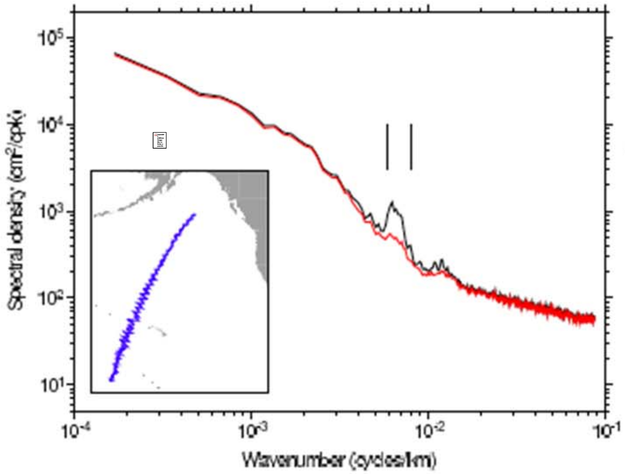
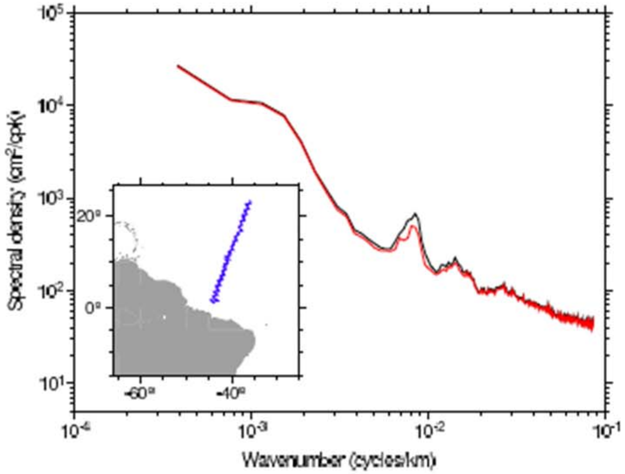
An Approach to Handling Non-Stationary Internal Tide

Gary Egbert, Lana Erofeeva
CEOAS, Oregon State University

Thanks to Jay Shriver for supplying HYCOM SSH

Along track wave-number spectra





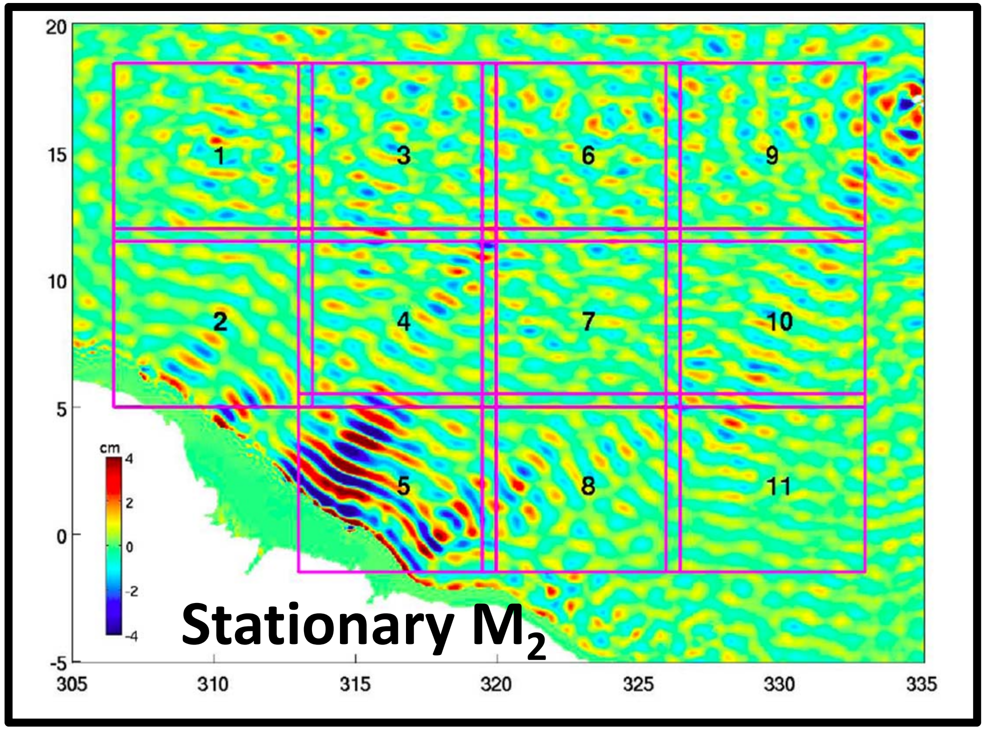
Red/Black: with/without stationary internal tide removed

IT can be identified both from frequency and spatial wavelength

Idea: fit time-variable IT using a small number of basis functions

- **→ Time dependence from tidal frequency**
- **→ Spatial structure derived from a numerical model (HYCOM)**

- **HYCOM model run for one year (2016)**
- **Steric SSH**
- **Estimate and remove stationary tide (M_2, S_2, N_2, K_1, O_1, P_1, M_4)**



Harmonic analysis in

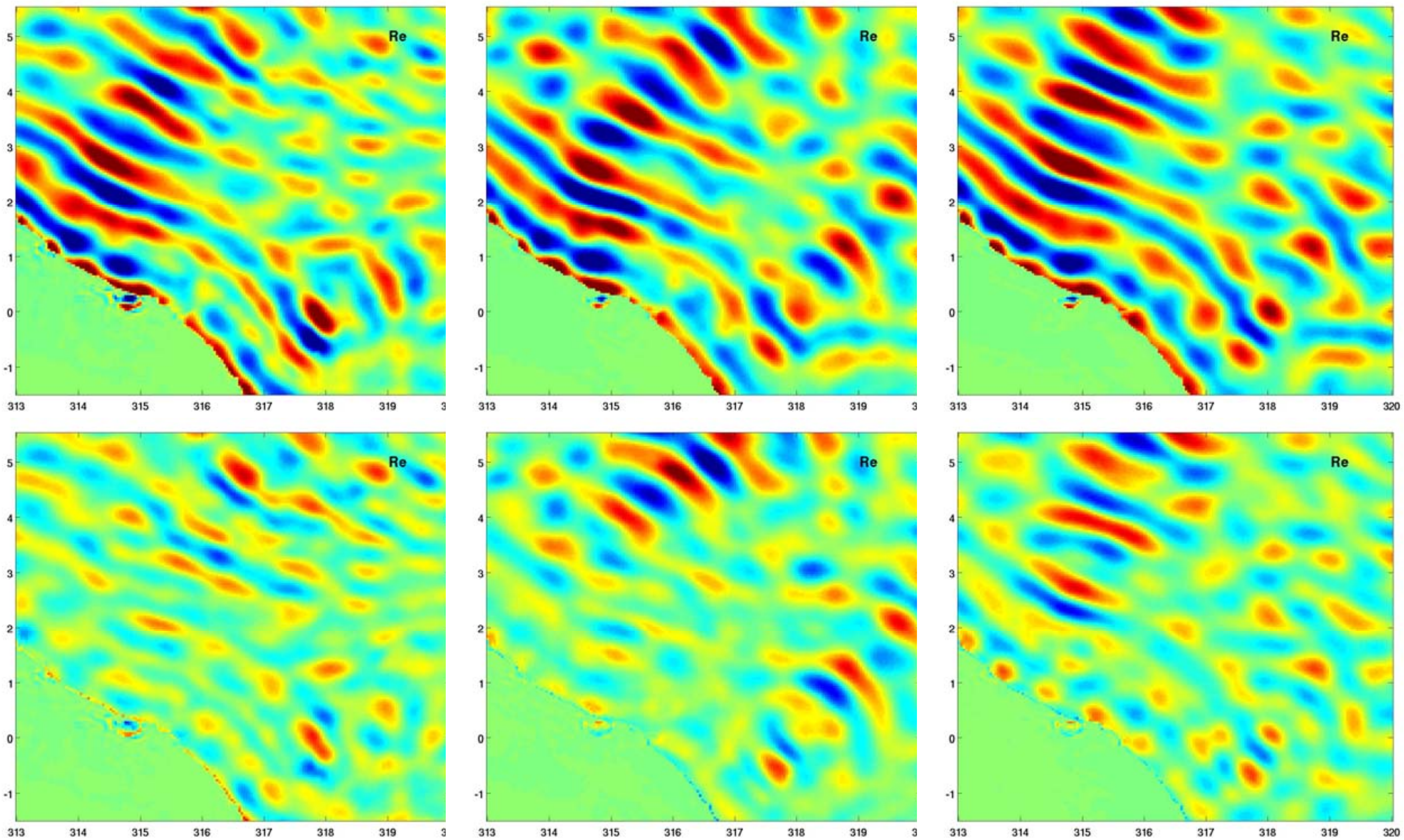
- **10°×10° spatial patches**
- **14 day time windows**

