How well do momentum diagnostics explain extratropical stratospheric variability in reanalysis datasets?

A contribution to S-RIP

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Momentum diagnostics in reanalysis data-sets

Zonal-mean momentum equation

- Explain the dynamical evolution of the zonal-mean flow
- Wave forcing
- Large scale-circulation

Ideally we would like the momentum equation to:

- Be consistent from one data-set to the other
- Provide realistic forcing

However:

- Differences between reanalyses (Lu et. al. 2014)
- Differences with respect to observations (Kozubek et. al. 2014)

Therefore, it is important to evaluate the skill and characterize differences among reanalysis data-sets

Our goal

Evaluate the **consistency** of **zonal mean momentum diagnostics** in the stratosphere using reanalysis data-sets.

"Ability to fully explain zonal wind acceleration from the available forcing terms of the zonal-mean momentum equation"

- What are the sources of variability among reanalyses?
- Are reanalysis datasets improving?

Data-sets

Acronym	Short-name	Span	Provider
ERA-40	E40	1957-2002	ECMWF
ERA-Interim	E-I	1979-	ECMWF
NCEP-NCAR	N-N	1948-	NCEP
NCEP-DOE	N-D	1979-	NCEP
NCEP-CFSR	N-C	1979-	NCEP
JRA-25	J25	1979-2014	JRA
JRA-55	J55	1958-	JRA
JRA-55C	J55C		JRA
MERRA	ME	1979-	NASA
MERRA2	ME2		NASA

Diagnostics are presented from 1979-2010

The zonal momentum equation

$$\frac{\partial \bar{u}}{\partial t} = f\bar{v} - \bar{v}\frac{1}{a\cos\phi}\frac{\partial(\bar{u}\cos\phi)}{\partial\phi} - \bar{\omega}\frac{\partial \bar{u}}{\partial p} - \frac{1}{a\cos^2\phi}\frac{\partial(\cos^2\phi\overline{u'v'})}{\partial\phi} - \frac{\partial(\overline{\omega'u'})}{\partial p} + \bar{R}$$

