Response of tropical cyclone NILAM on surface metrological parameters

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Abstract

Using the data of Mini Boundary Layer Mast (MBLM) located at Vignana Bharathi Institute of Technology, Hyderabad (17.47°N, 78.72°E), studies have been made to find the changes in metrological parameters due to cyclone NILAM which passed close to Hyderabad during 30th October – 3rd November 2012. Deep depression was found over Southeast and adjoining Bay of Bengal near Latitude 9.5°N and 86°E. It moved westward and intensified into a cyclonic storm NILAM which moved northwestwards, passed 480 km away from Hyderabad on 2nd November 2012 and there after got dissipated over Rayalaseema region of India. The wind speed between 30th October to 3rd November were found to get enhanced (~2 times) compared to the control days' average. The regular diurnal variations of temperature were not observed during the active days. Particularly the temporal variations of temperature were almost nil during 1st and 2nd November, 2012. Drop in pressure of ~6hpa could be noticed during NILAM affected days. Wind shear also gets enhanced by 2 times at all the three levels (4m, 8m & 15m). Wave activities have been investigated by using Fast Fourier Transform analyses (FFT). It is observed that the diurnal oscillation dies down during these active days whereas Inertia Gravity Waves (IGW) gets enhanced. The temporal variations of the wave activity has been clearly brought out in the wavelet analyses using Morlet Wavelet.

Mesospheric ozone loss caused by energetic electron precipitation

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Energetic particle precipitation affects the middle atmospheric neutral chemistry and ozone balance, e.g. through production of odd hydrogen (HO_x). Recent studies have provided clear evidence of the connection between precipitating radiation belt electrons and mesospheric hydroxyl (OH) (Andersson et al., 2012; Verronen et al., 2011). By analyzing OH time series from Microwave Limb Sounder (MLS/AURA) and radiation belt electrons fluxes from Medium Energy Proton and Electron Detector (MEPED/POES), they showed that for the considered time period 2004-2009 energetic electron precipitation (EEP) has measurable effects in about 30% of cases.

Here we combine 10 years of observations (2002-2012) from Global Ozone Monitoring by Occultation of Stars (GOMOS/ENVISAT), Sounding of the Atmosphere using Broadband Emission Radiometry (SABER/TIMED), MLS/AURA and MEPED/POES instruments to show the significance of the EEP to the mesospheric ozone variability at geomagnetic latitudes 55-65^{o} N/S. Our results indicate that strong EEP events can cause significant ozone depletion up to about 90%, being comparable to the effect caused by strong solar proton forcing. The impact of such events can reach down to about 60-65 km altitude. At 75 km, in about 75% (90%) of the selected EEP cases (daily mean electron count rates higher than 150) in the North (South) we have observed ozone decrease of 5-72% relative to the average values before the events. The large EEP-induced ozone loss combined with the frequent EEP events occurrence can cause significant changes in the chemistry of the middle atmosphere and should be included in atmospheric modeling of polar mesosphere.

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How do Major SSWs Develop in Present and Future Climate?

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A major sudden stratospheric warming (SSW) is a dramatic event that causes strong anomalies in the stratospheric winter circulation. This phenomenon is due to upward propagating planetary waves originating in the troposphere, which break in the stratosphere and interact with the mean flow, leading to the break-down of the polar vortex during mid-winter. Planetary waves of different amplitude and zonal wave numbers (1-3) can propagate upward into the stratosphere causing this wave-mean flow interaction. Therefore major SSWs do not always develop in the same way. Although most of the major SSWs follow increased planetary wave activity of the zonal wavenumber-1, a quarter of these events are caused by an amplified zonal wavenumber-2 (Bancalà et al., 2012 *JGR*). Thus, we distinguish major SSWs between wavenumber-1 (W1) and wavenumber-2 (W2) events based on the planetary wave activity preceding the warming phase of the polar vortex. This major SSW classification differs from that adopted by Charlton and Polvani (2007) that distinguish the SSWs according to the post-warming behaviour of the vortex. Results based on observations have clearly revealed a difference between the W2 / W1 ratio in the pre-warming phase and the splitting / displacement ratio of the post-warming phase, which means that not all wavenumber-1 events lead to a vortex displacement.

In this study, the pre-warming classification will be used to describe the stratospheric winter variability simulated by the new generation of high-top climate models. In particular, by investigating present climate simulations, we will address the ability of CMIP5 and CCMVal2 models to simulate the pre-warming phase of major SSWs and also determine whether the observed W2 / W1 relationship is reproduced. The occurrence of major SSW is also linked with tropospheric blockings and El Nino Southern Oscillation frequency. Finally, we will investigate the effect of future climate changes on the occurrence and seasonality of major and final SSWs as well as for tropospheric blockings.

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Tropical ascent rates derived from the water vapour tape recorder - a comparison study with SHARP models and observations

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The Brewer-Dobson Circulation (BDC) is an important feature of stratospheric dynamics, as it determines the transport of atmospheric constituents in the stratosphere. It is so far not clear how the BDC reacts to a changing climate induced by increasing greenhouse gas (GHG) concentrations. The vast majority of state-of-the-art climate models simulate a strengthening of the BDC in the recent past, while the longest available observational age-of-air datasets indicate a slight decrease in BDC strength or no significant trend. Measuring the strength of the BDC involves several difficulties. The two common measures of the BDC strength, the tropical upwelling through the 70 hPa pressure surface and the age of stratospheric air, appear to correlate relatively well in climate models. However, observational age-of-air datasets are sparse, and to assess the tropical upwelling velocity with high accuracy on the global scale turns out to be hardly feasible. Additionally, the direct connection between tropical upwelling and the midlatitudinal age of lower stratospheric air is questionable.

The H2O tape recorder, the water vapour anomalies transported upward through the tropical lower stratosphere, allows for the derivation of another measure of the tropical ascent rates and, thus, the strength of the BDC.

Simulations performed with the ECHAM6 General Circulation Model (GCM) show that the tropical upward transport velocity derived from the tape recorder is strongly sensitive to the representation of the middle atmosphere in climate models (see Fig. 1).

The research group Stratospheric Change and its Role for Climate Prediction (SHARP) brings together climate models of different complexity as well as observational datasets obtained from different satellite instruments. In this study, tropical ascent rates are derived from both model and observational datasets. The collaboration of the different groups within the SHARP activity allows for a robust assessment of the quality of the models' capability to simulate the upward transport of air through the stratosphere, and yields the opportunity to validate the response of the BDC strength to a changing climate.

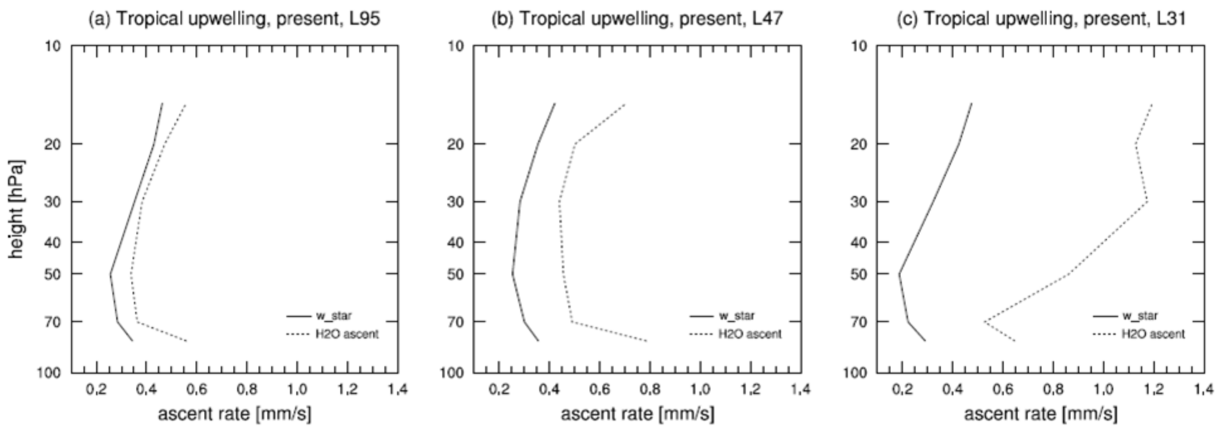

Figure 1: Vertical profiles of the vertical transport velocities derived from the water vapour tape recorder are shown and compared to the tropical upwelling velocities calculated via the Transformed Eulerian Mean framework. The data was obtained from 50-year present-day time-slice simulations performed with the ECHAM6 GCM with 95 (a), 47 (b), and 31 (c) model levels.

The response of quasi-biennial oscillation to climate change in HadGEM2-CC

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Out of around fifteen stratosphere-resolving models that contributed climate projections to the Coupled Model Intercomparison Project Phase 5 (CMIP5) HadGEM2-CC was one of the few models to exhibit a realistic tropical quasi-biennial oscillation (QBO). The response of this HadGEM2-CC QBO to climate change has been analysed in an ensemble of twenty-first century Representative Concentration Pathway 8.5 (RCP8.5) scenario simulations. For the mid-stratosphere (10 hPa) all the ensemble members projected a decrease in both the amplitude and period of the oscillation. The amplitude decreases, on average, from about 29 m/s at the beginning of the twenty first century to about 24 m/s at the end of the century. The concomitant average decrease in the period from around 26 months to around 21 months is however somewhat counter-intuitive since, as with nearly all model projections, the tropical upwelling increases in HadGEM2-CC in response to greenhouse gas induced climate change. The reasons for the period and amplitude responses are investigated further by considering the different terms in the zonal-mean zonal momentum budget for the tropical stratosphere. Asymmetries in the response between the eastward and westward phases of the oscillation are considered too.

Impact of Tropical Land Convection and interplays between Water Vapor, Ice Water Cloud and Temperature in the TTL

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The tropical deep overshooting convection is known to be the most intense above the continental areas such as South America, Africa and the Maritime Continent. However, the impact of the convection on the Tropical Tropopause Layer (TTL) remains faintly characterized and its impact at global scale broadly unknown and debated. In our analysis, we use the 8-year of MLS water vapor (H2O), cloud ice water content (IWC) and temperature (T) datasets to highlight the interplays between these parameters and their role in the variability of the TTL. At the tropical scale, we showed a surface dependence in term of strength of convection through the diurnal variability of H2O from the Upper Troposphere (UT) to the Lower Stratosphere (LS), resulting in a larger signal above continents than semi-continental-semi-oceanic places such as the Maritime Continent. A weaker diurnal cycle of H2O in the UT interpreted as the result of a weaker convective activity was also point out in the northern hemisphere with respect to the southern. At the regional scale, while in the UT the correlation between IWC and H2O is mostly greater than 0.8, we found in the TTL a strong anti-correlation (down to -0.6) between IWC and H2O, and stronger anti-correlation (down to -0.9) between IWC and T, together with a strong correlation (up to 0.9) between H2O and T. In the UT, it was interpreted as the direct and simultaneous injection of H2O and ice crystals (also formed in-situ) by the overshoots, while in the TTL, the seasonal cycle of the cold point tropopause interacts with the variability of IWC and H2O. This relationships between T, H2O and IWC appears to be consistent with the variability calculated over the 8-year of the MLS datasets showing a 0.3% increase of T together with a 7-8% increase of H2O and a -4% decrease of IWC in the TTL in most of our areas of study.

Balance model for equatorial planetary scale dynamics

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Large-scale mid-latitude atmospheric dynamics is balanced, in the sense that it is dominated by slow advective motions and devoid of fast inertia-gravity waves; in addition, the mass and wind fields are found to satisfy balance relations such as the geostrophic balance. Numerical models have to respect this balance in order to produce realistic model outputs.

Although classical balance theories such as the quasi-geostrophic theory works well in the mid-latitudes, they all fail near the equator. Our lack of understanding of balance in the tropics is exemplified by the fact that reanalyses products yield vastly different estimates of the dominant modes of low-frequency tropical variability, for example equatorial Kelvin waves. This arises because most tropical observations are of temperature, not wind, and any projection of temperature measurements into winds requires an assumption about the nature of balance. Yet there is at present no consensus on how to do this in the tropics.

Our goal is to derive a balance theory for planetary scale tropical dynamics that includes Kelvin waves. This precludes the use of a potential vorticity (PV) based model as Kelvin waves have zero PV and will be invisible. We follow the modified asymptotic expansion used by Warn *et al.* (1995) and use the mass variable to describe the slow dynamics. The small parameter is defined as the ratio of meridional to zonal lengthscales, which can also be interpreted as a separation in timescale. The resulting balance model filters inertia-gravity and mixed Rossby-gravity waves while retaining Rossby and Kelvin waves. The slow balance dynamics is characterized by a semi-geostrophic balance in the zonal winds, while the meridional winds vanishes at leader order.

In this work we focus on the balance dynamics in the presence of diabatic heating. Through the use of a shallow water model, we will explore the dynamics of the model under forcings at different timescales. An interesting result is that even though in many cases the balance model fails to capture the dynamics in the full shallow water model, the balance relations remain accurate even in the isotropic limit. The implication is that the balance relations are potentially very useful in data assimilation models in constraining large-scale tropical dynamics.

Characteristics of Gravity Waves during Tropical Cyclone Events in ECMWF Analyses

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Current operational numerical weather prediction models (NWPs) are likely to produce high-quality analyses in the upper troposphere and the lower stratosphere. In particular, the assimilation of GPS radio occultation bending angles beginning in late December 2006 has improved temperature information in ECMWF data in the Southern Hemisphere and the description of tropical cyclones (TCs). Thus ECMWF analyses reveal the presence of a large fraction of stratospheric inertia-gravity wave spectrum with vertical and horizontal wavelengths >2 km and ranging between 100 and 2,000 km respectively. Previously, such gravity waves (GWs) have been observed during TC events. The present study is focused on characteristics of TC-related GWs derived from ECMWF data in the south-west Indian basin for TC seasons between late 2006 and 2013.

Sampling unexplored regions of the tropical UTLS: planning for the next major field campaign in the tropical warm pool

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The upper troposphere and lower stratosphere (UTLS) region couples the stratosphere to the troposphere. In the tropics, the transition layer where processes from both spheres interact, referred to as the tropical tropopause layer (TTL), is a crucial region for chemistry-climate interactions globally. It is the predominant route for troposphere to stratosphere transport, and so conditions in the TTL set the entry concentrations of traces gas (e.g. water vapour, short lived halogen species). Despite important progress in recent years, much still remains to be understood. The dynamical, radiative and chemical characteristics of the UTLS region set both spatial and temporal constraints on observing and modelling systems.

The TTL is typically defined as the region extending from the main convective outflow (near 10–14 km) up to the cold point tropopause (near 16–17 km). Hence, observations require field campaigns with research aircraft that can reach the higher regions of the UTLS. From mid-January to mid-February 2014 (i.e., just after the SPARC 2014 General Assembly), the tropical warm pool (TWP) will host a major field campaign, which involves two consortium programs, namely the US National Aeronautics and Space Administration (NASA) Airborne Tropical Tropopause Experiment (ATTREX) project and UK Natural Environment Research Council (NERC) Coordinated Airborne Studies in the Tropics (CAST) project. A summary of the motivations and objectives of the programs will be given. Unexplored regions of the tropical UTLS will be explored by high altitude (up to 65,000 feet) flights by a NASA Global Hawk unmanned aircraft, complemented by lower-level flights by the NERC/Met Office BAe-146 aircraft, ozone soundings and ground-based instrumentation (e.g. aerosol lidar). An account of the instrumentation deployed (including the payload of the aircrafts) will be presented.

The distribution of convection across the equatorial Pacific changes with the El Niño–Southern Oscillation (ENSO) pattern. What the ENSO pattern will be at the time of the SPARC 2014 General Assembly is not known with certitude at the present time. Projections indicate a neutral pattern, which means that the TWP will be a region of active convection. To plan for the field campaign and identify which flight strategy to adopt for the different possible scenarios, typical periods of El Niño, La Niña and neutral pattern over the equatorial Pacific have been simulated with the Lagrangian Met Office's Numerical Atmospheric-dispersion Modelling Environment (NAME) and Eulerian Weather Research and Forecasting (WRF) numerical models. One key question addressed is where will the Global Hawk sample air that has been lifted up from low level. A detailed analysis of the transport and distribution of tracers of different lifetimes will be presented and placed in context with the ultimate aim of providing answers to this key question.

A study of cloud occurrences and properties in the UTLS region during summer monsoon seasons using CALIPSO and Cloudsat observations across Pakistan

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Recently, with the launching of the “A-train” constellation satellites by NASA, Cloudsat and CALIPSO (launched in April 2006), vertical resolution study of clouds and aerosols is possible including classifications conducted from space. While the former carries a Cloud Profiling Radar (CPR), the latter satellite has the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIOP) which were designed to act as complementary instruments towards studying clouds and aerosols in greater detail.

Using observational data from both of these satellites, we conduct a multi-year analysis that is from 2006-2012, of the UTLS (Upper Troposphere and the Lower Stratosphere) region across Pakistan, specifically around the summer monsoon season. Pakistan is recently challenged due to massive flooding in the past three years as well as earlier brief monsoon seasons of low precipitation and short drought periods. Thus, this is motivated towards understanding the deep convective and related dynamics in this season which can possibly influence cloud and aerosol transport in the region. Further, while global studies are done extensively, the goal of this study is to conduct a detailed study of cloud, aerosols and their interplay, across Pakistan. Due to lack of ground observations, the dedicated focus on the UTLS domain using such vertical profiling satellites in this region is valuable and new as there are no ground observations being done. This is important as both the properties and dynamics of clouds and aerosols have to be studied in a wider context in order to better understand the monsoon season and its onset in this region.

Using the CALIPSO Vertical Feature Mask (VFM), Total Attenuated Backscatter (TAB) and Depolarization Ratio (DR) as well as the combined Cloudsat’s 2B-GEOPROF-LIDAR (Radar-Lidar Cloud Geometrical Profile) and 2B-CLDCLASS-LIDAR (Radar-Lidar Cloud Classification) products, we find the presence of thin cirrus clouds in the UTLS region in the periods of June-September from the 2006-2013. There are differences in the day observations as compared to night in both of these satellite observations with the latter period has more occurrences of clouds in the UTLS region. The dedicated Cloudsat products 2B-CLDCLASS (cloud classification) and 2C-TAU (Cloud Optical Depth) confirm the presence of sub-visual and thin cirrus clouds during the summer monsoon season. Further, from CALIPSO observations, there is significant presence of aerosol layers before the onset of precipitation in the troposphere. This thickness ranges from 1-4 km, with the larger thickness observed from during the 2009-2012 period. Implications of these findings are detailed in this presentation.

Downward coupling process through TTL : a case study using a global non-hydrostatic model

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We have reported an enhancement of tropical convection and abrupt change of tropical circulation during the Stratospheric Sudden Warming (SSW) events by mainly the observational data [Eguchi and Kodera, GRL, 2007; Eguchi and Kodera, SOLA, 2010; Kodera et al., JMSJ, 2011]. These results suggest that the stratospheric meridional circulation impacts on the tropical convection. To understand the responsible process, investigation of the vertical velocity and the diabatic heating rate in the Tropical Tropopause Layer (TTL) region are crucial. However, these quantities cannot be measured directly. Therefore, in the present study investigation was made by using a global nonhydrostatic model which does not make use of the cumulus parameterization, NICAM (Nonhydrostatic ICosahedral Atmospheric Model) [Satoh, et al 2008].

The model integration was initiated from the observed field from 20 December 2009. The daily mean data derived from three hourly (hourly) outputs for 3D (2D) variables are analyzed in the present study. The horizontal grid size of 14 km and vertically stretched 40-layers (z= 0 ~38 km) are used. A sudden warming event is reproduced around 15 January 2010 in the model, although the date of the onset was approximately one week earlier than that in the real atmosphere. Here, the onset date is defined by the polar temperature tendency at 10 hPa (80-90N).

