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SUMMARY OF RESEARCH ACTIVITIES FOR 1991

Enhanced Research Program on the Long-Range Climatic Effects of Increased Atmospheric Carbon Dioxide—A Continuation

to be carried out by NCAR
with support from the
Department of Energy

as an increment to NCAR's
continuing program of research
sponsored by the
National Science Foundation

Principal Investigator: Warren M. Washington
Coinvestigator: Gerald A. Meehl

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Summary

In the past year, we have reached several important milestones in the modeling and analysis of increased greenhouse-gas-caused climate change. Some of this work was highlighted in the recent update of the 1992 Intergovernmental Panel on Climate Change report. Our milestones are (1) analysis of the ongoing control and transient experiments out to 70 years, (2) development and testing of a new-generation coupled model, (3) analysis of natural variability and El Niño-Southern Oscillation (ENSO) climate change, (4) examination of the role of cirrus albedo in global climate sensitivity, (5) participation in various model intercomparisons, and (6) assistance with an exhibit on the greenhouse effect at the Franklin Institute Museum in Philadelphia, Pennsylvania. (Although this latter activity was not part of our planned research, we felt that our contribution to the exhibit would benefit science education.)

1. Analyses of Control and Transient Experiments

We have continued to analyze climate variability and climate anomalies from a slow increase of carbon dioxide (CO_2) in the global coarse-grid coupled climate model (Meehl et al., 1992b). Annual mean surface air temperature differences for several regions show that the Northern Hemisphere warms faster than the Southern Hemisphere and that land areas warm faster than ocean. The high northern latitudes outside the North Atlantic contribute most to global warming but also exhibit greater variability, while the high southern latitudes contribute least because of deep mixing in the circumpolar ocean (Figure 1). Geographic patterns of regional climate anomalies forced by increased CO_2 in the model are more evident with a longer averaging interval taken later in the integration. We have recently initiated further examination of trends and variability in the coupled model through the use of empirical orthogonal function analysis.

In collaboration with David Karoly (Monash University, Melbourne, Australia), we have continued to explore the possibility of using the consistent zonal mean cross-section temperature change patterns from a number of model simulations as an example of a CO_2 climate-change signal that could be detected in observations (Karoly et al., 1992). Several other candidate mechanisms that could also produce such climate-change signals (e.g., increases of sea-surface temperature (SST), ENSO, and decreases of stratospheric ozone concentrations) were also studied. The other candidate mechanisms all had somewhat different signatures compared to the CO_2 signal in zonal mean temperatures as a function of height.

2. New Generation of Coupled Atmosphere, Ocean, and Sea-Ice Model

We have made considerable progress in putting together a new set of coupled atmosphere, sea-ice, and ocean models for global-change studies. These models are configured to run very efficiently on present-day supercomputers. Figure 2 shows the present synchronous coupled climate model with atmosphere (R15), and ocean and sea-ice dynamical components of 1° (the latter using the method of Flato and Hibler). The thermodynamic part of the sea-ice model has three levels, as devised by A. Semtner. Preliminary tests are encouraging in that the coupled model is yielding realistic distributions of sea-ice thickness, fractional area, and velocities. These quantities are much closer to observations than previous modeling studies of greenhouse-gas impacts. In comparing the model with observations (mostly from NASA satellite), we extensively used NASA Arctic and Antarctic sea-ice atlases for monthly ice limits and concentrations.

We configured a 1° 20-level ocean model for greenhouse sensitivity studies. This resolution is greatly enhanced over our previous 5° 4-level ocean version. We have completed several 100-year runs of the 1° ocean model with observed forcing and we are now comparing these integrations with available observations. This 1° model is also being compared with the eddy-resolving 0.5° version of A. Semtner and R. Chervin. The 1° version produces a realistic simulation of the major ocean circulations (Figures 3, 4, and 5) and regions of eddy activity as confirmed by satellite observations. This is an example of how pre-EOS data are instrumental in building better climate models—in this case, ocean and sea-ice models.

The atmospheric model is an updated version of the Community Climate Model (CCM0) (R15) which has an improved cumulus convection scheme, cirrus albedo, surface albedos, and surface hydrology. The coupled system will be configured to use CCM2 when it becomes available, starting with studies with a slab (50 m) ocean.

