Spatial distribution and the interdecadal change of leading modes of heat budget of the mixed-layer in the tropical Pacific and the association with ENSO

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Objects:

(1) What are the ***leading modes*** of ocean mixed-layer heat budget terms in GODAS in the tropical Pacific and the association with ENSO?

(2) What are ***interdecadal changes*** of these leading modes and their association with ENSO?

Main Approaches:

(1) Use combined-EOF (cEOF) including 6 terms (Qu, Qv, Qw+Qzz, Qq, Total, and observed SST tendency) to identify the leading modes of the 6 terms in the whole period (1979-2010), 1979-1999, 2000-2013, to examine the leading modes and their interdecadal changes.

(2) By calculating lead-lag correlations of the PC1/PC2 with different variables to examine the connection of the leading modes with ENSO and the interdecadal changes.

Data:

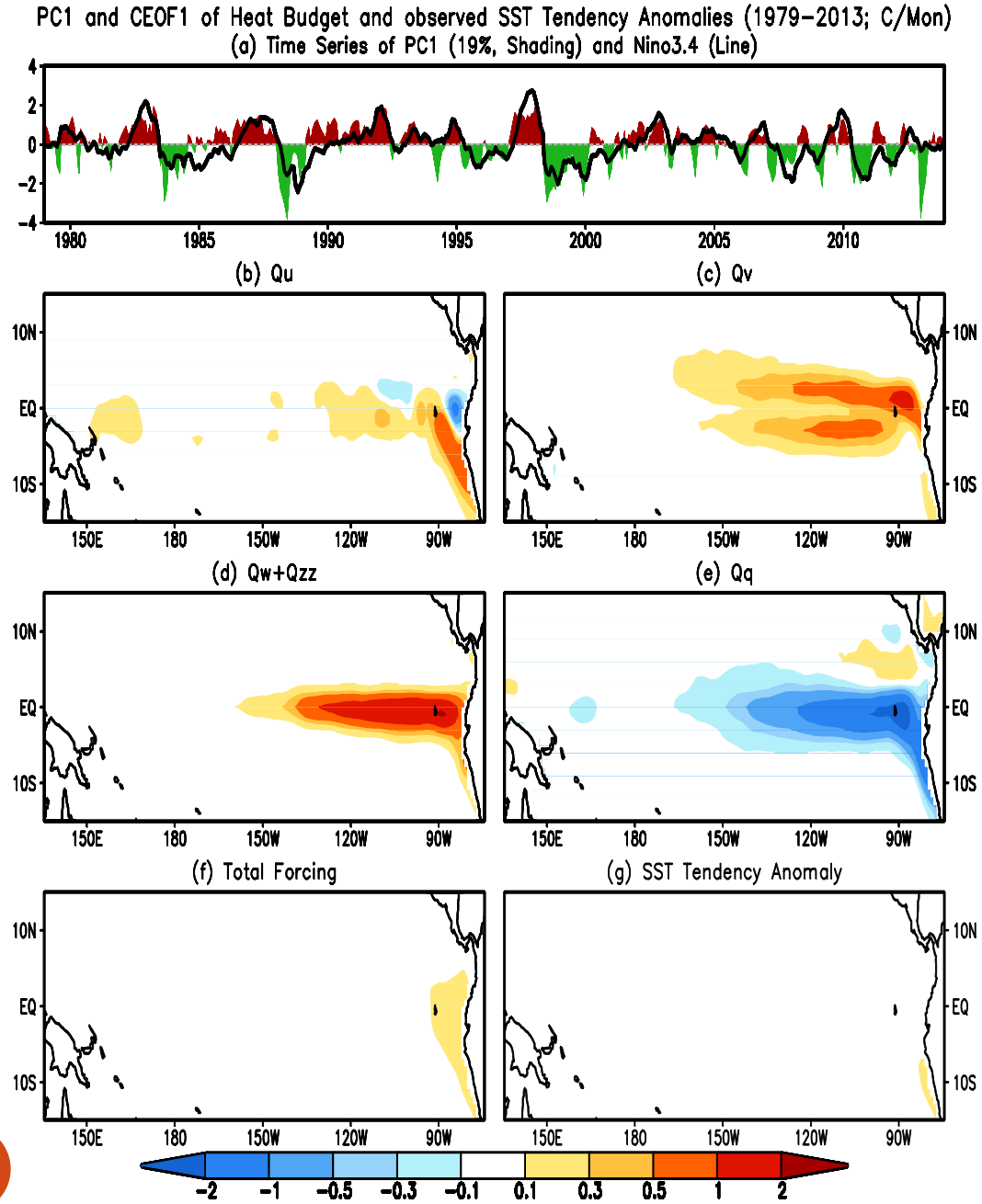
(a) The main dataset used in this work is the heat budget diagnosis of ocean mixed layer (Huang et al. 2010) from GODAS. The tendency of ocean temperature of the ocean mixed layer is defined as:

$$\frac{\partial T}{\partial t} = Q_u + Q_v + Q_w + Q_{zz} + Q_q + R$$

Where, $\partial T/\partial t$ is the tendency of mixed layer ocean temperature. Q_u is zonal advection, Q_v is meridional advection, Q_w is vertical entrainment, Q_{zz} is vertical diffusion, and Q_q is adjusted surface heat flux. The adjusted surface heat flux (Q_q) is the net surface heat flux plus heat flux correction (introduced by a relaxation of model SST to observed SST) minus the penetrative shortwave radiation. The sum of all Q terms is referred to as total forcing in this work. R is the residual term, which contains the effect of horizontal heat diffusion and the contributions of the sub-monthly processes.

(b) Surface wind stress from R2, and the depth of 20°C isotherm (D20), ocean temperature and current from GODAS.

