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PRELIMINARY FINDINGS FROM THE GEOSTATIONARY INTERFEROMETER OBSERVING SYSTEM SIMULATION EXPERIMENTS (OSSE)

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PRELIMINARY FINDINGS FROM THE GEOSTATIONARY INTERFEROMETER OBSERVING SYSTEM SIMULATION EXPERIMENTS (OSSE)

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1. Introduction

Mesoscale numerical weather prediction (NWP) in the future will depend increasingly on data available from earth observing systems. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) has designed and implemented a software system that enables quantitative assessment of the value of different atmospheric measurements to operational mesoscale numerical forecasts. Using the construct of an Observing System Experiment (OSE), where existing operational observing systems are assimilated into an analysis/forecast system and quantitatively assessed in a controlled software environment, the CIMSS software system has been extended to include proposed observing systems. These assessments are performed as Observing System Simulation Experiments (OSSEs), where future-observing systems can be compared to existing systems to determine their relative potential for improving forecast skill.

The hypothesis for this OSSE is that measurements from a geostationary (GEO) interferometer, with the ability to measure radiation at high spectral resolution, will significantly improve the accuracy of numerical weather forecasts as compared to radiometer measurements made with limited spectral resolution. The information and potential forecast impact from the geostationary interferometer (GEO-I) derived temperature, moisture, and winds is compared to that of the current operational filter radiometer (GEO-R) onboard the Geostationary Operational Environmental Satellite (GOES). The impact is measured with a robust conventional observing network already in place.

The value of various measurements can be assessed from information content theory. This indicates the potential for a measurement to contribute to an operational assimilation system; it is quantified by computing how much the synthesized measurements reduce the "information entropy" of the assimilation system (Huang and Purser 1996). If the "information entropy" reduction (IER) is minimal, the measurements are not adding information. If the IER is significant, the measurements are contributing information and can improve the forecast provided they are assimilated properly and the forecast model has the pre-requisite skill. There has been an indication of significant IER from the GEO-I; Menzel (1999) shows geostationary high spectral resolution soundings containing radiosonde-like information in moist atmospheres available for temperature and moisture profiling every hour at a spacing of 50 km in clear skies.

An OSSE is the combined measure of the information content of a component of the observing system and the ability of the analysis/forecast system to effectively utilize the information. If there is no impact, it could be either lack of new information or under-developed skill in the model for assimilating new information.

This paper summarizes a Geo-Interferometer OSSE, emphasizing the impact on improved moisture analysis and forecast. It is felt that the most significant impact of geostationary high spectral resolution measurements will be in better depiction of moisture gradients horizontally and vertically.

2. OSSE Design

There are four major components of an OSSE. First, a state of the art NWP system is necessary to generate a nature run; output from this model is taken to be the "true" state of the atmosphere. Second, observations that are characteristic of the observing systems under consideration are synthesized from the nature run forecasts. Third, an independent operational NWP system assimilates the synthesized observations to produce a forecast. Fourth, forecast impacts are assessed against a control.

The forecast model used to produce a "true" atmosphere must be calibrated against reality and have a known performance history. The observations synthesized from the "true" atmosphere must mimic, as close as possible, real observations from the observing system under investigation.

The OSSE described here measures impact over a limited area. Other OSSEs have measured impact on a global scale (Baker 1995; Atlas 1998) where pre-specified lateral boundary conditions do not influence the results. In order to mitigate the influence of boundaries on this regional OSSE, the validation area is restricted to a sub-domain well within the OSSE domain.

Measurements from various components of the composite observing system over the North American region are synthesized from the truth atmosphere by superimposing typical measurement error structures on the "true" atmospheric parameter being measured directly or inferred.

2a. Generate "true" atmosphere

The University of Wisconsin Non-hydrostatic Modeling System (UW-NMS) was used to create a four-dimensional atmosphere consisting of the model dependent variables (Tripoli 1992). These data define "truth" for the OSSE.

UW-NMS is a non-hydrostatic weather prediction model used for atmospheric research. Recent research applications include investigating the interaction of deep convection with mesoscale and synoptic-scale weather and tropical cyclones. The model has been used to examine the organization of tropical cloud clusters, tropical cyclogenesis, polar lows, gravity waves and other mesoscale organization within wintertime baroclinic cyclones. It can also simulate the mesoscale organization of lake effect snowstorms, severe storms including super cells, multi-cells and derechos, mid-latitude mesoscale convective complexes, and large eddies in the planetary boundary layer (PBL).

The model is readily reconfigured. It can be configured for resolutions down to 250 meters. It uses a local spherical coordinate system in the horizontal and a height coordinate system in the vertical with step topography using a terrain following variable grid spacing near the ground. Multiple two-way interactive nesting of the grid is available with, moveable inner grids. The gridscale microphysics parameterization contains cloud water, rain, pristine crystals, snow, aggregate crystals, and graupel. A modified Emanuel convective parameterization scheme is used to simulate non-resolved convection. An explicit long/short wave radiation parameterization incorporating clouds is used. Diffusion is based on a Total Kinetic Energy (TKE) prediction.

In this work, the UW-NMS was configured with a horizontal resolution of 60 km for a pilot experiment. Ideally, the "true" atmosphere should be two to four times the resolution of the simulated observing system (e.g. 20-km resolution for simulating 80-km data) so that errors are representative. The horizontal domain was chosen to be as large as practical, with a verification area nested within to isolate the influence of the pre-defined lateral boundary conditions. The OSSE domain is shown in Figure 1. The model vertical resolution was chosen to be two-times the resolution of the observing system to be simulated. For the pilot study the UW-NMS was initialized with the Eta model from the National Centers for Environmental Prediction (NCEP), on the NCEP 104 grid at 25 hPa layers (NWS 1999). A 12-hour UW-NMS forecast was generated to allow "spin up"; thereafter one-hour forecasts were individually saved out to 24 hours (the next 12-hour period). These hourly fields define the "true" atmospheric state.

A measure of how good "truth" is can be found in Figure 2. Using raobs as verification, the UW-NMS nature run forecast temperatures are found to be within 1 to 1.5 C from 850 to 500 hPa for 12 to 24 hours.

This OSSE is focused on data from August 28, 1998. A weak cold front (see Figure 1), associated with an upper level short wave, was moving through the Midwest. An area of convection is present in northwest Texas. The most significant weather is Hurricane Bonnie threatening Cape Hatteras. Clear skies are ample and infrared soundings are possible over most of the model domain.

