Verisk | Atmospheric and Environmental Research

Quality Control in the Planetary Boundary Layer:

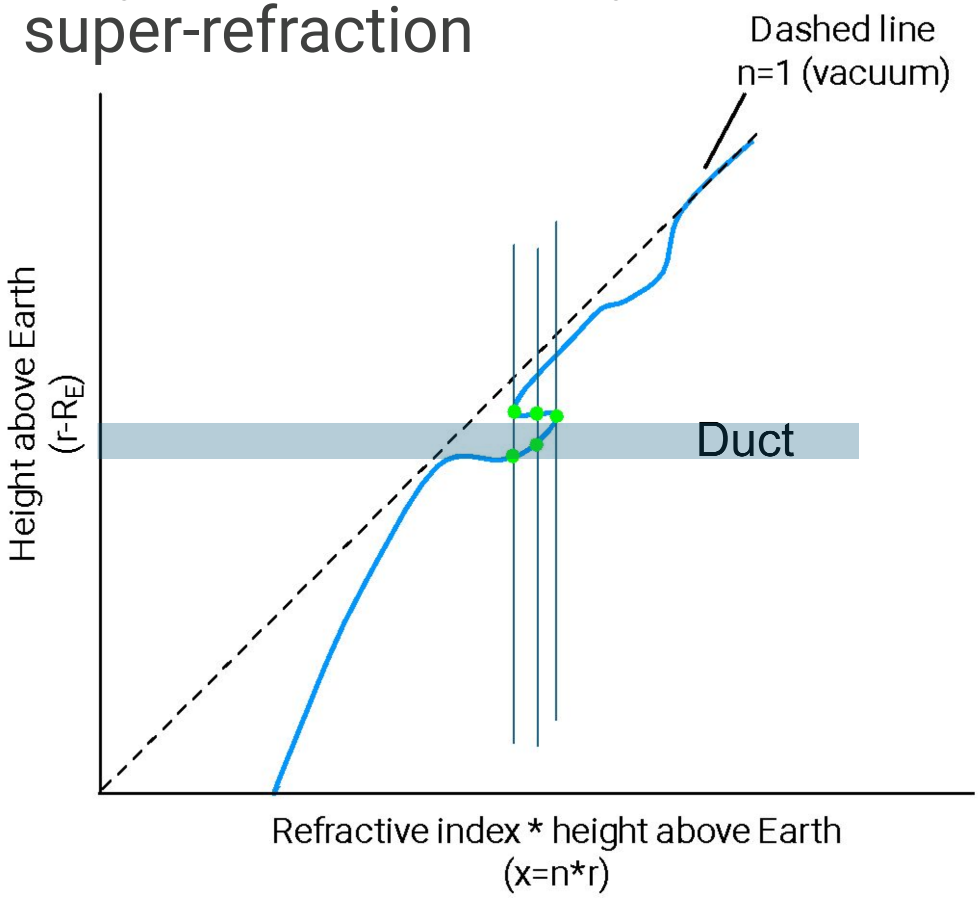
An Intercomparison of GNSS Radio Occultation Retrievals Processed by UCAR, JPL, and ROM SAF

Sara Vannah, Stephen Leroy, Chi Ao, Kuo-Nung Wang, Kevin Nelson, Feiqin Xie, Rob Kursinski, Stig Syndergaard, Igor Polonsky

IROWG-10 Sept. 16, 2024

Bias & error in the Planetary boundary layer (PBL)

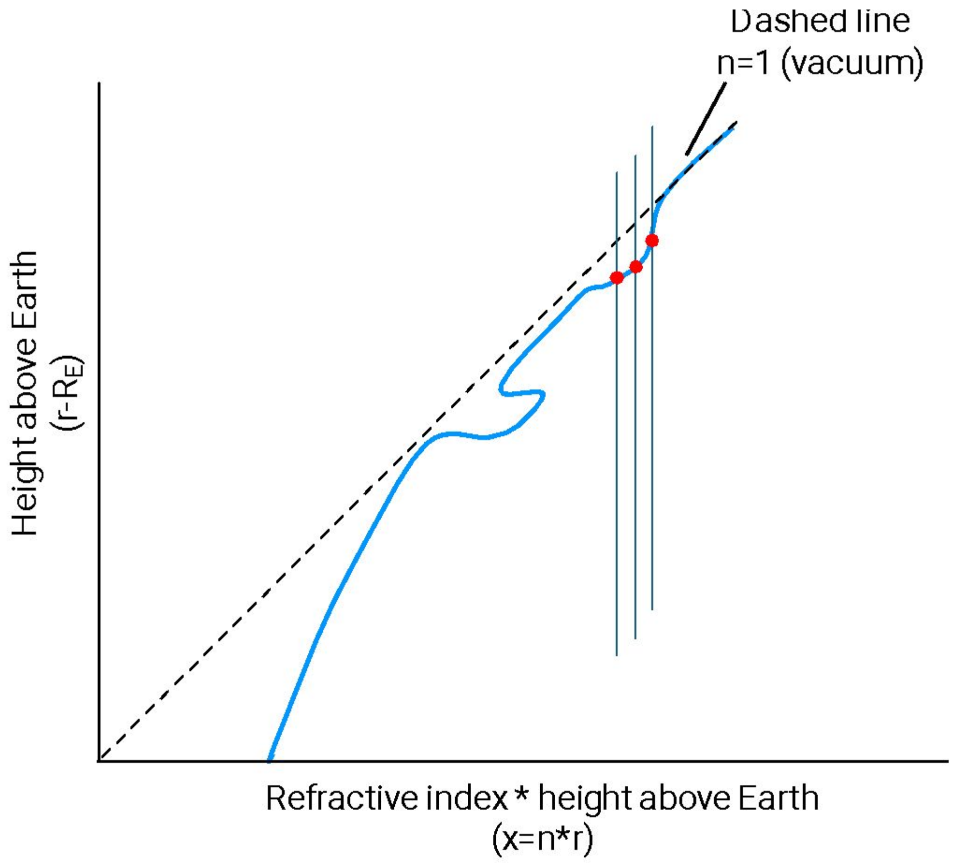
- Moist air in PBL, Tropics creates sharp refractivity gradient
- Very sharp refractivity gradient creates super-refraction



Abel integral over dx will miss values in the duct

Bias & error in the Planetary boundary layer (PBL)

- Moist air in PBL, Tropics creates sharp refractivity gradient
- Very sharp refractivity gradient creates super-refraction
- (Less) sharp gradient creates multipath



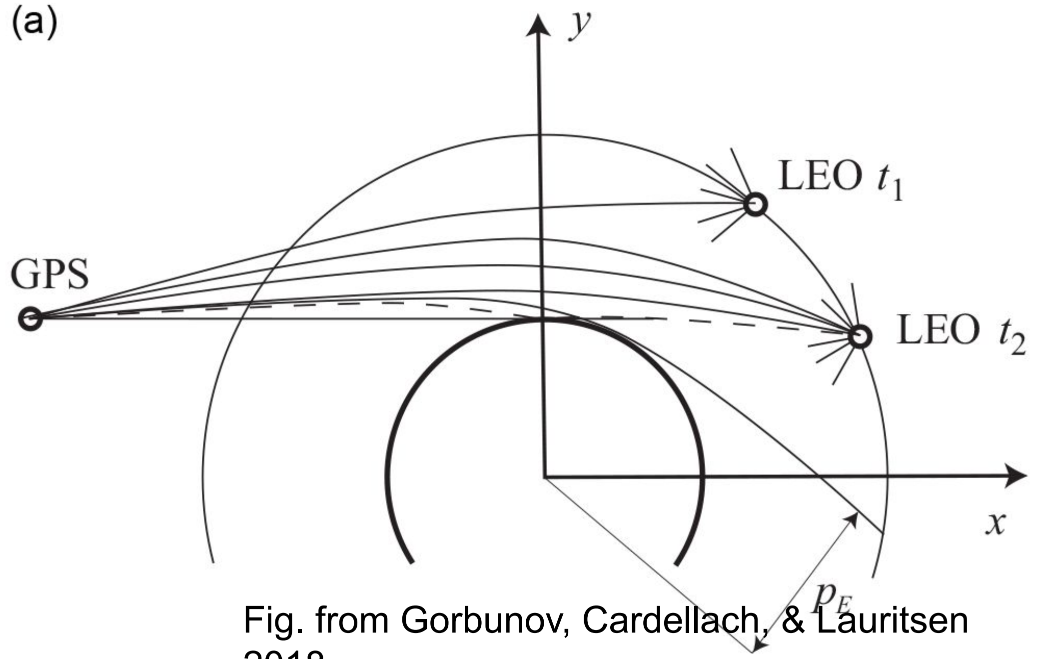


Fig. from Gorbunov, Cardellach, & Lauritsen 2018

Bias & error in the Planetary boundary layer (PBL)

