Observing System Simulation Experiments for an Early-Morning-Orbit Meteorological Satellite in the Joint Center for Satellite Data Assimilation

Sean P.F. Casey[1,2,3,4], Lars Peter Riishojgaard[1,2], Michiko Masutani[2,5], Jack Woollen[2,5], Tong Zhu[2,4] and Robert Atlas[6]
[1]*Earth System Science Interdisciplinary Center (ESSIC)*
[2]*Joint Center for Satellite Data Assimilation (JCSDA)*
[3]*Cooperative Institute for Climate and Satellites (CICS)*
[4]*NOAA/NESDIS/STAR*
[5]*NOAA/NWS/NCEP/EMC*
[6]*NOAA/AOML*

Introduction

Following the reconfiguration of the nation's most important future meteorological satellite program into two separate programs, JPSS (NASA/NOAA) and DWSS (DoD), the agencies implementing these new systems are now in the process of reassessing the expected impacts of their respective systems. In the case of polar orbiters, one of the primary applications is data assimilation and numerical weather prediction (NWP), and the impact on forecast skill of numerical models is therefore one of the most important assessment metrics.

Over the last 10-15 years, Observing System Simulation Experiments (OSSEs; see e.g. Arnold and Day 1986, Atlas et al. 1985, Atlas 1997, Masutani et al.,2010a) have been conducted assessing the impact of new candidate observing systems on numerical weather prediction applications and for preparing to immediately benefit from observing systems that have already been approved for future deployment by Stoffelen et al (2006), Masutani et al. (2010b), Riishojgaard et al, (2012).

Since 2006, the Joint Center for Satellite Data Assimilation has coordinated Joint OSSE collaboration across a number of groups within NASA and NOAA. The backbone of the collaboration is the shared use of a simulated realization of a long sequence of atmospheric states—the "Nature Run" in OSSE terminology—provided by the European Centre for Medium-Range Weather Forecasts, and coordinated validation, simulation of observations and calibration of the OSSE systems (Andersson and Masutani, 2010).

The Joint Center has made this Joint OSSE capability available to the DWSS for assessment of the expected consequences of a variety of possible programmatic decisions regarding e.g. an instrument payload located in the so-called "early morning orbit" (0530 Local Equatorial Crossing Time). This orbit has traditionally been covered by the Defense Meteorological Satellite Program (DMSP), and was one of the two orbits intended to be covered by the NPOESS program.

Data/Methodology

The basic question addressed through the impact experiments described here is the following: What is the expected impact on medium-range forecast skill of the Nation's primary global operational numerical weather prediction system, namely the NCEP Global Forecast System. In order to assess this, the following five baseline experiments have been performed:

1. A control run in which all relevant observations from observing systems (conventional and space-based) other than DWSS are assimilated (cntrl)
2. Same as 1., but without any early morning orbit coverage (no NOAA-16/DMSP-F17) (nossmis)
3. Same as 2., but with JPSS (i.e. CrIS and ATMS) added in the early morning orbit (atmscris)
4. Same as 2., but with VIIRS in the early morning orbit (i.e., polar winds) (viirs)
5. Same as 2., but with VIIRS and ATMS in the early morning orbit (atmsvirs)