→ Time-resolved estimates of M_2 IT with low frequency resolution

Patch 5

M2 HA
14 day
window

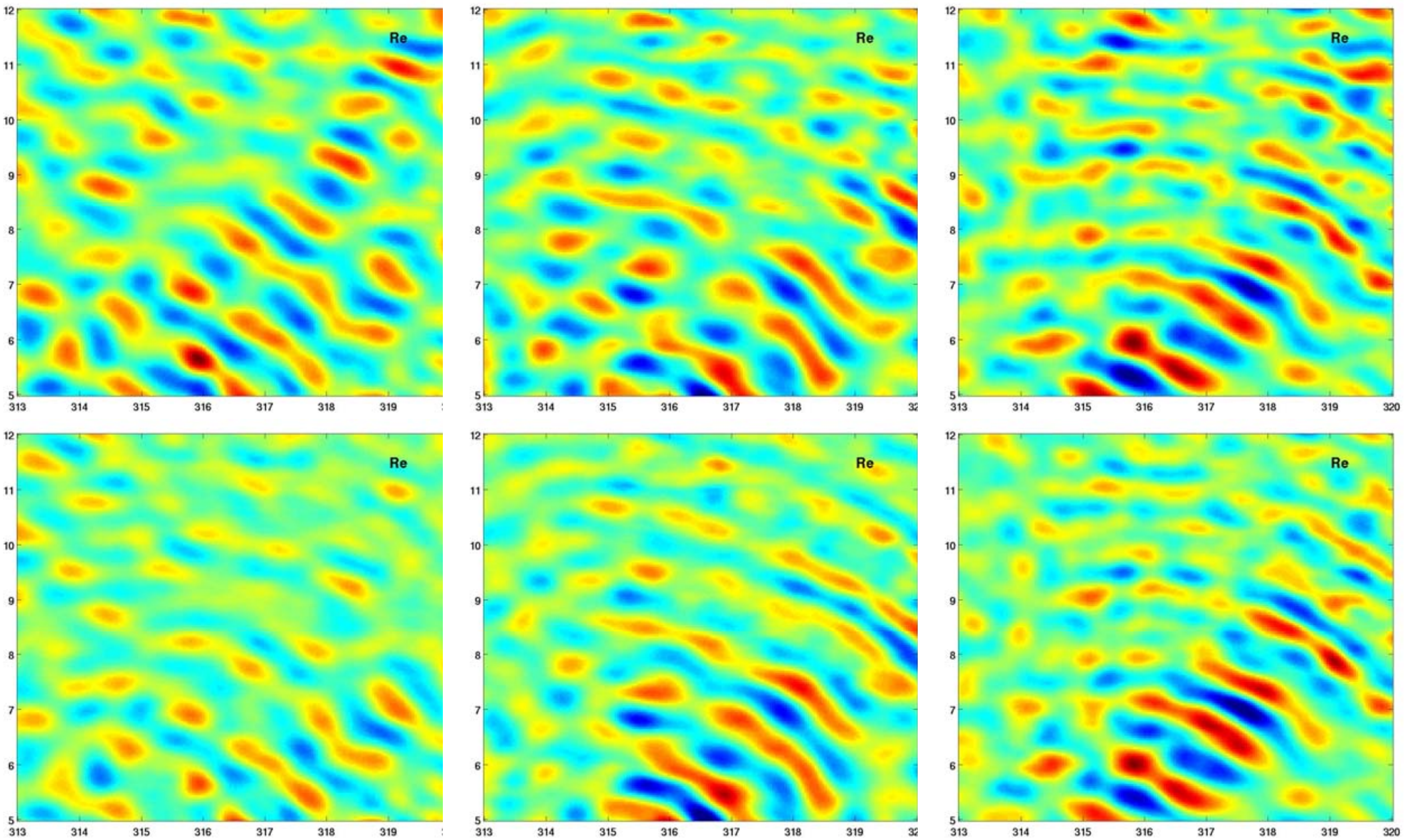
Non-
stationary
part



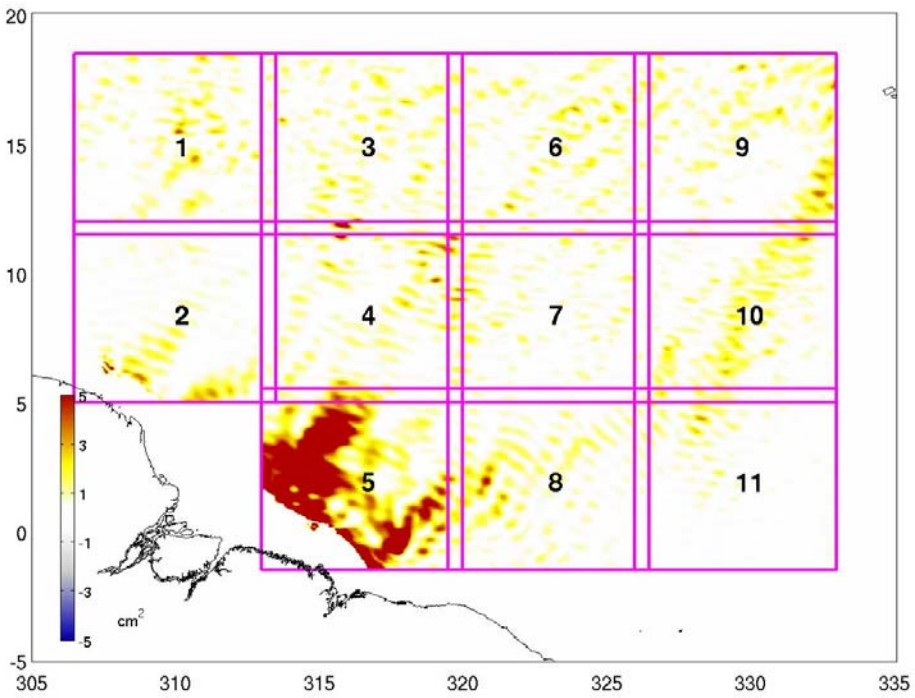
Patch 4

M2 HA 14 day window

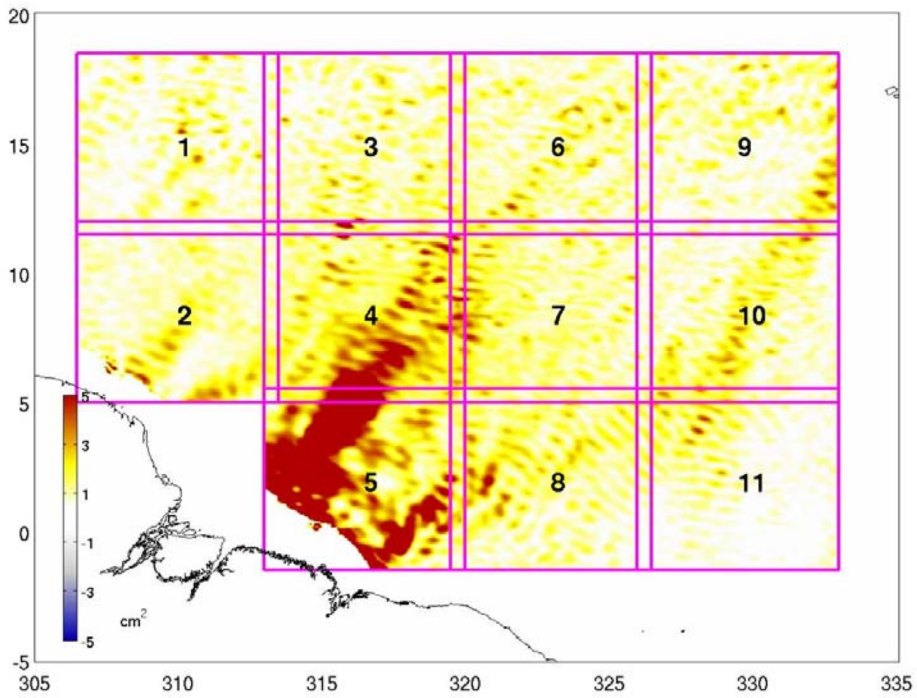
Non-stationary part



Variance in M2 Internal tide: HYCOM

