Kyoto International Community House, Kyoto, Japan
March 13(Tue) to 17(Sat), 2001

Japan-U.S. Seminar

Coupling of the troposphere and stratosphere by dynamical, radiative and chemical processes

Abstracts

13th(Tue)

13-1

Issues in stratosphere-troposphere coupling

Theodore G. SHEPHERD

University of Toronto

An overview is given of current issues concerning the coupling between the stratosphere and troposphere. The tropopause region, more generally the upper troposphere/lower stratosphere (UT/LS), is the region of direct contact where exchange of material takes place. Dynamical coupling through energy and momentum transfers occurs non-locally. The location of the tropopause has implications for radiative forcing of climate, through its effect on the distribution of relatively short-lived greenhouse gases. Some outstanding puzzles in our current understanding will be identified. Attention will be focused on possible climate sensitivities, and how these may be tested and constrained. Results from the Canadian Middle Atmosphere Model (CMAM), a fully interactive radiative-chemical-dynamical general circulation, will be used to illustrate some of the points.

13-2

Importance of stratosphere-troposphere coupling in climate change studies

V. RAMASWAMY

NOAA/GFDL, Princeton University

Coupling between the stratosphere and troposphere plays an important role in climate change investigations. Changes in the concentrations of radiatively-active species in the stratosphere affect the heat balance of the troposphere e.g., the loss of ozone in the stratosphere over the past two decades, and the transient increase in stratospheric aerosol concentrations following volcanic eruptions. Besides a direct effect arising due to radiative transfer mechanisms, there also occur dynamical influences acting in response to the initial radiative perturbation. First, we investigate the consequence of the observed stratospheric ozone depletion for the "radiative forcing" of the troposphere. The results obtained under the Fixed Dynamical Heating assumption (i.e., with only radiative coupling) are contrasted with those obtained from a general circulation model (GCM) simulation (i.e., with radiative-dynamical coupling). In a similar manner, we also examine the radiative forcing and effects on the troposphere due to aerosols resulting from the 1991 Mt. Pinatubo volcanic eruption.

Conversely, the stratosphere is affected by radiatively-induced changes in the troposphere e.g., increase in well-mixed greenhouse gases and ozone. These can induce a direct radiative effect, as well as dynamical effects e.g., change in the tropospheric meridional heating gradient which affects wave activity and hence the state of the stratosphere. An important outcome is the variability introduced in the stratosphere. We investigate this issue by using two sets of GCM simulations. First, we examine the variations in stratospheric temperatures in a long (50 years) unforced integration of the model in which the SSTs, although seasonally varying, are fixed from one year to the next. This simulation highlights the "natural" modes of the model's stratosphere-troposphere system. Second, ensemble GCM integrations forced by observed SSTs over the period 1982-1997 are performed. Both sets of simulations offer perspectives into the stratosphere's variability. Quantitative estimates of the dynamical variability of the stratosphere are particularly important for identifying whether a given stratospheric temperature change lies outside the limits of "natural" variability and hence is statistically significant. The inferences from the simulations bear directly on the ability or inability to make unambiguous causal attributions of the observed changes in stratospheric temperatures e.g., long-term global-and-zonal-mean trends and transient perturbations following a volcanic eruption.

13-3

Ozone variations in middle atmosphere general circulation models with chemistry

Masaaki TAKAHASHI(1)**, M. Takigawa**(2) **and T. Nagashima**(1)

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Ozone chemical processes in the stratosphere are important for the dynamics of the middle atmosphere. New general circulation models which include atmospheric chemical processes (ozone chemistry) explicitly have been constructed. The model is based on Center for Climate System Research/National Institute for Environmental Studies (CCSR/NIES) Atmospheric General Circulation Model. Horizontal resolution is T21 coarse resolution, because many chemical species for transport are included. Vertical resolution is 32 layers model. The chemical species are fully interactive to physical fields in the model atmosphere. Using a model, temperature and ozone variations in the stratosphere are discussed.

Stratospheric aerosol chemistry is also included in the model with homegeneous ozone chemistry. Heterogeneous chemistry on the stratospheric aerosol is also considered. In the model, stratospheric aerosols are dominantly (80%) formed by OCS (Carbonyl Sulfide) in the quiet situation (no volcanic eruptions), and formed 20% by SO_2 transported from the troposphere into the stratosphere. We also conducted numerical simulations for the case of Pinatubo eruption in June 1991. The injected SO_2 are tranported from the equatorial region to the polar region, and changed to the sulfate aerosol. Two and three years temporal behaviors of ozone and stratospheric temperature seem to be similar to those of observed.

We will also present numerical results of ozone hole simulation.

13-4

Increased CO_2 and solar variability influences on the troposphere through wave-mean flow interactions

David RIND

NASA/GISS

A variety of climate forcings are now thought to be able to influence planetary wave dynamics in the troposphere by affecting the propagation of planetary waves out of the troposphere. On time-scales ranging from the interannual to decadal, this interaction between planetary waves and stratospheric zonal wind changes may produce significant tropospheric responses. In a two part discussion, evidence for this type of interaction is discussed.

The first part focuses on the impacts of increased greenhouse gases. Increased atmospheric CO_2 concentrations can be shown to influence planetary wave refraction so as to produce an intensified residual circulation in the subtropical lower stratosphere, with a resultant increase in transport of tropospheric species into the stratosphere. The higher latitude component of this phenomena is associated with an increase in the high phase of the Arctic Oscillation, thought to be responsible at least in part for various current climate changes, including surface air temperature and sea ice variations in the Northern Hemisphere. It is shown in GCM experiments that the low latitude response appears qualitatively robust over a wide range of tropical warming magnitudes, although the quantitative circulation change depends upon the degree of tropical warming. The extratropical response depends upon the magnitude of high latitude warming; with greater high latitude warming, relative to lower latitudes, there is less of an Arctic Oscillation phase change, or even none at all.

In the second part, the relationship between solar heating, the phase of the QBO and planetary wave propagation is discussed. While the QBO alters the latitudinal gradient of the zonal wind, solar heating, in association with ozone response, alters the vertical gradient of the zonal wind. Both gradients affect the refractive properties of planetary waves uniquely for each individual combination of tropical east/west winds and solar maximum/minimum activity. Indications are that interannual variations in tropospheric temperature may well result from such QBO/solar cycle variations, as has been suggested by observations.

13-5

Interannual variations of the general circulation and polar stratospheric ozone losses in a general circulation model

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Department of Earth and Planetary Sciences, Kyushu University

Interannual variations of the general circulation and polar stratospheric ozone losses are investigated by using a general circulation model (GCM) developed at Kyushu University. The GCM includes simplified ozone photochemistry interactively coupled with radiation and dynamics in the GCM. Polar ozone depletion is brought about in the GCM by a parameterized ozone loss term. We performed an 'ozone depletion experiment' over successive 50 years with stratospheric ozone losses formed over the Arctic and Antarctic polar regions, along with a 'control experiment' which is a simulation without the ozone loss term.

Results of the ozone depletion experiment show large interannual variations of the general circulation and polar ozone losses especially in the Northern Hemisphere winter and spring. There exists a high correlation between the persistence of the strong and cold polar vortex and the occurrence of the large ozone depletion; it is found that the latter are caused not only by dynamical conditions in the stratosphere, e.g., the strength and coldness of the polar vortex and planetary wave activities, but also by interaction mechanisms between dynamical and ozone fields. Hence, the interannual variability of the general circulation in the stratosphere becomes larger than that in the control experiment.

Moreover, dynamical influences of the stratospheric ozone losses could extend to the troposphere; overall three-dimensional patterns of the interannual variations in dynamical fields during the Northern Hemisphere spring are annular and coincide well with those of the Arctic Oscillation.

13-6

Coupled modeling of the lower and middle atmosphere

Byron A. BOVILLE, F. Sassi and R. Garcia

NCAR

This talk will focus on outstanding issues in modeling the lower and middle atmosphere. These issues include the role of the parameterized gravity waves and of resolved waves generated by convection in determining the circulation of the middle atmosphere. The influence of changes in numerical approximations will also be addressed. Ideally, this should not be an important issue but it will be shown that the middle atmosphere can be affected to a distressing large extent by approximations of comparable accuracy. Finally, the vertical extent of the model required to avoid artificial damping layers will be discussed.

13-7

How well can we represent the tropopause region in climate models?

Steven PAWSON

Goddard Earth Science and Technology Center, Data Assimilation Office

The region in the vicinity of the tropopause is known to be governed by complex interactions between many different processes, including cloud microphysics, radiation transfer, vertical transport of air (especially near or above convective clouds), and horizontal transport of air. The tropopause region has traditionally been located above the level of major interest for climate models, but below the region studied in middle atmospheric models. Climate-middle atmosphere models, developed primarily to study the interactions between ozone and climate, need to represent the tropopause region accurately, because exchange of air masses and constituents (especially water vapor) between the troposphere and stratosphere depends crucially on the behaviour of this region. This paper will examine aspects of our ability to adequately model the upper troposphere and lower stratosphere: vertical and horizontal resolution will be examined, with studies of how they impact cross-tropopause transport; aspects of the physical parametrizations in present models will also be examined, with some emphasis on the radiation balance of the tropopause region.