1: Leading patterns for the whole period: 1979-2013



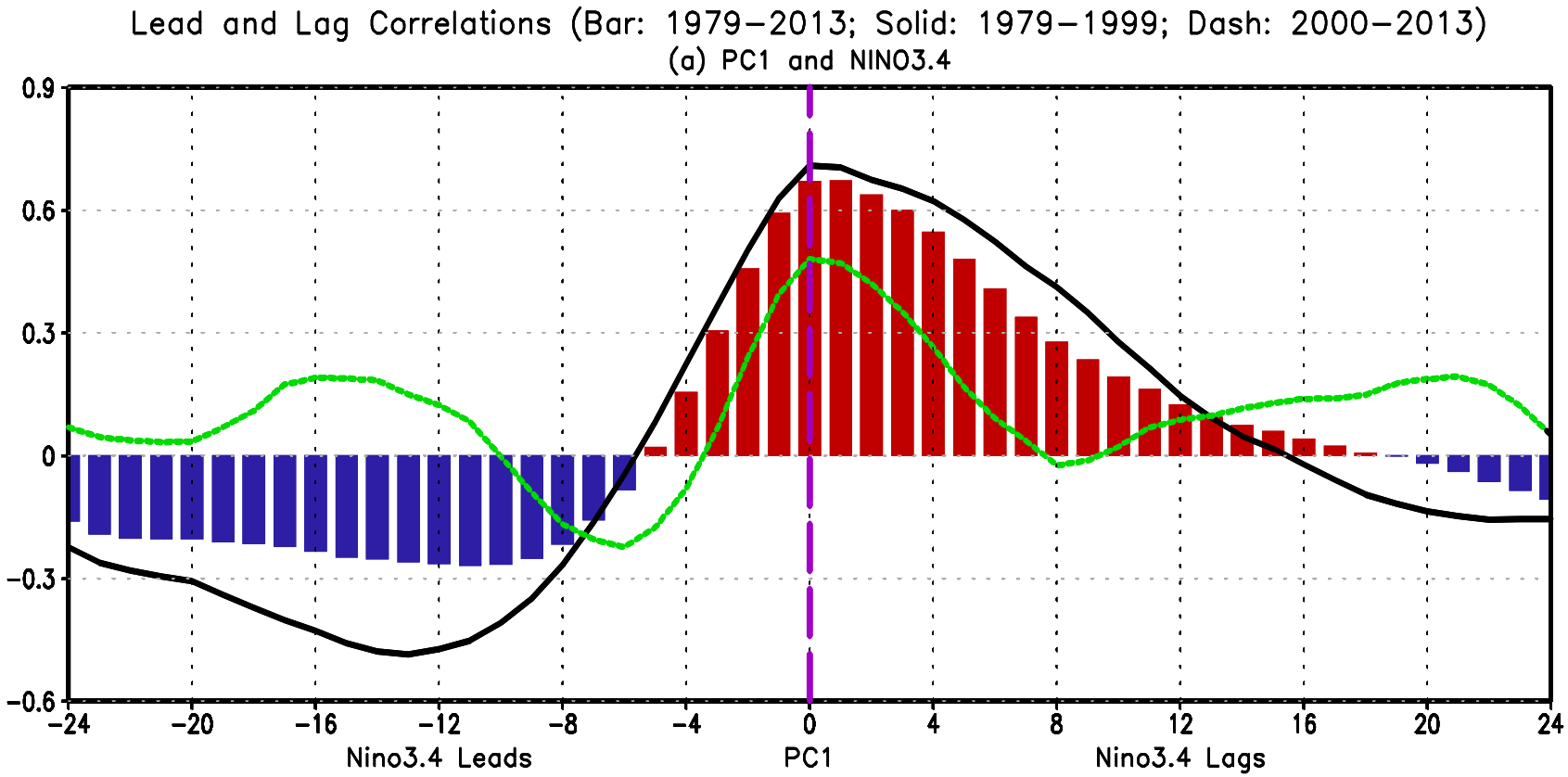
cEOF1: Peak phase of ENSO

(a) both total forcing and SST tendency are small.

(b) Qu, Qv, Qw+Qzz (Qq) are positive (negative), suggesting that peak phase occurs while the dynamical and thermodynamic contributions are in balance.

© maximum values are along the equator for Qu, Qw+Qzz, Qq, off-the-equator for Qv.

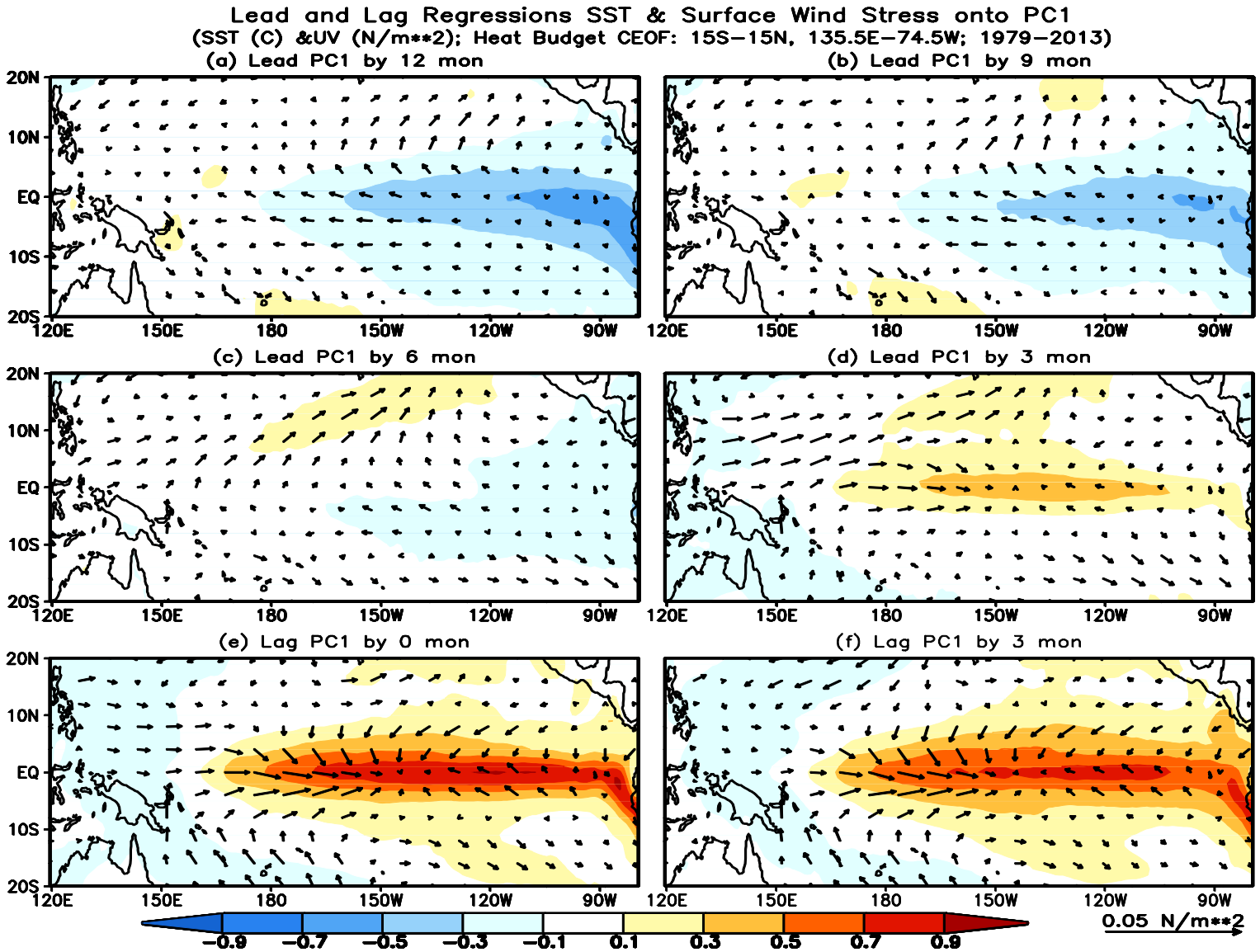
(d) variability of PC1 became smaller after 2000, consistent with our (JC, 2013) and others previous works.



