Adiabatic, Constrained, Stochastic Eddy Parameterisation

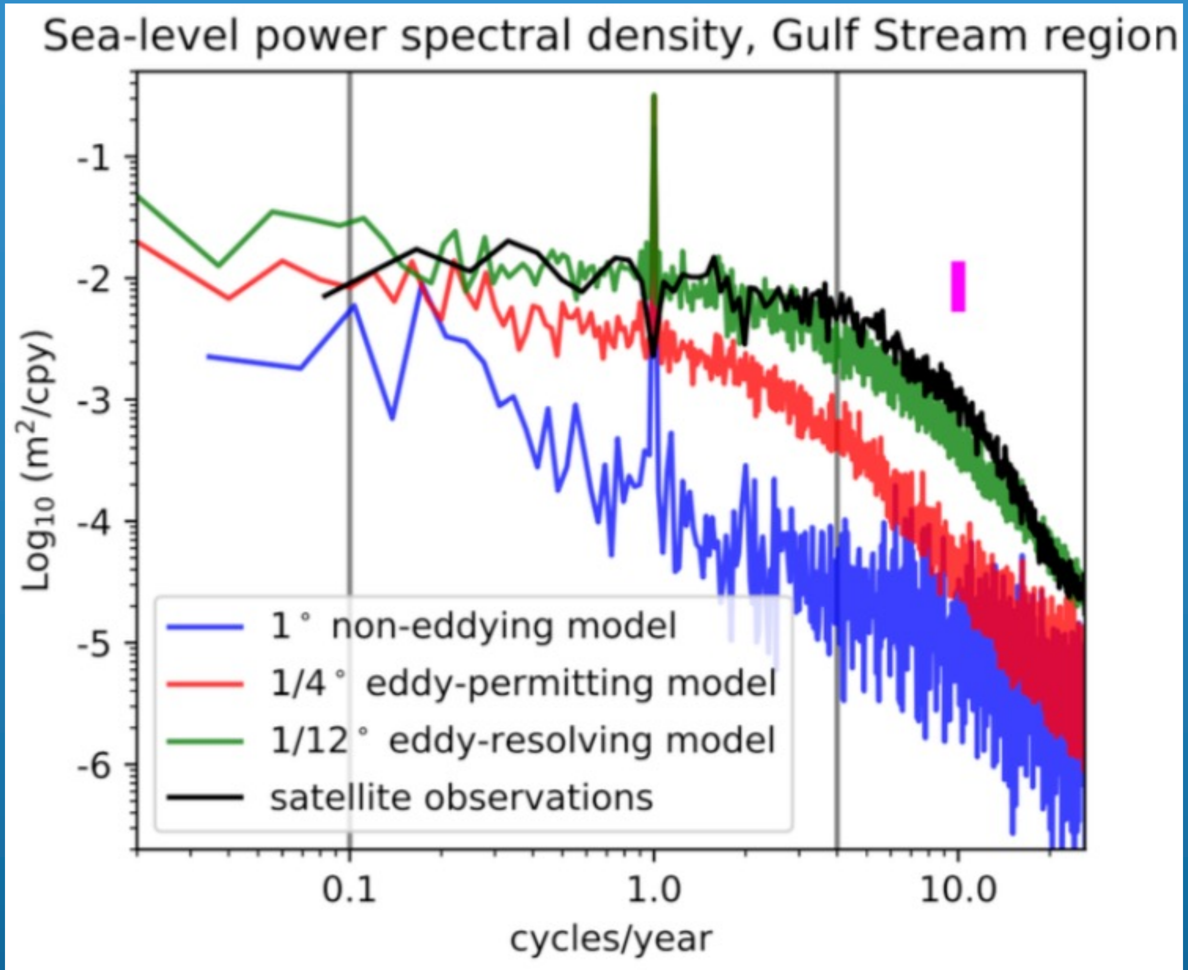
National Oceanography Centre

Chris Wilson, Chris W. Hughes, Adam T. Blaker & Simon D. P. Williams

"Eddy-resolving" models compare more closely with observations, but are computationally expensive

For decadal-scale or ensemble climate modelling (CMIP7), we still must rely on mesoscale "eddy-permitting" models

However, "eddy-permitting" models have too much viscous dissipation of KE



Unrealistic climate variability on seasonal and longer scales – loss of potential predictability

