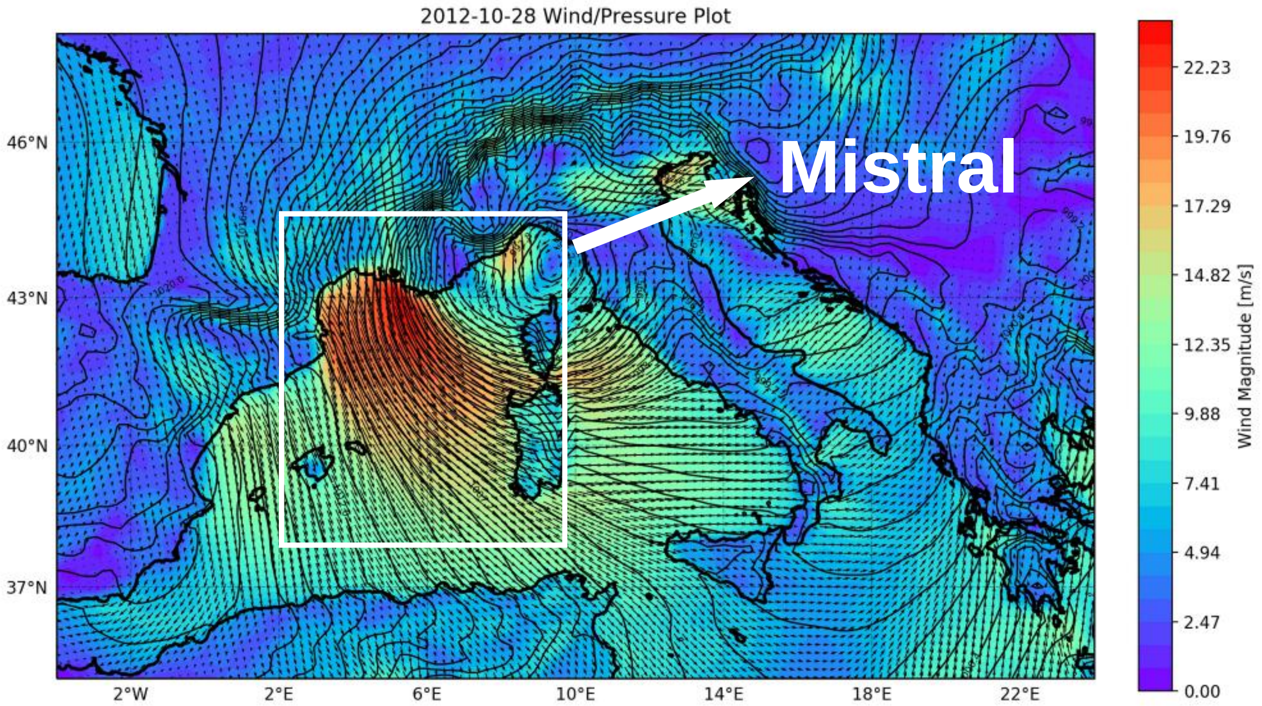
Untangling the Mistral and Seasonal Effects of Atmospheric Forcing on Deep Convection in the Gulf of Lion

Douglas Keller[†], Romain Pennel[†], Yonatan Givon[‡], Shirah Raveh-Rubin[‡], and Philippe Drobinski[†]

What and Why?

Deep convection in the open ocean is the occurrence of a convective system that reaches from the sea surface to the sea floor. It mixes the entire water column and promotes nutrient and mineral dispersion for the marine biology[1-4]. In the Gulf of Lion, it aids the general circulation of the Mediterranean Sea[5]. The purpose of this work is to determine the effects the Mistral has on deep convection in the Gulf of Lion.



