Cloudy Atmospheric Boundary Layer (ABL) Observations over Subtropical Eastern Oceans from COSMIC GPS Occultation (VOCALS/Southeast Pacific Science)

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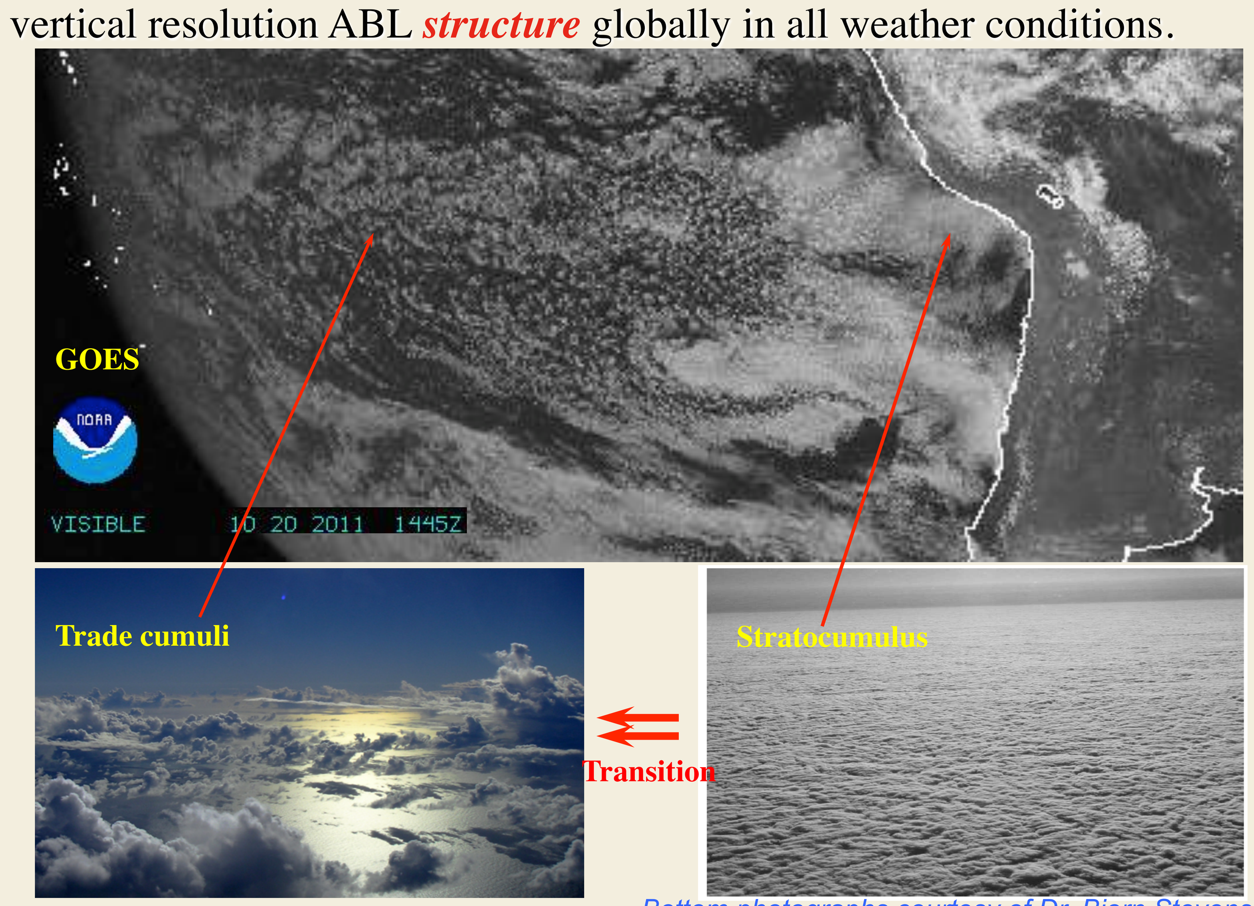
Motivations