Explains zonal wind tendency in function of

- Forcing by meridional circulation
- Forcing by eddies

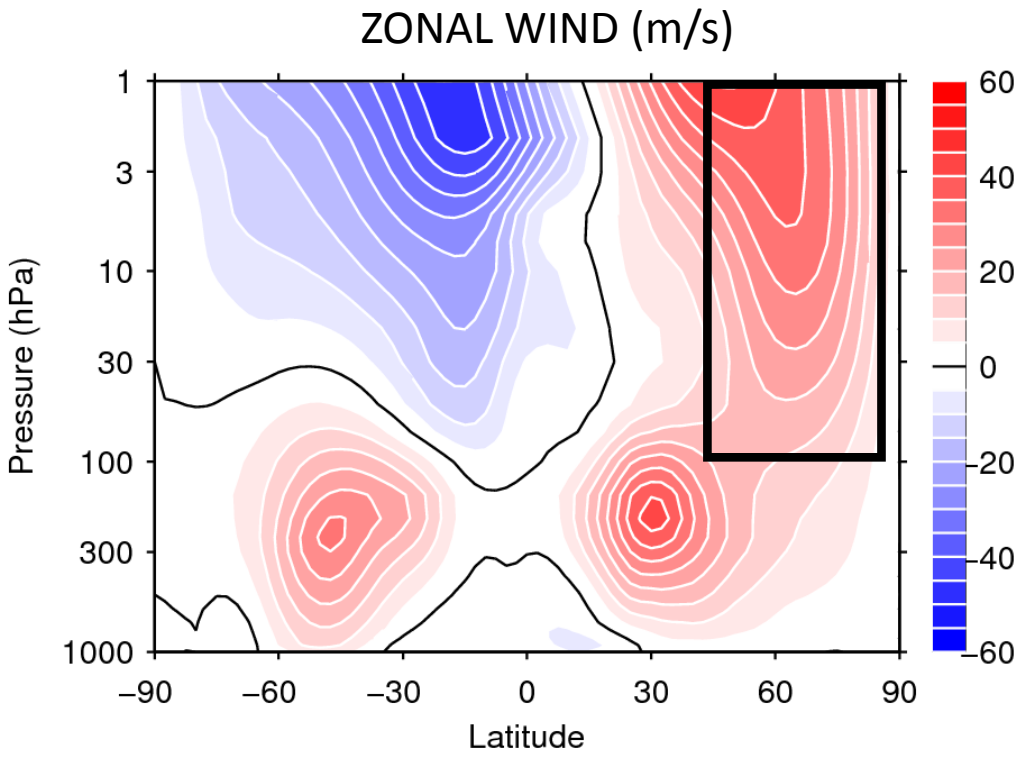
Evaluate

conformity of zonal wind tendency and forcing terms.

consistency, is the sum of forcing terms equal to zonal wind tendency?

importance of non-QG terms.

