Impact of uncertainties in the horizontal density gradient upon low resolution global ocean modelling

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1. Uncertainties in the computation of density

2. Stochastic parameterization

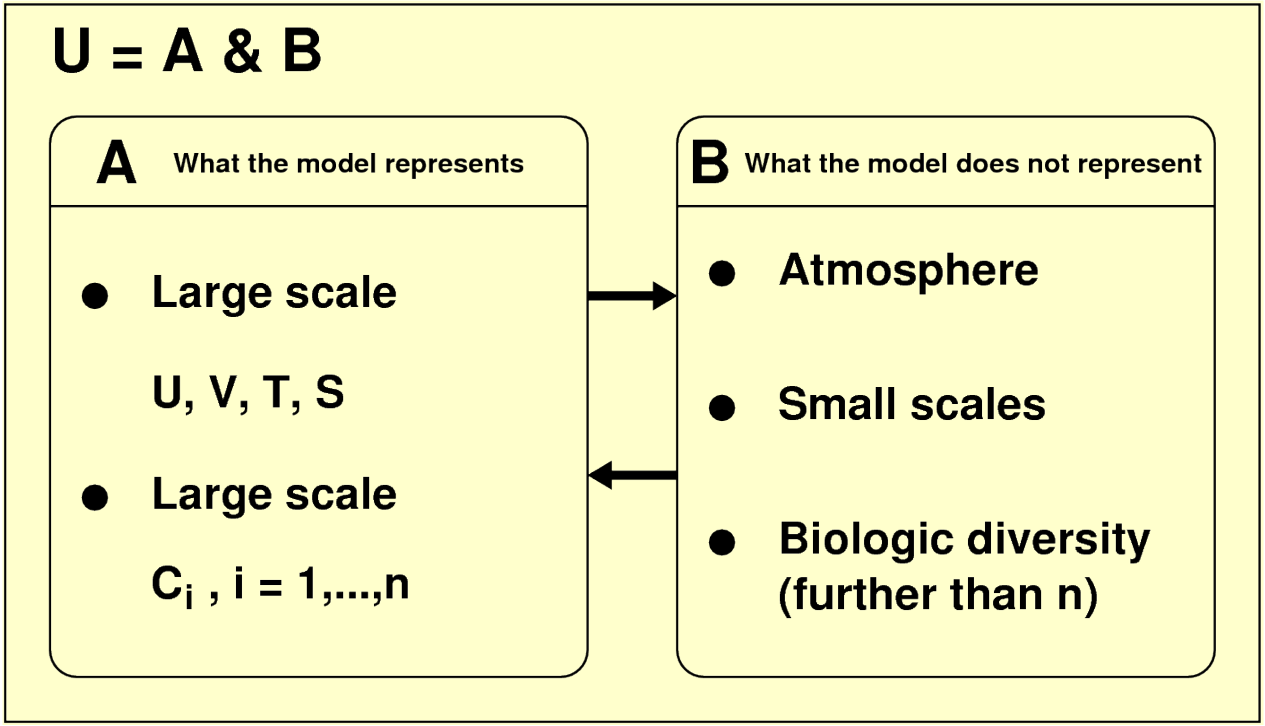
3. Impact on the model simulation

4. Conclusions

1

Uncertainties in the computation of density

1. Basic ideas: définition of the system



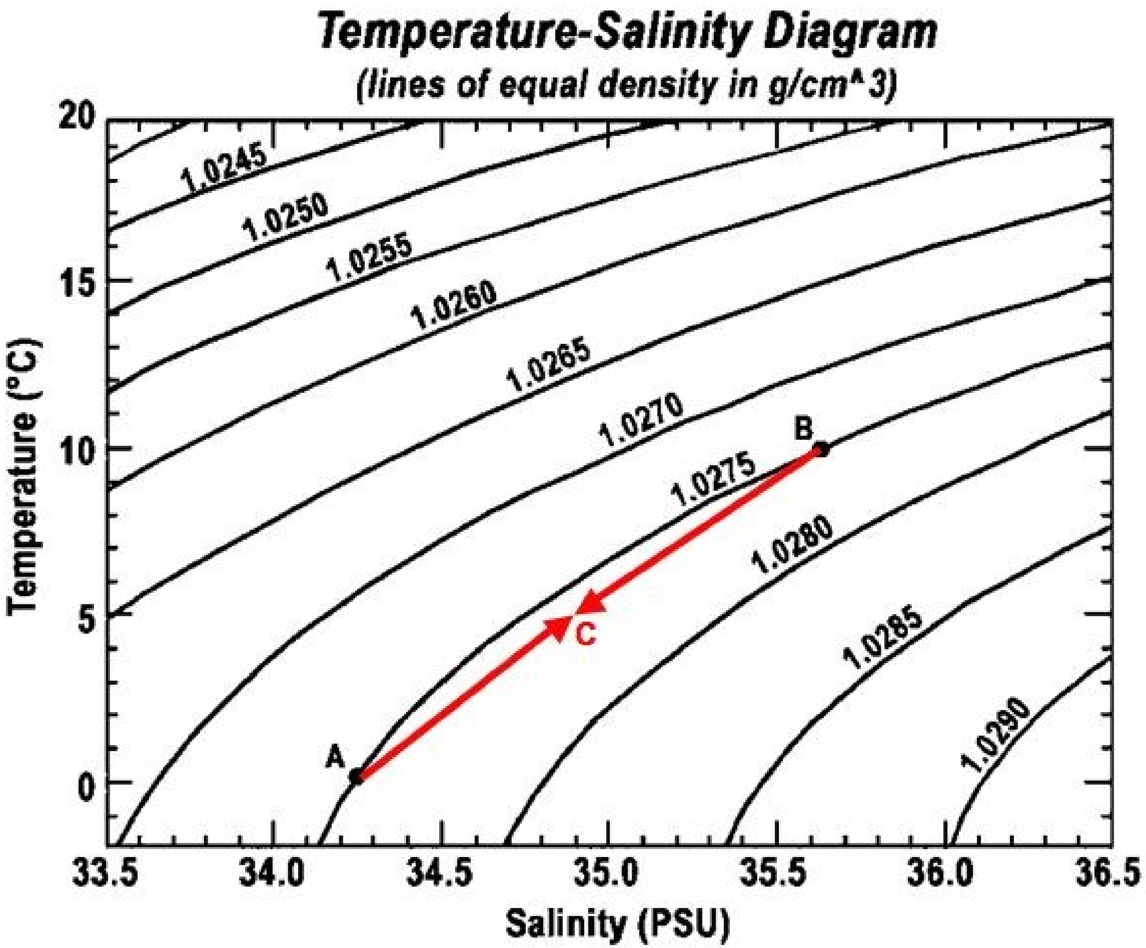
- Even if the dynamics of **U** can be assumed deterministic,
  the system **A** alone **cannot be assumed deterministic**.

- To obtain a deterministic model for **A**, one must assumed, either
  that **B** is known (→ atmospheric forcing), or
  that the effect of **B** can be parameterized (→ paramétrisation of unresolved scales or unresolved biologic diversity).

→ B is the main source of uncertainty in the model.

1. Uncertainties in the computation of density (1)

In the model, the large-scale density is computed form large-scale temperature and salinity, using the sea-water equation of state.

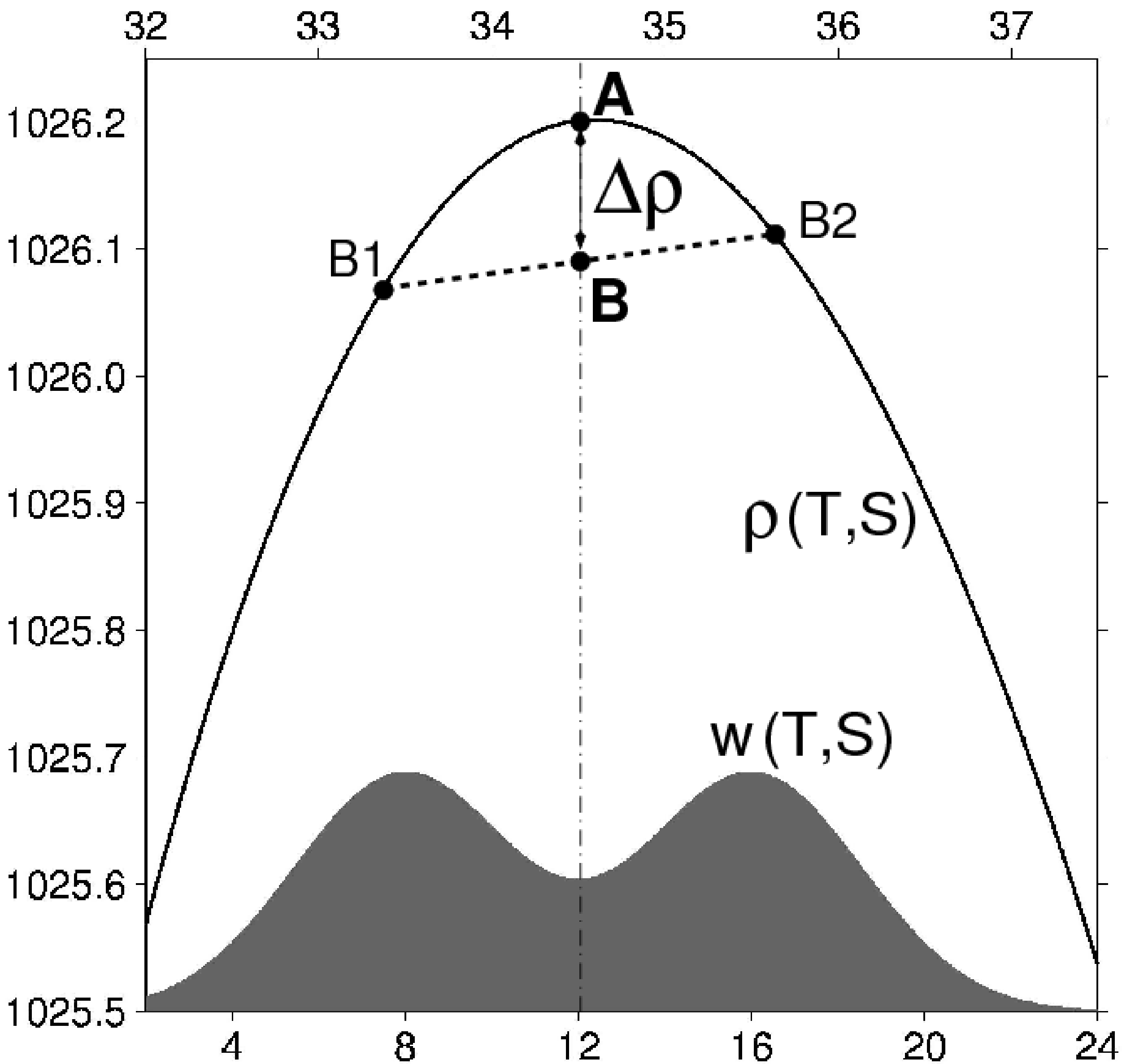


(a)
Mixing waters of equal density but different T&S systematically increases density (cabbeling)

(b)
Averaging T&S equations systematically overestimates density (in a fluctuating, non-deterministic way)

However, because of the nonlinearity of the equation of state, unresolved scales produce an average effect on density.

