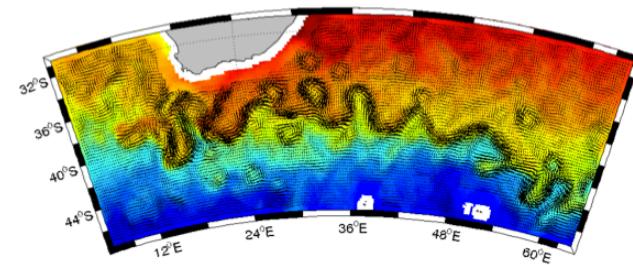
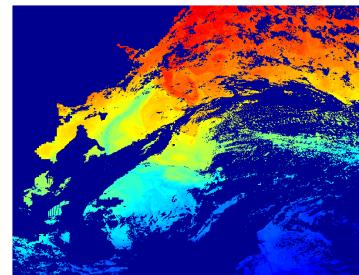




Institut  
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# **ANR-NFSC EMOCEAN : The upper ocean dynamics at high-resolution from space anywhere and anywhen?**

**R. Fablet**

Telecom Bretagne, département SC

UMR LabSTICC/TOMS

<http://perso.telecom-bretagne.eu/ronanfablet>



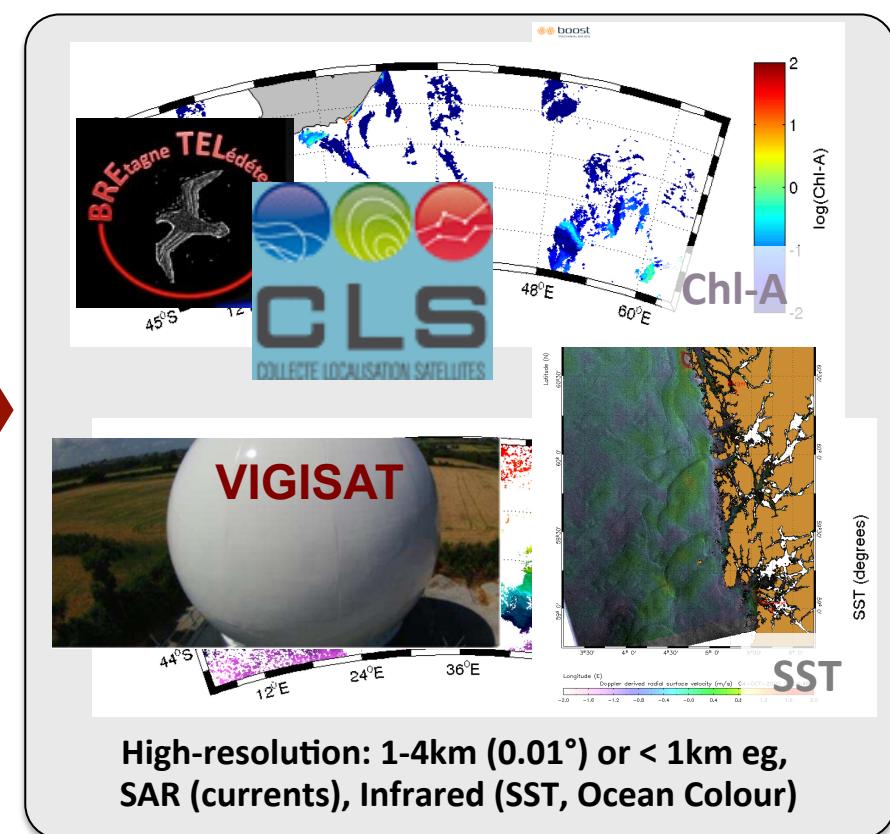
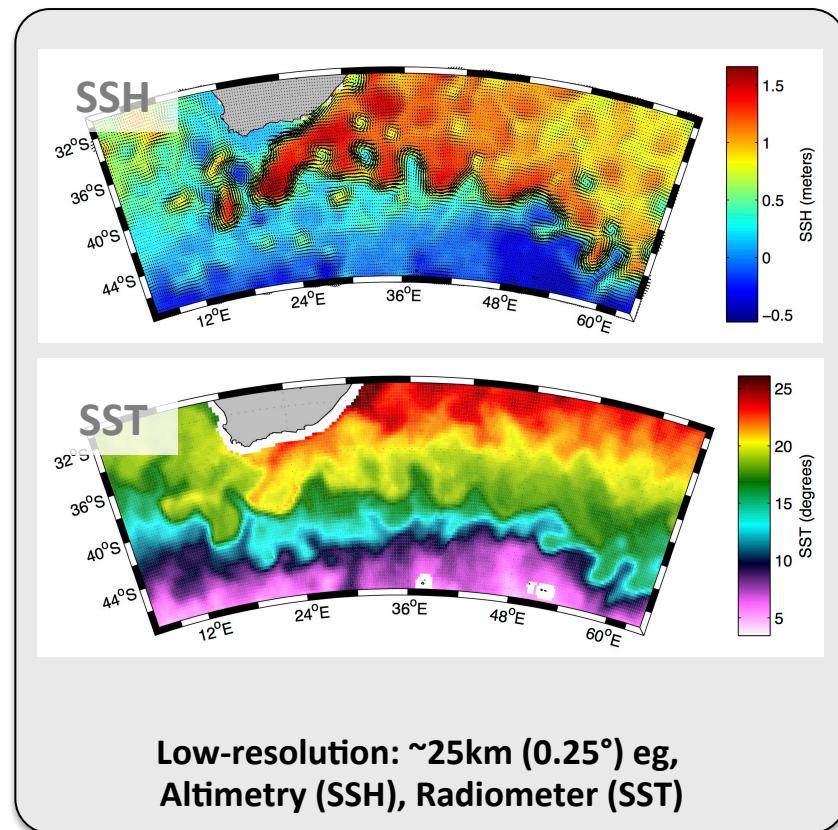


