Understanding Anomalous Eddy Vorticity Forcing in North Atlantic Oscillation Events

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This study proposes an anomalous eddy vorticity forcing (EVF) decomposing procedure to investigate physical mechanisms responsible for the formation of the anomalous EVF associated with North Atlantic Oscillation (NAO) events. Utilizing the Geophysical Fluid Dynamics Laboratory (GFDL) dynamical core atmospheric model, a series of NAO initial-value short-term experiments are conducted. Applying the EVF decomposing procedure to the results of these experiments, the anomalous nonlinear EVF associated with the NAO events in the model can be decomposed into several fundamental linear eddy-eddy interaction terms and an unimportant nonlinear eddy-eddy interaction term. Compared with the NAO-free situation, synoptic-scale eddies have faster (slower) eastward phase speeds during the positive (negative) NAO events. Through a synoptic-scale eddy-eddy interaction mechanism, the behaviors of anomalous EVF components in the positive (negative) NAO events are well explained by synoptic-scale eddies with faster (slower) eastward phase speeds. Therefore, synoptic-scale eddies with faster (slower) eastward phase speeds are responsible for the development of the anomalous EVF associated with positive (negative) NAO events. Note that at the initial-stage of the NAO initial-value experiments, the faster (slower) phase speeds of the synoptic-scale eddies are specified by modifying the initial value fields, and then are amplified/maintained by the strengthening (weakening) zonal wind at the middle and high latitudes associated with the approaching positive (negative) phase NAO. Therefore, this study indicates that the properties of the synoptic-scale eddies at the initial-stage determine the upcoming NAO anomalies.

Keywords: The North Atlantic Oscillation, transient eddy forcing, dynamics

A comparison of the momentum budget in reanalysis datasets during sudden stratospheric warming events

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The agreement between reanalysis datasets is evaluated during sudden stratospheric warming (SSW) events using the zonal-mean momentum budget. Zonal-mean variables reveal a good agreement among datasets for the fast warming and weakening of the polar vortex in the lower stratosphere. Eddy fluxes and forcings for zonal-mean zonal wind acceleration are also relatively similar in the lower atmosphere. This agreement is, however, severely degraded in the mid-to-upper-stratosphere. Discrepancies among reanalyses are particularly large during the onset of SSW events, a period characterized by unusually strong fluxes of planetary-scale waves from the troposphere to the stratosphere, and are substantially smaller after the onset. The discrepancies are also typically larger for the most intense SSW events. While the largest uncertainty in the momentum budget originates from the Coriolis torque, momentum flux convergence also presents a non-negligible spread among the reanalyses. The uncertainty of all terms of the zonal-mean momentum equation among reanalyses is reduced in the latest reanalysis products.

Does stratospheric sudden warming occur more frequently during ENSO winters than during normal winters?

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Stratospheric sudden warming (SSW) events exhibit pronounced interannual variability. Based on WMO definition of SSW, it has been suggested that SSW events occur more preferably during El Niño-Southern Oscillation (ENSO) winters (both El Niño and La Niña winters) than during normal winters. This nonlinear relationship is re-examined here by considering six different definitions of SSW. For all definitions, SSW events are detected more frequently during El Niño winters than during normal winters, in consistent with an enhanced planetary-scale wave activity. However, a systematic relationship is not found during La Niña winters. While two SSW definitions, including WMO definition, show an increased SSW frequency during La Niña winters, other definitions show no change or even a reduced SSW frequency. This result is insensitive to the choice of reanalysis datasets and ENSO index, indicating that the reported ENSO-SSW relationship is not robust but dependent on the details of SSW definition. Implication of this finding to SSW-related downward coupling and surface climate variability is also discussed.

Keywords: Stratospheric sudden warming, El Niño-Southern Oscillation, Interannual variation of polar vortex, Stratospheric-tropospheric coupling

New definition of stratospheric warming events in the Northern Hemisphere based on geometry of the polar vortex

