Do sudden stratospheric warmings boost convective activity in the tropics?

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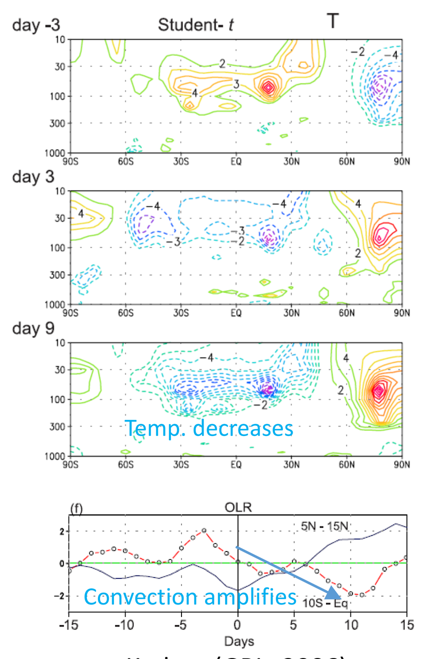
Introduction

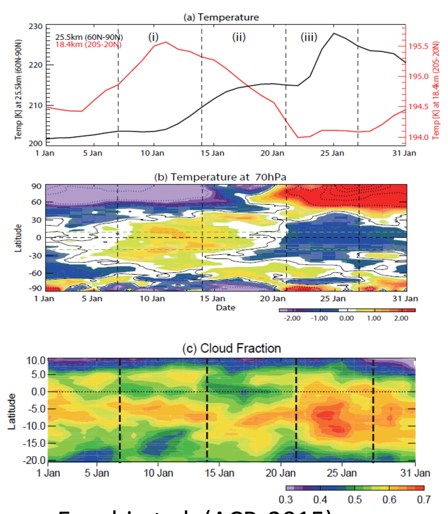
Recent studies have shown robust relationships in tropical stratosphere-troposphere coupling especially in QBO-MJO (e.g., Yoo & Son, 2016; Marshall et al., 2017; Nishimoto & Yoden, 2017; Son et al., 2017; Lim et al., 2019), partly thanks to historical data accumulation and model development. Influence of a stratospheric circulation change related to sudden stratospheric warming (SSW) on the tropical troposphere is examined many previous studies (e.g., Kodera, 2006; Eguchi et al., 2015). However, SSW is low frequent and short period phenomena, so that to separate the influence of SSWs on tropical troposphere from the internal tropospheric variation, analysis by use of large sample number is needed.

In this study, we examine impact of the stratospheric circulation change related to SSW on the tropical troposphere using large ensemble simulations with a 60 km global atmospheric model MRI-AGCM3.2 (d4PDF).

