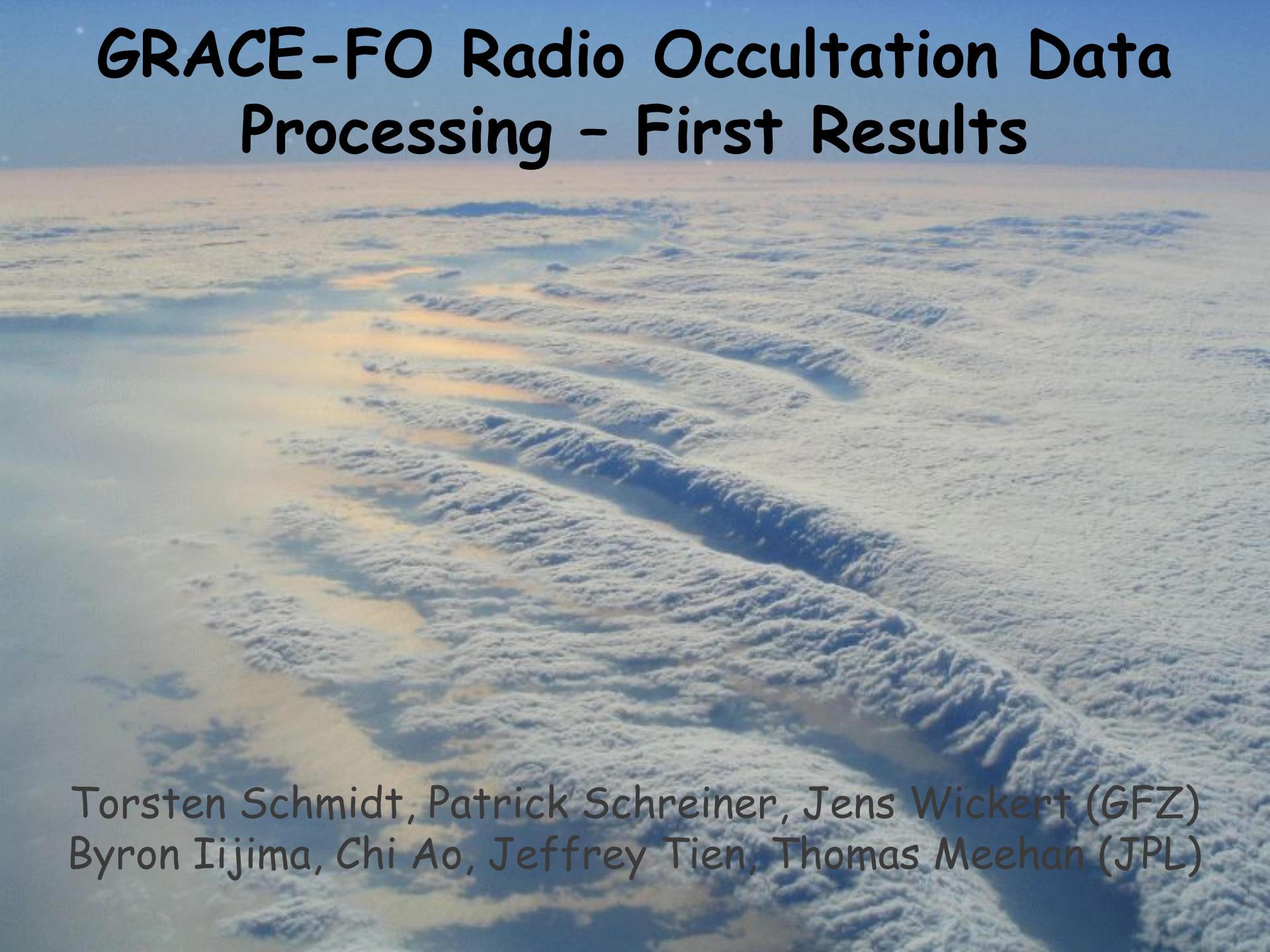
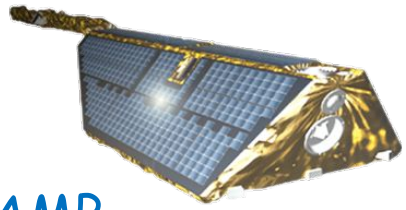
GRACE-FO Radio Occultation Data Processing – First Results



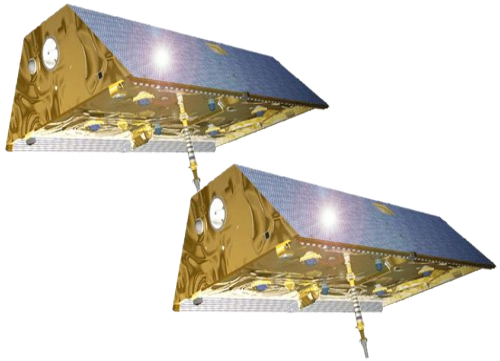
Torsten Schmidt, Patrick Schreiner, Jens Wickert (GFZ)
Byron Iijima, Chi Ao, Jeffrey Tien, Thomas Meehan (JPL)

GFZ radio occultation missions

Completed



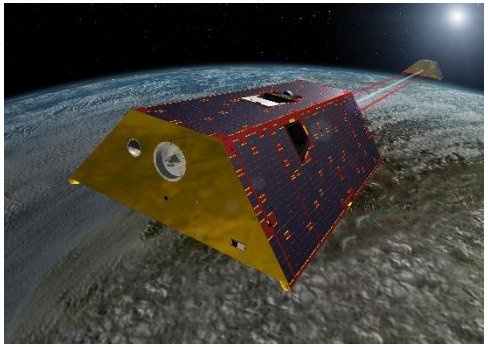
CHAMP
2001-2008
setting



GRACE A/B
2006-2017
setting

Current

TerraSAR-X since 2008, setting
Tandem-X since 2011, rising



GRACE Follow-on
GRACE-C, rising
since 2020

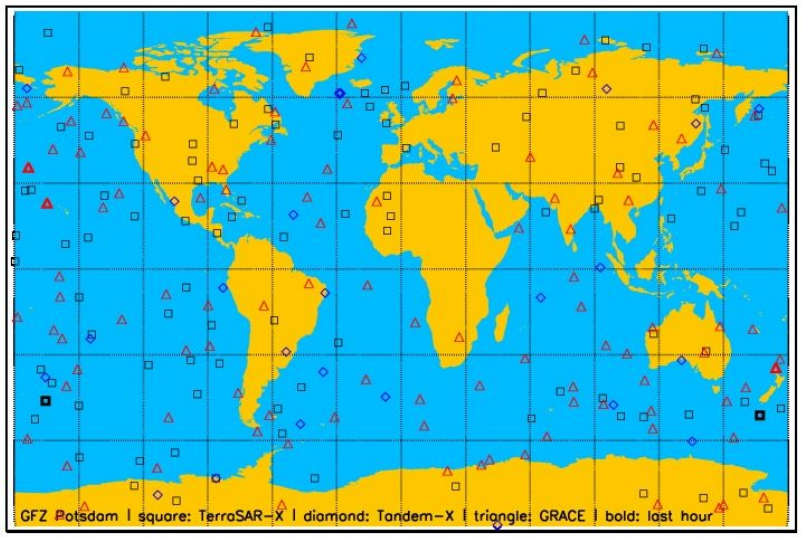
NRT processing at GFZ

www-app2.gfz-potsdam.de/pb1/GASP/GASP2/CHAMP/RO_EXPERIMENT/index_ro_experiment.html

Near-real time radio occultation processing

TSX TDX GRC

11 April 2021 (Day of Year: 101)



Comparison to ECMWF short-range forecast

TSX Refractivity Dry temperature

TDX Refractivity Dry temperature

GRC Refractivity Dry temperature

GRC special Refractivity (L2p/L2c/L5) Dry temperature (L2p/L2c/L5)

GRC special OL/CL transition height Lowest altitude

GRACE and GRACE Follow-on (GFO) nomenclature:

GRACE-A = GRA
GRACE-B = GRB

GFO
GF1 = GRACE-C = GRC
GF2 = GRACE-D = GRD

GRC test data: ftp.gfz-potsdam.de/pub/incoming/tschmidt/TESTBUFR

GRACE Follow-on milestones

- Launched on May 22, 2018.
- Twin satellites follow each other in orbit (in about 490 km) separated by about 200 km.
- Send constantly microwave and laser signals to each other to measure the distance between them. Gravity field estimation Main goal of the mission!
- Summer 2018 problems with IPU on GF2 (switched to second IPU in autumn 2018)
- After some (setting) test ROs from GF2 in summer 2018 no ROs for about one year
- Software updates and updated reader (last on March 2020) by JPL
- Continuous stable RO data from GF1 (rising occs) since March 2020

About 250-280 occultations daily

GRACE-FO Instrument Processing Unit

Courtesy of Thomas Meehan and Jeffrey Tien

- Based on TriG-Lite design
- Ka/K band tracking for micron-level inter-satellite ranging measurement
- Track up to 12 dual frequency GPS Satellite
  - Real-time PVT (position/velocity/timing)
  - 1-sec pseudorange and phase measurements for post-processed precise orbit determination (POD)
- GPS radio occultation
  - L1CA/L2P, L1CA/L2C, or L1CA/L5
  - Rising radio occultation on the leading satellite
  - Setting radio occultation on the trailing satellite
  - Up to 300 profiles per day per satellite
- Programmable RF downconverter able to receive all L band signal
  - Reconfigurable Software allows additional capabilities (e.g. Galileo GNSS RO) to be added later

GPS radio occultation antenna

Zenith pointing GPS antenna

Instrument Processing Unit (IPU)

GRACE Follow-on (GFO) data processing

RO reader (from JPL) output

Courtesy of Angela Dorsey, JPL

Currently tracking L1CA, L2P, L5 (prn30, prn32), L2C RO since March 2020.

