Unsupervised Learning Reveals Geography of Global Ocean Dynamical Regions

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Motivation

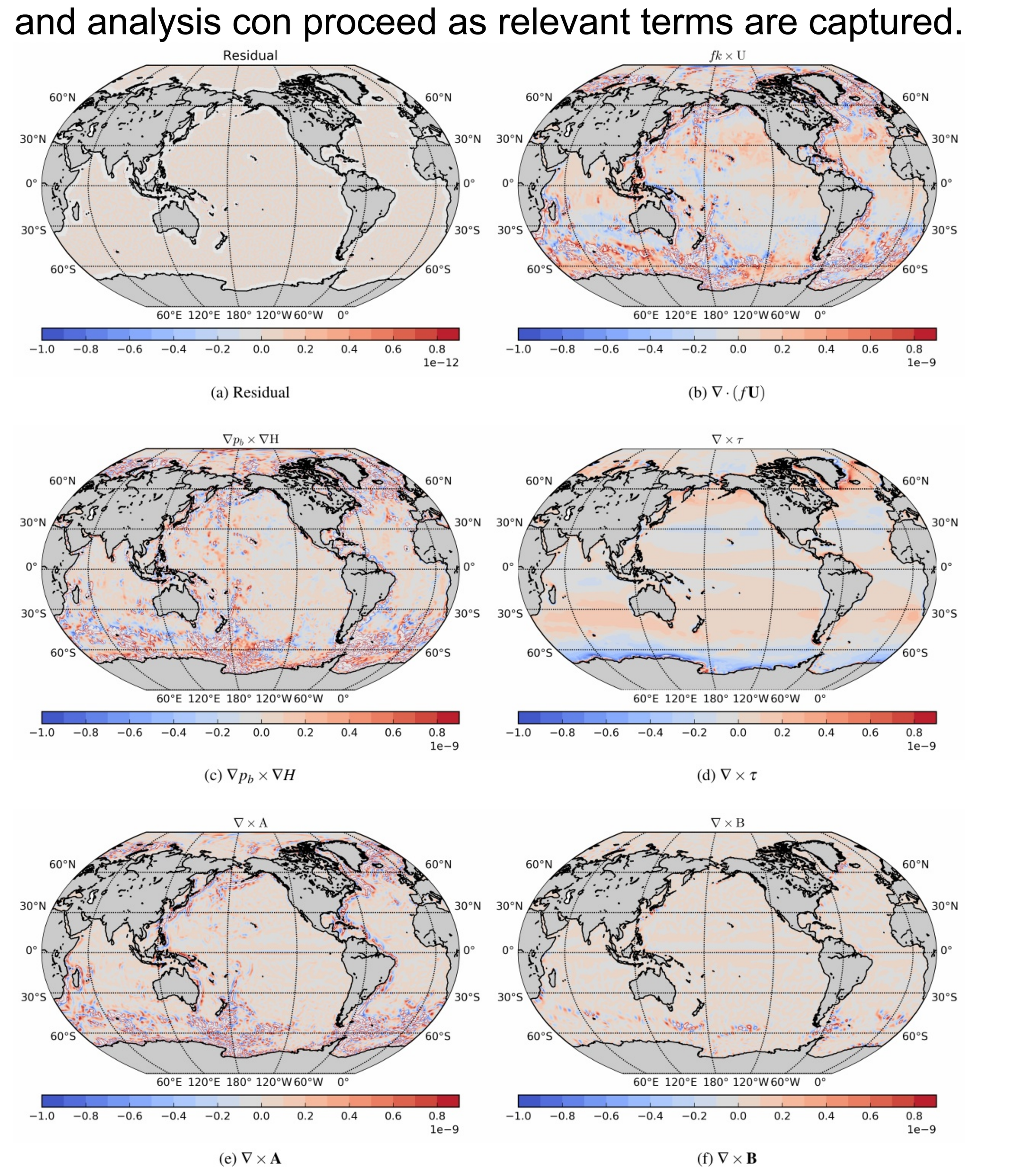
- Identify physical regimes in the global ocean
  - Do they exist?
  - Can we find expected regimes?
- Close barotropic vorticity (BV) budget in ECCOv4r2 State Estimate.
- Use BV, applying machine learning.
  - Identified regions
  - Assess dynamics

The 20 year 1° ECCOv4r2 State Estimate was used fitting the MITgcm to observational data in a dynamically consistent way, suitable for budget analysis.

