Retrieved Products from Simulated Hyperspectral Observations of a Hurricane

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Objective

Demonstrate via Observing System Simulation Experiments (OSSEs) the potential utility of flying high spatial resolution AIRS class IR sounders on future LEO and GEO missions.

The study simulates and analyzes radiances for 3 sounders with AIRS spectral and radiometric properties on different orbits with different spatial resolutions.

1) "Control run" AIRS spatial resolution 13 km at nadir on LEO in Aqua orbit
2) High spatial resolution LEO sounder 2 km at nadir – "ARIES"
3) 5 km spatial resolution sounder on a GEO orbit – radiances simulated every 72 minutes

All radiances are generated using "truth" fields consistent with a simulated Atlantic hurricane generated by Bob Atlas and co-workers at AOML.

Goals

- Demonstrate the potential improvements in retrieved products obtained with high spatial resolution
- Send the products to AOML for use in OSSE Data Assimilation Experiments

Generation of Model Truth Data: Part I

This experiment uses model products generated every 6 minutes at a 1 km spatial resolution over a moving roughly 4.5°latitude x 4.5°longitude spatial domain covering a storm track in the Atlantic Ocean.

The model provided 1 km spatial resolution values of surface pressure, p_s, surface skin temperature T_s, temperature profile $T(p)$ from the surface to 50 mb, water vapor profile $q(p)$ from the surface to 50 mb, and cloud cover (0 or 1) at all vertical levels.

Tom Pagano and William Mathews at JPL generated 3 sets of "model truth" values of all parameters to be used in each experiment by averaging the 1 km model values over the instrument Fields of View (FOVs) in the spatial domain sampled at the appropriate model times – every 12 hours for LEO and every 72 minutes for GEO, and sent the three different "truth" data sets for us to use in our experiments.

Model "truth" was used both to simulate radiance observations and to evaluate the retrieved products.

Generation of Model Truth Data: Part II

We simulated AIRS radiances for each FOV by using the operational AIRS Radiative Transfer Algorithm (RTA) and adding actual AIRS channel random noise values.

The AIRS RTA requires more information than is provided in the “model truth” we obtained from JPL:

- $T(p)$ and $q(p)$ from the surface to 0.004 mb
- Complete profiles of trace gases
- Multi-layer fractional cloud cover $\alpha(p)$ as seen from above

We have made some simplifications which should not affect the relative results obtained from different sampling scenarios.

1) We extrapolated model $T(p)$ and $q(p)$ truth above 50 mb by using differences from climatology.
2) We used climatological values of the concentrations as a function of pressure of all trace gases.
3) We generated values of fractional cloud cover as seen from above as a function of pressure $\alpha(p)$.

This was the most important and most difficult part of the simulation study

Generation of $\alpha(p)$

The model truth provided by JPL contained fractional cloud cover α as a function of p for each FOV.

Starting from the top of the atmosphere, we grouped non-zero values of α into contiguous groups as a function of p.

The first group went from p_1 to p_2, the second from p_3 to p_4, etc.

We selected the largest cloud fraction $\alpha(p_{mid-1})$ between p_1 and p_2 which occurred at p_{mid-1}.

We set $p_c(1)$ to be p_{mid-1} and $\alpha(1)$ *to be* $\alpha(p_{mid-1})$. This was taken as the fractional cloud cover $\alpha(1)$ as seen from above for the top level cloud at $p_c(1)$.

We repeated this procedure for the second group of clouds between p_3 and p_4 and determined in an analogous way $p_c(2)$, and set $\alpha(2)$ equal to the product of $\alpha(p_c(2))$ and $(1-\alpha(1))$.

We repeated this procedure for each contiguous set of non-zero cloud fractions, each time setting the cloud fraction $\alpha(n)$ equal to the product of $\alpha(p_c(n))$ and $(1-\sum_{j=1}^{n-1}\alpha(j))$

This insured that $\sum_{j=1}^{n}\alpha(j)$ is between 0 and 1.

Retrieval Algorithm Used in the Experiments

We analyzed simulated channel radiance data for all three experiments in an identical fashion using the operational AIRS Version-6 AIRS Only (AO) retrieval algorithm with a minor modification. Version-6 AO was used because we did not simulate observations for an accompanying MW sounder such as AMSU-A.

AIRS Version-6 AO uses empirical "tuning coefficients" to account for systematic errors in both the radiative transfer physics used in the calculation compared to the truth, as well as instrument calibration errors. In this experiment, the same physics was used to analyze the data as was used to compute the radiances, and there were no calibration errors. Consequently, we set all AIRS Version-6 AO tuning coefficients to zero in our analysis.

