Use of GNSS radio occultation measurements for climate studies

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The EUMETSAT Network of Satellite Application Facilities

ROM SAF Radio Occultation Meteorology

Introduction

GNSS radio occultation (GNSS-RO) measurements are now routinely assimilated into numerical weather prediction (NWP) systems. They complement the information provided by satellite radiances because:

- GNSS-RO measurements have good vertical resolution.
- GNSS-RO can be assimilated without bias correction.
- The measurements are globally distributed.

The GNSS-RO measurements have a significant impact on NWP temperature biases in the lower/middle stratosphere. They are also assimilated in climate reanalyses such as ERA-Interim. As the GNSS-RO time series lengthens, they are likely to have an increasingly important role in climate monitoring and climate model development.

The EUMETSAT Radio Occultation Meteorology Satellite Application Facility (ROM SAF) is now producing geophysical climatologies for such applications.

Background

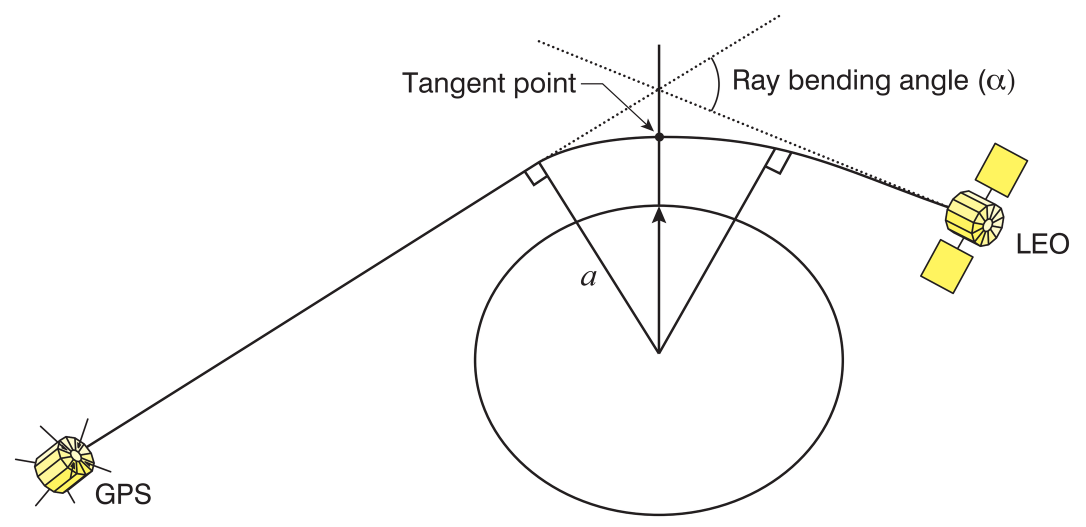

Figure 1 Illustration of the GNSS-RO geometry and the impact parameter *'a'*.

The GNSS-RO measurement geometry is illustrated in Figure 1. The fundamental measurement is time-delay with an atomic clock. This can be processed to bending angle, α, as function of impact parameter (~height), a. An Abel transform is used to estimate the refractive index, n.

$$n(x) = 1 + 10^{-6} N = \exp\left(\frac{1}{\pi}\int_x^{\infty} \frac{\alpha(a)}{\sqrt{a^2 - x^2}}\, da\right)$$

In the stratosphere, the refractivity, N, is proportional to the atmospheric density. The pressure, P, is estimated by integrating the hydrostatic equation. The temperature profile, T(z), is derived using the ideal gas law. Some a priori information is required to estimate N, P and T profiles. The information content of the measurements is greatest in the vertical interval between 10 km to ~35 km.

Most NWP centres assimilate bending angle profiles, and the measurements have significantly reduced stratospheric temperature biases (Figure 2). GNSS-RO measurements from different instruments, processed at different centres, now have consistent bias characteristics (Figure 3). The assimilation of GNSS-RO data has improved consistency in the stratosphere between climate reanalyses (Figure 4). Climatologies derived from GNSS-RO could provide an important new data source for climate model developers. Some initial testing has been performed at the Met Office Hadley Centre (Figures 5,6).

