Ocean Model Development and Ocean Forecasting Systems

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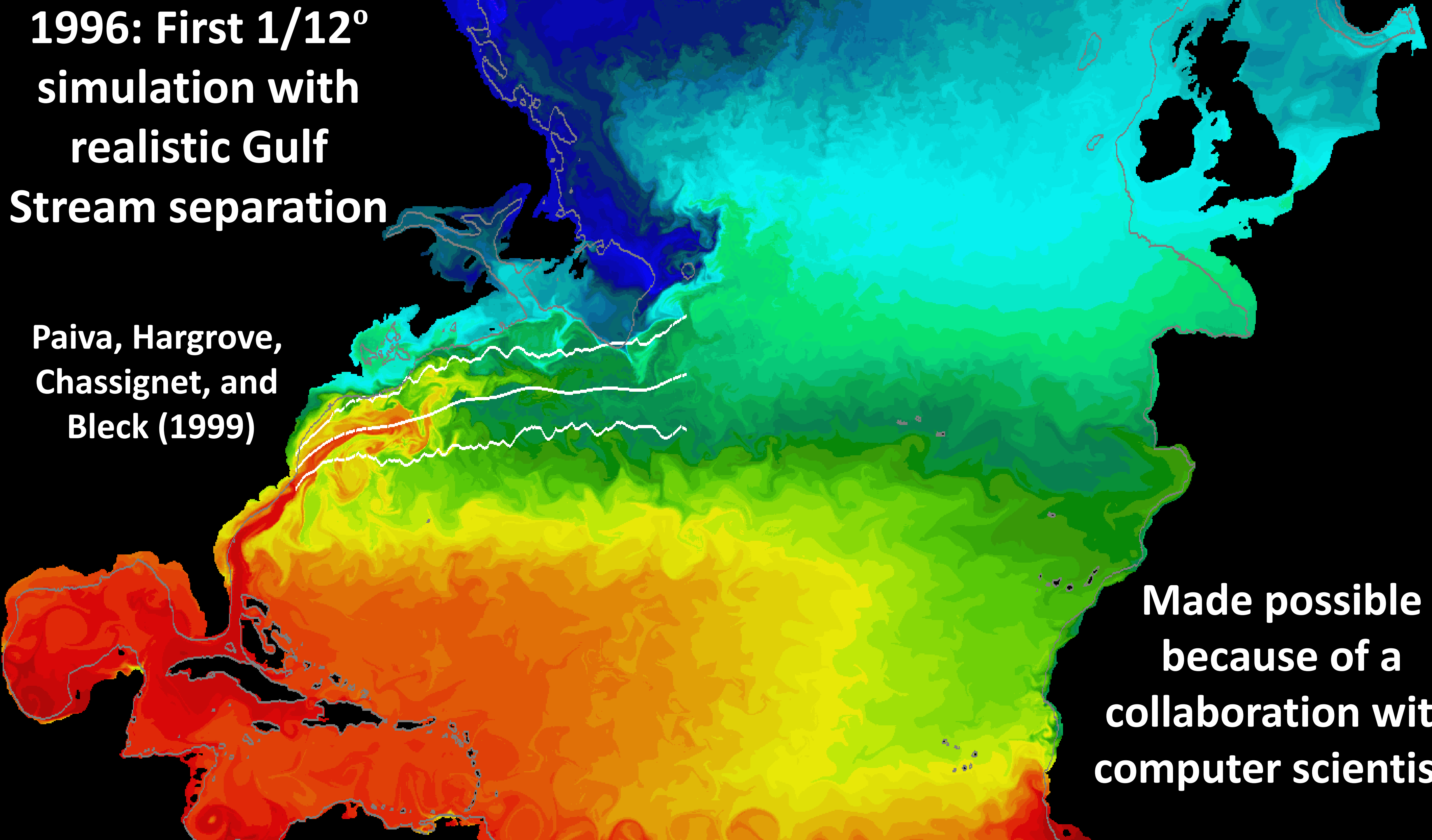
OceanPredict '19

Advancing the science and application of ocean predictions

1996: First $1/12^{o}$ simulation with realistic Gulf Stream separation



Paiva, Hargrove, Chassignet, and Bleck (1999)

Made possible because of a collaboration with computer scientists

20 years later

- Routine global ocean prediction at 1/12° (~6 km at mid-latitudes) (Mercator, HYCOM GOFS 3.1, BlueLINK, etc.)
- Soon global ocean prediction at 1/25° (~3 km at mid-latitudes) with tides (HYCOM GOFS 3.5)
- Under development, the US Navy ESPC coupled system (also called Navy Earth System Model or NESM)
  - Ensemble configuration: consists of the atmospheric model NAVGEM T359 (37 km) and 60 levels, the ocean model HYCOM 1/12.5° and 41 layers, sea ice CICE 1/12.5° (3.5 km), and the land module within NAVGEM. Probabilistic (ensemble) forecasts are 0-45 days once a week with 15 members.
  - Deterministic configuration: as above, except for 1/25° ocean model
- Prototypes global and basin-scale ~1/50° simulations (~1.5 km at mid-latitudes) with tides (MITgcm, NEMO, HYCOM)

