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Variation of Rossby Waves and Gulf Stream in North Atlantic derived from Altimetry and Microwave–SST using Ensemble Empirical Mode Decomposition

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1. Introduction:

Oceanic Rossby waves are thought to be related to climatic changes due to variability in forcing, due to both the wind and buoyancy. Both barotropic and baroclinic waves cause variations of the sea surface height, although the length of the waves made them difficult to detect until the advent of satellite altimetry. It has been reported that the Rossby waves affect the meridional overturning circulation (MOC) by modifying the basin-wide east-west density gradient and thus Rossby wave activity could account for short-term fluctuations of several Sverdrups for the thermal wind contribution to MOC. Using Ensemble Empirical Mode Decomposition (EEMD), we extract significant six modes and a residual from altimetry and microwave-SST measurements. We identified that the modes 3, 4 and 5 are associated with the Rossby waves in the North Atlantic Ocean.

Two questions for this study

1. Does NAO modulate oceanic Rossby waves?
2. Do Rossby waves modulate meridional transport in the western boundary?

2. Empirical Mode Decomposition (EMD) and Results

- Identify the local maxima and local minima of the original signal shown with solid line (Figure 1)
- Compute the mean values (m_1) by averaging the upper envelop and the lower envelop. Subtract m_1 from the original ($X(s)$) to obtain the first step for the first IMF (IMF-1) (Eq. 1).
- $$h_1 = X(s) - m_1 \quad (1)$$
- The EMD process makes each Intrinsic Mode Function (IMF) acquire zero crossing by removing the mean. Calculate the first residual component by subtracting IMF-1 (h_{1k}) from the original signal, where k is the number of Sifting process until h_1 becomes IMF. Once the first set of Siftings results in an IMF, define

$$h_{1k} = C_1, \quad (2)$$

Generate the residue, r_1, of the data by subtracting C_1

$$r_1 = X(s_0 - s_1). \quad (3)$$

- Repeat the steps above until the final residual component becomes a monotonic function and no more IMFs can be extracted.

EMD method (Huang et al., 1998) was further developed as Ensemble Empirical Mode Decomposition by Wu and Huang (2009).

