The Eighth Conference on the Middle Atmosphere was held in Atlanta, Georgia, on 7–10 January 1992. Over 100 papers were presented, emphasizing areas of current interest such as advances in numerical modeling, the dynamics of the tropical middle atmosphere, polar photochemistry and dynamics, and new observational techniques. Two sessions highlighted preliminary results from the Upper Atmosphere Research Satellite.

1. Introduction

The Eighth Conference on the Middle Atmosphere was held in conjunction with the 72d Annual Meeting of the American Meteorological Society on 7–10 January 1992 in Atlanta, Georgia. The title of this year’s conference, a change from the traditional “Conference on the Meteorology of the Middle Atmosphere,” reflects the growing breadth of the field, which now encompasses research in atmospheric radiation, photochemistry, and cloud and aerosol microphysics, as well as atmospheric dynamics.

Approximately 85 contributed papers and 15 invited papers were presented in 16 sessions. The presentations emphasized areas of continuing interest as well as some new topics, including advances in numerical modeling, progress in theoretical and observational understanding of the dynamics of the tropical middle atmosphere, recent findings on the dynamics and photochemistry of the polar stratosphere, and new observational techniques and systems. As regards the latter, the conference highlighted some of the first results from the recently launched Upper Atmosphere Research Satellite.

Following are brief summaries of the topics covered in each session. The complete conference program appeared in the October 1991 issue of the Bulletin.

2. Session summaries

a. Session 1: Two-Dimensional and Mechanistic Models (A.K. Smith, chair)

Papers presented in this session focused on two aspects of two-dimensional modeling of the middle atmosphere: representation of wave processes and the response of the circulation to changes in external heating. Tung discussed model simulations where the interannual variability of the middle atmosphere over a 10-year span was derived from observations. The modeled ozone showed better agreement with observations when the rate of isentropic mixing was low in the tropics and when significant vertical mixing was included above approximately 30 mb.

Garcia and Solomon described calculations wherein eddy transport and mean flow driven by Rossby waves were computed from an interactive wave model. They showed that nonlinear effects ("wave breaking") can be simulated by means of a parameterization similar to that used by Lindzen for gravity waves. The impact of the Rossby wave parameterization on trace species such as \( \text{N}_2\text{O} \) was discussed; computed distributions of this trace gas were found to compare well with available observations.

Hitchman described and compared several calculations that illustrated the behavior of a two-dimensional model under hypothetical conditions. Huang described the sensitivity of the thermal budget in a two-dimensional model to changes in the solar heating rate. She found that in the stratosphere, increased solar heating led to a more vigorous mean meridional circulation; in the mesosphere, increased solar heating led indirectly to large changes in the circulation, primarily through changes in the wave driving.

Waltersheid and Hocking presented a theoretical description of Stokes drift due to gravity waves and calculated the dispersion rate for Boussinesq and compressible cases. The diffusion rate for trace species with gradients along potential temperature surfaces was found to be large (\( K_{zz} \) of order \( 10^2 \text{ m}^2 \text{ s}^{-1} \)) in...
the mesosphere. In the final paper of the session, Gille and Lyjak described observations of the eddy transport of ozone in the transformed Eulerian framework. They found that the position of the region of largest transport correlated well with seasonal changes in the ozone chemical destruction rate.

b. Session 2: Modeling of Planetary Waves and Sudden Warmings (M. H. Hitchman, chair)

Although stratospheric sudden warmings have been studied intensively for over two decades, they remain difficult to predict and many aspects of the dynamics are not well understood. Six contributed papers were presented, reporting on recent work with general circulation models. In the multiyear integration of the Geophysical Fluid Dynamics Laboratory (GFDL) "SKYHI" model, Hamilton found considerable interannual variability, with examples of warmings occurring by amplification of zonal wave 1, then wave 2, and by the reverse sequence. He also found that dynamically active and dynamically quiet winters tended to occur in clusters: in a 10-year run, stratospheric sudden warmings occurred in a group of five successive years, while no warmings were produced in the remaining years. This is an intriguing indication of interannual dynamical memory in the model.

