Whole Atmosphere Data Assimilation and Forecast Experiments

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0. The Research

- To extend the NCEP's GSI (gridpoint statistical interpolation) analysis system for the whole atmosphere data assimilation (DA), using WAM (whole atmosphere model) as the forecast model
- To conduct data assimilation and forecast experiments for the sudden stratospheric warming (SSW) events, and examine their effects on the upper atmosphere and ionosphere

1. WDAS: Whole Atmosphere Data Assimilation System

1.a WAM: Whole Atmosphere Model

- An extension of the NCEP's GFS (Global Forecast System) model
- Extended GFS from ~60 km to ~600 km
- Added more physical processes
- Included ionospheric effects: Joule heating and ion drag

1.b GSI: Gridpoint Statistical Interpolation

- NCEP's operational analysis system for both regional and global analysis
- Using the 3-d variational (3D-Var) analysis techniques
- Extended to work with WAM model
- Background error covariance calculated from WAM 'free' runs

1.c IAU: Incremental Analysis Update

- To reduce the excessive damping of waves in the upper atmosphere (a common problem for whole atmosphere data assimilation) during WAM-GSI DA cycle, an IAU scheme is implemented in WAM-GSI DA system ==> WAM-GSI-IAU = WDAS (Whole atmosphere DA System).
- The "Analysis Incremental" (Analysis - Forecast) is introduced into model as a constant forcing (spread over a 6-hour window center around the analysis time) at each time step in WAM during WDAS DA cycle.
- No digital filter is necessary in WDAS DA cycle, and digital filter is not used in the WDAS DA cycle.

1.d Observational data and GSI convergence

- All conventional and satellite observational data used in the GDAS (NCEP's operational Global DA System) are used in WDAS.
- Typical convergence in GSI minimization iterations is normally achieved during WDAS DA cycle (e.g., Figure 1).

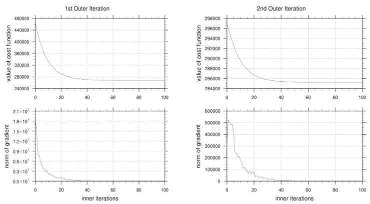

Figure 1. Typical convergence in GSI minimization iterations.

2. Data Assimilation and Forecast Experiments

- Data assimilation and forecast experiments are done with WDAS for two SSW events in Jan-Feb 2009 (SSW2009) and in Jan-Feb 2010 (SSW2010). A preliminary DA and forecast experiment for SSW2011 is also shown in Figure 3a.

2.a Data assimilation experiments

- DA experiments were performed for a major stratospheric warming in Jan.-Feb. 2009 (SSW2009: a vortex split type of SSW) and SSW in Jan.-Feb. 2010 (SSW2010: a vortex displacement type of SSW), and preliminarily for a minor warming in Jan 2011.
- Figure 2 shows the 60N-polarcap temperature from WDAS analysis, and compares with the operational GDAS analysis.

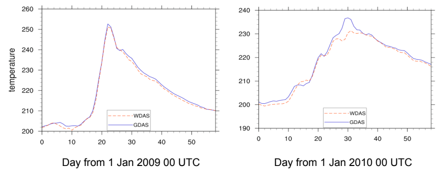

Figure 2. The 60N-polarcap temperature at 10 hPa from WDAS analysis: Left panel for SSW2009, right panel for SSW2010.

2.b Forecast experiments

- A few forecast experiments are conducted using WDAS analysis.
- Figure 3 shows the 60N-polarcap temperature from WAM forecasts (WAM-FCST): 21-day for SSW2009 and 2-month for SSW2010, and compares with the operational GFS forecasts (GFS-FCST), and WDAS analysis (WDAS-ANAL) and GDAS analysis (GDAS-ANAL).
- Figure 3a shows some preliminary results for SSW2011.

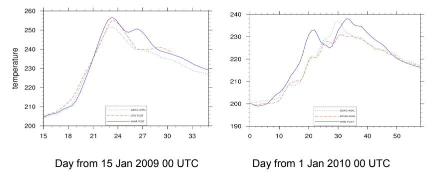

Figure 3. The 60N-polarcap temperature at 10 hPa from WAM forecasts. Left panel for SSW2009: initialized on 15Jan2009 00UTC ; right panel for SSW2010: initialized on 1Jan2010 00UTC.

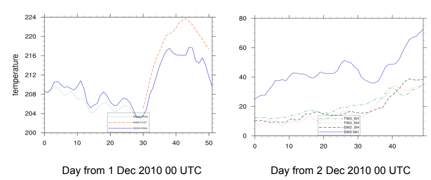

Figure 3a. Preliminary results for SSW2011: Left panel for the 60N-polarcap temperature at 10 hPa from WDAS analysis (WDAS-ANAL) and forecast (WAM-FCST) initialized on 1Jan2011 00UTC, and comparing with GDAS analysis (GDAS-ANAL; right panel for maxima of SW2 and TW3 (as in Figure 4): but showing WDAS analysis for Dec2010 and WAM forecast for Jan2011.

