The ROM SAF Reanalyses

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Background

GNSS-RO is now a key observing system for climate reanalyses. It is an "**anchor measurement**" in NWP and reanalysis because it can be assimilated without bias correction to the NWP model. The consistency of global atmospheric temperature reanalyses in the stratosphere has improved significantly since 2006, with the launch and assimilation of COSMIC/FORMOSAT-3 (e.g., Figure 1, from Ho *et al*, 2019, BAMS, accepted).

The mean state of the reanalysis should be determined primarily by the anchor measurements. Eyre (2016, QJRMS., 142: 2284-2291. doi:10.1002/qj.2819) showed that observations bias corrected with a variational approach can still reinforce an NWP model climate bias and fight the anchor measurements. *How many anchor measurements we need is an open question*.

The ROM SAF has completed two low resolution (T159~125 km) reanalyses with the ERA5 system for 20070101-20151231 period, based on just the anchor measurements:

- The first reanalysis assimilates just reprocessed bending angles from the ROM SAF (GRAS, COSMIC, GRACE, CHAMP) and AMSU-A channel 14: **(RO)**
- The second also assimilates conventional data, apart from aircraft temperatures: **(RO+CONV)**

The daily and monthly mean gridded ROM SAF reanalysis datasets are available using ECMWF's web-api system (see Table 1).

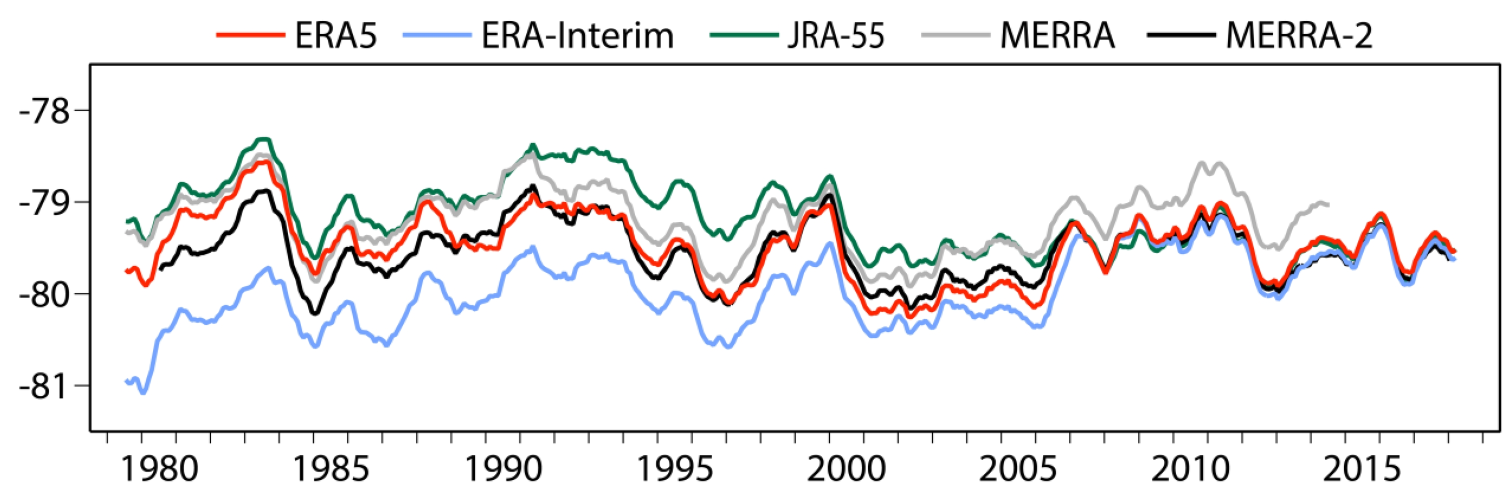

Figure 1: Timeseries of 12 month running averages of 100 hPa temperatures (Celsius) in the tropics (± 20 lat). ERA5, ERA-Interim, JRA-55 and MERRA-2 assimilate GPS-RO data, but MERRA did not. The reanalyses converge in 2006 after the assimilation of COSMIC/FORMOSAT-3 data.

