M. Joan Alexander
NorthWest Research Associates, CoRA Office

Gravity waves: Contrasting observations and their representation in climate models

Observations of gravity waves entered a new era in the last decade with high-resolution satellite measurements giving global coverage. Estimates of gravity wave pseudomomentum flux became possible, which offer the chance to test and improve the treatment of gravity wave effects on the general circulation in global models. These data remain limited in both spatial and temporal sampling, leading to large remaining uncertainties in the important gravity wave properties, and these limitations likely contribute to the delay in associated changes in climate model parameterizations. So today, parameterizations of gravity wave drag remain largely guided only by theoretical and local-area numerical modelling studies, and the parameterizations are still tuned primarily with the consideration of giving the best representation of large-scale circulation and temperature structure. Can observations be used to improve on this state-of-the-art? This talk will show global comparisons of observed and modelled gravity wave parameters, and also focus in on local-area case studies that illuminate strengths and weaknesses of parameterizations of gravity wave sources. (The global comparisons are derived from an international team's work supported by ISSI and SPARC. For a list of team members and goals see http://www.issibern.ch/teams/gravitywave/index.html .)

Analyzing the preconditioning of major SSWs in ECMWF assimilations

Severin Bancalà (1), Kirstin Krüger (1), Gloria Manney (2,3)

Email: sbancala@geomar.de

(1) GEOMAR | Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
(2) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
(3) New Mexico Institute of Mining and Technology, Socorro, NM, USA

Major Sudden Stratospheric Warmings (SSWs) can develop differently. By analyzing ERA-40 reanalysis data Bancalà et al. (2012) showed that, although most of the major SSWs follows increased activity of the zonal wavenumber-1, a quarter of these events are caused by an amplified zonal wavenumber-2. To identify which zonal wavenumber is responsible for the poleward eddy heat transport thus the major SSW, the planetary waves are analyzed during the pre-warming phase to distinguish between wavenumber-1 (W1) and wavenumber-2 (W2) events. This approach, which classifies the warmings based on the preconditioning of the polar vortex, differs from that adopted by Charlton and Polvani (2007) that distinguishes the SSWs according to the post-warming phase. Results for ERA-40 data have clearly revealed this difference, showing rather different W2/W1 ratio compared to the splitting/displacement ratio of Charlton and Polvani, which means that not all wavenumber-1 events lead to a vortex displacement. In this study, the preconditioning criterion will be applied to the ERA-Interim data in order to determine how the W2/W1 ratio changes if a different data assimilation is considered. Also we will investigate if the inclusion of 10 additional reanalysis years significantly changes this relationship. Comparison between the ECMWF data assimilations will then be performed to determine possible discrepancies between ERA-40 and ERA-Interim datasets (i.e. the NH winter 1994/1995). We believe that this classification can be a good diagnostic tool to investigate major SSWs in the different data assimilations but also for addressing the ability of CCMVal and CMIP5 models to simulate the preconditioning of major SSWs realistically.

Fitness of meteorological analyses by ECMWF and CMC to model tracer transport in the Arctic vortex 2010-2011

S. Chabrillat, Q. Errera, K. Lefever, Y. Christophe (BIRA-IASB)
A. Inness, J. Flemming, A. Untch (ECMWF),
M. Charron, R. Ménard, Y. Rochon, J. de Grandpré (Env. Canada)
O. Stein (FZJ) ; F. Baier (DLR)

We evaluate the capacity of several recent models of stratospheric chemistry (BASCOE CTM, MOZART, IFS-MOZART, SACADA, GEM-BACH) to simulate transport in the exceptional vortex of the Arctic winter 2010-2011. Correct modelling requires an adequate representation of subsidence in the well-isolated vortex, which must lead to vortex-averaged abundances of N2O decreasing with time until a final sudden stratospheric warming ends the event. This decrease is readily observed by Aura-MLS and is a standard diagnostic of transport in the polar vortex.

Here we use as reference the analyses of Aura-MLS observations, as delivered by the BASCOE 4D-VAR system. All the models are based on the same hybrid-pressure vertical grid as the underlying NWP system. It is shown that none of these models is able to simulate correctly the descent of N2O-poor air masses in the lower part of the vortex (where ozone depletion occurs), independently of their advection algorithm or coupling scheme with the meteorological assimilation system. Hence this failure is attributed to the meteorological analyses themselves. We show the results obtained with four datasets of meteorological analyses: three delivered by ECMWF (Operational, ERA-interim, MACC) and one by CMC (Operational GEM 4D-VAR). One model (BASCOE CTM) was driven by all four datasets, allowing a rigorous comparison. Each dataset leads to different disagreements between the CTM simulations and the chemical analyses, even though there is good agreement between the temperature analyses.

These comparisons point to some areas requiring improvement in current NWP systems to allow correct modelling of the polar stratosphere. These areas include at least the gravity wave breaking parameterizations (physics modules) and the (lack of) observational constraints on the vertical wind fields.

Title :
The stratospheric extension of the Canadian global deterministic medium range weather forecasting system and its impact on tropospheric forecasts.

Authors :
Martin Charron*, Saroja Polavarapu, Mark Buehner, P. A. Vaillancourt, Cécilien Charette, Michel Roch, Josée Morneau, Louis Garand, Josep M. Aparicio, Stephen MacPherson, Simon Pellerin, Judy St-James, and Sylvain Heilliette

* Presenting author

Abstract :
A new system which resolves the stratosphere was implemented for operational medium range weather forecasts at the Canadian Meteorological Centre. The model lid was raised from 10 to 0.1 hPa, parameterization schemes relevant to the stratosphere were introduced and a new radiation scheme was implemented. Because of the higher lid height of 0.1 hPa, new measurements between 10 and 0.1 hPa were also added. This new High Top system resulted not only in hugely improved forecasts of the stratosphere, but also in large improvements in medium range tropospheric forecast skill. Most of the stratospheric and tropospheric forecast improvement is obtained without the extra observations in the upper stratosphere. However, these observations further improve forecasts in the winter hemisphere. The large improvements in stratospheric forecast skill are found to be due to the higher lid height of the new model. The new radiation scheme helps to improve tropospheric forecasts. However, the degree of improvement seen in tropospheric forecast skill could not be entirely explained with these purely forecast experiments. It is hypothesized that the cycling of a better model within the data assimilation procedure provides improved initial conditions which result in improved forecasts.

