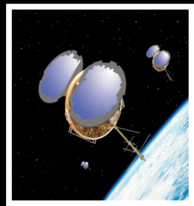


Improvement of the Temperature and Moisture Retrievals in the Troposphere using AIRS and GPS Radio Occultation Measurements

Shu-peng Ho, Y. H. Kuo and S. Sokolovskiy

National Center for Atmospheric Research, Boulder, Colorado

Corresponding author address : Dr. Shu-Peng Ho, Atmospheric Chemistry Division, NCAR, PO BOX 3000 Boulder, Colorado, 80307-3000. E-mail address: spho@ucar.edu, Tel: (303)497-2922

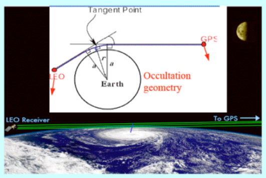
Objective

•Temperature and water vapor play a crucial role in weather and climate. With high vertical resolution, the Atmospheric InfraRed Sounder (AIRS) can provide global sounding profiles that are comparable to that from the radiosondes [Fetzer et al, 2003] in terms of accuracy.

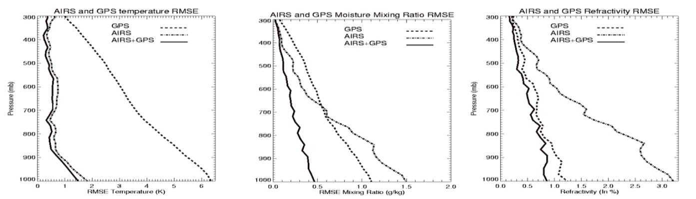
•However, AIRS retrievals still encounter poor resolving power in the lower troposphere, accurate temperature and water vapor profiles in the Planetary Boundary Layer (PBL) cannot usually be obtained.

•Global Positioning System (GPS) radio occultation (RO) is the first technique that can provide high vertical resolution all-weather refractivity (N) profile, which depends on pressure (P), temperature (T) and moisture (W). However, in the moist lower troposphere, the refractivity retrievals from GPS RO data are usually negatively biased due to (i) GPS receiver tracking errors and (ii) propagation effects induced by horizontal layered refractivity irregularities, in particular, by the super-refraction (SR).

•The Objective of this study is to combine the high spectral resolution AIRS measurements and GPS RO soundings to obtain the best global temperature and moisture retrievals in the troposphere and quantify their improvements in terms of the information content .



Simulation results: concurrent inversion of GPS RO and AIRS data in the troposphere



• A multi-variable regression method is used to retrieve atmospheric T and W profiles from simultaneous AIRS and GPS measurements. The regression equation is the following:

$$\delta X = \sum_{i=1}^{4} a_{ij}\delta f_i(N_{ij}) + \sum_{k=1}^{n} b_k BT_k$$

where $f_i(N_{ij})$ is a linear, quadratic, logarithmic and the inverse function of refractivity (*N*), respectively, $\delta f_i(N_{ij})$ is the departure of from its mean, and f_i is the corresponding regression coefficient and *j* is the index of pressure level; *k* is the index of AIRS brightness temperature (*BT*), *b* is the corresponding regression coefficient for AIRS brightness temperature, and *n* is the total number of AIRS channels used. *X* is the combination of retrieved *T* and *W* profiles. δX is the departure of *X* from its mean.

•The fast and accurate AIRS transmittance model (Standard Alone AIRS-Radiance Transfer Algorithm package – SARTA) from University of Maryland Baltimore County (UMBC) AIRS team [Strow et al., 2002] is used to simulate AIRS brightness temperature.

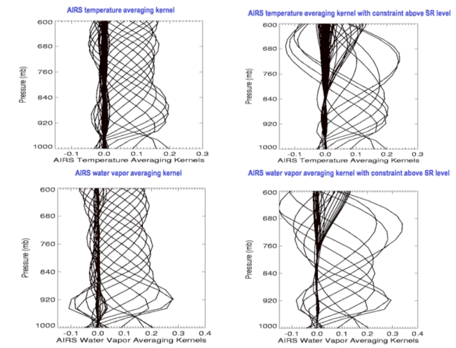
•We use AIRS channels with instrument noises less than 0.4 K in this retrieval algorithm. About 2000 AIRS channels are used. The GPS RO refractivities are also simulated using these NOAA 88b radiosonde sounding profiles. The global mean RO observation errors are randomly added to the corresponding RO signals.

