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).

On the chosen day below, a strong **cyclone occurred over the North Atlantic**, **frontal systems evolved over the Pacific** & **equatorial waves** were active in the tropical belt.

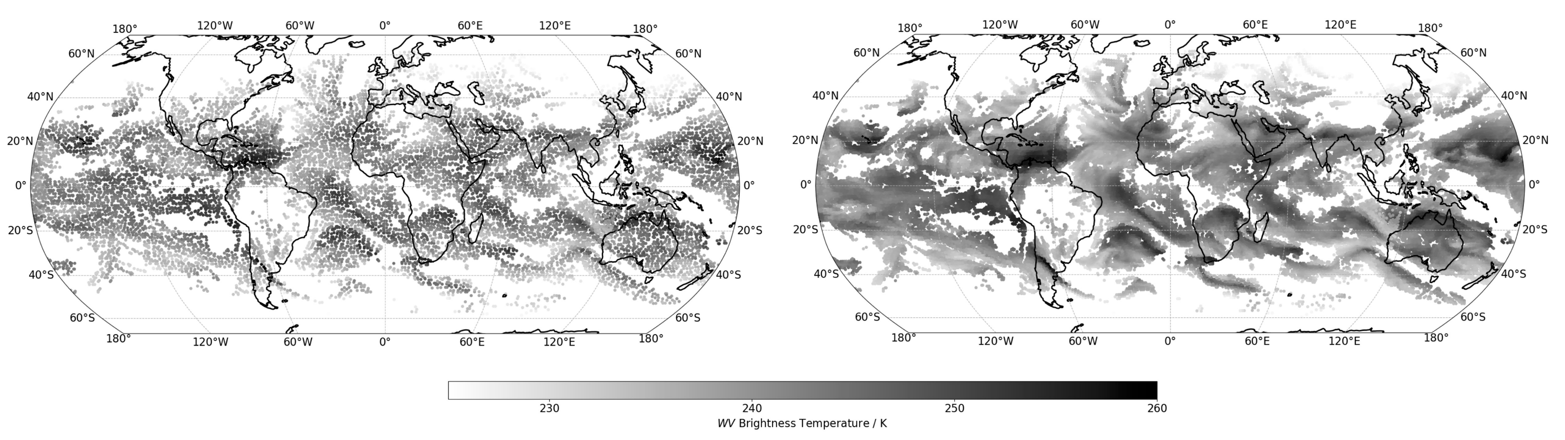
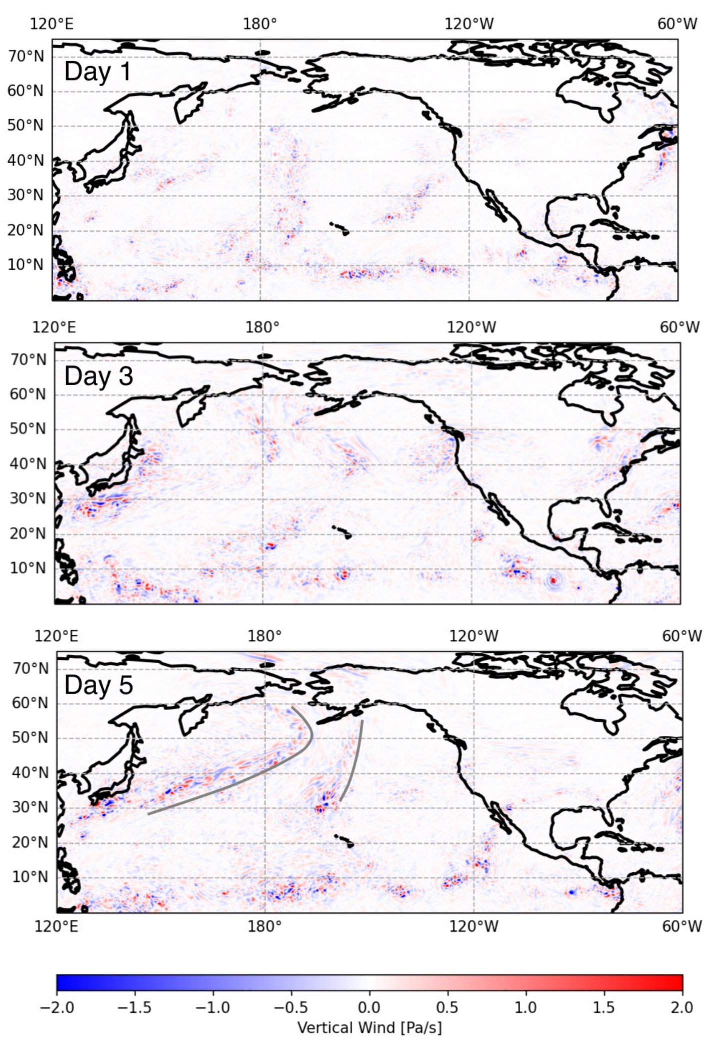


