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Sub-Mesoscale Currents and Contaminant Analysis in the Mediterranean Sea Using Markov Chains

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Goals:

- Develop a rapid, data-driven framework for forecasting the dispersion of marine contaminates in the Eastern Mediterranean Sea, based on Markov chain Models.
- Identify and visualize dynamic oceanic provinces, highlighting transport boundaries and connectivity patterns shaped by regional flow structures.
- Estimate time of moving between provinces.
- Asses the impact of spatial resolution by comparing simulation at different grid scales, emphasizing the role of sub-mesoscale currents in pollutant transport.
- Analyze seasonal variability.

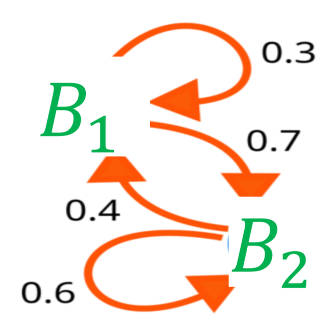
Particles Release Simulation

- Simulation is done by *Parcels* and velocity data recordings per season (summer, winter) and grid resolution (300m, 3km)
- 37 days of recordings, 1 sample/hr
- 2,500,000 particles in total

$$P_{ij} \approx \frac{\#\,of\ particles\ in\ B_i\ at\ t\ that\ evolve\ to\ B_j\ at\ t+T}{\#\,of\ particles\ in\ B_i\ at\ t}$$

Construct a Transition Matrix *P*, push forward to get next state:

$$\pi^{(1)} = \pi^{(0)} \cdot P$$



Lagrangian Geography

- Transition matrix spectral analysis
- Clustering provinces in the Mediterranean sea with "Sparse EigenBasis Approximation" (SEBA) Algorithm and K means method
- Compare between seasons, and grid resolution

