Comparison of atmospheric boundary layer structure as detected by COSMIC GPS radio occultation soundings and simulated by the WRF model

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Scientific Motivation

- Our understanding of the planetary boundary layer (PBL) over the ocean is poor due to a lack of observations.
- Model performance of PBL prediction is not good due to a lack of observations.
- COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate), with the implementation of the open loop tracking technique, allows radio occultation (RO) soundings to penetrate the lower troposphere, and to provide an estimate of PBL height.

Study Approach

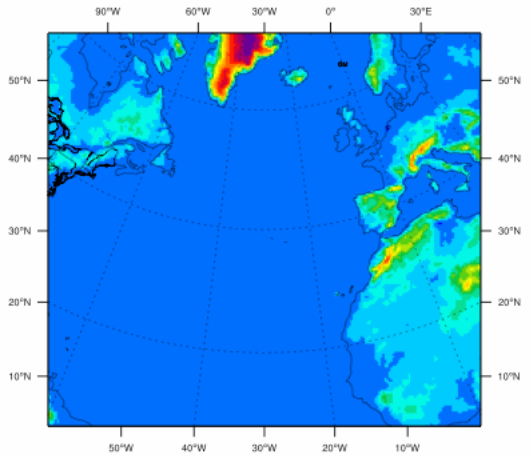
1. Analyzes the PBL structure detected by COSMIC GPS RO data
2. Examine the ability of WRF model forecasts in capturing PBL structure
3. Examine the ability of ECMWF and NCEP analyses in capturing PBL structure

Data Source

- Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) refractivity
- European Centre for Medium-Range Weather Forecasts (ECMWF) analysis
- National Center for Environmental Prediction (NCEP) analysis
- Weather Research and Forecasting (WRF) Model simulations

WRF Simulation Setup (Ⅰ)

- 36 km horizontal resolution, 34 /51 levels with 50hPa model top
- WSM 6-class graupel microphysics, RRTM longwave radiation, Dudhia shortwave radiation, Kain-Fristch Cu parameterization and YSU boundary layer scheme
- integrate 24hr for each day's simulation using NCEP/AVN analyses as initial and boundary conditions
- time period: March 2007
- study domain: the North Atlantic Ocean



WRF Simulation Setup (Ⅱ)

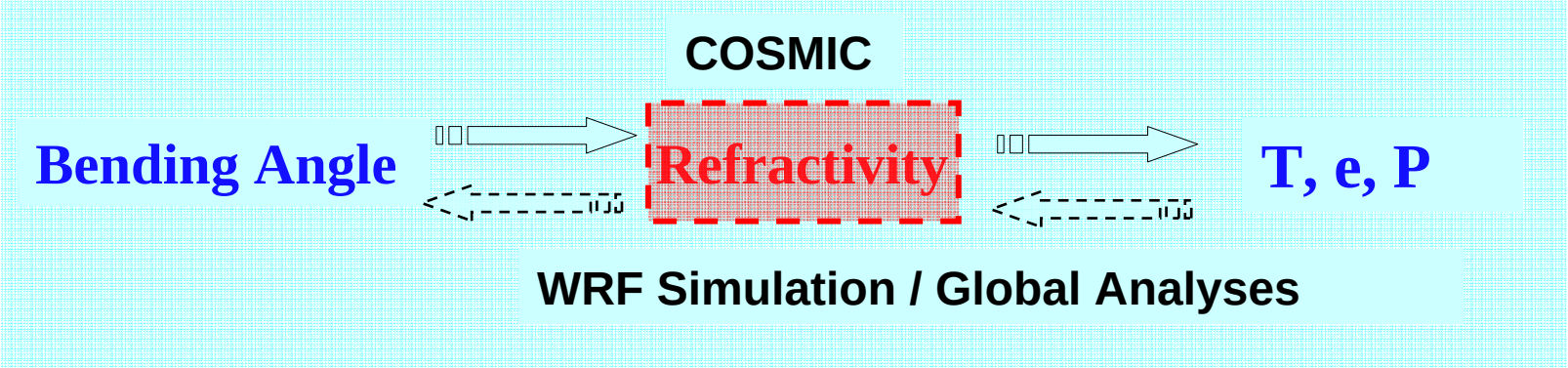
- Calculate refractivity using the following formula:

$$N = 77.6\frac{P}{T} + 3.73 \times 10^5 \frac{P_W}{T^2}$$

where N refractivity, T temperature in Kelvins, P total air pressure and Pw partial pressure of water vapor in hPa

- Search the model grid point closest to RO soundings both in time and space, then interpolate the simulated refractivity into the standard pressure levels (1000, 925, 850,…….50hPa) using linear interpolation method. Model output frequency is 0.5 hr.

