# The need for ocean observations and data assimilation for coupled predictions and why we care about coupling when doing predictions

**Kristian Mogensen, Co-Pilot and some humans**

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# Two perspectives on the title of the talk

## Co-Pilot

Responses to Kristian's questions about the title

## Kristian

His own opinion as a grumpy old man

## Is there any consensus

or is Kristian just a grumpy old man?

# Let's start with AI's perspective to the title of the talk

Or the collective knowledge used to train AI

# Why should we predict the ocean according to AI?

The ocean is both a driver of predictability and a place where forecasts support decisions.

### UNDERSTAND THE EARTH SYSTEM

The ocean stores and transports heat, carbon and freshwater, shaping weather, climate and ecosystems.

### IMPROVE WEATHER AND CLIMATE PREDICTION

SST, subsurface heat, currents and sea ice influence atmospheric evolution from days to seasons.

### SUPPORT DECISIONS AT SEA AND ON THE COAST

Forecasts inform marine safety, search and rescue, offshore operations, fisheries and coastal hazards.

**The ocean has memory. Prediction turns that memory into information about the future.**



# What AI thinks about ocean DA and coupled predictions



# Coupling gives the atmosphere a responsive ocean



**A changing lower boundary**
The ocean predicts sea-surface temperature (SST) as weather evolves, rather than holding it fixed or prescribing it independently.



**Heat and moisture respond to the ocean**
Changes in SST alter surface heat fluxes and evaporation, influencing near-surface air temperature and convection.



**Storms feel their own ocean cooling**
Strong winds mix colder water upwards. The cooler surface can reduce the storm's heat supply, improving the representation of intensity feedbacks.



**Ocean memory supports longer forecasts**
Slowly evolving ocean conditions help sustain predictability. Coupling represents feedbacks important for tropical variability and seasonal forecasts.

# Coupling gives the ocean responsive atmospheric forcing

**The atmosphere can react to the ocean**
In a forced ocean model, prescribed weather cannot respond to the simulated SST. Coupling closes that feedback loop.

**Surface fluxes track both evolving systems**
As SST changes, the atmosphere adjusts its heat and moisture exchange. Winds drive mixing, while heating and cooling change upper-ocean stratification.

**Both systems follow the same event**
A storm changes ocean temperature and mixing. The ocean then modifies the atmosphere that supplies subsequent forcing, supporting a more coherent forecast.

**Better physics creates the opportunity for better skill**
Benefits depend on model bias, resolution and initial conditions. Coupled data assimilation can reduce initialisation shock, but coupling alone does not guarantee improvement.

# Ocean initial conditions matter in coupled predictions

**The initial SST sets the first air–sea exchanges**
Sea-surface temperature (SST) errors affect heat and moisture fluxes from the outset, influencing the atmosphere as well as the ocean.

**Subsurface structure controls the response to weather**
Mixed-layer depth and stratification determine how readily winds entrain colder water. Similar initial SSTs can evolve differently after the same storm.

**Ocean heat content carries memory into the forecast**
The initial thermocline and stored heat influence later SST evolution. This ocean memory supports seasonal predictability, including ENSO.

**Consistency across the interface limits initialisation shock**
Ocean and atmosphere analyses need compatible surface states. Better ocean initialisation can improve skill, but coupled-model biases can mask the gains.

# Ocean initial conditions matter in forced ocean predictions

**The forecast inherits the ocean's existing circulation**
Initial currents, fronts and eddy positions shape their subsequent evolution. Atmospheric forcing alone cannot specify the correct starting ocean state.

**The starting water column controls the response**
Temperature and salinity profiles set stratification and mixed-layer depth. The same wind and heat forcing can therefore produce different ocean responses.

**Initial-state uncertainty limits local forecast skill**
Errors in eddy position can produce large local current and temperature errors. Ocean observations and assimilation constrain the start, while ensembles represent remaining uncertainty.

**Forcing and initial conditions remain separate error sources**
Prescribed weather drives the ocean without receiving its feedback. Better initial conditions improve the starting point, but cannot remove errors in the imposed forcing.

# Observations anchor the ocean's initial state



**They locate the real ocean state**
A model can simulate plausible currents and eddies in the wrong place. Observations constrain their actual position and the temperature and salinity fields.



**They reveal the water beneath the surface**
SST alone cannot determine ocean heat content or stratification. Subsurface profiles constrain the thermocline and the water available for mixing.



**Assimilation combines measurements with ocean dynamics**
The analysis blends quality-controlled observations with a model forecast, accounting for their uncertainties and spreading information into unobserved regions.



**Better analyses benefit both forecast types**
Coupled forecasts carry ocean-state errors into air–sea feedbacks. Forced forecasts inherit errors in ocean circulation and structure even with accurate atmospheric forcing.

# Which observations matter most?

For global physical ocean initialisation, Argo profiles, satellite SST and altimetry form a complementary core. Their relative value depends on the forecast target.

| Observing system | What it constrains | Especially important for |
|---|---|---|
| **Argo temperature and salinity profiles** | Heat content, thermocline and density stratification | Subsurface state and ocean memory in both forecast types |
| **Satellite SST, checked against in-situ data** | Surface temperature and thermal fronts | Initial air–sea heat exchange and surface-temperature forecasts |
| **Satellite altimetry (sea-level anomalies)** | Sea-level structure, eddies and geostrophic circulation | Mesoscale features and currents in ocean forecasts |
| **Tropical moorings** | Frequent local measurements of upper-ocean evolution | Equatorial variability and ENSO initialisation |