3. Natural Variability and ENSO Climate Change

We have continued to study the effects on ENSO of increased CO_2 in several model versions (Meehl et al., 1992a). The global coarse-grid coupled model shows that ENSO continues to function in the tropical Pacific, but the ENSO SST anomalies are superimposed upon a warmer average SST caused by the mean increase of atmospheric CO_2. This warmer mean SST causes the evaporation, low-level moisture convergence, and resulting precipitation to be proportionately greater than in present-day events. The anomalous east-west Walker circulation is then intensified, and areas prone to drought during ENSO experience increased risk of more severe moisture deficits in an increased CO_2 environment. The change in climate basic state due to the mean increase of CO_2 and resulting decrease of equator-to-pole temperature gradient is associated with altered extratropical teleconnections during ENSO events with increased CO_2. The Pacific North American teleconnection pattern, evident in present-day composite ENSO events, is more zonal in the ENSO events in the increased CO_2 environment (Figure 6), resulting in changes of areas of anomalous warming and cooling in the extratropics, particularly over North America.

In a separate study based on these results, it was shown that, in the paleoclimate record, ENSO could have a different signature in the extratropics compared to present because of past climate basic states that were significantly different from the present (Meehl and Branstator, 1992).

In one of our earlier studies, we noted a biennial tendency for ENSO oscillations in the coupled model used for our CO_2 climate sensitivity experiments (Meehl, 1990). In a further exploration of this phenomenon, we studied the biennial signals of the observed coupled ocean-atmosphere system in the tropical Indian and Pacific Ocean regions (Meehl, 1992a). Analysis of vertical ocean temperature profiles from hydrographic station data showed that changes in upper-ocean heat content contribute to the persistence of SST anomalies on the annual time scale. These anomalies are important to a biennial mechanism (first proposed by Meehl in 1987). Results also suggested that both the Indian and Pacific Oceans are actively involved in ENSO, and that ENSO could be an amplification of the biennial cycle in the observations and the coupled model.

4. Role of Cirrus Albedo in Global Change

It has been hypothesized that cirrus albedo changes can have a major effect on climate and thus a limiting effect on global warming due to increased greenhouse gases. The suggestion is that penetrative convection under the conditions of warm ocean temperatures is strong enough to put large amounts of moisture into the upper troposphere and to generate dense cirrus clouds capable of reflecting sizable amounts of solar energy. It is well known that clouds can enhance or decrease the greenhouse effect. The simplified conventional wisdom is that, if low-level clouds increase, they will increase the planetary albedo and cool the climate system. Likewise, if cirrus clouds, which are not usually highly reflective of solar radiation, increase, the trapping of infrared radiation within the troposphere will increase the surface and tropospheric temperatures.

We tested the hypothesis of cloud cirrus feedback by modifying cloud albedo in the radiation package in a version of the CCM, with albedos specified for low (0.6), middle (0.3), and high (0.15) clouds. When the ocean surface temperature exceeded 303 K, the middle and high clouds increased linearly to 0.6 within the range of 303 to 308 K. The climate model in this study makes use of a penetrative convection scheme, which enables water vapor to be easily transported to the mid- and upper tropical troposphere where it can yield more tropical warming for doubled CO_2 concentration. This increased sensitivity may show up more in climate models with penetrative convection than in models with convective adjustment. The penetrative scheme adds a significant amount of water vapor, with an accompanying change in lapse rate, to the entire tropical tropospheric column in which precipitation occurs. Because water vapor is the largest greenhouse gas in the atmosphere, it further enhances the greenhouse effect. The reduced solar absorption, suggested in the mechanism hypothesized by Ramanathan and Collins (1991) with respect to dense cirrus, can counter the strong water vapor feedback process. It, however, is not a local phenomenon in that the general circulation changes and the compensation mechanisms play major roles. In regions such as parts of the Indian Ocean, where the SST may be higher than 300 K, this mechanism is not invoked because regional dynamics do not allow large-scale cumulus convection. Thus, other mechanisms like evaporation and circulation changes must play important roles in limiting the SSTs. Increasing the cirrus albedo in the model keeps the tropical temperature of the simple mixed-layer ocean model near 303 K and cools the entire planet. Increasing the cirrus albedo as a function of the SST (above 303 K) lowers the tropical and global temperatures. There is evidence in this study that a definite limit on the SSTs is not taking place, but the overall increase in planetary albedo is creating a negative feedback, thus causing a cooler planet than there would otherwise be. Another important finding in this model study is that surface air temperature increase from doubled CO_2 is less in a model study with the cirrus albedo feedback than without.