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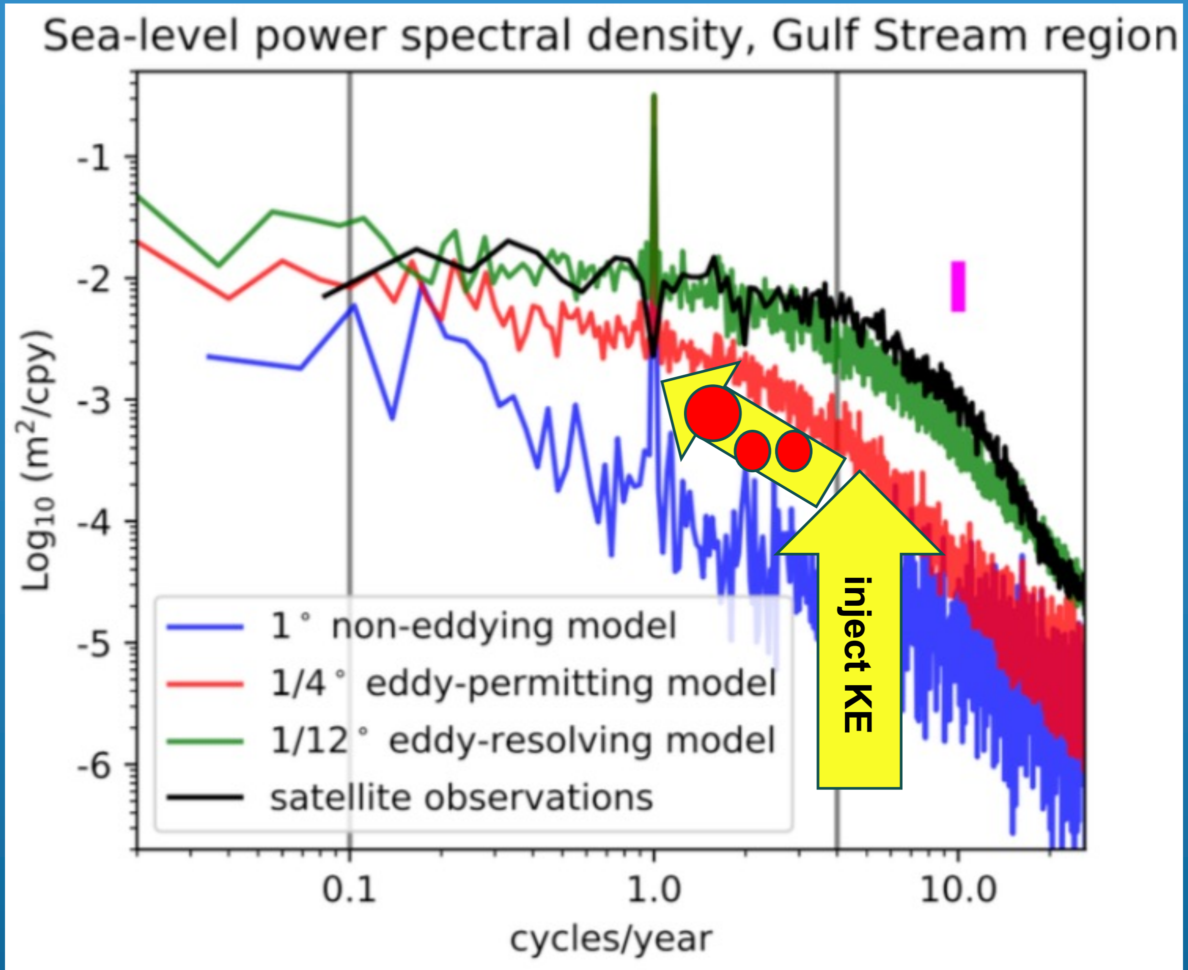

Use a Kinetic Energy Backscatter parameterization to energise the partially-resolved eddies

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Control simulations

NEMO “GYRE” :

“Eddy-resolving” (top) 1/12°
(coarse-grained to 1/4°)