In the NICAM simulation, the latitude of active convection moved from the northern hemisphere (NH) to the southern hemisphere (SH), and the temperature at the lower stratosphere and the TTL region became cooler after the onset of SSW, similar to the observation. The increase of the upward velocity occurred in the TTL in the southern tropics simultaneous to an increase in diabatic heating rate. The change of vertical wind and diabatic heating rate gradually penetrated from the lower stratosphere to the upper troposphere in the equatorial SH during periods i (14-17 January) and ii (18-21 January). Intensification of upward velocity occurred in the whole troposphere during the period iii (22-25 January).

The result of analysis of the other parameters, mass stream function, diabatic heating rate, and static stability, suggests that the penetration of the stratospheric variability into the TTL occurs through the following two processes.
1) Period i and ii: Upwelling due to an enhanced stratospheric meridional circulation produced a cooling in the TTL, which was compensated by a diabatic heating due to an increased convective activity in the equatorial SH.
2) Period iii: Increase of the upwelling in the equatorial SH led to a suppression of convective activity in the tropical NH. These created convergence and divergence of water vapor, respectively, in the lower troposphere. The moisture convergence in the SH further enhanced convective activity there and this process involving a positive feedback resulted in the meridional shift of the convective zone in the troposphere.
The details of the downward coupling process through the TTL will be shown in the presentation.

Two examples of gravity-wave mean-flow interactions observed from satellite: The QBO and the summertime mesospheric jet

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Gravity waves (GWs) play an important role in the momentum budget of Earth's atmosphere. In general circulation models (GCMs) and chemistry climate models (CCMs) the effect of GWs on the atmospheric background flow is usually simulated by GW drag parameterizations. These parameterizations are however very simplified and global observations of GWs are required to improve their parameter settings or to provide information about the part of the spectrum of GWs that interacts with the background wind.
We derive GW momentum fluxes and drag from temperature observations of the satellite instruments HIRDLS and SABER using the method by Ern et al. (2004, 2011).
The first example of GW mean-flow interaction that we investigate with these observations is the generation of jet instabilities in the decaying summertime mesospheric westward wind jets by dissipating GWs. Enhanced GW drag is observed by SABER directly on top of the jet instabilities. These jet instabilities lead to the excitation of quasi two-day waves (QTDWs) shortly after the summer solstices of the respective hemisphere. Non-uniformities of the global distribution of GWs that are observed during summer in the subtropics might contribute to details of the QTDW excitation. SABER observations of QTDW EP-fluxes and QTDW drag are qualitatively in good agreement with a modeling study by Pendlebury (2012). Main results of this comparison are published in Ern et al. (2013).
Another example of GW mean-flow interaction is the quasi-biennial oscillation (QBO) of the zonal wind in the tropical stratosphere. The QBO influences atmospheric dynamics over a wide range of altitudes and latitudes and it even impacts the surface weather and climate at mid and high northern latitudes. However climate models still have large difficulties in reproducing a realistic QBO. Therefore global observations are needed for better constraining the model dynamics in the tropics.
GW spectra derived from HIRDLS observations in the tropics (10S-10N) indicate that critical level filtering is the main QBO-related GW dissipation process. GW drag from HIRDLS and SABER is compared to the different terms in the tropical momentum budget of the ERA-Interim reanalysis. Peak values of observed GW drag are about 0.4 m/s/day during QBO eastward wind shear, and about 0.3 m/s/day during westward wind shear. Qualitatively, there is good agreement between observed GW drag and the missing drag in the ERA-Interim momentum budget. Absolute values of observed and ERA-Interim missing drag are about the same during QBO eastward wind shear. During westward wind shear observations are about two times lower than ERA-Interim. This imbalance could be an indication for uncertainties in the advection terms of the ERA-Interim momentum budget. We observe also high intermittency of GWs in the tropics close to their source levels, and QBO simulations might be improved by including this effect.
These two examples of GW mean-flow interactions show that GW distributions observed from satellite give a very consistent picture of the dynamics of the middle atmosphere, and meaningful results are obtained. Satellite observations of GWs have already served to guide the GW parameterization used in the ECMWF model (Orr et al., 2010), and they are currently being used for comparison with climate models in the SPARC GW initiative (e.g., Geller et al., 2013, in print). Our results indicate that GWs observed from satellite can provide even more information and can help to further improve the representation of GWs in GCMs/CCMs.

Effect of cyclone NILAM on atmospheric parameters and characteristics of Inertia Gravity Wave over Hyderabad (17^0 N, 78.4^0 E)

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Cyclone Nilam was originated in the Bay of Bengal near 9.5^0 N and 86^0 E. The cyclone move northwestwards and passed through a distance of 480 km from Hyderabad on 2nd November, 2012. It was later dissipated in the Rayalaseema region. Balloon flights were carried out from Vignana Bharathi Institute of Technology, Ghatkesar, Hyderabad with high resolution GPS radiosondes (EnSci) on-board between 30th October to 23rd November, 2012. There was one flight on each day at 11:30 LT (6 GMT) and four balloon flights were conducted on each day between 5th and 10th November at a gap of 6 hours to have a time series of 120 hours. The effect of the cyclonic storm was seen clearly between 30th October to 3rd November. Mean profiles of winds, temperature between 8th to 23rd November have been considered as control data for comparison with active days. Large variations in winds and temperature were observed in tropospheric region. Zonal and meridional winds are found to get enhanced by ~ 25 and 8 m/s respectively. Temperature was found to decrease by 5 – 6 degrees in the same altitude region. Quadratic fits were removed from the vertical profiles of winds to get fluctuation profiles. They were then high-pass filtered with a cut-off of 5 km and subjected to power spectral density (PSD) analyses. The vertical wavelength of IGW is observed to increase during the active days. Other IGW parameters like horizontal wavelength, intrinsic period, phase speed etc. are also found to change during the cyclone.

The Potential Impacts of Vertical Mixing on the Tropical Tropopause Layer Temperature Structure

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The tropical tropopause layer is a region of great importance for the atmosphere, with the tropical tropopause layer temperature structure controlling stratospheric water vapour and thin cirrus cloud formation. Many processes contribute to tropical tropopause layer temperature, including convection and radiative cooling, and in this work we show that vertical mixing can have a significant impact on the tropical tropopause layer temperature structure. In addition, vertical mixing is important for tracer transport (e.g. ozone; Fujiwara *et. al.*, 1998) providing further motivation for this study.

Vertical mixing occurs through the Kelvin-Helmholtz instability and can be triggered in regions of low stability, such as the upper troposphere, and also in regions of high shear, such as in large amplitude equatorial waves in the tropical tropopause layer. However there is much uncertainty as to how such mixing occurs in the real atmosphere and there is quite some variation in how vertical mixing is represented between different models (Flannaghan and Fueglistaler, 2011). Model parametrisations of vertical mixing can result in significant diabatic heating and momentum forcing terms that are highly sensitive to how mixing is parametrised. Here, we quantify the potential impact of mixing by examining the effect of these diabatic terms in a dry dynamical core. We find that differences in the diabatic terms arising from mixing can cool the tropical tropopause by approximately 4 K in a dry dynamical core. We estimate thee order of magnitude of the response in a more comprehensive model to be approximately 1 K at the tropopause. This tropopause temperature response is very significant in the context of stratospheric water vapour.

Mixing schemes are very non-linear, and, as a consequence, the lack of resolved gravity waves in current general circulation models leads to a large artificial reduction in the amount of mixing in models. We quantify this effect using high resolution gravity wave resolving datasets and model output, and find that taking gravity waves into account can dramatically change the distribution of mixing in models.

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Modelling of Hector overshooting convection and its implications on water vapour distribution in the TTL and lower stratosphere

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Overshooting convection penetrating the tropical tropopause layer (TTL) and the lower stratosphere plays an important role in the redistribution of water vapour. Modelling studies and in situ measurements show the hydration potential of convective overshooting partly by direct injection of ice particles into the stratosphere and subsequent sublimation. Also moisture plumes above the thunderstorm anvil can lead to hydration of stratospheric air. However, processes leading to dehydration of the TTL may also impact the stratospheric humidity by limiting the amount of water vapour carried aloft. While the large scale drives some of the dehydrating processes, others are of convective origin, for example gravity waves and cooling associated with overshooting turrets. Improving our understanding of overshooting convection and its influence on TTL water vapour will ultimately place better constraints on the budget of water vapour in the stratosphere.

In this study we use three-dimensional cloud resolving (WRF-ARW) simulations of Hector thunderstorms to study the aforementioned effects. The simulations focus on Hector events that have also been probed by aircraft during the SCOUT-O3 field campaign, conducted from Darwin, Northern Australia in late 2005. We will show comparisons of modeled and observed clouds as well as detailed comparisons between the model results and radiosonde observations. The cases include single and multi-cellular Hector events and one event where ice crystals have been injected into the stratosphere (as evidenced by the in situ measurements). The resulting hydration and dehydration potentials of the direct and indirect effects of the deep convection will be shown and we will give an estimate of the net effect of Hector on the water vapour transport into the stratosphere.

Interannual variability of the 3D residual circulation and tracer transport in the stratosphere and mesosphere

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The time-mean mass circulation and tracer transport of the middle atmosphere, also known as the Brewer-Dobson circulation, is usually examined by the zonal-mean (2D) residual circulation. Still the picture of the evolution of the 2D residual circulation is uncertain, because the calculated changes of both the 2D residual circulation and the 2D wave driving strongly differ among the models used in the assessments, as well as between the models and assimilations. Local changes in the mass circulation might be stronger and more significant than those identified by the 2D approach, but examinations of the three-dimensional (3D) residual circulation are very sparse. The aim of the presented project work is to investigate the interannual and decadal changes of the 3D residual circulation based on a new formulation of Kinoshita et al. (*J. Met. Soc. Japan*, 2010) and Kinoshita and Sato (*J. Atmos. Sci.*, 2013a,b). First results of this project have shown that the 3D residual circulation of northern hemisphere winter shows a pronounced zonal asymmetry, including cross-polar residual flow patterns in the stratosphere and mesosphere and associated downwelling in the centre of the polar vortex located over North-West Siberia (Demirhan-Bari et al., *J. Geophys. Res.*, 2013). This picture is similar to the 3D diabatic circulation shown by Callaghan and Salby (*J. Atmos. Sci.*, 2002).

In the presented paper the interannual variations of the 3D residual circulation are investigated based on daily-mean wind fields which we derived from Aura/MLS temperature, ozone and water vapour profiles (the profiles are provided by NASA under http://aura.gsfc.nasa.gov), assimilations of ERA-Interim (provided by ECMWF) and MERRA (provided by NASA), and long-term simulations with the high-altitude general circulation and chemistry model HAMMONIA (data provided by H. Schmidt, MPI-Met, Hamburg). The results show that the Quasibiennal Oscillation of stratospheric winds over the tropics (QBO) largely modulates the structure of the extra-tropical 3D residual circulation in both the stratosphere and mesosphere (e.g., planetary wave-1 during QBO-East and planetary wave-2 during QBO-West during northern winter), which further modulates the transport of stratospheric O_3 and strato- and mesospheric H_2O. A detailed analysis of the 3D wave driving elucidates the processes leading to these variations, in particular a change in orographically excited planetary Rossby waves due to a change in local transient wave trains and associated gravity wave propagation. It is also demonstrated that the QBO-induced variations in the local downwelling might lead to a change in the mass distribution of the troposphere, i.e. to a change in the distribution of high and low geopotential height anomalies at surface pressure level towards negative phase of North-Atlantic Oscillation. Long-term variations of the 3D residual circulation and tracer transport are discussed, e.g., those forced by the 11-year solar cycle or by anthropogenic greenhouse gas emissions, for both the Northern and Southern Hemisphere. The results demonstrate that the 3D residual circulation provides a useful diagnostic for understanding the observed interannual and decadal changes in the stratosphere and mesosphere and for a process-oriented validation of high-altitude climate-chemistry models.

Stratospheric and mesospheric wind fields derived from Aura/MLS temperatures and tracer distributions

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The spatial limitations in the global coverage and maximum altitudes (≈30km) of wind measurements by standard radiosondes implicate large uncertainties in the upper stratospheric and mesospheric wind fields produced by assimilations and model simulations, because of the lack in validation. The aim of the paper is to fill this gap by deriving daily-mean global wind fields from Aura/MLS temperature, water vapour (H_2O) and ozone (O_3) profiles. The Aura/MLS data (provided by NASA under http://aura.gsfc.nasa.gov) include a high temporal and spatial profile density which allows the construction of daily-mean three-dimensional fields of temperature, H_2O and O_3 for a 10°x10° grid in longitude and latitude. In a first step horizontal and vertical winds are derived based on the temperature fields via standard balanced equations, similar as used by Gabriel et al. (*Atmos. Chem. Phys.*, 2011) and Demirhan-Bari et al. (*J. Geophys. Res.*, 2013). In a second step the balanced wind fields are optimized via an inversion calculation of the tracer transport, where the observed day-to-day variations of O_3 and H_2O are used as input. The results are verified based on local wind profiles derived from Lidar and Radar measurements.

For illustration, wind fields derived from the Aura/MLS data are shown for the time period 2005-2010, in comparison to ERA-Interim assimilations (data provided by ECMWF) and simulations with the high-altitude general circulation and chemistry model HAMMONIA (data provided by H. Schmidt, MPI-Met, Hamburg). In particular, the results show pronounced wave one patterns in the meridional and vertical wind fields during northern winter in both the stratosphere and mesosphere, in relation to the wave one pattern in temperature. In comparison to the quasi-geostrophically (qg) balanced and the optimized vertical winds derived from Aura/MLS, the amplitude of the qg-balanced vertical winds of the assimilations are slightly underestimated whereas the total vertical winds are extremely perturbed. In this context we demonstrate that deficiencies in the vertical wind patterns produced by the models might have a significant impact on the structure of the polar vortex and associated circulation patterns in the middle atmosphere and the troposphere. Further, the comparison between Aura/MLS and HAMMONIA shows that the stationary wave patterns of the upper stratosphere and lower mesosphere are strongly underestimated by the model because of too strong transient waves, with inherent effects on the vertical coupling of the stratosphere and mesosphere via the modulation of gravity wave propagation characteristics, as proposed by the findings of Smith (*J. Atmos. Sci.*, 2003). Hemispheric differences and seasonal variations in the wind fields and associated circulation patterns of the upper stratosphere and mesosphere, as well as their interannual variability, are discussed. Overall the results provide a new tool for validating upper stratospheric and mesospheric wind fields produced by assimilations and high-altitude model simulations, and an improved understanding of vertical coupling processes.

Changing ENSO Influences on the QBO

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It has been shown by Taguchi (2010) that QBO periods were longer and amplitudes larger during periods of La Niña than during periods of El Niño during the period 1953-2008. Garfinkel and Hartmann (2007) have shown that the sign of the correlation between ENSO and QBO indices changed from negative during the first half of this period to positive during the second half of this period. These results should be better understood since it has been shown that there is QBO modulation of water vapor concentrations entering the stratosphere; there are analyses indicating QBO influences on typhoon tracks and on tropical convection; and there appear to be a QBO influence on Atlantic hurricanes.

With the Taguchi (2010) and Garfinkel and Hartmann (2007) results as background, it is shown here that during both the first and second halves of the overall period, from the 1950s to the present, QBO periods are longer during La Niña than during El Niño, but that QBO amplitudes were only larger during La Niña in the second half of this period, and, if anything, QBO amplitudes were larger during times of El Niño during the earlier half of the overall period. A proposed explanation for this is given in terms of the convectively forced gravity waves that play a large role in giving rise to the QBO. The low OLRs, characteristic of tropical deep convection, have broader longitudinal extent over the tropical Pacific during times of El Niño during both the first and second parts of this overall period. Given this, we hypothesize that this implies a larger zonally-averaged gravity wave momentum flux during El Niño, and hence a shorter period than is the case during times of La Niña during both the first and second halves of the overall period. Furthermore, we also show that there was more very deep tropical convection during times of La Niña than during El Niño during the period 1992-2010, and this was not the case during the period 1974-1984. More vigorous tropical convection, with latent heat release of greater depth, should force a broader gravity wave phase velocity spectrum, and this should give a QBO with larger amplitude. Modeling results support these explanations.

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Theory and observation of gravity waves generated from convection

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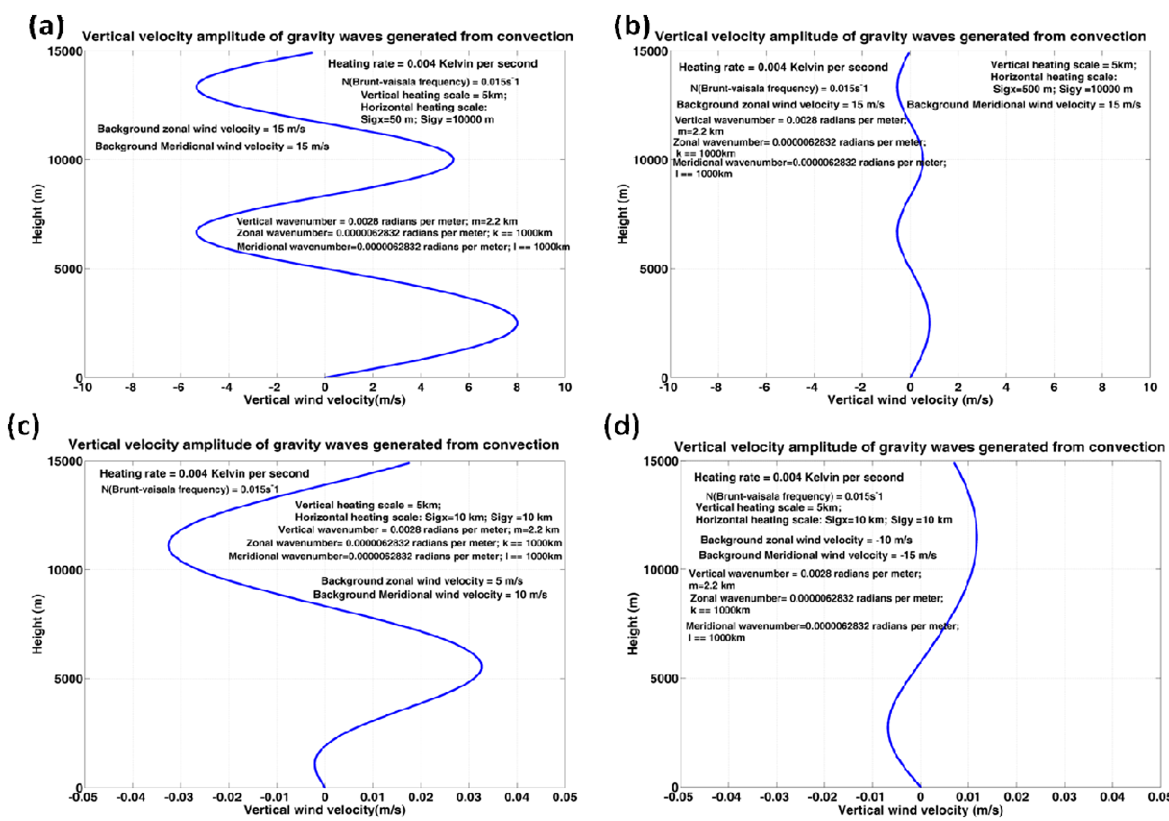
Particularly in the tropical region, the contribution of gravity waves (mesoscales and high frequencies of few tens of minutes periodicity), generated from latent heating, associated with convection to the middle atmospheric structure and dynamics is significantly large. Since it is impractical to operate large number of radars to determine the wave characteristics, we parameterized these gravity waves by solving the primitive equations of atmospheric fluid dynamics with latent heating included as the forcing function in the thermodynamic equation and adopting these following background conditions, namely, $N=0.015s^{-1}$, horizontal scale of 100 km, heating frequency and rate of 0.02 cycles/minute and 0.004 Ks^{-1} respectively, vertical and meridional heating scales of 5 and 10 km respectively, horizontal and vertical wavenumbers of 1000 km and 2.2 km respectively, cases (a and b) horizontal wind velocities of 15 m/s; zonal heating scales of 50 and 500 m, cases (c and d) = (5 and 10 m/s) and (-10 and -15 m/s) and zonal heating scales = 10 km respectively, the height profiles of vertical wind velocity are estimated. Figs. 1a-d show the calculated height profiles (0-15 km) of vertical wind velocity (m/s) associated with 50 minute oscillation gravity waves. It is found that limited and confined heating region with larger background horizontal wind velocities can generate efficiently larger amplitude gravity waves. Studies of comparison with MST radar determined wave characteristics including momentum fluxes will be presented.



