Environment and Climate Change Canada | Environnement et Changement climatique Canada

Canada

ROMEX studies at Environment Canada, with ~20000 RO profiles/day

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Preamble I

- **Study adding a large amount of RO Data, beyond the operational base at ECCC (2022)**

- **Objectives**
  - **Are sources technically ready for operations?**
  - **Identify any technical limitations yet unknown**
  - **Overview and quantify impact**
  - **Provide actionable recommendations**

- **Summary of results**
  - **Data generally identified as ready**
  - **Some identified as requiring some review for optimal use**
  - **Issues with the system were identified, which required some attention**
    - **Review N vs BA**
    - **Review PBL**
    - **Review anchors**
    - **Some biases requiring attention (small, but these data are anchor)**

- **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
  - High density only tropical (C2)

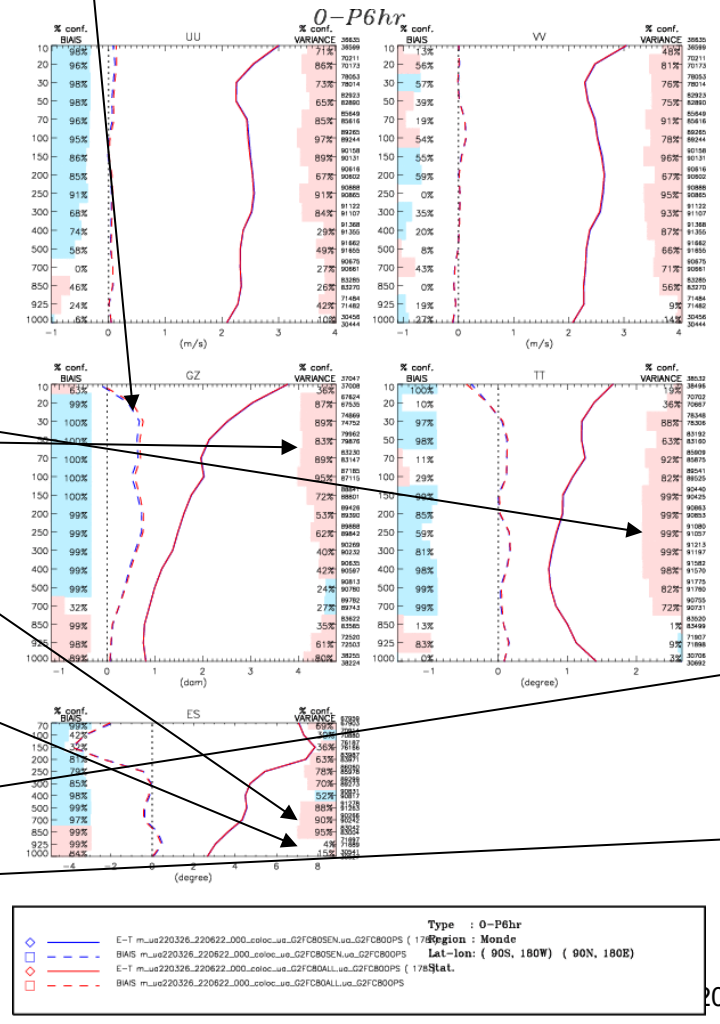
- **Addition (~10000 prof/day, mostly polar)**
  - **Sentinel**
  - **Research licenses**
    - **Spire** (~6000 prof/day, polar, GPS+GLO+GAL, set)
    - **GeoOptics** (about **500** prof/day, polar, GPS+GLO+GAL, NRT irregular delivery)
    - **PlanetIQ** (about **3300** prof/day, polar, GPS+GLO+GAL+BEI, received offline, direct agreement ECCC/PIQ)

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

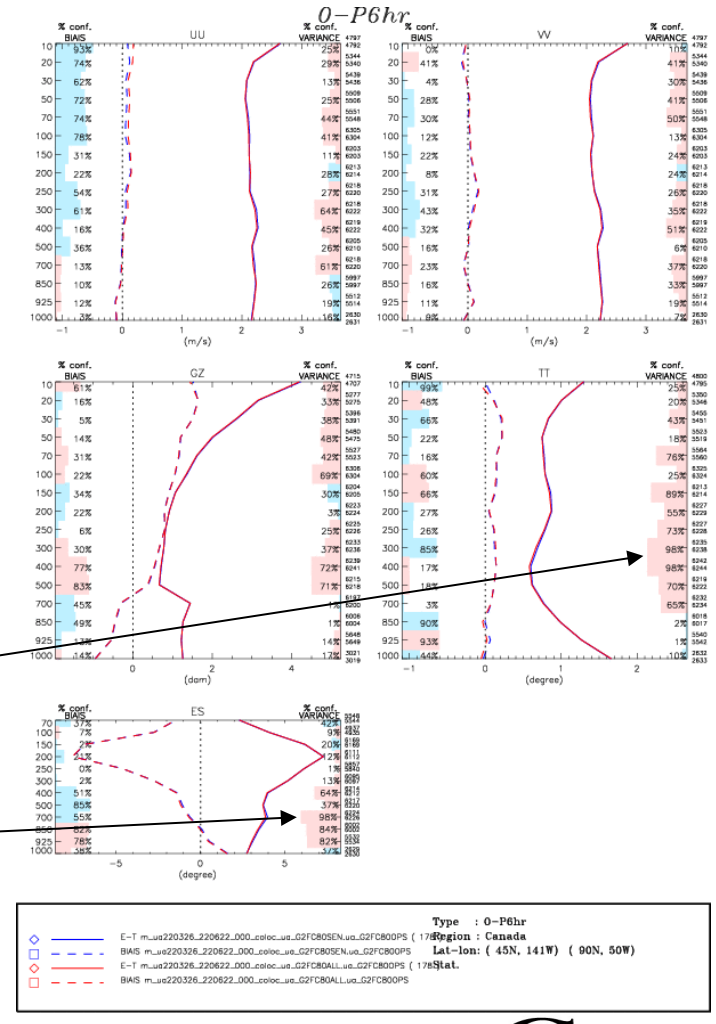
I assume this induced GZ bias to be negligible, ~1-2e-4

