Wave Workshop 2025, Santander, Spain

Developing data assimilation techniques to reduce uncertainty in numerical wave forecast :

Evaluating the forecast skill improvement from assimilating persistent buoys vs. high spatial coverage satellite altimeters

Duphrin Joseph[1], Jeff Hansen[1], Marzieh H Derkani[1], Arthur Filoche[1]

[1] The University of Western Australia, Australia

Introduction

Errors in wave forecasts remain common, particularly for swells.

Data assimilation (DA) offers a method to reduce errors and is becoming more common in operational wave forecasting. Historically, DA for operational wave models has been limited due to a lack of observations.

🌎 **Global wave observations are increasing** through satellite missions and buoy deployments

- Buoys offer long-dwell in time but low spatial coverage
- Satellite altimeters offer high spatial coverage but no persistence in time

❓ **But key questions remain:**

👉 Does long-dwell or high coverage have a greater impact on improving forecast skill?

👉 How does **data density** within each platform influence the strength and persistence of forecast corrections?

Experimental set up

- 3-month long forecast runs that assimilate Significant Wave Height (SWH) observations from buoys and altimeters using optimal interpolation.

4 Systems considered

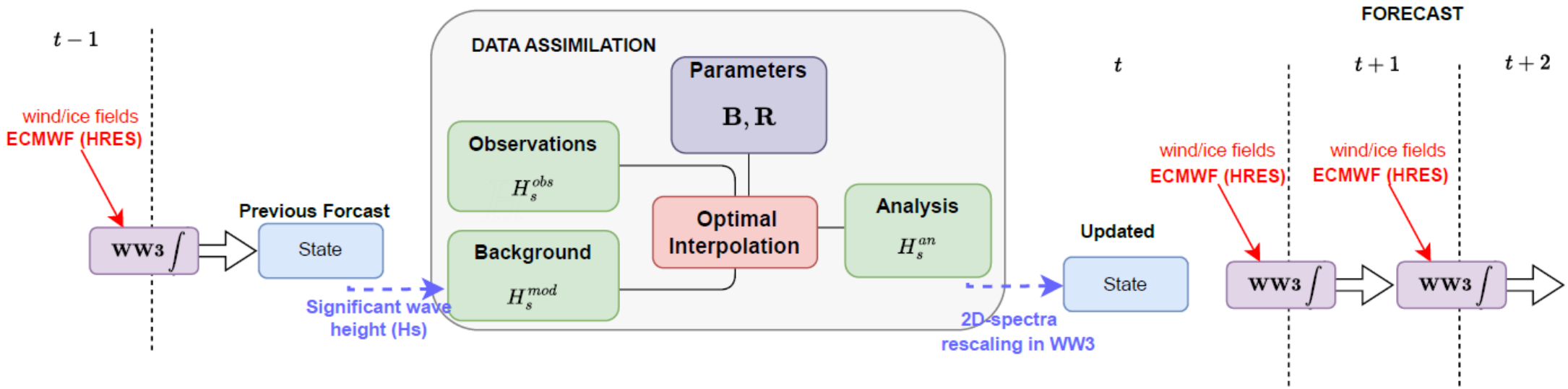
No Data Assimilation

Altimeter-only assimilation 

Buoy-only assimilation 

Combined altimeter + buoy assimilation  ✚ 

DA Framework



Model Information

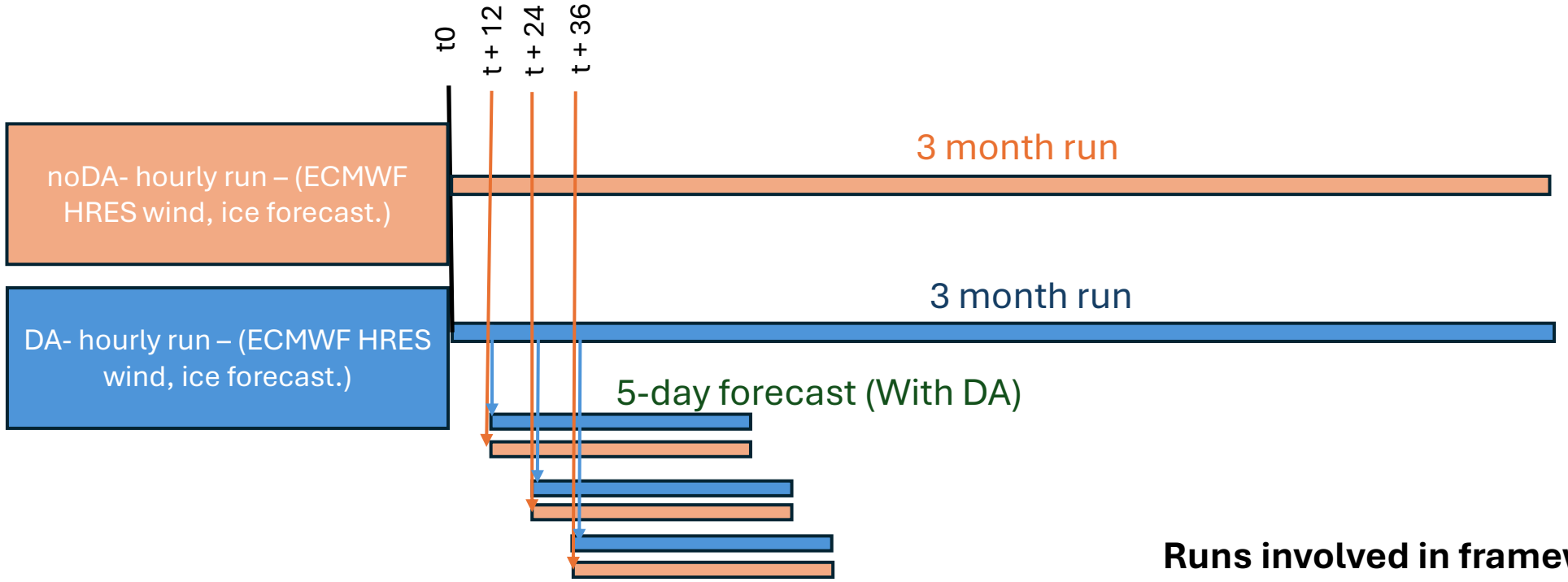
Model: WaveWatchIII

Grid resolution: 0.4°× 0.4°

Inputs: ECMWF HRES wind and ice forecast

- SWH is assimilated to the WW3 model every hour using an offline method.

