Geostationary Extended Observations Sounder radiance proxy data simulation

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1. Background

- Geostationary Extended Observations (GeoXO) satellite system scheduled for launch in the 2030s
- GeoXO Sounder (GXS): US first GEO hyperspectral resolution infrared sounder (Table 1 and Fig. 1)
- Part of WMO GEO ring: GeoXO (US), MTG (Europe), FY4 (China), and Himawari-10 (Japan)
- An unprecedented level of sounding information (T/Q/U/V) for weather forecasting and nowcasting capabilities
- Abundant information for trace gases
- How to simulate GXS proxy data for various qualitative and quantitative applications
- See Schmit et al (presentation 13.2 at 8:45am on Feb 1) for more information about GXS applications

Requirements	Value
Spectroscopy type	Grating
Spectral Range	680-1095 and 1689-2250 cm^{-1}
Spectral Resolution	0.625 cm^{-1}
GSD	4 km
Refresh Rate	60 minutes for Sounding Disk
NEdN (mW/(m^2 sr cm^{-1}))	0.06 for midwave (228-234 K) 0.2 @ 800-1095 cm^{-1} (218-234 K) 0.352 @ 718-800 cm^{-1} (224 K) 0.352-2.5 (TBR) @ 680-718 cm^{-1} (224 K)

Table 1. Key requirements for GXS

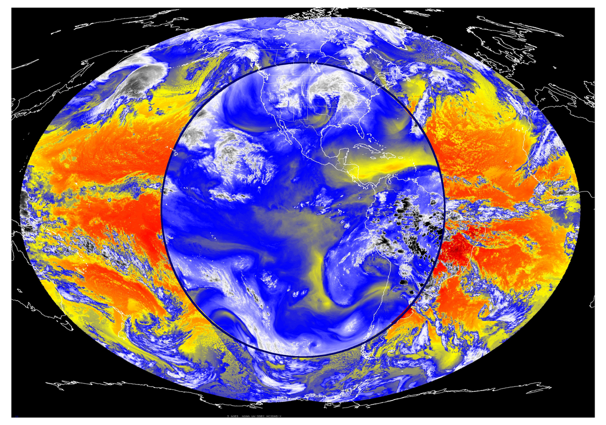

Fig. 1. GXS Sounding Disk coverage (center oval), with GXI combined coverage

2. Proxy data simulation

2.1 Spectral response function (SRF)

- Fourier Transform spectroscopy (FTS) vs grating spectroscopy (Fig. 2)
- FTS uses Sinc function with Hamming Apodization
- Grating uses CIRAS (an AIRS like grating CubeSat from Tom Pagano of JPL) idealized SRF with diffraction considered
- Grating system was selected recently. All existing work assumed FTS.
- SRF based on latest Performance Operational Requirement Document (PORD)

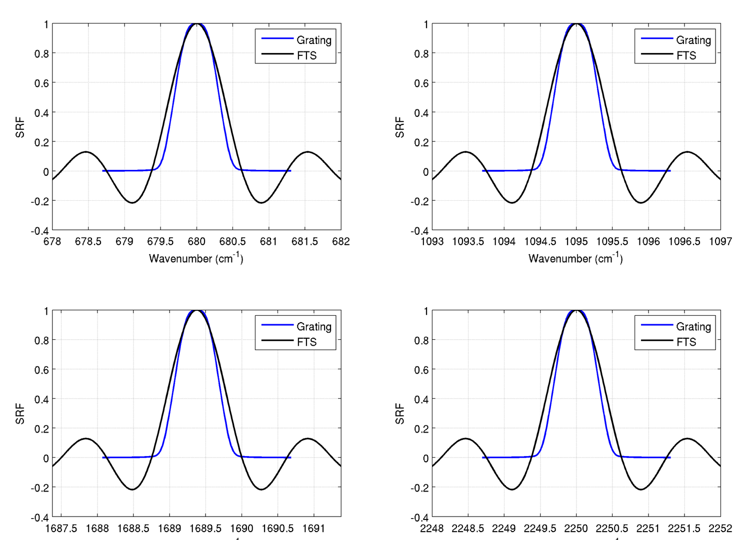

Fig. 2. SRF for an FTS and a grating system with a spectral resolution of 0.625 cm^{-1}.