AIRS Version-6 AO uses Neural-Net coefficients which were trained on observed AIRS cloudy radiances to generate the first guesses T_s^0, $T(p)^0$, and $q(p)^0$ used in the physical retrieval process. We used the same coefficients in this experiment and they performed extremely well beneath 300 mb. This shows that our simulation methodology, including the generation of $\alpha(p)$, was very realistic. $T_s^0(p)$ had biases at and above 300 mb.

Important Characteristics of Version-6 AO

All retrievals are performed on a 3x3 grouping of AIRS FOVs, referred to as an AIRS Field of Regard (FOR). Therefore the spatial resolutions of retrieval experiments are given by three times the experimental FOV sizes.

Version-6 AO derives for each FOR channel *i* clear-column radiances $\hat{R}_i$, which represent what the instrument is thought to have seen if the entire FOR were cloud free. Values of $\hat{R}_i$ are used to determine the final retrieved surface and atmospheric state *X*. Cloud parameters α_j, p_{cj} are determined to be consistent with the observed radiances and the state *X*.

Version-6 AO uses Quality Control (QC) methodology which assigns to each FOR a pressure p_{QC}, down to which the retrieval is considered to be acceptable. Cloud products are generated and used for each FOR. *T(p)* and *q(p)* products are generated for each FOR, but used only from the top of the atmosphere down to p_{QC}.

Higher spatial resolution increases the spatial coverage of acceptable retrievals as a result of more cloud variability in the FORs. Higher spatial resolution also allows for the ability to better resolve features varying rapidly in space such as cloud cover and *q(p)*.

