Transport and Mixing in the Stratosphere and Troposphere

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Research Objectives

Long-term changes in the composition of the atmosphere are known to have significant effects on atmospheric chemistry and stratospheric ozone. Increasing levels of greenhouse gases have the potential to change the global climate in the middle and upper atmospheres, as well as in the troposphere. Volcanic eruptions, El Niño events, and other natural variations can also cause changes in atmospheric composition and climate. Whether the causes are natural or manmade, changes in the global climate system can have impacts on human society. In order to understand and predict the consequences of these changes, and of control measures such as the Montreal Protocol, it is necessary to understand the complex interactions between radiation, chemistry, and dynamics in the atmosphere. Much of the uncertainty in our understanding of atmospheric processes comes from an incomplete understanding of atmospheric transport. A complete and self-consistent model of transport requires not only an understanding of trace-species transport, but also the transport of dynamically active quantities such as heat and potential vorticity. Therefore, the goal of the proposed research is to better understand large-scale transport and mixing processes in the middle atmosphere and troposphere.

Summary of Results

Bowman and Cohen [1997] analyzed a simple model of transport by the Hadley circulation in the tropical troposphere. They found that much of the observed interhemispheric exchange of air could be explained by the seasonal cycle of the Hadley circulation. We are conducting GCM experiments to extend this project to more realistic flows (see below). Our goal is to understand which parts of the global circulation are responsible for interhemispheric tracer transport and mixing in the troposphere.

Hu [1996] and Bowman and Hu [1997] analyzed tropical mixing barriers in the GFDL SKYHI stratospheric general circulation model. The strength of the mixing barriers was found to vary with season and altitude. The applicability of the results to the real atmosphere is limited by the lack of a realistic quasi-biennial oscillation in the version of SKYHI used for this study.

In collaborative work with the Polar Ozone and Aerosol (POAM) group at Naval Research Lab, Bowman et al. [1998] found evidence of potentially serious systematic errors in the global stratospheric analyses produced by NCEP, the UKMO, and the Goddard DAO analysis systems. The anomalies consist of stationary wave patterns in the summertime stratospheric easterlies, a region from which waves should largely be excluded. Swinbank et al. [1999] suggest that improperly assimilated tides are responsible for much of the wavenumber 1 component of the stationary waves. Much of the remaining error may be due to uncorrected biases between different radiosonde types used in different geographic regions. Because the stratospheric data are so important for dynamical and chemical transport studies, it is hoped that these problems will be addressed and corrected in future stratospheric data sets and in reanalyzed data.

Hoppel et al. [1999] studied the origins of zonal variability in ozone that occurs during the summer in the northern-hemisphere stratosphere. Most of the variability appears to result from stirring by waves in the summer stratospheric easterlies. Wagner [1999] and Wagner and Bowman [2000] carried out a more detailed analysis of the summertime dynamics. They found that the zonal wind profile does filter the wave spectrum, but large-scale stationary and westward-propagating waves do penetrate into the stratospheric easterlies. Although waves in the summer are weak compared to winter, the mean circulation in summer is also weak, so the waves can effectively mix the summer stratosphere. These results support Hoppel et al.'s conclusion that transport is largely responsible for the spatial variability of ozone in the summer stratosphere.

We have been developing theoretical models of the dispersion of air parcels in the stratosphere. Statistical analysis shows that air parcel trajectories can be characterized as Lévy flights, which are random walk processes in which the statistics of the random walk have divergent second moments. A paper on this subject has been published [Seo and Bowman, 2000].

Advances in dynamical systems theory, referred to as lobe dynamics, have been shown to have important applications to understanding atmospheric transport. Numerical methods have been developed to apply lobe dynamics theory to real atmospheric flows. With lobe dynamics it is possible to identify mixing barriers and make quantitative transport and mixing calculations. A manuscript containing these results has been submitted [Bowman, 2000]

Research has also continued on the problem of characterizing and understanding the large-scale transport circulation of the troposphere. A first step in this study has been submitted for publication [Carrie and Bowman, 1999]. We have developed a simple theoretical correspondence between the Green's function solutions of the tracer transport equation and Lagrangian trajectories. We are using this approach to develop a discrete numerical approximation to the transport Green's function for a passive, long-lived tracer. A manuscript describing the transport in an idealized GCM will be submitted in 2000.

On a specific topic, Rogers [1999] used TOMS aerosols retrievals and three-dimensional trajectories to investigate the transport of smoke from biomass burning in Mexico and Central American during 1998. This event had significant impacts on large parts of the United States. They found that northward transport was unusually strong that year, but that intensity of smoke in the U.S. was primarily due to unusual smoke production, not transport alone. A manuscript on this research is nearly finished and will be submitted for publication in 2000.

Publications

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