- 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
- At higher latitudes (e.g Canada):
  - Same signatures, with weaker significance
  - Yet, some T, q, above 90%

Northern Hemisphere

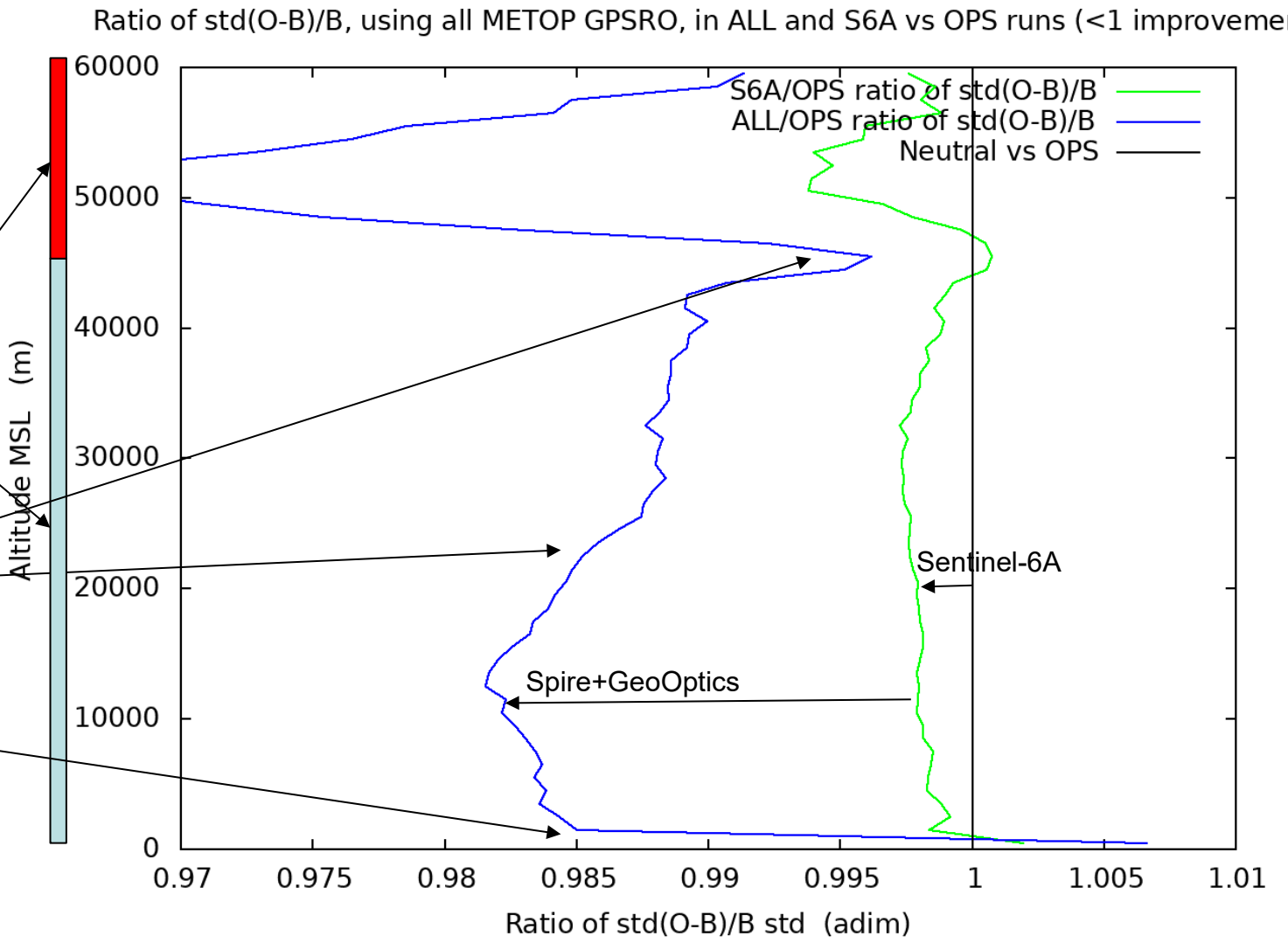


Canada



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)
- Progressive impact adding subsets
- 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 later)
  - More impact develops below 20 hPa (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



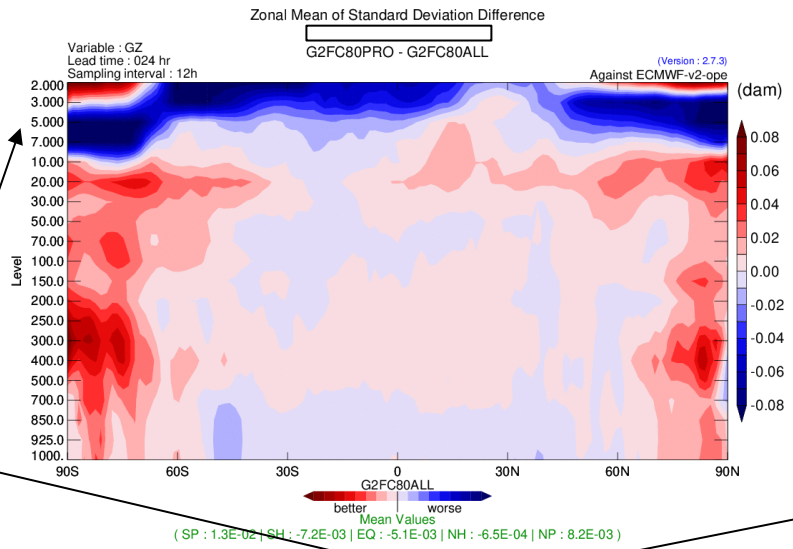
Verif III: Against external (ECMWF) analysis