1. Uncertainties in the computation of density (2)



ρ(T, S)
non-linear eq. of state

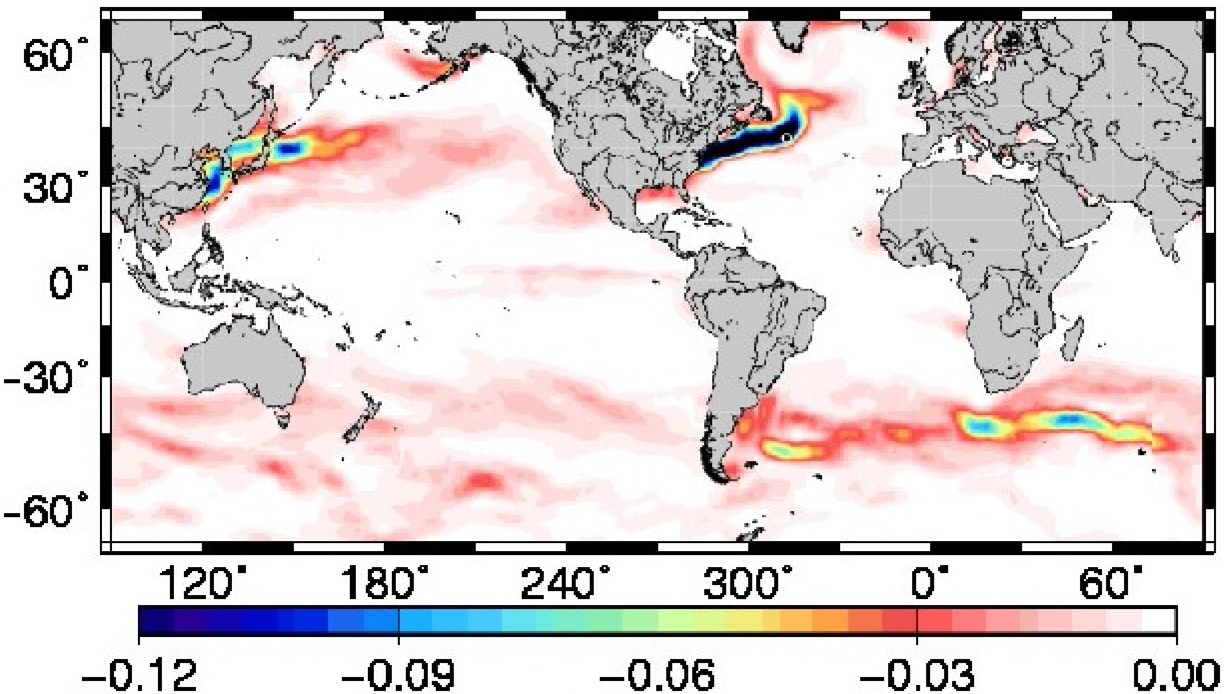
w(T, S)
distribution of unresolved T&S fluctuations

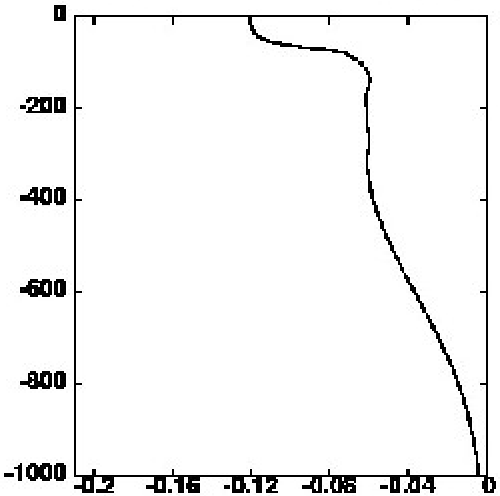
ρ_A
density computed from averaged T&S

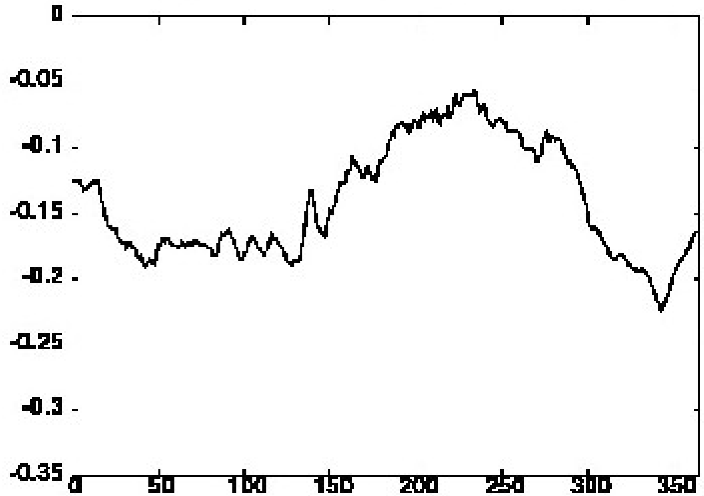
ρ_B
density taking into account unresolved T&S fluctuations

$\Delta\rho$
density misfit

1. Estimation de Δρ from ocean reanalysis data







(a)
Start from T&S reanalysis data at ~ 1/4° resolution

(b)
Use an averaging operator to downscale data to model resolution (~ 2°)

(c)
Δρ = density misfit between applying the averaging operator <u>before and after</u> the equation of state

→ Lower bound for the required density correction.

2

Stochastic parameterization

2. Stochastic equation of state for the large scales

Stochastic parameterization

using a set of random T&S fluctuations
ΔT_i et ΔS_i , i=1,...,p
to simulate unresolved T&S fluctuations

$$\rho = \frac{1}{2p}\sum_{i=1}^{p}\left\{\rho\left[T+\Delta T_i, S+\Delta S_i, p_0(z)\right] + \rho\left[T-\Delta T_i, S-\Delta S_i, p_0(z)\right]\right\}$$

Leading behaviour of Δρ:

$$\Delta\rho = \frac{\partial^2\rho}{\partial T^2}\left(\frac{1}{2p}\sum_{i=1}^{p}\Delta T_i^2\right) + 2\frac{\partial^2\rho}{\partial T\partial S}\left(\frac{1}{2p}\sum_{i=1}^{p}\Delta T_i\Delta S_i\right) + \frac{\partial^2\rho}{\partial S^2}\left(\frac{1}{2p}\sum_{i=1}^{p}\Delta S_i^2\right)$$

No effect if the equation of state is linear.
Proportional to the square of unresolved fluctuations.

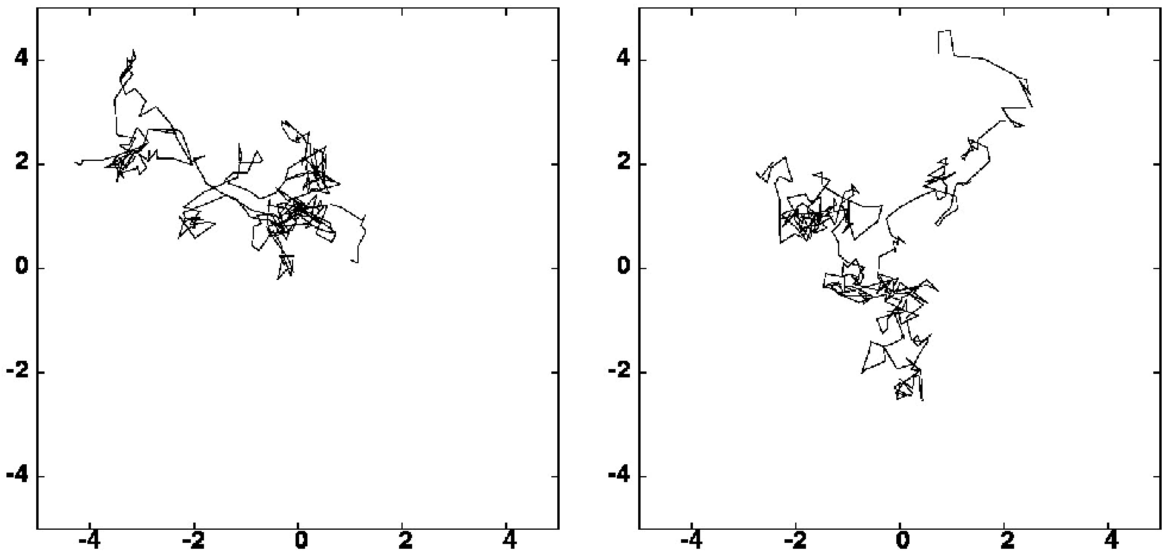
2. Random walks to simulate unresolved temperature and salinity fluctuations

Computation of the random fluctuations ΔT_i et ΔS_i

as a scalar product of the local gradient with random walks ξ_i

$$\Delta T_i = \boldsymbol{\xi}_i \cdot \nabla T \quad \text{and} \quad \Delta S_i = \boldsymbol{\xi}_i \cdot \nabla S$$

