Interannual variation of zonal mean state and mean meridional circulation

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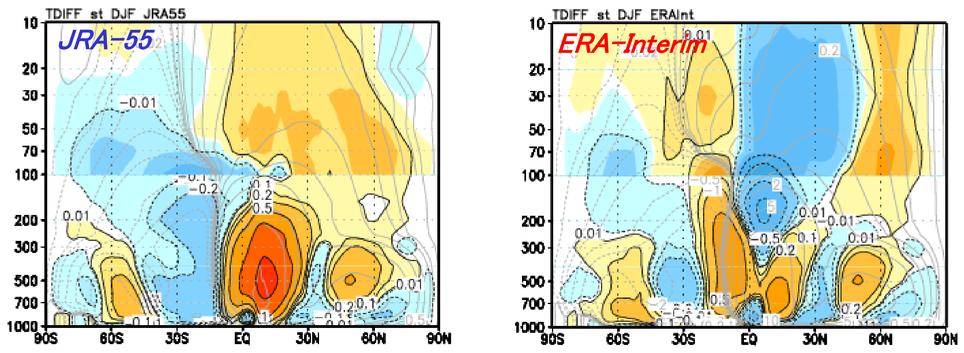
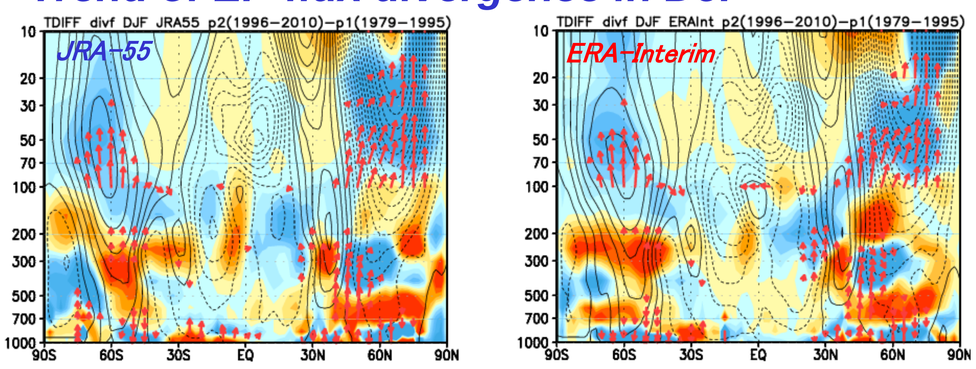
Motivation:

Trend of mass streamfunction in DJF



•Meridional circulation trend pattern in JRA-55 is different from that in ERA-Interim.

Trend of EP-flux divergence in DJF



•EPFD trend in JRA-55 is similar to that in ERA-interim.

Difficult to explain meridional circulation trend by wave interaction trend. How is the ENSO signal?

Summary

•The zonal mean climate variability associated with ENSO and its formation mechanism are investigated in relation to wave-mean flow interactions using reanalysis datasets.

•Narrowing of the Hadley circulation, strengthening of the extra-tropical direct circulation, and consistent modulation of the EP flux divergence are confirmed as features of the ENSO signal.

•The wave propagation modulations in the mid latitude lower troposphere are probably induced by baroclinicity modulation in the subtropical lower troposphere. They contribute to enhancing the extratropical meridional circulation.

•EP flux divergence signal in the subtropics upper troposphere, and the EP flux in the mid-latitude indicates poleward propagation anomalies in the upper troposphere.

•This anomaly contributes weakening of the equatorward wave propagation, narrowing of the Hadley circulation and to maintenance of westerly wind strengthening on the equatorward flank of the subtropical jet.

Data and Method

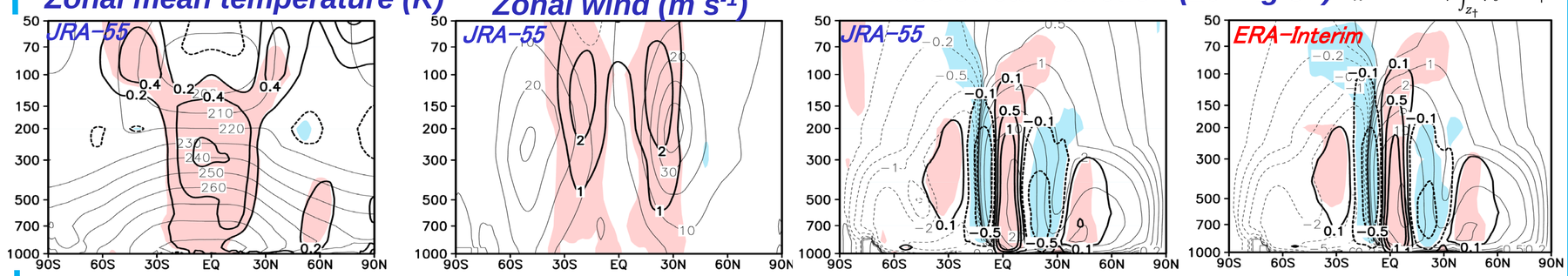
•Atmospheric reanalysis:
JRA-55[Kobayashi et al., 2015]
ERA-Interim[Dee et al., 2011],
•Climatology period: 1981-2010
•Residual mean-meridional circulation diagnosed from the mass-weighted isentropic zonal mean (MIM) meridional velocity [Iwasaki, 1989].
•Regression analysis using NINO3 index.
•Statistical period: 1979-2016

$$F \equiv a\,\rho_0 \cos\phi \begin{bmatrix} -\overline{(u'v')^*}, \\ -\overline{(u'w_\dagger')^*} + \dfrac{1}{ag\rho_0\cos\phi} p \overline{\left[\dfrac{\partial\Phi}{\partial\lambda}\right]_{z_\dagger}} \end{bmatrix}$$

