Weather & Space Weather RO Data from PLANETIQ Commercial GNSS RO

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PlanetiQ Goals & Objectives

- Maximize RO impact on state estimation, understanding of processes and prediction of Weather, Climate & Space Weather
  - *QUALITY*: COSMIC-2 GNSS RO performance via smallsats
  - *COVERAGE*: Full global & diurnal cycle
  - *QUANTITY*: 50,000+ occ/day => 100 km sampling across the globe every 24 hours

- Flexible design

  Can increase sampling density if needed by adding more satellites

  My goal: 200,000 occ/day => 100 km sampling every 6 hr NWP cycle for H_2O vapor & winds

PlanetiQ Solutions

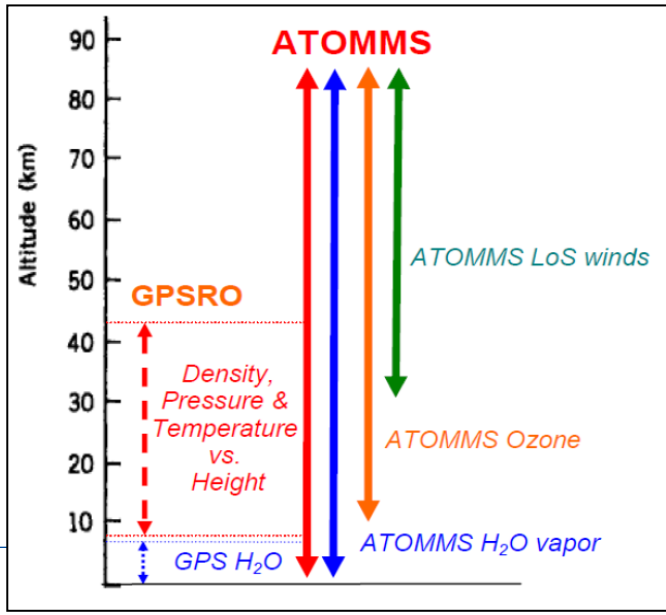
GNSS RO

- Currently assembling and testing new GNSS RO receivers, designed from scratch
  - Track all 4 GNSS constellations, dual frequency
  - Deliver COSMIC-2 performance (≥2000 v/v)

    ⇒ Should enable routine profiling to surface for NWP & climate
  - Minimize SWaP to work on smallsats
  - Fully reprogrammable on orbit
- Smallsat w/ propulsion to position & de-orbit

ATOMMS (in development)

- More info, more accurate & extends to higher altitudes

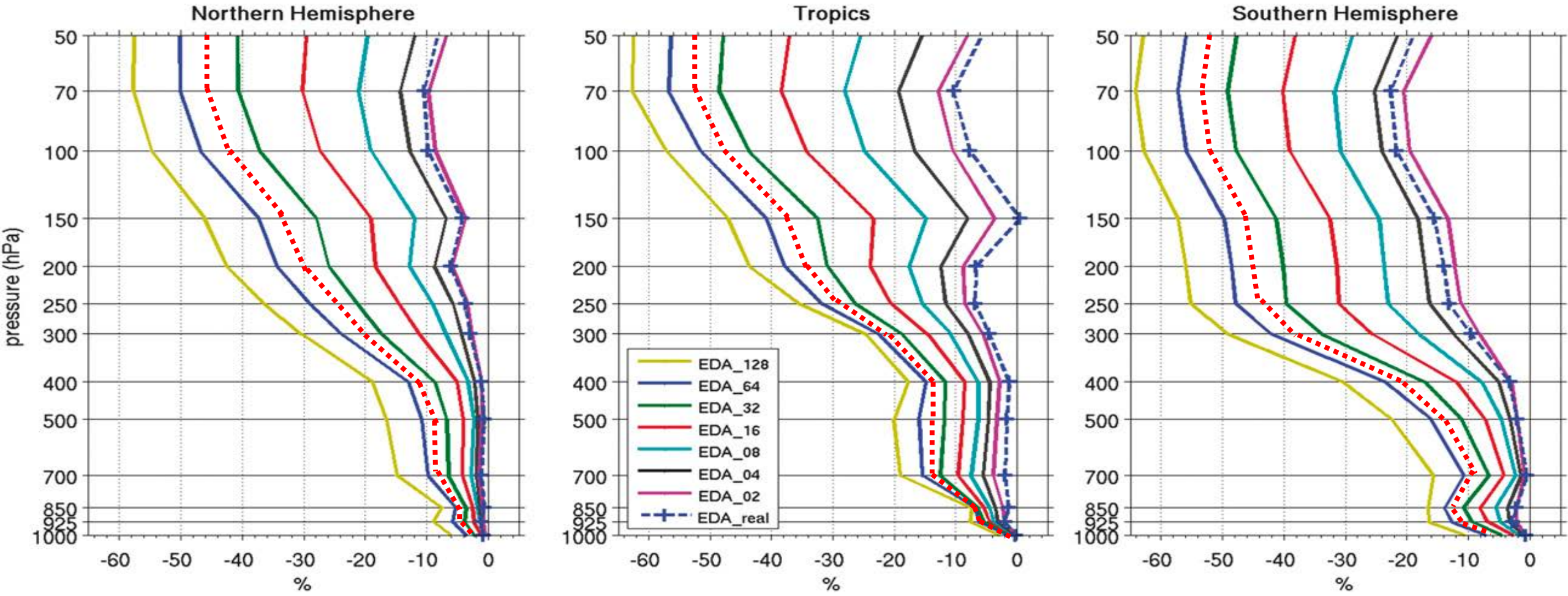


Weather and Climate

- Goal is dense, very high vertical resolution, high precision & accuracy profiling, with all-weather coverage, over any surface, across the globe
- Big predicted impacts on NWP
  - *"use of radio occultation observations provides information on the higher-vertical-resolution structure, whereas the radiances provide very accurate information but only about large-scale features in the vertical."* Kwon, English, Bell, Potthast, Collard, and Ruston (2018)
- Will give a talk updating water vapor studies on Monday

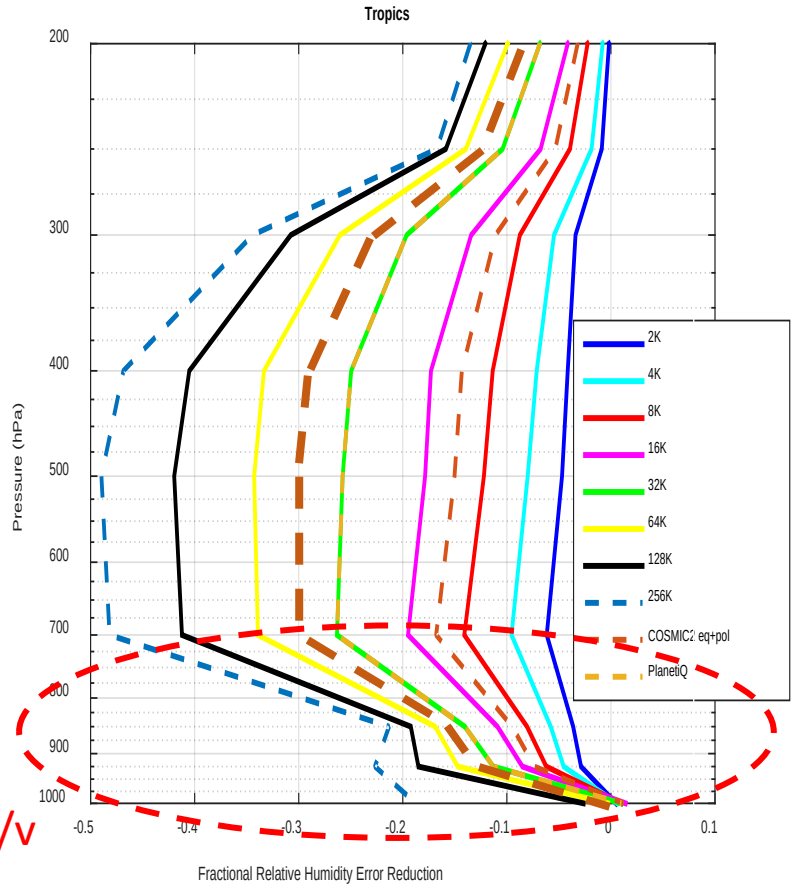
Predicted Reductions in Temperature Analysis Errors

