Tropical and Extratropical Connections Associated with QBO and ENSO

M. Taguchi[1]

[1]Masakazu Taguchi, Aichi University of Education, Kariya, Japan

In this presentation, I will discuss two aspects of tropical and extratropical connections associated with the QBO: modulation of the QBO especially by the ENSO, and effects of the QBO and ENSO on the Northern winter stratosphere.

Observations have shown that the QBO is modulated with several factors such as the annual cycle, ENSO, and global warming. For example, we show that the QBO signals exhibit weaker amplitude and faster phase propagation for El Niño than for La Niña conditions. These modulations of the QBO can occur with those of wave activity/driving and/or residual mean vertical wind, although explicit diagnoses of these effects, e.g., using reanalyses data, are difficult partly due to nature and quality of the data. Simulating QBO modulations in a GCM will be also challenging.

It is well understood that the QBO and ENSO both affect time mean states of the Northern winter stratosphere resulting in nonlinear changes, whereas their effects on variability, such as MSSWs, are relatively unexplored. We examine changes in MSSW frequency with the QBO and ENSO using the NCEP/NCAR reanalysis data. We find that the MSSW frequency changes nonlinearly with the two factors as the time means: in particular, the MSSW probability is very high for La Niña and QBO easterly winters. The MSSWs for these winters occur with moderate wave forcing from the troposphere and relatively poleward wave propagation in the stratosphere. The 2006 MSSW is a characteristic case that shows these features. We will also examine reproducibility of these changes in GCM/CCM data.

Benefits of a New Wave Scheme for Trajectory Modeling of Stratospheric Water Vapor

J.-E. Kim[1], M. J. Alexander[2]

[1]Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, Colorado;
[2]NorthWest Research Associates, CoRA Office, Boulder, Colorado

Changes in stratospheric water vapor affect the fluxes of longwave radiation and influence surface temperature changes (Solomon *et al.,* 2010). Temperature in the tropical tropopause layer (TTL) is a key controlling factor of stratospheric water vapor, since slow ascent of air is dehydrated due to extremely cold temperatures in the TTL. Trajectory models have been used to simulate water vapor entering the stratosphere. Since trajectory simulations are based on temperatures and winds from analysis or reanalysis data, having realistic representation of temperatures in reanalysis data is critical to the dehydration results. However, there are uncertainties in the mean and variability in reanalysis data temperatures. Mean temperatures can be relatively easily adjusted to observational values. On the other hand, including unresolved or underrepresented waves in trajectory models requires a series of assumptions, and parameterized waves differ from realistic waves in important ways.

Here, we present a new wave parameterization scheme developed particularly for trajectory simulations. Temperature variability from reanalyses and radiosonde observations in the Western Pacific shows ERA-interim and MERRA have smoother temperature anomaly characteristics with weaker wave amplitudes. Moreover, interpolating temperatures in the vertical coordinate, which is the conventional way of using temperature from reanalyses in trajectory calculations, dampens wave amplitudes significantly. To overcome these problems in the representation of temperature variability we suggest a different interpolation approach: interpolating amplitudes and phases of waves in Fourier space. We show our scheme produces fine scale wave features with realistic amplitudes and intermittency. By amplifying underrepresented waves from reanalyses, the cold point tropopause height becomes more variable as it is affected by waves and cold point temperatures also dropped by about 0.5-1.5 K in the Western Pacific.

We further investigate how much the new method enhances the global representation of TTL waves and cold point temperatures. We also extend our study to include horizontal wind variability, and address wave effects and uncertainty issues on trajectory transport pathways. The results have important implications for modeling variability in stratospheric water vapor.

Reference: Solomon *et al., Science* **327,** 1219 (2010).

The Cloud Radiative Heating in the Upper Troposphere Lower Stratosphere over the Indian Subcontinent

E. Johansson[1, 2], A. Devasthale[1], T. L'Ecuyer[3], A. Ekman[2, 4] and M. Tjernström[2, 4]

1) Swedish Meteorological and Hydrological Institute, 601 76 Norrköping, Sweden
2) Meteorological Institute, Stockholm University, Stockholm, Sweden
3) Department of Atmospheric and Oceanic Sciences, University of Wisconsin-Madison, USA
4) Bert Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden

Monsoonal circulation is one of dominant modes of seasonal variability that affects the livelihood of millions over the Indian subcontinent. It is therefore important to understand various processes influencing monsoon, especially those dealing with atmospheric interactions. Convective cloud systems cover much of the subcontinent during the summer season and these systems occur in a wide range of spatio-temporal scales ranging from individual convective towers with the lifetime of some hours to mesoscale systems covering hundreds of kilometres and sustaining for days. The importance of radiative heating/cooling produced by these systems during monsoon is pointed out in a number of studies, including their role in influencing the processes occurring in the upper troposphere and lower stratosphere. However, very little is known regarding the vertical structure of cloud radiative heating and its pre- to post-monsoon transitioning.