Experimental set up

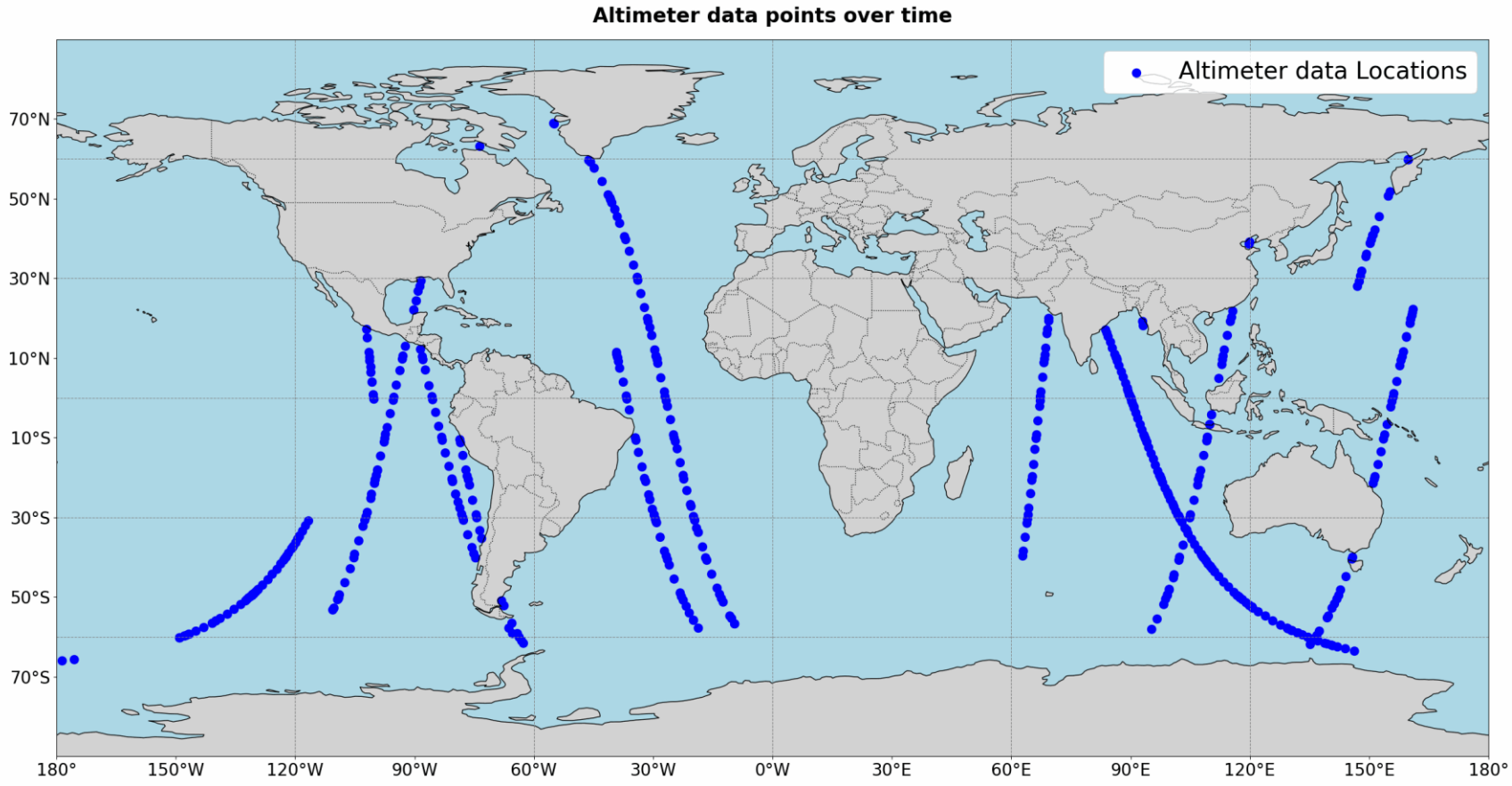


Runs involved in framework

1. NoDA,
2. Buoy DA,
3. Altimeter DA,
4. Altimeter + Buoy DA

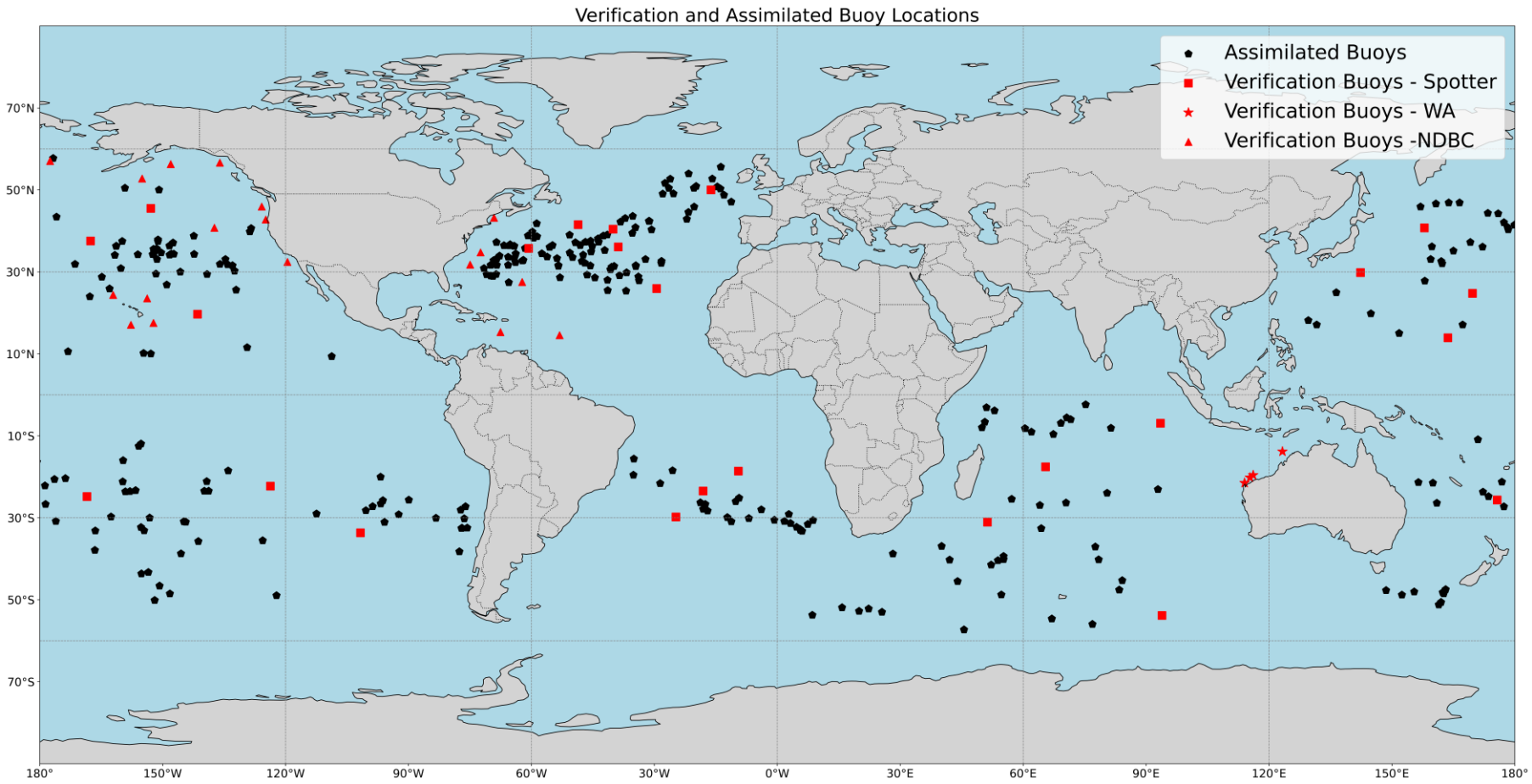
Assimilated and verification data

- Altimeter data from 7 different satellites were assimilated (CFOSAT, CRYOSAT, JASON3, Sentinel-3A, Sentinel-3B, Sentinel-6A, HY-2B)