2.2 Radiative Transfer Models (RTM)

- CRTM does not have GXS coefficients yet
- Method 1: converting CRTM simulated IASI spectrum to GXS in Fourier domain. Time consuming with more than IASI 8000 channels
- Method 2: CIMSS in-house RTM model
  - Pressure layer Fast Algorithm for AtmoSpheric Transmittances (PFAAST)
  - All sky capability, coupled with the Texas A&M cloudy model
- Method 3: generate RTTOV coefficients
- Using different RTMs for radiance simulation and applications (i.e. retrievals and assimilations) avoids perfect RTM issue in simulation studies

2.3 NWP field

- ECMWF Experimental nature run at global 1-km resolution (XNR1K) from Oak Ridge Leadership Computing Facility (OLCF) at Oak Ridge National Laboratory
- 15-minute interval
- 3 local severe storm cases over CONUS from August/September 2019
- Limited to Continental US (CONUS) to reduce data volume
- 36-72 hours for each case (total 158 hours)
- 1 full disk case (18 hours)
- Information of atmosphere, surface and clouds as input for RTM
- Spatially interpolated to GXS 4-km field of views with angle considered

2.4 Proxy datasets

- Output in NetCDF format, variables include
  - T, Q, U, V, skin temperature, emissivity, surface pressure, cloud fraction
  - Latitude, longitude, satellite zenith and azimuth angles, solar zenith and azimuth angles
  - Brightness temperature, and observation noise
  - Cloud top pressure, cloud optical thickness, cloud particle size, and phase

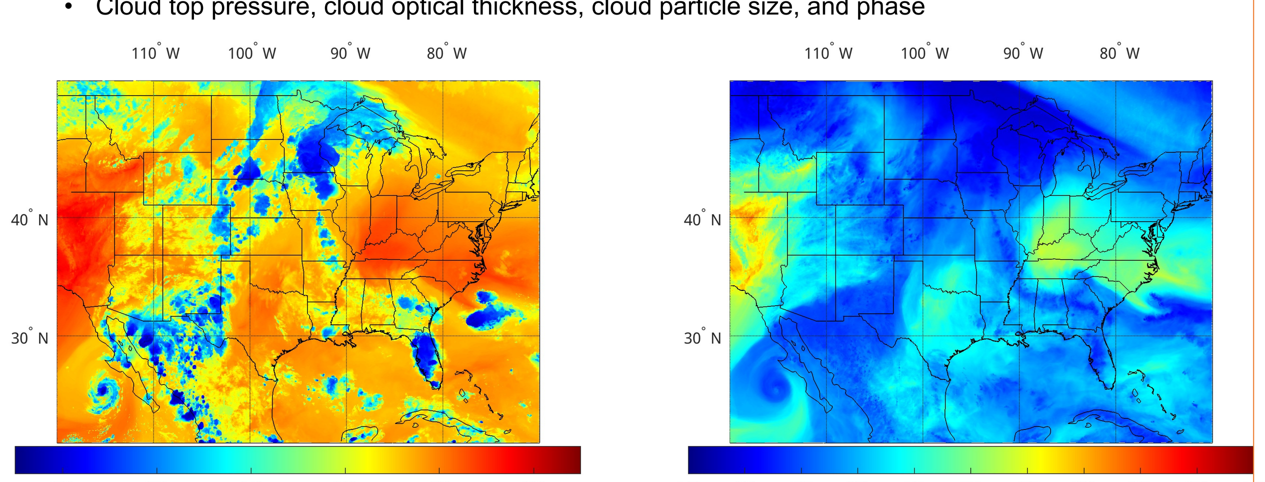

Fig. 3. Simulated GXS CONUS brightness temperature (K) of 1947.75 cm^{-1} for all sky (left) and clear sky (right). Clear sky assumes no clouds at all.

3. Simulated BT

3.1 CONUS (PFAAST)

- A low level water vapor of 1947.75 cm^{-1} (Fig. 3)
- More water vapor in cloudy region leading to colder BT in clear sky
- The Pacific tropical cyclone is in dissipating stage because not enough moisture into it

3.2 Full Disk (PFAAST)

- Typical clouds (high thick, thin cirrus, low) over ocean
- Clear assumes no clouds at the low cloud location
- Low clouds only affect low peaking channels while high clouds affect all tropospheric channels (Fig. 4)