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It is known that a few kinds of warming events occur in the Northern Hemisphere (NH) winter polar stratosphere. (Labitzke 1982). In early winter, the polar vortex often displaces substantially from the Pole mainly in the middle and lower stratosphere, which is called Canadian warming (CW; Manney et al. 2001) in the NH. In the middle of winter, polar stratospheric temperature sometimes increases rapidly, accompanied by collapse of the polar vortex. Such an event is called stratospheric sudden warming (SSW; Scherhag 1952). In the end of winter, a relatively sudden warming called stratospheric final warming (SFW; Black et al. 2006) occurs every year, followed by the summer state of the polar stratosphere. Traditionally, zonal mean zonal wind is used to define SSWs (Butler et al. 2015) and SFWs (Black et al. 2006). Although their definition is simple and easy to deal with, CWs, SSWs, and SFWs may be confused. Moreover, the polar vortex has notable horizontal structure during SSWs and SFWs, which cannot be captured by the definition based on zonal mean quantities. Mitchell et al. (2013) and Seviour et al. (2013) proposed new definition of SSWs based on moment diagnostics, where the polar vortex is approximated as an equivalent ellipse (Hu 1962; Waugh 1997). The moment diagnostics allow them to define displacement and splitting SSWs separately by using centroid latitude and aspect ratio of the polar vortex. However, SSWs in their definition may include CWs and SFWs. Note also that there is almost no clear definition for CWs.
In our study, CWs, SSWs, and SFWs are defined by applying moment diagnostics to geopotential height field at 3, 10, and 30 hPa in the polar region. The three kinds of warming events are clearly distinguished in our definition.
First, displacement, splitting, and disappearance events are defined at each altitude. To detect displacement events, centroid latitude is used as in the previous studies. Displacement events are categorized into major and minor ones according to how far the polar vortex displaces from the Pole. Splitting events are defined using kurtosis, which is measure of bipolarity (Mattewman et al. 2009). If geopotential height at all the lattice points in the polar region is larger than background value in the moment diagnostics, the events are defined as disappearance events.
Next, CWs, SSWs, and SFWs are defined based on the events identified above. Displacement-SFWs (D-SFWs) and splitting-SFWs (S-SFWs) are first defined if displacement and splitting events are followed by disappearance events, respectively. SSWs and CWs are then distinguished according to at which altitude the polar vortex is more perturbed. If the polar vortex displaces further from the Pole in the lower stratosphere than in the upper stratosphere, the events are defined as D-CWs. Otherwise, the events are defined as D-SSWs. If splitting events occur only in the lower stratosphere, the events are defined as S-CWs. Other splitting events are defined as S-SSWs.
We performed composite analysis in each category of each warming phenomenon. It is shown that the definition based on geometry of the polar vortex is consistent with a dynamical aspect of each warming phenomenon. We will investigate longitudinal structures of the polar vortex and material circulation during CWs, SSWs, and SFWs, using formulae of three-dimensional residual mean flows applicable to both Rossby waves and gravity waves derived by Kinoshita and Sato (2013).

Keywords: Canadian warming, stratospheric sudden warming, stratospheric final warming

Predictability of Arctic Polar-night Jet Oscillation Events and Its Impact on the Forecast Skill of Tropospheric Circulation

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The predictability of the extratropical stratosphere and its impact on the forecast skill of tropospheric circulation in the Northern Hemisphere are examined in the framework of Polar-night Jet Oscillation (PJO). The PJO is the dominant low-frequency mode in the winter stratosphere characterized by the poleward and downward propagation of the zonal-mean zonal wind anomalies.

By using extended-range ensemble forecast datasets provided by the Japan Meteorological Agency, we have projected statistical properties of forecast results to a phase space spanned by two leading empirical orthogonal functions representing the PJO behavior. As a result, following characteristics of predictability variations during both anomalously weak and strong events of the stratospheric polar vortex (part of such events corresponds to sudden warmings and vortex intensifications) are obtained: (1) During prominent PJO conditions, regardless of weak or strong vortex events, the forecast skill of long-lasting anomalies in the lower stratosphere is significantly enhanced for forecasts starting after the onset of anomalous events. (2) The forecast skill not only in the lower stratosphere but also in the troposphere is improved after the setup of anomalous events. However, the reduction of tropospheric forecast error sometimes becomes obscure due to tropospheric internal variabilities, especially after strong vortex events. (3) In contrast to the same positive impact on the forecast skill in the lower atmosphere, the forecast uncertainty of the stratospheric condition shows different feature depending on the strength of the stratospheric polar vortex: During weak vortex events, the temporal evolution of the ensemble spread changes drastically from the exponential growth (saturates at high level) to the linear one (remains small) associated with the breakdown of the polar vortex. On the other hand, during strong vortex events, forecasts show large uncertainty throughout the event, because the westerly wind condition in several members of ensemble forecast permits intermittent upward propagation of planetary waves although the time-averaged flux from the troposphere is anomalously low.

Thus, this study provides comprehensive knowledge for the impact and uncertainty of stratosphere-troposphere coupling in a state-of-the-art ensemble prediction system. Our results and methodologies would also be particularly useful for real-time monitoring of sub-seasonal to seasonal forecasts.