13-8

Nonhydrostatic effects in the parameterization of non-orographic gravity-wave drag

John SCINOCCA

Canadian Centre for Climate Modelling & Analysis

In this study the parameterization of drag associated with non-orographic gravity waves in general circulation models is considered. In general, for computational efficiency current parameterization schemes make the hydrostatic approximation. The main consequence of this approximation is the neglect of the physical process of back-reflection. Here, an efficient implementation of the non-hydrostatic parameterization scheme suggested by Warner and McIntyre (1996) is developed and used in fully interactive multi-year climate simulations. In this way we identify qualitative and quantitative effects of including back-reflection in the parameterization of non-orographic gravity waves.

The results indicate that the momentum flux launched into the stratosphere at mid-latitudes can be reduced by as much as 75% due to the process of back-reflection. The momentum flux launched at tropical latitudes, however, is relatively unaffected and, so, is effectively larger in the non-hydrostatic scheme. This has important consequences for the forcing of tropical oscillations such as the SAO and QBO in the model. It is also found that the new scheme improves middle-atmosphere wind biases present in the model when compared to the climate produced by the default hydrostatic non-orographic GWD parameterization used currently.

14th(Wed)

14-1

Stratospheric dynamics and the transport of trace constituents

R. Alan PLUMB

M.I.T.

Together, meteorological and chemical observations, and fluid dynamical theory, have led us to a rather comprehensive understanding of how the stratospheric transport system works. Chaotic stirring by waves effects transport of tracers both through the direct effects of the stirring and through the indirect effect of inducing a meridional circulation (itself consequent on the stirring of potential vorticity). In the midlatitude stratosphere, Rossby waves are clearly the dominant stirring agent. However, there are several lines of evidence to suggest that the effects of mesospheric gravity wave breaking are important in trace gas concentrations in the polar vortices, all the way down to the lower stratosphere. There is still some uncertainty about the dominant components of transport within the tropical stratosphere.

14-2

Denitrification and nitrification in the Arctic stratosphere during the winter of 1996-1997

Yutaka KONDO[(1)]**, H. Irie**[(2)]**, M. Koike**[(3)]**, G.E. Bodeker**[(4)] **and Y. Sasano**[(5)]

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During winter and spring, reactions on Polar Stratospheric Cloud (PSC) particles free reactive chlorine from its reservoir species enabling it to catalytically destroy ozone. This reactive chlorine can be deactivated by nitrogen dioxide (NO_2), produced from photolysis of HNO_3 and reaction with OH. Sedimentation of HNO_3 containing particles causes irreversible loss of reactive nitrogen (NO_y) (denitrification), which in turn inhibits the deactivation of chlorine and extends ozone depletion throughout the winter and early spring. Concentrations of HNO_3, N_2O, ozone, and aerosol in the lower stratosphere inside the Arctic and Antarctic vortices were observed by Improved Limb Atmospheric Spectrometer (ILAS) on board the Advanced Earth Observing Satellite (ADEOS) from November 1996 to June 1997. First, HNO_3-N_2O correlations obtained at 16-23 km inside the Arctic and Antarctic vortices in early winter are compared. The HNO_3-N_2O correlation in the Arctic was controlled by descent inside the vortex and mixing with air outside the vortex, leading to a non-linear correlation at N_2O lower than 120 ppbv. In the Antarctic, the linear region extends to lower N_2O mixing ratios due to reduced mixing through the vortex boundary. The degree of denitrification was evaluated using these reference correlations. It has been found that denitrification occurred between 18 and 23 km in the Arctic in mid-late February soon after the Arctic vortex cooled below ice saturation temperature (TICE). Denitrification exceeding 40 % was observed only in air masses that experienced temperature below TICE. Increases in HNO_3 by evaporation of the particles (nitrification) between 13 and 15 km occurred 0-3 days after denitrification was observed, indicating particle radii of 5-10 mm or larger. The degrees of denitrification and nitrification were largest deep inside the vortex where the temperature was lowest. Redistributed HNO_3 abundances at each altitude were calculated by integrating the area-weighted changes in the HNO_3 concentration. The maximum extent of denitrification was located at 18-19 km, which correlates with the area cooled below TICE. The decrease in the total HNO_3 amount at 18-22 km in February and early March agrees with the increase at 12-16 km to within their combined error ranges, confirming conservation of HNO_3 during sedimentation and evaporation of HNO_3 containing PSC particles. Denitrification in the Antarctic occurred in June 1997. The conditions required for denitrification in the Antarctic was found to be similar to those in the Arctic.

14-3

Stratospheric aerosols and PSCs observed with satellite sensors

Sachiko HAYASHIDA

Nara Women's University

The importance of stratospheric aerosols/PSCs is well recognized for their role on ozone destruction through heterogeneous reactions (Hofmann and Solomon, 1989) and their significant effect on the global radiation balance especially after major volcanic eruptions (e.g., Minnis et al., 1993). Space-borne sensors have the advantage of being able to monitor the global distribution of aerosols and the frequency of PSCs. This talk gives an overview of the time development of stratospheric aerosol distribution based on SAGE II measurements. Global budget of sulfate and its distribution in the stratosphere were estimated based on the SAGE II extinction coefficients at multiple wavelengths.

The extinction and nitric acid observed with ILAS (Improved Limb Atmospheric Spectrometer) over Arctic in 1997 were also utilized to derive the composition of PSCs. Combined use of the extinction data with nitric acid data clearly suggested the formation of STS (type 1b) particles in January 1997 over the Arctic. Some cases of type 1a particles were also found in February and March. The formation processes of various types of PSCs based on those satellite data will be discussed.

14-4

Structure of the polar vortex in 1996/1997 Arctic winter as revealed by ILAS observations of minor-constituents and meteorological data

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The 1996/1997 Arctic winter is a characteristic winter because the polar vortex was maintained until the beginning of May 1997, that is, the polar vortex was stable and maintained abnormally long. This brought about abnormally low total ozone in March 1997 (e.g., Newman et al., 1997). In this paper, the structure of the 1996/1997 Arctic polar vortex is investigated using minor-constituents data (O_3, HNO_3, NO_2, N_2O, CH_4, H_2O, aerosol) of ILAS (Improved Limb Atmospheric Spectrometer), and meteorological analysis data of UKMO and ECMWF.

A main advantage of ILAS, an ozone layer sensor aboard ADEOS (renamed "Midori" after the launch), is to provide longitude-height cross-sections of trace species at a latitude per day in both polar regions: it covers the stratosphere with altitude resolution of 1 km (e.g., Sasano et al., 1999). The measurement latitude in the Arctic changed around 65 degrees North in December 1996 to around 70 degrees North in March 1997. ILAS measured the inside, the edge, and the outside of the polar vortex because the polar vortex developed in winter is not symmetric with respect to longitude. ILAS thus gives basic information on the structure of the polar vortex that is one of the main factors determining ozone distribution.

The speed of downward motion in the polar vortex is regarded as an index of degree of isolation of the polar vortex. Using long-lived tracer (CH_4, HF, and H_2O) data of HALOE (Halogen Occultation Experiment) aboard UARS (Upper Atmosphere Research Satellite), several authors have carried out estimates of downward motion for the Antarctic polar vortex (Russell et al, 1993; Schoeberl et al., 1995; Kawamoto and Shiotani, 2000). No work of the kind has been carried out for the Arctic polar vortex because it is not so much stable as the Antarctic one and frequency of HALOE measurements in high latitudes is low. By using long-lived tracer data of ILAS, we try to make an estimate of downward motion speed in the stable polar vortex of 1996/1997 Arctic.

The mixing of the polar vortex air in the "horizontal" direction is also estimated to evaluate the degree of isolation of the polar vortex. For the evaluation, plots of ILAS data in cross-sections of potential temperature - potential vorticity based equivalent latitude are carried out. Moreover, a new method named time threshold diagnostics (TTD), having been developed by Sugata (2000) for estimating effective flux of air parcels across given boundaries, was applied with use of ECMWF data.

14-5

Transport, mixing and chemistry in the tropopause region

Peter HAYNES

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Transport of air within the troposphere and the lower stratosphere is quantified by following large numbers of air parcels using analysed wind fields. We define different regions (stratosphere, troposphere, boundary layer) using criteria based on combinations of potential vorticity (PV), water vapour and geometric height and consider the statistics of the time since visiting those regions as a function of position (defined using combinations of pressure, latitude, potential temperature and PV-based equivalent latitude).

We find that the troposphere is clearly defined as a region for which average times for transport from the boundary layer are relatively short (less than 30-40 days). These average times increase sharply across the tropopause and indeed the sharp increase provides a useful objective definition of the position of the tropopause (e.g., in terms of equivalent latitude as a function of potential temperature).

We compare the quantitative picture of transport obtained by our analysis with that obtained by previous analyses based on isentropic velocity fields.

