N92-14543

A. CLIMATOLOGICAL STRATOSPHERIC MODELING (673-61-07-30)

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C. TO INVESTIGATE, WITH THE USE OF A 3-D GLOBAL CLIMATE/MIDDLE ATMOSPHERE MODEL, THE IMPACT OF CLIMATE CHANGE ON THE MIDDLE ATMOSPHERE.

D. During 1988 the GISS 3-D GLOBAL CLIMATE/MIDDLE ATMOSPHERE MODEL was published in two parts. In the first part the model's mean climate for the region between the surface and 85km was discussed based on a 5 year run. The contributions of eddies, the mean circulation and the parameterized gravity wave drag were detailed for both the momentum and thermal fields. Included was a discussion of modeling experiences gained in generating the final version of the model.

In the second part the MODEL VARIABILITY on different time scales was reviewed and compared with observations. It was shown that the model has realistic inter-and intra-seasonal variability, implying that it was not rigidly tuned to produce the mean fields. The role of eddies, the mean circulation, and the gravity wave drag in generating interannual variability was discussed, and it was shown that variations in gravity wave drag, generated by variations in tropospheric processes, were an important component in the modeled variability. The model-generated stratospheric warmings were also presented.

During 1989 the model was used to investigate the EFFECT OF DOUBLED CARBON DIOXIDE ON THE MIDDLE ATMOSPHERE. Carbon dioxide was doubled in both the troposphere and stratosphere, and the sea surface temperatures were increased in accordance with results from the GISS climate model. Additional experiments were run with different sea surface temperature distributions, and doubling the carbon dioxide only in the troposphere or stratosphere.

The results showed that the eddy energy in the middle atmosphere increases in the doubled CO_2 climate, which increases the intensity of the residual circulation. The timing of stratospheric warmings appears to change in response. The potential significance of this change for stratospheric assessments is discussed.

E. Rind, D., Suozzo, R., Balachandran, N.K., Lacis, A., and Russell, G., 1988: The GISS Global Climate-Middle Atmosphere Model. Part I: Model Structure and Climatology. J. Atmos. Sci., 45, 329-370.

Rind, D., Suozzo, R., and Balachandran, N.K., 1988: The GISS Global Climate-Middle Atmosphere Model. Part II: Model Variability Due to Interactions between Planetary Waves, the Mean Circulation and Gravity Wave Drag. J. Atmos. Sci., 45, 371-386.

Rind, D., Suozzo, R., Balachandran, N.K., and Prather, M., 1989: Climate Change and the Middle Atmosphere. Part I: The Doubled CO_2 Climate. Accepted for publication in J. Atmos. Sci.

General Circulation of the Southern Hemisphere Stratosphere

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Research Objectives

The goal of this project is to better understand the dynamical processes at work during the seasonal evolution of the Southern Hemisphere (SH) stratosphere and the reasons for the observed interhemispheric differences in the stratospheric circulation. Our approach to the research is based on two complementary lines of investigation. One uses observational data and aims to provide a three-dimensional picture of the stratospheric circulation. The other uses three-dimensional, primitive-equation numerical models of the atmosphere to test hypotheses arising from the analysis of observational data.

Summary of Progress and Results

The spring circulation in the SH stratosphere evolves in a way that is broadly reproduced year after year. In September, the warm air is over the polar region in the upper stratosphere. Around the strong westerly vortex are transient anticyclones, which develop over the Indian Ocean, travel eastward, and decay over the Pacific Ocean. In October, the westerly vortex becomes highly distorted as a strong, persistent (though fluctuating), planetary-scale anticyclone develops in a preferred geographical location (90°E-180°). Finally, in November, the vortex breaks down first in the upper stratosphere and then later (and more slowly) in the middle stratosphere. The geographical preference for development of the disturbances is persuasive evidence of a strong connection with zonal asymmetries in surface conditions, particularly with those in orography.

We have illustrated the dramatic changes from winter to spring in the shape of the polar vortex in the stratosphere of the SH using perspective plots of the three-dimensional structure of the isotach and potential vorticity fields. The vortex - an essential meteorological component of the Antarctic 'ozone hole' phenomenon - extends from the upper troposphere. It evolves from a cone, slightly expanding with height and nearly symmetric about the pole, to an inverted cone, distorted and displaced from the pole. The changes in vortex structure from winter to summer are larger in the upper than in the lower stratosphere. In spring, radiative temperature increases are expected to be larger and occur earlier in the upper stratosphere. As a result, the breakdown of the polar vortex is faster and more complete at higher levels.