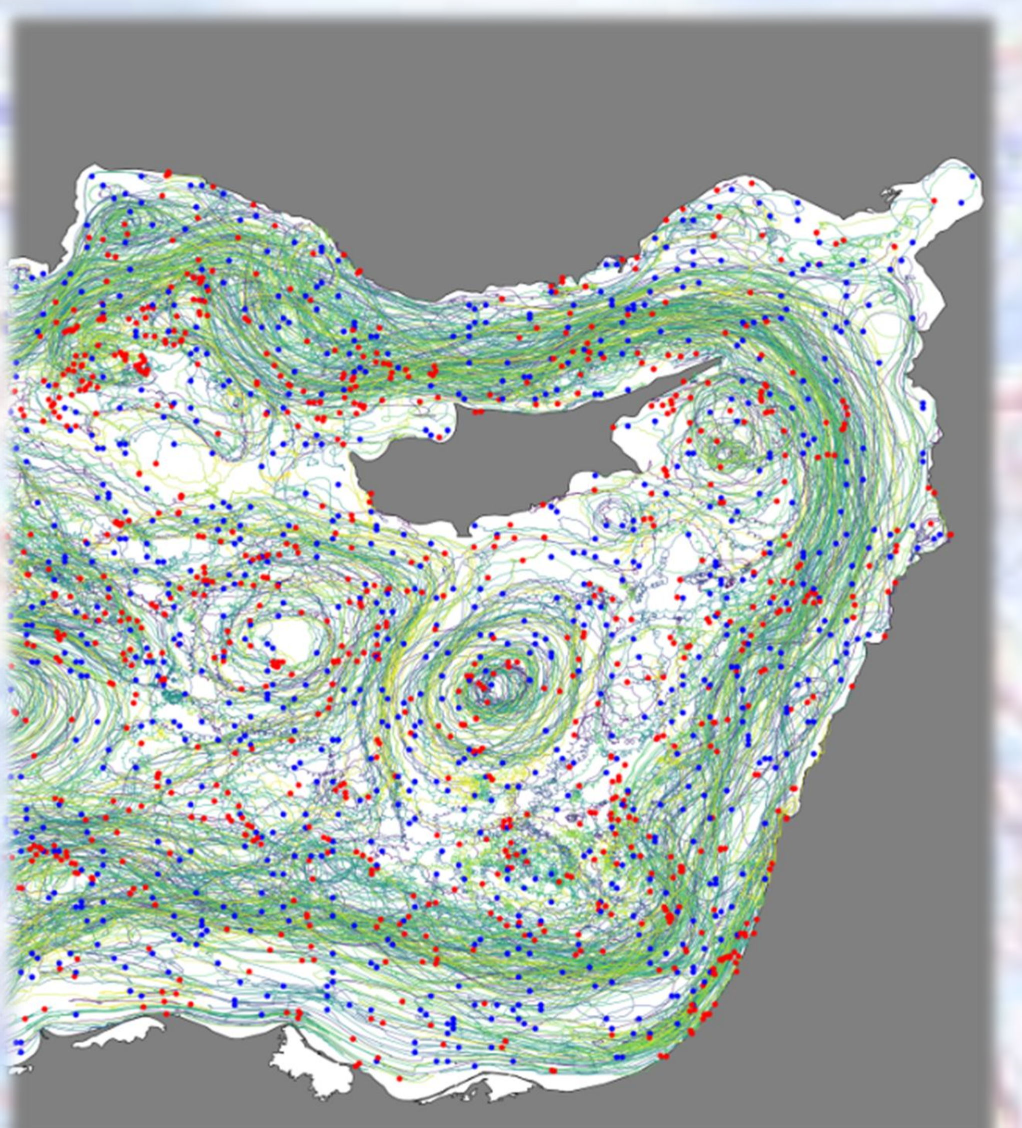
Hitting Time Map / Connectivity Map

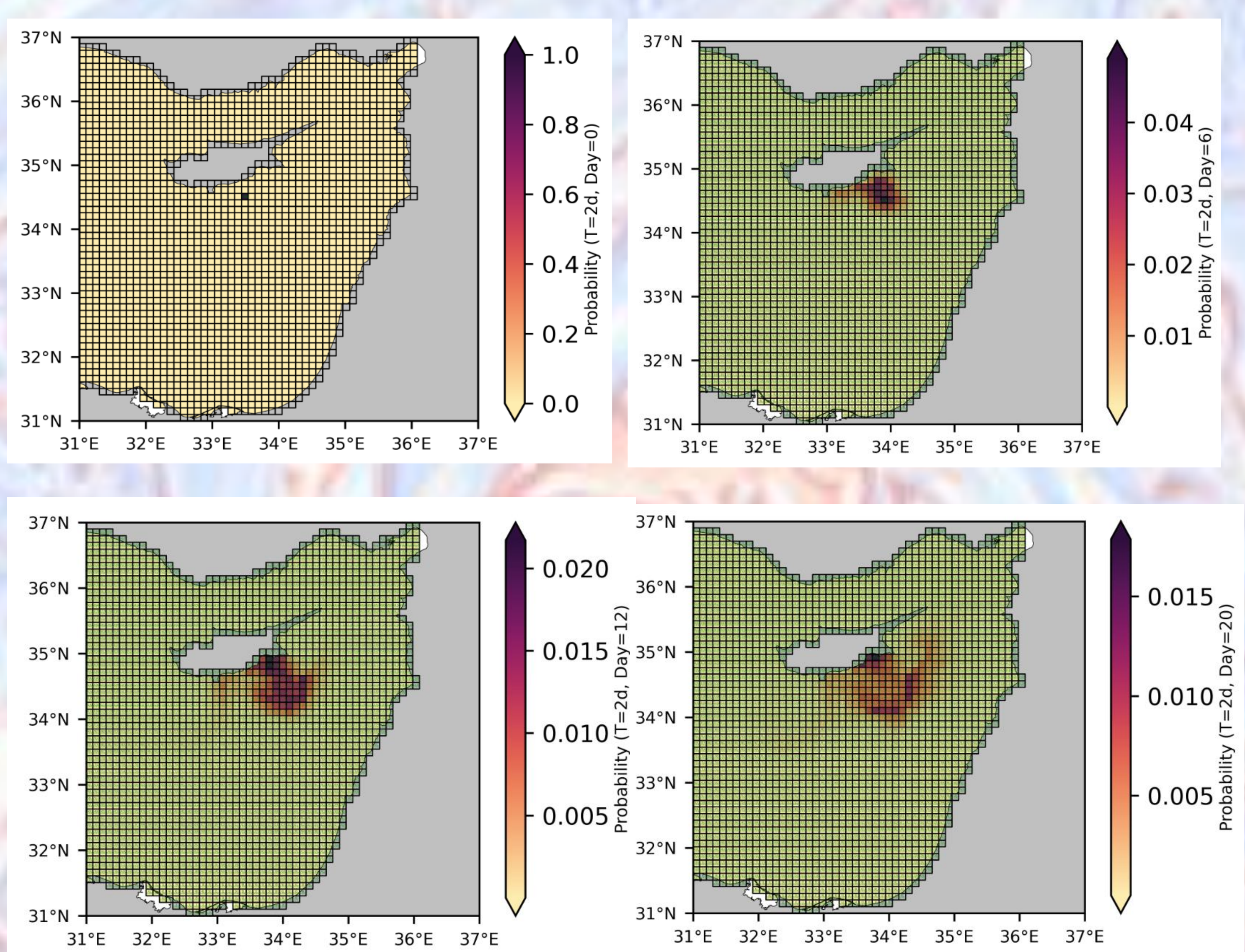
- Estimate the transition time (tau) between provinces (in days).

