Sandy Supplemental Grant Recipient Quarterly Progress Report

Quality Control and Impact Assessment of Aircraft Observations in the GDAS/GFS

Award Number: NA13NWS4830022

The National Oceanic and Atmospheric Administration
National Environmental Satellite Data and Information Service
Center for SaTellite Applications and Research (STAR)

For the Period
1 October 2014 – 31 December 2014

On behalf of
The Cooperative Institute for Meteorological Satellite Studies (CIMSS)
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I. Introduction

Cooperative Institute Description

The Cooperative Institute for Meteorological Satellite Studies (CIMSS) is a collaborative relationship between the National Oceanic and Atmospheric Administration (NOAA) and the University of Wisconsin-Madison (UW-Madison). This partnership has and continues to provide outstanding benefits to the atmospheric science community and to the nation through improved use of remote sensing measurements for weather forecasting, climate analysis and monitoring environmental conditions. Under the auspices of CIMSS, scientists from NOAA/NESDIS and the UW-Madison Space Science and Engineering Center (SSEC) have a formal basis for ongoing collaborative research efforts. CIMSS scientists work closely with the NOAA/NESDIS Advanced Satellite Product Branch (ASPB) stationed at the UW-Madison campus. This collaboration includes a scientist from the National Climate Data Center (NCDC), who joined the NOAA NESDIS employees stationed at CIMSS.

CIMSS conducts a broad array of research and education activities, many of which are projects funded through this Cooperative Agreement with NOAA. This Cooperative Agreement identifies four CIMSS themes:

1. Satellite Meteorology Research and Applications, to support weather analysis and forecasting through participation in NESDIS product assurance and risk reduction programs and the associated transitioning of research progress into NOAA operations,
2. Satellite Sensors and Techniques, to conduct instrument trade studies and sensor performance analysis supporting NOAA's future satellite needs as well as assisting in the long term calibration and validation of remote sensing data and derived products,
3. Environmental Models and Data Assimilation, to work with the Joint Center for Satellite Data Assimilation (JCSDA) on improving satellite data assimilation techniques in operational weather forecast models, and
4. Outreach and Education, to engage the workforce of the future in understanding and using environmental satellite observations for the benefit of an informed society.

CI Management and Organizational Structure

CIMSS resides as an integral part of the Space Science and Engineering Center (SSEC). CIMSS is led by its Director, Dr. Steven Ackerman, who is also a faculty member within the UW-Madison Department of Atmospheric and Oceanic Sciences. Executive Director Wayne Feltz provides day-to-day oversight of the CIMSS staff, science programs, and facilities. The education and outreach activities at CIMSS are coordinated by Senior Outreach Specialist Margaret Mooney. The individual science projects are led by University Principal Investigators (PIs) in conjunction with a strong and diverse support staff who provide additional expertise to the research programs. CIMSS is advised by a Board of Directors and a Science Advisory Council.

The CIMSS administrative home is within the Space Science and Engineering Center (SSEC), a research and development center within the UW–Madison's Office of the Vice Chancellor of Research. The independent CIMSS 5-year review panel for administration wrote that they were "…impressed by the people, systems and processes in place." The SSEC mission focuses on geophysical research and technology to enhance understanding of the Earth, other planets in the Solar System, and the cosmos. To conduct its science mission on the UW-Madison campus, SSEC has developed a strong administrative and programmatic infrastructure. This infrastructure serves all SSEC/CIMSS staff.

The CIMSS mission includes three goals:

- Foster collaborative research among NOAA, NASA, and the University in those aspects of atmospheric and earth system science that exploit the use of satellite technology;
- Serve as a center at which scientists and engineers working on problems of mutual interest can focus on satellite-related research in atmospheric and earth system science;
- Stimulate the training of scientists and engineers in the disciplines involved in atmospheric and earth sciences.

Executive Summary of CI Banner Research Activities

CIMSS is a collaboration between NOAA and UW–Madison that has increased the effectiveness of research and the quality of education in the environmental sciences. In a *Space Policy* article in 1986, William Bishop, former acting Director of NESDIS, noted, "Remote sensing from space can only thrive as a series of partnerships." He used CIMSS as a positive working example of the government-academia partnership, noting "The Institute pioneered the computation of wind speeds at cloud heights by tracking cloud features from image to image. These are now a stable product provided from the satellites to the global models at the National Meteorological Center." CIMSS continues to be a leader in the measurement of winds from satellite observations and leads the way in many other research endeavors as outlined above. There is great value to NOAA and UW-Madison in this long-term collaboration known as CIMSS.

II. Funded Project

Award Number: NA13NWS4830022

Project Title: Quality Control and Impact Assessment of Aircraft Observations in the GDAS/GFS

PI: Dr. David Santek

NOAA Sponsor: Andrew Collard and Stephen Lord

NOAA Sponsoring Organization: NOAA NWS/EMC

Reporting Period: 1 October 2014 – 31 December 2014

Description of Task I Activities

Primarily activity involves quarter reporting.

