Combination of NOAA16/ATOVS Brightness Temperatures and the CHAMP Data to get Temperature and Humidity Profiles

Éva Borbás[1], Jun Li[1] and W. Paul Menzel[2]

[1]Space Science and Engineering Center, University of Wisconsin / Madison
[2]NOAA/NESDIS Office of Research and Applications, 1225 West Dayton St., Madison, WI 53706, USA

Summary. This paper examines whether the radio occultation (RO) measurements of the tropopause region are able to improve radiometric tropospheric profile retrievals, as represented by the ATOVS (Advanced TIROS Operational Vertical Sounder) temperature and humidity soundings from the NOAA16 (National Oceanic and Atmospheric Administration) satellite. First, a simulation study is presented wherein a statistical regression was used to infer temperature and humidity retrievals from ATOVS brightness temperatures and GPS (Global Positioning System) refractivity data. The ATOVS and GPS combination yields improved tropospheric profiles when compared to those inferred from either system alone. A sensitivity test was also performed to investigate how large GPS refractivity error can be and still improve the radiometric retrievals; even tripling the GPS refractivity observation errors yields improved retrievals. Second, the preparations to repeat the same study with real GPS (CHAMP) and ATOVS data are described. Collocations of GPS and CHAMP data were collected and the CHAMP data were evaluated against NWP profiles. CHAMP GPS validation suggested that CHAMP data would be able to improve the ATOVS retrievals as simulations with comparable GPS errors had showed positive retrieval impact. Future work will include application of regression approach for inferring retrievals after a statistically adequate number of collocations have been collected.

Key words: GPS occultations, ATOVS radiances, temperature profile retrieval, statistical regression

1 Introduction

Radiometric techniques using measurements from polar orbiting infrared (IR) and microwave (MW) sounders are used to infer temperature and moisture profiles in the lower and upper troposphere. While the current passive IR/MW remote sensing systems have limited skill for inferring temperature and moisture profiles around the tropopause and in the stratosphere, the GPS radio occultation can provide very accurate upper tropospheric and stratospheric refractivity profiles which are related to temperature and humidity. This study intends to use the RO measurements to get ancillary information around the tropopause region to improve radiometric tropospheric profile retrievals**.** First, in Section 2 and 3 a simulation study is presented: a statistical regression was used to get temperature and humidity retrievals from the combination of the radiometric and geometric (RO) systems. For validation, the retrievals were compared to those inferred from either system alone. An error sensitivity test was also performed to investigate how big GPS refractivity error can be and still improve the radiometric temperature or humidity retrievals. Second, in Section 4 and 5 we prepare to repeat the same study on real GPS (CHAMP=CHAllenging Minisatellite Payload) and sounder (ATOVS) data: collocations were made and the data was evaluated. The application of regression method used in the simulation study is pending after a statistically adequate number of collocations of occultations, soundings, and radiosonde observations have been collected.

2 Simulation approach

The simulation study uses a one year radiosonde dataset from 1988 (NOAA88), which contains 7547 profiles globally distributed in time and space. The profiles are interpolated into 42 vertical pressure levels between 0.1 and 1050 hPa.

The infrared and microwave brightness temperatures were calculated in a radiative transfer formulation (Huang and Li 1999) to represent the NOAA ATOVS. The ATOVS includes one IR instrument called High Resolution Infrared Sounder (HIRS) with 19 IR channels and two MW instruments called Advanced Microwave Sounder Unit (AMSU) A and B with 20 channels. Nominal instrument noise (Goodrum et al. 2000) plus 0.2 K forward model error is randomly added to the calculated radiances for simulation.

The GPS refractivity profiles were simulated on 16 fixed pressure levels between 5 and 30 km (from 12.6 hPa to 596 hPa) using the NOAA88 radiosonde (RAOB) temperature and humidity profiles. The working equation for GPS relates the atmospheric index of refraction to atmospheric temperature and moisture. The refractivity (N) equation (Smith and Weintraub 1953) is written

$$\mathbf{N} = 77.6\frac{\mathbf{P}}{\mathbf{T}} + 3.73*10^5\frac{\mathbf{P_w}}{\mathbf{T}^2}\,, \tag{2.1}$$

where P is the atmospheric pressure (hPa), P_w is the water vapor partial pressure (hPa), T is the temperature of the atmosphere. The magnitude of the noise in the refractivity profile was assumed to be 0.3 % in every level (Kursinski et al. 1997). GPS vertically correlated measurement errors were generated based on the method described in Healy and Eyre (2000).

