GNSS radio occultations: processing at GFZ and applications for weather and climate research

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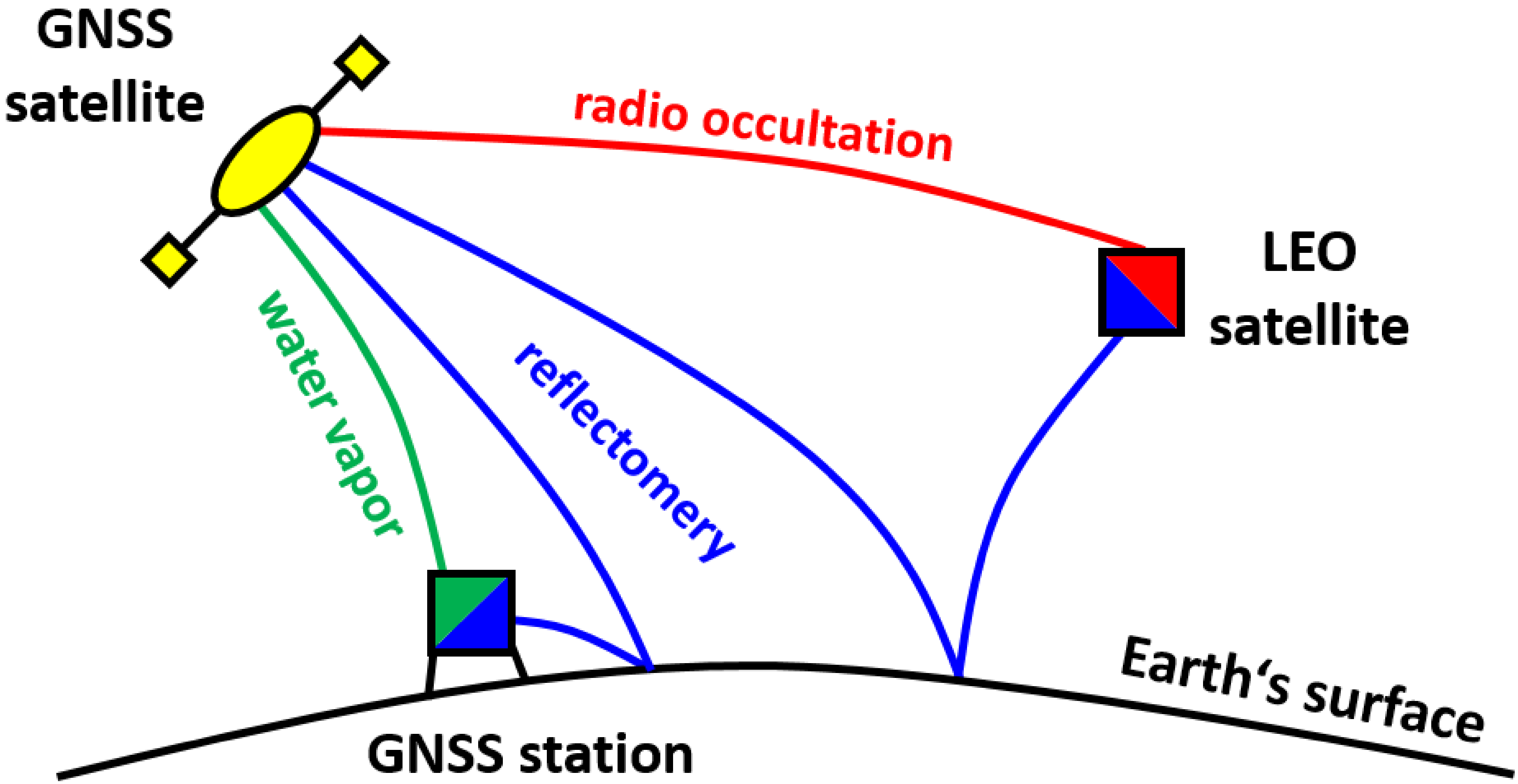
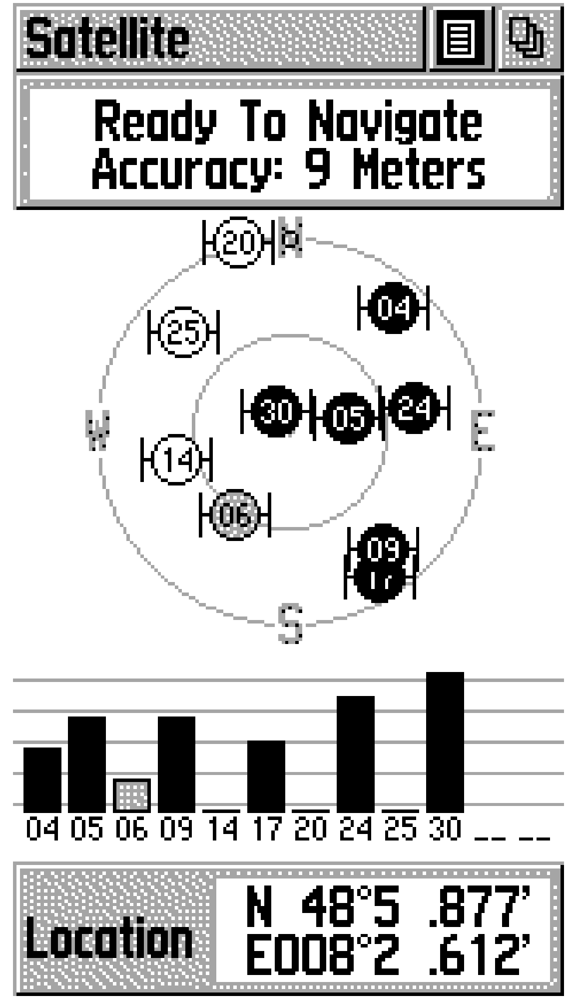
GNSS meteorology at GFZ Potsdam