Verisk | Atmospheric and Environmental Research

- Moist air in PBL, Tropics creates sharp refractivity gradient
- Sharp refractivity gradient creates super-refraction
- Less strong refractivity gradient creates multipath
- Truncation, SNR, radio-holographic filter width
- Quality control, sampling bias

- Follow up to upper troposphere, lower stratosphere (UTLS) studies:
  - Ho, Hunt, Steiner, et al., 2012
  - Ho, Kirchengast, Leroy, et al. 2009
  - Steiner, Hunt, Ho, et al. 2013

Approach

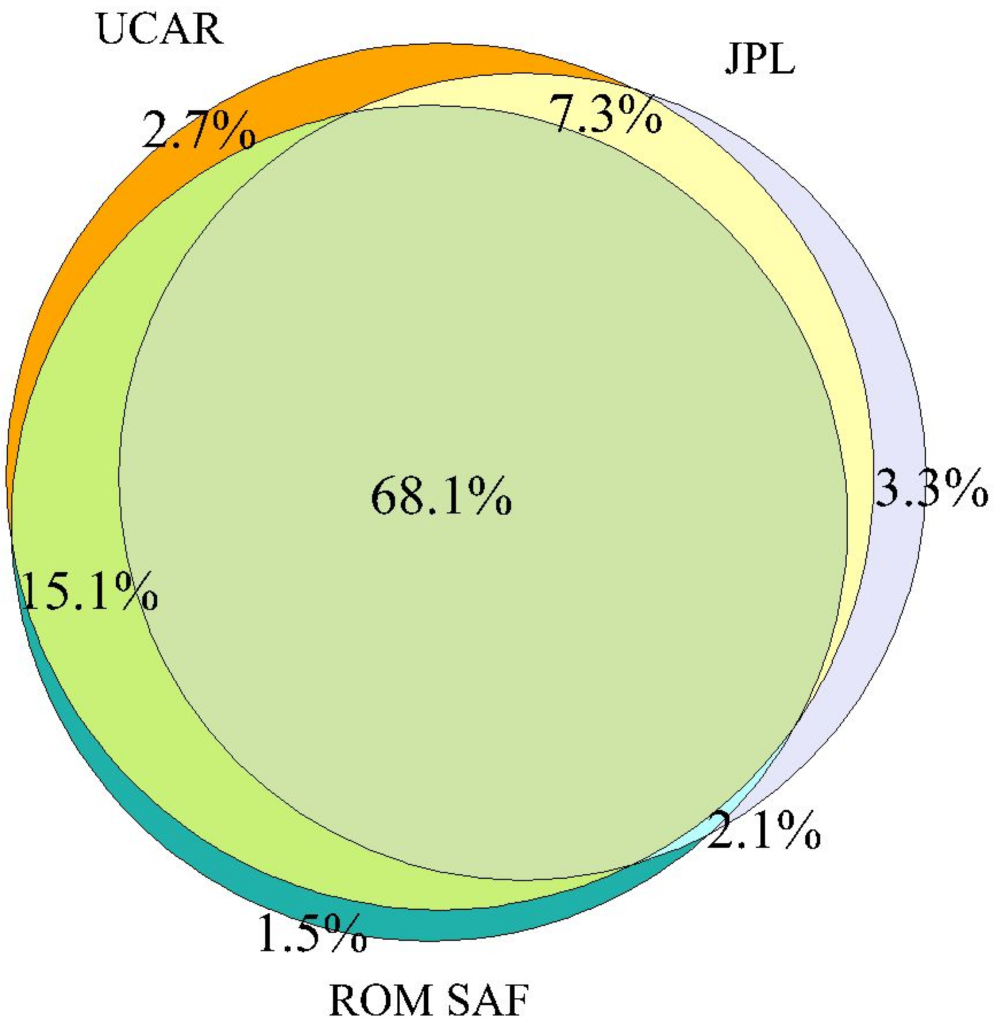
- Use GNSS radio occultation (RO) data AWS Registry of Open Data
- Assess COSMIC-1 in 2008
  - High-performance
  - Processed by all three centers: provides common dataset
    - ROMSAF: CDR COSMIC-1
    - UCAR: repro2021
    - JPL: version 2.6
  - Sufficient time for robust analysis
  - High yield early in mission

1. Motivation & Approach
2. Results
    1. Quality control
    2. Penetration depth
    3. Inter-center refractivity bias
    4. Truncation sampling bias
    5. ERA5-RO refractivity bias
3. Conclusions

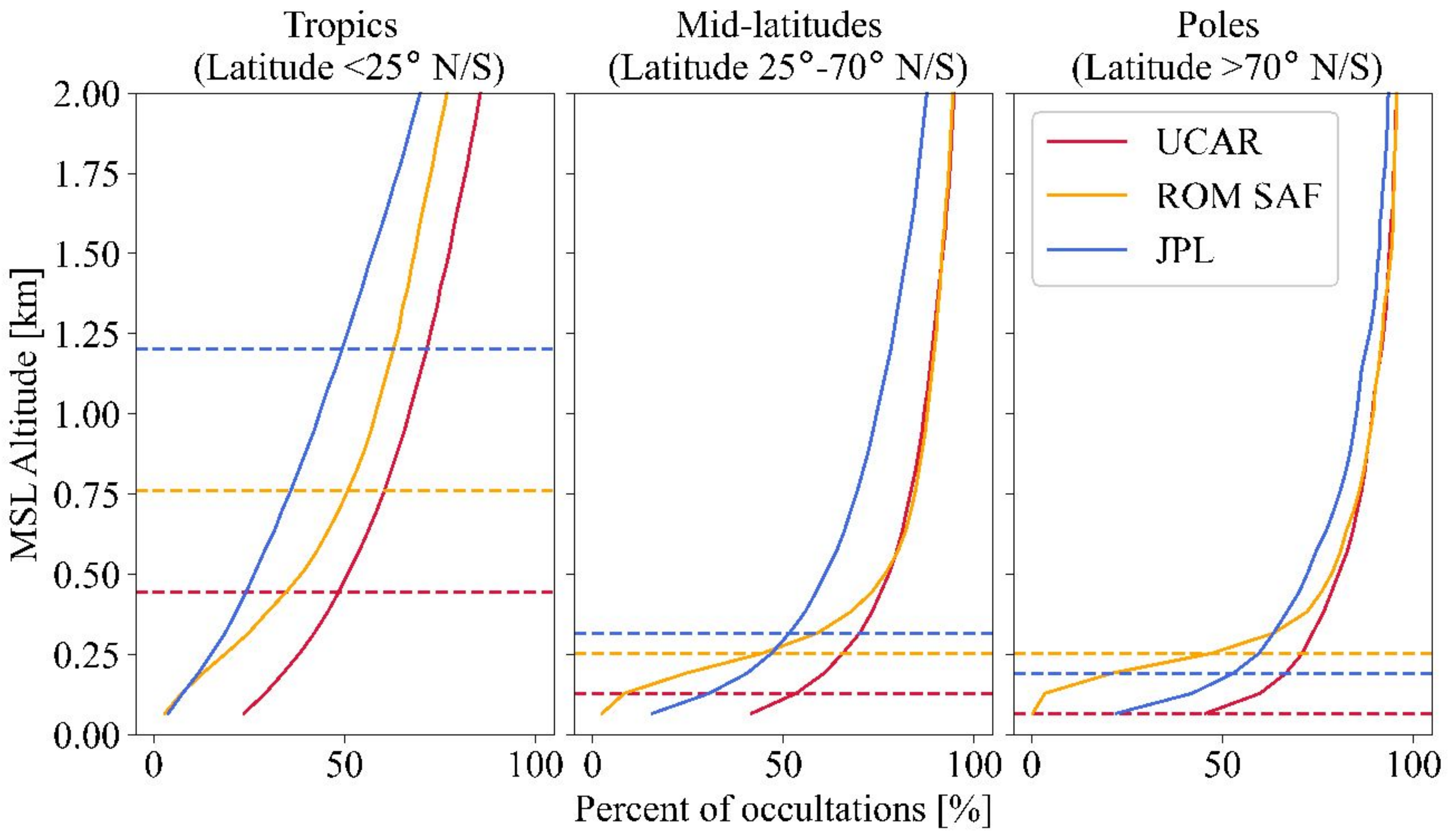
Quality control

- 2/3rds of data processed by all 3 centers
- Large UCAR-ROM SAF overlap
- UCAR processes the most (93.2%), followed by ROM SAF (86.8%), followed by JPL (80.8)%

