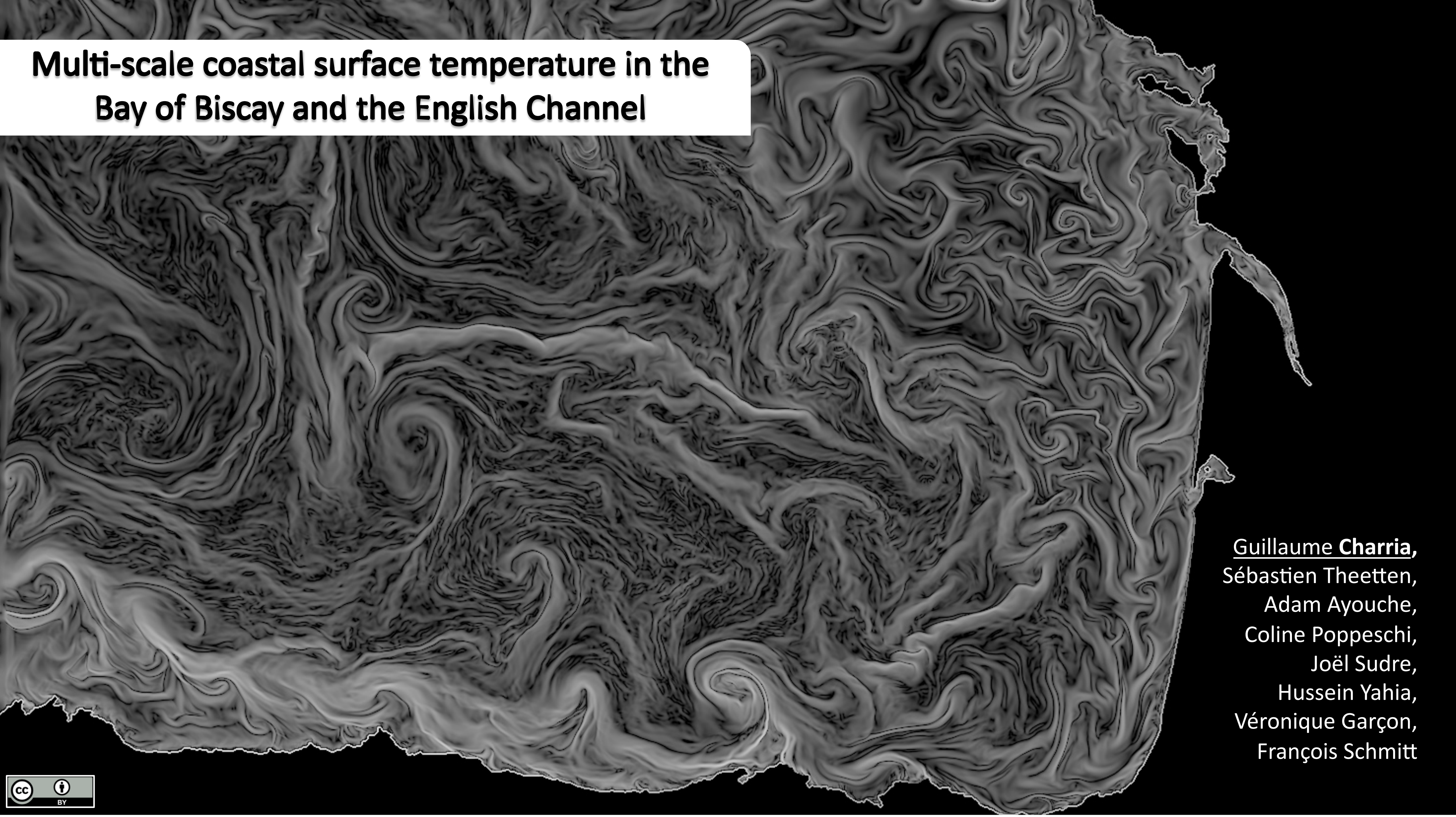
Multi-scale coastal surface temperature in the Bay of Biscay and the English Channel



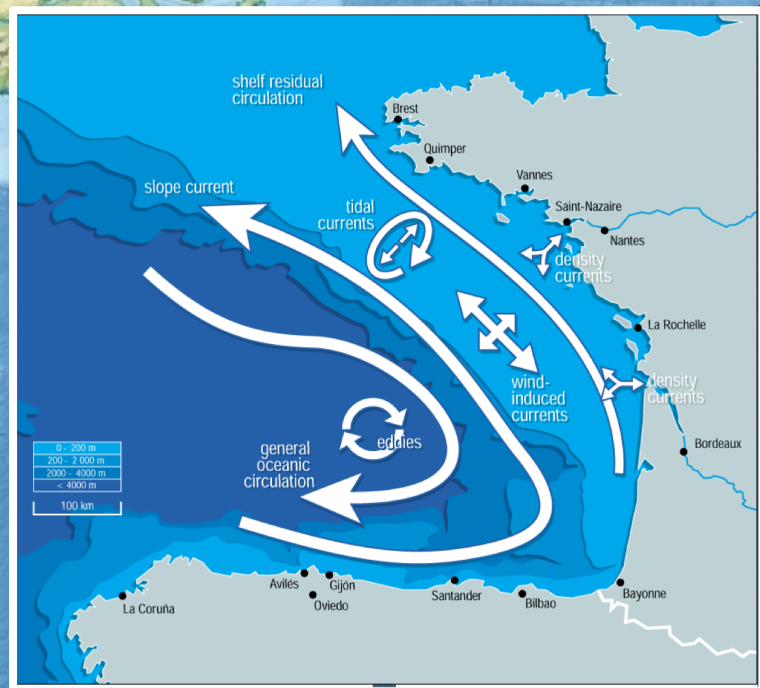
Guillaume **Charria**,
Sébastien Theetten,
Adam Ayouche,
Coline Poppeschi,
Joël Sudre,
Hussein Yahia,
Véronique Garçon,
François Schmitt

Additional comments on the slide: Those few slides illustrate ongoing work on exploring multi-scale coastal dynamics and interactions in the Bay of Biscay and the English Channel. Work done in collaboration with colleagues from LOPS, LEGOS, INRIA and LOG laboratories. (background image illustrates the frontal activity in the Bay of Biscay highlighted using singularity exponent analysis – Turiel et al., 2008; Yahia et al., 2010; Maji et al., 2013; Sudre et al., 2015; Yelekci et al., 2017)

Background & Objectives

Characterize multi-scale interactions (spatial and temporal) in the Bay of Biscay
linked with large scale circulation and interannual evolutions

Ferrer et al., 2009



Additional comments on the slide: The Bay of Biscay, in the NE Atlantic is a region where three main dynamical regimes can be observed. Over the shelf with weak residual currents, a strong seasonal variability and a dynamics driven by tides, rivers and wind (Koutsikopoulos and Le Cann, 1996; Charria et al., 2013). Over the shelf break, with a fluctuating slope current, genrating instabilities and eddies (e.g. Akpinar et al., 2020). In the deep ocean with an anticylonic circulation fed by the North Atlantic subtropical gyre circulation. Here, we will aim to characterize multi-scale interactions (spatial and temporal) in the Bay of Biscay.

