterns of climate change obtained from instantaneous CO₂ doubling experiments.

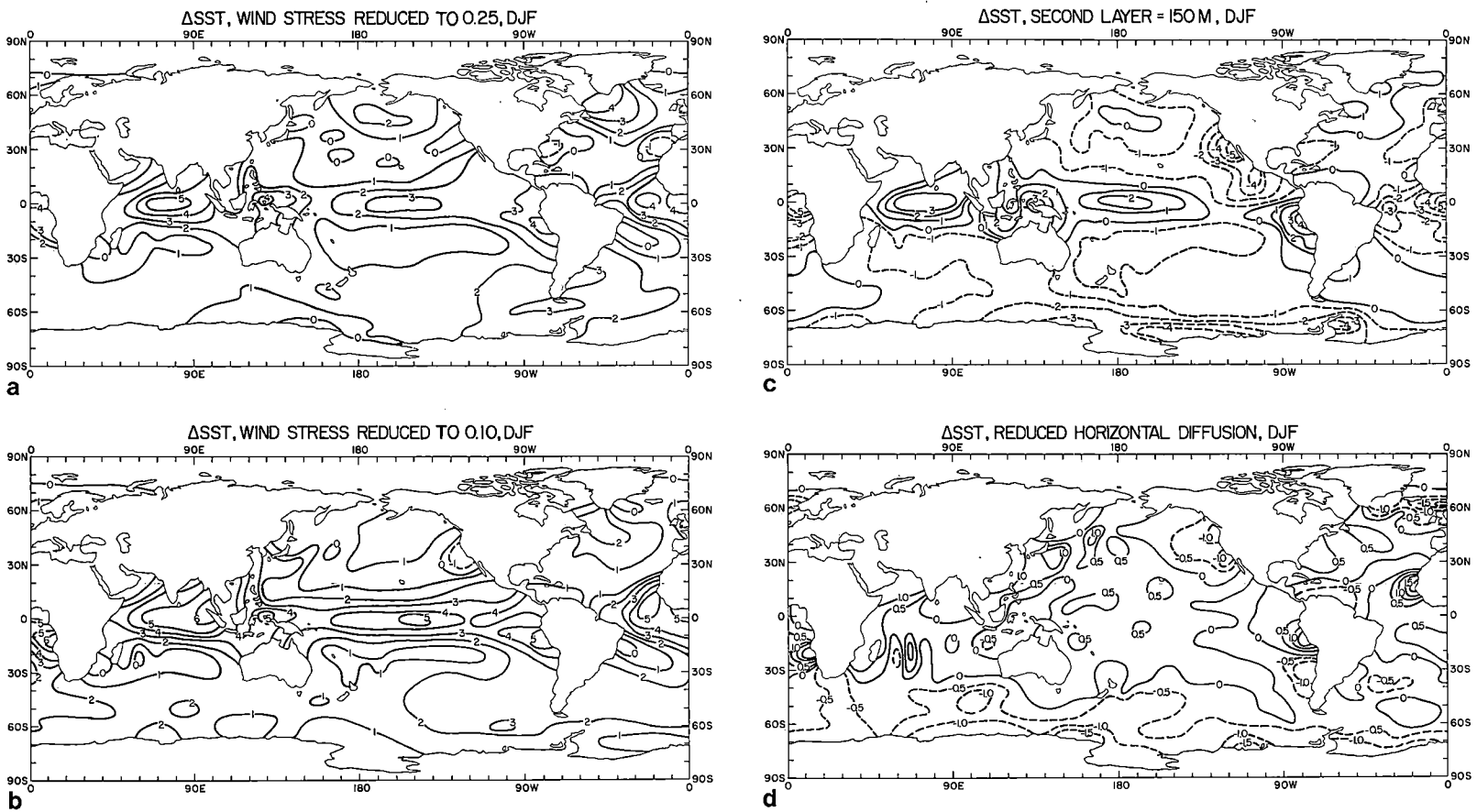


Fig. 37 a-d. Geographical distribution of SST differences (°C) for DJF. **a** Wind stress reduced to 0.25 original value; **b** wind stress reduced to 0.10 original value; **c** second-layer thickness reduced for 450 m to 150 m; **d** horizontal heat diffusion reduced to 0.50 original value

Table 2. Description of ocean model parameter experiments

Experiment	Parameter	Difference calculated
1	Wind stress reduced to 0.25 original values	Year 8 (minus control)
2	Wind stress reduced to 0.10 original values	Year 8 (minus control)
3	Second layer changed from 450 m to 150 m (run with wind stress reduced to 0.25)	Year 5 (minus year 5 of experiment 1)
4	Horizontal heat diffusion reduced from 4×10^4 to 2×10^4 m ² s ⁻¹ (run with wind stress reduced to 0.10)	Year 3 (minus year 3 of experiment 2)

Because of the model's shortcomings and the uncertainties of simulated regional changes caused by CO₂ increase, we will substantially improve the next generation of atmospheric-oceanic models to go along with improved computational techniques and increased computing capabilities. The processes and feedbacks identified in this study will be scrutinized in hopes of further quantifying the effects of increased CO₂ on climate.

Appendix

A number of parameter studies are described here to explain the factors contributing to the SST distribution computed by the coupled model. Since many inherent limitations of the present coarse-grid ocean model were documented previously (Washington et al. 1980; Meehl et al. 1982; Meehl 1984), it was anticipated that the coupled model described in the present paper would reflect those model characteristics. Tropical SSTs are consistently too cold in the coupled model and high-latitude SSTs are too warm (Fig. 10). It was thought that this was partially a result of the coarse-grid computational requirement that horizontal heat diffusion be kept at a large value. Consequently, heat from low latitudes is diffused to high latitudes with the net effect of colder-than-observed tropical SSTs and higher-than-observed high-latitude SSTs and resultant less-than-observed sea-ice distribution in the polar regions.

Another important characteristic of the SST simulation in previous studies with this ocean model is the equatorial upwelling of cold water which is very sensitive to wind-stress forcing. The magnitude of wind-stress forcing from the atmospheric model determines the strength of the equatorial upwelling in the ocean model. When upwelling occurs in the ocean, water is brought to the surface from the second layer and the cold water from this deep second layer results in low SSTs that reflect the temperature of that layer. This second layer is 450 m in the present model (the surface layer is 50 m).

To determine the sensitivity of the SST simulation to elements of the ocean formulation, several brief experiments were performed in which these parameters, thought to be important to the SST simulation, were varied. Table 2 lists the four experiments, the parameters that were changed, and the

years over which the differences were performed. Experiment 1 simply multiplied the wind stresses produced by the atmospheric model by 0.25 before they were communicated to the ocean model. These changes in wind stress were not included in the atmospheric model calculation. Experiment 2 was similar to experiment 1, except that the model wind stresses were multiplied by 0.10. Experiment 3 took the model set-up of experiment 1 and shallowed the second layer from 450 to 150 m. Experiment 4 took the model configuration of experiment 2 and reduced the horizontal heat diffusion. It was hypothesized that, by reducing wind forcing to weaken the upwelling, or by reducing the depth of the second layer such that the temperature of that shallower layer would be higher than the original 450-m-deep layer, or by reducing the horizontal heat diffusion to more effectively keep heat from lower latitudes from diffusing to higher latitudes, the tropical SSTs would increase and be closer to the observed values.

The wind-stress reduction experiments addressed the problem of the representativeness of wind stresses computed from winds at the lowest atmospheric model layer at $\sigma=0.991$ (actually about 100–200 m above the surface). It could be imagined that wind stresses at the ocean surface would be somewhat weaker if the $\sigma=0.991$ winds were reduced to the surface in some way to account for Ekman spiral effects. To assess the SST sensitivity in the coupled model to this important parameter, two different wind-stress reductions were tested.

Ocean mixed layers are seldom 500 m thick, especially in the tropics (e.g., Meehl 1984). Yet that is the effective representation of upper-ocean mixing with two layers of thicknesses of 50 and 450 m. The second layer was made shallower in the model to represent an effective upper-ocean mixed layer of 200 m (surface layer of 50 m and second layer of 150 m). In this configuration, the third layer was 1800 m (changed from 1500 to take into account the 300 m pared from the second layer), and the fourth layer remained at 2000 m. It was hypothesized that the shallower second layer would be warmer than the 450-m second layer. Consequently, when upwelling occurred in the tropics, relatively warmer water would come to the surface and the tropical SSTs would warm accordingly.

Horizontal heat diffusion is important in the coarse-grid model simulation (Meehl et al. 1982). To maintain computational stability with time-varying forcing (which includes a great deal of high-frequency variability), the horizontal heat diffusion was increased in the coupled model over the previous value when the ocean model was run with a smooth annual cycle of monthly mean observed forcing. An experiment was run with the horizontal heat diffusion set back to its original value. This run became numerically unstable after 4 years because of the above-mentioned computational difficulties and a buildup of small-scale features, but the pattern of SST differences in the third year was informative as to the role of horizontal heat diffusion in the coupled model.

Figure 37 shows the differences in SST for DJF (JJA differences are similar) for the four parameter experiments. Reducing the wind stress forcing to 0.25 (experiment 1, Fig. 37a) results in increases of tropical SSTs on the order of 3°–5°C due to the decrease of upwelling. Further reduction of the wind stress to 0.10 of its computed value from the atmospheric model weakens tropical upwelling even more and SSTs increase by up to 6°C (experiment 2, Fig. 37b). Shallowing the second layer to 150 m has the expected effect in the tropics — SSTs become higher there as a result of the warmer, shallower second layer (experiment 3, Fig. 37c). The shallower second layer also has the added benefit of reducing high-latitude SSTs. The second layer is better able to cool at higher latitudes and vertical mixing results in lower SSTs there. Reducing the

horizontal heat diffusion (experiment 4, Fig. 37d) has the expected result of warmer tropical SSTs and cooler high-latitude SSTs.

These parameter experiments demonstrate that inherent limitations of wind-stress forcing and the configuration of the coarse-grid ocean model cause many of the problems with the simulated SSTs in the coupled model. A finer-resolution (horizontal and vertical) ocean model and a better prescription of wind-stress forcing would alleviate some of the difficulties with the simulation of SSTs in the coupled model.

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References

- Alexander RC, Mobley RL (1976) Monthly average sea-surface temperatures and ice pack limits on a 1° global grid. *Mon Weather Rev* 104:143-148
- Bates G, Meehl GA (1986) The effect of CO₂ concentration on the frequency of blocking in a general circulation model coupled to a simple mixed layer ocean. *Mon Weather Rev* 114:687-701
- Bourke W, McAvaney B, Puri K, Thurling R (1977) Global modeling of atmospheric flow by spectral methods. In: Chang J (ed) *Methods in computational physics, general circulation models of the atmosphere*. Academic Press, New York, pp 267-324
- Bryan F (1986) High latitude salinity effects and interhemispheric thermohaline circulations. *Nature* 323:301-304
- Bryan K (1969) Climate and the ocean circulation: III. The ocean model. *Mon Weather Rev* 97:806-827
- Bryan K, Lewis LJ (1979) A water mass model of the world oceans. *J Geophys Res* 84:2503-2517
- Bryan K, Spelman MJ (1985) The ocean's response to a carbon dioxide-induced warming. *J Geophys Res* 90:11679-11688
- Bryan K, Komro FG, Manabe S, Spelman MJ (1982) Transient climate response to increasing atmospheric carbon dioxide. *Science* 215:56-58
- Bryan K, Manabe S, Spelman MJ (1988) Interhemispheric asymmetry in the transient response of a coupled ocean-atmosphere model to a CO₂ forcing. *J Phys Oceanogr* 18:851-867
- Carissimo BC, Oort AH, Vonder Haar TH (1985) Estimating the meridional energy transport in the atmosphere and ocean. *J Phys Oceanogr* 15:82-91
- Chervin RM (1981) On the comparison of observed and GCM simulated climate ensembles. *J Atmos Sci* 38:885-901
- Cox MD (1975) A baroclinic numerical model of the world ocean: Preliminary results. *Numerical Models of Ocean Circulation*, National Academy of Science, Washington, DC, pp 107-120
- Cox MD (1985) An eddy resolving numerical model of the ventilated thermocline. *J Phys Oceanogr* 15:1312-1324
- Crutcher HL, Meserve JM (1970) Selected level heights, temperatures and dew points for the northern hemisphere. Rep NAVAIR 50-1C-52, Naval Weather Service Command, Washington, DC
- Dickinson RE, Meehl GA, Washington WM (1987) Ice-albedo feedback in a CO₂ doubling simulation. *Climatic Change* 10:241-248
- Gates WL, Han YJ, Schlesinger ME (1985) The global climate simulated by a coupled atmosphere-ocean general circulation model: Preliminary results. In: Nihoul JCJ (ed) *Coupled ocean-atmosphere models*. Elsevier Oceanogr Ser 40:131-151
- Han YJ (1984) A numerical world ocean general circulation model. *Dyn Atmos Oceans* 8:141-172
- Hansen J, Lacis A, Rind D, Russell G, Stone P, Fung I, Ruedy R, Lerner J (1984) Climate sensitivity: Analysis of feedback mechanisms. In: Hansen JF, Takahashi T (eds) *Climate processes and climate sensitivity*. Maurice Ewing Series 5:130-163
- Hansen J, Fung I, Lacis A, Rind D, Lebedeff S, Ruedy R, Russell G (1988) Global climate changes as forecast by Goddard Institute for Space Studies three-dimensional model. *J Geophys Res* 93:9341-9364
- Hartmann DL, Ramanathan V, Berroir A, Hunt GE (1986) Earth radiation budget data and climate research. *Rev Geophys* 24:439-468
- Hastenrath S (1980) Heat budget of tropical ocean and atmosphere. *J Phys Oceanogr* 10:159-170
- Hellerman S, Rosenstein M (1983) Normal monthly wind stress data over the world ocean with error estimates. *J Phys Oceanogr* 13:1093-1104
- Herman GF, Johnson WT (1978) The sensitivity of the general circulation to Arctic sea ice boundaries: A numerical experiment. *Mon Weather Rev* 106:1649-1664
- Hsiung J (1985) Estimates of global oceanic meridional heat transport. *J Phys Oceanogr* 15:1405-1413
- Jaeger L (1976) Monatskarten des Niederschlags für die ganze Erde. *Ber Dtsch Wetterd* 139:38 pp
- Knauss JA (1978) *Introduction to Physical Oceanography*. Prentice-Hall, Englewood Cliffs, NJ, 338 p
- Levitus S (1982) *Climatological Atlas of the World Ocean*. NOAA Professional Paper 13, National Oceanic and Atmospheric Administration, Washington, DC, 173 p, 17 microfiche
- Levitus S (1987) Rate of change of heat storage of the world ocean. *J Phys Oceanogr* 17:518-528
- MacCracken MC, Luther FM (eds) (1985) *Projecting the Climatic Effects of Increasing Carbon Dioxide*. DOE/ER-0237, United States Department of Energy, Washington, DC, 381 p
- Manabe S (1969) Climate and the ocean circulation: I. The atmospheric circulation and the hydrology of the earth's surface. *Mon Weather Rev* 97:775-805
- Manabe S, Stouffer RJ (1980) Sensitivity of a global climate model to an increase of CO₂ concentration in the atmosphere. *J Geophys Res* 85:5529-5554
- Manabe S, Stouffer RJ (1988) Two stable equilibria of a coupled ocean-atmosphere model. *J Clim* 1:841-866
- Manabe S, Wetherald RT (1975) The effects of doubling the

- CO₂ concentration on the climate of a general circulation model. *J Atmos Sci* 32:3-15
- Manabe S, Smagorinsky J, Strickler RF (1965) Simulated climatology of a general circulation model with a hydrologic cycle. *Mon Weather Rev* 93:769-798
- McAvaney BJ, Bourke W, Puri K (1978) A global spectral model for simulation of the general circulation. *J Atmos Sci* 35:1557-1582
- Meehl GA (1984) A calculation of ocean heat storage and effective ocean surface-layer depths for the northern hemisphere. *J Phys Oceanogr* 14:1746-1760
- Meehl GA (1988) Tropical-midlatitude interactions in the Indian and Pacific sectors of the southern hemisphere. *Mon Weather Rev* 116:472-484
- Meehl GA (1989) The coupled ocean-atmosphere modeling problem in the tropical Pacific and Asian monsoon regions. *J Climate* (in press)
- Meehl GA, Albrecht BA (1988) Tropospheric temperatures and southern hemisphere circulation. *Mon Weather Rev* 116:953-960
- Meehl GA, Washington WM (1985) Sea surface temperatures computed by a simple ocean mixed layer coupled to an atmospheric model. *J Phys Oceanogr* 15:92-104
- Meehl GA, Washington WM (1986) Tropical response to increased CO₂ in a GCM with a simple mixed layer ocean: Similarities to an observed Pacific Warm Event. *Mon Weather Rev* 114:667-674
- Meehl GA, Washington WM (1988) A comparison of soil-moisture sensitivity in two global climate models. *J Atmos Sci* 45:1476-1492
- Meehl GA, Washington WM, Semtner AJ Jr (1982) Experiments with a global ocean model driven by observed atmospheric forcing. *J Phys Oceanogr* 12:301-312
- Mitchell JFB, Hills TS (1986) Sea-ice and antarctic winter circulation: A numerical experiment. *Q J R Meteorol Soc* 112:953-969
- National Research Council (1982) Carbon Dioxide and Climate: A Second Assessment, National Academy of Sciences, Washington, DC, 72 p
- Newell RE, Kidson JW, Vincent DG, Boer GJ (1972) The General Circulation of the Tropical Atmosphere and Interactions with Extra-Tropical Latitudes, vol 1. M.I.T. Press, Cambridge, MA, 258 p
- Oort AH (1983) Global atmospheric circulation statistics, 1958-1973. NOAA Professional Paper 13, National Oceanic and Atmospheric Administration, Washington, DC, 180 p
- Oort AH, Vonder Haar TH (1976) On the observed annual cycle in the ocean-atmosphere heat balance over the Northern Hemisphere. *J Phys Oceanogr* 6:781-800
- Parkinson CL, Comiso JC, Zwally HJ, Cavalier DJ, Gloersen P (1987) Arctic sea ice 1973-1976: Satellite passive-microwave observations. National Aeronautics and Space Administration, NASA SP-489, Washington, DC, 296 p
- Philander SGH, Hurlin WJ (1988) The heat budget of the tropical Pacific Ocean in a simulation of the 1982-83 El Niño. *J Phys Oceanogr* 18:926-931
- Philander SGH, Seigel AD (1985) Simulation of El Niño of 1982-1983. In: Nihoul JCJ (ed) Coupled ocean-atmosphere models. Elsevier Oceanogr Ser 40:517-541
- Pitcher EJ, Malone RC, Ramanathan V, Blackmon ML, Puri K, Bourke W (1983) January and July simulations with a spectral general circulation model. *J Atmos Sci* 40:580-604
- Ramanathan V (1981) The role of ocean-atmosphere interactions in the CO₂ climate problem. *J Atmos Sci* 38:918-930
- Ramanathan V, Pitcher EJ, Malone RC, Blackmon ML (1983) The response of a spectral general circulation model to refinements in radiative processes. *J Atmos Sci* 40:605-630
- Rogers JC (1989) Seasonal temperature variability over the North Atlantic Arctic. Proc 13th Climate Diagnostics Workshop, U.S. Department of Commerce, Washington, pp 170-175
- Rogers JC, van Loon H (1979) The seesaw in winter temperatures between Greenland and northern Europe. Part II: Some oceanic and atmospheric effects at middle and high latitudes. *Mon Weather Rev* 107:509-519
- Schlesinger ME, Jiang X (1988) The transport of CO₂-induced warming into the ocean: An analysis of simulations by the OSU coupled atmosphere-ocean general circulation model. *Climate Dyn* 3:1-17
- Schlesinger ME, Mitchell JFB (1985) Model projections of equilibrium climatic response to increased carbon dioxide. In: MacCracken MC, Luther FM (eds) The Potential Climatic Effects of Increasing Carbon Dioxide. DOE/ER-0237, United States Department of Energy, Washington, DC, pp 81-147
- Schlesinger ME, Mitchell JFB (1987) Climate model simulations of the equilibrium climatic response to increased carbon dioxide. *Rev Geophys* 25:760-798
- Schlesinger ME, Gates WL, Han YJ (1985) The role of the ocean in CO₂-induced climate change: Preliminary results from the OSU coupled atmosphere-ocean general circulation model. In: Nihoul JCJ (ed) Coupled ocean-atmosphere models, Elsevier Oceanography Series 40:447-478
- Schneider SH, Thompson SL (1981) Atmospheric CO₂ and climate: Importance of transient response. *J Geophys Res* 86:3135-3147
- Semtner AJ (1974) An oceanic general circulation model with bottom topography. Numerical Simulation of Weather and Climate, Tech Rep 9, University of California, Los Angeles, 99 p
- Semtner AJ (1976) A model for the thermodynamic growth of sea ice in numerical investigations of climate. *J Phys Oceanogr* 6:379-389
- Semtner AJ (1987) A numerical study of sea ice and ocean circulation in the Arctic. *J Phys Oceanogr* 17:1077-1099
- Semtner AJ, Chervin RC (1988) A simulation of the global ocean circulation with resolved eddies. *J Geophys Res* 93:15502-15522
- Semtner AJ, Mintz Y (1977) Numerical simulation of the Gulf Stream and mid-ocean eddies. *J Phys Oceanogr* 7:208-230
- Spelman MJ, Manabe S (1984) Influence of oceanic heat transport upon the sensitivity of a model climate. *J Geophys Res* 89:571-586
- Taljaard JJ, van Loon H, Crutcher HL, Jenne RL (1969) Climate of the upper air: Southern Hemisphere, Vol 1, Temperatures, dew points and heights at selected pressure levels. NAVAIR 50-K-55, Chief Nav Oper, Washington, DC, 135 p
- Thompson SL, Schneider SH (1982) Carbon dioxide and climate: The importance of realistic geography in estimating the transient temperature response. *Science* 217:1031-1033
- Trenberth KE (1979) Mean annual poleward energy transports by the oceans in the southern hemisphere. *Dyn Atmos Oceans* 4:57-64
- van Loon H, Taljaard JJ, Jenne RL, Crutcher HL (1971) Climate of the upper air: Southern Hemisphere, Vol 2, Zonal geostrophic winds. Tech Note STR-57, National Center for Atmospheric Research, Boulder, Colorado
- Washington WM, Meehl GA (1983) General circulation model experiments on the climatic effects due to a doubling and

- quadrupling of carbon dioxide concentrations. *J Geophys Res* 88:6600-6610
- Washington WM, Meehl GA (1984) Seasonal cycle experiment on the climate sensitivity due to a doubling of CO₂ with an atmospheric general circulation model coupled to a simple mixed-layer ocean model. *J Geophys Res* 89:9475-9503
- Washington WM, Meehl GA (1986) General circulation model CO₂ sensitivity experiments: Snow-sea ice albedo parameterization and globally averaged surface air temperature. *Climatic Change* 8:231-241
- Washington WM, Williamson DL (1977) A description of the NCAR global circulation models. In: Chang J (ed) *Methods in Computational Physics* 17, Academic Press, New York, pp 111-172
- Washington WM, Semtner AJ, Meehl GA, Knight DJ, Mayer TA (1980) A general circulation experiment with a coupled atmosphere, ocean, and sea ice model. *J Phys Oceanogr* 10:1887-1908
- Wilson CA, Mitchell JFB (1987) A doubled CO₂ climate sensitivity experiment with a global climate model including a simple ocean. *J Geophys Res* 92:13315-13343

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Characteristics of Coupled Atmosphere-Ocean CO₂
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ABSTRACT

The community climate model at the National Center for Atmospheric Research has been coupled to a simple mixed-layer ocean model and to a coarse-grid ocean general circulation model (OGCM). This paper compares the responses of simulated climate to increases of atmospheric carbon dioxide (CO_2) in these two coupled models. Three types of simulations were run: (1) control runs with both ocean models, with CO_2 held constant at present-day concentrations, (2) instantaneous doubling of atmospheric CO_2 (from 330 to 660 ppm) with both ocean models, and (3) a gradually increasing (transient) CO_2 concentration starting at 330 ppm and increasing linearly at one percent per year with the OGCM. The mixed-layer and OGCM cases exhibit increases of 3.5°C and 1.6°C , respectively, in globally averaged surface-air temperature for the instantaneous doubling cases. The transient forcing case warms 0.7°C by the end of 30 years. The mixed-layer ocean yields warmer-than-observed tropical temperatures and colder-than-observed temperatures in the higher latitudes. The coarse-grid OGCM simulates lower-than-observed sea-surface temperatures (SSTs) in the tropics and higher-than-observed SSTs and reduced sea-ice extent at higher latitudes. Sensitivity in the OGCM after 30 years is much lower than in simulations with the same atmosphere coupled to a 50-m slab-ocean mixed layer. The OGCM simulates a weaker thermohaline circulation with doubled CO_2 as the high-latitude ocean-surface layer warms and freshens and the westerly wind stress decreases. Convective overturning in the OGCM de-

creases substantially with CO₂ warming. Geographical distributions of surface-air temperature change in the transient case show regional climate anomalies different from those in the instantaneous CO₂ doubling OGCM case, particularly in the North Atlantic and northern Europe. These two sets of experiments demonstrate that different ocean models and types of CO₂ forcing in the climate system result in different CO₂ climate responses. Earlier studies with energy-balance climate models confirm that instantaneous CO₂ doubling simulations respond differently to transient simulations.

1. Introduction

This paper discusses coupled atmosphere-ocean experiments with a simple mixed-layer ocean model and a dynamical ocean model developed at the National Center for Atmospheric Research (NCAR). The focus is on demonstrating the effects on the climate system of sea-ice albedo feedback, horizontal ocean heat transport, thermohaline circulation, and convective overturning.

The earliest simulations of coupled atmosphere-ocean models included a simple ocean component and assumed a saturated surface based upon a surface energy balance. This type of ocean can be thought of as a shallow swamp, having no seasonal heat storage and no vertical or horizontal heat transport (e.g., Manabe and Wetherald, 1975; Washington and Meehl, 1983, 1986). Because the ocean is a wet surface with no seasonal ocean heat storage, such a model requires annually averaged solar forcing.

The next generation of simple coupled atmosphere-ocean models made use of a shallow constant mixed layer with a thickness of $\simeq 50$ m. This coupling allowed for an annual cycle and a crude approximation of seasonal heat storage but no horizontal or vertical heat transport (e.g., Washington and Meehl, 1984; Manabe and Stouffer, 1988), and thus could better be compared with observations. Hansen et al. (1984, 1988) and Wilson and Mitchell (1987) have used models that, in addition to the mixed-layer ocean, prescribed seasonal horizontal ocean heat transport. This

type of formulation necessarily produces sea-surface temperatures (SSTs) that are close to observed values compared to mixed-layer formulations without specified ocean heat transport. However, since the specified heat transport cannot change as ocean temperature and sea ice respond in climate-change sensitivity experiments, an important, and perhaps crucial, feedback mechanism is eliminated.

A number of CO₂ climate sensitivity studies with a simple mixed-layer ocean formulation have been conducted at NCAR: (1) intercomparison of the observed, computed, and simple mixed-layer SSTs, as well as the surface-energy balance (Meehl and Washington, 1985); (2) changes of tropical circulation in the model (Meehl and Washington, 1986); (3) changes in atmospheric circulation as indicated by persistent height anomalies or "blocking" (Bates and Meehl, 1986); (4) assessment of ice-albedo feedback in the model (Dickinson et al., 1987); (5) tropical-midlatitude interactions (Meehl, 1988); and (6) soil-moisture sensitivity (Meehl and Washington, 1988).

A more recent type of model used at NCAR for studying the sensitivity of climate to increased CO₂ is an atmospheric model coupled to an ocean general circulation model. This type of coupled model needs extremely long computer runs, even with coarse-resolution oceans, due to the long adjustment time of the global ocean model. Examples of CO₂ experiments with ocean general circulation models (OGCMs) coupled to atmospheric models include Bryan et al. (1982), Bryan and Spelman (1985), and Bryan et al. (1988), using a Geophysical Fluid Dynamics Laboratory (GFDL) model with idealized geographical domain (a sector of the

globe); and Schlesinger et al. (1985) and Schlesinger and Jiang (1988), using an Oregon State University model with a realistic geographical domain. In several of these studies, CO_2 was increased instantaneously to investigate the transient response of the system. The GFDL coupled models followed the coupling method of Manabe (1969) and Bryan (1969) which includes the seasonal cycle. Some recent results of NCAR CO_2 studies with an OGCM coupled to an atmospheric model (Washington and Meehl, 1989) are shown here with a system that includes the seasonal cycle. An assessment of errors introduced from the respective components of the NCAR coupled models (mixed layer and OGCM) has been performed for the Indian and Pacific sector tropics (Meehl, 1989).

The CO_2 experiments in this paper use the atmospheric model described in Washington and Meehl (1983, 1984). Section 2 describes the atmospheric, oceanic, and sea-ice models, along with the method of coupling the atmospheric and oceanic models and how the experiments were conducted. Section 3 compares simulations with the observed atmosphere, ocean, and sea-ice distributions. Section 4 discusses the differences between a control simulation with 330 ppm and instantaneous doubling of CO_2 concentrations; zonal and some geographical distributions are also shown. Section 4 also describes a transient experiment with a gradually increasing (one percent per year) concentration of CO_2 . Section 5 summarizes the differences in climate sensitivity between the simple mixed-layer ocean model and an OGCM in terms of a CO_2 increase. Also included are suggestions for improvements in the various aspects of the coupled model system.

2. Description of atmospheric, oceanic, and sea-ice components

Figure 1, a schematic of the components of the coupled ocean-atmosphere sea-ice model, shows atmospheric and oceanic levels at the left and physical processes at the middle and right. (See Washington and Meehl, 1984, for mixed-layer details, and Washington and Meehl, 1989, for OGCM details.) The atmospheric component of the interactive climate model, a version of the NCAR community climate model (CCM), has nine levels and uses the spectral transform method for computing horizontal nonlinear transport terms with a truncation wavenumber of rhomboidal 15. The horizontal resolution is approximately 4.5° in latitude and 7.5° in longitude. The radiation-cloudiness scheme is as described in Ramanathan et al. (1983), where the cirrus formulation assumes an emissivity of unity. The blackbody assumption precludes the possibility of cloud-emissivity climate feedbacks. The surface-hydrology cycle uses model-derived rates of precipitation, evaporation, and sublimation to simulate the changes of soil moisture and snow cover, as described in Washington and Meehl (1984) and Meehl and Washington (1988), whose treatment is similar to that of Manabe (1969).

The simple mixed-layer ocean has a thickness of 50 m with no transports or diffusion into the sides or bottom of the layer. The heat fluxes into and out of the top of the ocean's mixed layer are the sum of radiative, latent, and sensible heat fluxes. As noted in the introduction, several modeling groups (e.g., Hansen et al.,

1984; Wilson and Mitchell, 1987) have used a horizontal ocean heat flux which also compensates for atmospheric model deficiencies so as to keep the model climate close to the observed. It is unclear how this affects the model sensitivity to climate change, however, since such flux correction limits the ocean feedback mechanisms.

The OGCM uses primitive equations for a hydrostatic Boussinesq ocean with a rigid lid and follows a numerical method developed by Bryan (1969) and Semtner (1974, 1987). Large-scale bottom topography has been included. This OGCM was used in an earlier asynchronously coupled prototype model (Washington et al., 1980). Various sensitivities of the OGCM have been analyzed by Meehl et al. (1982). If adjacent vertical layers become statically unstable, then convective adjustment or overturning is invoked, thus returning the respective layers to a stable state by uniformly mixing temperature and salinity in the two layers. Table 1 summarizes the major characteristics of the OGCM.

Table 1. World ocean model characteristics

1) Vertical coordinate	depth
2) Horizontal domain	global (latitude and longitude)
3) Horizontal resolution	5°
4) Horizontal approximation of derivatives	second-order
5) Vertical resolution	$\Delta z_1 = 50 \text{ m}, \Delta z_2 = 450 \text{ m},$ $\Delta z_3 = 1500 \text{ m}, \Delta z_4 = 2000 \text{ m}$
6) Time step	$\Delta t = 1800 \text{ s}$
7) Topography	included
8) Convective adjustment	included
9) Salinity flux at surface	included
10) Computed sea ice	included

Small-scale features—mid-ocean eddies and concentrated aspects of the western boundary currents—are not resolvable by the 5° latitude-longitude horizontal grid. The parameterization of subgrid-scale processes is discussed in Washington and Meehl (1989). Sea ice forms when ocean temperature becomes equal to the approximate freezing point for sea water. The amount of growth and melting of sea ice depends upon the energy balance at the top of sea ice, as described in the zero-layer model of Semtner (1976).

Atmospheric and oceanic models essentially are coupled synchronously and communicate with each other once every model day. For the mixed-layer ocean model, the sum of surface-energy fluxes is used at the top of the layer, and for the OGCM the atmospheric model provides wind stress, precipitation minus evaporation, and the sum of the surface-energy fluxes to the top of the ocean. The ocean models furnish surface-temperature and sea-ice data to the atmospheric model (interactions shown schematically in Fig. 2 for the OGCM).

The experiments with a mixed-layer ocean were started from the end of the annual mean solar forcing experiment, as described in Washington and Meehl (1984). The doubled CO_2 ($2\times\text{CO}_2$) and control ($1\times\text{CO}_2$) experiments were run through 11 years, with the last three years of the experiment used in the time average of the results that follow.

