Assimilation of AIRS Data at NRL

Benjamin Ruston, Clay Blankenship, William Campbell, Rolf Langland, and Nancy Baker

Naval Research Laboratory, Monterey, CA, USA

Abstract

The Navy Operational Global Atmospheric Prediction System (NOGAPS) is the U.S. Department of Defense's high-resolution global weather prediction system, and is used for operational medium-range weather prediction, forcing for operational mesoscale and oceanographic models, and numerical weather prediction (NWP) research. The analysis for NOGAPS is produced by the NRL Atmospheric Variational Data Assimilation System (NAVDAS). The topic of this research is the direct assimilation of AIRS radiances using NAVDAS, and the resulting forecast impacts realized by NOGAPS. As of Oct. 2006, AIRS assimilation at NRL is in pre-operational testing with daily monitoring and case-studies used to adjust the channel selection and quality control. The state of AIRS assimilation made a significant from before ITSC-15, Oct 4-10 of 2006, and after. Before the conference AIRS assimilation compared to a control run produced neutral to slightly negative anomaly correlations in both the Northern and Southern hemisphere. While the individual channel sensitivities to the reduction or increase in 24-hour global forecast error showed a mixture of beneficial and non-beneficial impacts. Exploiting the collaborative discussions and suggestions from ITSC-15 attendees along with the guidance from the adjoint analysis the quality control and channel selection were revised. This new AIRS assimilation run compared to control now produces slightly positive Southern hemisphere anomaly correlation. Refinement of the observation errors and examination of an adjoint analysis from the new assimilation run continue to make subtle refinements to the system. However, the experiences at the TOVS study conference have proven that a rapid positive contribution to the assimilation system can be realized by active collaboration between NWP centers.

Introduction

The NAVDAS assimilation system used at NRL is the tool available for direct radiance assimilation to the U.S. Navy model NOGAPS. The NASA-AQUA satellite is flying both the Atmospheric Infrared Sounder (AIRS) and an Advanced Microwave Sounding Unit (AMSU) sensor; both are undergoing assimilation testing within NAVDAS. NAVDAS assimilation of AMSU/A radiances from NOAA15, 16, 17, and 18 have all shown positive impacts in anomaly correlation, tropical cyclone track errors, and fewer forecast "busts." The AIRS sensor is a high spectral resolution spectrometer with 2378 bands in the thermal infrared (3.7 - 15.4 µm) and 4 bands in the visible (0.4 - 1.0 µm). The assimilation strategy at this time is focused solely on the thermal infrared bands. Successful assimilation of AIRS data has shown positive impacts on NWP forecasts for the National Center for Environmental Prediction (NCEP), the Meteorological Service of Canada (MSC), the UK Met Office, and the European Center for Medium-range Weather Forecasting (ECMWF). NRL plans to leverage their research and provide parallel radiance monitoring and additional analysis techniques to the global community.

The AIRS radiances are assimilated by NAVDAS, using the Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM). The CRTM produces both the simulated brightness temperature and the Jacobians of the individual sensor channels with respect to the model input fields. The forecast model NOGAPS is used to test forecast sensitivity to the radiances. The adjoints of NAVDAS and NOGAPS are used to analyze the individual channel impacts on the reduction or increase in a moist total error norm, and can be used to determine beneficial or non-beneficial impacts on the system. The following sections discuss the implementation methodology, report on some results from the various systems, summarize the outcomes, and discuss the future plans for assimilating AIRS and other hyperspectral instruments.

Methodology

The AIRS data provided to NRL by NCEP is a 324-channel subset also containing collocated AMSU footprints. There are two alternating "golf-balls" which at this time only the first is being used. The data is roughly at 50km resolution, but is further thinned to approximately 300km to better handle the volume of data as well as reduce any horizontal observation error correlations (which are assumed to be zero). The 324-channel subset was further reduced by examining the temperature Jacobians using ECMWF model input up to 0.1 hPa. Those channels with sensitivity at and above the NOGAPS model top, currently at 4 hPa, were removed. When the temperature Jacobians, scaled by the natural log of the layer thickness (in hPa), exceeded 0.1 the channel was rejected. Similarly, the scaled ozone Jacobians was examined for any layer where a threshold of 0.1 was exceeded. This produced a 108 channel group to be used in assimilation. Because of questions in the surface emissivity and Bi-direction Reflectance Distribution Function (BRDF) the longwave window channels in the 12 – 10.4 µm range, and the shortwave window channels from 4.0 – 3.7 µm were monitored but not assimilated. The downwelling solar term is not provided for the radiative transfer calculation; as a result, the channels with wavelengths shorter than 4.6 µm were only assimilated at night.