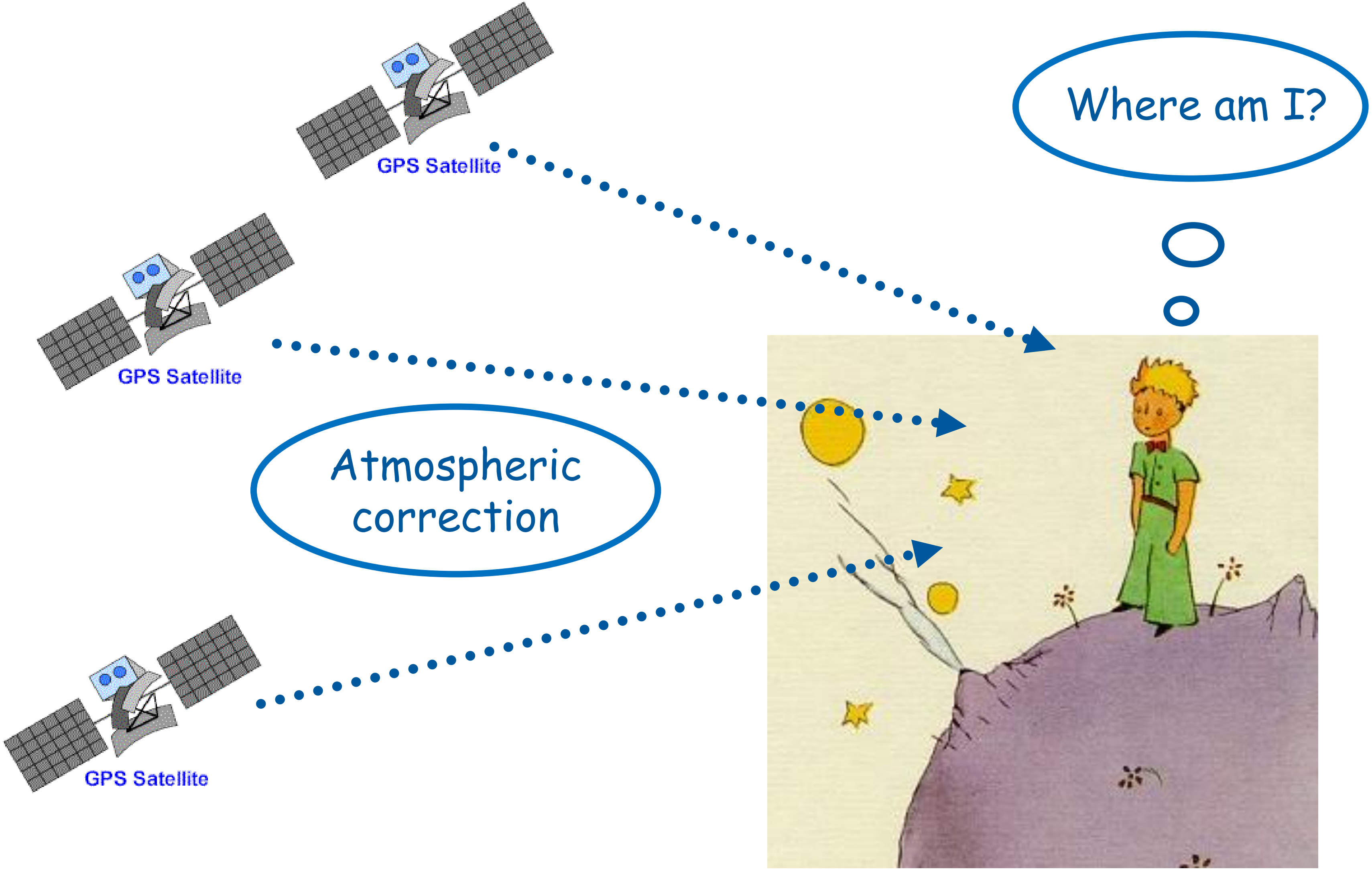


GNSS for positioning

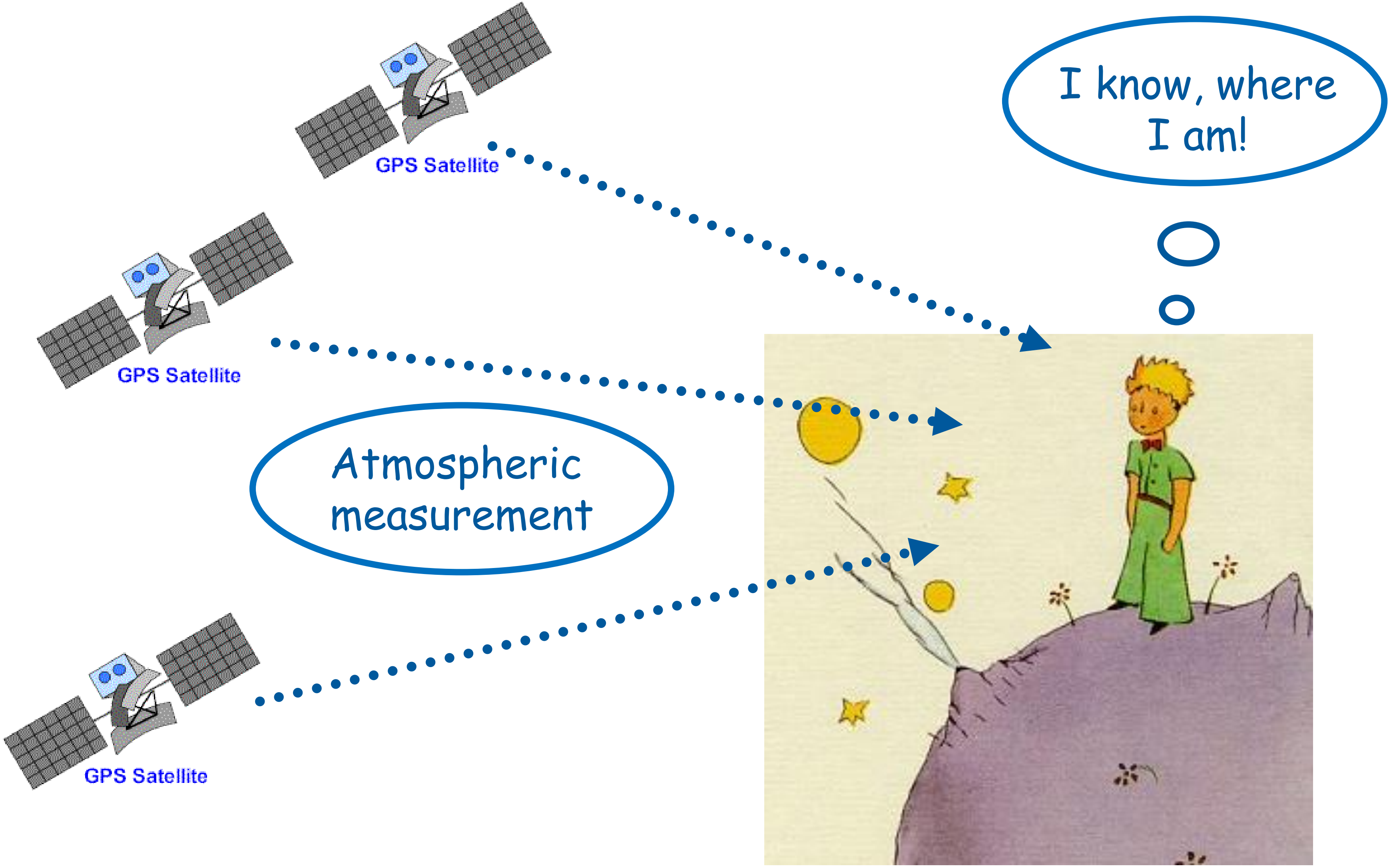


But applicable for remote sensing of the atmosphere?