Figure 3 describes how the OGCM experiments were conducted with $1\times\text{CO}_2$, $2\times\text{CO}_2$, and slowly increasing CO_2 (or transient forcing). The ocean model started

from the end of the uncoupled model experiment with observed atmospheric forcing (≈ 50 years), where the first year was forced by a Newtonian-type observed zonally averaged temperature and salinity distribution (Meehl et al., 1982). This forcing decreased the time required to bring the overall zonal temperature and salinity patterns to roughly that of the observed. The atmospheric part of the coupled model began from the last year of Washington and Meehl's (1984) climate simulation, which used a simple mixed-layer ocean. The coupled model system was run for 16 years with several changes in ocean diffusion parameters. The model was then run for an additional 30 years for the $1\times\text{CO}_2$, $2\times\text{CO}_2$, and transient experiments.

Although the overall system is far from complete equilibrium, the top parts of the ocean model appear to change little from year to year. Figure 4 shows the time evolution of globally averaged ocean-surface temperature and ocean surface temperature differences from the coupled model with $1\times\text{CO}_2$, $2\times\text{CO}_2$, and transient forcing (slowly increasing) CO_2 OGCM experiments. The globally averaged ocean temperature in the top model layer with $1\times\text{CO}_2$ exhibits a very slow cooling trend or climate drift ($\approx 0.02^\circ\text{C}$ per year), whereas the $2\times\text{CO}_2$ experiment shows little globally averaged drift. The climate drift of the coupled model is substantially smaller than the increased CO_2 warming signal. The transient experiment depicts a small warming by year 30. In the $2\times\text{CO}_2$ experiment, the upper part of the ocean warms quickly and shows a smaller secular change in the 15- to 30-year range. The globally averaged SST difference (Fig. 4) between the $2\times\text{CO}_2$ and $1\times\text{CO}_2$ experiments is about 1.2°C and 1.6°C for globally averaged surface-air temperature

at 30 years, which is larger than the value found at 20-25 years by Bryan et al. (1982) and Schlesinger et al. (1985). The transient experiment shows a much smaller difference of about 0.7°C after 30 years for surface-air temperature increase and about 0.3° to 0.4°C for globally averaged SST differences. See studies with simpler energy-balance climate models (e.g., Schneider and Thompson, 1981; Thompson and Schneider, 1982) where equilibrium and transient behavior are explored.

The depth-versus-latitude pattern of climate drift in the ocean for the three cases is similar, with small-amplitude changes occurring in the surface layer, cooling of the second layer (less than 0.05°C per year), a warming of the third layer (less than 0.03°C per year), and a slight warming of the bottom layer (less than 0.005°C per year). Most of the climate drift is removed by subtracting the control case averaged over the same time period.

3. Simulation of observed climate

Given the present state of coupled model simulations, many of the errors in ocean-surface temperatures can be attributed to a limited knowledge of cloudiness, radiation, and surface transfers of sensible heat, momentum, salinity, and moisture. Nevertheless, the basic aspects of the climate system can be simulated. Figure 5 compares the latitude-versus-pressure distribution of zonally averaged temperature from the two coupled models with the observed data of Newell et al. (1972) for December-January-February (DJF) and June-July-August (JJA). The mixed-layer ocean model shows vividly the effects of lack of ocean dynamics on model climate since the surface temperatures are too warm in the tropics and too cold in the polar regions. Conversely, in the OGCM experiment, temperatures near the surface in the tropics are cooler by up to 5°C in the zonal average than the observed in the tropics, and in the higher-latitude Southern Hemisphere (SH), ocean temperatures are substantially warmer than the observed in both seasons. The OGCM yields cooler tropical and subtropical ocean temperatures than the mixed-layer ocean version, principally because equatorial upwelling and substantial poleward heat transport are not present in the mixed-layer model. Overall, the tropospheric and stratospheric simulations are similar in both ocean models, with one important exception—the overall tropospheric latitudinal temperature gradient in the OGCM is less, partly due to the effects of the ocean poleward heat transport (heat from low latitudes is exported to high latitudes).

Through the horizontal temperature gradient, which can be related to the vertical wind shear via the thermal wind relationship, the zonal wind maxima are smaller in mid- and high latitudes in the simulation with the OGCM. Figure 6 shows the zonally averaged zonal wind component as a function of latitude and pressure for the two seasons. During DJF, some features with the OGCM simulation are closer to the observed of Newell et al. (1972) and van Loon et al. (1971) than to the model with the mixed-layer ocean (Washington and Meehl, 1984). In the DJF simulation, there is a continuous distribution of easterlies throughout the midtroposphere in the OGCM and the midlatitude westerly jet streams are weaker, a result of the warmer-than-observed high-latitude temperature distribution.

The surface-air temperature geographical distributions for both coupled models are shown in Fig. 7. In the Atlantic and Pacific Oceans, the Northern Hemisphere (NH) winter shows more northward-shifted zonal temperature gradients with the OGCM than the experiment with the mixed-layer ocean. Temperatures are substantially warmer over the North Atlantic and near the edge of Antarctica. Over the tropical ocean, surface temperatures in the present model are more than 5°K too low in places. Continental temperatures over North America, Asia, and Africa are similar in the two simulations. The simulation of less-than-observed sea-ice distribution, noted by Washington and Meehl (1989) for the OGCM, is caused by substantially warmer-than-observed surface-air temperatures in the SH, a result of large horizontal ocean heat transport. At high southern latitudes, this poleward heat transport is mainly attributed to horizontal diffusion which must be kept at

a large value to maintain computational stability in the coarse-grid ocean model (Washington and Meehl, 1989).

The geographical surface-salinity distribution from the OGCM is compared with annual mean observations from Levitus (1982) in Washington and Meehl (1989). In the coupled model, because river runoff is not considered, there is no fresh-water input to the oceans from the land areas. In spite of the simplifications and limitations of the model, most of its major features are simulated. This can be explained partly by the fact that salinity fluxes at the top of the ocean contribute little to the total salt content of the oceans over the time scale of these experiments (50-60 years). The salinity distribution is still heavily influenced by the initial distribution. The subtropical maxima of salinity in the North Pacific and North Atlantic are simulated, including the maxima in the North Atlantic, while the Antarctic circumpolar and Arctic Ocean minima are also simulated.

The latitude-depth distribution of the zonally averaged temperature for DJF from the model is shown in Fig. 8 and compared with the observed of Levitus (1982). JJA is not shown because it is similar, except near the poles. Even though the general pattern is simulated, the permanent thermocline is not as sharp as the observed, which can be partly explained by the coarse vertical resolution. In the equatorial region, surface temperatures are too cold and the simulated surface temperatures near 60°S are too warm. The latitude-depth distribution of salinity (Fig. 9) shows that the zonal mean surface features are reproduced with relatively higher salinity in the subtropics and lower salinities at higher latitudes and in the

equatorial tropics. Beneath the surface layer are discrepancies mainly involving the penetration of high-salinity water near 35°N and the relatively lower salinity values in the SH mid- and high latitudes.

4. Differences in $2\times\text{CO}_2$, transient CO_2 , and $1\times\text{CO}_2$ experiments

Most climate simulations of greenhouse warming have been with an instantaneous doubling of CO_2 . This section describes such experiments with the NCAR coupled models as well as an additional experiment of increasing the CO_2 concentration by one percent per year.

The associated zonal mean temperature changes in the atmosphere for a doubling of CO_2 are shown in Fig. 10 for both types of ocean models. In the NH of the OGCM, the reduction of sea ice during DJF is associated with a maximum warming of $+5.0^\circ\text{C}$ at the surface near 75°N , largely a result of the ice-albedo feedback. This feedback process, which shows largest change in winter, is caused by increased solar absorption during the summer months (Washington and Meehl, 1984). Similar ice-albedo effects are not evident in the SH (Fig. 10d) because of the near absence of sea ice around Antarctica in the OGCM. Both winter and summer temperature differences with the mixed-layer ocean show throughout the troposphere a warming of about $2^\circ\text{--}4^\circ\text{C}$, with strong upper tropospheric warming in the tropics (Fig. 10a,c). At most latitudes, stratospheric cooling increases above about 18 km to at least $5^\circ\text{--}6^\circ\text{C}$ at the top of the model. Warming at the surface is roughly $2^\circ\text{--}3^\circ\text{C}$, except at high latitudes in the winter hemispheres. During DJF, warming increases to more than 7°C near 65°N , and a warming of about 13°C occurs near 60°S during JJA (Fig. 10a,c). Both temperature maxima are near the sea-ice margin. The vertical

pattern of atmospheric temperature change in Fig. 10 in the mixed-layer version is similar to that of the OGCM.

Figures 11a and b depict latitude depth of zonal mean differences, $2\times\text{CO}_2$ minus control, for (a) temperature and (b) salinity for DJF. The ocean warming has penetrated into the third model layer with largest concentration near the surface ($+1.7^\circ\text{C}$ near 60°N and $+1.3^\circ\text{C}$ around 50°S). Schlesinger and Jiang (1988) found similar maxima in their coupled model simulation. In addition, the minima of warming in the ocean in the tropics and high latitudes are quite different from those in the ocean mixed-layer model results. The zonal mean salinity differences (Fig. 11b) also show large changes in the surface layer of the ocean where salinity decreases in the midlatitudes and high latitudes. The OGCM shows salinity increases in the subtropics and a decrease near the equator. These changes in salinity indicate alterations of precipitation minus evaporation as well as changes of vertical mixing. Warmer SSTs caused by CO_2 doubling produce increased evaporation at most latitudes. Precipitation increases correspond to areas of salinity decreases, and vice versa for precipitation decreases. Washington and Meehl (1989) discuss the effects on salinity distributions of lack of river runoff.

Geographical difference patterns of surface-air temperature change $2\times\text{CO}_2$ minus control for the two ocean types are shown in Fig. 12 for DJF and JJA. The temperature differences are much larger in the mixed-layer ocean model with the largest values over the edges of the sea ice, whereas the differences with the OGCM are smaller and not obviously associated with sea-ice position. As noted earlier,

because the control simulation with the OGCM has much less sea ice, especially in the SH, there should be less sea-ice albedo feedback on temperature. Although the difference satisfies a significance test (Chervin, 1981; Washington and Meehl, 1984, 1989), the results are sensitive to the control climate. The transient simulation exhibits a different geographical pattern for reason other than dissimilar ocean models, as will be discussed later.

In Fig. 12, the large warming in areas of sea-ice reduction is statistically significant during DJF. During JJA, significant warming is not as uniform over the NH. The CO₂-caused warming in the SH is smaller—about 1–2°C. The small areas of cooling are not statistically significant. With the earlier set of experiments, Washington and Meehl (1983) demonstrated that cooler SSTs in the tropics contributed to reduced atmospheric moisture amounts and less sensitivity. Other groups have found similar dependence of sensitivity on the control temperature distributions.

It is noteworthy that, after 30 years, this model produces less CO₂ warming than the simple mixed-layer ocean version. Lower tropical OGCM SSTs are associated with reduced atmospheric moisture, and the warmer high-latitude SSTs result in less-extensive sea ice. Both factors contribute to less feedback and lower sensitivity.

Ice albedo as a feedback is important in that more extensive sea ice leads to greater model sensitivity (Washington and Meehl, 1986). Estimates for the simple mixed-layer ocean version show that ice-albedo feedback contributes more than a

degree to the 3.5°C global warming (Dickinson et al., 1987).

Changes in soil moisture for the two ocean types are qualitatively similar (Fig. 13). During winter over the NH midlatitude continents, there are mostly increases of soil moisture, and during the summer season in these regions there are areas of both increase and decrease. The OGCM allows for circulation changes in the ocean, a distinct advantage over the mixed-layer ocean. From a comparison of the zonally averaged wind stress over the ocean for the control, the $2\times\text{CO}_2$ cases, and the observed of Hellerman and Rosenstein (1983), Washington and Meehl (1989) found that the model agreed well with the observed. Washington and Meehl (1989) also show that changes in wind stress have a profound effect on the tropical ocean temperatures such that a reduction in wind stress can result in a warming of the equatorial waters by several degrees. This is due to the close association in the model of wind stress, upwelling, and SST. That is, reduced wind stress results in weakened upwelling and higher SSTs. In the midlatitudes, the doubled CO_2 experiment exhibits a noticeably reduced westerly wind stress of 0.03 N m^{-2} and a warming of the ocean surface layer at those latitudes.

The changes in the zonal mean mass circulation in the ocean caused by doubling CO_2 are large (Washington and Meehl, 1989). Figure 14a shows the global meridional overturning from the control experiment during DJF (Washington and Meehl, 1989), and Fig. 14b shows the difference in circulation between the $2\times\text{CO}_2$ and $1\times\text{CO}_2$ experiments. Unfortunately, there are no reliable observations of this quantity with which to compare the model results. Negative values indicate coun-

terclockwise circulation and positive values are clockwise. In the control near the surface are shallow wind-driven cells, with deeper overturning near 40–50° latitude below the wind-driven surface cells in both hemispheres. A weak upward mass circulation is seen near 60°S.

The difference of meridional streamfunction (Fig. 14b) has positive values with anomalous clockwise circulation in the NH and the converse in the SH with anomalous counterclockwise circulation. Because of the reduction of the westerly wind stress in the $2\times\text{CO}_2$ experiment, the shallow, wind-driven midlatitude cells weaken in both hemispheres. The deep-ocean midlatitude cells also weaken. The warming and freshening of the surface layer are especially evident near 50°N where sinking is weaker in the deep ocean. Washington and Meehl (1989) examine this process more closely for the North Atlantic.

Bryan and Spelman (1985) showed, in a coupled ocean-atmosphere sector model, a similar partial collapse of the ocean thermohaline circulation with a quadrupling of CO_2 after 25 years of simulation due to a warming and freshening of the upper ocean from the effects of increased CO_2 . Bryan (1986) further demonstrated with specified atmospheric forcing that changes of the thermohaline circulation in a basin-ocean model are associated with changes in the surface salinity forcing. Moreover, these salinity perturbations can cause rapid mass circulation changes. The Washington and Meehl (1989) results with a coupled global ocean-atmosphere model with realistic geography and bottom topography lend support to other model results. These experiments indicate that warming and freshening of

the high-latitude surface layer make the oceans more stable and weaken the thermohaline circulation on relatively short time scales (tens of years). The weakening of the westerlies in the $2\times\text{CO}_2$ experiment is associated with decreased overturning between the upper layers of the model.

Unique to the OGCM is the possibility of convective overturning. When this occurs in the OGCM, there are rapid vertical fluxes of heat and salinity. The convective mechanism of the ocean model devised by Bryan (1969) and used in the OGCM specifies that, if the densities in two adjacent layers are statically unstable, then the temperature and salinities in the two layers are uniformly mixed, yielding a stable stratification. The process is repeated for the next pair of layers. Depending upon the preexisting condition, this can mean an upward flux of heat or downward flux of salt or, under certain conditions, both. Killworth (1982) has shown the geographical locations of deep convection in the observed ocean and Reid (1965) for locations of intermediate waters. Because the model does not simulate all of the observed temperature and salinity distributions, particularly at the higher latitudes in the North Atlantic, errors exist in some of the locations. The control ($1\times\text{CO}_2$) and the difference ($2\times\text{CO}_2 - 1\times\text{CO}_2$) experiments of convective overturning between levels 1 and 2 are shown in Fig. 15 for the late winter season in each hemisphere—Feb-Mar-Apr for NH, and Aug-Sept-Oct for the SH. Convective overturning, less frequent between layers 2 and 3, rarely occurs between layers 3 and 4. If convective overturning occurs every time during the year, the value is unity in Fig. 15; if it occurs half the time, the value is 0.5.

Convection occurs mainly in the fall and winter of both hemispheres, suggesting that in the model it is predominantly temperature-driven rather than salinity-driven. Important exceptions occur in the Mediterranean, Red, and Caspian Seas where convection takes place year-round. In these regions, the large evaporation causes a salinity-driven overturning of the first two layers.

The $2\times\text{CO}_2-1\times\text{CO}_2$ difference (Fig. 15) shows a substantial decrease in convection, particularly in the higher latitudes, indicating an increased stratification of the model, as expected with a CO_2 warming.

Another major difference between the mixed-layer ocean model and the OGCM is the presence of ocean-heat transport in the latter. This quantity consists of (1) the meridional overturning component; (2) the gyre component, such as the midlatitude gyres in the North Pacific and North Atlantic; and (3) subgrid-scale lateral diffusion. Figure 16a shows the components from the control case, and the total values can be compared with observed latitudinal estimates from Oort and Vonder Haar (1976), Trenberth (1979), Hastenrath (1980), and Carissimo et al. (1985) in Fig. 16b. In low and subtropical latitudes, the largest horizontal heat transport is meridional overturning, and in the middle and high latitudes the largest contributor is diffusion transport, especially in the SH. Employing a smaller horizontal diffusivity for heat yields more heat transport by meridional and gyre components (Meehl et al., 1982), but the total transport remains the same. Cox (1985) has shown similar compensations with higher-resolution models in which ocean eddies are resolved. Increasing ocean resolution, therefore, decreases lateral diffusion heat

transport and increases the gyre component. Figure 16c depicts the total annual mean horizontal ocean heat transport for $2\times\text{CO}_2$ and $1\times\text{CO}_2$. Transport decreases at the midlatitudes, in large part a result of a decrease in diffusion caused by a slackening of the north-south oceanic temperature gradient. The small increase of poleward transport near 10°S is associated with a somewhat stronger meridional circulation in the model's second layer.

The annual cycles of ocean heat storage among the observed, the mixed-layer ocean model, and the OGCM are remarkably similar, thus establishing that a simple mixed layer can account for heat storage in the upper ocean at least to the first order (Meehl and Washington, 1985; Washington and Meehl, 1989).

A great deal of interest has been generated in the differences between experiments with instantaneous increase of CO_2 and the effects of a gradual increase of CO_2 with time. Washington and Meehl (1989) extensively discuss such experiments. The present paper concentrates on how the ocean type may affect the result. At the end of the transient experiment (years 26–30), the temperature change in the ocean appears similar in some respects to the temperature change in the early part (years 6–10) of the $2\times\text{CO}_2$ experiment where most of the warming is at the top of the ocean (Fig. 17). Small changes, evident in the transient experiment compared to the CO_2 doubling case, are mostly near the surface with maxima of warming near 45°S and 20°N . Poleward of 30°N , cooling takes place in the zonal mean with a maximum at 65°N and is reflected in the atmospheric zonal temperature difference (Fig. 18). Apparently, the cooling in the zonal mean ocean temperatures at the high

latitudes in the NH results in a cooling of the atmosphere zonal mean through the troposphere. As discussed in Washington and Meehl (1989), the circulation changes in the NH of the transient case are associated with the southward advance of the sea-ice limit in conjunction with southward advection of cold air and the cooling of SSTs into the North Atlantic region.

The response of the transient case is different because the changes in forcing are much slower and the climate system has a chance to evolve more gradually than the $2\times\text{CO}_2$ case. Although some patterns of changes are similar, the transient time evolution allows the ocean to adjust to changes in atmospheric circulation. This strongly suggests that the $2\times\text{CO}_2$ instantaneous experiments may not be reasonable analogues to a gradual increase of CO_2 . The transient experiment will be discussed further in the next section.

5. Discussion and conclusions

Despite the shortcomings and errors in simulated ocean temperature of the coupled atmosphere-OGCM, it simulates many features of the present climate system. The zonal mean patterns of temperatures and winds in the atmosphere are reproduced, as are the ocean zonal mean temperatures, salinities, heat transport, and heat storage. The most important errors are colder-than-observed tropical SSTs and warmer-than-observed high-latitude temperatures. There is very limited extent of sea ice in the Bering Sea and around Antarctica. From the additional parameter studies discussed in Washington and Meehl (1989), the following are important factors that contribute to the SST distribution computed by the coupled model: (1) decreased wind-stress forcing results in less equatorial upwelling and warmer tropical SSTs, (2) a decrease in the depth of the second layer results in warmer water brought to the surface and higher SSTs in the tropics; (3) a shallower second layer at extratropical latitudes results in cooler SSTs at those latitudes following similar reasoning; and (4) a decrease in the horizontal heat diffusion results in less heat diffused out of the low and midlatitudes, warmer tropical SSTs and cooler high-latitude SSTs.

The coupled model has lower sensitivity to increased CO_2 after 30 years of integration compared to the coupled model with a 50-m slab-ocean mixed layer (Washington and Meehl, 1984). The mixed-layer model has warmer-than-observed

tropical SSTs and cooler-than-observed high latitude, causing overextensive sea ice. As a result of warm tropical SSTs and overextensive sea ice, the mixed-layer model is very sensitive to CO₂-induced warming (3.5°C globally averaged surface air temperature change for a doubling of CO₂). Conversely, the OGCM has cool tropical SSTs, reduced sea-ice extent, and a sensitivity of 1.6°C after 30 years of integration, suggesting that the sensitivity of the real climate system to a doubling of CO₂ is somewhere between the two sets of experiments.

Patterns of temperature change in the atmosphere are similar for the two types of ocean with CO₂ instantaneously doubled. Warming occurs in the troposphere with the largest surface air temperature change taking place where sea ice has retreated poleward. Soil moisture changes are also similar in both sets of experiments.

CO₂ warming in the ocean is confined mostly to the upper portion, especially in the surface layer near 60°N and 50°S. Through increases in precipitation, weakened westerly wind stress, and reduced overturning, salinity amounts decrease at high latitudes of each hemisphere. Salinity also increases in the subtropics. The resultant warming and freshening of the high-latitude ocean surface layer stabilize the ocean and cause a weaker thermohaline circulation.

The transient experiment shows the greatest changes to ocean temperatures in the ocean surface layer, and most of the troposphere warms while the stratosphere cools. Important differences from the 2×CO₂ instantaneous experiment, such as cooling in the North Atlantic and, to a lesser extent, the northwest Pacific, suggest

that patterns of climate change from an instantaneous CO₂ doubling experiment may not be accurate analogues to climate change from a transient or slowly increasing CO₂ amount.

Analysis of observations (e.g., Karoly, 1989) indicates a secular cooling trend in the lower troposphere over regions of the North Atlantic and North Pacific with warming over the rest of the NH similar to that noted in the transient case (Fig. 19). Over the North Atlantic, the more recent cold years in that region (1960s through 1980s) have been characterized by a sea-level pressure anomaly pattern similar to that noted in the transient case for the coupled model (Fig. 20). In particular, the centers of positive SLP anomalies over the North Atlantic and negative SLP anomalies over the subtropical Atlantic and northern Europe are similar between the transient case and the more recent observations (Fig. 20).

The correspondence of recent observed temperature and circulation anomalies with those simulated during the latter period of the coupled model transient case raises two intriguing possibilities: (1) both the actual and the simulated coupled system display climate anomaly regimes on decadal time scales that function in similar ways and the correspondence is coincidental; or (2) the coupled model is actually simulating the real transient response to the observed slow increase of CO₂ presently taking place. Clearly, further inspection of the observed climate regimes in these regions, as well as additional analysis of climatic regimes in the coupled model, is warranted. In addition, because of model shortcomings and failure to reproduce all of the regional aspects of climate, one should be cautious in using the

climate changes exhibited by these experiments. Increased resolution and improved physical processes are necessary in the next generation of coupled atmosphere-ocean general circulation models.

ACKNOWLEDGMENTS

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REFERENCES

- Bates, G. and G.A. Meehl, 1986: The effect of CO₂ concentration on the frequency of blocking in a general circulation model coupled to a simple mixed layer ocean. *Mon. Wea. Rev.*, **114**, 687-701.
- Bryan, K., 1969: Climate and the ocean circulation: III. The ocean model. *Mon. Wea. Rev.*, **97**, 806-827.
- Bryan, F., 1986: High latitude salinity effects and interhemispheric thermohaline circulations. *Nature*, **323**, 301-304.
- Bryan, K. and M.J. Spelman, 1985: The ocean's response to a carbon dioxide-induced warming. *J. Geophys. Res.*, **90**, 11,679-11,688.
- Bryan, K., S. Manabe, and M.J. Spelman, 1988: Interhemispheric asymmetry in the transient response of a coupled ocean-atmosphere model to a CO₂ forcing. *J. Phys. Oceanogr.*, **18**, 851-867.
- Bryan, K., F.G. Komro, S. Manabe, and M.J. Spelman, 1982: Transient climate response to increasing atmospheric carbon dioxide. *Science*, **215**, 56-58.
- Carissimo, B.C., A.H. Oort, and T.H. Vonder Haar, 1985: Estimating the meridional energy transports in the atmosphere and ocean. *J. Phys. Oceanogr.*, **15**, 82-91.

- Chervin, R.M., 1981: On the comparison of observed and GCM simulated climate ensembles. *J. Atmos. Sci.*, **38**, 885-901.
- Cox, M.D., 1985: An eddy resolving numerical model of the ventilated thermocline. *J. Phys. Oceanogr.*, **15**, 1312-1324.
- Dickinson, R.E., G.A. Meehl, and W.M. Washington, 1987: Ice-albedo feedback in a CO₂ doubling simulation. *Climatic Change*, **10**, 241-248.
- Hansen, J., I. Fung, A. Lacis, D. Rind, S. Lebedeff, R. Ruedy, and G. Russell, 1988: Global climate changes as forecast by Goddard Institute for Space Studies three-dimensional model. *J. Geophys. Res.*, **93**, 9341-9364.
- Hansen, J., A. Lacis, D. Rind, G. Russell, P. Stone, I. Fung, R. Ruedy, and J. Lerner, 1984: Climate sensitivity: Analysis of feedback mechanisms. In *Climate Processes and Climate Sensitivity*, J.F. Hansen and T. Takahashi, eds., Maurice Ewing Series, **5**, 130-163.
- Hastenrath, S., 1980: Heat budget of tropical ocean and atmosphere. *J. Phys. Oceanogr.*, **10**, 159-170.
- Hellerman, S. and M. Rosenstein, 1983: Normal monthly wind stress data over the world ocean with error estimates. *J. Phys. Oceanogr.*, **13**, 1093-1104.
- Karoly, D.J., 1989: Northern Hemisphere temperature trends: A possible greenhouse gas effect? *Geophys. Res. Lett.*, in press.

- Killworth, P.D., 1982: Deep convection in the world ocean. *Rev. Geophys. Space Phys.*, **21**, 1-26.
- Levitus, S., 1982: *Climatological Atlas of the World Ocean*. NOAA Professional Paper 13, Department of Commerce, Rockville, MD, (U.S. GPO, Washington, DC), 173 pp., 17 microfiche.
- Manabe, S., 1969: Climate and the ocean circulation: I. The atmospheric circulation and the hydrology of the earth's surface. *Mon. Wea. Rev.*, **97**, 775-805.
- Manabe, S. and R.J. Stouffer, 1988: Two stable equilibria of a coupled ocean-atmosphere model. *J. Climate*, **1**, 841-866.
- Manabe, S. and R.T. Wetherald, 1975: The effects of doubling the CO₂ concentration on the climate of a general circulation model. *J. Atmos. Sci.*, **32**, 3-15.
- Meehl, G.A., 1988: Tropical-midlatitude interactions in the Indian and Pacific sectors of the southern hemisphere. *Mon. Wea. Rev.*, **116**, 472-484.
- Meehl, G.A., 1989: The coupled ocean-atmosphere modeling problem in the tropical Pacific and Asian monsoon regions. *J. Climate*, in press.
- Meehl, G.A. and W.M. Washington, 1985: Sea surface temperatures computed by a simple ocean mixed layer coupled to an atmospheric model. *J. Phys. Oceanogr.*, **15**, 92-104.

- Meehl, G.A. and W.M. Washington, 1986: Tropical response to increased CO₂ in a GCM with a simple mixed layer ocean: Similarities to an observed Pacific Warm Event. *Mon. Wea. Rev.*, **114**, 667-674.
- Meehl, G.A. and W.M. Washington, 1988: A comparison of soil-moisture sensitivity in two global climate models. *J. Atmos. Sci.*, **45**, 1476-1492.
- Meehl, G.A., W.M. Washington, and A.J. Semtner, Jr., 1982: Experiment with a global ocean model driven by observed atmospheric forcing. *J. Phys. Oceanogr.*, **12**, 301-312.
- Newell, R.E., J.W. Kidson, D.G. Vincent, and G.J. Boer, 1972: *The General Circulation of the Tropical Atmosphere and Interactions with Extra-Tropical Latitudes*, **1**, M.I.T. Press, Cambridge, MA, 258 pp.
- Oort, A.H. and T.H. Vonder Haar, 1976: On the observed annual cycle in the ocean-atmosphere heat balance over the Northern Hemisphere. *J. Phys. Oceanogr.*, **6**, 781-800.
- Ramanathan, V., E.J. Pitcher, R.C. Malone, and M.L. Blackmon, 1983: The response of a spectral general circulation model to refinements in radiative processes. *J. Atmos. Sci.*, **40**, 605-630.
- Reid, J.L., Jr., 1965: *Intermediate Waters of the Pacific Ocean*. The Johns Hopkins Oceanographic Studies, **2**, 85 pp.

- Rogers, J.C., 1989: Seasonal temperature variability over the North Atlantic. *Proceedings of the Thirteenth Annual Climate Diagnostics Workshop*, Cambridge, MA, 31 Oct.-4 Nov. 1988, U.S. Dept. Commerce, Washington, DC, 170-175.
- Schlesinger, M.E. and X. Jiang, 1988: The transport of CO₂-induced warming into the ocean: An analysis of simulations by the OSU coupled atmosphere-ocean general circulation model. *Climate Dynamics*, **3**, 1-17.
- Schlesinger, M.E., W.L. Gates, and Y.J. Han, 1985: The role of the ocean in CO₂-induced climate change: Preliminary results from the OSU coupled atmosphere-ocean general circulation model. In *Coupled Ocean-Atmosphere Models*, J.C.J. Nihoul, ed., Elsevier Oceanography Series, **40**, 447-478.
- Schneider, S.H. and S.L. Thompson, 1981: Atmospheric CO₂ and climate: Importance of transient response. *J. Geophys. Res.*, **86**, 3135-3147.
- Semtner, A.J., 1974: An oceanic general circulation model with bottom topography. *Numerical Simulation of Weather and Climate*, Technical Report No. 9, University of California, Los Angeles, CA, 99 pp.
- Semtner, A.J., 1976: A model for the thermodynamic growth of sea ice in numerical investigations of climate. *J. Phys. Oceanogr.*, **6**, 379-389.
- Semtner, A.J., 1987: A numerical study of sea ice and ocean circulation in the Arctic. *J. Phys. Oceanogr.*, **17**, 1077-1099.

Thompson, S.L. and S.H. Schneider, 1982: Carbon dioxide and climate: The importance of realistic geography in estimating the transient temperature response. *Science*, **217**, 1031-1033.

Trenberth, K.E., 1979: Mean annual poleward energy transports by the oceans in the southern hemisphere. *Dyn. Atmos. Oceans*, **4**, 57-64.

van Loon, H., J.J. Taljaard, R.L. Jenne, and H.L. Crutcher, 1971: *Climate of the Upper Air: Southern Hemisphere, Vol. 2, Zonal Geostrophic Winds*. NCAR Technical Note, NCAR/TN STR-57, National Center for Atmospheric Research, Boulder, CO.

Washington, W.M. and G.A. Meehl, 1983: General circulation model experiments on the climatic effects due to a doubling and quadrupling of carbon dioxide concentrations. *J. Geophys. Res.*, **88**, 6600-6610.

Washington, W.M. and G.A. Meehl, 1984: Seasonal cycle experiment on the climate sensitivity due to a doubling of CO₂ with an atmospheric general circulation model coupled to a simple mixed-layer ocean model. *J. Geophys. Res.*, **89**, 9475-9503.

Washington, W.M. and G.A. Meehl, 1986: General circulation model CO₂ sensitivity experiments: Snow-sea ice albedo parameterization and globally averaged surface air temperature. *Climatic Change*, **8**, 231-241.

Washington, W.M. and G.A. Meehl, 1989: Climate sensitivity due to increased CO₂: Experiments with a coupled atmosphere and ocean general circulation model. *Climate Dynamics*, in press.

Washington, W.M., A.J. Semtner, G.A. Meehl, D.J. Knight, and T.A. Mayer, 1980: A general circulation experiment with a coupled atmosphere, ocean, and sea ice model. *J. Phys. Oceanogr.*, **10**, 1887-1908.

Wilson, C.A. and J.F.B. Mitchell, 1987: A doubled CO₂ climate sensitivity experiment with a global climate model including a simple ocean. *J. Geophys. Res.*, **92**, 13,315-13,343.

FIGURE LEGENDS

Fig. 1 Schematic of vertical-layer structure of coupled atmosphere-ocean model depicts various physical processes and interactions.

Fig. 2 Schematic of synchronous coupling method for atmospheric and oceanic sea-ice models.

Fig. 3 Description of running of coupled experiments. At the left, the atmospheric and oceanic models were run separately and then coupled for 16 years. At the right, the control ($1\times\text{CO}_2$) was extended for 30 years, and an instantaneous $2\times\text{CO}_2$ experiment and a transient CO_2 experiment were run for 30 years, with CO_2 increasing one percent per year.

Fig. 4 (a) Time evolution of globally averaged ocean surface temperature ($^{\circ}\text{C}$) for $1\times\text{CO}_2$, $2\times\text{CO}_2$, and transient CO_2 experiments; (b) time evolution of ocean surface temperature differences from part (a) ($^{\circ}\text{C}$).

Fig. 5 Zonal mean temperatures as a function of latitude and height (K). Computed values are three-month seasonal averages taken over the last three (mixed layer) and five (OGCM) years of the respective control cases. Observed values are long-term, three-month seasonal means from Newell et al. (1972): (a) mixed layer for DJF; (b) OGCM

for DJF; (c) observed for DJF; (d) mixed layer for JJA; (e) OGCM for JJA; (f) observed for JJA.