Systematic Inclination of Tropical Upper-troposphere Clouds Revealed from Satellite Observations and Model Simulations

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Abstract

Upper-troposphere (UT) clouds (including anvils, cirrus, and convective overshoots) play a key role in Earth's radiation budget, hydrological cycle, and atmospheric circulations. Most cloud structures are slantwise in nature, and their global statistics have rarely been studied. Interpretation based on an over-simplified cloud vertical structure can lead to substantial errors in cloud measurements and the derived cloud radiative properties.

Using CloudSat ice water content (IWC) measurements along the meridional direction, we found that tropical ice clouds between 11 and 17 km tilt systematically poleward in both hemispheres with the separation lines collocated with the tropical deep convective zones. This finding relies on the fact that the slantwise integration of IWC along the dominant cloud inclination should yield the largest ice water path (IWP) values. The tilt feature identified from IWP difference between simultaneous forward and backward viewing angles is most prominent at the two flanks of the tropical deep convective zones. This finding is further confirmed by Aura Microwave Limb Sounder (MLS) day and night (D-N) brightness temperature differences, where we found ~ 50% of these D-N differences to be strongly correlated with CloudSat IWP difference in the tropics and are independent of cloud diurnal variations. Single isolated UT clouds at the peripheries of massive convective features orient the same way as ice cloud internal structures.

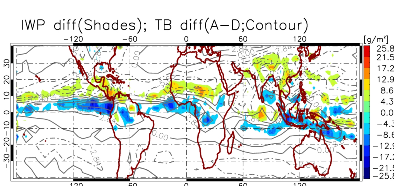

Fig. 1: 4-yr JJA average of IWP difference derived from CloudSat IWC profiles between 11 and 17 km (shades; warm/cold color means northward/southward tilt) and D-N brightness temperature difference derived from Aura MLS 640 GHz channel (contours; positive/negative values are solid/dashed); From Gong et al. (2013, in preparation).

Large-scale divergence circulation at the UT and convective gravity wave modulation are proposed as two causes of the observed systematic tilt. To validate our hypotheses, cloud-resolving WRF simulations are conducted over tropical Eastern Pacific near Central America. With a 3-km horizontal resolution and devoid of cumulus parameterization, the ensemble of three simulations qualitatively reproduces the observed large-scale cloud tilt, but fails to capture the small UT cloud orientation, which suggest other factors (gravity wave modulation, model-resolution, etc) might play a major role here. Companioned lower-resolution (10 km) runs with cumulus parameterizations can barely produce any tilt structures.

Ignoring effects from systematic cloud inclinations can cause as large as 20% errors in retrieving cloud optical depth and cloud occurring frequencies. The impacts on radiation and GCM representation of clouds will also be discussed.

Atmospheric Tides in the Low Latitude Thermosphere and Their Response to a Sudden Stratospheric Warming in January 2010

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Atmospheric tides are one of the most important driving forces in atmospheric circulation and energy exchange. Sudden stratospheric warming (SSW) is suggested playing an important role in coupling lower atmosphere with thermosphere. This study is very useful in helping people to better understand and modellers to better describe the thermospheric dynamics.

An extensive analysis of atmospheric tides in the low latitude thermosphere and their responses to a major SSW event (January 18-23, 2010) is presented. The analysis is based on observational data from the Arecibo dual-beam incoherent scatter radar during January 14-23 in 2010. To our knowledge, this is the first time that the vertical structure and variability of the diurnal and semidiurnal tides in the F-region meridional wind for winter conditions have been revealed. Additionally, the F-region tidal response to the SSW event is discussed for the first time in the low latitude. Important findings of the present study are as follows. (1) The diurnal tide with an evanescent phase structure dominants the F-region meridional wind field. The diurnal tide has a peak amplitude of 45 m/s occurring at about 245 km and it is very stable throughout the nine consecutive days' observation. Below 114 km, the vertical structures of the diurnal tide in the meridional and zonal components are consistent, which resemble the classical solar $S_{1,\,1}$ tidal mode. (2) The F-region semidiurnal tide is much weaker and has larger interval-to-interval variability than the diurnal tide. In the E-region, the semidiurnal amplitudes in the meridional and zonal components grow continuously in the altitude ranges from 106 to 121 km, and 100 to 115 km, respectively. The vertical wavelength of the zonal component is estimated as 45 km above 100 km, which is close to the solar $S_{2,\,4}$ and $S_{2,\,5}$ tidal modes. (3) The semidiurnal and terdiurnal tides respond strongly to the SSW while the impact that the SSW has on the diurnal tide is limited. During the SSW event, the amplitudes of the semidiurnal and terdiurnal tides are enhanced in the F-region but reduced in the upper E-region.

Observed General Circulation Changes up to the Mesopause Level Associated with Sudden Warming Events

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A westerly polar vortex, which characterizes normal stratospheric winter circulations, is highly distorted and breaks down in association with the occurrence of stratospheric sudden warming (SSW) events. Although the vortex evolution occurs very quickly, noticeable circulation changes may continue for a longer period in large atmospheric regions; numerous studies on such changes have been devoted for the region up to the stratopause level from both observational and theoretical aspects. However, observational evidence is still fragmentary in the mesosphere during SSW events, because global data capable of comprehensive analyses are still insufficient for the region. Hence, in this study, we make global grid-point data for geopotential and temperature fields up to the mesopause level derived from Aura MLS data, to make dynamical analyses for global wind and temperature changes up to the mesopause level during the recent SSW events. It is found that large circulation changes also occur in the polar mesosphere, which might be caused, at least partly, by large-scale waves internally formed in the lower mesosphere and/or propagating upward from the stratosphere. The enhancement of large-scale wave activity in the mesosphere depends on changing background wind structure of the upper stratosphere and the lower mesosphere in association with the SSW. In addition, equatorial circulations might be also modulated by SSW events, e.g., the strength of semi-annual oscillations near the stratopause as well as in the mesosphere. Plausible modulation mechanisms will be discussed in the presentation.

The Impact of Compositional Changes on Radiative Damping Rates in the Stratosphere

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The radiative relaxation of circulation anomalies in the middle atmosphere is relevant to many features of the stratospheric circulation, including the recovery from stratospheric sudden warmings, the damping of tropical waves that drive the QBO, and the seasonal cycle of the tropical lower stratosphere.

Changes in the composition of the middle atmosphere projected over the 21st century are expected to lead to a change in the strength of this radiative 'spring.' We quantify changes in both longwave and shortwave damping rates in a comprehensive chemistry-climate model, the UM-UKCA. The damping is projected to strengthen by 10 to 30% through most of the stratosphere under an approximate doubling of CO_2, primarily due to the increase in emitter density. We also quantify the effect of these radiative changes on the amplitude of the lower stratospheric tropical seasonal cycle.

Spontaneous QBO-like Oscillations in Atmospheric Model Dynamical Cores

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The Quasi-Biennial Oscillation (QBO) is a tropical oscillation of the zonal wind regime whose impact is felt globally throughout the stratosphere, and even in the troposphere and mesosphere. Therefore, the ability of an atmospheric General Circulation Model (GCM) to simulate the QBO is considered an important model characteristic, which has been under investigation for almost three decades. Typically, it is believed that the moist convective parameterization is the key GCM component that triggers tropical waves, thereby forcing wave-mean flow interactions. In addition, additional gravity wave drag (GWD) parameterizations are often applied in GCMs to supply additional momentum forcing. Such setups incorporate highly nonlinear interactions between the GCM dynamical core (the resolved fluid flow component) and moist convection or the GWD scheme. This makes it difficult to distinguish the causes and effects of waves and their wave damping mechanisms. We disentangle these interactions.

We show that QBO-like oscillations can also be simulated in dry dynamical cores when driven by the Held and Suarez (1994) forcing. Neither topography nor moisture is present. The Held-Suarez forcing consists of Rayleigh friction of the low-level winds and a Newtonian relaxation of the temperature towards a prescribed equilibrium temperature, thereby mimicking the effects the boundary-layer friction and radiation. We discuss the curious finding that spontaneous QBO-like oscillations are supported in three (SLD, EUL, SE) of the four dynamical cores of the Community Atmosphere Model version 5 (CAM5). CAM5 has been developed at the National Center for Atmospheric Research (NCAR) and supports the spectral transform semi-Lagrangian (SLD), spectral transform Eulerian (EUL), Spectral Element (SE) and Finite-Volume (FV) dynamical cores. These dynamical cores solve the identical 'primitive equation' set and therefore expose the impact of different numerical schemes on QBO-like simulations. The QBO-like signals have long periods between 3.5-13 years and occur in the upper stratosphere, different from observations. However, the amplitudes, asymmetries and meridional extents closely resemble the observed QBO. We take an in-depth look at the wave characteristics of the dry dynamics in the QBO region, assess the wave-mean flow interactions through Transform Eulerian Mean (TEM) analysis, and shed light on the role of diffusion as a contributing, mostly counteracting, switching mechanism. Furthermore, the impact of additional GWD forcing on the QBO simulations is explored.

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Wave Activity and Spectral Characteristics in the Lower Stratosphere Associated with the West African Monsoon

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In the tropics, the main source of gravity waves is the thermal forcing through convection (Pandya and Alexander 1999; Berès et al, 2002). The wind is also a source of gravity waves through vertical shear and the variations of speed. The West African monsoon is characterized by strong convective activity and the presence of altitude jets (the African Easterly Jet and the Tropical Easterly Jet) that modulate the intensity of the West African monsoon (Fontaine et Janicot, 1992; Sultan 2002). The present work analyzes the characteristics (energy and spectral parameters) of waves observed in the tropical and equatorial lower stratosphere of West Africa during the monsoon 2006 with the aim to identify globally the types of waves having vertical wavelengths less than 4 km and attaining the lower stratosphere of the West African region. The study focuses on five (05) meteorological stations in West Africa located in the belt 04°N-18°N and is made using high-resolu tion radiosonde data provided by the African Monsoon Multidisciplinary Analyses (AMMA) campaign and OLR data (Outgoing Longwave Radiation).

Comparison of annual cycle of wave activity shows weaker values of total energy density during the dry period and a peak at the highest activity of convection for tropical sites and two peaks of enhanced activity for equatorial area with a strongest peak matching the period of intense convection. Spectral parameters suggest the presence of inertia-gravity wave (IGW) over the tropical area while the same parameters in addition to analyses of temperature and horizontal wind variances strongly suggest the presence of Kelvin and Mixed-Rossby Gravity waves in addition to IGW over the equatorial zone. Interaction of wave with the Quasi-Biennal Oscillation (QBO) shows that in the tropics as well as at equatorial latitude, the most probable explanation of the 2-year quasi-periodic total energy density variation is the difference of the QBO wind amplitude, direction and its shear.

Weakening stratospheric quasibiennial oscillation and trends in tropical mean upwelling

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The zonal-mean zonal circulation in the tropical stratosphere is dominated by the quasibiennial oscillation (QBO) between prevailing easterlies and westerlies with periods of about 28 months (Baldwin et al. 2001). The vertical structure of the QBO in the lowermost stratosphere is linked to the mean upwelling there (Saravanan 1990; Kawatani et al. 2011, Kawatani et al. 2012; Watanabe and Kawatani 2012), which itself is a key factor in determining stratospheric composition. Here we report on an analysis of near-equatorial radiosonde observations for 1953–2012 and reveal a previously unknown long-term trend of weakening amplitude in the QBO of zonal flow in the tropical lower stratosphere. The trend is particularly notable at 70 hPa, where amplitudes dropped by roughly 1/3 over the period. This trend is also apparent in the global warming simulations of the four models in the Coupled Model Intercomparison Project Phase 5 (CMIP5) that realistically simulate the QBO. This effect is most reasonably explained as resulting from a trend of increased mean tropical upwelling in the lower stratosphere. Almost all comprehensive climate models have projected an intensifying tropical upwelling in global warming scenarios (Butchart et al. 2006; Garcia and Randel 2008; McLandress and Shephered 2009), but attempts to estimate changes in the upwelling by using observational data have yielded ambiguous, inconclusive, and/or contradictory results (Engel et al. 2009; Stiller et al. 2012; Young et al. 2012). Discovery of a significant trend in the lower stratosphere QBO amplitude provides strong support for the existence of a long-term trend of enhanced upwelling near the tropical tropopause and this trend can be considered a subtle, but robust, indicator of the response of the climate system to anthropogenic forcing over recent decades. The reference of this work is Kawatani and Hamilton (2013).

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Dehydration, Hydration and Horizontal Transport in the Tropical UT/LS from Balloon and Satellite Observations.

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High-resolution in-situ balloon measurements of water vapour, aerosol and temperature in the tropical UT/LS are used to evaluate the processes controlling stratospheric water budget: dehydration by freeze-drying, hydration by cross-tropopause overshooting updrafts and long-range horizontal transport. The obtained in-situ evidences of these phenomena are put into a wider context through analysis of water vapour and tropopause multi-year climatology inferred from Aura MLS and COSMIC GPS satellite observations and simulations using the CLaMS Chemistry Transport Model (CTM).

The balloon soundings were conducted during the Austral summers of 2012 and 2013 in Bauru, Brazil (22.3 S) in the frame of the French ANR TRO-pico project, aimed at characterizing the variability and frequency of convective water injections into the stratosphere and improving the understanding of their role with respect to the cold trap at broad scale. The payloads flown during both campaigns included a Pico-SDLA diode laser hygrometer, a FLASH-B Lyman-alpha hygrometer, and a COBALD aerosol backscatter sonde, as well as other instruments for measurement of gas-phase and particle constituents. The water vapour profiles obtained by the two totally different measurement techniques are in close agreement, demonstrating high quality of the observations.

The signatures of long-range horizontal transport are inferred from a series of vertical profiles obtained in March 2012, which show coincident enhancements in water vapour and aerosol at specific levels in the lowermost stratosphere. Trajectory analysis unambiguously links these features to advection from the southern hemisphere extra-tropical stratosphere, containing more water and aerosol, as demonstrated by MLS and CALIPSO global observations. The intrusion of mid-latitude air is successfully reproduced by the CLaMS CTM, showing water- and ozone-rich filaments extending to 20 S.

The signatures of local cross-tropopause transport of water are observed in several soundings during both 2012 and 2013 campaigns, revealing water vapour enhancements ranging from 0.7 to 7 ppmv at different levels between 375 K and 405 K. These are shown to originate from convective overshoots upwind detected by the local IpMet's S-band radar. The relative contribution of the horizontal transport and that of local updrafts to the stratospheric humidity is evaluated using local and global observations together with CTM simulations.

Evidence of an anomalously cold and dry TTL and concurrent formation of subvisible cirrus clouds at the tropopause is provided by the balloon soundings in January-February 2013. The sequence of water vapour profiles compared to the climatology comprehensively reflects the competition between freeze-drying and hydration by overshooting. Space-borne Aura MLS water vapour and COSMIC GPS temperature observations are used to upscale the local balloon soundings and to derive the spatio-temporal evolution of the dry and cold anomaly around the tropopause above South America.

Tropical Cold-Point Tropopause: Climatology, Seasonal Cycle, and Intraseasonal Variability Derived from COSMIC GPS Radio Occultation Measurements and CMIP5 models

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The fine-scale structure of the tropical cold-point tropopause (CPT) is examined using high-resolution temperature profiles derived from Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) Global Positioning System (GPS) radio occultation measurements for 4 years from September 2006 to August 2010. Climatology, seasonal cycle, and intraseasonal variability are analyzed for three CPT properties: temperature (T-CPT), pressure (P-CPT), and sharpness (S-CPT). Overall findings are then applied to the state-of-the-art climate models that have participated in the Coupled Model Intercomparison Project Phase 5 (CMIP5).

Climatological P-CPT is largely homogeneous in the deep tropics, whereas T-CPT and S-CPT exhibit local minima and maxima, respectively, at the equator in the vicinity of deep convection regions. All three CPT properties, however, show coherent seasonal cycle in the tropics; the CPT is colder, higher (lower in pressure), and sharper during boreal winter than during boreal summer. This seasonality is consistent with the seasonal cycle of tropical upwelling, which is largely driven by stratospheric and near-tropopause processes, although the amplitude of the seasonal cycle of T-CPT and S-CPT is likely modulated by tropospheric circulations. On intraseasonal time scales, P-CPT and T-CPT exhibit homogeneous variability in the deep tropics, whereas S-CPT shows pronounced local variability and seasonality. The wavenumber–frequency spectra reveal that intraseasonal variability of CPT properties is primarily controlled by Kelvin waves, with a non-negligible contribution by Madden–Julian oscillation convection. The Kelvin waves, which are excited by deep convection but often propagate along the equator freely, explain the homogeneous P-CPT and T-CPT variability. On the other hand, the vertically tilted dipole of temperature anomalies, which is associated with convectively coupled equatorial waves, determines the local structure and seasonality of S-CPT variability.

Most of CMIP5 models successfully reproduce the spatiotemporal structure of the temperature in the CPT region in comparison to COSMIC observations and reanalysis data. The interannual variability associated with El Niño-Southern Oscillation and intraseasonal variability associated with equatorial waves are also reasonably well captured. However, the models show non-negligible biases in several aspects: 1) most models have a warm bias around the CPT; 2) large inter-model differences occur in the amplitude of the seasonal cycle in 100-hPa temperature; 3) several models overestimate lower stratospheric warming in response to volcanic aerosols; 4) temperature variability associated with the quasi-biennial oscillation and Madden-Julian oscillation is absent in most models; 5) equatorial waves near the CPT exhibit a wide range of variations among the models with unrealistically persistent Kelvin waves in several models. These results suggest that dynamical and physical processes near the CPT still need to be improved in the climate models.

A study of the tidal periodicity of mesospheric gravity waves observed with MF radar at Poker Flat, Alaska

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The interaction between gravity waves and tidal waves has been studied by using observations (e.g., Saskatoon, Canada (Manson et al. 1998), Rothera, Antarctica (Beldon and Mitchell, 2010)), although the phase relation between them was not fully understood. In Alaskan region, we have been observing the neutral wind velocity in mesosphere to lower thermosphere with a MF radar since October 1999, deployed at Poker Flat Research Range of Geophysical Institute, University of Alaska Fairbanks (65°N, 147°W). The long-term wind velocity data at Poker Flat was analysed for 10 years of 1999 – 2008 to show daily and seasonal behaviours and climatology of gravity waves and tides. The purpose of this study is to improve the understanding of coupling processes of gravity waves and tidal waves from observation and modelling data.

