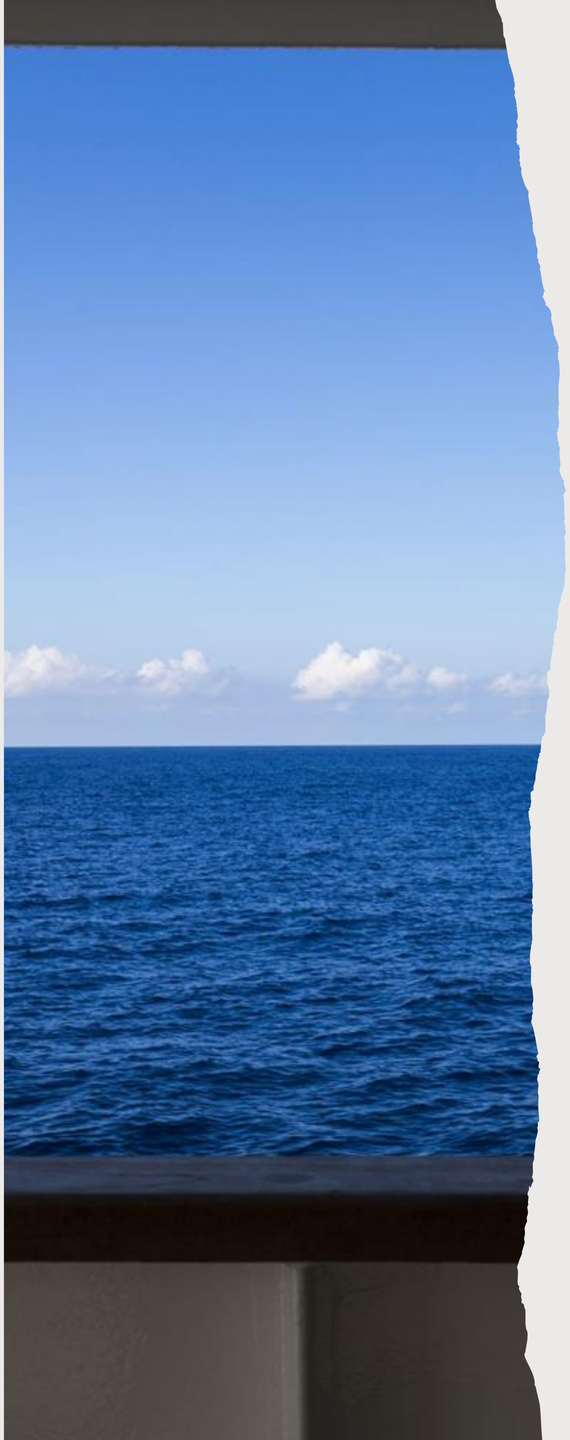

The ocean-atmosphere coupled system in the framework of the Lampedusa climate station

by

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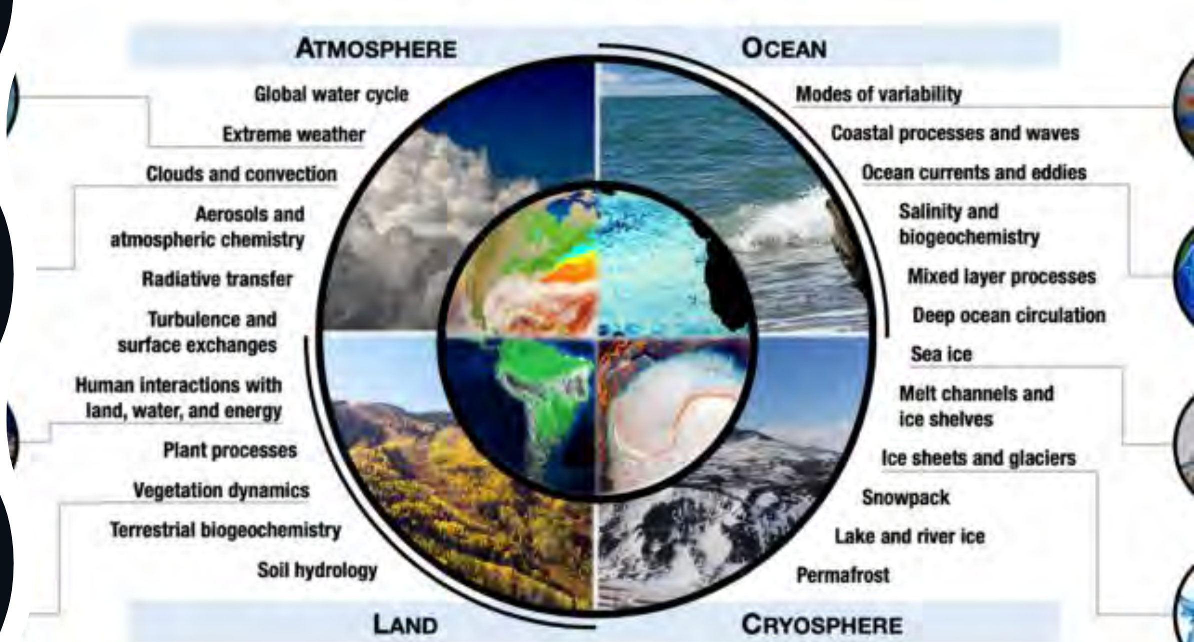
THE CLIMATE SYSTEM IS CHAOTIC AND MULTISCALE,

