Mitigation of Systematic Ionospheric Error in GNSS RO Refractivity Retrievals

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Updates on CLARREO-related tasks

1. Trends and variability of the tropical width from RO, reanalysis, and climate models
   - Presented at AMS Annual Meeting 2017
   - Paper close to submission
2. Uncertainty analysis (per datum) continuing
   - Augmented to include multi-scale noise (not sufficient to consider high-freq noise only)
   - Similar approach from Schwarz et al. 2017
3. Awarded NASA ROSES NDOA grant to develop multi-mission, multi-center obs4MIPs monthly gridded RO refractivity dataset.

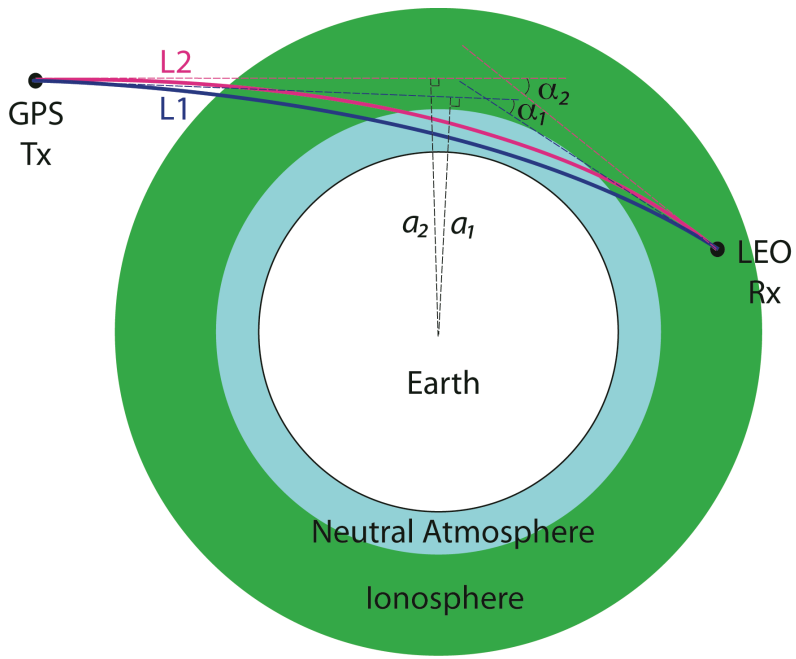
Residual ionosphere error

- Standard method
- New method proposed by Healy et al. (“kappa” method)
- Preliminary results
- Summary & discussion

Rule of thumb: $dT/T \sim - dN/N$

$dN/N = 0.1\%$ -> $dT \sim -0.2$ K in lower stratosphere

Standard method



Standard approach to remove ionospheric effect in RO is to form linear combinations of bending angles in impact parameter space (instead of phase delays in time) [Vorob'ev and Krasil'nikova, 1994 or VK94]

$$\alpha_c(a) = \alpha_{L1}(a) + \frac{f_2^2}{f_1^2 - f_2^2}(\alpha_{L1}(a) - \alpha_{L2}(a)),$$

$$N = N_{neut} + N_{ion}$$

$$N_{neut} = a\frac{P}{T} + b\frac{P_{wv}}{T^2}$$ Non-dispersive

$$N_{ion} = c\frac{n_e}{f^2} + \ldots$$ Dispersive

Residual error

Kursinski et al. 1997

Neutral bending at 60 km ~ 5 micro-rad

Iono bending at 60 km ~ 300 micro-rad

Table 2. Error Due to Incomplete Calibration of the Ionosphere

Solar and Diurnal Cycles	Fractional Bending Angle Error at 60 km	Fractional Refractivity Error at 55 km	Height (km) Where Fractional Refractivity Error = 0.001
Solar maximum, daytime	-0.065	-0.03	38
Solar maximum, nighttime	-0.004	-0.0017	51
Solar minimum, daytime	-0.0025	-0.0012	53
Solar minimum, nighttime	-0.0001	-0.00005	>> 60

Although the error is small below 25 km, it is significant for climate trend detection since the error is

- **Systematic**
- **Dependent on solar cycle**
- **Dependent on diurnal cycle**

Kappa method

Based on VK94, Healy and Culverwell (2015) shows that the residual iono error is

$$\Delta\alpha \simeq -a \frac{k_4^2}{(f_1 f_2)^2} \int_a^\infty \frac{(2r^2 - a^2)\frac{\mathrm{d}(n_\mathrm{e}^2)}{\mathrm{d}r}}{(r^2 - a^2)^{3/2}} \mathrm{d}r.$$

This is always negative!
Standard IC underestimates ionospheric bending

HC15 proposes the following modification to remove ionospheric effect:

$$\alpha_\mathrm{c}(a) = \alpha_\mathrm{L1}(a) + \frac{f_2^2}{f_1^2 - f_2^2}(\alpha_\mathrm{L1}(a) - \alpha_\mathrm{L2}(a)) + \kappa(a)(\alpha_\mathrm{L1}(a) - \alpha_\mathrm{L2}(a))^2,$$

The effectiveness of this method depends on the weak variability of kappa and how well we can estimate it.