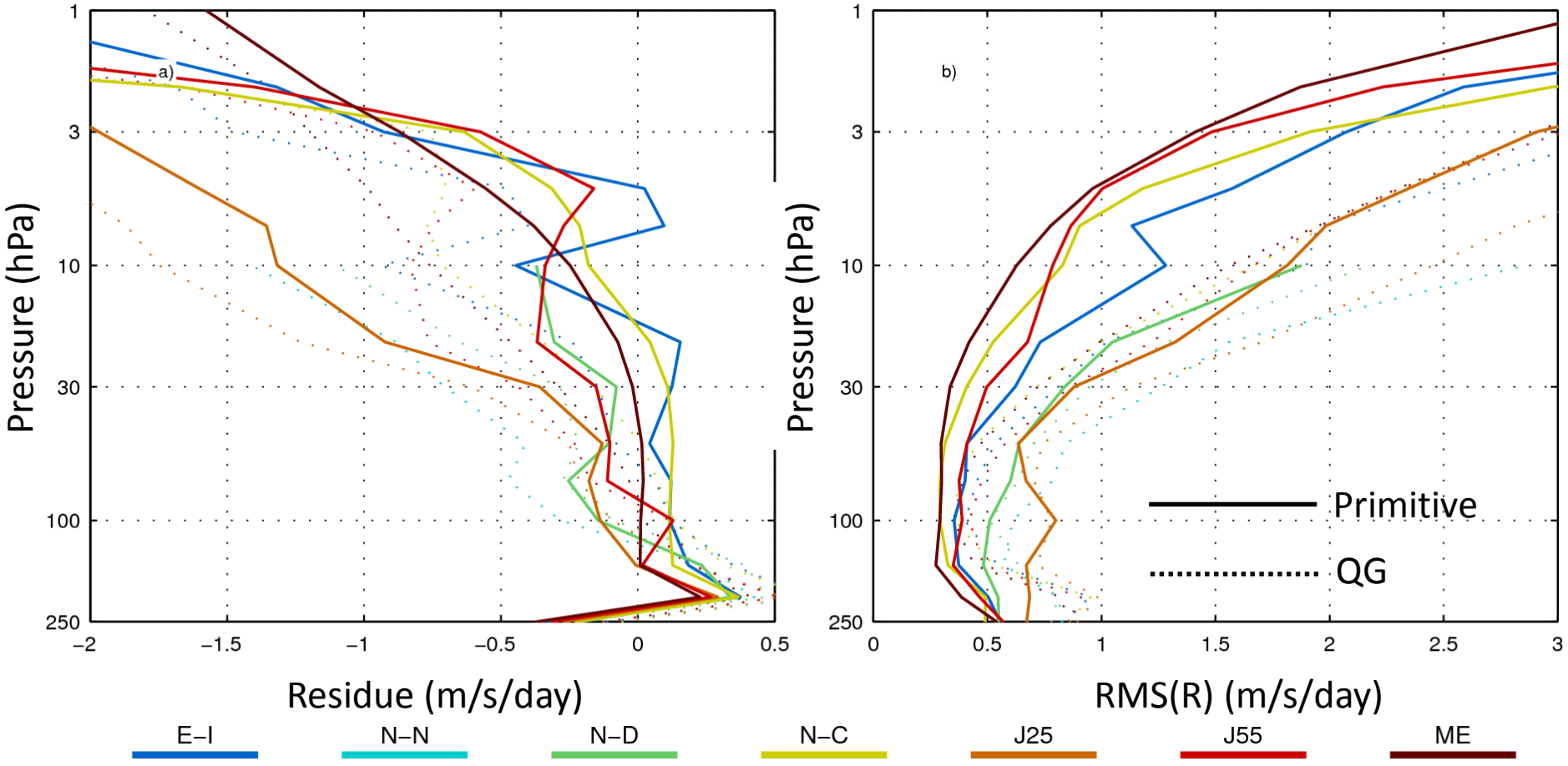
Area of interest



In **winter (DJF)** large amount of wave activity propagates from the troposphere to the stratosphere resulting in large fluctuations in the strength of the **stratospheric vortex**

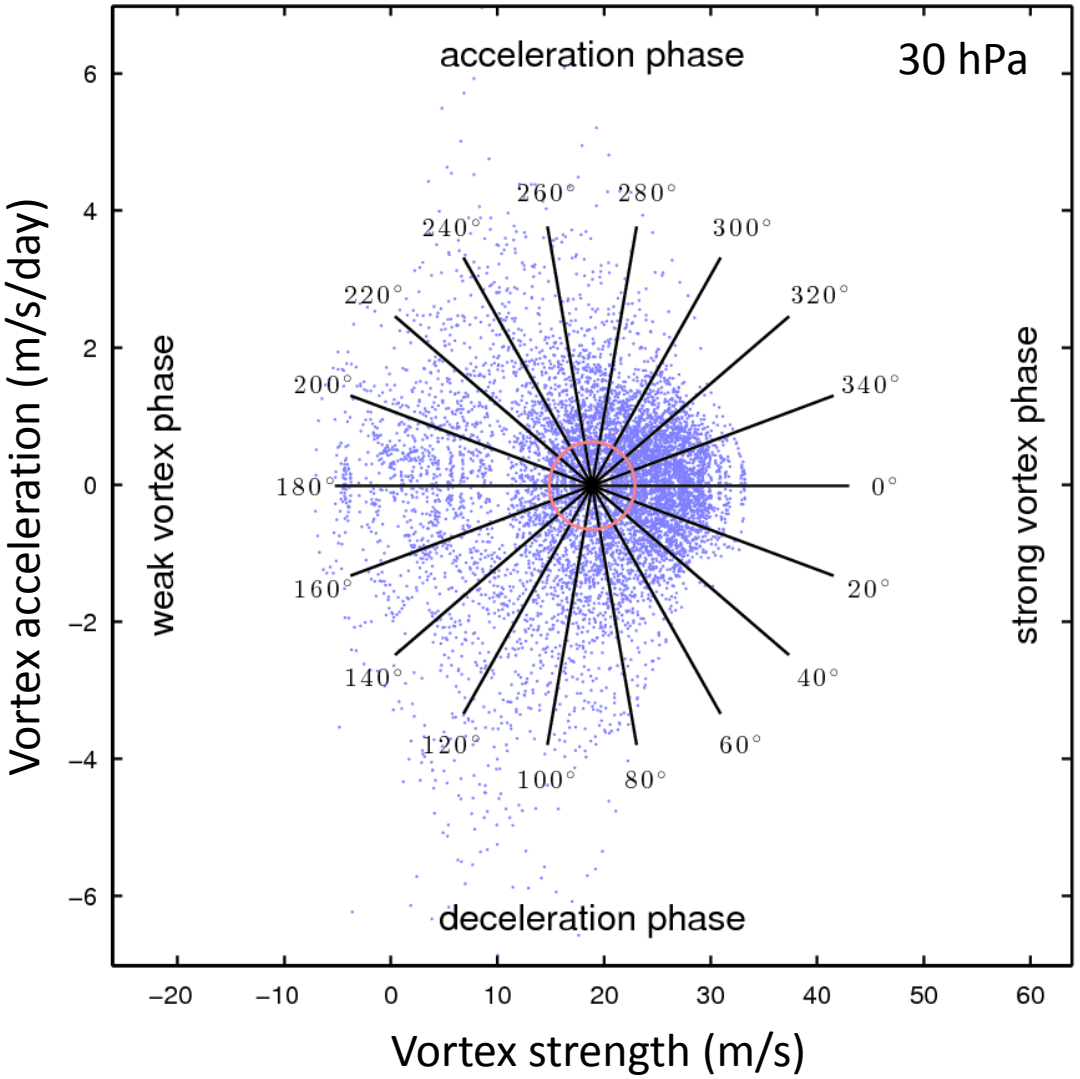
- Averaged from 45N to 85N
- Diagnostics performed at all pressure levels.