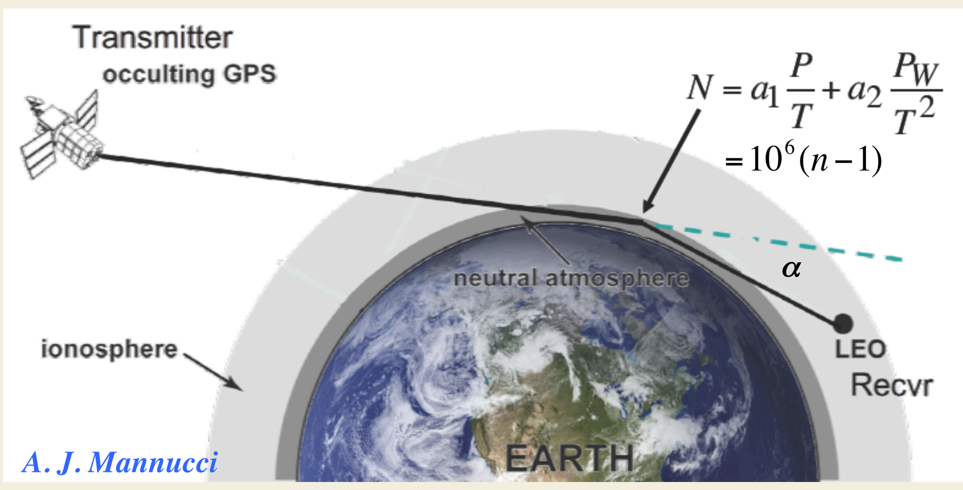
- **Low cloud feedback** remains large *uncertainty* in climate models (IPCC-2007).
- **Atmospheric boundary layer** (**ABL**) processes control low clouds evolution.
- Global observation of ABL thermodynamic structures is **absent**.
- **Transition** from **stratocumulus to trade cumuli** remains big challenges in weather and climate models.
- **GPS Radio Occultation** (**RO**) soundings could fill the gap by providing high vertical resolution ABL *structure* globally in all weather conditions.



Bottom photographs courtesy of Dr. Bjorn Stevens

GPS Radio Occultation (RO) Technique

GPS radio occultation senses the atmospheric using GPS radio signals that traverse the atmosphere as a moving receiver sets or rises behind the horizon relative to the GPS satellite. The time delay of the GPS signals due to the refraction (bend) of the signal in the atmosphere is precisely recorded, which can be used to infer the bending angle and refractive index of the atmosphere.



$$N = a_1\frac{P}{T} + a_2\frac{P_W}{T^2} = 10^6(n-1)$$

1. Snell's law in spherically symmetric atmosphere:

$$\alpha(a) = -2a\int_a^\infty \frac{1}{n}\frac{dn}{dx}\frac{dx}{\sqrt{x^2-a^2}}$$

2. Abel Inversion (*Fjeldbo et al.*, 1971)

$$n(r) = EXP\left[\frac{1}{\pi}\int_a^\infty \frac{\alpha(x)dx}{\sqrt{x^2-a^2}}\right]$$

Data Used for ABL Studies

- Six-satellite **COSMIC** (Constellation Observing System for Meteorology, Ionosphere and Climate) **RO** data (2007-2009-SON, ~2000 daily soundings).
- **VOCALS-Rex** (VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment) ship-borne radiosonde soundings (213 profiles, 10-m vertical sampling) over Southeast Pacific Ocean from Oct. 20 to Dec. 1, 2008.
- Analyses Data (2007-2009-September, October and November):
  - **ECMWF-YOTC** (Year of Tropical Convection) analysis (0.25 deg, 91 levels)
  - **NCEP-FNL** (final) analysis (1deg * 1deg, 26 pressure levels)
  - **GMAO-GEOS-5** (2/3 deg * 1/2 deg, 72 pressure levels).

