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 April 2015 – 30 June 2015

On behalf of
The Cooperative Institute for Meteorological Satellite Studies (CIMSS)
Space Science and Engineering Center (SSEC)
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Table of Contents

I. Introduction 3
  Cooperative Institute Description 3
  CI Management and Organizational Structure 3
  Executive Summary of CI Banner Research Activities 4
II. Funded Project 4
III. Research Progress 6

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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 April 2015 – 30 June 2015

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

In the absence of routinely-produced forecast fit-to-observation data that was not obtainable on the NOAA computer (Zeus), we performed our own fit-to-observation measurement using a total-column precipitable water measurement derived from GPS radio occultation. Time and computer resources did not permit finishing a December 2014 – January 2015 experiment, and statistics gathered from the shorter run that had been completed to-date were not helpful because of their dependence on a very small number of large-impact events. However, we were able to run an experiment over the majority of the April – May 2014 (first season) time period with radiosondes removed in 10 locations that receive dense and consistent coverage from AMDAR. We plan on writing and submitting a manuscript to the American Meteorological Society's *Weather and Forecasting* journal based on our findings.

a) Forecast fit-to-observations using GPS precipitable water data

Total(-column) precipitable water is derived from GPS data and interpolated to regular latitude/longitude points on the GFS output grid, and serves as an observed reference state. The total precipitable water forecast from the GFS is compared to the reference state, and root-mean-squared error (RMSE) in total precipitable water is computed over the continental US from both the control forecast with no AMDAR q-observations, and from the experiment assimilating AMDAR q-observations. The RMSE was computed each day from 05 April – 29 May 2014 for each six hours between analysis-time and the 72 hr forecast.

The RMSE plot (Fig. 1) in both the control forecast and the experiment forecast show an increase in RMSE with forecast time, which is expected. The RMSE in the experiment is less than the control for the analysis-time and all forecast lead times out to 72 hours; however, the differences are only statistically significant out to 18 hours.

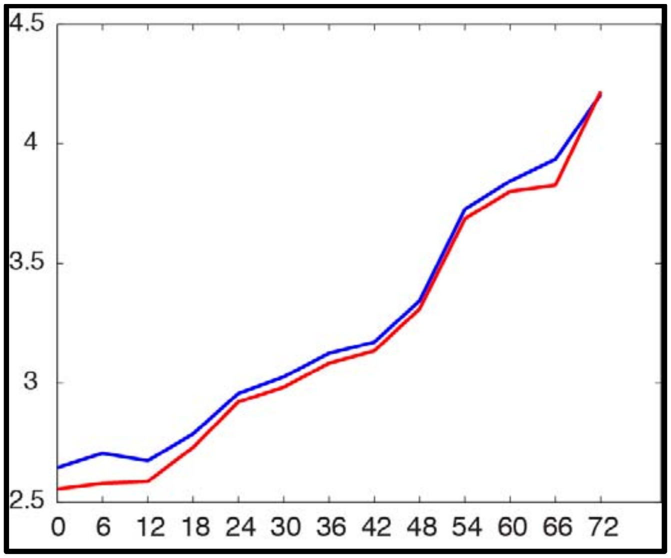

Figure 1. Root mean squared error (RMSE) of the GFS total-column precipitable water forecast over the continental US, compared to observations derived from GPS radio occultation. RMSE from the control forecast is provided in blue, and RMSE from the experiment is provided in red. RMSE is evaluated from analysis-time to 72 hrs.

This demonstrates a positive impact on the short-range moisture forecast from the assimilation of AMDAR moisture observations, consistent with positive impact observed in the precipitation Equitable Threat Score and Bias Score (see previous quarterly report for details).

b) Radiosonde exclusion experiment (April – May 2014)

There is a significant level of interest in determining how redundant radiosonde observations and AMDAR observations are, especially when a radiosonde launch site is located very close to a major airport where AMDAR observation profiles are gathered routinely. Considering that this project is tasked with the assimilation of AMDAR moisture observations, the question of redundancy between radiosonde and AMDAR observations is likewise focused on their impact on the moisture analysis and forecast.

