Retrieved products from simulated hyperspectral observations of a hurricane

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ABSTRACT

This research uses GCM derived products, with 1 km spatial resolution and sampled every 10 minutes, over a moving area following the track of a simulated severe Atlantic storm. Model products were aggregated over sounder footprints corresponding to 13 km in LEO, 2 km in LEO, and 5 km in GEO sampled every 72 minutes. We simulated radiances for instruments with AIRS-like spectral coverage, spectral resolution, and channel noise, using these aggregated products as the truth, and analyzed them using a slightly modified version of the operational AIRS Version-6 retrieval algorithm. Accuracy of retrievals obtained using simulated AIRS radiances with a 13 km footprint was similar to that obtained using real AIRS data. Spatial coverage and accuracy of retrievals are shown for all three sounding scenarios. The research demonstrates the potential significance of flying Advanced AIRS-like instruments on future LEO and GEO missions.

Keywords: High spatial resolution, Infrared Sounder, AIRS, OSSE, retrievals, hyperspectral

1. INTRODUCTION

The objective of this paper is to demonstrate, via a simulation study, the potential utility of flying advanced Infra-red sounders on future satellite missions with spectral and radiometric characteristics similar to those of AIRS (Atmospheric Infra-Red Sounder**)**. Instruments for two types of future satellite missions are addressed. The first study addresses a higher spatial resolution AIRS-like instrument on a future Low Earth Orbiting (LEO) satellite mission. The second study addresses the utility of flying a high spatial resolution version of AIRS on a Geostationary (GEO) satellite mission. These studies had two different, but related research objectives. The first research objective was to demonstrate the type of results we will be able to achieve if we had such sounders on future missions. The second objective was to send our Quality Controlled (QC'd) retrieved values of temperature and water vapor profiles to Bob Atlas and co-workers at the NOAA Atlantic Oceanographic Meteorological Laboratory (AOML) for their use in observing system simulation experiments (OSSE's). Both studies use satellite radiances that we simulated using surface and atmospheric conditions consistent with those generated by a forecast model run by Bob Atlas and co-workers, called the Nature Run, over the time period July 29, 2005 through August 10, 2005[1]. The Nature Run simulated the formation and evolution of a hypothetical hurricane in the North Atlantic Ocean. Pagano et al.[2] developed and used methodology to simulate a satellite orbit track to provide sample locations and footprints of the infrared sounder configurations over the region of interest. The data sampled was obtained from the OSSE Nature Run developed by AOML and the University of Miami (UM). Pagano et al. [2] sampled the Nature Run at the sounder locations with values averaged over the instrument footprints. Model conditions averaged over the footprints of three instruments were generated, corresponding to the AIRS footprint in LEO, a hypothetical high spatial resolution sounder in LEO called ARIES (Advanced Remote-Sensing Imaging Emission Spectrometer), and a hypothetical GEO sounder. The Nature Run "truth" data set was used in the simulation of the satellite observations as well as in the validation of retrieved products. The Nature Run was explicitly developed by the NOAA AOML and the University of Miami (UM) for the purposes of testing the value of various meteorological measurement strategies on hurricane forecast improvement. The Nature Run provides values of geophysical parameters of the atmospheric surface state in three dimensions over the region of the simulated hurricane for the 13 day period July 29, 2005 through August 10, 2005. The model geophysical parameters we used include: surface skin temperature; atmospheric temperature and water vapor profile; and cloud cover for a given latitude, longitude, and time. All model vertical profiles are reported on 60 pressure levels up to 50 mb. Values of all model geophysical parameters were averaged over the footprint and reported as "truth" for each instrument footprint and time. Each instrument therefore had its own truth file.

AIRS sampling characteristics were selected as the baseline for our LEO observation experiments since this represents the current state of the art with atmospheric sounding from space. AIRS footprints have a spatial resolution of 13kmx13km at nadir and a twice daily revisit time with a 1:30 am/pm equatorial crossing local time. The footprint at nadir is nominally circular for AIRS and grows with scan angle. Scan angles were obtained from an AIRS Level 1B granule and the difference between adjacent angles fit to a polynomial to give a footprint growth function. A similar method was used for the track direction. The analytic formula used to determine the footprint size at each footprint location contributes less than 10% error to the size at any location. We also simulated footprints for a proposed higher spatial resolution sounder, ARIES, with a 2 km x 2 km spatial resolution from LEO, but still with only a revisit twice daily. There would be numerous advantages of flying ARIES, otherwise equivalent in capability to AIRS, but with a 2 km spatial resolution, on a LEO Satellite. The current operational AIRS Science Team Version-6 retrieval algorithm performs accurate QC'd retrievals under almost all cloud conditions. Accurate QC'd retrievals can be produced down to the surface as long as there is sufficient cloud contrast within the 3x3 arrays of AIRS 13 km Fields of View (FOVs) contained in an AIRS Field of Regard (FOR), over which surface and atmospheric parameters are retrieved[3]. The 2 km spatial resolution of ARIES would result in more cloud contrast within the FOV's in the FOR and allow for more accurate retrievals down to the surface with better spatial coverage. Having higher spatial resolution would also be very beneficial towards achieving better and more accurate soundings with regard to geophysical parameters that vary rapidly in space, such as water vapor profiles, trace gas concentrations, and clouds themselves. Surface conditions over land, such as elevation, temperature, and surface emissivity, can also vary rapidly in space. The 2 km spatial resolution of ARIES would lead to significantly improved surface and lower tropospheric atmospheric conditions retrieved over land as a result of decreased scene variability over the FOR. The sampling locations for ARIES were produced by oversampling the AIRS sampling pattern. Finally, for the GEO simulation, the sampling locations were produced for a 5 km x 5 km nominal ground resolution from GEO, with all observations taken at nadir. A spatial resolution of 5 km was chosen based on the Hyperspectral Environmental Suite (HES) Performance Operational Requirements Document (PORD) requirement 3.2.5.2.1.0-2 that requires the IFOV to be less than 140μm (5 km from GEO) for bands with wavelengths greater than 3μm in Severe Weather/Mesoscale (SW/M) mode. More details are given in Pagano et al.[2].