NOAA Strategic Goal(s)

NOAA Mission Goals

1. Climate Adaptation and Mitigation: An informed society anticipating and responding to climate and its impacts
2. Weather-Ready Nation: Society is prepared for and responds to weather-related events

NOAA Strategic Plan-Mission Goals

1. Serve society’s needs for weather and water
2. Understand climate variability and change to enhance society’s ability to plan and respond
3. Provide critical support for the NOAA mission

III. Research Progress

Three areas were investigated during this quarter:

a) a comparison of aircraft moisture observations to co-located radiosondes,

b) the impact of the aircraft moisture observations on the global analysis, and

c) the impact of the aircraft observations on other observations in the GSI.

These are results based on control and experiment runs for 21-31 October 2013 and 25 March - 19 April 2014 using the GDAS/GFS at T670 resolution on zeus. The experiment assimilated the aircraft moisture data using the same quality control and error settings as used in the North American Model (NAM).

a) Comparison of aircraft moisture data to radiosondes

As a continuation of the work from the previous quarter, a further examination of the differences between aircraft moisture observations and radiosondes that were assimilated in the experiments was done. Figure 1 shows the difference in the vertical profiles of moisture between aircraft observations and co-located radiosondes for the experiments in late October 2013 (Figure 1a) and Spring 2014 (Figure 1b). In both cases, a difference is evident in the low levels (< 850 hPa), with aircraft observations more humid than radiosondes. Also, for the October case (Figure 1a), another substantial difference appears at midlevels, as aircraft observations are drier than radiosondes. After further examination, it appears that the difference at midlevels is mainly due to large moisture differences in southern locations (<35°N) (not shown). However, this disparity is not present in the second experiment so the difference at midlevels may be due to the impact of a particular event, smaller sample size, or the synoptic weather conditions.

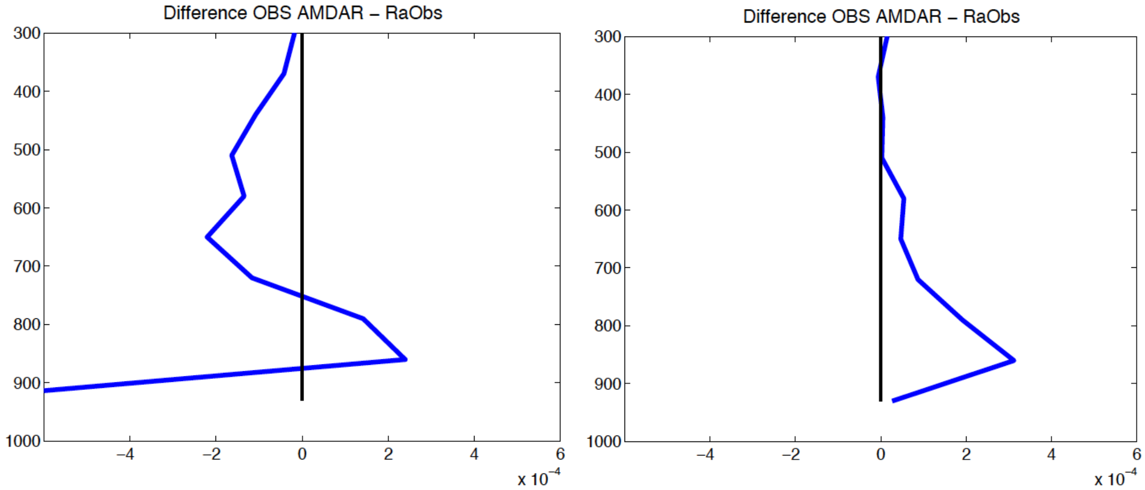

Figure 1: Difference in vertical profiles for moisture (kg/kg) between aircraft observations and radiosondes. (a) Left panel: 10-day October 2013 experiment; (b) Right panel: 25-day March/April 2014 experiment.

b) Impact of the aircraft moisture observations on the global analysis

In the previous quarterly report (October 2013), time-averaged RMSD between the control and experiment showed differences over tropical land areas, well away from the AMDAR observations. To examine this further, daily maps of relative humidity RMSD were plotted from the beginning of each experiment.

The upper-left panel in Figure 2 is day 1 of the experiment and depicts a relatively large RMSD (> 5%) in the locations where the AMDAR observations are found, which is expected. The remaining panels show the moisture difference grows over time, most evident in the tropical land regions.