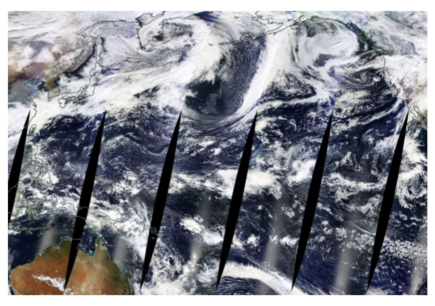
Figure 1) Assimilated clear-sky observations from all geostationary satellites from the WV 6.2 micrometer band for a chosen sample on Dec. 2nd at 7 UTC: **75 km (right)** showing a more continuous coverage versus the previous operational **125 km (left)** spatial thinning of observations globally.

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)?

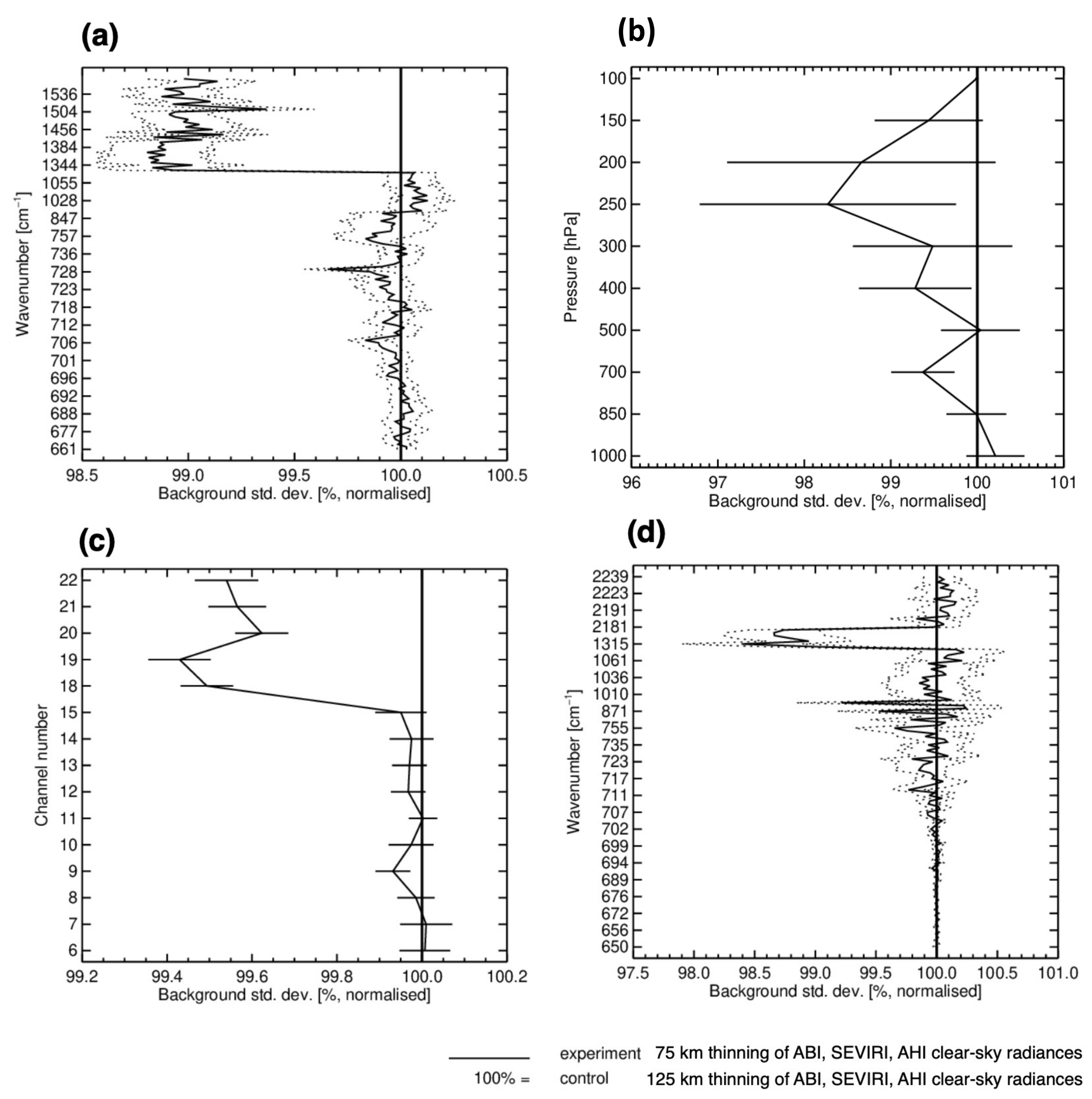


Figure 3) Improvements over a wide range of observations. We show the same experiment as outlined in the previous figures for the whole winter season 2022/23. Chosen for comparison are the **CrIS instrument (a)**, conventional **radiosondes which are especially sensitive to upper and mid troposphere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

