Pre-Operational Assimilation Testing of the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager/Sounder (SSMI/S)

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Introduction

On October 18th, 2003, the Defense Meteorological Satellite Program (DMSP) successfully launched DMSP F16 satellite with the first Special Sensor Microwave Imager Sounder (SSMI/S) instrument aboard. The SSMI/S is a conically-scanning passive microwave radiometer that includes seven temperature-sounding channels peaking below 30 km (channels 1-7), and six peaking between 30 km and 80 km (channels 19-24) (Fig. 1).

Fig. 1: SSMI/S weighting functions for the U.S. Standard Atmosphere

The channels that peak at 40 km or below are similar to channels 3-14 of the cross-track-scanning Advanced Microwave Sounding Unit A (AMSU-A) instrument aboard the NOAA series satellites. One of the questions that we hope to answer is whether radiance data from
a conically-scanning instrument can be successfully assimilated into an operational numerical weather prediction (NWP) model, given that an uncertainty of less than 0.4K in the temperature sounding channels must be achieved to improve forecast skill.

Two calibration anomalies were discovered, and must be corrected before the radiance data can meet the stringent requirements of NWP data assimilation systems. The first anomaly was due to nonzero reflector emission contaminating the scene temperatures. At both the Met Office and the Naval Research Laboratory (NRL), a reflector emissivity correction is performed in a similar fashion. The second anomaly was due to a solar intrusion onto the warm load calibration target. At Fleet Numerical Meteorology and Oceanography Center, the Northrop-Grumman algorithm (Fourier filtering) is used to correct the gain, which is used by NRL; at the Met Office, the contaminated data is flagged and not used. The details of the calibration anomaly detection and mitigation are discussed in Swadley et al. (2006) and Bell et al. (2006). Note that these anomalies came to light using data assimilation and NWP models, which offer global spatial and temporal coverage. The coverage of global models, and the high accuracy of NWP temperature fields (yielding high accuracy in forward modeled brightness temperatures), provide a validation tool that complements existing ground based and aircraft based approaches to Cal/Val, which by their very nature have limited spatial and temporal coverage. For the SSMI/S instrument, data assimilation tests were necessary to detect the calibration anomalies that depended on orbital position, time of day, time of year, and instrument inclination relative to the Sun.

**Met Office Assimilation Tests**

The control run for one month from December 12th, 2005 through January 11th, 2006 used the Met Office unified model at N216 horizontal resolution and 50 vertical levels to 0.1 hPa. The data assimilation system was 3DVar, and included the three AMSU instruments aboard NOAA-15, 16, and 18, plus the Atmospheric Infrared Sounder (AIRS), Special Sensor Microwave Imager (SSM/I) wind speeds, feature-track winds, and scatterometer winds (QuikSCAT and ERS-2). Channels 2-7 and 23, all of which are temperature sounding channels peaking below 40 km, were assimilated after being thinned to approximately 4000 obs/channel/6-hour window. Observation errors were set to 0.5K in channels 2-4 and 1.0K in channels 5-7, approximately twice that of their AMSU-A analogs. The radiative transfer model used was RTTOV-7 with 43 levels to 0.1 hPa. The airmass bias correction scheme for the AMSU and AIRS instruments was a two-predictor Harris & Kelly scheme (Harris and Kelly, 2001), using 850-300 hPa thickness and 200-50 hPa thickness, along with a simple global scan bias correction.

The first test run added the DMSP F16 SSMI/S instrument to the full operational system. The results showed small but significant positive impact (Fig. 2). Southern Hemisphere (SH) mean sea-level pressure (PMSL) forecasts improved by 1-3% at days 1-4 and 500 hPa height anomaly correlations (AC) improved by 1-2% at days 2 and 3. The root-mean-squared error (RMSE) of the Tropical 850 hPa winds at day 3 and 250 hPa winds at
day 1 improved by ~1%. Northern Hemisphere (NH) results were neutral, except for a 2% PMSL forecast degradation at 5 days.

![Verification vs observations](image)

**Fig. 2**: RMSE change for Met Office experiment 1 (negative indicates improvement)

The control run for the second test denied data from the NOAA-15 AMSU instruments (A and B), and the second test run added SSMIS data. The purpose of the second test was to evaluate the performance of SSMI/S as a risk reduction sensor, in case of failure of one or more NOAA satellites before the launch of National Polar-orbiting Operational Environmental Satellite System (NPOESS) and NPOESS Preparatory Project (NPP) satellites. NOAA-15 is the oldest satellite with AMSU-A, and is in a similar orbit to DMSP F16. There is a real danger that one or more NOAA satellites will fail well before the earliest NPP launch, and only the DMSP satellites can possibly replace them. The results of the second test are similar to the first test. SH PMSL forecasts improved by 1-3% at days 1-4, and 500hPa AC improved by 1-2% at days 2-3. Neutral impact in the Tropics and the NH (Fig. 3). Along with some further testing not reported here, the results of the Met Office SSMI/S assimilation tests were sufficiently positive for operational implementation; SSMI/S transitioned to operations in late September, 2006.
Fig. 3: RMSE change for Met Office experiment 2 (negative indicates improvement)