# Sensing the ocean from space at high-resolution: how and why?



## Satellite ocean sensing: context

■ From low-resolution ..... to high-resolution

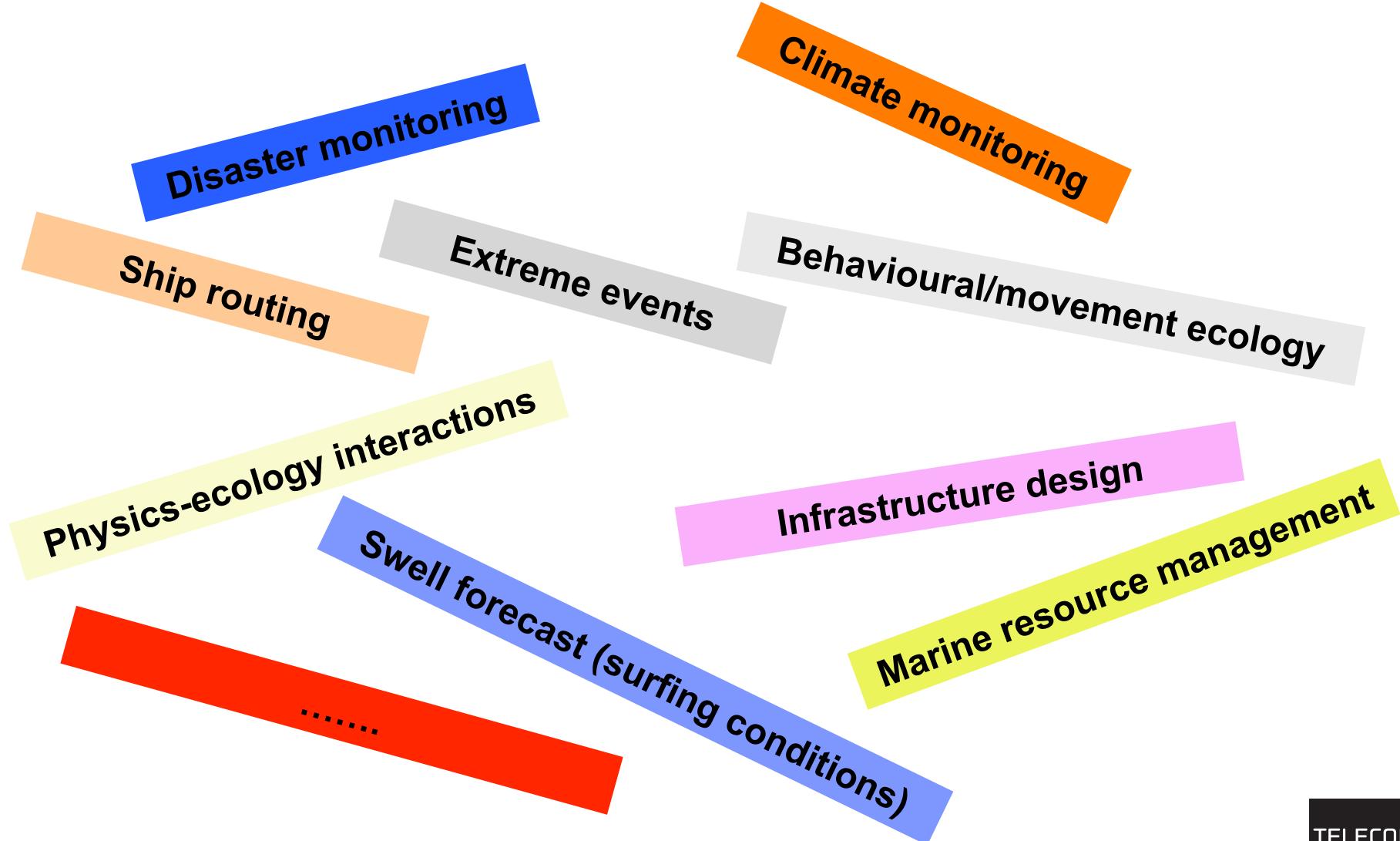


### Key issue

*How to deliver daily HR geophysical field anywhere and anywhere from the irregular space-time sampling of satellite sensors ?*



# High-resolution ocean sensing: what for?





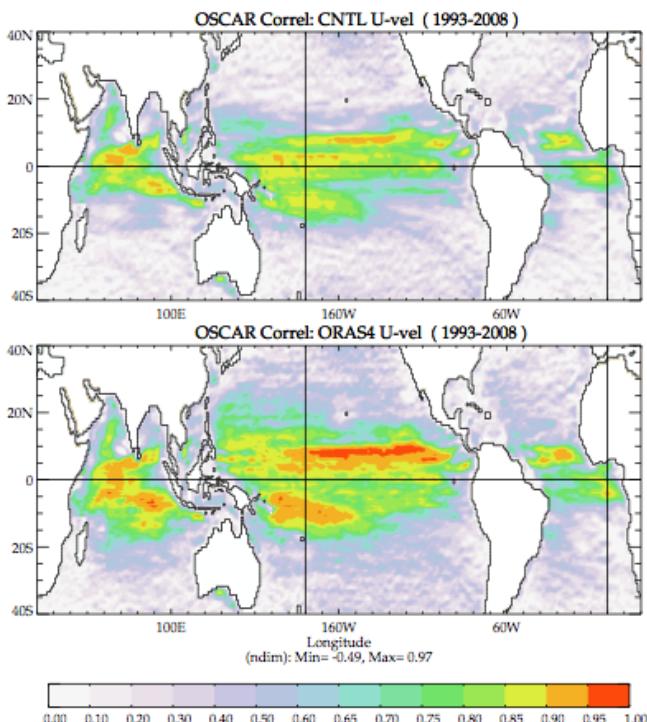
**The upper ocean dynamics at high-resolution: from an irregular space-time sampling to anywhere and anywhen?**

**A signal processing perspective:  
challenges and expected contributions**

# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ ***The state-of-the-art: model-driven data assimilation***

- **Objective:** combine a prior ocean model and available observations
- **Operational models:** eg, *NEMOVAR* (ECMWF), *Wavewatch III* (NOAA)



$$\left. \begin{array}{l} d_t X = F(X, \xi, t, \theta) \\ Y_t = H(X, \zeta, t, \Phi) \end{array} \right\}$$

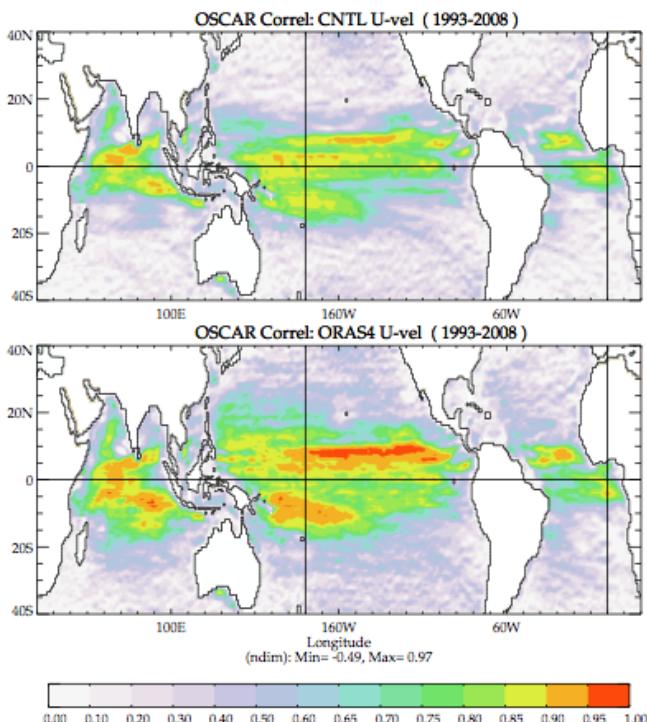
*Dynamical model*

*Observation model*

# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ *The state-of-the-art: model-driven data assimilation*

- **Objective:** combine a prior ocean model and available observations
- **Operational models:** eg, *NEMOVAR* (ECMWF), *Wavewatch III* (NOAA)



## ■ *Limitations:*

- *Complexity of the numerical resolution*
- *Model complexity vs. Model « genericity »*



