Poleward Shift in Monsoon Low Level Jet in a Warming Scenario

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ABSTRACT

The Low Level Jetstream (LLJ) transports moisture from the surrounding Oceans to Indian land mass and hence an important component of the Indian Summer Monsoon. Widening of tropical belts and poleward shifts in mid-latitude jetstreams has been identified as major impacts of global warming on large-scale atmospheric dynamics. A general northward shift in ISM circulation has been suggested recently, based on the Coupled Model Inter-comparison Project (CMIP5) simulations. Here, we investigate the current and projected future changes in LLJ in observations as well as in CMIP5 simulations. A poleward shift in the monsoon LLJ has been detected both in the observations and coupled model simulations. The poleward shift is also reflected in the future projections in a warming scenario, with the magnitude of shift depending on the degree of warming. Consistent with the LLJ shift, a drying (wet) trend in the southern (northern) part of the Western coast of India is also observed in the last three decades. Further analysis reveals that enhanced land-sea contrast resulted in a strengthening of the cross-equatorial Sea Level Pressure gradient over Indian Ocean, which in turn resulted in the northward shift of the zero absolute vorticity contour from its climatological position. The poleward shift in zero absolute vorticity contour is consistent with that of LLJ core (location of maximum low-level zonal winds).

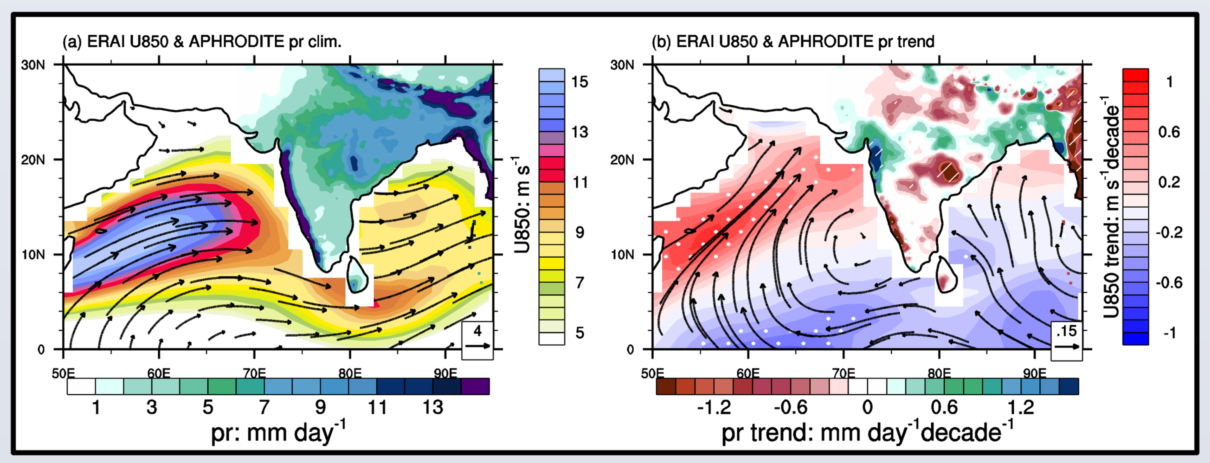

Figure 1: (a) Climatological JJAS mean (1981 – 2000) oceanic winds at 850 hPa, (vectors, m s^{-1}) and land precipitation (mm day^{-1}) and (b) Linear trends (1979 – 2007) in JJAS mean winds (vectors, m s^{-1} $decade^{-1}$), and land precipitation (mm day^{-1} $decade^{-1}$). The shading over the ocean shows (a) climatology and (b) linear trend in oceanic zonal winds at 850 hPa. Winds are from ERA-Interim and precipitation from APHRODITE. Stippling (dashes) show regions with statistically significant ($p<0.05$) trends in zonal winds (precipitation).