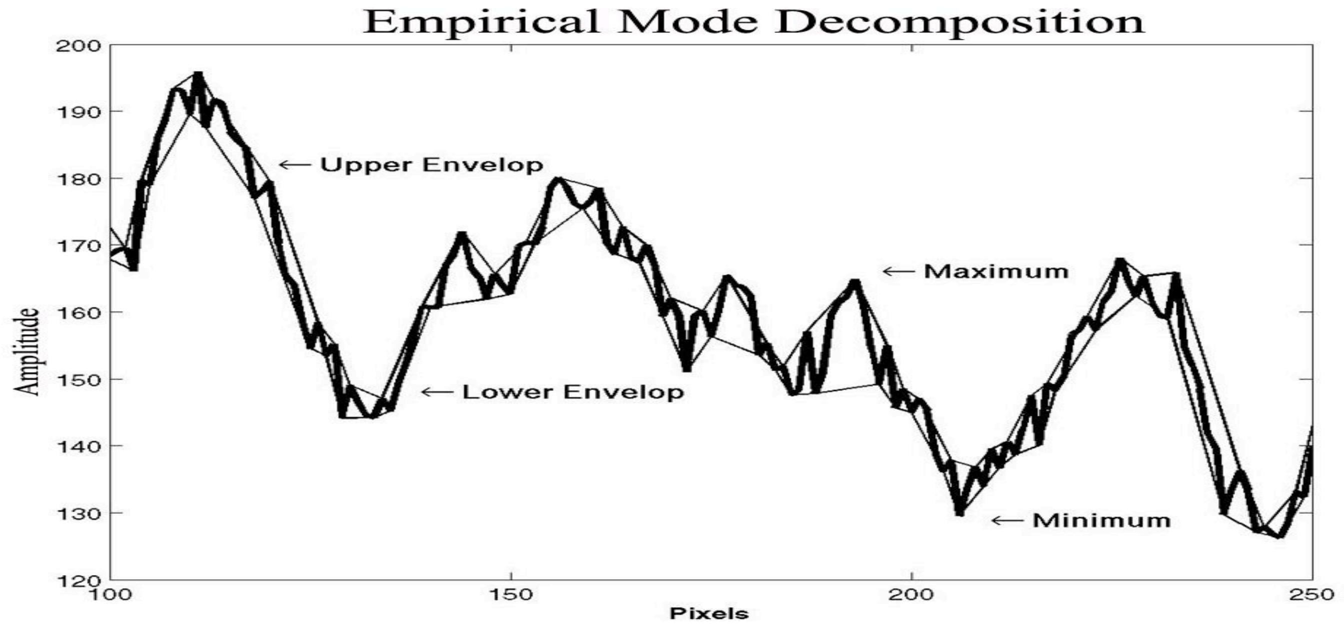

Figure 1: Process to obtain the first IMF. For higher modes, the process is repeated until the mode has no local maximum and minimum.

Sea Surface Height Anomaly (SSHA)

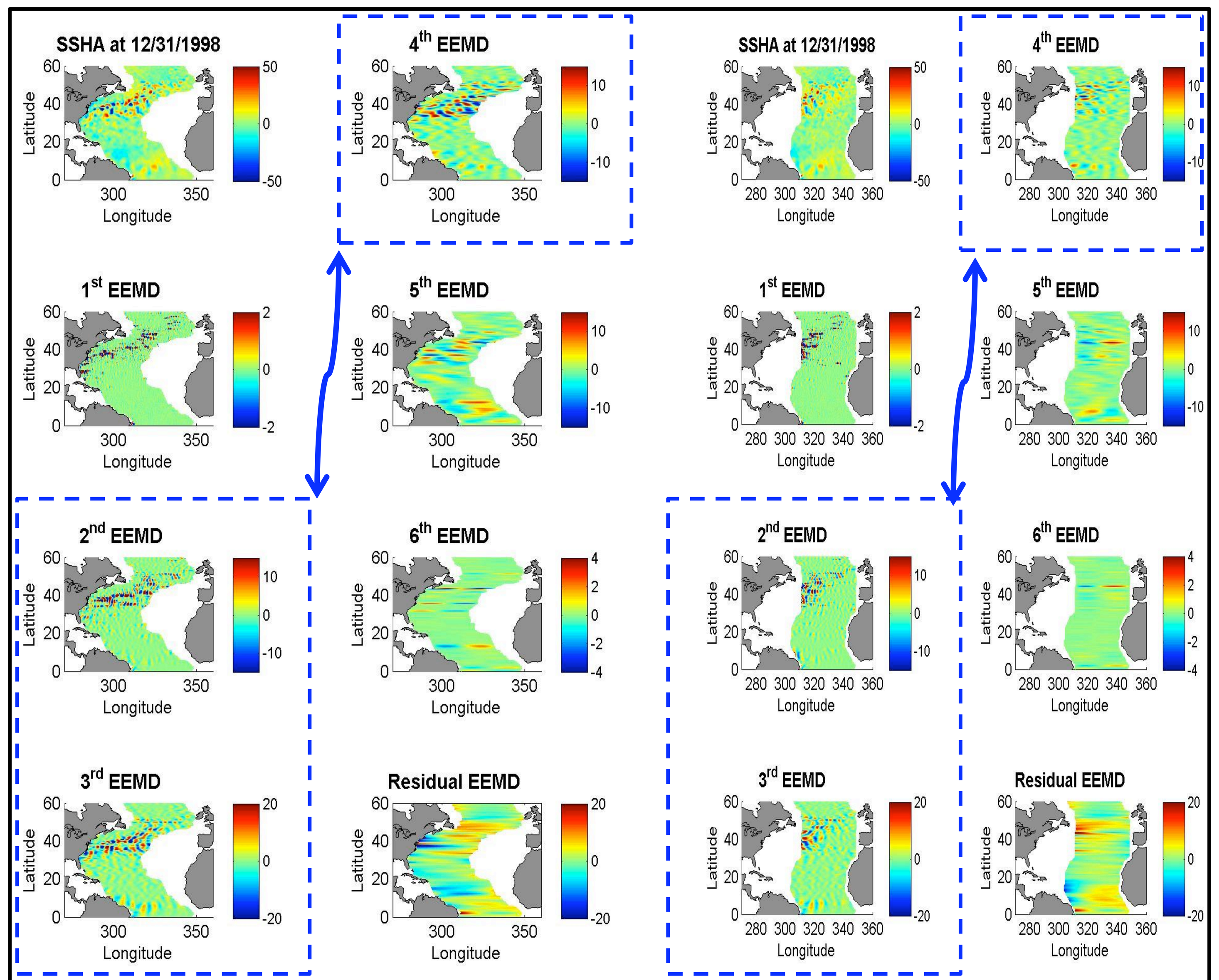

Fig. 2a: SSHA in NW Atlantic Fig. 2b: SSHA in NE Atlantic

Microwave Sea Surface Temperature (SST)

