Ocean-wave-atmosphere-coupling in the AROBASE modelling system for coastal wave warning and sensitivity to flux parameterisation

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4th International Workshop on Waves, Storm Surges, and Coastal Hazards – 2025/09/22

Objectives

Deepen understanding of the physics of ocean-wave-atmosphere interactions and improve the realism of simulations

- Represent phenomena in **detail (kilometer scale)**
- Ensure **consistency** of data obtained by/provided to models throughout simulations
- Take into account **feedbacks** in a **multi-component system (couplings)**
- Focus on **complex exchange processes**

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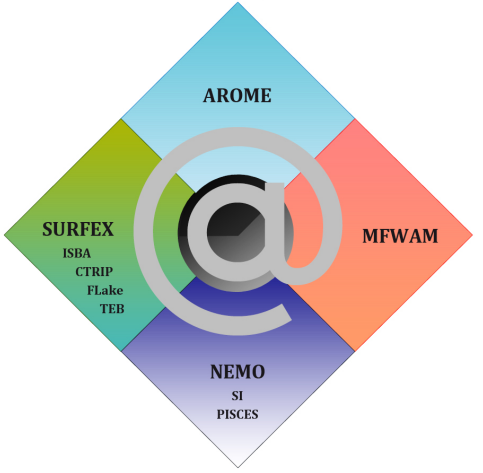
Operational application

- Insert **wave coupling** into a **new numerical tool** for weather forecasting at Météo-France: the **AROBASE km-scale multi-coupled modelling system**
- Improve **forecasting** of meteorological situations, including those involving **coastal risks**



AROBASE
(AROme-Based coupled SystEm)

Plan

1. Study cases: well anticipated storms
2. Coupled modelling system
3. Results
4. Conclusion

1. Study cases:
two well-anticipated storms

Eunice storm (22/02/18)

Strong winter storm

southern Great Britain; northern France, Belgium and Germany; Netherlands...

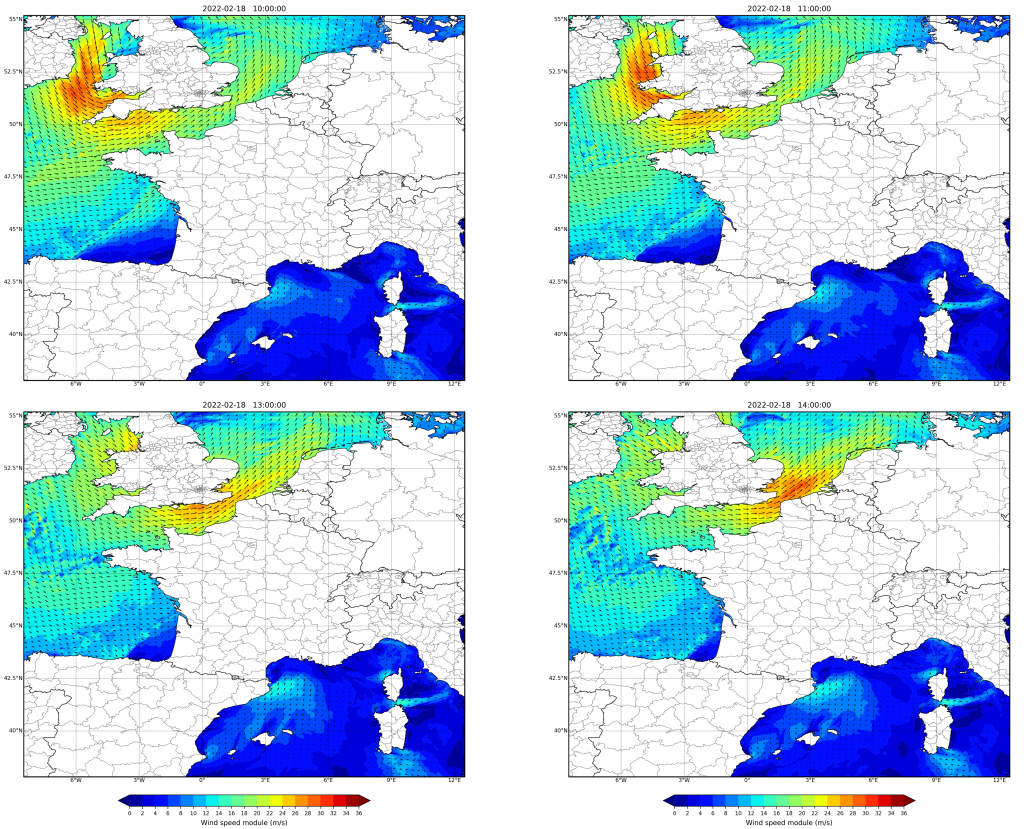
Météo-France: orange alert

for ***strong winds*** and ***waves flooding***

Combination of coastal flooding factors

in some places:

- strong winds and gusts
  - south of England: 196 km/h
  - Pas-de-Calais: 176 km/h
- high waves
- temporary surge
- high tide +
  high tidal coefficient (90)



AROME wind (10m) forecast

►►► **Coastal flooding** (Pas-de-Calais, Somme, Seine-Maritime)

Ciarán storm (23/11/1-2)

Severe autumn storm

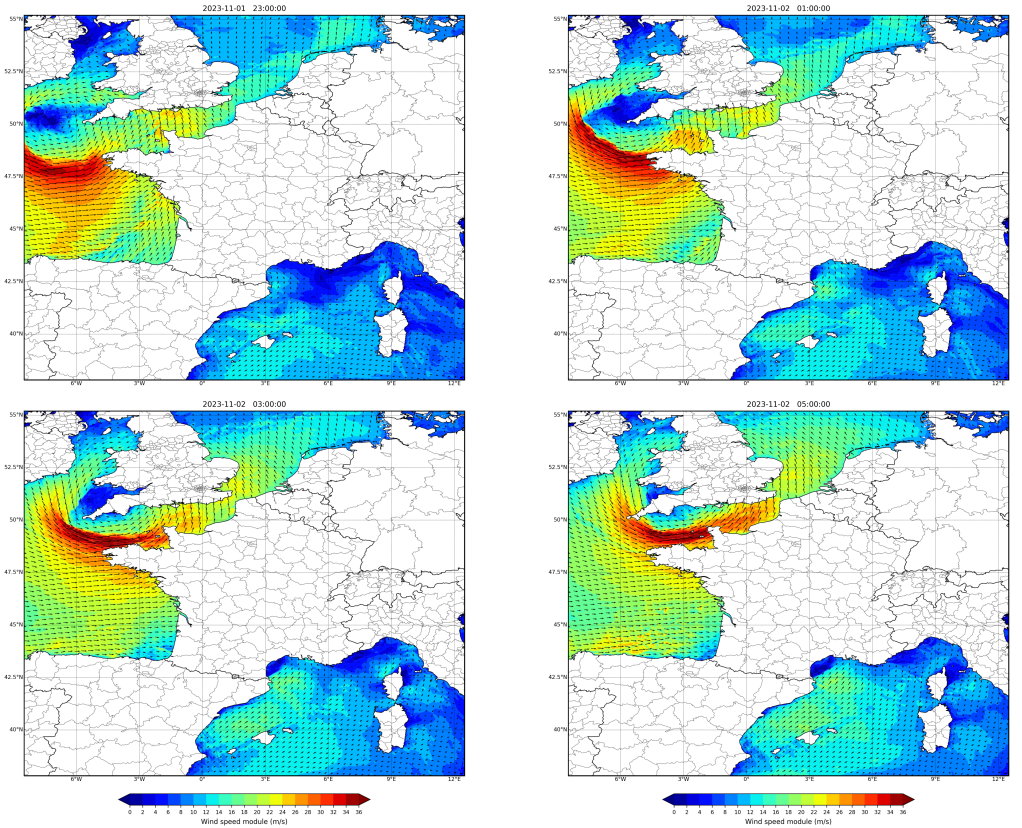
Brittany; Normandy; English Channel;
south and south-east of England

Météo-France: red and **orange alerts**
for ***strong winds*** and ***waves flooding***

Record-breaking conditions observed

- Very strong winds and gusts
  (> 170 km/h in Brittany)
- Very high waves
  - 12m at the tip of Brittany
  - 8-10m on the Atlantic coast
  - 4-8m in the English Channel
  - $H_{1/3}$ 13,6m and H_{max} 21,1m
    at Pierres-Noires buoy
- High storm surge (80-120 cm)

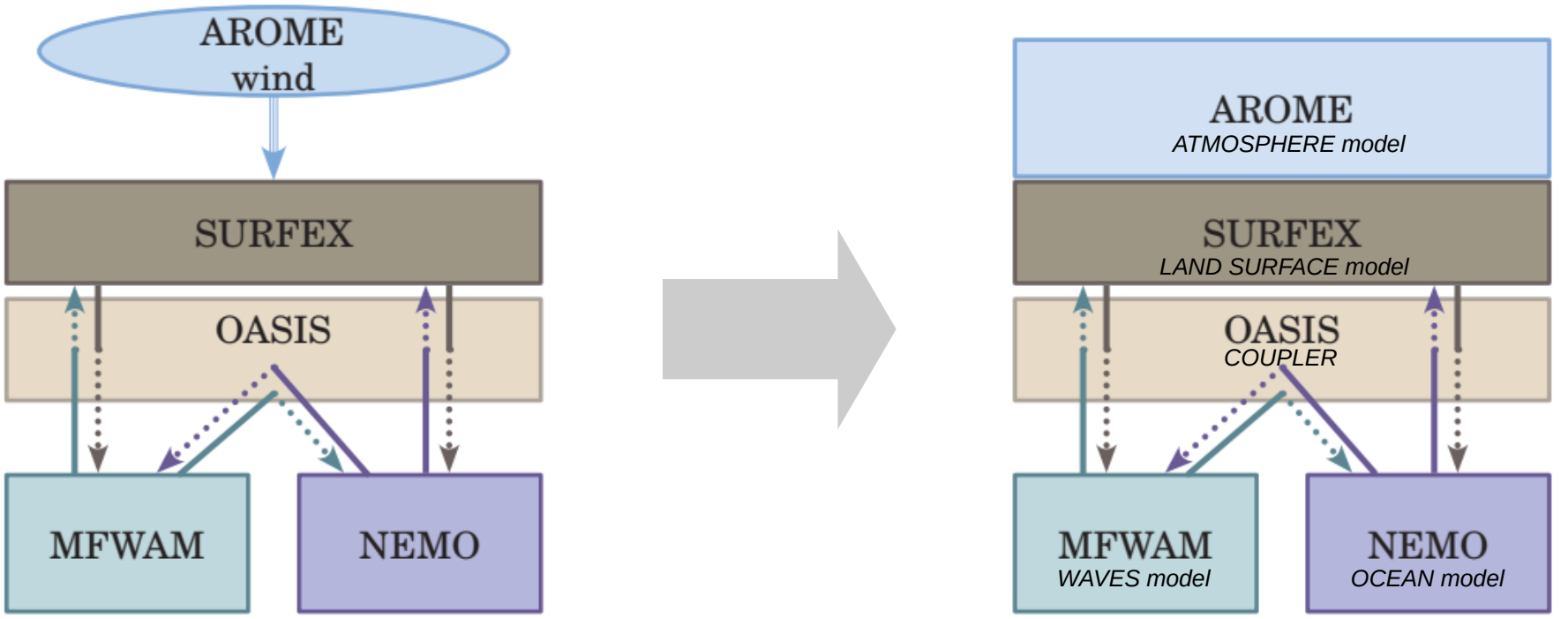
However: medium tidal coefficient (71)
+ storm surge out of phase with high tide



