ENSO Related Inter-Annual Lightning Variability from the Full TRMM LIS Lightning Climatology

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Abstract

The El Niño/Southern Oscillation (ENSO) contributes to inter-annual variability of lightning production more than any other atmospheric oscillation. This study further investigated how ENSO phase affects lightning production in the tropics and subtropics using the Tropical Rainfall Measuring Mission (TRMM) Lightning Imaging Sensor (LIS). Lightning data were averaged into mean annual warm, cold, and neutral 'years' for analysis of the different phases and compared to model reanalysis data. An examination of the regional sensitivities and preliminary analysis of three locations was conducted using model reanalysis data to determine the leading convective mechanisms in these areas and how they might respond to the ENSO phases.

Data and Methods

- Oceanic Niño Index (ONI) as outlined in Table 1 [Huang et al., 2017]
    - ENSO years kept ENSO max in one year (e.g. ENSO 2000 ran from 4/1/00 to 3/31/01)
- Lightning Data
    - TRMM LIS Low Resolution Time Series (LRTS) [Cecil et al., 2014]
    - 2.5° × 2.5° spatial resolution
- Model Data
    - NCEP/NCAR 40 Year Reanalysis Project (NCNC) [Kalnay et al., 1996]
    - 2.5° × 2.5° daily averages

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1998	2.2	1.9	1.4	1	0.5	-0.1	-0.8	-1.1	-1.3	-1.4	-1.5	-1.6
1999	-1.5	-1.3	-1.1	-1	-1	-1	-1.1	-1.1	-1.2	-1.3	-1.5	-1.7
2000	-1.7	-1.4	-1.1	-0.8	-0.7	-0.6	-0.6	-0.5	-0.5	-0.6	-0.7	-0.7
2001	-0.7	-0.5	-0.4	-0.3	-0.3	-0.1	-0.1	-0.1	-0.2	-0.3	-0.3	-0.3
2002	-0.1	0	0.1	0.2	0.4	0.7	0.8	0.9	1	1.2	1.3	1.1
2003	0.9	0.6	0.4	0	-0.3	-0.2	0.1	0.2	0.3	0.3	0.4	0.4
2004	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.6	0.7	0.7	0.7	0.7
2005	0.6	0.6	0.4	0.4	0.3	0.1	-0.1	-0.1	-0.1	-0.3	-0.6	-0.8
2006	-0.8	-0.7	-0.5	-0.3	0	0	0.1	0.3	0.5	0.7	0.9	0.9
2007	0.7	0.3	0	-0.2	-0.3	-0.4	-0.5	-0.8	-1.1	-1.4	-1.5	-1.6
2008	-1.6	-1.4	-1.2	-0.9	-0.8	-0.5	-0.4	-0.3	-0.3	-0.4	-0.6	-0.7
2009	-0.8	-0.7	-0.5	-0.2	0.1	0.4	0.5	0.5	0.7	1	1.3	1.6
2010	1.5	1.3	0.9	0.4	-0.1	-0.6	-1	-1.4	-1.6	-1.7	-1.7	-1.6
2011	-1.4	-1.1	-0.8	-0.6	-0.5	-0.4	-0.5	-0.7	-0.9	-1.1	-1.1	-1
2012	-0.8	-0.6	-0.5	-0.4	-0.2	0.1	0.3	0.3	0.3	0.2	0	-0.2
2013	-0.4	-0.3	-0.2	-0.2	-0.3	-0.3	-0.4	-0.4	-0.3	-0.2	-0.2	-0.3
2014	-0.4	-0.4	-0.2	0.1	0.3	0.2	0.1	0	0.2	0.4	0.6	0.7

Table 1: ONI values for each three-month averaging period. Colored values indicate ONI threshold met; colored shading indicates inclusion in the study as either a warm (red), cold (blue), or neutral (gray) year with 16 total years.

