Studying trends and variability of dramatic atmospheric events using long time series of NWP satellite monitoring statistics

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Introduction:

The substantial longevity and stability of many operational satellite instruments offers a unique opportunity to study the variability and evolution of a number of different dramatic atmospheric event using long time statistics of observation departures with respect to fixed NWP reanalysis systems. With nearly 15 years of continuous observations, instruments like AIRS and AMSUA provide a detailed look on long term and seasonal variability of CO2 concentrations, wildfire production of poisonous atmospheric gasses (e.g. hydrogen cyanide), Sudden stratospheric warming events, and orographic gravity waves. Statistics based on fixed analysis systems is very useful to isolate the trends driven by the climate. The impact of instrumental drift and the effects of the evolving observing system need to be taken into account before reaching conclusions. This can be achieved by exploiting redundancies in the observing system (e.g. many AMSUA and GPSRO instruments) and also by comparing statistics from various analysis systems (operational analysis, ERA-Interim and ERA-5). In this poster we explore the variability of southern hemispheric orography waves and how these atmospheric prominent features are handled by two reanalysis systems (ERA-Interim and ERA5 based on IFS cycles 31R2 and 41R2 respectively). The availability of nearly 15 years of AIRS observations is very useful to study the trends in the evolution of CO2 concentrations. Significant wild fire events have a clear signature on Infrared tropospheric channels sensitive to Hydrogen Cyanide (HCN). Long time series from AIRS are useful to study the frequency and severity of these events (at least during the past 15 years). Sudden stratospheric warming events are a marked feature of the stratosphere in winter time. These events are believed to be related to the on-set of cold episodes in Europe and consequently they are considered useful for the improvement of extended range forecasts. Long time series of satellite observations are useful to study the variability of such events and how they are handled by forecasting systems.

Orographic gravity waves:

Orographic gravity waves are a typical feature of Southern hemispheric winter when strong tropospheric airflow hit mountains. The amplitude of the waves is small in the troposphere but increases significantly with height while spreading downstream (Fig 1 and 2). They are responsible for significant momentum and energy transport. Modern NWP systems are able to represent such waves but errors in their amplitude and phase can cause large differences from observations. Orographic gravity waves have a clear signature on microwave and infrared channels peaking in the stratosphere. They are also detectable using Radio occultation measurements. The statistics presented here are derived from NOAA-15/AMSUA used operationally from 1999 to present time. O-B (observation minus Background) exhibit large random errors in winter time in the stratosphere. The episodes of orographic gravity waves makes the errors even larger (see Fig 3 and 4 presenting long time series of AMSUA channel 13 statistics in West and East of Patagonia)

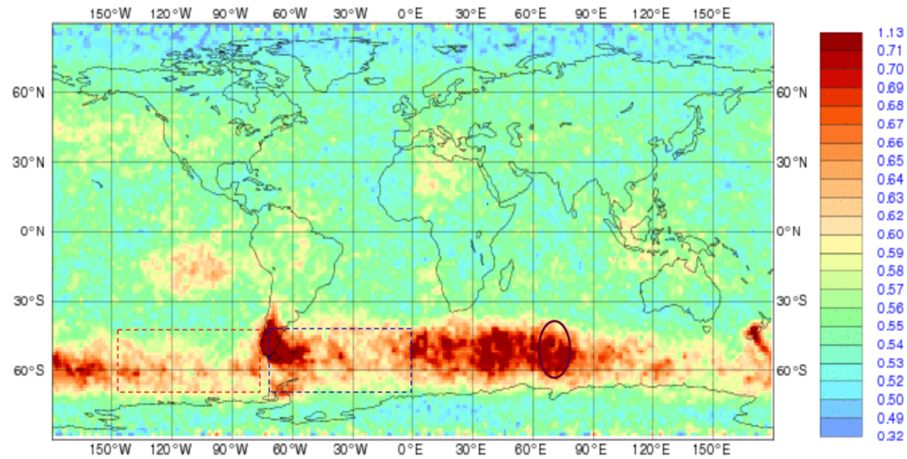

Figure 1: Standard deviation of O-B for Metop-A/AMSUA Ch13 covering the period from 6/5/2014 to 7/6/2014 (boxes show the geographic regions for the time series of figure 3 and 4)

