Application of Complex Networks to the Study of Tropical Cyclones

Multi-layer network for sub-seasonal prediction
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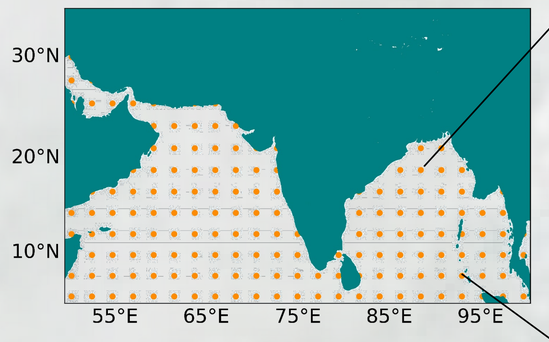
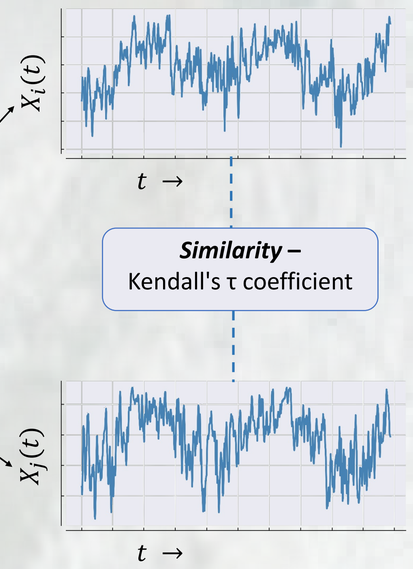
TROPICAL CYCLONE DETECTION



ERA5 Reanalysis Mean Sea Level Pressure (MSLP) anomaly , $0.75° \times 0.75°$, Land-masked.



- **Evolving Networks:**
- **Link Strength:** 5% strongest correlations as links.
- **Network measures:**
  - **DEGREE** k – No. of connections of a node in a network

$$k_i = \sum_{j=1}^{n} A_{ij}$$

  - **LOCAL CLUSTERING COEFFICIENT** C – measure of the degree to which nodes in a graph tend to cluster together

$$C_i = \frac{\sum_{j,h} A_{ij} A_{ih} A_{jh}}{k_i(k_i - 1)}$$

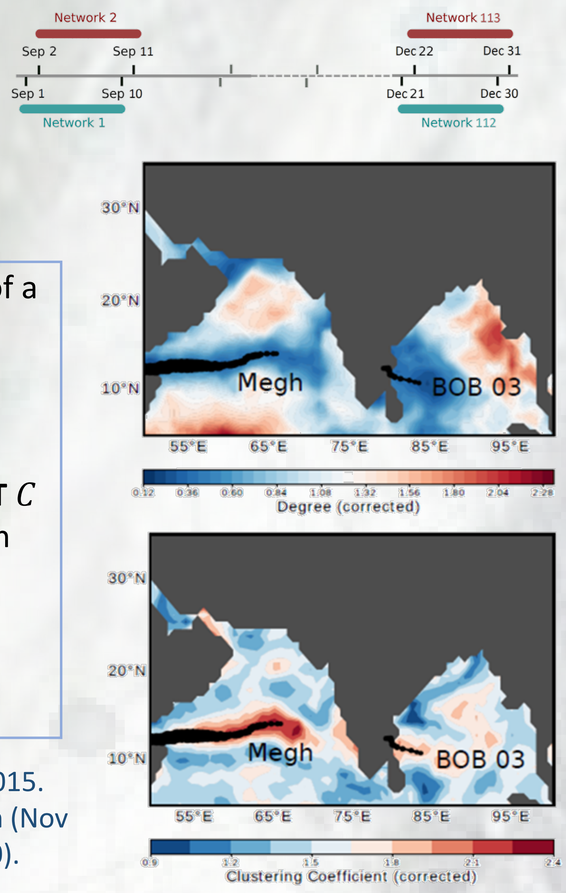


Fig: Network snapshot for Nov 3-12, 2015. Extremely Severe Cyclonic Storm **Megh** (Nov 5-10) and Deep Dep. **BOB 03** (Nov 8-10).

Key Finding: Network indicators have striking connection with cyclone tracks.