Assimilated and verification data

- 306 Buoys from Sofar open-source spotter archive data were assimilated

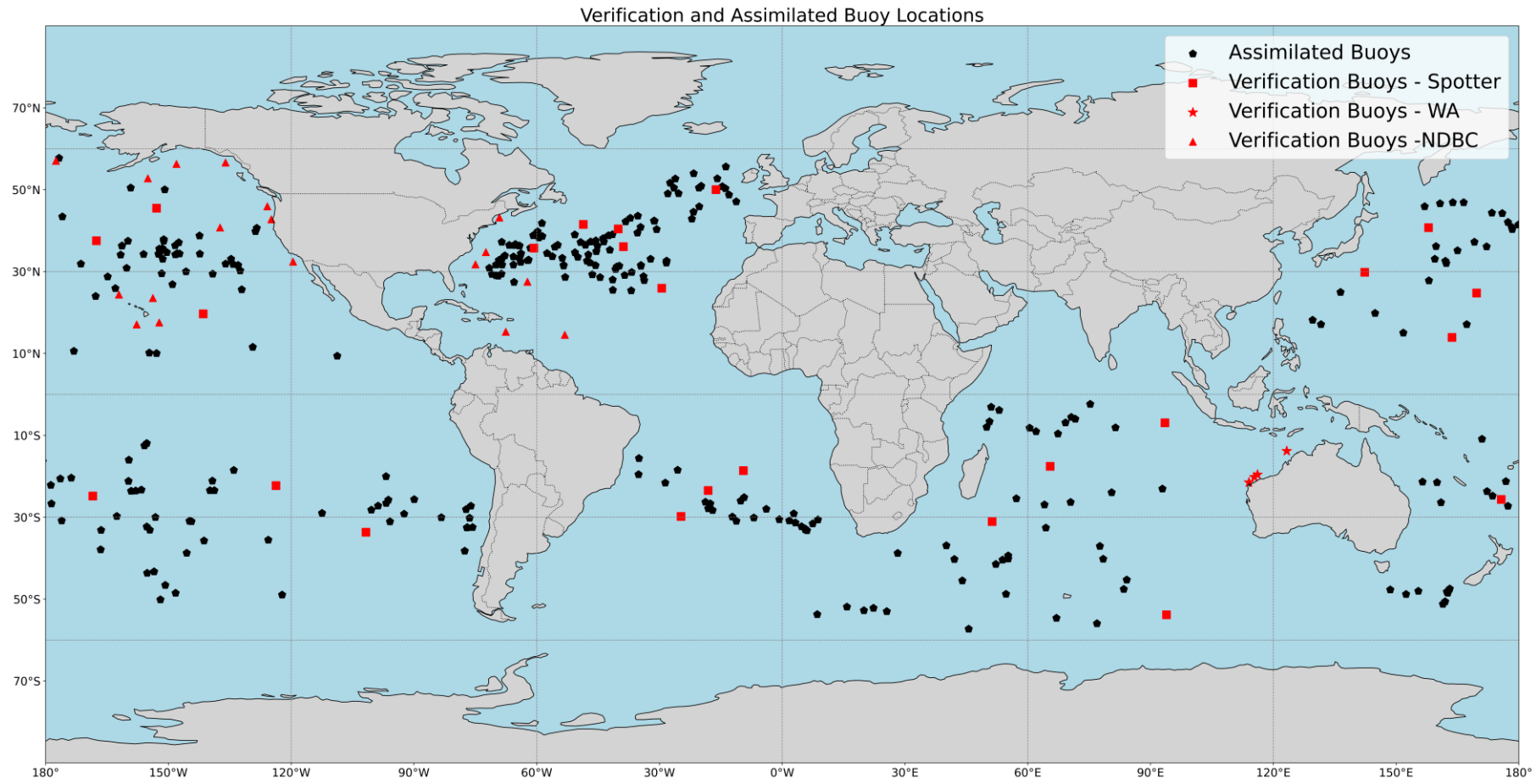


Assimilated and verification data

- 42 Buoys were used as verification locations (Not assimilated).

- Verification buoys are selected based on:

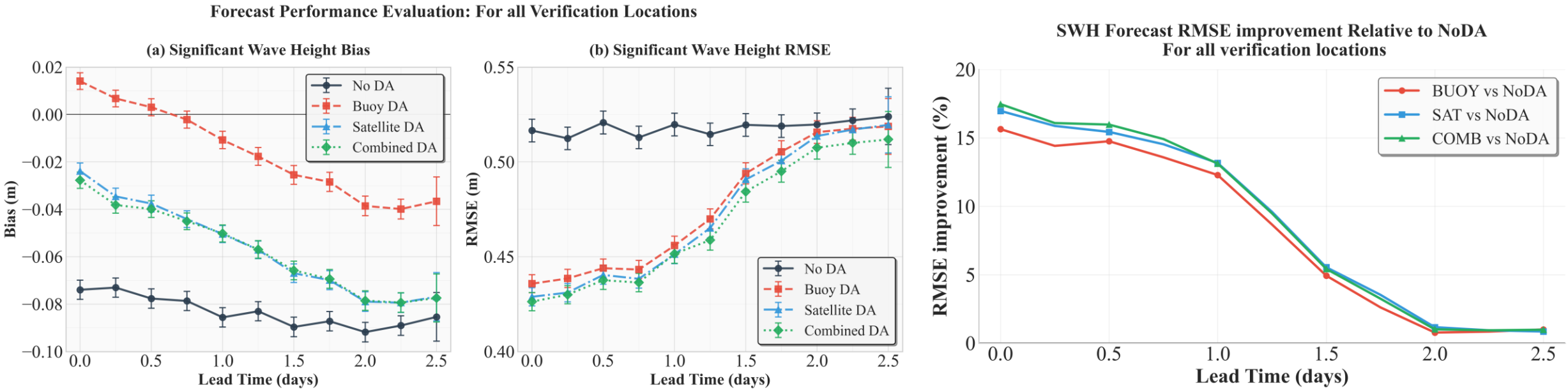
1. Location,
2. Importance of the region
3. Proximity to the verification locations.



Results

