Downscaling Ocean Conditions:

Initial Results using a Quasigeostrophic and Realistic Ocean Model

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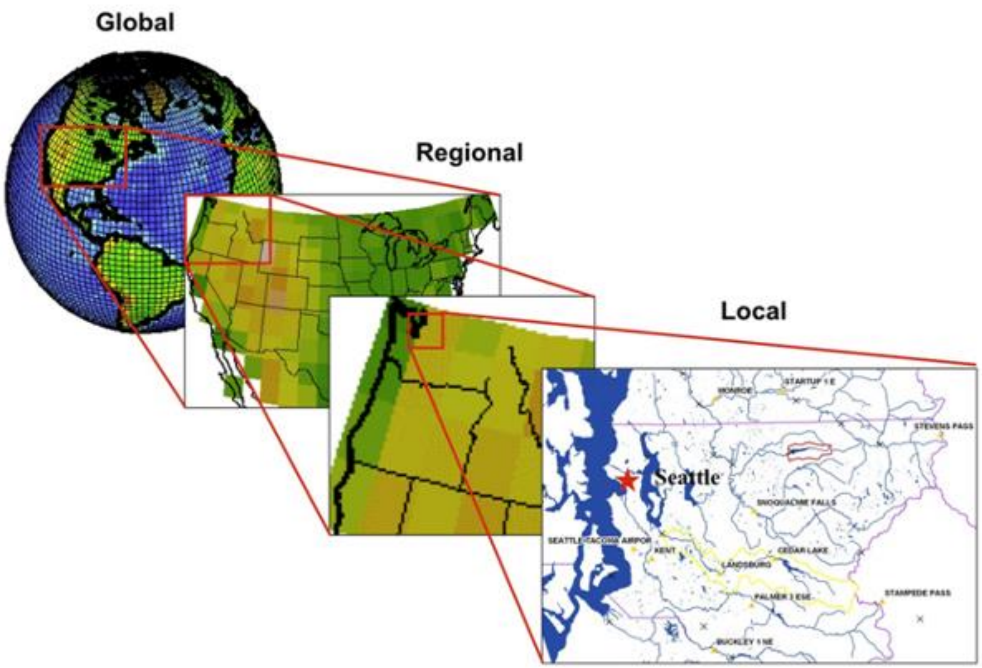
Outline of Talk

- Background and Motivation
- Approach
- Idealized Application
- Northwest Atlantic Application

Motivation

Need for historical reconstructions, predictions and projections of physical oceanographic conditions on **regional scales**

- The local scale variability is often **controlled** by processes operating on **large scales**
- Model large parts of the ocean with regions of increased resolution (**Downscaling**)
- Several **problems** with **nesting**



National Climate Predictions & Projections Platform (NCPP): http://www.esrl.noaa.gov/

Coupling of Large and Small Scales

- **Henshaw et al., (2003):** Accurate reconstruction of the small scale variability from the time history of the large scales.
- **Large scales** can guide reconstruction, prediction and projections over limited areas.

Atmospheric Spectral Nudging (e.g., von Storch et al., 2000): Coarser resolution fields are used to drive the higher resolution model in the **interior** and not just the **boundaries**.

$$\psi_a = \psi_f + \underbrace{\gamma\langle\psi_i - \psi_f\rangle_L}_{\textbf{Spectral nudging term}}$$

ψ_f : regional model forecast

ψ_i : independent estimate of the true field (coarser resolution model)

$<>_L$: spectrum that corresponds to large scales

γ: Nudging coefficient

Downscaling Ocean Conditions

Will it work in the ocean?

The different ocean length scales can be coupled through:

- N**on-linearity** of the governing equations
- Surface **forcing**
- Reflection of the **Rossby waves** by the western boundary

Important Atmosphere and Ocean differences:

- Internal **Rossby radius** of deformation
- **Lateral boundaries**
- Relative **few observations** of the ocean

One step further: Assimilate available sparse point observations along with the large scale information .