The quality control performed on the data consisted of an overall data integrity check, cold cloud detection, and lastly a screen employing thresholds determined from observation minus background statistics. The initial quality control on the data is an integrity check which examines the data for unphysical brightness temperature or scanning geometry. The following two checks both required simulated brightness temperature generated by the CRTM. First a check for cold cloud is performed using a two window channel at 10.662 and 3.775 µm, and two water vapor channels at 7.240 and 7.158 µm. The simulated brightness temperatures assume a clear sky profile, and the check looks for observations much colder than those simulated. The final quality control check had thresholds for each channel determined from histograms of the difference between non-bias corrected observed and simulated brightness temperature. The thresholds were chosen at $1/(2 \cdot e)$ on the negative and positive tails of the histogram leaving ~63% of the points passing the quality control. The addition of a more physically based quality-control such as the McNally and Watts (2003) method was implementation into the system following ITSC-15.

The bias correction of the data used a scan correction followed by a two-predictor airmass correction. The scan bias at this time is a global scan bias correction for each channel. The airmass correction uses layer thicknesses of 850-200 hPa and 200-50 hPa. The bias-correction will be updated using a dynamic 2-week sliding bin, but for these experiments the bias coefficients are generated manually as the system continues to be tuned.

Results

In addition to daily radiance monitoring, a case study period from July 25 – September 02, 2006 was chosen for closer examination. For this time period, we have performed radiance assimilation cycles, forecasts out to 5 days, and observations sensitivities via the adjoints of NAVDAS and NOGAPS. The challenges posed by assimilating over 100 channels of information were great. The observation count assimilated by the system including conventional observations, satellite winds, and AMSU satellite radiances is approximately 300,000 observations. The additional of the AIRS and collocated AMSU doubled this observation count. Much work was devoted to making necessary changes to the system to accommodate this larger observations count. Examination of the results from the AIRS assimilation run done prior to attending the ITSC-15 found a slight degradation in the self-analysis of the 500 hPa height anomaly correlation in both Northern and Southern hemispheres. A new channel subset and quality control procedure has shown an improvement in these anomaly correlation results. The improvement came after implementing changes which incorporated the suggestions and improvements discussed with fellow researchers at ITSC-15. In this section we will first discuss some insights from the first assimilation run (that preceding ITSC-15), and then show some comparison results between the control run, the initial AIRS assimilation run, and the latest assimilation run.

In the initial AIRS assimilation run, the bias correction values were updated multiple times: Aug 04, Aug 10, Aug 14, Aug 19, and Aug 25. These were performed after changes to the quality control, and additional screening was implemented. The bias correction did reveal issues of cloud contamination which were seen in histograms of the difference between observation and simulated observation. The histograms that were cloud contaminated displayed non-gaussian shapes and often negative tails. The bias correction also identified two troublesome channels. The first was a noisy channel (ch2357 at 3.785 μm), which has been identified as a “popping” channel, which was erroneously included in the channel subset. Lastly, channel 2112 at 4.182 μm, is sensitive to layers not in local thermodynamic equilibrium and consequently is not modeled properly.

