A study of the middle atmosphere dynamics using a gravity-wave resolving GCM
- The KANTO project –

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Presented by Kaoru Sato (U. Tokyo) on 1 Sept. 2008 at SPARC 4th general assembly

Purpose of the KANTO project

Recently-available high-resolution GCM can simulate gravity waves explicitly (e.g. Hamilton et al, 1999; Koshyk et al., 1999; Sato et al., 1999; Kawatani et al., 2003, 04, 05; Watanabe et al., 2006).

The purpose of our study is

- to quantitatively understand dynamical characteristics of small-scale physical processes including
  - GWs, EQWs, trapped RWs, inertial instabilities
  - fine structure around the tropopause and stratopause
  - layered and filamentary structures of tracers
- to elucidate their roles in the large-scale thermal structure, global circulations and equatorial oscillations of the middle atmosphere,

using long-period simulation data obtained from a gravity-wave resolving GCM .

Topics of this talk

1. Gravity waves:
   Climatology and contribution to the global momentum balance
   Watanabe et al. (JGR, 2008;POSTERP108),
   Sato et al. (in preparation)
2. Fine structure of the stratopause:
   Subtropical stratopause temperature maximum in winter
   Tomikawa et al. (JGR, in press)
3. The QBO:
   Relative roles of equatorially-trapped waves and internal gravity waves
   Kawatani et al. (JAS, to be submitted; POSTERP55).
4. Fine structure of the UTLS:
   Vertical and lateral mixing processes
   Miyazaki et al. (in preparation; POSTERP59)

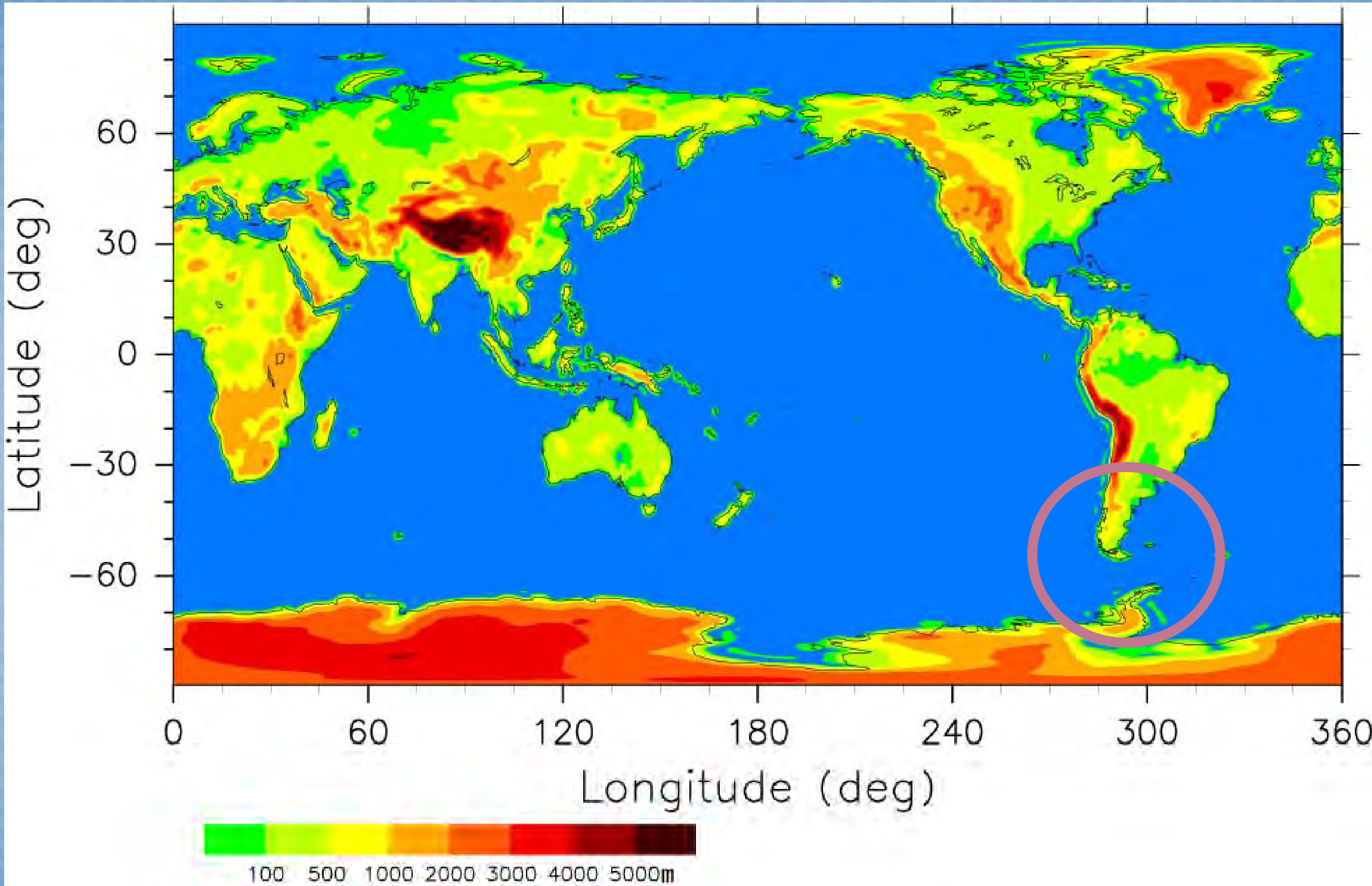
The Kanto project

T213L256 CCSR/NIES/FRCGC AGCM (5.7b)

- T213 ($\Delta x = \Delta y \sim 60$km)
- L256 (Δz =300 m) surface ~ 85km
- Radiation: mstrnX (*Sekiguchi and Nakajima* 2007) solar 9 bands and terrestrial 10 bands
- Cumulus parameterization: prognostic Arakawa-Schubert
- No gravity wave parameterizations
- Richardson number dependent vertical diffusion (Mellor-Yamada level 2.0)
- Realistic topography, SST, and sea ice
- Time step: 30 seconds
- Sampling time interval: 1 hour
- Simulated period: 3 years

30TB!

Topography of T213 GCM



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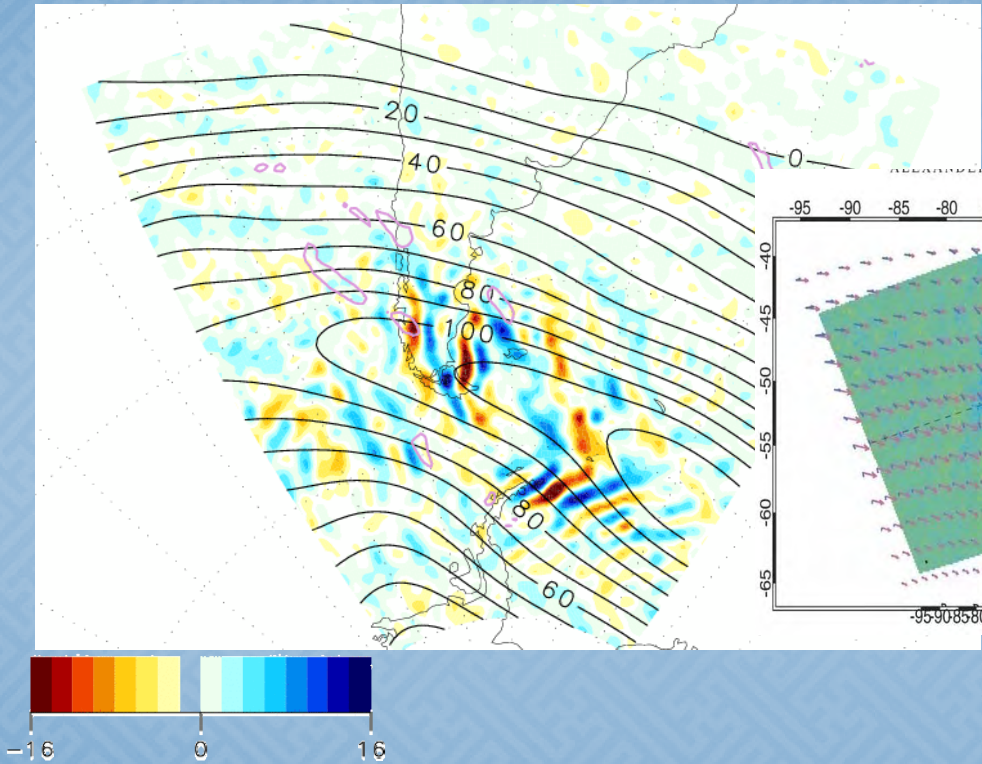
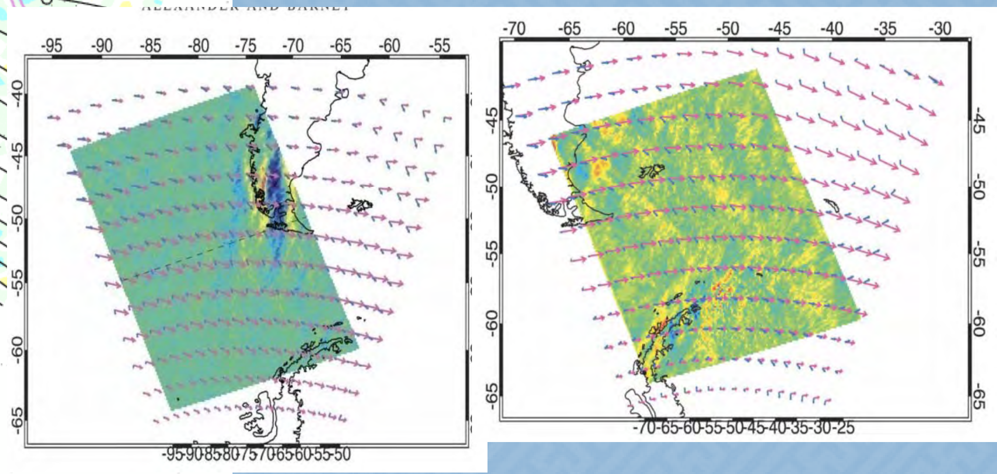
Comparison with observations
- gravity waves -