2. PREPARATION FOR AIRS-LIKE RADIANCES AND RETRIEVALS

All retrievals performed in this study use the AIRS Science Team Version-6 retrieval algorithm[3] with minor modifications. These retrievals were run in the operational AIRS Version-6 AIRS Only (AO) mode because we did not simulate radiances for an accompanying microwave sounder such as AMSU, which accompanies AIRS on Aqua. A single AIRS Version-6 retrieval is performed using observed radiances $R_{i,j}$ in a contiguous 3x3 array of AIRS Fields of View (FOVs) where $R_{i,j}$ is the observed radiance in AIRS channel i in FOV j. The first step in our preparation for generation of AIRS retrievals for a given sounding scenario was to group the truth fields for each footprint into contiguous groups of 3x3 FOVs. As a result of this, model "truth" data from some FOVs were left over and were excluded from our simulation study. We used the AIRS Version-6 Radiative Transfer Algorithm (RTA) to generate channel and footprint radiances $R_{i,j}$ as a function of the "truth" for FOV_j. The model truth field provided values of surface pressure, surface skin temperature, and temperature and water vapor profiles up to 50 mb. The AIRS RTA requires values of temperature and water profiles, as well as concentrations of other trace gas constituents, up to 0.004 mb. We extrapolated the "truth" values of $T(p)$ and $q(p)$ above 50 mb according to differences from climatology to provide the necessary input into the RTA. We also used climatological values for all other trace gas concentrations as part of the state used to generate the radiances. Even though use of climatology simplified the retrieval problem in some ways, we felt that leaving out stratospheric variability of $T(p)$ and $q(p)$, as well as the variability of trace gas concentrations such as $O_3(p)$ was somewhat orthogonal to the issue of the effects of differing spatial resolution, and therefore was a reasonable simplification for the purposes of the simulation study. Given the "truth" state for FOV_j, we generated channel radiances using the AIRS RTA and then added appropriate values of random noise to radiances values of each channel using the AIRS channel $NE\Delta N_i$ file. If a channel was missing from real AIRS data because it was in a spectral gap or the detector was dead, we did not generate values of $R_{i,j}$ for that channel.

The most difficult, and most important, aspect of our study was in the simulation, for each FOV_j, of the distribution of fractional cloud cover as seen from above. For a given 1 km x 1 km model grid point, the Nature Run provides values of 0 or 1 at different pressure levels where 0 means the model has no cloud cover at that pressure and 1 means a cloud exists at that pressure in that model grid point. The model clouds are 3 dimensional. Therefore, the model can contain a cloud which exists in many contiguous pressure intervals. There may then be a gap of cloud cover in the vertical over many pressure intervals, and then another interval of higher pressures (lower heights) containing cloud cover again, etc. The model "truth" for average cloud cover as a function of height over the instrument footprint was generated by averaging the values of cloud cover as a function of height over all the 1 km model grid points contained in the FOV. The "truth" fractional cloud cover distribution as a function of height for FOV_j as generated in that manner, was not directly useful for the purposes of computing channel radiances $R_{i,j}$, however, as $R_{i,j}$ depends on the fractional cloud cover in FOV$_j$ as a function of height as seen from above. We used the following procedure to generate reasonable cloud distributions as seen from above in a given FOV. We separated the model FOV cloud distributions into contiguous pressure groups, having no zero cloud fractions in any of the pressures in the group. Then, starting from the top (lowest pressure) group we selected the pressure within the group which has the largest cloud fraction for the FOV. We assigned that to be the FOV cloud fraction for a cloud at that pressure, and assigned zero cloud fractions to all lower pressures, and also assigned zero down to the next contiguous cloud pressure group. We performed the same procedure again over the cloud pressure interval in the next group, that is, within the next cloud pressure interval. We set FOV cloud fractions at all pressures within that next group to zero except for the one that had the highest cloud fraction. This time, if indeed there are multiple cloud pressure groups for a single FOV, the FOV cloud fraction assigned in the second cloud pressure interval was taken to be the model value multiplied by one minus the cloud fraction of the top level. If, for example, the pressure level in the top group was assigned a cloud fraction of 10%, and the model cloud fraction for the appropriate pressure in the second group was 60%, the cloud fraction for the second group was set to be 54%. We repeated this process with regard to setting FOV cloud fractions and cloud top pressures for all contiguous pressure intervals each time multiplying the next group cloud fraction by one minus the sum of the top cloud fractions, etc. This procedure ensures that whatever the final cloud distribution for that FOV comes out to be, the total FOV cloud fraction as seen from above summed over all levels lies between zero and one.

2.1 Examples of model truth scenes

Figure 1 gives a depiction of the progression and intensification of the storm in terms of truth values of temperature (K) and specific humidity (g/kg) at 600 mb and 300 mb taken from the 5 km x 5 km GEO run. All results show the truth fields at the