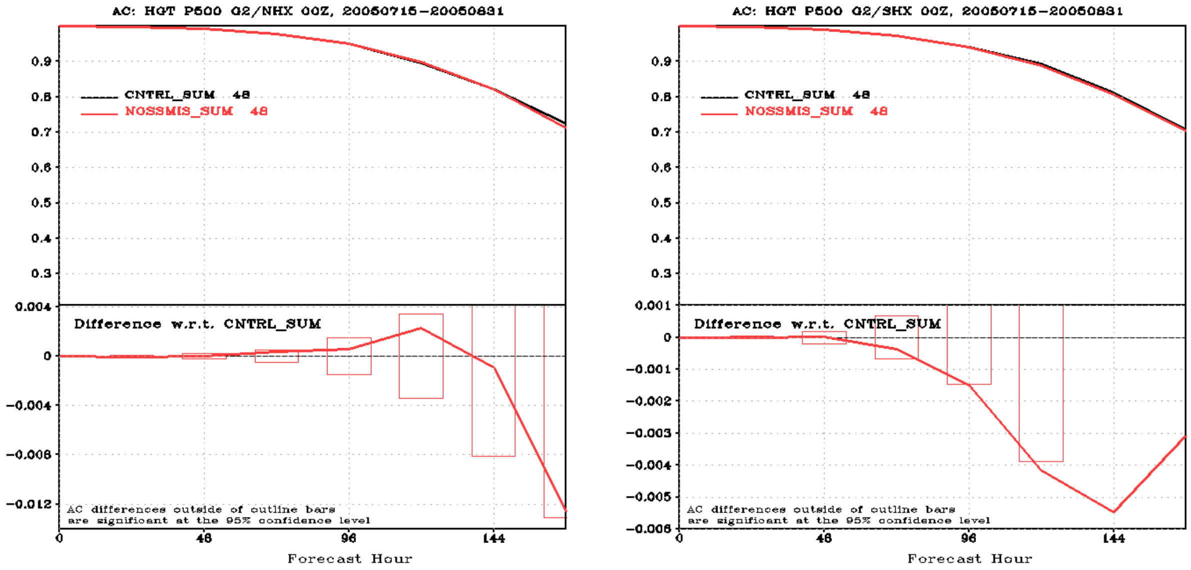

Figure 1. Experiment impacts on 500 hPa anomaly correlation. (left) Northern Hemisphere. (right) Southern Hemisphere.

Most of the instruments for which data were simulated for these experiments had real equivalents with available data in May and June 2012. Orbits & Latitude/Longitude information from these two months were used to simulate the instruments that were used for all five experiments, as well as SSMI/S-F16 for the cntrl case. Observations from ATMS & CrIS onboard Suomi/NPP were shifted 120° west in longitude to simulate these observations in the new early-morning-orbit for atmscris (and atmsvirs for ATMS). MODIS observations from Aqua were also shifted 120° west in longitude and used to simulate viirs measurements for cases viirs and atmsvirs.

Simulation of radiance was conducted using Community Radiative Transfer Model (CRTM) developed at JCSDA (Han et al, 2006, Weng et al. 2006). Some evaluations of simulated radiance for early OSSE are described in Zhu et al. (2012).

We use the NCEP GDAS system based on the May 2011 version of GFS, coupled with a May 2012 version of the GSI trunk. While GDAS is currently run operationally at a horizontal resolution of T-574 (roughly corresponding to 25 km), we use here a horizontal resolution of T-382 (or 40 km, the resolution previously used for operations), as we are limited by the T-511 resolution of the current nature run. Two experimental periods were chosen; one encompassing the months of July and August 2005 (_sum) of the nature run, and one encompassing the months of January and February 2006 (_win). Results for the Northern Hemisphere summer period (_sum) are discussed below; results for the second period will be available in the near future. For each period, the first two weeks are discarded as a spin-up period; the experiment then encompasses the remaining 45 days for forecast impact analysis.

Impact of Removing SSMI/S

The first question to answer is whether the lack of early morning sounding coverage affects medium-range weather forecast skill. To do this, we first compare experiment nossmis to the cntrl case. Figure 1 shows the impact of the test experiments on 500 hPa Anomaly Correlation (AC) for the Northern (left) and Southern (right) hemispheres. AC is correlation between forecast and the best estimate of truth and varies between 0 and 1. Therefore higher values of AC indicate better forecast. Rectangles in the lower portion of the figures denote the 95% confidence interval; curves above or