2b. Simulate observations

Measurements from the conventional surface network, radiosonde observations (RAOBS), profilers, aircraft observations (ACARS), and geostationary sounders (GEO-R radiometer and GEO-I interferometer) were synthesized in this OSSE. Temperature, moisture, and wind profiles, for a given component of the observing system, were synthesized from the "true" atmosphere by superimposing measurement error structures representative of that component of the observing system. The observation errors associated with each observation type in this OSSE are listed in Table 1; they have been inferred from the listed references (Huang et al. 1992; Menzel et al. 1998; Nieman et al. 1997; Rodgers 1990; Schmidlin 1988; Schwartz and Benjamin 1995; Strauch et al. 1987).

The data coverage for the geostationary sounders is shown in Figure 3a. Gaps in the coverage simulate cloudy fields-of-view. Data coverage from the raobs, surface, ACARS and profilers is shown in Figure 3b.

2c. Assimilate synthesized observations

The synthesized measurements were assimilated at hourly intervals over a 12-hour period in the 40km Mesoscale Analysis and Prediction System (MAPS), also known as the Rapid Update Cycle (RUC), from the Forecast Systems Laboratory (Benjamin et al. 1998). This operational forecast system was designed to assimilate observations at hourly intervals making it a good choice for these experiments. Boundary conditions were provided by the NCEP Eta model (NWS 1999), projected onto the AWIPS 211 grid (at 80 km resolution) with a vertical resolution of 50 hPa; this grid has a different projection than the NCEP 104 grid used in the "truth" run. Following the 12-hour assimilation period, a 12-hour forecast was generated. The experiments were repeated four times: (1) with perfect observations, where temperature, moisture, and wind profiles extracted directly from the "nature" run were assimilated (BEST); (2) with conventional observations only (CONV), that include surface observations, raobs, aircraft observations, and profiler data; (3) with CONV and GOES Radiometer (GEO-R) data; and (4) with CONV and GOES Interferometer (GEO-I) data. The BEST and CONV runs represent the range of performance that can be expected from the RUC for this case. The GEO-R and GEO-I fall inside this range. The previous 1-hour forecast from MAPS is used as the background profile for the next analysis cycle, just as it would in an operational system.

2d. Assess impact of synthesized observations

The impact of the observations on the assimilation system is assessed by comparing forecasts from each of the experimental runs. The ability of each observing system to steer the forecast toward "truth" is evaluated in a verification area (reduced in size from the full OSSE domain to mitigate boundary effects) by comparing each assimilation run to the "true" atmosphere generated by the UW-NMS model.

3. Pilot study results

3a. Validation against 'Truth'

The impact of the simulated observing systems was assessed by comparing each experimental forecast RUC run to "perfect observations" extracted from the UW-NMS "truth" run. RMS errors, biases and S1 skill scores were computed in the verification area (see Figure 1). The plots show the 12-hour assimilation period and the 12-hour forecast period for a total of 24 hours.

Skill scores in this paper follow the form of Anthes (1983) where S1=100 (sum(abs(de)) / sum(abs(dG))) where de=error in the horizontal gradient, dG=larger of grad(fcst) and grad(observed), and the summation is taken over the verification area. The lower the value the better the analysis or forecast; scores greater than 80 indicate little skill and scores better than 30 are considered excellent. The figures in this paper show skill scores for mixing ratio.

3b. Observation density assessment

The ability of the RUC to assimilate large amounts of information was investigated. RUC analyses were performed for 00 UTC on 28 August 1998 using UW-NMS "true" profiles at six increasing observation densities. The density (number) of temperature and moisture profiles ranged from 60 km (6000) to 240 km (250). The resulting analyses were then compared to "truth" to determine the quality of the data fit; results can be found in Figure 4. The RUC analysis does not improve appreciably with temperature measurements at better than 150 km spacing, while it is continuing to improve with moisture measurements at better than 60 km.

3c. "True" observations (BEST)

True temperature and moisture profiles (approximately 5000 were generated in cloud free regions by the UW-NMS every hour) were assimilated over a 12-hour period, at one-hour intervals. Data quality control was turned off. No errors were added to these observations. A one-hour forecast was used as the background for each data insert. The root-mean-square fit of the background and the analysis to the "nature" run is calculated at each insertion time. This experiment represents the perfect assimilation cycle, or the best temperature/moisture assimilation that can be expected from the optimum interpolation analysis used in the RUC.

3d. Geostationary Radiometer (GEO-R) and Geostationary Interferometer (GEO-I)

Several experimental simulations were completed to compare the impact of assimilating retrievals with various error characteristics. The root-mean-square error (RMSE), bias, and S1 skill scores of each simulation are computed against the "true" run in the verification area.

Figure 5 demonstrates the relative benefit of the GEO soundings over no data (CONV data were denied); it also shows how close the GEO comes to perfect (no noise) observations. During the 12-hour assimilation, the RUC 700 hPa relative humidity (RH) drifts from 12 to 14% RMSE with respect to truth without any additional data input. Hourly GEO-R brings this down to 10%; hourly GEO-I produces an even better 5% RMSE. Assimilating perfect hourly profiles allows the RUC to accomplish 2% RMSE. In the 12 hour forecast these numbers change to 17% (NO DATA), 14% (GEO-R), 12% (GEO-I), and 10% (PERFECT DATA). The differences during the RUC assimilation cycle are reduced in the 12-hour RUC forecast; the 5% incremental improvement of GEO-I over GEO-R in the assimilation cycle is reduced to 2% incremental improvement in the 12 hour forecast. Biases go from 0 C (NO DATA), -2 C (GEO-R and GEO-I), and -6 C (PERFECT DATA) in the assimilation to -1, -1, -2, and -4 C respectively in the forecast. Skill scores drift 10 points for no data and 5 points for GEO data. In summary for RMSE of 700 hPa RH, GEO-R goes one third of the way from no data to perfect data, while GEO-I goes two-thirds of the way.

Figure 6 shows the impact of GEO soundings and winds on 700 hPa RH when superimposed on conventional (CONV) data. During the assimilation, CONV data allows the RUC to agree within 11% RMSE of truth. GEO-R reduces this to 9%; GEO-R is providing 700 hPa moisture information beyond that provided by the conventional data. GEO-I improves the RMSE further to 6%. In the RUC 3 hour forecast, the RMSE are 11, 9 and 7% for CONV, GEO-R and GEO-I respectively. At 12 hours, the RMSE become 14, 14, and 12%; some of the improvement from GEO-I data has been lost.