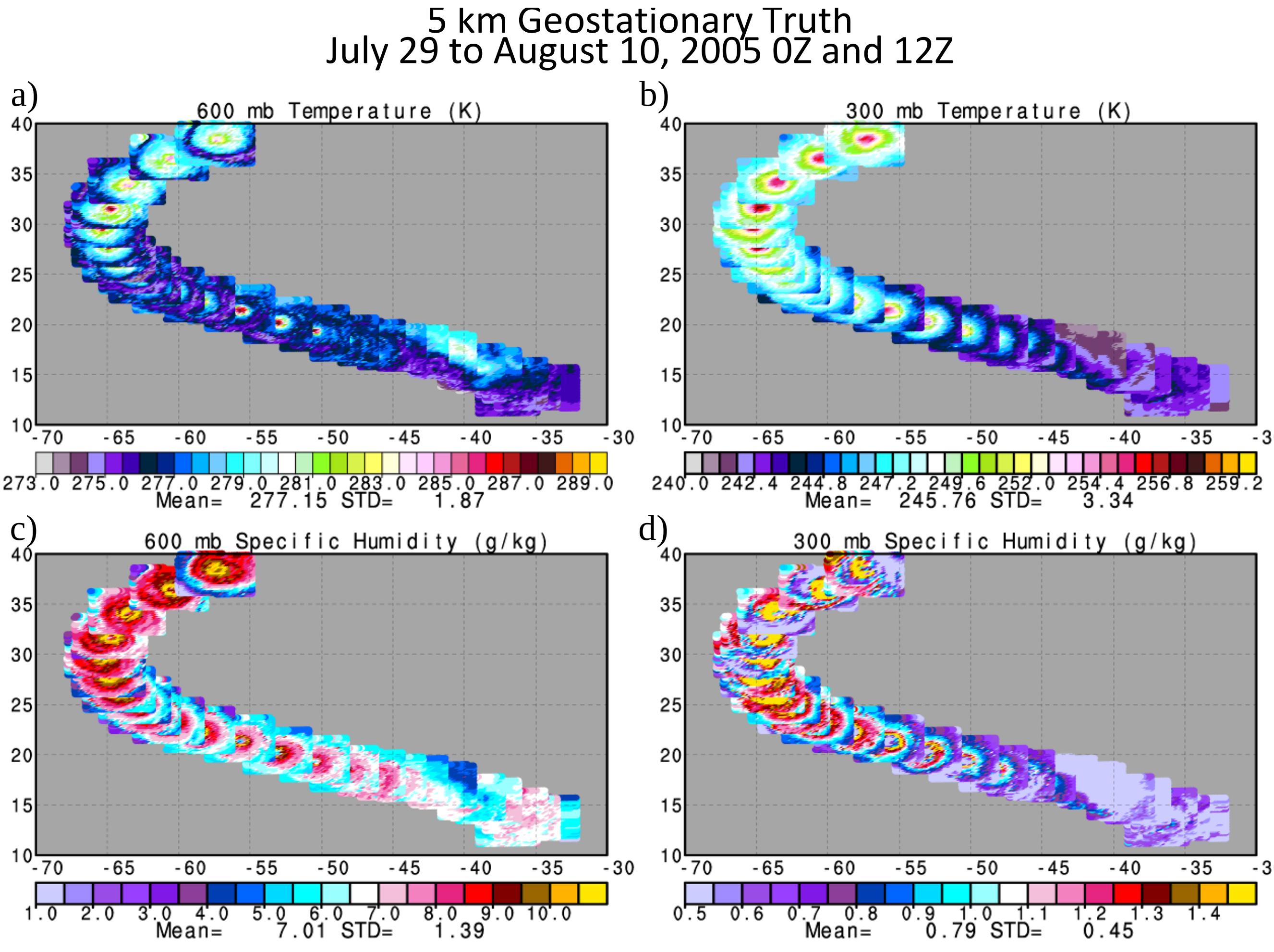

Figure 1. Nature Run truth values of *T(p)* and *q(p)* for the 5 km GEO experiment sampled every 12 hours.

center of the 15 km x 15 km FOR, sampled every 12 hours. Model data for each time period covers a spatial area of roughly 4.5° latitude by 4.5° longitude, which moves in time. The model "truth" was generated every 72 minutes (20 times per day), from which we also generated radiances and performed retrievals for each time period. Figure 1 shows model fields twice per day, for the time periods closest to 0Z and 12Z. Even so, there is significant overlap of the spatial areas covered in consecutive time periods. The storm begins to form and then intensify around August 3. The roughly circular nature of the storm is clearly observed in Figure 1. Both 600 mb and 300 mb temperatures are warmest at the center of the storm and cooler surrounding it. Central temperatures warm considerably as the storm intensifies. A similar, but not identical, spatial structure is found in the 600 mb and 300 mb specific humidity fields, which are very moist at the center of the storm, and much drier surrounding it, with a very large increase in central specific humidities as the storm intensifies.

Figure 2 shows a blowup of select model geophysical parameters for the time period August 5 0Z in which the storm has already formed. A single dot represents the value of truth for the central FOV of the 3x3 array (FOR) over which the retrievals are generated. Figure 2a shows both the cloud top pressure and total cloud fractions as seen from above. Results are shown in seven different color scales indicative of ranges of retrieved cloud top pressure, as shown in the caption beneath each figure. Shades of reds and purples indicate differing amounts of high clouds, blues and greens indicate mid-level clouds, and oranges and yellows indicate low clouds. Lighter colors indicate lower cloud fractions, and more intense colors indicate larger cloud fractions. The center of the model area contains relatively small amounts of low (yellow) clouds. This area is surrounded by large amounts of high (low pressure) clouds, shown in dark red. The area of high cloud cover is not symmetric however, and has a swirl structure in the northwestern edge of the model area, with some almost clear (white) areas toward the upper central portion of the scene. Clouds are also somewhat lower in height (purple) near these clear areas. Figures 2b