Two other studies used versions of the U.K. Meteorological Office (UKMO) model. Manney et al. focused on final warmings and on frontlike baroclinic zones that evolve during a warming. A synoptic description revealed vertical temperature gradients in some regions to be as high as 10 K km⁻¹. Farrara and Mechoso performed a systematic study of successively higher wave-forcing amplitudes in the Southern Hemisphere for wave 1, wave 2, and waves 1 and 2 together. For a wave-1 forcing of 100 m, 10-mb amplitudes were strongest in fall, with a secondary maximum in spring, similar to the observed Southern Hemisphere. For 400 m, the situation was similar to the Northern Hemisphere winter. The largest interannual variability was found for 300-m forcing. Wave 2 was sometimes generated in situ, further evidence that important stratospheric wave features are often independent of the forcing.

Other investigators used a more mechanistic approach to probe the dependence of warmings on changes in the basic state. By combining the upper- and lower-level flow from different periods, Smith found that the occurrence of a sudden warming at 10 mb is not sensitive to the basic state above 10 mb. By initializing the model with observations for different dates, she found that the occurrence of a sudden warming was primarily dependent upon the degree of "preconditioning" (poleward displacement of the lower stratospheric jet) on the initial date, and was rather independent of the temporal evolution or spectral makeup of the disturbances. Observations show that upward propagation of Rossby wave activity into the stratosphere is usually confined to high latitudes and that tropospheric forcing may or may not lead to such propagation. Chen and Robinson found that upward propagation is very sensitive to the gradients of buoyancy frequency and vertical wind near the tropopause. For the same tropospheric forcing, more wave activity was found in the stratosphere for reduced gradients. Reduced gradients, however, led to smaller tropospheric amplitudes. The seasonal evolution of the high-latitude tropopause, therefore, might affect the tropospheric long-wave pattern.

In a Lagrangian analysis, Pierce et al. showed that diabatic processes tended to increase potential vorticity outside of the polar vortex, enhancing the "surf zone" signature, where intermediate values of potential vorticity (PV) encroach equatorward. At all latitudes, spatial truncation caused a reduction of area enclosed by PV isopleths. This may be interpreted as due to irreversible deformation in an entrophy cascade, coupled with small-scale dissipation, and is the primary cause for erosion of the polar vortex in the model. High-resolution trajectory analyses showed linear lengthening of material contours with time in the vortex, but exponential lengthening outside, characteristic of chaotic advection.

c. Session 3: Three-Dimensional Models I (W.L. Grose, chair)

An invited paper by Rood and Mahlman discussed the simulation of stratospheric transport with three-dimensional models. They emphasized the role of small-scale motions in the momentum and constituent budgets and noted that very high resolution is necessary to simulate the fine structures found in observations.

Fairlie et al. reported on their work with a three-dimensional transport model of the stratosphere and mesosphere. The flow field for the transport model is taken from a global, primitive equation model (the UKMO's Stratosphere/Mesosphere Model). The results were successful in demonstrating the feasibility of combining two quite disparate models.

A series of simulations describing the seasonal evolution of the middle atmosphere was presented by Fisher et al. These experiments used a 3D, primitive equation, mechanistic model forced at the bottom boundary. By varying the amplitude of the forcing, the authors explored the response of the model for conditions varying from a linear regime to one that was highly nonlinear. For weak forcing, the model produced a double peak in the seasonal evolution of wave amplitudes, reminiscent of that observed in the South-
ern Hemisphere. As the forcing was increased, warminglike events developed with eastward and poleward advection of anticyclones as the polar vortex weakened.

The final two papers discussed recent efforts to develop stratospheric models. Pawson et al. presented results obtained from a model based on the European Centre for Medium-Range Weather Forecasts (ECMWF) general circulation model, but with its vertical domain extended into the mesosphere. The simulations exhibited an improved circulation in the middle atmosphere after altering the formulation for radiation in the troposphere. Nielsen and Allen presented some preliminary studies conducted with a 3D mechanistic, spectral model derived from the NCAR Community Climate Model (CCMO) with a lower boundary on a constant pressure surface.

d. Session 4: Three-Dimensional Models II
(J. D. Mahlman, chair)

This session emphasized applications of "self-consistent" 3D models (i.e., models that more or less determine their own tropospheric meteorology). This is in distinct contrast to many of the studies presented in the previous two sessions, wherein conditions near the tropopause are prescribed in accordance with climatology.

Grose and Eckman described a pioneering attempt to use the Langley 3D model to investigate stratospheric transport and chemical destruction. Their study clearly demonstrates the remaining computational barriers to thorough treatments of either chemical or transport processes. McLandress et al. utilized the Canadian AES parameterization of gravity waves to investigate the impact on middle atmosphere zonal winds. They showed, for plausible choices of parameters, significant impact above the middle stratosphere. These kinds of sensitivity studies remain hampered by the lack of observational data on tropospheric gravity-wave amplitudes, wavelengths, and phase speeds.

