The AROBASE project

AROME-BASed coupled SystEm
Application de la Recherche à l'Opérationnel pour l'assemBlage d'Arome avec des Systèmes Environnementaux

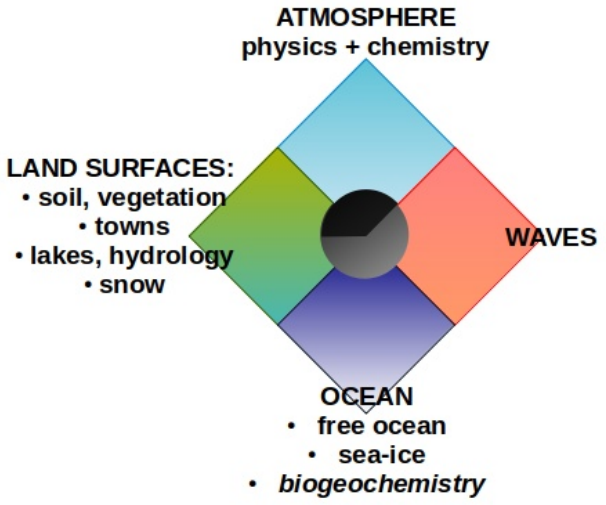
Development of a kilometre-scale multi-coupled modelling and forecasting system and first results

C. Lebeaupin Brossier, F. Sevault, G. Faure, M.-N. Bouin, J. Beuvier, S. Bielli, L. Corale, A. Dalphinet, S. Malardel

SCREEN CAPTURE WELCOME

1. Motivations & outlines of AROBASE

Assemble a fine-scale modelling system including atmosphere physics & chemistry + ocean (sea-ice, biogeochemistry) + waves + land surfaces (soil, vegetation, towns, snow, lakes, hydrology)



Prepare couplings for the new generation of the regional climate system model CNRM-RCSM

→ based on AROME to reach the kilometre scale

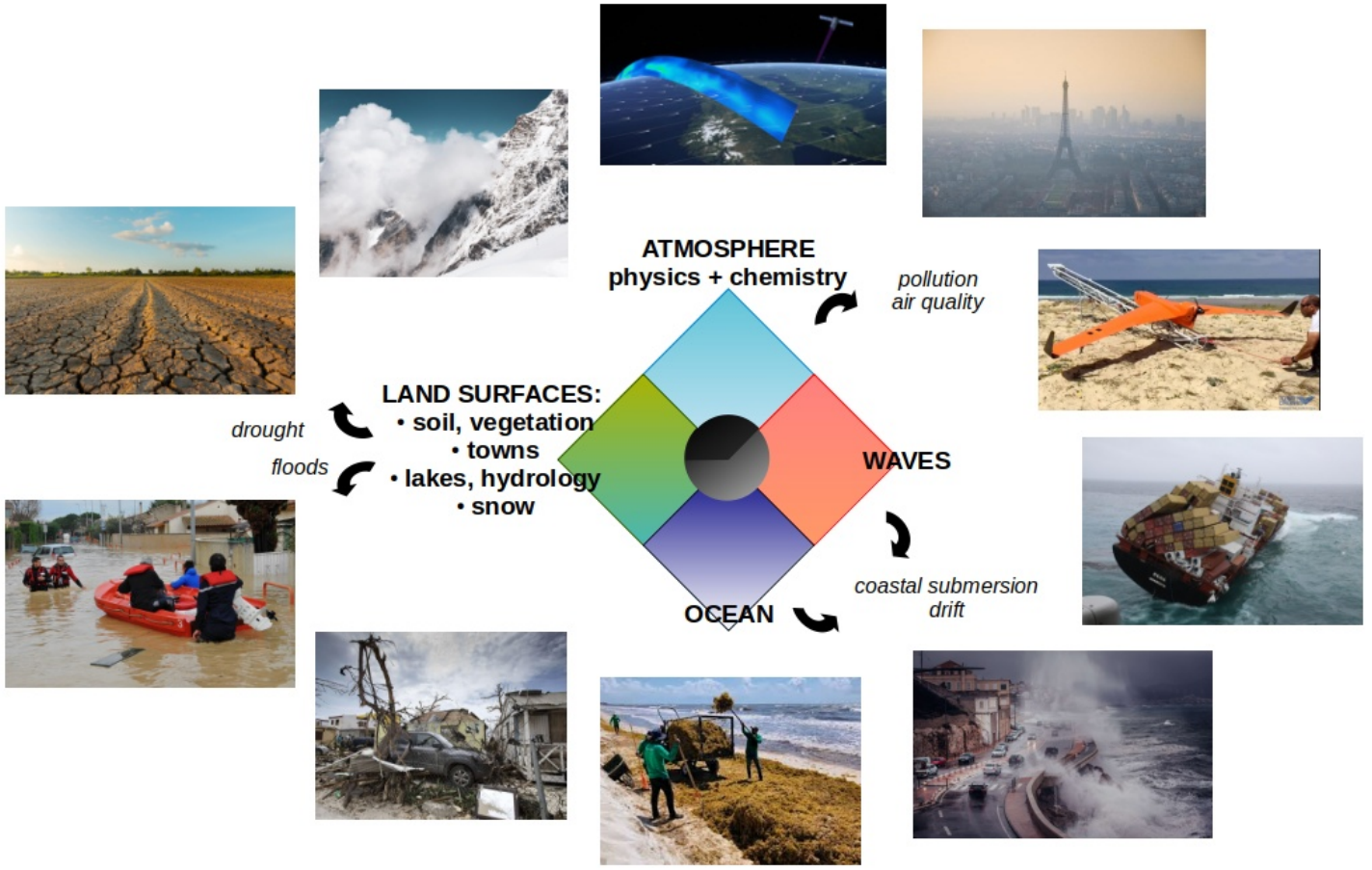
A system for NWP

→ AROBASE must be inserted in the same environment as Météo-France NWP systems

A research and collaborative numerical tools to better understand and represent the exchange processes at km-scale

with possibility to deploy on various regions depending on interests

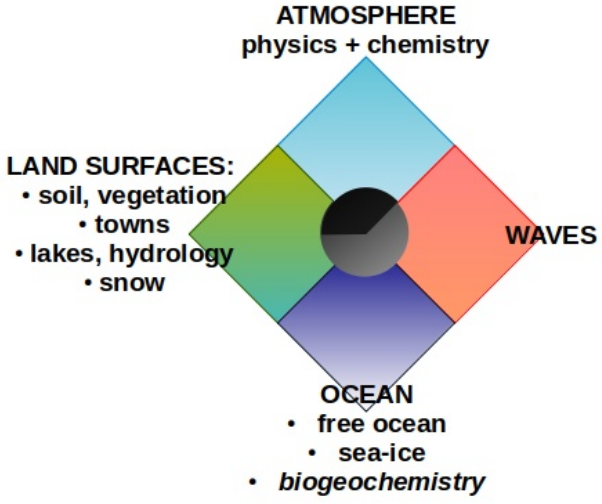
1. Motivations & outlines of AROBASE

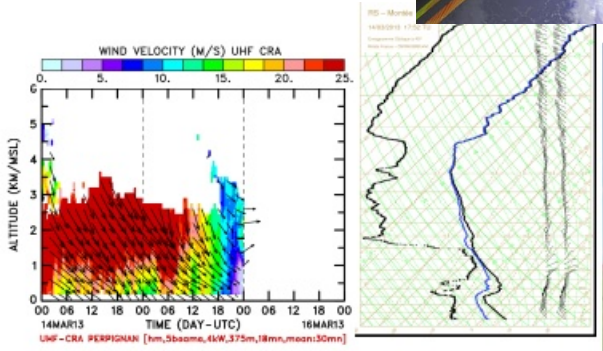


New opportunities of improvements for downstream applications from more integrated and consistent forecasts

1. Motivations & outlines of AROBASE

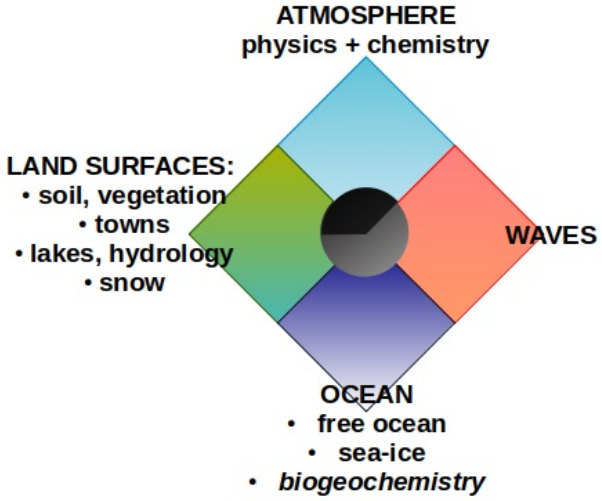
Use more largely existing observations of the different components and prepare the arrival of new observations for evaluation

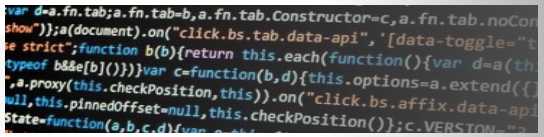




1. Motivations & outlines of AROBASE

Ensure that the assembled system complies with new computing methods inside component models (or that replace them) and manage the evolutions for new HPC architectures





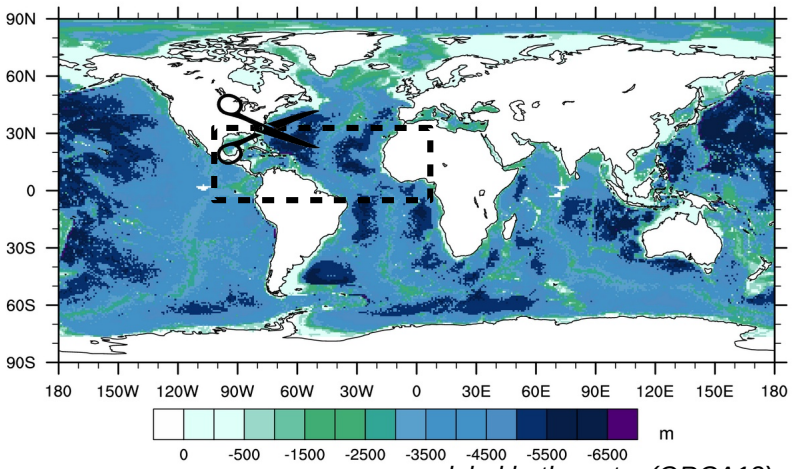
2. Assemble a research numerical tool

Assemble Earth System components to represent key processes and interactions:

- atmosphere (physics + chemistry): **AROME** [+ chemistry/aerosols library from ACCALMIE],
- land surfaces: **SURFEX** (ISBA: soil/vegetation, TEB: town, Flake: lakes, snow) + hydrology (river routing) **CTRIP** [+ chem emissions ACCALMIE],
- ocean (blue, white, green): **NEMO** (+SI^3 +PISCES)
- waves: **MFWAM**

Criteria for models choice:

- modularity (possibility to interchange models)
- transportability (different domains)
- internal expertise(s) or close collaborations
- continuum for our coupled systems: NWP ↔ AROBASE/research ↔ CNRM-RCSM (-ESM)