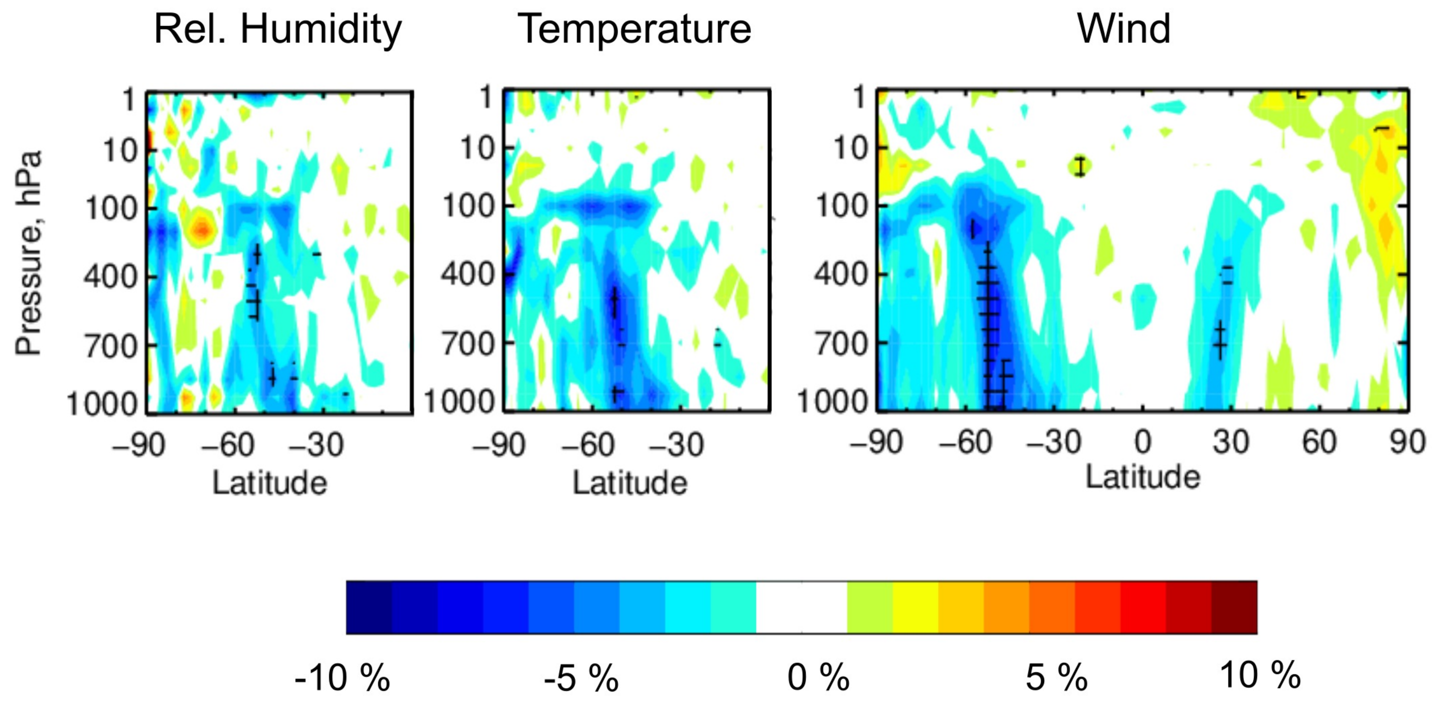


Figure 4) An improvement *with reduced root-mean-square error (RMSE) in blue* occurs in forecasted relative humidity, temperature, and wind. The improvement on the southern hemisphere correlates with the position of the **jet stream**, in the presented **5-day forecast (T+120 h)**. We ran the experiment from December 1st 2022 onwards for six weeks at operational resolution. We calculate the RMSE with respect to own analysis.

5. Impact on wind errors in kinetic energy diagnostics

In comparison to the control run, the **error of kinetic energy** is globally reduced, especially in the longer range **+120 h** forecast (Figure 5). The calculation are shown for the same experiments as diagnosed above.