Fig. 6 Mean zonal (east-west) wind component u as a function of latitude and height (m s^{-1}). Computed values are compiled as in Fig. 5. Observed SH tropospheric values are geostrophic winds for (c) January and (f) July, from van Loon et al. (1971). All other observed values are three-month seasonal means from station data (Newell et al., 1972): (a) mixed layer for DJF; (b) OGCM for DJF; (c) observed for DJF (SH, January); (d) mixed layer for JJA; (e) OGCM for JJA; (f) observed for JJA (SH, July).

Fig. 7 Geographical distribution of surface air temperature ($\sigma=0.991$ K). Computed values are compiled as in Fig. 5. Sea-ice values are stippled for mixed layer and observed. (a) mixed layer for DJF; (b) OGCM for DJF; (c) observed for DJF; (d) mixed layer for JJA; (e) OGCM for JJA; (f) observed for JJA.

Fig. 8 Zonally averaged (a) computed temperature (DJF, $^{\circ}\text{C}$) and (b) observed annual mean temperature (Levitus, 1982, $^{\circ}\text{C}$). Contours every 2°C . Computed JJA patterns are qualitatively similar.

Fig. 9 Zonally averaged (a) computed salinity (o/oo) for DJF and (b) observed annual mean salinity (Levitus, 1982). Computed JJA patterns are qualitatively similar.

Fig. 10 Zonal mean atmospheric temperature differences ($^{\circ}\text{C}$) $2\times\text{CO}_2$ minus control ($1\times\text{CO}_2$): (a) mixed layer for DJF, (b) OGCM for DJF; (c) mixed layer for JJA; (d) OGCM for JJA.

Fig. 11 Zonally averaged (a) ocean temperature ($^{\circ}\text{C}$) and (b) salinity differences (o/oo) between $2\times\text{CO}_2$ and $1\times\text{CO}_2$ (DJF) experiments for years 26–30.

Fig. 12 Geographical distributions of surface air temperature differences ($^{\circ}\text{C}$, $\sigma=0.991$), $2\times\text{CO}_2$ minus control ($1\times\text{CO}_2$): (a) mixed layer for DJF, (b) mixed layer for JJA; (c) OGCM for DJF; (d) OGCM for JJA. Cross-hatching indicates differences significant at the five-percent level or greater.

Fig. 13 Soil moisture differences (cm), $2\times\text{CO}_2$ minus control, for five-year averages from coupled model. Stippling shows decrease of soil moisture in $2\times\text{CO}_2$ experiment. Hatching indicates difference significant at five-percent level or greater; (a) DJF; (b) JJA.

Fig. 14 Zonally averaged meridional overturning streamfunction (DJF) for years 26–30: (a) control, (b) $2\times\text{CO}_2$ minus control. Positive values indicate clockwise circulation. Units are Sverdrups ($10^6 \text{ m}^3 \text{ s}^{-1}$).

Fig. 15 (a) convective adjustment between top two layers on the ocean model for the winter seasons in both hemispheres; a value of 1.0 means con-

vective adjustment occurs every time step; (b) same as part (a) except for the difference $2\times\text{CO}_2$ minus control case.

Fig. 16 Annual mean ocean heat transport for (a) observed estimates; (b) components for the control case; (c) total values for control and $2\times\text{CO}_2$.

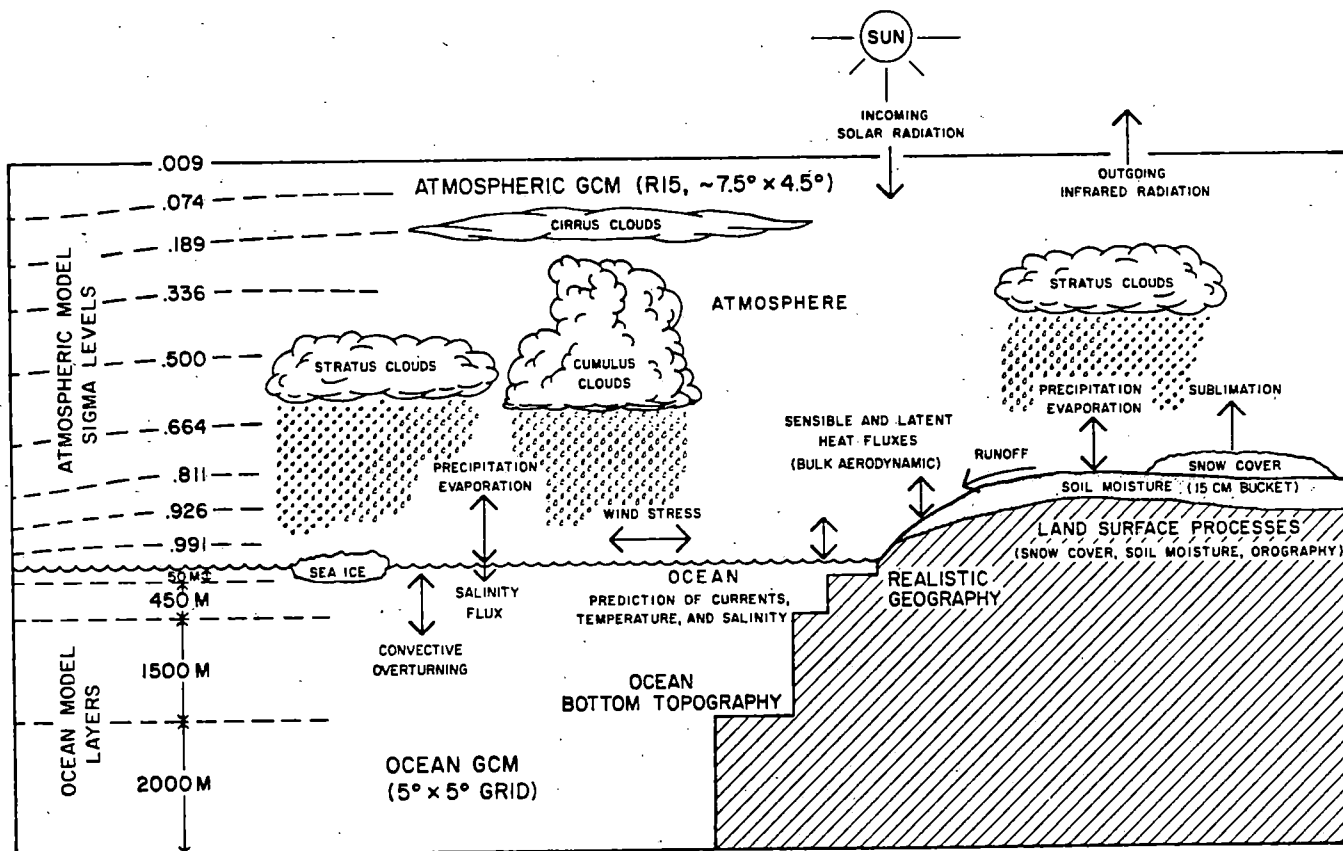
Fig. 17 Zonally averaged ocean temperature differences ($^{\circ}\text{C}$): (a) $2\times\text{CO}_2$ minus control years 6–10 (DJF), (b) transient minus control years 26–30 (DJF).

Fig. 18 Zonally averaged atmospheric temperature of transient minus control for years 26–30 ($^{\circ}\text{C}$): (a) DJF, (b) JJA.

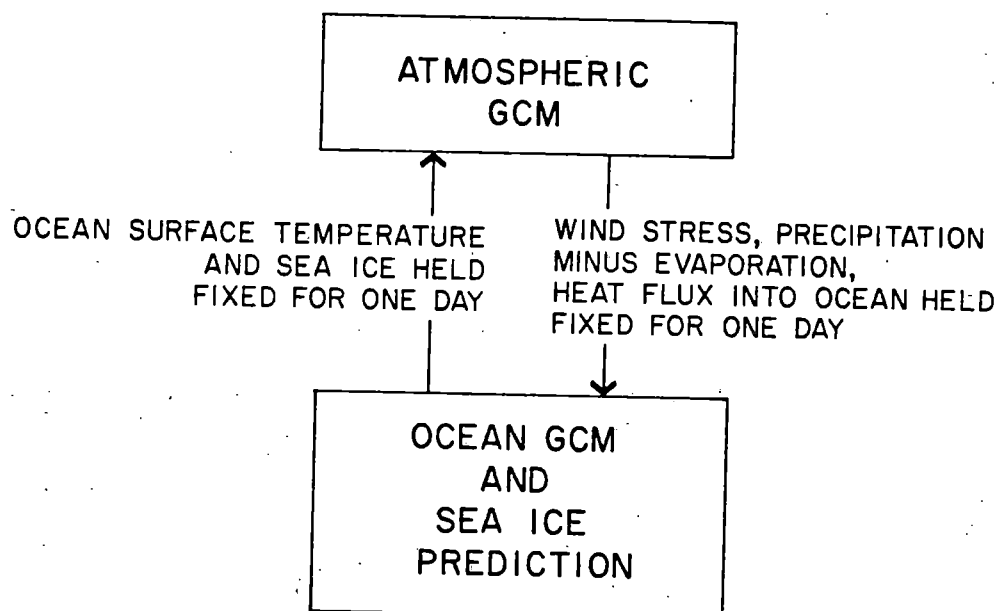
Fig. 19 (a) trend in $^{\circ}\text{C}/\text{century}$ of the least-squares fit to the time series of annual temperature anomalies in the lower troposphere (700 mb) derived from radiosonde data. Stippled areas indicate cooling trend (negative values); positive values indicate warming trend (after Karoly, 1989); (b) temperature difference for DJF, transient (years 26–30) minus control for the lower troposphere of the coupled model (sigma level = 811.). Stippled areas indicate cooling at mid- and high latitudes greater than 0.5° .

Fig. 20 (a) northern winter seasonal difference in sea-level pressure, mean pressure of the 1920s and 1930s minus mean pressure during more recent years (after Rogers, 1989); (b) sea-level pressure difference for

DJF, transient (years 26-30) minus control. Solid contours indicate positive sea-level pressure anomalies in transient case.

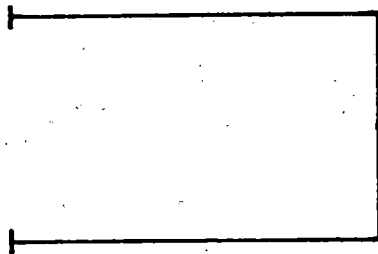


SYNCHRONOUS COUPLING METHOD



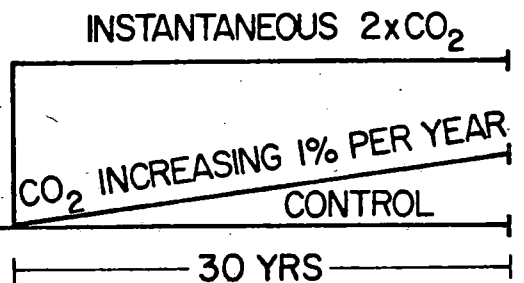
COUPLED MODEL EXPERIMENTS

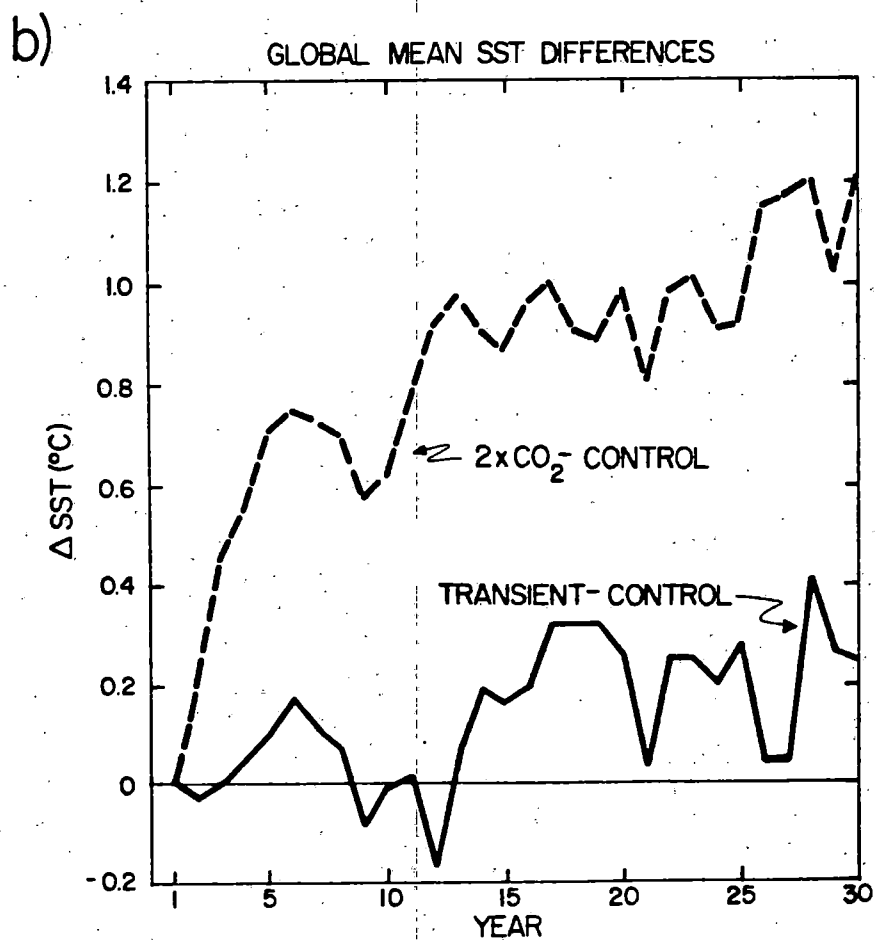
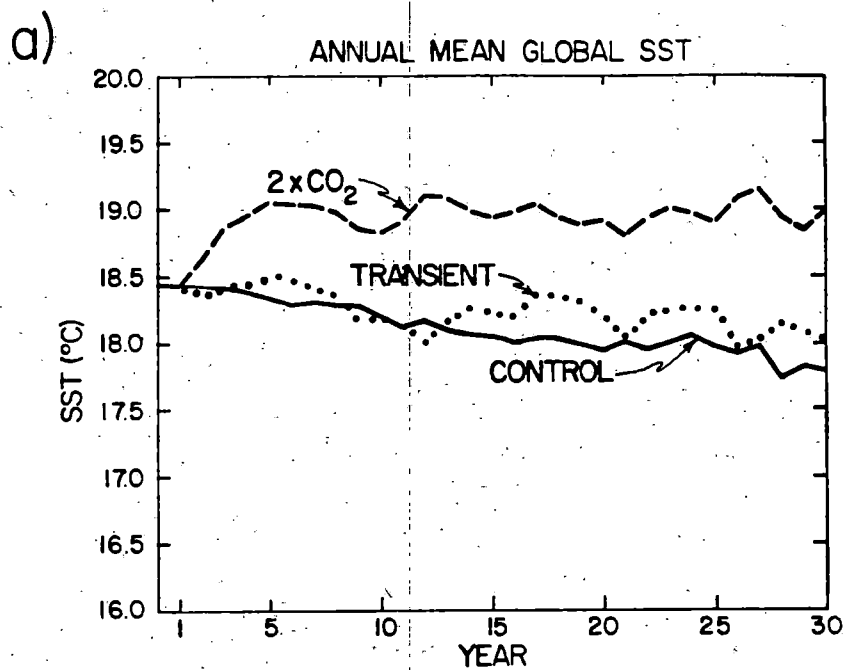
OCEAN WITH OBSERVED
ATMOSPHERIC FORCING (50YRS)
(INITIALIZED FIRST YEAR
WITH OBSERVED CROSS SECTION
OF T AND S)



ATMOSPHERE WITH 50M
MIXED LAYER FOR 15 YRS
(PRECEDED BY SPIN-UP)

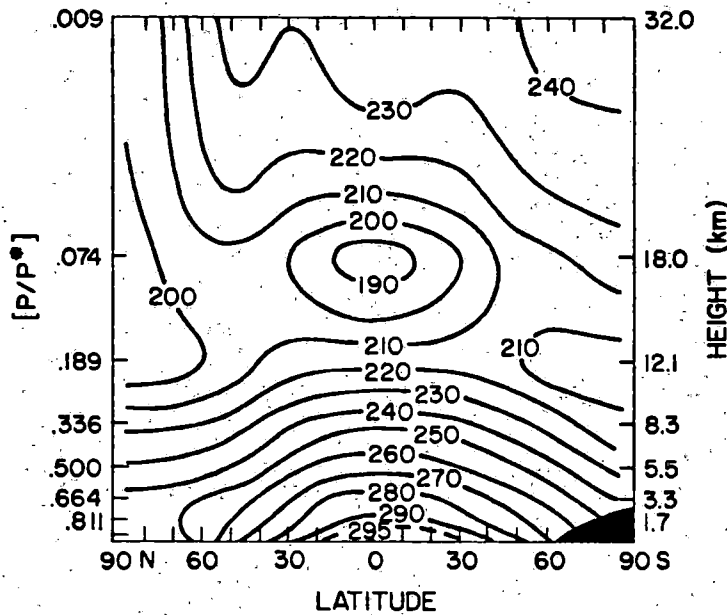
COUPLED (16 YRS)





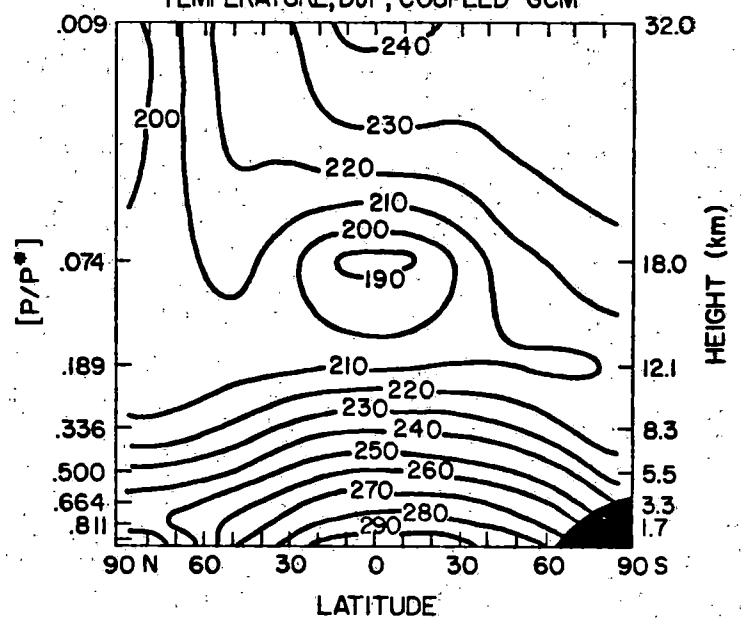
a)

MIXED LAYER
COMPUTED TEMPERATURE, DJF



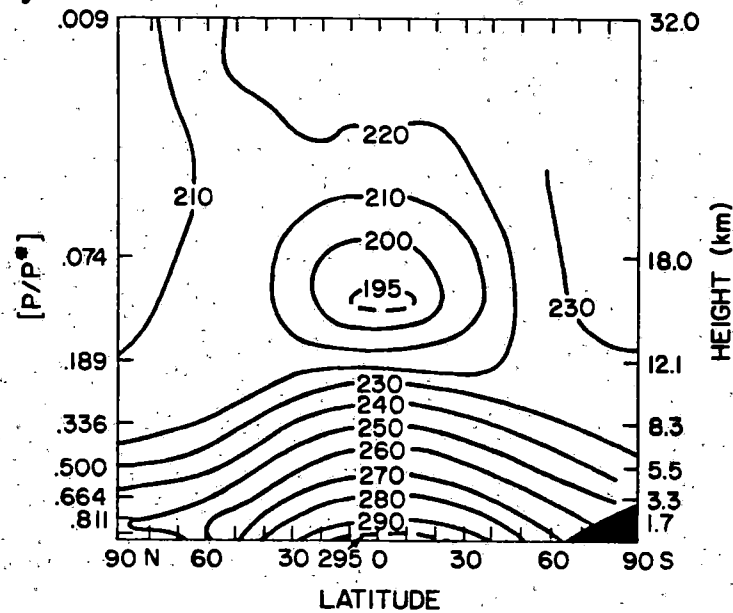
b)

OCGM
TEMPERATURE, DJF, COUPLED GCM



c)

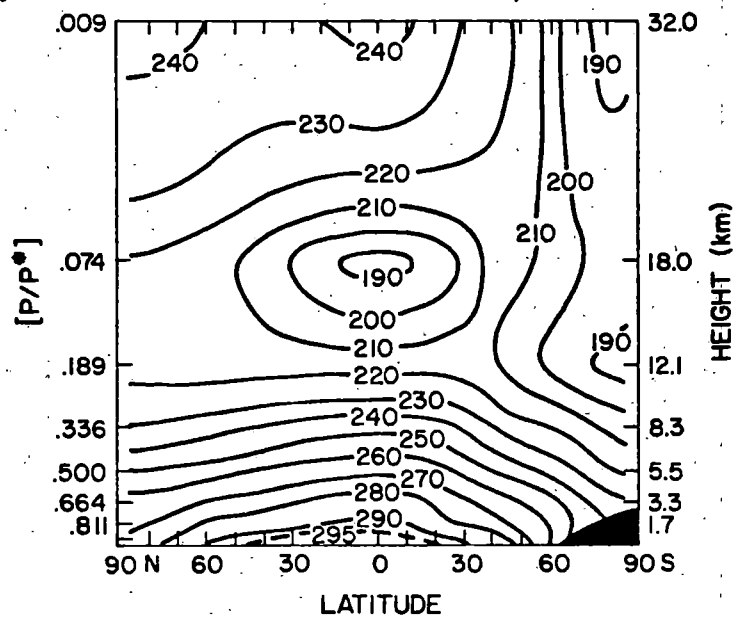
OBSERVED TEMPERATURE, DJF



5 a,b,c

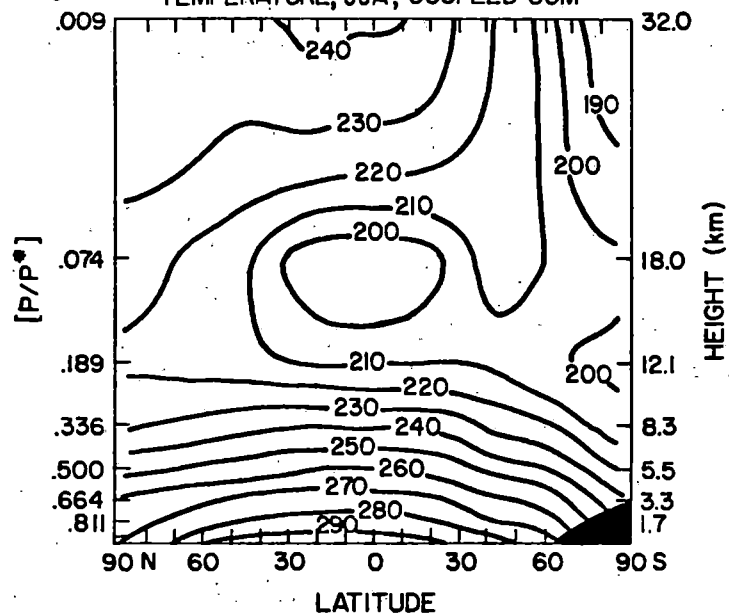
d)

MIXED LAYER
COMPUTED TEMPERATURE, JJA



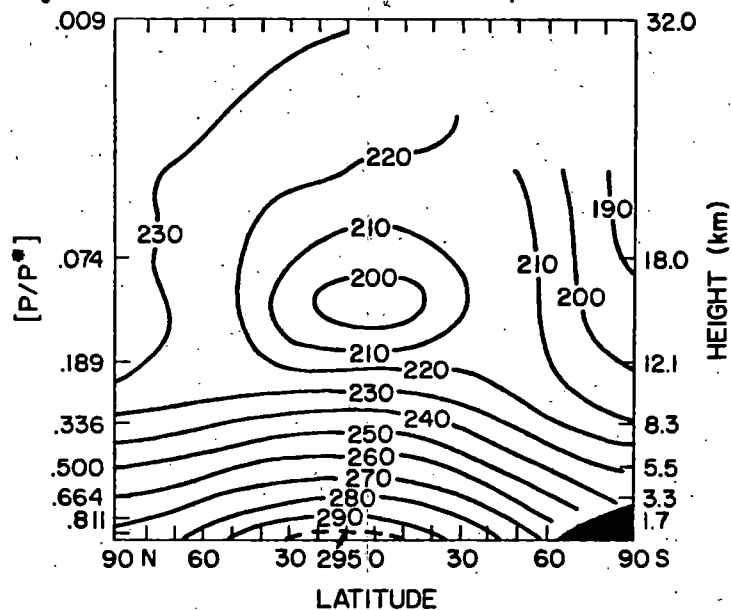
e)

OCGM
TEMPERATURE, JJA, COUPLED GCM



f)

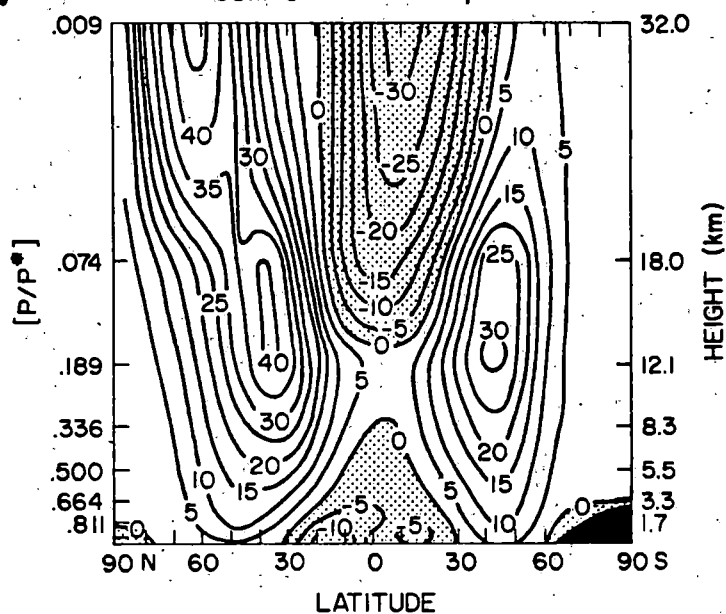
OBSERVED TEMPERATURE, JJA



5 def

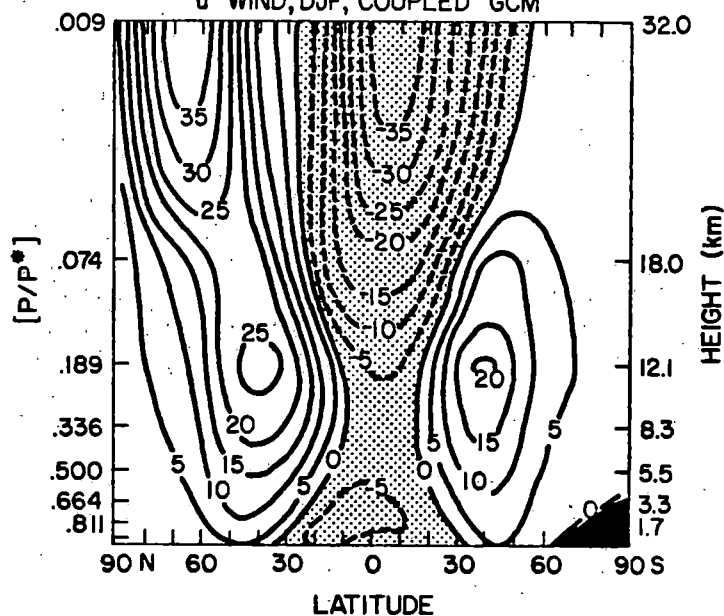
a)

MIXED LAYER
COMPUTED u WIND, DJF



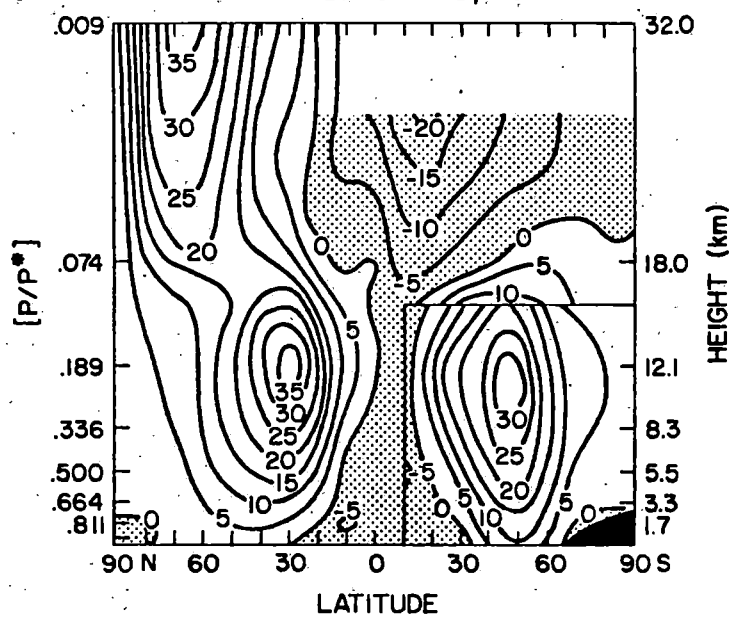
b)

OCGM
u WIND, DJF, COUPLED GCM



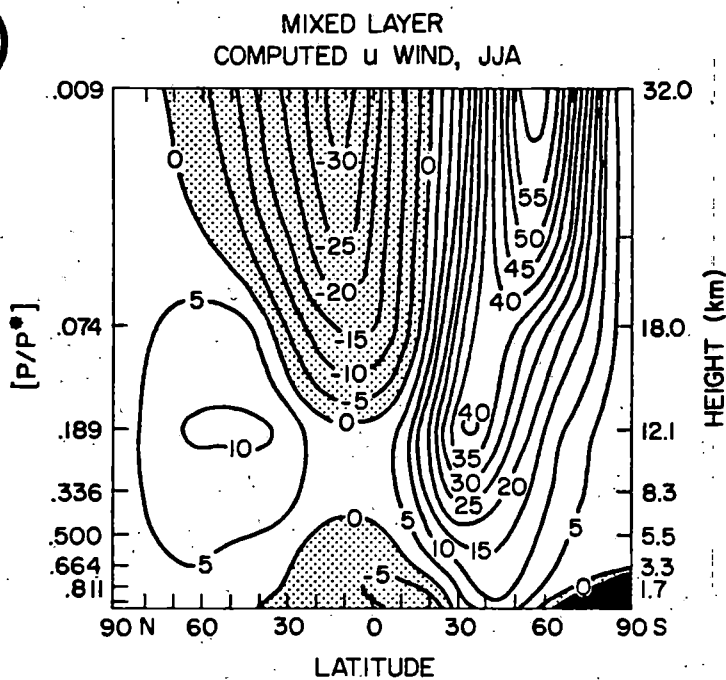
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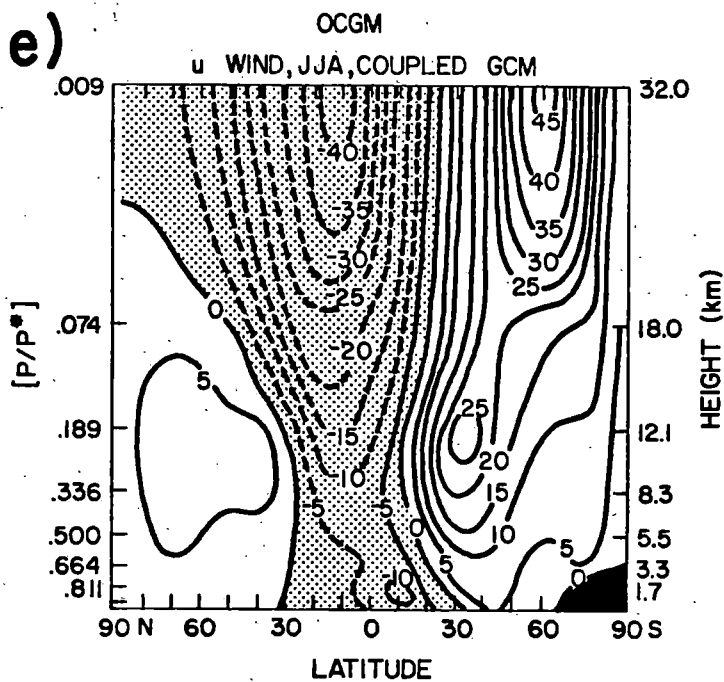


6 a,b,c

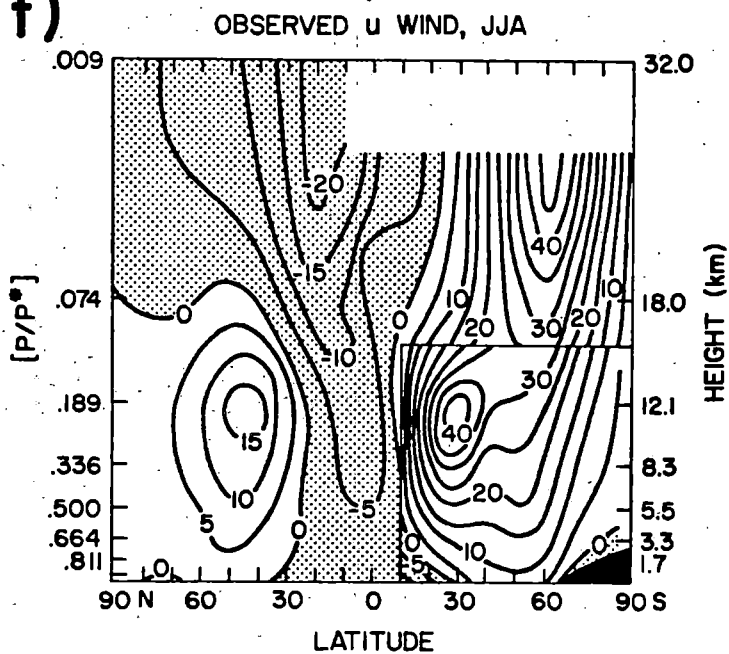
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e)