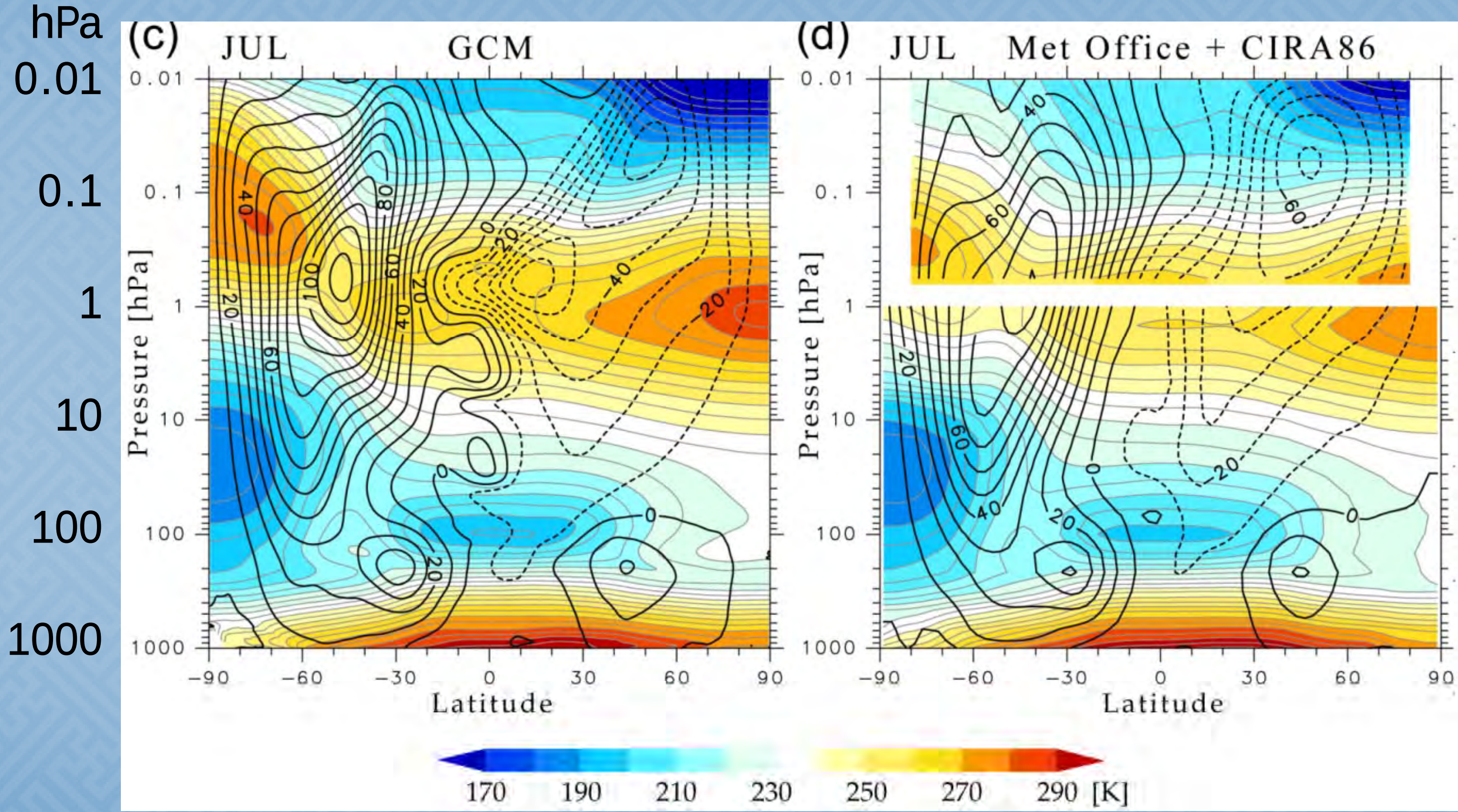
Kanto model data

About 3 hPa



AIRS observation data
Alexander & Barnet (JAS,2007)

Comparison with observation - Zonal mean fields of U and T -



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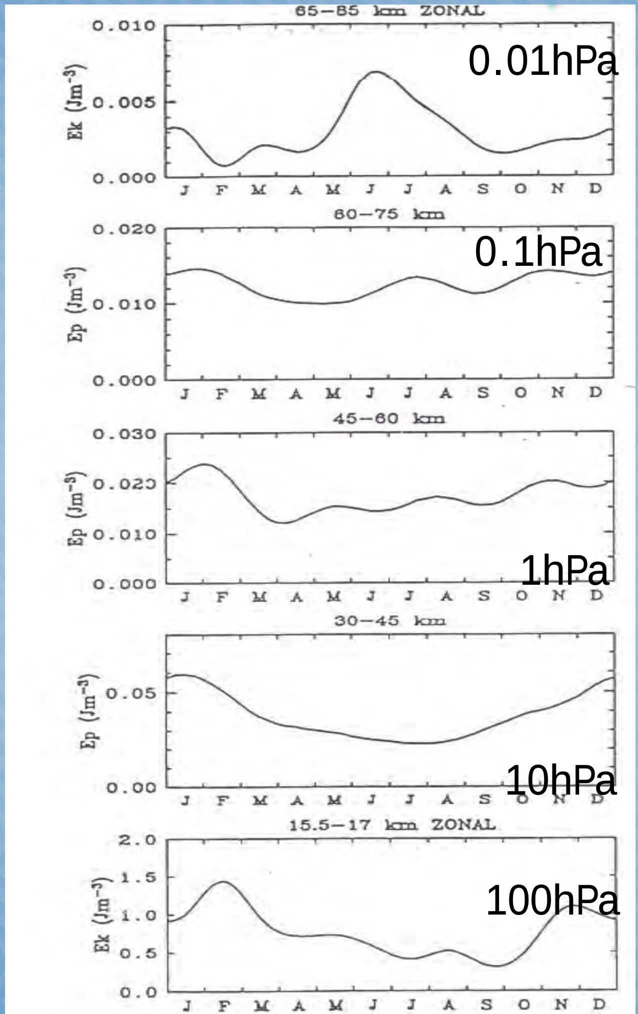
Comparison with observation
-Seasonal variation of gravity wave energy -

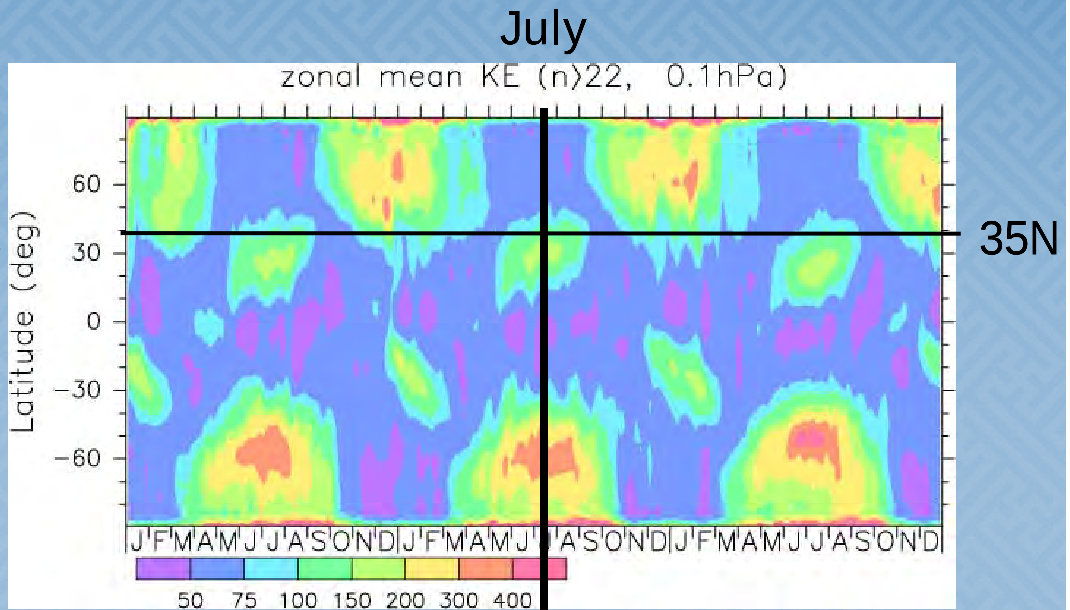
Midlatitude

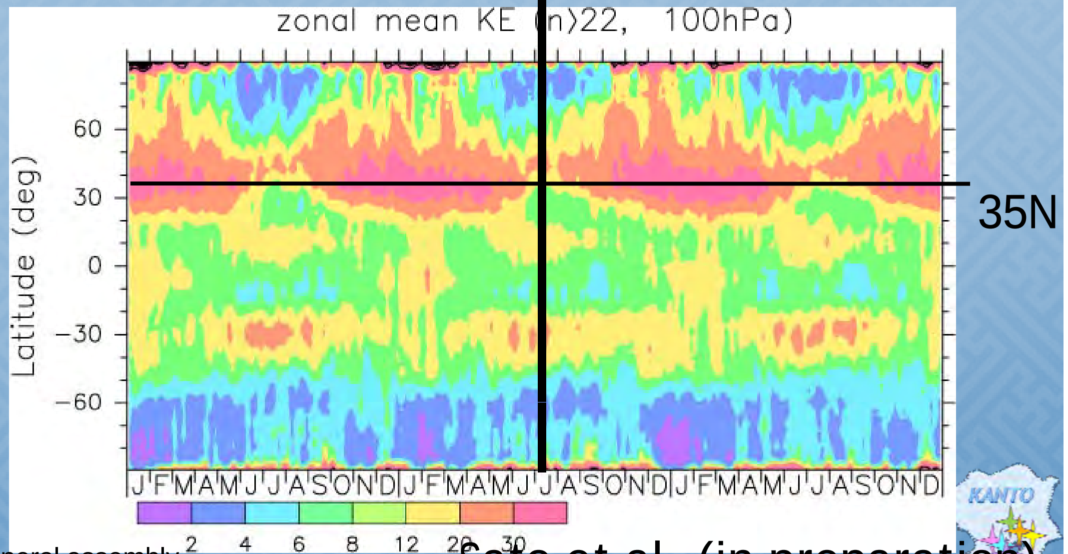


Jan July

Tsuda et al. (JATP, 1992)