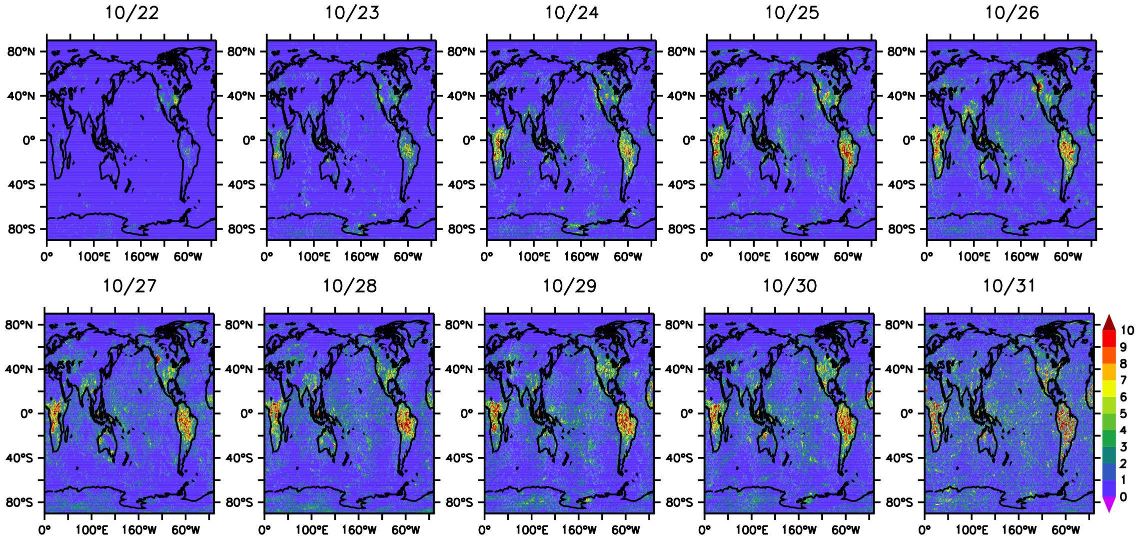

Figure 2: RMSD for σ995 relative humidity (percent) between the experiment and control run for each analysis-period from 21-31 October 2013. Global-mean RMSD averaged across all analysis-periods is 0.92.

Like in October 2013 experiment, relatively large RMSD is found over North America (where the AMDAR observations are), South America, and Africa during most of the Spring 2014 case (Figure 3). The magnitude of the RMSD appears to grow rapidly in the first few days of the run, but then stabilizes.

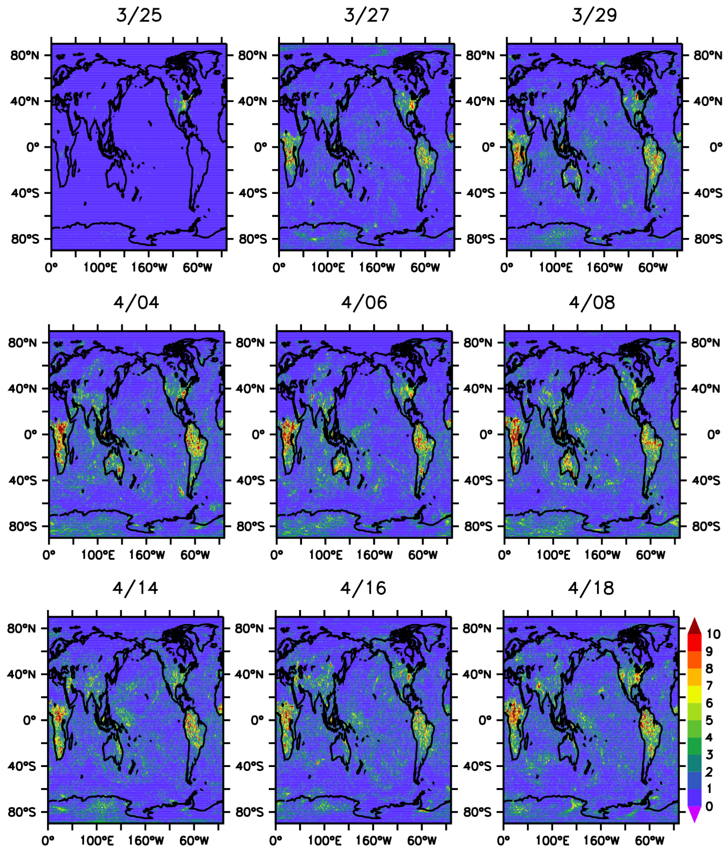

Figure 3: RMSD for σ995 relative humidity (percent) between the experiment and control run for each analysis-period from 25 March - 19 April 2014. Global-mean RMSD averaged across all analysis-periods is 1.19.

c) Impact of assimilating AMDAR moisture observations

Moisture observations from AMDAR are assimilated into the GDAS on 6-hourly cycles from 2014032500 – 2014041918. The first week of assimilation is removed from analysis to allow for spin-up. The impact of these observations is analyzed from two perspectives: (1) a model-space perspective where the mean difference in analysis low-level (900 hPa) relative humidity is compared between the experiment and a control with no AMDAR moisture observations, and (2) an observation-space perspective where mean profiles of US radiosonde (moisture) observations are computed to observe changes in their assimilation as a result of assimilating AMDAR observations.