First, we extracted these waves from the MF radar observation data. In this study, harmonic analysis was carried out for periods of 48, 24, 12, and 8 hours, which are extracted from the 5 day time series of wind velocity using. Gravity waves are defined as the 1 ~ 12 hour period component of difference between observed wind velocity and these harmonic components. The method is applied to 30-minute-average data to calculate the 5 day running mean amplitude and phase of tidal waves. We made 1- day composite plots of kinetic energy of gravity waves for periods of 1 ~ 4 hours and harmonic components. The results show that the kinetic energy of gravity waves has two peaks in 3 ~ 6 UT and 12 ~ 15 UT respectively, which tend to coincide with the time when easterly wind of the 12 hour component is switched westerly. This feature commonly recognized in April to August.

On the other hand, the phase relation between 12 hour components of zonal wind and kinetic energy of gravity waves shows that their phase agrees for more than 10 days in several years. To examine whether this relation can be explained by some interaction between tidal waves and gravity waves, we add orographic gravity wave drag model (Alexander and Dunkerton 1999) into the background state defined as the sum of monthly mean and harmonic components of zonal wind. The result shows that the gravity wave drag has period of 12 hours and changes in time with the phase of harmonic components. Thus, it is suggested that the phase agreement between 12 hour components of zonal wind and kinetic energy of gravity waves can be interpreted as the result of gravity wave dissipation on the tidal field.

We will also use the simulation data from a high-resolution general circulation model to discuss more detail of underlying physical processes of the observed gravity wave – tidal wave relation.

Wave forcing of the Quasi-Biennial Oscillation

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This study investigates the resolved wave forcing of the Quasi-Biennial Oscillation (QBO) based on the Max Planck Institute Earth System Model with T63 L95 resolution. The model internally generates a QBO which, compared to ERA-Interim, is realistic in many aspects. The QBO of the zonal wind is the dominant mode of variability in the tropical stratosphere and is driven by a large spectrum of waves which transport zonal momentum from their tropospheric sources to the shear zones associated with the QBO westerly and easterly jets. Previous studies discussing the QBO's wave forcing in detail were based on high resolution models which resolved most of the wave spectrum important for the QBO. However, models with much lower spectral and vertical resolutions, such as the model applied here, are still the backbone of today's climate modeling, and little has been reported about the resolved wave forcing in such models. Consistent with previous studies, resolved waves with planetary wave-numbers lower than 40 contribute up to 50% and 30% to the forcing of the QBO westerly and easterly jet, respectively. The resolved wave drag mostly comes from waves with planetary wave-numbers lower than 20. The model underestimates the strength of the tropospheric wave sources with wave-numbers higher than 20 and periods shorter than two days, which suggests that also the wave momentum at theses spectral ranges is too low. The study compares the wave-number frequency spectra of the e-folding time of wave induced perturbations due to long wave radiation and horizontal diffusion. For large scale equatorial waves, long wave radiative damping, which increases with decreasing vertical wave number of the waves, is more efficient than diffusion. For small scale gravity waves, horizontal diffusion is the most important damping mechanism. Due to the radiative and diffusive wave damping, the wave momentum decreases with increasing distance from the tropospheric wave sources, even in the absence of critical levels. Hence, the westerly and easterly wave momentum available to force the QBO jets decreases with increasing altitude of the zero wind lines marking the onset of the easterly and westerly jets.

The influence of spectral resolution on modeling the Quasi-Biennial Oscillation

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The Quasi-Biennial Oscillation (QBO) of the tropical stratosphere is driven by a continuous spectrum of waves. This study compares the QBO wave forcing based on AMIP-type simulations with two versions of the ECHAM6 atmospheric model with spectral truncations of T63 and T255 (1.9° and 0.4° horizontal resolution, respectively) and 95 vertical levels (700 m vertical resolution). Owing to the wide range of scales, from planetary scale Matsuno type equatorial waves to small scale gravity waves, it is not yet possible to close the stratospheric momentum balance based on observations, which is why atmospheric models are still the optimal choice for studies on QBO dynamics. To internally generate the QBO, general circulation models either have to parametrize unresolved small scale waves and their interaction with the resolved flow or have sufficient horizontal and vertical resolution to resolve the waves necessary to drive the QBO. This study shows how the QBO changes when increasing the model resolution and thus, replacing parts of the parametrized gravity wave spectrum by resolved waves. In the low and high resolution version of the applied model, the sum of the resolved and parametrized wave forcing of the QBO jets is equal during most of the quasi-biennial cycle. Due to its lower amplitude, the oscillation in the high resolution version needs less momentum to swing back and forth, thus, the QBO period is 7 months shorter. The lower amplitude is due to increased resolved easterly wave drag within the QBO westerly jet in the upper stratosphere. In the lowermost stratosphere, waves with wave numbers up to 30 are stronger in the low resolution version. However, the horizontal diffusion, which weakens the waves as they propagate away from the tropospheric wave sources towards the zero wind lines below the QBO jets, is stronger too. Hence, the resolved wave forcing in the low resolution version is mostly due to waves with wave numbers lower than 20, whereas in the high resolution version, waves with wave numbers up to 120 contribute considerably to the momentum balance.

Seasonal Aspects of the Quasi-Biennial oscillation in the Max Planck Institute Earth System Model and ERA-40

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Observations show that the quasi-biennial oscillation (QBO) of the tropical stratosphere is modulated by the seasonal cycle. At every altitude, phase transitions cluster in a specific season and the QBO phases progress more rapidly in boreal winter and spring than in summer and fall, which results in the tendency of the QBO easterly jet to stall below 30 hPa between June and February. To investigate these seasonal aspects of the QBO within the fully coupled global climate system, this study employs the Max Planck Institute Earth System Model, which internally generates a realistic QBO compared to the ERA-40 dataset. The modeled QBO is forced with resolved and parametrized waves. At 5 hPa, the seasonal distribution of the onset of QBO westerly jets clusters in spring and fall due to the coupling of the QBO and the semi-annual oscillation . This seasonal clustering of the westerly jets extends throughout the stratosphere, shifting to later months with increasing pressure. QBO westerly jets starting in the upper stratosphere in fall propagate to the middle stratosphere more slowly than westerly jets starting in spring. This is attributed to seasonal modulations of the QBO forcing and enhanced wave filtering by the QBO westerly jet in the lower stratosphere in fall and winter compared to spring and summer. The observed stalling of the QBO easterly jet in the lower stratosphere and the accompanied prolonged persistence of the QBO westerly jet in the vicinity of the tropopause are attributed equally to seasonal variations of the resolved and parametrized wave forcing and the advective forcing.

Reference:

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Sulfur and Halogen Release from Large Tropical Volcanic Eruptions to the Stratosphere – a Potential Ozone Hole Scenario

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Large, explosive volcanic eruptions inject gases (sulfur dioxide, carbon dioxide, halogen compounds), aerosols and solid particles (ashes) into the stratosphere. If the eruption takes place in the tropics, the climate influence is global due to the distribution of sulfate aerosols, potentially damping the global warming scenario for a few years. Volcanic sulfate aerosols also enhance the ability of stratospheric halogens (Chlorine and Bromine) to deplete the ozone layer, as was observed after the 1991 eruption of Pinatubo in the Northern Hemisphere under high anthropogenic chlorine loading. On the other hand the effect of volcanic halogen release from present-day, small to medium size (halogen poor) eruptions on the ozone layer is currently neglected as it is believed not to play a significant role. However, if large amounts of volcanic sulfur and halogens together reach the stratosphere, they have high ozone depletion potential.

In this study we address the climate and ozone effects of past explosive eruptions, taking the sulfur and halogen loading of the stratosphere into account. The volcanic volatiles are derived by the petrological method, combing extensive volcanic field work with novel analytical methods, i.e., to detect Bromine in volcanic minerals. New data sets of the Sulfur, Bromine and Chlorine release from the Central American Volcanic Arc from large and highly explosive eruptions over the past 200ka were compiled (Metzner et al., 2012; Kutterolf et al., 2013). Single eruptions produced Bromine output of 4–600kt, giving an average emission of 27kt per event (Kutterolf et al., 2013). Finally, the climate and ozone relevance of different strength eruptions, in terms of their sulfur and halogen release, is assessed. The strongest eruption with almost 700Mt SO_2 injections into the stratosphere is projected to have cooled the Earth's surface with a maximum up to 3K. The average Bromine and Chlorine loading to the global stratosphere would have been 3ppt and 1500ppt, respectively, when assuming only a 10% halogen entrainment to the stratosphere. This together would account for 185% (59%) of the preindustrial (present-day) equivalent effective stratospheric Chlorine loading. We thus conclude that large tropical volcanic eruptions had and have the potential to substantially deplete ozone on a global scale, eventually forming future ozone holes.

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Cly chemistry in the mesosphere observed by SMILES

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Global distributions of the atmospheric compositions were observed for wide vertical range by the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) from the Exposed Module (EM) of the Japanese Experiment Module (JEM) on the International Space Station (ISS) between 12October 2009 and 21 April 2010. The JEM/SMILES mission is a joint project of the National Institute of Information and Communications Technology (NICT) and the Japan Aerospace Exploration Agency (JAXA). The latitude coverage of SMILES observation is normally 38^{o}S - 65^{o}N. The SMILES instrument employed 4 K submillimeter-wave superconductive heterodyne receivers, and obtained spectra with unprecedented low noise, which is one order of magnitude better performance than previous microwave/sub-millimeter limb instruments in space. SMILES observations provided global distributions of $\mathbf{O_3}$, $\mathbf{H^{35}Cl}$, $\mathbf{H^{37}Cl}$, **ClO**, **HOCl**, $\mathbf{HO_2}$, and temperature in the mesosphere. We found active chlorine chemistry with these data. The presentation will discuss present the global distributions of chlorine compounds and its chemistry and dynamics in the mesosphere.

In situ measurements of UTLS humidity: Effects of small-scale temperature fluctuations and of data quality

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Measurements of water vapor at the very low mixing ratios (< 10 ppmv) prevalent in the UTLS are important for understanding climate and air chemistry. Reliable measurements are difficult and disagreements between high-precision hygrometers are common. We show that data sets of relative humidity (RH_{ice}) are dominated by effects of small-scale temperature fluctuations and of present data quality, which both limit their information content.

The 2011 MACPEX campaign with the NASA WB-57 carrying seven in situ hygrometers provided an unprecedented opportunity to investigate advances in these measurements. Figure 1A shows the correlation of H_2O mixing ratios measured by two instruments, FISH and CIMS, during one mission flight(1) in comparison with three combinations of accuracies and precisions of both instruments. While during certain flight legs the instruments show differences which are largely explained by their precision, during others large offsets with respect to each other exist (lower branch), which can only be explained if the extremes in accuracy errors are assumed in opposing directions for both instruments.

Figure 1B shows an application to RH_{ice} inside cirrus clouds(2) derived from FLASH and OJSTER (corrected by FISH). Figure 1C provides the modeling results of water uptake by the ice particles. Comparison with Fig. 1B shows that the measured RH_{ice} is to a large degree determined by the effects of small-scale temperature fluctuations, which is an inherent and unavoidable uncertainty in such measurements (colored range in Fig. 1C). The most extreme scatter in Fig. 1B can be fully explained by superimposing T fluctuations and instrumental uncertainties (black points in Fig. 1C). Together, these two sources of uncertainty leave no room for having to invoke unconventional processes causing high in-cloud RH_{ice}.

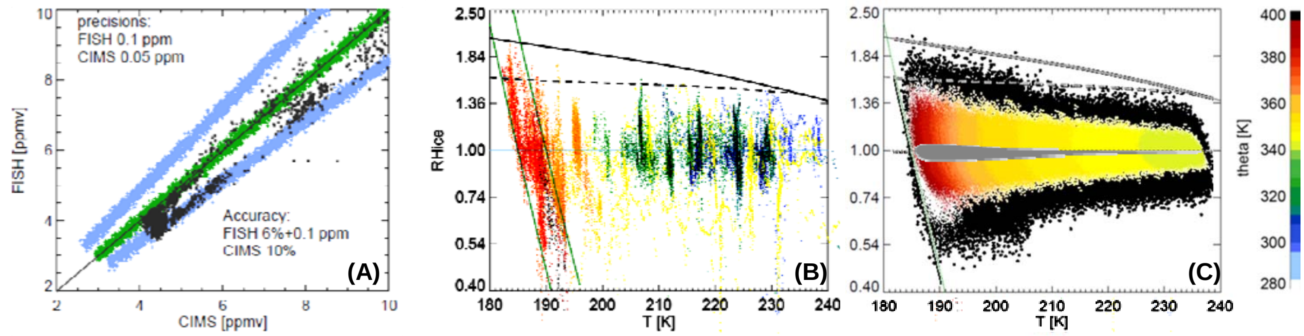

Figure 1. (A) Black points: FISH-CIMS correlation of H_2O mixing ratios measured on 26 April 2011 during the MACPEX campaign(1). Blue and green points: three combinations of accuracies and precisions of both instruments. **(B)** In-cloud RH_{ice} measured by FLASH/OJSTER and corrected by FISH(2). **(C)** Microphysical model generated RH_{ice} distribution assuming a typical ice particle distribution. Gray narrow band: without small-scale temperature fluctuations and assuming the measurements to be accurate. Colored range: with ubiquitous small-scale temperature fluctuations. Black margin: with temperature fluctuations and taking accuracies and precisions of the FLASH/OJSTER hygrometers and of the temperature measurement into account.

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Patterns of Southern Hemisphere Climate Change and their Relationships

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Trends in surface atmospheric variables, namely temperature, wind speed, and direction, cloud cover, and precipitation, display subtle patterns that are likely linked to climate change and the major modes of climate variability. In particular, in the Southern hemisphere extra-tropics patterns of variation are strongly impacted by the Sothern Annular Mode (SAM) and the relationships between trends in different variables can also be explained with respect to physical changes linked to the SAM. This study aims to examine variations in a range of variables and the relationships between these changes in reanalyses and model output. In particular, we aim to identify whether the patterns of relationships that might be expected a priori based on our underlying knowledge are reproduced in the climate model, and also attempt to identify the relative impacts of greenhouse gas and stratospheric ozone depletion forcings on these relationships.

We will examine the extra-tropical patterns in the trends of a range of atmospheric variables in reanalyses (ERA-interim and MERRA) and derive the underlying relationships between these trends and variability within these measures. We will then complete a similar analysis on the output from a 20th century run of an atmosphere-ocean-chemistry coupled climate model to examine the ability of this model to simulate the observed trends and importantly their interdependencies. We will then compare the trends and their relationships in the Southern hemisphere extra-tropics for runs which include and neglect ozone forcings. We hope that this will allow us to identify the relative importance of greenhouse gas and stratospheric ozone depletion forcings on the patterns observed and their relationships, providing a more holistic analysis than previously considered.

Equatorial wave activity during 2007 over Gadanki, a tropical station

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Winds data obtained from ECMWF Re-Analysis (ERA) during January – December, 2007 are analyzed to investigate equatorial wave activity over Gadanki, a tropical station in the altitude range 1 – 50 km. FFT analyses have been carried out on continuous data sets of two months each after filtering the data appropriately for < 10 days and 10 – 25 days period band. Oscillations with 3 - 5 days, 6 - 9 days and 12 - 20 days are found to be prominent in the troposphere and stratosphere. The amplitudes of the oscillations in all the period bands are found to decrease as they propagate from upper troposphere to lower stratosphere. Their propagation direction is eastward during November to April when the winds are westward in the troposphere. The oscillations are found to be filtered out in the mid-stratosphere and they pick up again in the upper stratosphere between 40 and 50 km. The propagation of the waves depends highly on the background wind system. Wavelet analyses have been carried out to find the temporal variation of the wave activity.

Present and Future changes of the TTL using a Lagrangian approach

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The main entrance region for trace gases, travelling from the troposphere into the stratosphere, is the tropical tropopause layer (TTL). The upper boundary of the TTL can be defined by the cold point temperature, which is lowest over the West Pacific and maritime continent where most air masses reach the TTL due to strong convective uplifts. A broadening of the tropical belt over the last few decades has been suggested by several recent studies (e.g. Seidel et al. 2008) based on different definitions of the tropical borders such as the Hadley cell width or the frequency of high tropopause days. The widening of the tropical belt is an important aspect of climate change with possibly far-reaching implications for tropospheric circulation systems and precipitation patterns. While most existing studies of the expansion of the tropical belt focused on the upper troposphere and lower TTL, possible changes of the upper TTL and in particular the cold point tropopause are still unclear.

In this presentation, we analyze possible present and future changes of the upper TTL based on a Lagrangian approach. For this purpose, we determine the Lagrangian cold point (LCP) from trajectory calculations and investigate changes of the width of the LCP distribution. Our study is based on the ERA-Interim reanalysis from 1979-2011 and future climate projections from a variety of climate models. Different coupled chemistry climate models (CCMs) within the CCMVal - 2 project (REF-B1 and REF-B2 simulations) and one coupled climate model from CMIP5 (MPI-ESM; historical and RCP 8.5 simulations) were analyzed for three different decades 1990s, 2040s and 2090s. The model simulations by CMAM REF-B2 and MPI-ESM include a coupled ocean.
The main entrance region of air masses travelling to the stratosphere above the maritime continent is captured by all models. The LCP diagnostic reveals an increase of the LCP temperature of around 1K from the 1990s to the 2090s. Based on ERA-Interim we detect a significant broadening of the upper TTL of 1.2°/decade for the analyzed period 1979-2011, which is not captured consistently by all models. Future simulations project a small positive change in the width of the upper TTL towards the end of the 21st century. Additionally, an increase of the LCP frequency of 5-20% over the maritime continent and a decrease over other geographical regions highlights the importance of the tropical West Pacific for air mass transport into the stratosphere in a future climate.

Vertical profiling of ozone, RH and temperature from the central Himalayas: Influence of dynamical processes and biomass burning

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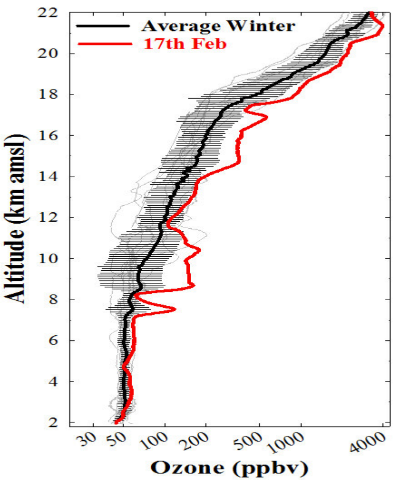
Observations of vertical distribution of ozone, and other trace gases including water vapour, aerosols and meteorological parameters are very limited over the tropical Asia, particularly in South Asia. Higher water vapour, intense solar radiation and increasing levels of trace species are making this region more complex for understanding the physical, dynamical and chemical process over this region. Monsoon system, over this region, is one of the largest regional climate phenomena and has major influence on the regional atmospheric composition. One of the most populated regions (The Indo-Gangetic Plain, IGP) of the world and a variety of anthropogenic and biogenic emission sources are also housing in South Asia.