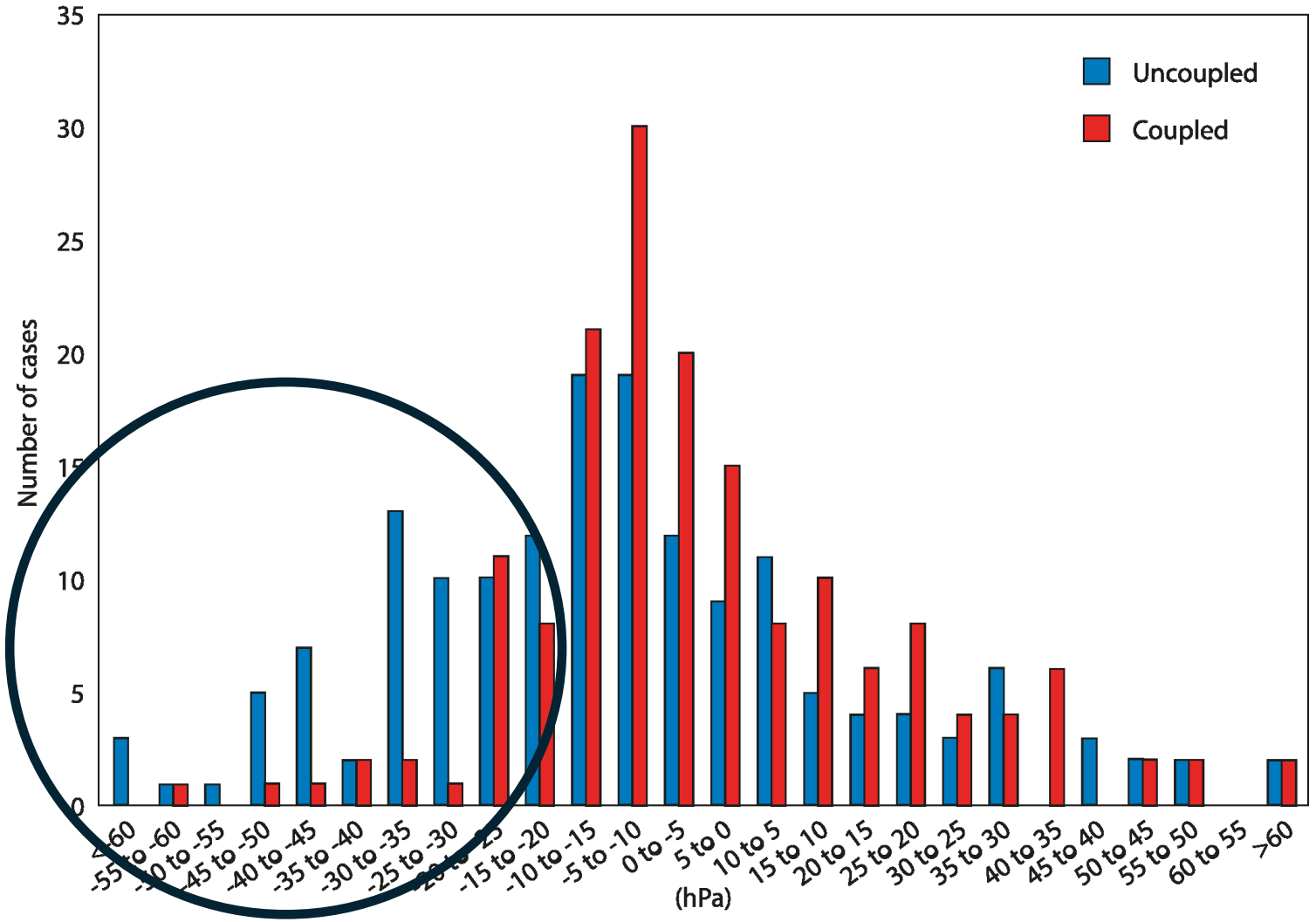


Regional priorities differ: sea-ice observations matter in polar seas, while gliders and coastal measurements fill local gaps. There is no universal ranking.