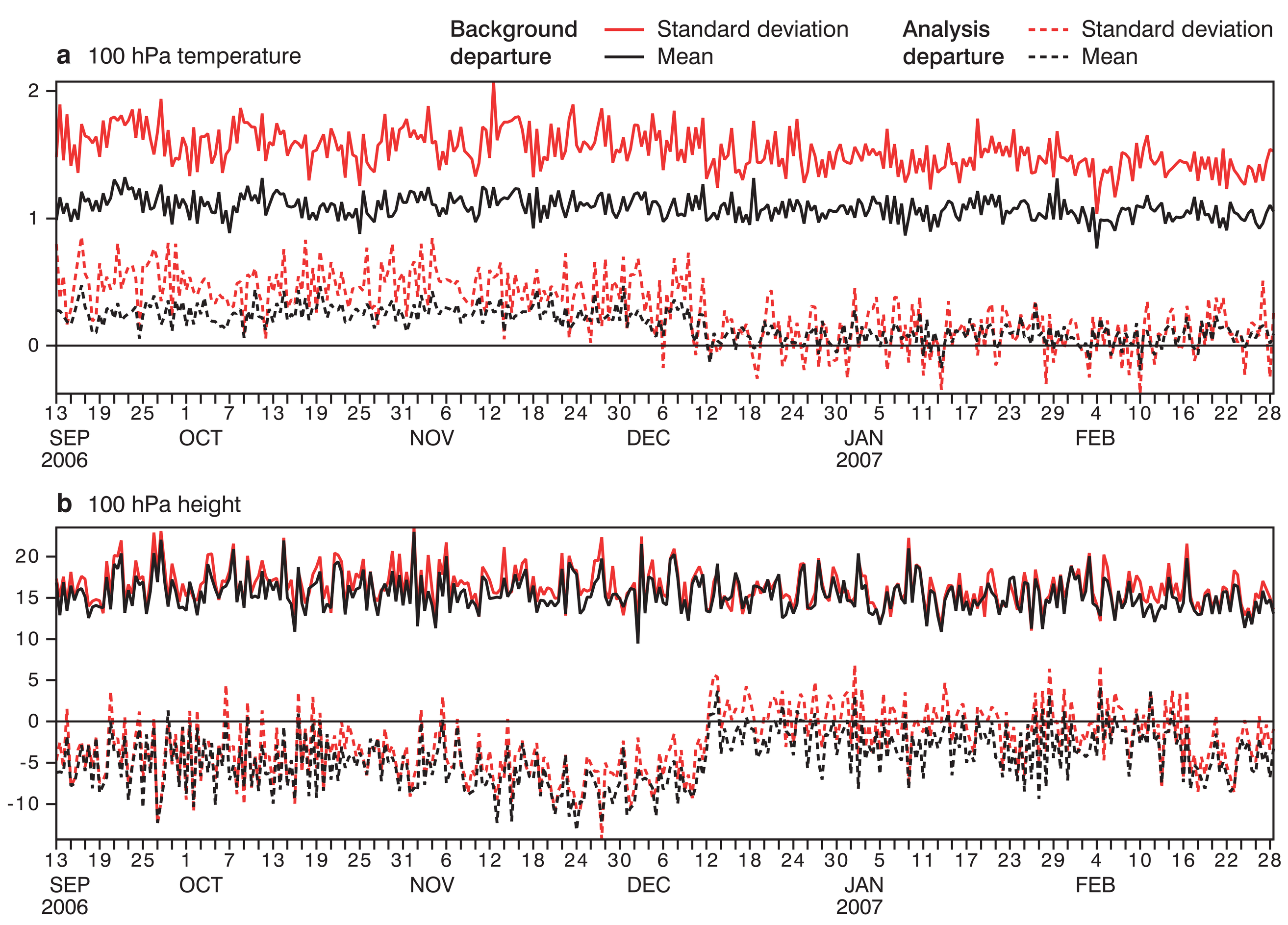

Figure 2 Time series of the mean and standard deviation of the operational background departure and analysis departure for (a) temperature and (b) height radiosonde measurements at 100 hPa. The sample numbers are typically 270 and 220 per day, for the temperature and height departures, respectively.