Consistency versus height



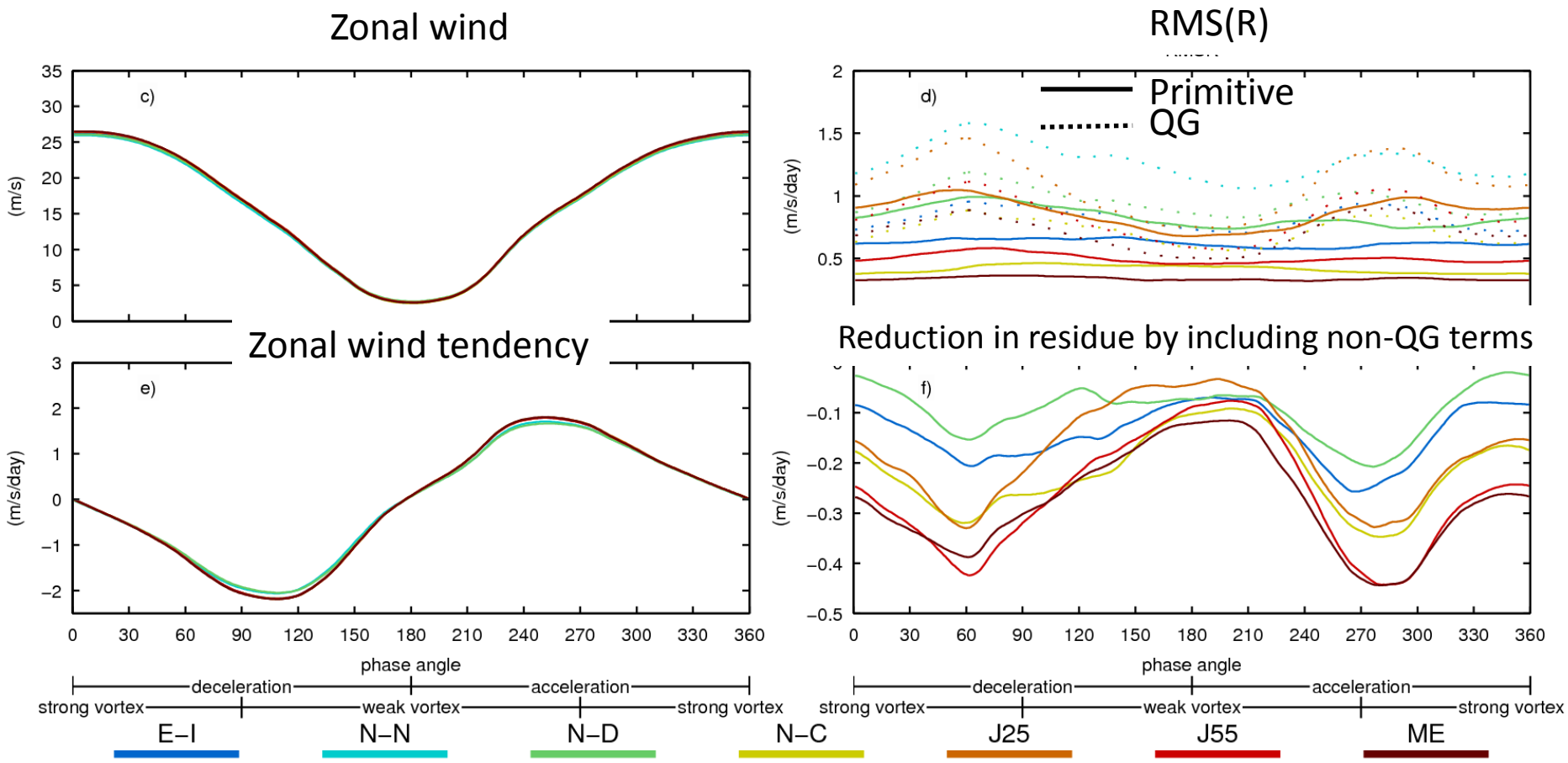
- Residue is small in the lower stratosphere
- Residue is large in upper stratosphere (lack of parameterized GWD)
- Residue is smaller in later reanalysis data sets.

