Effects of atmosphere and ocean horizontal model resolution on upper ocean response forecasts in four major hurricanes

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Introduction

- Tropical cyclones are one of the most destructive weather systems on Earth
- A key element in accurate modelling and prediction tropical cyclones is the exchange of heat and momentum between the ocean and the atmosphere
  - This implies that the we need to use a coupled atmosphere-wave-ocean modelling system
- In this talk we present some results from increasing the resolution of the atmosphere (IFS) and ocean components (NEMO) of the ECMWF coupled prediction system
- The ocean response is evaluated against ALAMO floats
  - Air-Launched Autonomous Micro Observer
  - Rapid (~2 hours) cycling temperature and salinity measurements
- Hurricanes studied: Irma 2017, Florence 2018, Teddy 2020 and Ida 2021
  - Storms determined by the availability of ALAMO float

Setup for these experiments

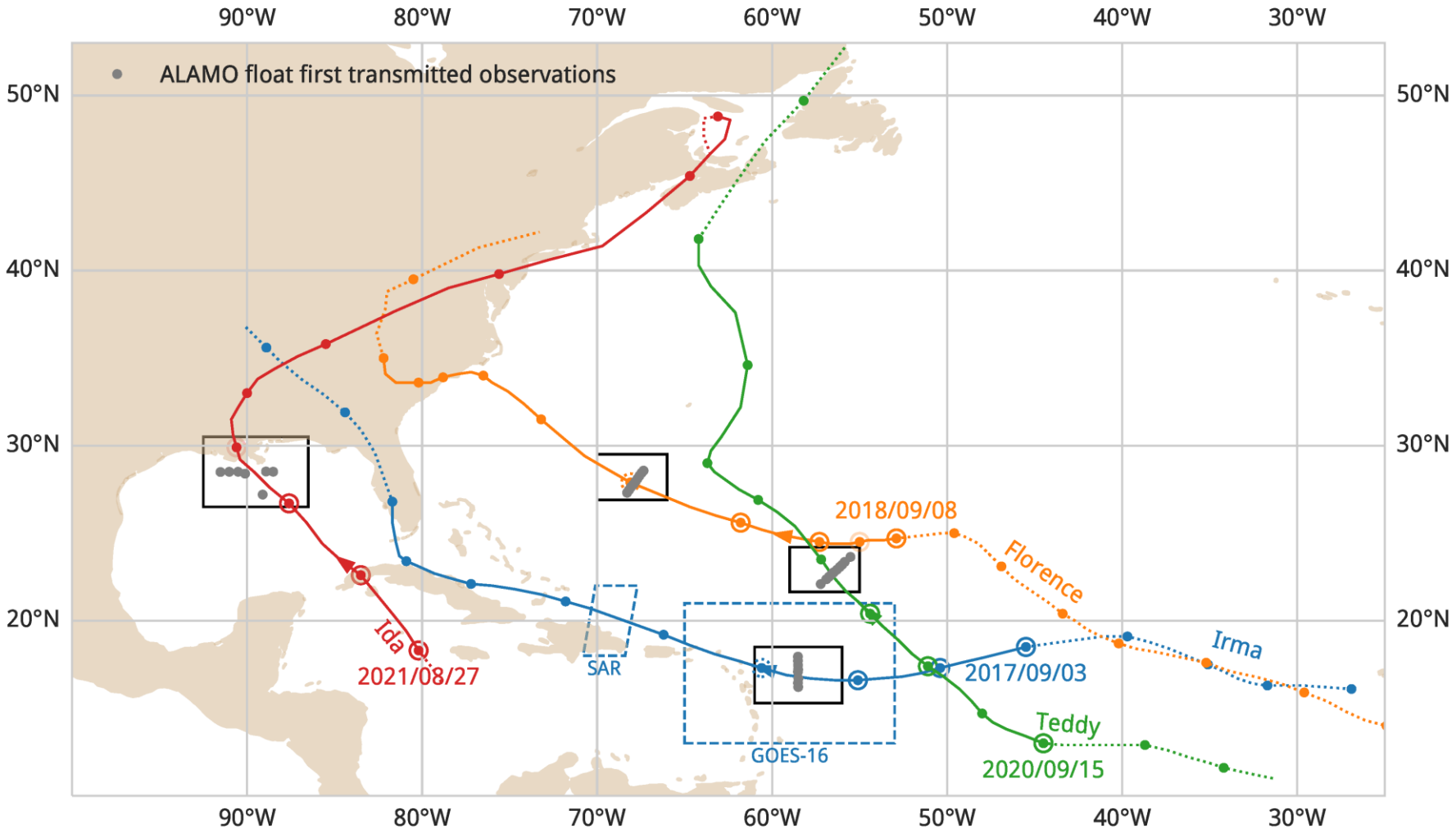
- Based on the ECMWF Integrated Forecasting System (IFS) version CY47R3
  - Operational from 12 October 2021 to 27 June 2023
  - Consists of an atmosphere model, a wave model (based on WAM) and an ocean model (NEMO)
  - Operationally we run this with a 9-km atmospheric resolution and a 25-km ocean resolution
- For the experiments we tests the following resolution combinations:
  - Ocean: 25 and 8 km
  - Atmosphere: 9, 4.4, 2 and 1.4 km (only 8 km ocean for 1.4 km atmosphere)
- Operational like setting otherwise but only 7-day forecasts to save computational costs
- Operational 9 km atmospheric initial conditions interpolated for resolutions higher than 4.4-km
- Ocean initial conditions generated from a simple scheme with a forced ocean model relaxed strong to SST from OSTIA
  - Ocean initial condition from a proper data assimilation system would be better, but we did not have that capability at the time for these runs