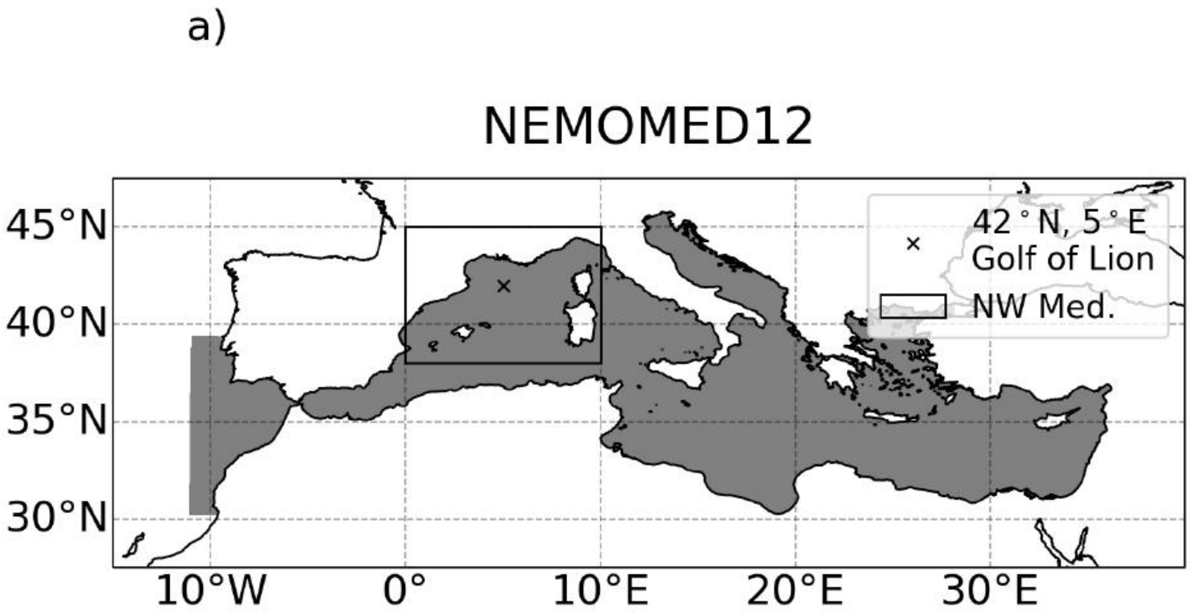
[1]Severin et al. (2017) "Open-ocean convection process: A driver of the winter nutrient supply and the spring phytoplankton distribution in the Northwestern Mediterranean Sea"
[2]Donoso et al. (2017) "Zooplankton community response to the winter 2013 deep convection process in the NW Mediterranean Sea"
[3]Mayot et al. (2017) "Influence of the Phytoplankton Community Structure on the Spring and Annual Primary Production in the Northwestern Mediterranean Sea"
[4]Auger et al. (2014) "Interannual control of plankton communities by deep winter mixing and prey/predator interactions in the NW Mediterranean: Results from a 30-year modeling study"
[5]Beuvier et al. (2012) "Spreading of the Western Mediterranean Deep Water after winter 2005: Time scales and deep cyclone transport"

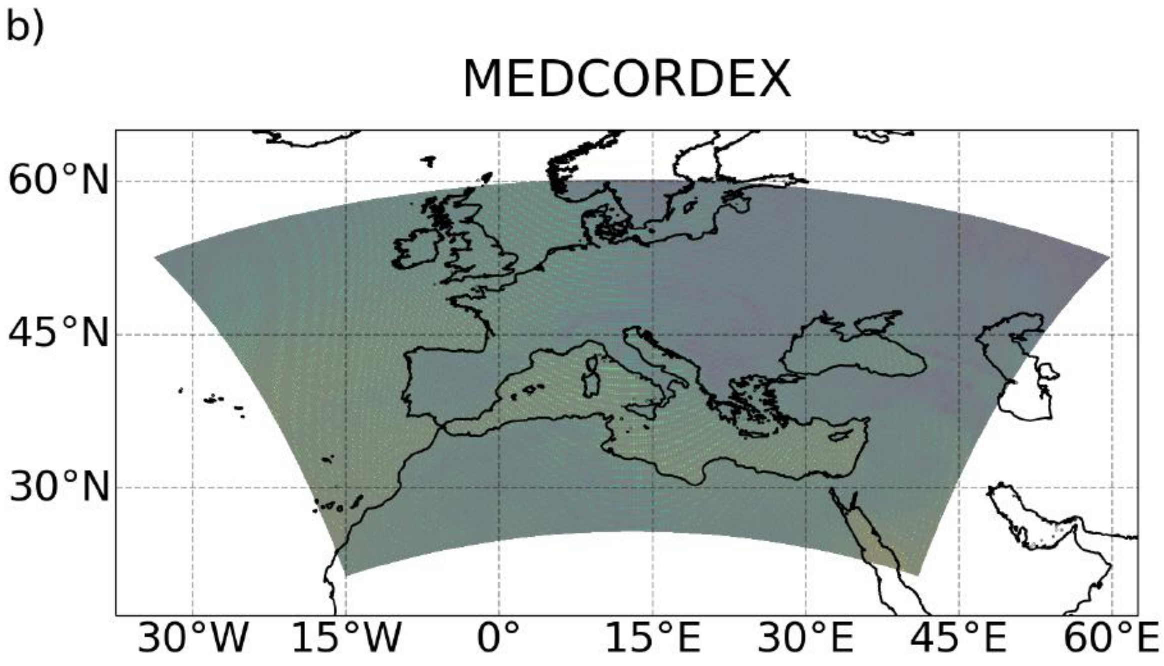
[†]Laboratoire de Météorologie Dynamique, IPSL, CNRS, Palaiseau, France
[‡]Department of Earth and Planetary Sciences, Weizmann Institute of Science, Rehovot, Israel