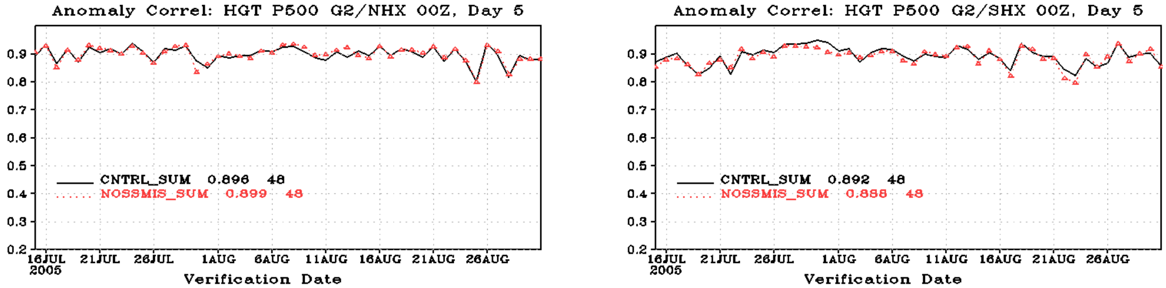

Figure 2. Time progression of day 5 (120 hour) anomaly correlation. (left) Northern Hemisphere. (right) Southern Hemisphere.

below these rectangles are said to be statistically significant, while curves within the rectangles are considered non-significant to two standard deviations. Some differences are noted in the Northern Hemisphere; however, none of these differences can be considered significant. In the Southern Hemisphere, forecasts 4 and 5 days out (96 & 120 hours, respectively) show significant negative impact following the removal of SSMI/S.

Figure 2 shows time series of day 5 (120 hour) AC. For the northern hemisphere (left), the curves remain similar, with one day (29 July) where cntrl significantly outperforms nossmis, and one period (9-13 August) where nossmis slightly outperforms cntrl. In the southern hemisphere plot (right), we see many days where cntrl outperforms nossmis, such as the period from 27-30 July, 17 August, and 22-23 August.

Figure 3 shows the impact of losing SSMI/S on tropical wind speed Root Mean Square Errors (RMSE) at 200 hPa (left) and 850 hPa (right). Since RMSE indicate the magnitude of difference between forecast and estimated truth, smaller RMSE indicate a better forecast. At 200 hPa there are significant RMSE increases at day 1 and 2. In the lower troposphere, significant increases are noted at days 2, 3, and 5.

Contrary to data assimilation and NWP using actual data, the “true” state of the atmosphere is perfectly known in the context of an OSSE (since it is given by the nature run), and we can therefore

