Indian Ocean Double Inter-Tropical Convergence Zones and the Indian Summer Monsoon

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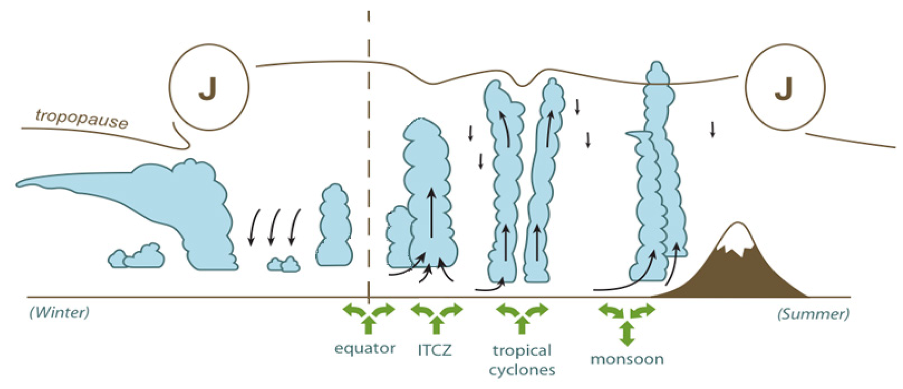
Abstract

The Inter-Tropical Convergence Zone (ITCZ) is a persistent band of organized convection in the tropics that arises due to the surface convergence of the Hadley cells. The location and intensity of the ITCZ is heavily influenced by sea surface temperature and low-level latent heat transport. The ITCZ undergoes an annual march across the equator, and during the summer moves north over India and the Bay of Bengal, affecting the Indian summer monsoon. Occasionally a second parallel band of convection forms to the south, referred to as a double-ITCZ. Double-ITCZs in the tropical east Pacific have been heavily studied, and their development is understood to be linked to seasonal changes in sea-surface temperature. The existence of double ITCZs over the tropical Indian Ocean is well documented, but the underlying mechanism is poorly understood. We develop an algorithm to identify this phenomenon in NOAA outgoing longwave radiation data, and create a thirty-year record of double-ITCZ occurrence. We then use this record to investigate linkages between summer-time double-ITCZ occurrence and intra-seasonal variability in the Indian summer monsoon, and discuss possible physical mechanisms.

1. Background

The Inter Tropical Convergence Zone (ITCZ) is a persistent convective feature over the tropical oceans, and is associated with the upward branch of the Hadley cells. The ITCZ is observable as a zonal band of convection in multi-day means of remote sensing products. Its exact structure and location changes with season, state of El Nino, and daily meteorological variability. Occasionally, two parallel bands of convection will form simultaneously, this is known as a Double ITCZ. This phenomenon is well documented and understood in the tropical East Pacific, but cases of DITCZs over the Indian Ocean have received relatively little attention. The presence of the Indian continent and seasonal convection associated with the summer monsoon make the atmospheric and ocean dynamics in this region unique, and DITCZ formation in this region is likely determined by several factors including sea surface temperature and cross equatorial flow [1,2]. We investigate this phenomenon and its interaction with the Indian summer monsoon.