William H Daffer(1), Gloria L. Manney(1,2), Michael J. Schwartz(1)

(1) Jet Propulsion Laboratory, California Institute of Technology
(2) New Mexico Institute of Mining and Technology

Intercomparisons of upper tropospheric/lower stratospheric jet and tropopause diagnostics in operational data assimilation products

The upper tropospheric/lower stratospheric (UTLS) jets are important in defining atmospheric circulation and transport, particularly in the vicinity of the extra-tropical tropopause. We have developed methods for characterizing the UTLS jets and tropopauses from operational assimilated meteorological analyses. Here we describe our methods of identifying and cataloging the jets and tropopauses and present results from several meteorological datasets. We include comparisons of different GEOS-5 versions, the different algorithms used for calculating the locations of the tropopauses and comparisons of jet and tropopause products derived from GEOS-5 with the ERA-Interim and other data assimilation products.

Variability and trends in effective diffusivity from reanalysis, and their implications for stratospheric circulation changes

Sean Davis, Eric Ray, Karen Rosenlof

Effective diffusivity is one means of quantifying mixing in the upper troposphere and stratosphere. Here, we calculate the normalized effective diffusivity from reanalysis potential vorticity fields, and remove variability associated with known cycles (e.g., annual cycle, QBO, solar cycle) to compute trends from multiple reanalyses. We compare the variability and trends, highlighting regions of agreement and disagreement among the reanalyses. Although not in complete agreement, several reanalyses contain positive trends in effective diffusivity in the southern hemisphere stratosphere (> ~400 K) along the boundary between the upwelling and downwelling branches of the Brewer-Dobson circulation. These increases in effective diffusivity, if real, represent an increase in mixing between the so-called “tropical pipe” and midlatitudes. Using a simplified “tropical leaky pipe” model, we show that increases in mixing can help resolve some of the apparent discrepancy between the increase in midlatitude age-of-air in observations and intensified B-D circulation in GCMs and satellite observations.

A multi-diagnostic intercomparison of tropical width time series using models, reanalyses, and satellite observations

Sean Davis, Karen Rosenlof, Paul Young

Poleward migration of the latitudinal edge of the tropics of ~0.25 – 3º decade^{-1} has been reported in several recent studies based on satellite and radiosonde data, and reanalysis output covering the past ~30 years. To date, it has been unclear to what extent this large range of trends can be explained by the use of different data sources, time periods, and edge definitions. In this presentation, we address these issues by applying a suite of tropical edge latitude diagnostics based on tropopause height, winds, precipitation/evaporation, and outgoing longwave radiation (OLR) to six reanalyses and four satellite data sets. These diagnostics include both previously used definitions and new definitions designed for more robust detection. The wide range of widening trends is shown to be primarily due to the use of different data sets and edge definitions, and only secondarily due to varying start/end dates. We also show that the large trends (> ~ 1º decade^{-1}) previously reported in tropopause and OLR diagnostics are partially due to the use of subjective definitions based on absolute thresholds. Statistically significant Hadley cell expansion based on the mean meridional streamfunction of 1.0 – 1.5º decade^{-1} is present in three of four reanalyses that cover the full time period (1979-present), whereas other diagnostics yield trends of -0.5 – 0.8° decade^{-1} that are mostly insignificant. These results are compared to model trends calculated over both the 20th and 21st century in the CMIP3 output.

Title: On the prognostic treatment of stratospheric ozone in the Environment Canada global NWP model

Presenting author: J. de Grandpre(1)

Coauthors: S. Chabrillat(3),C.A. McLinden(2), Y. J. Rochon (2), R. Menard(1)

Affiliations:
(1)Environment Canada, Dorval, Canada;
(2)Environment Canada, Downsview, Canada;
(3)Belgium Institute for Space Aeronomy, Brussels, Belgium

Abstract

The recent upward extension of the data assimilation system at the Meteorological Service of Canada (MSC) from 10 hPa to 0.1 hPa has significantly improved meteorological analysis within the stratospheric region. This modeling effort has given the opportunity of producing ozone analyses which that will bring several benefits to the operational system. Ozone assimilation has been performed with simplified and comprehensive modeling approaches for evaluating the impact of model uncertainties in different regions. Both chemical schemes have been evaluated over different periods against satellites and ozone sonde measurements. Multi-year integrations have been also performed for evaluating species seasonal variability and mass conservation properties of the transport scheme. The study illustrates the strength and limitations of simplified methods for addressing stratospheric chemical modeling within an integrated dynamical-chemical NWP system.

On the control of stratospheric water vapor and the implications for climate change

A.E. Dessler* (Texas A&M University) and M.R. Schoeberl (STC)

Results from a trajectory model of stratospheric water vapor are presented. Comparisons to satellite measurements show good agreement, giving confidence in the accuracy of the model. Analysis of the model shows that surface temperature and lower stratospheric water vapor are weakly anti-correlated on both long and short time scales. This suggests that the stratospheric water vapor feedback may be slightly negative.

* = presenting author

Spectral Representation of Spatial Correlations in Variational Assimilation Systems with Grid Point Models: Application to the Belgian Assimilation System of Chemical ObsErvations (BASCOE)

Q. Errera, BIRA-IASB, Belgium
R. MÃcnard, Environment Canada, Canada

One of the critical aspects of any assimilation system is the formulation of a background error covariance matrix (BECM) which is sufficiently compact to be implemented numerically and sufficiently complex to represent correctly the real error covariances of the first guess field. In the late nineties, meteorological centers have implemented relatively powerful BECM where the spatial correlation matrix is defined in the spectral space. In this configuration, the horizontal correlations are assumed to be homogeneous and isotropic. Moreover, non-separable vertical correlations can be implemented.

The goals of this study are numerous. First, it aims at presenting this method by focusing on a univariate assimilation and for global models. Usually, this method is implemented in meteorological spectral models with the physical grid being the (non-equally spaced) Gaussian grid. We will show that the method can be applied directly to equally spaced physical grid without operating a transformation from the Gaussian grid to the model grid, which necessarily degrades the analyses. This method has been implemented in the stratospheric chemistry data assimilation system BASCOE. Statistics of the background error correlations are estimated using the NMC method for separable and non-separable vertical correlations. Results from real test cases will be shown using Envisat MIPAS and EOS Aura MLS observations.

A Climatology of Stratopause Temperature and Height in the Polar Vortex and Anticyclones

Jeff France
University of Colorado, Boulder

Abstract:A global climatology of stratopause temperature and height is shown using 7 years of Microwave Limb Sounder satellite data, from 2004 to 2011, and compared with the Navy's Operational Global Atmospheric Prediction System model (NOGAPS) and a 40 year run from the free running Whole Atmosphere Community Climate Model (WACCM) 4 an. Stratopause temperature and height is interpreted in the context of the polar vortices and anticyclones. Multi-year, monthly mean geographic patterns in stratopause temperature and height are shown to depend on the location of the polar vortices and anticyclones. This is the first study to show that the stratopause is, on average, 20 K colder and 5-10 km lower in the Aleutian anticyclone than in ambient air during the Arctic winter. During September in the Antarctic the stratopause is, on average, 10 K colder inside anticyclones south of Australia. The regional temperature and height anomalies, which are due to vertical ageostrophic motion associated with baroclinic instability, are shown to be climatological features. The mean structure of the temperature and height anomalies is consistent with moderate baroclinic growth below the stratopause and decay above. This work furthers current understanding of the geography of the stratopause by emphasizing the role of synoptic baroclinic instability, whereby anticyclones establish zonally asymmetric climatological patterns in stratopause temperature and height. This work highlights the need to consider zonal asymmetries when calculating upper stratospheric temperature trends.