cEOF1: Peak phase of ENSO:

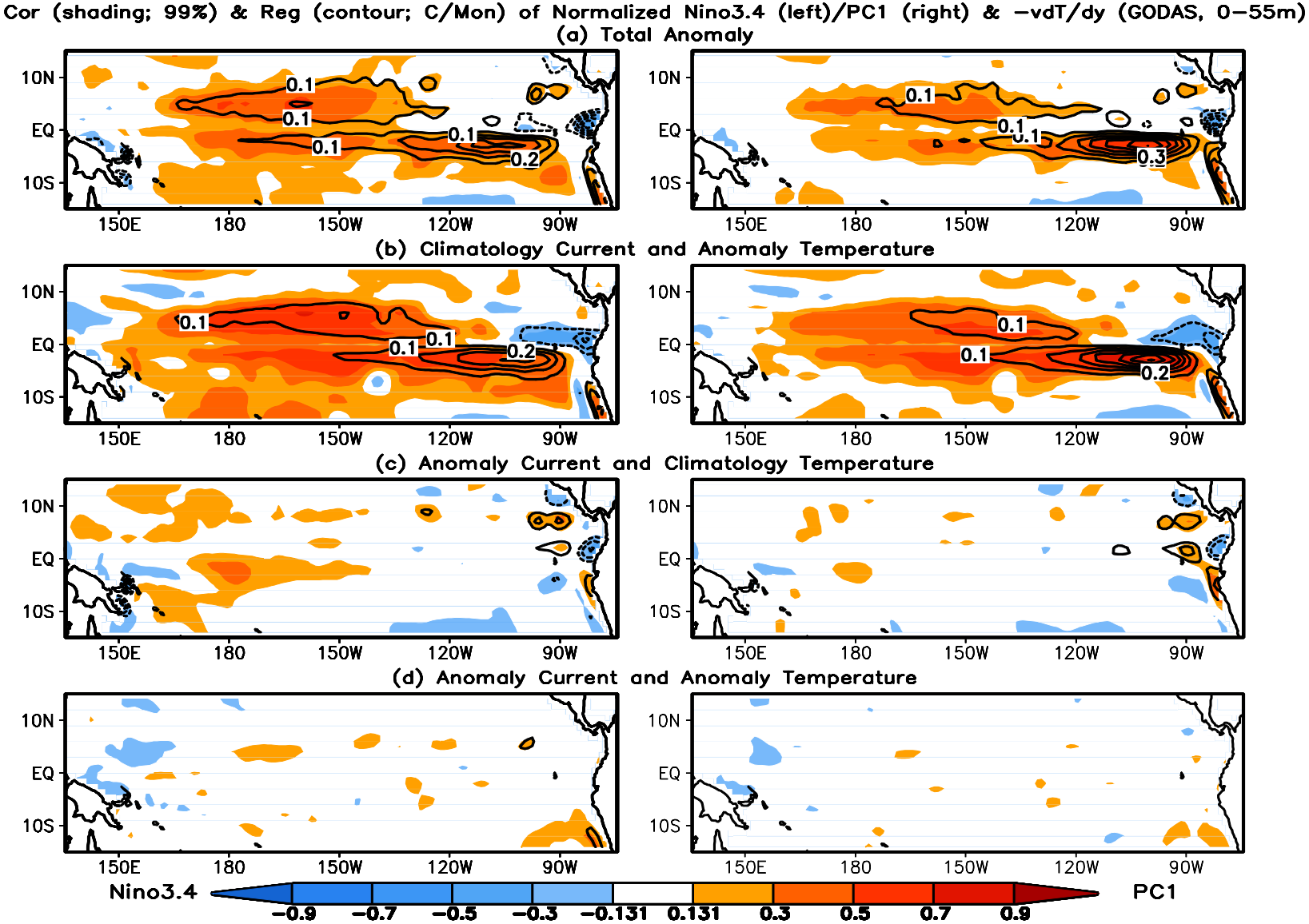
Maximum correlation presents when Nino3.4 lags PC1 by 0-1 month

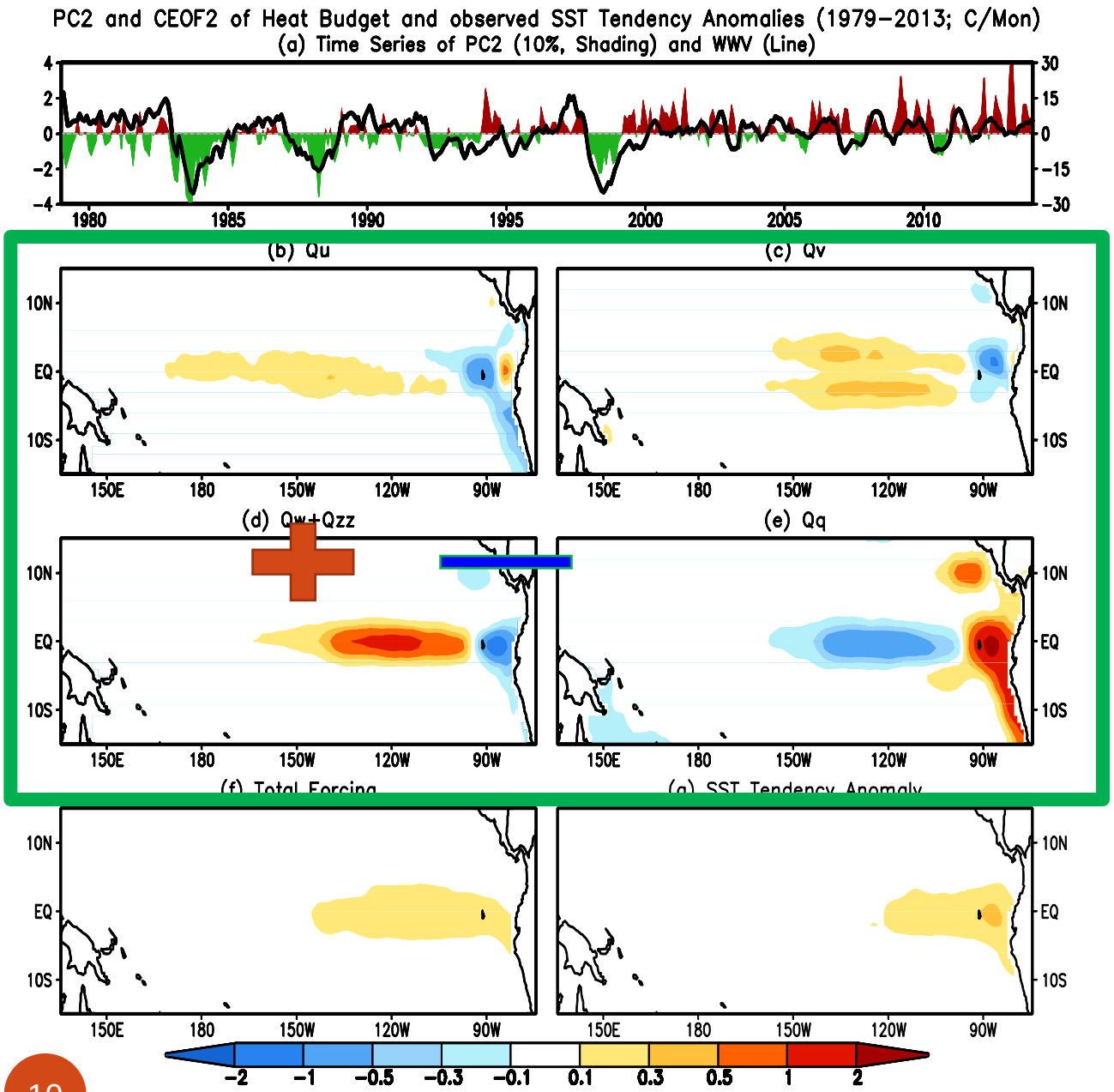
cEOF1 is tied up ENSO peak phase and associated with Bjerknes feedback processes (SST and wind stress anomaly regressions onto PC1)