Model hindcasts and remotely sensed observations to explore multi-scale coastal dynamics

MARS3D primitive equation model ***(http://wwz.ifremer.fr/mars3d)***

Resolution

Horizontal: 1km and 4km
Vertical: 40 sigma levels
Temporal: daily outputs

3 simulations

CROCO primitive equation model ***(http://www.croco-ocean.org/)***

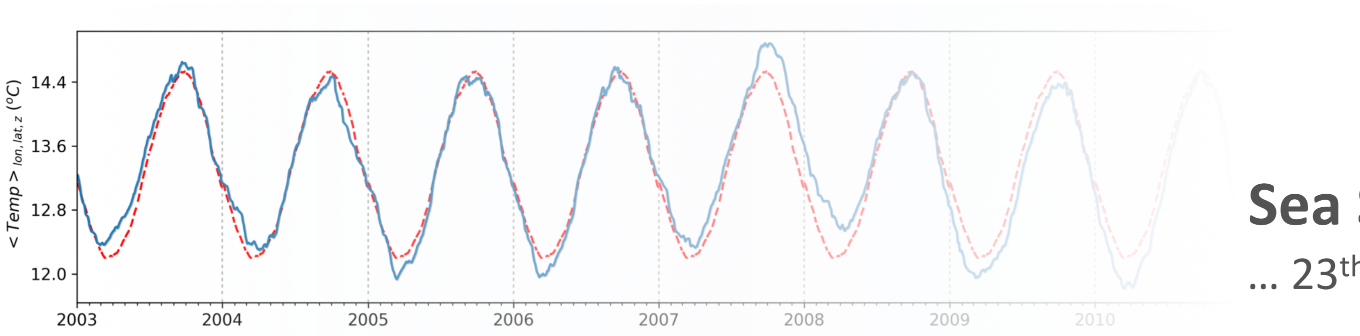
Resolution

Horizontal: 400m
Vertical: 40 sigma levels
Temporal: hourly outputs

MODIS (onboard Aqua & Terra) Level 2 ungridded SST products

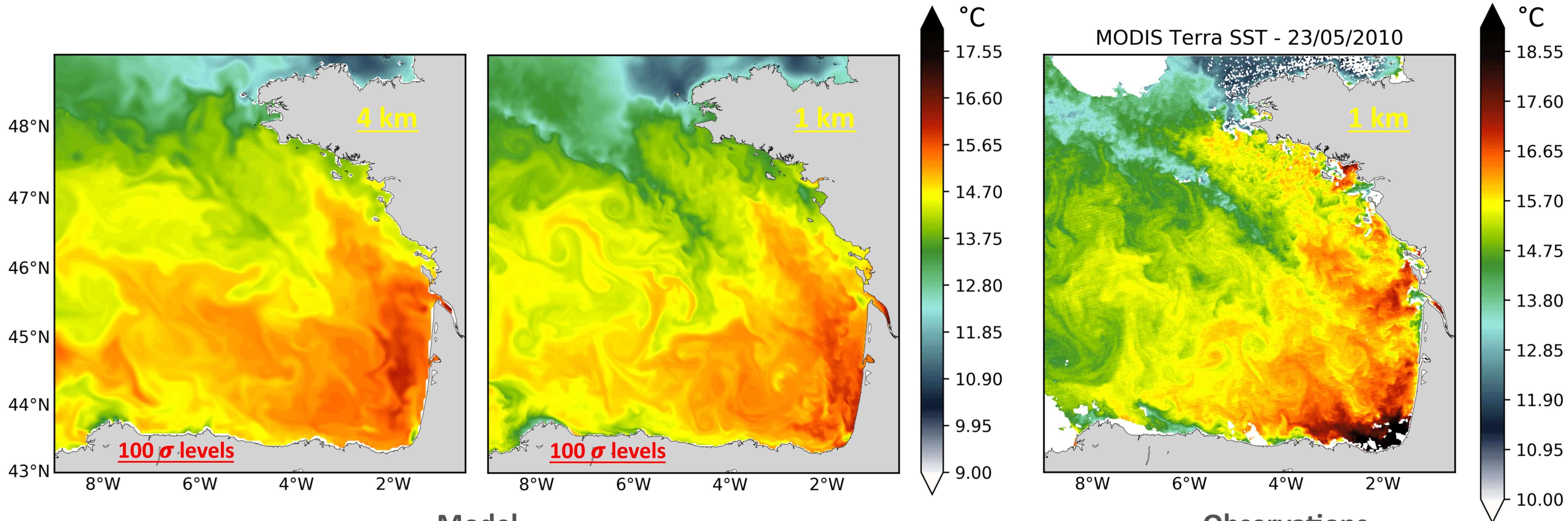
Resolution Horizontal: ~1km / Temporal: swath-related

Additional comments on the slide: To understand those scale interactions, we performed 3 simulations (presented here … other simulations done but not presented here, please contact author for more details) using 2 primitive equation models (MARS3D and CROCO). In this presentation we focus on the comparison of 3 resolution simulations (4km, 1km and 400m).



