

Towards the new ocean wave reanalysis in the future ERA6

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European Centre for Medium-range Weather Forecasts (ECMWF)

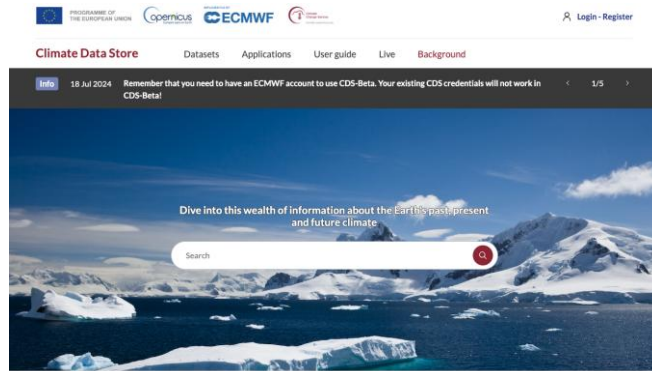




Climate
Change

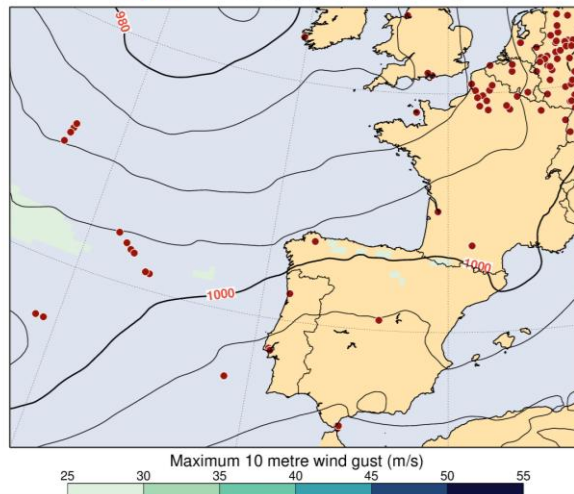
1. ECMWF ERA5 global reanalysis for atmosphere and waves

ERA5 has over **200,000 users** providing **petabytes** of climate data
> 20,000 citations, estimated economic value ~ 1 billion euros



.. to historical extreme cases ..

ERA5 14 February 1941, 18 UTC

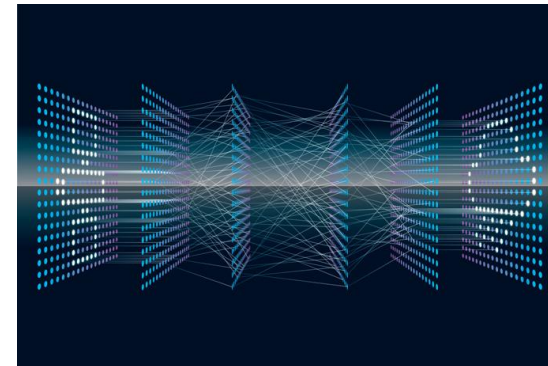


From accurate timely climate monitoring, ..



1. The first year warmer than 1.5°C above the pre-industrial average
2. Record number of days above 1.5°C in 2024

.. and leading training set for data-driven
weather forecasting and much more ...



2. ERA6 will benefit from an additional 8 years of R&D at ECMWF & improved compute capacity

Configuration: 75 years of reanalysis, to be maintained close to real time once completed, based on IFS Cy49r2

- Higher **horizontal resolution of 14km (TCo799) for all components** (ERA5 31km for atmosphere, 40km for waves)
- Uncertainty estimate at 28km (TCo399) from 11-member ensemble (63km for ERA5)

Science :

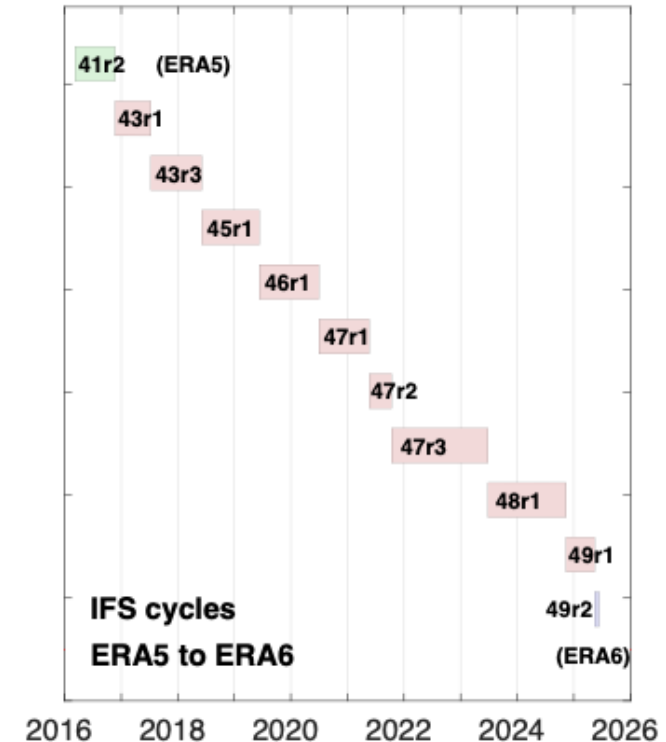
- 8 years of additional R&D at ECMWF (10 model cycles)
- **Ocean** model (NEMO4) fully coupled in DA trajectories

Ingest the best observations:

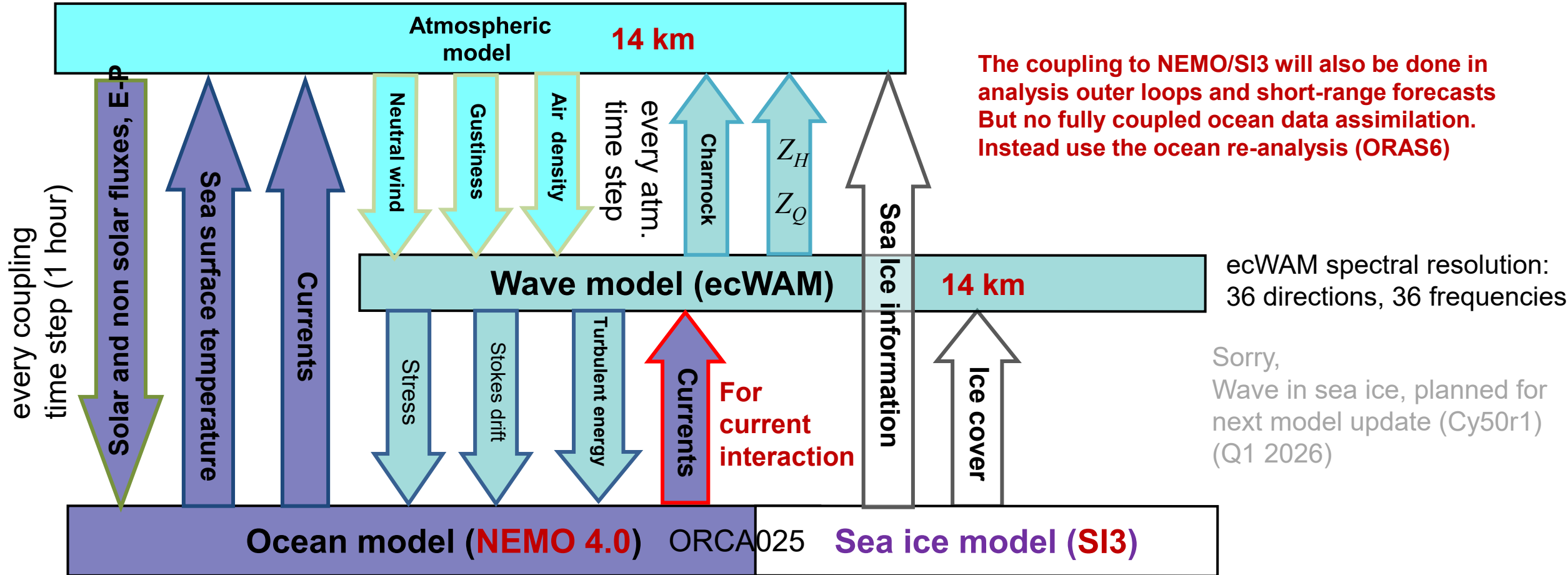
- Satellite+ in-situ reprocessing and data rescue. (e.g. ESA sea state CCI)

Products: based on user requirements

- 3D+2D **ocean parameters**
- **Height levels** for the lowest part of the atmosphere
- Hourly, for extended list of (new) parameters (2d wave spectra will again be available)
- **Daily** in addition to monthly **precalculated statistics**
- **GRIB2**



ECMWF Earth System Model for ERA6



3. Specific wave model developments

- Over the years, we have implemented changes in ecWAM that have resulted in a better control of the drag coefficient for strong winds (IFS documentation, part VII, ECMWF, 2024).

