Impact of stratospheric and tropospheric data assimilation on the mesosphere during the 2002 Antarctic SSW

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1. Motivation

- The mesosphere is largely unconstrained in data assimilation systems due to poor observation coverage.
- The mesosphere is mainly driven by vertically propagating (resolved and unresolved) waves from below.
- These waves, originating in the troposphere and propagating through the stratosphere, can be better represented below the mesosphere by a data assimilation system. For the parameterized gravity waves, the observational influence comes through filtering of the gravity wave fluxes by the resolved winds.
- Through the "corrected" waves the information of data assimilated below the mesosphere can be carried into the mesosphere (during the model integration), and consequently can constrain mesospheric motions.

2. Canadian Middle Atmosphere Model Data Assimilation System (CMAM-DAS)

Model:
- T47 spectral model with 71 levels from 0-95 km.
- The non-orographic gravity-wave drag (GWD) parameterizations of Scinocca (2003), interactive chemistry, radiation and dynamics.
- 44 species advected, 127 gas-phase chemical reactions chemistry, heterogeneous chemistry
- Incremental analysis updating (IAU) is applied for initialization.

Data assimilation scheme:
- CMC 3D-variational (3DVAR) assimilation scheme
- Only dynamic variables are assimilated every 6 hours.
- Conventional obs including sondes, aircraft, surface obs, etc. and AMSU channel 5-13
- Online background check including bias correction, quality control, thinning, etc

Important notes:
In 3DVAR, the background error correlations are defined so that information from observations below 1 hPa is not spread above 1 hPa *during the data assimilation step.*

Information of observations below 1 hPa can be spread into the mesosphere only through the vertically propagating (resolved and unresolved) waves *during the model integration (6-h forecast).*

Therefore CMAM-DAS analyses can be used to examine the constraint on mesospheric motions imposed by the data assimilation below.

3. Diagnostics of SH stratospheric sudden warming (SSW):

3.1 stratospheric warming and mesospheric cooling

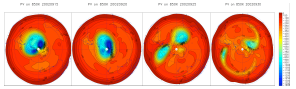
Black lines: time series of CMAM-DAS temperature analyses on 10hPa(a) and 0.1hPa (b)

Red lines: three forecasts, starting from Sept. 6, 7 and 9, respectively, that fail to capture the SH SSW (misses)

Green lines: three forecasts, starting from Sept. 17, 18 and 19, respectively, that capture the SH SSW (hits)

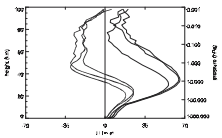
During the SSW, stratospheric warming and mesospheric cooling indicates strong coupling between the stratosphere and mesosphere.

3.2 split of PV



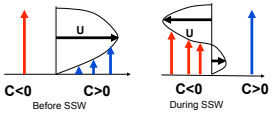
CMAM-DAS PV on 850K (~10hPa)

3.3 reversal of zonal wind



Vertical profile of CMAM-DAS zonal mean zonal wind at 60S, averaged over Sept. 25 to Oct. 1, 2002, for each of the hits (thick lines) and misses (thin lines)

3.4 critical level filtering of the GWs during SSW



The reversal of wind in the stratosphere during the SSW changes the filtering condition for the vertically propagating waves, and thus has impact on stratosphere and mesosphere coupling. Therefore the influence of DA below the stratopause on the mesosphere can be better demonstrated during the SSW.

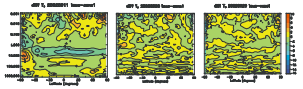
4. Impact of data assimilation (DA) below the stratopause on the mesosphere

IAUC: control data assimilation experiment
IAUP: same as IAUC but with perturbed initial condition (6 day forecast) on Sept. 11, 2002
IAUF: forecast from Sept. 11, 2002 with initial condition slightly different from IAUC analyses
IAUG: same as IAUC but with different initial conditions and without the nonorographic GWD scheme in the model.
IAUGP: same as IAUG but with same initial condition as IAUP on Sept. 11 2002

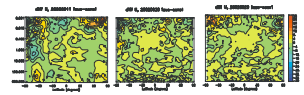
4.1 control DA (IAUC) vs. DA with initial perturbation (IAUP)

temperature difference between IAUC and IAUP

Sept.11, 2002 Sept. 20, 2002 Sept. 29, 2002



zonal wind difference between IAUC and IAUP

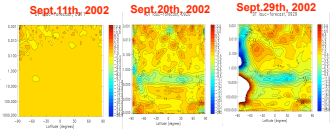


Decrease of the differences between IAUC and IAUP with time above the stratopause is due to the data assimilation below the stratopause which constrains the model in this region and the GWD parameterization in CMAM which transfers this constraint into the mesosphere.

