Studies at Environment Canada with 20000 RO profiles/day

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Included commercial data supplied by

- NOAA (Spire, GeoOptics)
- PlanetIQ

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Preamble I

- We present a study adding a large amount of RO Data to the operational base at ECCC (2022)
- Objectives at the time were
  - Deciding if those sources were technically ready to become operational
  - Identify any technical limitations yet unknown
  - Overview and quantification of impact
  - Basis for decision making
- Summary of results
  - Some data identified as ready
  - Some identified as requiring some review
  - Issues with the system were identified, which required some attention
    - Review N vs BA
    - Review PBL
    - Review anchors
- These lessons being relevant, we will discuss them here
- Since accuracy in the range 0.1% to 0.01% is under discussion
  - Also some important comments on the structure of obs operator

Preamble II Reaching 20k prof/day

- **RO Data that was operational at ECCC in the study period ~10000 prof/day**
  - METOP-B & C, COSMIC-2, FY-3D, KOMPSAT-5, TERRASAR-X, TANDEM-X, PAZ, GRACE-C,D

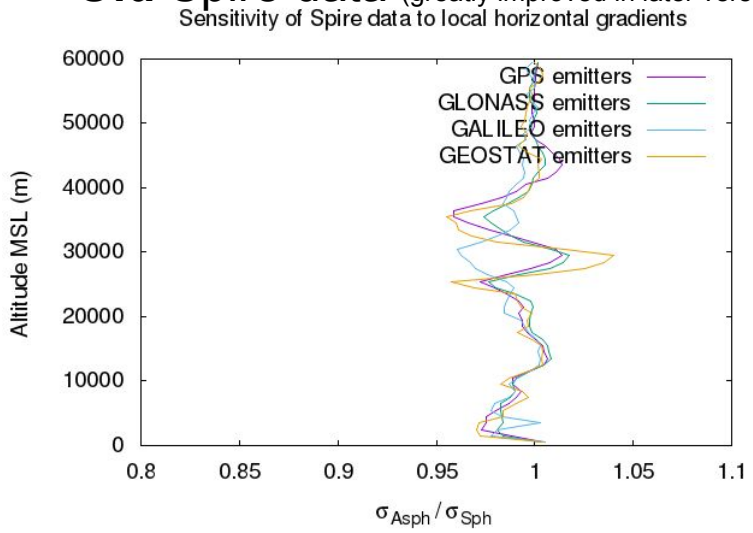
- **Upcoming at the time** (available, waiting final acceptance)
  - Sentinel-6A (~800 prof/day, polar, GPS+GLO, rise & set)

- **Massive addition**
  - **Research licenses** through NOAA, EUMETSAT, and **direct research agreements**
    - **Spire** (~6000 prof/day, polar, GPS+GLO+GAL, set)
      - **6000** from NOAA
      - **1500** from EUMETSAT
    - **GeoOptics** (about **500** prof/day, polar, GPS+GLO+GAL, NRT irregular delivery)
    - **PlanetIQ** (about **3300** prof/day, polar, GPS+GLO+GAL+BEI, received offline, direct agreement ECCC/PIQ)
  - Existing pool estimated at additional 12000-20000 (not included here)

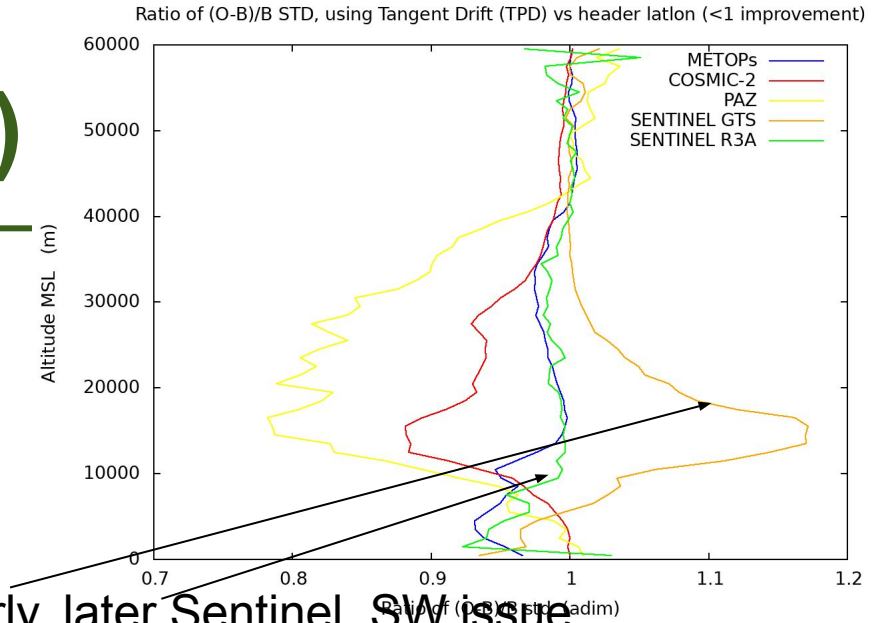
Thresholds to add value (Contrasts)

- Can data identify model's skill?
  - Model has very high skill at large scale, progressively less at smaller scales.
  - Data able to discriminate model **intermediate** value?
    - No value at too large scale, skill **too good to improve**
    - No value at too small scale, skill **too bad to help**
  - **Test intermediate scales (10-100 km)** (use 2 different H(x): the **best** and a slightly **degraded**)
    - Here "best" contains eg TPD, plane rotation, "degraded" does not apply these
    - Preliminary data of most sources often not sensitive
    - UCAR, EUMETSAT software ok.
  - Check if data can identify best vs degraded
  - **Data unable to discriminate intermediate skill, unlikely to add skill.**
  - Example of contrast here, others possible

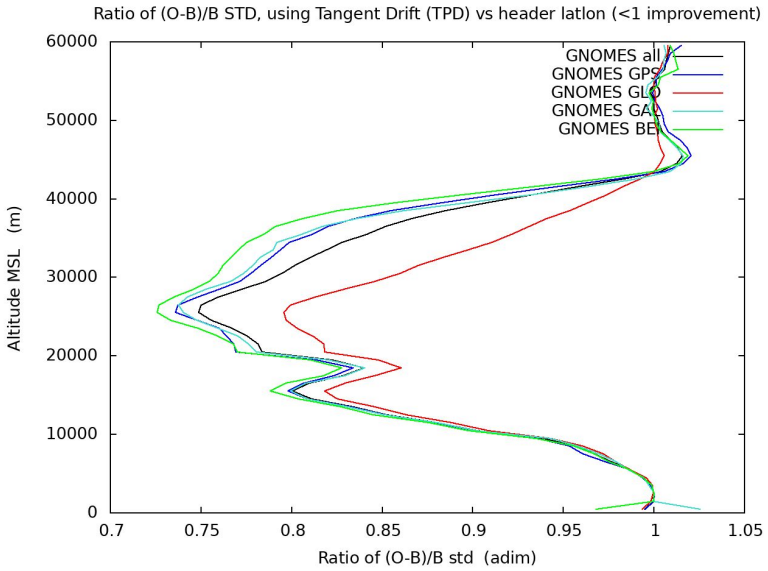
Old Spire data (greatly improved in later versions)



Slant Contrast test heuristically found to be necessary and nearly sufficient (at present)



