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# Radio Occultation Bending Angle Anomalies During Tropical Cyclones

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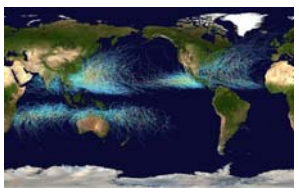
## Objective

The tropical deep convection affects the radiation balance of the atmosphere changing the water vapor mixing ratio and the temperature of the upper troposphere and lower stratosphere (UT/LS). The aim of this work is to better understand these processes and to investigate if severe storms leave a significant signature in radio occultation profiles in the tropical tropopause layer.

## Case selection

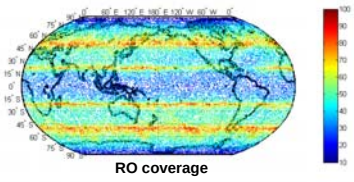
We selected the tropical cyclone (TC) tracks and they were compared with GPS/MET, SAC-C, CHAMP, GRACE and COSMIC Radio Occultations (ROs). 1194 coincidences were found between ROs and TCs considering a time window of 3h and a space window of 300km from the eye of the TC, 77% of coincidences are coming from COSMIC project. Then we selected all the cases with available co-located radiosondes.



TC tracks

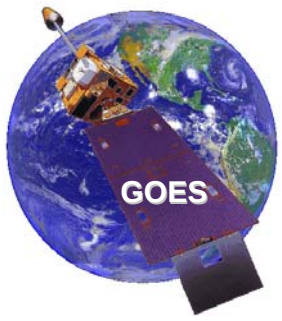
| | GPSMET | SACC | CHAMP | GRACE | COSMIC | Total |
|---|---|---|---|---|---|---|
| 1995 | 1 | | | | | 1 |
| 2001 | | 13 | 9 | | | 22 |
| 2002 | | 27 | 28 | | | 55 |
| 2003 | | | 29 | | | 29 |
| 2004 | | | 40 | | | 40 |
| 2005 | | | 33 | | | 33 |
| 2006 | | | 12 | | 179 | 191 |
| 2007 | | | 9 | 18 | 194 | 221 |
| 2008 | | | 20 | 22 | 335 | 377 |
| 2009 | | | | 14 | 211 | 225 |
| | 1 | 40 | 180 | 54 | 919 | 1194 |

Number of coincidences



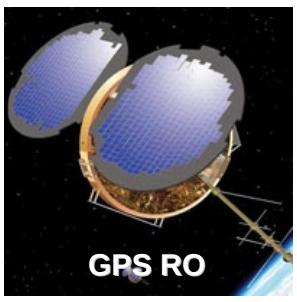
RO coverage

## Datasets & Methods




From GOES, we used the brightness temperatures at 6.8 microns (water vapour channel) and the 10.7 microns. In clear sky conditions (and low level clouds) the brightness temperature in the water vapour channel is smaller than the brightness temperature at 10.7 microns. When the overshooting is present, there is an inversion and the brightness temperature and 6.8 microns becomes larger by a few degrees.


From the radiosondes (RAOBs) we used the temperatures and water vapour profiles. A double-peak (two local minima) in temperature, one at the tropopause, and one a couple of km higher corresponding to an increase of water vapour, suggests the presence of overshoot (Danielsen, 1982)



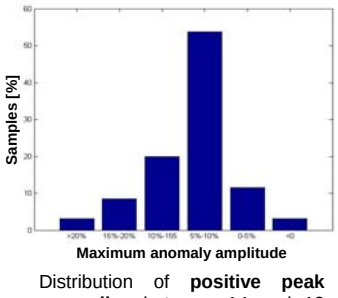

The GPS receiver, measures the phase and amplitude of two L-band signals. The bending angle is calculated from the phase and amplitude and refractivity is computed using Abel inversion. Temperature, pressure and water vapour are derived via a one-dimensional variational (1Dvar) approach involving the refractivity and the ECMWF model.

$$N=77.6*P/T+3.73*10^5*p_w/T^2$$

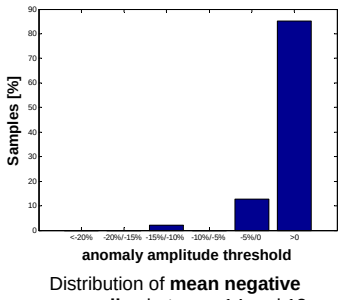
(N is refractivity, T is the temperature, P is pressure, $p_w$ is water vapour pressure)

## Statistics

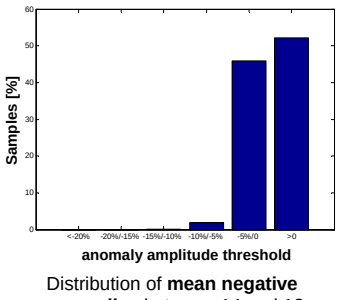
During TCs the bending angle anomaly always shows a positive spike between 14 and 18 km of altitude (97% of the storms and 100% of the TC). Almost the 90% of TCs has a positive mean bending angle anomaly between 14 km and 18 km, while in no-TC conditions the probability to get positive or negative mean anomaly is evenly distributed.



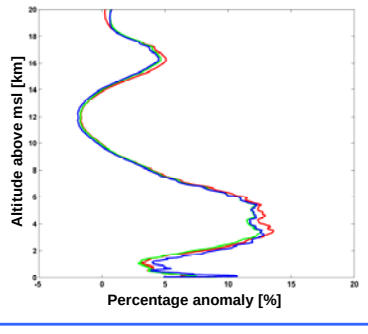

Distribution of **positive peak anomalies** between 14 and 18 km **during TCs**.