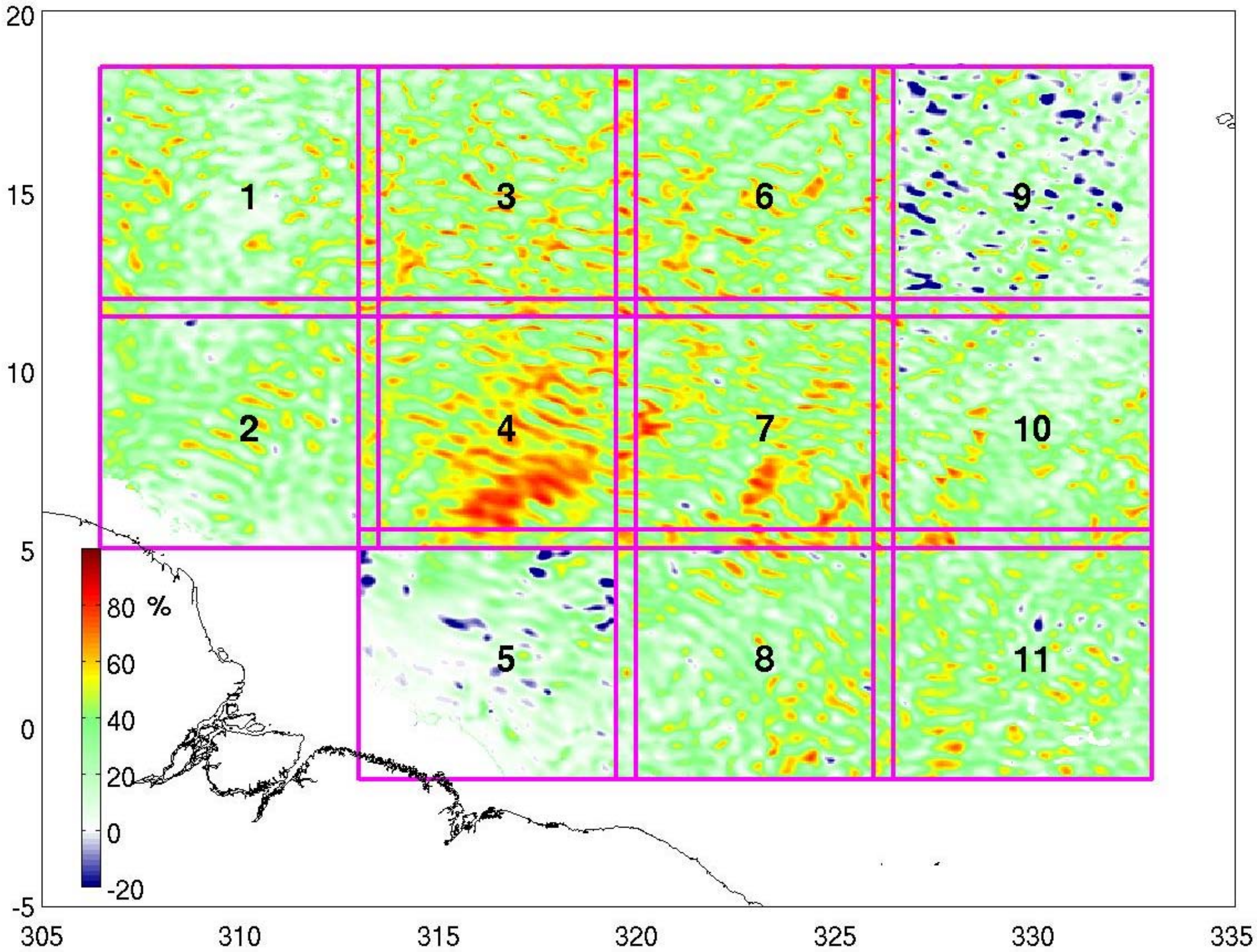


Stationary (over 1 year)

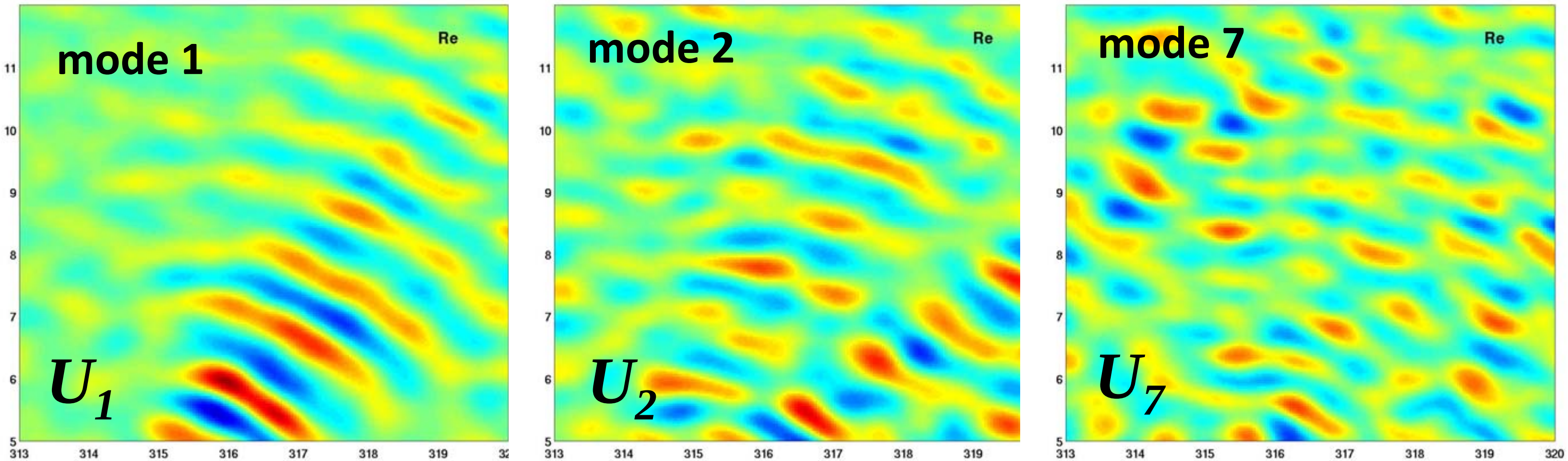


Harmonic Analysis in 14 day windows

M2 internal tide in one year HYCOM run: percent non-stationary



Use principal Components Analysis (PCA) of sequence of windowed HA estimates to define dominant spatial modes of non-stationary M2 internal tide:



Real parts of some modes for patch 5

PCA model for non-stationary IT in time window j

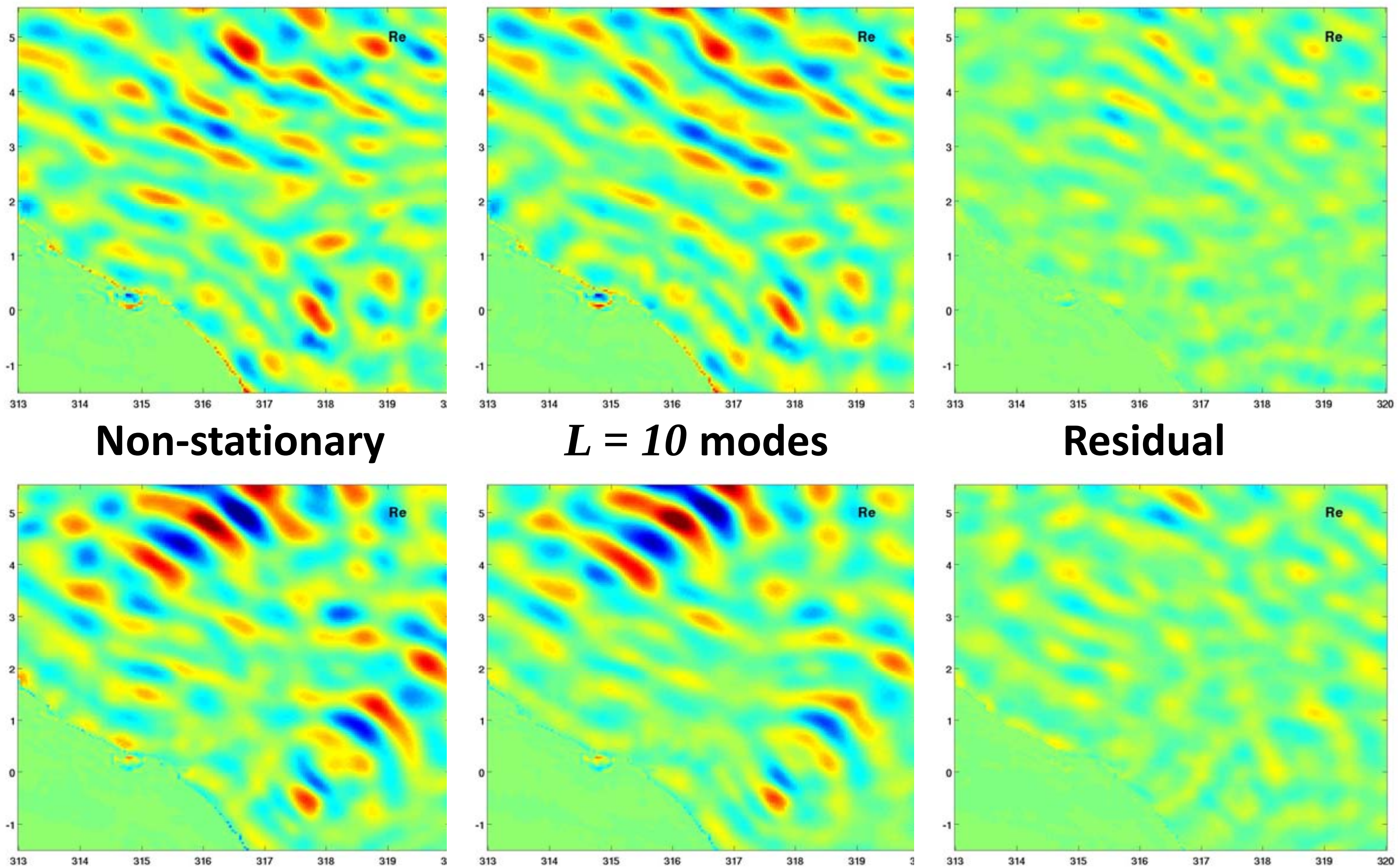
$$H_j(\mathbf{x},t) = \mathrm{Re}\left[\sum_{l=1}^{L} c_{lj} \underbrace{U_l(\mathbf{x}) e^{j\omega t}}_{L=10 \text{ spatio-temporal basis functions}} \right]$$

ω = nominal M2 frequency

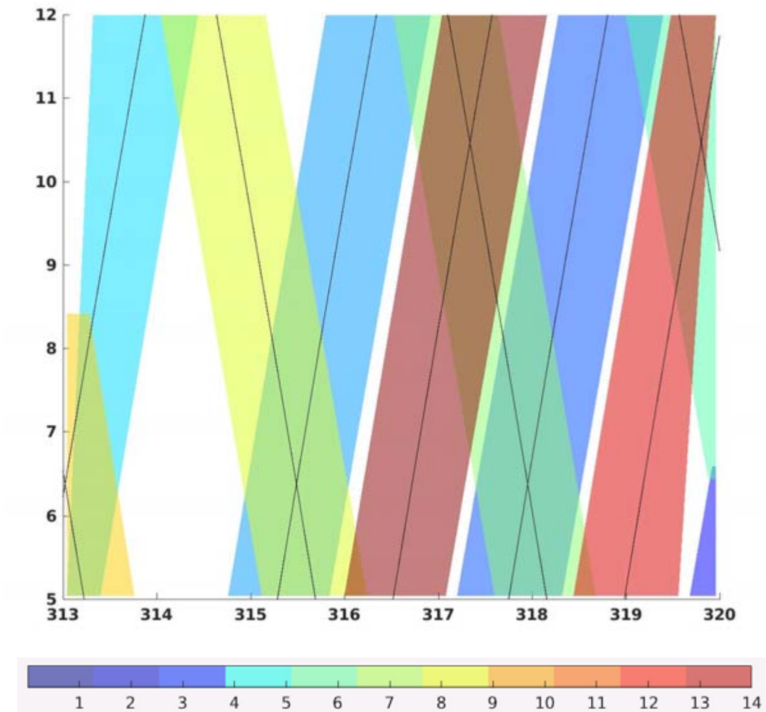
- Coefficients vary with time window
- Can adapt to a model that is continuous in time (with resolution of temporal variations defined by window length used for HA)

Approx. with PCA model

(two time windows)



How well can we recover non-stationary IT from sparse sampling in space and time provided by SWOT?