# No more pure AI content: Kristian’s perspective

With uglier slides

# Impact of the ocean on the atmosphere: tropical cyclones

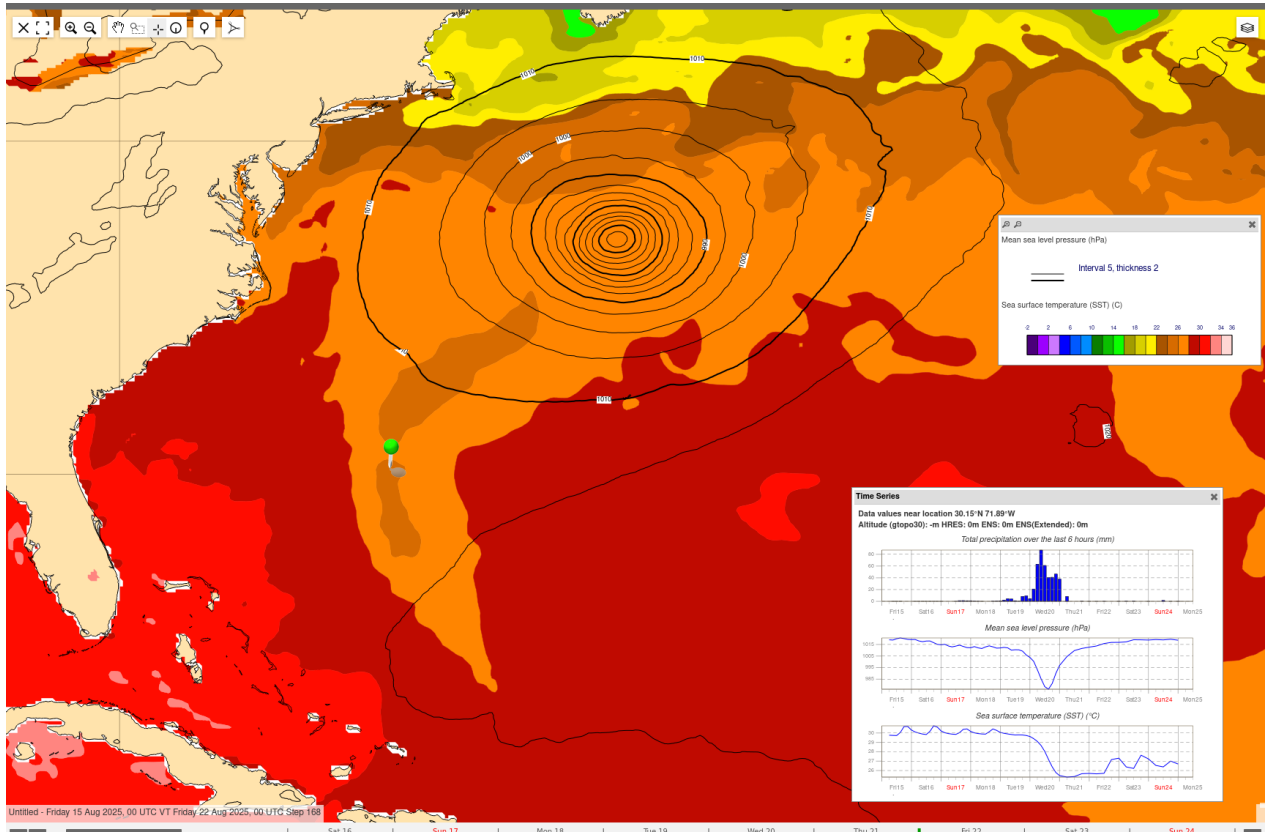



- An average of 2 years experimentation with same atmospheric initial conditions
- Day 7 core pressure error distribution
- **Coupling reduces the number of too intense cyclones in the model**
- As atmospheric model resolution increases, we expect this to become even more important
- Confirmed with 5 km tests

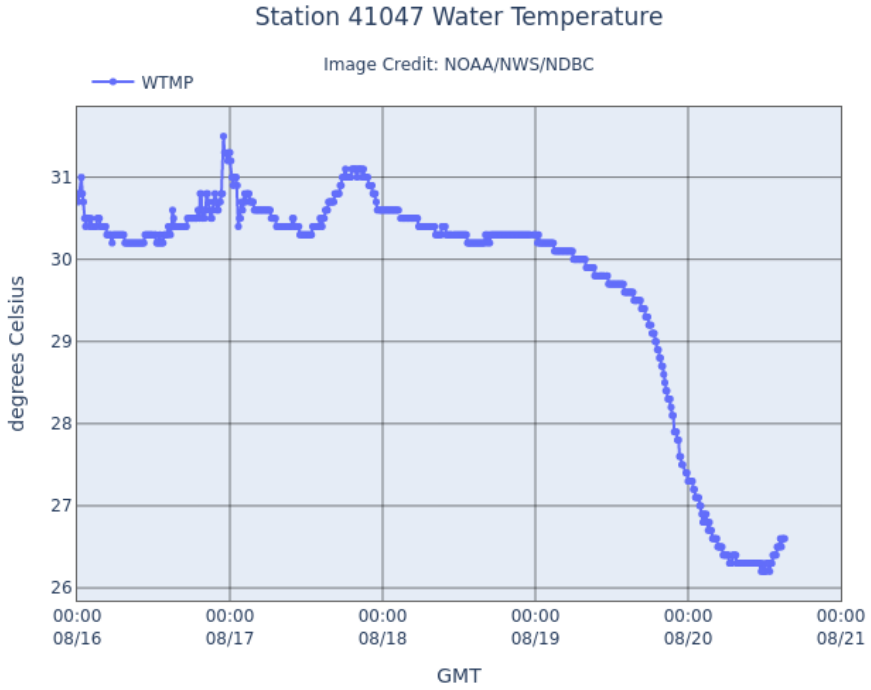
# Impact of the atmosphere on the ocean: tropical cyclones