S-T coupling in the tropics: SSW-tropical convection



Kodera (GRL, 2006)
NCEP/NCAR Composite

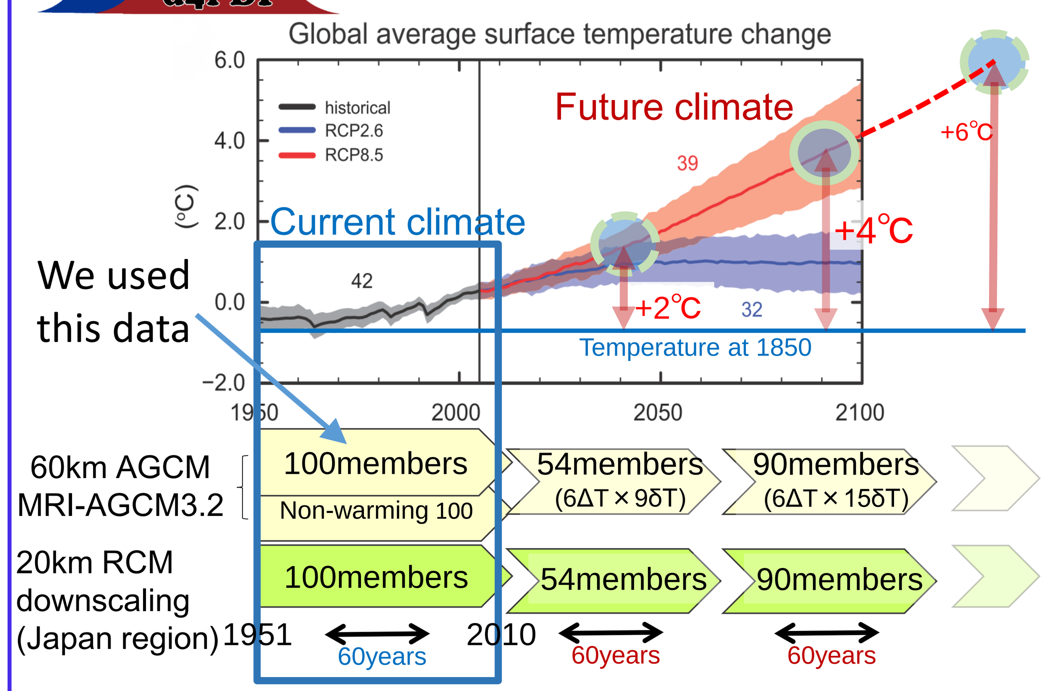


Eguchi et al. (ACP, 2015)
Non-hydrostatic model (NICAM) study (1 event)

- During SSWs, large scale meridional circulation induces upwelling and temperature decreasing in the tropical stratosphere.
- Cumulus convection amplifies in SH

d4PDF

d4PDF: database for Policy Decision making for Future climate change (Mizuta et al., BAMS, 2017)



Data information

Dataset name	d4PDF* (Mizuta et al., BAMS, 2017)
Model name	MRI-AGCM3.2H
Horizontal resolution	TL319 (~60km)
Vertical resolution	64 levels (top at 0.01hPa)
Period & Ensemble	1951-2010, 100 member (6000 years)
Perturbation for Ens.	Initial value and small perturbation of SST
Cumulus convection	Yoshimura et al. (2014) (Tiedtke-based)
SST + Sea ice	COBE-SST2

*Database for Policy Decision making for Future climate change

- Five day mean anomaly, which is departure from daily climatology and 41-day mean, is used in this study.
- No QBO due to lack of nonorographic GWD
- TC tracking method: Murakami et al. (Clim. Dyn., 2012)
- d4PDF is published data and includes scenario of future (+2 K and +4 K) and non-global warming climate. Please check "d4PDF".

Selecting SSW-related tropical upwelling events

1. From December to March, 50 hPa tropical upwelling (averaged over 20S-20N) is maximum for ± 20 days and larger than 0.1 mm/s.
2. Large deceleration* (< -2.0 m/s/day) of zonal mean U averaged over 50-70N occurs at 10, 3, or 1 hPa up to 10 days before the date of [1].
3. Strong tropical upwelling (larger than 0.1 mm/s) between 30 and 1 hPa also occurs in 5 days before and after the date of [1].

Total [1] events: 9590	$\overline{w}$*(30-1hPa) ≧ 0.1 mm/s	$\overline{w}$*(30-1 hPa) < 0.1 mm/s
∂U/∂t* (10-1 hPa) ≦ -2.0 m/s/day	6117 Use these events	1176
∂U/∂t (10-1 hPa) > -2.0 m/s/day	973	1324

*Zonal wind deceleration is calculated from the difference between two seven-day mean values of U (50-70N) spaced over eight days (similar method to Kodera, 2006)

Why is tropical upwelling metric used?

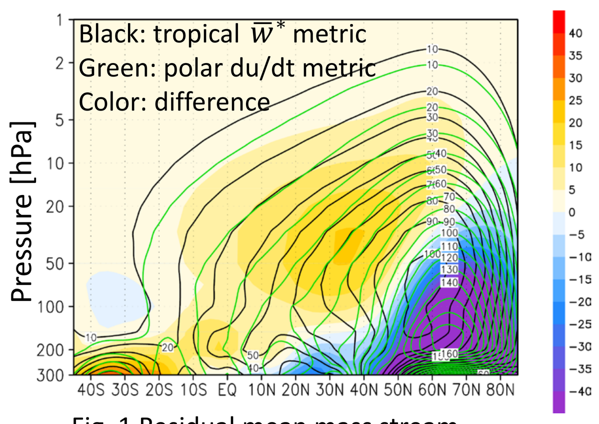


Fig. 1 Residual mean mass stream function anomaly (day 0)