Method

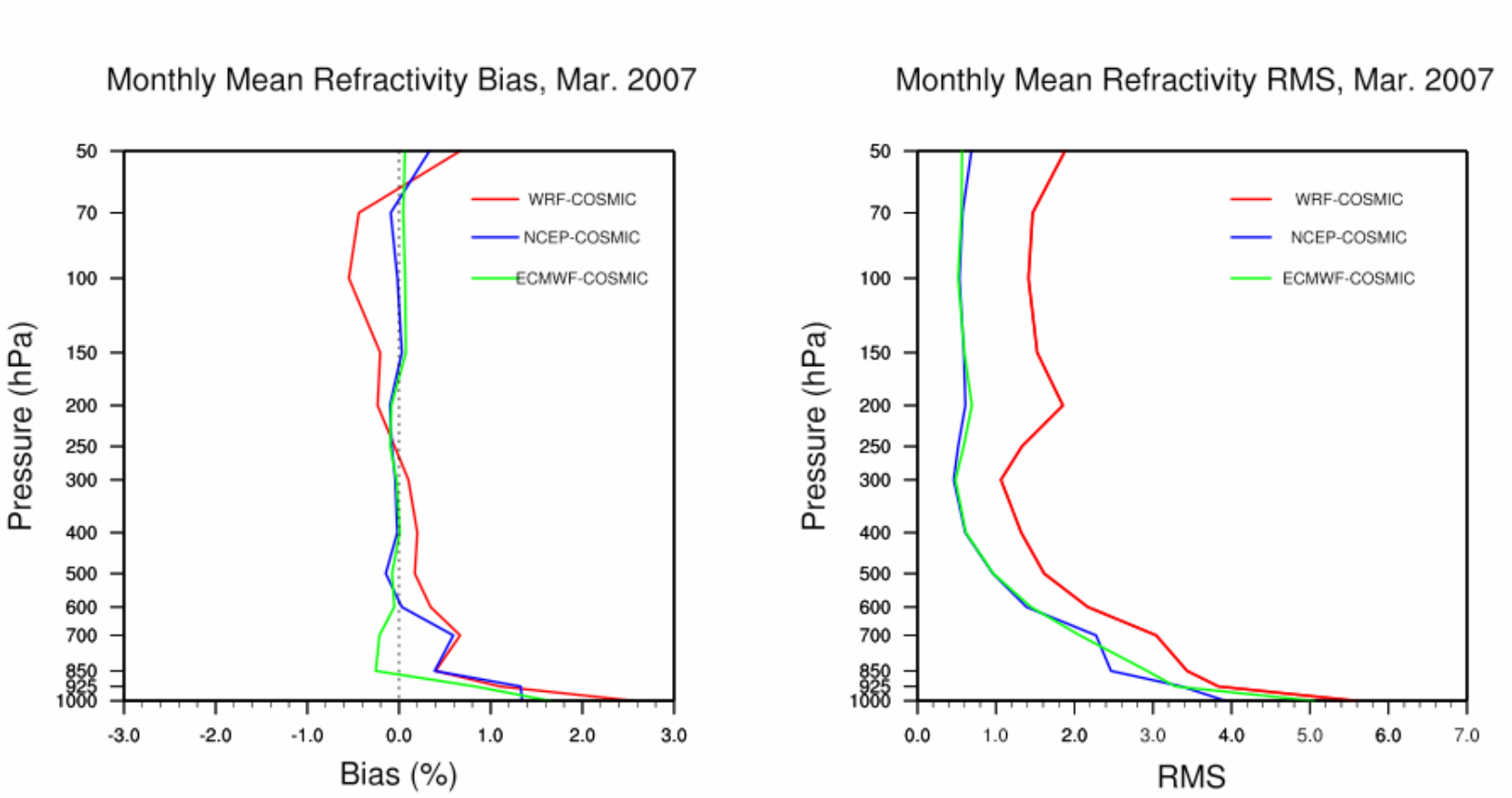


$$Bias_{i,j} = (M_{i,j} - COSMIC_{i,j}) / COSMIC_{i,j} * 100\%$$

$$RMS_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (Bias_{i,j})^2}$$

Where M stands for the WRF forecasts, ECMWF and NCEP analyses, respectively. I is the index of RO, and j is the index of vertical level.