Is residue dependent on the state of the stratosphere?



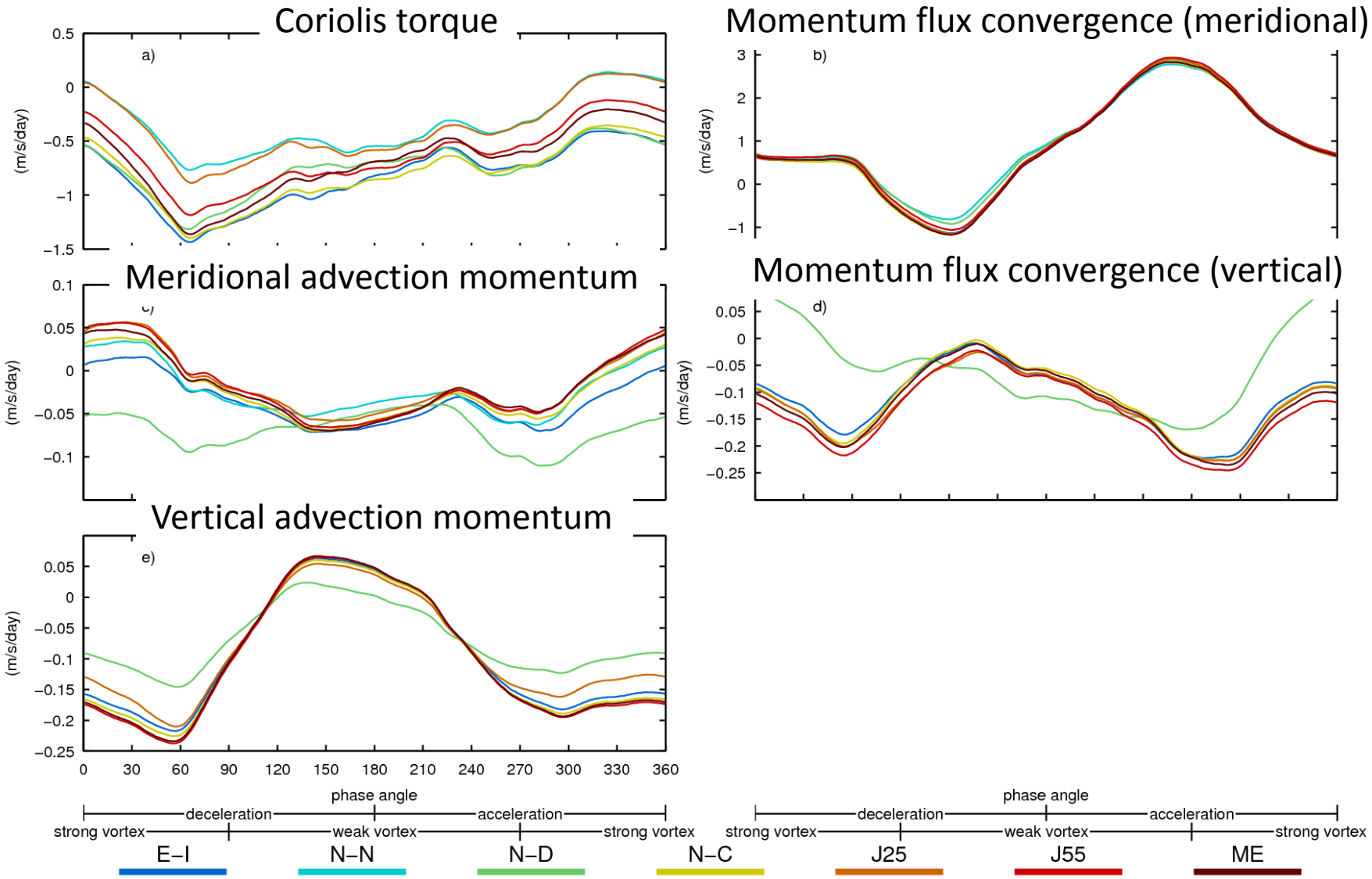
- 6-hourly zonal wind and zonal wind tendency are mapped onto a polar plane based on the normalized distributions of the two quantities.
- Consistency and conformity of forcing terms will be evaluated during the **vacillation cycle**