Figure 7 shows the impact of GEO soundings and winds closer to the boundary layer at 850 hPa. During the assimilation cycle, GEO-R and CONV fluctuate around 11% RMSE for 850 hPa RH; sometimes the GEO-R is degrading the CONV result. However, the GEO-I clearly improves CONV; the GEO-I RMSE is 5%. The high spectral resolution data provides information about moisture low in the troposphere that the RUC is assimilating successfully. In the RUC 3 hour forecast, the RMSE are 11, 10 and 7% for CONV, GEO-R and GEO-I respectively. At 12 hours, the RMSE become 17, 15, and 14%; again some of the improvement from GEO-I data has been lost.

Figure 8 explores the effect of noise on the GEO soundings and winds. Stepping from GEO-R to GEO-I sounding performance in three equal steps, the RMSE performance is found to vary in a roughly linear fashion. Obviously the better instrument noise performance produces better soundings that the RUC assimilates for improved 850 hPa RH depiction.

3e. Geostationary Interferometer (GEO-I) versus two polar orbiting Interferometers (LEO-I)

The impact of soundings from polar orbit are now compared to those from geostationary orbit. Figure 9 compares GEO-I soundings and winds versus LEO-I soundings, where two polar orbiting interferometers with microwave help in clouds are covering the model domain every six hours in two swaths separated by 100 minutes. The hourly GEO-I is found to provide information beyond that provided by the polar orbiting data alone. During the assimilation cycle, 850 hPa RH RMSE is 11, 8 and 5% for CONV, LEO-I, and GEO-I respectively. In the RUC 3-hour forecast, the RMSE are 11, 9 and 7% for CONV, LEO-I and GEO-I respectively. At 12 hours, the RMSE become 17, 15, and 14% respectively.

4. Conclusions

RUC analysis at 40 km resolution does not improve appreciably with temperature measurements at better than 150 km spacing (roughly 4X the model resolution), while it continues to improve with moisture measurements at better than 60 km (1.5X the model resolution). GEO-R provides moisture information at 700 hPa, but not at 850 hPa. GEO-I has two times as much temperature and moisture information as GEO-R, and GEO-I resolves boundary layer moisture. As demonstrated by the GEO-R' and GEO-I' experiments, the GEO impact appears to be linear with noise. Finally, LEO-I does not equal GEO-I moisture performance. Hourly high spectral observations make obvious improvements to regional model performance; 3-hour forecasts retain more of the benefit than 12-hour forecasts.

5. Future plans

There are several areas in which these experiments will be refined. The pilot study consists of a single case with fairly benign weather apart from Hurricane Bonnie. This will be expanded to 14-day test periods with winter and spring conditions. Also, real not simulated retrievals will be assimilated in the RUC. Subsequently, radiances will be assimilated when 3DVAR is available for the RUC.

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Table 1. Observation Errors

Obs type	*No. profiles**		*Temp error*	*Moisture error*		*Wind error*
RAOB	98		0.3 C	0.5 C (dew pt)		0.4 m/s
all sky > 300 hPa						
SFC	600		0.3 C	0.5 C (dew pt)		0.4 m/s
ACARS	3000		1 C	na		1 m/s
all sky > 300 hPa						
Profilers	31		na	na		1 m/s
all sky > 300 hPa						
GEO-R						
soundings	3500		2.0 C	1.0 (mixing ratio)		
clear skies > 100 hPa		bias	0.27 C	0.053		
winds	9000					
clear skies					300 hPa	5.0 m/s
					400	4.5
					500	4.0
cloudy skies					200	4.5
					300	4.0
					400	3.5
					500	3.5
					700	3.0
					850	2.5
GEO-I						
soundings	4500		1.0 C	0.5 (mixing ratio)		
clear skies > 100 hPa		bias	0.1 C	0.02		
winds	14000					
clear skies					200 hPa	3.5 m/s
					300	3.2
					400	3.0
					500	2.6
					700	2.0
cloudy skies					200	3.0
					300	2.6
					400	2.3
					500	2.3
					700	2.0
					850	2.0