THE NUMERICAL MODELS ARE OUR LABORATORY, TOGETHER WITH THE INTEGRATED OBSERVATION SYSTEMS ARE THE PREREQUISITE CONDITIONS REQUIRED TO THE FULL UNDERSTANDING OF THE CLIMATE VARIABILITY AND RELATED PROCESSES.



THE COUPLED ATMOSHERE-OCEAN SYSTEM IS THE MAIN SOURCE OF VARIABILITY OF THE CLIMATE SYSTEM

The WDC and THC are fully coupled as a feedback system.

The **two-way feedback loop** can have a significant effect on the dynamics of the coupled system.

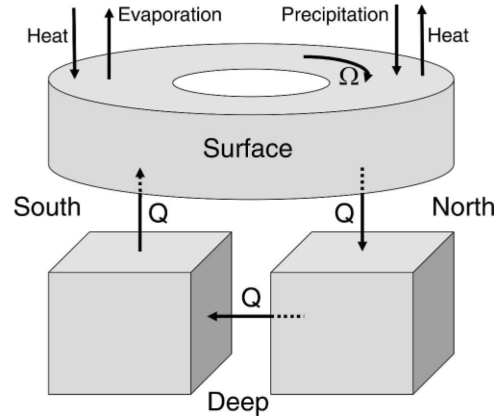
The thermohaline circulation (THC) affects the meridional atmospheric temperature gradient and therefore the atmospheric wind and the wind-driven ocean circulation.

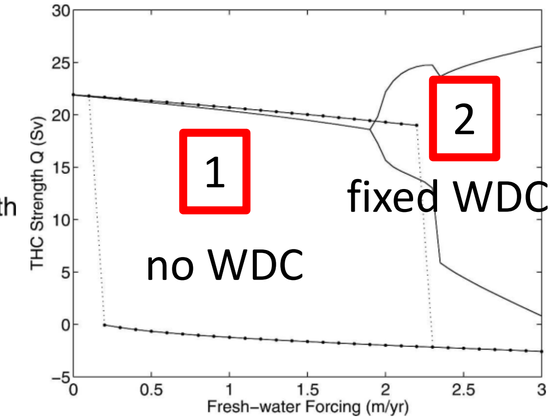
The wind-driven circulation (WDC), in turn, advects salinity anomalies that, when advected to water-mass formation regions, can enhance or decrease the overturning circulation.