Stratocumulus-topped Boundary Layer

ABL Height Definition: Height of Maximum Refractivity Gradient

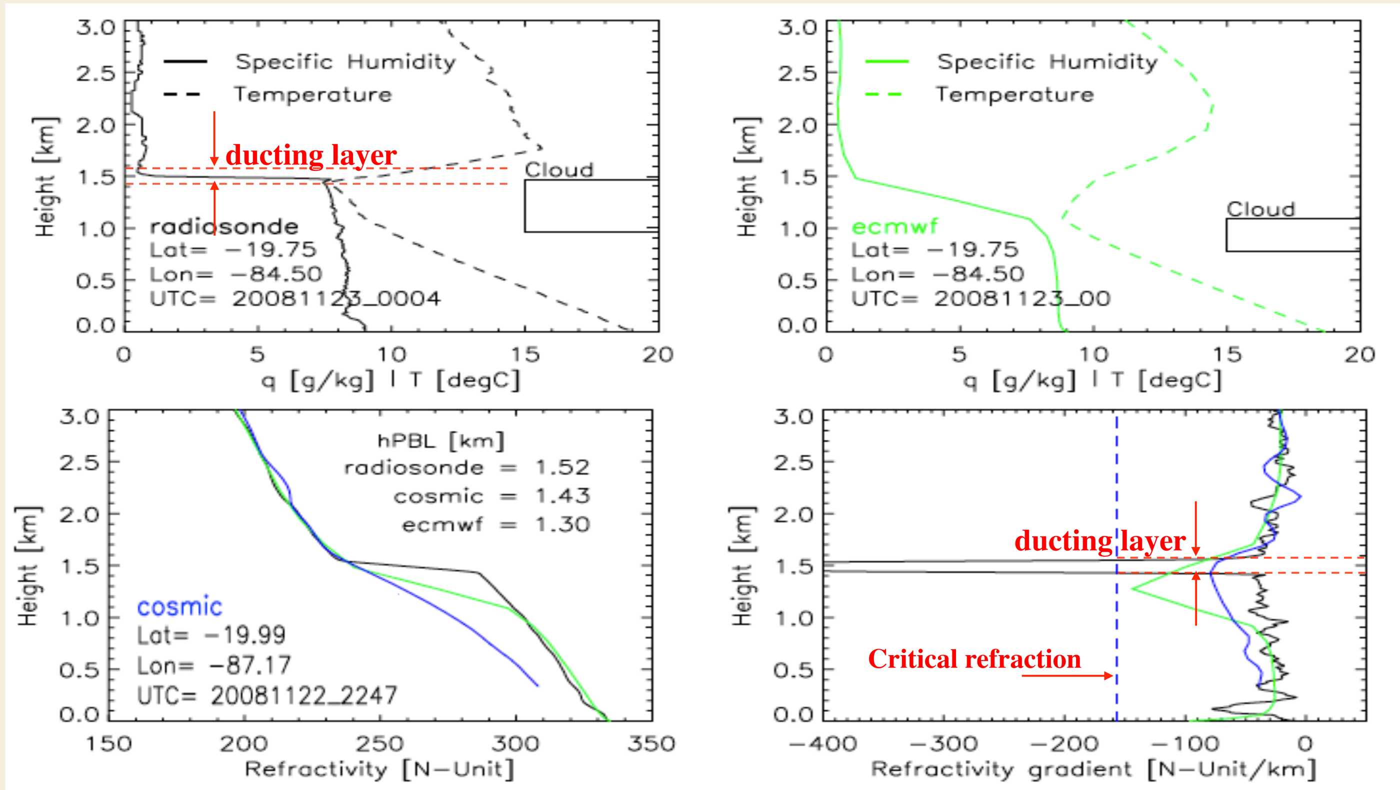


Fig. 1 Close coincident **radiosonde** (Black) from VOCALS campaign with the **ECMWF-YOTC** analysis (Green) and **COSMIC RO** profile (Blue). A ducting layer across the ABL top is shown with refractivity gradient exceeds critical refraction (-157 N-unit/km).