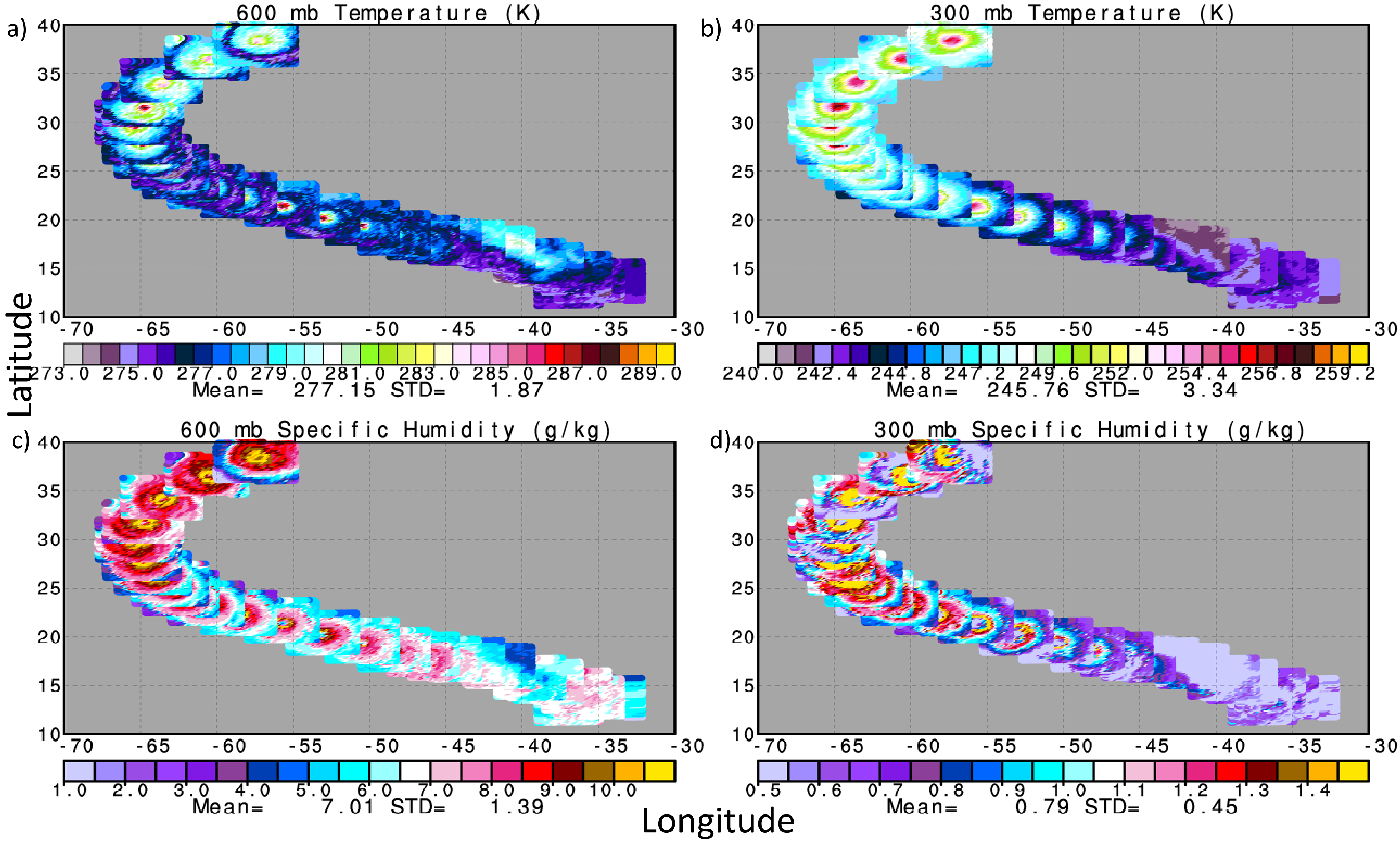
Sample Truth Fields

The next two figures show truth fields of select quantities as represented by the 5 km resolution GEO experiment over the spatial domain of the model at that time. Truth fields are plotted as colored dots at the center of each 15 km x 15 km FOR. The size of the dots are such that they roughly cover 15 km x 15 km areas.

Cloud parameters $\alpha(i)$, $p_c(i)$ are retrieved for multiple cloud layers in each FOR. We plot effective single layer cloud products α and p_c for each FOR where α is given by the sum of all cloud fractions a seen from above ($\alpha = \sum_{i=1}^{n} \alpha(i)$) and p_c is given by the weighted average of all the different cloud pressures in the FOR ($p_c = (\sum_{i=1}^{n} \alpha(i) p_c(i)) / (\sum_{i=1}^{n} \alpha(i))$)