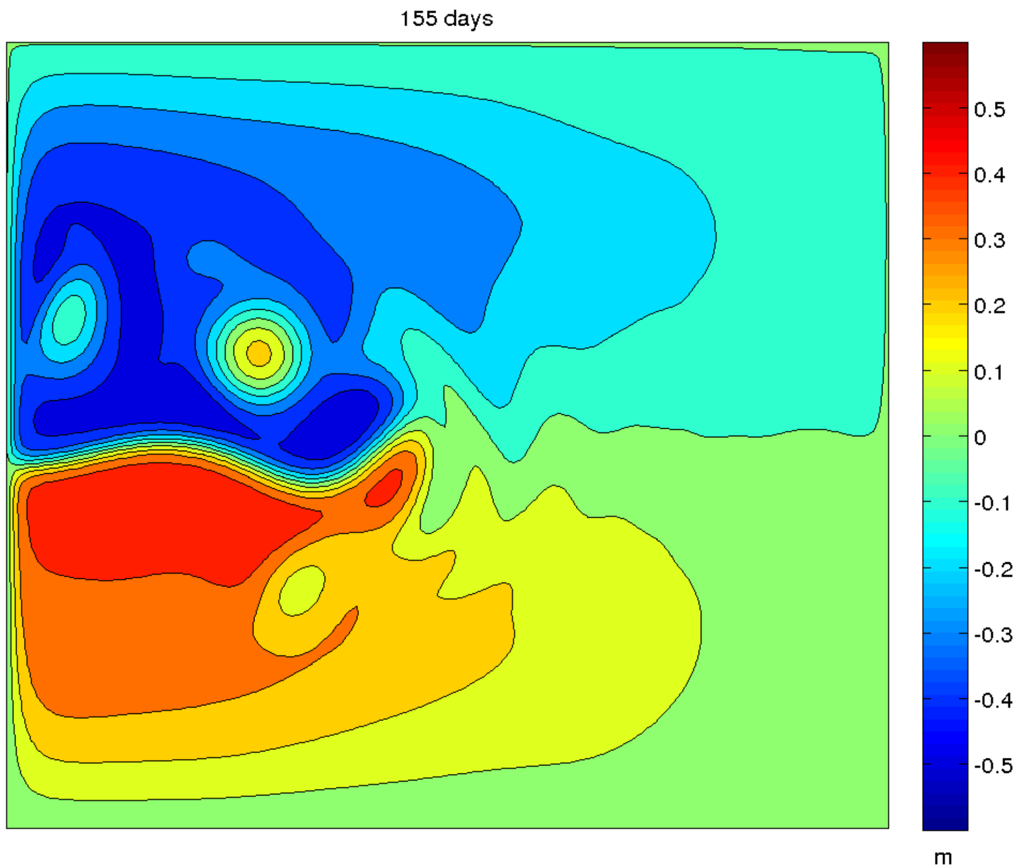
QG Model Application

- Rectangular ocean (3600x2800 km with resolution 20km) on **beta plane**

- **1/2 layer** model

- The model is forced by a **steady zonal** wind distribution that generates two gyres separated by a meandering ocean jet

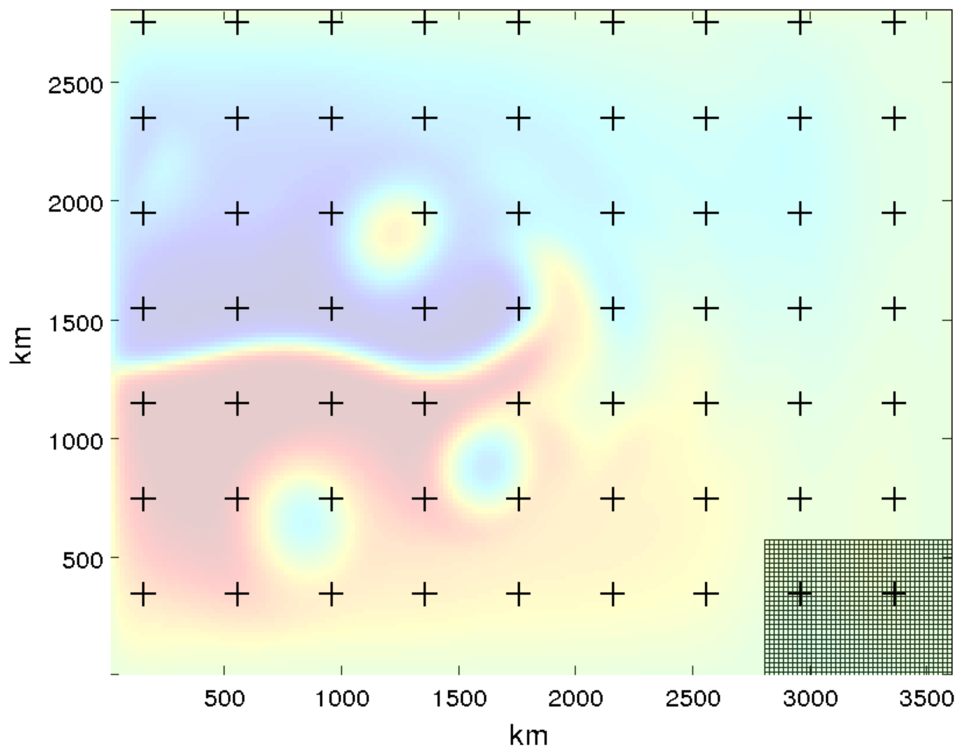
- Scale separated using 2D discrete **Fourier transform**