- From Harnisch, Healy, Bauer and English (2013)

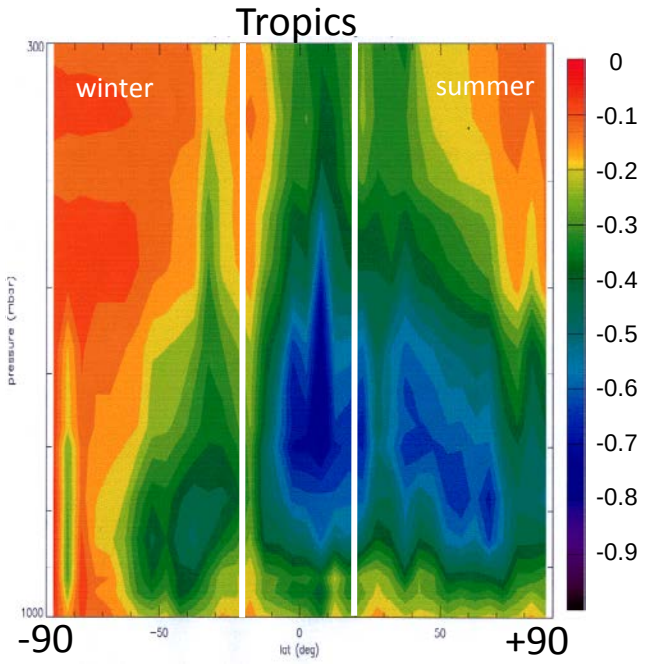


Predicted Reduction of Humidity Analysis Errors

Harnisch, Healy, and Bauer (2012) EDA simulation results



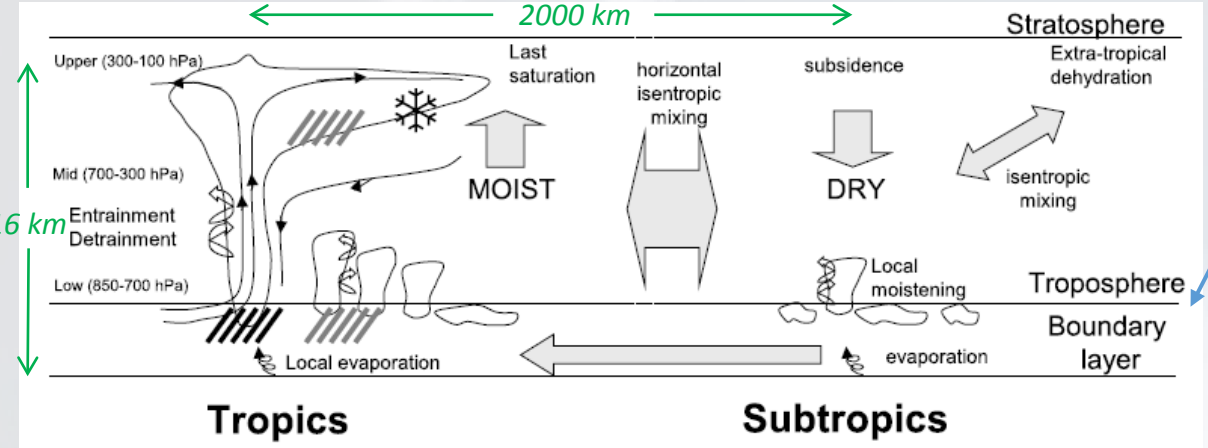
Big question: How much will lower troposphere moisture improve with >2000 v/v measurements



Kursinski, Healy and Romans (2000)

- Based on 1995 GPS-MET flywheel results.
- Essentially assumes a RO profile every grid point every NWP update cycle

Routine profiling to the surface requires very high SNR

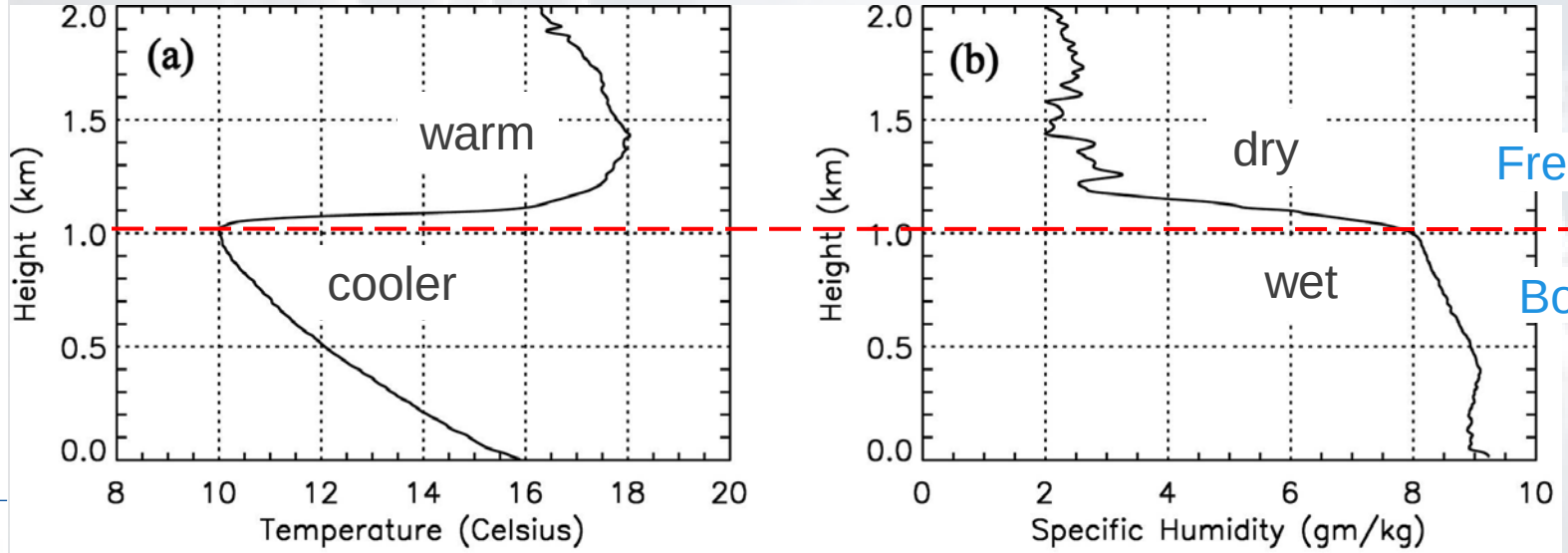


Super-refraction:
Very large refractivity gradients occur at transition between dry free troposphere & wet boundary layer.

