Monthly and zonally averaged zonal wind information in the equatorial stratosphere provided by GNSS radio occultation

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with thanks to Mark Ringer

ROM SAF workshop

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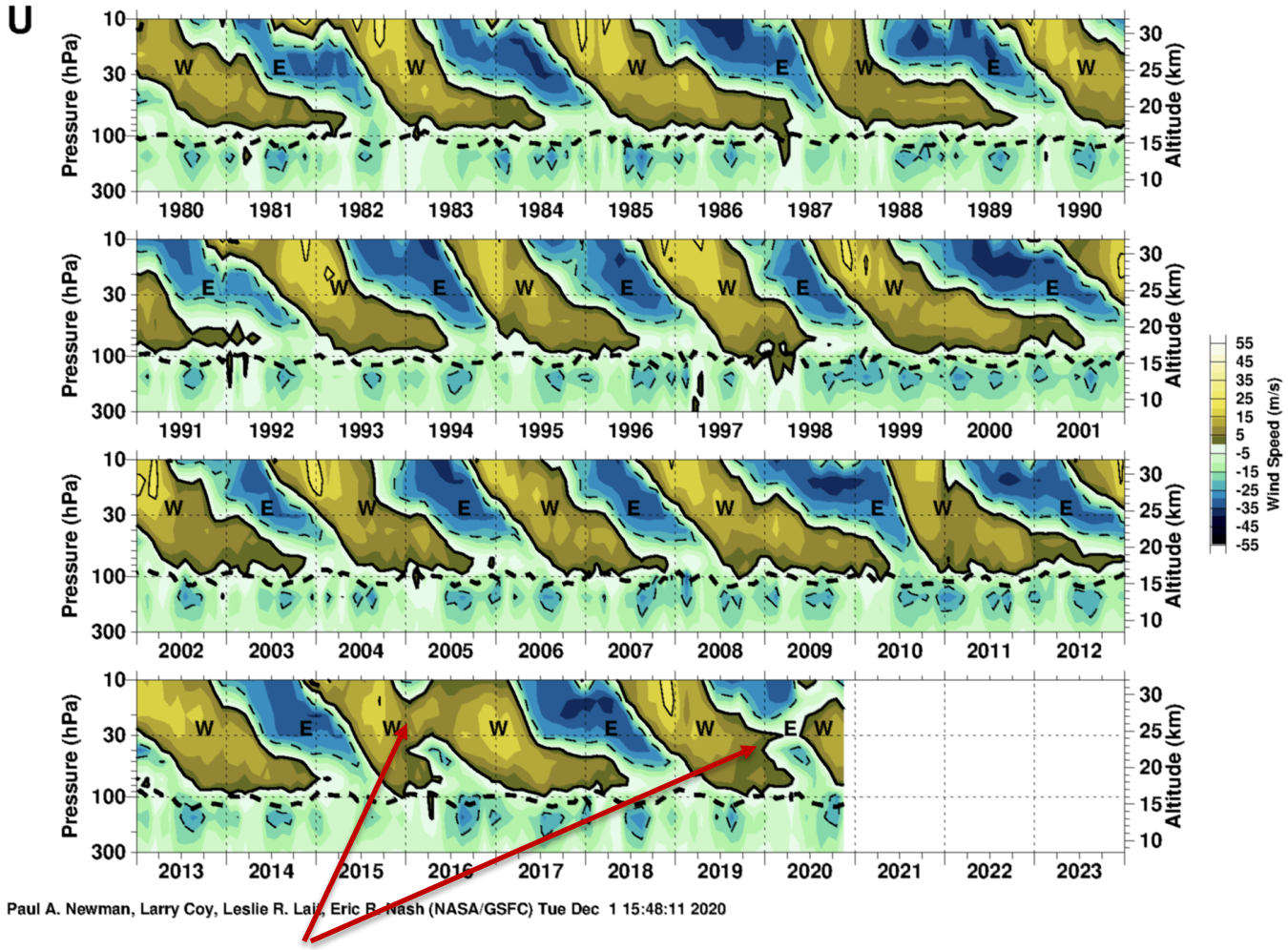
ECMWF

EUMETSAT ROM SAF
RADIO OCCULTATION METEOROLOGY

Background: QBO

- Quasi-periodic (period ~28 months) zonal wind oscillation in the **equatorial** stratosphere.
- Driven by **Kelvin**, **gravity** and **mixed Rossby-gravity** waves. Exact contribution of each wave type not known.
- **Short vertical wavelength** waves likely important.
- **Question:** Can we derive QBO from **GNSS-RO geopotential height observations**?

Zonally-averaged tropical zonal wind



QBO disruptions

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Method

- **Question:** Can we derive QBO from GNSS-RO geopotential observations?