Mote and Holton examined the simulation of stratospheric water vapor in NCAR's CCM2 model. Their results reaffirm earlier GCM studies that showed very large sensitivities to relatively modest model temperature errors in regions near the frost point, such as the equatorial tropopause or the southern winter polar vortex. Rood et al. utilized a new 4D data-assimilation technique to examine a number of aspects of stratospheric chemistry and transport as inferred through satellite measurements. Their results show potentially important sensitivities to the model choices for computing 3D advection, particularly near the tropopause.

Lamarque and Hess employed a novel modeling technique to examine the character of stratosphere-troposphere exchange. They use a mesoscale model to investigate the nonconservative fluxes through a potential vorticity surface characterized as typical of the tropopause. Because of the need to have a self-consistent diabatic heating field, the method would appear to hold the most promise for quantitative advance through use of a global model at high spatial resolution. Knox used potential vorticity diagnostics in the Haynes–McIntyre isentropic control volume form to look at upper-stratospheric structures at the equator. The NCAR CCM2 model has provided data that shows an encouraging level of consistency when applied to this diagnostic approach.

e. Session 5: Ozone Depletion: Current Issues
(J. Rodriguez, chair)

This session included invited papers by Solomon, Tolbert, and Brasseur, and a contributed paper by Rodriguez. The presentation by Solomon provided an excellent summary of recent observational and theoretical developments in our understanding of the processes leading to ozone reductions both in Antarctica and in the global stratosphere. Solomon pointed out how observations of the altitude and seasonal behavior of ClO and OClO in Antarctica, coupled to observations of other species such as HCl, ClNO3, and NO2, have established chlorine catalysis as the mechanism responsible for the Antarctic ozone hole. She also discussed recent findings regarding heterogeneous chemistry on sulfate aerosols, and processing of air masses by polar stratospheric clouds (PSCs) both inside and outside the polar vortices.

Tolbert presented results from laboratory measurements of rates for relevant heterogeneous reactions, both on PSC-like surfaces (ice, nitric acid trihydrates) and on sulfuric acid solutions typical of aerosols in the global Junge layer. Reactions considered included conversion of chlorine reservoir species such as ClNO3 and HCl to active chlorine, and conversion of N2O5 to nitric acid. Measurements of the rate of the heterogeneous reaction of formaldehyde (CH3OH) on sulfuric acid surfaces were also presented; this process has not been previously studied. The rates for reactions involving HCl, ClNO3, and N2O5 are very fast on solid ice and nitric acid trihydrates. The uptake of HCl for ice crystals and nitric acid trihydrates was also discussed. The reactions of N2O5 and CH3OH on sulfuric acid aerosols are surprisingly fast and fairly independent of temperature, making it plausible that they occur in the global Junge layer.

Brasseur presented two-dimensional simulations of the response of stratospheric ozone to different natural and anthropogenic perturbations. These included: changes in solar activity during the 27-day solar rotation and the 11-year solar cycle; ozone response to injection of NOx by proposed hypersonic
aerosol flying in the stratosphere; response of ozone to chlorine chemistry in the polar region; and response of ozone to heterogeneous processes occurring in the global sulfate layer, particularly after aerosol enhancement due to volcanic eruptions. Simulations of the effect of the eruption of Mount Pinatubo indicate that reductions in ozone column as large as 15%–20% could occur in the Northern Hemisphere mid- to high-latitudes, depending on the specific heterogeneous processes active in the enhanced aerosol layer.

Rodriguez discussed how inclusion of the heterogeneous reaction of NO$_3$ on sulfate aerosols is changing our understanding of the photochemical budget of ozone in the lower stratosphere. In particular, this reaction reduces the relative importance of NO$_x$-catalyzed ozone removal, and increases that of chlorine-catalyzed and HO$_x$-catalyzed processes. As a result, model simulations predict that stratospheric ozone will be insensitive to NO$_x$ injections by hypersonic aircraft, but could respond to possible perturbations in lower stratospheric water due to climate change.

f. Session 6: Dynamics of the Polar Vortices (R.B. Rood, chair)

Section 6 consisted of four presentations that examined the wintertime vortices in both the Northern and Southern hemispheres. The papers focused on the mixing of air perturbed by heterogeneous chemistry on PSCs into areas outside the polar vortex. The two invited papers were based primarily on data from the airborne polar ozone missions. The two contributed papers were model simulations.