Early, later Sentinel, SW issue



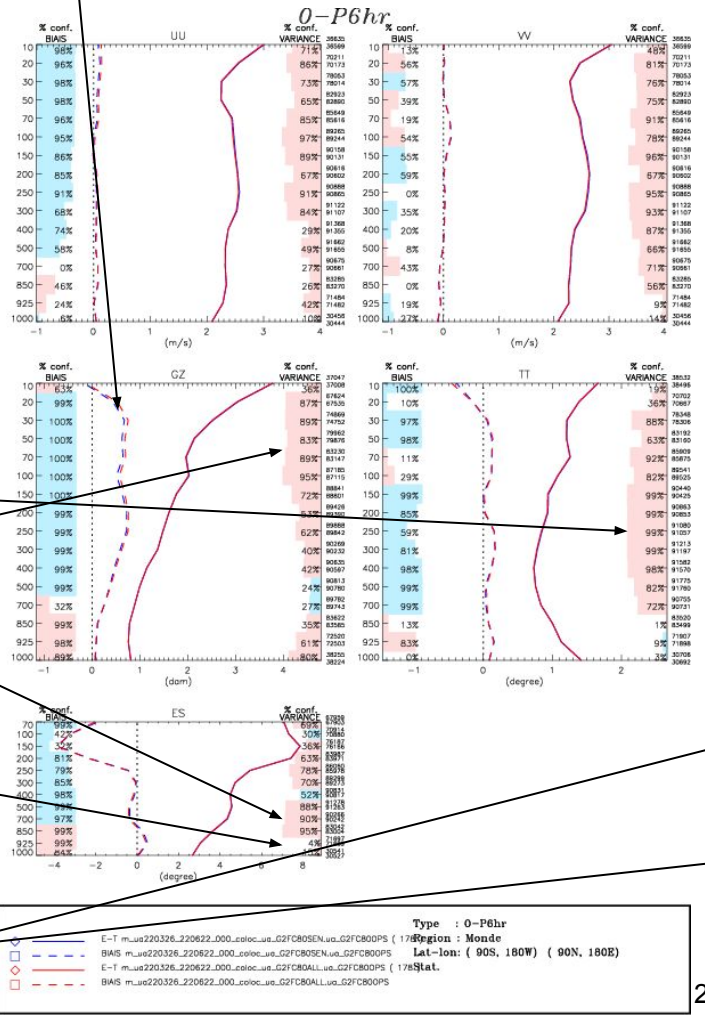
Several GNOMES, HW/signal issue

Results I: RS Verif (high data density areas) (Mar-Jun 2022)

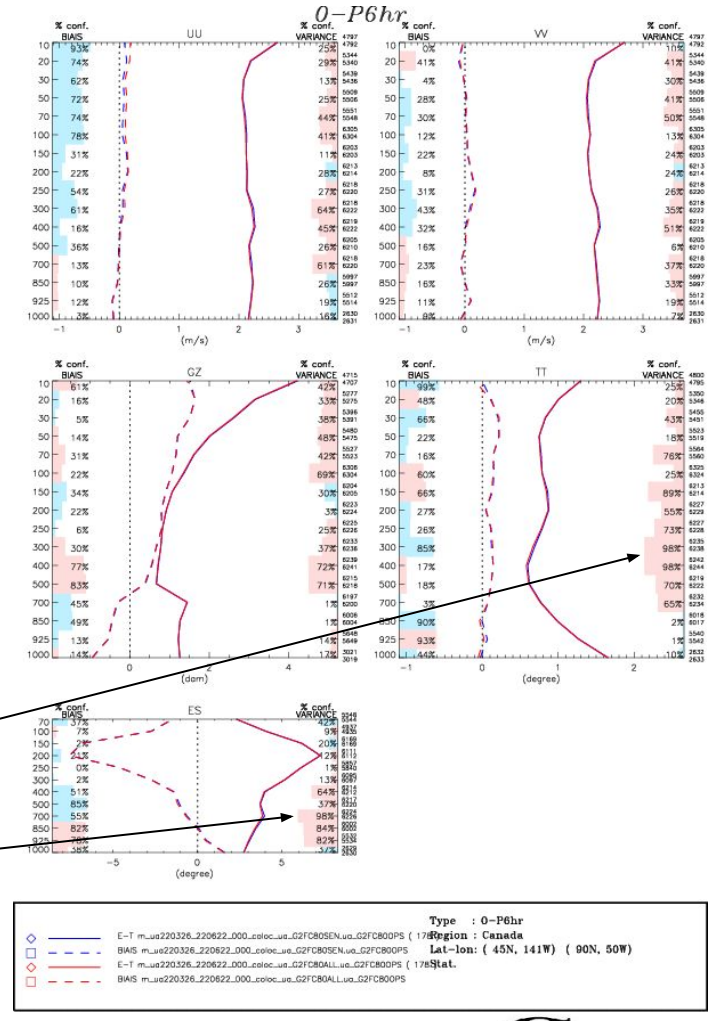
I assume this induced GZ bias to be negligible, ~1-2e-4

- Thermodynamic, wind, moisture
- High data density regions
  - not exactly global, but interesting to see if there is a **benefit when sampling is already dense**
- General positive tendency. Two items to note:
  - Peak T impact at 300 hPa
    - GZ impact derives from T
  - Noticeable q impact in upper PBL/ low free troposphere
    - This signature is weak at lower data densities
  - But neutral **below** PBL
- Limited to Canada:
  - Same signatures, with weaker significance
  - Yet, some T, q, above 90%