Some of the implications of transport and mixing in the tropopause region for the distribution of chemical species will be discussed. In the region between 300K and 340K there are significant cross-tropopause contrasts in ozone and water vapour and mixing between tropospheric and stratospheric air parcels leads to enhanced levels of hydroxyl radical, with consequences for the evolution of ozone and NO_x.

14-6

Transport of chemical species across the tropopause

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Quantitative knowledge of rates of transport of chemical species across the tropopause is critical for understanding the chemistry of both the stratosphere and troposphere. For example, the rates and details of mass transport into the tropical and extratropical stratosphere control the degree to which short-lived tropospheric species can enter the stratosphere and contribute to chemical processes there. Transport of reactive species such as ozone and NO_y from the stratosphere to the troposphere can affect tropospheric chemistry on both regional and global scales. Aircraft observations relevant to understanding the exchange of chemical species across the tropical and extratropical tropopause will be highlighted, with an emphasis on global-scale processes and controls. Recent research into the isotopic composition of long-lived stratospheric species, such as CO_2, O_2, CH_4, and N_2O will also be discussed, creating new motivation for studying the rates of strat-trop exchange. Unusual isotope signatures are produced by photochemistry in the stratosphere and destroyed or diluted by biospheric processes at Earth's surface. Once the stratospheric production rates of these signatures and the rates at which they are transported to the troposphere (on annual to millennial time scales) are known, a time series of measurements in the troposphere (in real time or through bubbles trapped in ice cores) will yield new proxy information on how the biosphere responds to environmental change on a variety of time scales. Thus, through strat-trop exchange, the biosphere affects stratospheric chemistry (as discovered in the 1960s) but, also, stratospheric chemistry can provide a new means of probing global biogeochemical processes and their coupling to climate.

14-7

Long-term stratospheric water changes deduced from multiple sources: What does this imply about tropical troposphere-stratosphere transport?

Karen H. ROSENLOF

NOAA Aeronomy Laboratory

For the data comparison chapter of the SPARC Water Vapor Assessment, a number of instruments using both in situ and remote techniques for measuring water vapor in the upper troposphere and stratosphere were assessed. Using both direct and indirect comparisons, it was found that most instruments agreed to within ±10%.

Additionally, comparisons were made among estimates of seasonal cycle amplitudes, stratospheric entry values, and long term changes from various instruments. Long term changes computed from a number of time series covering the past 40-50 years strongly suggest that the northern hemisphere mid-latitude water vapor increases seen in recent measurements made since 1980 have been taking place over a considerably longer period of time. This analysis also suggests that there are vertical gradients in the trends, with large positive trends seen in the lowermost stratosphere, a minimum in the layer between the tropical tropopause and the 500 K isentropic surface, and large positive trends again in the layer from 500 K to the stratopause. The positive trends noted are approximately twice what would be implied by the surface increase in methane.

Analysis of recent satellite data shows that the vertical structure in trends described above is present globally. For the UARS satellite period (1992 present), estimates of the Lagrangian-mean circulation will be presented that indicate a change in the width of the tropical tropopause that would produce water vapor changes as observed. Evidence that this change in the tropical circulation has been occurring over a longer period will be shown from NCEP tropopause analysis.

14-8

Results from the Soundings of Ozone and Water in the Equatorial Region (SOWER)/Pacific Mission

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(3) *NOAA/CMDL*, (4) *Kyoto University*

The Soundings of Ozone and Water in the Equatorial Region/Pacific Mission (SOWER/Pacific) is intended to improve our knowledge on the ozone and water vapor distributions by making coordinated radio sonde observations in the Pacific region along the equator. We present results from the observation campaigns since March 1998. These are roughly two-week long and have been conducted repeatedly in the period of February-March (F-M) and September-October (S-O) to capture the atmospheric behavior during local rainy/dry seasons and strong/weak pumping from the extratropical stratosphere. Additionally we have conducted GPS radiosonde and ozonesonde observations from a research vessel in the eastern tropical Pacific during the period September to October 1999.

Data obtained at San Cristobal, Galapagos (0.90S, 89.62W) show clear seasonal variation between the F-M and S-O periods. The tropopause is higher and colder in F-M than S-O as expected from stronger extratropical pump in F-M than S-O. Water vapor mixing ratio around the tropopause is smaller in F-M than S-O in association with the tropopause temperature. Ozone mixing ratio in the upper troposphere is larger in S-O than F-M, suggesting leakier condition in S-O than F-M.

Water vapor profiles around the tropopause are highly variable. In 1998 S-O campaign observations, there are two characteristic profiles, one is saturated and the other is not. With use of daily radiosonde data we found this water variability can be understood as the passage of Kelvin waves.

In the ship cruise data we usually see layered structure in ozone and humidity profiles. Low (high) relative humidity corresponds to high (low) ozone concentration in several kilo-meter down to several-hundred-meter vertical scales. It seems that the tropical troposphere over the cruise should be viewed as the pile of atmospheric layers originated from either the inter-tropical convergence zone (wet and low ozone) or the mid-latitudes (dry and high ozone).

14-9

Changes in column ozone correlated with the stratospheric EP flux

William RANDEL

NCAR

Variability in planetary wave forcing from the troposphere to the stratosphere is reflected in changes in ozone transport, due to fluctuations in the Brewer-Dobson circulation and eddy mixing. This work examines the space-time patterns of correlations between column ozone tendency and planetary wave Eliassen-Palm (EP) flux into the lower stratosphere, using monthly mean data for 1979-2000. Strong correlations are found during winter - spring in both hemispheres, with out-of-phase ozone changes between the tropics and high latitudes. Correlations are small over NH midlatitudes (40-50 N). The observed statistics can be extrapolated to zero wave forcing, providing an estimate of ozone evolution in the absence of planetary wave forcing ('no dynamics'). Direct calculations show that interannual variability in EP flux contributes only a small fraction ($\sim$ 20%) of the decadal-scale 'trends' in ozone over NH midlatitudes.

15th(Thu)

15-1

On the role of cumulus-driven mixing in the tropical tropopause layer

Steven SHERWOOD

Yale University

A role for convection in helping to form the tropical tropopause, and in dehydrating the stratosphere, has long been postulated but seldom addressed in depth. In this brief talk I will overview recent observational and modeling work in this area, concerning both dehydration of the stratosphere and the more general question of dynamics at the top of the tropospheric boundary layer. The modeling work does not establish beyond question that this mechanism is important, but does indicate that the importance of convective overshooting to the stratospheric moisture budget cannot be ruled out on the basis of either the infrequent nature of overshooting convection, nor the observed profiles of water vapor and ozone—as these are all consistent with a strong convective influence. The modeling work shows how cloud microphsyics could influence stratospheric moisture. I will also present recent observational evidence that tropospheric aerosols, deep convective clouds, and stratospheric moisture may be connected.

15-2

The role of the equatorial Kelvin wave in stratosphere-troposphere exchange

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(2) *Center for Climate System Research, University of Tokyo*

Fujiwara et al. (JGR, 1998) first observed a stratosphere-troposphere exchange event associated with an equatorial Kelvin wave around the tropopause and the coupled convections in the troposphere, by conducting an intensive observation with ozonesondes and radiosondes in Indonesia in May-June 1995. By using a general circulation model incorporating a simplified ozone photochemistry, the present study investigates large-scale disturbances which cause the variations of ozone and water vapor around the equatorial tropopause. Eastward-moving large-scale equatorial gravity waves are found to be dominant to modulate the minor constituents' distribution around the equatorial tropopause in the model. A case over the Indian Ocean in the northern summer is investigated in detail. The disturbance can be regarded as an equatorial Kelvin wave at the tropopause level, coupled with active convections in the troposphere. Associated with the downward-displacement (and suppressed-convection) phase of this system, stratospheric dry, ozone-rich air moves downward into the upper troposphere. At the opposite phase, physical and dynamical processes above the organized active convections prevent the lower stratosphere from excess water. Thus, the dryness around the equatorial tropopause is maintained during the passage of such a system. Analysis of four-year integration data reveals that such disturbances are especially active over the Indian Ocean in the northern summer. This is probably related to the development of the summer monsoon circulation over south Asia.

15-3

The balance of processes governing stratosphere-troposphere exchange at the tropical tropopause

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(1) *NCAR*, (2) *University of Colorado, Boulder*

A variety of different processes are important for the exchange of air and water vapor across the tropical tropopause into the stratosphere. Recent work on the role of convection, cirrus clouds, transport and the stratospheric wave driven circulation is revisited. New diagnostics of the effect of convection on the tropopause region are discussed. The variability of these processes on timescales from the diurnal to the seasonal and annual is discussed. Convection plays an important role in lofting air into the tropopause region, but is not the dominant process for moving air into the stratosphere. The role of cirrus clouds and transport in the tropopause region is also discussed.

15-4

Mass transport and wave packets in low frequency variations

Koji AKAHORI

Department of Computational Science and Engineering, Nagoya University

The interaction between baroclinic disturbances and the background flow without topographic Rossby waves generates low frequency variations of the zonally symmetric component. In this study, low frequency variability is investigated in terms of mass transport and downstream development.