Observation data was collected from the first experiment to determine where AMDAR observations most densely and consistently overlap with radiosonde observations. For the purposes of this experiment, an AMDAR observation was considered to be ‘collocated’ with a radiosonde observation if it exists spatially within 0.5 degrees of a radiosonde and was taken within an hour of the radiosonde launch. Observations are binned by pressure-level into 25 bins spaced between the surface and 300 hPa (the highest elevation where moisture observations are permissible for assimilation). The percentage of the profile at a radiosonde site is observed by AMDAR observations based on what percent of the 25 bins contain collocated AMDAR observations; likewise, the percentage of time in which AMDAR observations are available at the site is determined by the percentage of analysis-periods where AMDAR observations are collocated with the radiosonde site (regardless of the coverage of the profile). A final score is computed by multiplying the mean fractional vertical-coverage of the profile by the mean time-coverage at the site. From this data, ten radiosonde launch sites were chosen for the experiment:

Site	**Index**	**City**	**State**		**Lat**	**Lon**
KMFL	72202	MIAMI	FL	US	25.76	-80.38
KTBW	72210	TAMPA	FL	US	27.71	-82.40
KFFC	72215	ATLANTA	GA	US	33.36	-84.57
KFWD	72249	FORT WORTH	TX	US	32.84	-97.30
KOHX	72327	NASHVILLE	TN	US	36.25	-86.56
KVEF	72388	LAS VEGAS	NV	US	36.05	-115.18
KLWX	72403	STERLING	VA	US	38.98	-77.49
KDNR	72469	DENVER	CO	US	39.77	-104.87
KOAK	72493	OAKLAND	CA	US	37.74	-122.22
KOKX	72501	UPTON	NY	US	40.87	-72.86

These ten locations are spread throughout the continental US, which makes their exclusion less susceptible to the impact caused by the exclusion of a tight cluster of observations in a single location. For the purposes of the experiment, the radiosonde observations from these ten sites were removed entirely, and AMDAR observations (including moisture observations as per the first experiment) are assimilated. A comparison between the first experiment (radiosondes + AMDAR) and this experiment (subset of radiosondes + AMDAR) allows for an examination of how much impact the well-(AMDAR-)covered radiosondes have on the analysis and forecast.

The impact of the excluded radiosondes is examined in three ways: Precipitation skill scores, forecast fit-to-observations of GPS total precipitable water data, and ob-minus-analysis statistics.

Contrary to expectations, Equitable Threat Score (ETS) and Bias Score are improved in the 12-36 hour forecast of precipitation for amounts between 0.2 to 15 mm/day, when the ten radiosonde launch sites are excluded (Fig. 2). The experiment demonstrates improved ETS scores for the 0.2 to 5 mm/day bins, and improved bias scores for the 0.2 to 15 mm/day bins. No clear explanation can be given, other than perhaps that the AMDAR moisture observations are higher quality than the radiosonde observations – this may be indicated by lower ob-minus-background scores for AMDAR observations than radiosonde observations (see previous quarterly report for details).

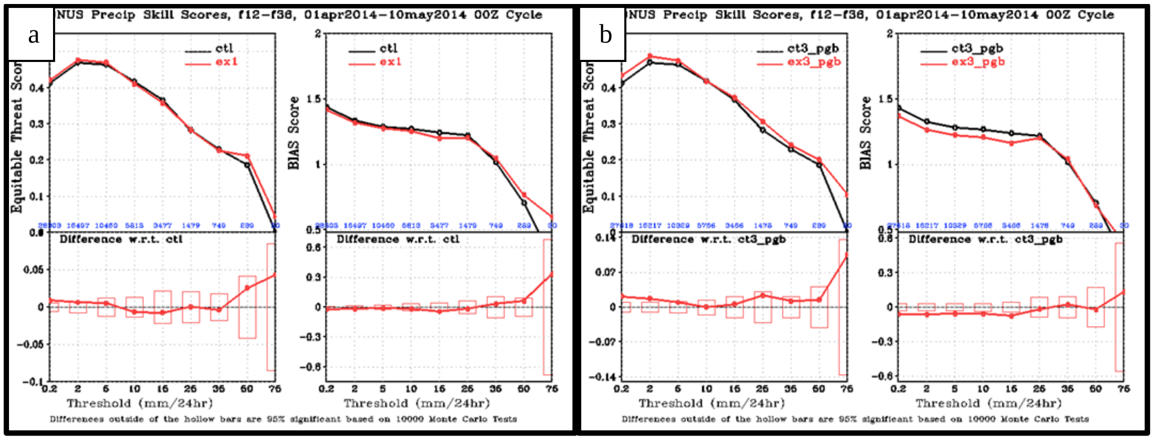

Figure 2. Equitable Threat Score (left panels) and Bias Score (right panels) for (a) the first experiment, and (b) the experiment with excluded radiosondes. Both curves (red) are compared to the same control (black) which includes radiosondes but no AMDAR moisture observations. Differences between experiment and control are displayed on the bottom half of the panel, with bars indicating the value necessary for statistical significance. Both experiments and the control are evaluated from 01 April – 10 May 2014.

