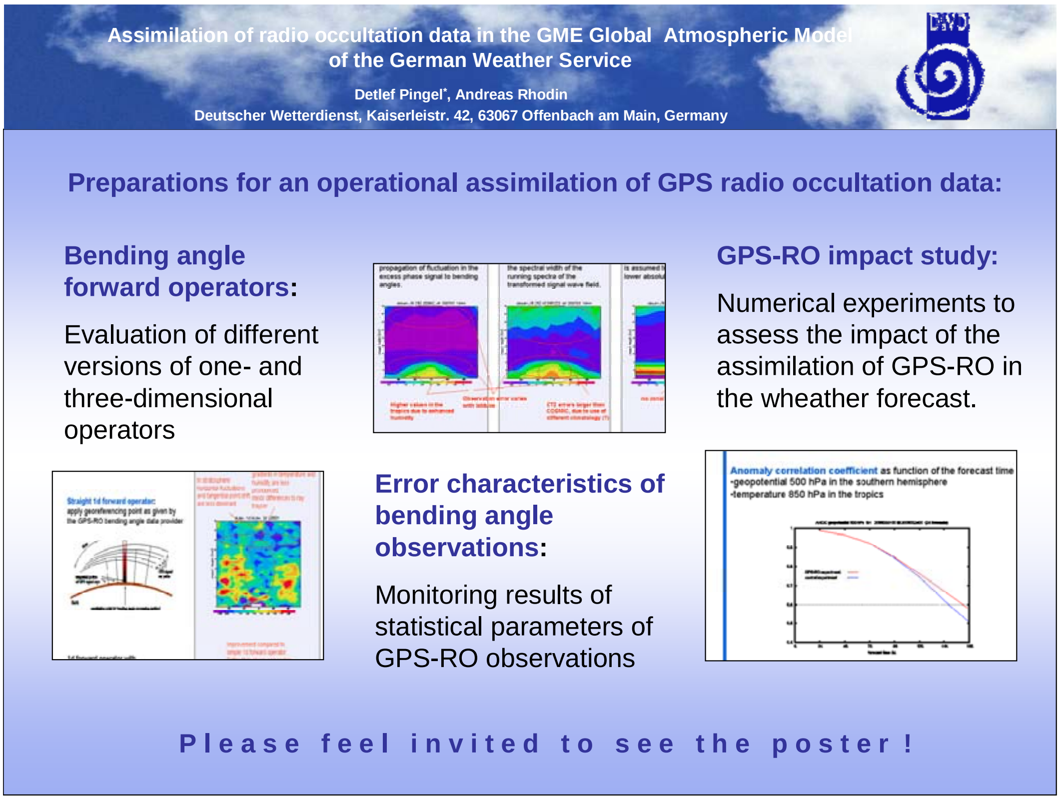
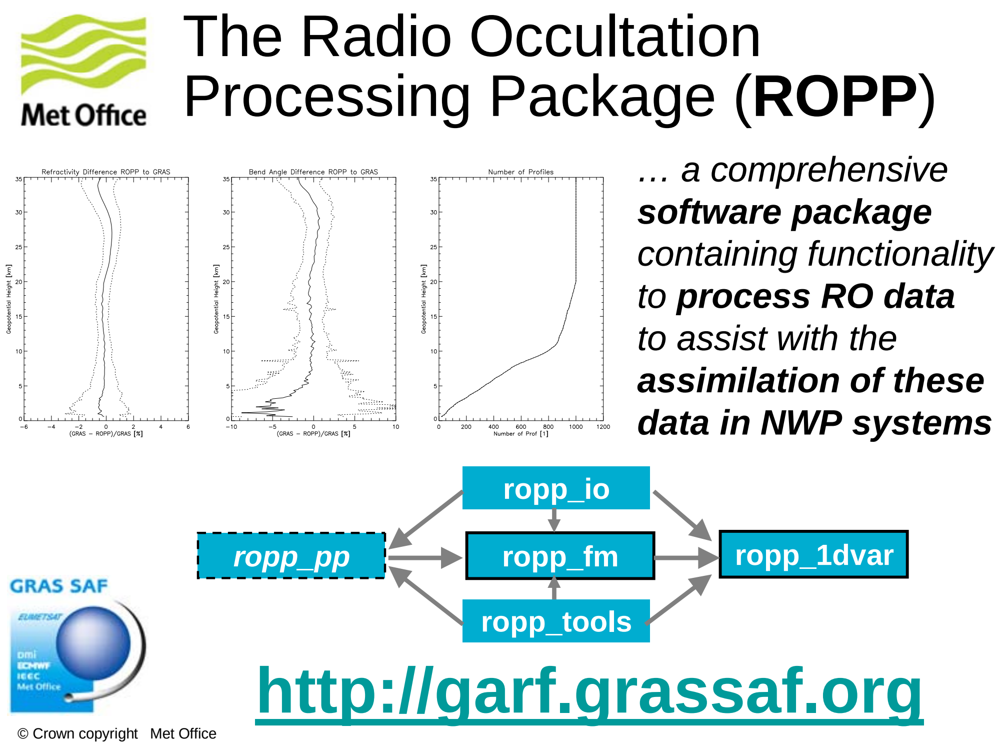
Poster presentations