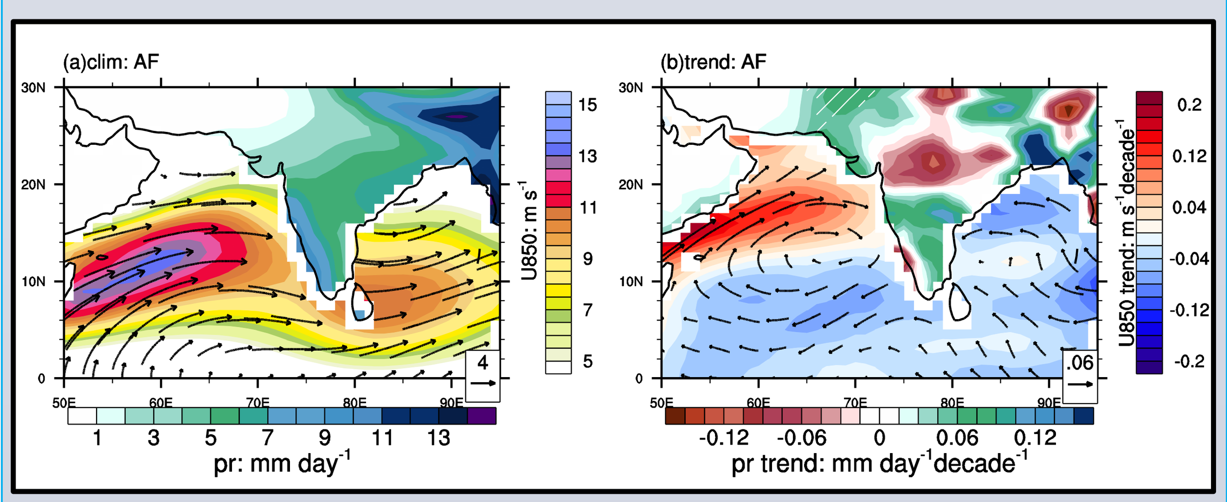

Figure 2: (a) Same as Fig. 1a, except for ensemble mean of historical All Forcing (AF) simulations (1981 – 2000) and (b) Linear trend (1979 – 2005) for AF ensemble.

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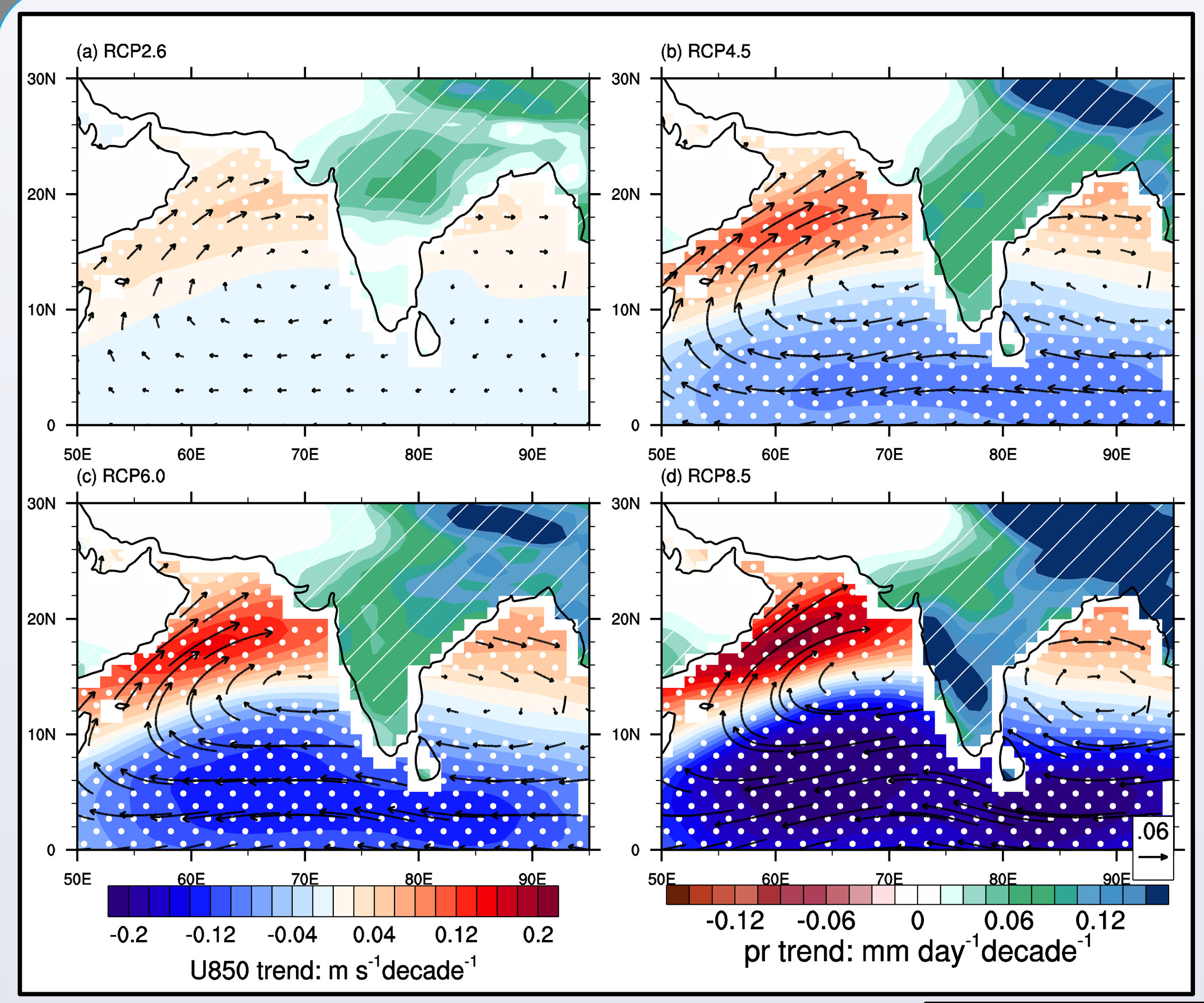