1) Model-space analysis-differences

The mean 900 hPa relative humidity field across all analyses 2014040100 – 2014041918 was computed for analyses including AMDAR moisture observations (the experiment) as well as analyses where no AMDAR moisture observations were assimilated (the control). Figure 4 shows the mean difference in the analyzed low-level moisture over the continental US.

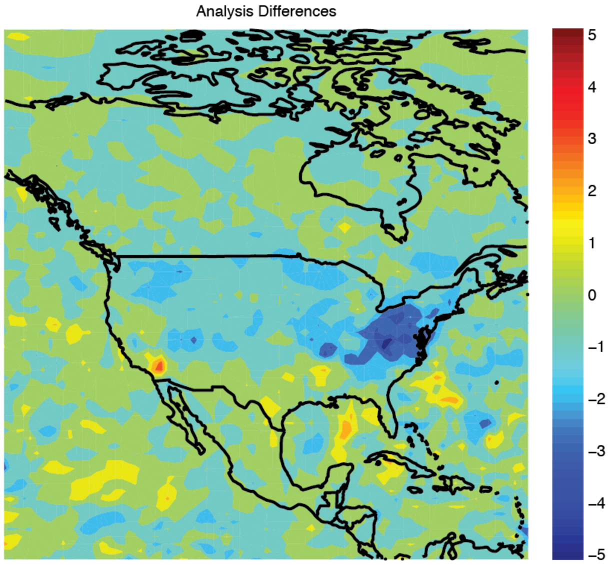

Figure 4: Mean difference (experiment – control) in analysis of the 900 hPa relative humidity (in percent).

The mean difference is typified by a drier analysis over the mid Atlantic and small regions of enhanced moisture in the Gulf of Mexico, along the mid Atlantic coast, and in southern California. The mean analysis-difference is a combination of two impacts from assimilated AMDAR moisture observations: (1) the impact of directly assimilating AMDAR moisture observations at each analysis time, called the increment, and (2) the impact of previously assimilated AMDAR moisture observations on the model background that serves as the first-guess for the analysis. The mean background-difference and mean increment-difference are provided in Figure 5.

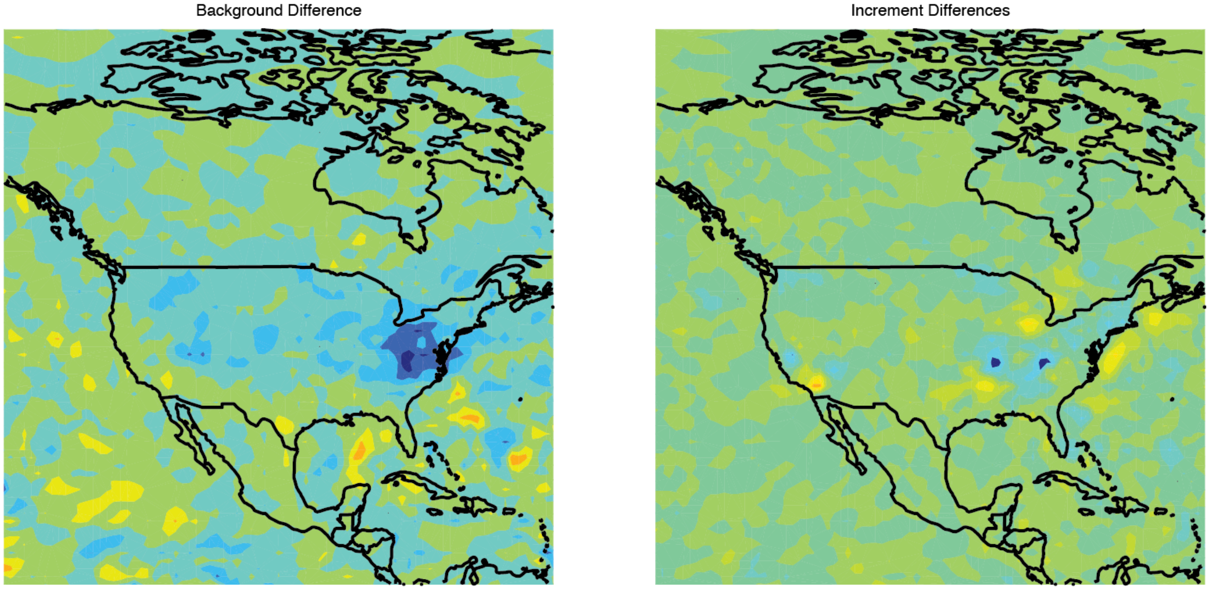

Figure 5: Mean difference in model background (left) and analysis increment (right) for 900 hPa relative humidity (in percent).

