Coupled ocean-wave-atmosphere simulations with sea spray over the Gulf of Lion

FRANCE ENERGIES MARINES
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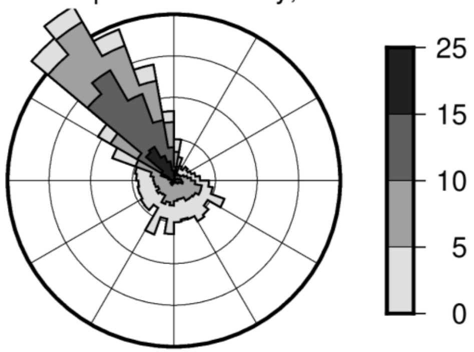
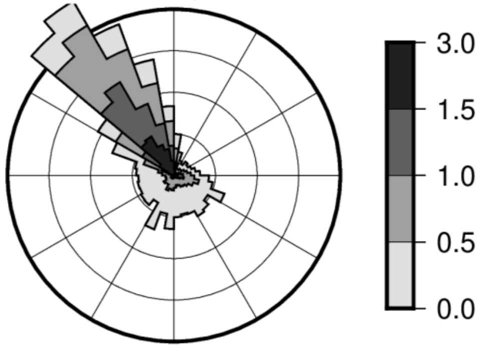
ORE Context

FOWT deployment in the Mediterranean Sea

- 3 wind farm pilot projects (3 x 25-30MW in 2022)
- 2 tenders in 2022 (2 x 250 MW)
- More to come…

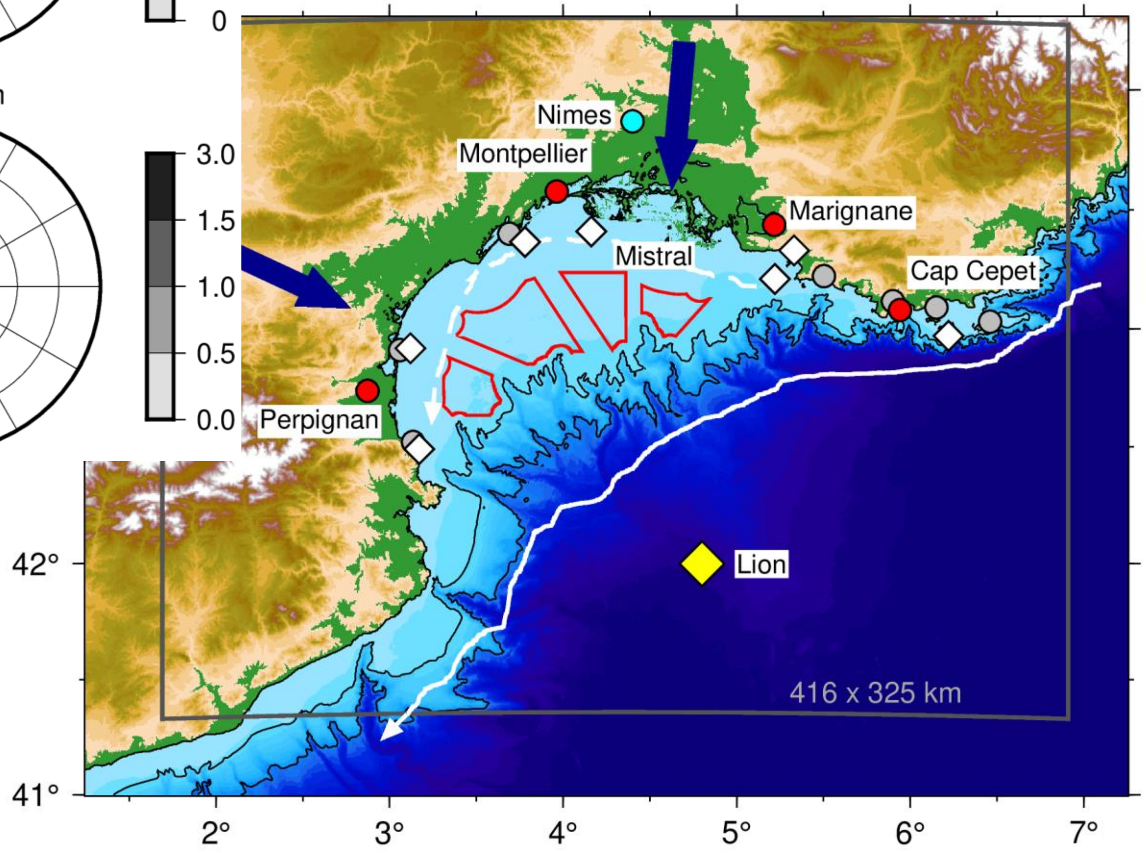
- Precise knowledge of met-ocean for:
  - Wind resource assessment
    - Site mapping and wind farm design
    - 0.1 m/s = 10M£/year for commercial farms (Hasager, 2013)
  - Structural loads (fatigue and extreme)
  - Installation at sea, interventions for operations and maintenance, dismantling





Gulf of Lion Specifities

- Frequent strong orographic winds
- Intense small scale winter storms
- Short fetch waves
- Strong air-sea coupling
- Deep water



Coupled Model Framework

- Common horizontal grid – 1.3 km
- Meso-NH:
  - 70 vertical levels (10-900m)
  - WASP v2 bulk fluxes
  - WENO5 15s
- Croco:
  - 80 vertical levels
  - WENO5 60s
- WAVEWATCH III®:
  - 32 frequencies (0.05 + 1.1fi)
  - 24 directions
  - ST4 (MED)

Codes versions:

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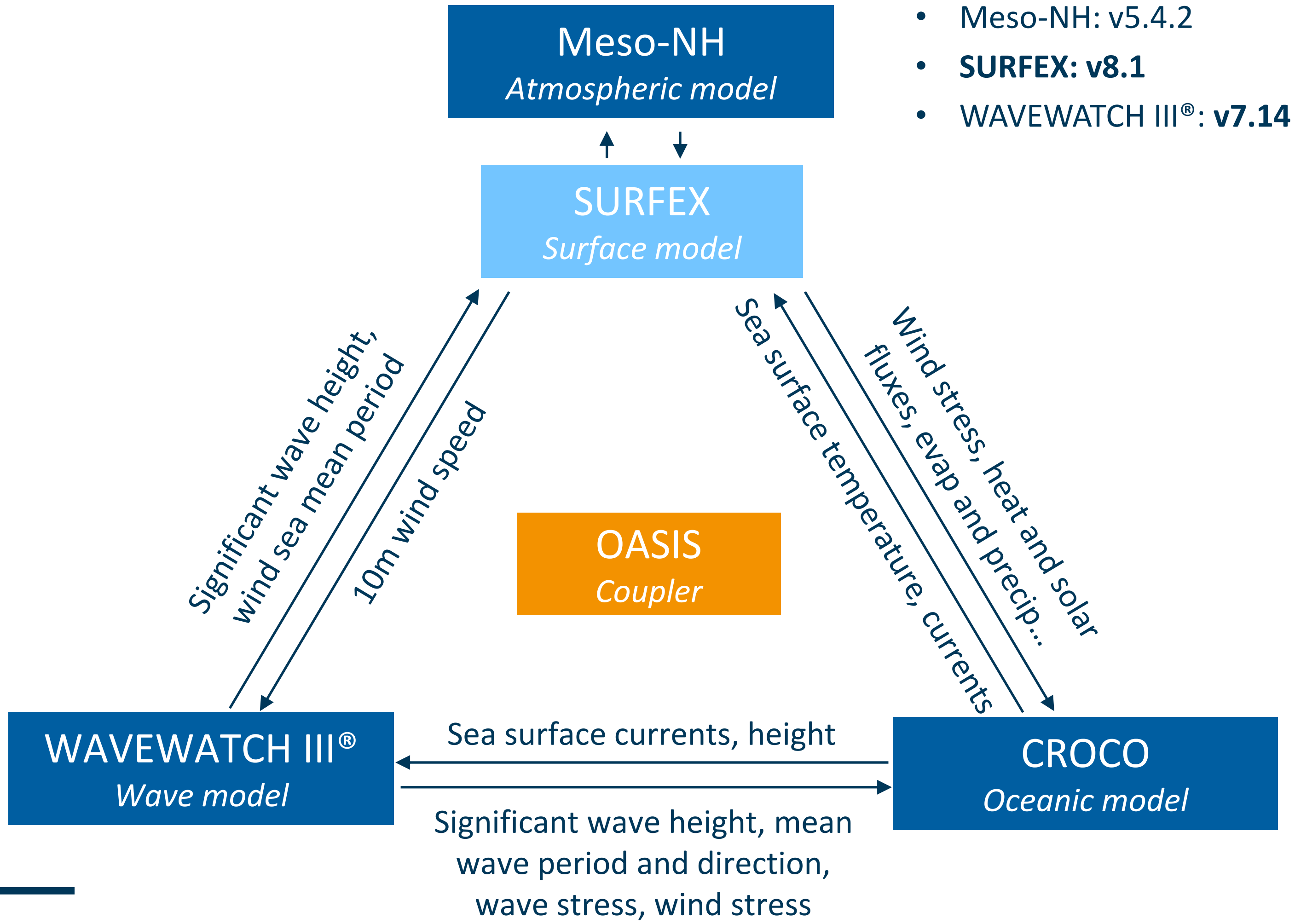
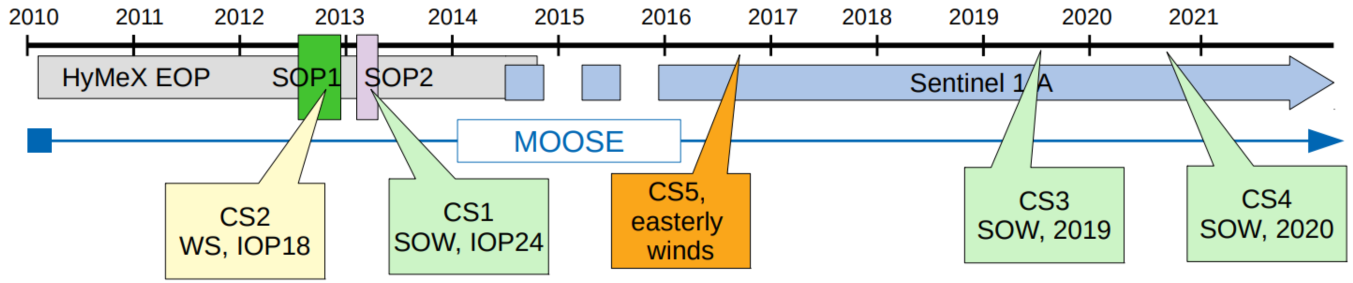
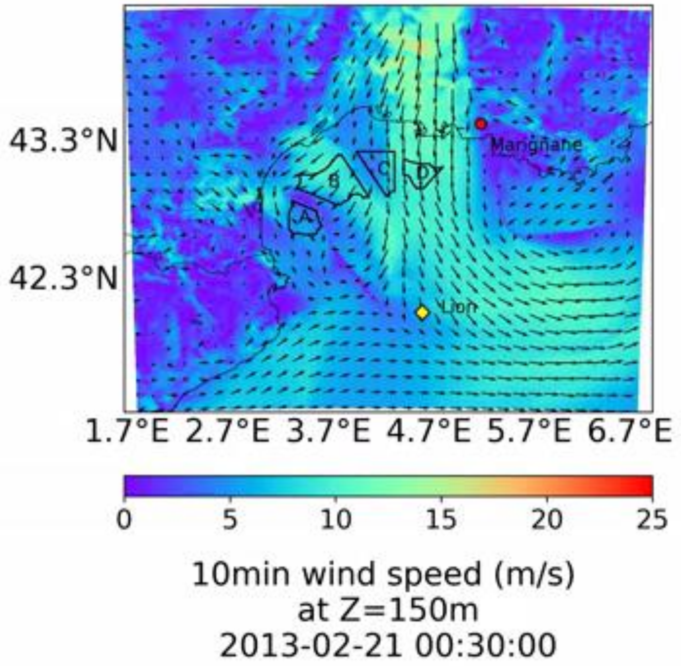
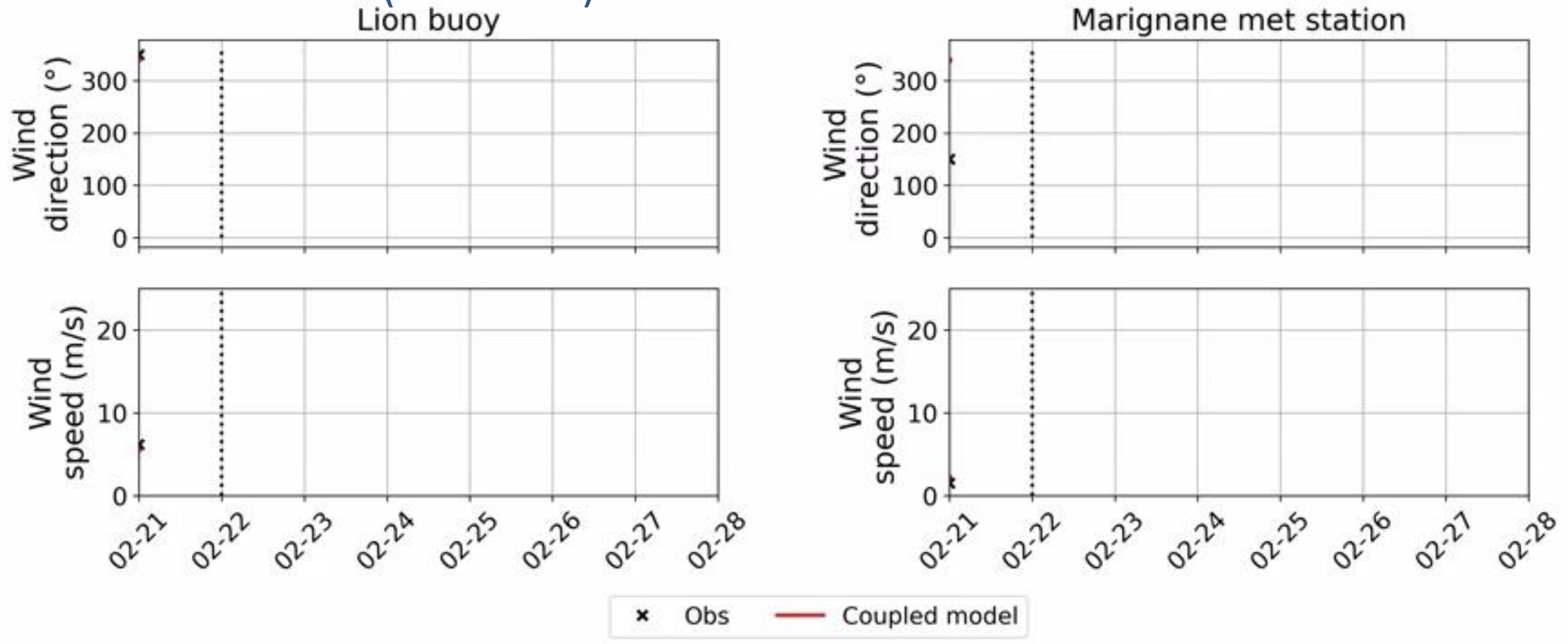


Case Studies – Model Validation



CS1 (HyMeX POI 24) - Mistral and Tramontane event (Feb 2013)