Setup for these experiments 2

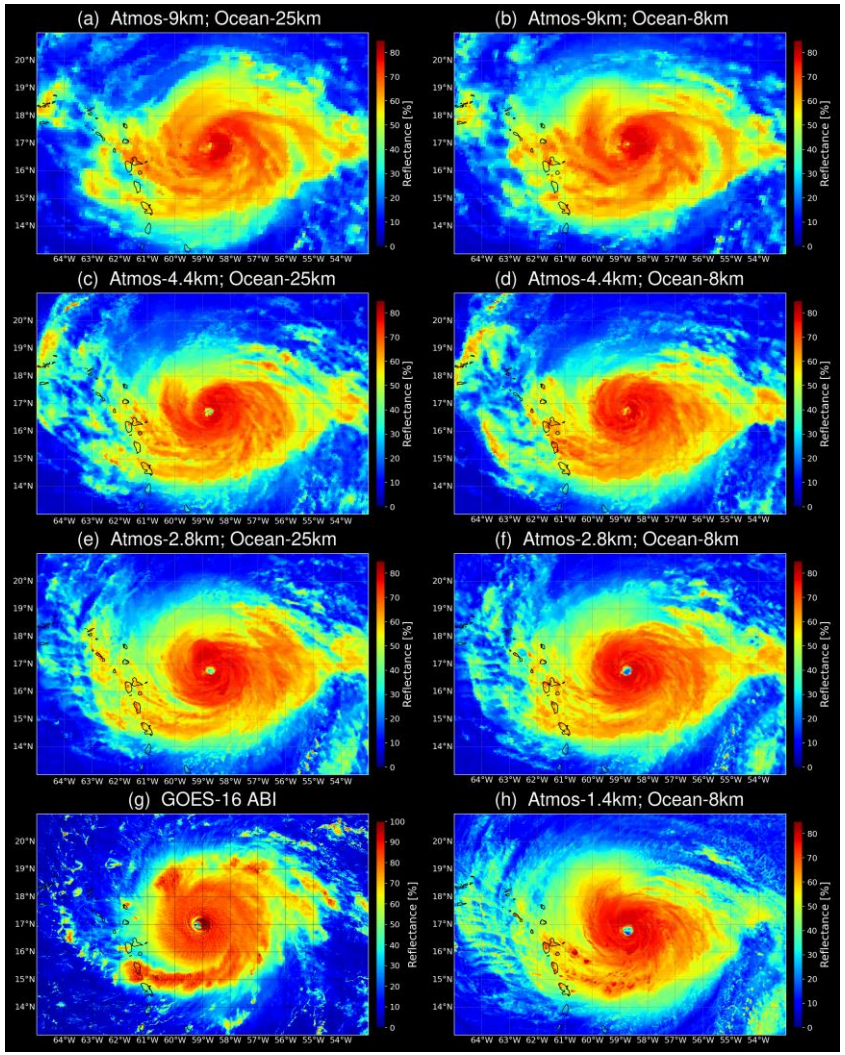
- Small number of integrations due to cost:
  - All runs but the 1.4-km+8-km runs were done on the ECMWF Atos BullSequana XH2000
  - The 1.4-km+8-km runs were done on DOE Summit under the INCITE 2022 program

Hurricane	Start dates
Irma 2017	2017090300 2017090400, 2017090500+, 2017090600
Florence 2018	2018090800 2018090900 2018091000 2018091100+ 2018091200
Teddy 2020	2020091500 2020091700 2020091800+
Ida 2022	2021082700 2021082800 2021082900+ 2021083000