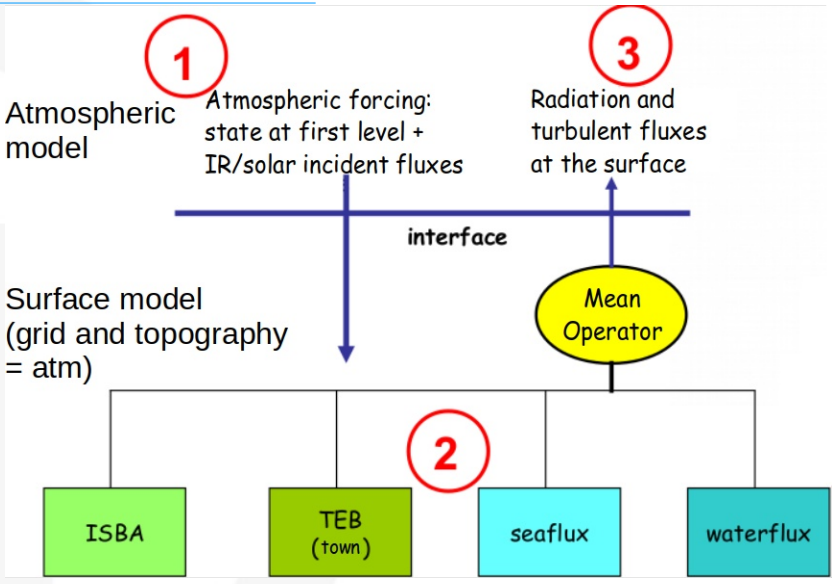


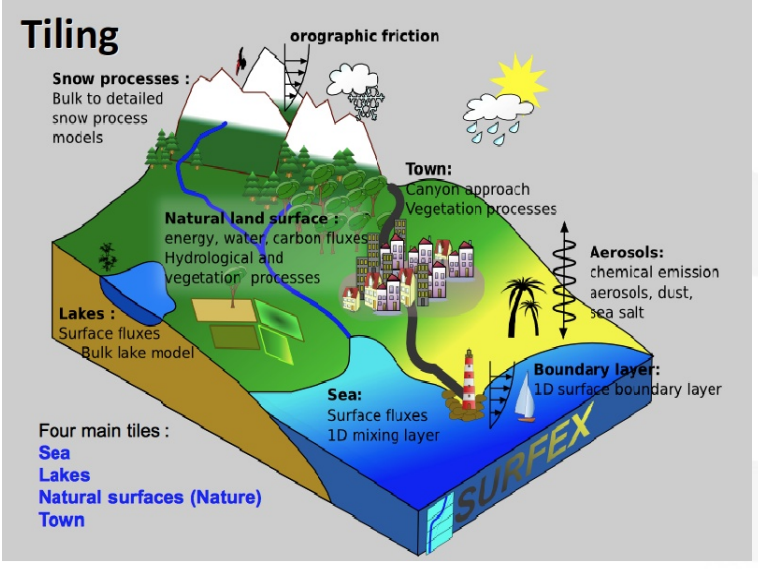
global bathymetry (ORCA12)

2. Assemble a research numerical tool

AROME:
Model for kilometric-scale Numerical Weather Prediction at Météo-France
Used as Convection-Permitting Regional Climate Model (CP-RCM)

Coupled to **SURFEX**



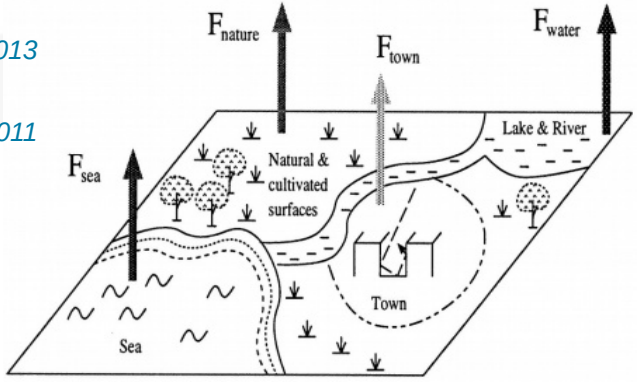


The SURFEX model

Masson et al. 2013

And its uses in AROME

Seity et al. 2011

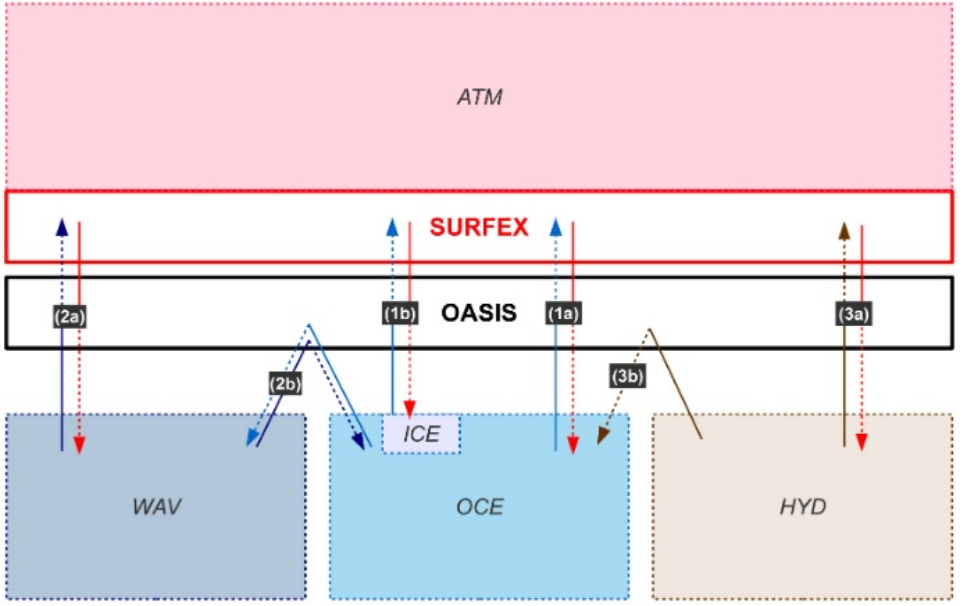


2. Assemble a research numerical tool

AROME:
Model for kilometric-scale Numerical Weather Prediction at Météo-France
Used as Convection-Permitting Regional Climate Model (CP-RCM)

Coupled to **SURFEX**
with an interface with the ***OASIS*** coupler available

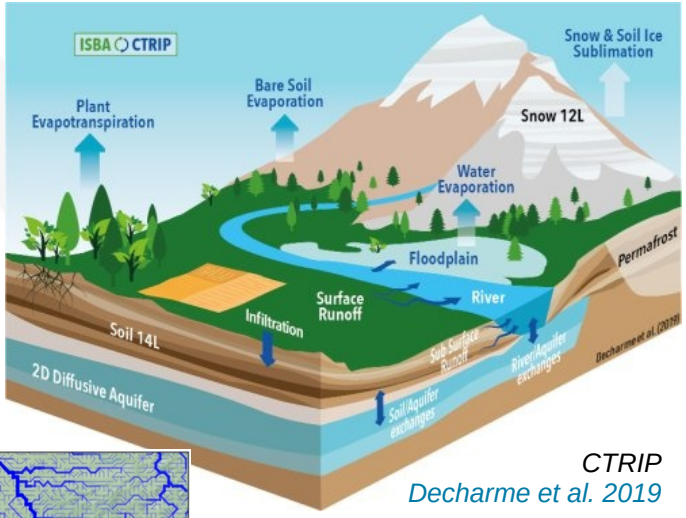
AROME and SURFEX will include a inline library of aerosols and chemistry processes developed in the joined ACCALMIE project (PI: V. Guidard, Q. Libois - CNRM)



The SURFEX-OASIS coupling interface (collab. CNRM-LOPS-LAERO-LACY-CECI/CERFACS)
Voldoire et al. 2017

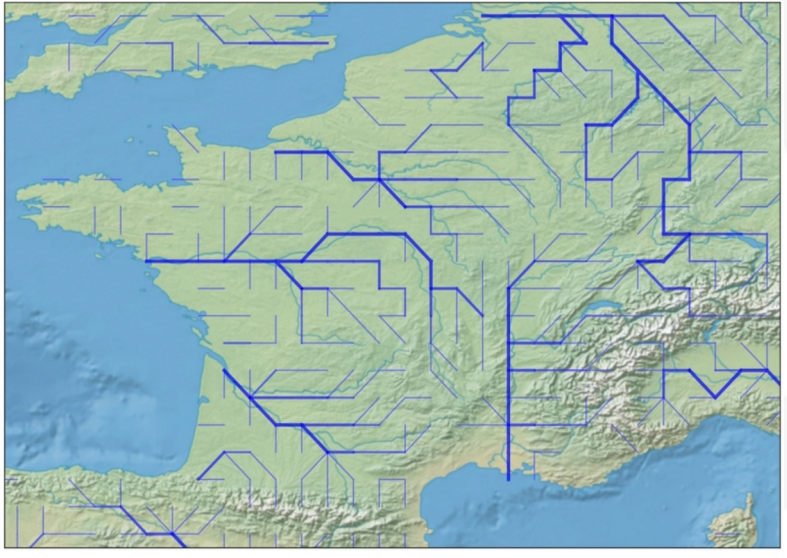
2. Assemble a research numerical tool

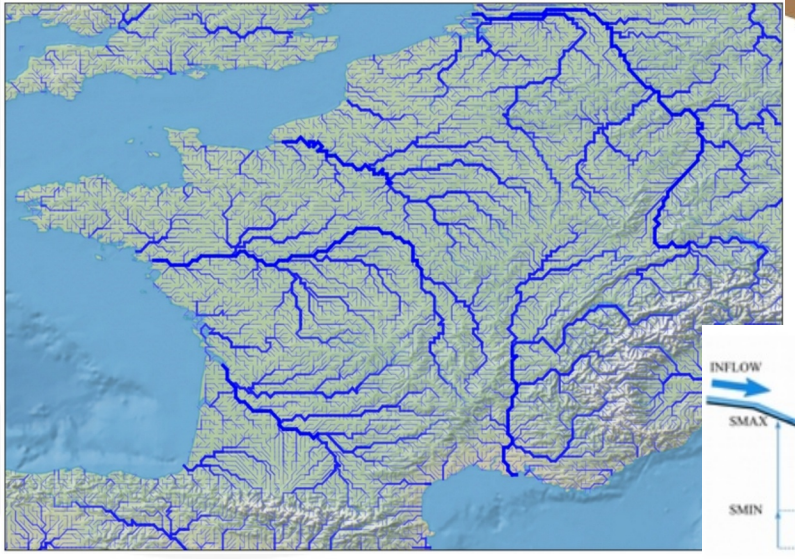
CTRIP:
for the simulation of rivers routing
coupled to ISBA and NEMO through the SURFEX/OASIS interface
Available with a new global resolution of 1/12°, to test in regional + addition of anthropic effects (irrigation/dams)



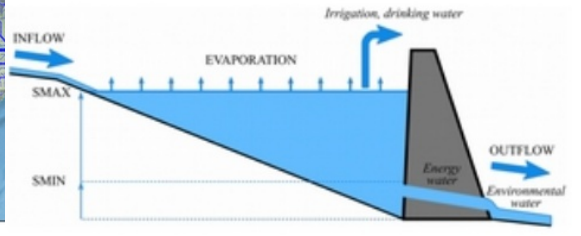
CTRIP
Decharme et al. 2019

CTRIP-D12
Munier and Decharme 2022



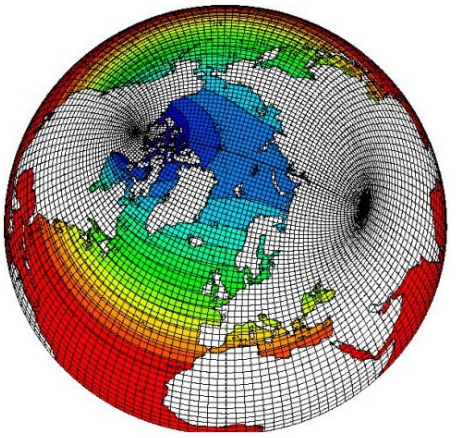


Dams modeling
Sadki et al. 2023

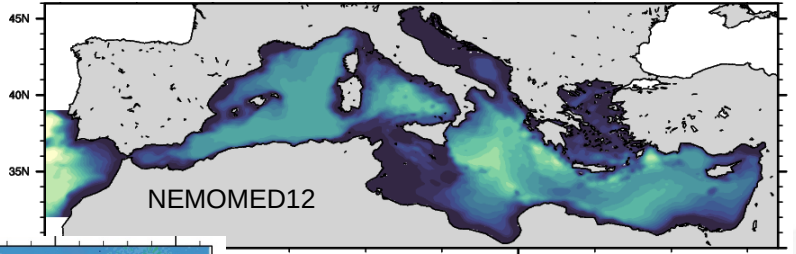


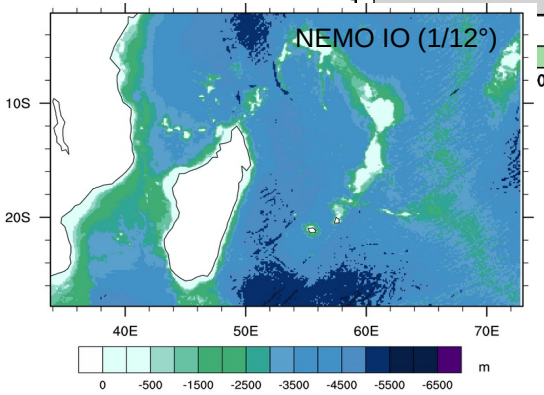
2. Assemble a research numerical tool

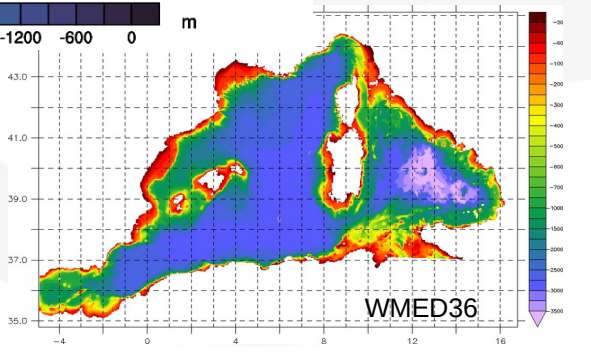
NEMO:
Model of operational oceanography in Europe;
Widely used in the research community (processes and climate);
Includes an interface with the OASIS coupler for exchanges with atmosphere, rivers and waves;
Several regional configurations deployed and coupled