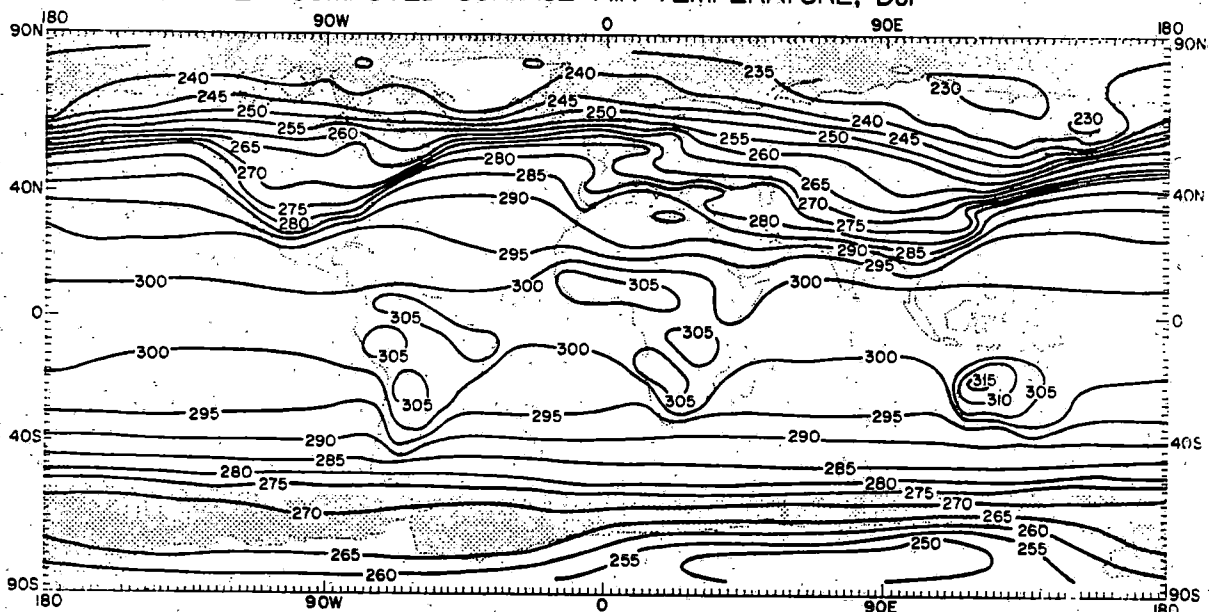


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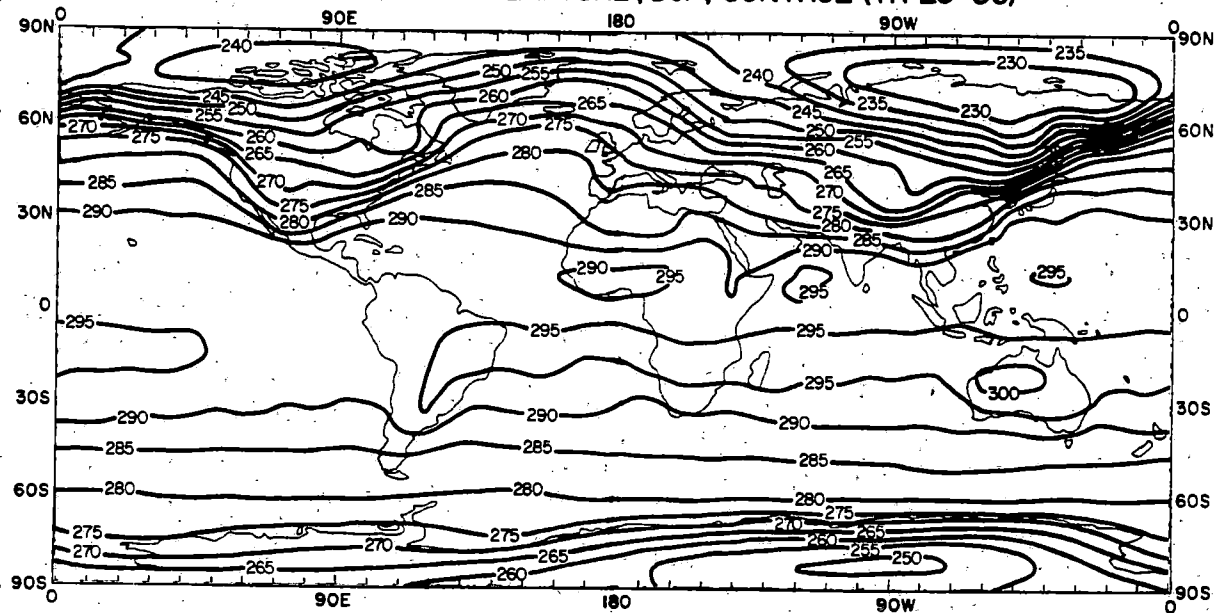


6 d,e,f

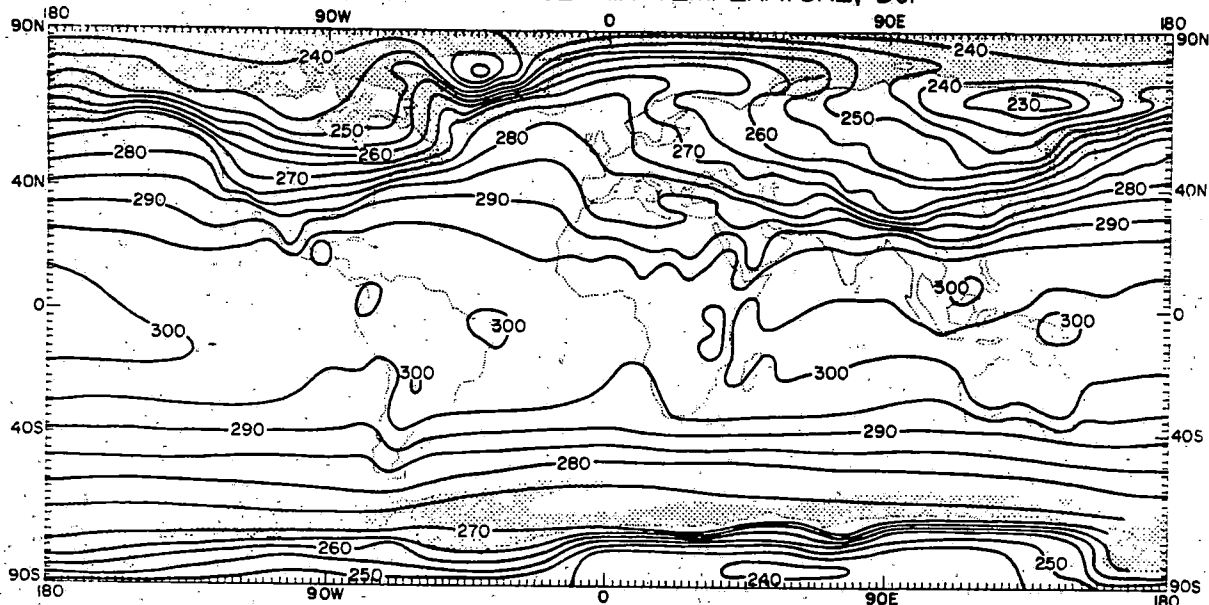
a) MIXED LAYER COMPUTED SURFACE AIR TEMPERATURE, DJF



b) OCGM SURFACE AIR TEMPERATURE, DJF, CONTROL (YR 26-30)

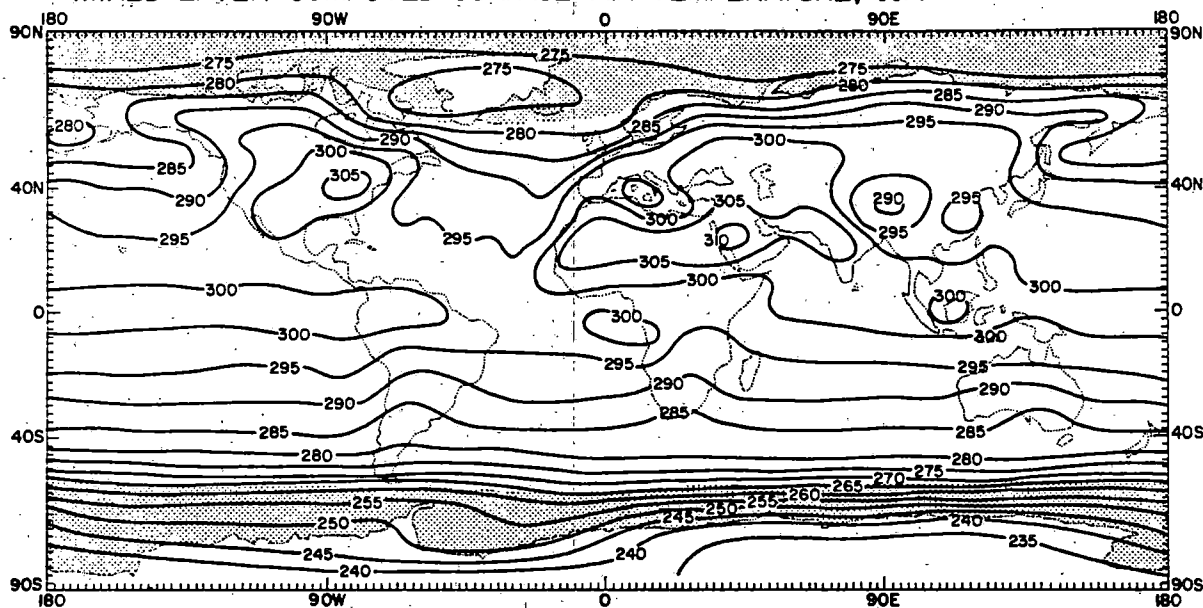


c) OBSERVED SURFACE AIR TEMPERATURE, DJF

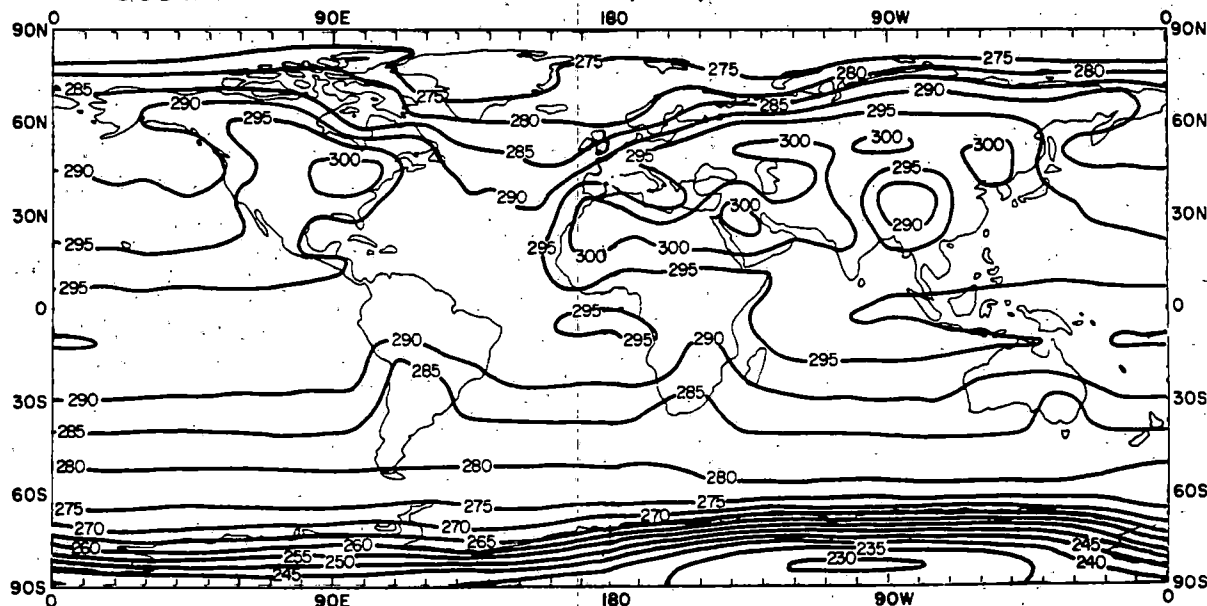


7abc

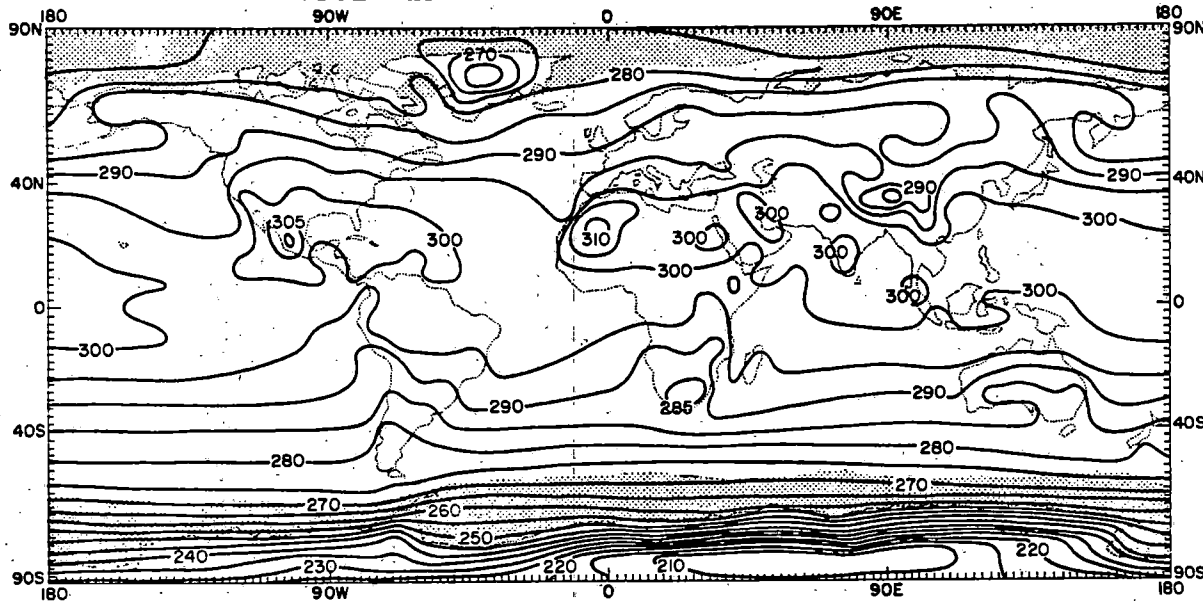
d) MIXED LAYER COMPUTED SURFACE AIR TEMPERATURE, JJA



e) OCGM SURFACE AIR TEMPERATURE, JJA, CONTROL (YR 26-30)

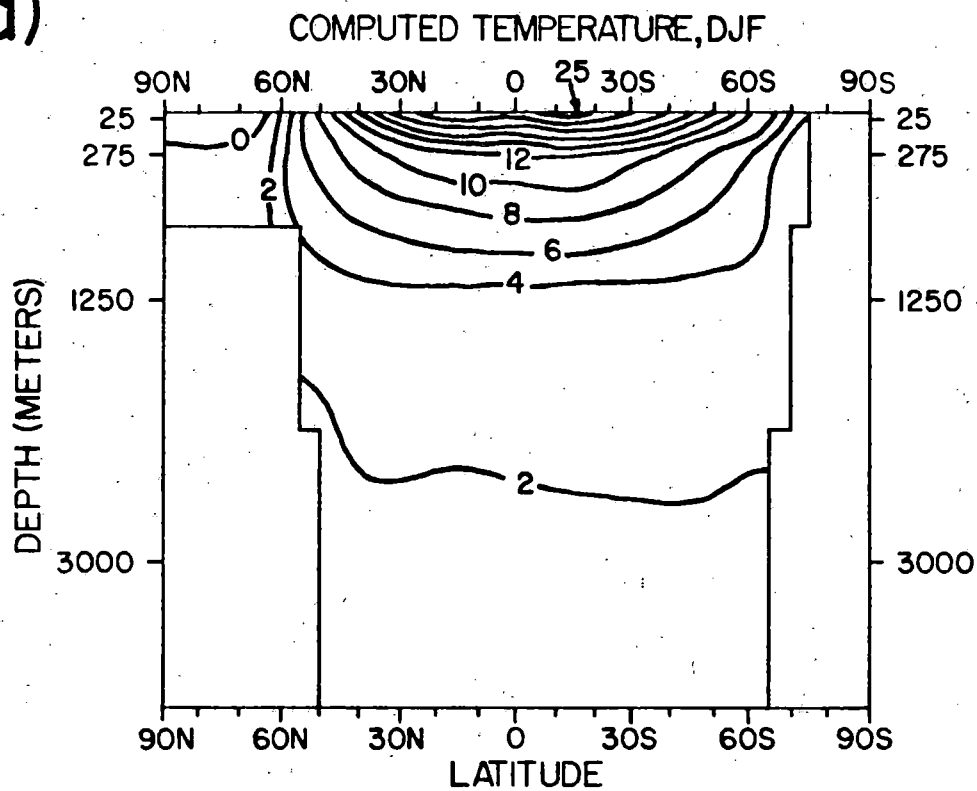


f) OBSERVED SURFACE AIR TEMPERATURE, JJA

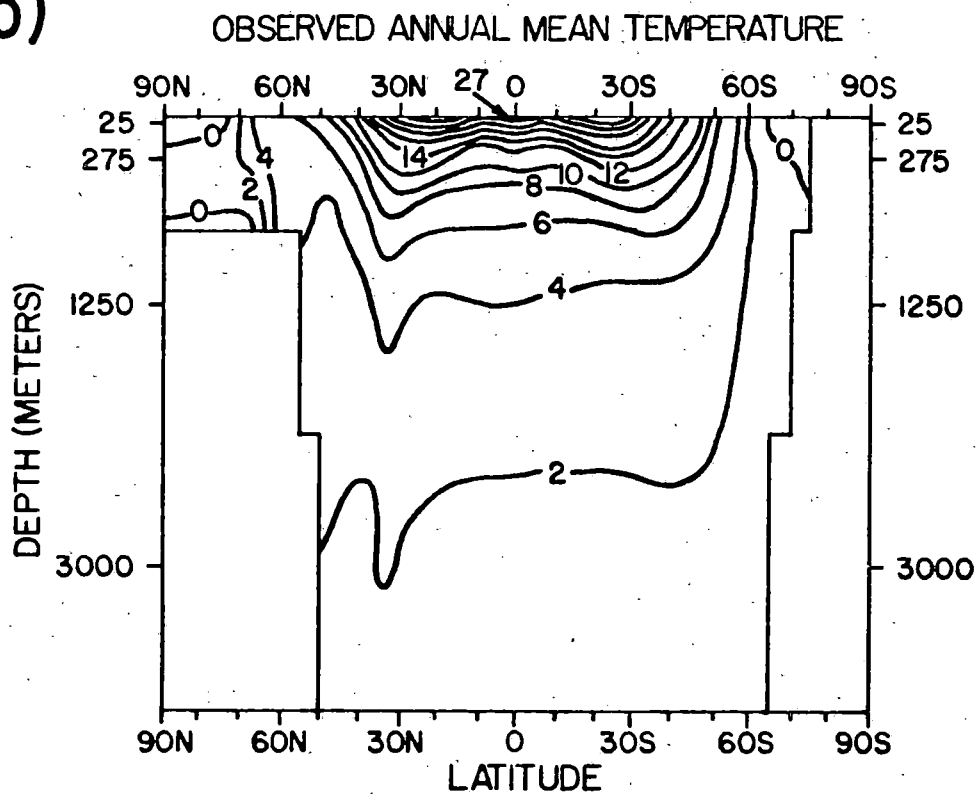


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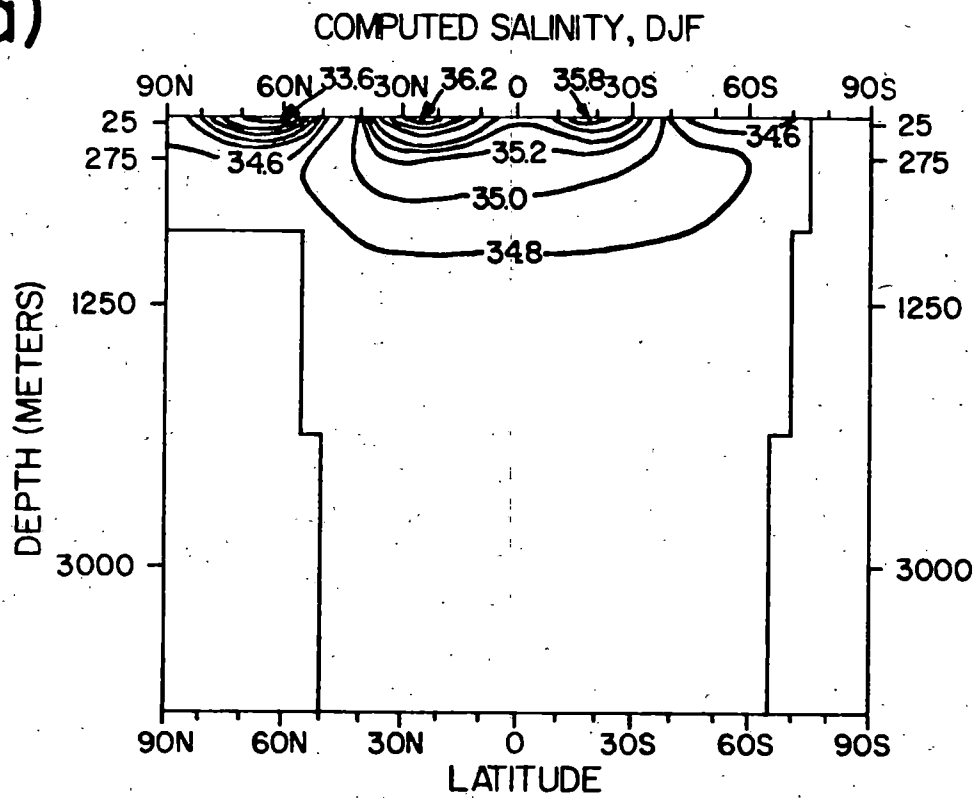
(a)



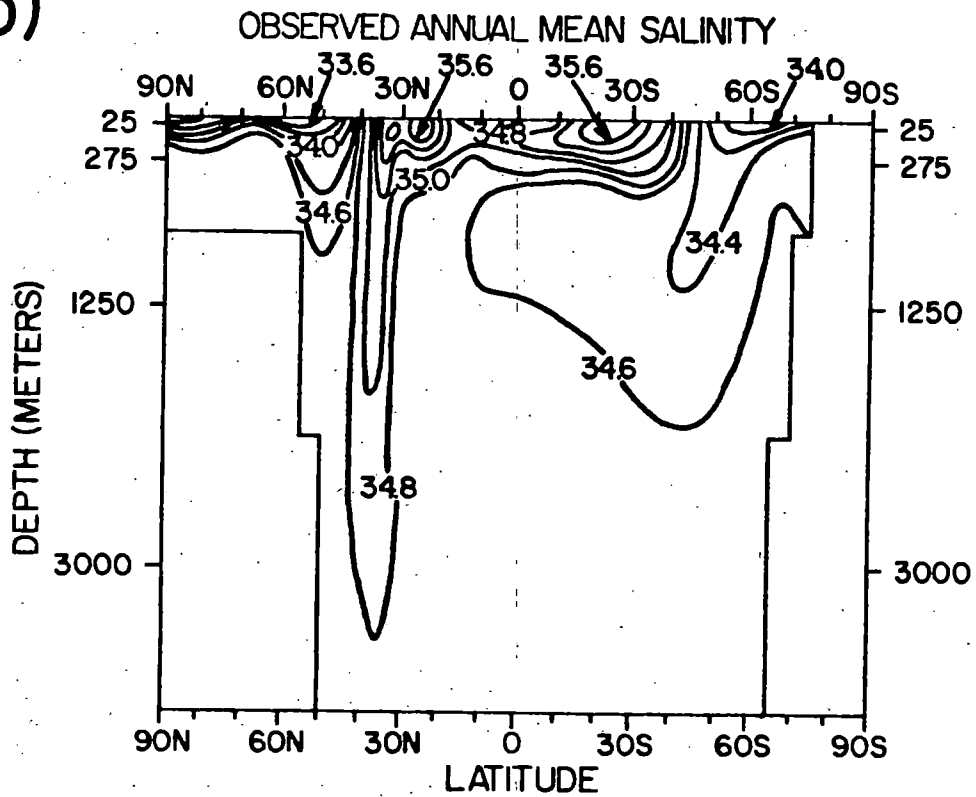
(b)

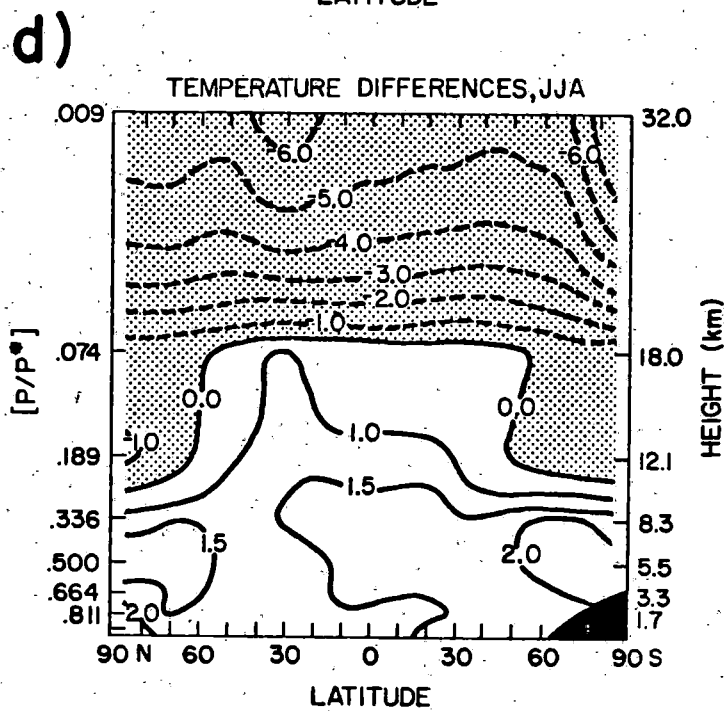
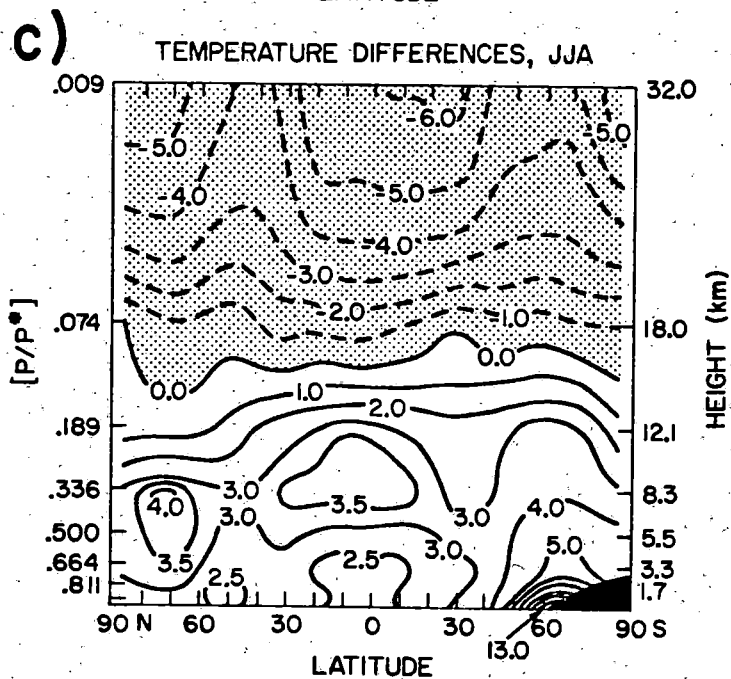
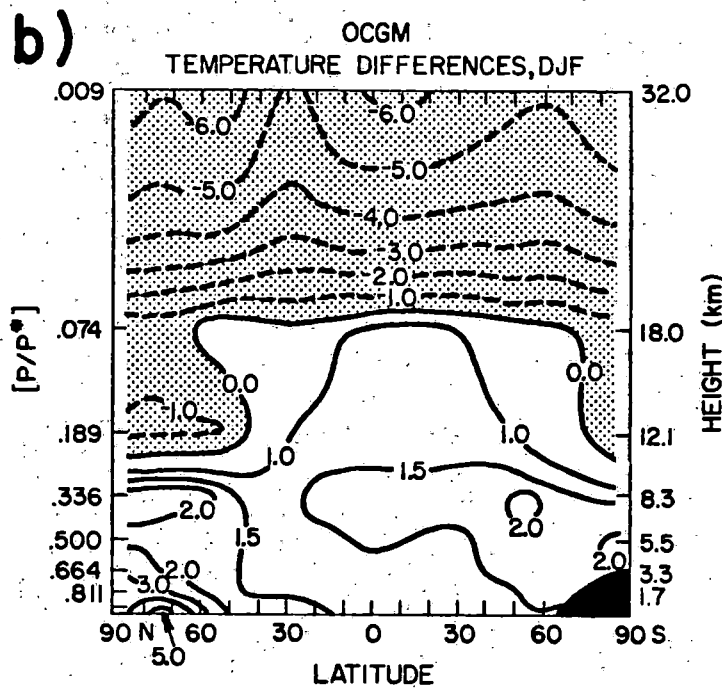
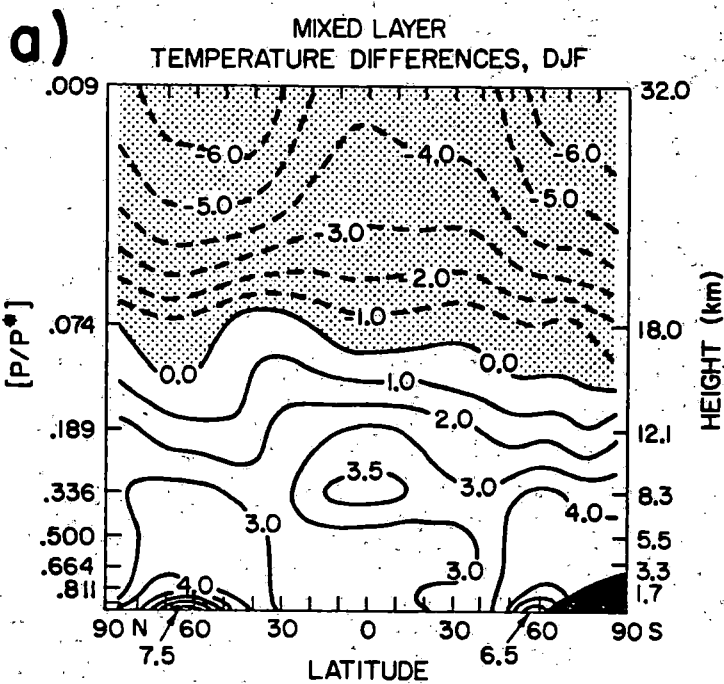


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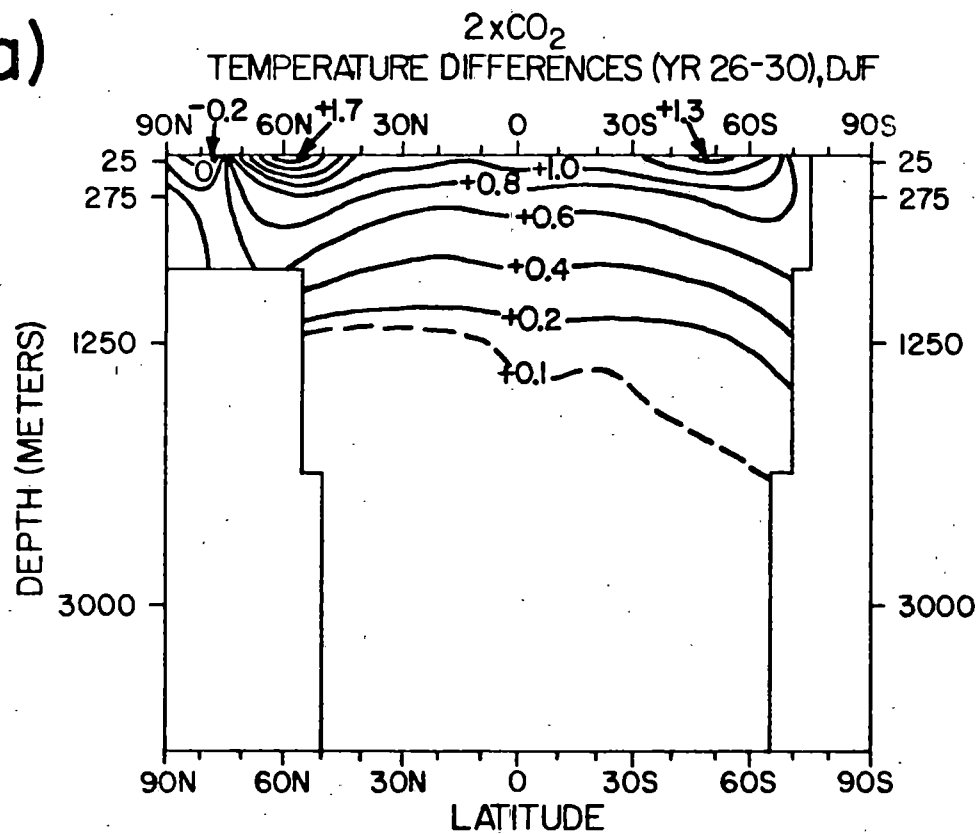