Experiment ID	Name	Description	Stream	Dates
21	rom_saf_21	Assimilating the reprocessed ROM SAF bending angle data plus AMSU-A channel 14	ea	20070101-20151231
22	rom_saf_22	As experiment 21, but adding conventional data not corrected with VarBC. No aircraft temperatures.	ea	20070101-20151231

Table 1: ROM SAF datasets. For access details, data retrieval scripts see, https://confluence.ecmwf.int/display/ROMSAF/The+EUMETSAT+ROM+SAF+reanalyses

Selected results

The official ERA5 reanalysis is run at TL639 (~31 km), uses flow dependent error statistics, *and it clearly produces superior weather forecasts* to the low resolution ROM SAF reanalyses. However, we are interested in how well the assimilated ROM SAF GNSS-RO data can reproduce and constrain the mean state, particularly in the stratosphere.

Figure 2 shows the time-series of monthly mean temperature differences (**subtracting off the ERA5 value**) at 100 hPa in the tropics. This includes ERA-Interim and a low-res ERA5 control. The **RO** reanalysis is within 0.2 K of ERA5, and is ~0.1K warmer than **RO+CONV**. All low-res reanalyses are ~0.1 K warmer than ERA5, because of a known resolution dependent cold bias in the ECMWF model (See Shepherd *et al*. ECMWF tech memo, 824) .

The ERA-Interim time-series has a discontinuity around 2010, associated with the change in the operational COSMIC processing (November, 2009). The "drop" in ERA-Interim bias ~2014 occurred when GNSS-RO was accidently removed from ERA-Interim. ***Although already noted in the ERA-interim logs***, the ROM SAF team at DMI independently identified this ERA-Interim problem during their level 3 GNSS-RO product validation.

Zonally averaged (RO-ERA5) and (RO-low-res) differences are shown in Figure 4 and 5, respectively.

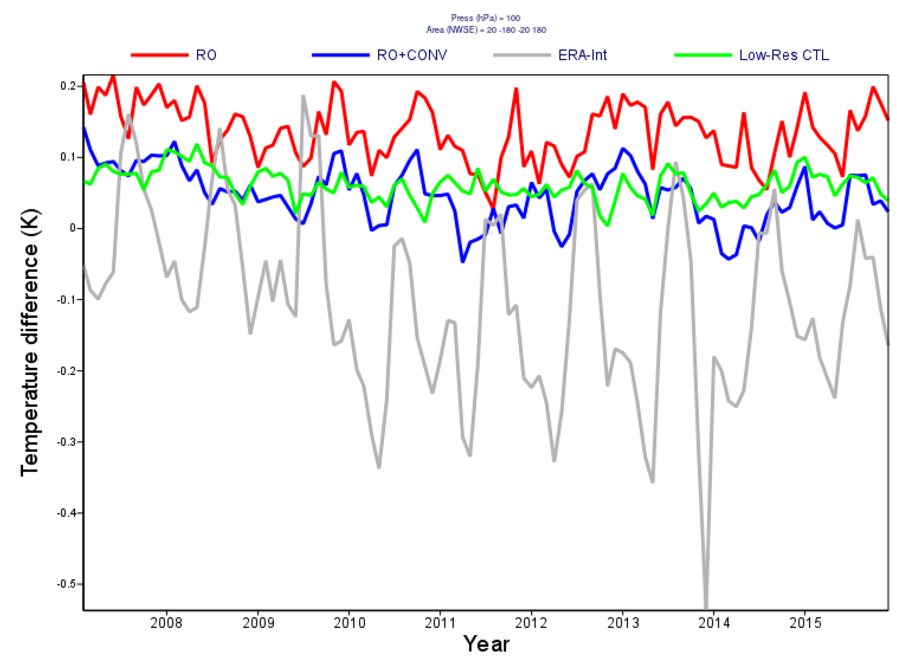

Figure 2: Timeseries of the monthly mean temperature differences (e.g. RO minus ERA5) for ± 20 lat.