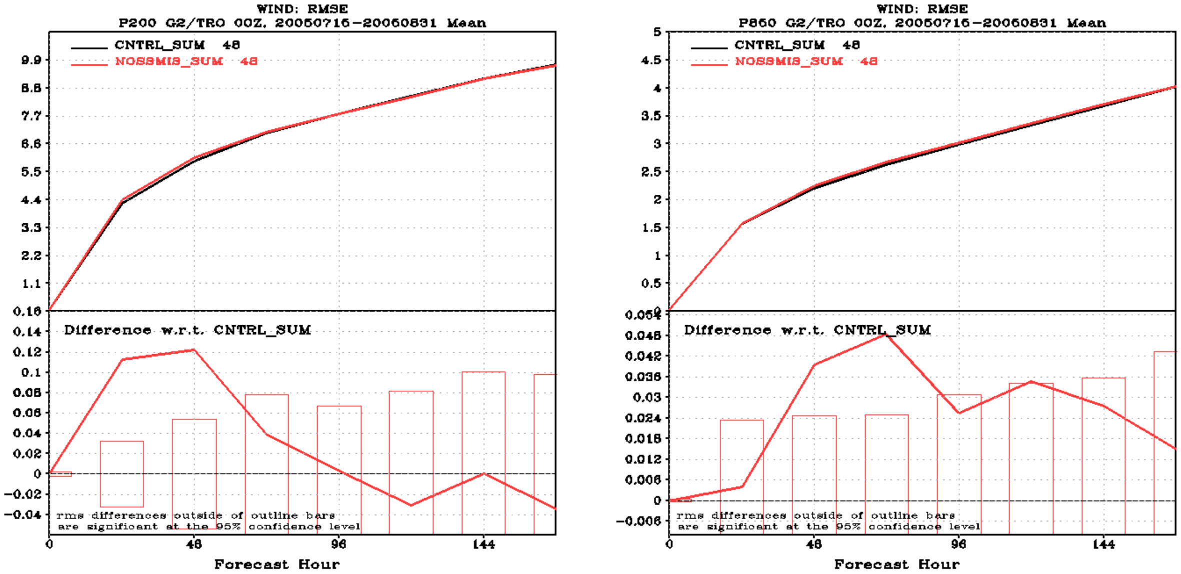

Figure 3. Impact of losing SSMI/S on wind speed RMSE. (left) 200 mb. (right) 850 mb.

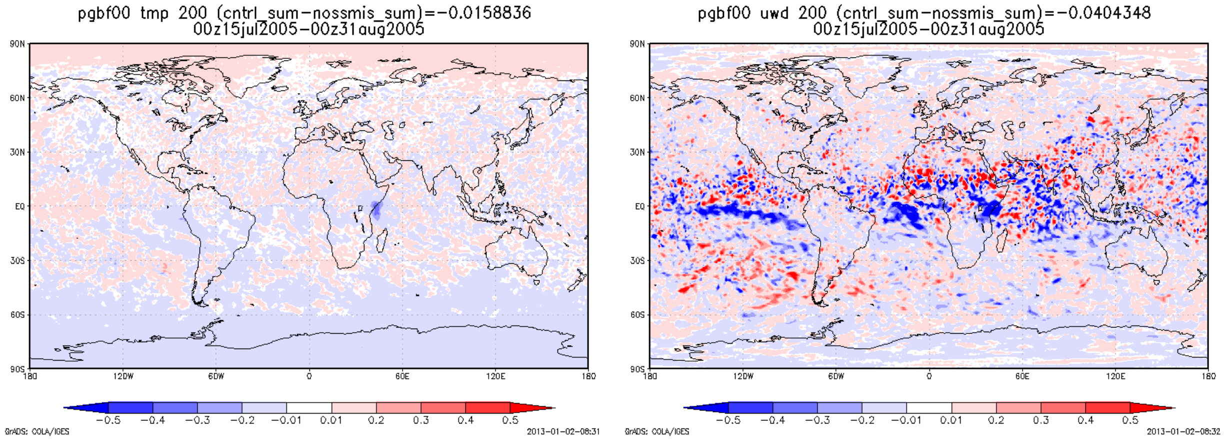

Figure 4. Difference of time mean RMSE (analysis-NR) between cntrl and nossmis. (left) 200 mb temperature. (right) 200 mb zonal wind. Blue areas indicate degraded analysis in nossmis.

compare both experiments to the nature run to see which experiment is closer to "truth" over time. In Figure 4, pink/red colors on right indicate areas where nossmis is closer to the nature run; blue is where cntrl is closer to nature run. It is clear that removing the SSMI/S data causes significant analysis biases in 200 hPa temperature (left) and zonal wind (right). Temperature effects are most pronounced in Southern Hemisphere, while wind effects are most pronounced in tropics.