In this context, we provide an observational perspective by investigating following scientific aspects using the state-of-the-art satellite based estimates of cloud radiative heating/cooling from combined CloudSat and CALIPSO dataset, covering the five year period of 2007-2011.

- The absolute and relative contributions of different cloud types, especially high clouds, nimbostratus, altostratus and deep convective cores as well as all clouds combined to the total radiative heating in the UT/LS region.
- The zonal vertical heating gradients and their pre-to-post monsoon transitioning.
- The role of intraseasonal oscillations in shaping the total cloud radiative heating.

Representation of Tropical Clouds, Dehydraion and the Tropopause Layer in global models

Andrew Gettelman[1]

[1]National Center for Atmospheric Research

The Tropical Tropopause Layer (TTL) is a critical region for understanding chemistry and climate. The TTL helps set the chemical budget of the stratosphere, and the climate of the stratosphere through dehydration processes that regulate stratospheric water vapor, and clouds that influence the climate of the troposphere all the way down to the surface. The important processes governing clouds and water vapor are represented in global models to varying degrees of fidelity. This presentation will review the current state of knowledge of cloud formation processes and how they are represented in global chemistry-climate models. This includes cirrus and convective cloud microphysics (and dynamics), ice nucleation, large-scale dynamics and wave motions. These processes occur on scales from the microscale to the global, spanning 12 orders of magnitude, and they must be represented in global models.

Global models are generally able to predict ice nucleation processes and the formation of cirrus clouds. Some models can represent ice supersaturation. An outstanding issue is the relationship between in-situ formed cirrus and convective detrainment: but this may be a 'false' distinction since most water is supplied by convection anyway. Unique ice nucleation mechanisms at low temperatures may not be captured by models. Models represent many classes of wave motions important in the TTL, but may miss some of them. Fine gradients in the TTL in the vertical especially may not be captured by models. Convective motions are only crudely represented, but the global impact of convection is well represented.

New observations and techniques are available to constrain models, and these models are being used to simulate the future evolution of the TTL under expected anthropogenic forcing of climate. A case will be made for why the tropical tropopause temperature should increase in the future as the planet warms, and this would be expected to alter water vapor in the stratosphere. The implications for surface climate will be discussed.

The Relationship of the Asian Summer Monsoon to the Tropical Upper Troposphere and Lower Stratosphere

K. Mohanakumar

Department of Atmospheric Sciences, Cochin University of Science and Technology
Cochin 682016, India

Asian summer monsoon (ASM) is the most energetic system of the global atmospheric circulation in the northern hemisphere. The chemical, radiative and dynamical properties of the upper troposphere and lower stratosphere (UT/LS) over the ASM regime are quite distinct in many ways and are discussed in this presentation. Moisture values in the tropical UT/LS region show strong seasonal variability with largest values occur during June to September, associated with the summer monsoon season. Water vapour in the upper troposphere and lower stratosphere has an important influence on the climate system and plays a crucial role in stratospheric chemistry. It is, therefore, important to understand the processes which determine its transport and distribution in these regions of the atmosphere.

Transport of anthropogenic aerosols in the UT/LS region during ASM increases cloud ice, water vapour and temperature, indicating that aerosols play an important role in enhancement of cloud ice in the upper troposphere. Simulation studies show persistent maxima in aerosol concentration within the anticyclone in the UT/LS during the summer monsoon, when convective activity over the Indian subcontinent is highest. Model simulations indicate boundary layer aerosol pollution as the source of the UT/LS aerosol layer and identify the monsoon convection as the dominant transport process. Transport of aerosols in to the stratosphere is also observed over the convectively intense monsoon region. Aerosol induced circulation instigates weakening of the Hadley circulation and increased vertical transport around the southern part of the Himalayas and reduction in monsoon precipitation over the Indian region.

Stratospheric quasi-biennial oscillation (QBO) and the tropospheric circulation show a significant association with the biennial periodicity of the Indian summer monsoon. The presence of Low Level westerly Jetstream (LLJ) at 1.5 km and strong Tropical Easterly Jetstream (TEJ) around 14 km produces a strong vertical shear in the troposphere. Vertical shear of zonal wind in the UT/LS region is quite strong during the period of the westerly phases of the QBO, whereas, the shear becomes weak when QBO is in its easterly phase. It has been noted that during the westerly phases of the QBO, the Asian summer monsoon is quite active and during the easterly phase the monsoon is found to be generally weak or moderate. In the tropospheric biennial oscillation (TBO) cycle, strong monsoon years are associated with westerly anomalies in the lower stratosphere and easterly anomalies in the upper troposphere. Reverse is noted during the years of weak monsoon. The zonal wind anomalies exhibit a dipole structure in the troposphere, which changes alternately with the strength of the monsoon. Middle troposphere over the monsoon region seems to be modulating the QBO-TBO interaction. Lower stratospheric westerly anomalies in the winter indicate an active monsoon in the next summer, and easterlies indicate a weak monsoon in biennial scale.