However, when performing a forecast fit-to-observations with GPS total precipitable water data, the experiment with excluded radiosondes is degraded to statistical significance (Fig. 3). The RMSE of the experiment is higher than the experiment that includes both radiosondes and AMDAR moisture observations (compared to a common control that includes radiosondes but no AMDAR moisture observations), and the differences are statistically significant both in the short-range forecast (6-12 hrs) as well as the medium-range (72 hrs). This is inconsistent with the precipitation skill score information shown above; however, the precipitation skill score is computed over small regions where precipitation develops in the model, whereas the RMSE of total precipitable water is computed over the entire continental US, with observations available to measure forecast skill every day. For this reason, we believe that the RMSE test is more comprehensive.

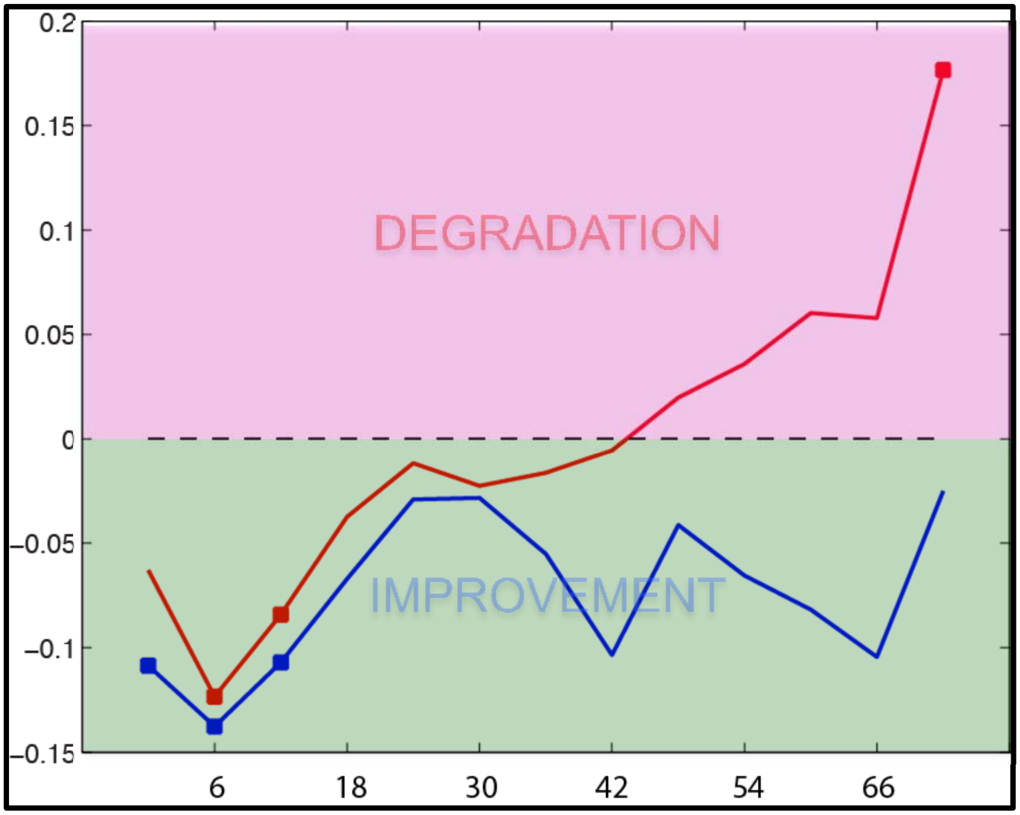

Figure 3. Improvement or degradation of root mean square error (RMSE) of total precipitable water, relative to control forecast. Values are provided for the first experiment including both radiosondes and AMDAR moisture observations (blue) and the experiment with AMDAR moisture observations and excluded radiosondes (red). Dots indicate time periods where the difference between experiment and control is statistically significant. Both experiments and the control are evaluated from 01 April – 10 May 2014.

Another way to approach the issue is to ask the question: “How much does the analysis change when radiosondes are removed, as a function of how many AMDAR observations are present?” This is a way to quantify the impact of missing radiosonde observations and relate it to how sparse or dense the AMDAR observation network is.

AMDAR moisture observations collocated with the ten excluded radiosondes were evaluated on two criteria: (1) what is the change in ob-minus-analysis between the experiment with radiosonde removed, versus the experiment where the radiosonde is retained, and (2) how many collocated AMDAR moisture observations are present. While (1) is a simple measure of the routinely collected ob-minus-analysis metric, (2) is a statistic that comes from the AMDAR/radiosonde collocation work performed earlier – the number of AMDAR moisture observations determined to be in the "neighborhood" of any given AMDAR moisture observation is the number of observations within 0.5 degrees of the radiosonde launch site, within 1 hour of the launch, and within one of the 25 pressure-bins between the surface and 300 hPa.

