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Tropical-Extratropical Teleconnections in Boreal Summer: Observed Interannual Variability

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ABSTRACT

Maximum covariance analysis is performed on the fields of boreal summer, tropical rainfall and Northern Hemisphere (NH) 200 hPa height for the 62-year period of record 1948-2009. The leading mode, which appears preferentially in summers preceding the peak phases of the El Niño-Southern Oscillation (ENSO) cycle, involves a circumglobal teleconnection (CGT) pattern in the NH extratropical 200 hPa height field observed in association with Indian monsoon rainfall anomalies. The second mode, which tends to occur in summers following ENSO peak phases, involves a Western Pacific-North America (WPNA) teleconnection pattern in the height field observed in association with western North Pacific summer monsoon rainfall anomalies. The CGT pattern is primarily a zonally oriented wave train along the westerly waveguide, while the WPNA pattern is a wave train emanating from the western Pacific monsoon trough and following a great circle. The CGT is accompanied by a pronounced tropical-extratropical seesaw in the zonally-symmetric geopotential height and temperature fields and the WPNA is observed in association with hemispherically-uniform anomalies. These ENSO-related features modulate surface air temperature in both tropics and extratropics. ENSO also affects the wave structure of the CGT and WPNA indirectly, by modulating the strengths of the Indian and western North Pacific monsoons. Linear barotropic mechanisms, including energy propagation and barotropic instability of the basic state flow, also act to shape and maintain the CGT. The implications of these findings for seasonal prediction of the NH extratropical circulation are discussed.

It is well known that ENSO can affect the NH circulation during the boreal winter. Here we have shown that it can also excite a strong extratropical circulation response in the boreal summer preceding the peak phase of an El Niño or La Niña event and a weaker, but sometimes detectable response in the summer following the event. ENSO affects the extratropical circulation during the boreal summer by relocating the monsoonal heat sources.

Global scale co-variability between NH 200 hPa geopotential height (0-87.5ºN) and tropical rainfall (15ºS-30ºN) has been analyzed by applying Maximum Covariance Analysis (MCA) to a 62-year-long dataset consisting of JJA-means. This analysis yields a comprehensive picture of the global scale tropical-extratropical teleconnections that reveals how tropical heating anomalies force an NH extratropical response on the interannual timescale. Emphasis has been placed on assessing the role of the summer monsoons in mediating the response. In Fig. 1 we present a schematic diagram that highlights complementary roles of ENSO and monsoons in driving tropical-extratropical teleconnections during various phases of the ENSO cycle.

The leading MCA mode M1, which accounts for 47% of the squared covariance between tropical rainfall and NH 200 hPa height links the CGT pattern with precipitation anomalies over Indian monsoon regions. The

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CGT is mainly confined within the wave guide associated with the westerly jet stream. The centers of action of the CGT tend to occur at preferred longitudes, which is reproduced in the left hand panel of Fig. 1. The second MCA mode M2, which explains another 25% of the squared covariance, reflects the relationship between summer rainfall anomalies in the WNPSM and the WPNA teleconnection pattern (right hand panel of Fig. 1).

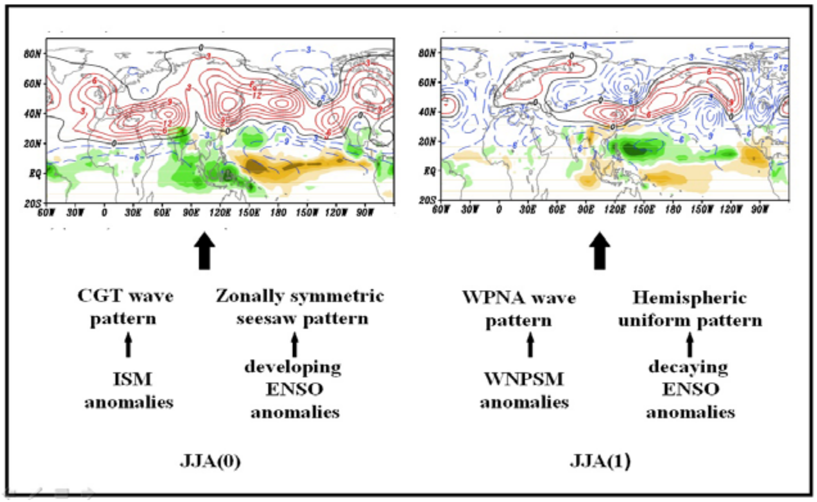

Fig. 1 Schematic showing the role of ENSO in organizing monsoon rainfall and the zonally-symmetric and wave components of the boreal summer (JJA) circulation in Year (0) preceding and Year (1) following the peak phases of the ENSO cycle. See text for further details.

The extratropical circulation patterns in M1 and M2 closely resemble the leading EOFs of the NH upper-tropospheric circulation. The CGT pattern (M1, EOF2) and the WPNA pattern (M2 and EOF1) both exert a substantial impact on surface temperature over tropical and extratropical land areas. The CGT pattern is linked to Indian summer monsoon variability, while the WPNA pattern is more connected with the WNPSM. The CGT explains most of interannual variability along the westerly jet. Thus, the CGT is the primary agent in conveying the influence of tropical thermal forcing to the NH extratropics.

M1 and M2 are associated with developing and decaying phases of extreme in the ENSO cycle, respectively. The strong tropical SST anomalies observed during the summer preceding the peak phases of the ENSO cycle excite a strong extratropical response. In the summers following the peak phase of the ENSO cycle, ENSO-related rainfall anomalies are too weak to produce a robust extratropical response. The asymmetry between the strength of the extratropical patterns in the pre- and post- peak phase summers is largely a reflection of the seasonality of the ENSO cycle itself, and, in particular, the predictability barrier in the boreal spring.

The circulation patterns associated with M1 and M2 both contain zonally symmetric and zonally asymmetric components (Fig. 1). The wave components of the CGT and WPNA patterns are mainly related to the ISM and WNPSM forcing, respectively. The zonally symmetric component exhibits a deep equivalent barotropic structure. M1 is marked by an out of phase relationship between tropospheric temperature anomalies in the tropics and extratropics while the zonally symmetric component of M2 tends to be spatially homogeneous throughout the tropical and extratropical NH. These zonally symmetric features exhibit a distinctive pattern of evolution in association with the ENSO cycle, with the tropical-extratropical seesaw prevailing in summers preceding the peak phase and the hemispheric uniform pattern prevailing in the summers following the peak phase. Tropical and extratropical land surface temperatures vary in a similar manner.

We have shown evidence suggesting that linear, barotropic mechanisms, including energy propagation and barotropic instability of the midlatitude basic flow, shape the structure of the CGT and contribute to its prominence. Such internally generated extratropical variability can exist in the absence of tropical forcing but may also be excited by tropical forcing.

Our results suggest that three different factors are instrumental in producing tropical-extratropical teleconnections during the boreal summer. ENSO forces a zonally symmetric response in the tropics and extratropics and it also modulates the rainfall in the ISM and other regional NH monsoons. The monsoons, in turn, act to excite the wave components of the CGT and WPNA patterns. Internal dynamics of basic state flow contributes to the characteristic structure of the CGT as well as to its maintenance.