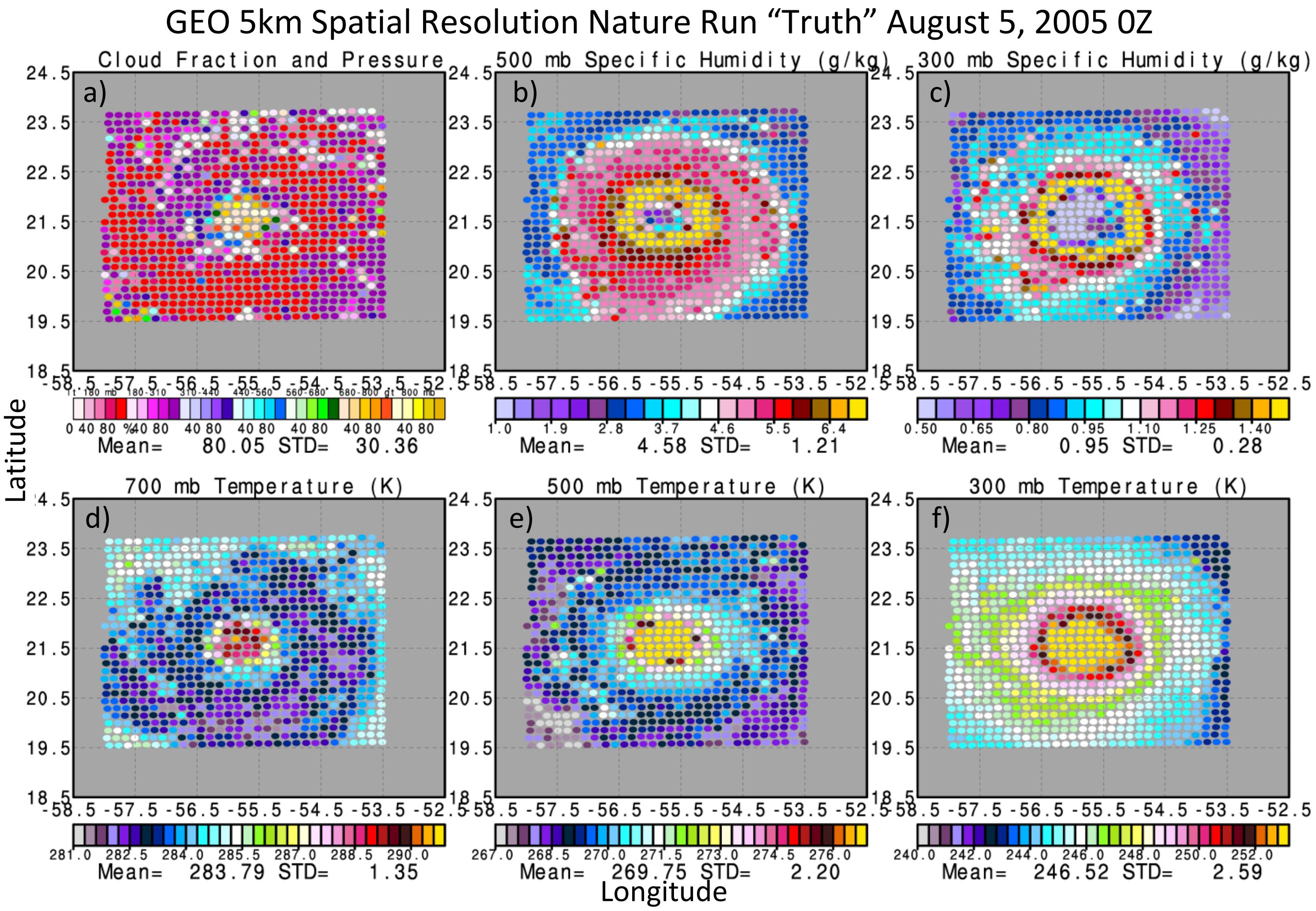

Figure 2. Nature Run truth values of select fields for the 5 km GEO experiment for the time period August 5, 2005 At 0Z. A dot represents values at the center FOV of each 15 km x 15 km FOR.

and 2c show model specific humidities at 500 mb and 300 mb. There is a roughly circular structure to the 500 mb specific humidity field, with very high values on the order of 6.8 gm/kg surrounding the center of the model area, which is marked by considerable upwelling, and a very dry area of 500 mb specific humidity at the center with values closer to 3 g/kg, which is a result of downwelling motion in this region. Some spiral structure is observed with regard to 500 mb specific humidity as well. It is interesting to note that while the spatial structure of 500 mb specific humidity is in some sense similar to that of cloud cover, the areas of high and low 500 mb specific humidity tend to be shifted somewhat to the east of those of cloud cover. Patterns of model 300 mb specific humidity are again similar, but different from those of the cloud cover and 500 mb specific humidity. Values of 300 mb specific humidity area again very low at the center of the storm with values near 0.5 g/kg, and are very high with values near 1.5 g/kg surrounding it, but with a tighter structure than that of 500 mb specific humidity, and with spiral features that are less evident than at 500 mb. Figures 2d, 2e, and 2f show model truth temperatures at 700 mb, 500 mb, and 300 mb respectively. The center of the storm is marked by locally high temperatures at all pressure levels, with values that cool as you go further from the center of the storm with spatial structures that are less spatially coherent than those of specific humidity.

3. RESULTS OF RETRIEVAL EXPERIMENTS

The following sections explain how we performed retrievals using the simulated radiance data for each experiment and demonstrate the results of these experiments in terms of both accuracy compared to their own truth fields, and more importantly, the spatial coverage of Quality Controlled results.

3.1 Retrieval methodology

All retrievals were done using the AIRS Science Team Version-6 AIRS Only retrieval methodology, but with a few modifications resulting from simplifications in the methodology used to simulate channel radiances. The AIRS Science Team Version-6 retrieval methodology[3] uses the same RTA in the analysis of observed AIRS radiances that we used to simulate the AIRS radiances. Therefore, there was no need to apply any tuning coefficients to the simulated radiances. Tuning coefficients are used in the analysis of real AIRS data to account for errors in both instrument calibration as well as errors in the radiative transfer physics used in the retrieval process.

AIRS Version-6 utilizes a Neural-Net based first guess which uses observed channel radiances to generate a first guess surface skin temperature and an atmospheric temperature and water vapor profile for each AIRS Field of Regard (FOR). Retrievals are performed on a FOR basis. We used the Version-6 Neural-Net coefficients as part of our retrieval scheme in this experiment. It was very encouraging that the Version-6 Neural-Net coefficients, which were trained on observed AIRS data, performed very well on our simulated radiances beneath 300 mb. Performance degraded at and above 300 mb because the upper tropospheric and stratospheric temperatures used in the simulation study were not realistic enough. The fact that Neural Net coefficients trained on observed AIRS radiances worked well when used on simulated radiances means that our radiance simulation methodology must have been extremely realistic, at least in the mid-lower troposphere. Version-6 also generates case-by-case, level-by-level, error estimates for temperature profiles and uses thresholds of these error estimates for QC purposes. We used an analogous methodology with regard to QC for our simulated retrievals. All retrievals have a case dependent pressure, p_{qc}, ranging from 30 mb to the surface pressure, which defines the pressure down to which we feel the retrieval is acceptable for use for the purposes of this OSSE experiment. Temperature and water vapor retrievals are flagged as QC=0 down to and including p_{qc}, and flagged as QC>0 beneath that pressure. QC=0 means use the temperature and water vapor at this pressure level for assimilation purposes, and QC≠0 means do not use the temperature or water vapor at this pressure level. We sent Bob Atlas and co-workers our retrieved products for use in their OSSE experiment, including level-by-level error estimates and QC flags.

