Persistence of dispersal kernel features in the Florida Keys under average and extreme climatic conditions

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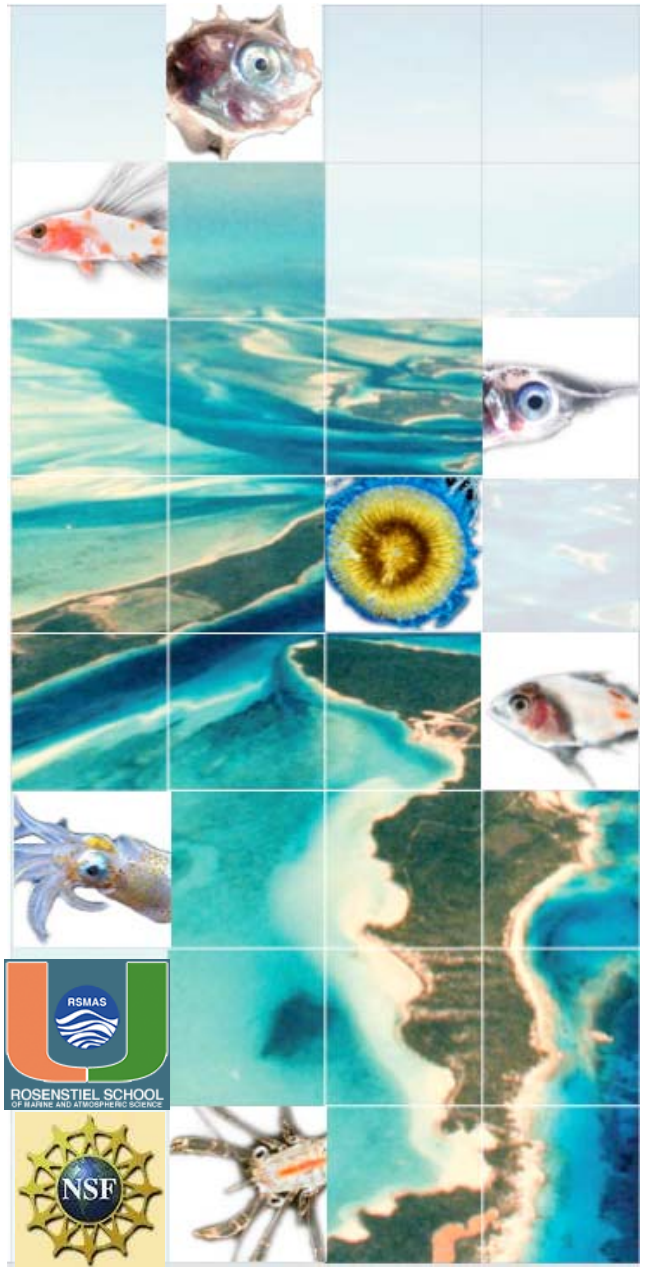


Linking Science to Management
A Conference & Workshop on the Florida Keys Marine Ecosystem
October 19-22, 2010 | Duck Key, Florida | Hawks Cay

Problem & Questions

Circulation in the Florida Keys is highly dynamic with eddy evolution linked to the meandering of the Florida Current

➡ Dispersal kernels, the function that describes the probability of dispersal, may vary spatially and temporally, possibly differing among spawning events

–can we quantify this variability and is there local retention?

–are there any persistent (**predictable over space**) larval dispersion features?

–what are the locations and related processes that accumulate or disperse larvae over the coral reef track?

–what is the cumulated impact of hurricanes perturbation?

The Connectivity Modeling System (CMS)

A Flexible IBM to Measure Dispersal Characteristics and Marine Population Connectivity

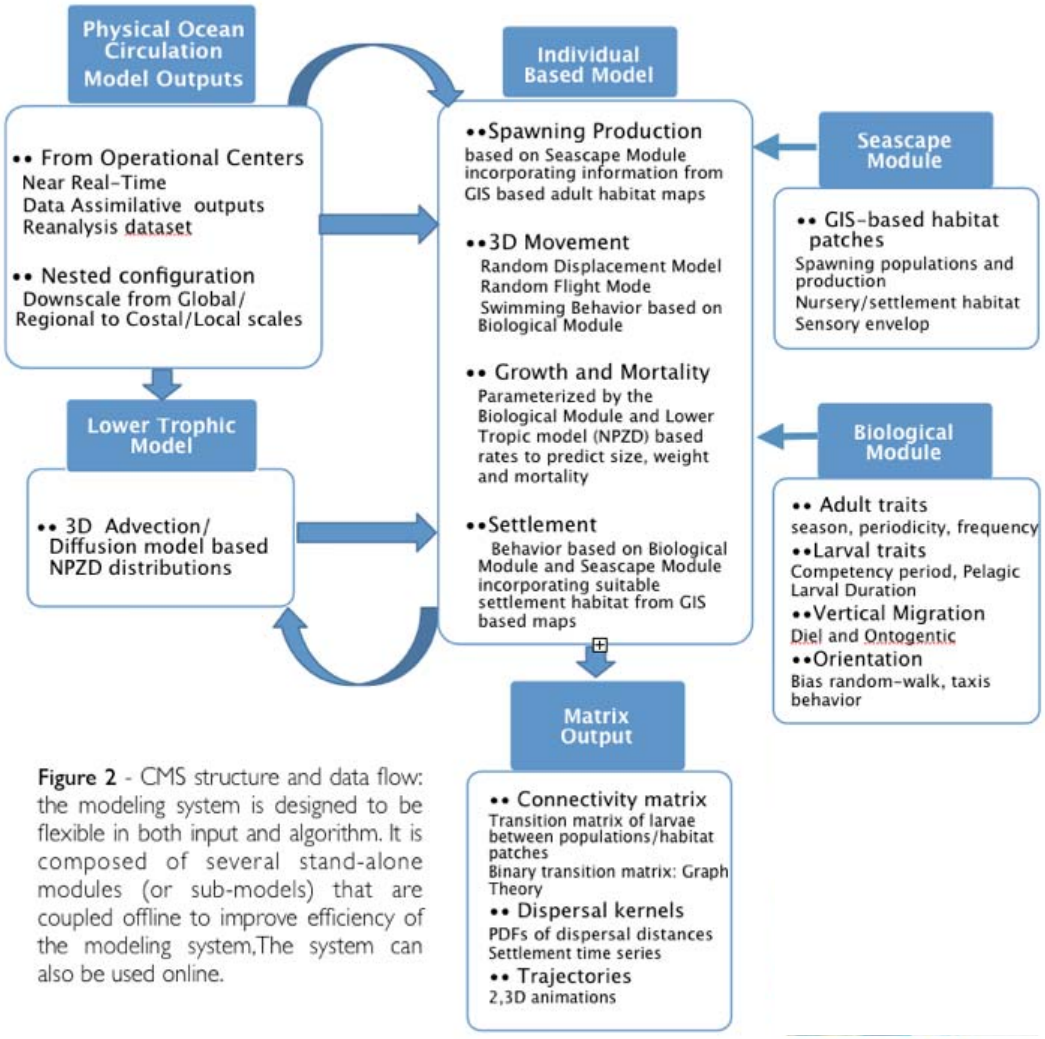


Figure 2 - CMS structure and data flow: the modeling system is designed to be flexible in both input and algorithm. It is composed of several stand-alone modules (or sub-models) that are coupled offline to improve efficiency of the modeling system,The system can also be used online.

Some innovative features

✓ Is circulation Model Neutral - can be used with outputs from several popular ocean circulation models. Information from circulation models is internally regridded to a regular Longitude-Latitude-Depth describing the study region.

✓ Is Multi-Scale: Can be run in a nested configuration for regional connectivity studies. Information from several coastal models nested within a given regional model can be used to focus resolution at specific locations

✓ Uses community tools such as NetCDF and OPeNDAP to simplify data management. CMS is OPeNDAP enabled - required inputs are downloaded on-the-fly from Ocean Reanalysis and Near-Real-Time ocean forecasting centers.

✓ Can be used offline and online: Primarily designed to be used as an offline tool. However, efforts are underway to couple online CMS to ocean models using Earth System modeling Framework (ESMF)

✓ Has flexible biological, GIS-based habitat, and genetic matrix-based modules: The CMS is a spatially-explicit, coupled physical-biological IBM with particle swimming behavior and trophic levels interactions (NPZ).