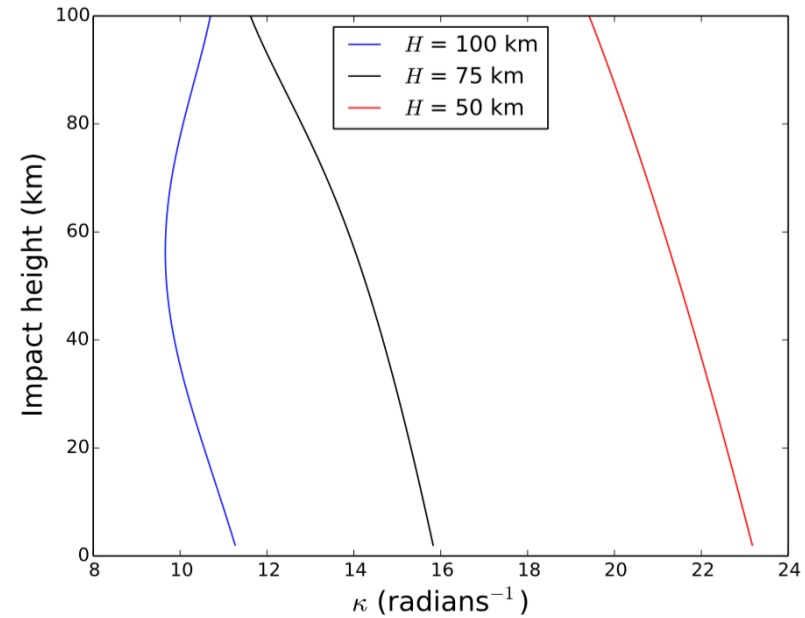
Chapman profiles

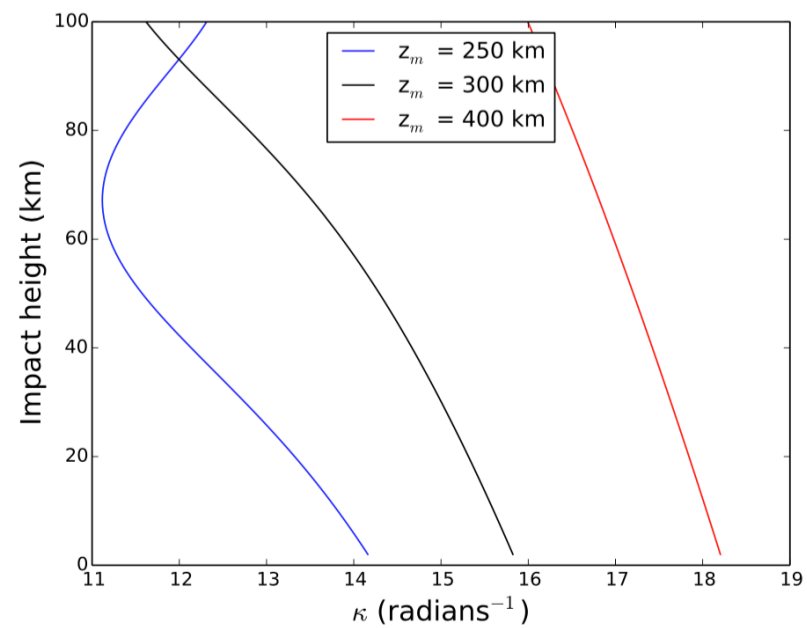
$$n_e(r) = n_e^{\max} \exp\left(\frac{1}{2}(1 - u - \exp(-u))\right)$$

$$u = \frac{r - r_m}{H}.$$

$$\Delta\alpha(a) \simeq -\left(\frac{f_1 f_2}{f_1^2 - f_2^2}\right)^2 \left(\frac{1}{2\pi H}\right) \left(\frac{\sqrt{r_m^2 - a^2}\,(2r_m^2 + a^2)}{4 a r_m}\right) \times (\alpha_{L2} - \alpha_{L1})^2$$