Location of hurricanes considered in this study



Detailed case study 1: IRMA



High resolution gives more realistic structure of the hurricane

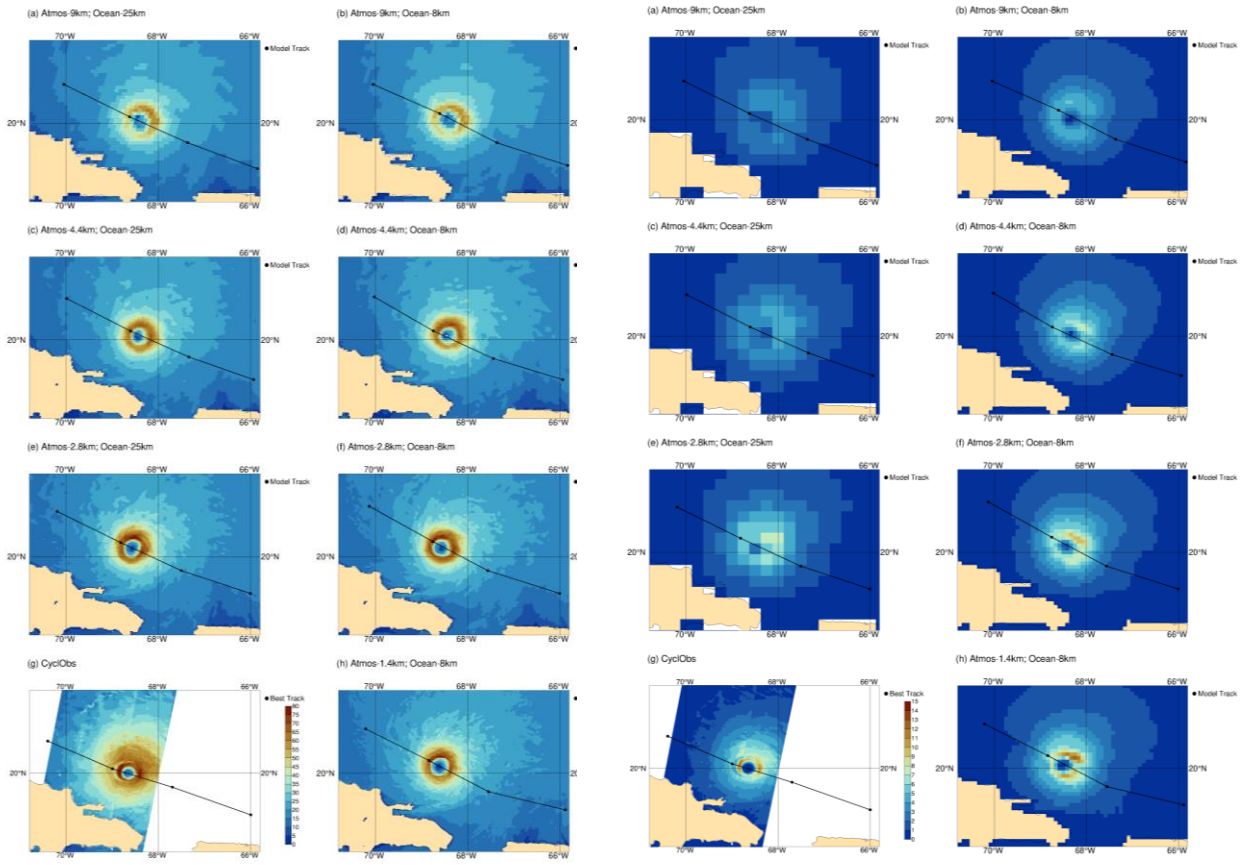
Detailed case study 2: IRMA

9 km

4.4 km

2.8 km

OBS/1.4 km

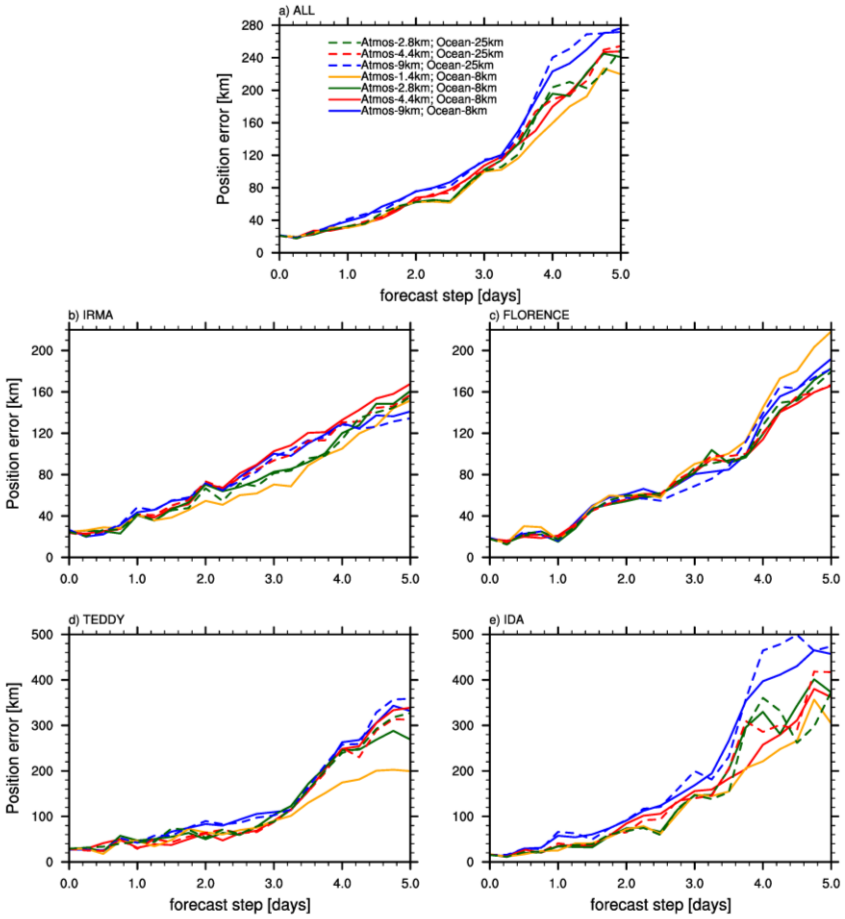