Result : ENSO signal of zonal mean field and mean meridional circulation

JFM mean Zonal mean anomalies regressed on to the JFM mean NINO3 index (thick line),

Zonal mean temperature (K) | Zonal wind (m s^{-1}) | Mass streamfunction (10^{10}kg s^{-1}) $\chi = 2\pi a \cos\phi \int_{z_\dagger}^{\infty} \rho_0 \overline{v^*} dz_\dagger$



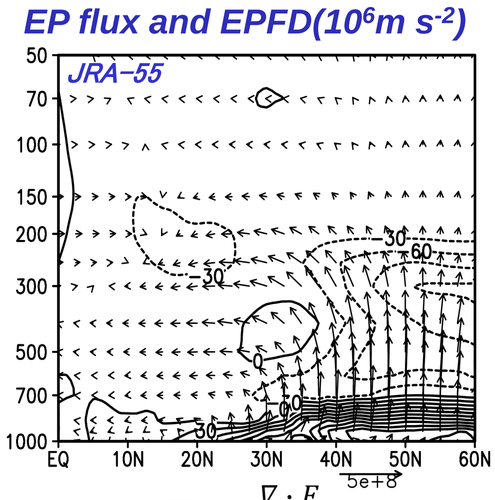
Shading :95% significance level of the t statistic. Zero contours of regression are omitted.

•Warming in the upper-tropical troposphere

•Strengthening of the upper flank of the subtropical jets

▪Narrowing of Hadley cell
▪Enhancing the extratropical meridional circulation

Climatology over NH EP flux and EPFD(10^6m s^{-2})

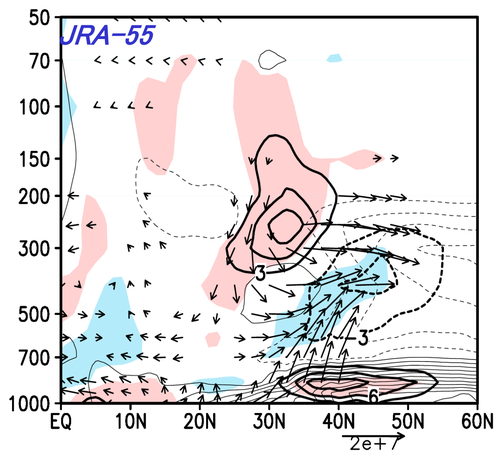


$$0 \sim f\overline{v^*} + \frac{\nabla \cdot F}{a\,\rho_0 \cos\phi}$$

Equilibrium condition

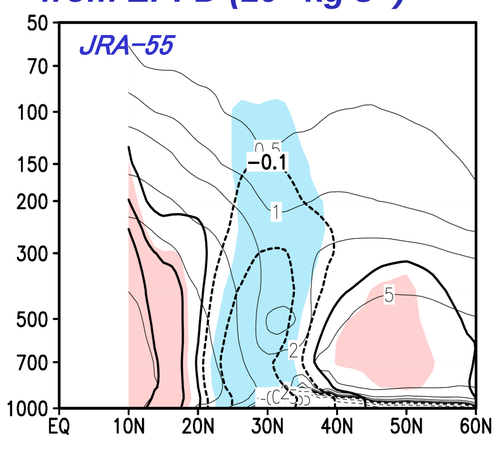
EPFconv corresponds poleward wind

EP flux and EPFD(3x10^{-6}m s^{-2})



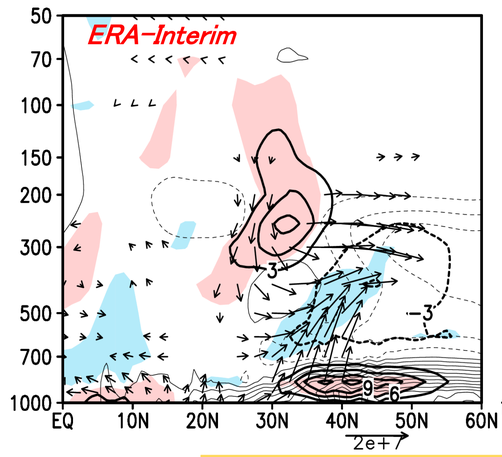
•Upward EPFz anom: lower trop
•Polerward EPFy anom: upper trop

Mass streamfunc estimated from EPFD (10^{10}kg s^{-1})