Northern Hemisphere

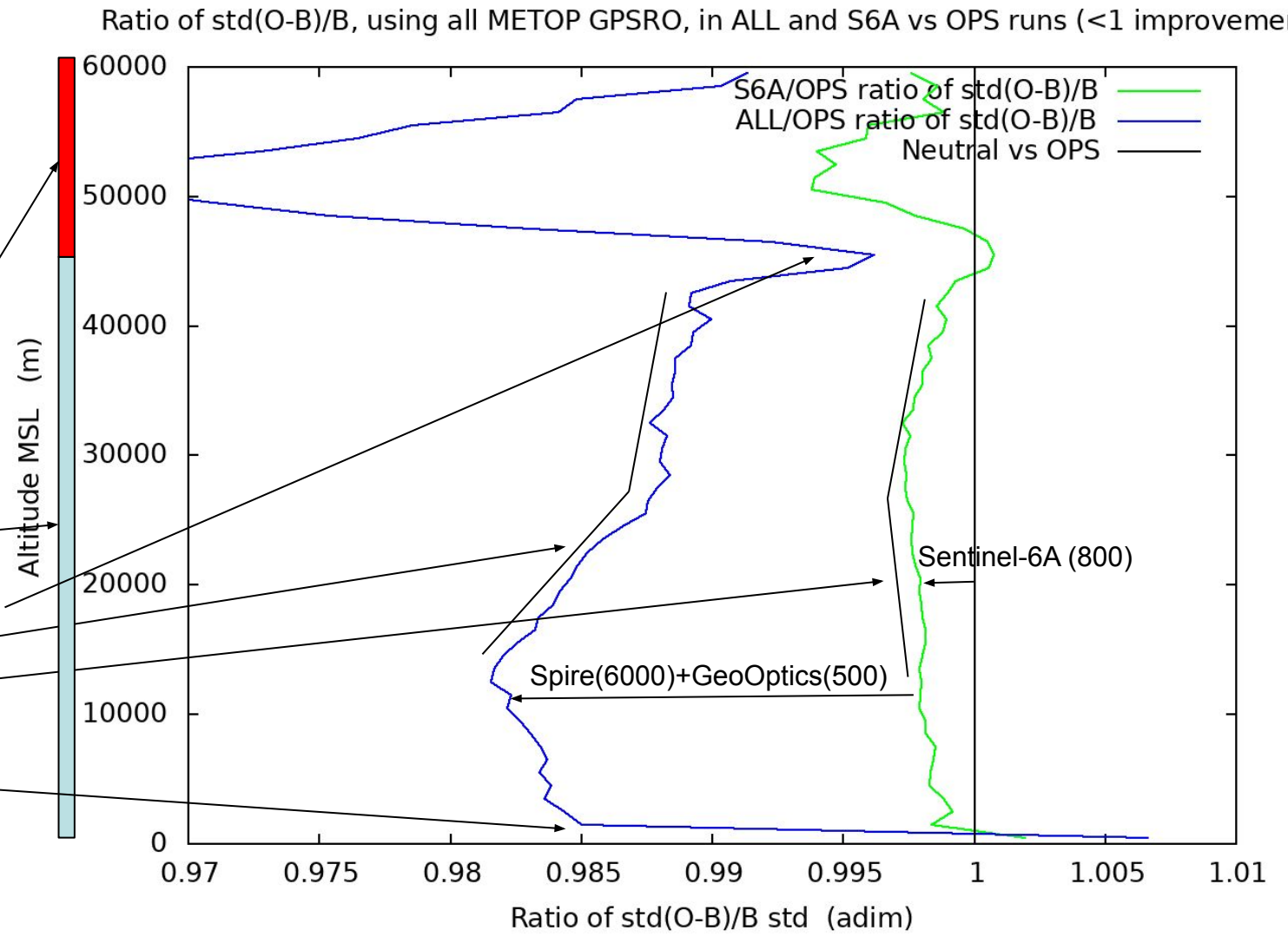


Canada



Verif II: against RO from METOPs

- Thermodynamic, also RO
- Global sampling, very uniform land/ocean, populated/not.
- Not uniform in latitude: **denser sampling at high latitudes** (7x poles vs equator)
- Not uniform in local time
- None of the RO data (neither METOP/RO, nor S6A, Comm, …) are bias corrected.
- Global profiles/day in (parethesis)
- Prime results:
  - Most column sees benefit (<1 hPa, <45 km MSL)
    - Above 1 hPa probably not meaningful
    - Weakness ~1hPa related to anchoring of radiance bias correction (to be addressed IC4)
  - More impact below 20 hPa (25 km MSL)
    - Not seen in current Sentinel-6A
    - Note that Sentinel has a bug (suboptimal <25 km MSL)
  - Near surface (< 1 km MSL): probably not meaningful
    - RO not designed to measure the surface layer
    - and these data are in fact rejected in assimilation



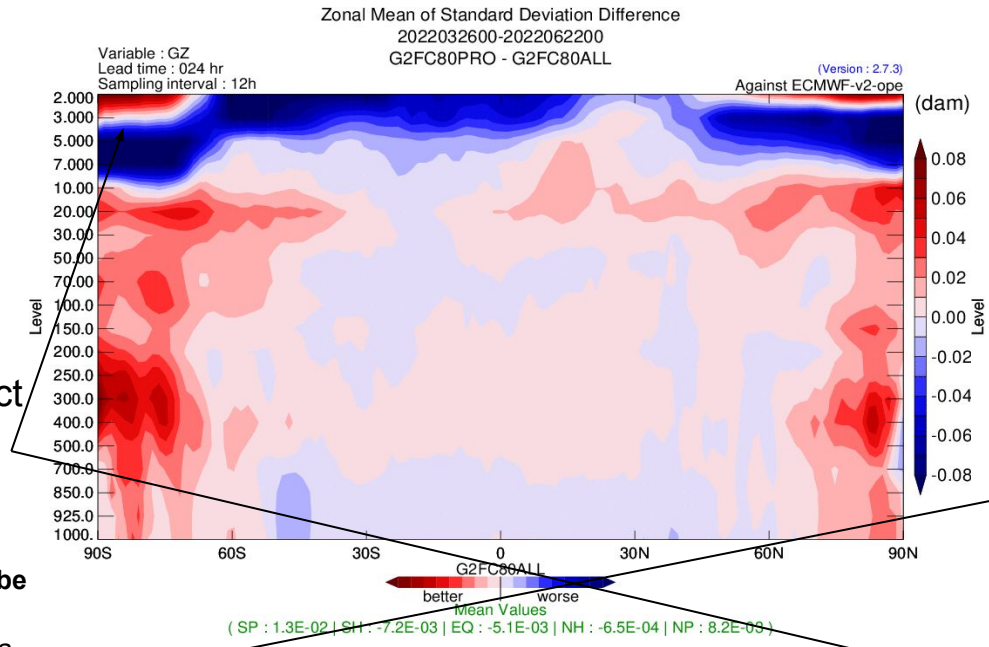
Verif III: Against external (ECMWF) analysis