Sampling time: 14 day window

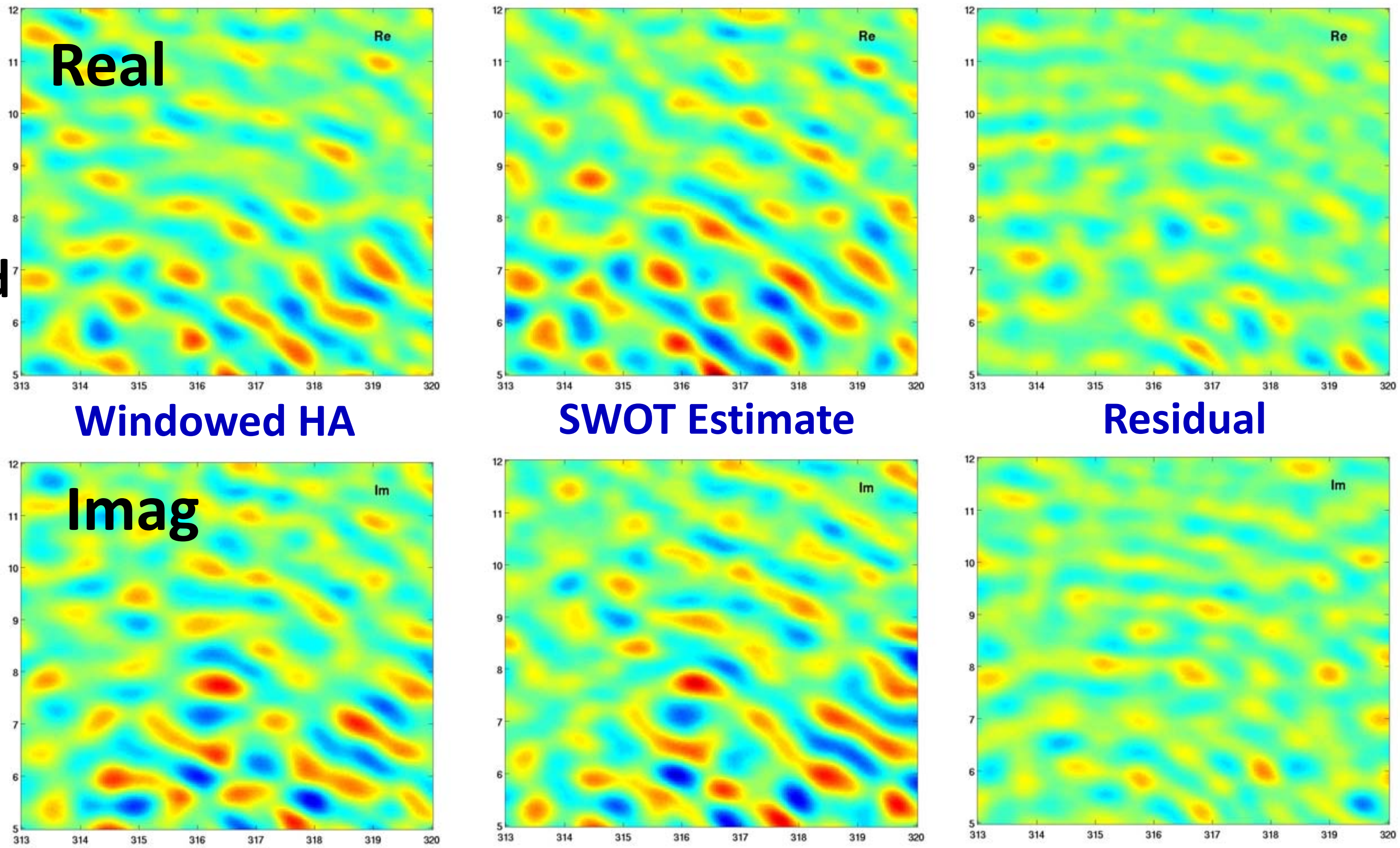
Test this by

→ sampling HYCOM steric SSH with (approximate) SWOT pattern

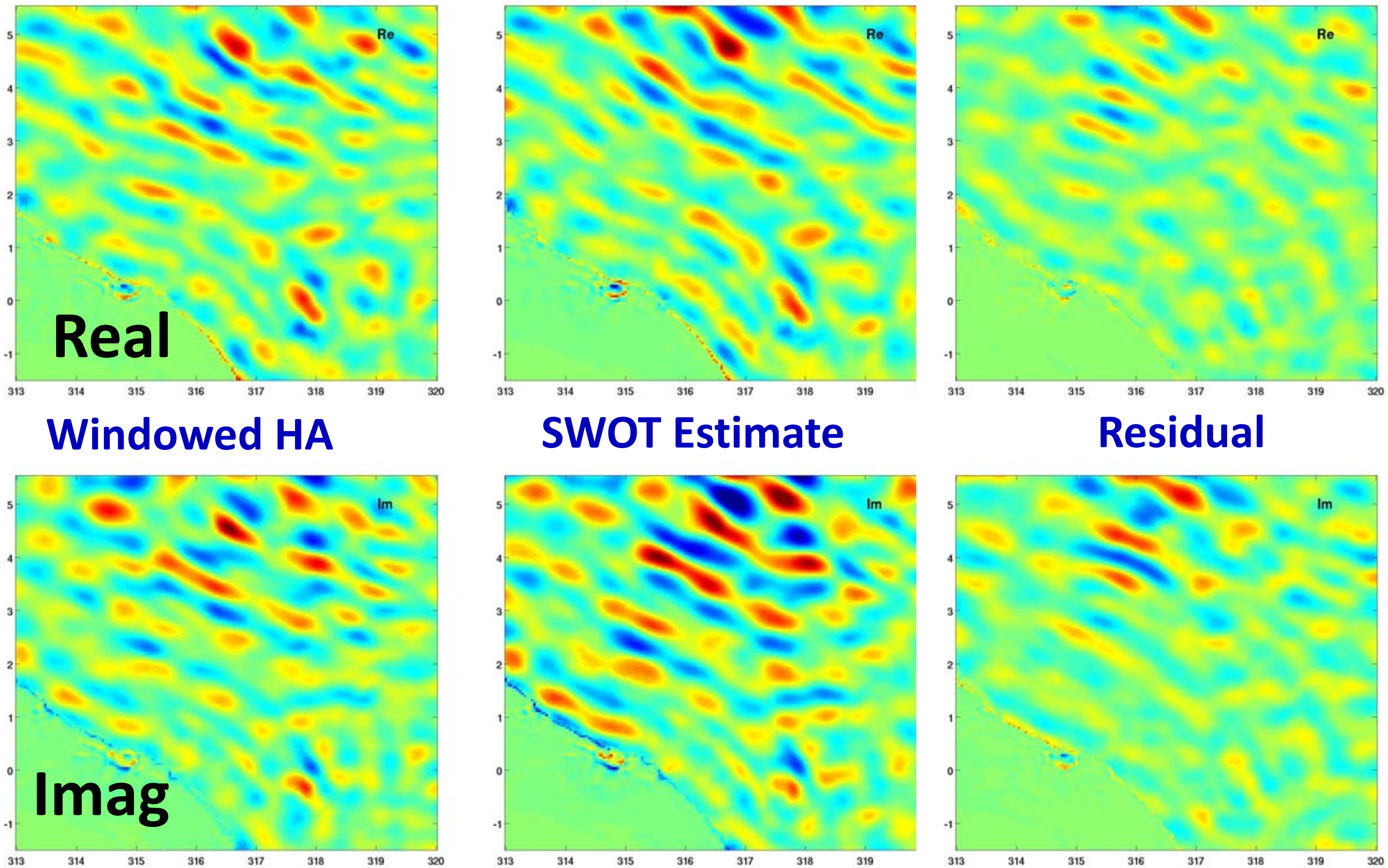
→ Fit sampled data with least-squares to estimate coefficients of PCA model

$$H_j(\mathbf{x},t) = \mathrm{Re}\left[\sum_{l=1}^{L} c_{lj} U_l(\mathbf{x}) e^{i\omega t}\right]$$