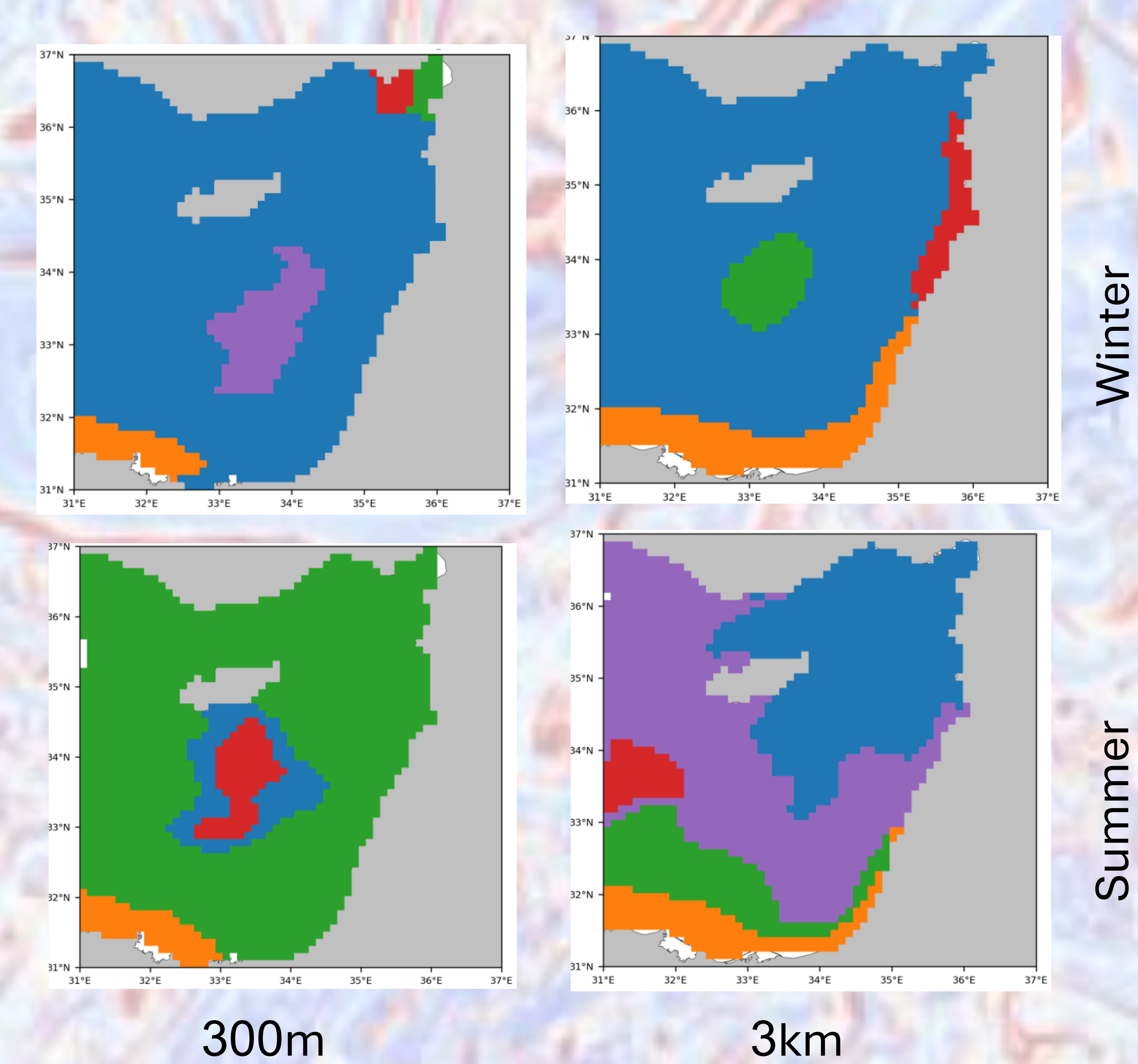
Define $A = \Omega \setminus B$ — all boxes *not* in province B

$\tau_i = 0$ if $i \in B$ $\quad \tau_i = T + \sum_j P_{ij}\tau_j$ if $i \notin B$

Solve the system: $(\mathrm{Id} - P|_A)\cdot\tau = T \cdot \mathbf{1}$







Destination

Source	a	b	c	d
a	0	42	89	18
b	21	0	73	19
c	61	61	0	18
d	18	19	18	0