We have also highlighted the region (generally confined to the lower stratosphere) where temperatures are cold enough for the formation of polar stratospheric clouds (PSCs) - thought to be a key component in the chemical processes leading to ozone destruction. A comparison of lower stratospheric temperatures during winter and spring in the two hemispheres reveals that, in late winter and early spring, conditions suitable for PSC formation are the rule in the SH and the exception in the Northern Hemisphere (NH).

The spring circulation in the NH stratosphere is, in some years, qualitatively similar to that in the SH. For example, the NH final warmings in 1982 and 1985 are similar to SH final warmings in that a persistent anticyclone highly disturbs the westerly circulation. The similarity is closer in 1982, when the breakdown of the westerly circulation proceeds from higher to lower levels, than in 1985, when easterlies develop in the middle stratosphere a few weeks before the westerly circulation in the upper stratosphere turns to easterly. However, during some NH final warmings the flow is much more zonally symmetric and the transition to the summer circulation even more gradual than in the SH.

The build-up in fall of the stratospheric vortex in the northern and southern hemispheres proceed in a broadly similar way - e. g., in both hemispheres the westerly vortex tends to build first in the upper stratosphere - but are notably different in several aspects. The fall stratospheric cooling is comparable in magnitude in the two hemispheres, but the largest temperature changes occur in the upper stratosphere in the NH and in the lower stratosphere in the SH. The seasonal temperature changes have less interannual variability in the SH than in the NH. In the NH, the intensity and position of the jet core can have substantial interannual variations. In the SH, on the other hand, it behaves in a similar way year after year. Sudden warmings are more intense in the NH than in the SH. In both hemispheres, however, one of the major differences between sudden warmings in fall and spring is that the former involve relatively small increases in temperature over the polar region while the latter involve large increases.

We have examined the extent to which the SH stratospheric circulation in early winter is determined by the tropospheric forcing using the U. K. Meteorological Office stratosphere-mesosphere model (SMM) in which fields at the lower boundary, located in the upper troposphere, are prescribed. The SMM is a global, primitive-equation model incorporating an advanced radiation calculation and a parameterization of gravity wave effects. We compare control and anomaly simulations performed with the model for several early winters. Control and anomaly simulations differ in that the initial and boundary conditions are an exact or modified version of the corresponding fields in the observational dataset, respectively. Control simulations are generally very accurate.

Three cases were considered, 1980, 1985 and 1983. In all three cases, zonal wavenumber one (wave 1) in the middle troposphere has large amplitude in early June. In both 1980 and 1985 there is a large upward Eliassen-Palm flux in the upper troposphere and a large, eastward traveling disturbance in the stratosphere. In 1983, on the other hand, the Eliassen-Palm flux in the upper troposphere and the stratospheric disturbances are both weak.

We found that the broad features of the stratospheric disturbances observed during early winter 1980 and 1985 can be simulated by retaining in the initial and boundary conditions only the zonal mean and wave 1. There are, however, important differences between the evolution of the flow in the wave 1-only simulations and that in the control. On the other hand, the simulation is poor if wave 1 at the lower boundary is modified so that its amplitude remains constant in time. These results suggest that the stratospheric and tropospheric circulations during early winter in the SH are strongly coupled.

In the course of our study on planetary-scale disturbances in the SH stratosphere and troposphere during winter we have carried out an empirical orthogonal function (EOF) analysis of winter 500 mb geopotential height anomalies. An earlier EOF analysis using a different dataset pre-filtered the anomalies to exclude wavenumbers five and higher; we do not. The different pre-processing of data affects the results. All three distinct planetary flow regimes identified in the winter circulation of the SH by a pattern correlation method are captured by the new set of EOFs; only two of those regimes were captured by the earlier set. The new results, therefore, lend further support to the idea that EOFs point to distinct planetary flow regimes.

Journal Publications

Mechoso, C. R., A. O'Neill, V. D. Pope and J. D. Farrara, 1988: A study of the 1982 stratospheric final warming in the Southern Hemisphere. *Quart. J. Roy. Meteor. Soc.*, **114**, 1365–1384.

Farrara, J. D., M. Ghil, C. R. Mechoso and K. C. Mo, 1989: EOFs and multiple flow regimes in the southern hemisphere winter. *J. Atmos. Sci.*, in press.

Mechoso, C. R., A. O'Neill, J. D. Farrara, V. D. Pope, M. Fisher and B. Kingston, 1989: On the breakdown of the stratospheric polar vortex in the southern hemisphere. In preparation.

O'Neill, A., V. D. Pope, and C. R. Mechoso, 1989: Final warmings in the Northern Hemisphere stratosphere. In preparation.