GNSS for positioning

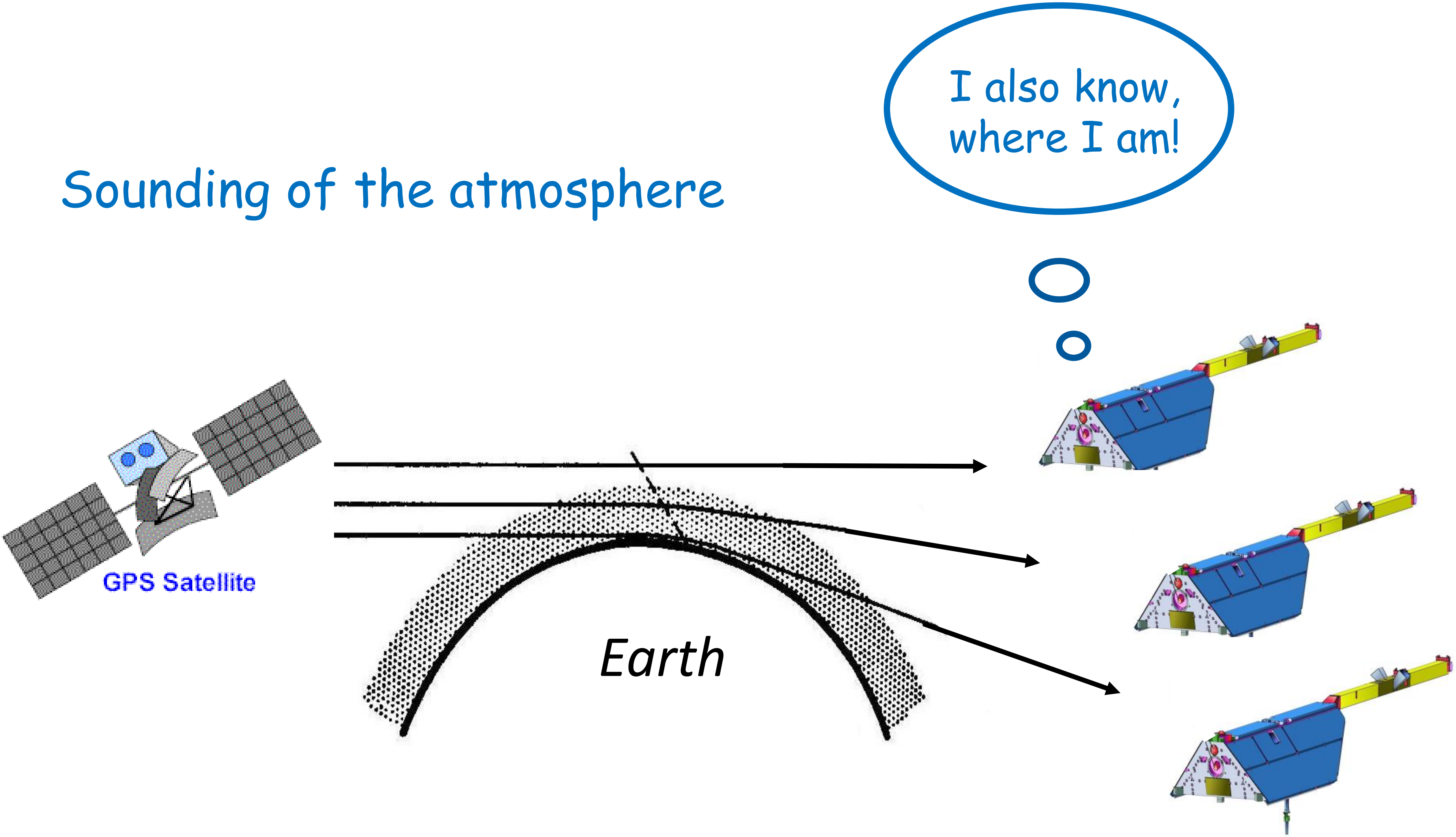


GNSS-based remote sensing

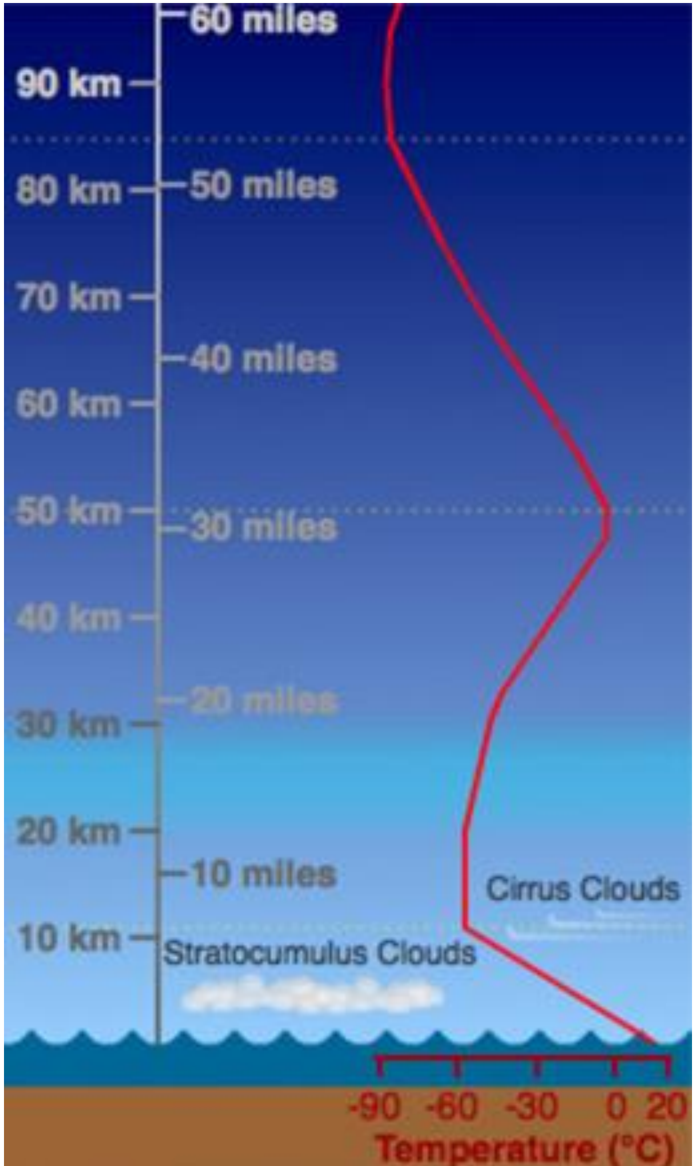


GNSS-based remote sensing

Sounding of the atmosphere



Vertical structure of the atmosphere



Mesopause

Mesosphere

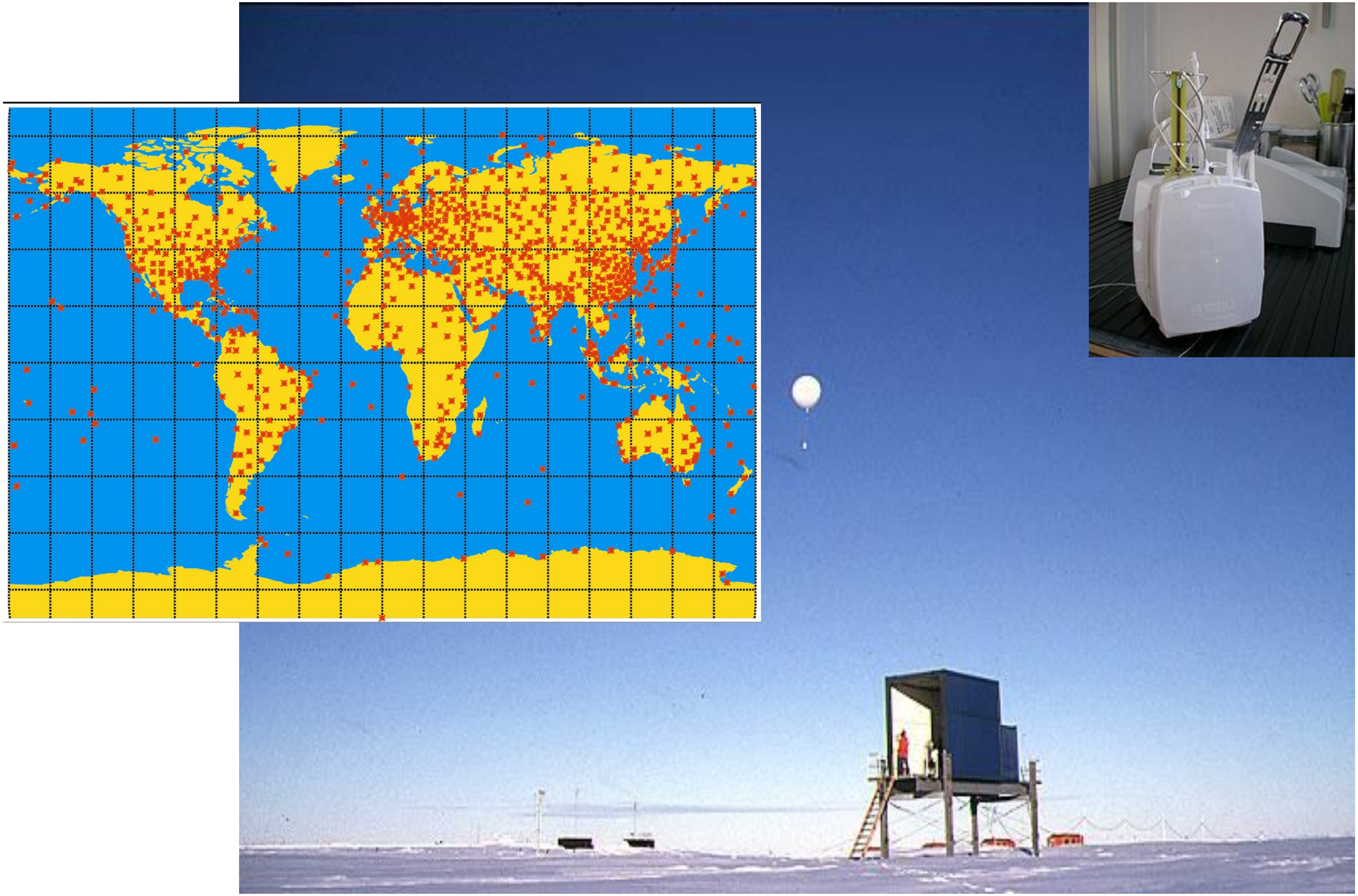
Stratopause

Stratosphere

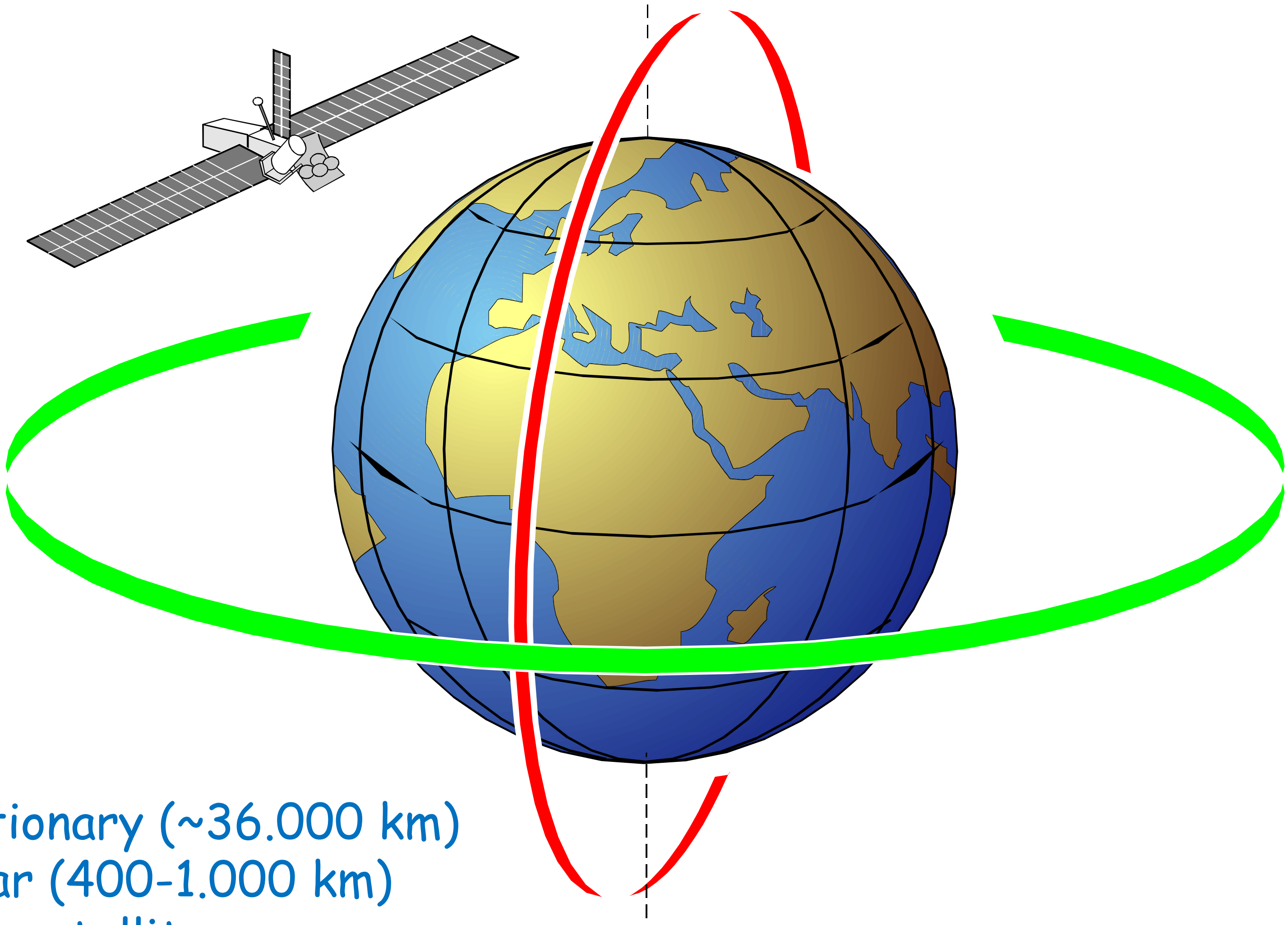
Tropopause

Troposphere

Classical method: radiosondes

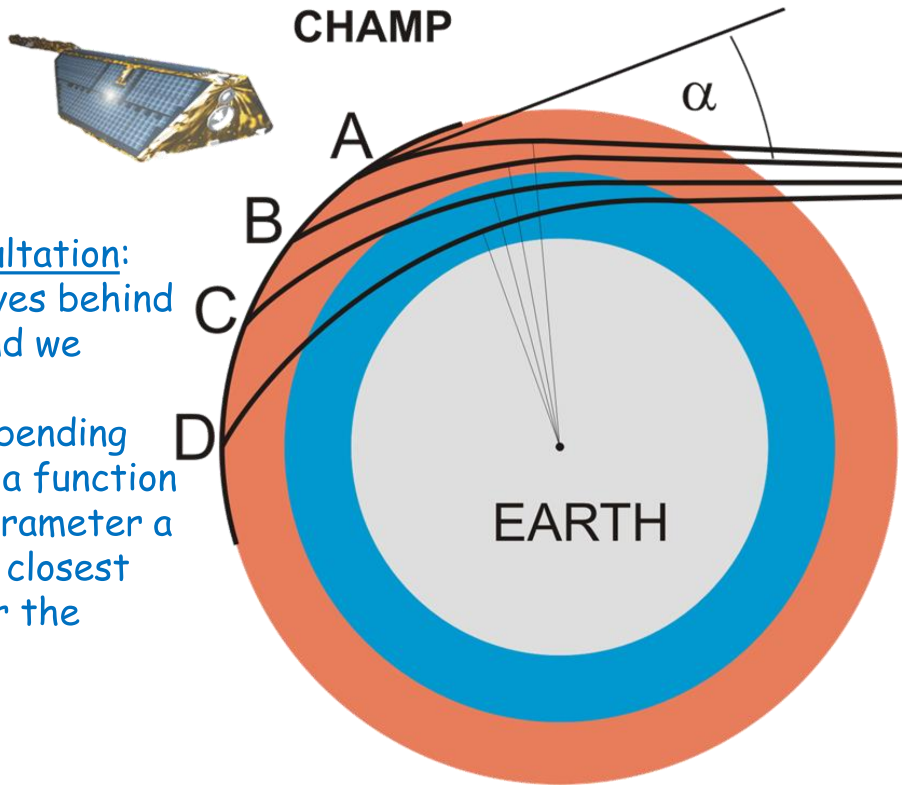


Remote sensing with satellites

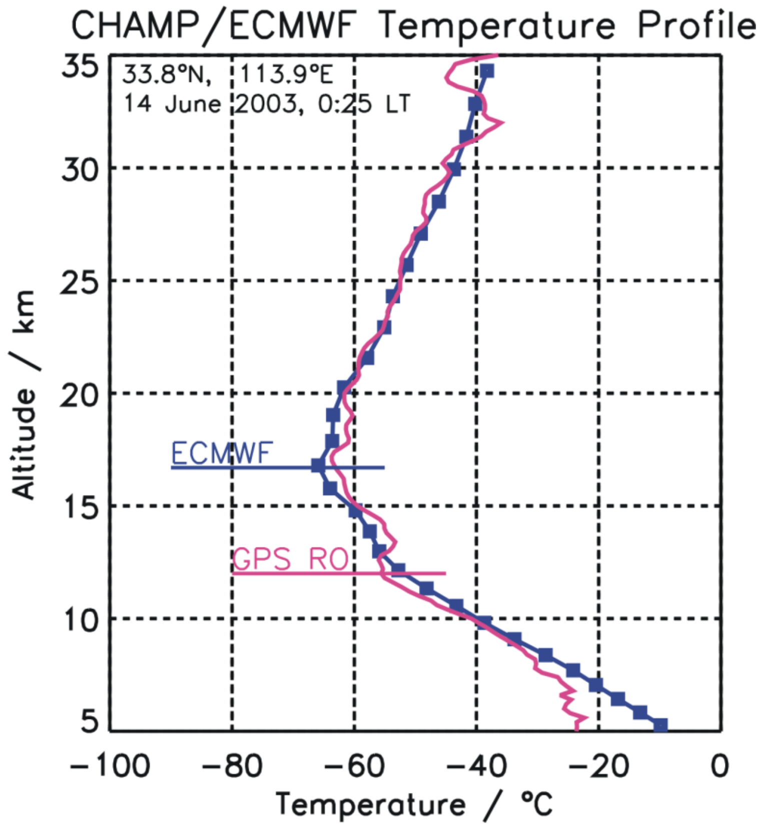


Geostationary (~36.000 km)
and polar (400-1.000 km)
orbiting satellites

Radio occultation method



<u>Setting occultation</u>: the LEO moves behind the earth and we obtain a profile of bending angles, a, as a function of impact parameter a (distance of closest approach for the straight line path).

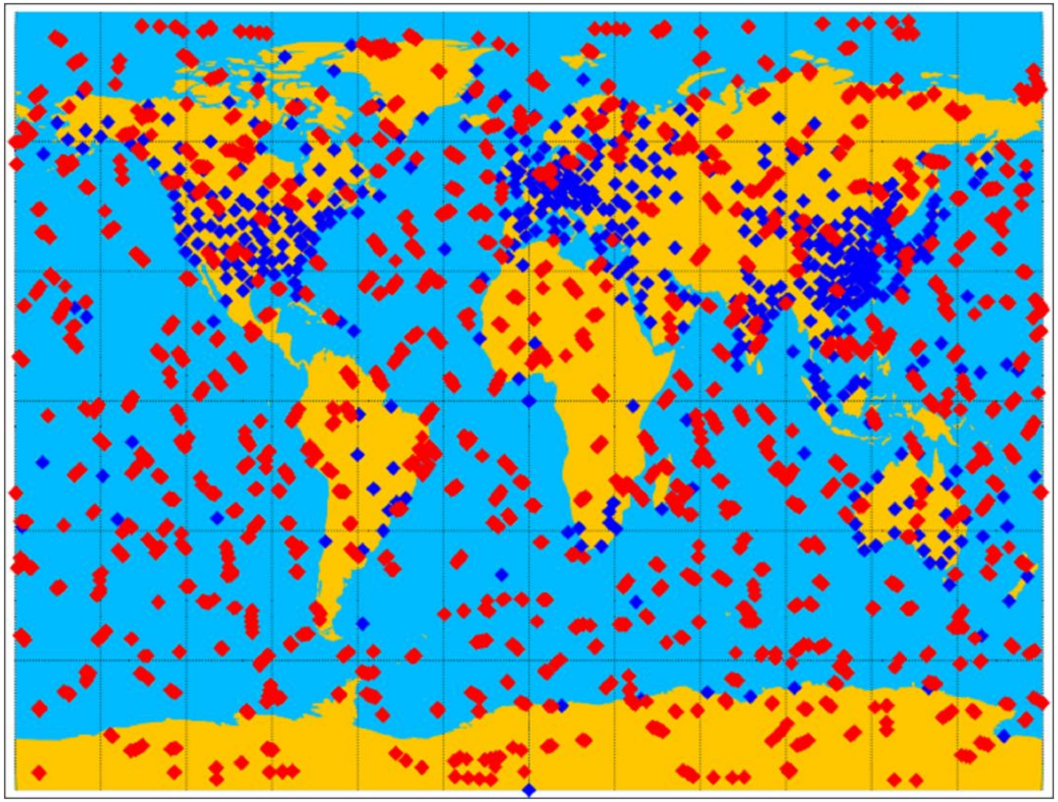


$$\ln n(r) = \frac{1}{\pi}\int_a^{\infty} da' \frac{\alpha(a')}{\sqrt{a'^2 - a^2}}$$