- Use **equatorial beta-plane geostrophic balance** (Fleming & Chandra, 1989) with monthly-mean reprocessed GNSS-RO geopotential height from **ROM SAF** on 5^0 latitude grid with 200m vertical spacing.

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

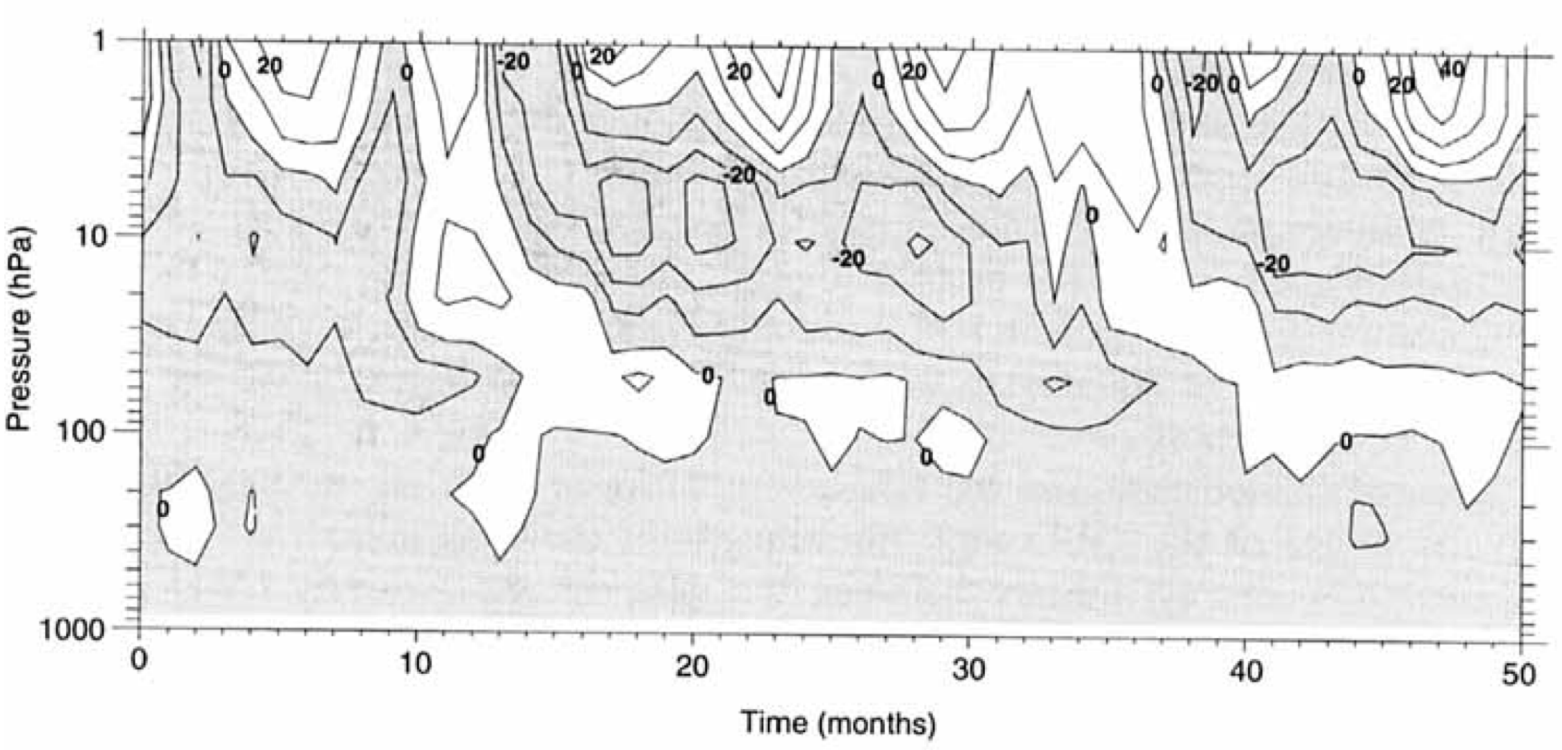
- Gridded ROM SAF data very easy to use and download.

- Compare to radiosonde observation of zonal wind at Singapore and with ERA5 zonal wind reanalysis.

Previous QBO derivation using Fleming & Chandra balance from TOVS

- Using Fleming & Chandra (1989) balance, QBO previously derived from the TIROS Operational Vertical Sounder (TOVS) (Scaife et al. 2000).

- But the amplitude of the QBO derived from TOVS is **too low** (Randel et al. 2004). Possibly due to too poor vertical resolution of TOVS?