5. Model Intercomparisons

Indian summer monsoon characteristics were compared in a number of general circulation model (GCM) simulations in preparation for a more detailed analysis of monsoon sensitivity experiments (Meehl, 1992b). These models included several versions and resolutions of the CCM at NCAR, as well as a GCM from the Bureau of Meteorology Research Centre in Melbourne, Australia. The results were surprisingly consistent in showing that larger land-sea temperature contrast (between southern Asia and the Indian Ocean) results in a stronger monsoon with more precipitation. The results also suggest that the effects of land-surface conditions could be as strong as those of interannually varying SSTs for year-to-year changes in Indian monsoon intensity. This result has implications for sensitivity of the Indian monsoon to an increase of CO_2 in the atmosphere.

As another part of our studies of the factors contributing to monsoon sensitivity, we reviewed the role of tropical topography in global climate (Meehl, 1992c). The Tibetan Plateau provided the strongest topographical forcing of any of the tropical regions considered. Upper-level heating, as well as the mechanical effects associated with the elevated topography of the Plateau, has a significant influence on global climate. Other tropical continental areas without elevated topographical heat sources can maintain monsoon regimes, but not of comparable intensity. This result has implications for the expected increase of land-sea temperature contrast with increased CO_2.

We also participated in an intercomparison of coupled model simulations of ENSO (Neelin et al., 1991). The results showed that the coarse-grid coupled GCMs (such as the one we have used for CO_2 sensitivity studies) simulated coupled sets of anomalies that appeared in the eastern equatorial Pacific and moved west (SST modes), while the higher-resolution coupled models produced coupled anomalies that either developed in place or slowly propagated from west to east (ocean modes). This intercomparison clarified the relative role of internal ocean wave dynamics in the models' simulations of ENSO.

6. Science Museum Exhibit

The Franklin Institute Science Museum, Philadelphia, Pennsylvania, is putting together an exhibit entitled "Greenhouse Earth" that describes many aspects of the greenhouse effect, such as the carbon cycle, ozone, clouds, water vapor, solar radiation, and climate change. The exhibit will open in Philadelphia in February 1992 and travel to various museums throughout the country during the next two years (June to August 1992 at the Museum of Science, Boston, Massachusetts; October to December 1992 at SciPort, Shreveport, Louisiana).

One portion of the exhibit covers the use of computer models to simulate the climate. It is an interactive touch-screen display that teaches some of the basic concepts about global climate change, the greenhouse effect, and computer modeling. It allows the viewer to examine various future climates based upon choices involving fossil-fuel use. Our contribution was twofold—to provide consultation on the use of computer models and to provide computer images of potential surface temperature change based upon future scenarios.

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FIGURE LEGENDS

Figure 1. Time series of warming in various regions (Meehl et al., 1992b).

Figure 2. Schematic of interactive components of the coupled atmosphere, ocean, and sea-ice model.

Figure 3. Simulation from ocean model showing Atlantic time mean upper-ocean currents and the Gulf and other strong flows.

Figure 4. Simulation from ocean modeling showing Pacific instantaneous upper-ocean currents and the weak eddy in the tropical Pacific.

Figure 5. Simulation of return circulation of thermohaline "conveyor-belt" circulation at Atlantic Ocean bottom, showing the deep flow of the North Atlantic water into the southern hemisphere.

Figure 6. Sea-level pressure anomalies in (a) observed ENSO events, (b) $1\times CO_2$ ENSO events, and (c) $2\times CO_2$ ENSO events (Meehl et al., 1992a).