* number of observations during the 12 hour assimilation cycle

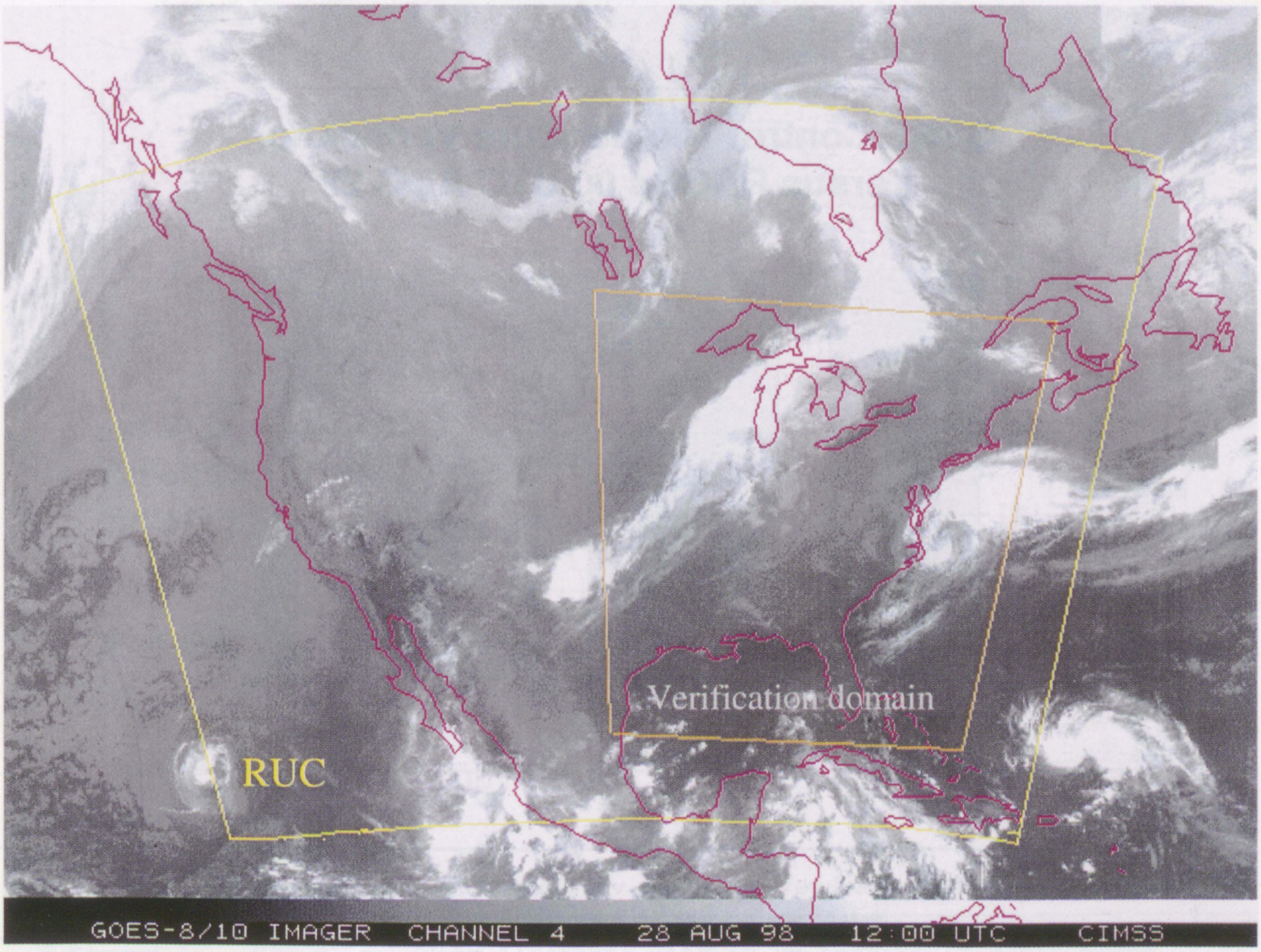


Figure 1. OSSE domain.

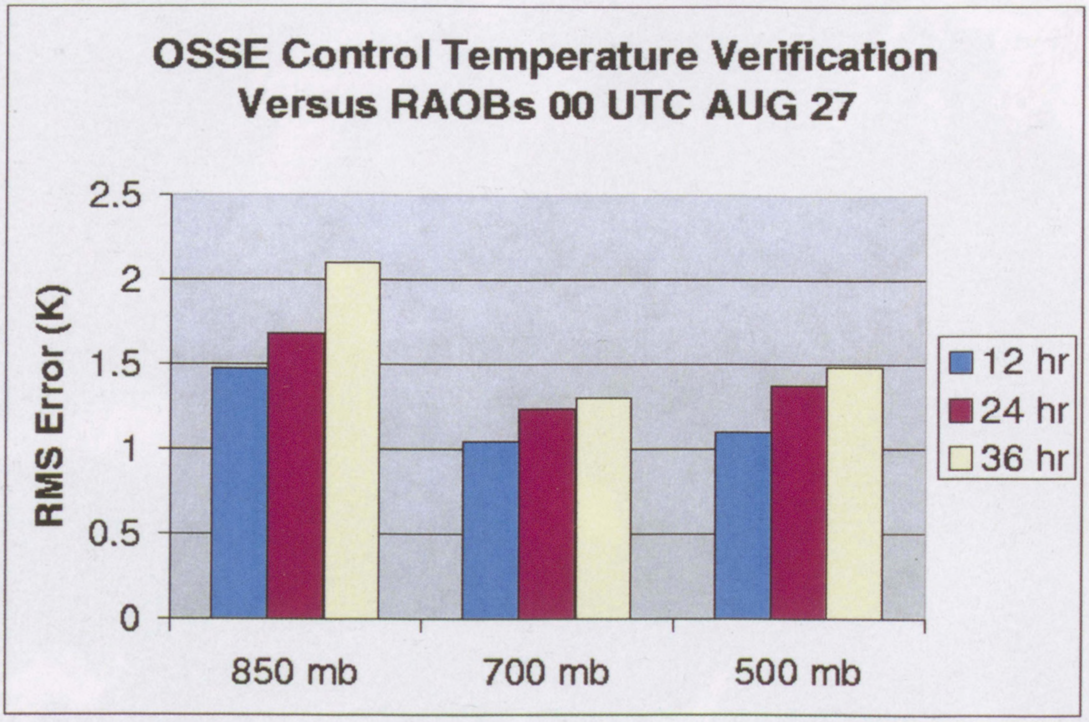


Figure 2. UW-NMS (Nature) forecast verification against raobs.

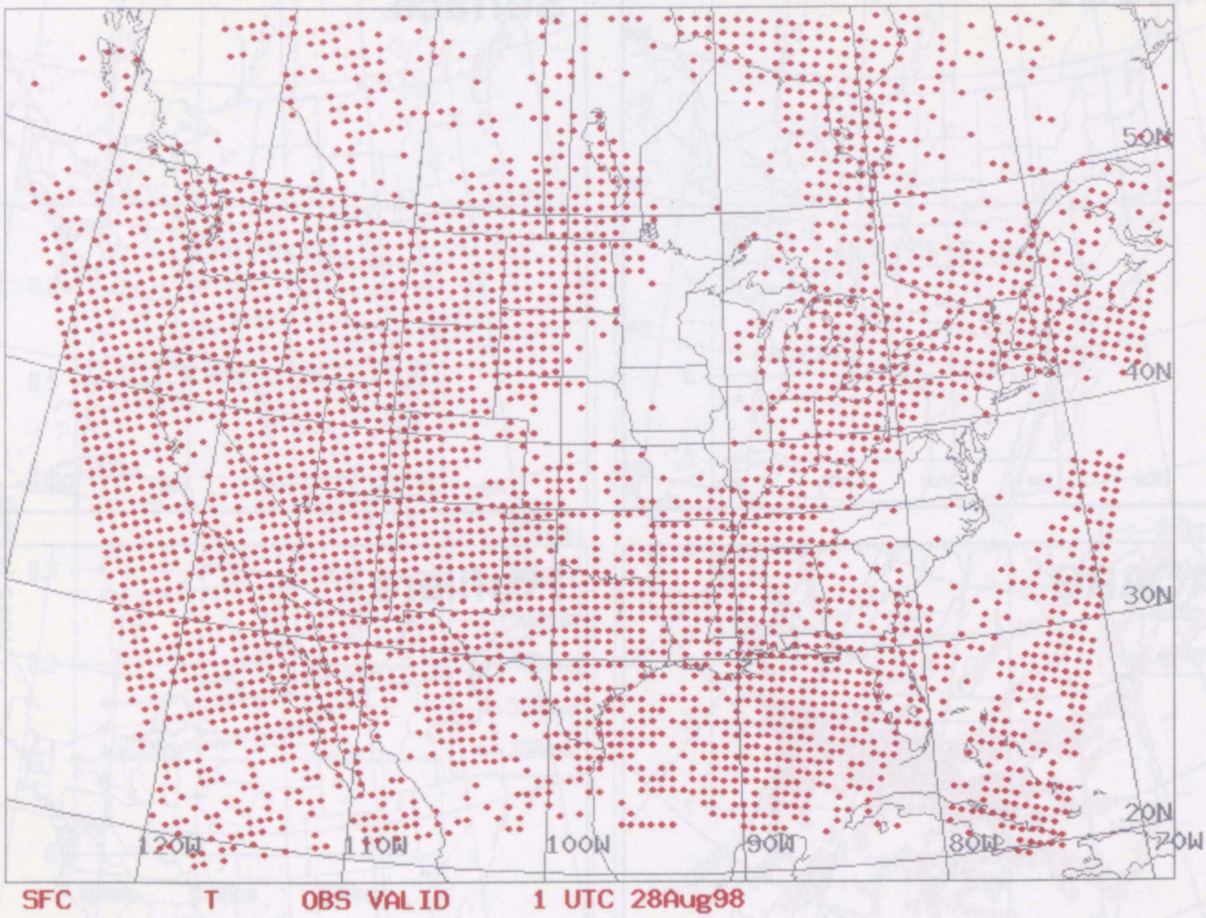


Figure 3a. GEO-R sounding locations with 60 km spacing in clear skies.