Number of COSMIC-1 refractivity retrievals by each center in 2008



Penetration depth



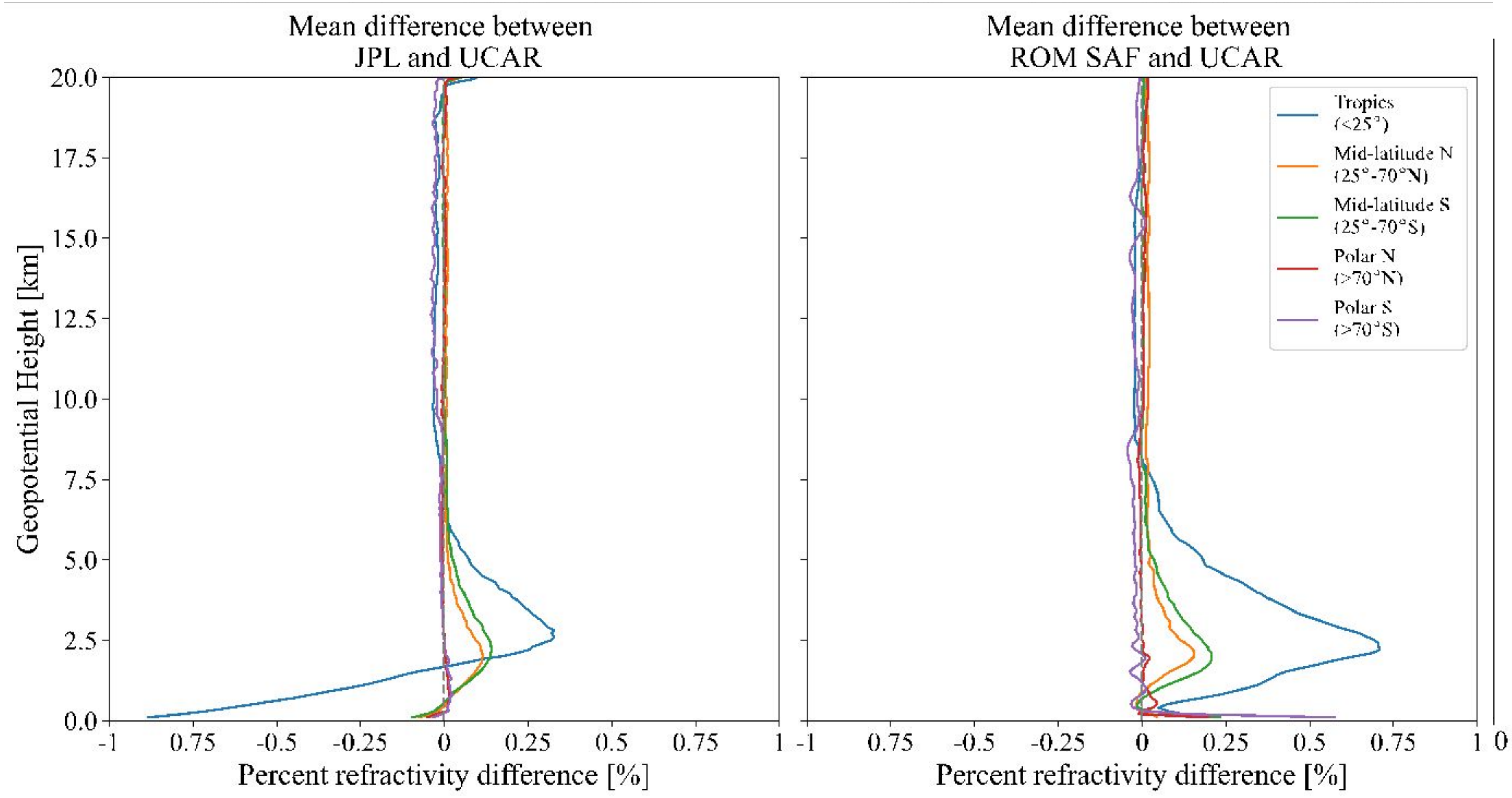
Dashed lines indicate altitude that 50% of occultations penetrate

- Ocean-only
- JPL has most conservative truncation criteria
- Sensitive to PBL moisture in the Tropics
  - ROM SAF truncates earlier than UCAR

Inter-center refractivity bias

- Outlier refractivity biases up to 10-15%
- Mean biases ~0.1-1%
- Refractivity differences sharply increase in PBL, especially in Tropics
- Key areas of interest at ~2.6km and ~0.8km

