Zonal Structure of anomalies in tropical atmospheric energy budgets

Michael Mayer[1,*] and Leopold Haimberger[1]

[1]Department of Meteorology and Geophysics, University of Vienna, Austria

*mima@univie.ac.at

1. Introduction

The variability of the vertically integrated tropical energy budget is evaluated, employing third-generation reanalyses European Re-Analysis Interim (ERA-I), Climate Forecast System Reanalysis (CFSR) and Modern Era Retrospective-analysis for Research and Applications (MERRA).

The divergence of total energy (TEDIV), latent heat (VIMD) and dry static energy (DSEDIV) transport can be computed from eqs. (1) and (2) (all symbols have their usual meaning). Results only make sense when the mass budget of the reanalyses is balanced.

$$TEDIV = \langle \nabla_2 \cdot F_{total} \rangle = Rad_{TOA} - F_S - \frac{\partial \langle e^{fc} \rangle}{\partial t} \quad (1)$$

$$VIMD = \langle \nabla_2 \cdot F_{latent} \rangle = -L \cdot P - L \cdot E - L \cdot \frac{\partial \langle q^{fc} \rangle}{\partial t} \quad (2)$$

Divergences averaged over the tropical belt (20N-20S) and thus tropical total energy export show only small variability (±4%) which is on the order of the uncertainty of the obtained values (Mayer and Haimberger, 2012). In contrast, the tropical energy budgets show a pronounced zonal anomaly structure associated with El Niño-Southern Oscillation (ENSO) which is investigated in this work.