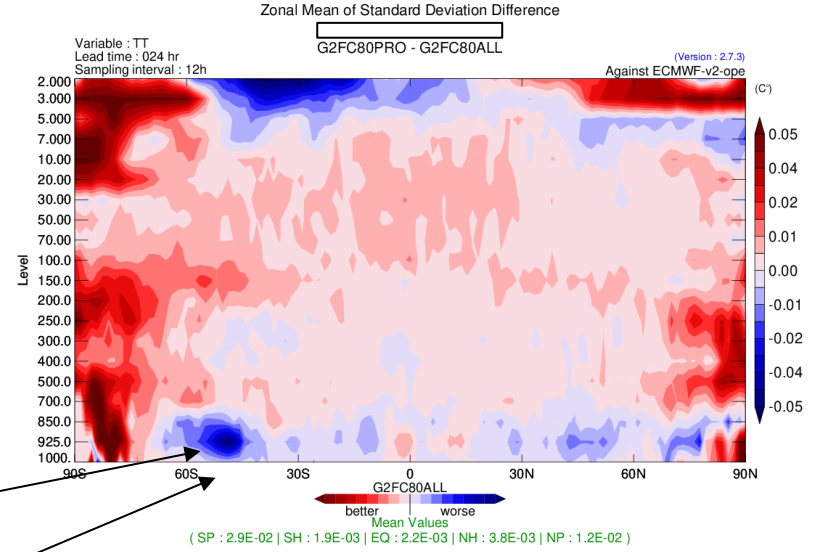
Generally positive

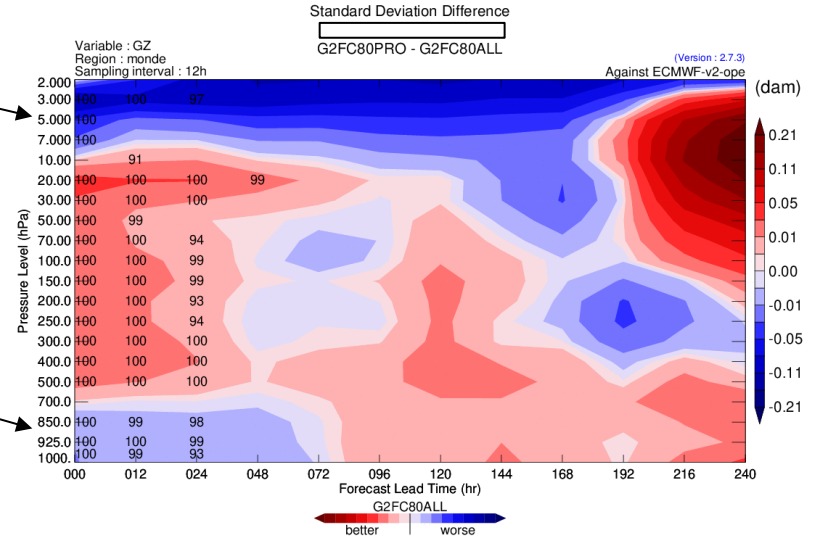
- Typical structure of data from polar satellites (higher impact at high lat)

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
  - Worse in SW Atlantic



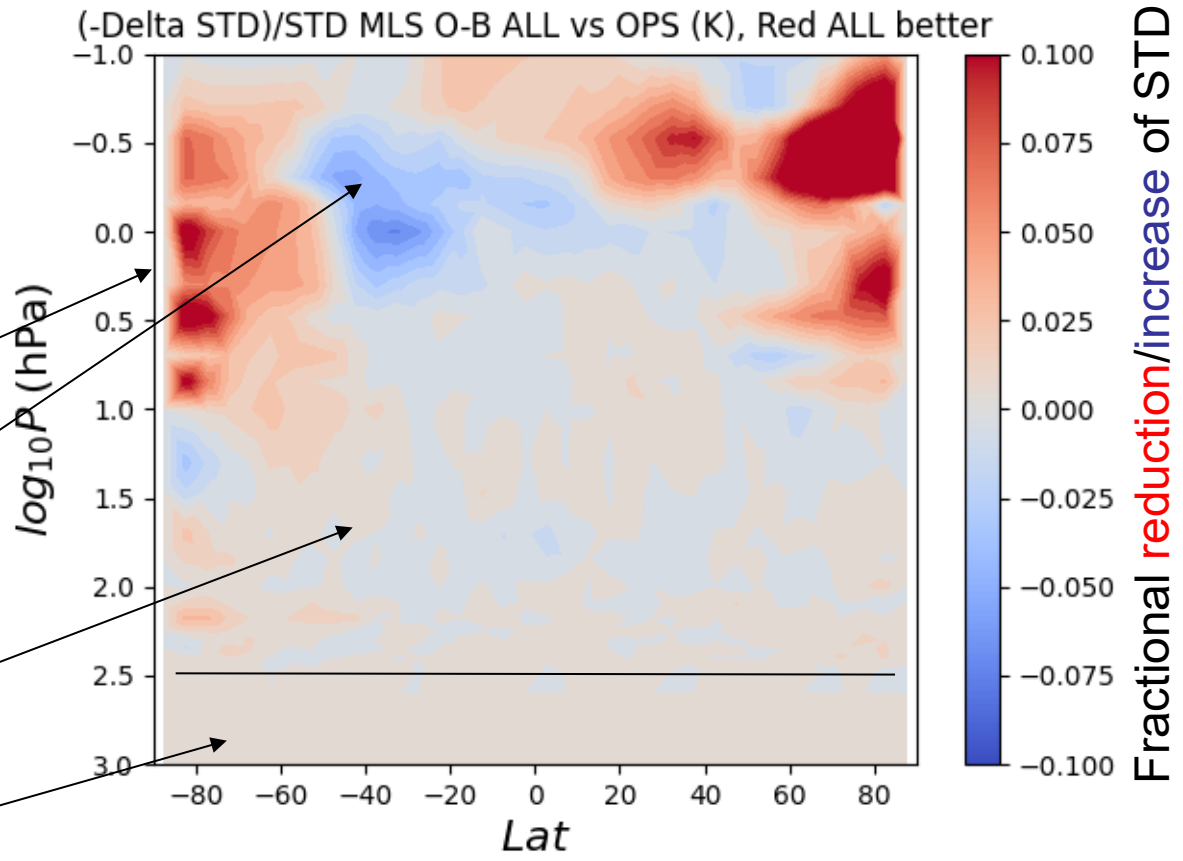




Verifications IV: MLS (Microwave limb sounder)