Douglas Keller, Romain Pennel, Yonatan Givon, Shirah Raveh-Rubin, and Philippe Drobinski

How?

To separate out the effects of the Mistral, two NEMO[6] simulations (in NEMOMED12 configuration[7] *a)*) were run, forced by two WRF[8] datasets (ran with the MEDCORDEX[9] constraints and domain *b)*).

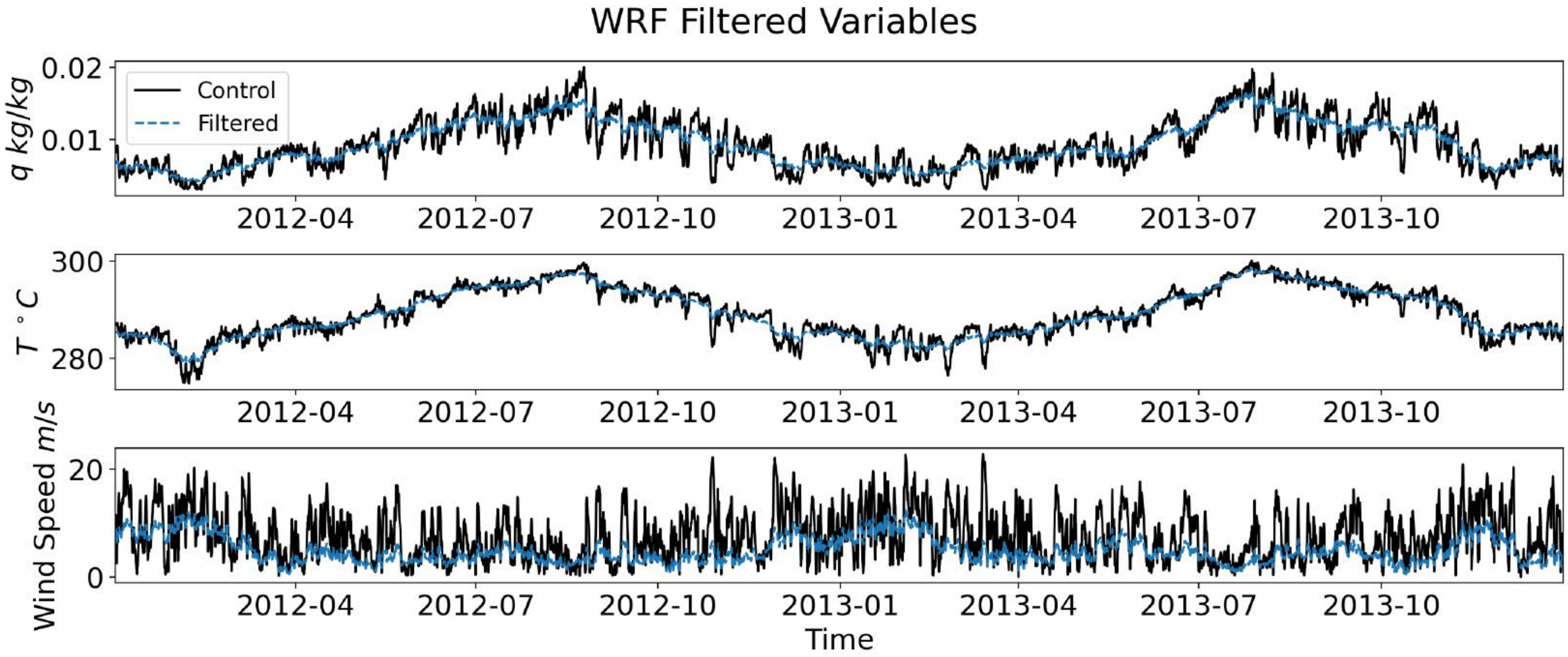




[6]NEMO Ocean model: https://www.nemo-ocean.eu/
[7]NEMOMED12: https://sourcesup.renater.fr/wiki/morcemed/nemconfig
[8]Weather Research and Forecasting model: https://www.mmm.ucar.edu/weather-research-and-forecasting-model
[9]MEDCORDEX WRF: https://sourcesup.renater.fr/wiki/morcemed/wrfconfig

Douglas Keller, Romain Pennel, Yonatan Givon, Shirah Raveh-Rubin, and Philippe Drobinski