kappa

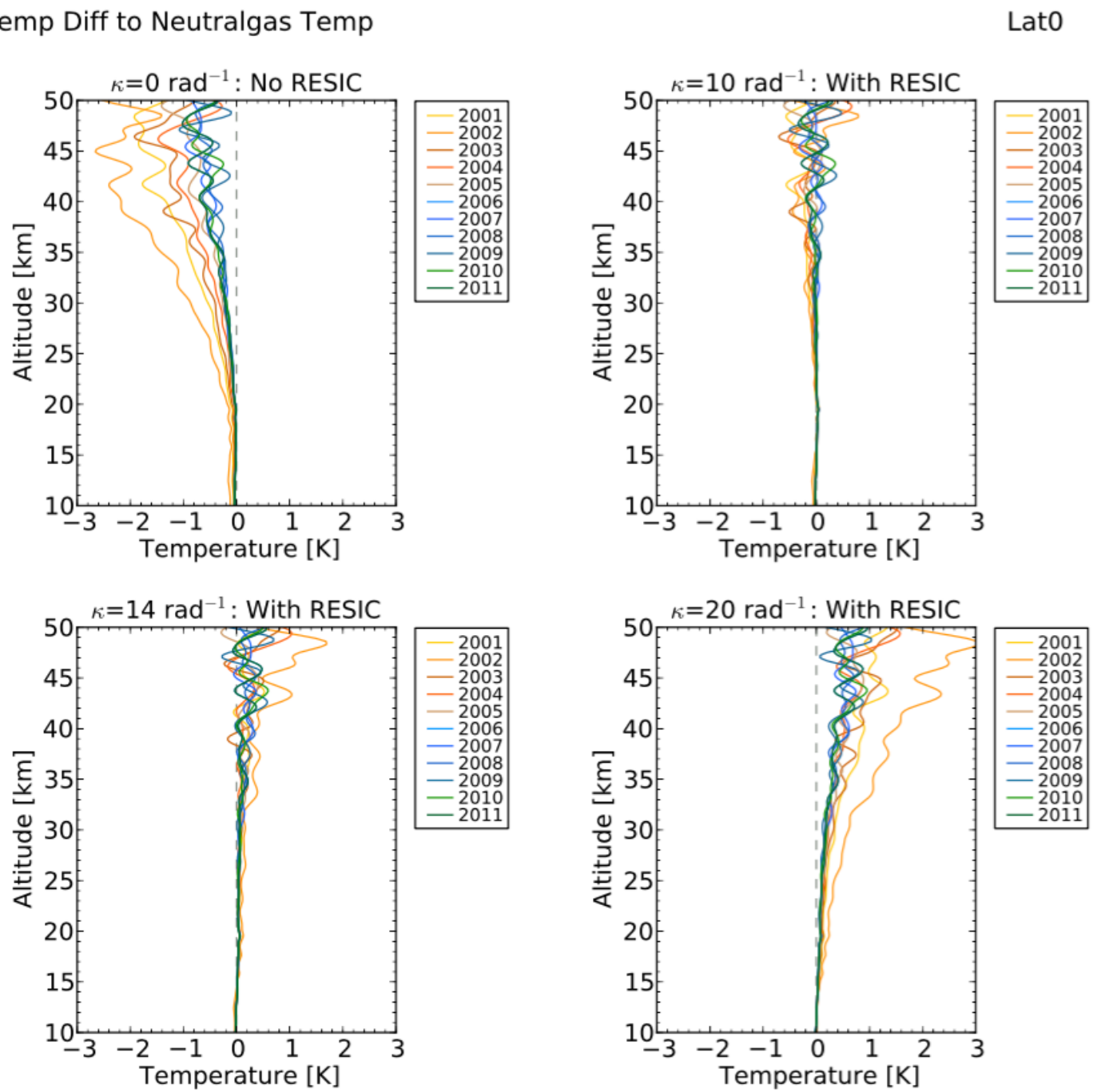




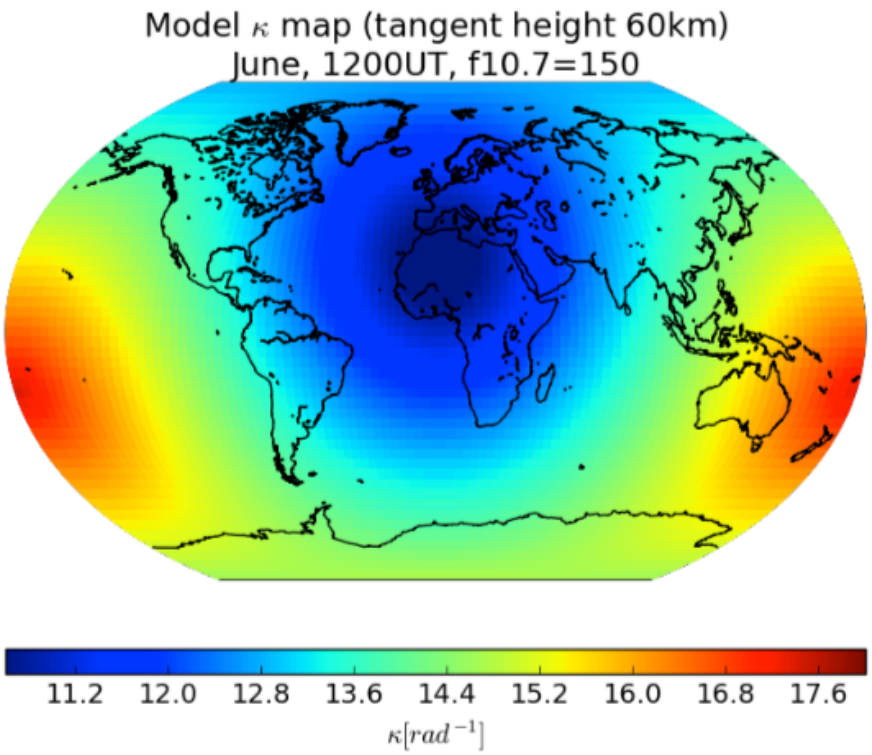
Simulation study (3D iono model)