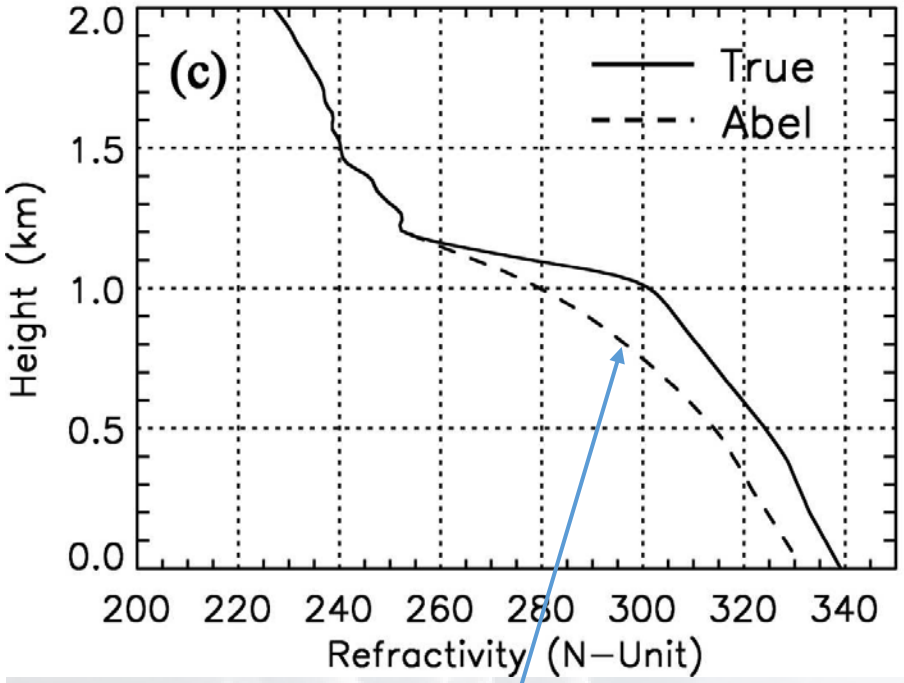
- Causes radius of curvature of ray path bending to become smaller than radius of Earth.

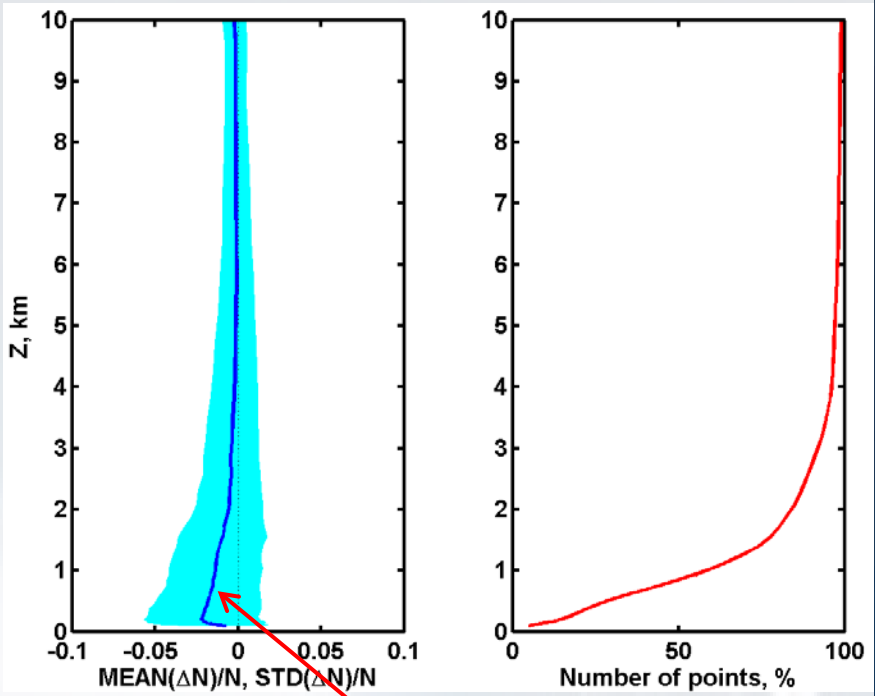
⇒ Systematic underestimate of refractivity.

⇒ **NWP centers limit the weight given RO data in lowermost troposphere**



Quality - Super-refraction Challenge





Systematic underestimate of refractivity results when the standard “Abel” retrieval is used in the presence of Super-Refraction

- Systematically underestimated refractivity assimilation would cause underestimate of severe weather. *Very bad!!*
- NWP centers give little weight to RO data in lowermost troposphere to avoid this bias