Sea Surface Temperature

… 23th May 2010

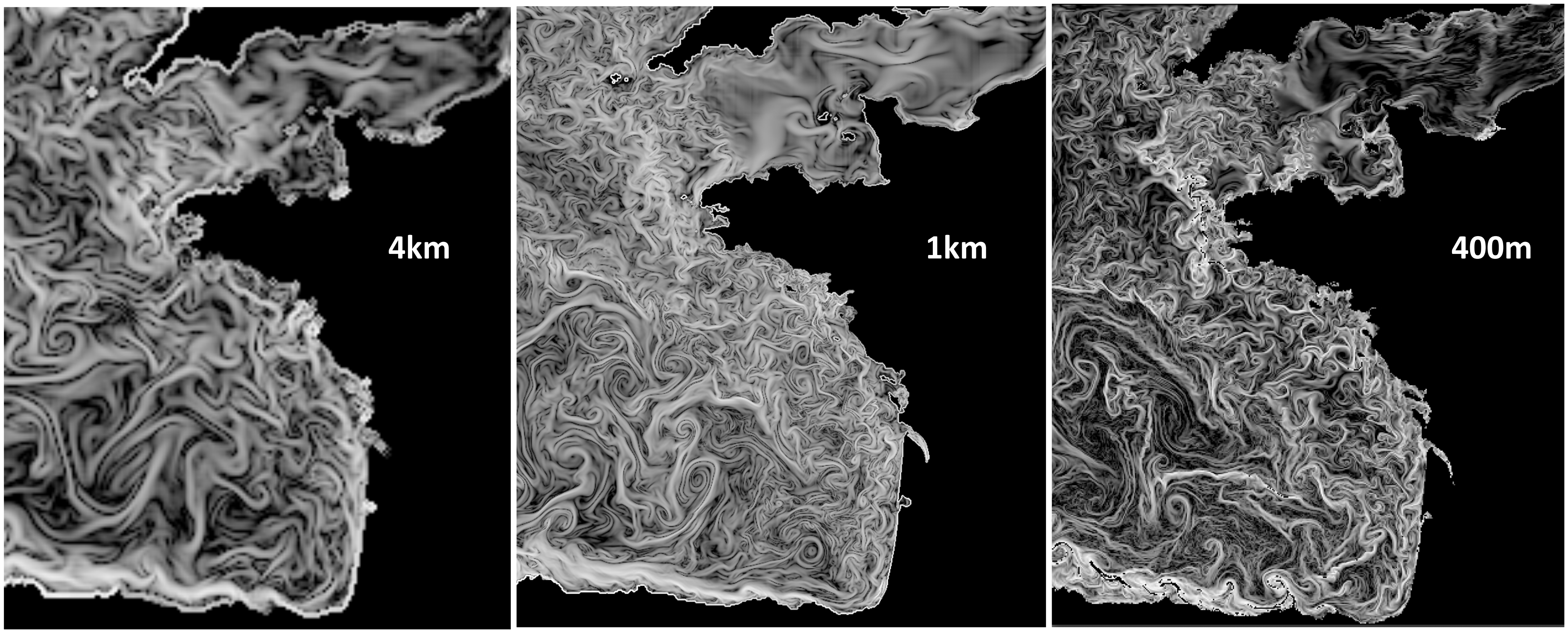


Model

Observations

Additional comments on the slide: Simulations were validated using several in situ and remotely sensed observations. Here an example with MODIS remotely sensed Sea Surface Temperature. Example of comparison during May of the Sea Surface Temperature from model (left) and observation (right). We can see some improvements related with the gap of solved processes between 4km and 1km resolution . 1km resolution allows solving shelf mesoscale processes as you can see over the shelf break around 47N/4.5W with the cooling of surface water due to internal tides and mesoscale eddies. Over the shelf, the warm tongue flowing to the North is reproduced with a limited extent to the North. In the South-Eastern Bay of Biscay, temperature are underestimated in simulations most probably related with atmospheric fluxes used to force the ocean model.

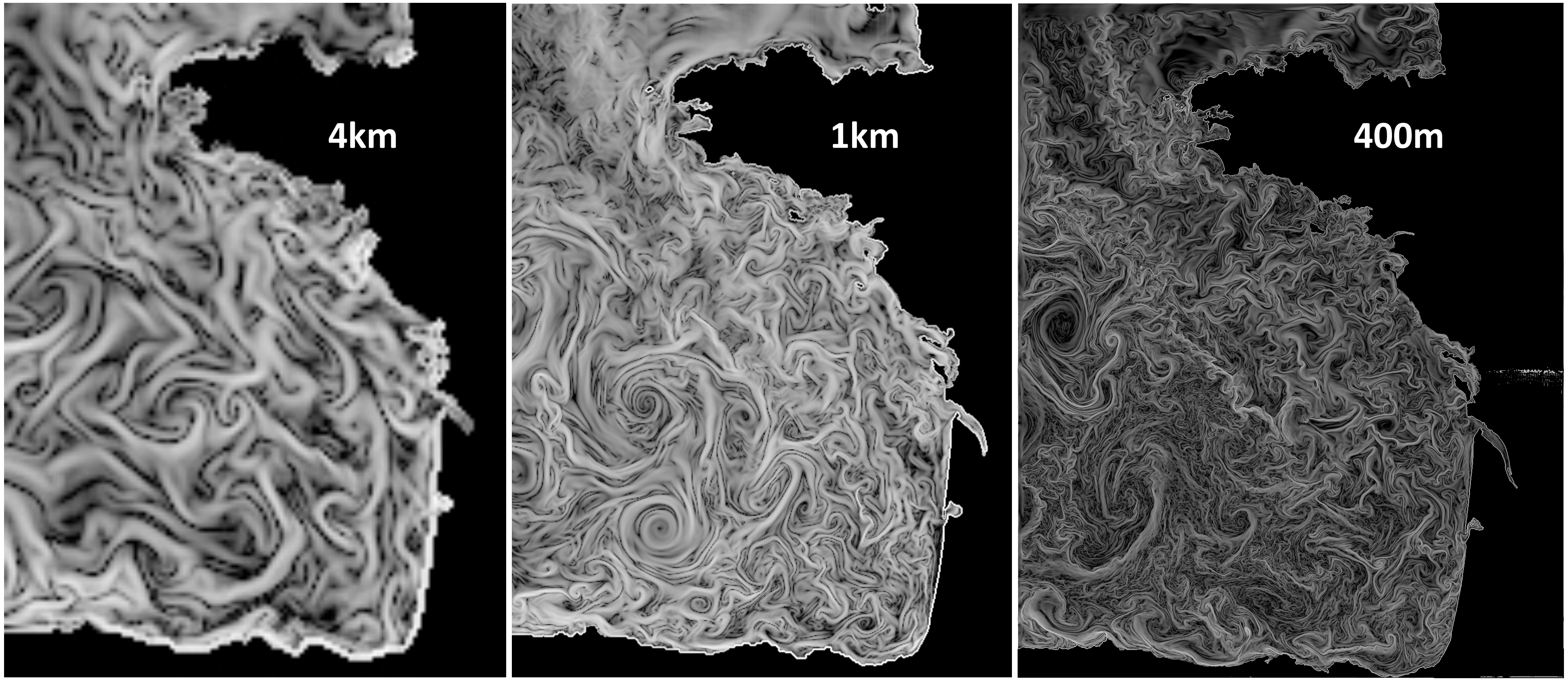
Singularity exponents in the Bay of Biscay (19/09/2007)



Singularity exponents: method described in *Turiel et al., 2008; Yahia et al., 2010; Maji et al., 2013; Sudre et al., 2015; Yelekci et al., 2017*