Results

Regional Sensitivities

- Warm Phase Positive Magnitude Anomalies (Figure 2)
    - Argentina, Central Africa, Mexico & GOM, East Asia, Middle East, Eastern Indian Ocean
- Cold Phase Positive Magnitude Anomalies
    - North Brazil, Southern Africa, Australia, Eastern USA, Western Equatorial Atlantic, Red Sea
- Neutral Phase Positive Magnitude Anomalies
    - The two global lightning maxima of Lake Maracaibo and the Democratic Republic of the Congo, central South America, Eastern Australia, Himalayas, Northern Arabian Peninsula
- Percentage anomalies are dominated by the oceans and deserts, where flash rates rarely exceed 0.25Flkm^{-2}Yr^{-1} and therefore can be dominated by singular events

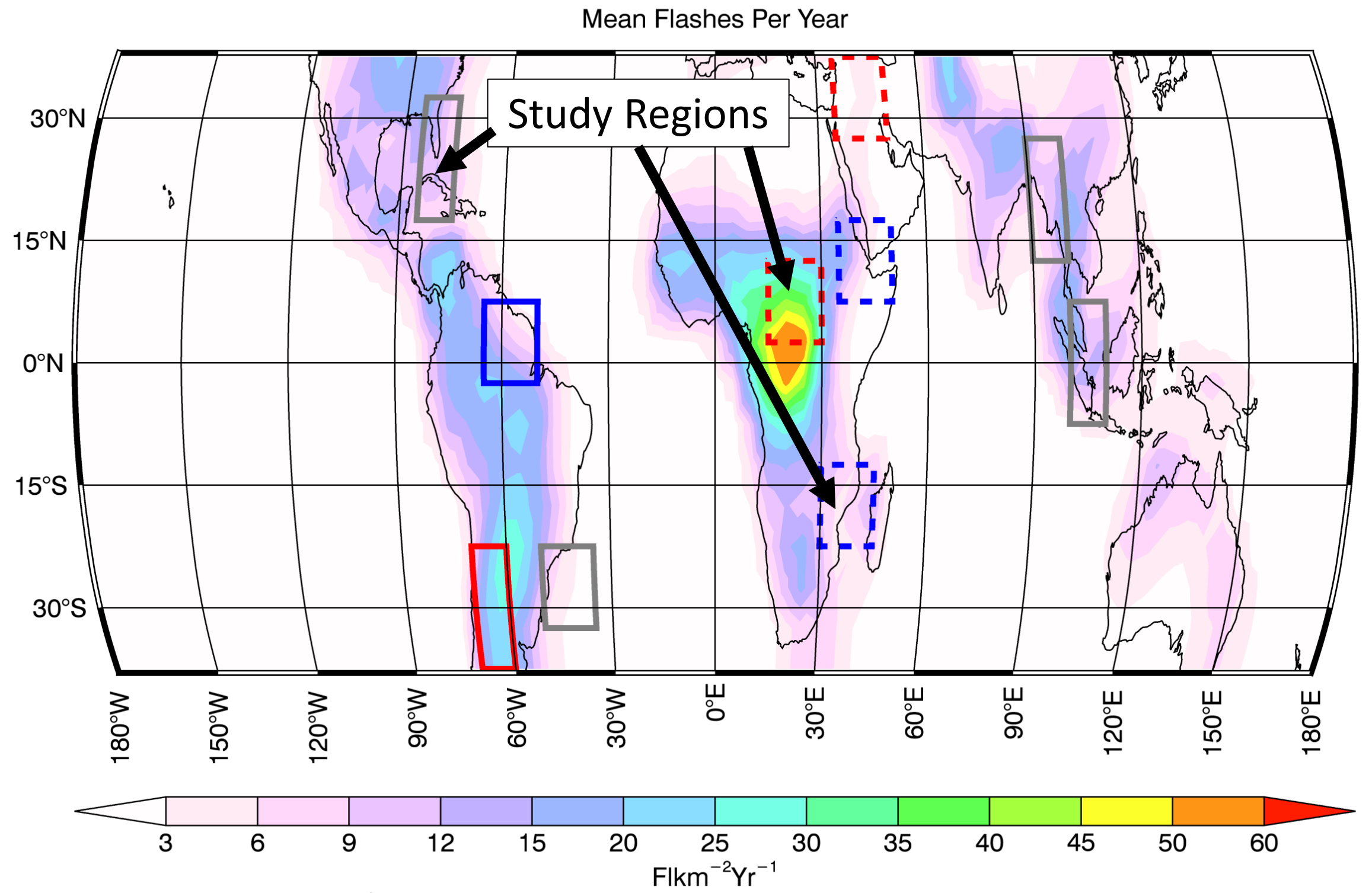

Fig. 1 All regions chosen for closer investigation. Red boxes are warm phase regions, blue are cold, and gray are neutral. Dashed boxes are teleconnections, solid are direct connections.