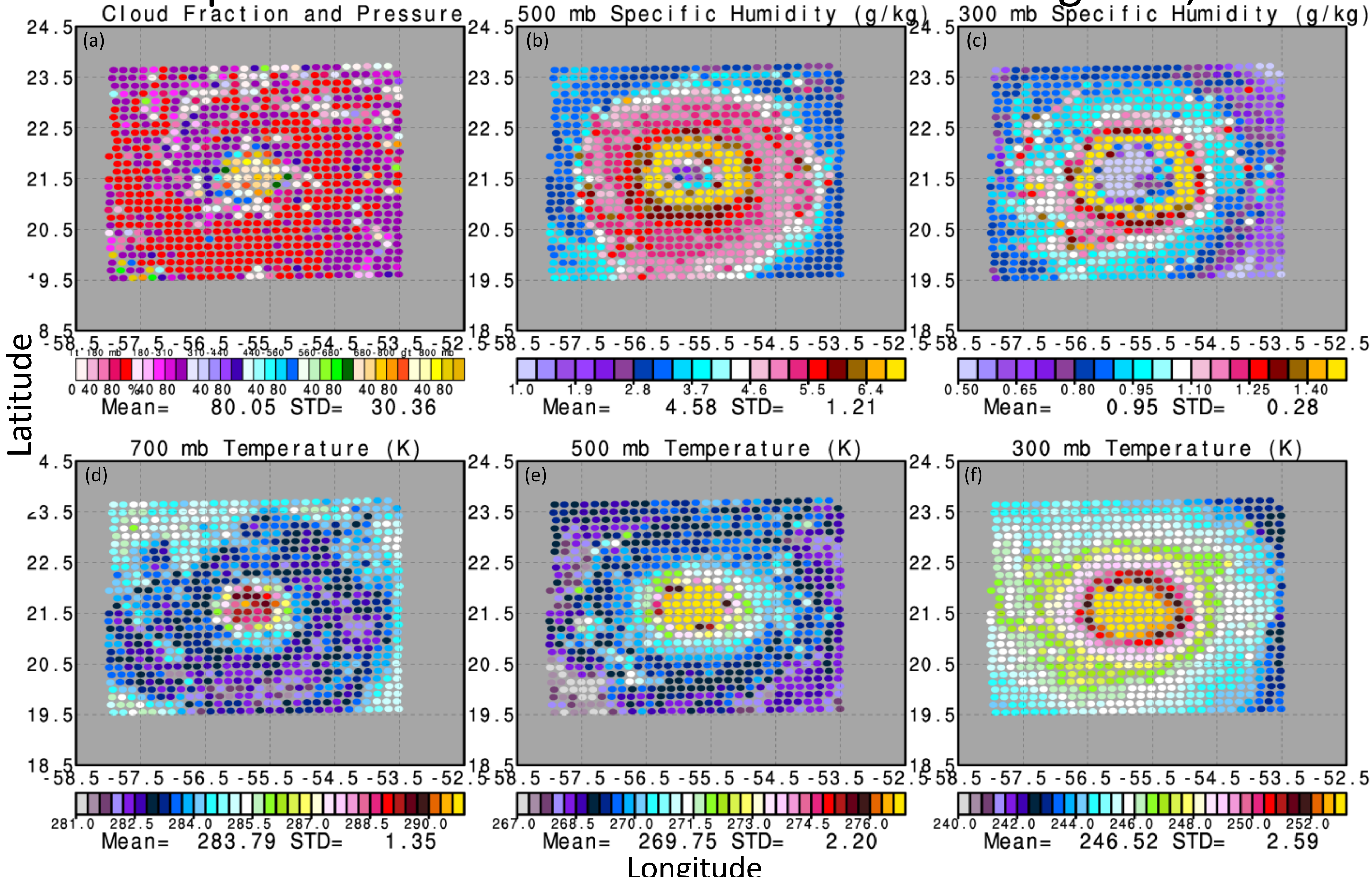
5 km Geostationary Truth

July 29 to August 10, 2005 0Z and 12Z



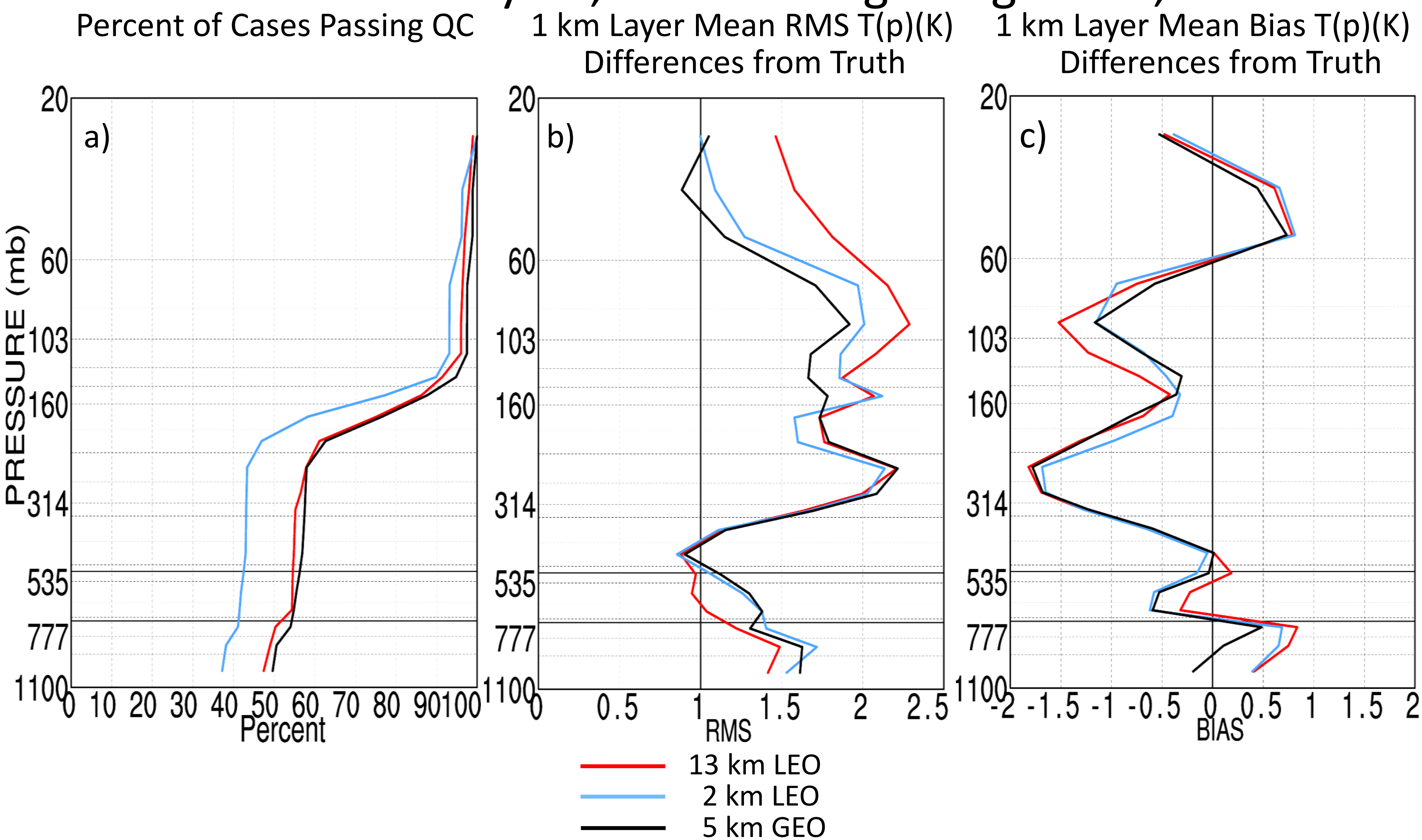
Nature Run truth values of *T(p)* and *q(p)* for the 5 km GEO experiment sampled every 12 hours. The storm begins to intensify around August 3 0Z. The locations of the center of the storm are clearly observed as a function of time.