Low frequency variations in the mean zonal flow and baroclinic eddies with a time scale of 100 days, in spite of the equinox condition, are observed in a simplified primitive equation model without topography. These low frequency variations are similar to intraseasonal variations in the Southern Hemisphere. A modified Lagrangian-mean diagnostics of tracer transport in the stratosphere is extended to study the low frequency variations in the troposphere from a viewpoint of mass conservation. In the active baroclinic eddies phase, mixing of the potential vorticity associated with the dissipation process is enhanced and stabilizes the basic flow field. In the inactive baroclinic eddies phase, the recovery of the potential temperature field by thermal forcing is relatively important and increase the instability. As a result of the non-conservative process cycle, the meridional Lagrangian circulation of the mass around the tropopause at midlatitudes is formed. We also obtained similar picture from a high-resolution primitive equation model experiments with more sophisticated radiative and moisture processes.

The activity of such baroclinic disturbances is also characterized by downstream development phenomena in which the wave packets propagate faster than the phase speed of each unstable eddy. Dominance of the zonally symmetric component in low frequency variations would be caused by the downstream development. In order to clarify the essence of the downstream development, we performed 2D barotropic instability experiments; the dynamics of which are analogue to that of the 3D baroclinically unstable atmosphere from the point of potential vorticity. First, similar wave packets are found only for some appropriate forced profiles in forced-dissipated experiments using the shallow-water equation model on a rotating sphere. Next, parametric experiments of initial value problem using the β-plane non-divergent model are performed. They show that the appearance of downstream (upstream) development depends on the relationship between the sign of β and the direction of a basic flow. For an efficient undulation of adjacent fluid by disturbances at the leading edge to occur, the phase of Rossby waves must be fixed by means of background flow. A group velocity of the wave packet can be approximately estimated based on these factors.

15-5

Influence of the vertical structure of gravity wave drag on the mean age of air and ozone in the lower stratosphere

Dylan B.A. JONES, A.E. Andrews, H.R. Schneider and M.B. McElroy

Harvard University

The sensitivity of mean age of air in the stratosphere to the vertical structure of mass exchange between the tropics and midlatitudes is examined with a two-dimensional model with consistent advective and diffusive transport. The NASA Models and Measurements Intercomparison II (MMII) revealed that there are large differences between models in the calculated distribution of long-lived trace gases and in the mean age of air. It was found that in the lower stratosphere most models significantly underestimated the mean age of air as well as the tropical-extratropical gradient in mean age. We use estimates of mean age of air and age spectra in the midlatitude lower stratosphere, derived from observations of CO_2, to constrain transport from the tropics to midlatitudes. The empirical age spectra for the midlatitude lower stratosphere are bimodal with peaks at $\sim$ 1 and 5-6 years, suggesting that air is supplied to the extratropical lower stratosphere by two distinct paths, one fast and one slow. We show that the young peak can be produced by rapid horizontal transport out of the tropics in the lower stratosphere, while the older peak represents downward advection of air into the extratropical lower stratosphere by the mean meridional circulation. To reproduce the latitudinal gradient in mean age in the lower stratosphere as well as the bimodal age spectra derived for the midlatitude lower stratosphere, the rate of horizontal transport from the tropics to midlatitudes between 20-30 km must be slower than that at higher and lower altitudes. Slow horizontal transport between 20-30 km can generally not be obtained by reducing only the diffusive component of transport. Horizontal advective transport in this region, which is sensitive to the distribution of gravity wave drag in the lower and middle stratosphere, must also be weak.

15-6

Effect of synoptic-scale disturbances on appearance of medium-scale tropopausal waves over the western Pacific

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Characteristics of appearance of medium-scale tropopausal wave disturbances (with horizontal scales of 2000–3000 km) over the midlatitude western Pacific are investigated using global operational analysis data, based on horizontal distribution of potential temperature on a surface of constant potential vorticity which almost corresponds to the tropopause in the extratropics. One typical case is associated with the development of a synoptic-scale high potential temperature anomaly over West Siberia. In this case, low potential temperature in the polar region is advected equatorward by the anticyclonic flow on the east of the high potential temperature anomaly and then eastward by the midlatitude westerly jet, while being stretched. Accordingly, the horizontal gradient of potential temperature is enhanced over East Asia, followed by the appearance of the medium-scale waves. These features suggest that synoptic-scale disturbances play a role both in bringing a favorable condition for the existence of the medium-scale waves and in triggering the waves.

15-7

Stratosphere troposphere coupling inferred from SAGE II and HALOE measurements

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The Stratospheric Aerosol and Gas Experiment (SAGE) II and the UARS Halogen Occultation Experiment (HALOE) instruments have provided a comprehensive data-base for characterizing stratospheric trace gas species and aerosols. There is still a need to continue monitoring long-term behavior of these parameters in order to expand current understanding of fundamental middle atmosphere chemical and physical processes. An opportunity exists to investigate the SAGE II and HALOE data products in detail to understand the unexplained interannual variability that is evident in some of the constituents. Interannual variability in upper stratospheric CH_4 concentrations is shown to be a significant part of the overall temporal variations seen in the HALOE observational record. This interannual variability may complicate the identification and interpretation of longer-term trends in other constituents such as O_3 and HCl. In this study we show that this interannual variability is strongly correlated with quasi-biennial oscillations (QBO) and El Nino Southern Oscillation (ENSO) anomalies. The physical mechanism for the QBO/tracer coupling is well understood (Grey and Russell, 1999, JAS). QBO westerlies tend to duct EP fluxes towards the pole, leading to increased momentum deposition and stronger residual circulations. QBO easterlies tend to cause increased subtropical absorption of the Eliassen-Palm (EP) fluxes and weaker residual circulations. The physical mechanism for the ENSO/tracer coupling is currently under investigation, but is likely to be associated with ENSO driven modulations of the amplitude of the Northern Hemisphere tropospheric planetary waves, particularly the Pacific-North-American (PNA) pattern. Warm-phase ENSOs lead to enhanced PNA patterns and stronger vertical EP fluxes in the stratosphere, which strengthens the stratospheric residual circulation. The converse is true for cold-phase ENSOs. Together, the QBO and ENSO forcings lead to significant interannual variations in the strength of the stratospheric circulation. The combined effects of QBO and ENSO driven circulation anomalies on interannual stratospheric tracer variability is currently being investigated using the LaRC IMPACT model, a fully coupled chemical/dynamical model of the Earth's Atmosphere (Pierce et al., 2000, JGR).

15-8

Breakup of the polar vortex in the Northern and Southern late winters

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The Improved Limb Atmospheric Spectrometer (ILAS) on board the Advanced Earth Observing Satellite (ADEOS) made measurements of stratospheric minor gases and aerosols in the Arctic and Antarctic polar region from November 1996 to June 1997. We focused on profiles of long-lived gases (e.g., nitrous oxide) on the periods of the vortex breakup in both hemispheres: November-December in the Southern hemisphere and April-May in the Northern hemisphere, and confirmed that they well follow dynamical processes. The large differences of mixing ratios are seen between inside and outside the polar vortex when the polar vortex exists. This means that the westerly jet acts as a barrier. Moreover, as the polar vortex breaks up, the large differences also disappear, and the mixing of the air inside and outside the polar vortex can be seen. This event moves downward in both hemispheres as time passes. On the basis of an analysis of wind fields, the downward speed is almost constant in the Southern hemisphere, on the other hand, it has variability in the Northern hemisphere. The difference between two hemispheres seems to be caused by the difference of the form of the westerly jet, that is, the propagation of the planetary waves.

15-9

Observed changes in the frequency of occurrence of extreme weather events following stratospheric circulation anomalies

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Baldwin and Dunkerton (2001) have demonstrated that pronounced anomalies in the strength of the wintertime polar vortex precede long-lived (1-2 months) anomalies in the surface signature of the Northern Hemisphere annular mode. In turn, Thompson and Wallace (2001) have shown that fluctuations in the surface signature of the annular mode impact the frequency of occurrence of extreme weather events such as cold air outbreaks and high wind events throughout the Northern Hemisphere, not just over the Atlantic sector as suggested in previous studies. Motivated by the results of these papers, here we assess the direct linkage between anomalies in the strength of the lower stratospheric polar vortex and the incidence of extreme weather events throughout the Northern Hemisphere. Preliminary results are encouraging: cold air outbreaks occur with (significantly) greater frequency over much of eastern Asia, Europe, and North America during the two months following stratospheric warmings, and high wind events occur with greater frequency over the Pacific Northwest and Northern Europe during the two months following strong vortex conditions.

15-10

Wave/mean-flow interaction in the Southern Hemisphere: Composite analysis with respect to the QBO phases

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In the Southern Hemisphere, interannual variability of the stratospheric circulation is the largest in spring. The evolution of the polar-night jet in this season and its relationship with the planetary wave propagation are investigated from the view of a composite analysis with respect to the QBO westerly (W) and easterly (E) phases.

