On the benefit of assimilating clear-sky radiances every 75 km globally at sub-hourly time scales

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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).

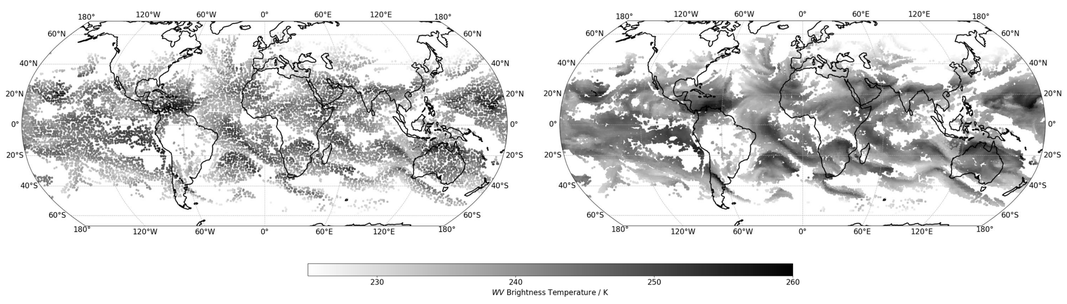
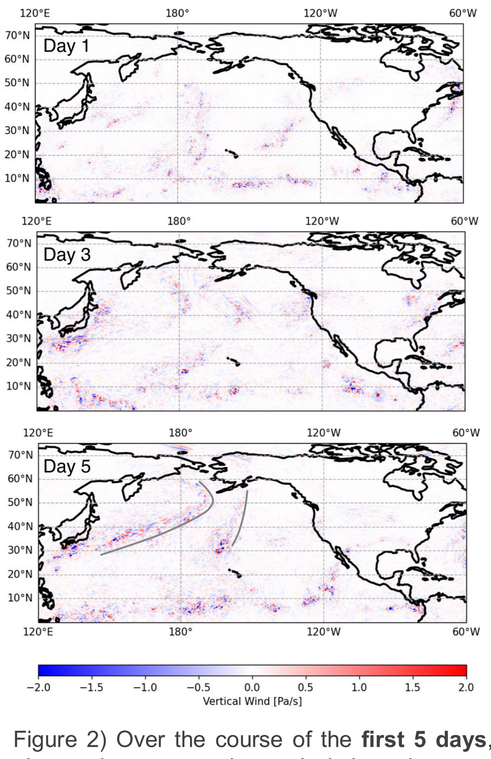


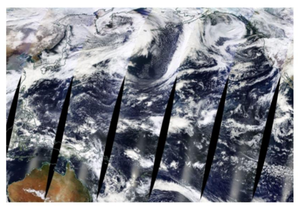
Figure 1) Assimilated clear-sky observations from all geostationary satellites from the WV 6.2 micrometer band for a chosen sample on Dec. 2nd at 7 UTC, when a strong cyclone occurred over the North Atlantic: **75 km (right)** versus the operational **125 km (left)** spatial thinning of observations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

