SCIENTIFIC PROGRAMS AND ACTIVITIES

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Organizing Committee:
Saroja Polavarapu and Theodore Shepherd
Physics, University of Toronto

WCRP World Climate Research Programme

Environment Canada Environnement Canada

Abstracts

Back and forth nudging algorithm for data assimilation problems
by

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The standard nudging algorithm consists in adding to the state equations of a dynamical system a feedback term, which is proportional to the difference between the observation and its equivalent quantity computed by the resolution of the state equations. The model appears then as a weak constraint, and the nudging term forces the state variables to fit as well as possible to the observations. The backward nudging algorithm consists in solving the state equations of the model backwards in time. A nudging term, with the opposite sign compared to the standard nudging algorithm, is added to the state equations, and the final obtained state is in fact the initial state of the system.

The back and forth nudging algorithm (BFN) consists in solving first the forward nudging equation and then the direct system backwards in time with a feedback term. After resolution of this backward equation, one obtains an estimate of the initial state of the system. We repeat these forward and backward resolutions until convergence of the algorithm. The theoretical convergence of this algorithm can be obtained in the case of a linear system, or a very simple nonlinear ODE (Lorenz equations), under some observation hypothesis.

From a numerical point of view, we compared this algorithm to the 4D-VAR on nonlinear systems such as Lorenz, Burgers' equations, and a quasi-geostrophic ocean model. In all cases, the first iterations of the BFN algorithm were more efficient than the 4DVAR ones. Moreover, it is still the case in presence of model or observation errors. Finally, its implementation is very easy because it requires neither the linearization of the equations nor any minimization process.

Surface measurements of size and composition of particulate matter at Eureka, Nunavut
by
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Significant levels of synthetic organic pollutants (so-called persistent organic pollutants, or POPs) such as pesticides, PCBs and semi volatile industrial chemicals have been found in the Arctic snow pack and wildlife, providing unequivocal evidence for the long range transport of these materials into the Arctic. Both the origins of these materials and the mechanisms responsible for their transport have been investigated for many years.

It is generally accepted that gas phase transport occurs via the "grasshopper" mechanism, which is an annual cycle in which the materials are sequentially volatilized and dispersed in the summer and deposited back to the surface in the winter. The lower average temperatures at high latitudes cause the retention of the materials that are deposited there, with the result that they become more concentrated with time in the high Arctic and bio-accumulate in the ecosystem to levels at which they become a hazard to the health of the species at the top of the food chain. Using the methods of regional chemical transport modelling, we have shown previously that at mid-latitudes a significant fraction of the transport of these semi-volatile organics results from their partitioning to atmospheric particulate matter (PM). In the size range below about 1 μm, intercontinental transport of PM is possible, providing an additional mechanism for the transport of these organics to the Arctic. To determine whether this mechanism is responsible for some of the POPs detected in the Arctic, we have installed an Aerosol Mass Spectrometer to measure size distribution and composition of the PM arriving at the Polar Environmental Atmospheric Research Laboratory (PEARL), at 80N;86W near Eureka, Nunavut. We will report the results of our initial measurements, which were made during 2007. When combined with semi-Lagrangian trajectory modelling, these results will identify the most probable sources of the contaminated PM.

The impact of ground based ozone monitoring on stratospheric ozone assessments: A case study using sequential and variational data assimilation
by
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Data assimilation using chemistry-transport models is commonly used to derive consistent analysis of ozone related stratospheric chemistry. However, based on historic satellite data it is also possible to simulate the potential information gain by ground based ozone soundings. Today, ground based observations are indispensable to validate satellite instruments. Their potential role for routine stratospheric data assimilation is therefore of special relevance for planning future satellite missions. Here, we present results of an Observing System Experiment (OSE) using ERS-2/GOME observations to simulate different ozone sonde station networks with respect to existing networks like that of GAW and NDAAC. The sequential assimilation system ROSE/DLR is applied to study the long-term impact of routine ground based observations on assimilated ozone fields. To highlight the respective change in information content, analysis and first-guess errors are discussed. In parallel the 4DVAR SACADA system is used to analyse the sensitivity of ozone related chemistry to ozone sonde observations for certain atmospheric conditions, e.g., ozone hole versus dynamically distorted episodes. Our results show that continuous ground based ozone soundings can lead to significantly improved ozone maps via data assimilation. While the Northern Hemisphere has an already well established station network, the greatest impact is expected by increasing the number of observations in the Southern Hemisphere and especially the Tropics.

How will a changing stratosphere affect high-latitude climate?
by
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Recent research has shown that changes to the circulation of the lower stratosphere affect tropospheric weather and climate, especially at high latitudes. For example, the ozone hole in the Southern Hemisphere spring has not only cooled the polar lower stratosphere and increased the strength of the stratospheric circumpolar winds, but also affected Antarctic surface climate.

During the past 25+ years the composition of the stratosphere has changed significantly, with higher abundances of anthropogenic greenhouse gases and ozone-depleting substances (ODSs), together with a concomitant thinning of the ozone layer. With the recent stabilization of stratospheric ODSs following the Montreal Protocol we are near the turnaround point in ozone depletion, so that the past climate impacts of ODSs and ozone depletion are about to change sign against a background of continued increases in most greenhouse gases, which will tend to cool the stratosphere. Chemistry-climate models predict that ozone recovery will not be a simple reversal of ozone depletion. Rather, the stratospheric cooling from increasing greenhouse gases will, overall, accelerate the recovery of the ozone layer, so that pre-1980 ozone abundances are expected to be reached sometime around the middle of this century.

Nearly all climate models with well-represented stratospheres predict an enhancement of the Brewer-Dobson circulation under climate change, suggesting that the northern polar stratosphere will be warmer during winter and spring, even while the rest of the stratosphere becomes colder. Because of the very real possibility of dynamical responses to the stratospheric changes, predictions of the evolution of polar climate could be substantially different, especially in the winter and spring in the Northern Hemisphere and spring and summer in the Southern Hemisphere.

Measurements of atmospheric trace gases in the Arctic: First light measurements from the new FTIR spectrometer at PEARL
by
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In order to fully understand the mechanisms and processes which result in ozone depletion and climate change, quality measurements of atmospheric trace gases from high latitude observatories are essential. The atmospheric observatory at Eureka (80N, 86W) has recently been rejuvenated by the Canadian Network for the Detection of Atmospheric Change (CANDAC).