Overall RMSE and Bias for the period of analysis (for Significant Wave Height (SWH))

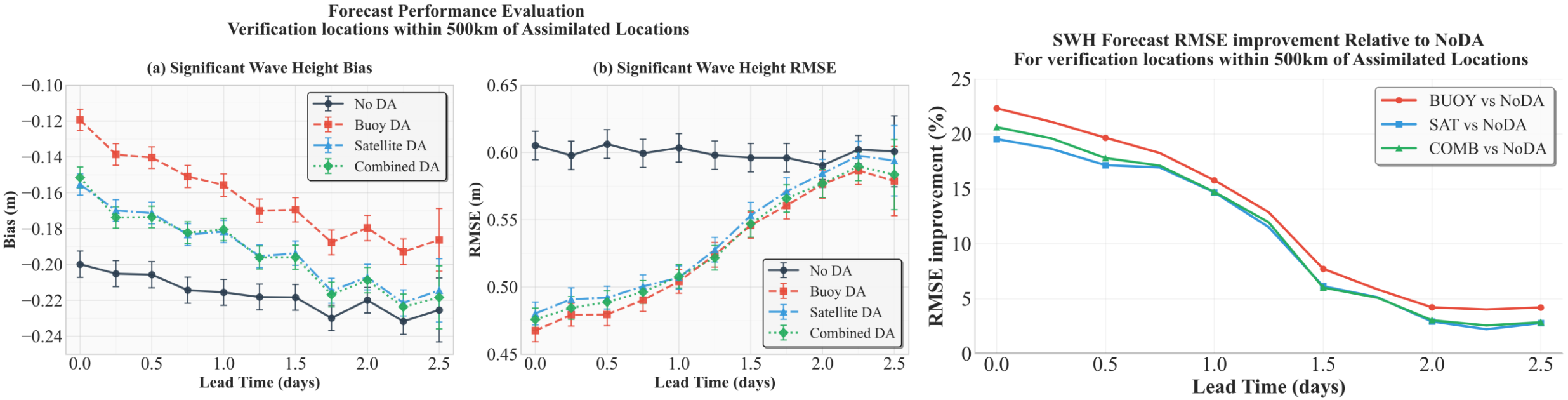
- RMSE shows significant improvement in the first 24 hours of the forecast across all DA cases.
- Altimeter and combined (with buoy) assimilation shows the greatest forecast improvement compared to buoys alone (17% improvement over NoDA).
- In bias, the SWH is consistently underestimated in NoDA simulations. However, the altimeter and combined assimilation was able to improve this.