Assimilating **GPS RO** data in **HIRLAM**

EUMETSAT

DMI

Elena Padorno

Proposal of EUMETSAT fellowship work

Bending angle or refractivity to assimilate?

- Advantages and drawbacks of the different products.

- HIRLAM characteristics.

Conclusions and objectives

Assimilating **GPS RO** data in **HIRLAM**

EUMETSAT

DMI

Objectives: *- Assimilate refractivity in HIRVDA (3D-Var System), first with a 1D observation operator.*

- Set of impact experiments.

- Include a 1D operator for bending angle.

- 2D observation operator for refractivity and bending angle.

Methodology

Current and future work:

- software to develop.

Climate monitoring using GPS radio occultation bending angles

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2. ECMWF, Reading, UK

Introduction

The aim of this work is to investigate the potential of using GPSRO bending angle as a climate variable, specifically its suitability for monitoring and detecting climate change signals over the next fifty years. The rationale for using bending angle is to minimise the sensitivity to structural uncertainty which occurs with derived products (e.g. temperature or even refractivity) and results from the introduction of *a priori* information in the additional processing steps. In addition, we compare the climate signals obtained using bending angle to those derived from the temperature sounding channels of AMSU, and discuss the potential advantages of the GPSRO data in the upper troposphere-lower stratosphere region in the tropics.

Bending angle profiles are calculated off-line using output from the Met Office Hadley Centre climate model, HadGEM1, integrated over the twenty-first century according to the IPCC SRES A1B scenario for emissions of greenhouse gases and other forcing agents. The climate model fields used are monthly mean, 3-D profiles of temperature, pressure and humidity for the period 2000-2055. The bending angles are calculated at a fixed set of 110 impact heights, equally spaced at 250 m intervals. Full details of these calculations are given in Ringer and Healy (2008). In a similar manner, monthly mean AMSU channel brightness temperatures are calculated from the climate model fields for the same period using the fast radiative transfer model RTTOV.

Trend detection with GPSRO bending angles

Figures 1(b)-(f) show the evolution of the climate change signal in the zonal mean bending angle profiles from the present-day through to the 2050s. The signal in the tropical lower stratosphere emerges after a decade, is clearly identifiable by the 2020s and continues to intensify through to the 2050s. It is accompanied by a signal in the tropical mid-stratosphere which, though weaker initially, is of comparable size by the 2050s. The signals at polar latitudes in the mid-stratosphere are more variable over the first 20 – 30 years and are not clearly established until the 2040s. In the upper troposphere a signal of opposite sign emerges, the upper boundary of which follows the zonal variation of the height of the tropopause: this delineates the warming of the troposphere due to increased greenhouse gases from the cooling of the stratosphere. In the lower troposphere the increased water vapour as the climate warms dominates and the bending angle signal is positive.