• Regression coefficients are computed using a training set of data, which are generated between simulated *N* and AIRS brightness temperature from 2179 NOAA88b profiles. For GPS only retrieval, b_k are equal to zero, where for AIRS only retrievals, a_{ij} are all equal to zero.

Averaging Kernels for AIRS and Constrained AIRS above Super-Refraction level

• The state vector retrieved from the AIRS measurements may be represented as the weighted mean of the true state and the *a priori* state. The large averaging kernel value at different vertical levels represents that the retrieved results are weighted less by the *a priori* state but weighted more by the mean of the true state.

• By using AIRS and GPS combined retrieval profiles as the first guesses for AIRS physical retrieval and strongly constrain its variation by reducing the corresponding variance value above the super-refraction level (~700 mb in this analysis), more AIRS information above the SR level are squeezed for profile retrieval below the SR level as demonstrated in the larger averaging kernel values below the SR level.



Information Content Analysis of AIRS combined GPS

•For GPS RO Signals, the refractivity (N) is related to the pressure (P), the temperature (T) and the partial pressure of water vapor (*PW*) by the following equation:

$$N = 77.6\frac{P}{T} + 3.73\times10^5\frac{P_W}{T^2}$$

•To demonstrate how much independent information is presented in AIRS, GPS and AIRS combined with GPS measurements, their Degrees of Freedom for Signals (DFS) [Rodgers, 2000] are computed.

• DFS is the trace of the averaging kernel matrix.

•Averaging kernel provides one measure of the vertical resolution of the retrievals and is defined as

$$A_{avg} = (K^T E^{-1} K + C^{-1})^{-1} K^T E^{-1} K$$

where *C* is the *a priori* background covariance matrix; instrument noise and forward model error are described by the covariance matrix E, and K is the temperature and water vapor weighting function.

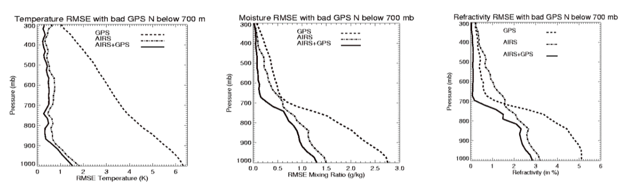
• To construct *C* and for further simulation analysis, the NOAA 88b clear sky radiosonde temperature and water vapor and ozone profiles are used to represent the global sounding data. This NOAA-88b dataset contains 2584 clear sky radiosonde temperature and water vapor profiles collected from a wide range of locations distributed globally in 1988.

• By using the NOAA88b global temperature and moisture sounding data, we can generate the background covariance matrix *C*, and the DFS for AIRS, GPS and AIRS combined with GPS are listed as below

Temperature and water vapor DFS for AIRS, GPS and AIRS combined with GPS

	AIRS	GPS	AIRS+GPS
DFS for Temperature	16.1	12.4	17.9
DFS for Water Vapor	10.2	20.5	23.6

Simulation results: discarding GPS RO data in lower Troposphere under SR conditions



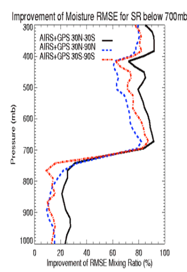
To demonstrate how the AIRS (A) data can improve GPS (G) RO inversion performance under Super-refraction conditions, a two-step strategy is implemented.

1. Assuming GPS RO signals below 700 mb are biased, we replace N below 700 mb in the dependent dataset (2179 profiles) by the mean *N* profile (which is computed from the dependent set of NOAA 88 simulated *N* profile). The new regression coefficients for the combined AIRS and GPS RO inversions are generated from the new dependent GPS RO *N* profiles and AIRS simulated brightness temperatures. The independent dataset (405 profiles) remains unchanged. In this case, the best retrieval results above 700 mb are mainly from the combined AIRS and GPS data. The information below 700 mb is mainly from AIRS data.
2. Under the condition that we are confident in retrieval result above 700mb, we use the combined retrieved profiles as the first guesses for AIRS physical retrieval [Ho et al., 2005] and strongly constrain its variation by reducing the corresponding variance value (~0.3 K for temperature and ~0.001 g/kg for moisture) above 700 mb in the background covariance matrix. Since AIRS weighting functions are significantly overlapped, the strong constraining of AIRS inversion above 700 mb results in that more AIRS information in the middle troposphere is used for T and W retrievals below 700mb.