3. Tidal Wave Analysis

- WDAS DA and forecast experiments provide an opportunity to examine the whole atmosphere response of real SSW events in WAM.
- Space-time wave/spectral analysis are done on hourly model output, and eastward and westward wave propagations are resolved accordingly. Only analysis for zonal wind is shown.

3.a Tidal waves in WDAS analysis

- Significant changes in tidal waves are found in E-region during SSW events; and some of the changes appears to be global with changes both both northern hemisphere (NH) and southern hemisphere (SH).
- Figure 4 shows the maxima of SW2 (semidiurnal, westward propagating, zonal wave number 2) and TW3 (terdiurnal, westward propagating, zonal wave number 3) wave amplitudes:
  - SW2 attained its maxima in NH about 10 days after SSW peak, quite closely followed the stratospheric warming trend earlier, indicating strong influence from lower atmospheric planetary waves (PWs).
  - TW3 started to increase when SSW began and while SW2 was declining (see also Figure 6). It is highly possible that resonant wave-wave interactions (between SW2, DW1, and TW3) have contributed to the rapid growth of TW3 in the early stage of SSW.
  - Global responses to SSW are indicated in the changes of these waves in the SH.

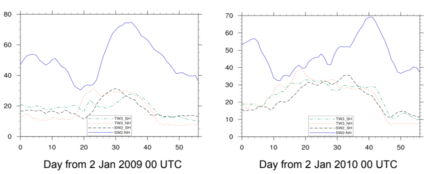

Figure 4. The maxima of SW2 and TW3 of WDAS analysis from model levels 80-130 (with maxima in the E-region, see Figure 6) for northern hemisphere (NH) and southern hemisphere (SH) separately: Left panel for SSW2009 and right panel for SSW2010.

3.b Tidal waves in WAM forecasts

- Tidal waves in WAM forecasts initialized from WDAS analysis are remarkably consistent with the WDAS analysis.
- Figure 5 shows the maxima of SW2 and TW3 waves in the extended WAM forecasts, and compares with the WDAS analysis.

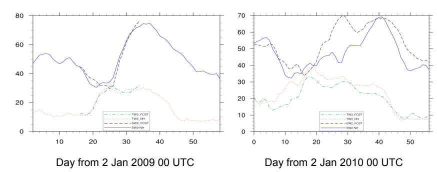

Figure 5. The maxima of SW2 and TW3: Compare forecast (FCST) with WDAS analysis. The left panel is for a 21-day forecast for SSW2009 initialized on 15Jan2009 00UTC; right panel is from a 2-month forecast during SSW2010. Only maxima in the northern hemisphere (NH) are shown.

3.c More tidal wave analysis

- Figure 6 is the latitudinal-vertical view of the SW2 and TW3 amplitudes in WDAS analysis. Model levels from 80-130 (~70-230 km) are shown in the vertical.
- Very similar results to Figure 6 for SSW2009 (not shown, but see Figure 5) are obtained from the extended (21 days) WAM forecasts, initialized from the WDAS analysis on 15Jan2009 00UTC.

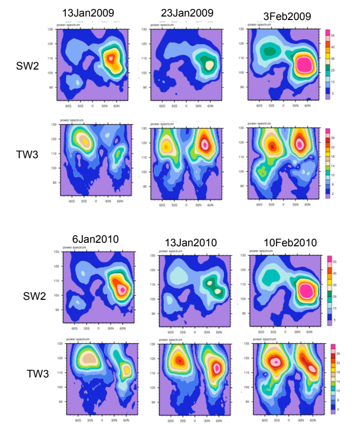

Figure 6. The vertical distribution of SW2 and TW3: showing their changes before and after SSW: Upper 6 panels for SSW2009, lower 6 panels for SSW2010.

4. Summary

- The NCEP's GSI analysis system is extended to work with the whole atmosphere model (WAM), and an incremental analysis update (IAU) scheme is implemented in the data assimilation cycle.
- The whole atmosphere data assimilation system (WDAS) thus formed is used to conduct data assimilation and forecast experiments for the 2009 and 2010 (and preliminarily 2011) sudden stratospheric warming (SSW) events.
- Good agreement is found between WDAS analysis and the NCEP's operational GDAS analysis.
- Tidal wave analysis shows significant increase in both SW2 and TW3 wave amplitudes in the E-region. These enhancements could have significant impact on the E-region dynamo, hence ionospheric electrodynamics.
- The increase of SW2 during SSW is attributed to influence of upward propagation of planetary waves from the lower atmosphere, while the rapid growth of TW3 in the early stage of SSW is attributed largely to the resonant wave-wave interactions between SW2, DW1 and TW3.
- These tidal wave responses during SSW appears to be global in scale.
- The extended forecasts show fairly consistent tidal wave response to SSW events.

5. Acknowledgements

- Ming Hu for discussions and help on using GSI with WAM; Daryl Kleist for providing us background statistics calculated from WAM 'free' runs; and Fei Wu for work on WAM.
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