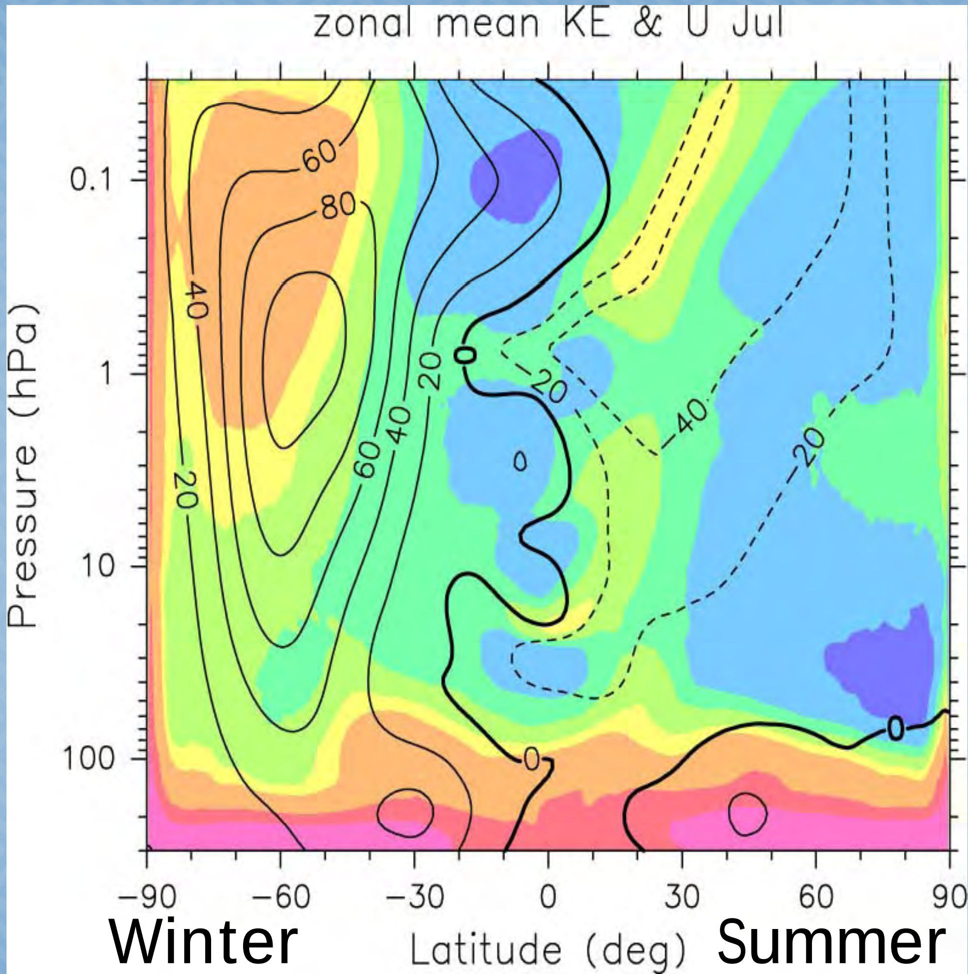
July





Sato et al. (in preparation)

Gravity wave energy in the meridional cross section in July

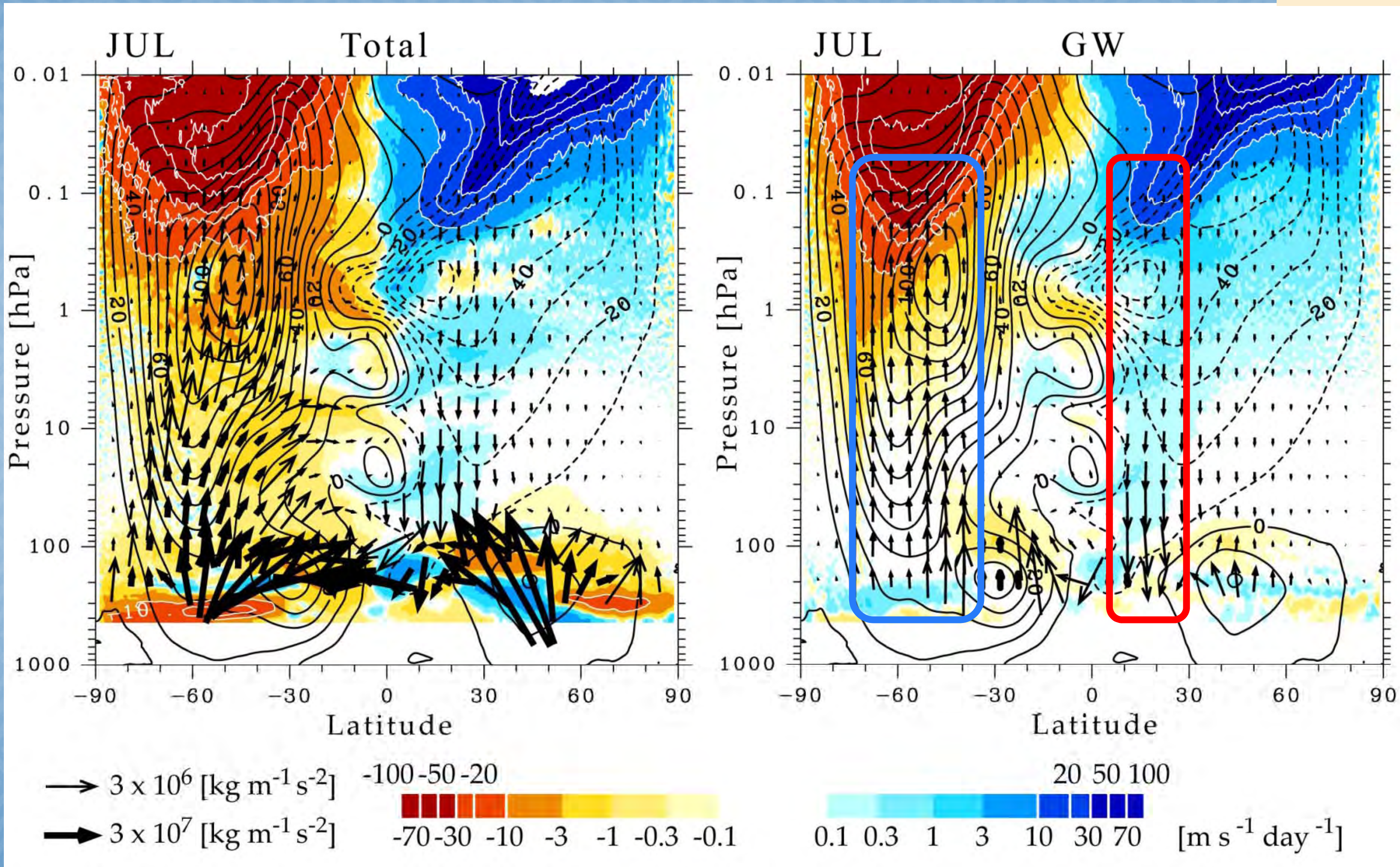


It seems that zero wind lines control the distribution of GWs.

Sato et al. (in preparation)

E-P flux and its divergence in July

U: Contour
E-P Flux: Vector
Wave force: Color



Watanabe et al. (JGR, 2008)

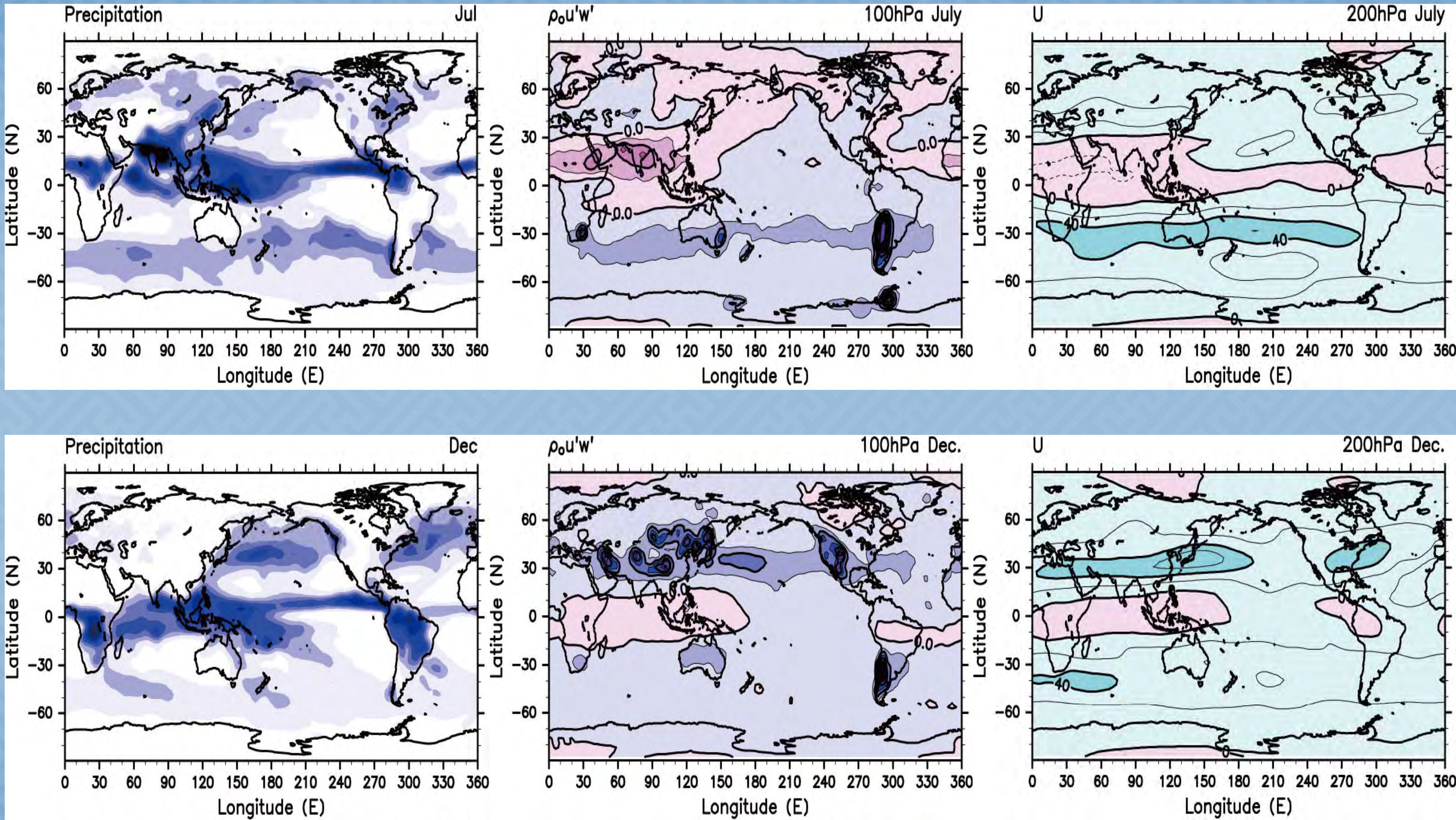
GW sources

Pink: positive
Blue: negative

Precipitation | $\overline{u'w'}$ at 100hPa | $\overline{U}$ at 200hPa

July

Dec.