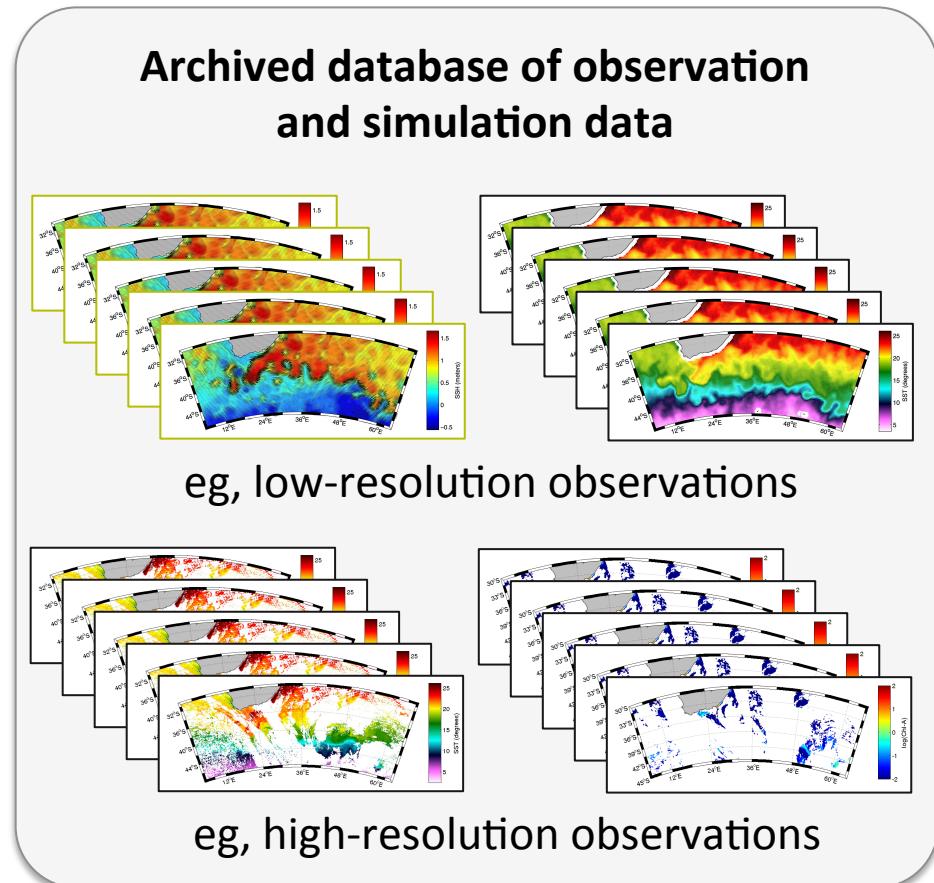
# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ *Towards data-driven assimilation models: why?*

HR observations are irregularly sampled in space and time.

But ....

- 1) low resolution observations are generally available
- 2) we may learn a lot from past observations.

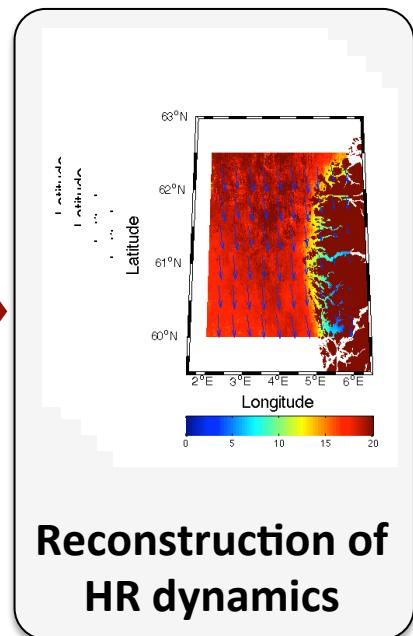
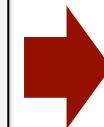
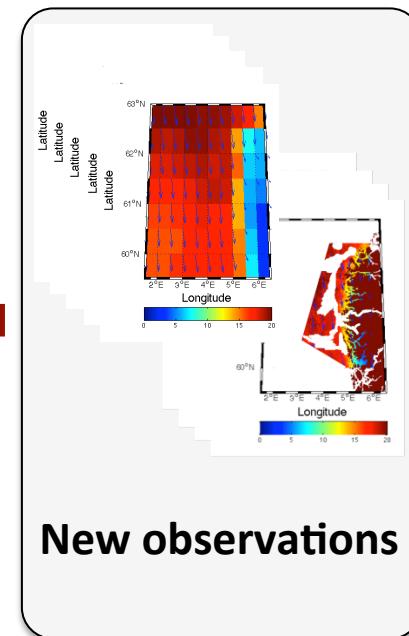
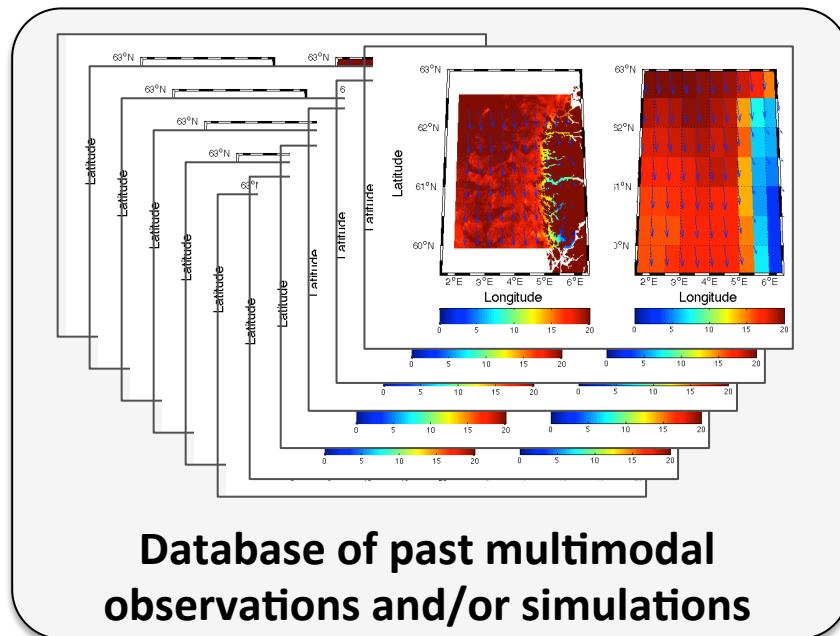


**Key objective: learning new multi-scale/multi-modal representations of ocean dynamics from multi-sensor remote sensing archives**



# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ Towards data-driven assimilation models: our strategy

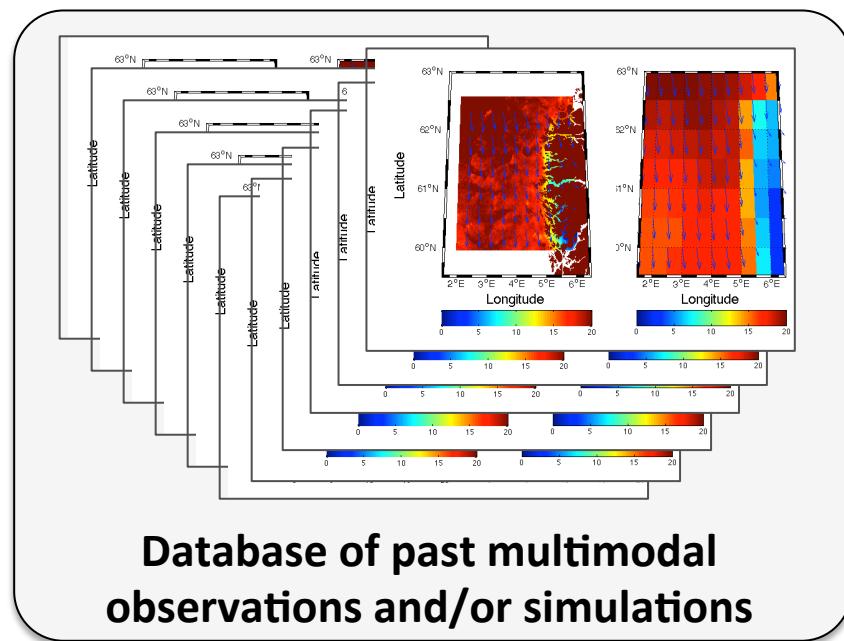


**Key objective: learning new multi-scale/multi-modal representations of ocean dynamics from multi-sensor remote sensing archives**



