On the benefit of assimilating denser geostationary water vapor radiances

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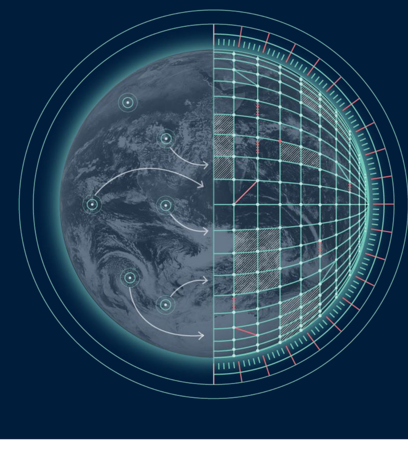


1. Approaching finer scales for all GEOS in 4D-Var

Geostationary radiances provide a unique perspective of the dynamics in Earth's atmosphere with a very high spatial (3 km) & temporal (10 min) resolution. Radiances in water vapor bands may represent clear-sky & cloudy pixels of the atmosphere. **As severe weather events evolve at these high spatial and temporal scales**, a more accurate representation of observations at these temporal and spatial scales may significantly improve the forecast of these events (Figure 1).

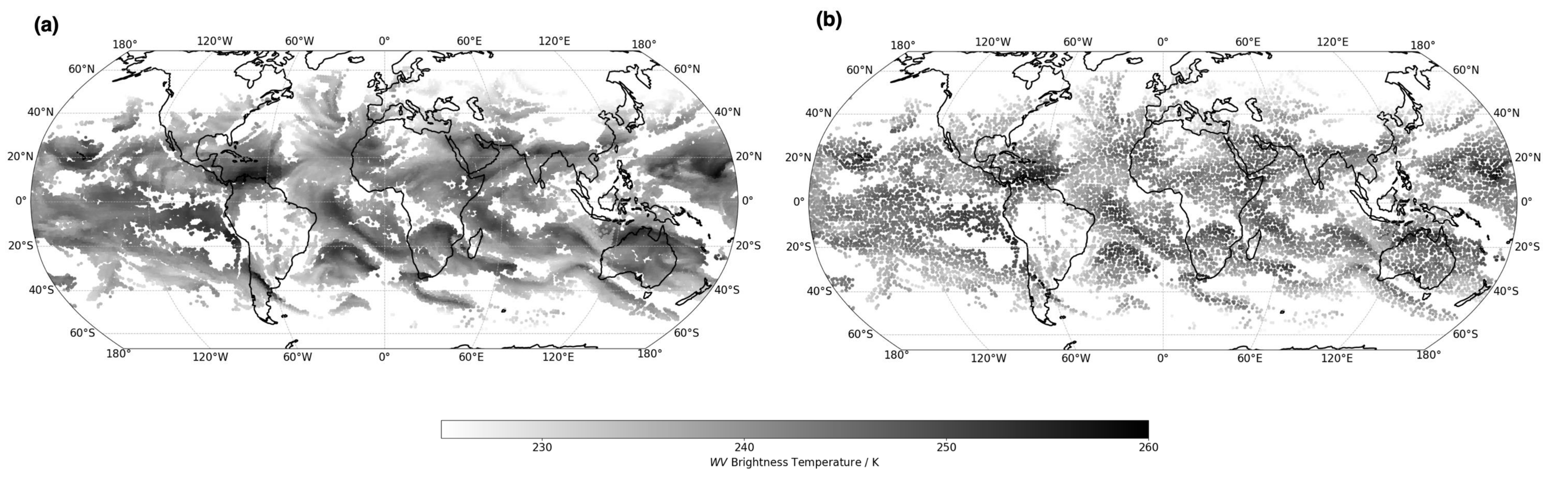
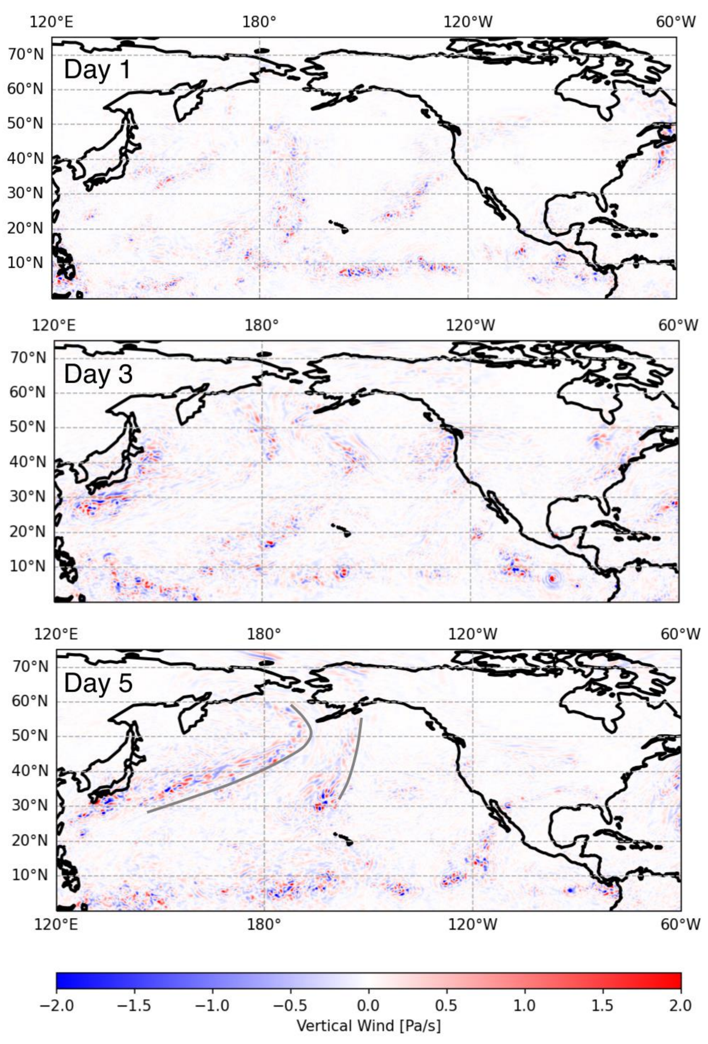