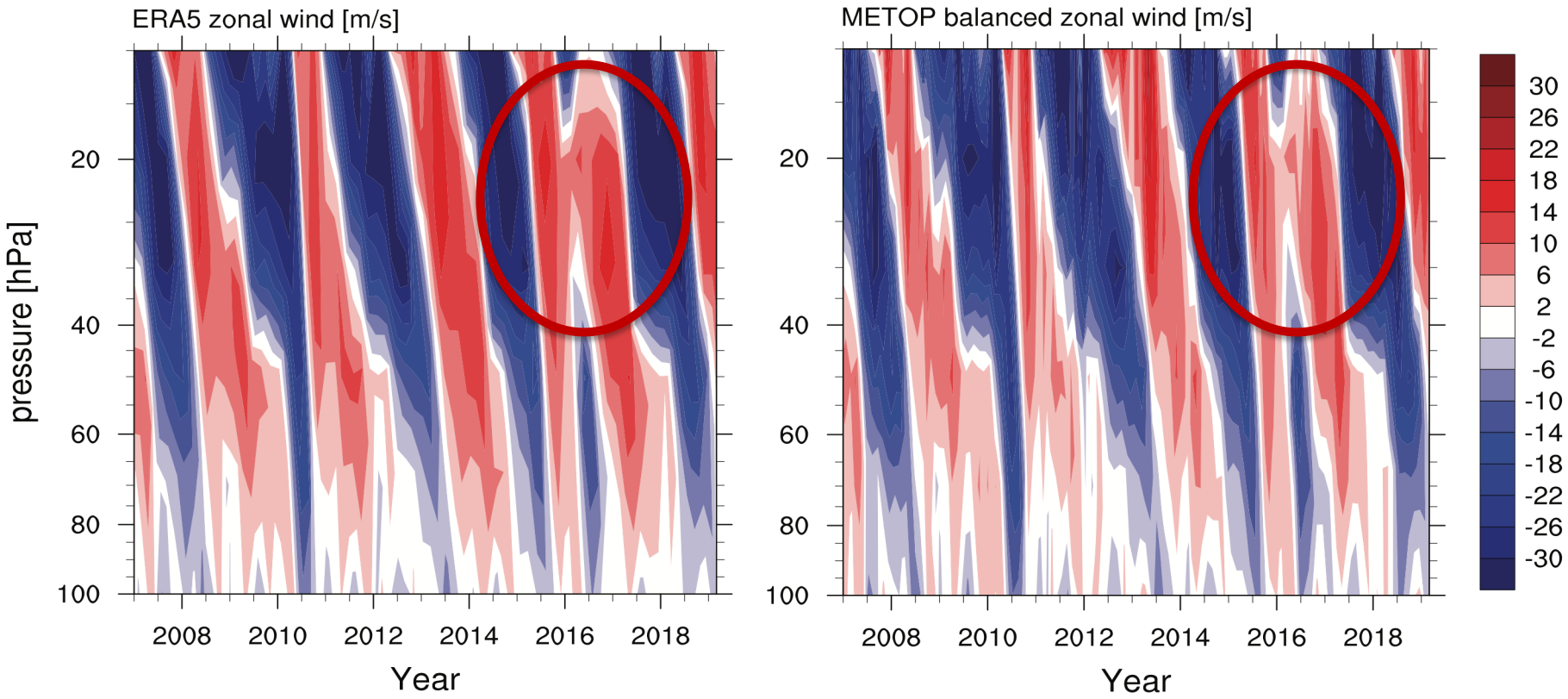


$$\overline{U} \simeq -\frac{1}{\beta}\frac{\partial^2 \overline{\Phi}}{\partial y^2},$$

Scaife et al. (2000)

Results

- **Question:** Can we derive QBO from GNSS-RO? **Yes,** even the QBO disruption.



Averaging is between 5N and 5S.

Healy, Polichtchouk & Horanyi (2020, QJRMS)