GWs with positive u'w' are likely emitted from convection.
GWs with negative u'w' are emitted from topography, baroclinic waves and jets.

Sato et al. (in preparation)

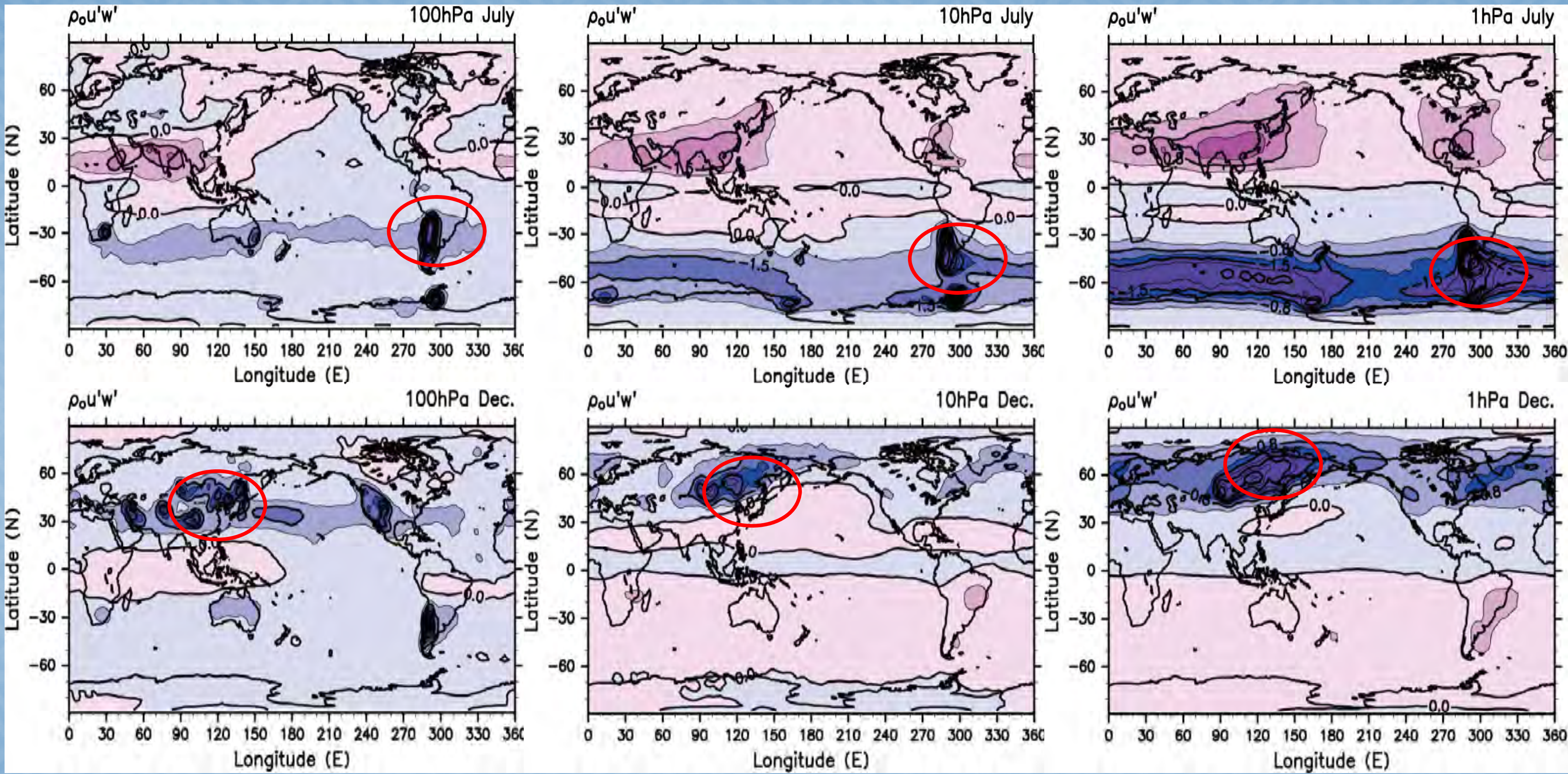
Horizontal distribution of $\overline{u'w'}$

Pink: positive Blue: negative

100hPa 10 hPa 1 hPa

July

Dec.

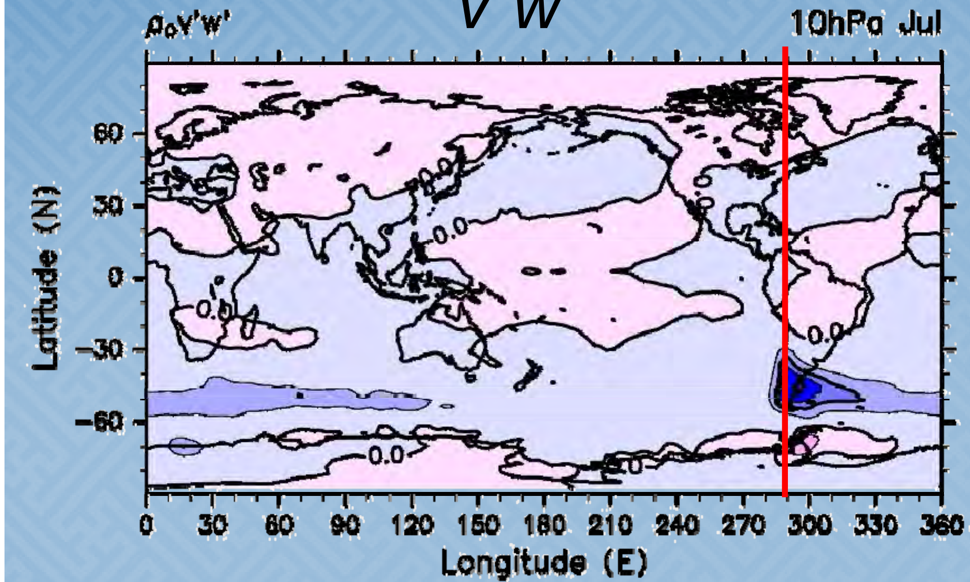


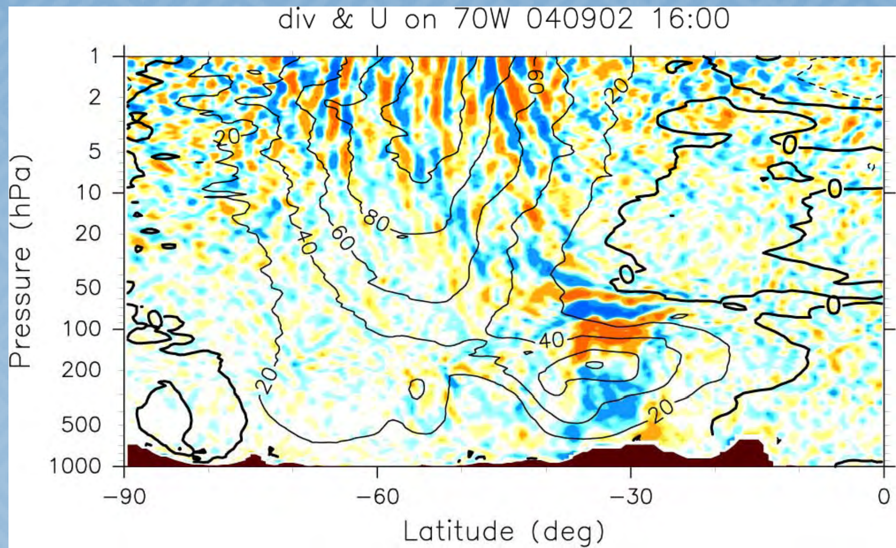
It seems that GWs with negative *u'w'* propagate toward higher latitudes

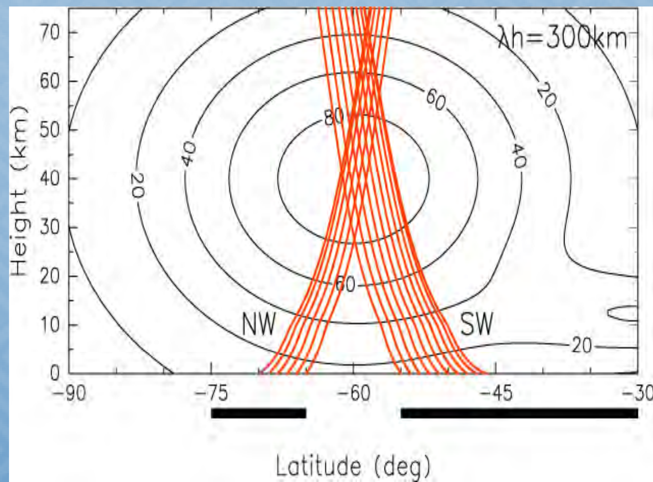
Sato et al. (in preparation)

Gravity waves near the Andes and Antarctic Peninsula

v'w'







Both lateral propagation and the existence of critical layers are important for the dominance in the polar night jet region.