AROME wind (10m)
forecast

2. Coupled modelling system

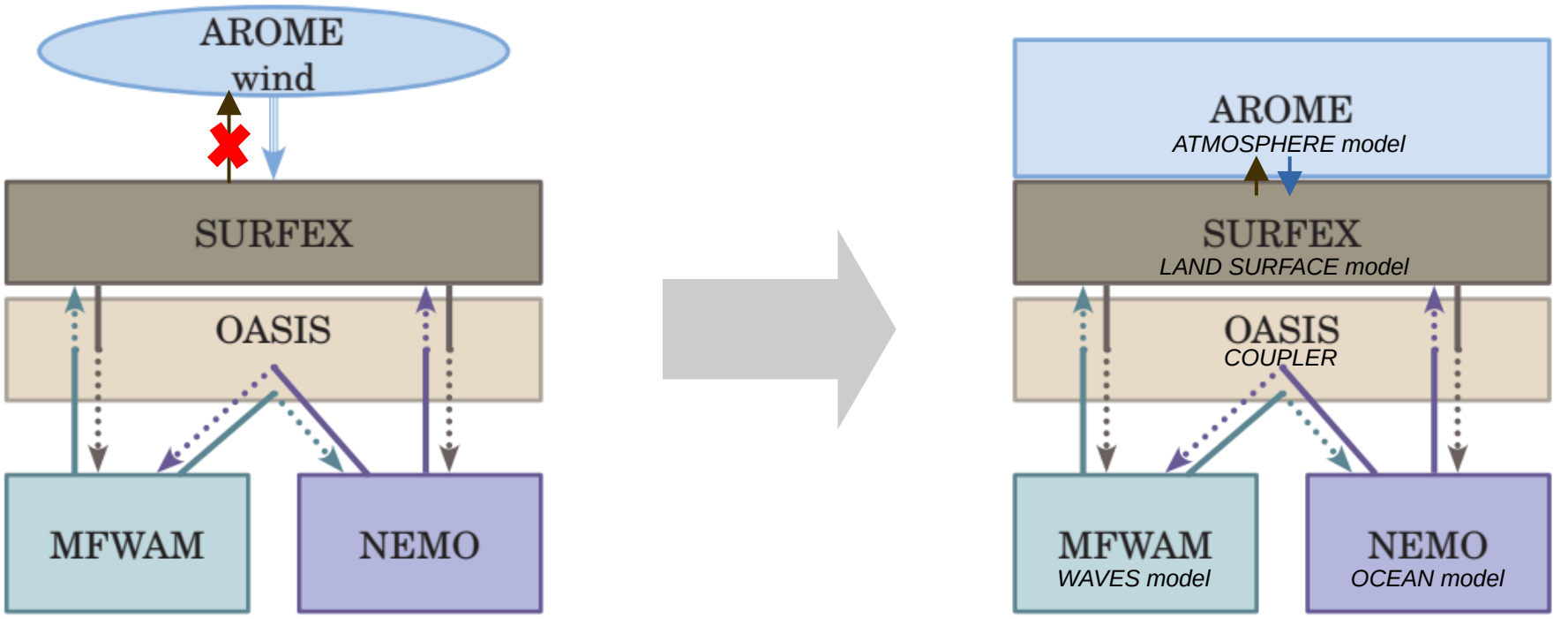
Assembling the coupled system



Study coupled system

AROBASE target coupled system

Assembling the coupled system



Study coupled system

AROBASE target coupled system

Configuration of the experiments

Couplings

experiment	W-FRC (forced)	A-FRC (forced)	CPL1-AW (1 coupling)	CPL1-AO (1 coupling)	CPL2-AW-AO (2 couplings)	CPL3-AWO (3 couplings)
models	--- MFWAM ---	SURFEX --- ---	SURFEX MFWAM ---	SURFEX --- NEMO	SURFEX MFWAM NEMO	SURFEX MFWAM NEMO
couplings	--- --- ---	--- --- ---	AW-(WA) --- ---	--- AO-(OA) ---	AW-(WA) AO-(OA) ---	AW-(WA) AO-(OA) WO-OW

Parameterisations

- COARE0
- COARE1
- COARE2
- WASP
- ECUME

6 couplings x 5 parameterisations = 30 configurations

30 configurations x 2 storms = 60 experiments

Turbulent fluxes at the air-sea interface

For the calculation of **turbulent air-sea fluxes** (momentum τ, latent heat LE and sensible heat H), several **parameterisations** are available in SURFEX. The calculation of these fluxes is partly based on transfer coefficients C_x, which depend on the stability of the atmosphere and are themselves functions of neutral transfer coefficients c_{xn}.

ECUME		c_{xn} = neutral wind polynomials from multi-campaigns calibration	*without wave coupling*
ECUME-Wave		MFWAM **C_D** (Giordani et al., sub.)	*with wave coupling*
		c_{xn} = function of α_{ch}	
COARE (Fairall et al., 2003)	**0**	α_{ch} (Smith)	
	1	α_{ch} = function of **T_p** (Oost)	
	2	α_{ch} = function of **H_s** (TY01)	
WASP		α_{ch} = function of **$T_{p'}$** (Bouin et al., 2024)	

Depending of the choice of parameterisation, **α_{ch}, T_p, H_s** or **$T_{p'}$** is:

without wave coupling	*with wave coupling*
function of AROME wind	taken from MFWAM

α_{ch}: Charnock coefficient
H_s: sea surface height (wind+swell)
T_p: peak period of sea (wind+swell)
$T_{p'}$: peak period of wind sea

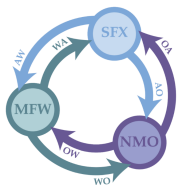
3. Results

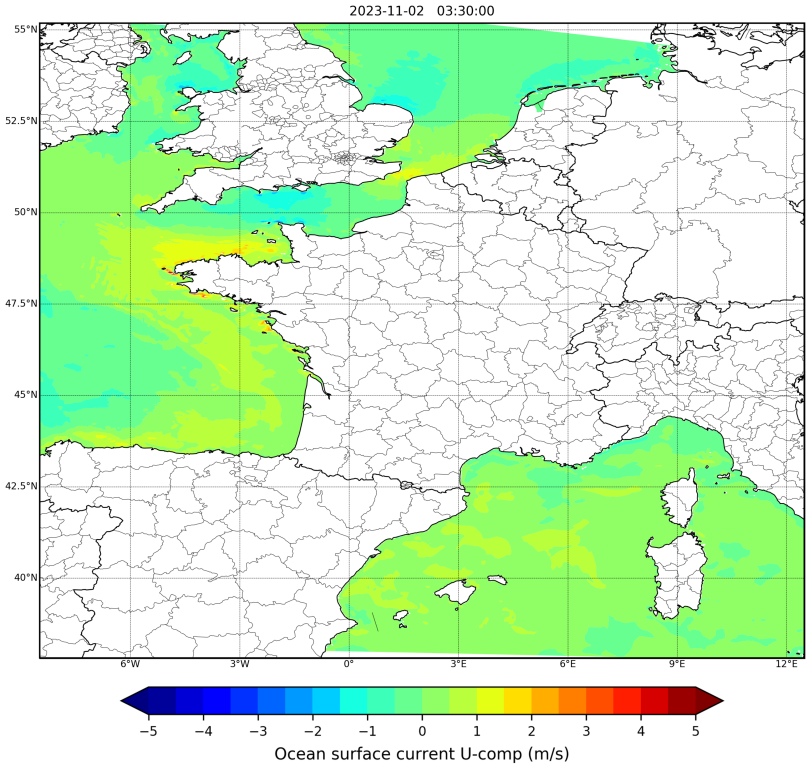
Couplings sensitivity

CIARÁN – effect of ocean/wave coupling on NEMO

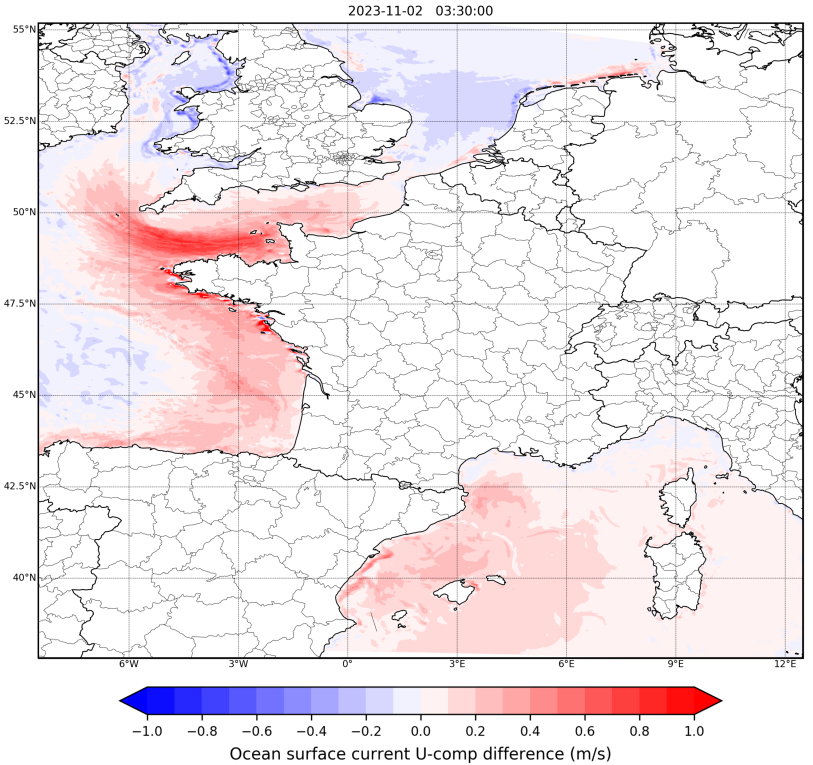
COARE0 (Fairall et al., 2003)