The relation between water entering the stratosphere and the strength of the diabatic residual circulation

S. Fueglistaler[1], Y.S. Liu[2] , T.J. Flannaghan[1], F. Ploeger [3], P.H. Haynes[4]

[1]Princeton University, Princeton, USA; [2]University of Edinburgh, Edinburgh, UK; [3]FZ Juelich, Juelich, Germany; [4]Cambridge University, Cambridge, UK

Stratospheric water is strongly constrained by temperatures in the tropical tropopause layer (TTL). The dissipation of upward propagating waves forces a diabatic residual circulation which lowers temperatures in the TTL about 10 - 20 Kelvin below local radiative equilibrium, with General Circulation Models suggesting a strengthening of the residual circulation in response to increasing greenhouse gas concentrations. Changes in the strength of the residual circulation affect water entering the stratosphere $[H_2O]_{entry}$ via its impact on temperature. We use radiative transfer calculations to estimate the zonal mean temperature adjustment in response to a range of prescribed perturbations of diabatic upwelling. We define ``Clausius-Clapeyron scaling'' (CC-scaling) of $[H_2O]_{entry}$ if changes in $[H_2O]_{entry}$ follow the saturation mixing ratio changes at tropopause levels. We show that $[H_2O]_{entry}$ may scale less than expected from Clausius-Clapeyron. Using trajectory calculations, we show that the departure from CC-scaling is a direct consequence of the change in residence time in the TTL associated with the perturbation in upwelling. In absolute terms, this residence time effect induces an equivalent frost point temperature change of $[H_2O]_{entry}$ of about 3.5 Kelvin for a perturbation in diabatic heating of 1 Kelvin/day. Depending on the length scale of the dynamical forcing, the departure from CC-scaling ranges from about -8% for deep stratospheric circulation changes to about -12% for changes in the `shallow branch' of the stratospheric residual circulation. The effect reported here also implies that model biases in upwelling translate into biases in $[H_2O]_{entry}$, and we show that for a spurious drift in ERA-Interim temperatures due to assimilation of COSMIC GPS temperature data the residence time effect nearly perfectly (but fortuitously) cancels the effect of the temperature change on $[H_2O]_{entry}$ for diabatic trajectories. Our results for stratospheric water vapor show that atmospheric water vapor can depart substantially from CC-scaling even when cloud microphysical aspects of dehydration remain unchanged.

Long-term changes in the Brewer-Dobson Circulation: the role of the residual circulation and mixing

H. Garny[1], T. Birner[2], H. Bönisch[3], M. Dameris[1]

[1]Deutsches Zentrum fuer Luft- und Raumfahrt (DLR), Institut fuer Physik der Atmosphaere, Oberpfaffenhofen, Germany; [2]Colorado State University, Fort Collins, Colorado, USA; [3]Institute for Atmospheric and Enviromental Sciences, Goethe University Frankfurt, Frankfurt am Main, Germany

The stratospheric Brewer-Dobson circulation is often quantified by the integrated transport measure stratospheric age of air (AoA). AoA is influenced both by mean transport along the residual circulation and by two-way mixing. Global models project an intensification of the Brewer-Dobson circulation and thus decrease in AoA. However, the role of changes in two-way mixing are not well understood yet.

In this study we use a method that allows us to quantify the effect of mixing on AoA from global model data. AoA is contrasted with a hypothetical age – the age air would have if it was only transported by the residual circulation, the residual circulation transit time (RCTT). The difference of AoA and RCTT is interpreted as the additional aging by mixing. Mixing causes air to be older almost in the entire lower stratosphere (AoA > RCTT). Only in the extratropical lowermost stratosphere, air is younger than if it was transported only by the residual circulation (AoA < RCTT).

By using conceptual models to interpret results from global models, it is shown that two-way mixing across the subtropics is mainly responsible for the aging by mixing. The two-way mixing mass flux is found to be tightly coupled to the strength of the residual circulation, i.e. the advective mass flux. This implies that for an uniform increase in the residual circulation, mixing effects will amplify the decrease in AoA. If, however, only the lower stratospheric shallow branch of the residual circulation strengthens, AoA decreases within the shallow branch but can increase at higher levels. This increase is caused by the effects of enhanced mixing mass fluxes in the lower stratosphere associated with the shallow branch intensification.