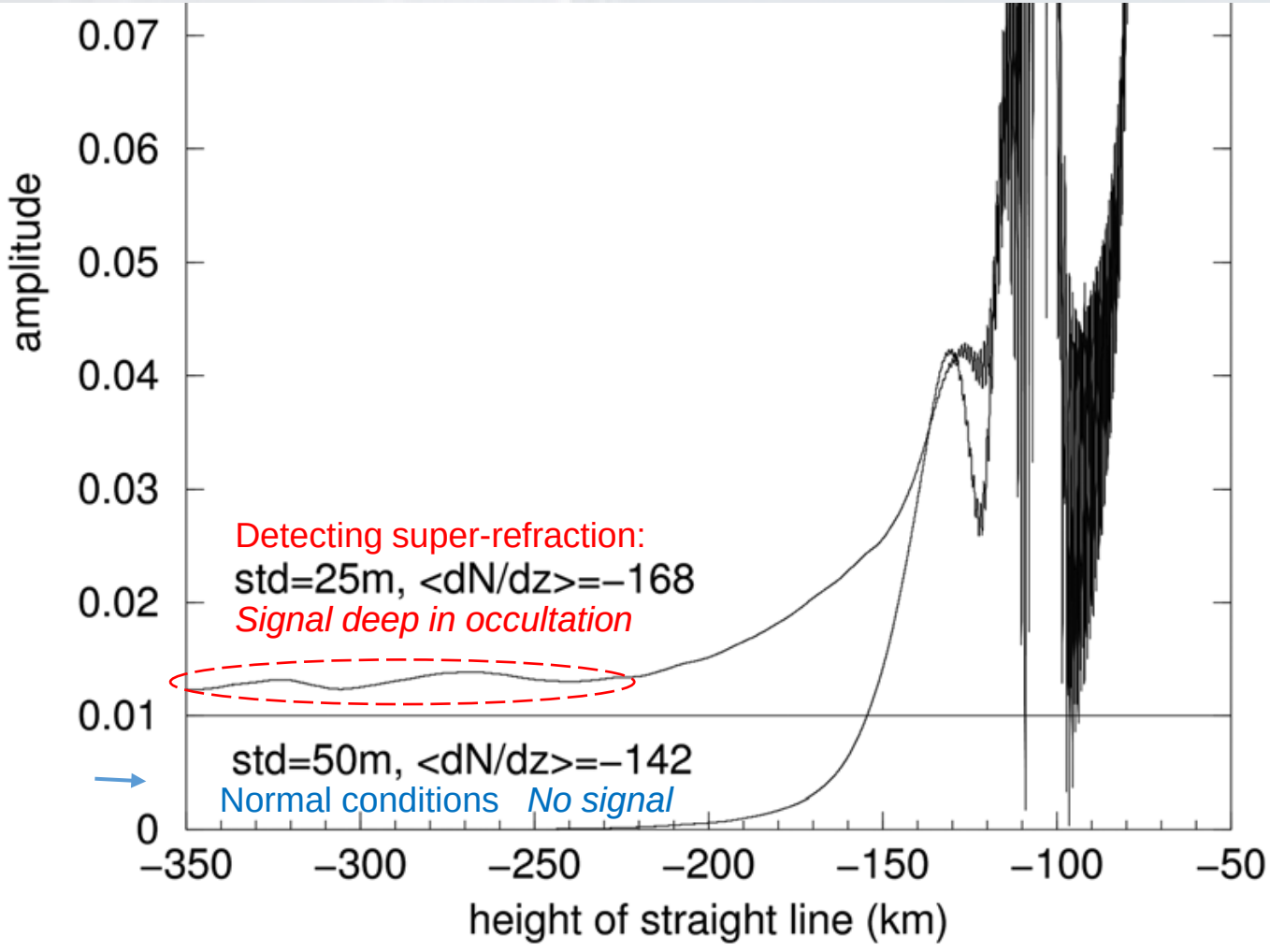
<u>Two-part solution (at least):</u>

1. Xie et al., 2006 retrieval method accounts for effects of super-refraction
2. Need to know when SR is occurring which requires very high SNR.

Quality - Super-refraction Challenge

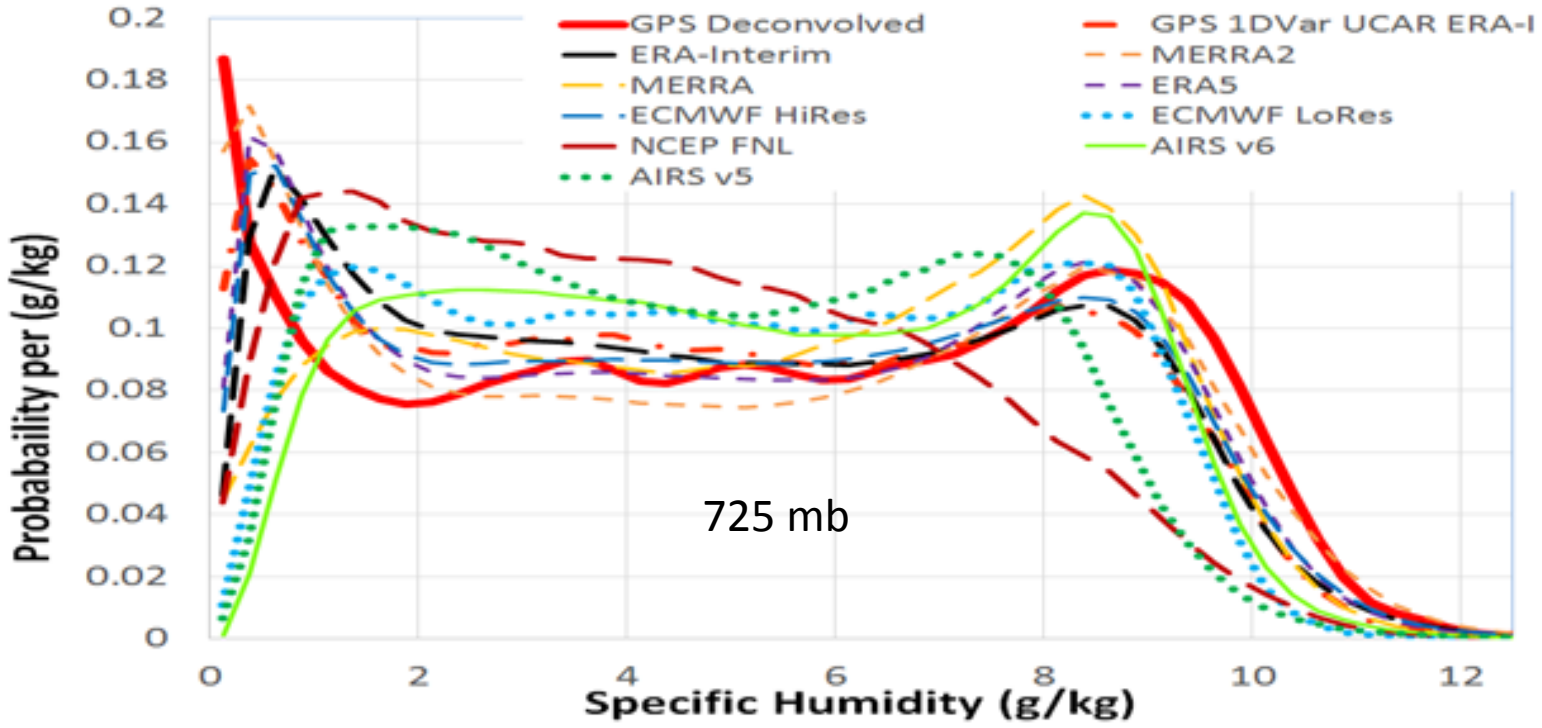
Detecting presence of super-refraction:

Sokolovskiy et al. (2014) showed that reliable occultation signal observations in the presence of super-refraction requires an **SNR of about 2000 v/v**



Planetary Boundary Layer (PBL) sensing

- NAS Decadal Survey emphasized better understanding of PBL.
- GNSS RO humidity histograms provide very unique and powerful constraints on the hydrological and energy cycles
- To understand exchange between PBL and free troposphere, need histograms both above and inside PBL
- Requires unbiased, complete sampling inside the PBL, which I hope the 2000 v/v SNRs will enable



Space Weather

GNSS Products:

- Slant TEC
- Electron density profiles (EDP)
- Amplitude & Phase Scintillations

Performance:

- Meets COSMIC2 TEC & scintillation specifications
- More accurate N_e profiling via denser sampling

Data Formats

- Deliver data in COSMIC-2 formats where applicable
  - podTec
  - opnGns
  - BUFR
  - Delivered ~2M neutral and ionosphere simulated occultations to USAF for evaluation.
- Each of these formats has some open questions associated with them

