# Combining GPS occultations with AIRS infrared measurements for improved atmospheric sounding

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## Abstract

After simulating the effect of Global Positioning System Radio Occultation (GPS/RO) data on infrared (IR) and microwave (MW) measurements and confirming the results with tests on real ATOVS and CHAMP (CHAllenging Mini-satellite Payload) data, the focus of this work has turned to combining high spectral resolution AIRS measurements with GPS data in regression-based profile retrievals.

Atmospheric Infrared Sounder (AIRS) and Advanced Microwave Sounding Unit (AMSU) data from the Aqua satellite collocated with radiosondes (for validating retrievals) and GPS measurements from the CHAMP and SAC-C satellites were collected from September 2002 to December 2003. 1872 collocations were found under all weather conditions. After testing various cloud masks, 379 clear sky collocations remained.

This paper presents the results after testing two regression algorithms on these data: a linear statistical regression algorithm and a principal component regression. A new in-house training dataset was used to determine the regression coefficients. Calculated AMSU and AIRS brightness temperatures for a fixed number of optimal channels and calculated GPS refractivity profiles were regressed against radiosonde temperature and humidity profiles. These regression coefficients were then applied to the 379 collocations (real data) and the retrievals were validated with radiosonde data. GPS is found to provide valuable upper tropospheric information that improves the profile retrieval from AIRS and AMSU.

## Introduction

The motivation to study the combination of the active remote sensed GPS data and the passive high spectral resolution infrared radiometric measurements (like AIRS) was to get better quality atmospheric temperature and moisture retrievals than the two systems would give alone. This was considered likely because the two systems have complementary characteristics (Collard and Healy, 2003), especially around the tropopause region: the GPS/RO system provides good absolute accuracy near the tropopause with very good vertical resolution but poorer horizontal resolution, while the IR sounding system has high horizontal but poorer vertical resolution. In additional, an earlier study (Borbas et al. 2003) on simulated and real narrow band ATOVS data showed that adding GPS/RO measurements to the retrieval method produced improved atmospheric temperature and humidity profiles.

The GPS/RO system is an active limb sounding system. The American GPS consists of 24 satellites, which transmit radio signals on two frequencies. The receiver is generally located on a Low Earth Orbiting (LEO) satellite. An occultation occurs from the standpoint of a receiver satellite, whenever a GPS (transmitter) satellite rises or sets over the Earth and the ray from the transmitter traverses the Earth's atmospheric limb. The ray path through the atmosphere is reflected according to Snell's law. With exact knowledge of the locations of the receiving and transmitting satellites, the refractive index (or refractivity) of the atmospheric layer through which the ray passes can be derived. The movement of the two satellites produces the vertical profile of refractivity. Currently two GPS LEO satellites are in operation and provide atmospheric measurements, the German CHAMP and the Argentinean SAC-C satellite.

Radiances from AIRS, the high spectral resolution infrared sounder, along with brightness temperatures from AMSU were used in this combination study. The AIRS and AMSU instruments were launched on the NASA Earth Observing System (EOS) Aqua satellite in May 2002. More information about the AIRS instrument and measurements can be found in (http://airs.jpl.nasa.gov/).

## Input data and method to produce combined AIRS+AMSU+GPS retrievals

AIRS, GPS/RO from both CHAMP and SAC-C satellites, and radiosonde data for validation were collected between September 2002 and October 2003. Over 100,000 AIRS-RAOB collocations (from the NASA/JPL so called prepqc matchup files) and about 60,000 and 100,000 SAC-C and CHAMP occultations were collocated from the NASA/JPL Genesis website for this study. The criteria for collocation were time separation of 3-hours or less, and distance separation of 300 km or less. These data yielded 1082 AIRS-RAOB collocations with CHAMP data and 790 collocations with SAC-C data.

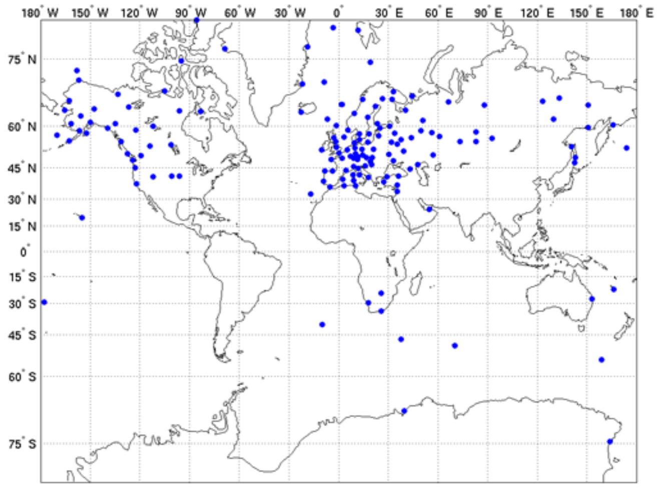

Fig. 1: Location of “clear sky” AIRS + AMUS + GPS + RAOB collocations.