Results

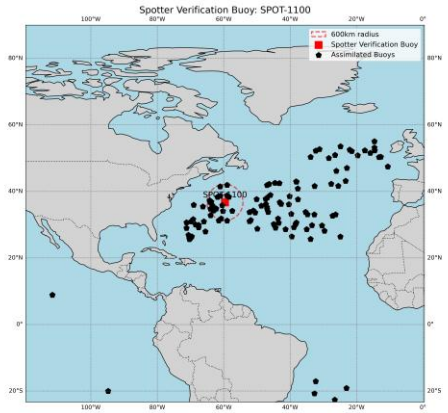
RMSE and Bias in SWH for the period of analysis for location where assimilated buoys are within 500km of the verification location

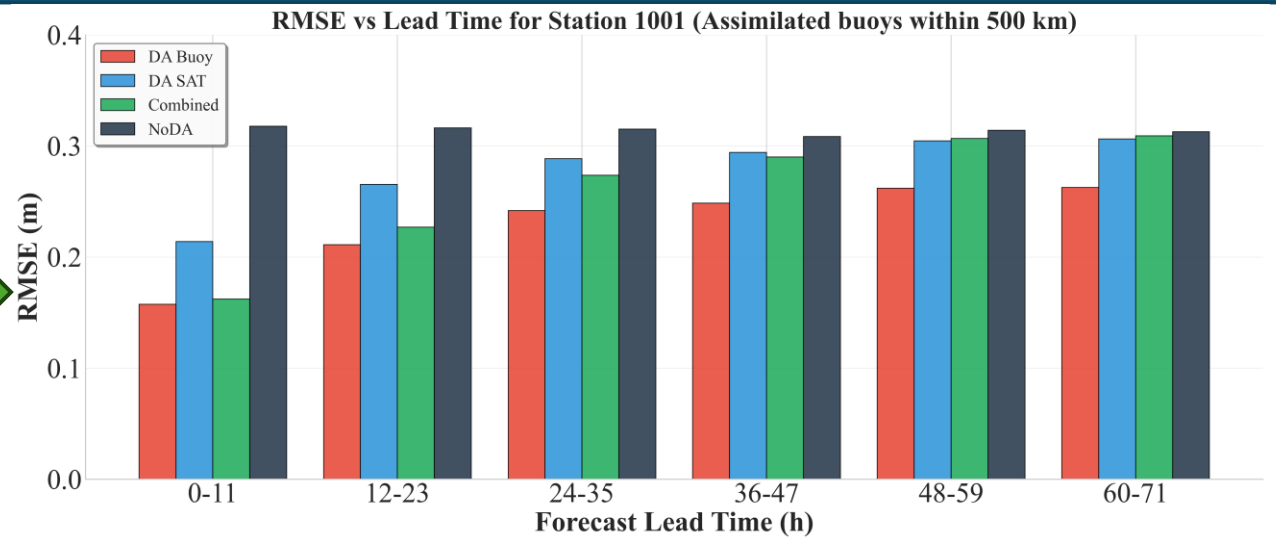
- When the assimilated buoy locations are close to the verification locations, assimilating the buoys provided a greater reduction in forecast errors compared to the altimeter and combined assimilation.



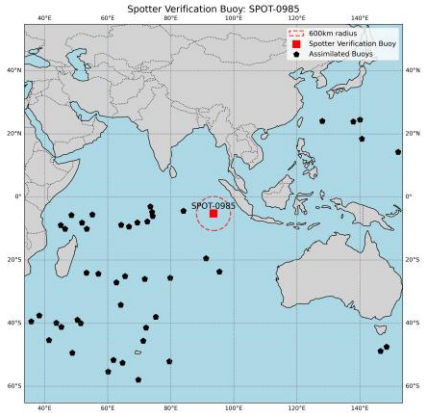
RMSE Comparison for Two Locations (Nearby vs. Distant)