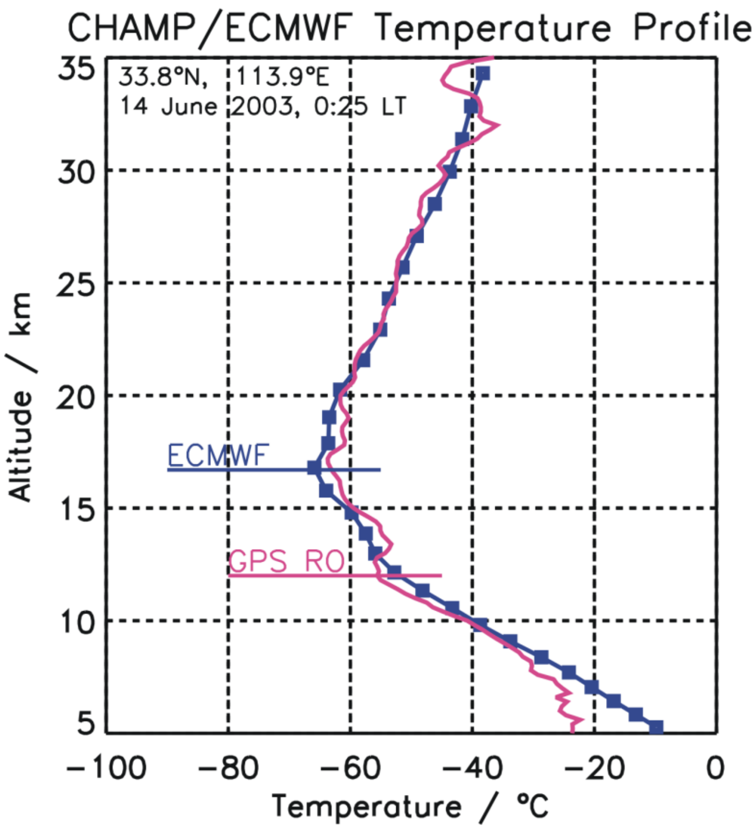
$n = n(r)$

$$N = (n-1)\times 10^6 = 77.6\frac{p}{T} + \cancel{3.73\times 10^5 \frac{p_w}{T^2}}$$

Radio occultation characteristics



High vertical resolution
Global coverage

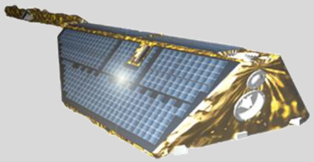


Weather independent
Calibration free
Long-term stable

Radio occultation missions

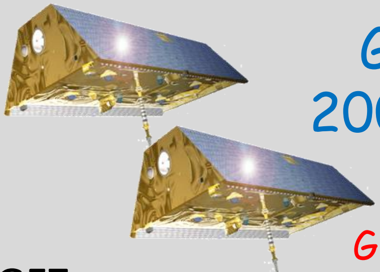
GPS/MET
1995/1997

SAC-C
2001…2011



CHAMP
2001-2008

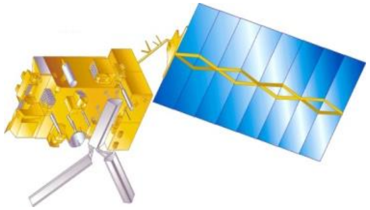
GFZ



GRACE
2006-2017

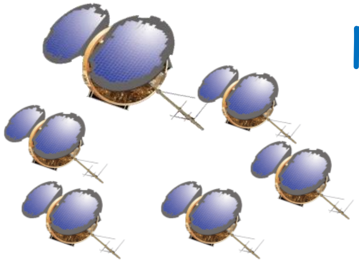
GRACE-FO
launched in 2018

GFZ



Metop-A,B
since 2006

Metop-C
launched in 2018



FORMOSAT-3/
COSMIC
since 2006

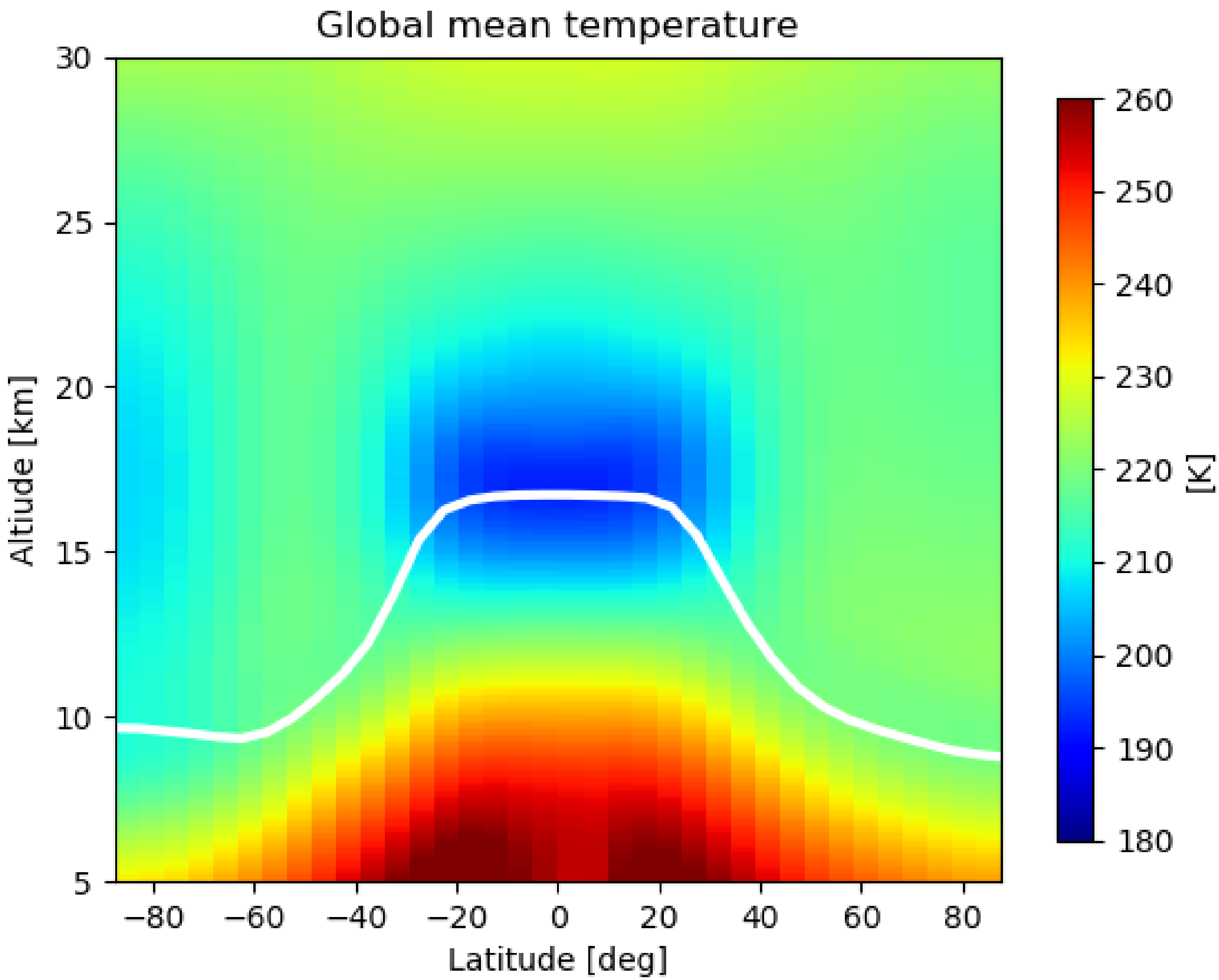
COSMIC-2
launched in 2019

TerraSAR-X since 2008
Tandem-X since 2011

GFZ

Also private companies (Spire, since 2017)

Temperature climatology 2002-2018



Data base

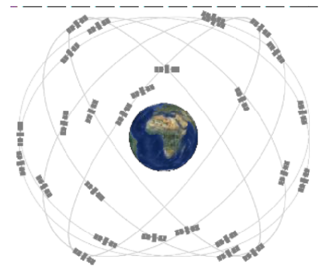
CHAMP
GRACE
COSMIC
Metop

(update Schmidt et al., ASR, 2010)

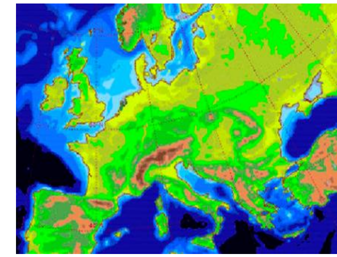
Radio occultation processing system

LEO data via GFZ polar receiving station

GPS and LEO orbits from GFZ orbit group

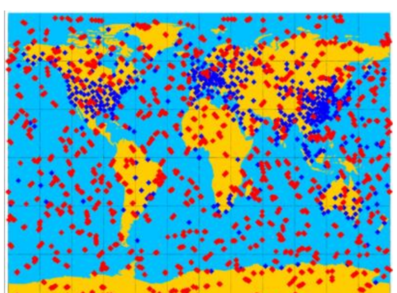


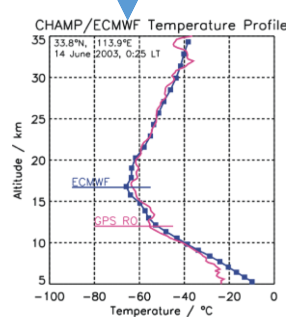
External weather data for validation (ECMWF)



Operational Radio Occultation Processing System

Bending angle, refractivity and temperature profiles for weather centers and other data user.