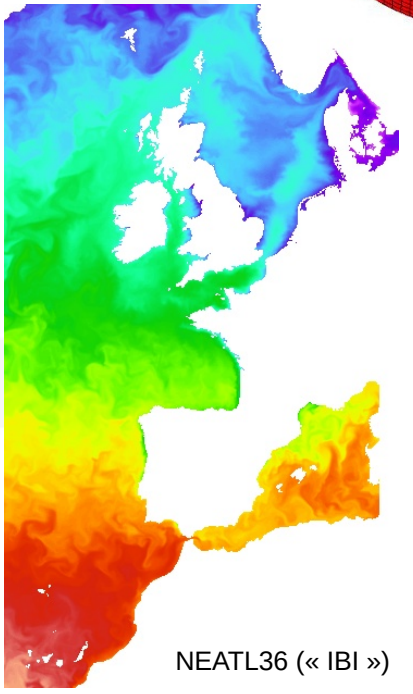


NEMO ORCA025 (1/4°) grid





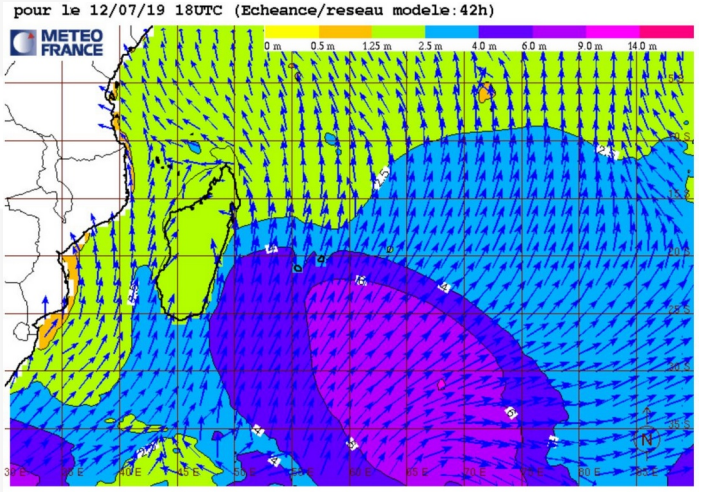




NEATL36 (« IBI »)

2. Assemble a research numerical tool

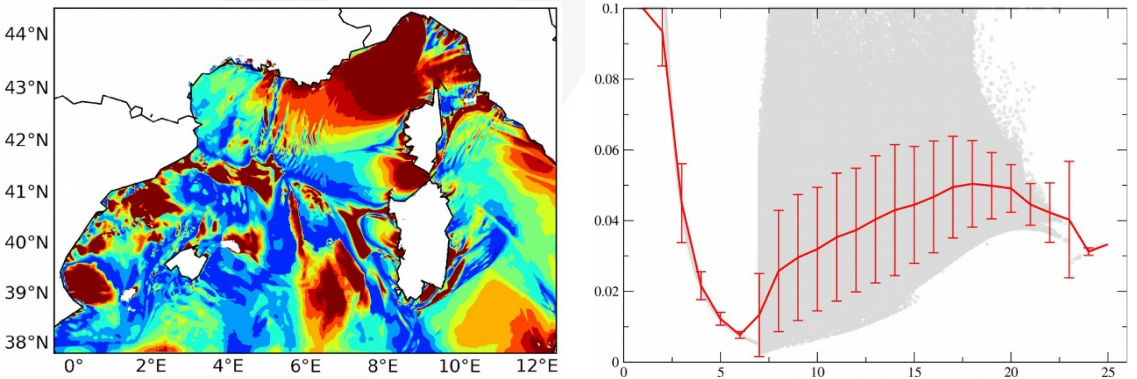
MFWAM:
Model for marine forecast at Météo-France with a significant and specific place in the forecast chain;
An internal code expertise with regular exchanges with ECMWF for the code evolutions;
Possibility to reach the kilometric resolution for regional domains as proposed for AROBASE



Regional MFWAM forecast for South-West Indian Ocean

Work steps for including MFWAM coupling:

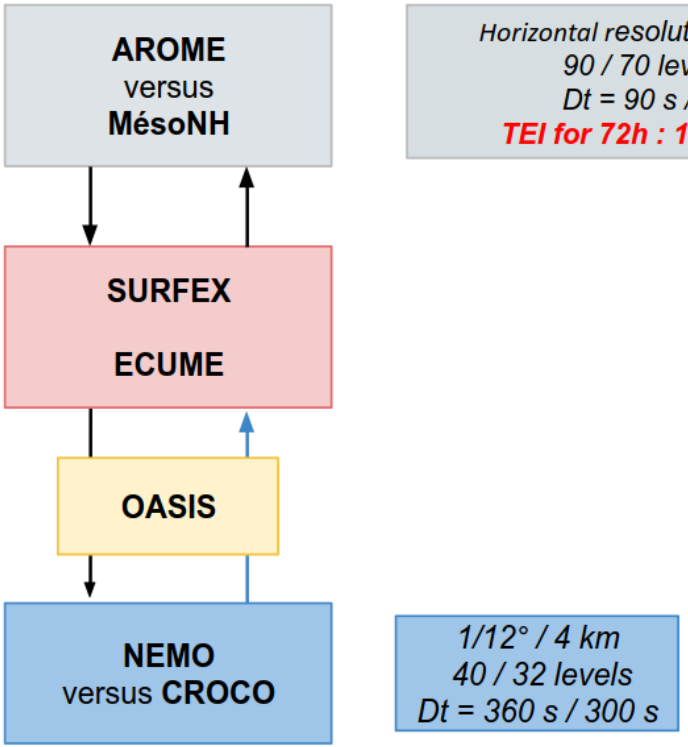
- *Wave-Age Stress dependent Parameterization "WASP" (Bouin et al. sub)*
- *Insertion of OASIS interface in MFWAM for W-A and W-O exchanges*



14 oct 2016 00UTC: Charnock parameter map and as a function of 10m-wind speed (AROME forecast, WASP, initial start : 13 oct 2016 00UTC) – Sauvage et al. 2020

2. Assemble a research numerical tool

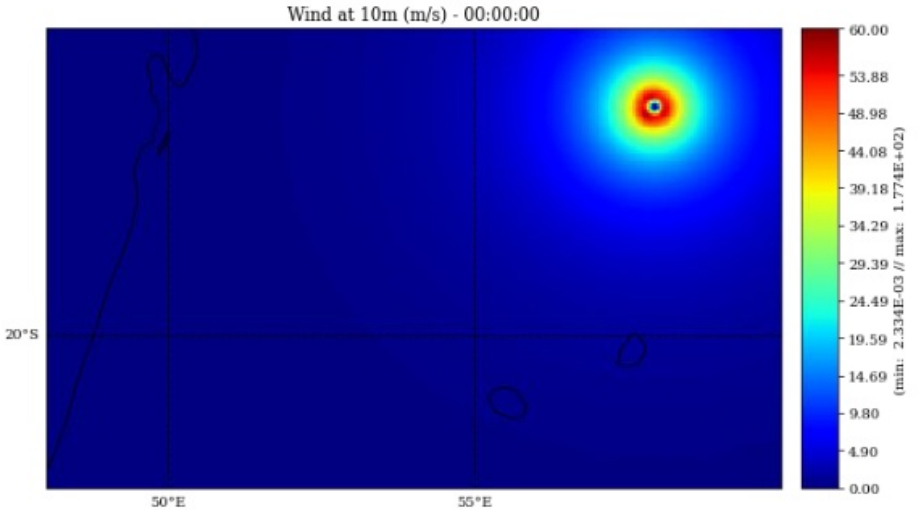
Idealised Tropical Cyclone test cases @LACY



Horizontal resolution : 4 km
90 / 70 levels
Dt = 90 s / 4s
TEI for 72h : 14j / 240j

1/12° / 4 km
40 / 32 levels
Dt = 360 s / 300 s

Coupled systems for idealised TC studies



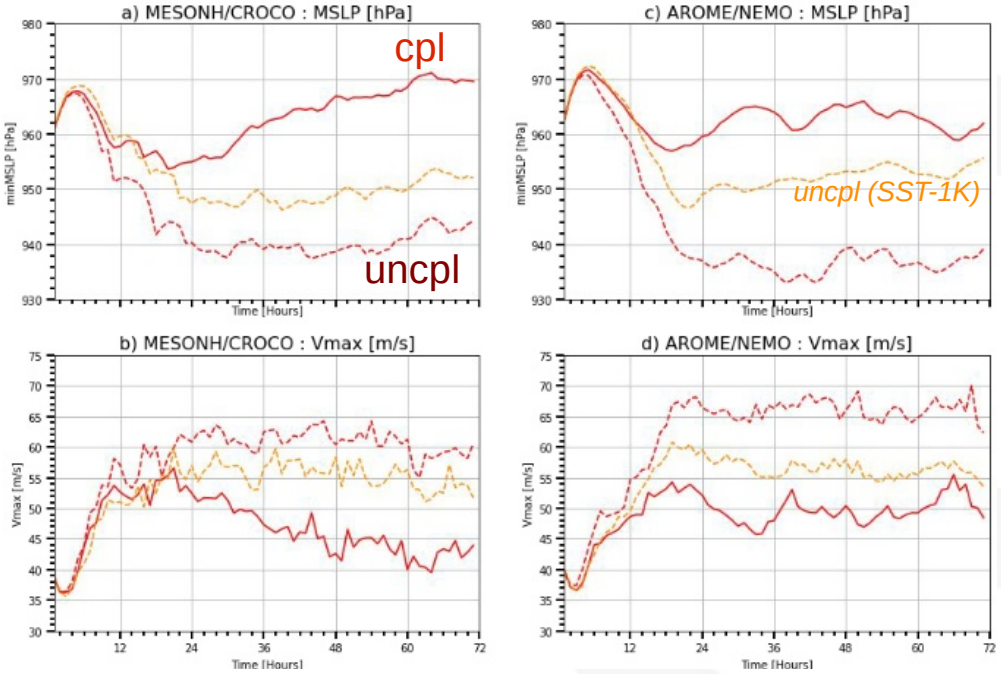
- TC environment (horizontally uniform): mean state around TC CILIDA (2018 in SOOI)
- SST=28.34°C
- Holland wind bogus: vmax=56m/s ; radius (vmax)=19km

- Parametrisations in both atmospheric models:
  - Microphysics: ICE3
  - Radiation: RRTM
  - Turbulent: TKE (CBR)
  - Surface air-sea scheme: ECUME