25.km 8.km 25.km 8.km

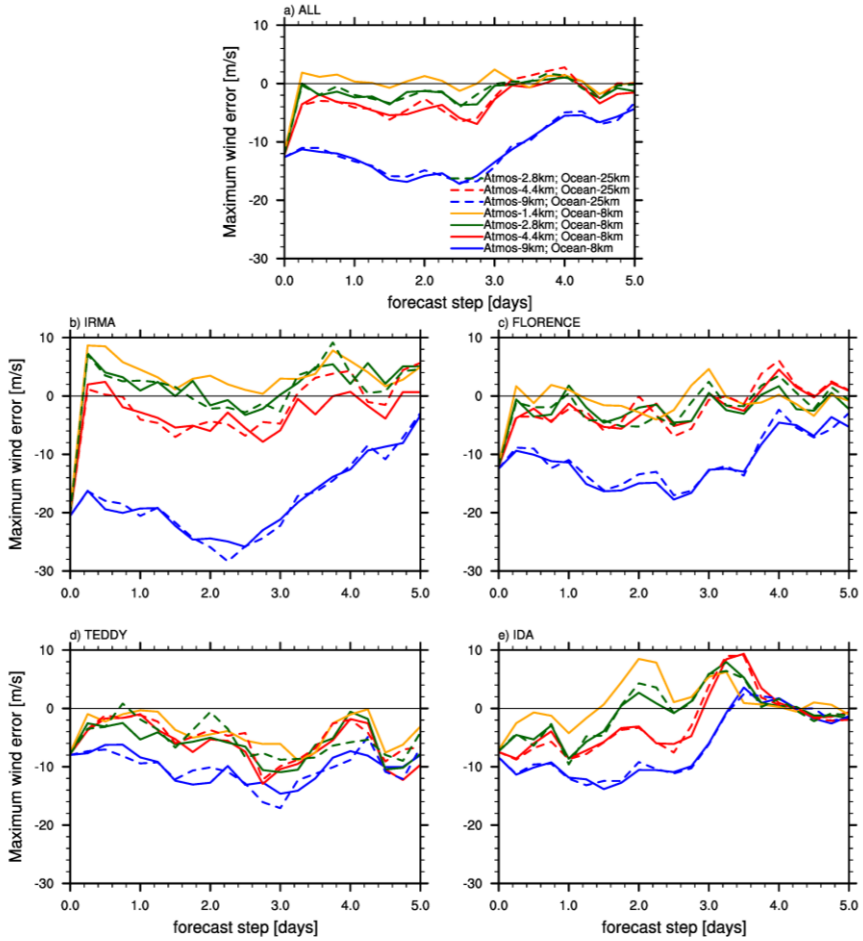
Wind atmosphere grid Stress ocean grid

- Increasing atmosphere resolution downwards
- Increasing ocean resolution from left to right
- Bottom left is observation for SAR
- Winds are not sensitive to ocean resolution
- But stress on the ocean grid is