- I_Sig1 In-phase correlation product for signal 1 (L1 CA) over 1/numPoints seconds
- Q_Sig1 Quadrature correlation product for signal 1 (L1 CA) over 1/numPoints seconds
- I_Sig2 In-phase correlation product for signal 2 (L2P, L2C, or L5) over 1/numPoints seconds
- Q_Sig2 Quadrature correlation product for signal 2 (L2P, L2C, or L5) over 1/numPoints seconds
- phaseModelSig1 CA model (cy)
- phaseModelSig2 P2/L5 model (cy)
- pseudoRangeSig1 CA pseudorange (m)
- pseudoRangeSig2 P2/L2C/L5 pseudorange (m)

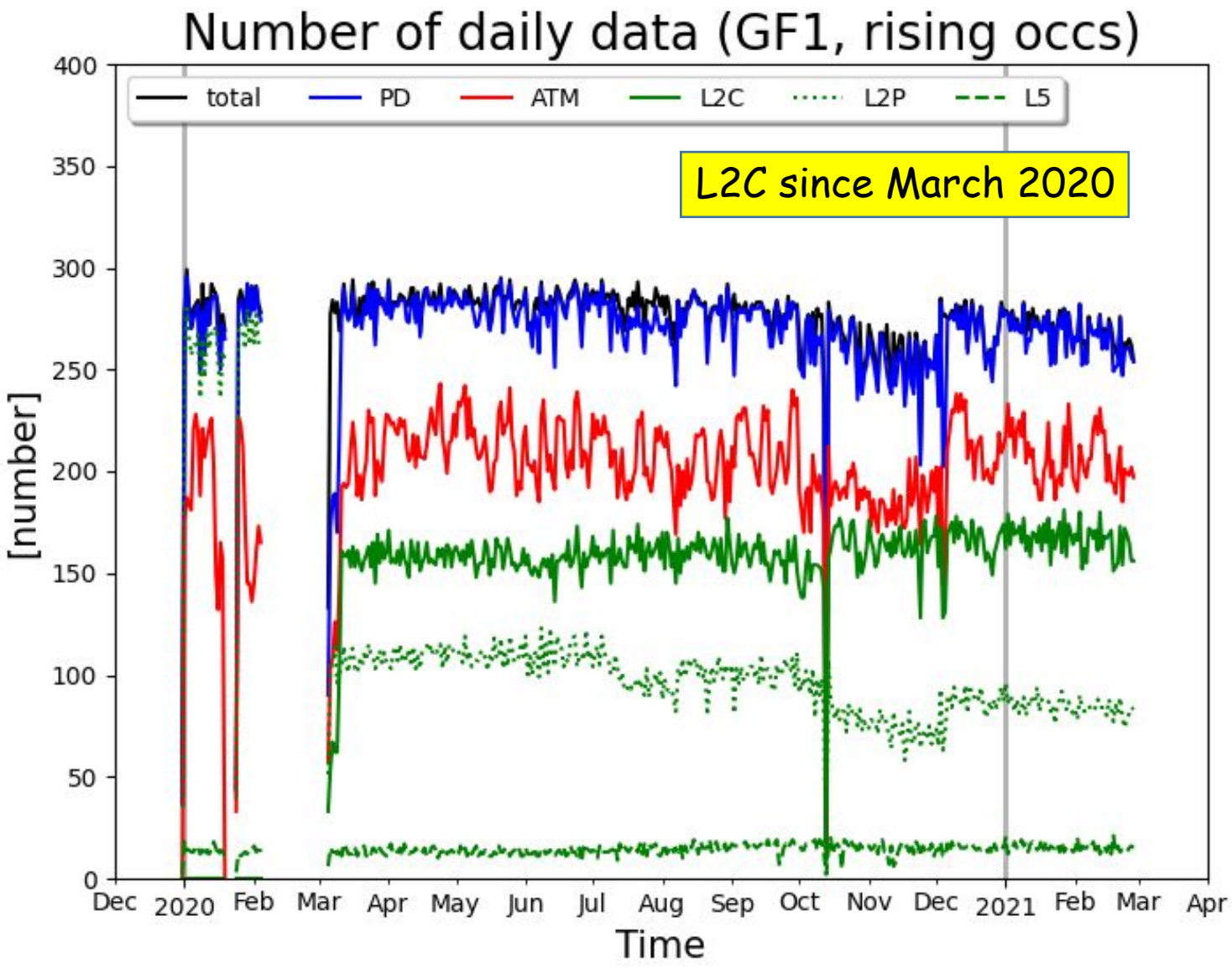
```
617199765 0.427297960 OL prn9  -7612  11941  -4099  -2851  61507796.511785  89457943.403831  29171682.617979  29171700.762967
617199765 0.447297564 OL prn9  -10817  9227  -5143  -6441  61507172.199523  89457456.939741  29171682.617979  29171700.762967
617199765 0.467297168 OL prn9  -13249  6762  -5934  -14352  61506547.885446  89456970.586664  29171682.617979  29171700.762967
617199765 0.487296772 OL prn9  -14703  2141  -6845  -21014  61505923.569677  89456484.070308  29171682.617979  29171700.762967
617199766 -0.500 CL prn9  14911  0  451  0  61505527.019257  89456174.785529  29165741.606538  29165750.345726
617199766 -0.480 CL prn9  15111  0  93  0  61504902.646376  89455688.454518  29165741.606538  29165750.345726
617199766 -0.460 CL prn9  15571  0  2225  0  61504278.256473  89455202.088007  29165741.606538  29165750.345726
617199766 -0.440 CL prn9  15854  0  1211  0  61503653.873963  89454715.542321  29165741.606538  29165750.345726
```

$$TotalPhase = PhaseModelSig + \frac{atan2(Q_{Sig} * B, I_{Sig} * B)}{2\pi} + C_n$$

$$SNR = Factor * \sqrt{I_{Sig}^2 + Q_{Sig}^2}$$

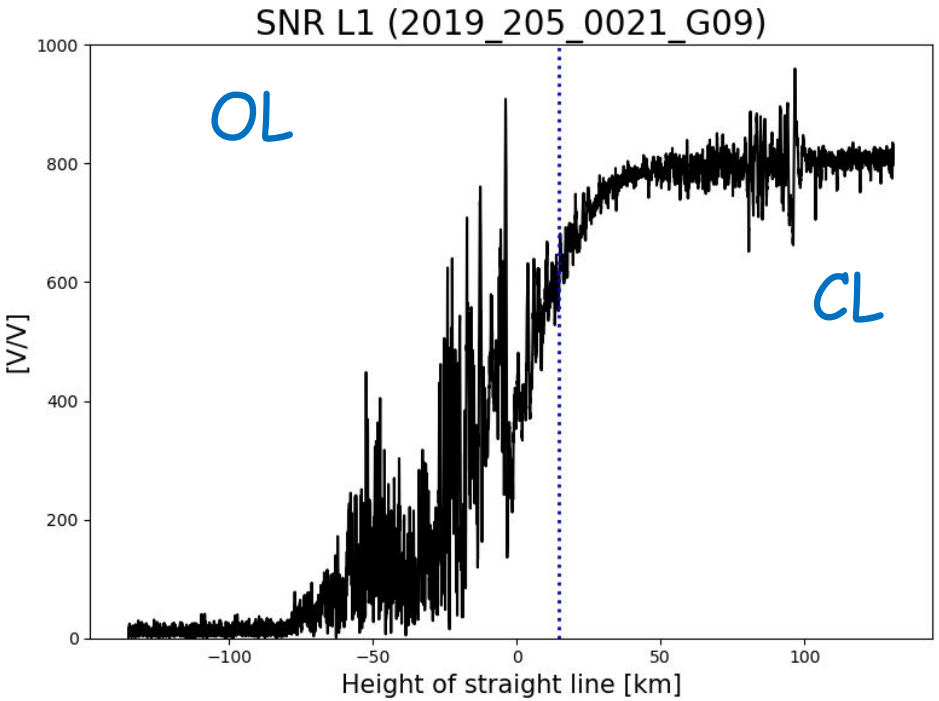
B: navbit correction (from GFZ navbit data network), C_n: phase unwrapping