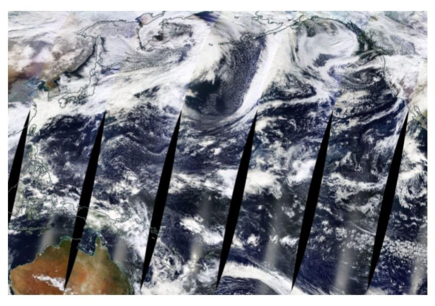
Figure 1) Assimilated clear-sky observations from all geostationary satellites from the WV 6.2 micrometre band for a chosen sample on Dec. 2nd at 7 UTC, when a strong cyclone occurred over the North Atlantic: **75 km (a)** versus the operational **125 km (b)** spatial thinning of observations globally.

2. Upscale propagation of the impact

We incorporate smaller spatial scales via higher-resolution water-vapor radiances for all geostationary satellites: GOES, METEOSAT, and HIMAWARI and compare the impact to the previous experiments with observations every 125 km.



Below is a satellite image for Dec. 4th for clarity:



We see an **upscale propagation over time from the first day of cycling until day 5** (Figure 2), when calculating the **difference of the analysis of vertical wind at 500 hPa** with relatively denser geostationary satellite observations versus the operational configuration. The gray lines are indicative of frontal systems in the North Pacific.

Figure 2) Over the course of the **first 5 days**, small-scale differences between the analysis based on finer observations versus the analysis based on coarser observations cascade upscale. Plotted is the vertical wind at the 500 hPa isosurface. The assimilation window is a typical 12 h window as in operations for IFS.

3. Effect in comparison to other instruments

How do our results compare to short-range forecasts of humidity and temperature sensitive quantities in other instruments (Figure 3)?