3.2 Sample results of all experiments

Figure 3 shows composite statistics for all retrievals run for each experiment over the period of the Nature Run, July 29 through August 10, 2005. Results for the 2 km LEO simulation run are shown in blue, results for the 13 km LEO experiment are shown in red, and results for the 5 km GEO experiment are shown in black. All statistics include only those retrievals at a given pressure level which have a QC flag of 0, that is, only cases down to p_{qc} for any given FOR. Care must be taken in the interpretation of these figures because the ensembles of cases included in the statistics are different for each experiment. For

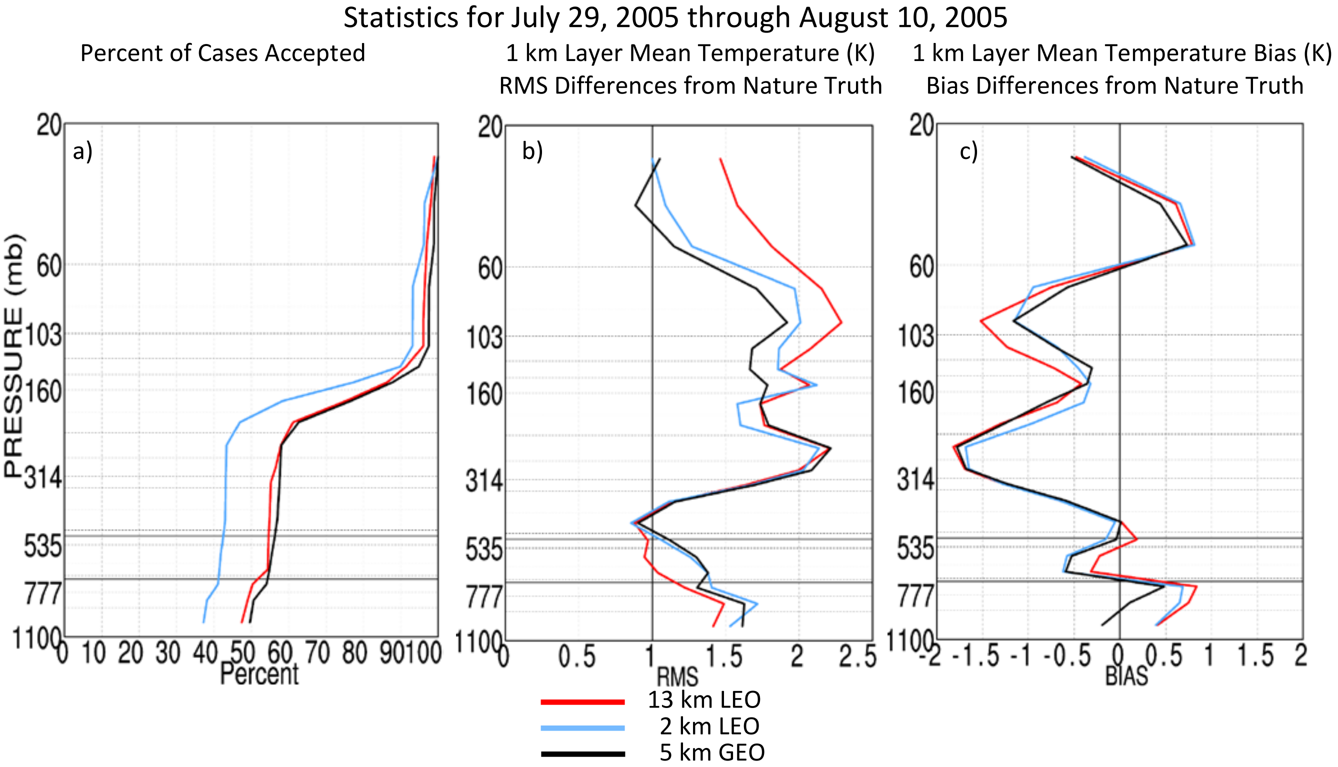

Figure 3. Percent yield, RMS differences from truth, and bias differences from truth of QC'd *T(p)* retrievals.

one thing, the GEO experiment includes results of all the cases which were run 72 minutes apart. The LEO cases were observed every 12 hours, consistent with LEO spatial coverage. Moreover, some time periods in the LEO experiment had no data whatsoever, because the spatial area covered by the model fell in orbit gaps. Finally, LEO footprints grow in size as the instrument scans away from nadir, while GEO footprints are all the same size. Therefore, the ensembles used in these three experiments relate to similar types of atmospheric scenes, but are also different from each other. In addition, the truth fields in the higher spatial resolution experiments had more spatial variability than in the lower resolution truth fields.

Figure 3a shows the percentage of cases, as a function of pressure, in which retrieved temperatures were accepted (had a QC flag of 0) as compared to all cases in which observations were simulated. These acceptance yields are close to 100% at the top of the atmosphere for each experiment, and are roughly 38% and 48% and 52% at the surface for the 2 km and 13 km LEO experiments and 5 km LEO experiment respectively. These % yields are actually quite high given that we are looking at retrievals in the presence of a hurricane. At first glance, this result gives the impression that retrievals are performing better with a 13 km spatial resolution than with a 2 km resolution, but this is an extremely misleading result because there are roughly 42 times as many cases being analyzed for the 2 km spatial resolution experiment as compared to the 13 km experiment. What is really important is the relative spatial coverages and accuracy of the retrieved temperatures for each experiment as a function of height. The different spatial coverage will be shown later. Figure 3b shows the RMS differences of retrieved temperatures with QC=0 from the collocated Nature Run truth, which is sampled at the same spatial locations. Figure 3c shows their biases, given by retrieved temperature minus truth. Error statistics are not significantly different for each experiment, but as will be shown later, many retrievals with 2 km spatial resolution occur in spatial regions containing large amounts of high cloud cover, in which there are essentially no accepted 13 km spatial resolution retrievals at all. Spatial coverages of accepted retrievals at different pressures for the 5 km LEO experiment lie between those of the other two experiments. RMS errors of all three experiments are similar to each other and are the order of 1K-1.5K beneath about 300 mb, but are a little larger above 300 mb. The bias structures of all three experiments are very similar to each other as well. The larger RMS errors above 300 mb result primarily from biases in the retrievals. The bias structures of the retrievals are similar to the bias structures in the Neural-Net guesses, which are even larger than those found in the retrievals. Figure 2 shows that the temperature structure of the truth varies by 5K or more over the course of a scene. This implies that with RMS errors on the order of 1K-1.5K, the spatial structure of the retrievals should be similar to that of the truth.

