13.3 **OBSERVING SYSTEM SIMULATION EXPERIMENTS FOR UNMANNED AIRCRAFT SYSTEMS: PRELIMINARY EFFORTS**

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1. INTRODUCTION

Unmanned Aircraft Systems (UAS) is an emerging technology that has many potential applications for observing the atmosphere. These aircraft are able to reach areas that are too dangerous or difficult for manned aircraft to fly, enabling new observations in currently data-poor areas.

To determine the best use of these aircraft in supplementing the current observational network, a series of Observing System Simulation Experiments (OSSEs) is under way. The results of these OSSEs will be used to assist in the planning of future UAS missions when improvement of numerical weather forecasts is the goal.

The UAS OSSEs are part of a Joint OSSE project, a large collaborative effort among multiple agencies (Masutani et al, 2007, 2008, 2009). The Earth Systems Research Laboratory of the National Oceanic and Atmospheric Administration (ESRL/NOAA) is contributing to the larger Joint OSSE effort by assisting with the evaluation of the Nature Run (see section 3) and calibration of the synthetic observations.

2. UAS PROGRAM

NOAA has initiated a UAS Program to coordinate UAS activities and evaluate the potential uses of UAS in fulfilling agency goals.

2.1 *UAS Platforms*

UAS encompass a wide range of platforms, each with different capabilities. The aircraft range from 'micro' vehicles that can carry only a few grams of payload, to full-sized aircraft that can carry hundreds of kilograms of payload and fly continuously for hours to days. There are usually tradeoffs among the payload, flight altitude, and flight duration of the aircraft. Part of the OSSE effort will be to determine the best suite of aircraft and instruments to optimize forecast improvements.

2.2 *UAS Test beds*

The NOAA UAS Program has established three test beds for UAS operation and evaluation.

A Pacific test bed will focus on atmospheric river events that cause flooding in the western United States. UAS will be used to observe the atmospheric river structure over the east Pacific, where few in-situ observations are currently available.

The Arctic test bed will observe the arctic climate and ocean conditions, including sea ice and marine mammals. Arctic lows can rapidly intensify over the Arctic Ocean and cause severe erosion along the north coast of Alaska. UAS observations in this data-poor region may improve forecasting of these arctic lows.

The hurricane test bed will use UAS to improve tropical cyclone forecasts in the Atlantic basin. UAS may be flown in the boundary layer of the hurricane, where current observations are impossible, to study the interface between the storm and the ocean. High-altitude UAS, having a greater flight radius than manned aircraft, can be used to monitor the cyclone while it is still far from land, and can loiter in the vicinity of the storm for hours to provide continuous monitoring.

3. OSSE

An OSSE has several elements (Atlas, 1997). 1) Nature Run. The Nature Run is typically an extended free integration of a well-tested numerical forecast model. The output of this integration serves as the "true" atmosphere. 2) Synthetic observations are then generated from the Nature Run, for all current observing systems as well as for the proposed new observing system. Plausible errors are added to the synthetic observations. 3) The synthetic observations are then assimilated into a different numerical model and used to generate forecasts. The Global Forecast System (GFS) numerical weather prediction model was chosen as the forecast model, with the Gridpoint Statistical Interpolation (GSI) data assimilation package. 4) Finally, the forecasts, initialized with and without the proposed new observations, are verified against the Nature Run. By performing data-denial experiments with the synthetic observations, using the Nature Run as 'truth', the impact of the new observing system can be quantified (Lord et al, 1997).

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3.1 *Nature Run*

The European Centre for Medium-Range Weather Forecasts (ECMWF) has generated a Nature Run from a 13-month, continuous free integration of its operational forecasting model (Masutani et al, 2008). The model run was made at T511 spectral resolution with 91 vertical sigma levels, starting from the analysis at 00 UTC, 01 May 2005, running until 18 GMT, 31 May 2006. Two shorter global model runs were made at T799 resolution; one running from 27 September 2005 to 01 November 2005, the second running from 10 April 2006 to 15 May 2006.

The Nature Run fields were evaluated to determine whether the representation of the atmosphere is sufficiently realistic for use in an OSSE. There are several atmospheric phenomena that are of specific interest for the UAS OSSE: tropical cyclones, atmospheric rivers, and arctic lows.

Tropical cyclones were found to be reasonably well represented in the Nature Run for a model of intermediate resolution (Reale et al, 2007). Due to the relatively low resolution of the Nature Run (~40 km) in comparison to the scale of the storm inner core structure, the OSSE will focus on tropical cyclone track forecasting rather than intensity forecasting.