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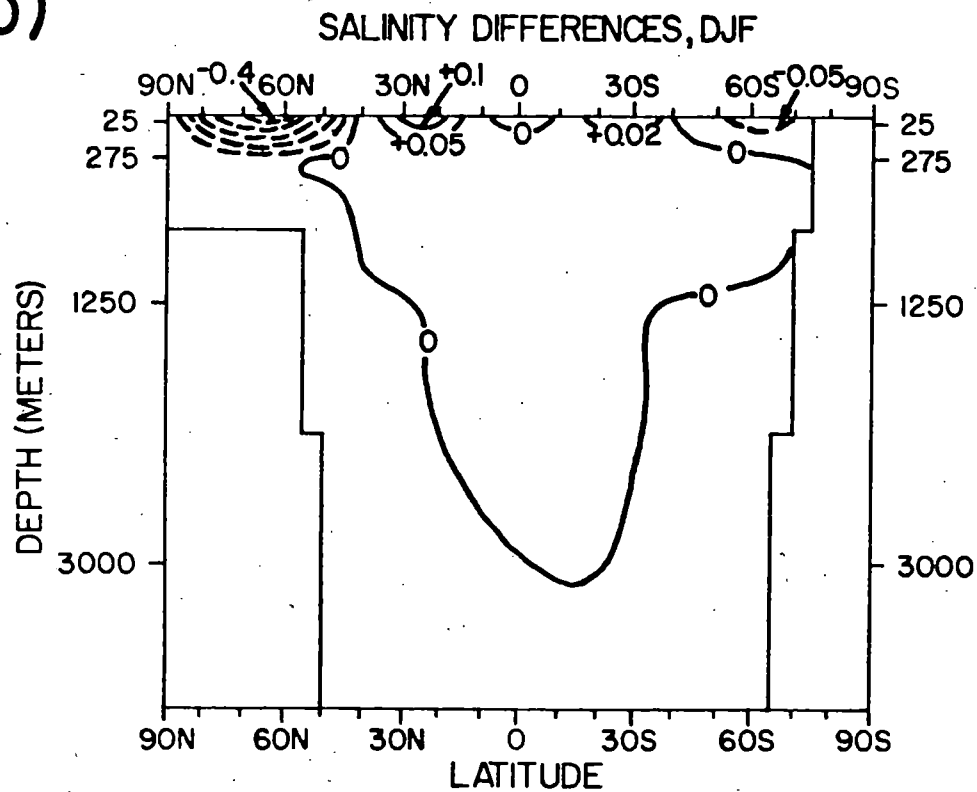




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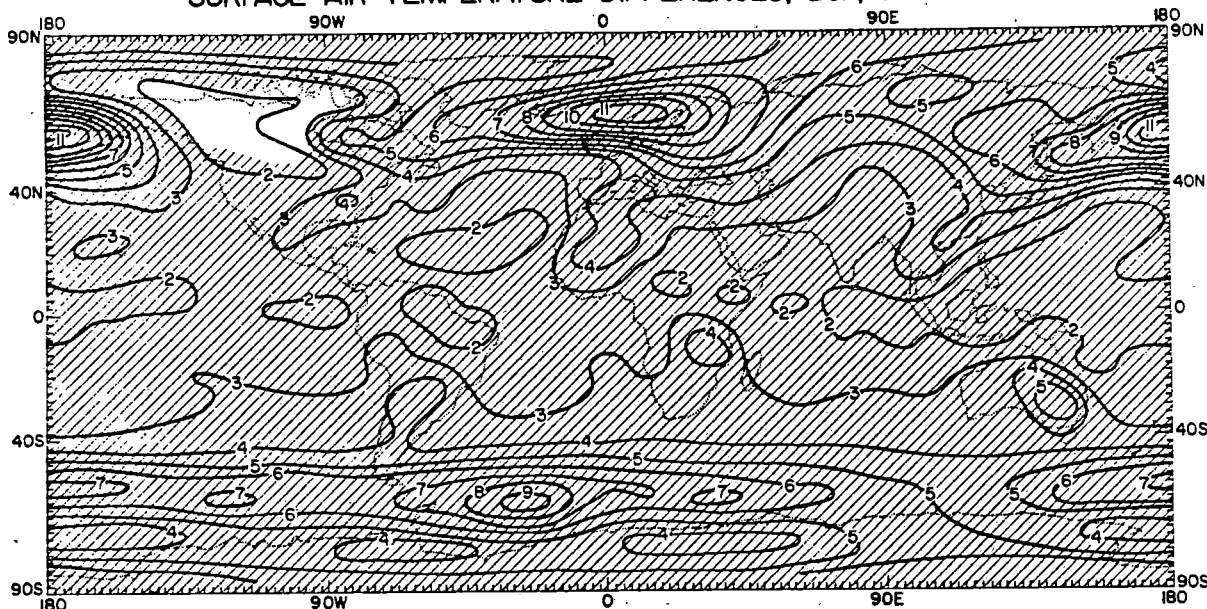


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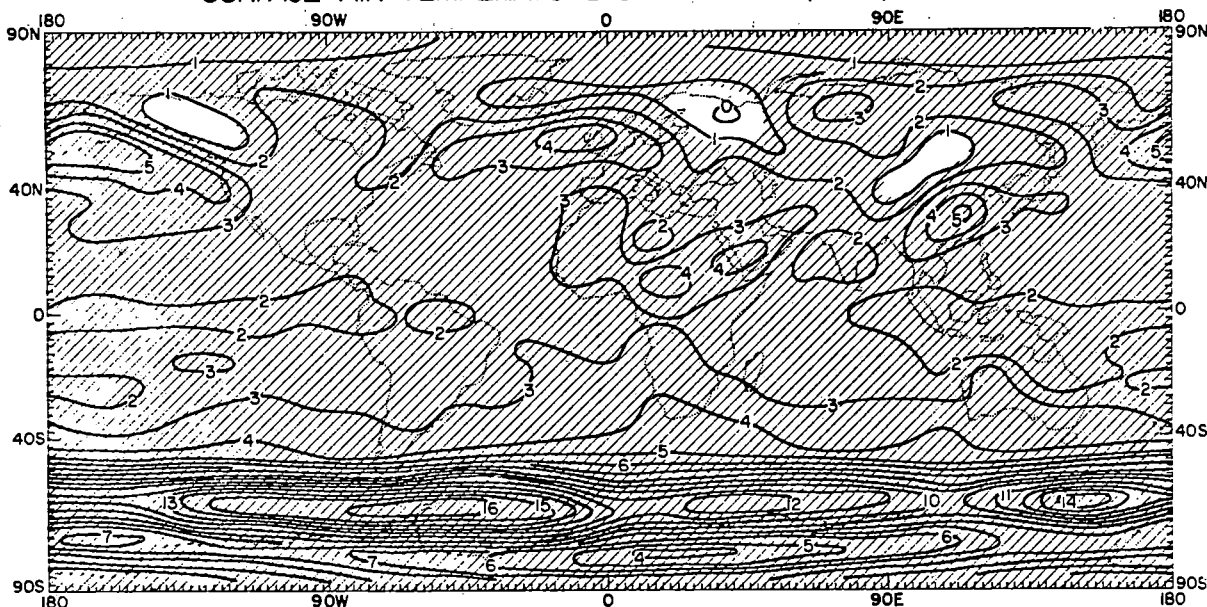
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MIXED LAYER
SURFACE AIR TEMPERATURE DIFFERENCES, DJF, 7 YEARS

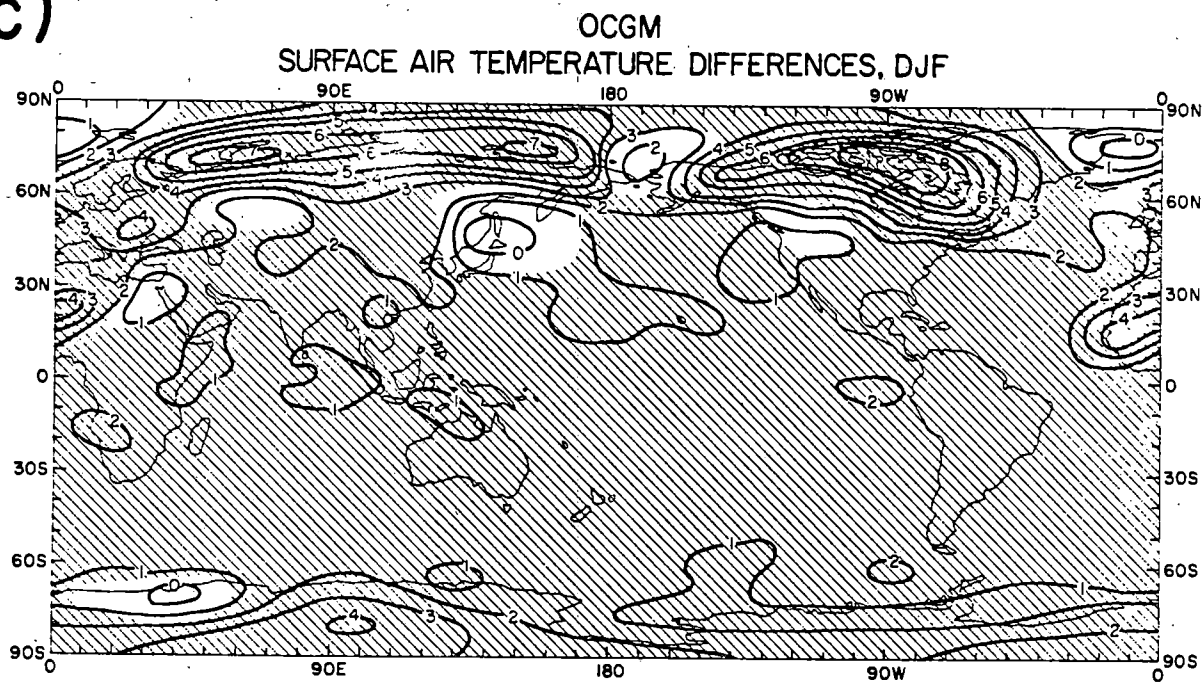


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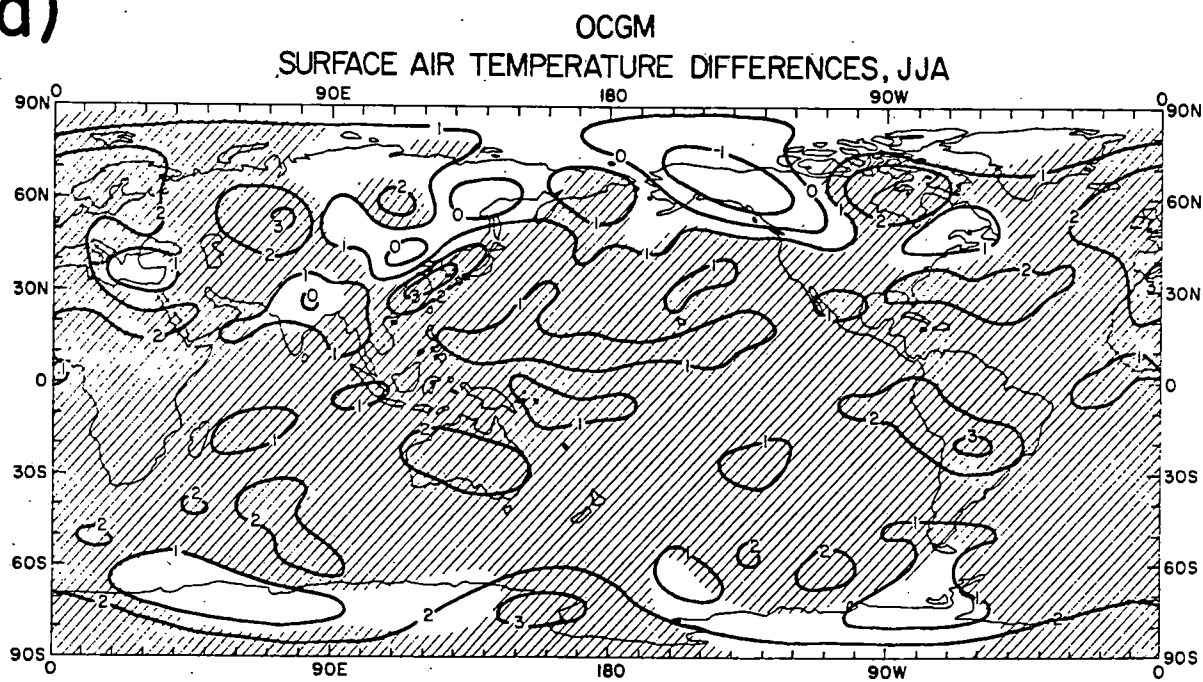
MIXED LAYER
SURFACE AIR TEMPERATURE DIFFERENCES, JJA, 7 YEARS



(c)

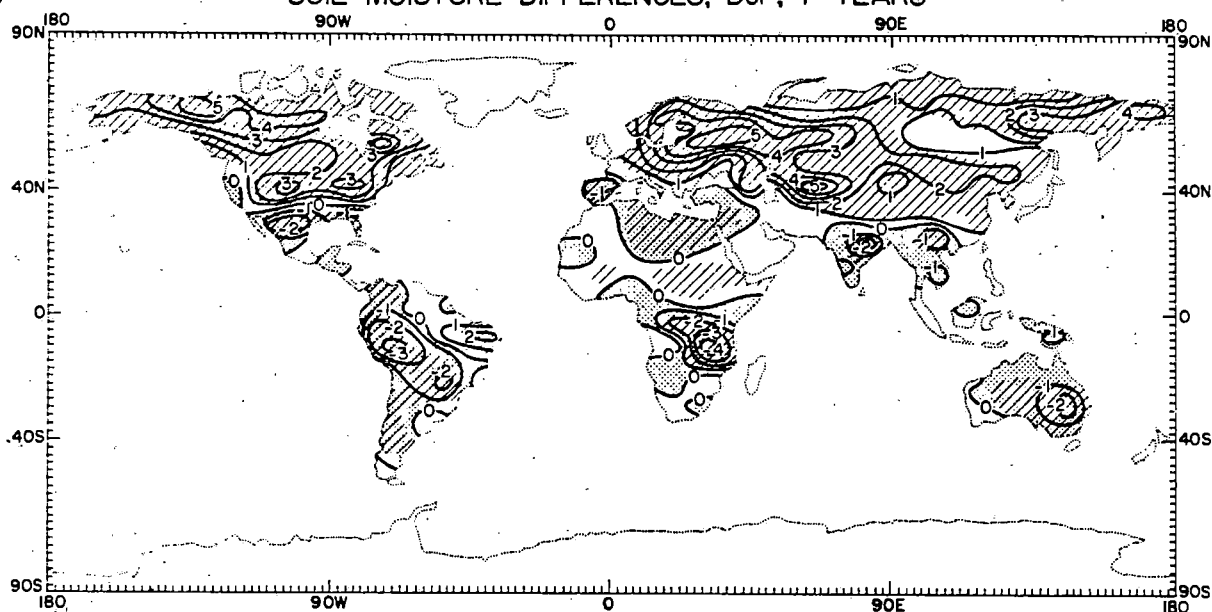


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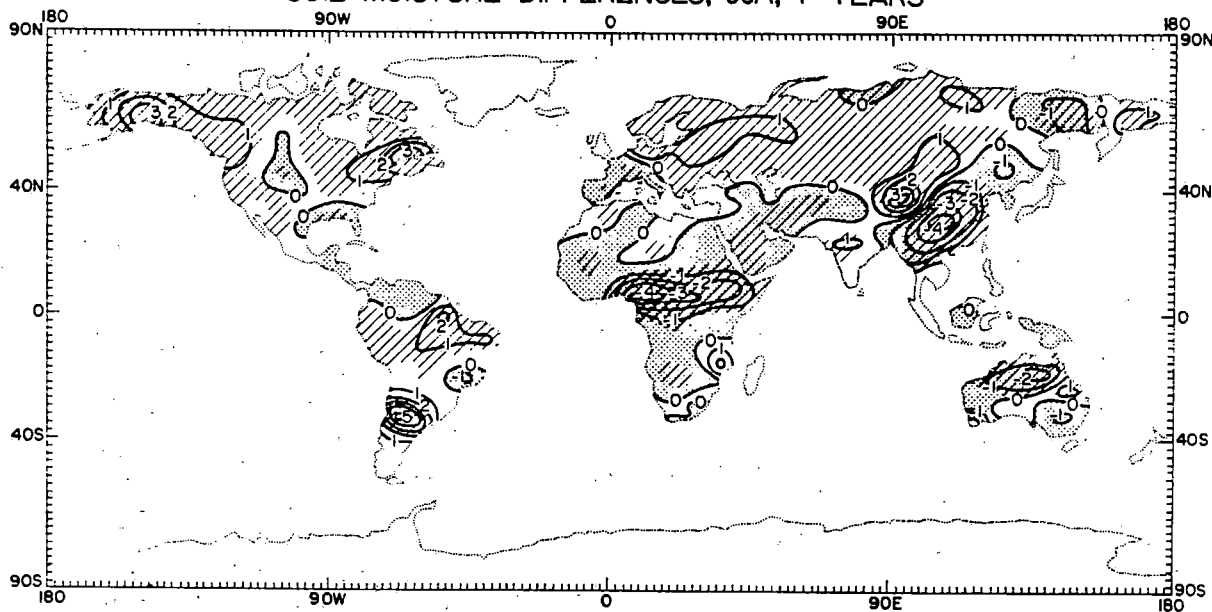
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MIXED LAYER
SOIL MOISTURE DIFFERENCES, DJF, 7 YEARS



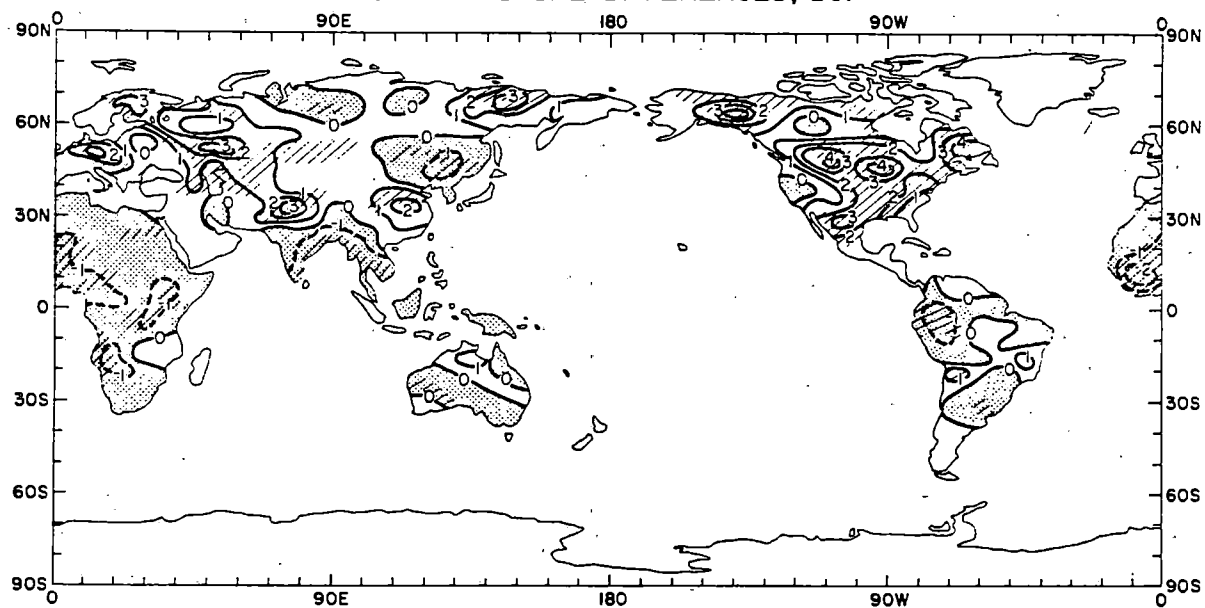
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SOIL MOISTURE DIFFERENCES, JJA, 7 YEARS



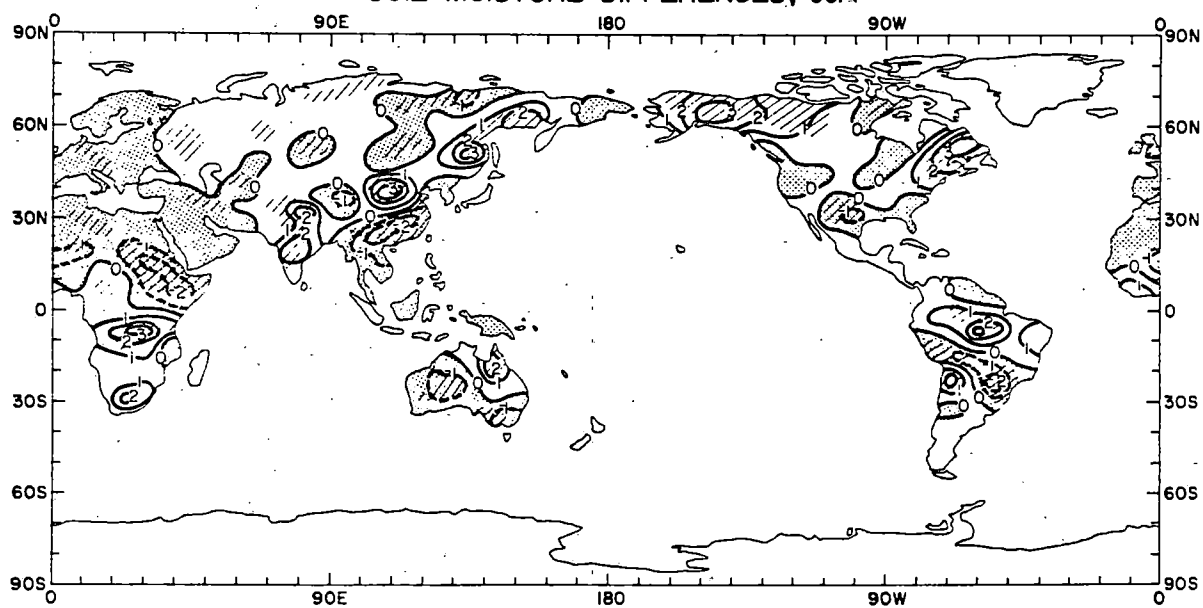
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OCGM
SOIL MOISTURE DIFFERENCES, DJF

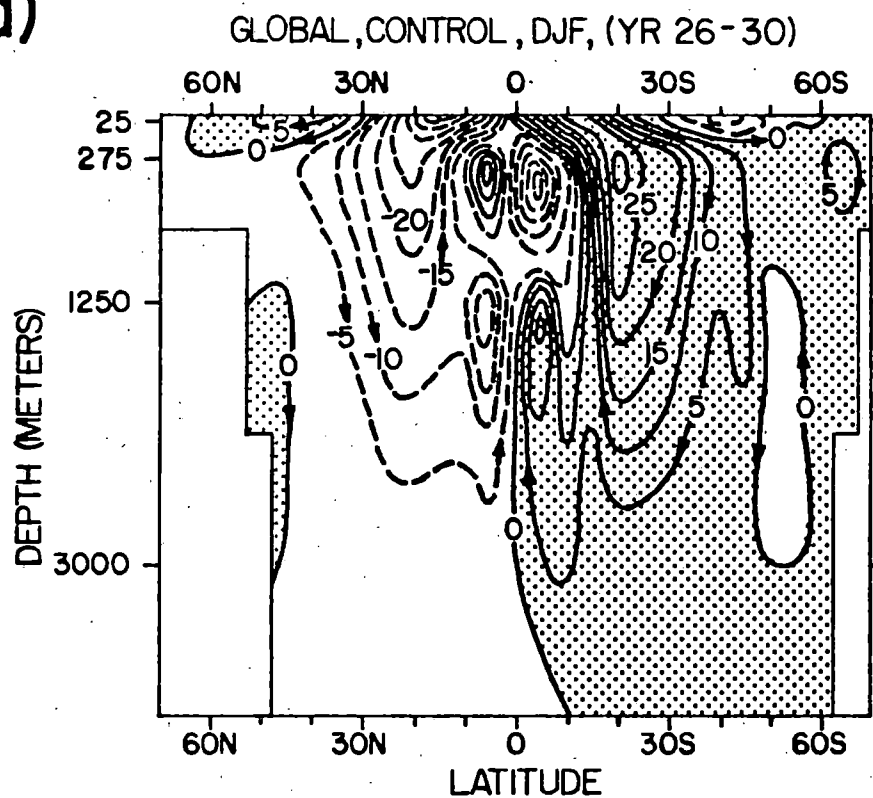


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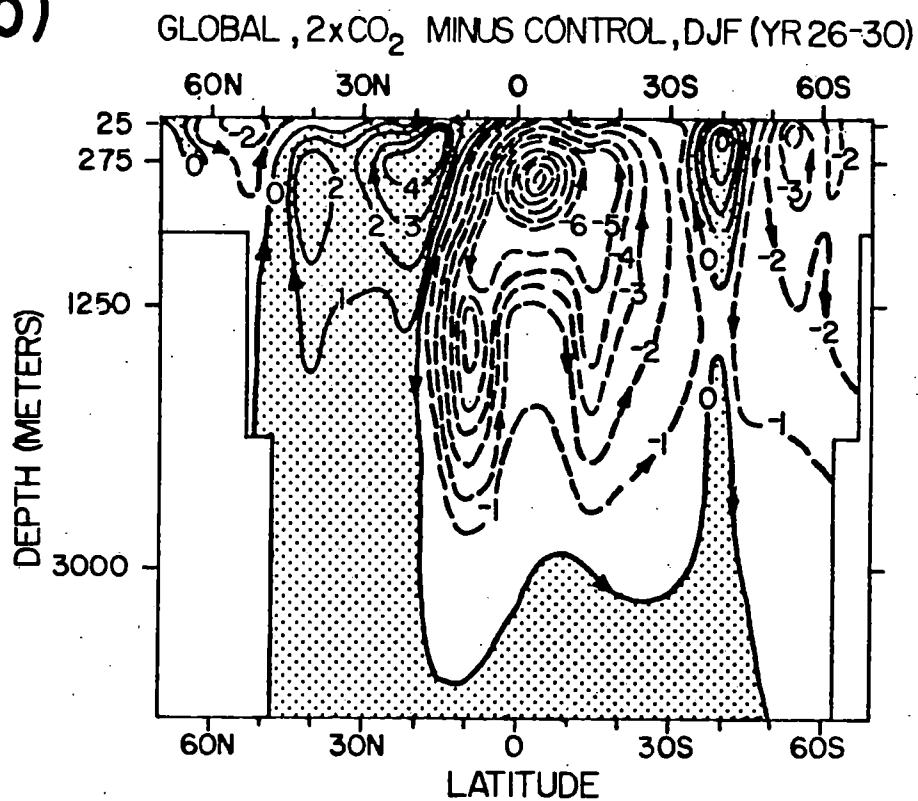
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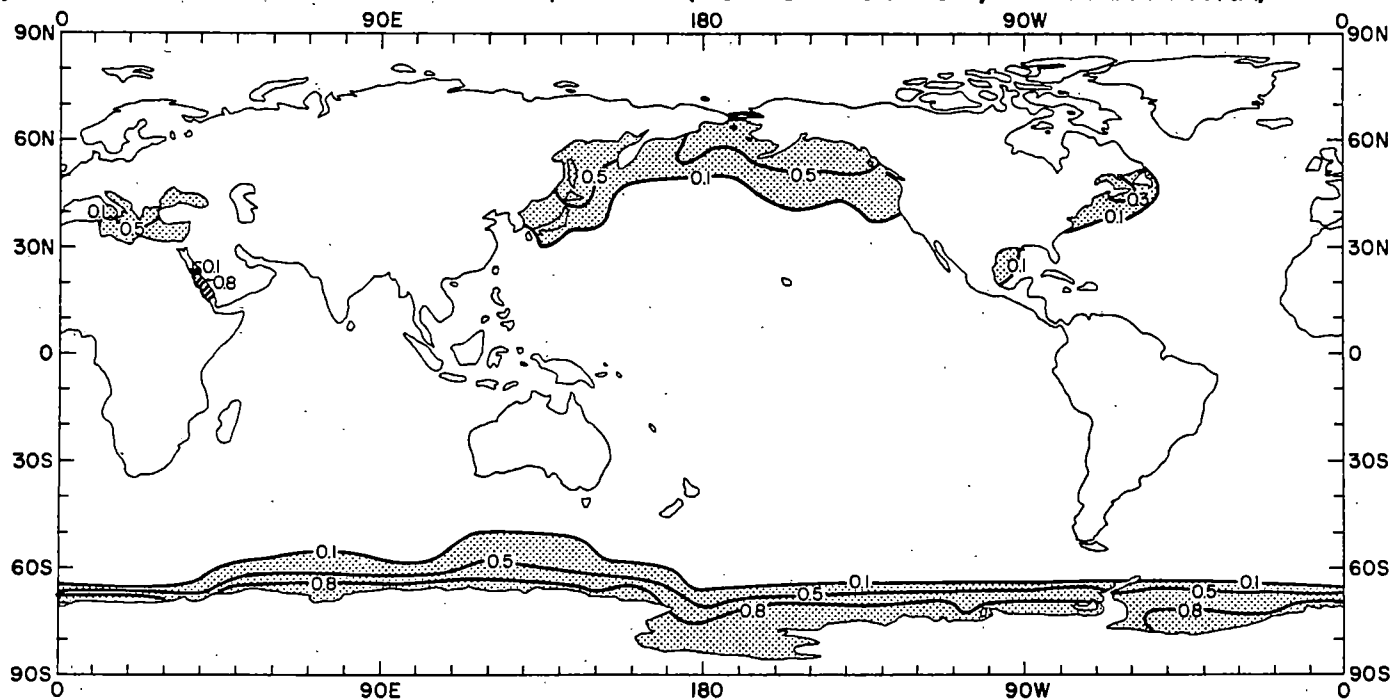
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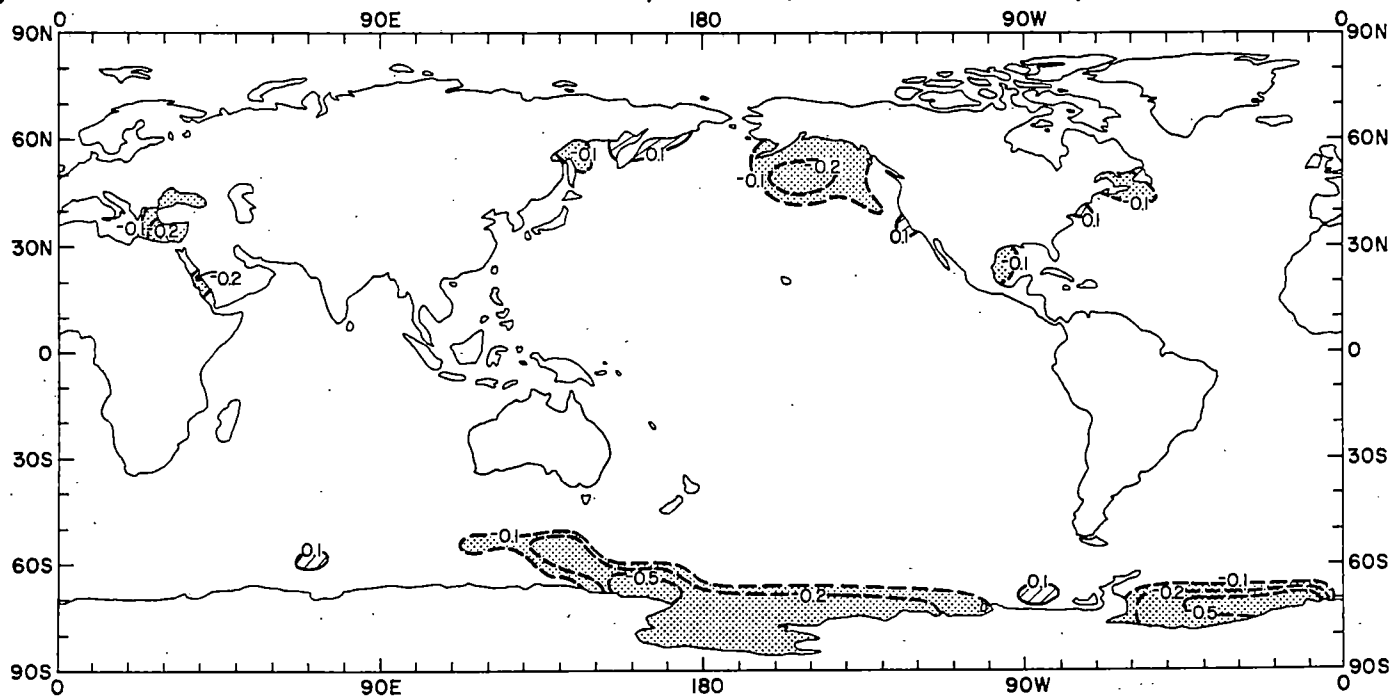
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a) CONVECTIVE ADJUSTMENT, WINTER (AUG-SEP-OCT: SH; FEB-MAR-APR: NH)