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SPARC Reanalysis/Analysis Intercomparison Project (S-RIP)

Masatomo FUJIWARA (Hokkaido University, Japan), Saroja POLAVARAPU (Environment Canada, Canada), and David JACKSON (Met Office, UK)

Available global reanalysis data sets will be investigated for the major middle atmospheric diagnostics under the collaboration between the SPARC community and the reanalysis centers. The purposes of this project are to have a good communication platform between the SPARC community and the reanalysis centers, to understand the current reanalysis products, and to contribute to future reanalysis improvements in the middle atmosphere region. The project will have three major components: (1) the management team which consists of the three authors and one reanalysis representative and deals with the overall coordination, (2) the scientific working group which consists of ~10 persons and suggests the diagnostics covered and has the responsibility for editing and writing the final report, and (3) all SPARC-related researchers who make the data analysis, write journal papers, and contribute to the final report. The project will hold two or three dedicated workshops in the next 2 to 3 years, where analysis results are discussed among the SPARC community and the reanalysis centers, and produce the final report as a SPARC report, which reviews the then past and near-future publications. The project duration is expected to be 3-5 years for the first phase. In this workshop, we will explain the project in detail and discuss potential diagnostics list and intercomparison guidelines that the scientific working group will finalize. We also discuss the potential scientific working group membership and the terms of reference.

Stratospheric Predictability and the Arctic Polar-night Jet Oscillation

Peter Hitchcock
Dept. of Applied Math and Theoretical Physics
Cambridge University

Theodore G. Shepherd
Dept. of Physics
University of Toronto

Gloria L. Manney
Jet Propulsion Laboratory, California Institute of Technology and
New Mexico Institute of Mining and Technology

The presence of long statistical decorrelation times in the extratropical winter stratosphere, and the realization that the troposphere shows clear indications of stratospheric influence, presents a tantalizing potential source of predictability at seasonal timescales. Attempts to exploit this source of predictability, however, have met with mixed success. I will argue that one reason for this mixed success is that the predictability implied by these decorrelation timescales arises only when the stratospheric flow is in a particular configuration (a notion that is difficult to convey using a single climatological timescale). Specifically, the recovery of the Arctic polar vortex following a subset of major stratospheric sudden warmings exhibits a very robust pattern of evolution, characterized by extremely persistent anomalies in the lowermost stratosphere. The circulation during these episodes, termed Polar-night Jet Oscillation events, is governed predominantly by radiative processes as a result of the strong suppression of planetary wave activity in the polar vortex. This suppression, which can persist for as long as three months, is likely to lead to significantly enhanced predictability in the stratosphere. Given the influence of the associated stratospheric anomalies on the tropospheric circulation below, this may extend to the troposphere as well.

Assimilation of SSMIS UAS brightness temperature observations for mesospheric analysis

Karl Hoppel, Steve Swadley
Naval Research Laboratory

A major impediment for achieving ground to space NWP capability, is the lack of near-real-time middle atmospheric state measurements for assimilation. The only operationally available source of extensive meteorological observations in the mesosphere is provided by the Upper Air Sounding (UAS) channels of the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager/Sounder (SSMIS) instruments. To date, this data has been underutilized because: 1) typical global NWP models do not span the required vertical range (surface to 100 km), and hence do not include mesosphere; and 2) the fast radiative transfer (RT) models used in data assimilation systems lacked explicit treatment of the Zeeman effect on the oxygen molecule's interaction with the geomagnetic field in the microwave 60 GHz range at altitudes above 40 km. Version 2 of the Community Radiative Transfer Model (CRTM) has implemented the Zeeman-splitting spectroscopy calculations required for the UAS channels. In this poster we evaluate the utility of assimilating the newly developed SSMIS Unified Pre-Processor for the UAS (UPP-UAS) channels by comparing the radiances with the CRTM calculations using coincident SABER temperatures profiles. We also show an example UAS assimilation analysis using the Navy Global Environmental Model (NAVGEM).

Title: Intercomparison of operational stratosphere-resolving global NWP systems
Author: David Jackson
Affiliation: Met Office, Exeter, UK

Many, if not all, global NWP systems now resolve the whole stratosphere, and it is important to review the use and performance of these systems in operational NWP, in order to understand the impact the representation of the stratosphere has on tropospheric weather forecasts, and also to identify the ongoing research challenges.

In this presentation, the stratosphere-resolving models used in operational global NWP systems around the world are documented and intercompared, with a focus on parametrization schemes relevant to the middle atmosphere (eg radiation, gravity waves). The performance of each NWP system in the stratosphere is summarised. Also discussed is the important question of the impact of the better representation of the stratosphere on tropospheric analyses and forecasts (eg from better use of satellite data, stratosphere / troposphere interaction and its impact on medium range forecasts). Finally, future research plans and challenges are summarised.

Assimilating MOPITT CO Observations in GEOS-CHEM using a Weak Constraint 4D-Var algorithm

Martin Keller (1), Dylan B. Jones (1), Daven Henze (2), Zhe Jiang (1)

(1): University of Toronto
(2): University of Colorado at Boulder

Systematic forward model errors pose a substantial problem for data assimilation systems, as the assimilation methods currently in use assume that the forward model is perfect. Recently, methods allowing the additional estimation of model errors within the context of 4D-Var, normally referred to as "weak constraint 4D-Var", have been developed. This weak constraint 4D-Var method has been implemented in the GEOS-CHEM chemical transport model to assess the feasibility of estimating transport model errors within the context of chemical source estimation as well as to study the impact of model biases on these estimates. A particular problem that has received attention recently is the vertical transport of trace gases associated with parametrized convection, which can potentially have detrimental impacts on the depiction of the distribution of trace gases in the UTLS. I will present results from the assimilation of MOPITT V5 CO observations and will discuss some of the merits as well as problems associated with this new technique, focusing on vertical transport errors associated with parametrized convection in the tropics.