1. Cy43r3, November 2016 : a cap on the maximum spectral steepness (Magnusson et al. 2019).
2. **Cy46r1**, June 2019 : the wind input and whitecap dissipation source terms of Ardhuin et al. (2010).
3. Cy47r1, June 2020 : a capping of the Charnock coefficient for tropical cyclones winds above 33 m/s (Majumdar et al. 2023, ECMWF, 2024).
4. **Cy49r1**, November 2024: a model for the role of gravity-capillary waves on the surface stress and the inclusion of a nonlinear wind input growth rate (Janssen and Bidlot, 2023), ECMWF 2024). Sea state dependent heat and moisture fluxes (Janssen and Bidlot, 2018).

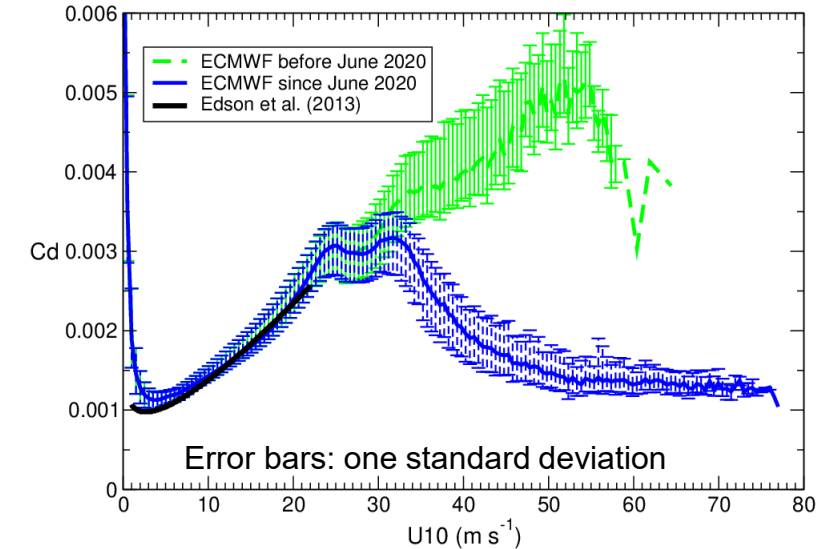


Drag coefficient v 10m wind speed:

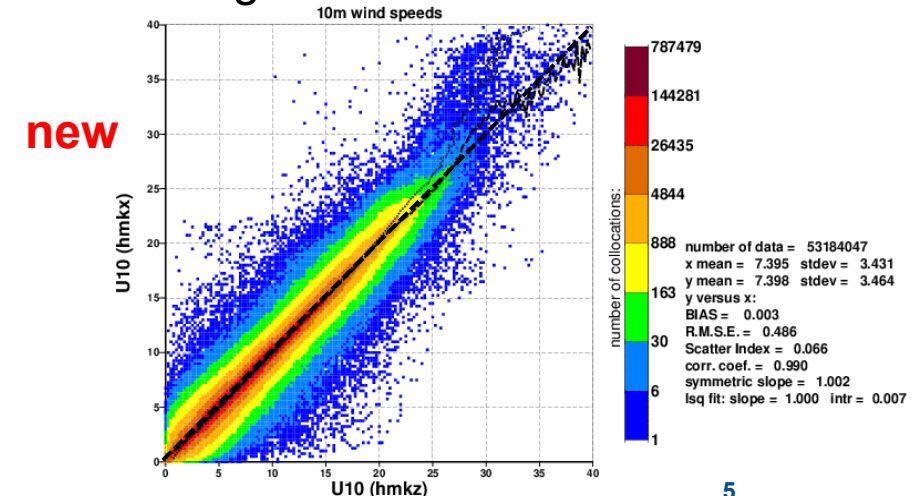
During Hurricane Laura, 27 August 2020

Tco2559 forecast step 24 to step 78 by 1 hrs

start date 2020-08-24, 12 UTC

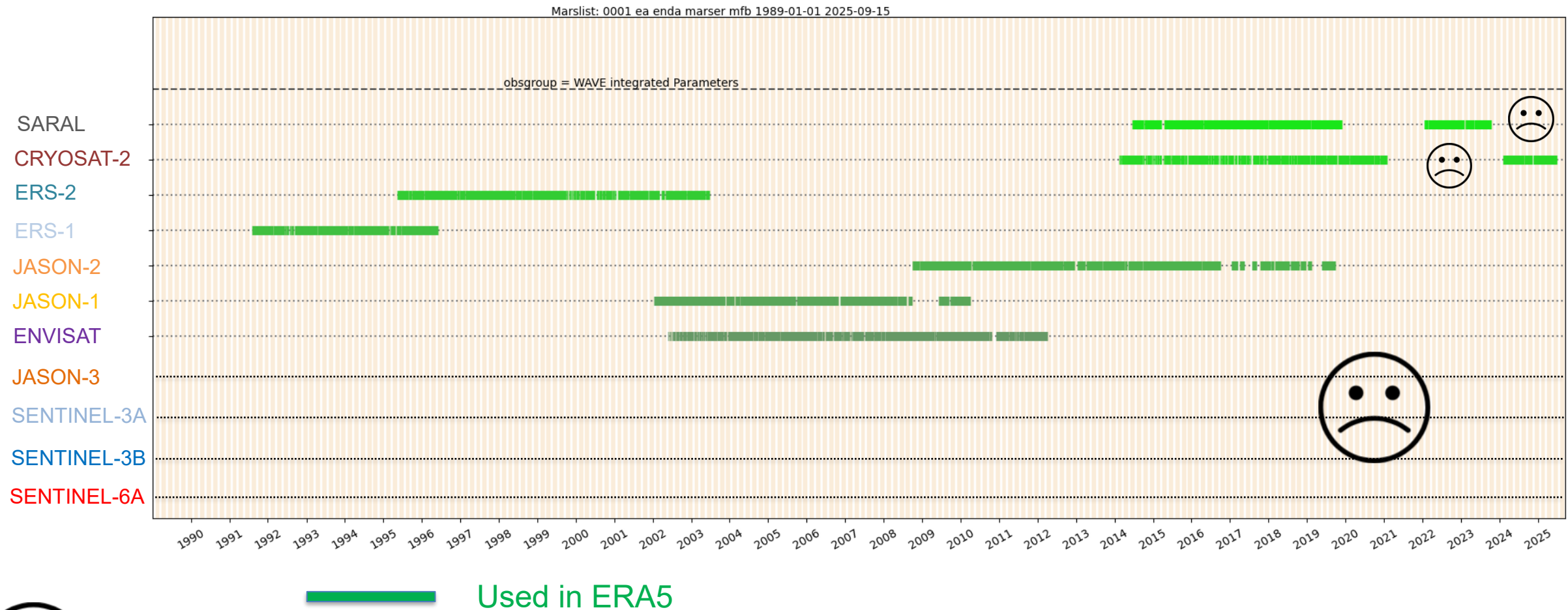


Higher surface winds:



Forecast data from all sea points with U10 > 5 m/s (relative grid) from 20201225 00UTC to 20201230 00UTC, forecast step 24 by 6

4. Altimeter wave height data usage in ERA5



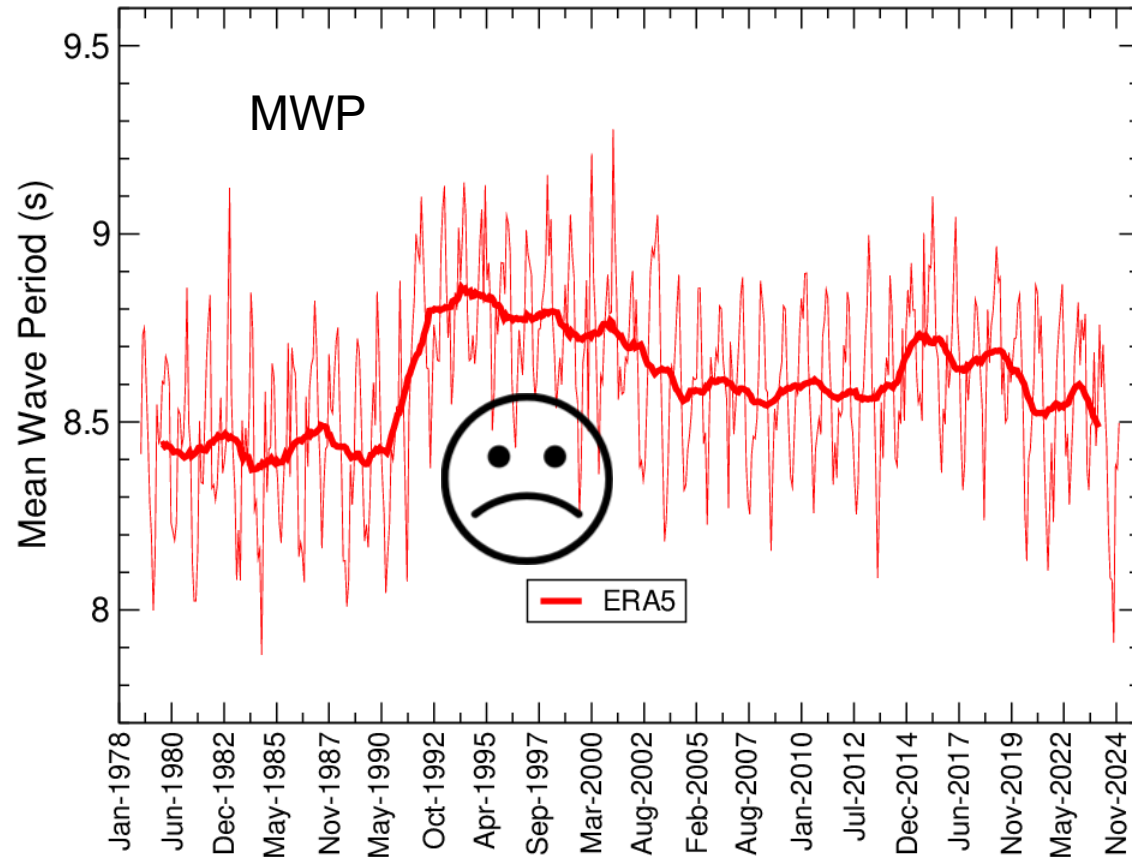
Recent changes to the altimeter wave height observing system were not implemented in ERA5...

