Deep Learning-Based Retrievals from Spire's Hyperspectral Microwave Sounder (HyMS)

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Goa, India

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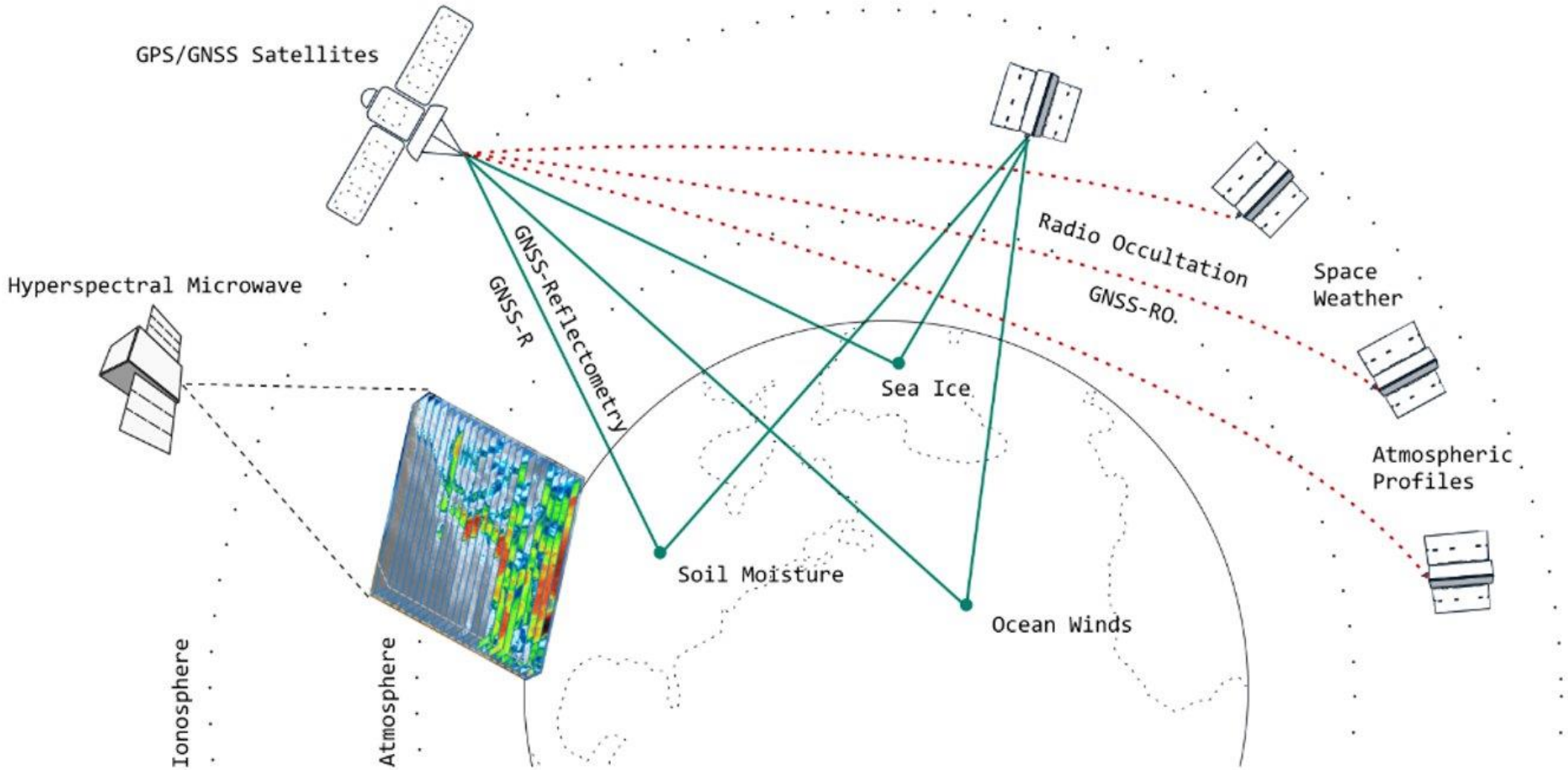
Spire's Observing System