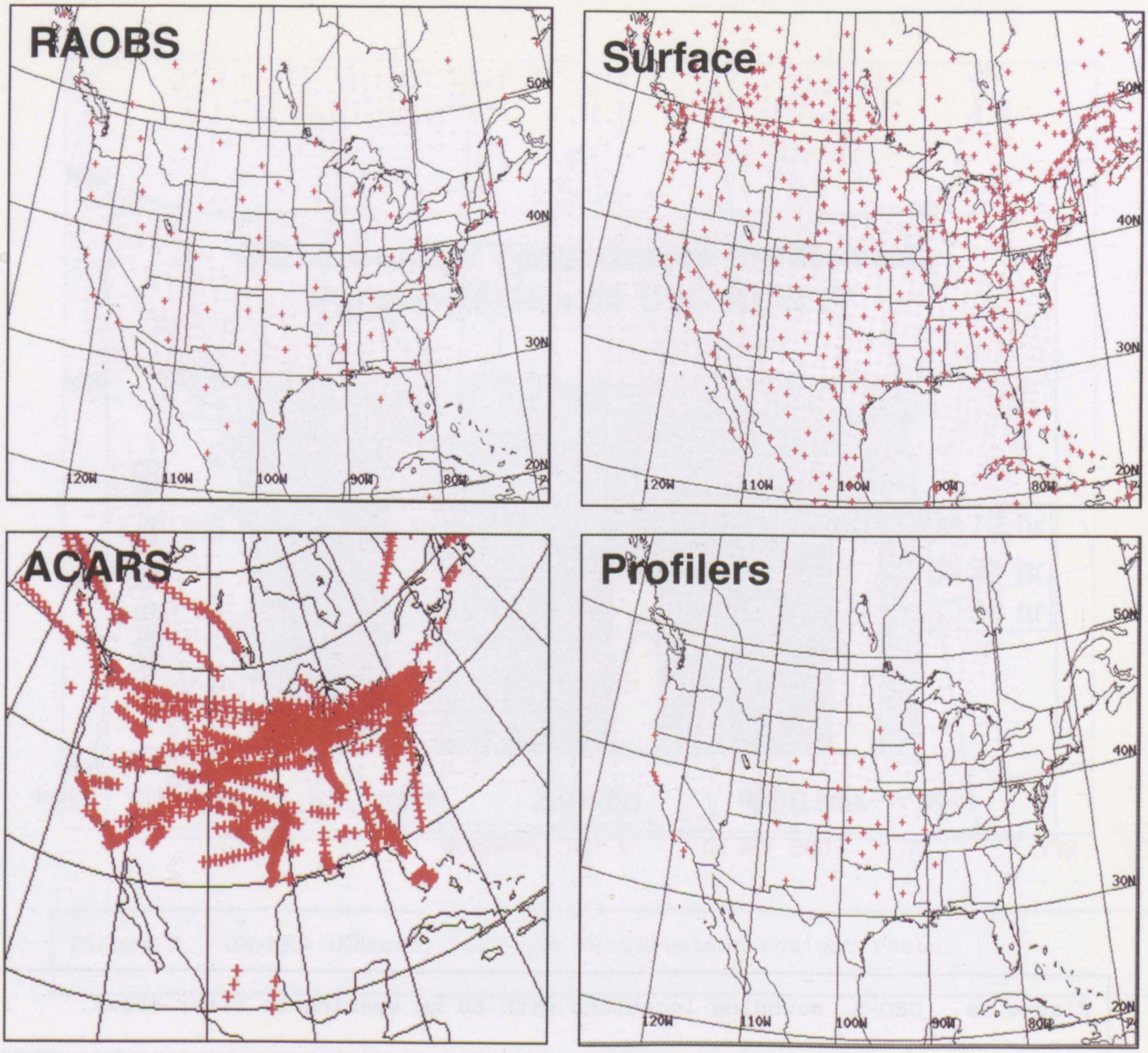


Figure 3b. Data coverage from components of the conventional observing system.