and

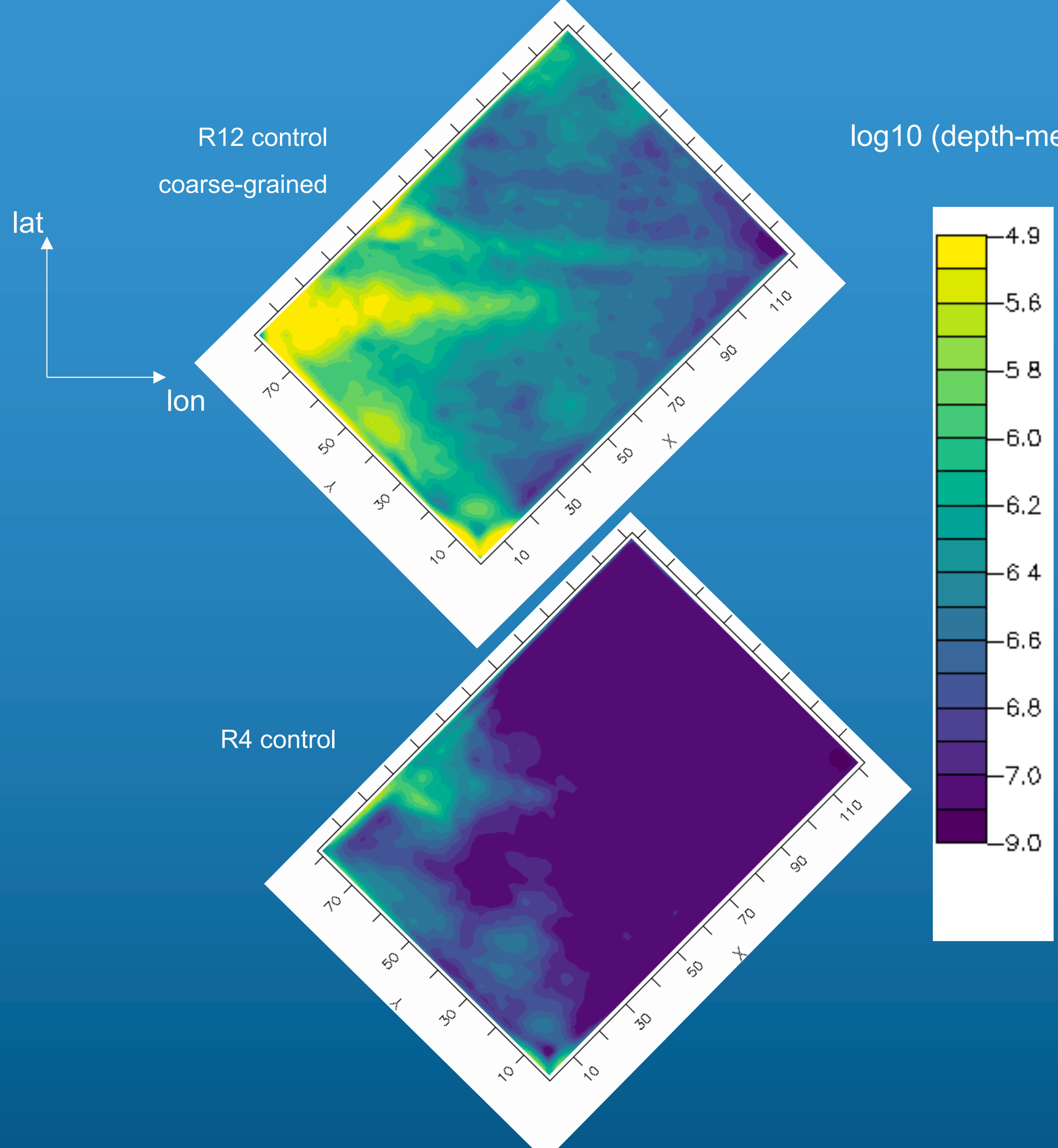
“eddy-permitting” 1/4°
(bottom)

flat bottom, seasonal surface wind and buoyancy forcing

each with 30 z-levels

bi-Laplacian viscosity
constant diffusivity

Lévy et al. (2010)



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1. Why adiabatic? Mesoscale eddies are predominantly adiabatic in the ocean interior. Adiabatic eddy forcing preserves watermass structure in multidecadal climate runs.

2. Considerations for a KE backscatter forcing/parameterization: Desirable to respect both the numerics (undoing the action of excessive viscous dissipation) and the physics (capture the scales, processes of the unresolved eddies).

3. How do others approach the problem? a) by applying a negative viscosity (usually a slightly different formulation to the actual viscous damping, e.g. Laplacian forcing for bi-Laplacian dissipation);
b) stochastic forcing – to mimic the missing effects of nonlinear interactions due to geophysical turbulence

4. What is our approach? Generate stochastic forcing designed around the numerics and around the physics , based on autoregressive modelling order-n (AR(n)).
We use the adiabatic framework of the "semi-prognostic method" to generate an eddy momentum forcing by changing the density "seen" by the hydrostatic equation:

Stochastic forcing, proportional to instantaneous viscous dissipation
~ model timestep

Pressure gradient force to wiggle isopycnals up and down

$$\frac{\partial P}{\partial z} = -(\rho - \rho_c)g \quad \Longrightarrow \quad \frac{\partial \mathbf{u}}{\partial t} = \ldots + \frac{1}{\rho_0}\nabla P_{eddy}$$

Fit to variability characterizing mesoscale eddies ~ days to weeks?