Global Mean: issue in ERA5

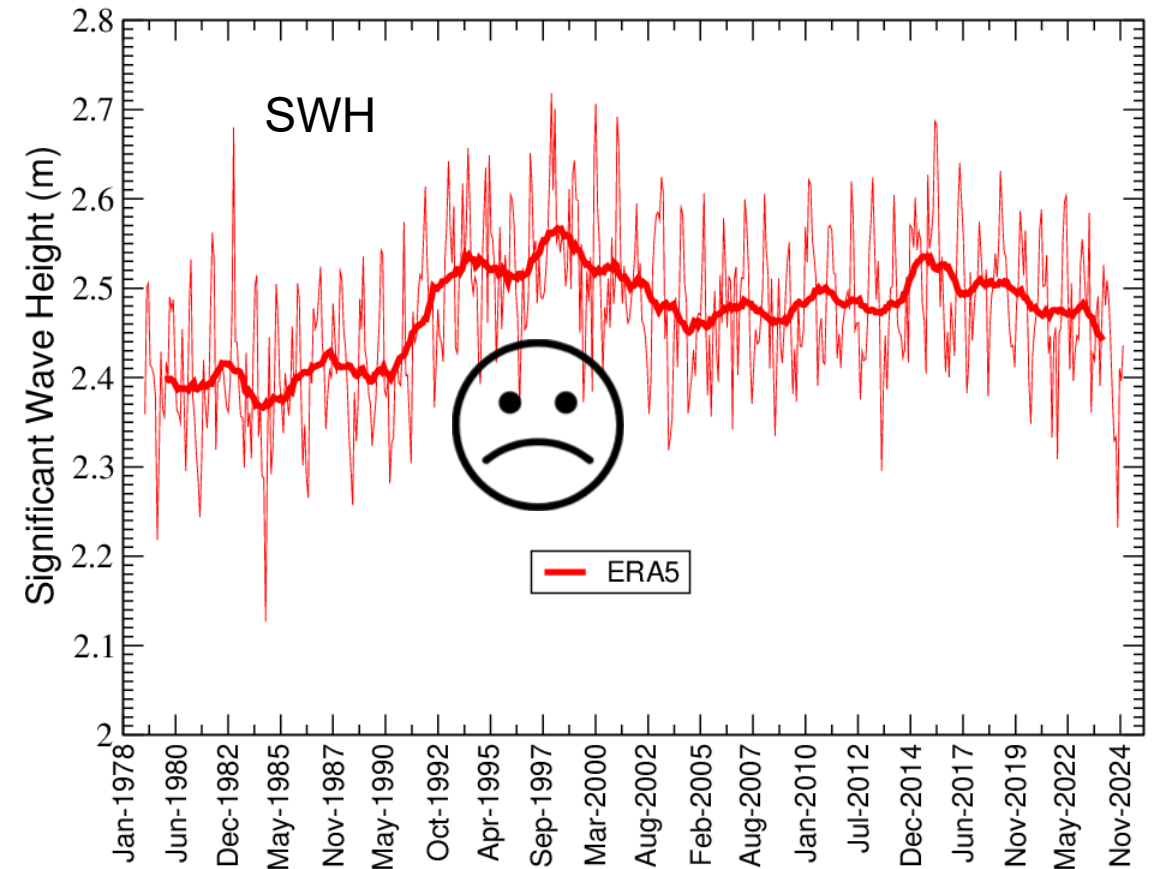
Also, there has been a sub-optimal use of altimeter wave height data in ERA5.

For instance, we have identified different issues with the bias corrections that was applied to ERS-1&2 ...

Global Mean

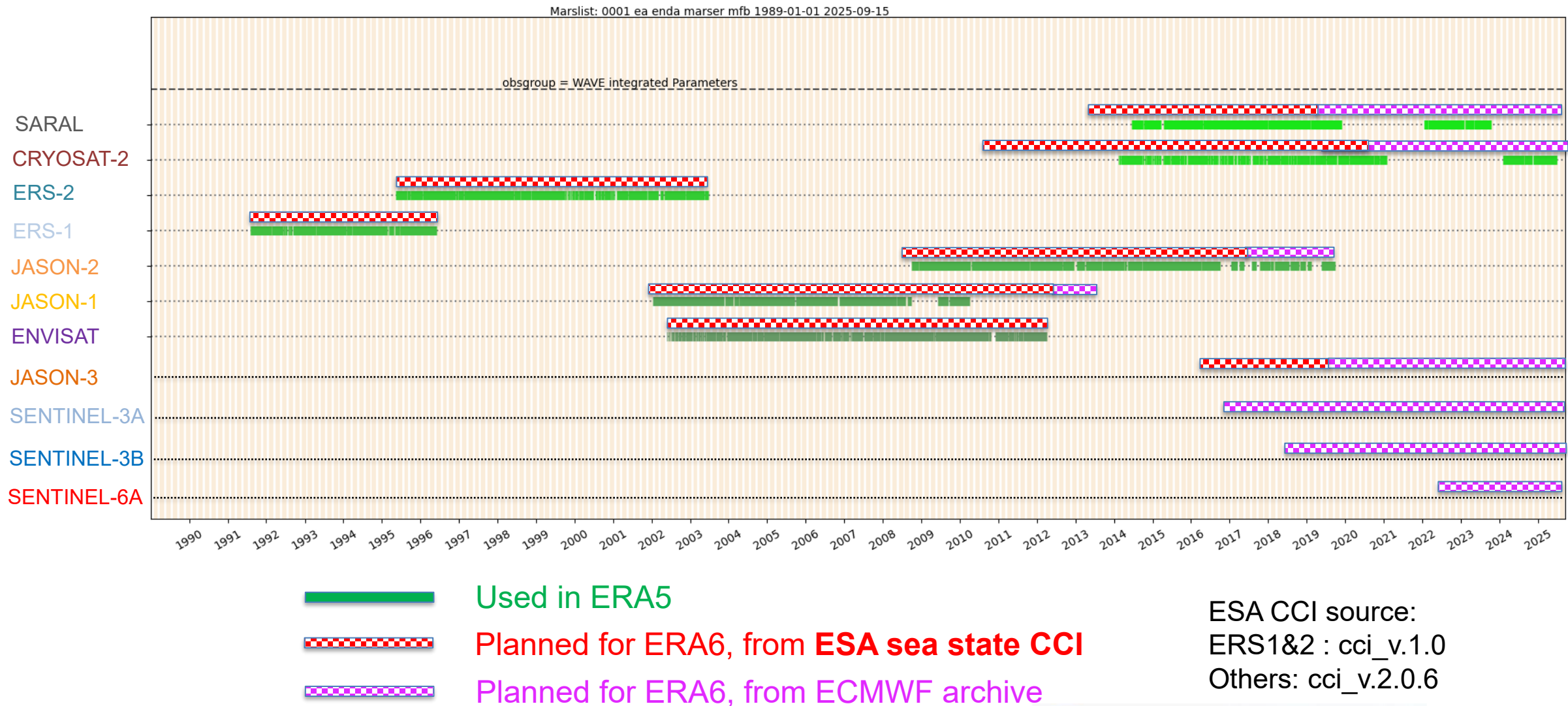


Global Mean



Thin lines: monthly average
Thick lines: 2-year running mean

5. Altimeter wave height data usage in ERA5 and planned periods of ERA6 use



Altimeter wave height data calibration in ERA6: dedicated wave hindcasts

- To mitigate any future mishaps in the use of altimeter wave height data, we ran ecWAM standalone.
- Data analysis (DA) was performed for the full period from 1991 to present.
- Altimeter were bias corrected with respect to analysis experiments.
- Hindcast were based on the same configuration as planned for ERA6,
- Forced by hourly ERA5 neutral 10m wind speed, surface air density, wind gustiness and sea ice cover.
- Based on an early prototype for ERA6, the ERA5 winds were adjusted, mostly for high winds:

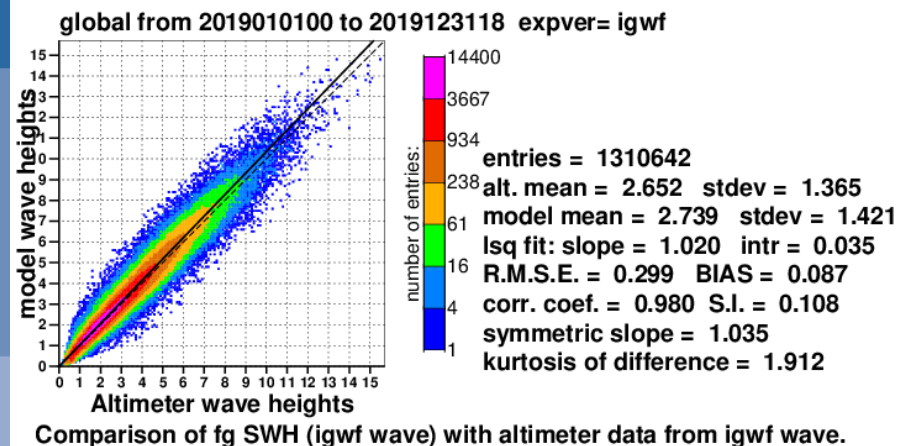
$$U10 = 1.01 * U10 \quad \text{for } U10 \leq 15.5 \text{ m/s}$$

$$U10 = 1.14 * U10 - 2.015 \quad \text{for } U10 > 15.5 \text{ m/s}$$

- With or without surface currents from ECMWF latest ocean reanalysis ORAS6.