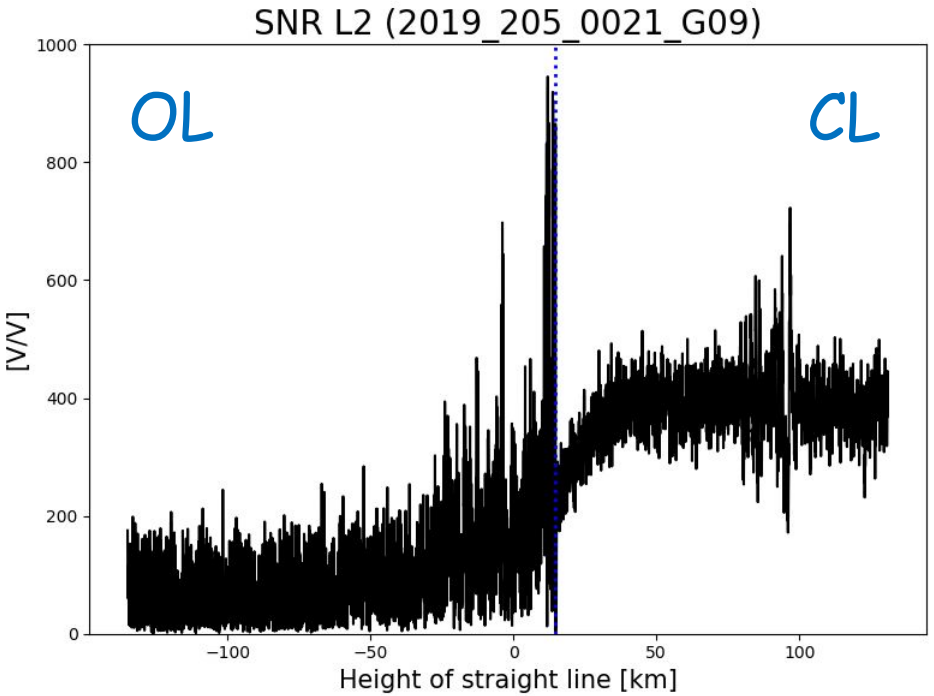
GRC number of data 01/2020-02/2021



GRC SNR example

$$SNR = Factor * \sqrt{(I^2 + Q^2)}$$

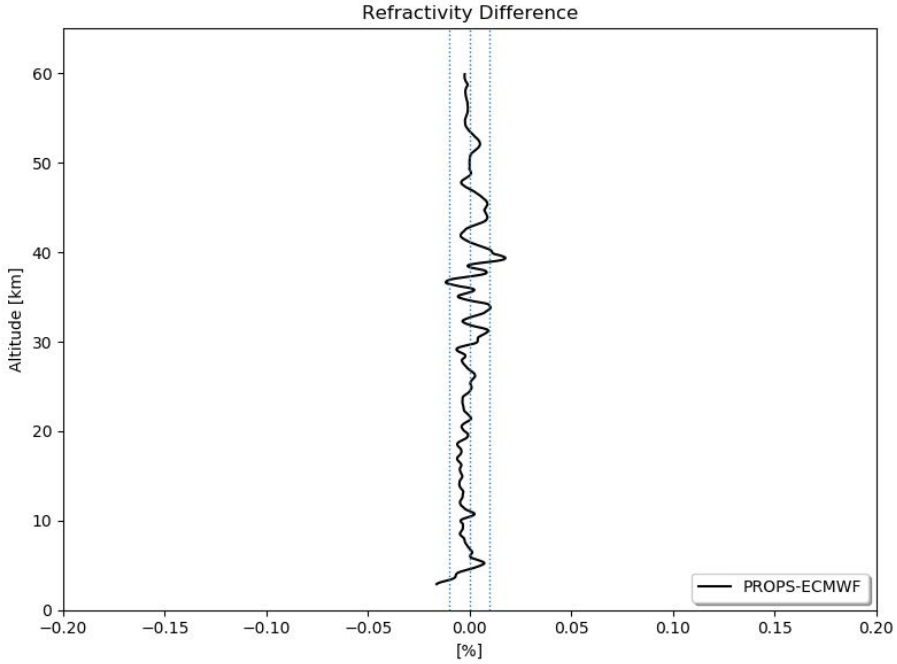


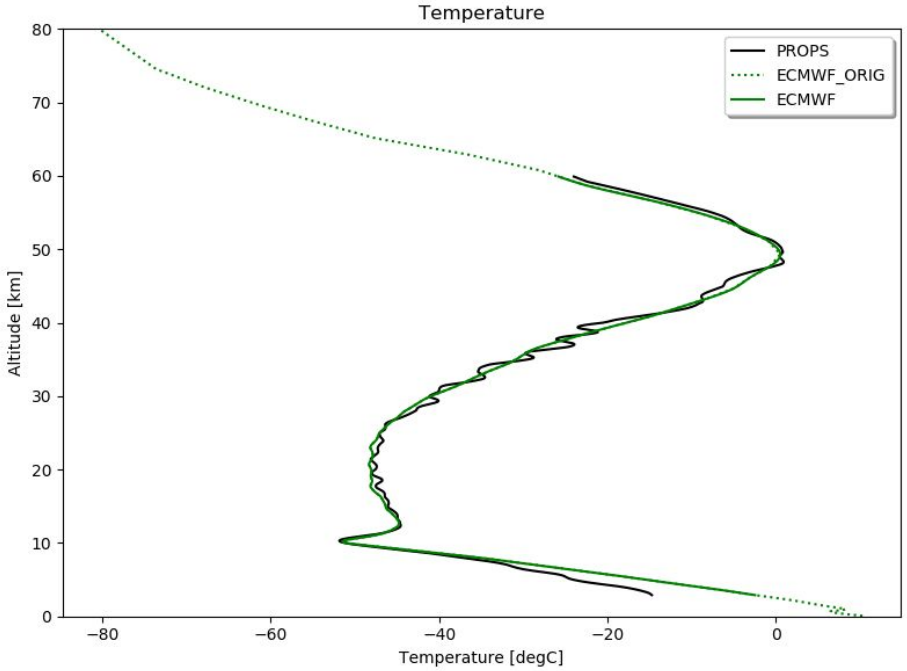


GRC data processing at GFZ

2020.219, 22:41 UTC, 67.5N, 50.8E, prn17

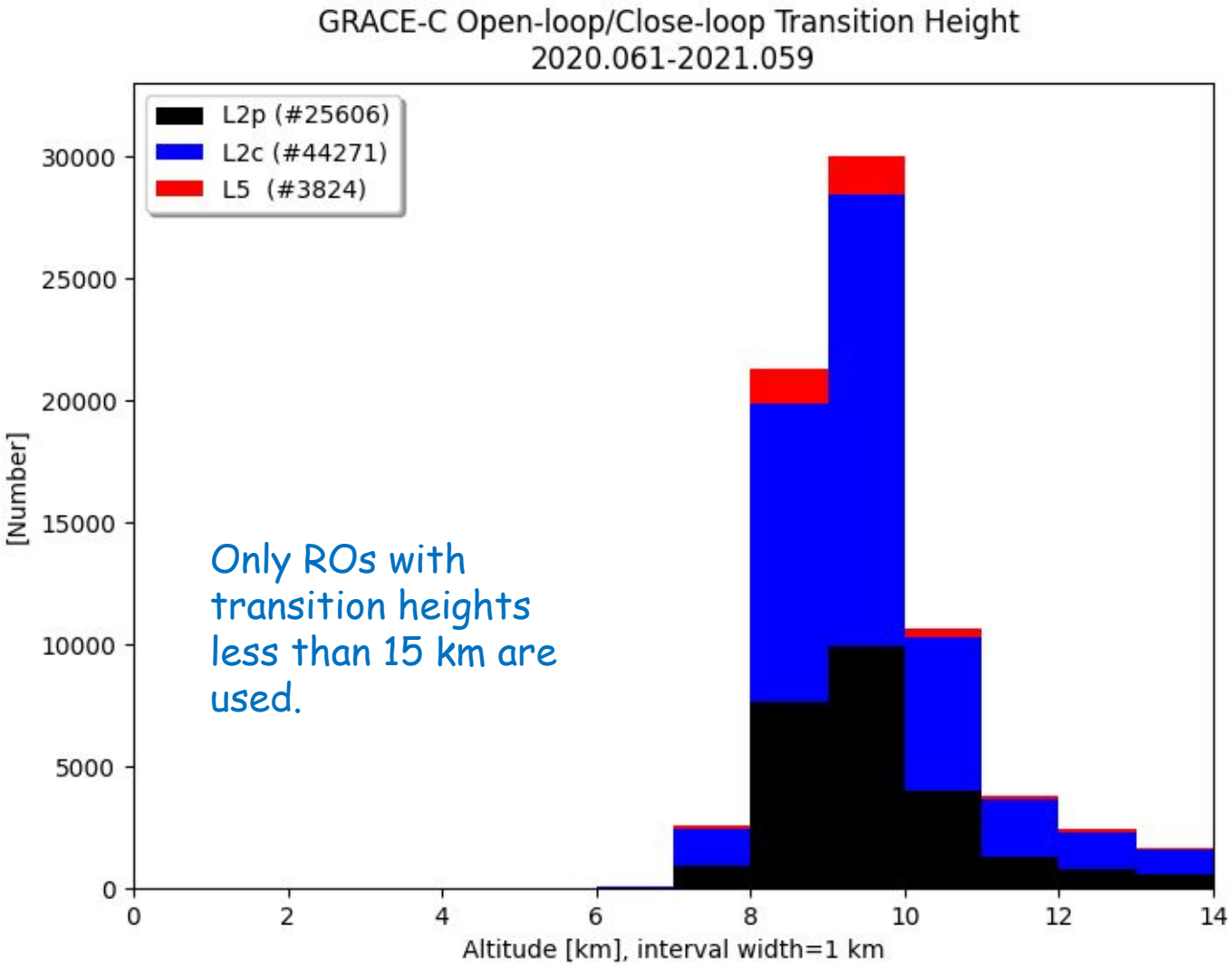
Comparison with ECMWF operational analysis





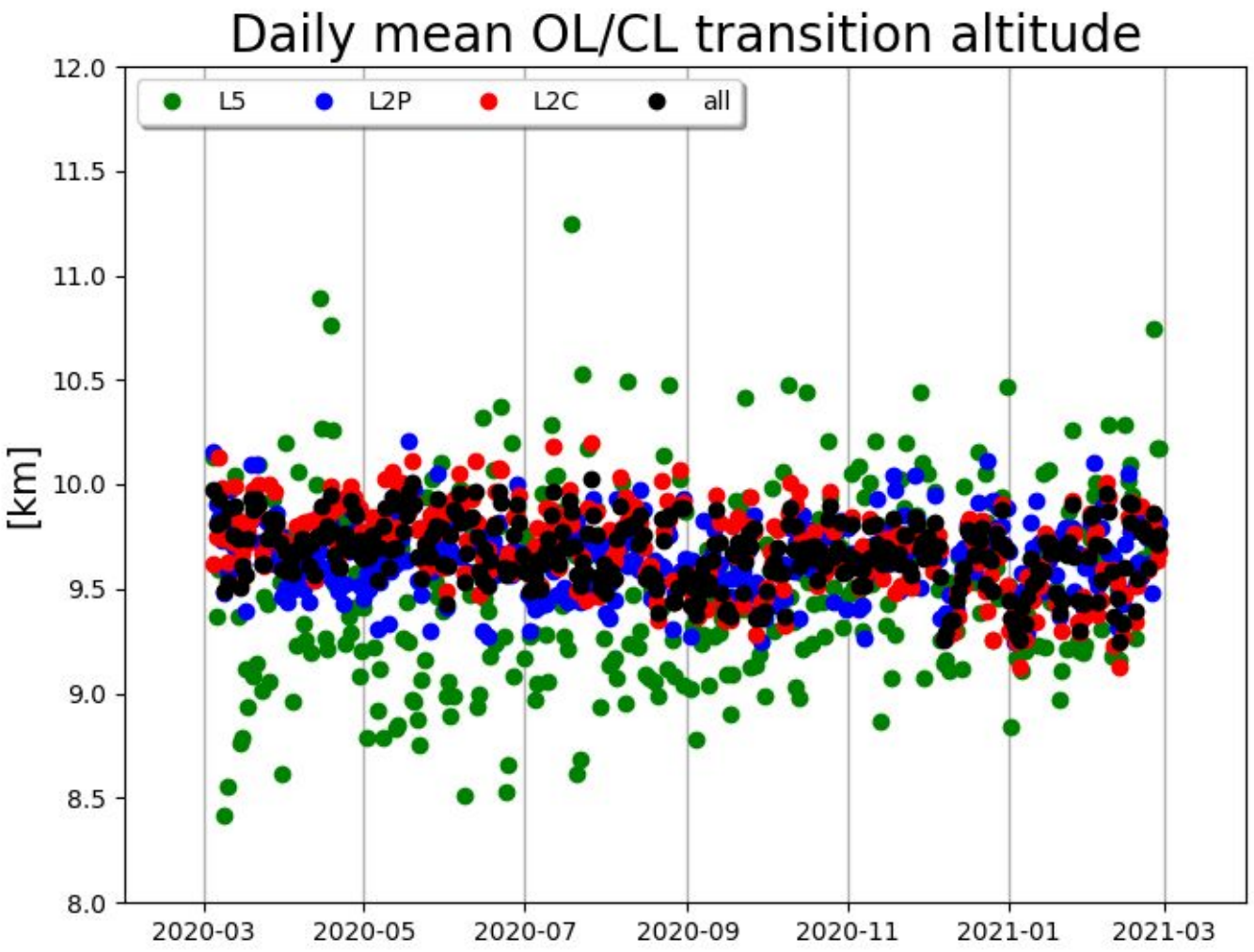
PROPS: Potsdam Radio Occultation Processing Software
Combination of old (excess phase) with new parts based on ROPP (L2 correction, CT2)