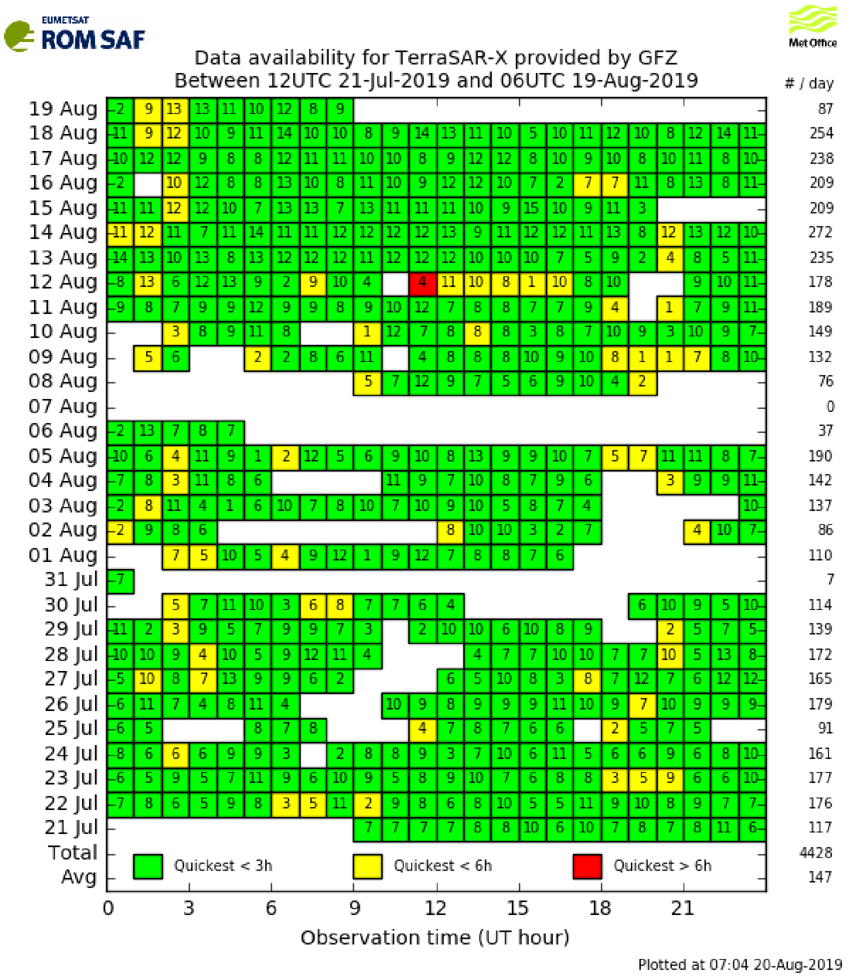


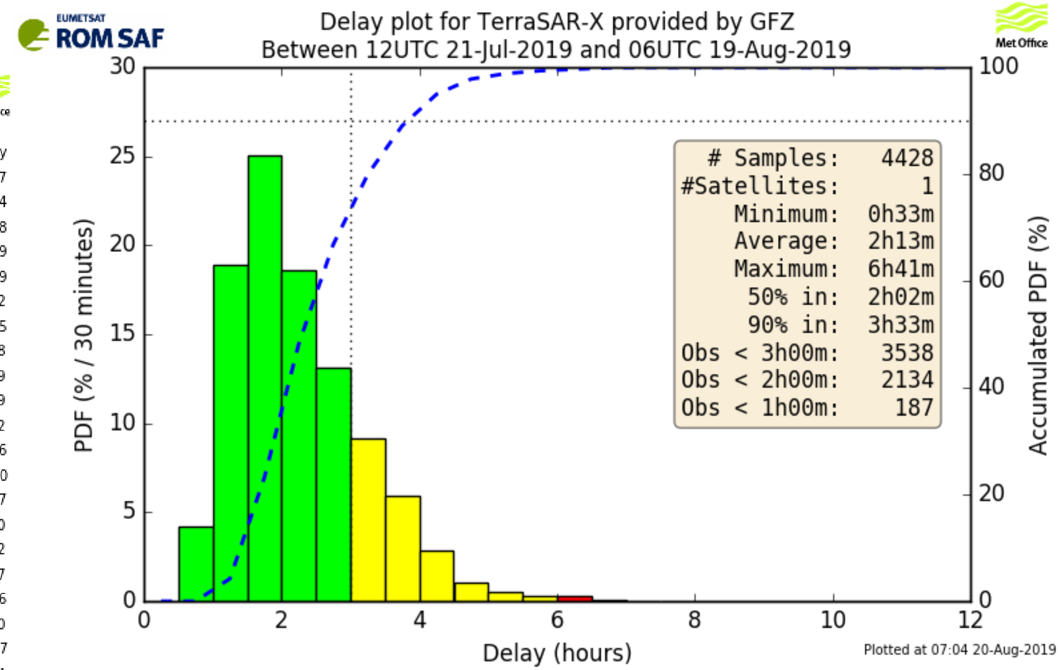
Data Center

User

Example: TerraSAR-X data delivery

21 July to 19 August 2019

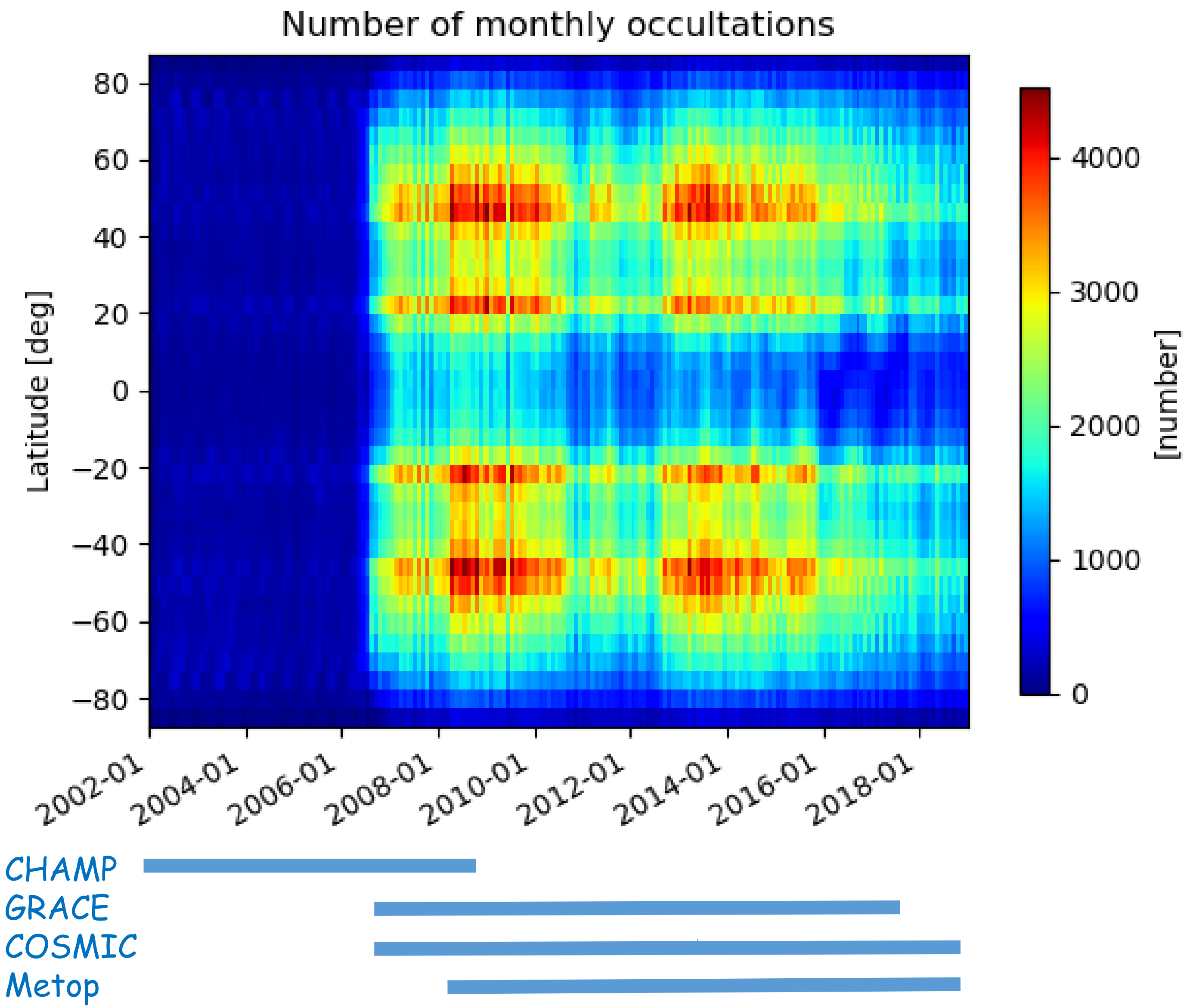




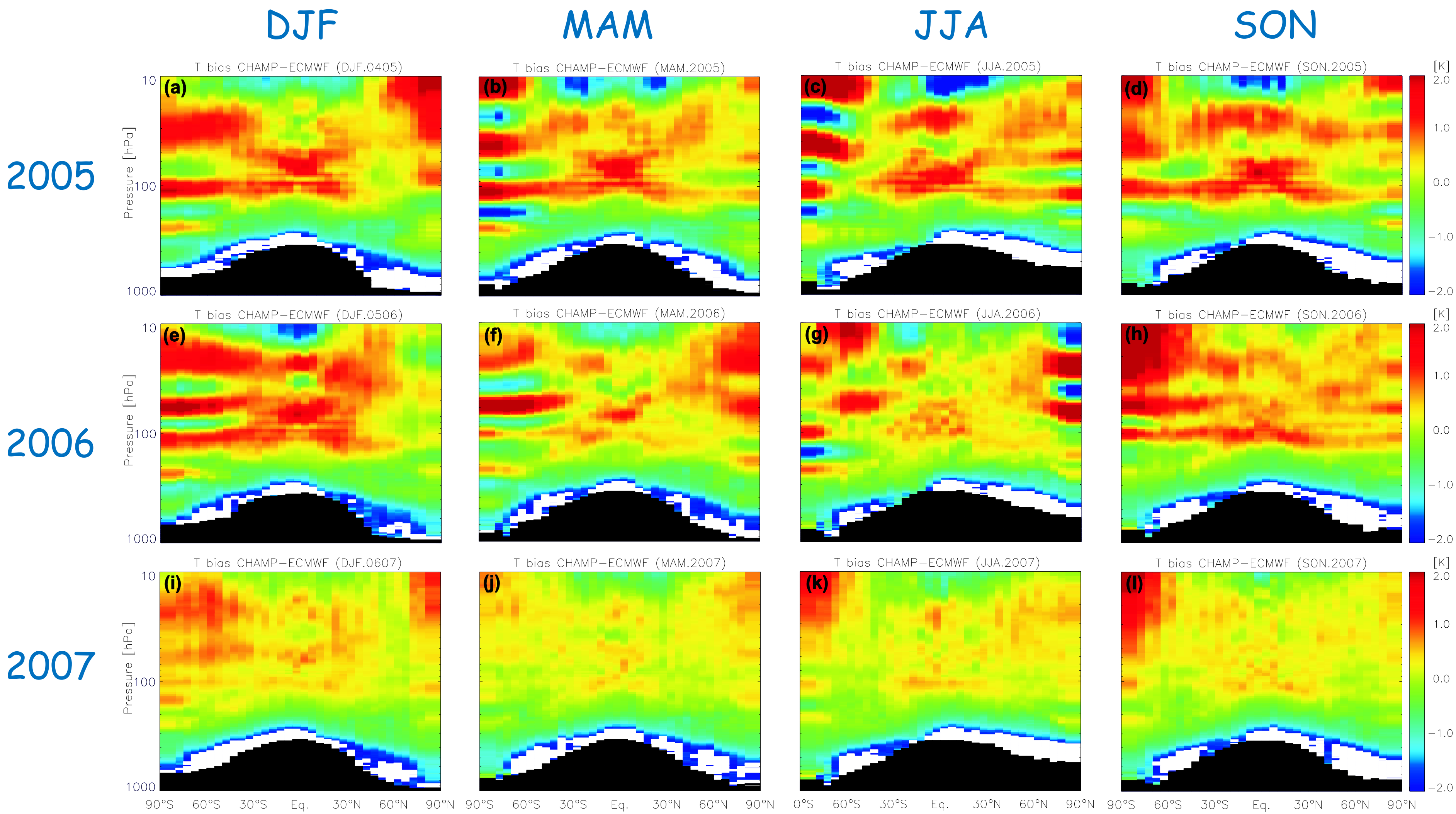
Mean time delay between onboard measurements and data availability is about 2 hours.

90% of all data are delivered within 3 hours.