Main results

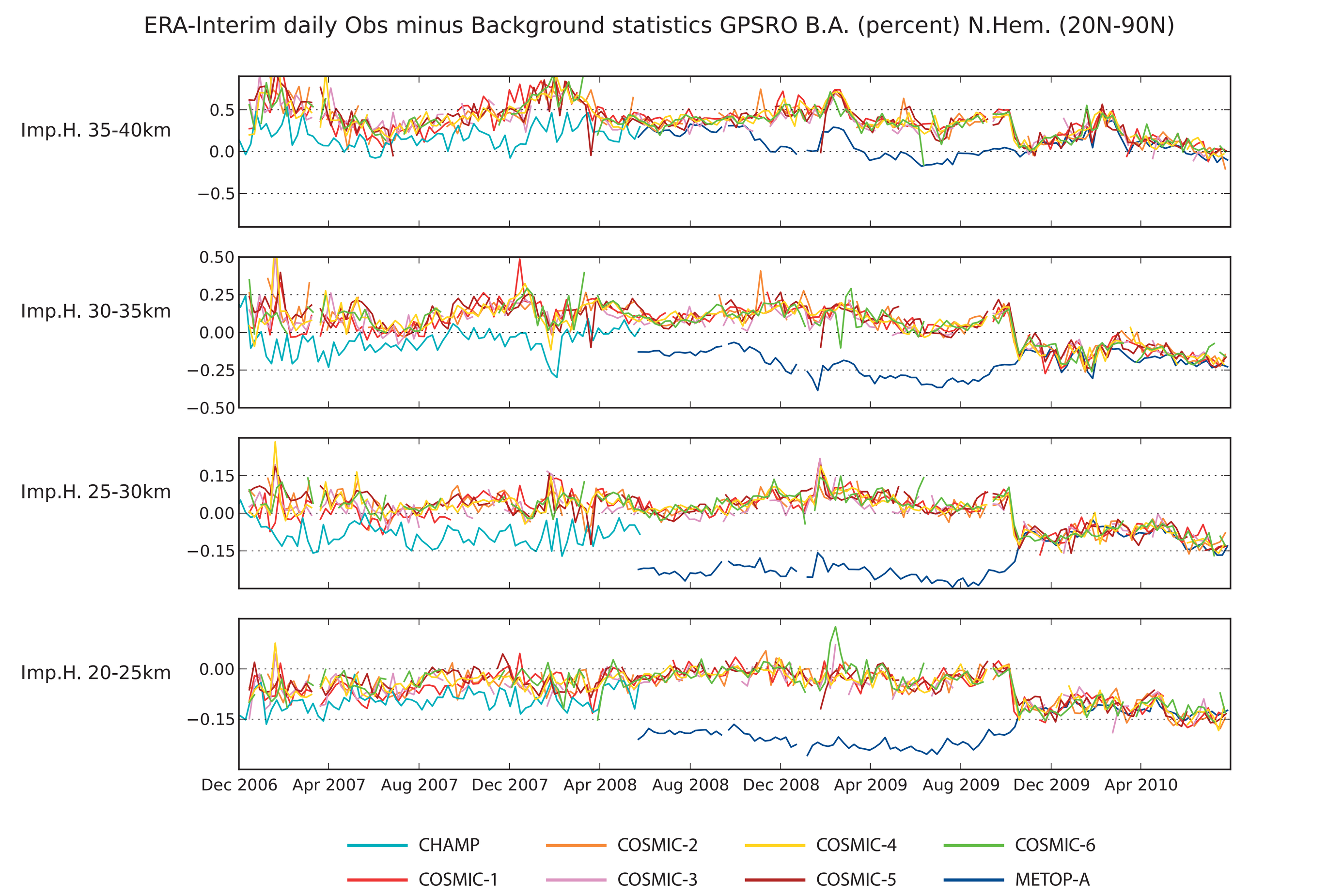

Figure 3 It has been claimed that GNSS-RO instruments are interchangeable, and do not require overlap periods for calibration. However, bending angle (observed minus simulated) bending angle departure statistics initially showed small but clear differences between the COSMIC and Metop-A GRAS measurements. This was caused by an error in the COSMIC processing, which was corrected in November 2009.