ACE-FTS measurements of anthropogenic ozone depleting substances

Felicia Kolonjari[1], Kaley A. Walker[1, 2], Chris D. Boone[2], Susan Strahan[3], Chris McLinden[4], Gloria L. Manney[5,6],William H. Daffer[5], and Peter F. Bernath[2, 7,8]

[1]Department of Physics, University of Toronto, Toronto, Canada
[2]Department of Chemistry, University of Waterloo, Waterloo, Canada
[3]Universities Space Research Association & NASA Goddard Space Flight Center, Greenbelt, USA
[4]Environment Canada, Toronto, Canada
[5]Jet Propulsion Laboratory, Pasadena, USA
[6]Department of Physics, New Mexico Institute of Mining and Technology, Socorro, USA
[7]Department of Chemistry & Biochemistry, Old Dominion University, Norfolk, USA
[8]Department of Chemistry, University of York, York, UK

The depletion of stratospheric ozone is primarily caused by catalytic reactions of ozone and atomic chlorine. Stratospheric photodissociation of chlorofluorocarbons (CFCs) is the major source of this chlorine. To fulfill the need for safe, stable replacements of CFCs, hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), have been developed. Monitoring the changing global distribution of CFCs in addition to their replacement species is critical to understanding the recovery of the ozone layer in a changing climate. Launched in August 2003, the Atmospheric Chemistry Experiment (ACE) is a mission on-board the Canadian satellite SCISAT. The primary instrument on SCISAT is a high-resolution infrared Fourier Transform Spectrometer (ACE-FTS). With its wide spectral range, the ACE-FTS is capable of measuring an extensive range of gases including key CFC and HCFC species.

The global distributions of CFC-11, CFC-12, and HCFC-22 have been computed from measurements by ACE-FTS. In particular, the use of HCFC-22 as a replacement for CFC-11 and CFC-12 has led to an observable increase in its atmospheric abundance. The rapid increase in the concentration of HCFC-22 over the course of the ACE mission is of concern due to both its ozone depletion potential and its global warming potential. Although more predominant in the distribution of HCFC-22 concentrations, seasonal and inter-hemispheric variations are observed for all species studied here. Comparisons to ground-based and air-borne measurements show good agreement with the ACE-FTS measurements. Comparison of results from transport models driven by assimilated winds with global trace gas datasets can provide insight on the representation of transport in such models. Fields from the Global Modelling Initiative (GMI) Combined Stratospheric-Tropospheric Model (driven by winds from the MERRA reanalysis) show reasonably good agreement with the observed distribution of CFCs. However, the HCFC-22 surface boundary conditions used in the GMI simulation have a slower than observed growth and lack an interhemispheric gradient as observed for 2004-2010. This impacts model gradients in the UT/LS.

Monitoring air quality: the role of OSSEs in determining the future global observing system

W.A. Lahoz

NILU, Norway and CNRM/Météo-France, France

The need to monitor air quality is recognized world-wide. This involves, inter alia, measurements of key pollutants (e.g. ozone and carbon monoxide) in the lowermost troposphere at spatio-temporal scales relevant to monitor, forecast and manage air quality on a daily basis (temporal frequencies less than 1 hour; spatial scales less than 10 km). This presentation identifies the role of data assimilation observing system simulation experiments (OSSEs) in determining the future observing system to monitor air quality, with focus on lower troposphere measurements of ozone and carbon monoxide. Caveats associated with setting up and interpreting OSSEs are discussed. OSSEs performed to assess the added value of the proposed geostationary satellite platform MAGEAQ (Monitoring the Atmosphere from Geostationary orbit for European Air Quality), as well as the added value of other observing platforms of the global observing system for monitoring air quality (low earth orbit satellites; ground-based data) are presented to illustrate the concept.

Aura MLS Near-Real-Time Processing Stream for use in Data Assimilation and in Support of SEAC4RS

Alyn Lambert, Nathaniel J. Livesey, William G. Read, Lucien Froidevaux, Michael J. Schwartz, Gloria L. Manney*, Haley Nguyen, W. Van Snyder, Vincent S. Perun, Paul A. Wagner, Igor Yanovsky, and David T. Cuddy

Jet Propulsion Laboratory, California Institute of Technology
* also at New Mexico Institute of Mining and Technology

The Microwave Limb Sounder (MLS) on the Aura satellite launched in July 2004 has produced daily global atmospheric data for over 7 years. Since March 2008 MLS has provided temperature, geopotential height and ozone data products in near-real-time (NRT) with 90% of the data being available within three hours of the satellite observation time. We report on the recent testing of an improved near-real-time retrieval algorithm to produce temperature, geopotential height, ozone and water vapor on 12 levels per decade, and carbon monoxide, nitric acid, nitrous oxide and sulfur dioxide on 6 levels per decade in pressure. The MLS team expects the new NRT data products to be available before August 2012 in a production stream at the Goddard DISC to support the NASA led Southeast Asia Composition, Cloud, Climate Coupling Regional Study (SEAC4RS).

Doppler Wind and Temperature Sounder

R. S. Lieberman, D. C. Fritts, and L. L. Gordley

A new approach for measuring high altitude winds and temperatures has been presented by Gordley and Marshall (2011). The technique employs gas filter correlation radiometry from low Earth orbit to simultaneously measure the Doppler shift and line width of emission spectra, from which wind and kinetic temperature can be inferred. The products of the Doppler Wind and Temperature Sounder (DWTS) are profiles of daytime and nighttime temperature and cross-track winds between 25 to 250 km with less than 2% uncertainty, at intervals of 10 km along-track. Above 110 km and below 50 km, the along-track wind component is also determined, thus enabling recovery of the horizontal vector wind. DWTS measurements therefore far exceed current capabilities. We present several DWTS sampling scenarios and demonstrate its capability to retrieve planetary-scale variations in global temperature and vector winds.

Tidal variability in NOGAPS-ALPHA

R. S. Lieberman, NWRA, Boulder, CO
D. E. Siskind, NRL, Washington, D. C.

Diurnal and semidiurnal tides in the mesosphere exhibit variability on day-day-day and weekly timescales. This variability has been linked to tropospheric convection, and to interactions with wintertime planetary waves. In recent years there have been many studies suggesting ionospheric responses to sudden stratospheric warming (SSW) events, and tides are thought to be one of the key agents that couple these two regions. However, the time scales involved in SSW are too short for defining tidal diagnostics from precessing satellites such as TIMED. One way to circumvent the limitations imposed by the satellite sampling is to use an assimilative model that naturally captures the relevant physics that produces tides.

Recently, a new version of the The Navy Operational Global Atmospheric Prediction System (NOGAPS) Advanced Level Physics High Altitude (ALPHA) has been developed that is initialized by the assimilation every 6 hours, but uses the physics based forecast model to provide output on a 1-hourly cadence. This product allows global definitions of diurnal, semidiurnal and higher-order tidal harmonics on a day-to-day, or at least week-to-week basis. This presentation will highlight tidal variability during Northern hemisphere planetary wave activity in winter of 2009. We also demonstrate possible links between high-latitude tides and polar mesospheric clouds.