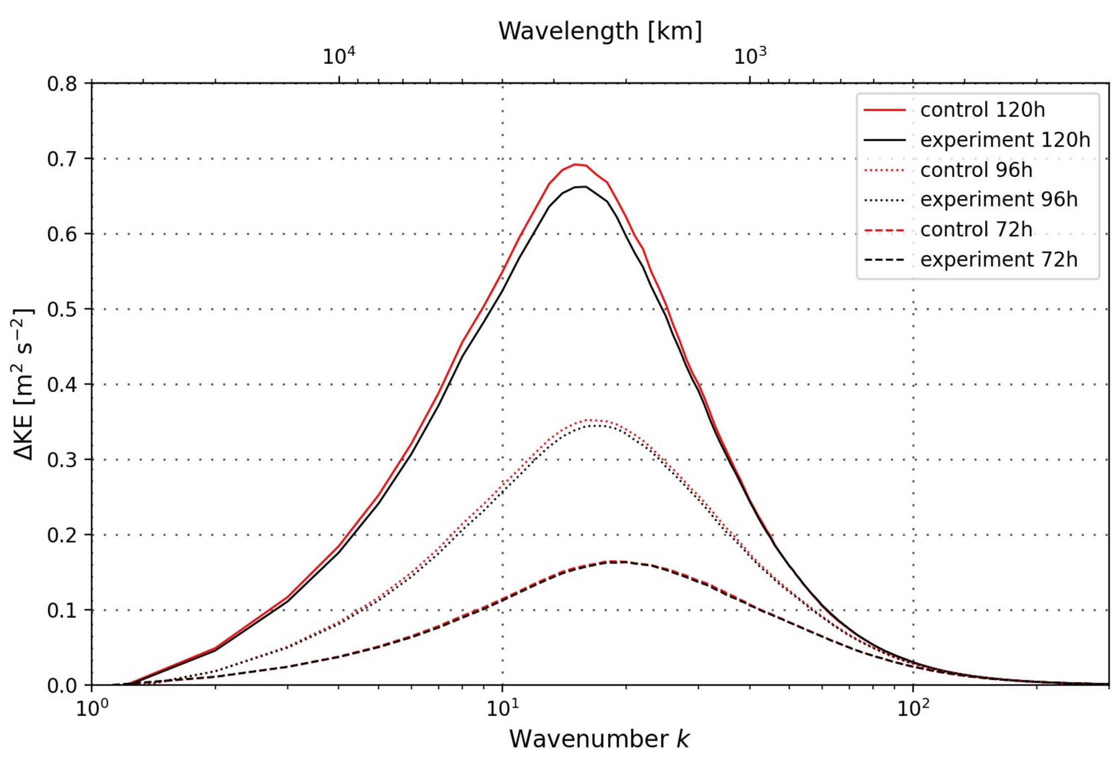


Figure 5) The kinetic energy difference between analysis and forecasts are calculated for selected lead times globally, in wavenumber space for the experiments from December 1st, 2022 onwards for six weeks.

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).

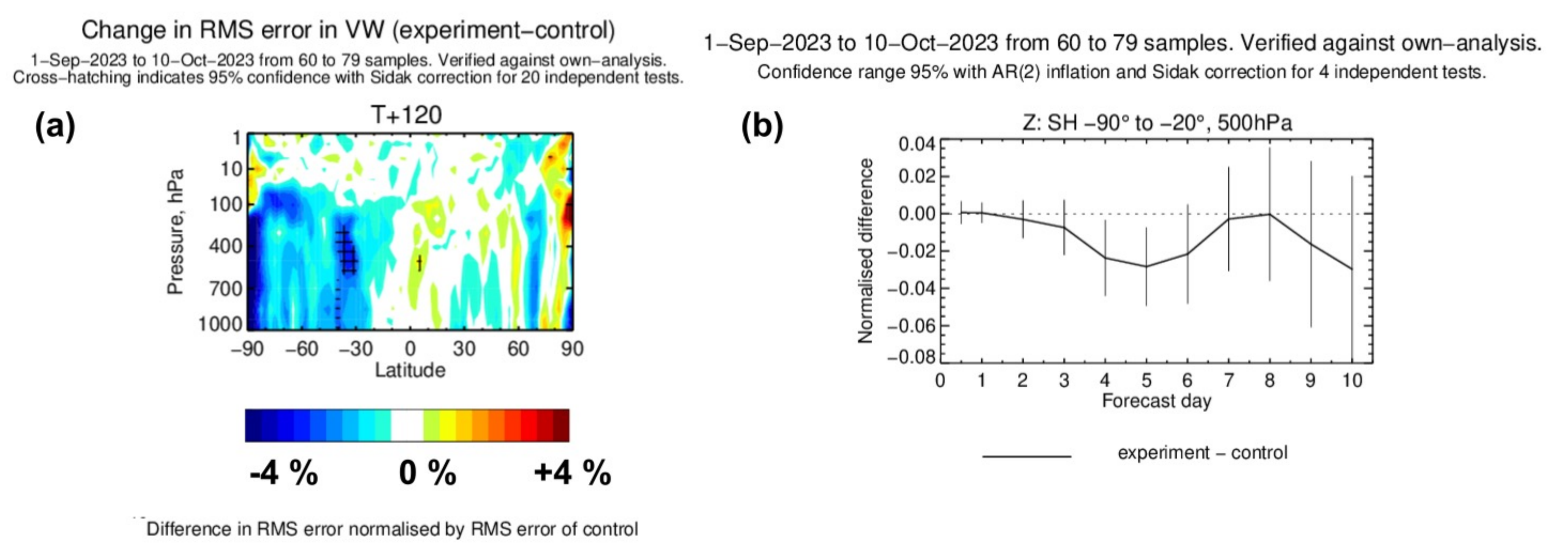


Figure 6) Improvements *with reduced error in blue* occur in medium-range when assimilating spatially more frequent HIMAWARI-9 observations every 30 min: on the austral jet **(a)**, as well as on the 500 hPa geopotential surface **(b)** from September 1st 2023 onwards for six weeks. We calculate the RMSE with respect to own analysis.

7. Lessons learnt & brief outlook

i. GEOS clear-sky radiances are assimilated at **75 km instead of 125 km globally** in the current *IFS cycle 50r1* 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.**

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