The depth integrated (Barotropic) vorticity:

$$0 = \underbrace{\nabla\cdot(f\mathbf{U})}_{\text{Planetary vorticity advection}} + \overbrace{\frac{1}{\rho_0}\nabla\times(p_b\nabla H)}^{\text{Bottom Pressure Torque}} + \underbrace{\frac{1}{\rho_0}\nabla\times\tau}_{\text{Wind and bottom stress}} + \overbrace{\nabla\times\mathbf{A}}^{\text{Non-linear torque}} + \underbrace{\nabla\times\mathbf{B}}_{\text{Viscous torque}} \quad \text{(Eq 1)}$$

Fig. 1: BV budget ($10^{-9}ms^{-2}$, eq 1). The residual is orders of magnitude smaller ($10^{-11}ms^{-2}$), meaning noise is small and analysis con proceed as relevant terms are captured.



Global Regimes

The clusters are sorted by percentage are covered of the ocean, presented globally in Fig. 2 and each cluster and its associated area averaged term balance in BV is presented as a bar graph.

- Cluster 1 covers 43±3.3% of the ocean area. Surface and bottom stress torque are balanced by the bottom pressure torque (BPT) and the non-linear torque.
- Cluster 2 covers 24.8 ± 1.2%, where the beta effect balances the BPT.
- Cluster 3 covers 14.6±1.0%, characterized by a 'Quasi-Sverdrupian'regime where the beta effect is balanced by the wind and bottom stress term.
- The small region of Cluster 4 has baroclinic dynamics covering 6.9 ± 2.9% of the ocean.
- Cluster 5 occurs primarily in the Southern Ocean, and mirrors Cluster 4.
- Residual 'dominantly non-linear' regions highlight where the BV approach is inadequate, found in areas of rough topography in the Southern Ocean and along western boundaries.

Table below summarizes the dynamical balances colours indicate negative (blue) or positive (red):

Cluster	Area	Leading terms
1	43±3.3%, Depth coherent (Fig. 3a)	$\nabla\times\tau_{sb}+\nabla\times\mathbf{A}\approx\nabla p_b\times\nabla H$ (Fig. 3b)
2	24.8±1.2%, Interior flow (Fig. 3c)	$\nabla\times\tau_{sb}\approx\nabla p_b\times\nabla H+\nabla\cdot(f\mathbf{U})$ (Fig. 3d)
3	14.6±1%, Quasi-Sverdrupian (Fig. 3e)	$\nabla\times\tau_{sb}\approx\nabla\cdot(f\mathbf{U})$ (Fig. 3f)
4	6.9±2.9%, Interior flow, vertical (Fig. 4a)	$\nabla\times\tau_{sb}\approx\nabla\cdot(f\mathbf{U})+\nabla p_b\times\nabla H$ (Fig. 4b)
5	1.9±1%, Interior flow, Southern Ocean (Fig. 4c)	$\nabla\times\tau_{sb}\approx\nabla\cdot(f\mathbf{U})+\nabla p_b\times\nabla H$ (Fig. 4d)
6-50	8.9 ± 0.3%, Dominantly non-linear (Fig. 4e)	$\nabla\cdot(f\mathbf{U})\approx\nabla\times\mathbf{A}+\nabla\times\tau_{sb}$ (Fig. 4f)