OL-CL transition height

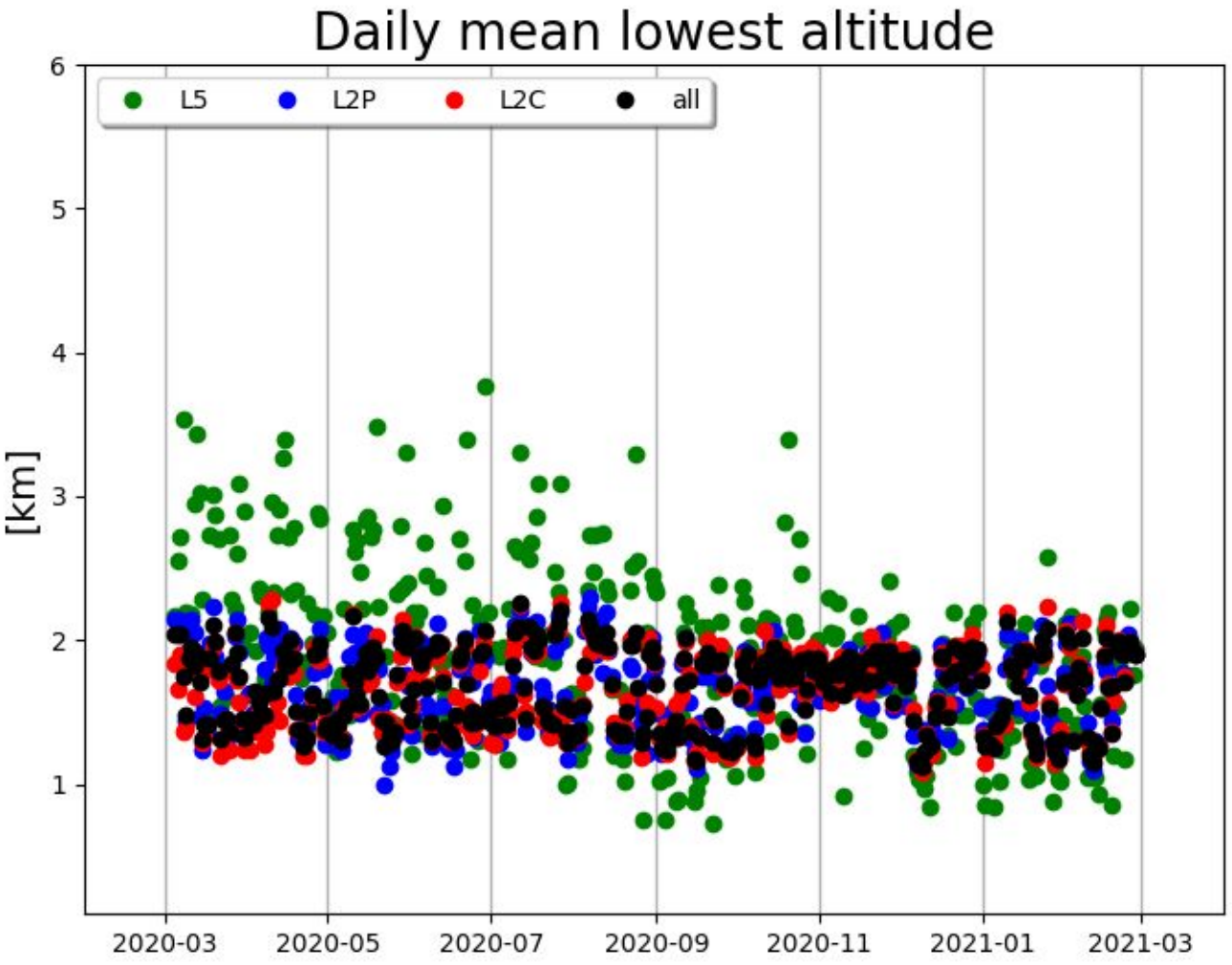


Only ROs with transition heights less than 15 km are used.

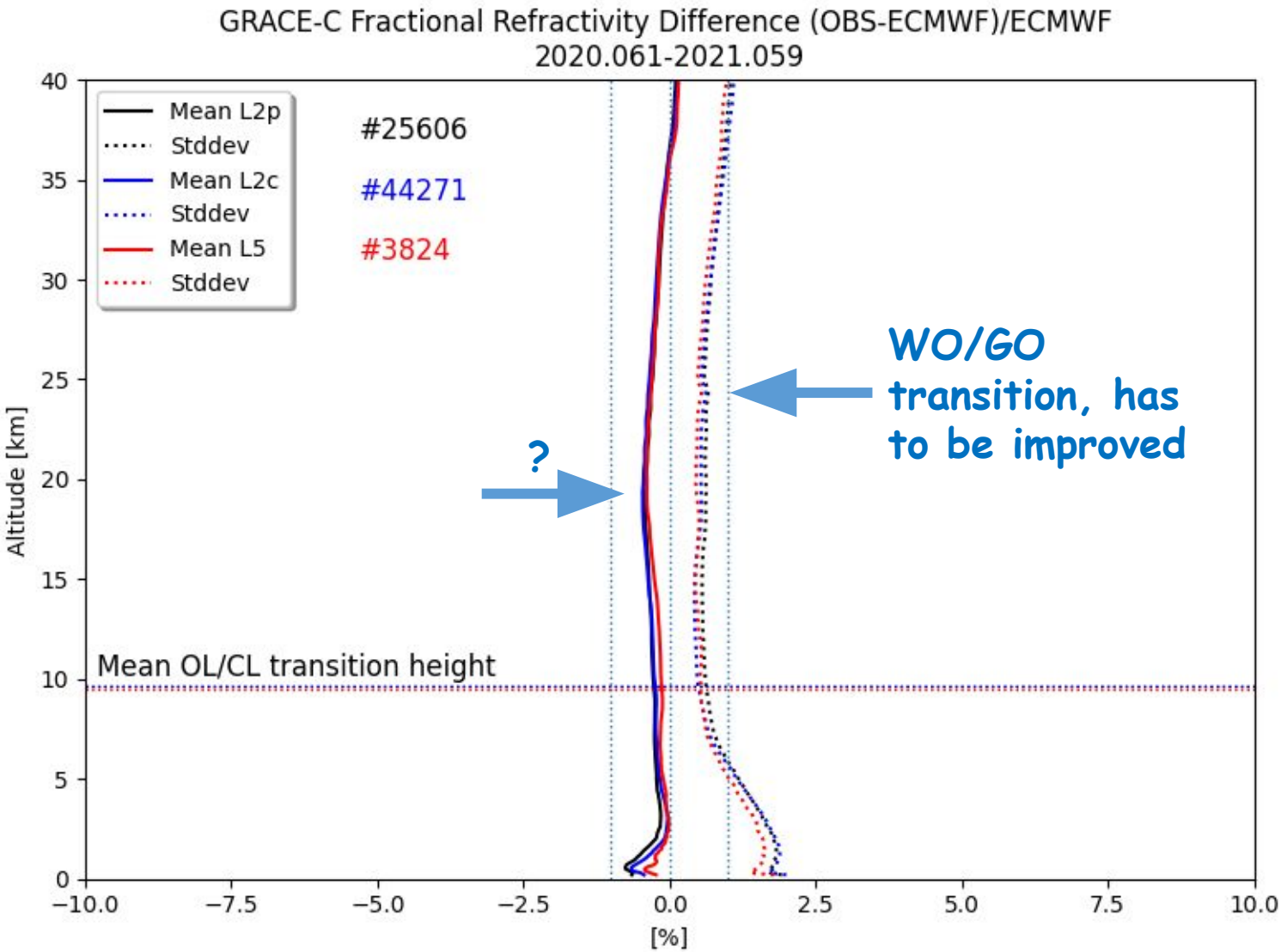
Daily mean OL-CL transition height



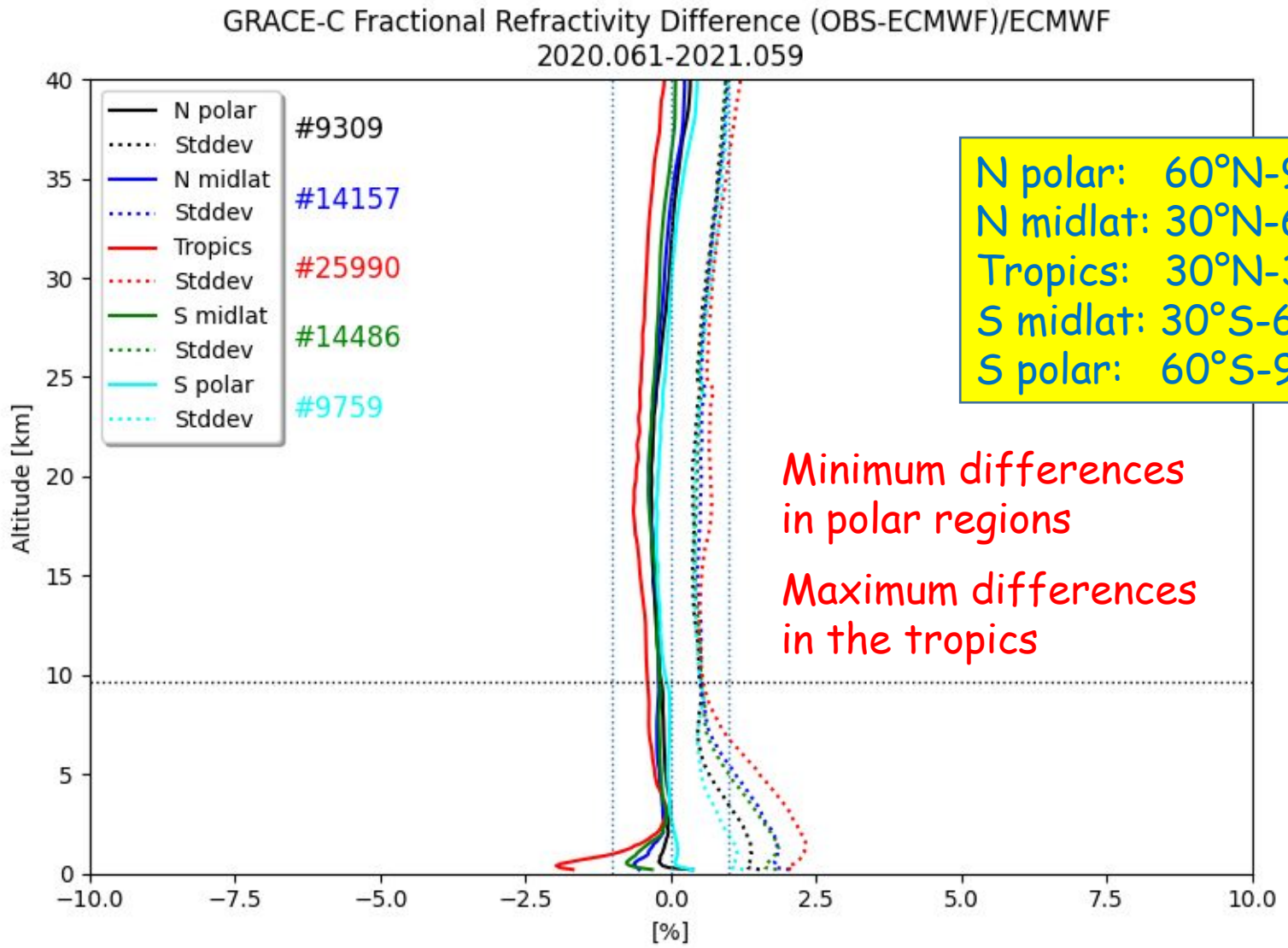
Daily mean lowest height above geoid



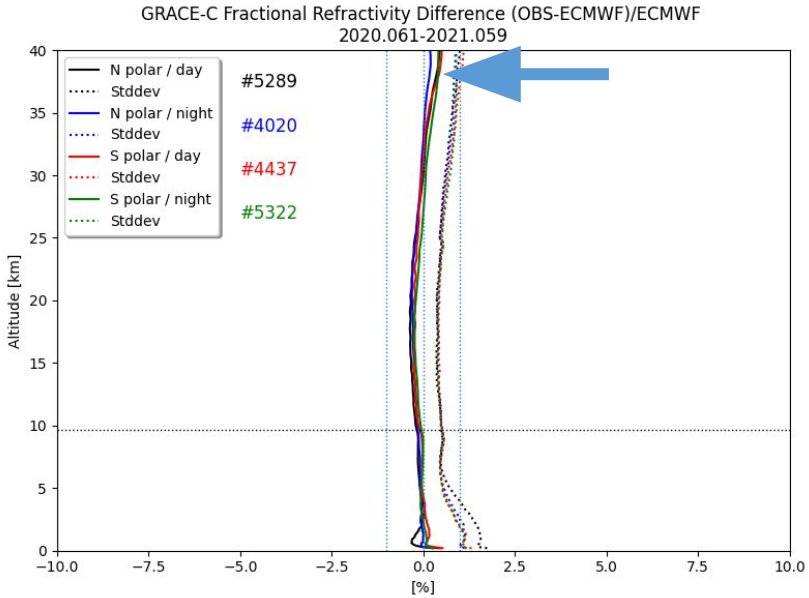
N differences for different L2 variables