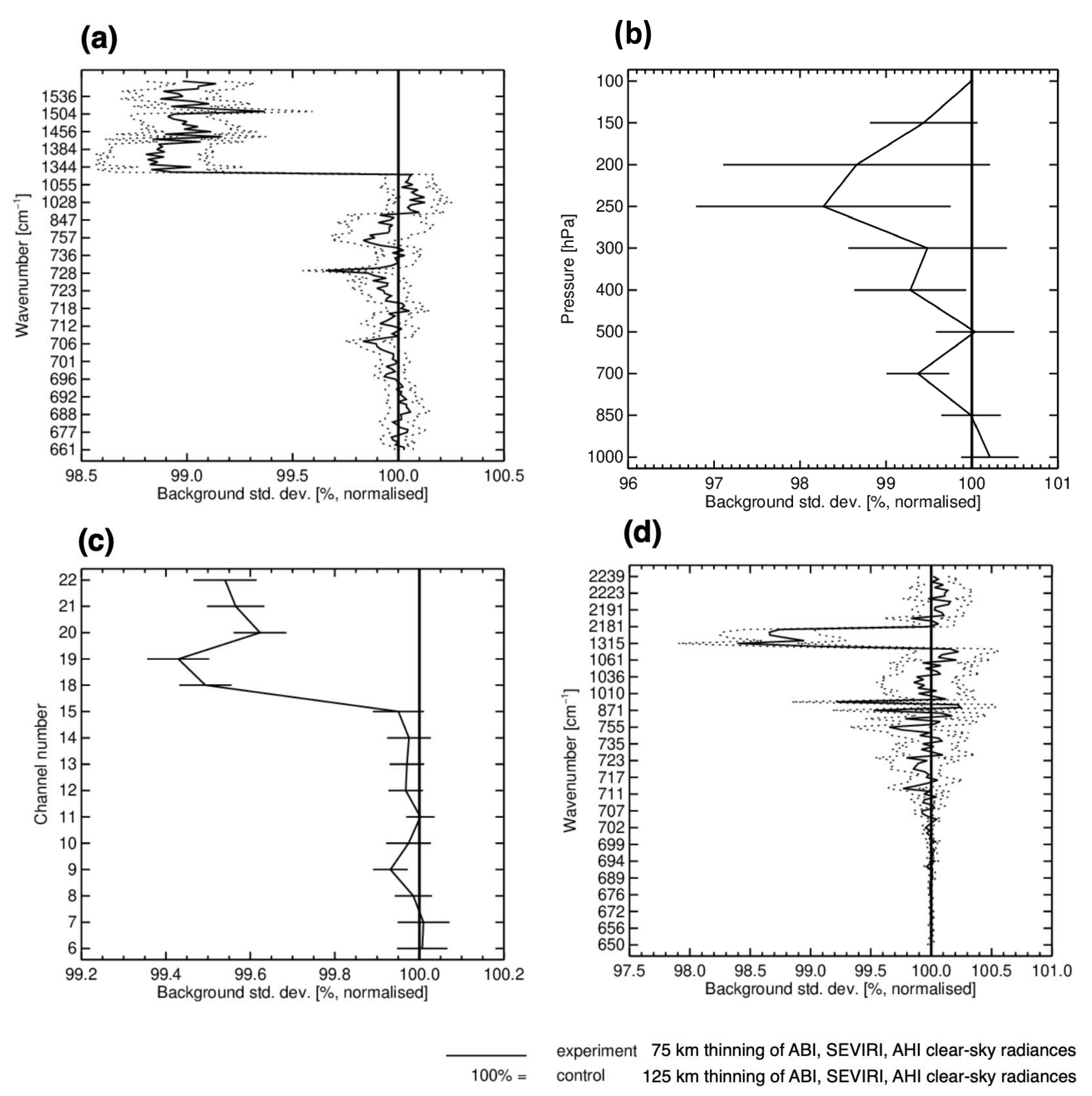
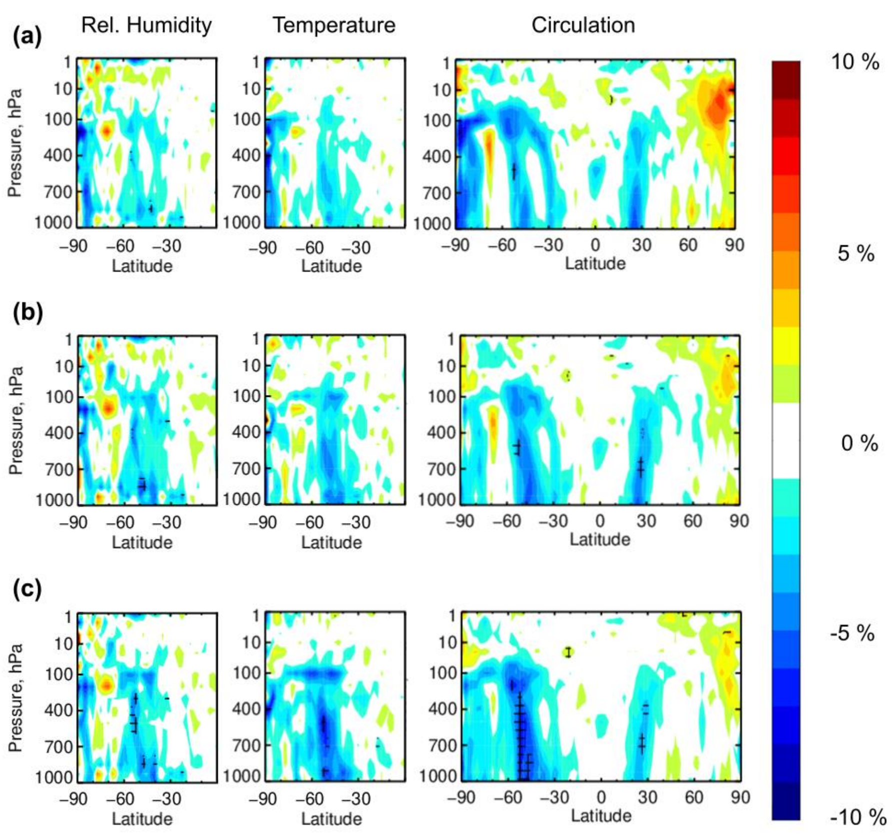