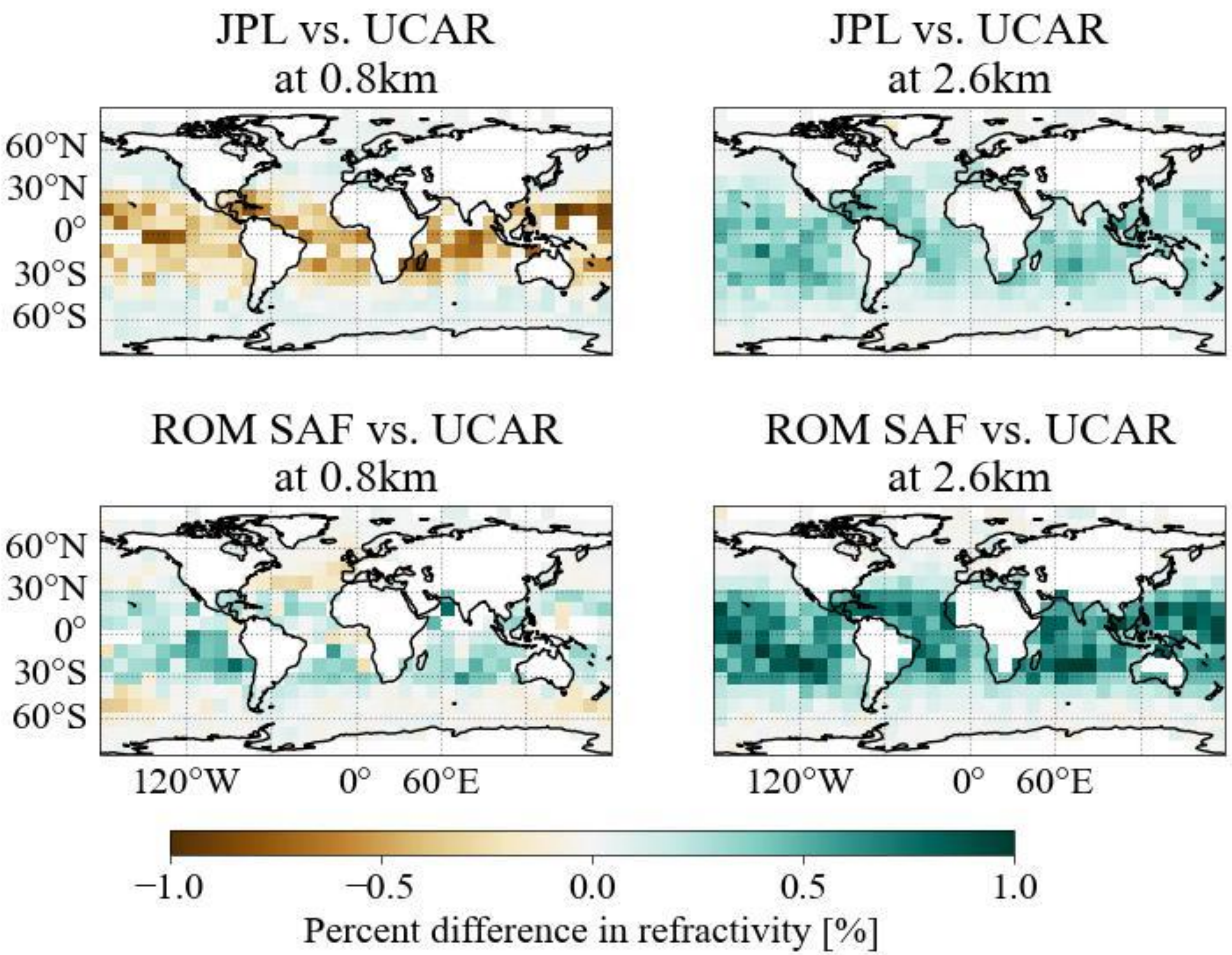
DJF 2008



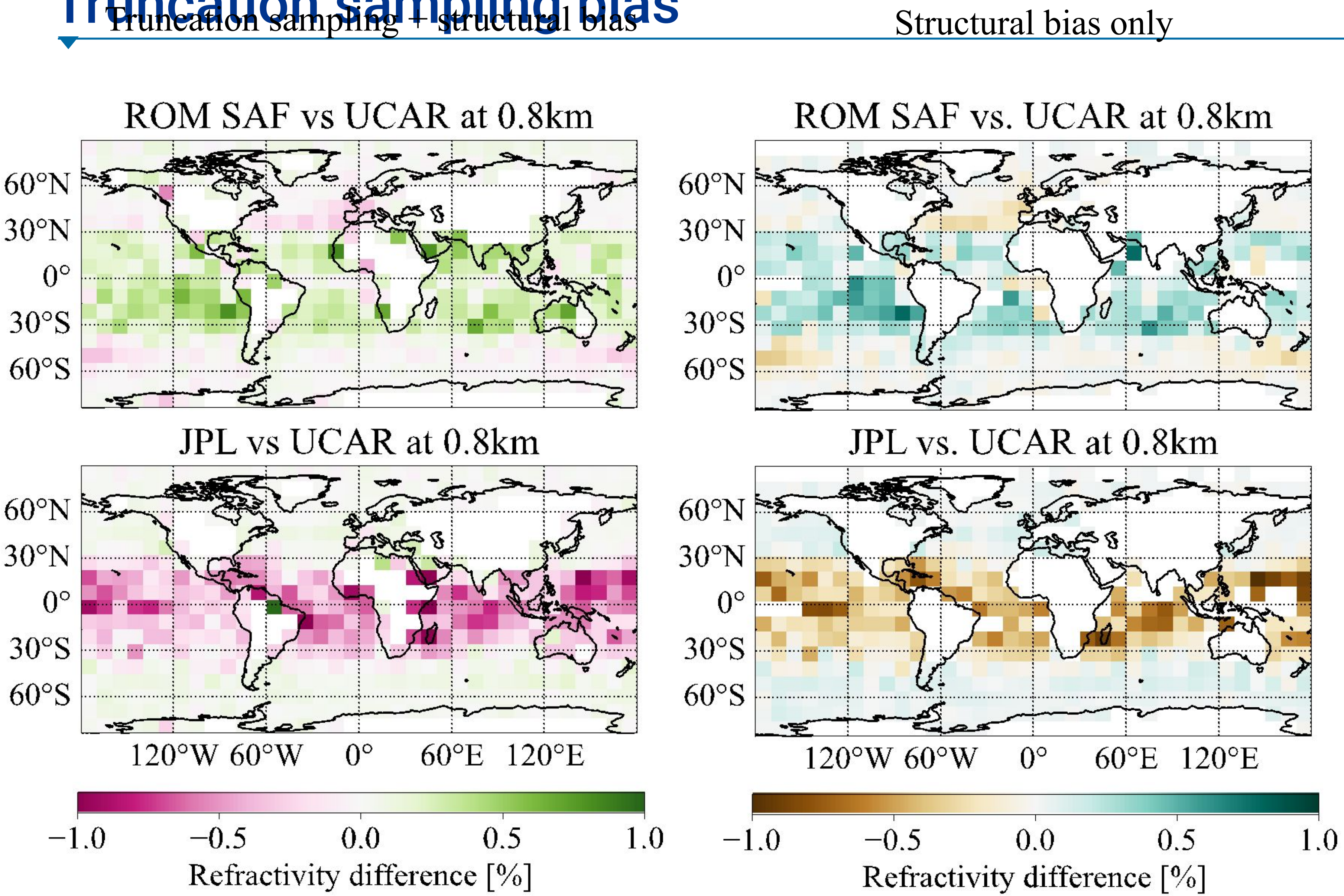
Inter-center refractivity bias

- UCAR refractivity between ROM SAF and JPL at 0.8km, with signs changing outside Tropics
  - Conservative truncation causes negative bias in Tropics
  - Sign flips outside Tropics
- ROM SAF and JPL globally higher refractivity than UCAR at 2.6km
  - Sokolovskiy et al. 2010: SNR is primary driver of uncertainty at 2.6km, noise causes positive bias – UCAR high smoothing?
- Future: Modify ROPP to test parameters