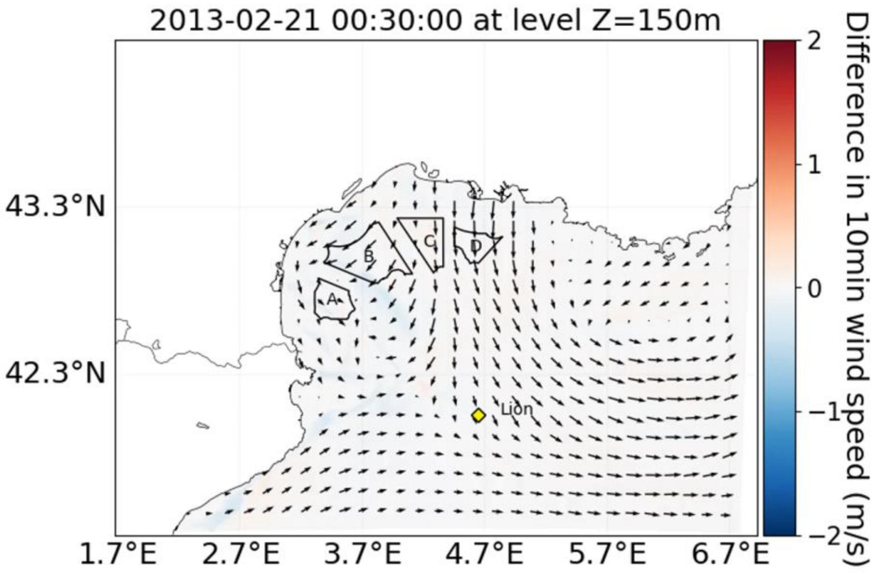




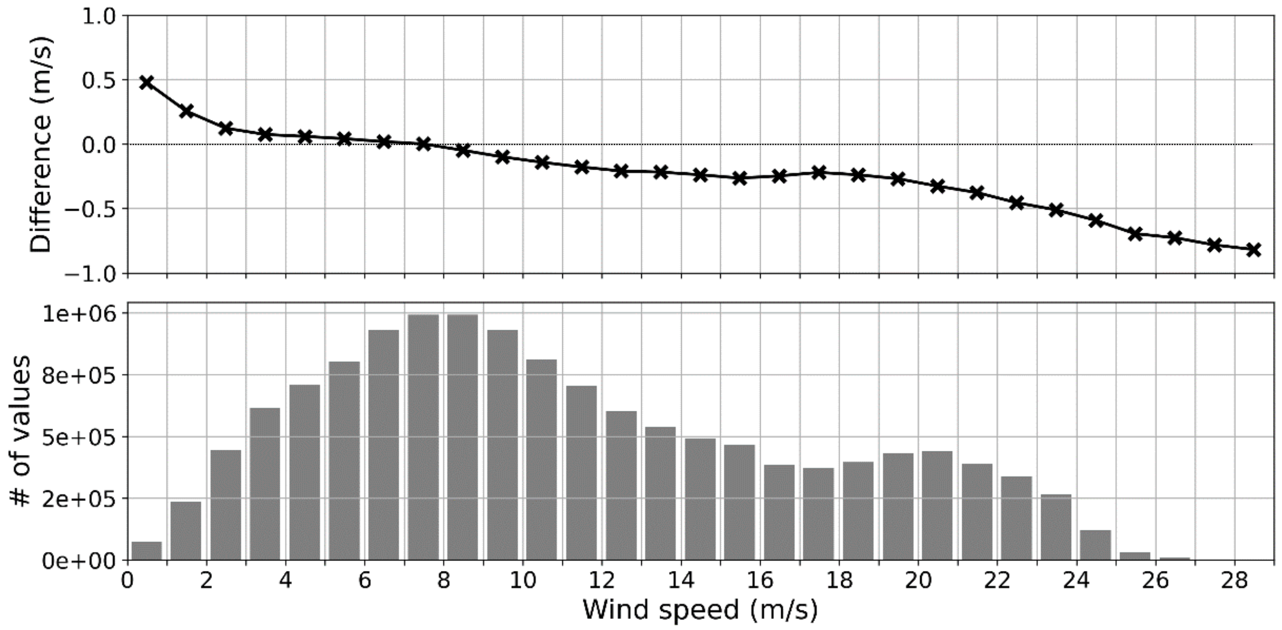
Impact of waves on winds

High winds generate waves … and waves act as roughness which slows down winds

Wind speed difference at 150 m
(coupled model – uncoupled model)

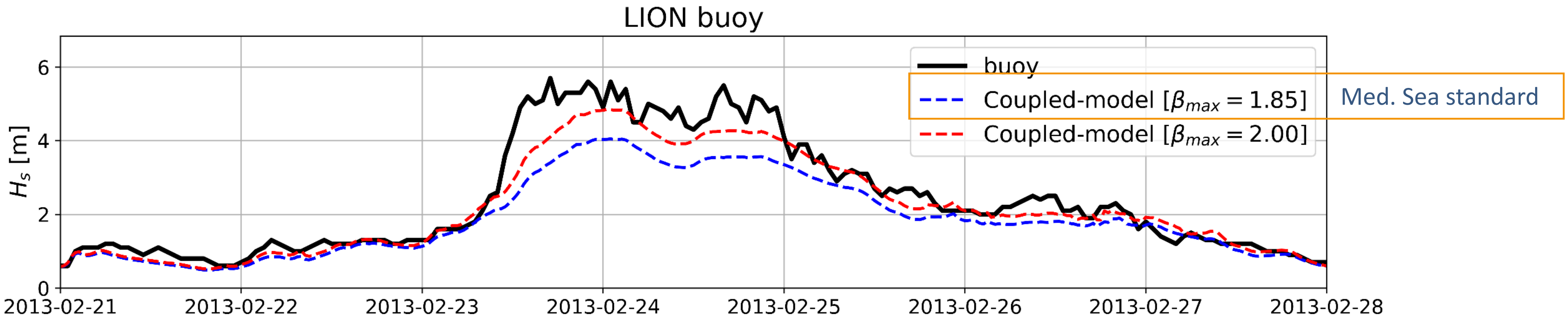


Binned averaged wind speed difference at 150 m
(coupled model – uncoupled model)



Wave model in short fetches

- Ardhuin *et al*. (2010) physical package
  - Underestimation of highest waves, even with increased β_{max} parameter (wind input boost)
- Ongoing development of a new wave breaking parametrisation
  - More accurate results in short fetch conditions
  - Better wave breaking statistics