Comparison of Different Early-Morning-Orbit Alternatives

After seeing the effects of losing SSMI/S, we now want to see which of the three suggested payload configurations for the early morning orbit would have the greatest forecast impact. We now use case nossmis as the base case, and compare the remaining four experiments (cntrl, atmscris, viirs, atmsvirs) to nossmis. Figure 5 shows the 500 hPa AC for the Northern (left) and Southern (right) hemispheres. In the Northern Hemisphere, only atmsvirs has a significant positive impact on the forecast, here for days 6 and 7. All other experiments/forecast times show a non-significant impact. For

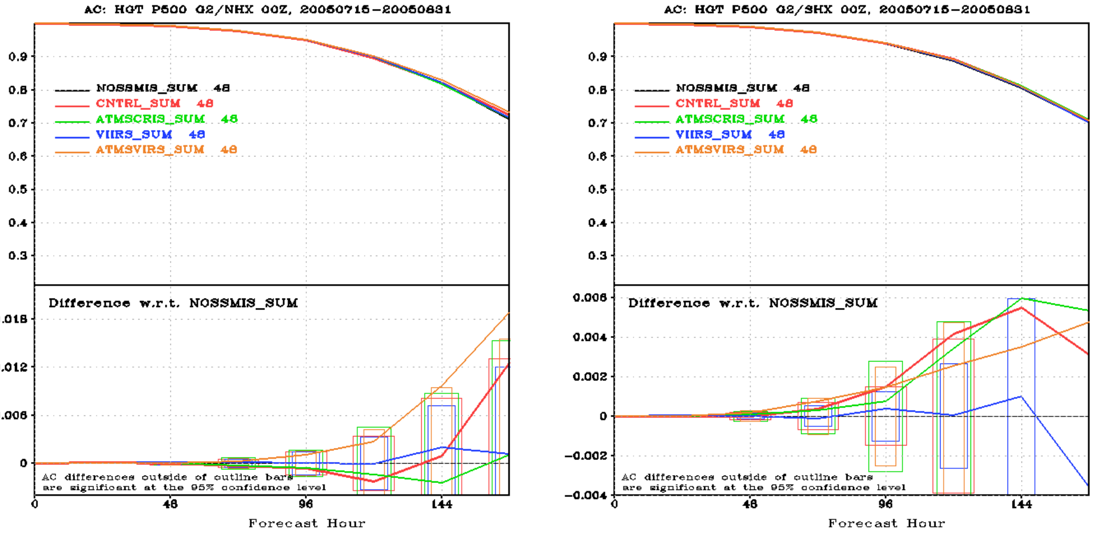

Figure 5. Experiment impacts on 500 hPa anomaly correlation. (left) Northern Hemisphere. (right) Southern Hemisphere.

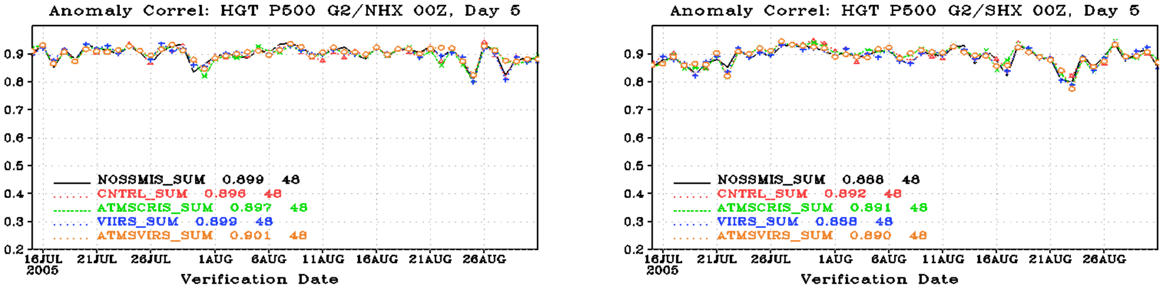

Figure 6. Experiment impacts on 500 hPa anomaly correlation. (left) Northern Hemisphere. (right) Southern Hemisphere.

the Southern Hemisphere, the cntrl case shows a significant impact at days 4 and 5, while no other cases/forecast times show a statistically significant impact.