Vacillation cycle – stratospheric state & residue



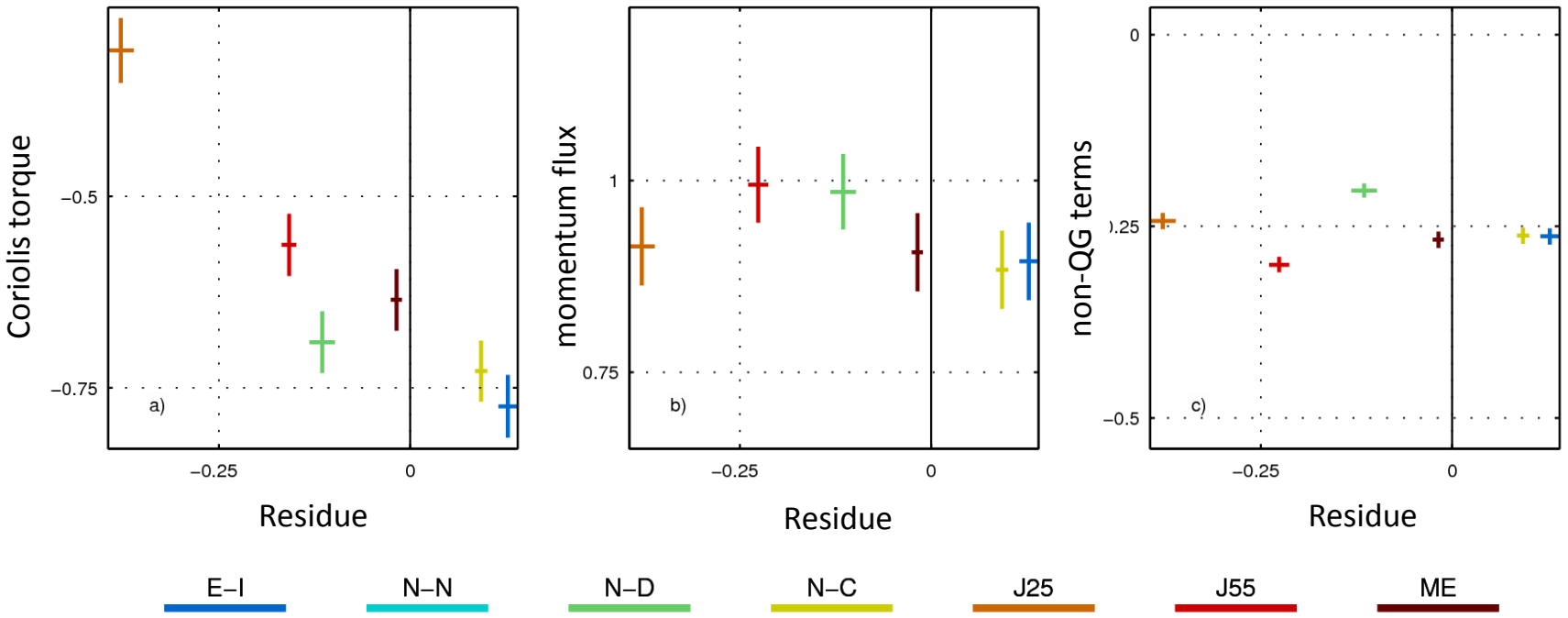
- Non-QG terms contribute to reduce residue during deceleration and acceleration phases