## TC Erin 2025

ECMWF operational forecast

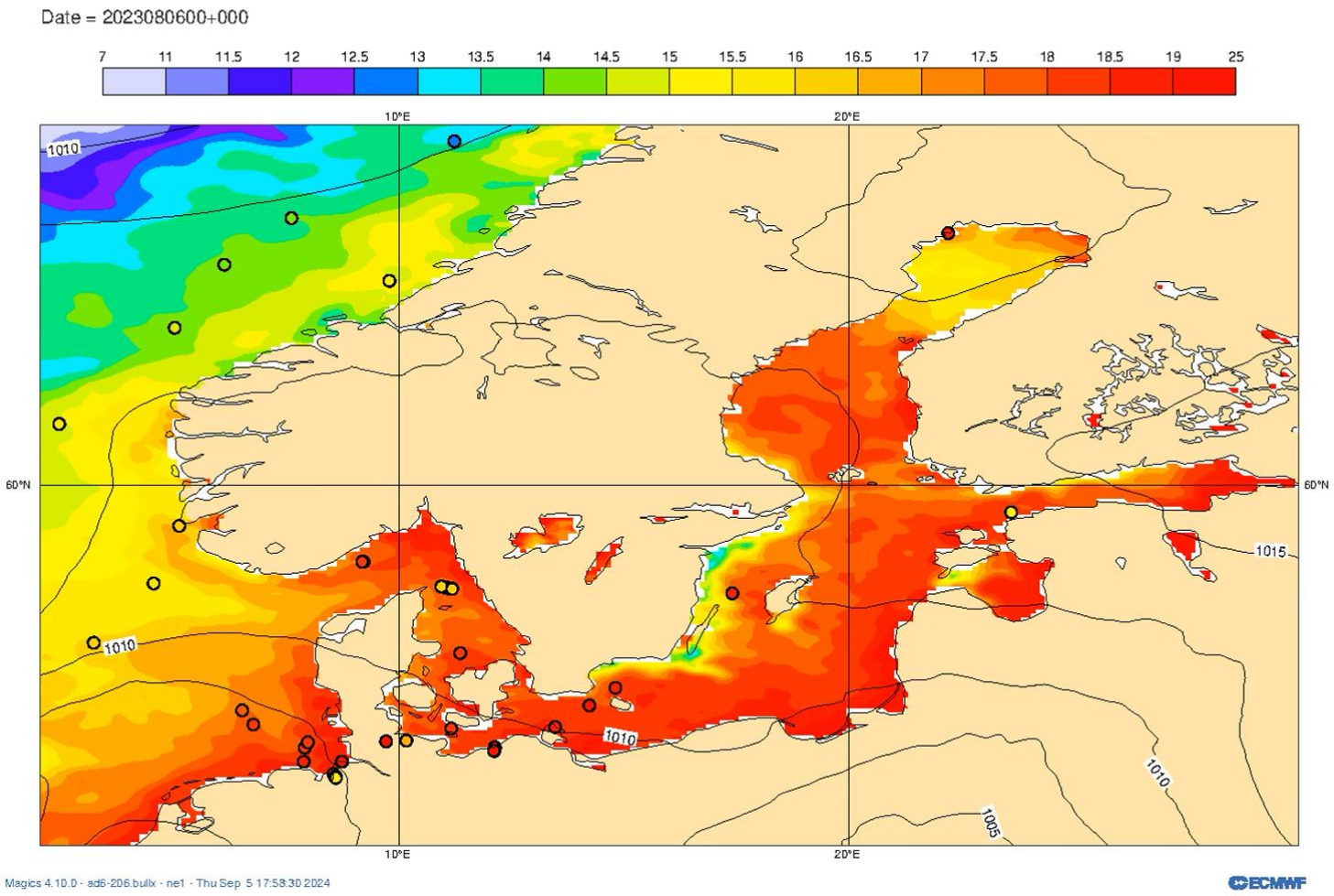



## Observed water temperature




**Model cooling occurs later than observed because the tropical cyclone propagates too slowly in the model**

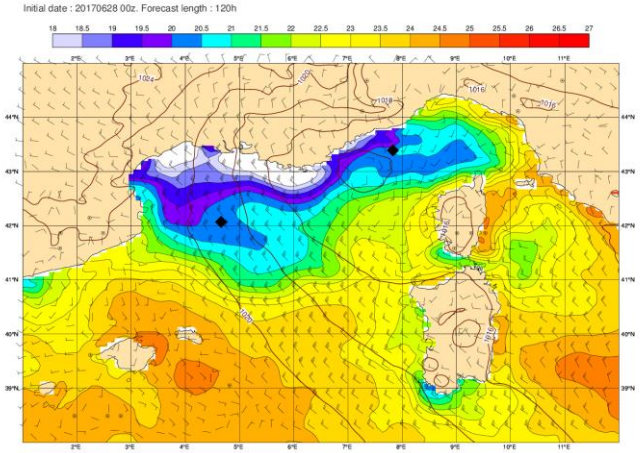
# Extra-tropical cyclones: Storm Hans in the Baltic



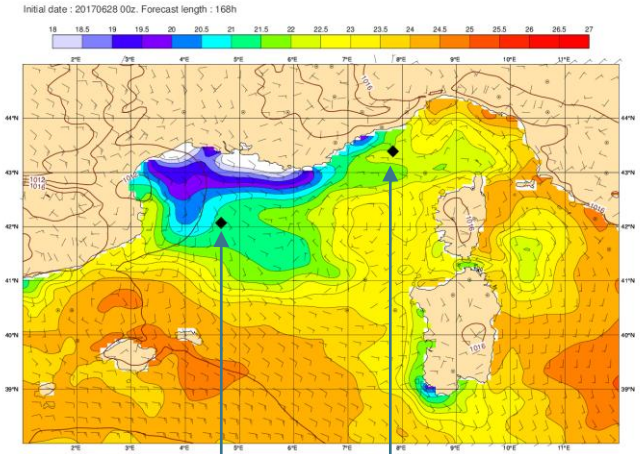

- Circles show ships operating in the Baltic. Notice the ferries moving back and forth.
- **As the storm develops, the Baltic cools by several degrees.**
- This is the ECMWF model. I expect other models could show this too.

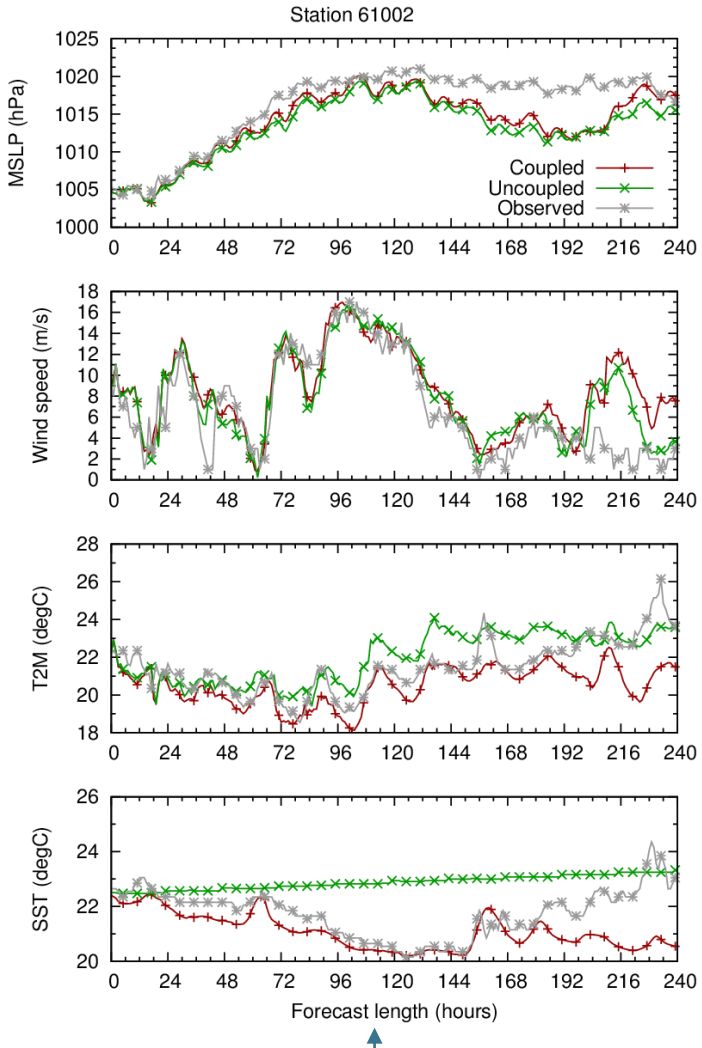
# Mediterranean Sea: Transition from Mistral to calm conditions