Database 2002-2018



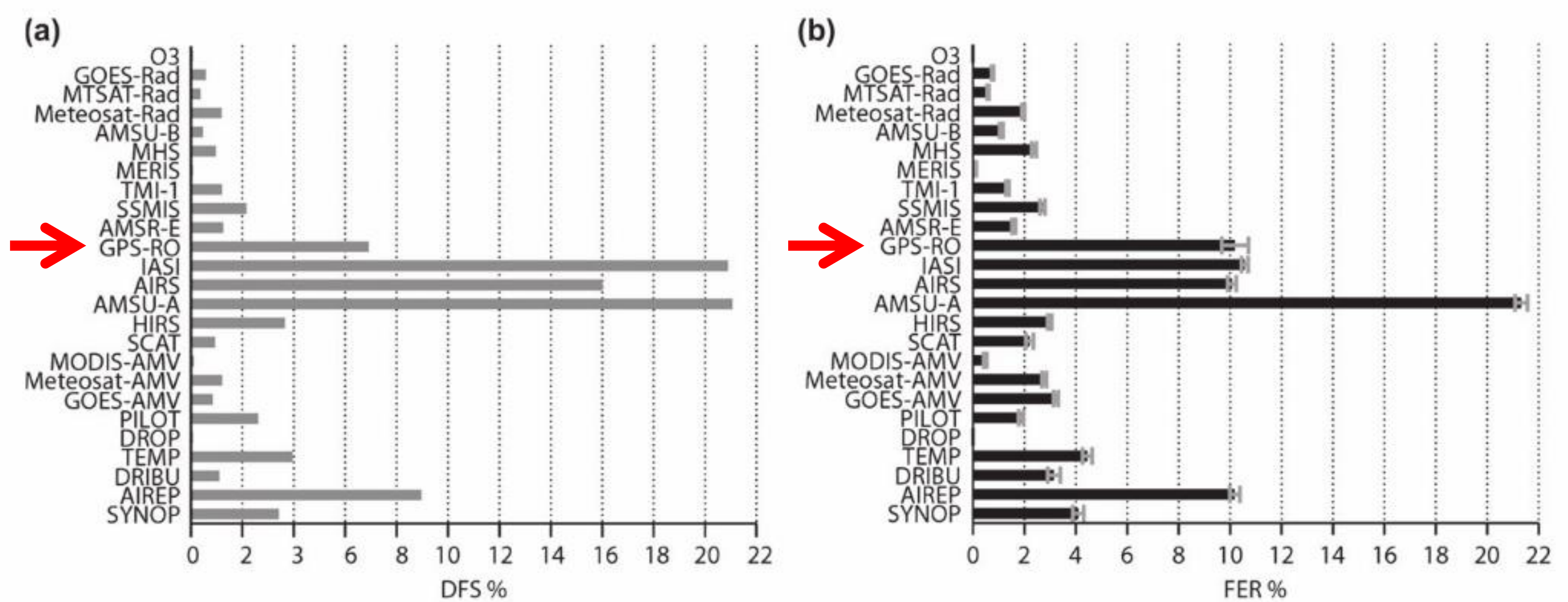
Impact of RO data at ECMWF



(from Schmidt et al., *AG*, 2008)

Impact of RO data at ECMWF

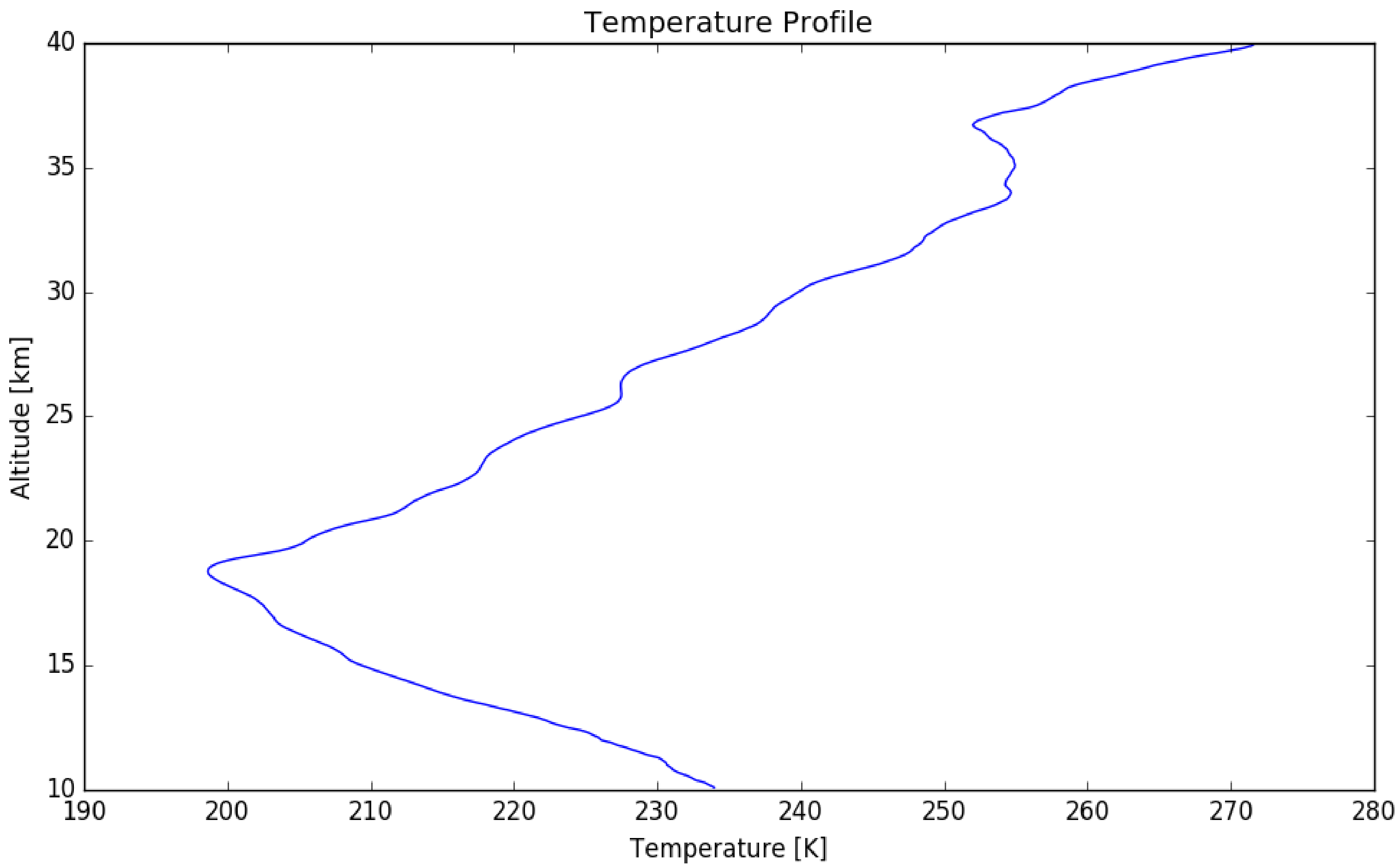
"GPS-RO is found to have the largest mean influence among satellite observations in the analysis. It is the fourth best satellite system for analysis information content and the second largest satellite contributor together with IASI and AIRS to decreasing the 24 h forecast error."



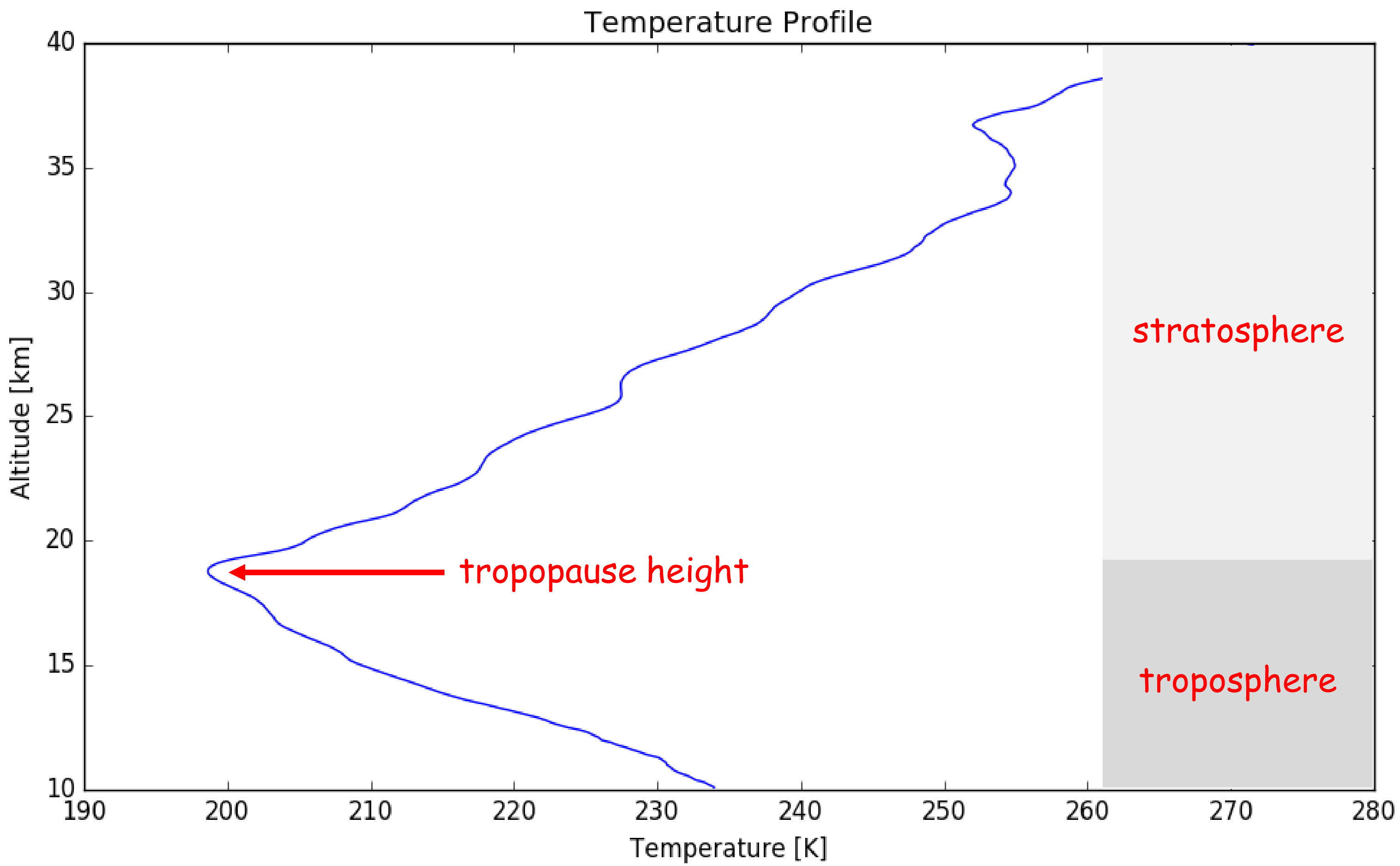
In the ECMWF system, GPS-RO provides the 7% of all observations (left) and 10% of forecast error reduction (right).