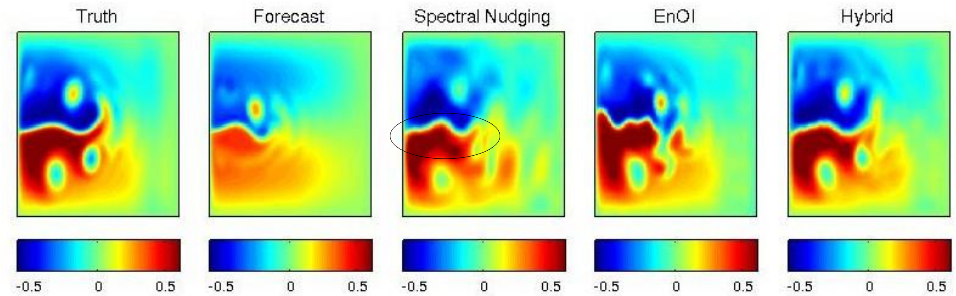
Description	Run	Period	Initial Condition	Assimilation
Spinup	SP	several decades	Rest	No
Forecast	FC	1000 days	End of run SP	No
Ensemble	EN	18 years	End of run FC	No
Truth	TR	1000 days	End of run EN	No
Spectral nudging	A1	1000 days	End of run SP	Large-scales from run TR
EnOI	A2	1000 days	End of run SP	Point obs from run TR
Hybrid	A3	1000 days	End of run SP	Large-scales and point obs

- Several twin experiments performed

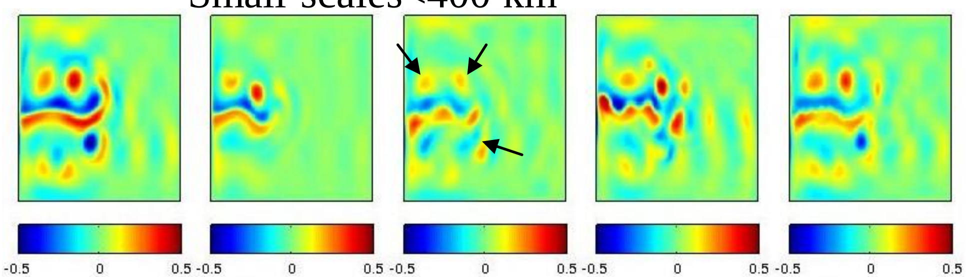
- **Large scales** and **pseudo-observations** are generated by the model using different initial conditions



QG Model Results

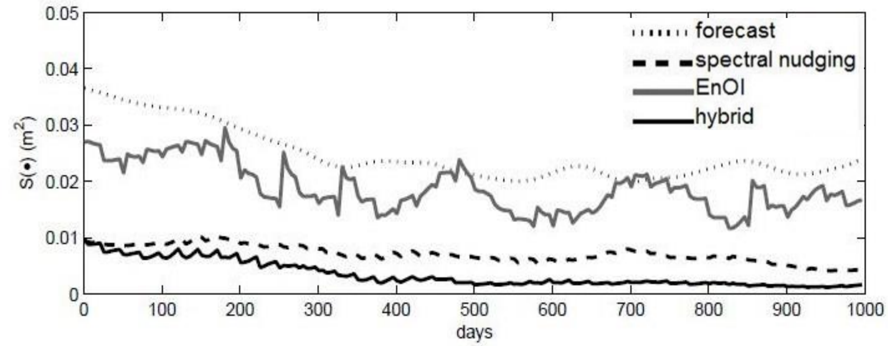


Small-scales<400 km



Spectral nudging removed unrealistic jet meanders and placed the **eddies** at the **correct location** (however eddies too weak)