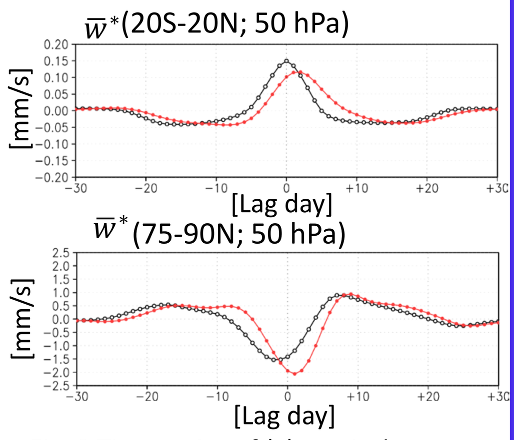
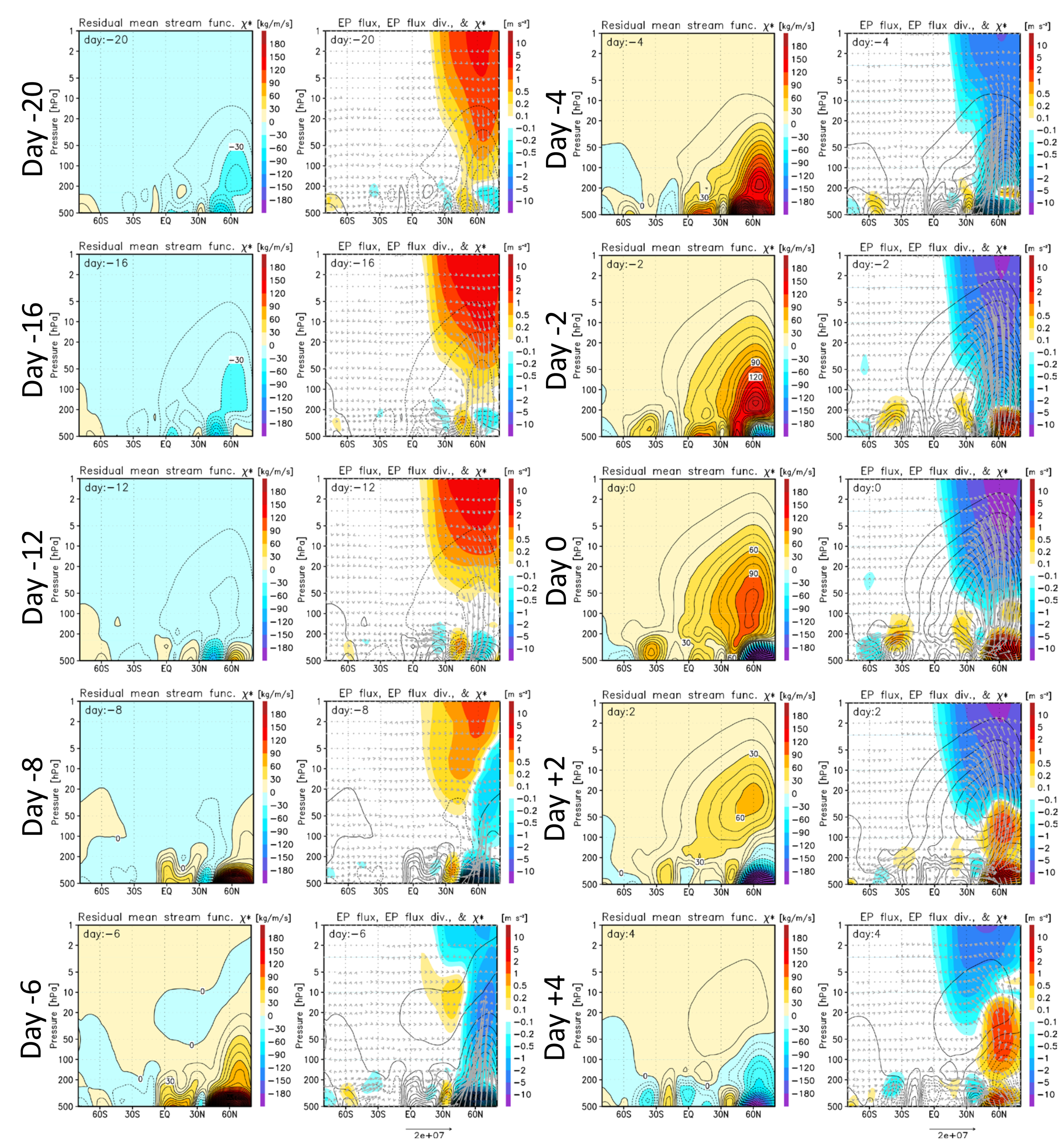


Fig. 2 Time series of (a) tropical upwelling and (b) time change rate of zonal mean zonal wind. Black (red) indicates w* (du/dt) metric.