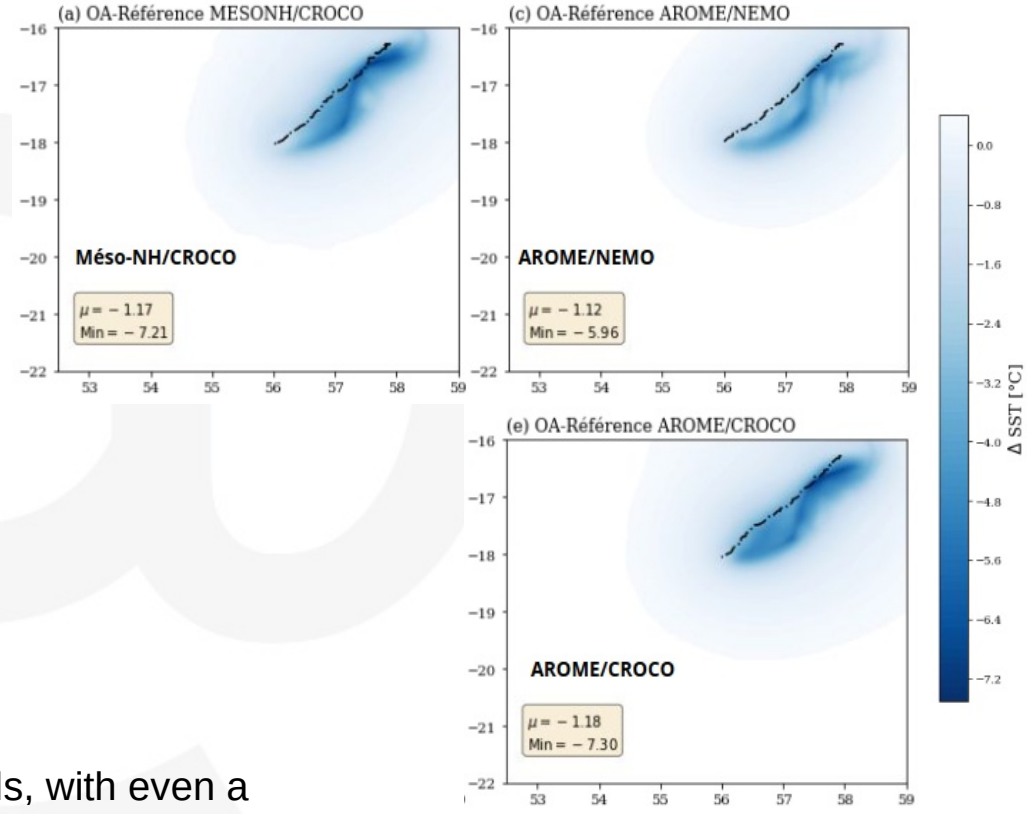
2. Assemble a research numerical tool

Idealised Tropical Cyclone test cases @LACY

Pmin (hPa, top) and Vmax (m/s, bottom) for MesoNH (left) and AROME (right)



SST differences between t=+72h and t0 (shading) and TC trajectory (dashed line)



TC more intense in AROME (non coupled and coupled)

TC much less intense in the coupled runs, in both models, with even a decaying TC after 24h in MesoNH

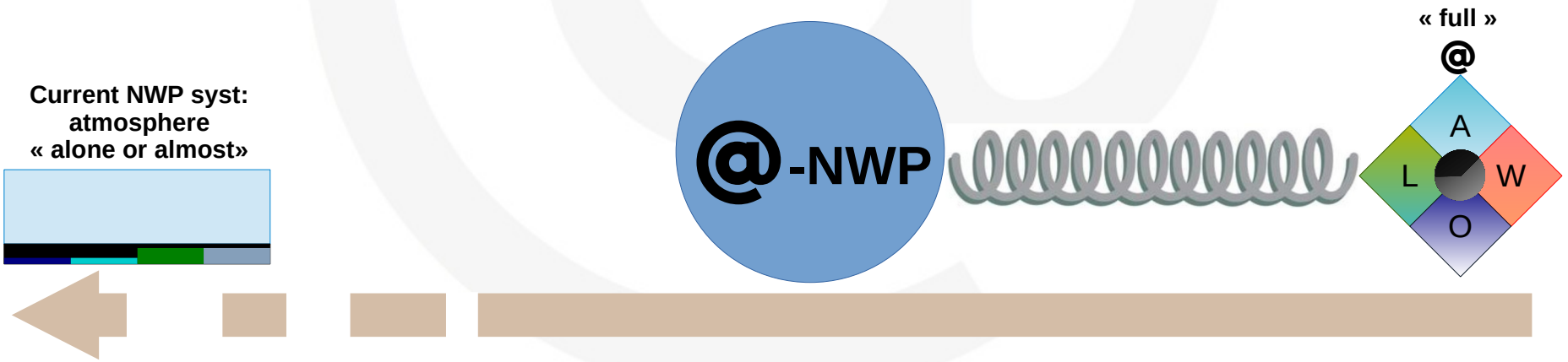
Stronger cooling with CROCO

3. Which coupling(s) for km-scale NWP?

AROBASE is designed as a **numerical prediction** system, and thus must be inserted in the production tools, the dedicated analyse methods and uses, **in line with AROME**.

Benefits of gradual complexity induced by couplings will be examined specifically for numerical prediction taking into account the operational constraints:

- **Evaluation of coupling benefits** on forecasts: skill scores & case studies; several kind of forecasts; advantages for the production chain / sequence
- **Estimate of costs**: numerical costs; running time : constraints on models and coupling methods, costs of pre-/post-treatment, transferts to (new) users, costs of maintenance…



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→ *1st phase:* ***Atmosphere – ocean – waves****:*

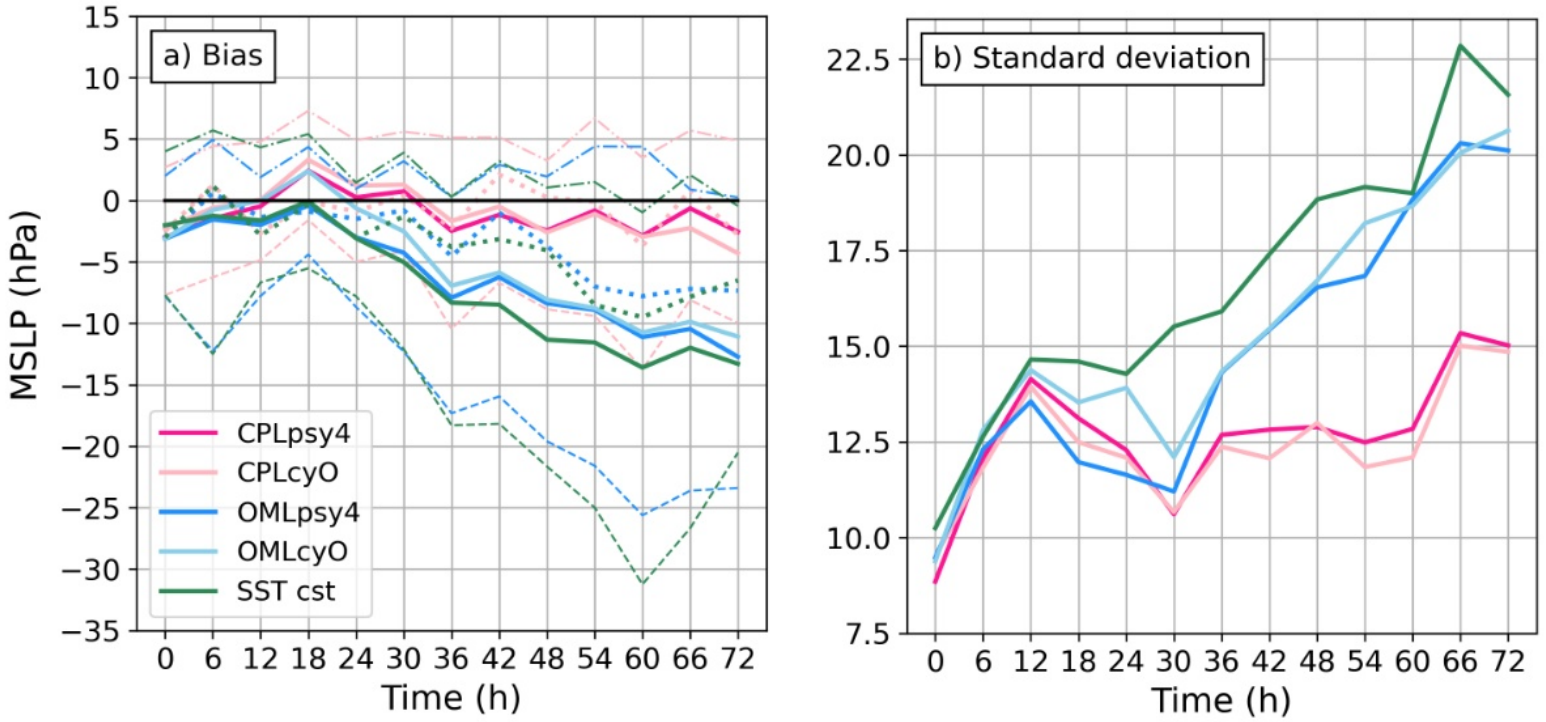
	AROME FR	AROME-OM	*intermediate steps*	AROBASE NWP demonstrator
ocean	constant SST OI+OSTIA restoring	Inline 1D model (IC=GLO12)	*Initialisation (perturbation), coupling frequency*	3D interactive
waves	Ø		*forcing*	interactive
sea turbulent fluxes parameterization	iterative without wave effect		*+ taking waves into account*	following state of the art with wave parameters into account

→ *2nd phase:* ***+ Chem + Hydrology****: to conclude on the advantage of one component (or bloc) coupling in presence of the others*

3. Which coupling(s) for km-scale NWP?

Impact of 3D ocean coupling for tropical cyclone forecast:

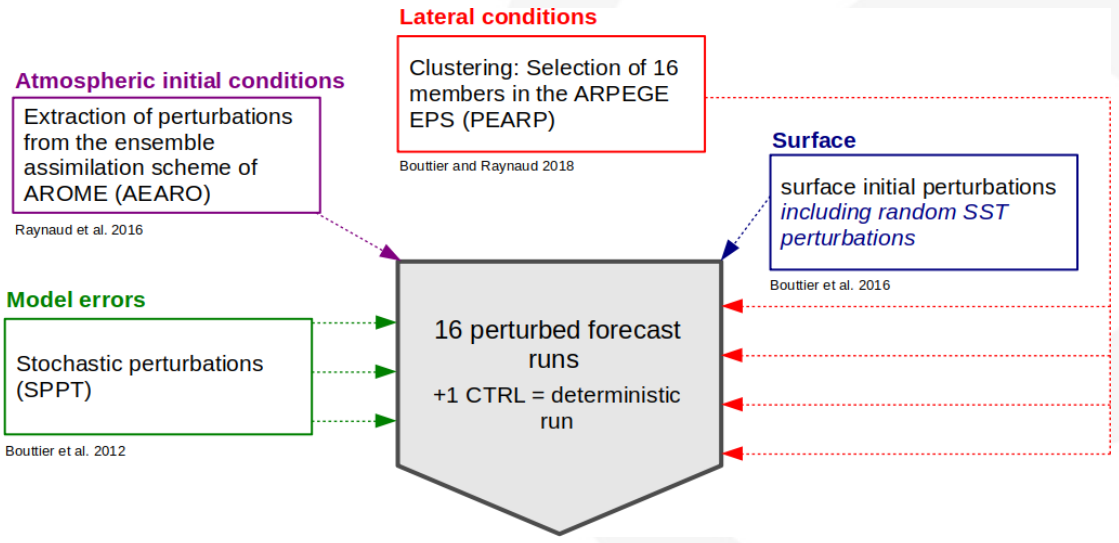
Skill scores of AROME Indian-Ocean forecast (7 cyclones, 31 forecast runs)
uncoupled (SST cst), coupled with a 1D model (OML) or NEMO (CPL)
+ ocean starts from global ocean forecast (psy4) or the previous CPL forecast (cyO)



Corale et al. 2023

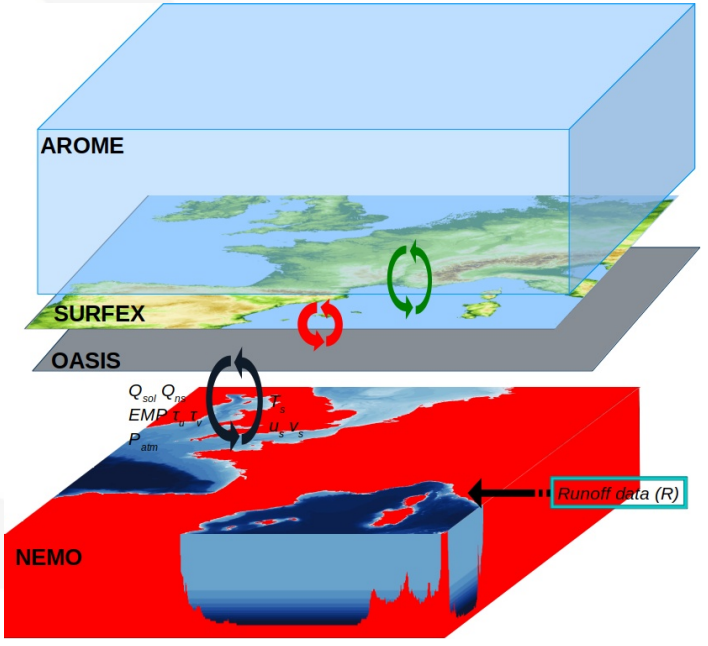
3. Which coupling(s) for km-scale NWP?