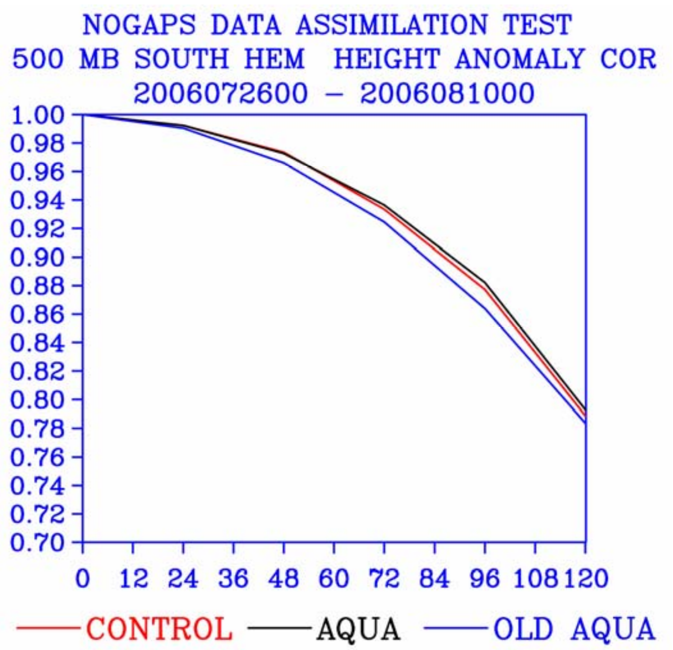

Fig. 1: The self-analysis of 500 hPa height anomaly correlation from Jul. 26 – Aug. 10, 2006. The figures shows a control run versus the latest AIRS + AMSU (AQUA) run and the previous run (OLD AQUA).

The results from the initial run of AIRS assimilation suffered from issues of quality control and channel selection. Utilizing support and suggestions from the ITSC-15 changes were made to both following the conference. Channel selection was revised using guidance from both the Meteorological Service of Canada (MSC) and the ECMWF, in addition to the results from the adjoints of NAVDAS and NOGAPS. This resulted in about a 20 channel increase in the number of infrared channels in the 13 – 15 μm range, and a subsequent removal of about 20 channels from the water vapor region. The new channel list consists of 115 AIRS channels (17 of which are monitored and not assimilated), this new channel list is shown in Table 1. The quality control was improved by adding the methodology of McNally and Watts (2003), to help screen cloud affected pixels, while retaining information above cloud top. Additional tuning of this quality control procedure will be required to optimize it for the NAVDAS system. However, these two changes alone have shown a significant improvement in the anomaly correlations for the Southern hemisphere. Figure 1 shows a control run versus the latest AIRS + AMSU run (called AQUA) and the previous run (called

OLD_AQUA). Though a dramatic improvement in the anomaly correlations over control has not been realized a significant improvement over the initial AIRS assimilation run is shown, with the new assimilation run producing slightly positive impacts for a two-week period. These results continue to be very encouraging.

The adjoints of NAVAS and NOGAPS are used to assess the observation impact on an energy-weighted forecast error norm from August 17 – September 02 for the latest assimilation run. Details of this analysis method can be found in an article by Langland and Baker (2004). Figure 2 shows the results of this analysis for the AMSU and AIRS instruments aboard the NASA-AQUA satellite. The most beneficial impact from AMSU came from channels 5, 6, and 9 while NOGAPS model top of 4 mb is believed to be impacting channel 10, and a bias correction problem seems to be persisting for channel 08. The AIRS longwave channels in the 15-13 µm range showed strong beneficial impact by reducing the forecast error. The low model top is believed also to impact AIRS channels 169, 175, and 198. The water vapor channels 1301 – 1852, and the shortwave channels 1865 – 1901 showed mixed impacts, with the outliers being nice beneficial impacts from channels 1923 and 2113. The results of this analysis will be used to aid in any modifications of the AIRS channel subset, and is an excellent tool to help make quantitative decisions on channel selection, and additional care to be taken in assimilating some of the higher peaking channels.