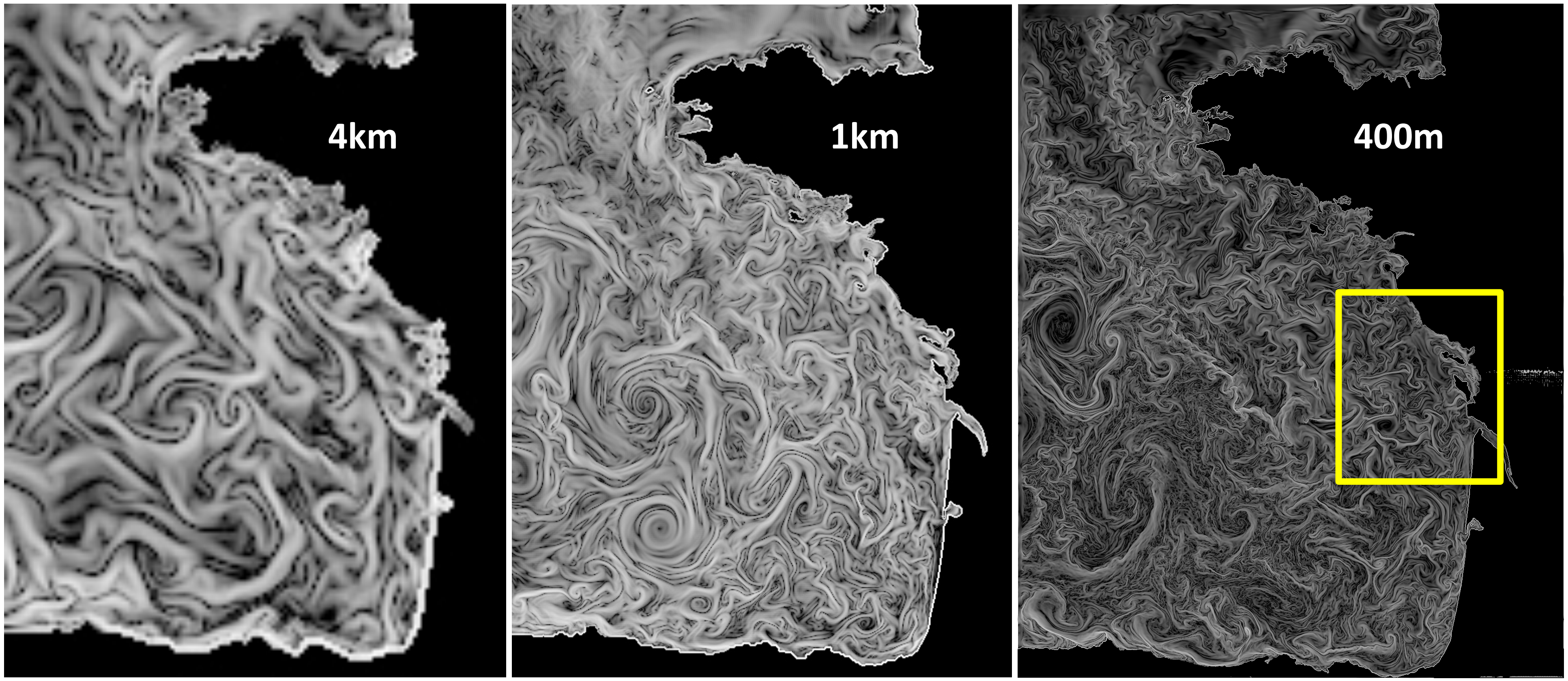
Additional comments on the slide: An efficient way to highlight turbulence (related with eddies, filaments and fronts) in sea surface temperature is the use of singularity exponent (SE) computation. Then, we can infer a global picture of existing scales in simulations. Here, you can see SE for 19/09/2007 in the 3 simulations. We clearly see the impact of the horizontal resolution in solving fine scale processes. In 4km resolution, fronts are wide and describing structures larger than expected scales (around the deformation radius over the shelf: 6-8km). A 1km, the mesoscale is better reproduced and we can distinguish shelf and deep ocean balance scales on the map. At higher resolution we start solving processes below the deformation radius (submesoscale) and then we start to see small structures (with very short time life) like in the tidal front (Ushant front) front of the French Brittany.

Singularity exponents in the Bay of Biscay (30/09/2008)



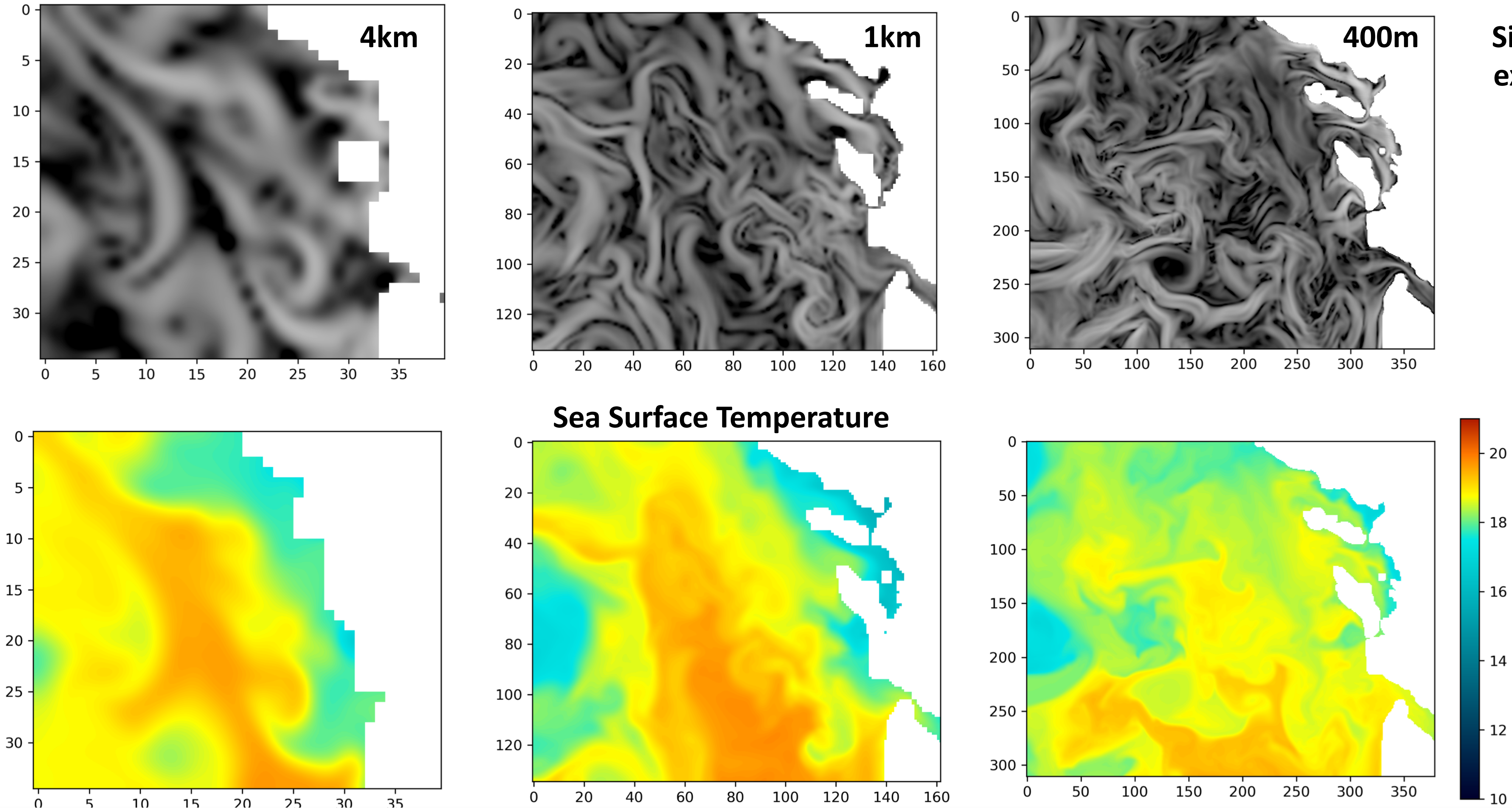
Additional comments on the slide: *This is another example (one year later) to show the strong interannual variability (known at large scale – Charria et al., 2017) but also at fine scale. We can note the development of large scale coherent eddies in the deep ocean at 1km that we can also observe (not exactly at the same place) at 400m resolution. At 400m, we can also much more submescale features in the deep ocean.*

