FINAL REPORT
for
NASA Grant NAG 5-2787
Period Covered: 11/15/94-11/14/98

"Dynamical Analysis of MLS and ISAMS Data
From the Upper Atmosphere Research Satellite"

John L. Stanford, Principal Investigator

GOALS:

The primary goal of this project is to investigate two aspects of upper stratosphere and mesosphere circulation dynamics using data from the Upper Atmosphere Research Satellite's (UARS) Microwave Limb Sounder (MLS) and Improved Stratospheric and Mesospheric Sounder (ISAMS) instruments. The first aspect involves observational analyses and comparison with model predictions for the polar night "4-day wave". The second project focus is the distribution of carbon monoxide (CO) in the middle atmosphere and circulation features that can be deduced from analyses of such a tracer and comparison with atmospheric circulation models.

RESULTS:

Excellent results were made on both aspects of this grant. These results may be summarized as:

(i) A major investigation was initiated and completed using UARS Microwave Limb Sounder (MLS) data. The study detailed the occurrence of the 4-day wave in the southern polar winter upper stratosphere and lower mesosphere, and enhanced our understanding of 4-day wave dynamics and its affect on ozone. The results have appeared in print (Allen et al., 1996) and the abstract is given below.

(ii) An investigation of the occurrence of medium-scale waves in midlatitude upper tropospheric water vapor data derived from the UARS MLS was initiated, completed and published (Stone et al., 1996). The abstract is given below.

(iii) Upper tropospheric constituent transport modeling has been investigated by Stone et al. (1997). The National Center for Atmospheric Research Community Climate Model CCM2 was used to study constituent transport induced by midlatitude medium scale waves. The results are given in a paper by Stone, et al. (1999) that is to appear shortly. The abstract is given below.

(iv) An investigation of the dynamics of tracer constituents in the upper stratosphere and mesosphere using carbon monoxide retrievals from the UARS ISAMS (Improved Stratospheric and Mesospheric Sounder) instrument has been carried out for the Northern Hemisphere winter period. This represents the most detailed analyses of the ISAMS CO data to date. The results are to appear next month in Allen et al. (1999), and the abstract is given below.

PUBLICATIONS SPONSORED IN PART BY GRANT NAG 5-2787:

1. SPACE-TIME INTEGRITY OF ISAMS AND MLS TEMPERATURE FIELDS AT KELVIN WAVE SCALES

E. M. Stone, J. L. Stanford, J. R. Ziemke, and D. R. Allen, Department of Physics and Astronomy, Iowa State University, Ames, IA, 50011

F. W. Taylor, C. D. Rodgers, and B. N. Lawrence, Department of Atmospheric, Oceanic, and Planetary Physics, University of Oxford, UK

E. F. Fishbein, L. S. Elson and J. W. Waters, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

J. Geophys. Res., 100, 14089-14096 (1995)

Abstract:

Space-time analyses, which are sensitive to details of retrieval and gridding processes not seen in zonal and time means, are used to investigate the integrity of version 8 gridded retrieved temperatures from the Improved Stratospheric And Mesospheric Sounder (ISAMS) on the Upper Atmosphere Research Satellite (UARS). This note presents results of such analyses applied to ISAMS tropical data. Comparisons are made with Microwave Limb Sounder (MLS), also on UARS, temperatures.

Prominent zonal wave number 1 features are observed with characteristics similar to those expected for Kelvin waves. Time versus longitude plots reveal quasi-regular eastward phase progression from November 1991 to mid-January 1992. The perturbations extend throughout the upper stratosphere and lower mesosphere (altitudes of 32-64 km), exhibiting peak-to-peak amplitudes of up to 2-3 deg K and periods from approximately 2 weeks in mid-stratosphere to approximately 1 week at higher altitudes. Faster Kelvin waves with periods of 3-5 days are also found in the lower mesosphere. Height versus time plots reveal downward phase and upward group velocities, consistent with forcing from below. Vertical wavelengths are approximately 20 km for the slower mode and about twice this scale for the faster 3-5 day mode. The features are trapped within 10-15 degrees of the equator. Kelvin wave signature in ISAMS and MLS temperatures are compared at 10 and 1 hPa. Good agreement is found, illustrating the internal consistency and ability of both ISAMS and MLS temperature grids to capture relatively small amplitude features with space-time scales of fast, zonally asymmetric equatorial modes.

2. BAROCLINIC WAVE VARIATIONS OBSERVED IN MLS UPPER TROPOSPHERIC WATER VAPOR

E. M. Stone and W. J. Randel, National Center for Atmospheric Research, Boulder, Colorado

J. L. Stanford, Department of Physics and Astronomy, Iowa State University, Ames , Iowa

structure of the 4-day wave resembles the potential vorticity "charge" concept, wherein a PV anomaly in the atmosphere (analogous to an electrical charge in a dielectric material) induces a geopotential field, a vertically oriented temperature dipole, and circulation about the vertical axis.