✓ The CMS Matrix NetCDF Output is designed for population connectivity studies

Ocean circulation module
nested FKEYS-HYCOM 1/100º coupled to multi-scale CMS

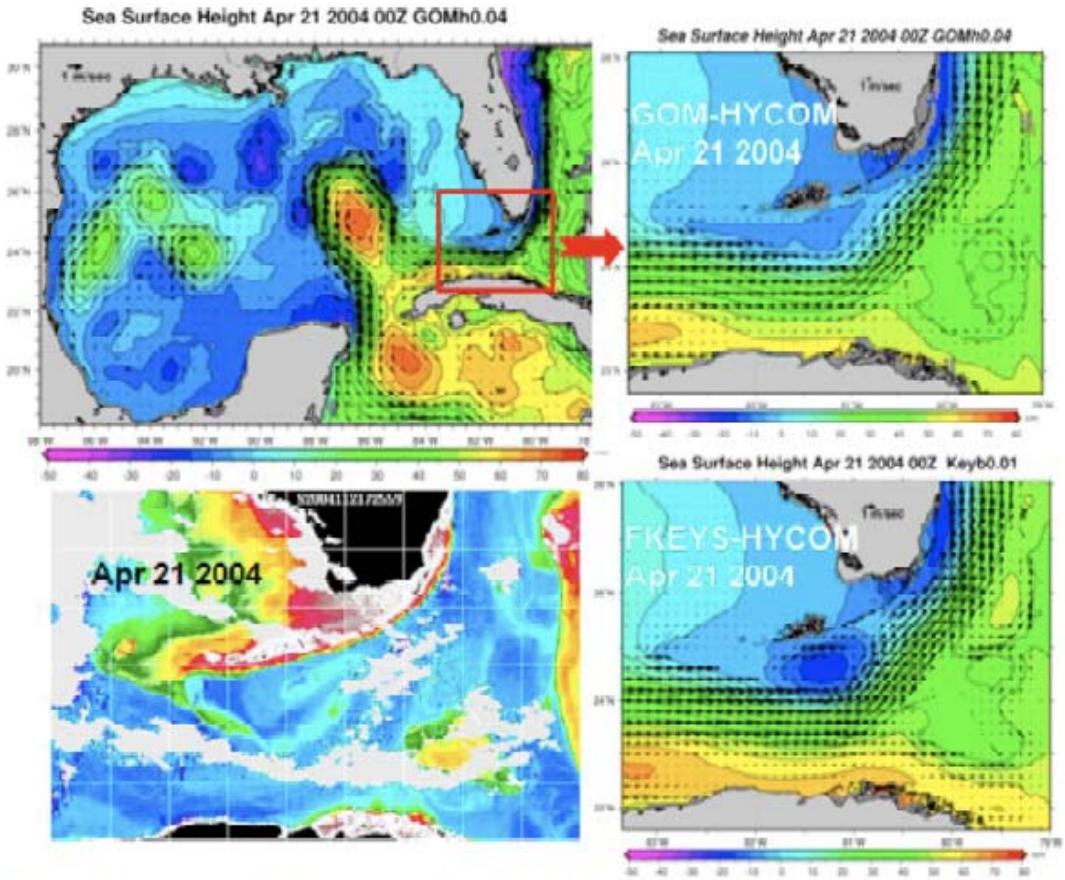


Figure C-2. Simulated Sea Surface Height (SSH) and surface current with GOM-HYCOM on Apr 21, 2004 (top left: full domain, top right: subdomain of FKEYS shown with red box), satellite-observed ocean color image from SeaWiFs (bottom left), and simulated SSH and surface current with FKEYS-HYCOM.

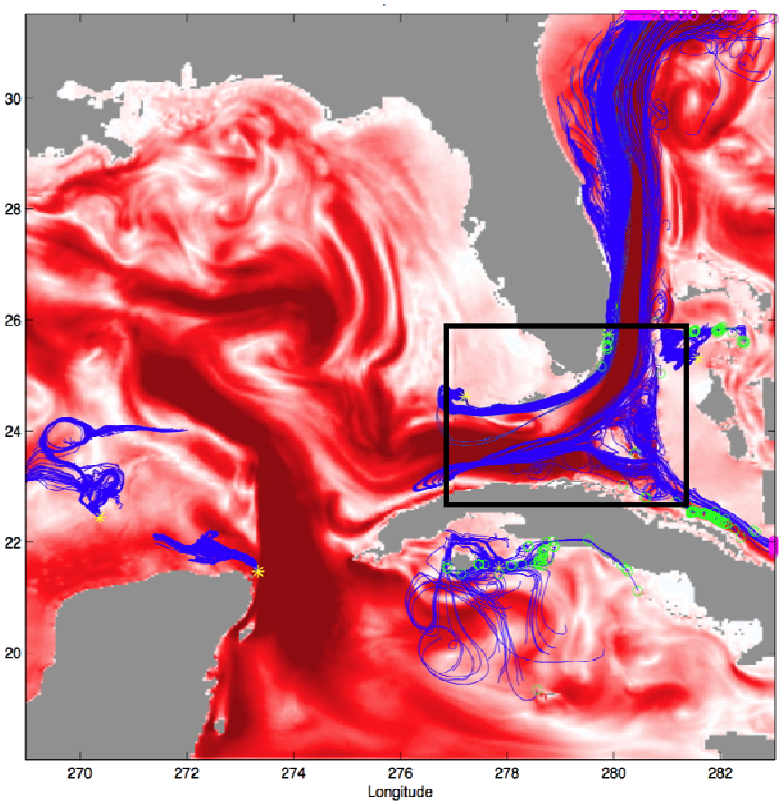
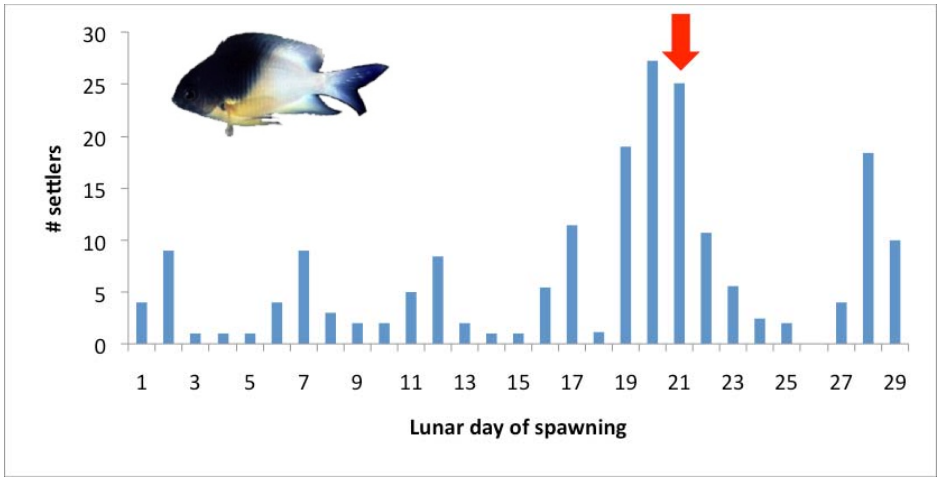
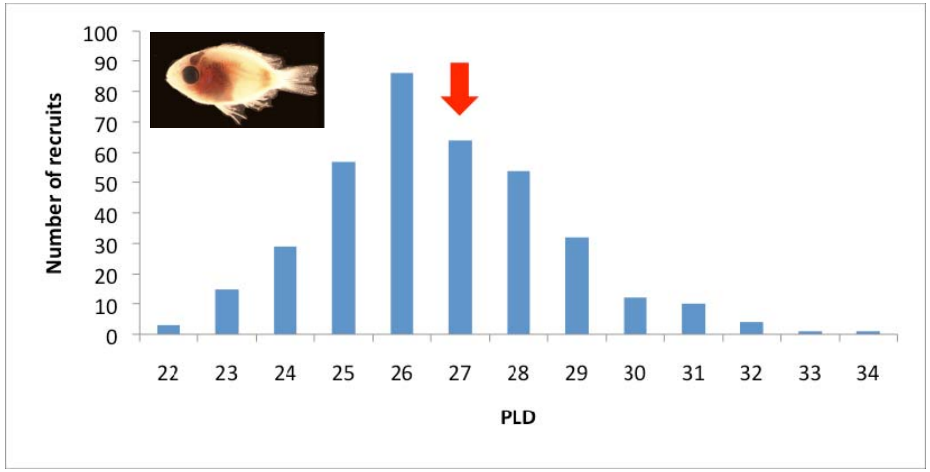


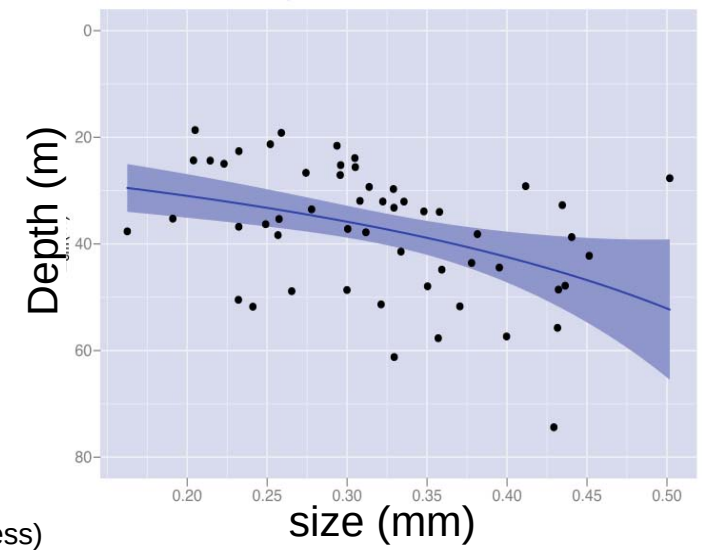
Figure 2. CMS Multi-scale modeling: The IBM module utilizes information from the nested models to compute trajectories of individual larvae/particles moving from the coastal to the oceanic environment and back.