Random walks



Assumptions

AR1 random processes

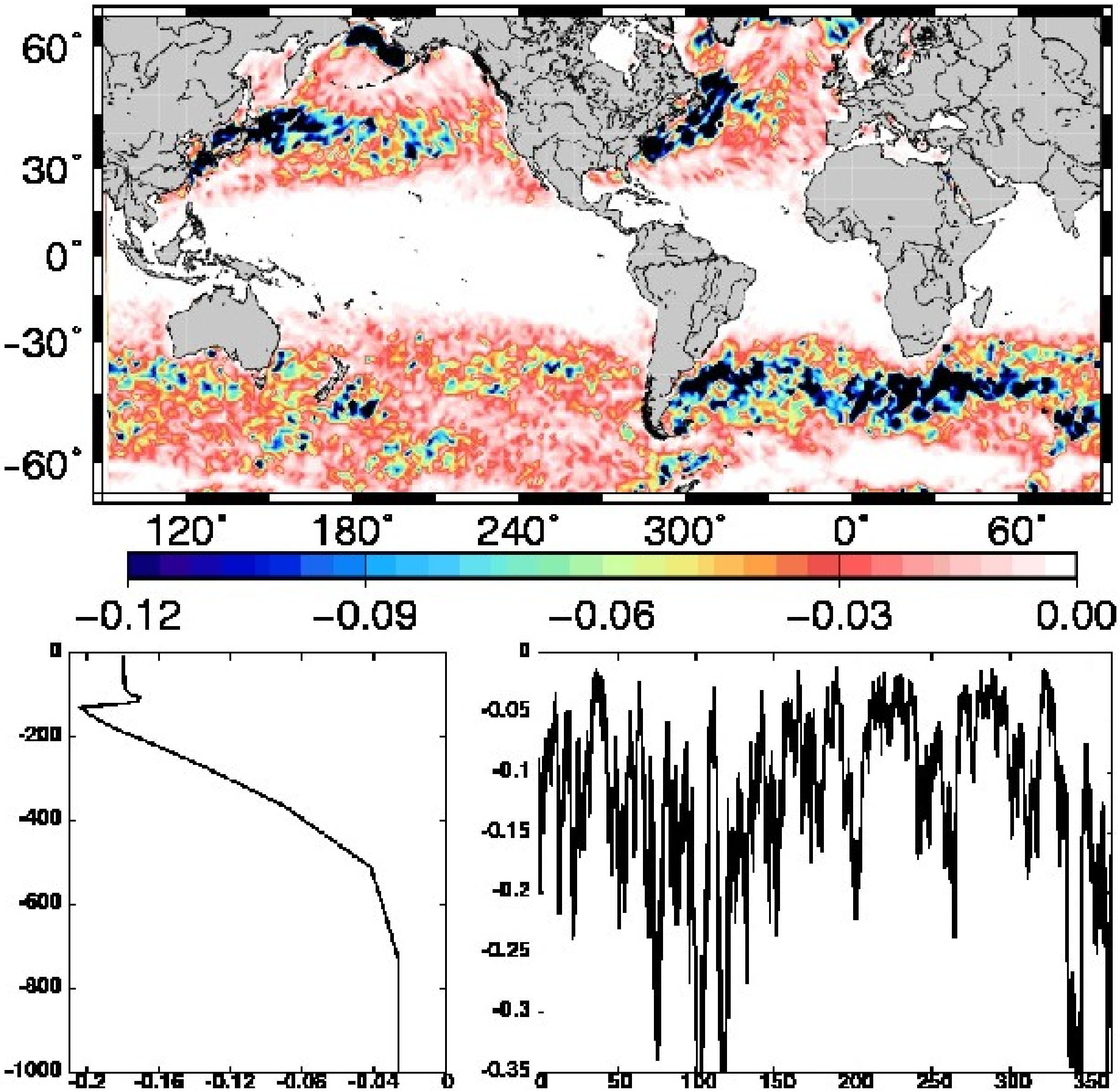
uncorrelated on the horizontal

fully correlated along the vertical

5-day time correlation

horizontal std: 2-3 grid points
vertical std: <1 grid point

2. Resulting density correction (Δρ) in a low resolution model (ORCA2)



Δρ is computed,
in a fully autonomous way,
by the low resolution model

Qualitatively similar
to previously estimated
lower bound

but

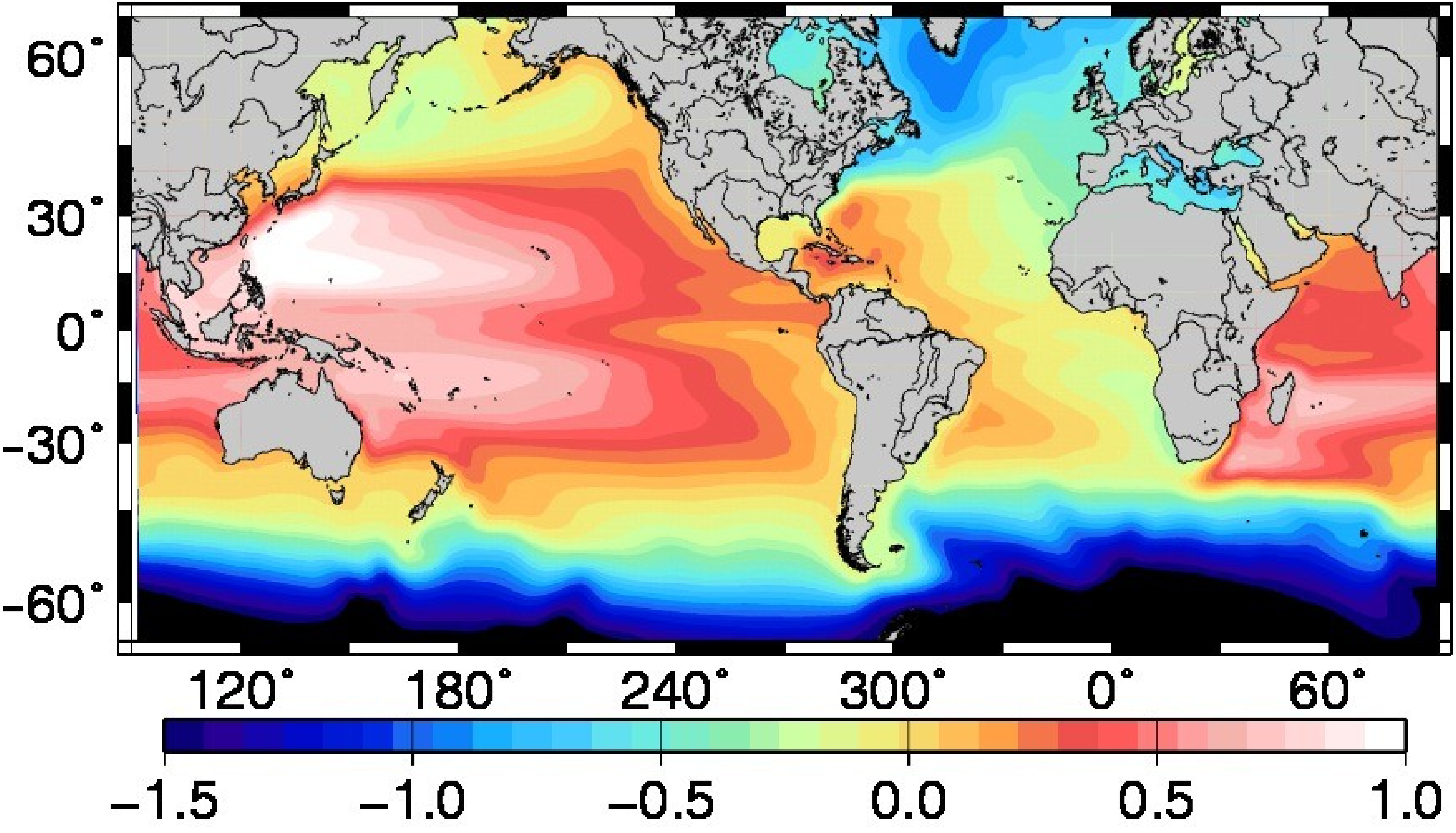
about twice as large
(i.e. T&S fluctuations
about 40% larger)