A new Bruker IFS 125HR Fourier transform infrared spectrometer was installed at the Polar Environment Atmospheric Research Laboratory (PEARL), 610 m above sea level, in July 2006. With a resolution of 0.0035 cm-1 and the capability of making automated measurements of approximately 15 different trace gases in the mid-infrared region, this instrument promises to be an essential component of the Arctic observing network.

This presentation will introduce the instrument and present preliminary results from the 2006 first-light and 2007 polar sunrise campaigns.

Detection of Antarctic Ice Polar Stratospheric Clouds from AIRS Assimilation
by
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The distribution and nature of Antarctic polar stratospheric clouds (PSCs) is determined by synoptic, planetary, and gravity waves, which vary on interannual, seasonal, monthly, daily, and hourly time scales. This paper uses AIRS radiance observations with the GEOS-5 data assimilation system to construct maps of ice PSCs in the Antarctic. The basis of the work is that the AIRS channels near 6.79 um, primarily used to detect the tropospheric moisture distribution, are sensitive to the presence of cirrus and PSCs in the atmosphere above their level of peak sensitivity under clear-sky conditions. This study uses differences between AIRS radiance observations and clear-sky radiance computations based on the GEOS-5 background fields to infer the presence of ice PSCs in the atmosphere, based on observed-minus-forecast brightness-temperature differences of -2 K. This sensitivity threshold was determined using meteorological fields from GEOS-5 to construct Lagrangian trajectories along which the Integrated Microphysics and Aerosol Chemistry on Trajectories

(IMPACT) model is applied to simulate PSC microphysics, heterogeneous and gas-phase chemistry; PSC particle densities were used in the Moderate Resolution Atmospheric Transmission (MODTRAN) radiation code to establish sensitivities to the presence of PSCs. POAM observations of ice PSCs show a high degree of correlation with AIRS O-Fs below -2 K. Further comparisons with PSC data from CALIPSO and POAM provide a basis for validation and interpretation of the AIRS PSC maps.

Seasonal variations in the MLT tides in the 120E meridian
by
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The authors report in this presentation the seasonal variations in major atmospheric tides in the mesosphere and lower thermosphere region in the meridian at 120 ?E. The SABER/TIMED temperature measurements covering Nov. 2004 to Jan. 2006 were used to extract tidal components with Fourier-leastsquares fit and FFT analysis, and to reconstruct the diurnal, semidiurnal and terdiurnal tides in the meridian. The migrating diurnal tides increase with altitude and attain maxima at 97 km height, then decrease sharply with altitude. The tides of other frequency increase with altitude and attain significant amplitude at 97 km height. Considering the behavior in the vertical of the amplitudes, the authors placed their focus on introducing estimation results obtained at the 97-km altitude. For the tides of each frequency, the migrating and nonmigrating components were examined separately, and their respective contribution to the whole of the tides were evaluated. The primary results showed that migrating component plays dominant role in characterizing the general temporal and spatial distribution for both diurnal and semidiurnal tides. Regarding the diurnal tides, contribution of migrating component is the most dominant one during spring equinox, which is characterized by the amplitude maxima at the equator and that at the tropics for both hemispheres. Moreover, the temporal variation of the diurnal tides at the tropical latitude in Northern hemisphere is consistent to the analysis result obtained by using meteor radar wind measurements taken in Wuhan (30 ?N, 114 ?E). Contributions of nonmigrating tides are more significant in other seasons. During summer solstitial time in 2005, tidal modes (1, 0), (1, 2), (1, -3) and (1, -2) contribute together to form a diurnal tides active area from 10 ?N to 30 ?S with the maximal amplitude 20K at the Equator. Due to the domination of migrating component, semidiurnal tides occur at the tropical latitudes in both hemispheres. In northern hemisphere, the active tides area centers at autumn equinox with maximum 13K. And in southern hemisphere, the active area centers at the time in between spring and summer equinox. The influences of nonmigrating semidiurnal components are also clear during other seasons as several other centers with maximal amplitude are seen. Confined in the latitude range 40 ?S-40 ?N, terdiurnal components exhibit much weaker activity with much smaller amplitudes than that of the diurnal and semidiurnal components. Current estimation results suggest that nonmigrating terdiurnal components have

amplitudes that are as large as and during most times larger than that of migrating component, thus predominate the global distribution of terdiurnal tides in 2005.

Temperature correlation between the lower atmosphere and the MLT region
by
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The airglow temperature in the Mesosphere and Lower Thermosphere (MLT) region has been measured using a Spectral Airglow Temperature Imager (SATI) at Resolute Bay (74.68 N, 94.90 W) since November 2001. The MLT temperature anomalies are compared to the lower stratospheric radiosonde temperature anomalies at Resolute Bay for five years. A positive relationship of the MLT temperature at the altitude 87 km and the lower stratospheric temperature at 22.5 km is found during the period. The MLT temperatures are also compared to the upper stratospheric temperatures of SABER. A negative relationship between the MLT temperature and the upper stratospheric temperature at the altitude 55 km is found during the period. The lower atmospheric temperature and the MLT temperature are also compared with the solar flux variation as a function of QBO phase and season.

Evolution of the Arctic polar vortex during 2004/05 and 2005/06 winter seasons based on the analysis of MetO assimilated fields
by
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The atmospheric polar vortex is a dominant feature of winter middle atmosphere. Knowledge of Arctic polar vortex structure and behavior can provide information on the background atmosphere for chemical and dynamical studies at the PEARL station. To characterize polar vortices the MetO (UK Met Office) assimilated fields have been subjected to the Q-diagnostic. As a part of the diagnostic, potential vorticity, (PV), stream function, relative vorticity and the rate of strain and rotation in wind field (Q) have been calculated at several isentropic surfaces (20-50 km). Evolution of the Arctic polar vortex is demonstrated for two winter seasons: 2004/05, with only a few relatively weak stratospheric disturbances, and 2005/06, with a major sudden stratospheric warming at the end of January. In addition data from 12 meteor and MF radars have been used to compare dynamical processes at mesospheric heights with the polar vortex structure. It is shown that the arrangement of radar wind vectors is consistent with cyclonic motion around the pole and they matched the MetO winds well at corresponding locations during “quiet” days; while on occasions during the stratospheric disturbances radar and MetO winds demonstrated opposite directions.