# The upper ocean dynamics at high-resolution anywhere and anywhen?

## ■ Towards *data-driven assimilation models*



$$\left. \begin{array}{l} d_t X = F(X, \xi, t, \theta) \\ Y_t = H(X, \zeta, t, \Phi) \end{array} \right\}$$

*Dynamical model*

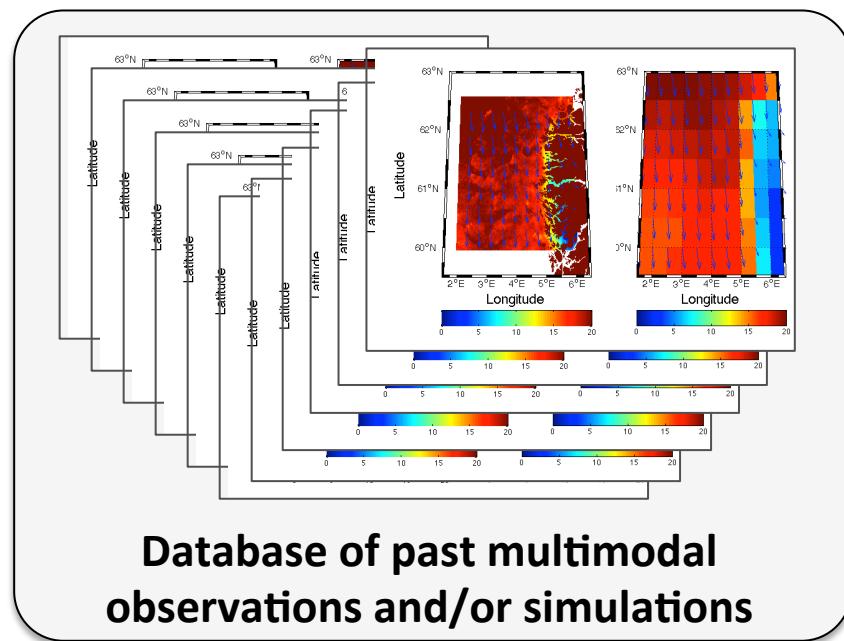
*Observation model*

**Key objective: statistical learning and probabilistic representations for both the dynamical and observation models**



# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ Preliminary results (1): *Model-free stochastic assimilation*



*Non-parametric  
Dynamical model*

$$d_t X = F(X, \xi, t, \theta)$$

$$Y_t = H(X, \zeta, t, \Phi)$$

*Observation model*

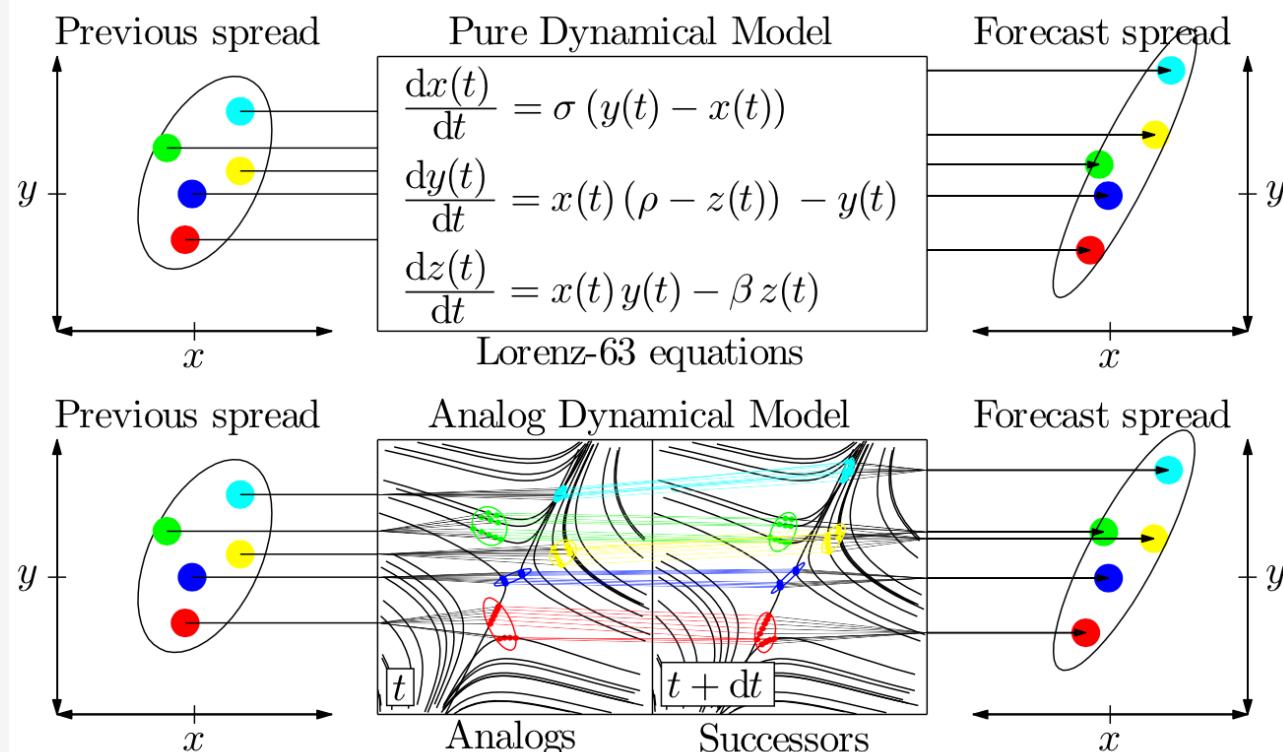
**Model-free/data-driven dynamics for the assimilation  
of geophysical systems**