The first presentation by Schoeberl used long-lived tracer data from aircraft, a trajectory model, and a radiation model to develop a height–latitude description of the circulation in both the Northern and Southern hemispheres. The high amount of consistency that was found between the two independent model calculations was used to argue that the results were particularly robust. Schoeberl found that the vortex was quite isolated from middle latitudes with mixing of perturbed air limited to air from the edge of the polar vortex on the equatorward side of the stratospheric jet stream.

Tuck presented arguments based on O$_3$, ClO, H$_2$O, and N$_2$O data to demonstrate that air that had vortical characteristics was present outside of the vortex. These data were then interpreted with the aid of the ECMWF meteorological analysis and associated trajectory analyses. Tuck showed connectivity of "parcels" of high potential vorticity air at 30°F to the edge of the polar vortex. The argument was made that the diabatic descent in the vortex must be more vigorous than calculated by Schoeberl and that the polar vortex was a "flowing processor" and not isolated from the rest of the hemisphere.

Mahlman presented a paper that investigated the radiative and dynamical effects of the Antarctic ozone hole. Mahlman discussed multiyear simulations of the 3° x 3.6° SKYHI model in which an ozone hole was imposed based on conditions of sunlight, water vapor, and high cyclonic vorticity. The results showed some memory from year to year of the springtime ozone depletion, with the depletion being more dramatic in the upper troposphere, where the recovery time was long. The model also showed substantial changes in the dynamical structure of the ozone-depleted vortex in spring.

In the final paper, Bowman presented the results of a mechanistic model that was used to investigate the formation of streamers of ozone pulled off of the Southern Hemisphere vortex. This research was motivated by the presence of clear streamers in gray tone plots of the TOMS data. Bowman investigated both wave-1 and wave-2 forcing, and found the wave 2 a more efficient vehicle. The traveling wave 2 disturbance recreated many of the characteristics of the TOMS data.

g. Session 7: Observations of Constituents and Aerosols in the Stratosphere (G.P. Brasseur, chair)

This session offered a variety of observational studies of stratospheric chemical constituents and aerosols. McCormick presented an invited paper on Mt. Pinatubo aerosols as measured by SAGE II. He showed global maps of aerosol loading that clearly indicated the initial containment of the volcanic debris in the tropics followed by spread to higher latitudes. Dispersion into the Southern Hemisphere takes place first, during the course of southern winter, and is followed several months later by transport into the Northern Hemisphere. This sequence may be due to the timing of the eruption, which occurred early in Southern Hemisphere winter. The poleward spread of the aerosol appears to take place in multiple layers, suggesting that different transport processes (synoptic-scale waves at lower altitude, planetary waves higher up) are important.

In related papers, Thomason and Poole discussed characteristics of stratospheric aerosols in Antarctica, and their evolution as a function of season, which is very strong within the Antarctic polar vortex. Lin inferred aerosol size distributions using SAGE II data and illustrated the relationship between Antarctic aerosols and ozone depletion. Collins et al. presented lidar observations of PSCs made at the South Pole in 1989–90. They showed that PSCs form in distinct layers a couple of kilometers in thickness throughout the altitude range 12–28 km.

Papers dealing with water vapor in the upper tropo-
sphere and stratosphere were presented by Chiu and Pfister. Chiu used SAGE II data to derive distributions of relative humidity in the upper troposphere. He showed that there exist centers of high relative humidity over South America, central Asia, and the western Pacific, and that these centers migrate in the north–south direction as a function of season. Pfister and coworkers presented data from the STEP 1987 field experiment in Darwin, Australia, and compared it with previous studies based on data from Panama. The Panama observations suggest that water vapor is injected into the stratosphere as a result of convective overshoot and mixing in cumulus anvils, but this mechanism was not evident in the Darwin data. On the other hand, anvil injection was observed during the ferry flights to Darwin, which suggests that the Darwin results may not be representative of conditions in the western Pacific. Thus, the mechanism whereby air injected into the stratosphere is dehydrated to the commonly observed mixing ratio of about 3 ppmv remains poorly understood.

h. Session 8: Ozone Variations: Causes and Effects (M.R. Schoeberl, chair)

The first paper in this section was an invited presentation by Prather, who outlined the High-Speed Research Program (HSRP). The goal of this NASA program is to assess the impact of a commercial fleet of aircraft operating in lower stratosphere using engines with low NOx emissions. The HSRP funds the building of several new stratospheric instruments to be carried by experimental aircraft. HSRP also funds several theoretical investigations aimed at predicting the transport rate of pollutants out of the flight corridors and the overall impact of the aircraft emission on ozone. A specific aircraft campaign (SPADE) to examine the chemistry in the lower stratosphere using the NASA ER-2 was slated to begin in late August 1992.