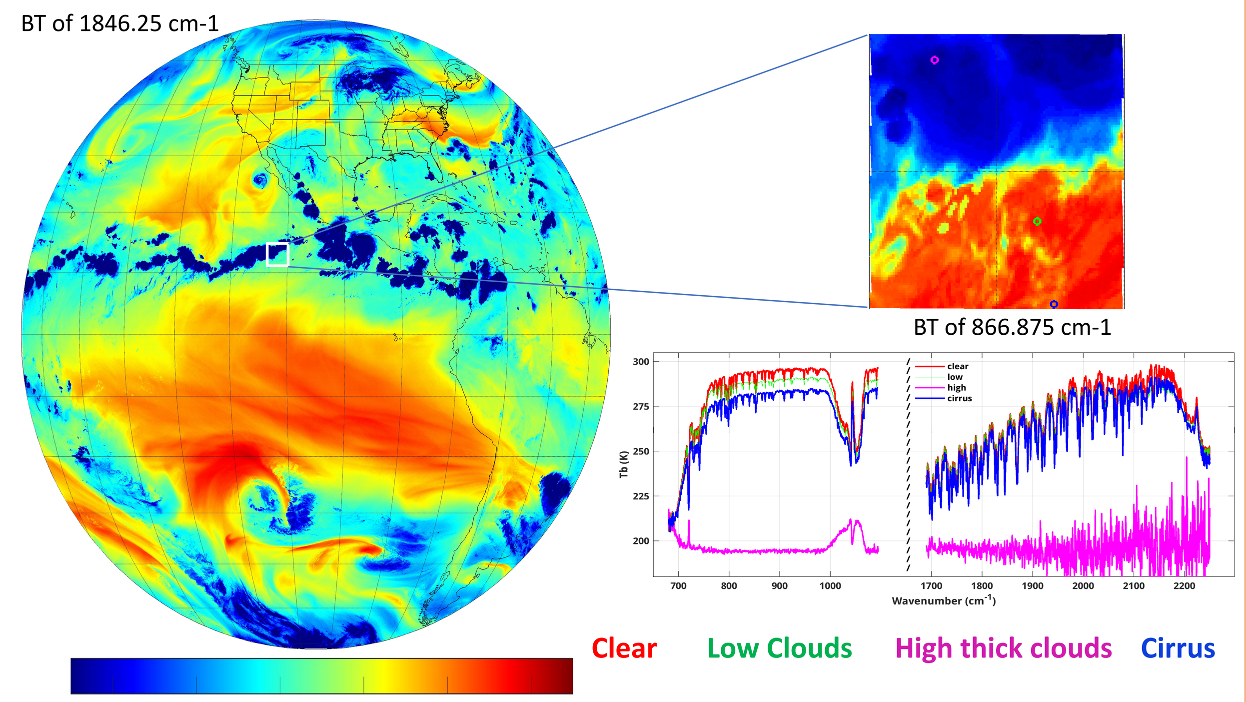

Fig. 4. Simulated GXS full disk all sky brightness temperature (K) of 1846.25 cm^{-1} (left, a midlevel water vapor channel) and zoom in of 866.875 cm^{-1} (right, a window channel), and individual spectra for different cloud types. Clear in red assume no clouds at the low cloud location.

4. Potential applications

4.1 Levels of sounding information

- CRTM and RTTOV provide k-matrix
- PFAAST may use perturbation method to generate Jacobians (time consuming)
- Jacobians indicate levels of atmosphere sensitive to specific gases: Carbon Dioxide, Carbon Monoxide, Ozone, Nitrous oxide (Fig. 5)