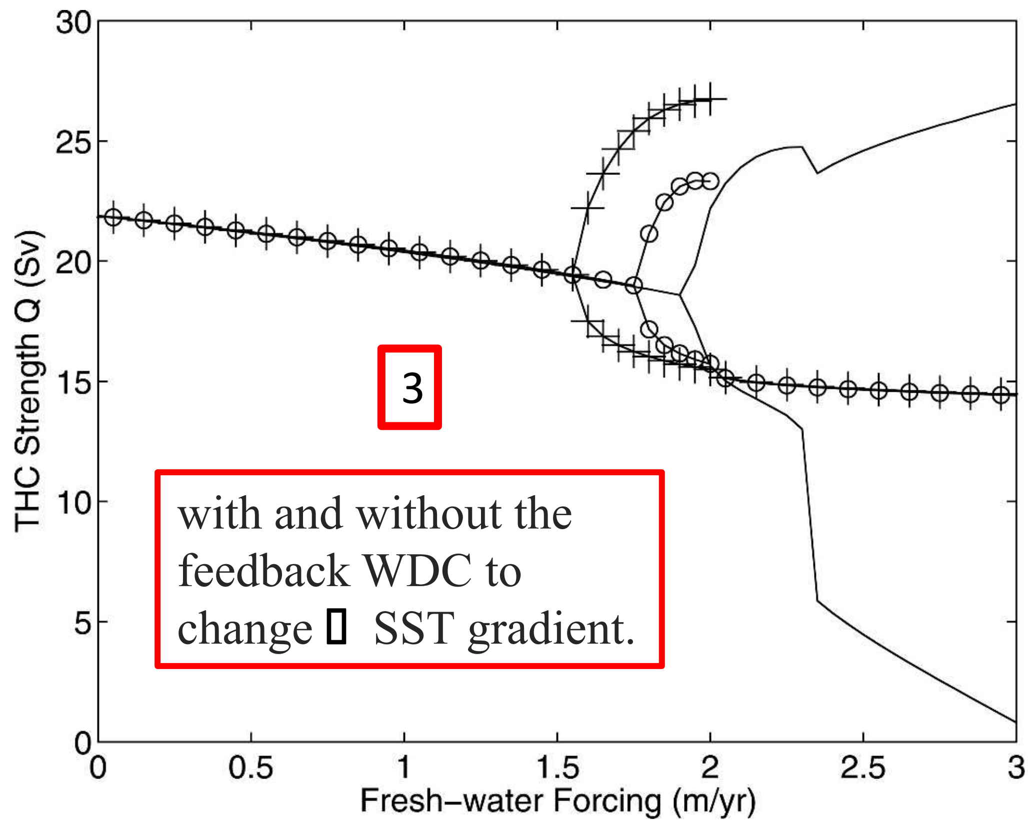
Semplified model

For a reasonable choice of parameters, the feedback destabilizes the THC equilibrium for low freshwater forcing. For higher freshwater forcing, the feedback results in a new stable equilibrium instead of the large amplitude oscillation that develops without feedback

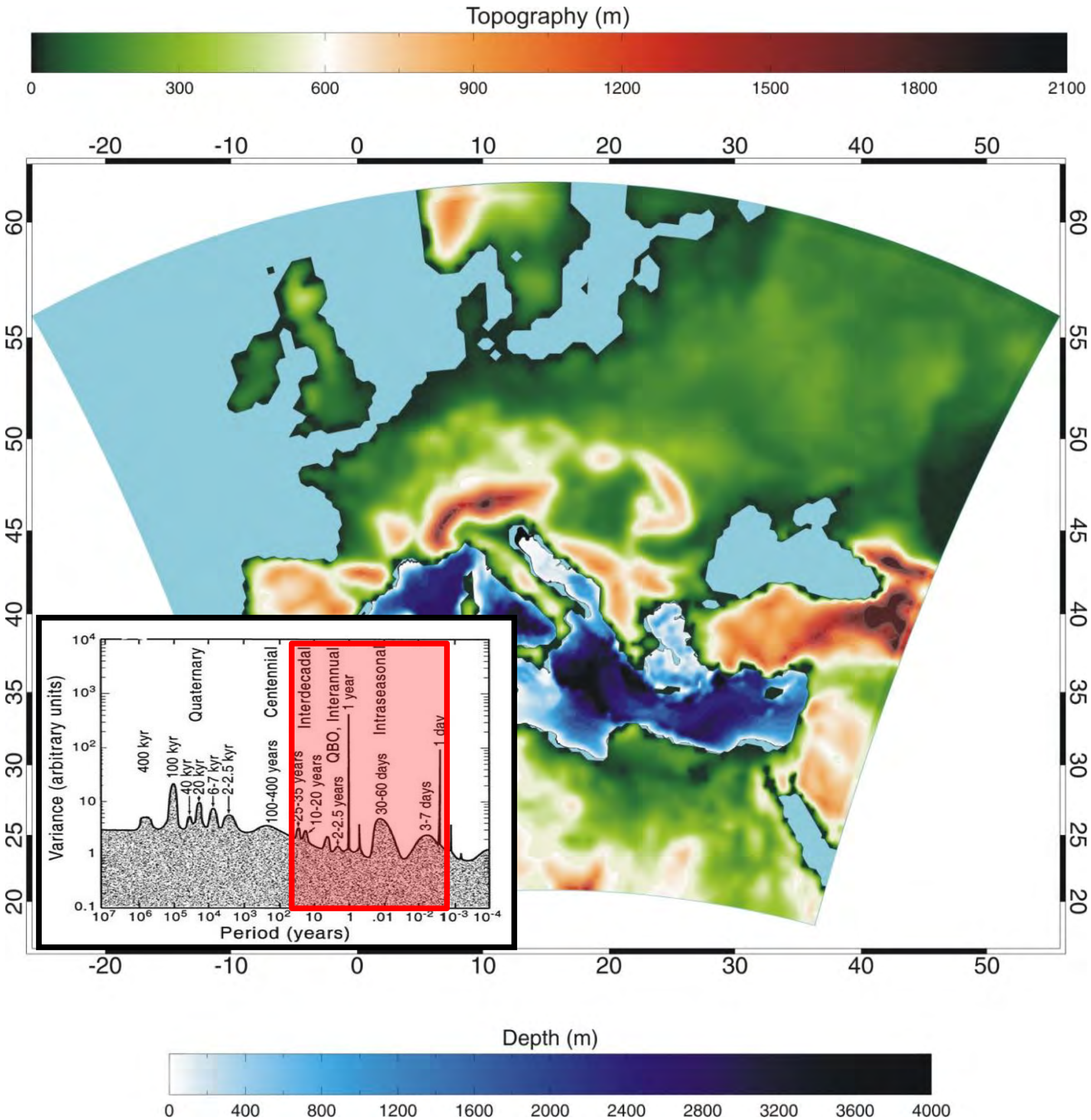
(D. G. MacMynowski and E. Tziperman, 2006).