- 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**



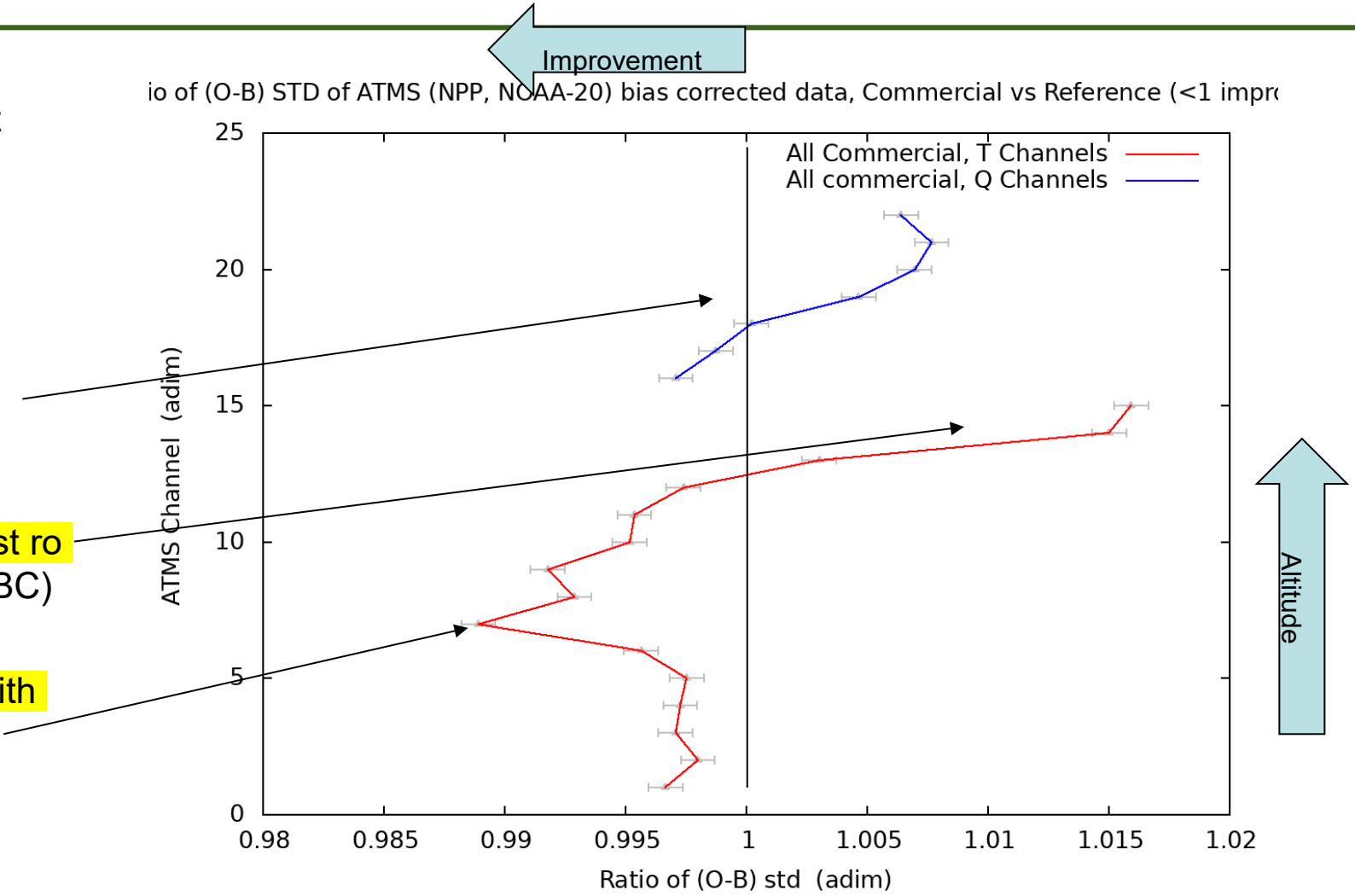
Verifications V: ATMS (NPP & NOAA-20)

- 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 BC channels clash against ro anchoring (and drag the third, dynamic BC)