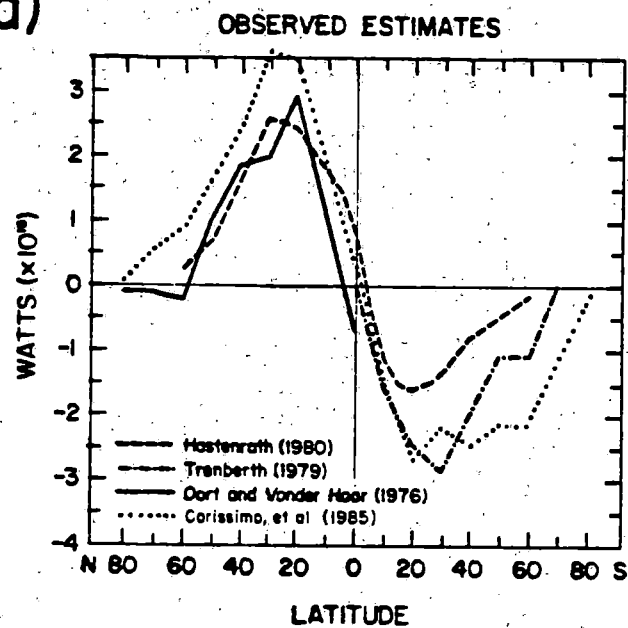


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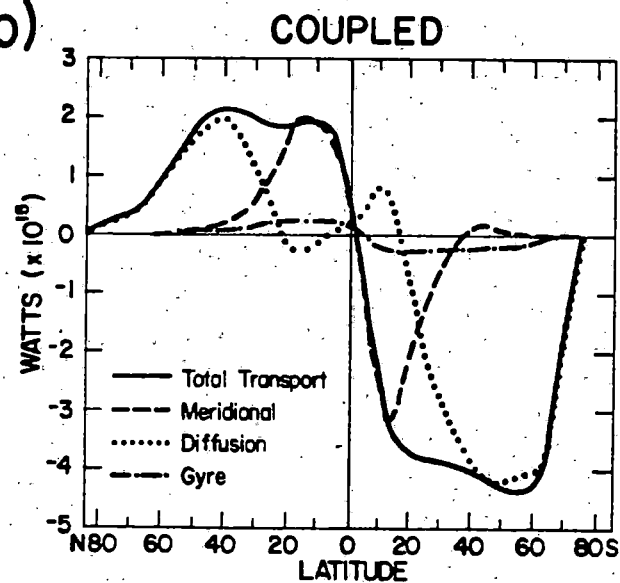


OCEAN HEAT TRANSPORT

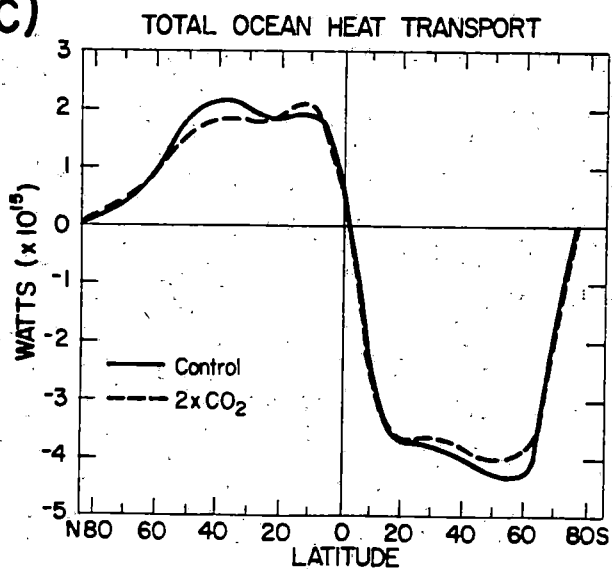
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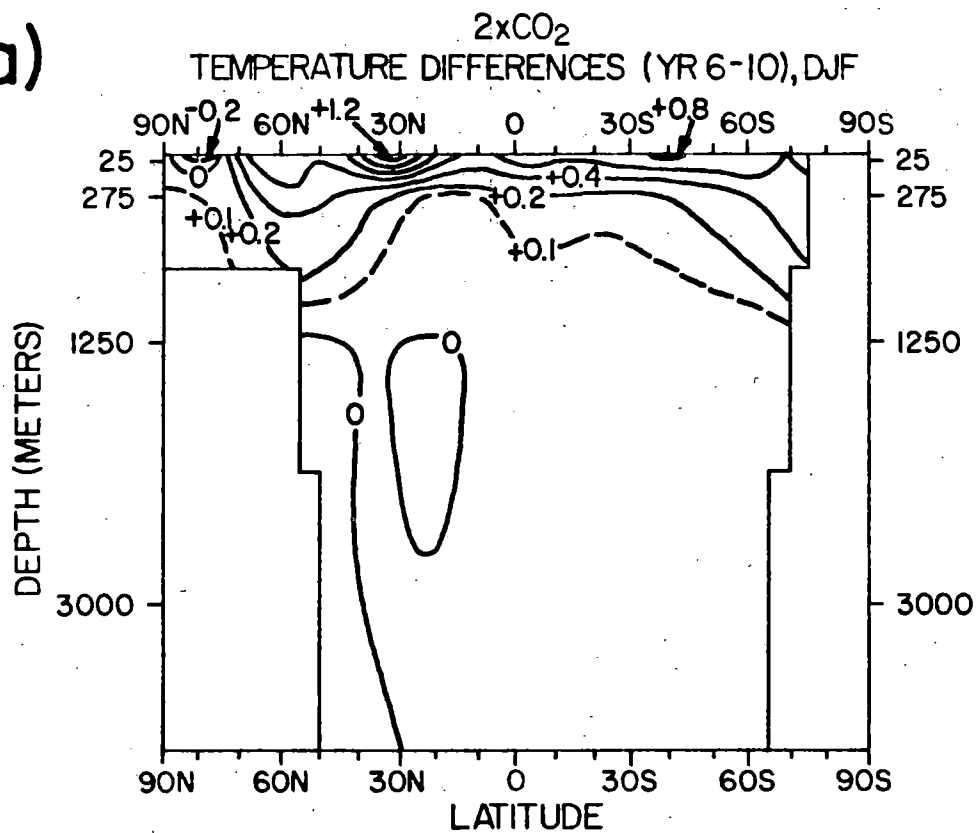
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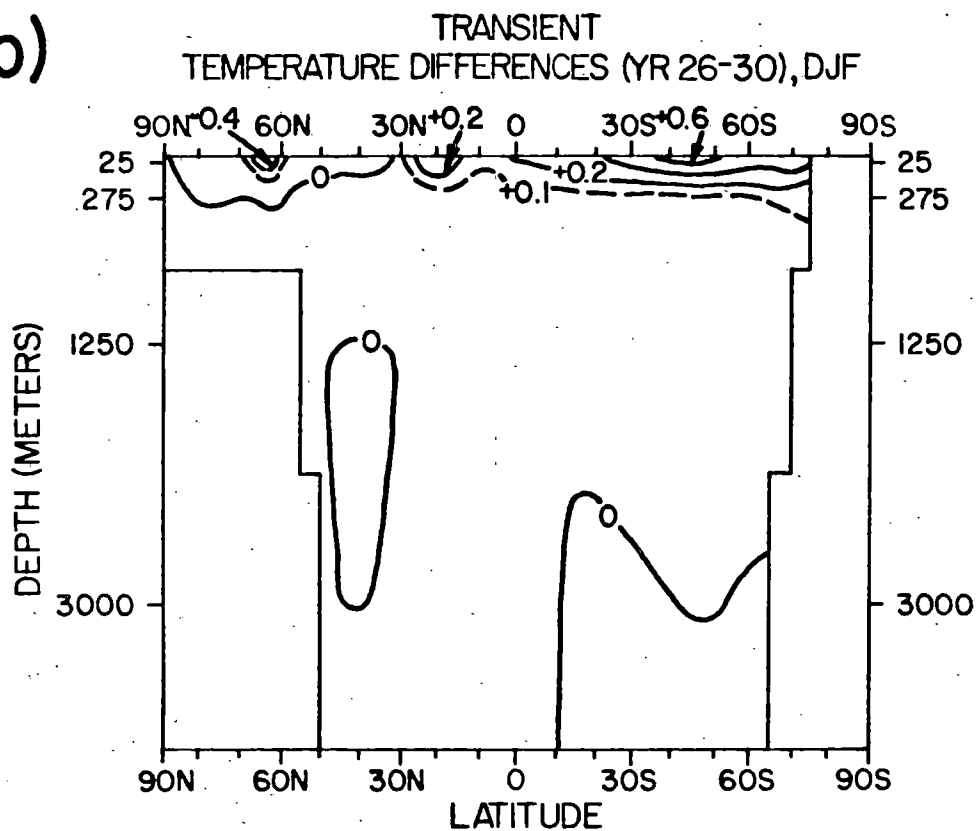
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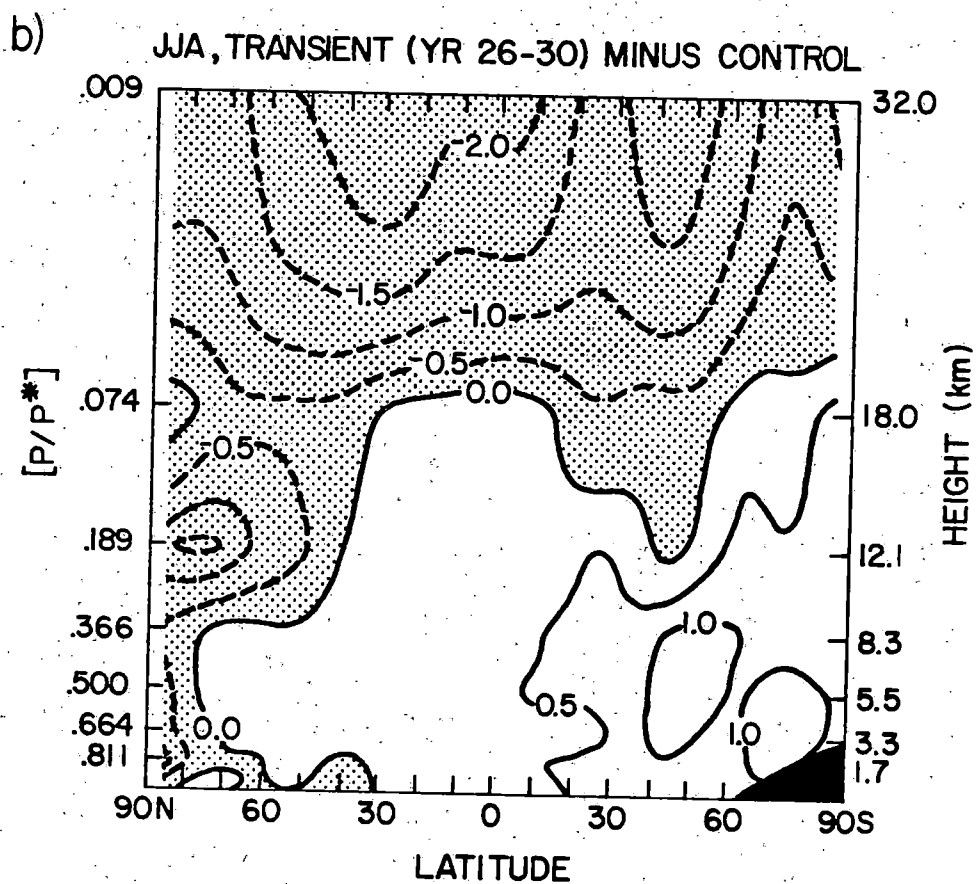
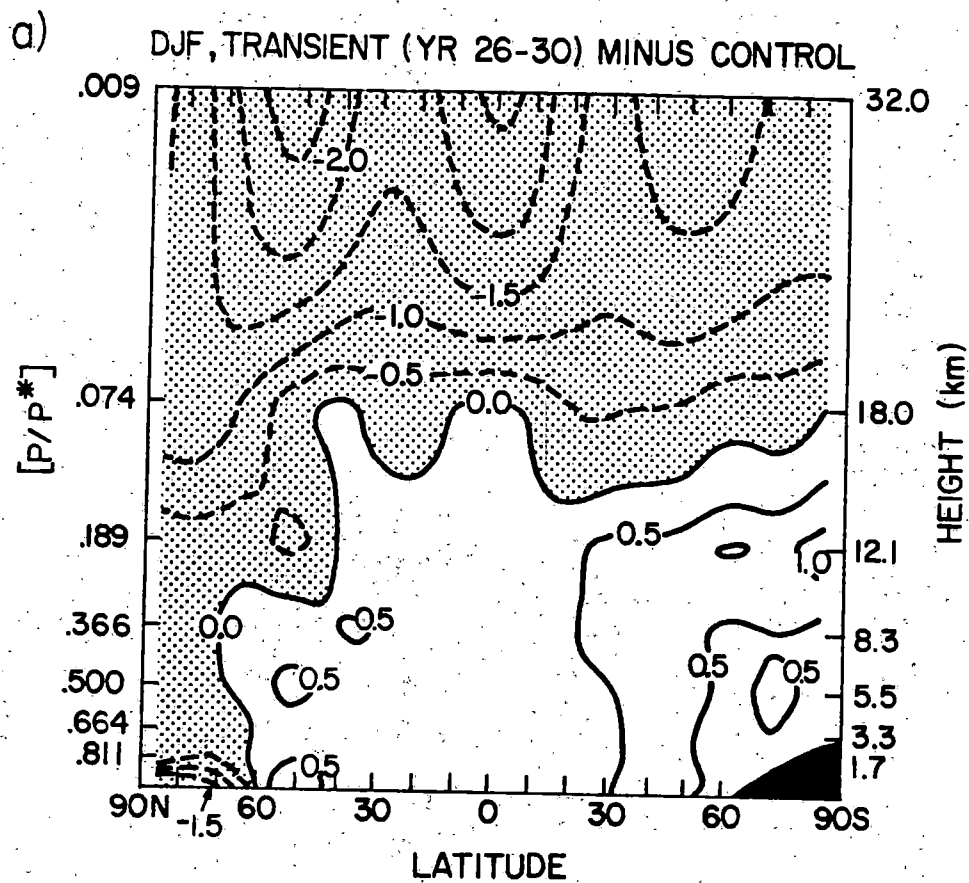


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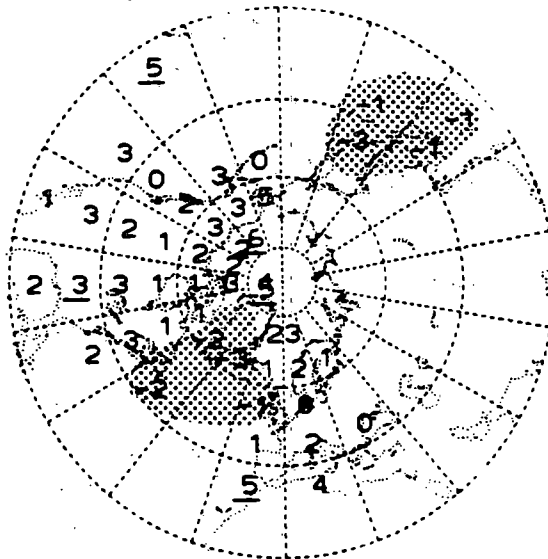


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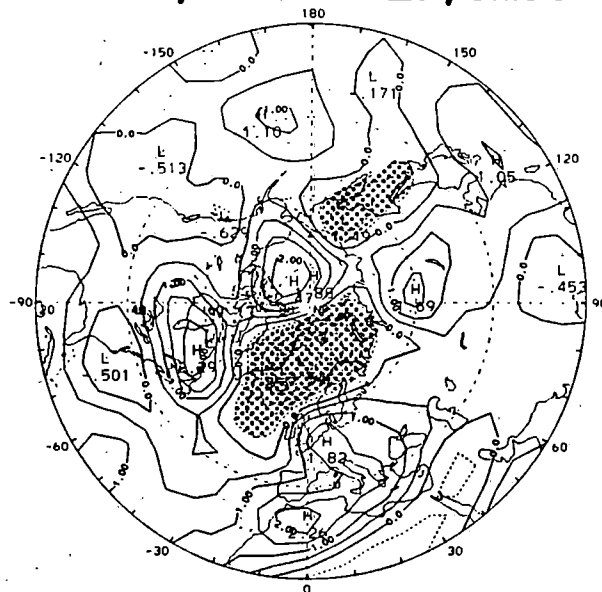




a) TREND OF ANNUAL T, 700 MB (KAROLY, 1989)

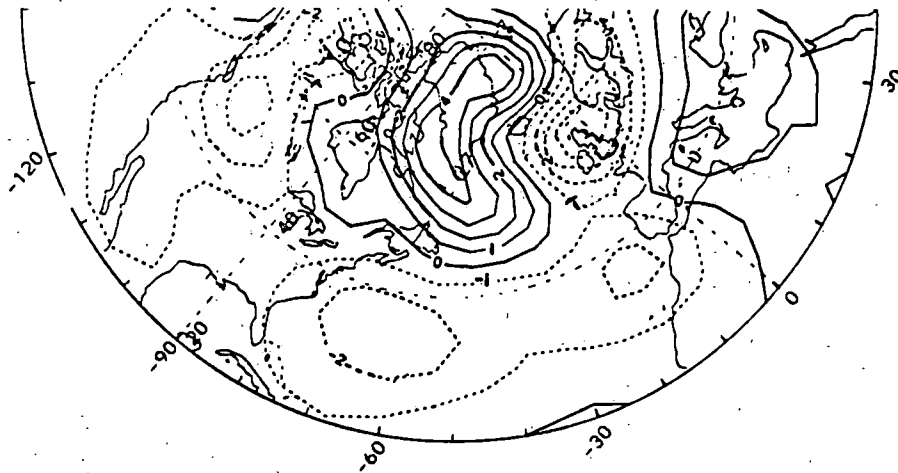


b) DJF, TRANSIENT ΔT , 811.0 S

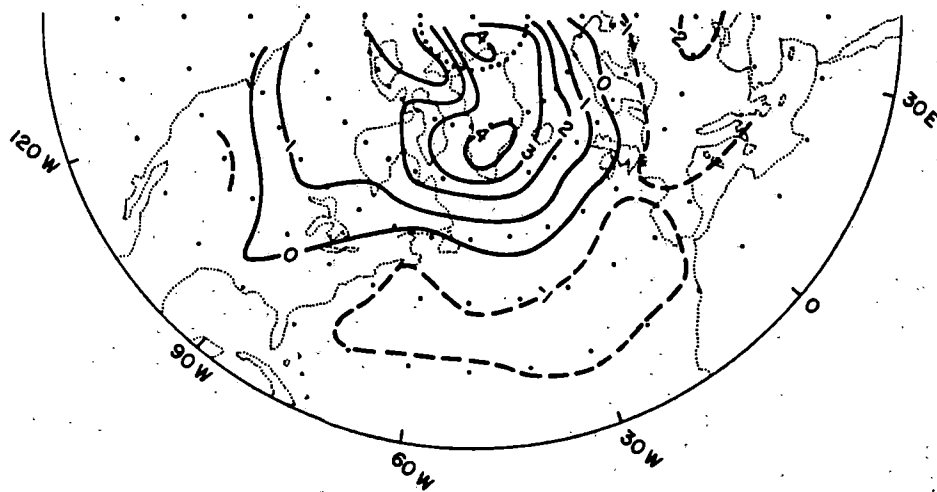


SLP DIFFERENCES

a) TRANSIENT MINUS CONTROL (YR 26-30)



b) OBSERVED, RECENT MINUS 20'S-30'S





EXECUTIVE OFFICE OF THE PRESIDENT

OFFICE OF MANAGEMENT AND BUDGET

WASHINGTON, D.C. 20503

ASSOCIATE DIRECTOR
FOR NATURAL RESOURCES,
ENERGY AND SCIENCE

1/26/90

Gov. SUNUNU

DICK DARNAN

ALAN BROMLEY

FYI. re: Soviet action on
the international environmental conference
front.

Summary of Gorbachev speech may
be of interest to POTUS prior to 2/5
E.O.C.

Bob G.

Withdrawal/Redaction Sheet

(George Bush Library)

Document No. and Type	Subject/Title of Document	Date	Restriction	Class.
01. Cable	From American Embassy Moscow Re: Summary of Global Forum on Environment and Development for Survival (6 pp.)	1/22/90	P 5	

Collection:

Record Group: Bush Presidential Records
Office: Chief of Staff, White House Office of
Series: Sununu, John, Files
Subseries: Issues Files
WHORM Cat.:
File Location: IPCC Address (1989) [1]

Open on Expiration of PRA
(Document Follows)
By JP (NLGB) on 5/12/05

Date Closed: 12/2/2004	OA/ID Number: 29161-002
FOIA/SYS Case #: 1998-0004-F[1]	Appeal Case #:
Re-review Case #: 2005-0426-S	Appeal Disposition:
P-2/P-5 Review Case #:	Disposition Date:
AR Case #:	MR Case #:
AR Disposition:	MR Disposition:
AR Disposition Date:	MR Disposition Date:

RESTRICTION CODES

Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]
P-3 Release would violate a Federal statute [(a)(3) of the PRA]
P-4 Release would disclose trade secrets or confidential commercial or financial information [(a)(4) of the PRA]
P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [(a)(5) of the PRA]
P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]
(b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]
(b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]
(b)(4) Release would disclose trade secrets or confidential or financial information [(b)(4) of the FOIA]
(b)(6) Release would constitute a clearly unwarranted invasion of personal privacy [(b)(6) of the FOIA]
(b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]
(b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]
(b)(9) Release would disclose geological or geophysical information

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MCO-00 CIAE-00 EB-00 DINT-05 DODE-00 H-01 HUD-02
IO-19 NSF-02 NSAE-00 COME-00 L-03 TRSE-00 PH-00
EPA-04 PA-02 CEA-01 NAS-01 DOTE-00 FEMA-02 OMB-01
STR-18 HHS-06 INRE-00 AGR-00 ACDA-13 JUSE-00 SP-00
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P 221728Z JAN 90
FM AMEMBASSY MOSCOW
TO SECSTATE WASHDC PRIORITY 3975
INFO AMCONSUL Leningrad
WHITEHOUSE WASHDC
MOSCOW POLITICAL COLLECTIVE
USIA WASHDC 4508
USMISSION USUN NEW YORK

UNCLAS SECTION 01 OF 06 MOSCOW 02489

DEPT FOR EUR/SOV, OES, EB, H; PLEASE PASS EPA
(WAXHONSKIY), NSF (SHER), AND NAS/HAI

WHITE HOUSE FOR CSTI/O'NEILL, CEQ, AND ULLAND

USIA FOR GURDIE

E.O. 12356: N/A

TAGS: SENV, TSPL, ECON, PARM, KSCA, A/, UR, US
SUBJECT: GORBACHEV ON THE SORRY STATE OF THE PLANET,
AND WHAT WE ALL NEED TO DO ABOUT IT: GLOBAL FORUM ON
ENVIRONMENT AND DEVELOPMENT FOR SURVIVAL, MOSCOW,
JANUARY 13-19

REF: A) 89 MOSCOW 36521; B) 89 MOSCOW 28809 C) 89
MOSCOW 22965

1. SUMMARY: THE GLOBAL FORUM ON ENVIRONMENT AND
DEVELOPMENT FOR SURVIVAL ("GLOBAL FORUM") CERTAINLY
SUCCEEDED AS A WORLD MAGNET FOR ENVIRONMENTAL
NOTABLES. GORBACHEV'S CLOSING SPEECH, STRESSING THE
THREAT TO THE BIOSPHERE, SERVED AS THE HIGH (AND
CLOSING) POINT OF THE CONFERENCE. GORBACHEV
DESCRIBED SIX CONCRETE PROPOSALS FOR FUTURE
INTERNATIONAL ENVIRONMENTAL ACTION, INCLUDING
PROTECTING ANTARCTICA (PLACING THE CONTINENT WITHIN
AN "INTERNATIONAL ENVIRONMENTAL PRESERVE" -- SHADES
OF GREENPEACE'S "WORLD PARK"); AND A RENEWED CALL FOR
A COMPREHENSIVE TEST-BAN TREATY. IN ADDITION TO
GRAND GATHERINGS, THE FORUM ALSO HELD A NUMBER OF
SCIENTIFIC MEETINGS WHICH, ACCORDING TO SCIENTISTS
PRESENT, PROVIDED A RARE CHANCE FOR THE WORLD'S
ENVIRONMENTAL EXPERTS TO MEET FACE TO FACE. THE
MEETING REPORTEDLY ENDED ALMOST DEVOID OF CONCRETE
TECHNICAL PLANS OR SUGGESTIONS, BUT MANY INDIVIDUAL
"HALLWAY DISCUSSIONS" WILL LEAD TO SEPARATE
INITIATIVES IN BILATERAL OR MULTILATERAL GOVERNMENTAL
FORA OR THROUGH THE EFFORTS OF THE MANY
ECOLOGICALLY-CONCERNED FOUNDATIONS (EARTHWATCH,
GREENPEACE, ETC). END SUMMARY.

GLOBAL FORUM - GENERAL

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2. PARTICIPANTS AT THE FORUM COMMENTED TO US THAT
THE ATTENDANCE LIST PROVIDES A TRUE WORLD'S WHO'S WHO
IN ENVIRONMENTAL ISSUES. A FEW OF THE MORE NOTABLE
PARTICIPANTS ON THE INTERNATIONAL SIDE INCLUDED
UNITED NATIONS SECRETARY GENERAL JAVIER PEREZ DE
CUELLAR, FORMER NORWEGIAN PRIME MINISTER GRO

BRUNDTLAND, JACQUES COUSTEAU, UNITED NATIONS
POPULATION FUND EXECUTIVE DIRECTOR DR. NAJIS SADIK,
UNDP ADMINISTRATOR WILLIAM DRAPER III, NOBEL PEACE
LAUREATE ELIE WIESEL, UNESCO DIRECTOR GENERAL
FEDERICO MAYOR, UNICEF EXECUTIVE DIRECTOR GRANT, THE
GRAND MUFTI SHEIKH DR. AHMAD KUTARD, AND INDIAN
AMBASSADOR TO THE U.S. DR. KARAN SINGH. OVER ONE
HUNDRED SIXTY AMERICANS ATTENDED, INCLUDING SENATORS
GORE, WIRTH, AND FEEL AS WELL AS WORLDWATCH
INSTITUTE FOUNDER LESTER BROWN, CARL SAGAN,
AMBASSADOR ANGIER BIDDLE DUKE, AND A NUMBER OF
NOTABLE NATIVE-AMERICAN LEADERS AND CLERGY. SOVIET
PARTICIPANTS WERE ALL OF THE FIRST RANK, STARTING
WITH GORBACHEV, WHO GAVE THE CLOSING ADDRESS.
ACADEMICIANS VELIKHOV, YABLOKOV, SHEYNOLIN, RUDENKO,
AND DEPUTY FOREIGN MINISTER PETROVSKIY ALL SPOKE AT
THE FORUM. VELIKHOV AND YABLOKOV, OF COURSE, WERE
PRIMARY ORGANIZERS.

3. SEVERAL VISITS TO THE FORUM AND CONVERSATIONS
WITH VARIOUS U.S. ATTENDEES REVEALED A CONSENSUS: THE
"MAIN EVENTS" OF THE CONFERENCE, WHERE BIG-NAME
SPEAKERS HELD FORTH, PRODUCED FEW SURPRISES; THE CORE
SUCCESS OF THE FORUM WAS INSTEAD IN ITS GATHERING
TOGETHER A NUMBER OF ENVIRONMENTAL AND ENERGY EXPERTS
FOR MANY PRODUCTIVE EXCHANGES IN THE SMALLER SEMINARS
AND ON THE MARGINS OR "HALLWAYS." U.S. FUSION AND
ENERGY EFFICIENCY EXPERT JOHN HOLDREN, OF U.C.
BERKELEY, STATED THAT ALMOST EVERY ONE OF THE WORLD'S
FOREMOST EXPERTS IN THE FIELD OF ENERGY EFFICIENCY
AND CONSERVATION WAS PRESENT IN THE SEMINAR ON THAT
TOPIC. (WE HAVE URGED HOLDREN, WHO WORKS ALSO WITH
THE U.S.-SOVIET FUSION EXCHANGE, TO CONTACT
DEPARTMENT'S OES TO PROVIDE FULL DEBRIEF). EMBASSY
IS POUCHING SCHEDULE OF EVENTS AND SPEAKERS, PLUS

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ACTION OIS-09

8478

MOSCOW 02489 02 OF 06 221758Z
CONCRETELY, THESE NEW "ECOLOGICAL POLITICS" MEANT:

8478

INFO LOG-00 ADS-00 AID-00 INR-05 EUR-00 SS-00 OIC-02
MCO-00 CIAE-00 FB-00 DINT-05 DODE-00 H-01 HUD-02
IO-19 NSF-02 NSAL-00 COME-00 L-03 TRSE-00 PM-00
EPA-04 PA-02 CIA-01 NAS-01 DOTE-00 FEMA-02 OMB-01
STR-18 HHS-06 INRL-00 AGRI-00 ACDA-13 JUSE-00 SP-00
DOEE-00 H-01 CIO-01 PRS-01 E-01 T-01 /114 W

-----071424 221941Z /47

P 221726Z JAN 90
FM AMEMBASSY MOSCOW
TO SECSTATE WASHDC PRIORITY 3976
INFO AMCONSUL Leningrad
WHITEHOUSE WASHDC
MOSCOW POLITICAL COLLECTIVE
USIA WASHDC 4809
UCMISSION USUN NEW YORK

UNCLAS SECTION 02 OF 05 MOSCOW 02489

DEPT FOR EUR/DOV, OES, EB, H; PLEASE PASS EPA
(WAXMONSKIY), NSF (CHER), AND HAS/HAF

WHITE HOUSE FOR OSTI/D'NEILL, CEG, AND DELAND

USIA FOR GURDIF

E.O. 12356: N/A
TAGS: ENV, TSFL, ECON, PARM, NSCA, AY, OR, US
SUBJECT: GORBACHEV ON THE SORRY STATE OF THE PLANET,

MATERIAL GATHERED AT THE FORUM, TO EUR/DOV, SMITH,
POUCH REGISTRY NO. 8543862; THIS CABLE THUS REFRAINS
FROM PASSING ON SUCH INFORMATION IN GREAT DETAIL.

GORBACHEV SPEECH: THE CHAIRMAN STEPS FORTH,
ENVIRONMENTALLY

4. CHAIRMAN GORBACHEV'S KREMLIN SPEECH ("PRAVDA,"
JANUARY 20) CLOSED THE FORUM ON FRIDAY, JANUARY 19.
WE PROVIDE ITS DESCRIPTION AHEAD OF CHRONOLOGY
BECAUSE IT SERVED AS A HIGH AND FOCUSING POINT FOR
THE ENTIRE WEEK. GORBACHEV, PARAPHRASING KANT,
DISCUSSED THE NEED FOR AN "ECOLOGICAL IMPERATIVE."
NATURE -- THE BIOSPHERE -- IS UNDER IMMEDIATE THREAT,
PLACING US, HE STATED, UNDER AN OBLIGATION TO TAKE
ACTION. GIVEN THE FRAGILITY OF THE WHOLE ECOSYSTEM,
GORBACHEV BELIEVES THAT TO REFRAIN FROM ACTION NOW IS
TANTAMOUNT TO SUICIDE. THERE IS A NEED, HE SAID, TO
CHANGE OUR DEVELOPMENT POLICIES IN ORDER TO GUARANTEE
THAT MOST FUNDAMENTAL HUMAN RIGHT: THE RIGHT TO LIFE.

5. GORBACHEV ACKNOWLEDGED SOVIET ECOLOGICAL
SHORT-SIGHTEDNESS; HE PRAISED THOSE SOVIET SCIENTISTS
WHO HAD CALLED ATTENTION TO IT IN EARLIER,
PRE-PERESTROYKA TIMES. HE STATED THAT PERESTROYKA
HAD CHANGED THE SOVIET ECOLOGICAL VIEW, CITING THE
NEW ANNUAL ENVIRONMENTAL REPORT PUBLISHED BY
GOSKOMPRIRODA AND DETAILING PROBLEMS OF AIR AND WATER
POLLUTION, SOIL DEGRADATION, AND OTHER THREATS TO
HEALTH AND LIFE. (WE ARE POUCHING COPIES OF THIS
REPORT IN THE GLOBAL FORUM PACKAGE, AS WELL AS TO EPA
AND NAS.)

6. GORBACHEV BRIEFLY OUTLINED THE NEW SOVIET
APPROACH TO ECOLOGY, AS TYPIFIED AT THE FIRST SESSION
OF THE CONGRESS OF PEOPLE'S DEPUTIES: THE SESSION
CALLED FOR A NEW LOOK AT DEVELOPMENT IN ALL ITS
ASPECTS, INCLUDING OUR RELATIONSHIP WITH NATURE.

--CHANGES IN INDUSTRIAL ACTIVITY (WITH AN EYE TO
ECOLOGICAL CONSEQUENCES AND RATIONALIZATION OF
INDUSTRY IN TERMS OF ENERGY, RESOURCE, AND LOCAL
CIRCUMSTANCES);

--MORE CONCERN WITH IMPROVEMENT OF THE PEOPLE'S
HEALTH AND LIFE-STYLE;

--PROVIDING MAXIMUM SUPPORT FOR SCIENTIFIC RESEARCH;

--GIVING PRIORITY TO ECOLOGICAL EDUCATION IN GENERAL;

7. GORBACHEV THEN BRIEFLY DISCUSSED:

--THE LATEST SUPREME SOVIET DECREE ON THE ENVIRONMENT
(REF A), WHICH CALLS FOR ESTABLISHING NORMS AND
CONSERVATION OF BIOLOGICAL RESOURCES AMONG OTHER
THINGS;

--THE COMPLEX TASK OF HARMONIZING MAN AND NATURE,
WHICH MUST INVOLVE LEGISLATIVE AND EXECUTIVE ORGANS,
SCIENTISTS AND EDUCATORS, SOCIAL ORGANIZATIONS AND
MOVEMENTS, AND INDIVIDUAL INITIATIVE; AND,

--COMPLIMENTED THE CONCERNS OF THE "GREENS," BUT
CAUTIONED THAT IT IS TOO SIMPLE MERELY TO SAY "CLOSE
THIS OR THAT FACTORY OR INDUSTRY"; SUCH AN APPROACH
IS THE WRONG ANSWER. HE STRESSED THAT APPROPRIATE
ACTION MUST TAKE INTO ACCOUNT NOT JUST NATURE'S
NEEDS, BUT PEOPLE'S AS WELL.