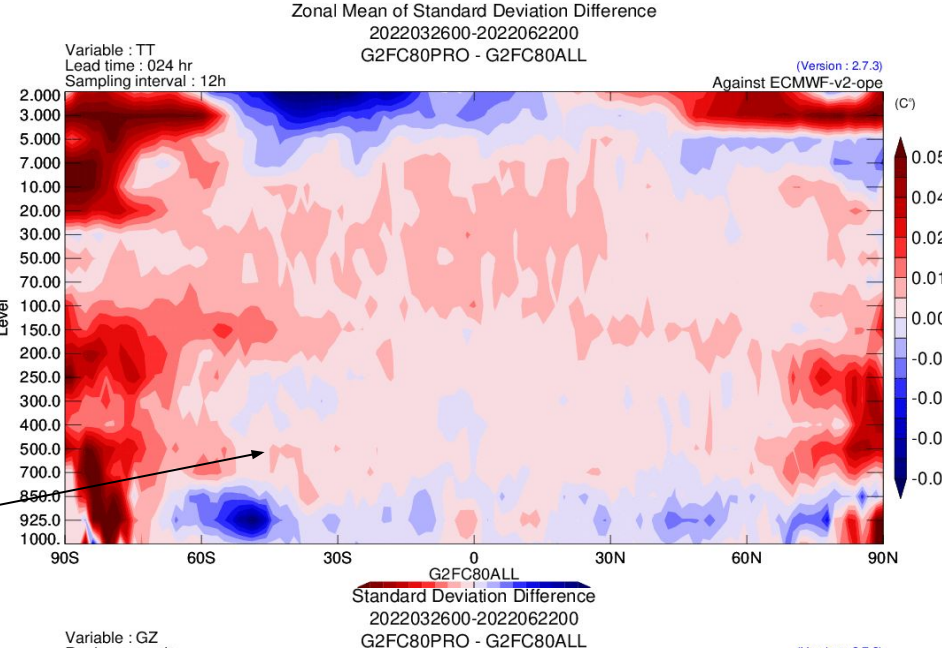
Generally positive

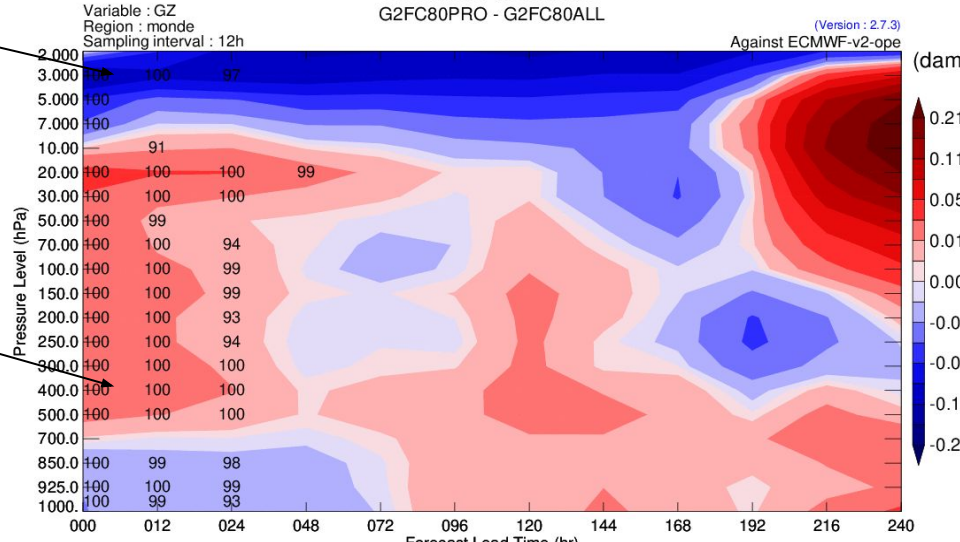
- Typical structure of polar satellites (higher impact at high lat)

But there are some negative effects identified

- Anomalous negative impact upper stratosphere
  - **Already Identified** as anchoring clash during radiance bias correction (ro against static channels). **To be addressed in IC4.**
  - Not problematic below 10hPa
- Some TT, HU negative impact at low alt **(PBL?)**
  - Coherent with RS weak response at low altitude
  - Fine just above PBL
  - Not yet critical, but statistically significant
  - Must be addressed before increasing data further
  - Likely IC4

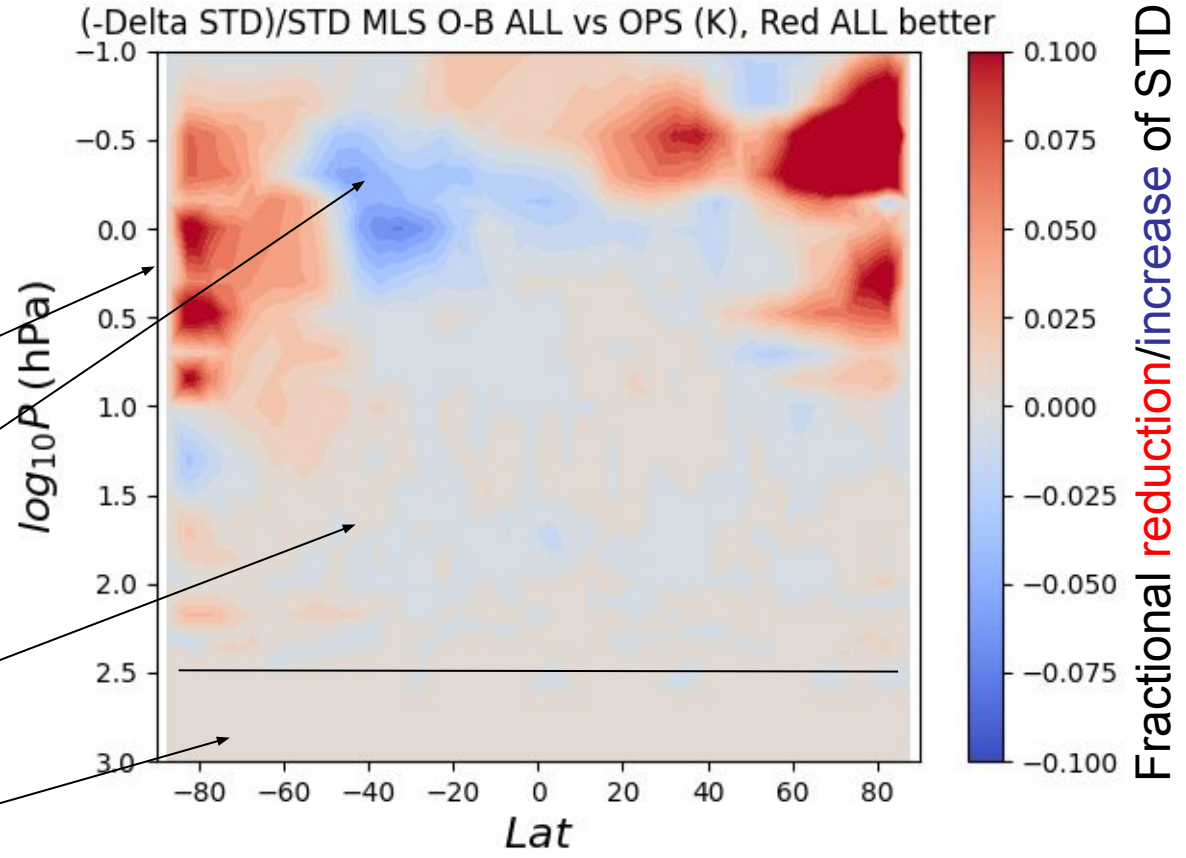






Verifications IV: MLS (Microwave limb sounder)

- Thermodynamic, but not RO
- Global, uniform weight by latitude
- Not uniform local time
- Not assimilated
- Limb geometry, moderately high vertical resolution. **Reaches model's lid.**
- As radiances, subject to bias. To simplify relative radiometer_vs_model bias, we mostly ignore bias here, look **only to STD**.



- Large mid-upper stratosphere improvements in the poles
- Degradation in upper stratosphere (later identified as collision of radiance anchors, ro against static channels). No impact below. **TBA in later research**.
- Generally positive elsewhere
- MLS **not sensitive below 300 hPa**

