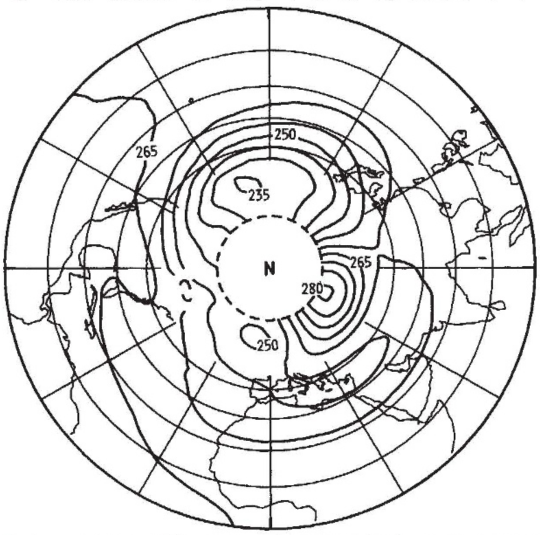
Meteorology

Stratospheric planetary waves

from David Andrews

FOR several decades, meteorologists have known that the winter stratosphere is frequently disturbed by wave-like events of planetary scale. Recently, great progress has been made in exploring the dynamics of these waves and understanding their influence on the stratosphere as a whole. These advances have been brought about by a combination of observational studies based on data from satellites, 'experiments' with computer models of the stratosphere and theoretical investigations.

Much of the impetus for the exciting developments in this area has come from the increasing availability of large amounts of data — with worldwide coverage over several years — provided by orbiting satellite instruments. We now possess extensive data-bases, including measurements of stratospheric temperatures, winds, pressures and the concentrations of chemical constituents such as ozone and methane. The figure shows a stereographic map of a typical stratospheric planetary wave, as revealed by temperature measurements from Oxford University's Stratospheric and Mesospheric Sounder on the Nimbus 7 satellite.



Polar stereographic map of stratospheric temperature (degrees Kelvin, contour interval 5 degrees) at 1 mbar (near 45 km altitude) on 7 January 1982. Inner circle, 70°N; outer circle, Equator. (Courtesy of M. Corney, Oxford.)

In parallel with these observational studies, there has been an increased use of numerical models of the stratosphere. These models solve the mathematical equations which (to a good approximation) express our current understanding of the basic physical principles governing atmospheric behaviour. One use of models is to attempt to predict the future development of the stratosphere, rather as weather-forecasting models are used for the troposphere. Models can also perform idealized hypothesis-testing experiments, to refine our knowledge of the dominant mechanisms controlling the structure of the stratosphere.

The large amounts of data provided by these observational and computational studies must be organized into forms suitable for analysis by stratospheric meteorologists. A popular approach is to separate each atmospheric field into a 'zonal mean' part (obtained by averaging around latitude circles) and a 'wave' part, given by the departure from that mean; another method uses transient deviations from a time mean. The most useful average will depend on the phenomenon under consideration, and in some cases no simple average may be particularly appropriate.

The basic linear theory of planetary (or Rossby) waves propagating on a zonally-symmetric mean flow has been well established for many years. Only comparatively recently, however, has the two-way nonlinear interaction between these waves and the mean flow received much attention. In common with other examples of wave-mean flow interactions in fluids, it is a subject in which naive physical arguments — perhaps based on inappropriate analogies with simpler wave systems — can sometimes be seriously misleading[1]. Physical interpretation must be supported by a quantitative theoretical framework, and current developments in dynamical meterology are going some way towards providing such a framework.

Several recent studies illustrate the variety of ways in which meteorologists are handling and interpreting stratospheric and tropospheric data. In a paper[2] in *Journal of the Atmospheric Sciences*, Hartmann, Mechoso and Yamazaki use the 'zonal mean/wave' separation, for which the theory of wave–mean flow interaction is now quite well developed[3]. Previously, authors have contrasted the quasi-stationary planetary waves dominating the northern stratospheric winter with the eastward-travelling disturbances which are the most prominent waves in the southern stratospheric winter[4]. The novel feature of Hartmann *et al.*'s work is that it focuses on data from the Southern Hemisphere; it is the first detailed quantitative analysis of Southern Hemisphere waves and their interaction with the zonal-mean flow.

Another pair of papers, by McIntyre and Palmer[5,6], use no explicit averaging, but present satellite-derived maps of 'Ertel's potential vorticity' on a roughly horizontal surface of constant entropy in the mid-stratosphere. Both potential vorticity and entropy are approximately conserved by air parcels as they move, and the maps provide blurred but fascinating pictures of stratospheric motions during a large-amplitude planetary-wave event in January 1979. They suggest that large air masses are rapidly and irreversibly deformed during this event into long thin filaments, which may in turn break up into eddies. McIntyre and Palmer call this process 'planetary-wave breaking', by analogy with the breaking of ocean waves on a beach; they also propose that the theory of 'nonlinear critical layers'[7,8] may model some aspects of the dynamics of such events. More work still needs to be carried out to confirm the reliability of potential vorticity maps, to assess the significance of wave-breaking events for the stratosphere as a whole and to understand their dynamics in detail. Nevertheless, the papers of McIntyre and Palmer open up interesting new possibilities for studying stratospheric waves.

Similar developments are taking place in research into tropospheric waves. For example, Hoskins, James and White have developed a theory for interpreting the interaction of transient cyclones with the time-averaged flow[9]. This approach may prove useful in the analysis of 'blocking' situations, such as that responsible for the British drought of 1976; isentropic potential vorticity maps are beginning to be of diagnostic value here too.

These recent studies highlight the use being made by meteorologists of an increasing number of theoretical tools for probing the behaviour of atmospheric waves, thereby enlarging our knowledge of the principles of large-scale atmospheric dynamics. A better grasp of fundamentals will in turn be of enormous aid in the solution of such vital practical problems as modelling the transport of chemical pollutants which might threaten the ozone layer and predicting the influence of increased atmospheric carbon dioxide on climate. Even weather-forecasting will surely benefit from a deeper understanding of the dynamics of the atmosphere. ☐

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