CMS - Biological Module
Incorporation of species-specific empirical data (*Stegastes partitus*)





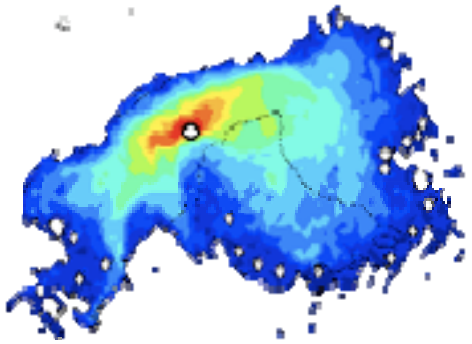
- Spawning: lunar-cyclic egg production all year-round (back-calculated from late-stage larval otolith)
- Pelagic larval Duration (PLD): mean 27d (range: 22-34 d) back-calculated from otolith of recruits
- Ontogenetic vertical migration: from *in situ* observations

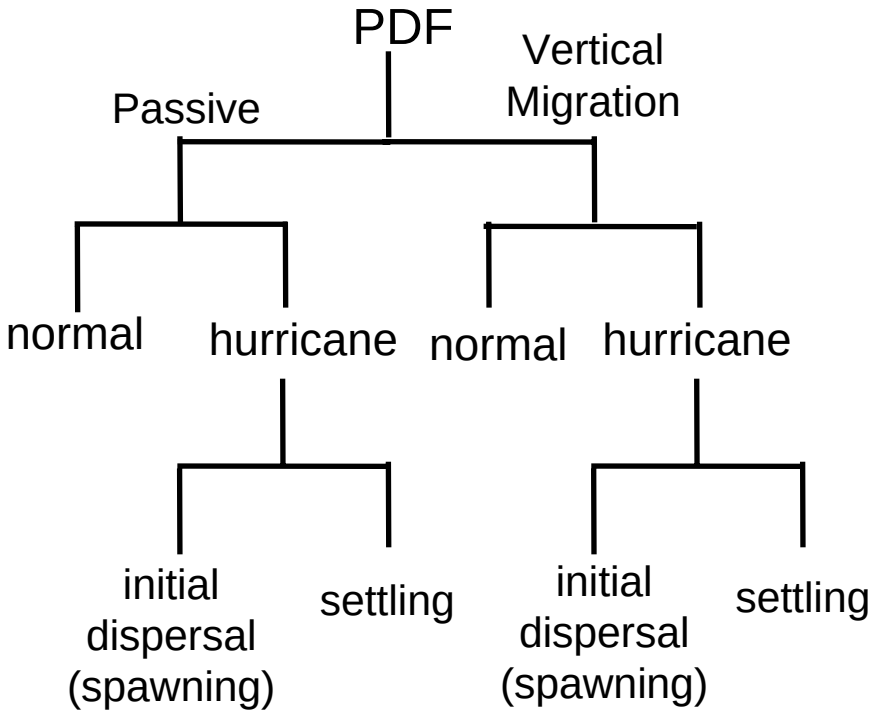


Paris and Cowen 2004, Irisson et al. 2010, Sponaugle and Rankin, in press)

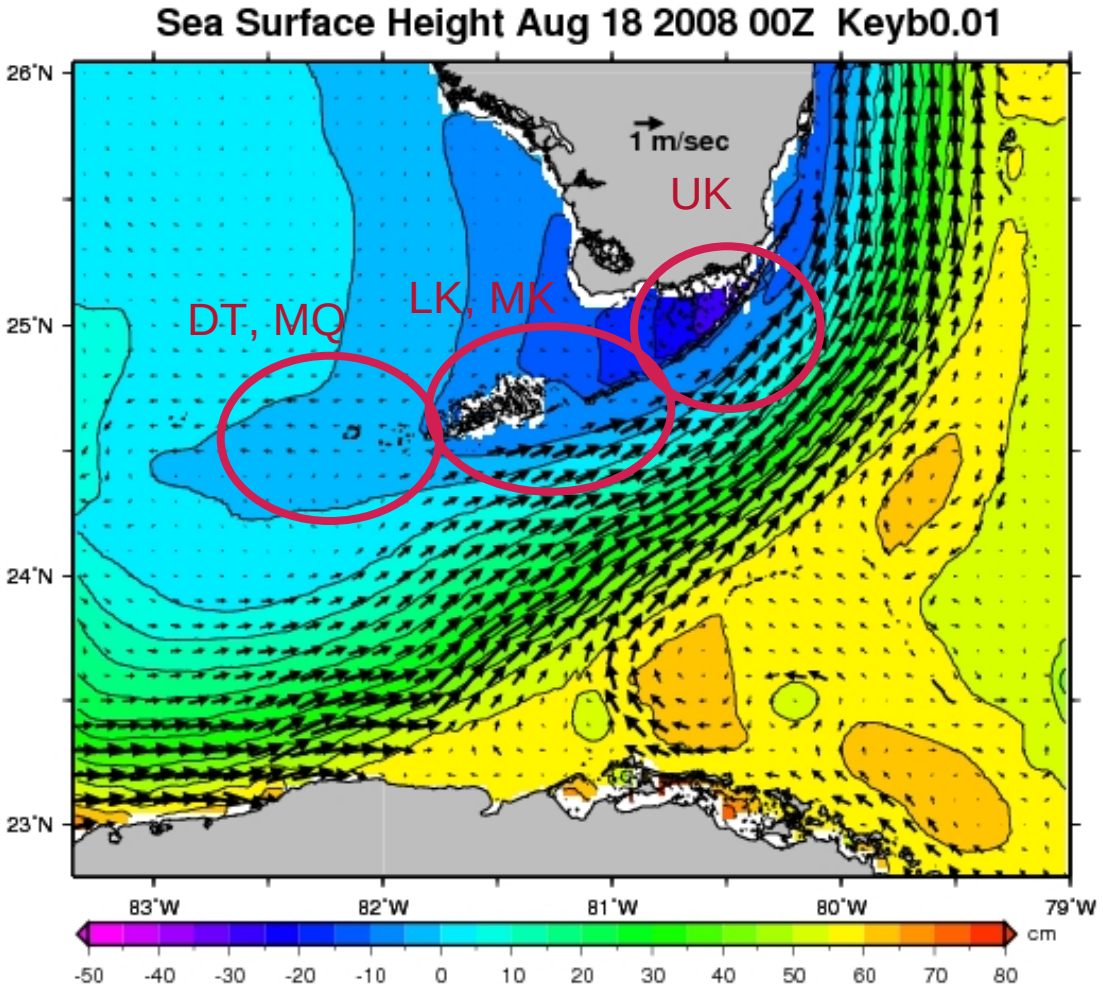
Larval-tracking simulations
Estimating larval PDFs and Connectivity

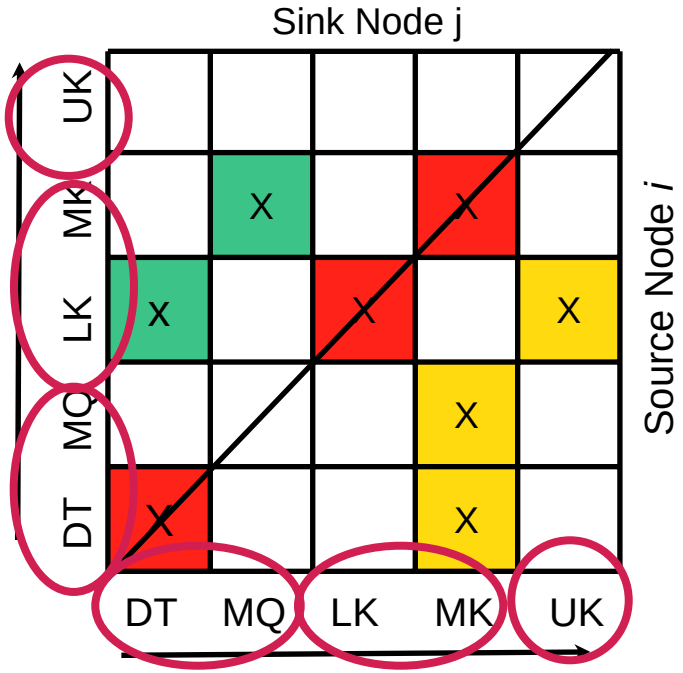
- OGCM: FKEYS 1/100 (900 m)
- LSPM: CMS
- Ensemble simulations: 500 particles, 15 d release frequency for 5 yr.
- Integration time: 30 d
- Initial Conditions: - 47 nodes (10 km x 5 km) along the coral reef track and grouped in 3 regions: Western Keys (WK, n = 14) , Lower and Middle Keys (LMK, n = 15) , Upper Keys and Biscayne Bay (UK, n = 18)
- Particle behavior:
- surface passive
- migrating in the upper 100 m
- Hurricane scenarios: releases during hurricane passage
- PDFs of particle displacement released at (X_0, Y_0) during ΔT