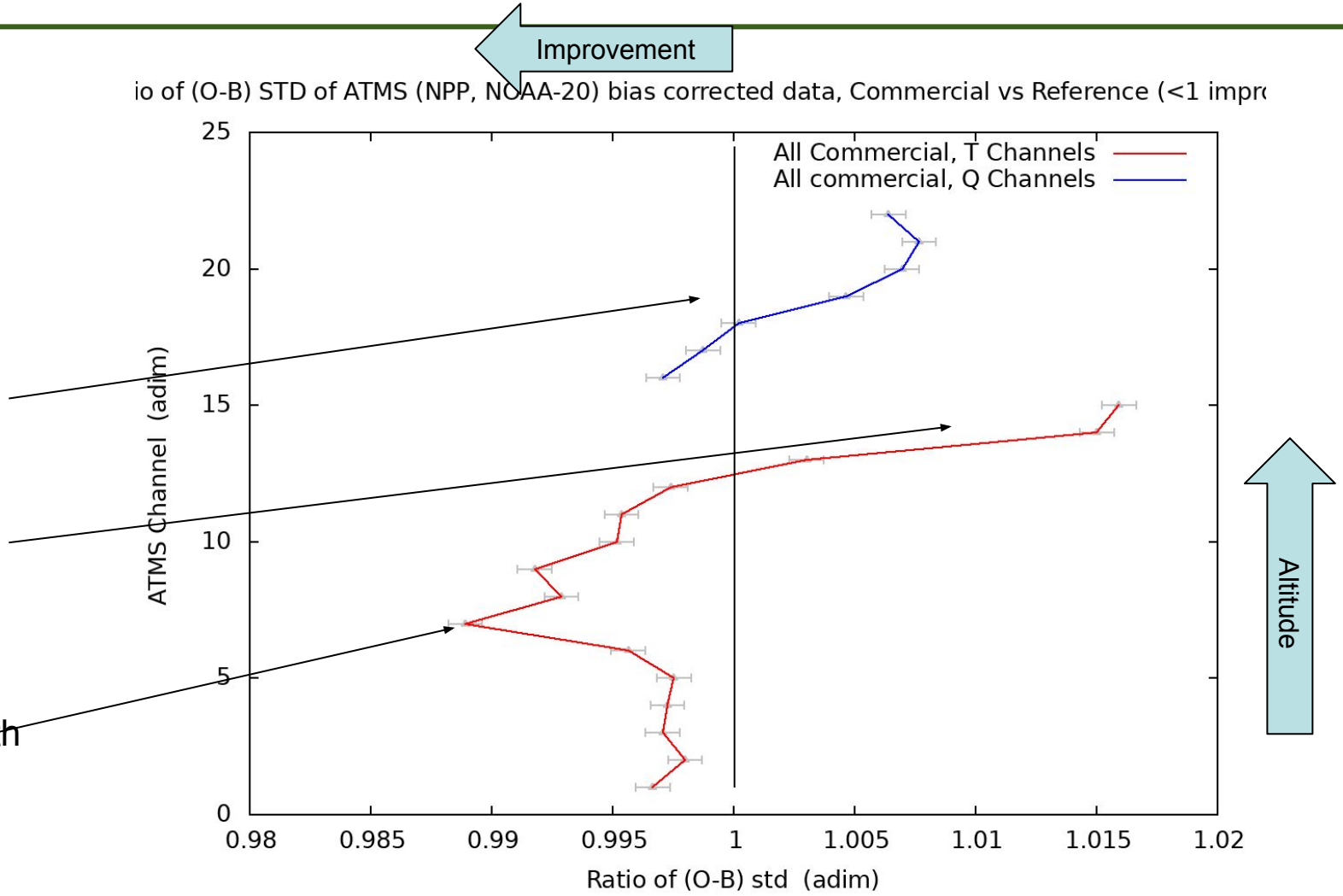
Verifications V: ATMS (NPP & NOAA-20)

- Thermodynamic, profiled, but not RO
- Global, also weigthed towards higher lat
- Not uniform local time
- Subject to bias, under bias correction
  - This may be non-trivial

- Moisture channels confirm some mixed behavior TBA

- Upper 2 static channels clash against ro anchoring (and drag the third upper)

- Other temperature channels coherent with general improvement, particularly upper tropo, low strato



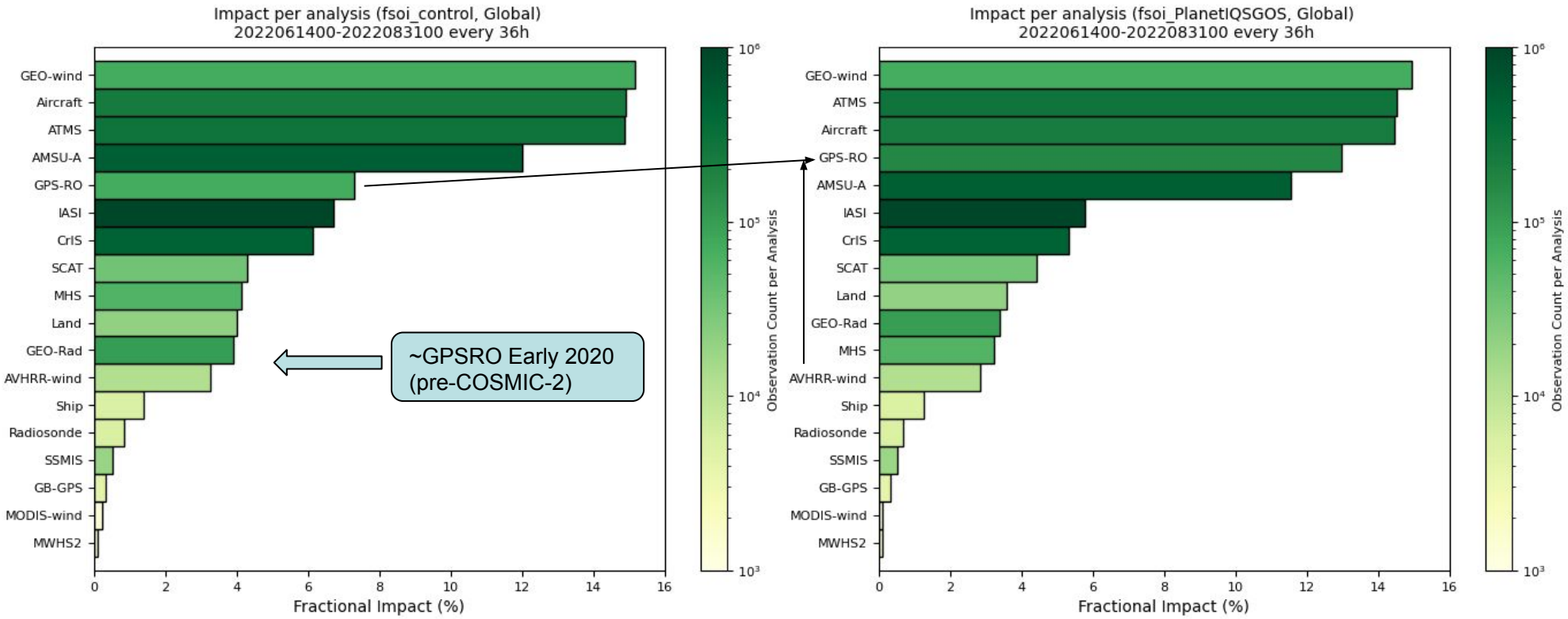
Verifications VI: 24h FSOI, Global weighted, dry norm

Test with all available data included

GPSRO advanced **ahead of AMSU-A**

See jump from pre-COSMIC2.