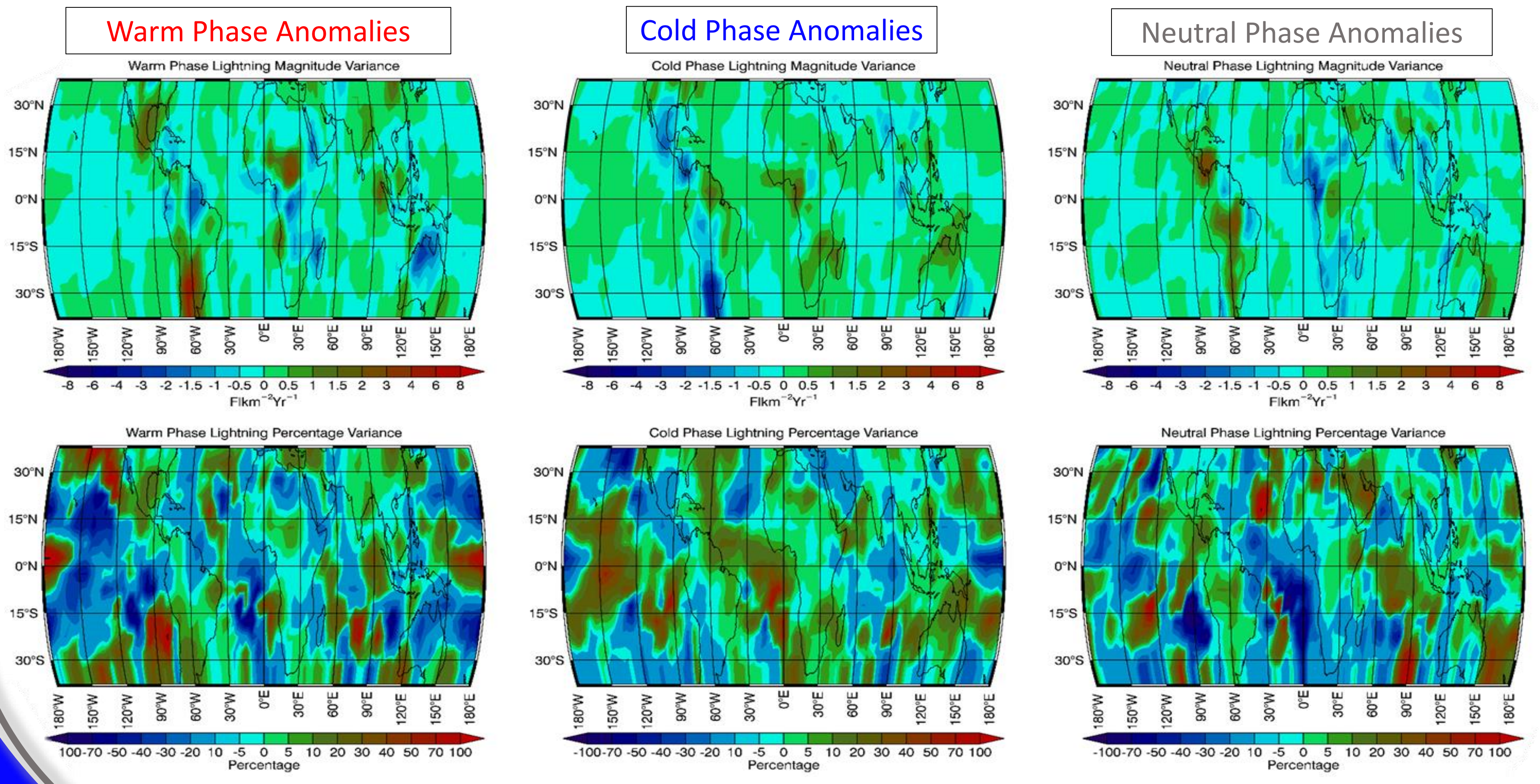

Fig. 2 Total deviation from the mean for the warm (left), cold (center), and neutral (right) phases in Flkm^{-2}Yr^{-1} (top) and percent of the mean annual flash rate for the cell (bottom)