Keywords: stratosphere-troposphere coupling, predictability, seasonal forecast

A three-week total ozone reduction over Rio Gallegos in Argentina in November 2009 and its relation to blocking in the troposphere

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A three-week total ozone reduction over the southern tip of South America in November 2009 was reported by de Laat et al. (2010). Such long lasting low total ozone is unusual for this region and season. Ozone vertical profile measurements at Rio Gallegos, Argentina (51°S, 69°W), by ozone LIDAR suggest that isentropic surfaces of 675K and 475K over Rio Gallegos were inside the Antarctic polar vortex around November 13-14 and 22-23, respectively (Wolfram et al., 2012); thus, the low total ozone lasted for three weeks. Analyses of the total ozone observed by OMI, and ERA-Interim and JRA-55 reanalysis data indicate that the low total ozone event was caused by a polar vortex migration toward the South American continent at the time of the vortex breakup, and that the migration is associated with an enhanced wave flux from the troposphere to the stratosphere at around 120-150°W and 50-60°S. In November, a large positive deviation of a 500 hPa geopotential height from the zonal-mean was evident. This large positive deviation was considered to be a blocking by diagnosing the geopotential height filed in accordance with the method of Mendes et al. (2012). These results suggest a relation between the long-term low total ozone event over Rio Gallegos and a blocking phenomenon in the troposphere of the Southern Hemisphere through wave propagation from the blocking region.

Keywords: ozone, polar vortex, South America, blocking, wave flux

Redecrease of HCl total column density observed with Fourier transform infrared spectroscopy at Tsukuba

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Chlorine species such as chlorofluorocarbon usually saved as reservoir molecules such as HCl at the stratosphere. It is converted to active chlorine under the specific conditions in early spring in the Polar regions. Then it causes ozone depletion. Therefore the amount of stratospheric HCl is one of the potential index of ozone depletion.
The total HCl have begun to decrease worldwide from the second half of 1990 's under the Montreal Protocol. But Mahieu et al. [2014] found the reincrease of HCl density at the Northern hemisphere lower stratosphere after 2007 by the high-resolution Fourier transform spectrometer (FTIR) observations at 8 stations including Tsukuba under the Network for the Detection of Atmospheric Composition Change from 1997 to 2011. They made it clear that the reincrease caused by the short-term deceleration of the atmospheric circulation in the Northern hemisphere for several years by comparing of atmospheric model and observational result.
In this study, we analyzed time series of HCl total column density at Tsukuba from 2001 to 2016 to make it clear that the reincrease of HCl total column density after 2007 is " short-term".
The temporal variation of derived HCl total column density increase from 2007 to 2011, and again decrease from 2012, which indicates that the increase after 2007 was really short-term. Further, we confirmed that downward flow at the lower stratosphere at 36°north was strengthened from 2007 to 2012 and upward flow was strengthened after 2012 by analyzing zonal mean residual vertical velocity using ERA Interim reanalysis datasets made by European Centre for Medium-Range Weather Forecasts. Downward flow leads the increase of the column of HCl and upward flow leads the decrease. Thus, this result consist with the temporal variations of HCl total column density. However, it'll be necessary to check the variation of the global residual vertical velocity to see the variation of stratospheric general circulation which carries HCl .

Keywords: FTIR, Ozone depletion, Hydrogen Chloride

Latitudinal distributions of gravitational separation and mean age of the stratospheric air observed using a balloon-borne cryogenic air sampler

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We have collected the stratospheric air samples over Japan, the Arctic, Antarctica and equatorial regions at height levels from 10 to 35 km since 1985 by using two kinds of cryogenic air samplers on board a scientific balloon (Honda et al., 1996; Morimoto et al. 2009). The air samples were analyzed for atmospheric greenhouse gases and related air components, and we reported many findings such as spatiotemporal variations in the stratospheric CO2 concentration and gravitational separation of major atmospheric components (e.g. Aoki et al., 2003; Ishidoya et al., 2013). Recently, many studies have focused on “mean age” of stratospheric air derived from clock tracers such as CO2 and SF6 to evaluate changes in the Brewer-Dobson circulation (BDC) responding to climate change (e.g. Engel et al., 2009; Ray et al., 2014). However, as Ray et al. (2014) reported, it is difficult to separate the competing effects on the mean age between mean circulation and mixing only from CO2 and SF6 ages since the mean age becomes younger and older by an enhancement of mean circulation and mixing, respectively, as the consequences of accelerating of BDC. In this regard, gravitational separation of stratospheric air, observed firstly by our observations, is expected to be an additional tool to constrain detail changes in BDC. Both the age and gravitational separation are unaffected by any chemical processes ideally, however the cause of gravitational separation, mass-dependent molecular diffusion superimposed on mass-independent atmospheric transport, is fundamentally different from the cause of age. Therefore, competing effects on gravitational separation between mean circulation and mixing are also expected to be different from those on age. In this study, we present latitudinal distributions of gravitational separation and CO2 age and discuss the advantages of the simultaneous analyses of age and gravitational separation to the stratospheric circulation study.