On the basis of a set of chemistry-climate model simulations, we analyse the long-term trends in AoA , and quantify the role of changes in the residual circulation and possible changes in mixing on those trends. A better understanding of the processes responsible for modelled AoA changes might help to reconcile current discrepancies with observed records of AoA.

Transport across the TTL

B. Legras[1] -A.-S. Tissier[1],, A. Tzella[2]

[1]Laboratoire de Météorologie Dynamique, IPSL, CNRS/ENS/UPMC/Ecole Polytechnique, UMR 8539, Paris, France
[2]University of Birmingham, UK

The Tropical Tropopause Layer (TTL) is a transit region between the troposphere and the stratosphere in which the air detrained from convective anvils is further processed through cirrus clouds before entering the stratosphere.
Transfer properties across the TTL are important to determine the composition of air entering the stratosphere, in particular its water content. We review what can be learned from the calculations of Lagrangian transport and mixing within the TTL, using analysed winds and observations / parametrisation of gravity waves and turbulence and the limitations of this approach due to uncertainties in the dynamical effect of clouds. We show that fast and slow pathways coexist in the TTL, depending mostly on the horizontal transport. Convective sources, as characterized from trajectories combined with satellite data, are prevalent in Asia, both during winter and summer, with shortest pathways associated with Tibetan plateau during summer. Variability and trend of the transport across the TTL is discussed.

Mass Fluxes and Detrainment Rates Over the Maritime Continent: Implications for Stratospheric Composition

R. Schofield[1], W. Frey[1], M. Hassim[1], T. P. Lane[1], M. Rex[2], H. Deckelmann[2]

[1]School of Earth Sciences and ARC Centre of Excellence for Climate System Science, The University of Melbourne, Melbourne, Victoria, Australia
[2]Alfred Wegener Institute, Potsdam, Germany

Convective processes rapidly deliver boundary layer air, free tropospheric air and water vapour to the tropical tropopause layer. With global circulation models now linking ocean and atmospheric processes, the representation of convection is vital to close many important biogeochemical cycles, which play major roles in stratospheric chemistry. This work examines the mass fluxes and detrainment rates for 2 week-long studies over the maritime continent region. Specifically, the SCOUT-O3 and TWP-ICE campaigns conducted out of Darwin, Australia, in November-December 2005 and January-February 2006 respectively, are examined. Convection permitting versions of the weather research and forecasting model (WRF) are compared with the 3 hourly ERA-Interim archived values for mass flux and detrainment, representative of observational/coarse model convection. The implications of global and mesoscale representations of deep convection on the delivery of boundary layer short-lived halogen and sulfur species to the tropical tropopause layer and ultimately the stratosphere is discussed. The role that these varying scales play in the observed stratospheric ozone in the tropical region where convection is a major driver is also investigated.

Decadal changes in PV intrusion events and its impact on deep convection over the tropics from climate change perspective

Debashis Nath, Wen Chen

Center for Monsoon System Research, Institute of Atmospheric Physics, CAS, Beijing, China

Abstract: The subject of high latitude-tropical interactions and the transport of stratospheric dry air into the tropics and the subtropics have significant impact on deep convection and precipitation over the tropics especially Pacific and Atlantic sectors. It is well known that during Northern hemisphere winter months (December-March), in the upper troposphere the equatorial westerly ducts are important for extratropical and tropical interactions. The Rossby waves are able to propagate through westerlies, and thus the ducts are preferred locations for the cross-equatorial wave propagation. *Waugh and Polvani* (2000) have focused on the occurrence of Rossby wave breaking events and transport of extratropical air deep into the tropics.

In the present study, we have addressed the climatological features of these intrusion events like, (a) the decadal change in the number of events over Pacific, Atlantic and Indian Ocean sectors, and its impact on the tropical convection and rainfall, (b) the modulation of intrusion frequency by changes in the upper tropospheric flows caused by climate change, in relationship with ENSO, and (c) the shift in the location of SST warming pattern towards the warm pool in relation to the strength of easterly wind in the upper troposphere.

For our analysis, we have used the ECMWF/NCEP reanalysis products for potential vorticity and wind data, monthly mean Outgoing Longwave Radiation data (NOAA interpolated) as a proxy of convective activity, monthly mean CMAP precipitation data (NCEP), monthly mean CAPE data (NCEP and ECMWF) and static stability data (NCEP), monthly mean Sea Surface Temperature data, ENSO Index data and the CMIP5 model data to compare the observed results with model analysis.

A strong decadal variability in the number of intrusion events has observed over Pacific, Atlantic and the Indian Ocean sectors. We have also noticed to have a close correlation with the increase in convective activity over the tropics. The changes in the SST anomaly over the central and eastern Pacific Ocean have influenced the strength and the frequency of the ENSO, which in turn modulate the number PV intrusion events in the decadal time scale.