Larval-tracking simulations
Estimating larval PDFs and Connectivity



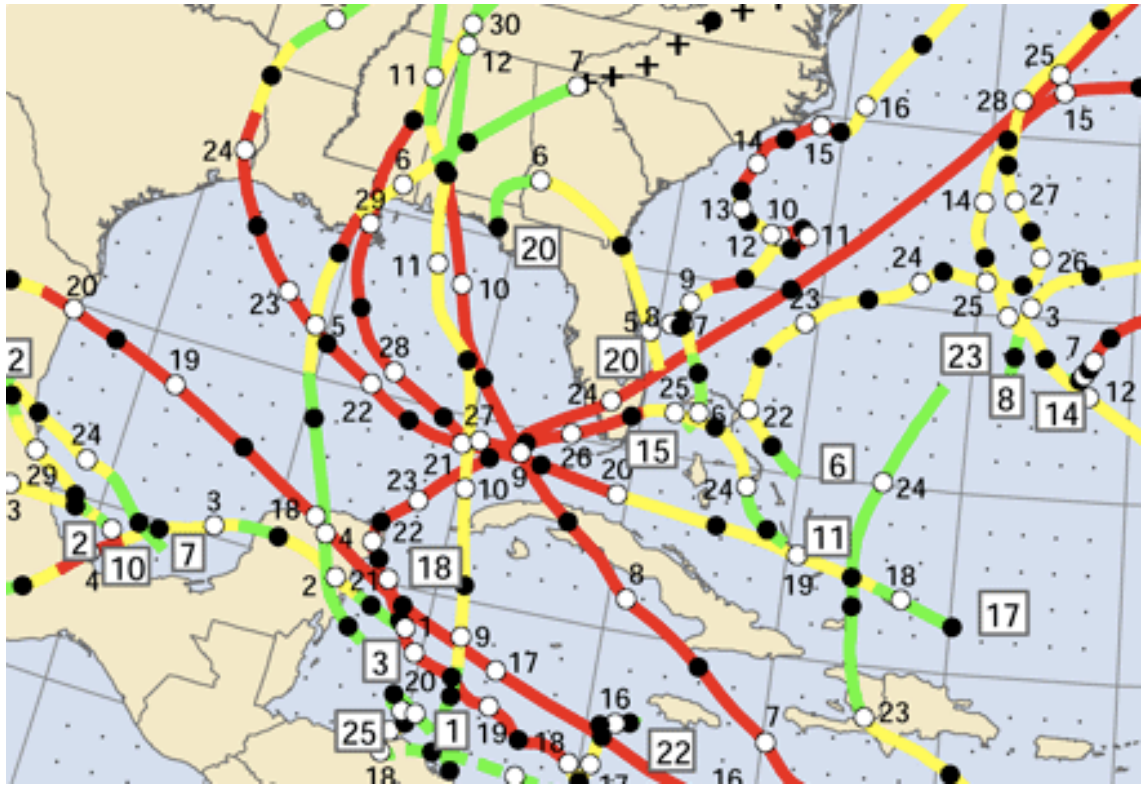


no connectivity (larval flux)
i = j , self-seeding
upstream transport
downstream transport

Hurricanes passage over the Florida Keys from 2004-2008

Florida Keys hurricane scenario

Charley 13-14 August 2004
Ivan 14-15 September 2004
Jeane 26-27 September 2004
Dennis 9-10 July 2005
Katrina 25-27 August 2005
Rita 20-22 September 2005
Wilma 23-25 October 2005
Ernesto 29-31 August 2006
Fay 18-20 August 2008



➡Frequent but ephemeral
➡larval duration ~ 30 days
➡examine effect when occurs 1) during initial dispersion (spawning) and 2) during the end of the pelagic duration (settlement)

Wilma (2-3) 23-25 October 2005

Fig. 3. KBYX WSR-88D composite reflectivity image of Hurricane Wilma at 0219 EDT, 24 October 2007.

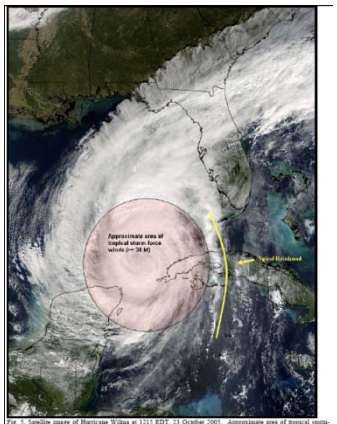
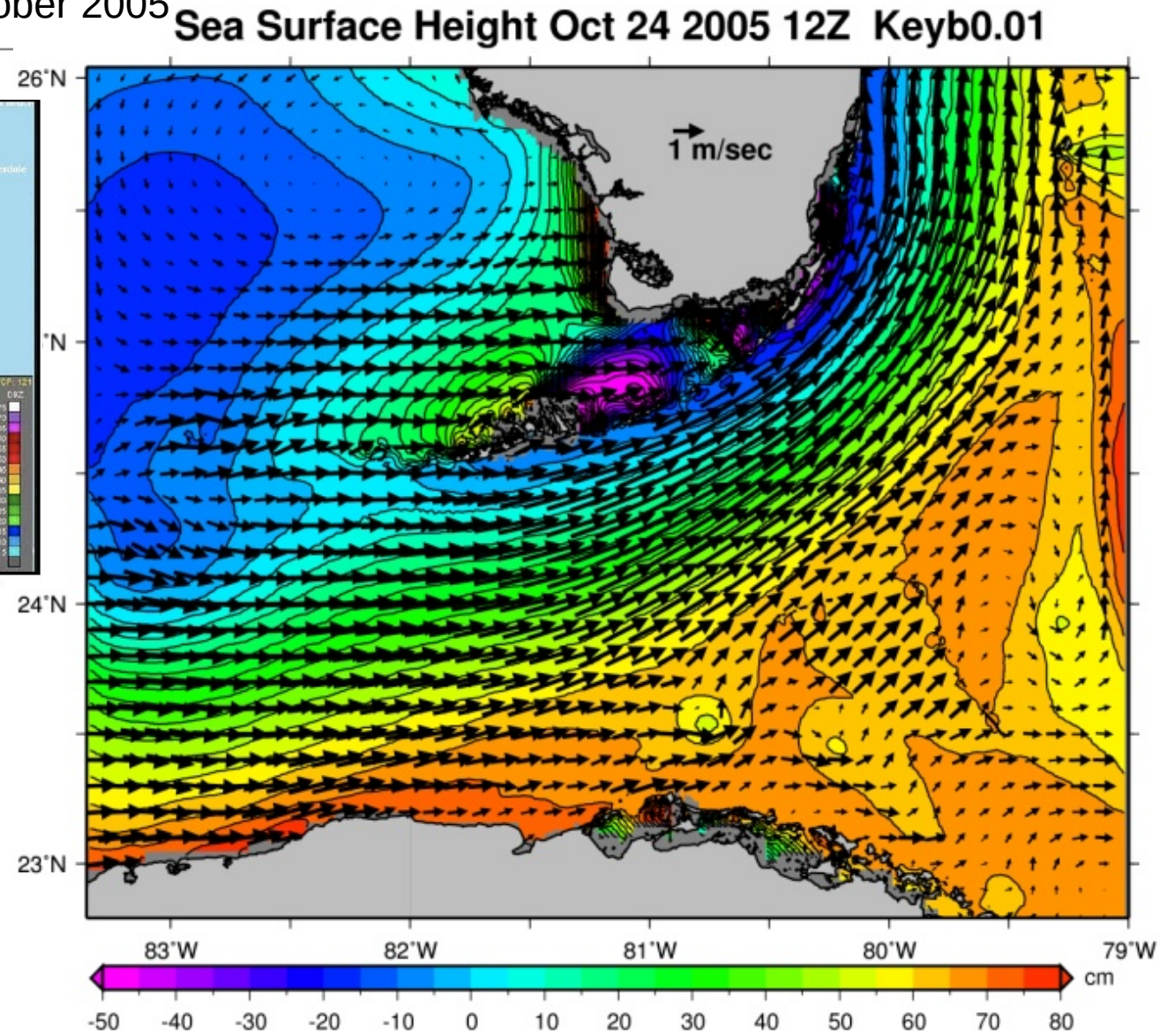


Fig. 5. Satellite image of Hurricane Wilma at 1215 EDT, 23 October 2005. Approximate area of tropical storm-force winds (one-minute average, 10-meter wind speeds greater than or equal to 34 kt) shaded in red; an outer spiral rainband denoted by bold yellow line east of storm center. Image courtesy of MODIS Rapid Response Project at NASA/GSFC.