For the next generation forecasting systems

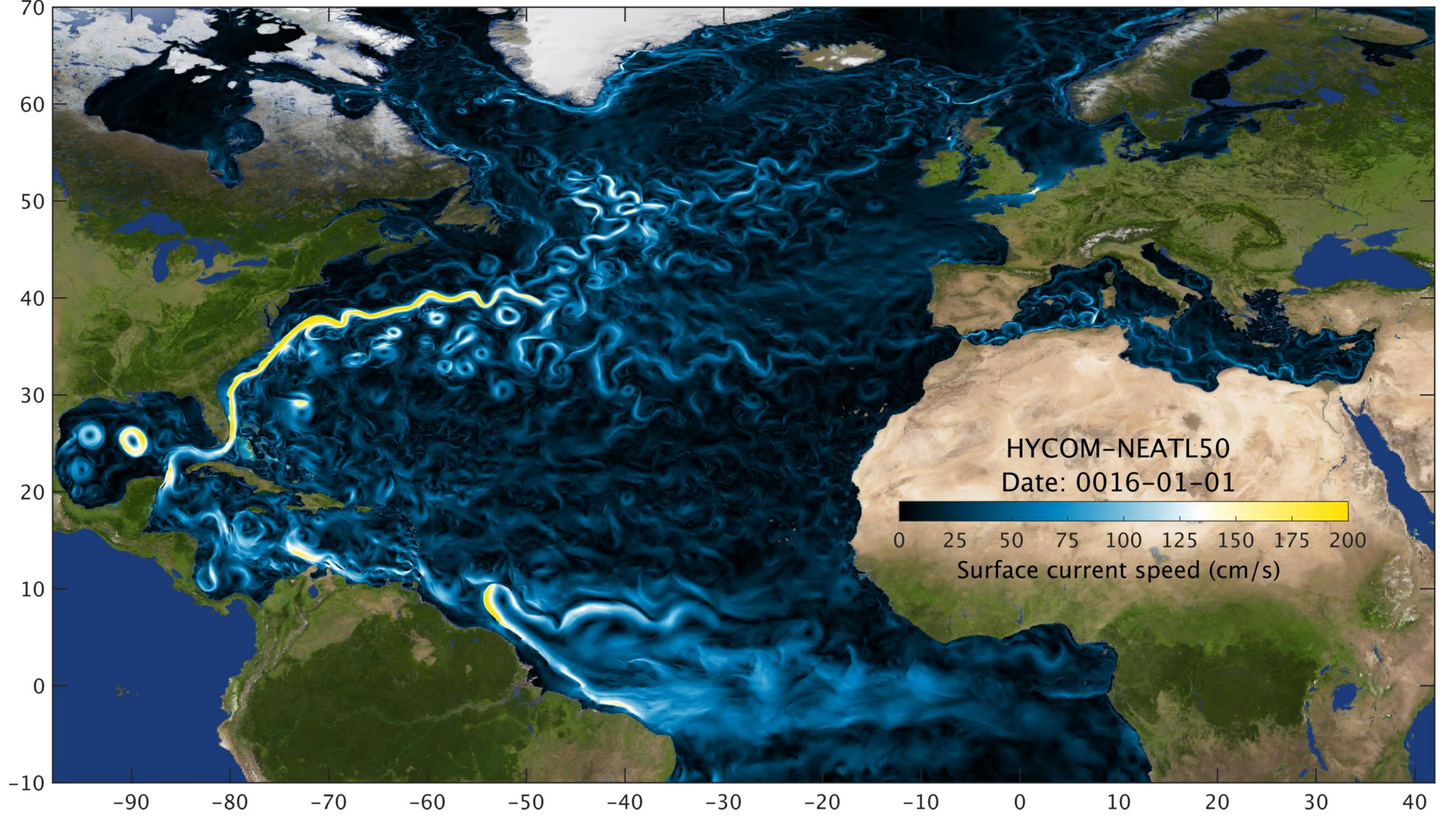
- **Should we focus on increased resolution (1/50°, 1/100°, i.e. submesoscale resolving)) for global deterministic forecasts?**