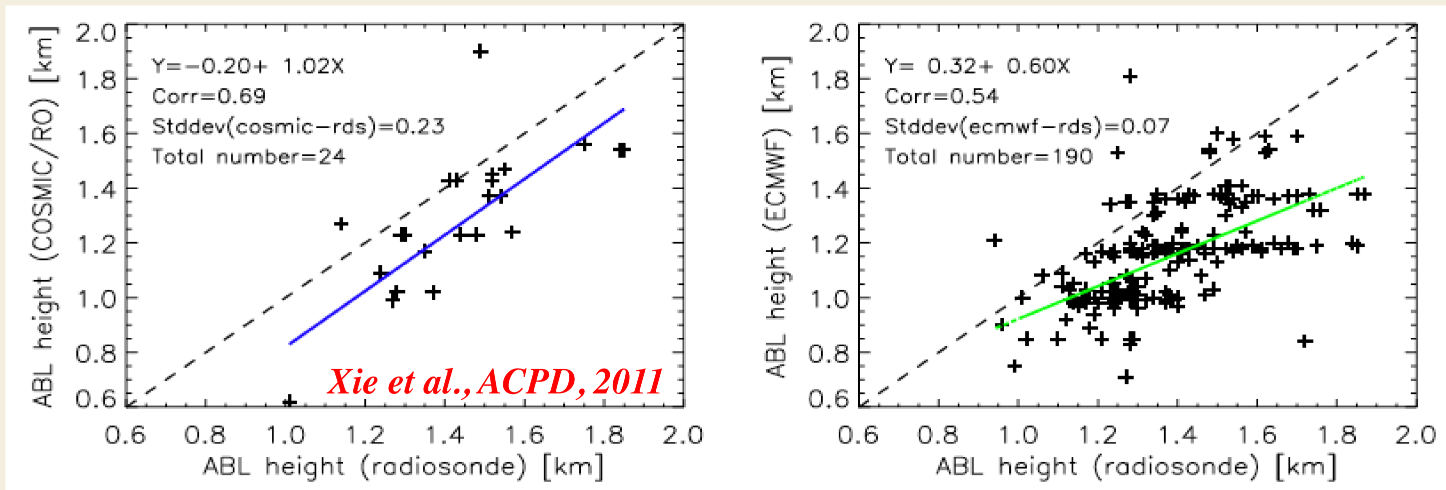


Fig. 2 (Left) scatter-plot of **ABL height** of radiosonde (100-m smoothed) and the near-coincident COSMIC RO soundings (plus) with the linear fit (blue-solid); (Right) scatter-plot of ABL height for collocated radiosonde and ECMWF-YOTC analysis (plus) with the linear fit (green-solid).