DJF 2008



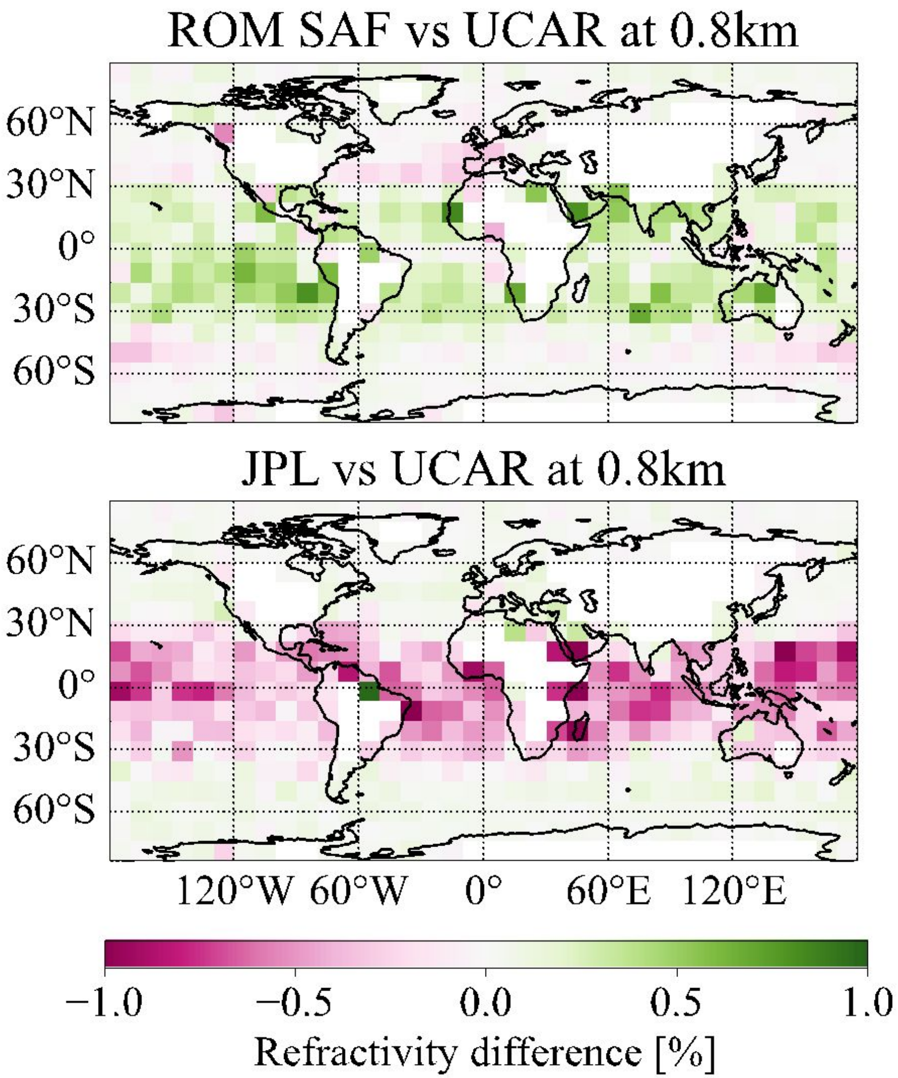
Truncation sampling bias

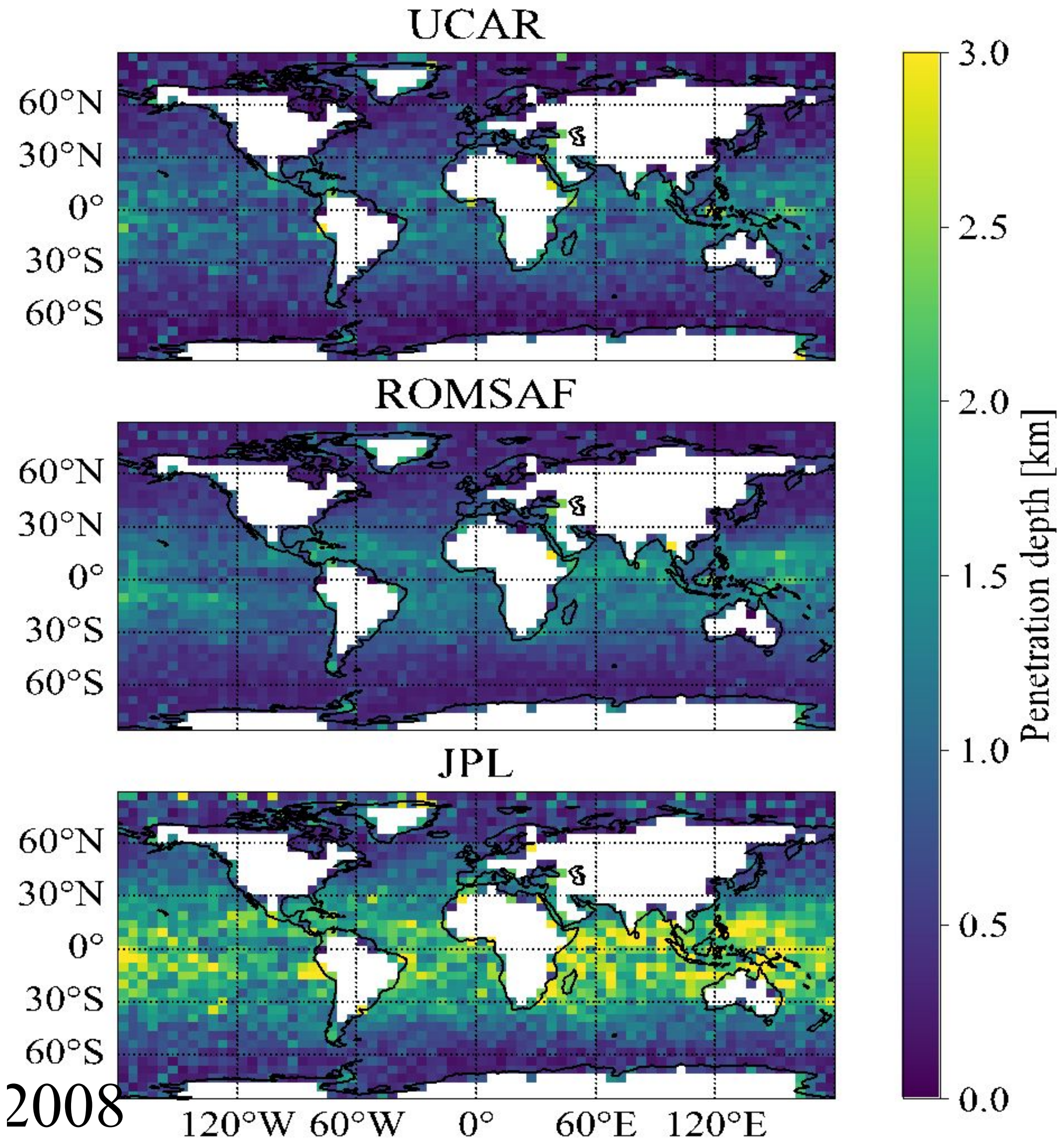


- Sampling bias: RO coverage, quality control by each center
- Truncation sampling bias: subset by occultations processed by all centers, but differing penetration depths result in sampling bias low in atmosphere
- Structural bias: bias in profile