Figure 6 shows time series of day 5 (120 hour) AC. As before, little daily variation is noted among the different experiments. However, the mean AC scores suggest that atmsvirs performs slightly better than the other experiments in the northern hemisphere (left), while atmscris and the cntrl case perform slightly better than the other experiments in the southern hemisphere. Also note that adding polar winds from VIIRS alone appears to have no impact at all compared to the nossmis case.

Figure 7 shows the impact of the test experiments on the tropical wind speed RMSE at 200 hPa (left) and 850 hPa (right). At 200 hPa, cases cntrl and atmscris show significantly lower RMSE at 24 and 48 hours. The atmsvirs case is also significantly lower at 24 hours, although the magnitude is less than that of cases cntrl and atmscris. The contribution of viirs is non-significant throughout, both at 200 and 850 hPa (right). Case atmsvirs is the most significant at this level, showing large reductions in RMSE for forecast days 2-6. The cntrl case is significant at days 2 & 3, where case atmscris is significant at days 5 & 6.

We derive a comparative metric (TD_{tot}) reflecting cumulative distance from nature run truth between two OSSE experiments, by computing RMSE(nossmis-NR)-RMSE(exp2-NR) formed at each level and gridpoint sampled over some period of time, then horizontally and vertically averaging the gridpoint differences to produce a single composite value:

$$TD_{tot} = \sum_{i=1}^{n} (p_i - p_{i-1}) \frac{[A(p_{i-1}) + A(p_i)]}{2}$$

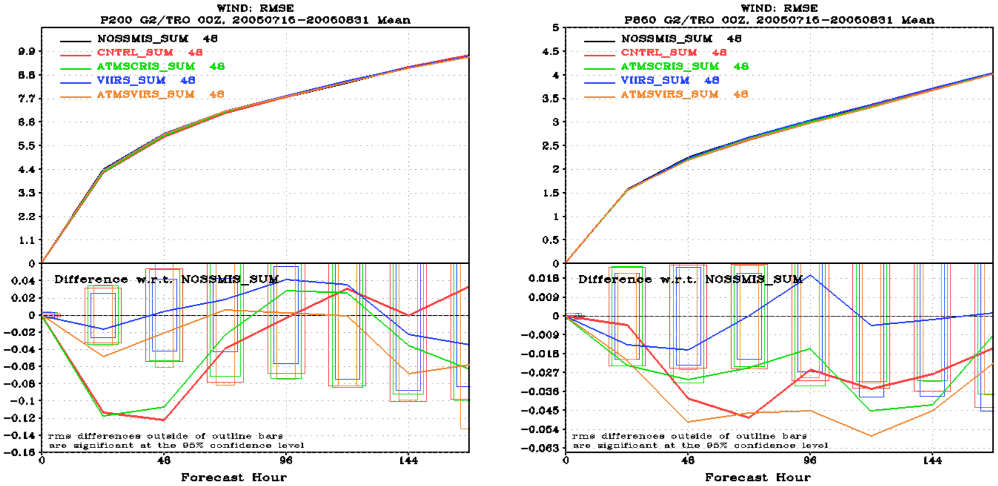

Figure 7. Experiment impacts on wind speed RMSE. (left) 200 mb. (right) 850 mb.