The stratospheric zonal wind in November is stronger in the W than in the E, as was shown by Baldwin and Dunkerton (1998). It implies that the deceleration in October is larger in the E. This is consistent with the result for the convergence of the Eliassen-Palm (E-P) flux; the convergence at the stratosphere in October is larger in the E. Furthermore, it is found that the upward component of the E-P flux from the troposphere in October is larger in the E, which supports the larger convergence at the stratosphere.

Also the tropospheric results for the equatorward component of the E-P flux and zonal wind are shown. They may have a certain connection with the upward flux, and hence the evolution of the stratospheric wind.

15-11

Earlier days of equatorial middle atmosphere studies — personal retrospective —

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An historical review is presented, in a personal retrospective manner, on the development of our understanding of the equatorial middle atmosphere dynamics.

Starting from the dawn in early 1960's, which is the age just after the IGY as symbolized by the discovery of the stratospheric QBO, some interesting episodes of pioneering works made at the University of Tokyo are recollected.

Then the expansion into the equatorial upper stratosphere and mesosphere around 1980 at Kyoto University for the SAO and fast Kelvin waves with the aid of rocket and satellite observations is reviewed, in connection with the phase of international Middle Atmosphere Program(MAP), where observational and theoretical studies of planetary waves and gravity waves have been strikingly developed as well.

Finally, suggestions will be given to young scientists in our field for future developments in the new Century.

16th(Fri)

16-1

Short vertical wavelength Kelvin waves revealed by equatorial radiosonde data

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Stratospheric zonal wind and temperature oscillations observed in a 30 day time series of 4 times per day radiosonde data taken as part of Nauru99, show a strong negative quadrature relationship at periods of 9.5 days and 5 days. The 9.5 day waves have vertical wavelength of about 5 km, and are deduced to be Kelvin waves of zonal wavenumber 2; the 5 day waves have vertical wavelengths in the range of 3-4 km, and are deduced to be Kelvin waves of zonal wavenumber 4. Vertical momentum fluxes associated with the 9.5 and 5 day modes are estimated to be 1×10^{-4} m^2s^{-2} and 2×10^{-4} m^2s^{-2}, respectively. These are smaller than momentum fluxes associated with traditional wavenumber 1 Kelvin waves.

16-2

Convectively generated gravity waves in the tropics

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In the past few decades several theories have been proposed to account for excitation of waves by cumulus convection. Some of them suppose diabatic heating as the dominant forcing term in the linearized equation of wave, while others suppose mechanical forcing which could serve in several ways (i.e., as moving mountains, oscillators, etc.). Which of the mechanisms are dominant has not well been investigated. The answer could depend on the scale and type of wave questioned as well as other factors such as the mean flow in the troposphere.

In this presentation the wave excitation mechanisms will be reviewed and examined by using data from numerical models: a mesoscale model that resolves cumulus convection explicitly and a global model in which cumulus convection is parameterized.

16-3

Characteristics of gravity waves in the stratosphere reveled by the GPS/MET data

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GPS/MET (Global Positioning System/Meteorology) experiment has successfully provided profiles of atmospheric temperature in the upper troposphere and stratosphere from April 1995 to February 1997 by means of radio occultation observations of GPS signals. We have extracted mesoscale temperature perturbations from individual GPS/MET profiles, and estimated potential energy Ep, presumably caused by atmospheric gravity waves. Taking advantage of the global coverage of the GPS/MET data, we have studied a global distribution of Ep in the stratosphere.

Our analysis shows that the largest Ep values at 20-30 km are generally centered around the equator between 25N and 25S with considerable longitude variations, and they are particularly enhanced over the Indonesia, Africa and south America. This result strongly suggests that atmospheric gravity waves are generated by tropical convection. Above 30 km altitude, Ep tends to become larger at midlatitudes with larger Ep values in winter months in both hemispheres.

Longitude variations of Ep at 20-30 km are analyzed in a latitude range of 35-55S during a prime time in February, 1997 when GPS/MET was operated in a mode without anti-spoofing. We have found a clear evidence that Ep is significantly enhanced over the Andes mountain range, indicating the generation of mountain lee waves due to interaction between the mean winds and topography.

We have re-analyzed temperature profiles with a vertical resolution of 200 m during three prime times under A/S-off condition in June/July 1995, October 1995 and February 1997, and calculated the vertical wavenumber spectrum of the normalized temperature fluctuations. The spectra at 20-30 km agree very well with radiosonde observations as well as a model spectrum assuming a linear saturation of gravity waves. We have calculated the normalized temperature variance integrating the spectra for two wavelength ranges: 10-2.5 km and 2-0.4 km. The seasonal and latitudinal variations of the gravity wave activity are evident. In particular, the temperature variance values are largely enhanced near the equator for both long and short wavelength ranges at 20-30 km.

16-4

Gravity waves in the polar middle atmosphere

Kaoru SATO

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Gravity waves are considered to be important for dynamics and chemistry in the polar middle atmosphere. However, there are only a limited number of studies of gravity waves in the polar region mostly because of difficulty of their observation.

The gravity wave source is one of the significant issues, because wave parameters such as wavelengths and phase velocities which are essential to consider the gravity wave effects on the large-scale field are highly dependent on the source. Dominant sources of gravity waves in the polar regions, namely topography, the polar-night jet, and tropical convection, are discussed based on recent observational and numerical studies.

At NIPR, several projects to examine gravity waves in the polar regions have been started. They are the cruise experiment of the latitudinal scan of the stratosphere, the intensive radiosonde observations at Syowa Station in the Antarctic, and the MST (Mesosphere, Stratosphere, and Troposphere) radar construction at Syowa Station. The current status of these projects is also introduced.

16-5

The global signal of the 11-year sunspot cycle in the stratosphere: Observations and models

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Earlier studies used the data from four solar cycles, to examine the global structure of the signal of the 11-year sunspot cycle (SSC) in the stratosphere and troposphere, using correlations between the solar cycle and heights and temperatures at different pressure levels. Here, this work is expanded to show the differences of geopotential heights and temperatures between maxima and minima of the SSC. These studies put the earlier work on a firmer ground and give quantitative values for comparisons with models.

16-6

The interannual variation of the stratospheric circulation in the northern hemisphere spring associated with the QBO

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The interannual variation of the wave amplitude of the stationary wave number one in March is observed from the monthly-mean geopotential height field from 1993 to 1996. By analyzing the daily synoptic charts of the geopotential height fields, it is found that the mechanism of wave development in the even years is different from that in the odd years. The first mechanism is wave development by the strong upward EP flux from the troposphere and its convergence in the stratosphere. The other one is wave development by the wave-wave interaction in the upper stratosphere. In the latter case, the wave amplitude of the monthly mean geopotential height becomes much stronger than that of the former. Wave development through wave-wave interaction is observed to depend on the zonal mean zonal wind structure at the mid-latitude upper stratosphere. The zonal wind distribution determines the dissipation rates of the waves, and which have significant influences on wave development. The zonal wind is associated with the temperature distribution, which also shows a biennial variation. The temperature anomaly in the middle latitude region is consistent with the effects of the secondary meridional circulation associated with the equatorial quasi-biennial oscillation. The NCAR CCM was used to verify the influences of zonal winds on planetary wave propagation. The model results support the role of the zonal wind in the upper stratosphere middle latitude for determining propagation and amplification of the planetary wave.

16-7

Modulation of the seasonal tropopause environment by the stratospheric quasibiennial oscillation

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The influence of the stratospheric quasibiennial oscillation (QBO) on the seasonal tropical tropopause region is explored using 41 years (1958-1998) of meteorological fields from the National Centers for Environmental Prediction (NCEP). Three physical mechanisms have been proposed in the literature which could link the QBO to the strength of tropospheric convection, and hurricanes in particular: 1) a higher, colder tropopause can enhance the efficiency of energy conversion, 2) stronger wind shear across cloud tops can disrupt the coherence of convection, and 3) reduced inertial stability at outflow level can promote convective strength. Primary variables examined include seasonal mean tropopause temperature, tropopause pressure, 70-150 hPa wind shear, geopotential height and wind at 150 hPa, and relative vorticity at 150 hPa. Global fields of outgoing longwave radiation (OLR) during 1974-1998 are also examined as an indicator of convective strength, with reduced OLR being linked to deeper, stronger convection. These quantities are binned according to QBO zonal wind shear in the lower stratosphere (Huesmann and Hitchman, 2000). QBO westerly minus easterly shear (W-E) fields are shown, with statistical significance evaluated using Student's t-test.

During QBO westerly shear the tropopause is warmer and lower equatorward of 20 degrees latitude. This effect is most pronounced when and where the tropopause is highest: boreal winter and near major convective centers. In the subtropics the tropopause is cooler and higher during QBO westerly shear, amplifying the Tibetan High during boreal summer. Cross-tropopause shear associated with the QBO has a uniform sign equatorward of 30 degrees. The time mean easterly shear present in much of the tropics is diminished by QBO westerly shear, except near the equator over Amazonia and from Africa to the date line, where the seasonal mean westerly shear is augmented. During QBO westerly shear, OLR is enhanced (convection is reduced) in Southeast Asia, Central Africa, and the Gulf of Panama during boreal summer and in Amazonia, southern tropical Africa, and Indonesia during boreal winter. Notable exceptions are reduced OLR during QBO westerly shear northeast of Australia in boreal winter and in the Eastern Pacific. Since hurricanes occur in the band ± 10 to 25 degrees and wind shear varies with season and region, the response of hurricanes to the QBO should be different in different regions. This 41 year data record supports Gray et al.'s (1992) hypothesis that QBO westerly shear promotes more strong hurricanes in the North Atlantic due to diminished shear strength, but also by a higher, colder tropopause in the maturation phase. A qualitative ranking of the importance of the three mechanisms is: tropopause temperature, wind shear, then outflow inertial stability.