GEO 5km Spatial Resolution Nature Run “Truth” August 5, 2005 0Z



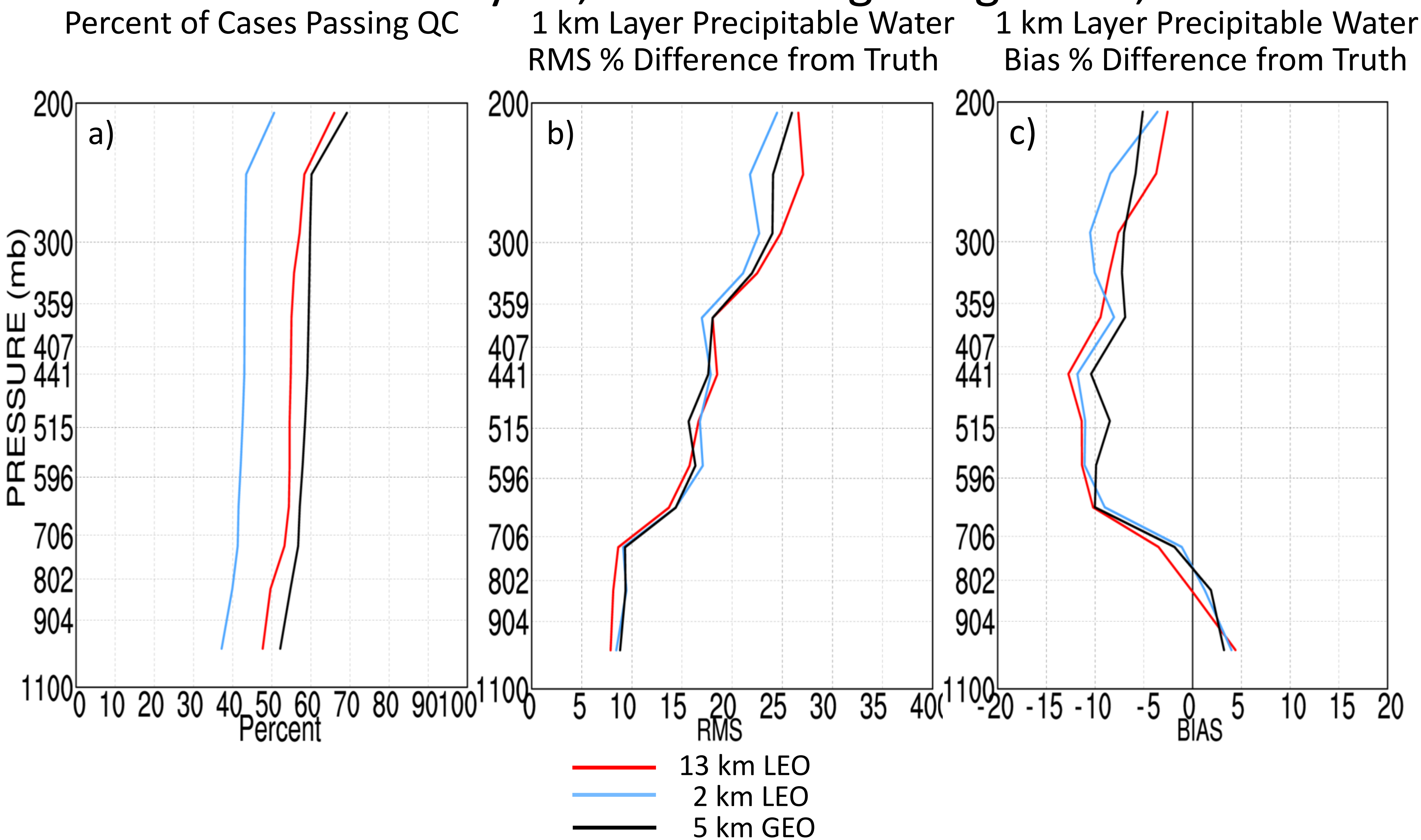
Nature Run truth values of select fields for the 5 km GEO experiment for the time period August 5, 2005 at 0Z. Dark red and purple colors in (a) indicate large amounts of high cloud cover. The storm is marked by a swirl surrounding a region of low (yellow) clouds and a locally dry and warm area as shown at different pressures.