All scales



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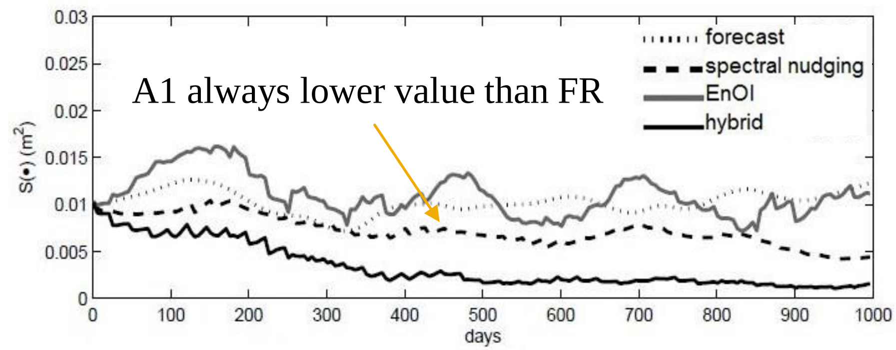
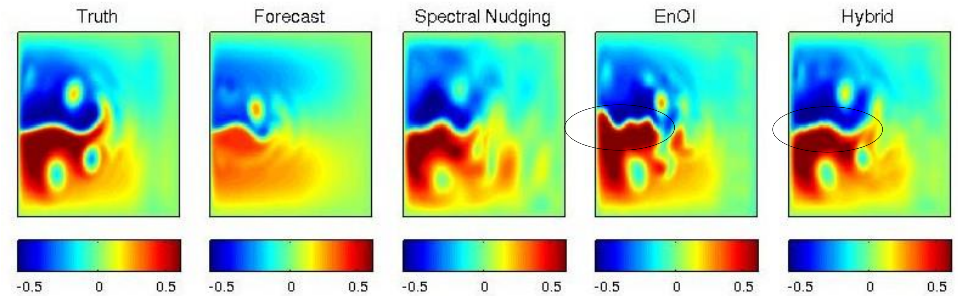


Spectral nudging also **reduced the small scale error**

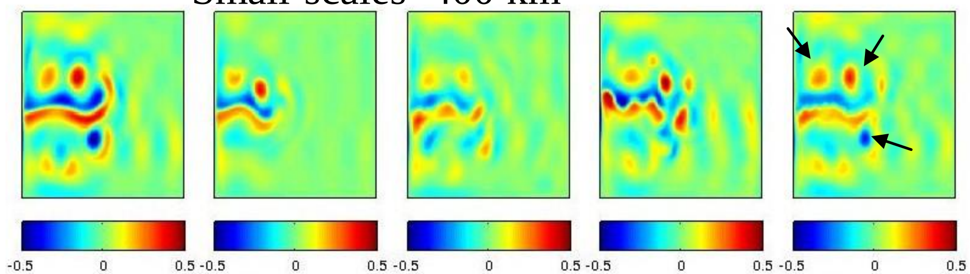
QG Model Results



•**EnOI** : **unrealistic** jet and eddies **position**

•**Hybrid** : **eddies** and meanders have the **correct location** and **intensity**

Small-scales<400 km

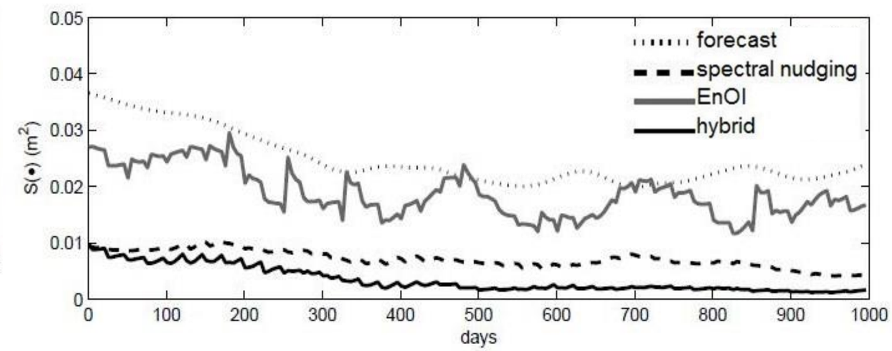


•**EnOI error fluctuation**: error inflated when the observation array cannot detect the eddies

•Hybrid **outperforms** spectral nudging and EnOI.