Unique role of Qv: expand the SSTA in meridional direction

(Qv anomaly was mainly determined by advection of anomalous T by climatological meridional current and tended to broaden the ENSO SSTA pattern meridionally)





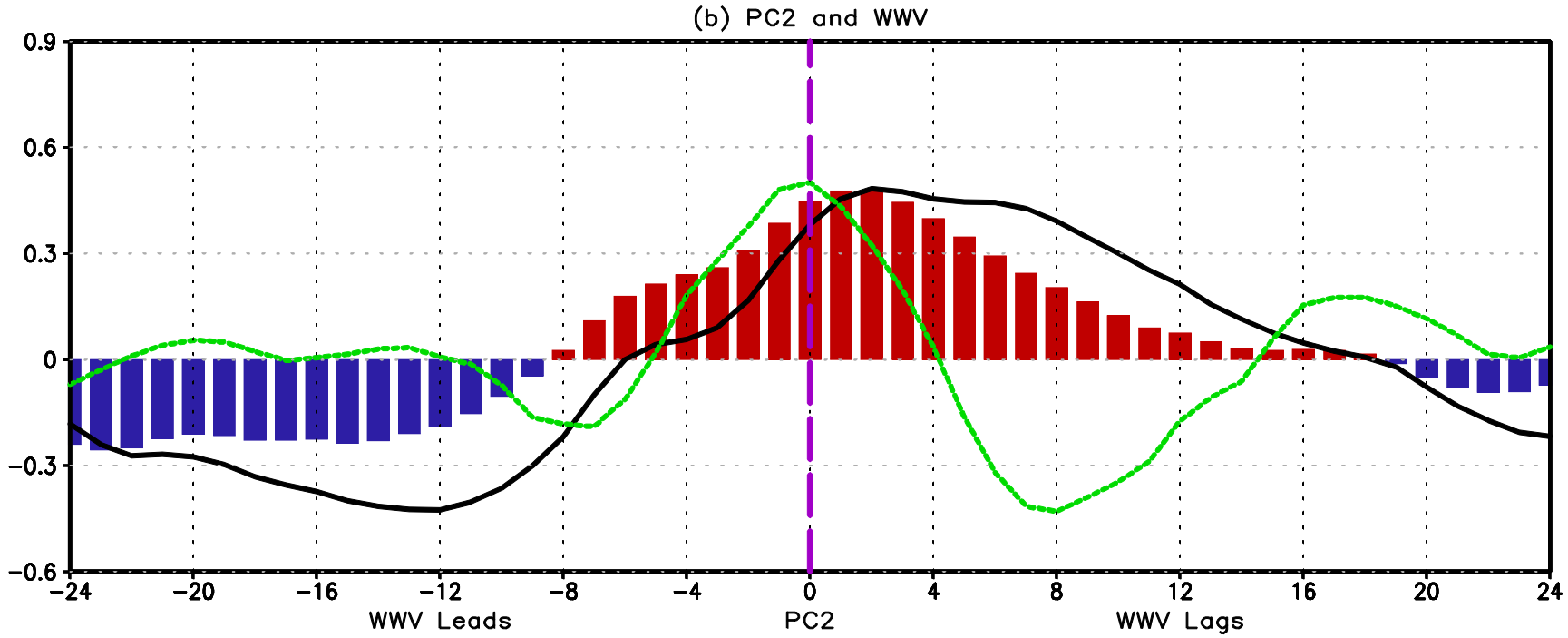
cEOF2: development phase of ENSO

(a) both total forcing and SST tendency are positive and comparable.

(b) Qu, Qv, Qw+Qzz (Qq) are positive (negative) in c&e Pacific and negative (positive) in the far e. Pacific, suggesting that the development phase occurs while the dynamical (thermodynamic) contribution is positive (negative) in c&e Pacific and negative (positive) in the far e. Pacific.

© variability of PC2 also became smaller and positive after 2000, consistent with our (JC, 2013) and others previous works.

Correlation of PC2 and WWV: Bar: 1979-2013; Solid & Black: 1979-1999; Dash & Green: 2000-2013

