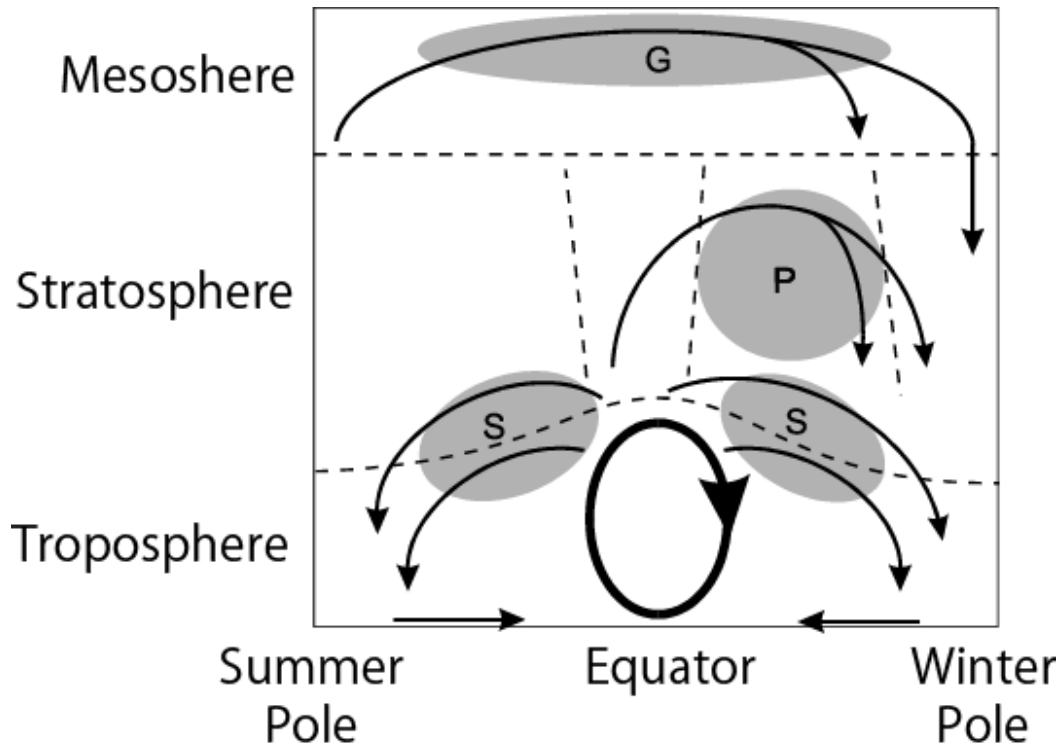


The big picture of my research

- Material circulation in the middle atmosphere
 - mainly driven by waves
 - affects the thermal and chemical structure of the middle atmosphere
 - increasing evidence of **zonally asymmetric structure** of the material circulation (Hitchman and Rogal 2010; Gabriel et al. 2011)



Schematic

G: gravity waves

P: planetary-scale waves

S: synoptic-scale waves

(Plumb 2002)

The big picture of my research

- Formulation of 3-D Residual mean flows (Kinoshita and Sato 2013a)
 - Applicable to both Rossby waves and gravity waves

$$\bar{u}^* = [u] + \bar{u}^S = [u] + \left(\frac{\bar{S}_{(p)}}{f} \right)_y - \frac{1}{\rho_0} \left(\frac{\rho_0 \overline{u' \phi'_z}}{N^2} \right)_z$$

$$\bar{v}^* = [v] + \bar{v}^S = [v] + \left(\frac{\bar{S}_{(p)}}{f} \right)_x - \frac{1}{\rho_0} \left(\frac{\rho_0 \overline{v' \phi'_z}}{N^2} \right)_z$$

$$\bar{w}^* = [w] + \bar{w}^S = [w] + \left(\frac{\overline{u' \phi'_z}}{N^2} \right)_x + \left(\frac{\overline{v' \phi'_z}}{N^2} \right)_y$$

where

$$\bar{S}_{(p)} = \frac{1}{2} \left(\overline{u'^2} + \overline{v'^2} - \frac{\overline{u' \phi'_y}}{f} + \frac{\overline{v' \phi'_x}}{f} \right)$$

Bar: zonal mean

Prime: deviation from zonal mean

Bracket: time mean

✂ extended Hilbert transform applied to flux terms (Sato et al. 2013)

Powerful tool to investigate the longitudinal structure of the material circulation

The big picture of my research

The big picture of my research is.....

to investigate longitudinal structure of the stratospheric material circulation by using the formulation of 3-D residual mean flow during warm and cold events in both hemispheres.

- Warm events
 - in the Northern Hemisphere ⇒ currently analyzed
 - Canadian warming (CW; Manney et al. 2001)
 - stratospheric sudden warming (SSW; Mitchell et al. 2013)
 - stratospheric final warming (SFW; Black et al. 2006)
 - in the Southern Hemisphere
 - South Pacific warming (SPW; Farrara et al. 1992)
 - minor SSW
 - SFW ⇒ already published (Hirano et al. 2016, see my publication list)
- Cold events
 - “refrigerator” (Shaw and Perlwitz 2014)

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