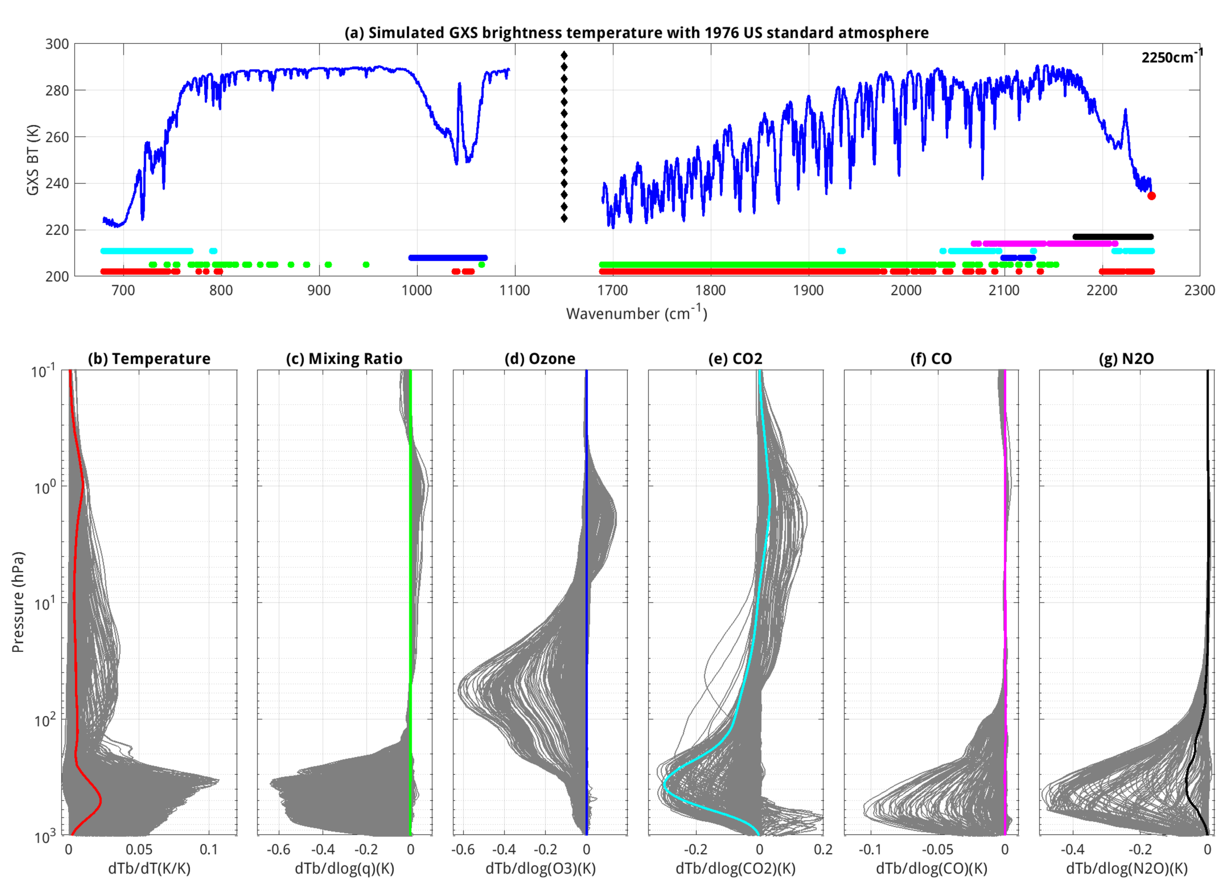

Fig. 5. Jacobians of selected atmospheric sounding parameters. US 1976 standard atmosphere is used as input with RTTOV to simulate GXS brightness temperature spectrum (top) and Jacobians (bottom). Different colors in top panel mark different spectral region of different gases.

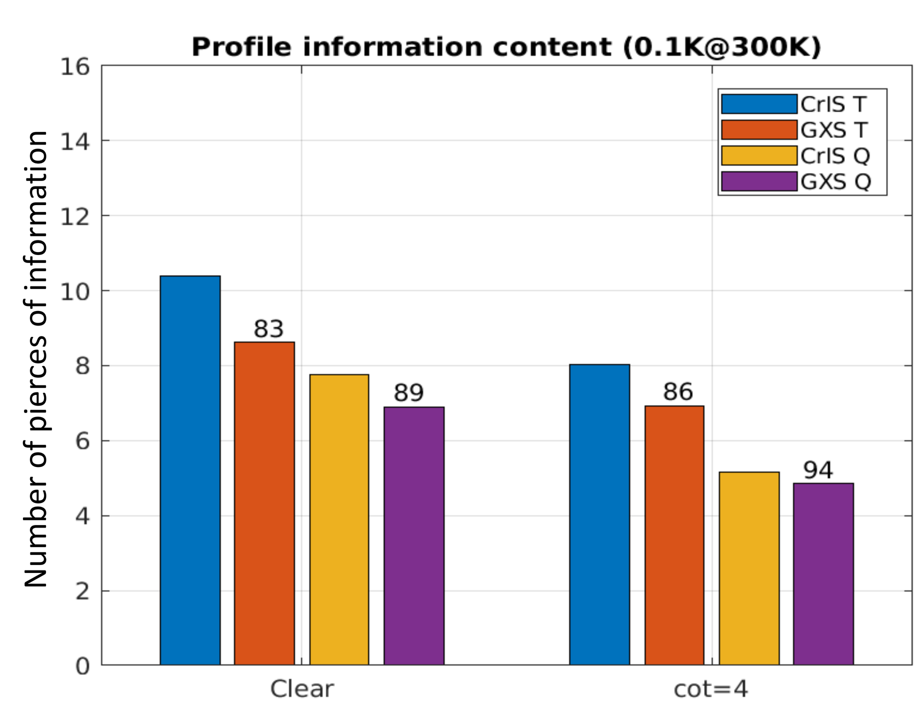

Fig. 6. Number of pierces of information for GXS and CrIS. CrIS uses longwave and midwave while GXS uses all spectral channels. Clouds are added at 300 hPa with a cloud optical thickness of 4.