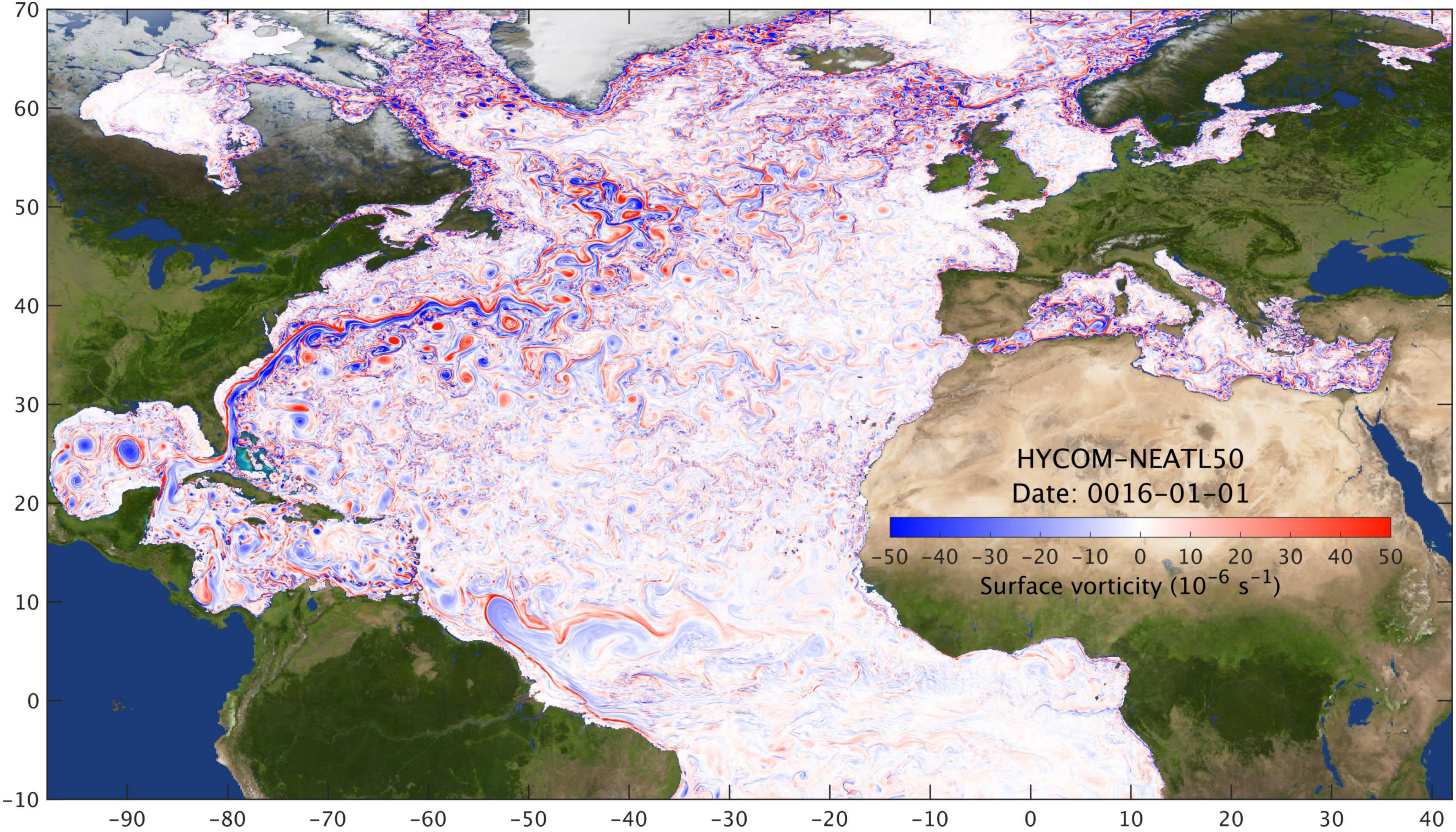
or

- **Should we use ensemble forecasts at lower resolution (1/12°) with improved unresolved subgrid scale physics?**

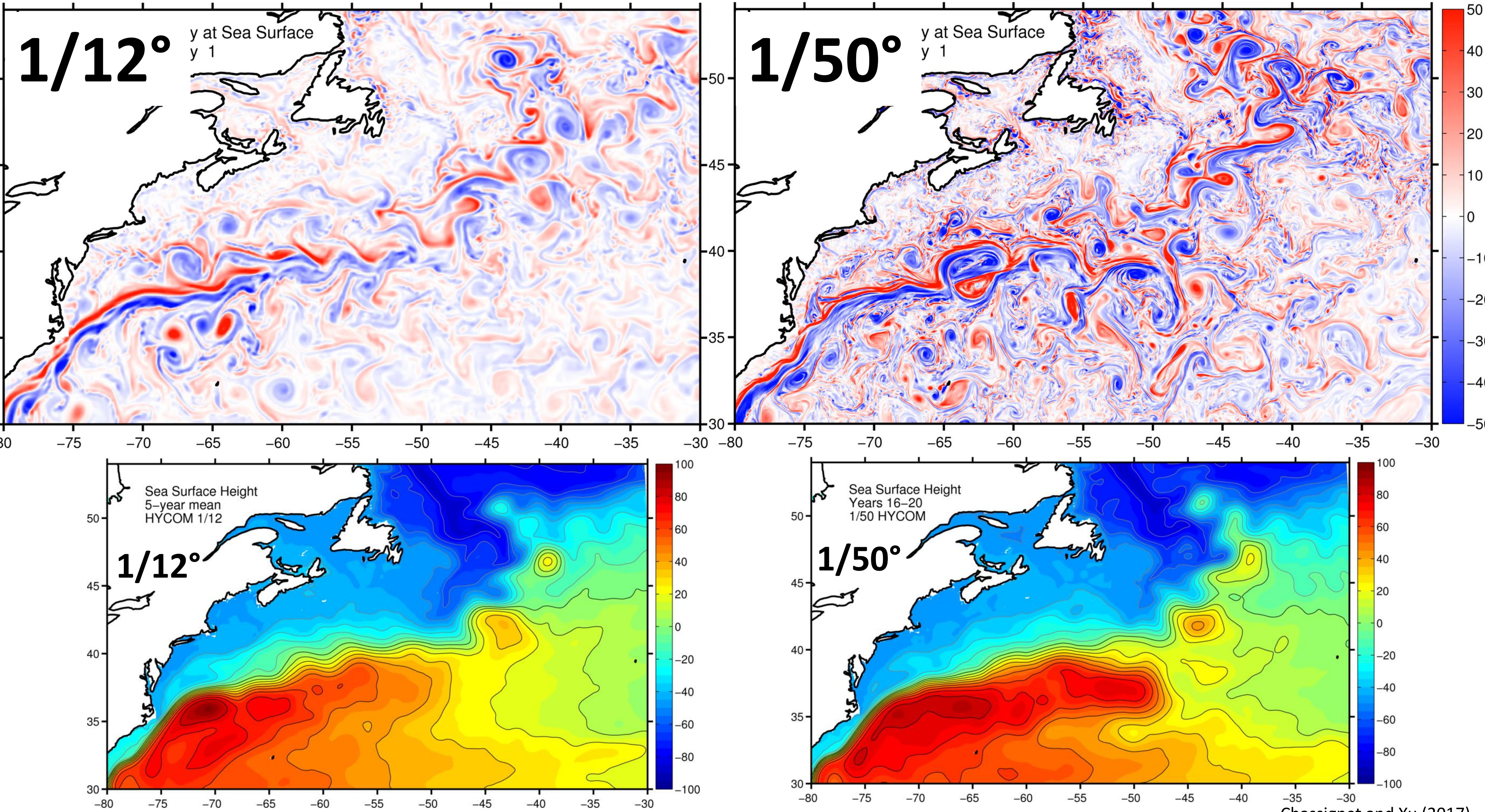
Increasing resolution

- 1/12°, 1/25°, 1/50°, 1/100°?
- What is the added value?