By defining the percentage improvement of RMSE of W (RMSEW) for AIRS (A) and GPS (G) from RMSEW for AIRS as

$$RMSEW_{IMP} = 100\times\frac{(RMSEW_A - RMSEW_{A,G})}{RMSEW_A}$$

The percentage improvement of RMSEW(A,G) from RMSEW (A) for Tropics (30N-30N), North Hemisphere (30N-90N), and South Hemisphere (30S to 90S) are shown.

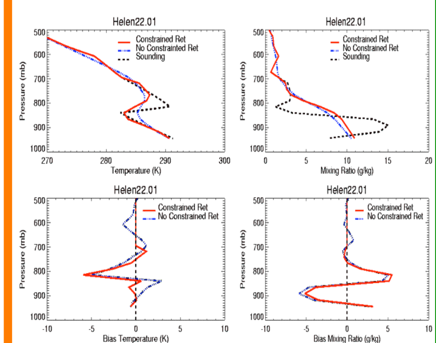


Simulation Results: a special case of super-refraction

• We apply above algorithm for one radiosonde N-profile with identified super-refraction condition.

• Results show that the GPS RO data above 700 mb strongly constrain AIRS observation and resolve temperature near 850 mb, which is better than that from AIRS alone observations.

• This result demonstrates that AIRS measurements provide unbiased refractivity, although at low resolution, in the PBL by significantly improving the GPS refractivity that otherwise is biased due to the SR effect.



Conclusions

• AIRS data are significantly correlated. AIRS measurements can provide 16 and 10 independent pieces of information about temperature and water vapor profiles, respectively where GPS RO data provide more than 20 independent pieces of information for vertical moisture profile. When combining AIRS and GPS RO data, the GPS RO signals help to improve AIRS moisture information content from 10.2 to 23.6; AIRS information helps to partition GPS RO refractivity into moisture and temperature and improve temperature information content from 12.4 (assuming GPS N is only used for the temperature retrieval) to 17.9.

•The AIRS temperature RMSE is within 1 K above 900 mb and 1.8 K near the PBL while the moisture RMSE is less than 0.5 g/kg above 500 mb and less than 1.8 g/kg below 500 mb. When both AIRS and GPS RO measurements are used simultaneously, they constrain each other and provide better accuracy of inverted temperature and moisture profiles than when the AIRS and the GPS RO measurements are inverted separately. The mean RMSET of all layers is 0.67 K. The RMSEW are even more significantly improved on the RMSEW and the RMSEW since most GPS RO affects mainly moisture retrievals in the troposphere. The mean RMSEW of all layers is 0.43 g/kg.

• GPS RO refractivities from current CHAMP and SAC-C data are significantly negatively biased in lower troposphere over regions with strong vertical moisture gradients due to tracking errors and propagation effects we have demonstrated that AIRS retrievals can provide unbiased GPS refractivity. Additionally, since we are confident in the combined AIRS and GPS retrievals above SR level, we can strongly constrain AIRS inversion above SR level and improve AIRS retrieval below since AIRS measurements are strongly correlated. The water vapor retrieval uncertainty from the constrained AIRS retrieval is improved about 80% above SR level compared to AIRS only retrievals. The improvement is dramatically decreased below SR level to about 20%. For the considered SR cases, while AIRS may not resolve sharp humidity inversion on top of the PBL, the GPS RO data above the SR level strongly constrain AIRS observation and resolve the temperature structure better than AIRS alone by providing unbiased refractivity information in the PBL.

Reference

Ho, S.-P., Y. H. Kuo, and S. Sokolovskiy, Improvement of the Temperature and Moisture Retrievals in the Troposphere using AIRS and GPS Radio Occultation Measurements, in preparation for Applied Optics, 2005.

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