α_{ch} (Smith)





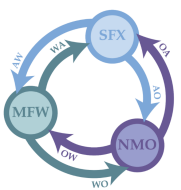
Ocean surface current U-comp
Ref: CPL3-AWO
(COARE0)



Ocean surface current U-comp
Diff: CPL3-AWO − CPL2-AW-AO
(COARE0)

COARE0 (Fairall et al., 2003)

α_{ch} (Smith)



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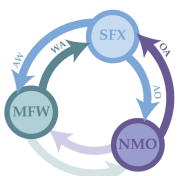
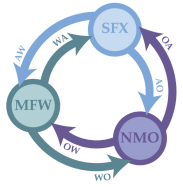


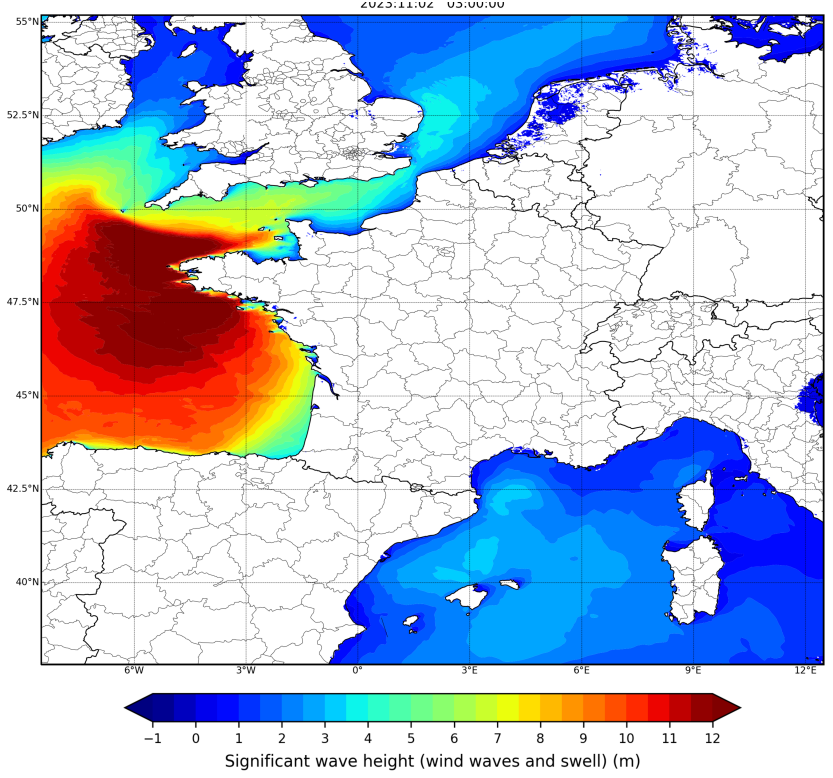
Couplings sensitivity

CIARÁN – effect of ocean/wave coupling on MFWAM

COARE0 (Fairall et al., 2003)

α_{ch} (Smith)

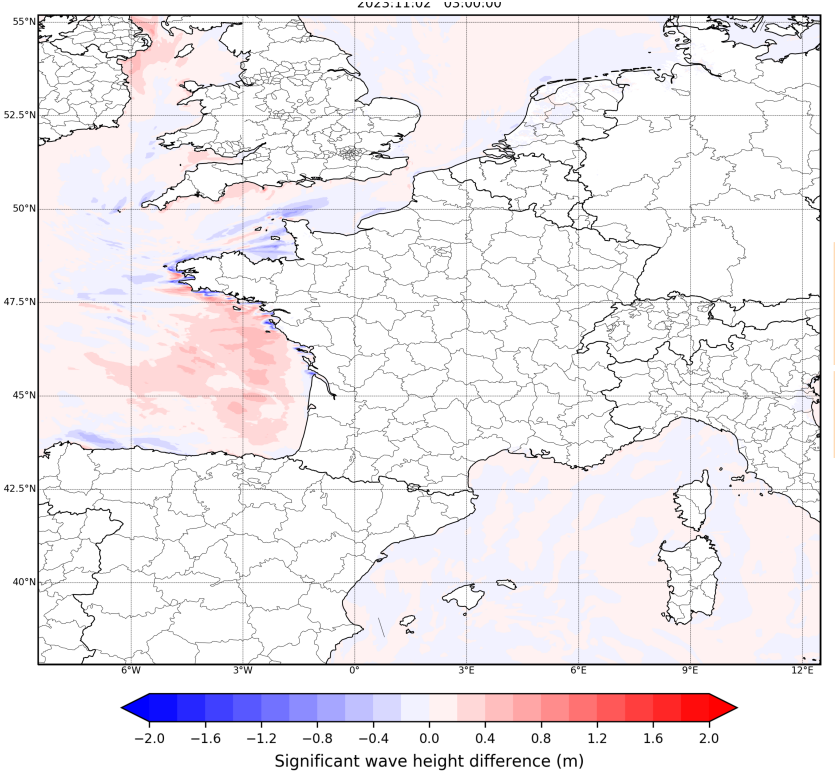




SWH

Ref: CPL3-AWO

(COARE0)



SWH

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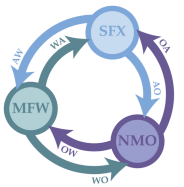
(COARE0)

COARE0 (Fairall et al., 2003)

α_{ch} (Smith)



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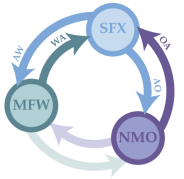

Couplings sensitivity

	on SURFEX	*on NEMO*	*on MFWAM*
Effect of (WA) coupling	**momentum flux, heat fluxes**	surface currents, SSH (even SST)	None
Effect of (OA) coupling	**heat fluxes** (consistent SST in the coupled model)	None	None in Eunice case, some in Ciarán case
Effect of WO-OW coupling	heat fluxes	**surface currents (even SST)**	**SWH, periods, Stokes currents**

Comparative study of the different experiments
→ isolation of the effect of each coupling (even without feedback on atmosphere)

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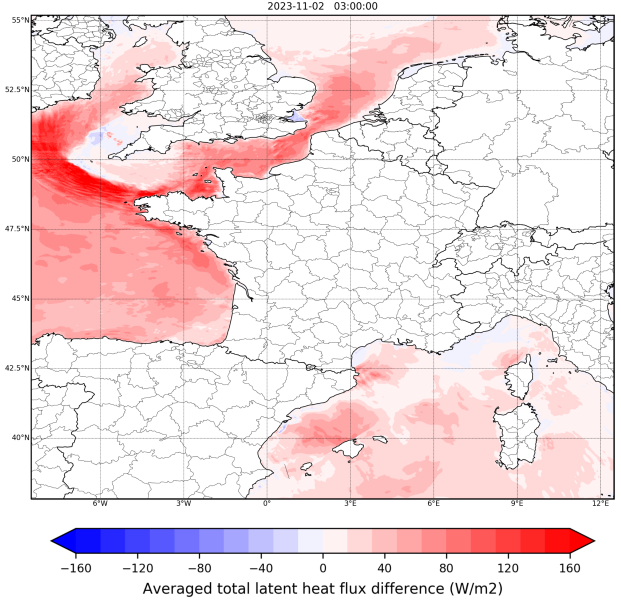
Effect of WO-OW coupling	heat fluxes	**surface currents (even SST)**	**SWH, periods, Stokes currents**

Comparative study of the different experiments
→ isolation of the effect of each coupling (even without feedback on atmosphere)

A coupling between 2 components can have an effect on the 3rd one: the whole is greater than the sum of its parts

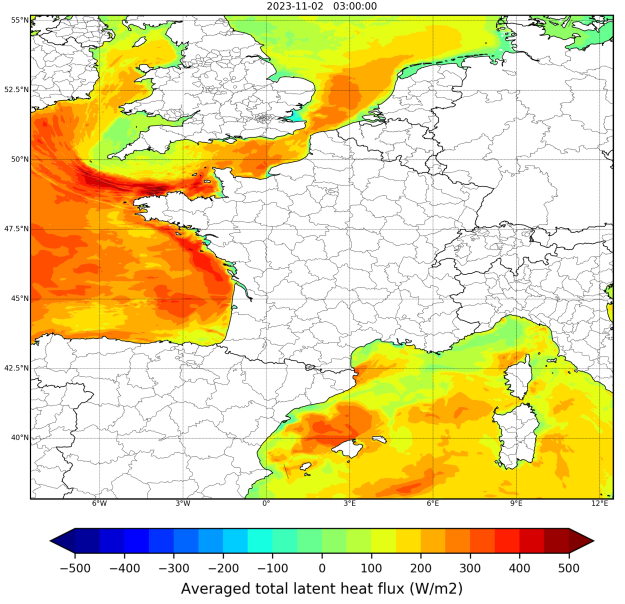
Turbulent fluxes parameterisation sensitivity