SIX CONCRETE SOVIET ENVIRONMENTAL PROPOSALS -

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INFO LOG-00 ADS-00 AID-00 IHR-05 EUR-00 SS-00 DIC-02
MCO-00 CIAE-00 EB-00 DINT-05 DODI-00 H-01 HUD-02
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FPA-04 PA-02 CFA-01 NAS-01 DOTE-00 FEMA-02 DIB-01
STR-18 HHS-06 INRI-00 AGRI-00 ACDA-13 JUSE-00 SP-00
DOFE-00 H-01 CEO-01 PRG-01 E-01 T-01 /114 W

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INFO AMCONSUL Leningrad
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UNCLAS SECTION 03 OF 06 MOSCOW 02489

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(MAXMONCHIK), NSF (ISHER), AND NAS/NAE

WHITE HOUSE FOR OSTP/O'NEILL, CEO, AND DELAND

USIA FOR GURROFF

E.O. 12356: N/A
TAGS: GENV, TSPL, ECON, PARM, KSCA, AY, UR, US
SUBJECT: GORBACHEV ON THE SORRY STATE OF THE PLANET,

8. GORBACHEV FINISHED HIS SPEECH BY UNDERLINING THE
NEED FOR INTERNATIONAL COOPERATION AND THE NEED TO
FOCUS ON INTERNATIONAL ENVIRONMENTAL POLICIES.
STRESSING THAT THE SOVIET UNION FAVORS SUCH ACTIONS,
GORBACHEV ANNOUNCED A "BEGINNING" WITH THE FOLLOWING
SIX POINTS:

--THE USSR EMPHATICALLY SUPPORTS THE ENVIRONMENTAL
PLANS AND AGENCIES OF THE U.N. AT THE 1992 UNEP
CONFERENCE IN BRASILIA, THE SOVIETS BELIEVE IT
POSSIBLY USEFUL TO ADOPT AN INTERNATIONAL CODE OF
ECOLOGICAL ETHICS AND A GLOBAL PLAN OF ACTION WHICH
WOULD, AMONG OTHER THINGS, SYMBOLIZE A NEW APPROACH
TO THE ENVIRONMENT AS WE ENTER THE 21ST CENTURY.

--THE USSR BELIEVES IT NECESSARY TO DEVELOP AN
INTERNATIONAL REGIME TO PRESERVE UNIQUE ECOLOGICAL
ZONES WHICH HAVE PLANETARY SIGNIFICANCE; THEIR FIRST
CANDIDATE IS ANTARCTICA. BOTH THE UNIQUE ECOSYSTEMS
AND RESEARCH OPPORTUNITIES OF AN UNspoiled ANTARCTICA
MUST BE PRESERVED. THE SOVIET UNION STANDS READY TO
PARTICIPATE IN SUCH AN INTERNATIONAL PLAN. OTHER
AREAS RIPE FOR INTERNATIONAL EFFORTS ARE THE BLACK
SEA/MEDITERRANEAN BASIN, THE TROPICAL RAIN FOREST,
AND CORAL REEF SYSTEMS.

--THE USSR BELIEVES IT WOULD BE USEFUL TO CREATE AN
INTERNATIONAL COOPERATIVE SYSTEM FOR ECOLOGICALLY
CLEAN TECHNOLOGIES. FOR THIS REASON, GORBACHEV
EXPRESSED HIS KEEN DISAPPOINTMENT AT THE LACK OF
INDUSTRIAL PARTICIPATION IN THE "GLOBAL FORUM."

--THE USSR BELIEVES AN INTERNATIONAL MECHANISM TO
MONITOR THE ENTIRE BIOSPHERE SHOULD BE ESTABLISHED.

--THE SOVIET UNION SUPPORTS THE ESTABLISHMENT OF A
EUROPEAN ENVIRONMENTAL PROTECTION AGENCY, AND STANDS
READY TO PARTICIPATE IN JOINT EFFORTS WITH THIS
AGENCY. THE SOVIET UNION ALSO SEES THE NEED TO

CREATE AN INTERNATIONAL "GREEN CROSS," WHICH WOULD
HELP GOVERNMENTS IN DEALING WITH ECOLOGICAL
DISASTERS, OR A CENTER FOR "ECOLOGICAL FIRST AID"
UNDER U.N. AUSPICES. THE USSR IS PREPARING FOR THE
U.N. SECRETARY GENERAL A LIST OF SOVIET EXPERTS WHO
WOULD BE AVAILABLE TO HELP IN SUCH DISASTERS, UPON
THE REQUEST OF THE SECRETARY GENERAL.

--THE USSR RENEWS ITS OFFER TO CEASE NUCLEAR TESTING
WHEN THE U.S. IS READY TO DO SO.

OBSERVERS' REACTION. SOMETHING OLD, SOMETHING NEW,
SOMETHING BORROWED, SOMETHING ... GREEN (1)

9. ALTHOUGH EACH OF THE VARIOUS PARTICIPANTS TO WHOM
WE SPOKE LIKED A PARTICULAR PART OF THE GORBACHEV
SPEECH (INvariably a PART WHICH TOUCHED CLOSE TO HIS
OWN INTERESTS IN ECOLOGY), THE GENERAL THEME WAS
PRAISE THAT GORBACHEV, DESET BY HUGE OTHER PROBLEMS
AND A HOME-GROWN ECOLOGICAL DISASTER, WAS WILLING TO
COME FORWARD TO "SAY IT ALL." HE MADE NO EFFORT TO
SWEEP UNDER A RUG THE SOVIETS' OWN ENVIRONMENTAL
NIGHTMARE (DISCLOSED, FOR EXAMPLE, IN REF C), OR TO
CLAIM THAT THE SOVIETS KNOW THE SOLUTIONS. TAKING
THE HIGHER ROAD, HE ADMITS FRANKLY THEY HAVE NO
SOLUTIONS, STRESSING THE NEED FOR HIGHER-LEVEL
INTERNATIONAL THINKING ON THESE ISSUES. ONE ENGLISH
PARTICIPANT AT THE CONFERENCE COMMENTED THAT HE FINDS
IT INTERESTING, AND IRONIC, THAT SUCH A SPEECH HAS
COME FIRST FROM SOVIET LEADERSHIP, EXPRESING HOPE
THAT THE ADMINISTRATIONS OF HMG AND OTHER WESTERN
COUNTRIES WILL ACT SIMILARLY.

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ACTION OES-09

8488

MOSCOW 02489 04 OF 06 221759Z

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INFO LOG-00 ADS-00 AID-00 INR-05 EUR-00 SS-00 OIC-02
MCO-00 CIAE-00 EB-00 DINT-05 DODE-00 H-01 HUD-02
IO-19 NSF-02 NSAE-00 COME-00 L-03 TRSE-00 PM-00
EPA-04 PA-02 CEA-01 NAS-01 DOTE-00 FEMA-02 OMB-01
STR-18 HHS-06 INRE-00 AGRE-00 ACDA-13 JUSE-00 SP-00
DOEE-00 M-01 CEO-01 PRS-01 E-01 T-01 /114 W

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P 221728Z JAN 90
FM AMEMBASSY MOSCOW
TO SECSTATE WASHDC PRIORITY 3978
INFO AMCONSUL LENINGRAD
WHITEHOUSE WASHDC
MOSCOW POLITICAL COLLECTIVE
USIA WASHDC 4811
USMISSION USUN NEW YORK

UNCLAS SECTION 04 OF 06 MOSCOW 02489

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(WAXMONSKIY), NSF (SHER), AND HAS/NAE

WHITE HOUSE FOR OSTP/O'NEILL, CEO; AND DELAND

USIA FOR GUROFF

E.O. 12356: N/A

TAGS: ENV, TSPL, ECON, PARM, KSQA, AY, UR, US
SUBJECT: GORBACHEV ON THE SORRY STATE OF THE PLANET,

10. WE FOUND INTERESTING ALSO WHAT GORBACHEV DECLINED TO SAY. HE CHOSE NOT TO USE THE FORUM TO TRY TO ADVANCE ANY NEW marginally-ecological issues (SOME WESTERN PARTICIPANTS EXPECTED HIS ANNOUNCEMENTS ON MILITARY- OR TROOP- OR ARMS-REDUCTION MEASURES); THE ONLY "OLD SAW" IN THIS SIXSOME FROM THE MILITARY ARENA WAS THAT ON A TEST-BAN, HARDLY A NOVEL (OR MOVING) APPEAL. WE WERE STRUCK THAT HE DECIDED TO PUSH THE ANTARCTIC TO THE FORE, FIRST BY OUR BELIEF THAT THIS MAY BE THE FIRST SUCH PROPOSAL BY A WORLD LEADER (AND ANTARCTIC TREATY PARTY) IN SUCH A MAJOR FORUM, AND SECOND BECAUSE THE ANTARCTIC, WHILE DEFINITELY A PROBLEM, CAN HARDLY BE AMONG HIS MAJOR DOMESTIC CONCERNS. THE SOVIETS HAVE BEEN FLOGGING THE IDEA OF CATASTROPHY BILATERALS IN SEVERAL MARKETS, INCLUDING AN AGREEMENT IN PLACE WITH ITALY. THE EUROPEAN ENVIRONMENTAL AGENCY RINGS SYMPATHETICALLY WITH GORBACHEV'S "COMMON EUROPEAN HOME" APPROACH (NOTE THAT THIS LEADER OF A NATION WHOSE ASIAN PART IS AT LEAST AS LARGE AS ANY NATION WHOLLY IN ASIA PROPOSED NO "ASIAN ENVIRONMENTAL PROTECTION AGENCY"). THE IDEA OF USING SPACE -- SOVIET TECHNOLOGY FOR SPACE REMAINING ONE OF THE RELATIVELY FEW AREAS WHERE THIS NATION CAN MAKE TRULY WORLD-CLASS, UNIQUE CONTRIBUTIONS -- FOR ENVIRONMENTAL MONITORING HAS BEEN A CONSTANT SOVIET THEME, INCLUDING IN THE U.N. AND WITH THE U.S. FINALLY, IN "GREEN CROSS" AND SOME OTHER ITEMS IN GORBACHEV'S LIST, WE SEE THE CONTRIBUTIONS OF SPEECH DRAFTERS LIKE ALEKSEY YABLOKOV, WHO EARLIER PROPOSED A U.S.-SOVIET DIRECT "GREEN LINE" FOR ECOLOGICAL AND OTHER EMERGENCIES.

MEDIA COVERAGE

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11. SOVIET MEDIA COVERED THE FORUM FAIRLY STEADILY, BRIEFLY REPORTING HIGHLIGHTS OF VARIOUS SPEECHES. INTERVIEWS WITH CONFERENCE "NAMES" APPEARED DAILY;

FOR EXAMPLE, ON JANUARY 22, CARL SAGAN AND SOVIET CLIMATE CHANGE EXPERT ACADEMICIAN GEORGIY GOLITSYN REVIEWED THE DANGERS OF THE GREENHOUSE EFFECT AND ITS THREAT TO THE FUTURE. ON ANOTHER OCCASION, RADIO MOSCOW QUOTED LIBERALLY FROM WESTERN PRESS ENGLISH-LANGUAGE INTERVIEWS OF THE SOVIETS' OWN ALEKSEY YABLOKOV. IN KEEPING WITH THE CULTURAL/SPIRITUAL SIDE OF THINGS, THE PAPERS ALSO CARRIED AN INTERVIEW WITH A SOVIET ROCK STAR AND SEVERAL RELIGIOUS FIGURES, SIDE BY SIDE WITH A DISCUSSION BY A DELEGATE FROM ZIMBABWE ON THE PREVENTION OF DESERTIFICATION. THE BIG PRESS EVENT, HOWEVER, WAS GORBACHEV'S CLOSING ADDRESS, IN THE KREMLIN ON FRIDAY, JANUARY 19. WORLD-WIDE SPECIAL SATELLITE AND MEDIA ARRANGEMENTS CARRIED THE SPEECH LIVE. (WE PRESUME ADDRESSEES HAVE FBIS OR OTHER FULL-TEXT CAPABILITIES).

CONFERENCE THEMES

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12. THE FORUM OPENED FOR BUSINESS OVER THE WEEKEND OF JANUARY 13-14, WITH A NEWS MEDIA SEMINAR ("COMMUNICATING GLOBAL ISSUES IN THE 1990'S") OPENED BY ACADEMICIAN AND CHAIRMAN VELIKHOV AND CHAIRED BY MFA PRESS SPOKESMAN GENNADIY GERASIMOV AND TARZIE VITTACHI, THE FORUM'S MEDIA ADVISOR. THE TOPICS CENTERED ON DISCUSSIONS OF NATURAL RESOURCES. ON SUNDAY, THE SAME FORMAT CONTINUED, BUT SHIFTED EMPHASIS TO EDUCATIONAL AND CULTURAL DIMENSIONS.

13. U.N. SECRETARY GENERAL PEREZ DE CUELLAR'S JANUARY 15 ADDRESS FORMALLY OPENED THE FORUM; THAT DAY'S THEME CENTERED AROUND THE STATE OF THE GLOBAL ENVIRONMENT, WITH KEYNOTE ADDRESSES BY YABLOKOV.

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ACTION OCS-09

8492

MOSCOW 02489 05 OF 06 221800Z
WERE SWAMPED. END COMMENT.

8492

INFO LOG-00 ADS-00 AID-00 INR-05 EUR-00 SS-00 OIC-02
MCO-00 CIAF-00 EB-00 DINT-05 DODE-00 H-01 HUD-02
IO-19 NSF-02 NSAE-00 COME-00 L-03 TRSE-00 PM-00
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STR-18 HHS-06 INRI-00 AGRE-00 ACDA-13 JUCE-00 SP-00
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P 221728Z JAN 90
FM AMEMBASSY MOSCOW
TO SECSTATE WASHDC PRIORITY 3979
INFO AMCONSUL Leningrad
WHITEHOUSE WASHDC
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USIA WASHDC 4212
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UNCLAS SECTION 05 OF 06 MOSCOW 02489

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E.O. 12356: N/A
TAGS: SENV, TSPI, ECON, PARM, KSCA, AY, UR, US
SUBJECT: GORBACHEV ON THE SORRY STATE OF THE PLANET,

SENATOR GORE, AND DR. COUSTEAU.

14. JANUARY 16 FEATURED "THE EARTH AND NATURE" AND
"THE EARTH AND HUMAN SOCIETY"; JANUARY 17,
"TECHNOLOGY, INDUSTRY AND URBANIZATION: THE URBAN
ENVIRONMENT"; JANUARY 18, "GLOBAL EDUCATION."
SIMULTANEOUSLY WITH THESE LARGER MEETINGS, SMALLER
SCIENTIFIC MINI-SEMINARS (E.G., A SERIES OF
ENERGY-EFFICIENCY WORKSHOPS COVERING EVERYTHING FROM
SOLAR COOKERS TO ENERGY EFFICIENCY IN CONSTRUCTION),
COMMISSIONS, AND OTHER SIMILAR GATHERINGS TOOK
PLACE. THE FINAL PLENARY ON FRIDAY, JANUARY 19, TOOK
PLACE AT THE KREMLIN.

15. EMBASSY COMMENT: WE PROVIDE NO DEPTH ON CONTENT
OF THESE MEETINGS AND EVEN THE MORE-IMPORTANT
"HALLWAY SESSIONS" FOR THREE REASONS:

--THE LARGER ONES THAT WE WERE ABLE TO ATTEND WERE
ADORNED WITH THE USUAL AND PREDICTABLE CALLS, IN MANY
LANGUAGES, ACCENTS, AND EVEN IN ONE LONG RELIGIOUS
CHANT, FOR MORE ATTENTION TO ECOLOGICAL PROBLEMS.
THAT ATTENTION IS UNQUESTIONABLY NECESSARY, BUT MOST
SPEAKERS WERE LONG ON COMPLAINTS WHILE SHORT ON
SOLUTIONS. THE PRESENCE OF CHURCH AND SPIRITUAL
LEADERS IN THE LARGER MEETINGS ENSURED A CERTAIN
AMOUNT OF DISCUSSION OF THE MORAL, AS OPPOSED TO THE
SCIENTIFIC AND ENGINEERING, ASPECTS OF ENVIRONMENTAL
CONSERVATION.

--ON THE OPPOSITE END OF THE SPECTRUM, THE SCIENTIFIC
MEETINGS WERE SO TECHNICAL AND SPECIFIC THAT
REPORTING ON THEM WOULD ONLY DUPLICATE INFORMATION
U.S. EXPERTS LIKELY ALREADY POSSESS; AND

--EMBASSY'S OWN NARROW RESOURCES, WHEN COVERING ALSO
THE WORTHY ECOLOGICAL AND S&T-RELATED CONCERNS OF THE
THREE SENATORS (CEPTELS REPORT THEIR INTERACTIONS
HERE) AND OTHERS IN TOWN FOR THIS OR RELATED EVENTS,

EXTRACURRICULAR MATERIAL

17. THE CONFERENCE TABLES OFFERED A WEALTH OF
PAMPHLETS AND INFORMATION SHEETS RANGING FROM UNDP
MATERIAL, INFORMATION ON THE U.S. SENATE-SPONSORED
"INTERPARLIAMENTARY CONFERENCE ON THE GLOBAL
ENVIRONMENT" (APRIL 29-MAY 2), INFORMATION ON THE
SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT
ACTIVITIES (LOS ANGELES AREA), TO INFORMATION ON "THE
CENTER FOR OUR COMMON FUTURE" IN GENEVA. THE
SENATORS AND THEIR STAFFS ALSO WORKED EFFECTIVELY THE
HALLWAYS AND BREAKFAST TABLES DISCUSSING U.S.
CONCERNS ON ENVIRONMENTAL ISSUES, ADVANCING THE
SUBJECT OF THE SPRING INTERPARLIAMENTARY
ENVIRONMENTAL CONFERENCE IN WASHINGTON (CEPTELS).
AMONG THE MATERIALS AVAILABLE WERE SEVERAL PRIVATE
SOVIET OFFERINGS, SUCH AS AN INFORMATION LEAFLET FROM
THE "INNOVATION UNION, INTERLAB INNOVATION CENTER" IN
MOSCOW, OFFERING COLLABORATION IN DEVELOPMENT OF
CLEAN TECHNOLOGIES. SOME OF THESE SOVIET PROPOSALS
APPEARED BACKED BY PATENTS AND PRESTIGIOUS
ORGANIZATIONS (THE ACADEMY OF SCIENCES) AND MIGHT BE
OF FURTHER INTEREST. TALL OF THIS INFORMATION WILL
BE POUNCHED TO THE DEPARTMENT WITH THE FORUM SCHEDULE.

COMMENTS

18. THIS CONFERENCE ROLLED TOGETHER SUCH A ERJAD AND
DEEP COLLECTION OF ENVIRONMENTAL TALENT AND
LEADERSHIP FOR TWO DIFFERENT REASONS: BOTH "ECOLOGY"
AND "THE SOVIET UNION" ARE "IN" ITEMS, AMONG THE

*just call him the
next environmental
president!*

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ACTION OES-09

INFO	LOG-00	ADS-00	AID-00	INR-05	EUR-00	SS-00	OIC-02
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	IO-19	NSF-02	NSAE-00	COME-00	L-03	TRSE-00	PM-00
	EPA-04	PA-02	CEA-01	NAS-01	DOT-00	FEMA-02	OMB-01
	STR-18	HHS-06	INRE-00	AGRE-00	ACDA-13	JUSE-00	SP-00
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TO SECSTATE WASHDC PRIORITY 3980
INFO AMCONSUL LENINGRAD
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USIA FOR GUROFF

E.O. 12356: N/A
TAGS: SENV, TSPL, ECON, PARM, KSCA, AY, UR, US
SUBJECT: GORBACHEV ON THE SORRY STATE OF THE PLANET,

HIGHEST-INTEREST ITEMS ON TODAY'S GLOBAL STAGE. THE SOVIETS CERTAINLY EXPRESSED NO REGRETS OVER THE ATTENTION, NOR LOST ANY OPPORTUNITIES TO PRESS FOR FURTHER AND DEEPER CONTACTS AND COOPERATION IN ENVIRONMENT. THE PARTICIPANTS IN THE FORUM HAD OPPORTUNITIES EACH EVENING FOR CHOICES AMONG AT LEAST FOUR DIFFERENT ACADEMIC/INTELLECTUAL/ECOLOGICAL PROGRAMS AT WELL-RESPECTED SOVIET INSTITUTIONS, SUCH AS THE "HOUSE OF SCHOLARS."

19. NO ONE PUTS ON A GOOD PROPAGANDA SHOW LIKE THE SOVIETS; THIS OLD-TIME SKILL HAS PERSERVERED THROUGH EVEN THE TOPSY-TURVY EVENTS OF CHANGES HERE. OBVIOUSLY, MANY OF THE PRINCIPAL SOVIET PLAYERS, STARTING WITH GORBACHEV, WILL BENEFIT FROM THE INTERNATIONAL EXPOSURE AND FROM THEIR ALIGNMENT BEHIND ENVIRONMENTAL CONCERNS. NONETHELESS, THE GATHERING APPARENTLY WAS A USEFUL AND INFREQUENT OPPORTUNITY FOR MANY PLAYERS IN THE ENVIRONMENTAL AREA, AND MANY POWERFUL POLITICAL FIGURES (INCLUDING SEVERAL U.S. SENATORS) TO MEET, TO BEND A FEW EARS, AND EVEN TO HAVE THEIR OWN BENT A BIT. IN THAT RESPECT, THE FORUM HAS TO RATE A SUCCESS. END COMMENT.

20. LENINGRAD MINIMIZE CONSIDERED. MATLOCK

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Withdrawal/Redaction Sheet

(George Bush Library)

Document No. and Type	Subject/Title of Document	Date	Restriction	Class.
02. Memo	From David Q. Bates to Chriss Winston Re: President's February 5 Speech to Intergovernmental Panel on Climate Control (IPCC) [page 4 not found] (5 pp.)	2/1/90	B5	

Collection:

Record Group: Bush Presidential Records
Office: Chief of Staff, White House Office of
Series: Sununu, John, Files
Subseries: Issues Files
WHORM Cat.:
File Location: IPCC Address (1989) [1]

Open on Expiration of PRA
 (Document Follows)
 By JP (NLGB) on 5/12/05

Date Closed: 12/2/2004	OA/ID Number: 29161-002
FOIA/SYS Case #: 1998-0004-F[1]	Appeal Case #:
Re-review Case #: 2005-0426-S	Appeal Disposition:
P-2/P-5 Review Case #:	Disposition Date:
AR Case #:	MR Case #:
AR Disposition:	MR Disposition:
AR Disposition Date:	MR Disposition Date:

RESTRICTION CODES

Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]
 P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]
 P-3 Release would violate a Federal statute [(a)(3) of the PRA]
 P-4 Release would disclose trade secrets or confidential commercial or financial information [(a)(4) of the PRA]
 P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [(a)(5) of the PRA]
 P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]
 (b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]
 (b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]
 (b)(4) Release would disclose trade secrets or confidential or financial information [(b)(4) of the FOIA]
 (b)(6) Release would constitute a clearly unwarranted invasion of personal privacy [(b)(6) of the FOIA]
 (b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]
 (b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]
 (b)(9) Release would disclose geological or geophysical information

EPA - Zoellick
EPA - Watkins

THE WHITE HOUSE
WASHINGTON

Bromley
Bernthal
DOE

February 1, 1990

MEMORANDUM FOR CHRISS WINSTON

FROM: DAVID Q. BATES 

SUBJECT: President's February 5 Speech to IPCC

In addition to specific comments and suggested modifications to the language of the draft of the President's speech on Monday to the IPCC that may be forthcoming from members of my staff, three principal points should be made:

- (1) The speech varies significantly from the outline prepared by the Department of Energy and EPA, which was reviewed and approved (with some minor modifications) by the DPC Global Change Working Group at its meeting on Tuesday. A copy of that outline is attached.
- (2) The speech does not contain any reference to the White House conference/seminar on scientific and economic research scheduled to be held this spring. This meeting was announced in Malta and will be co-chaired by Drs. Bromley and Boskin and Chairman Deland. There was consensus among the Working Group that the dates for the meeting should be announced as part of the speech. The invitees need not be named, with only a general reference to a representative group of nations in attendance. It could be built into those portions of the text that note the current gaps in scientific and economic knowledge and presented as the President's method of facilitating the development of the needed knowledge and becoming more personally informed on these issues.
- (3) The speech also does not reaffirm the President's offer, also made at Malta, to host the first negotiating session for a framework convention on global change following the completion of the work of the IPCC. The inclusion of this point, which need not be elaborate, was also a consensus recommendation of the Working Group.

per Zoellick

"Slighter revolution on our hand"
Bromley, DOE
EPA, CEQ

"people will walk out"
Doesn't at all talk about
"no regrets policy"

"How the sciences is
discussed
reflects disbelief"
Pres. will have a major
major explosion
will even lose the support
of the Japanese

Proposal for Presidential Speech
before the
Intergovernmental Panel on Climate Control (IPCC)

1. General statement of commitment to and concern for the global environment and economic development.
 - Reiterate determination that the President will take active role in addressing concern about global climate change.
 - Reiterate Secretary Baker's approach (spelled out in January 1989).
 - Reiterate Noordwijk commitment to greenhouse gas stabilization as soon as possible, consistent with the requirement for global economic growth that can enhance the quality of life for people everywhere.
 - Stress strong U.S. commitment to environment; e.g., domestic programs, leadership in forging international agreements on environment, assistance to and cooperative efforts with developing countries and current or former centrally planned economies.
2. U.S. Supports the IPCC Process
 - Stress need for international cooperation.
 - Congratulations to IPCC sponsors, the United Nations Environment Program (UNEP), the World Meteorological Organization (WMO) and to Dr. Bolin of Sweden, IPCC Chairman.
 - Establishment of the IPCC has filled the need for an orderly, intergovernmental process to assess scientific understanding, evaluate potential impacts and develop appropriate response options.
 - Welcome IPCC reports due in August.
 - U.S. is committed to playing a leadership role through our chairmanship of the Response Strategies Working Group (RWSG) and supporting IPCC as best forum for global climate change policy development.
 - Support for UK proposal at UN to continue IPCC.

3. Past and Ongoing U.S. Contributions and Views on Key Issues of Convention and Emissions Limiting Agreements

-- Science

- o U.S. budget is the largest in the world and is rising, nearly \$500 million in FY 1990 and to increase to almost \$1 billion in FY 1991.
- o Importance of all countries, no matter what their level of development or economic system, contributing to understanding of the science. This cooperation needs to take several forms:

- cooperation in assessment of state of the science; and

- cooperation in monitoring and analysis of climate change.

✓ Periodic international reassessment of the science at fixed intervals to aid in our decision making.

-- Technology Development

- o U.S. has active technology development programs to improve the efficiency of both supply and demand side technologies, and reduce greenhouse gas emissions.
 - More efficient fossil fuel generation technologies.
 - Renewable and energy efficiency technology initiative.
 - Conservation technology: end-use efficiency.
 - Nuclear: new generation with enhanced safety features under development.
- o Any framework convention should provide for regular assessments of the state of technology development to determine the availability and cost of technologies.

- U.S. is sensitive to the need for technology transfer to other countries.
 - o Clean coal, renewable, conservation, end-use services for technology transfer, and nuclear.
 - o A.I.D. appropriation bill.
 - o EPA/Peace Corps agreement.
 - o Change in World Bank policy.
 - o EPA's IETTAB and DOE's CORECT program to examine technology transfer.
 - o Policy aid package.
- Economics
 - o Follow-up on Administration commitment to develop real data on costs of various response strategies and assess new response measures.
 - o Challenge others to do the same.
 - o Offer technical support to those who need it.
- Policy
 - o President should encourage consideration of truly innovative responses including:
 - comprehensive approach: all major greenhouse gases are included; and
 - trading of emission permits.
 - o President should define general criteria for future agreements to limit greenhouse gas emissions:
 - market mechanisms such as "integrated resource" planning and consistency with economic growth in all countries; and

- Demonstrate U.S. willingness to facilitate the process.
- To further the debate, U.S. will host international environmental meeting composed of senior science, economics and environmental officials from all nations.

WHITE HOUSE STAFFING MEMORANDUMDATE: 2/1/90 ACTION/CONCURRENCE/COMMENT DUE BY: 2/1/90 5:00 PMSUBJECT: PRESIDENTIAL REMARKS: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

	ACTION FYI			ACTION FYI	
VICE PRESIDENT	☐	☒	MCCLURE	☒	☐
SUNUNU	☐	☒	NEWMAN	☐	☐
SCOWCROFT	☒	☐	PORTER	☒	☐
DARMAN	☒	☐	ROGICH	☒	☐
BATES →	☒	☐	UNTERMAYER	☐	☐
CARD	☐	☒	ROGERS	☐	☒
CICCONI	☐	☒	WINSTON	☐	☒
DEMAREST	☒	☐	PINKERTON	☒	☐
FITZWATER	☐	☒	DELAND	☒	☐
GRAY	☒	☐	BROMLEY	☒	☐
HAGIN	☐	☐		☐	☐

REMARKS: Please forward any comments directly to Chriss Winston, Rm. 122, x2930, no later than 5:00 PM TODAY, Tuesday, February 1, with a copy to my office. Thank you.

RESPONSE:

James W. Cicconi
 Assistant to the President
 and Deputy to the Chief of Staff
 Ext. 2702

1990 JAN 32 PM 12:04

(Lange/Cawley)
February 1, 1989
10:45 A.M.
[IPCC.DOC]

PRESIDENTIAL ADDRESS: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
GEORGETOWN UNIVERSITY
MONDAY, FEBRUARY 5, 1990
10:15 A.M.

Thank you, Dr. Bolin [Bo-leen]. Professor Obasi. Dr. Tolba. Delegates of the World Meteorological Congress, and the United Nations Environment Program. Let me thank and congratulate all of you, for taking on an issue of such great importance. The decisions this organization makes will have a profound effect on the world's environmental and economic policy.

In the post-war era, we've produced the most technologically advanced creations of man. We've also gained new understanding -- though still incomplete -- of the most ecologically fragile creations of nature.

But unfortunately, somewhere along the way, we picked up a bias, that has harmed both man and nature: a mistaken belief that there is a divergence of interests -- a logical division -- between the natural world and we who inhabit it.

Nothing could be further from the truth -- or more central to the work of this Panel. You are called upon to strike an unprecedented international bargain: a convergence between global environmental policy, and global economic policy, where both sides benefit -- and neither is compromised.

You are called upon to end the environmental cold war.

This will be possible only if we understand that economic growth and environmental integrity are not contradictory priorities. One reinforces and complements the other.

A sound environment is the basis for the continuity and quality of human life and enterprise. And strong economies allow nations to fulfill the obligations of environmental stewardship. Where there is economic strength, such stewardship is considered a necessity. But where there is poverty, it is too often a luxury.

For that reason, I believe we must usher in a new era of global cooperation: for environmental protection and economic growth. For intelligent management of industrial and natural resources. Above all, for sustainable development -- around the world.

The United States believes the I.P.C.C. is the best forum to develop policy on global climate change. We're committed to international cooperation on this issue. And we consider it vital, that the community of nations is drawn together -- in an ordered, rational way -- to assess the potential for climate change.

The state of the science; the social and economic impacts; and the right response strategies: all are crucial components to a global resolution. The stakes here are very high.

There is no question that human activities are changing the atmosphere in unexpected and unprecedented ways. Since the mid-

1800s, the level of carbon dioxide in the atmosphere has gone up by 25 percent.

What we don't yet understand is the extent of the alterations we've brought about -- and how they're linked to a significant, imminent climate change.

Last fall, many clear thinkers -- among them, world leaders -- were citing a significant thinning of sea ice at the poles as evidence that global warming had arrived. Recent observations show that the polar ice sheets are not melting, they're growing in size.

I'm not prepared -- academically, or otherwise -- to draw conclusions. But I have noticed something about the scientists drawing the conclusions.

Those who see climate change as a clear and present danger represent one distinct minority. Those who discount it completely, represent another minority. But many scientists -- if not most -- are not ready to claim that the extent of global climate change can now be reliably detected -- or predicted. That may be to their credit.

When he was observing the fervor of the French Revolution, the English poet William Blake wrote, "The best lack all conviction, while the worst are filled with passionate intensity." Here, too, we are called upon for action based on observation -- not media-driven emotion, or the politics of apocalypse. The decisions being made are too important to be compromised intellectually -- or polarized politically.

Questions remain: about the reflective effects of cloud cover, the cooling effects and CO2 absorption of oceans, and other sinks and feedback mechanisms we don't yet understand. Those questions, among others, suggest that we should attend to what is known about climate change -- and work to know more.

Current computer models are marvels of mathematics. Still, they cannot yet be said to represent reality -- and cannot be expected to predict the future. Above all, responsible policy cannot rest on the shifting sands of hypothesis and a chaos of conjecture.

In the search for answers, the United States continues to lead the world. We're seeking hard data and new ways to improve the science. Because what science now knows with confidence, policy-makers can't use. And what policy-makers need to make decisions, science doesn't yet know.

In spite of this uncertainty, some suggest we should act now, on the chance that significant climate change becomes certain. Others point to the opposite edge of that sword: any meaningful preemptive policies would bring only the certainty of prohibitive expense; conflict with Third World development; and declining standards of living, worldwide.

I believe we can do better. There is a reasoned middle ground, that matches policy to emerging scientific knowledge -- and reconciles environmental protection to economic development.

With every word, with every decision made here, we're also making a commitment that is profoundly personal. I think all of

us understand, deep inside, how the actions we take now speak to the future.

Last week, in my State of the Union address, I spoke of stewardship. I believe it's something we owe our children and grandchildren -- because the earth we stand upon is only borrowed, never owned.

So the United States remains committed to a leadership role on environmental issues. In our domestic programs. Our work to forge international agreements. Our assistance to developing and East Bloc nations. And here, by leading the Response Strategies Working Group.

Overall, we're already doing more than any other country to understand and address global warming -- in terms of financial and human resources, **by more than a factor of ten.**

I just proposed a budget to our Congress for fiscal 1991 that devotes a total of over [\$70] billion to environment-related work. Funding for the U.S. Global Change Research Program will increase by nearly 60 percent, to over \$1 billion.