AROME-NEMO coupling over Metropolitan France:
used for OA coupled ensemble forecasts



AROME ensemble forecast (PEARO)

AROME-NEMO coupled system over Metropolitan France



What are the role of SST perturbations on ensemble forecast @km?
How to perturb the ocean model efficiently for short-range NWP?
How perturbations propagate with coupling?

4. Synergy with observations

Re-use available **observations** (case studies, field campaigns) for model and/or parameterization validation in coupled mode

→ Inventory of documented cases of interest for AROBASE validation and physical process studies.

Provide AROBASE outputs for scientific exchanges and interact to **collect the needs** of downstream production/applications

→ Interactions with users, including forecasters

→ Running AROBASE on some case studies (define the number during the project) and period of interest

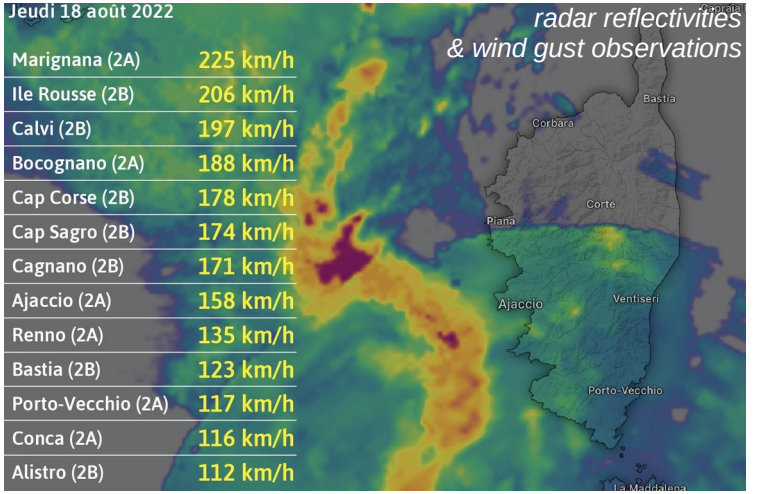
→ Provide AROBASE forecasts and test their use for downstream applications

Evaluate the **possibilities of AROBASE deployment** to compare to new observing systems of components and their interfaces and/or to support observing field campaigns or new measurement platforms

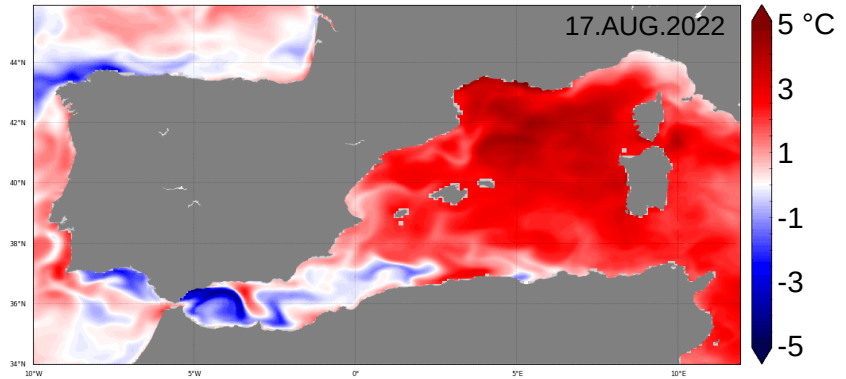
5. Case study

Investigating the air-sea exchanges and coupling for thunderstorm in Corsica 18 Aug. 2022 … in a context of a (marine) heat wave

thunderstorm structure in bow echo / Ajaccio / 18 Aug. 2022
via Twitter @BacciChristian



SST anomaly from CMEMS global product



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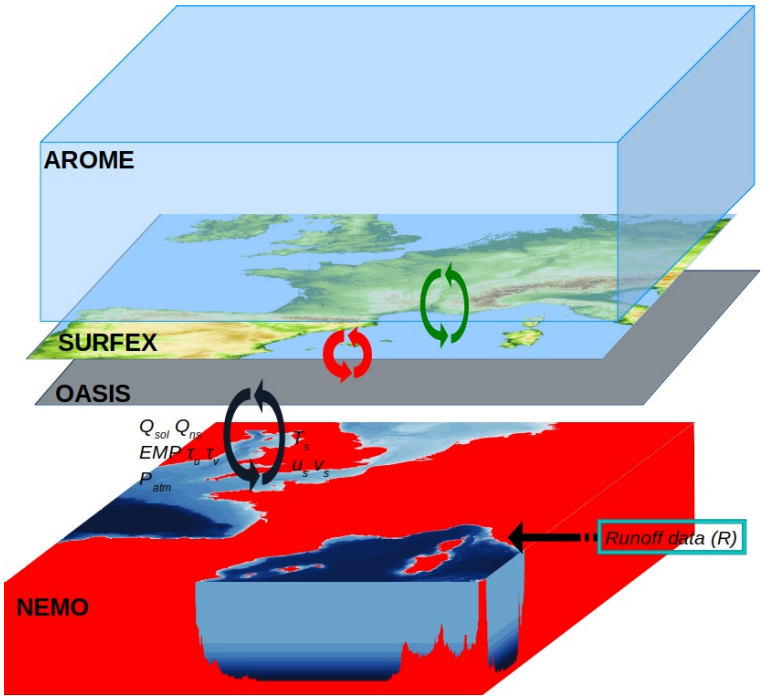


AROME-NEMO coupled system over Metropolitan France

ocean model **NEMO-FRA36** Madec et al. 2022	coupler **OASIS** Craig et al. 2017	atmospheric model **AROME France** Seity et al. 2011; Brousseau et al. 2016
v4.2	• SST • zonal and meridian components of surface current	cy46t1
Δt = 150s	→	Δt = 50s
Δx = 1/36°	**coupling frequency**: 600s	Δx = 1.3 km
50 z-levels	**interpolation method**: bilinear	90 η-levels
I.C. = FRA36 restart	←	I.C. = AROME-FR analyse (Météo-France)
L.C. = GLO12 (Mercator Ocean)	• net solar flux • net non-solar flux • feshwater flux • zonal and meridian components of wind stress • surface pressure	L.C. = ARPEGE (Météo-France) forecast

5. Case study

Investigating the air-sea exchanges and coupling for thunderstorm in Corsica 18 Aug. 2022

Simulation name	model(s)	SST	Turbulent sea flux parametrization
OPER	AROME FR 1.3 km	AROME SST analysis 00UTC → constant during the forecast	ECUME(v6)
ARO_sstpsy	AROME FR 1.3 km	GLO12 instantaneous SST field → constant during the forecast	ECUME(v6)
ARO_sstfra	AROME FR 1.3 km	FRA36 + GLO12 instantaneous SST field	ECUME(v6)
OA	AROME FR 1.3 km - NEMO-FRA36	FRA36 restart, then evolving during the forecast + GLO12 outside (non-evolving)	ECUME(v6)
OA_wasp	AROME FR 1.3 km - NEMO-FRA36	FRA36 restart, then evolving during the forecast + GLO12 outside (non-evolving)	WASP with Tp=f(Ua)
OA_wasp_tpm	AROME FR 1.3 km - NEMO-FRA36	FRA36 restart, then evolving during the forecast + GLO12 outside (non-evolving)	WASP with Tp from MFWAM

close to future standard for AROME forecast

"true" ocean coupling impact

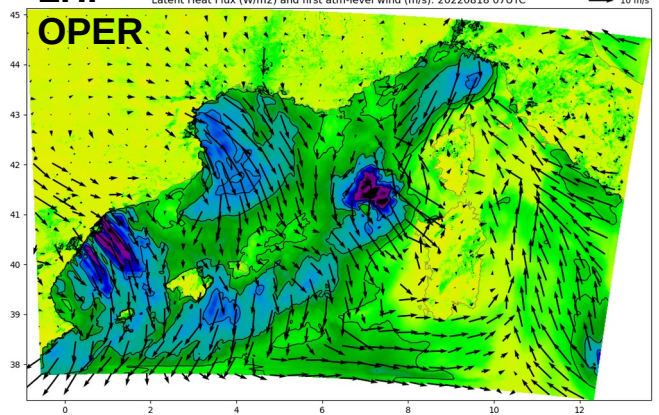
param. tests + atm-waves coupling preparation

5. Case study

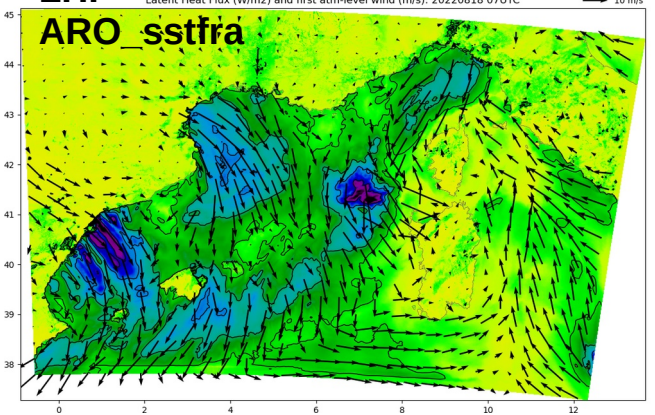
Investigating the air-sea exchanges and coupling for thunderstorm in Corsica 18 Aug. 2022

→ *sensitivity at sea surface*

LHF
OPER

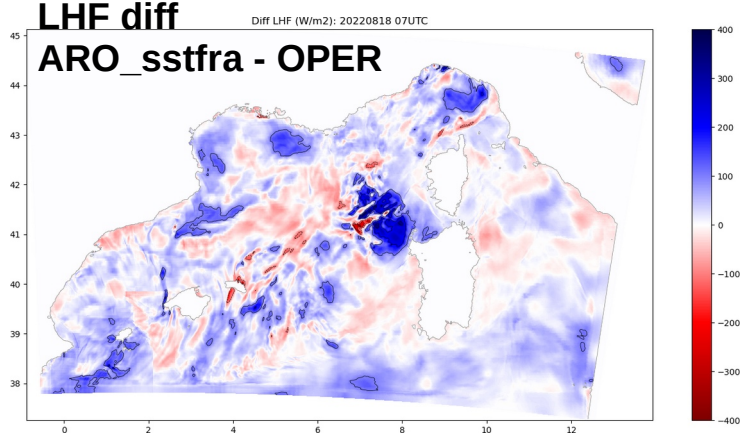


LHF
ARO_sstfra

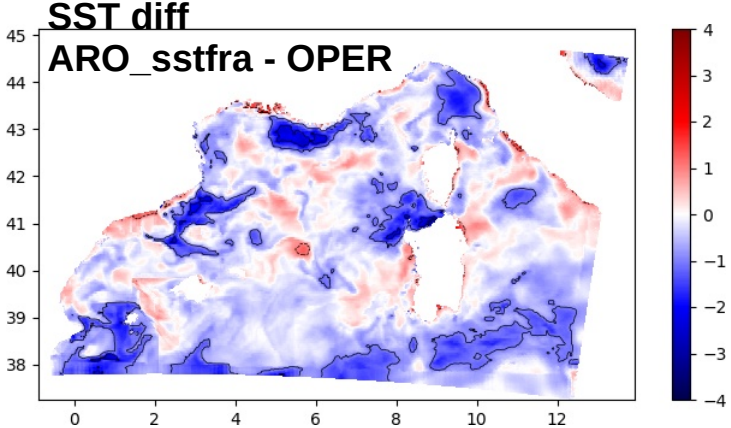


Response of sea surface heat fluxes directly related to SST differences at first order (+ some small changes in wind in the front/convective area)