Pan-Arctic Study of the Coupled Tropospheric Stratospheric and Mesospheric Circulation

by
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We present an IPY observational study that combines lower-resolution global data from satellite observations and meteorological analyses (e.g., National Centers for Environmental Prediction (NCEP), National Center for Atmospheric Research (NCAR), UK Meteorological Office (MetO)) with higher-resolution data from an Arctic observing network of Rayleigh lidar systems to address questions in the aeronomy of the stratosphere and mesosphere and the linkages to the troposphere. We will employ an observing network of Rayleigh lidars at the Arctic Lidar Observatory for Middle Atmosphere Research, Andoya, Norway (69 N, 16 E), Eureka Stratospheric Observatory, Eureka, Nunavut, Canada (80°N, 86°W), Poker Flat Research Range, Chatanika, Alaska, USA (65 N, 147 W), Sondrestrom Upper Atmospheric Research Facility, Kangerlussuaq, Greenland (67 N, 51 W) to provide the high-resolution temperature measurements (~ 500 m, 10's of minutes) of the stratosphere and mesosphere (~40-80 km). We illustrate this IPY study with observations from January 2003 that shows the evolution of the stratospheric vortex and anti-cyclones during a period of extensive interaction.

General Characteristics of Stratospheric Singular Vectors

by
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Leading singular vectors have been computed for a numerical weather prediction model that can resolve dynamical structures within the stratosphere and lower mesosphere. The norm applied at the final time is the commonly used energy norm but confined to measuring the stratosphere. These stratospheric singular vectors are described by presenting three examples. They are produced using either of two initial norms that weight perturbations within the troposphere versus stratosphere very differently. For either initial norm, singular values are typically smaller than their tropospheric counterparts and they are less geographically local. They also retain their relevance to corresponding nonlinear evolutions for longer periods and larger amplitudes. For these reasons, stratospheric SVs may be useful for explaining observed stratospheric dynamical behaviors.

Ground-based Zenith-sky DOAS Measurements of Trace Gases at Eureka, Nunavut
by
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The University of Toronto Ground-Based Spectrometer (UT-GBS) is a portable zenith-sky-viewing UV-Visible spectrometer, assembled in 1998. Since then it has participated in eight polar sunrise field campiagns at the Polar Environmental Research Laboratory (PEARL) in Eureka, Nunavut (80N, 86W, Feb. - Apr. 1999-2001, 2003-2007). In August 2006, a second instrument (the PEARL UT-GBS) was permanently installed at PEARL as part of the refurbishment of the lab by the Canadian Network for the Detection of Atmospheric Change (CANDAC). Vertical column density amounts of ozone and NO2 are regularly retrieved, while slant column densities of BrO and OClO are retrieved when possible.

We will discuss measurements from the 2004 – 2007 Canadian Arctic ACE Validation Campaigns, which were held as part of the validation effort for the ACE (Atmospheric Chemistry Experiment) satellite. Also participating in these campaigns were three other UV-Visible zenith-sky viewing spectrometers.

The addition of the second UT-GBS instrument with a suntracker allows for direct Sun measurements to be taken at the same time as zenith-sky measurements. Combining the slant columns from both viewing geometries allows for the separation of BrO into tropospheric and stratospheric partial columns. Direct Sun measurements were made for the first time during the 2007 campaign. Plans for future measurements with both UT-GBS instruments will be discussed.

On the extraction of wind information from the 4D-var assimilation of chemical constituents
by
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In partnership with the European Space Agency (ESA) and the Belgium Institute for Space Aeronomy (BIRA-IASB), Environment Canada has developed an assimilation system for addressing chemical weather issues. It is based on the stratospheric extension of the operational weather prediction global model with a lid at 0.1 hPa. The model is coupled with a comprehensive on-line photochemical module to incorporate dynamical, radiative and photochemical interactions. In the stratosphere, TOVS-AMSU-a radiances and radiosondes observations are assimilated whereas MIPAS occultation measurements are used for the assimilation of temperature and chemical constituents such as ozone,

methane and nitric acid. In the case of 4D-Var cycles, the system uses long lived constituents from MIPAS as passive tracers in the tangent-linear and adjoint models for inferring wind increments in the lower stratosphere where wind observations are sparse. Analysis of the results will focus on the limitation of using a simplified chemistry in the incremental 4D-Var.

The mesospheric polar vortices in GEOS, WACCM, SABER, and EOS-MLS
by
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Satellite data analysis is combined with global modeling to characterize the 3-D structure and day-to-day variability of the polar vortex in the mesosphere. We use satellite temperature and geopotential height data from the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument and temperature, carbon monoxide, and methane data from the Microwave Limb Sounder (MLS) instrument to characterize the structure of the upper stratospheric and mesospheric polar vortex in each hemisphere on a daily basis. The mesospheric vortex, as seen by these satellite instruments, is then compared to the representation of the mesospheric vortex in the GEOS-4 and GEOS-5 data assimilation systems as well as in the Whole Atmosphere Community Climate Model (WACCM). We will show the 3-D structure of the mesospheric vortex at times when the stratospheric vortex is strong as well as how this structure is modified during stratospheric warming events. This work will conduct model/observation intercomparisons of the mesospheric vortex as a means to determine the need for data assimilation in the mesosphere and above.

The benefits of in-line advection - Assessing the transport characteristics of the CMAM-DAS
by
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DAS-driven chemical transport models (CTMs) are known to be excessively dispersive and to produce erroneous distributions of long-lived tracers. This is reflected in too-young age of air, and results from noise in the assimilated winds. While CTMs are driven off-line by analyzed wind fields sampled at a certain frequency, CMAM-DAS calculates advection within the model code (in-line), hence providing higher temporal resolution. This procedure should mitigate the effects of noise and make 3D-Var analyses useable for advection of chemical species. In this study we test this hypothesis by investigating the transport characteristics of the CMAM-DAS. Comparisons with ACE-FTS satellite data and ER-2 aircraft measurements show that mixing barriers are well represented and latitudinal gradients in N_2O, NO_y, and O_3 are retained in the

CMAM-DAS, confirming our expectations. We conclude that in-line calculation of advection represents a way ahead in order to improve tracer transport in DAS.