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



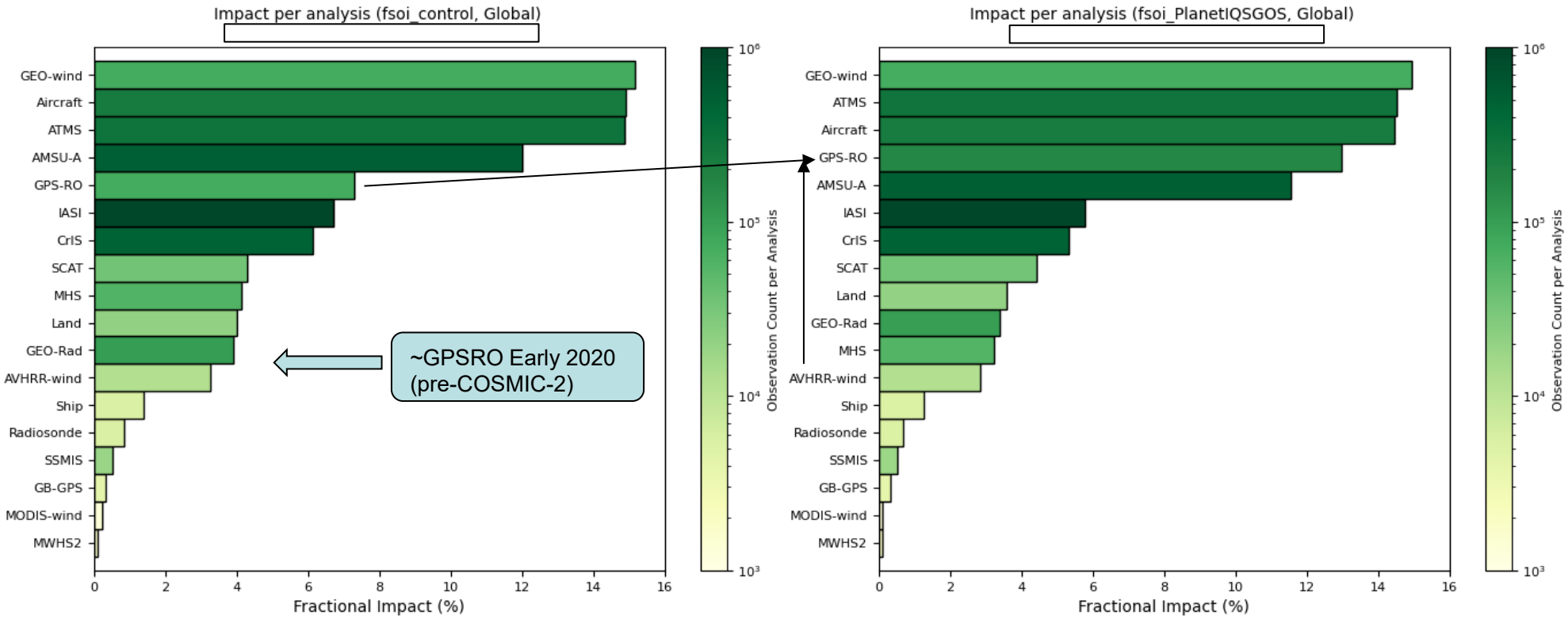
Verifications VI: 24h FSOI, Global weighted, dry norm

Test with all available data (20k run) included

GPSRO advances **ahead of AMSU-A**

Note jump from pre-COSMIC2 (the other large addition)