Current and Future Plans at NCEP for Reanalysis

Craig Long[1], Wesley Ebisuzaki[1], Robert Kistler[2], Jack Woollen[2]
1-NOAA/National Weather Service/NCEP/Climate Prediction Center
2-NOAA/National Weather Service/NCEP/Environmental Modeling Center

NCEP was one of the first weather centers to produce a reanalysis of previous years using a fixed numerical analysis and forecast model. The NCEP/NCAR (R1) reanalysis began production in 1994 and produced a reanalysis from 1948 to the present. Some errors were diagnosed in R1 and in 1996 the NCEP/DOE reanalysis (R2) began to run. Both are currently running. Satellite derived temperature retrieval profiles from NESDIS are assimilated. These models are quite old by today's standards. In 2010, NCEP created the Coupled Forecast System Reanalysis (CFSR). However, its primary purpose was to create initial conditions for the hindcast calibrations of Climate Forecast System (CFS) version 2, which became operational in April 2011. With this purpose in mind, this reanalysis was coupled with the ocean, cryosphere, and land surfaces. It uses Gridpoint Statistical Interpolation (GSI) to assimilate satellite radiances. It was run for the period 1979 to present, continues to run in real time as the assimilation component of the CFS. A comprehensive evaluation of this CFSR by CPC scientists revealed several issues when assessing the CFSR as a climate reanalysis. NCEP has since been resolving these issues and is working toward running a follow-on reanalysis that will be able to replace R1. Our presentation will focus on the merits of R1 and R2, why they need to be replaced with a newer more comprehensive reanalysis, an examination of the CFSR, and NCEP's efforts to resolve the issues within the CFSR and produce a quality reanalysis to replace R1.

Usefulness of the Recent Reanalyses to Provide Indicators of Climate Change

Craig Long[1], Amy Butler[1], and Jeannette Wild[2]
1-NOAA/National Weather Service/NCEP/Climate Prediction Center
2-NOAA/National Weather Service/NCEP/Climate Prediction Center/Wyle

Reanalyses use multiple satellite and surface observation systems to produce a comprehensive analysis of the atmosphere's dynamical, thermal, and chemical state with time. By removing the noise of ever changing analysis models and transitions from one satellite to the next, a better data record for climate studies is expected. Reanalyses have been successful for assessing how the climate has been changing. But can they tell us how much the climate has been changing, i.e. are the reanalyses useful for generating climate trends. The answer may vary both geographically and vertically in the atmosphere. We will present two comparisons of long term satellite data sets with their reanalysis generated duplicate. Both data sets have been used by the climate community to characterize climate change. One data set is the MSU-4/AMSU-9 long term temperature time series and trends. The other is the SBUV/2 profile ozone data set. Even though both of the satellite data sets are assimilated into the CFSR, MERRA, and ERA-Interim reanalyses it is uncertain whether these reanalysis retain the observations' characteristics. This is because these reanalyses assimilate other data which may alter the signal provided by these two satellite data sets. A comparison of the correlation of the long term time series with the reanalysis generated ones is presented as well as a comparison of the trends. We will present what the possible causes are if the correlations and trends vary significantly. We conclude with a discussion about the usefulness of the reanalysis data for climate trends.

Abstract for the 2012 SPARC Data Assimilation Workshop
Socorro, New Mexico, USA, 11–13 June 2012

Climatology and Variability of Upper Tropospheric/Lower Stratospheric Jets from MERRA Reanalysis

Gloria L. Manney(1,2,3), William H. Daffer(1), Michaela I. Hegglin(4), Steven Pawson(5), Michael J. Schwartz(1), Michelle L. Santee(1)

(1) Jet Propulsion Laboratory, California Institute of Technology
(2) Now at NorthWest Research Associates
(3) New Mexico Institute of Mining and Technology
(4) Department of Meteorology, University of Reading, Reading, UK
(5) NASA/Goddard Space Flight Center

Jets are key dynamical features that define the circulation and organize transport in the upper troposphere/lower stratosphere (UTLS). The wintertime stratospheric polar night jet often extends down into the UTLS and can thus play a significant role in UTLS transport. Multiple tropopauses are common in the regions surrounding the upper tropospheric jets, and are associated with cross-tropopause transport. We use a recently developed method of characterizing the UTLS jets and tropopauses to develop a climatology of the upper tropospheric jets in relation to multiple tropopauses and the stratospheric polar night jet from the 33-year MERRA reanalysis. A jet coordinate framework is used to view dynamics and transport in relation to the upper tropospheric jets. Interannual variability and evidence for trends are discussed. We compare the climatology of MERRA assimilated ozone in relation to the jets and tropopauses to that from the ~7.5-year record of Aura Microwave Limb Sounder measurements, to assess whether the MERRA ozone product captures features of the large-scale climatology. Some comparisons with similar products derived from the ERA-Interim reanalyses will be presented.

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Stratospheric Sudden Warming Signatures in Satellite Data and Data Assimilation Systems: Stratopause Evolution and Transport

Gloria L. Manney(1,2), Ken Minschwaner(2), Saroja Polavarapu(3), Shuzhan Ren(3), Karl W. Hoppel(4), Fabrizio Sassi(4), Michael J. Schwartz(1), William H. Daffer(1), Kirstin Krüger(5), Steven Pawson(6)

(1) Jet Propulsion Laboratory, California Institute of Technology
(2) New Mexico Institute of Mining and Technology
(3) Environment Canada & University of Toronto
(4) Naval Research Laboratory
(5) IFM-GEOMAR
(6) NASA/Goddard Space Flight Center

Four of the most intense and prolonged stratospheric sudden warmings (SSWs) on record have occurred in the past eight years, a period with a uniquely comprehensive set of satellite measurements covering the upper troposphere/lower stratosphere (UTLS) through the mesosphere. Prior to the launch of instruments such as Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) and the Aura Microwave Limb Sounder (MLS), information on both temperatures and constituents in the upper stratosphere/lower mesosphere (USLM) region was particularly sparse. Here, the evolution of the stratopause during recent prolonged SSWs is described using MLS and SABER data, and compared with operational (ECMWF, GEOS-5) and research (CMAM, NOGAPS-ALPHA) data assimilation system (DAS) products. The NOGAPS-ALPHA DAS has a higher model top than GEOS-5 and ECMWF and assimilates MLS and SABER temperatures and MLS ozone and water vapor. The CMAM-DAS has a high model top and includes a more sophisticated non-orographic gravity-wave drag scheme than GEOS-5 and ECMWF. In both cases, these improvements result in better representation of large-scale transport in the USLM and much better representation of the stratopause during the SSWs.

