Effects of GPS/RO refractivities on IR/MW retrievals

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Abstract

The ability of Global Positioning System Radio Occultation (GPS/RO) to improve tropospheric profile retrievals was examined. Retrievals were performed using IR and MW radiometric measurements from the ATOVS (Advanced TIROS Operational Vertical Sounder) on current NOAA polar orbiting satellites and simulated high spectral resolution infrared measurements from the Cross-track Infrared Sounder (CrIS) planned for the future NPOESS. First a simulation study will be presented wherein a statistical regression is used to get temperature and moisture retrievals from the combination of the ATOVS/CrIS brightness temperatures (BTs) and GPS/RO refractivity data. Retrievals from the ATOVS/CrIS and GPS/RO combination is found to yield tropospheric profiles in better agreement with those from radiosondes than profiles inferred from either system alone. Second, the associated study with real GPS/RO (CHAMP and SAC-C satellite measurements) and sounder (NOAA16/ATOVS) data is also shown.

Introduction

For weather prediction and climate research, accurate observations of the atmospheric moisture and temperature with good temporal and spatial coverage are required. The existing operational meteorological satellites rely primarily on passive radiometric techniques that provide good information on lower tropospheric temperature and upper tropspheric moisture and little information around the tropopause. On the other hand the GPS/RO measurements using active limb sounding technique have been shown to provide accurate information of the upper level temperature and lower tropospheric moisture. While ATOVS IR/MW measurements have good horizontal but limited vertical resolution, the GPS/RO has high vertical resolution (better than 500m for 0-18 km) but limited horizontal resolution (150-300 km). This study examines whether the combination of these two complementary systems are able to provide better quality temperature and moisture profile retrievals around the tropopause region of the atmosphere.

Simulation study - method

The NOAA88 radiosonde (RAOB) dataset containing 7547 temperature and moisture profiles is used to simulate IR and MW BTs representing the NOAA/ATOVS and NPOESS/CrIS measurements, GPS refractivities and surface observations. All 39 channels for ATOVS measurements and a subset of 393 (optimal) channels (from 1403) for CrIS measurements are simulated for this study.

A fast and accurate transmittance model called PFAAST (Pressure–layer Fast Algorithm for Atmospheric Transmittances) (Hannon et al. 1996) is used to simulate ATOVS and CrIS data. Nominal instrument noise plus 0.2 K forward model error is randomly added to the BTs calculated in the simulation. The GPS/RO refractivity profiles are simulated with 1 km vertical resolution between 6 and 28 km from the NOAA88 temperature and moisture profiles using an algorithm provided by the Met Office in the United Kingdom (Healy and Eyre, 2000). Vertically correlated noise is added to the simulated refractivity profiles using the method of Healy and Eyre (2000) and the error estimation of Kurskinski et al. (1997). The surface temperature and moisture observation is inferred from the values at the lowest level of the radiosonde profiles. Errors of 0.5 K and 10 % are assumed for the surface temperature and moisture (mixing ratio) respectively.

A statistical regression approach is used for retrieving temperature and humidity profiles. Both linear and quadratic terms for BTs, GPS/RO refractivities, and surface observations are included in the regression relationship. Regression coefficients are derived from 90 % of all profiles; the remaining 10 % are used for validation. Bias and RMS differences are computed between the retrievals and the true (NOAA88 RAOB) profiles in 1 km vertical layers for temperature profiles and 2 km vertical layers for moisture profiles. The moisture differences are normalized by the true value of the mixing ratio to derive a percentage difference.

Simulation study - results

Retrievals are calculated using different combinations of measurements (ATOVS, CrIS, GPS/RO and surface data): and RMS and bias differences are determined with respect to RAOB profiles (Figure 1). Large RMS values in the retrievals using only GPS/RO data above and below the tropopause region occur because only a vertical subset (between about 400 hPa and 20 hPa) of GPS/RO profiles is used. However, it can be seen that the GPS/RO data plays an important role between 300 hPa and 100 hPa for temperature retrievals and has little effect on moisture retrievals since GPS/RO profiles are used above the 400 hPa, where the water vapor content is small. GPS/RO improves CrIS + AMSU temperature profile retrievals around the tropopause level by 0.4 K and ATOVS temperature retrievals by 0.8 K. More detailed comparisons can be found in the work of Borbas et al. (2003).