Altimeter wave height data calibration in ERA6:

Global bias correction of the altimeter data with respect to the model first guess.

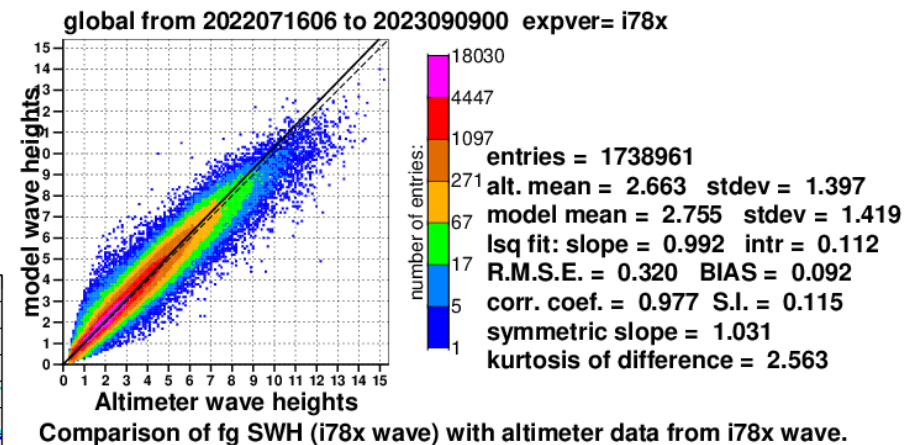
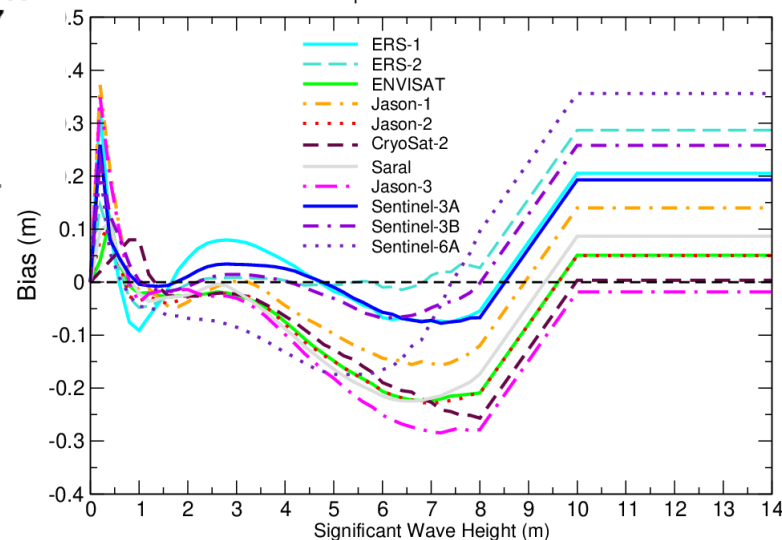


Jason-3

Corrections for different periods

Examples

Altimeter Significant Wave Height bias correction
with respect to CY49R2 hindcasts



Sentinel-6A

ERS-1: 19920801-19940731

ERS-2: 20080101-20110707

ENVISAT: 20070101-20120408

Jason-1: 20020114-20061031

Jason-2: 20080704-20170518

Saral: 20130314-20190131

CryoSat-2: 20100716-20200709

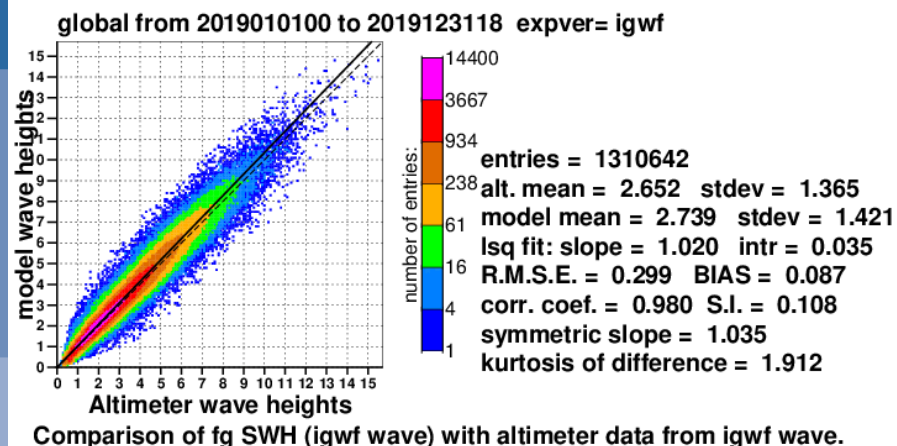
Sentinel-3A: 20190401-20220630

Sentinel-3B: 20200701-20250922

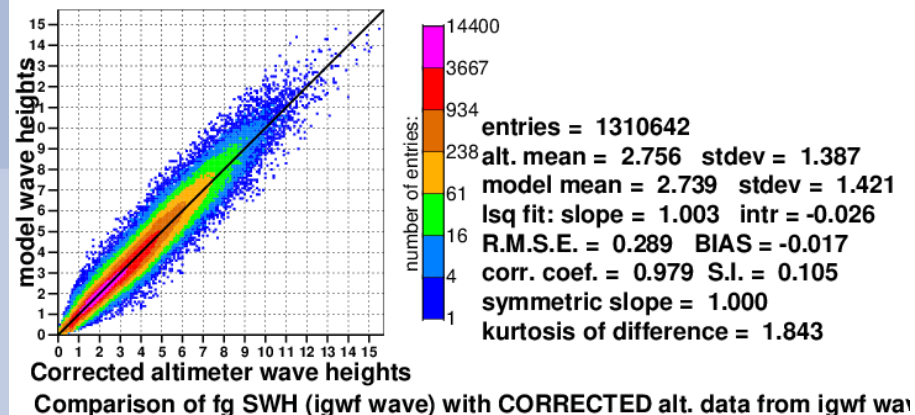
Sentinel-6B: 20220716-20250410

Altimeter wave height data calibration in ERA6:

Global bias correction of the altimeter data with respect to the model first guess.