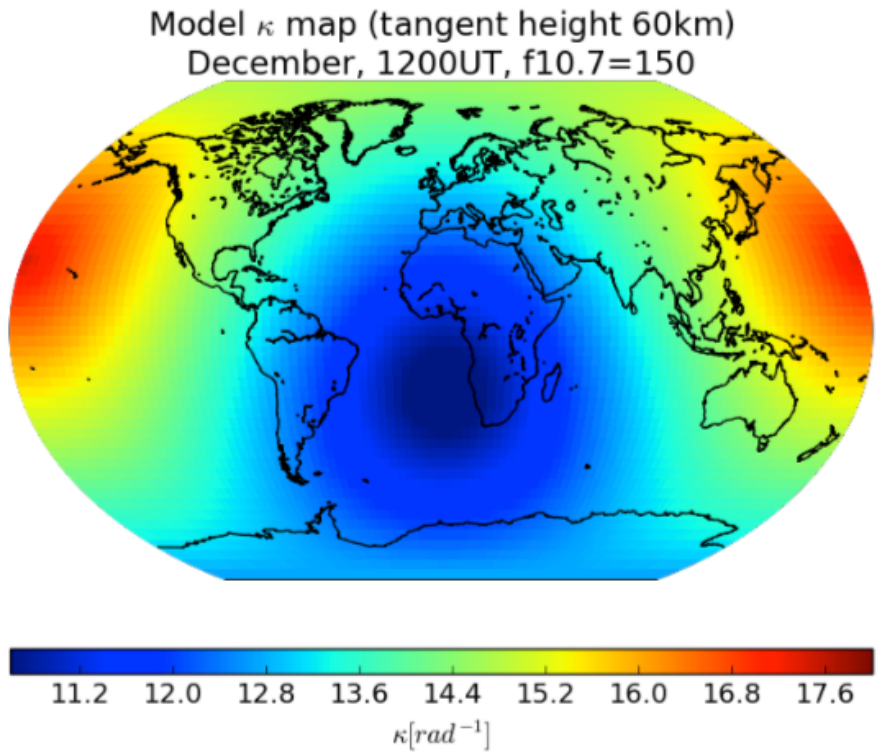
Temperature Error

Danzer et al., AMT, 2015



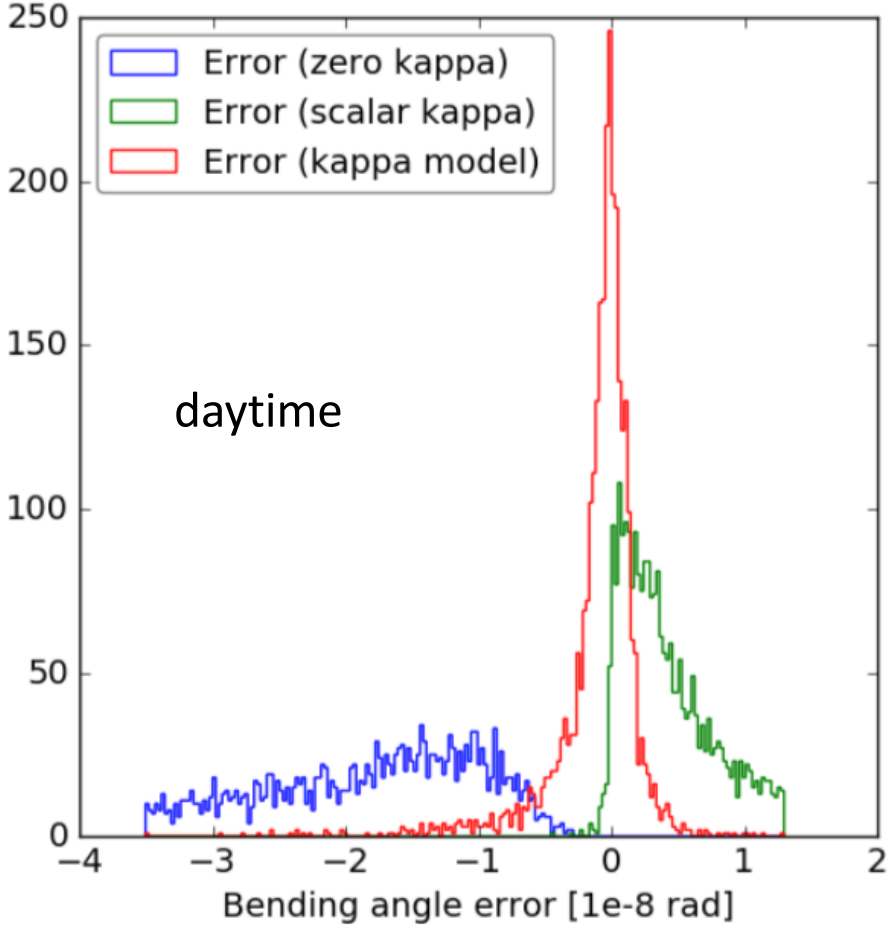
Climatology of kappa

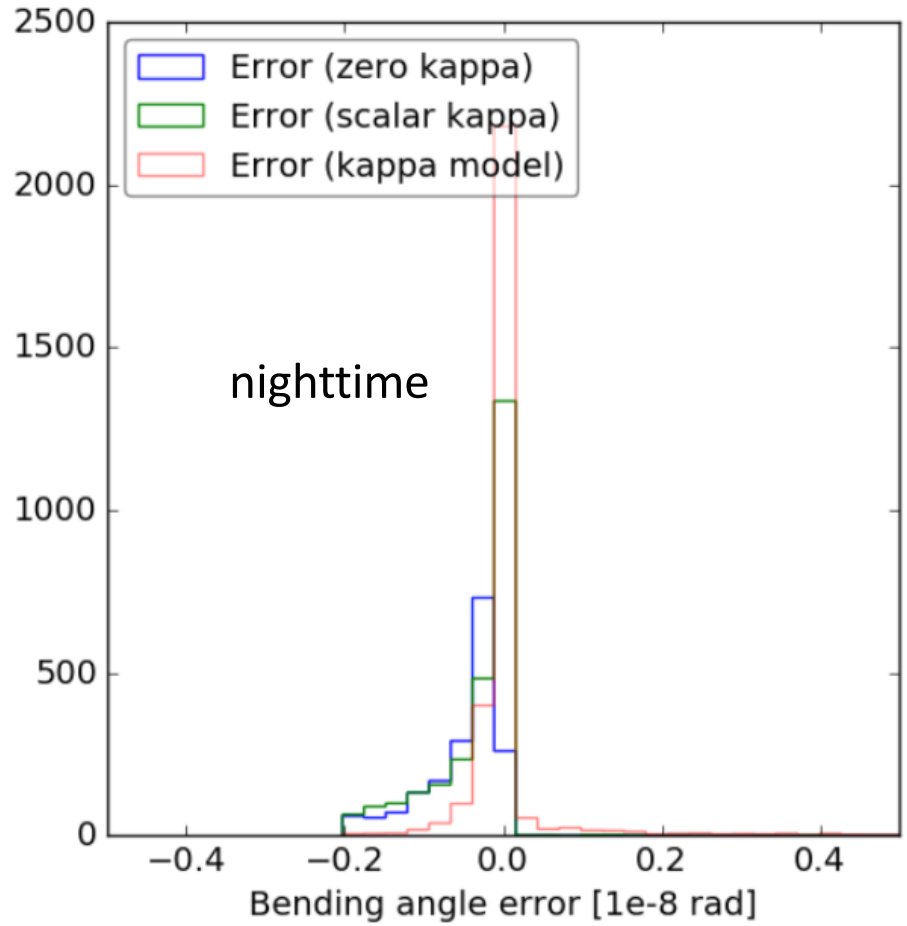




Angling, ROM-SAF Report, 2016

Simulated BA Error

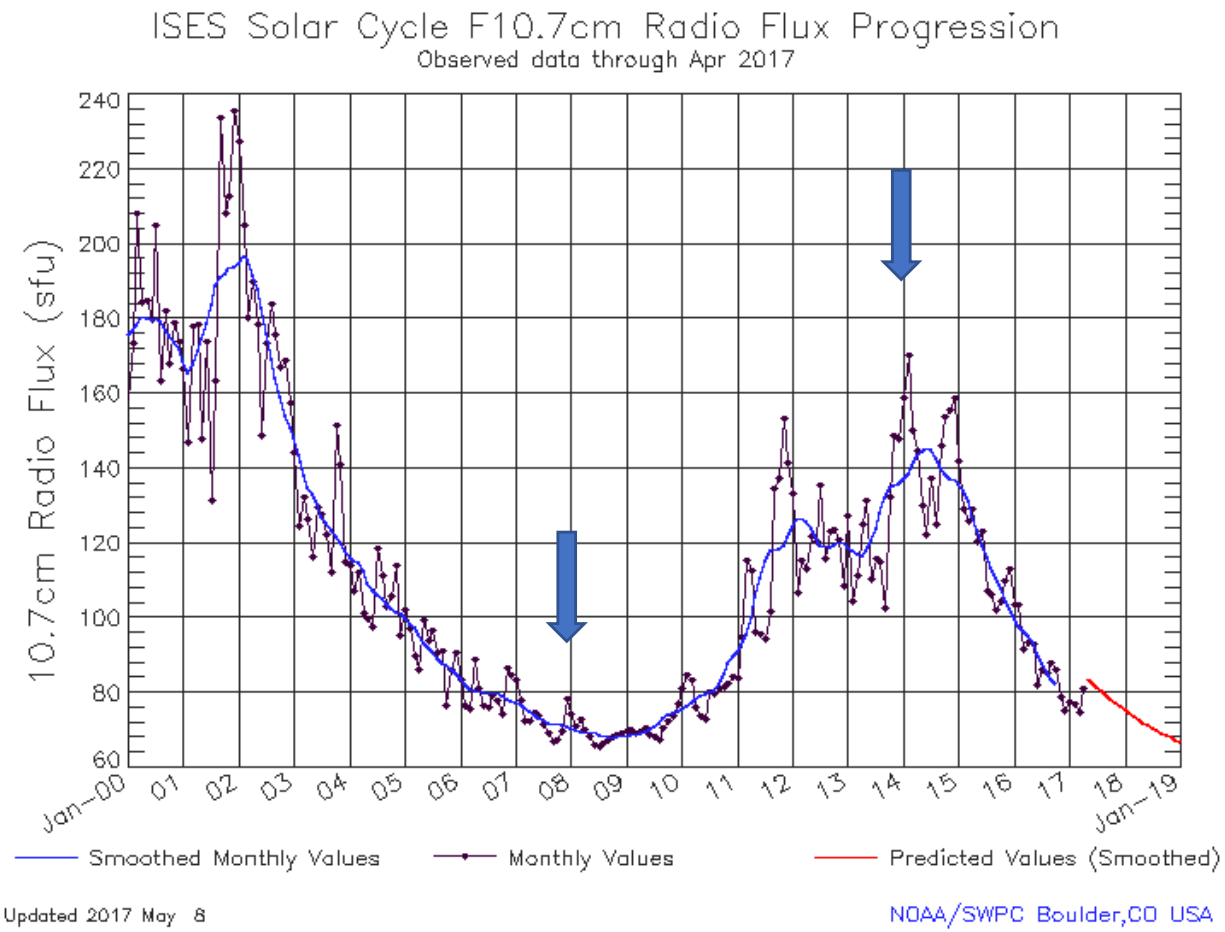