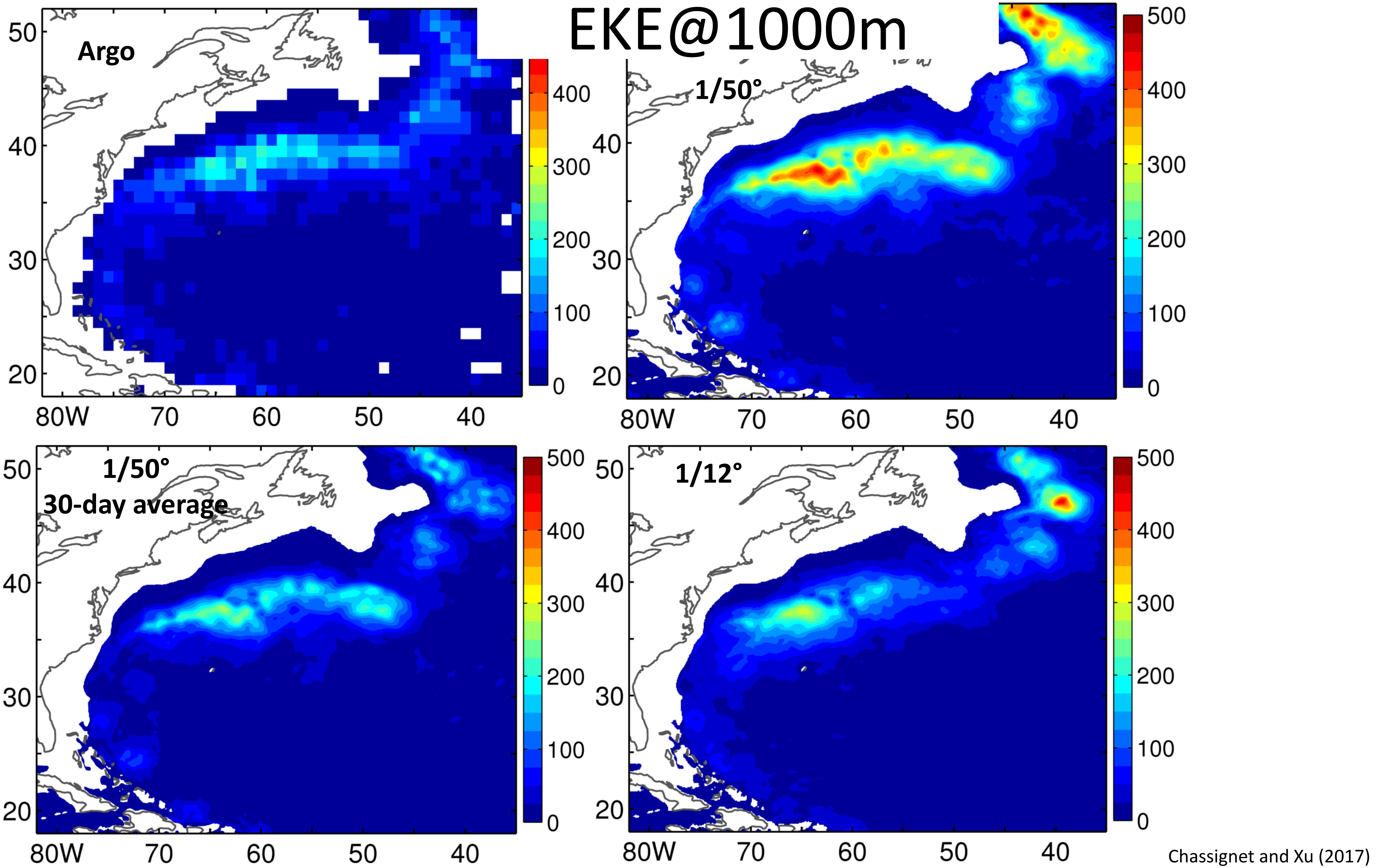

HYCOM-NEATL50
Date: 0016-01-01
0 25 50 75 100 125 150 175 200
Surface current speed (cm/s)
70
60
50
40
30
20
10
0
-10
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40



HYCOM-NEATL50
Date: 0016-01-01
-50 -40 -30 -20 -10 0 10 20 30 40 50
Surface vorticity (10^{-6} s^{-1})
70 60 50 40 30 20 10 0 −10
−90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40



Chassignet and Xu (2017)