Singularity exponents in the Bay of Biscay (30/09/2008)



Additional comments on the slide: We will now concentrate on a specific region over the shelf (yellow rectangle).

Submesoscale over the shelf ?



<u>*Additional comments on the slide*</u>*: In this shelf region close to the main river estuary (Gironde river), where we aim reproducing short time scale and small scale features (related with river plume instabilities for example – Ayouche et al., 2020 – under review), we clearly observe the need of the high resolution to reproduce small scale features. At 4km, we clearly see how we fail to resolve mesoscale features (6-8km scales overs the shelf). At 1km, we simulate a more detailed dynamics coherent with the large scale circulation (warm tongue flowing to the North and colder water related with the plume). At 400m, we can note that even the global structure is changing. Smaller features appear (as expected) but the surface temperature is different. More investigations are in progress to evaluate those small scales but first investigations seem to show that small scale features like the western extent of warm waters correspond to observed features not reproduced in other simulations.*

Conclusions & perspectives

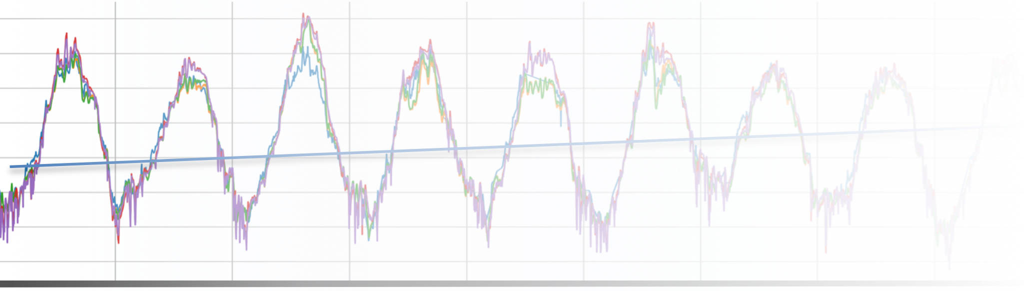
Bay of Biscay: a multi-scale laboratory

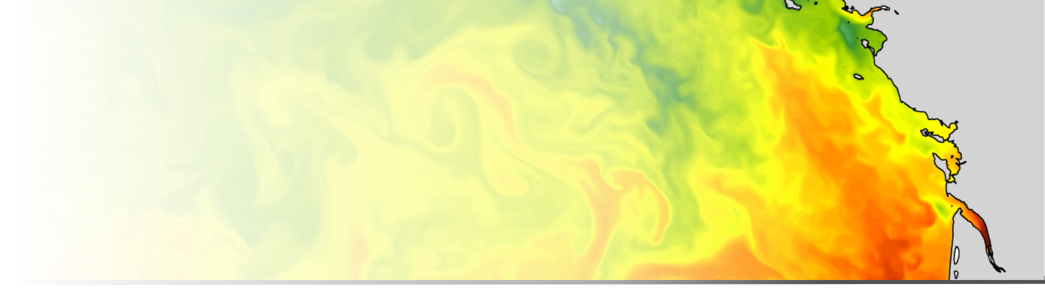
We have

Increased model spatial resolution and fit-for-purpose tools (here Singularity exponents)

The recent 400m simulation allows:

- Reproducing fine scale dynamics and the regional circulation,
- Exploring instability dynamics (source of vertical mixing) including the shelf with length scales around 6-8 km
- Improving our understanding of fine scale dynamics and their interactions with larger scales





Conclusions & perspectives

Bay of Biscay: a multi-scale laboratory

We have

Increased model spatial resolution and fit-for-purpose tools (here Singularity exponents)

The recent 400m simulation allows:

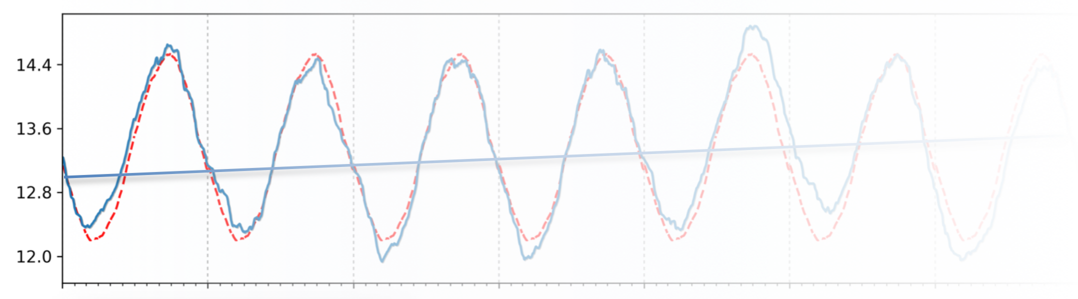
- Reproducing fine scale dynamics and the regional circulation,
- Exploring instability dynamics (source of vertical mixing) including the shelf with length scales around 6-8 km
- Improving our understanding of fine scale dynamics and their interactions with larger scales

What about the temporal scales ?

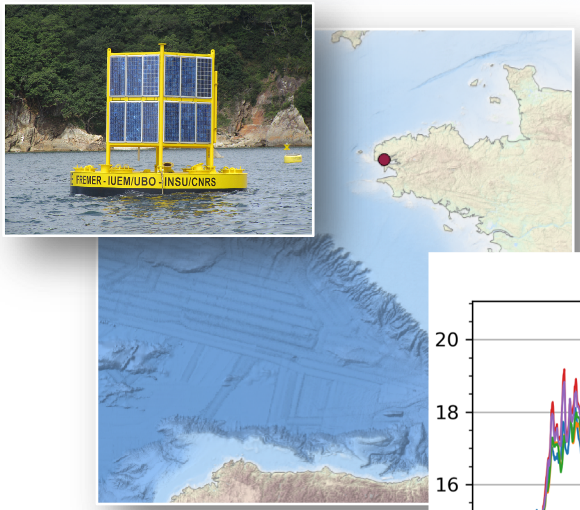
The impact of **interannual large scale** forcings on **fine scale dynamics**

The sensitivity of **interannual trends** to **fine scale simulated processes**

First try using Empirical Mode Decomposition ...