LHF diff
ARO_sstfra - OPER



SST diff
ARO_sstfra - OPER



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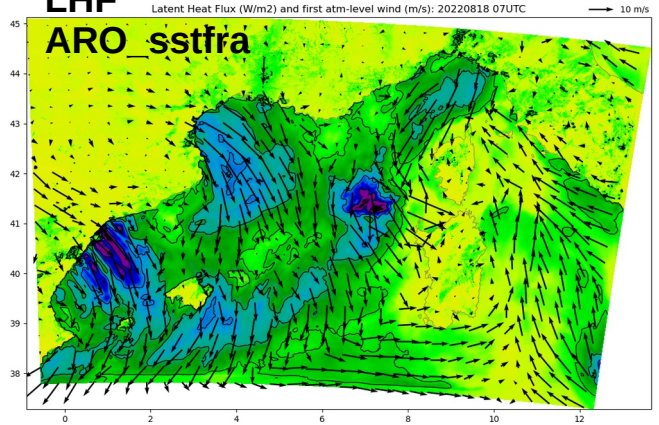
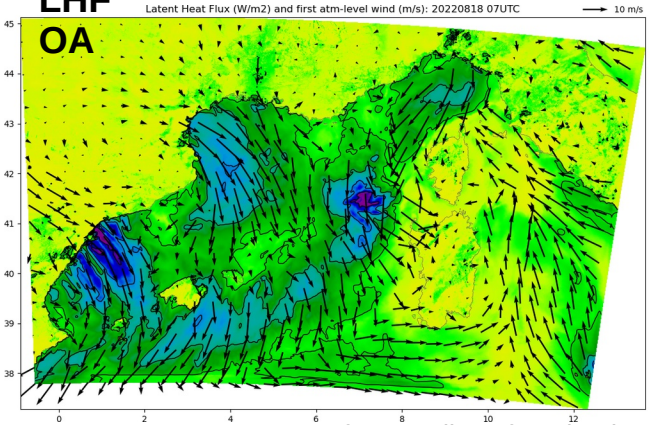
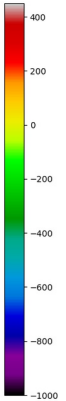
LHF
ARO_sstfra



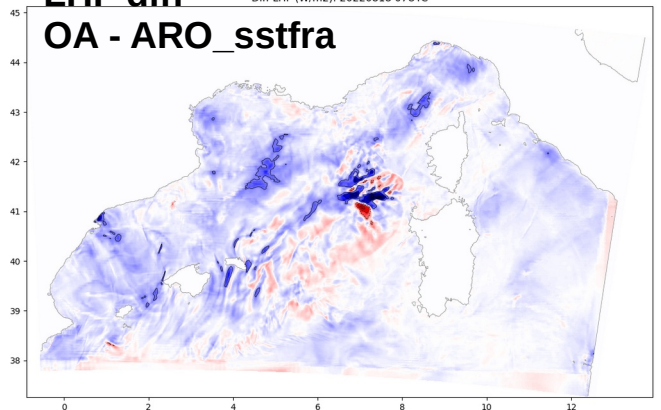
LHF
OA

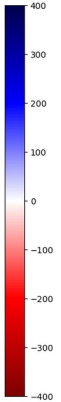




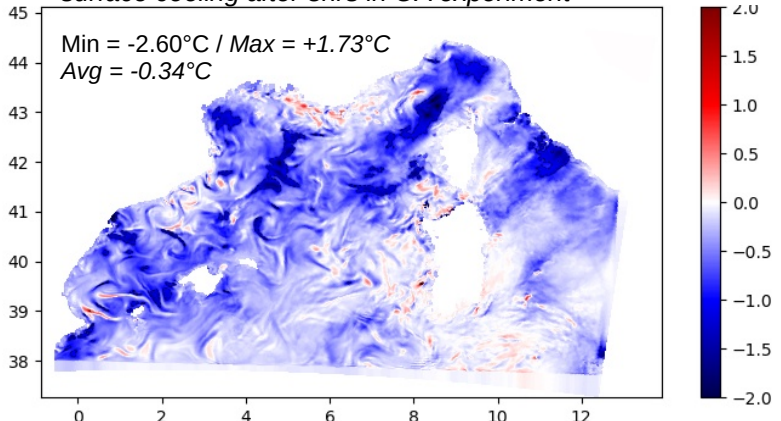
Interactive ocean coupling leads to a rapid and intense surface cooling that moderates the heat and moisture exchanges

LHF diff
OA - ARO_sstfra





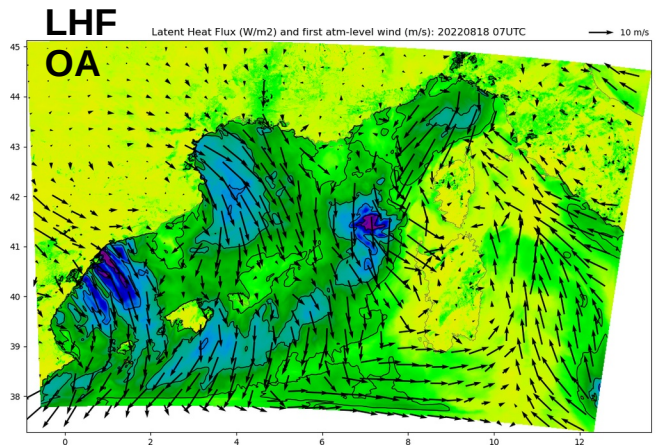
surface cooling after 8hrs in OA experiment

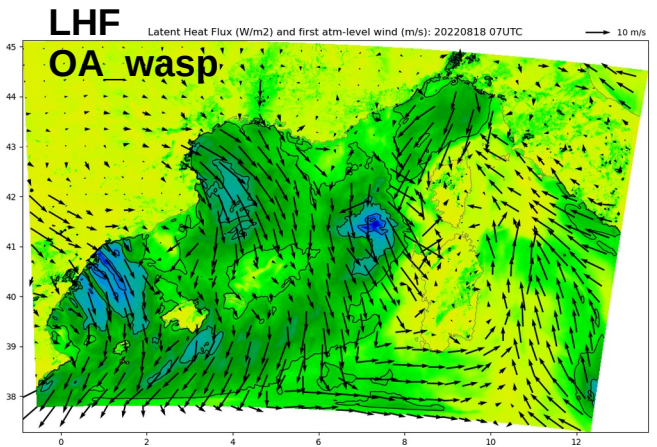


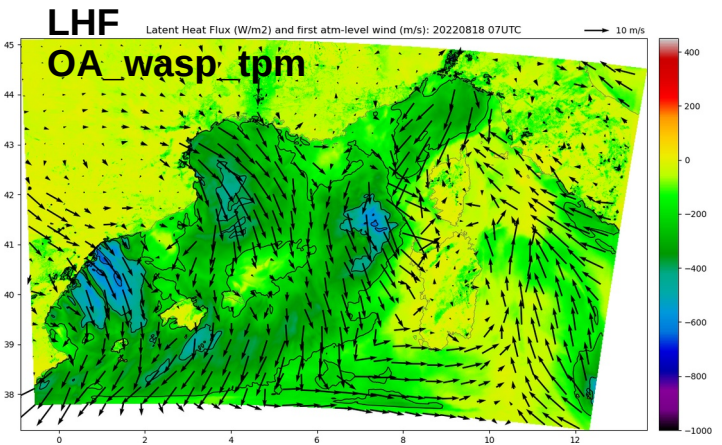
5. Case study

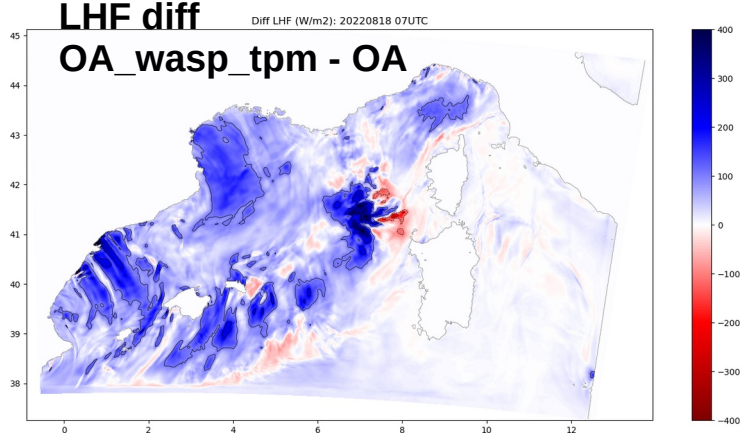
Investigating the air-sea exchanges and coupling for thunderstorm in Corsica 18 Aug. 2022

→ *sensitivity at sea surface*









The change of sea surface flux parameterization induces major changes in the air-sea exchanges.

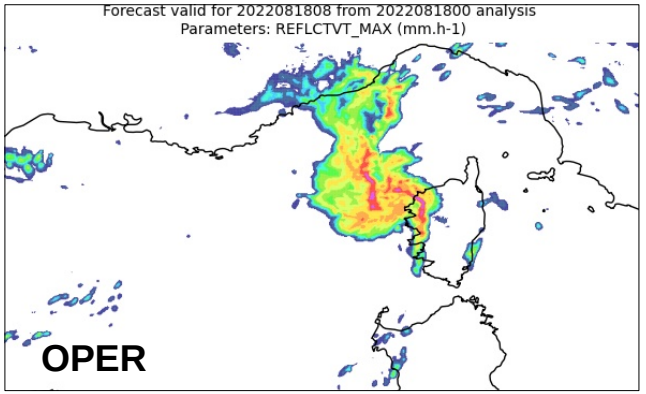
With WASP (compared to ECUME), in OA coupled mode:

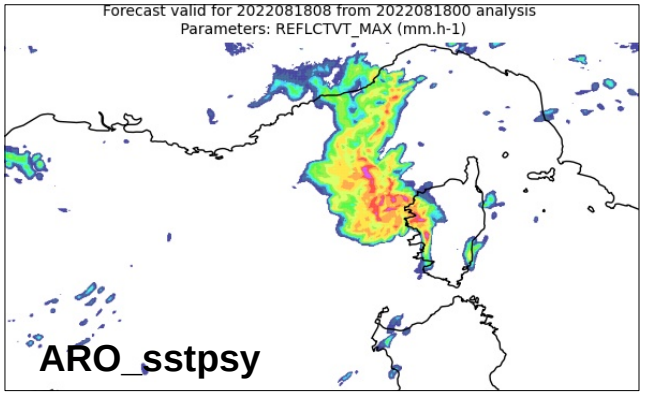
increase in roughness / drag → *lower wind* → ***less intense heat fluxes*** → *smaller surf cooling* + *lower unstability*

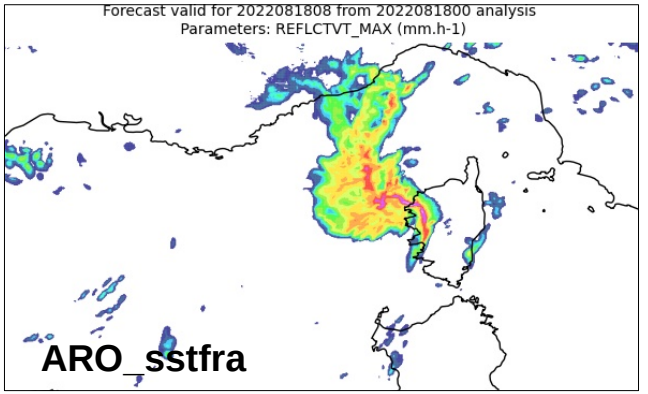
5. Case study

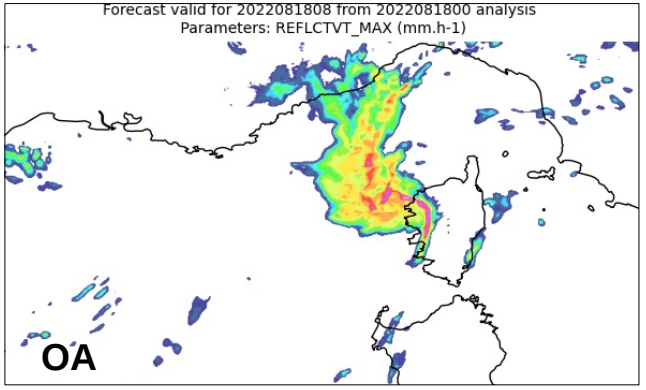
Investigating the air-sea exchanges and coupling for thunderstorm in Corsica 18 Aug. 2022