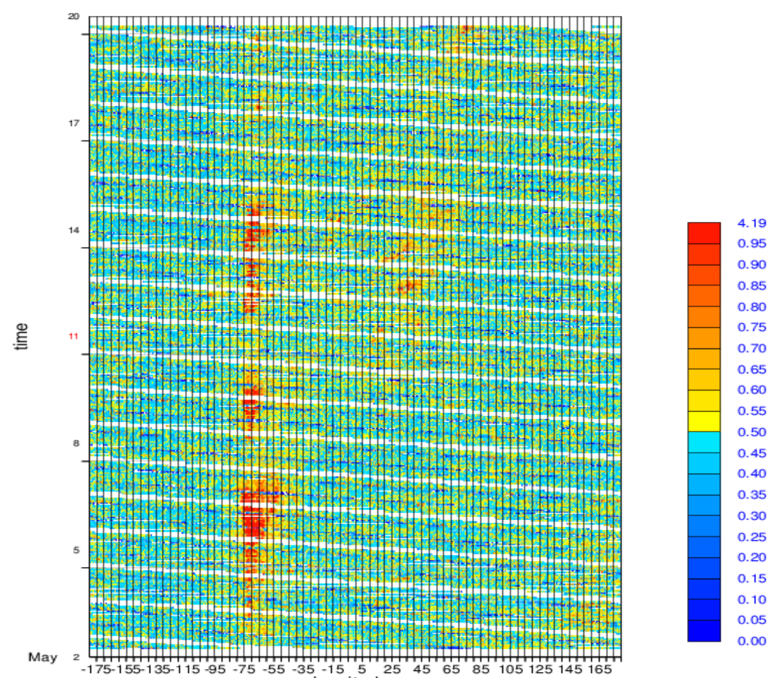

Figure 2: Time vs longitude of O-B Standard deviation for Brightness temperature from all available AMSUA Ch13 covering the period from 3/5/2014 to 20/5/2014

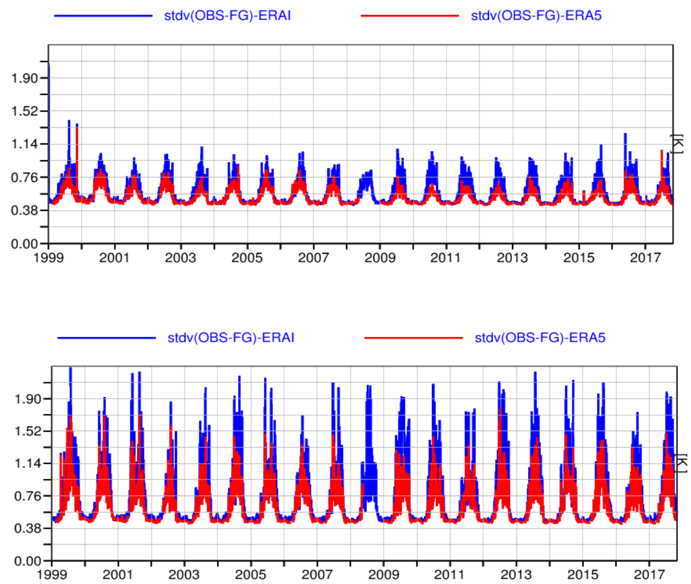

Figure 3 and 4: O-B Standard deviation for brightness temperature from NOAA-16 AMSUA Ch13 from 1999 to 2017. Left panel represents statistics in an upstream area to the West of Patagonia (40S-70S and 140W-80W) and downstream to the East of Patagonia (40S-70S and 80W-40W). Blue represents statistics from ERA-Interim and Red statistics from ERA5.

Statistics in Fig 3 indicate that Patagonia gravity are omnipresent in winter time with an onset on May. Their amplitude is quasi similar from year to year. ERA5 (Red) seems to represent better the waves compared to ERA-Interim. The exploration of time series indicate that gravity waves episodes occur intermittently and tend to last between one and three days. The analysis of one of the episodes (6 May 2014) indicate the presence of waves in both the model and observations (translated by stripes of cold and warm brightness temperatures). The mismatch between observations and the models appear to be horizontally and vertically (which might be partly related to phasing errors). Figure 5 and 6 show the large alternated values of positive and negative O-B. The pattern is different between ERA5 and ERA-Interim.