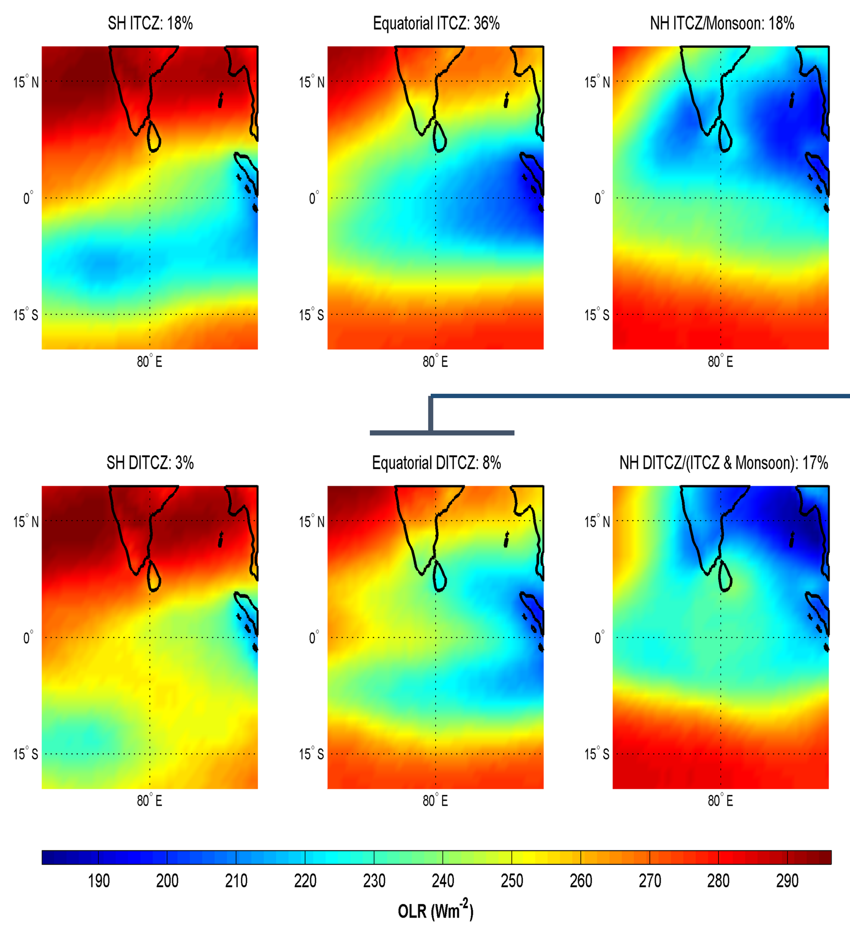


Schematic of various convective processes over the tropical Indian Ocean.

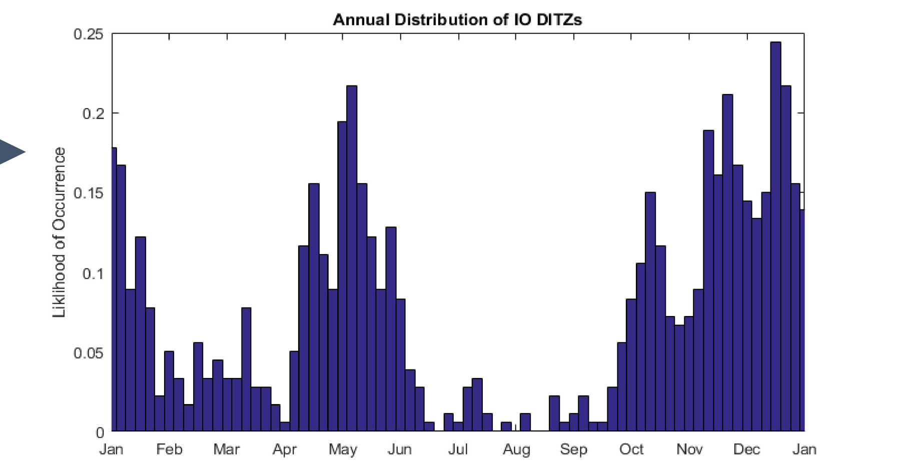
2. Detecting DITCZ Occurrences

Double ITCZs are observable in Outgoing Longwave Radiation (OLR) data where the associated high/cold cloud tops appear as low values. We have developed an algorithm [3] to detect cases of double inter-tropical convergence zones in a 35-year record of OLR observations. By cataloging past DITCZ occurrences we hope to gain insight in to the underlying physical processes.