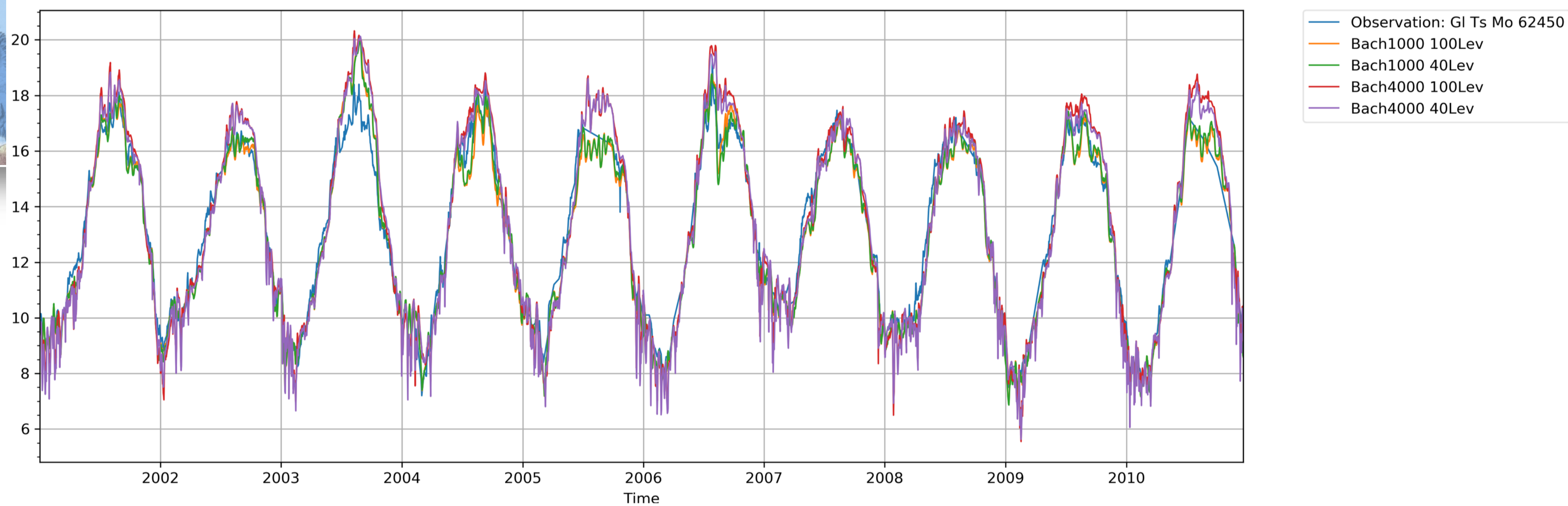
Fine scale dynamics and trends



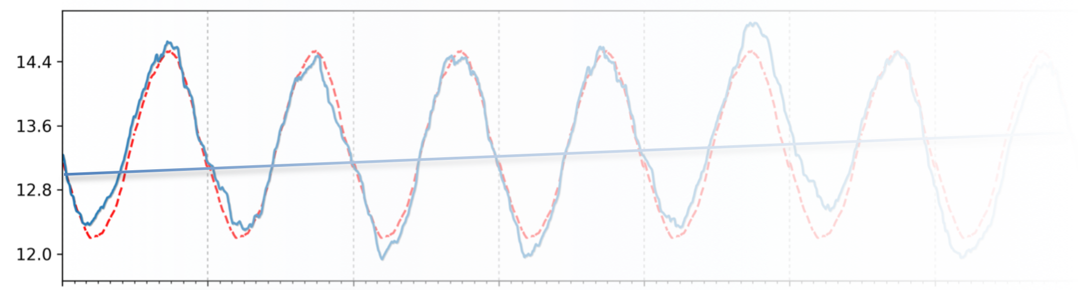
1 *in situ* reference

4 simulations
(1km / 4km and
40 / 100 vertical levels)

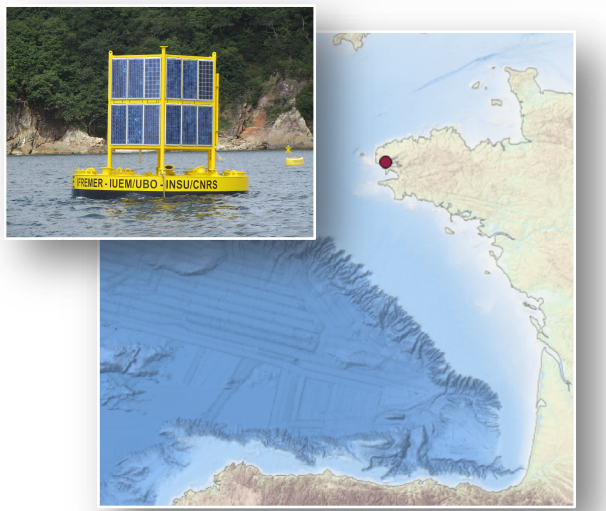
Temperature (observed and simulated)



Additional comments on the slide: Comparison over 12 year of 4 simulations (4km and 1km horizontal resolution and 40 and 100 vertical layers) with in situ continuous observations. (1) validation purpose: simulation aim reproducing main observed features with better scores for the 1km resolution. (2) we can investigate temporal observed and simulated scales.