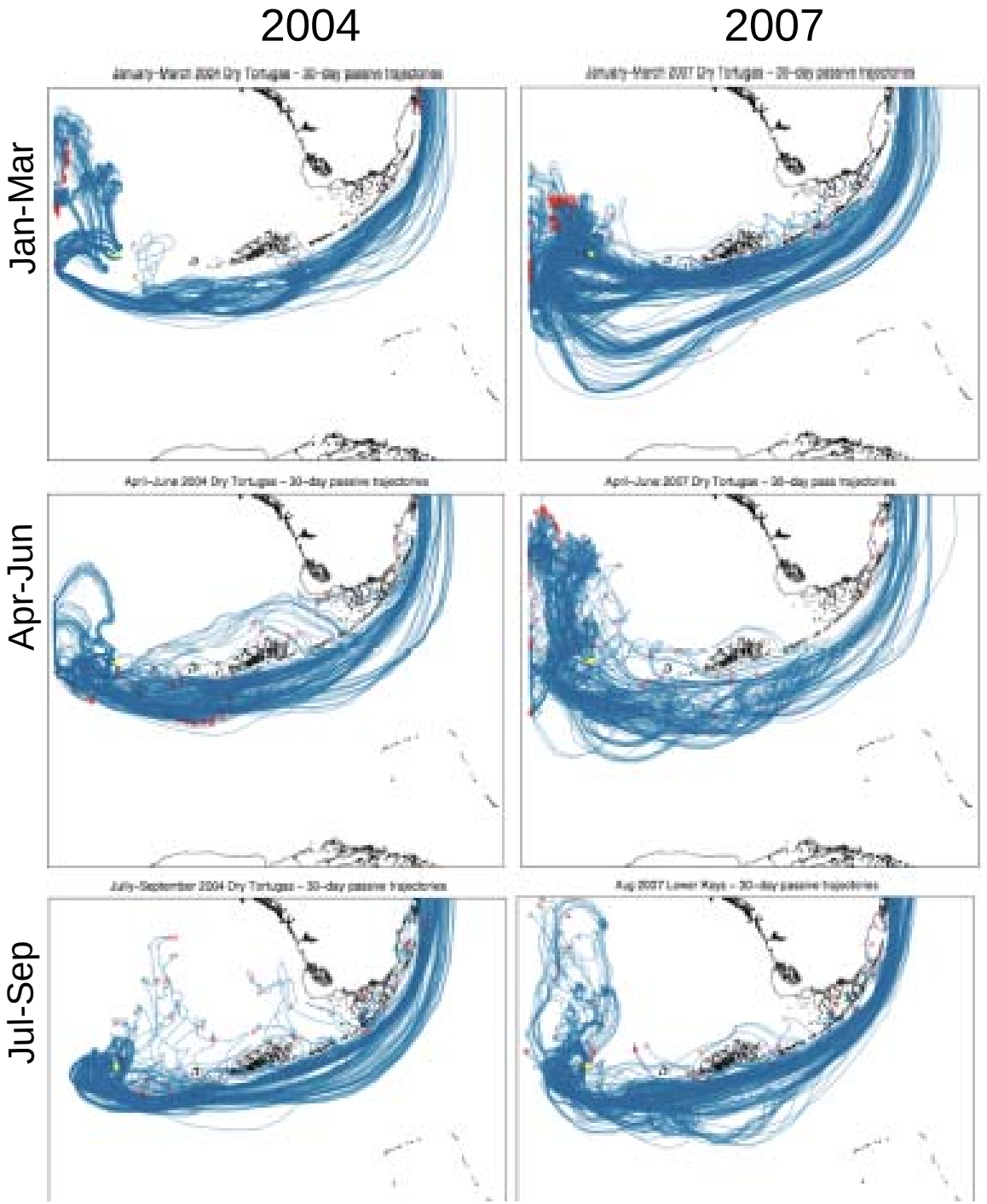


Seasonal & inter-annual variability

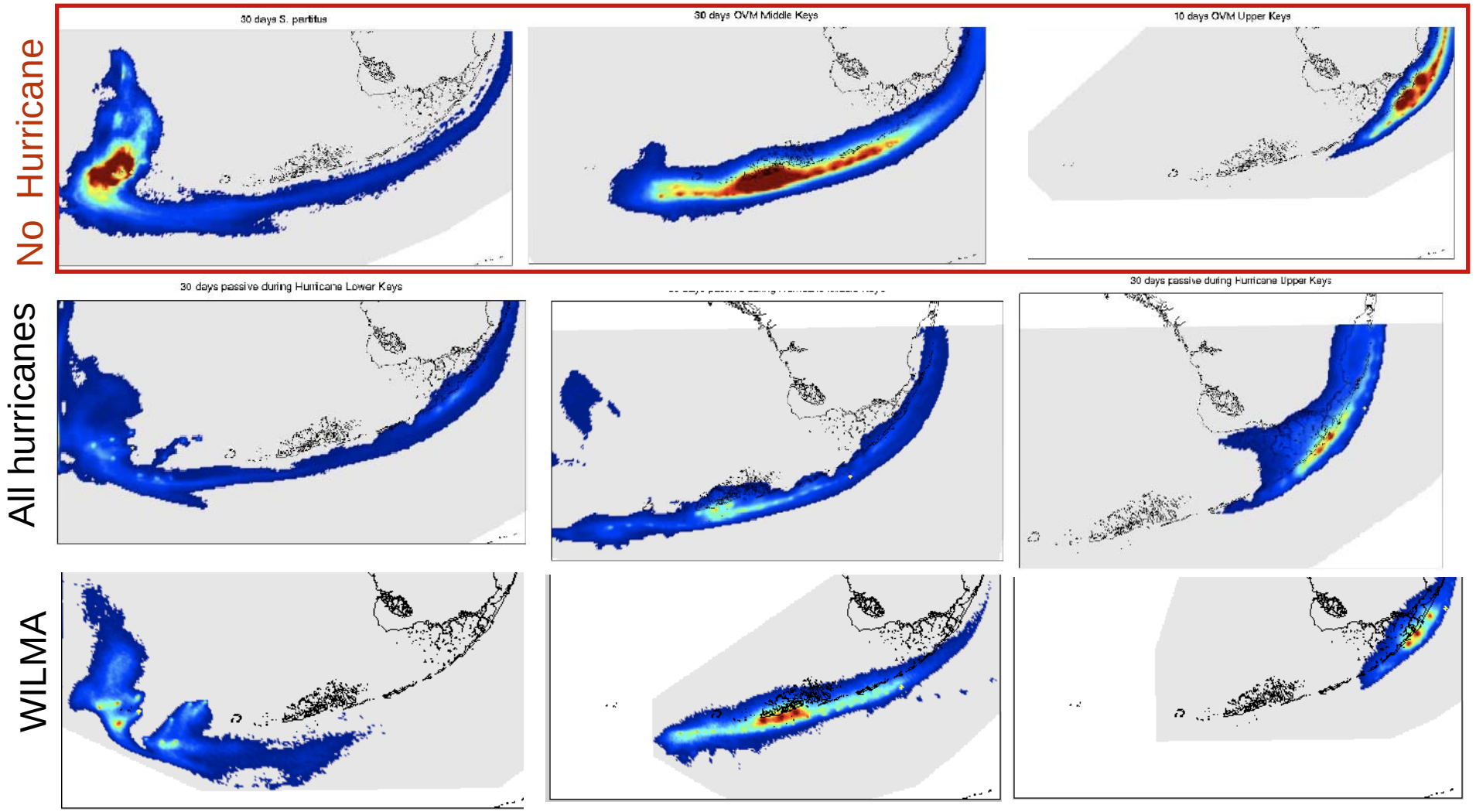
➡ sensitivity to the date of release leading to different dispersal patterns

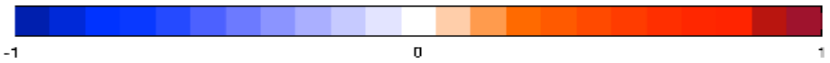
➡trajectories depict turbulent dispersion with a cascade of meso-scale, sub-meso-scale eddies

➡ need of Lagrangian PDFs to quantify dispersion and describe patterns

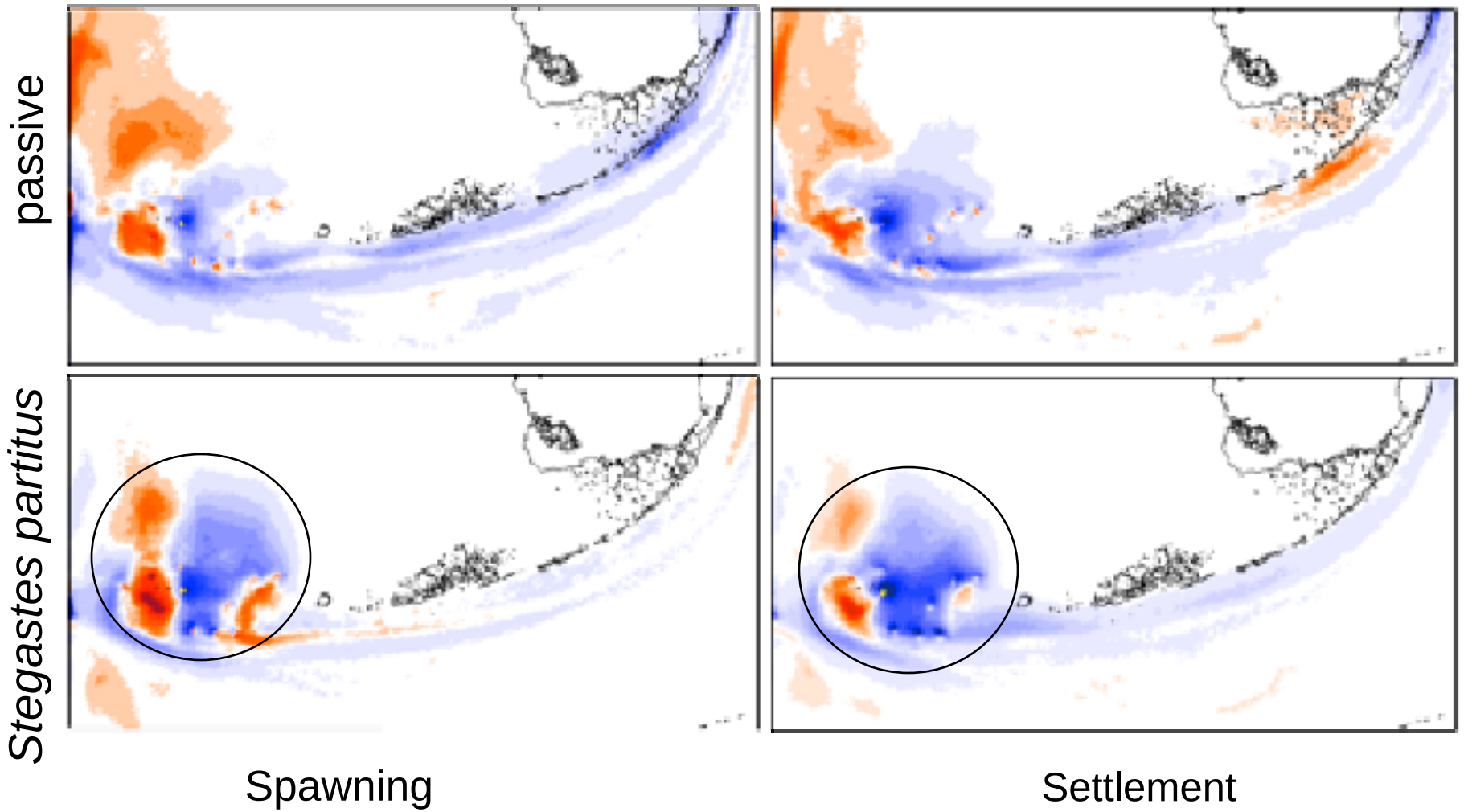


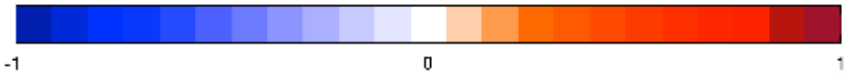
Effects of hurricanes on dispersion: cumulative (n=9) vs. single event (n=1)