***Source:** Cardinali and Healy, Impact of GPS radio occultation measurements in the ECMWF system using adjoint-based diagnostics, Q. J. R. Meteorol. Soc. 140: 2315–2320, doi:10.1002/qj.2300, 2014.*

Atmospheric studies with RO data



Atmospheric studies with RO data

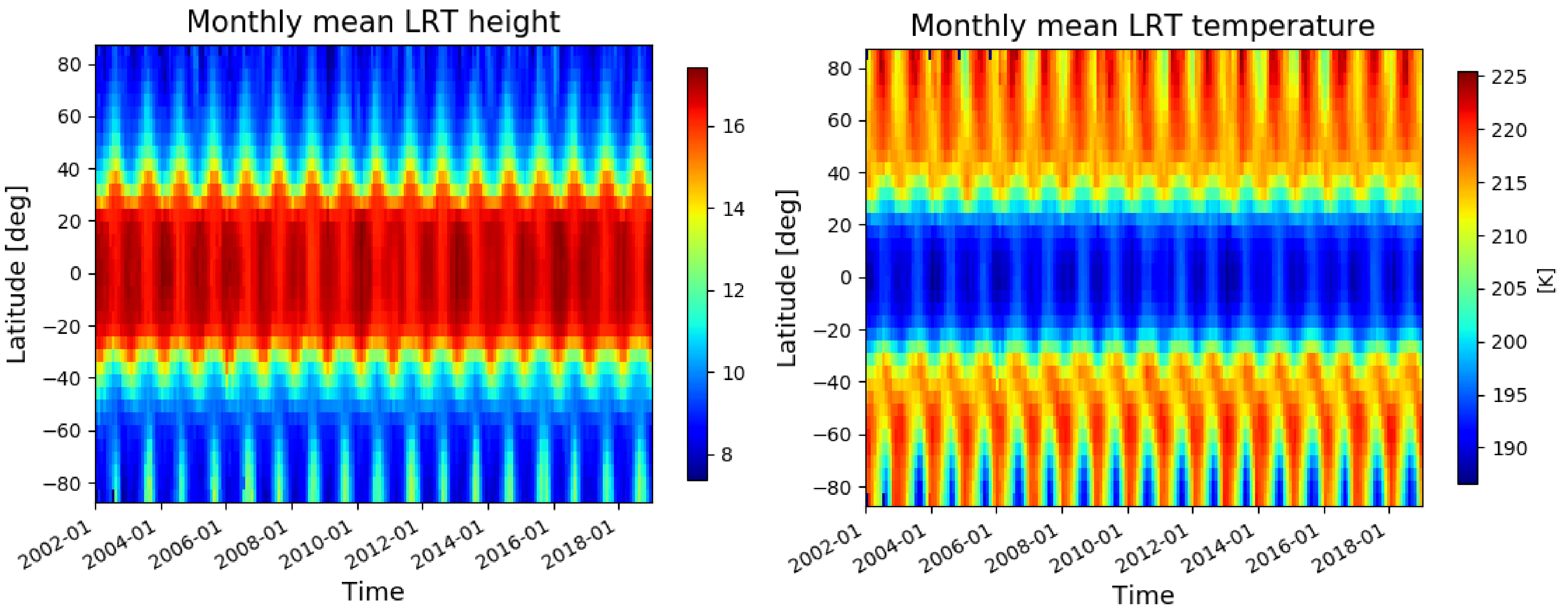


- Temperature monitoring in the UTLS
- Tropopause dynamics – multiple tropopauses, TIL
- Gravity wave analysis – potential energy, momentum flux estimation

Tropopause climatologies

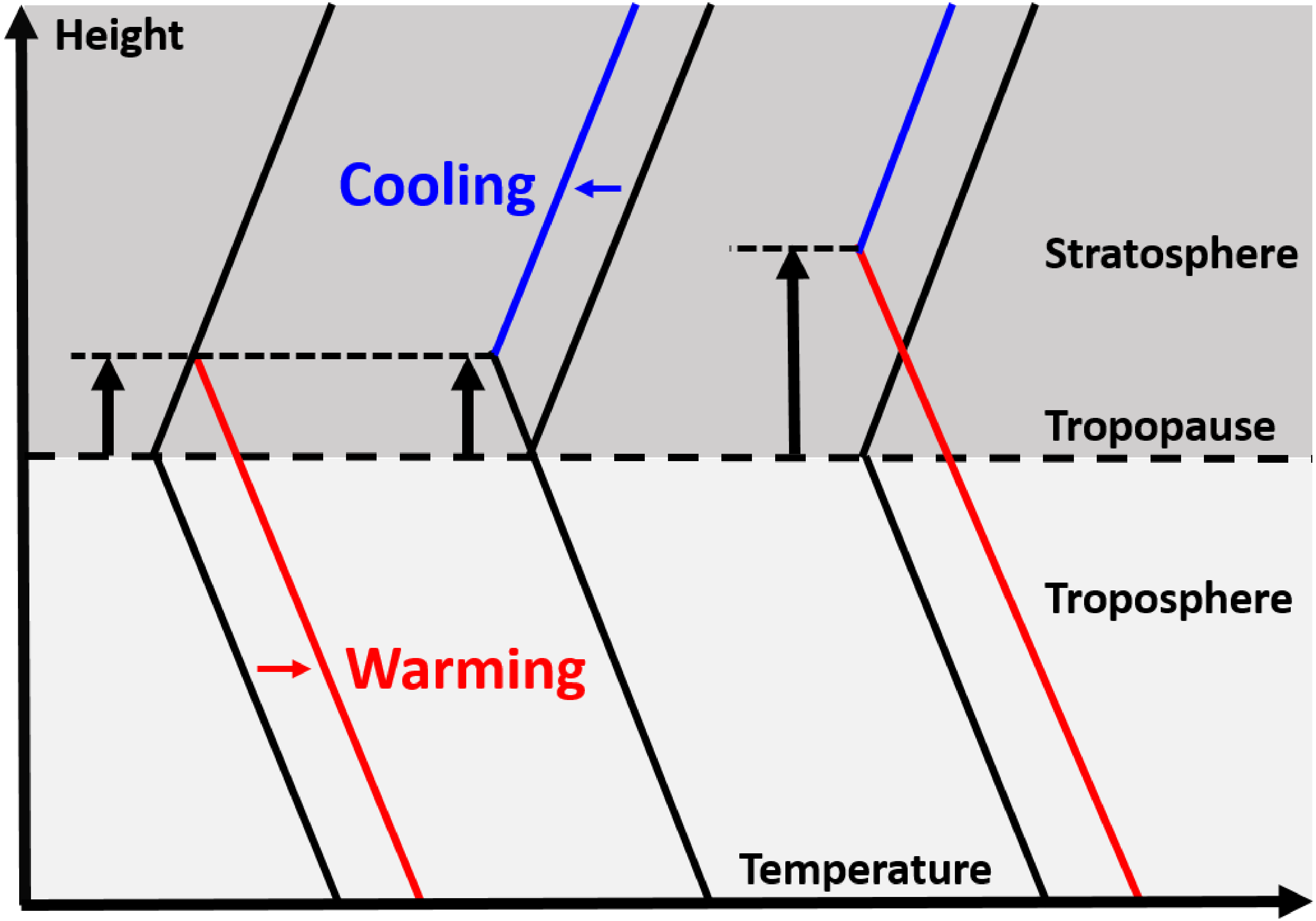
Setup

- Lapse-rate tropopause (LRT) estimation after WMO
- Zonal monthly means (Jan 2002 to Dec 2018, 204 months)
- 5 degree latitude bins centered at 87.5°N … 87.5°S



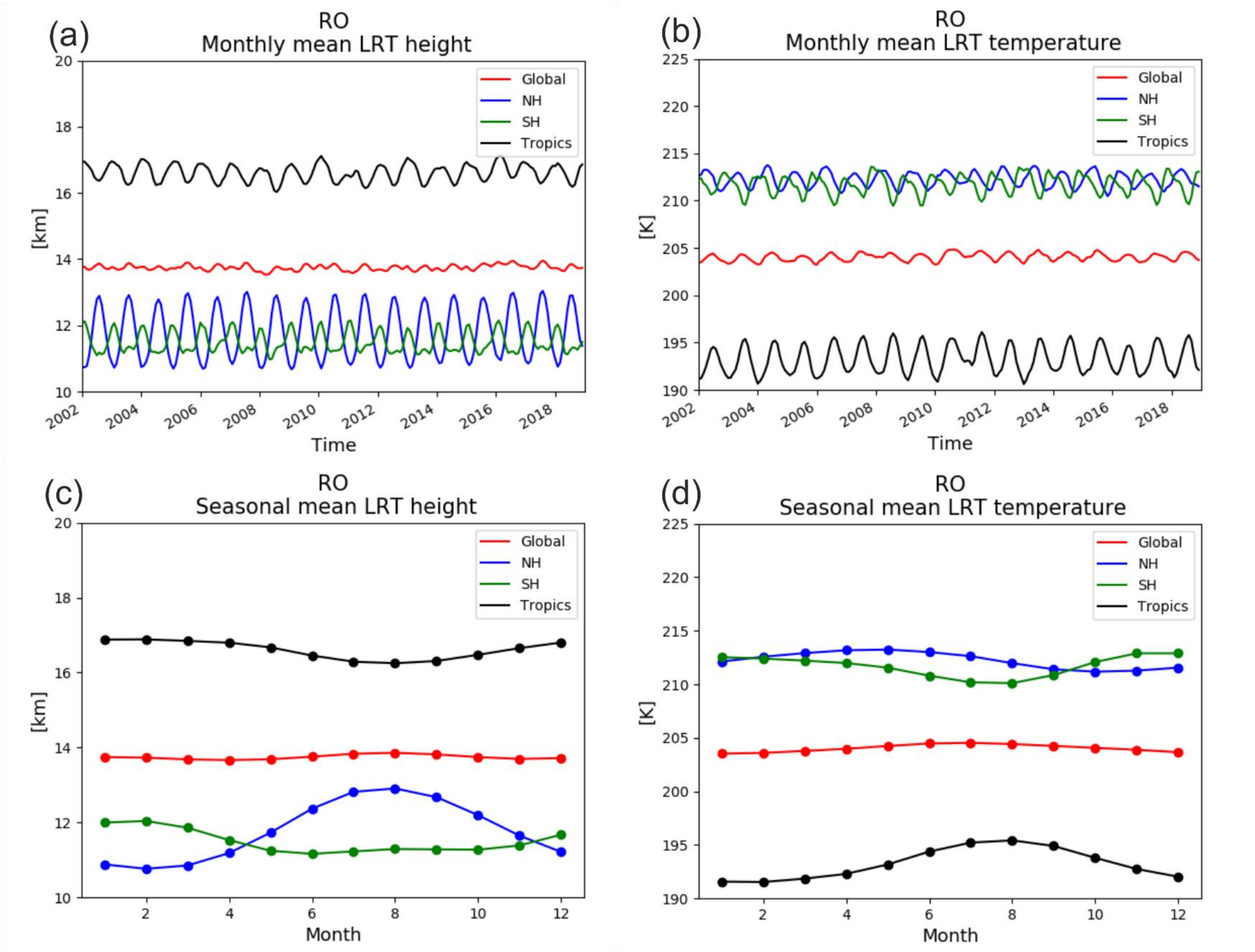
Update from Schmidt et al., 2004-2010; Schmidt, 2019, in preparation