Following Prather's talk, Douglass presented calculations of the transport of material out of the flight corridor regions using Goddard S.F.C. assimilated data (STRATAN). She showed that conditions varied considerably depending on the local synoptic systems and the altitude of the deposition. For example, even tropical emissions could be picked up by midlatitude cyclones. A study by Geller and his coworkers used STRATAN data to diagnose the ozone budget. They compared their results to LIMS data and showed good agreement. Remsberg described the various stratospheric databases that are being developed at NASA's Langley Research Center. Large disagreements between databases were sometimes apparent, and Remsberg pointed out that models are thus poorly constrained by these datasets.

The last paper in the section was given by Miller of NOAA/NMC. Using a radiative transfer model, he and colleagues at Livermore Laboratory estimated the trend in lower-stratospheric temperatures expected as a result of ozone loss rate observed in ozonesonde data. Compared with rawinsonde temperature observations, the computed global temperature trend was larger by a few tenths of a degree, although the shape of the temperature trend was in good agreement with observations.

i. Session 9: Tropical Dynamics I (K.P. Hamilton, chair)

This session had three interesting papers, mainly concerned with aspects of the semiannual oscillation (SAO). Dunkerton gave a review of current problems in the theory of the stratosphere semiannual oscillation. He focused particularly on the observed interhemispheric asymmetry of the SAO and on the very strong vertical shears characteristic of the westerly acceleration phase.

Garcia presented a paper, coauthored with Sassi, that described a simulation of the stratosphere SAO in the NCAR Community Climate Model (CCM2). He noted that the easterly phase of the SAO was quite well simulated. He showed that the meridional circulation associated with inertial instability plays an important role in shaping the region of mean easterlies that pushes across the equator. In contrast to the good simulation of the easterly phase, the westerly phase of the simulated SAO is too weak and the observed equatorial minimum in nitrous oxide mixing ratio is not well reproduced in CCM2.

Avery reported on observations of the mesopause SAO from several meteor wind radars located at low latitudes. Notable among the available data are those from the Christmas Island (2 N) radar. These show that a significant SAO extends up to at least 95 km. Avery's observations also clearly showed that, just as for the stratopause SAO, the mesopause oscillation is characterized by a stronger first cycle (January–June) than second cycle (July–December).

j. Session 10: Tropical Dynamics II: The Quasi-Biennial Oscillation and Its Effects (T.J. Dunkerton, chair)

Session 10 included both observational and theoretical talks relating to the quasi-biennial oscillation (QBO) and its effects on tropics and extratropics. The quest for a successful three-dimensional simulation of the QBO without a priori specification of wave forcing continues. Saravanan discussed 3D modeling using a mechanistic model and a more realistic (extended ECMWF) GCM. The simpler model specified tropical heat sources at certain frequencies, generating realistic equatorial waves and mean flow oscillation like
the original 1D Holton and Lindzen experiment. Using in situ forcing (rather than a tropopause boundary condition like other authors) it was shown that tropospheric upwelling prevented QBO descent into that region. In contrast, a more realistic GCM did not yield the necessary radiating waves or oscillation; possibly a QBO was inhibited by other factors as well (e.g., mixing).

Fortunately, the atmosphere has already determined how to produce a QBO, and remaining talks discussed its morphology (e.g., the EOF analysis by Pawson et al.) and effects on extratropical dynamics and global variation of trace species. Together these have made the QBO a topic of active research in recent years. Trepte and Hitchman displayed the evolution of SAGE II aerosol under the influence of the QBO. Under near-isothermal conditions and steady-state physics, aerosol is regarded as a quasi-passive tracer; its distribution, in any case, shows unmistakable effects of QBO meridional circulation cells. Some examples: “splitting” of the aerosol distribution by outflow beneath the westerly shear zone, ascent within the easterly shear zone, outflow and stretching deformation of the aerosol above the easterly shear zone (similar to that seen in angular momentum from 2D models). These are remarkable observations that (along with recent ozone and NO\textsubscript{2} data) show an in situ tropical effect of the QBO. They also reveal a strong concentration gradient at the edge of the tropics—possibly a semipermeable “barrier” to meridional transport. Observations of Pinatubo aerosol show the same gradient with occasional wisps being torn off to midlatitudes by circulation patterns in the lower stratosphere. It will be interesting to see whether the subtropical gradient exists as strongly in chemical species as there are now “ferry” flights across this region to support polar ozone expeditions.