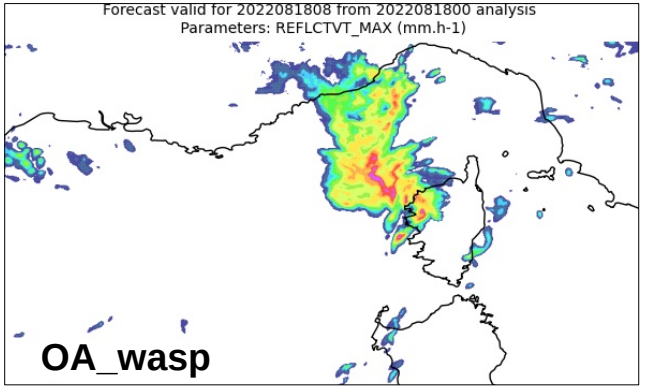
→ *sensitivity of convective system*

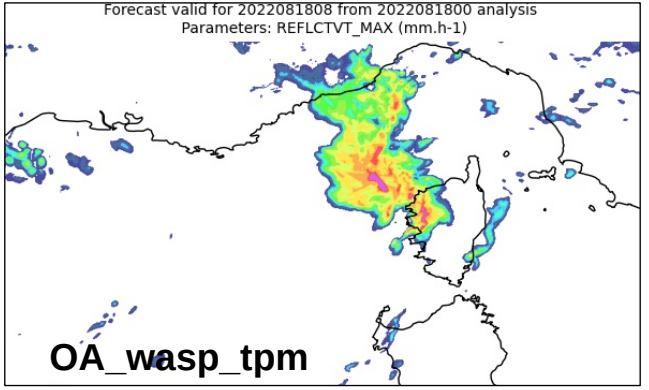












5. Case study

Investigating the air-sea exchanges and coupling for thunderstorm in Corsica 18 Aug. 2022

Preliminary conclusions:

- A small sensitivity to SST of the convective system despite modifications of surface fluxes. Some « what if » experiments (without warm anomaly) can be run…
- The ocean interactive coupling allows to take into account the rapid and intense ocean response with large mixing/cooling related to NW wind and convective system (up to -2.5°C in 8 hrs)
- The largest modifications are obtained with changes in the sea surface fluxes parameterization, that is in the heart of the OAW coupling:

  → Investigations on this specific aspect must be pursued, in particular at high-resolution and for strong [low] wind situations

6. Summary

New research tool at km-scale for understanding and representation of exchange processes, with a shared coupling interface between CNRM's climate models, Météo-France's NWP systems and even very small scale models (LES with MesoNH)

- Significance of the modularity criteria, that aims to facilitate collaborations with several modelling communities, and to ensure flexibility in order to answer and anticipate the various needs

A coupled system for numerical prediction (weather, air quality, sea state and upper-ocean) which imposes strong constraints (stability, performance, maintenance,…) but also opportunities to test new developments (physical parametrizations, new numerical methods) with dedicated analyse tools.

Deployment capacity on regions of interest (transportability), in particular for specific needs related to observation (field campaigns, new observing platforms,...)

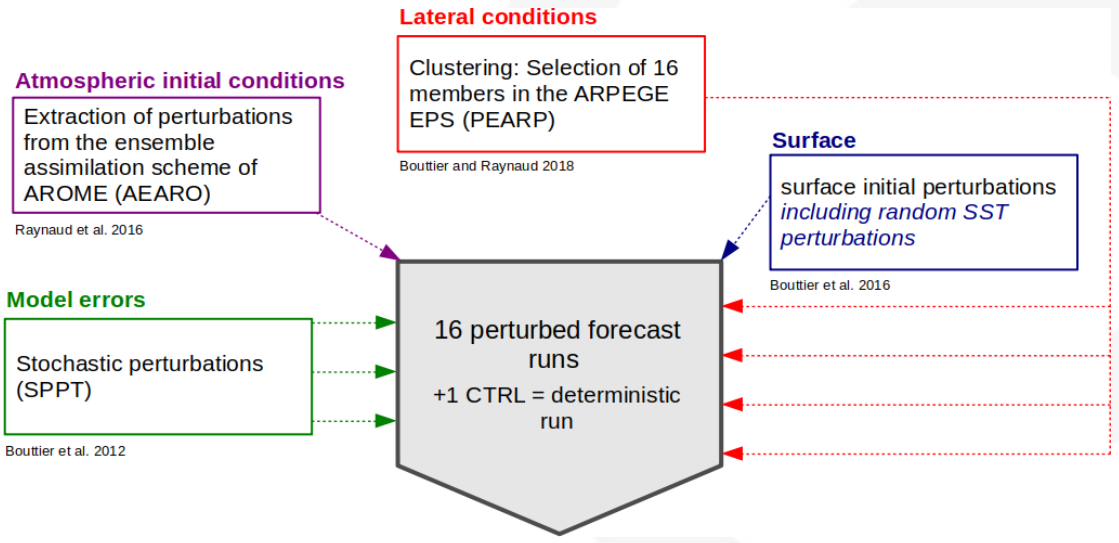
New possibility to provide modelling products, more integrated and more consistent, for the scientific community (ex : boundary conditions for very HR models), institutional product (wave/submersion vigilance, NWP downstream applications) and general public (with more integrated information on severe situations notably)

Thank you
for your attention!

cindy.lebeaupin-brossier@meteo.fr

Coupled ensemble forecast at kilometric scale

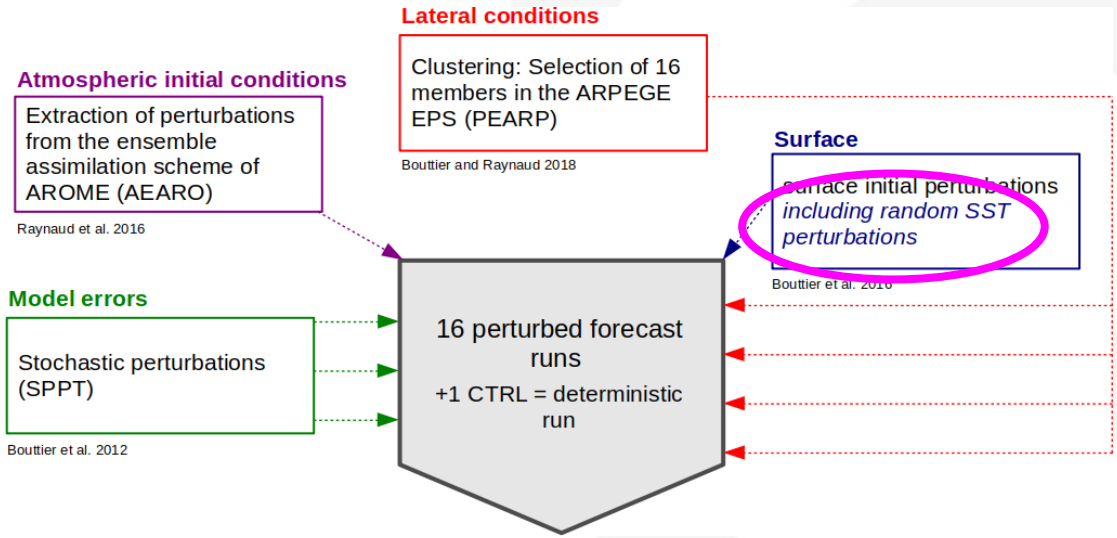
AROME-NEMO coupling over Metropolitan France:
used for OA coupled ensemble forecasts



AROME ensemble forecast (PEARO)

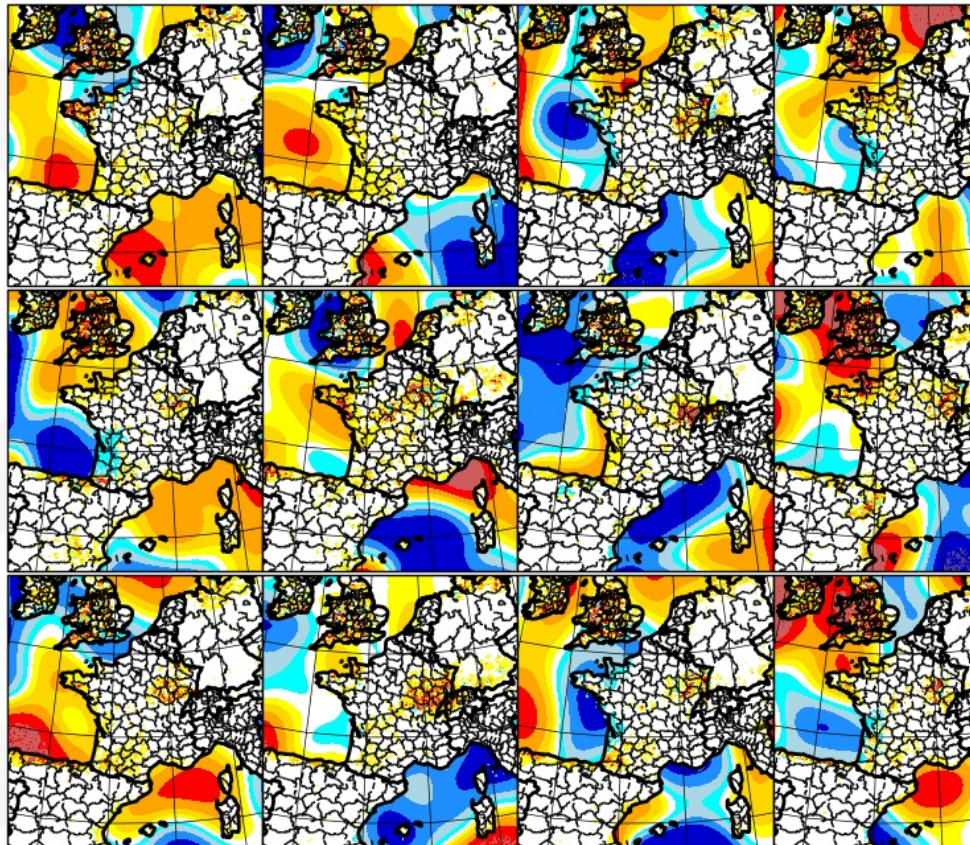
Coupled ensemble forecast at kilometric scale

AROME-NEMO coupling over Metropolitan France: used for OA coupled ensemble forecasts



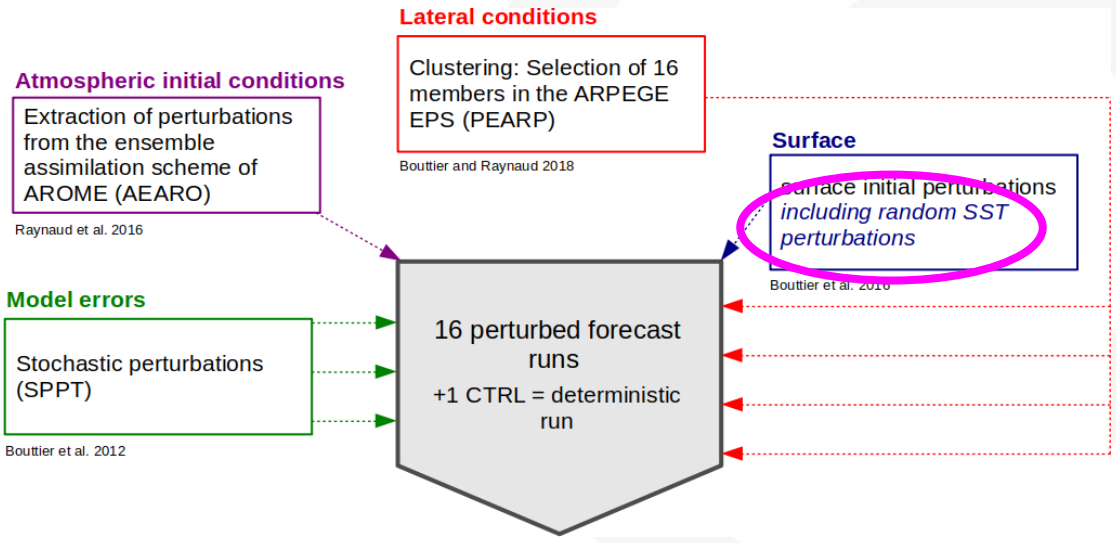
AROME ensemble forecast (PEARO)