more high frequency
fluctuations

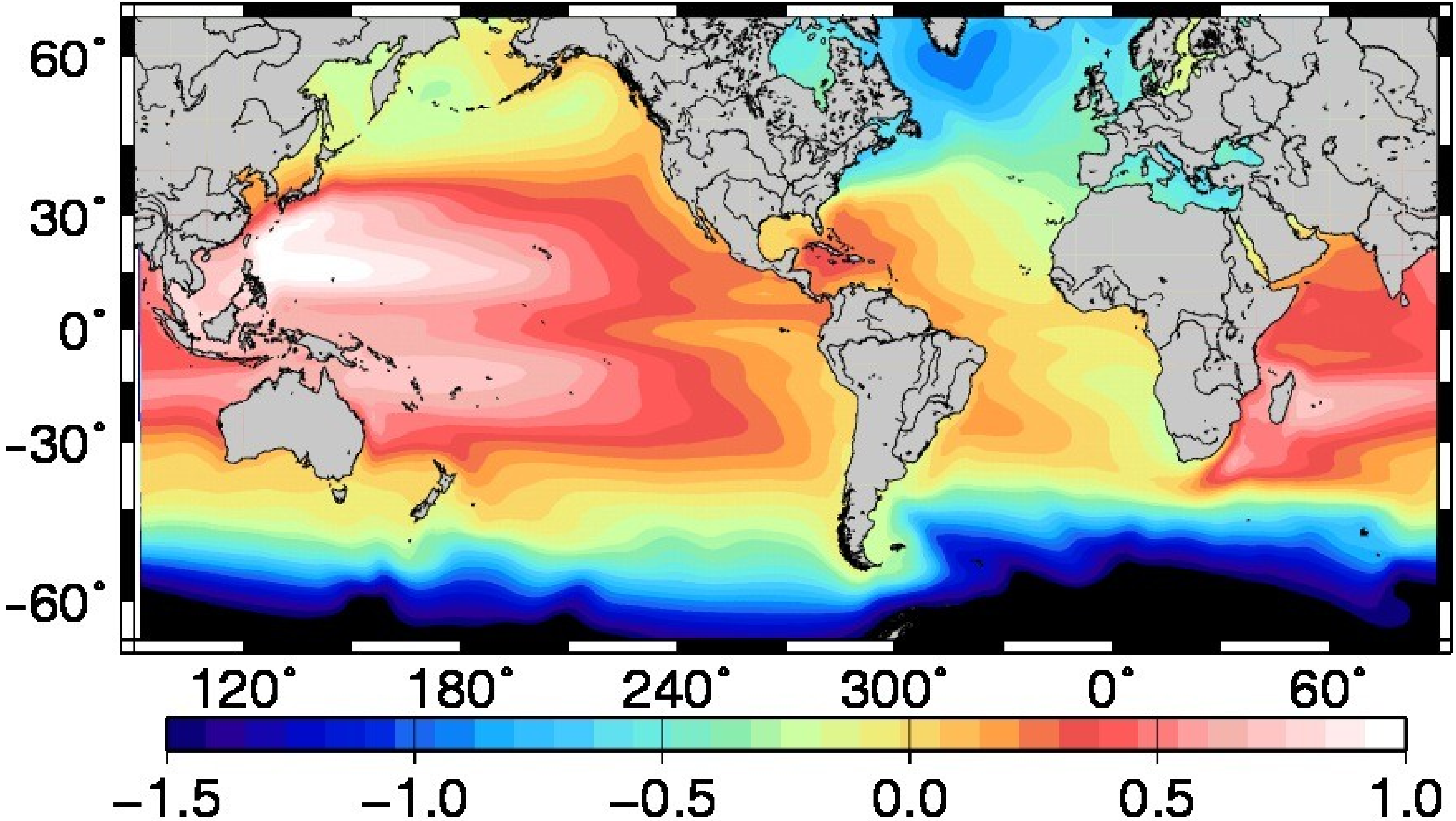
3

Impact on the model simulation

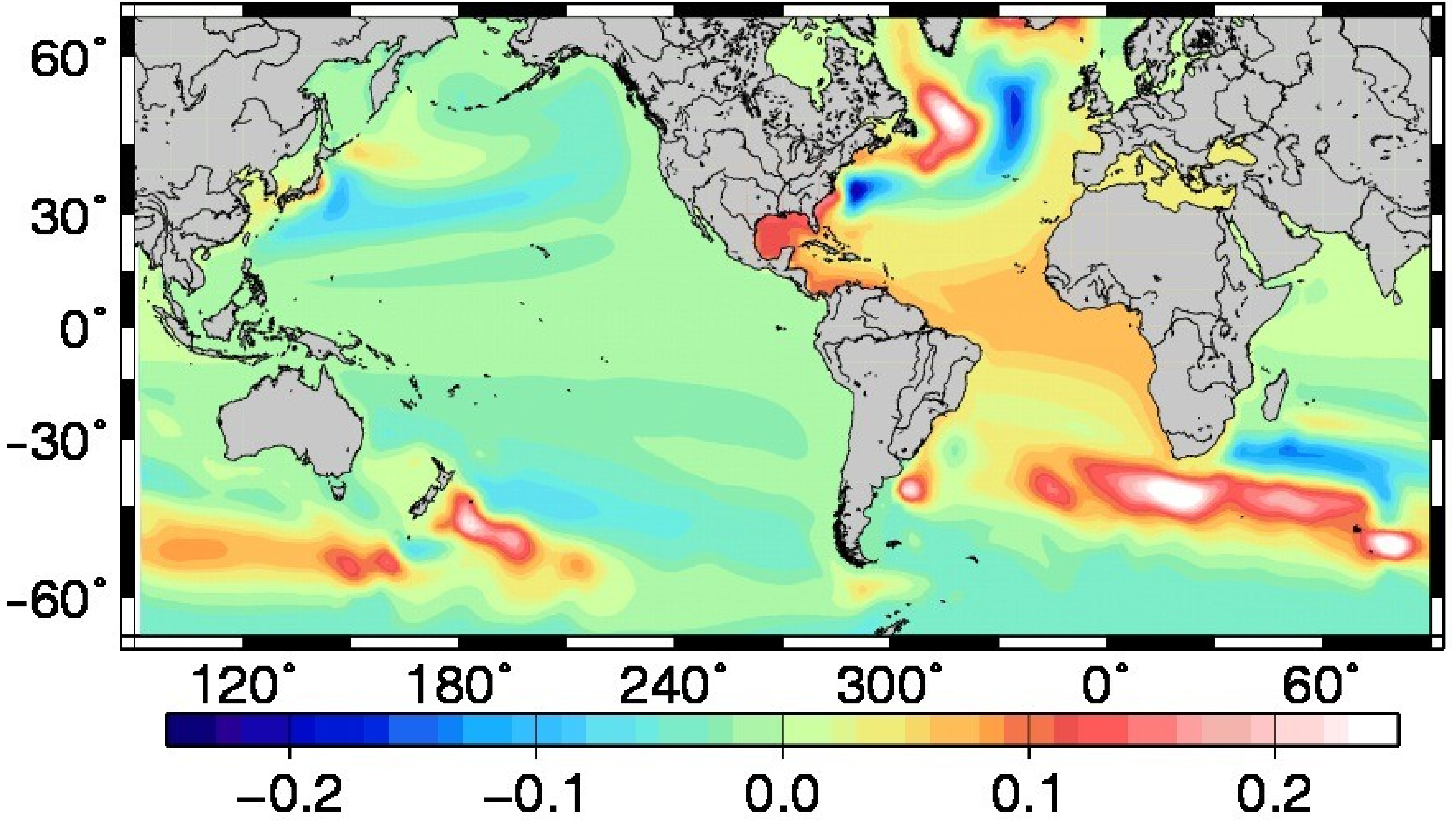
3. Mean sea surface elevation (standard)



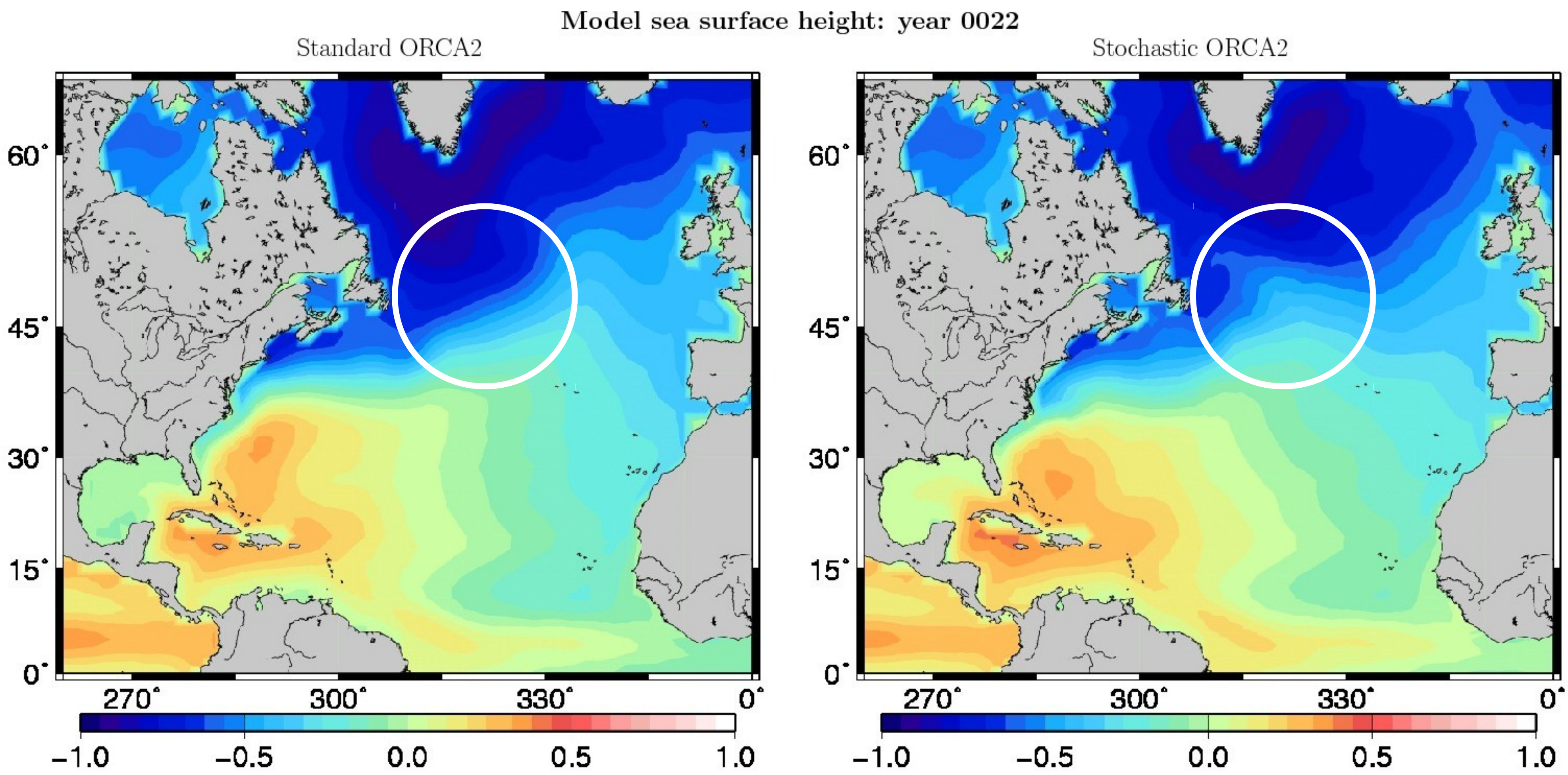
3. Mean sea surface elevation (stochastic)



3. Mean sea surface elevation difference



3. Fluctuations: sea surface elevation in the North Atlantic



Standard simulation: (almost) no intrinsic interannual variability
Stochastic simulation: significant intrinsic interannual variability