Figure 4 shows analogous results pertaining to QC'd water vapor profile retrievals. Water vapor profile results are shown in terms of RMS % difference $(q(p)-q(p)^{truth})/q(p)^{truth}$ for 1 km layer integrated precipitable water vapor within 1 km layers starting from the surface and extending upwards to 200 mb. RMS errors of all 3 experiments are again similar to each other, and are on the order of 8% in the lower troposphere and 15% in the mid-troposphere. Figure 2 shows that the truth specific humidities vary by more than a factor of 2 over a scene. Therefore, QC'd patterns retrieved values of specific humidity should again match those of the truth reasonably closely.

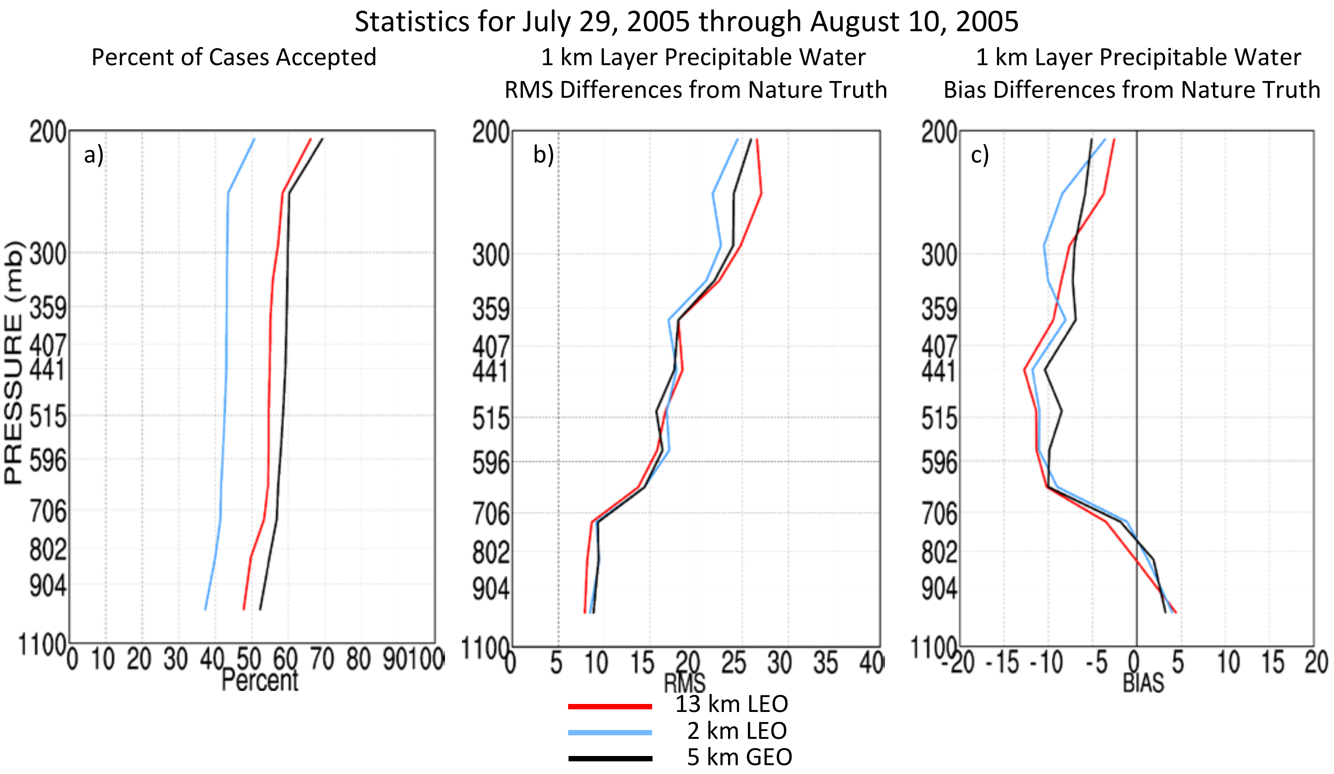

Figure 4. Percent yields, RMS % differences from Truth, and bias % differences from Truth of QC'd $q(p)$ retrievals.

Figure 5 shows spatial plots of retrieved results for the time period August 5, 0Z for the GEO sampling experiment. The potential locations of the dots are identical to those in Figure 2. Figure 5 is otherwise analogous to Figure 2, but shows values of QC'd retrievals for the 5km GEO experiment. Retrievals are plotted at the center of the 3x3 array of AIRS FOVs used for a given retrieval and are therefore at the same locations as those shown for the Truth in Figure 2. Cloud products are always retrieved. Retrievals ($QC \neq 0$) are rejected in some FORs. The centers of those FORs show up as gaps in Figure 5. Spatial patterns of all retrieved quantities are very similar to those of the truth. It should be noted that the truth is sampled at the central FOV of the scene, while retrievals are meant to be representative of the atmosphere as averaged over the FOR, which is comprised of the 3x3 array of the FOVs in the FOR. Areas containing large amounts of high cloud cover (dark red and dark purple in Figure 2a and Figure 5a), tend to show up as gaps in Figures 5b-5f. Nevertheless, the structures of retrieved fields in the vicinity of the storm match truth very closely.

Figure 6 shows analogous retrieval results and coverage for the 2 km LEO experiment, sampled at roughly the same time as shown for the GEO experiments in Figure 2 and Figure 5. The size of the dots in Figure 6 is the same as that in Figures 2 and 5. In Figure 6, the center of each dot is the center of the FOR, which is sampled every 6 km x 6 km at nadir, and grows to larger separations as the instrument scans to each side of nadir. Unlike in Figures 2 and 5, many dots overlap in Figure 6