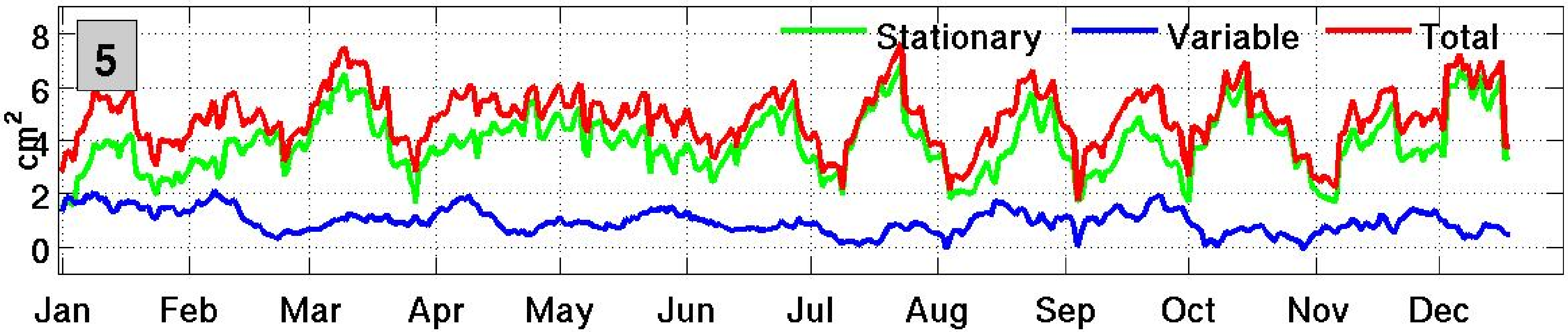
Actual and estimated non-stationary



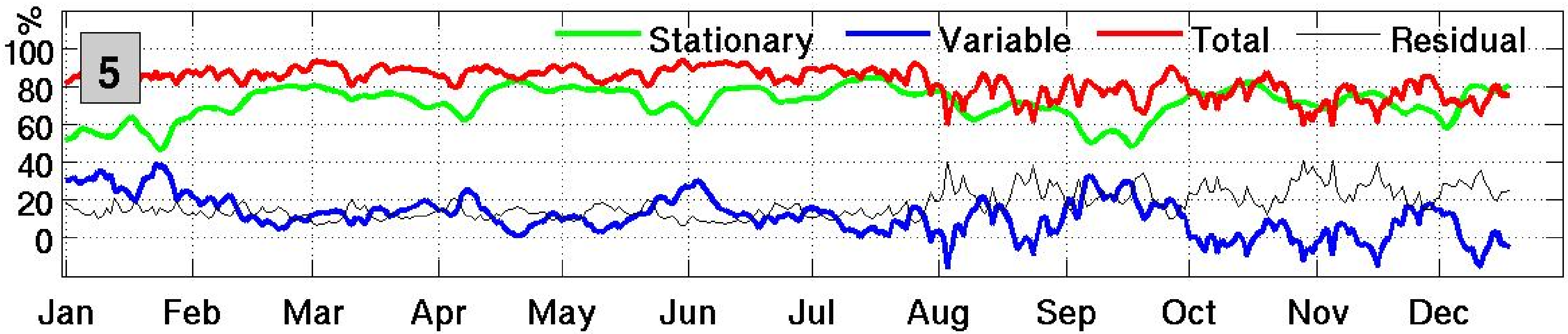
Actual and estimated non-stationary



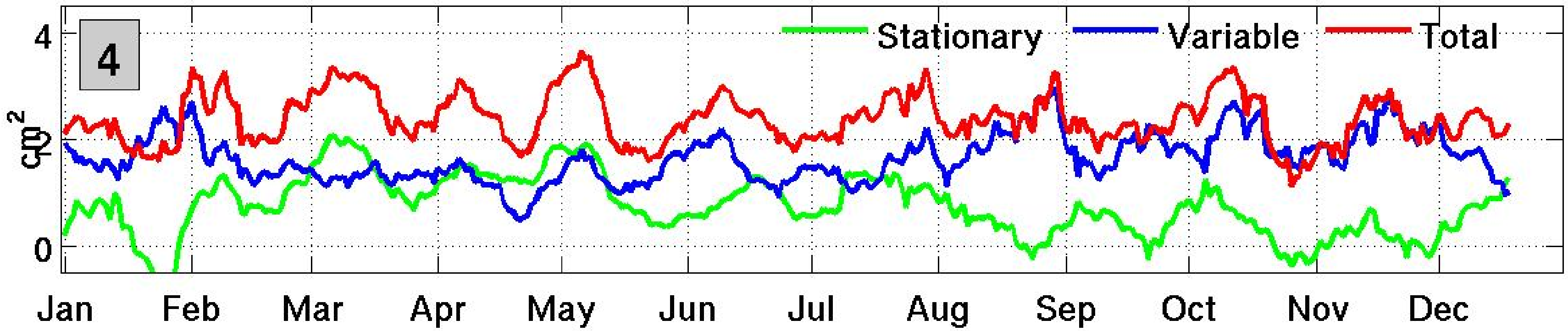
Patch 5: Variance reduction in SWOT data



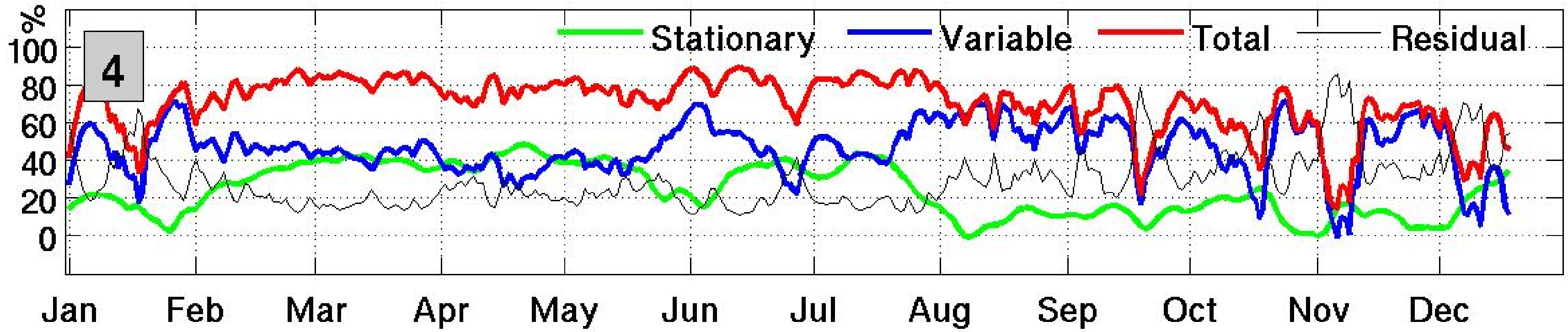
Percent of total M2 HA signal fit



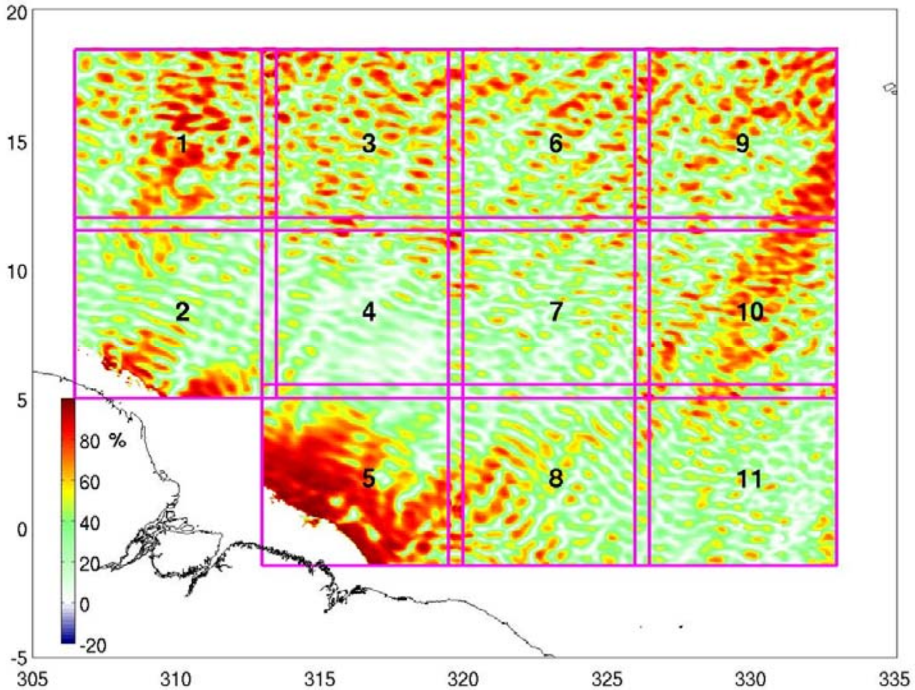
Patch 4: Variance reduction in SWOT data