One WRF dataset was left unmodified (*Control*) and the other was filtered (*Filtered*) with a moving mean to remove the Mistral signature in the atmospheric forcing, yet keeping the large time scale variations.



Douglas Keller, Romain Pennel, Yonatan Givon, Shirah Raveh-Rubin, and Philippe Drobinski

What We're Measuring

The stratification index[10], *SI*, is a useful way to describe the stratification of a water column, along *z*, through the Brunt-Väisälä frequency, N^2:

$$SI = \int_0^D N^2 z dz = \frac{D^2}{2} N^2$$

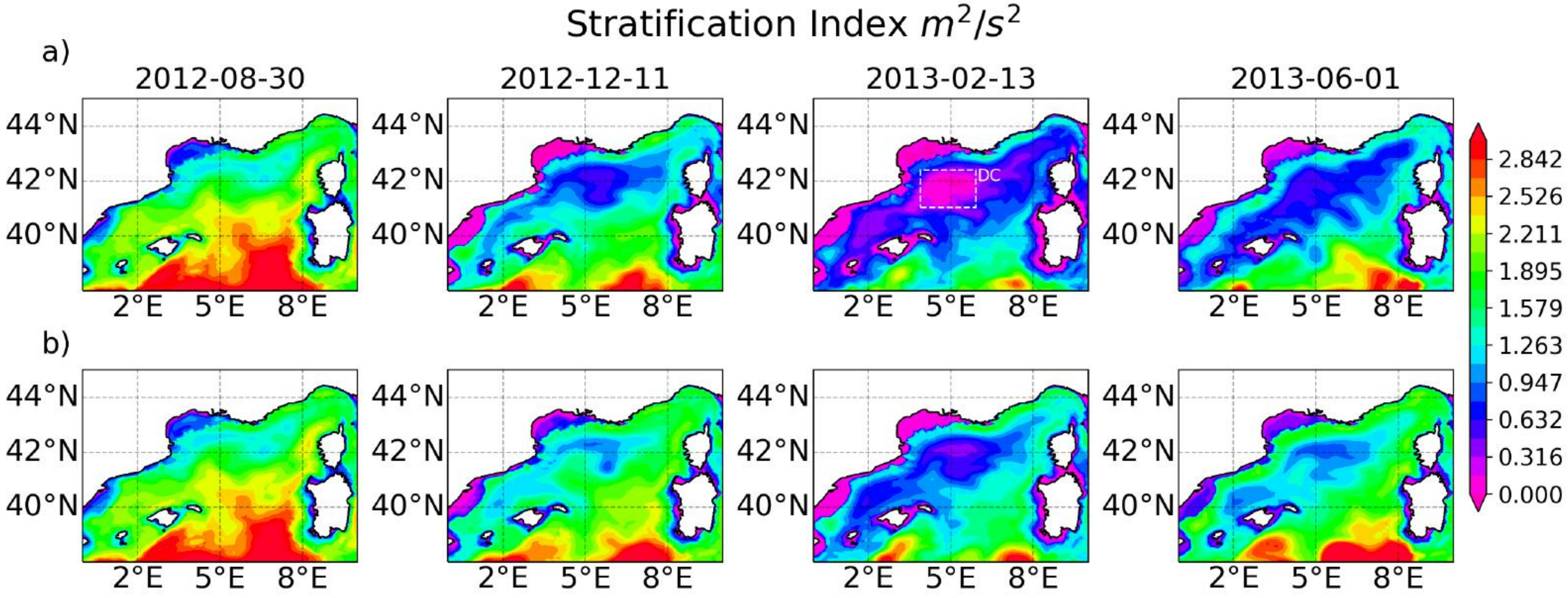
This allows us to put a single number to a water column to measure deep convection.