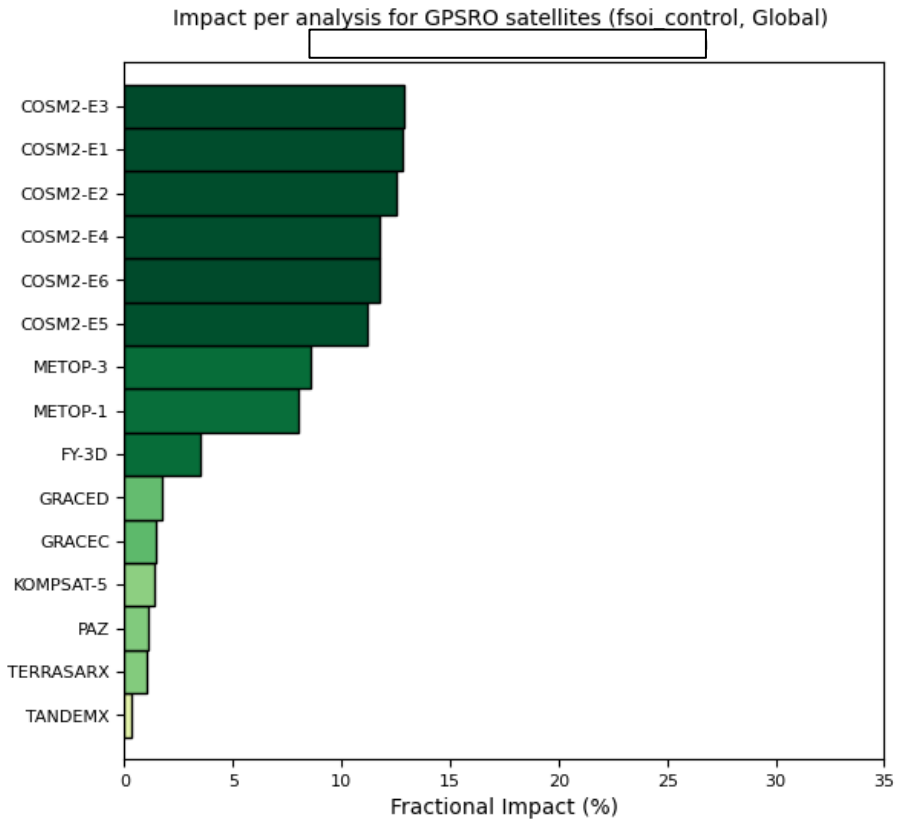
Not saturated at 20k/day

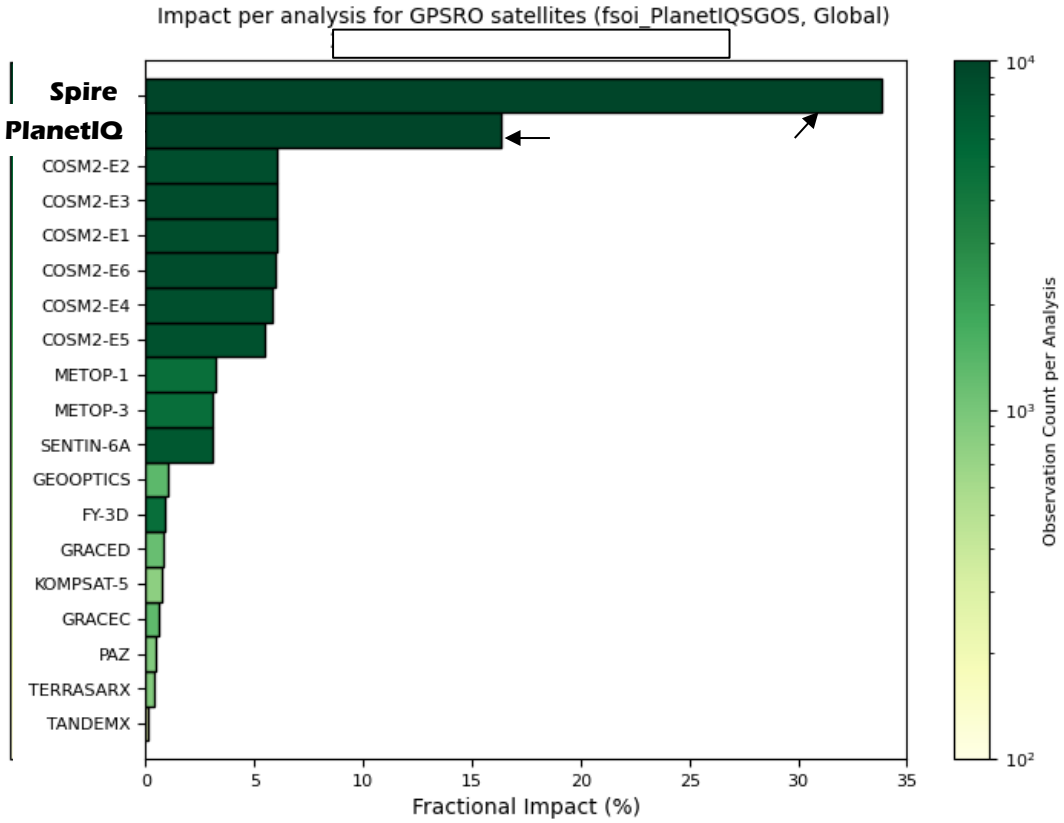


Added Sentinel-6A, GeoOptics, some Spire, PlanetIQ

Verifications VII: Global-weighted FSOI (only RO)

FSOI Impacts by source of the control, and the 20k run



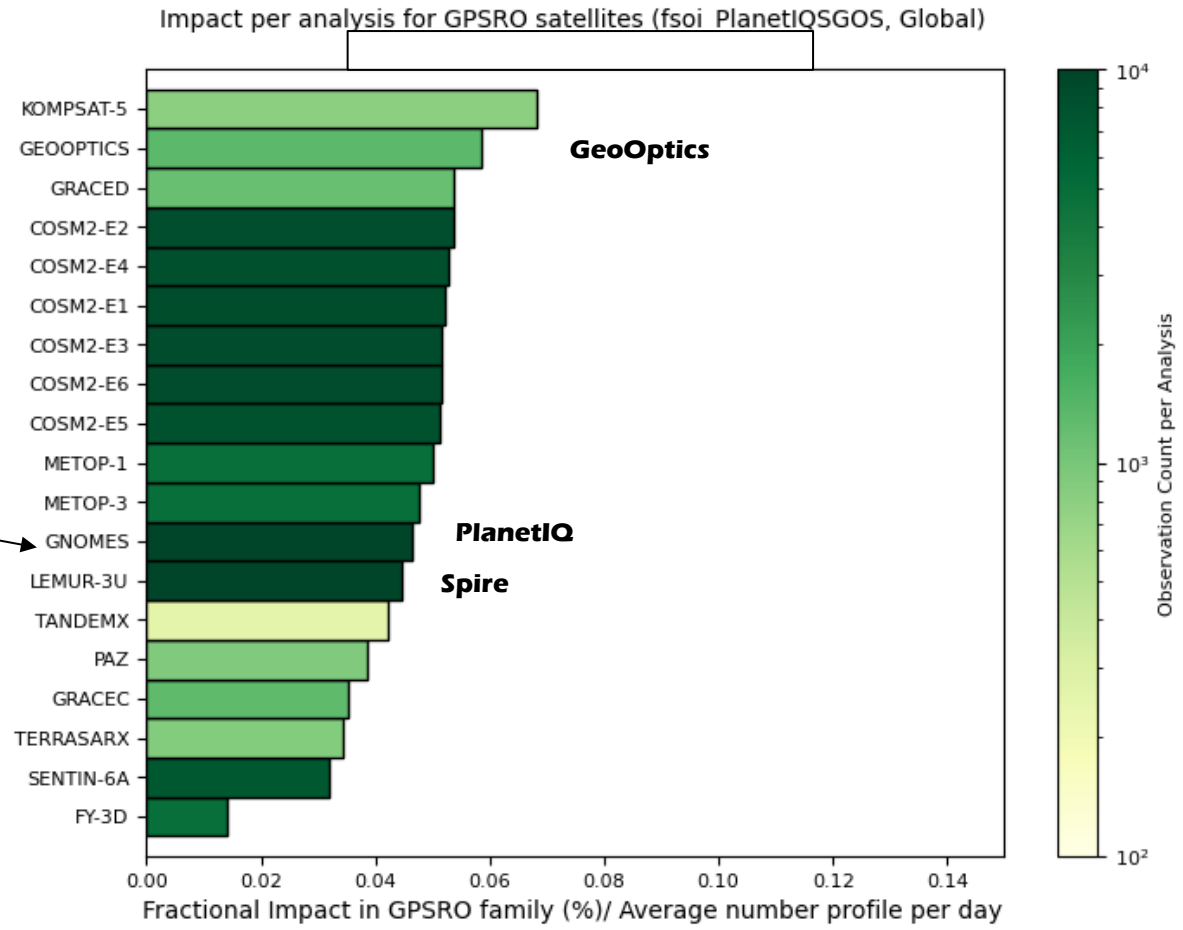


Added Sentinel-6A, GeoOptics, Spire, PlanetIQ

Verifications VIII: FSOI (Normalized by Number of profiles)

Comparison of FSOI impact/profile in the 20k run, for several missions/satellites

- Very similar across satellites
- New data explored here good, but mostly due to its **volume** (otherwise average by unit profile)
- Some differences, but all sources within moderate range once normalized