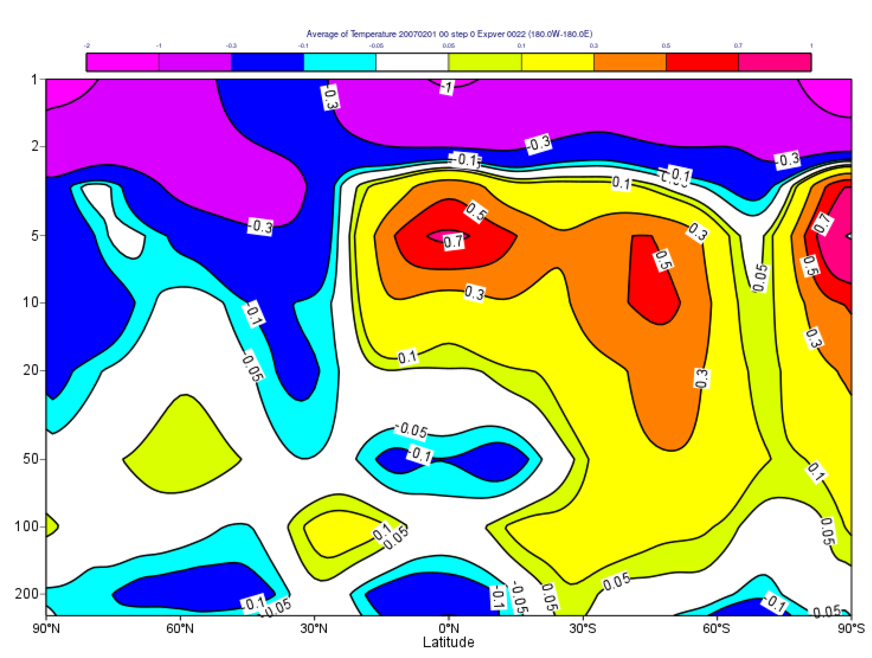

Figure 3: The zonally averaged (RO minus ERA5) temperature differences, for 200702-201512.

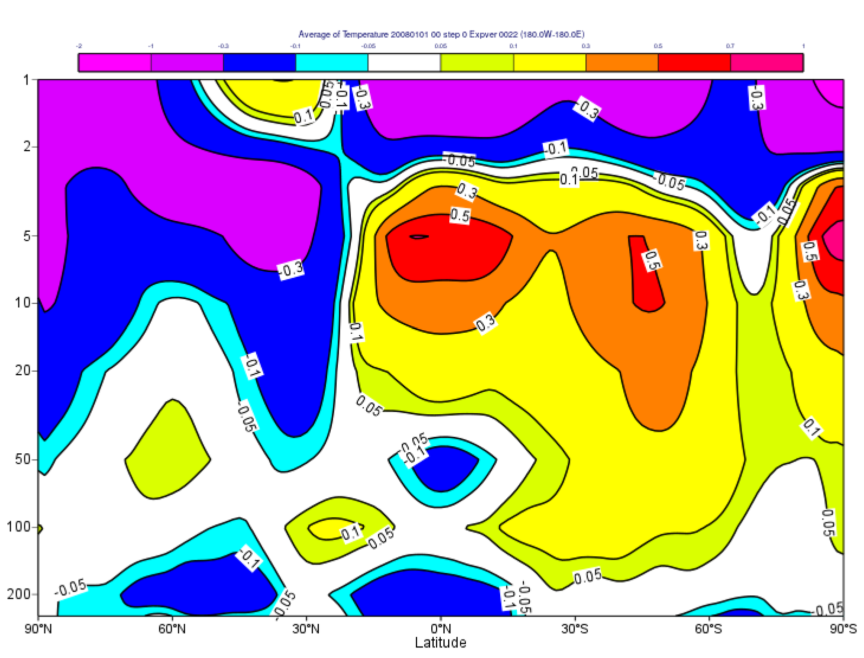

Figure 4: Zonally averaged (RO-LowRes CTL) temperature differences.