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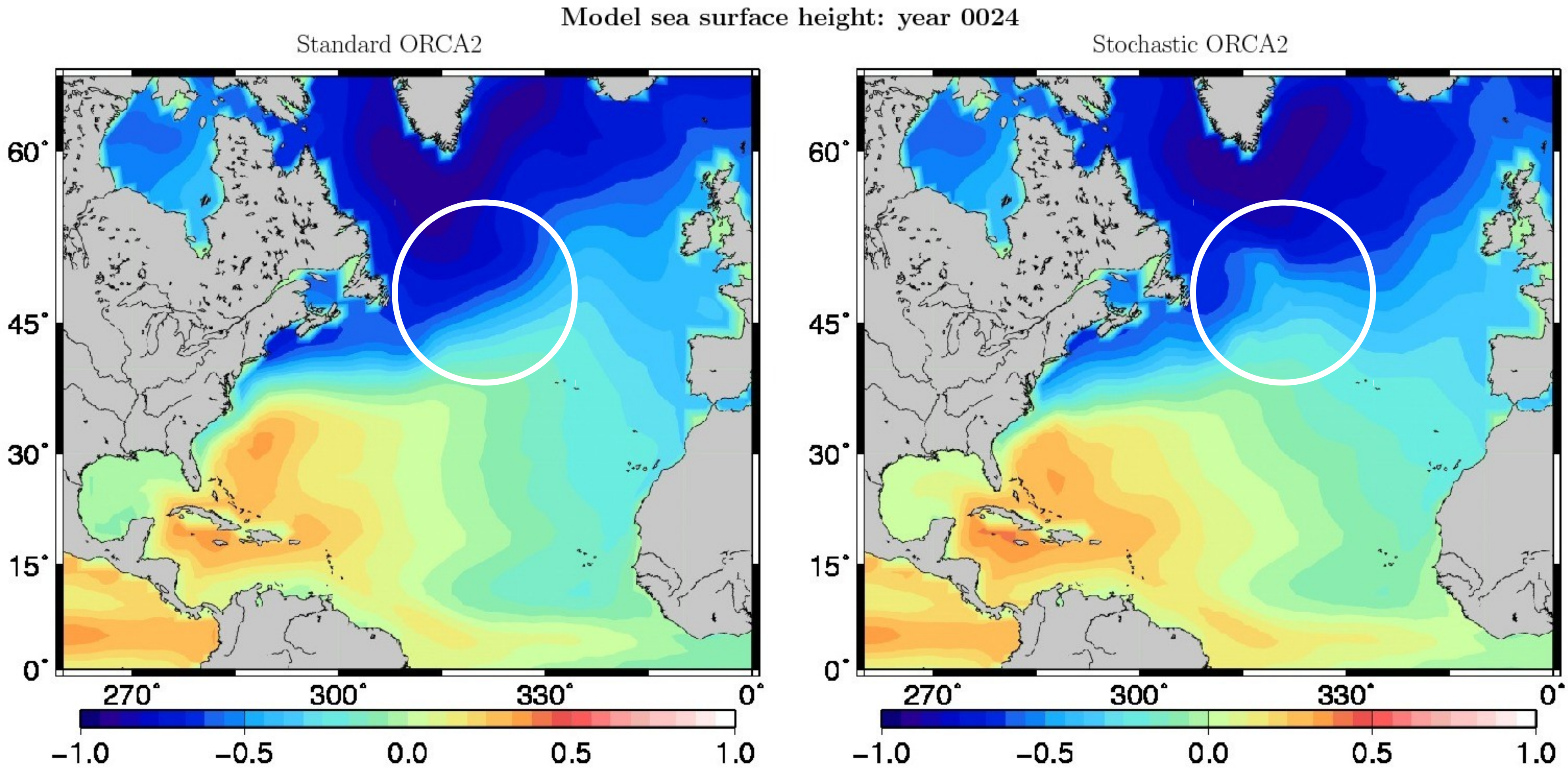

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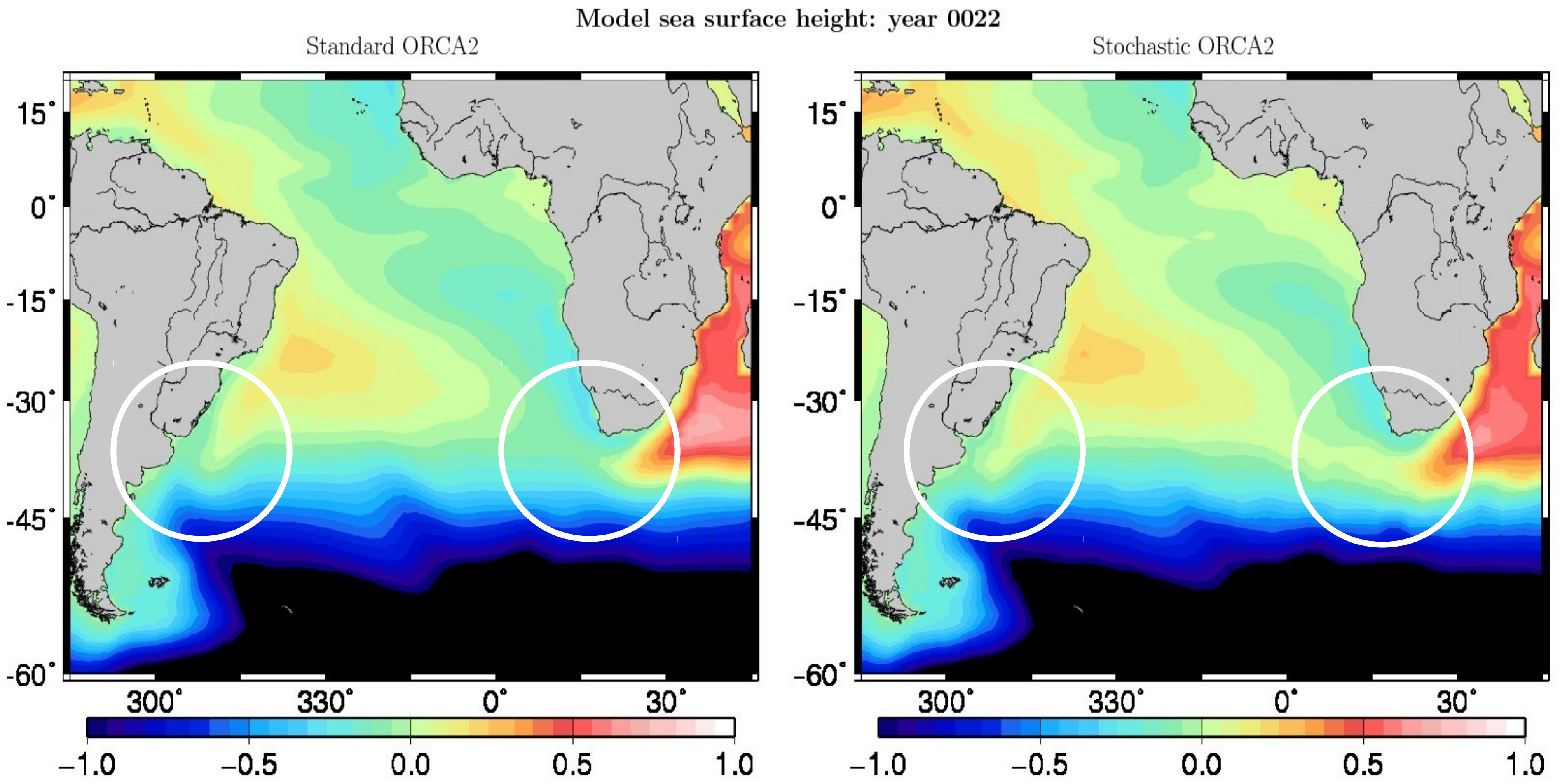
3. Fluctuations: sea surface elevation in the South Atlantic



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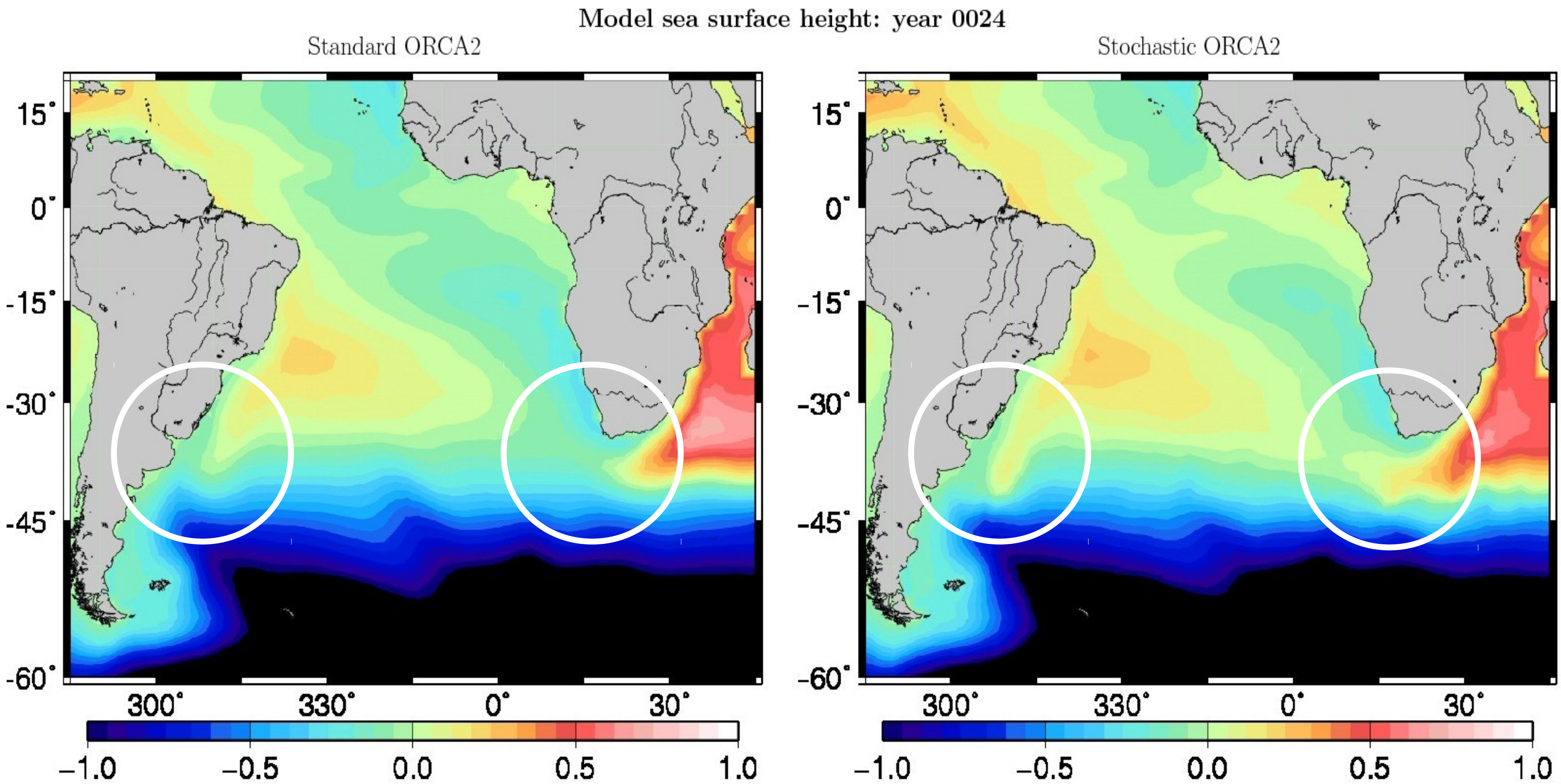

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Stochastic simulation: significant intrinsic interannual variability

