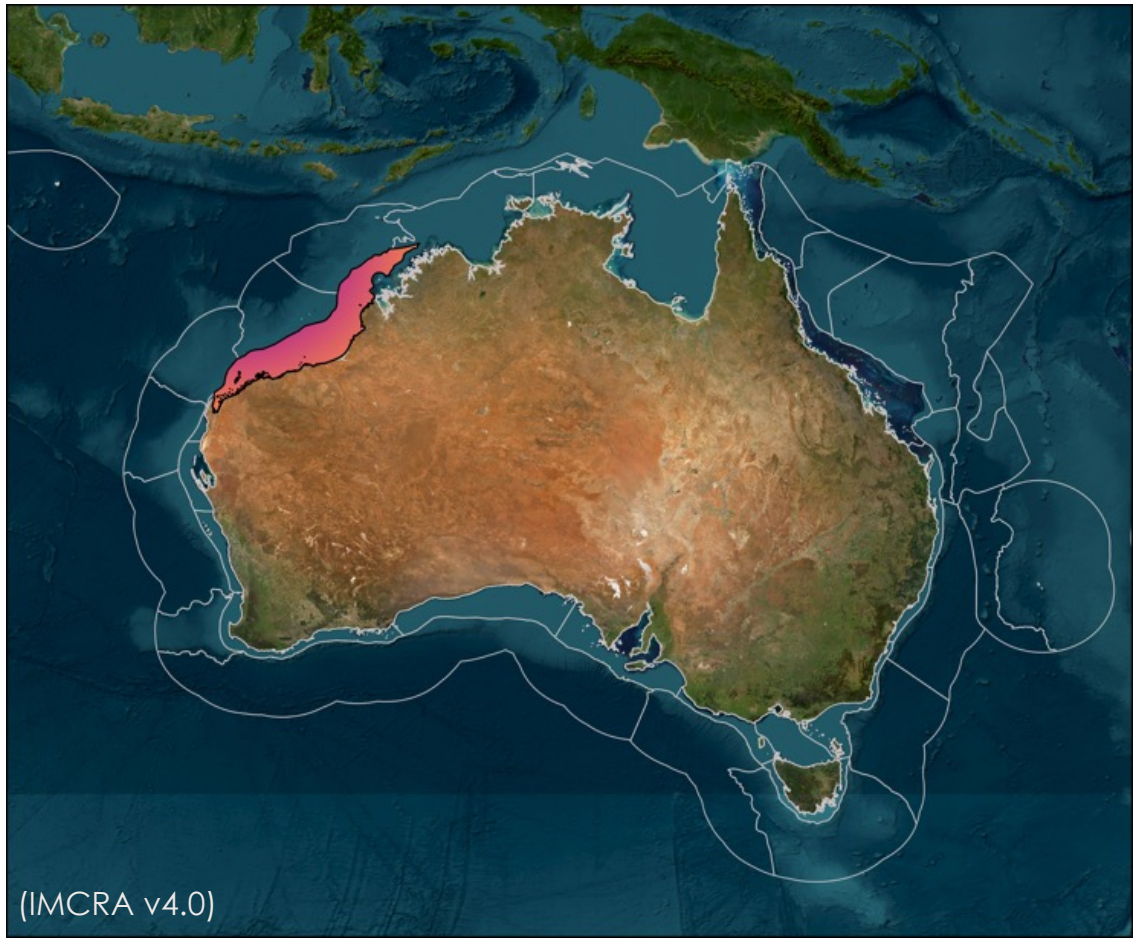
Investigating Data Assimilation Methodologies for Improved Swell Prediction Accuracy

Marzieh H. Derkani, Jeff Hansen, Stefan Zieger,
Seyed Mostafa Siadatmousavi, Duphrin Joseph

Southern Ocean Swell

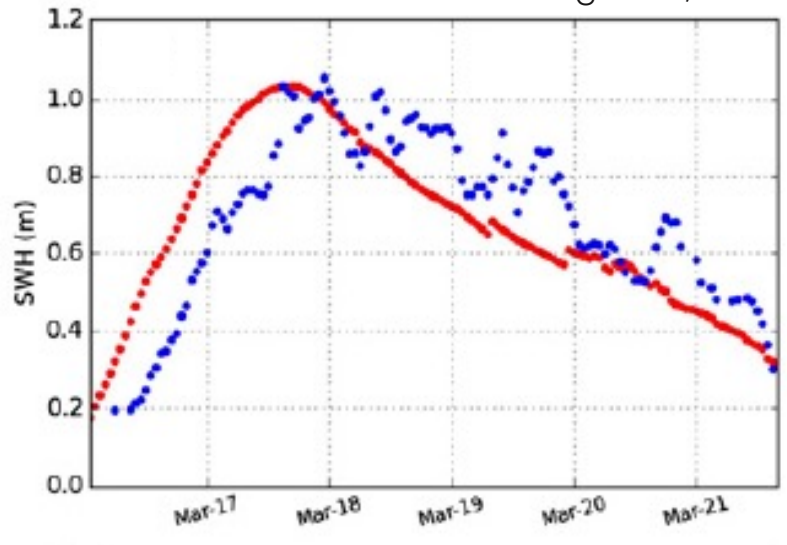
Southern Ocean is a major swell generation region for much of the world's oceans



Swell at Northwest Shelf

Inaccuracies in swell prediction

Jiang et al., 2016

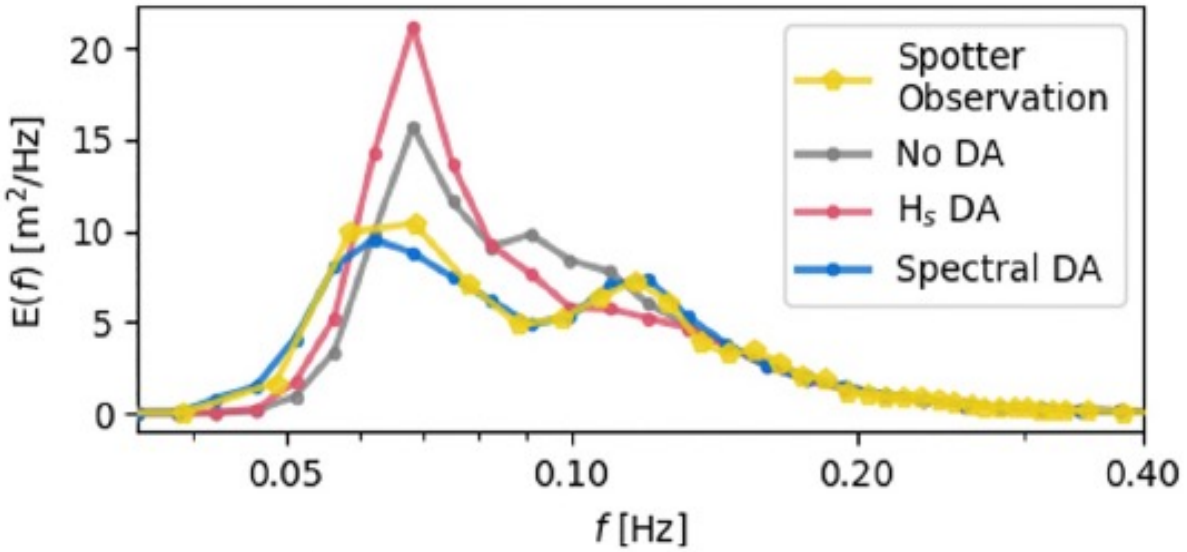


Caused by limitations in:

- Observational data,
- Theoretical assumptions, and
- Their implementation.

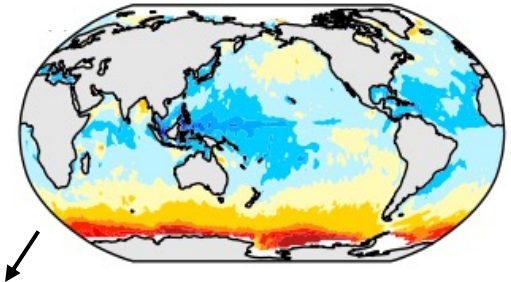
Incorporating wave observations through data assimilation can reduce uncertainty in swell predictions