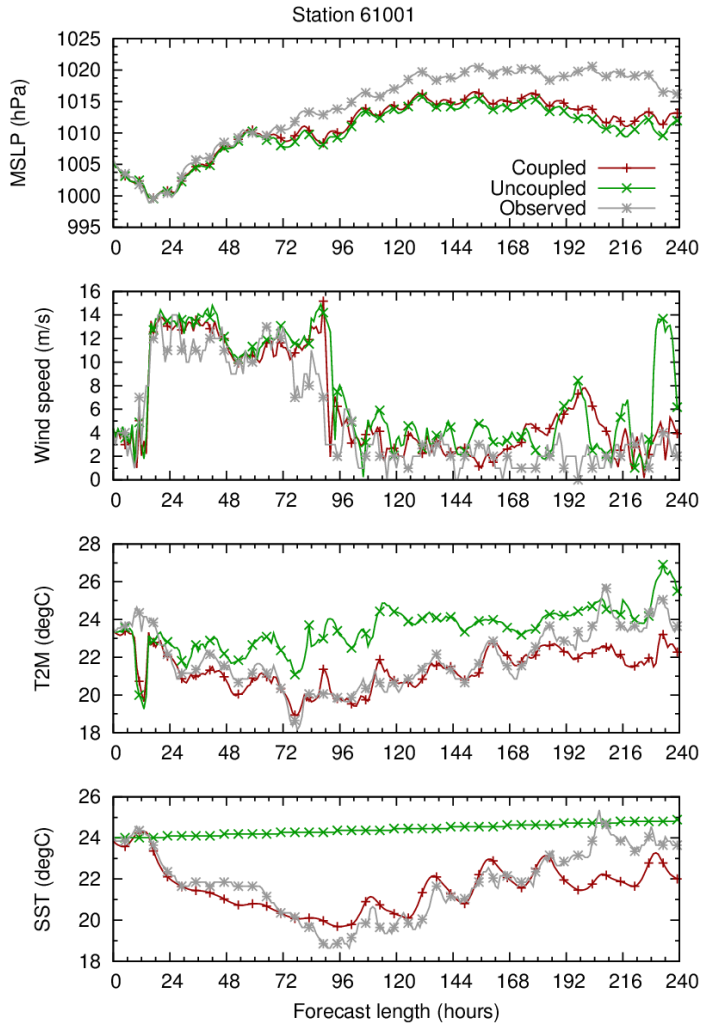
## Day 5



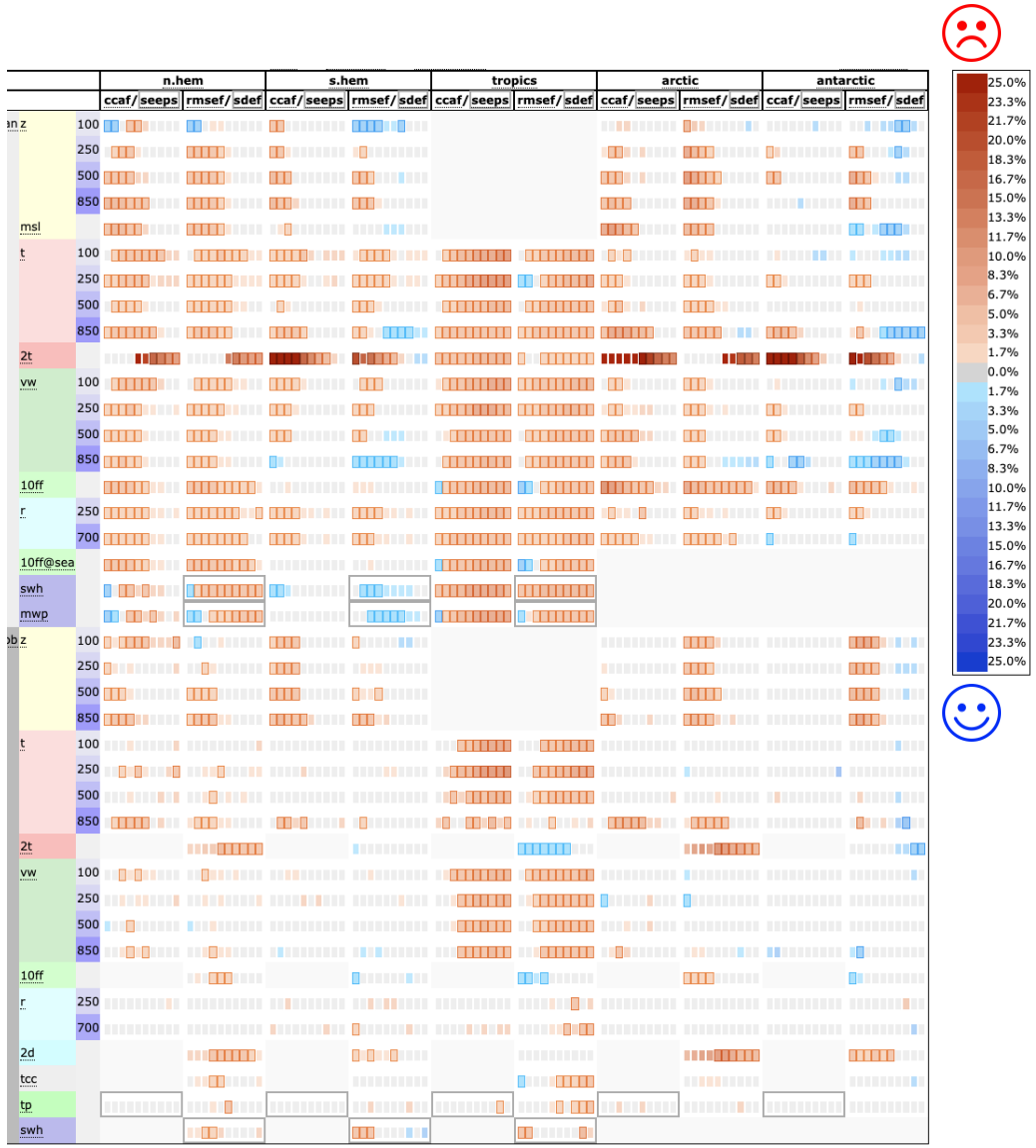

## Day 7



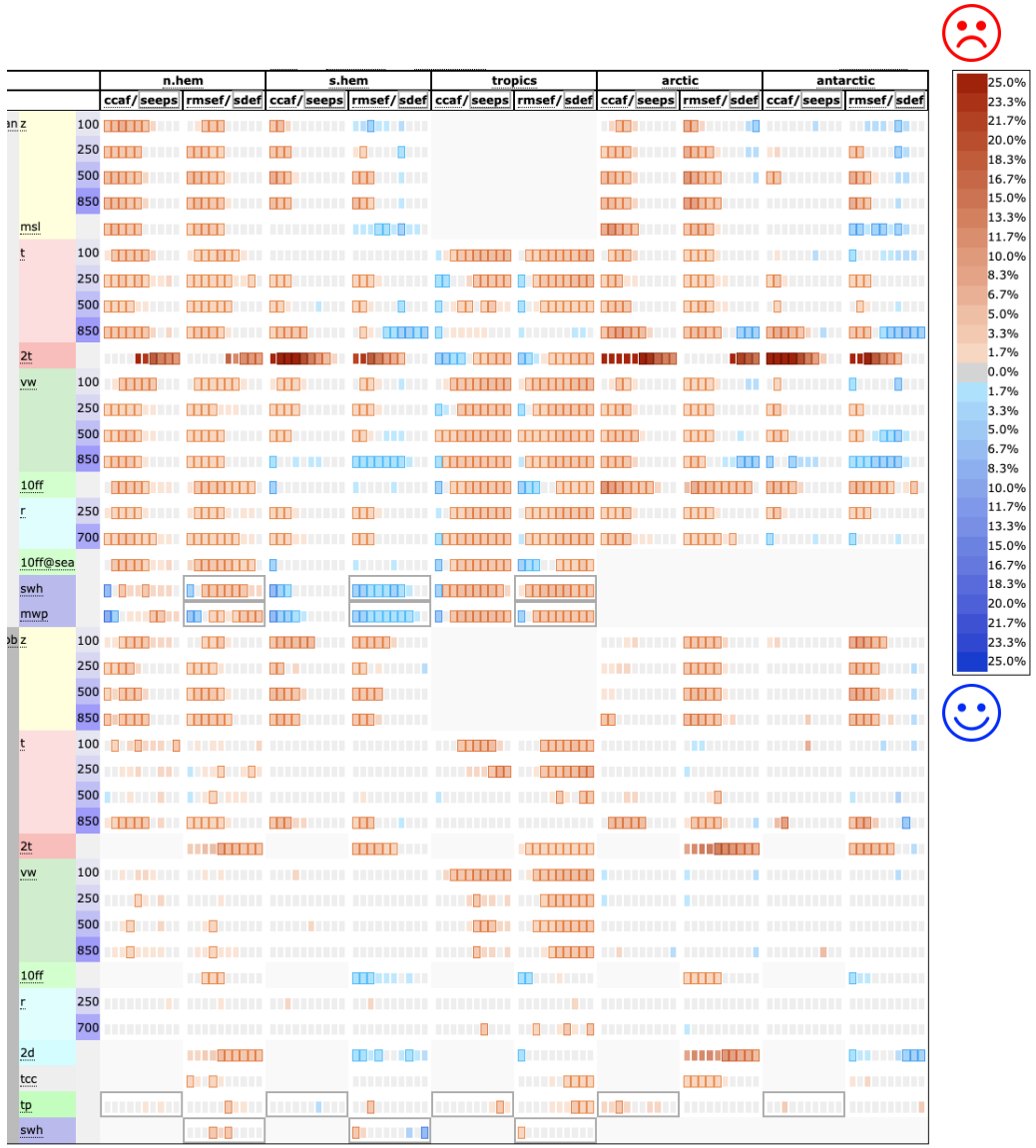



# Impact of ocean observations and DA on coupled weather forecasts 1:




- ECMWF uncoupled using OSTIA SST and sea ice concentration versus coupled performance with a recent model version
- Scorecards showing many atmospheric (ccaf) and (rmsef) scores against the analysis (top half) and observations (bottom half) if we returned to the uncoupled model for NWP forecasts
  - Same atmospheric initial conditions and verifying analysis
  - Red is bad, blue is good
- The impact of the ocean model with ocean DA initial conditions on the atmospheric fields is large and almost always positive
- **We are happy not to be happy with the uncoupled model without ocean data assimilation ☺**