ABL Height Climatology over SE Pacific

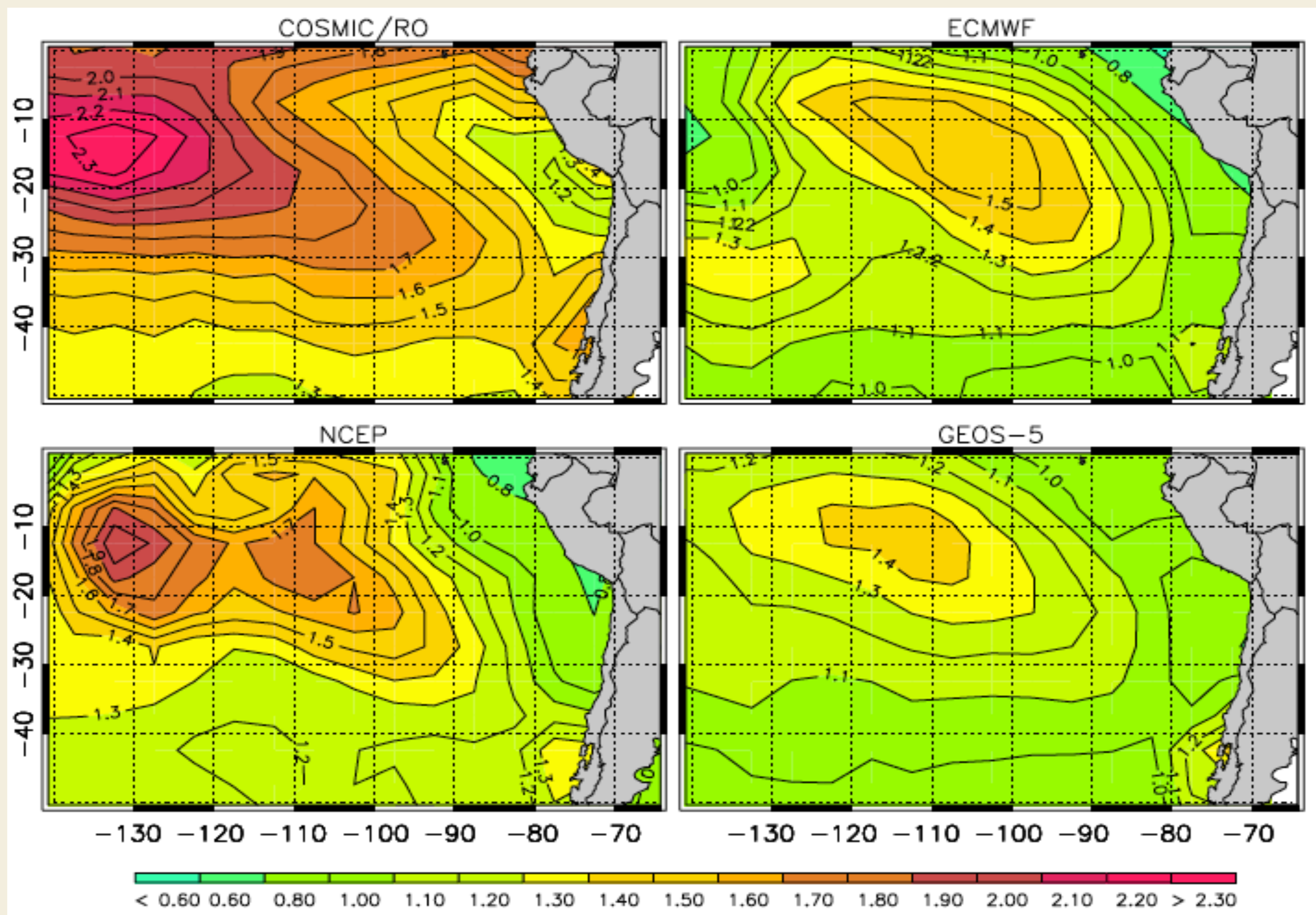


Fig. 3 COSMIC-RO ABL height climatology (2007-2009-SON) compared with three global analyses: ECMWF-YOTC, NCEP FNL and GMAO-GEOS-5 (sampled at RO sounding locations).

Maximum Gradient at the ABL Top & the *N*-bias

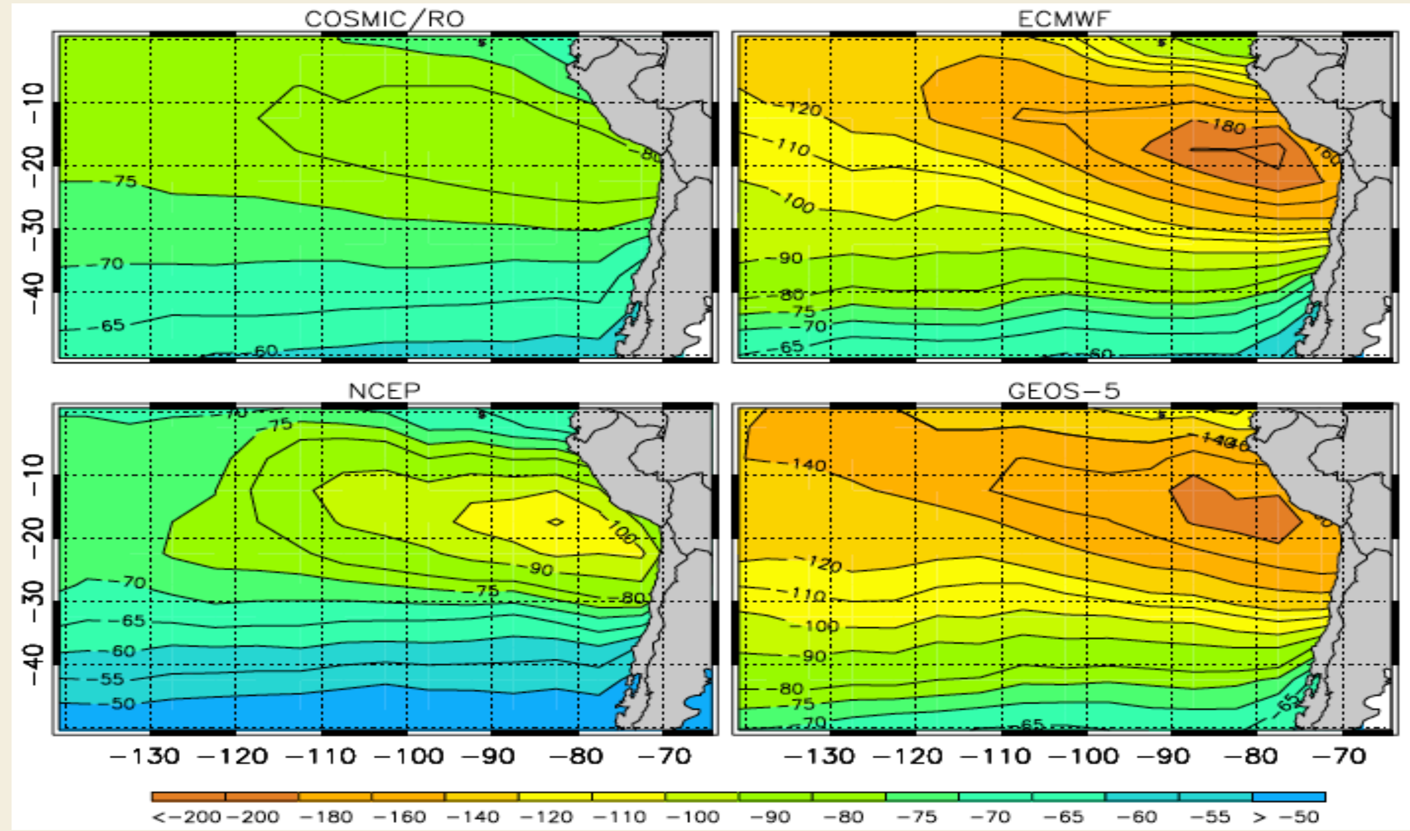


Fig. 4 Maximum refractivity gradient at the top of the ABL for COSMIC RO and analyses

