Loop Current Transport and Dispersal dynamics in the Gulf of Mexico

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Abstract

Transport, connectivity, and dispersal both within and outside of the Gulf of Mexico impact important processes such as biological and pollutant dispersal. The Loop Current is a key flow feature within the Gulf of Mexico that affects transport. This research pairs Network Theory and Lagrangian oceanographic modeling (Lagrangian Flow Networks, LFN) to study the connectivity within the Gulf as a function of the Loop Current state. Surface-following particles are used to simulate Lagrangian transport over the observational record using a HYCOM ocean model reanalysis simulation coupled with the LFN particle tracking model computed on TACC supercomputers. The particle simulations are used to determine regions of connectivity, or hydrodynamic provinces, as a function of the Loop Current state, using machine learning. These provinces inform us about biological and pollutant transport variability, such as larval connectivity and harmful algal blooms.

1. The Gulf of Mexico (GoM)

Large, productive, warm-water sea; home to a multitude of habitats and organisms

The LC is a dominant oceanographic feature in the GoM.

<u>Three main states:</u>

1. Retracted, direct entry and exit
2. Extended, LC extends northward before exiting
3. Detached, transitional state where the LC sheds an eddy

The Loop Current affects crucial processes within and outside of the GoM relevant to socioeconomically, including:

- biological transport
- retention processes
- and pollutant transport

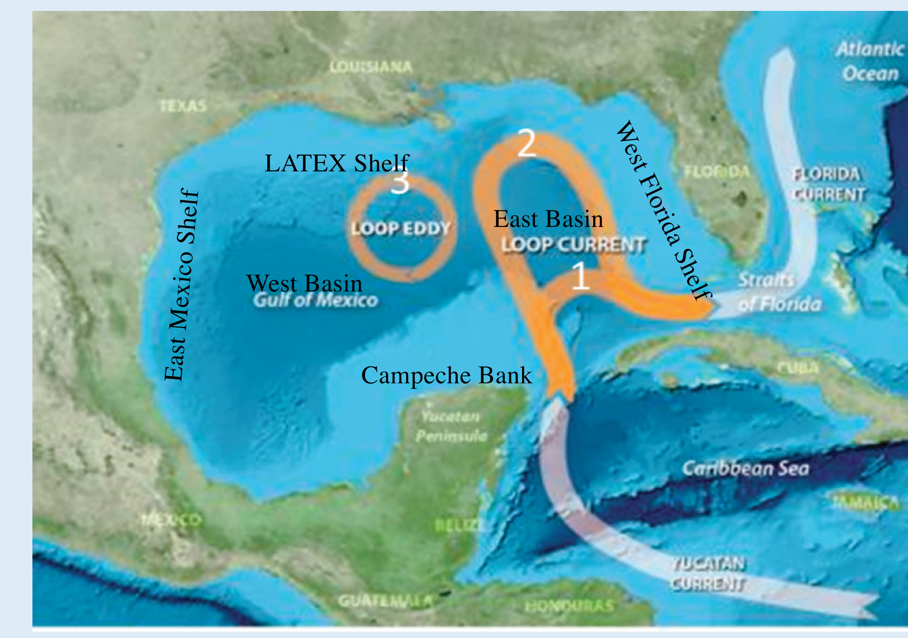

Figure 1: Loop Current System showing the Loop Current in a 1) retracted state, 2) extended state, with 3) a typical LC eddy (NASEM, 2018). Black text labels indicate areas of interest for this research.

Hypothesis: The LC sets up regular flow patterns in the Gulf of Mexico affecting transport and dispersal.

2. Lagrangian Flow Network (LFN)

TACC was used to run the LFN, which is a Lagrangian particle dispersal model paired with network theory tools (Rossi et al., 2014)

- Transport by a continuous, time-dependent, 2- or 3- dimensional flow (ocean or atmosphere)
- Set of point-like objects (nodes) and pairwise connections among them (links)

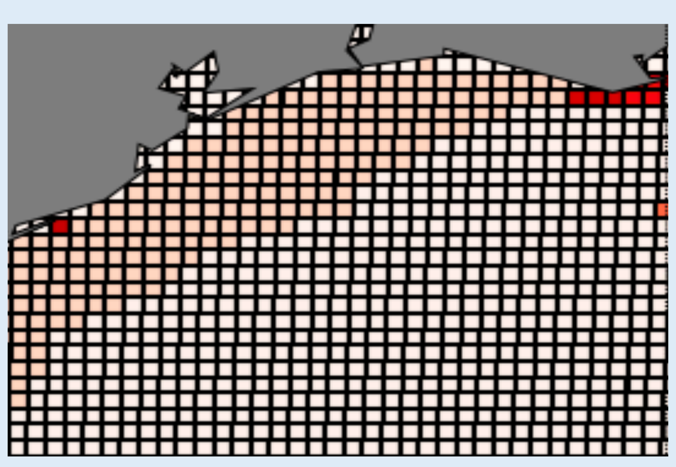

Figure 2: <u>Discretization: from continuous to point-like</u>
Section of the GoM grid
Nodes are defined as 2-D boxes covering the whole domain.
Node size = 1/10°