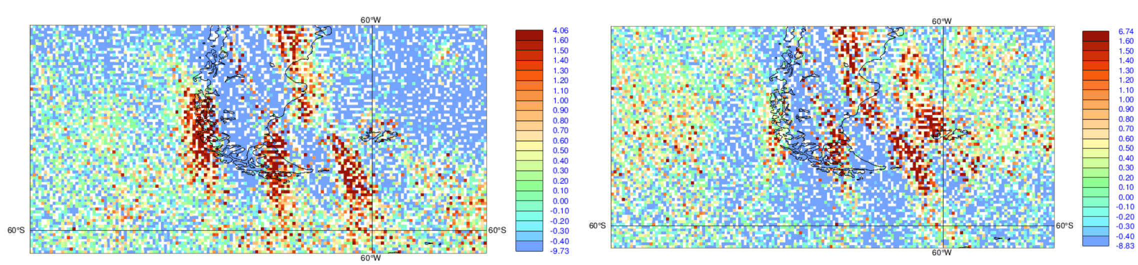

Figure 5 and 6: Mean O-B for Brightness temperature from all AMSUA Ch13 covering 12h period on 6/5/2014. Left statistics are from ERA5. Right panel represents statistics from ERA-Interim.

Sudden stratospheric warming

Sudden stratospheric warming (SSW) events are common in winter time over the North Hemispheric polar regions. The onset of these events is associated with a rapid warming of the stratosphere by few tens of degrees. SSW events are the result of a disruption of the arctic polar night jet leading, in strong cases, to the reversal of westerlies. Once initiated higher up in the stratosphere, the SSW effects propagate downward. It is believed that this downward propagation can be associated days later with cold outbreaks over Europe. Modern NWP systems are in general able to forecast these events but they struggle in predicting the details of the onset, decay and spatial details. As a consequence large errors are observed when comparing stratospheric peaking observations (microwave, Infrared and GPSRO) against model forecasts. Figure 7 shows long time series of the standard deviation of O-B from NOAA15 AMSUA channel 13 (peaking around 5 hPa) over the North polar area. The statistics are from ERA-Interim (Blue) and ERA-5 (Red). ERA-5 seems to handle significantly better the stratospheric warming events thanks to a numerical fix that was implemented in the IFS cycle 41R1 reducing resolution dependent numerical instabilities triggered by SSW. The increased resolution in ERA-5 is also contributing to the reduction of the random errors. Statistics from the operational analysis (Figure 8) were affected by large random errors (similar to ERA-Interim) till the implementation of the cycle 41R1 (May 2015). Figures 9 and 10 show a closer look at one of the severe cases (Jan 2013). Both systems (ERA-Interim and ERA-5) are able to predict the temperature increase (onset) and decrease (decay) but ERA-5 has more details thanks to the higher spatial resolution and has less random errors thanks to 41R1 semi-lagrangian numerical fix.

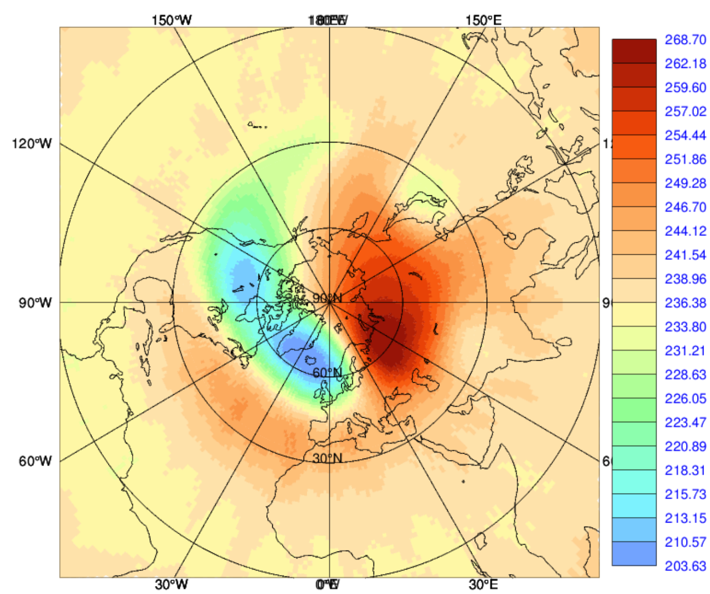

Figure 10: Observed brightness temperatures (in K) from all available AMSUA Valid from 06/01/2013 09UTC to 07/01/2013 UTC