Dynamics of Stratospheric Planetary Waves

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Objectives

We are investigating the dynamics of stratospheric planetary waves using a time dependent linear model. The fundamental question being addressed is: What factors control how much planetary wave activity enters the stratosphere and where it is deposited?

We intend to extend the results of previous linear calculations by including the transience of realistically evolving wave packets. Attention will be focused on: the sensitivity of the distribution of planetary wave driving to modifications of the zonal flow associated with "preconditioning" and the quasi-biennial oscillation; comparisons with a new Rossby wave parameterization scheme developed for use in two-dimensional models by Hitchman and Brasseur (1988); the importance of the zonal flow in the lower stratosphere in determining how much planetary wave activity enters the stratosphere from the troposphere; and the roles of wave-induced changes in the zonal flow and realistic dissipation by radiative transfer and breaking internal gravity waves in determining the distribution of planetary wave driving.

Progress

The time dependent model has been developed and tested. Diagnostic code has been prepared, focusing on the complete budget of Eliassen-Palm wave activity in the model. Numerical experiments, exploring the influence of the mean flow on the time integrated EP flux convergence for wave 1 events, are underway. This work will form the basis for Mr. Ping Chen's PhD dissertation.

In collaboration with Prof. Matthew Hitchman (University of Wisconsin, Madison) we are comparing results from the Hitchman-Brasseur Rossby wave parameterization with the results of a full steady linear calculation. So far these results have been encouraging, and have suggested possible minor modifications of the parameterization.

A. Title: Studies of Large Scale Stratospheric Dynamics Using a Numerical Model Coupled with Observations

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C. Abstract of Research Objectives:

The research addresses questions of the interaction of planetary waves with the mean flow in the stratosphere. Experiments are being run with a global quasi-geostrophic model extending through the middle atmosphere (15-100 km or 0-100 km). Observed zonal mean fields are used in the model to investigate the dependence of wave propagation and wave - mean flow interaction on the basic state for observed cases. Topics that are being or will be studied are 1) the role of preconditioning and/or resonance in observed sudden stratospheric warmings; 2) the effect of stratospheric flow structure on planetary wave propagation in the troposphere; and 3) the impact of tropical and subtropical wind variations on waves in the winter hemisphere. The results are expected to contribute to our understanding of stratospheric dynamics, and will therefore also be important for understanding the transport of trace chemical species in the stratosphere.

D. Summary of Progress and Results

The quasi-geostrophic, time-dependent model used in these studies is fully operational at this time. The model differs from other mechanistic model used for wave-mean flow interaction studies mainly in that it extends to the earth's surface. The zonal mean basic state varies with time due to driving by diabatic heating, interaction with planetary waves and an imposed Rayleigh friction damping. The heating that drives the zonal mean can be either a realistic solar heating, with Newtonian cooling relaxation, or a relaxation back to a prescribed climatological value. In the former case a value of Rayleigh friction that is large in the mesosphere is necessary; in the latter, both the Newtonian cooling and the Rayleigh friction are weak. The realistic heating is needed for long time integrations (more than a few weeks), while a simple relaxation is sufficient for shorter integrations. A geopotential is specified at the top and bottom boundaries or, in the case of a lower boundary at the earth's surface, the residual vertical velocity is set to zero.

A single zonal wave (either wavenumber 1 or 2) is calculated in the model and is allowed to interact with the basic state. The wave geopotential depends on the boundary values and on the (complex) index of refraction squared, which varies strongly with the speed and structure of the basic state zonal wind. Newtonian cooling and Rayleigh friction are included. The wave is forced by a specified lower boundary geopotential perturbation at the tropopause, by a vertical velocity at the earth's surface, or by an internal heat or vorticity source within the troposphere.

The model domain is global, and extends to 100 km. The lower boundary can be located near the tropopause (15 km) or at the earth's surface. The wave and mean geopotential are computed at alternate time steps using an implicit time differencing scheme. The implicit time differencing allows long time steps (12 hours) and makes the model very economical to run.

A number of tests have been run on the model using, as input, observations from the February 1979 sudden stratospheric warming. These indicate that, despite the simplifications inherent in the model, it does a good job of simulating the dynamical evolution of the warming. Tapes of NMC data for the troposphere and stratosphere for other periods have been acquired to use with the model in order to investigate the dynamical processes important during other observed sudden warmings. These other events will be compared and contrasted to the February 1979 case to determine which features are unique to particular events, and which are found in general. These data are now being reviewed to determine the best periods for use in the model simulations.