There are no differences between ATOVS + GPS/RO and CrIS + GPS/RO temperature retrievals around the tropopause; the GPS/RO provides the main information around the tropopause region, but the differences above and below the tropopause indicate that CrIS measurements improve the profiles between 10 hPa and 700 hPa. Using CrIS data in the moisture retrievals is crucial. A comparison of the ATOVS and CrIS moisture retrievals (the vertical subset of GPS/RO profiles used in this study has no effect on moisture) shows an improvement of more than 10 % leading to an RMS difference between CrIS retrievals and RAOB profiles less than 10 % in every layer of the atmospheric column. The use of surface observations is significant in both the temperature and moisture retrievals (right panels in Fig. 1.).

The impact of various levels of GPS/RO refractivity noise is also studied (Borbas et al., 2003). Even with triple refractivity observation noise, GPS/RO improves ATOVS temperature retrievals by 0.5 K between 85 and 350 hPa pressure levels.

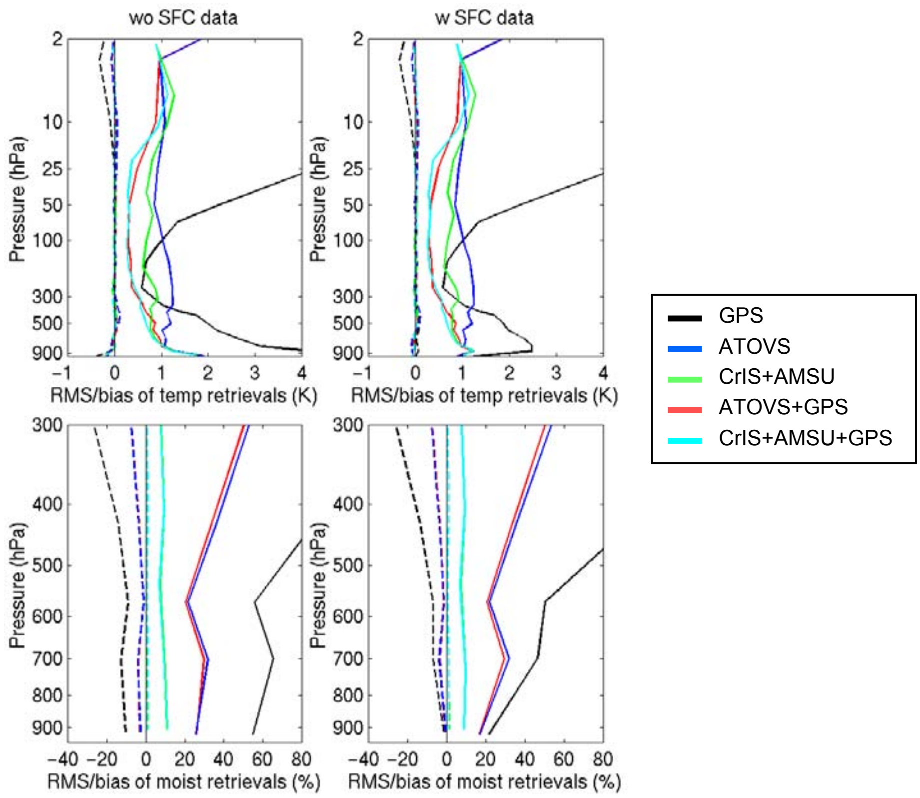

Fig. 1: RMS (solid lines) and bias (dashed lines) differences of the temperature (Kelvin) (top panels) and moisture (percentage difference of derived mixing ratio) (bottom panels) retrievals derived from only GPS (black), only ATOVS (blue), from CrIS + AMSU (green), ATOVS and GPS/RO data together (red), and CrIS + AMSU + GPS data altogether (cyan) with respect to the RAOB profiles. On the right panel surface (SFC) data are also added to all kind of retrievals.