Tropopause height as a climate indicator



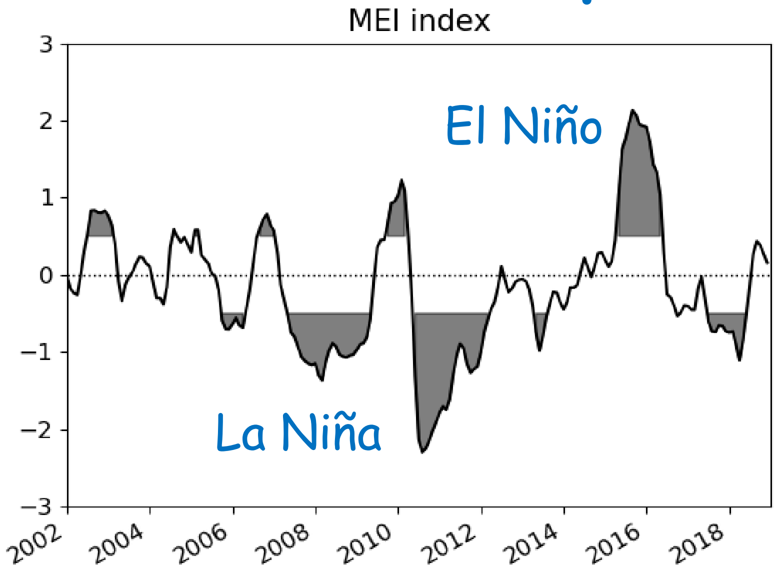
Schmidt, 2019, in preparation

Tropopause height and temperature



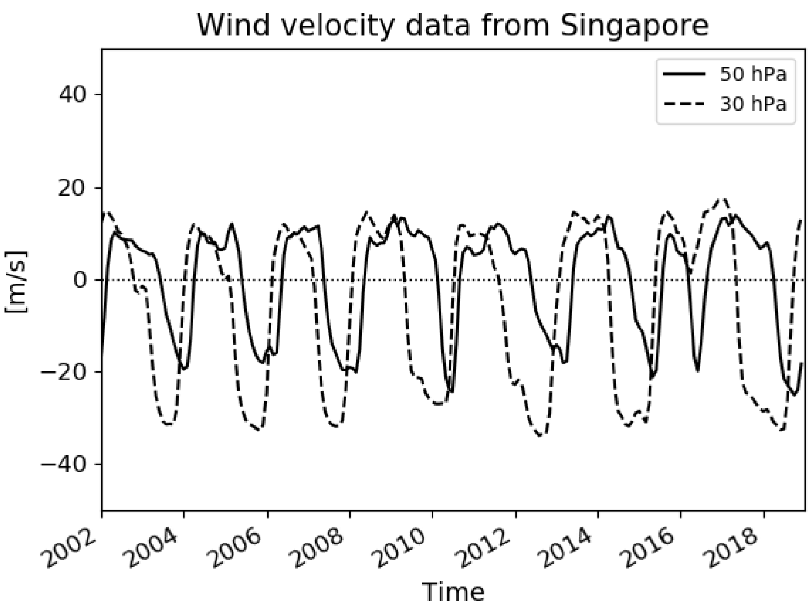
Schmidt, 2019, in preparation

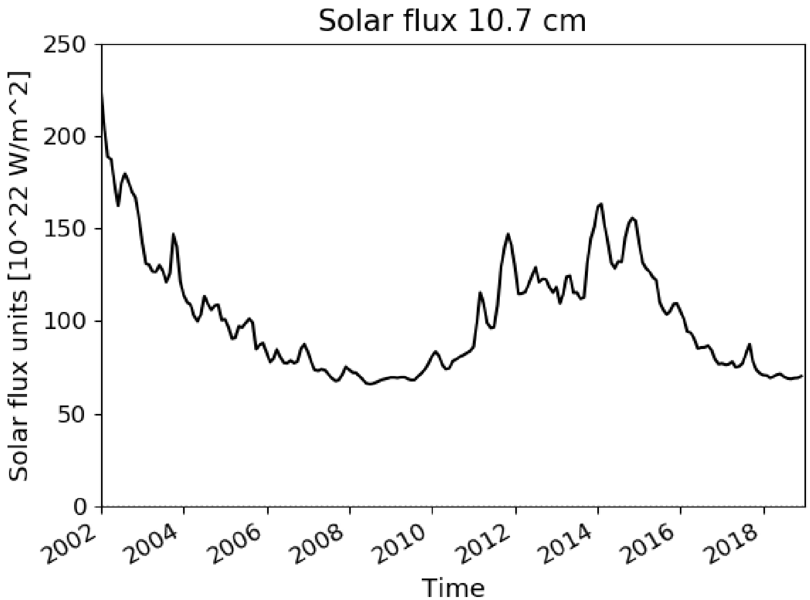
Multiple linear regression



$$A(t) = \alpha + \beta \cdot t + \gamma_1 \cdot QBO_{50} + \gamma_2 \cdot QBO_{30} + \delta \cdot ENSO + \varepsilon \cdot SOLAR$$

β: *linear trend term*



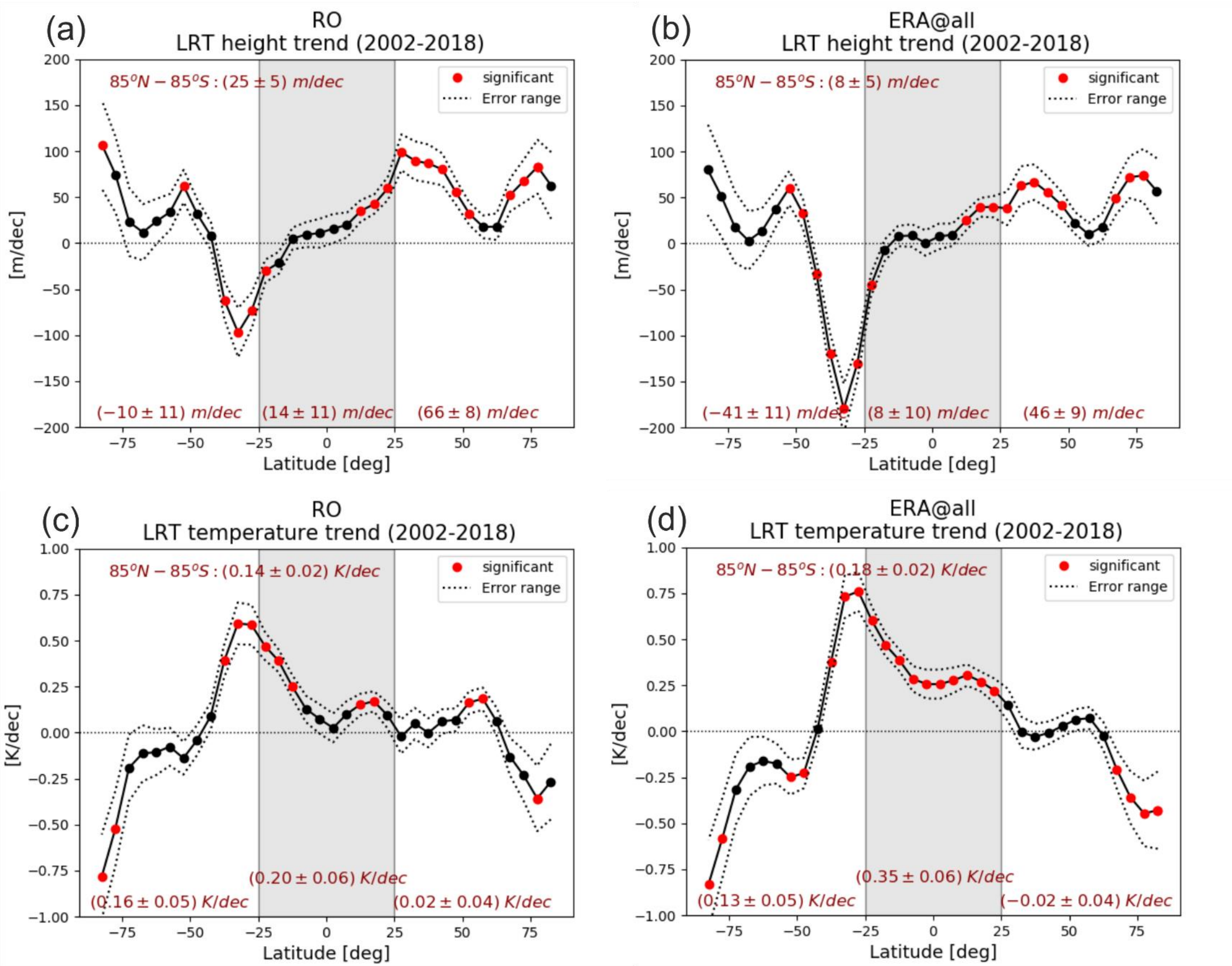


Schmidt, 2019, in preparation

Zonal LRT height and temperature trends

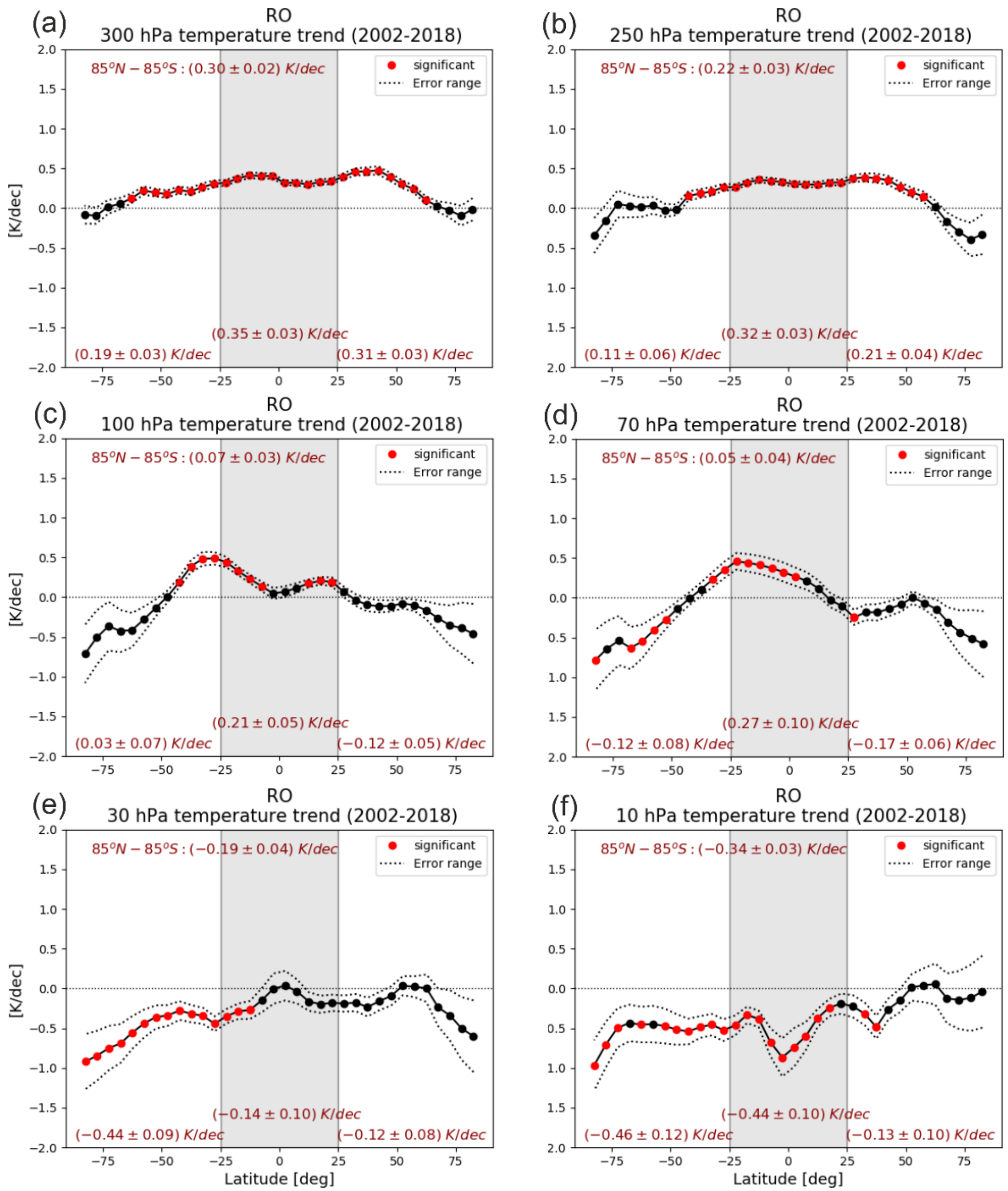
RO

ERAi



Schmidt, 2019, in preparation

Temperature trends at pressure levels



Upper troposphere

warming !

Transition zone

Lower stratosphere

cooling !

Schmidt, 2019, in preparation

Summary

- GPS RO is a satellite-to-satellite limb measurement.
- Information content studies suggest GPS RO should provide good temperature information in the upper troposphere and lower/mid stratosphere. Operational assimilation of GPS RO supports this.
- We have nearly two decades of RO data.
- GPS RO data can serve as a climate benchmark data set.
- Several applications of GPS RO data in the UTLS:
  - Temperature monitoring,
  - Gravity wave analysis,
  - Tropopause dynamics

Thank you for your attention!