3. Fluctuations: interpretation

Nonlinearity of the equation of state → scales interactions

Unresolved T&S fluctuations

↓

Unknown fluctuations of the large scale density

↕

Continual exchange of potential energy
between the unresolved scales and the large scales

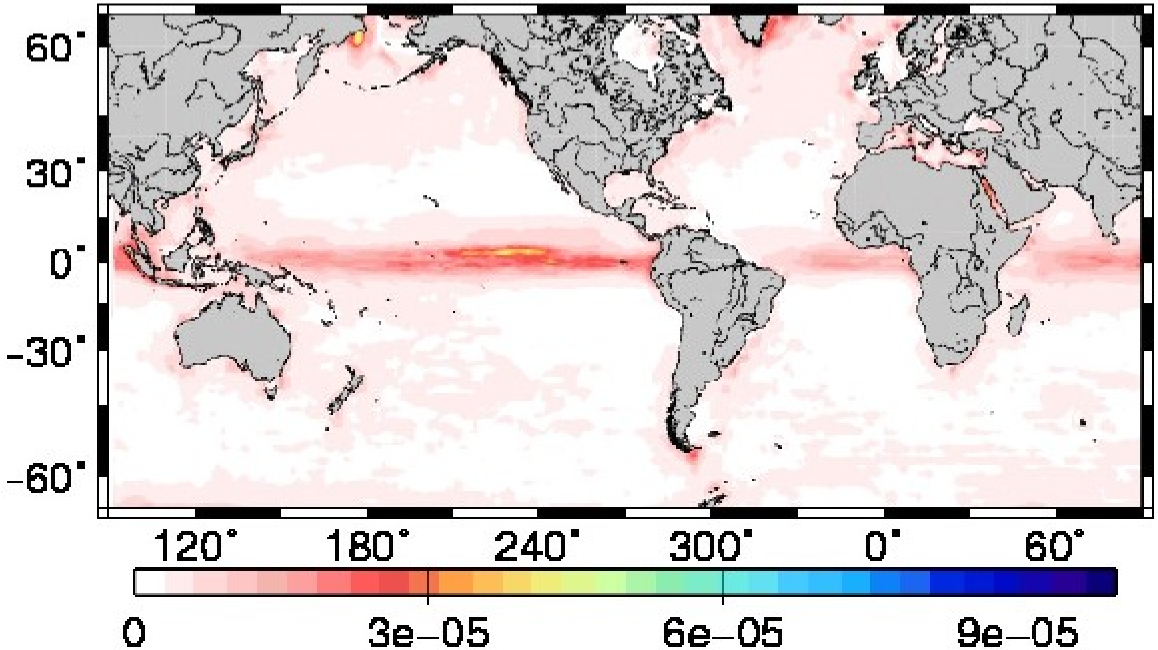
↓

Flux of information from the smaller scales
constantly re-structuring the large scale flow

↑

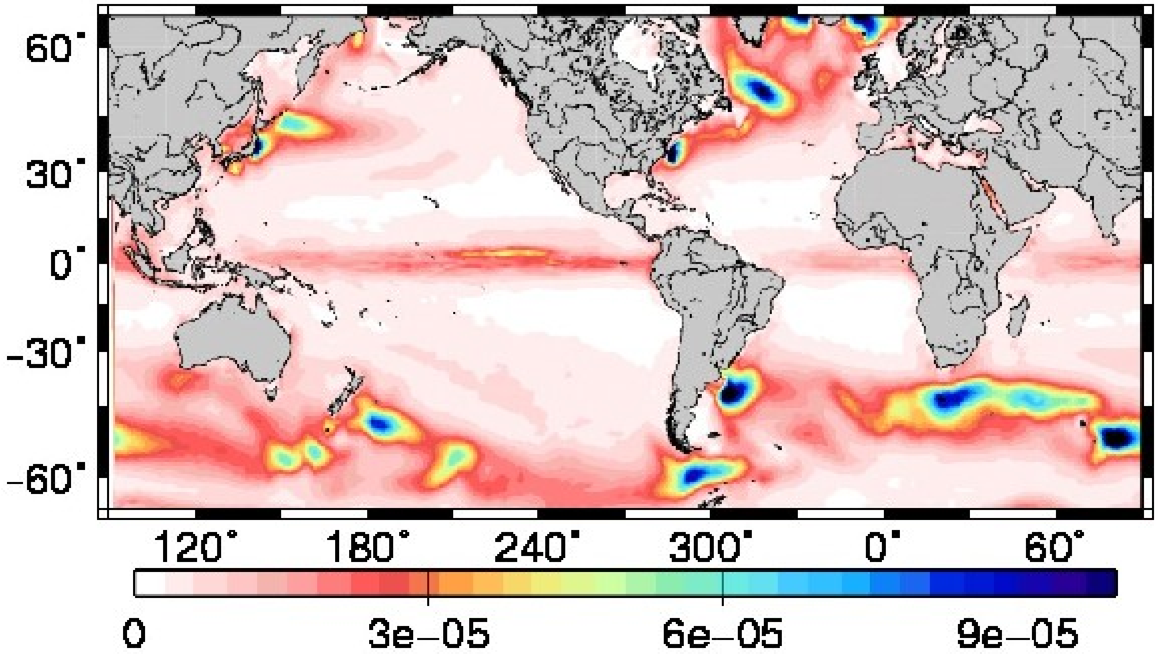
In the stochastic parameterization, the missing information
is provided by the random numbers, which produce
a continual re-organization of the large-scale density field

3. Impact on vertical velocity (at 100 m depth)



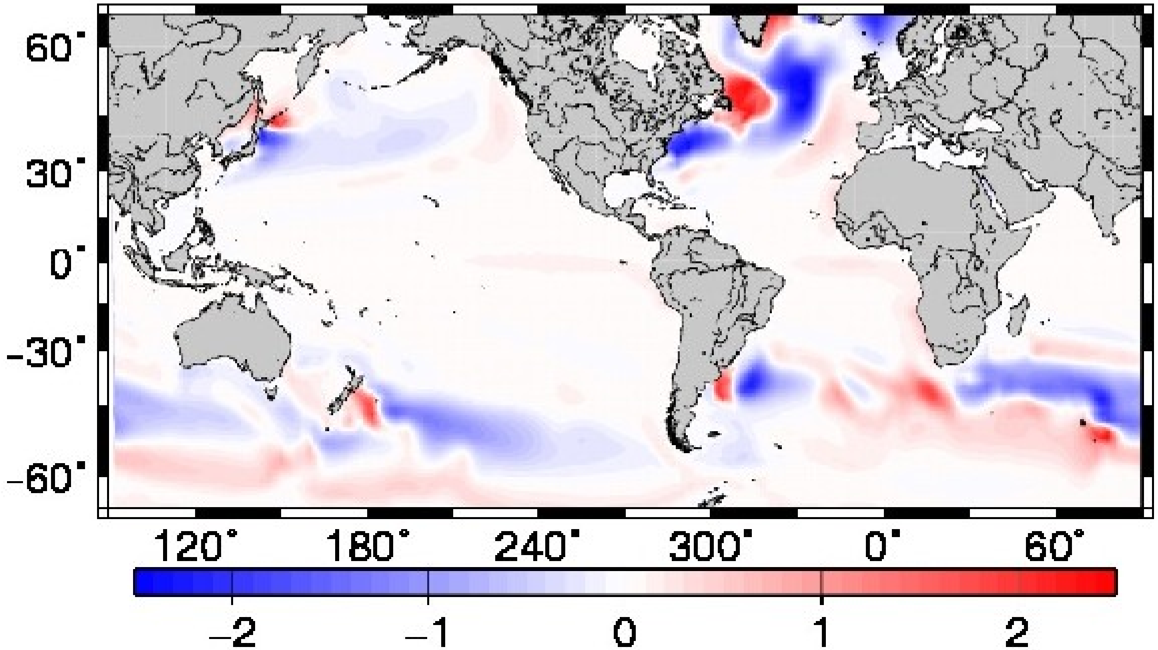
Continual adjustment of the model circulation to geostrophy