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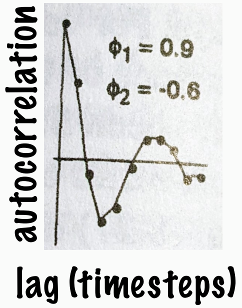

Pressure gradient force to wiggle isopycnals up and down

$$\frac{\partial P}{\partial z} = -(\rho - \rho_c)g$$

$$(\rho_c)_t = b\,\Sigma_{i=1}^{n}\, a_i\, \rho_{t-i\Delta t} + \epsilon_{t-i\Delta t}$$

Fit to variability characterizing mesoscale eddies ~ days to weeks?

numerics : AR(2) forcing in semi-prognostic method

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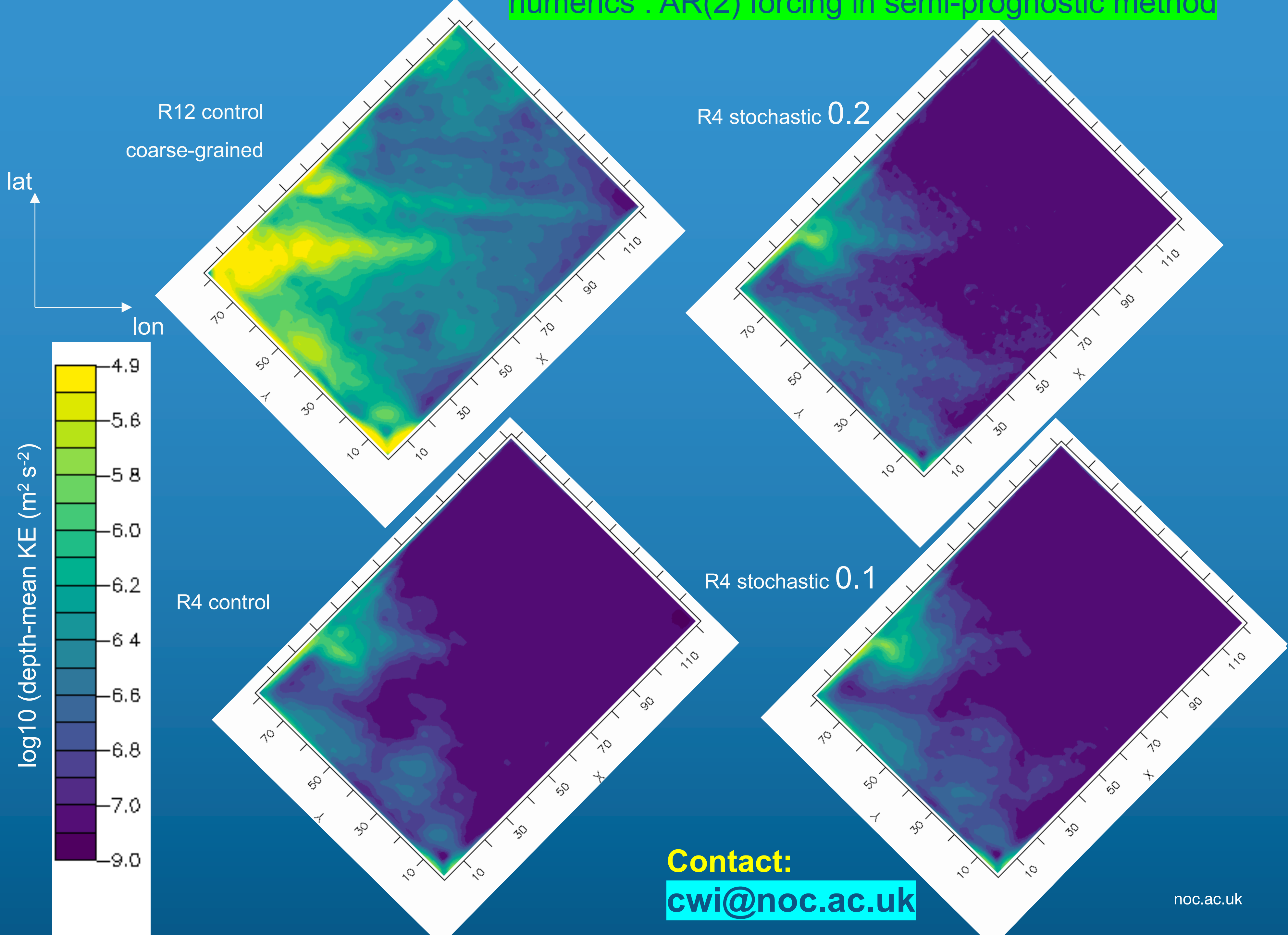