PLANETiQ

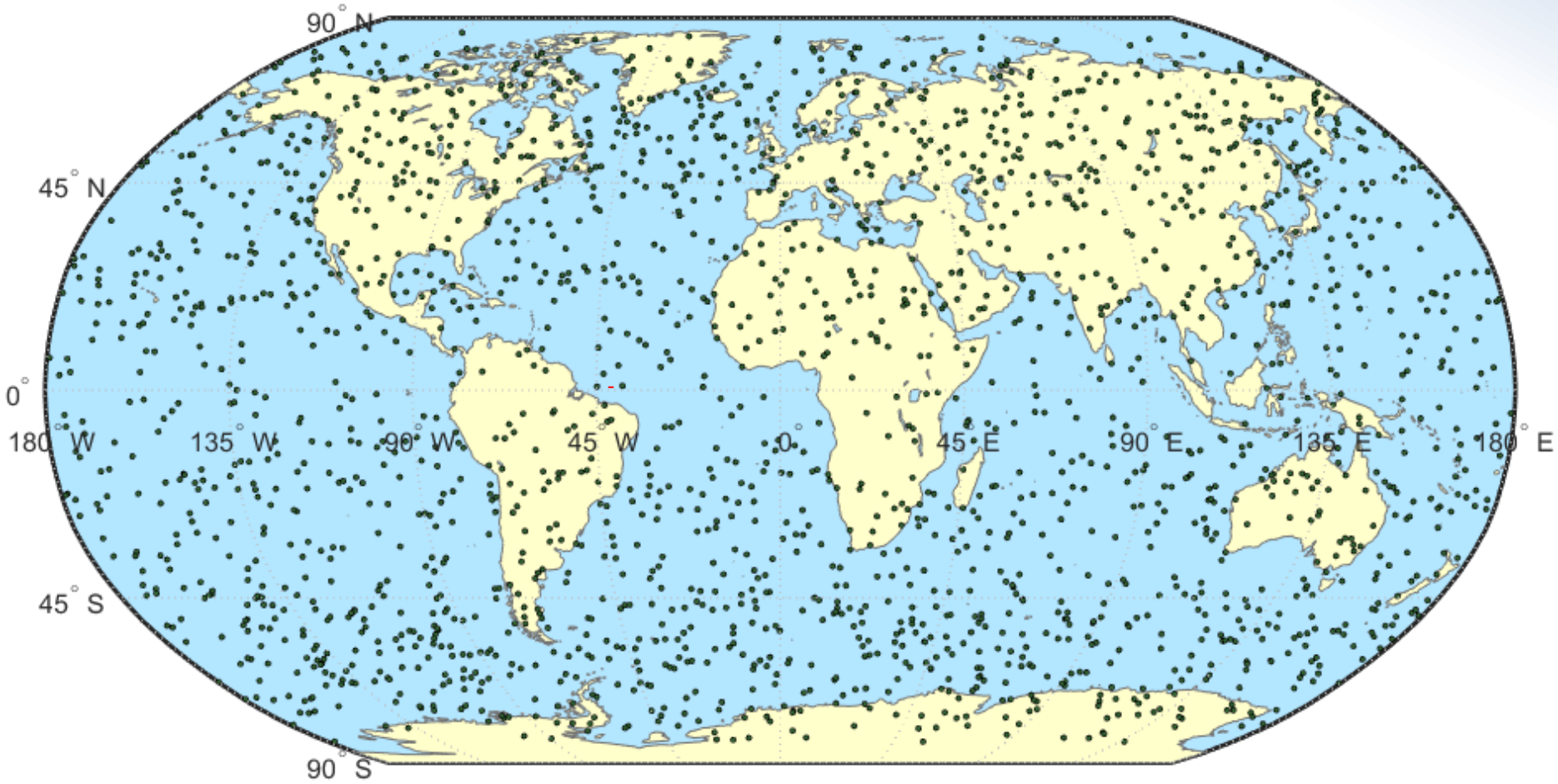
Mission Timeline

- Mission design
  - Most satellites will be in polar orbits for global coverage
    + Some in lower inclinations for denser low latitude coverage
  - 550-720 km altitude to profile most of the ionosphere
  - Sequence of piggyback launches, then dedicated launches

- First two satellites launch Q1 2020
  - 4 satellites by end of 2020
  - Add satellites to fill out constellation & coverage by end of 2022