Stratospheric and Mesospheric Assimilation using the NOGAPS-ALPHA/NAVDAS forecast model
by
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A high altitude extension of the Navy Operational Global Atmospheric Prediction System (NOGAPS) Advanced Level Physics, High Altitude (ALPHA) is under development at the US Naval Research Lab. This research model has extended the altitude range of NOGAPS from the lower stratosphere into the mesosphere, and has been used to study stratospheric warmings [Siskind et al, 2005 JGR] and mesospheric dynamics [Siskind et al, 2007 GRL] Recently, the NRL Atmospheric Variational Analysis System (NAVDAS), has also been extended to begin assimilating measurements over the full pressure range of NOGAPS-ALPHA. Initial tests are being performed using temperature measurements from the NASA's Microwave Limb Sounder (MLS) and the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instruments, along with univariate MLS ozone and water vapor analyses. The temperature assimilation is being used to tune the forecast model and study the impact of improved stratospheric initial conditions on stratospheric forecasts. This presentation describes the assimilation system and examines the impact of the assimilation on understanding and forecasting the stratospheric major warming of Jan/Feb 2006.

Impact of Different Representations of Ozone on Tropospheric Weather Forecasts
by
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Ozone can potentially have a large impact on Numerical Weather Prediction (NWP) products. For example, improved representations of ozone can lead to better temperature analyses and forecasts (via more accurate radiative heating rates) and better assimilation of satellite radiances. Improved ozone analyses can also lead to improved surface UV forecasts. Until recently, the availability and quality of ozone observations, and the understanding of the performance of the ozone assimilation scheme, have not been sufficient for these advances to have been realised. However, with the introduction of new ozone observations from satellites and the growing maturity of ozone assimilation techniques it is now appropriate to revisit these issues.

The first part of this presentation describes how the addition of EOS Microwave Limb Sounder (EOS MLS) ozone observations to the Met Office ozone assimilation scheme improves the quality of the ozone analysis. The chief positive benefits are seen in the lower stratosphere, with reductions of mean errors in both the extratropics and tropics. In particular, the representation of winter stratospheric ozone depletion, low ozone near the summer pole, and ozone near the tropical tropopause is considerably improved with the addition of the EOS MLS data.

In the second part of the presentation a series of experiments is run to examine how changing the ozone fields used in the forecast model radiation scheme can impact on the accuracy of tropospheric forecasts. Currently, the operational Met Office NWP system uses the ozone climatology of Li and Shine (1995) for this purpose. A series of experiments was run with several alternative representations of ozone, including: assimilated ozone from two analyses (one with EOS MLS data included in the assimilation and one with them excluded), ECMWF ozone analyses imported into the system and an updated ozone climatology from SPARC.

The NWP index is a measure of the skill of the tropospheric forecasts. Our results show a positive impact on the NWP Index when the Li and Shine ozone climatology is replaced by the SPARC climatology and by both the assimilated ozone fields. However, the use of the ozone ECMWF fields caused a deterioration in the NWP index. Longer-period forecasts also hint at potential benefits of improved representations of ozone to extended range tropospheric forecasts.

Equatorial waves as a balance relationship in global data assimilation
by
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Tropical analysis displays the largest uncertainties in global data assimilation. Besides the lack of observations, the assimilation process would also benefit from a tropical balance relationship incorporated in the background error. It has been suggested to use equatorial waves as a mass/wind balance relationship. This approach is tested in the idealized setup of a global shallow water model. It is demonstrated that the application of an incomplete relationship based on geostrophy alone leads to a misinterpretation of observational data and thus to enhanced errors in the analysis. Only the combination of geostrophy and equatorial waves improves the tropical analysis. Furthermore, its applicability to a full 3D-GCM extending into the middle atmosphere is explored. As a first step the background error covariances are calculated in terms of the equatorial waves. The horizontal structure of the background error is then interpreted in terms of the convectively excited equatorial waves. The vertical correlations provide further information about the vertical propagation of the waves. Finally, the performance of the equatorial wave approach is compared with alternative balance relationships, such as semi-geostrophy.

Stratospheric Circulation—AO—Mei-yu Anomaly
by
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The relationship between stratospheric circulation variation and climate is an important component of the SPARC/WCRP. The Mei-yu is an outstanding climate event in East Asia and has important impacts on the economic and societal development in China and Japan. So it has been paid more attentions how about the relation of Mei-yu anomaly to stratospheric circulation variation. Based on the data analyses, this study will show that the Mei-yu in summer is evident correlation with the circulation anomaly at the stratosphere in winter. And the influence process of the tratospheric circulation on the Mei-yu is also shown: the stratospheric circulation anomaly will cause AO (Arctic Oscillation) variation at first; then different pattern of the AO will lead to the tropospheric circulation anomaly in East Asia in summer, which is favorable to enhance or reduce the Mei-yu rainfall.

Intercomparison and fusion of EOS/MLS and TIMED/SABER temperatures
by
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Data from the Earth Observing System (EOS) and the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) satellites are combined in order to maximize their space-time information content for studies of waves in the mesosphere. A statistical comparison has been carried out for temperatures from the EOS Microwave Limb Sounder (MLS) and the TIMED Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) during spatiotemporal coincidences of the two instruments. Relative to SABER EOS/MLS has a slight warm bias in the stratosphere, and a more substantial cold bias at mesospheric altitudes. Both offsets are removed by applying an empirical correction to MLS temperatures. RMS differences range between 2K and 4K in the stratosphere, and rise steeply in the mesosphere. The datasets have been merged in order to analyze diurnal tides over sub-yaw length intervals.

Assimilation of Multiple Ozone Products into the NCEP Operational Forecast Model.
by
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Recently, there has been a vast increase in the number of total and profile ozone data products available from either operational or research satellites. With the current assimilation techniques and schemes there is little distinction between data coming from the operational instruments and instruments of opportunity. At NCEP the operational ozone data assimilated has always and only been from the SBUV/2. In preparation for its replacement (the Ozone Mapper and Profiler Suite, OMPS) on the National Polar-orbiting Operational Environmental Satellite System (NPOESS), NCEP has revised the way ozone data is assimilated into the Gridpoint Statistical Interpolation (GSI) scheme expanding its capabilities to assimilate additional total and profile ozone data. We will discuss the benefits of assimilating the new SBUV/2 version 8 data and the OMI total ozone data into the operational GFS model not only in terms of ozone forecasting but also how other fields, such as temperature and winds, are affected. Additionally, we will present test results from assimilating the MLS, HIRDLS, and OMI ozone profile data, which are not currently available in 'near real time' or of sufficient quality for operational assimilation. We will discuss the process and results of validating the total and profile ozone analyses and forecasts. Lastly, we will discuss our plans for assimilation of MetOp GOME-2 total ozone data into the GFS model. The GOME-2 total and profile data are the next ozone data sources planned to be assimilated operationally into the GFS.