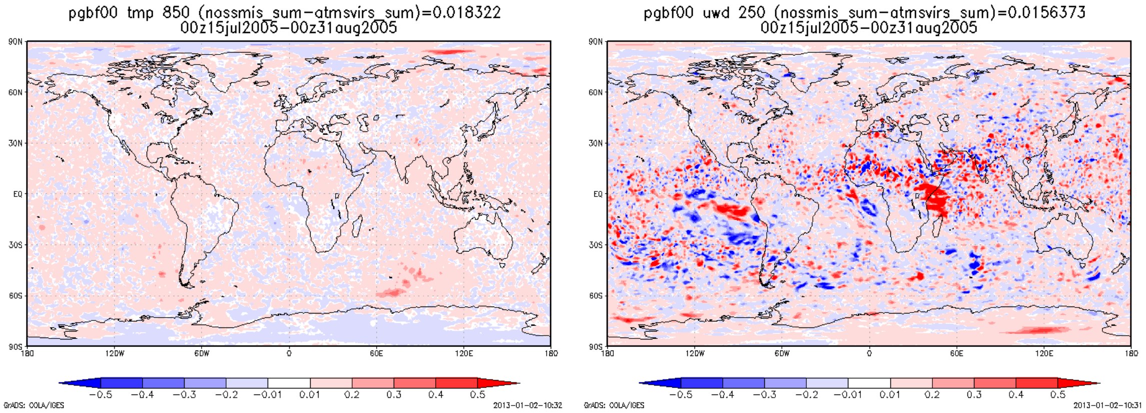

Figure 8. Difference of time mean RMSE (analysis-NR) between nossmis and atmsvirs. (left) 850 mb temperature. (right) 250 mb zonal wind. Red areas indicate improved analysis in atmsvirs.

Here A_i is the global area average of (RMSE(nossmis, level i)-RMSE(experiment, level i)) and p_i is the pressure at level i. We then find the following TD_{tot} values for temperature for all analyses:

- TD_{tot}(atmsvirs)=4.81 K
- TD_{tot}(atmscris)=4.54 K
- TD_{tot}(cntrl)=3.13 K
- TD_{tot}(viirs)=0.4 K

The greatest temperature improvement due to atmsvirs in the lower troposphere (850 hPa, Figure 8, left). The greatest zonal wind improvement, on the other hand, is in the upper troposphere (250 hPa, Figure 8, right). Note the large lat/lon variations present in the 250 hPa zonal wind chart compared to the 850 hPa temperature chart. The atmscris experiment does slightly better than atmsvirs in mid-troposphere (600 hPa, not shown); atmscris and atmsvirs yield similar results on model forecast.

We can also compute TD_{tot} for different analysis times, to see how the different data sources affect the analysis. For example, we can calculate TD_{tot} values for temperature forecasts 96 hours from forecast run time (Day 4):

- TD_{tot}(atmscris)=5.17 K
- TD_{tot}(atmsvirs)=3.01 K
- TD_{tot}(cntrl)=3.13 K
- TD_{tot}(viirs)=0.4 K

The greatest temperature improvement with atmscris is in upper troposphere (300 hPa, Figure 9, left). The greatest zonal wind improvement is also in upper troposphere (250 hPa, Figure 9, right), though large variations are clearly visible. Note that atmscris performs better than atmsvirs in forecasts when both were similar in analyses.

Preliminary Conclusions/Future Work

The initial results of the early-morning-orbit OSSE demonstrate the importance of a meteorological satellite in this orbit. Losing SSMI/S leads to decreases in model analysis and forecast