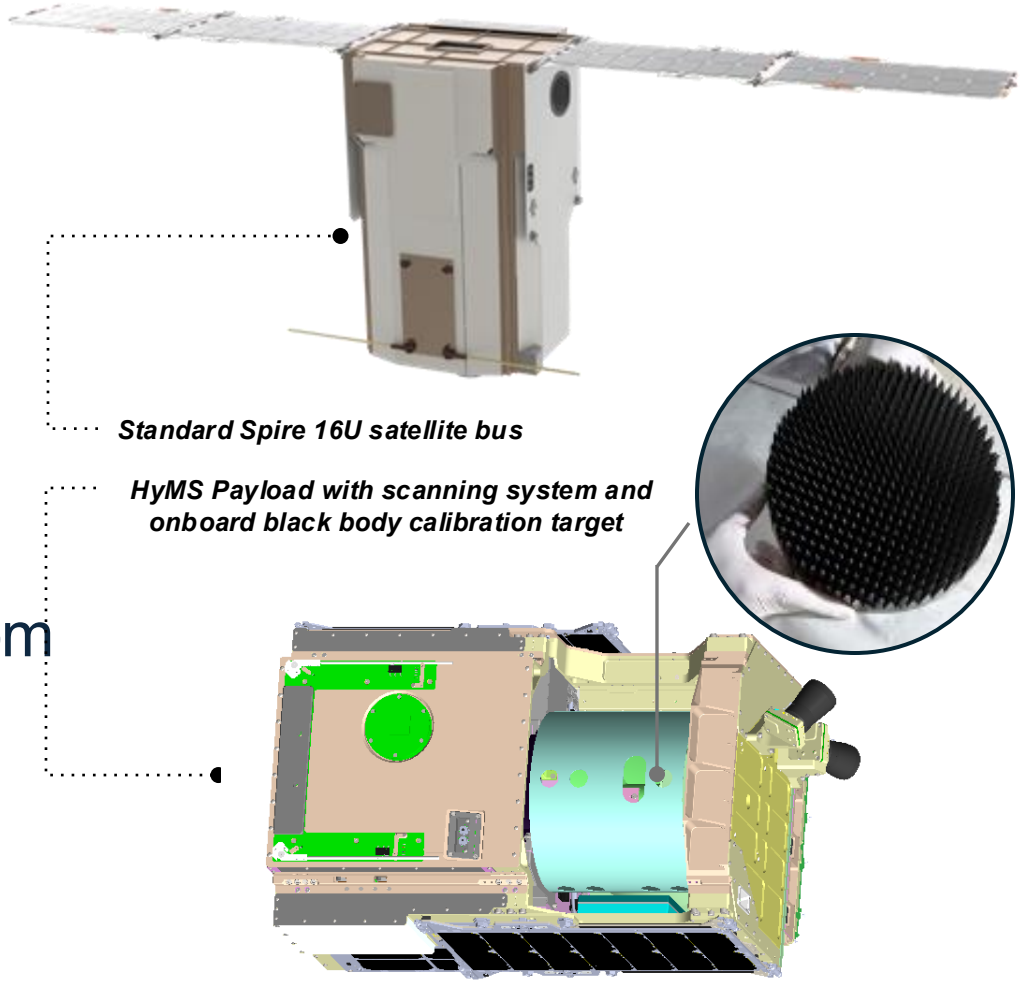


In-Orbit Demonstration of the HyMS:

- Integrate instrument into Spire 16U LEMUR spacecraft
- Sample oxygen and water vapor bands from space
- Demonstrate free-flying instrument performance in orbit
- Assess and understand data collected from HyMS

See Manju Henry's presentation for more information

SRFs, NEDTs, CRTM coefficients available upon request



Hyperspectral capability through ultra-wideband spectrometer

HyMS Retrievals

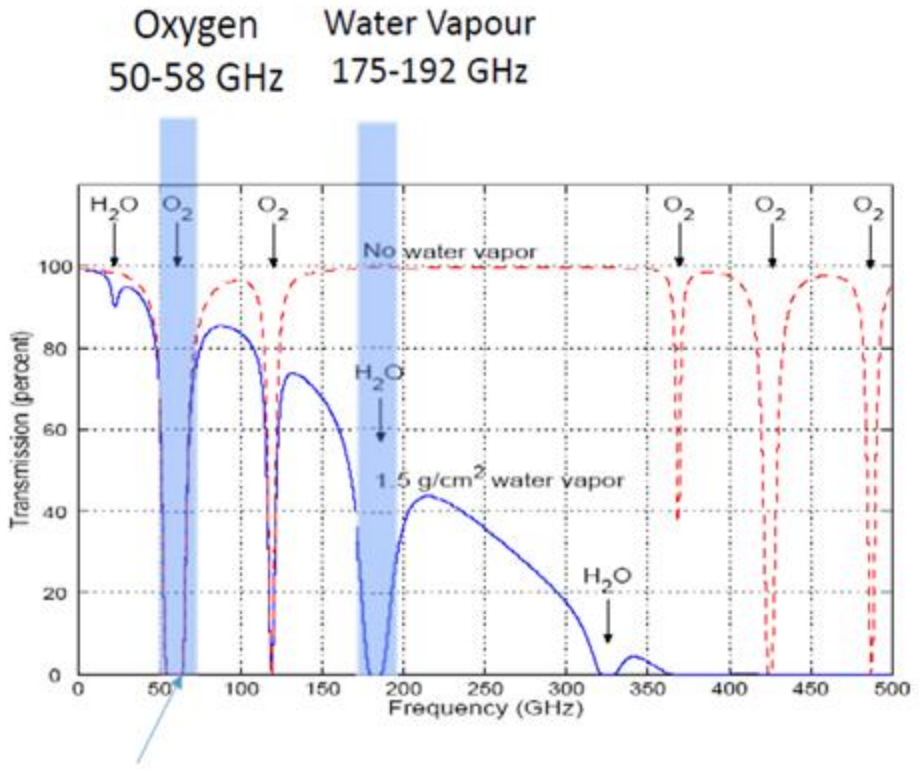
Goal: Generate retrievals of temperature, humidity, pressure, cloud profiles and precipitation

Motivation for developing retrieval algorithm:

- Understand theoretical capabilities of novel HyMS instrument, over all surface types, and in clear, cloudy and precipitating scenes
- Understand resolution trade-off and perform channel selection

Method: Generate synthetic HyMS observations from the CRTM in a variety of scenes and train a deep neural network on ECMWF analyses.