Global aerosol forecasting and data assimilation in GFS/GSI: Overview and Progresses

by

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The NOAA National Centers for Environmental Prediction (NCEP) Global Forecast System/Global Data Analysis System (GFS/GDAS) is the decision support tool used by NOAA for medium-range numerical weather prediction. The forecast model, GFS, is a global spectral model with meteorology data assimilation using the Gridpoint Statistical Interpolation (GSI). The chemical and aerosol components that are important to the radiation transfer computation and the description of long-range transport impact on the US air quality are currently treated in a primitive way in the GFS/GDAS. In specific, aerosols in GFS are currently prescribed based on a climatology and GDAS assumes background aerosol conditions. The NOAA/NWS/NCEP/EMC is developing an aerosol forecasting and assimilation capability in GFS/GDAS to provide the lateral boundary conditions to the CMAQ-WRF regional air quality model as well as to improve the radiation feedback in the GFS simulations. The aerosol modules are based on the NASA Goddard Chemistry Aerosol Radiation and Transport (GOCART) model. Both offline and in-line approaches are in progress. We will overview the progress of the NCEP global aerosol modeling system and the approach on the chemical data assimilation.

Polar Stratopause and Tropopause Evolution and Transport and Implications for Assimilated Analyses

by
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Until very recently, global, multi-annual datasets covering the upper stratosphere/lower mesosphere (USLM) and upper troposphere/lower stratosphere (UTLS) were largely unavailable; detailed knowledge of both regions is critical to understanding climate change and ozone recovery. Some operational assimilated analyses, including those from the European Center for Medium-Range Weather Forecasts (ECMWF) and NASA's Global Modeling and Assimilation Office (GMAO), are now provided at levels into the mesosphere; however, with no direct data constraints and few data with which to compare them, their quality is highly dependent on the underlying general circulation models and assimilation methods and is largely unknown. The Aura Microwave Limb Sounder (MLS), Atmospheric Chemistry Experiment-Fourier Transform Spectrometer (ACE), and Sounding of the Atmosphere with Broadband Emission Radiometry (SABER) instruments now provide unprecedented global, multi-annual, multi-species datasets covering the upper troposphere through the mesosphere, including high-quality temperature data through the mesosphere. We use MLS, SABER, ACE-FTS, and ground-based data, to detail the evolution of the stratopause during recent polar winters, and to assess the ability of analyses to capture observed behavior. In addition to ECMWF and GMAO analyses, we show preliminary results from Canadian Middle Atmosphere Model (CMAM) assimilations with a model top above 0.001 hPa and a comprehensive online chemistry-transport module, and from preliminary experiments assimilating MLS and SABER data in NRL's NOGAPS-ALPHA system. Relationships to vortex structure in assimilated analyses, and consistency of that structure with long-lived trace gas transport is also explored. While analyses are better constrained by temperature data near the tropopause than in the upper stratosphere and above, many uncertainties remain, and comprehensive trace gas datasets have heretofore been sorely lacking. We compare tropopause structure in MLS data and analyses, and present examples aimed at evaluating the consistency of MLS trace gas data with transport (both on- and off-line) by assimilated winds. The examples shown here will focus on the polar winter, to show analyses that will be done for IPY, and include stratopause/tropopause evolution during stratospheric sudden warmings and examination of interannual and interhemispheric variability.

Near-Real-Time Processing Plans for Aura MLS Data for Use in Data Assimilation

by
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The Microwave Limb Sounder (MLS) aboard the Aura satellite, launched July 15, 2004, has already obtained 3 years of daily global atmospheric data. The dataset includes temperature, geopotential height, and a number of constituents such as O3, H2O, CO, N2O, HNO3, HCl, ClO, BrO, OH, HO2, with retrievals spanning the upper troposphere to the mesosphere (or higher) in some cases. Close to 3500 profiles are retrieved (per product) each day; ice water content (IWC) and ice water path (IWP) information is also obtained. A significant amount of these 3 years of data has been reprocessed using the version 2.2 algorithms (the 2nd public release of MLS data). Several groups have already performed successful assimilation experiments using MLS data, especially O3 and temperature; some of this work is reported on elsewhere at this Workshop.

The MLS team is working on a fast but accurate production stream for a select number of products (mainly T, O3, and H2O), in order to enable near-real-time processing and data assimilation using some of the MLS capabilities. We discuss the plans for creating such a data stream from MLS and early test results using a preliminary subset as an example.

An overview of the dynamics of the mesosphere and lower thermosphere
by
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The mesosphere and lower thermosphere (MLT) contain a rich spectrum of atmospheric waves ranging from global-scale tides and planetary waves to meso-scale gravity waves. A detailed picture of the MLT is emerging as satellite observations of this region increase. In tandem with this growth in global observations, have been advancements in general circulation models which now extend upward to include the MLT. The assimilation of observations in the MLT is therefore an obvious step which would not only consistently blend models and measurements but also enhance the usefulness of daytime-only measurements, for example. However, data assimilation in the MLT is currently not possible due to difficulties arising from the short time scales in the MLT. This talk overviews the current understanding of the dynamics of the MLT through a series of observational and modelling results. Since a good model is a requirement for a good assimilation system, focus is placed on the ability of models to simulate the observed large-scale flow in the MLT. Benefits of assimilating MLT measurements, such as daytime-only data, are also discussed.

Coupled chemistry-dynamics data assimilation
by
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In partnership with the Belgium Institute for Space Aeronomy (BIRA-IASB), the Institute for Meteorology and Climatology (IMK) in Karlsruhe Germany, York University in Toronto, Environment Canada has developed a coupled chemistry-dynamics model and assimilation system for addressing chemical weather issues. The model is based on the stratospheric extension of the Canadian operational weather prediction Global Multiscale Environmental (GEM) model with a lid at 0.1 hPa. The model is coupled with a comprehensive on-line photochemical module developed at BIRA for the Belgian Assimilation System for Chemical Observations from Envisat (BASCOE), and incorporates chemical-radiative interactions. The Canadian variational assimilation system has also been extended to include chemical variables, and in particular cross error covariances between ozone and the meteorological variables and between long-lived species with balance operators. The incremental 4D Var extension to chemical variables uses the adjoint of tracer transport. The study focuses on the stratosphere and the use of Envisat observations. In addition to the standard meteorological observations used in NWP operations, AMSU-a radiances of channels 11-14, MIPAS ESA and MIPAS IMK retrievals as well as GOMOS dark limb measurements of temperature and chemical constituents (such as ozone, water vapor, methane, nitrous oxide, nitrogen dioxide, nitric acid) were assimilated. Several data assimilation cycles throughout the period August-November 2003 have been performed for the validation of the different components of the system. Both 3D-Var and 4D-Var cycles have been performed to evaluate the impact of the assimilation methods on the results. An overview of the study will be presented. Some of the highlights are: An improved AMSU-a bias correction, the impact of radiative feedback from ozone on the model predictability, the impact of MIPAS ESA temperature on transport of long-lived species, the assimilation of several chemical species using 3D-Var, and the use of 4D-Var assimilation of long-lived species to infer winds.