Distribution of **mean negative anomalies** between 14 and 18 km **during TCs**.

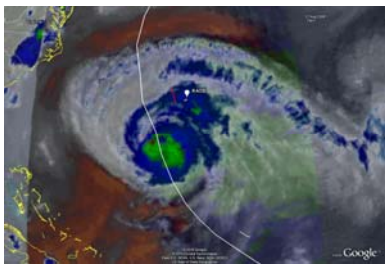



Distribution of **mean negative anomalies** between 14 and 18 km **during NO TC status.**

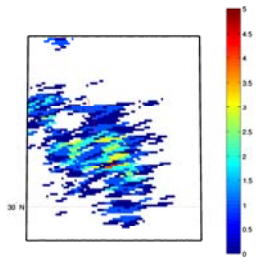



The averaged bending angle anomaly for all the 1194 cases is shown in the figure in respect to the man annual bending angle of COSMIC 2009 (red line), the COSMIC climatology (green line) e the climatology from all the GPS RO missions (blue line).

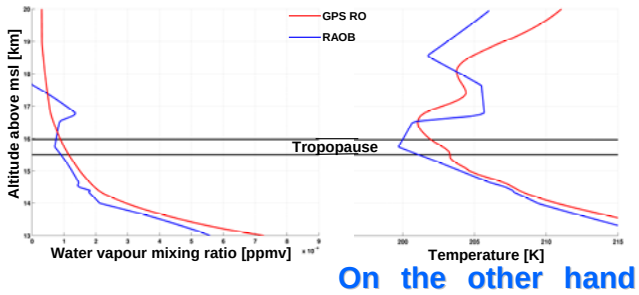
## Analyses – Bill 2009



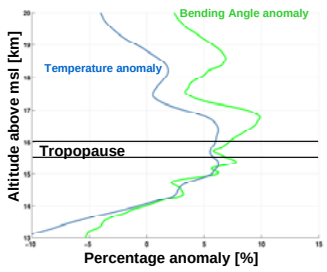
This radio occultation was acquired on 22nd of August 2009 at 8.27 UTC, in the Atlantic Ocean when the hurricane Bill was weakening from category 3 to category 2. The distance between the RO and the RAOB was 98.32 km. The RAOB was acquired at 11 UTC.



This figure shows the difference of brightness temperature at 6.8 microns and the brightness temperature at 10.7 microns on the RO area from GOES 11 (the RO is the red line). An inversion from 3 hours before the RO until 1 hour later on the same area is present, consequently some overshoot should be expected.



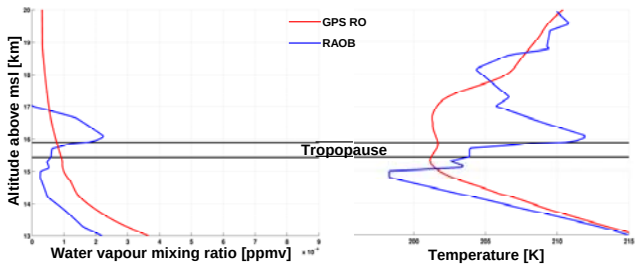

The radiosonde shows an increase of water vapour mixing ratio just below 17 km of altitude and the temperature profiles with two minima, fully corroborating the hypothesis of Danielsen.



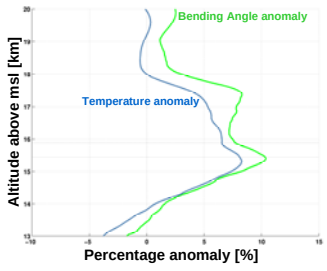

On the other hand we can not see the same variations in the RO profiles. The bending angle anomaly, as usual during TCs, has a local maximum above the tropopause and the amplitude of the anomaly is 10% larger than the climatology in the same area. From the bending angle anomaly we can clearly recognize the variation in temperature but the double-peak from the RO temperature anomaly profile is less evident.

## Analyses – Danny 2009

This radio occultation was acquired on 29th of August 2009 at 8.39 UTC, in the Atlantic Ocean during the tropical storm Danny. The distance between the RO and the RAOB was 193 km. The RAOB was launched at 6 UTC. GOES data are not available.




Also in this case, the radiosonde shows an increase of water vapour mixing ratio just above the tropopause and the temperature profiles with two minima, but the RO profiles do not confirm it.




The bending angle anomaly, however, shows the double peak which is not evident in the RO temperature anomaly profile. The bending angle variation is probably due to the temperature variation, but the sensitivity of the bending angle is higher and it can recognize also small variations, otherwise not detectable.

## Conclusions

- Bending angle anomaly profile shows a clear TC signature in the UT/LS
- Bending angle anomaly sensitivity is higher than sensitivity of the other parameters
- Bending angle could be used as an indicator of convective towers

## Future work

- Systematic detection of double peaks above the tropopause
- Selection and comparison of all co-located ROs and radiosondes
- Use of lightning dataset as indicator of thunderstorm and convection
- Detection of cloud top altitude and cloud top temperature using A-train dataset

## Contacts & Reference

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Measurements of the upper troposphere and lower stratosphere during tropical cyclones using the GPS radio occultation technique, R. Biondi, T. Neubert, S. Syndergaard and J. Nielsen, Advances in Space Research, 2010, doi:10.1016/j.asr.2010.05.031