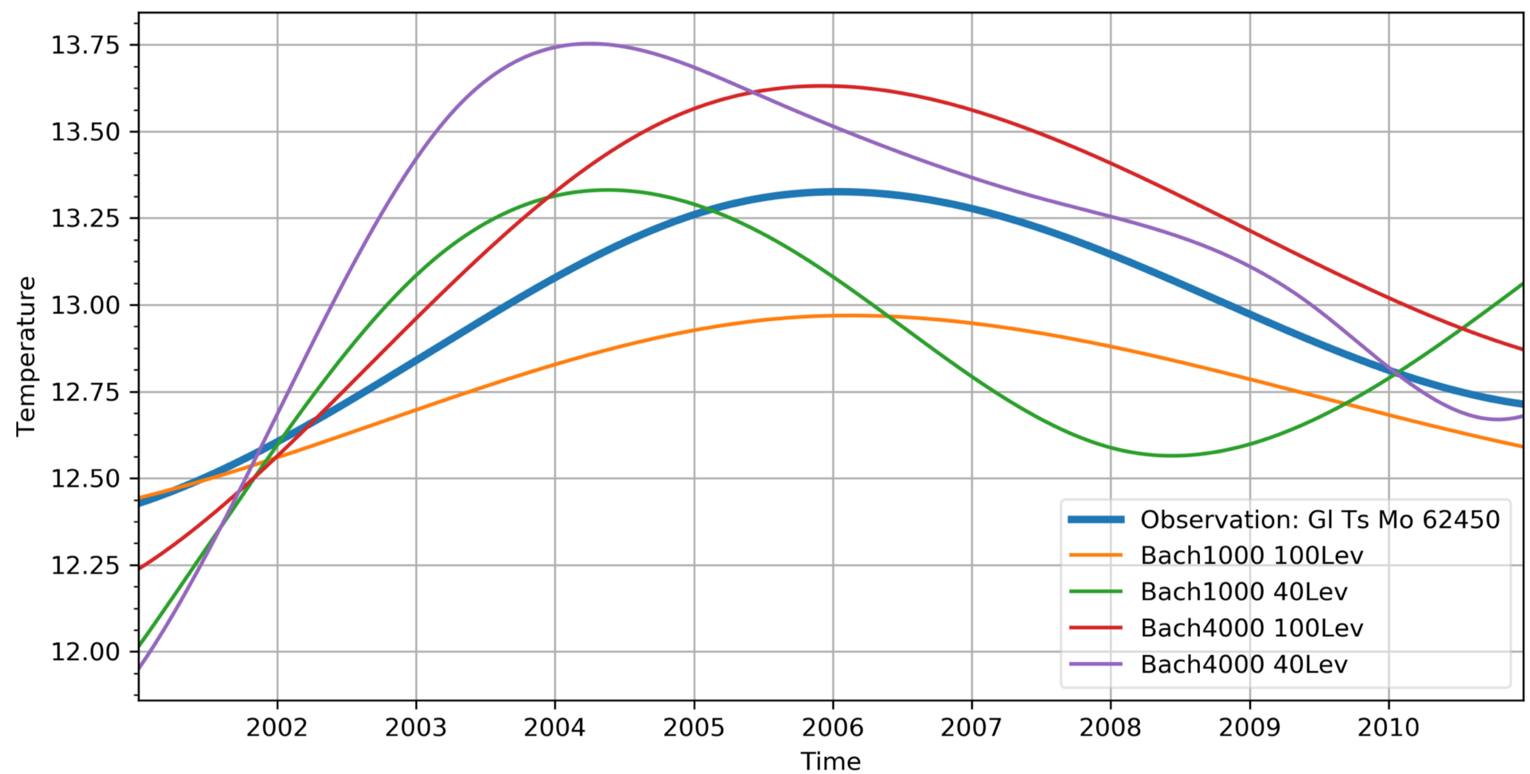
Fine scale dynamics and trends



1 *in situ* reference

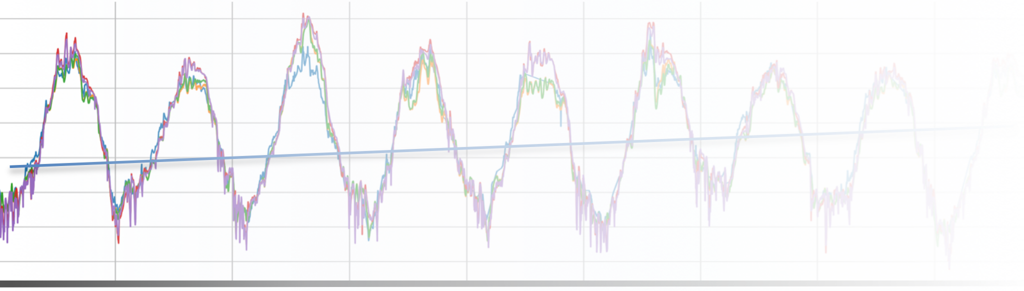
4 simulations
(1km / 4km and 40 / 100 vertical levels)

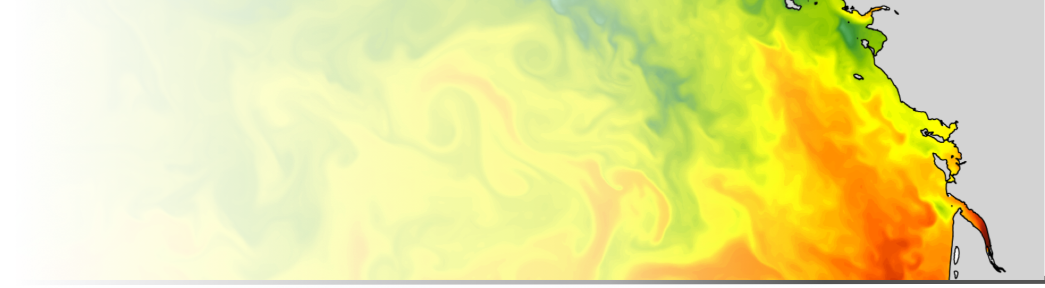
Residual from EMD* algorithm (= temperature trends)



**EMD: Empirical Mode Decomposition (e.g. Schmitt and Huang, 2016; Ben Ismail et al., JMS, 2016)*

<u>Additional comments on the slide</u>: Here an example when we consider trends (ie. Residual after an AMD decomposition). We can see very different behaviours following simulations. For unexplained reasons, 100 vertical layers simulations seem to better reproduce observed trends for all horizontal resolutions. At this stage, more investigations are needed to explain this result.





Overall conclusions

Bay of Biscay: a multi-scale laboratory

We have

Increased model spatial resolution and fit-for-purpose tools (here Singularity exponents)

The recent 400m simulation allows:

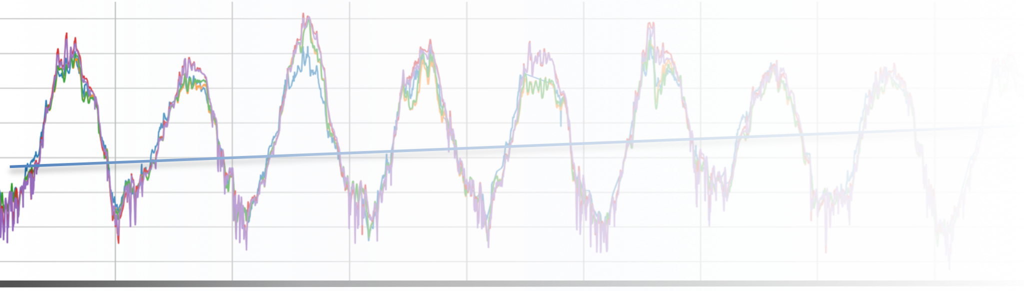
- Reproducing fine scale dynamics and the regional circulation,
- Exploring instability dynamics (source of vertical mixing) including the shelf with length scales around 6-8 km
- Improving our understanding of fine scale dynamics and their interactions with larger scales

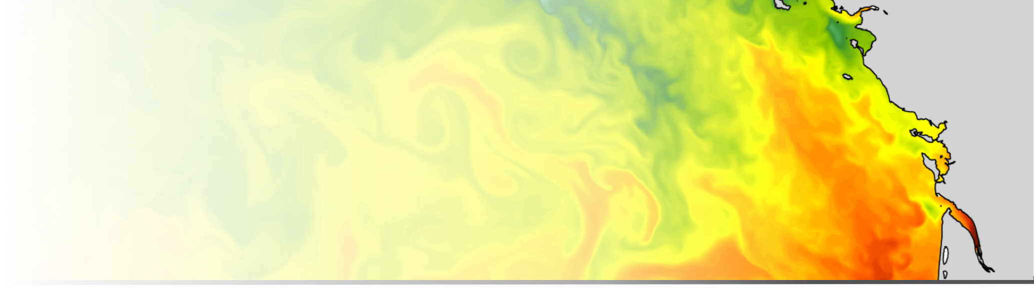
What about the temporal scales ?