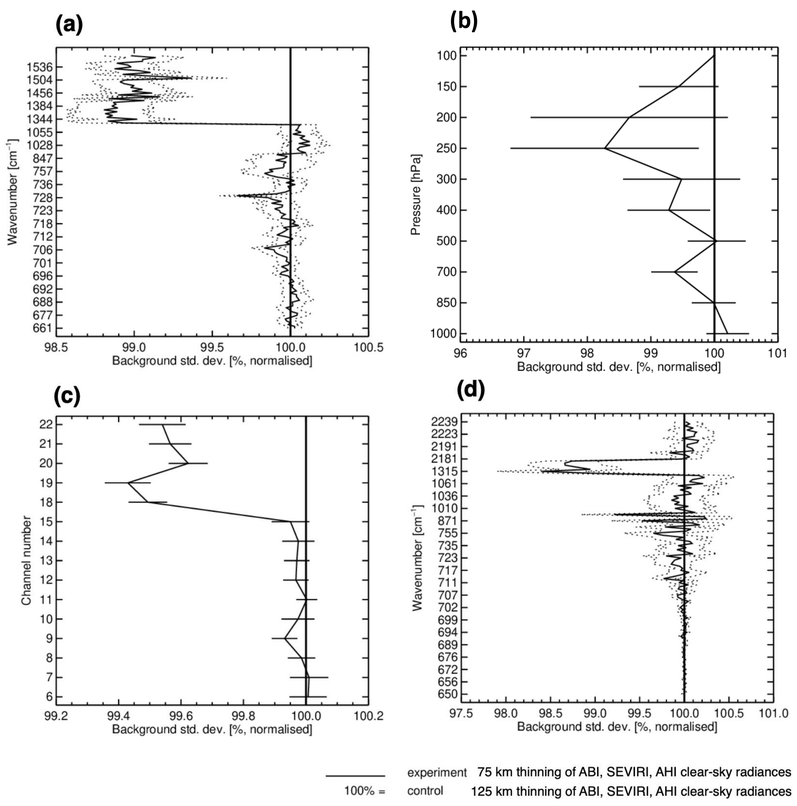


Figure 3) Improvements over a wide range of observations. We show the same experiment as outlined in the previous figures for the whole winter season Nov-Jan 2022/23. Chosen for comparison are the **CrIS instrument (a)**, conventional **radiosondes which are especially sensitive to upper and mid troposphere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

4. 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 25 days an improvement of the 5-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 occurs**.

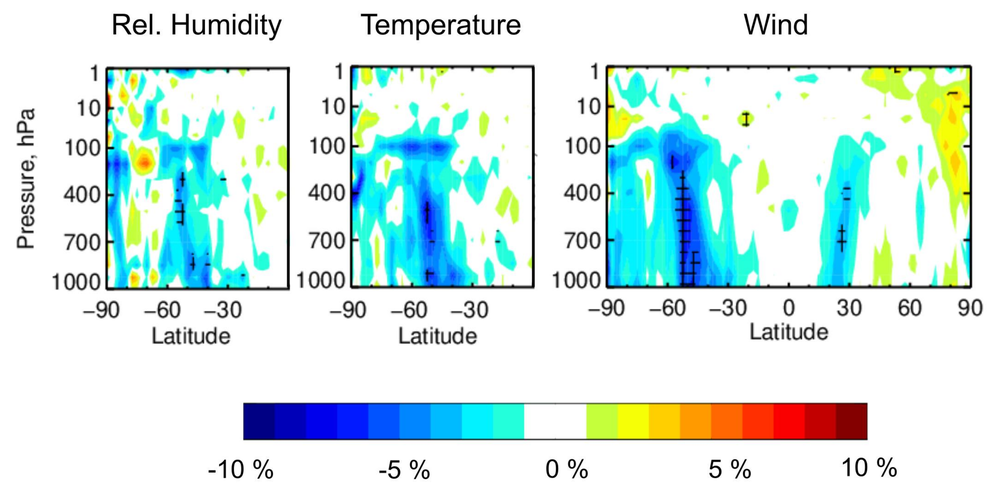
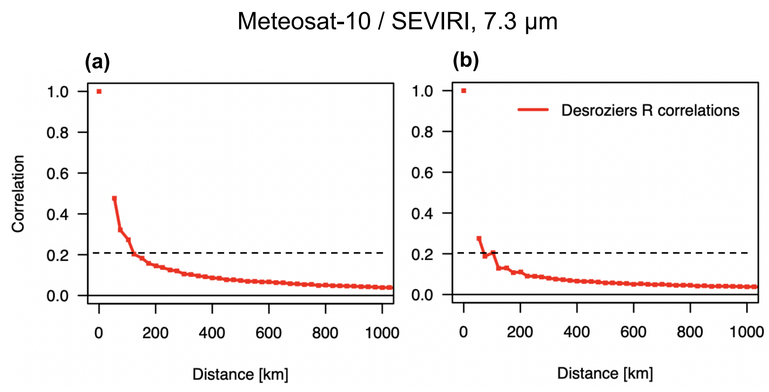