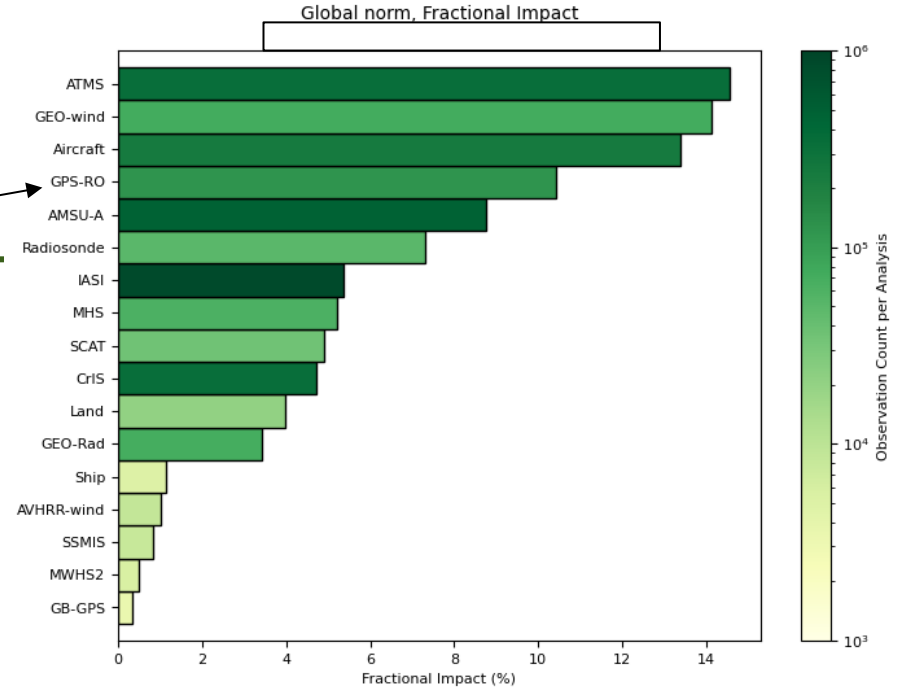


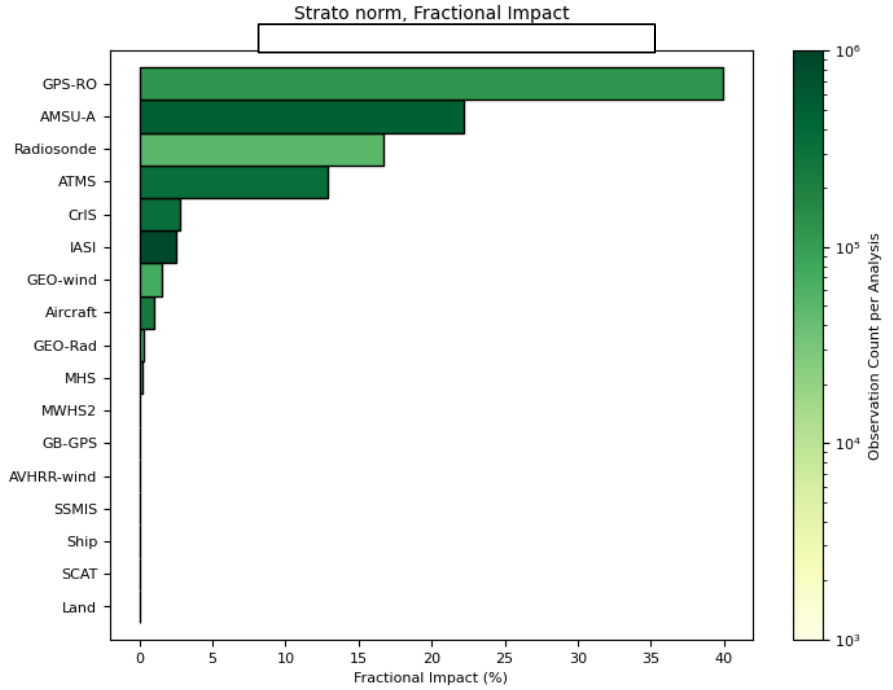
Verifications IX: FSOI strato

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
  - Already dominating strato at 20k prof/day





Brief

- Added data showed **improvement at short-mid range**.
  - At 6h, the new data (Sen+Spire+GeoOp+PlanetIQ), thermo fcst error reduced, spreading to wind, moisture
    - **Approx: 0.4% per 1000 occultations/day reduction in background uncertainty (4% here)**
  - Statistically significant impacts to METOP/RO, RS (UTLS/T, PBL/Q, midtropo/wind), ATMS.
  - Very large impact strato both hemispheres.
- Compatible signature against ECMWF, ATMS/Temp, AMSUA, weak in ATMS/Q, AMSUB
- Net benefit, can safely reach 20k/day but
- Issues identified, becoming dangerously large above 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 sources are positive.
  - Differences between emitters & receivers, in agreement with our understanding (clock stability, SNR)
  - Good results from homogeneous data processing across missions (with **well tested EUMETSAT and UCAR software**)

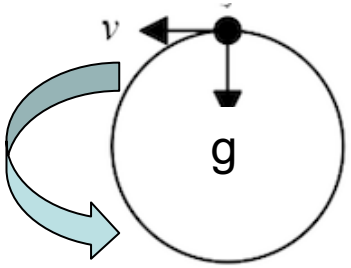
Some details about observation operator I

- If accuracy in range 0.1%-0.01% is required, bias sources are relevant:
  - Reference gas eqn
    - compressibility → pressure/altitude relationship
    - moisture fraction/partial pressure
  - Reference refractivity
    - Coefficients, nonlinearity
  - Gravity model
    - Altitude, latitude variation (perhaps longitude? i.e. local variability)
    - Coriolis
  - Description of MSL
    - Osculating sphere
    - Geoid shape, perhaps local variability?
    - Gravity tides?