Atmospheric rivers are related to Rossby waves in the midlatitude jet that draw moisture plumes out of the tropics. The Nature Run has midlatitude Rossby waves that are similar in character to those found in the NCEP (Kistler, 2001) and ECMWF (Uppala, 2005) reanalyses, in terms of wavenumber, phase speed, and group velocity. There are numerous atmospheric river events in the eastern Pacific in the Nature Run which would be suitable for a UAS OSSE.

In the Arctic, polar lows that strengthen rapidly over the Arctic Ocean are most common during the boreal autumn. There are several polar lows in the Nature Run which are candidates for the OSSE – these lows originate as midlatitude systems in the north Pacific and move poleward into the Arctic, where they cause high wind events along the northern coast of Alaska.

3.2 *Calibration*

Calibration consists of a series of observing system experiments (OSEs), first using archived real observations, then repeated with synthetic observations. The data impact of the synthetic observation experiments should ideally be statistically similar to that seen in the real-data experiments. Error characteristics of the synthetic data can be adjusted if it is necessary to calibrate the data impact.

The observations chosen for the data denial experiments were RAOB, AMSU-A, aircraft, GOES, and AIRS. These observing systems were chosen to investigate both satellite and conventional data, as well as platforms that are expected to have a large and small data impact. A control run which uses all available observations was also performed.

Due to the large computational expense of the calibration procedure, the OSEs were performed with a T126 version of the GFS/GSI system. Two seven-week periods were chosen for each OSE – the first from 01 July 2005 to 20 August 2005; the second from 01 January 2006 to 20 February 2006. These two periods were chosen to sample two different seasons. At the time of this writing, the July-August experiments with real data are complete, and the January-February experiments are under way.

The analysis impact I_a is calculated by finding the root mean square (RMS) difference between the data denial analysis fields and the control analysis field:

$$I_a = \frac{\iint \sqrt{(A_d - A_c)^2} \cos\phi d\phi d\lambda}{4\pi} \quad (1)$$

where A_d is the data denial analysis field, A_c is the control analysis field, φ is latitude, and λ is longitude. A time series of the global mean RMS error for the zonal wind field for each observation type in the July case is shown in Figures 1 and 2. There is an initial adjustment period during the first two weeks of the experiment where the data-denial analyses drift away from the control run.

The largest data impact on the analyses is seen with the RAOB and AMSU-A observations, which have consistently large impact throughout the depth of the troposphere for wind, temperature, and specific humidity (the latter two variables not shown). AMSU-A has particularly strong impact for lower tropospheric humidity. GOES observations have the weakest impact. The AIRS and aircraft data have largest impact in the

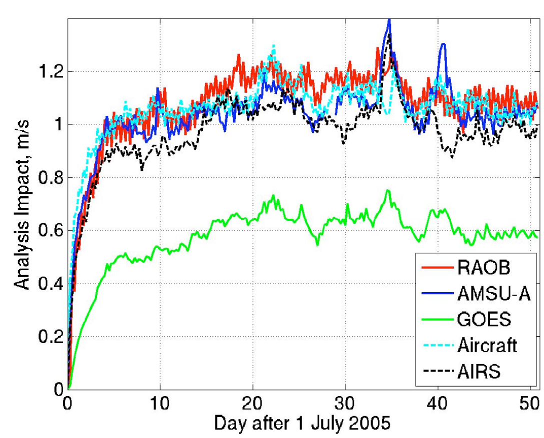

Figure 1. Analysis impact I_a (defined by (1)) as a function of forecast hour, 300-mb zonal wind field, for the indicated observation types. Red line, RAOB; dark blue line, AMSU-A; green line GOES; dashed cyan line, Aircraft; dashed black line, AIRS.

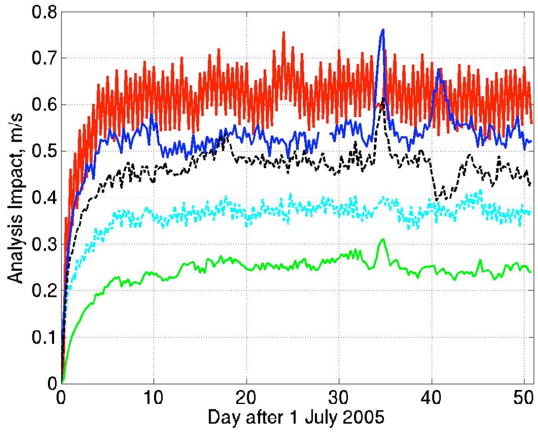

Figure 2. As in Figure 1, for 850-mb zonal wind field.

upper troposphere (Figure 1), but weaker impact at lower levels (Figure 2). The significant peaks in analysis impact are caused by data outages of a particular observation type. The 4 August 2005 peak in AMSU-A, GOES, aircraft, and AIRS impact is due to missing RAOB data, while the 11-12 August peak in AMSU-A is caused by an outage of AIRS data. These results are generally in agreement with other data impact studies for the GFS/GSI system (Zapotocny et al. 2008).