[10]Somot (2005) "Modélisation Climatique du Bassin Méditerranéan : Variabilité et Scénarios de Changement Climatique"

Douglas Keller, Romain Pennel, Yonatan Givon, Shirah Raveh-Rubin, and Philippe Drobinski

What We Got

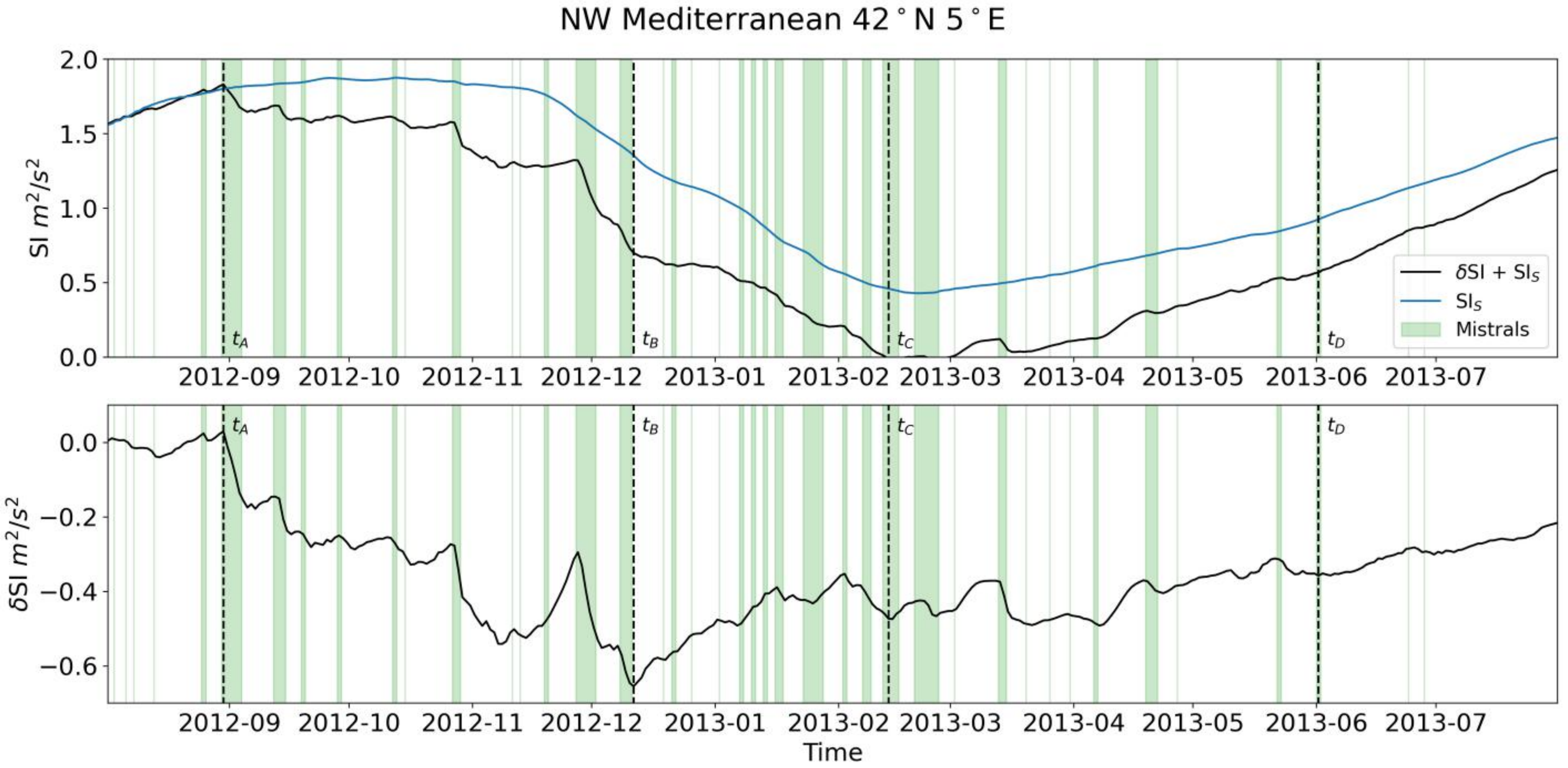
The maps of *SI* show that filtering the atmospheric forcings (*b)*) has a strong effect on the ocean simulation and the water columns remain much more stratified than in the unfiltered simulation (*a)*).