The AIRS-RAOB collocations were made under all weather conditions. After testing various cloud masks (Ackerman et al. 1998) 379 clear sky collocations remained (those spectra with 10 or more channels with brightness temperatures (BT) differences greater than 7 K with respect to forward calculations from the RAOB profile were deemed to be cloudy). Figure 1 shows the location of the clear sky collocations and Figure 2 shows the clear sky AIRS observed brightness temperatures.

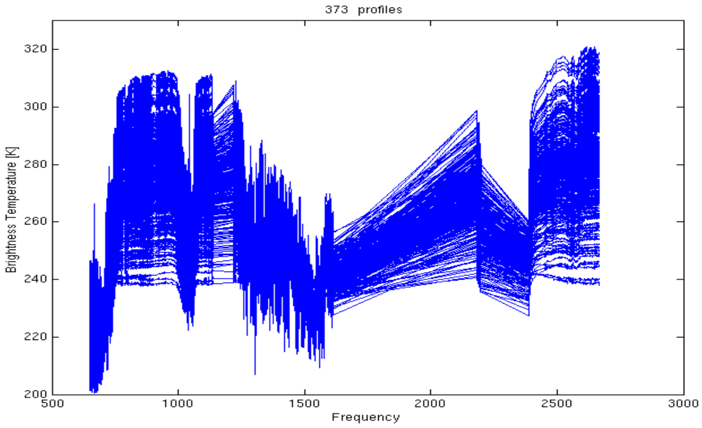

Fig. 2: The observed “clear sky” AIRS brightness temperatures.

After collecting a clear sky test dataset containing 379 collocated samples, statistical and principal component (PC) statistical regression algorithms were tested further on AIRS-only retrievals using various subsets of channels. First a regression algorithm was developed with considerations for ecosystem-based emissivities and a new relationship for surface-skin temperatures; the latest version of the in-house training dataset of 12208 profiles (Borbas et al. 2005). The calculated AIRS brightness temperatures for a fixed number of optimal channels (and GPS refractivity profiles with triple pre-estimated vertically correlated noises) were regressed against the temperature and moisture profiles. The satellite viewing angle, month, and surface pressure were also used in the regression. Then the regression coefficients were applied to the real data collocations. Next, a principal component regression (Smith and Woolf, 1976, Huang and Antonelli, 2001) was also applied to the same training dataset to calculate a second set of regression coefficients. 30 eigenvectors calculated from the covariance matrix of radiances simulated from the training dataset were used in this method. The Stand-Alone Radiative Transfer Algorithm (SARTA) forward model (Strow et al. 2003) was used to calculate AIRS radiances from the training dataset. The retrieval products are the temperature, moisture and ozone profiles, total precipitable water vapor (TPW), total ozone, surface skin temperature and surface emissivity. The PC regression algorithm using 1688 selected channels gave the best quality temperature retrievals around the tropopause region (Fig. 3.), and this was selected for the further combined AIRS/AMSU/GPS study.

The AIRS PC algorithm, which is part of the International MODIS/AIRS Processing Package (IMAPP), developed by Weisz et al. (2003), was modified to accommodate the addition of AMSU and GPS data. GPS profiles between 8 and 26 km with 200 meter vertical resolution were used in this comparison. To determine the regression coefficients, GPS/RO refractivity profiles were calculated from the training data using the method described by Healy and Eyre (2000) and Kurskinski et al. (1997). Only measurements from atmospheric-sensitive AMSU channels were used. The AMSU fast transmittance model is a microwave adaptation of PLOD/PFAAST (Hannon et al., 1996) based on line-by-line calculations with the MPM model (Liebe et al. 1993).

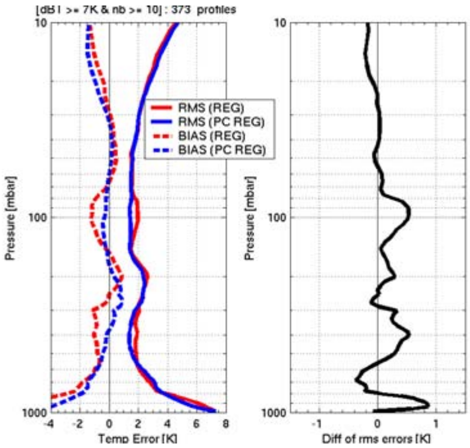

Fig 3**:** Left: comparison of using statistical regression method (red) and statistical PC eigenvector regression method (blue) for AIRS temperature retrievals. Right: the difference of the two rms error profiles is shown.