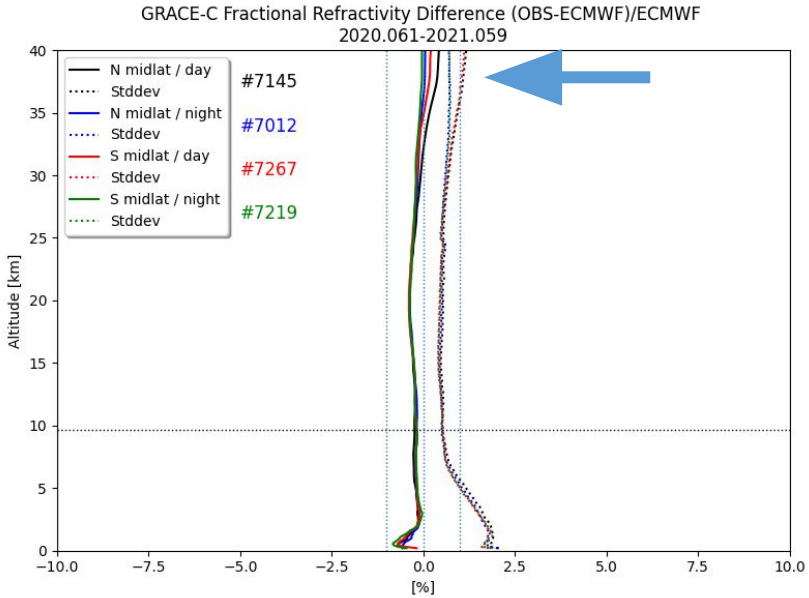


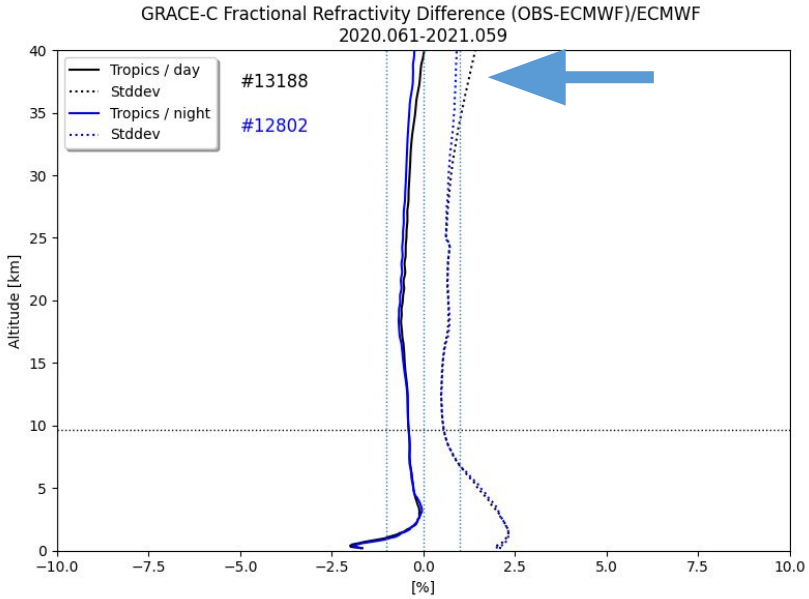
N differences for different regions



N day/night differences



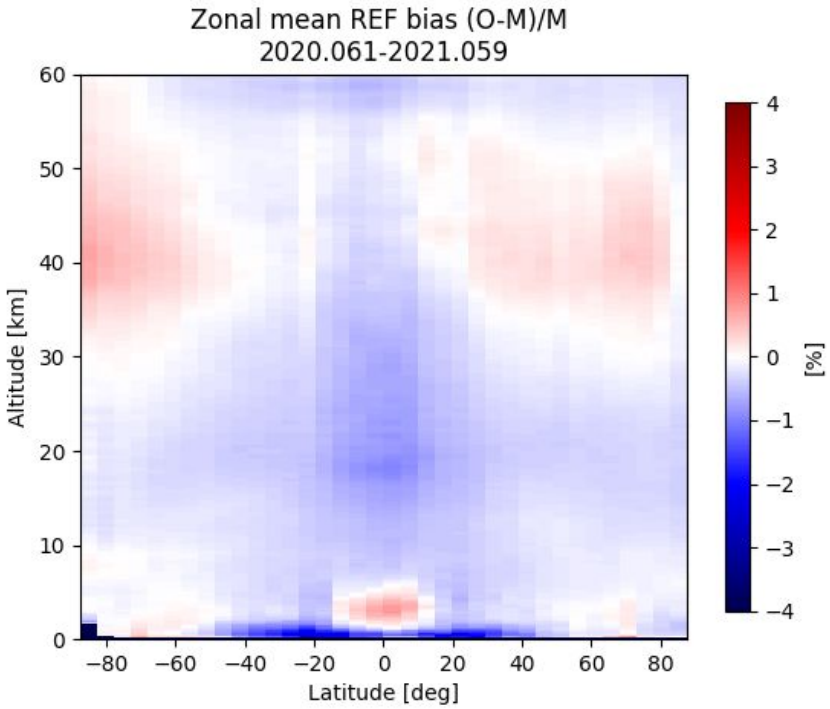


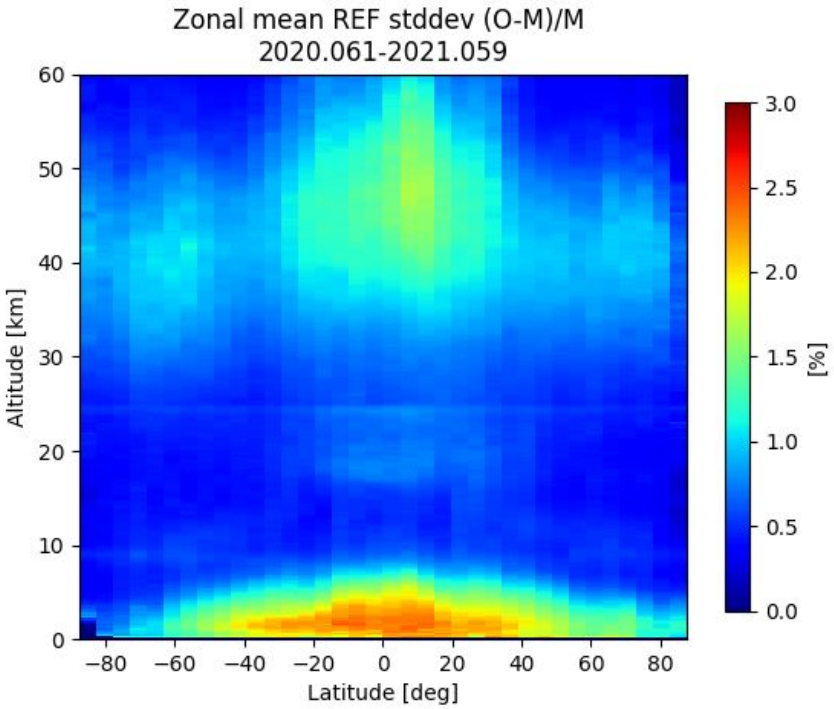


Some differences above 35 km

GRC vs. ECMWF operational analysis

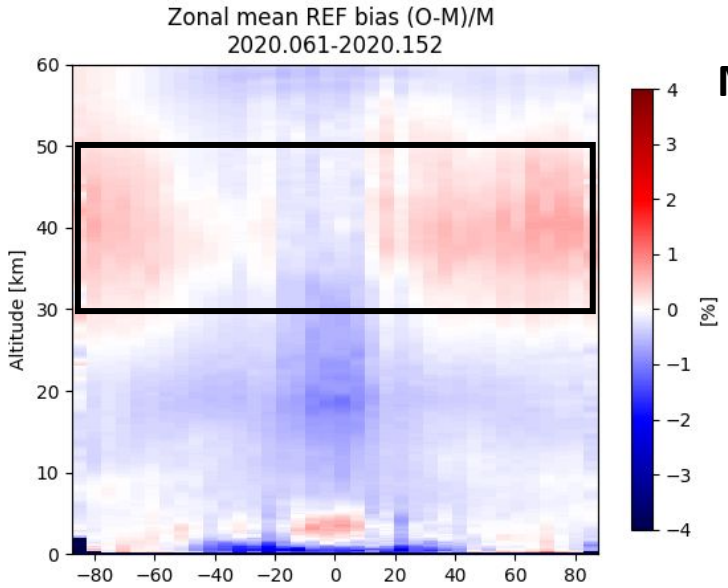
Zonal mean fractional refractivity (bias, stddev)
March 2020 – February 2021 (#73.701)





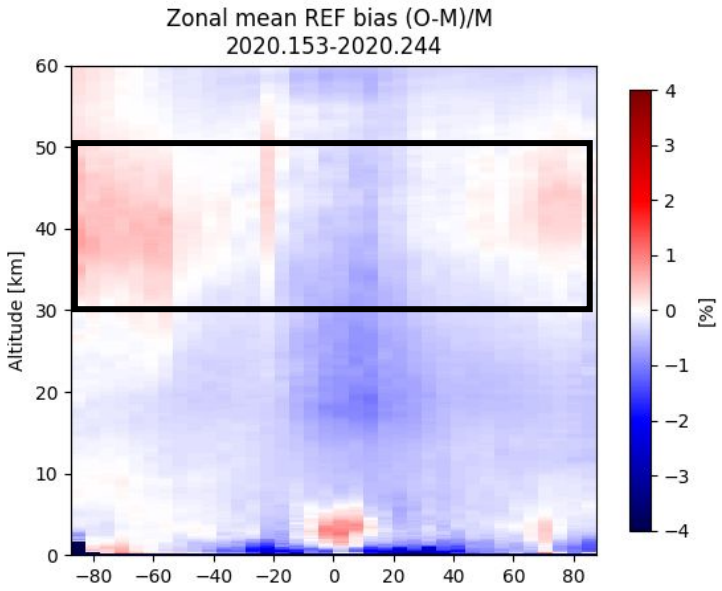
Tropics: bias of -0.5% to -0.6% in the tropopause region, positive bias below 5 km
Extratropics: slightly hemispheric differences above 30 km