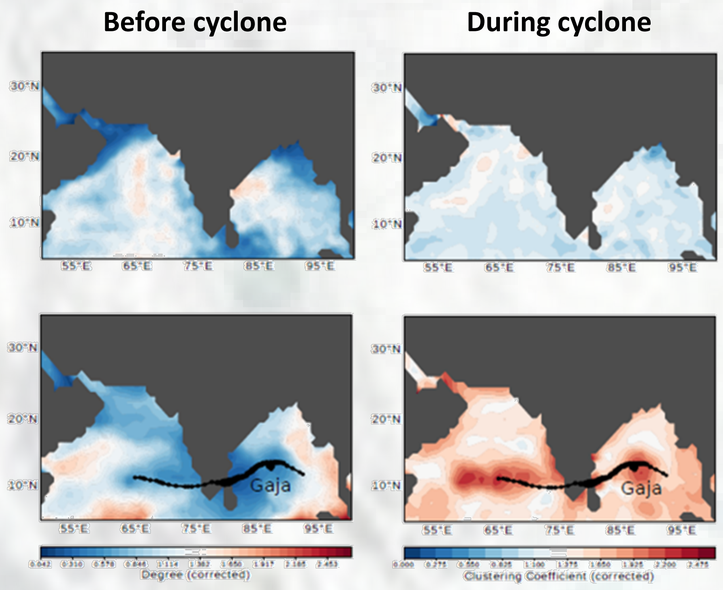
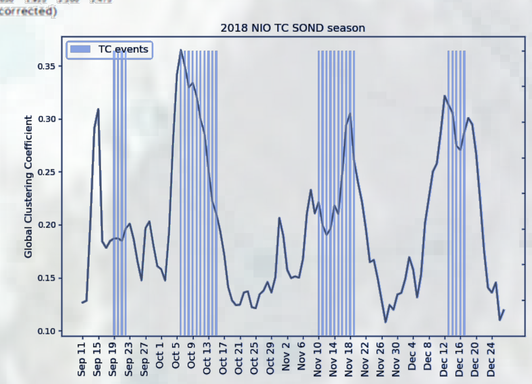


Fig: Network snapshot **before** (*top* panel; Oct 29-Nov 7, 2018) and **during** (*bottom* panel; Nov 10-19, 2018) Very Severe Cyclonic Storm **Gaja** which occurred during the period Nov 10-19, 2018.



Key Finding: Regional weather system undergoes a characteristic spatial re-organization in the connectivity structure during a cyclone – formation of "*localized structures*" of high connectivity.

Gupta, S., *et al.*,. *Clim Dyn* **57,** 3355–3364 (2021).

BINARY CYCLONE INTERACTION

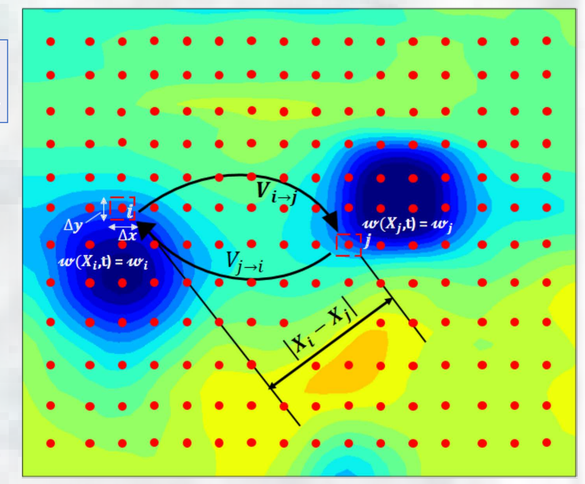
- **Directed Evolving Networks:**

ERA5 Reanalysis Relative Vorticity (ω) at different pressure levels (500-850 ysis hPa), $0.5° \times 0.5°$, 3-hrly.