Comparison of COSMIC refractivity with ECMWF, NCEP analyses and WRF simulation

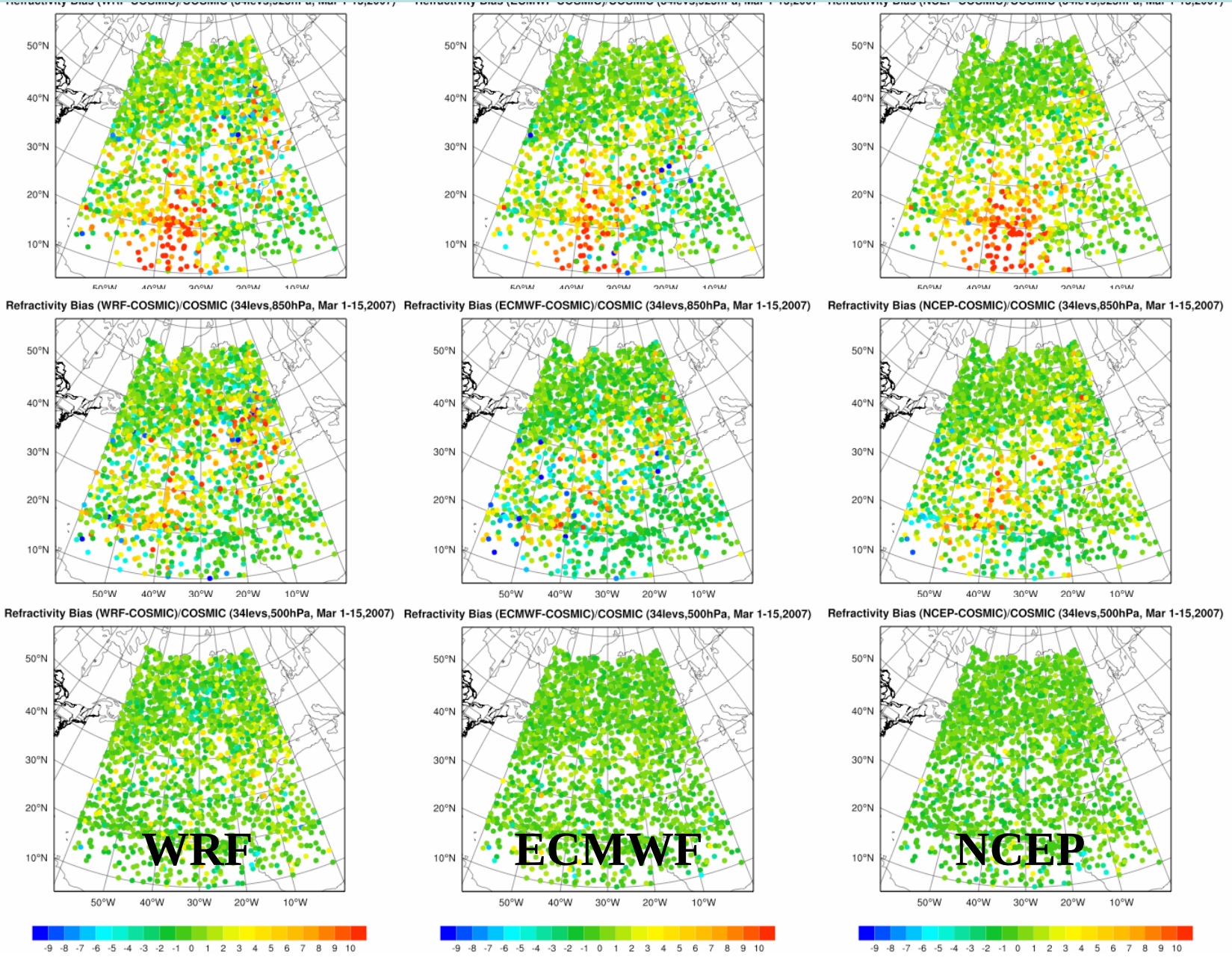


Distribution of Bias in fractional refractivity (Mar 1-15, 2007)

925hPa

850hPa

500hPa

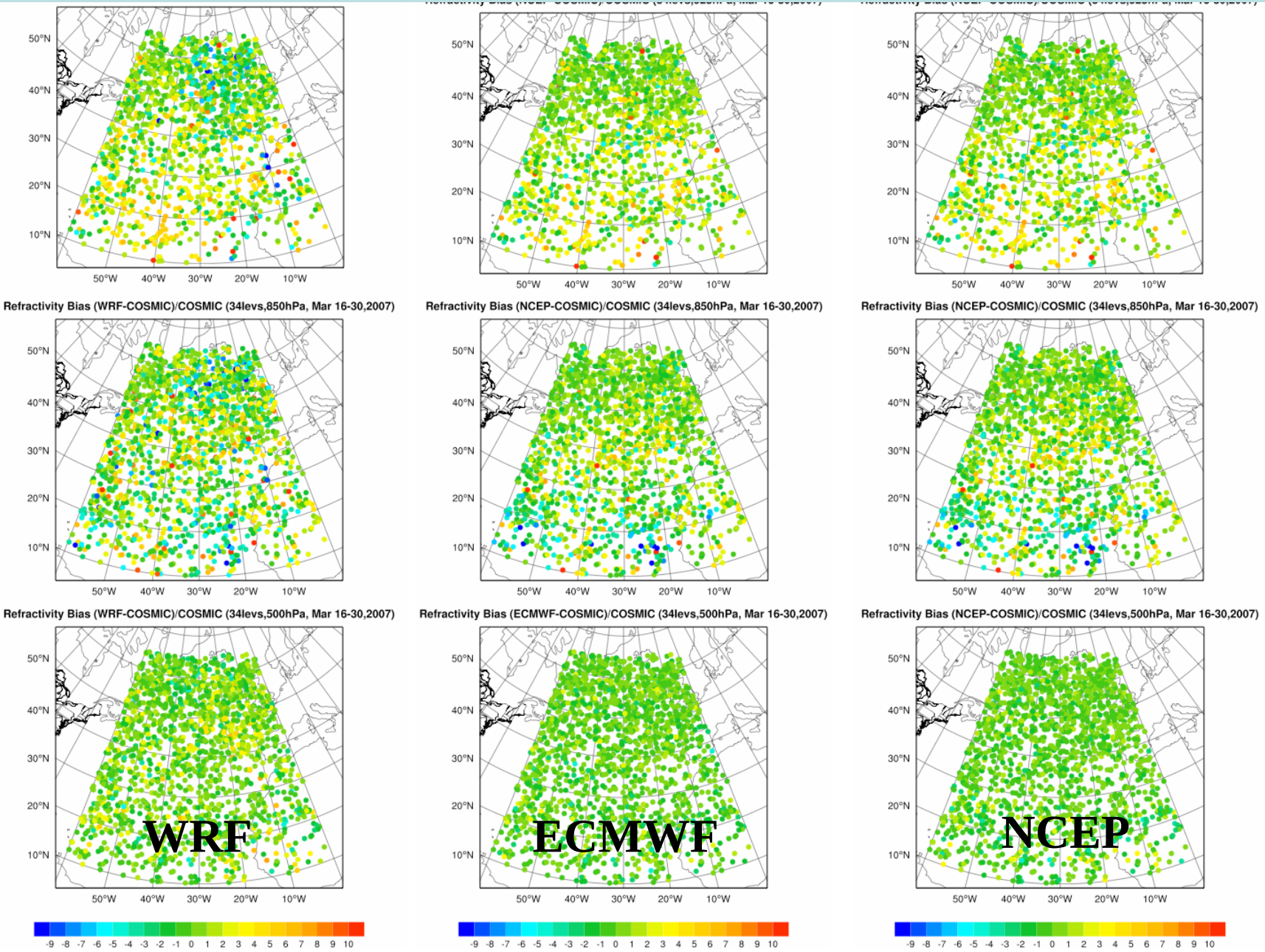


Distribution of Bias in fractional refractivity (Mar 16-31, 2007)

925hPa

850hPa

500hPa



Definition of Atmospheric Boundary Layer Height

$$\Delta = Max\left(\frac{\partial N}{\partial Z}\bigg|_{Top} - \frac{\partial N}{\partial Z}\bigg|_{Bottom}\right)_i$$