Impact of Hurricanes on larval dispersion: PDFs Anomalies (2004-2008) Western Keys

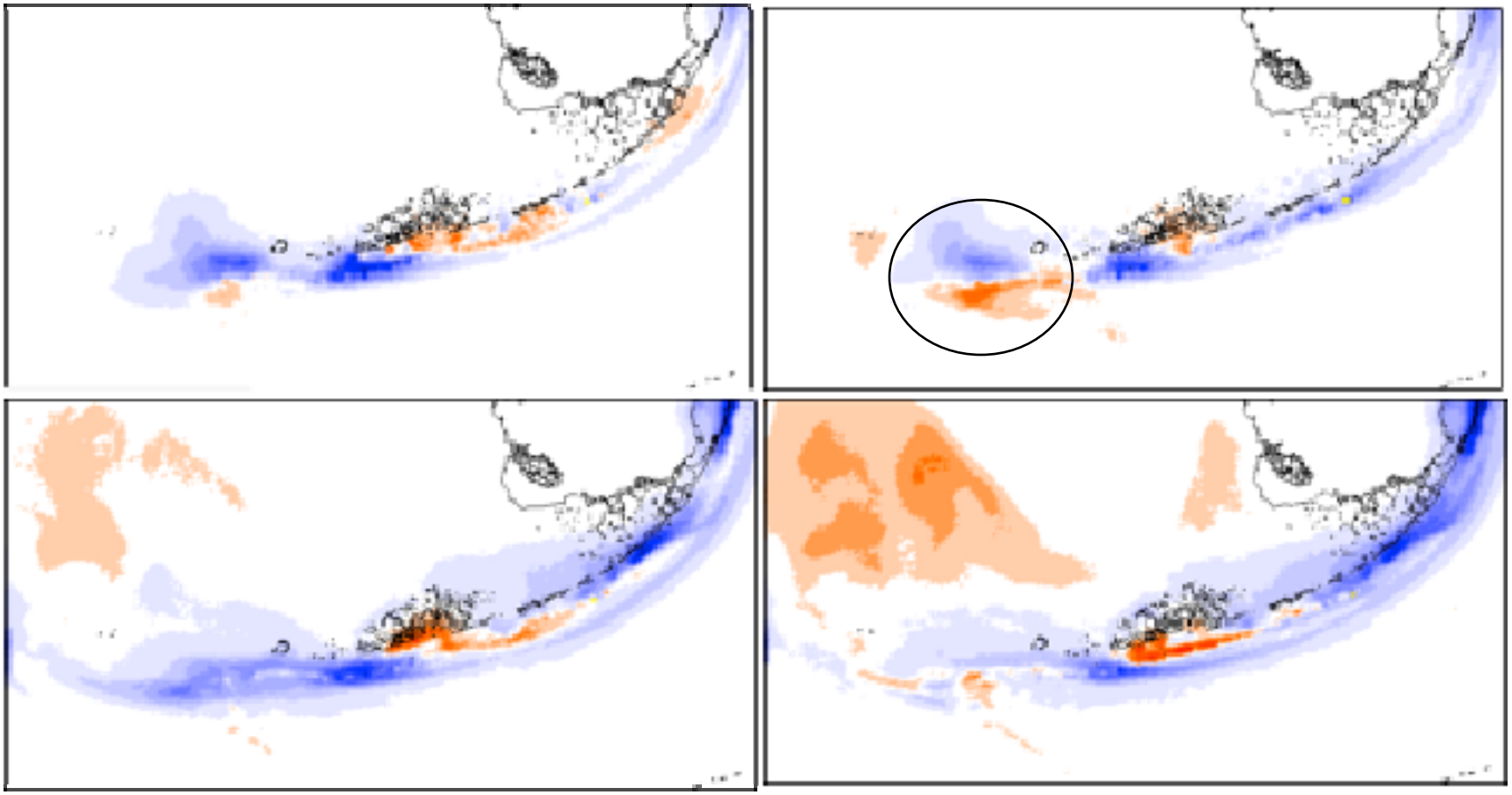




Impact of Hurricanes on larval dispersion: PDFs Anomalies (2004-2008) Lower and Middle Keys

passive

S. partitus

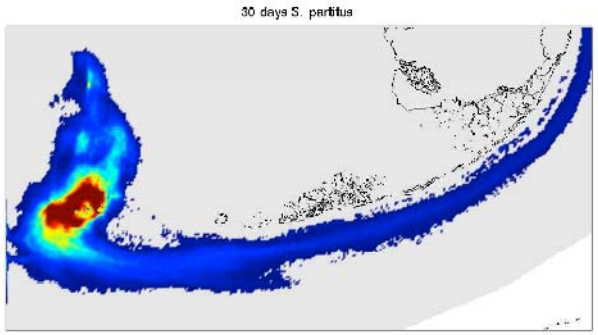


Spawning

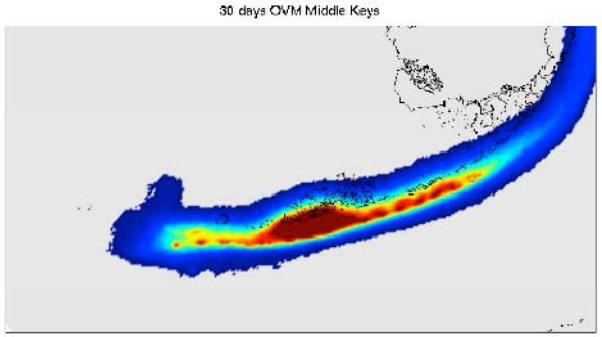
Settlement

Effect on larval PDFs on connectivity (2004-2008):

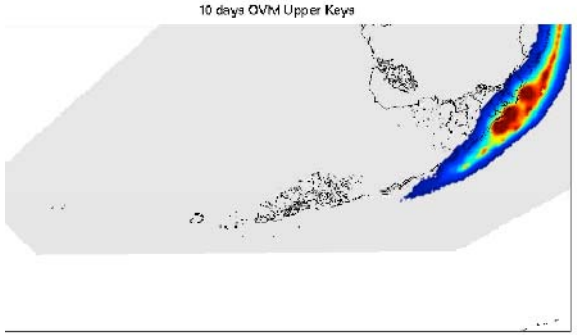
Dry Tortugas (DT)
Marquesas (MQ)

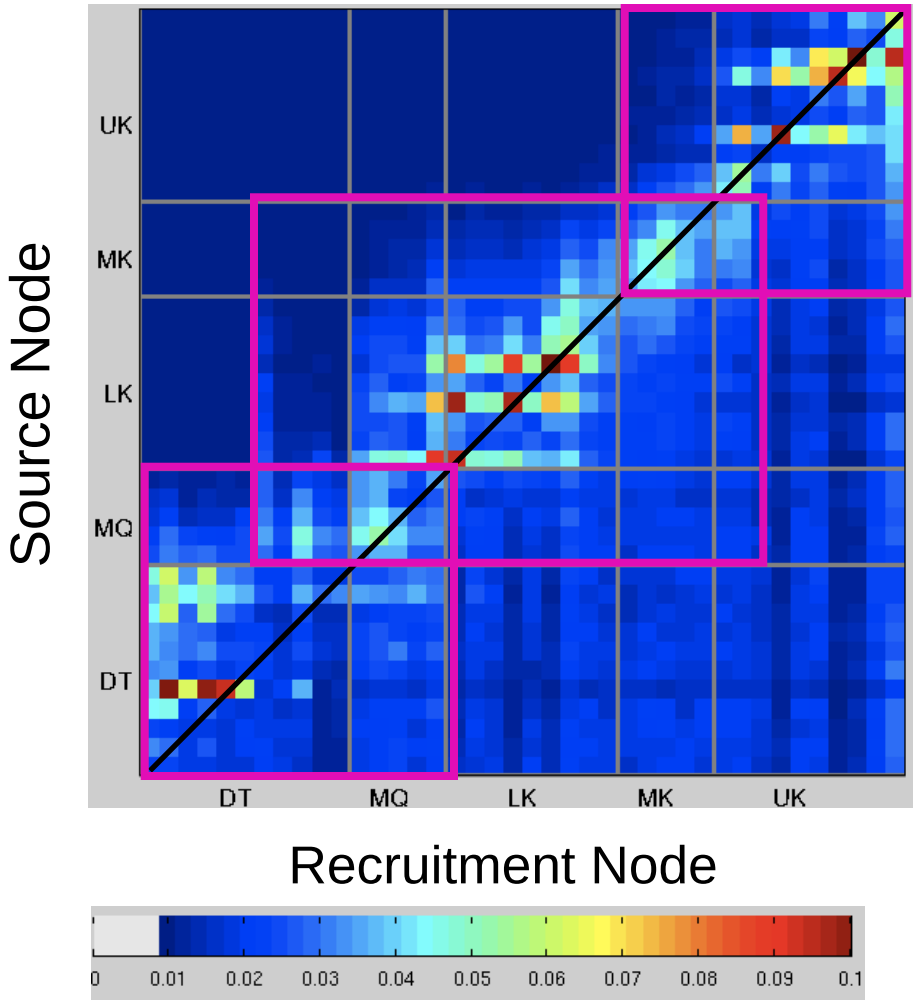


Lower Keys (LK)
Middle Keys (MK)