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It is known that the QBO contributes to column ozone variations largely through its modulation of the prevailing meridional circulation, but the column is also subject to tropospheric phenomena such as ENSO. Interestingly, a talk by Hasebe focused attention primarily on the zonally averaged ozone signal (including the so-called 4-year oscillation) and discussed a possible relation with ENSO. In a related talk, however, Shiotani revealed that the major effect of ENSO is in the east–west ozone gradient—presumably as convection is displaced longitudinally in the Pacific sector during warm events and subtle changes in tropopause height alter the column amount. Nevertheless, the zonal mean ozone and E–W gradient appear related, suggesting that ENSO has a measurable effect on the axisymmetric component of Hadley circulation and/or tropopause height.

Studies by Baldwin and Dunkerton and by Hollandsworth demonstrated a remote effect of the QBO on polar vortex evolution in the winter stratosphere (the Holton–Tan oscillation) and subtropical upper stratosphere. Zonal winds were weaker, and planetary Rossby wave activity stronger, during the QBO east phase at 40 mb. Baldwin also discussed decadal variability prominent in the upper stratosphere in early winter (correlated with the solar cycle) and an apparent decadal modulation of the QBO signal (principally in the polar lower stratosphere during late winter).

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k. Session 11: Tropical Dynamics II: Waves
(R.R. Garcia, chair)

An invited paper by Hendon and Salby presented work on the relationship between tropical convection and wave motions in the stratosphere. They have used data from the International Satellite Cloud Climatology Program (ISCCP) to define the spatial and temporal characteristics of deep convection in the tropics. Their analysis indicates that the observed space–time spectrum of convection centered on the equator is consistent with the observed distribution of Kelvin wave activity in the stratosphere. Generation of antisymmetric Rossby–gravity waves, however, requires convection similarly distributed in latitude and fluctuating at periods near 4–5 days. Such convective activity is observed in restricted longitude regions in the central Pacific, but it is not well correlated to antisymmetric wave activity in the stratosphere, suggesting that other mechanisms (e.g., forcing from extratropical latitudes) are involved.

Mancini and Hamilton showed that a linear model can reproduce the wave motions generated in the full SKYHI general circulation model if the linear model is forced with convective heating fields taken from the SKYHI model. This suggests that forcing of equatorial waves can be understood in terms of tropical convective forcing and linear wave propagation. These results do not hold, however, for westward-propagating Rossby normal modes, which the linear model fails to reproduce. Apparently, these normal modes are forced by mechanisms other than tropical convective heating.

Geller and Zhang suggested a mechanism whereby
variations in sea surface temperature can affect the forcing of equatorial waves. O’Sullivan showed by means of numerical calculations how changes in the zonal mean winds in the lower stratosphere associated with the QBO can modulate the effect of planetary Rossby waves on the polar vortex. During the easterly phase of the QBO, Rossby waves are confined farther poleward and are able to affect the polar vortex more strongly than during the westerly phase. The results have obvious implications for understanding the coupling between the tropical and high-latitude QBOs.

Boville presented simulations of the tropical QBO carried out with a mechanistic three-dimensional model derived from the NCAR Community Climate Model by removing the troposphere and imposing wave forcing at the new lower boundary (100 mb). An oscillation resembling the observed QBO is produced—the first time that such behavior has been generated with a three-dimensional model.

l. Session 12: Observations of the Middle Atmosphere (J. Stanford, chair)

Salby and Shea considered recent evidence for a 10–12-yr oscillation in the lower-stratospheric height field, in which the north polar region is correlated with the 10.7-cm solar flux when years with westerly and easterly QBO are separated. Salby and Shea showed that even though Monte Carlo tests suggest the high covariances found are not accidental, aliasing of interannual variability, introduced in the westerly–easterly separation of the data, can produce spurious correlations.