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Title: High Altitude Data Assimilation at the Naval Research Laboratory: Recent Results and Future Directions

J. McCormack (presenter)**,** Code 7646, Space Science Division, Naval Research Laboratory, Washington DC
L. Coy, Code 7646, Space Science Division, Naval Research Laboratory, Washington DC
S. Eckermann, Code 7646, Space Science Division, Naval Research Laboratory, Washington DC
K. Hoppel, Code 7227, Remote Sensing Division, Naval Research Laboratory, Washington DC

To improve the observational characterization of middle atmosphere dynamics, the Naval Research Laboratory (NRL) has developed a high-altitude atmospheric data assimilation system (DAS) capable of generating global synoptic meteorological analyses every 6 hours from the ground to the lower thermosphere (~90 km altitude). This DAS is based on the existing high-altitude version of the Navy Operational Global Atmospheric Prediction System (NOGAPS), known as NOGAPS-ALPHA (Advanced Level Physics-High Altitude). In addition to assimilating operational meteorological observations in the 0-50 km altitude range, the NOGAPS-ALPHA DAS also assimilates temperature and constituent measurements from instruments on NASA research satellites such as Aura MLS and TIMED SABER using a three-dimensional variational (3DVAR) approach. This unique data set provides a global description of middle atmospheric dynamics that we have used to investigate nonlinear interactions between planetary waves and tides in the mesosphere and lower thermosphere (MLT). We present recent DAS results describing the morphology of the quasi-two day wave, five day wave, and migrating diurnal and semidiurnal tides during summer in both Northern and Southern Hemispheres over the 2005-2010 period. We also investigate the possible link between the occurrence of major stratospheric sudden warmings (SSW's) during Northern winter and tidal motions in the equatorial MLT region, which has been proposed to explain unusually large ionospheric disturbances observed following SSW's in January 2009 and 2010. Preliminary results from a new high-altitude 4DVAR DAS based on the Navy Global Environmental Model (NAVGEM) will also be presented.

Assimilating Observations of Atmospheric Angular Momentum: Synthetic-Observation Experiments with NCAR's Community Atmosphere Model

Lisa Neef, Katja Matthes

Helmholtz-Zentrum für Ozeanforschung Kiel (GEOMAR), Düsternbrooker Weg 20, 24105 Kiel

Exchange of angular momentum between the atmosphere and the solid Earth excites changes in the rotation of the Earth, that is, wobbles of the rotational pole (polar motion) and small fluctuations in the rate of rotation of the Earth (i.e. in the length-of-day, or LOD). These changes range from subdaily to decadal, and while very small, can be observed at high precision by space geodetic techniques. Observations of polar motion and LOD reflect the atmosphere's total angular momentum, and thus represent an integral measure of the atmospheric state. They can therefore be used to observationally constrain atmospheric models.

We apply this constraint to NCAR's Community Climate Model 5 (CAM5) using an Ensemble Square Root Filter within the Data Assimilation Research Testbed (DART). We present a set of perfect-model experiments wherein observations of three atmospheric angular momentum (AAM) components are assimilated daily over several months. The effects of localization, inflation, and observation frequency restoration are tested. These experiments allow us to asses the amount of information gained from the observations, relative to concomitant runs with either no assimilation or using a set of more traditional meteorological observations.A major challenge of this approach is that the AAM observations represent spatial integrals, meaning that a set of observations does not correspond to a unique state-space solution. We show that information about the true state can nevertheless be gained from this assimilation, despite the integral nature of the observations, and discuss the complementarity of these observations to more spatially-localized observations.

Joint Assimilation of Tropospheric Emission Spectrometer and Microwave Limb Sounder Ozone Measurements in the GEOS-Chem Chemistry Transport Model

Jessica L. Neu (1), Kevin W. Bowman (1), Nathaniel J. Livesey (1), Michelle L. Santee (1), Meemong Lee (1)

(1) Jet Propulsion Laboratory, California Institute of Technology

We present results for a joint assimilation of O3 measurements from the Aura Tropospheric Emission Spectrometer (TES) and Microwave Limb Sounder (MLS) instruments in the GEOS-Chem chemistry-transport model using a 3-Dvar assimilation system. We show that O3 from either instrument alone improves performance relative to sondes over North America from near-surface (900 hPa) to the middle stratosphere (10 hPa). As expected, TES measurements provide a larger correction in the troposphere and MLS measurements provide a larger correction in the stratosphere. The joint assimilation reduces the error to within 10% over the entire pressure range for most of continental U.S. We discuss the characteristics of the assimilation, including the interplay between the measurements in the region in which they overlap and the vertical propagation of information, and address the potential for “chemical reanalysis” products for model evaluation.

A model independent technique based on the ensemble Kalman Filter to estimate unresolved gravity wave drag: Evaluation in the Lorenz 96 model

M. Pulido (*), G. Scheffler and J. Ruiz

The forcing by small-scale gravity waves has important effects on the general circulation of the middle atmosphere. General circulation models (GCM) can not resolve these small-scale waves so that GCMs have a systematic bias if the effects of these unresolved waves are not parameterized. In this work, we develop a technique based on data assimilation principles that estimates objetively the systematic bias of a model. The assimilation technique is based on the ensemble Kalman filter and estimates objetively the forcing terms in the momentum equations, apart from the model state, using an augmented state space. As a first evaluation to the potential of the developed technique, we applied it to the Lorenz 96 equations using twin experiments (observations are generated synthetically with the model). We show that the technique is able to localize spatially and temporally sources of model errors, so that it has the potential to constrain gravity wave parameterizations from observations. An important aspect of this new proposed technique is that it is model independent, i.e. it could be applied in any general circulation model to estimate missing gravity wave drag without sustantial modifications.

Studies of the tropical tropopause region and polar ozone loss -- Two areas that are particularly sensitive on uncertainties in meteorological fields from data assimilation systems

Markus Rex
Alfred Wegener Institute for Polar and Marine Research

Gridded meteorological fields from data assimilation systems are the basis for a wide range of studies in atmospheric science. Based on examples from two regions in the atmosphere the presentation will show how such studies are affected by uncertainties in these products. (1) Polar ozone loss studies respond sensitively on just small uncertainties in temperature fields because the activation of chlorine species into ozone destroying radical forms is an extremely non-linear process, which is triggered by a threshold in temperature. The presentation will show the relation between calculated ozone losses and assumed biases in the temperature field and will discuss the robustness of such calculations in the presence of uncertain input data. (2) Uncertainties in the vertical wind fields from DA systems are often a limiting factor for stratospheric transport studies and in particular for studies of processes in the Tropical Tropopause Layer. Sparse time sampling in six hourly fields together with noise components or wave induced short term fluctuations can result in unrealistic diffusion dominated vertical transport of species in the presence of steep vertical gradients across the tropopause. Ways to deal with these limitations of DA data products in atmospheric process studies will be discussed.