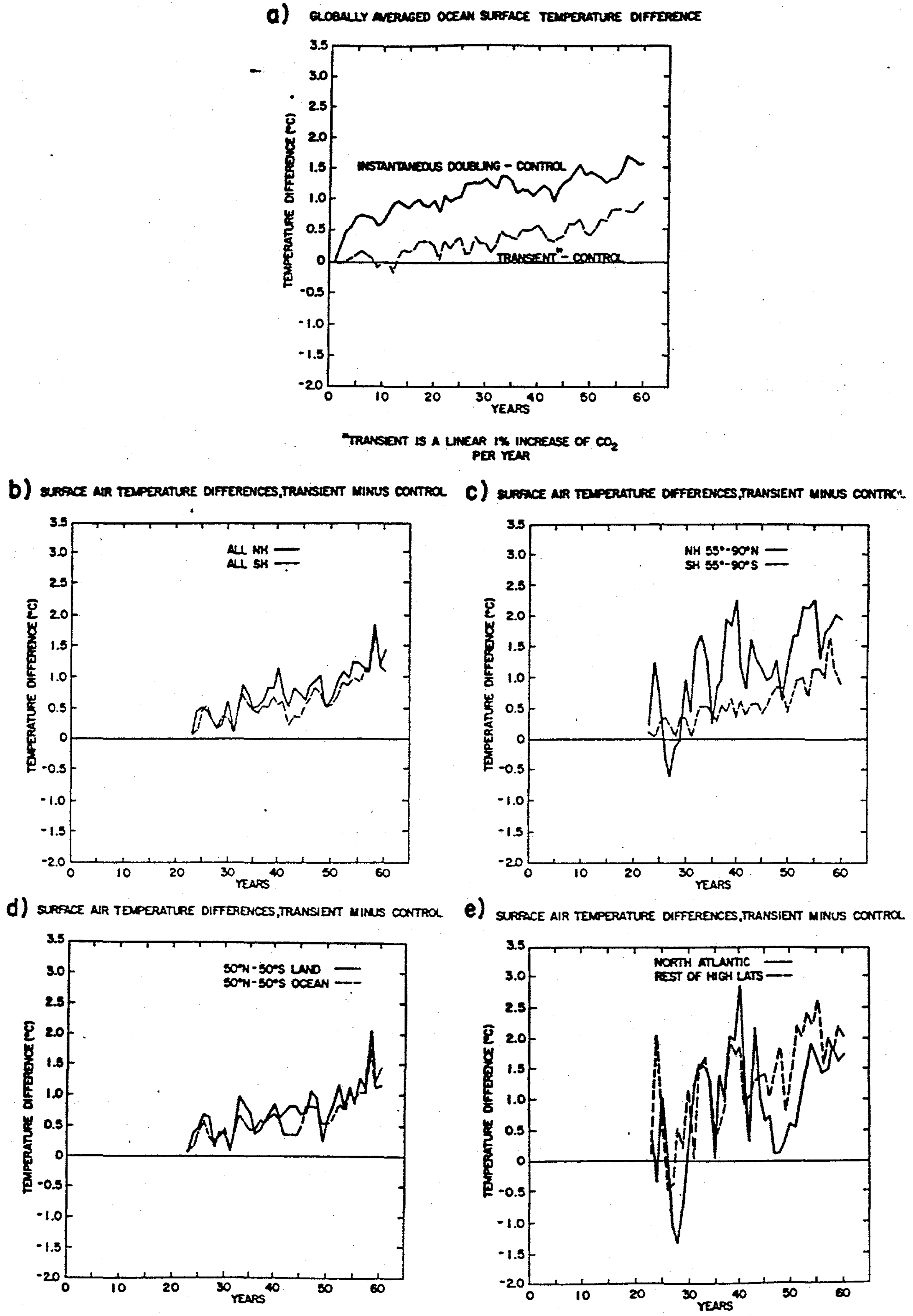