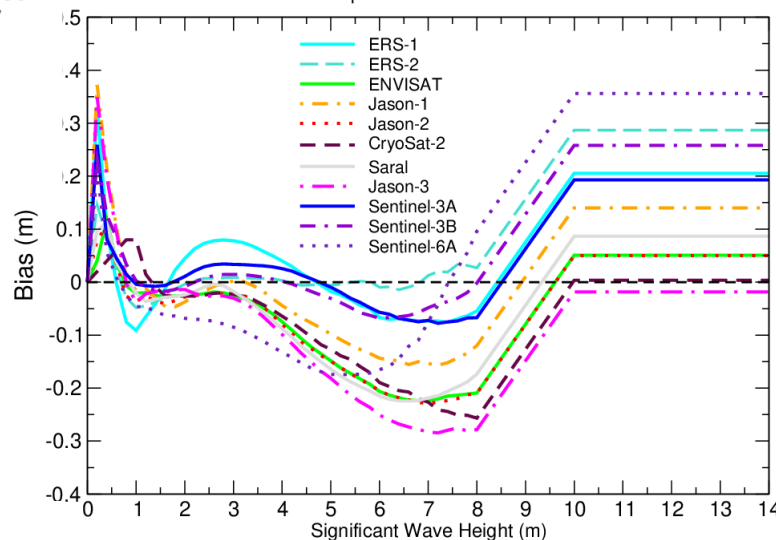
Jason-3



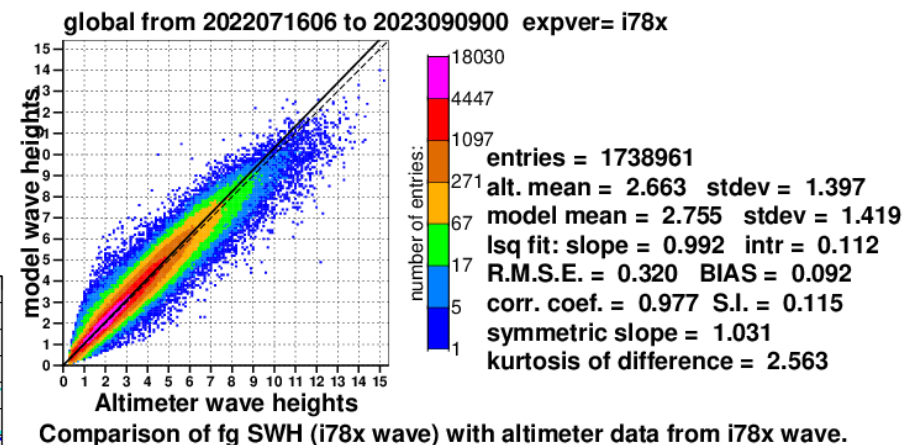
Corrections for different periods

Examples

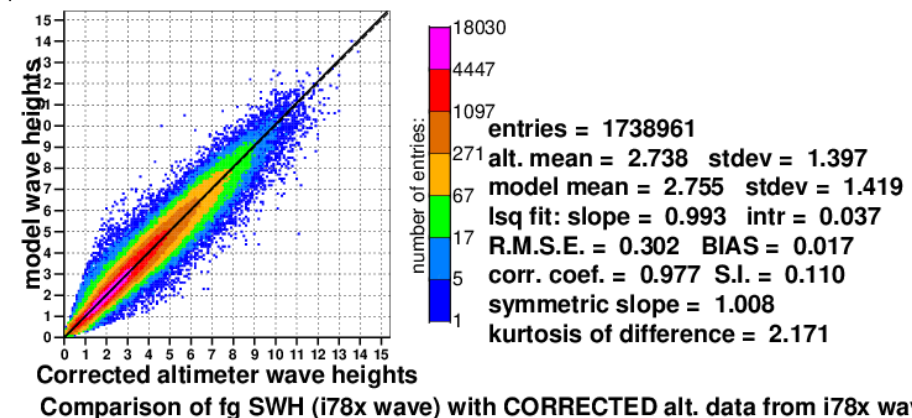
Altimeter Significant Wave Height bias correction
with respect to CY49R2 hindcasts



ERS-1: 19920801-19940731
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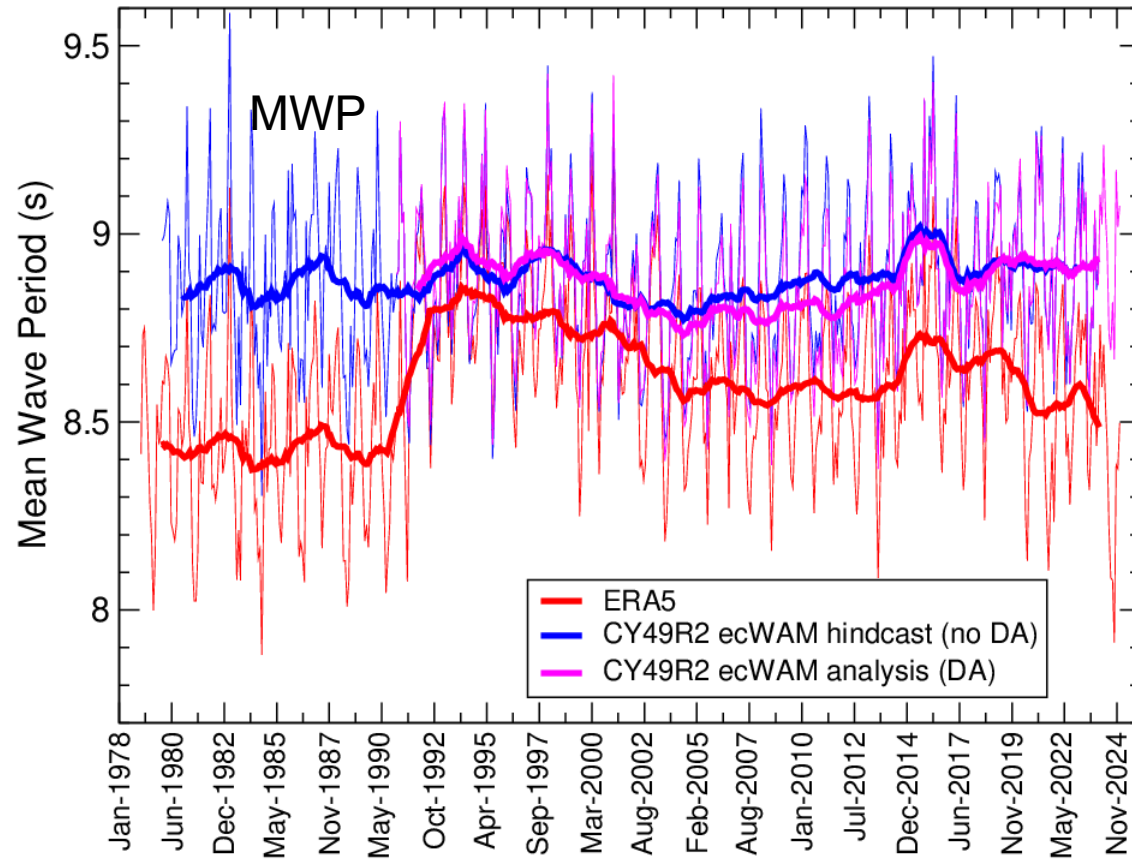
Sentinel-6A



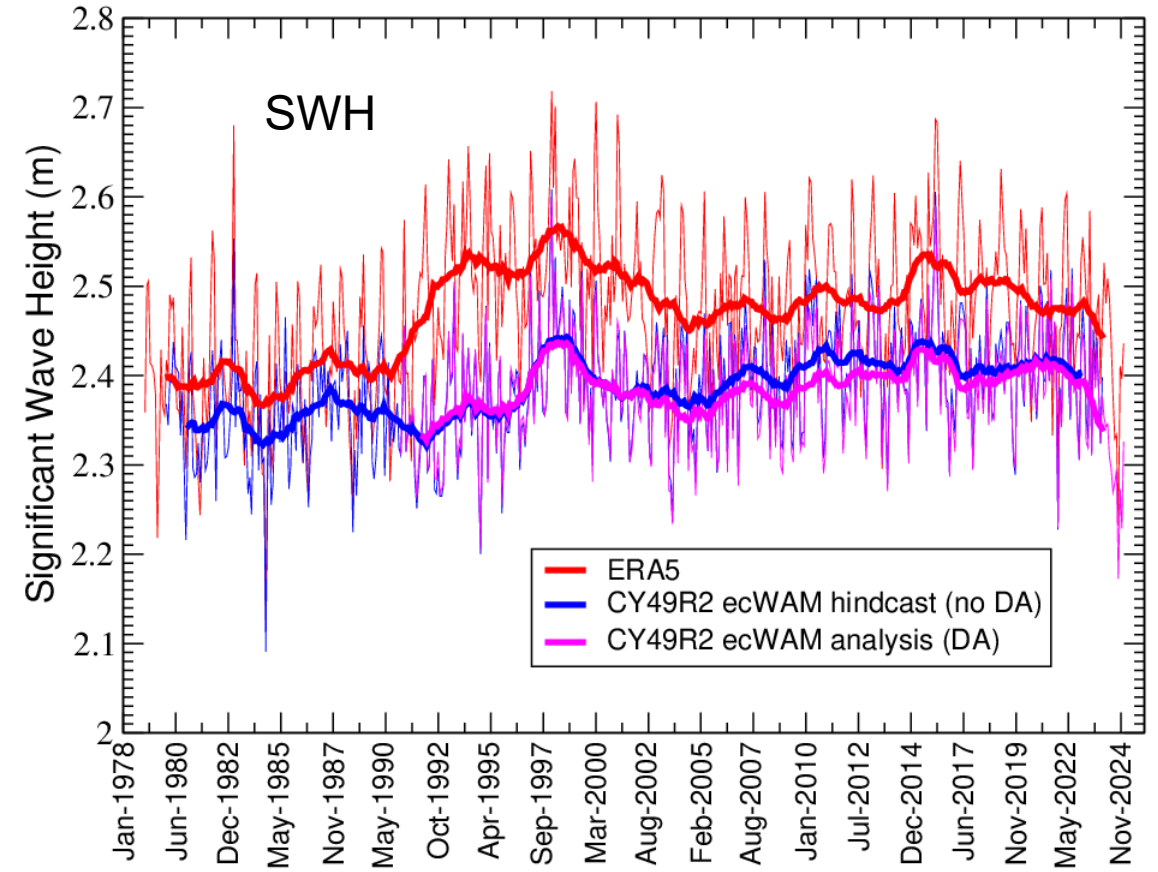
Global Mean:

- ERA5
- CY49R2 ecWAM hindcast (no DA)
- CY49R2 ecWAM analysis (DA)

Global Mean



Global Mean



6. Comparison with in-situ observations: yearly Scatter Index

Hindcast without data assimilation.