Fig. 2

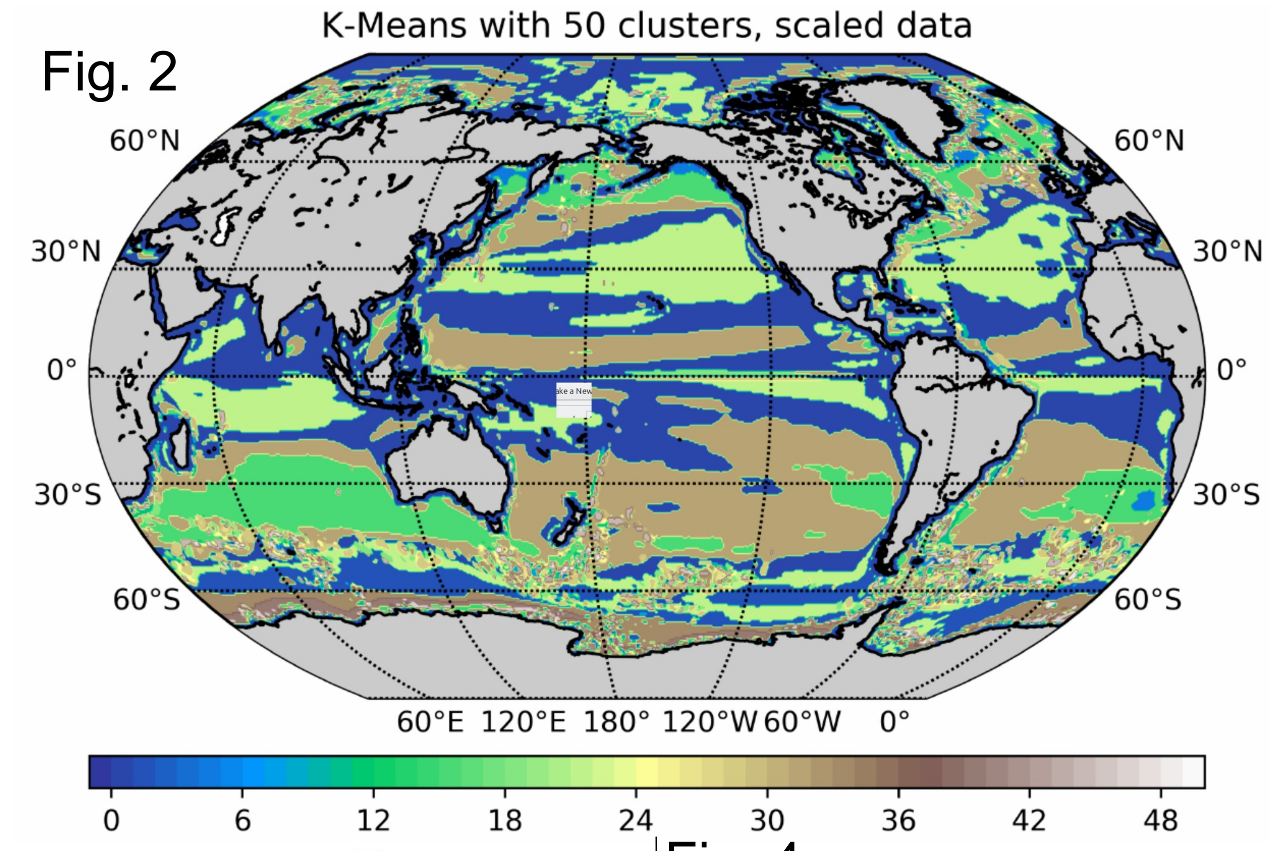


Fig.3