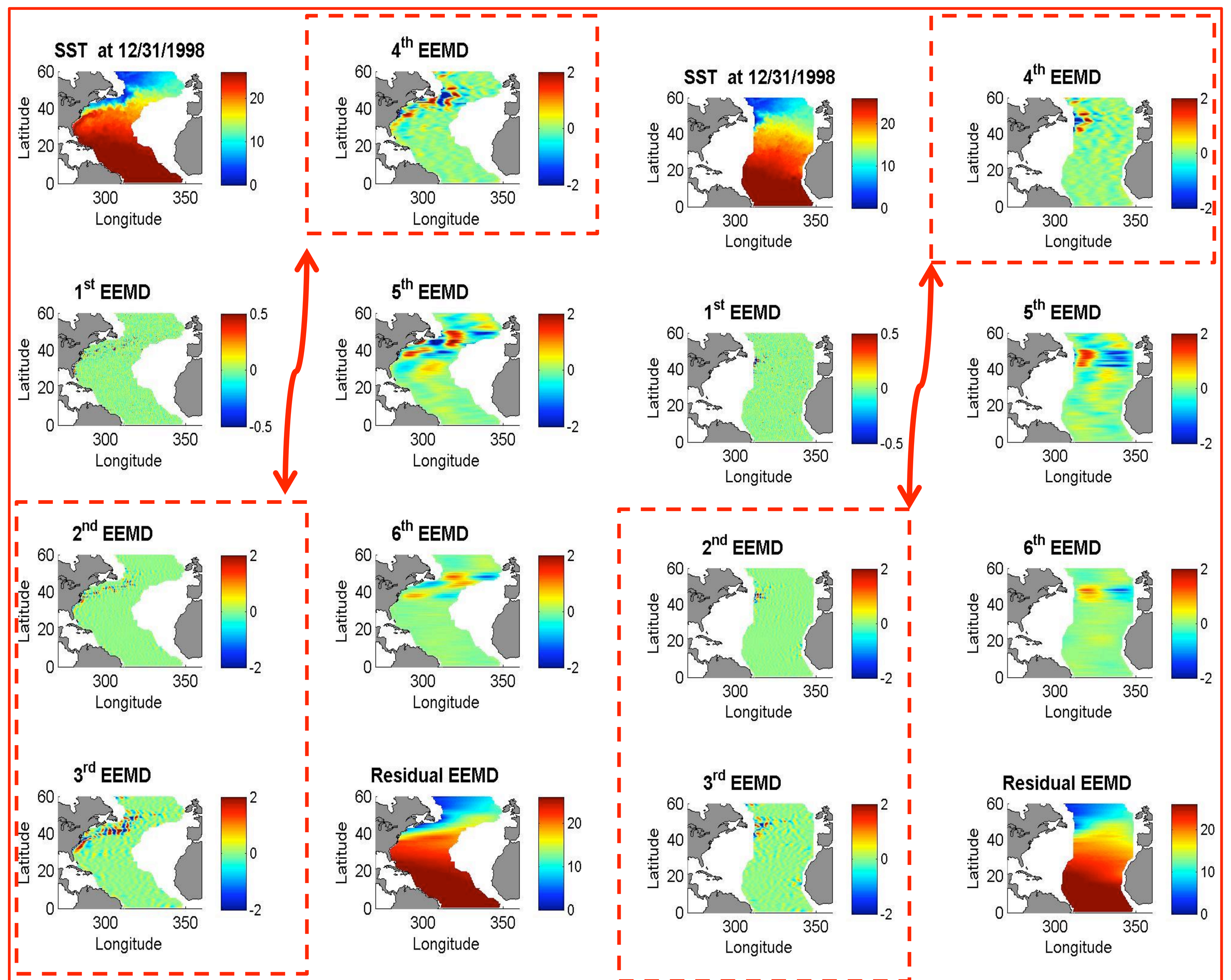

Fig. 3a: SST in NW Atlantic Fig. 3b: SST in NE Atlantic

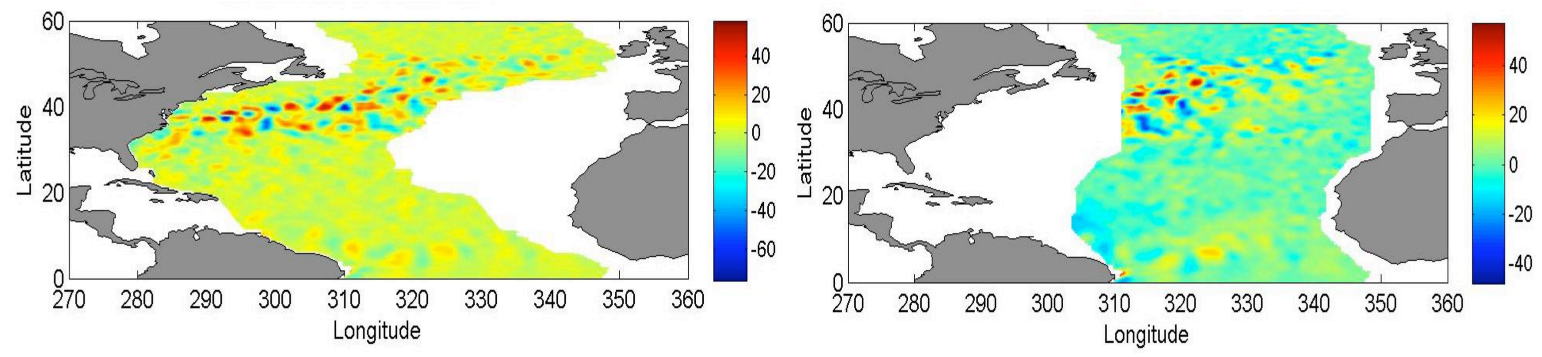

Fig. 4: Combined modes 2,3, and 4 for SSHA

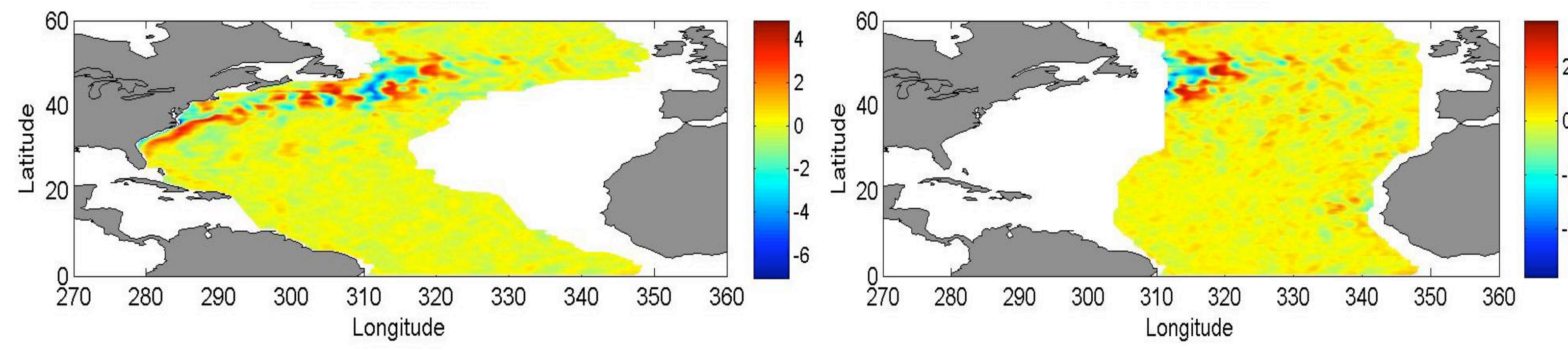

Fig. 5: Combined modes 2,3, and 4 for SST

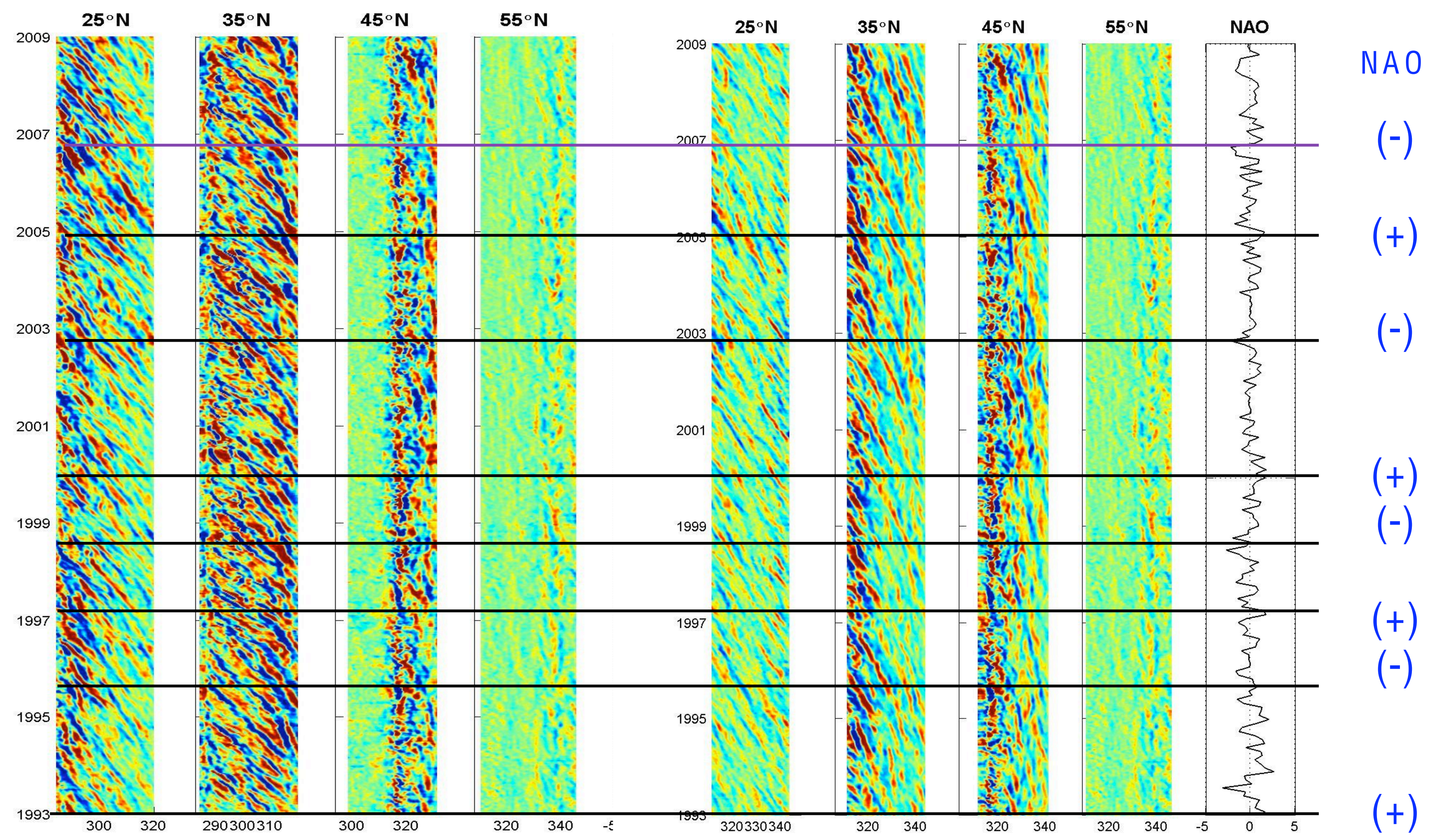

Fig. 6: Hovmoller diagrams for modes 3,4, and 5 in NW and NE Atlantic

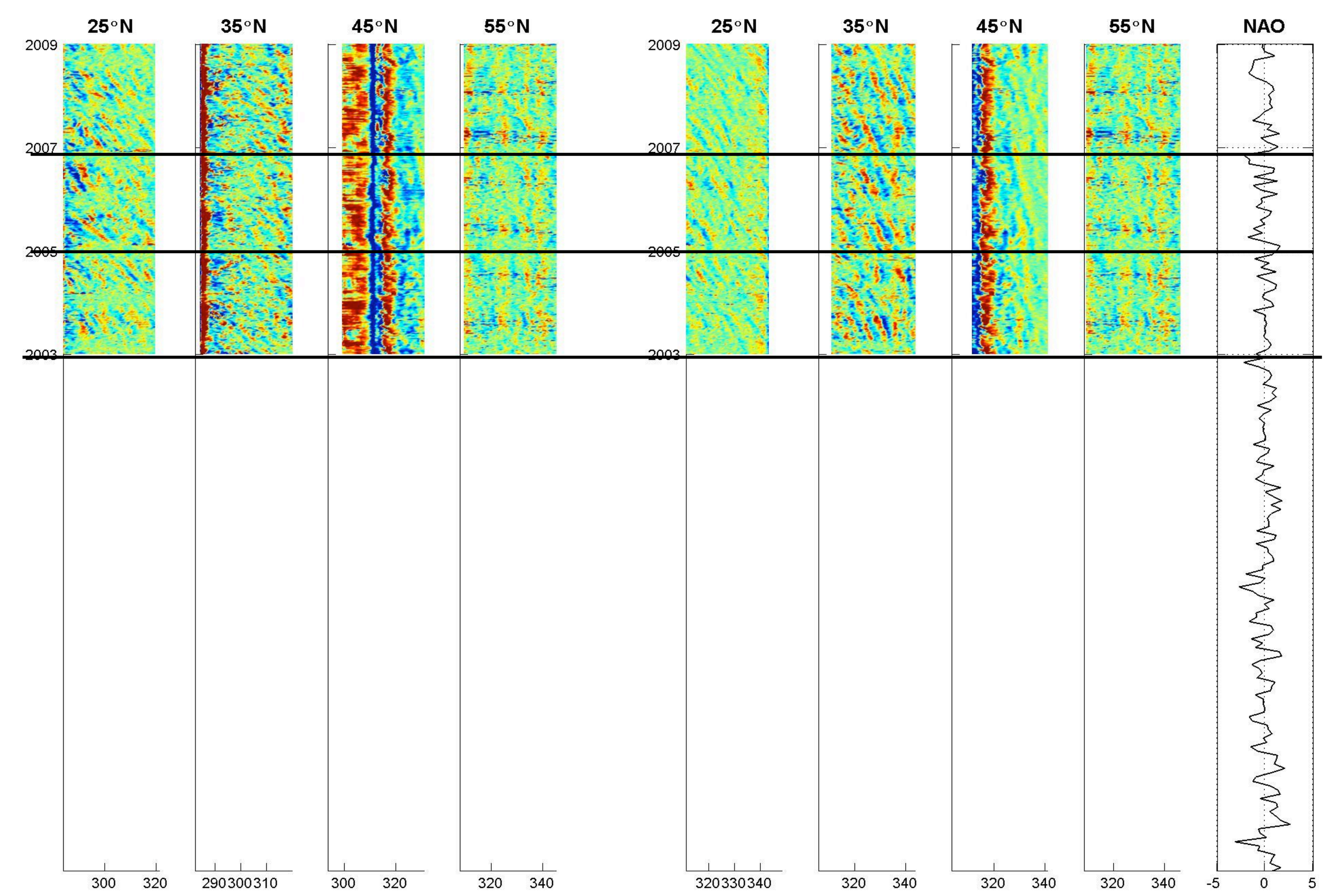