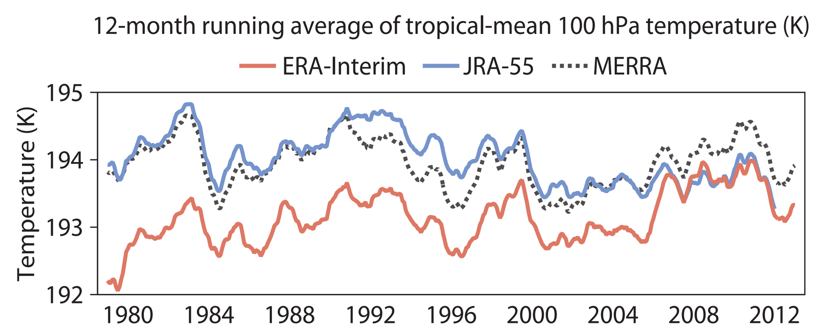

Figure 4 The assimilation of GNSS-RO measurements since 2006 has improved the consistency of climate reanalyses in the stratosphere. ERA-Interim and JRA-55 both assimilate GNSS-RO measurements but MERRA does not. The GNSS-RO numbers increased by an order of magnitude at the end of 2006, with the introduction of COSMIC measurements.

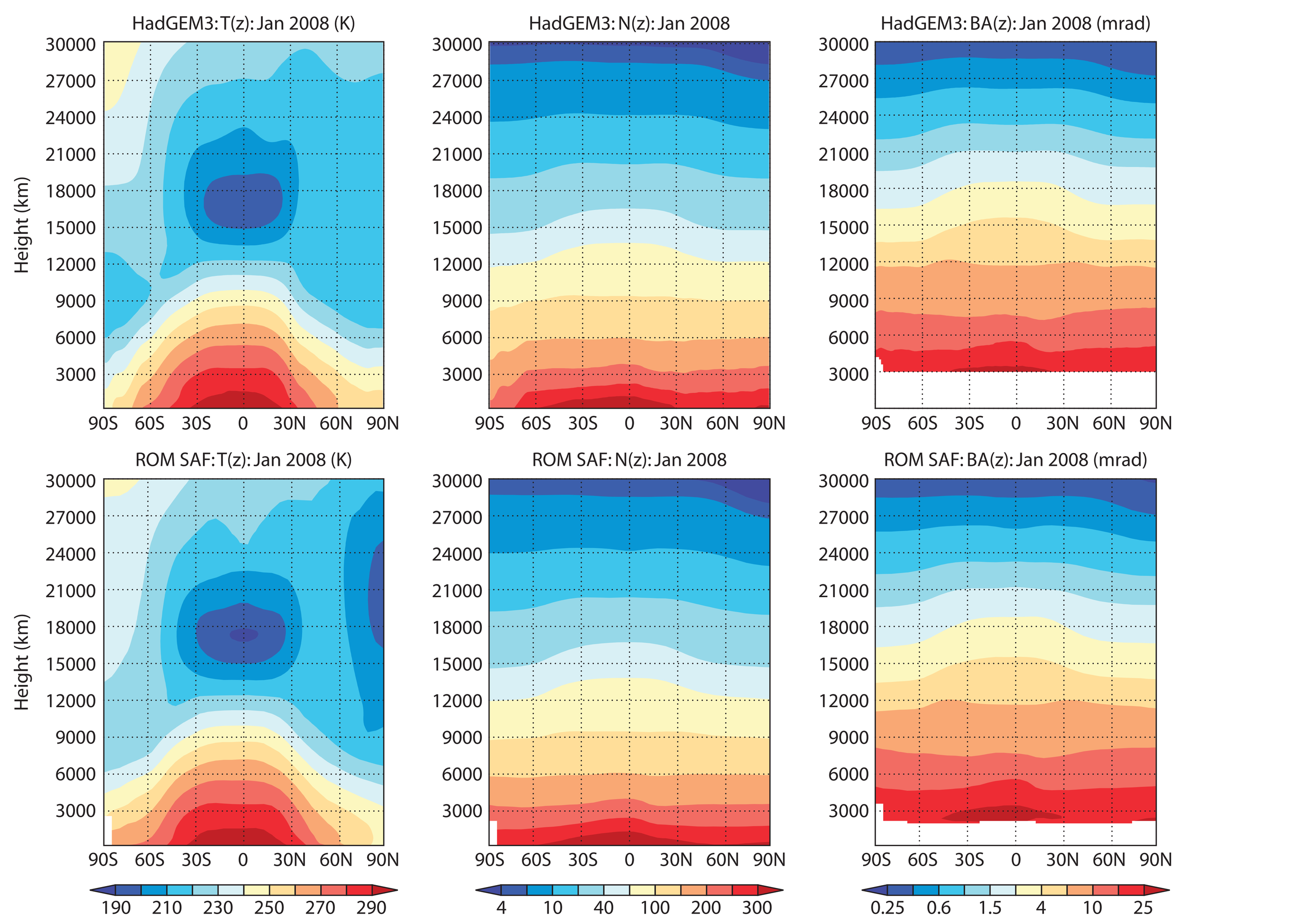

Figure 5 ROM SAF is producing bending angle, refractivity and temperature zonally averaged climatologies, suitable for testing climate models, particularly in the upper troposphere and stratosphere (See *http://www.romsaf.org/climate_monitoring/index.php*). Forward models mapping the model state information to refractivity and bending angle space are also available (See *http://www.romsaf.org/software.php*).

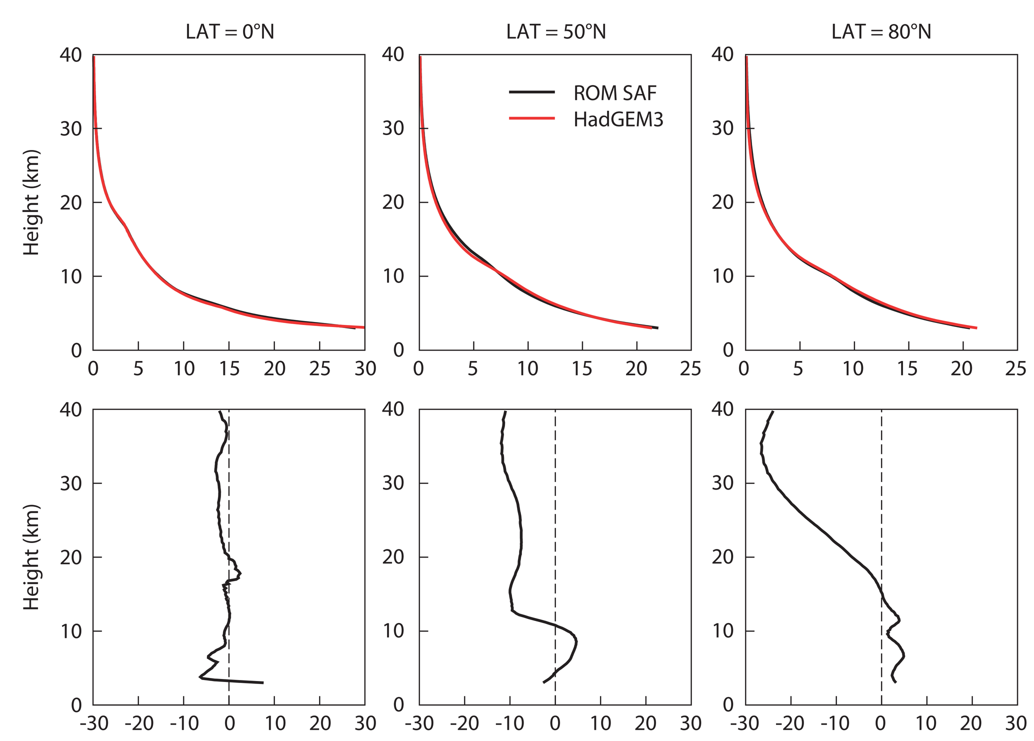

Figure 6 Preliminary study. The Met Office Hadley Centre have developed the capability to map their model state to bending angle space, for comparison with the GNSS-RO climatologies. The upper shows the Hadley Centre and ROM SAF mean bending angle profiles. The lower panel shows the fractional differences.

Summary

GNSS-RO observations have had a significant impact in operational NWP and climate reanalyses since 2006. They reduce temperature biases in the upper-troposphere and stratosphere, because they can be assimilated without bias correction. The bias characteristics of measurements from different instruments are now consistent. The GNSS-RO measurements should be useful for climate monitoring and testing climate models. Climatologies are being produced routinely. A preliminary study using GNSS-RO to validate a climate model is being performed at the Met Office Hadley Centre.

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Figure 4 was provided by Dr Adrian Simmons (ECMWF).

Further reading

http://www.romsaf.org/index.php

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