Left panels: control

Right panels: with stochastic, adiabatic forcing

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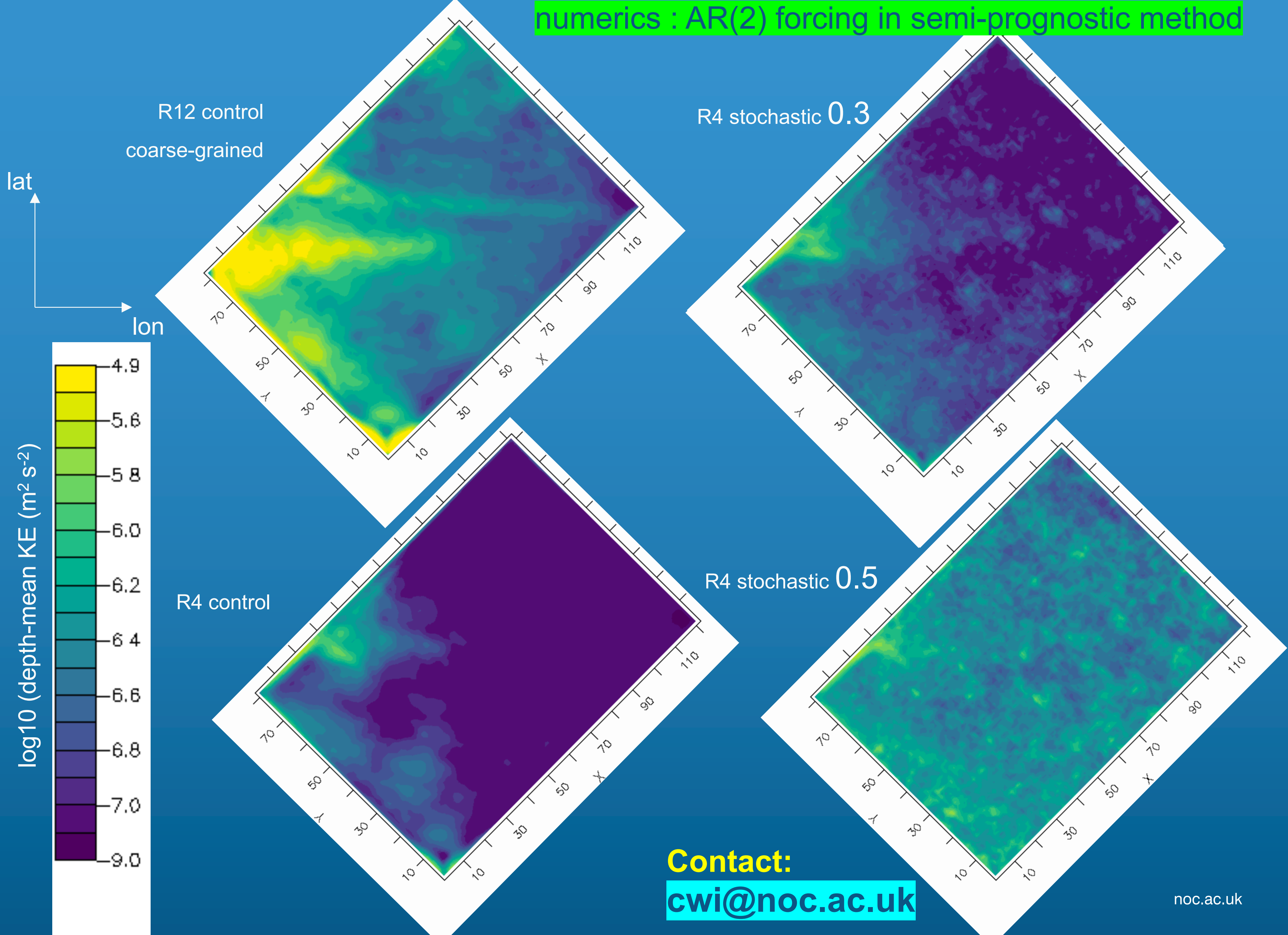
numerics : AR(2) forcing in semi-prognostic method

Summary:

In this first phase, we explored the near-timestep, near-gridscale "undoing of numerical overmixing of KE" – an ADIABATIC KE backscatter forcing

The AR(2) stochastic model can energise the flow and cause feedbacks which extend the jet

Further development is required including exploring parameterization of eddy physical scales



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Supplementary

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How is our method different from the stochastic equation of state in NEMO?
(Brankart et al., 2013; 2015)

- We do not directly alter the density or tracer field

- We generate a perturbation to the dP/dz term in the hydrostatic equation, which is then integrated in the vertical and differentiated in the horizontal to generate a momentum forcing, which is like the grad P term from the standard hydrostatic equation.

- Within the loop that calculates dP/dz in the hydrostatic equation, a dummy density term is used on the r.h.s. but then replaced after the loop.