Truncation sampling bias

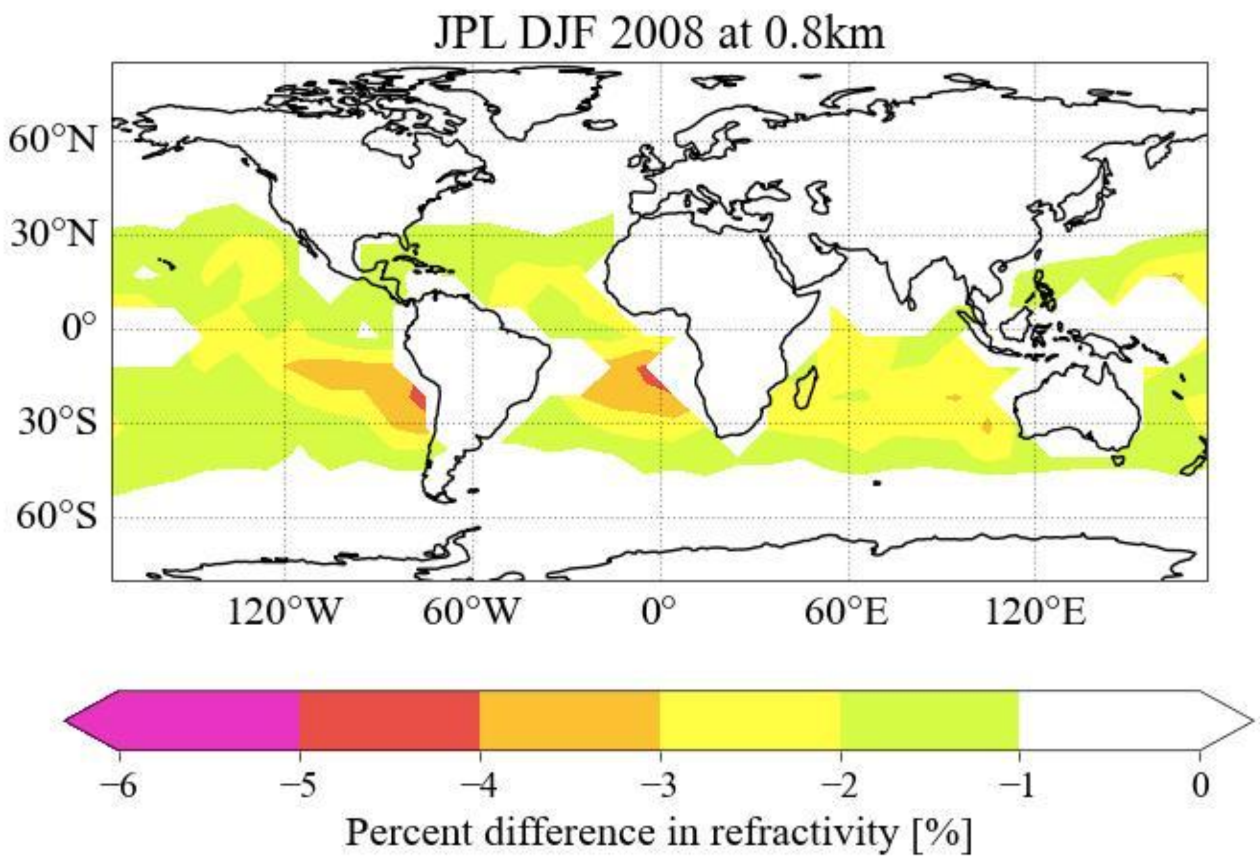
Truncation sampling + structural bias





- Example: mid-Pacific positive truncation sampling bias

ERA5-RO refractivity bias: Validate with Xie et al. 2010



JPL January 2008 at 0.8km

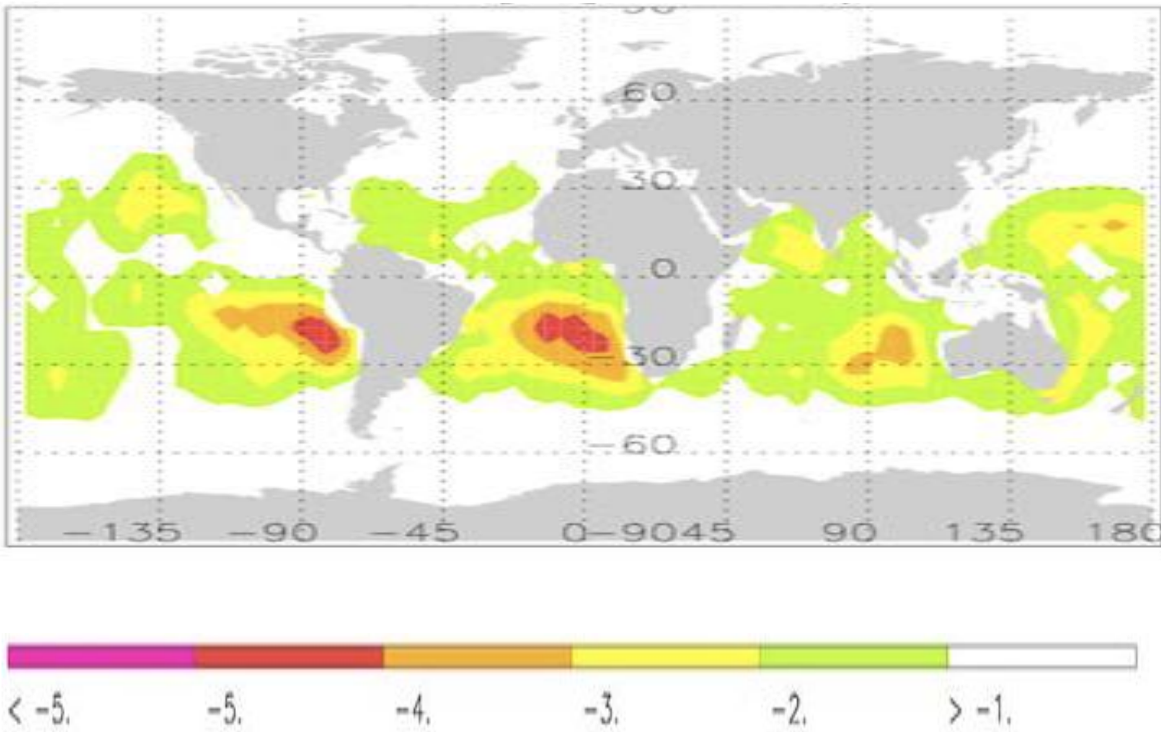
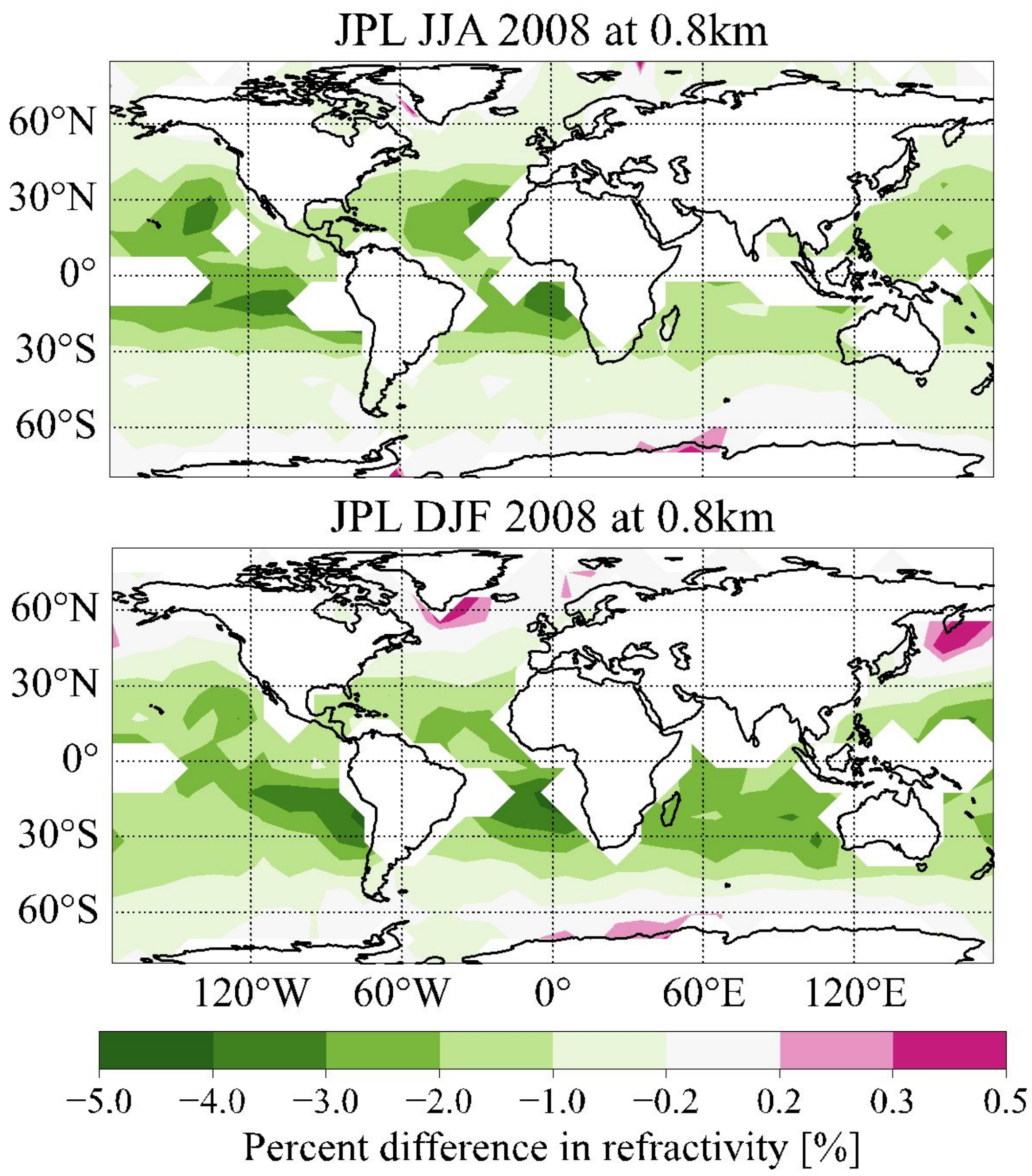


Fig. from Xie et al. 2010

- ERA5 vs. ERA interim give similar results

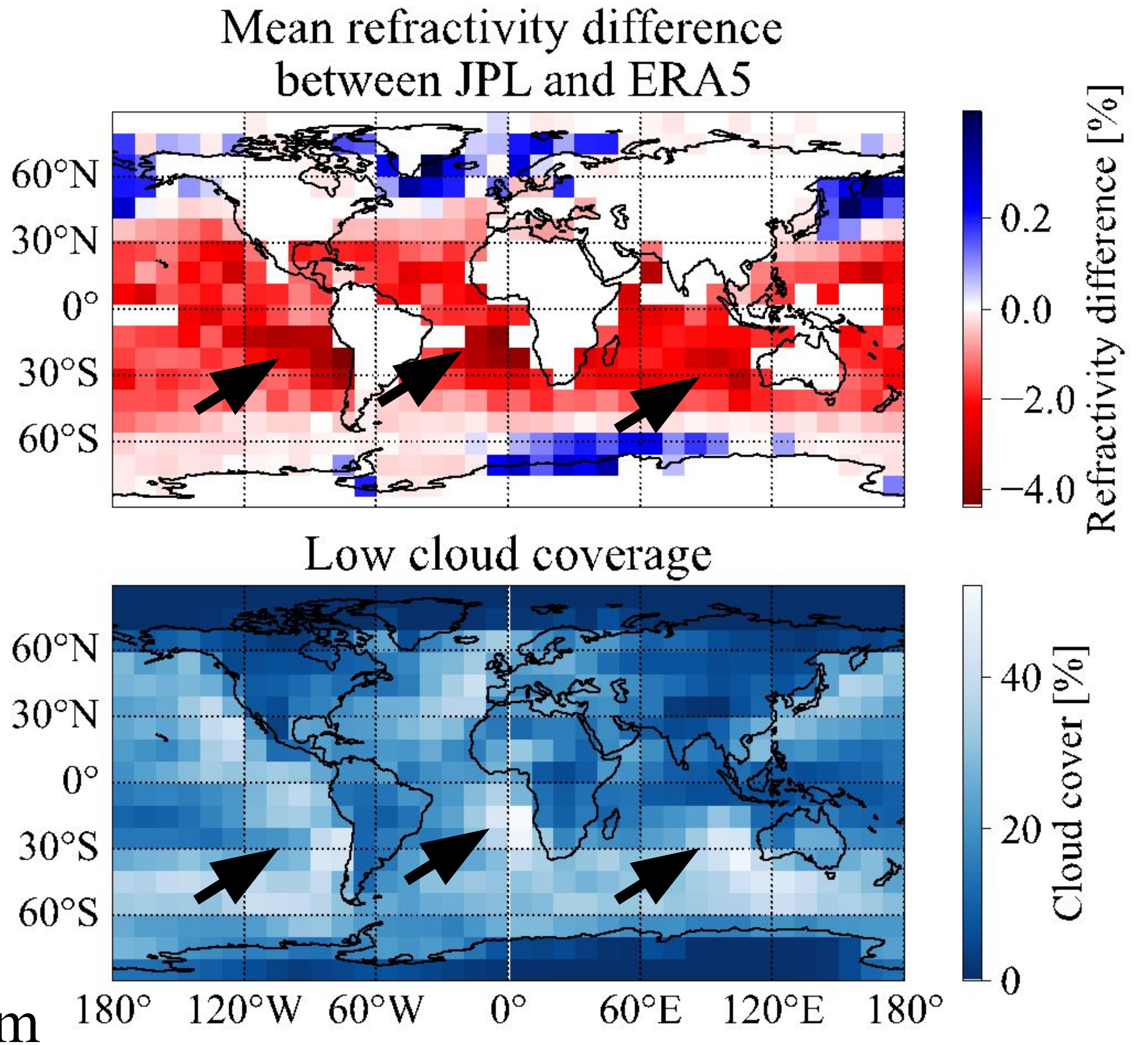
ERA5-RO refractivity bias

- Expanding allowed levels shows positive bias at high latitudes
  - Winter hemisphere
  - Model physics?
- Future: vertical profile of positive bias regions



Refractivity bias – clouds?