Study with real data – data collection and evaluation

To expand this retrieval study to real data, NOAA16/ATOVS radiance observations are collocated with GPS/RO data measured from the German CHAMP and Argentinean SAC-C satellites. NOAA-16 ATOVS radiances are converted to BTs using the ATOVS and AVHRR Processing Package (AAPP) (Klaes and Schraidt, 1999) and the International ATOVS Processing Package (IAPP) (Li et al., 2000). For each HIRS FOV, a cloud detection algorithm (Li et al. 2000) is applied. In overcast conditions, only AMSU channels are used. GPS/RO and ATOVS collocations are found within 3 hours and 300 km. In cases of multiple collocations, the collocation with more clear pixels or better temporal collocation is chosen. ATOVS BTs are the average of the clear pixel values or the average of all 9 cloudy pixel values in overcast conditions. A simple quality control is performed on the data as follows: data in polar regions (higher than 70 latitude) are excluded from the study and differences exceeding 10 % between GPS/RO and RAOB and GPS/RO and NWP derived refractivity profiles are rejected.

The number of occultations between July 2001 and July 2002 for each GPS satellite is over 25000 separately. The highest density of the GPS observations is around the sub-polar and polar region (one-third of the total number) providing help in this890 data sparse polar region. Validation of GPS/RO refractivity profiles is made with calculated refractivities from interpolated RAOB (for four selected months representing the four seasons) and AVN/NCEP analyses (for the whole year) temperature and moisture profiles. Validation is done separately over the seasons and for different regions of the Earth. Both results (see Fig. 2 and 3) show that the quality of CHAMP data is better (more obvious in the NWP validation, on Fig. 2) than SAC-C. Both CHAMP and SAC-C datasets have large biases in the tropical and mid-latitude areas. Overall, the quality of SAC-C and CHAMP refractivity data is within 1% (the estimated error of the refractivity profiles was 0.3 %).

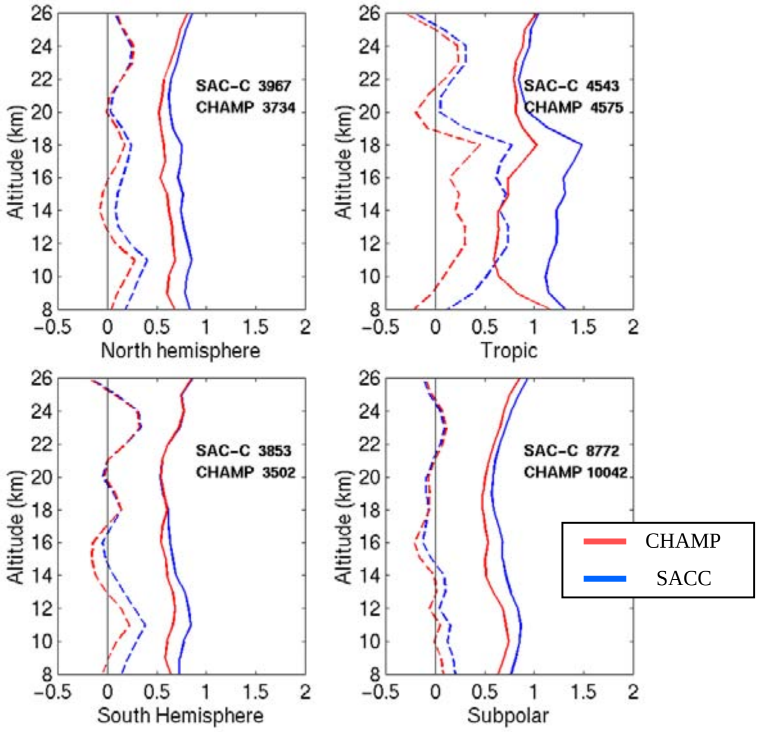

Fig. 2: Validation of CHAMP (red lines) and SAC-C (blue) refractivities profiles (in percentage of refractivity units) with computed profiles from the NCEP analyses between July 2001 and May 2002. The collocations are separated for four regions: Tropical (between 0° and ±25° latitude), North and South mid-latitude (between 25° and 50° latitude in the northern and southern hemisphere) and sub polar (between 50° and 70° in both northern and southern hemisphere) region. Solid lines indicate the RMS and dashed lines indicate the bias differences. The number of collocations is also shown.

Study with real data – validation of temperature retrievals

Collocated ATOVS BTs and CHAMP and SAC-C refractivities are regressed against NWP (AVN/NCEP) profiles to generate algorithm coefficients. ATOVS and CHAMP/SAC-C data collocated with RAOBs are used for validation and are excluded from the regression calculations.

CHAMP refractivities at 23 levels (between 8 and 30 km with 1 km vertical resolution), 16 HIRS BTs (excluding channels 17-19, the short wave infrared), 12 AMSU-A BTs (excluding channels 1,2 and 15), and 4 AMSU-B BTs (excluding channel 1) are used in the regression to determine temperature profiles.