In view of this, an observational facility was setup at ARIES, Nainital (29.4N, 79.5E; 1950 m) in the central Himalayas and at two sites in the IGP region. Regular, once in a week, balloon borne measurements of ozone, RH, temperature and GPS winds are being made since January 2011. Surface observations of different trace gases (Ozone, CO, NO, NOy, light NMHCs, SO_2, CO_2 and other GHGs) and aerosols are also being made at this site. A strong seasonal cycle in the lower tropospheric ozone with highest values during spring (~ 100 ppbv) and lowest during summer-monsoon (20-40 ppbv) is discerned. Elevated ozone levels (~120 ppbv) were observed in the middle-upper troposphere along with very high wind speed (~50 m/s) which indicates the role of dynamics in bringing ozone rich air from higher altitude. The signatures of ozone downward transport have also been noticed in TES water vapour and PV. In contrast, such influence is seen to be weaker in the eastern part of the Himalayas. A very clear enhancement (20-30 ppbv) in the lower tropospheric ozone is seen that is induced by the biomass burning. Realizing the importance of this central Himalayan region, more frequent (00, 06, 12, and 18 GMT) radiosonde were launched during June 2011-March 2012 (~1000 launches) and observations were carried out using doppler Lidar, microwave radiometer, ceilometers, AOS, etc under first ARM mobile facility (AMF1), DOE, USA. Further analysis of these observations with the help of air trajectories, satellite data and WRF-Chem model will be presented.



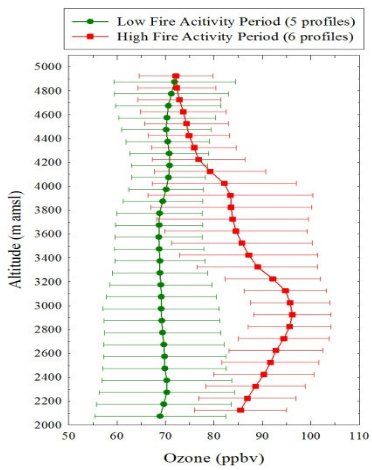


Figure: Events of downward ozone transport and influence of biomass burning in the central Himalayas.

Simulation of Inter-annual and Inter-seasonal Variations of Tropospheric Water Vapour over south Asia using RegCM4

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In this study, the tropospheric water vapour mixing ratio (WVMR) over south Asian regions is simulated using Regional Climate Model (RegCM4). The inter-annual and inter-seasonal variations of tropospheric WVMR are investigated through a 30 years climate simulation. The model is integrated at 30 km horizontal resolution with 23 vertical levels over south Asia [30E-120E & 15S-45N] for the period of 1981 to 2010. The model simulated WVMR decadal climatology for four seasons i.e. winter (DJF), summer (MAM), monsoon (JJAS), autumn (ON) over south Asia is prepared and analysed. Inter-annual and inter-seasonal variations of tropospheric WVMR are analysed over south Asian regions at different pressure levels. The simulated WVMR indicates the tropospheric mean WVMR is increased by 0.1-0.6 kg/kg during 1991-2000 over south Asia in autumn, summer & winter and decreased by ~0.2kg/kg in monsoon, while it is decreased by 0.1-0.3 kg/kg during 2001-2010 in all four seasons. The results also indicate that the effect of WVMR varies region-wise. The simulated decadal WVMR climatology is also compared with the decadal mean temperature climatology during 1981-2010 in all four seasons over the region. The role of tropospheric water vapour in regulating the air temperature at different pressure levels are also discussed in this study. The overall study indicates that the spatial distribution water vapour plays an important role, to some extent, for the regional warming or cooling over south Asian regions.

Key words: Regional Climate Model, Tropospheric Water Vapour Mixing Ratio, South Asian Regional Warming/ Cooling, Inter-seasonal and Inter-annual Variability

A diagnostic tool for the temperature structure around the tropical tropopause

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Around the tropical tropopause low temperatures generally occur to the east of tropical active convection around the equator and to the west in the subtropics, forming a horseshoe-shaped structure. This structure resembles a stationary wave response known as the Matsuno–Gill pattern, which is induced by the heating generated by the convective activities near the equator.

To quantitatively capture its variability, we established an index characterizing the horseshoe-shaped structure. This index then revealed the significant relationship with convective activities with the intraseasonal, seasonal, and interannual timescales by using contemporary reanalyses from ECMWF and OLR from NOAA. The seasonal and interannual variability is related to the convective activities in the three monsoon regions: the South Asian monsoon and the North Pacific monsoon areas during the northern summer and the Australian monsoon area during the southern summer. During the southern summer the horseshoe-shaped structure index is also related to convective anomalies associated with the El Nino-Southern Oscillation cycle, shifting eastward in El Nino years. With the interannual timescale, the index is significantly related to the MJO-like eastward propagating convective activities during the southern summer.

The horseshoe-shaped temperature structure index can be a useful diagnostic tool to assess the reproducibility of the tropical tropopause temperature in GCM models. I will show you some results to investigate the relationship between the horseshoe-shaped temperature structure and the OLR repoduced in CMIP5 models.

The residual mean circulation in the tropical tropopause layer driven by tropical waves

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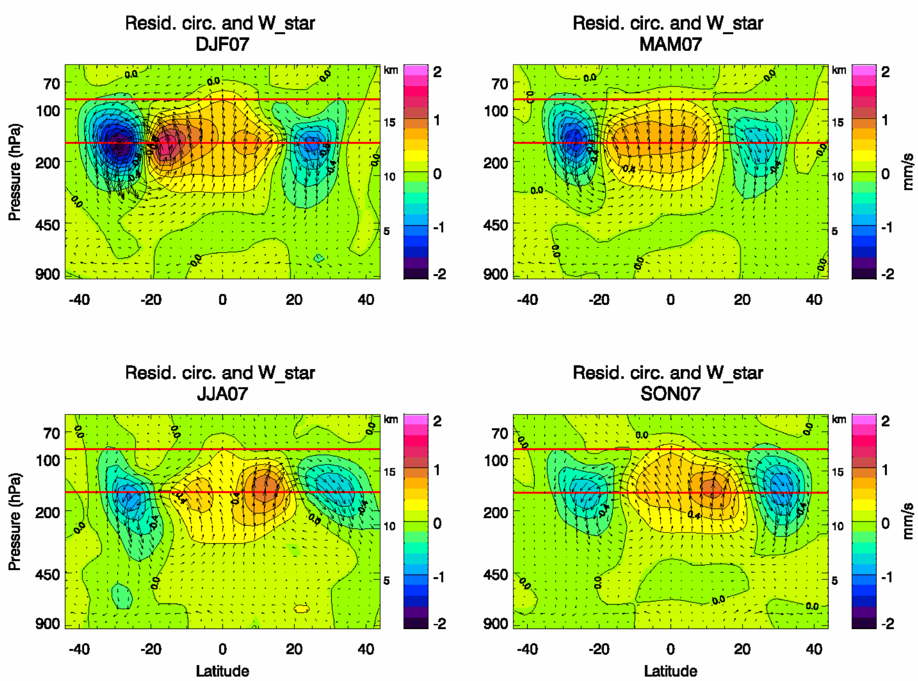
We use latent heating estimates derived from rainfall observations to construct model experiments that isolate equatorial waves forced by tropical convection from mid-latitude synoptic-scale waves. These experiments are used to demonstrate that quasi-stationary equatorial Rossby waves forced by latent heating make a substantial contribution to the observed residual mean upwelling across the tropopause transition layer within 15^{o} of the equator. The seasonal variation of the equatorial waves and the mean meridional upwelling they cause is examined for two full years from 2006 to 2007. We find that changes in equatorial Rossby wave propagation through seasonally varying mean winds is the primary mechanism for producing a seasonal variation in the residual mean upwelling in the tropical tropopause layer, with maximum upwelling during Boreal winter and Spring a factor of two larger than the minimum upwelling during Boreal summer. This variability seems to be due to small changes in the mean wind speed in the tropics. Seasonal variations in latent heating have only a minor effect on seasonal variations in tropical tropopause upwelling, but interannual variations in the heating have a more significant effect. We also find that Kelvin waves drive a small downward component of the total circulation over the equator that may be modulated by the quasi-biennial oscillation.



Residual mean circulation (vectors) and the residual mean vertical velocity (contours) for equatorial waves forced by heating derived from TRMM rainfall, averaged over four seasons in 2007. This figure shows the results for a simulation with monthly zonal mean background winds derived from NCEP.

An assessment of tropical stratosphere variability within past and present global climate models

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For more than a decade researchers have successfully assessed QBO variability within a select number of global climate models (GCMs). But of all models recently used in CMIP5, only 4 include convincing QBO variability. This suggests that: (1) outstanding issues remain for modeling the QBO, or (2) undesirable effects occur outside the tropical stratosphere, which deter inclusion of a QBO.

QBOi represents a modelling centre led initiative, to explore the sensitivity of the QBO to changes in resolution, and parameterised physics relevant to the tropical stratosphere. Although running new simulations is a key part of QBOi, a useful and valuable first step is assessing the state of past and present QBO modelling.

Here we present first results collating QBO-relevant information within configurations of past and present GCMs. Emphasis is on simple metrics, using standard model output, to characterise the key characteristics of tropical stratosphere variability. Simple metrics include: QBO amplitude over separate westerly and easterly phases, mean period and range, descent rates for separate QBO phases, height of wind maxima and the latitude extent of QBO variability. Other diagnostics useful for assessing those necessary conditions required to support a QBO, include total wave momentum at the tropopause and mean upwelling.

Odin/SMR's Contribution to a Better Understanding of Energetic Particle Precipitation Indirect Effect

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The Sub-Millimeter Radiometer (SMR) on board the Odin platform, launched in 2001, is a limb emission sounder measuring trace gases in the stratosphere, mesosphere, and lower thermosphere. Odin is a Swedish-led satellite project funded jointly by Sweden (SNSB), Canada (CSA), Finland (TEKES), and France (CNES), with support by the 3rd party mission programme of the European Space Agency (ESA).

Energetic Particle Precipitation (EPP) represents an important solar-terrestrial coupling mechanism because of its important implications for atmospheric chemistry. These effects can be direct (formation of NO_x and HO_x radicals) or indirect. Magnetospheric electron precipitation into the polar atmosphere during geomagnetic perturbations leads to nitric oxide formation in the polar upper mesosphere and lower thermosphere (UMLT). In the winter hemisphere, generated NO_x can be transported downward into the stratosphere by the meridional circulation, and thus affect the middle atmosphere composition. This mechanism is called EPP indirect effect. SMR supplies the scientific community with a 10 year NO data set, and measurements of several other related species. This instrument can therefore contribute to a better understanding of this effect in many ways.

SMR is involved in the SPARC project HEPPA-MMI (High Energy Particle Precipitation in the Atmosphere – Model-Measurement Inter-comparison). The goal of this international working group is to get a better understanding of EPP-induced middle atmospheric changes, and to assess the ability of current models to reproduce those phenomena. The work is based on inter-comparisons between measurements from several instruments and results from different models, focusing on the 2008/2009 northern hemisphere polar winter. This period is characterized by peculiar dynamical conditions. A major sudden stratospheric warming (SSW) indeed occurred, followed by the reformation of a strong upper stratospheric vortex. This phenomenon was associated with a descent particularly efficient in the following weeks. Besides, SMR has observed a major midwinter warming that occurred last winter, in January 2013. This event was even stronger than the one that occurred in 2009, with a higher potential to influence the middle atmospheric composition. And finally, the 10 year NO data set from Odin/SMR can be used to construct a 3D nitric oxide empirical model in the UMLT, that can be of great benefit for modelers who want to reproduce EPP indirect effect in their models.

Upper Tropospheric Humidity, Supersaturation and Cirrus Formation

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Observations of persistent high supersaturations with respect to ice inside cirrus clouds are challenging our understanding of cloud microphysics and of climate feedback processes in the upper troposphere. We present a critical review of the topic, spanning the field from basic concepts of ice nucleation and growth, to addressing laboratory evidence for supersaturations and cloud-scale modeling, all the way to observations of high and very high supersaturations. Persistent supersaturations – if real – impact the radiative budget (direct and cloud-related) and chemistry of the upper troposphere and stratosphere, and limit our understanding of long-term stratospheric humidity trends.

Ice nucleation and ice particle growth lead to characteristic relaxation times (τ) of the saturation ratio. Supersaturations can only be maintained for long times when continued cooling of the air mass occurs. As τ is inversely proportional to the number of ice particles present in an air mass, some estimates of too high supersaturation might be due to artifacts from ice particle shattering. However, small ice particles in the upper tropical troposphere should be less affected by this problem.

Laboratory studies of ice nucleation and growth provide some evidence in favor of the occurrence of persistent supersaturations involving non-conventional processes (cubic ice, glassy particles, low mass accommodation of H_2O on ice, foreign molecules such as HNO_3 blocking growth sites, extreme crystal habits). Furthermore, coupled dynamics/microphysics may support supersaturations through processes from the cloud-scale to small-scale temperature fluctuations, and turbulence.

Instrument uncertainties in hygrometer measurements are a most crucial point in this discussion: starting with what we learned from chamber experiments such as AquaVIT[(1)], via the quality-control revisions of datasets from certain instruments, e.g. the Cryogenic Frostpoint Hygrometer[(2)] or the FISH/FLASH and FISH/OJSTER tandems[(3)], to the point of new techniques such as in-flight calibration[(4)]. However, determining instrumental uncertainties and error propagation remains difficult, and declassing particular instruments is almost impossible. Instrument-related uncertainties call for in-flight checks or calibrations of hygrometers under the extreme humidity conditions in the upper troposphere.

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Ground-based observation of the long-term variability in the extra-tropical mesosphere and the inter-annual coupling with the stratosphere/ troposphere

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For the mesosphere long-term measurements are seldom. The indirect LF-phase height measurement at Kühlungsborn (Northern Germany) for an altitude of about 82 km was started in February 1959 and run over 50 years without any large breaks. We used a new homogenized data set of daily detrended phase heights for a constant level of electron density from 1959-2009. A mean smoothed seasonal cycle has been subtracted from each year. Finally, the calculated spectrum shows beside a strong annual and decadal cycle, three peak-periods which may be linked to stratospheric/ tropospheric processes: i) for about 30 months, ii) for about 3.4 years, and iii) for about 5 years. Due to the strong coupling between atmospheric layers of the mesosphere and stratosphere/ troposphere, a dynamical origin of these peak-periods of long-term variability is assumed. In order to examine the dynamical coupling between atmospheric layers of the northern hemisphere we used combined reanalysis data of ECMWF (ERA-40 and ERA-Interim) for 50 years with an overlap of about 20 years. For the 30 months period we found a strong correlation with the quasi-biennial oscillation (QBO) of the subtropics of the stratosphere, which implies a dynamical relationship to the extra-tropical mesosphere. The possible mechanism of this dynamical relationship is presented and discussed. Furthermore, results for the other two inter-annual periods are shown and discussed.

Evidence of much more convective troposphere to stratosphere transport in the Southern than in the Northern tropics and tentative explanation

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Convective overshooting over tropical land areas is a key contributor to troposphere-to-stratosphere exchange, shown to inject in the lower stratosphere adiabatically cooled air (Pommereau and Held, 2007; Cairo et al., 2011; Khaykin et al., 2013), trace and chemically active gases (Ricaud et al., 2007, 2010), tropospheric clean air diluting the aerosols (Vernier et al., 2011) and ice crystals (Corti et al., 2007; Nielsen et al., 2007; Khaykin et al., 2009) resulting in the humidification of the lower stratosphere (Carminati et al., 2013). But unexpectedly, all above studies are displaying more intense signal during the austral summer and over southern continents where those events can reach 20-21 km, in contrast to the northern tropics where they are limited to altitude below the tropopause. This suggests that troposphere to stratosphere transport by convective lofting is much more vigorous in the Southern Hemisphere than in the Northern Hemisphere with its implication on the composition of the stratosphere.

The tentative explanation for that is the higher albedo and the larger tropospheric desert dust and anthropogenic aerosols load of the northern tropical continents, limiting the daytime increase of Convective Available Potential Energy (CAPE), compared to the smaller albedo and the cleaner troposphere over the rain forest of the southern continents in the summer.

Shown in the presentation will be the experimental evidence from various observations of the difference of convective transport intensity between the two hemispheres, and a tentative explanation of the origin of the CAPE difference by its relation with aerosol optical depth.

Carbon monoxide as a tracer for tropical troposphere to stratosphere transport in the Chemical Lagrangian Model of the Stratosphere (CLaMS)

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Transport from the troposphere to the stratosphere occurs mainly in the tropics, but there are open questions regarding many aspects of the transport pathways. Variations in the mixing ratio of trace gases of tropospheric origin entering the stratosphere in the tropics are therefore of interest for assessing troposphere to stratosphere transport fluxes in the tropics. Tropospheric source gases are further of interest because of their impact on the composition of the tropical lower stratosphere. Here, we present a simplified chemistry scheme for the Chemical Lagrangian Model of the Stratosphere (CLaMS) for the simulation, at comparatively low numerical cost, of CO, ozone, and long-lived trace substances (CH_4, N_2O, CFC-11, CFC-12, and CO_2) in the lower tropical stratosphere. The boundary conditions at the ground are represented for the long-lived trace substances CH_4, N_2O, CFC-11, CFC-12, and CO_2 based on ground-based measurements. The boundary condition for CO in the free troposphere is deduced from MOPITT measurements. In this way, transport patterns in the tropopause region can be described without a full simulation of tropospheric chemistry. With this model set-up, events of localised enhanced pollution cannot be accurately reproduced. However, we find that the zonally averaged tropical CO anomaly patterns (CO tape-recorder) simulated by this model version of CLaMS are in good agreements with observations (Figure 1).

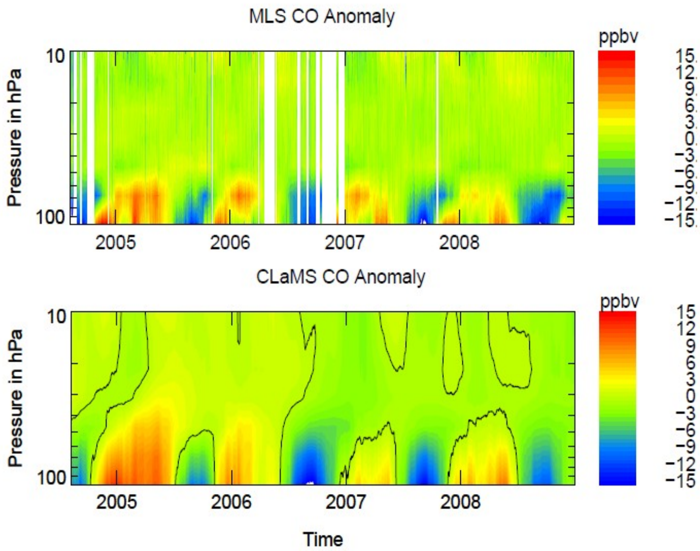

Figure. 1. Comparison of CO anomalies, zonally averaged in the latitude band ±15° from MLS measurements (top panel) and the CLaMS simulation (bottom panel) for the time period 8. 8. 2004 to 29. 12. 2008. The CLaMS values were vertically smoothed with a top hat function (with a width of 3 km) to approximately take into account the field of view of the MLS instrument.