Figure 3: Linear trends (2006 – 2099) in oceanic winds at 850 hPa (vectors; m s^{-1} $decade^{-1}$) and precipitation (mm day^{-1} $decade^{-1}$) for (a) RCP2.6, (b) RCP4.5, (c) RCP6.0, and (d) RCP8.5 scenarios respectively. Shaded regions over oceans depict trends in zonal winds at 850 hPa and that over land shows precipitation trend. Stippling show regions with statistically significant ($p<0.05$) trends.

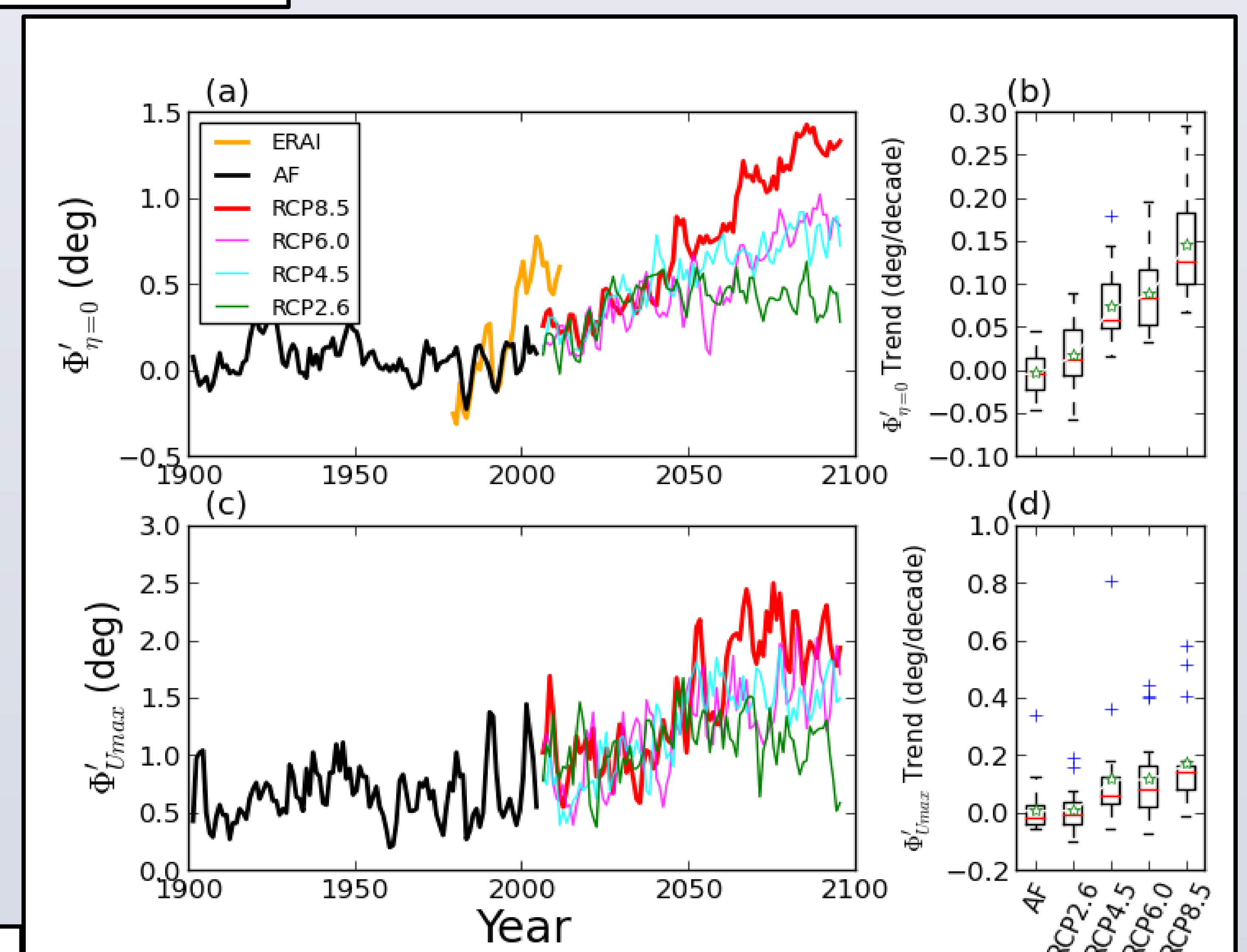


Figure 4: (a) Time series of anomalies in the latitude (degrees) of zero absolute vorticity ($\Phi'_{\eta=0}$) over Arabian Sea, (b) box plot showing linear trends in latitudinal shift (degrees $decade^{-1}$) in $\Phi'_{\eta=0}$ for various CMIP5 experiments. (c) and (d) are same as (a) and (b) except for the LLJ core. The ensemble mean trends are represented by asterisks in (c) and (d). The LLJ core latitude is defined as the latitude of 850 hPa zonal wind maximum over the Arabian Sea (50°E – 70°E, 5°N – 25°N). Three year running mean is applied to all time series. Trends are statistically significant at 5% level for RCP4.5, RCP6.0, and RCP8.5 experiments and for ERAI.