Statistics for July 29, 2005 through August 10, 2005



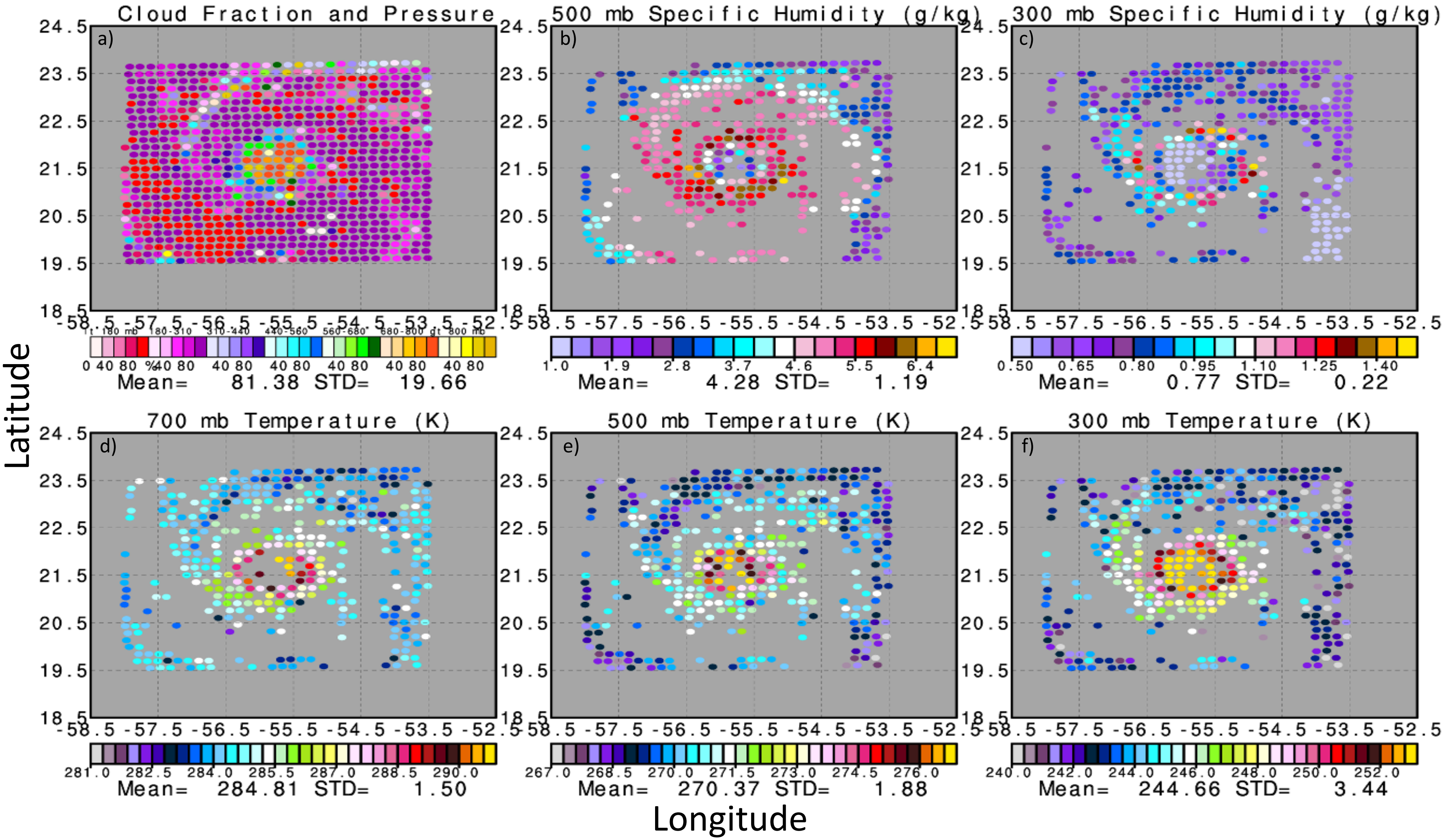
Percent yield, RMS differences from truth, and bias differences from truth of QC'd *T(p)* retrievals up to 20 mb. Retrieval error structures are similar for all experiments. Retrieval biases above 300 mb follow, and are smaller than, those of the Neural-Net guess. Percentages of accepted cases at 2 km resolution are poorer than those at lower spatial resolution. This is misleading because there are many more cases at 2 km.