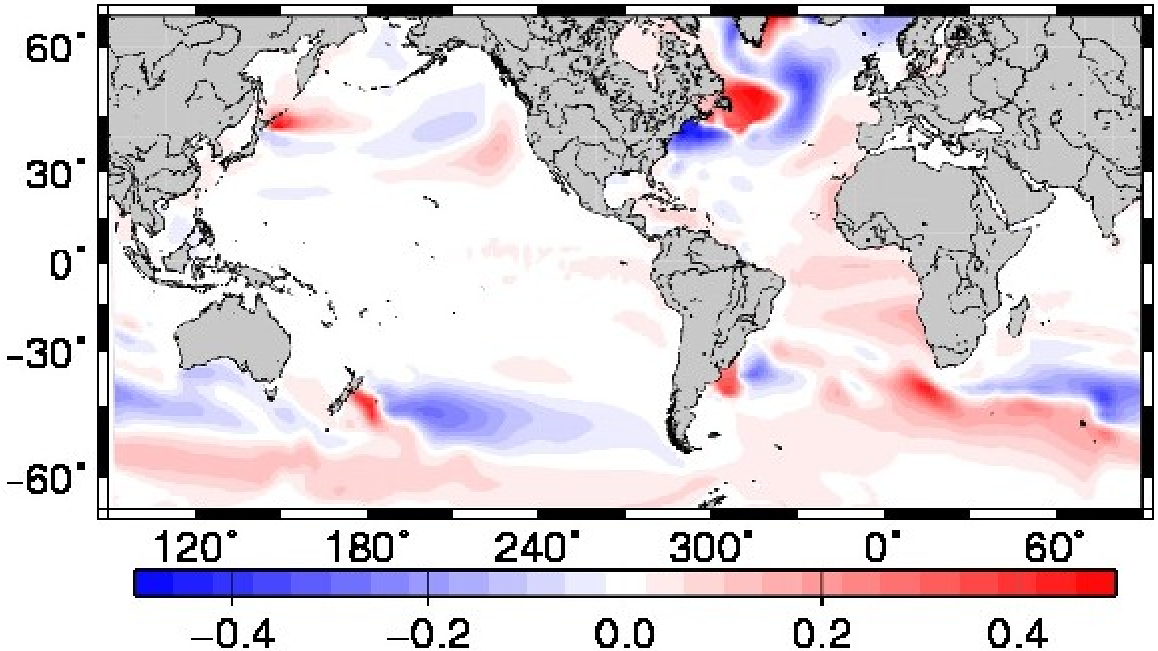
↓



Additional vertical velocities

3. Averaged SST & SSS difference





Modification of the mean flow

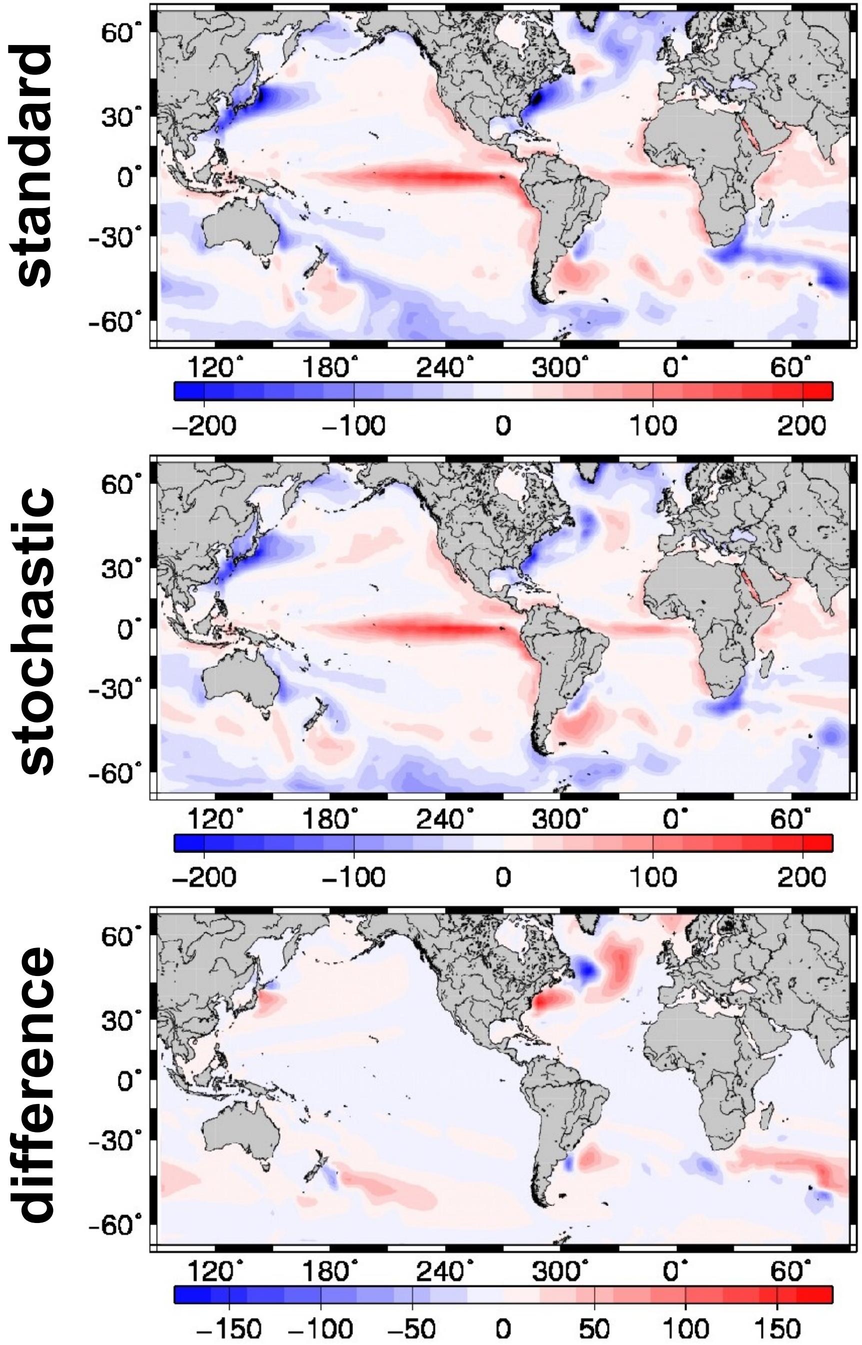
↓

Modification of the mean SST & SSS

↓

Modification of air/sea interactions

3. Impact on the average net heat flux



In a forced ocean model, an irrealistic flux is produced if the sea surface temperature is inconsistent with the atmosphere.

↓

A reduction of spurious fluxes is a good indication that the position of the fronts has been improved.

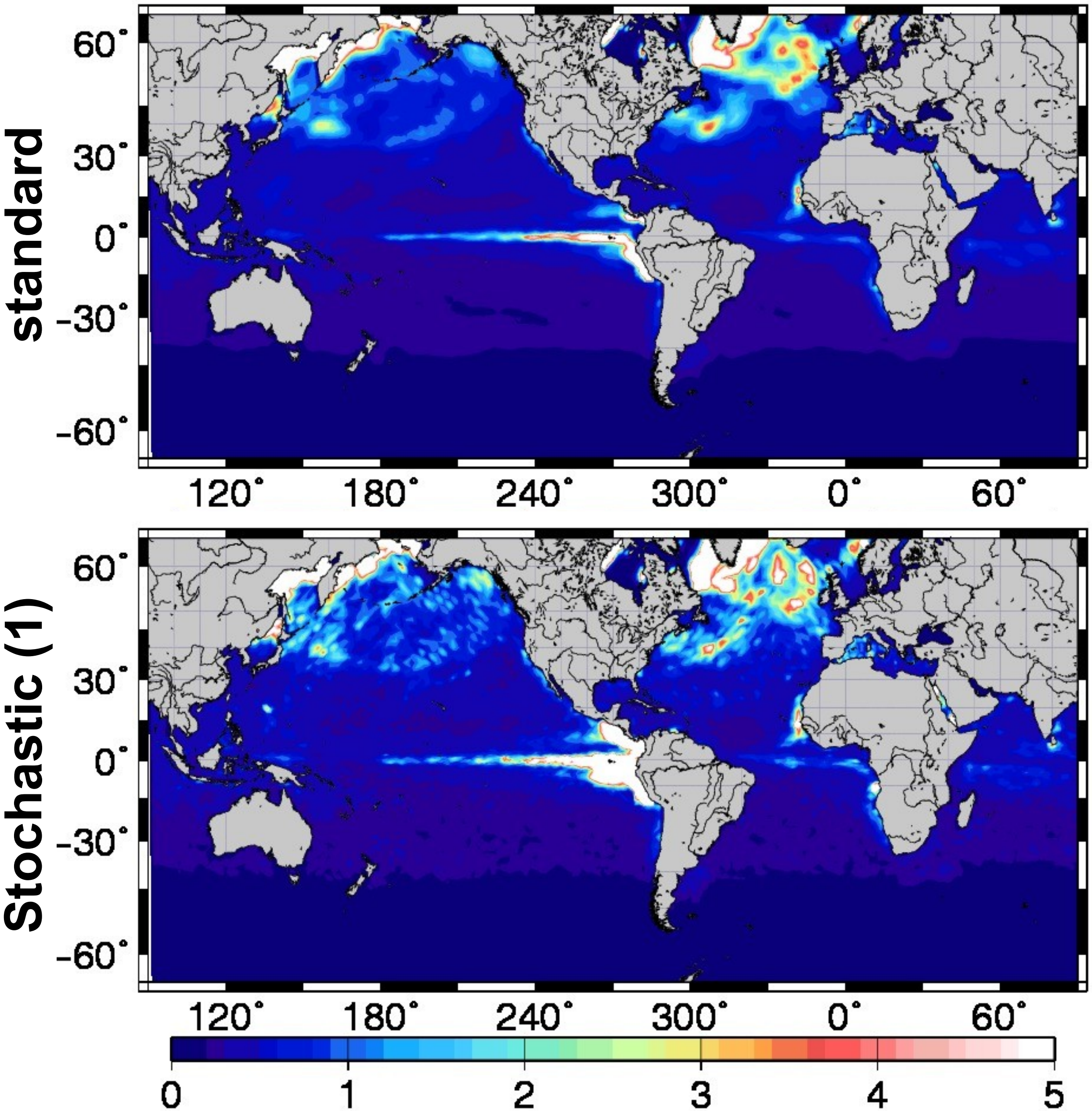
↓

Uncertainties in the large scale density associated to the nonlinearity of the equation of state can have a significant impact on the simulated earth's climate

3b

Impact on the ecosystem model

3b. Simulation of uncertainties due to unresolved biologic diversity



Uncertainty simulated by a 50% multiplicative noise applied to model tendencies (as in Buizza et al. 1999)

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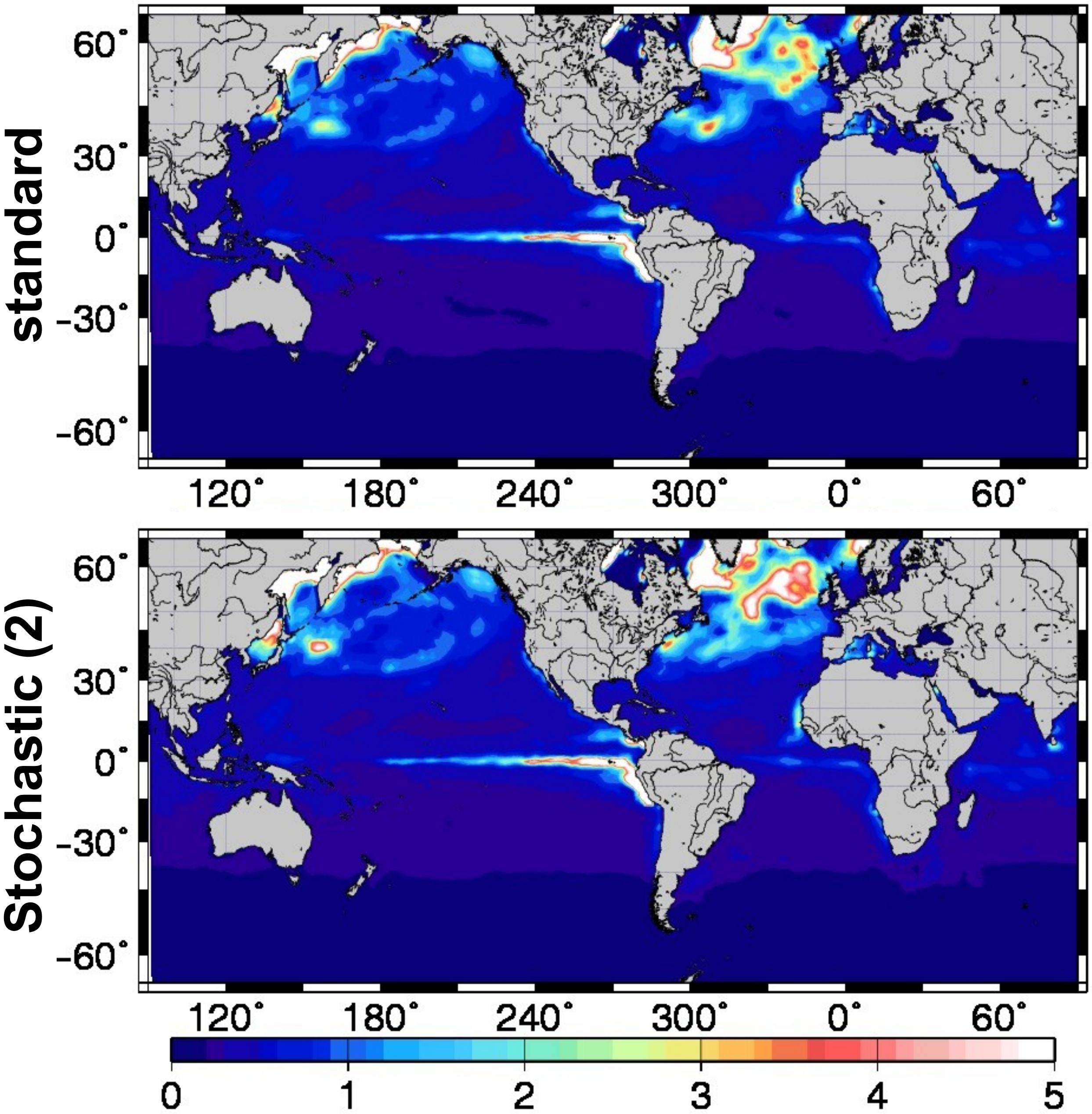
Strong mean effect in the tropical Pacific