4.2 Information content analysis

- 1976 US standard atmosphere
- CrIS LW+MW
- Clouds reduce information content
- GXS has considerately less information content than CrIS, however GXS is less affected by clouds than CrIS (Fig. 6)

4.3 Fingers up for temperature inversion

- Temperature inversion in lower atmosphere above surface
- Happens at clear night when surface temperature colder than air temperature
- The water vapor absorption channels in longwave window band sensitive to low level moisture
- With temperature inversion, the online channels may exhibit warmer brightness temperature than off line channels (fingers up). Opposite for no inverse (fingers down)
- Midwave channels, in strong water vapor absorption band, show weaker fingers down for inversion than no inversion without distinctive fingers up
- 15-min resolution offers a unique opportunity to see how the temperature inversion builds up at night and quickly dissipates in the morning

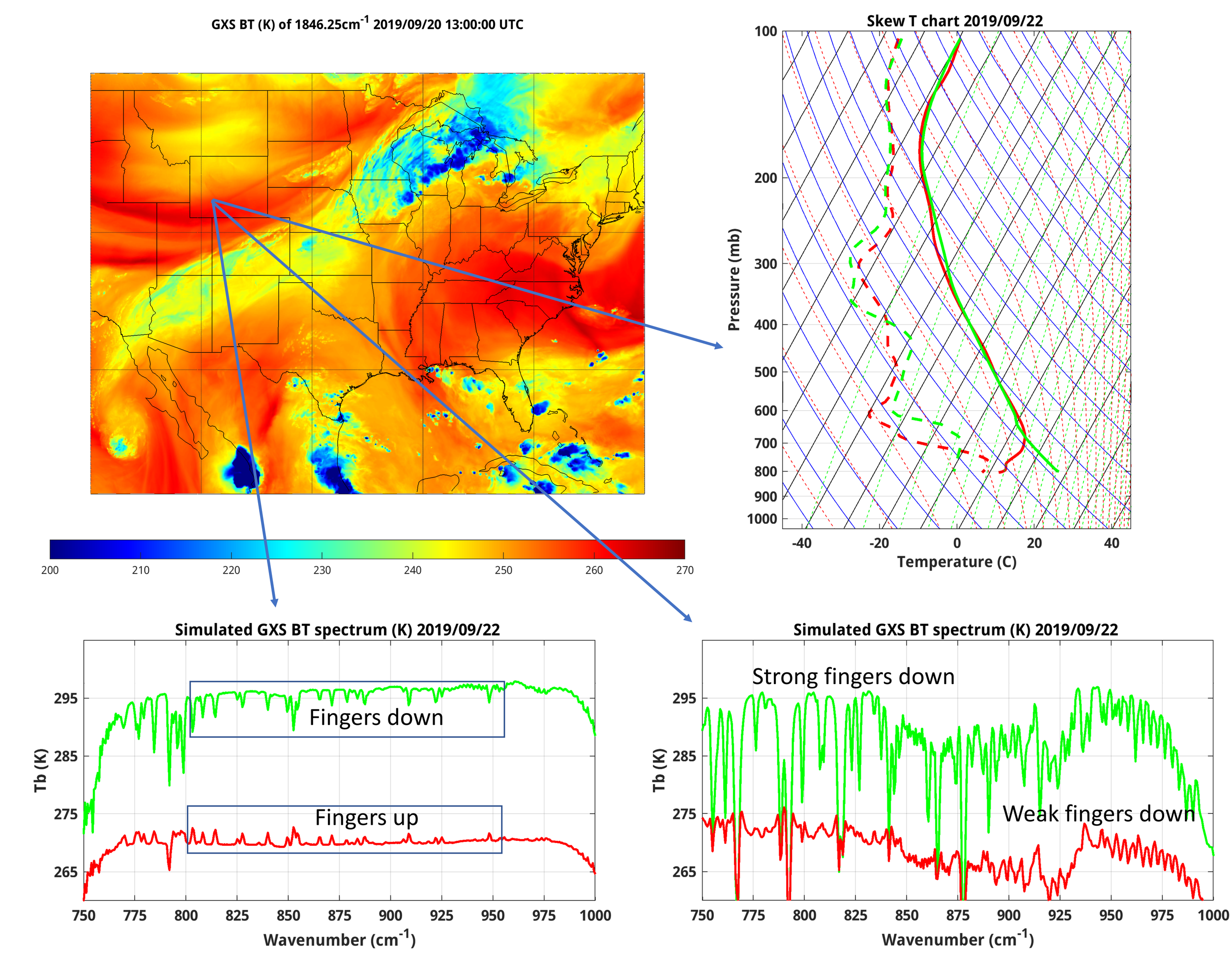