Band Selection and Spectral Resolution

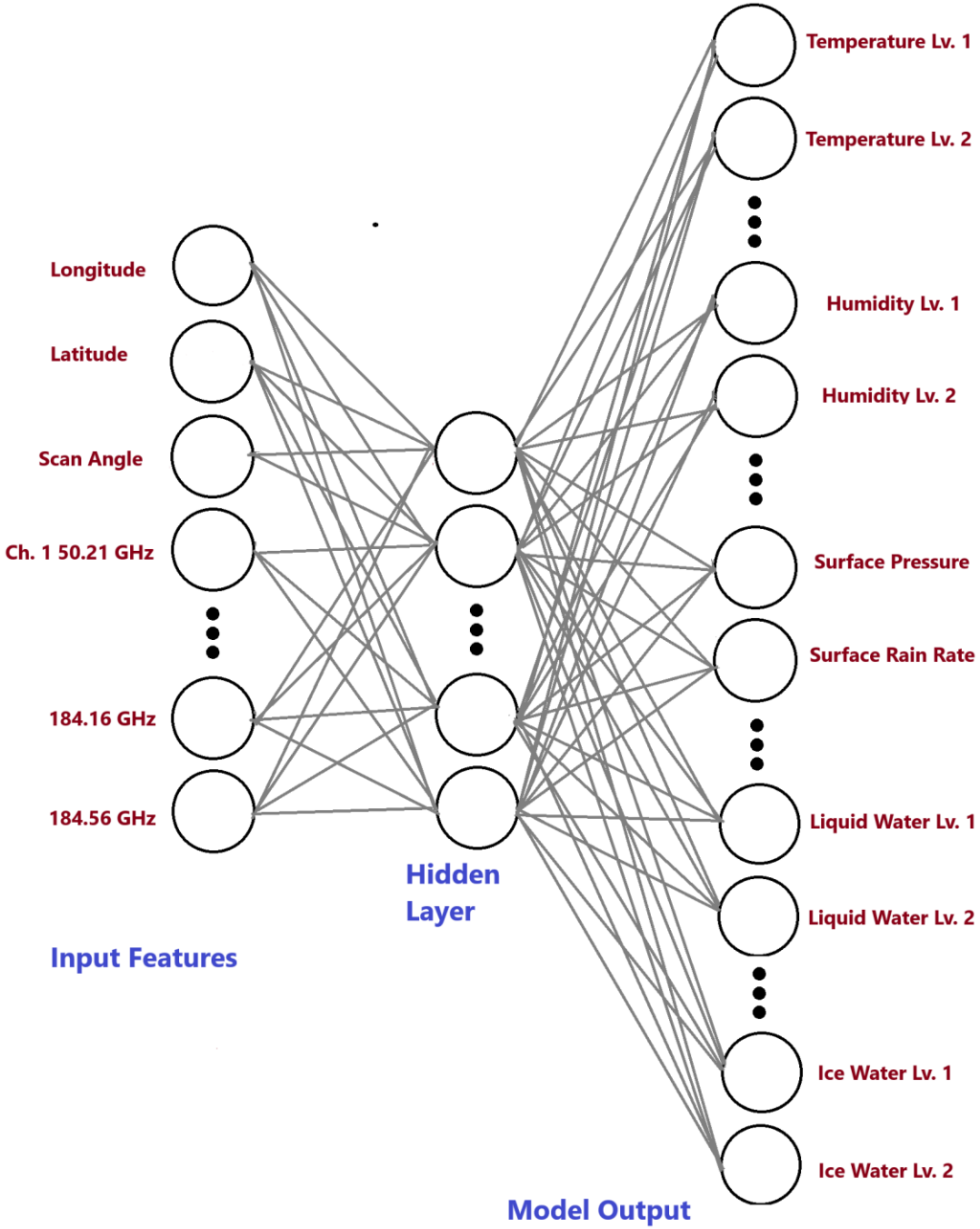


Two key molecular species:

- Atmospheric oxygen (50-58 GHz)
- Atmospheric water vapor (175-192 GHz)

Spectral Resolution: 1714 channels

- 5 MHz for oxygen band
- 40 MHz for water vapor band



Neural Network Retrieval Study

Input features: Simulated HyMS brightness temperature spectrum, location and scan angle