Gravity Waves in Four-Dimensional Data Assimilation
by
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In the mesosphere and upper stratosphere, modeled flows are dominated by gravity waves. For data assimilation, it is difficult to formulate covariance models for these regions, since traditional balance constraints do not represent the full system. A related problem occurs in the tropics, where there is no clear timescale separation between vortical modes, gravity waves, and equatorial waves. Both regions have fewer observations than the midlatitude troposphere, making accurate data assimilation a greater necessity.

It is not clear to what extent 4D assimilation schemes are able to develop accurate covariance fields in the context of an unbalanced state and/or unclear timescale separation. We investigate this problem using a simplified model of a chaotic vortical mode coupled to a linear gravity wave of a given amplitude and frequency, and compare the three most basic types of 4D data assimilation: the Extended Kalman Filter (EKF), Ensemble Kalman Filter (EnKF), and 4D variational assimilation (4D-Var). It is shown that each method's ability to recover the vortical mode, when an gravity wave is present in the true state but not observed, depends on the accuracy of modeled covariances between fast and slow normal-mode variables. dLikewise, the ability to extract both modes from observations which contain both timescales of motion depends both on the estimated fast-slow covariances, as well as the estimated error variance ascribed to the gravity wave.

The EKF is shown to be very limited in the estimation of covariances between fast and slow variables, and thus tends to return faulty analyses, but it nevertheless remains useful as long as the fast variables are observed and observations are very frequent. The EnKF and 4D-Var offer two ways of alleviating the problems found in the EKF, but the accuracy of each method depends several other complicating factors.

A study of the CMAM_DAS using simulated observations
by
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The forecast errors in CMAM-DAS were investigated using simulations with the known truth (taken from a free model run). Observations were simulated at locations of actual measurements. The results may be helpful in a few aspects. 1. This is an independent approach to the estimation of error covariances when, contrary to other methods, we know the truth. 2. This provides the ability to investigate the sensitivity of the assimilation to its different components in isolation [model, observations (variances, bias, type and distribution), assimilation system components (3D-Var approach, the minimization method)]. 3. This is a simple way to investigate the extent of predictability in the mesosphere and the possibility of assimilating mesospheric observations.

Assimilation of Lagrangian Data in Oceanography
by

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Within the framework of Global Ocean Data Assimilation Experiment (GODAE), an increasing amount of data are available. A crucial issue for oceanographers is to exploit at best these observations, in order to improve models, climatology, forecasts, etc.

Thanks to the international program Argo and to more localized experiments (such as SAMBA, ARCANE-Eurofloat, ACCE), a new type of data is now available: positions of floats drifting at depth in the ocean. Unlike other data, mainly Eulerian, these ones are Lagrangian: the measuring instrument move in the flow.

I will present methods and results about 4D-Var assimilation of Lagrangian data in the OPAVAR ocean model: implementation, sensitivity studies, assimilation of noisy observations, comparison with a classical method, complementarity with temperature data.

Estimating ozone radiative forcing based on satellite observations
by
Mark Parrington
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Recently available satellite measurements, such as those from the Tropospheric Emission Spectrometer (TES) on the NASA EOS Aura platform, are providing for the first time, global datasets of the distribution of trace gases in the lower atmosphere. One application of this data is in constraining physical and chemical processes in numerical models.

Presented here are initial results from a study of the impact of constraining the global tropospheric ozone distribution, with ozone profiles retrieved from TES, on the radiative forcing in a general circulation model. Ozone data from TES are first assimilated into a version of the Geophysical Fluid Dynamics Laboratory's chemistry-climate model AM2-Chem in which the model dynamics are constrained by nudging to NCEP reanalyses. The assimilated ozone field is then used to constrain the radiation calculation in AM2-Chem, with no dynamical constraints imposed, to assess the impact on the radiative forcing through changes to the outgoing longwave radiation and model dynamics (T, u, v, w etc).

The constraint of data assimilation in the stratosphere and troposphere on mesospheric motions
by
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Due to the poor data coverage in the mesosphere, motions in the mesosphere are largely unconstrained by observations in most data assimilation systems. It is well known that the mesosphere is largely controlled by vertically propagating waves from below. Since these waves (gravity waves, planetary waves etc.), originating in the troposphere and propagating through the stratosphere, can be better represented below the mesosphere by a data assimilation system, it is expected that the information of data assimilated below the mesosphere can be carried into the mesosphere by the "corrected" waves, and consequently can drive the mesosphere close to reality.

In the Canadian middle atmosphere data assimilation system (CMAM-DAS) the forecast model (CMAM) has the model lid at 100km and the observations assimilated in the 3dvar system are below the stratopause (1mb). Therefore it is an ideal tool to examine the constraint on motions in the mesosphere imposed by the data assimilation below.

We first launch two assimilation experiments starting from different mesospheres. The differences in the mesosphere drop very quickly after a few assimilation cycles and become very small after one month indicating a strong constraint on the mesosphere from the data assimilation below. To see if the constraint is realized mainly via gravity waves, another assimilation experiment with different initial mesospheres and non-orographic gravity wave drag turned off is launched. Unlike the first two experiments mesospheric differences in this experiment increase steadily with time (temperature difference in the two poles and wind difference almost everywhere in the mesosphere). This suggests that gravity waves are important agents through which the data assimilated below the mesosphere is able to impose a constraint on mesosphere.