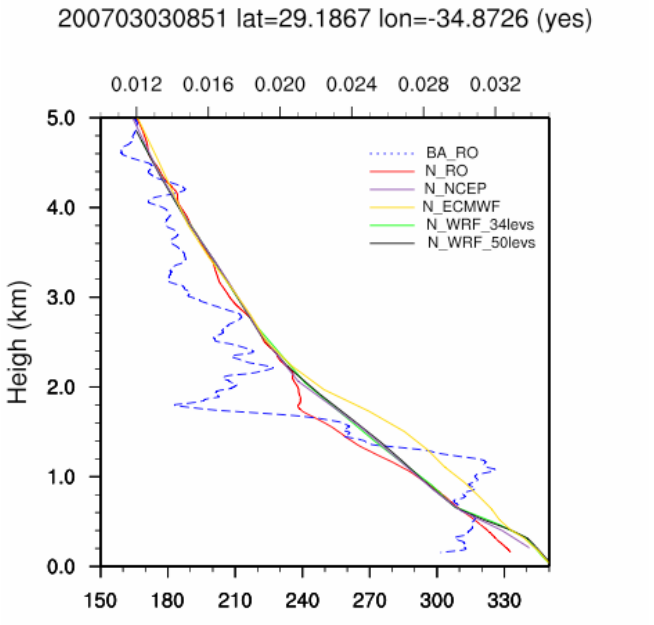
where N is refractivity, Z is height, I is height index. It has two restrictions:

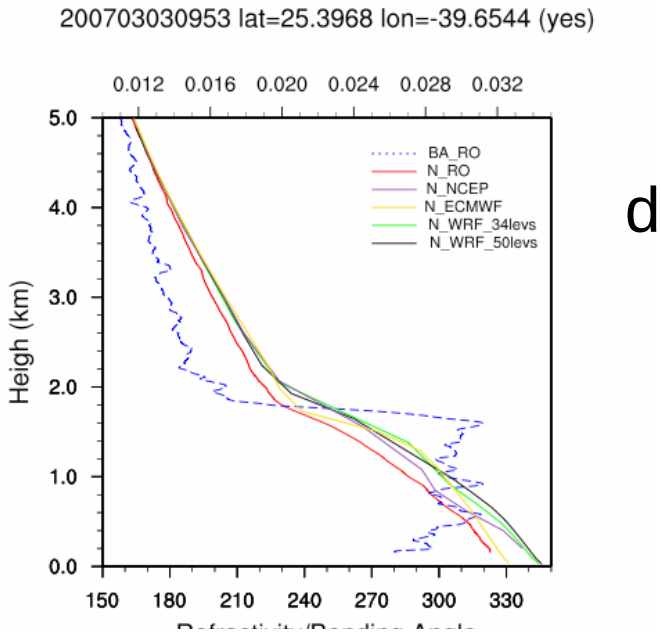
$$Z_{bottom0} \le 0.5Km$$

$$\Delta \ge 45 / Km$$

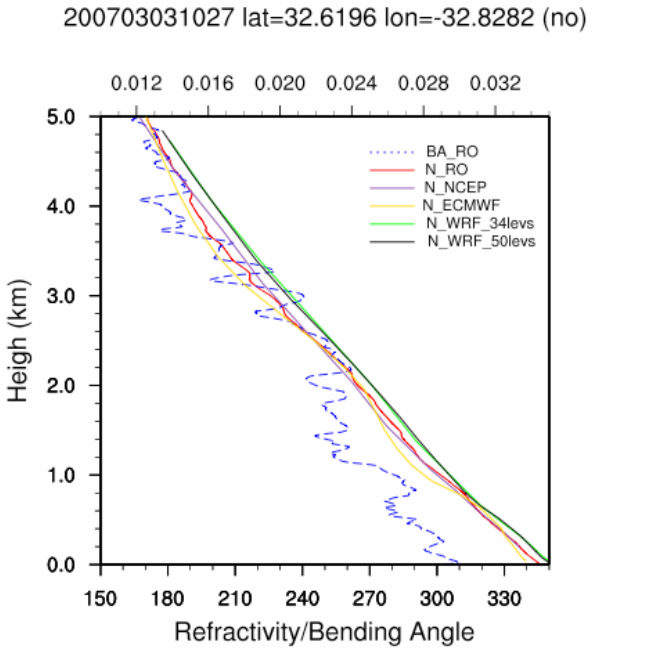
We interpolate each sounding into 3000 equally spaced vertical levels between the RO bottom and 6.5Km height, then use the sliding average method to look for the maximal variation of gradient, and take its top height as PBL height.

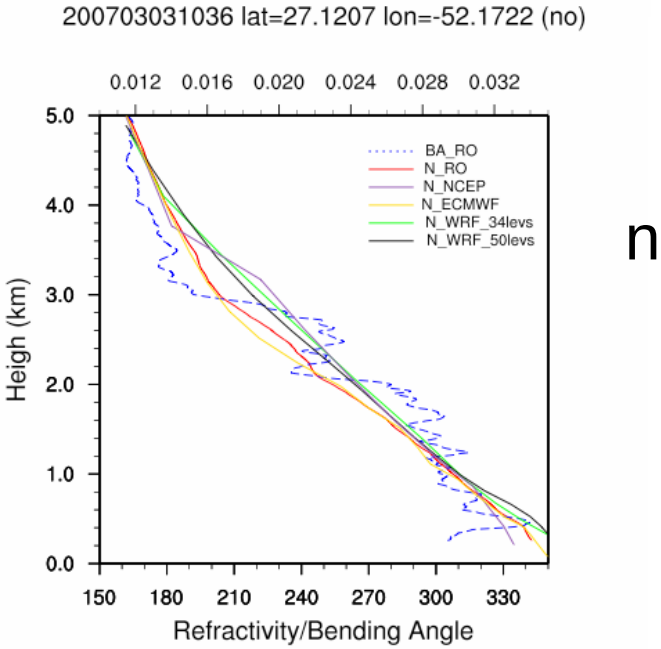
Typical cases which can or cannot detect PBL height