2. Longitude-time variability

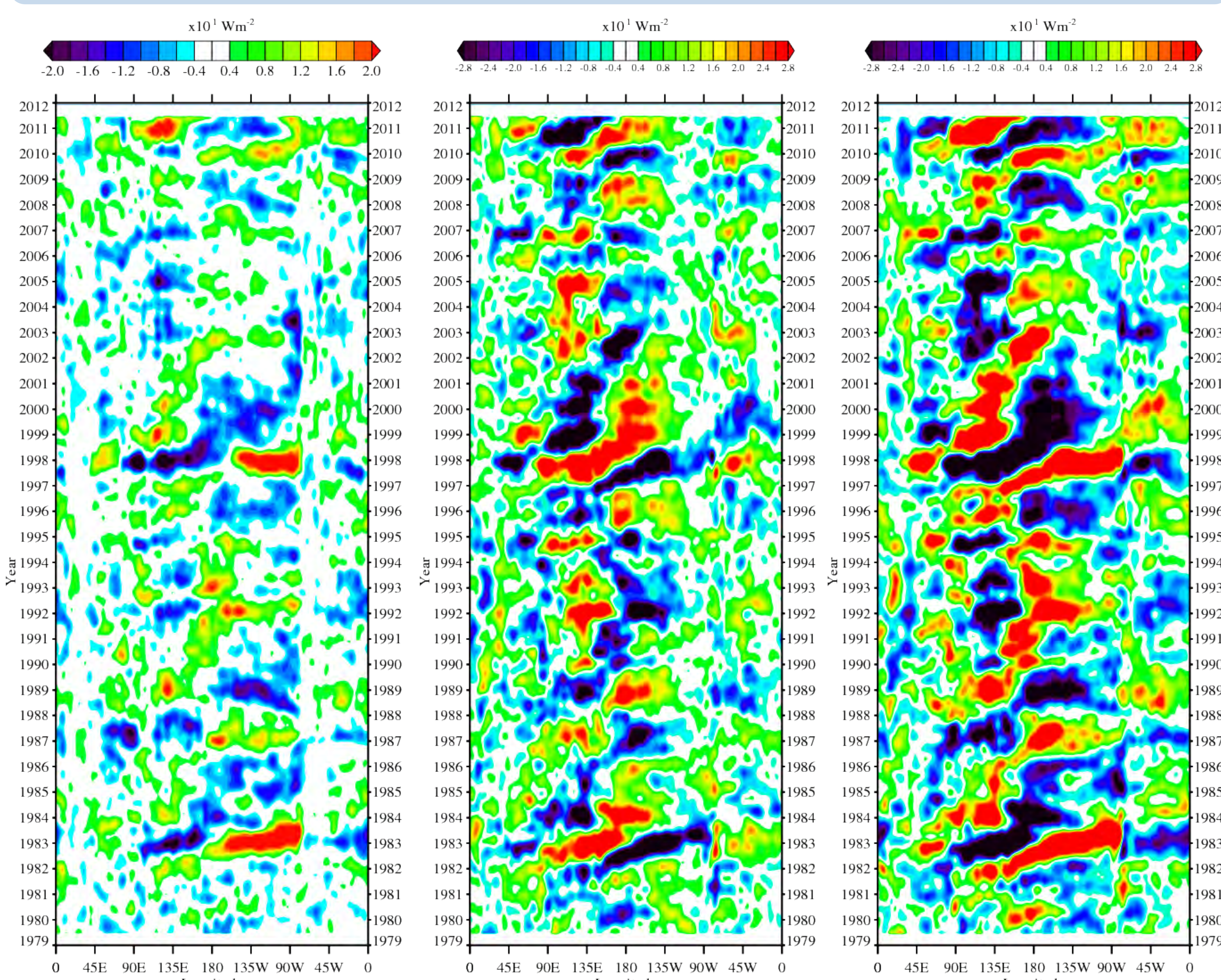

Fig. 1. Longitude-time hovmoeller plots of anomalous TEDIV (left), VIMD (middle) and DSED (right) from ERA-I, averaged between 20N and 20S (2° longitudinal resolution, based on monthly averages).

Anomalies on the order of up to $\pm 15 Wm^2$ in TEDIV and up to $\pm 30 Wm^2$ in DSED and VIMD can be seen in Fig. 1. DSED and VIMD show a quadrupole anomaly structure with extreme values over the Indic Ocean, Indo-Pacifc Warm Pool, Eastern Pacifc and the Atlantic. During warm ENSO phases, DSEDIV (which is closely related to diabatic heating processes) exhibits positive anomalies over the Eastern Pacifc and Indic Ocean, while VIMD anomalies have the opposite sign. Thus, VIMD anomalies indicate changes of atmospheric circulation, leading to changes in diabatic heating.

TEDIV tends to show a dipole structure with one extreme value over the Indo-Pacific Warm Pool and one over the Eastern Pacific. As Rad_{TOA} generally shows weak variation, positive TEDIV anomalies relate to stronger than normal surface fluxes, i.e. when the atmosphere is gaining energy from the ocean.

The effects of known temporal inhomogeneities related to assimilation of SSM/I radiances have been reduced by using split climatologies (1979-1991, 1992-2002, 2003-) in all figures. Without the splitting, the described patterns are noticeably more noisy but clearly visible in ERA-I and also the other two reanalyses (not shown).

Reference: Mayer, M. and Haimberger, L. (2012): Poleward atmospheric energy transports and their variability as evaluated from ECMWF reanalysis data. J. Climate, 25, 734–752.

Acknowldegements: FWF project P21772 , Advanced Study Program (ASP) NCAR.

3. Composites

Anomaly composites of tropical VIMD for the three strongest El Niños after 1978 (1982/83, 1986/87 1997/98) show a region of stronger than normal moisture convergence over the Indo-Pacific Warm Pool, around 18 months before the peak of the event. This anomaly gradually propagates to the Eastern Pacific where it diminishes at 90E around 12 months after the El Niño (Fig. 2). Analogous plots for DSED show a mirrored image, but even stronger, as there is additional contribution from stronger than normal radiative flux convergence (not shown). TEDIV shows this transition to a much smaller extent.

Results from all three employed reanalyes agree remarkably well.