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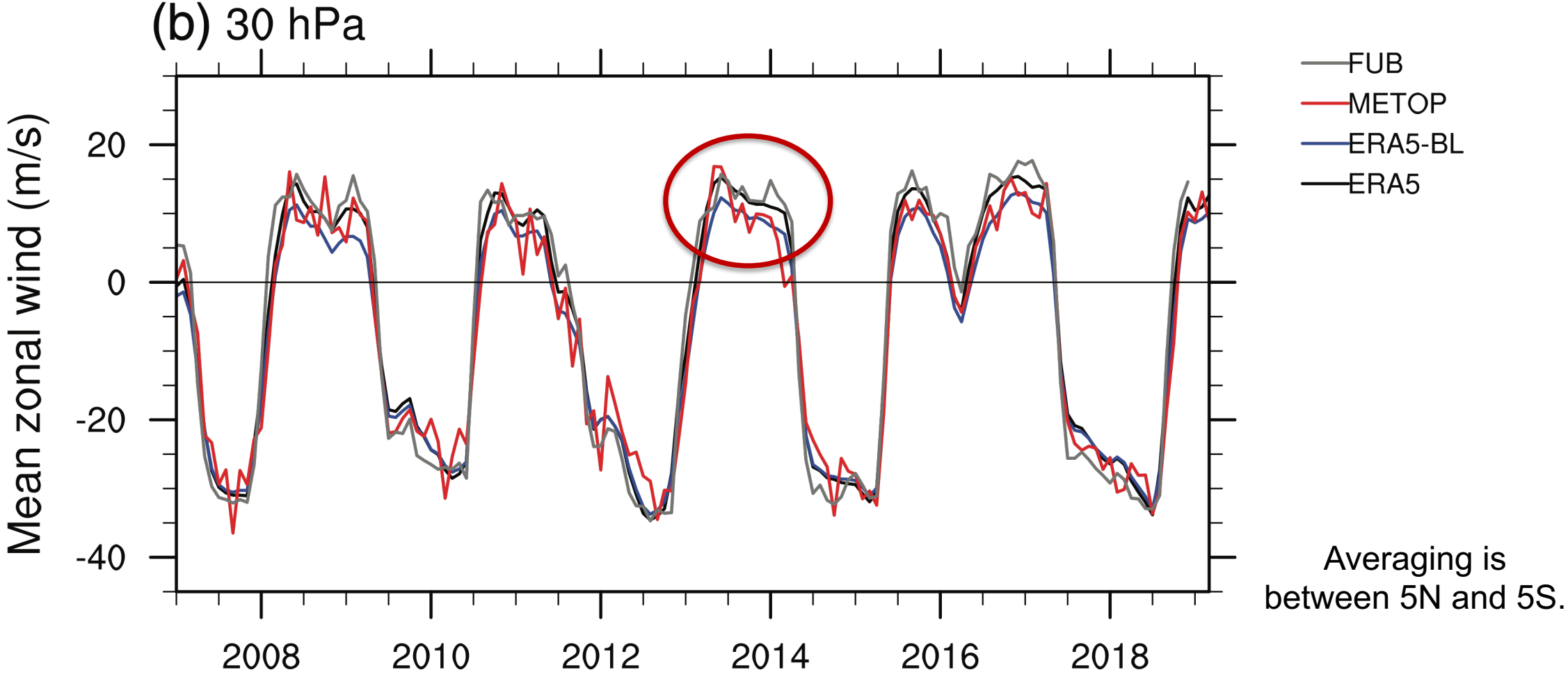
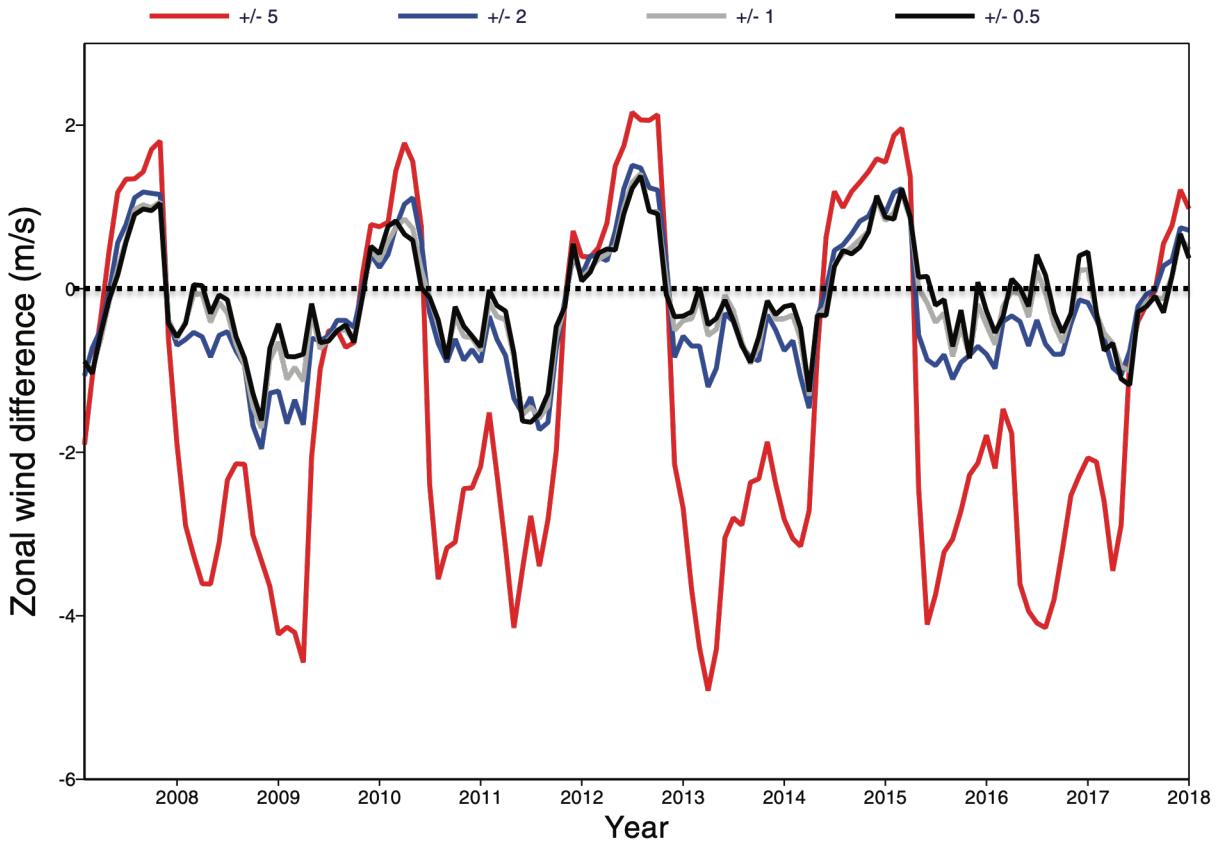
Results