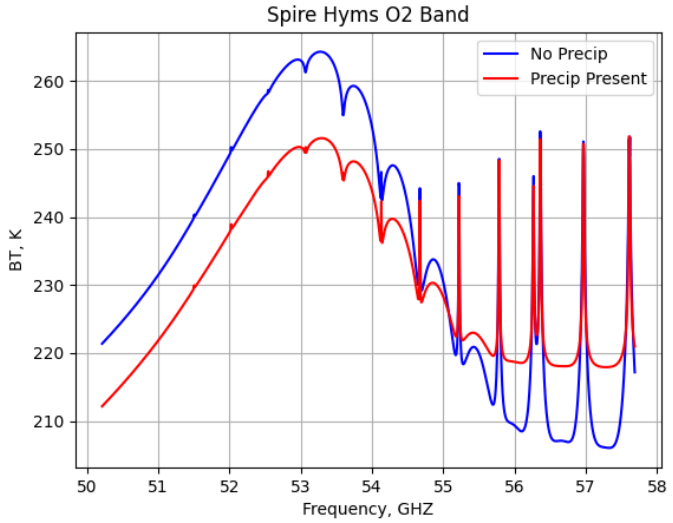
One hidden layer with 250 nodes

Output: temperature and humidity profiles, surface pressure, surface rain rate

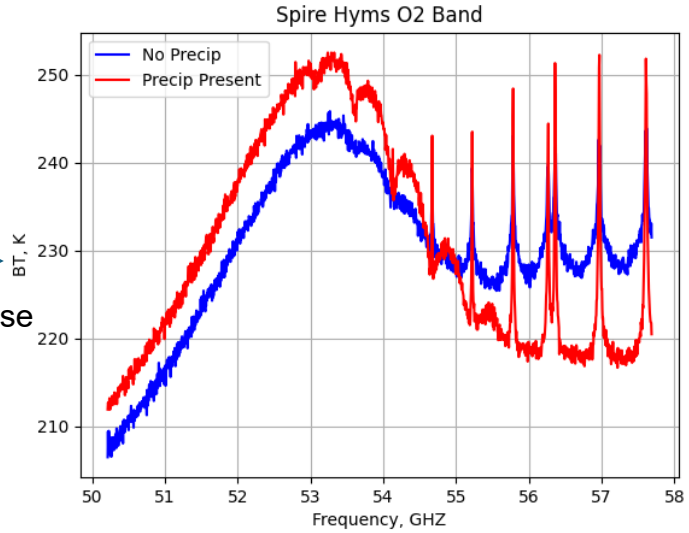
Eventually plan to add cloud properties (liquid and ice water)

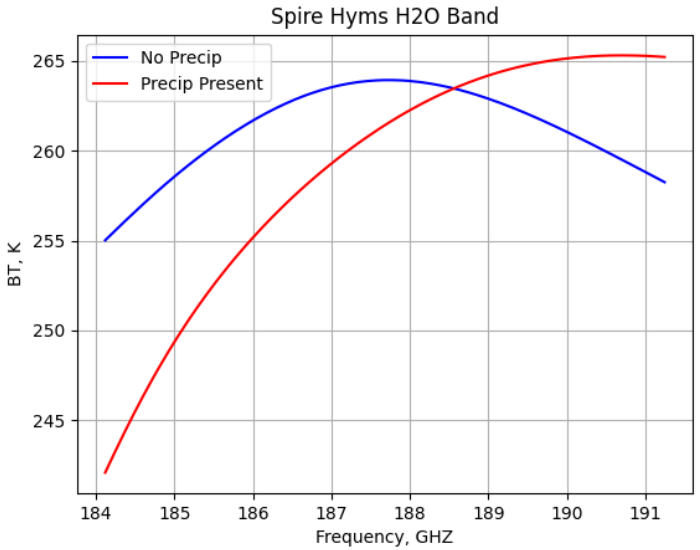
Training set generated from 25K randomly sampled HyMS spectrums generated from ECMWF profiles from Jan-April 2025.

Retrieval Study



Add noise





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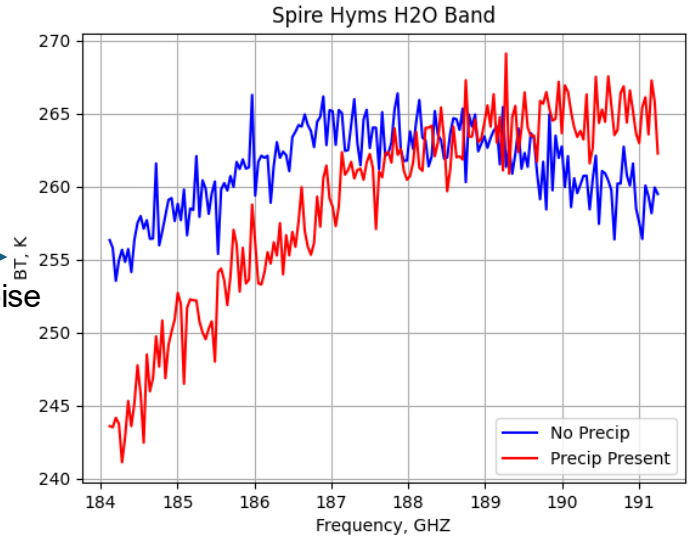
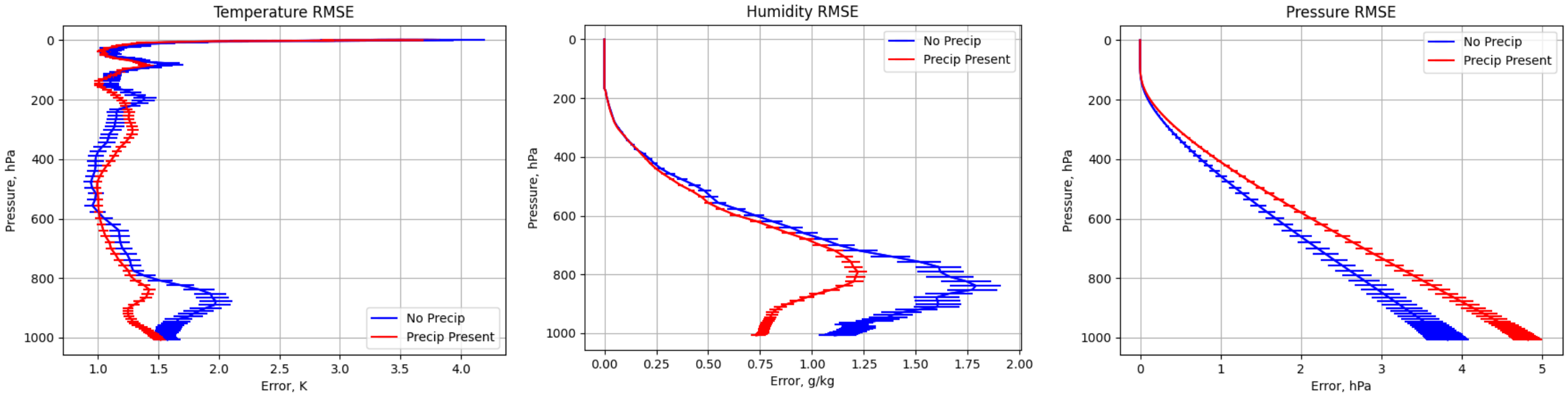


Initially test with 1714 HyMS channels, with 5 MHz resolution in the oxygen band and 40 MHz resolution in the water vapor band.