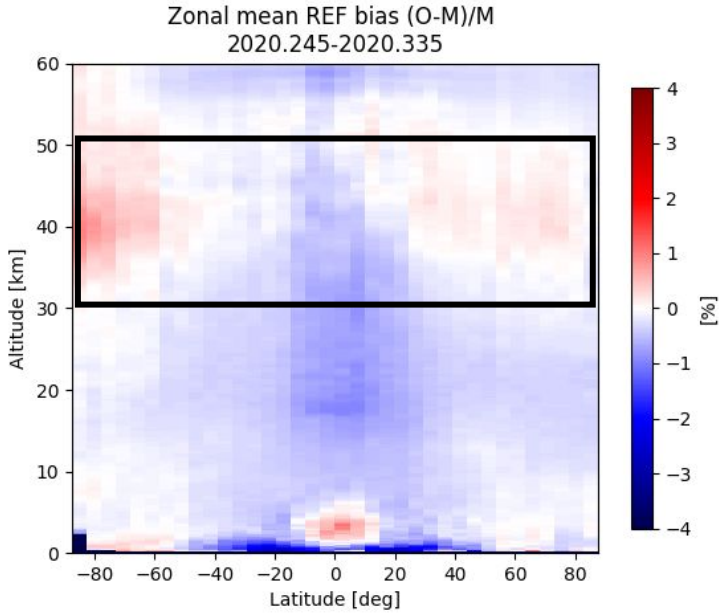
Seasonal refractivity bias



MAM

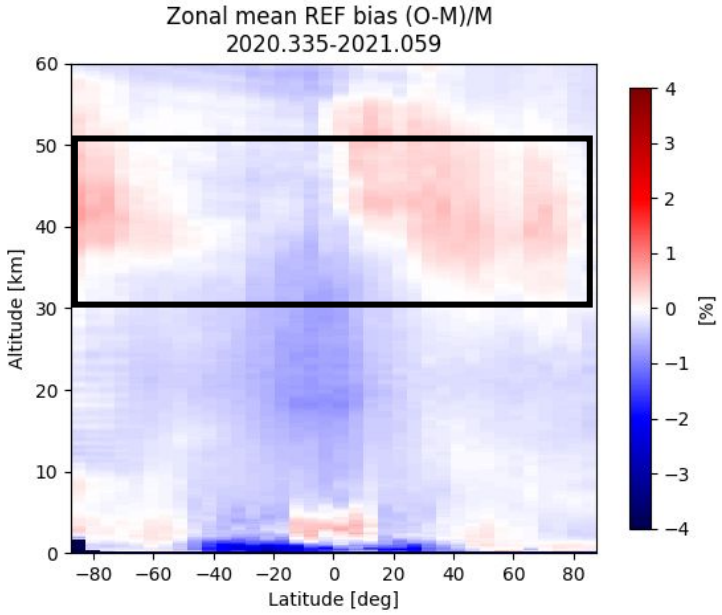
JJA



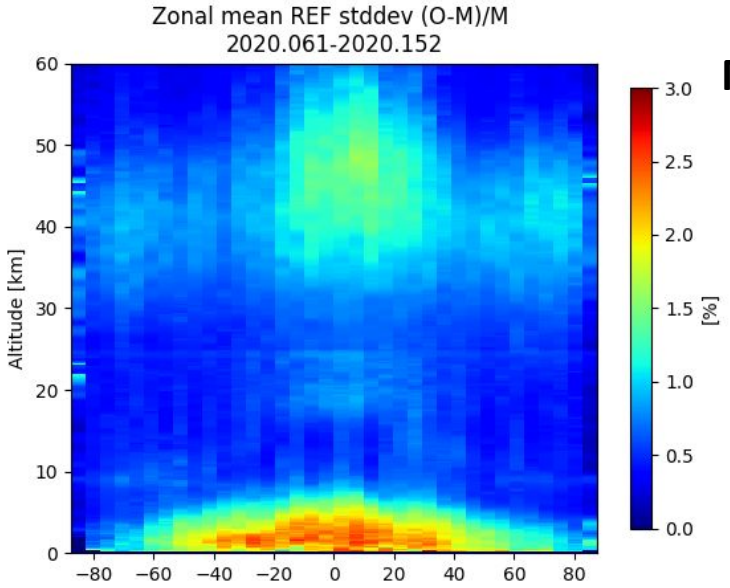


SON

DJF

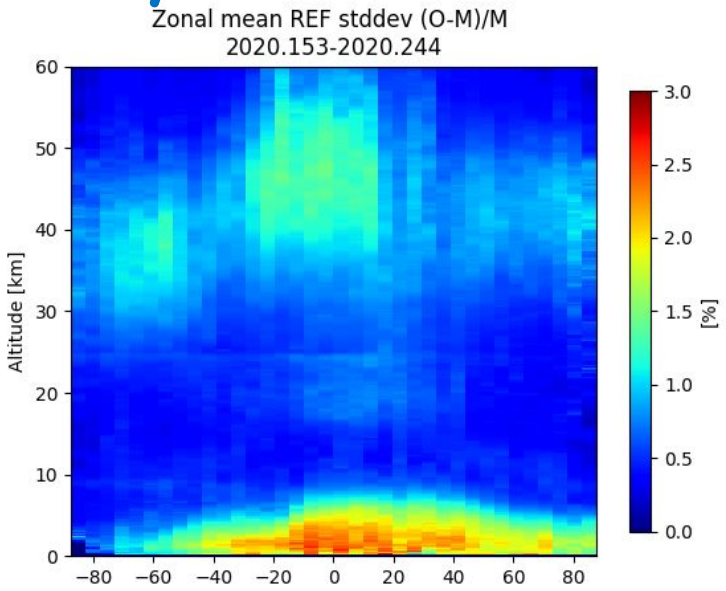


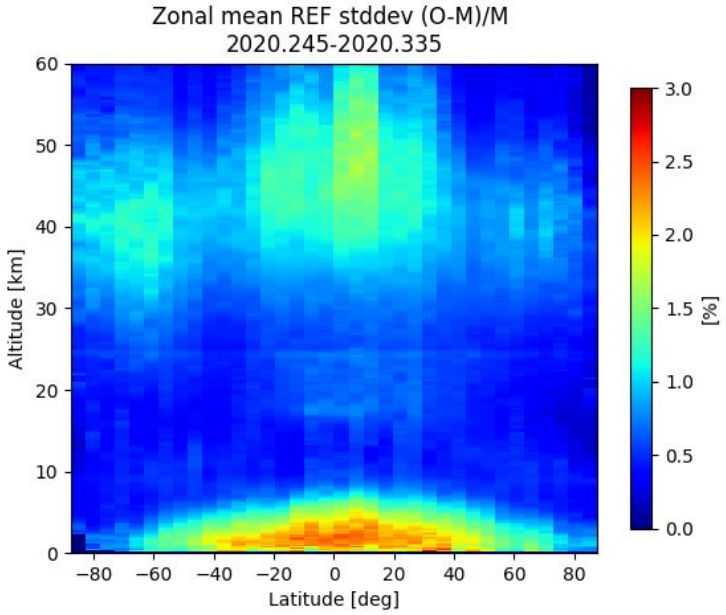
Seasonal refractivity stddev



MAM

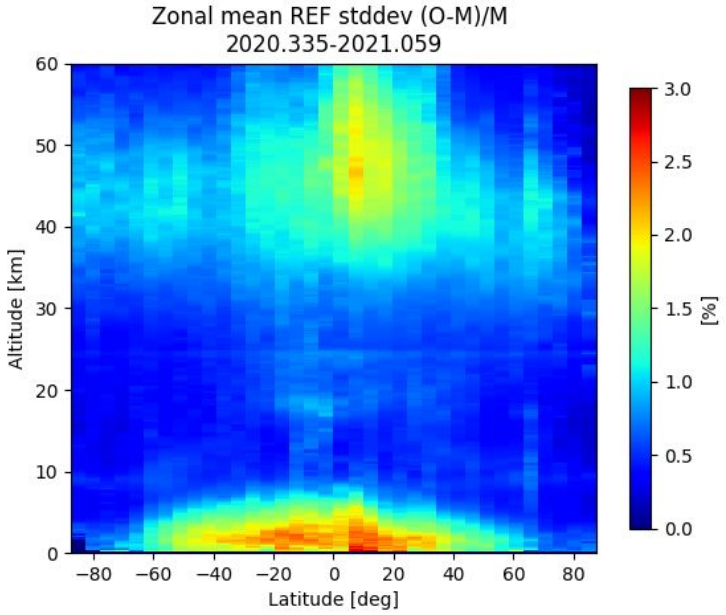
JJA





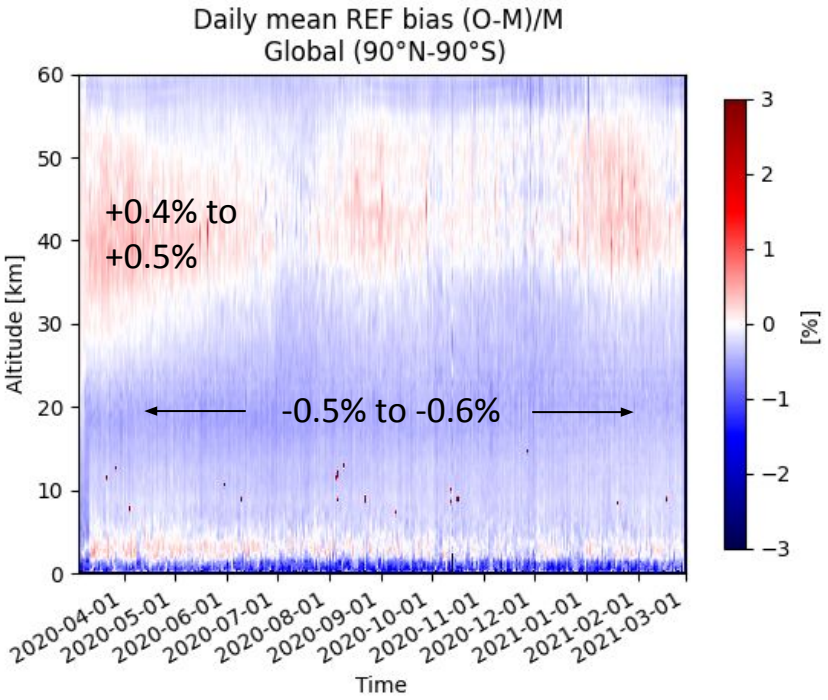
SON

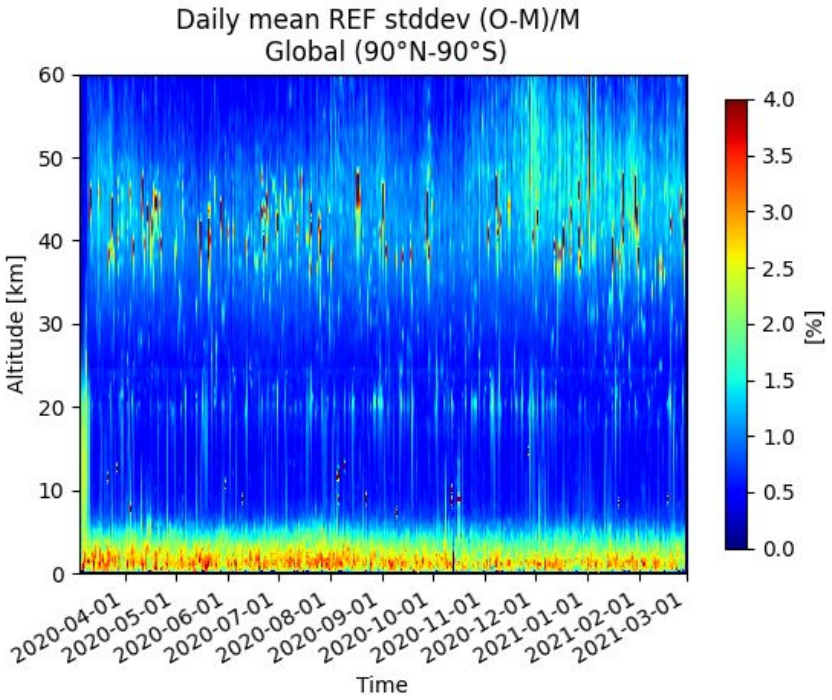
DJF



Temporal variation of bias and stddev