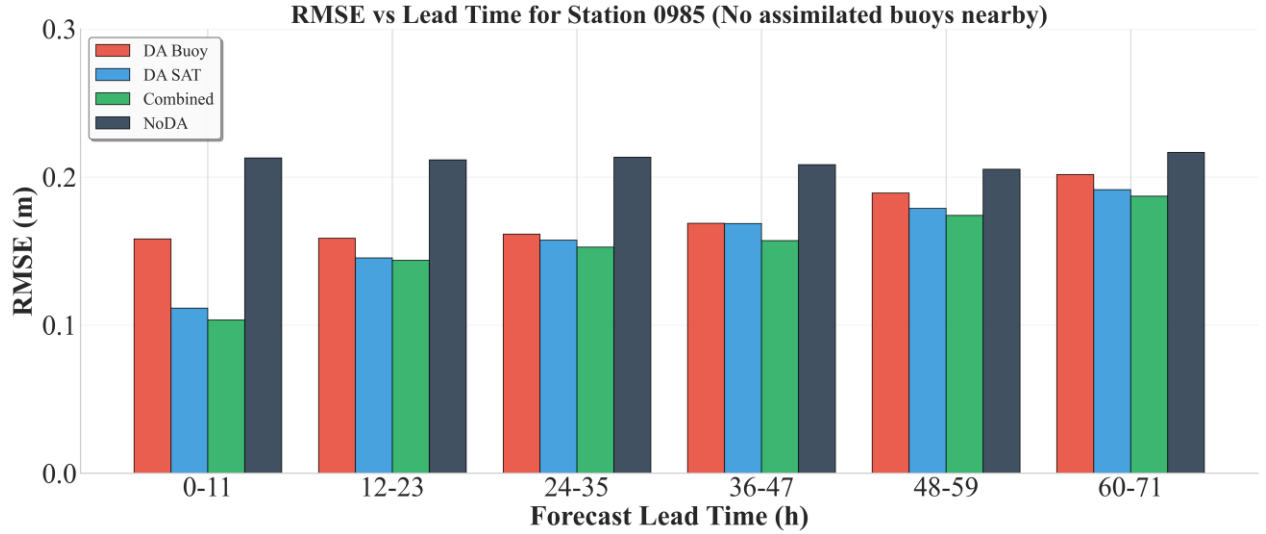
- When assimilated buoys are within 500 km of the verification location forecast errors are reduced the greatest in the buoy only assimilation across the entire forecast window



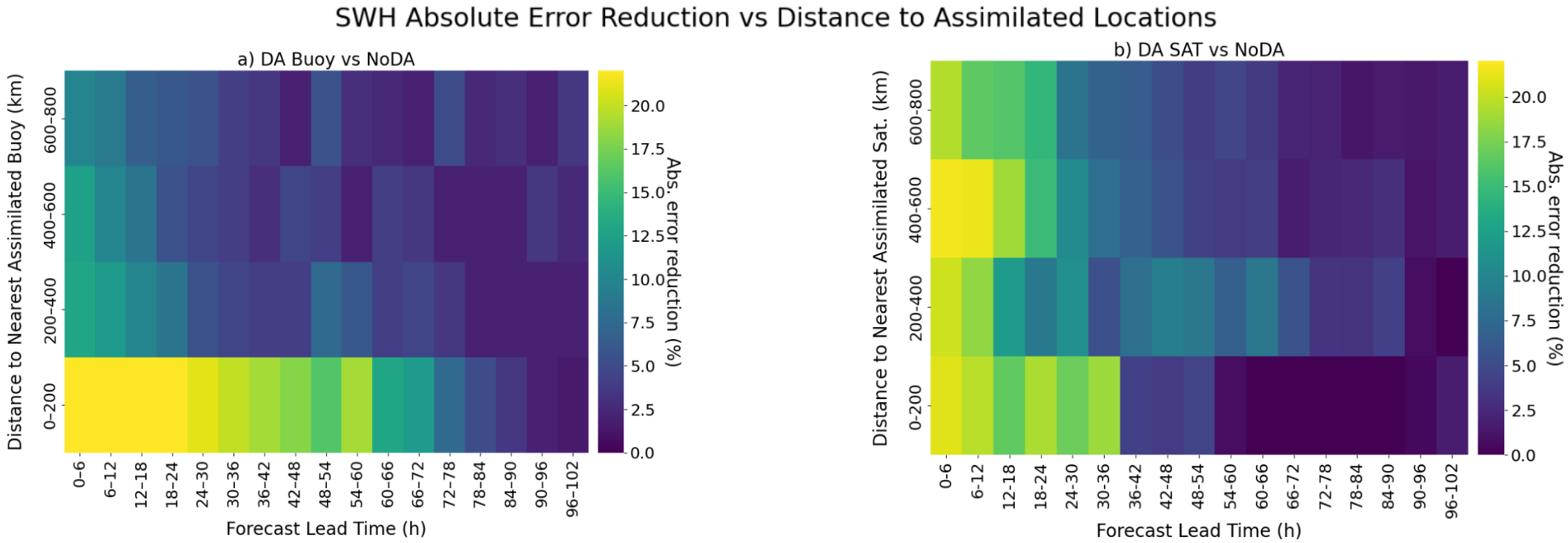


- When assimilated buoys are >500 km from the verification buoy, the altimeter and combined assimilation runs reduced forecast error the most across the entire forecast period.