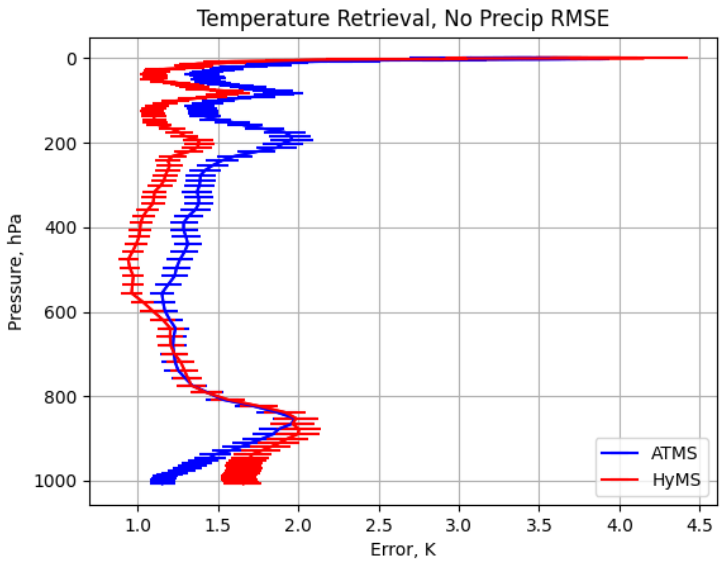
Generate synthetic observations, and add noise
Nedt=0.6 for oxygen band
Nedt = 1.6 for water vapor band

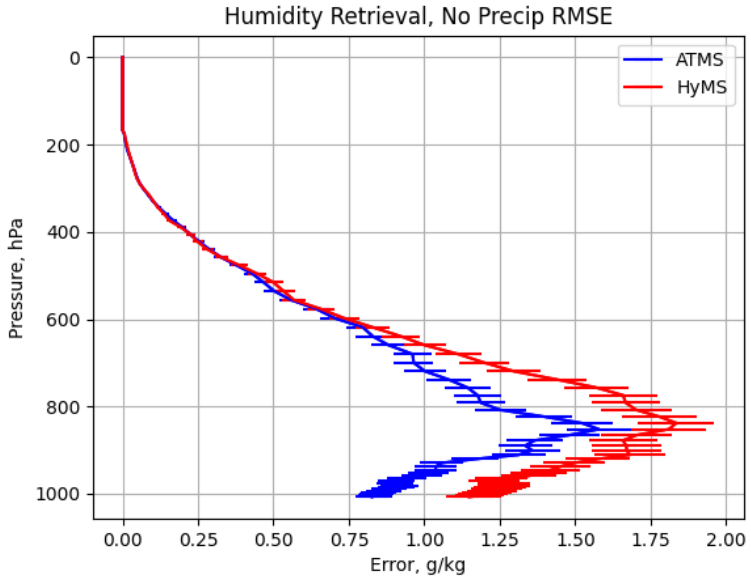
Retrieval Study

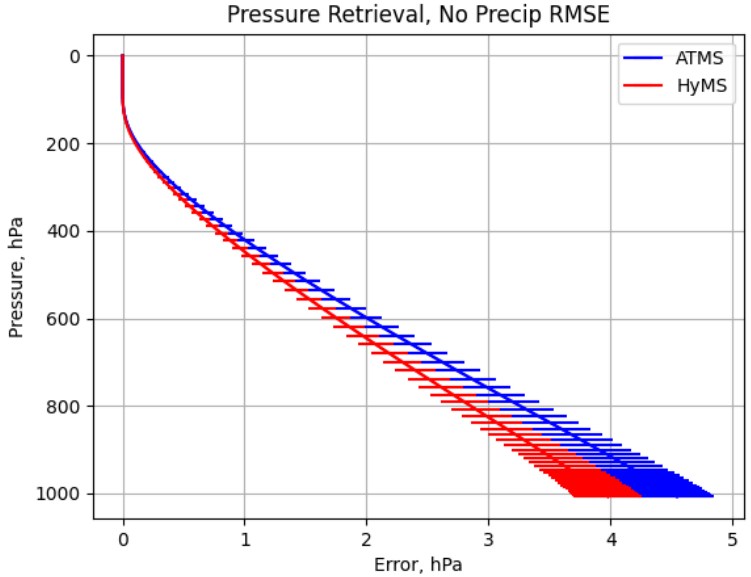


HyMS temperature, humidity and pressure retrieval accuracy, in the absence and presence of precipitation.
Uses 1714 with 5 MHz resolution in oxygen band (NEDT=0.6K), 40 MHz resolution in water vapor band (NEDT=1.6K). Atmospheric pressure is computed based on retrieved surface pressure.