CIARÁN
turbulent latent heat flux



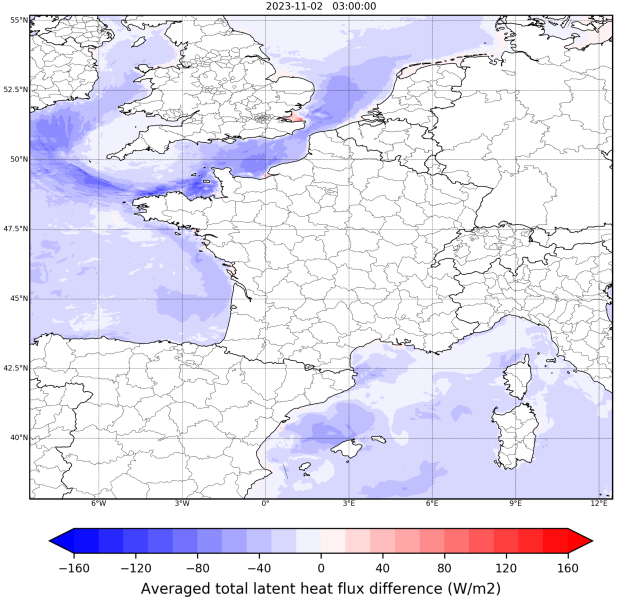
CPL3-AWO
Diff: ECUME-Wave − COARE0

ECUME-Wave (Giordani et al., sub.)	MFWAM **C_D**	–	**COARE0** α_{ch} (Smith)



***Ref**: CPL3-AWO*

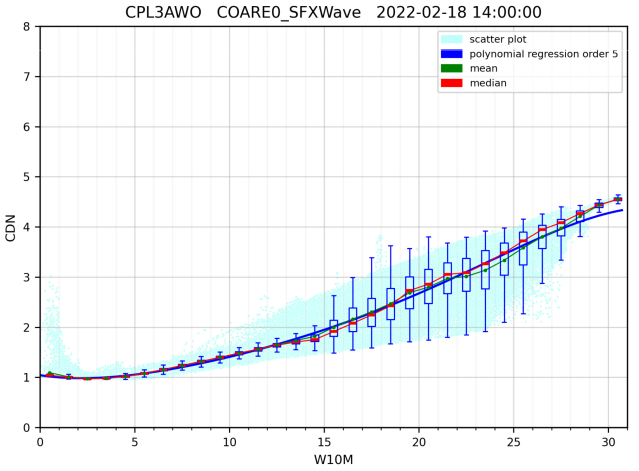
COARE0 (Fairall et al., 2003)	α_{ch} (Smith)

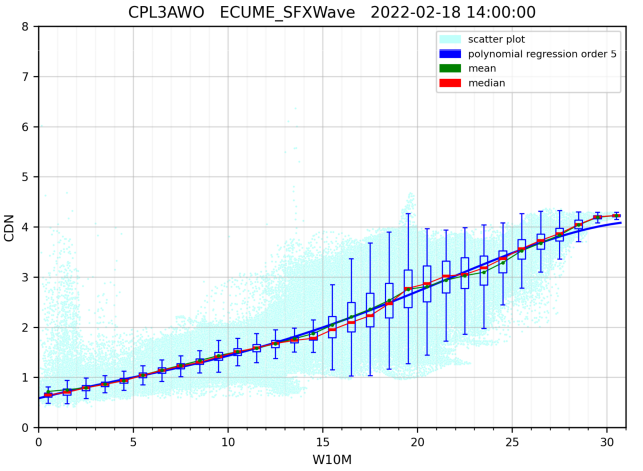


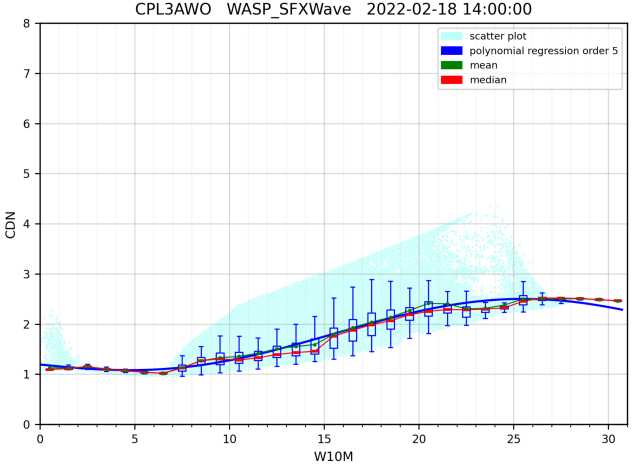
CPL3-AWO
Diff: WASP − COARE0

WASP (Bouin et al., 2024)	α_{ch} function of $T_{p'}$	–	**COARE0** α_{ch} (Smith)

CDN as a function of wind



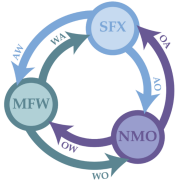




EUNICE, 22/02/18 at 14:00

CPL3-AWO

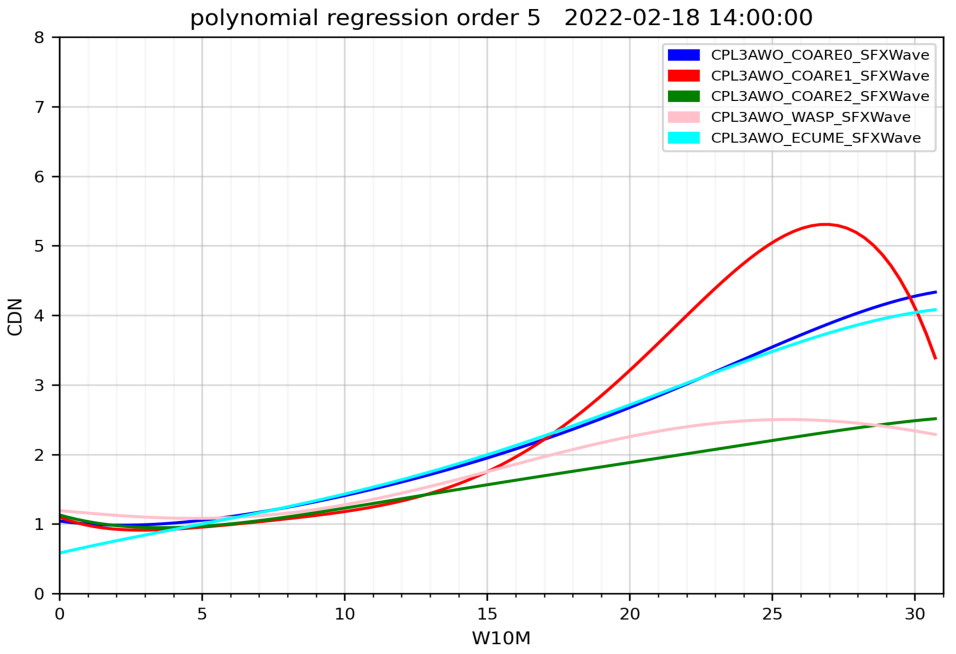
- COARE0 (ref)
- ECUME
- WASP



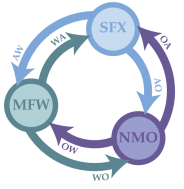
→ dispersion (non-linear and non-local relationship with wind)