Predictive skill of Hurricane track and intensity

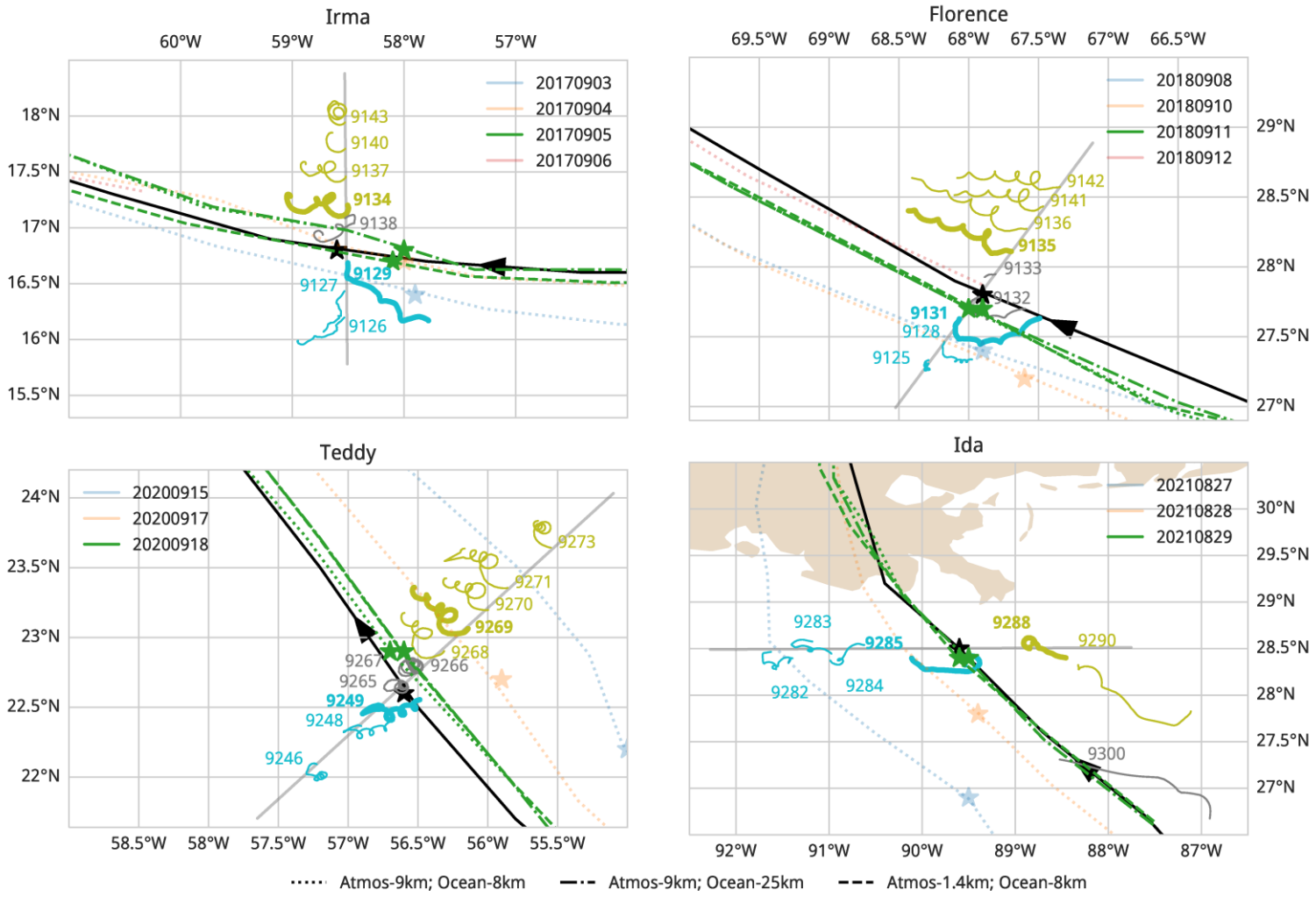


Track error

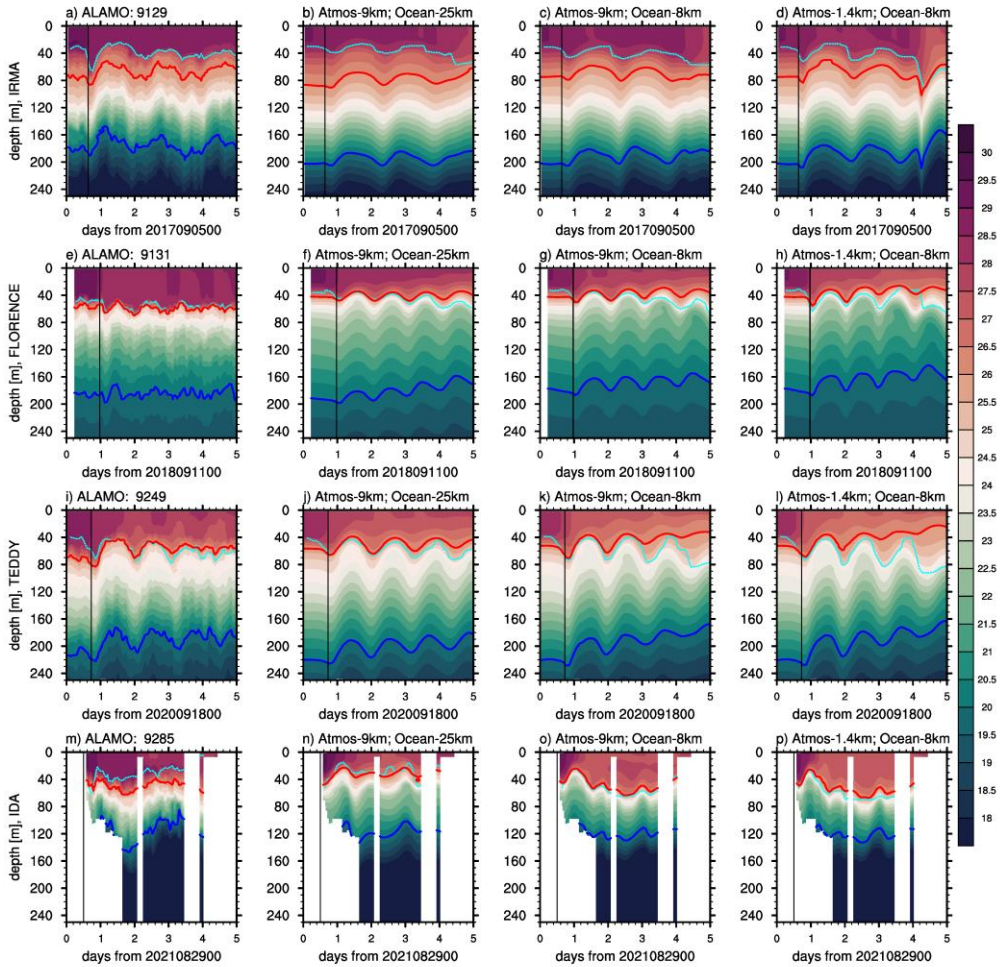