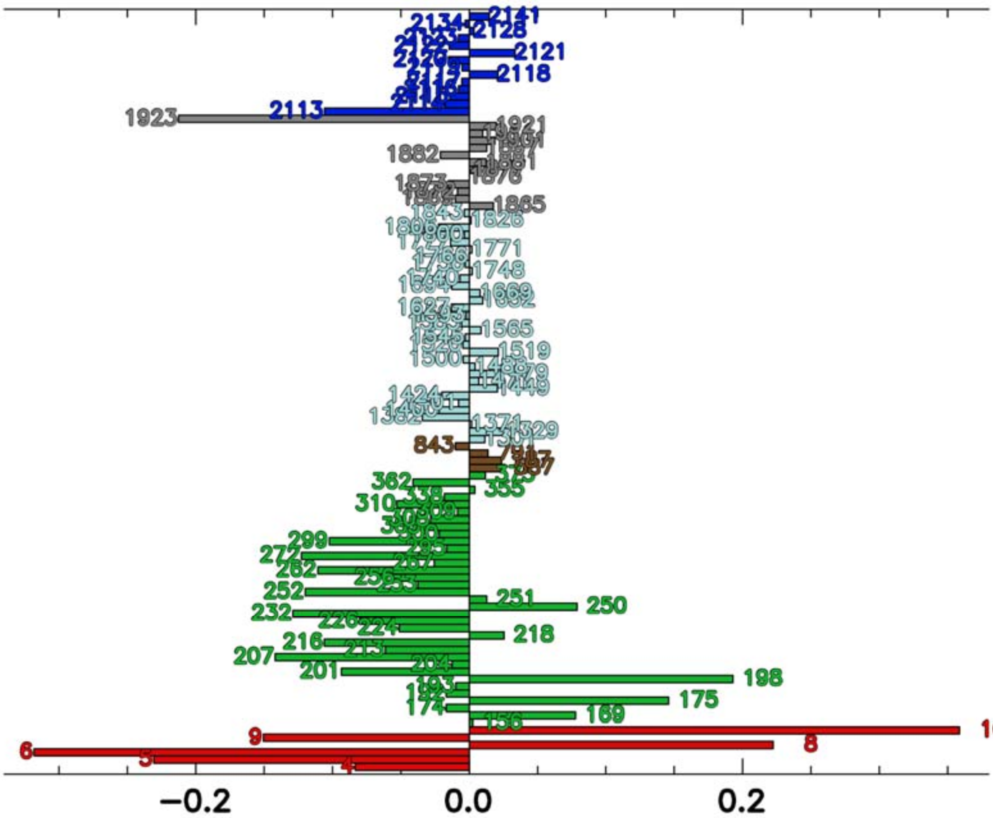

Fig. 2: The energy-weighted total error norm in J ·kg^{-1} for Aug. 17- Sep. 02, 2006. Values less than zero indicate a reduction in 24-hr global forecast error, while positive values an increase. AMSU channels are in red at the bottom of the plot, and AIRS channel number is listed along its corresponding error bar.

Summary and Future Work

The work to this point has shown AIRS data can be assimilated by the NAVDAS system without any systematic errors. Further adjustment of the channel selection and quality control is needed to realize greater impacts of the observations in the forecasting system. The adjoints of NOGAPS and NAVDAS are a powerful tool for assessing the individual channel influence on the total model error. These adjoint analyses will be very valuable in the future for both channel selection and to identify sensor degradation. The final operational system may have to use a smaller number of channels to meet the operation run-time limitation. The results of the adjoint analysis will help lead channel selection. The greatest impacts are being realized by AMSU and AIRS in the longwave region from 13 – 15 μm. Inclusion of just these channels would reduce the observation count by a factor of about 3, and may help NAVDAS meet the runtime criterion imposed by the center. Benefits from the shortwave channels around 4.5 and 4.1 μm also give beneficial impact, and inclusion of channels 1923 and 2113 in particular is being considered for a truncated channel subset. Of course if additional computing resources become available, a larger channel subset can be used to more fully exploit the information provided by hyperspectral sounding.

The immediate plans for improvement in the system include updating the quality control, and screening of higher peaking channels. Examination of the Jacobians of the higher peaking channels is being performed. A threshold will be developed for the different channels bands which will be used to screen channels with appreciable sensitivity at the model top. Additional quality control procedures include tuning of the ECMWF (McNally and Watts, 2003) cloud detection method for the NAVDAS system, and implementing some quality control used for AIRS emissivity regression techniques (Goldberg et al., 2003). In the next run we plan to exclude the water vapor channels, but will retrain those previously selected in the shortwave though further reduction is likely in the initial version transferred to the US Navy operational center.