# The upper ocean dynamics at high-resolution anywhere and anywhen?

## ■ Preliminary results (1): *Model-free stochastic assimilation*

**Model-free stochastic assimilation** (e.g.  
EnKF, particle filter)

**Proof-of-concept validated** on chaotic  
dynamics (Lorenz model)



**Model-free/data-driven dynamics for the assimilation  
of geophysical systems**

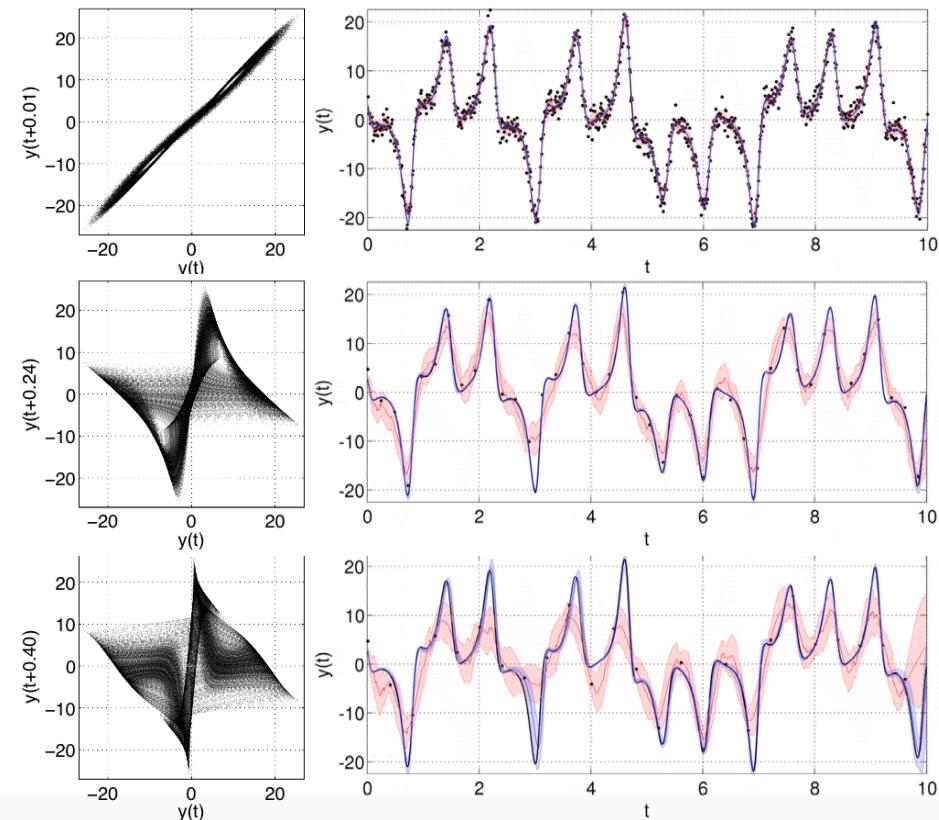
# The upper ocean dynamics at high-resolution anywhere and anywhen?

## ■ Preliminary results (1): *Model-free stochastic assimilation*

*Experiments for different sampling rate between consecutive observations*

*Comparison to a simple linear AR(1) model (red)*

*State-of-the-art performance when the number of training examples is large enough*

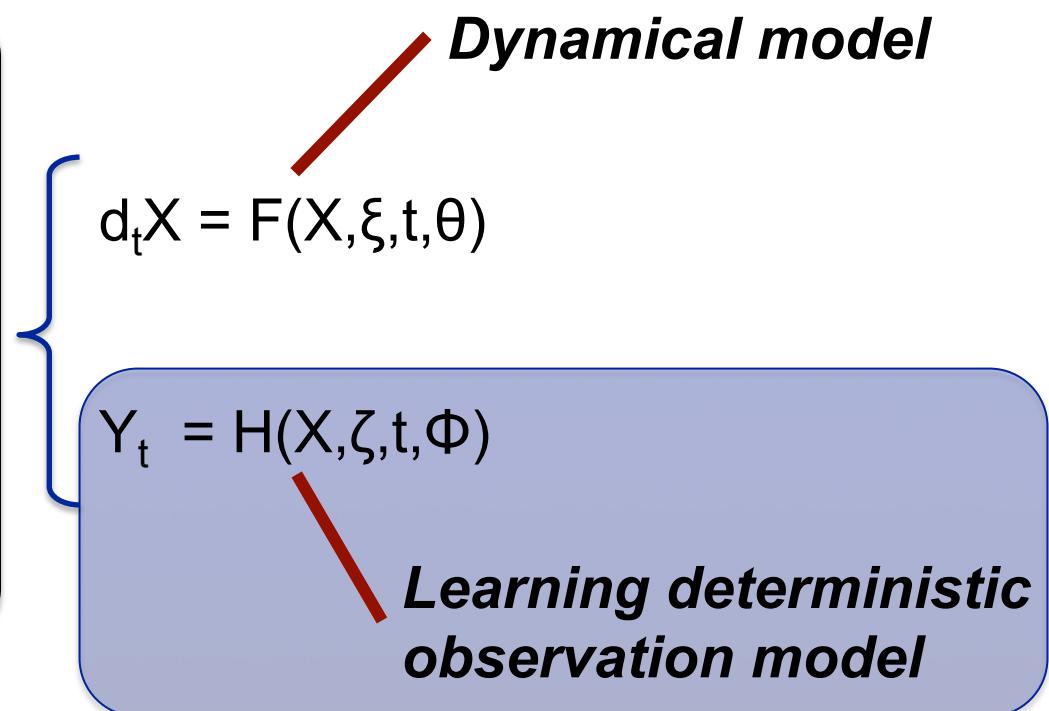
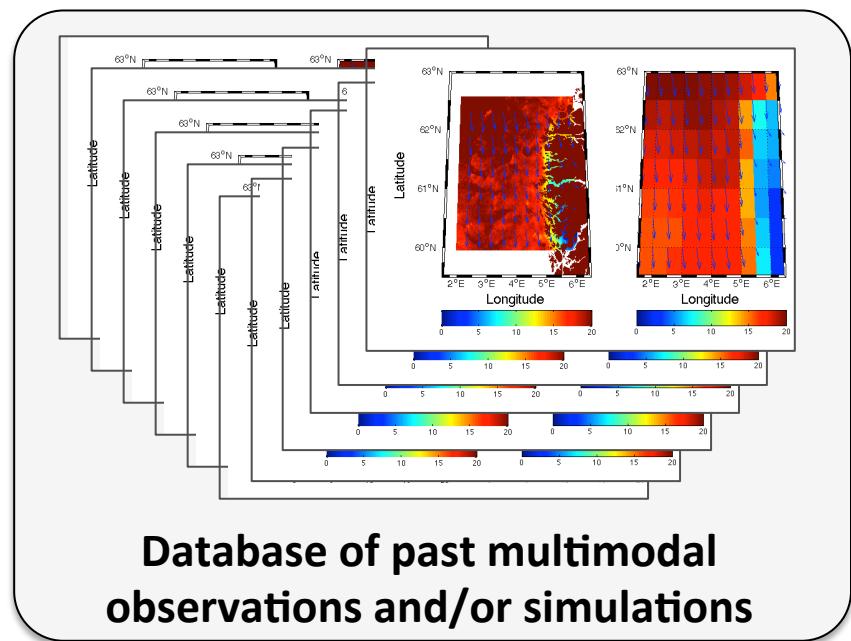


**Model-free/data-driven dynamics for the assimilation  
of geophysical systems**



# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ Preliminary results (2): deterministic transfer function