New 3D-Var Dynamical Constraints at Environment Canada
by
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Environment Canada
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New dynamical constraints are investigated in the context of the 3D-Var global data assimilation system used by Environment Canada. Flow dependence in the mass-wind balance is introduced by replacing statistical, time-averaged covariances with the Charney and hydrostatic balances, linearized about the background state. The Charney balance performs well in the extra-tropics and has some value in the tropics. A new constraint is also imposed on the velocity potential by employing the quasigeostrophic omega equation and continuity equation. This is done in order to limit spurious mixing caused by the insertion of observations which are not in balance with the background and with each other. The GCM used in the assimilation system is a variant of the operational model at Environment Canada (GEM), which has a relatively high lid (0.1 hPa) and includes a comprehensive online chemistry package (BIRA). The new constraints have been implemented using the hybrid vertical coordinate for consistency with the model. Resulting balanced increments are shown to compare favorably with output from a free-running model. The utility of the new constraints is examined in online 3D-Var experiments, comparing with the previous statistical approach, and focusing in particular on the tropical region. The impact on forecast scores is also discussed.

Assimilation of MIPAS chemical constituents during a major EPP-NOx event over Antarctic winter 2003
by
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Coauthors: Richard Ménard, Jean de Grandpré, Yves Rochon and Yan Yang

The stratospheric chemical constituents retrieved from MIPAS (Michelson Interferometer for Passive Atmospheric Sounder) instrument has been assimilated using the Canadian 3D-VAR system in a new coupled dynamical-chemical stratospheric model(GEM-BACH). The MIPAS data products onboard the ENVISAT satellite, one of the most largest observation platform ever launched to space, include temperature and various gas vertical profiles from limb sounding in the mid-infrared part of the spectrum. The period of study is austral winter 2003 where a considerable flux of NOx was reported to descend to the stratosphere linked with an EPP event (Energetic Particle precipitation). Such phenomenon can modify substantially the NOx budget of upper stratosphere and participate in catalytic processes controlling ozone of polar regions. The goal of the study is to evaluate how the assimilation system can handle the phenomenon given that there is no provision for the model to simulate EPP (or similar geomagnetic events) and its indirect effects in the stratosphere.

3D-FGAT assimilation of MIPAS-IMK and GOMOS chemical data
by
Yves J. Rochon
Environment Canada
Coauthors: Simon Chabrillat, Richard Ménard, Yan Yang, Alain Robichaud, Cécilien Charette

In partnership with the Belgium Institute for Space Aeronomy, Environment Canada has developed a coupled chemistry-dynamics model and assimilation system for addressing chemical weather issues. This system has been tested and developed using observations from MIPAS and GOMOS, two limb-scanning instruments aboard ENVISAT. The main dataset used in this study is MIPAS-ESA. Here we present the assimilation of the stratospheric chemistry observations from two other datasets: MIPAS-IMK ($O3$, $NO2$, $HNO3$, $ClONO2$) and GOMOS ($O3$, $NO2$). After a brief description of the datasets and set-up of the assimilation experiments, we will present the background and observation error statistics obtained by the Hollingsworth-Lonnberg method from a first-pass MIPAS-IMK assimilation. We will compare the MIPAS-IMK and GOMOS analyses with the MIPAS-ESA analyses, to show that GOMOS observations bring useful information to complement the MIPAS-ESA dataset, while MIPAS-IMK observations are an interesting alternative for assimilation of chemically active species.

Stratospheric influences on surface winter climate and prospects for seasonal forecasting

by

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The influence of stratospheric variability on surface winter climate is investigated in modelling experiments, observational datasets and seasonal hindcasts. Stratospheric changes appear to be important for the very rapid warming of Europe in winter between the 1960s and 1990s and associated changes in the frequency of climate extremes. The winter of 2005/6 is used as a case study to illustrate how this influence occurs in individual years. Finally, hindcasts with general circulation models are used to assess potential improvements in seasonal forecasts.

Cross validation of MIPAS/SAGE II and MIPAS/HALOE trace gas observations by means of four dimensional variational assimilation

by

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One of the objectives of four dimensional variational data assimilation is the possibility to cross validate retrieved profiles from different space borne instruments. Usually this task is accomplished by comparing an ensemble of collocated profiles, which coincide within some predefined maximum distance and a maximum time separation. This technique is common practise, but the selection of collocation criteria is somewhat arbitrary and problematic: Either the statistical basis for cross validation remains poor (strict selection) or the large distances in space and time (lax selection) introduce unquantifiable errors. The use of chemically consistent constituent fields obtained by 4D-var data assimilation offers a more satisfying approach to the cross validation challenge. Without applying any artificial criteria, a global analysis produced by processing observations of one instrument can be compared to profiles retrieved from another sensor, which have been withheld from the assimilation procedure.

We have assimilated MIPAS observations from several periods in 2002/2003 using the stratospheric chemistry assimilation system SACADA. The resulting global fields of trace gas distributions are used to compare them to SAGE II and HALOE retrievals. For this comparison it is essential to have an error estimate for the 4D-var analyses. As error margins are not delivered by the 4D-var

system, we use an estimate of the analysis error covariance matrix in observation space. As a prerequisite, special care has been taken to specify the observation and background error covariance matrices sufficiently realistic. The results of conventional cross validation studies are -where available- compared to the results of our 4D-var based cross validation study.

Investigating Middle Atmospheric Chemistry at the Polar Environment Atmospheric Research Laboratory (PEARL)

by

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The recently established Polar Environment Atmospheric Research Laboratory (PEARL) is located in the Canadian high Arctic at Eureka, Nunavut (80?N). It is being equipped with a suite of instrumentation to investigate chemical and physical processes in the atmosphere from the ground to 100 km. One of four research themes being pursued at PEARL is that of Arctic Middle Atmosphere Chemistry, which is focussed on the question of “What is the composition of the Arctic atmosphere above the site and how is it changing with time?” The overall goal of this theme is to improve our understanding of the processes controlling the Arctic stratospheric ozone budget and its future evolution, using measurements of the concentrations of stratospheric constituents, in conjunction with dynamical, radiative, aerosol/PSC, and meteorological observations also made at PEARL. The complexity of the atmosphere and the different spectroscopic signatures of its many chemical constituents make it impossible to measure all relevant species using any one remote sounding technique. Rather, these measurements will be made using the complementary capabilities of several of the PEARL instruments, including an ozone lidar, a Fourier transform infrared spectrometer, a UV-visible grating spectrometer, and an Atmospheric Emitted Radiance Interferometer. This presentation will provide an overview of the Arctic Middle Atmosphere Chemistry theme, including its scientific motivation, objectives, and planned measurements and science activities. Activities in the first year will be discussed, along with some of the early measurements.