Fig. 7. (top left) Simulated GXS CONUS all sky brightness temperature (K) of 1846.25 cm^{-1} at 13 UTC; (top right) the skew T (solid for temperature and dashed for dew point) of selected location at 13 UTC (red) and 23 UTC (green); (lower left) the longwave spectrum of the selected location; and (lower right) the midwave spectrum of the selected location. Note the strong temperature inversion in skew T chart corresponds to the fingers up in absorption channels in window band.

4.4 Conceptual demonstration of GXS sounding information

- T/Q/U/V profiles (not under thick clouds)
- T/Q can be retrieved from radiance measurements
- U/V can be retrieved from radiance measurements or Q retrievals (see Ma et al., poster 83 at 3:00pm Jan 29)

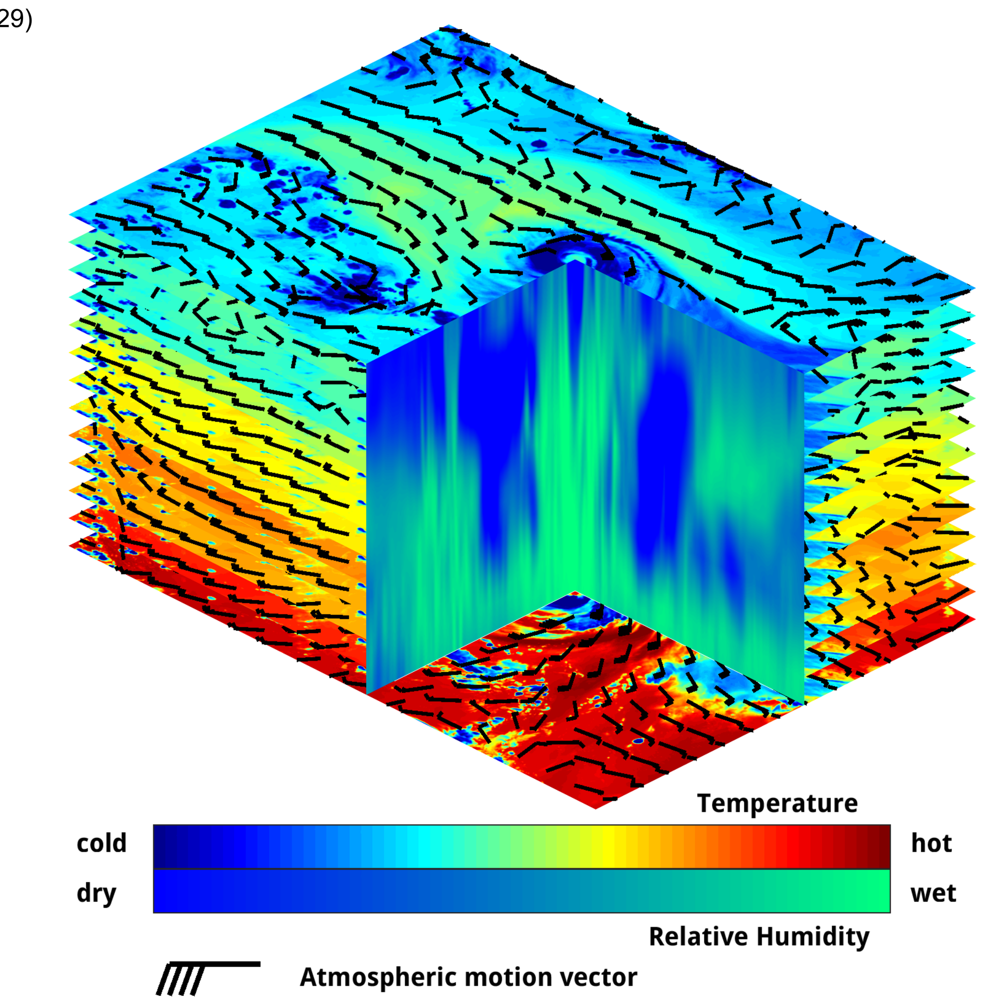

Fig. 8. 3-D sounding information from GXS. The horizontal imagery are brightness temperature from selected water vapor channels sensitive to different level of atmosphere. The wind barbs are overlaid with the brightness temperature imagery. The vertical imagery are the relative humidity. Note the tropical cyclone eye has warmer brightness temperature and lower relative humidity.