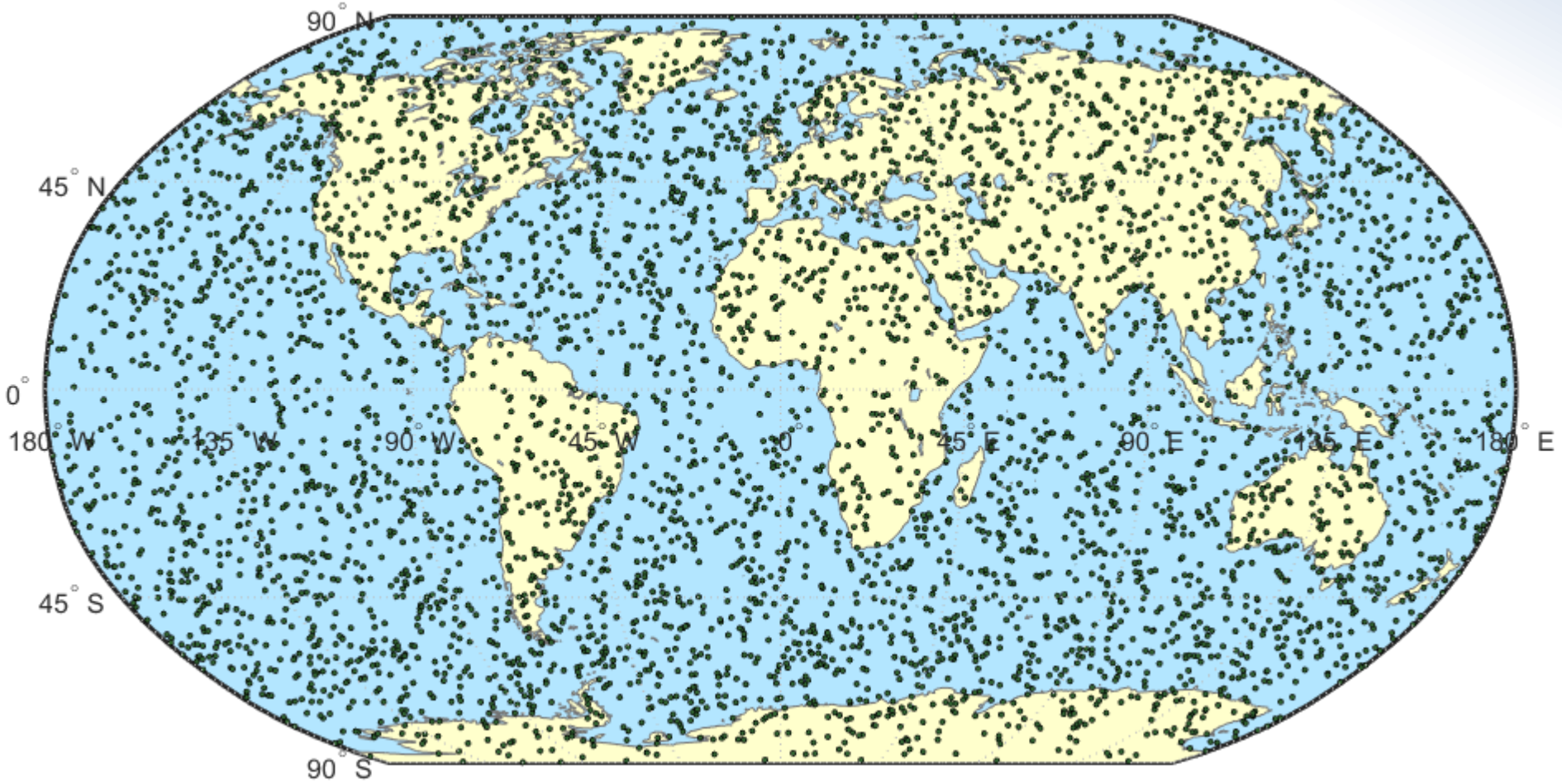
Evolution of RO Coverage

- COSMIC 6 satellites ~2,000 occ/day



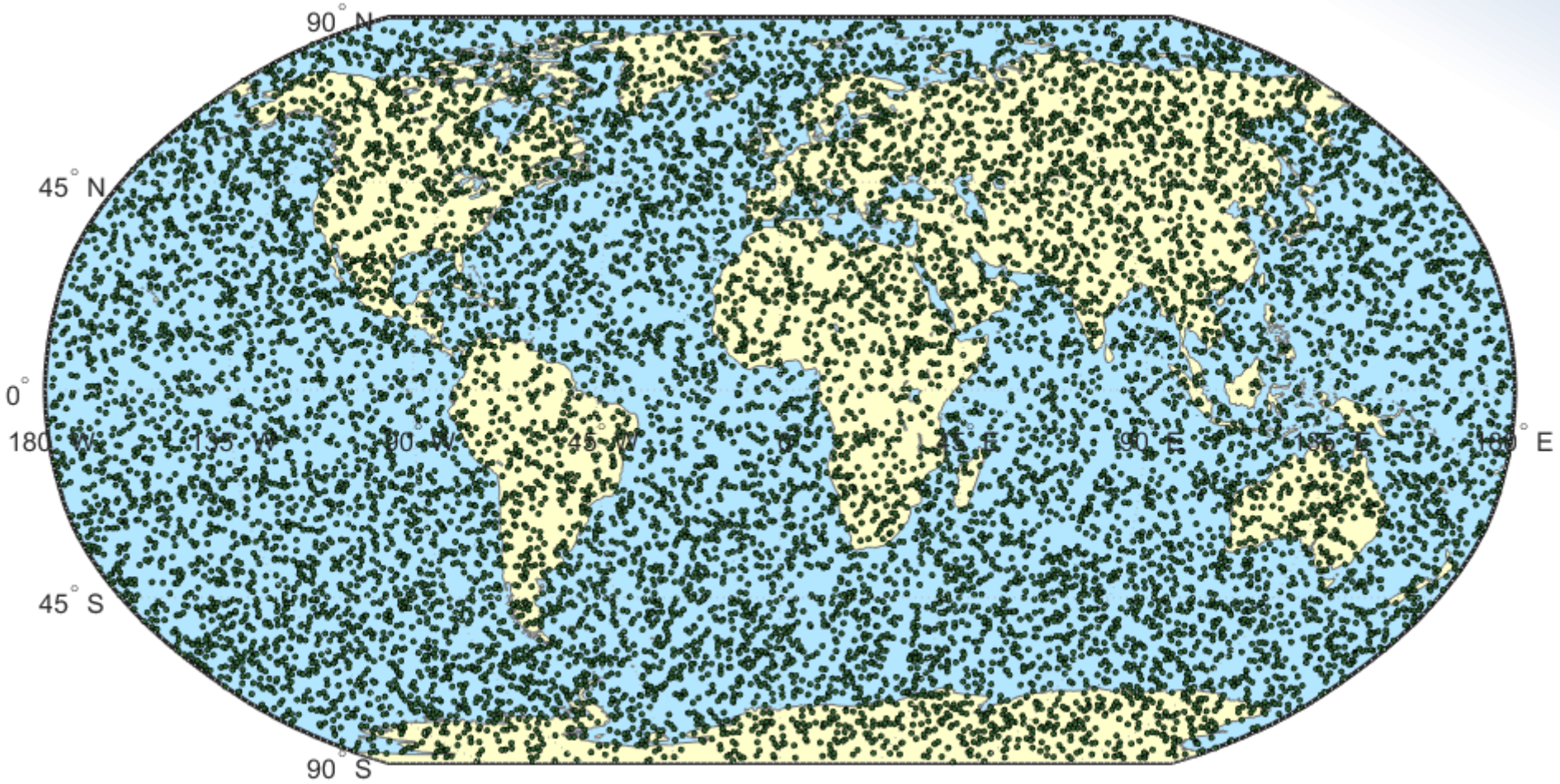
PlanetiQ Coverage

- Early 2020: 5,000 occ/day ≈ COSMIC 2B



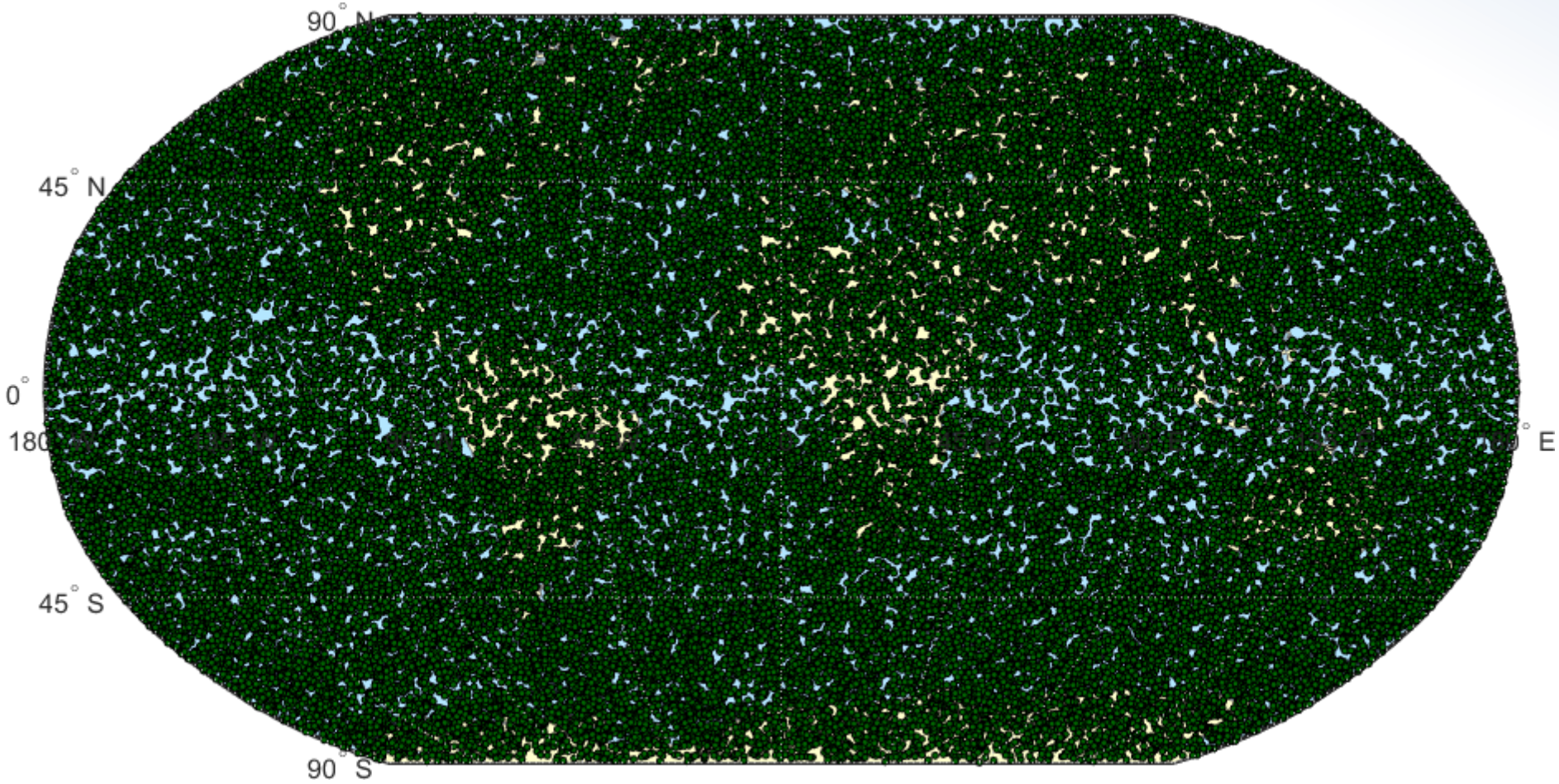
PlanetiQ Coverage