# Impact of ocean observations and DA on coupled weather forecasts 2:



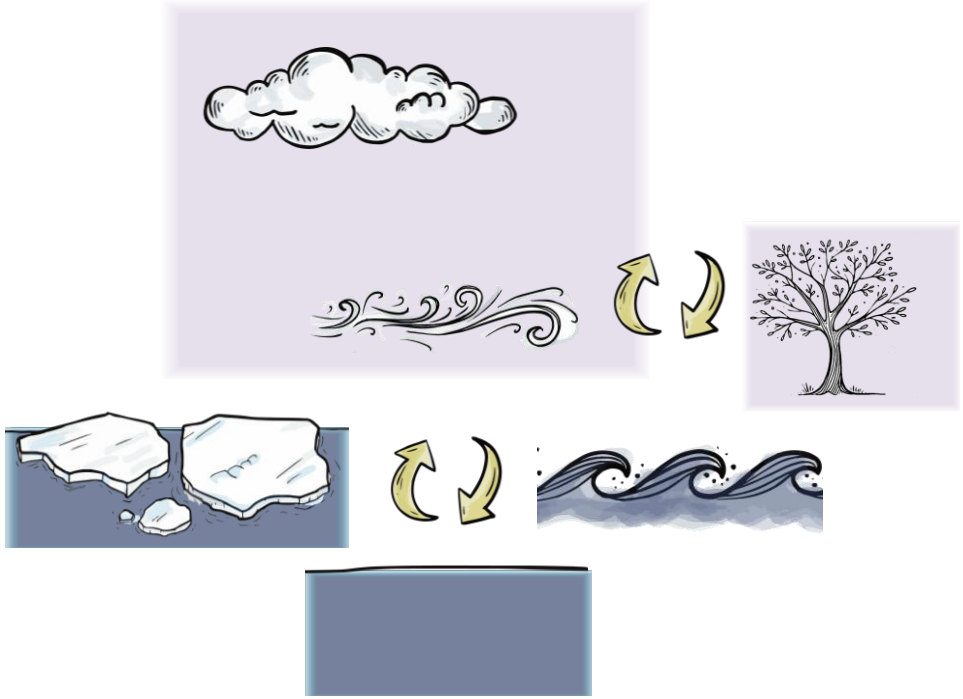

- ECMWF uncoupled using the SST and sea ice concentration (CI) from an ORAS6 like system versus coupled performance with a recent model version
- In this case we have used our best effort to create a good initial state of SST and CI using an ocean DA system which combines information from OSTIA, in-situ T/S observations, altimeter and sea ice concentration to estimate SST and CI at initial time.
- It is better than on the previous slide, but the combination of both ocean DA and coupled models is hard to beat
- **Data assimilators and modelers should be a team!**

# What about ML for “coupled” forecasts?

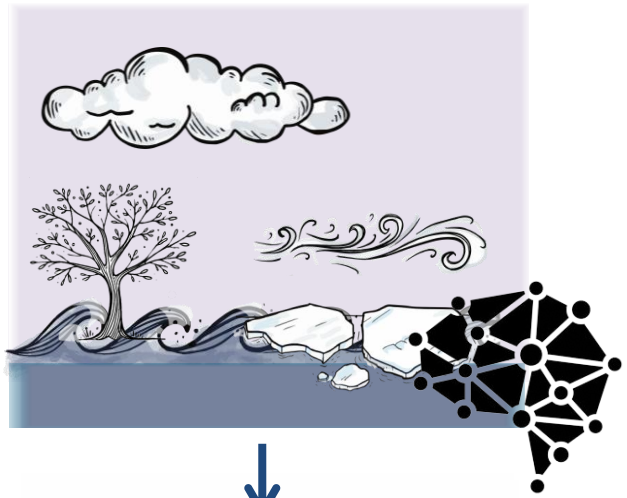
Slides from Sara Hahner and Lorenzo Zampieri