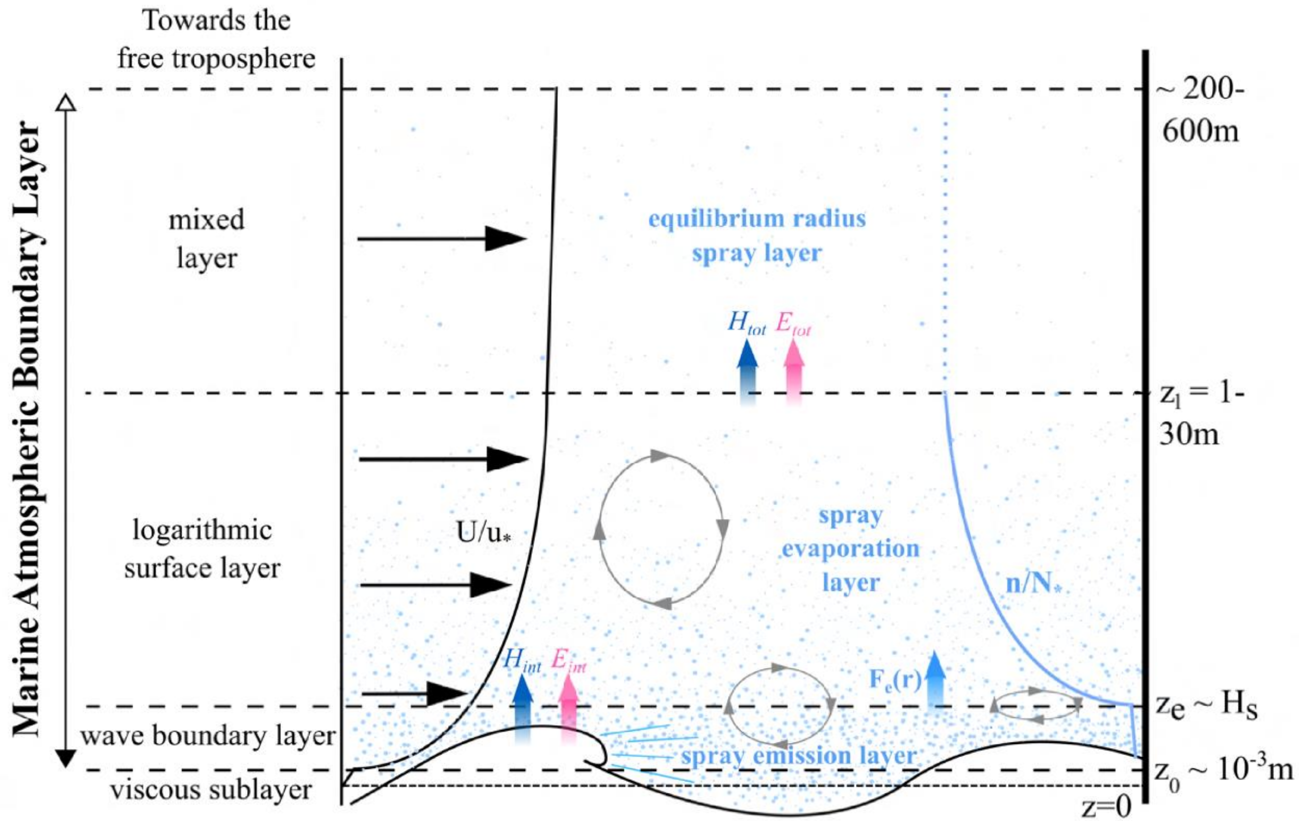
SEA SPRAY

Sea-Spray Challenges

- Quantifying
  1. Impact momentum and fluxes → surface layer parametrizations

→ Once ejected, droplets
1. Are accelerated or decelerated by atmospheric flow & fall
   → momentum exchange
2. Equilibrate temperature
   → heating of atm
3. Evaporate
   → latent heat extraction + cooling of atm

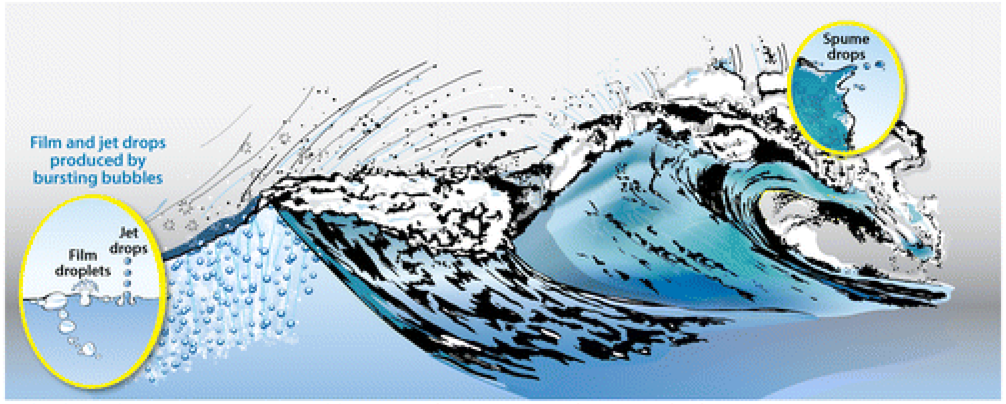
→ Droplet load has a stabilizing effect



Bruch (2021)

Sea-Spray Challenges

- Quantifying
  1. Impact momentum and fluxes → surface layer parametrizations
  2. Production → Sea Spray Generation Function (SSGF)



Veron F. 2015.
Annu. Rev. Fluid Mech. 47:507–38

- Bubble-Generated
  - Film Drops (r_0 = 0.01–2 µm)
  - Jet Drops (r_0 = 2–200 µm)
- Spume Drops (r_0 = 10–2300 µm)

Sea Spray – impact on the MABL

NB: THERE ARE MANY KEY UNRESOLVED ISSUES

→ Transport & evolution in MABL

→ **Sea Spray Generation**

Environmental parameters considered:

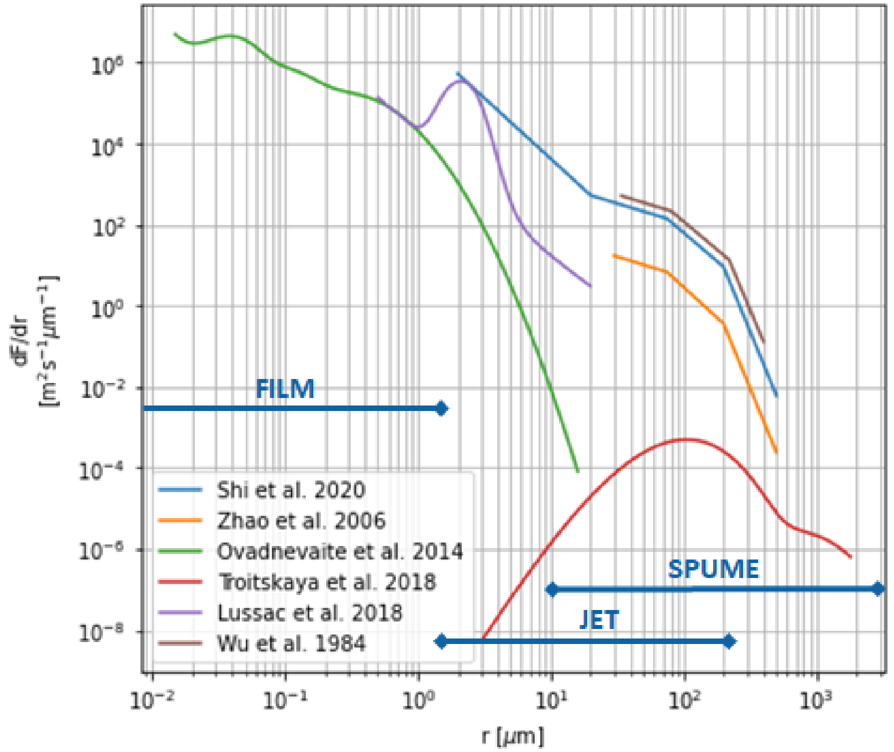
1. Wave Breaking Dissipation (Fairall et al., 2009; Lenain & Melville, 2017; Deike, 2021)
2. Whitecapping (Shi et al., 2020)
3. Wave Steepness (Bruch et al. 2021)
4. Fetch (Lussac et al., 2018)
5. Wave dependent Reynold numbers / wave age (Troitskaya et al., 2018)