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Keywords: gravitational separation of the stratospheric air, age of the stratospheric air, balloon-borne cryogenic air sampler, Brewer-Dobson circulation

Seasonal variations and trends of greenhouse gases in the upper troposphere/lowermost stratosphere by flask-based aircraft measurements between Europe and Japan

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As part of the CONTRAIL project, we have conducted measurements of greenhouse gases (CO_2, CH_4, N_2O, and SF_6) by monthly air sampling in the upper troposphere/lowermost stratosphere (UT/LMS) onboard commercial airliners between Europe and Japan since April 2012. The observed mixing ratios showed sharp gradients around the dynamical tropopause defined by potential vorticity calculated from the meteorological reanalysis fields. In the UT north of 50 N, CH_4 and SF_6 were higher and seasonal phase of CO_2 were earlier than in the lower latitudes. In the LMS up to potential temperature of 50 K above the tropopause, CH_4, N_2O, and SF_6 exhibited seasonal variations with maxima in November/December and minima in April/May. The remarkable seasonal variation in the LMS is explained by the subsidence of air from the deeper stratosphere in spring and by the efficient flushing of the LMS with tropospheric air in autumn. We observed persistent increasing trends of the all greenhouse gases over the past 5 years both in the UT and LMS. Our measurements constitute a unique data set in the UT/LMS useful for investigating temporal and spatial variations of these radiatively and chemically important greenhouse gases.

Keywords: Greenhouse gases, Upper troposphere/Lower Stratosphere, Aircraft measurement

The Relationship between Boreal summer Intra-seasonal Oscillation and the Stratospheric Circulation

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Boreal summer intra-seasonal oscillation (BSISO) is a phenomenon that active convective region migrate northward in the Indian Ocean and the western Pacific with a period of 30 −90 days. In this study, statistical relationships between BSISO and the stratospheric circulation are examined focusing on the variabilities of the zonal wind fields both in the troposphere and stratosphere. BSISO index based on Kikuchi et al. (2012) and the Japanese 55-year Reanalysis (JRA-55, Kobayashi et al. 2015) are used for composite analysis. To represent the zonal mean fields, the mass-weighted isentropic zonal mean (MIM) Method (Iwasaki 1989) is applied to JRA-55. The MIM method is suitable for the examination of zonal momentum budget, and enables analysis of a single hemispheric cell, such as Blewer-Dobson circulation in the stratosphere and the extra-tropospheric direct circulation. In order to extract variability synchronized with BSISO or lower (higher) frequent variability than BSISO, temporal filtering based on Duchon (1979) is also carried out to the zonal mean fields obtained by the application of the MIM method.

We found some characteristic features of the zonal wind field during the significant BSISO: Hemispheric symmetry westerly anomalies are observed from mid-troposphere up to the tropical tropopause layer (TTL) just after the northward migration of active convective region in BSISO region, and move poleward in both hemispheres in spite of meridional asymmetry of the convective activity: In the extra-tropical upper stratosphere of the Northern Hemisphere, both easterly anomalies and positive potential temperature anomalies are statistically significant during the northward migration of active convective region. Moreover, our results also reveal that the amplitude of BSISO is extraordinarily large during the strong low-frequency easterly anomalies at around the 20 hPa level associated with quasi-biennial oscillation (QBO) and suggest influence of the stratospheric circulation on the activity of BSISO in the troposphere.

Keywords: Boreal summer intra-seasonal oscillation, Mass-weighted isentropic zonal mean, Stratospheric circulation, Quasi-biennial oscillation

Investigating the tropical tropopause layer and the lower stratosphere using global models

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The tropical tropopause layer (TTL) is the transition region from the troposphere to the stratosphere, and acts as a gateway to the stratosphere. Understanding all processes that control the TTL, and incorporating them in models, is an important prerequisite for reliable predictions of changes in the TTL in a changing climate and for predicting how these changes in turn feedback, e.g., via stratospheric ozone chemistry, on the global climate system. Over the past two decades, large efforts have been undertaken to improve data coverage in the TTL with the necessary vertical, spatial, and temporal resolution required to accurately characterize the transitional character of the TTL. However, due to a lack of global observations it is still not clear how the connection between the stratosphere and troposphere occurs and how it modulates the convective activity. The purpose of this research is to establish an integrated study of internal processes in the tropical tropopause layer and the lower stratosphere and to deepen understanding on atmospheric environmental change through systematic simulations and analysis of various tracers (i.e., ^{222}Rn, SF_6, CO_2, CH_4, and others) and meteorological parameters (temperature, wind, water vapor and others). This study focuses on the age of air and gravitational separation in the stratosphere.

Keywords: the tropical tropopause layer, the lower stratosphere, the age of air

A method for obtaining high frequency, global, IR-based Convective Cloud Tops for studies of the TTL

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Models of varying complexity that simulate water vapor and clouds in the Tropical Tropopause Layer (TTL) show that including convection directly is essential to properly simulating the water vapor and cloud distribution. In boreal winter, for example, simulations without convection yield a water vapor distribution that is too uniform with longitude, as well as minimal cloud distributions. Two things are important for convective simulations. First, it is important to get the convective cloud top potential temperature correctly, since unrealistically high values (reaching above the cold point tropopause too frequently) will cause excessive hydration of the stratosphere. Second, one must capture the time variation as well, since hydration by convection depends on the local relative humidity (temperature), which has substantial variation on synoptic time scales in the TTL.