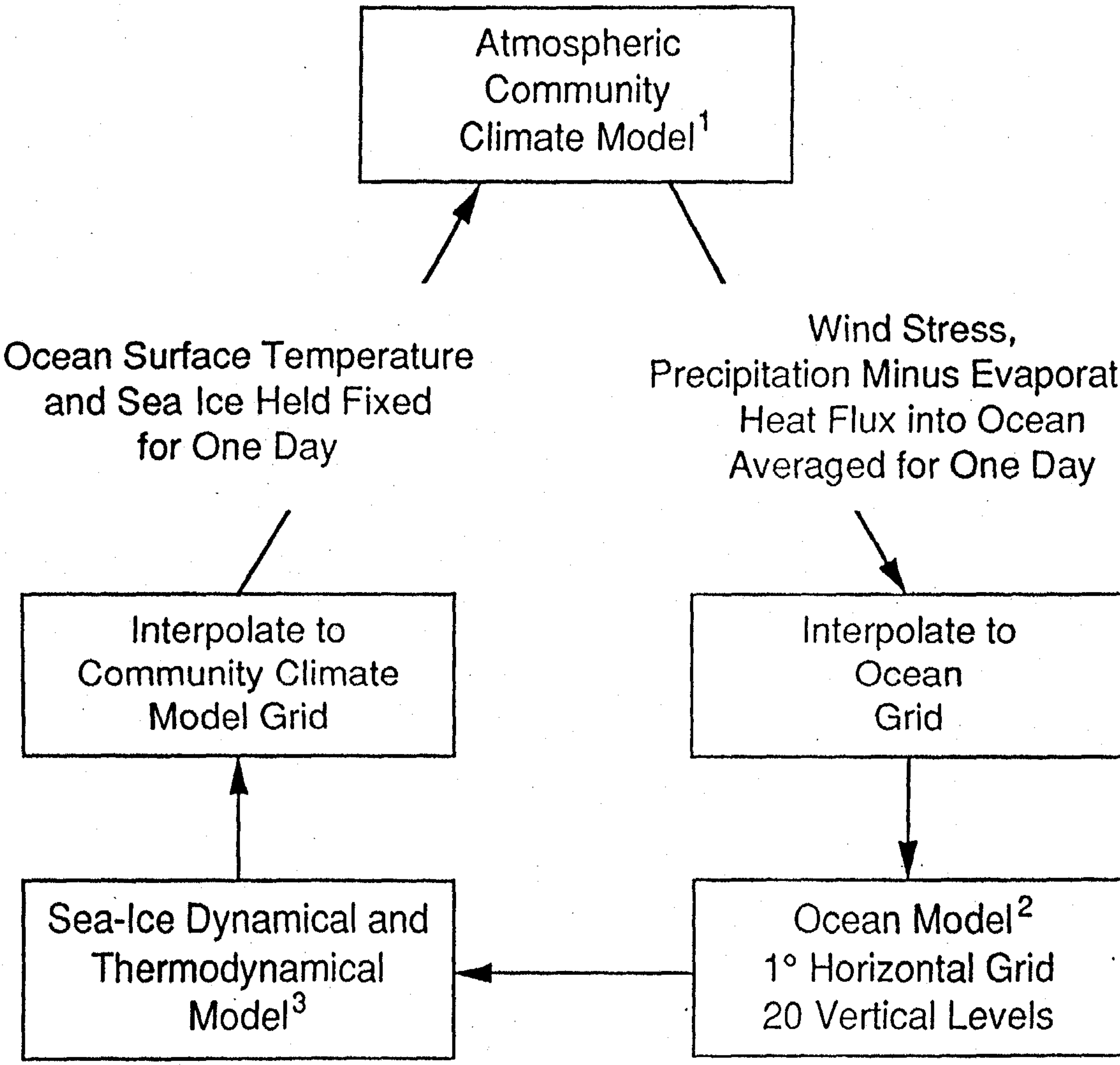