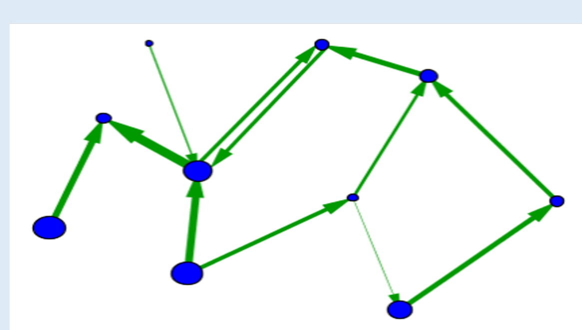

Figure 3: <u>Network: links & weights</u> Directional link is est. if an exchange of fluid occurs among 2 nodes.
The weight of such link is proportional to the amount of fluid transported

[Rossi et al., 2014]

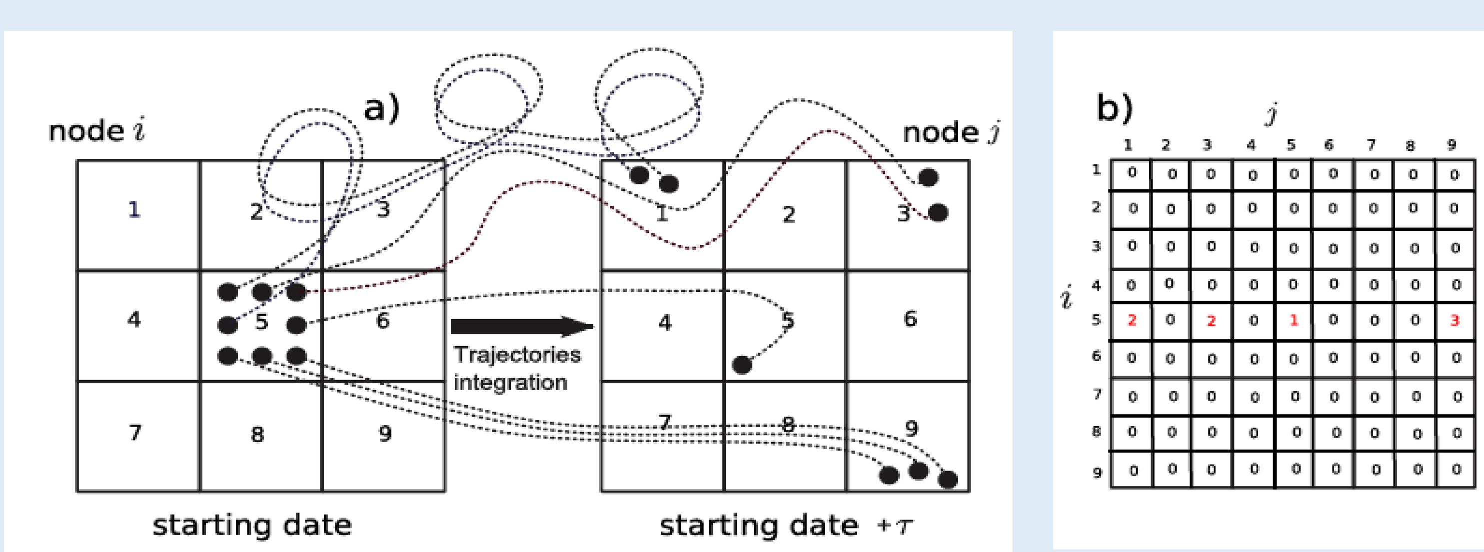

Figure 4: <u>Matrix Construction</u>
a) Particles begin in node *i* . Trajectory integration is applied over timescale, τ. Particles end in node *j*
b) Matrix output is grid *j* x *i*

[Ser-Giacomi et al., 2015]

3. Hydrodynamic Provinces

Community detection with *Infomap*: finds the sets of nodes that are strongly connected among the set and weakly connected outside the set

- Hydrodynamic provinces in which particles are more likely to disperse within the province rather than to other provinces, for a given timescale, τ.