Statistics for July 29, 2005 through August 10, 2005



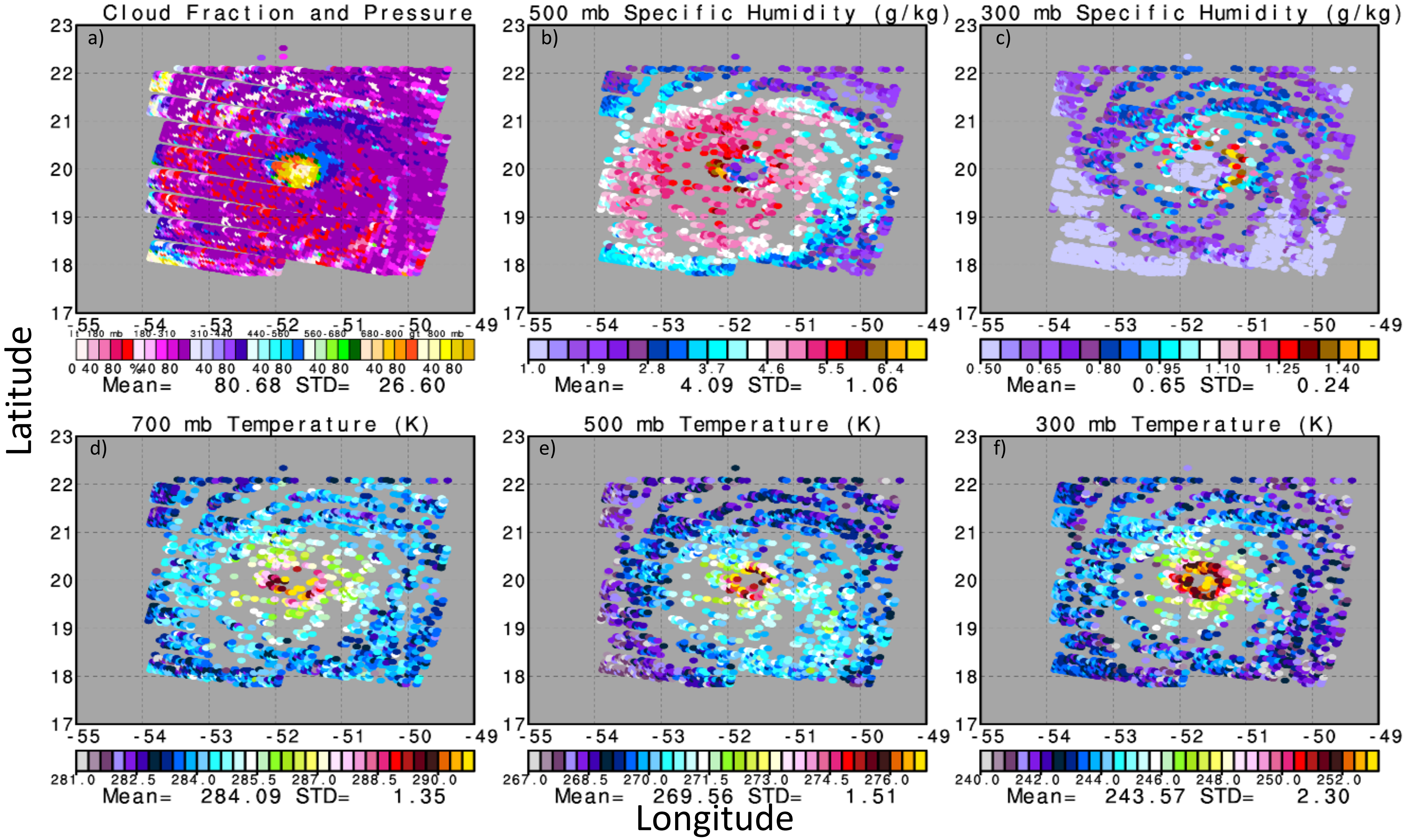
Percent yields, RMS % differences from Truth, and bias % differences from Truth of QC'd *q(p)* retrievals up to 200 mb. Accuracy of *q(p)* retrievals is again similar in all experiments. There are big differences in the spatial coverages of accepted retrievals however, as shown in the next three figures.