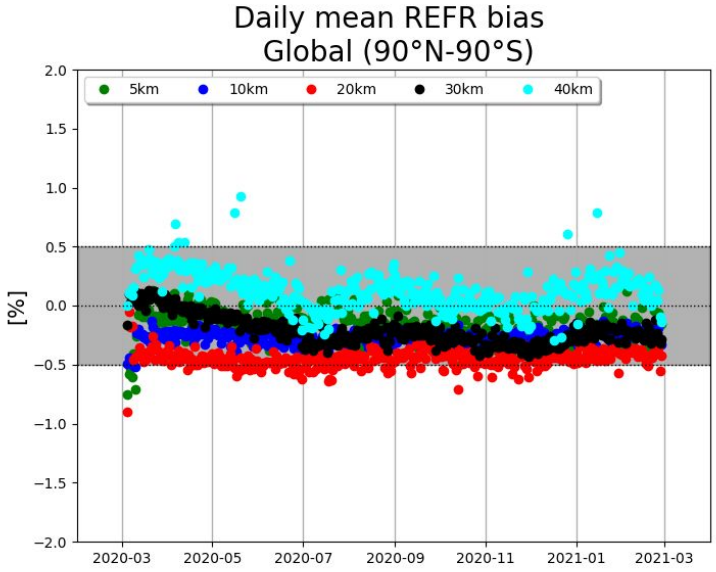
Daily mean fractional refractivity (bias, stddev)
90°N-90°S



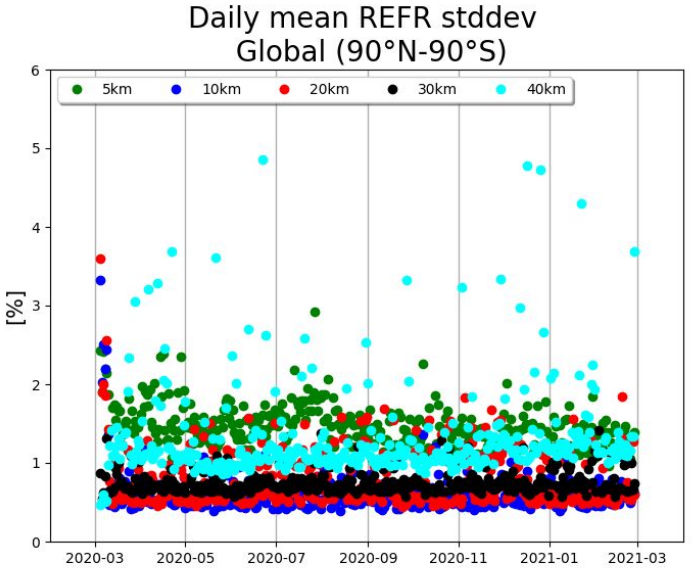


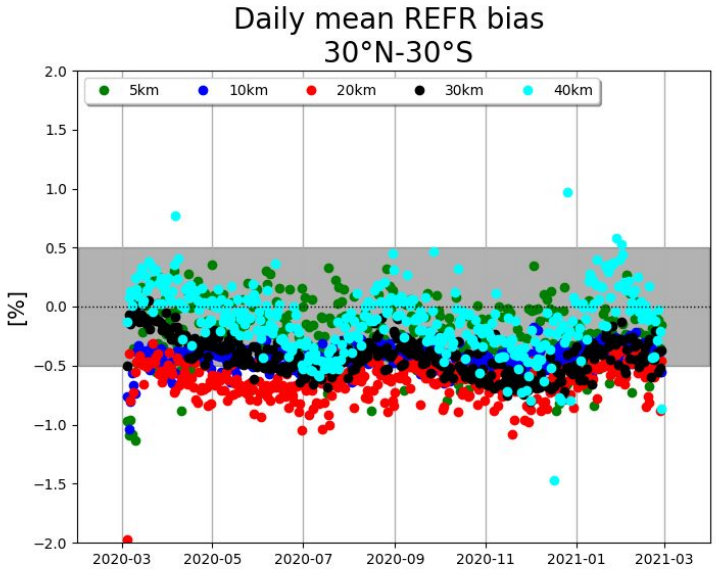
No significant trends in bias and stddev,
but some seasonal variations in higher altitudes

Temporal variation of bias and stddev

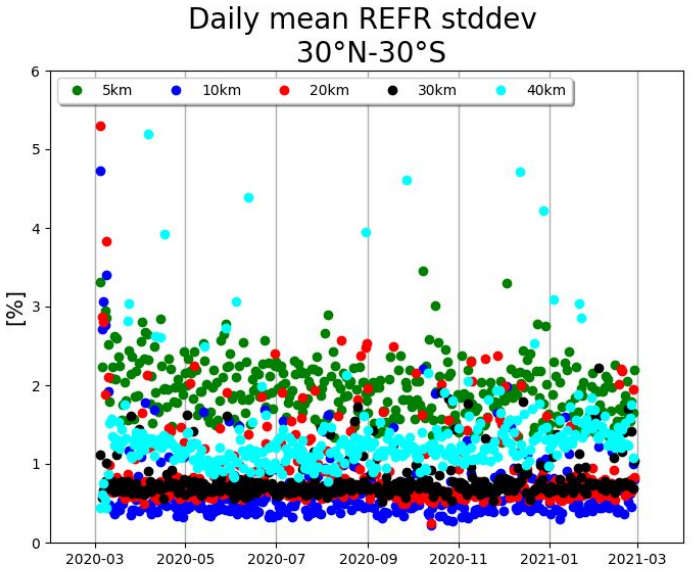


Global





Tropics



GRC comparison with COSMIC-2

Co-located COSMIC-2 NRT data ($\Delta d \leq 300$ km, $\Delta T \leq 3$ hrs)