Houghton et al., 2022 & 2023



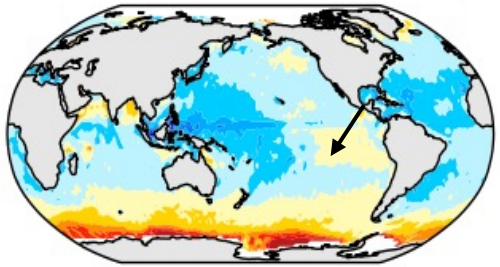
Data Assimilation

Wave Observations
+ Errors



Wave Forecast
+ Errors

Data Assimilation



Wave Analysis
+ Errors

Australian Government
Bureau of Meteorology

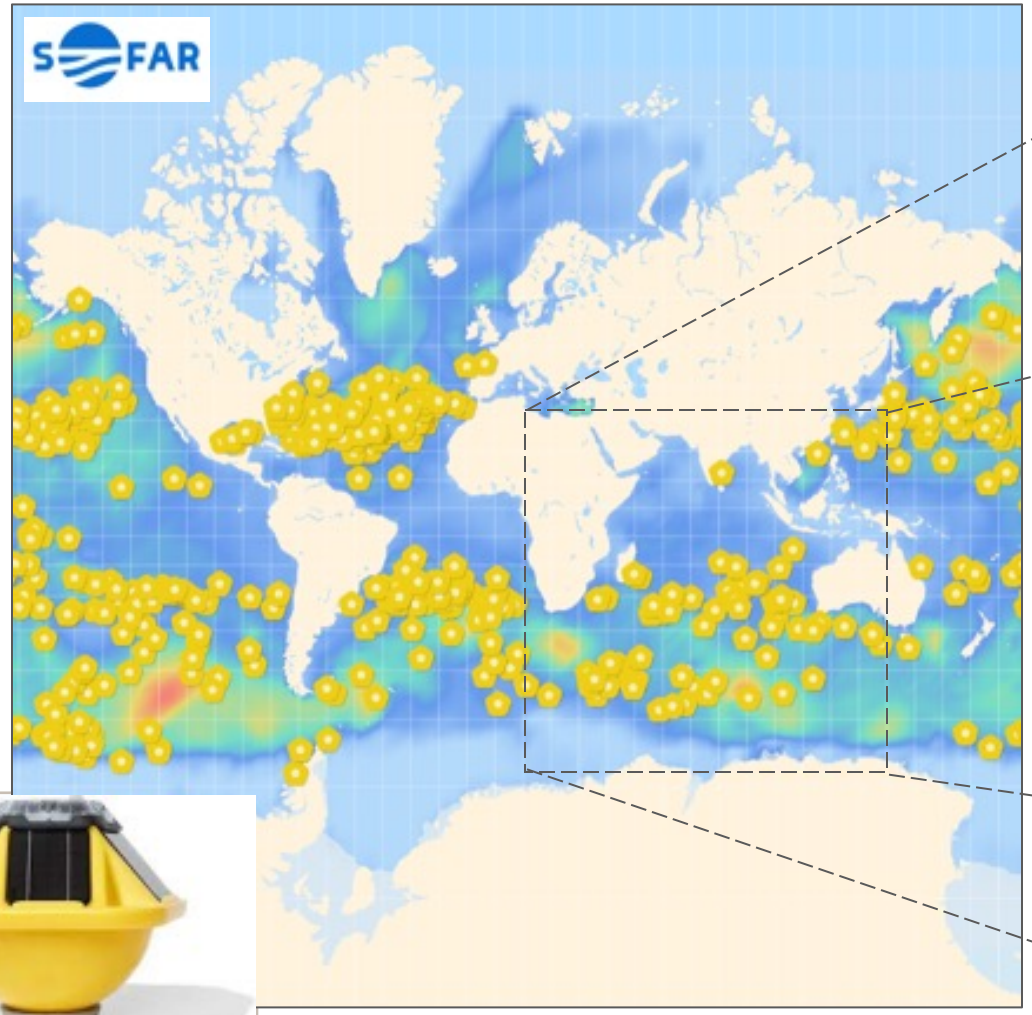
Model	Name	Data Assimilation
Atmospheric	ACCESS	4D VAR
Ocean	OceanMAPS	Ensemble KF
Wave	AUSWAVES	No DA

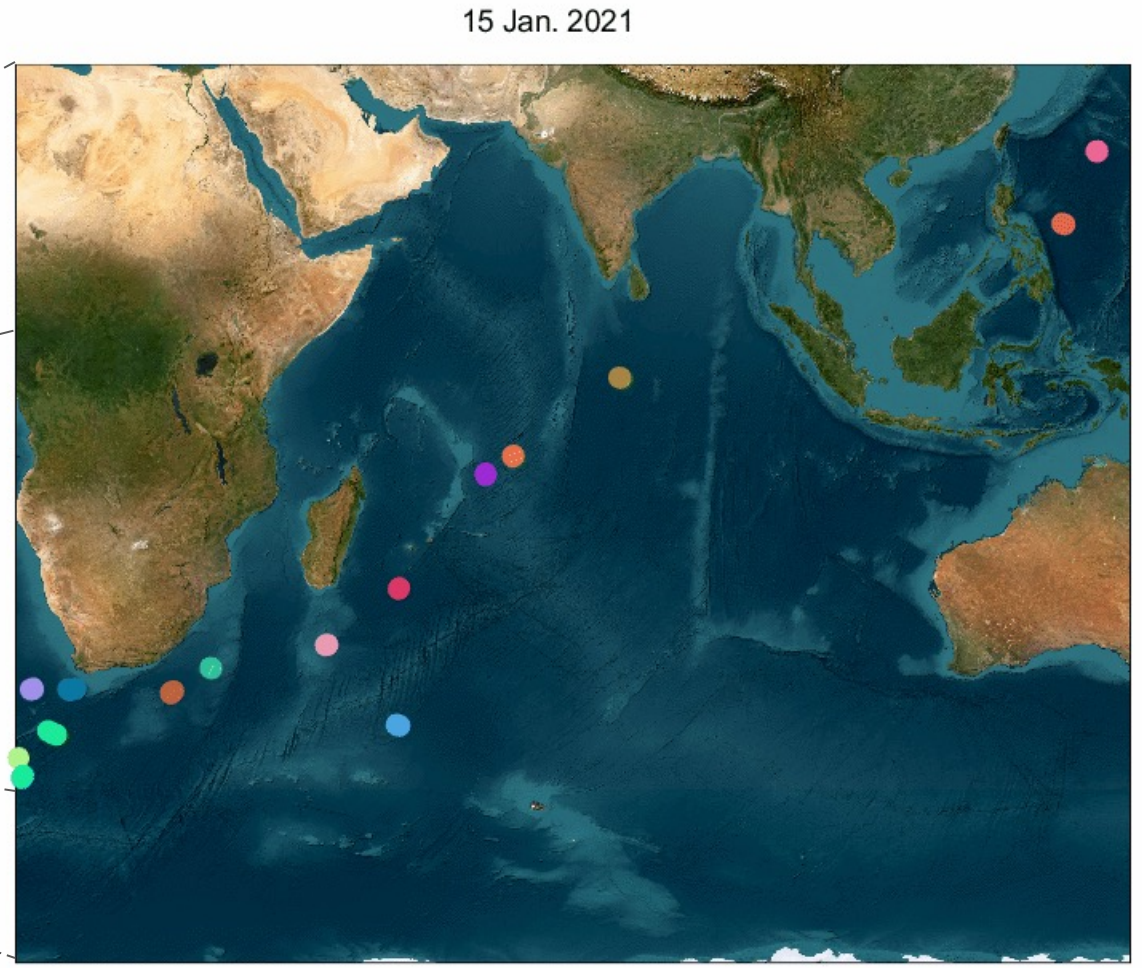
DA in operational wave models (e.g., ECMWF and MeteoFrance): reliant on bulk parameters.

Objective:

Develop spectral wave assimilation methods to improve the prediction capabilities of operational forecasts with a focus on swells.