TIMED/SABER observations of lower mesospheric inversion layers at low and middle latitudes

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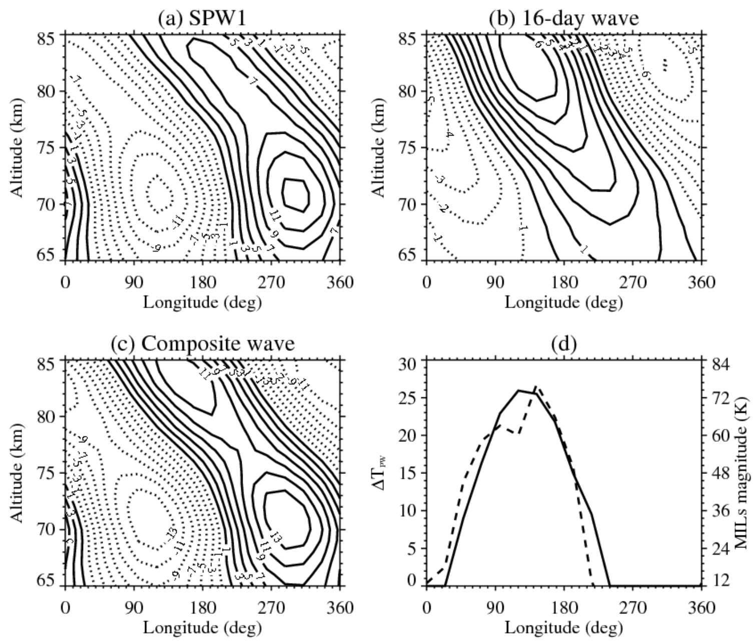
We present the global distribution, seasonal, and interannual variations of the lower mesospheric inversion layers (MILs) using SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) temperature data. We show that both the characteristics and the formation mechanisms of large spatiotemporal-scale lower MILs are latitude dependent. At low latitudes, the monthly zonal mean amplitude of the lower MILs exhibits a semi-annual cycle and reaches a maximum of ~40 K in spring and a secondary maximum of ~30 K in autumn. On the equator, the semi-annual oscillations in the background and diurnal-migrating-tide temperatures could contribute more than 12 and 25 K, respectively, suggesting they are the key causes of large spatiotemporal-scale lower MILs at low latitudes. At middle latitudes, the monthly zonal mean amplitude of the lower MILs exhibits an annual cycle with its maximum in the range 24–33 K in winter. In addition, their longitudinal distribution and daily variation in winter are closely correlated with the transient structure of a composite wave composed of stationary and westward-propagating quasi-16-day planetary waves with zonal wavenumber 1. The correlation coefficient between the lower MILs and the composite wave can sometimes reach unity. The composite planetary wave could contribute temperature enhancements of at least 15–20 K to the lower MILs. Thus, we believe that the transient structure of planetary waves is also an important cause of the large spatiotemporal-scale lower MILs in winter at middle latitudes, in addition to previously proposed mechanisms.



Cloud and radiative balance changes in response to ENSO in observations and models

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Observations and four GFDL AGCMs' are used to analyze the relation between variations in spatial patterns and area-averaged quantities in the top-of-atmosphere radiative fluxes, cloud amount and precipitation related to El Niño over the period 1979-2008. El Niño is associated with an increase in tropical average sea surface temperature, large local temperature anomalies, and tropical tropospheric warming. We find that model biases in the basestate translate into corresponding biases in anomalies in response to El Niño, with the models' anomaly PDFs of high clouds and precipitation in reasonable agreement with the biases of their mean state. The pattern and amplitude of model biases in reflected shortwave (SW) and outgoing longwave radiation (OLR) follows expectations based on their biases in cloud amount: models with a positive cloud amount bias have too strong local responses to El Niño in cloud amount, SW, OLR, and precipitation.

Tropical average OLR increases in response to El Niño in observations and models (correlation coefficients r in range 0.4 to 0.6). Weaker correlations are found for SW (r: -0.6 to 0), cloud amount (r: -0.2 to +0.1) and precipitation (r: -0.2 to 0). Compositing El Niño events over the period 2001-2007 yields similar results. These results are consistent with El Niño periods being warmer due to a heat pulse from the ocean, and a remarkably weak response in clouds and their radiative effect, despite a large rearrangement in the spatial structure of the tropical circulation, and despite substantial differences in the mean state of observations and models.

The Effects of Imposed Stratospheric Cooling on the Maximum Intensity of Tropical Cyclones in Axisymmetric Radiative-Convective Equilibrium

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The effects of stratospheric cooling and sea surface temperature (SST) warming on tropical cyclone (TC) potential intensity (PI) are explored using an axisymmetric cloud-resolving model run to a state of radiative-convective equilibrium (RCE). Almost all observationally constrained datasets show that the tropical lower stratosphere has cooled over the past few decades. Such cooling may affect PI by modifying the storm's outflow temperature, which together with the SST determines the thermal efficiency in PI theory. Results show that warming near and above the model tropopause (~90 hPa), with fixed SST, decreases the PI at a rate of -1 m s^{-1} K^{-1}. Most of this trend comes from a large decrease (increase) in the thermal efficiency component of PI as the stratosphere warms (cools). SST warming (with fixed stratospheric temperature) increases the PI by roughly twice as much per degree, at a rate of about 2 m s^{-1} K^{-1}. Most of the PI trend under SST warming comes from large changes in the air-sea thermodynamic disequilibrium. The predicted outflow temperature shows no trend in response to SST warming, however the outflow height increases substantially. Under stratospheric cooling, the outflow temperature decreases and at the same rate as the imposed cooling. These results have considerable implications for global PI trends in response to climate change. Tropical SSTs have warmed by about 0.15 K $decade^{-1}$ since the 1970's, but the stratosphere has cooled anywhere from 0.3 K $decade^{-1}$ to over 1 K $decade^{-1}$ depending on dataset. Therefore, global PI trends in recent decades appear to have been driven more by stratospheric cooling than by surface warming.

Deep cloud structure of the Mesoscale Convective Systems (MCS): Impact of MCS on the Atmospheric Boundary Layer (ABL) and the Tropical Tropopause Layer (TTL)

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The Tropical Cloud Systems, widely known as Mesoscale Convective Systems (MCSs), are the building blocks of the Tropical Climate and Weather phenomena on all scales. MCSs play a significant role in the tropical hydrological cycle and the energy budget. MCSs account for a large portion of the precipitation in the tropics. Deep convection within MCS influence moistening and drying of the TTL, a key factor for the Global Climate Change. Therefore, our focus has been to study the observed deep cloud structure of the MCS over both the land and the oceans, and examine their impact on TTL and the surface layer. Merged IR Brightness temperatures (IRBRT) and TRMM 3B42 rainfall data for the region [65E-110E:10S-25N], micrometeorological surafce layer and upper air measurements made during 2009-2011 from PRWONAM instrumentation network; wind and turbulence data from Indian MST Radar, and the upper air data from an international field programme JASMINE (Webster et al, 2002) over the Bay of Bengal are analysed here .

Over the land and the ocean, MCSs have been identified and selected based on spatial imageries of IRBRT and rainfall (Houze et al., 2004) for which complete set of measurements were available. The major inferences are 1. surface pressure couplets (Meso high and Meso low) with significant pressure variations associated with strong updrafts and downdrafts and increasing surface wind speed are observed during the passage of MCSs, 2. scaling laws, namely, the linear dependence of drag on wind speed, the sensible heat flux following the free convection law, bulk coefficients varying as U^{-1} are found obeying during deep convection, 3. the deep convection penetrated beyond tropopause in terms of Doppler width, 4. the lowering of Cold point Tropopause (CPT) temperature and the corresponding CPT Altitude (CPTA) during deep convection are significant unlike in the normal case determined by normal temperature lapse rates. TTL thickness (CPTA-LRMA) shrinks during the convective conditions. The results obtained here would pave the way for proposing parameterization of Tropical Tropopause Layer variations during deep convection for application in global circulation models.

Climate impact of Asian Monsoon Convection

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Asian monsoon is a gigantic source of deep convection, which may act as agent to transport water vapour, short lived substances, aerosols and chemical constituents in to the UTLS region. The proposal is for investigating the impact of the Asian monsoon convection onto the climate using a state of the art GCM. The focus will be on the sensitivity to the convective processes and their representation, the microphysics of convection and the boundary layer processes over land and ocean. The impact will be studied at the regional scale on organisation of convection and precipitation. This investigation may pave the way for better predicting the extreme weather events of the Asian region. Thus, it is suggested to interface GEWEX and SPARC activities in experimental programme, observational analysis and modeling studies. A SPARC project with international participation is envisaged to meet the study proposed here.

Madden – Julian Oscillations over a Tropical Indian Station Using Radar and ERA data of winds

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Abstract:

The Madden ï Julian oscillation (MJO) activity over Gadanki (13.5°N, 79.2°E), a low latitude station is examined using four years MST radar data of winds (4ï 20 km) between January 2006 and December 2009. Wind data obtained from ECMWF Re-Analysis (ERA) for the same latitude ï longitude and for the same period have also been used to study the wave activity in the same altitude region. MJO in two period bands 4 - 7 week and 10 - 13 week could be clearly identified with amplitudes of ~4ms^{-1} in zonal winds. Meridional winds also showed similar oscillations but with lesser amplitudes (~ 2.5ms^{-1}). FFT analyses were performed on yearly data and the inter-annual variability of the oscillations could be clearly appreciated. Wavelet analyses were carried out to find the temporal variation of the oscillations. The results obtained using radar and ERA data are found to agree to a good extent. Outgoing Longwave Radiation (OLR) data is also used to study the relation between convection and MJO activity. A significant correlation is not observed.

Evaluating NOy transport from the lower thermosphere in the KASIMA model

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Transport of NOx from the lower thermosphere to the mesosphere and subsequently to the stratosphere during polar winters can be an important supply of additional NOy in the middle atmosphere, besides N2O oxidation. This mechanism couples solar and geomagnetic activity to the chemical budget of the middle atmosphere, and can in principle affect climate via chemical-dynamical interaction and stratosphere-troposphere coupling. As part of the upper branch of the meridional circulation of the middle atmosphere, the downward transport of NOX in the mesosphere is mainly determined by the exerted gravity wave drag. Satellite observations of the last decade clearly showed that in the Arctic especially after strong sudden stratospheric warmings the downward transport can be very effective. The exact mechanism which brings lower thermospheric NOx to the mesosphere, that is molecular compared to eddy dissusion, is still under discussion. Here we compare model simulations with the 3D model KASIMA with observations of the MIPAS instrument on ENVISAT. We show that adjusting the source spectrum of gravity waves in a Lindzen type gravity wave drag parameterization stronger downward transport after strong stratospheric warmings and a prevailing elevated stratopause is simulated with our 3d mechanistic model KASIMA. We examine the transport properties of the model in the adjusted configuration for the Arctic winters in the period 2001 to 2012. The additional NOy transported into the middle atmosphere and the subsequent ozone loss is estimated assuming an additional NOx source in the lower thermosphere. The simulated additional NOy time series closely resembles the observations.

Evidence of ENSO's delayed effect in winter stratosphere

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Abstract

By examining the temporal and spatial relationship between ENSO and the extratropical stratospheric variability in the Northern Hemisphere, this study provides evidence showing that, the main effect of ENSO on the Northern winter stratosphere is rather a delayed than a concurrent effect, especially in the core timescale (3-5 year) of ENSO. Though there exists general negative correlation between ENSO and the strength of the polar vortex, but the maximum correlation is found in the next winter season after the mature phase of ENSO event, rather than in the concurrent winter. Specifically, the stratospheric polar vortex tends to be anomalously warmer and weaker in both the concurrent and the next winter season following a warm ENSO event, and vice versa, but the polar anomalies in the next winter are much stronger and with a deeper vertical structure than that in the concurrent winter. ENSO and the polar vortex variability are intimately coupled at the timescale of 3-5 year. Our analysis also shows that, the delayed stratospheric response to ENSO is characterized with poleward and downward propagation of temperature anomalies, suggesting an ENSO-induced interannual variability of the global mass circulation in the stratosphere. Particularly, in response to the growing of a warm ENSO event, there exist warm temperature and positive isentropic mass anomalies in the midlatitude stratosphere since the preceding summer. The presence of an anomalous wavenumber-1 in the concurrent winter, associated with an anomalous Aleutian high, results in a poleward extension of warm anomalies into the polar region, and thus a weaker stratospheric polar vortex. However, the midlatitude warm temperature and positive isentropic mass anomalies persist throughout the concurrent winter till the end of the next summer. In comparison with the concurrent winter, the strengthening of poleward heat transport by an anomalous wavenumber-2 in the next winter results in a much warmer and weaker polar vortex accompanied with a colder midlatitude stratosphere.

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Non-migrating tides appearing in a high vertical resolution GCM

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Atmospheric tides are global scale waves with periods that are harmonics of a solar day. They are primarily excited in the troposphere and the stratosphere, and then, propagate upward. Tides are generally classified into two components: migrating (Sun-synchronous) and non-migrating (non-Sun-synchronous) tides. Migrating tides are basically dominant and were examined by many previous studies. In contrast, a much fewer studies considered non-migrating tides particularly in the troposphere and the stratosphere, while they are also important in the tropical region. Therefore, the whole picture of how non-migrating tides are excited and propagate into the upper atmosphere is still unclear. The purpose of this study is to reveal the three-dimensional structure of non-migrating tides and its seasonal-to-interannual variations in the region from the troposphere to the mesosphere, as well as to clarify the underlying physical processes.

In this study, data from a high-resolution (T213L256) global spectral climate model (Watanabe et al., 2008) are analyzed. This model covers quite a wide height range from the ground surface to the upper mesosphere (80 km in altitude), enabling us to investigate the full tidal coupling between the lower and upper atmosphere. Also, the vertical resolution is ~300 m in the vertical, which is almost sufficient to simulate realistic propagation and momentum deposition of gravity waves including tides. We compared the model data with data from COSMIC GPS-RO measurements and TIMED/SABER satellite measurements, and confirmed that the model captures the observed characteristics at least qualitatively.

In the model data, we clearly see that non-migrating tides are mainly excited by the deep convections over the two large continents, that is, over Africa and South America. These excited tides are propagating three-dimensionally like internal inertia-gravity waves, not covering the whole globe before reaching the upper stratosphere. During the propagation, the tides interact with background zonal wind associated with quasi-biannual oscillation (QBO) and stratospheric semiannual oscillation (SAO). This process appears to be important for the characteristic tidal features in the upper mesosphere (e.g., the predominance of “wave-4” structure) and their seasonal-to-interannual variations. The impact of tides on the background zonal wind profiles through the momentum deposition will be also assessed in the presentation.

Predictability of the Quasi-Biennial Oscillation

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We present initialised multiannual climate predictions of the QBO. Unlike other sources of climate predictability which are related to the ocean, land surface or cryosphere, the very long timescale of the QBO suggests that it could perhaps be a unique source of multiannual predictability that is internal to the atmosphere. Using state of the art decadal hindcast predictions over the latter part of the 20th century we quantify actual predictability of the QBO against observational analysis.

Predictability of the QBO exceeds that of other modes of climate variability such as the El Niño-Southern Oscillation, with positive correlation skill scores extending out to 3 years or more. We examine how predictability varies with the phase of the QBO and determine the most favourable conditions for long range predictions. There is also evidence from observational analyses that the QBO may have a significant impact on the extratropical surface climate, particularly in winter. We examine whether the signals apparent in observational records are reproduced in decadal hindcasts and therefore whether the QBO can currently contribute to ultra long range predictions of surface winter weather.

Effects of a Convection-based Gravity Wave Parameterization in a General Circulation Model: The Link from Variable Wave Sources to the QBO

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Tropospheric waves are the key element in driving stratospheric wind systems, most prominently the tropical QBO. Due to the limited grid point resolution of general circulation models (GCM), unresolved waves like gravity waves need to be parameterized in such models. Focusing on the tropics, gravity waves are dominantly driven by tropical convection, being highly variable in temporal occurrence and geographical distribution. However, parameterizations of gravity wave drag force (GWD) include most commonly constant wave forcings. In this study, we implement a gravity wave parameterization based on convection (CGWD) in the GCM ECHAM6, we show the dependence of the gravity wave momentum fluxes on the convection scheme, and we highlight improvements on QBO characteristics on the seasonal timescale.

The implemented parameterization, after Beres, produces gravity wave spectra as function of background wind and latent heating properties within convective regions. We show that both the vertical extent of latent heating and the maximum value of latent heating are the most decisive properties for wave spectra characteristics. Since both properties are products of the convection scheme, we show that a realistic representation of cloud depth distribution and heating rate statistics are essential for producing a realistic source spectrum of gravity waves.

Since gravity wave spectra are strongly coupled to convection properties and the background wind, we observe a strong temporal and regional variability in gravity wave spectral shapes and amplitudes. Regionally different background winds over South America and the Indonesian archipelago result in different shapes of the source spectra, with either dominating westerly or easterly waves. On the temporal variability, we observe a strong seasonal cycle in the amount of momentum flux excited by the parameterization, whose imprint we observe in QBO characteristics.

To the authors knowledge, this is the first time that an atmospheric GCM produces a realistic QBO with a purely convection-based gravity wave parameterization. Compared to the previously employed GWDs in ECHAM6, with spatially and temporally constant sources, the QBO simulated with CGWD shows, on one hand, a slight deterioration of the vertical extent of the easterly jet. On the other hand however, the windspeeds of the jet maxima and the variance of wind alteration show an improvement. Furthermore, the seasonality of the QBO jets downward propagation is modeled more realistically with CGWD.

For the latest result, we apply an EOF analysis on the QBO zonal winds and on the individual drag components of the momentum budget of the QBO. The analysis shows that the seasonality of CGWD dominates the seasonality of the downward propagation of the QBO jets. Therefore, due to a more realistic, seasonally varying excitation of parameterized wave fluxes from convection, the modeled QBO shows an improvement in its jet downward propagation rate.

In situ Measurements in the Outflow of the Asian Summer Monsoon during the HALO ESMVal Campaign

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The circulation patterns associated with the Asian Summer Monsoon (ASM) can effectively transport pollutants into the upper troposphere and lower stratosphere (UTLS). Thereby, pollutants from south-east Asia may have a large scale impact on the atmospheric composition in the UTLS and climate.

We report on in situ measurements from the new German research aircraft HALO in the outflow of the ASM during the ESMVal (Earth System Model Validation) campaign in September 2012. The ASM outflow was sampled over the Indian Ocean and Arabian peninsula at altitudes up to 15.5 km. Sharp gradients in trace gas mixing ratios were observed when intercepting outflow air with large enhancements in the mixing ratios of CO, SO_2, NO, HNO_3, NO_y, CH_4, O_3. Two distinct outflow layers were observed at altitudes between 8.5-10.5 km and 13-14.5 km. Air mass backward trajectory calculations indicate that the pollutants of the lower layer were uplifted in close vicinity of the Himalayas whereas the origin of the pollutants in the upper layer is the Gulf of Bengal. Interestingly, the composition of the upper outflow layer is also influenced by in mixing of stratospheric air as indicated by increased mixing ratios of stratospheric tracer including HCl.

The airborne observations are compared with simulations with the global chemistry-climate model EMAC in nudged mode. EMAC overestimates CO and O_3 and underestimates HNO_3 in the sampled air of the ASM outflow. Potential explanations of these discrepancies will be discussed based on model sensitivity studies.

Long-term observations of gravity wave activity in the lower stratosphere with GPS radio occultation data

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Global gravity wave (GW) parameters (potential energy and vertical flux of absolute horizontal momentum) are retrieved from GPS radio occultation (RO) data.
The RO technique uses GPS signals received aboard low Earth orbiting satellites for atmospheric limb sounding. Atmospheric temperature profiles are derived with high vertical resolution. The GPS RO technique is sensitive to GWs with small ratios of vertical to horizontal wavelengths.
Since 2006 the six-satellite U.S./Taiwan FORMOSAT-3/COSMIC mission delivers about 2000 global distributed radio occultations daily. This gives the possibility for the determination of the absolute momentum flux (MF) as an important parameter for the quantification of GW influence to the atmospheric circulation.
In this presentation we discuss MF distributions in the lower stratosphere derived from triples of spatio-temporal nearby temperature fluctuation profiles for different seasons. The results are compared with other MF climatologies. Possibilities and limitations of the method will be addressed. In addition to the MF results long-term climatologies and trends of the potential energy and vertical wavelengths derived from several RO missions since 2001 will be presented.