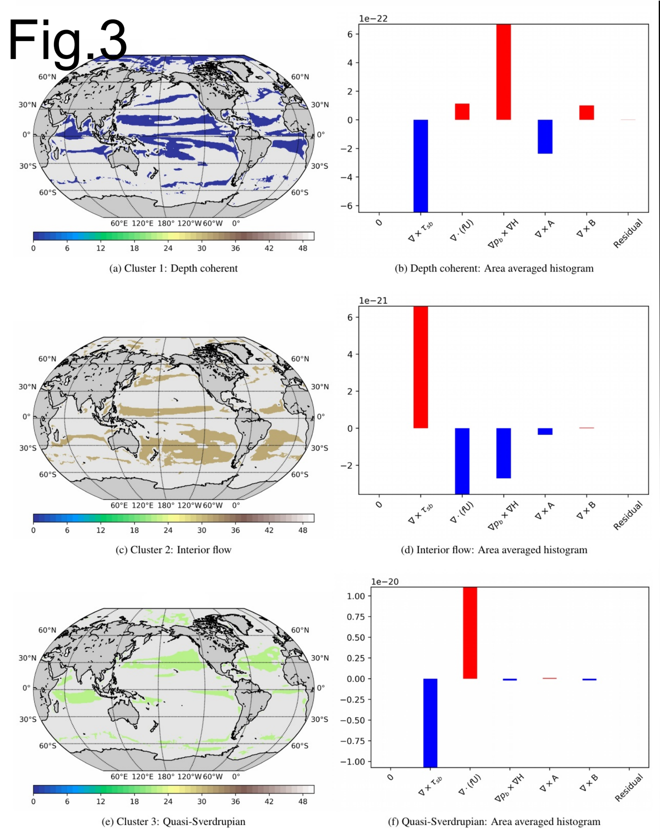
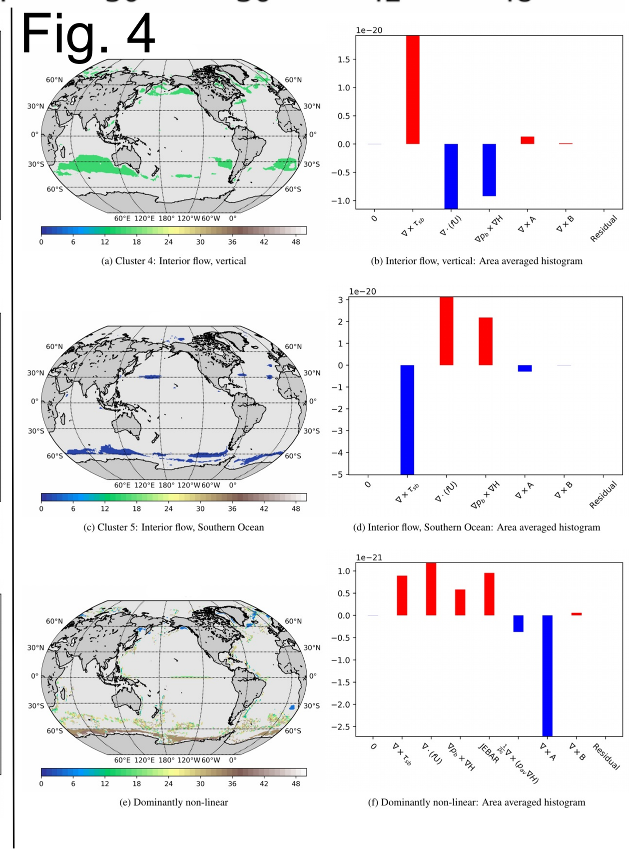