Not saturated at 20k/day



Added Sentinel-6A (since approved), GeoOptics, Spire, PlanetIQ

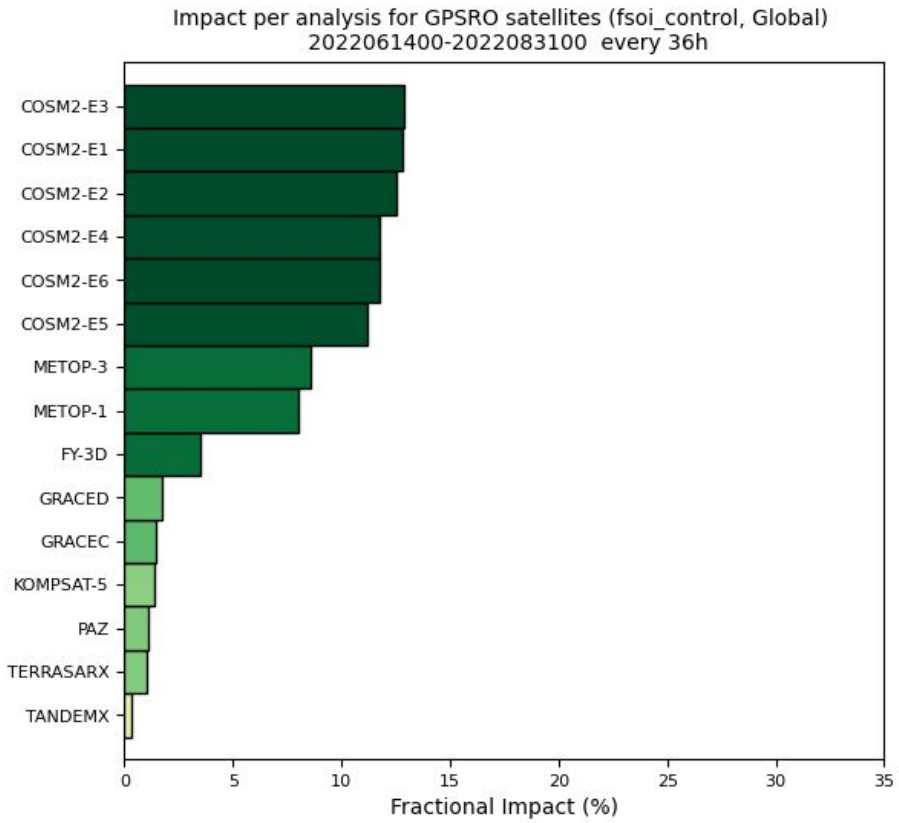
Verifications VII: Global-weighted FSOI (only RO)

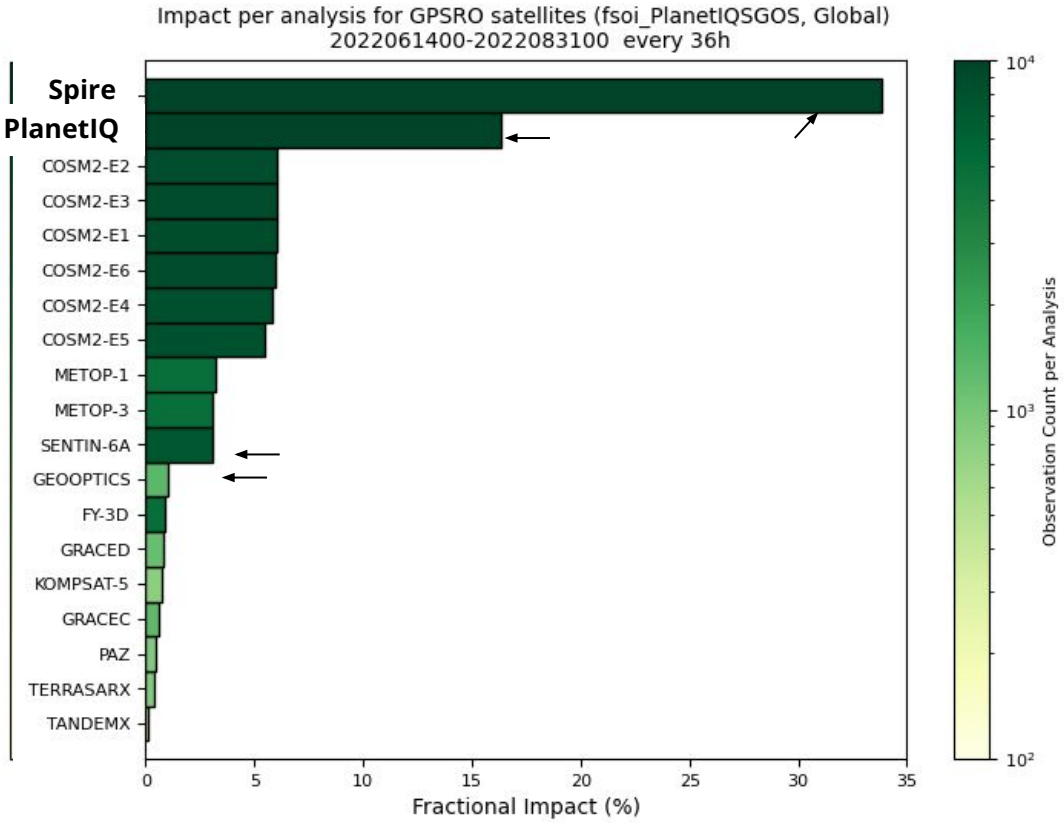
Test with all available data included

GPSRO advanced **ahead of AMSU-A**

Note: only 2/3 of the **new data** here will be available (licensed) in Jan-Jun 2023

In late 2023, volume may be higher than test shown here. To follow.