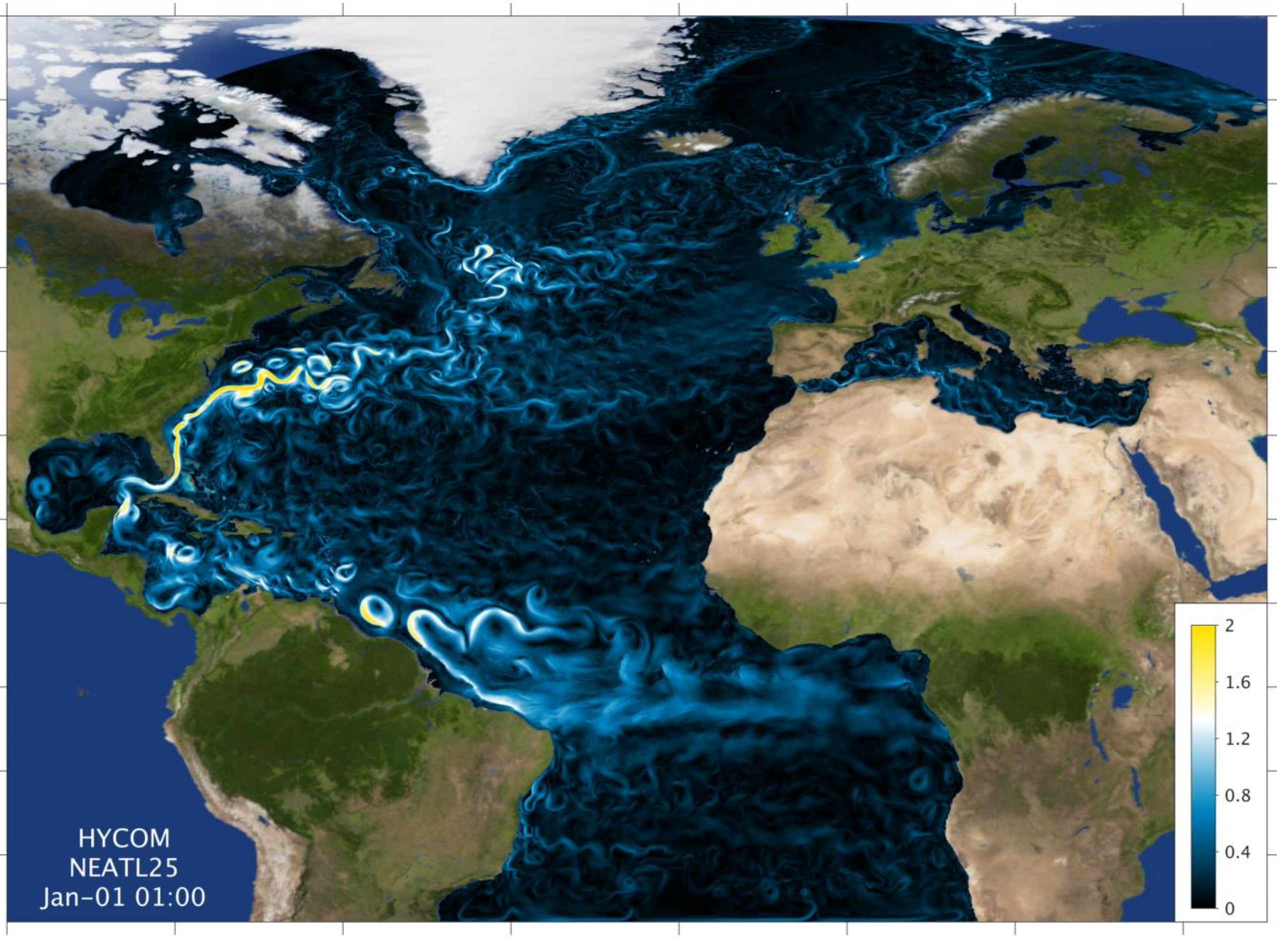

EKE@1000m
Argo
1/50°
1/50°
30-day average
1/12°
50
40
30
20
80W
70
60
50
40
0
100
200
300
400
500
Chassignet and Xu (2017)

Increased resolution

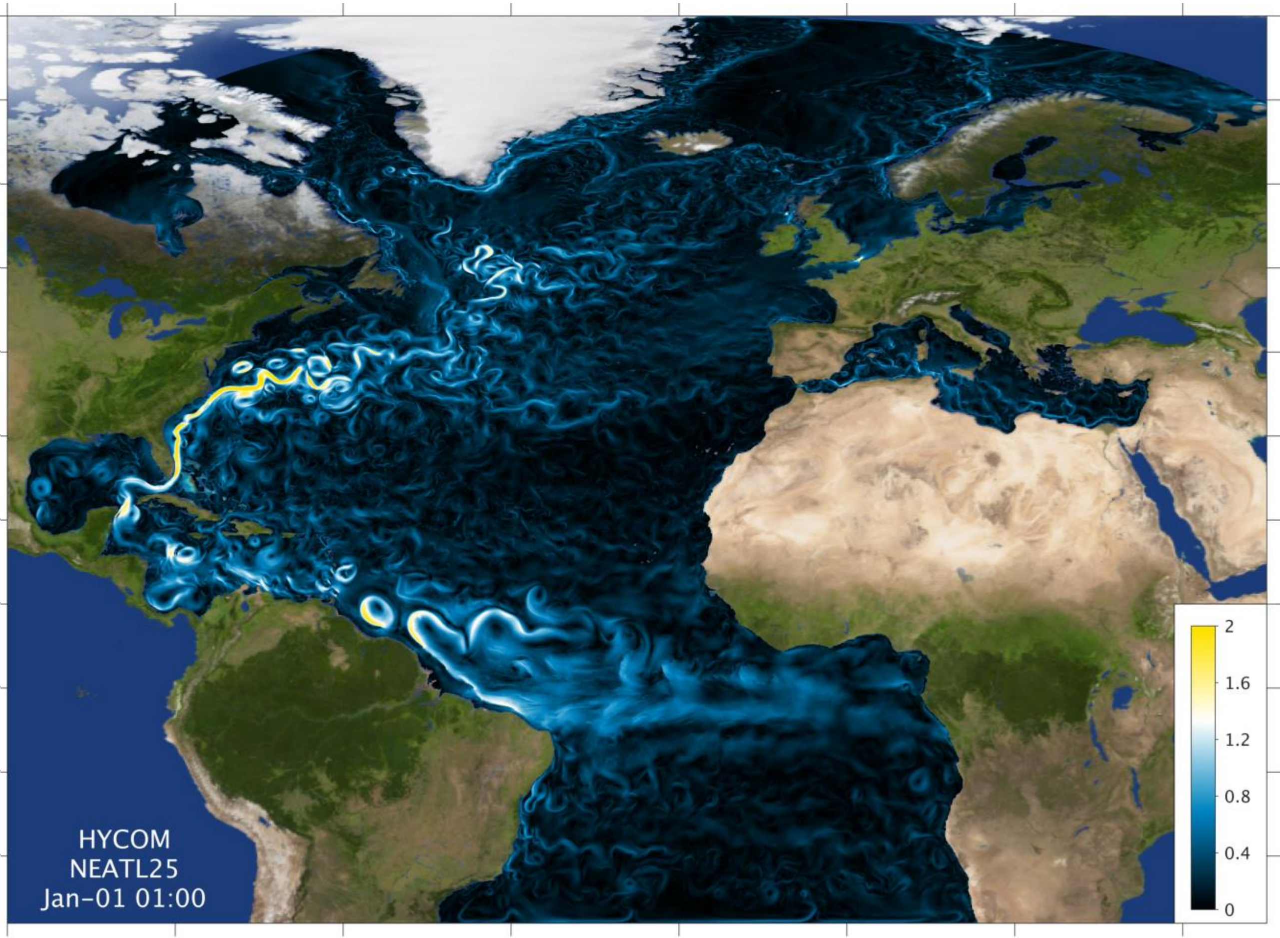
- **Leads to significant improvement in western boundary current pathways with resolution ~1/10^{o} and another potential leap at 1/50^{o}, i.e. submesoscale eddy resolving (10 km) – possible regime shift when the level of EKE becomes comparable to observations**
- **Challenge for ocean prediction since the latest satellite observations will only fully resolve the mesoscale (i.e. SWOT) => multi-scale (spectral) data assimilation is needed to retain information below the mesoscale as one increases the resolution. Same challenge for data assimilation with tides.**