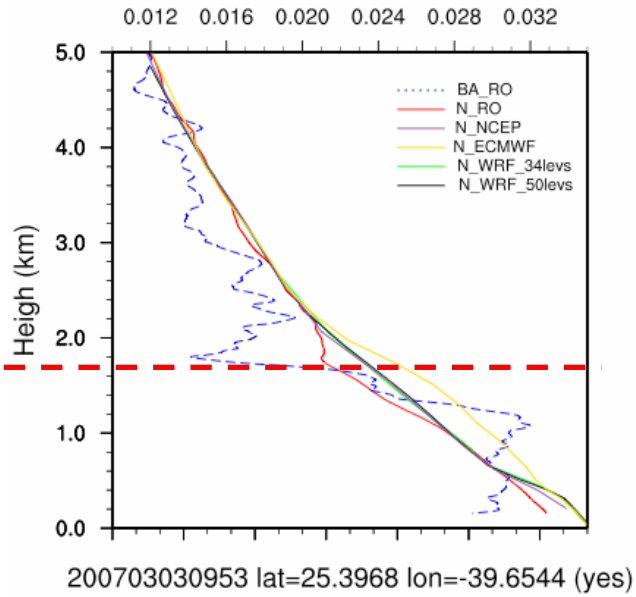
detect



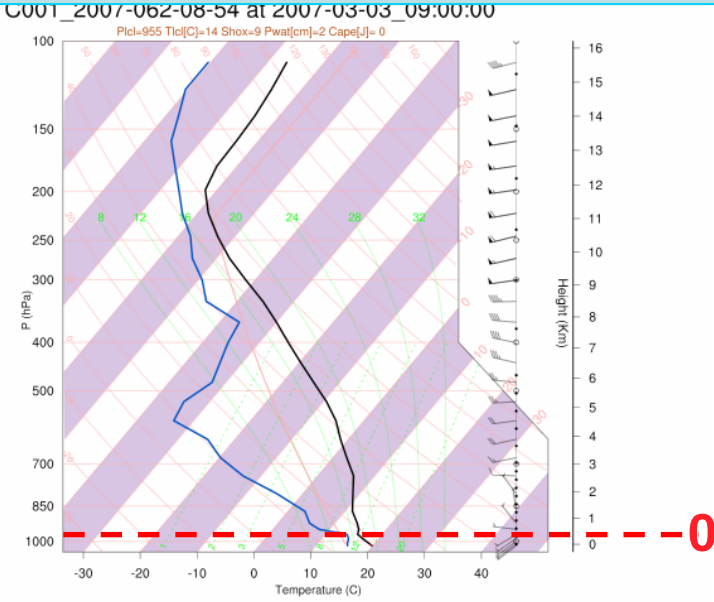


not detect

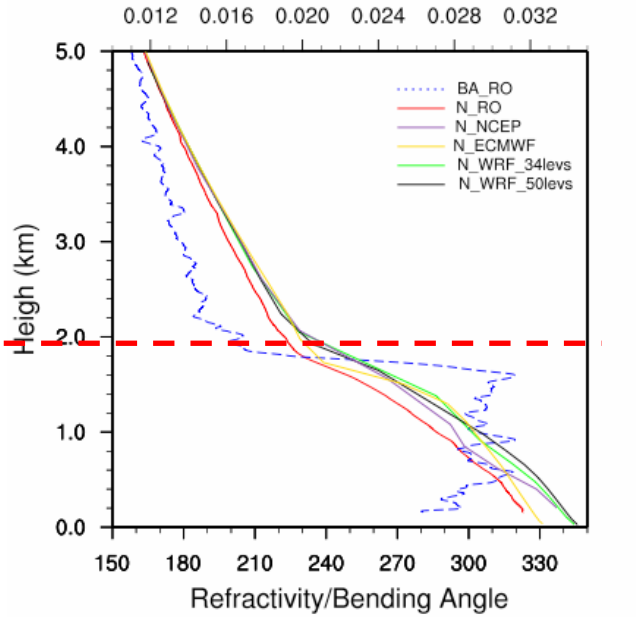
Comparison of PBL height based on refractivity and other meteorological parameters from the WRF forecasts