Vacillation cycle – forcing terms



- **Coriolis torque** shows largest discrepancy among all forcing terms

Residue vs forcing term



- One-to-one relationship between **residue** and **Coriolis torque**

Conclusions

- Parameterized forcing, such as GWD, poses a serious limitation to consistency of momentum budget in the upper stratosphere.
- Substantial improvement consistency is observed over generations of reanalysis data-sets
  - Part of this improvement is related to a better representation of non-QG terms.
  - Most improvement is attributed to the Coriolis torque acting on the meridional circulation

$$\frac{\partial \bar{u}}{\partial t} = f\bar{v} - \bar{v}\frac{1}{a\cos\phi}\frac{\partial(\bar{u}\cos\phi)}{\partial\phi} - \bar{\omega}\frac{\partial\bar{u}}{\partial p} - \frac{1}{a\cos^2\phi}\frac{\partial(\cos^2\phi\,\overline{u'v'})}{\partial\phi} - \frac{\partial(\overline{\omega'u'})}{\partial p} + \bar{R}$$

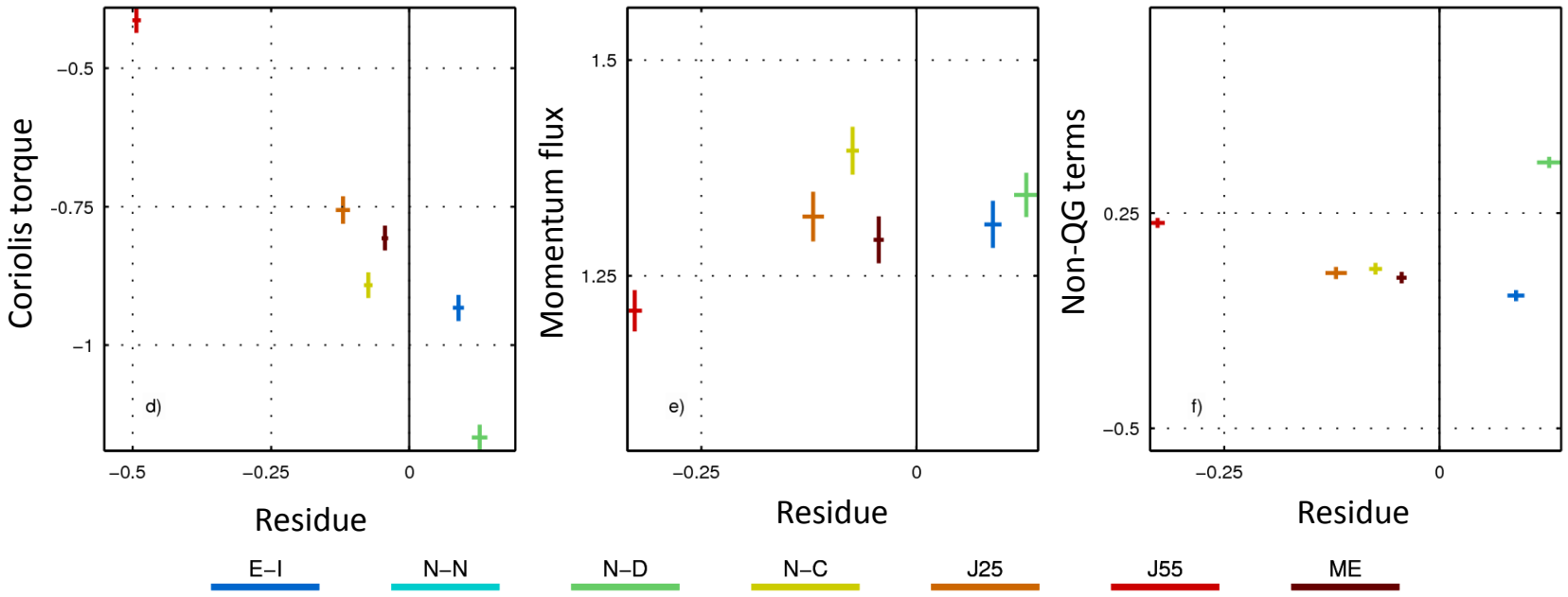
Future work :