Climate Model (full coupled): PROTHEUS Model (Artale et al., 2010; Soto-Navarro et al., 2020)



Model domain

Model components

RegCM3

18 sigma vertical levels

30 Km horizontal resolution

BATS + IRIS

BATS: Biosph.-Atmosph. Transfer Scheme

IRIS: interactive RIvers Scheme

SST ↑ **OASIS 3 Freq. 6h** ↓ **HF-WF-Wind**

MedMIT

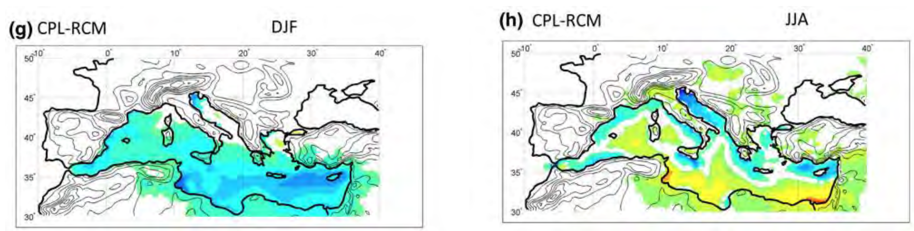
42 zeta vertical levels (partial cell)

1/8° x 1/8° horizontal resolution

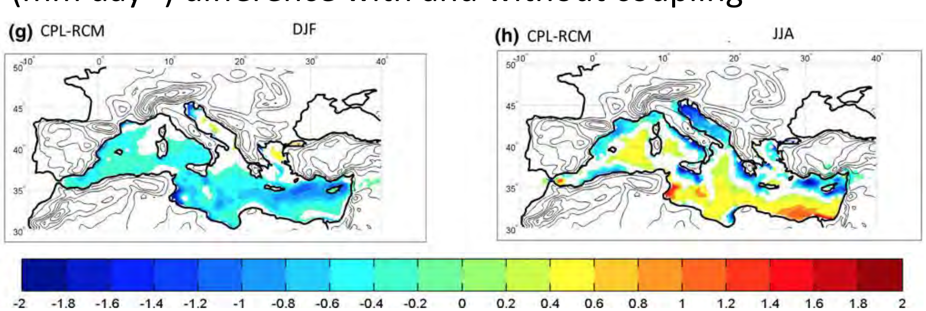
Selected results of the numerical simulations with Protheus and difference coupled-no-coupled (Artale et al., 2010)

- The coupled model is capable of significantly improve the description of air-sea interactions in terms of sensible and latent heat, **especially at small scales and for intense events;**
- The coupling does not affect the bulk characteristics of the atmospheric model;
- Spatial correlation is low, strong bias (seasonally depending).