This paper describes a method for obtaining high frequency (3-hourly) global convective cloud top distributions which can be used in trajectory models. The method uses rainfall thresholds, standard IR brightness temperatures, meteorological temperature analyses, and physically realistic and documented corrections IR brightness temperature corrections to derive cloud top altitudes and potential temperatures. The cloud top altitudes compare well with combined CLOUDSAT and CALIPSO data, both in time-averaged overall vertical and horizontal distributions and in individual cases (correlations of .65-.7). An important finding is that there
is significant uncertainty (nearly .5 km) in evaluating the statistical distribution of convective cloud tops even using lidar. Deep convection whose tops are in regions of high relative humidity (such as much of the TTL), will cause clouds to form above the actual convection. It is often difficult to distinguish these clouds from the actual convective cloud due to the uncertainties of evaluating ice water content from lidar measurements.

Comparison with models show that calculated cloud top altitudes are generally higher than those calculated by global analyses (e.g., MERRA). Interannual variability in the distribution of convective cloud top altitudes is also investigated.

Keywords: Tropical Tropopause Layer, Convection, Hydration, Dehydration

Interannual and intraseasonal variations of clouds in the upper Tropical Tropopause Layer observed by CALIOP

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Cloud variations in the tropical tropopause layer (TTL) during northern winter are investigated using the 10-year CALIPSO observations, in particular focusing on the cloud top level above the cold point tropopause (above approximately 18 km). The 10-year climatology of the TTL cloud shows higher occurrence frequency over South America, Africa, and the western-central Pacific. Interannual variation of the TTL clouds is strongly related with the TTL temperature variations associated with Quasi Biennial Oscillation (QBO) and El Nino and Southern Oscillation (ENSO). The TTL clouds associated with QBO appear/disappear simultaneously over South America, the equatorial Africa, and western-central Pacific. On the other hand, the TTL clouds associated with ENSO vary with the see-saw pattern between the western and central Pacific. We also investigated intraseasonal variations during December 2009 - February 2010. It is suggested that the temperature perturbation associated with the equatorial Kelvin wave and the sudden stratospheric warming (SSW) are important for the cloud formation. Interestingly, the TTL clouds occurred only over South America, Africa, and western-central Pacific along the Kelvin wave going east.

Keywords: tropical tropopause layer (TTL), CALIPSO, cloud

The Impact of Convection and Gravity Waves on Stratospheric Water and Upper Troposphere Cloud Fraction

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Using our forward-domain-fill trajectory model we have run a series of experiments to explore the impact of convection and gravity waves on TTL cloud fraction and stratospheric water vapor. We compare results using MERRA convective fields and a satellite-based estimate of convective cloud heights. Gravity wave information comes from the Loon super pressure balloons. We compare our results to MLS stratospheric water vapor and CALIOP cloud fraction. The use of the high spatial resolution satellite-based convective cloud heights produces little change in model stratospheric water, but a nearly 50% reduction in model high cloud fraction (well below the observed cloud fraction) compared to the model results when we use the MERRA convective fields. Using the observed gravity wave temperature fields, cloud fraction increases, but the fluctuations produce too much cloud unless we attenuate the gravity wave fields below the tropopause –as is observed in radiosonde data. The end results, observed convection plus observed gravity waves, are in excellent agreement with observations. Overall, these results suggest that mid-frequency gravity waves play a more significant role in the cloudiness of the TTL region than previously recognized.

Keywords: Stratosphere, Cirrus , Dehydration, Tropics

Tropopause Layer Change on Different Time Scales

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Together with a comparatively small warming trend in global surface temperature, or warming hiatus, during the last 15 years, there are stagnations in the rising and thickening trends in the tropopause layer, which is sensitive to climate change. In this study, the variation of the vertical boundaries and thickness of the tropopause layer on different time scales and their contributions to the recent tropopause layer hiatus are investigated using the radiosonde observations from the Integrated Global Radiosonde Archive during 1960-2013.
The results confirm that global trends of rising tropopause layer boundary heights and thickening of the tropopause layer have stalled during recent years. The seasonal amplitude of each tropopause layer parameter become larger during the hiatus period (2002-2013) than that during the pre-hiatus period (1960-1997), except for the tropical tropopause layer top boundary. Moreover, the correlations between the tropopause height and corresponding temperature suggested by previous studies exist in all latitude bands in the period 1960-2013, with anti-correlations in the extratropical tropopause layer and positive correlation in tropical tropopause layer top boundary. In addition, the seasonal trends in the tropopause layer parameters show that significant trend difference occur during winter and spring.

