Poster presentations

Assimilation of radio occultation data in the GME Global Atmospheric Model of the German Weather Service
Detlef Pingel*, Andreas Rhodes
Deutscher Wetterdienst, Kaiserleistr. 42, 63067 Offenbach am Main, Germany

Preparations for an operational assimilation of GPS radio occultation data:

**Bending angle forward operators:**
Evaluation of different versions of one- and three-dimensional operators

**GPS-RO impact study:**
Numerical experiments to assess the impact of the assimilation of GPS-RO in the weather forecast.

**Error characteristics of bending angle observations:**
Monitoring results of statistical parameters of GPS-RO observations

Please feel invited to see the poster!

The Radio Occultation Processing Package (ROPP)

... a comprehensive software package containing functionality to process RO data to assist with the assimilation of these data in NWP systems

http://garf.grassaf.org
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  

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

Mark Ringer¹, Sean Healy² and Viju John¹

¹. Met Office Hadley Centre, Exeter, UK
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.

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


# Lecturers

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
</table>
| Chi Ao             | Jet Propulsion Laboratory  
|                    | M/S 138-308, 4800 Oak Grove Drive  
|                    | Pasadena CA 91109, USA  
|                    | chi.o.ao@jpl.nasa.gov                                                       |
| Josep Aparicio     | Data Assimilation and Satellite Meteorology Division  
|                    | Meteorological Service of Canada  
|                    | 2121 Transcanada Hwy, H9P 1J3 Dorval, QC, Canada  
|                    | josep.aparicio@ec.gc.ca                                                    |
| Estel Cardellach   | IEEC/ICE-CSIC, Campus UAB/Fac Ciencies  
|                    | Torre C-5-parell-2 planta  
|                    | 08193 Bellaterra, Spain  
|                    | estel@ieec.uab.es                                                          |
| Lidia Cucurull     | Joint Center for Satellite Data Assimilation NOAA  
|                    | 5200 Auth Road  
|                    | Suitland MD 20746, USA  
|                    | cucurull@ucar.edu                                                          |
| Dick Dee           | ECMWF  
|                    | Shinfield Park  
|                    | Reading Berks RG2 9AX  
|                    | dick.dee@ecmwf.int                                                         |
| John Eyre          | Met Office  
|                    | Fitzroy Road  
|                    | Exeter EX 1 3PB  
|                    | john.eyre@metoffice.gov.uk                                                 |
| Sean Healy         | ECMWF  
|                    | Shinfield Park  
|                    | Reading Berks RG2 9AX  
|                    | sean.healy@ecmwf.int                                                       |
| Ching-Yuang Huang  | Department of Atmospheric Sciences  
|                    | National Central University  
|                    | No.300, Jhongda Rd., Jhongli, Taiwan 32001, Taiwan (R.O.C.)  
|                    | hcy@atm.ncu.edu.tw                                                         |
| Gottfried Kirchengast | Wegener Center for Climate and Global Change  
|                    | University of Graz  
|                    | Leechgasse 25, A-8010 Graz, Austria  
<p>|                    | <a href="mailto:Gottfried.kirchengast@uni-graz.at">Gottfried.kirchengast@uni-graz.at</a>                                           |</p>
<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bill Kuo</td>
<td>UCAR COSMIC P.O. Box 3000 Boulder, CO 80307, USA <a href="mailto:Kuo@ucar.edu">Kuo@ucar.edu</a></td>
</tr>
<tr>
<td>E.R. Kursinski</td>
<td>Department of Atmospheric Sciences, University of Arizona 1118 E. 4th St, Tucson, AZ 85721-0081, USA <a href="mailto:kursinski@atmo.arizona.edu">kursinski@atmo.arizona.edu</a></td>
</tr>
<tr>
<td>Kent Lauritsen</td>
<td>Danish Meteorological Institute, Research Department Lyngbyvej 100 DK-2100 Copenhagen, Denmark <a href="mailto:kbl@DMI.dk">kbl@DMI.dk</a></td>