Winds, Coriolis and Gravity

- 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:

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

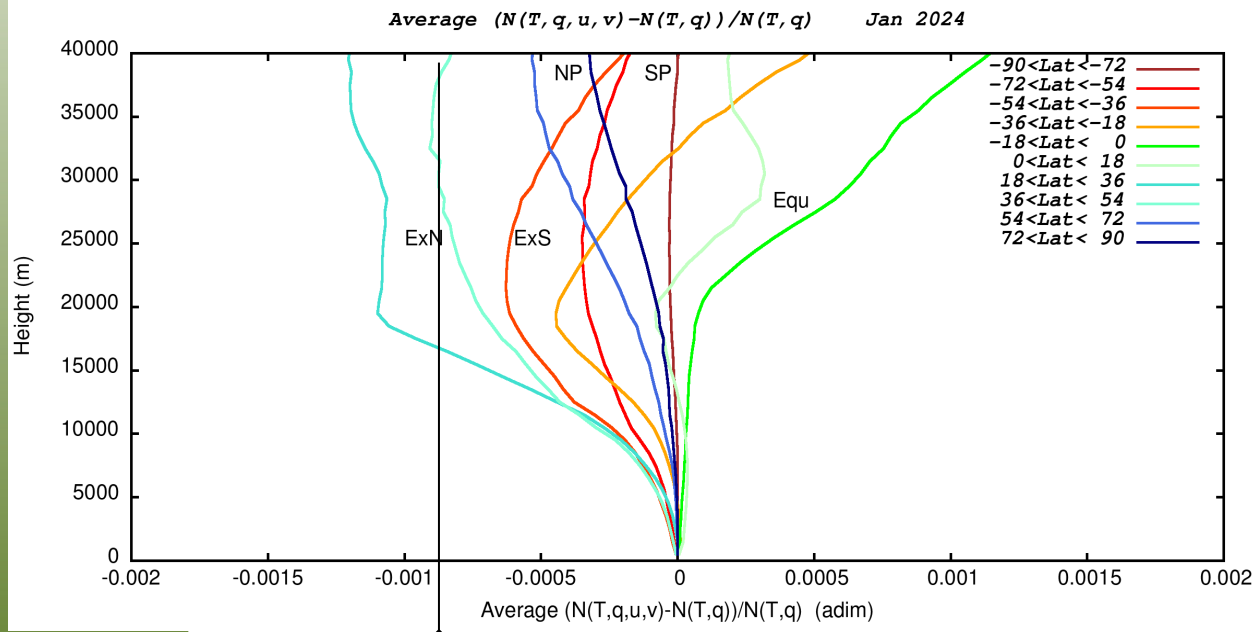
Which is in the range of 0.1%-0.01% for average meteorological u, v

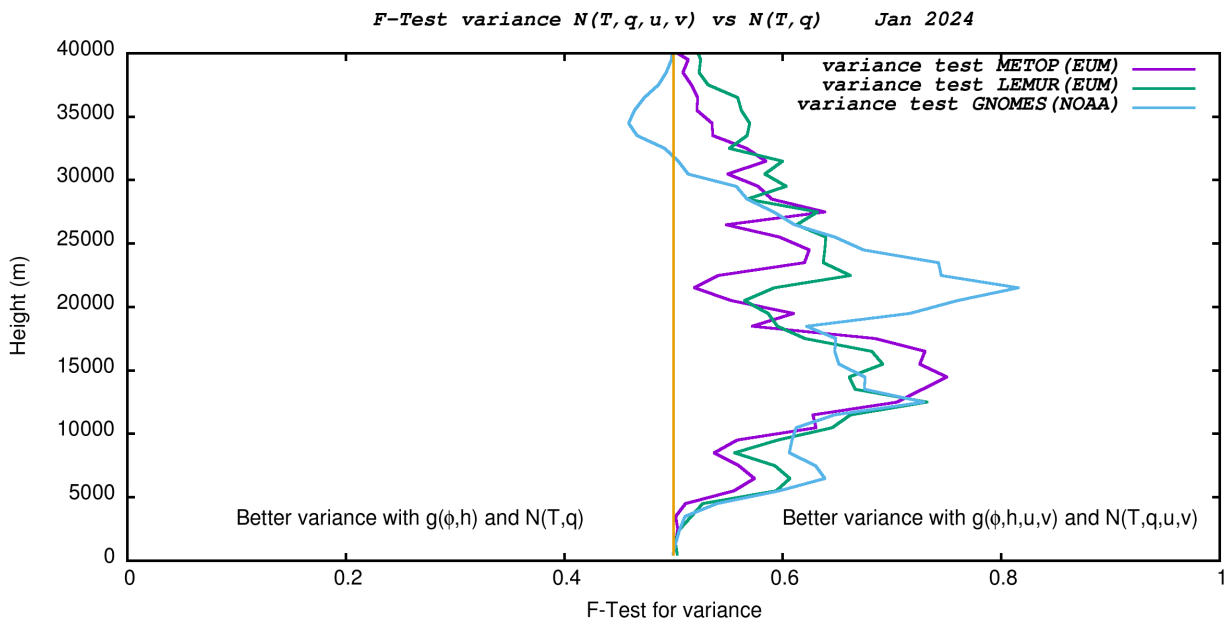
Included at ECCC in 2009, present in these tests.

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

~~$H(T,q)$~~ but $H(T,q,u,v)$





- here, wind would shift levels ~6m higher (weaker gravity, slower decay of P, density)

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**)

- 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 processing versions were not ready, or marginally ready
  - Well-tested software by EUMETSAT, UCAR appears ok, encouraged to upgrade all NRT processing to this quality
- Free atmosphere (700-10 hPa) ready to accept more data, but hints of localized issues
  - Midlatitude PBL, upper strato

- Detectable signature of wind dependence in Observation operator (through effective gravity)
  - Non-negligible net impact in bias
  - This 20k run was done with wind effect on.