16-8

Interannual variability in the lifecycle of stratospheric polar vortices

Darryn WAUGH and P.-P. Rong

Johns Hopkins University

Examination of meteorological analyses shows that is large interannual, and smaller decadal and longer time scale, variations in the timing of the breakup of the Arctic vortex. These variations are correlated with the strength and coldness of the spring vortex as well as with the upper tropospheric/lower stratospheric eddy heat flux prior to the breakup. The latter correlation indicates that the variability in the wave activity entering the stratosphere over late-winter to early-spring plays a key role in the variability of the vortex persistence on both interannual and decadal time scales.

The timing of the vortex breakup is also found to play a large role in the characteristics of the breakup. In years when there is an early breakup there is a gradual decay of coherent vortex fragments and a gradual change in mixing properties, whereas there is a rapid transition for late breakups.

To examine the processes controlling the above aspects of the vortex lifecycle we have performed simulations using a shallow water model, in which there is time-varying topographic forcing (to mimic upward propagating Rossby waves) and relaxation to a seasonally-varying state (to mimic the seasonal variation in radiative forcing). By varying the different parameters in the model we examine the relative roles of changes in the wave and radiative forcing in determining the timing and characteristics of the vortex breakup.

16-9

Intraseasonal oscillations in the wintertime polar stratosphere

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This study investigated the intraseasonal variability in the wintertime polar stratosphere as shown in the UKMO UARS assimilation data. The results of the spectral analyses applied to the daily zonal wind fluctuation in the upper atmosphere suggest the existence of a quasi-periodic oscillation in the subseasonal timescale (longer than two weeks). This oscillation explains about 40 percents of the total variances of the daily zonal wind departure from the seasonal cycle (i.e., the first three harmonics) in the winter polar regions.

The EOF analysis was applied to the band-pass (20-to-80 days) filtered zonal wind in the Northern and South Hemisphere, respectively, to extract the major spatial structures and their corresponding temporal evolution. The first two EOF's are dominated by a wavenumber one structure in the high latitudes of both hemisphere and appear to be in quadrature in both time and space. These two structures are named the Arctic and Antarctic pattern, respectively. The former explains about 66 percent of the total variance at 30 hPa, and the latter explains about 47 percent at 10 hPa. Both patterns exhibit an equivalent barotropic structure extending from the upper troposphere to the upper stratosphere. The time-lag relationship suggests that the first two modes constitute an eastward propagating mode. While the Antarctic pattern exhibits the characteristics very similar to a pure traveling wave, the Arctic pattern comprises of both standing and traveling wave. The latter tends to amplify over the Eurasian and North American continents. There is strong seasonal dependency. Both patterns appear only during the winter.

To objectively determine the local wavenumber and frequency of the traveling patterns, the Complex Singular Value Decomposition (CSVD) was applied to the zonal wind departure in the both Northern and Southern Hemisphere. The features described above appeared as the first eigenmodes in the respective CSVD analysis. The first eigenmodes, which correspond to the Arctic and Antarctic patterns, exhibit a spatial structure with a scale equivalent to the local wavenumber 0.92 and 1.03 at 50°N and 50°S, where the amplitude maximum are located, respectively. The local angular frequencies for both patterns are about 0.2 rad/day and are equivalent to 10.5 m/s and 9.2 m/s for the Arctic and Antarctic pattern, respectively. The most likely oscillatory period is about 28.3 for the Arctic pattern and 32.5 days for the Antarctic pattern.

The 27-day period had been found in both UV and ozone concentration fluctuation and has been attributed to the solar rotation effect. The patterns identified in this study appear to have the similar periodicity. Whether these two patterns are forced by the solar heating remains to be seen. Lagged regression analysis is being performed to examine the spatial and temporal structure of both patterns and to explore their relationship with the ozone and UV fluctuation. Further analysis is being carried out to investigate the effect of these two patterns on the stratosphere-troposphere coupling.

17th(Sat)

17-1

The northern hemisphere annular mode: A survey

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The existence of annular modes–patterns of atmospheric variability that are fundamentally zonally symmetric– remains controversial. Citing the lack of linear temporal correlation between sea-level pressure fluctuations over the Atlantic and Pacific sectors, Ambaum, Hoskins and Stephenson have recently argued that the Northern Hemisphere annular mode (NAM) could be an artifact of EOF analysis: a misrepresentation of the sectoral North Atlantic Oscillation (NAO) or a degraded (linear) signature of nonlinear, 'regime-like' behavior in the hemispheric circulation. The case that the NAM is real rests on a variety of statistical and dynamical evidence: in particular its remarkable structural and dynamical similarity to the Southern Hemisphere annular mode.

Also at issue is the question of how best to describe the coupling between troposphere and stratosphere in the NAM. Should the NAM be viewed as a single, loosely connected entity extending from the earth's surface all the way up to the stratopause level (as in the multi-level EOF analysis of Baldwin and Dunkerton) or as an exclusively tropospheric phenomenon which is sometimes coupled with independently occurring vacillations of the wintertime stratospheric polar night jet (independently represented as a 'polar jet oscillation' or 'PJO'), as suggested by Kodera?

In support of Kodera's view, the tropospheric NAM and its Southern Hemisphere counterpart both appear to be sustained by the positive feedback of the eddy fluxes of zonal momentum by baroclinic waves upon the anomalies in the zonally symmetric flow. These wave-mean flow interactions are concentrated near the tropospheric jetstream level. In contrast, the stratospheric variability that occurs in association with the NAM involves vacillations in which the zonal flow interacts with the planetary waves. Model simulations indicate that once initiated, these vacillation cycles have a life of their own, independent of the ongoing wave forcing from the troposphere. The observations indicate that the NAM-related variability at stratospheric levels exhibits much stronger seasonality and a much redder frequency spectrum (when active) than the NAM-related variability at tropospheric levels. The e-folding time scale of latter is only on the order of 10 days: long by tropospheric standards but short compared to the time scale of the evolution of the polar night jet.

Yet despite these marked differences in morphology, evolution and seasonality of wave-mean flow interaction in the troposphere and stratosphere, it isn't obvious how to unequivocally separate them in practice. A residual 'tropospheric NAM index' derived by regressing out the stratospheric variability is bound to be sensitive to the precise manner in which the latter is defined. If the prescription is not entirely correct, the error would impart a spurious low frequency signal to the residual tropospheric index. Even in the absence of such ambiguities, a tropospheric NAM index that was constrained to be linearly independent of a stratospheric 'PJO' would be difficult to interpret. An alternative analysis strategy would be to simply apply a low-pass filter to the tropospheric index of the NAM to remove the variability at frequencies higher than those at which the stratosphere is capable of interacting with the troposphere. Investigators who rely on monthly mean data are already employing such a filter, de facto.

17-2

Coupled stratosphere and troposphere variability in the northern hemisphere winter

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Climate Research Department, Meteorological Research Institute

The relationship between stratospheric sudden warmings (SSWs) and slowly propagating zonal wind anomalies during the northern hemisphere cold season is first investigated using two leading empirical orthogonal functions (EOFs) of zonal-mean zonal wind. Intraseasonal variability of the polar night-jet is characterized by the poleward and downward propagation of the zonal-mean zonal wind anomalies. This poleward and downward propagation of wind anomalies (hereafter referred to the Polar-night Jet Oscillation, PJO) can be translated as rotation of state vector in a plane spanned by the two EOFs. Major SSWs occur in phase with the PJO. Movement of the state vector suggests quasi-periodicity of the order of 4 months, although generally only one cycle is achieved during a major warming winter. This characteristic feature can be compared to the stratospheric vacillation cycle in a mechanistic model. It is also found that changes in meridional propagation of tropospheric planetary waves occur in phase of the PJO. Accompanying tropospheric circulation changes are characterized as changes in the Arctic Oscillation.

Conversely the role of the stratospheric variability in the AO is investigated by selecting 18 large month-to-month variation events. It is shown that although tropospheric features are very similar, the vertical structure of the AO differs considerably depending on whether it is initiated by a downward propagation of zonal-mean zonal wind anomalies from the stratosphere or it is produced within the troposphere.

17-3

Stratosphere-troposphere coupling in the Southern Hemisphere associated with interannual variability and longer-term trends

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A brief review will be given of observed trends in ozone, temperature and circulation in the Southern Hemisphere stratosphere over the last 20-30 years. The focus is on changes in the winter and spring associated with the strengthening of the Antarctic circumpolar vortex, colder temperatures over the polar cap, and strengthening of the Antarctic ozone hole. These trends are discussed in the context of the typical modes of year-to-year variability of the SH stratosphere and possible links to variability and trends in the SH troposphere. Separate analyses have identified changes in the circulation of the SH troposphere in middle and high latitudes associated with a strengthening of the zonal flow.