- High bias regions roughly track cloud coverage in eastern ocean stratocumulus regions
  - Southwest Peru
  - Southwest Africa
  - Western Australia



DJF 2008 at 0.8km

Cloud data from ISCCP

1. Motivation & Approach
2. Results
    1. Quality control
    2. Penetration depth
    3. Inter-center refractivity bias
    4. Truncation sampling bias
    5. ERA5-RO refractivity bias
3. Conclusions

Conclusions

Verisk | Atmospheric and Environmental Research

- About 2/3 of COSMIC-1 occultations processed by all 3 centers, UCAR processes most
- Truncation sampling bias:
  - Penetration depths weaker in Tropics (likely due to super-refraction)
  - JPL has most conservative penetration depth at all latitudes
- Structural bias:
  - UCAR truncation between ROM SAF and JPL, creates inter-center bias at 0.8km
  - ROM SAF and JPL higher refractivity at 2.6km – smoothing/radio-holographic filter?
  - Negative refractivity biases strongest in Tropics, winter hemisphere
  - Positive bias regions at 0.8km in Antarctica, Greenland, eastern Russia
  - Negative bias regions correlate with low cloud coverage

Thanks to:
NASA Decadal Survey Incubator, grant 80NSSC22K1103

Refractivity bias

Blue = truncate shallow in atmosphere
Red = truncate deep in atmosphere
Dashed = additional background noise added

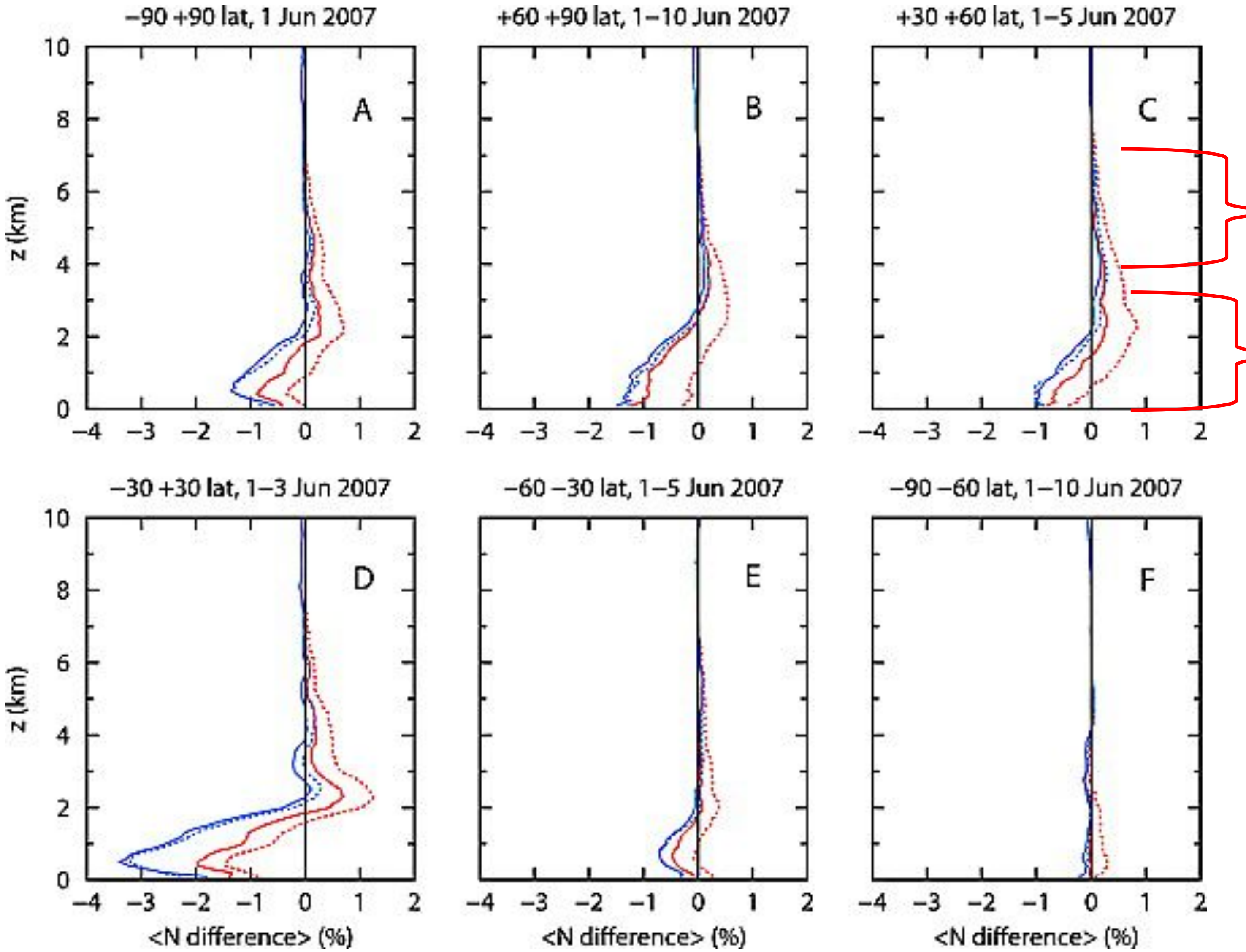


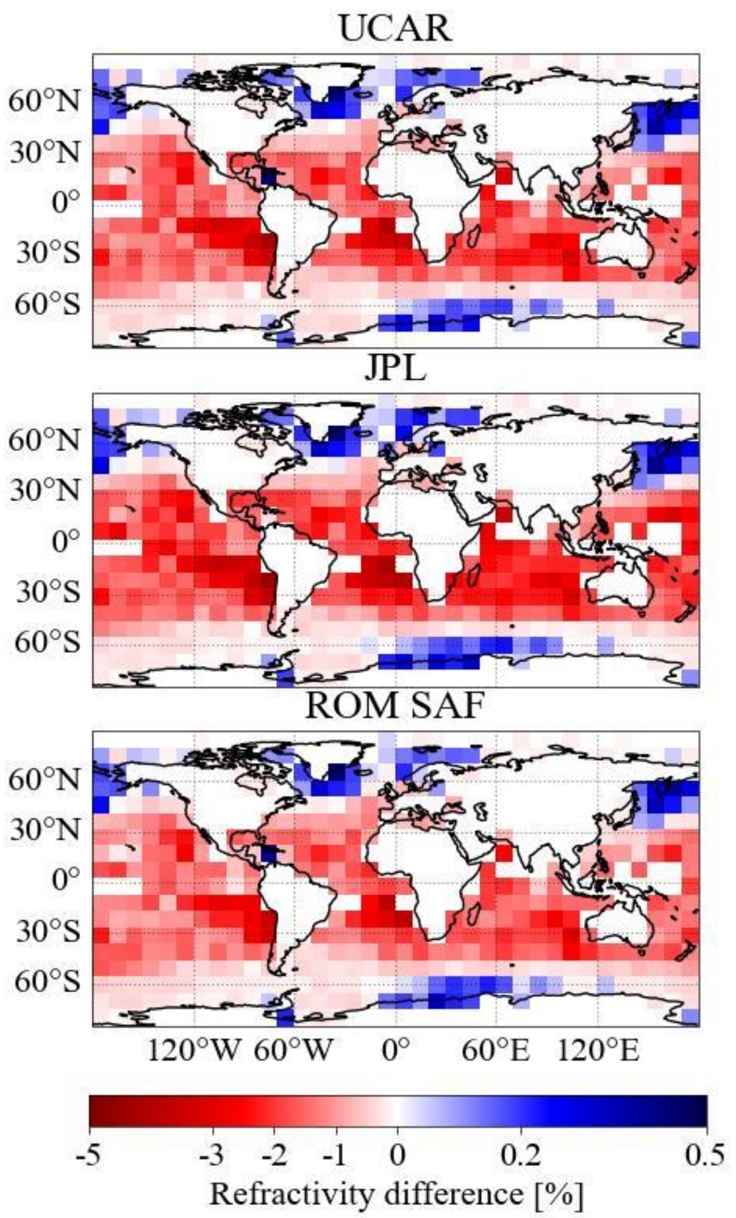
Fig. from Sokolovskiy et al. 2010

SNR is primary driver of uncertainty higher in atmosphere, positive bias

Truncation has large impact lower in atmosphere, negative bias for conservative truncation

ERA5-RO refractivity bias

- Locations of negative bias regions consistent between centers
- Strength of negative bias largest in JPL, especially southeast Africa



DJF 2008
at 0.8km

Why the Planetary Boundary Layer (PBL)?