1 Jan – 28 Feb 2021

Pairs found between 45°N and 45°S

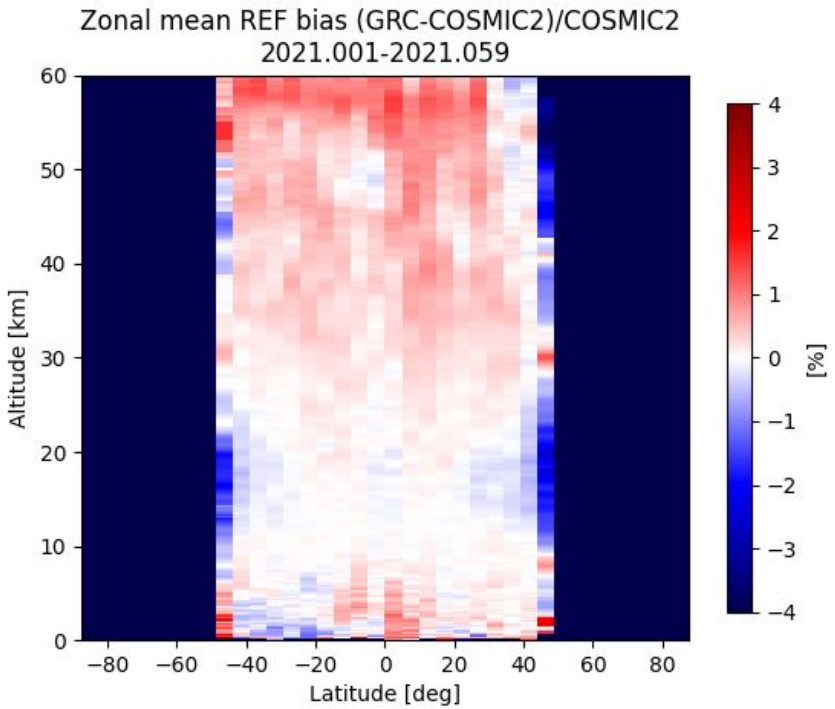
#ALL = 4593

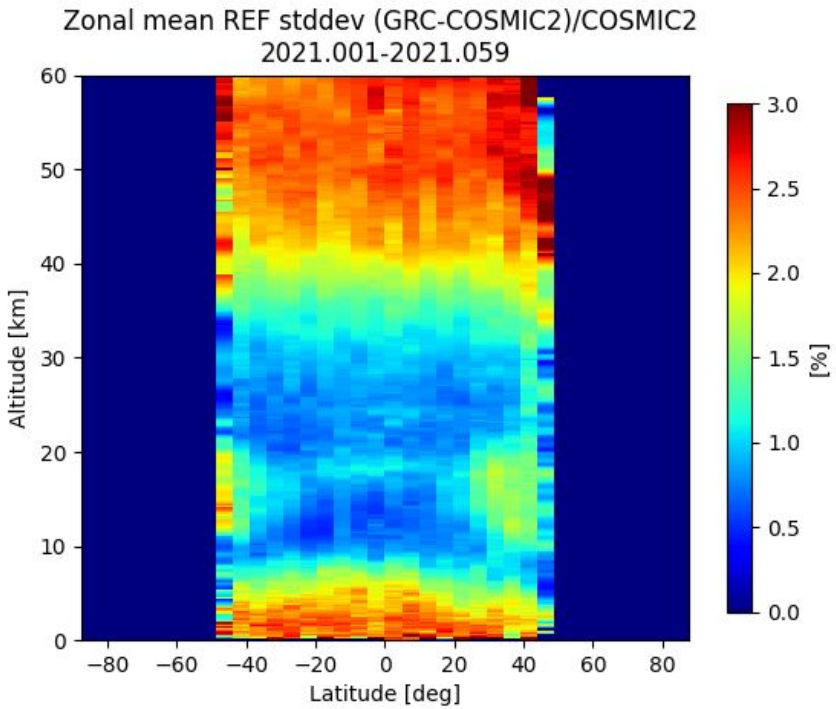
#Jan = 2324
#Feb = 2269

GRC comparison with COSMIC-2

Co-located COSMIC-2 NRT data (Δd≤300 km, ΔT≤3 hrs)
1 Jan – 28 Feb 2021

Fractional refractivity (GRC-COSMIC2)/COSMIC2

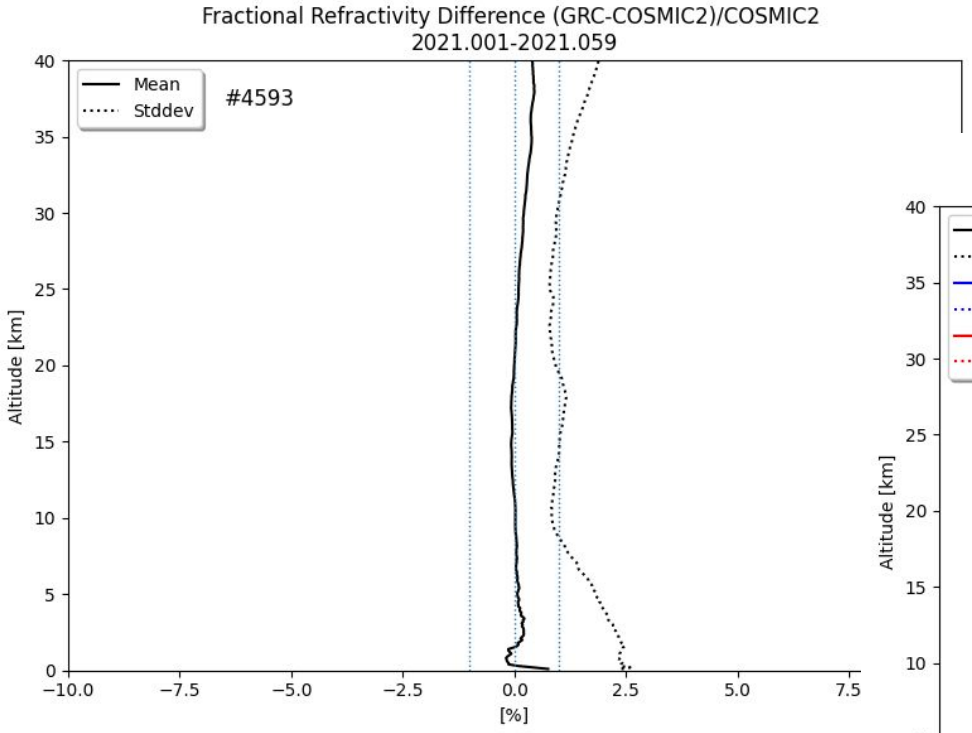


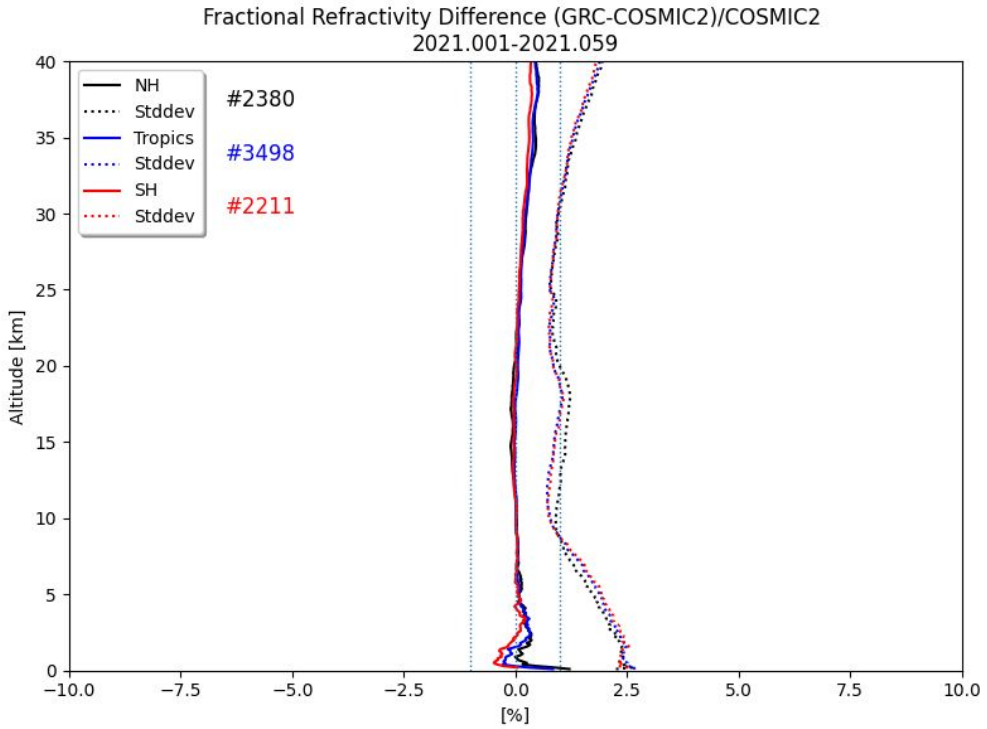


GRC comparison with COSMIC-2

Co-located COSMIC-2 NRT data (Δd≤300 km, ΔT≤3 hrs)
1 Jan – 28 Feb 2021

Fractional refractivity (GRC-COSMIC2)/COSMIC2

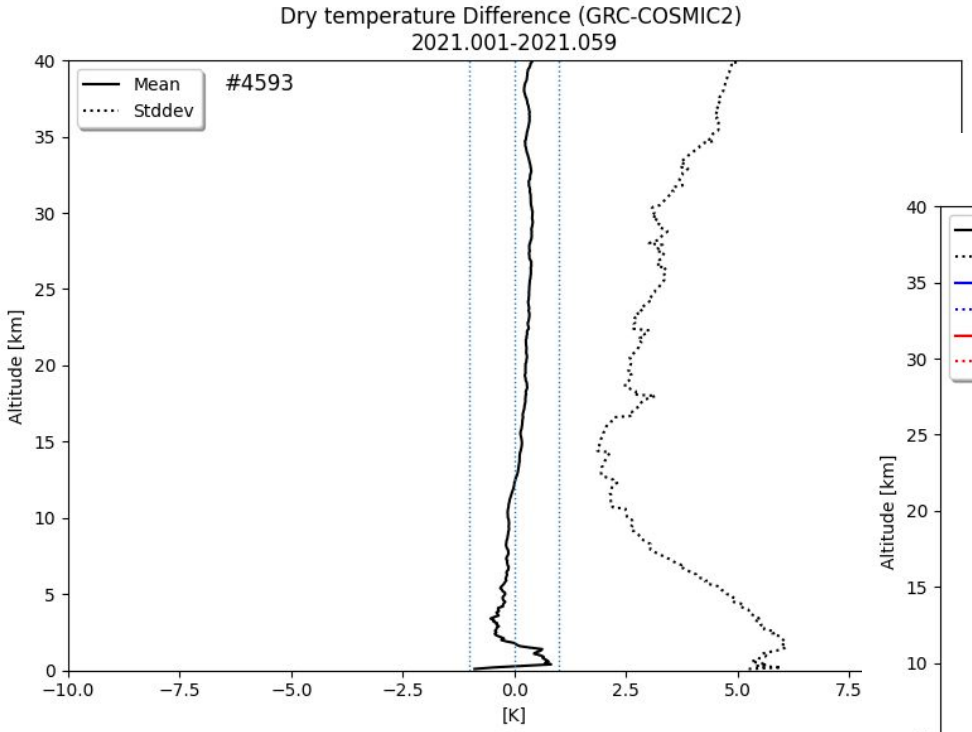


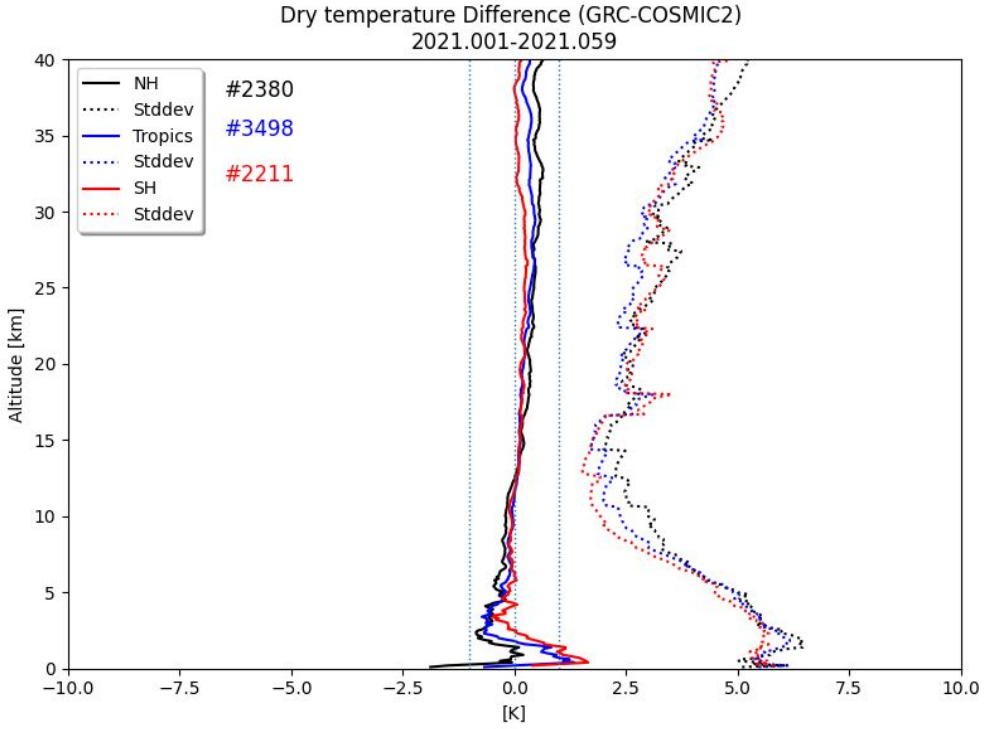


GRC comparison with COSMIC-2

Co-located COSMIC-2 NRT data (Δd≤300 km, ΔT≤3 hrs)
1 Jan – 28 Feb 2021

Dry temperature (GRC-COSMIC2)





Summary

- Continuous GRACE-FO data since March 2020
- Rising occultations on GRC
- About 200 successfully processed occultations daily
- Slightly negative refractivity bias in comparison to operational ECMWF data
- Good agreement of refractivity and dry temperature with co-located COSMIC-2 data in the tropics
- Further improvements of retrieval software (e.g., GO/WO transition)
- Test bufr data for NRT usage available: ftp.gfz-potsdam.de/pub/incoming/tschmidt/TESTBUFR
- Setting occultations on GRD in discussion