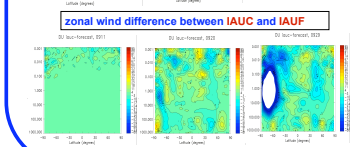
4.2 control DA (IAUC) vs. forecasts (IAUF)

temperature difference between IAUC and IAUF

Sept.11th, 2002 Sept.20th, 2002 Sept.29th, 2002



zonal wind difference between IAUC and IAUF

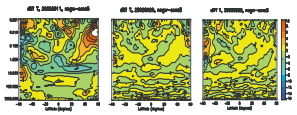


Without the data assimilation below the stratopause the differences between IAUC and IAUF increase dramatically in both troposphere and stratosphere, and these differences allow the model mesosphere to drift apart.

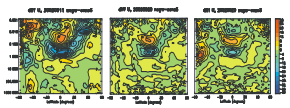
4.3 IAUG vs. IAUGP

temperature difference between IAUG and IAUGP

Sept.11th, 2002 Sept.20th, 2002 Sept.29th, 2002



zonal wind difference between IAUG and IAUGP

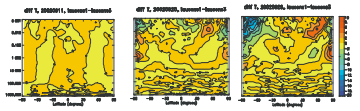


When the GWD is turned off, data assimilation information is carried into the mesosphere by resolved waves only. The decrease of the differences in the mesosphere suggests that the resolved waves can spread observation information below the stratopause into the mesosphere.

4.4 DA with GWD (IAUP) vs. DA without GWD (IAUGP)

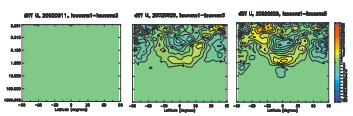
temperature difference between IAUP and IAUGP

Sept.11, 2002 Sept. 20, 2002 Sept.29th, 2002



Removing the GWD scheme changes the mesospheric climate. Assimilation of obs below the stratopause cannot counter this change.

zonal wind difference between IAUP and IAUGP



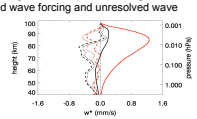
5. Contributions of resolved waves and unresolved waves in propagating DA information into the mesosphere

- During the SSW the mesospheric cooling is mainly due to the upwelling of the vertical component of the residual circulation (w). w is directly related to the forcing of resolved and unresolved waves according to the "downward control" theory.
- The role of resolved waves and unresolved waves in producing the mesospheric cooling can be identified by comparing w calculated based on the resolved wave forcing and unresolved wave forcing.

Big difference in w (calculated from the unresolved waves) between the "hits" (red solid) and "misses" (black solid) in the upper mesosphere suggests that the reversal of the stratospheric zonal wind during the SSW has a great impact on the unresolved waves.

The mesospheric cooling (W>0) during the SSW is mainly driven by the unresolved waves propagating through the stratosphere with reversed zonal wind into the mesosphere.

Forecasts that capture the SSW have less warming (downwelling) due to resolved waves than those that miss the SSW (compare dashed curves).



Red: the ensemble of w from forecasts that capture the SH SSW (hits).

Black: the ensemble of w from forecasts that miss the SSW (misses).

_____: subgrid waves
----------: resolved waves
……….: planetary waves (k<5)

6. Conclusions:

- **Due to the high lid of CMAM, CMAM-DAS analyses can be used to examine how observations below stratopause help to constrain mesospheric analyses**
- **Unresolved GWs (in GWD schemes) make a big contribution to spreading the information of observations into the mesosphere during our SSW simulation. DA information is also carried into the mesosphere by resolved waves.**
- **In the future, the additional benefit of assimilating mesospheric observations on mesospheric analyses will be assessed**

7. References:

Ren, S. S.M. Polavarapu, and T. G. Shepherd (2008), Vertical propagation of information in a middle atmosphere data assimilation system by gravity-wave drag feedbacks. *Geophys. Res. Lett.*, *35*, L06804, doi:10.1029/2007GL032699.

Polavarapu, S., S. Ren, Y. Rochon, D. Sankey, N. Ek, J. Koshyk, and D. Tarasick, 2005, Data assimilation with the Canadian Middle Atmosphere Model, *Atmos. Ocean*, *43*, 77-100.

Haynes, P. H., C. J. Marks, M. E. McIntyre, T. G. Shepherd, and K. P. Shine, 1991, On the downward control of extratropical diabatic circulations by eddy-induced mean zonal forces, *J. Atmos. Sci.*, *48*, 651-678.

Scinocca J. F., 2003, An accurate spectral nonorographic gravity wave drag parameterization for General Circulation Models, *J. Atmos. Sci.*, *60*, 667-682.