- Mid-2021: 15,000 occ/day



PlanetiQ Coverage

- 2022: ~50,000 per day



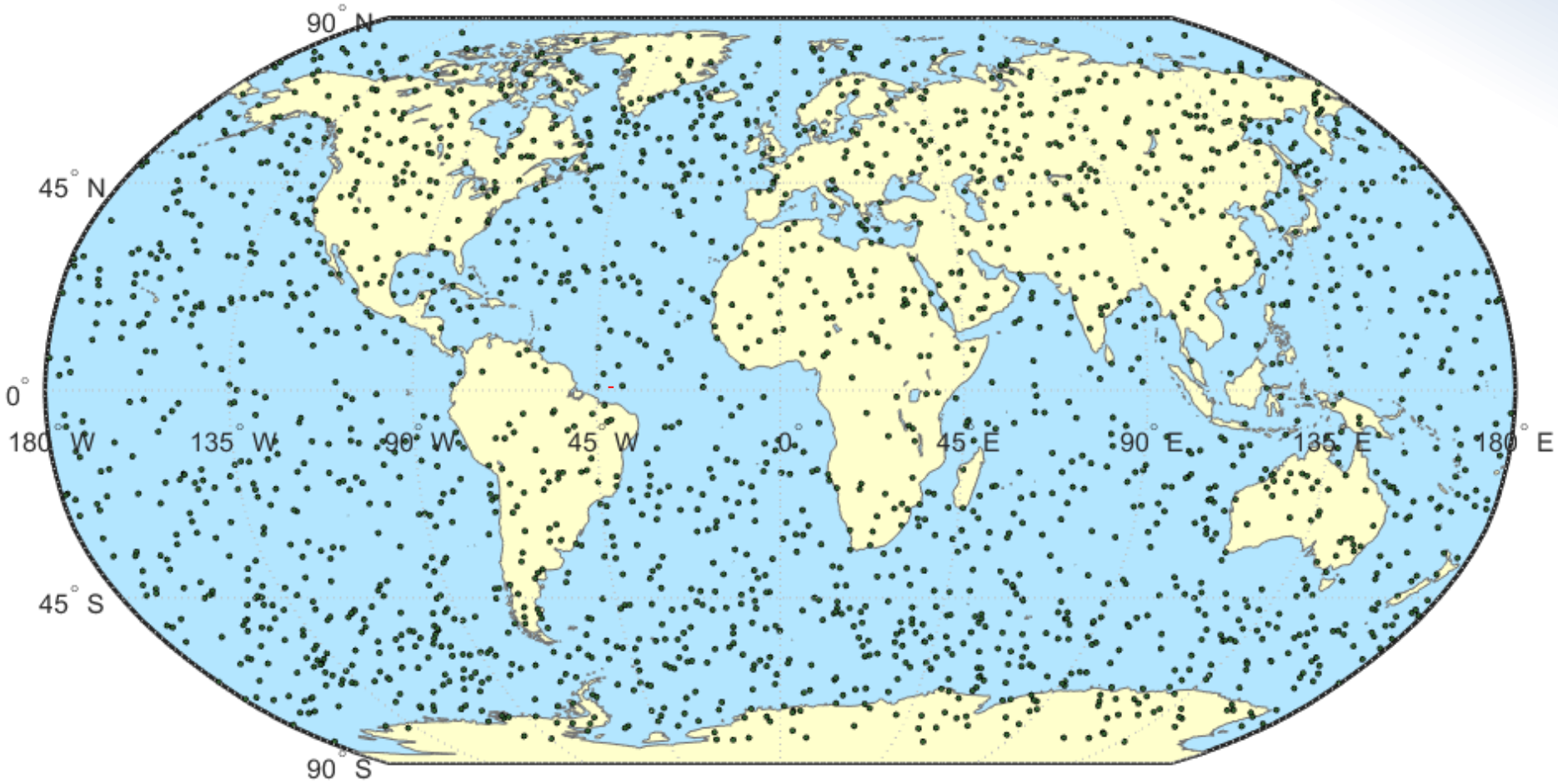
Sampling density

Occultations	PlanetiQ		COSMIC
50,000	1 day	<=	~1 month
12,500	6 hours	<=	6 days
2,000	1 hour	<=	1 day
500	15 min.	<=	6 hours