Increased patchiness (as in observations)

3b. Simulation of uncertainties in the computation of density (as described before)



Increased vertical velocities

↓

Increased nutrient supply

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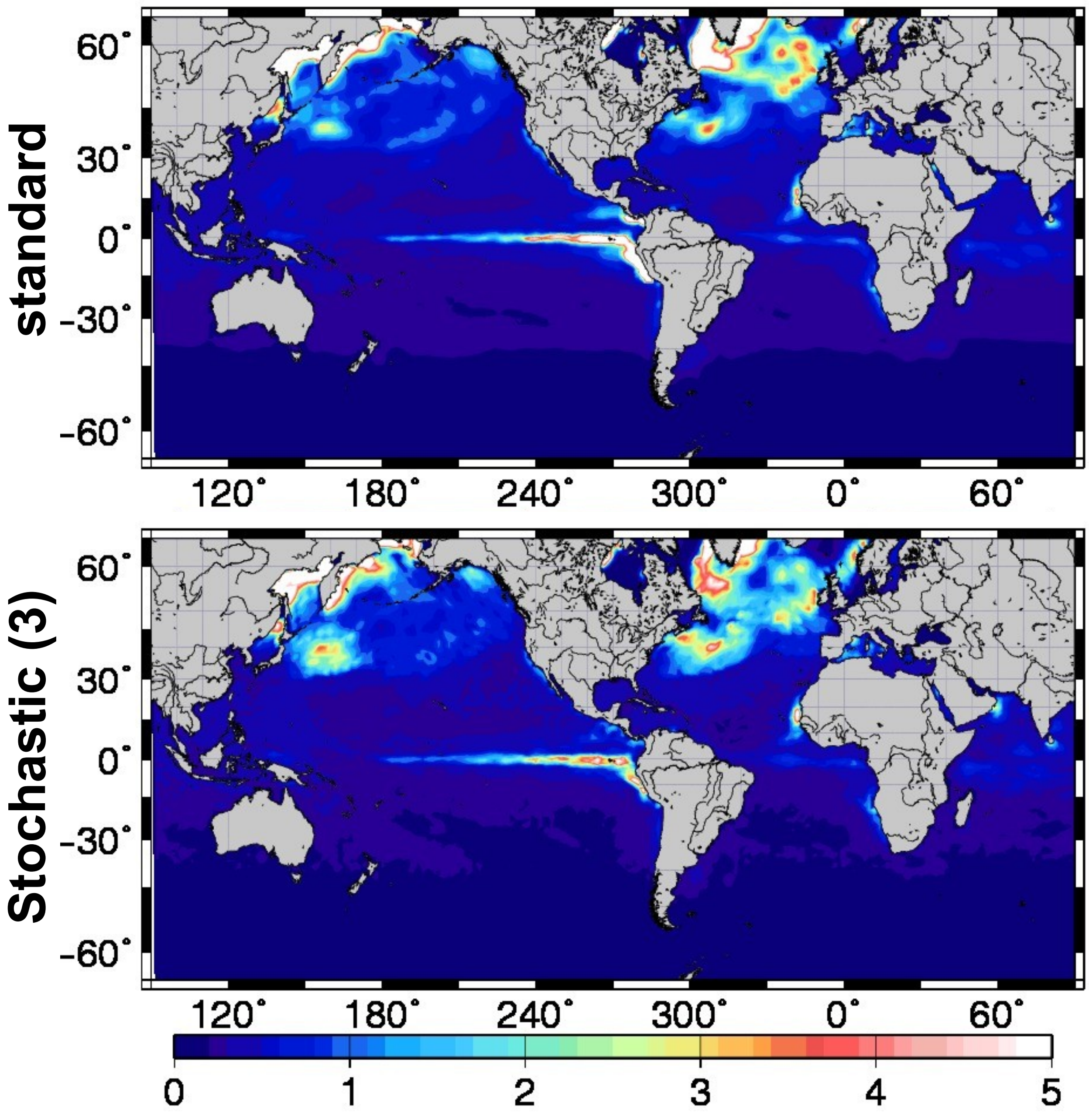
Increased primary production

3b. Simulation of uncertainties due to unresolved scales in biogeochemical tracers



The ecosystem model depends on strongly nonlinear functions of tracers concentrations

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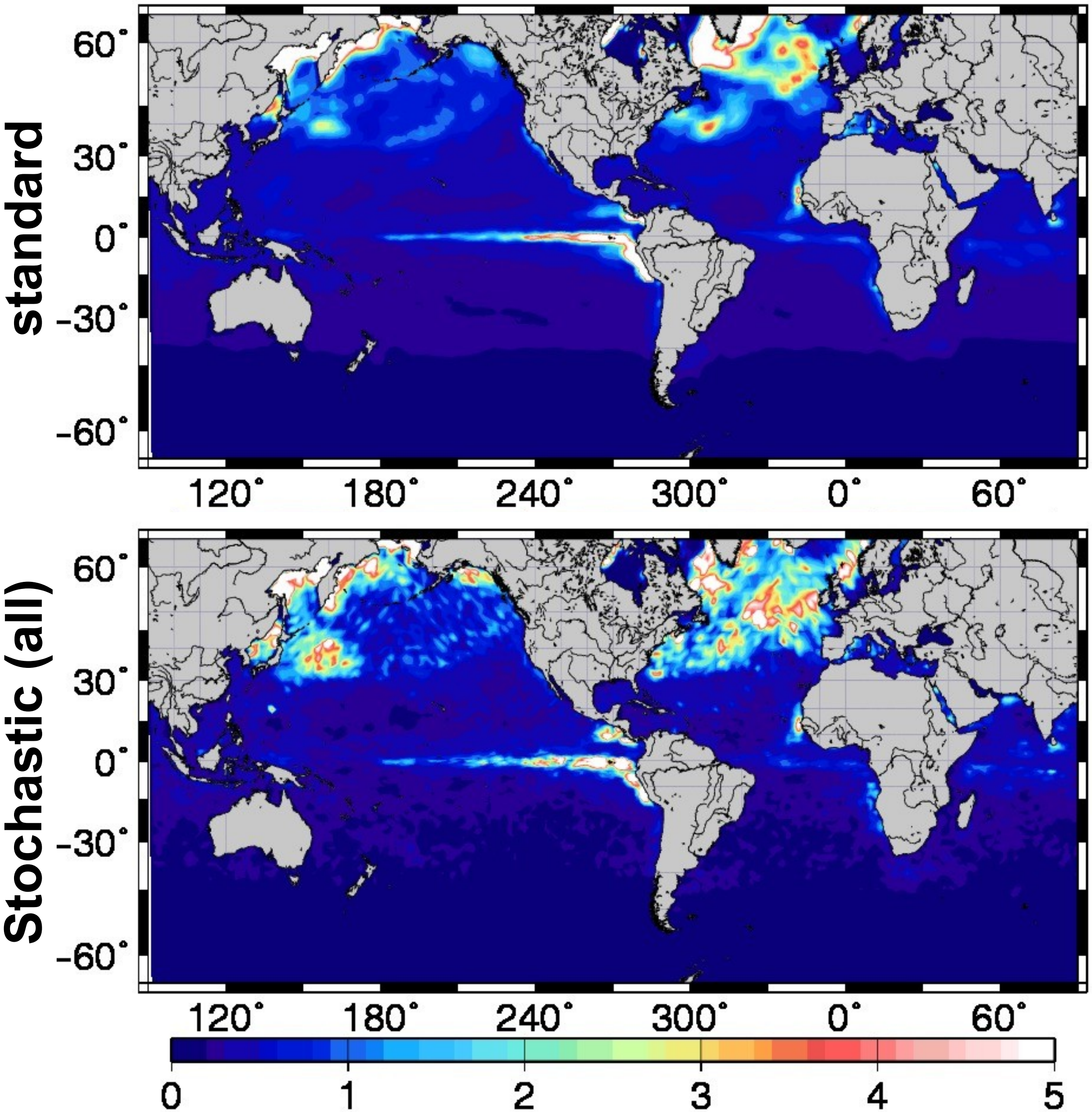
Uncertainties due to unresolved scales, which can be simulated as explained for the equation of state

↓

Primat production locally increased or decreased according to model nonlinearities

3b. Simulation of all three kinds of uncertainties together



Strong interactions between uncertainties

↓

Strong effect on the mean large scale structure (probably deterministic) and on tracer patchiness (non-deterministic)

↓

More consistent with ocean colour observatons ?

4

Conclusions

Conclusion 1:

The explicit simulation of uncertainties can explain and reduce biases in ocean models

Conclusion 2:

Uncertainties are such that marine systems cannot be described by deterministic models.