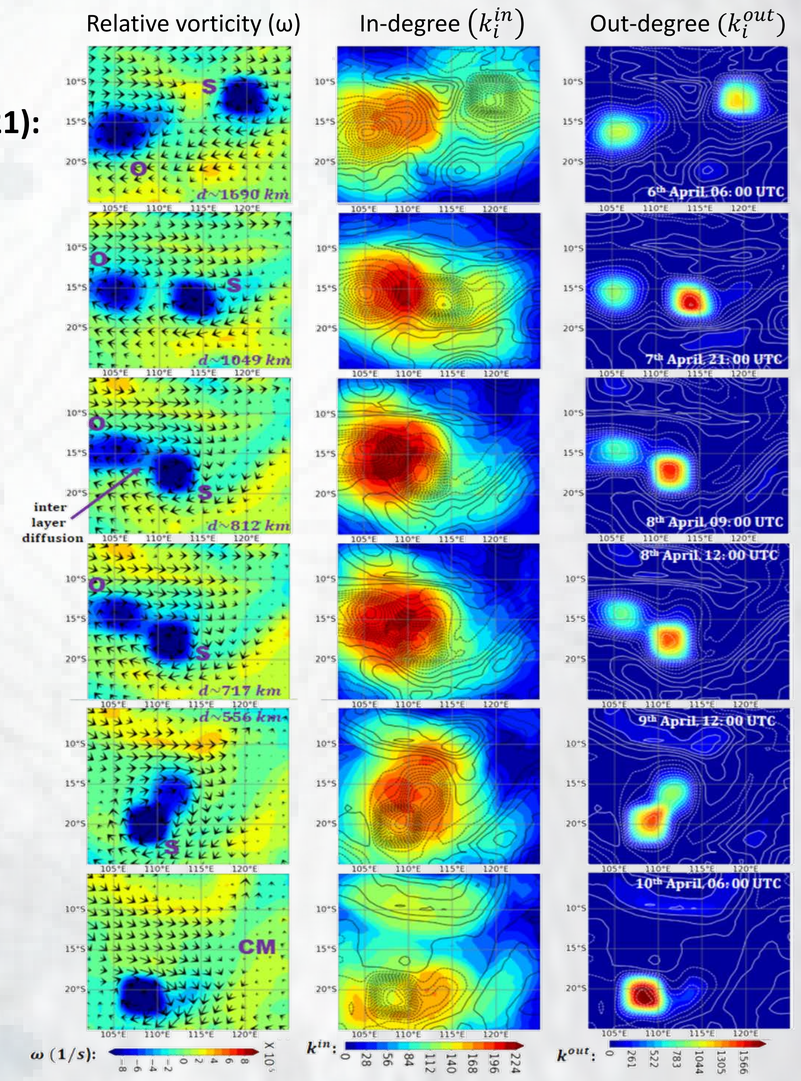
- **Nodes:** Flow elements at grid points.
- **Links** ($V_{i\rightarrow j}$): Velocity Induced by vorticity of node i on node j, estimated using *Biot-Savart Law*,

$$V_{i\rightarrow j} = \frac{|\gamma_i|}{2\pi |X_i - X_j|}, \text{ where } \gamma_i = \omega(X_i)\Delta x \Delta y$$

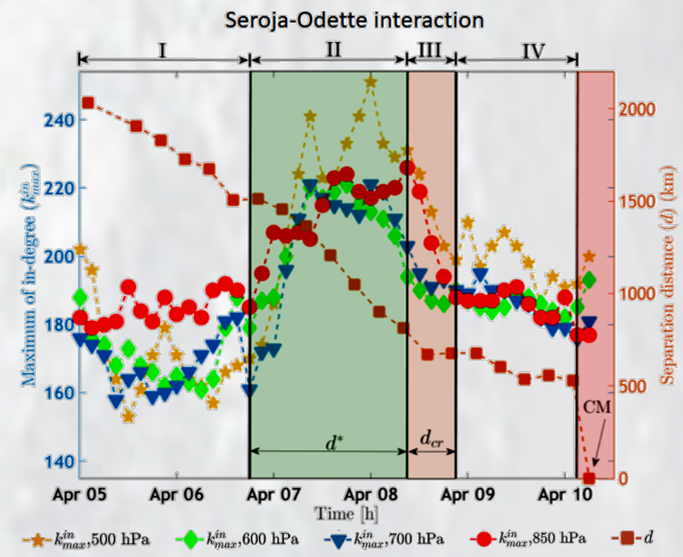
- ***Directed:*** $V_{i\rightarrow j} \neq V_{j\rightarrow i}$
- ***Unweighted:*** Highest 5% induced velocities considered for $V_{i\rightarrow j} \rightarrow A_{ij}$



- **Network measures:**
  - **IN-DEGREE** k_i^{in} – No. of incoming connections of a node in a network $k_i^{in} = \sum_{j=1}^{n} A_{ji}$
  - **OUT-DEGREE** k_i^{out} – No. of outgoing connections of a node in a network $k_i^{out} = \sum_{j=1}^{n} A_{ij}$
- **Seroja-Odette Complete Merging (CM) (Apr 6-10, 2021):**
  - **In-degree increases** as the cyclones come closer.
  - **In-degree decreases** again when cyclones are closer than a certain critical distance (merging starts).
  - Highest **Out-degree** → Cyclone which **dominates** the interaction field.
  - Network measures can quantify the changes during the interaction between two cyclones.



Key Finding: Network indicators are *better candidates* than the separation distance to classify the stages of binary interaction before a cyclone merger.



De, S., Gupta, S., et al. (2022), arXiv:2205.11789 (*Under Review*).

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