Forecast improvement vs Distance to the assimilated observation

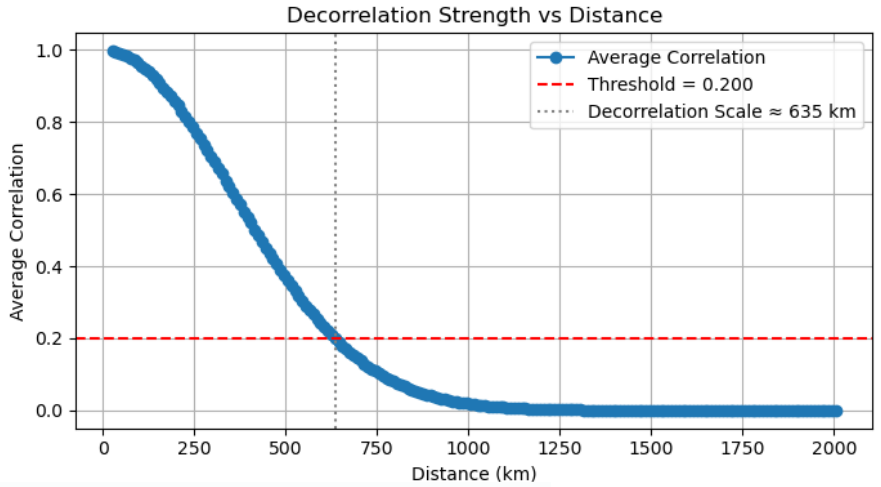


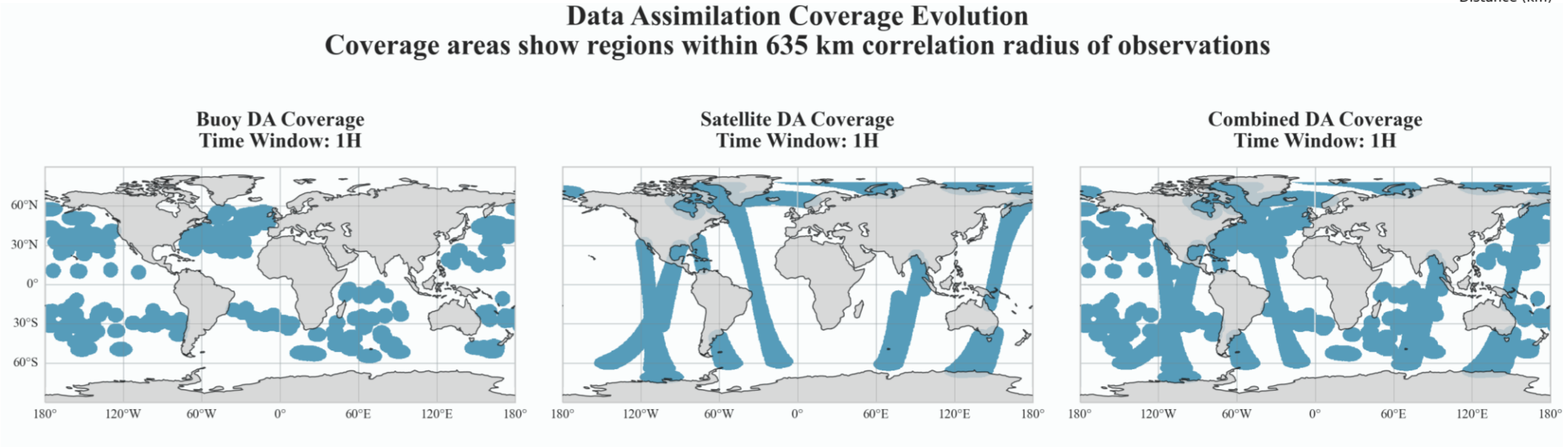
- **Buoy DA** shows significant forecast improvements at longer lead times, but primarily near the assimilated locations due to the localized and persistent corrections.
- **Altimeter DA** improves forecasts over much broader spatial regions. The reduction in forecast errors decays rapidly in time. The improvements does not have any strong dependence to the distance to the nearest assimilated data.

Global Coverage (Satellite vs Buoys)

Satellite altimeters provide coverage across the globe within ~ 12H of continuous assimilation.

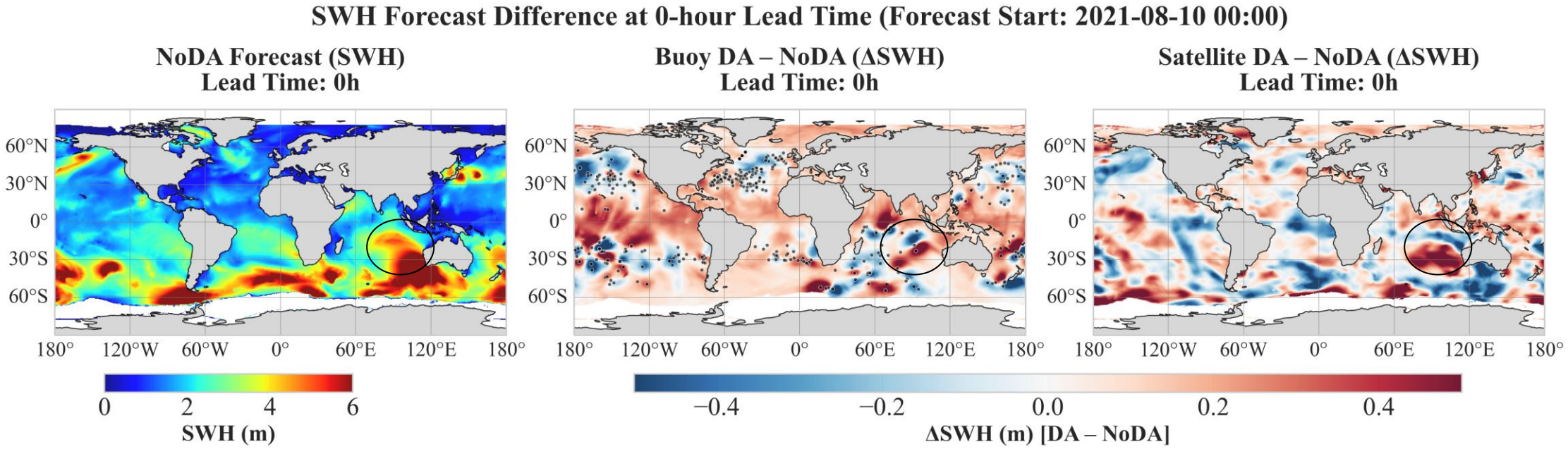
As the assimilation time increases the coverage of combined and satellite assimilation is almost the same leading to similar improvements.