Wind speed error

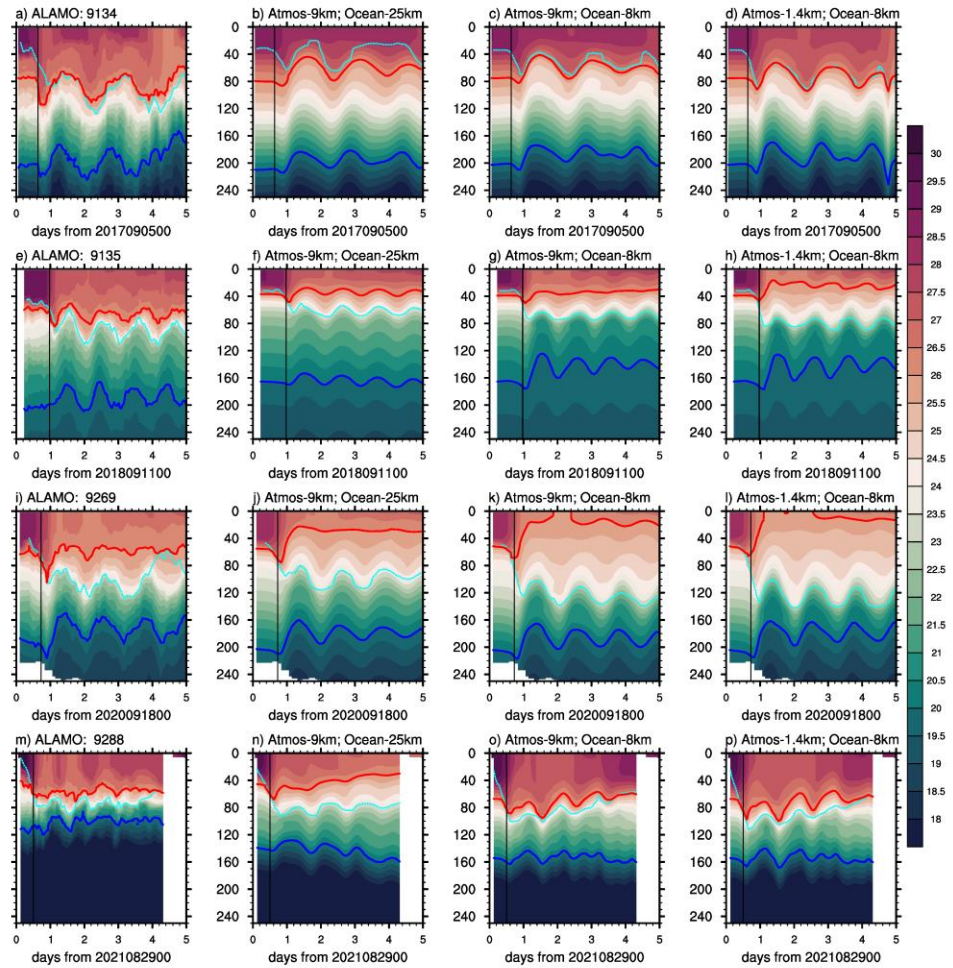
Position of ALAMO floats relative to track