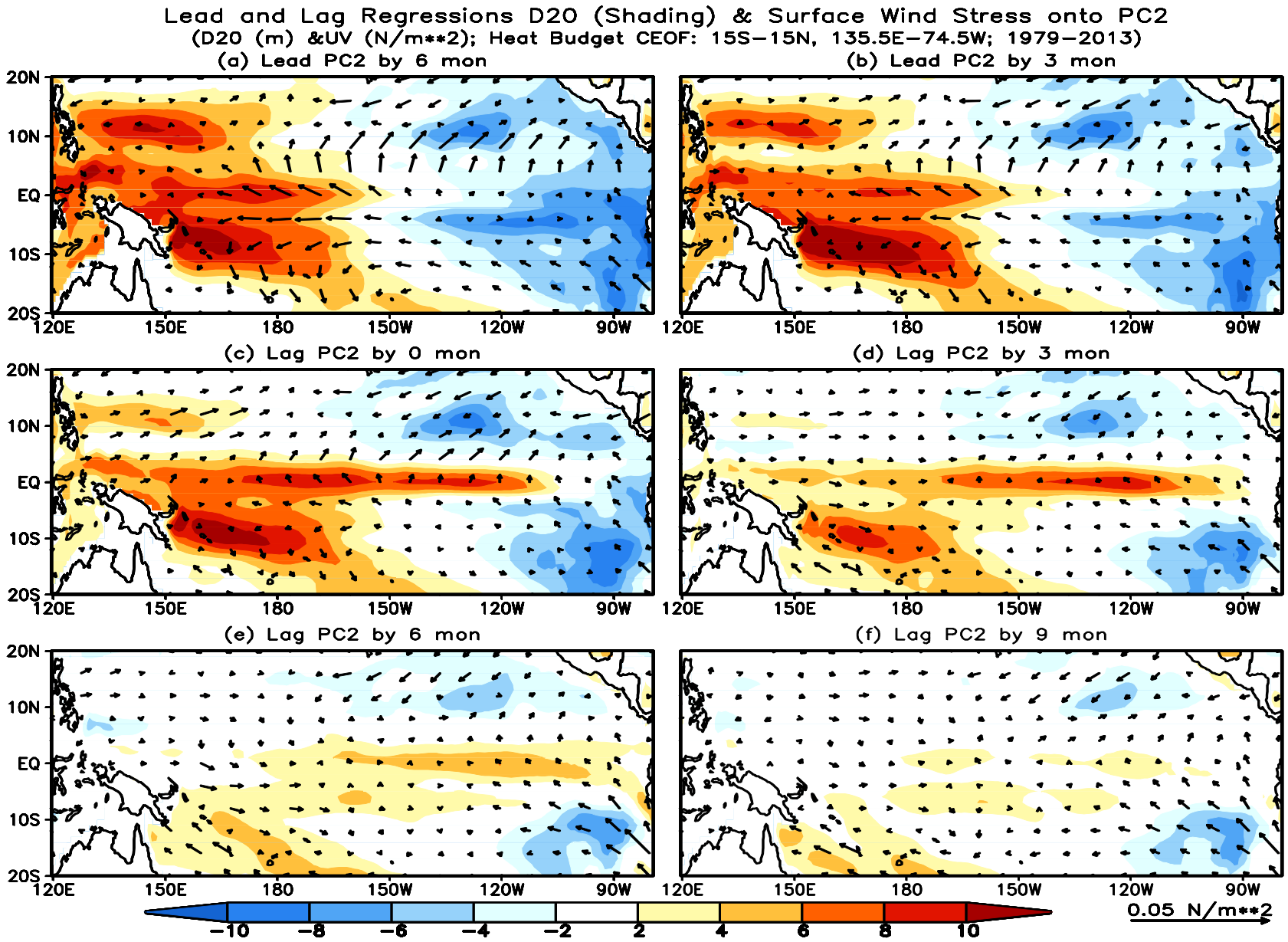


cEOF2: Development phase of ENSO

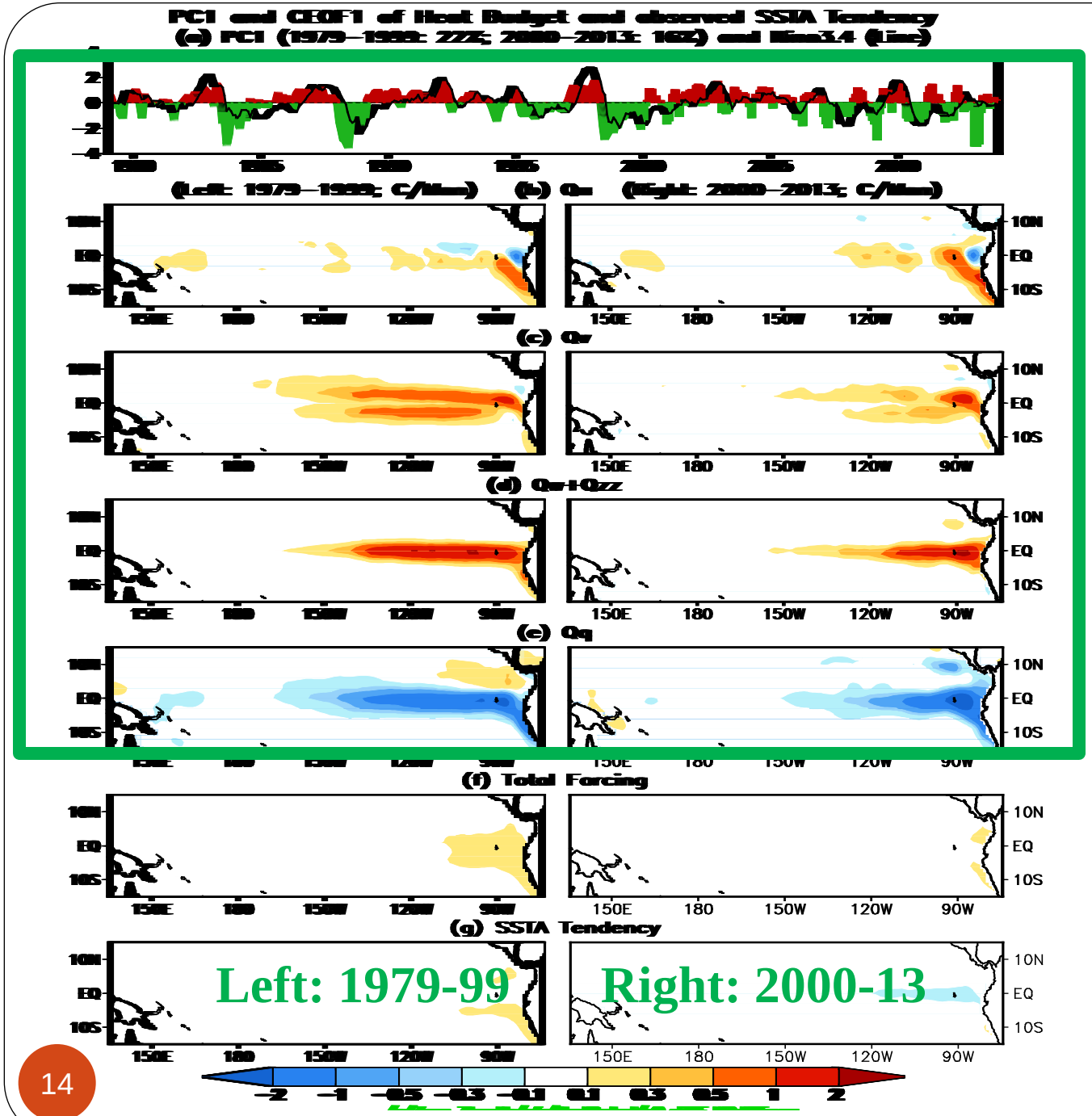
Maximum correlation presents when wwv lags PC2 by 1-2 months, suggesting that cEOF2 may be mainly associated recharge/discharge process.