Sato et al. (in preparation)

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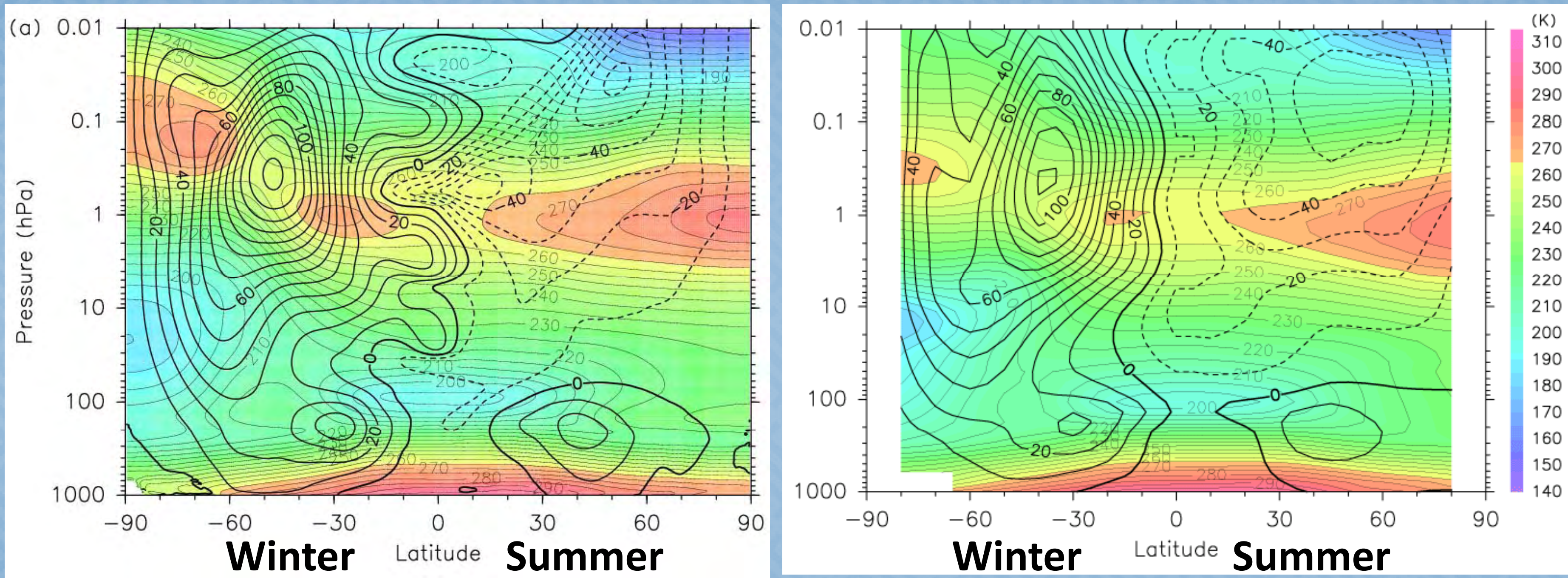
   Sato et al. (in preparation)
2. **Fine structure of the stratopause**:
   Subtropical stratopause temperature maximum in winter
   Tomikawa et al. (JGR, in press)
3. The QBO:
   Relative roles of equatorially-trapped waves and internal gravity waves
   Kawatani et al. (JAS, to be submitted; POSTERP55).
4. Fine structure of the UTLS:
   Vertical and lateral mixing processes
   Miyazaki et al. (in preparation; POSTERP59)

Temperature maximum at the subtropical stratopause in winter

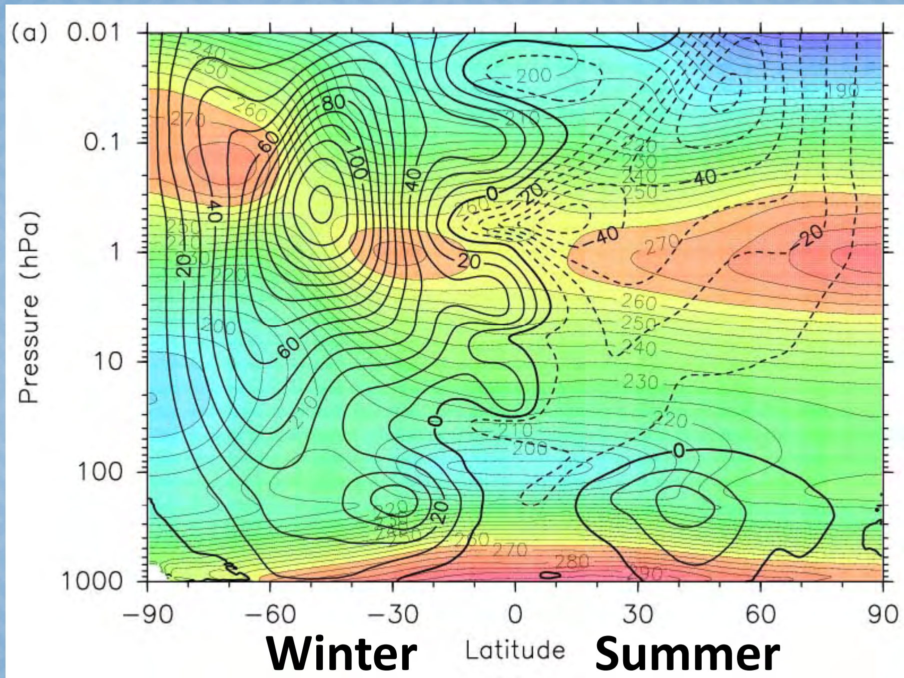
Model **CIRA86**



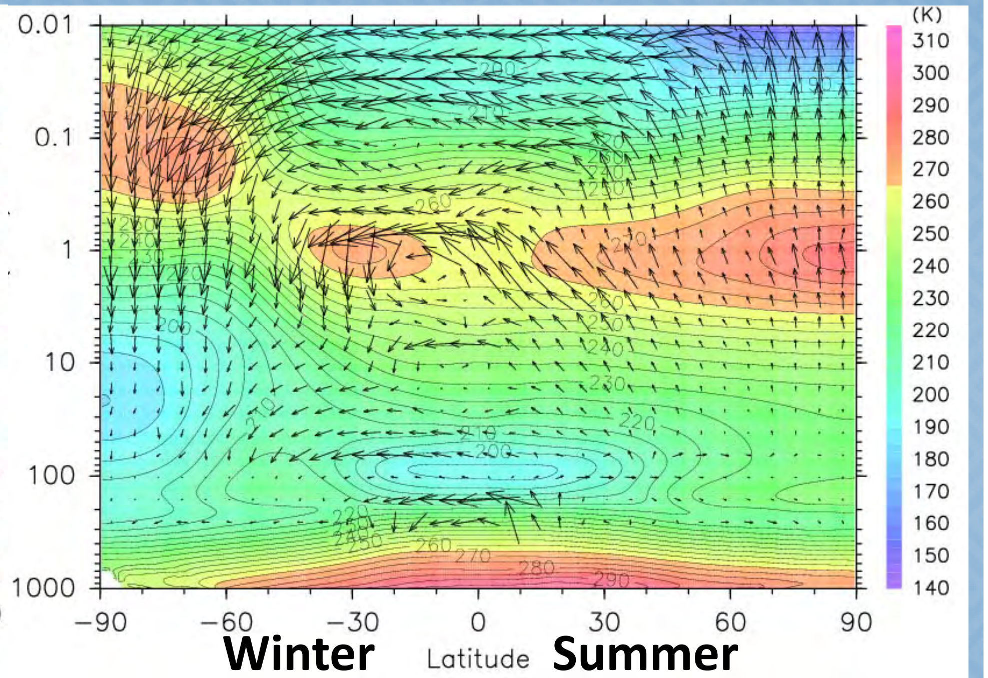
Tomikawa et al. (JGR, 2008)

Temperature maximum at the subtropical stratopause in winter

Model



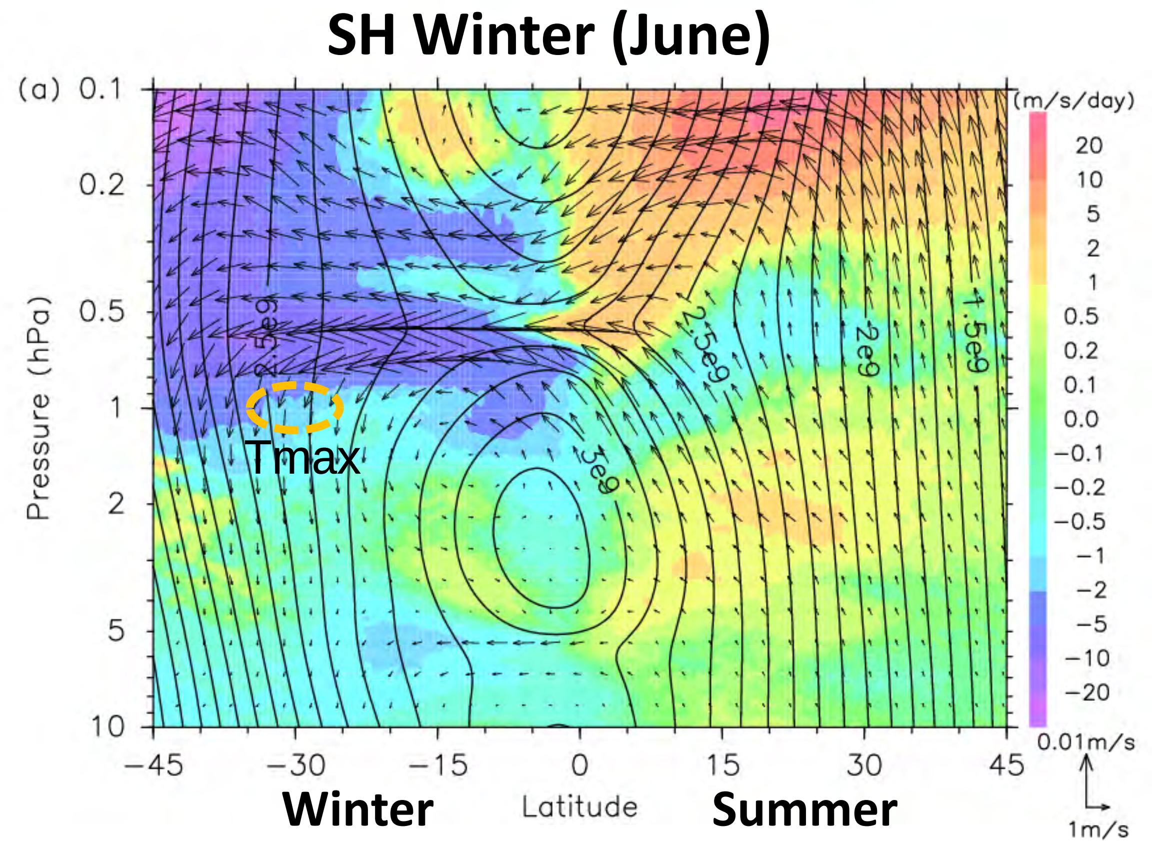
T and (v*, w*)



The temperature maximum seems to be related to the residual circulation that is dominant in the low latitude region.