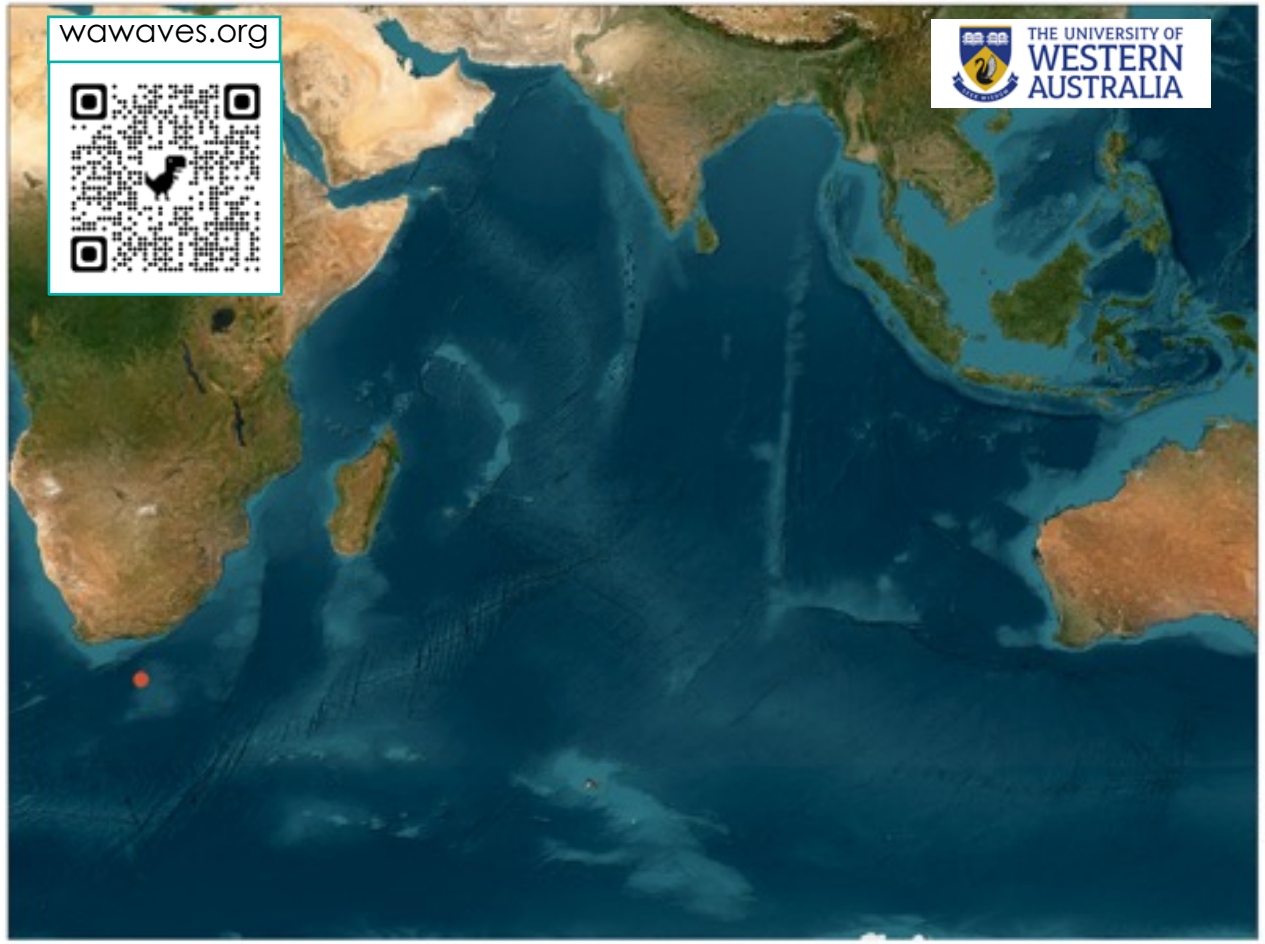
SOFAR's Network of Spotter Buoys

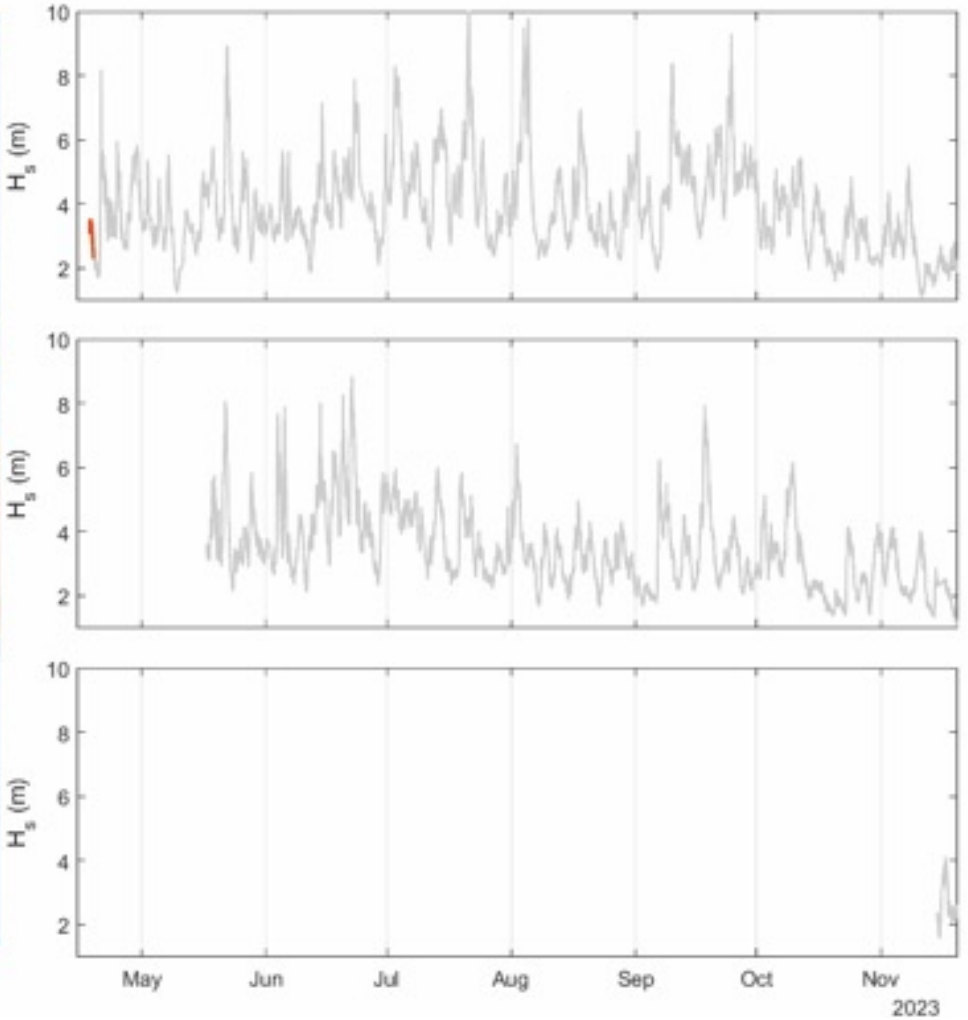




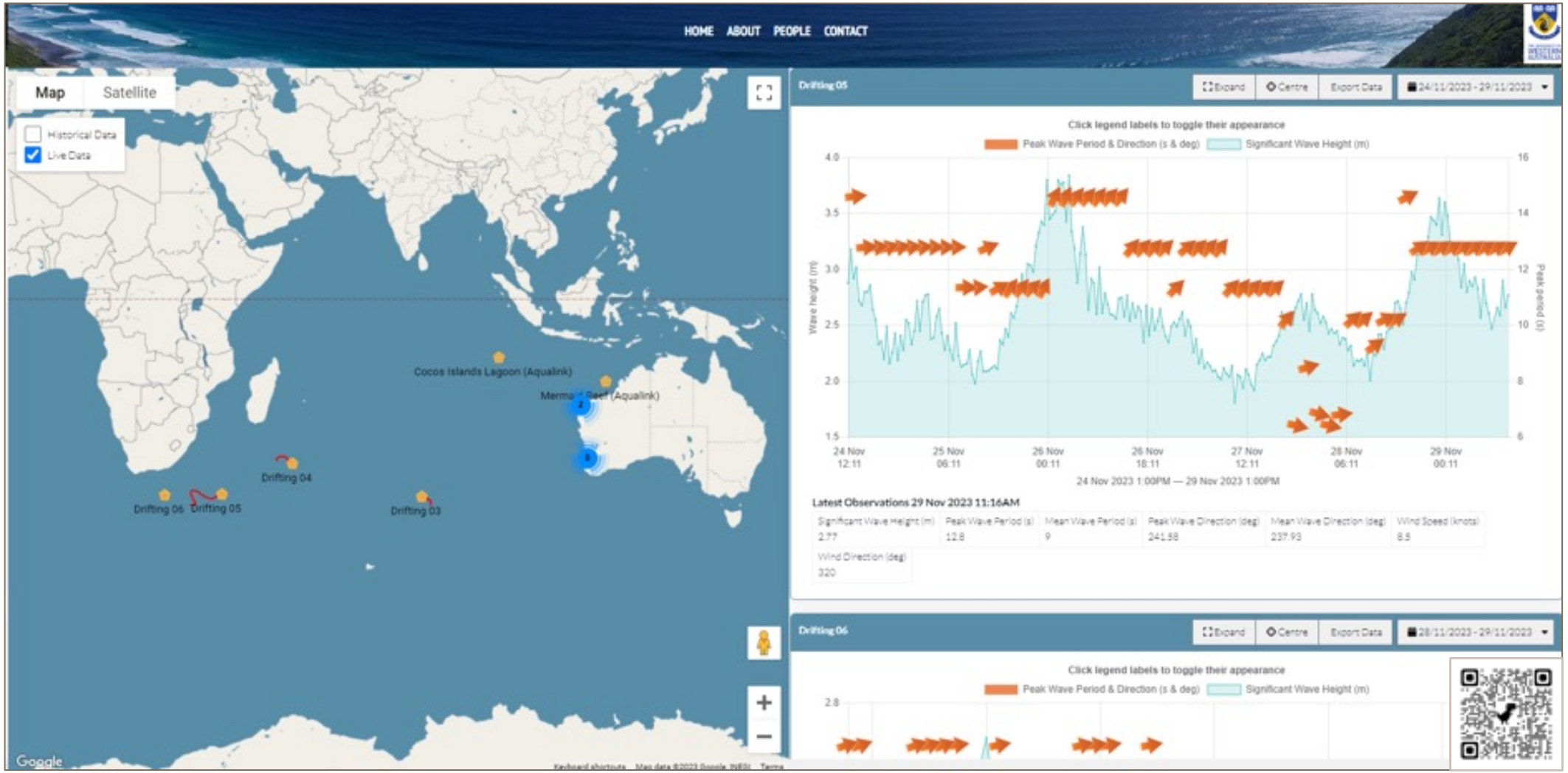
Observational Data

18 Apr. 2023





WAWAVES.org


HOME ABOUT PEOPLE CONTACT
Map
Satellite
Historical Data
Live Data
Cocos Islands Lagoon (Aqualink)
Drifting 04
Drifting 06
Drifting 05
Drifting 03
Drifting 05
Expand
Centre
Export Data
Click legend labels to toggle their appearance
Peak Wave Period & Direction (s & deg)
Significant Wave Height (m)
Wave height (m)
Peak period (s)
24 Nov 12:11
25 Nov 06:11
26 Nov 00:11
26 Nov 18:11
27 Nov 12:11
28 Nov 06:11
29 Nov 00:11
24 Nov 2023 1:00PM — 29 Nov 2023 1:00PM
Latest Observations 29 Nov 2023 11:16AM
Significant Wave Height (m)
2.77
Peak Wave Period (s)
12.8
Mean Wave Period (s)
9