Ancillary information about the surface conditions was inferred from temperature and humidity values at the lowest level of the radiosonde profiles.

2.1 Retrieval method

Temperature (K) and humidity (mixing ratio g/kg) profiles were retrieved from simulated brightness temperatures, simulated GPS refractivities and simulated surface observations using a statistical regression. Both linear and quadratic terms for all these variables were included in the regression. The regression equation used in this study is the following:

$$\mathbf{x_i} = \mathbf{a_{io}} + \sum_{j=1}^{M} \mathbf{a_{ij} Tb_j} + \sum_{k=1}^{M} \mathbf{b_{ik} Tb_{ik}^2} + \sum_{l=1}^{N} \mathbf{c_{il} N_l} + \sum_{m=1}^{N} \mathbf{d_{im} N_{im}^2} + \mathbf{e_i T_{sfc}} + \mathbf{f_i T_{sfc}^2} + \mathbf{g_i Rh_{sfc}} + \mathbf{h_i Rh_{sfc}^2}, \quad (2.1.1)$$

where x_i is the predictand (variable to be predicted) in the ith pressure level from the 42 pressure levels, Tb is the ATOVS brightness temperature, N is the GPS refractivity, T_{sfc} and Rh_{sfc} is the surface temperature and relative humidity, a, b, c, d, e, f, g , and h are the regression coefficients, M is the number of the ATOVS channels (39) and N is the number of the GPS pressure levels (16). Results for ocean and land are combined in this analysis. Regression coefficients were computed from 90 % of all radiosonde profiles (training dataset) and the remaining 10 % (test dataset) were used for validation. Bias and rms errors were computed between the retrievals and radiosonde profiles in 1 km layers for temperature profiles and 2 km layers for humidity profiles. For humidity, these errors were normalized by the true value of mixing ratio to derive percentage.

3 Results of the simulation study

Retrievals were calculated from the different information sources (e.g. ATOVS, GPS and surface data), and the rms and bias errors were determined between these retrievals and radiosonde profiles. To study the impact of one type of information, the differences of rms and bias errors with and without that information were plotted. Figure 1. shows the improvement (difference of rms errors) of GPS data on temperature (first column) and humidity (second column) retrievals computed from IR brightness temperatures (upper panels) and combination of IR and MW brightness temperatures (lower panels). The figure shows that the combination of radiometric (IR and MW) and geometric (RO) information yields improved tropospheric temperature and moisture profiles when compared to those inferred from the radiometric system alone. The GPS temperature improvement is most significant (max. 2 K) when the HIRS brightness temperatures only were used in the retrievals. Adding AMSU data in the retrievals the GPS improvement is moderated (max. 0.8 K). For humidity the GPS improvement is less significant than it was for temperature since the refractivity profile was used only above 5 km where the water vapor content is already very low. A study of the impact of various levels of GPS refractivity noise was also performed. The temperature and humidity retrievals were determined from ATOVS brightness temperatures and GPS refractivity using nominal, double, triple GPS observation errors and without GPS data (see Figure 2). Even tripling the GPS refractivity observation errors improved the ATOVS retrievals over retrievals without any GPS information.

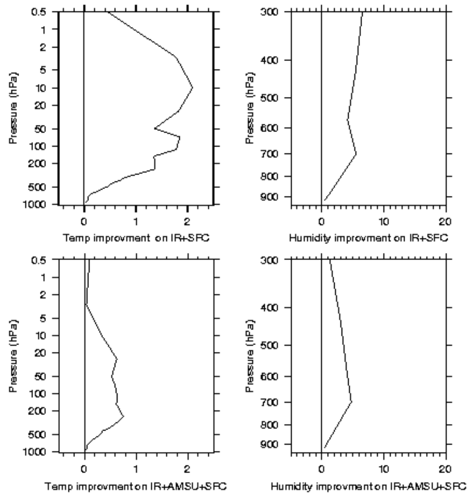

Fig. 1. GPS improvements (difference of rms errors) on temperature (K) (first column) and humidity (%) (second) retrievals derived from infrared (HIRS), microwave (AMSU) and surface (SFC) data. Retrievals without AMSU (upper panels) and with (lower panels) are shown