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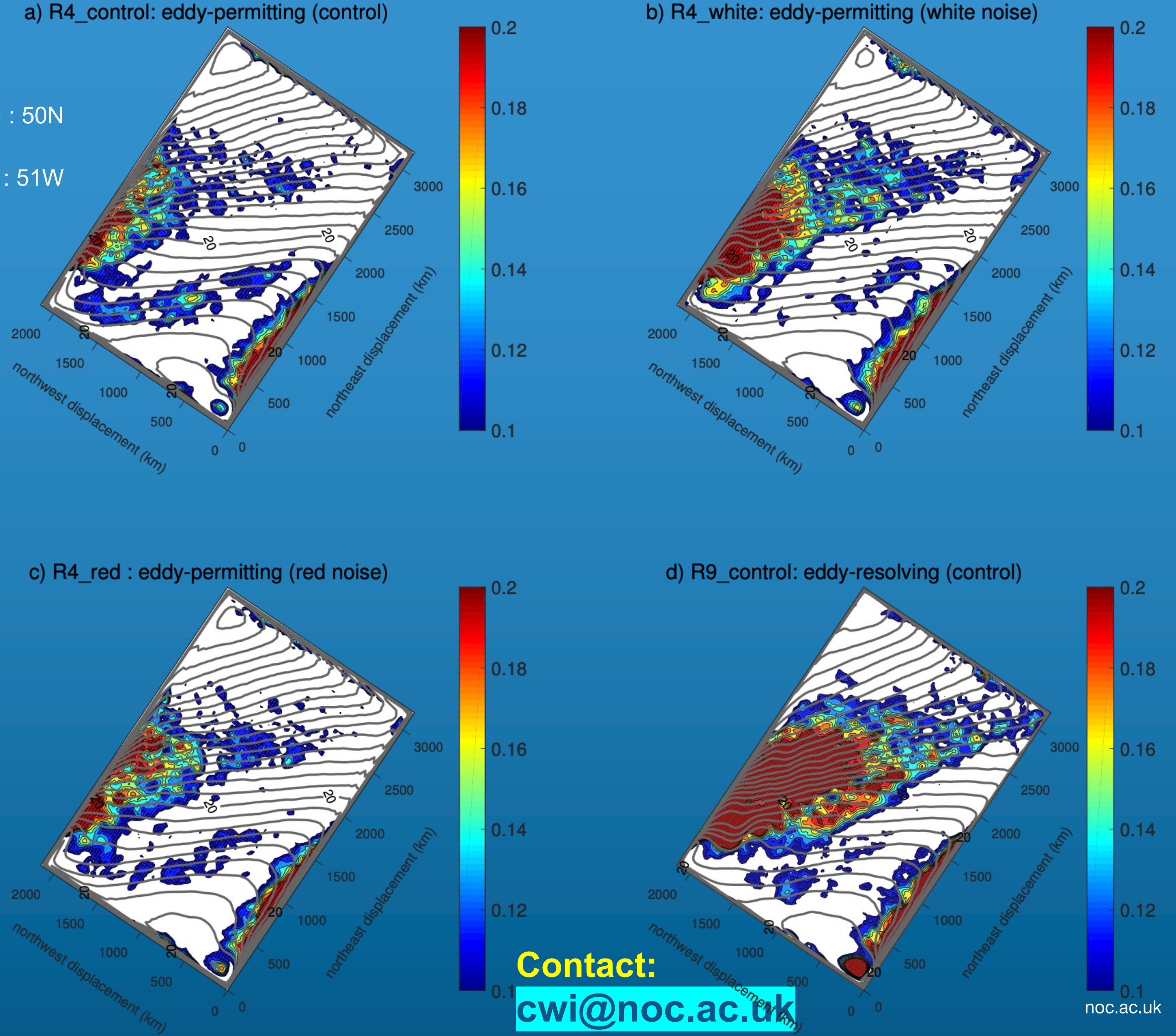
NEMO

SST 15N : 50N

86W : 51W

1/4 deg.
& 1/9 deg.