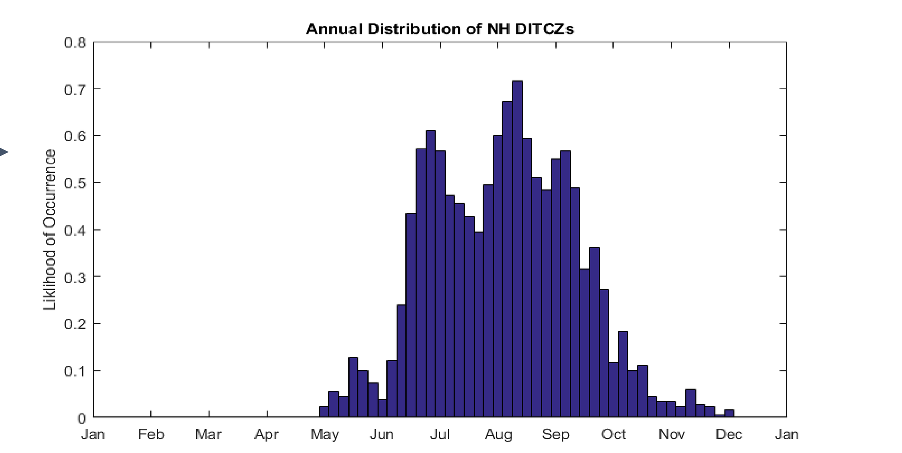
The detection scheme used here involves comparing 5-day averaged OLR to six different filter kernels, and classifying the data according to the best match. The comparison is done using a fuzzy logic based metric. The six filters used here represent single or dual bands of convection north, south and over the equator. Information about the frequency and shape of these different convective regimes is shown to the right.



Composited Outgoing Longwave Radiation Data (1979-2014) for six different convective regimes. The top and bottom rows are cases of single and dual bands of convection (DITCZs) respectively. The columns separate cases by latitude of the main convective bands. The middle bottom panel shows the Indian Ocean double ITCZ as defined in the literature [2,4]. The bottom right shows a frequent scenario in which there is strong convection over the Indian continent associated with the monsoon, and a weak, secondary band of convection forms over the equator.



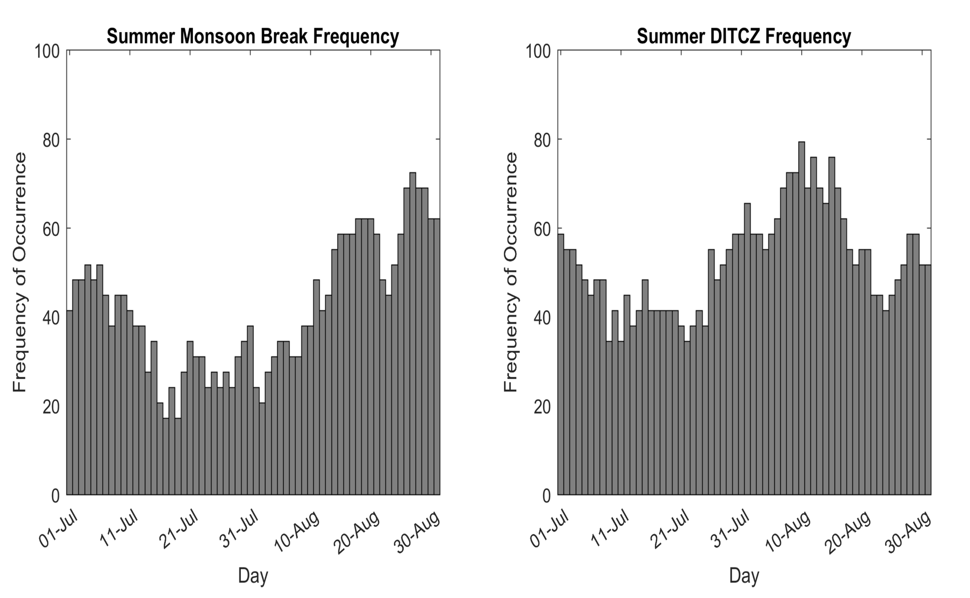
Probability density function of Double ITCZ occurrences over the tropical Indian Ocean, composited between 1979 and 2014. These cases are characterized by simultaneous bands of convection north and south of the equator and typically occur during the seasonal transition periods, with the majority occurring between October and January.