Geomagnetic activity signatures in wintertime stratosphere

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Here we present analysis of the ERA-40 and ERA Interim meteorological re-analysis datasets for signatures of geomagnetic activity in zonal mean zonal wind, temperature, and Eliassen-Palm flux in the Northern Hemisphere extended winter (November–March). Geomagnetic activity driven signatures have been found in various meteorological and climate records, but, thus far, it has remained unclear which mechanism or mechanisms would be responsible for communicating geomagnetic activity variations to climate variables such as stratospheric and tropospheric temperatures. In our analysis we found that for high geomagnetic activity levels, the stratospheric polar vortex becomes stronger in late winter, with more planetary waves being refracted equatorward, leading to positive Northern Annular Mode anomalies. The statistically significant signals first appear in December and continue until March, with poleward propagation of the signals with time, even though some uncertainty remains due to the limited amount of data available ($\sim$50 years). Our results also indicate that the geomagnetic effect on planetary wave propagation has a tendency to take place when the stratosphere background flow is relatively stable or when the polar vortex is stronger and less disturbed in early winter (*Seppälä et al.*, 2013). These conditions typically occur during high solar irradiance cycle or westerly QBO.

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Middle Atmospheric Dynamics and Structure in Sub-tropical and Tropical Regions: Possible Interconnections

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Latitudinally, the Earth's atmosphere is divided into low, mid, and high latitude regions. There is a region, bridging tropical (low-latitude) and mid-latitude, known as Sub-tropical region. The dynamical and radiative processes operative in these regions are significantly different. Tropical regions have the influence of northern as well as southern hemispheres. There are various uncertainties in the behaviour of sub-tropical regions, many questions viz., (i) Are the sub-tropical regions affected more by mid-latitude processes or low-latitude processes? (ii) Upto which latitude does the other hemisphere influence? (iii) How are these region coupled? (iv) What are the temporal and spatial characteristics of the middle atmospheric processes in the tropical and sub-tropical region and their interconnections?, etc. To answer few such questions, we have done a comprehensive study of middle atmosphere in the tropical and sub-tropical regions in India. Two Rayleigh lidar are operational in India, one at Mt. Abu (24.5^{o}N, 72.7^{o}E), and another at Gadanki (13.5°N, 79.2°E), representing the sub-tropical and tropical regions, respectively. Both the systems are nearly identical and probing similar height regions (~ 30-80 km). The systematic and statistical errors in deriving temperature are found to be similar for both the stations (as ~1 K at 50 km, ~3 K at 60 km and ~10 K at 70 km). Nightly mean temperature profiles are utilized to obtain average temperature profile for each month and are compared with the temperatures observed by Halogen Occultation Experiment (HALOE), on-board Upper Atmospheric Research Satellite (UARS), SABER onboard TIMED, the CIRA-86 and MSISE-90 and Indian Low latitude model temperatures. Observed temperature profiles are in qualitative agreement with CIRA-86 and MSISE-90 model below 50 km, and the agreement is better during winter months. Quantitatively there are significant differences noted, up to 12 K, above 50 km. The mean values of the stratopause height and temperature are found to be 48 km and 271 K, respectively. Seasonal variation shows equinoctial and summer maxima below 55 km, whereas above 70 km winter maximum with equinoctial minima are present. Comparative study of thermal structure with Gadanki, a tropical station, revealed significant differences in the thermal structure over tropical and sub-tropical locations. Long term changes in the middle atmospheric thermal structure, due to Solar variability and increasing anthropogenic activities, have also been studied using about 11 years (1998-2008) lidar observations over both the locations. Furthermore, Lomb Scargle periodogram and wavelet transformed are used for characterizing middle atmospheric annual Oscillations (AO), Semi-annual Oscillations (SAO) and Quasi Biennial Oscillations (QBO) in the tropical and Sub-tropical regions using Lidar and Satellite observations.

Stratospheric Temperature Characteristics and its Association with Ozone over a High Altitude Location

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Earth's middle atmosphere plays vital role in the Earth's climate as variety of physical and chemical process are taking place in this region. Stratosphere is a reservoir of good ozone, which protects us from harmful ultraviolet radiations emanating from the Sun. Ozone and temperature are intricately associated with each other in the Stratosphere. Characteristics of sub-tropical stratospheric temperature structure and its associations with ozone are studied using about 400 nights of Rayleigh Lidar observations during 1997-2009 over a high altitude station, Mt. Abu (24.5^{o}N, 72.7^{o}E, Height above sea level ~1670 meters). Monthly mean temperatures show two distinct maxima in the stratopause region (~45-55 km), occurring over February-March and September-October. The temperature shows a prominent annual and semi-annual oscillation. A comparison with the satellite (Halogen Occultation Experiment, HALOE onboard UARS) and SABER onboard TIMED data shows qualitative agreement, but quantitatively significant differences are found. The temperatures from Lidar are ~ 3-5 K warmer in the stratospheric region than temperatures observed from the satellites. A comparison with the models, CIRA-86 and MSISE-90, showed differences of about 4-5 K in the stratosphere, with deviations somewhat larger for CIRA-86. Observed differences are higher, ~8 K, during equinoctial periods. Heating and cooling rates have been estimated from temperature climatology. An average heating rate of about 2.5 K/month during equinoxes and cooling rate of ~ 4 K/month during November-December are found in altitude region of 50-70 km. Relatively weaker heating and cooling rates are found in 30-50 km region. A detailed study between stratospheric temperature, observed by Lidar, and ozone observed by Total Ozone Measuring Mission (TOMS), HALOE onboard UARS and SABER onboard TIMED revealed a strong correlation during winter months than during summer months. FFT and Wavelet transform are used, at an altitude of every 4 km, in the time series of temperature and ozone observed by Lidar and Satellites in the stratosphere and dominant annual oscillation and quasi biennial oscillations are found. Overall, in the height range of ~ 30-48 km a good correlation (r^2=0.61) between temperature and ozone is observed over Mt. Abu.

The possible effects of nitric oxide variations in the upper atmosphere on temperatures in the lower atmosphere

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During the Maunder Minimum in the mid-17th to early 18th century, a period of extremely low sunspot occurrence, surface temperatures were at their lowest within the Little Ice Age. It is currently being debated within the solar community whether there will be another Maunder Minimum-like event, beginning within the next decade. Will this potential period of low solar activity lead to a similar cooling of surface temperatures? We will explore this possibility, with a prolonged decrease in thermospheric nitric oxide (NO) concentrations as a potential contributing mechanism in affecting lower-atmospheric temperatures. NO plays a major role in the lower thermospheric energy budget, and in the winter polar regions, upper atmospheric NO_x ($NO + NO_2$) is transported down into the stratosphere where it plays a role in the local ozone chemistry. Measurements from the OSIRIS (Optical Spectrograph and InfraRed Imaging System) instrument on the Odin satellite have shown that NO concentrations in the upper mesosphere-lower thermosphere are strongly dependent on solar activity. In an epoch of low solar activity, upper-atmospheric NO concentrations will be at a minimum. Using the Whole Atmosphere Community Climate Model (WACCM), supplemented with the OSIRIS NO measurements, we will investigate the effect of a prolonged period of low thermospheric NO concentrations on the lower atmosphere.

Solar variability impacts on the middle atmosphere – investigations using satellite observations and global models

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The middle atmosphere, and especially the upper stratosphere and mesosphere, can be affected significantly by solar variability. Changes in both solar UV radiation and the fluxes of high-energy solar and magnetospheric particles vary considerably throughout the solar cycle. Both can affect the chemical composition of the upper stratosphere and mesosphere directly. The chemical composition of the lower thermosphere is greatly affected by photo-ionization and auroral particle precipitation; trace gases from the lower thermosphere can be transported down into the mesosphere and stratosphere during polar winter. The mesospheric and upper stratospheric odd-nitrogen budget can be significantly enhanced by this indirect effect especially during winters with strong sudden stratospheric warming events and large geomagnetic activity. Direct impacts of high-energy particle precipitation are the formation of the ozone-loss precursors NOx (N, NO, NO_2) and HOx (H, OH) by ionization and subsequent ion-chemistry. Variations in the UV solar flux will affect the O_2 formation, and therefore, the formation rate of O_3. Increases in NOx and HOx lead to enhanced ozone loss rates. Temperatures and dynamics of the middle atmosphere will be affected because of changes in the O_3 radiative heating rates and to some extent also due to changes in mesospheric chemical heating rates of HOx and Ox (O, O_3) reactions.

We use data from the satellite instruments MIPAS and SCIAMACHY on ENVISAT to investigate the impact of solar variability on the chemical composition of the stratosphere and mesosphere. First results include the detection of a significant impact of magnetospheric particle precipitation on NOx down to 46 km as well as a 27-day solar cycle in upper stratospheric NO_2, ozone, and temperature. A global three-dimensional chemistry-transport model covering the middle atmosphere and lower thermosphere is used to evaluate our understanding of the observed changes. The model includes forcing from changing UV radiation and by variable fluxes of precipitating protons and electrons. This allows to quantify the direct impact of solar activity on the middle atmosphere as well as the indirect impact by NOx transport from the lower thermosphere into the middle atmosphere during polar winter. A free-running chemistry-climate model reaching up into the upper mesosphere is used to assess the impact these chemical changes can have on temperatures and dynamics throughout the middle atmosphere.

A Quantitative Measure of Polar Vortex Strength Using the Function M

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Changes in the dynamics of the stratospheric polar vortices can have a significant effect on the composition of air in the polar stratosphere, including mixing ratios of ozone, as well as chemical species that descend to the stratosphere from the mesosphere via the energetic particle precipitation indirect effect (EPP IE). The dynamics of the vortex barrier are particularly important since the barrier isolates the polar stratosphere from air at lower latitudes.

The “function M” is a recently proposed measure for quantifying transport in dynamical systems. We show that it can be used, not only to visualize the dynamics and structure of the stratospheric polar region in a detailed way, but also to provide a basis for quantitative measures that can capture important aspects of vortex dynamics. Two such measures have been developed and calculated daily for December 2009-February 2010 in the Northern hemisphere and August-October in 2009 and 2010 in the Southern hemisphere, for potential temperatures of 600, 700 and 900 K. We discuss a measure of vortex barrier strength and permeability based on the average value of the function M near the equivalent latitude of the vortex edge. The second measure is the area associated with values of M above a threshold, which is used to calculate a measure associated with the area of the vortex. Both measures are found to be potentially useful, with the area-based measure producing the most convincing results. We also discuss a strong linear correlation between values of the function M and the time period that M is calculated over, which suggests that the dynamical structure of the polar vortex is coherent over periods of at least 30 days in most cases. However we display a period during an SSW where this coherence does not exist, identifying another potential usage of the function M.

The Deep-Propagating Gravity-Wave Experiment (DEEPWAVE) over New Zealand

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Though intermittent in space and time, tropospheric generation of atmospheric gravity waves is recurrent, transporting momentum and energy out of the troposphere to sinks in the stratosphere and mesosphere that in turn sustain planetary-scale forcings that impact the global meteorology and climate of the near-space environment (10-100 km). Finite computing resources force weather and climate prediction models to operate at space-time resolutions that do not fully resolve gravity waves, so that the forcing effects of unresolved gravity waves must be parameterized. These parameterizations are simplified and to some extent arbitrarily tuned, and so depend on observations to constrain their “free” parameters. Yet the small space-time scales and vertically deep extent of gravity waves tax the resolution, precision and vertical range of atmospheric observing techniques, such that observations of gravity waves almost always provide an incomplete picture of their end-to-end dynamics and effects.

The objective of the DEEPWAVE experiment is to fill in many of these gaps by observing deep-propagating gravity waves over their life cycle: from tropospheric genesis through to propagation and breakdown in the stratosphere, mesosphere and lower thermosphere. DEEPWAVE is based around a six-week field measurement campaign from an operating base in Christchurch, New Zealand during the austral winter of 2014, and is sponsored by the U.S. National Science Foundation and the Naval Research Laboratory. The primary observational asset will be the NSF/NCAR Gulfstream V research aircraft, newly instrumented with gravity-wave-resolving remote sensors (dropsondes, microwave temperature profiler, two lidars, and an airglow imager) designed to observe gravity waves from the troposphere up to ~100 km. Besides the excellent local supporting infrastructure, Christchurch was chosen as an base for the mission due to: (a) its proximity to the Southern Alps, a major source of orographic gravity waves; (b) its location directly beneath peak winds of the vortex jet that permit deep propagation of waves into the mesosphere, (c) access to nonorographic and small-island sources of deep-propagating gravity waves over the Southern Ocean, and (d) its identification as a “hot spot” of elevated stratospheric gravity-wave activity in satellite climatologies. This abundance of local gravity-wave sources, in a regional environment with strong stable vortex westerlies allowing deep vertical propagation to ~100 km, provides an ideal “natural laboratory” for observing, studying and modeling the dynamics and effects of deep propagating orographic and nonorographic gravity waves.

This talk will provide an overview of DEEPWAVE: the scientific objectives and open questions, the instrumentation and data that will be acquired, the associated forecasting and modeling support, the network of ground-based correlative observations, and the anticipated wider payoffs for climate and weather models. We also stress the major leveraging support that we anticipate from international scientists and partner organizations, including the New Zealand Met Service, the Met Office, the Australian Bureau of Meteorology, the Australian Antarctic Division, and the German Aerospace Center (DLR), among others.

Formation of the tropical cold-point tropopause by baroclinic eddies in a dynamic-core GCM

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The role of baroclinic eddies in the formation of the cold-point tropopause (CPT) is examined by performing a series of dynamic-core GCM integrations with Held-Suarez type thermal forcings. The simple model successfully generates a distinct tropical cold-point temperature around 100 hPa that is quantitatively similar to the observed CPT. Specifically the modelled CPT temperature is well below (~10° K colder) the prescribed radiative equilibrium temperature (Te) to which the model's temperature is kept relaxed over time, and this is mainly caused by tropical upwelling in the upper troposphere and lower stratosphere, resulting from deposition of easterly momentum by extratropical synoptic-scale waves with zonal wavenumbers four to nine.

Sensitivity tests are conducted by varying meridional temperature gradient and vertical stratification of Te profile. The modelled CPT temperature is found to decrease with increasing midlatitude baroclinicity (e.g., with increasing meridional temperature gradient or decreasing vertical stratification), confirming the baroclinic formation of the CPT in the model. Additional experiments are also carried out with an axisymmetric model configuration where eddies are absent by setting zonal wavenumber to be zero in the model. The resulting temperature profiles exhibit no hints of the CPT independent of extratropical baroclinicity. These results suggest that baroclinic eddies play an important (at least a non-negligible) role in the formation of the tropical upwelling and cold-point tropopause.

Can the MIPAS-observed pattern of mean age of air trends be explained by shifts of the subtropical mixing barriers?

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Stiller et al. (2012) have derived a complex latitude-/altitude dependent pattern of linear increases and decreases (further-on called trends) of stratospheric mean age of air from MIPAS SF6 observations over the years 2002 to 2010. Similar complex trend patterns are found from MIPAS analyses for other tracers as well, like O3 (Eckert et al., 2013), NOy (Funke et al., in preparation), CFC-11, CFC-12 (Kellmann et al., 2012), and HCFC-22 (Chirkov et al., in preparation). They are also reproduced by model calculations with the Karlsruhe Simulation Model of the Middle Atmosphere (KASIMA) nudged to ERA-Interim analyses. The hemispheric asymmetry in the trend patterns hints towards a shift of the global distributions of the tracers towards South, which could be realized by a shift of the subtropical mixing barriers. The positions of the subtropical mixing barriers and their dependences on altitudes, seasons, and the QBO phases have already been derived by Palazzi et al. (2011) from a set of satellite observations. Here we analyse the trends of the mixing barrier positions over the period of the MIPAS observations. Indeed, a shift of both the Northern and Southern hemispheric mixing barrier to the South by about 5 to 10 degrees can be derived. In our contribution, we present our analyses and provide some tentative explanations for the reasons of the shifts.

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The StratoClim Aircraft Field Campaign: Studying Processes Relevant to the Climate Impact of the Asian Monsoon Circulation

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StratoClim (Stratospheric and upper tropospheric processes for better climate predictions) is a collaborative project funded within the FP7 Environment Program of the European Commission. The main goal is to produce more reliable projections of climate change and stratospheric ozone through a better understanding and improved representation of key processes in the Upper Troposphere and Stratosphere (UTS) emplyoing an integrated approach bridging observations from dedicated field activities, process modelling on all scales, and global modelling with a suite of CCMs and ESMs. With stratospheric sulfur and aerosol as one of its key objectives, StratoClim is expected to become a backbone of the recently established SPARC initiative SSiRC (Stratospheric Sulfur and its Role in Climate).

To properly model the injection of pollutants and natural compounds including H_2O and sulfur species into the UTS as well as the accompanying aerosol formation processes, the transport pathways of air masses from the free troposphere through the UTS into the stratosphere and their chemical and micro-physical transformations need to be known. However, only insufficient observations are available for the tropical regions of interest such as the Asian Monsoon (AM) region that is the dominant input region of air into the stratosphere in NH summer. The StratoClim aircraft field campaign now planned for the monsoon season 2015 will help to close this observational gap by providing spatially highly resolved measurements throughout the UTS in and around the AM region. We will focus on UTS processes governing the trace gas transport, chemical transformations as well as new aerosol formation processes. The campaign features the Russian high-altitude research aircraft M55 Geophysica with a ceiling altitude of up to 20.5 km equipped with an up-to-date suite of instruments supplying a quite complete set of chemical, physical, and micro-physical parameters.

We will present the motivation and major objectives of the campaign as well as detailed aircraft and instrument specifications and will discuss flight and analysis strategies designed to maximize the return towards a detailed process understanding of the most important trace gas pathways into the tropical UTS and associated aerosol formation in and around the AM circulation.