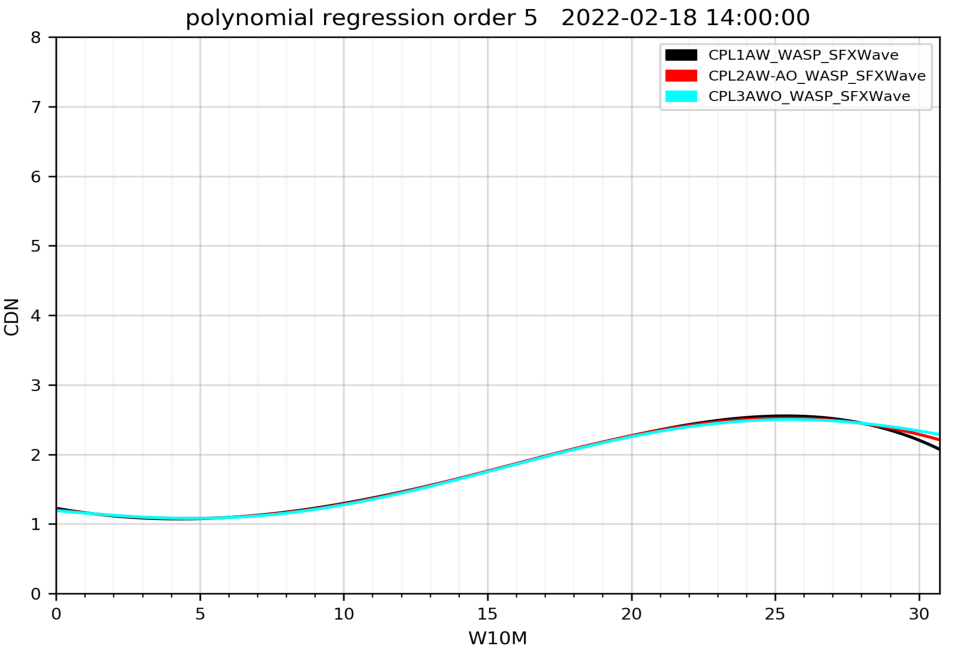
CDN as a function of wind

EUNICE, 22/02/18 at 14:00



CPL3-AWO couplings
different parameterisations



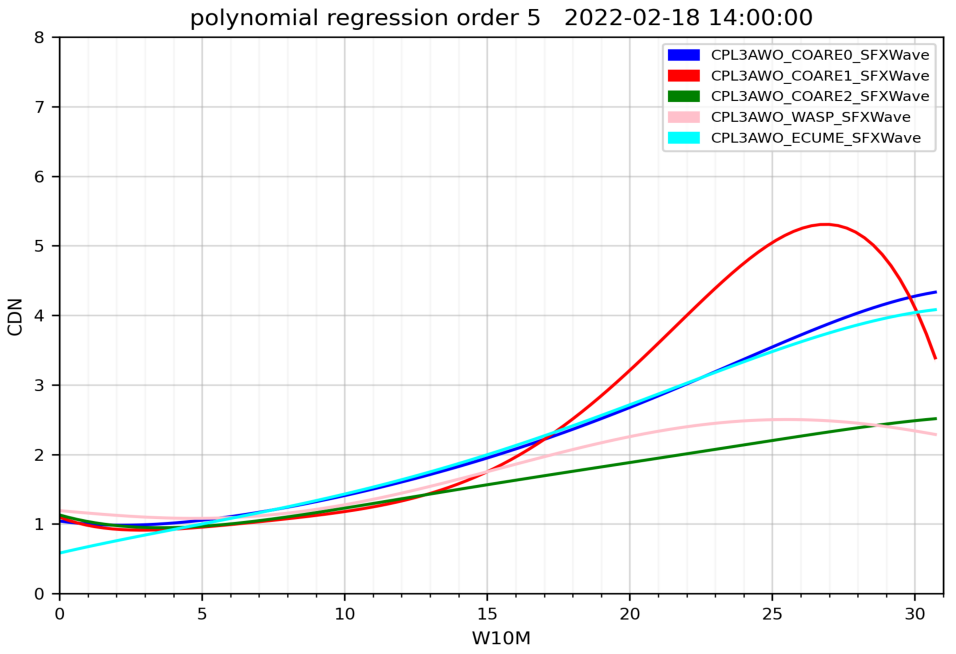


different couplings
WASP parameterisation

WASP (Bouin et al., 2024)	α_{ch} function of $T_{p'}$

CDN as a function of wind

EUNICE, 22/02/18 at 14:00



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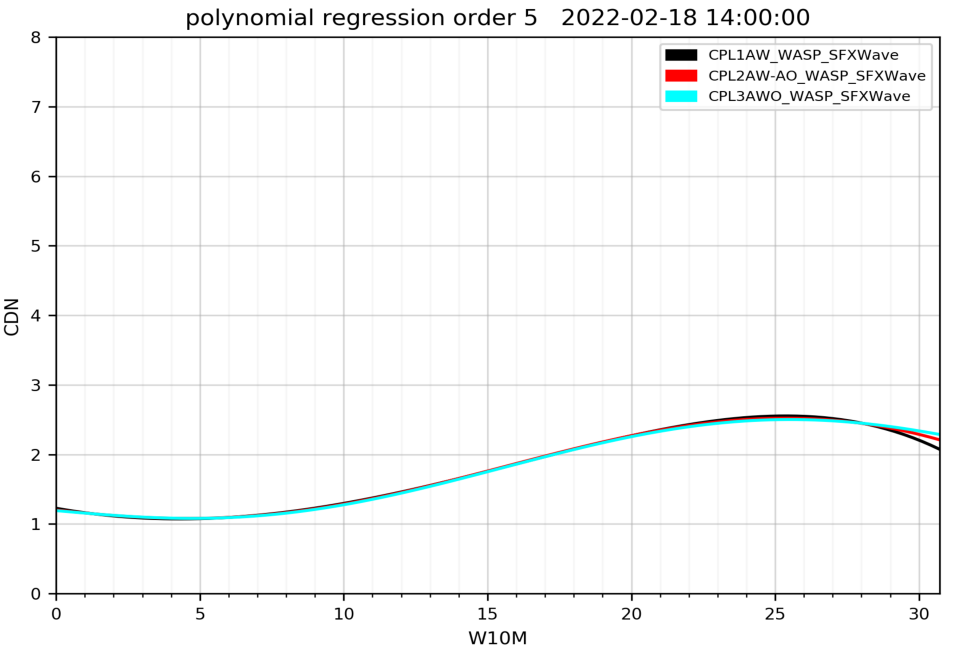


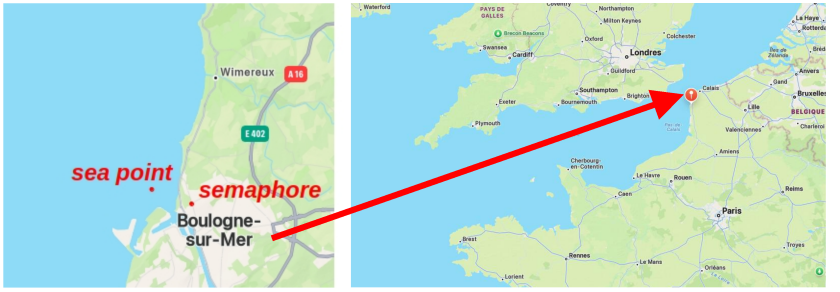
different couplings
WASP parameterisation

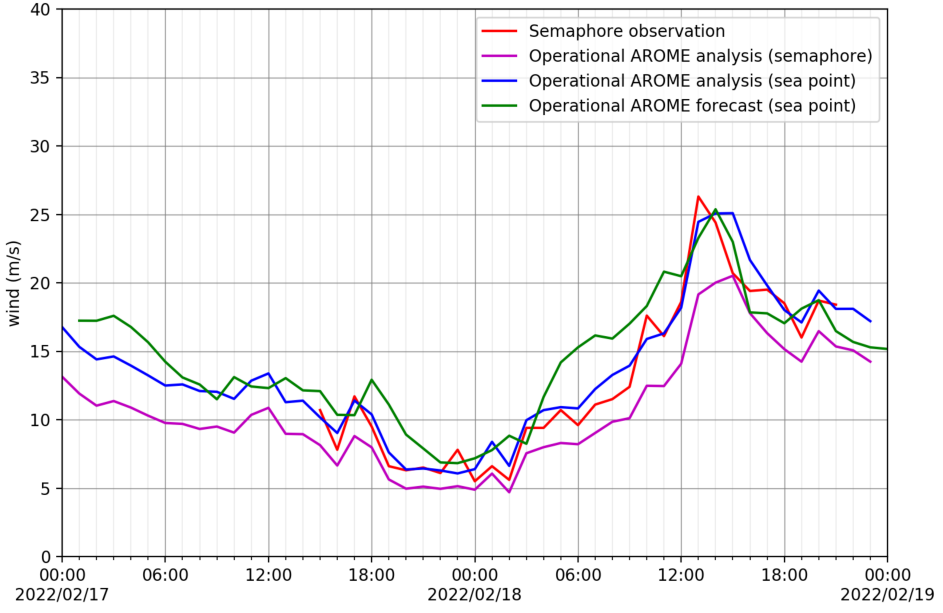
Parameterisation choice has more impact on transfer coefficients and turbulent fluxes than couplings choice

SWH and wind timeseries

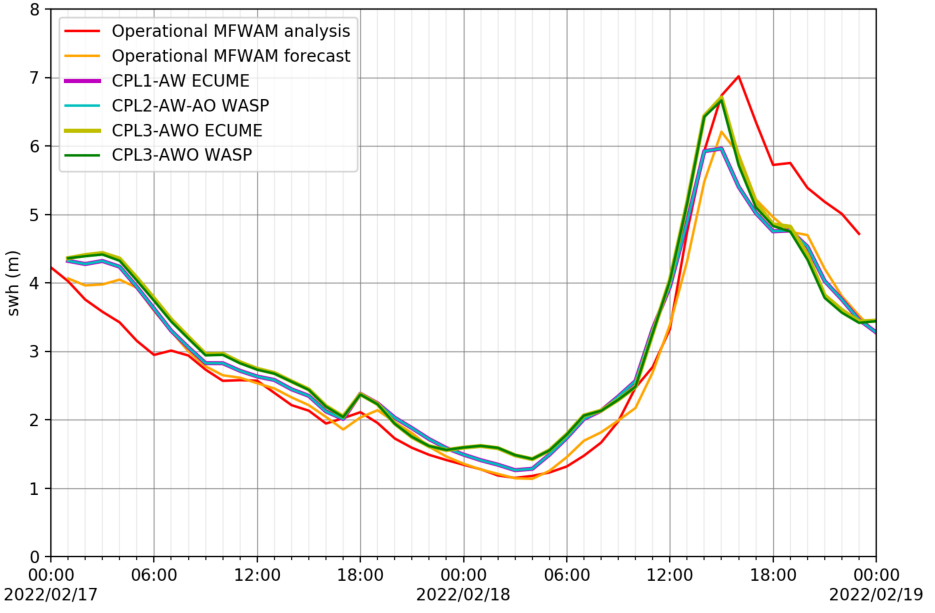
Eunice storm at Boulogne-sur-mer

Comparison of **10m-wind** and **SWH** between in-situ **observations** (semaphore), **analysis** and operational **forecasts** (MFWAM 0.025° (Météo-France) and different **experiments** (CPL*)





wind (10m)



SWH

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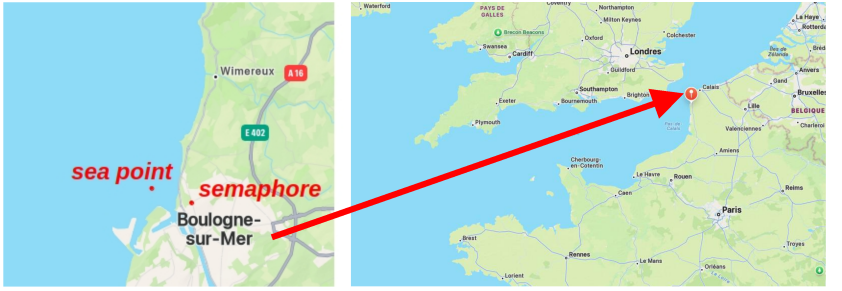