- Tropical upwelling at 50 hPa is a suitable metric for tropical upwelling event related to large stratospheric meridional circulation.
- du/dt (50N-70N) metric tends to extract polarly gathered meridional circulation.

According to their amplitudes, phases of tropical upwelling peak and polar downwelling peak do not match well.

Wave forcing and meridional circulation



[Day -12] Downward EP flux anomaly in extratropical stratosphere and equatorward EP flux convergence in subtropical troposphere.

[Day -8] tropical upwelling occurs in troposphere and upward EP flux anomaly onset.

[Day -6] EP flux convergence and clockwise meridional circulation occurs in the extratropical troposphere and stratosphere

[Day -4] The meridional circulation widely spreads in NH stratosphere and troposphere. Tropical upwelling in the troposphere is further enhanced and reaches its peak.

[Day 0] Strong EP flux convergence and meridional circulation in the stratosphere. EP flux divergence in the extratropical troposphere.

[Day +2] EP flux convergence and meridional circulation in the stratosphere shrinks gradually.

Fig. 3 Meridional distribution of (left) residual mean mass stream function and (right) (vector) EP flux, (color) EP flux divergence anomalies, and (contour) same as left from lag -20 to +4 day.

Is convective activity amplified during SSW?

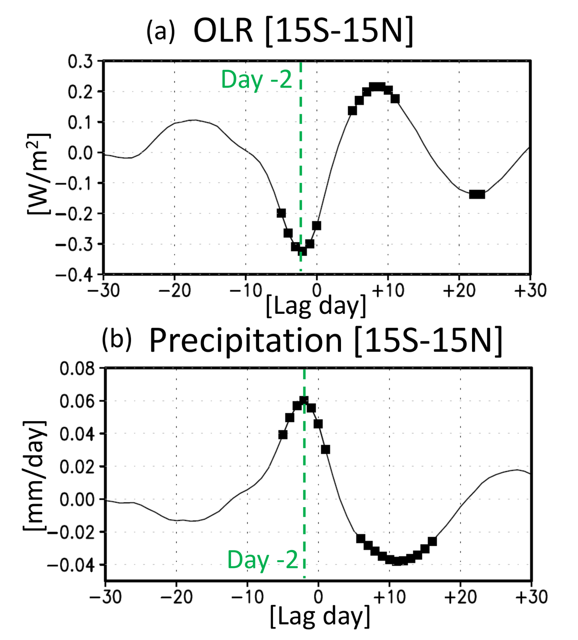


Fig. 5 Time series of (a) Outgoing Long wave radiation and (b) precipitation averaged over 15S-15N. Black squares indicate 99% significant level

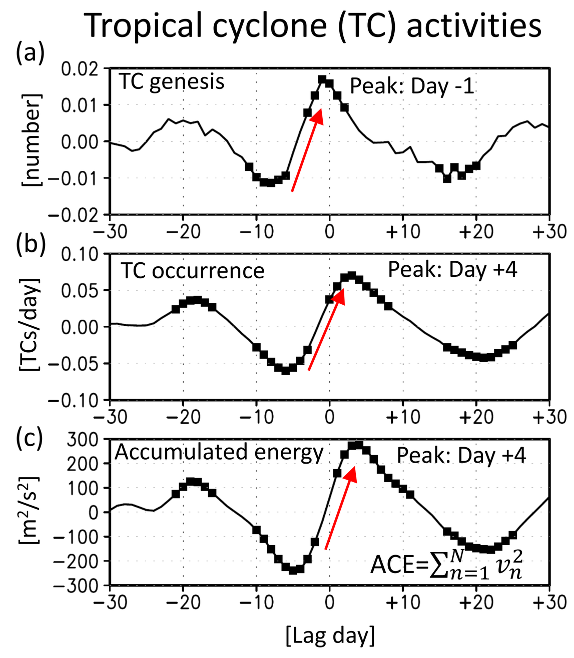


Fig. 6 Time series of (a) tropical cyclone (TC) genesis number (b) TC occurrence frequency, and (c) accumulated TC energy (ACE). Black squares indicate 99% significant level