$$\frac{dF}{dr_0} = f_1(U_{10}, W, \ldots) f_2(r_0)$$

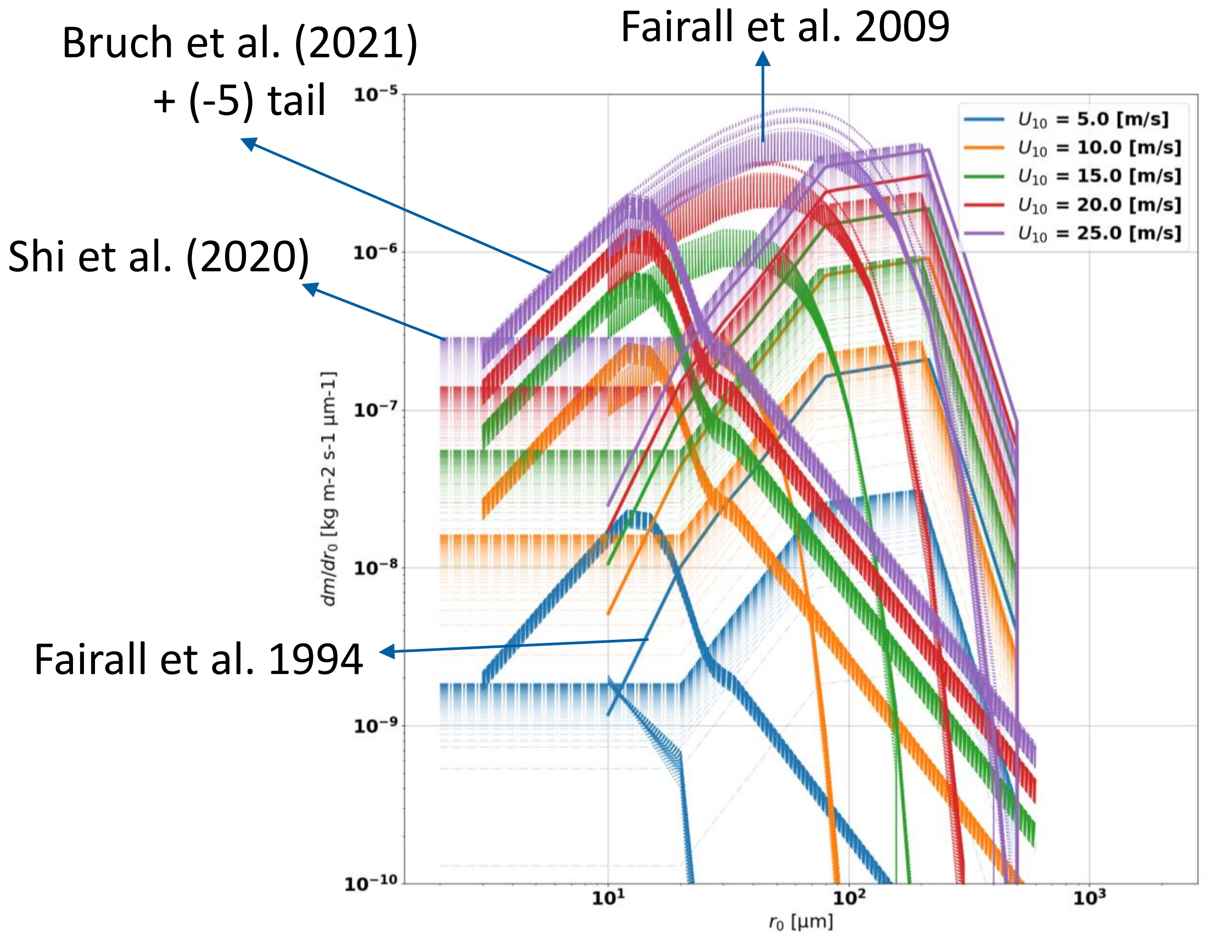
Dependence on environmental parameters

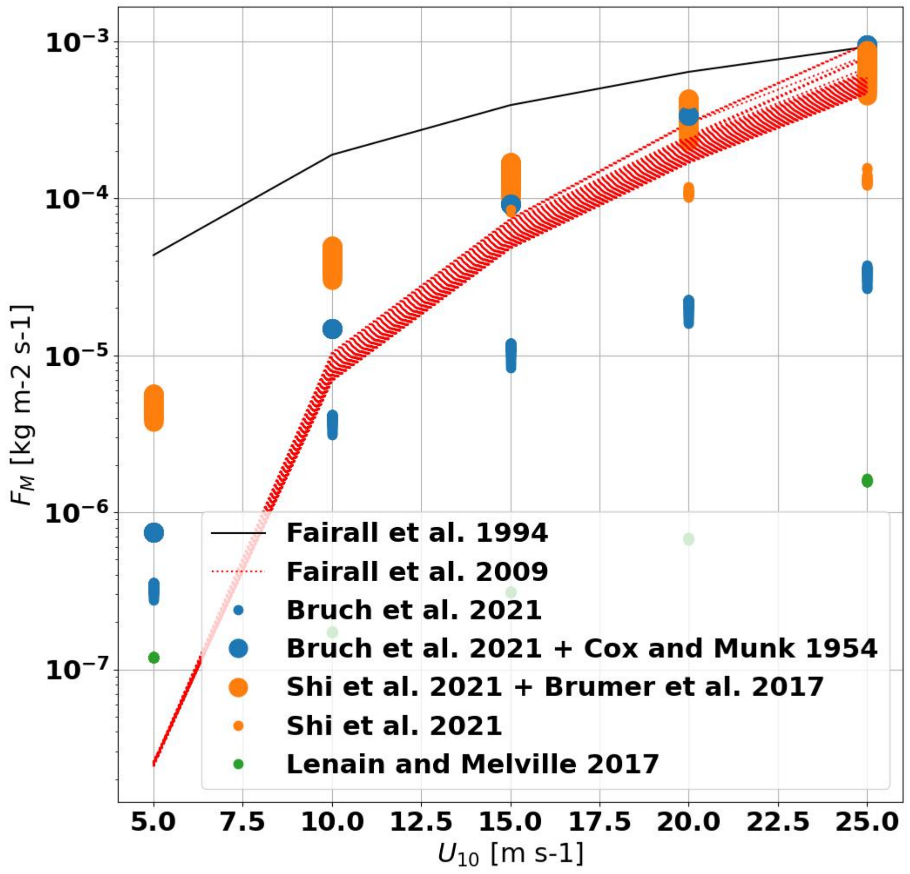
Size Spectrum

U_{10} = 15m/s; cp/U_{10} = 0.6; Hs =1m; W = 1.1%



Sea Spray Generation Function (SSGF)





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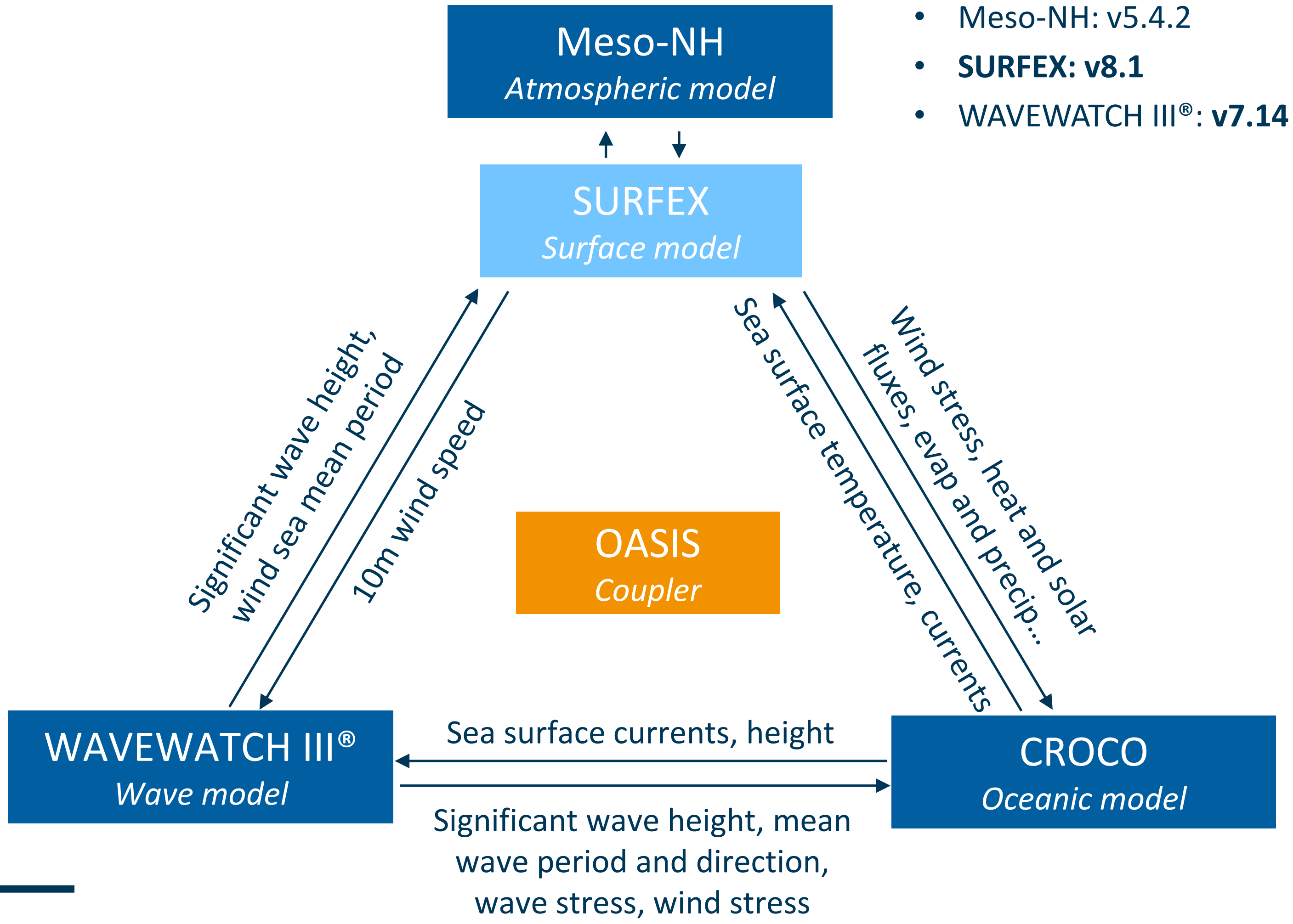

