Neural Network Retrievals of Precipitation and Atmospheric Temperature and Moisture Profiles from ATMS and CrIS

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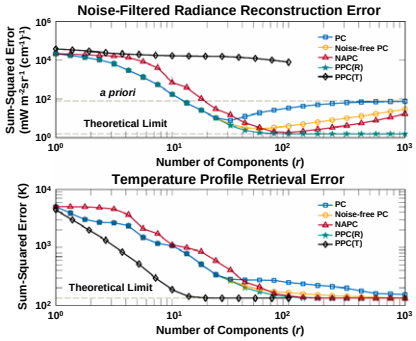
Abstract

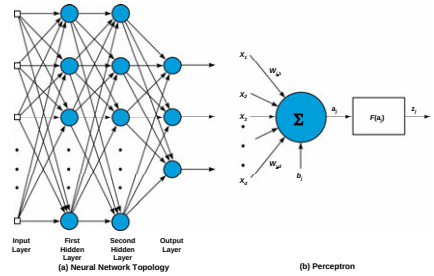
Two examples of neural-network-based atmospheric retrieval algorithms being developed for the ATMS and CrIS NPP/NPOESS sensors are presented. First, we consider the retrieval of atmospheric temperature and moisture profiles in the presence of clouds from hyperspectral radiance measurements in the thermal infrared. The effects of clouds are estimated and corrected using stochastic cloud clearing (SCC). A projected principal components (PPC) transform is then used to reduce the dimensionality of and optimally extract geophysical information from the spectral radiance data, and a multilayer feed-forward neural network (NN) is subsequently used to estimate the desired geophysical profiles. This algorithm offers the numerical stability and efficiency of statistical methods without sacrificing the accuracy of physical, model-based methods. We will present results based on proxy data from the AIRS and AMSU sensors. Second, we consider the retrieval of precipitation rate from passive microwave radiance measurements at frequencies near the oxygen and water vapor resonances at 50–60 GHz and 183.31 GHz, respectively. In this case, the models relating the precipitation rate to the radiance intensities measured by the sensor are extremely complicated and difficult to validate. The use of neural networks to empirically learn the statistical relationship between rain rate and spectral intensity obviates the need for complex and, often, inaccurate models in the retrieval algorithm.

The SCC/NN Algorithm

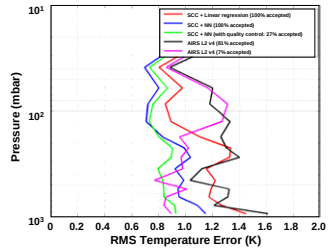
- Based on statistics derived from a set of training data; in this case, over 500,000 temperature and moisture profiles from the ECMWF forecast were co-located with AIRS/AMSU observations
- Cloud-cleared radiances are estimated by the SCC algorithm
- Global operation: Land/Ocean, Day/Night, all latitudes
- Altitude-dependent quality control
- 100–1000 times faster than heritage algorithms

Performance comparisons of the PC (where the components are derived from both noisy and noise-free radiances), NAPC, and PPC transforms for a hypothetical 1750-channel infrared (4 μm–15 μm) sounder. Two projected principal components transforms were considered, PPC(R) and PPC(T), which are, respectively, 1) maximum representation of noise-free radiance energy, and 2) maximum representation of temperature profile energy. The first plot shows the sum-squared error of the reduced-rank reconstruction of the noise-free spectral radiances. The second plot shows the temperature profile retrieval error (trace of the error covariance matrix) obtained using linear regression with *r* components.





The structure of the multilayer feed-forward neural network (specifically, the multilayer perceptron) is shown in (a), and the perceptron (or node) is shown in (b). A single hidden layer is used to retrieve temperature and two hidden layers are used to retrieve moisture. Typically, 25–50 nodes are used.

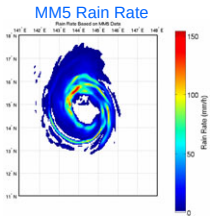


Temperature profile retrieval performance for the SCC/NN algorithm is compared with SCC + linear regression as well as the AIRS Level 2 algorithm. Moisture retrieval performance shows similar trends.

Retrieval of Rain Rate Using ATMS

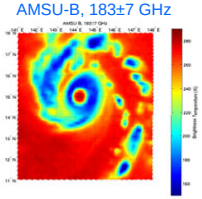
- MM5 Numerical Weather Prediction (NWP) model provides temperature profile, water vapor profile, hydrometeor profile, and other cloud microphysical properties
- ATMS observations were simulated using radiative transfer calculations based on TBSCAT [Rosenkranz, 2002]
- Improved hydrometeor modeling due to Surussavadee & Staelin (2006)
- Accurate matching of brightness temperatures on MM5 grid to ATMS resolution and geolocation using "satellite geometry" toolbox for MATLAB
  - Computing angular offset of surface locations from boresight
  - Computing satellite zenith angles from scan angle
  - Computing geolocation from scan angle
- Estimation of surface rain rate was performed using a single-layer neural network rain rate was performed using a single-layer neural network trained to MM5 output

MM5 Rain Rate

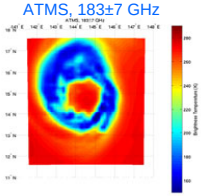


MM5 data: 8 Dec 2002, 1600 to 1800 UTC
NOAA-16 AMSU-A/B data: 8 Dec 2002, around 1626 UTC

AMSU-B, 183±7 GHz

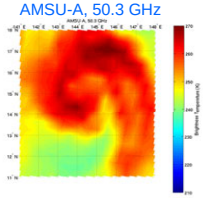


ATMS, 183±7 GHz

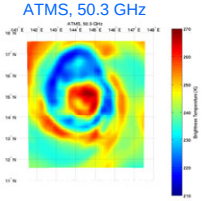


Simulated ATMS 183±7-GHz data show reasonable agreement with AMSU-B. The morphology difference between AMSU observations and MM5 predicted radiances is due to the inaccuracy of the NCEP analyses used to initialize the MM5 model.

AMSU-A, 50.3 GHz



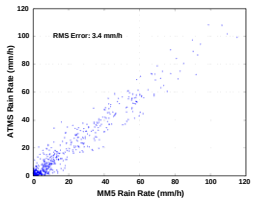
ATMS, 50.3 GHz



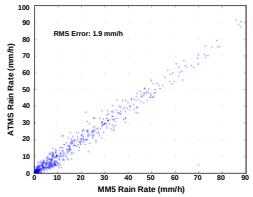
Simulated ATMS 50.3-GHz data with finer resolution and sampling show finer features than AMSU-A.

ATMS Precipitation Retrieval Algorithm

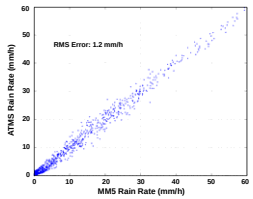
1.1° ATMS vs. MM5



2.2° ATMS vs. MM5



5.2° ATMS vs. MM5



- 22 channels and the satellite zenith angle were input to neural network
- Typhoon data shown in the brightness temperature images were used
- Training, validation, and testing sets each had 1521 examples
- Results shown for 1.1°, 2.2°, and 5.2° resolution precipitation rates

Summary

- Two neural-network-based algorithms for retrieving precipitation and atmospheric profiles from CrIMSS have been presented
- The algorithm accuracies meet or exceed those of heritage algorithms at a substantially reduced computational burden
- A system for simulating ATMS data using MM5/TBSCAT has been developed and shows reasonable agreement with observed AMSU data
- A preliminary ATMS precipitation retrieval algorithm has been developed for a single typhoon and shows good agreement with MM5

References

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