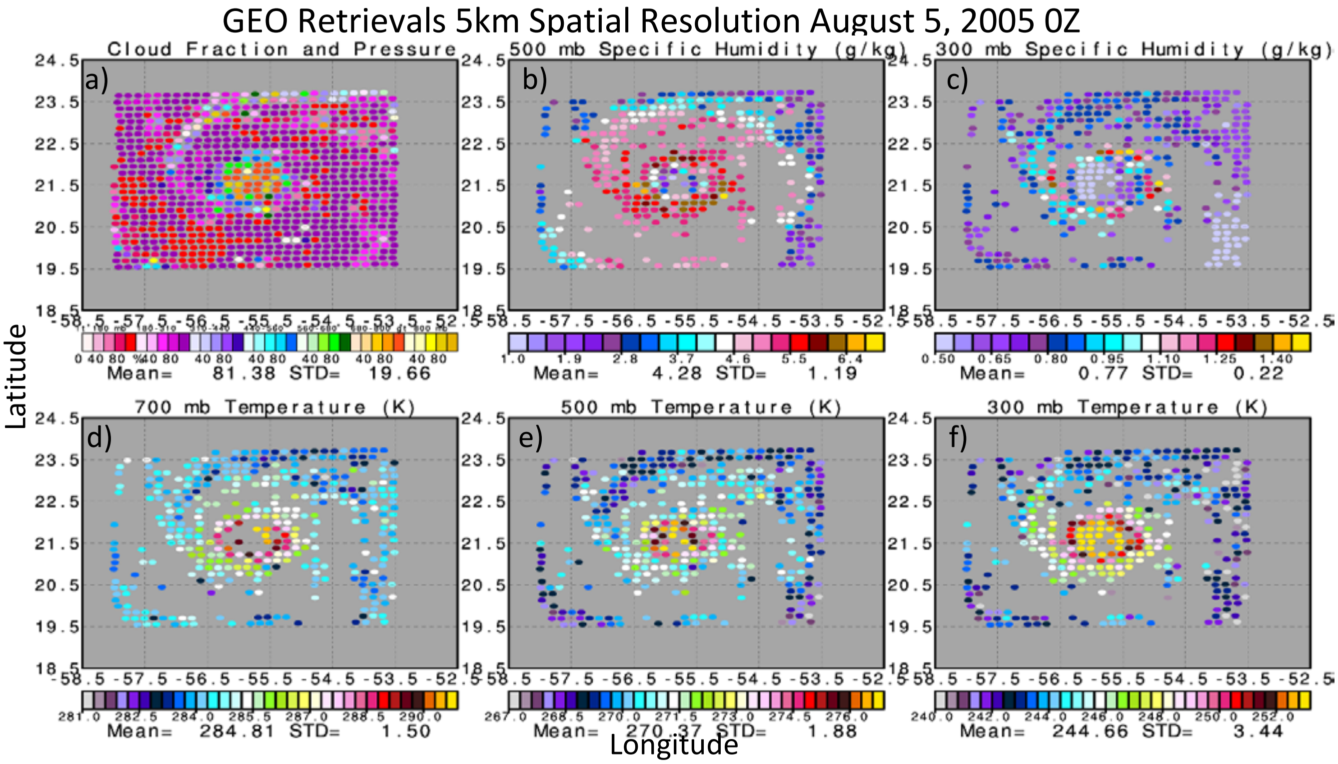

Figure 5. QC’d retrieved values of select fields for the 5 km GEO experiment at August 5 0Z. Retrieved values represent average values over the 15 km x 15 km FOR. FORs in which the retrieved values are rejected show up as gray.

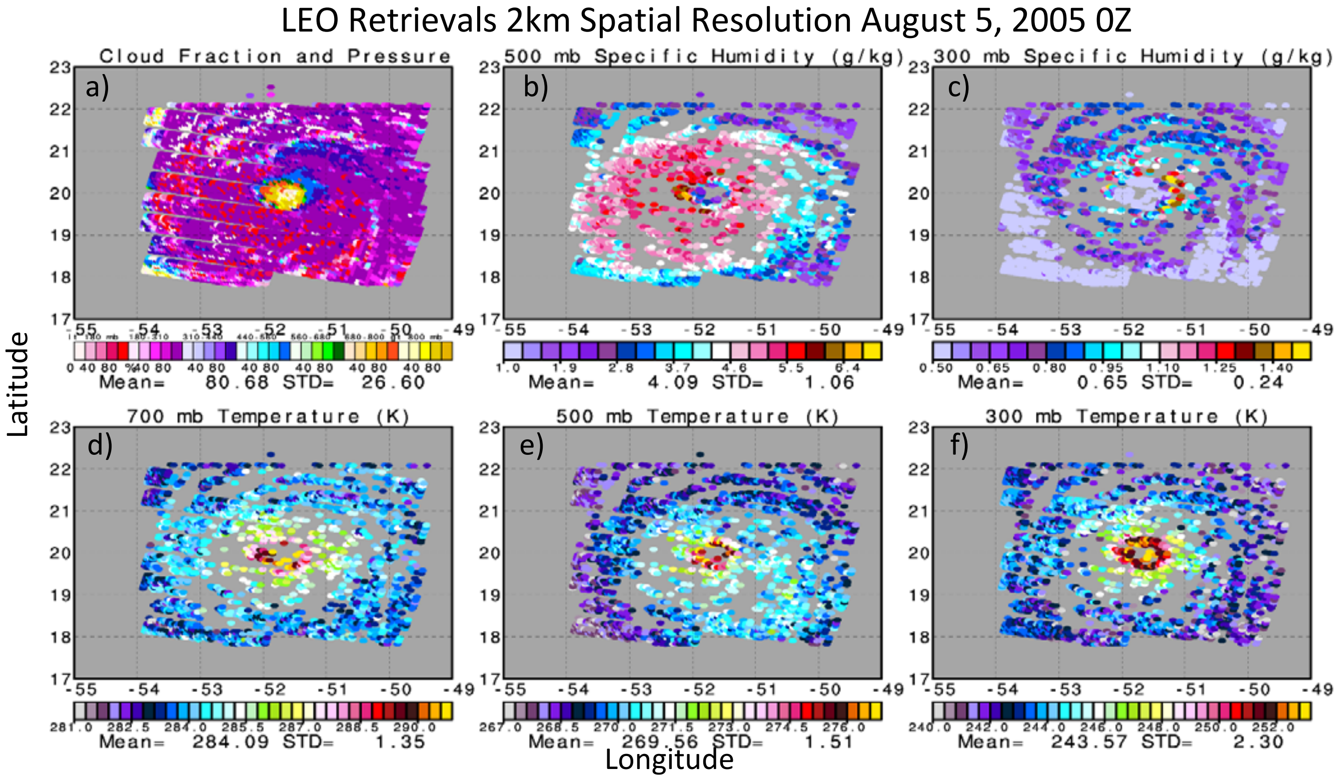

Figure 6. QC’d retrieved values of select fields for the 2 km LEO experiment at August 5 0Z. Retrieved values represent average values over the 6 km x 6 km FOR. FORs in which the retrieved values are rejected show up as gray.