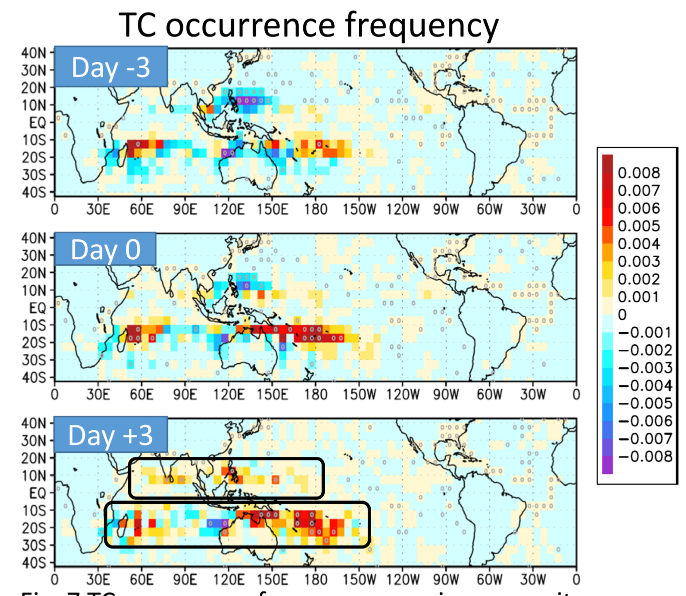


Fig. 7 TC occurrence frequency map in composite days (a) day -3, (b) day 0, and (c) day +3. Grey dots indicate 99% significant level

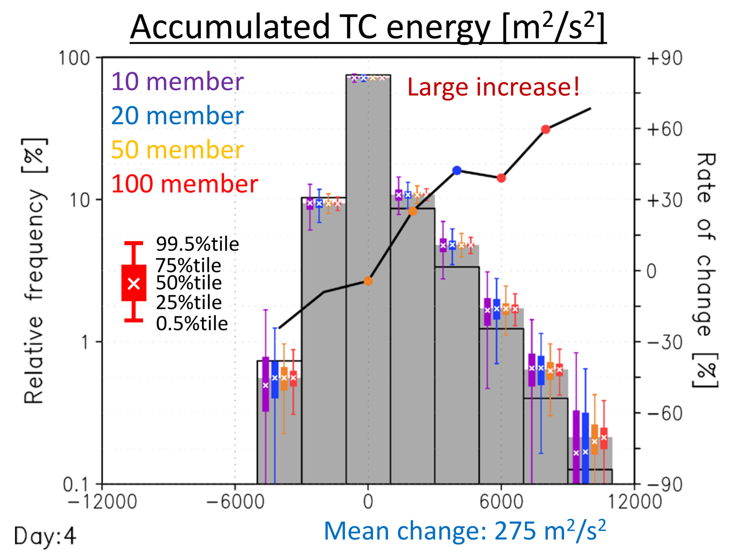


Fig. 8 Relative probability distribution of accumulated TC energy. Black bars are relative freq. in all simulation days in DJFM, gray bars are relative freq. in All SSW events (Day: 4), and black line is proportional rate [%; right axis]. Error bars are calculated from 1000 sets of corresponding number of ensembles chosen by the bootstrap method. Color dot of black line means 99% statistically significant in corresponding ensemble members.