+ Using altimeter wave height assimilation (DA).

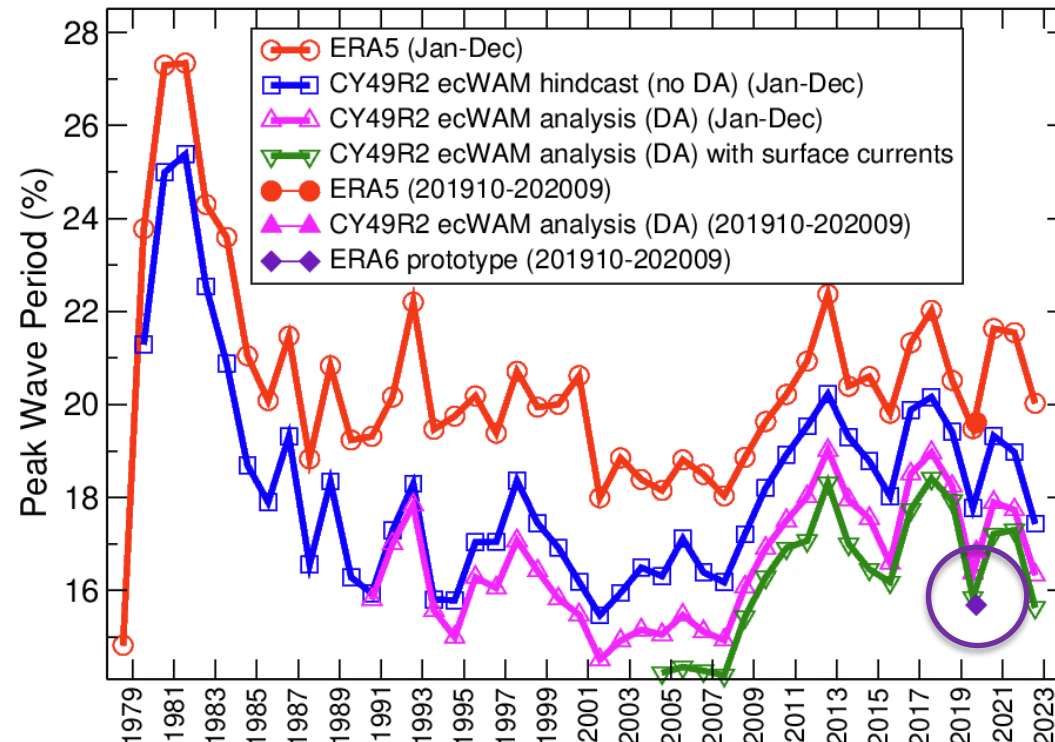
+ Using ocean surface current from ORAS6 for wave-current interaction.

Compared to ERA5.

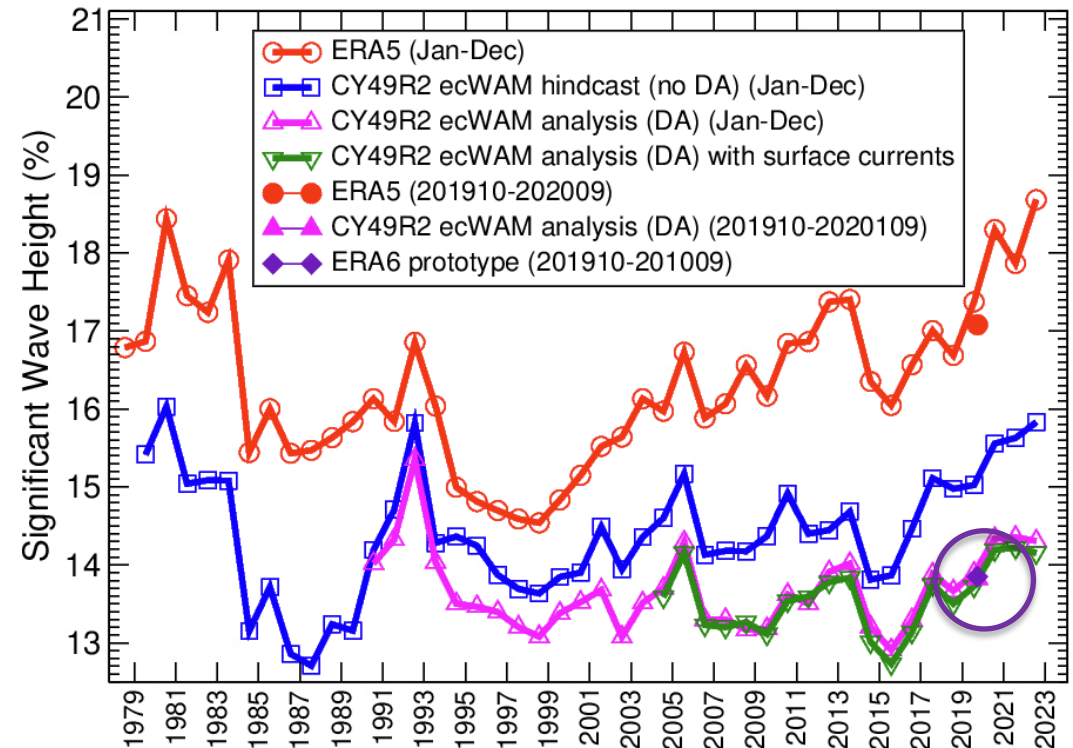
The one-year ERA6 prototype which will use CY49R1 + Altimeter DA + Ocean surface currents is also shown



Annual Scatter Index against in-situ observations



Annual Scatter Index against in-situ observations



Scatter Index: standard deviation of the difference normalized by the mean of the observations

7. Status of ERA6, summary/outlook

ERA6 is coming

production is to about to start

First spin-up years (2006/2016) nearing completion

Expect 2007 onwards public by start of 2027.

- ✓ Higher resolution 14km
- ✓ Additional 8 years R&D
- ✓ Ocean component
- ✓ More and better use of observations
- ✓ Ensure 49r2 also works well back in time
- ✓ Resolve several ERA5 issues

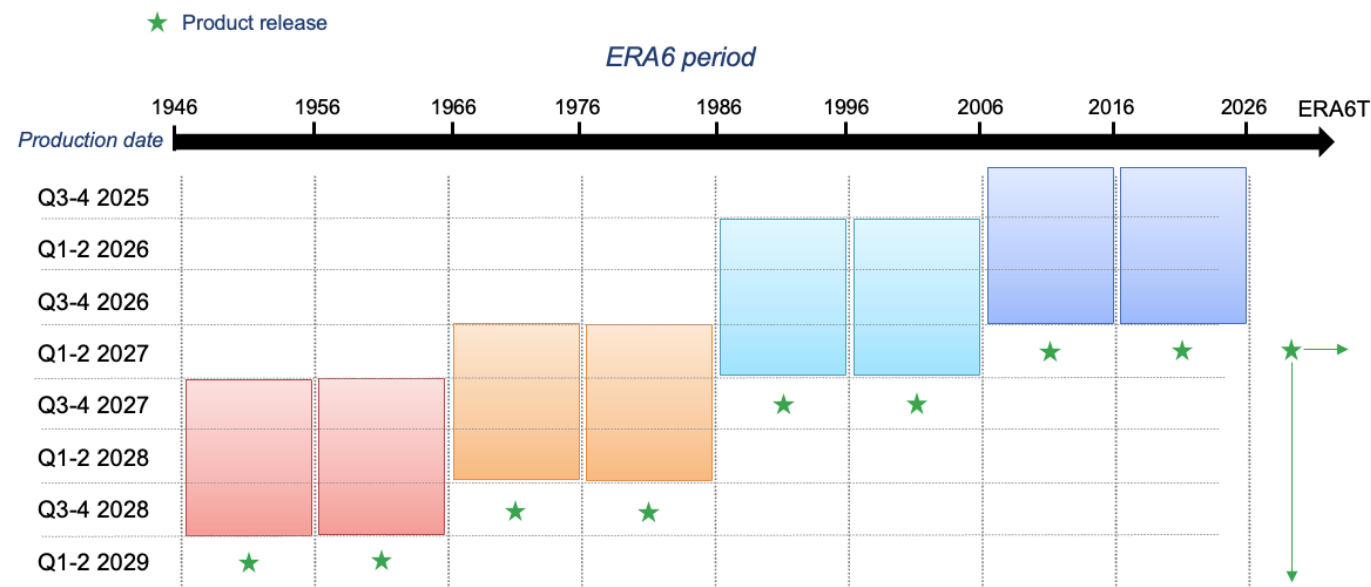
More products:

- ✓ Ocean fields, height levels
- ✓ GRIB2 format
- ✓ Daily/monthly statistics

ERA5T will be maintained for the time being

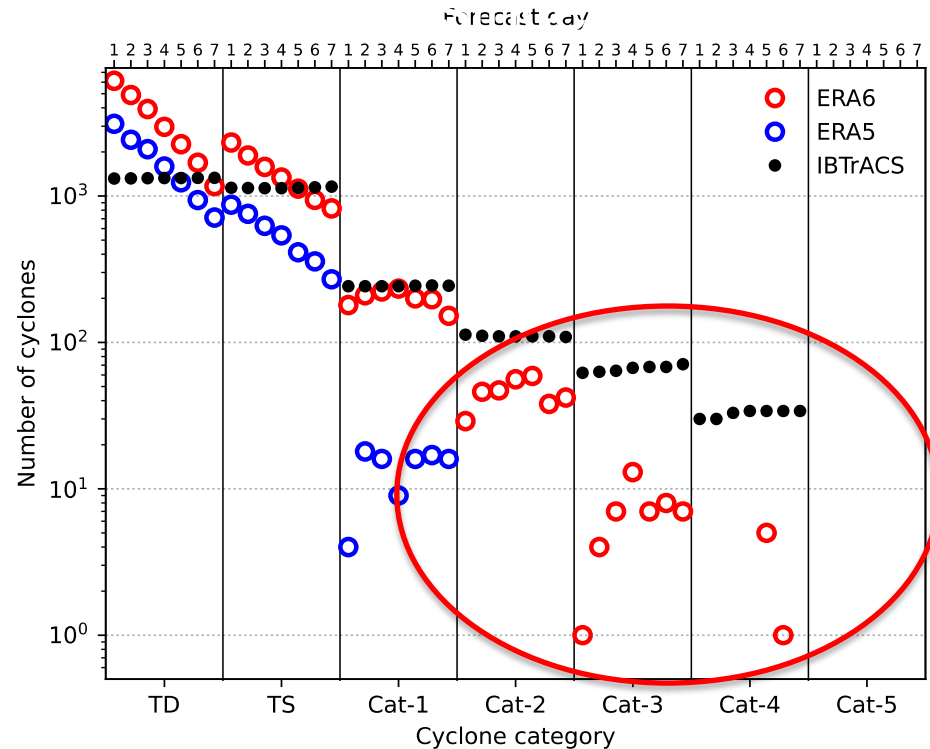


ERA6 planned production timeline

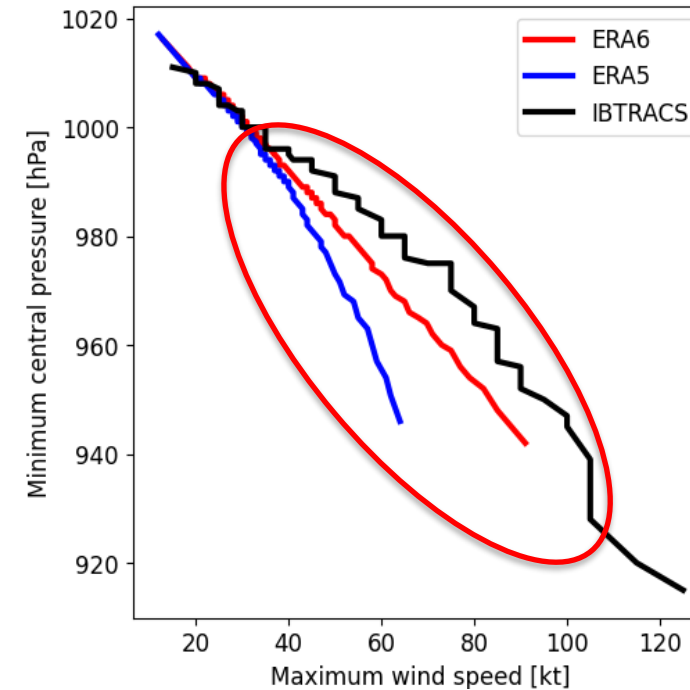


Not forgetting ERA5, which will continue to be produced and monitored for some time

Improvements in the representation of tropical cyclones in an ERA6 prototype



Logarithmic scale of the y axes to highlight differences in the stronger intensity categories.



Verification of 12-month ERA6-like experiment.

- Forecasted numbers of Cat-1 hurricanes now fit well to observed numbers.
- ERA6 captures Cat-2 to Cat-4 hurricanes, which were missing in ERA5.
- TC track errors reduced by almost 1 day at lead times larger than 2 days.
- Deeper core pressure and higher wind speeds on average
- ERA6 features smaller TCs compared to ERA5 (smaller average maximum wind radii)
- Pressure-wind relationship is also more consistent with observations, now qualitatively similar to the operational IFS
- All forecast models inherit the deficiencies in ERA5. ERA6 will offer improvements in this regard.

Outline

1. ERA5: the current global atmosphere and wave reanalysis.
2. ERA6: the next global reanalysis
3. Wave model component in ERA6.
4. Sub-optimal altimeter wave height data usage in ERA5.
5. Planned altimeter wave height data usage in ERA6.
6. Expected gain in performance for ERA6 (waves).
7. Summary and outlook.

References

IFS documentation CY49R1–Part VII, 2024: ECMWF wave model. ECMWF Tech. Rep. CY49R1, 120 pp.
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Øyvind Breivik, Kristian Mogensen, Jean-Raymond Bidlot, Magdalena Alonso Balmaseda, and Peter A.E.M. Janssen, 2015: Surface Wave Effects in the NEMO Ocean Model: Forced and Coupled Experiments. JGR, doi: 10.1002/2014JC010565

Janssen, P.A.E.M., 1997: Effect of surface gravity waves on the heat flux. ECMWF Technical Memorandum 239.
<http://www.ecmwf.int/en/elibrary/technical-memoranda>

Peter A.E.M.Janssen and Jean-Raymond Bidlot, 2018: Progress in Operational Wave Forecasting, Procedia IUTAM Volume 26, 2018, Pages 14-29.
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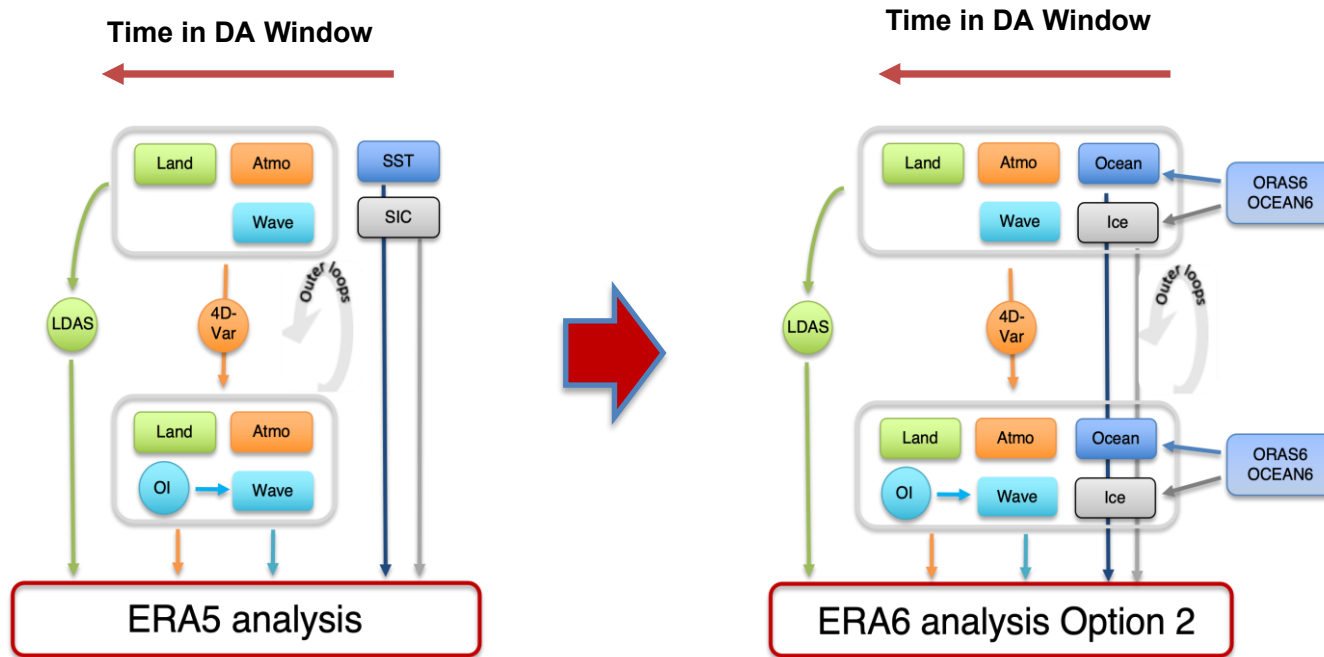
Peter A.E.M.Janssen and Jean-Raymond Bidlot, 2023. Wind–Wave Interaction for Strong Winds" (10.1175/JPO-D-21-0293.1) *Journal of Physical Oceanography*, vol. 53, no. 3.
<https://journals.ametsoc.org/view/journals/phoc/53/3/JPO-D-21-0293.1.xml>

S. Majumdar, L. Magnusson, P. Bechtold, J-R Bidlot, J. Doyle, 2023 : Advanced tropical cyclone prediction using the experimental global ECMWF and operational regional COAMPS-TC systems, Mon. Wea. Rev., 151, 2029–2048.
<https://doi.org/10.1175/MWR-D-22-0236.1>