Tides and the large ocean circulation

HYCOM 1/25° no tides

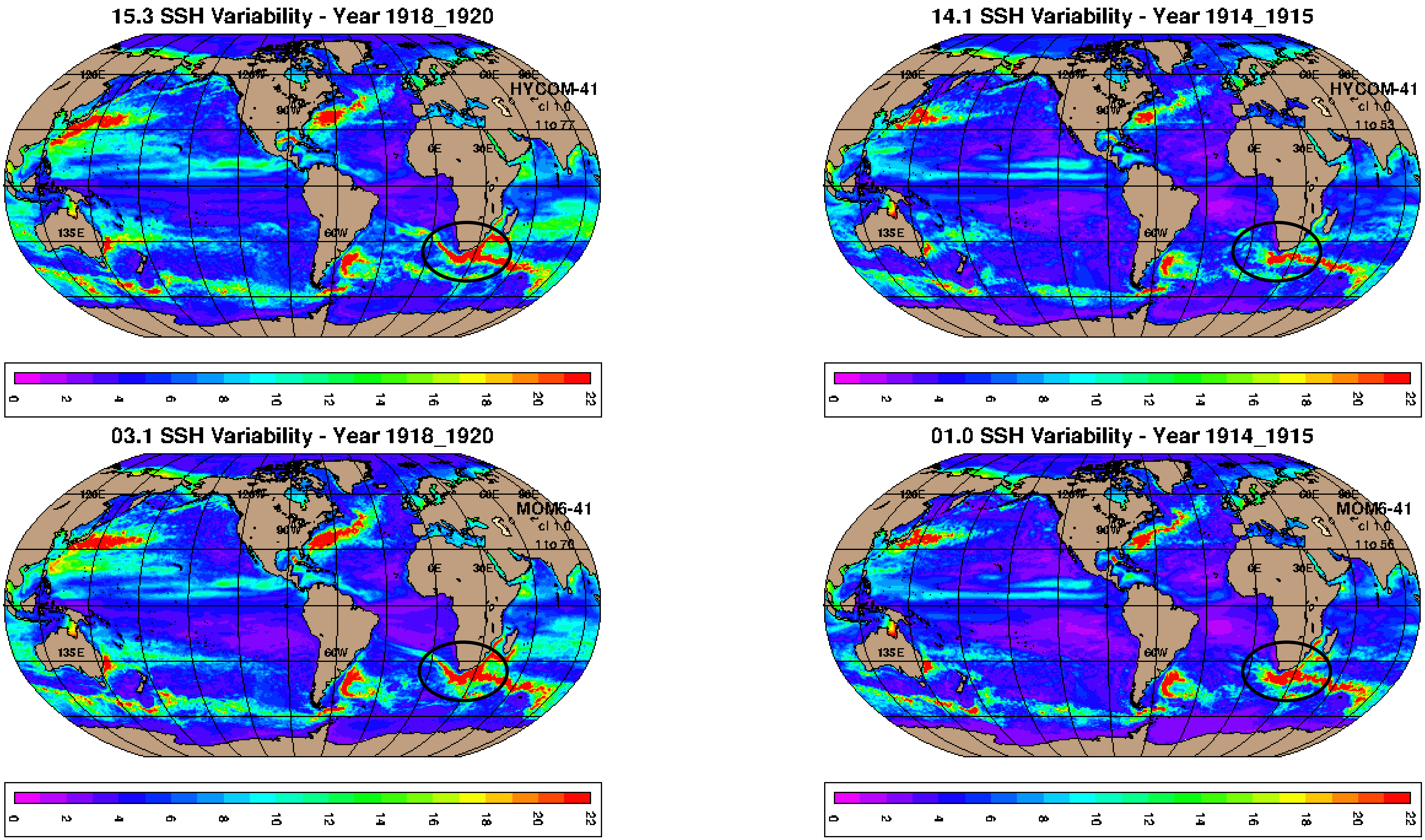


HYCOM 1/25° with tides



Wind forcing

- The HYCOM 1/50^o North Atlantic simulations were forced using stress computed from atmospheric wind velocities and had a level of EKE comparable to observations.
- One should however take into account the wind shear when computing the stress. i.e., $U_{atmosphere}$-U_{ocean}. This results into an eddy-killing effect and a decrease in EKE by 30%. It also does not take into account ocean-atmosphere feedback (Renault et al. , 2019).


15.3 SSH Variability - Year 1918_1920
HYCOM-41
cl 1.0
1 to 77
14.1 SSH Variability - Year 1914_1915
HYCOM-41
cl 1.0
1 to 53
03.1 SSH Variability - Year 1918_1920
MOM6-41
cl 1.0
1 to 76
01.0 SSH Variability - Year 1914_1915
MOM6-41
cl 1.0
1 to 56
0 2 4 6 8 10 12 14 16 18 20 22

Renault et al. (2019) show imprints of surface ocean current on the surface wind in satellite observations and atmosphere–ocean coupled models.