Wave forcing, tropical upwelling, and static stability

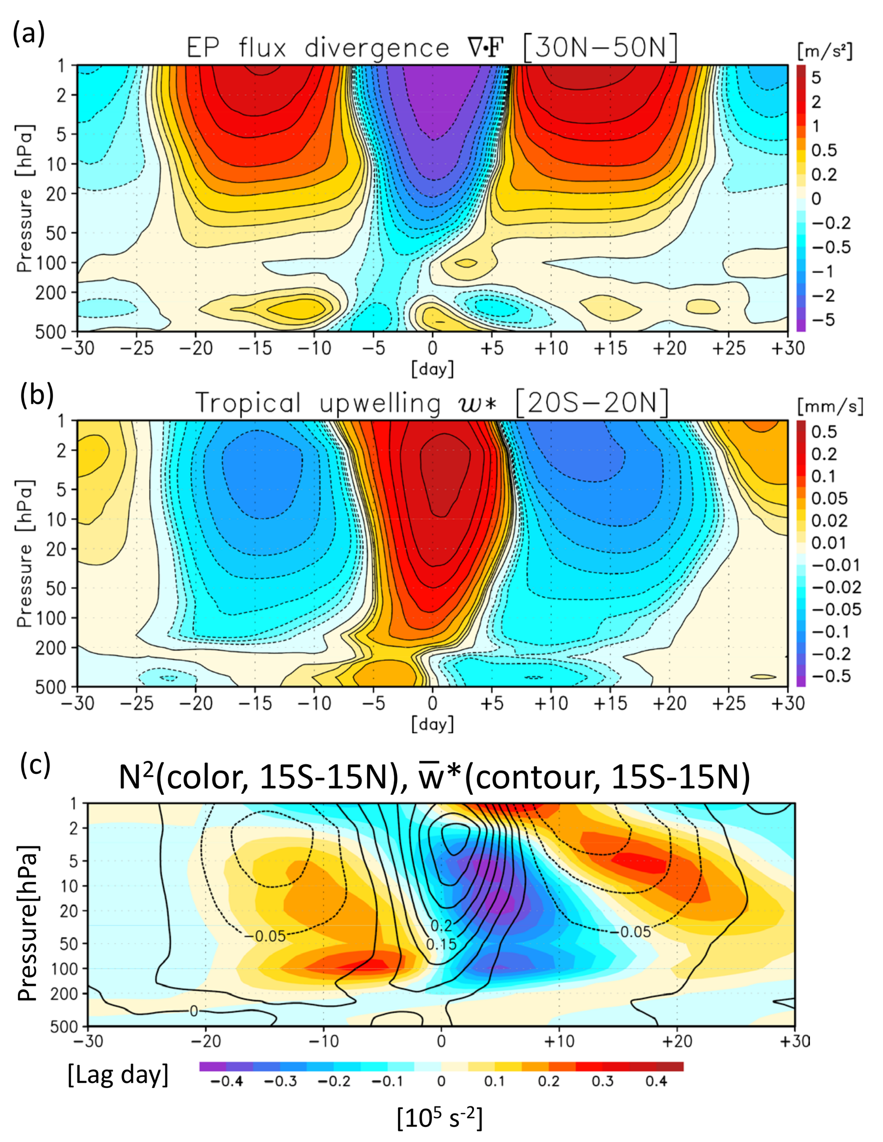


Fig. 4 Time-height cross section of (a) EP flux divergence averaged over 30N-50N, (b) residual mean vertical velocity averaged over 20S-20N, and (c) (color) static stability (contour) same as (b).

- EP flux divergence anomalies averaged over 30N-50N largely explain time evolution of tropical upwelling.
- EP flux convergence upwelling in the troposphere precedes that in the stratosphere.
- Tropical upwelling in the stratosphere and upper troposphere decreases temperature and reduces static stability.

- Tropical mean OLR and precipitation amplify and reach their peaks on day -2 (Fig. 5).
- TC genesis number (peak day -1), TC occurrence frequency, and accumulated TC energy (peak day +4) are also enhanced during SSW events (Fig. 6).
- TC occurrence frequency increases in the western Pacific and southwestern Indian Ocean (Fig. 7).

- Although statistically significant differences are shown in convection related variables, their amplification is small (e.g., S/N ratio ~0.1 in TC related metrics).
- Large increase (more than 30% increase) occurs in probability of extreme TC activity events (> 3000 m²/s², Fig. 8).

Summary

- During SSW events (6117 events), associated with strong wave dissipation in the extratropical stratosphere, tropical upwelling is induced in both stratosphere and troposphere.
- Around upwelling peak, cumulus convection related variables like OLR, precipitation, and tropical cyclone activities amplify in whole tropics (statistically significant but low S/N ratio).
- Relative probability in extreme TC activity events (e.g., high accumulated energy events) increases significantly (more than 30 % increase).

Future work

Large ensemble simulation study brings many findings. However, there is a question "is cumulus convection signal due to SSW quantitatively realistic?"

- As seen in seasonal NAO prediction, models tend to underestimate S/N ratio.
- Vertical resolution of this model (MRI-AGCM3.2H) might not enough, and QBO is not driven spontaneously.
- Difficulty to reproduce very intense tropical cyclone (Category 4-5)
- Better models might bring better (higher?) estimation of S/N ratio.