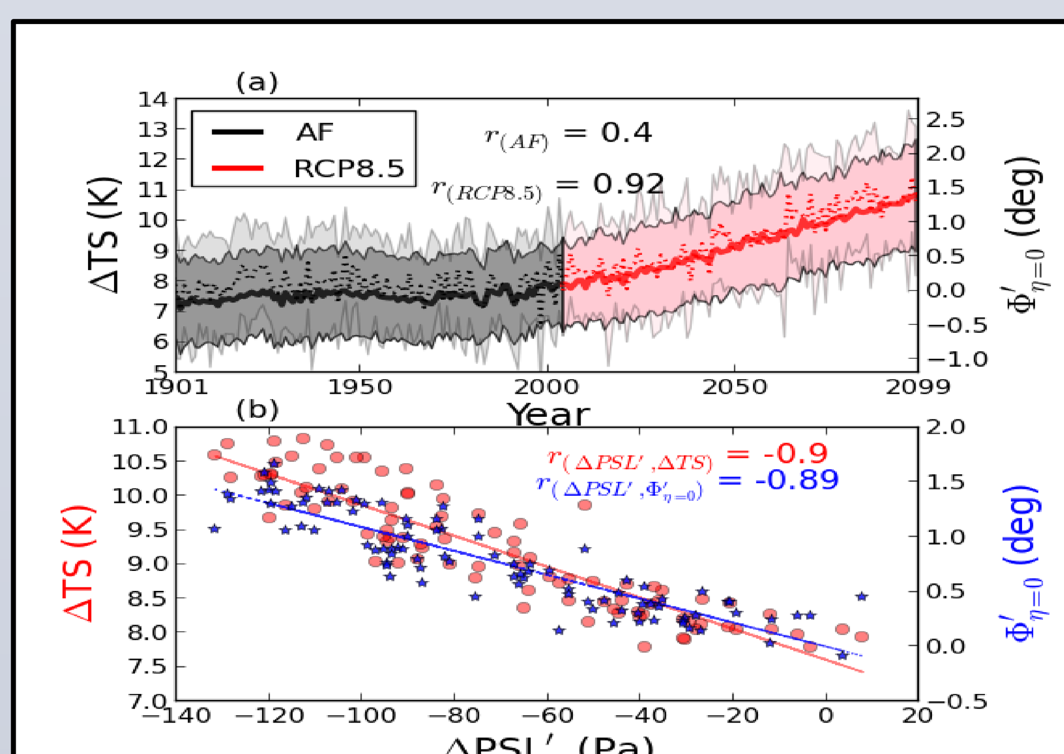


Figure 5: (a) Inter-annual variability in land-sea temperature contrast (K; bold line) and the anomaly in mean latitudinal position of zero absolute vorticity (degrees; broken line). The data for this plot are constructed from historical AF simulations (1901 – 2005) and RCP8.5 simulations (2006 – 2099); (b) Scatter plot showing the relationships between land-sea temperature contrasts and north-south PSL gradient and anomaly in the latitudinal position of zero absolute vorticity (RCP8.5). The shading in (a) shows ensemble spread. Correlations between the parameters are indicated. All correlation values are statistically significant ($p<0.05$).