Stanford, Ziemke, and Gao applied a self-consistent iterative calculation technique to SAMS N₂O and CH₄ data to obtain residual mean and effective transport winds, and fields of diffusion coefficient Kₓᵧ. The effective transport winds appear to be more realistic. Rosenlof and Holton calculated EP fluxes from UKMO height data to estimate the mean meridional residual circulation by means of the downward control principle of Haynes et al. The mass flux across 100 mb was similar to that obtained by Holton in his 1990 study using data at only two levels. The results are unreliable in the tropics, however. Further work with the full TEM equations is in progress.

Shiotani, Shimoda, and Hirota studied interannual variability of Southern Hemisphere stratospheric winds, finding a double maximum in zonal wind at 60°S (in August and October) and anticorrelation between 30° and 60°S. Miles, Grose, and Lingenfels examined wave-1 disturbances observed in LIMS data for Southern Hemisphere summer. The results are consistent with linear predictions from linear models of vertical propagation. Randel, Lait, and Manney discussed the 4-day wave observed in the winter polar stratosphere and showed that it is primarily due to barotropic instability associated with the “double jet” structure in the upper stratosphere and mesosphere.

m. Session 13: Radiative Processes in the Middle Atmosphere (M. Mlynczak, chair)

This session included an invited paper by Mlynczak and two contributed papers. Mlynczak presented results on solar and chemical heating in the mesosphere and lower thermosphere. He showed that the heating efficiency of solar radiation can be substantially less than unity in this region of the atmosphere because some fraction of the absorbed solar energy is not converted to heat, but instead ends up as internal energy of excited photolysis products, which radiate back to space. Absorbed solar energy can also reside in photolysis products and be released at different times and places than originally absorbed. These findings are of significance for understanding the thermal budget of the mesosphere/lower thermosphere, and the mechanisms in question should be considered in future thermodynamic models of the region.

Wehrbein has studied the role of CO₂ cooling in the vicinity of polar mesospheric clouds (PMCs). He finds that published IR heating rates for the 15-μm band of CO₂ are not applicable to the very cold temperatures in the vicinity of the summer polar mesopause. A paper by Rosenfield addressed the question of radiative balance in the polar stratosphere, including the radiative effects of PSCs.
possible exchange of energy between these components of the wind field.

Roper presented wind measurements from the IDI and incoherent scatter radars that were involved in the AIDA campaign at Arecibo. The wind spectra indicated steady 12-h and 6-h periodicities and a highly variable 24-h oscillation. The line-of-sight velocities from the two techniques were in good agreement. The wave structures in the variance profile differed by 90°, however. A possible explanation for this difference is that one technique was tracking the wind and the other was tracking the advection of the temperature.

Another comparison of radar techniques was presented by Van Baelen. Similarities and differences between the Doppler beam swinging, spaced antenna, and interferometry techniques were discussed and quantified.

Two planned satellite-instrumentation programs were also presented. Kumer proposed a new geostationary research satellite that would provide infrared earth-limb measurements with high spatial and temporal resolution. Diurnal cycles of trace species, cloud structures, and other parameters would be retrieved. This project is in the feasibility study stage and input from the middle-atmosphere community is encouraged. Gille spoke about the new features of the HRDLS instrument that is to be flown on EOS. In order to meet the scientific goals of this mission, the new instrument aims to provide much improved vertical and horizontal resolution as compared to earlier instruments. It also will sample the tropopause/lower-stratosphere region—a region that in the past has been monitored only sparsely with satellite instrumentation.

o. Session 15: UARS I (J. Waters, chair)

This session included four papers describing UARS experiments (HALOE, HRDI, WINDII, CLAES), one discussing gravity-wave drag in the middle atmosphere with application of the UARS ISAMS data, and one describing initial comparisons of UARS and NMC data.

Russell et al. described preliminary results from HALOE (the Halogen Occultation Experiment). HALOE uses solar occultation to obtain profiles of O₃, HCl, HF, CH₃, H₂O, NO, and NO₂. Preliminary profile measurements for all these molecules were presented, and found to be in good agreement with expectations.

Hays described HRDI (High-Resolution Doppler Imager) and showed preliminary results. HRDI uses a Fabry–Perot interferometer to measure atmospheric winds from Doppler shifts in O₂ lines. Initial results were shown for wind profiles in the mesosphere and lower thermosphere; the measurement precision in the mesosphere is approximately 5 m s⁻¹, and features attributed to gravity waves have been observed. Good stratospheric signals have also been obtained.