Tomikawa et al. (JGR, 2008)

Absolute Angular Momentum Distribution and Meridional Circulation



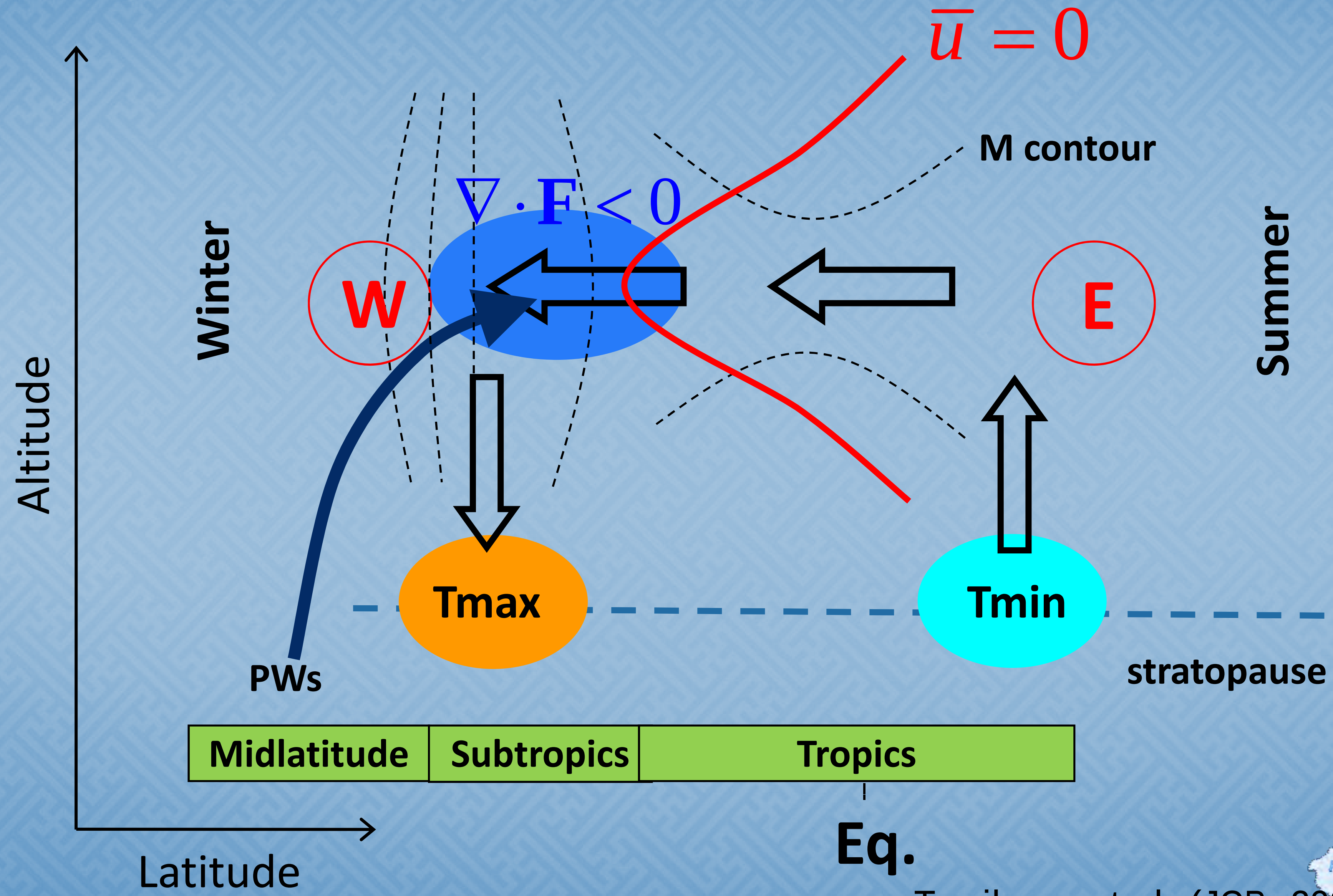
Tropics :
Cross-equatorial flow along nearly-horizontal contours of absolute angular momentum

Winter Subtropics :
Poleward flow driven by E-P flux convergence

EP flux divergence (colors)
Absolute angular momentum (contours)
Residual-mean circulation (vectors)

Tomikawa et al. (JGR, 2008)

Mechanism



Tomikawa et al. (JGR, 2008)

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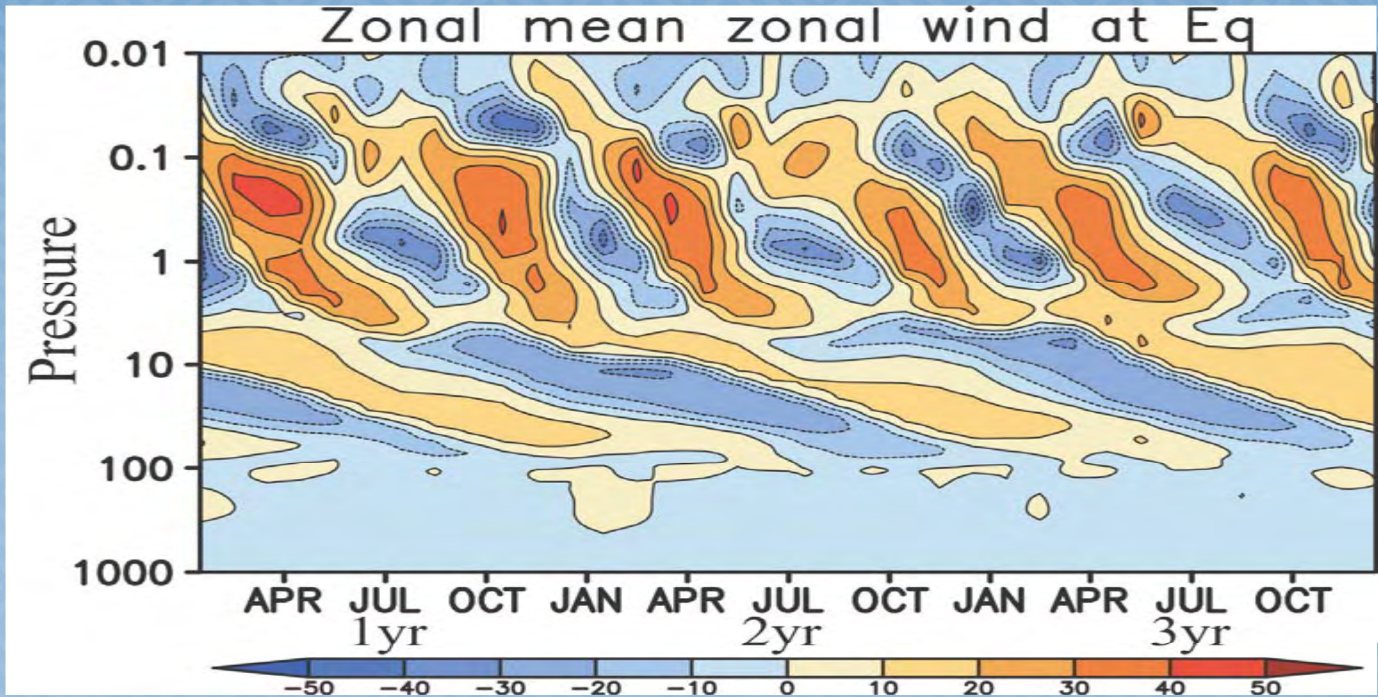
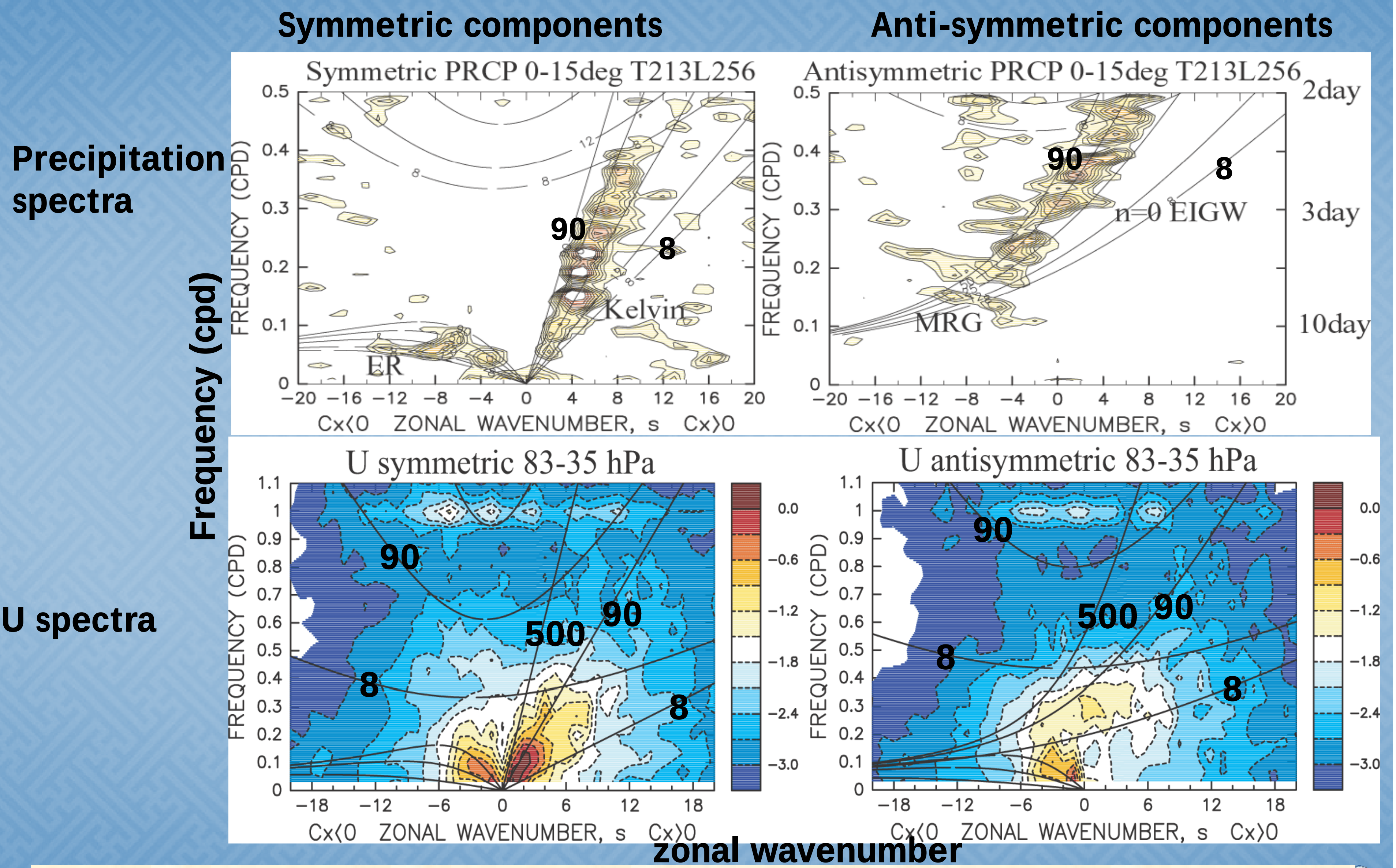
Simulated SAO and QBO-like oscillation at the equator