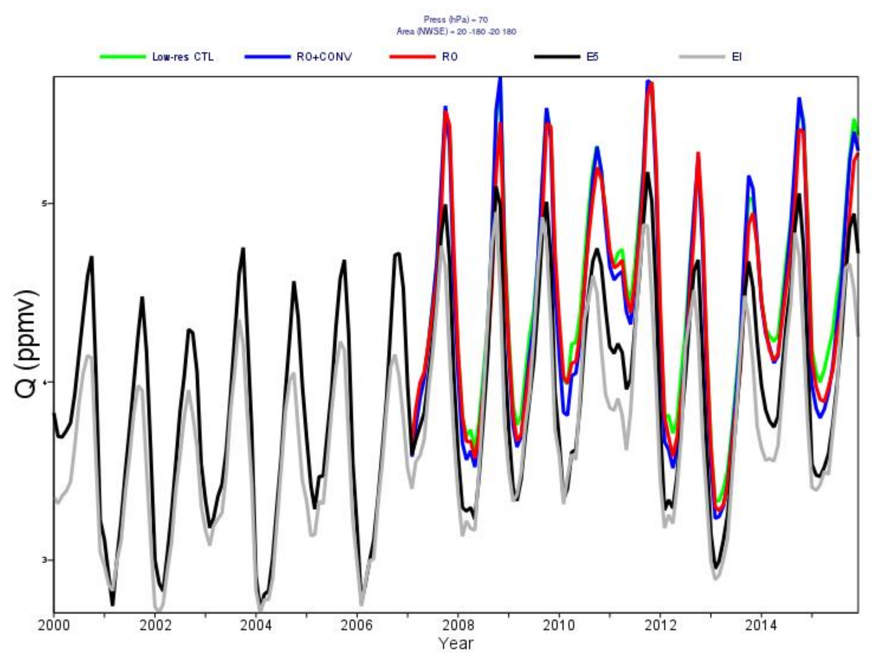

Figure 5: Time-series of monthly mean 70 hPa humidity values in the tropics.

Stratospheric water vapour

The GNSS-RO measurements do not provide information on stratospheric water vapour directly – we assume it is zero in standard temperature retrieval.

It is well known that the water vapour entering the stratosphere through the tropical tropopause layer (TTL) is dehydrated at the cold point tropopause. The reanalyses do not assimilate stratospheric humidity measurements, and the stratospheric humidity depends heavily on the representation of this process (plus chemistry in the stratosphere).

The GNSS-RO warms the TTL and this increases the stratospheric humidity in the reanalysis (Figure 5). The RO, RO+CONV and Low-res CTL reanalyses are in good agreement with ERA5, apart from the positive shift associated with the cold bias in ERA5.

Tropical stratospheric zonal winds

We have found a **surprisingly(?)** good representation of the QBO of the tropical stratospheric zonal winds in the RO reanalysis, **assimilating no wind measurements** (e.g., Figure 6). The impact of the QBO on GNSS-RO temperature climatologies has been noted previously (e.g., Randel et al. 2003, JGR, 105, ACL 7-1-ACL 7-12), , but we also find that realistic **zonally averaged zonal winds can be retrieved directly from the curvature of the zonally averaged geopotential height climatology**, using (**Fleming and Chandra, 1989, J. Atmos. Sci., 46, 860–866**) (see Figure 7),

$$\overline{U} \simeq -\frac{1}{\beta}\frac{\partial^2 \overline{\phi}}{\partial y^2}$$

Ongoing work suggests that the GNSS-RO data improves the consistency of the QBO in ERA5 and ERA-Interim reanalysis through improved geopotential heights in the tropics. This is consistent with Kawatani et al. (2016, ACP, 16, 6681-6699), who have noted a gradual improvement of the QBO in reanalyses as more satellite temperature information is assimilated.