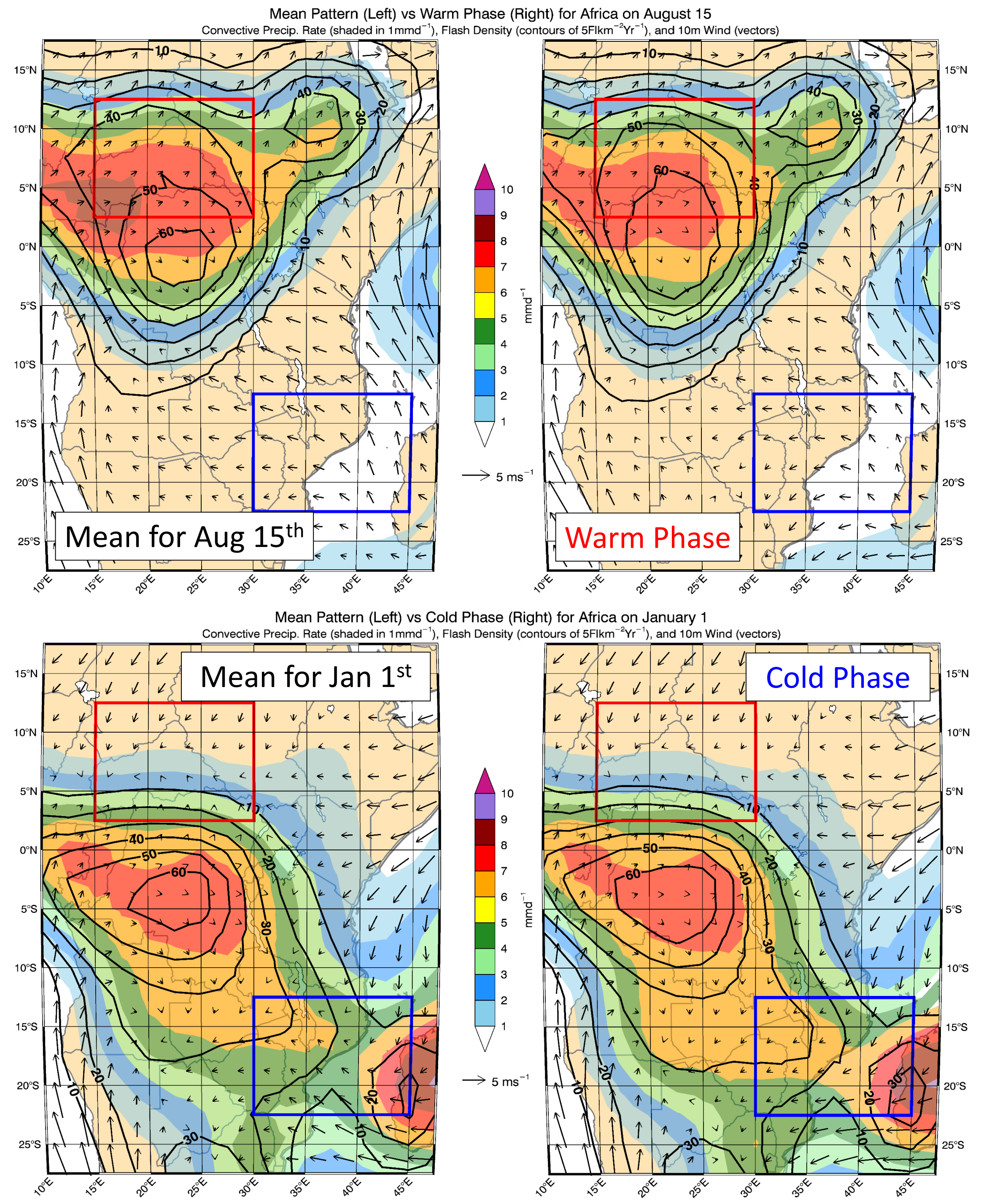

Fig. 3 LRTS, NCNC convective precipitation, and NCNC 10m wind. Central Africa (red box) and Southeastern Africa (blue box) . Mean pattern is on the left and the warm phase pattern is on the right for August 15th (top) and cold phase on the right for January 1st (bottom)

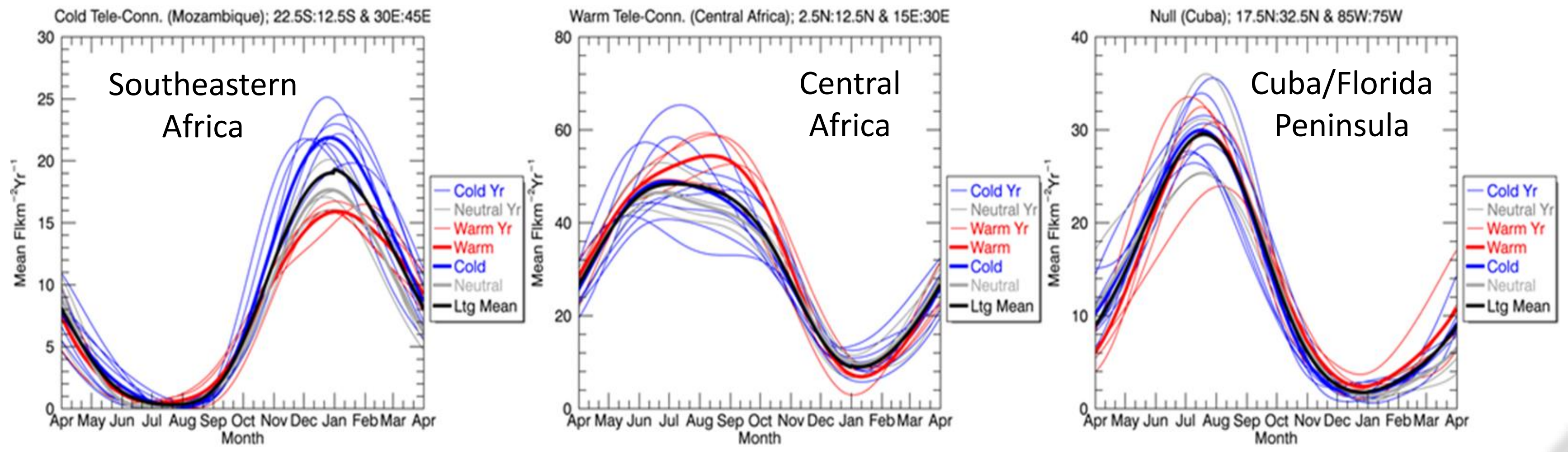

Fig. 4 ENSO Annual Patterns for the three study areas (Flkm^{-2}Yr^{-1}) with the Southeastern Africa (left), the Central Africa warm (center), and the Cuban null case (right)

Further Investigations

- Central Africa
    - Overall lower conv. precip. rate, but more lightning during warm phase
    - Lightning max longer and later during warm phase
    - Consistent shift, but some cold years have greater maxima
    - Little change in wind pattern
- Southeastern Africa
    - Higher conv. precip. rate, more lightning during cold phase
    - Enhanced northerly flow compared to mean phase, significantly more than warm phase (not pictured)
    - Very consistent pattern
- Cuba/Florida Peninsula
    - Annual variability hard to tie to ENSO phase, with positive and negative anomalies from all three phases (Fig 4)
    - More stable during warm phase, less during cold phase (Fig 5)