GEO Retrievals 5km Spatial Resolution August 5, 2005 0Z



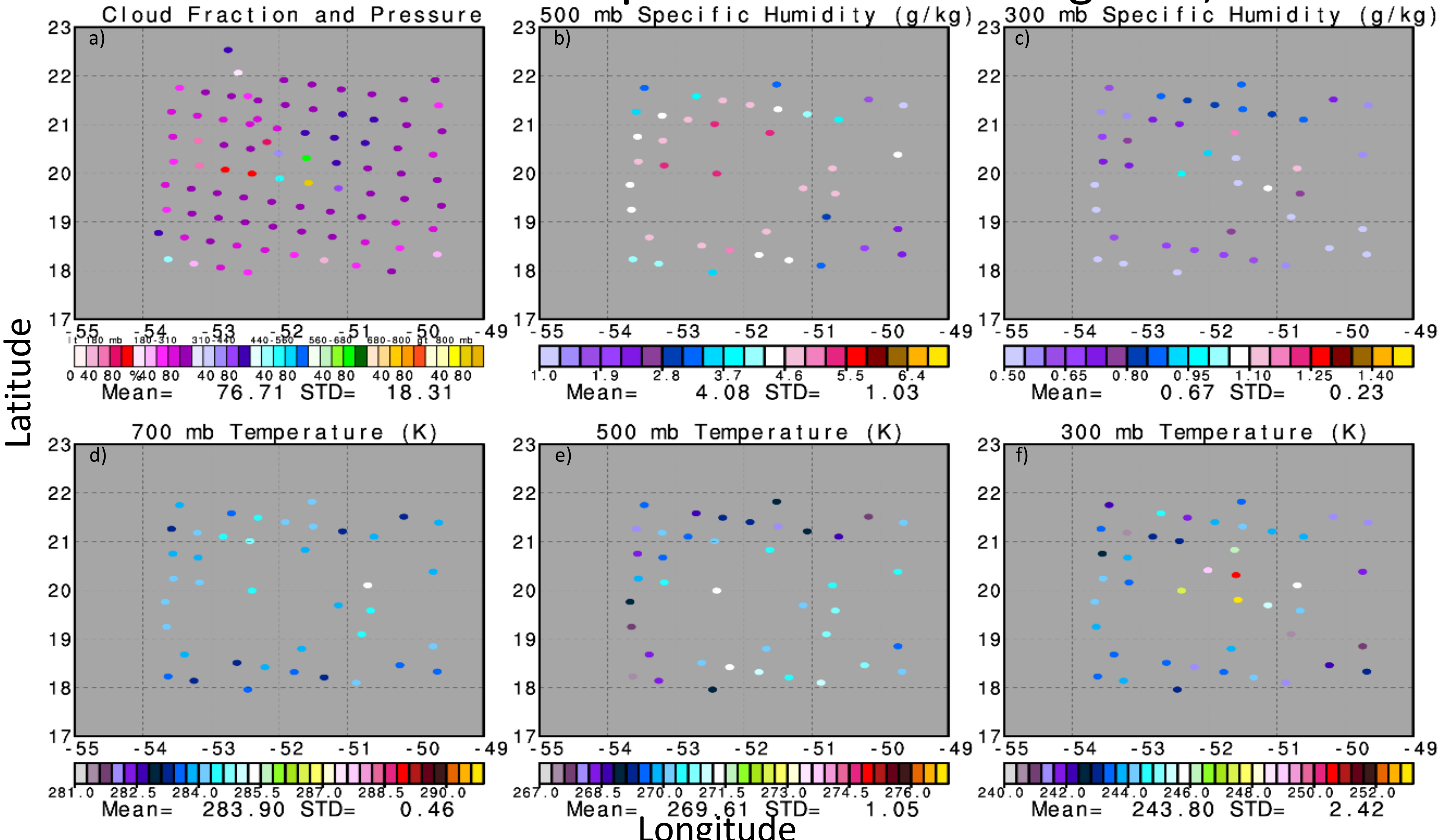
QC'd retrieved values of select fields for the 5 km GEO experiment at August 5 0Z. Results are shown for the 15 km x 15 km FOR. Cloud products are always determined. FORs in which the retrieved values are rejected show up as gray. Spatial structures agree with truth very well. Retrievals are rejected in areas with larger amounts of high cloud cover.

LEO Retrievals 2km Spatial Resolution August 5, 2005 0Z



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. 2 km resolution retrievals show even more coherent spatial structure than do 5 km retrievals. Also, contiguous spatial areas with missing retrievals are smaller at 2 km than at 5 km.

LEO Retrievals 13km Spatial Resolution August 5, 2005



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. While these are useful retrievals in the presence of a severe storm, much more information about the storm is obtained at higher spatial resolutions.

Summary – Simulation Methodology

We simulated radiances and performed retrievals for instruments with AIRS-like spectral and radiometric characteristics, but with different spatial resolutions and on different orbits.

1) 13 km x 13 km FOV's on LEO
2) 2 km x 2 km FOV's on LEO
3) 5 km x 5 km FOV's on GEO

The simulated radiances for each FOV use as truth surface and atmospheric conditions generated by a high spatial resolution model run at AOML which predicted the path and evolution of a severe Atlantic storm. The FOV "truth" for each experiment as a function of time was taken as the model truth averaged over that FOV at that time. The most difficult part of the simulation was in the generation of cloud cover as a function of height as seen from above for the FOV .

Summary – Retrieved Results

Retrievals were run using the AIRS Science Team Version-6 AIRS Only retrieval algorithm, which generates a Neural-Net first guess T_s^0, $T(p)^0$, and $q(p)^0$ as a function of observed AIRS radiances. AIRS Science Team Neural-Net coefficients performed very well beneath 300 mb using the simulated radiances . This means the simulated radiances are very realistic. First guess and retrieved values of *T(p)* above 300 mb were biased cold, but both represented the model spatial structure very well.

QC'd *T(p)* and *q(p)* retrievals for all experiments had similar accuracies compared to their own "truth" fields, and were roughly consistent with results obtained using real data. Spatial coverage of retrievals, as well as the representativeness of the spatial structure of the storm, improved dramatically with decreasing size of the instrument's FOV.

We sent QC'd values of *T(p)* and *q(p)* to Bob Atlas at AOML for use as input to OSSE Data Assimilation experiments.

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