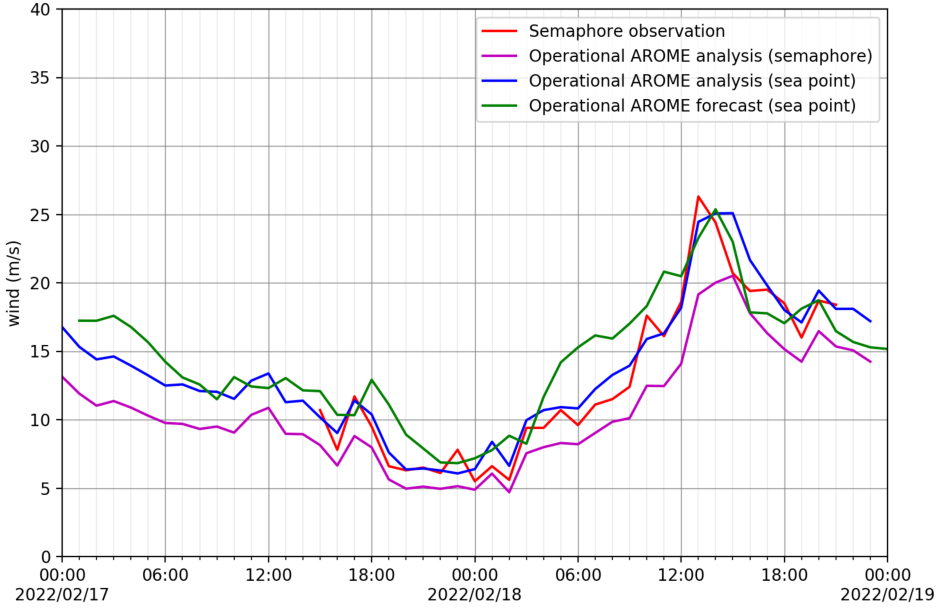

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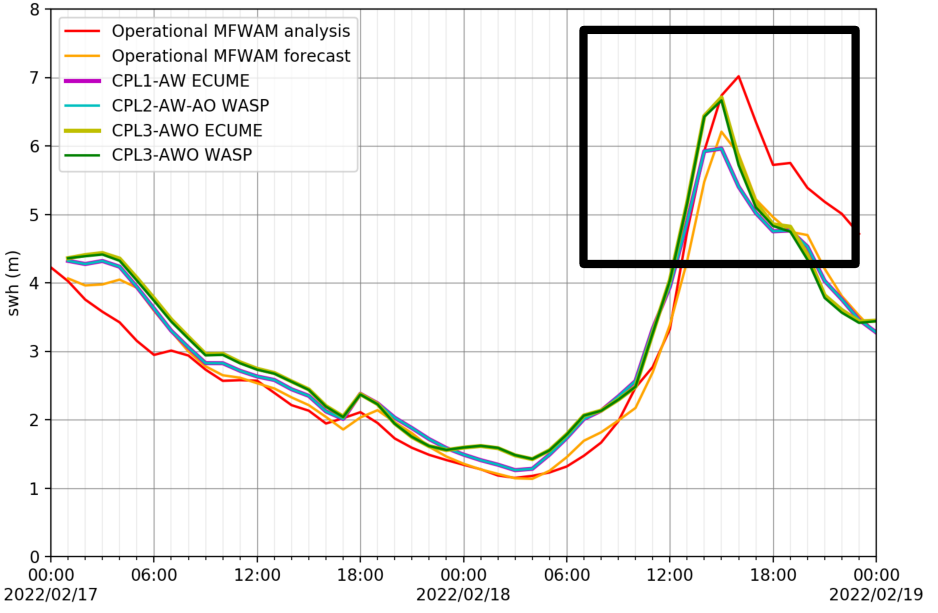
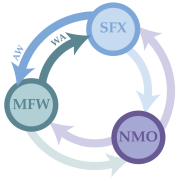


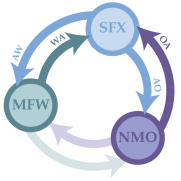
SWH

SWH and wind timeseries

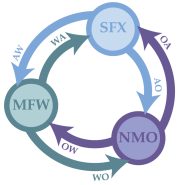
- Operational MFWAM analysis
- Operational MFWAM forecast
- CPL1-AW ECUME-Wave
- CPL2-AW-AO WASP
- CPL3-AWO ECUME-Wave
- CPL3-AWO WASP



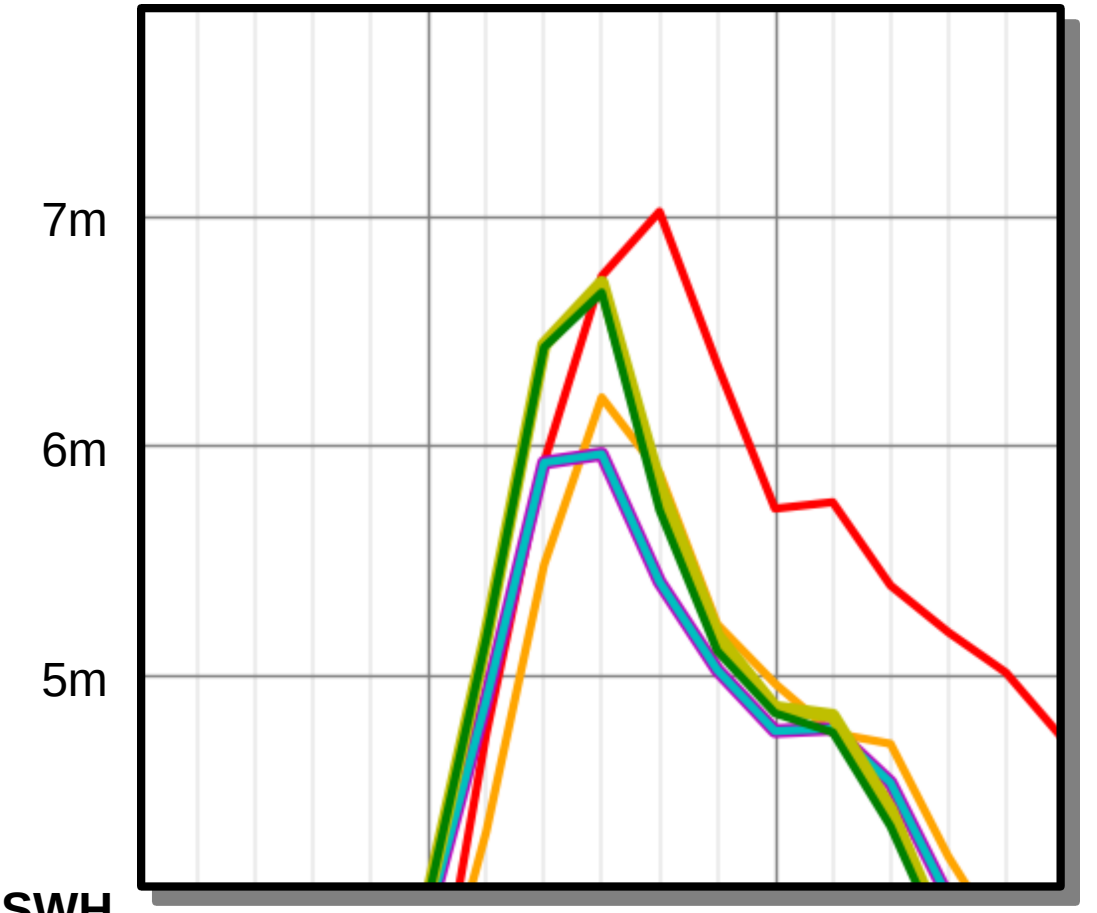
CPL1-AW



CPL2-AW-AO

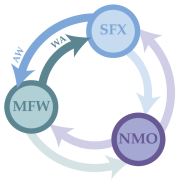


CPL3-AWO

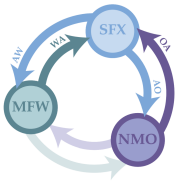


SWH and wind timeseries

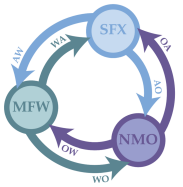
Operational MFWAM analysis
Operational MFWAM forecast
CPL1-AW ECUME-Wave
CPL2-AW-AO WASP
CPL3-AWO ECUME-Wave
CPL3-AWO WASP



CPL1-AW

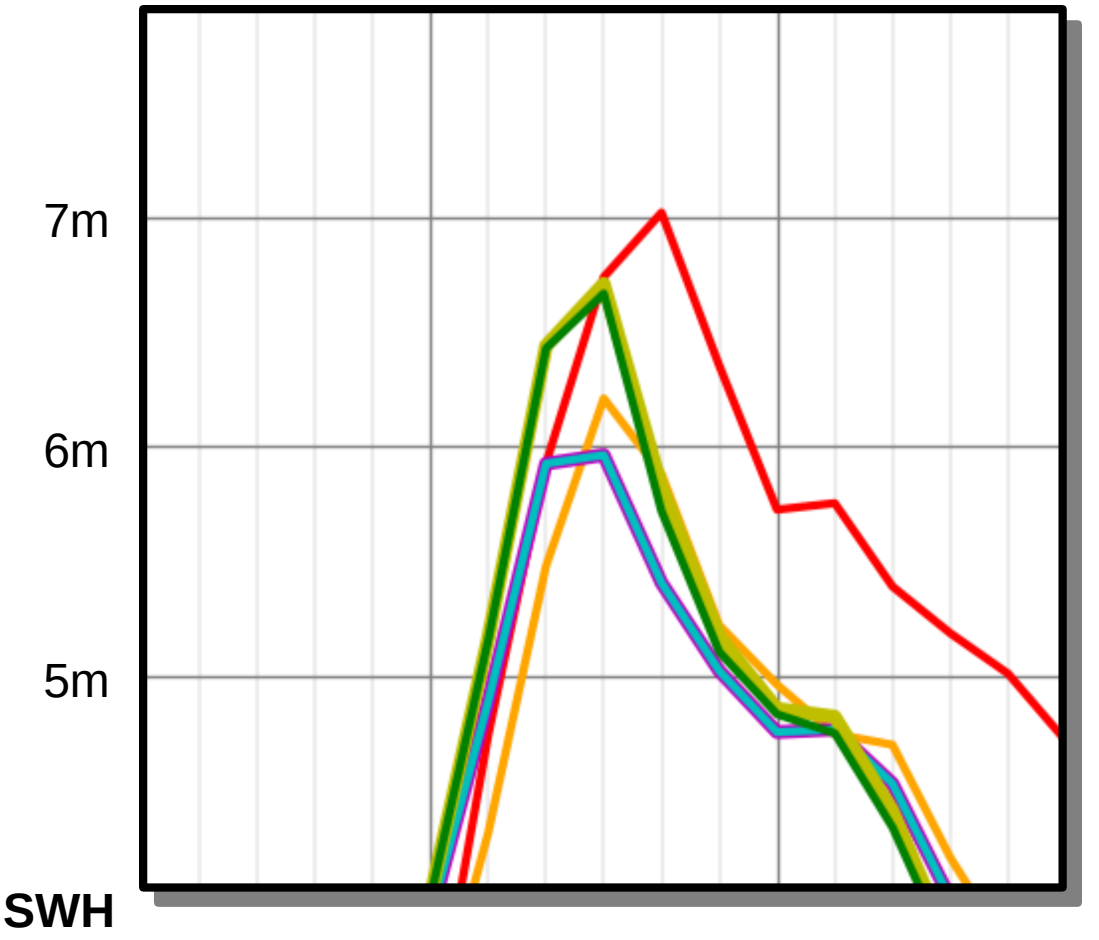


CPL2-AW-AO



CPL3-AWO

Ocean-waves coupling has more impact on MFWAM than parameterisation choice



4. Conclusion

Conclusion

- Study coupled model integrating **ocean-waves coupling**
- **New parameterisations** (WASP, ECUME-Wave)
- **Sensitivity studies**