The bending angle signal can be broken down into contributions from the different physical effects associated with the warming climate using the tangent linear version of the bending angle forward model. In the tropics, for example, we see four distinct maxima: a positive signal due to increasing water vapour in the lower troposphere (which dominates a negative change due to the increased temperature); a negative signal in the upper troposphere due to enhanced warming compared to the surface; a positive signal in the lower stratosphere (due primarily to the thermal expansion of the atmosphere below as it warms); and a positive signal in the mid-stratosphere arising primarily from the enhanced radiative cooling compared to the lower stratosphere. Given the particular qualities of the measurement this suggests that the bending angle itself is of great potential use both for climate monitoring and climate model evaluation.

Time series of the bending angle at the equator at altitudes of 12, 20, and 26 km (Fig. 2) show the clear evolution of the climate trends in response to the warming. Using a long, unforced, integration of the climate model we determine the variability and autocorrelation in the "noise" (defined as the variability in the monthly mean bending angle with the seasonal cycle removed) and use this to estimate when the climate signal in the bending angle becomes detectable (see Weatherhead et al. 1998). In this case we estimate the number of years which must elapse before the trend can be detected at the 95% confidence level, with a 90% probability.

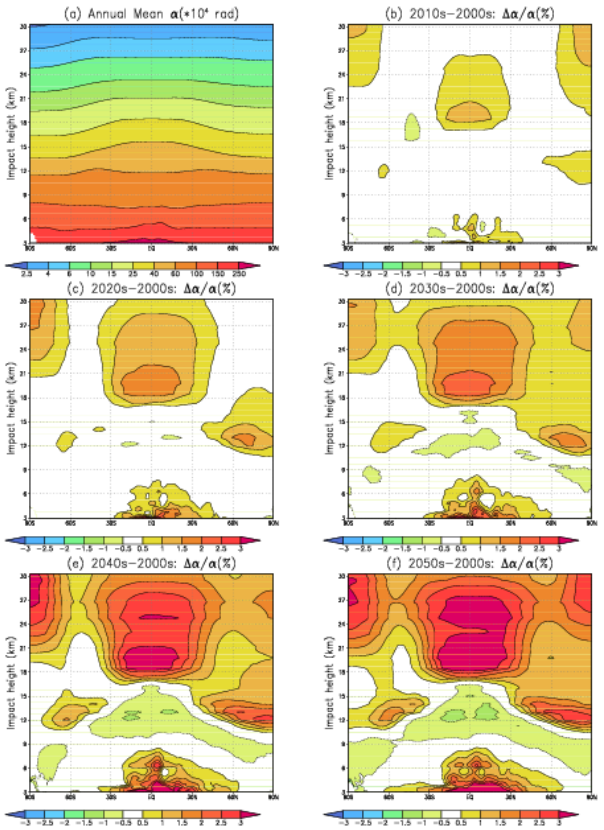

Figure 1(a) The annual, zonal mean bending angle profile for 2000 – 2005. (b) – (f) Evolution of the annual mean bending angle climate change signal from the 2010s to 2050s relative to the 2000 – 2005 mean.

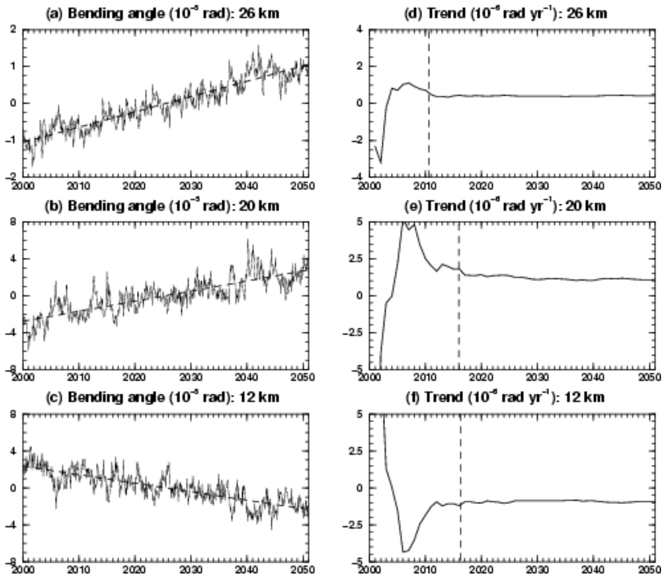

Figure 2 (a) – (c) Time series of monthly mean bending angle (seasonal cycle removed) at the equator at impact heights of 12, 20 and 26 km over the period 2000 – 2050. The dashed line shows the least squares linear trend. (d) – (f) Evolution of the bending angle trend with time at the same locations. The dashed vertical line indicates the estimated detection times (see text for definition).