## Results

The regression coefficients, derived as described above, have been applied to the real AIRS, and AMSU data (version 3.0.8.0) and GPS refractivity profiles from the CHAMP and SAC-C satellites. Root-mean-square (RMS) differences and biases between radiosondes and temperature and humidity retrievals with and without GPS data were computed. Figure 4 shows the difference of the RMS profiles with and without GPS data. A positive value indicates improvement by adding GPS data in the retrieval system. The greatest temperature improvement resulting from the inclusion of GPS occurs in the tropopause region: the magnitude of the improvement is about 0.4 K at the 100 hPa and 280 hPa pressure levels. For moisture some small positive effect can be noticed at the surface, in spite of the fact that the GPS data were included only in the layer from 8 km to 26 km.

AIRS+AMSU and AIRS+AMSU+GPS statistical regression retrievals were also compared to the operational (official) AIRS level 2 retrievals. The individual retrievals were studied in detail (see Fig. 5 for temperature and Fig. 6 for moisture). Figure 5 reveals that the AIRS+AMSU+GPS temperature retrievals follow the radiosonde profiles quite well around the tropopause.

## Conclusions

In this paper we have presented a combination of high spectral resolution AIRS infrared measurements plus AMSU microwave measurements with GPS data to obtain improved temperature and moisture profile retrievals. The AIRS+AMSU+GPS retrievals were validated with collocated radiosonde measurements and were compared to the official AIRS L2 products. Looking at the individual cases (subjective analysis), it can be concluded that in clear sky conditions AIRS L2 (collection 3) temperature retrievals perform better than AIRS+AMSU regression retrievals but worse than AIRS+AMSU+GPS temperature retrievals. For moisture, AIRS L2 retrievals are the best, followed by AIRS+AMSU+GPS combined retrievals, last are the AIRS+AMSU moisture retrievals (without GPS). Based on the radiosonde validation of AIRS+AMSU temperature retrievals with and without the GPS data, the largest improvement from the inclusion of GPS occurs in the tropopause region: 0.4 K at or near the 100 hPa and 280 hPa pressure levels. In the case of moisture retrievals, AIRS L2 profiles are the closest to the radiosonde data, followed by AIRS+AMSU+GPS, and last are AIRS+AMSU (without GPS) retrievals.

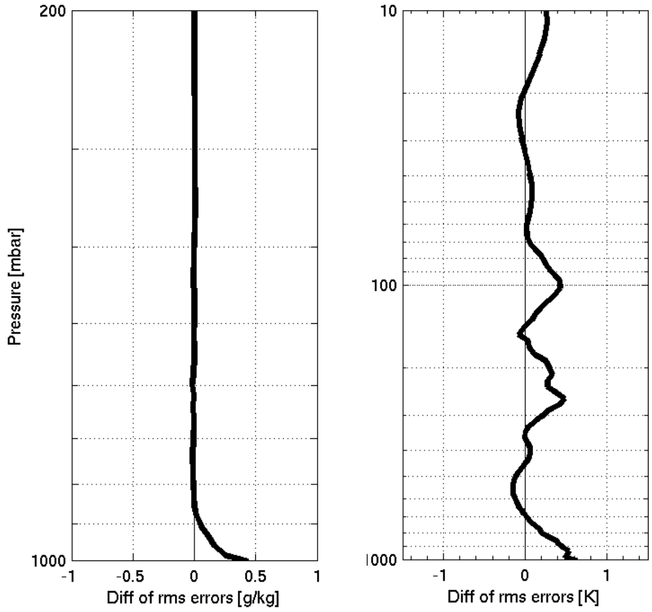

Fig. 4: Difference of rms difference profiles between radiosonde and AIRS+AMSU and AIRS + AMSU + GPS moisture retrievals (left panel) and temperature (right panel) retrievals. GPS refractivity profiles were added between 8 and 26 km with 200m vertical resolution.

## Future Plans

Our future research efforts will focus on expanding the AIRS+AMSU+GPS+RAOB collocated dataset to enable the generation of regression coefficients from real data (rather than simulated data using the training dataset), and to be able to do more precise and detailed validation by decreasing the distance and time separations in the collocation. Our aim is to update the comparison with the official AIRS L2 retrievals when version 4 becomes available. This study focused on the tropopause region; in the future the lower troposphere, where most of the atmospheric moisture is located, will also be investigated.