lat
lon



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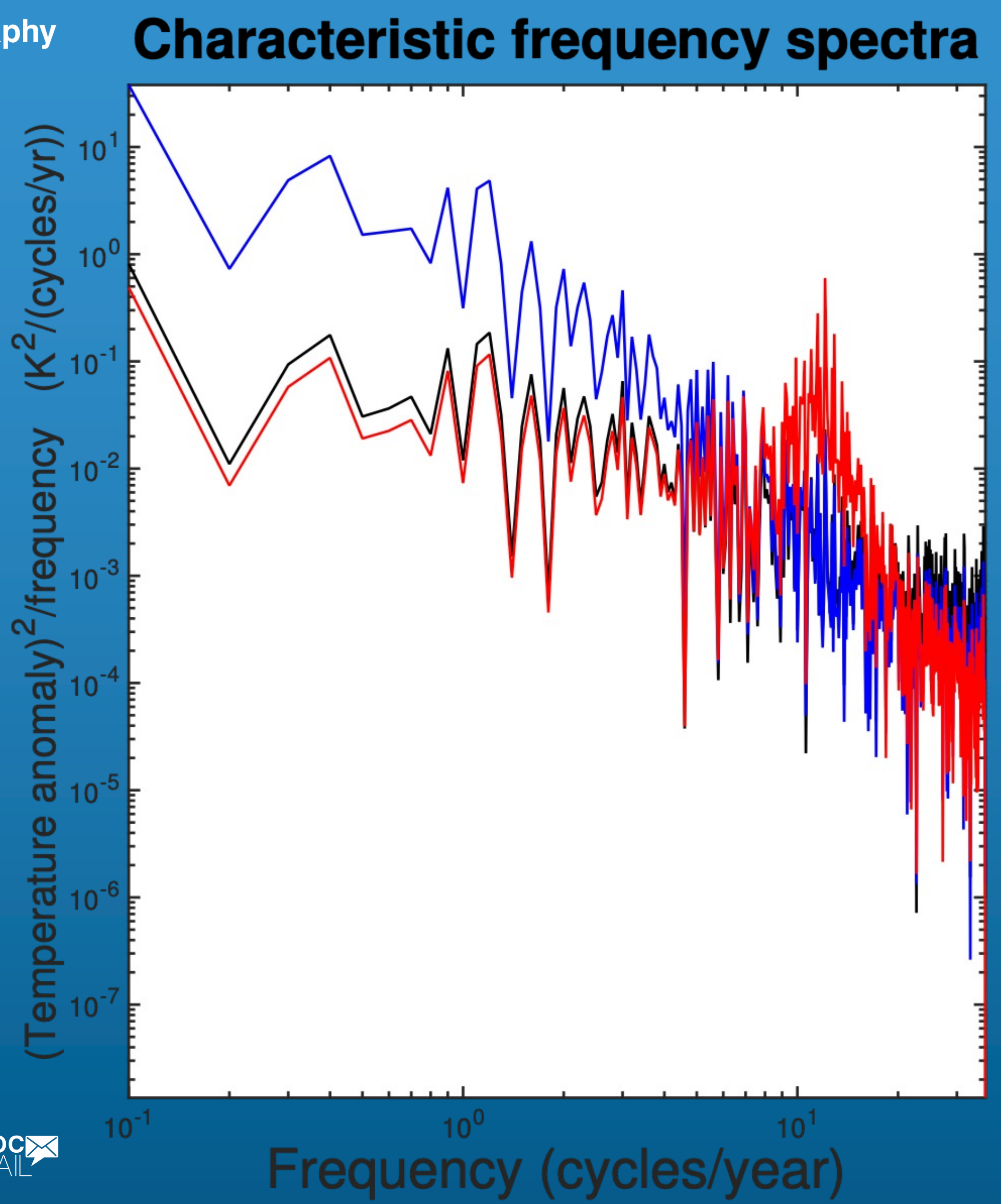
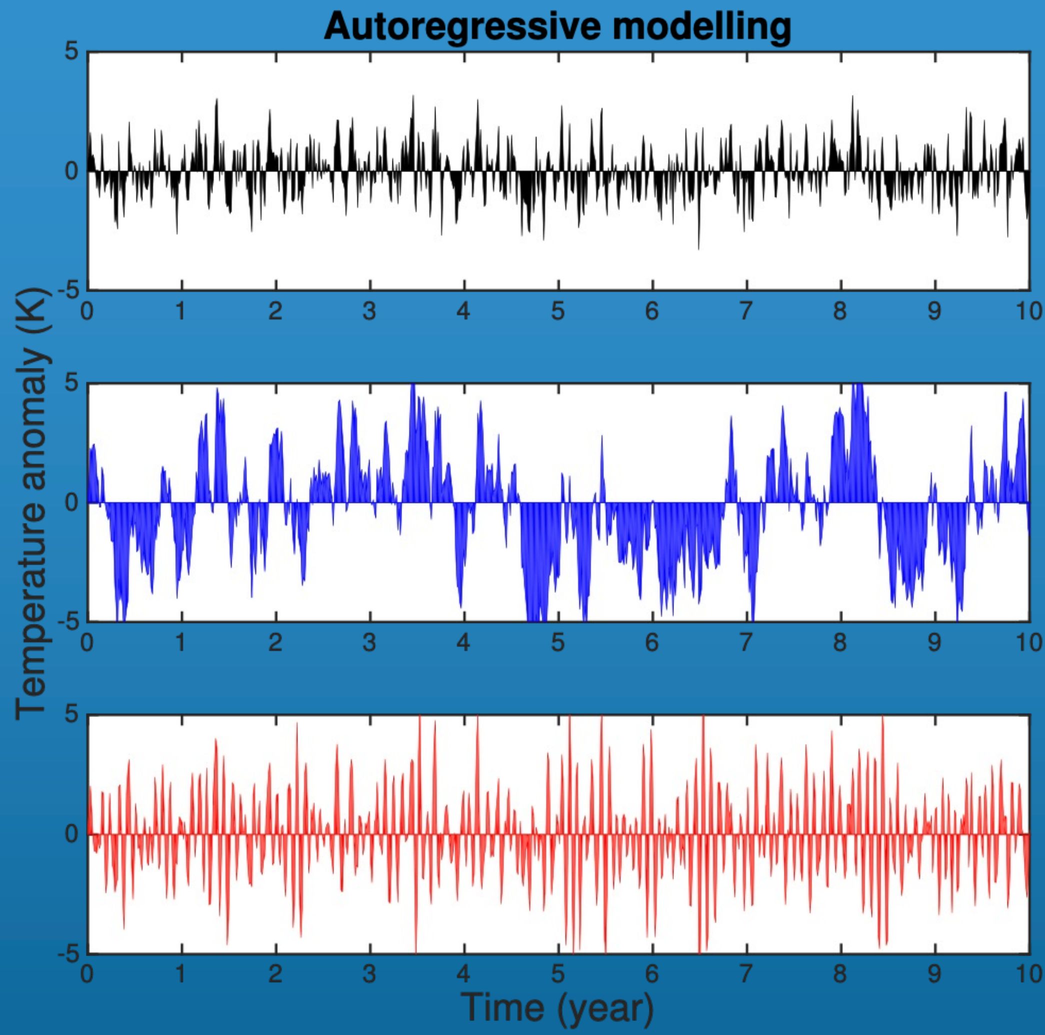
Generate stochastic forcing