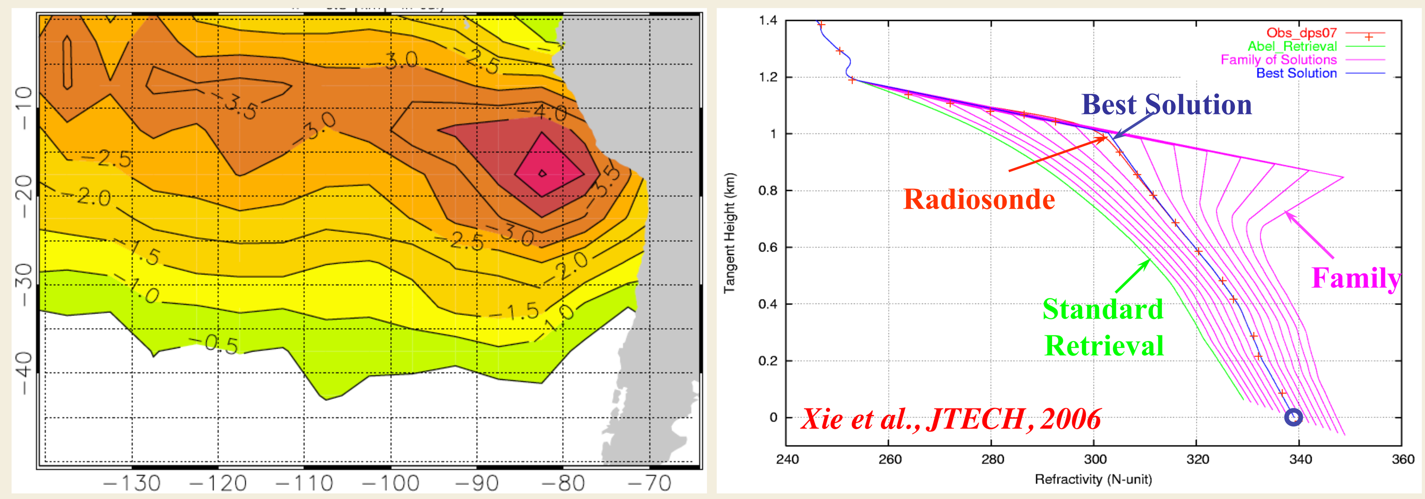


Fig. 5 (Left) Monthly mean refractivity difference (*N*-biases) between COSMIC RO and ECMWF YOTC analysis, i.e., *N*-bias = $(N_{RO}-N_{ECMWF})/N_{ECMWF}\times100$ [%] at 0.8 km altitude during July of 2007 and 2008. (Right) Simulation demonstrates the *N*-bias in standard RO retrieval (green) due to ducting and a family of solutions derived from reconstruction method.

Conclusions

- GPS RO signals are very sensitive to the sharp moisture gradient across the ABL top.
- COSMIC RO detects ABL height variations, which compares favorably to radiosondes.
- ECMWF analysis systematically underestimate the heights of the ABL and the gradient across the ABL top comparing with VOCALS radiosondes over southeast Pacific.
- All three analyses (ECMWF, NCEP & GEOS-5) produce shallower ABL and different spatial patterns of ABL heights comparing to COSMIC RO observations over SE Pacific .
- Ducting (or super-refraction) at the ABL top is the primary reason for systematic refractivity biases (*N*-biases) and the smaller gradient at the ABL top in RO sounding measurements .
- ABL heights derived from GPS RO should not be affected by the systematical *N*-bias.
- The biased ABL structure derived from GPSRO can be corrected with the aid of external constraints and provide global measurements of ABL vertical structures.

Acknowledgements

This research was supported by NASA grant through JPL/JIFRESSE-UCLA and partially by NOAA-NESDIS (NA08NES4400015). COSMIC RO profiles are provided by JPL. NCEP analysis data are provided by NCAR Research Data Archive (RDA), YOTC ECMWF analysis data are provided by ECMWF. We also thank Drs. Rob Wood (Univ. of Washington) for providing VOCALS soundings, Evan Fishbein (JPL) for help with ECMWF analysis and JPL GPS operational team: B. Iijima, M. Pestanal, T. Meehan and L. E. Young for RO soundings.

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WCRP Open Science Conference (October 24, 2011)