This implies that oceanic mesoscale eddies are losing kinetic energy to the atmosphere and conversely the atmosphere is rectified in the direction of surface oceanic currents, partly compensating the energy loss of the surface currents.

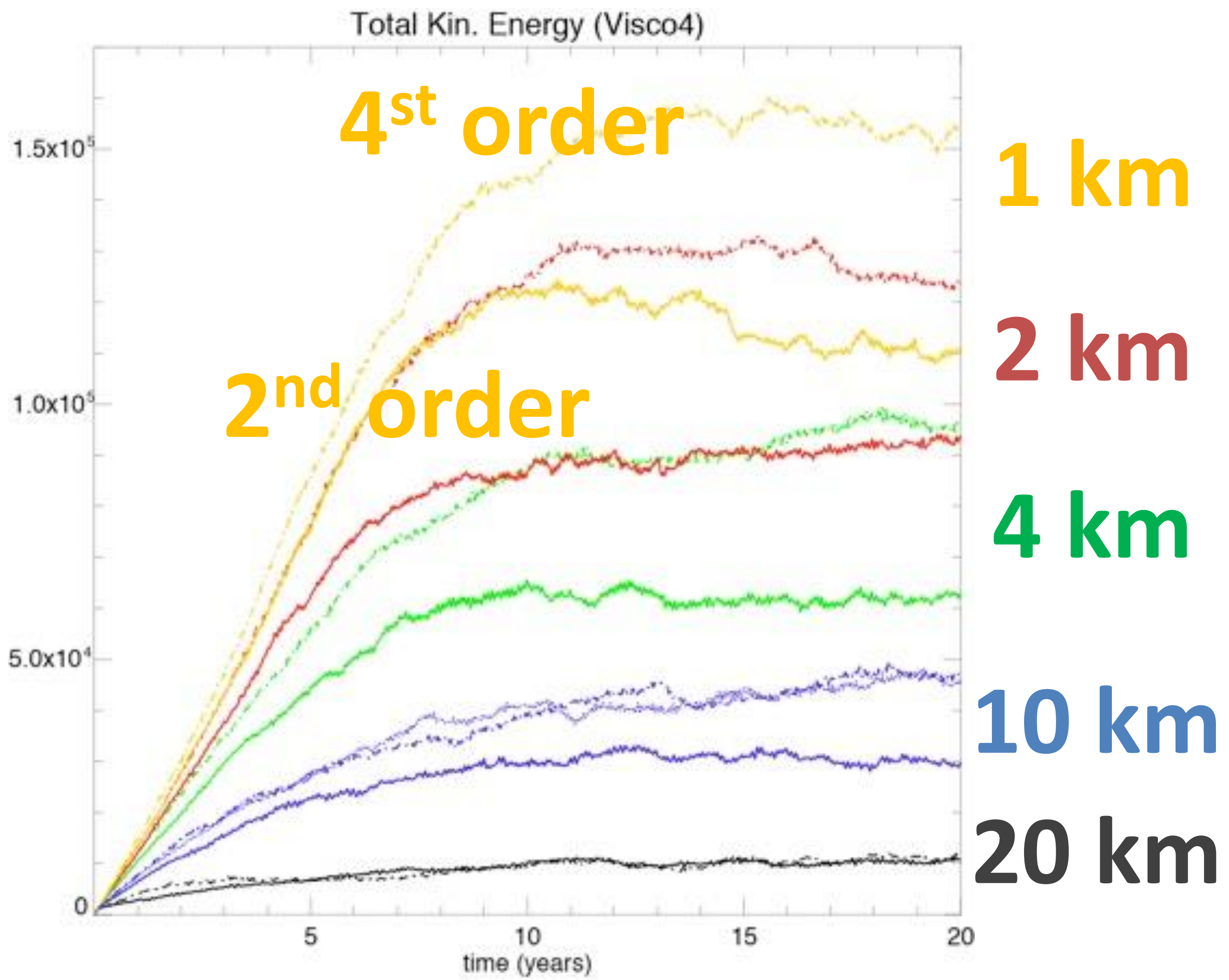
To represent this process in uncoupled ocean models, Renault et al. (2019) suggest two methods:

- **Correct the relative wind using a current-wind coupling coefficient s_w defined by $\Delta U = U_a - (1 - s_w) U_o$ with $s_w \approx 0.30$.**
- **Correct the surface stress using a current-stress coupling coefficient s_τ defined by $\tau = \tau_a + s_\tau U_o$ with $s_\tau = -2.9 \times 10^{-3}$ ($\mathrm{N m^{-4} s^2}$) $|U_a|$ + 0.013 ($\mathrm{N m^{-3} s}$).**

High order operators

- **How do we maintain the existing level of EKE and use relative winds?**
- **Can the EKE be increased by using different viscosity operators or increasing the order of the advection scheme from 2nd to 4th?**