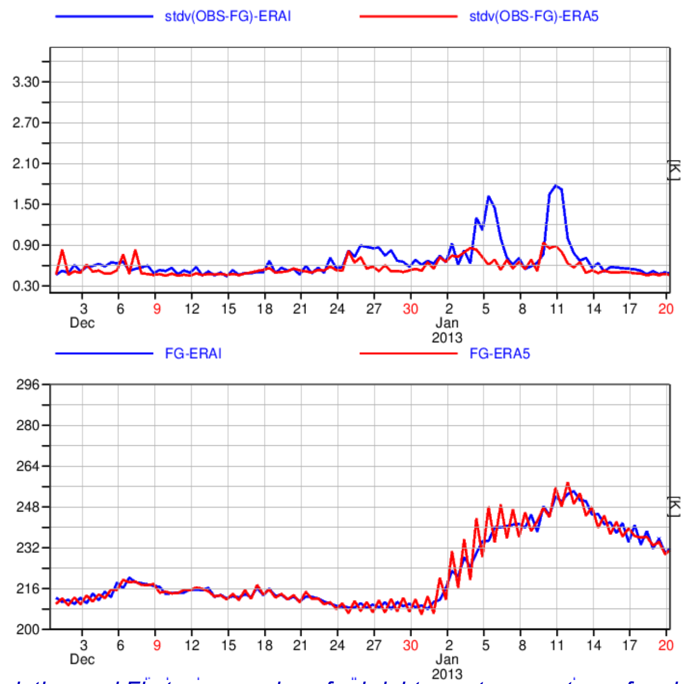

Figure 9: O-B standard deviation and First guess values for brightness temperatures for channel 13 from all available AMSUA over the North polar area. ERA-Interim (blue) and ERA-5 (Red)

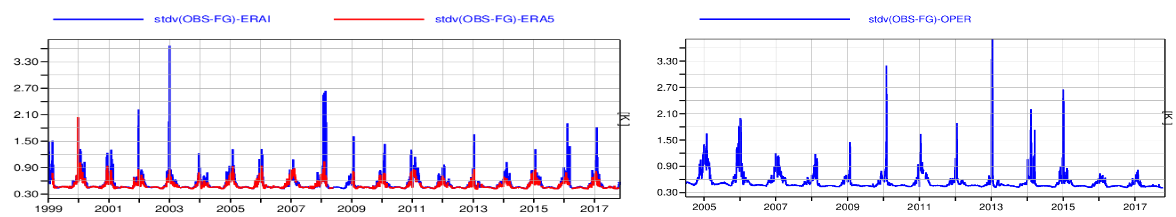

Figure 7 and 8: Mean O-B for Brightness temperature from all AMSUA Ch13 over the North polar area. Left panel shows statistics from ERA-Interim (Blue) and ERA5 (Red). Right panel represents statistics from the operational analysis.

Carbon Dioxide

CO2 concentrations are steadily increasing in the atmosphere due to human industrial activities. Such increase is contributing to the gradual global temperature rise. The concentrations of CO2 have a seasonal variation due to changes in vegetation. Parts of the infrared spectrum are sensitive to CO2 concentrations which makes them very useful to derive the amounts of CO2 in the atmosphere. AQUA/AIRS measured spectrum contain many CO2 sensitive channels. With nearly 15 years of operational use, AIRS is uniquely positioned to provide estimates of CO2 trends when assimilated in fixed analysis systems like ERA-Interim. Figure 11 shows long time series of mean O-B before and after bias correction of brightness temperatures from AIRS Channel 216 (peaking around 415 hPa) over the North Hemisphere extra-tropics from ERA-Interim and ERA5. Uncorrected O-B show a continuous decrease over time with seasonal variations due to changes in vegetation (which have an impact on CO2 intake). Such seasonal variations of CO2 are not represented in the radiative transfer model (RTTOV) used in the reanalysis witch has a fixed CO2 concentrations (equal to 377 ppmv in

ERA-Interim setup).The continuous decrease of uncorrected O-B is related to the cooling of brightness temperatures caused by the steady annual increase of CO2 in the atmosphere. The RTTOV model simulated brightness temperatures do not exhibit such cooling due to the usage of fixed CO2 concentrations. Assuming the ERA-Interim temperature biases are small in the troposphere, the time series of uncorrected O-B indicate that RTTOV prescribed CO2 concentrations are matching the real concentration around 2006. For the purpose of data assimilation the bias correction scheme is doing an efficient job in removing the biases in the reanalysis system.