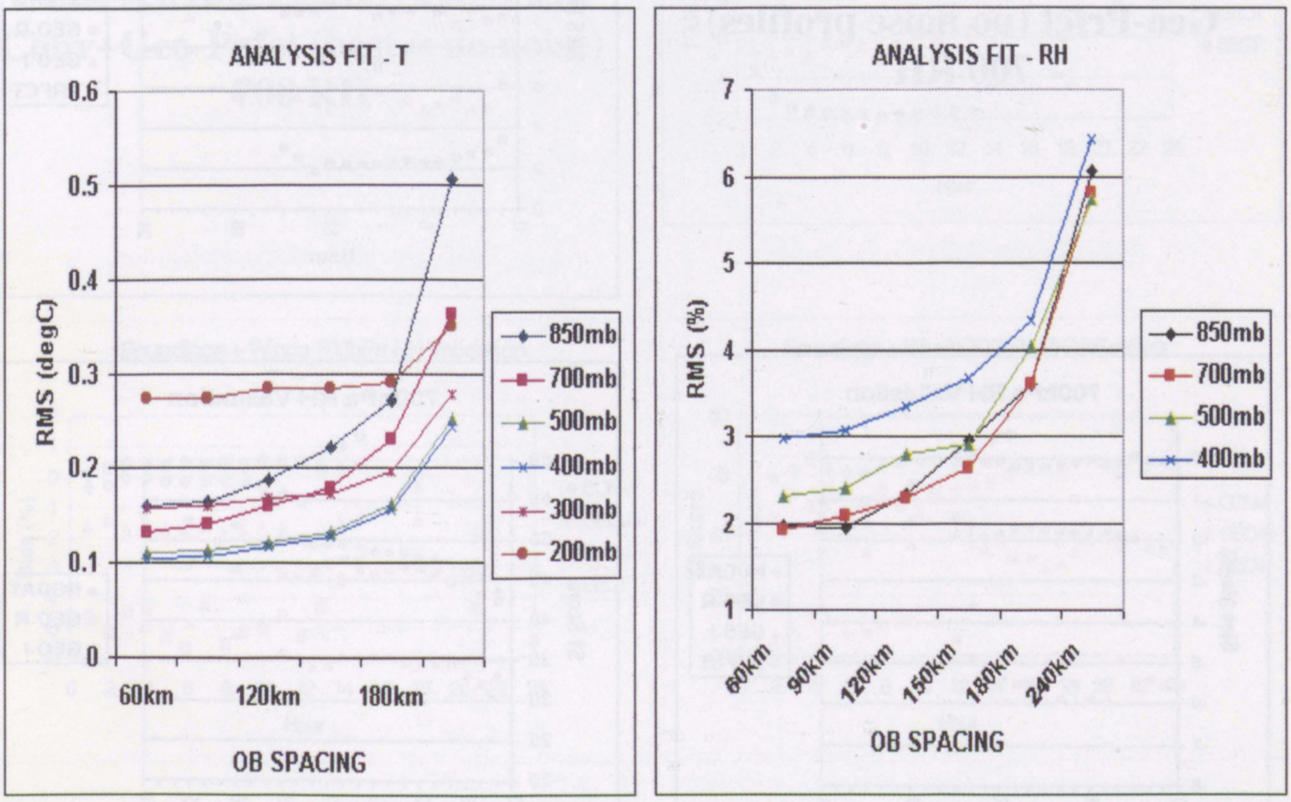
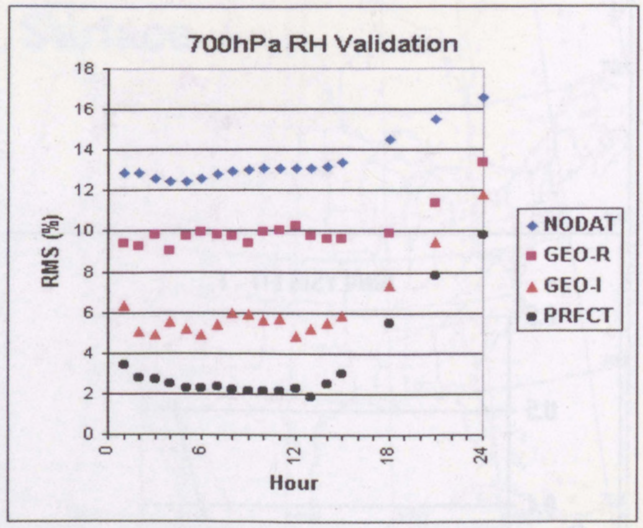
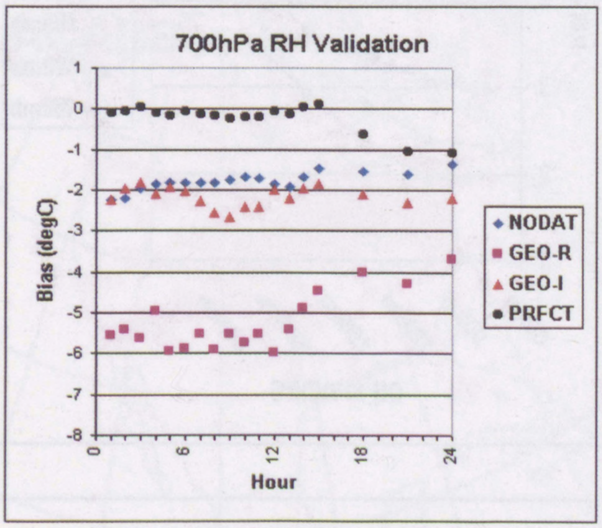


Figure 4. Analysis fits of temperature and relative humidity for different observation spacings.

Using only Geo soundings T and Td No Data vs Geo-R vs Geo-I vs Geo-Prfct (no noise profiles) 700 RH





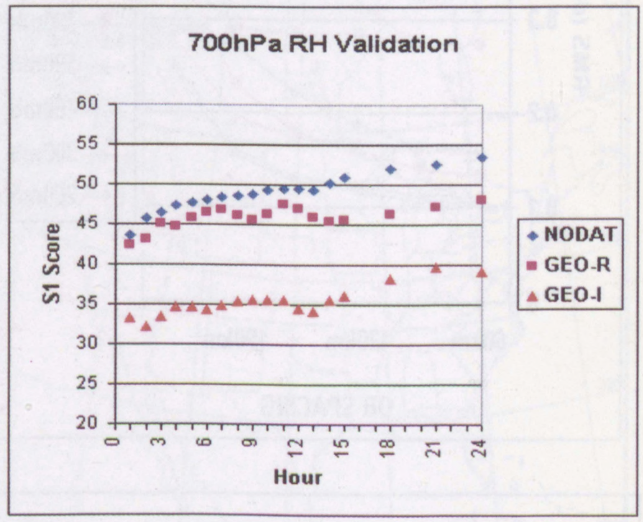
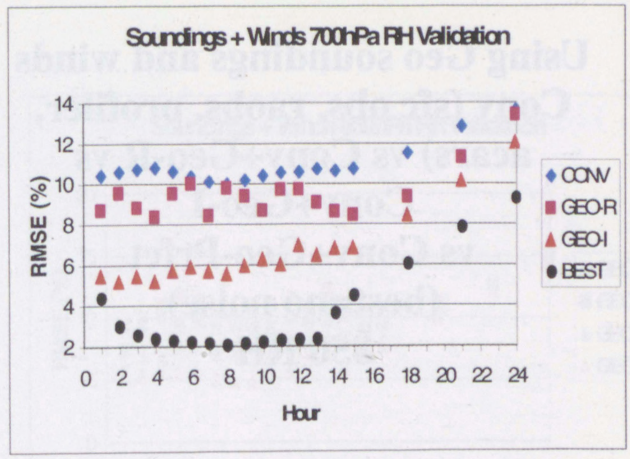
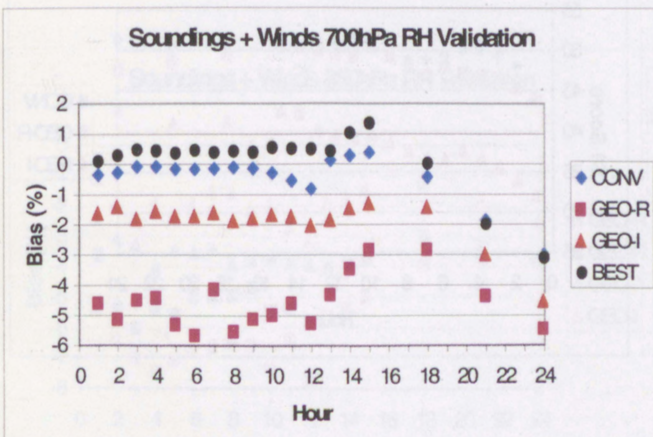


Figure 5. 700 RH results using only Geo soundings T and Td; No Data vs Geo-R vs Geo-I vs Geo-Prfct (no noise profiles). Hours 0 to 12 comprise the assimilation cycle and hours 13 to 24 are the forecast for 1 out to 12 hours.