# Coupling the Earth System components to a data-driven atmosphere model

Traditional NWP:
Multiple coupled models



**Joint ML model**



AIFS v2
ECMWF

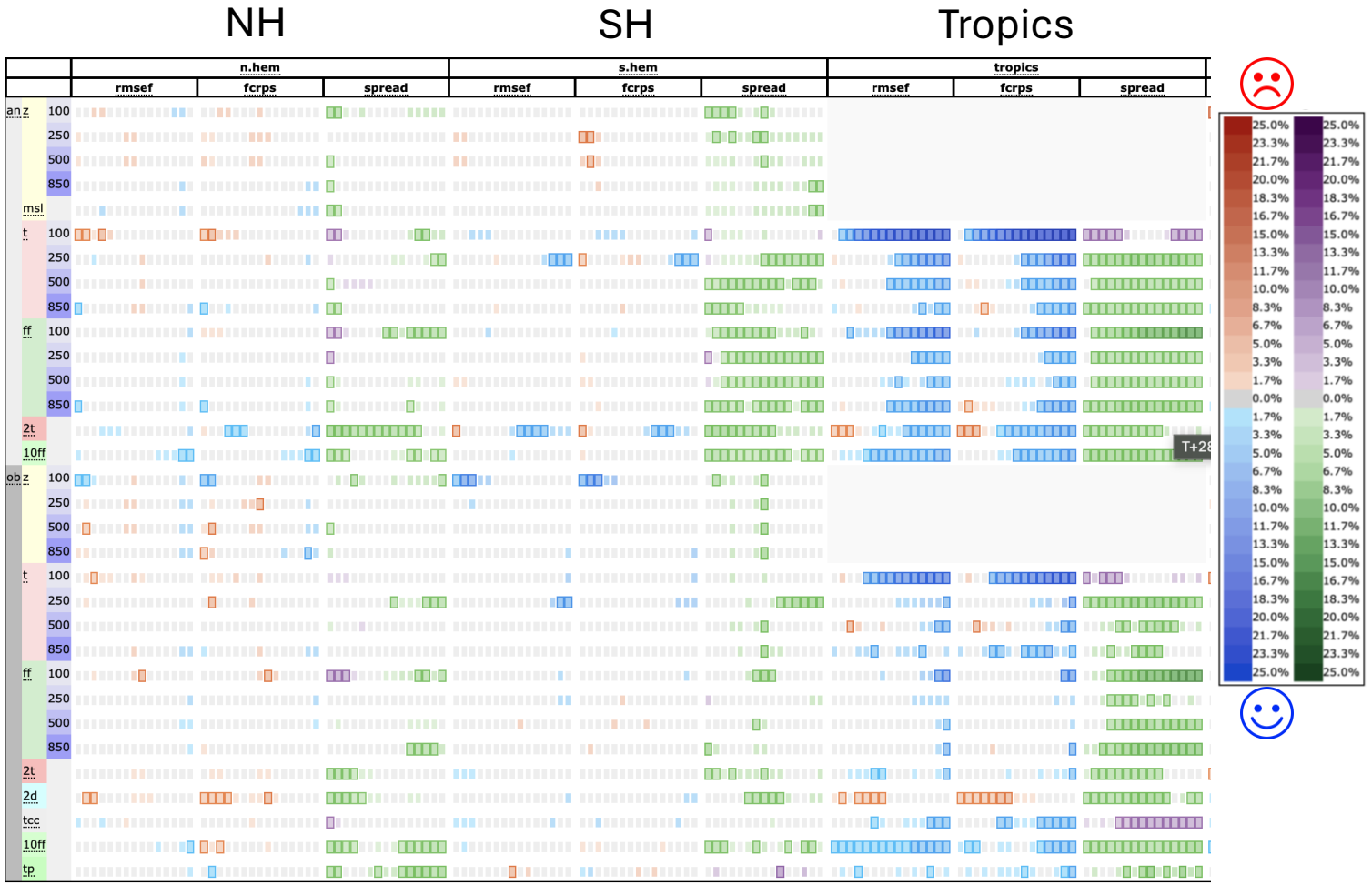
**Atmosphere, Land & Waves**

**Coming soon: surface ocean and sea ice**

# Ocean impact on the atmosphere is not just for physical models

**AIFS-ENS-v3 prototype with surface ocean**

MJJA 2026 – 12h frequency

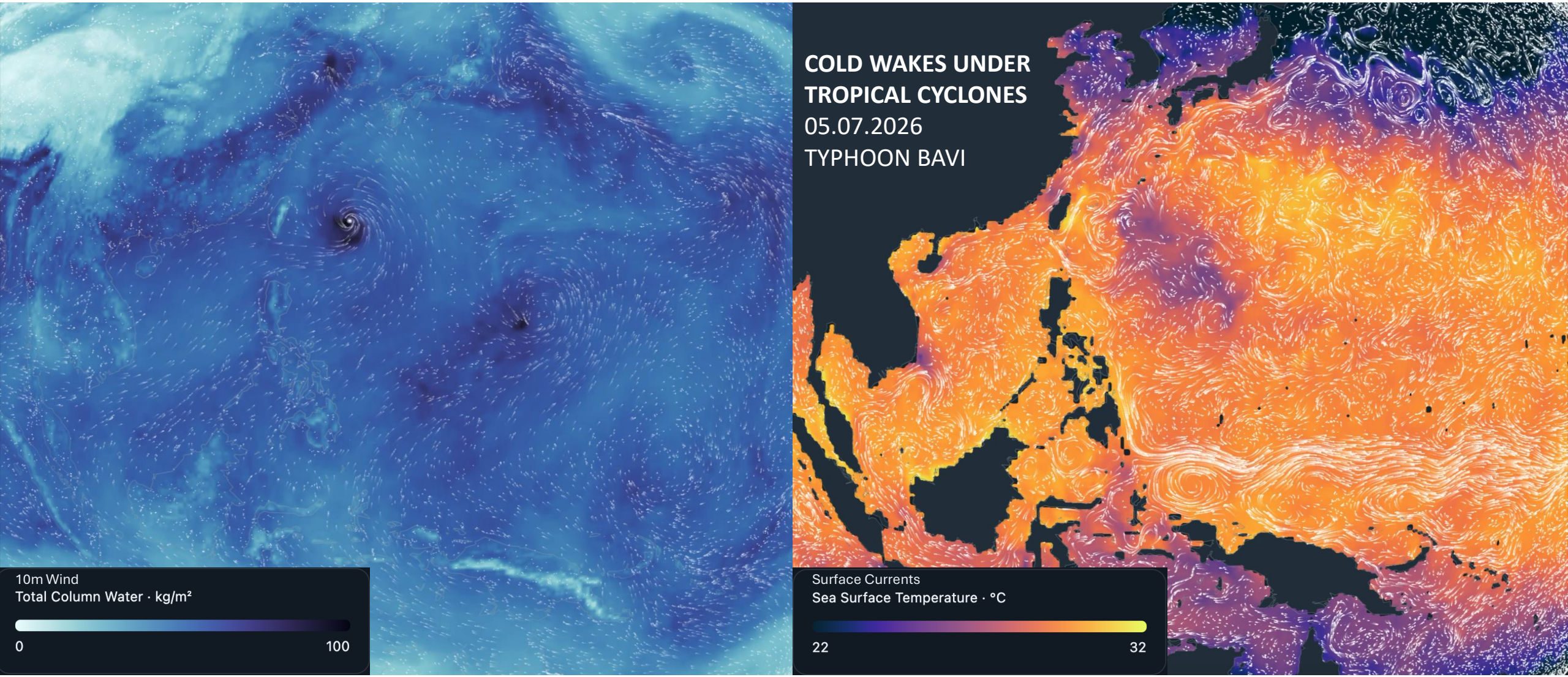



Modelling the surface ocean in a **joint setup** has a significant impact on **tropical scores** at medium-range lead times.

Fair CRPS is reduced (**blue colors**) for temperature and winds at all levels

Ensemble spread is also reduced (**green colors**)

# Also a joint ML model can learn the coupling between ocean and atmosphere



# Summary based on both AI and Kristian's opinions

- Forecasting centers use, or plan to use, coupled physics-based models to improve on atmosphere-only predictions on both global and local (including coastal) scales
- Ocean data assimilation is critical to these improvements
  - Coupled models also need good initial conditions
  - How much coupling do we need in data assimilation?
- Uncoupled ocean predictions also need good initial conditions
  - They also need good upper boundary conditions from atmospheric and ocean wave forcings
- Realistic initial conditions depend on a good observing network
  - Data assimilation experts must make the most of the existing network
  - Beyond this meeting's scope, we should work with observers to help sustain the network
    - Ocean observation experiments are one way to support this work
- Prediction systems may change dramatically, but the initial state will remain the basis for predicting the future

# Questions I would like us to discuss this week:

- What is the state of the art of coupled predictions systems and what is missing on the ocean feedback side?
  - Especially which coupled process and air-sea interactions needs improvements for progress
- With the rapidly changing AI landscape how we should create the best prediction systems for the future?
  - Can we even answer that question at the moment?
- Coupled DA is here to stay, but how much coupling do we need?
- Are there any new DA methods which can dramatically change what we do?
  - Applications of ML with DA?
- What is the future of ocean and coupled reanalyses?
- Is the value of different ocean observation types proposed by Co-Pilot accurate?
  - It didn't cover biogeochemistry, but I blame the human user (me) of the AI for his lack of knowledge in that field
  - Spoiler alert and shameless ECMWF promotion: I tend to agree here, but I think that Co-Pilot have been reading ECMWF's work on OSE's (see Hao's talk on Friday)

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