The differences in the background account for 74.5% of the analysis-difference, while the analysis-increment provided by assimilating the AMDAR moisture observations provides 24.6% of the observed analysis differences. The percent-contribution of each of these elements to the analysis-difference is computed using the dot-product of the state-vector for each element:

$$C\big|_{\mathbf{y}:\mathbf{x}} = dot(\mathbf{x},\mathbf{y}) / dot(\mathbf{x},\mathbf{x}) \qquad (1),$$

where **x** is the analysis-difference, and **y** is either the background-difference or the increment-difference. The 75/25 split in contribution is consistent over time, with the background-difference providing the majority of the analysis-difference, as shown in Figure 6.

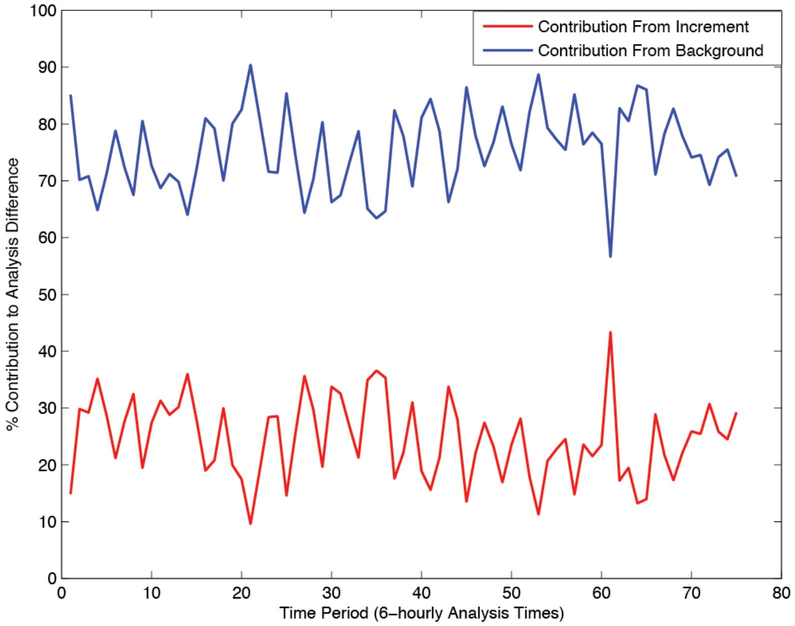

Figure 6: Time series of contribution of background-difference (blue) and increment-difference (red) to analysis-difference.

While the contribution of both elements to the analysis-difference is steady, there exists variation. Data were separated into a “high-increment” group (increment-difference accounts for more than the 95% confidence limit for the mean contribution), and a “low-increment” (increment-difference accounts for less than the 95% confidence limit for the mean contribution). Means of these subsets were produced separately. Increment-differences contribute on-average 31.2% of the analysis-difference in the high-increment group and 18.1% in the low-increment group. The high-increment group is typified by localized regions of drying and moistening from the analysis-increment, which gives the analysis-difference a muddled appearance (Figure 7).