Understanding the causes of discrepancies in Coriolis torque

- GWD?
- Radiation?
- Assimilation?

Residue vs forcing term

Southern Hemisphere

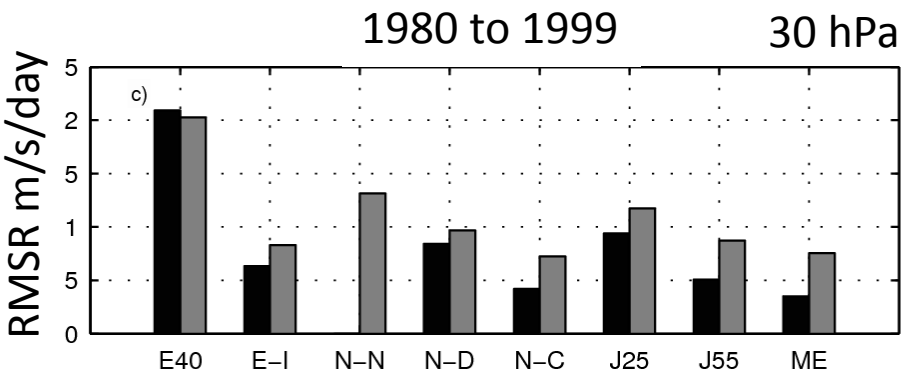


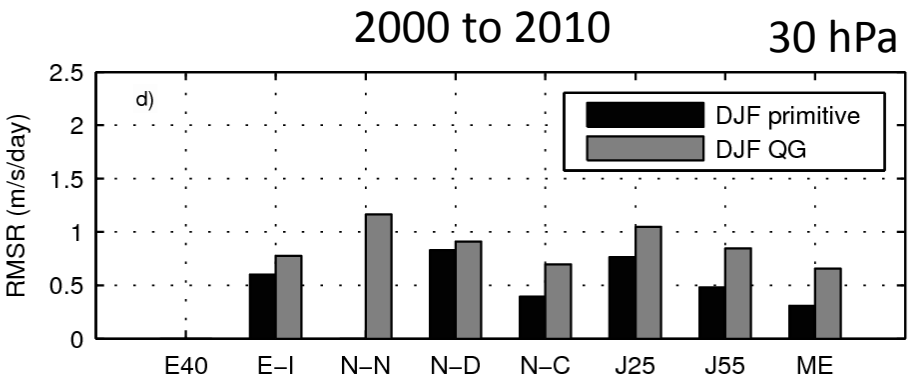
- The latest reanalysis, J55 shows large negative residue in SH since it largely underestimates deceleration by Coriolis torque

Improvement over generations

Improvement could be due to:

- observations
- assimilation of observations
- dynamical core





Residue is

- Smaller in newer reanalyses which benefit more from the non-QG terms
- Similar between 1980-1999 and 2000-2010

Reduction of residue is therefore most likely due to numerical methods employed in dynamical core and assimilation