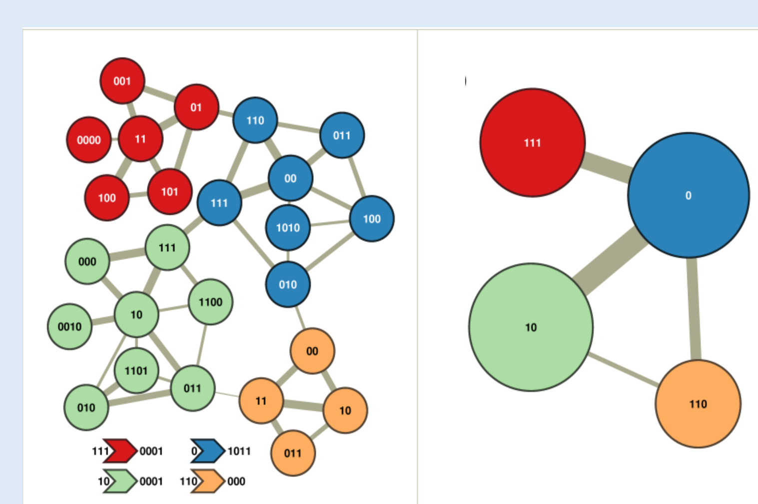

Figure 5: Community detection method

[Rosvall and Bergstrom, 2008]

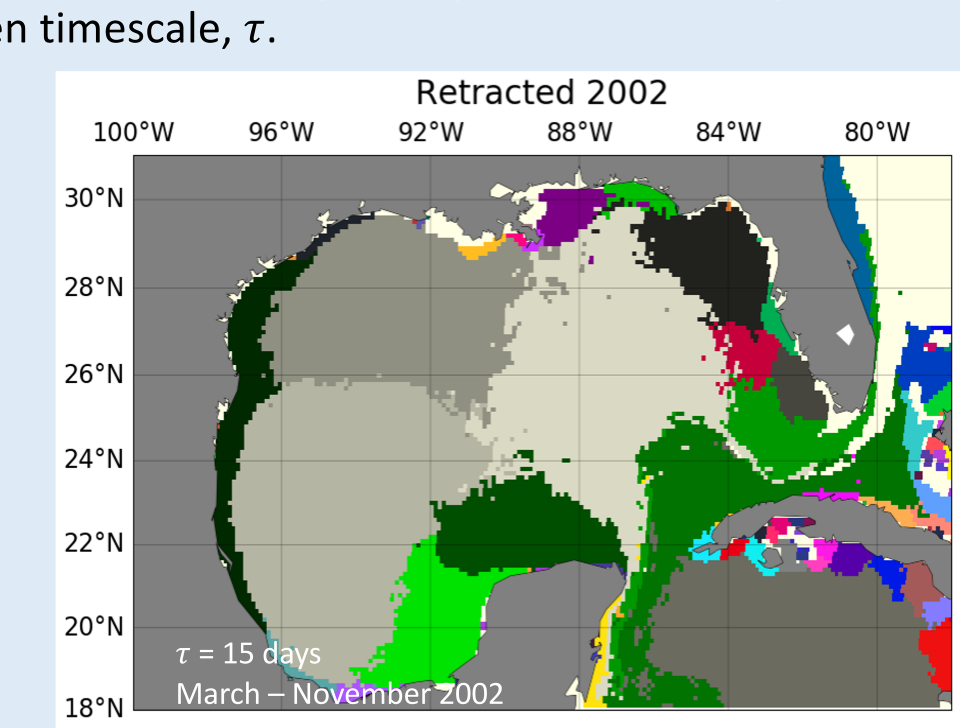

Figure 6: Retracted hydrodynamic provinces in the GoM

[Ser-Giacomi et al., 2015]

4. LFN Composites

Hydrodynamic provinces are determined by compositing matrix files from the LFN integration