Peak Wave Direction (deg)
241.88
Mean Wave Direction (deg)
237.93
Wind Speed (knots)
8.5
Wind Direction (deg)
320
Drifting 06
Expand
Centre
Export Data
Click legend labels to toggle their appearance
Peak Wave Period & Direction (s & deg)
Significant Wave Height (m)
Google

Other Observational Data

Satellite Observations

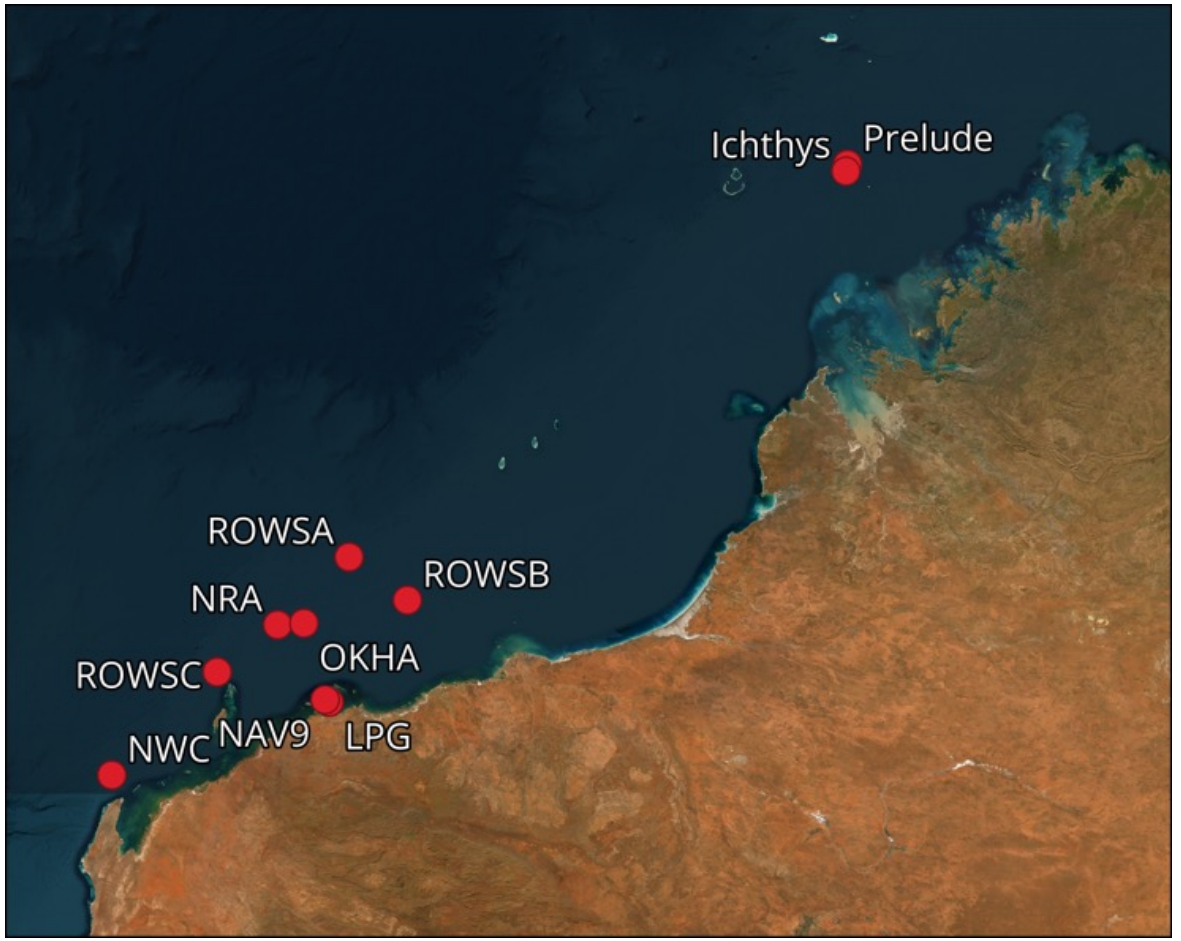
Mean parameters:

Altimeter

Wave Energy Spectra:

Synthetic Aperture Radar (SAR), and
Chinese-French Oceanography Satellite (CFOSAT).

Industry Operated Buoys at NWS



AUSWAVE-G3

Australian Government
Bureau of Meteorology

A multiple-resolution global wave model

Stefan Zieger and Diana J. M. Greenslade

May 2021

WaveWatch-III v6.07 wave model

Wind:
ACCESS-G3

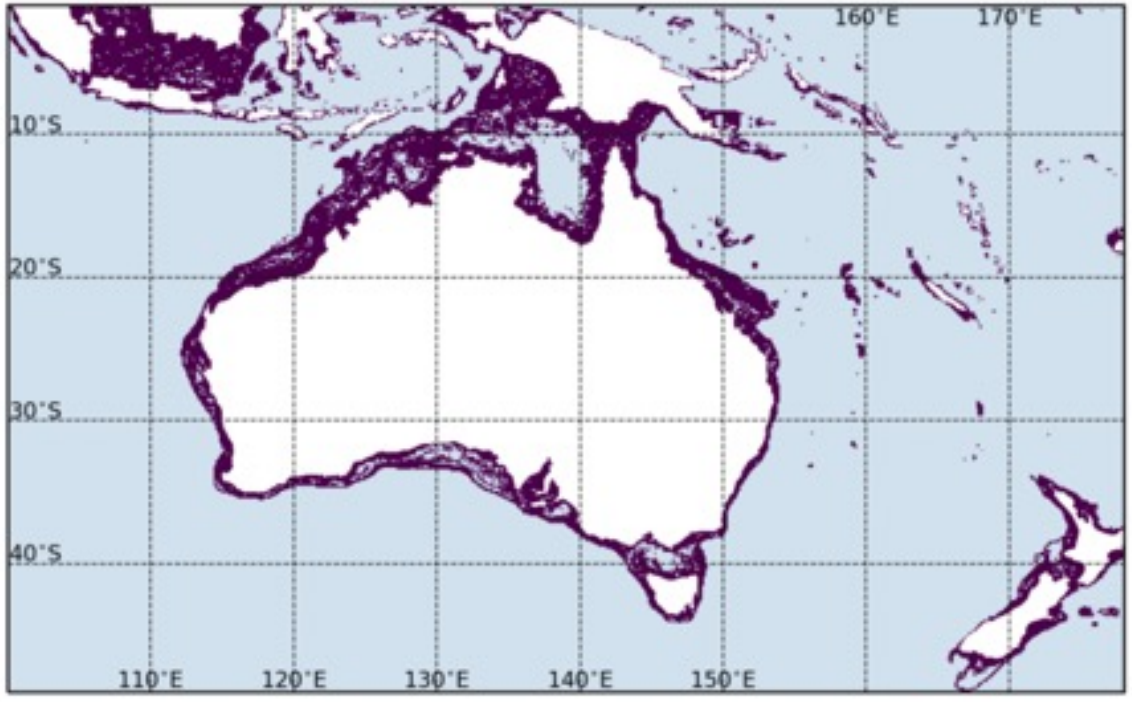
Current:
OceanMAPS

Spectral resolution:

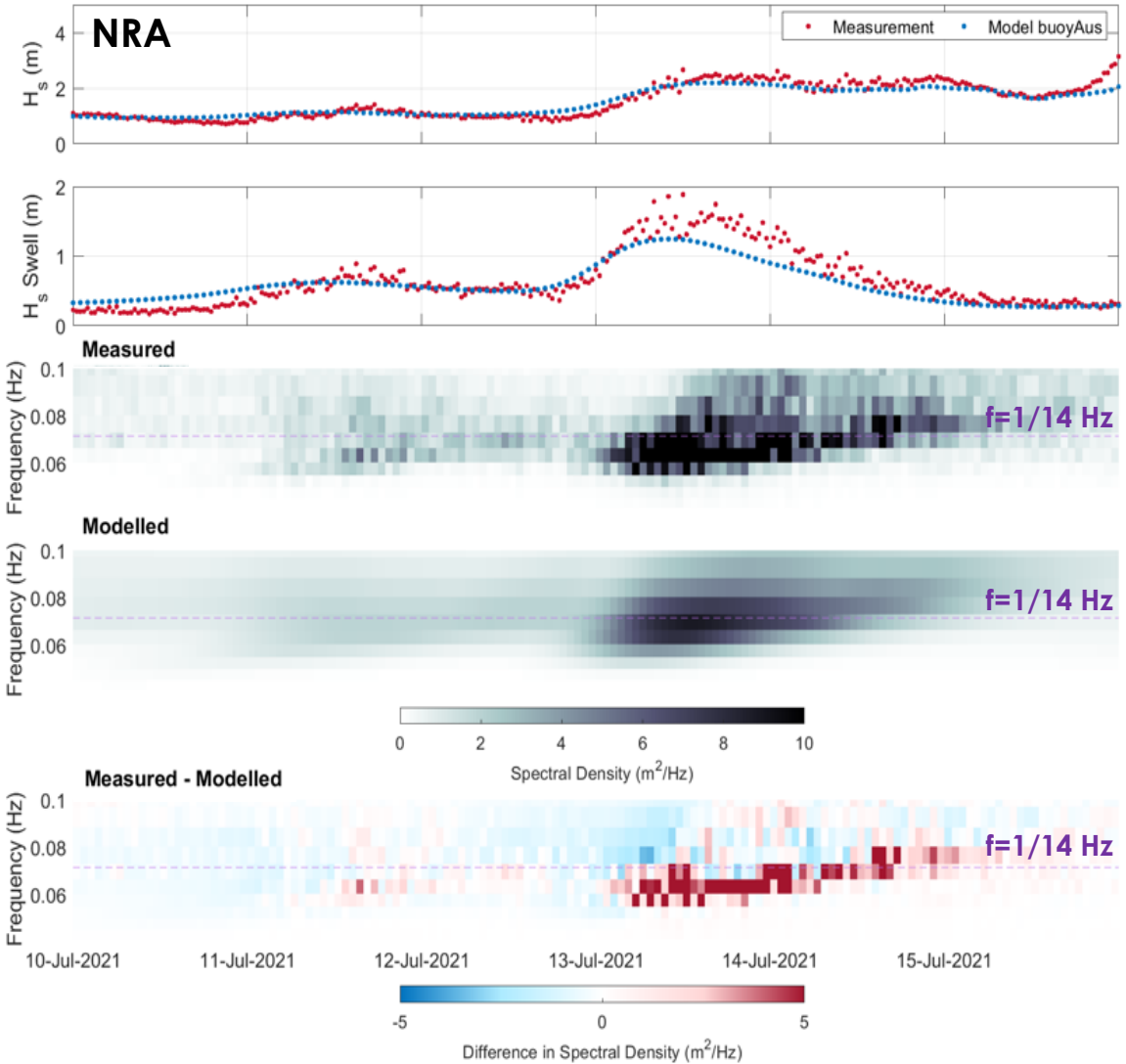
30 direction bins
28 frequency bins (0.0412Hz - 0.5401Hz)

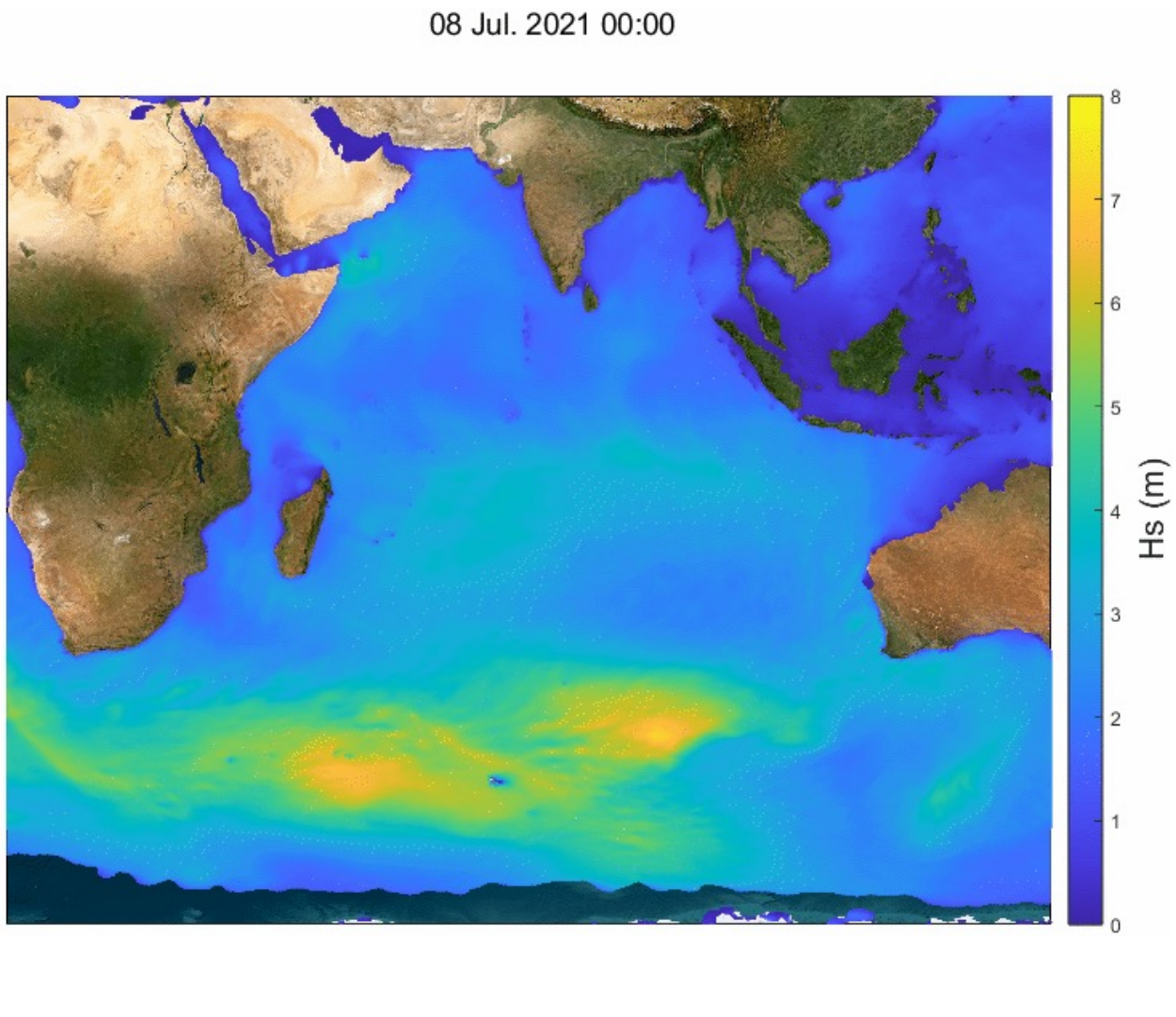
Spatial resolution:

~12km global with ~6km sub-grid

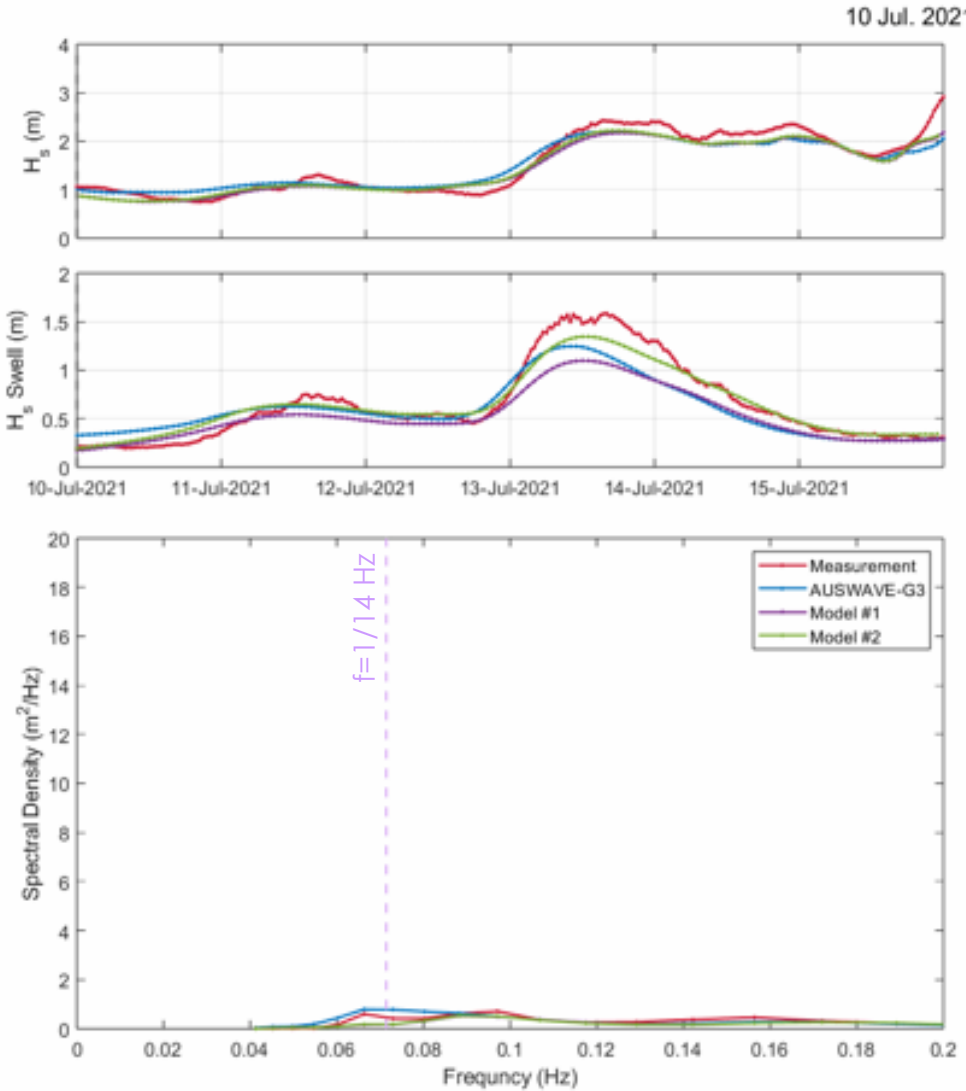


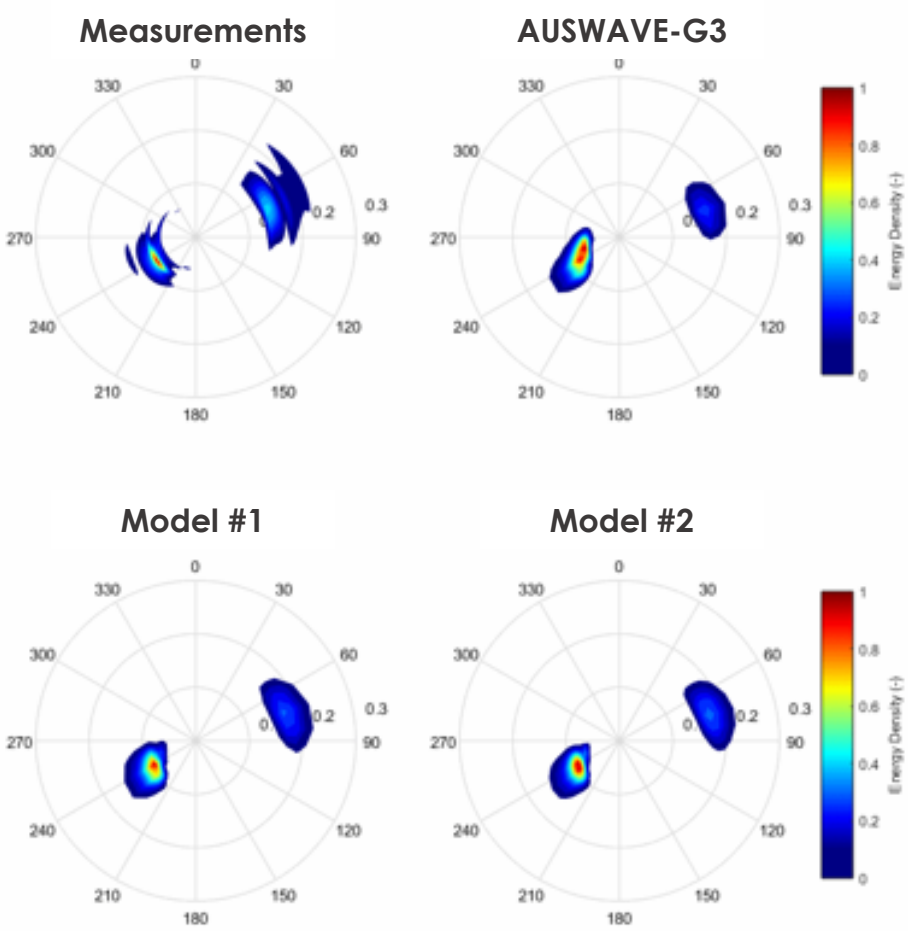
Assessment of AUSWAVE-G3





Assessment of AUSWAVE-G3

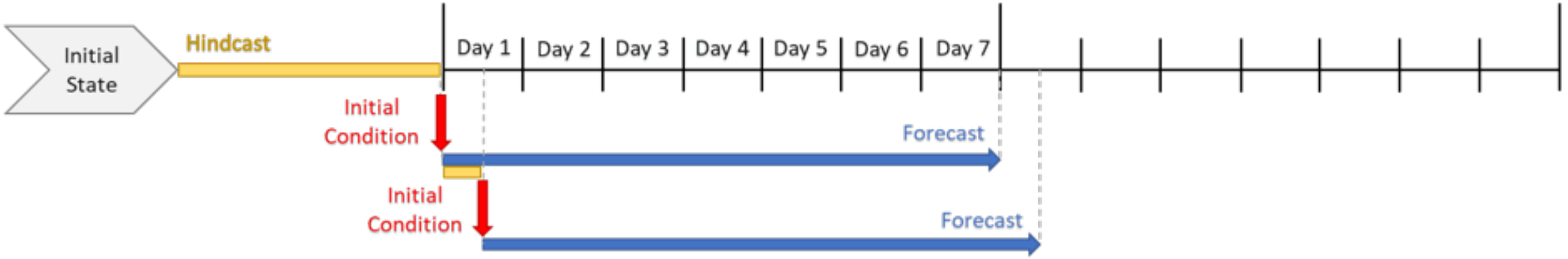




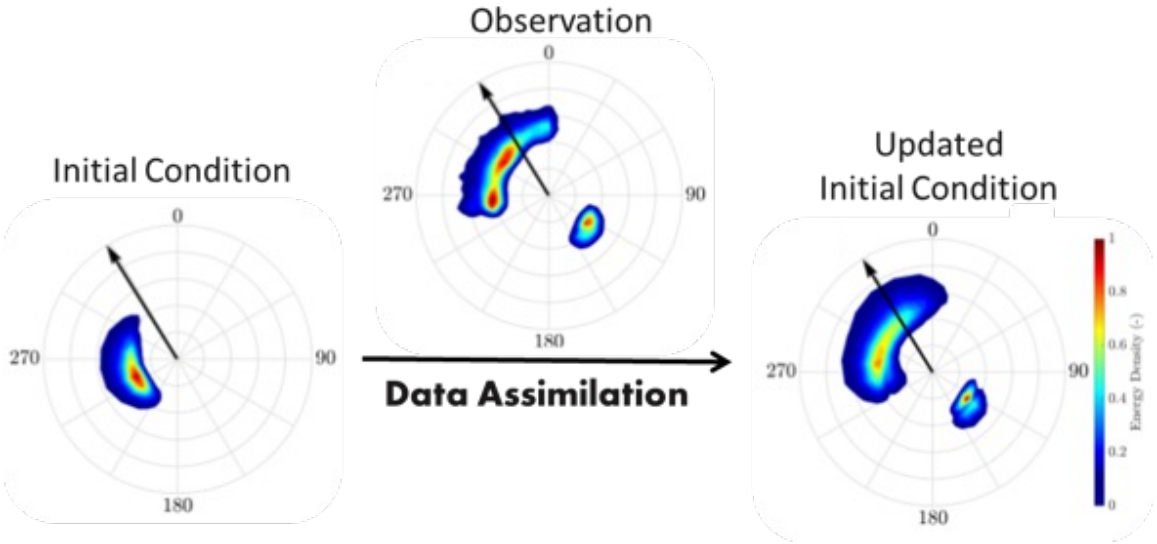
Model #1: Same as AUSWAVE-G3 with ECMWF winds and Copernicus currents.

Model #2: Same as Model #1 with increased spectral resolution (8° dirs. & 45 freq. bins).