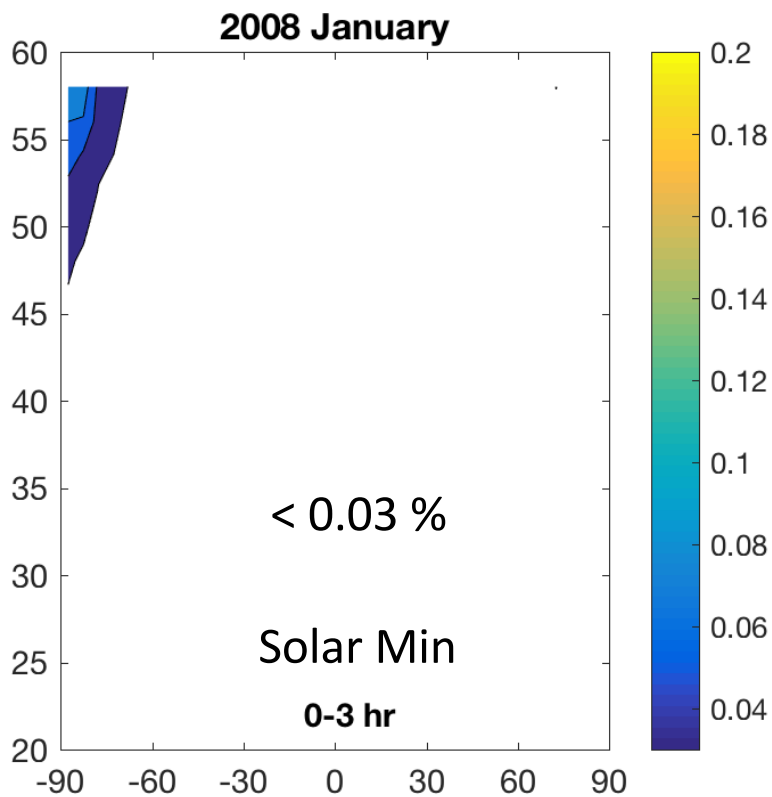
Angling, ROM-SAF Report, 2016

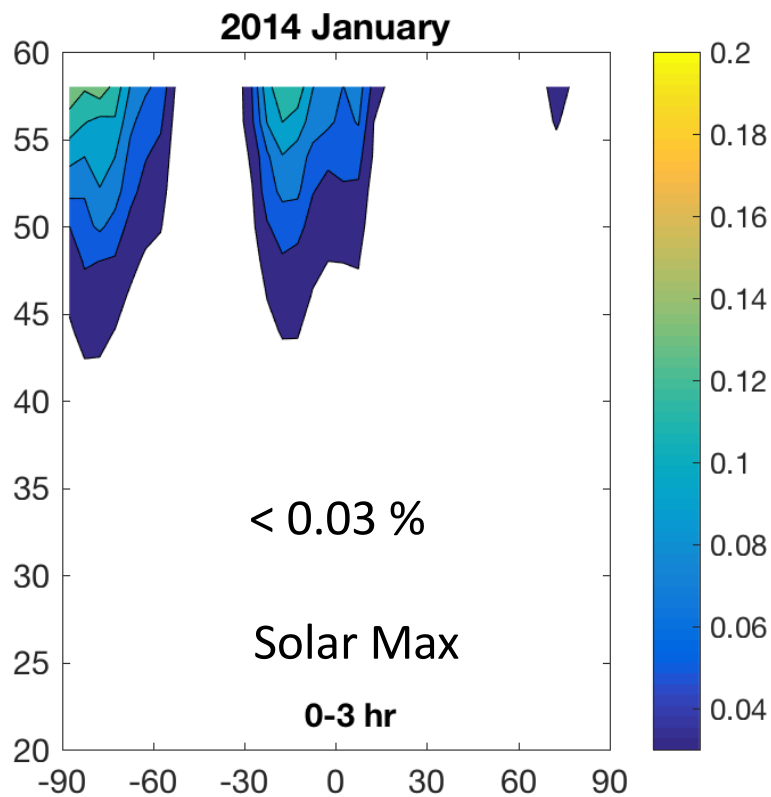
Results from COSMIC

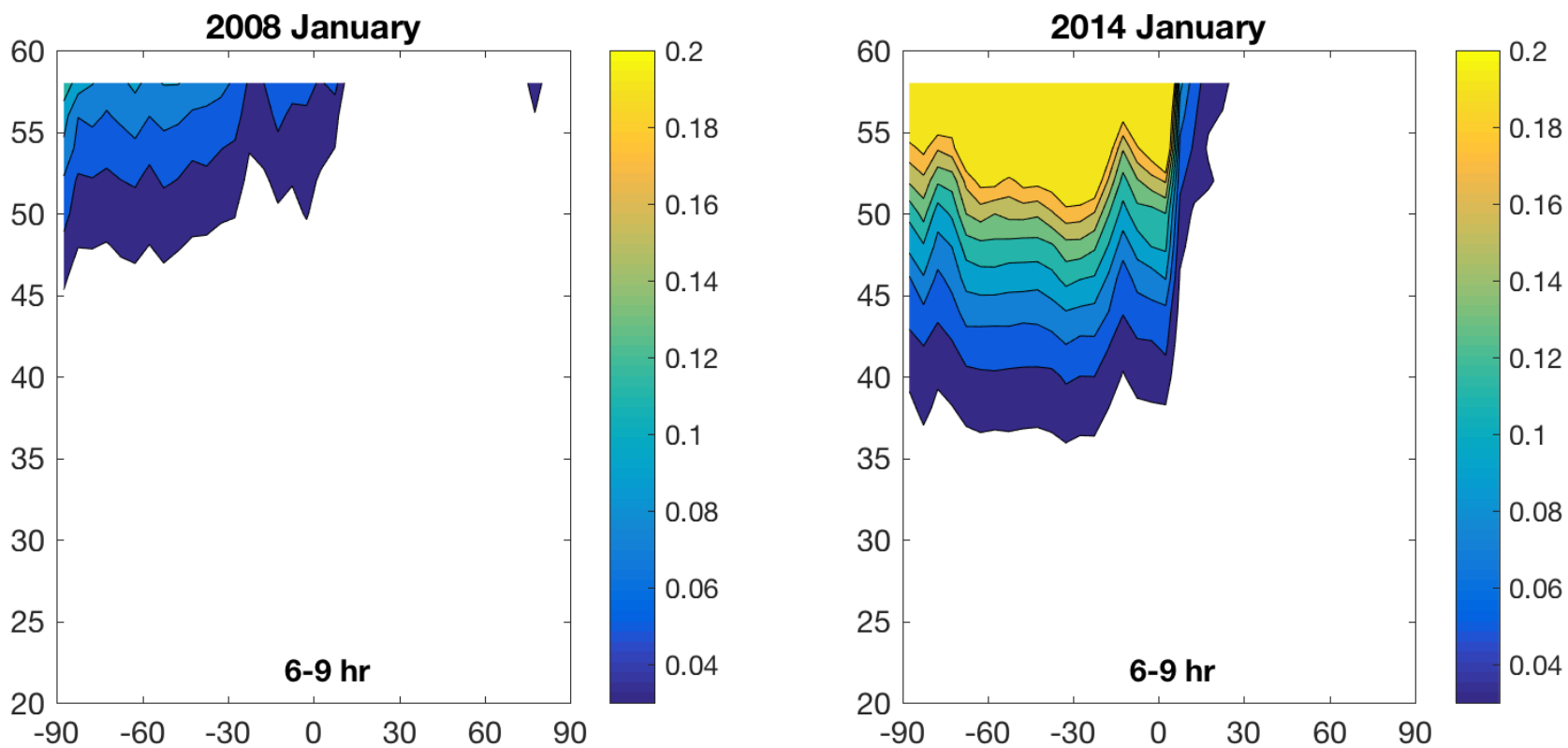
- A fixed value is used (kappa=14).
- solar min (2008) vs. solar max (2014)