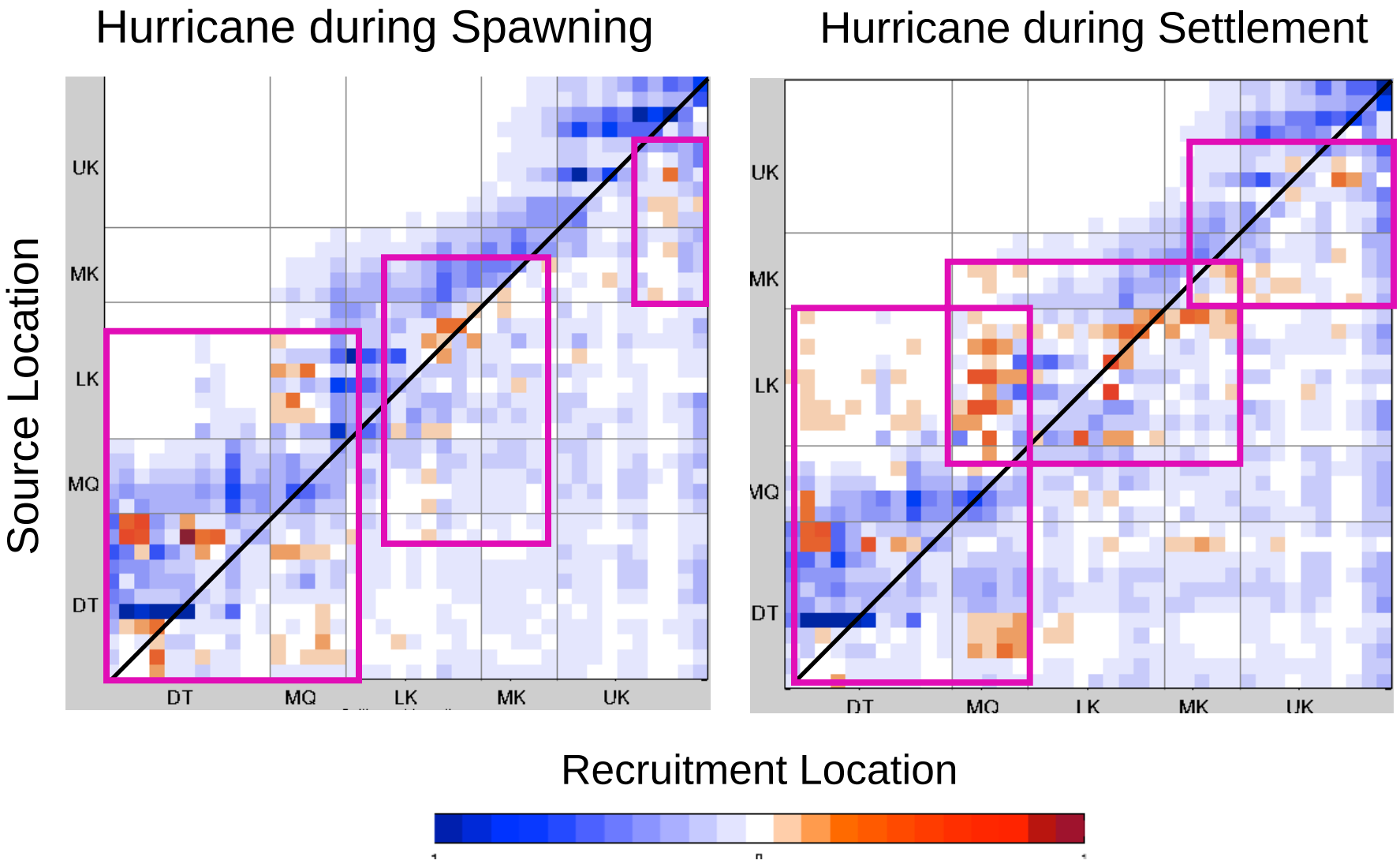


Upper Keys

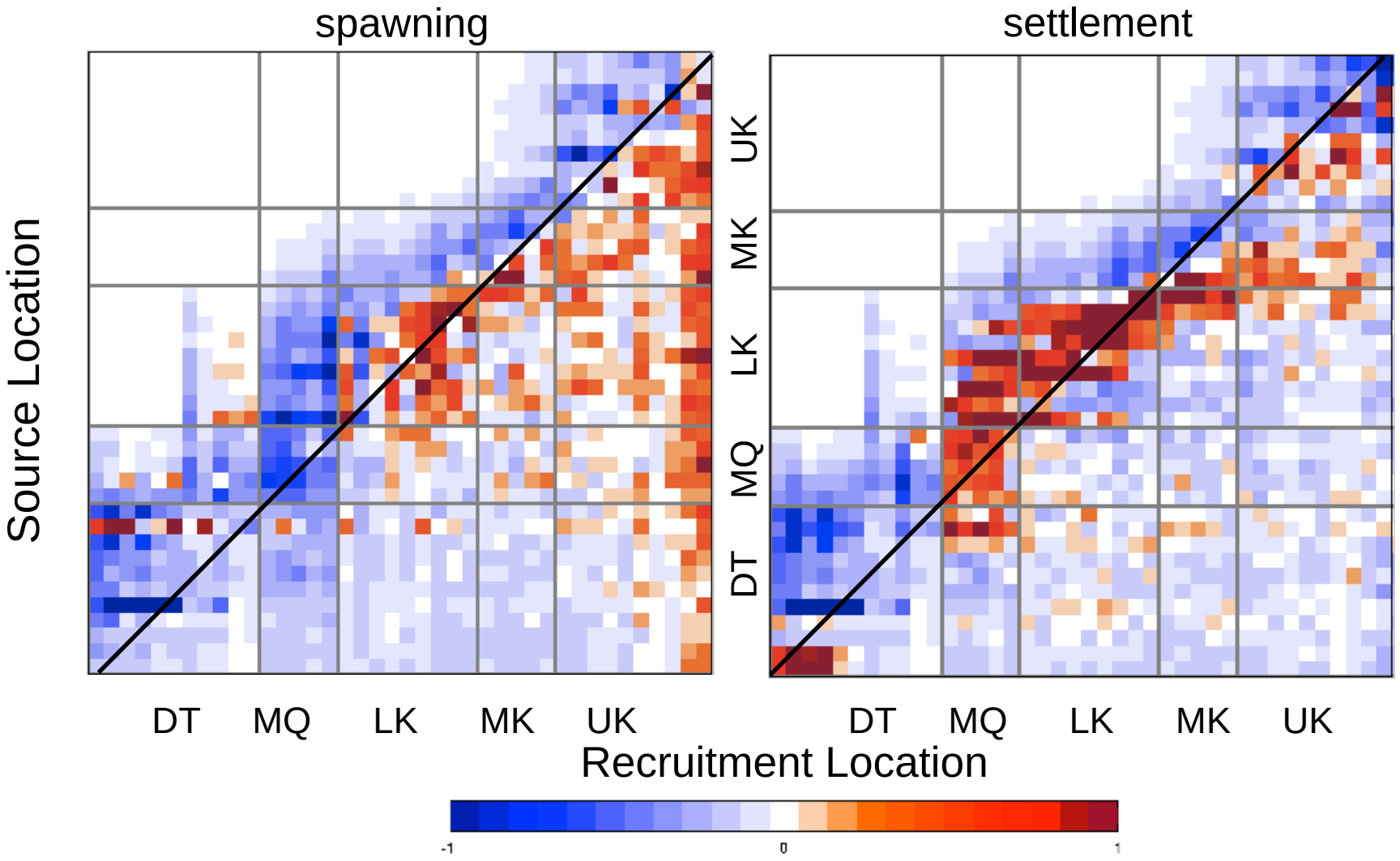




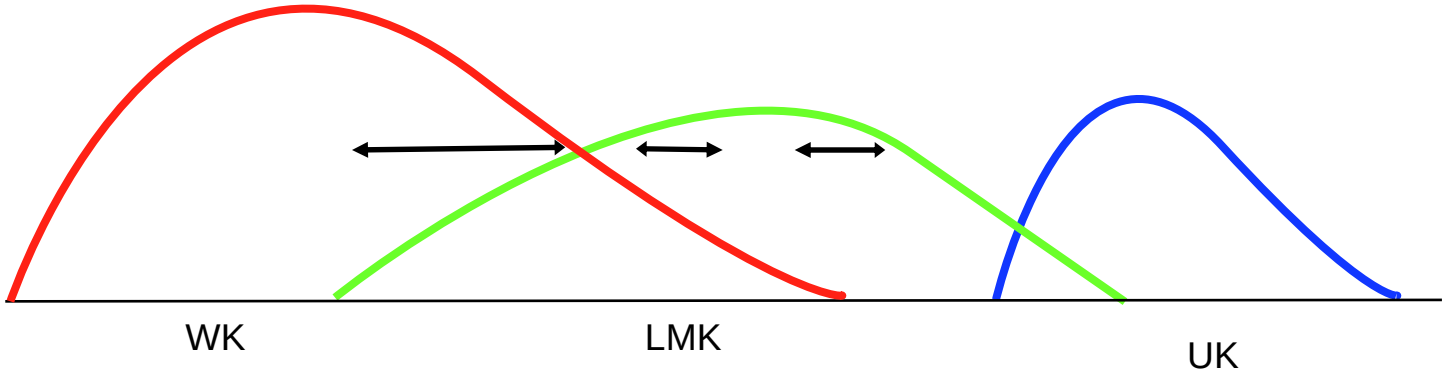
Impact of Hurricanes on Connectivity: Anomaly Matrix (2004-2008)