Figure 3) Improvements over a wide range of observations. We show the same experiment as outlined in the previous figures for the whole winter season Nov-Jan 2022/23. Chosen for comparison are the **CrIS instrument (a)**, conventional **radiosondes which are especially sensitive to upper and mid troposphere (b)**, humidity and temperature sensitive **ATMS (c)**, as well as **AIRS (d)**.

3. Impact of denser observations on the medium range

In comparison to previous experiments with denser observations from only one satellite as presented at EUMETSAT conference in Malmö (2023), a global impact on medium range forecast scores is now evident. Over the course of the first 14 days an improvement of the 4-day forecast of the circulation builds up in regions where the **Hadley cell occurs** on the **Southern Hemisphere** (SH). Over the first six weeks of the assimilation cycling, the improvement extends further into the the southern mid-latitudes, as well as the **upper troposphere where the jet stream is forecast**.



***The meridional circulation improves** especially over the southern oceans over the first 15 **(a)**, 20 **(b)**, & 25 days **(c)** of cycling.*

Figure 4) An improvement in the meridional wind forecast occurs in the southern hemisphere near the position of the **jet stream**, as well as on the **edge of the Hadley Cell** in the **4-day forecast (T+96 h).**

4. What about spatially correlated errors?

A major challenge in exploiting this type of high-resolution observations are spatially correlated errors. These errors are known to increase towards smaller spatial scales (Bormann & Bauer, 2010). We provide the spatially correlated observation errors for HIMAWARI-9 AHI (Figure 5).

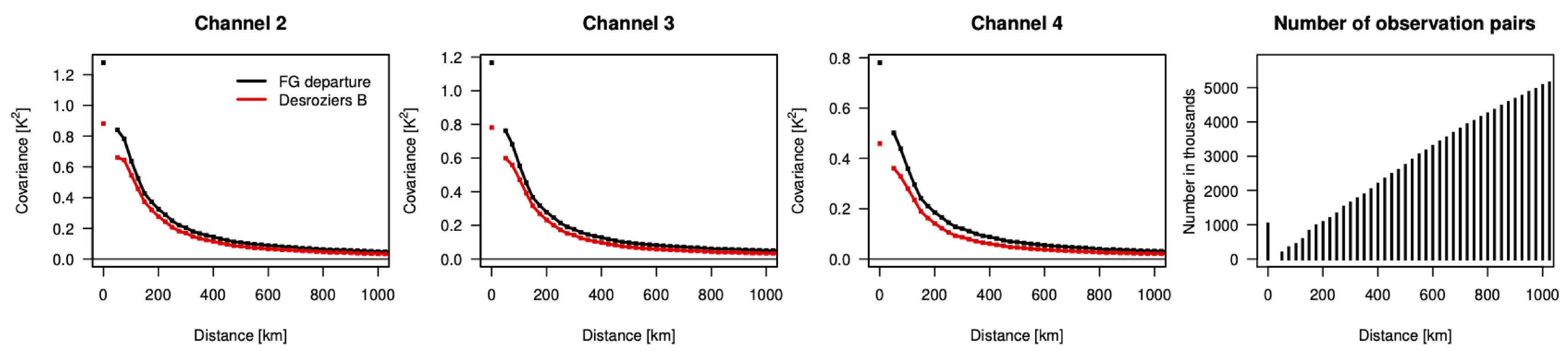


Figure 5) We compare spatially correlated errors of HIMAWARI-9. The statistical quantities are calculated over the area covered HIMAWARI for at least 10 days in a row until the statistics covergeces.

The relative increase in correlated errors appears small, i.e., << 1 K.

5. HIMAWARI brings additional information at 75 km

We incorporate smaller spatial scales via higher-resolution water-vapor radiances 6.2 µm, 6.9 µm & 7.3 µm bands (Figure 6).