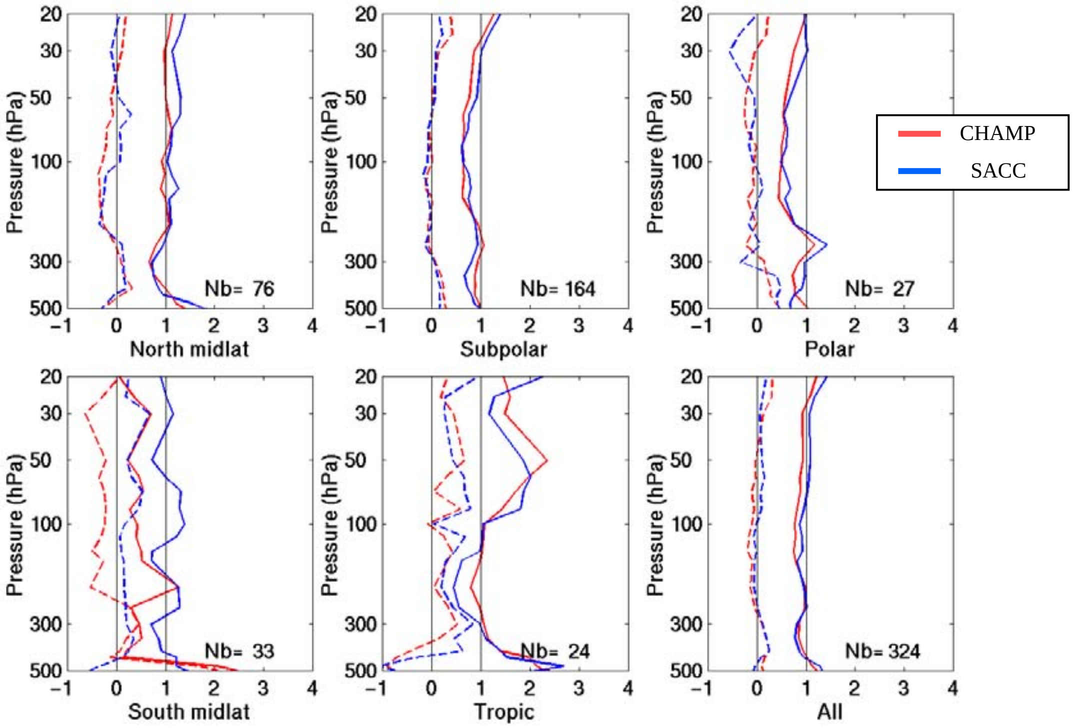

Fig. 3: Validation of CHAMP (red lines) and SAC-C (blue) refractivities profiles (in percentage of refractivity unit) with computed profiles from RAOB temperature and moisture profiles for April 2002 between 20 hPa and 500 hPa pressure levels. The collocations are separated for the same regions as Figure 2, but polar region (latitude higher than ±70°) and all cases (right bottom panel) is also added. Solid lines indicate the RMS and dashed lines indicate the bias differences. The number of the collocation is also shown.

Figure 4 shows temperature retrievals using only ATOVS and ATOVS + GPS/RO data compared to collocated RAOB data for four months (Oct 2001, Jan, Apr, and Jul 2002). The validation is done for cloudy and clear skies separately. The preliminary study with real data shows that the GPS/RO data has a positive impact on the ATOVS temperature retrievals from 670 hPa up to 25 hPa. GPS/RO (both CHAMP and SAC-C) data improves the radiometric (ATOVS) temperature retrievals around the tropopause by 0.5 K. In cloudy conditions the impact is larger than in clear skies.

Conclusions and Future Plans

The effect of GPS/RO measurements around the tropopause region on radiometric (infrared and microwave) tropospheric profile retrievals was studied.