The Atmospheric Chemistry Experiment (ACE): Mission Overview and Recent Results

by

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The Atmospheric Chemistry Experiment (ACE), also known as SCISAT-1, is a Canadian scientific satellite to perform remote sensing measurements of the Earth's atmosphere. It was launched on August 12, 2003 and has been operational for over 3.5 years. The primary instrument on-board SCISAT-1 is a high-resolution (0.02 cm-1) Fourier Transform Spectrometer (ACE-FTS) operating between 750 and 4400 cm-1. It also contains two filtered imagers to measure atmospheric extinction due to clouds and aerosols at 0.525 and 1.02 microns. The secondary instrument is a dual UV-visible-NIR spectrophotometer called MAESTRO (Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation) which extends the wavelength coverage to the 280-1030 nm spectral region.

The primary measurement technique for both instruments is solar occultation. From these measurements, altitude profiles of atmospheric trace gas species, temperature and pressure are obtained. The 650 km altitude, 74 degree circular orbit provides global measurement coverage with a focus on the Arctic and Antarctic regions. The primary goal of the ACE mission is to measure and to understand the chemical and dynamical processes that control the distribution of ozone in the upper troposphere and stratosphere, with a particular emphasis on the Arctic region. The mission status, current science results and validation program will be reviewed in this paper.

Tidal Signatures in the Extended Canadian Middle Atmosphere Model

by
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Migrating and non-migrating tidal components are among the dominant dynamical features in the mesosphere and lower thermosphere in model runs of the Extended Canadian Middle Atmosphere Model (CMAM). Although the migrating diurnal tide is the dominant component, other components are significant and in mid and high latitudes are as large or larger than this component. Spectral analyses of the diurnal, semidiurnal and terdiurnal signatures of the wind and temperature fields (sampled every three hours) from one year of a multiple year run show eastward and westward propagating components with wavenumbers as high as 5 to be present. Comparison of these results with satellite analyses show the tidal field in the extended CMAM to be reasonably realistic. Analysis of a separate run with a sampling interval of 5 minutes indicates that tidal harmonics up to at least 4 /day contribute. Appropriate treatment of these components will be one challenge that data assimilation in the mesosphere will need to meet.

Waves and Coupling Processes at the Polar Environment Atmospheric

Research Laboratory (PEARL)
by
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Waves are the primary means through which various regions of the atmosphere couple. At the Polar Environment Atmospheric Research Laboratory several instruments are being installed to investigate the nature of these coupling processes in polar regions. These instruments include the E-Region Wind Interferometer, the meteor radar, the Spectral Airglow Temperature Imager the PEARL All-Sky Imager, the ozone and Rayleigh/Mie/Raman lidar, the VHF and cloud radar, the Fourier Transform Spectrometer and the Atmospheric Emitted Radiance Interferometer. Together these instruments provide the means to determine the mean fields, and wave signatures associated with tides, planetary waves and gravity waves from the stratosphere to the mesopause region. Interpretation of these results will be supported with satellite observations, model results and analyses from data assimilation. Collaborations are being developed with other polar observatories so that a global view of these processes in the Arctic middle atmosphere can be developed. This effort will peak during International Polar Year.

Variability of Assimilated Ozone in the Upper Troposphere and Lower Stratosphere
by
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Ample evidence suggests that constraining constituent models with observations through data assimilation typically improves values of constituent concentrations in comparison with independent measurements. However, insertion of analysis increments into a model can introduce spurious variability or smooth out fine scale features. The question that we attempt to address is: How well and over what spatial scales can assimilated ozone reproduce the variability of ozone fields?

This study uses level 2 ozone data from the EOS Aura satellite. Ozone Monitoring Instrument (OMI) total column data and Microwave Limb Sounder (MLS) ozone profiles are assimilated into the GEOS-4 General Circulation Model at NASA's Global Modeling and Assimilation Office (GMAO). Independent aircraft data were obtained from the MOZAIC program. Statistical comparisons are presented for the Upper Troposphere – Lower Stratosphere (UTLS) region in the Northern Hemisphere for selected months in 2005. Distributions of ozone mixing ratios and their two-point differentials are shown.

Power spectra of ozone from the aircraft data are compared to those obtained from the assimilation and model simulations. These comparisons will provide information about the scales at which ozone distribution in the UTLS and the transport of ozone through the UTLS are well represented.

As a further test of assimilation results, impacts of assimilated ozone on the numerical weather prediction skill are investigated. In these experiments ozone data from OMI and MLS are assimilated into the GEOS-5 system at the GMAO. The analyzed ozone is then used in the forward model for assimilation of infrared radiances (e.g. from the AIRS instrument) as well as in the radiative heating rate computations in the general circulation model. We demonstrate large improvements in the GEOS-5 ozone fields and modest impacts on the weather prediction skill.

Constraining Zonal Mean Flow and Diurnal Tide by Space-borne Data
by
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This paper examines feasibility and limitations to use the satellite-based horizontal winds and temperatures to evaluate and constrain the balanced and forced components of model predictions in the upper atmosphere. The motivation of this study is to formulate the family of statistical estimation schemes that can provide constraints on the "missing" momentum tendencies, frequently associated with gravity effects. I discuss "technical" similarities between the data assimilation of wind data and application of sub-grid GW schemes in the numerical models. Several GW parameterization schemes have been considered to characterize their effects in the "windless atmosphere". The sensitivity of their numerics to specification of launch level parameters and background fields are discussed. The brief overview of the recent global HIRDLS temperature and tracer retrievals for studies of short-scale vertical waves will be presented.

Intercomparison of equatorial waves in the stratosphere in three data assimilation systems
by
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A significant part of the observed large-scale tropical variability is represented by equatorially trapped Rossy, Kelvin, mixed Rossby-gravity and equatorial inertio-gravity waves. Because of their vertical propagation, these waves are a driving mechanism for the tropical middle atmosphere and thus important to include in data assimilation procedures.

This study compares stratospheric variance distribution among various tropical wave motions in three global data assimilation systems (CMAM, CMC and ECMWF models). Analysis is performed by projecting dynamical fields (analysis increments and background errors) onto the analytical equatorial wave solutions. Obtained spectra are used as a forcing for an idealized stratospheric model to compare horizontal correlation structures and balance properties of data assimilation in various systems.

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