## Acknowledgements:

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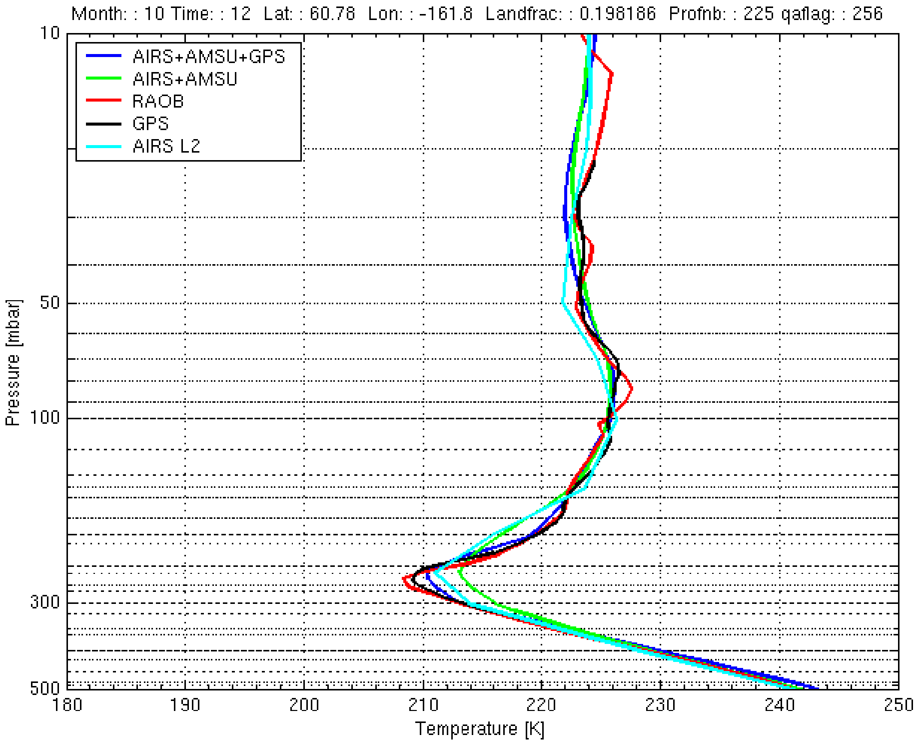

Fig. 5: Temperature profile comparison on October 12, 2003, 12 UTC over ocean.

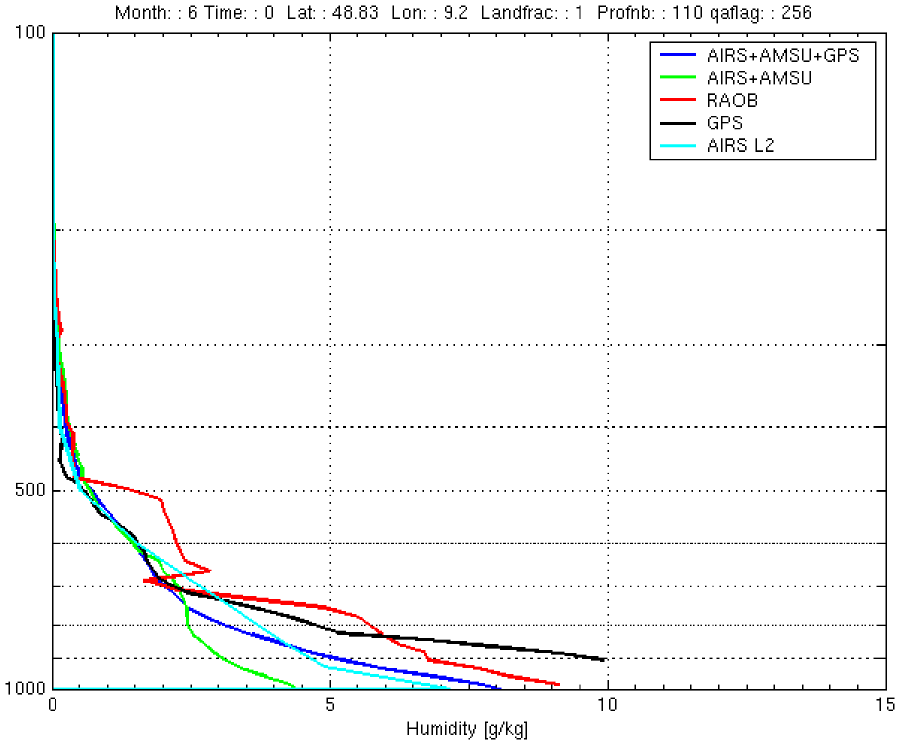

Fig. 6: Moisture profile comparison over land.

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