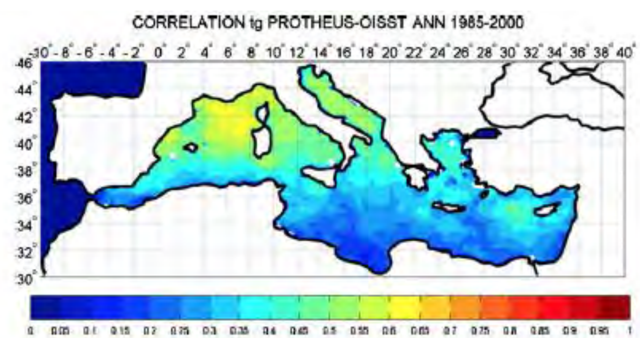
Spatial patterns of winter and summer mean 2m-temperature (°C)

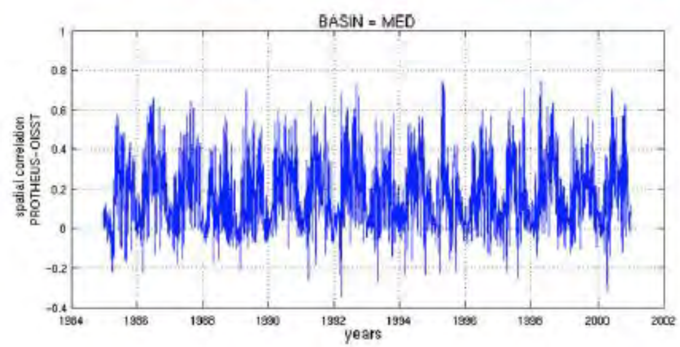


Spatial patterns of winter and summer mean evaporation (mm day^{-1}) difference with and without coupling



SST spatial correlation





OBSERVATIONS AND PARAMETERIZATION

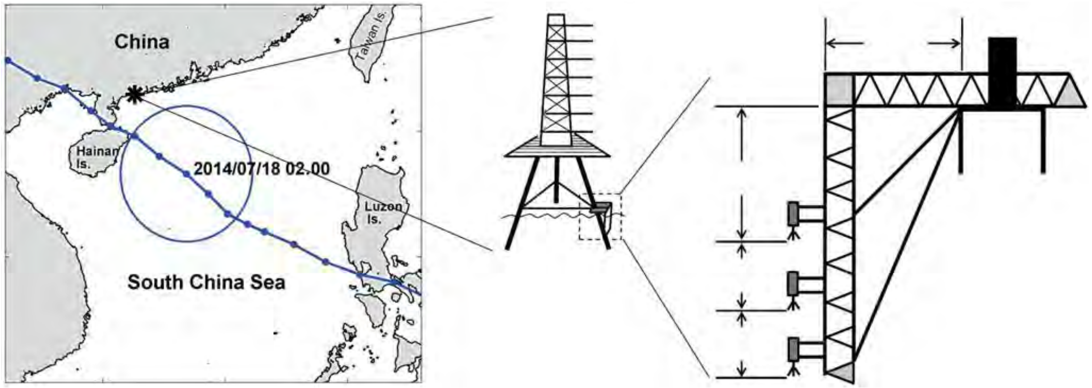
The main challenging physics for the atmosphere-ocean coupling

- The performance coupled atmosphere–ocean models depends critically on vertical mixing of energy and momentum in the water column and specifically on the surface layer;
- Under the free surface, waves and wave breaking, turbulence and mean shear currents all coexist, acting together and on each other to affect the mixing process downward into the water column below and upward to the air–sea interaction processes above;
- Their detailed resolution of the mixing processes is not in sight even now, and perhaps will not be for the near future.

Wave–turbulence interaction induced vertical mixing: effects in the climate models (Qiao F. et al., 2016).

- The experimental results indicate that the wave–turbulence interaction induced enhancement of the background turbulence is indeed the predominant mechanism for turbulence generation and enhancement.
- The **empirical mode decomposition (EMD)** method as a filter was used, which can decompose the data into a series of **intrinsic mode functions (IMFs)** and a **residual trend** varying monotonically.

The experiment site and the instrument installation locations.