Untangling the Mistral and Seasonal Effects of Atmospheric Forcing on Deep Convection in the Gulf of Lion

Douglas Keller, Romain Pennel, Yonatan Givon, Shirah Raveh-Rubin, and Philippe Drobinski

Only the simulation with the unfiltered atmospheric forcings (δSI + SI_S) experiences deep convection in the gulf. This occurs when SI equals null in mid-February. Deep convection cannot occur from the influence of Mistrals alone, as δSI isn't strong enough to overcome more than ~0.6 m^2/s^2 of stratification. The seasonal component, SI_S, is required too.



Douglas Keller, Romain Pennel, Yonatan Givon, Shirah Raveh-Rubin, and Philippe Drobinski

Simplified Model

The energy equation for incompressible flow[11] is the following:

$$\rho c_p \frac{DT}{Dt} = \frac{DQ}{Dt}$$

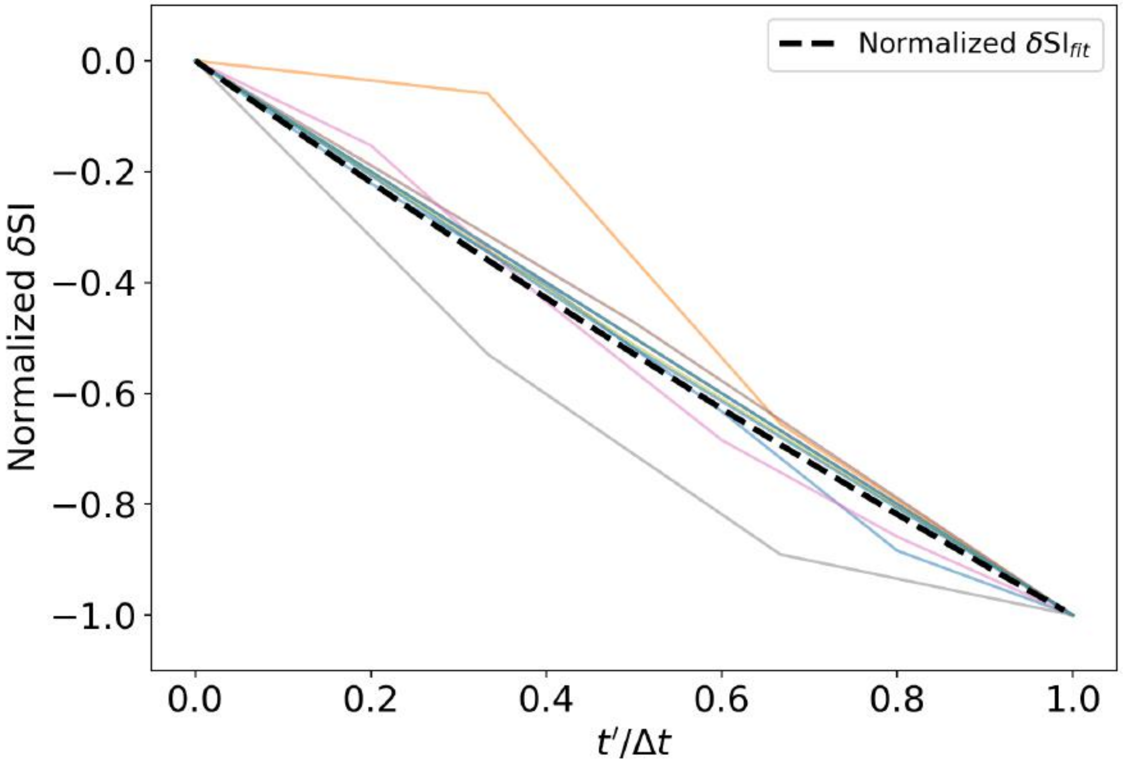
Reorganizing the equation into terms of N^2, adding a restoring term, $\alpha(\delta N^2)$, that connects the seasonal variation of N^2 with the variation due to the Mistral, δN^2, with a restoring coefficient, α, and taking the heat transfer due to the Mistral as $\delta F(t)$, we can relate δSI to $\delta F(t)$. If we assume $\delta F(t)$ is a pulse function of strength δF_k, duration Δt_k, and has a period of $\Delta \tau_k$, we get:

$$\delta SI(k) = \underbrace{\frac{D^2}{2}\frac{\delta F}{\alpha}(1 - e^{\alpha \Delta t})}_{\beta} \left(\frac{1 - e^{-\alpha \Delta \tau k}}{1 - e^{-\alpha \Delta \tau}} \right) (e^{-\alpha \Delta \tau})$$