Retrieval Study-Comparison to ATMS N20 No Precipitation Present

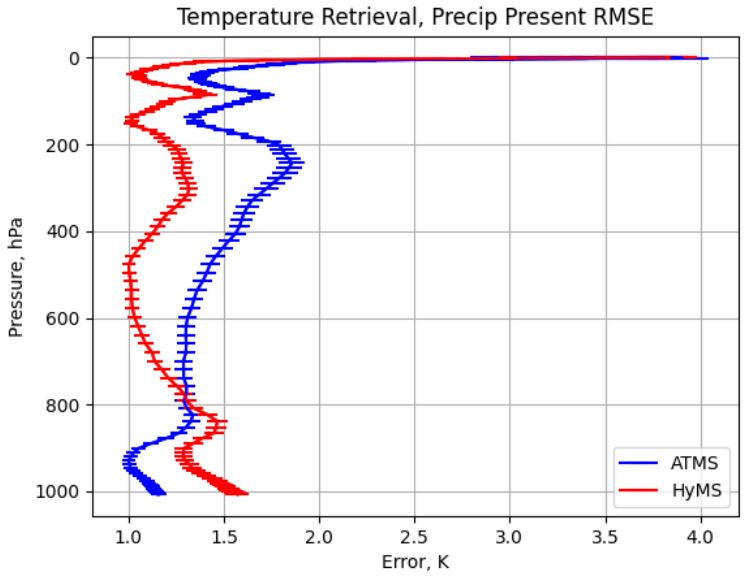


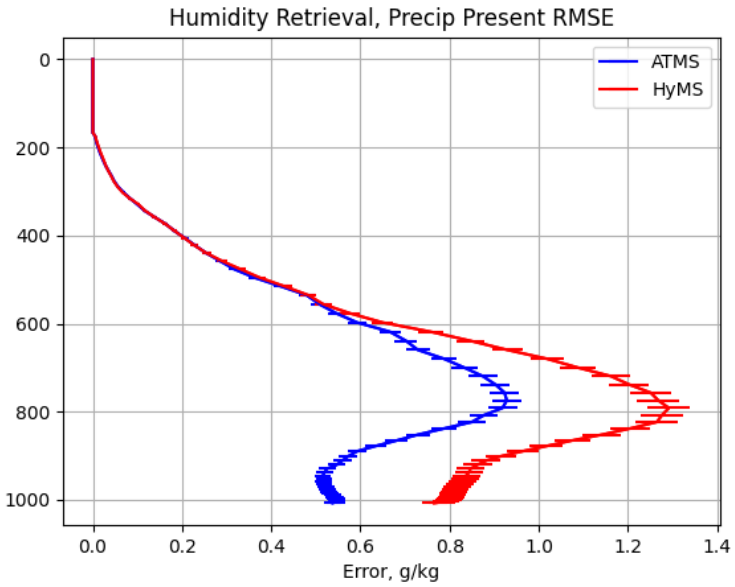


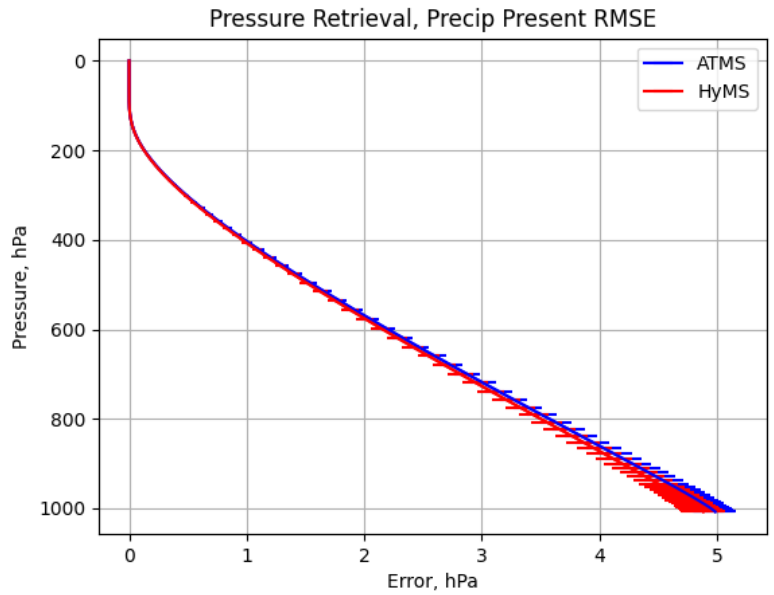


HyMS and ATMS N20 temperature, humidity and pressure retrieval accuracy, in the absence of precipitation.
HyMS retrievals used 1714 with 5 MHz resolution in oxygen band (NEDT=0.6K), 40 MHz resolution in water vapor band (NEDT=1.6K).
ATMS retrievals were generated from simulated observations, with noise added.