Data Assimilation in WaveWatch-III



Approach 1) Update the "Initial Condition"

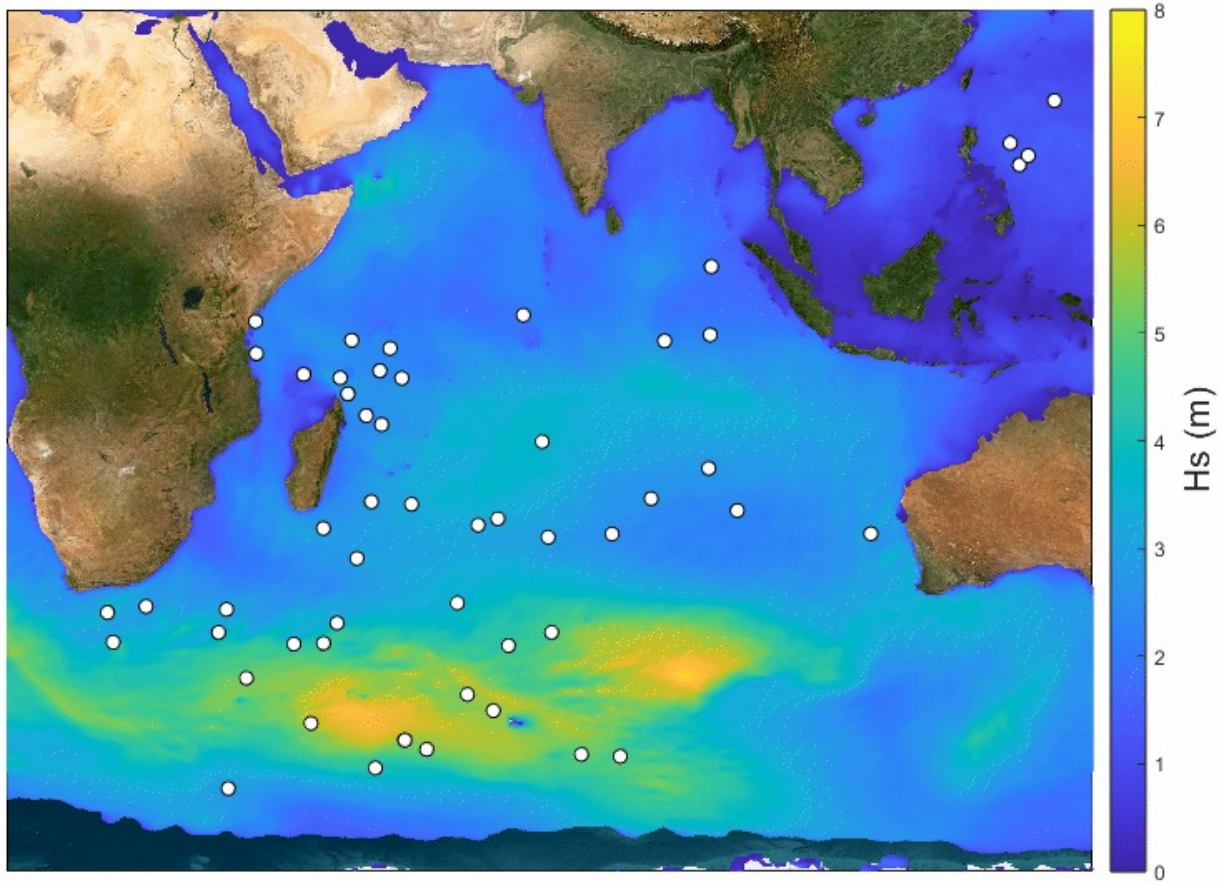


Approach 2) Incorporate the DA scheme into the model

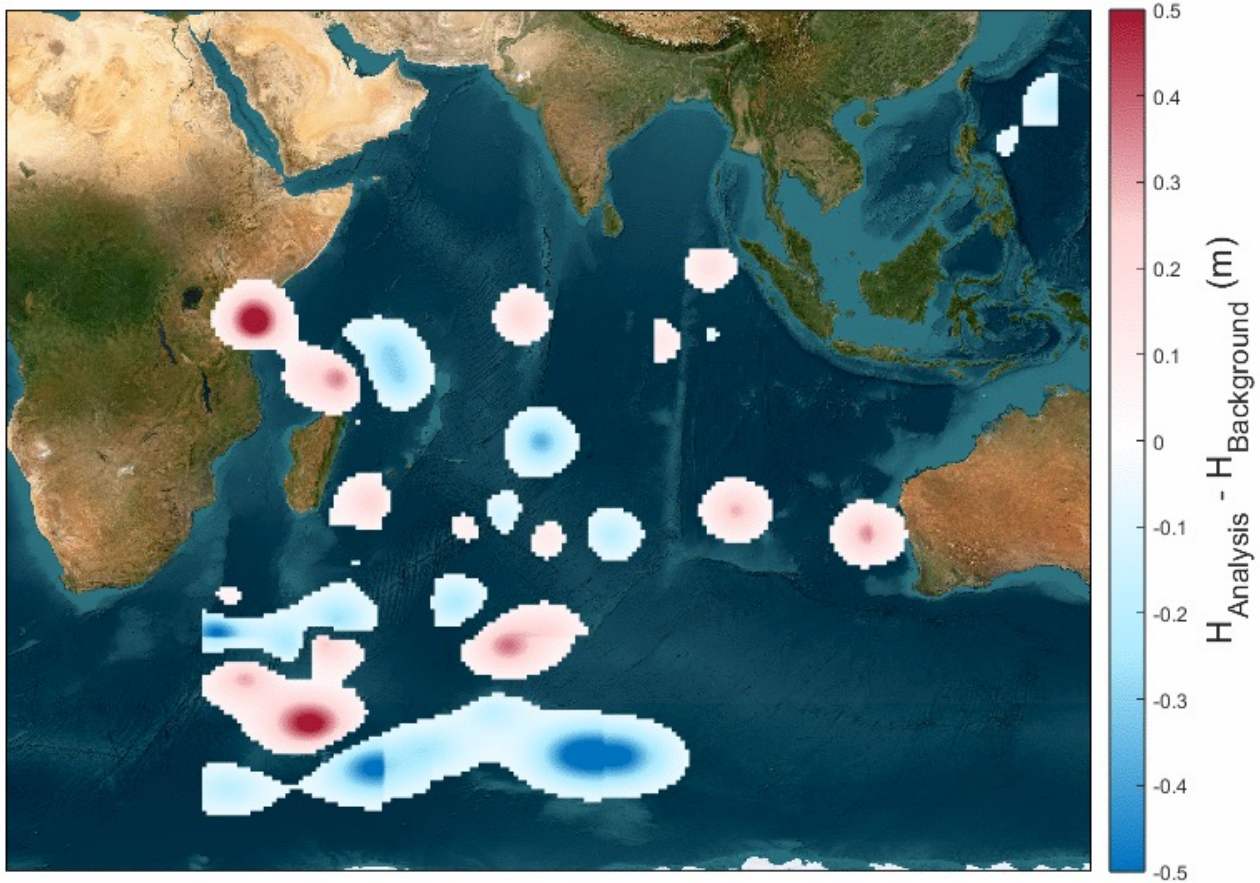
```python
def check_db():
    if not os.path.isfile(FILE_URI):
        db.create_all()

@app.route("/")
def home():
    check_db()
    all_books = db.session.query(Book).all()
    return render_template("index.html", books=all_books)

@app.route("/edit", methods=["GET","POST"])
def edit():

    if request.method == "POST":
        book_id = request.form["id"]
        book_to_update = Book.query.get(book_id)
        book_to_update.rating = request.form["rating"]
        db.session.commit()
        return redirect(url_for('home'))
```