The impact of **interannual large scale** forcings on **fine scale dynamics**

The sensitivity of **interannual trends** to **fine scale simulated processes**

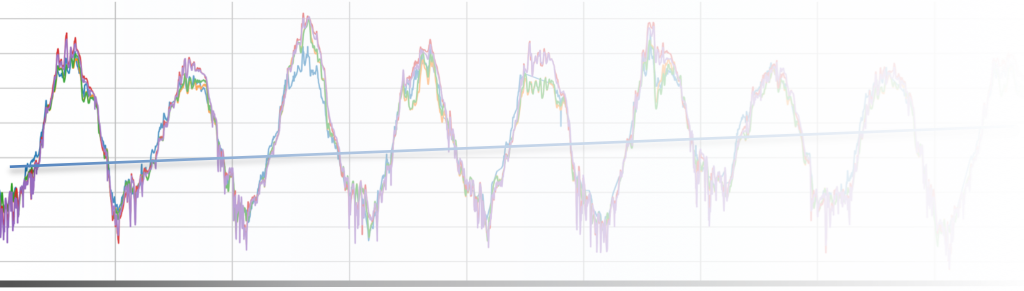
Empirical Mode Decomposition is an aproach considered to separate temporal scales and evaluate temporal scale interactions

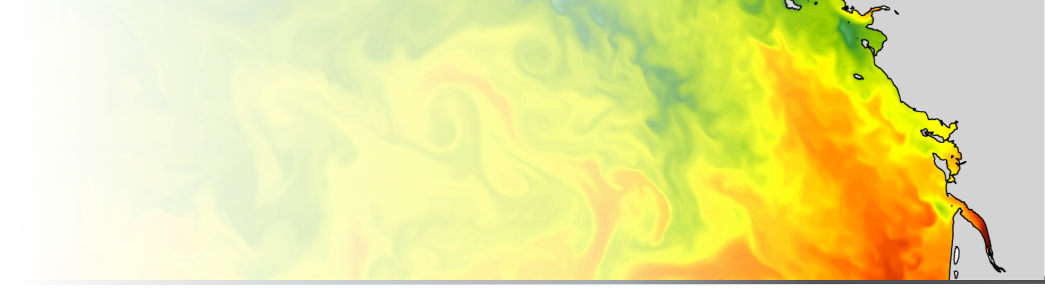




Thanks for your attention / reading ...

This work is part of the IMECO project, supported by the LEFE/MANU programme.





References

Akpınar, A., G. Charria, S. Theetten, F. Vandermeirsch, Cross-shelf exchanges Bay of Biscay, Journal of Marine Systems, doi: 10.1016/j.jmarsys.2020.103314, 2020.

Ayouche, A., X. Carton, G. Charria, S. Theetten, N. Ayoub, Instabilities and vertical mixing in river plumes: Application to the Bay of Biscay, Geophysical & Astrophysical Fluid Dynamics, under review, 2020.

Ben Ismail, D.K., Lazure, P., Puillat, I., 2016b. Statistical properties and time-frequency analysis of temperature, salinity and turbidity measured by the MAREL Carnot station in the coastal waters of Boulogne-sur-Mer (France). JOURNAL OF MARINE SYSTEMS 162, 137–153. https://doi.org/10.1016/j.jmarsys.2016.03.010

Charria, G., P. Lazure, B. Le Cann, A. Serpette, G. Reverdin, S. Louazel, F. Batifoulier, F. Dumas, A. Pichon, and Y. Morel, Surface layer circulation derived from Lagrangian drifters in the Bay of Biscay, Journal of Marine Systems, Volumes 109-110, Pages S60-S76, ISSN 0924-7963, 10.1016/j.jmarsys.2011.09.015, 2013.

Charria, G., S. Theetten, F. Vandermeirsch, Ö. Yelekçi, and N. Audiffren, Interannual evolution of (sub)mesoscale dynamics in the Bay of Biscay, Ocean Sci., 13, 777-797, https://doi.org/10.5194/os-13-777-2017, 2017.

Ferrer, L., A. Fontán, J. Mader, G. Chust, M. González, V. Valencia, Ad Uriarte, and M. B. Collins (2009), “Low-salinity plumes in the oceanic region of the Basque Country”, Continental Shelf Research, 29, 8, pages 970–984, DOI: 10.1016/j.csr.2008.12.014

Koutsikopoulos, C. and B. Le Cann (1996), “Physical processes and hydrological structures related to the Bay of Biscay anchovy”, Scientia Marina, 60, 2, pages 9–19, DOI: 10.1016/S0399- 1784(98)80020-0

Maji, S.K., Pont, O., Yahia, H., Sudre, J., 2013. Inferring information across scales in acquired complex signals. In: T. Gilbert, M. Kirkilionis, and G. Nicolis, (Eds.), Proceedings of the European Conference on Complex Systems 2012 Springer Proceedings in Complexity, Springer International Publishing, pp. 209–226.

Schmitt, F. G., & Huang, Y. (2016). Stochastic analysis of scaling time series: from turbulence theory to applications. Cambridge University Press.

Sudre, J., Yahia, H., Pont, O., Garçon, V., 2015. Ocean turbulent dynamics at super resolution from optimal multiresolution analysis and multiplicative cascade. IEEE Trans. Geosci. Remote Sens., 2015, TGRS 2014–00385.R2.

Turiel, A., Yahia, H., Pérez-Vicente, C.J., 2008. Microcanonical multifractal formalisma geometrical approach to multifractal systems: Part I. Singularity analysis. J. Phys. A: Math. Theor. 41, 15501.

Yahia, H., Sudre, J., Pottier, C., Garçon, V., 2010. Motion analysis in oceanographic satellite images using multiscale methods and the energy cascade. Pattern Recognit. 43, 3591–3604.

Yelekçi, O., G. Charria, X. Capet, G. Reverdin, J. Sudre, H. Yahia, Spatial and seasonal distributions of frontal activity over the French continental shelf in the Bay of Biscay, Continental Shelf Research, Volume 144, Pages 65-79, ISSN 0278-4343, http://dx.doi.org/10.1016/j.csr.2017.06.015, 2017.