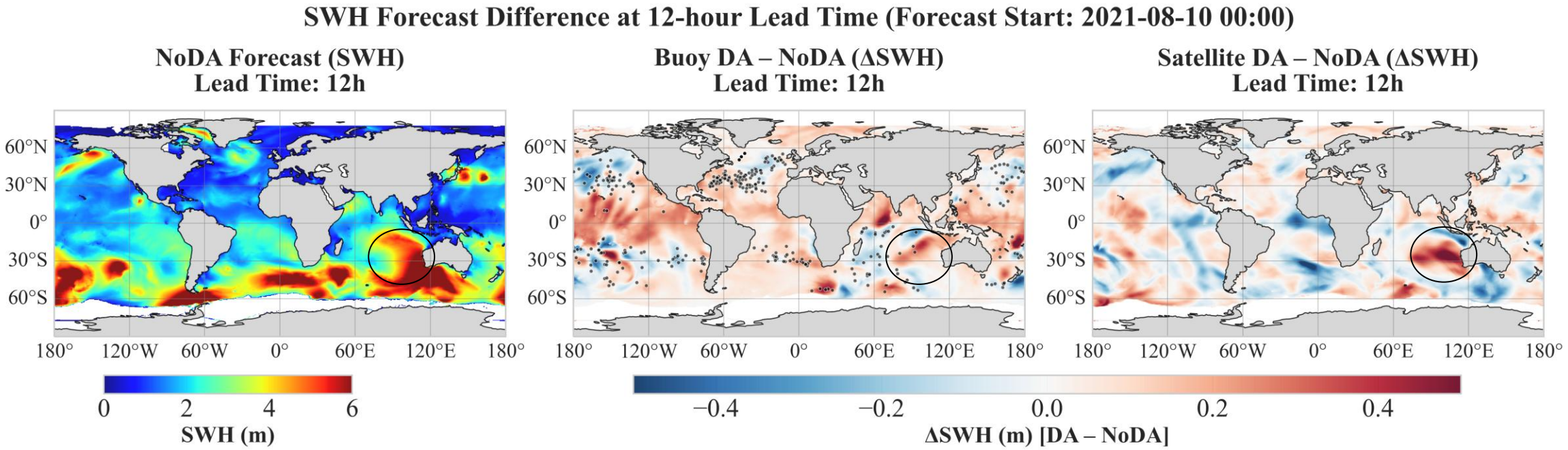
Spatial patterns of corrections over lead time

- **Buoy** corrections appear as tight, **localised patches** and strongly impacts **nearby regions**. But it has **limited spatial** and **temporal reach** at **far distance**.
- **Altimeter** corrections appear **widespread and smooth**.
- **Altimeter corrections** are better **matching** the spatial structure of the **model wave field**.

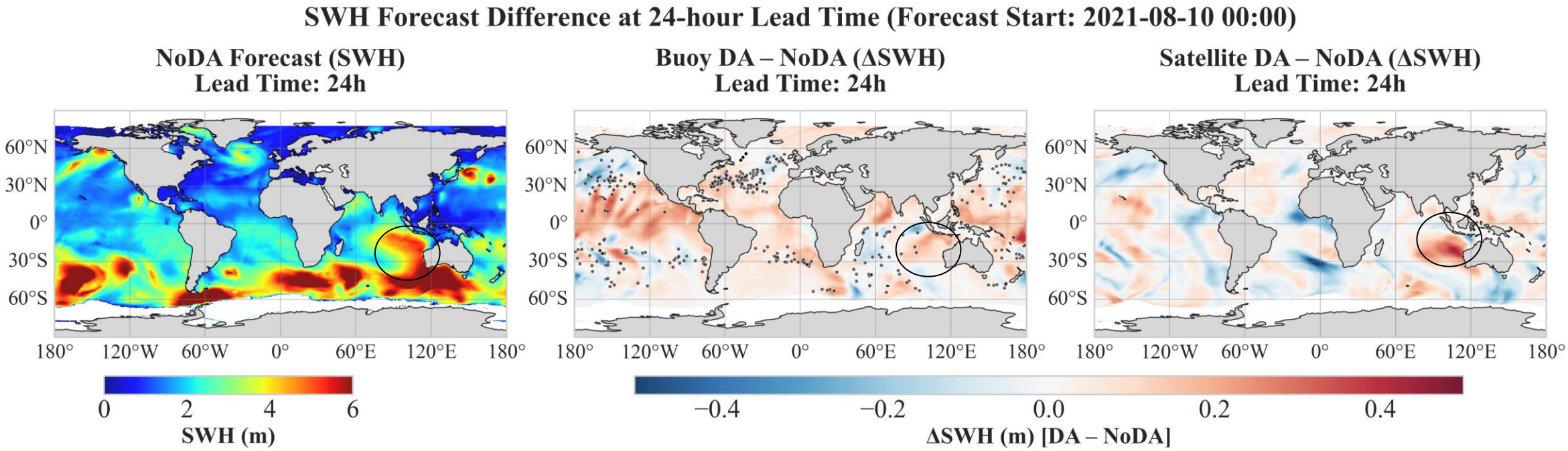


Spatial patterns of corrections over lead time

- The propagation of errors over time is aligned with the swell propagation direction in when altimeter data is assimilated due to the broad correction area.



Spatial patterns of corrections over lead time



Conclusions

- **Buoy DA**: High temporal resolution but limited spatial spread → stronger, persistent improvements near assimilation sites; effective for fixed stations and regional wave events.
- **Satellite DA**: Broad spatial coverage and repeated global sampling → widespread, large-scale corrections consistent with the background wave field.
- **Combined DA:** leverages both spatial reach and temporal persistence, but in most regions, the correction patterns are dominated by satellite influence.
- **Future work**: Buoys provide more than SWH; potential lies in assimilating additional parameters and full spectra.

Thank You