Coupled Model Framework

Improving model physics by adding sea spray related processes

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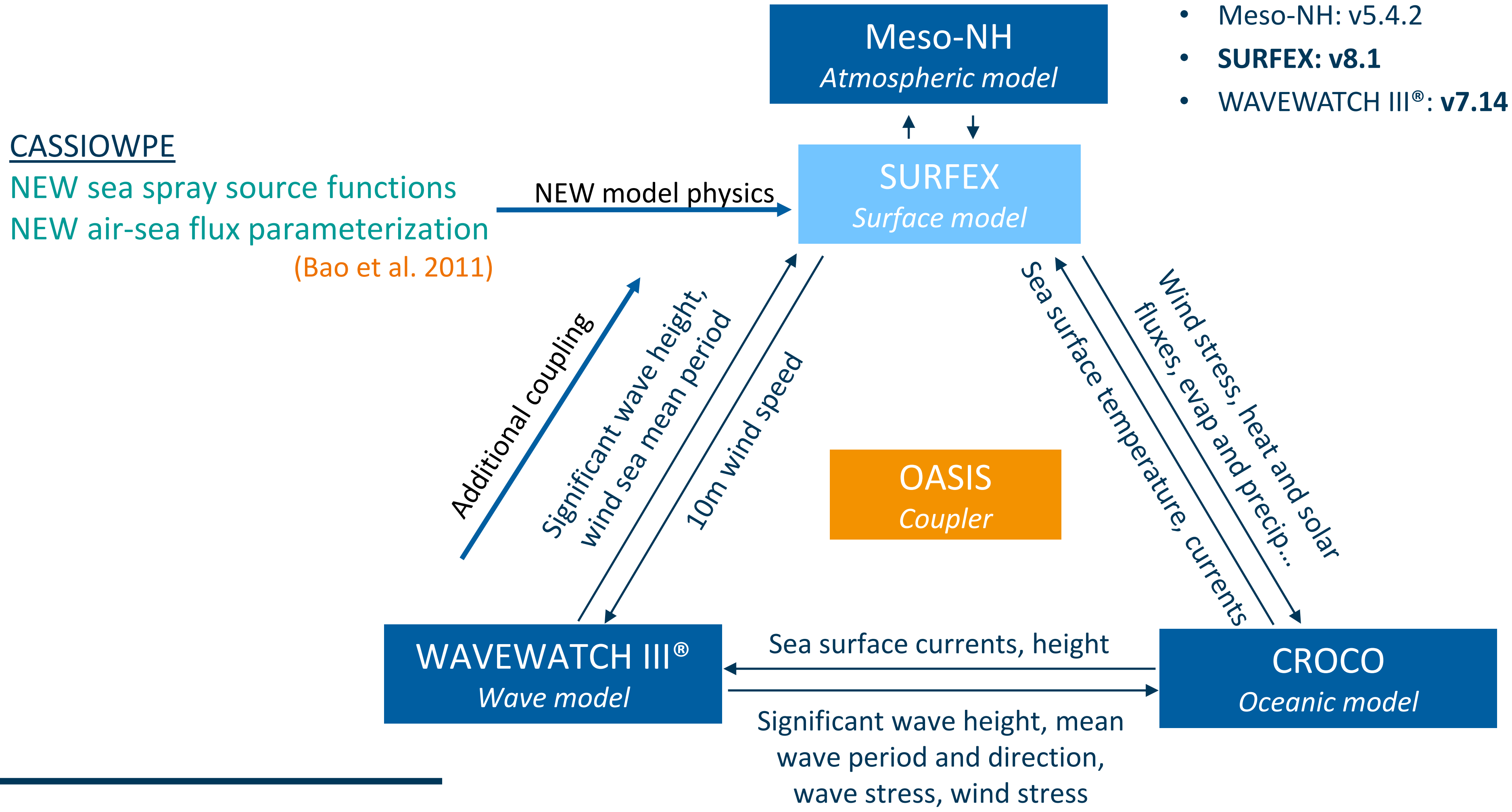

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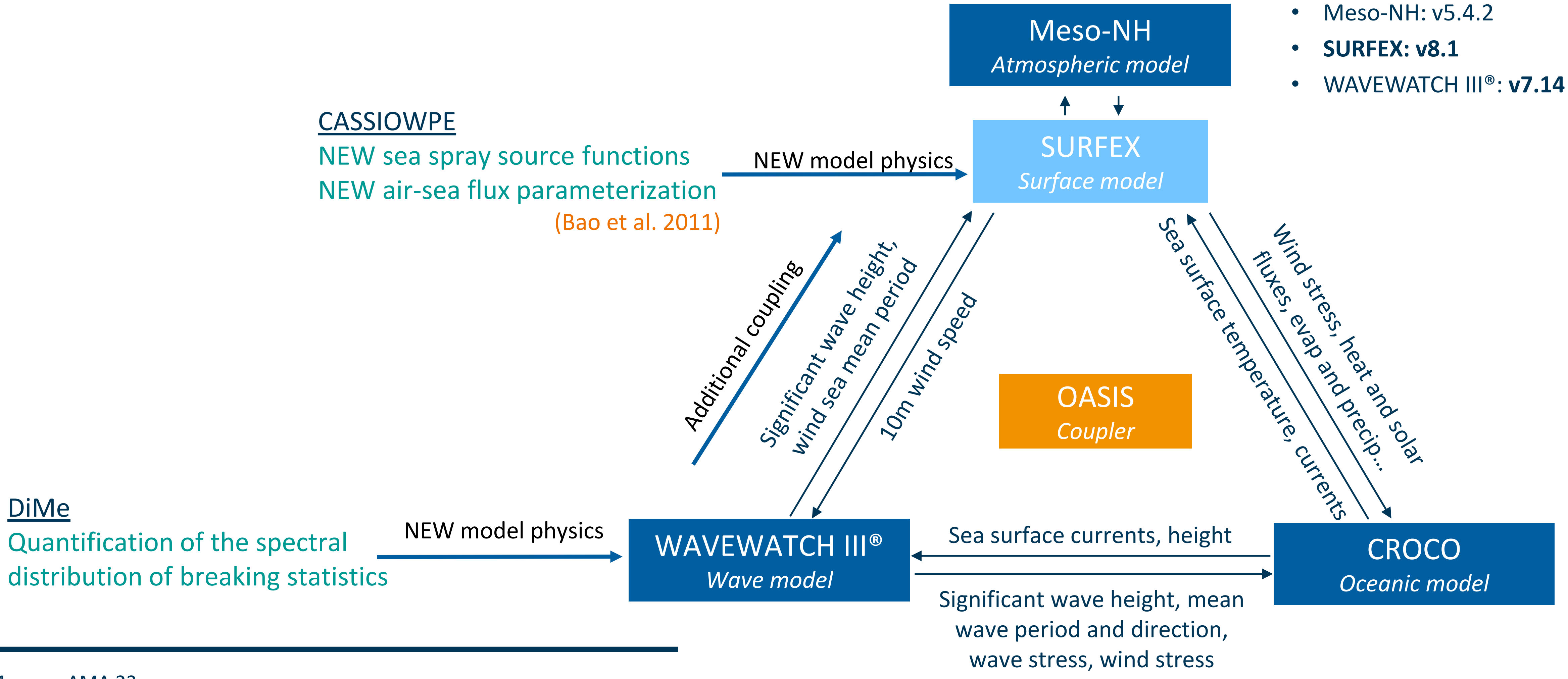
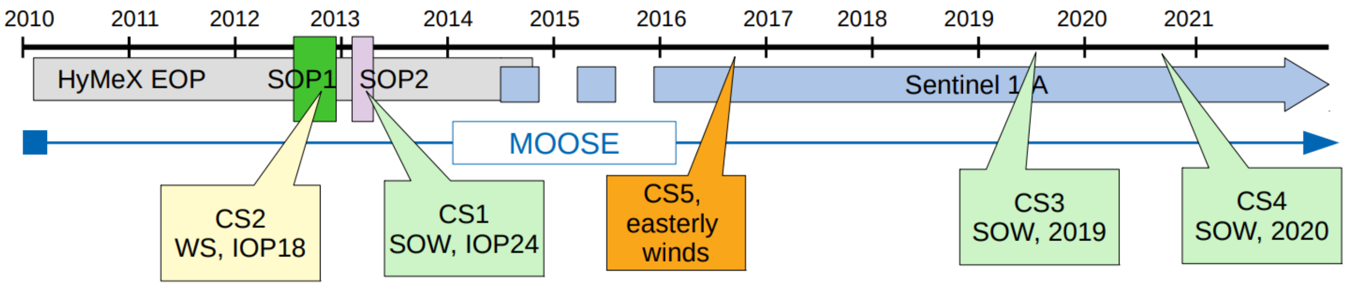
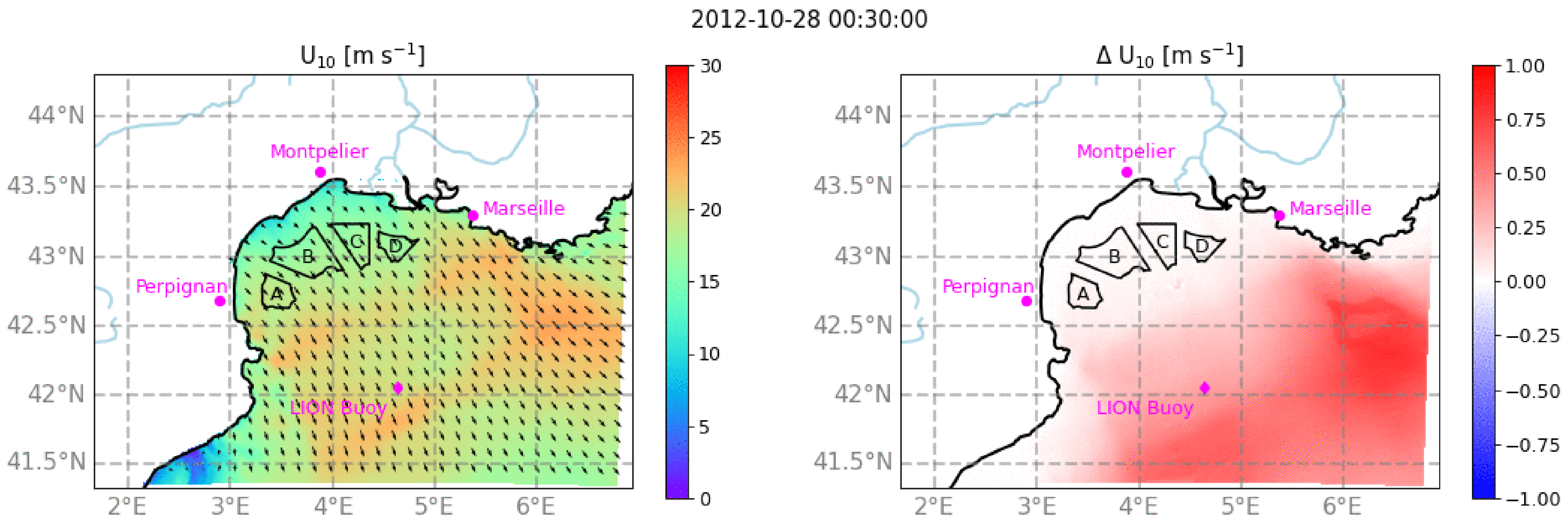