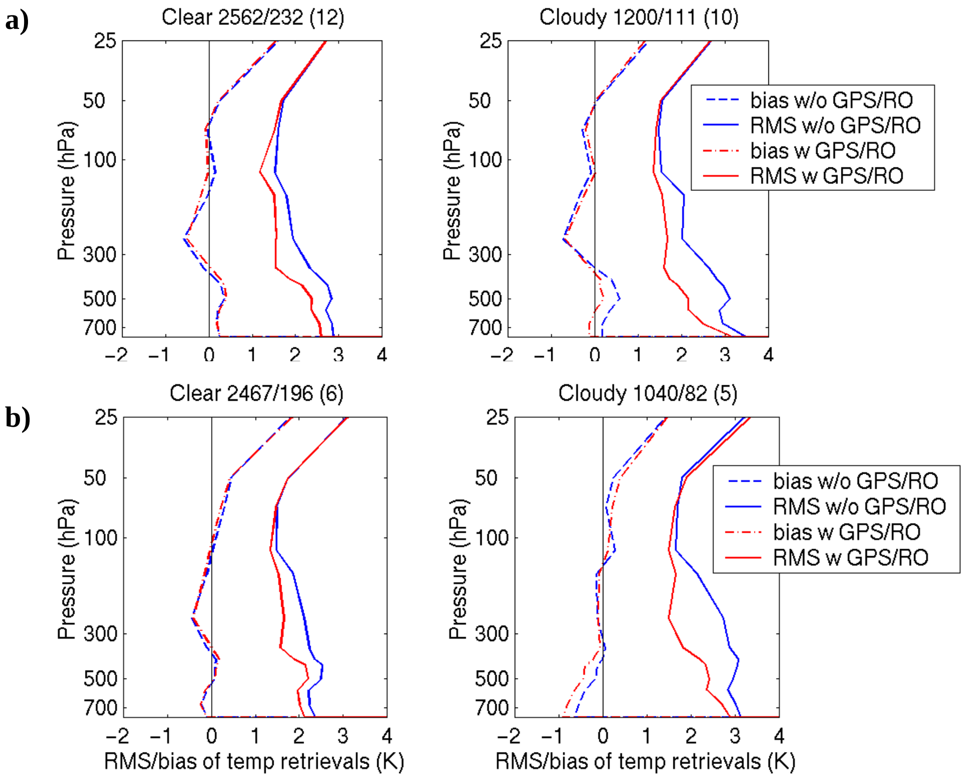

Fig. 4: RAOB validation of ATOVS temperature retrievals with (blue lines) and without (red) GPS/RO CHAMP (a) and SAC-C (b) data for four months (Oct 2001, Jan, Apr, and Jul 2002) separated into clear and cloudy situations. For each panel, the first number in the title indicates the number of training cases (using AVN NWP analyses), the second is the number of the test cases (with collocated RAOB profiles), and the third (in brackets) is the number of rejected (filtered) profiles. Dashed lines indicate the bias and solid lines indicate the RMS differences between the retrievals and the RAOB profiles.

A simulation study and a study using real data were presented wherein a statistical regression was used to generate temperature and moisture retrievals from the combination of passive (IR and MW sounders) and active (GPS/RO) systems. The simulation study shows that the combined systems produce improved tropospheric temperature profiles in comparison with radiosonde profiles over those inferred from either system alone. GPS/RO improves the ATOVS temperature profile retrievals by 0.8 K and the advanced IR sounder (CrIS) temperature retrievals by 0.4 K around the tropopause.

CHAMP and SAC-C refractivity measurements were compared with radiosonde and NWP analyses derived values. The measured and calculated refractivities have good agreement with RMS differences less than 1%.

The study of temperature profiles regressed from CHAMP/SAC-C and ATOVS data for four selected months representing the four seasons reveal that CHAMP/SAC-C refractivity measurements improve the ATOVS retrieval comparisons to radiosonde determinations. Near the tropopause at least 0.5 K improvement is found in clear conditions; the improvement over the cloudy skies is even larger.

Future work will be to increase the number of collocations, to use a larger vertical subset of GPS/RO refractivity profiles closer to the surface with more information about the moisture content of the lower troposphere, and to study combined retrievals with real CHAMP/SAC-C, AIRS (Atmospheric Infrared Sounder) plus AMSU data.

Acknowledgments

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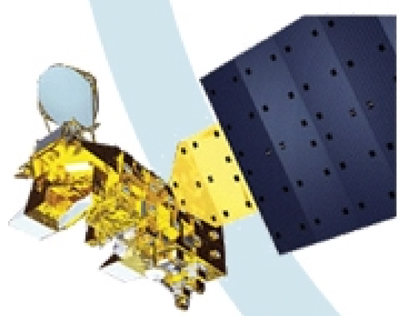

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