Shepherd and Thuillier described WINDII (Wind Imaging Interferometer). WINDII is a joint Canadian–French experiment that uses a Michaelson interferometer to measure winds, temperature, and emission rate in the 80–300-km altitude range. Preliminary results were presented.

The paper by Lawrence and Marks discussed the contribution to the momentum budget of the upper stratosphere and mesosphere of small-scale processes such as gravity waves. The approach was to calculate the vertical velocity from the thermodynamic equation, and to use that quantity together with observed temperature fields in an iterative determination of the momentum balance in the primitive equations. Results indicate that the inferred gravity-wave drag is highly asymmetric in longitude.

Roche and Kumer described the UARS Cryogenic Limb Array Etalon Spectrometer (CLAES). CLAES is designed to measure stratospheric profiles of temperature, pressure, O₃, H₂O, CH₃, NO, NO₂, N₂O, HNO₃, CIONO₂, HCl, CFC-11, and CFC-12. It derives these profiles from measurements of thermal spectral line emission at wavelengths between 3.5 and 13 μm. A scanning Fabry–Perot interferometer provides spectral resolution of 0.25 cm⁻¹, and the detectors are cooled to approximately 15 K to provide good sensitivity. Initial results were presented that included spectra, preliminary retrievals, and maps of stratospheric aerosol.

Geller et al. described potential uses of UARS data by the NOAA Climate Analysis Center. Since the launch of UARS, the NOAA stratospheric temperature data derived from the TIROS operational sounder have been routinely deposited in near-real time in the UARS Central Data Handling Facility for use by UARS investigators. Initial comparisons have been made between the NOAA temperature data (and, to a lesser degree, ozone data) and the UARS Microwave Limb Sounder (MLS) experiment, with encouraging results.

p. Session 16: UARS II (J. Russell, chair)

This session was devoted to a description of results from the MLS experiment. It included an overview of results, followed by a description of the forward-radiance model used in retrievals, discussion of the retrieval approach, some detail on the temperature-versus-pressure results, and a description of the synoptic mapping scheme. The MLS measures CIO at altitudes between 20 and 45 km, O₃ (15–80 km), H₂O (12–85 km), and temperature (30–60 km). The data presented included results showing for the first time a map of enhanced CIO on the 46-mb (~20 km) surface.
in the Antarctic spring (21 September) polar vortex. Levels of about 1.6 ppbv were observed over a 90° longitude range centered about 310°W. Ozone levels were greatly reduced in that same geographic region, and strong correlations were shown between these features and potential vorticity maps. An unplanned output from MLS was the measurement of enhanced SO₂ levels (≈11.5 ppbv) in the tropical latitudes resulting from the eruption of Mt. Pinatubo in June 1991. The data also show, in the same latitude band on the 46-mb surface, reduced ozone levels that are as low as values seen in the Antarctic ozone hole region (≈0.25 ppmv). It was noted that these levels are much less than the mean tropical ozone level observed from balloons. The data show the low-ozone air moving out of the tropical bands to midlatitudes as well. At the same time, no enhanced levels of ClO were observed in these regions. Recent measurements did show enhanced ClO at about 65°N (≈0.9 ppbv) off the North American continent and over Europe in a 15° latitude band.

MLS retrievals are performed at 5-km intervals at present, and the estimated precisions in the data are 0.3–0.6 ppbv for O₃, 0.3–0.6 ppbv for ClO, and about 3 ppbv for SO₂ at 26 km. No estimate was given for H₂O or temperature. Comparisons of O₃ with balloon data show agreement to within the error bars. Comparisons with SAGE II O₃ show agreement to 0.5–1 ppmv or about 15%. Temperature data have been compared with NMC data on a global scale. The globally averaged rms difference is about 4 K, with MLS being higher. Locally, some differences are nearly 8 K and appear to depend on latitude. Early comparisons with Table Mountain Observatory lidar data show agreement to within 5 K, except at the stratopause and above, where it is about 10 K. While the results from MLS are preliminary, with only limited validation at present, the data show some potentially significant findings and offer promise of revealing new stratospheric phenomena.

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Recent years have seen a significant upsurge of interest in research on the atmospheric and oceanic environment of the Arctic, particularly in the areas of leads in the pack ice, ocean–atmosphere–ice modeling, and broad questions of the stability of the arctic climate. This volume contains preprints of papers on all topics of interest in polar meteorology and oceanography, with special emphasis on katabatic and mountain winds, and on polar boundary layers.