$\Rightarrow$ Identify & resolve features as they evolve

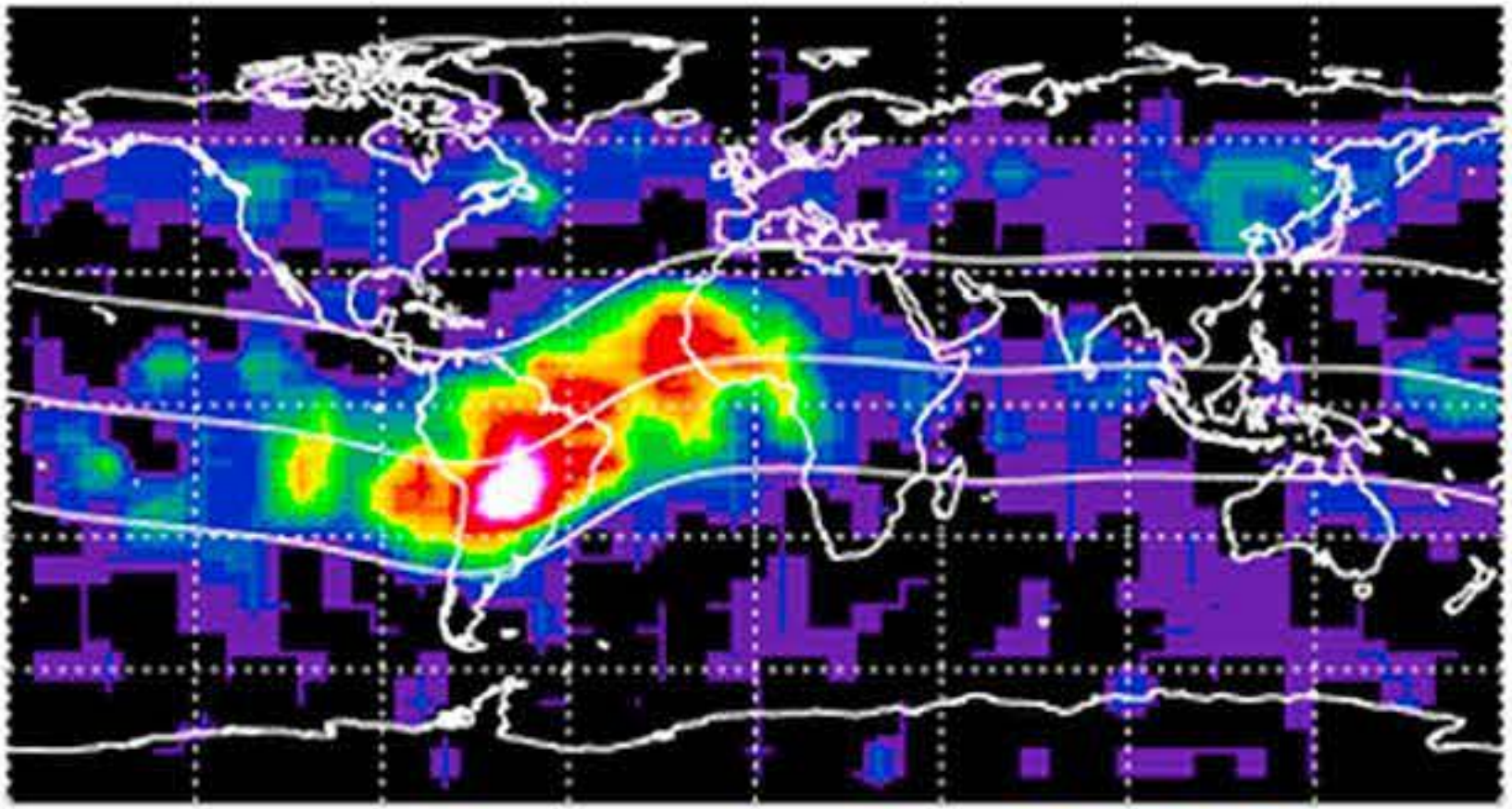
Evolution of RO Coverage

- COSMIC daily coverage => PlanetiQ **HOURLY** coverage



Scintillations

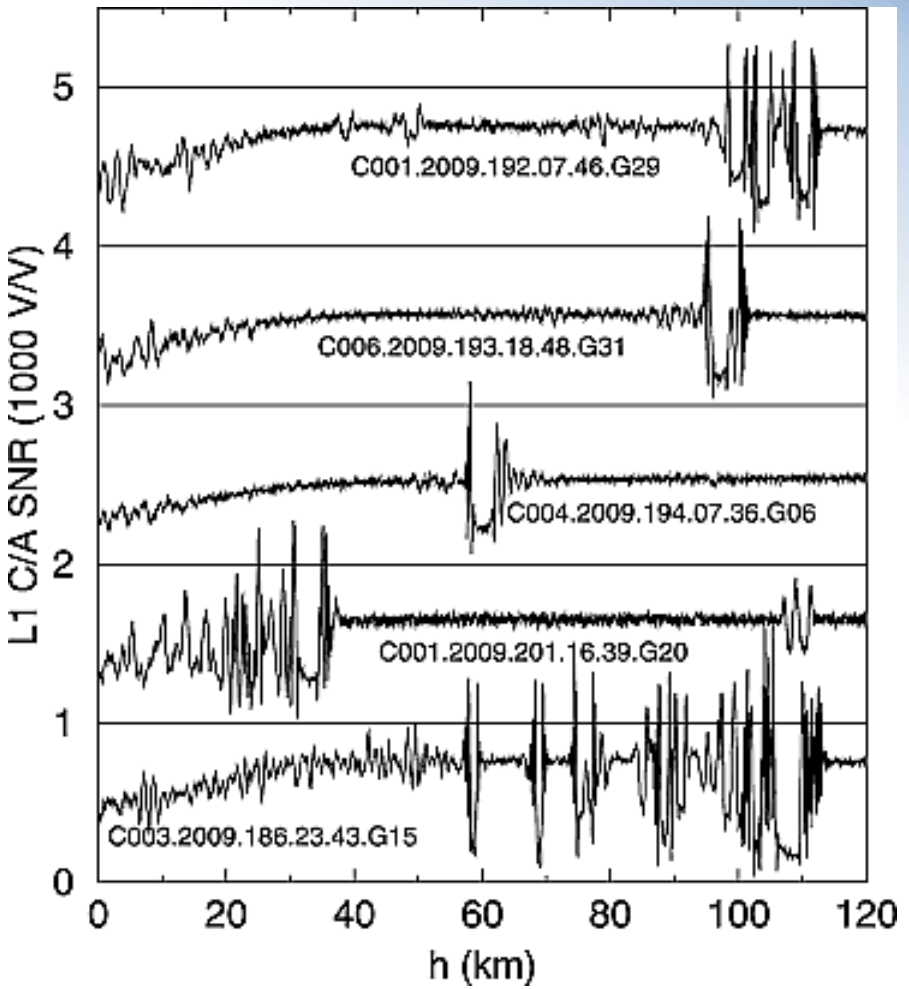
2K v. 50K ➡ Monthly map becomes a daily map



Dymond, RS 2012

Sporadic E-layers

- Sporadic E-layers are important because they modify/disrupt OTH communications and radar behavior
- RO is naturally suited to sensing sporadic E layers
- Examples of COSMIC results
- Very dense global coverage is coming…



Examples from Zeng & Sokolovskiy (2010) *GRL*

Latency

- First 2-4 satellites downlink data over each pole for an average latency of 25 minutes
- Subsequent satellites will carry real time sat-sat communications to deliver data within a few minutes for space weather

Future possibilities

- Hydrometeor sensing via dual linear polarization like PAZ ROHP
- Surface reflections
- ATOMMS
- Secondary payloads

NASA Issue

- NASA recently released an RFI about commercial data purchase RFP coming out to be in place by May 2020.
- Requires **at least 3 satellites**, independent of data quality, coverage etc.
  - PlanetiQ will not have 3 satellites on orbit by May 2020
  - PlanetiQ will have 1 or 2 w/ COSMIC-2 quality & global coverage producing 2000-5000 occ/day
  - No one at NASA seems to know where the 3 sat requirement came from
  - Stated rationale: "*As for the definition of a constellation, the current RFI is consistent with the previous RFI released in 2017. This definition will not be changed.*"
    - IOW, we did it this way last time so we're going to do it this way again. (*Not terribly innovative, in fact anti-innovative*)
  - Won't have another call for 12 to 18 months after this one

⇒ If (NASA-funded) scientists want access to PlanetiQ data in 2020, we will need NASA to remove the 3 satellite requirement before NASA's RFP comes out

PlanetiQ Summary

- Implementing new high performance GNSS RO receiver on smallsats
- First launch February 2020 >2,000 occ/day
- 5,000 occ/day by mid-2020 with pole to pole coverage (≈*COSMIC 2B*)
- Increase to 50,000 occ/day by end of 2022, w/ low latency
- >2000 v/v to enable routine profiling through PBL (hopefully)
- N_e profiling accuracy increases as sampling density increases
- Can increase sampling density still higher if needed
- Enables monitoring at increasingly finer temporal & spatial scales, globally.
- Other capabilities can be developed/added as well

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