These two statistics can be plotted on a phase-space (Fig. 4). Since the relationship between these two statistics is not linear, the correlation is low. However, the two statistics have a clear relationship: as the number of AMDAR observations in the "neighborhood" of a missing radiosonde increases, the impact of the missing radiosonde is diminished. Observations tend to fill an area of the phase-space that is described by an exponential-decay relationship. An exponential curve was fit to the 5 largest ob-minus-analysis values for each value of ob-density (the number of observations in the "neighborhood"), which defines an approximate upper-bound for the impact of a radiosonde based on the number of AMDAR moisture observations present.

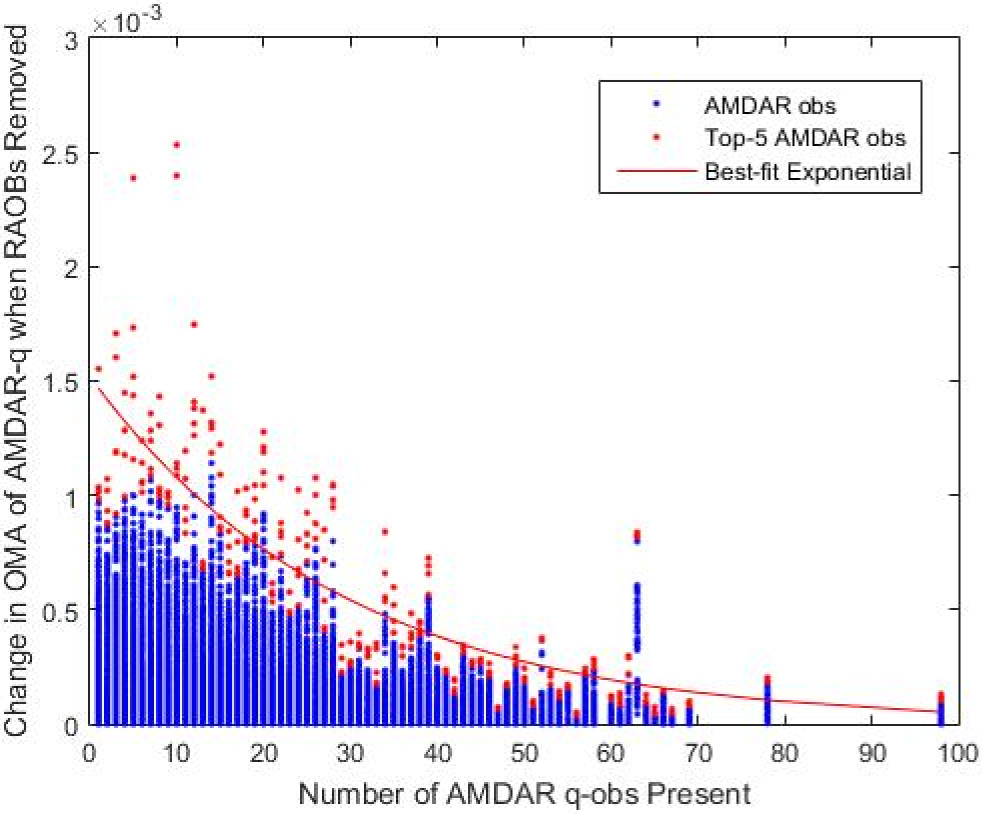

Figure 4. AMDAR moisture observation phase-space, plotting the observed change in ob-minus-analysis when the radiosonde is excluded (ordinate) versus the number of AMDAR moisture observations present (abscissa). Red dots are the top-5 largest values on the ordinate for each unique value on the abscissa, and the red line is an exponential best-fit curve to those points.

What this curve indicates is that, in order to diminish the impact of a radiosonde on the analysis, some threshold number of AMDAR observations need to be present. For example, to reduce the impact of a missing radiosonde below $0.5x10^{-3}$ kg/kg, one can expect that there need to be roughly 35 AMDAR observations in the neighborhood of the radiosonde.

What this analysis shows is that there is a highly variable amount of AMDAR coverage even at the best-covered radiosonde sites, and it is expected that permanently removing those radiosondes would have a statistically significant, negative impact on the model forecast. However, the question can be flipped on its head, and we can ask: “Where should an *additional* radiosonde launch be made to maximize its impact on the forecast?” – This sort of question is relevant to off-time radiosonde launches, which have been considered a useful adaptive observation technique for forecasting high-risk events (e.g. tropical cyclone landfall along the US coast). In this case, one can expect that off-time radiosonde launches should be restricted to those sites with the *least* AMDAR coverage, such that the radiosonde has the largest impact on the analysis.

Future Work

This project, as a Sandy Supplemental research project, ended June 30 2015. However, the results presented here are expected to be included in an upcoming submission to AMS *Weather and Forecasting*.