4. OBSERVATIONS OF MIDDLE ATMOSPHERE CO FROM THE UARS ISAMS DURING THE EARLY NORTHERN WINTER 1991/1992

D. R. Allen and J. L. Stanford Department of Physics and Astronomy, Iowa State University, Ames, IA

M. A. Lopez-Valverde Instituto de Astrofisica de Andalucia (CSIC), Granada, Spain

D. J. Lary Centre for Atmospheric Science, Cambridge University, U.K.

N. Nakamura Department of Geophysical Sciences, University of Chicago, Chicago, IL

A. R. Douglass NASA Goddard Space Flight Center, Greenbelt, MD

M. C. Cerniglia Applied Research Corporation, Landover, MD

F. W. Taylor and R. J. Wells Department of Physics, University of Oxford, U.K. to appear in J. Atmos. Sci., Vol. 56, 563-583, (Feb. 15, 1999 issue)

Abstract:

Observations of carbon monoxide in the upper stratosphere and lower mesosphere from the Upper Atmosphere Research Satellite Improved Stratospheric and Mesospheric Sounder (ISAMS) are presented during the dynamically active early northern winter 1991/1992. High CO mixing ratios saturate the polar vortex, as seen by comparing CO with Ertel potential vorticity (PV). 2D analyses of CO in potential temperature/equivalent latitude (derived from PV) coordinates indicate: (1) Increasing mixing ratio with altitude. (2) Large mixing ratios in the Arctic winter polar region due to downward advection from the mean meridional circulation. (3) A simple chemical model is used to show that the observed tropical upper stratosphere maximum is likely due largely to methane oxidation. (4) Downward transport from thermospheric source region is shown to strongly enhance CO in the mesosphere and upper stratosphere. ISAMS CO data are compared with CO output from the Goddard Space Flight Center 3D chemistry and transport model (CTM), initialized with ISAMS CO. ISAMS and CTM horizontal distributions and evolution compare favorably near the stratopause, even during highly dynamic periods. Disagreement in the zonal mean CO structures occurs several weeks into the model run, with CTM mixing ratios biased high in the upper stratosphere outside the polar vortex and low in the stratospheric vortex and lower mesosphere. Novel modified Lagrangian mean diagnostics applied to ISAMS and CTM data provide insight into horizontal mixing processes occurring during the merger of two anticyclones and massive vortex erosion from 1-16 January 1992.

5. TRANSPORT OF PASSIVE TRACERS IN BAROCLINIC WAVE LIFE CYCLES

E. M. Stone and W. J. Randel, National Center for Atmospheric Research, Boulder, Colorado

J. L. Stanford, Department of Physics and Astronomy, Iowa State University, Ames , Iowa

J. Atmos. Sci.(1999, in press)

Abstract:

The transport of passive tracers in idealized baroclinic wave life cycles is studied using output from the NCAR community climate model (CCM2). We simulate two life cycles, LCn and LCs, starting with baroclinically unstable initial conditions similar to those used by Thorncroft et al. (1993) in their study of two life cycle paradigms. LCn and LCs have different initial horizontal wind shear structures which result in distinctive non linear development. In terms of potential vorticity-potential temperature (PV-theta) diagnostics, the LCn case is characterized by thinning troughs which are adverted anticyclonically and equatorward, while the LCs case has broadening troughs which wrap up cyclonically and poleward. Four idealized passive tracers are included in the model to be adverted by the semi-Lagrangian transport scheme of the CCM2, and their evolutions are investigated throughout the life cycles. Tracer budgets are analyzed in terms of the transformed Eulerian mean (TEM) constituent transport formalism. Results for both LCn and LCs show transport that is downgradient with respect to the background structure of the tracer field, but with a characteristic spatial structure which maximizes in the middle to high latitudes. For the idealized tropospheric tracers in this study, this represents a net upward and poleward transport that enhances concentrations at high latitudes. These results vary little with the initial distribution of the constituent field. The time tendency of the tracer is influenced most strongly by the eddy flux term, with the largest transport occurring during the non linear growth stage of the life cycle. We also study the transport of a lower-stratospheric tracer, to quantify stratosphere- troposphere exchange for baroclinic waves.

6. Stanford, John L., 1999: THE 4-DAY WAVE. Chapter in RECENT ADVANCES IN STRATOSPHERIC DYNAMICS, T. R. Nathan and E. C. Cordero, Eds., Research Trends. (in press)

Abstract:

The "4-day wave" is a ubiquitous, eastward moving quasi-nondispersive feature located in the polar winter stratosphere and mesosphere. The phenomenon is observed in meteorological satellite data as relatively warm and cold pools of air, one atop the other and with associated wind vortices, circling the winter pole at high altitudes with period near 4 days. This paper reviews the considerable amount of accumulated observational and theoretical evidence for the 4-day wave, and describes its characteristics. The phenomenon is attributed to a form of instability resulting from strong gradients in the winter polar jet stream of the stratosphere and mesosphere. The 3-D structure of the 4-day wave may be understood with the paradigm of potential vorticity "charge". Temperature and wind anomalies are induced by the potential vorticity charge, itself generated by fluid instabilities

associated with strong polar night jet wind shear. The paradigm offers an elegant and conceptually satisfying explanation of 4-day wave physics. The 4-day wave modifies the climatology of the polar winter stratopause region, and furthermore provides an in situ source for mixing of chemical constituents in the otherwise isolated polar night middle atmosphere vortex. Implications of the latter for atmospheric chemistry remain to be fully explored.

Copies of reprints of these papers have been sent or will be when available, to the NASA Scientific and Technical Information Facility.

Copies of this report are being sent to Dr. Mark R. Schoeberl, UARS Project Scientist, Dr. Anne R. Douglass, UARS Deputy Project Scientist, and Dr. Charles H. Jackman, UARS Deputy Project Scientist, Code 916, Goddard Space Flight Center, Greenbelt, MD 20771, and two copies to the NASA Scientific and Technical Information Facility, 800 Elkridge Landing Road, Linthicum Heights, MD 21090

John L. Stanford
Principal Investigator
Professor of Physics
Iowa State University

Date 1/22/99

cc: Adrian R. Jefferson
Grant Negotiator
Code 216
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Mr. Richard Hasbrook
Contracts and Grants
213 Beardshear Hall
Iowa State University
Ames, IA 50011

Further information on our research is available at
http://www.public.iastate.edu/~atmos/homepage.html