Keywords: Tropopause Layer, Radiosonde

Extreme tropical lower stratospheric water vapor and ice amounts during 2015-2016 and their relation to ENSO, QBO, and convective overshooting

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In this presentation, we investigate the relative roles of tropical tropopause layer (TTL, ~14 –19 km) temperatures and overshooting on the tropical lower stratospheric water vapor budget using satellite observations, reanalyses, and dehydration trajectory modeling applied to the highly unusual El Niño-Southern Oscillation (ENSO) and stratospheric quasi-biennial oscillation (QBO) events of 2015-2016.

To first order, the TTL temperature field regulates the amount of water vapor entering the stratosphere by controlling the amount of dehydration in the rising air. Thus, modes of climate variability such as the stratospheric QBO, variations in tropical upwelling, ENSO have the potential to impact the stratospheric entry value of water vapor via their impact on TTL temperatures. Additionally, vigorous convection that overshoots the local tropopause might also have a direct impact on stratospheric water vapor in a manner that circumvents the TTL cold trap mechanism.

The El Niño and subsequent La Niña of 2015-2016 coincided with a remarkable perturbation to the concentration of water vapor entering the stratosphere in the tropics. At the end of 2015 during the El Niño, a decadal record amount of lower stratospheric water vapor was observed in the Western Pacific, followed by a record dry anomaly that occurred after the 2016 QBO "interruption" and during the La Niña.

Coincident with the record setting amount of water vapor at the end of 2015, the TTL Western Pacific cold pool was shifted eastward from its climatological position and aligned with the center of convection over the Central Pacific. Over this region, there was an extreme decadal record amount of convective cloud ice in the lower stratosphere observed by the CALIOP satellite lidar. A trajectory-based analysis that models hydration based solely on reanalysis temperature and wind fields can account for only about half of the observed tropical lower stratospheric moistening during this event. This suggests that unresolved dynamical processes associated with convection and/or sublimation of lofted ice particles also contributed to lower stratospheric moistening. These processes could contribute to climate change-induced stratospheric water vapor increases.

Keywords: stratospheric water vapor, tropical tropopause layer, convective overshooting, ENSO, QBO

Assessment of upper tropospheric and stratospheric water vapour and ozone in reanalyses as part of S-RIP

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Reanalysis datasets are widely used to understand atmospheric processes and past variability, and are often used as “observations” for comparison with climate model output. Because of the central role of water vapour (WV) and ozone (O_3) in climate change, it is important to understand how accurately these species are represented in the existing global reanalyses, and whether or not significant differences exist amongst them. We present results from the WV and O_3 intercomparisons that were performed as part of the SPARC (Stratosphere-troposphere Processes and their Role in Climate) Reanalysis Intercomparison Project (S-RIP). Comparisons are made over a range of timescales between the different reanalyses, and between reanalyses and observational datasets.

In addition to the intercomparisons, we discuss the treatment of WV and O_3 in reanalyses to aid future research and guide the interpretation of differences between the reanalysis fields. Because total column ozone (TCO) is assimilated in the newer reanalyses, these reanalyses generally reproduce TCO well except when data coverage is lacking, such as during polar night. We find that the vertical distribution of ozone is relatively well represented in reanalyses, particularly given that for most reanalyses there are only weak constraints on the vertical profile of ozone from observations, and that most have a simplistic representation of ozone photochemical processes.

In contrast to O_3, stratospheric WV data are not currently assimilated, with humidity observations typically used only in the troposphere below a specified vertical level at or near the tropopause. Thus, the fidelity of reanalysis stratospheric WV is sensitive to how accurately the fundamental drivers of stratospheric WV such as tropical tropopause layer temperatures, methane oxidation, and the stratospheric overturning circulation are represented. Because of these issues and the known deficiencies in the representation of stratospheric transport in reanalyses, we find much poorer agreement both amongst reanalyses and between reanalyses and independent observations. For these reasons, stratospheric WV from the current generation of reanalyses should not be used in scientific studies.

Keywords: ozone, water vapor, stratosphere, reanalyses, SPARC Reanalysis Intercomparison Project

Intercomparison of atmospheric tides in global reanalyses from the stratosphere to the lower-mesosphere

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Atmospheric tides in reanalyses are worth investigating because they are important lower boundary conditions of whole atmosphere model and also because they can be used for diurnal correction of satellite measurements. This study comprehensively assesses atmospheric tides in latest reanalyses (MERRA-2, MERRA, ERA-Interim, JRA55 and NCEP-CFSR), for both migrating and nonmigrating componennts in the region from the stratosphere to the lower-mesosphere, during the period of 2006-2012. SABER and MLS satellite measurements are used for comparison. It is found that all reanalyses reproduce realistic tides in a qualitative way, while the quantitative difference among the data sets depends on wavenumber and frequency. Particularly, there seems a systemeatic bias between SABER and reanalyses for diurnal migrating tide. We also analyzed long term changes in tides and found that they are artificially affected by the change in assimilated data.