Initial Conclusions

- **Regional Sensitivities**
    - Most areas consistent with previous literature
    - Potentially new regions include the three African regions of Central Africa, Southeastern Africa, and Djibouti/Red Sea
    - Most 'neutrally sensitive' regions' lightning from topography, differential heating, and land/sea contrast which are generally unaffected by ENSO
    - Some regions have a single response to ENSO phase (e.g. Central Africa warm phase), others are dipoles (e.g. Argentina, Southeastern Africa)
- **Central Africa- Warm Phase**
    - Maybe tied to ITCZ pattern shift with ENSO
    - Enhances and extends (in space and time) the peak lightning activity
    - Better aligns with max in annual moisture and CAPE
    - Evidence: northward extension of lightning, decrease in CP rate, stronger southerly winds in austral summer
- **Southeastern Africa- Cold Phase**
    - Indian Ocean High (IOH) may shift with ENSO during austral summer with weaker (stronger) easterlies during warm (cold) phase
    - May move ITCZ north during warm phase and south during cold phase
    - Southerly ITCZ produces more lightning in Madagascar and Mozambique
    - Evidence: higher CP rate and lightning, stronger northerly winds
- **Cuba/Florida Peninsula- Null Case**
    - Localized processes drive lightning and appear indifferent to ENSO phase
    - Potential 'net zero' effect between cold and warm phases

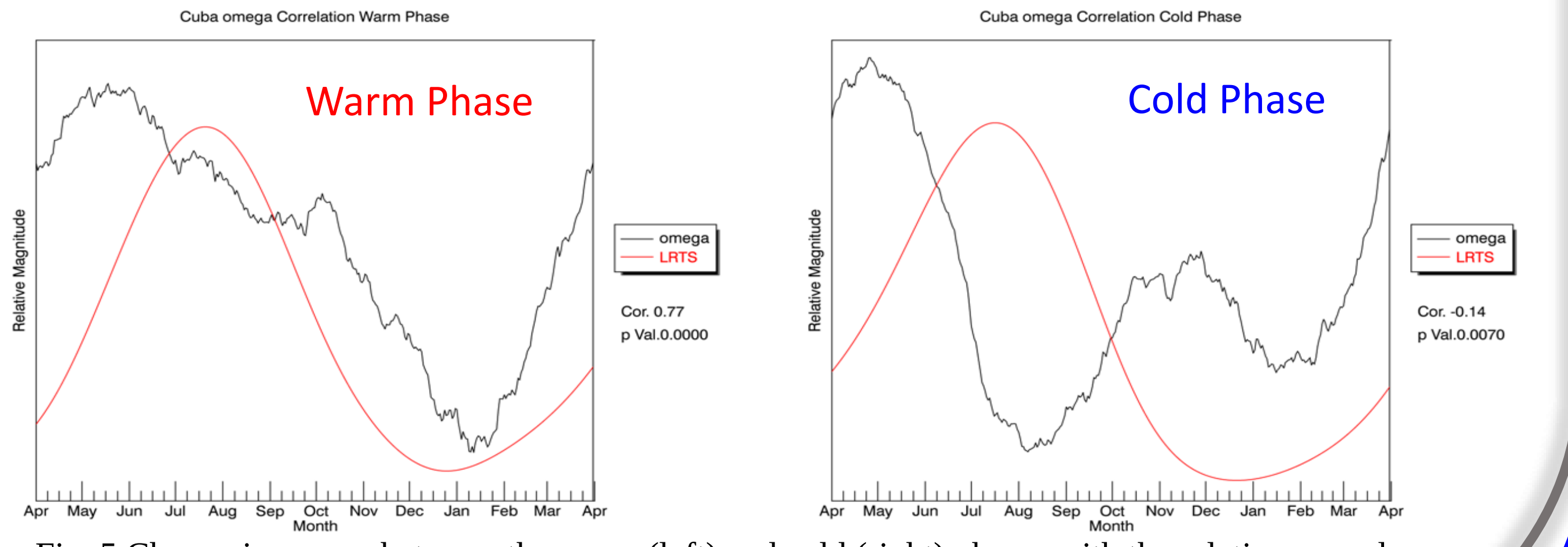

Fig. 5 Change in omega between the warm (left) and cold (right) phases with the relative annual trends for the NCNC omega (in black) and LRTS (in red)

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