- Westward phase of the QBO better represented by equatorial geostrophic balance.



Results

- But averaging ERA5 data over a narrower latitude band improves the balance approximation.
  →
- Useful to have a higher resolution latitude grid for ROM SAF data: 2^0 would be great!



ERA5: Balanced wind minus actual wind at 30hPa.

Reanalysis experiments

- **Question:** Can QBO be retrieved from ROM SAF bending angle profiles in the reanalysis system?

- Two reanalysis experiments performed:

  1) **RO:** Only assimilating ROM SAF bending angles + AMSUA channel 14 to constrain upper stratosphere.

  2) **RO+CONV**: as 1) + in situ data including wind observations from radiosondes.

- Description of these reanalyses can be found at:

https://confluence.ecmwf.int/display/ROMSAF/The+EUMETSAT+ROM+SAF+reanalyses

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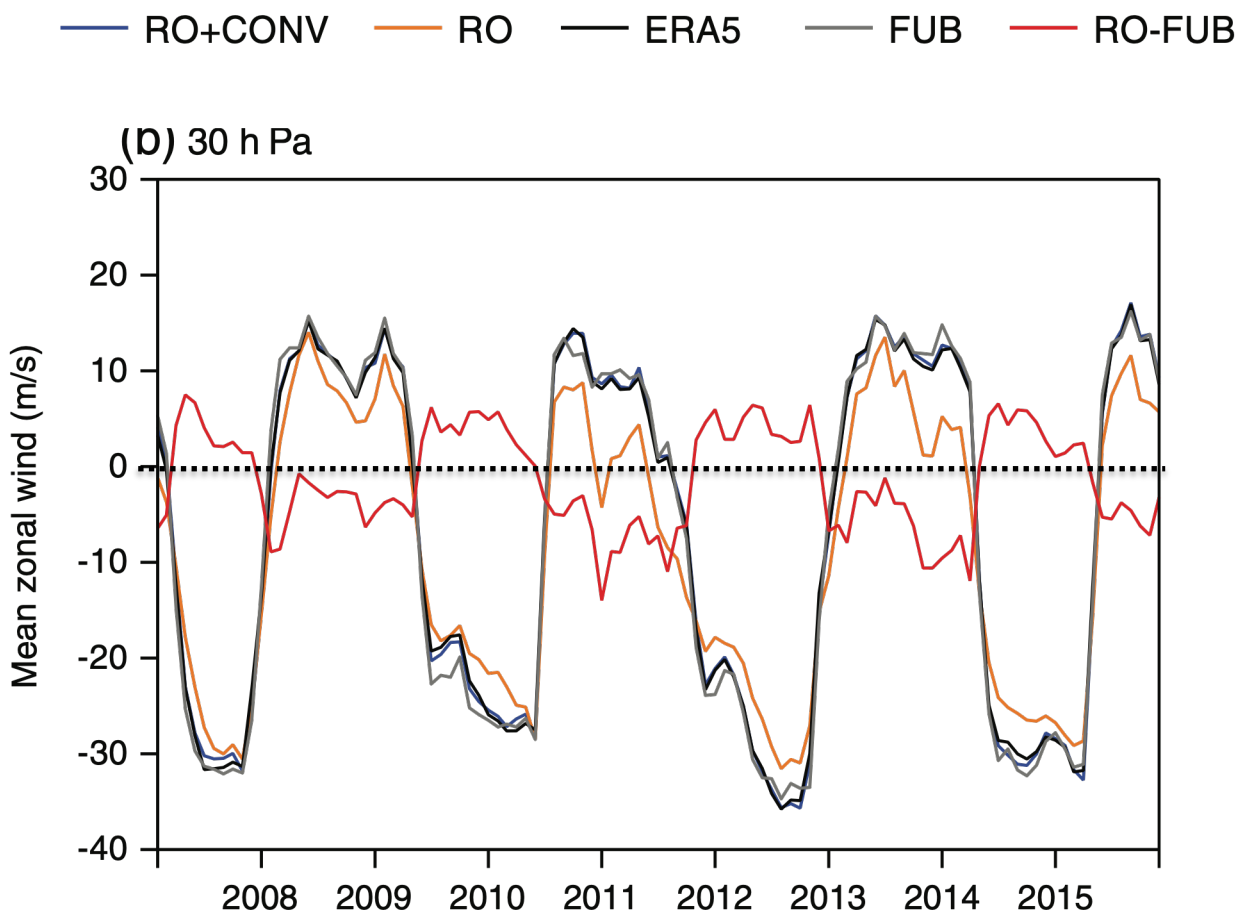
Reanalysis experiments: Results