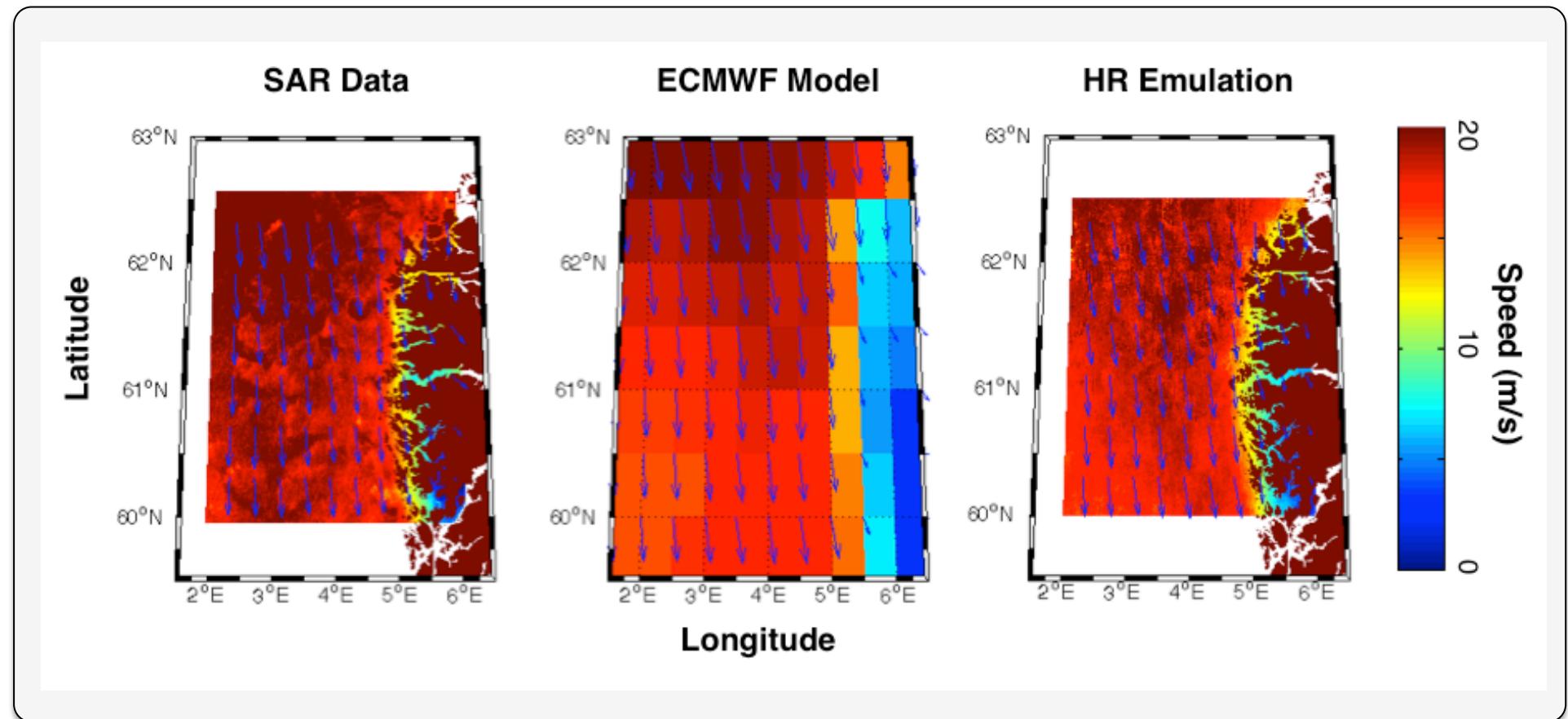
Learning ECMWF-to-SAR transfer functions  
for HR wind field emulation

He-Guelton et al. 2014



# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ Preliminary results (2): deterministic transfer function



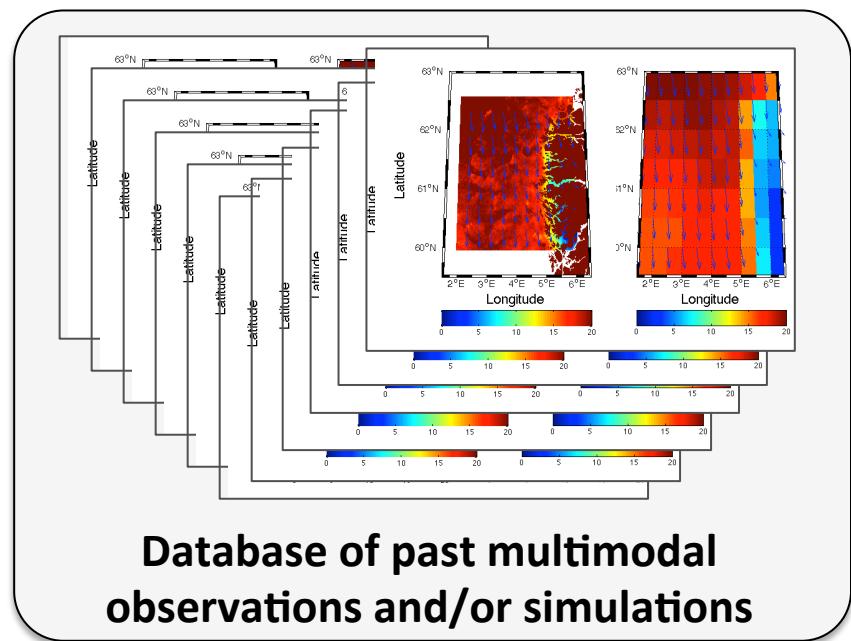
Learning ECMWF-to-SAR transfer functions  
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He-Guelton et al. 2014



# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ Preliminary results (3): stochastic transfer function