- Based on this understanding, a new parametrization for vertical mixing **as an additive part** to the traditional TKE approach is proposed:

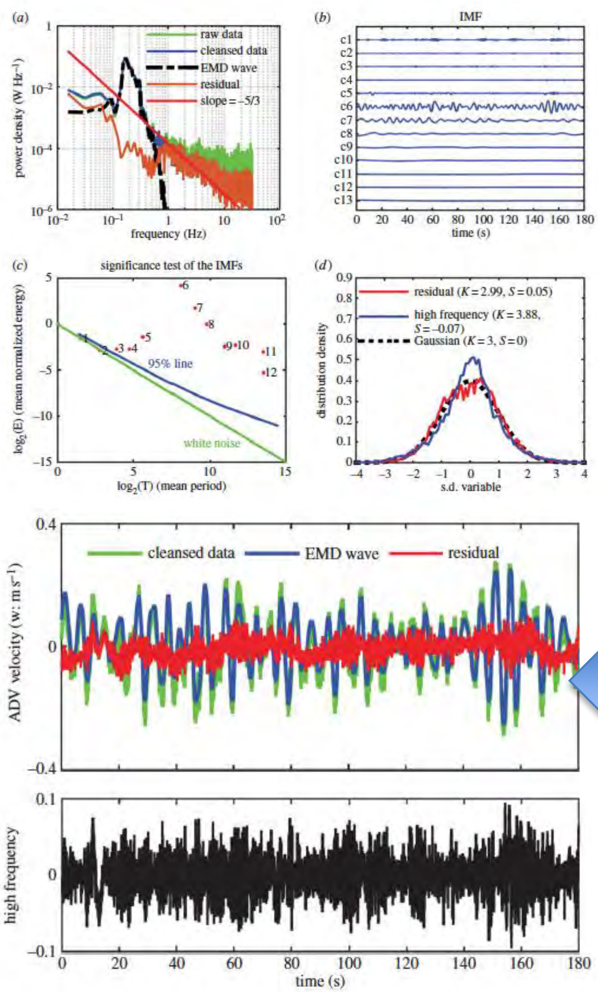
$$B_v = \alpha \int_k S(k) e^{-2|k|z} dk \cdot \frac{\partial}{\partial z} \left[\int_k \omega^2 S(k) e^{-2|k|z} dk \right]^{1/2}$$

B_v vertical viscosity induced by the non-breaking surface wave based to the Stokes drift S

Before and after an extreme atmosphere event

before

The Fourier spectra: raw and cleansed data, the part for waves and the residue after the wave motions have been removed through EMD.



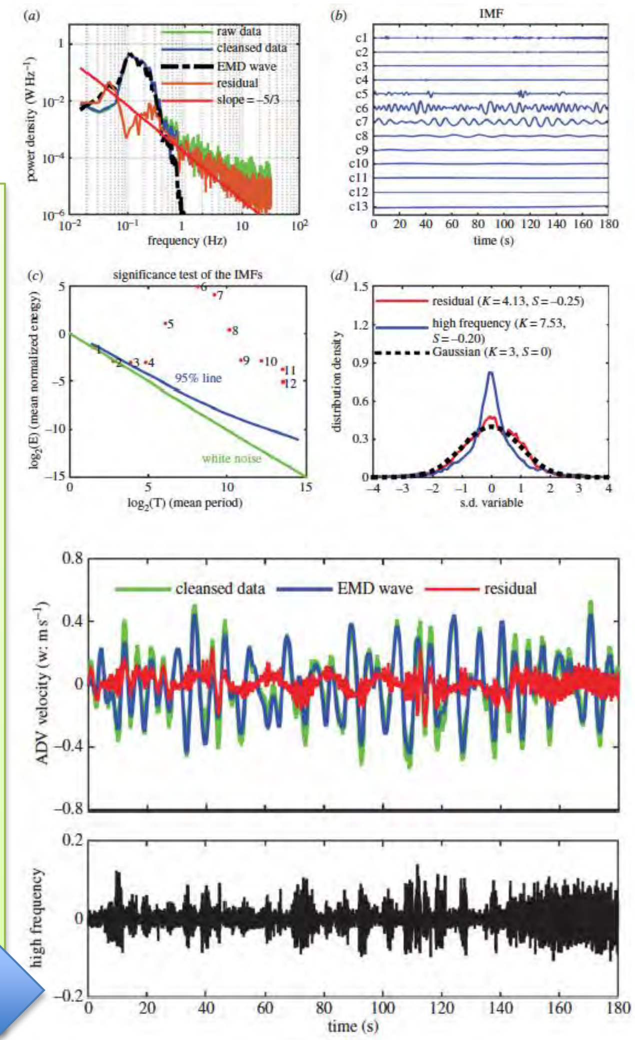
after

Note the broadening and down shift of the wave energy in the Fourier spectrum; nonlinear typhoon-induced waves have distorted all motions inducing non-Gaussian pdf.

separation of waves and turbulence components: the cleansed data (light green), wave motions (blue) reconstituted by components 6, 7; the residue (red) defined as the difference between the data and the wave motions; high-frequency turbulence and noise given in the lower panel.