because the size of a dot was designed for the GEO experiment, and covers roughly a 15 km by 15 km area. The retrieved values of all fields at a 2 km spatial resolution, especially cloud cover and water vapor, show more detailed structure than those found in the 5 km GEO experiment. This is because in the vicinity of the storm, the spatial structure of both cloud cover and water vapor is highly variable, and has more variability on a 2 km scale than on a 5 km scale. In addition, Quality Controlled results are obtained in larger contiguous spatial areas of the scene, especially near the center of the storm. This result indicates the twofold desirability of having an AIRS class sounder with a 2 km spatial resolution on either a LEO or a GEO satellite. Accurate products would be obtained with both higher spatial resolution, as well as with better spatial coverage. Higher spatial resolution would have significant additional benefits over land because of the high spatial variability of land surface characteristics such as surface elevation and surface skin temperature. These potential benefits over land were not tested in this experiment because all observations were over ocean.

Figure 7 shows analogous results for the 13 km LEO experiment. The dots are again plotted as the center of each nominally 39 km x 39 km FOR, and are of the same size as those in Figures 2, 5, and 6. At a 13 km AIRS-like spatial resolution, the spatial coverage is poor for the purpose of monitoring retrievals in the vicinity of a storm, and very little spatial variability is observed in the retrievals either with regard to cloud structure, which is generated at the center of each FOR, or temperature and water vapor structure. Indeed, in the vicinity of the storm, unlike with 5 km or 2 km spatial resolutions, to AIRS-like retrievals with a 13 km FOV give very few successful retrievals near the storm center, and do not depict the structure of the storm very well.

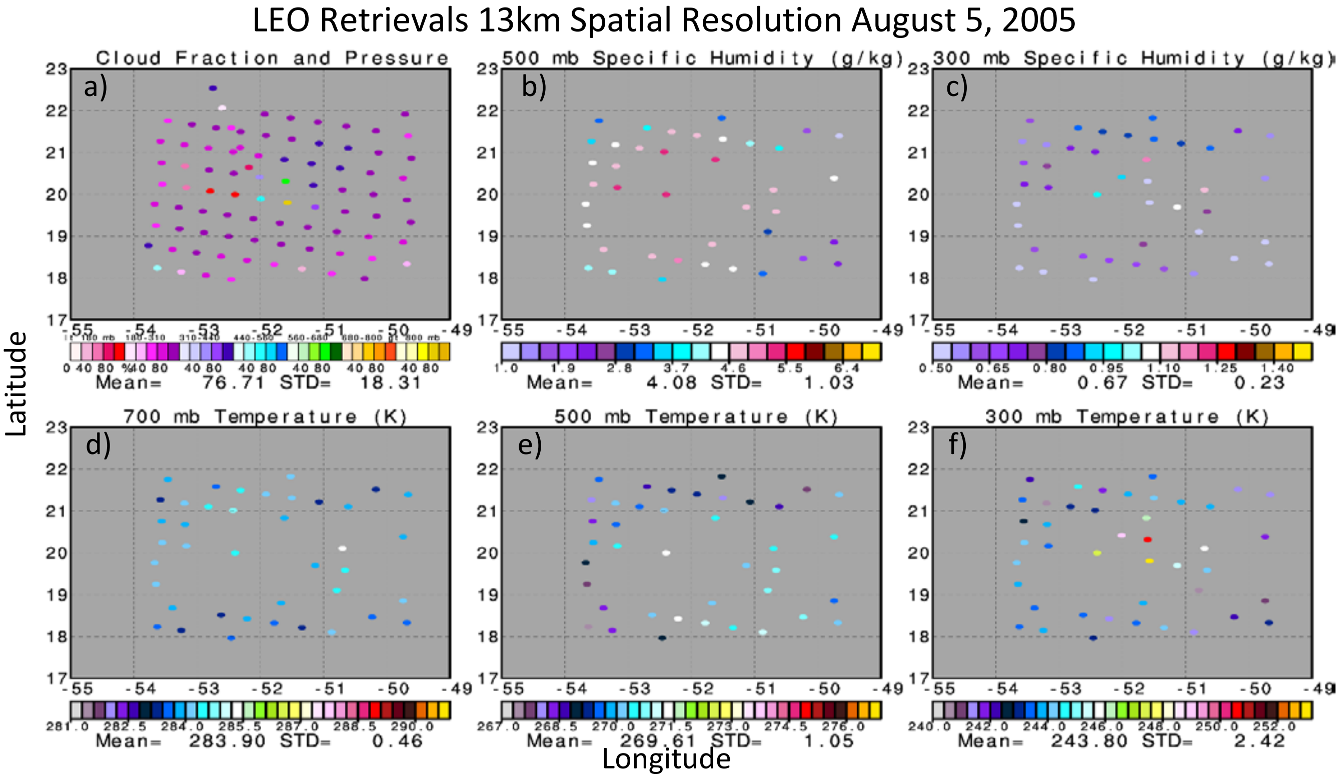

Figure 7. QC'd retrieved values of select fields for the 13 km LEO experiment at August 5 0Z. Retrieved values represent average values over the 39 km x 39 km FOR. FORs in which the retrieved values are rejected show up as gray.

4. SUMMARY

We conducted simulation experiments to indicate the potential relative performance of future AIRS-like sounders on both LEO and GEO orbits. We simulated and analyzed radiances for a LEO AIRS-like sounder with a 2 km spatial resolution, and a GEO AIRS-like sounder with a 5 km spatial resolution. We also simulated and analyzed results for a LEO sounder with the actual AIRS spatial resolution of 13 km for comparison purposes, both with results of the other experiments and also with results using observed AIRS data. All experiments used surface and atmospheric products derived from a model forecast, called the Nature Run, of a hypothetical Atlantic hurricane. Retrieval accuracies of all experiments, as compared to model truth averaged over the spatial resolution of instruments, were similar to each other, and indeed were similar to what is typically obtained using observed AIRS data. Much more significantly, however, was that both the spatial structure and spatial coverage of Quality Controlled retrievals improved dramatically with increase in spatial resolution, first from 13 km to 5 km, and even more so from 5 km to 2 km. This demonstrates the desirability of flying high spatial resolution AIRS-like sounders on future LEO and GEO satellite missions.

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