*Dynamical model*

$$d_t X = F(X, \xi, t, \theta)$$

$$Y_t = H(X, \zeta, t, \Phi)$$

*Learning stochastic observation model*

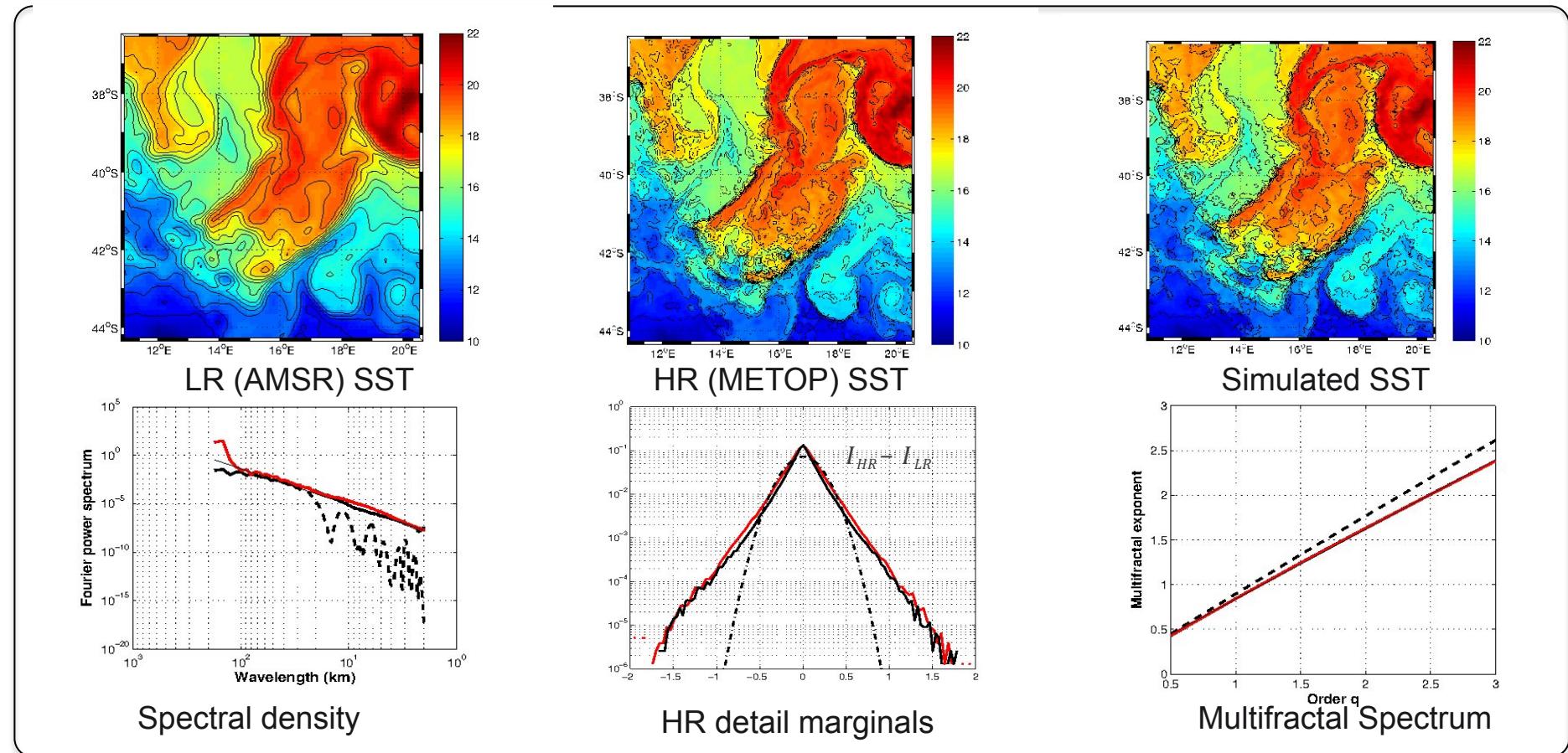
Learning stochastic LR-to-HR transfer functions  
for HR SST emulation<sup>16</sup>

Fablet et al, 2013



# The upper ocean dynamics at high-resolution anywhere and anywhere?

## ■ Preliminary results (3): stochastic transfer function

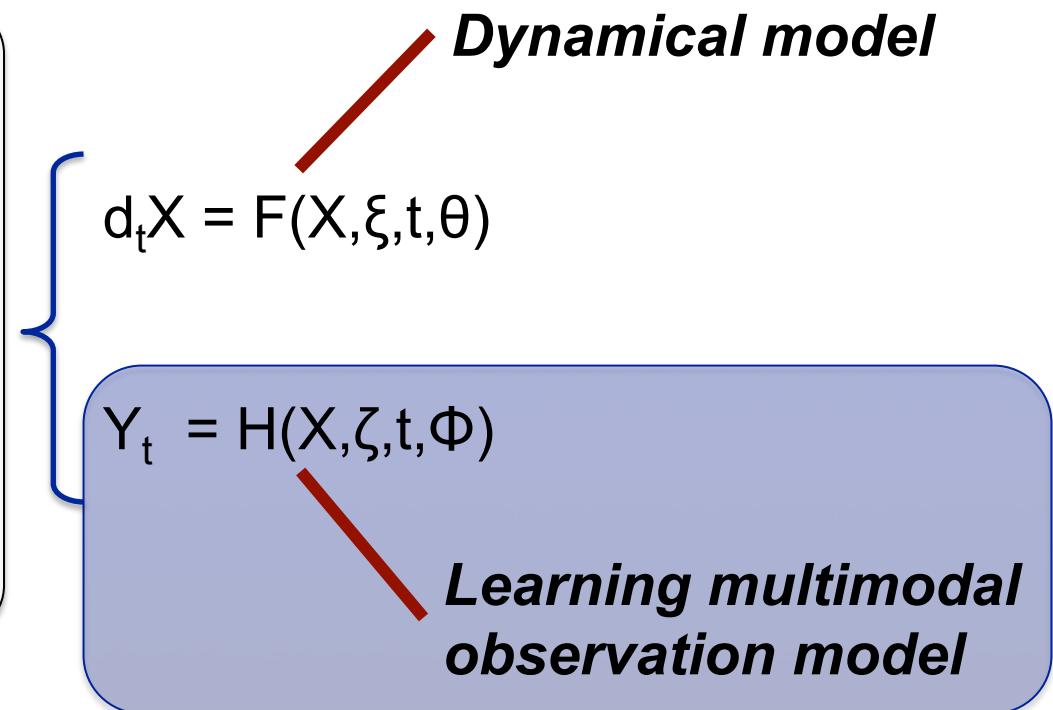
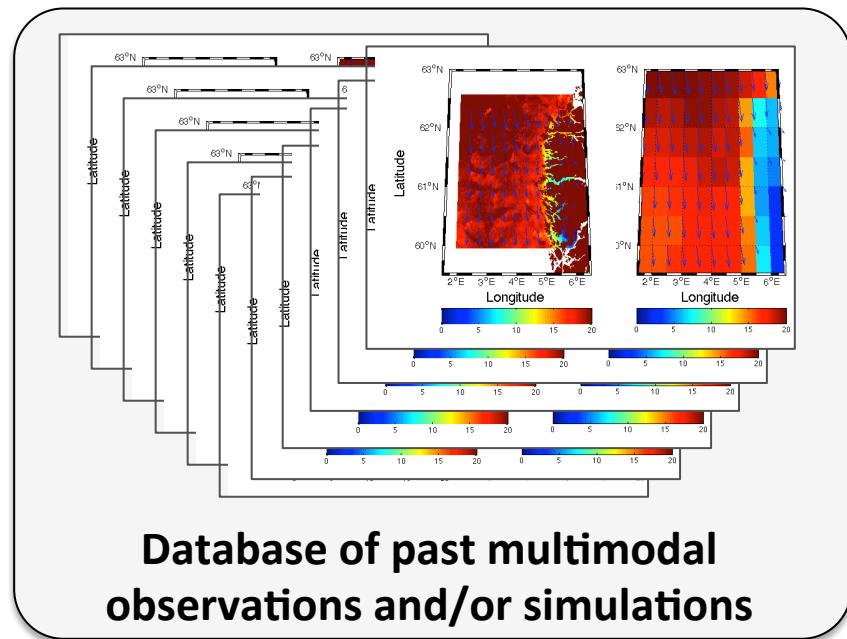