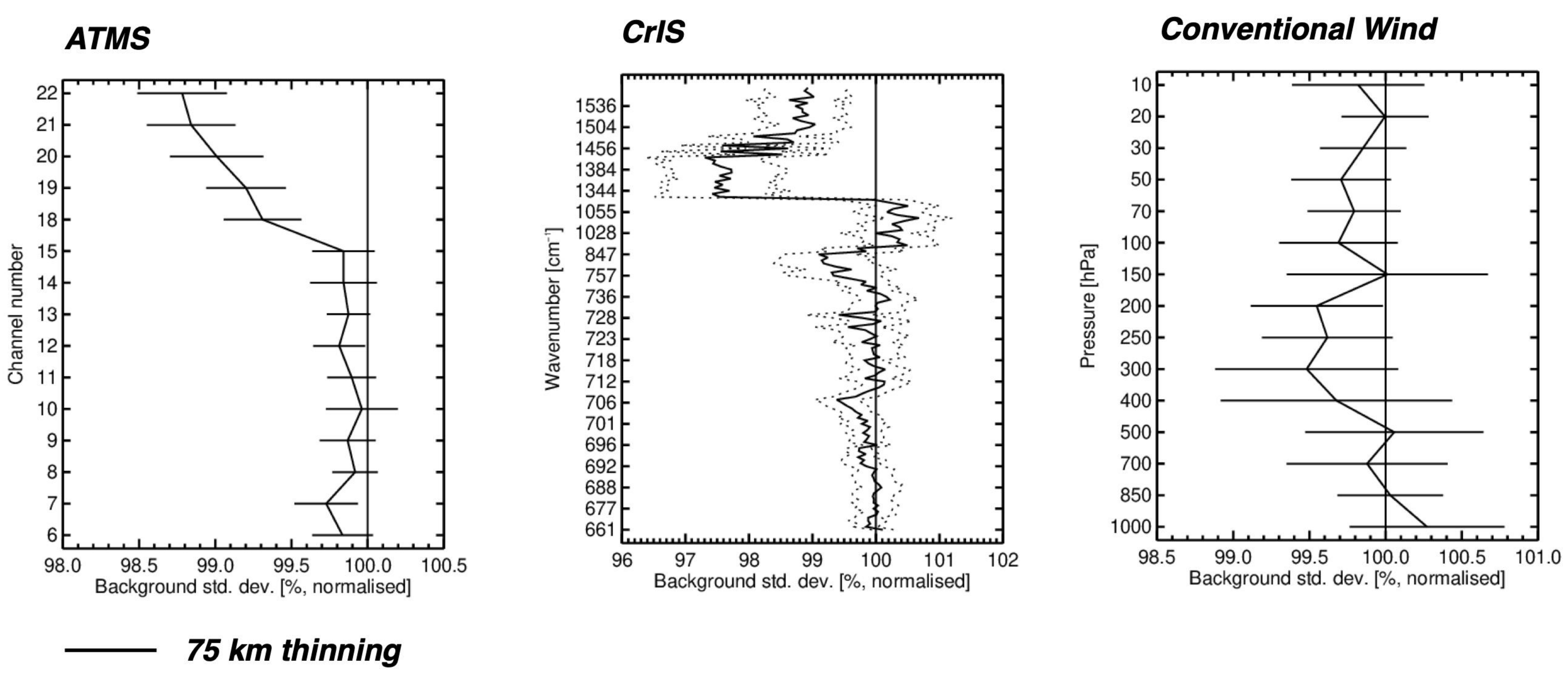


Figure 6) Improvements occur in short-range forecasts of water vapor sensitive model equivalents of ATMS, CrIS & conventional wind observations. The statistical quantities are calculated **over the area covered by HIMAWARI** for 30 days in June 2022.

6. Lessons learnt & brief outlook

i. GEOS clear-sky radiances are assimilated at 75 km globally in the next IFS cycle as the finer resolution improves the fit to other instruments in the short-range.

ii. We have an impact on the medium range when changing all satellites in syncrony.

iii. Currently, experiments are run to optimize the temporal sampling for HIMAWARI.

iv. Requirements for assimilating GOES observations at higher frequency, i.e., at 10-min time intervals were changing the observation error covariance matrix, using a 9 km resolution outer loop, as well as finer scale observations at 75 km.

v. **For Destination Earth (DestinE), we are evaluating how the finer resolution of observations can improve the forecasts of specific extreme events in the future.**

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