Comparison of Three Retrievals of COSMIC GPS Radio Occultation Results in the Tropical Upper Troposphere and Lower Stratosphere

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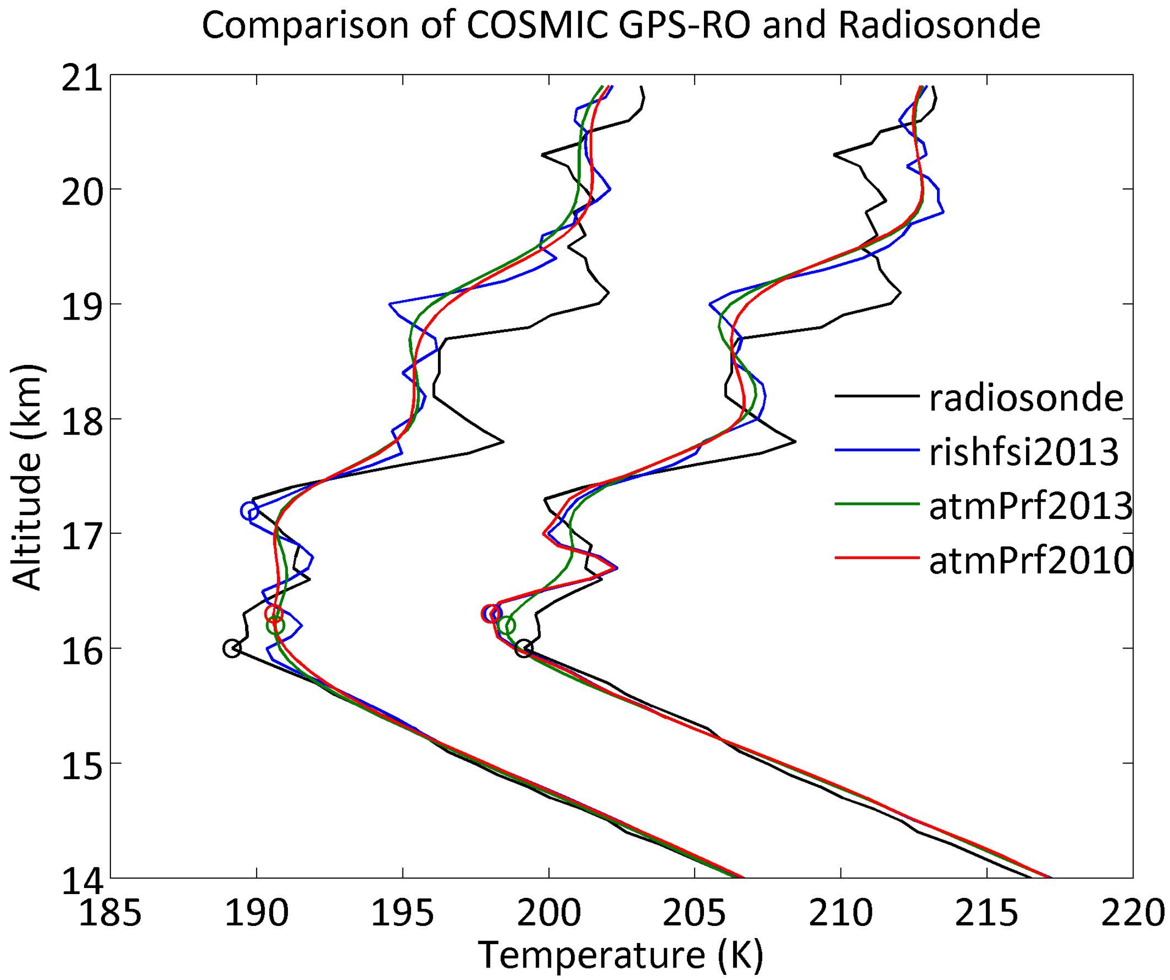
Combining Geometrical Optics (GO) and Wave Optics (WO), COSMIC Data Analysis and Archive Center (CDAAC) retrieved two sets of the dry atmosphere temperature (T) from COSMIC GPS radio occultation (GPS-RO), which are named as atmPrf2010 and atmPrf2013. The sewing height between WO and GO varied at 10-20 km for atmPrf2010, and it was fixed at 20 km for atmPrf2013. We also derived T by applying WO throughout the troposphere and the stratosphere up to 30 km altitude, which is named as rishfsi2013. The height resolution of the atmPrf2010 varied depending on the sewing height, while rishfsi2013 provides high-resolution T profiles up to 30 km. The T profiles by atmPrf2013 are smoothed over 500 m. Among the three datasets, we compared the T variations in the upper troposphere and lower stratosphere (UTLS) over the tropics from October 1, 2011, to March 31, 2012, when radiosonde soundings were conducted as the CINDY-DYNAMO 2011 campaign. The mean T profiles were consistent between atmPrf2010 and atmPrf2013. In the other hand, the rishfsi2013 results were colder/warmer than the CDAAC retrievals below/above the tropopause. The mean T difference between atmPrf2013 and atmPrf2010 was 0.17 K at the cold point tropopause (CPT), and −0.38 K at the lapse rate tropopause (LRT), respectively. The rishfsi2013 showed the colder T at CPT by −0.77 K and −0.59 K relative to atmPrf2013 and atmPrf2010, respectively, and the warmer T by 0.60 K and 0.20 K at LRT. During CINDY-DYNAMO we found 134 radiosonde soundings which coincided with GPS-RO within ±3 hours and collocated within 200 km from GPS-RO. The mean T difference at CPT from radiosondes was 0.32 K, 0.49 K and −0.24 K for atmPrf2010, atmPrf2013 and rishfsi2013, respectively. That is, both atmPrf2013 and atmPrf2010 had a positive bias at CPT, while rishfsi2013 had a negative bias. Similar comparisons at LRT were −0.45 K, −0.69 K, and −0.41 K, respectively, showing a positive bias for all GPS-RO retrievals. The rishfsi2013 is consistent with the retrievals at CDAAC and radiosondes, and it is useful for the studies of mesoscale T perturbations in the UTLS because of the good height resolution.