Using Geo soundings and winds Conv (sfc obs, raobs, profiler, acars) vs Conv+Geo-R vs Conv+Geo-I vs Conv+Geo-Prfct (best = no noise) 700 RH





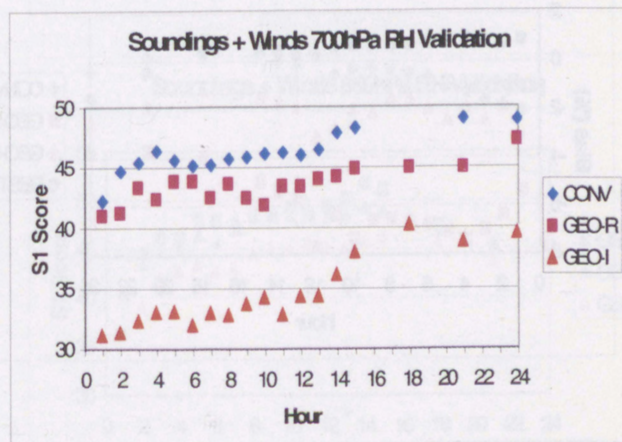
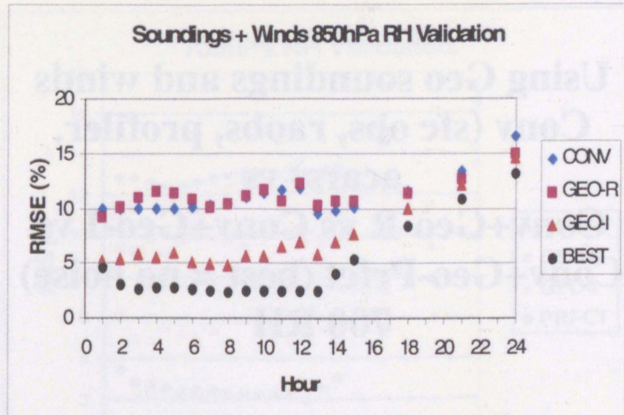
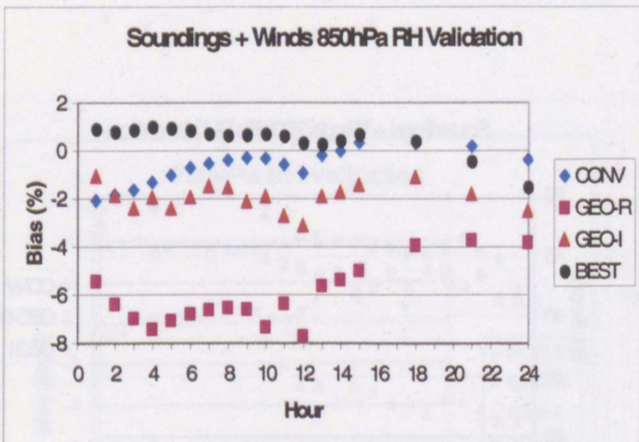


Figure 6. 700 RH using Geo soundings and winds Conv (sfc obs, raobs, profiler, acars) vs Conv+Geo-R vs Conv+Geo-I vs Conv+Geo-Prfct (best = no noise). Hours 0 to 12 comprise the assimilation cycle and hours 13 to 24 are the forecast for 1 out to 12 hours.

Using Geo soundings and winds Conv (sfc obs, raobs, profiler, acars) vs Conv+Geo-R vs Conv+Geo-I vs Conv+Geo-Prfct (best=no noise) 850 RH





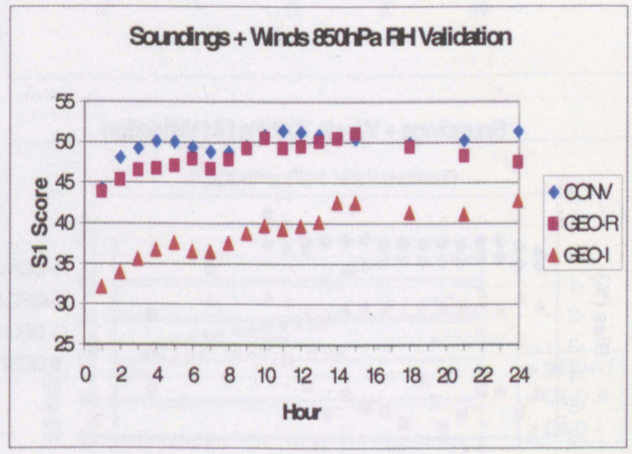


Figure 7. 850 RH using Geo soundings and winds Conv (sfc obs, raobs, profiler, acars) vs Conv+Geo-R vs Conv+Geo-I vs Conv+Geo-Prfct (best = no noise). Hours 0 to 12 comprise the assimilation cycle and hours 13 to 24 are the forecast for 1 out to 12 hours.