Comparison with AMSU

The microwave temperature sounding channels of MSU/AMSU have been used extensively for climate trend studies over the last decade, often with much debate surrounding the results and their interpretation (Karl et al. 2006). Here we use the same climate modelling framework and methodology to compare trends and detection times of some of the AMSU channels with the GPSRO bending angle estimates. The magnitude of the trends at the equator (Fig. 3, upper) clearly shows the complementary nature of the two measurements, with AMSU having the advantage as one moves lower into the troposphere (AMSU 6 and 7) and GPS having a much better signal-to-noise ratio in the upper troposphere/lower stratosphere and around the tropopause (cf. AMSU 8-11). This is also reflected in the estimated detection times (Fig. 3, lower). Of particular note are the small signal and corresponding long detection time (> 50 years) of the AMSU-9 channel. This arises because the weighting function of the AMSU-9 channel spans the upper troposphere/lower stratosphere in the tropics and the measurement consequently averages over the tropospheric warming and stratospheric cooling (Fig. 4), leaving only a small net residual signal. Note that this becomes much less of an issue at high latitudes, where AMSU-9 is an almost purely stratospheric channel. In effect, the climate signal in the tropics is in the "null space" of AMSU-9 measurement, a phenomenon which is well-known in retrieval theory and NWP applications of satellite data (Rodgers, 1990). The much better vertical resolution of GPSRO should enable the bending angle observations to provide clearer and more useful information regarding evolving temperature trends around the tropopause and to distinguish between the tropospheric warming and stratospheric cooling. It should also be noted that we have assumed a continuous series of well-calibrated, non-drifting, AMSU measurements in these calculations, so that these can be considered as the most optimistic estimates of the trends. GPSRO obviously has an advantage in this respect too.

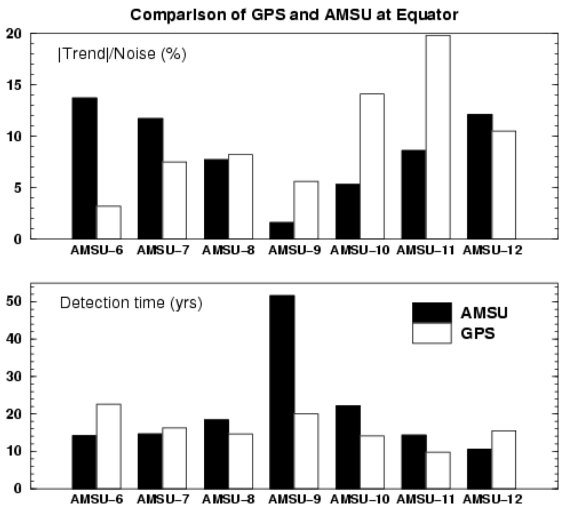

Figure 3: Comparison of signal-to-noise ratios and detection times for GPSRO bending angles and AMSU channels. GPSRO calculations are for the altitude of the peak in the respective AMSU channel.

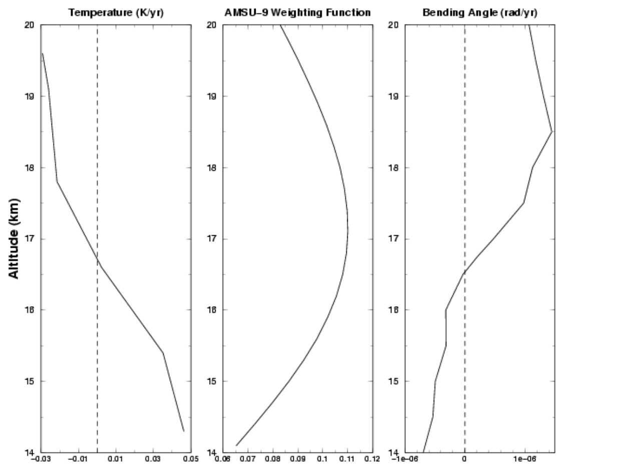

Figure 4: Trend in temperature (left) and bending angle (right) for 2000-2055. AMSU-9 weighting function (centre). All as a function of altitude.