- S-SAO: 1st cycle: U= -70 to 35 m/s
  2nd cycle: U= -50 to 35 m/s
- S-QBO: U= -25 to 15 m/s at 30hPa
  Period=15 mon (cf. real period=28 mon)

Kawatani et al. (JAS, to be submitted)

S-ω spectra of precipitation and u'

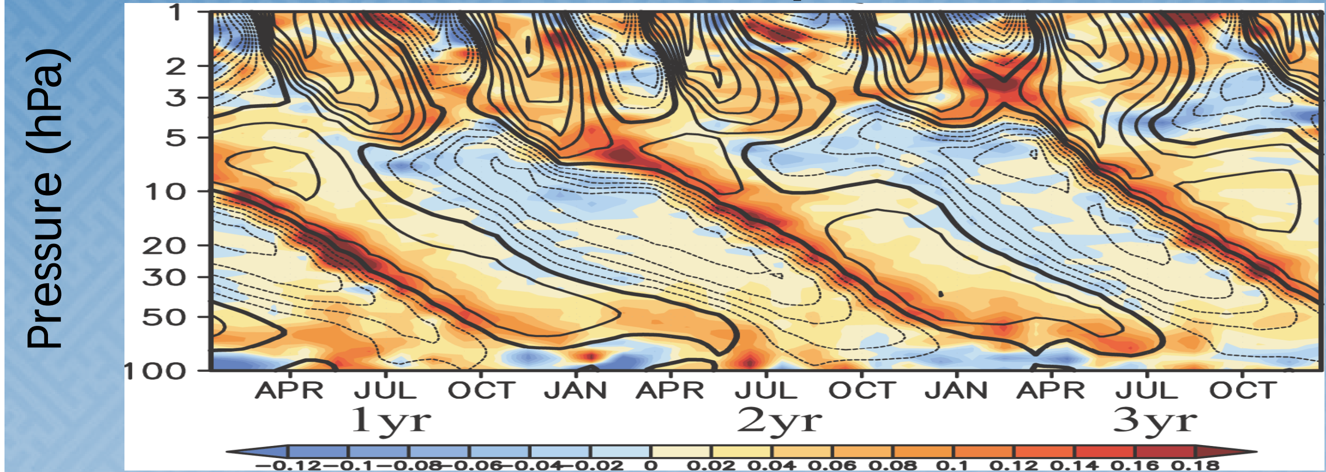


Our GCM well simulated convectively coupled EQWs and EQWs in the stratosphere

Kawatani et al. (JAS, to be submitted)

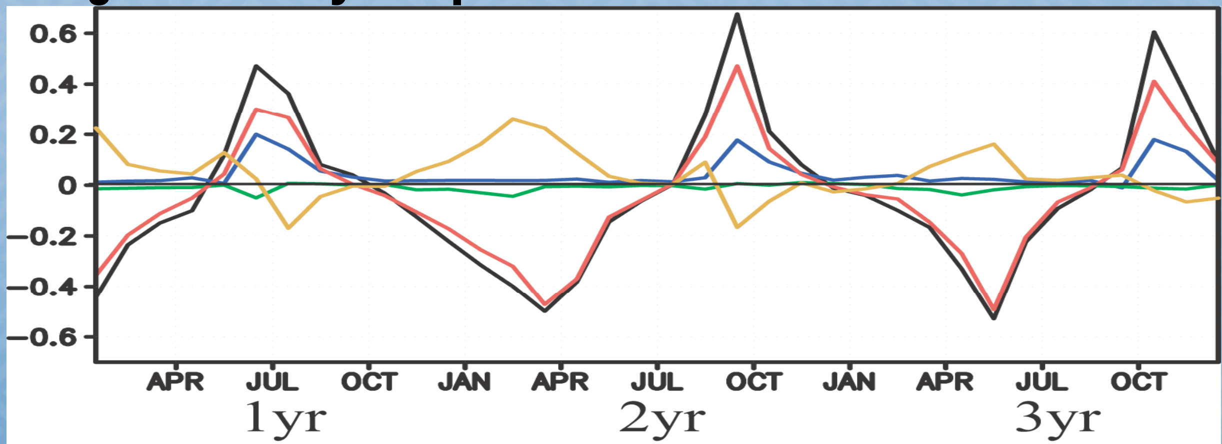
Contribution of EGWs and GWs to the QBO driving

EP flux div associated with equatorial waves for 10S-10N



Definition of EQWs:
2m<h<90m
eastward
(KW, n=1-2 GWs)
westward
(RGW, n=1-2 GWs, RW)

Driving forces by respective waves and residual circulation at 30hPa



Colors indicate
all waves
3-D IGWs
eastward EQWs
westward EQWs
v* & w*

Contribution to drive the QBO is 25-40% for eastward EQWs (westerly acceleration) and very small for westward EQWs (easterly acceleration)

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Kawatani et al. (JAS, to be submitted)

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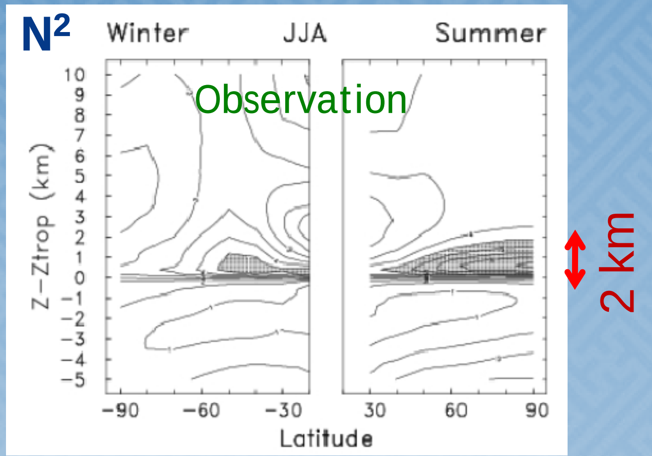
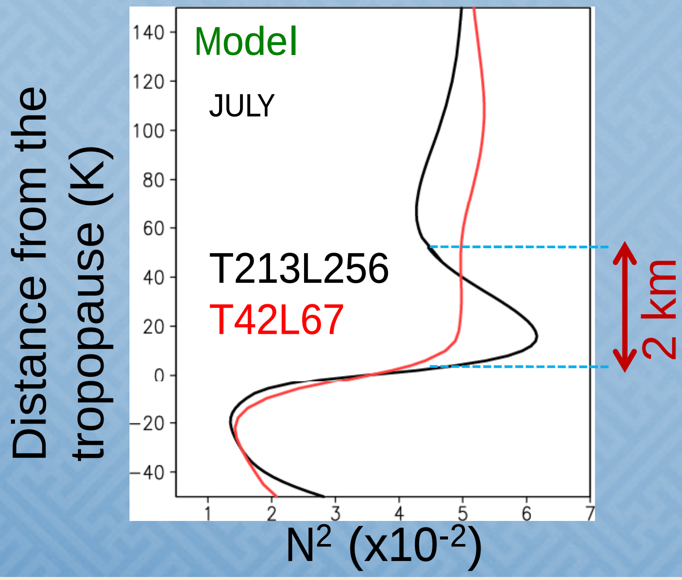
Fine structure of extratropical UTLS

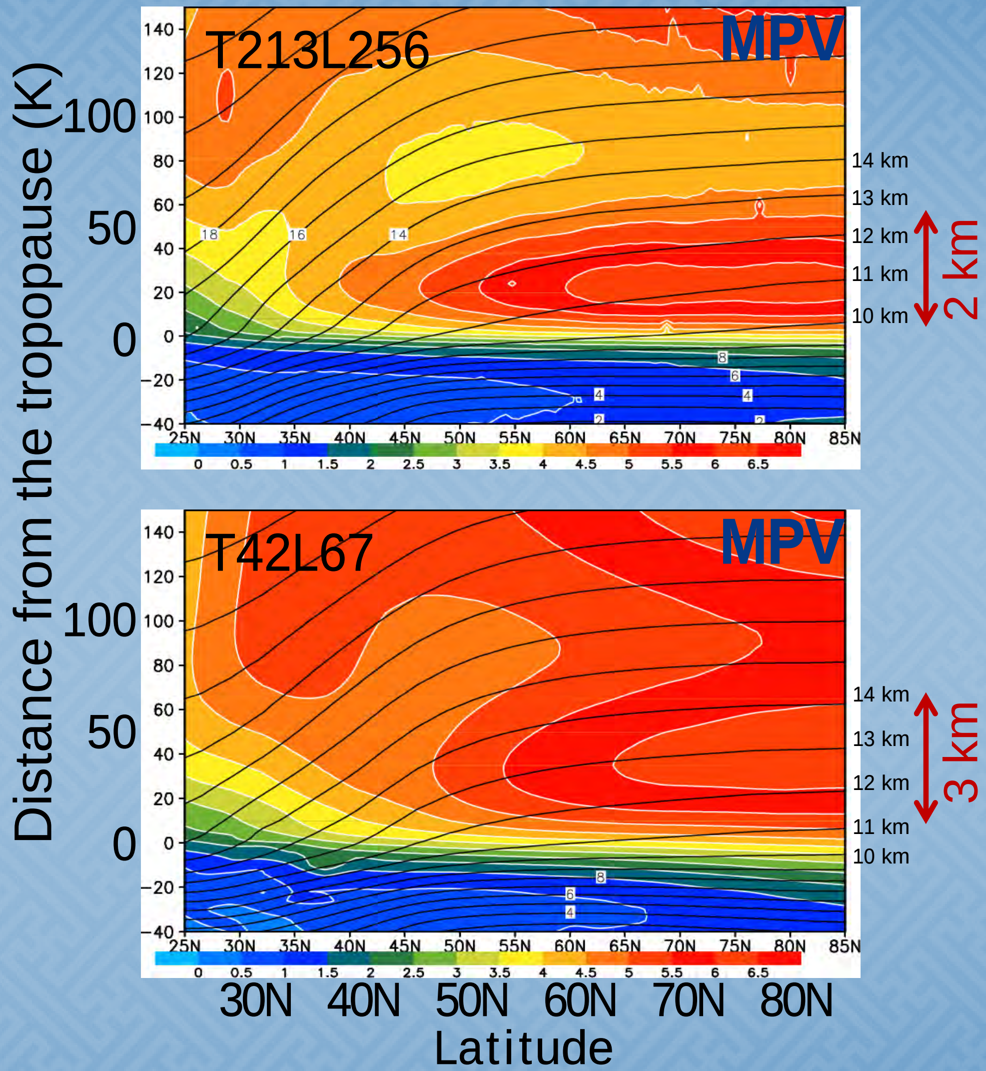
Tropopause inversion layer (TIL)