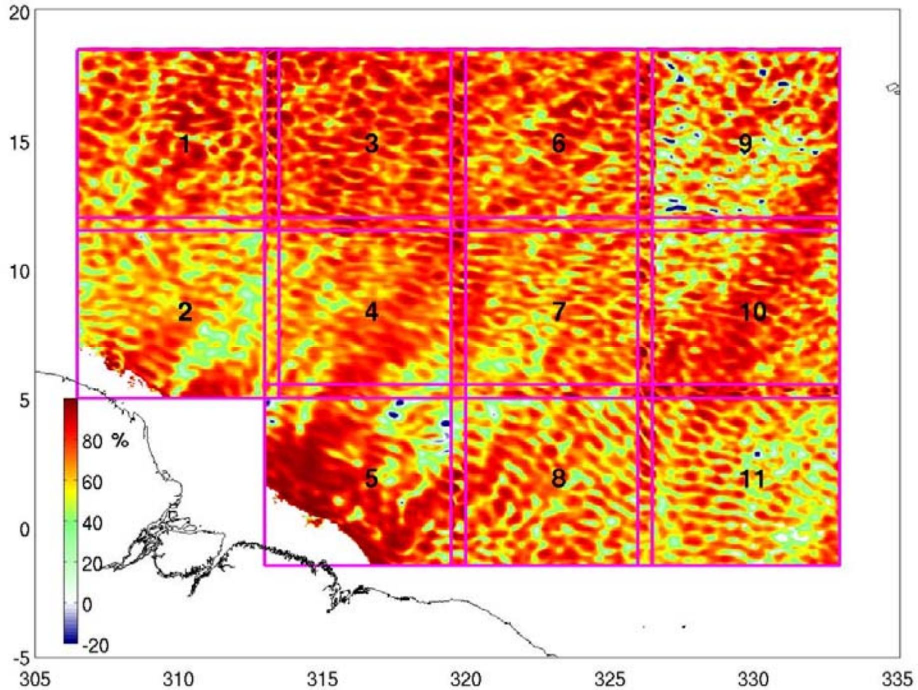
Percent of total M2 HA signal fit



Percent of 14 day HA M2 signal explained



Stationary



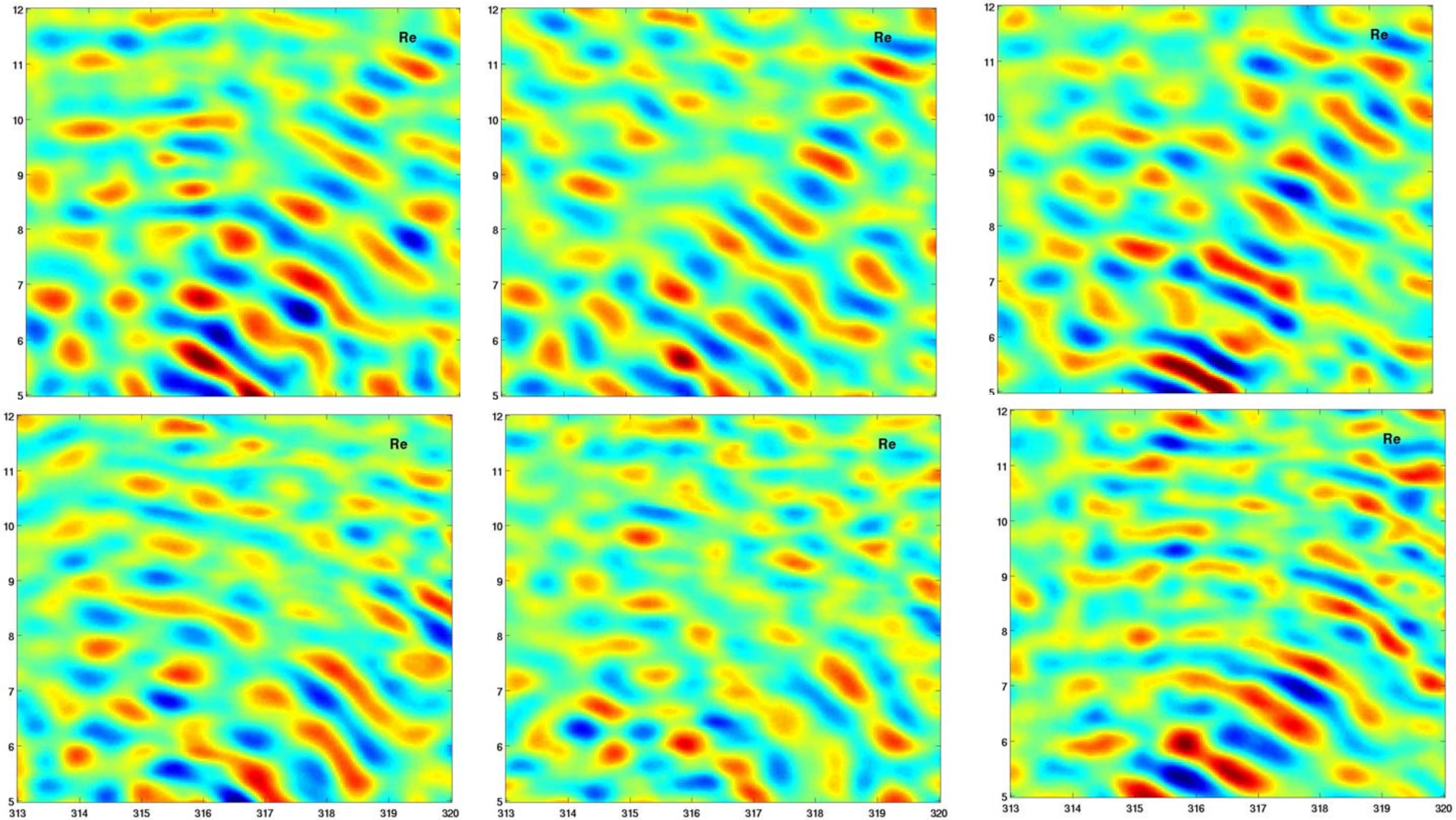
Stationary + PCA model ($L=10$)

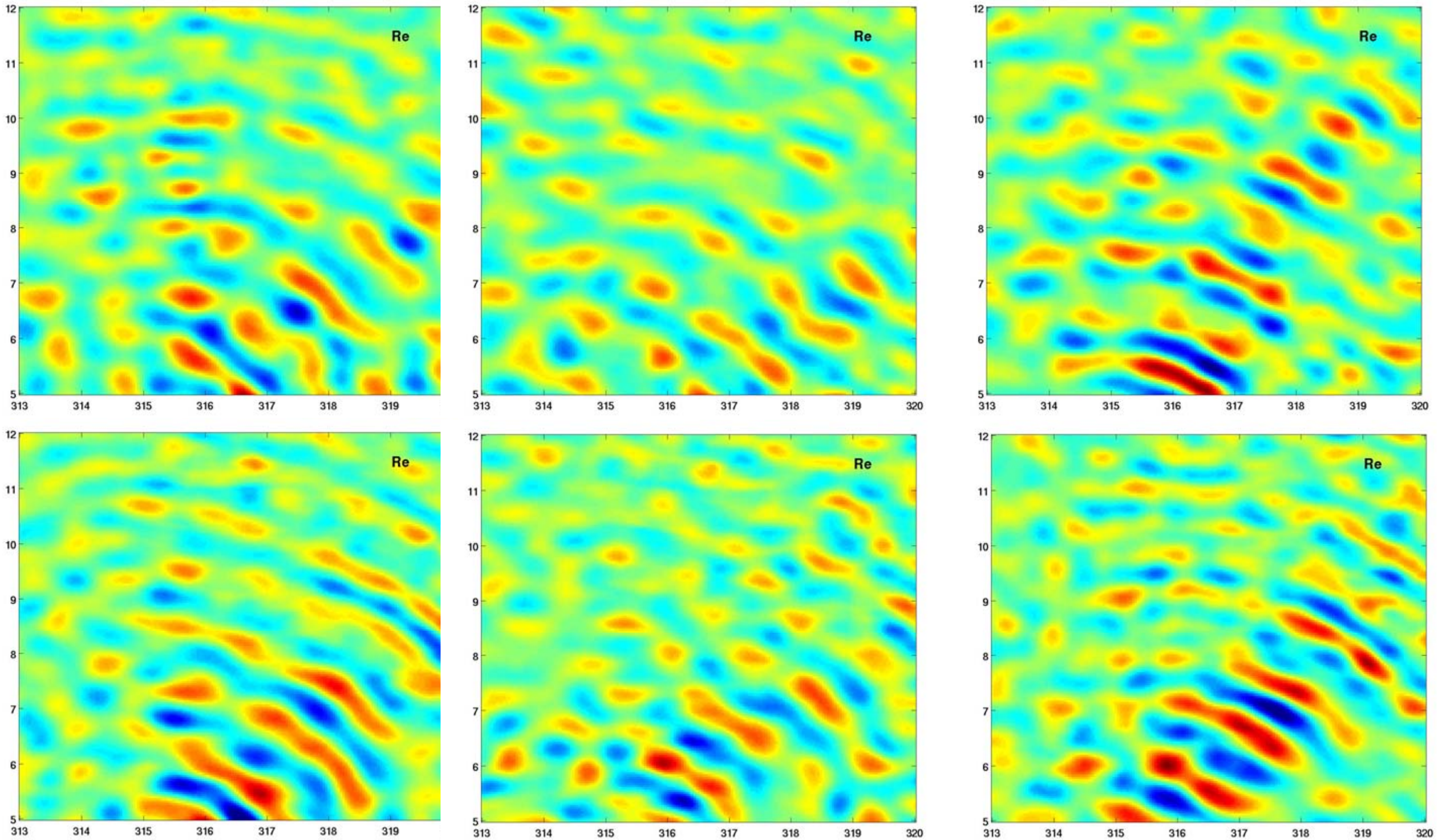
Basic Idea: derive small set of spatial basis functions for incoherent IT from a model, use these to fit SWOT data