4.5 T/Q Nowcasting for local severe storms

- See Li et al. for presentation 13.5 at 9:30am on Feb 1
- GXS Proxy data can be used to test T/Q sounding retrieval algorithms
- A deep neural network (DNN) was developed to understand the GXS sounding capabilities
- 100 Principal Component Analysis (PCA) of all 1563 channels used
- All sky: clear + regions lightly affected by clouds
- Robustness to the presence of cloud although more cloud impacts lead to reduced sounding retrieval quality in troposphere especially for moisture profiles (Fig. 9)
- Applications to local severe storm nowcasting show that
  - Scene had only 34% clear-skies, but retrievals worked for 80%
  - GXS able to characterize the pre-convective environment prior to local severe storm outbreak based on retrieved Lifted Index (Fig. 10), Convective Available Potential Energy (CAPE), and Total Precipitable Water (TPW)
  - 4 hours before the outbreak, instabilities start to build up in the region (not shown)
  - Useful instability information for forecasters

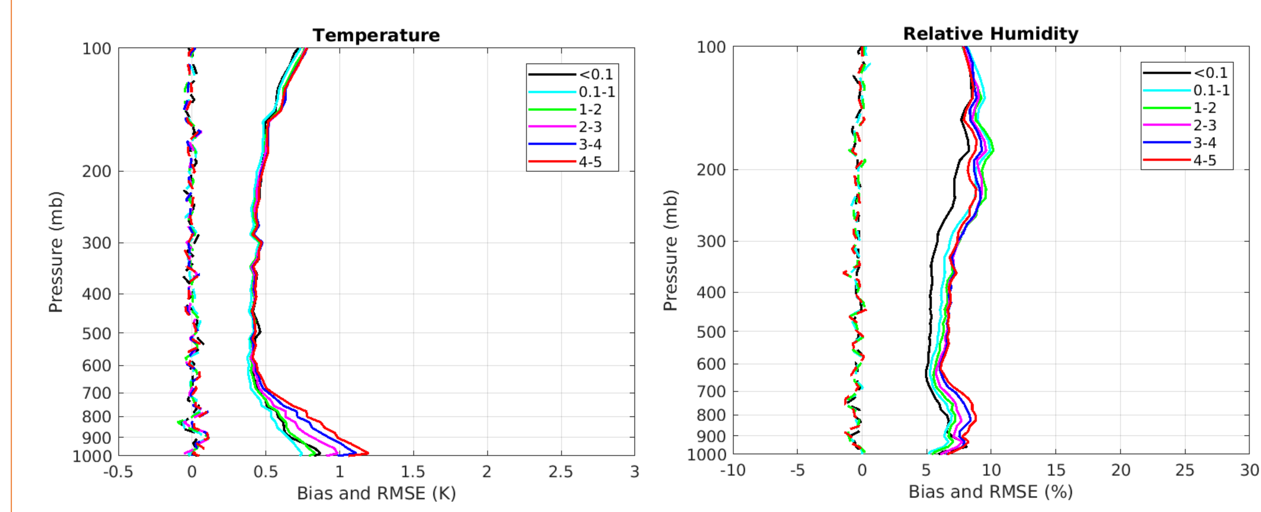

Fig. 9. The impact of clouds on the temperature (left) and relative humidity (right) sounding retrievals. Dashed lines are bias and solid lines are RMSE. Different colors represent different level of cloud impact, which is characterized by the brightness temperature difference (K) between cloudy and clear for a low level water vapor channel.