a) GLOBALLY AVERAGED OCEAN SURFACE TEMPERATURE DIFFERENCE
INSTANTANEOUS DOUBLING – CONTROL
TRANSIENT* – CONTROL
TEMPERATURE DIFFERENCE (°C)
YEARS
*TRANSIENT IS A LINEAR 1% INCREASE OF CO2 PER YEAR
b) SURFACE AIR TEMPERATURE DIFFERENCES, TRANSIENT MINUS CONTROL
ALL NH
ALL SH
c) SURFACE AIR TEMPERATURE DIFFERENCES, TRANSIENT MINUS CONTROL
NH 55°-90°N
SH 55°-90°S
d) SURFACE AIR TEMPERATURE DIFFERENCES, TRANSIENT MINUS CONTROL
50°N-50°S LAND
50°N-50°S OCEAN
e) SURFACE AIR TEMPERATURE DIFFERENCES, TRANSIENT MINUS CONTROL
NORTH ATLANTIC
REST OF HIGH LATS

Figure 1

SYNCHRONOUS COUPLING METHOD



[1]CCM
[2]A. Semtner and R. Chervin
[3]G.M. Flato and W.D. Hibler, III-dynamics; A. Semtner-thermodymamics

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Figure 2

ATLANTIC OCEAN CURRENTS
SHOWING GULF STREAM AND OTHER CURRENTS

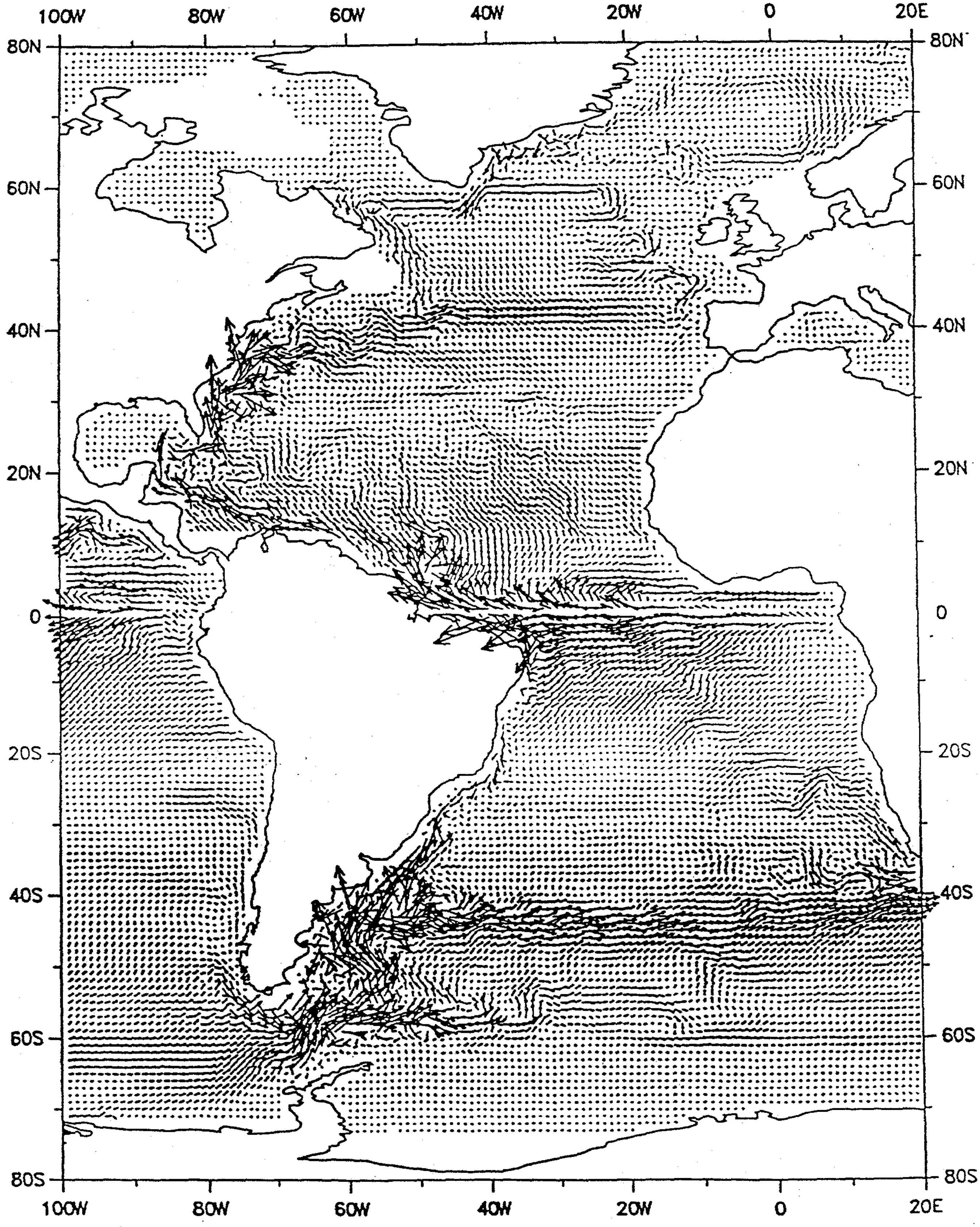
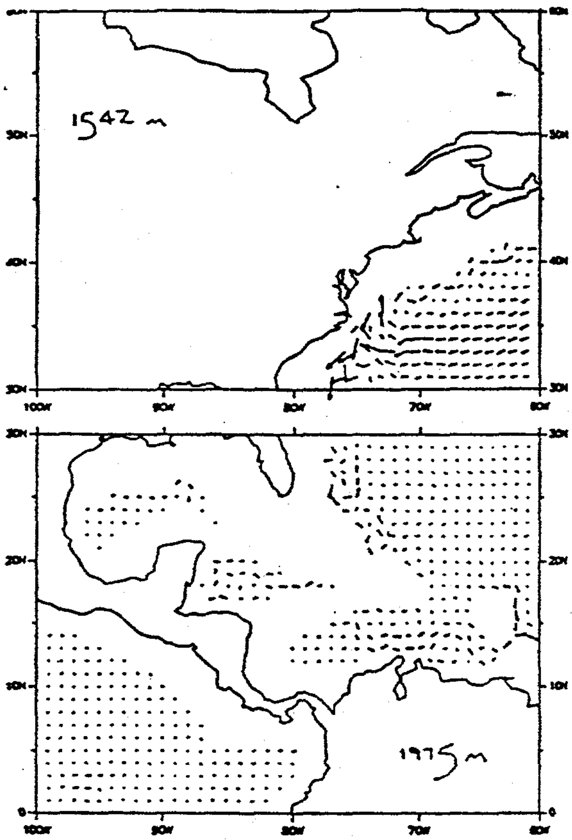
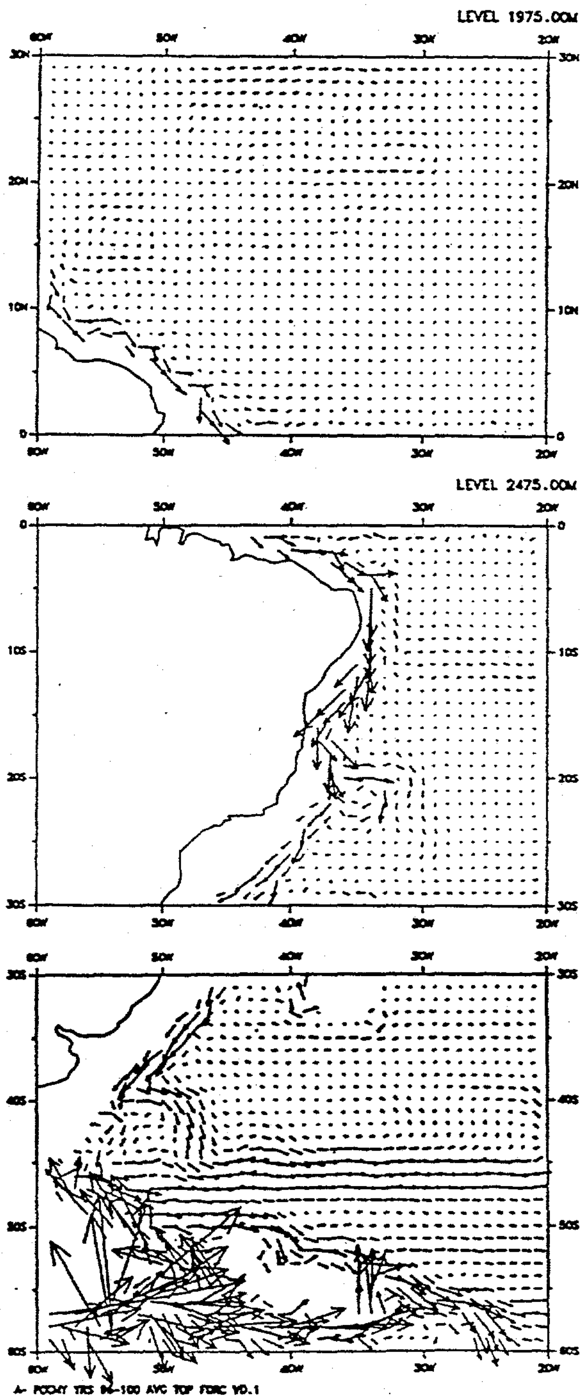