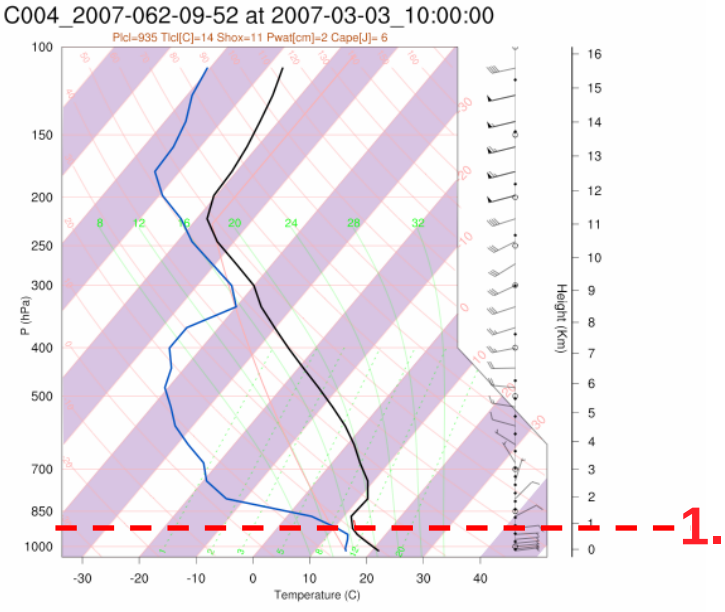
1.8Km



0.5Km

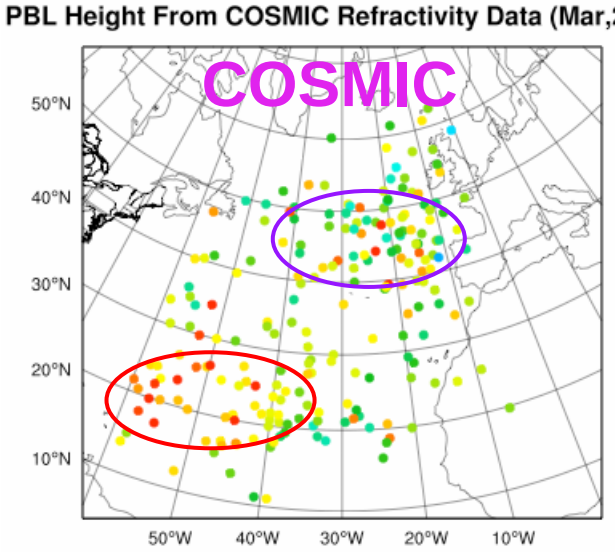


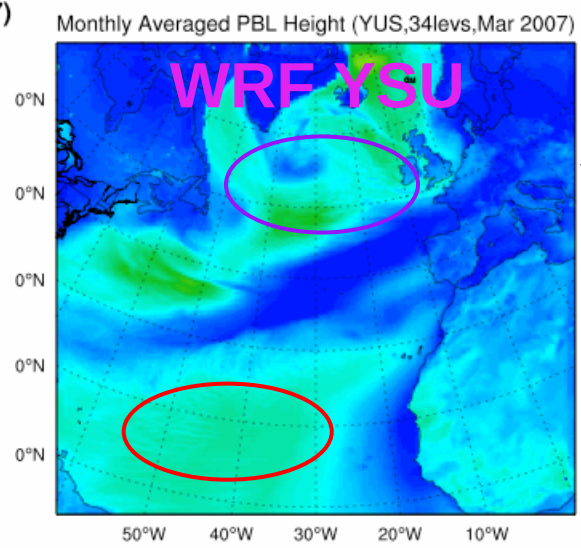
2.0Km



1.0Km

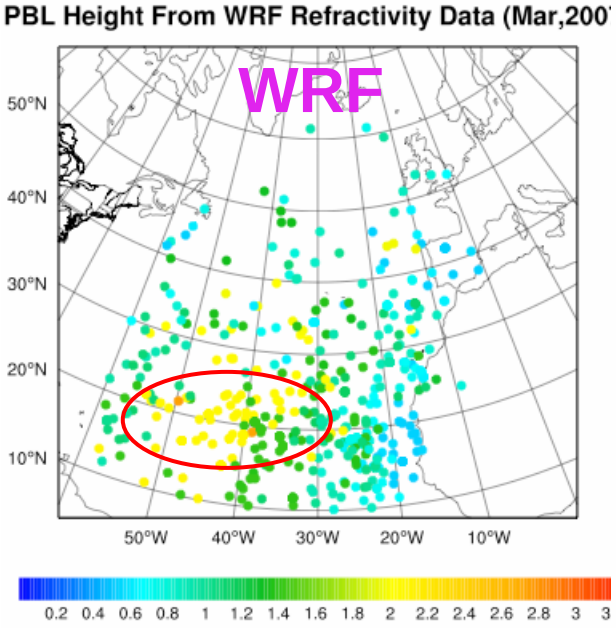
Distribution of PBL height detected by different data and the WRF YSU parameterization scheme