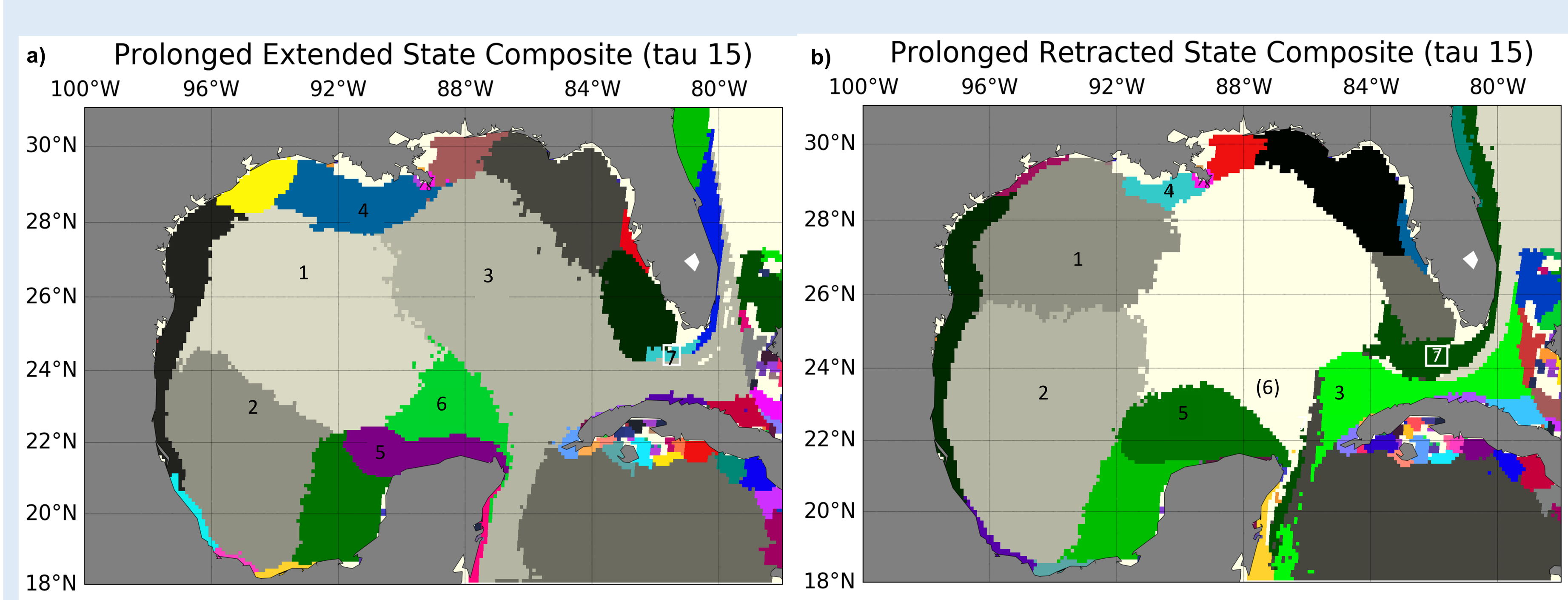

Figure 7: A composite of all the persisting a) extended states and b) retracted states from HYCOM GoM Reanalysis (1993 – 2012) with numbers notated on provinces for comparison between the two plots.

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References

Brenner, J., Voight, C., Mehlman, D., & Zaiken, I. B. (2016). Migratory Species in the Gulf of Mexico Large Marine Ecosystem: Pathways, Threats and Conservation. *The Nature Conservancy, Arlington, 93 Pp.*, 100.

Love, M., Baldera, A., Yeung, C., & Robbins, C. (2013). *The Gulf of Mexico Ecosystem: A Coastal and Marine Atlas*. New Orleans, LA: Ocean Conservancy, Gulf Restoration Center.

Lugo-Fernández, A., Leben, R. R., & Hall, C. A. (2016). Kinematic metrics of the Loop Current in the Gulf of Mexico from satellite altimetry. *Dynamics of Atmospheres and Oceans*, *76*, 268–282. https://doi.org/10.1016/j.dynatmoce.2016.01.002

National Academies of Science, Engineering and Medicine. (2018). *Understanding and Predicting the Gulf of Mexico Loop Current: Critical Gaps and Recommendations*. National Academies Press. https://doi.org/10.17226/24823

Rossi, V., Ser-Giacomi, E., López, C., & Hernández-García, E. (2014). Hydrodynamic provinces and oceanic connectivity from a transport network help designing marine reserves. *Geophysical Research Letters*, *41*(8), 2883–2891. https://doi.org/10.1002/2014GL059540

Rosvall, M., & Bergstrom, C. T. (2008). Maps of random walks on complex networks reveal community structure. *Proceedings of the National Academy of Sciences*, *105*(4), 1118–1123. https://doi.org/10.1073/pnas.0706851105

Ser-Giacomi, E., Rossi, V., López, C., & Hernández-García, E. (2015). Flow networks: A characterization of geophysical fluid transport. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, *25*(3), 036404. https://doi.org/10.1063/1.4908231

Weisberg, R. H., & Liu, Y. (2017). On the Loop Current Penetration into the Gulf of Mexico. *Journal of Geophysical Research: Oceans*, *122*(12), 9679–9694. https://doi.org/10.1002/2017JC013330