•Limited observations have **large impact** when used in combination with spectral nudging

All scales



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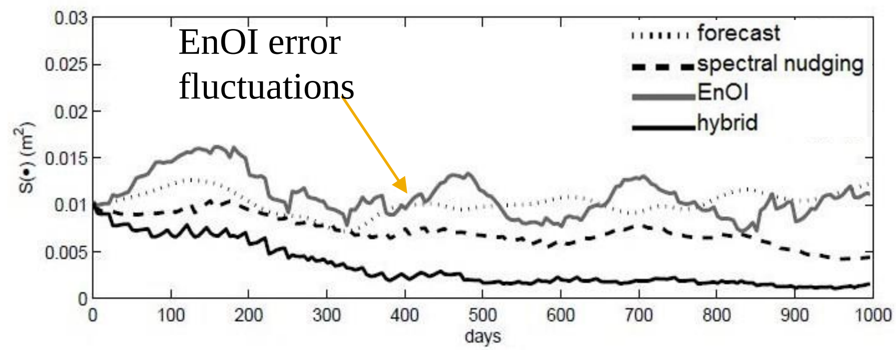
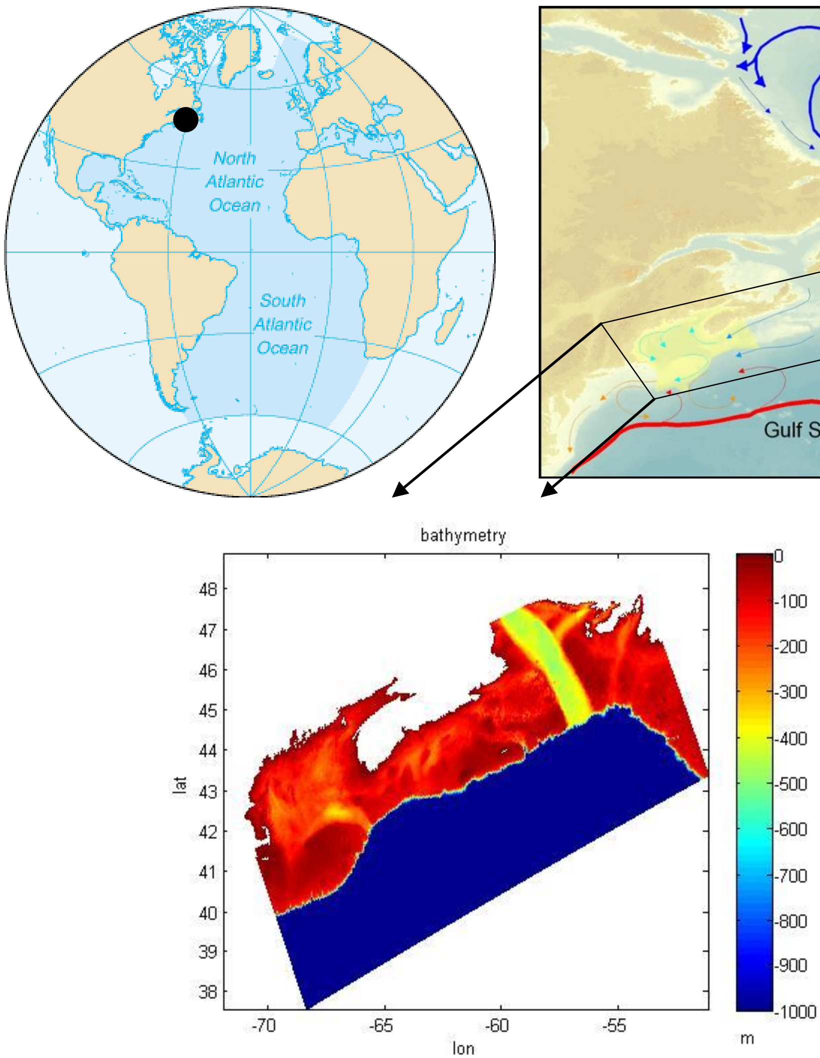
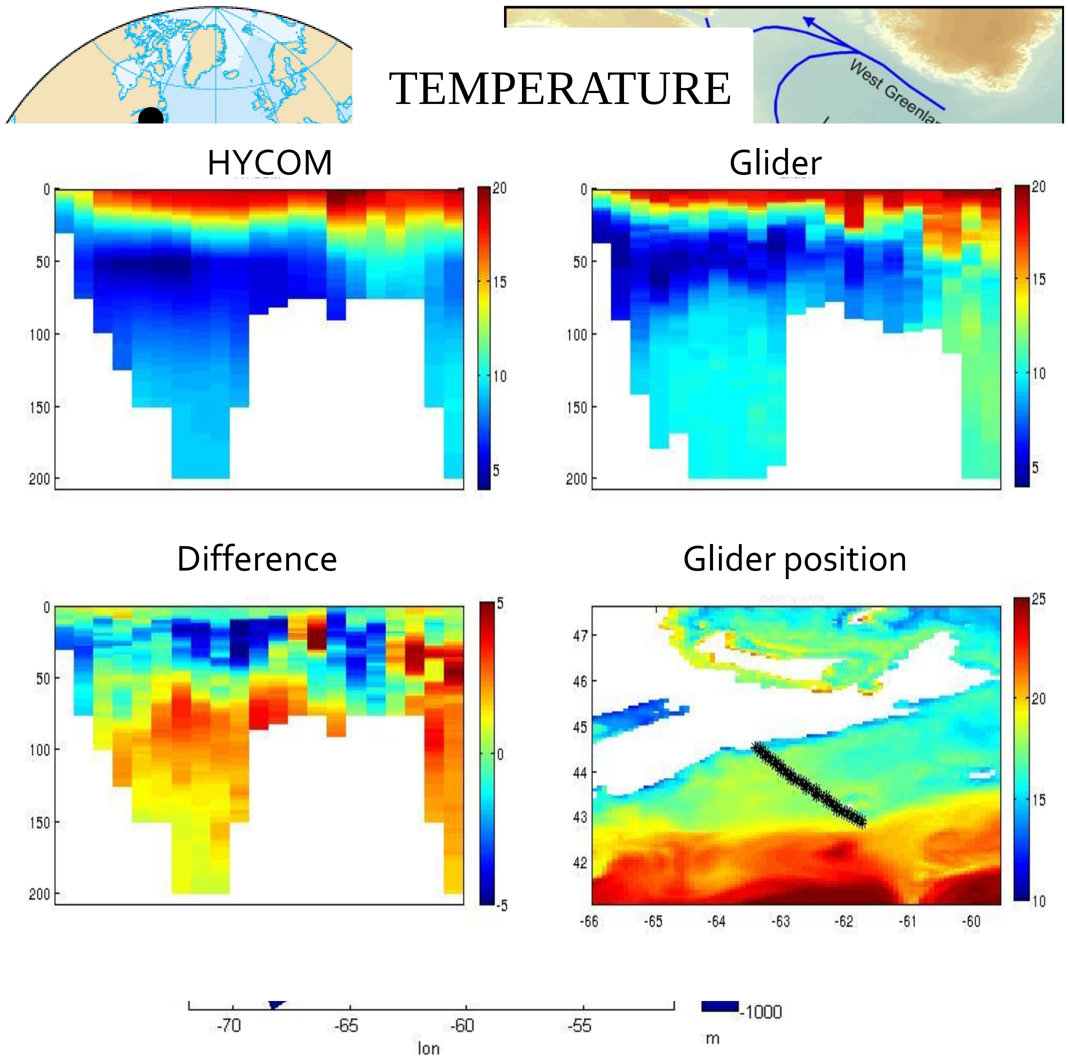