That will allow NASA to move forward with its "Mission to Planet Earth" -- and will fund the launch of the first U.S. Earth Observing System, to advance the state of knowledge about the planet we share.

We've already taken many steps that bring major benefits in their own right. Steps that make sense on their own merits, and that will **also** help reduce emissions of carbon dioxide and other

gases now building up in the atmosphere. **Let me outline them very briefly:**

We want to stabilize -- and reduce wherever we can -- both our energy consumption and our total emissions. So we're pursuing new technology development. Creating a revised Clean Air Act with incentives for industry to find creative, market-driven solutions. Working out a comprehensive review and revision of our National Energy Strategy. And launching a major reforestation initiative to plant a billion trees a year on private land across America.

We're also working through diplomatic channels, and through innovative measures like debt-for-nature swaps, to do more than simply reduce global deforestation. **We hope to reverse it.**

The economics of our response strategies to climate change are getting intensive study. We intend to develop real data on the costs of various response strategies, assess new measures, and challenge other nations to follow suit. And we will offer technical support to those who need it.

As we work to create **policy** to manage CO2 and other emissions, we want to encourage the most innovative responses. Wherever possible, we believe that market mechanisms should be applied -- and that policy must be consistent with economic growth and free market principles in all countries. But we will break the hold of the environmental cold war only through dialogue -- through a shared commitment to consensus.

If we hope to promote environmental protection and economic growth around the world, it will be important to work with, not against industry. That will mean moving beyond the tradition of command, control, and compliance -- toward a new kind of environmental cooperation. Many industries, in fact, are already providing crucial research and solutions. And a few are already ahead of us.

One power-plant management firm, just across the river in Virginia, donated \$2 million in 1988 for tree planting in Guatemala -- to compensate for a coal-fired plant it was building in Connecticut. And the company expects to couple tree-planting programs with all of the new power plants now on its drawing boards.

Where developing nations are concerned, some suggest we'll have to abandon the laissez-faire, free-market principles that allowed the industrial world to prosper. In fact, we think it's all the more crucial, in the developing countries, to apply the principles of the free market in the **service** of the environment.

To the extent we can accelerate the **advancement** of these nations, it will take **less** energy for them to produce wealth: in modern industrial countries, energy use per unit of G.N.P. has **declined** over time -- steadily, and dramatically.

So we need to work with the developing nations: Applying the power of the marketplace, considering technology transfer, and encouraging industry to assist developing nations in making quantum leaps in technologies. That will allow developing

nations to grow more quickly and easily -- and may help them avoid making the environmental mistakes we older nations have made.

As I said a moment ago, I believe we should make use of what we know. We know that the future of the earth **cannot** be compromised. We bear a sacred trust in our tenancy here -- and a covenant with those most precious to us: our children, and theirs.

We also know of the efficiency of economic incentive -- and that free markets yield the most creative solutions. We must now apply the wisdom of the market, in defense of the environment we share. It is time to heal this false schism. It is time to put an end to the environmental cold war.

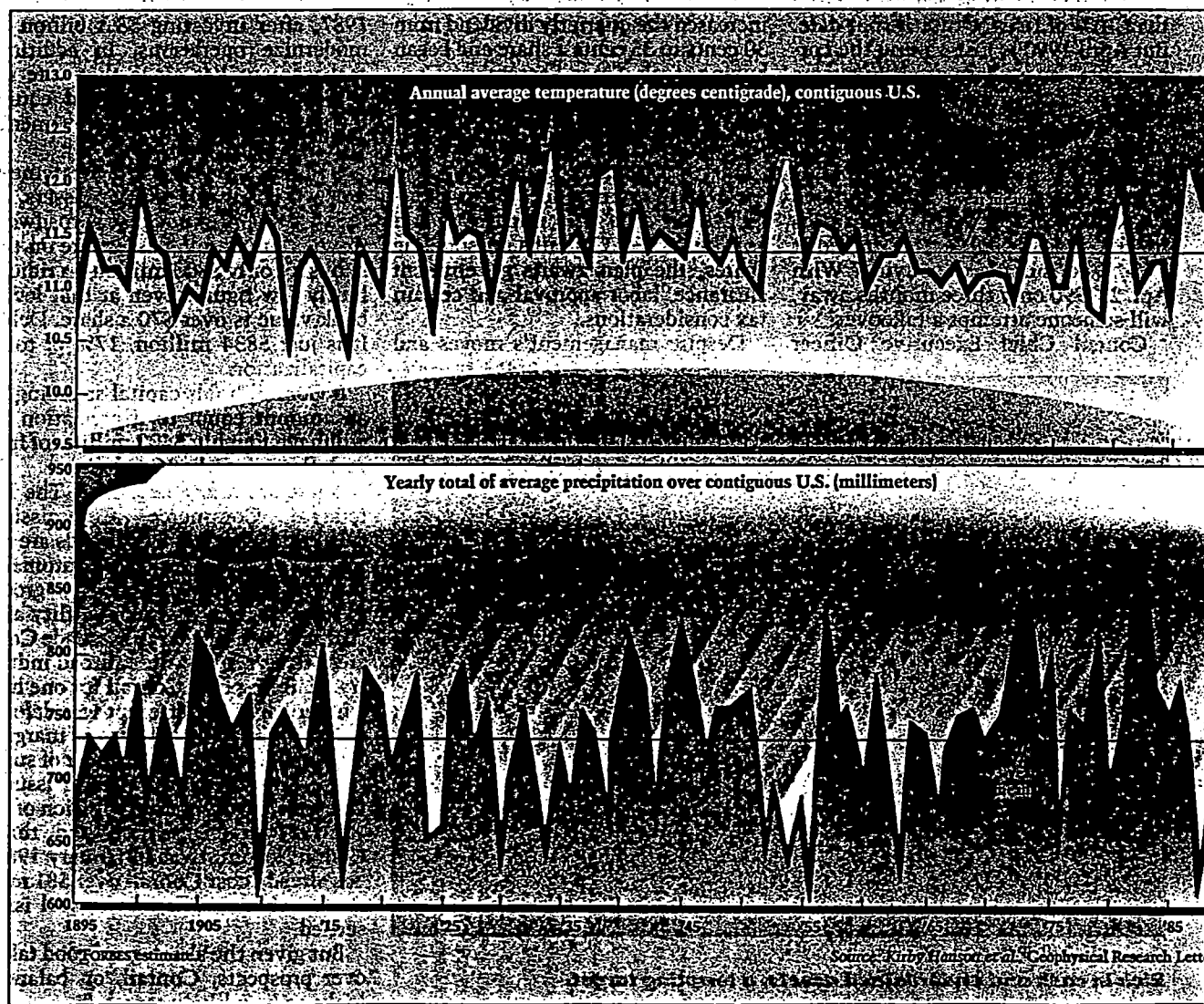
Working together, with good faith and earnest dialogue, I believe it can be done. But more important: We know it **must** be done.

Thank you -- and God bless you.

#

Apocalypse sells well in the media and even better on Capitol Hill. And that is why fears of the greenhouse effect threaten to push the U.S. into a costly environmental mistake.

THE GLOBAL WARMING PANIC



By Warren T. Brookes

ON NOV. 7 THE U.S. and Japan shocked environmentalists around the world by refusing to sign a draft resolution at a Netherlands international conference on global climate change calling for the "stabilization" of emissions of carbon dioxide (CO₂) and other "greenhouse gases" by the year 2000. Instead, they made the conference drop all reference to a specific year, and to a specific CO₂ reduction target. The Bush Administration view was set forth by D. Allan Bromley, the presidential science adviser, in testimony to Senator Albert Gore's subcommittee on Science, Technology & Space: "My belief is that we should not move forward on major programs until we have a reasonable understanding of the scientific and economic consequences of those programs."

President Bush was immediately

Fahrenheit 52 That's the average temperature in the U.S. for the period 1895-1987, as displayed in an academic journal article earlier this year by three meteorologists questioning the greenhouse effect. If there is a warming trend at all, it is very hard to see against the background of statistical "noise"—random annual variation. So, too, for rainfall, which has averaged 29 inches a year across the U.S. since 1895. Here we have reproduced the data from the academic article, with the original long-term average lines. We have also extended the history to cover 1988 and an estimate for 1989, extrapolated from January-November recordings. Scientists who are skeptical of the greenhouse theory don't deny that carbon dioxide can trap heat; they argue, rather, that the effect is much fainter and harder to predict than the alarmists want to believe.

Andrew Christie

savaged by environmentalists, and by politicians like Senator Gore (D-Tenn.). The Bush viewpoint does not sit too well with most of the media, either. Last January *Time* published a cover story on environmental catastrophes, declaring that greenhouse gases could create a climatic calamity. The *New York Times* weighed in a month ago with a story about how melting polar ice would flood the nations that can least afford to defend themselves, Third World countries like Bangladesh and India. Or perhaps you have seen the ads for Stephen Schneider's *Global Warming*, accompanied by a blurb from Senator Tim Wirth (D-Colo.). In his book this well-known climatologist paints a future of seas surging across the land, famine on an epidemic scale and ecosystem collapse.

Is the earth really on the verge of environmental collapse? Should wrenching changes be made in the world's industry to contain CO₂ buildup? Or could we be witnessing the 1990s version of earlier scares: nuclear winter, cancer-causing cranberries and \$100 oil? The calamitarians always have something to worry us about. Consider this: In his 1976 book, *The Genesis Strategy*, Schneider lent support to the then popular view that we could be in for another ice age, "perhaps one akin to the Little Ice Age of 1500-1850. Climatic variability, which is the bane of reliable food production, can be expected to increase along with the cooling."

At the very moment Bromley was testifying to Gore's subcommittee, MIT's prestigious *Technology Review* was reporting on the publication of an exhaustive new study of worldwide ocean temperatures since 1850 by MIT climatologists Reginald Newell, Jane Hsiung and Wu Zhongxiang. Its most striking conclusion: "There appears to have been little or no global warming over the past century." In fact, the average ocean temperature in the torrid 1980s was only an eighth of a centigrade degree (a quarter of a Fahrenheit degree) higher than the average of the 1860s. Ocean temperature is now virtually the same as it was in the 1940s. Since two-thirds of the buildup of CO₂ has taken place since 1940, the MIT data blow all of the global warming forecasts into a cocked hat. President Bush wisely told reporters: "You can't take a policy and drive it to the extreme and say to every country around the world, 'You aren't going to grow at all.'"

That is the central issue of the glob-

al warming debate, and it explains why the U.S. and Japanese position was supported by some 30 other developing nations which see that just as Marxism is giving way to markets, the political "greens" seem determined to put the world economy back into the red, using the greenhouse effect to stop unfettered market-based economic expansion.

In simplest terms, the earth's atmosphere does operate as a greenhouse. In addition to oxygen, nitrogen and water vapor, the atmosphere contains several gases that trap radiated heat, including methane and CO₂. Carbon dioxide is essential not only to warmth but to vegetation. It is also essential to life in another way: Without its heat-containing effect the planet would freeze, like the atmospherically naked moon.

Throughout most of human history that atmospheric blanket has held global temperatures at an average of about 60 degrees F., plus or minus 5 degrees F. During most of human history, the CO₂ concentration in that blanket has, until this century, hovered around 270 parts per million, although in earlier geologic epochs it reached as high as 20,000.

Over the last 100 years the CO₂ concentration has risen from 270 to today's level of 350. The culprit: man. Most of the greenhouse gas increase is the result of fossil fuel consumption. Add to that the rise in other man-generated trace gases—methane, nitrogen oxides and chlorofluorocarbons—and total greenhouse gases are now at 410 ppm. In other words, because of the combined effect of these gases, we have already gone over halfway to a doubling of CO₂. Even so, there has been less than half a degree of warming in the last 100 years.

What do the environmental pessimists make of all this? The earliest versions of their computer "general circulation models" predicted that the earth would warm up by anywhere from 3 to 5 degrees centigrade, or 5 to 9 degrees Fahrenheit, by the year 2050. The most extreme scenarios warn of coastal flooding (from melting ice caps) and rising inland droughts. However, as the level of sophistication of the models has risen, these forecast effects have been steadily reduced to a new range of 1.5 to 2.5 degrees centigrade.

One major exception to this declining rate of doom is the model run by James Hansen of the National Aeronautics & Space Administration, who shocked a congressional hearing in



Senator Gore contemplating sympathetic witness James Hansen. **Censorship? OMB merely said computer models are poor predictors.**

June 1988 during the middle of a scorching near-nationwide drought, by saying he was "99% confident" the greenhouse effect is now here.

Even though the vast majority of the climatological community was outraged by Hansen's unproven assertions, environmental advocate Stephen Schneider notes in *Global Warming*, "Journalists loved it. Environmentalists were ecstatic. Jim appeared on a dozen or more national television news programs. . . ."

By the end of 1988, with Hansen and Schneider's enthusiastic support, global warming was deeply embedded in the public consciousness. Now over 60% of the public is convinced it will worsen, even as the evidence of that alleged trend is under increasingly sharp and solid scientific attack.

On the contrary, that attack has been used as a premise for even more immediate action. As one TV anchorman argued, "Even if we aren't sure

it's true, shouldn't we take precautions and act now as if it were?"

Unfortunately, "taking such precautions" could well spell the end of the American dream for us and the world. Once CO₂ is in the atmosphere, we can't easily remove it. Since most of the forecast rise in the gas is a function of simple economic and population growth in the Third World, there is no realistic economic way to prevent a CO₂ doubling without slashing growth and risking a revolt of the have-not nations against the haves. The Washington, D.C.-based Center for Strategic & International Studies points out that, even though the U.S. is now the largest carbon fuel user, it's the developing countries that will quadruple their energy consumption by 2025. "By the middle of the next century, they will account for the bulk of the greenhouse gases emitted into the atmosphere, even if they succeed in doubling energy efficiency."

The Environmental Protection Agency finds that just to stabilize U.S. CO₂ emissions at present levels would force 30% taxes on oil and coal, while to meet environmentalists' demands for a 20% reduction in U.S. CO₂ emissions would require a tax of \$25 per barrel on oil, and \$200 a ton on coal, effectively doubling U.S. energy costs.

Unfortunately, the popular media don't seem to care. In May the national press erupted in a two-day firestorm when Hansen told Senator Gore's subcommittee that the Office of Management & Budget had censored his florid global warming testimony by adding the modest caveat, "These changes should be viewed as estimates from evolving computer models and not as reliable predictions."

Yet, at the moment of that testimony, 61 of the world's top climatologists, gathered for a five-day workshop in Amherst, Mass., were largely agreeing with OMB. *Science* magazine reported that most of the attendees were pleasantly surprised by OMB's efforts to control Hansen: "I can't say I agree with censorship, but it seems OMB has better people than I thought. I'd have to agree with their angle," said Rick Katz of the National Center for Atmospheric Research, one of the leading modelers.

Conference leader Michael Schlesinger, another top modeler (University of Illinois), agreed: "[Hansen's] statements have given people the feeling the greenhouse effect has been detected with certitude. Our current understanding does not support that. Confidence in its detection is now down near zero."

That conclusion was buttressed by one of the deans of U.S. climatology, Reid Bryson, a founder of the Institute for Environmental Studies at the University of Wisconsin, who said in July: "The very clear statements that have been made [by Hansen] that the greenhouse warming is here already and that the globe will be 4 degrees [centigrade] warmer in 50 years cannot be accepted."

On Dec. 24, 1988, Hansen received an unwelcome Christmas present in the form of a new research paper by one of the world's most universally respected climatologists, Thomas Karl, and two of his colleagues at the National Oceanographic & Atmospheric Administration, Kirby Hanson and George Maul. Their review of the best climate record in the world—that of the 48 contiguous United States—concluded: "There is no statistically significant evidence of an

overall increase in annual temperature or change in annual precipitation for the contiguous U.S. 1895-1987." Look at the chart on pages 96-97. As Karl says in an interview, "If there is a greenhouse warming effect, you can't find it in the U.S. records."

That news alone should have cooled off the global warming movement. But the environmentalists accepted Hansen's dismissal of the paper as "not significant" because the data covered only 1.5% of the earth's surface, not nearly enough to identify major trends.

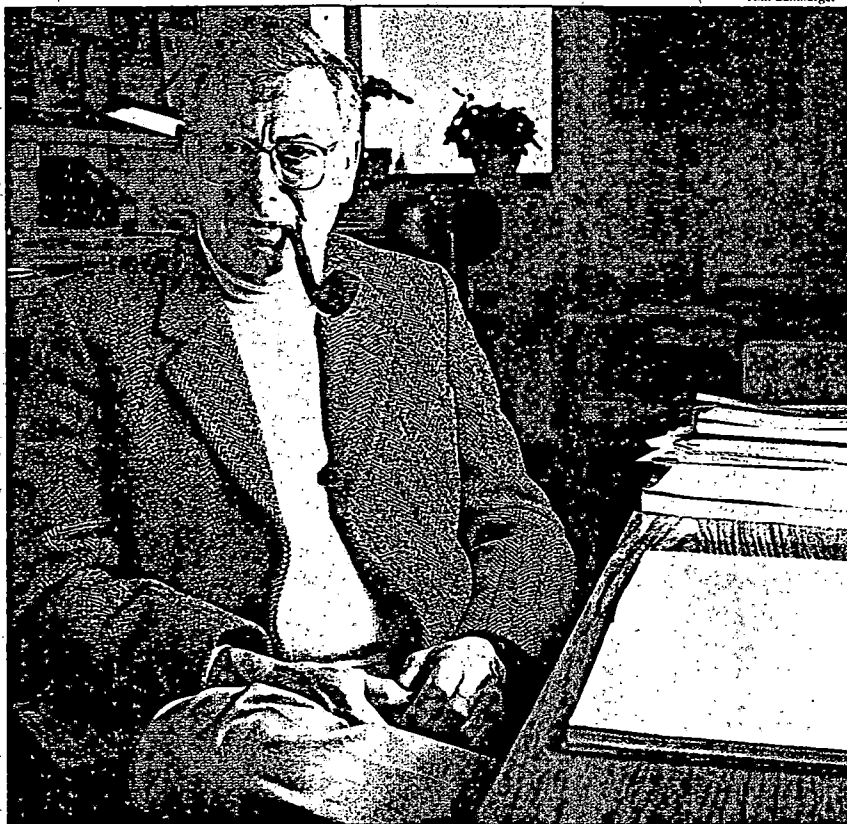
But MIT meteorologist Richard Lindzen says that Hansen's rebuttal is out of line. He points out that because of the law of large numbers—the fact that a large enough sample is likely to give an accurate picture of a larger population—"the absence of any trend in the record of the contiguous U.S. leads to the suspicion that all the trends in the global record may be spurious."

The major reason for this is that when you fully subject global temperature records (as Karl did the U.S. records) to adjustment for the effects of urbanization (cities are heat islands that artificially inflate temperature records), the global warming trend since 1880 has been only a third of a degree centigrade, and over the Northern Hemisphere land masses, no trend at all.

Here's another fact, noted by Hugh Ellsaesser of Lawrence Livermore Laboratories, that should trouble the calamity theorists: Most of the past century's warming trend took place by 1938, well before the rise in CO_2 concentration. From 1938 to 1970 temperatures plunged so sharply a new ice age was widely forecast. Furthermore, the warming trend since 1976 has been just the opposite of that forecast by the greenhouse model, with *cooling* in both the northern Pacific and North Atlantic.

In fact, the Northern Hemisphere shows no net change over the last 55 years, during which CO_2 concentration rose from approximately 300 to 350 ppm and other thermally active trace gases were in their steepest growth phases.

In spite of this clear lack of correlated warming evidence, one of the leading climate models now predicts that a 1% annual rise in CO_2 should, over 30 years, produce a 0.7-degree centigrade warming. But when Patrick Michaels of the University of Virginia applied that formula to the period from 1950 to 1988, when greenhouse



Reid Bryson of the University of Wisconsin

"Models are marvels of mathematics but crude imitators of reality."



Richard Lindzen, professor of meteorology at MIT

His prediction for the next century: a few tenths of a degree of warming.



Hugh Ellsaesser of Lawrence Livermore Laboratories
Surprise: At low latitudes, CO₂ actually thins the greenhouse blanket.

gases rose 1.2% per year, he found a tiny 0.2-degree warming in land temperatures, where the model would have predicted 1.3 degrees. When a model cannot come within 500% of explaining the past, it is useless as a predictor of anything.

As Reid Bryson concludes in a 1988 paper, "A statement of what the climate is going to be in the year A.D. 2050 is a 63-year forecast. Do the models have a demonstrated capability of making a 63-year forecast? No. A 6.3-year forecast? No. Have they successfully simulated the climatic variation of the past century and a half? No. They are marvels of mathematics and computer science, but rather crude imitators of reality."

The major weakness of the models is their assumption that the CO₂ buildup is the significant climate variable, and should *ceteris paribus* [all other things being equal] generate warming. But, as it turns out, the *ceteris* are decidedly not *paribus*.

One of those variables is cloud cover, which is at least 100 times more powerful in affecting temperatures

than greenhouse gases and is infinitely variable. Yet, because cloud cover has been documented only for a decade or so (by weather satellites), the models have little to go on. Until recently, the modelers assumed that warmth gave rise to the kind of clouds that trap heat, contributing still further to warming, in a vicious cycle. But in June 1988, V. Ramanathan of the University of Chicago and a team of scientists at NASA concluded from preliminary satellite data that "clouds appear to cool earth's climate," possibly offsetting the atmospheric greenhouse effect.

The supreme irony is that this "cooling effect," most pronounced in the Northern Hemisphere, coincides with the paths of coal-burning emission plumes with their high concentration of sulfur dioxide. That confirms a long-held thesis that sulfur dioxide creates "cool clouds." Of course, it is very upsetting to an environmentalist to discover that a pollutant has a beneficial side effect.

Sulfur dioxide emissions not only acidify rain, they combine with water

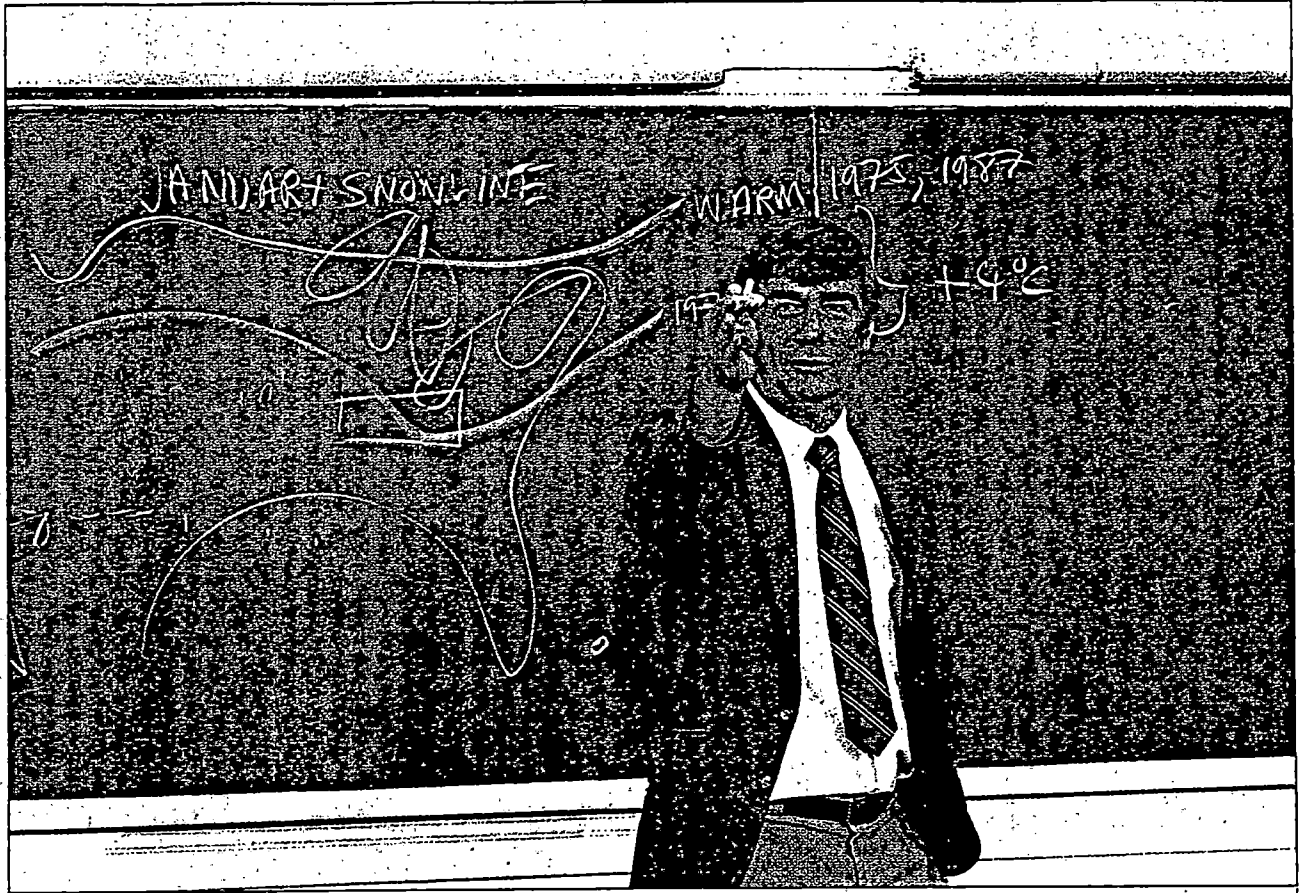
vapor to form what are known as "aerosols," which have the effect of brightening clouds and making them reflect more heat away from the earth. Wisconsin's Reid Bryson described this effect as early as 20 years ago. Bryson's thesis was scorned at the time. But last June, Thomas Wigley, one of England's top climatologists and a global warming enthusiast, conceded in a paper in *Nature* magazine that sulfur dioxide cooling "is sufficiently large that the effects may have significantly offset the temperature changes that resulted from the greenhouse effect."

Michaels says this could also explain in part why U.S. daytime highs (when brighter clouds have the most cooling effect) have actually declined substantially in the last 50 years, even as the nighttime lows have risen. "This should make you wonder," says Michaels, "why Hansen [and others] have only perturbed their models with CO₂, and not with SO₂ as well. If you only perturb the model with CO₂, it will predict the greenhouse warming effect. If you only perturb it with SO₂, you get an ice age."

Hugh Ellsaesser says the main reason the models have been so completely wrong in "predicting" the past is that they completely ignore the countervailing, thermostatic effects of the hydrological cycle of evaporation and condensation. Two-thirds of the predicted global warming is due not directly to CO₂'s radiative power but to an indirect effect: Carbon dioxide warming supposedly causes a threefold amplification of water vapor surface evaporation into the atmospheric blanket.

But Ellsaesser says in the warmer, tropical latitudes, where the temperature change from sea-level upward is most rapid, evaporation has the opposite effect. There, water vapor rises by deep convection in fast-rising towers. This in turn leads to more rapid condensation and precipitation, which then causes a drying and thinning of the upper atmosphere in a process called subsidence. "In the lower latitudes, a rise in CO₂ emissions will produce a 3-to-1 rise in greenhouse blanket *thinning* due to condensation. That's exactly the opposite of what the models predict," he says.

An eminent British scientist, Sir James Lovelock, says this hydrological process "is comparable in magnitude with that of the carbon dioxide greenhouse, but in opposition to it." National Oceanographic scientist Thomas Karl agrees: "We will eventu-



Patrick Michaels, professor of environmental science at the University of Virginia
His prediction for 1991: a heat wave, accompanied by a global warming panic.

ally discover how naive we have been in not considering CO₂'s effects on cloud cover and convection. As CO₂ speeds up the hydrological cycle, more convection creates more clouds and more cooling. So, the greenhouse effect could turn out to be minimal, or even benign."

MIT's Richard Lindzen thinks that correcting for deep convection alone could lower the global warming estimates by a factor of six. As a result, he says, "It is very unlikely that we will see more than a few tenths of a degree centigrade from this cause [CO₂] over the next century."

In the face of such mounting evidence, U.S. businesses may stop worrying about devastating legislative enactments. That could be a mistake. As Nobel economist James Buchanan argues, what drives Washington policymaking is not economic or scientific realities but "public choice," the pursuit of power and funding.

The public choice potential of global warming is immense. Under a global warming scenario, the EPA would become the most powerful government agency on earth, involved in

massive levels of economic, social, scientific and political spending and interference, on a par with the old Energy Department. Don't forget the energy crisis: During the 1970s, a great many less-than-honest scientists confidently predicted the world was about to run out of fossil fuels, and that by 1985, we'd be paying \$100 a barrel for oil, or more. We wasted billions on energy subsidies.

Senator Albert Gore is evidence of this public choice phenomenon. He seems determined to run his next presidential campaign at least in part on climate change, saving Mother Earth. Every year, at least one-sixth of the U.S. is classified by the government's Palmer Index as being in drought. Even though that index overstates the case, Gore could be looking at some very big political states—maybe California or Texas or Iowa—where his message will resonate with farmers and business. All he has to do is wait for a warm spell, and capitalize on what mathematicians call noise in the statistics.

Patrick Michaels explains: "We know that the Pacific Ocean current

known as El Niño tends to warm and cool in two-year cycles. Just as its warming cycle produced the 1987-88 droughts, in 1989 it cooled sharply, making the U.S. much cooler and wetter than Hansen had forecast, and that is likely to happen in 1990, again. But that means that 1991 and 1992 should be warmer and drier than usual as the El Niño current warms. It won't matter that this has nothing to do with global warming, the media will perceive it that way, and people will tend to believe it."

Bernard Cohen, a physicist at the University of Pittsburgh, warns, in a 1984 book: "Our government's science and technology policy is now guided by uninformed and emotion-driven public opinion rather than by sound scientific advice. Unless solutions can be found to this problem, the U.S. will enter the 21st century declining in wealth, power and influence. . . . The coming debacle is not due to the problems the environmentalists describe, but to the policies they advocate."

"Global warming" may well prove Cohen right. ■

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ALLIANCE FOR ACID RAIN CONTROL
444 North Capitol Street
Suite 526
Washington, DC 20001

FAX COVER SHEET

To: GOVERNOR JOHN SUNUNU JACKIE KENNEDY
From: NED HELME
Date: February 2, 1990
Message: JACKIE, PLEASE KEEP THIS MEMO IN CONFIDENCE
+ SHARE IT ONLY WITH THE GOVERNOR. MANY THANKS

Number of pages (including cover) 3

**IF THERE ARE ANY PROBLEMS WITH THIS TRANSMITTAL, PLEASE CALL THE
ALLIANCE AT (202) 624-8199.

Alliance for Acid Rain Control

Governor Rudy Perpich,
Chairman
Ned Helme,
Executive Director

444 North Capitol Street
Suite 526
Washington, D.C. 20001
(202) 624-5475

February 1, 1990

To: Governor Sununu

From: Ned Helme

RE: Problems in House Energy & Power on the Emissions Tax

With Governor Sullivan and Tony Earl, I've been meeting with members of the House Energy & Power Subcommittee in the last few days to counter the Dingell/Sharp onslaught supporting an emissions tax to help the Midwest. We have come away very concerned about potential defections of Republican members as well as oil-state Democrats on the Subcommittee and urge you to get involved personally.

As you probably know, the Republican Subcommittee members met to discuss acid rain and alternative fuels yesterday afternoon. Reportedly, members came away with the feeling that they may have to give in to Mr. Dingell and Mr. Sharp on the emissions tax in order to get what they want on alternative fuels, class of '85 and other issues in the Energy & Power Subcommittee. Mr. Lent reportedly has told other members that you had called him recently and urged him not to cave in on the emissions tax. While he reportedly said he could not vote for a tax, he still encouraged members to work closely with Mr. Sharp, because Sharp's support would be needed on alternate fuels and other issues. In particular, Reps. Barton, Fields, Callahan, Bilirakis and Dannemeyer need shoring up. During our past visits, they each have indicated opposition to cost-sharing. Sharp is expected to offer a substitute with the acid rain title debated first during markup, as a means to increase the pressure for the emissions tax.

On the Democratic side, we met individually yesterday with Reps. Synar, Walgren, Hall, Bates, Boucher and Cooper (not on subcommittee). Mr. Walgren indicated he was leaning toward voting for an emissions tax. Rep. Hall said he opposed taxes, but felt that he had to do something for Phil Sharp and "wanted to stay close to Mr. Dingell". Mike Synar told us he had told Phil Sharp that he would oppose any fees or taxes, but could perhaps support some cost-sharing through the allowance system. Bates, Cooper and Boucher are totally opposed to cost-sharing, with Jim Cooper planning to work in tandem with Rep. Carlos Moorhead to fight the emissions tax and other cost-sharing schemes. From earlier visits, we also count Markey and Richardson as solidly in our camp, giving us six solid votes counting Moorhead.

If we can hold six other Republicans (Dannemeyer, Fields, Nielson, Bilirakis, Barton, & Callahan), we will have 12 solid votes against an emissions tax, enough to strike it from a Sharp substitute. Dingell has six solid votes (Sharp, Bruce, Walgren, Oxley, & Swift) at this point, with Tauzin, Bryant, Hall and Lent unpredictable. You can see why we are concerned and why we need your direct help.

Senate Visits. On the Senate side, we met with 7 Senators late last week: Simpson, Wallop, Baucus, Bryan, Reid, Conrad, and Bingaman. All seven assured us they would never agree to any cost-sharing, including the apparently-dead "2 for 1" Byrd proposal. Western Democrats indicated that they would resist partisan appeals by Sen. Mitchell on this, as they view cost-sharing as a vitally important regional issue.

Thanks again for hanging so tough on this issue. I'll keep you posted as we make more visits with members in the coming weeks.

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

P.O. Box 3000, Boulder, Colorado 80307-3000