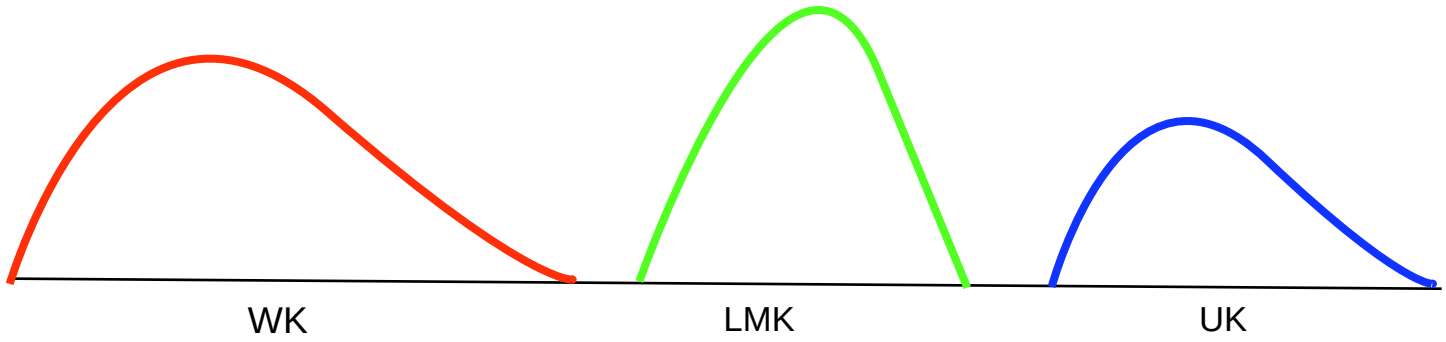


Anomaly Connectivity Matrix for single event - Wilma



Predicted connectivity changes in the FL Keys with increased hurricane activity

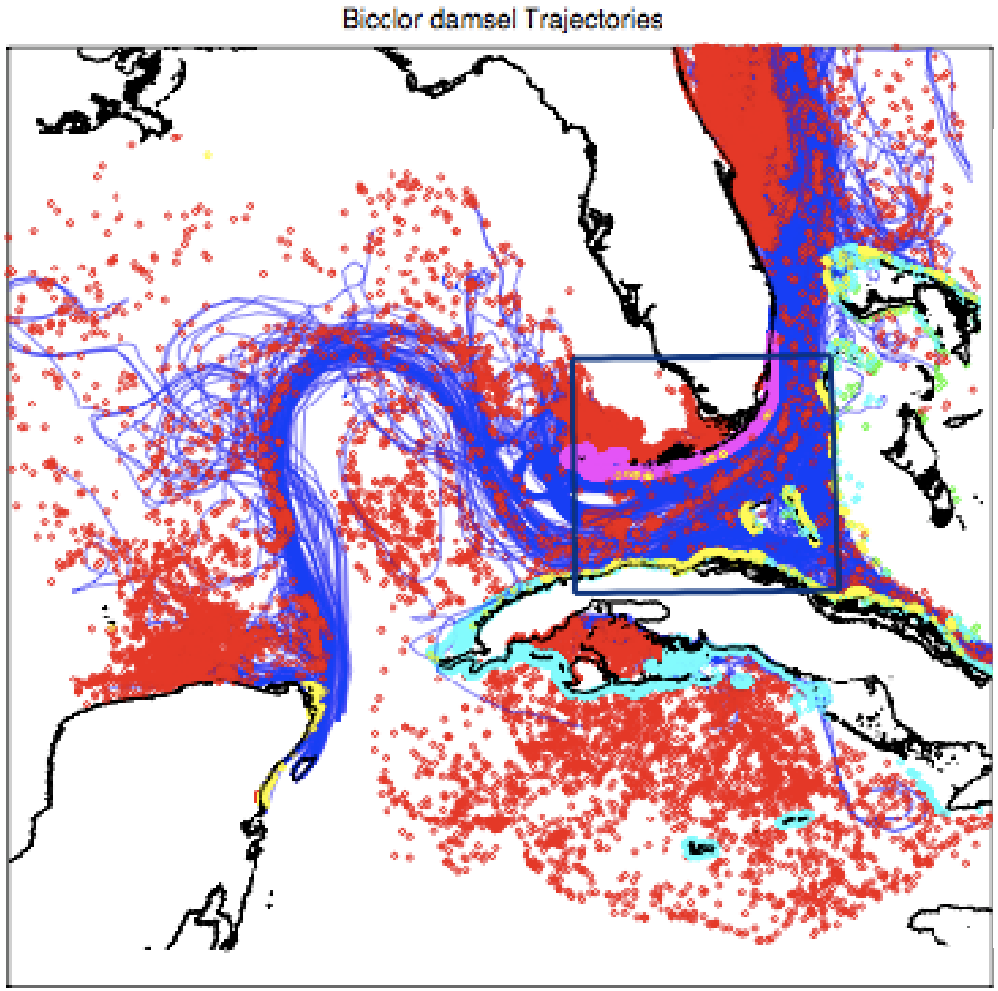




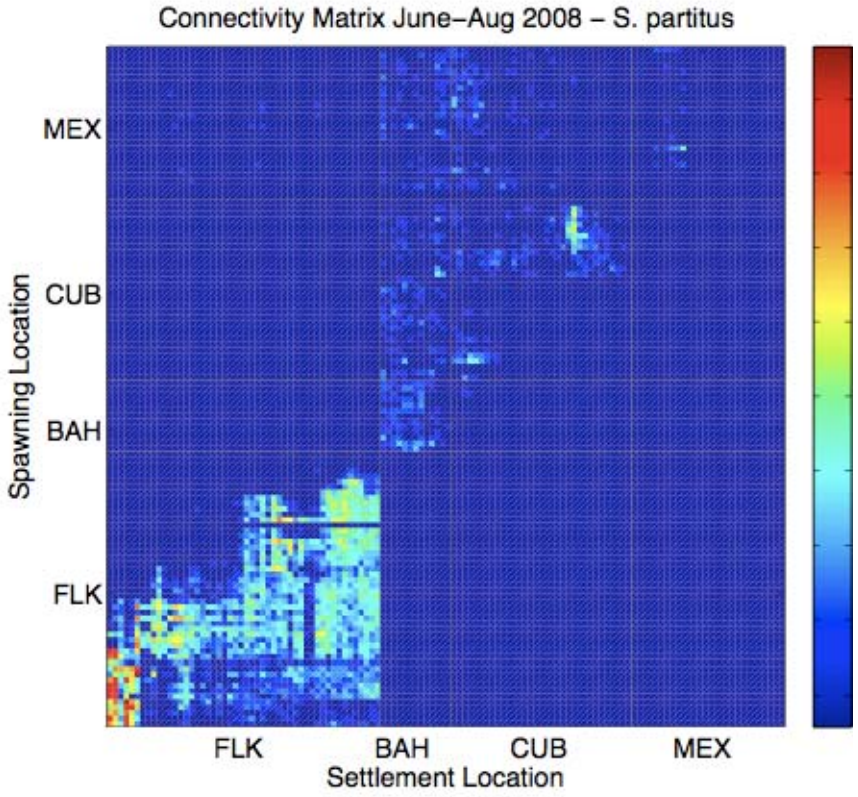
Summary of findings

1. Multi-nested approach necessary for accurate estimation of meso- submeso- and small-scale circulation, resolving features that are appropriate to investigate larval dispersion
2. Lagrangian PDF approach integrated over time
   - allows the identification of persistent features of larval densities in a highly variable environment
   - is also a powerful approach to anticipate the effect of increase hurricane activity on the biota
3. the analysis revealed that there are
   - there are distinct larval PDF features related to the eddy field
   - wind-driven circulation disrupts larval PDFs, vertical migration is critical for larval retention
   - for species that spawn all year round, the cumulated effect of hurricane results in decrease connectivity and local recruitment, specially during spawning in the Lower Keys and during settlement for the Dry Tortugas
   - however, single intense events generate transient features that contribute to successful LDD and/or punctuated local recruitment, which could sustain long lived species (storage effect)

Self-Recruitment vs. Subsidies?



Summer 2008



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Brian Keller

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Wilma in FLorida Keys, 23-25 October 2005