References

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Table 1: The new AIRS channel list taken from the 324-channel subset. Channels listed in red are monitored, but not assimilated.

324-subset	Channel	wavenumber (cm^{-1})	wavelength (μm)
67	156	694.40	14.401
73	169	697.99	14.327
77	174	699.38	14.298
78	175	699.66	14.293
85	190	703.87	14.207
86	192	704.44	14.196
87	193	704.72	14.190
88	198	706.14	14.162
89	201	706.99	14.144
90	204	707.85	14.127
91	207	708.71	14.110
93	213	710.43	14.076
95	216	711.29	14.059
96	218	711.87	14.047
98	224	713.61	14.013
99	226	714.19	14.002
101	232	715.94	13.968
102	239	717.99	13.928
104	250	721.24	13.865
105	251	721.54	13.859
106	252	721.84	13.854
107	253	722.14	13.848
108	256	723.03	13.831
111	262	724.82	13.796
112	267	726.33	13.768
113	272	727.83	13.739
114	295	734.15	13.621
115	299	735.38	13.598
116	300	735.69	13.593
117	305	737.24	13.564
118	308	738.17	13.547
119	309	738.48	13.541
120	310	738.79	13.536
125	338	747.60	13.376
126	355	753.06	13.279
127	362	755.33	13.239
128	375	759.57	13.165
134	587	843.91	11.850
136	787	917.31	10.901
137	791	918.75	10.884
138	843	937.91	10.662
179	1301	1236.54	8.087
181	1329	1251.36	7.991
182	1371	1285.48	7.779
183	1382	1291.71	7.742
184	1400	1302.04	7.680
185	1401	1302.61	7.677
189	1424	1316.06	7.598
190	1449	1330.98	7.513
193	1471	1342.24	7.450
195	1479	1346.34	7.428
196	1488	1350.99	7.402
197	1500	1357.24	7.368
198	1519	1367.25	7.314
199	1520	1367.78	7.311
201	1545	1381.21	7.240
202	1565	1392.15	7.183
204	1583	1402.15	7.132
205	1593	1407.77	7.103
207	1627	1427.23	7.007

324-subset	Channel	wavenumber (cm^{-1})	wavelength (μm)
210	1652	1441.89	6.935
211	1669	1468.83	6.808
214	1694	1484.37	6.737
218	1740	1513.83	6.606
219	1748	1519.07	6.583
221	1756	1524.35	6.560
223	1766	1544.48	6.475
224	1771	1547.88	6.460
225	1777	1551.98	6.443
229	1800	1567.89	6.378
231	1806	1572.09	6.361
233	1826	1586.26	6.304
234	1843	1598.49	6.256
236	1865	2181.49	4.584
240	1869	2185.12	4.576
241	1872	2187.85	4.571
242	1873	2188.76	4.569
244	1876	2191.50	4.563
245	1877	2192.41	4.561
246	1881	2196.07	4.554
247	1882	2196.99	4.552
250	1897	2210.85	4.523
251	1901	2214.57	4.516
252	1911	2223.94	4.497
255	1921	2233.38	4.478
256	1923	2235.27	4.474
287	2113	2392.07	4.180
288	2114	2393.05	4.179
289	2115	2394.03	4.177
290	2116	2395.01	4.175
291	2117	2395.99	4.174
292	2118	2396.98	4.172
293	2119	2397.96	4.170
294	2120	2398.95	4.168
295	2121	2399.94	4.167
296	2122	2400.92	4.165
297	2123	2401.91	4.163
298	2128	2406.86	4.155
299	2134	2412.83	4.145
300	2141	2419.83	4.133
301	2145	2446.19	4.088
302	2149	2450.30	4.081
303	2153	2454.41	4.074
304	2164	2465.80	4.055
305	2189	2492.08	4.013
307	2209	2513.49	3.979
308	2226	2531.98	3.949
309	2234	2540.77	3.936
311	2318	2600.50	3.845
313	2325	2607.89	3.835
314	2328	2611.07	3.830
316	2339	2622.79	3.813
318	2353	2637.87	3.791
319	2355	2640.04	3.788
321	2363	2648.75	3.775