Fig. 4



Unsupervised Learning

Dynamical regimes identified as groups/clusters (K) of terms in BV distinctly seperate from the rest.

Using unsupervised learning algorithm K-Means (MacQueen, 1967), the distance between BV terms (x) and initial stochastic guess for cluster center (c) is itteratively optimized minimizing J:

$$J = \Sigma_{j=1}^{K}\Sigma_{i=1}^{n}||\mathbf{x}_i^j - \mathbf{c}_j||^2$$

Robust clusters are determined using Information Criteria (Fig. 5 ,Akaike and Bayesian), and the spread in percentage area coverage of determined clusters is collected over 100 runs (Fig. 6, 2σ error).

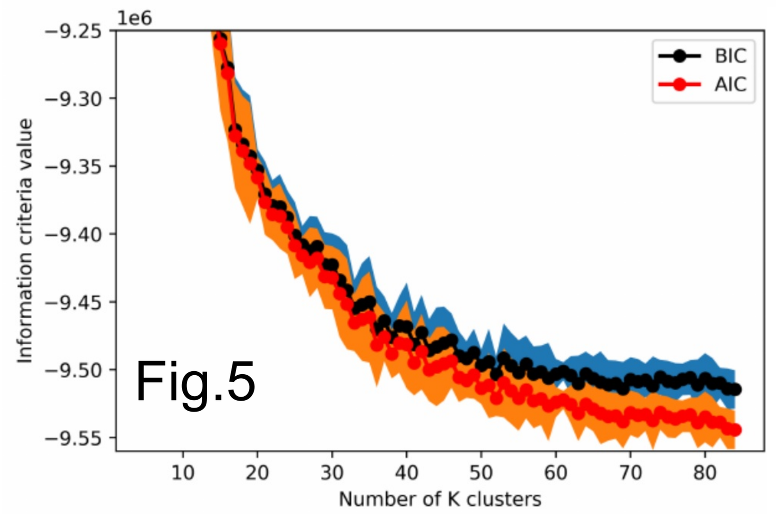


Fig.5

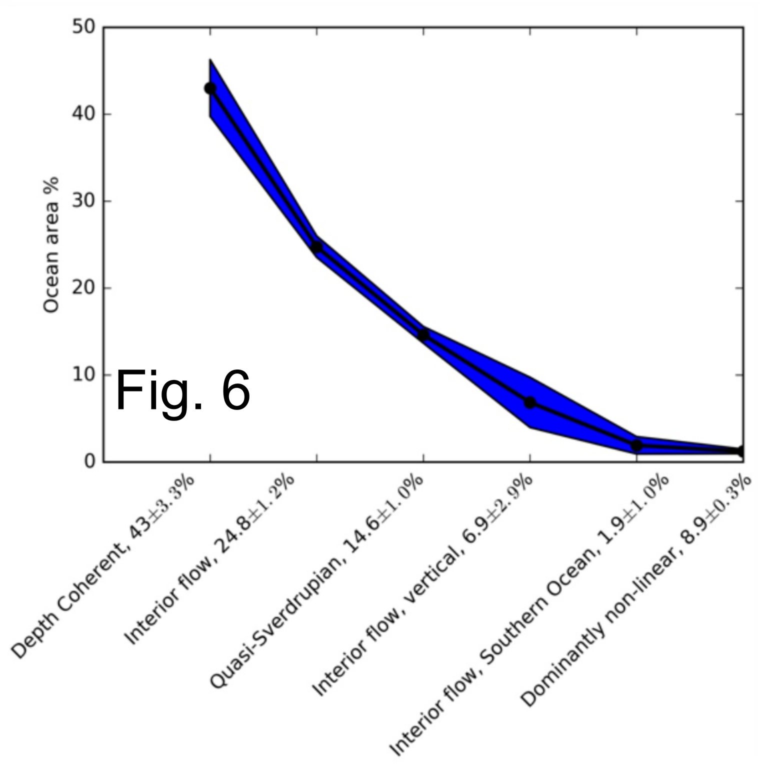


Fig. 6

Take Home

Does the ocean organize itself by global dynamical regions?

YES!

- A closed Barotropic Vorticity budget is presented
- The budget allows identification of dynamical regions using a clustering algorithm.
- ECCOv4 highlights that non-linear terms are important only is small areas.

Schematic (Fig.7) of regions with names and cluster numbers. The depth coherent area implies a coherent vertical structure in Cluster 1. The quasi-Sverdrupian gyre in Cluster 3 is unique due to lack of BPT. The Inteior flow, vertical, in Cluster 4 has a stronger momentum driven portion of the BPT, and topographic interactions begin to become important. The interior flow in Cluster 2 has a stronger baroclinic component to the BPT and feels topography. The Interior flow, Southern Ocean, in Cluster 4 is like the Interior flow in Cluster 2, but with contributions of opposite sign. The remainder is dominated by non-linear contributions, and the barotropic interpretation is not appropriate.

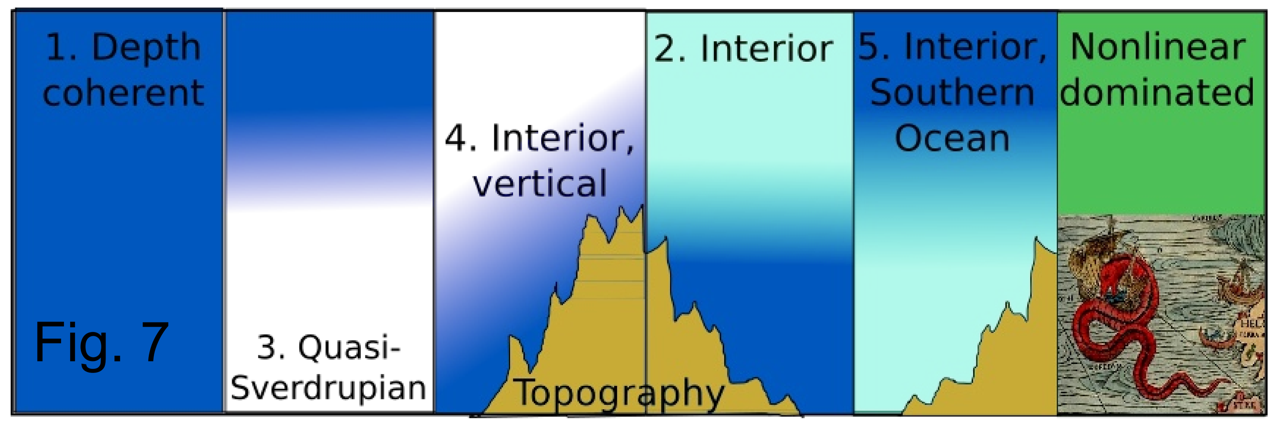


Fig. 7

- Using machine learning shows great promise for model analysis.
- Key dynamical regions associated with GS path and seperation suggest where careful attention to parameterisation is nessesairy
- Future work will repeat analysis at high resolution

For further details: paper in prep+poster

github.com/maikejulie/publications