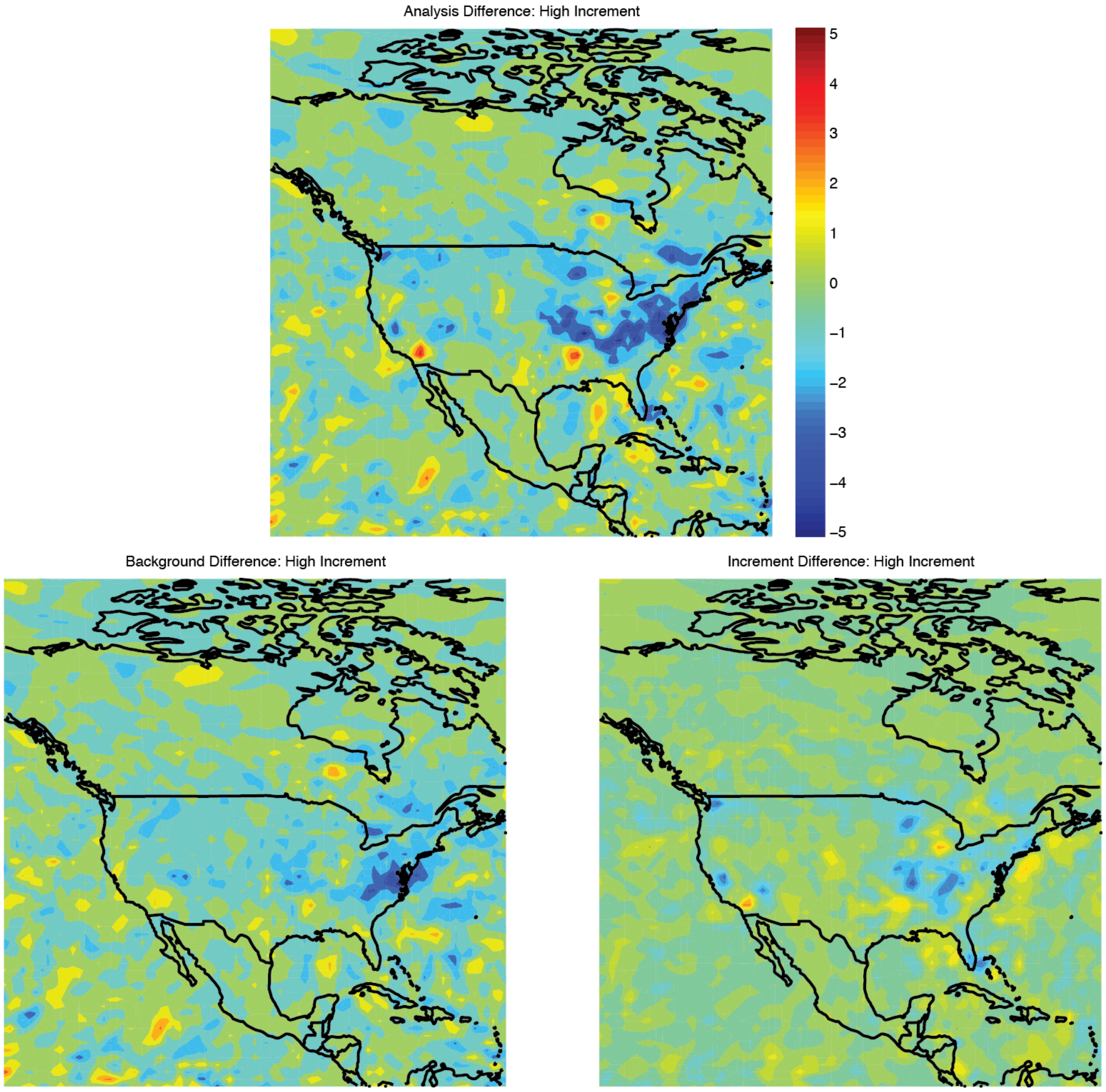

Figure 7: (Top) Mean analysis-difference (top), background-difference (left), and increment-difference (right) of high-increment group.

These localized regions of analysis-increment may either be from the AMDAR moisture observations themselves, or possibly also due to increased weight applied to nearby radiosonde moisture data (see below). The mean difference fields in the low-increment group show significantly less low-level drying over CONUS, and enhanced differences in coastal waters supplied entirely by the background (Figure 8). Drying in the mid Atlantic is almost entirely due to the background in these cases.