- **Question:** Can QBO be retrieved from ROM SAF bending angle profiles in the reanalysis system? **Yes,** though agreement with ERA5 improves with in situ obs. →
- Can retrieve zonal wind information just from geopotential height.

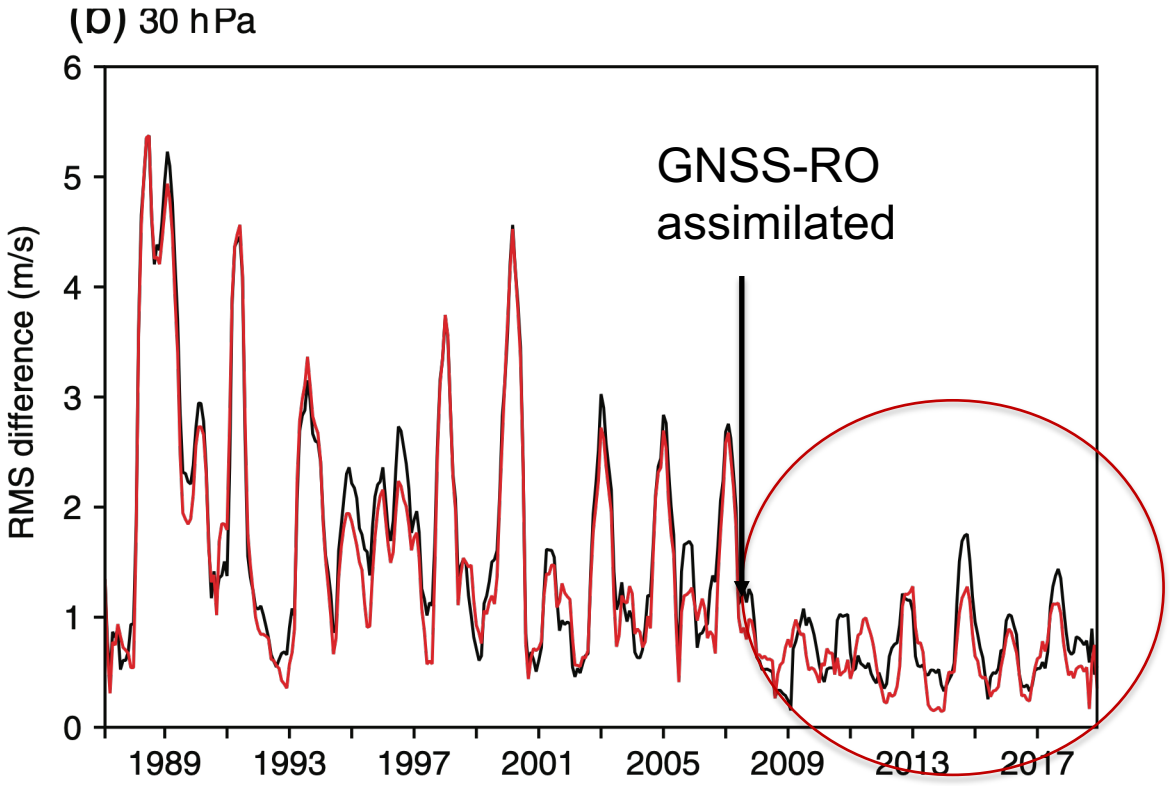


Healy, Polichtchouk & Horanyi (2020, QJRMS)

Consistency between ERA5 and ERA-Interim

- Since the assimilation of GNSS-RO, **consistency** between different reanalyses (here ERA5 and ERA-Interim) **has improved** in their representation of tropical winds.

- Better temperature information provided by GNSS-RO constrains zonal wind better in the stratosphere via equatorial geostrophic balance.