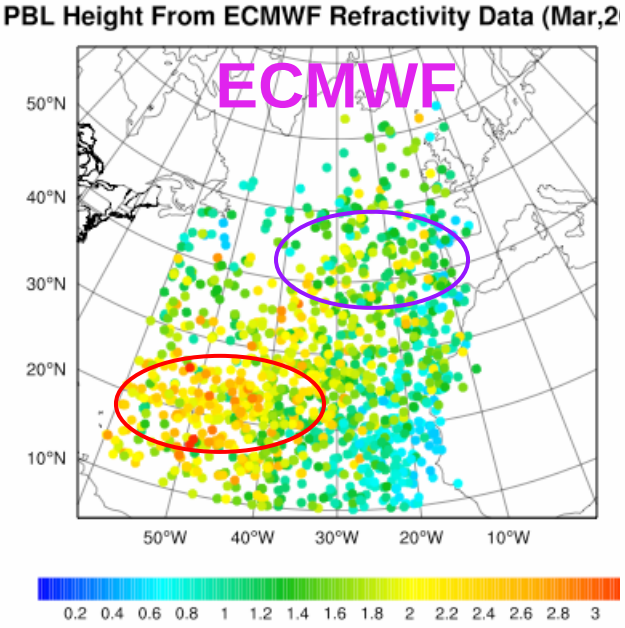


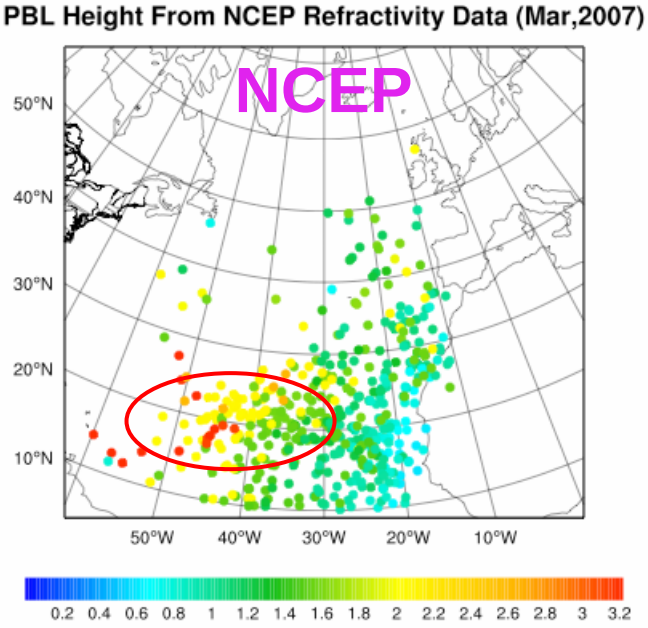


YSU: monthly mean

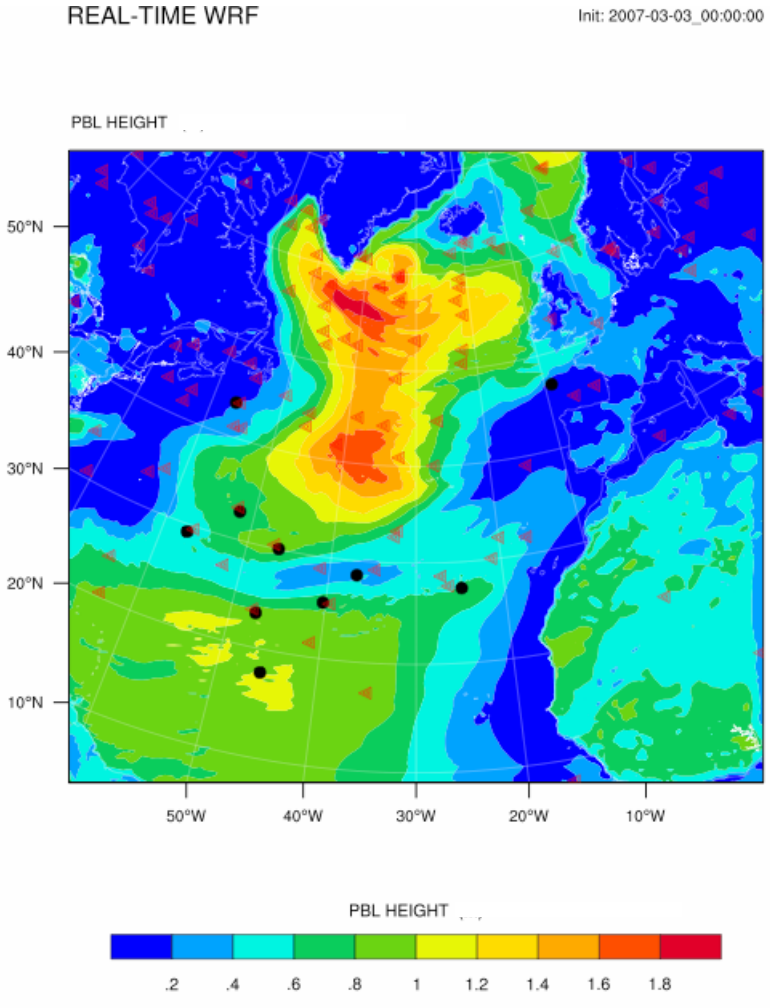
Others: daily







Why some COSMIC RO soundings can detect PBL height, and others do not ? What does its profile looks like? How is it affected by synoptic weather systems?

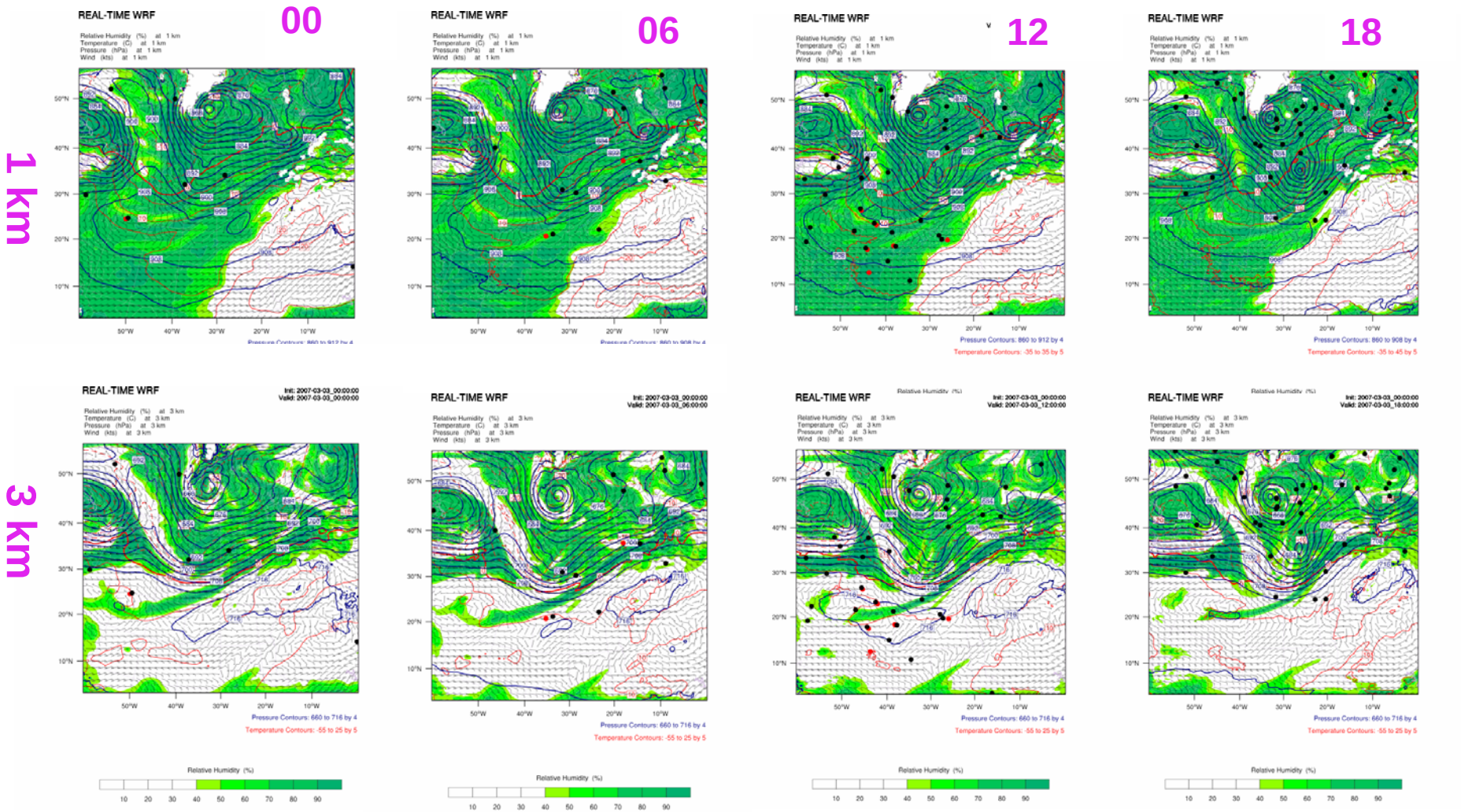


Shade: PBL height from WRF YSU scheme

Black points: RO (can detect PBL height)