Realistic Application



- Complex mean circulation and very high **tides**
- NEMO 3.1 with resolution **1/36°** and 52 vertical levels
- Atmospheric forcing: **NCEP Climate Forecast System Reanalysis (CFSR)**
- Tides (M2,S2,N2,K1,O2) from LEGOS (Laboratoire d'Etudes en Géophysique et Océanographie Spatiales)
- Initial conditions and open lateral boundaries**: HYCOM** (HYbrid Coordinate Ocean Model) + **NCODA** (Navy Coupled Ocean Data Assimilation) global **1/12°** analysis product

Realistic Application



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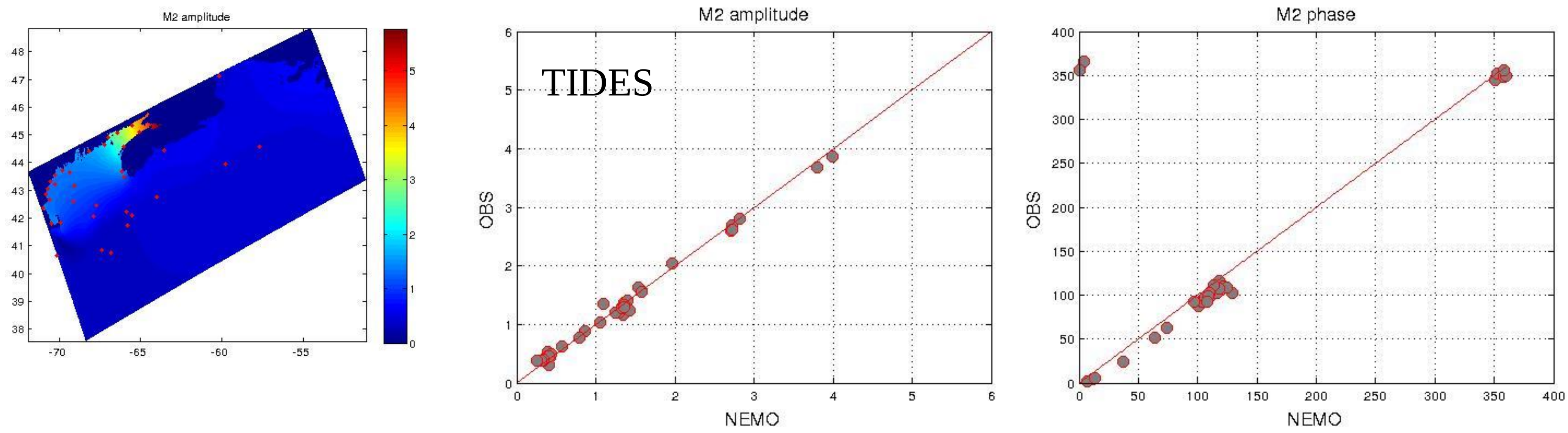
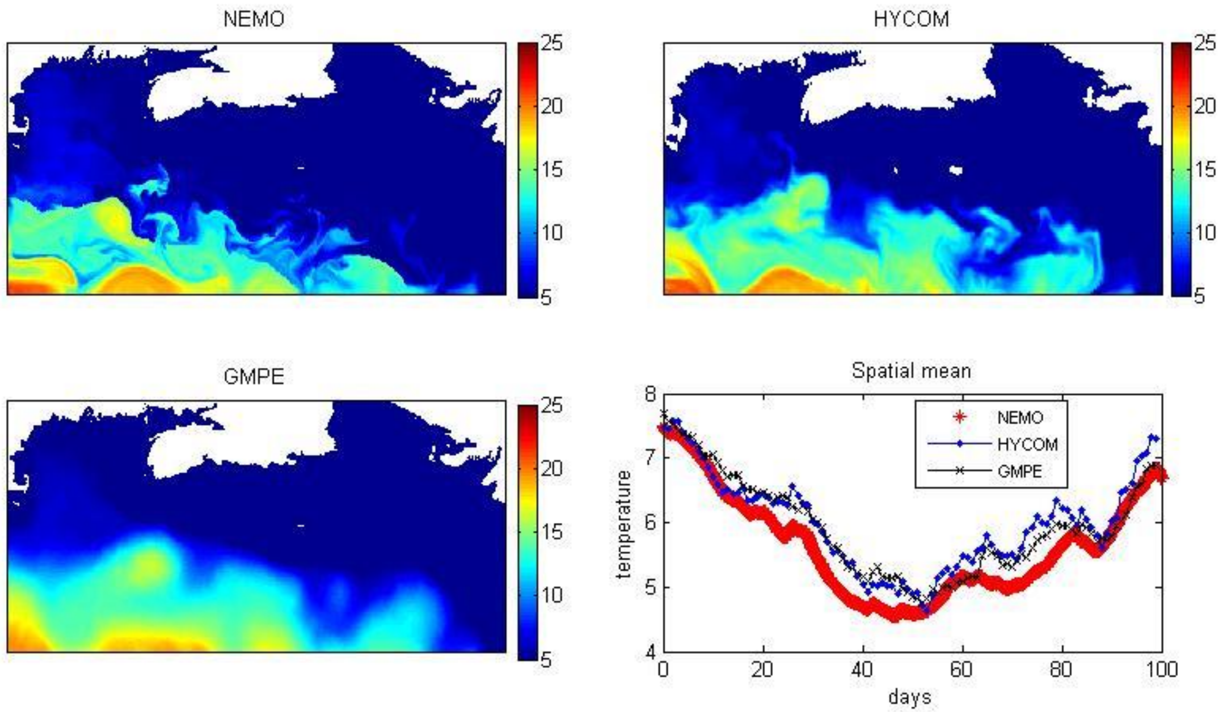