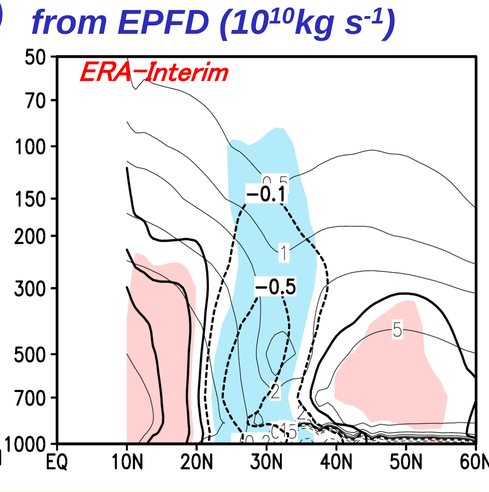


•ENSO signal of mass streamfunction estimated from EPFD shows consistent feature with original one.

EP flux and EPFD(3x10^{-6}m s^{-2})



Mass streamfunc estimated from EPFD (10^{10}kg s^{-1})



Interannual variation shows common features between the two reanalyses.

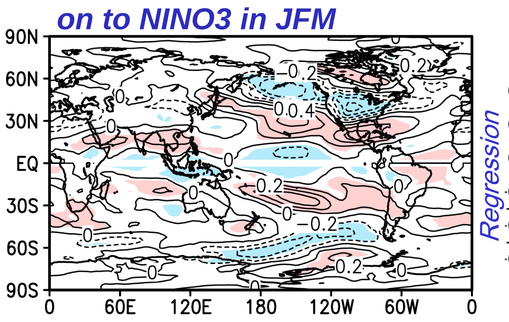
-> Robust Result !

Discussion : Why does the EPFz increase in mid-latitude lower troposphere?
Relation between upward EPFz anomaly and baroclinicity

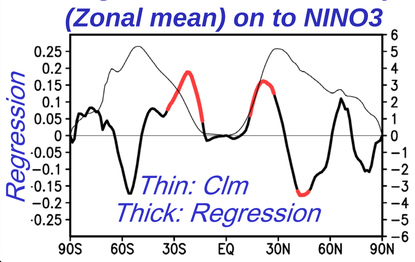
Baroclinicity (Eady growth rate Maximum) (Hoskins and Valdes, 1990)

$$\sigma_E = 0.31 \frac{1}{N} |f| \frac{(u_{500} - u_{850})}{(z_{500} - z_{850})}$$

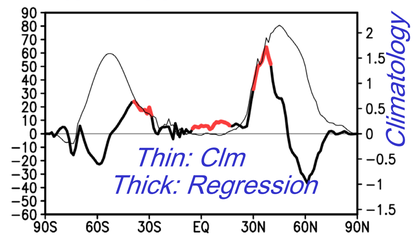
Regression of baroclinicity on to NINO3 in JFM



Regression of baroclinicity (Zonal mean) on to NINO3

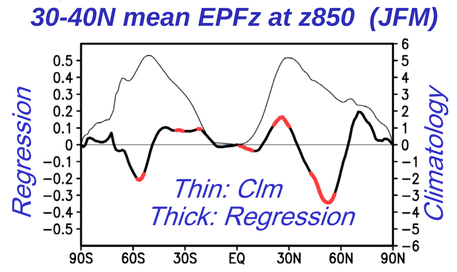


Regression of EPFz at 850hPa onto NINO3



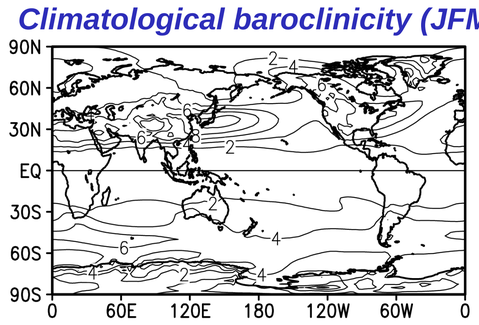
Red: 95% significance level

regression of baroclinicity on to 30-40N mean EPFz at z850 (JFM)



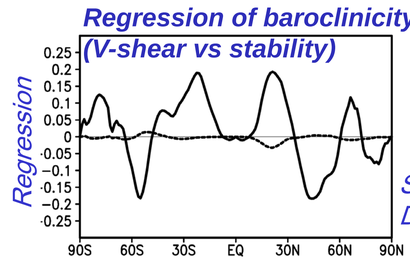
•Variation of 30N-40N mean EPFz at 850hPa is well correlated with baroclinicity in subtropics.

Climatological baroclinicity (JFM)



•ENSO signal of baroclinicity is large in subtropics.

Regression of baroclinicity (V-shear vs stability)



Solid: vertical wind shear
Dash: static stability

These relation suggest following process is working.

1. Meridional thermal gradient is enhanced in subtropics during ENSO warm phase.
2. Baroclinicity increases in subtropics lower troposphere.
3. Baroclinic wave is growing in 30N-40N and propagate upward.
4. EP-flux divergence anomalies are created in the mid latitude.