Red points : RO (the bottom height < 0.5Km)

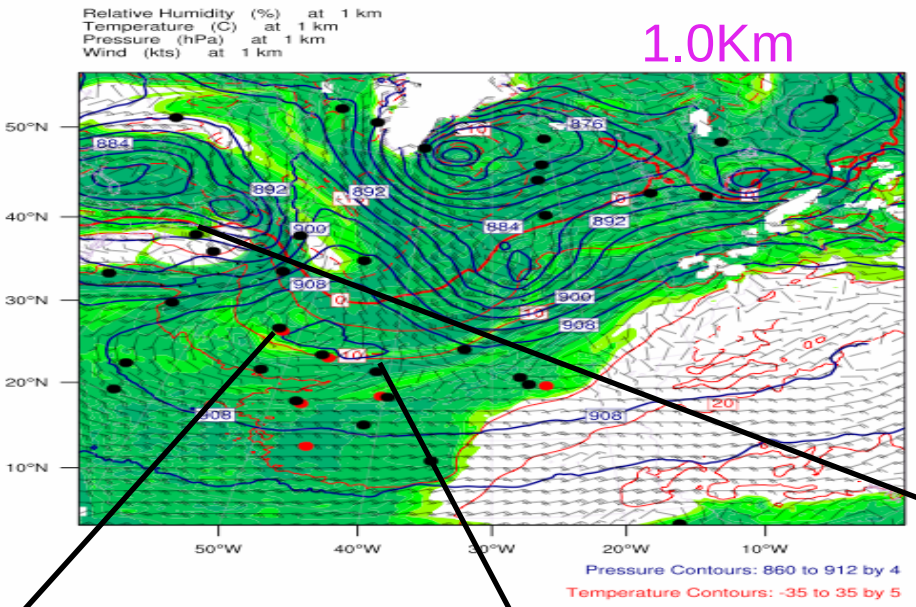
Evolution of synoptic weather system and COSMIC RO distribution on Mar 3, 2007



Red Line: Temperature **Blue line: Pressure** **Green Shade: relative humidity** **Vector : Wind**

Red points: RO (can detect PBL height) **Black points : RO (the bottom height < 0.5Km)**

Relationship between PBL height and synoptic weather system ?



Red Line: Temperature

Blue line: Pressure

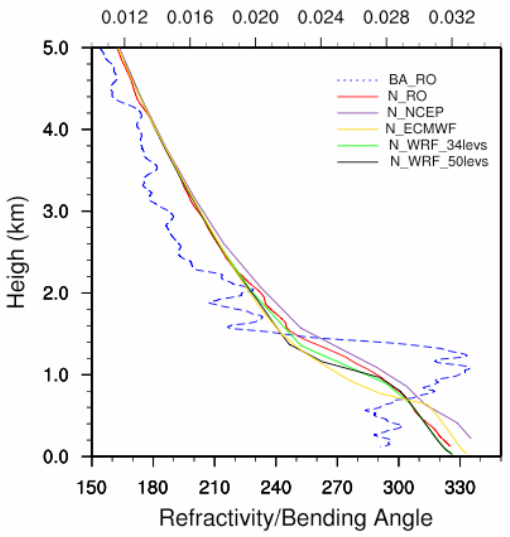
Green Shade: relative humidity

Vector : Wind

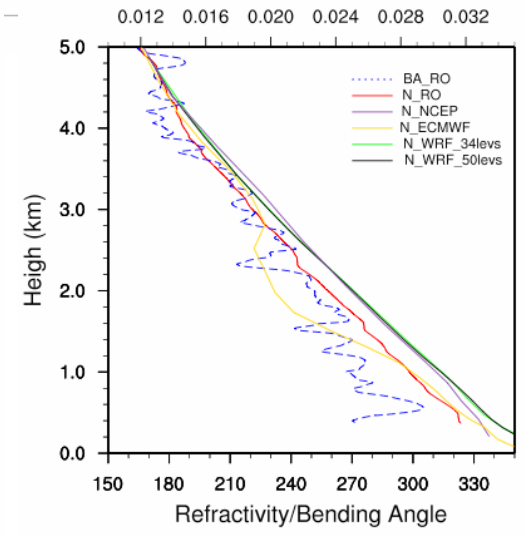
Red points: RO (can detect PBL height)

Black points : RO (the bottom height < 0.5Km)

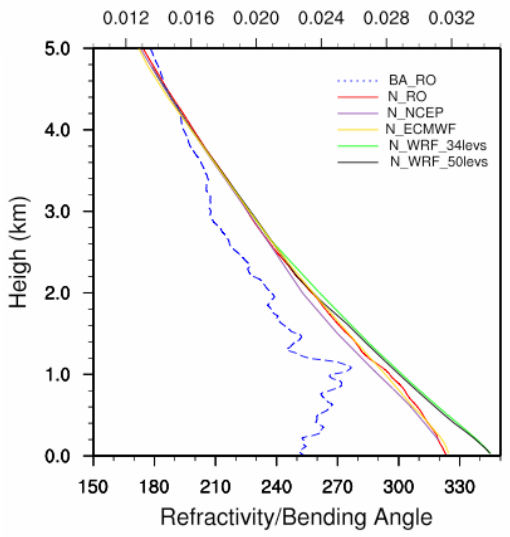
200703031118 lat=30.3584 lon=-46.9664 (yes)



200703031212 lat=28.7978 lon=-41.2343 (no)



200703031029 lat=41.1327 lon=-54.8928 (no)



Conclusions

- COSMIC refractivity sounding is a useful data set to verify modeling simulation and analyses.
- Differences between COSMIC and WRF forecasts and global analyses in lower troposphere refractivity is synoptic case dependent.
- There are noticeable differences in PBL height as estimated by COSMIC, WRF forecast, and ECMWF and NCEP/AVN analyses, both in geographical distribution and intensity.
- COSMIC is shown to give a higher PBL height compared with the WRF forecast and with the YSU PBL scheme.