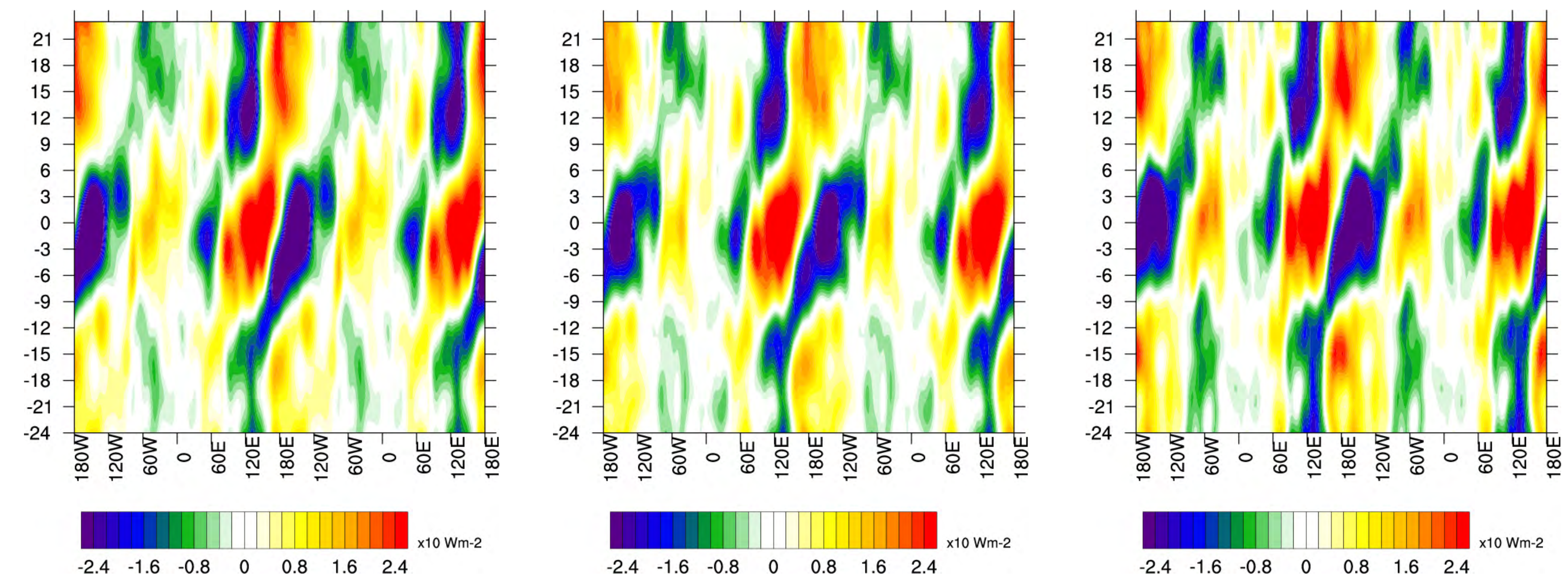

Fig. 2. Composites of tropical (20N-20S) VIMD from ERA-I, MERRA, CFSR for 82/83, 86/87, 97/98 El Niños, each event centered at the peak of its corresponding Niño 3.4 anomaly; Values of y-axis denote months before (negative) / after (positive) the SST maximum.

4. EOF analysis

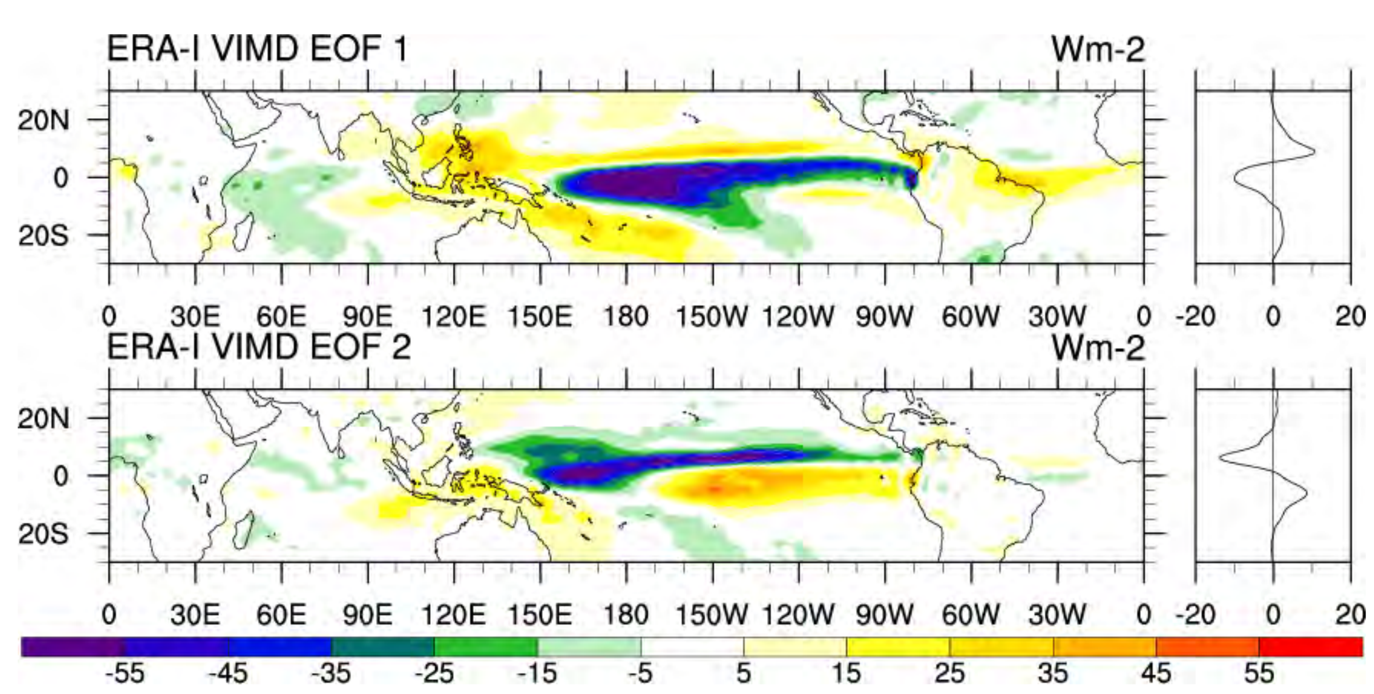

Fig. 3. EOF 1 (describing 27% of total variability) and 2 (16%) of ERA-I VIMD, multiplied by standard deviation of respective PCs (signs chosen for warm ENSO events).