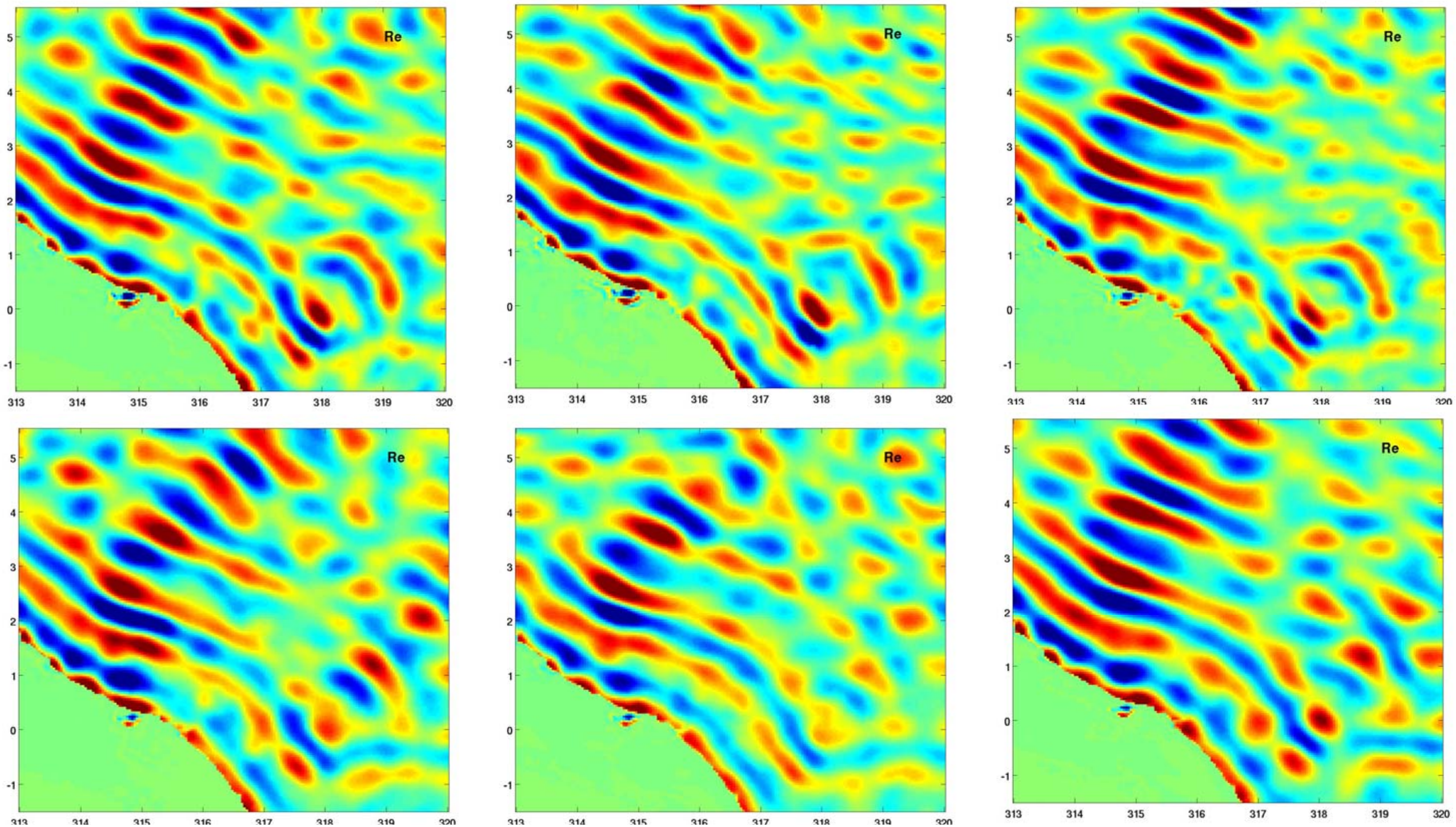
Using HYCOM basis functions, much of the incoherent IT in that moel can be recovered with SWOT sampling

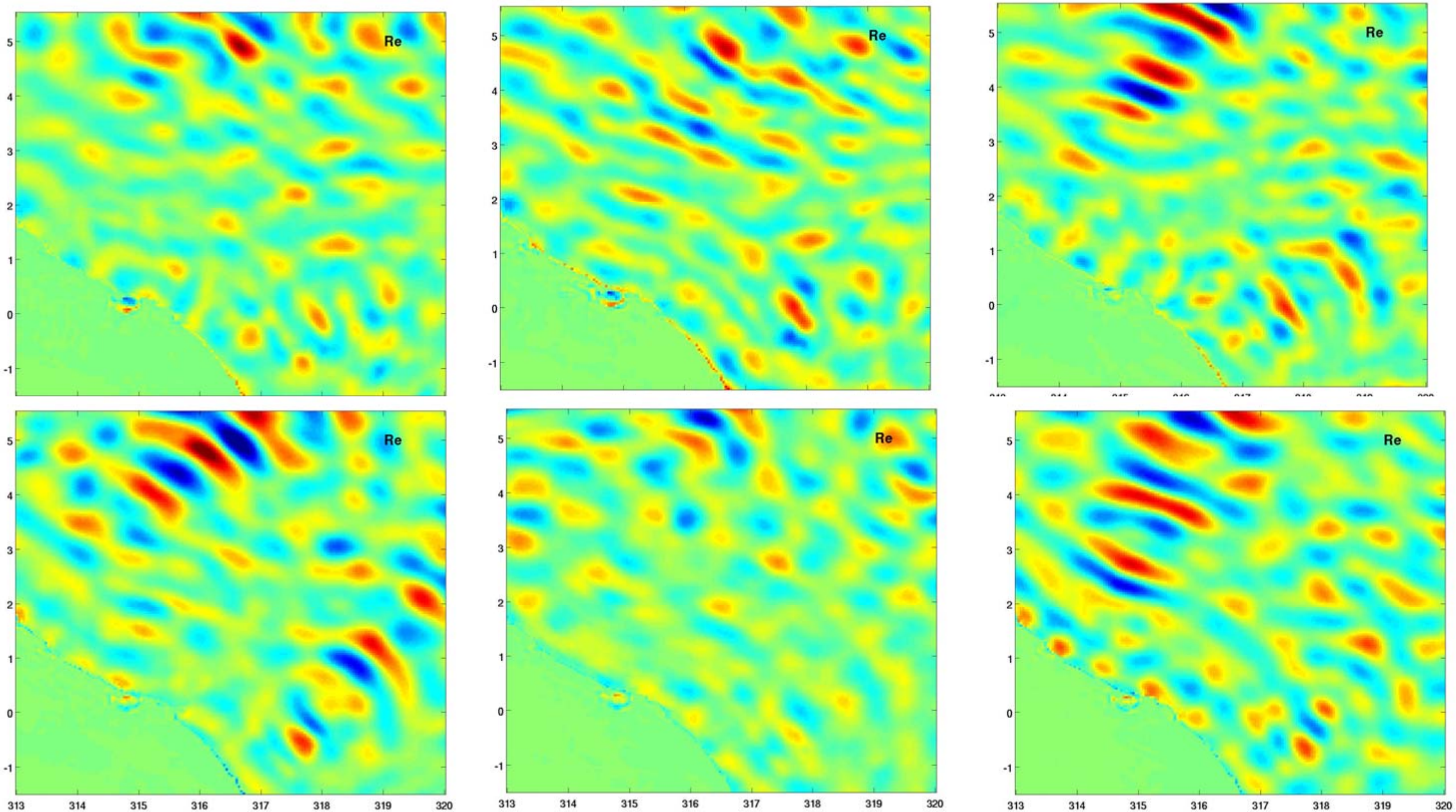
So far just a ”test of concept” – pretty incestuous, more challenging tests needed

Lots of potential refinements/extensions


Re
Re
Re
Re
Re
Re
12
11
10
9
8
7
6
5
313
314
315
316
317
318
319
320


Re
12
11
10
9
8
7
6
5
313
314
315
316
317
318
319
Re
12
11
10
9
8
7
6
5
313
314
315
316
317
318
319
320
Re
12
11
10
9
8
7
6
5
313
314
315
316
317
318
319
320
Re
12
11
10
9
8
7
6
5
313
314
315
316
317
318
319
Re
12
11
10
9
8
7
6
5
313
314
315
316
317
318
319
320
Re
12
11
10
9
8
7
6
5
313
314
315
316
317
318
319
320


Re
Re
Re
Re
Re
Re
5
4
3
2
1
0
-1
313
314
315
316
317
318
319
320


Re
Re
Re
Re
Re
Re
5
4
3
2
1
0
-1
313
314
315
316
317
318
319
320