The stratospheric mean meridional circulation as diagnosed from reanalyses

Karen Rosenlof
NOAA Earth Systems Research Laboratory, Chemical Sciences Division

On the global scale, the dominant dynamical feature that influences the zonally averaged distribution of temperature and species in the stratosphere is the Brewer-Dobson circulation (BDC), a wave-driven, Lagrangian mean, meridional mass circulation linking the tropics to the higher latitudes. The circulation can be broken down into three main parts; ascent in the tropics bringing tropospheric air into the stratosphere, poleward transport in the stratosphere and descent at middle and polar latitudes, ultimately bringing stratospheric air back into the troposphere. Understanding the observed variability of the BDC throughout the depth of the stratosphere is of interest for a range of climatic processes. Changes in the BDC will alter transport of anthropogenic species through the tropopause that can subsequently alter the radiative and chemical balance of the stratosphere. In this presentation I will discuss how we can use reanalysis output to diagnose mean characteristics and variability in the BDC, and how we can use stratospheric constituent observations to assess the quality of reanalysis output.

Variations in trace gas distributions in the upper troposphere and stratosphere deduced from Aura Microwave Limb Sounder measurements and their relationship to the strength of transport barriers diagnosed from meteorological analyses

Michelle L. Santee, Gloria L. Manney, Nathaniel J. Livesey, and William G. Read

Jet Propulsion Laboratory, California Institute of Technology, CA

Daily global trace gas measurements from the Microwave Limb Sounder (MLS) on NASA's Aura satellite, launched in July 2004, have enabled a comprehensive examination of the daily, seasonal, interannual, and interhemispheric variations in trace gas distributions in the upper troposphere and stratosphere. Here we use nearly eight years of MLS O3, HNO3, HCl, ClO, CH3Cl, H2O, CO, and N2O measurements to analyze these variations and correlate them to the strength of transport barriers as diagnosed from meteorological analyses. Among the topics we investigate are: chemical processing in and dispersal of chemically-processed air from the lowermost portion of the winter polar vortex and the "subvortex", the region below the strong dynamical confinement of the vortex proper; the occurrence of troposphere-to-stratosphere and stratosphere-to-troposphere transport associated with the summer monsoon circulations; and the influence of the quasi-biennial oscillation and the so-called atmospheric tape recorder on tropical trace gas abundances. The observed trace gas behavior is shown to be consistent with the evolution of transport barriers.

Impact of Gravity Wave Drag Parameter Estimation using Data Assimilation on the General Circulation of the Middle Atmosphere

G. Scheffler, M. Pulido
Universidad Nacional del Nordeste, Argentina.

The impact of using optimal parameters in a gravity wave drag (GWD) parameterization in a simple mechanistic atmospheric model is examined. Gravity wave drag parameters of the Scinocca scheme are estimated using a data assimilation technique. The hybrid assimilation technique uses 4D variational assimilation to estimate gravity wave drag from Pulido & Thuburn 2008 and a genetic algorithm to estimate the optimal parameters of the scheme. In this work, the impact on the general circulation of the middle atmosphere of a mechanistic model, the University of Reading model, using optimal gravity wave drag parameters is examined. A significant improvement of the model is obtained, in particular the RMSE diminishes significantly comparing a simulation with a standard set of parameters and a simulation with optimal parameters against Met Office analysis. Using latitude-dependent optimal parameters, important improvements on the Equatorial zonal winds are found without degrading without degrading high latitude jets. Different definition of the cost function used to obtain the optimal parameters are presented. In particular, a cost function that give more weight to the upper stratosphere - lower mosphere than the lower stratosphere resulted in an overall better performance. Some early results that evaluate the capability of this simple mechanistic model in representing the QBO by means of optimal parameters are shown. To conduct this experiment, the estimated parameters are assumed to change seasonally as expected from gravity wave sources.

Characteristics of multiple tropopauses in data assimilation systems as a context for analysis of satellite-based trace gas measurements

Michael J. Schwartz 1
Gloria L. Manney 1,2
William H. Daffer 1
Michaela I. Hegglin 3
Kaley A. Walker 4

The extra-tropical tropopause region is dynamically complex, with frequent occurrences of multiple tropopauses and of a "tropopause inversion layer" of enhanced static stability just above the tropopause. This tropopause structure is zonally-asymmetric and time-varying and, along with the UTLS jets, it defines the barriers and pathways that control UTLS transport. Data assimilation systems such as GEOS-5.2 or ECMWF-interim provide realistic temperature, PV and wind fields from which tropopause and jets may be identified. These in turn provide a context in which satellite-based measurements of trace gases in the extra-tropical tropopause region may be understood. Mid-latitude secondary tropopauses are typically extensions of the tropical tropopause across the subtropical jet. They can cover a large region, at times extending poleward beyond 60 degrees latitude, and may reach the polar subvortex, particularly during SSW events. In the upper part of these inter-tropopause layers, above the layer of enhanced static stability, air is found to have characteristics suggesting low-latitude, often tropospheric, origin. We examine MLS, HIRDLS and ACE-FTS UTLS trace gas profiles in the context of extra-tropical tropopause and UT jet structures identified from GEOS-5 fields to gain understanding of UTLS trace gas distributions and transport barriers. Some comparisons will be made with products from other data assimilation systems.

1 Jet Propulsion Laboratory, California Institute of Technology,Pasadena, CA
2 New Mexico Institute of Mining and Technology, Socorro, NM
3 Department of Meteorology, University of Reading, Reading, UK
4 Department of Physics, University of Toronto, Toronto, CA

Case studies of the middle atmospheric response to gravity wave drag using NOGAPS-ALPHA at varying resolutions

David E. Siskind
Space Science Division,
Naval Research Laboratory, Washington DC

It is well understood that gravity waves play a dominant role in the momentum budget of the middle atmosphere. Because they usually are manifest on spatial scales smaller than typical theoretical model grid sizes, their effects in global models must be accounted for by parameterizations, rather than via explicit resolution. The recent implementation of a high altitude data assimilation system with NOGAPS-ALPHA (Eckermann et al., 2009; Hoppel et al., 2008) offers a new tool to evaluate the role of gravity waves in shaping the structure of the middle atmosphere and its response to perturbations. Specifically, we employ several short and medium term forecasts and use the divergence of the forecast model from the analysis as a measure of forecast skill and, by implication, the validity of our assumptions concerning gravity waves. We evaluate the ability of our model, at various spatial resolutions, to simulate gravity wave driven features of the middle atmosphere such as the warm winter stratopause and the cold summer mesopause. Also, we address the relative roles of gravity waves and planetary waves governing the response of the middle atmosphere to sudden stratospheric warmings. We focus in particular on recent extended warmings where the conventional stratopause at 50 km disappears and reforms above 80 km. We use wave forcing diagnostics from the Transformed Eulerian Mean formulation to quantify the effects of differing assumptions and compare forecast results at T79, T239 and T479 spectral truncations. While T79 is clearly too coarse, progressive improvements are seen at T239 and T479 truncation.