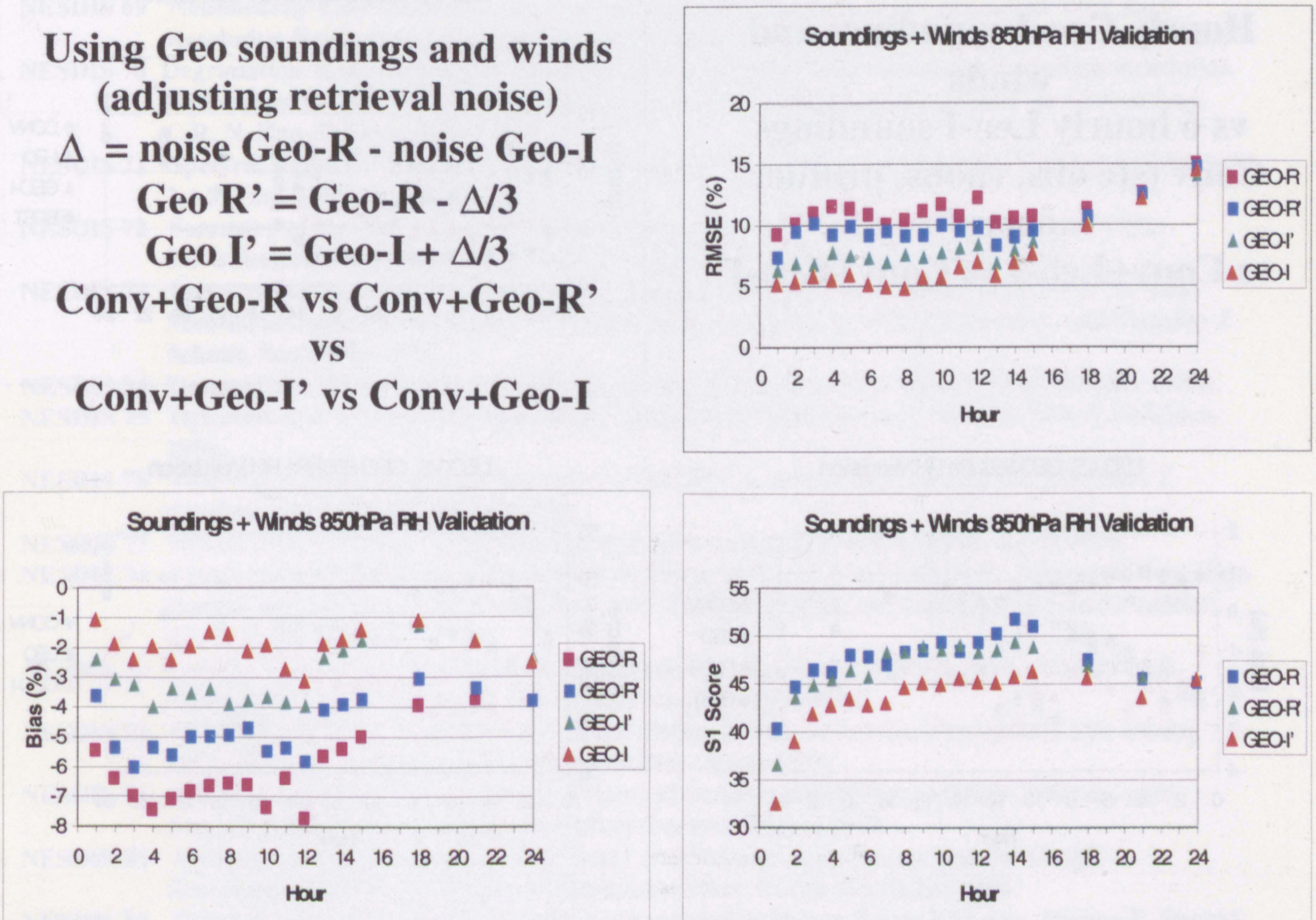
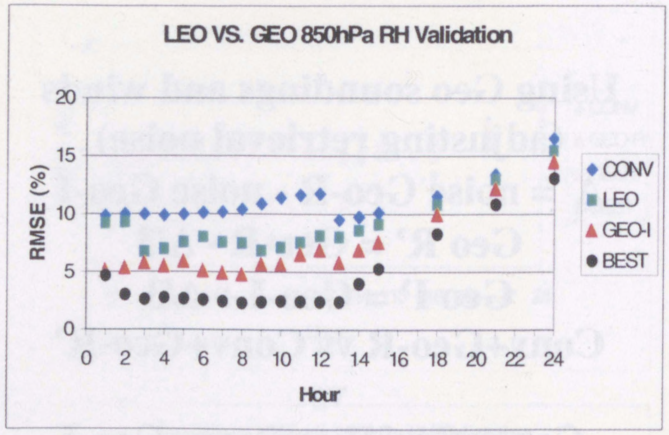
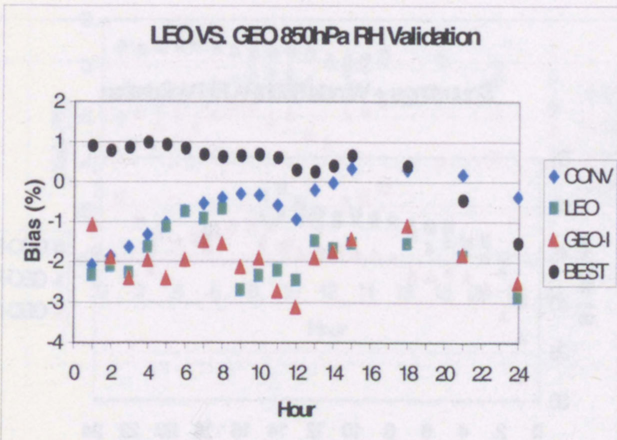


Figure 8. 850 RH using Geo soundings and winds (adjusting retrieval noise where Δ = noise Geo-R - noise Geo-I, Geo R' = Geo-R - Δ/3, Geo I' = Geo-I + Δ/3) comparing Conv+Geo-R vs Conv+Geo-R' vs Conv+Geo-I' vs Conv+Geo-I. Hours 0 to 12 comprise the assimilation cycle and hours 13 to 24 are the forecast for 1 out to 12 hours.

Hourly Geo-I soundings and winds vs 6 hourly Leo-I soundings Conv (sfc obs, raobs, profiler, acars) vs Conv+Leo-I vs Conv+Geo-I





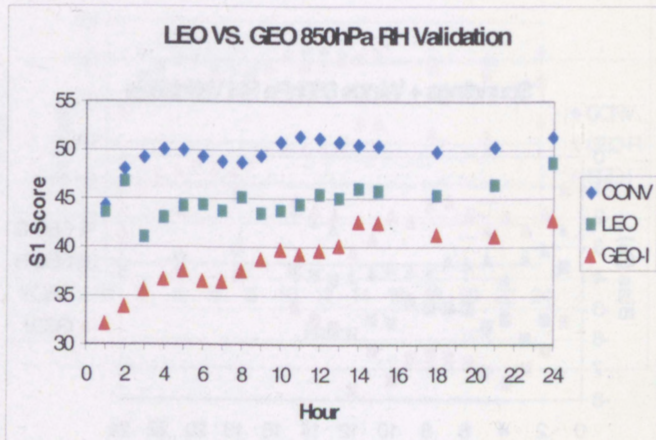


Figure 9. 850 RH using hourly Geo-I soundings and winds vs 6 hourly Leo-I soundings Conv (sfc obs, raobs, profiler, acars) vs Conv+Leo-I vs Conv+Geo-I vs Conv+Geo-Prfct (best = no noise). Hours 0 to 12 comprise the assimilation cycle and hours 13 to 24 are the forecast for 1 out to 12 hours.

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