Hemispheres dynamical coupling through diffusion of potential vorticity and breaking of subtropical jet by dissipating Rossby waves

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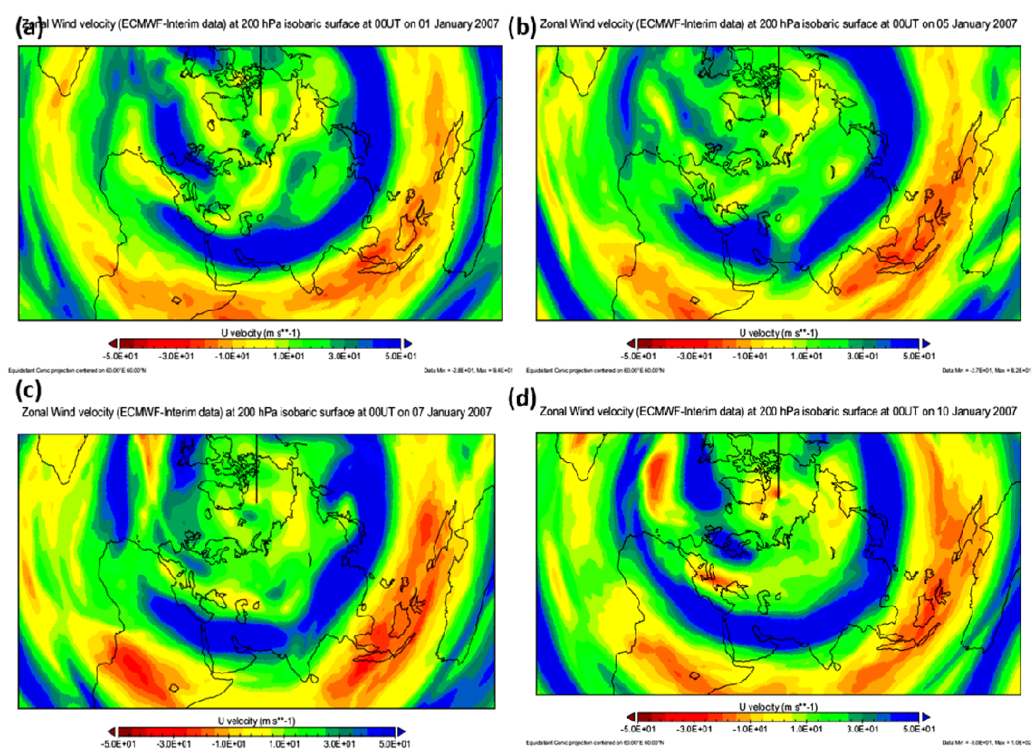
Anomalously large variations of the horizontal wind observed in the Indian tropical troposphere, by the Mesosphere Stratosphere Troposphere (MST) radar operating at 53 MHz at the Indian tropical station of Gadanki, for a few days centered around 7 January 2007 are examined in the present work. European Center for Medium Range Weather Forecasts (ECMWF-interim) 200 hPa level data are utilized to study the global scale characteristics of subtropical jet, propagation and dissipation of Rossby waves manifested in the meridional wind velocity, intrusion of potential vorticity from the mid latitudes to the equatorial region through disrupting the subtropical westerly jet etc. Here we report that the dissipating Rossby waves, emanated from the north Atlantic region and directed towards the Indian region, disrupted the subtropical jet and thus caused the intrusion of potential vorticity from the mid latitudes to the Indian equatorial region. This caused large variations of horizontal winds in the whole troposphere and even disrupted the Inter Tropical Convergence Zone (ITCZ) located in the southern tropical region for a few days. Global scale potential vorticity maps on isentropic surfaces show clear indication of dissipation of Rossby waves developed the intact nature, as indicated by the below figure, of breaking in the subtropical jet moving eastward. This breaking of the strong subtropical jet led to the diffusion of potential vorticity from the northern mid/high to low latitudes in the southern hemisphere and thus caused severe disruption in the ITCZ and its associated winds and temperature.



Convective sources and transport in the TTL

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We investigate how air parcels detrained from convective sources enter the TTL, or are rejected in the downward tropical flux, and travel across this region to reach the tropopause and the cold point.
The approach is based on the comparison of Lagrangian backward and forward trajectories. Backward trajectories are launched at the tropopause or above and run until they hit a cloud. Forward trajectories are launched at the detrainment level of clouds. Cloud tops are identified by satellite observations (brightness temperatures from geostationary satellites, altitudes from CALIOP) and fluxes proxies are provided by TRMM precipitation.
Results show that the warm pool region during winter and the Bay of Bengal / Sea of China during summer are the prevalent sources as already identified in many previous studies. We also show that in spite of generating very high convection, Africa is quite ineffective as providing air that remains in the TLL while on the opposite the Tibetan Plateau is the most effective region in this respect although its total contribution is minor.
We study the sensitivity of these results to the choice of the advecting wind (kinematic versus diabatic, ERA-Interim versus MERRA, most recent ECMWF analysis versus ERA-Interim).

Insights on TTL dehydration mechanisms from microphysical modelling of aircraft observations

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The Tropical Tropopause Layer (TTL), a transition layer between the upper troposphere and lower stratosphere in the tropics, serves as the entryway of various trace gases into the stratosphere. Of particular interest is the transport of water vapor through the TTL, as WV is an important greenhouse gas and also plays a significant role in stratospheric chemistry by affecting polar stratospheric cloud formation and the ozone budget. While the dominant control of stratospheric water vapor by tropical cold point temperatures via the "freeze-drying" process is generally well understood, the details of the TTL dehydration mechanisms, including the relative roles of deep convection, atmospheric waves and cloud microphysical processes, remain an active area of research.

The dynamical and microphysical processes that influence TTL water vapor concentrations are investigated in simulations of cloud formation and dehydration along air parcel trajectories. We first confirm the validity of our Lagrangian models in a case study involving measurements from the Airborne Tropical TRopopause EXperiment (ATTREX) flights over the central and eastern tropical Pacific in Oct-Nov 2011 and Jan-Feb 2013. ERA-Interim winds and seasonal mean heating rates from Yang et al. (2010) are used to advance parcels back in time from the flight tracks, and time-varying vertical profiles of water vapor along the diabatic trajectories are calculated in a one-dimensional cloud model as in Jensen and Pfister (2004) but with more reliable temperature field, wave and convection schemes. The simulated water vapor profiles demonstrate a significant improvement over estimates based on the Lagrangian Dry Point, agreeing well with aircraft observations when the effects of cloud microphysics, subgrid-scale gravity waves and convection are included. Following this approach, we examine the dynamical and microphysical control of TTL water vapor in the 30ºS-30ºN latitudinal belt and elucidate the dominant processes in the winter and summer seasons. Implications of the TTL dehydration processes for the regulation of global stratospheric humidity will be discussed.

A possible UT/LS coupling during dry and wet years of Indian summer monsoon circulation

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Abstract

The upper troposphere and lower stratosphere regions over India has been studied in relation to the Indian Summer Monsoon Rainfall (ISMR). In this study we have made an attempt to understand the characteristic features of zonal winds in the tropical Upper Troposphere and Lower Stratosphere (UT/LS) region during DRY and WET years of Indian summer monsoon season (June to September) over the Indian longitude belt (65^{o} East – to 90 ^{o} East) and its relation to Indian Summer Monsoon Rainfall (ISMR). It is found that in monsoons giving deficient (excess) ISMR called DRY (WET) year's equatorial upper troposphere zonal winds have westerly (easterly) anomalies and equatorial lower stratosphere opposite anomalies. Thus there is an upper troposphere/lower stratosphere dynamic coupling in zonal wind is observed over the study region during monsoon period and the intensity of coupling is correlated significantly with ISMR. It is also found that upper troposphere zonal wind averaged between 15^{o} North and 15^{o} South latitudes during monsoon period have a long-term trend and the strength of tropical easterly jet stream plays a role in the wet and dry years of monsoon circulation pattern.

Comparison of Modeled and Observed Effects of Radiation Belt Electron Precipitation on Mesospheric Hydroxyl and Ozone

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Energetic electron precipitation (EEP) is driven by solar activity and affects the polar middle atmosphere. EEP produces odd nitrogen (NO_x = N + NO + NO_2) and odd hydrogen (HO_x = H + OH + HO_2) through impact ionization, dissociation, and ion chemistry. HO_x and NO_x catalytically destroy ozone which could lead to EEP-driven changes in UV absorption, temperature, and dynamics with possible connections to ground-level regional climate. However, the assessment of this process and its importance is not straight forward, partly because there are issues related to the current satellite-based electron flux observations. Thus it is not clear if these observations can be used to accurately describe EEP in atmospheric models.

Observational studies have already shown that mesospheric hydroxyl (OH) is significantly affected by energetic electron precipitation (EEP) at magnetic latitudes connected to the outer radiation belt (*Verronen et al.*, 2011; *Andersson et al.*, 2012). Here we use the Sodankylä Ion and Neutral Chemistry (SIC) model to reproduce the changes in OH and ozone observed by the Microwave Limb Sounder (MLS/Aura) during four strong EEP events. The daily mean electron energy-flux spectrum, needed for ionization rate calculations, is determined by combining the Medium Energy Proton and Electron Detector (MEPED/POES) fluxes and spectral form from the IDP high-energy electron detector on board the DEMETER satellite. We show that in general SIC is able to reproduce the observed day-to-day variability of OH and ozone. In the lower mesosphere, the model tends to underestimate the OH concentration, possibly because of uncertainties in the electron spectra for energies $>$300 keV. The model predicts OH increases at 60–80 km, reaching several hundred percent at 70–80 km during peak EEP forcing. Increases in OH are followed by ozone depletion, up to several tens of percent. The magnitude of modeled changes is similar to those observed by MLS, and comparable to effects of individual solar proton events. Our results suggest that the combined satellite observations of electrons can be used to model the EEP effects above 70 km during geomagnetic storms, without a need for significant adjustments. However, for EEP energies $>$300 keV impacting altitudes $<$70 km, correction factors may be required.

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Sulfur transport into and through the tropical gateway to the middle stratosphere

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Stratospheric aerosol plays a significant role in the Earth's climate system. It directly attenuates the incoming solar radiation by partly scattering it back to space. It also exhibits indirect climate effects because heterogeneous reactions on aerosol surfaces influence the chemistry and composition of the stratosphere. Yet, our understanding of the formation, transport, variability and climate impact of stratospheric aerosol is still incomplete. Stratospheric aerosol has always been an issue in SPARC (e.g. Thomason and Peter, 2006). Recently, a new SPARC initiative "SSiRC" (= Stratospheric Sulfur and its Role in Climate) has been established with a particular focus on sulfur compounds, as the bulk of the stratospheric aerosol is made up of sulfuric acid (H_2SO_4) and water (H_2O) droplets (note that contributions from organic material and non-volatile components such as volcanic ash, soot, mineral dust, biomass-burning residues, meteoric material, inorganic salts, etc. could still play a significant role, in particular with respect to chemistry).

This presentation will focus on the transport of sulfur compounds into the middle stratosphere. Even though the climate forcing of sulfate aerosol starts already at tropospheric altitudes, the most persistent accumulation of particles in the stratosphere is the Junge layer, 7 – 10 km above the tropopause, where small particle sizes lead to long residence times. Here, also the chemical impact, e.g. on ozone, is greatest. In the absence of large volcanic eruptions injecting significant amounts of sulfur directly into the Junge layer, the aerosol or its precursors are transported to the middle stratosphere mainly within the tropical pipe in the ascending branch of the Brewer-Dobson circulation. Based on existing scientific literature as well as hitherto unpublished satellite and in-situ observations, we will discuss transport of sulfur compounds into this main source region for the middle stratosphere from various sources including volcanic eruptions into the upper troposphere and lower stratosphere, sulfur dioxide (SO_2) from anthropogenic and natural sources, and the chemically stable carbonyl sulfide (OCS) that is widely considered as a major source of stratospheric sulfur. We attempt to attribute sources to observed aerosol enhancements (regional, seasonal, irregular) and will also look at lifetimes of sulfur gases for transport regimes relevant to the sulfur sources named above.

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Recent UTLS Variability and Potential Climate Impacts

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The upper troposphere and lower stratosphere (UTLS) is a key region for the stratosphere-troposphere coupling and related to a variety of complex processes. The mechanisms for the characteristic UTLS variability, such as the evolution of the tropopause temperature and the tropopause inversion layer (TIL) are still not well understood. The recently discovered TIL is particularly sensitive to climate change and may have potential but unknown impacts on surface and stratospheric climate. Here, we use the Global Positioning System Radio Occultation (GPS-RO) data, WACCM simulations with high vertical resolution in the UTLS, as well as reanalyses data to investigate and explain the recent variability of the UTLS and its role in stratosphere-troposphere coupling.

A significant increase in the tropopause temperature as well as a remarkable weakening in the strength of the TIL over the past decade are captured by the GPS-RO data and also WACCM simulations. The reasons and contributions to this recent UTLS variability will be estimated with different factors, such as the sea surface temperatures (SST), radiative forcings, different scale of waves or circulations and subsequent re-distribution of radiating gases (i.e. O_3, H_2O). Potential impacts of the UTLS variability on the surface and stratospheric climate will also be discussed.

Vertical resolution dependence of gravity wave momentum flux simulated by a general circulation model.

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Dependence of gravity wave spectra of energy and momentum flux on global climate models' horizontal resolution (e.g., Koshyk and Hamilton, 2001; Hamilton et al. 2008) and time step (Shutts and Vosper, 2011) has been intensively studied. In contrast, much less attention has been paid for dependence of those gravity wave spectra on models' vertical resolution. The present study demonstrates dependence of gravity wave momentum flux in the stratosphere and mesosphere on the model's vertical resolution, which is evaluated by using a comprehensive global climate model JAGUAR (Watanabe and Miyahara, 2009) with a horizontal resolution of about 0.56^{o}. We performed a series of sensitivity simulations changing the model's vertical resolution in the middle atmosphere, i.e., 200 m, 300 m, 400 m, 500 m, and 1000 m; constant about 20-100 km height, and found that inertial gravity waves with short vertical wavelength simulated at higher vertical resolution play several important roles in determination of gravity wave momentum flux in the stratosphere and mesosphere.

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Differences in Reanalysis Estimates of Diabatic Heating in the Tropical UTLS and Implications for Cross-Tropopause Transport

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Estimates of diabatic heating differ significantly among modern reanalysis datasets. These differences have substantial implications for representations of transport and mixing, both within the reanalyses themselves and in models that use reanalysis data as input. Moreover, the diabatic heat budget provides additional perspectives and physical constraints for process evaluation in global models. Here, we describe differences in diabatic heating in the tropical upper troposphere (UT) and lower stratosphere (LS) among four widely used reanalyses: ERA-Interim (ERAI), the Modern Era Retrospective Analysis for Research and Applications (MERRA), the Climate Forecast System Reanalysis (CFSR), and the Japanese 25-year reanalysis and its continuation in the JMA Climate Data Assimilation System (JRA). We present annual mean climatologies of diabatic heating and thermodynamic variables for the period 2001–2010, and investigate how differences among these terms affect transport pathways and convective source distributions in the vicinity of the tropical tropopause.

Reanalysis estimates of diabatic heating are substantially different not only with respect to the distribution of net heating but in all comparable individual components, including terms arising from latent heating, radiative transfer, and parameterised vertical mixing. These differences highlight the large uncertainties that remain in the processes that control the heat budget in the tropical UTLS. Discrepancies in the magnitude and vertical extent of latent heating reflect continuing difficulties in representing moist convection within models. Discrepancies in radiative heating may be more surprising given the strength of observational constraints on temperature and tropospheric water vapor. The largest differences in the distribution of radiative heating are attributable to disparities in cloud radiative forcing, but important systematic differences are present even in the absence of clouds. Distributions of heating due to parameterised turbulent mixing have received comparatively less attention, but are interesting in light of known challenges in reconciling temperature observations and climate model simulations near the tropical tropopause.

Differences in the distribution of diabatic heating have direct effects on the thermodynamic structure of the tropical UTLS, as well as simulations of tracer transport and troposphere–stratosphere exchange. These effects are particularly striking in the context of the Asian summer monsoon anticyclone, which has long been recognized as an important pathway for tropospheric air entering the tropical lower stratosphere. Differences in the vertical and horizontal distributions of diabatic heating in this region affect the location and magnitude of the anticyclone as simulated by the forecast model, and substantially impact the implied distribution of convective sources for air entering the anticyclone.

Evidence for non-migrating tides produced by the interaction between tides and stationary planetary waves in the middle atmosphere

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In this work, 11-years (2002-2012) of TIMED/SABER global temperature data are used to study the nonlinear interaction between stationary planetary waves (SPWs) and tides in stratosphere and mesosphere. The holistic behavior of the nonlinear interactions between all SPWs and tides are analyzed from the point of view of energetics. The results indicate that the intensities of non-migrating diurnal, semidiurnal, terdiurnal and 6-hour tides are strongest during winter and almost vanish during summer, synchronous with SPW activity. Temporal correlations between the SPWs and non-migrating tides for these four tidal components are strong in the region poleward of 20° and below about 80 km. In the tropics, where the SPWs are very weak in all seasons, the correlations are small. Based on the more limited SABER observations at high latitudes, the correlations there are similar to those in midlatitudes during spring, summer and autumn; there are no high latitude observations by SABER in winter. These results show that nonlinear interactions between SPWs and tides in the stratosphere and the lower mesosphere may be an important source of the non-migrating tides that then propagate into the upper mesosphere and lower thermosphere.

FPI observations of nighttime mesospheric and thermospheric winds in China and their comparisons with HWM07

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We analyzed the nighttime horizontal neutral winds in the middle atmosphere (~87 km and ~98 km) and thermosphere (~250 km) derived from a Fabry-Perot Interferometer (FPI), which was installed at Xinglong station (40.2°N, 117.4°E) in central China. The wind data covered the period from April 2010 to July 2012. We studied the annual, semiannual and terannual variations of the midnight winds at ~87 km, ~98 km and ~250 km for the first time and compared them with Horizontal Wind Model 2007 (HWM07). Our results show: (1) At ~87 km, both the observed and model zonal winds have similar phases in the annual and semi-annual variations. However, the HWM07 amplitudes are much larger. (2) At ~98 km, the model shows strong eastward wind in the summer solstice resulting in a large annual variation while the observed strongest component is semiannual. The observation and model midnight meridional winds agree well. Both are equatorward throughout the year and have small amplitudes in the annual and semiannual variations. (3) There are large discrepancies between the observed and HWM07 winds at ~250 km. This discrepancy is largely due to the strong semiannual zonal wind in the model and the phase difference in the annual variation of the meridional wind. The FPI annual variation coincides with the results from Arecibo, which has similar geomagnetic latitude as Xinglong station. In General, the consistency of FPI winds with model winds is better at ~87 km and ~98 km than that at ~250 km. We also studied the seasonally and monthly averaged nighttime winds. The most salient features include: (1) The seasonally averaged zonal winds at ~87 km and ~98 km typically have small variations throughout the night. (2) The model zonal and meridional nighttime wind variations are typically much larger than those of observations at ~87 km and ~98 km. (3) At ~250 km, model zonal wind compares well with the observation in the winter. For spring and autumn, the model wind is more eastward before ~ 3:00 am but more westward after. The observed nighttime zonal and meridional winds on the average are close to zero in the summer and autumn, which indicates a lack of strong stable tides. The consistency of FPI zonal wind with model wind at ~250 km is better than the meridional wind.

Interaction between moist Kelvin waves and synoptic variability of precipitation over Congo basin

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Abstract

The synoptic structure and variability of moist synoptic Kelvin waves over the Congo basin during March to June (1979-2010) are explored using satellite-observed brightness temperature (Tb), outgoing longwave radiation (OLR) and National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis data. Based on composite methodology, we found that synoptic Kelvin waves (SKWs) activity is most predominant during March-May and it is centered at the equator where the convective active phase of these waves favors formation of convective synoptic systems. A brief analysis of an intense Kelvin wave in March-May 1984 (active year) shows a clear impact of the wave on convective development and daily rainfall over Congo basin.Convection is found to be less frequent immediately prior to the passage of the convectively active phase of the convectively coupled atmospheric equatorial Kelvin wave (CCKW), more frequent during the passage, and most frequent just after the passage. Otherwise, Results show marked interannual variability of Kelvin wave activity over Congo basin. The large synoptic variability of precipitation are observed from March-May which clearly denotes synoptic activity in this region. Interannual variability in the fluctuation strength of the wavelet power spectrum as well as in its distribution amount different periods. Strong signal is clearly found at period between 4-6 day and 7-9 day.The location of peak SWKs convection are consistent with high rainfall location and clearly impacted crops yield over this region.

Keywords: Congo basin, Synoptic Kelvin waves, Convection , 3-10 day precipitation variability, crops yield.

Do split stratospheric vortices reach higher?

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Sudden stratospheric warming events are associated with a split or displaced form of the stratospheric vortex. Occasionally, distinct mesospheric coolings occur which indicate their vertical extension. In the analysis of a permanent-winter simulation with the Kühlungsborn Mechanistic Circulation Model, we found several self-generated stratospheric warmings. A weak correlation between the form and the extension of the polar vortex is diagnosed. Dynamical aspects of this relation including planetary and gravity waves and their validation are discussed.