Fig. 7: Hovmoller diagrams for modes 3,4, and 5 in NW and NE Atlantic

3. Conclusions

- Rossby wave (RW) features (500- 1200km) were extracted from SSHA and SST using EEMD (Modes 2,3 and 4).
- Amplitudes of RW in NW Atlantic are higher (O(2cm)) than those in NE Atlantic (below 55°N), and phase speeds in NW Atlantic are faster than those in NE Atlantic (Osychny and Cornillon, 2004).
- No evidence of RW changes due to NAO (maybe data is too short!) , which is also checked with Cumulative Sums.
- Complex features of RW due to the Gulf Stream in NW Atlantic, especially near the Grand Banks (EEMD for SST)
- Open questions: What do other modes represent? What are the meridional transport near Grand Banks?

References

Huang, N., Z. et al., 1998: The empirical mode decomposition and Hilbert spectrum for nonlinear and nonstationary time series analysis. *Pro.Royal Society Mathematical, Physical and Engineering Science*, 454, 903–995.

Wu, Z., and N. E Huang, 2009: Ensemble Empirical Mode Decomposition: a noise-assisted data analysis method. *Advances in Adaptive Data Analysis*. 1, 1-41.

Osychny V.and P. Cornillon, 2004: Properties of Rossby Waves in the North Atlantic estimated from satellite data, *J.Phys. Oceangra*., 34, 61-76.