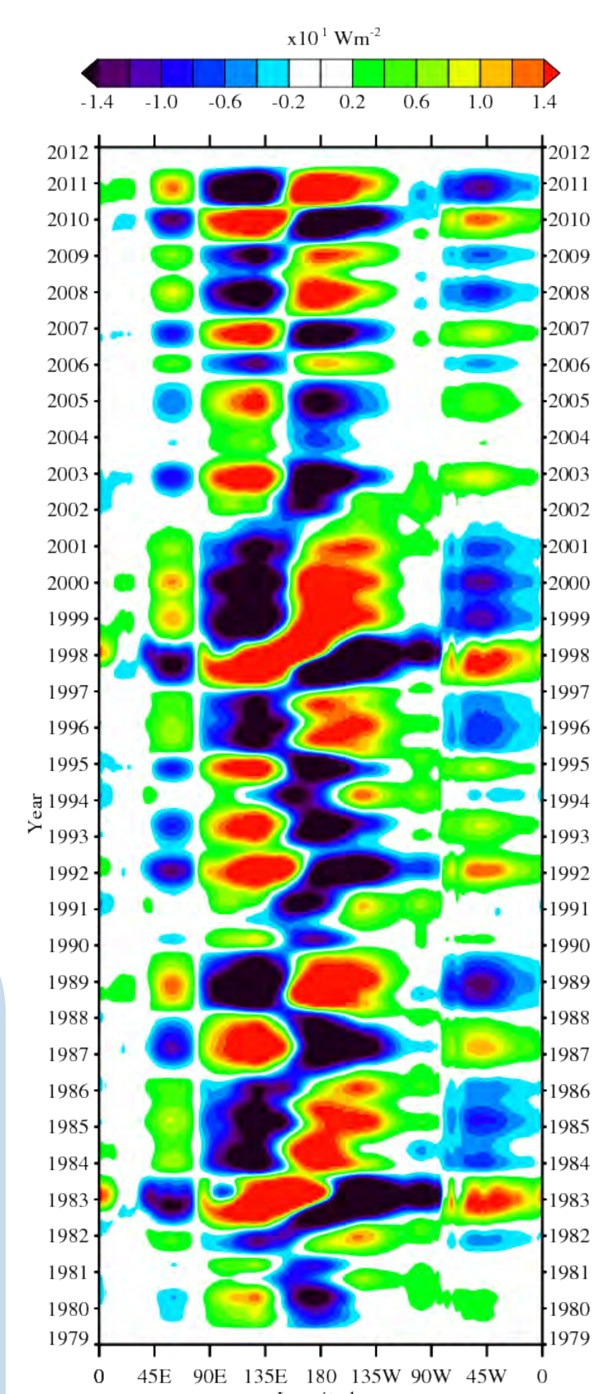

Fig. 4. Tropical (20N-20S) VIMD anomaly series reconstructed from EOF 1 and 2.

EOF 1 (Fig. 3) clearly depicts the quadrupole structure as seen from Fig. 1. PC 1 is correlated 0.95 at lag 0 with Niño 3.4 index. Thus, EOF 1 clearly depicts the atmospheric VIMD response to mature ENSO events.

EOF 2 shows a transition state with strongest moisture convergence near the dateline. PC 2 is correlated -0.78 at lag -3 with Trans-Niño-Index (TNI). EOF 2 thus describes the VIMD response to a central Pacifc warming event (“El Niño Modoki”).

Tropical VIMD anomaly series reconstructed from EOF 1 and 2 (Fig. 4) exhibits the basic structures already seen in Fig. 1.

5. Conclusions/Outlook

- Energy budget anomalies in the Tropics show remarkable zonal structures related to ENSO extreme phases quadrupole for DSEDIV and VIMD, dipole for TEDIV).
- DSEDIV and VIMD exhibit propagating anomaly patterns during the transition between ENSO extreme phases, i.e. seamless transition from La Niña to El Niño and vice versa.
- Composites for the strongest warm events confirm this picture.
- EOF analysis of tropical VIMD reveals one Canonical El Niño pattern (EOF 1) and one “El Niño Modoki” pattern (EOF 2).
- EOF 2 describes a transition phase (e.g. ahead of the big 82/83 and 97/98 Niños) but also a stationary “El Niño Modoki” state (e.g. early 2000s).
- PC 2 leading TNI suggest atmospheric circulation changes to be drivers for central Pacific SST anomalies.
- Need to extend analysis backward with reanalyses reaching back beyond the satellite era (JRA-55, ERA-Clim pilot reanalyses,…)