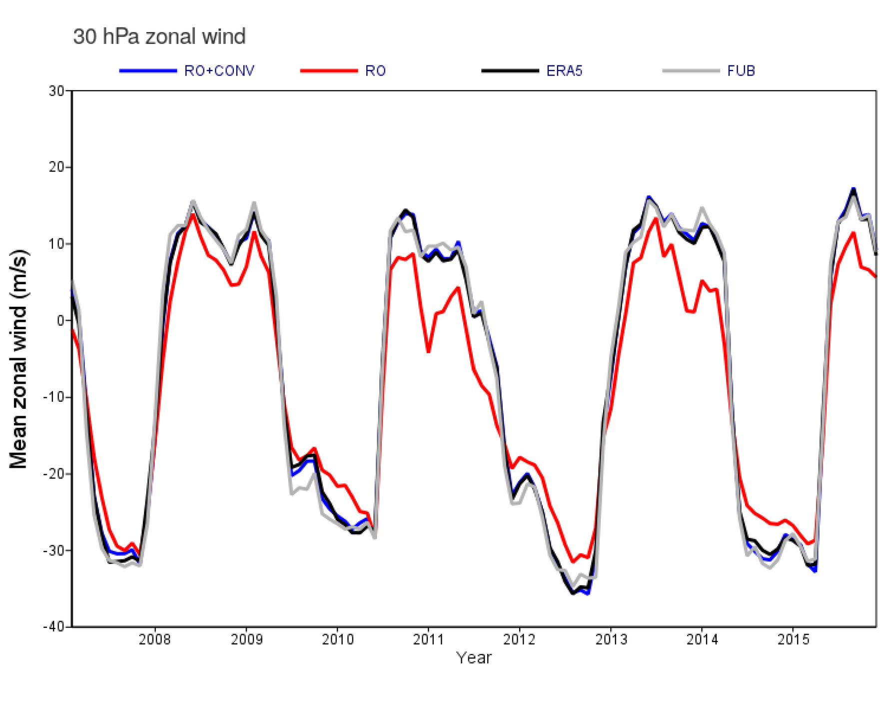

Figure 6: The 30 hPa zonal wind from the reanalyses and a FUB radiosonde zonal wind climatology.

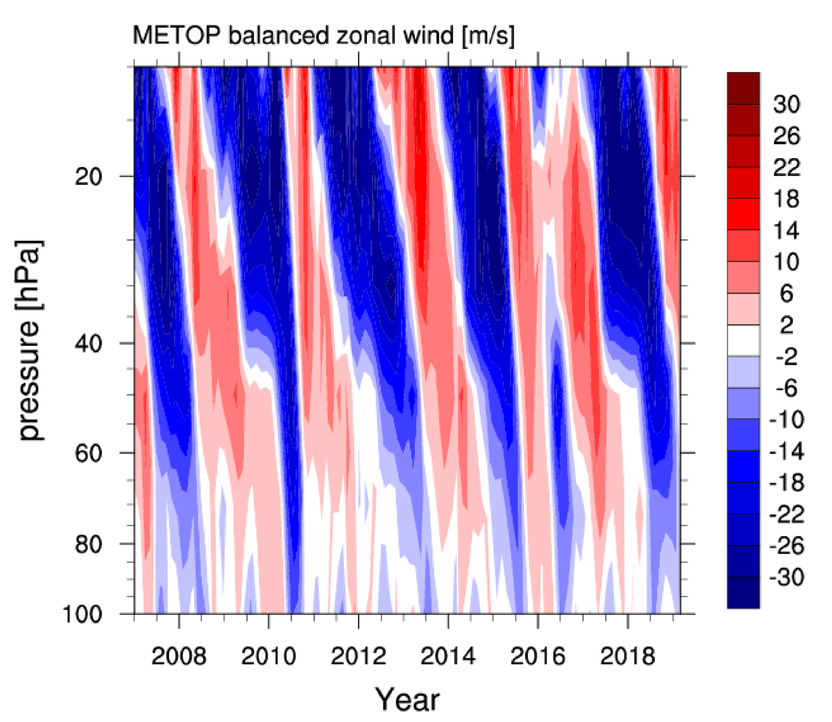

Figure 7: The zonally averaged tropical zonal winds retrieved from the curvature of the ROM SAF monthly mean geopotential height climatology.