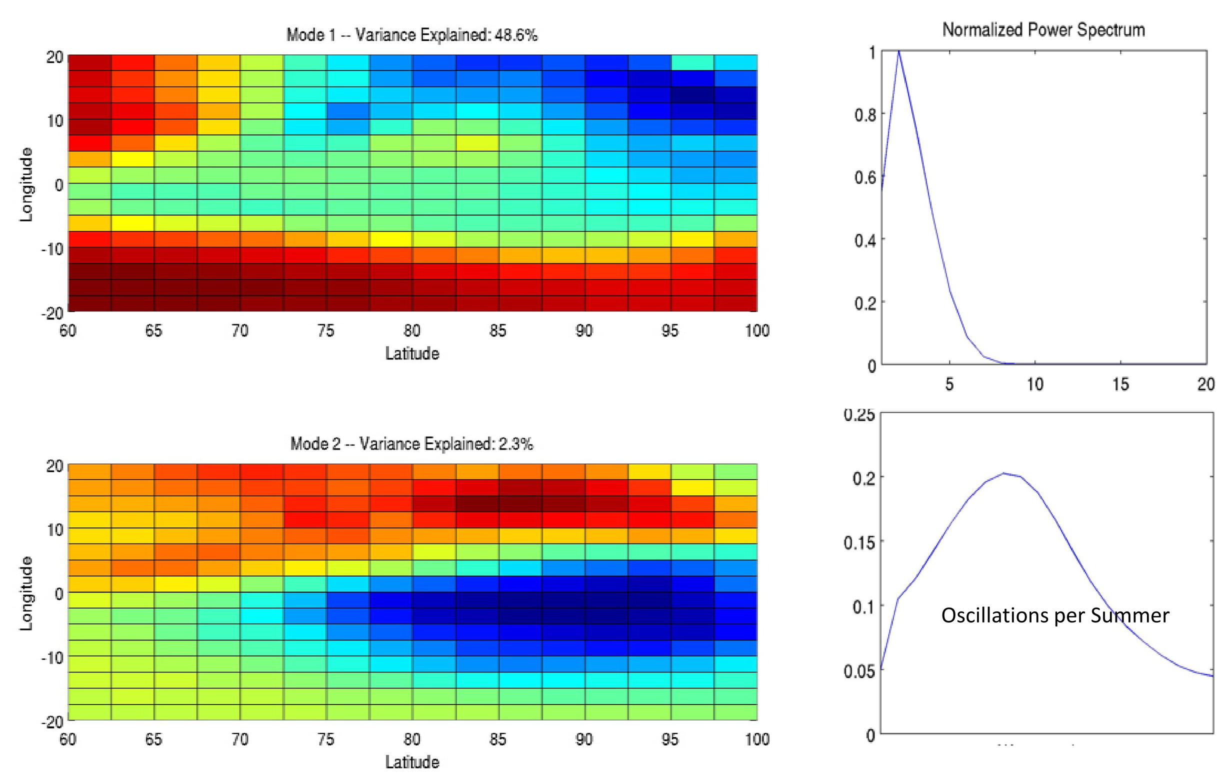


Probability density function of dual banded convection to the north of the equator. These cases occur almost exclusively during the summer monsoon season when the ITCZ has shifted to the north and the main convection is over the Indian continent. Occasionally a second band of convection forms near the equator.