Keywords: COSMIC GPS Radio Occultation, Full Spectrum Inversion, Retrieval Algorithm, UTLS


Comparison of COSMIC GPS-RO and Radiosonde
Altitude (km)
21
20
19
18
17
16
15
14
185
190
195
200
205
210
215
220
Temperature (K)
radiosonde
rishfsi2013
atmPrf2013
atmPrf2010

Development of a cloud particle sensor for radiosonde sounding

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A meteorological balloon-borne cloud sensor called the cloud particle sensor (CPS) has been developed. The CPS is equipped with a diode laser at ˜790 nm and two photodetectors, with a polarization plate in front of one of the detectors, to count the number of particles per second and to obtain the cloud-phase information (i.e. liquid, ice, or mixed). The lower detection limit for particle size was evaluated in laboratory experiments as ˜2 micro m diameter for water droplets. For the current model the output voltage often saturates for water droplets with diameter equal to or greater than ˜80 micro m. The upper limit of the directly measured particle number concentration is ˜2 cm^−3 (2 ×10^3 L^−1), which is determined by the volume of the detection area of the instrument. In a cloud layer with a number concentration higher than this value, particle signal overlap and multiple scattering of light occur within the detection area, resulting in a counting loss, though a partial correction may be possible using the particle signal width data. The CPS is currently interfaced with either a Meisei RS-06G radiosonde or a Meisei RS-11G radiosonde that measures vertical profiles of temperature, relative humidity, height, pressure, and horizontal winds. In the presentation, results from four flights, two in Japan and two in Indonesia, are discussed in detail.

Keywords: cloud, radiosonde

On the three-dimensional residual mean flow balanced with nonconservative terms

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The transformed Eulerian-Mean (TEM) equations describing wave-mean flow interaction have been widely used to understand dynamical circulation in the middle atmosphere. A lot of efforts have been made to generalize the TEM equations to three dimensions (3D) since 1980s. However, there are some differences between 2D and 3D TEM equations in the analysis, especially, the residual mean flows describing material transport induced by waves. For example, 3D residual horizontal mean flow includes the balanced flow (geostrophic flow) and residual vertical mean flow includes the flow due to the tilting of isentropic surface. These flows are not included in the 2D residual mean flows and do not relate to the material flows.

In the present study, we focus the relation between residual mean flows and nonconservative terms especially daibatic heating rate and derive the 3D material flow induced by waves.

Keywords: meridional circulation, middle atmosphere

Impacts of mesospheric westerly-jet instability on the middle and lower atmosphere

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Kodera et al. [ACP, 2016] reported that an exceptional event of a strengthening of the subtropical jet (STJ) occurred in the stratosphere in association with a sudden equatorward shift of the stratospheric polar night jet (PNJ) in early December 2011. The exceptional rapid downward extension of STJ was developed from the lower mesosphere to the lower stratosphere, and the impact of this event farther penetrated into the troposphere in two regions, in the northern polar region and the tropics. The abrupt transformation of the STJ and PNJ is found to be associated with little connection to the upward propagation of planetary waves from the troposphere.
Analyses of minor constituent and wind fields derived from Aura MLS observations show that the strengthening of the PNJ and STJ were originated from the upper mesosphere and its mechanism could be explained by a wave-mean flow interaction which seems to be caused by large-scale waves enhanced through barotropic and/or baroclinic instability in mid- to high latitudes of the mesosphere. The detailed mechanism for the strengthening of both PNJ and STJ in the mesosphere and the impact on the stratosphere and troposphere will be shown in the presentation.

Keywords: subtropical jet and polar night jet, mesosphere-stratosphere-troposphere interaction