- Follow up to upper troposphere, lower stratosphere (UTLS) studies (Ho, Kirchengast, Leroy, et al. 2009; Ho, Hunt, Steiner, et al., 2012; Steiner, Hunt, Ho, et al. 2013)
- Refractivity bias:
  - Downwelling at edges of Hadley cell prevent mixing
  - Super-refraction in PBL→ earlier truncation
- Xie et al. 2010 found spots of strong negative bias at edges of sub-Tropics

Red = downwelling, Purple = upwelling

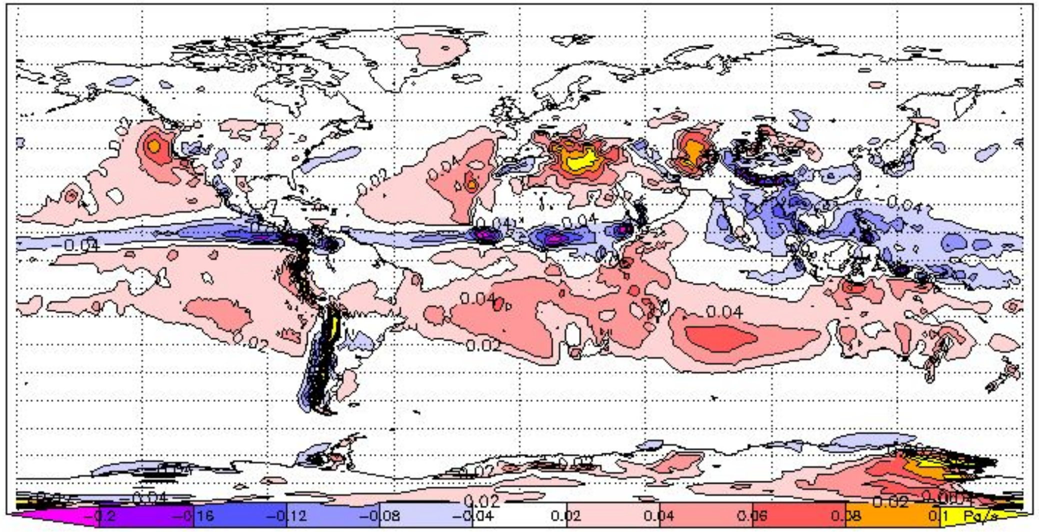


Fig. from ERA-40 reanalysis Connelly

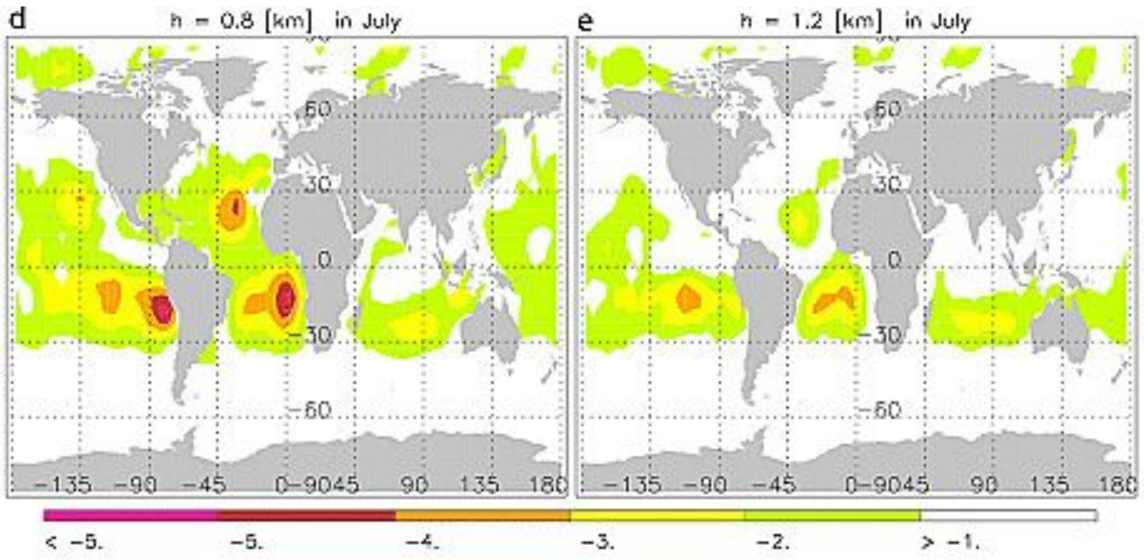
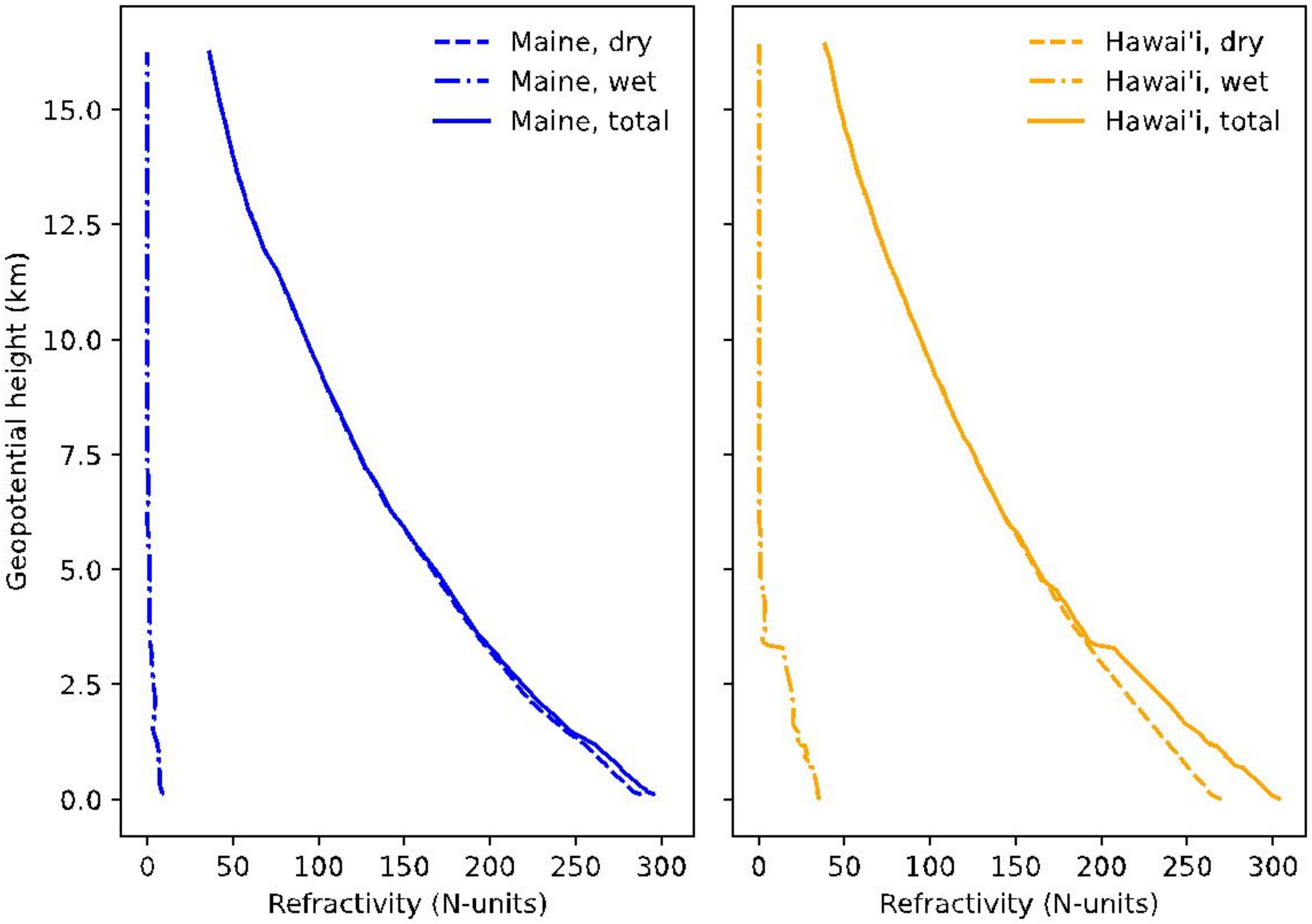


Fig. from Xie et al. 2010

Motivation: planetary boundary layer

- Wet refractivity contributes negligibly above ~3km
- Much higher wet refractivity in Tropics
- Uncertainty in wet refractivity very high low in atmosphere
  - Total refractivity uncertainty in PBL ~4%
  - Dry refractivity uncertainty in PBL ~0
  - Hawai'i wet refractivity uncertainty in PBL ~30%



Inter-center comparison: JJA

- Very similar to DJF