Retrieval Study-Comparison to ATMS N20 Precipitation Present

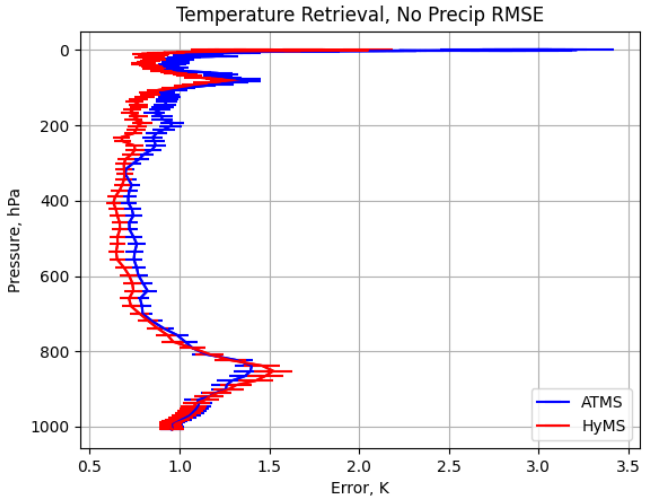


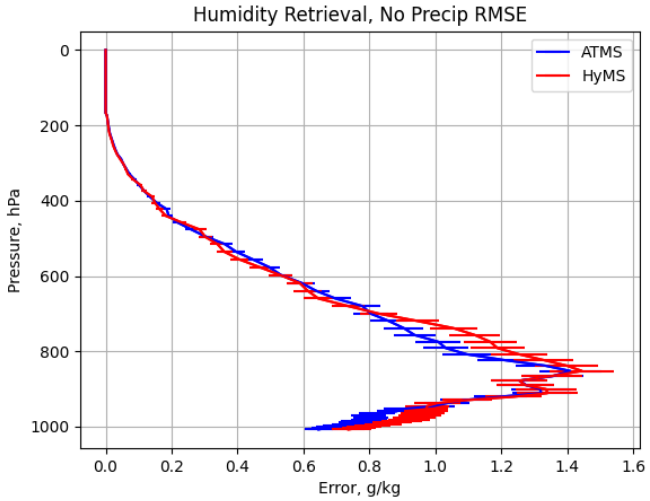


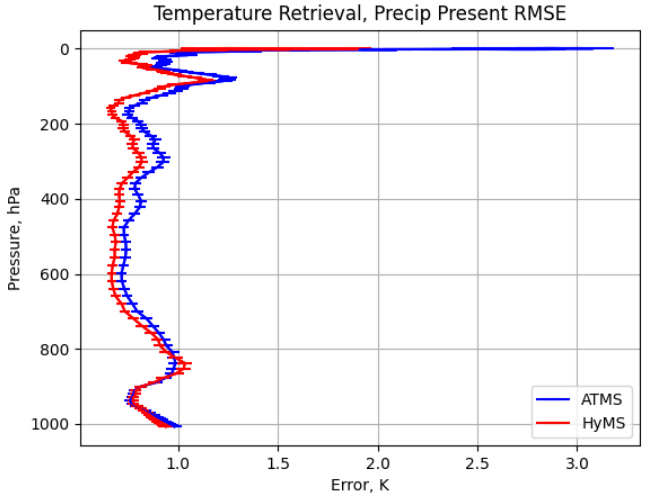


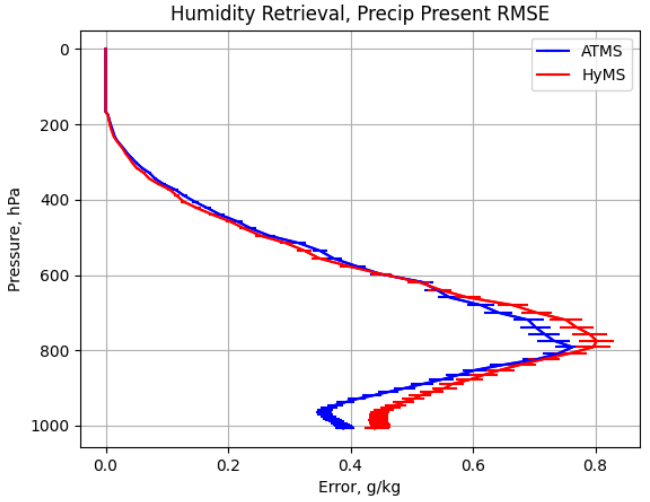
HyMS and ATMS N20 temperature, humidity and pressure retrieval accuracy, in the presence of precipitation.
HyMS retrievals used 1714 with 5 MHz resolution in oxygen band (NEDT=0.6K), 40 MHz resolution in water vapor band (NEDT=1.6K).
ATMS retrievals were generated from simulated observations, with noise added.

Retrieval Study-Comparison to ATMS N20 No Noise Added to Observations







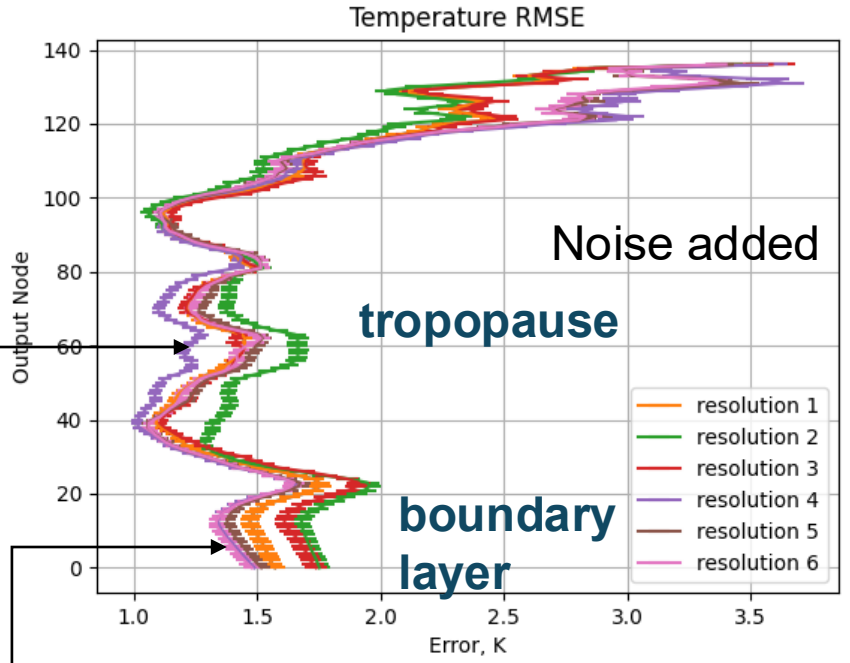


Perceived improvements to retrievals from ATMS are somewhat due to noise

HyMS channels are in the 58 GHZ and 183 GHz bands. ATMS has channels in these bands and other frequencies