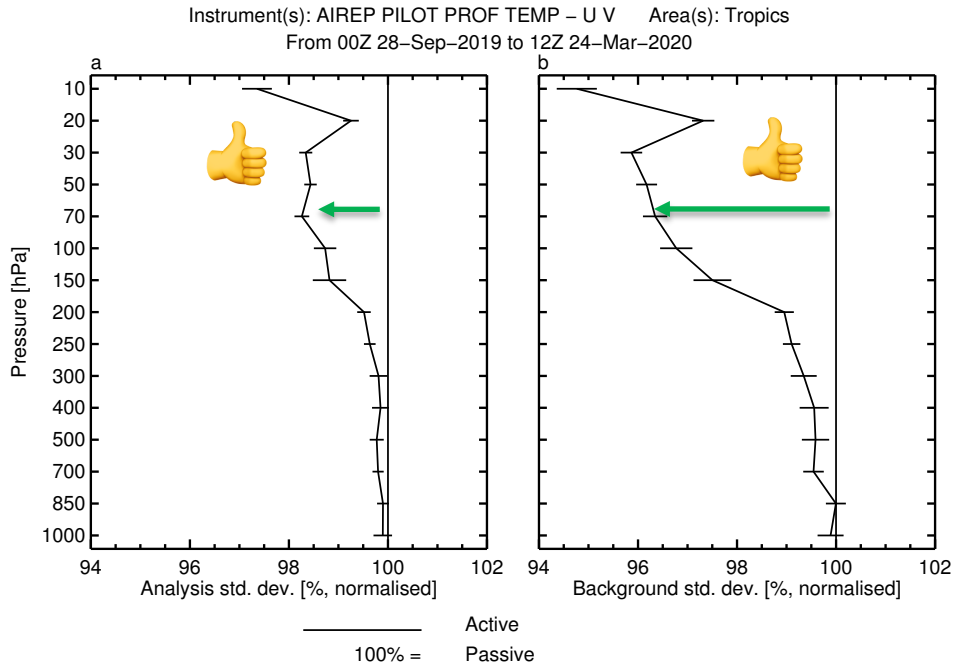


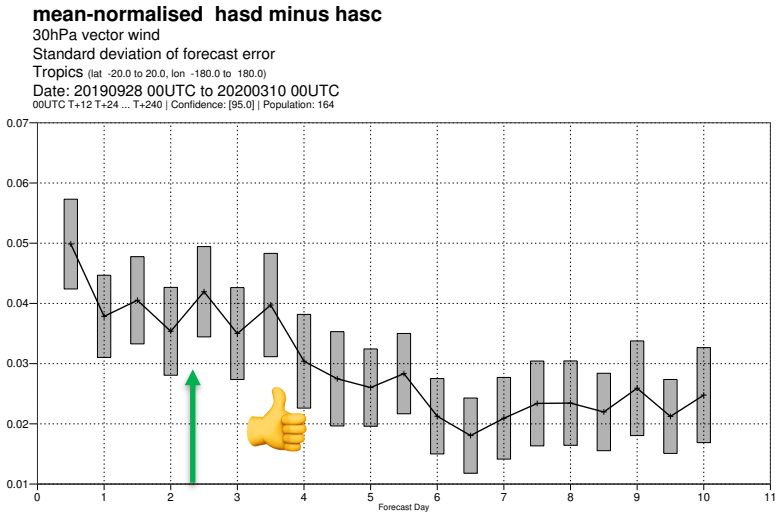
ERA5 minus ERA-Interim root-mean-square error differences of **tropical zonal wind** and **tropical balanced zonal wind**.

Impact of GNSO-RO COSMIC-2 data on ECMWF analysis & forecasts

- In **2019-2020 extra 3000 GNSS-RO** observations available between **40N/S from COSMIC-2** mission.

- Assimilating COSMIC-2 results in significant **improvement of tropical wind analysis** and **forecasts**. Can be understood via **equatorial geostrophic balance**.





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Summary

- QBO can be derived from ROM-SAF monthly gridded geopotential height zonal-mean climatology via equatorial geostrophic balance.
- Assimilation of ROM-SAF bending angles only into the ECMWF reanalysis system produces a reasonable QBO.
- Since assimilation of GNSS-RO in 2006, the consistency in the zonal wind in the equatorial stratosphere has improved between ERA-Interim and ERA5 → can be understood via equatorial geostrophic balance.
- Improvement in the tropical stratospheric wind analysis due to extra COSMIC-2 observations likely due to better balance constraint from these observations.
- Providing ROM-SAF gridded data on a finer latitude grid, would be useful.

What other type of ROM-SAF data would be useful?

- Assimilating COSMIC-2 data not only improves the zonal wind analysis, but also meridional wind analysis. Fleming & Chandra (1989) give a height-curvature relation for meridional wind:

$$V \approx \frac{1}{\beta}\frac{\partial^2 \Phi}{\partial \phi \partial \lambda}$$

- To see if meridional wind improvements due to GNSS-RO can be explained by the above balance data on latitude-longitude grid would be very useful.