Impact of Spray on Winds – Case Studies

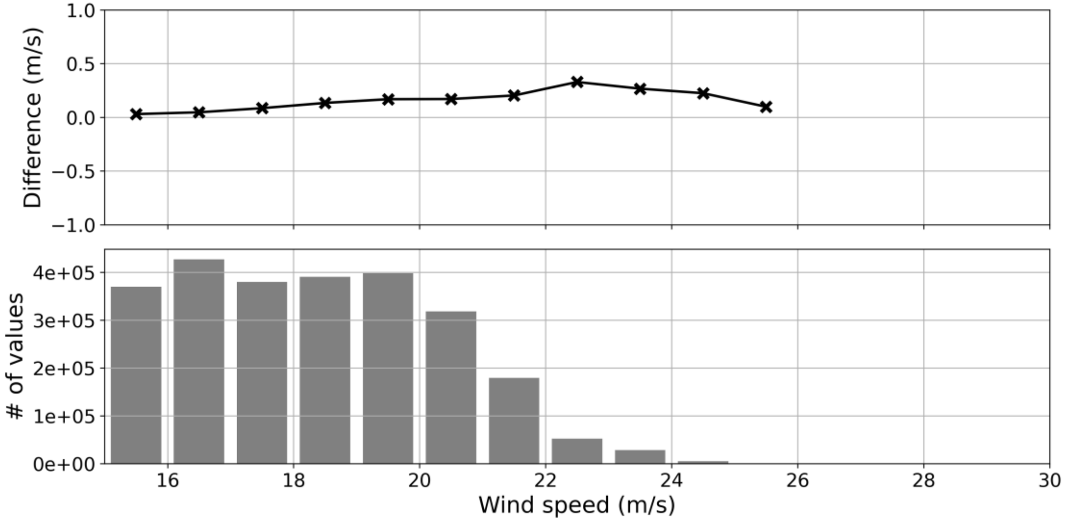


CS2

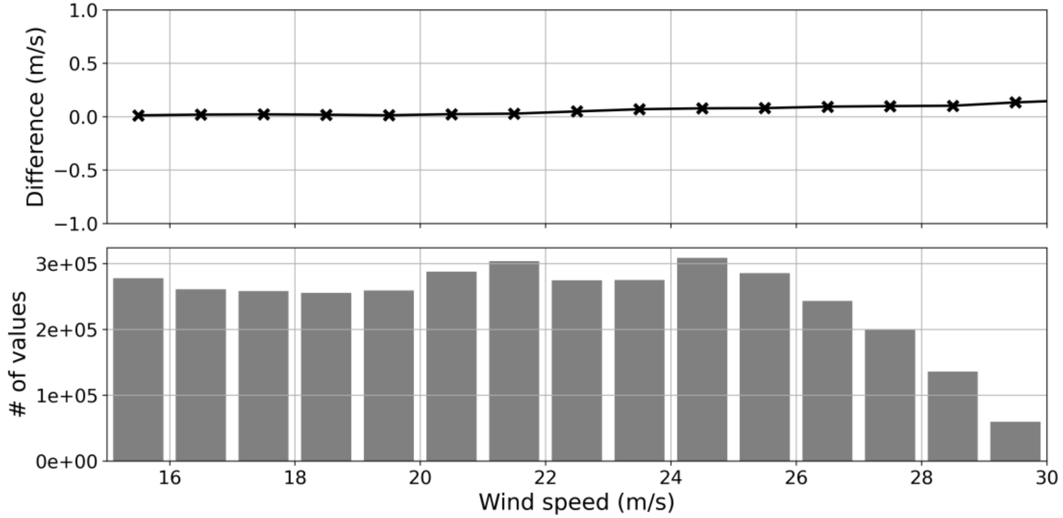


CS2 – Spray impacts on winds

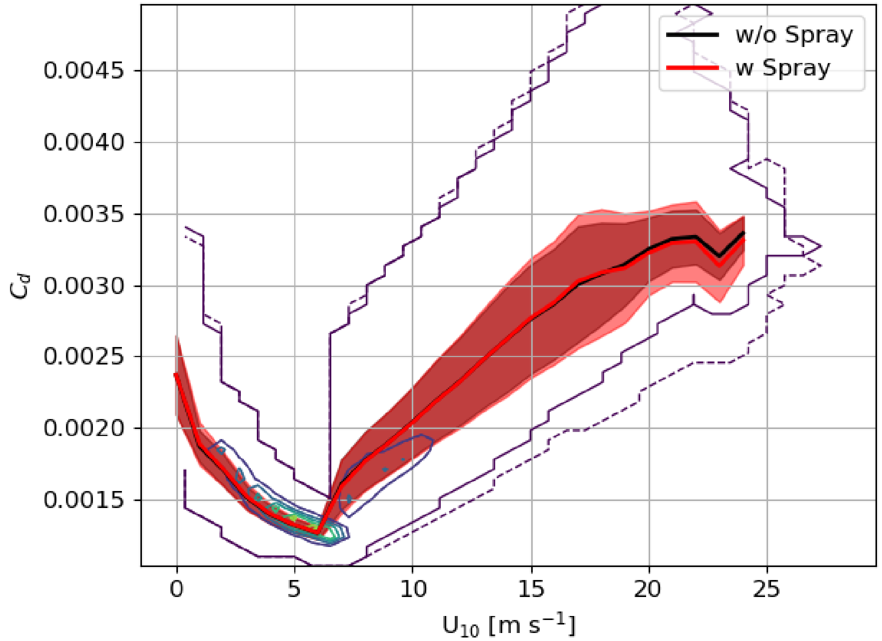
@ 5m



@ 150m



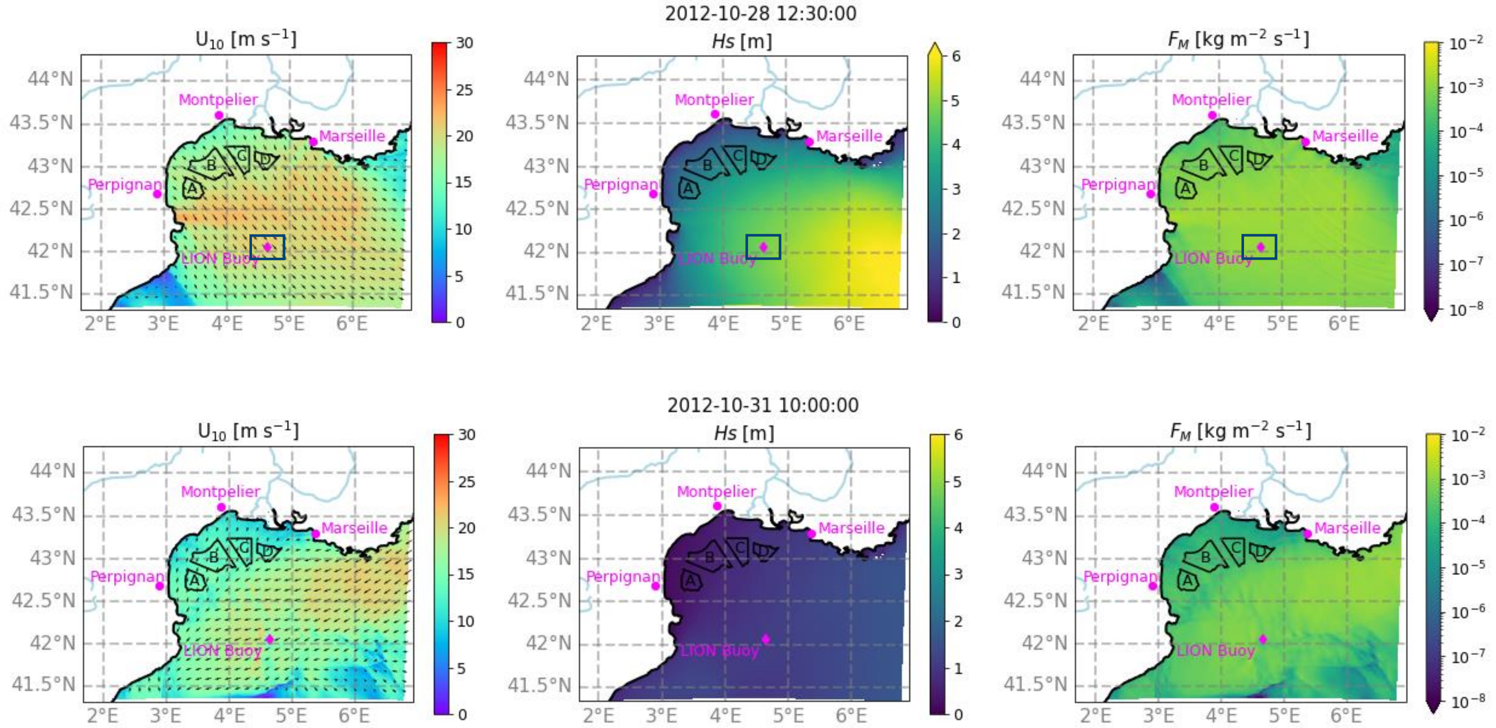
- Large local differences, dipoles ⟶ fronts shift
  - >2m/s difference in 10m wind magnitude
  - Difference amplified @ hub height
- Slight increase in mean horizontal winds
- Minimal impact on Cd

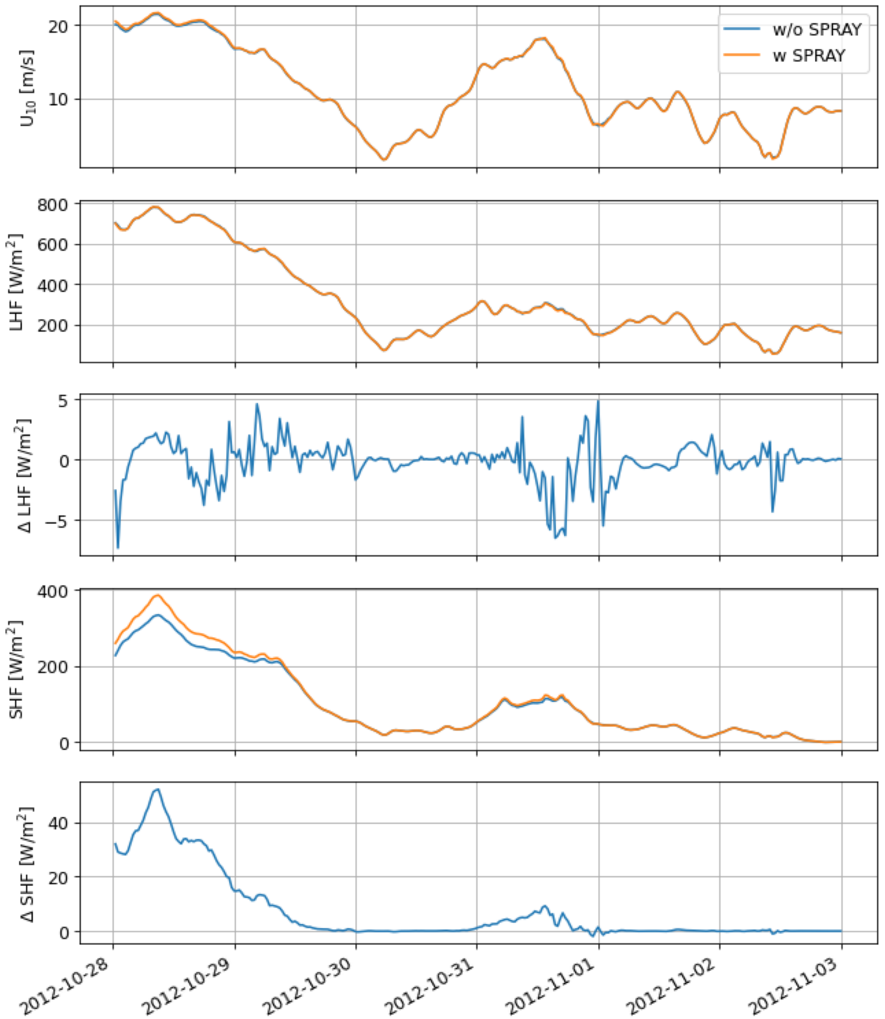


CS2 – Spray impacts on turbulent heat fluxes

Averages around LION buoy (deep convection region)

- Spray mediated LHF on O(0.1 %) of LHF but ΔLHF O(1 %)
- Spray mediated LHF and ΔSHF on O(10 %) of SHF





Preliminary conclusions and ongoing Efforts

- Framework ready to be applied to case studies (5 ongoing)
- Coupled results compare well to observations
- Spray impact
    - On winds is magnified with height
    - 10m winds by >2 m/s, but mostly near fronts
    - Sensible heat fluxes on O(10%)
    - Latent heat fluxes on O(<1%)

Work moving forward:

- 1 year hindcast
- Evaluating sensitivity of spray fluxes to choice of SSGF and degree of coupling
- Incorporating sea spray into LIMA microphysics scheme
- Linking sea spray production to breaking crest length statistics and water side turbulence
    - SUMOS Campaign
    - SUSTAIN experiment