Conclusion

- Study coupled model integrating **ocean-waves coupling**
- **New parameterisations** (WASP, ECUME-Wave)
- **Sensitivity studies**

Key points

- The **ocean-wave coupling** has a noticeable effect on both **ocean and waves models** but also on **surface turbulent fluxes**
- Depending on the component and variables considered, **parameterisation for surface turbulent fluxes** choice may have a **prevailing effect** on **couplings** choice

Thank you for your attention

Perspectives

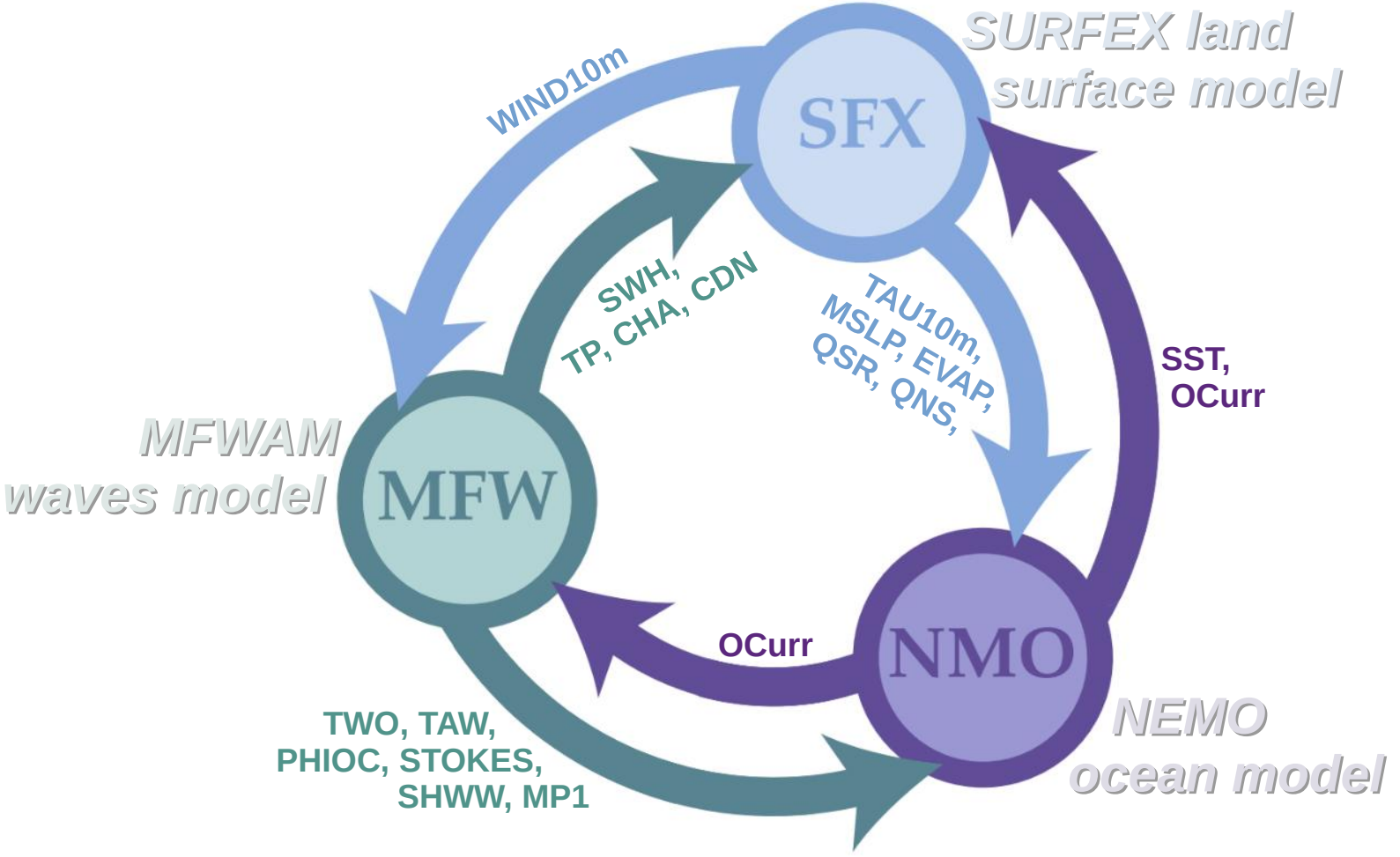
With the study coupled model

- Comparison with available observation
- Select and study cases of false detection and missed event

Next step towards integration into Météo-France forecasting system

- Feedback on the atmosphere
- Daily runs of the AROBASE system (simulation demonstrator)