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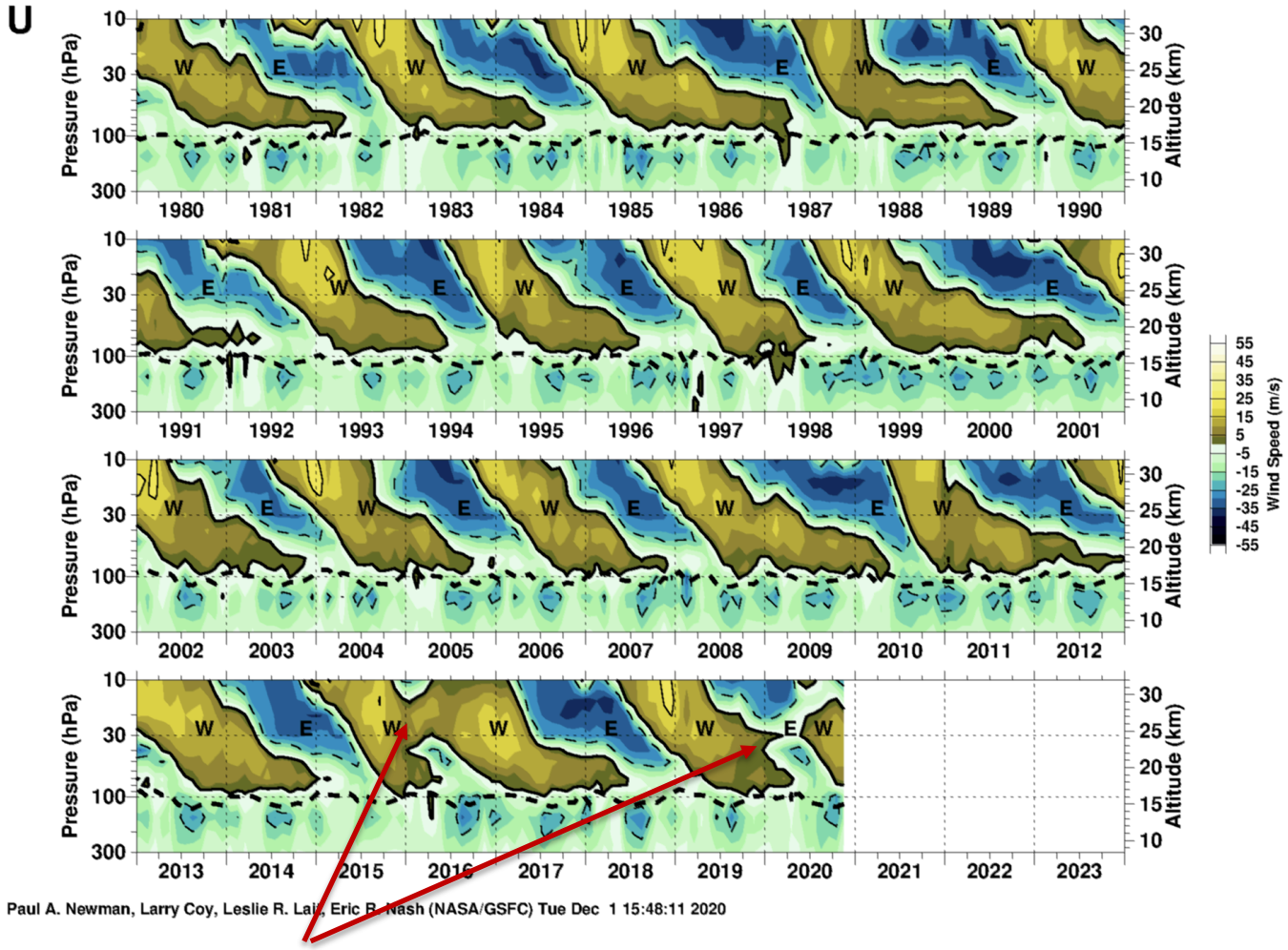

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What type of ROM-SAF data would be useful?

- It would be extremely useful to extract the wave information from RO data to understand which waves are resolved by the RO and therefore contribute to the QBO driving.

- For the wave analysis, the following would be useful:
  - Gridded temperature data on lat x lon grid and pressure or height levels.
  - Temporal frequency should be 1/day or less.

Other uses of ROM SAF data

- Can be used to diagnose free-running ECMWF model temperature biases. But gives almost identical results in the stratosphere as verifying against ERA5.

- Not clear what the benefit using ROM SAF data brings vs using ERA5 (or ERA-Interim) which assimilates GNSS-RO.