Retrieval Study-Spectral Resolution Tradeoff

Scheme	Description	Total Number of Channels
Resolution 1	1.22 MHz resolution within 15 MHz of absorption peaks, 57.6 MHz resolution in O_2 band, 21 MHz resolution in H_2O band.	4128
Resolution 2	1.22 MHz resolution within 7.5 MHz of absorption peaks, 57.6 MHz resolution in O_2 band, 78.1 MHz resolution in H_2O band.	1843
Resolution 3	As Resolution 1, but with 57.6 MHz resolution below 53 GHz.	2245
Resolution 4	4.8 MHz resolution in O_2 band, 42 MHz resolution in H_2O band	1714
Resolution 5	4.8 MHz resolution within 15 MHz of absorption peaks, 115.2 MHz resolution in O_2 band, 42 MHz resolution in H_2O band.	679
Resolution 6	4.8 MHz resolution within 15 MHz of absorption peaks, 57.6 MHz resolution in O_2 band, 42 MHz resolution in H_2O band.	768



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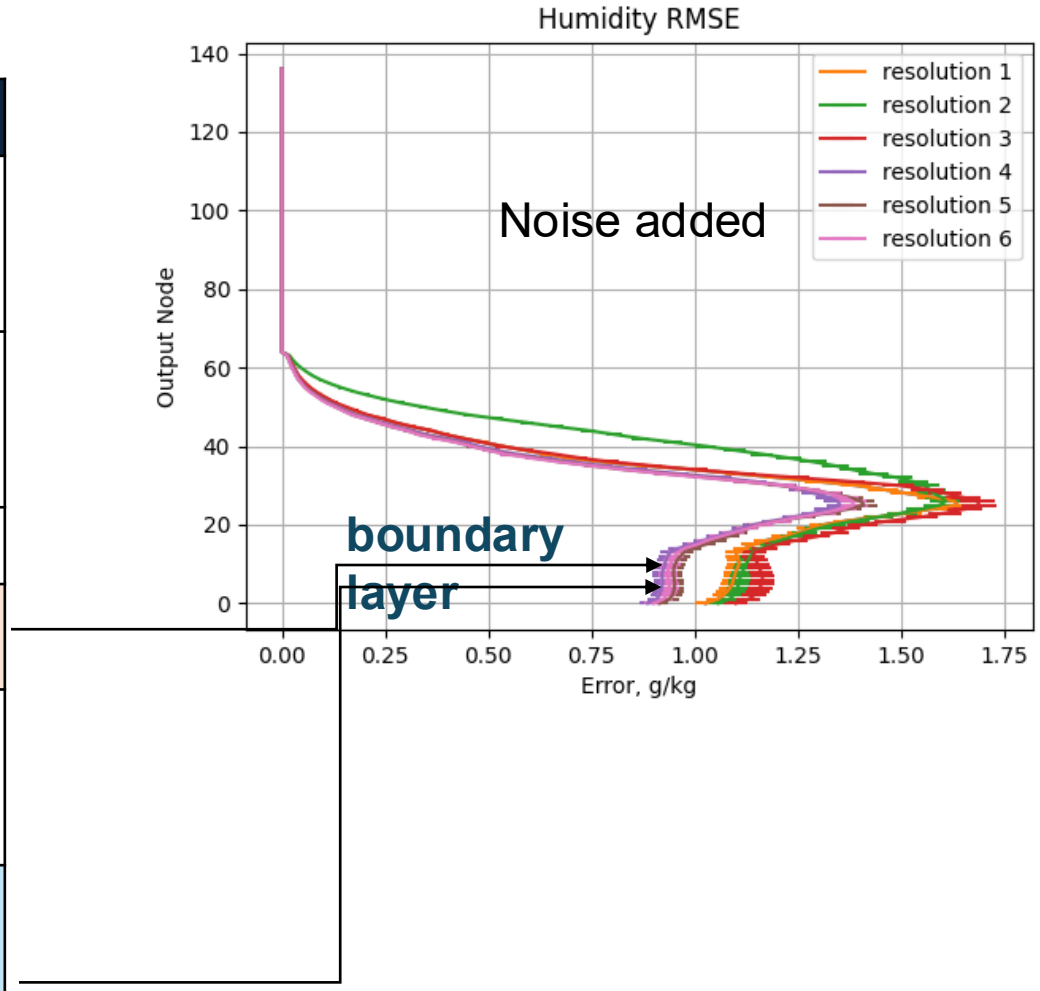

Conclusion

- The HyMS neural network retrieval algorithm was able to retrieve temperature, humidity and pressure profiles, in all-sky conditions
- Surface rain rate was also retrieved, with an RMSE of 2.56e-4 kg m^{-2} s^{-1} an approximate 4.3% error
- Retrievals had lower RMSE in the presence of precipitation. The spectra may capture scattering signatures across frequencies. This could improve temperature and humidity accuracy by constraining model errors.
- Comparisons with retrievals from simulated ATMS observations highlight differences between the assumed configurations: No surface channels used in the HyMS retrievals, and larger NEDT on HyMS 183GHz channels
- Upcoming work will add the 89 GHz channel to the retrieval algorithm, perform a deeper examination of surface rain retrieval, perform retrievals of cloud properties, and perform real retrievals once the HyMS is in orbit.

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