The calculation of forecast impact I_f is similar to that for analysis impact, but here the RMS error between the control forecast (F_c) and the verifying control analysis is compared to the RMS error between the data denial forecast (F_d) and the control analysis:

$$I_f = \frac{\iint \left\{ \sqrt{(F_d - A_c)^2} - \sqrt{(F_c - A_c)^2} \right\} \cos\phi \, d\phi \, d\lambda}{4\pi} \quad (2)$$

The forecast impact is calculated for each 120-hour forecast cycle at 00Z and 12Z. The first two weeks of July are excluded to avoid the analysis adjustment period. Figure 3 shows the global mean forecast impact as a function of forecast hour, averaged over all the forecasts from 15July to 15August.

The forecast impact for all observation types is greatest at the analysis time and decreases rapidly over the first 24 hours of the forecast. After approximately 72 hours, the forecast impact approaches an asymptote; for the 300-mb zonal wind shown in Figure 3, only the RAOB and AMSU-A experiments have a nonzero impact for the four-to five-day forecast. This rapid decrease in forecast impact has been seen previously in other impact studies by Zapotocny et al. (2007).

3.3 *Synthetic Observations*

Using the 13-month ECMWF Nature Run, synthetic observation data will be generated for the OSSE for all existing observation systems. The National Centers for Environmental Prediction (NCEP) data file archives are

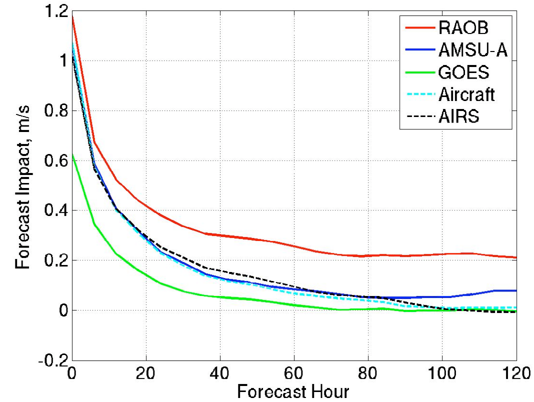

Figure 3. Forecast impact as a function of forecast hour, 300-mb u-wind field. Time mean taken over 00 and 12 UTC forecasts from 15 July 2005 to 15 August 2005.

used to extract the physical locations and observation times for both conventional and radiance observations. The conventional synthetic observational values are then generated by interpolating the Nature Run fields to the extracted locations and times. Efforts are ongoing at the National Environmental Satellite, Data, and Information Service (NESDIS) and the National Aeronautics and Space Administration (NASA) towards generation of the synthetic remotely sensed observations using multiple radiance transfer models. After interpolation, both conventional and radiance observations are ‘perfect’ aside from interpolation errors. Observational errors, instrument and representativeness errors, will be added and tested during the calibration process.

The initial UAS OSSE will focus on in-situ and direct measurement observations, such as dropwindsondes and aircraft measurements of temperature, wind, and humidity. Generation of remote sensing instrument observations is much more difficult. Remote sensing observations from UAS may be investigated in the future.

A synthetic dropsonde observation generator with an interface to the Nature Run has been created. The UAS is ‘flown’ through the Nature Run wind field, and the time and location of the dropsonde release is calculated. Horizontal displacement of the dropsonde is tracked as the sonde falls, and the sonde observations are interpolated from the Nature Run fields.

4. FUTURE WORK

Calibration of the OSSE is ongoing. Data denial experiments using archived real observations from winter 2006 are currently being conducted. After all the synthetic observations are generated, along with appropriate error characteristics, the data denial experiments with synthetic data will be performed.

Once calibration of the OSSE is complete, the actual experiments using synthetic observations will begin. Each experiment will be designed around the needs of the associated UAS Test bed to determine the optimal choice of UAS platform, onboard instrumentation, and location and timing of observations.

A regional OSSE may be desirable for the tropical cyclone UAS OSSE, in order to achieve resolution sufficient to forecast storm intensity. Regional OSSEs require a second high-resolution Nature Run, which is embedded within in a global Nature Run. Both a regional forecast model and a global forecast model must be run with synthetic observations, so that the global forecast model provides boundary conditions appropriate for the regional model.

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