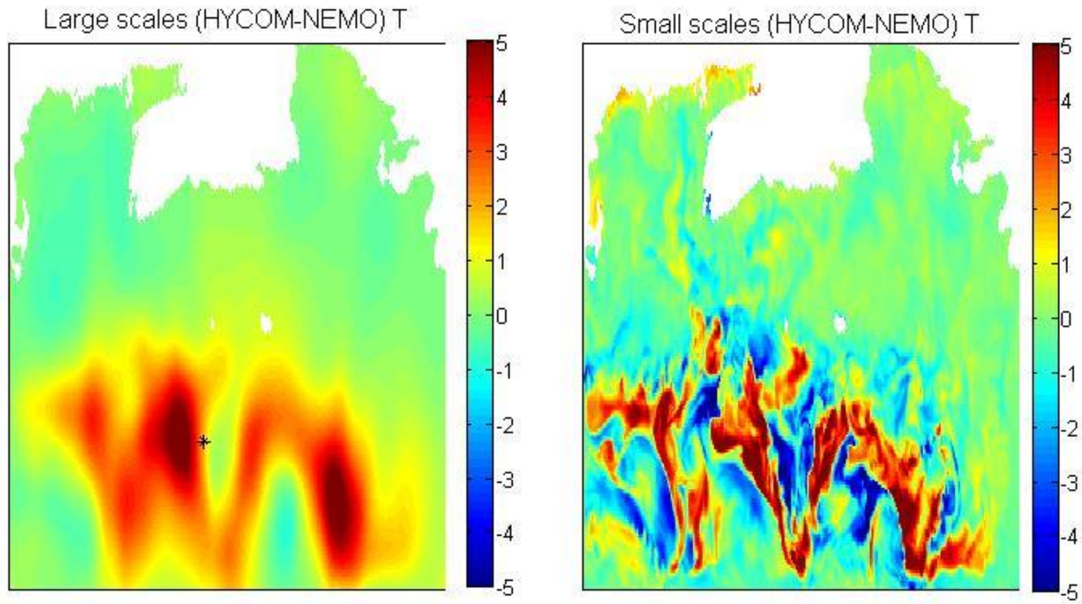
TEMPERATURE



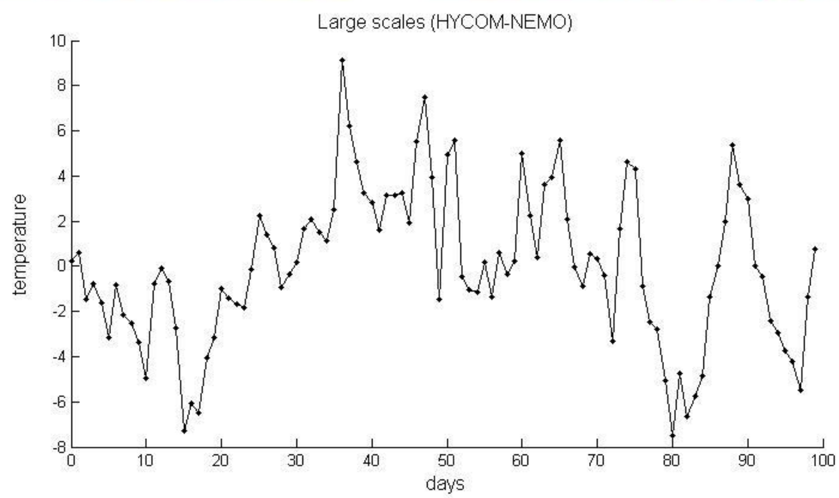
- Realistic **tides** and **general circulation**.
- Divergence of HYCOM and NEMO solutions.
- We want the model to:
  i) evolve **freely** for **length scales not resolved** by HYCOM
  ii) stay close to HYCOM on the **large scales.**

Large and small scales are defined using a **Butterworth filter**

TEMPERATURE



Cut off lengthscale ~ 500 km



Nudging coefficient **γ varying** in horizontal and vertical:

- Near the **coast** more model freedom.
- Near the **surface** stronger relaxation.

Summary

- The time history of ocean large scales can guide the reconstruction of the small scales
- Assimilation of sparse observations more effective with spectral nudging of large scales
- High resolution nested NEMO diverges from global HYCOM on both large and small scales
- Optimistic that constraining NEMO’s large scales will improve its prediction of the small scales

Thanks: Ocean Tracking Network (OTN), Marine Environmental Observation Prediction and Response Network (MEOPAR), Dr. Y. Lu, Dr. J-P. Paucin, Dr. V. Korabel

References

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Definition and Variability of Scales

Discrete Fourier transform:

$$a_{k_1,k_2} = \frac{1}{N_1 N_2} \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} e^{-i\varphi} \eta_{n_1,n_2}$$

$$\varphi = 2\pi \left(\frac{k_1 n_1}{N_1} + \frac{k_2 n_2}{N_2} \right)$$

Large scales:

$$\eta^L_{n_1,n_2} = \sum_{(k_1,k_2)\in K^c} e^{i\varphi} a_{k_1,k_2}$$

Small scales:

$$\eta^S = \eta - \eta^L$$

Most of the variance is captured from the fist 13 wavenumbers in the zonal and 12 in the meridional ($k^c=13$, 130 km)

$k^c=2$