Integrated Forecasting System (IFS) upgrades since ERA5



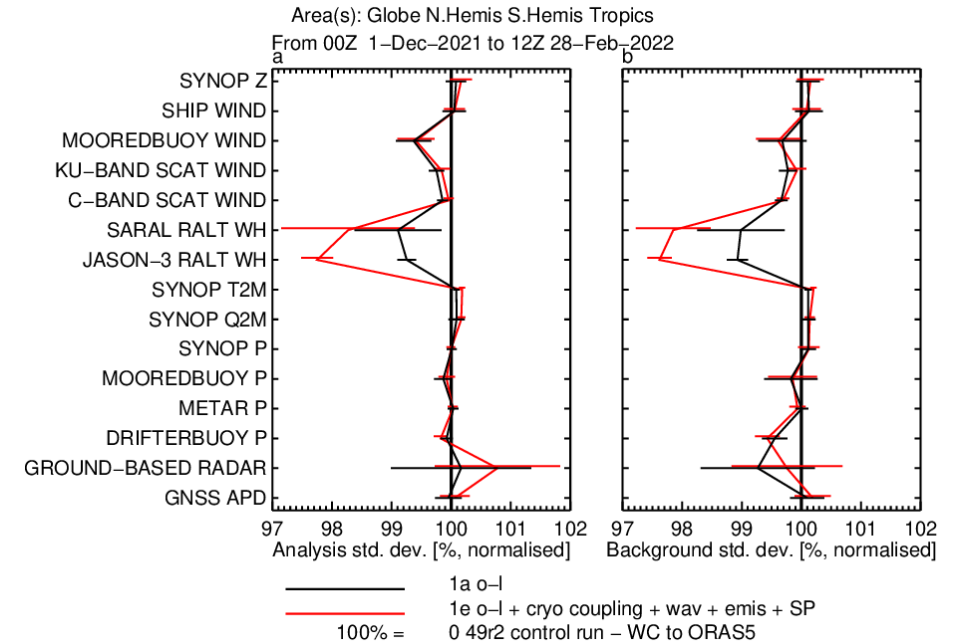
The ERA6 model is coupled with the ocean; but it gets the ocean initial state from ORAS6



Positive impact where you expect it

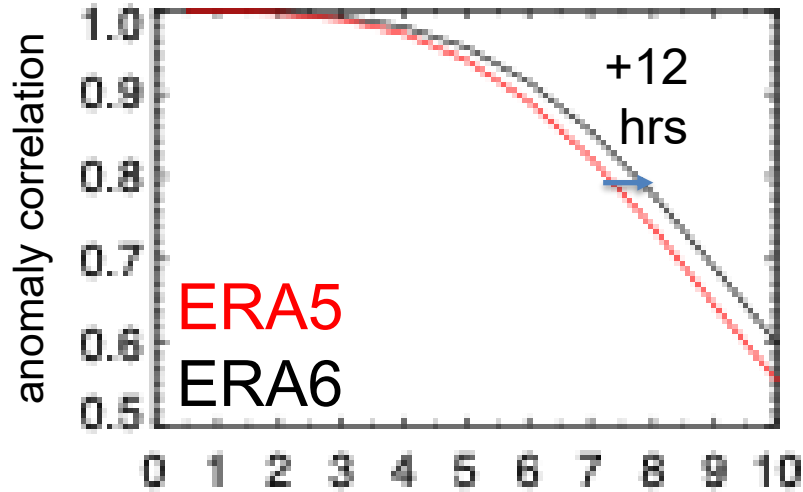
- near the surface, improved ocean wave forecasts (account for ocean currents)
- better fit to near ocean surface observations (scatt wind and alt Hs)
- SST/SIC evolving hourly rather than daily in ERA5, ocean currents

New! not in 49r1, but in ERA6 and 50r1



Performance of ERA6 prototype experiments

NH Z500 (Oct 2019 – Jan 2020)

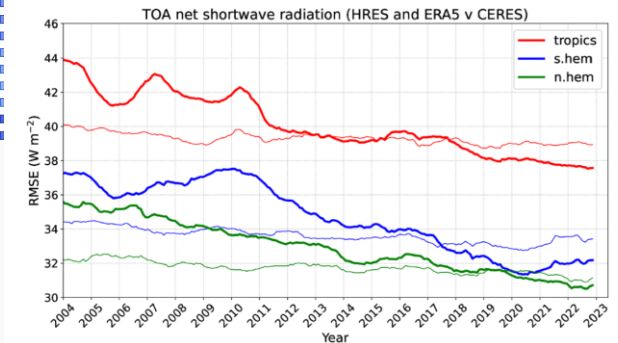
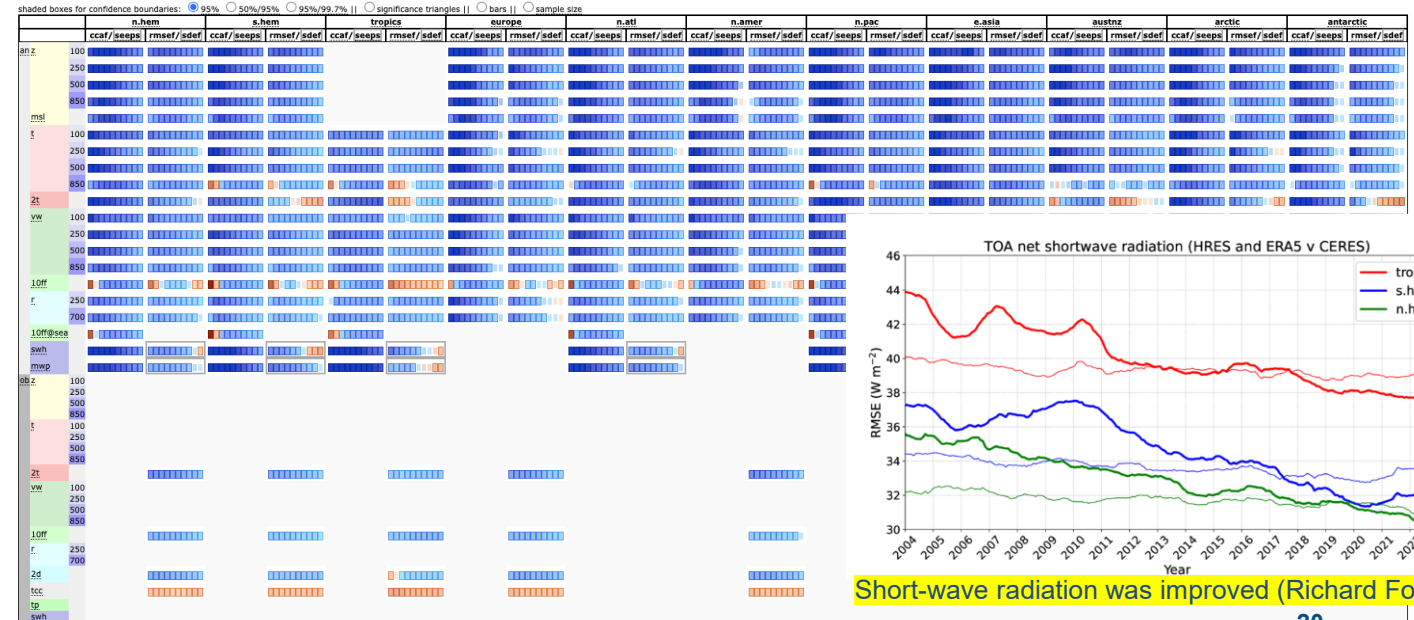
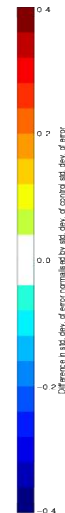
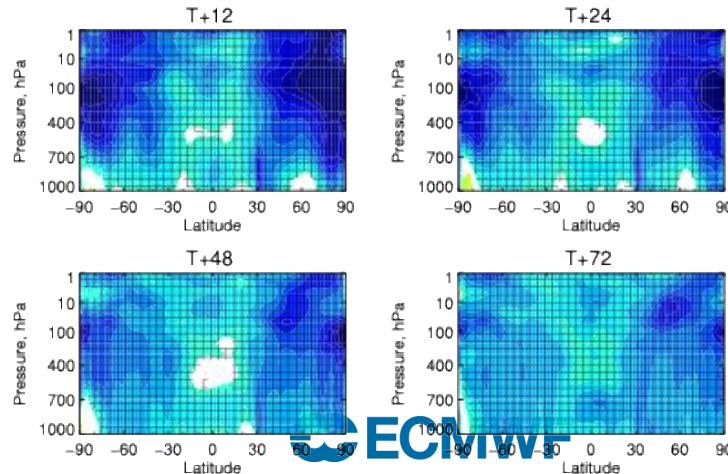


By this metric improvements from ERA5 to ERA6 are in-line with those achieved in previous generations of reanalyses

Scorecard pilot ERA6 vs ERA5: blue is better

Change in std. dev. of error in Z (ERA6-test (ind5)-ERA5)

1-Oct-2019 to 31-Jan-2020 from 226 to 245 samples. Verified against ocn-analysis. Cross-hatching indicates 95% confidence with Sidak correction for 20 independent tests.



Short-wave radiation was improved (Richard Forbes)