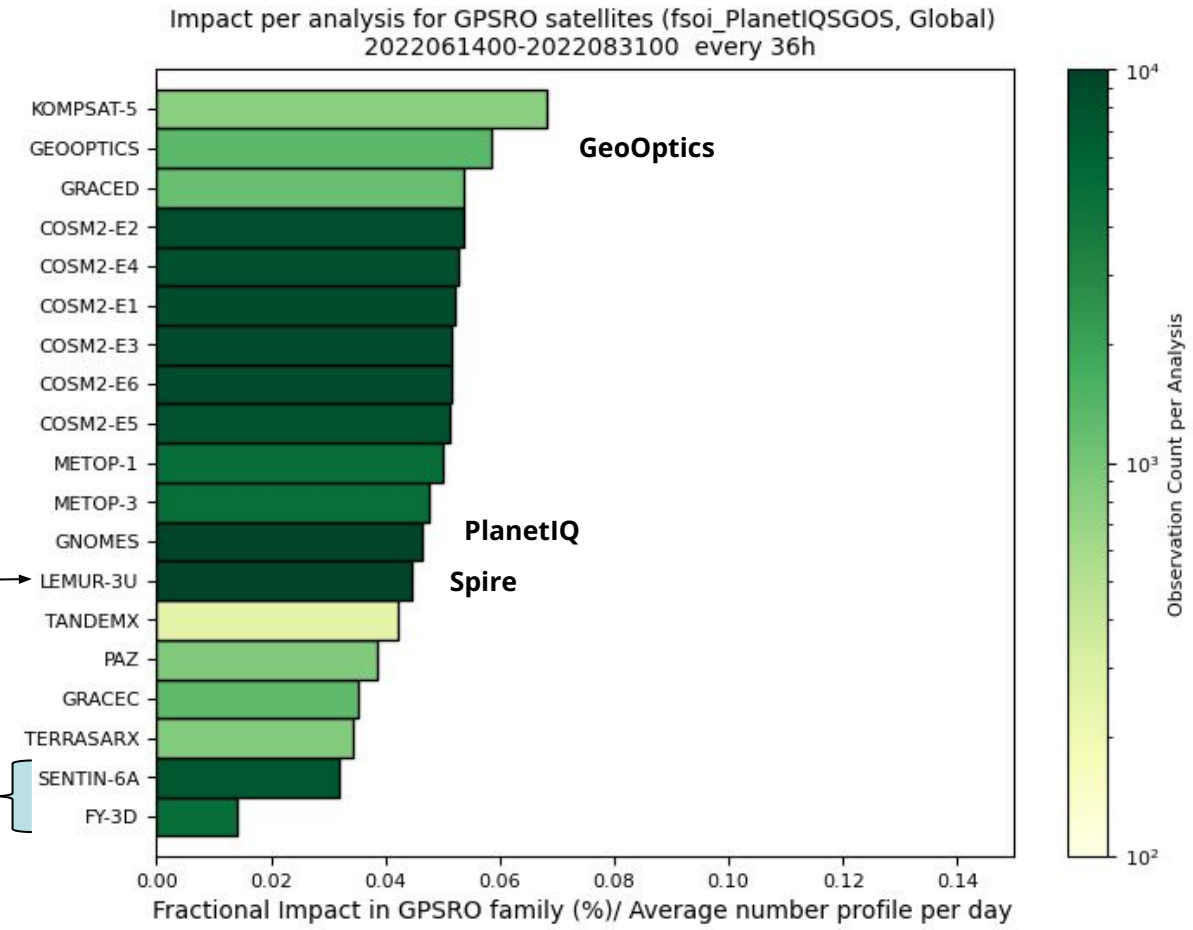


Added Sentinel-6A, GeoOptics, Spire, PlanetIQ

Verifications VIII: FSOI
Number of profiles as a quantitative measure

Comparison of FSOI impact/profile, for several missions/satellites

- Very similar across satellites
- New data proposed here good, but mostly due to **volume** (otherwise in the low average)
- Some ~outliers (known issues)

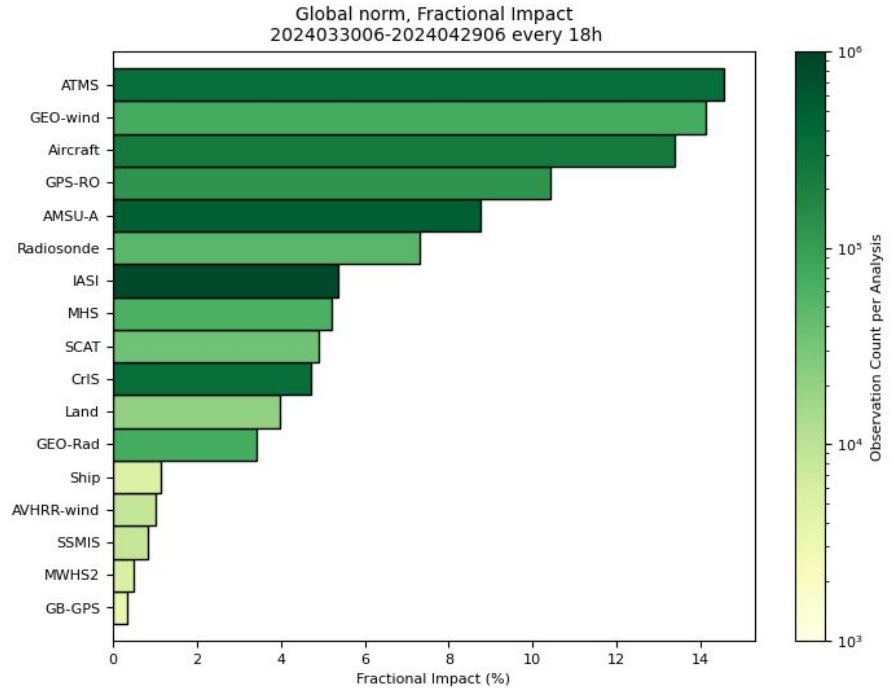


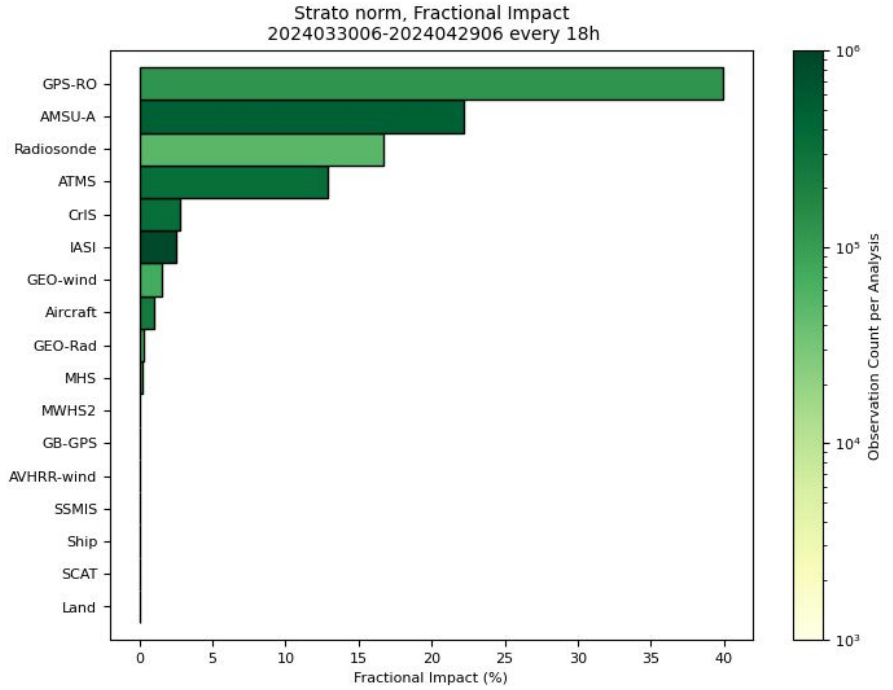
Verifications IX: FSOI strato

Comparison of FSOI (wet norm)

- all atmosphere
- only 100 hPa < p

- RO among best for entire atmosphere
- RO best 100 hPa <p
  - ~40% impact
  - Plus anchoring or radiances





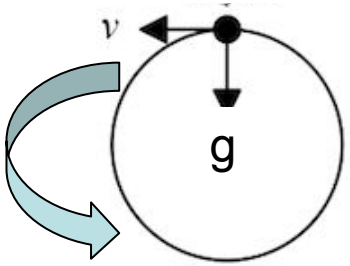
Brief

- Added data showed **improvement at short-mid range**.
  - At 6h, in the (Spire+GeoOp+PlanetIQ), thermo fcst error reduced by **3.5%**, similar properties
    - **Approx: 0.4% per 1000 occultations/day reduction in background uncertainty (4% here)**
    - Existing pool of extra ~10-15 kocc/day. **Potential of 8% reduction** at 6h field with already flying assets
  - Statistically significant impacts to METOP/RO, RS (UTLS/T, PBL/Q, midtropo/wind), ATMS.
  - Very large impact strato both poles.
- Compatible signature against ECMWF, ATMS/Temp, AMSUA, weak in ATMS/Q, AMSUB
- Net benefit, can safely reach 20k/day but
- Issues identified, should be solved before exceeding 20k/day:
  - **Should not keep adding data always stating to the system that it is bias-free (see mid-upper strato)**
  - Expected better more from **below-PBL**. Cause TBD, perhaps limits around ducting etc.
- FSOI shows that all data are positive.
  - Differences between emitters & receivers, in agreement with our understanding (clock stability, SNR)
  - Known issues with FY-3D and Sentinel-6A, causes identified, partially solved as of 2024
  - Homogeneous data across missions (**well tested EUMETSAT and UCAR software**)