</tr>
<tr>
<td>Stephen Leroy</td>
<td>Anderson Group, School of Engineering and Applied Sciences Harvard University Cambridge MA 02138, USA <a href="mailto:leroy@huarp.harvard.edu">leroy@huarp.harvard.edu</a></td>
</tr>
<tr>
<td>Paul Poli</td>
<td>Météo-France (CNRM) 42 Avenue Coriolis 31057 Toulouse Cedex 1, France <a href="mailto:paul.poli@meteo.fr">paul.poli@meteo.fr</a></td>
</tr>
<tr>
<td>Michael Rennie</td>
<td>Met Office Fitzroy Road Exeter EX 1 3PB <a href="mailto:michael.rennie@metoffice.gov.uk">michael.rennie@metoffice.gov.uk</a></td>
</tr>
<tr>
<td>Axel Von Engeln</td>
<td>EUMETSAT Am Kavalleriesand 31 D-64295 Darmstadt, Germany <a href="mailto:Axel.VonEngeln@eumetsat.int">Axel.VonEngeln@eumetsat.int</a></td>
</tr>
<tr>
<td>Jens Wickert</td>
<td>GeoForschungs Zentrum Potsdam Department of Geodesy and Remote Sensing Telegrafenberg, D-14473 Potsdam, Germany <a href="mailto:jens.wickert@gfz-potsdam.de">jens.wickert@gfz-potsdam.de</a></td>
</tr>
<tr>
<td>Name</td>
<td>Affiliation</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Dale Barker        | Met Office
FitzRoy Road
Exeter EX1 3PB
dmbarker@ucar.edu |
| Pierre Koclas      | Canadian Meteorological Centre
Meteorological Service of Canada
2121 Transcanada Hwy, H9P 1J3 Dorval, QC, Canada
pierre.koclas@ec.gc.ca |
| Jignesh Kshatriya  | ISRO
D3/7, Vikramnagar, Ambli-Bopal road, Ahmedabad,
Gujarat, India
k_jignesh@yahoo.com |
| Huw Lewis          | Met Office
Fitzroy Road
Exeter EX1 3PB
huw.lewis@metoffice.gov.uk |
| Christian Marquardt| Eumetsat
Am Kavalleriesand 31
64295 Darmstadt, Germany
christian.marquardt@eumetsat.int |
| Ismail Mert        | Turkish State Meteorological Office
Kalaba
Ankara Turkey
imert@meteor.gov.tr |
| David Offiler      | Met Office
FitzRoy Road
Exeter EX1 3PB
dave.offiler@metoffice.gov.uk |
| Elena Padorno      | DMI
Lyngbyvej 100
2100 Copenhagen Ø
Denmark |
| Detlef Pingel      | Deutscher Wetterdienst (DWD) - Referat FE 12: Datenassimilation
Kaiserleistraße 42
D-63067 Offenbach, Germany.
detlef.pingel@dwd.de |
| Mark Ringer        | Met Office Hadley Centre for Climate Change
FitzRoy Road
Exeter EX1 3PB
mark.ringer@metoffice.gov.uk |
<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marc Schröder</td>
<td>Deutscher Wetterdienst - Satellite Application Facility on Climate Monitoring, Dept. Climate and Environment P.O. Box 10 04 65, 63004 Offenbach, Germany <a href="mailto:marc.schroeder@dwd.de">marc.schroeder@dwd.de</a></td>
</tr>
<tr>
<td>Stig Syndergaard</td>
<td>Danish Meteorological Institute</td>
</tr>
<tr>
<td></td>
<td>Lyngbyvej 100</td>
</tr>
<tr>
<td></td>
<td>DK-2100 Copenhagen, Denmark</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:ssy@DMI.dk">ssy@DMI.dk</a></td>
</tr>
<tr>
<td>Chuen-Teyr Terng</td>
<td>Central Weather Bureau, Taiwan</td>
</tr>
<tr>
<td></td>
<td>64 Kung Yuan Road</td>
</tr>
<tr>
<td></td>
<td>Taipei, Taiwan 10048</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:gfs3@cwb.gov.tw">gfs3@cwb.gov.tw</a></td>
</tr>
<tr>
<td>Henrik Vedel</td>
<td>Danish Meteorological Institute</td>
</tr>
<tr>
<td></td>
<td>Lyngbyvej 100</td>
</tr>
<tr>
<td></td>
<td>DK 2100 Copenhagen, Denmark</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:hev@DMI.dk">hev@DMI.dk</a></td>
</tr>
<tr>
<td>Fritz Wollenweber</td>
<td>EUMETSAT</td>
</tr>
<tr>
<td></td>
<td>Am Kavalleriesand 31</td>
</tr>
<tr>
<td></td>
<td>D-64295 Darmstadt, Germany</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:fritz.wollenweber@eumetsat.int">fritz.wollenweber@eumetsat.int</a></td>
</tr>
<tr>
<td>Ismail Yucel</td>
<td>Middle East Technical University (METU)</td>
</tr>
<tr>
<td></td>
<td>METU Civil engineering Department, K4 Building</td>
</tr>
<tr>
<td></td>
<td>Inonu Blvd, 06531 Ankara, Turkey</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:iyucel@metu.edu.tr">iyucel@metu.edu.tr</a></td>
</tr>
</tbody>
</table>
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 (Univ Graz) .. 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

**Wednesday 18 June 2008**

0930-1215 Working group discussions and drafting of recommendations

1215-1345 Lunch

1345-1530 Plenary Session