Figure 4) An improvement in the meridional wind forecast occurs in the southern hemisphere near the position of the **jet stream**, as well as on the **edge of the Hadley Cell** in the **5-day forecast (T+120 h).**

5. Impact of 4 km global 4D-Var on 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 EUMETSAT-10 SEVIRI (Figure 5) in the previous setup **(a)** versus DestinE at 4 km **(b)**.



$$\tilde{\mathbf{R}} = E\left[\mathbf{d}_a\ \mathbf{d}_b^{\mathrm{T}}\right], \quad (1)$$

$$\mathbf{H}\tilde{\mathbf{B}}\mathbf{H}^{\mathrm{T}} = E\left[\mathbf{d}_b\ \mathbf{d}_b^{\mathrm{T}}\right] - E\left[\mathbf{d}_a\ \mathbf{d}_b^{\mathrm{T}}\right], \quad (2)$$

$\mathbf{d}_b$ are background departures & $\mathbf{d}_a$ are analysis departures of observations.

Figure 5) We compare spatially correlated errors of EUMETSAT-10/SEVIRI. The statistical quantities are calculated over the area covered by the satellite for six weeks.

6. HIMAWARI brings benefits at 75 km every 30 min

We incorporate smaller spatial scales via higher-resolution water-vapor radiances 6.2 µm, 6.9 µm & 7.3 µm bands and evaluate the forecast impact at the medium range (Figure 6).

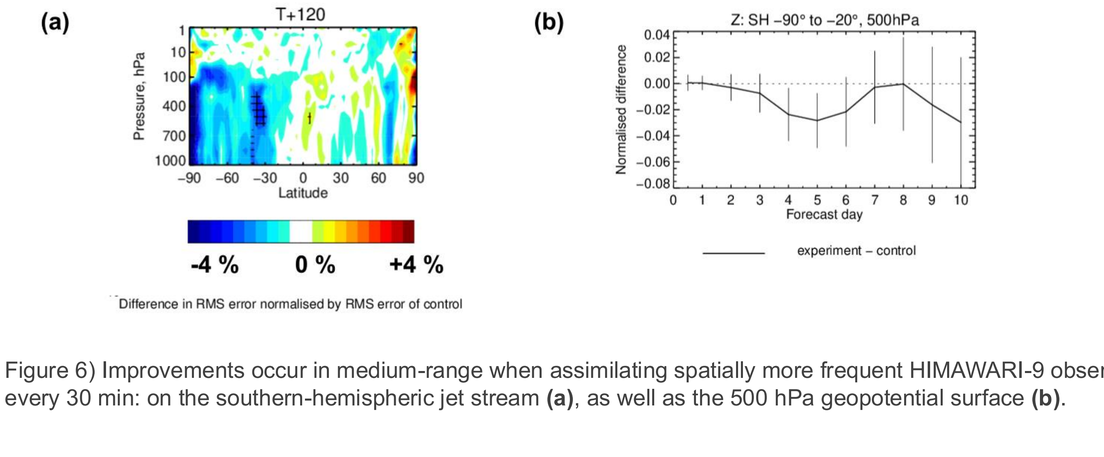


Figure 6) Improvements occur in medium-range when assimilating spatially more frequent HIMAWARI-9 observations every 30 min: on the southern-hemispheric jet stream **(a)**, as well as the 500 hPa geopotential surface **(b)**.

7. Lessons learnt & brief outlook

i. GEOS clear-sky radiances are assimilated at **75 km instead of 125 km globally** in the next IFS cycle as the finer resolution improves the fit to other instruments in the **short-range and medium range forecasts** when changing all satellites in **synchrony**.

ii. **Additional impact occurs when assimilating higher frequency** observations at sub-hourly time scales, for example every 30 min on top of the spatially denser observations.

iii. **DestinE experiments** exhibit **smaller spatially correlated errors**, allowing approach smaller spatial scales while maintaining the requirements of 4D-Var on a diagonal R matrix.

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

Funded by the European Union

Destination Earth implemented by ECMWF esa EUMETSAT