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Ensemble-based data assimilation for stratospheric chemistry

S. Skachko, Q. Errera, S. Chabrillat, Y. Christophe
BIRA, Ringlaan 3, 1180 Brussels, Belgium

Chemical transport models (CTM) are broadly used to forecast chemical species concentration or analyze the tropospheric pollution. As more chemical observations become available, the use of data assimilation methods, integrating observational data with model predictions to obtain an optimal state of the atmosphere, plays an essential role in air-quality forecasting as far as deriving information about unobserved species, support the measurement techniques etc. Since several years the Belgian Assimilation System for Chemical ObsErvations (BASCOE) consisting in a 3-dimensional chemistry transport model and 4-dimensional variational (4DVar) data assimilation approach has been successfully employed to assimilate stratospheric chemistry species. In this work we implement an ensemble Kalman filter (EnKF) into the BASCOE system to assess its performance and compare it with our 4DVar technique. We analyze different issues affecting the data assimilation process and consider a procedure to avoid the divergence of the filter applied to ozone concentration using assimilation of real data.

Parametrized observation operators and their application on illustrative 3D atmospheric chemical fields

T. Verhoelst (presenting); J.-C. Lambert; S. Vandenbussche

Belgian Institute for Space Aeronomy, Brussels, Belgium

The continuous enhancement of the resolution of atmospheric data assimilation systems poses new challenges for the ingestion of satellite observations which, in such systems, constrain the output of a chemical transport model. The common assumption that the information contributed by the satellite observation comes from the column over the ground footprint (for nadir sounders) or from the tangent point (for limb sounders), often lacks accuracy. Due to radiative transfer effects combining with scanning and orbital properties of the sounder, remote sensing by spectroscopic techniques yields only a smoothed perception of the atmospheric field. Horizontal smoothing properties can be characterised by the spread of the measured information and its geographic offset with respect to the footprint or tangent point. In some cases both the spread and the offset can be larger than the spatial resolution of the assimilation system. In such a situation, the classic observation operator consisting of a linear interpolation of the model at the footprint or tangent point may lead to non-negligible noise and bias.

In recent years we have developed parameterised observation operators for nadir, limb, and solar occultation satellite data. Here we use these operators on illustrative atmospheric fields to quantify the noise and bias introduced in model-observation comparisons when neglecting the actual sensitivity, spread and offset. We show that in the framework of data comparisons, like in data assimilation, scatter and bias can be reduced significantly when adjusting co-location criteria using the appropriate observation operators. With the drastic reduction in observational constraints for data assimilation anticipated in the 2nd half of this decade, and with the increased use of tracer-tracer correlations which also depend on co-location assumptions, the use of pragmatic observation operators at low computational cost in model-observation comparisons may be equally beneficial.

Recent Advances in Ozone Data Assimilation at the GMAO - Towards a New Reanalysis

K.Wargan, S.Pawson, J.E.Nielsen, M.Olsen, J.Witte, A.Douglass, S.Strahan, J.Joiner, P.K.Bhartia, N.Livesey, W.Read, P.Wagner, and H.Nguyen

This talk summarizes our ongoing work on improving the representation of ozone in the GEOS Data Assimilation Systems. We use data from two EOS Aura sensors: the total column ozone from the Ozone Monitoring Instrument (OMI) and high vertical resolution stratospheric profiles from Microwave Limb Sounder (MLS, version 3.3). As several previous studies have demonstrated assimilation of these data can constrain the stratospheric and tropospheric ozone columns with relatively good accuracy. However the representation of the vertical structures in the troposphere and near-tropopause region is often deficient. Since both these layers of the atmosphere are critical to our understanding of the radiative forcing as well as the ozone budget in the troposphere our current work focuses on improving the assimilated product between the surface and the 50 hPa pressure level.

We will talk about recent steps that we have taken towards refining the treatment of ozone in GEOS-5. We will discuss the impacts of improved tropospheric chemistry model, the introduction of efficiency factors ("averaging kernels") for OMI total ozone, and direct assimilation of radiances from the MLS instrument. In particular, advantages and challenges involved in assimilating limb radiances rather than retrieved product will be discussed. This work is, in part, a preparation for a planned reanalysis of the EOS Aura data from 2005 to present.

Uncertainty of the Stratospheric/Tropospheric Temperature Trends in 1979-2008: Multiple Reanalyses, MSUs and Radiosondes

JIANJUN XU
Environmental Science and Technology Center, College of Science,
George Mason University, Fairfax, VA 22030
Jxu14@gmu.edu

ALFRED M. POWELL, Jr.
Center for Satellite Application and Research(STAR)
NESDIS/NOAA, Camp Springs, MARYLAND, USA
Al.powell@gmu.edu

ABSTRACT

The trends and spreads of tropospheric and stratospheric temperature are discussed in terms of three groups of datasets in 1979-2008. These datasets include (a) three satellite observations of Microwave Sounding Units (MSU) measurements, (b) five radiosonde observations and (c) eight reanalysis products. The equivalent tropospheric and stratospheric temperature from radiosonde and reanalyses are calculated based on the vertical weighting function of the MSU channel 2 (CH2) and channel 4 (CH4) measurements, respectively. The results show that both cooling in the stratosphere and warming in troposphere significantly depends on the datasets and latitudes.

Troposphere-stratosphere interaction diagnostics of the 3D Eliassen-Palm flux and its association with the North Pacific SST in different NWP products.

Yulia Zyulyaeva and Sergey Gulev

P.P. Shirshov Institute of Oceanology, RAS, Moscow, Russian Fed. (yulia@sail.msk.ru)

We provide a comparative assessment of the magnitudes of the three-dimensional Eliassen-Palm (EP) flux and its association with the sea surface temperature (SST) anomalies in the North Pacific as revealed by several reanalyses. Our diagnostics was based on the daily data of the 3D structure of the zonal stratospheric circulation. We found that an event of strong upward propagation of planetary waves from the troposphere to stratosphere over the northern Eurasia region leads by approximately one month the starting data of the Sudden Stratospheric Warming (SSW). Amplification of the penetration of planetary waves into the stratosphere in December is strongly associated with the changes in the stratospheric dynamics in January, hinting on the "preconditioning" of the stratospheric warming. This linkage is clearly observed in the early winter (November-December), however was not identified during the mid-to-late winter (January-March).

In order to link the phenomenon to the ocean signal we analysed correlations between the characteristics of stratospheric dynamics and the SST anomalies in the North Pacific and found these correlations to be significant implying potential influence of the diabatic heating over the North Pacific on the magnitudes of 3D Eliassen-Palm flux.

The prominent downward propagation of the signal from the stratosphere was found in Labrador and South Greenland region. The intensity of this signal correlates with the NAM index, hinting (although still implicitly) on the link between stratospheric dynamics and blocking events in the troposphere.