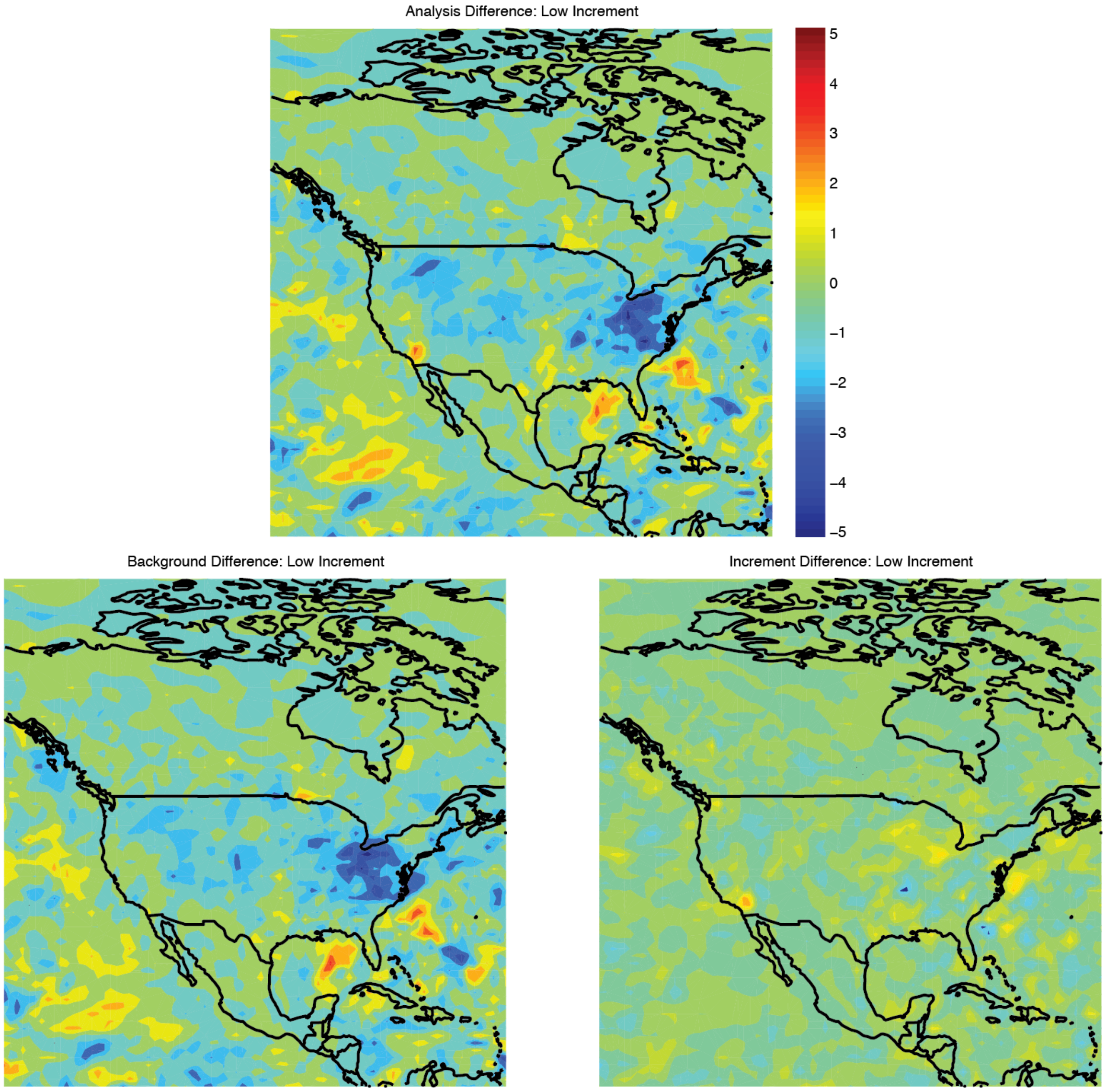

Figure 8: (Top) Mean analysis-difference (top), background-difference (left), and increment-difference (right) of low-increment group.

Future investigation will include looking into the specific circumstances in which the model analysis is relying heavily on the AMDAR increment, versus the background.

2) Observation space differences in radiosonde assimilation

Radiosonde moisture observations were collected at each analysis-time and assigned to the nearest US radiosonde launch site through a lookup-table. Observations were discretized into 25 evenly spaced pressure levels between the surface and 300 hPa, which is the limiting pressure level for allowing assimilation. Mean profiles are produced of various model statistics. Figure 9 shows the mean profile of ob-minus-background and ob-minus-analysis for radiosonde moisture observations, both before and after AMDAR observations are assimilated.

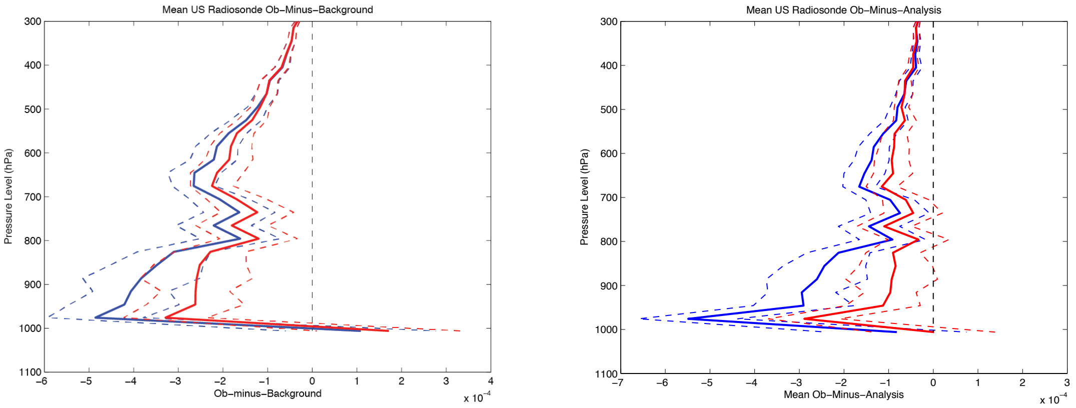

Figure 9: Profiles of mean ob-minus-background (left) and ob-minus-analysis (right) for radiosonde moisture observations. The blue line is for radiosondes in the control simulation with no AMDAR moisture observations. The red line is for radiosondes in the experiment. Dashed lines represent the 95% confidence interval surrounding the mean profile.