Learning stochastic LR-to-HR transfer functions  
for HR SST emulation



# The upper ocean dynamics at high-resolution anywhere and anywhen?

## ■ Preliminary results (4): multimodal transfer function

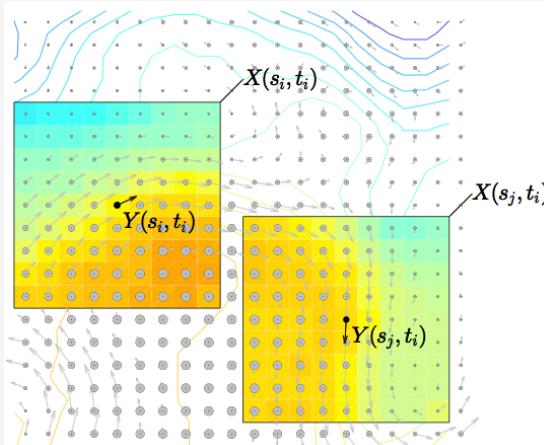


Towards high-resolution sea surface currents  
from a joint SST-SSH analysis

Tandeo et al, 2014

# The upper ocean dynamics at high-resolution anywhere and anywhere?

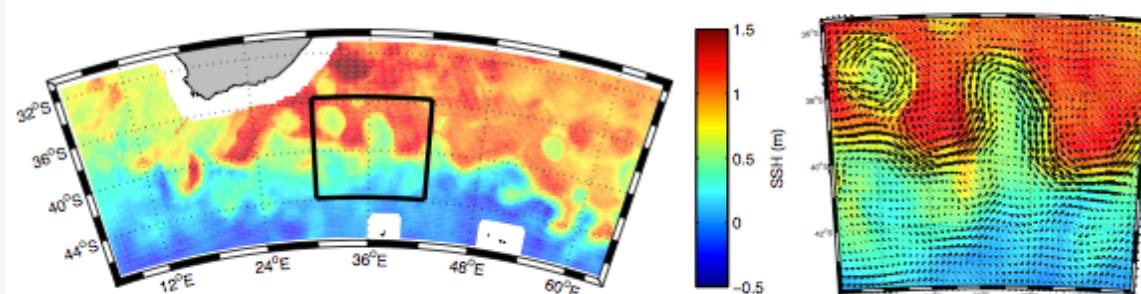
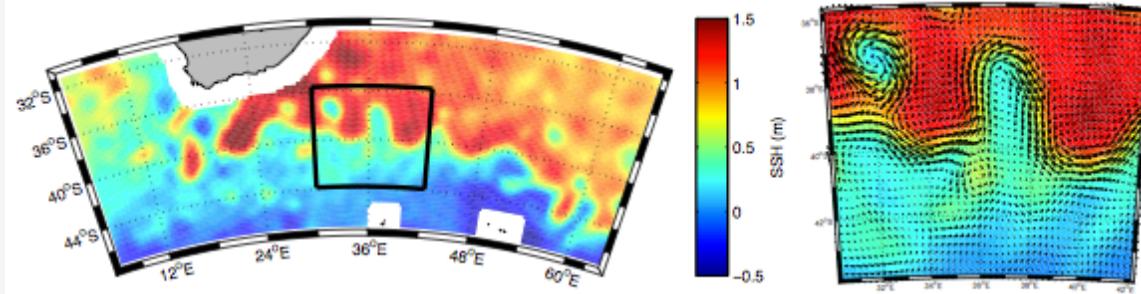
## ■ Preliminary results (4): multimodal transfer function



**SQG-like assumption:** local relationships between local SST patches and sea surface currents

**Learning from joint SST-SSH observations**

### *Application to a one-year AMSR/SST-AVISO/SSH series*

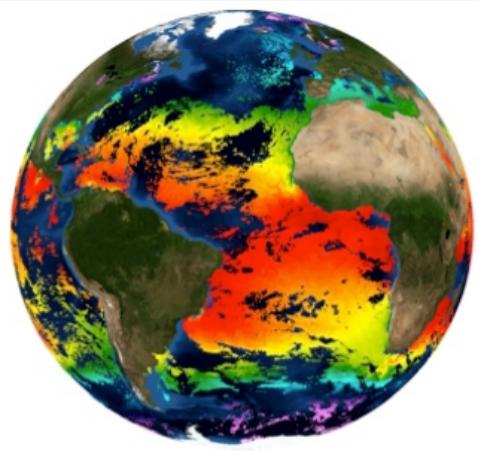


**Towards high-resolution sea surface currents  
from a joint SST-SSH analysis**



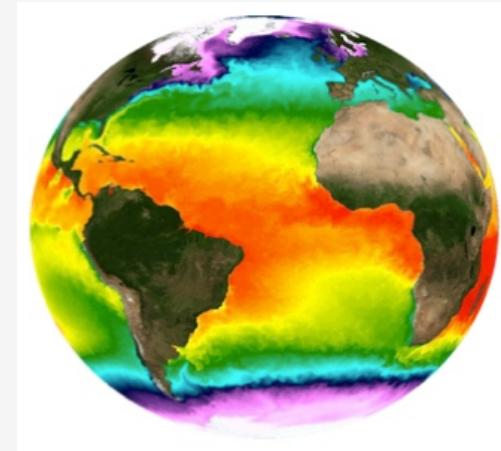
# The upper ocean dynamics at high-resolution anywhere and anywhen?

## ■ Preliminary results (4): big data challenge



**Nephelae demonstrator:** dedicated architecture to process terabytes-to-petabytes of data

<http://cersat.ifremer.fr/About-us/Infrastructure/Nephelae>



*Ex.: High-resolution Sea Surface Temperature*

*200Go daily to be processed to fill cloud gaps*

*Processing time :*

- Months with traditional system*
- 8 hours with Nephelae architecture*

**Towards high-performance architecture for ocean-big-data management and processing**

# The upper ocean dynamics at high-resolution anywhere and anywhere?

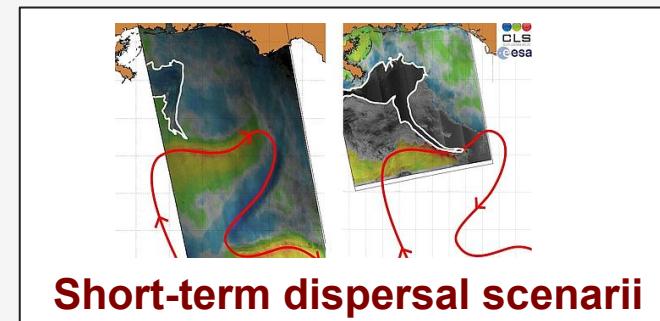
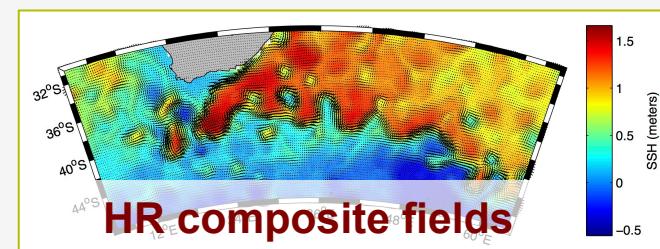
## ■ EMOCEAN project (2013-2016 ANR grant (French NSF))

**Partners:** *Telecom Bretagne (R. Fablet), Ifremer (B. Chapron), Ocean Data Lab (spin-off, F. Collard), OUC (G. Chen)*

### Main tasks

- Learning multi-modal data-driven representations of ocean surface dynamics
- Stochastic reconstruction of HR ocean surface geophysical fields from partial observation series
- High-performance architecture for "real-time" implementation

### Case-studies



## Acknowledgements

Joint work with B. Boussidi, P. Tandeo, R. Garello (Telecom Bretagne), E. Autret, B. Chapron, L. He-Guelton, H. de Pontual (Ifremer), F. Collard (Ocean Data Lab), A. Bertrand (IRD)