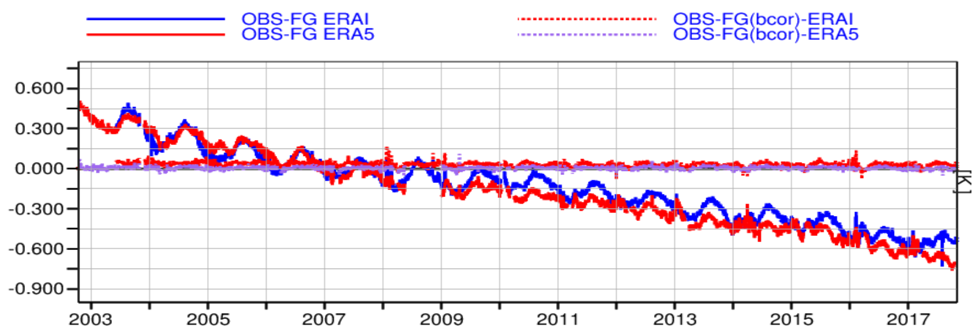

Figure 11: Mean O-B for Brightness temperature from AIRS Ch 216. Corrected and uncorrected statistics from ERA-Interim are in Blue. Red curves are for ERA5.

Wild fires

Widespread wild fire produces a cocktail of gases and particulate pollutants that are observed by operational satellite measurements. Carbon monoxide (CO) and Hydrogen Cyanide (HCN) are among these fire emitted gases. The monitoring of infrared spectral lines absorbed by these pollutants can be used to detect the frequency and intensity of such events. Figure 12 shows O-B standard deviation over the tropics of AIRS tropospheric Channel 221 which sensitive to HCN. The statistics highlight episodes of widespread fires in Indonesia that occurred in 2015 and 2014. The increased O-B indicate a significant mismatch between typical concentration of HCN (in RTTOV) and the actual values increased by the fire emissions. Such increased values led to significant cooling of brightness temperatures. The same signal was detected by similar channels from IASI and CrIS. The detection of these anomalies was automatically detected by ECMWF's alarm system and thanks to a collaborative effort the problem was traced back to the increased concentrations of HCN. As a consequence all HCN sensitive channels were temporarily removed to avoid impacting the analysis of temperature.

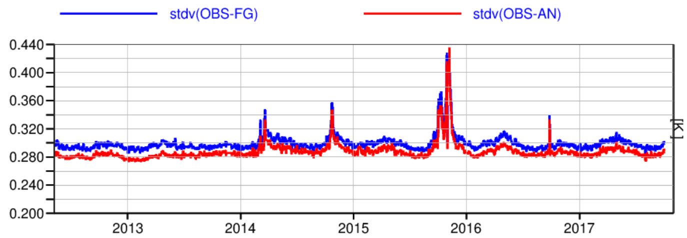

Figure 12: Standard deviation of O-B for Brightness temperature from AIRS Ch 221 over the tropics. Statistics are from the ECMWF operational 4D-VAR

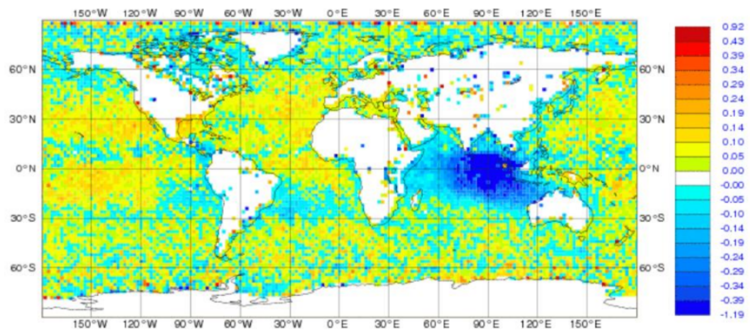

Figure 13: Mean O-B for Brightness temperature from AIRS Ch 221 for October 2015

Conclusions

Satellite data monitoring activity is mainly designed to detect data related issues using differences between observations and their model counterpart. However in many cases the large differences between the model and observations highlight difficulties encountered the models to predict certain severe atmospheric events. Long time series are very useful to highlight the variability and trends of such events. They are also useful to evaluate the impact of model upgrades.