CEOF2 is tied up ENSO development phase

(D20 and surface wind stress anomaly regressions onto PC2)

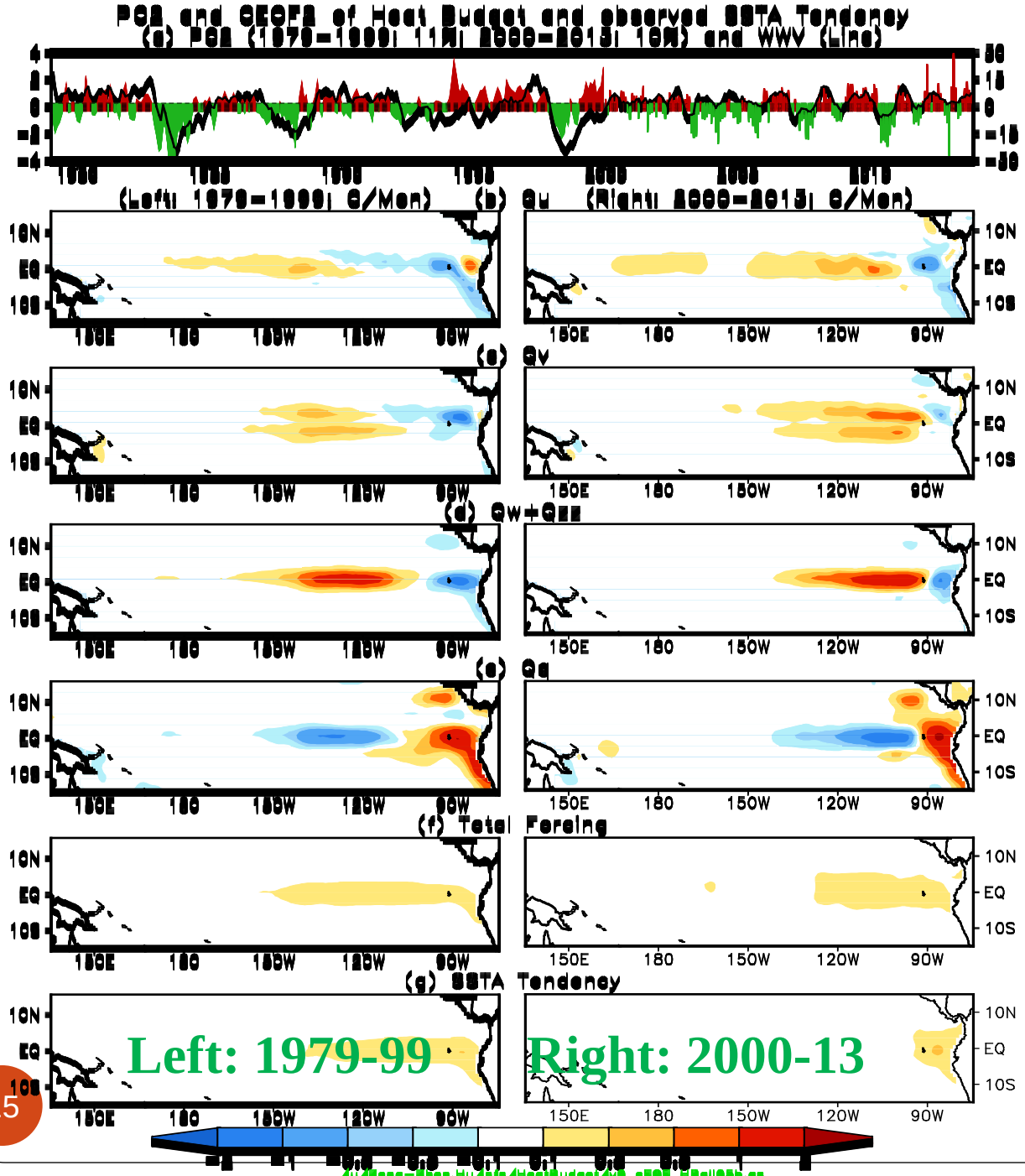


2: Interdecadal change of the leading patterns between two periods: 1979-1999 and 2000-2013



Compared with that in 1979-1999, the amplitude reduced for both cEOF1 and PC1 in 2000-2013:

Left: 1979-99
Right: 2000-13



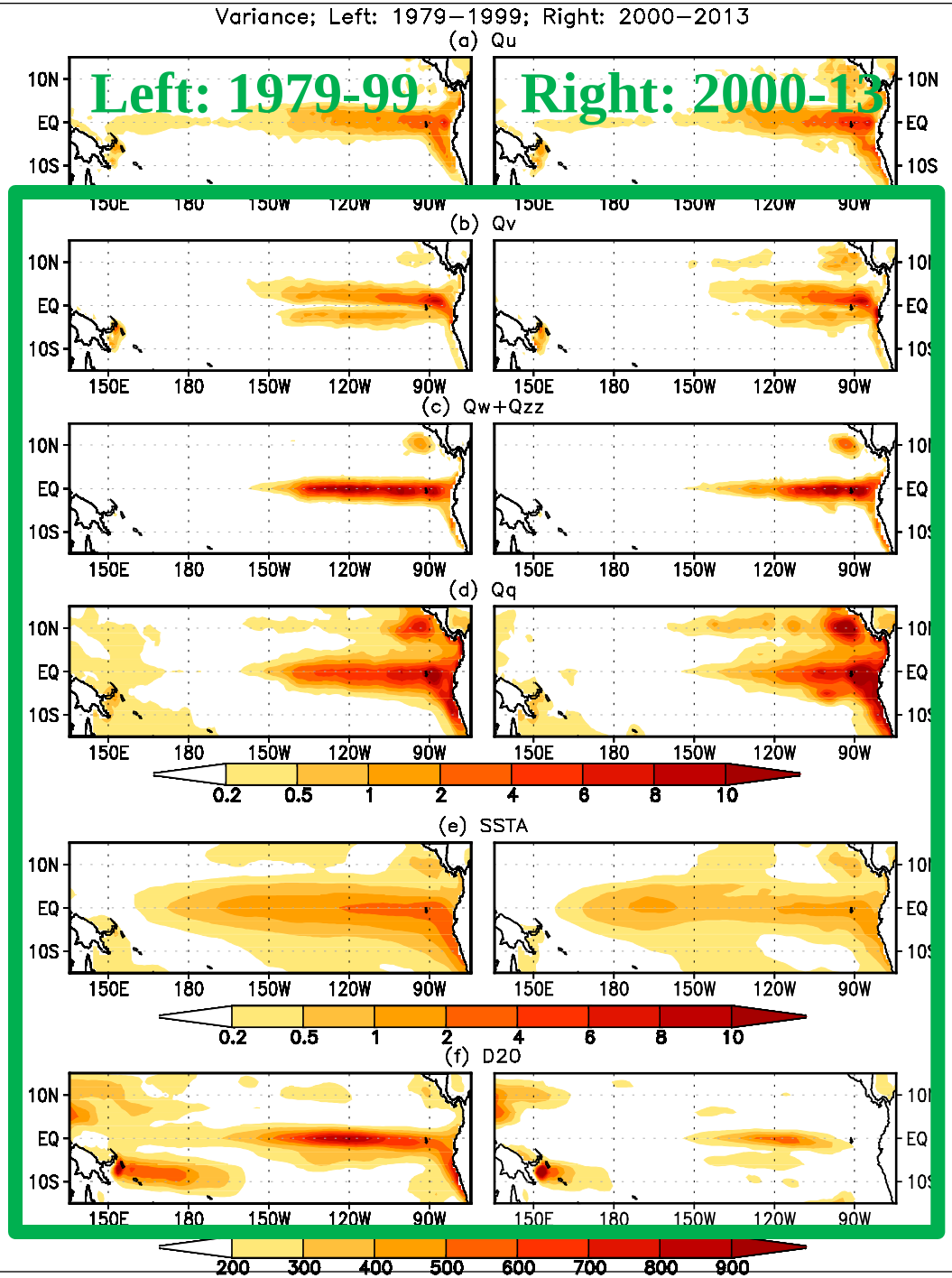
Little change for both cEOF2 and PC2 in two periods:

Left: 1979-99

Right: 2000-13

Left: 1979-99

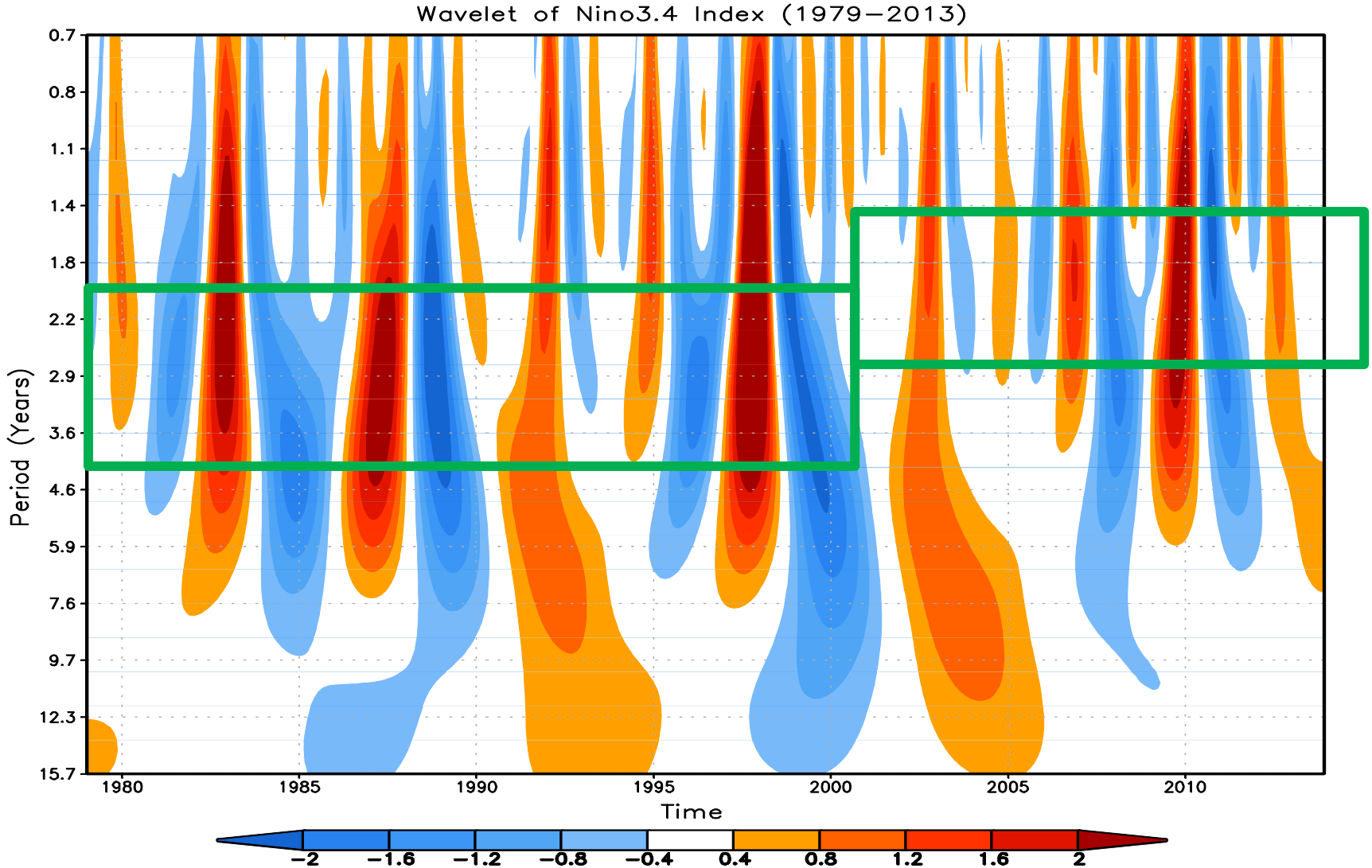
Right: 2000-13



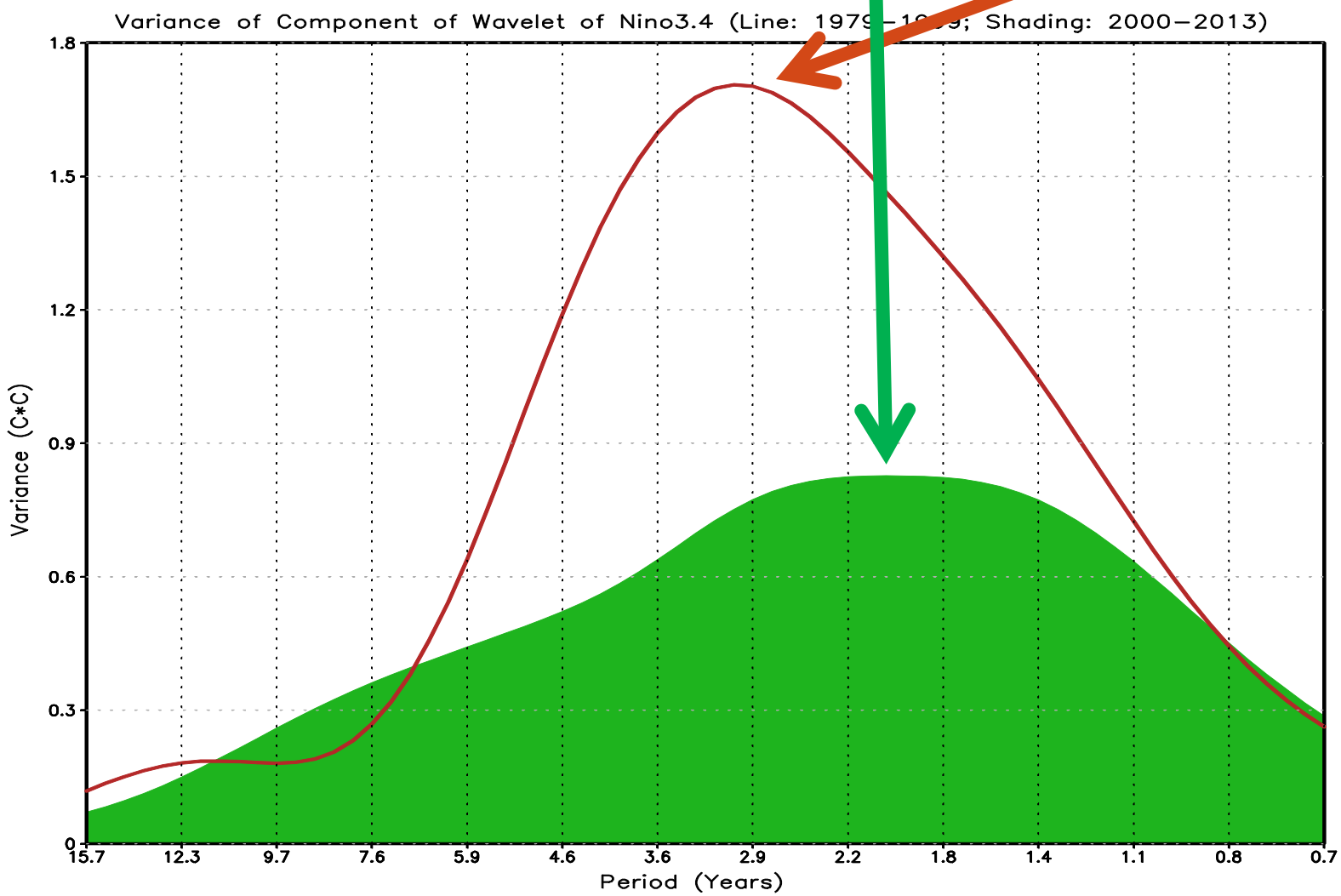
Compared with 1979-1999, variance decreased in 2000-2013:

Left: 1979-99; Right: 2000-13

Wavelet analysis of Nino3.4: Shortening of the period



Wavelet analysis suggests that ENSO shifts from 2-4 years averaged in 1979-1999 to 1.5-3 years after 2000



Results

- **cEOF1 corresponds to the ENSO mature phase**

  Qu: The contribution from the zonal advection was relatively small along the equator. Qw+Qzz (Qq): the vertical entrainment and diffusion (surface heat flux) had pronounced maxima with positive (negative) values along the equatorial central and eastern Pacific.

  Qv: The meridional advection displayed a different spatial pattern with large positive values on both sides of the equator and smaller values along the equator, expanding SSTA in meridional direction.

- **cEOF2 links to the ENSO development phase**

  The amplitudes of the dynamical and thermodynamical terms were smaller than that in cEOF1 and spatial distributions displayed an opposite variation between the Central American coast, and central and eastern tropical Pacific.

- **Interdecadal Variation (1979-1999 and 2000-2013):**

  Coupling in the tropical Pacific weakened at ENSO time scales.

  ENSO shifted to a relatively higher frequency regime from 2-4 years averaged in 1979-1999 to 1.5-3 years after 2000.

More Information

Hu, Z.-Z., A. Kumar, and B. Huang, 2015: Spatial distribution and the interdecadal change of leading modes of heat budget of the mixed-layer in the tropical Pacific and the association with ENSO. *Clim. Dyn.* (published online). DOI: 10.1007/s00382-015-2672-4.

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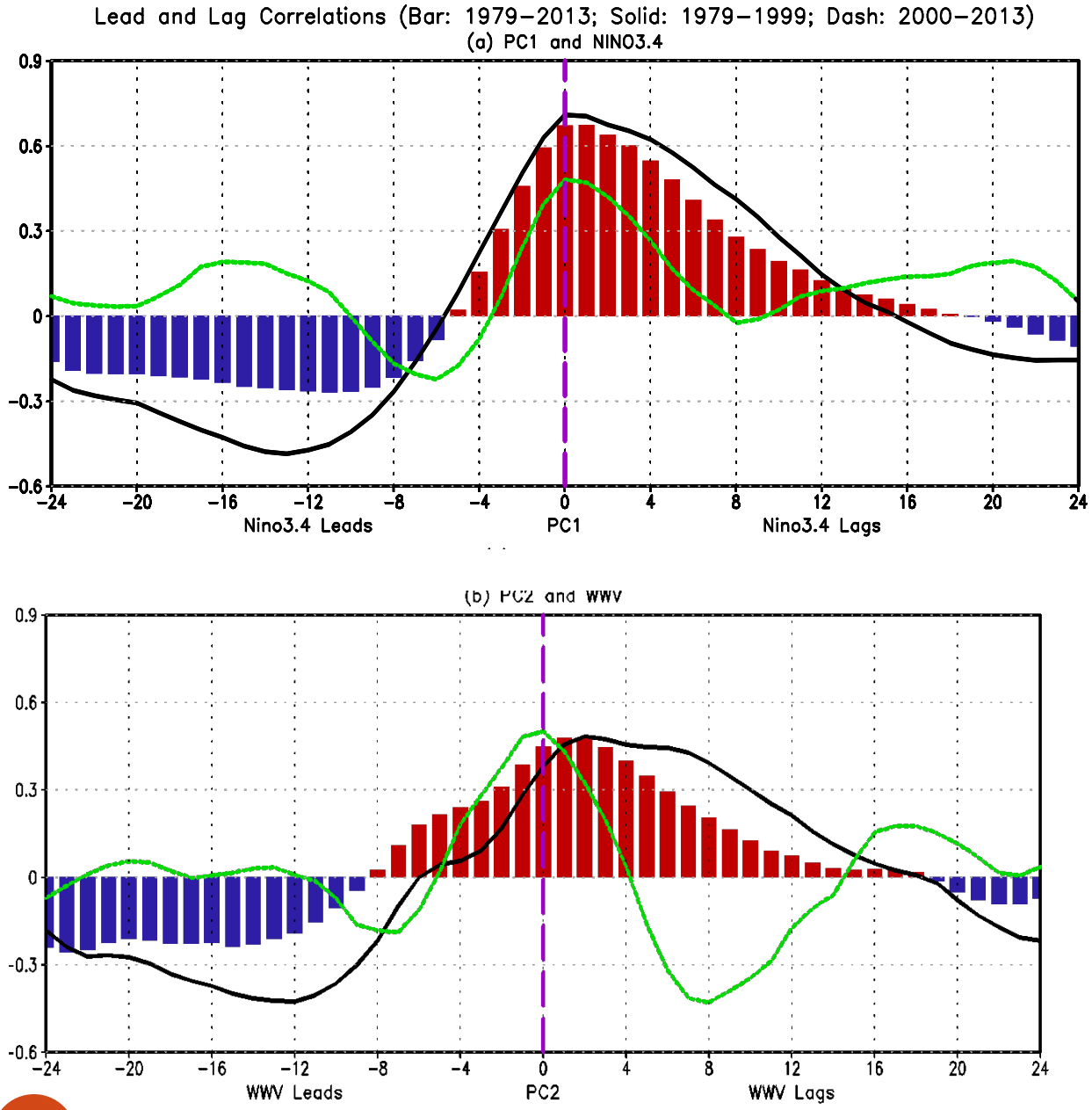

cEOF1 & cEOF2:

Compared with 1979-1999 (solid/dark line) and 1979-2013 (bar), frequency becomes higher for both PC1 &2, and correlation is smaller for PC1 in 2000-2013 (dashed/green line).