Assimilation of Hs

08 Jul. 2021 00:00

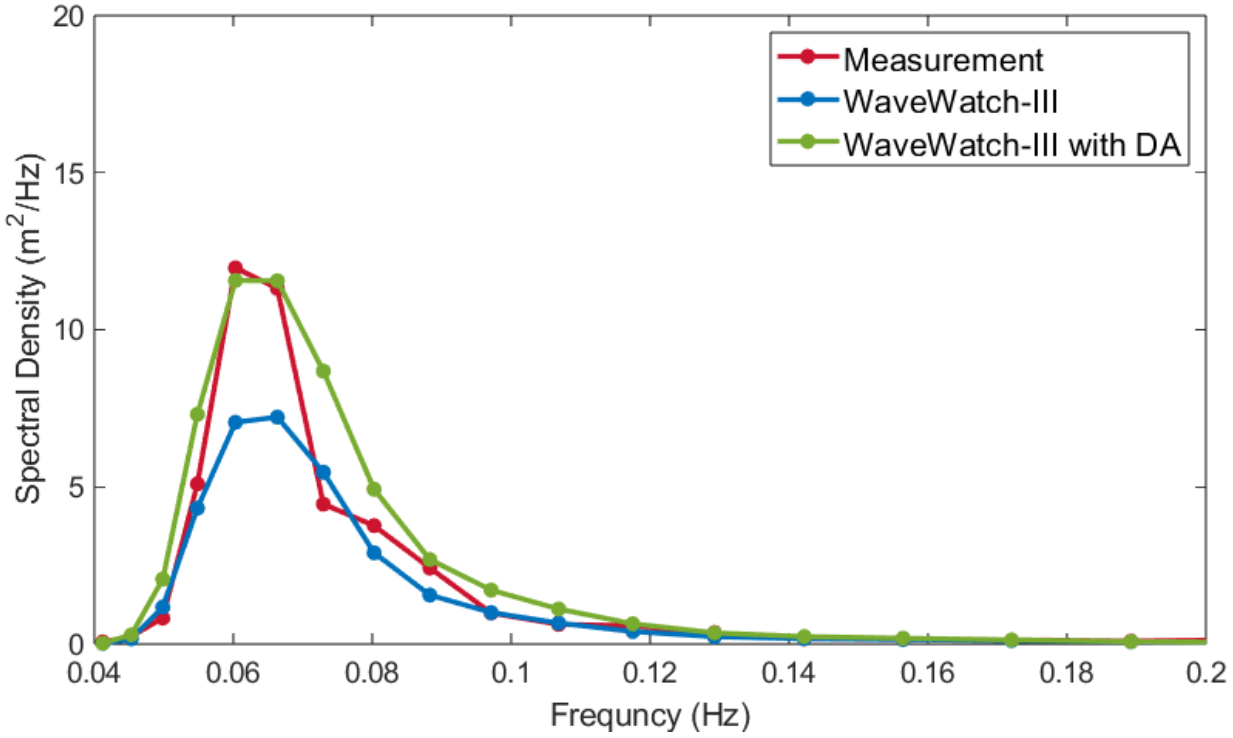


08 Jul. 2021 00:00

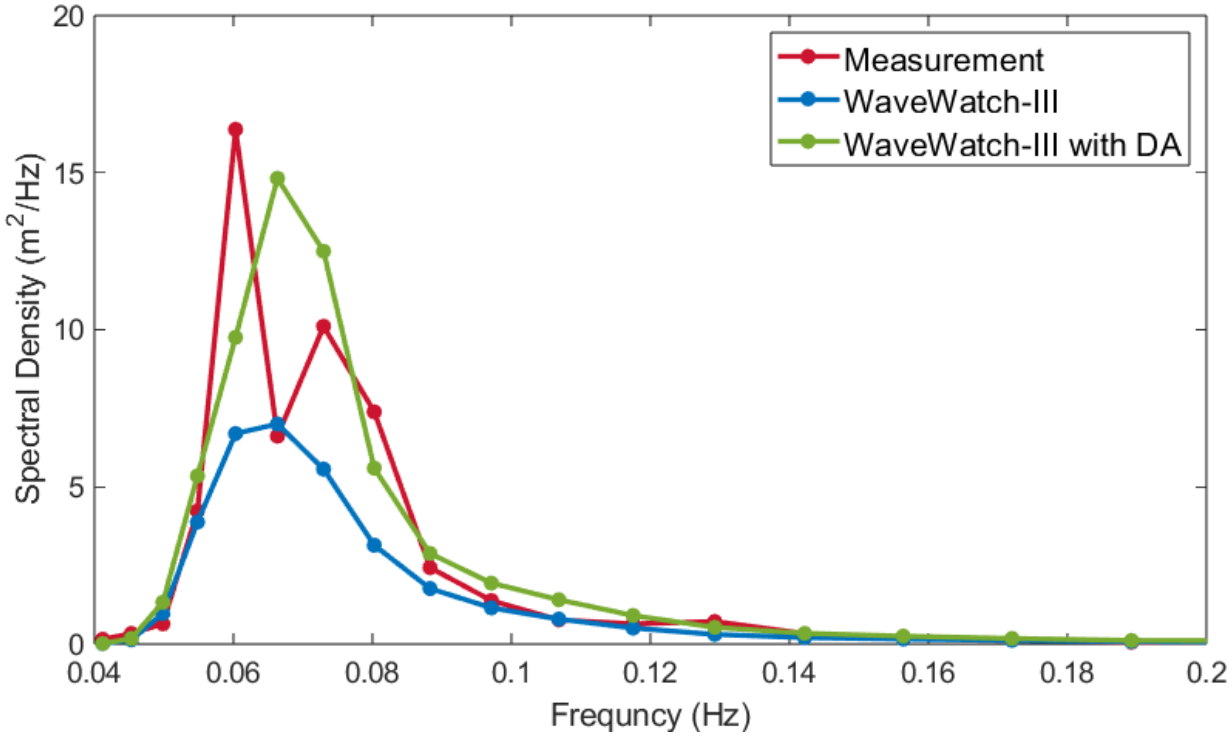


Assimilation of Partitioned Hs

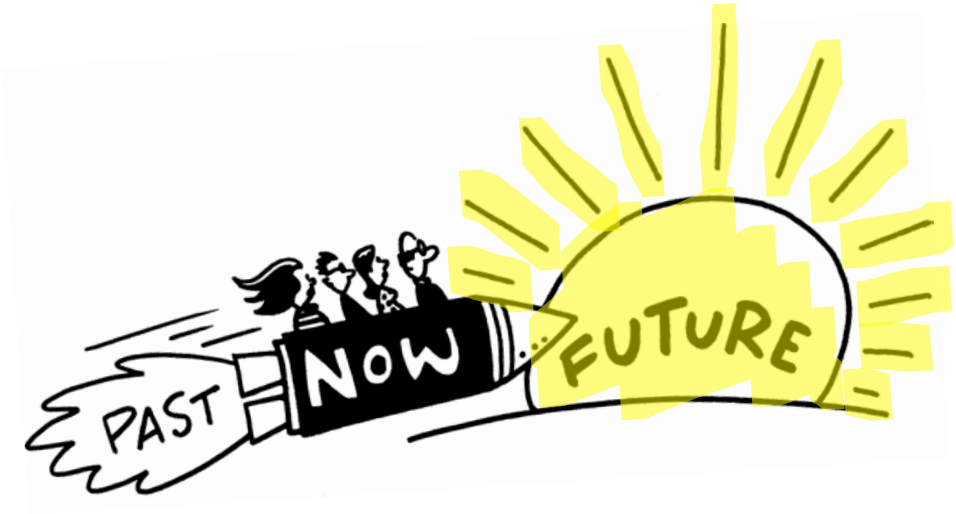
13 Jul 2021 13:00



13 Jul 2021 15:00

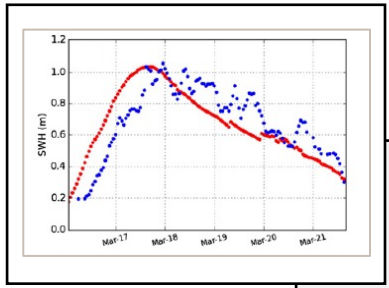


Next Steps…

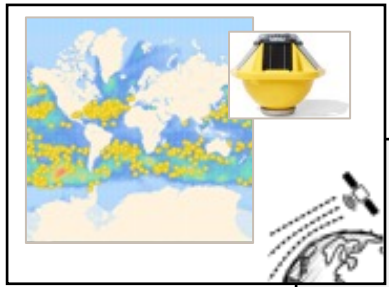


- Assimilation of observations in the spectral domain.
- Investigating alternative data assimilation techniques e.g., the Kalman Filter.
- Explore the model's performance with the assimilation of observations from various sources e.g., satellite.
- Improving the knowledge of the physical processes active in the swell propagation and decay.

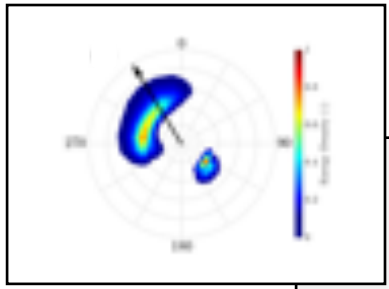
Summary



Inaccuracies in swell predictions (e.g., arrival time) impact offshore operations, coastal protection measures, and climate models.



Increased availability of wave observations provide an opportunity for improved wave predictions through techniques such as DA.



DA techniques applied to wave models predominantly rely on bulk parameters while the ultimate gain is in spectral assimilation.

Data Assimilation Methods

Data Assimilation

Variational

3D VAR

4D VAR

Sequential

Optimal Interpolation

Kalman Filter

Analysis Equation: $\boldsymbol{x^a = x^f + W(y - Hx^f)}$ (Innovation)

Kalman Gain: $\boldsymbol{W = C^f H^T (HC^f H^T + C^o)^{-1}}$

Gaussian: $\mathrm{P(i,j)} = \frac{V^f}{V^f + V^o} \exp\left(-\frac{(r_{ij})^2}{2L^2}\right)$

2nd Order Autoregressive: $\mathrm{P(i,j)} = \frac{V^f}{V^f + V^o}\left(1 + \frac{r_{ij}}{L}\right)\exp\left(\frac{-r_{ij}}{L}\right)$