When AMDAR moisture observations are assimilated, the radiosonde moisture observations appear to have a better fit to both the background and the analysis. Since the AMDAR data affects both the analysis background and the analysis increment, the beneficial impact observed in radiosondes can be coming from either or both sources. The analysis may be pulling closer to the radiosonde observations because there now exists AMDAR observations that corroborate the radiosondes. Alternatively, the AMDAR observations may be correcting a bias in the background moisture field that was limiting the effectiveness of the radiosondes. Another way to approach this analysis is to compute the analysis-impact of radiosonde observations:

$$o_i = \frac{\left(y_i - H\left(\mathbf{x}_a\right)\right)^2 - \left(y_i - H\left(\mathbf{x}_b\right)\right)^2}{\varepsilon_i^2} \qquad (2),$$

where y represents the observation, $H(\mathbf{x}_a)$ is the analysis interpolated to the observation, and $H(\mathbf{x}_b)$ is the background interpolated to the observation. The difference between the squared ob-minus-analysis and ob-minus-background is normalized by the square of the observation error. When this metric is negative, it means that the analysis pulled closer to the observation than the background was, indicating that the observation is contributing to the analysis increment. Figure 10 is the mean profile of analysis-impact of radiosonde moisture observations in the control and experiment.

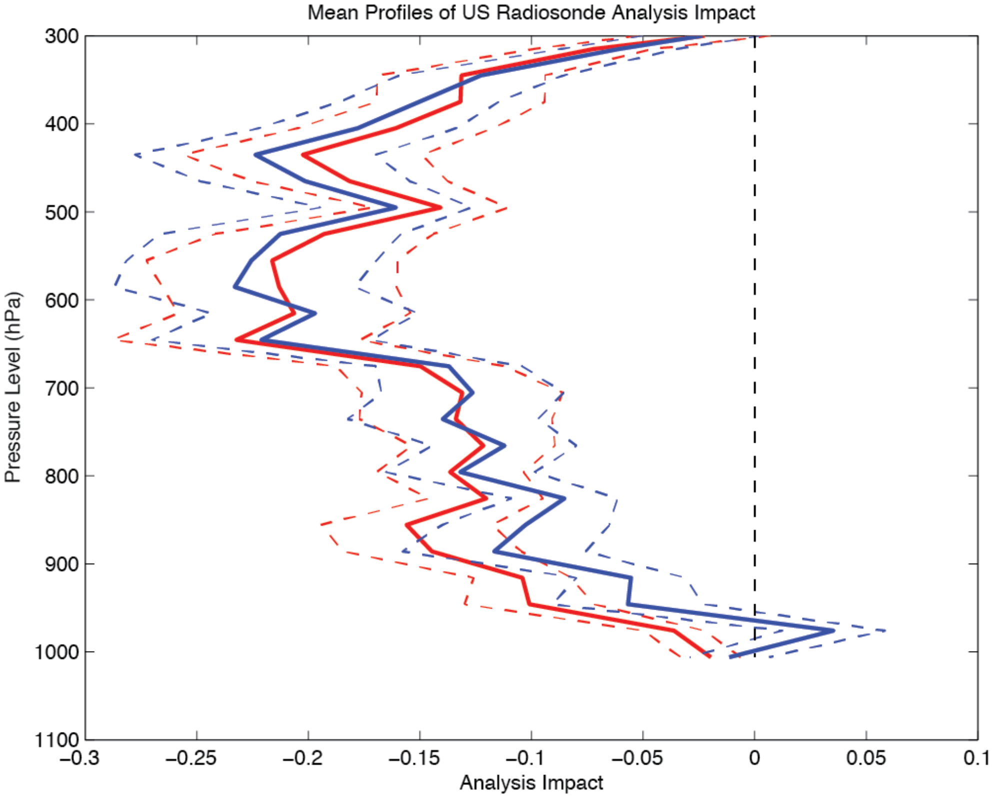

Figure 10: Mean profile of analysis-impact of radiosonde moisture observations. The blue line is the mean profile in the control, and the red line is the mean profile in the experiment. Dashed lines represent the 95% confidence limit around the mean.

There is a pronounced increase in analysis-impact for low-level radiosondes: radiosonde observations that the analysis had previously moved *away* from (positive values on the blue profile) are now observations that the analysis moved *toward*, when assimilating AMDAR moisture observations. The difference between the red and blue profiles surpasses a student's t-test at 95% confidence in the lowest levels.

The lowest levels of the model, in roughly the bottom 50 hPa, are the regions where AMDAR and radiosonde moisture data are most likely to disagree. This could introduce some problems with respect to assimilating low-level AMDAR data. However, the pronounced positive impact on radiosonde observations at these levels indicates that these data may be providing substantial positive benefit to the analysis near radiosonde sites.

3) Future work

A clear and concise strategy for assessing the *forecast* impact of AMDAR data is still needed.

Resolved Issues and/or Risks

None.

New Issues and/or Risks

None.