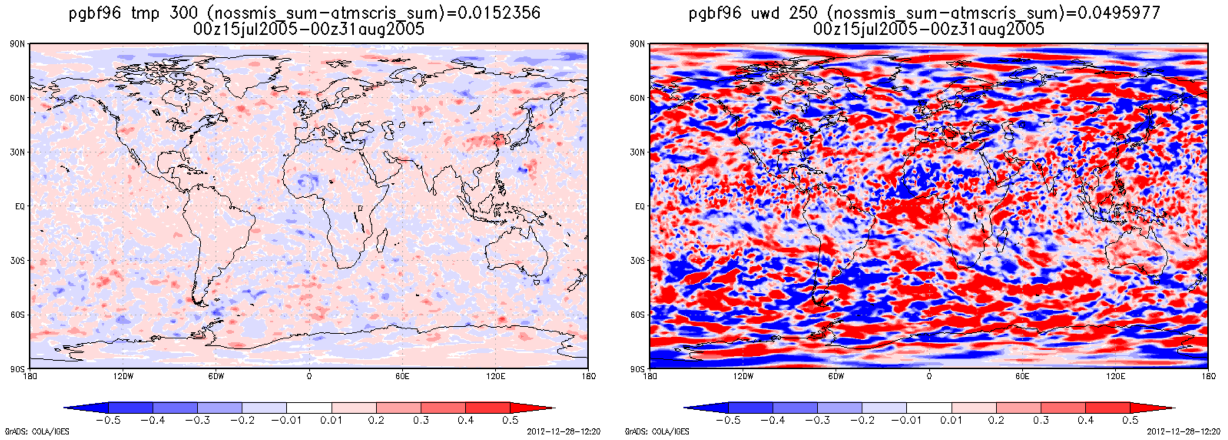

Figure 9. 96-hour forecast RMSE comparisons, as in Fig.8, between nossmis and atmscris. (left) 300 mb temperature. (right) 250 mb zonal wind.

skill, especially in the Southern Hemisphere and tropical wind fields. A positive impact is noted for a combination of ATMS/CrIS or a combination of ATMS/VIIRS; VIIRS alone causes little improvement.

It should be noted that so far only planetary-scale diagnostics have been performed for the experiments run. Tropical cyclone diagnostics as well as other regional measures are likely to shed additional light on the impact of data from an early morning orbit satellite mission and will be presented in the Final Report from this study. Additional diagnostics will include near-surface and flight level wind fields.

A further caveat is that only a single forecast cycle (00Z) per day was run. One of the advantages of a full complement of satellite sounders is that developing atmospheric waves are less likely to escape early detection. This can affect forecast skill dramatically at regional and local scales but it less likely to have an impact on the large-scale diagnostics shown here. A limited run of four forecast cycles per day is planned in order to shed additional light on this issue.

Future work will include continuing experiment for Jan/Feb, to compare hemispheric seasonal effects. Summer experiments will be rerun to include simulated GPS data, forecast runs at 00, 06, 12, and 18Z, and updated ATMS stratospheric channel weights.

References

Andersson, E. and M. Masutani, 2010: Collaboration on Observing System Simulation Experiments (Joint OSSE). ECMWF News Letter No. 123, Spring 2010, 14-16.

Arnold, C.P., Jr. and C.H. Dey, 1986: Observing-systems simulation experiments: Past, present, and future. Bull. Amer. Meteorol. Soc., 67, 687-695.

Atlas, R., et al., 1985: Simulation studies of the impact of future observing systems on weather prediction. Proc. Seventh Conf. on NWP, 145-151.

Atlas, R. 1997: Atmospheric observations and experiments to assess their usefulness in data assimilation. J. Meteor. Soc. Japan, 75, No. 1B, 111-130.

Han, Y., et al., 2006: JCSDA Community Radiative Transfer Model (CRTM) - Version 1. *NOAA Tech Report 122*.

Masutani, M., et al., 2010a: Observing System Simulation Experiments. In Data Assimilation: Making sense of observations, Eds. W.A. Lahoz, B. Khattatov and R. Ménard, Springer, 647-679.

Masutani, M., et al., 2010b: Observing System Simulation Experiments at the National Centers for Environmental Prediction. J. Geophys. Res., 114, doi: 10.1029/2009JD012528.

Riishøjgaard, L.P., et al., 2012: Observation System Simulation Experiments for a Global Wind Observing Sounder. Geophys. Res. Lett., 39, L17805, doi: 10.1029/2012GL051814.

Stoffelen, A., et al., 2006: ADM-Aeolus Doppler wind lidar Observing System Simulation Experiment. Q. J. R. Meteorol. Soc., 132, 1927-1948.

Weng, F., 2007: Advances in radiative transfer modelling in support of satellite data assimilation. J. Atmos. Sci., 64, 3803-3811.

Zhu, T., et al., 2012: Synthetic radiance simulation and evaluation for a Joint Observing System Simulation Experiment. J. Geophys. Res., 117, D23111, doi: 10.1029/2012JD017697.