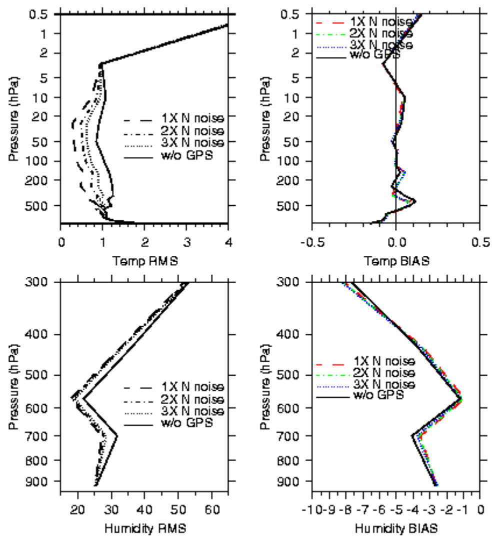

Fig. 2. Study of GPS noise on temperature (K) (upper panels) and humidity (%) (lower panels) retrievals using simulated ATOVS and GPS data. The rms (first column) and bias (second column) errors of retrievals using GPS refractivity profiles with 1X, 2X and 3X noise and without GPS data

4 Preparation of a retrieval study on basis of real data

4.1 Collocations of CHAMP occultations with ATOVS measurements

To start the retrieval study with real data, collocations between ATOVS field of views and CHAMP occultations were collected. 651 CHAMP occultations were available between May 28 and Jun 03, and August 26 and 27, 2001. GPS profiles were used only between 6 and 35 km, with 1 km vertical resolution and interpolated to 19 levels (from 42 levels) between 7 and 400 hPa. We assumed the ATOVS measurements were made at nadir and the occultations are vertical (no horizontal drift of the tangent point). When the drift of the tangent point during an occultation was larger than 300 km between the 6 and 35 km levels, the data were rejected (see the histogram in Figure 3.). The test dataset after filtering contained 583 occultations.

The NOAA16/ATOVS brightness temperatures were calculated at CIMSS/SSEC using the ATOVS and AVHRR Processing Package (AAPP) (Klaes and Schraidt 1999) and the International ATOVS Processing Package (IAPP) (Li et al. 2000). The global data were available with about 60 km horizontal resolution (a box of 3X3 HIRS pixel). Thresholds used for GPS-ATOVS collocations were 3 hours for time and 300 km for geographical distance. In multiple collocations, the selection prefers more clear pixels and closer times of GPS observation. ATOVS brightness temperatures are the average of the clear pixel values (or the average of all 9 cloudy pixel values in overcast conditions). 190 collocations between ATOVS and CHAMP measurements were found which number is very limited for doing statistical regression. So that instead of performing the regression study on real data, a quality check was made to see how realistic our GPS measurements are.

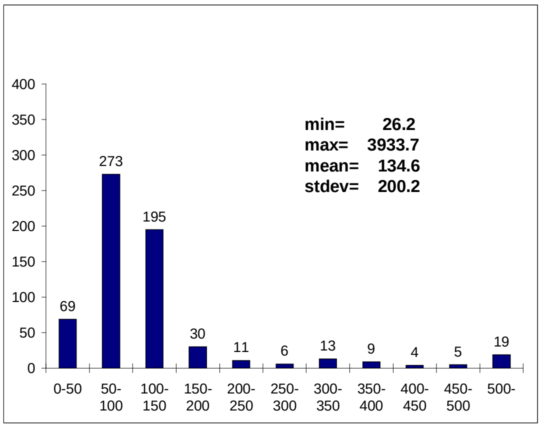

Fig. 3. Histogram of horizontal distances (km) of the occultation tangent points between 6 and 35 km levels

4.2 CHAMP refractivity comparison with NWP calculations

The AVN/NCEP (Aviation Version of the National Center for Environmental Prediction Global Spectral Model) numerical weather prediction (NWP) global model analyses (00, 06, 12, 18 UTC) were used to validate CHAMP refractivity profiles. The NWP temperature and humidity profiles were interpolated in time and space and then refractivity profiles were computed using equation (2.1). The data were horizontally interpolated from the 4 nearest grid points. Vertical interpolation was made from the 42 ATOVS pressure levels. The rms and bias errors of refractivity profiles derived from CHAMP measurements and NWP calculation around the tropopause region are shown on Figure 4. The fact that the rms error is below 0.8 % between 30 hPa and 300 hPa is very promising for retrievals from the combination of radiometric and occultation data, since the simulation GPS noise sensitivity test showed, even with tripling the GPS noise (1.2 %) the radiometric temperature retrievals were improved.