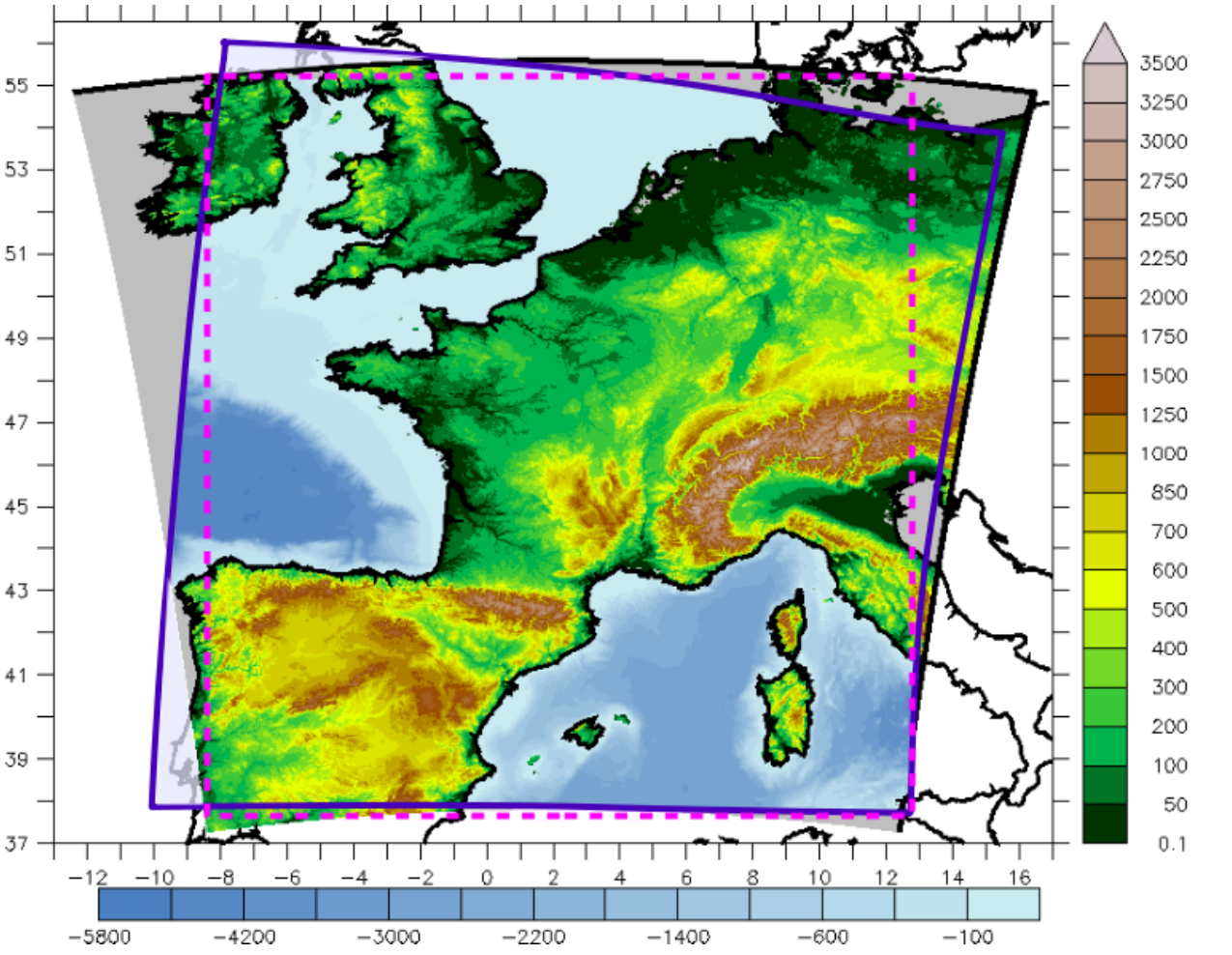
Assembling the coupled model



Turbulent fluxes parameterisation sensitivity

		COARE 1 – COARE 0				COARE 2 – COARE 0				ECUME – COARE 0				WASP – COARE 0			
		Negative diff	Neg and pos diff	Positive diff	No diff or poor diff	Negative diff	Neg and pos diff	Positive diff	No diff or poor diff	Negative diff	Neg and pos diff	Positive diff	No diff or poor diff	Negative diff	Neg and pos diff	Positive diff	No diff or poor diff
CPL1 AO SFX-Nowave	**SFX**	Q2M T2M	-	-	CD CDN FM CE CH H LE EVAP	Q2M T2M	-	-	CD CDN FM CE CH H LE EVAP	Q2M T2M	H	CE CH LE EVAP	CD CDN FM	H LE EVAP	-	Q2M T2M	CD CDN FM CE CH
	NMO	-	-	-	X	-	-	-	X	-	-	-	X	-	-	-	X
CPL2 AW-AO SFX-Wave	**SFX**	-	CD CDN H LE Q2M T2M	CE CH FM EVAP	-	CD CDN FM CE CH LE EVAP Q2M T2M	H	-	-	Q2M T2M	CD CDN H	CE CH LE EVAP	FM	CE CH FM LE EVAP	CD CDN H Q2M T2M	-	-
	NMO	-	X	-	SST	-	X	-	SST	-	-	-	X	-	X	-	SST
CPL3 AWO SFX-Nowave	**SFX**	-	Q2M	CD CDN T2M	FM CE CH H LE EVAP	-	-	CD CDN Q2M T2M	FM CE CH H LE EVAP	Q2M T2M	H	CD CDN CE CH LE EVAP	FM	LE	-	CD CDN Q2M T2M	CE CH FM H EVAP
	NMO	-	-	-	X	-	-	-	X	-	-	-	X	-	-	-	X
CPL3 AWO SFX-Wave	**SFX**	-	CD CDN H LE Q2M T2M	FM CE CH EVAP	-	CD CDN FM CE CH LE EVAP Q2M T2M	H	-	-	Q2M T2M	CD CDN H	CE CH **LE** EVAP	FM	CD CDN FM CE CH **LE** EVAP	H Q2M T2M	-	-
	NMO	-	X	-	SST	-	X	-	SST	-	-	-	X	-	X	-	SST

Grids and variables exchanged



NEMO-FRA36 (ORCA grid)

AROME-FR (conformal projection with zone E without SURFEX)

MFWAM-FR@1km (pseudo-regular long/lat grid, set in 1D and reduced)

Sensitivity studies

Impact drivers:

1. MFWAM configuration (integrated into coupled system vs. operational model)

- larger domain size
- better grid resolution (1km instead of 2.5km)
- better energy propagation at open boundaries

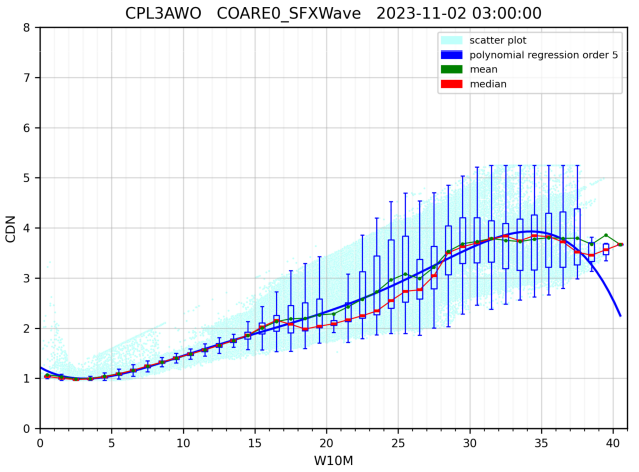
2. Couplings: what respective contributions?

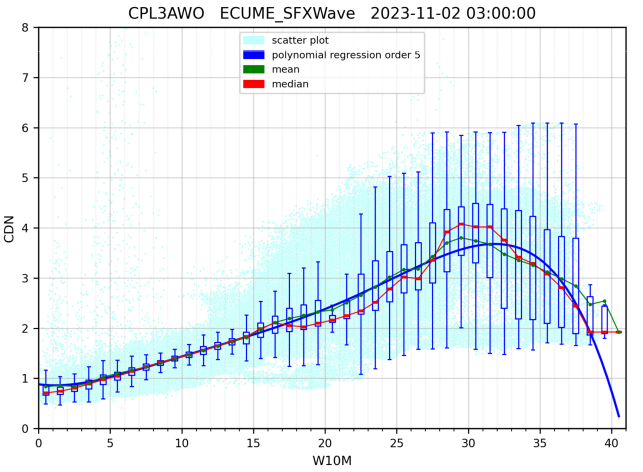
- 3 forced models → 3-components coupled system

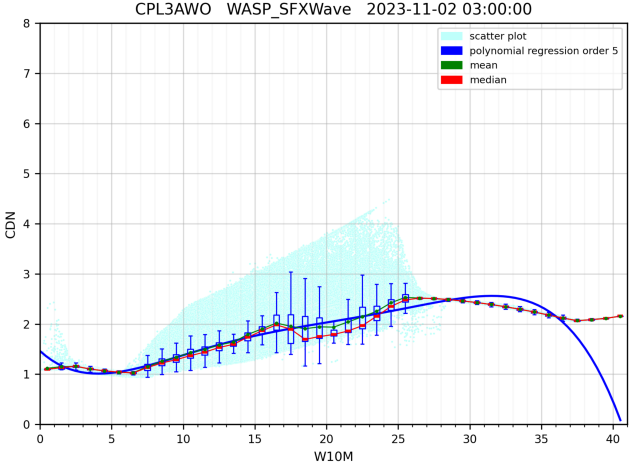
3. SURFEX turbulent fluxes parameterisation

- taking waves into account or not
- various options for calculating air-sea turbulent fluxes

CDN as a function of wind







CIARÁN, 23/11/02 at 03:00

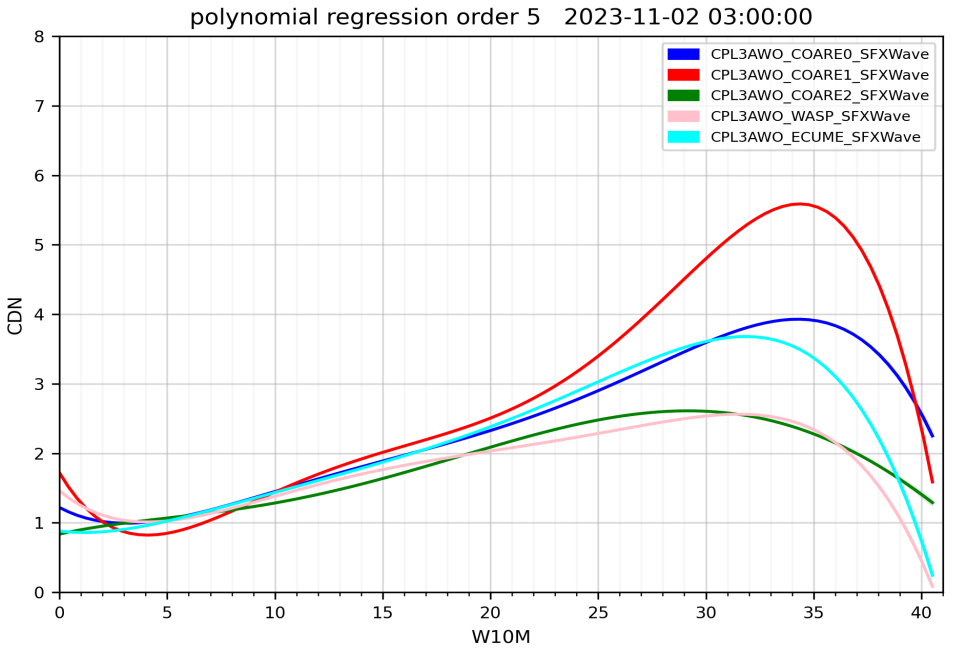
CPL3-AWO

- COARE0 (ref)
- ECUME
- WASP

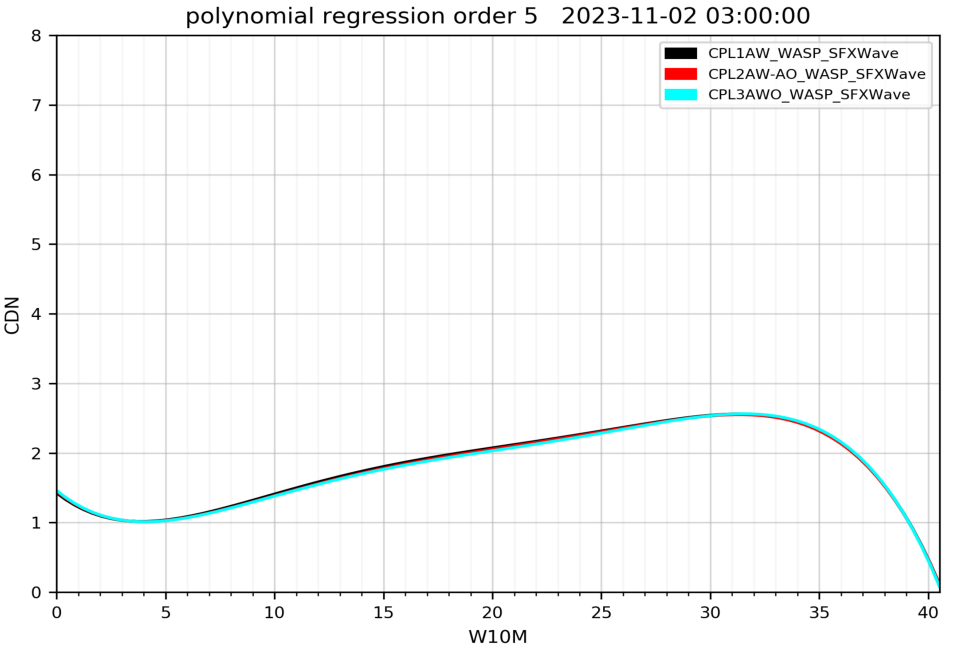
→ dispersion (nonlinear and nonlocal relationship with wind)

CDN as a function of wind

CIARÁN, 23/11/02 at 03:00



CPL3-AWO couplings
different parameterisations



different couplings
WASP parameterisation

SWH and wind timeseries

Ciarán storm at Pierres-Noires buoy

Comparison of 10m-wind and SWH between in-situ observations (buoy), analysis and operational forecasts (MFWAM 0.025° (Météo-France) and different experiments (CPL*).