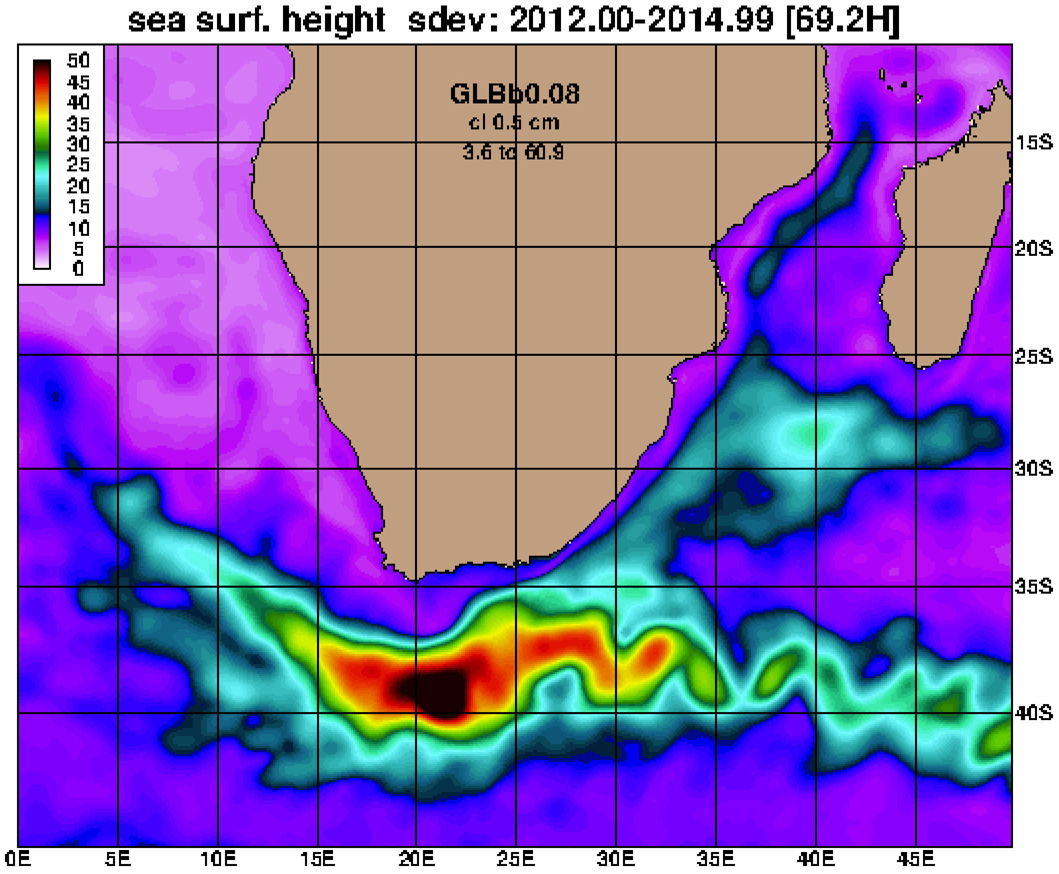
Two-gyre HYCOM box configuration



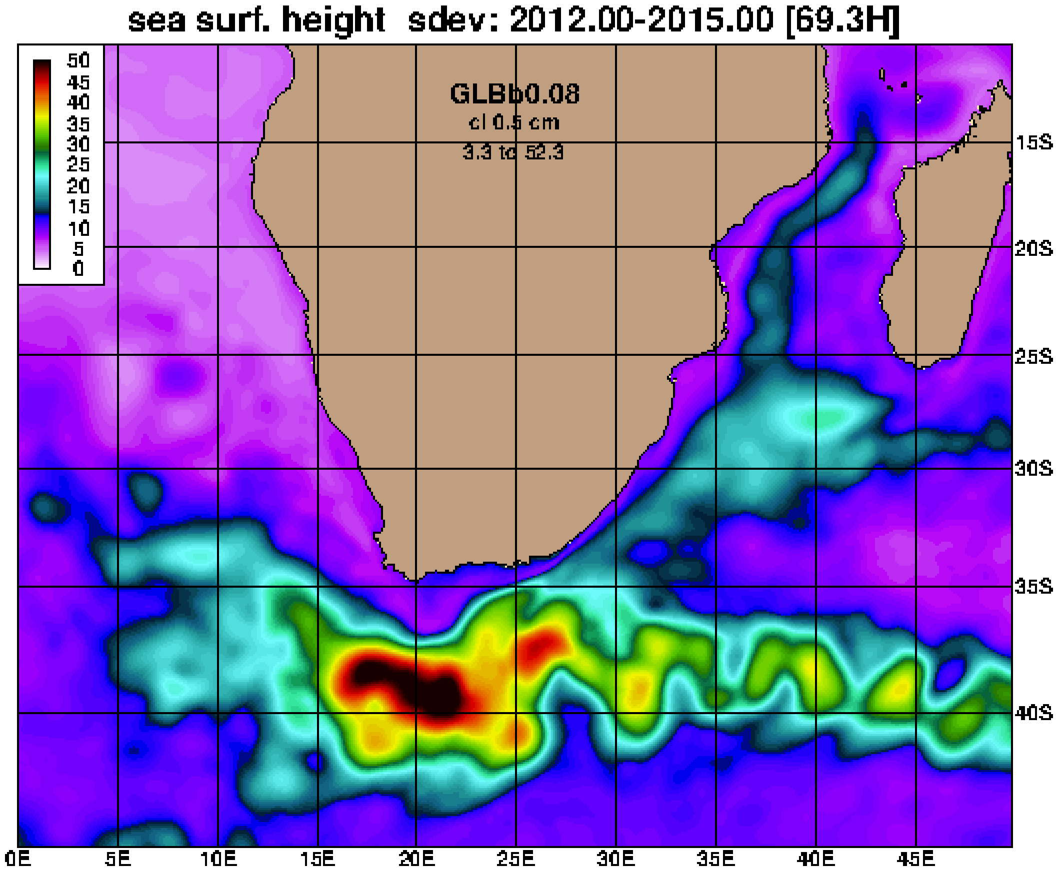
$$F = -\frac{A_4}{h}\nabla^2.(h\nabla^2\mathbf{u})$$

BIHARMONIC

2nd order advection scheme



4th order advection scheme



HYCOM global 1/12°

Moving forward

- **Should we perform ocean-only forecasts at increased resolution or coupled ocean-atmosphere-ice-land systems at lower resolution to incorporate ocean-atmospheric feedback?**
- **If ocean-only, one needs to take into account the ocean-atmospheric feedback, i.e. modification of the wind stress formulation as in Renault et al. (2019).**
- **One should also quantify the impact of high order numerical schemes and unstructured grids that take advantage of the latest computer architecture (i.e., GNuME). Continued key collaboration with computer scientists is essential.**

Questions?