Possible mechanisms for the trends in the lower stratosphere and troposphere are described, including stratospheric ozone depletion and greenhouse climate change. The possibility of feedbacks between these two mechanisms and dynamical links between the troposphere and the lower stratosphere in the SH are discussed.

17-4

Changes in weather patterns following stratospheric circulation anomalies

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Northwest Research Associates

With the exception of El Niño/Southern Oscillation, tropospheric weather patterns tend not to persist for more than a week or so, making long-range weather forecasts problematic. Circulation regimes within the stratosphere tend to persist longer, but the stratosphere is generally regarded as having little influence on surface weather patterns. I will present observations that show that large circulation anomalies often begin above the stratopause, and propagate downward at least to the lowermost stratosphere. Composites of weak vortex events and strong vortex events (defined by an annular mode index at 10 hPa) show that the circulation anomalies in the lower stratosphere persist for more than two months. This long persistence just above the tropopause appears to favour tropospheric anomalies of the same sign. During the 60 days following extreme circulation anomalies in the middle stratosphere, surface pressure anomalies resemble closely the Arctic Oscillation pattern. Storm tracks and the likelihood of midlatitude cyclones are also affected.

Although stratospheric circulation anomalies are caused by upward propagating planetary-scale waves, processes within the stratosphere do affect the likelihood of extreme events and subsequent changes in surface weather. The QBO in the equatorial stratosphere modulates the wave guide for upward-propagating planetary waves so that major stratospheric warmings are less likely when the equatorial winds are westerly (Holton and Tan, 1980). Weak vortex events are twice as likely when the QBO (40-hPa equatorial wind) is easterly, and strong vortex events are 2.75 times as likely when the QBO is westerly. Since the phase of the QBO can be anticipated up to a year in advance, this result implies a small degree of long-range forecastability. These results suggest that other processes within the stratosphere could have some influence on surface weather if they can affect the likelihood or timing of extreme circulation events in the stratosphere.

17-5

Tropical origins for recent North Atlantic climate change

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New evidence is presented that North Atlantic climate change since 1950 is linked to a progressive warming of tropical sea surface temperatures, especially over the Indian and Pacific Oceans. The latter is a behavior predicted to occur as a result of human-induced increases in greenhouse gases. The ocean changes alter the pattern and magnitude of tropical rainfall and atmospheric heating, the atmospheric response to which includes the spatial structure of the North Atlantic Oscillation (NAO). The slow, tropical ocean warming has thus forced a commensurate trend toward one extreme phase of NAO the last half-century.

17-6

Formation of the zonal asymmetry in wintertime circulations in an idealized AGCM: Westerly jet core, stationary eddy, and storm track

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A set of CCSR/NIES atmospheric general circulation model (AGCM) perpetual January experiments under idealized surface boundary conditions is performed to reveal the formation mechanism of the distinct zonal asymmetry observed in the wintertime upper tropospheric circulations. In particular, we focus upon the role of thermal forcings, such as extratropical continent-ocean heating contrast and tropical sea surface temperature (SST) distribution, in generating the subtropical westerly jet core and extratropical stationary eddies. The relationship between zonal localization of the storm track, near-surface baroclinicity, and extratropical stationary eddies is also investigated extensively.

First, by changing SST distribution in the AGCM without orography, we find that the tropical SST distribution plays a decisive role in producing the subtropical westerly jet core to the north of the tropical warm water pool. On the other hand, the effects of extratropical continent-ocean heating contrast, which has been widely believed as a major thermal forcing for the zonal asymmetry in westerly speed, are secondary. Aqua Planet runs further support this result.

Second, it is shown that the extratropical continent-ocean contrast, while forcing strong temperature variations in the lower atmosphere, induces only weak stationary eddies in high latitudes of AGCM. By contrast, zonal variations in the tropical SST induce strong stationary eddies both in the subtropics and extratropics. A robust jet core forms between the baroclinic subtropical and barotropic extratropical eddies. Because the balance between vortex tube stretching and absolute vorticity advection dominates in the time-mean vorticity equation, we find that the zonal variation in the divergence field induced by locally enhanced Hadley circulation due to the tropical warm water pool excites these stationary eddies.

Finally, we observe a variety of extratropical storm track organizations: In Aqua Planet experiments, zonally varying SSTs in the tropics make a rather zonally uniform storm track but force robust extratropical stationary eddies; Zonal variations in midlatitude SST, while exciting only weak stationary eddies, force a zonally localized storm track around the sharp meridional SST gradient; In another experiment with zonally uniform SST and an extratropical flat continent, the storm track is zonally uniform in spite of a strong maximum in near-surface baroclinicity off the east coast. Thus, neither large stationary eddy nor high baroclinicity automatically leads to a zonally localized storm track. We plan to discuss the localization of the storm track by examining the energetics of high-frequency eddies in the storm track region.

17-7

Internal interannual variations of the troposphere-stratosphere coupled system

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Internal interannual variations of the atmosphere are investigated by long time-integrations of a global circulation model which was modified from a troposphere-stratosphere-mesosphere GCM with some simplifications of physical processes. Under a purely periodic external condition of annual thermal forcing, 10 runs of 100-year integrations were done with different topographic amplitude of zonal wavenumber one from 0 m to 3000 m. If the amplitude is equal to zero or a small value, the interannual variation is very small, particularly in winter. The variation becomes large in spring for 400 - 600 m, which looks like the variation in the Southern Hemisphere (SH). If it is increased further ($\geq$ 1000 m), the variation becomes large in winter looking like the variation in the Northern Hemisphere (NH).

Two runs of 1000-year integrations were also done under the same purely periodic annual forcing to get statistically reliable frequency distributions of the interannual variations. The distributions for the topographic amplitude of 1000 m (NH-like) are positively skewed in autumn and bimodal in winter. On the other hand, those for 500 m (SH-like) have positive skewness for a longer months from autumn to spring and extremely large skewness is found in March. The time-series data analysis shows that the occurrence of the warm winters in the skewed distributions is well described by a Poisson process. That is, the warm winters occur at random from year to year, and preferred periodicity does not exist in the present internal interannual variability.

Based on these results and some perturbation experiments, the importance of nonlinear dynamical perspective is discussed, particularly to appreciate the effects of small-amplitude external interannual forcings such as the solar cycle, cooling trend in the stratosphere and so on. The existence of bimodality(or, multiple metastable states) in our troposphere-stratosphere coupled system is the key point.

Posters

P-1

Redistribution of reactive nitrogen in the arctic lower stratosphere in 1999-2000 winter

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We measured total reactive nitrogen (NO_y) in the Arctic lower stratosphere at 10-12 km from the NASA DC-8 aircraft during the SOLVE experiment in the winter of 1999-2000. The N_2O-NO_y correlation changed little in December 1999 and January 2000, while the NO_y values were slightly, however systematically higher in March 2000. Redistiribution of reactive nitrogen following denitrification at higher altitudes and subsequent mixing of these influenced air masses with surrounding ones were suggested as a cause of these observed results.

P-2

Redistribution of nitric acid in the arctic lower stratosphere during the winter of 1996-1997 analyzed with ILAS observations

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Denitrification (an irreversible removal of nitric acid) has a potential to affect springtime ozone recovery and future ozone layer in the stratosphere. The horizontal and vertical distributions of denitrification over the Arctic during the winter of 1996/1997 are presented. Based on them microphysical processes causing denitrification are discussed.

P-3

Composition of polar stratospheric clouds inferred from the ILAS data along with analysis of their temperature histories

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The Improved Limb Atmospheric Spectrometer (ILAS) captured many Polar Stratospheric Cloud (PSC) events during the winter and early spring of 1997 in the Northern Hemisphere and early winter of 1997 in the Southern Hemisphere. Comparison of the ILAS data with the theoretical predicted values for some PSC compositions and close examinations of temperature histories of all of the observed particles revealed that some typical type Ib PSCs were observed with the ILAS in mid-January and type Ia PSCs also in early March in the Arctic.

P-4

Development of a chemical model and comparison with ILAS data in the winter of 1997

Akiko KAGAWA and S. Hayashida

Nara Women's University

The purpose of this study is to develop a chemical model to apply to polar ozone studies. We integrated a chemical model with photodissociation coefficient, PSC growing effects, and a trajectory tool. Results from the model will be compared with ILAS(Improved Limb Atmospheric Spectrometer) data in the winter of 1997.

P-5

Meridional transport of minor species at the time of breakup of polar vortex observed by ILAS

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The ILAS onboard the ADEOS made measurements of minor species in both Arctic and Antarctic polar stratosphere from November 1996 to June 1997. During the course of breakup of polar vortices, it was found that air, which contains higher mixing ratios of minor species, penetrates into the polar vortex through the polar vortex boundaries. Moreover, the altitudes where main bodies of minor species penetrate in are found to depend on species and hemispheres. Causes of inter-hemispheric differences in comparison with planetary wave activities and/or wind fields are discussed.