Examples of perturbations applied operationally in AROME ensemble fct



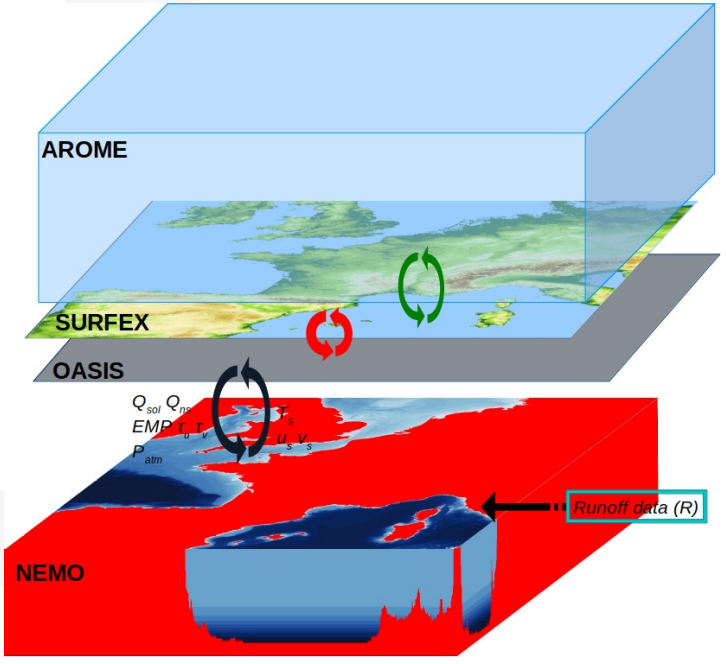
Coupled ensemble forecast at kilometric scale

AROME-NEMO coupling over Metropolitan France:
used for OA coupled ensemble forecasts



AROME ensemble forecast (PEARO)

AROME-NEMO coupled system over Metropolitan France

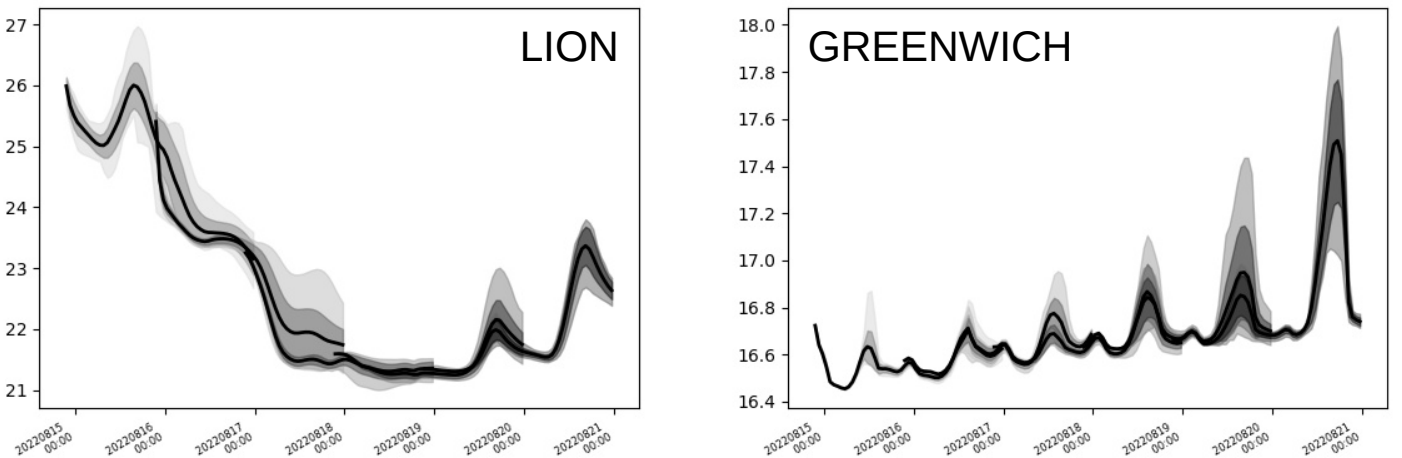


What are the role of SST perturbations on ensemble forecast @km?
How to perturb the ocean model efficiently for short-range NWP?
How perturbations propagate with coupling?

Coupled ensemble forecast at kilometric scale

AROME-NEMO coupling over Metropolitan France:
used for OA coupled ensemble forecasts
- How to perturb the ocean model efficiently for NWP?

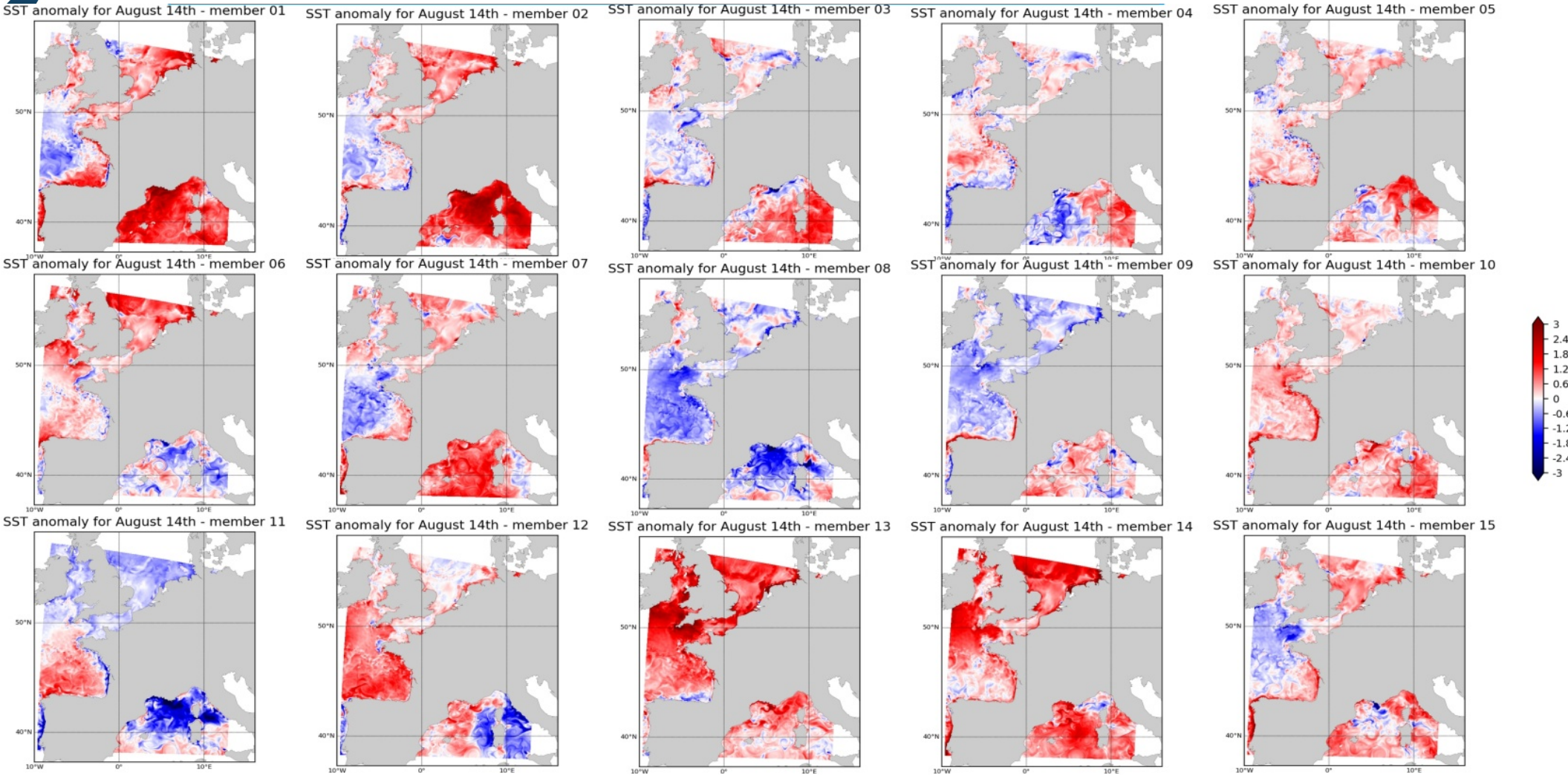
	model	Atm pert	Surf pert [SST]	Oce pert
PECPL_NO_PERT_OCE	AROME-NEMO	Yes	Yes for land [Prognostic SST in NEMO, initially the same for all members]	No (except due to coupling)
PECPL_WITH_PERT_OCEINIT	AROME-NEMO	Yes	Yes [Prognostic in NEMO]	Yes for initial state



*PECPL_NO_PERT_OCE: SST dispersion (**mean**, ±1std, min/max) for successive 48h-range forecast runs (from 14 Aug. 2021 21UTC to 18 Aug. 2021 21UTC) at LION [4.7°E-42.1°N] (left) and at GREENWICH [0°E-50.4°N] (right)*

Coupled ensemble forecast at kilometric scale

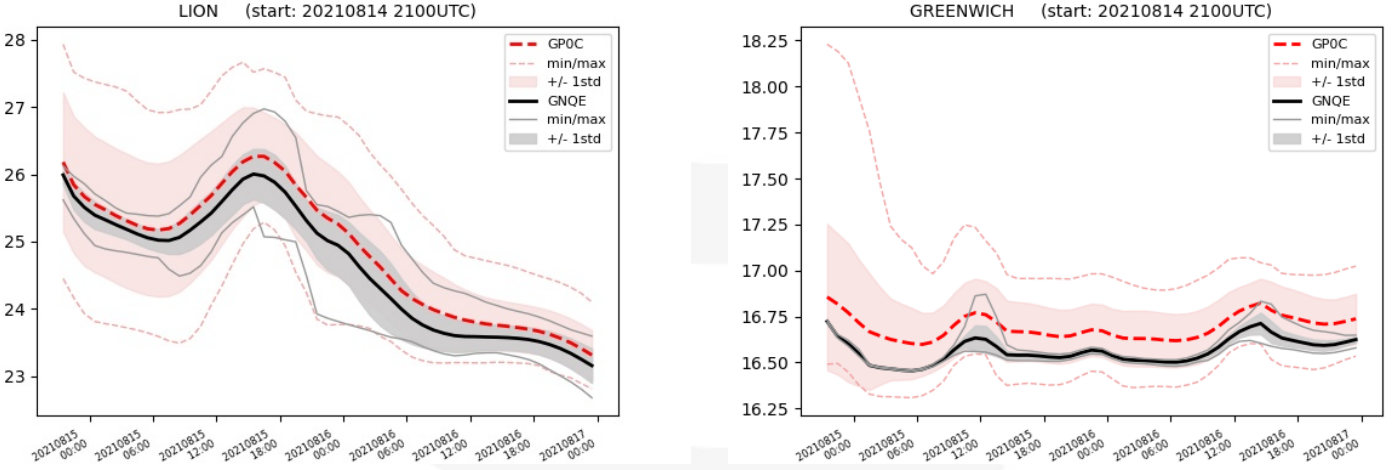
SST from perturbed ocean initial states



Coupled ensemble forecast at kilometric scale

AROME-NEMO coupling over Metropolitan France:
used for OA coupled ensemble forecasts
- How to perturb the ocean model efficiently for NWP?

	model	Atm pert	Surf pert [SST]	Oce pert
PECPL_NO_PERT_OCE	AROME-NEMO	Yes	Yes for land [Prognostic SST in NEMO, initially the same for all members]	No (except due to coupling)
PECPL_WITH_PERT_OCEINIT	AROME-NEMO	Yes	Yes [Prognostic in NEMO]	Yes for initial state



Comparison of SST dispersion between PECPL_NO_PERT_OCE [black] and PECPL_WITH_PERT_OCEINIT [red] for forecast run starting from 14 Aug. 2021 21UTC at LION [4.7°E-42.1°N] (left) and at GREENWICH [0°E-50.4°N] (right)