Conclusions

Our simulation studies indicate that GPSRO bending angle have the potential to identify climate trends in the 10-15 year time frame in the tropics, suggesting that it should be an important component of the climate observing system over the coming decades. GPSRO has clear advantages over microwave temperature sounders in many respects but can also be seen to provide complimentary information to those instruments. Indeed the key to using GPSRO optimally for climate studies will be to exploit this complementarity with information provided by other sensors such as AMSU, AIRS and IASI, in much the same way as is already done in global data assimilation systems at ECWMF, the Met Office and elsewhere.

References

Karl, T.R. et al. (Eds) (2006), Temperature trends in the lower atmosphere. Steps for understanding and reconciling differences, Climate Change Science Program, Washington, D.C.

Ringer, M.A. and S. B. Healy, 2008. Monitoring twenty-first century climate using GPS radio occultation bending angles, *Geophys. Res. Lett.*, **35,** L05708

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Programme

Monday 16 June 2008

0915-0940	*Registration and Coffee*	
0940-0945	Philippe Bougeault	Welcome
0945-1015	John Eyre (Met Office)..................	An introduction to GPS radio occultation and its use in NWP
1020-1050	Kent Lauritsen (DMI).....................	The work of the GRAS SAF
1055-1105	*Break*	

Status of Missions

1105-1135	Bill Kuo (UCAR COSMIC)	COSMIC status and prospects for COSMIC-2
1140-1210	Axel Von Engeln (EUMETSAT) ..	GRAS status and future European GPS radio occultation missions
1215-1330	*Lunch*	
1330-1400	Jens Wickert (GeoForschungs Zentrum Potsdam)	CHAMP, GRACE, SAC-C, TerraSAR-X/TANDEM-X: Science results, status and future prospects
1405-1435	E.R. Kursinski (UnivArizona)........	LEO-LEO occultation measurements: Concept and possible missions

Assimilation of GPS Radio Occultation Measurements

1440-1510	Lidia Cucurull (JCSDA).................	Assimilation of GPS radio occultation measurements at NCEP
1515-1540	*Tea/coffee*	
1540-1610	Paul Poli (CNRM)	Assimilation of GPS radio occultation measurements at Météo-France
1615-1645	Michael Rennie (Met Office)	Assimilation of GPS radio occultation measurements at the Met Office
16:50-17:20	Josep Aparicio (Meteorological Service Canada)..............................	Assimilation of GPS radio occultation measurements at the Meteorological Service of Canada
17:25-17:45	Poster presentations	
17:45	*Cocktail Party*	

Tuesday 17 June 2008

0915-0945 Sean Healy (ECMWF) ....Assimilation of GPS radio occultation measurements at ECMWF

0950-1020 Ching-Yuang Huang (Univ Taiwan) Impact of GPS radio occultation measurements on severe weather prediction in Asia

1025-1050 *Coffee*

PBL and Altimetry Applications

1050-1120 Chi Ao (JPL) ....Planetary boundary layer information from GPS radio occultation measurements

1125-1155 Estel Cardellach (Campus UAB)....Applications of the reflected signals found in GNSS radio occultation events

Climate/Reanalysis Applications

1200-1230 Stephen Leroy (Harvard Univ).......Testing Climate models with GPS radio occultation measurements

1235-1330 *Lunch*

1330-1400 Gottfried Kirchengast (UnivGraz)..Climate signal detection with GPS radio occultation measurements

1405-1435 Dick Dee (ECMWF) ....Reanalysis applications of GPS radio occultation measurements

1440-1450 Introduction to Working Groups

1550-1515 *Tea/coffee*

1515-1730 Working group discussions

1800 *Informal buffet in the ECMWF Restaurant*

Wednesday 18 June 2008

0930-1215 Working group discussions and drafting of recommendations

1215-1345 *Lunch*

1345-1530 Plenary Session