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A1) derive statistical models of the stochastic variability of density from the "truth" and use this to directly energise the missing mesoscale energy sources of APE and, via adjustment, KE.

Most basic: approach of Zang and Wunsch (2001)

For each mode,

for any variable,

$$\Phi(k,l,\omega,n,\phi,\lambda) = B_n(k)C_n(l)D_n(\omega)E_0(n)I(\phi,\lambda). \quad (29)$$

Hughes and Williams (2010)

Frequency domain: can improve ZW10 with AR(n) model

C10048 HUGHES AND WILLIAMS: COLOR OF SEA LEVEL SPECTRA C10048

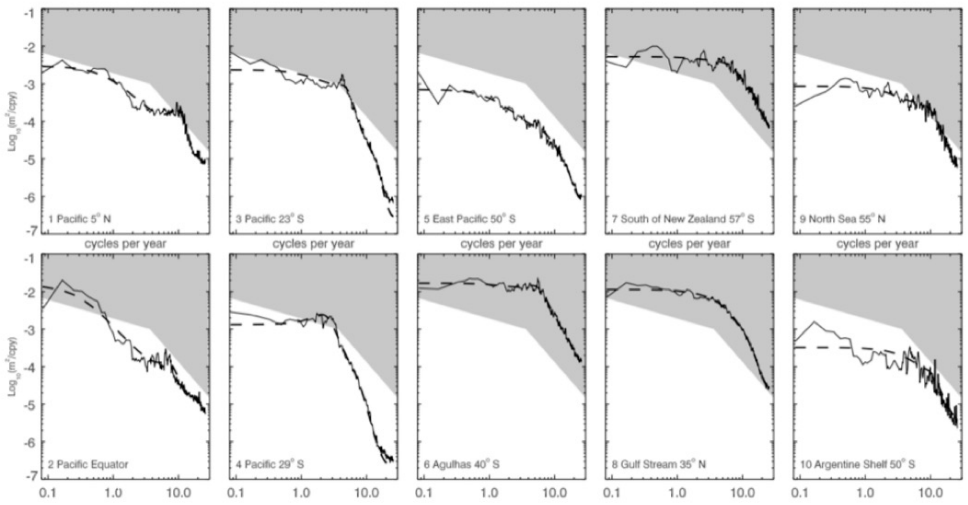

Figure 6. Power spectral densities as a function of frequency for spectra averaged over the 10 boxes shown in Figure 5b. Dotted lines show the corresponding AR(5) fit to the data. The shading covers the region above the line represented by the *Zang and Wunsch* [2001] spectrum at an arbitrary chosen amplitude.

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