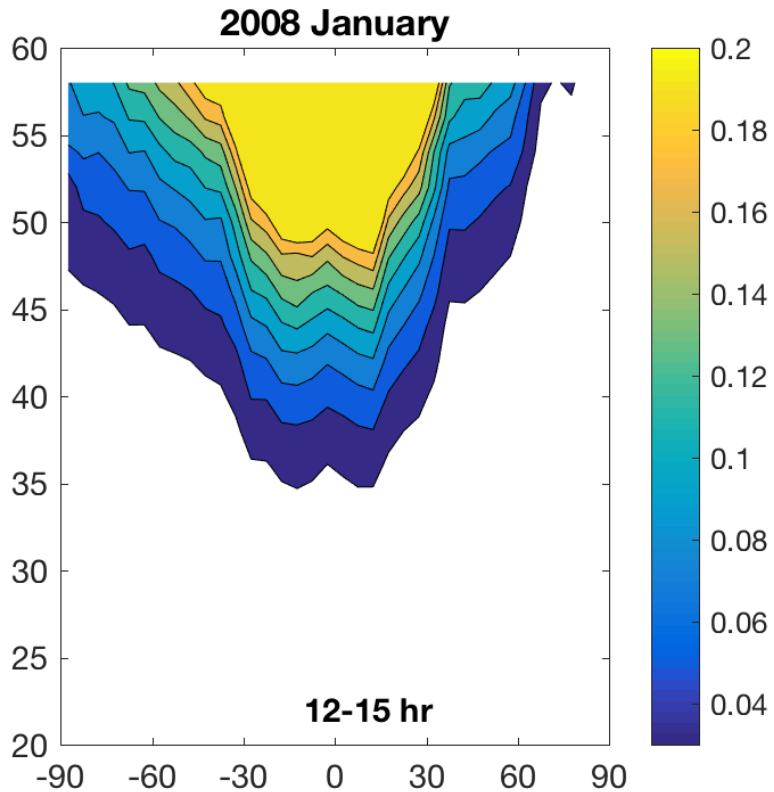


Refractivity difference N(kap=14)-N(kap=0) [%]






2008 January
6-9 hr
2014 January
6-9 hr
60
55
50
45
40
35
30
25
20
-90
-60
-30
0
30
60
90
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04