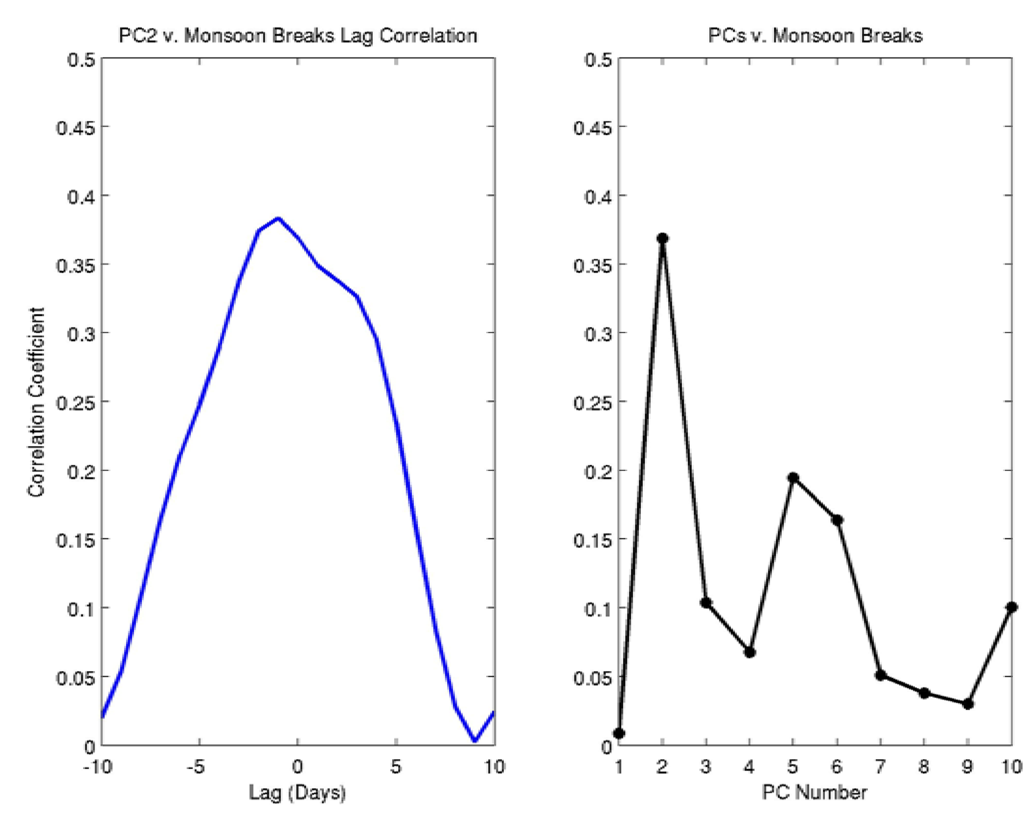
3. Relation to the Indian Summer Monsoon

The Indian summer monsoon undergoes multi-day breaks during which rainfall is significantly lower than the summertime average. The day-to-day variability in the summer monsoon has a significant regional impact and thus understanding how this variability occurs is important. We compare a time-series of historical breaks in the summer monsoon (derived for precipitation observations) to OLR data over the Indian Ocean. The climatologically averaged distribution of breaks in the summer monsoon has similar structure to the probability density function of dual banded convection to the north of the Equator.





Above, we perform an Empirical Orthogonal Function (EOF) analysis of summertime (July-August) OLR data over the Indian Ocean. The first two (dimensionless) EOFs (left) and the normalized power spectra of their associated principle components (right) are shown. The first EOF undergoes 1 oscillation per season and shows low OLR values over the Indian continent and the Bay of Bengal. It likely describes the annual onset of the summer monsoon. The second shows enhanced convection (low OLR) over the equator and reduced convection to the north. It oscillates at higher frequency, 5-15 times per summer and may be associated with breaks in the monsoon and DITCZs.



Right: instantaneous time correlation between the top ten principle components and monsoon breaks. The second principle component shows the highest correlation. Left: lagged correlations between the second principle component and breaks in the monsoon. There is high correlation even at multi-day lags indicating that this EOF (associated with equatorial convection during the monsoon) may be a good predictor for monsoon breaks.

4. Conclusions / Future Work

Dual parallel bands of convection occur frequently over the tropical Indian Ocean. This is not limited to equatorial DITCZs, and parallel bands of convection often occur north of the equator during the Indian summer monsoon. Formation of a secondary band of convection over the equator during the summer is correlated with breaks in the monsoon, and further study may lead to a better understanding of the intra-seasonal variability of the monsoon.

Future Research Questions :

- What initiates equatorial convection during the monsoon, and how does the meridional circulation change when it is occurring?
- What processes (specifically what changes in SST and cross equatorial flow) precede formation of equatorial DITCZs over the Indian Ocean?
- Can changes in equatorial convection be used to predict changes in the intensity of the summer monsoon?

5. References /Acknowledgements

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