P-6

Spatial distributions of upper tropospheric water vapor as observed by UARS Microwave Limb Sounder

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Water vapor(WV) plays several important roles through its radiative, chemical, and dynamical properties. The distribution of WV, especially tropical upper tropospheric WV(UTWV), influences the greenhouse effect and the space-time variations of WV in the stratosphere. We will discuss the spatial distribution in UTWV with UARS MLS data.

P-7

Quasi-biennial oscillation in vertical velocity inferred from trace gas data in the equatorial lower stratosphere

Masanori NIWANO and M. Shiotani

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Vertical velocity variations associated with the quasi-biennial oscillation (QBO) in the equatorial lower stratosphere are investigated with an annual cycle in total water ($[H_2O]+2[CH_4]$) profiles from the Halogen Occultation Experiment (HALOE).

P-8

The feedback of the ozone perturbations on the generation of the Quasi-Biennial Oscillation in the equatorial stratosphere

Teppei UETAKE[(1)], F. Hasebe[(1)], M. Takahashi[(2)] and T. Nagashima[(2)]

(1) *Ibaraki University*, (2) *University of Tokyo*

The hypothesis on the feedback of the ozone perturbations through absorption of shortwave radiation on the generation of the QBO in the equatorial stratosphere is examined by analyzing the 3-dimensional time-dependent dynamical/radiative/chemical fields simulated in the CCSR/NIES AGCM. The driving mechanism of the ozone QBO and the zonal wind acceleration due to the ozone feedback is presented.

P-9

Interannual variations of the general circulation and the Antarctic ozone hole in a general circulation model

Shingo WATANABE, T. Hirooka and S. Miyahara

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Interannual variations of the general circulation and the Antarctic ozone hole are investigated by using a general circulation model developed at Kyushu University. Their interaction mechanism and stratosphere-troposphere coupled variability will be discussed.

P-10

Estimation of isolation of the polar vortex using the Time Threshold Diagnostics

Seiji SUGATA and H. Kanzawa

National Institute for Environmental Studies

A new method, named time threshold diagnostics (TTD), was developed by Sugata (2000, JMSJ) for estimating effective flux of air parcels across given boundaries in the atmosphere. The TTD method is applied to the problem of isolation of the polar vortices in the 1996/1997 Northern Hemisphere winter and the 1996 Southern Hemisphere winter. Intensity of the isolation of the NH vortex in March 1997 is shown comparable with that of the SH one in Oct. 1996. Motions of air parcels across the vortex boundaries are also discussed for stable/unstable periods of the vortices, respectively.

P-11

Interannual variability of the mixing and transport inside the polar vortex of the middle and upper stratosphere in the winter southern hemisphere

Ryo MIZUTA and S. Yoden

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Horizontal mixing and transport inside the polar vortex of the middle and upper stratosphere are investigated using UKMO assimilated data. Strength of the mixing on isentropic surfaces is related to the instability of the polar night jet, and shows large interannual variability in 1990's.

P-12

Horizontal wind disturbances induced by inertial instability in the equatorial middle atmosphere

Hiroo HAYASHI and M. Shiotani

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Horizontal wind disturbances induced by inertial instability in the equatorial middle atmosphere are examined using rocketsonde observations at Kwajalein(9N,168E), with the help of temperature data from the LIMS on board the Nimbus 7.

P-13

Wave characteristics in the lower stratosphere over southeast Asian monsoon region revealed with GAME-T enhanced rawinsonde observations

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(2) *Faculty of Education, Fukushima University*

High frequency (3-hour interval) rawinsonde observations at NongKhai, Thailand (17N, 100E) have revealed clear wave structures. Frequency spectra show two isolated peaks at 1 day and near the inertial period (about 40 hours). Characteristics and generation mechanisms of these two waves are discussed.

P-14

Gravity wave characteristics in the Antarctic revealed by operational radiosonde observation data at Syowa station

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(1) *Department of Geophysics, Kyoto University,*
(2) *National Institute of Polar Research,* (3) *Japan Meteorological Agency*

Gravity waves in the Antarctic lower stratosphere are examined using operational radiosonde observations at Syowa station (69.0 S, 39.6 E). Temporal and vertical variations of wave characteristics, such as potential energy, direction of wave propagation, and ground-based phase speed, are compared with the variation of the background field.

P-15

Gravity wave activities associated with baiu front in a high resolution GCM simulation

Yoshio KAWATANI and M. Takahashi

CCSR, University of Tokyo

Gravity wave activities during the Baiu (early summer in Japan) season are investigated by a High Resolution (T106L60) general circulation model. It can be shown that the features of Baiu front and gravity waves are similarly reproduced compared with those of observed. The relation between gravity waves and frontal activities will be discussed.

P-16

Gravity wave radiation from instability of jets in shallow-water systems

Keiichi ISHIOKA[(1)], **N. Sugimoto**[(2)] **and S. Yoden**[(2)]

(1) *University of Tokyo,* (2) *Kyoto University*

Gravity wave radiation from instability of jets is examined using high-resolution shallow-water models on a sphere and f-plane. The origin of the gravity wave in the system is the curvature of the unstable jets. The mechanism of the radiation will be discussed.

P-17

On the role of synoptic disturbances in the maintenance of blocking flows

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The eddy-straining mechanism for the maintenance of blocking flows is reexamined by using an equivalent barotropic model on a beta plane. We find that the efficiency of the eddy-straining mechanism crucially depends on the dynamical property of the imposed eddies when the modon solution is assumed as the basic flow.

P-18

On the existence of subtropical anticyclone with equivalent barotropic structure over Japan in August

Takeshi ENOMOTO[(1)], **Y. Matsuda**[(1)], **and B.J. Hoskins**[(2)]

(1) *University of Tokyo,* (2) *University of Reading*

Within the planetary-scale structure of the upper-tropospheric Tibetan high formed during the NH summer, synoptic-scale stationary disturbances exist. A ridge over Japan corresponds to Ogasawara (Bonin) high. Our experiments using a primitive equation model with the climatological heating for August show that the stationary disturbances on the subtropical jet are induced mainly by the descent along the Silk Road over the desert. This phenomena near the tropopause is important not only for variations of the summer climate of Japan but also for the STE, water vapour exchange in particular.

P-19

Interannual variations of planetary waves in the southern hemisphere stratosphere and its relationship with the tropospheric circulation

Yasuko HIO and I. Hirota

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A statistical analysis is made of Southern Hemisphere stratospheric planetary waves for late winter in relation to the tropospheric circulation, especially to the transient baroclinic disturbances, by using the NCEP/NCAR reanalysis data-set for 20 years of September and October.

P-20

Relationship between planetary waves and polar vortex in the southern hemisphere stratosphere

Shinji USHIMARU

Numazu College of Technology

From the analysis of NCEP/NCAR reanalysis data, the following relationship between activity of planetary waves and variation of polar vortex in the SH stratosphere is found: In a year of stronger wave activity at the early winter, the polar vortex is stronger at the mid winter, while the wave activity is stronger at the late winter, which leads earlier breakdown of the vortex.

P-21

Effect of the solar activity on the polar-night jet oscillation

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Meteorological Research Institute

The effect of the solar activity on the Polar-night jet oscillations (PJOs) in Northern and Southern Hemispheres are investigated based on the observational data. It is found that the PJO preferably starts with the phase of the positive wind anomaly at the subtropics of the upper stratosphere in early winter due to the UV-heating contrast, when solar activity is maximized.

P-22

GCM experiments on the impact of surface boundary conditions on the arctic oscillation

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A set of AGCM experiments with idealized boundary conditions is conducted to examine the impact of boundary conditions (land-sea, orography and SST distribution) on the annular mode variability (the Arctic Oscillation). We also discuss the relationship between storm track organization and annular mode.

P-23

A numerical experiment on annular mode with a simple global circulation model

Masakazu TAGUCHI

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A numerical experiment with a simple global circulation model is performed to investigate annular mode in the troposphere and stratosphere; 10000-day integrations x 15 runs are done by changing amplitude of a sinusoidal surface topography. The experiment reveals that the annular mode changes with the amplitude in its nature.

P-24

Influence of surface topography on the annular variability

Noriyoshi TAKAHASHI, S. Nishizawa and S. Yoden

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A series of numerical experiments on the annular variability are done with an idealized global circulation model under a perpetual winter condition. Amplitude of a sinusoidal surface topography of zonal wavenumber 2 is changed from 0 m to 1000 m as an experimental parameter. EOF analyses are done for 9 runs of 4,000-day integrations under a perpetual winter condition in order to investigate the annular variability which is dependent on the amplitude of the planetary-wave forcing.

P-25

Overview of Stratospheric Platform R&D Program in Japan

Tamahiro KIMINO and M. Mori

Telecommunications Advancement Organization of Japan

The stratospheric platform is an unmanned airship kept at a stratospheric altitude of about 20 km for communications and earth observation purposes. It is equipped with a communications payload, observation sensors or other equipment. We present the oberview of this program.