2008 January
12-15 hr
60
55
50
45
40
35
30
25
20
-90
-60
-30
0
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0.18
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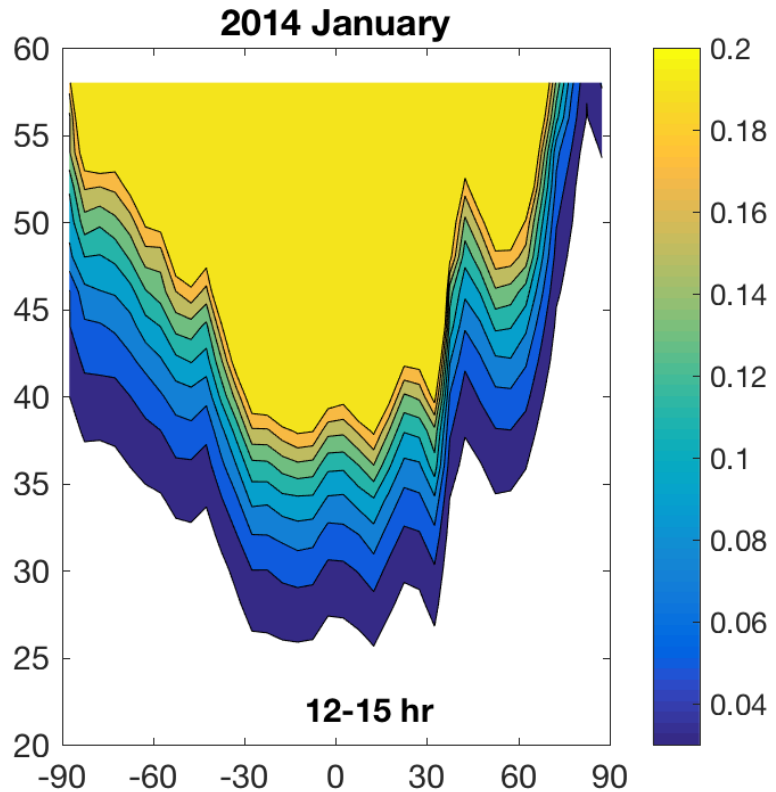
2014 January
12-15 hr
60
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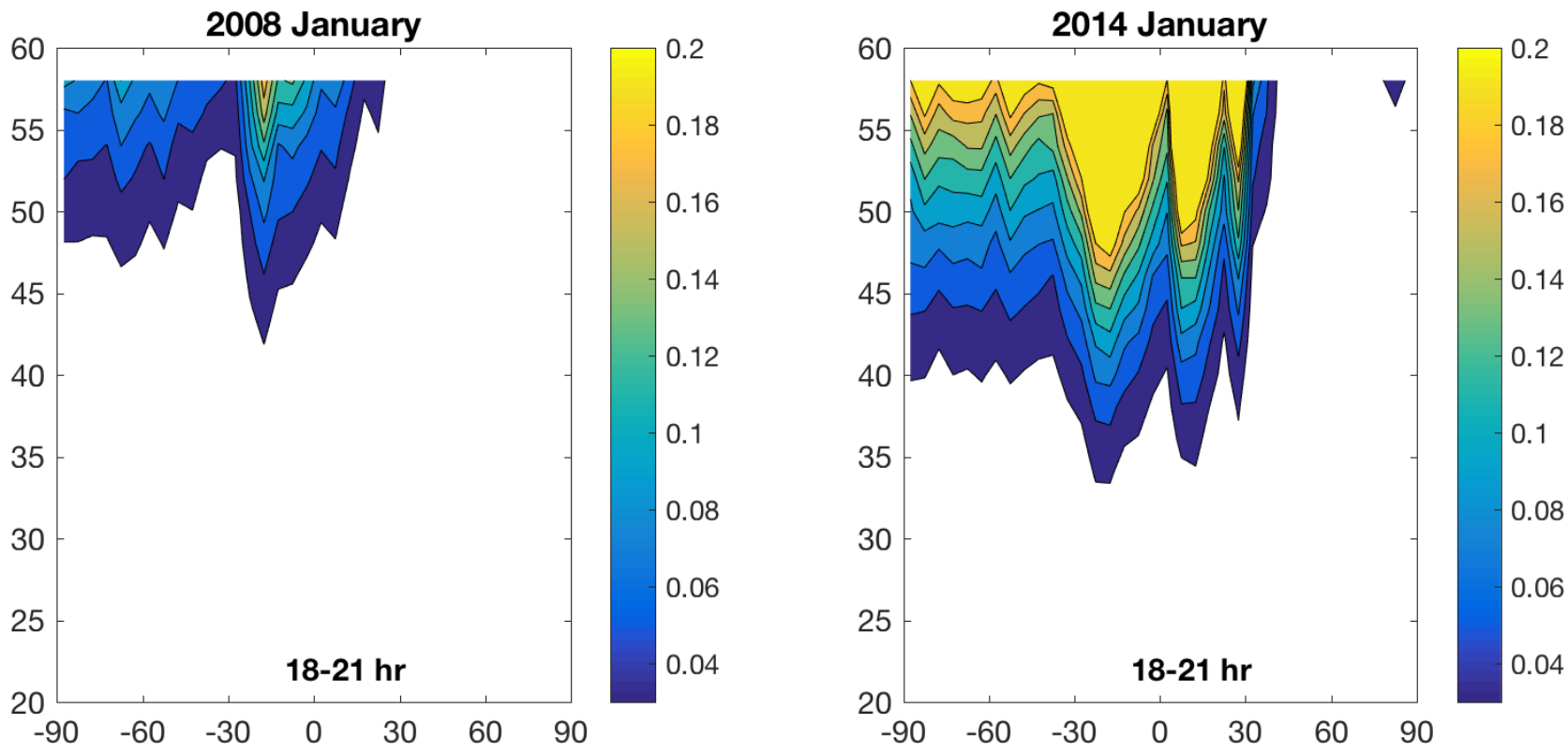
2008 January
18-21 hr
2014 January
18-21 hr
60
55
50
45
40
35
30
25
20
-90
-60
-30
0
30
60
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0.2
0.18
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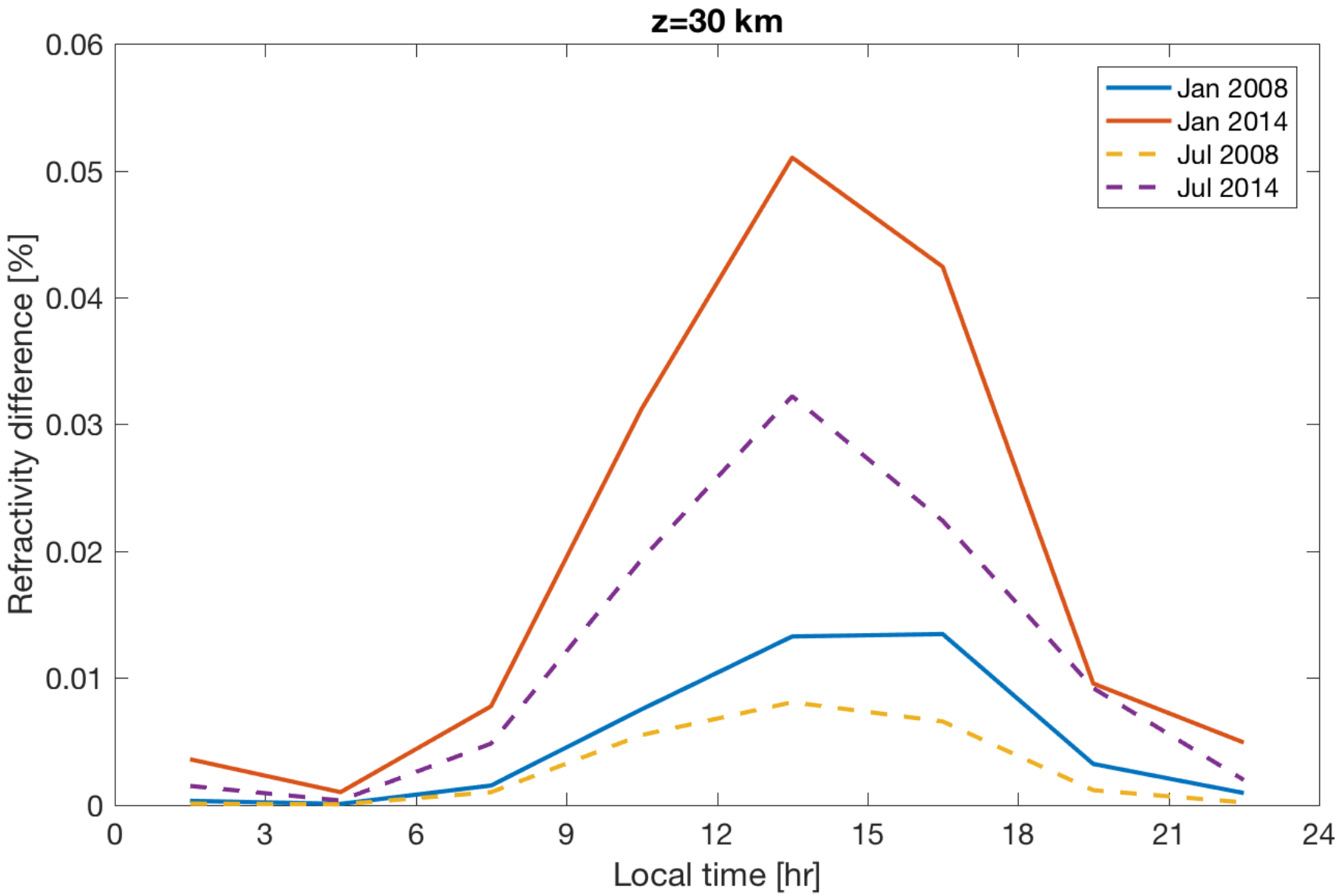
0.06
0.04