[11]White (2011) "Viscous Fluid Flow"

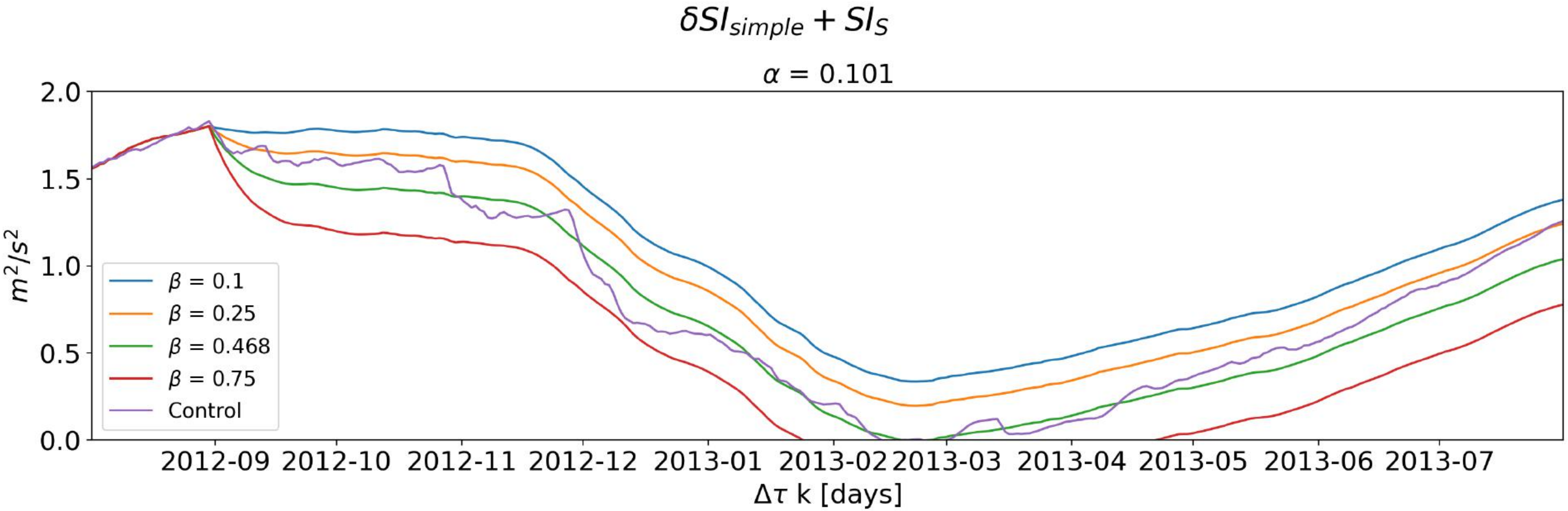
Douglas Keller, Romain Pennel, Yonatan Givon, Shirah Raveh-Rubin, and Philippe Drobinski

The simplified model (dashed line) fits very well to the NEMO simulation results (colored lines):



We can now see what happens when we change the intensity of the Mistral.

If β is the instensity of the Mistrals' effect, then reducing this intensity reduces the destratification:



Both the Mistral component and seasonal component are necessary to cause deep convection.

Douglas Keller, Romain Pennel, Yonatan Givon, Shirah Raveh-Rubin, and Philippe Drobinski

Key Points

Deep convection:

- is important for marine biology prosperity.
- in the Gulf of Lion preserves the current flow circulation of the Mediterranean Sea.
- can be tracked by the stratification of the water column. When stratification is equal to zero, deep convection occurs.
- needs both seasonal changes in the atmosphere and the Mistral winds to occur.

Take Away

If either the seasonal changes in the atmosphere or the Mistral winds change too much due to climate change, deep convection in the Gulf of Lion may become less frequent or disappear. This could lead to problems in the marine biology and the general flow circulation of the Mediterranean Sea.