5 Conclusions and future plans

This study uses radio occultation measurements of the tropopause region to improve radiometric (infrared and microwave) tropospheric profile retrievals. First, a simulation study was presented wherein a statistical regression was used to get temperature and humidity retrievals from the combination of the radiometric and

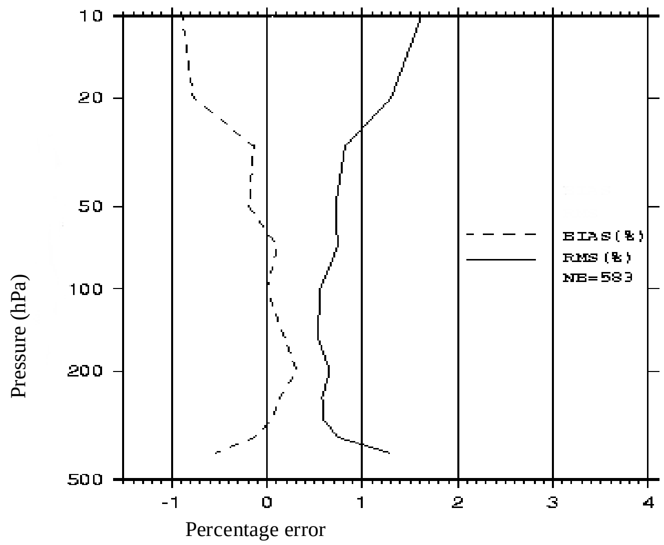

Fig. 4. The rms (solid line) and bias (dashed line) errors (%) of refractivity profiles near the tropopause region between the CHAMP measurements and NWP calculations (583 events)

geometric (RO) systems. The study showed that the combination yields improved tropospheric temperature and moisture profiles when compared to those inferred from either system alone. GPS improved the radiometric temperature profile retrievals around the tropopause level by 0.8 K, and moisture profile retrievals from 570 to 700 by about 4 %. Second, CHAMP data was evaluated against NWP profiles. The CHAMP GPS validation suggests that CHAMP data will be able to improve the radiometric retrievals as simulations with comparable GPS errors showed positive retrieval impact. However the CHAMP dataset needs to be expanded so that the regression computation can be run separately in clear and cloudy cases and also separately over the land and ocean.

Acknowledgements

We thank for GeoForschungsZentrum for providing the CHAMP data. This work was supported in part by NOAA Cooperative Agreement NAO7EC0676.

References

Goodrum G, Kidwell KB, Winston W (2000) NOAA-KLM User's Guide, September 2000 Revision. http://www2.ncdc.noaa.gov/docs/klm/index.htm

Healy SB, Eyre JR (2000) Retrieving temperature, water vapour and surface pressure information from refractivity-index profiles derived by radio occultation: A simulation study. Q J R Meteorol Soc 126: 1661-1683

Huang HL, Li J (1998) Determination of microwave emissivity from Advanced Microwave Sounder Unit measurements. In: Proceedings of SPIE, The International Society for Optical Engineering, 3503: 233– 237

Klaes KD, Schraidt R (1999) The European ATOVS and AVHRR Processing Package (AAPP) development. In: Technical Proceedings of the Tenth International ATOVS Study Conference, Boulder Colorado, pp 288-294

Kursinski ER, Hajj GA, Schofield JT, Linfields RP, Hardy KR (1997) Observing Earth's atmosphere with radio occultation measurement using the Global Positioning System. J Geophys Re 102: 23,429-23,465

Li J, Wolf W, Menzel WP, Zhang W, Huang H-L, Achtor TH (2000) Global Sounding of the Atmosphere from ATOVS Measurements: The Algorithm and Validation. J Appl Meteorol 39: 1248-1268

Smith EK, Weintraub S (1953) The constants in the equation for atmospheric refractive index at radio frequencies. Proc IRE 41: 1035-1037