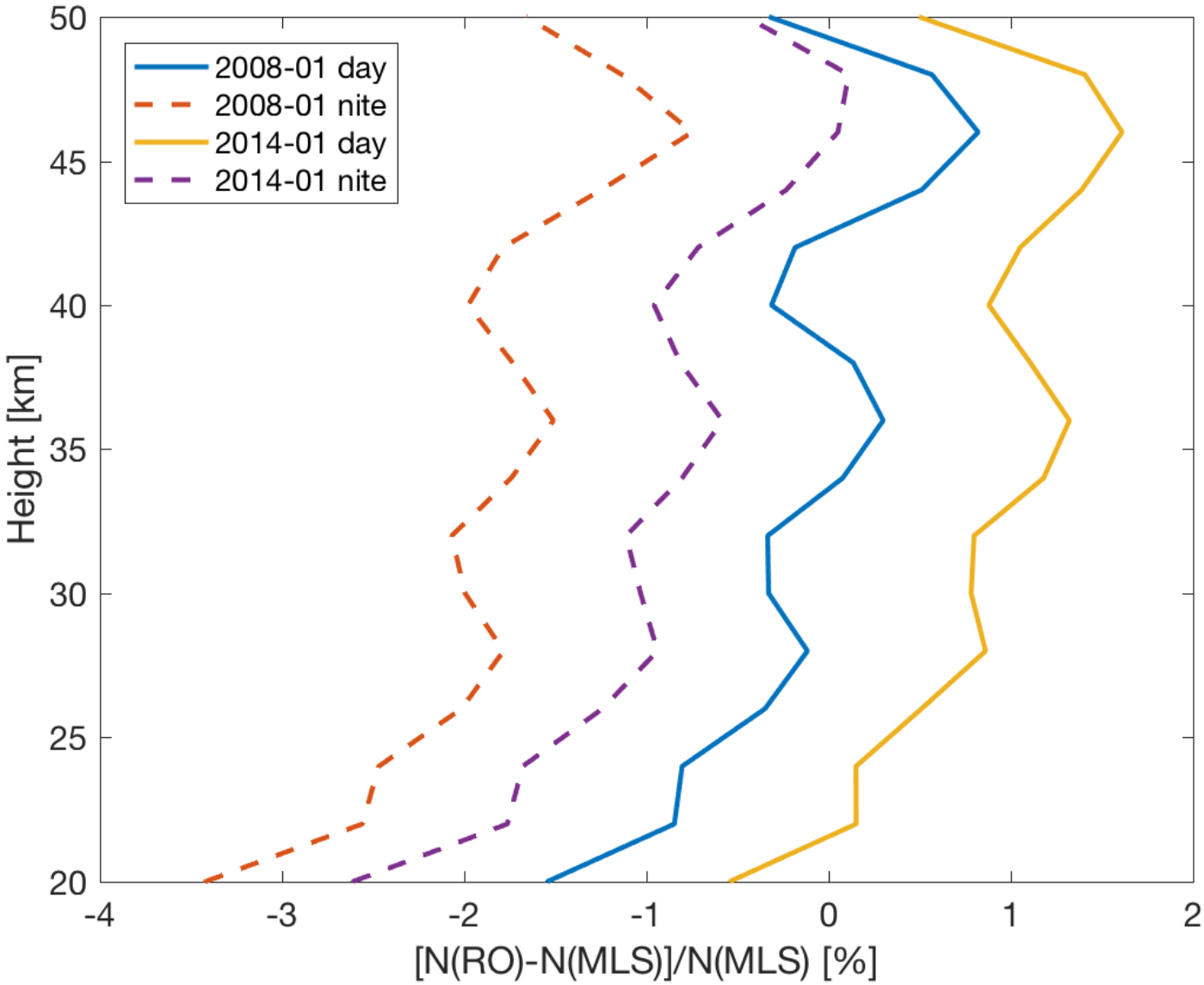
Fixed height, 10S-10N



Validation?

- Assessing the small difference in N/T (~ 0.2 K) is challenging. Need accurate lower strato measurements to compare with!
- However, it may be possible to take advantage of the systematic differences in solar activity (e.g., solar max vs solar min, day vs night).
- Start with Microwave Limb Sounder (MLS) Temperature and geopotential height retrievals.

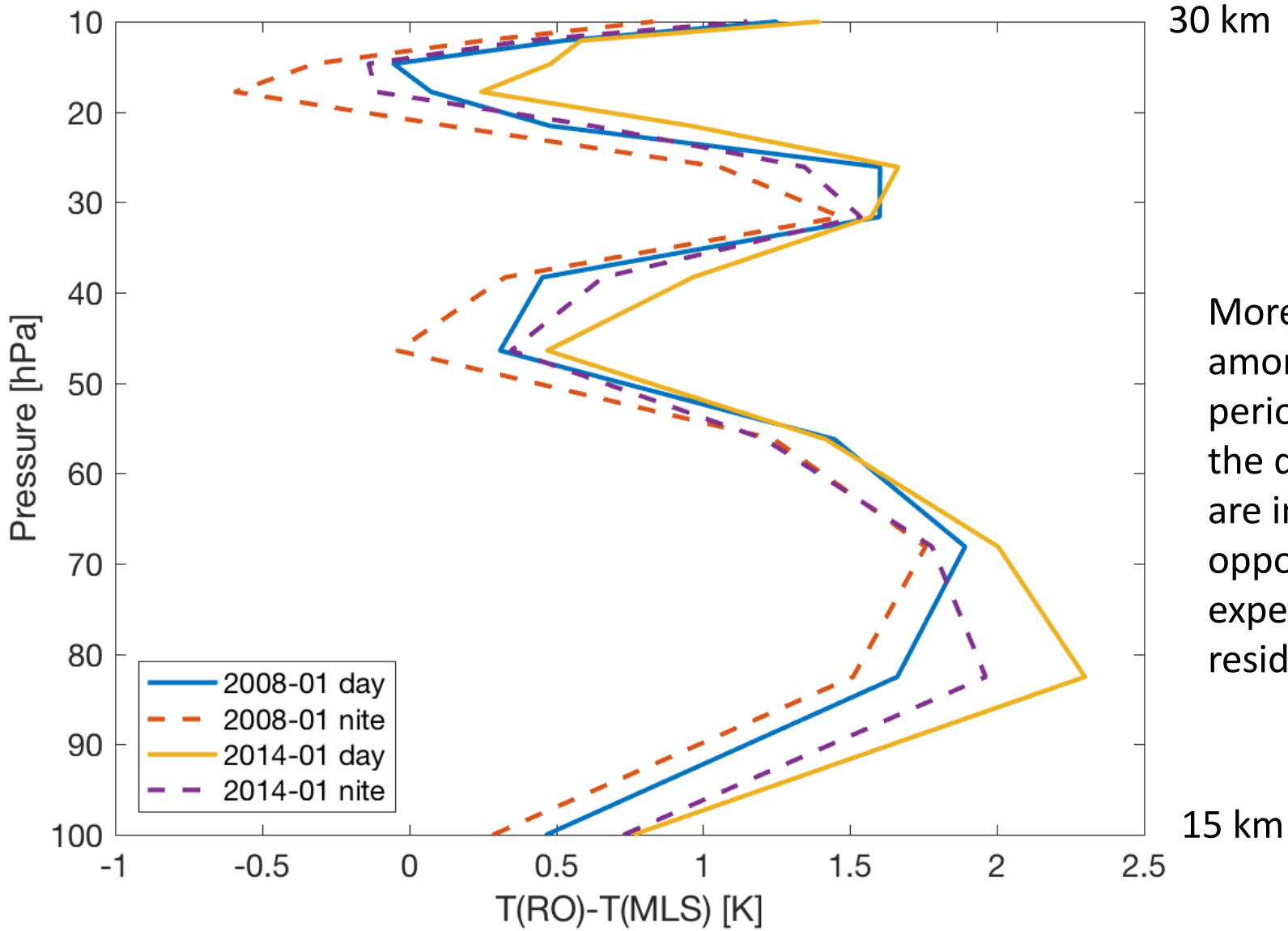
Refractivity comparison



Differences between the different periods in the sense expected. But way too large!

Biases in MLS GPH?

Temperature comparison



More consistent among the periods… but the differences are in the oppostie sense expected from residual iono.

Summary & Discussion

- The kappa-method is promising in reducing iono residual error.
- How to determine the right kappa? Is climatological value good enough?
  - Can we compute it using iono occultation retrieval?
  - What if we have 3 GNSS freq (L1, L2, L5)?
- At the very least, provides a simple/effective way to characterize retrieval bias from residual iono.
- How do we validate the retrievals? Would AIRS/IASI be useful?
- Single-frequency approach: solve for the ionosphere using (phase delay – group delay)
  - Noisier but no raypath separation effect