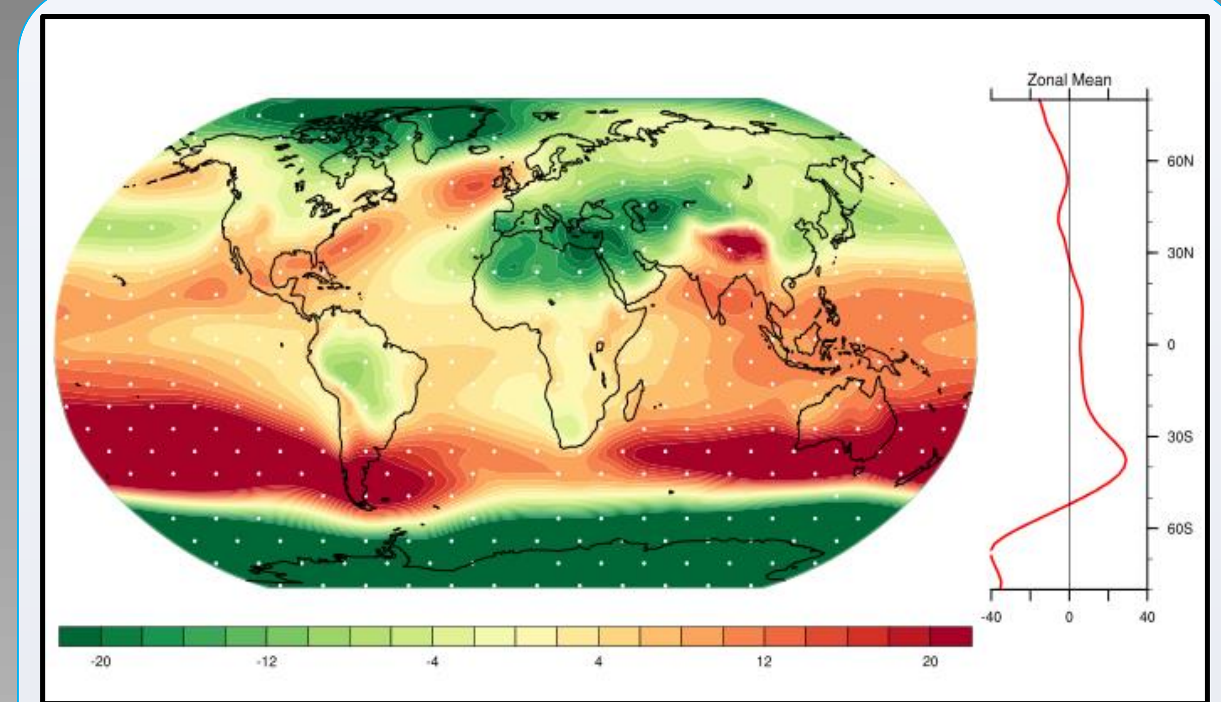
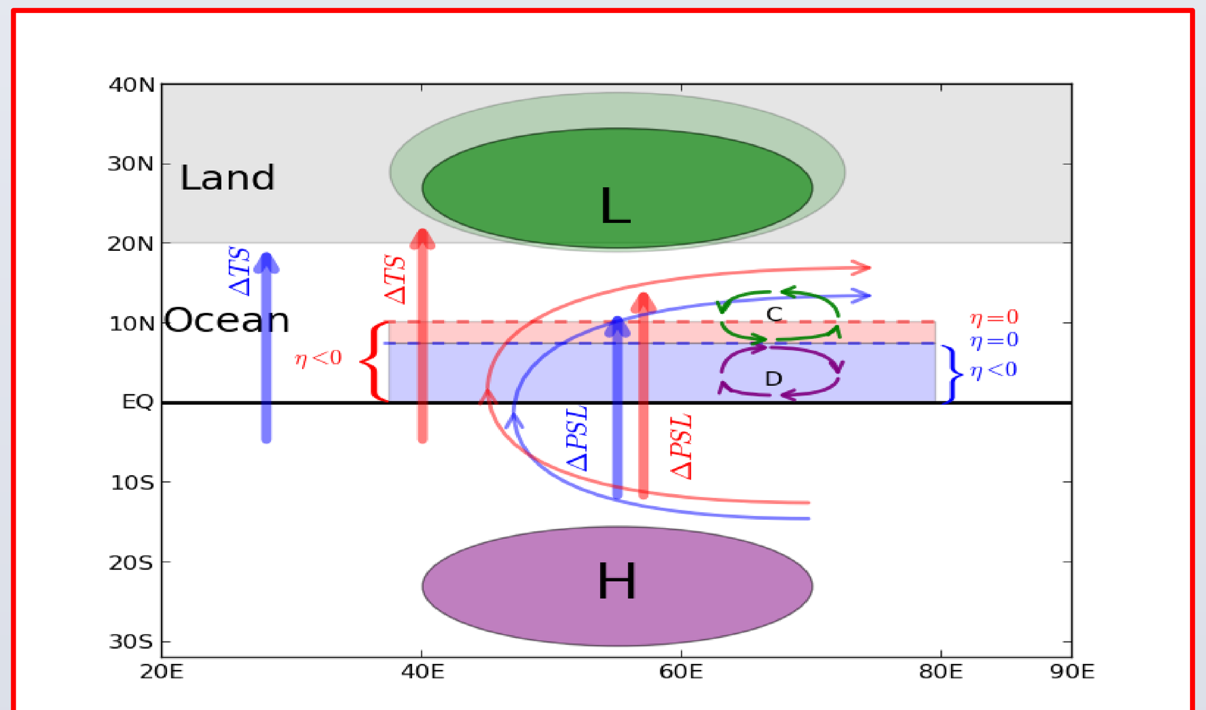


Figure 6: Linear trend (2006 – 2099) in Sea Level Pressure (Pa $decade^{-1}$) in RCP8.5 ensemble mean. Zonal mean of Sea Level Pressure trends are shown on right panel. Note the increased meridional pressure gradient over the Arabian Sea.

CONCLUSIONS



- The poleward shift in monsoon LLJ may be summarized as depicted in the schematic.
- The land surface experiences a faster rate of heating compared to the oceans, as the atmosphere warms under the influence of enhanced GHGs.
- The faster rate of heating over land results in a deepening of the low pressure area over land and subsequently strengthens the cross-equatorial pressure gradient.
- The stronger cross-equatorial pressure gradient pushes the low-level circulation and zero absolute vorticity contour further north. Poleward shift in η=0 will result in enhanced (decreased) area of divergence (convergence) north of equator.
- The poleward shift in LLJ and associated observed changes in precipitation over the West Coast of India raises concerns on the conservation of ecologically fragile Western Ghats region.