Examples of predicted upper ocean temperature compared to ALAMO floats

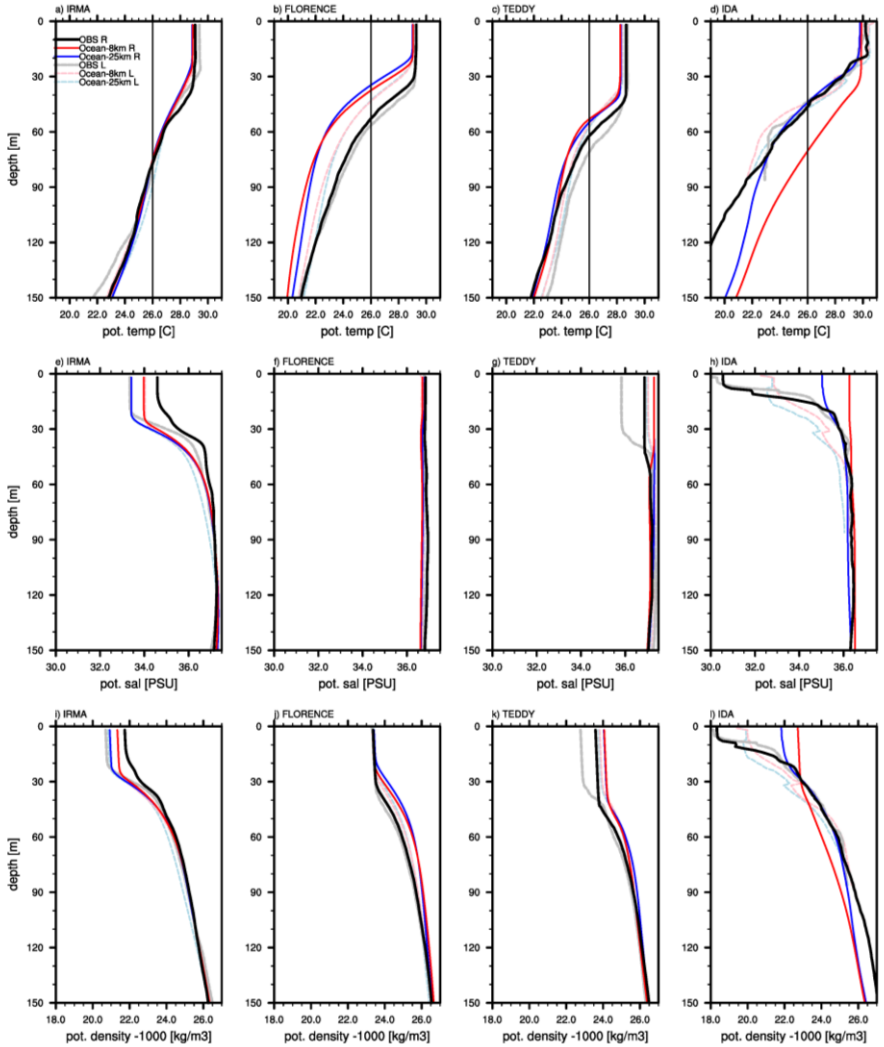


Left of track



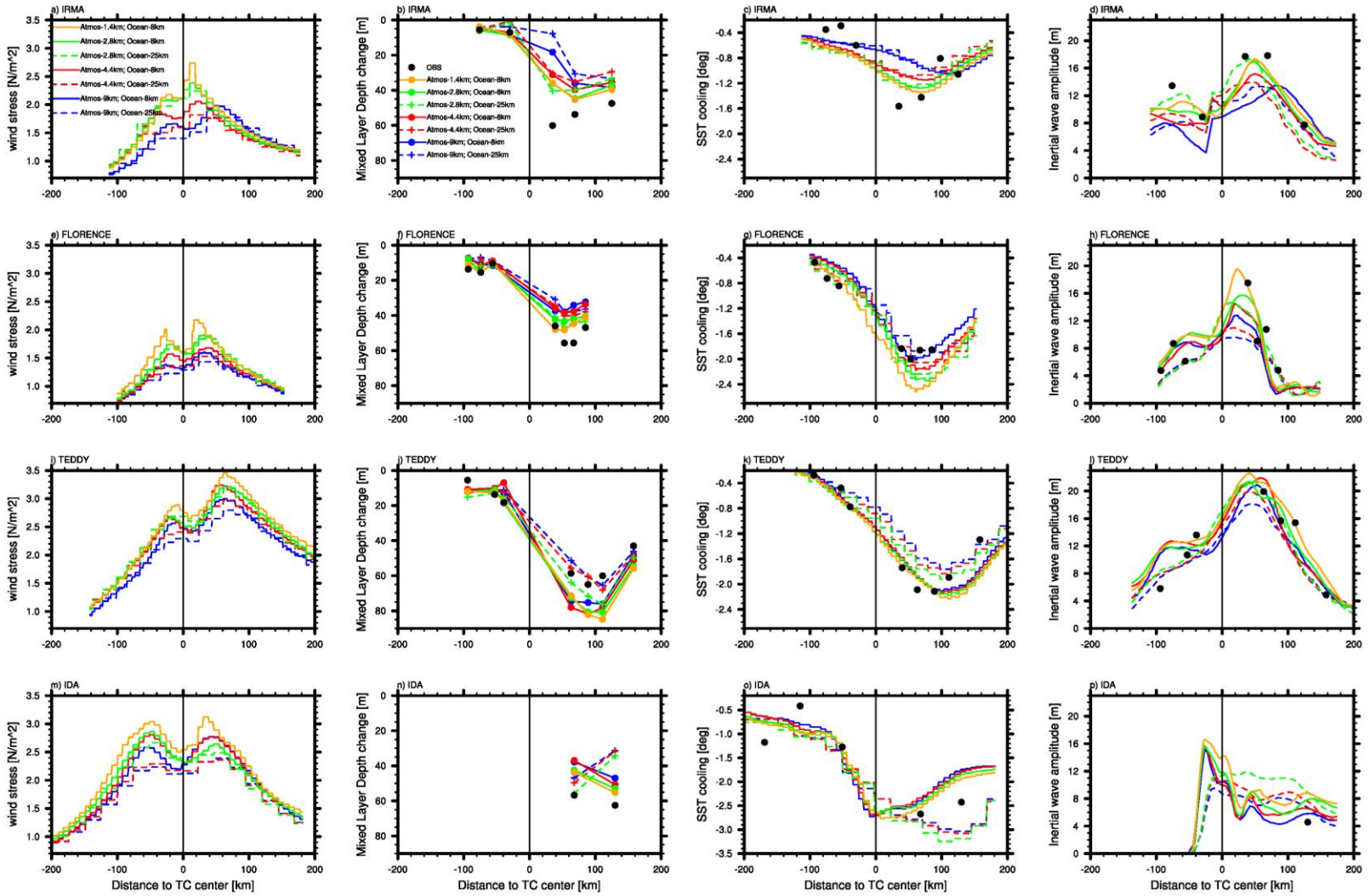
Right of track

Initial stratification of the ocean before the storm passage



- Averaged profiles left (L) and right (R) of track
- While the method is the same for generating ocean initial condition for 25 and 8-km resolutions, the ocean stratification in the initial conditions are different
- Not necessarily better for 8-km
- Ida is difficult due to the proximity to land in the Gulf of Mexico
- Errors in ocean initial conditions can lead to errors in forecast performance

Ocean model performance at the ALAMO locations



- Start date with + on table
- Time integrated ocean wind stress
- MLD deepening
- SST cooling
- Near-inertial oscillation amplitude based on the 20°C isotherm
- Higher ocean stress with both atmosphere and ocean resolution
- Better fit in general to the ALAMO data with higher resolutions
- Initial conditions just as important as resolution

Conclusions

- Increasing atmosphere and ocean model horizontal resolutions in the ECMWF IFS results in physically realistic atmosphere and ocean features in four major hurricanes.
- Atmospheric model horizontal resolution did significantly impact TC track and intensity forecast accuracy
- Ocean model horizontal resolution did not substantially impact TC track and intensity forecast accuracy in these storms
- Increased atmosphere and ocean model resolution mattered most within the TC core near the radius of maximum winds
- Accurate forecasts for the upper ocean response to TC passage required accurate ocean initial conditions
- Accurate forecasts for the upper ocean response to TC passage are likely critical in cases of slowly moving TCs and those over shallow warm or cool ocean mixed layers

Priorities for future work:

1. Increase atmospheric model horizontal resolution
2. Improve ocean initial conditions (coastal and open ocean)
3. Increase ocean model horizontal resolution
4. Continue to ground-truth model simulations using both atmospheric and ocean observations

Reference:
I. Polichtchouk *et al* 2024*:* Effects of atmosphere and ocean horizontal model resolution on tropical cyclone and upper ocean response forecasts in four major hurricanes. Under review in MWR.