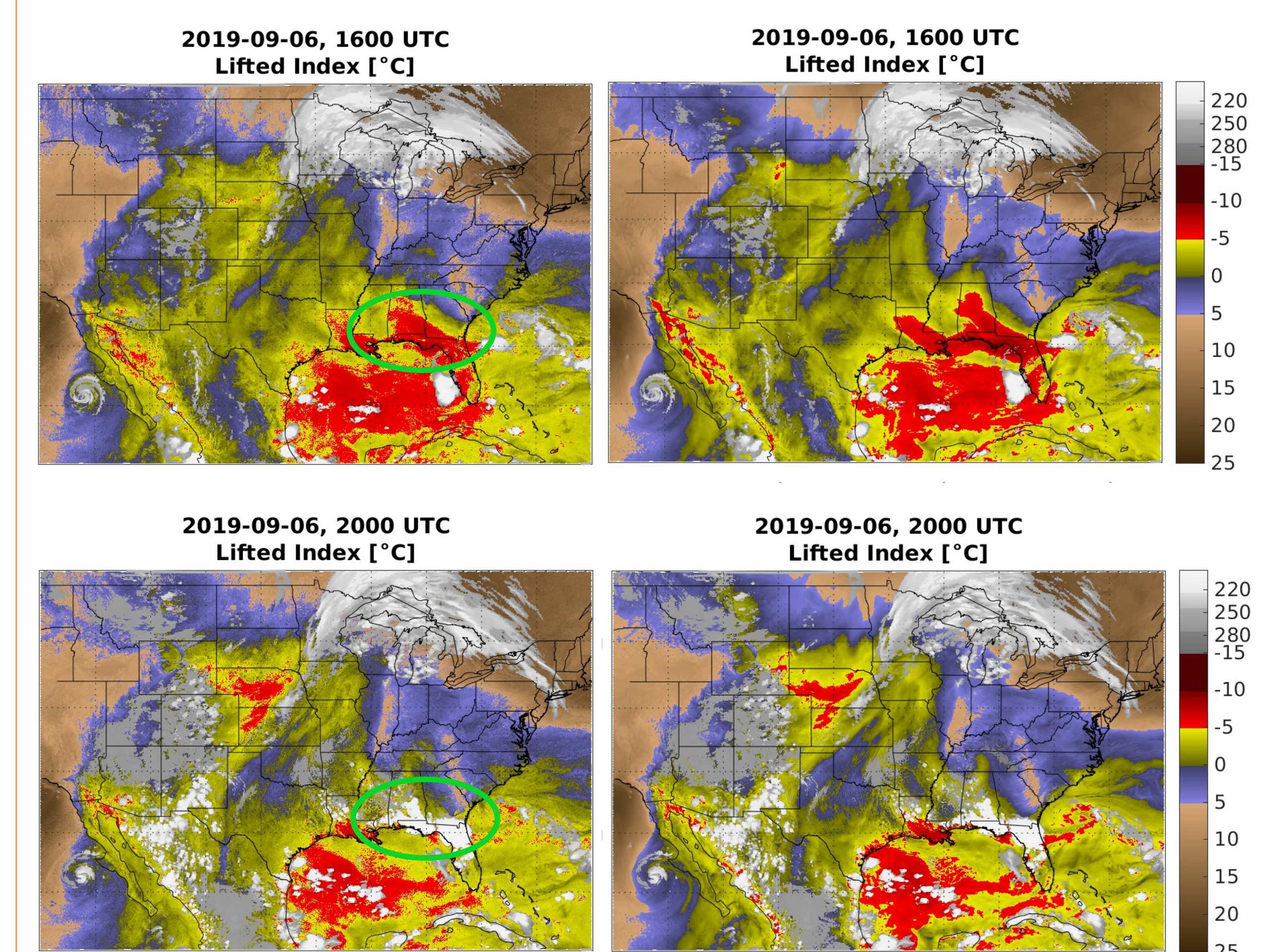

Fig. 10. The all sky lifted index (℃) from (left) GXS and (right) truth. Top row at 16 UTC and bottom row at 20 UTC on September 6 2019. The black and white regions are those having strong cloud impacts with low quality sounding retrievals and are thus disregarded.

5. Summary

- NOAA's next generation geostationary satellite system, the Geostationary Extended Observations (GeoXO) is scheduled to launch in 2030s.
- The GeoXO sounder (GXS) is going to be the nation's first GEO hyperspectral infrared sounder
- GXS with high temporal resolution will provide abundant sounding information on thermodynamics, dynamics, and trace gases
- GXS proxy datasets have been generated
  - 1-km ECMWF nature run (XNR1K) as input
  - Methodologies developed for CRTM and PFAAST
  - 3 CONUS local severe storm cases (36-72 hours) and 1 full disk case (18 hours)
  - Outputs in NetCDF including T/Q/U/V/Ts/Emis/lat/lon/geometry/BT/noise/clouds
  - Proxy datasets can be used for various quantitative and qualitative applications, including local severe storm nowcasting.
- Contact Zhenglong Li (zhenglong.li@ssec.wisc.edu) if interested in testing the GXS proxy datasets

6. Acknowledgement

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