Randel et al., 2007



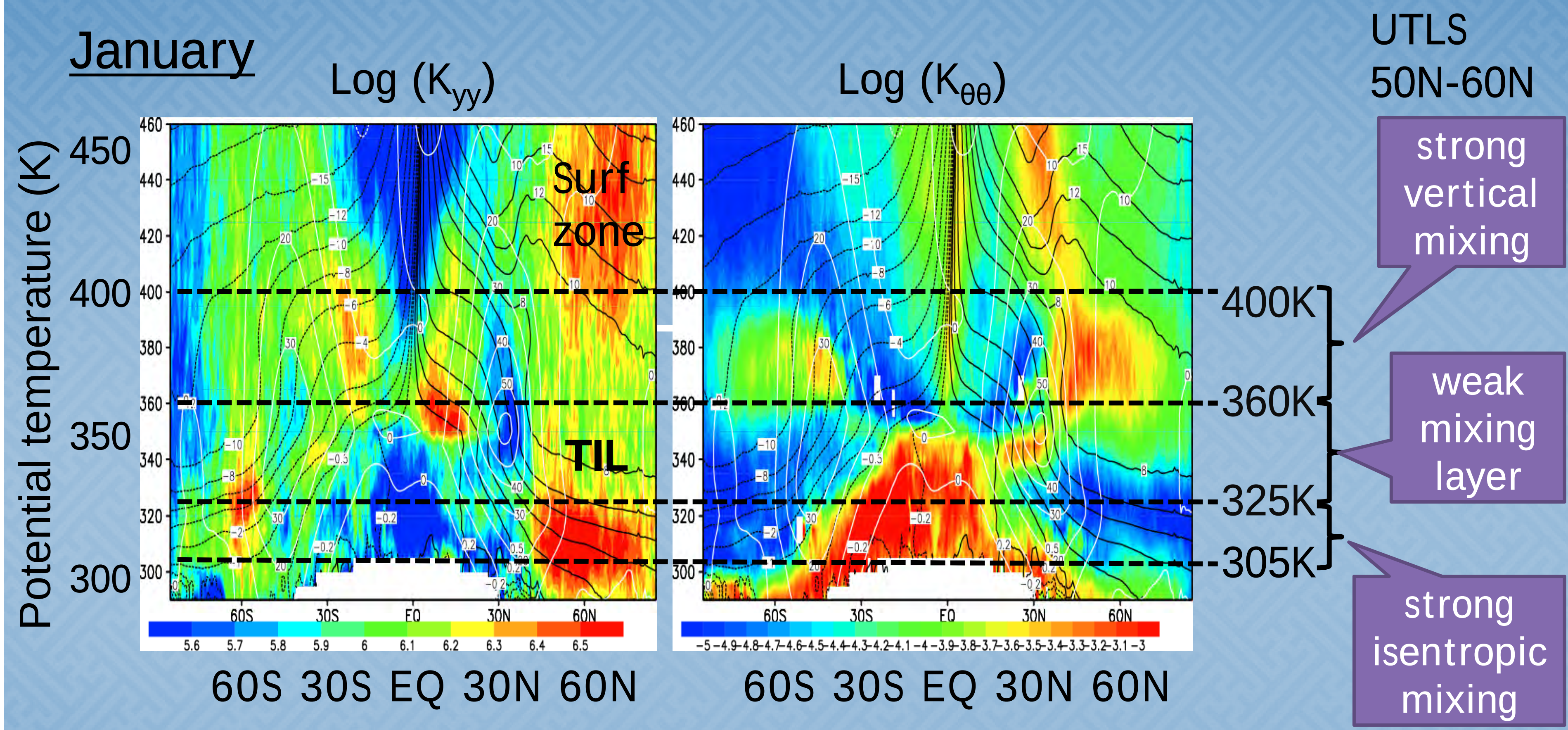
High MPV layer above the tropopause



Thermal and dynamical structures of the extratropical UTLS are realistically simulated for KANTO (T213L256) model.

Miyazaki et al. (in preparation)

Dominant Mixing processes in the UTLS region

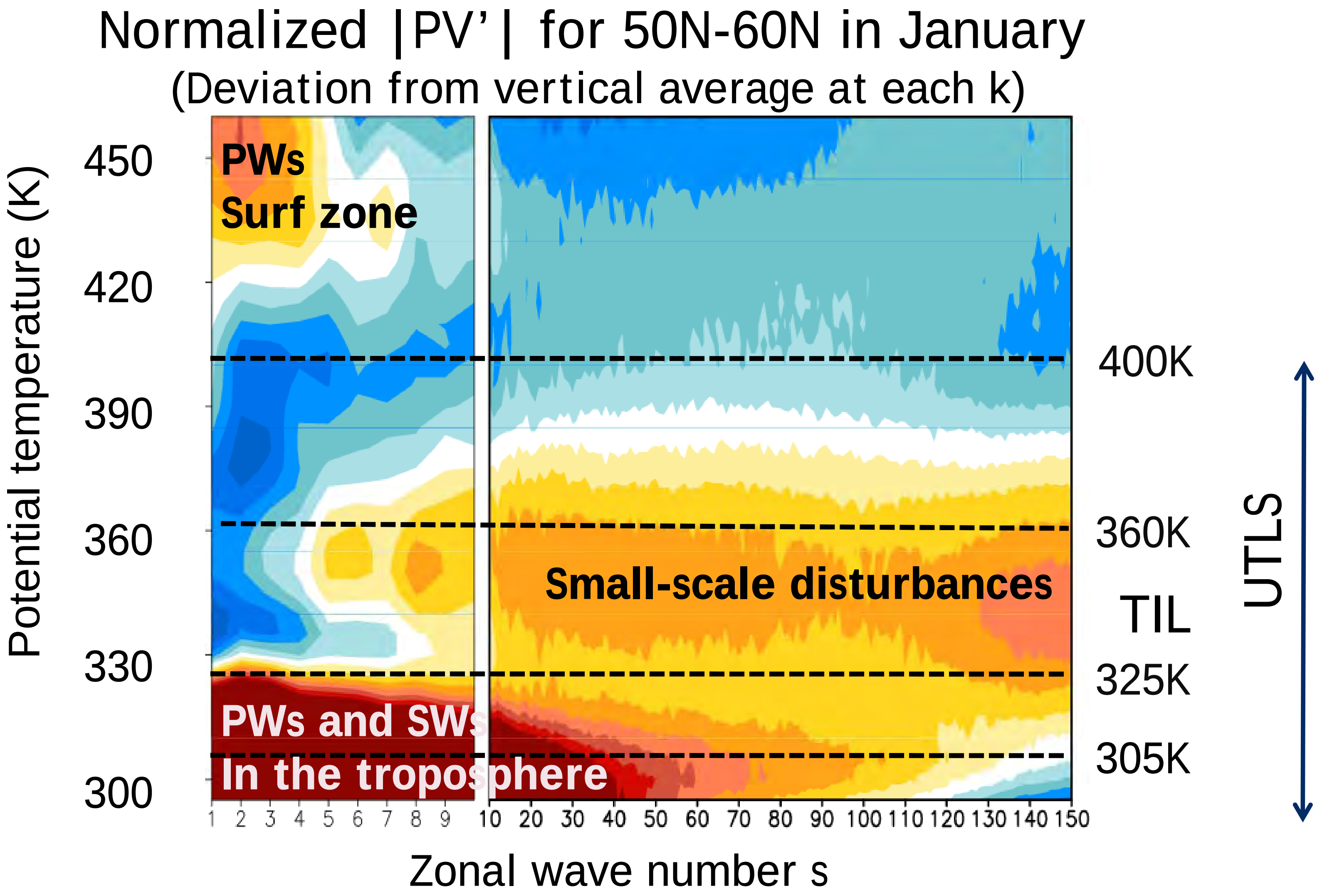


Three different mixing regions are present in the UTLS.

- Isentropic mixing is strong in the lower UTLS similar to in the surf zone.
- Diabatic mixing is strong in the upper UTLS.
- Both mixing processes are weak for TIL in the middle of UTLS.

Miyazaki et al. (in preparation)

Contribution to K_{yy} of each s component



Small-scale disturbances affect on the TIL mixing

Miyazaki et al. (in preparation)

Summary

- Based on 3-year simulation data from a gravity-wave resolving GCM, dynamics of the middle atmosphere including fine structures has been examined.
- The mean fields are realistic and a QBO-like oscillation spontaneously appears. GW characteristics are consistent with limited knowledge obtained by observations so far.
- Two latitude regions are important for GW propagation.
  - Negative u'w' in middle and high latitudes in winter
    - Topographic effects and spontaneous adjustment on the subtropical jet.
    - GWs propagating upward and poleward over the Andes in SH and Himalayan mountains in NH are important .
  - Positve u'w' in subtropical latitudes in summer
    - Convection in particular in the Indian monsoon region.

Summary - cntd.

- Existence of a temperature maximum in the winter subtropical stratopause is shown.
  - Residual circulation across the equator in the subtropical region maintains the T maximum.
  - An equatorial corridor associated with SAO easterly and a sideway effect by RW breaking are important.
- Driving force of the QBO-like oscillation is examined.
  - Westerly acceleration phase: EQWs and IGWs.
  - Easterly acceleration phase: IGWs. Contribution of EQWs are quite weak.
- Mixing characteristics in the UTLS are examined.
  - θ=360-400K: $K_{\theta\theta}$ is dominant.
  - θ=325-360K (TIL): Mixing is weak but small-scale fluctuations in PV are significant.
  - θ=305-325K: K_{yy} is dominant.

Future topics of the KANTO project

- More studies on interaction of GWs and the mean fields.
- More studies of gravity waves
  - Spectral characteristics
  - Gravity waves in polar regions and monsoon regions.
- More studies of mixing and transport processes in the UTLS
- Studies of the other kinds of small-scale disturbances
  - Trapped Rossby waves on the subtropical tropopause and the polar vortex.
  - Inertial instability in the equatorial and subtropical regions.
- Dynamics of the SAO and connection with the QBO
- Re-interpretation of satellite observations
- Improvement of GW parameterizations