NRL Assimilation Tests

The control run for forty days from November 11th, 2005 through December 21st, 2005 used the Navy Operational Global Atmospheric Prediction System (NOGAPS) at T239 horizontal resolution and 30 vertical levels to 4.0 hPa. The data assimilation system was 3DVar (the NRL Atmospheric Variational Data Assimilation System, NAVDAS), and included the three AMSU-A instruments aboard NOAA-15, 16, and 18 plus SSMI wind speeds and total precipitable water (TPW), feature-track winds, and scatterometer winds (QuikSCAT and ERS-2). No AIRS or AMSU-B data were included. Channels 2-7, temperature sounding channels peaking below 30km, were assimilated after being thinned to approximately 8000 obs/channel/6-hour assimilation window. Observation errors were set to 0.5K in channels 2-4 and 1.0K in channels 5-7. The radiative transfer model used was the Community Radiative Transfer Model (CRTM) with 30 layers to 4.0 hPa. The airmass bias correction scheme for the AMSU-A instrument was a two-predictor Harris & Kelly scheme (Harris and Kelly, 2001), using 850-300 hPa thickness and 200-50 hPa thickness, along with a simple global scan bias correction.
Initial tests at NRL showed a striking pattern in the SSMI/S innovations in all channels at all taus (0, 6, 12, and 18Z). The descending node looked “normal”, while the ascending node had a pronounced NH/SH pattern that was clearly not meteorological in nature (Fig. 4). We decided to do our tests with data from the descending node only, thinned to approximately 4000 obs/channel/6-hour assimilation window.

The first test run added the DMSP F16 SSMI/S instrument to the full operational system. The results were mixed. In the SH, the 500 hPa height AC showed improvement at days 4-5, and the 1000 hPa height AC showed improvement at days 3-5 (Fig. 5). In the NH, however, the 500 hPa height AC was degraded at day 5, and the 1000 hPa height AC was degraded at days 4-5 (Fig. 6). The Tropics were neutral, so the results are not shown here.

The control run for the second test denied data from the NOAA15 AMSU-A instrument, and the second test run added SSMI/S data (descending only). The results of the second test were completely neutral, showing that for our current configuration, the DMSP F16 SSMI/S cannot replace the NOAA 15 AMSU-A. Further tests are ongoing at NRL.
The second in the series of SSMI/S instruments, onboard DMSP F17, was successfully launched at 5:53 a.m. PST on November 4th, 2006. The SSMI/S instrument began operation and data transmission in early-orbit modes on November 9, 2006. F17 SSMI/S hardware modifications include a small fence mounted to the top of the canister, to prevent direct warm-load solar intrusions. The rim-mounted thermistor has been moved to the center on the back of the mirror, in order to provide a more accurate measure of the reflector temperature, yielding a better emissivity correction (should it be needed).
addition, the satellite has been placed in a terminator orbit, so that the spacecraft will always be in the sun, although the SSMI/S will be shaded by the solar panels for a large portion of the orbit. These changes, plus the prior experience of the Cal/Val team with DMSP F16, should lead to a better-characterized and more useful instrument than the first SSMIS.

**Summary and Conclusions**

Assimilation testing of the DMSP F16 SSMI/S instrument shows a neutral to slightly positive impact on top of current sensors in Met Office tests. In addition, the SSMI/S can partially compensate for a failed AMSU instrument. These results led the Met Office to transition SSMI/S to operations in late September, 2006. Despite the significant calibration problems of the instrument, these assimilation results warrant cautious optimism about the use of conically-scanning temperature sounders in NWP.

At NRL, assimilation testing showed mixed results (improved SH, degraded NH); however, we are encouraged by the Met Office results, and our assimilation testing is ongoing.

Future SSMI/S instruments will correct design flaws and calibration problems, and the performance of both existing and future SSMI/S instruments will improve as calibration anomaly mitigation strategies mature. We also hope to use the upper air sounding channels when NWP models extend through the mesosphere and into the thermosphere, and when fast radiative transfer models can effectively incorporate the Zeeman splitting of the atmospheric oxygen lines.

Finally, data assimilation experiments have shown their worth as part of the Cal/Val process. Aircraft underflights and cross-calibration with other satellites offer only limited spatial and temporal coverage, and would not have sufficed to pinpoint the calibration anomalies and suggest their physical origin.

**References**


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