Some details about observation operator I

- If accuracy in range 0.1%-0.01% is required, there is something relevant:
- Note the hypsometric eqn:

$$\Delta h = \frac{RT_v}{g_*} ln \frac{p_a}{p_b}$$



- Thickness of a layer: Under some pressure, itself adding some pressure
- Where g is the acceleration upon that layer… $g(\varphi, h)$, following for instance WGS84, but…
- Is all acceleration available to induce pressure?
- Not if there is wind (rotates faster/slower than solid Earth).
  - With wind, some g is spent forcing the air to follow Earth's curvature (not exerting pressure)
- $g(\varphi, h)$ is in equilibrium exactly at angular speed Ω (thus **at winds u=0, v=0**)
- Effective g:

$$g_* = g - \left(2\Omega u \cos\varphi + \frac{u^2 + v^2}{R} \right)$$

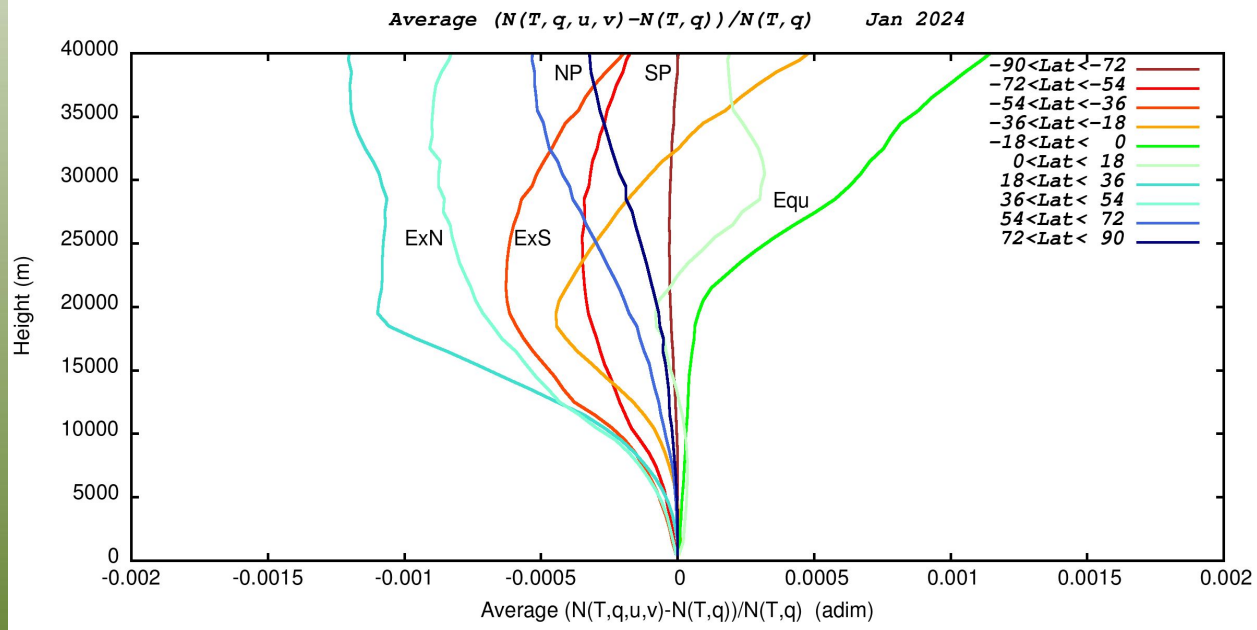
Which is in the range of 0.1%-0.01% for average meteorological u, v

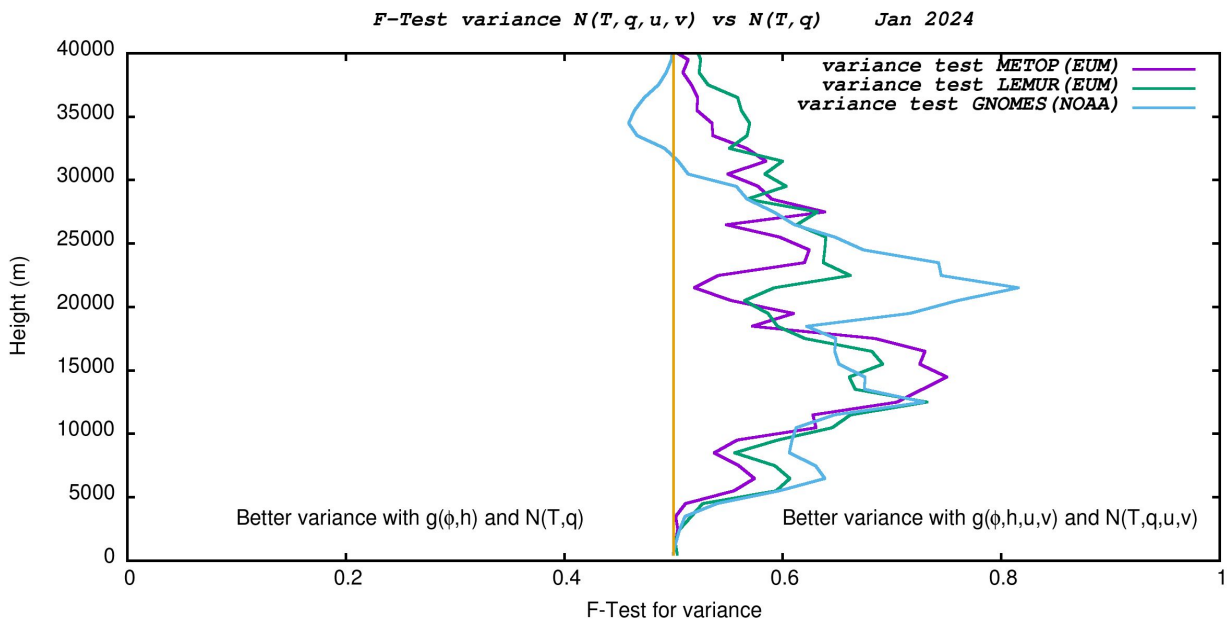
Included at ECCC in 2009, present in these tests.

Some details about observation operator II

- With eastwards wind (u>0), gravity appears slightly weaker (eg midlatitude)
- With westwards, stronger, eg Tropics
- With dominant winds mostly East, net nonzero
- Obs operator not strictly thermodynamical

$\cancel{H(T,q)}$ but $H(T,q,u,v)$





Conclusion

- Net benefit at 20000/day, but there were **issues identified**.

- Not necessarily data's fault, most likely our system
  - Clash of **anchoring** (upper static radiance channels)
  - **PBL** numeric response to assimilated data (filtering PBL RO data **did not help**)
  - Choice of N vs BA at low altitude may have relevance

- Potential future growth of data must be progressive, with time to fix any issues
- Hardware was **not** the limiting factor (some minor details through SNR)
- **Provider software appeared critical**:
  - **Earlier versions** received from SP, GO were **not ready for OPS or even test** (trivially verified)
  - Well-tested software by EUMETSAT, UCAR appears ok
- Free atmosphere (700-10 hPa) ready to accept more, but hints of localized issues
  - Midlatitude PBL

- Detectable signature of wind dependence in Observation operator (through effective gravity)