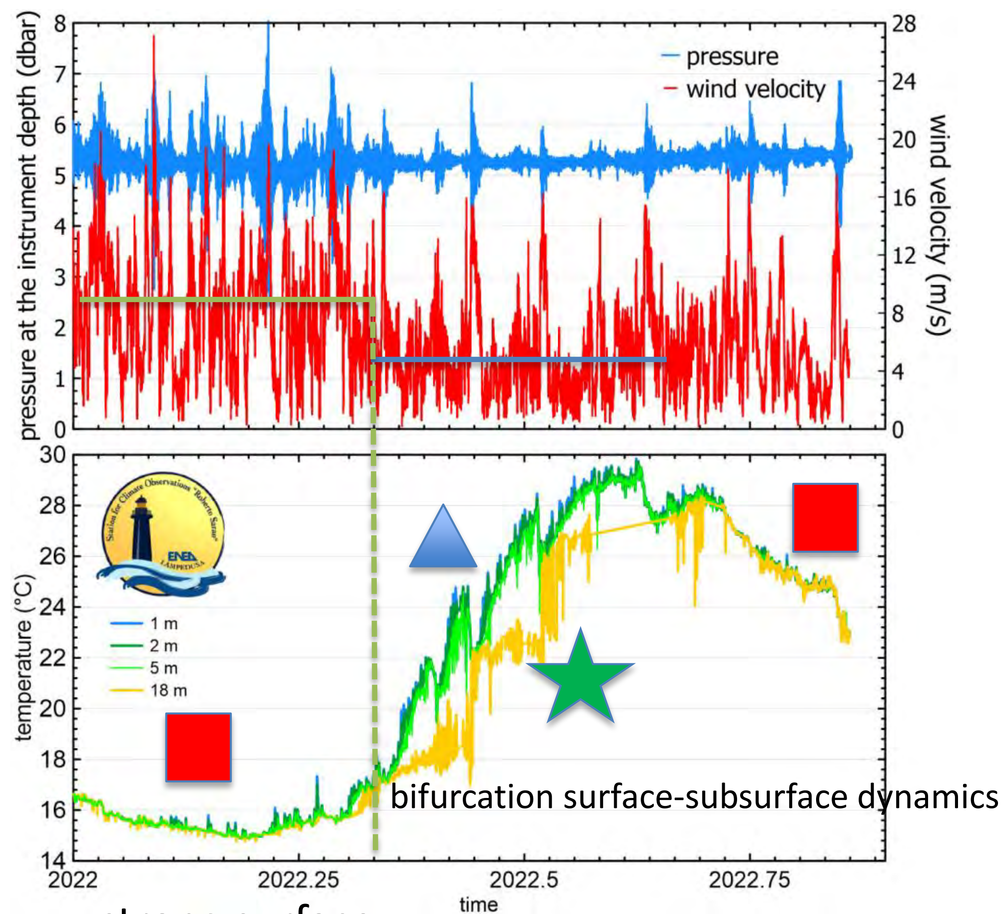
the broadening of the wave motion part of the spectrum has caused some leakage into

the high-frequency turbulence part of the data.



mixing, stratification, internal waves, extreme events in the *Lampedusa observation integrated system*

as the above parameterization and results have revealed, the Lampedusa climate station is a good site where realize in situ turbulence measurements and validation of the turbulence closure schemes.



strong surface stratification

extreme events

erosion of the thermocline

Conclusion

The atmosphere - ocean coupling system works as a feedback system, is still a grand challenge physical problem;

GCMs, had suffered from common problems such as the simulated SST are too high, the simulated mixed layer depth (MLD) is too shallow, or the simulated subsurface temperature is too low in the summer time especially for the Southern Ocean;

all these challenges indicate that the vertical mixing in the upper ocean has been underestimated;

The weak point of the governing equations of all GCMs is the turbulence closure schemes which have very high uncertainty;

Validation of turbulence closure schemes seems a solution to determining which kind of scheme should be selected using also in situ observations of the fine structure of the ocean upper layer (e.g. Lampedusa observation climate system).