Figure 4





DEEP FLOWING CURRENT
DRIVEN BY FORMATION OF
COLD SALINE WATER
IN N. ATLANTIC

Figure 5

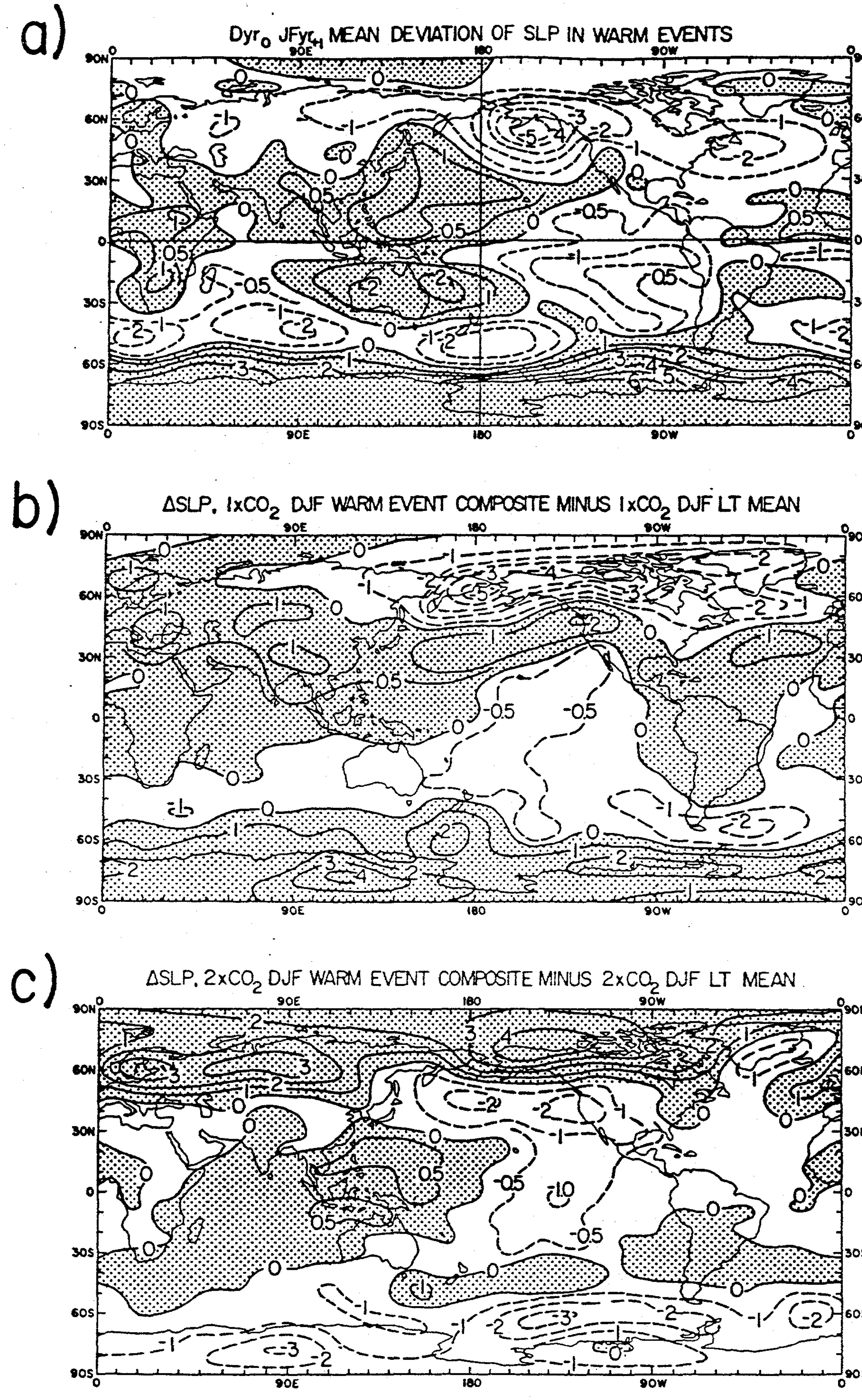

a)
Dyr0 JFyr+1 MEAN DEVIATION OF SLP IN WARM EVENTS
b)
ΔSLP, 1xCO2 DJF WARM EVENT COMPOSITE MINUS 1xCO2 DJF LT MEAN
c)
ΔSLP, 2xCO2 DJF WARM EVENT COMPOSITE MINUS 2xCO2 DJF LT MEAN
90N
60N
30N
0
30S
60S
90S
90E
180
90W

Figure 6

NCAR/DOE CO_2-Related Publications List

The following summary of NCAR publications, resulting totally or in part from DOE funding, can be divided into several broad areas—(1) obtaining climatic response from coupled model experiments, (2) verifying model, (3) improving and documenting cloud–radiation treatment, (4) documenting model, and (5) developing methods for applying model experiment results to climatic impact studies.

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