ERA5 reanalysis
&
ERA5 based ocean wave hindcast

Jean-Raymond Bidlot, Gil Lemos, Alvaro Semedo,

The C3S Reanalysis Team and ECMWF colleagues

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Overview

- Copernicus services.
- ERA5.
- ERA5 based wave hindcast.
- Comparison of the 10m wind and wave products with in-situ data.
- Ongoing comparison with CSFR and JRA55.
- WMO Lead Centre for Wave Forecast Verification LC-WFV.

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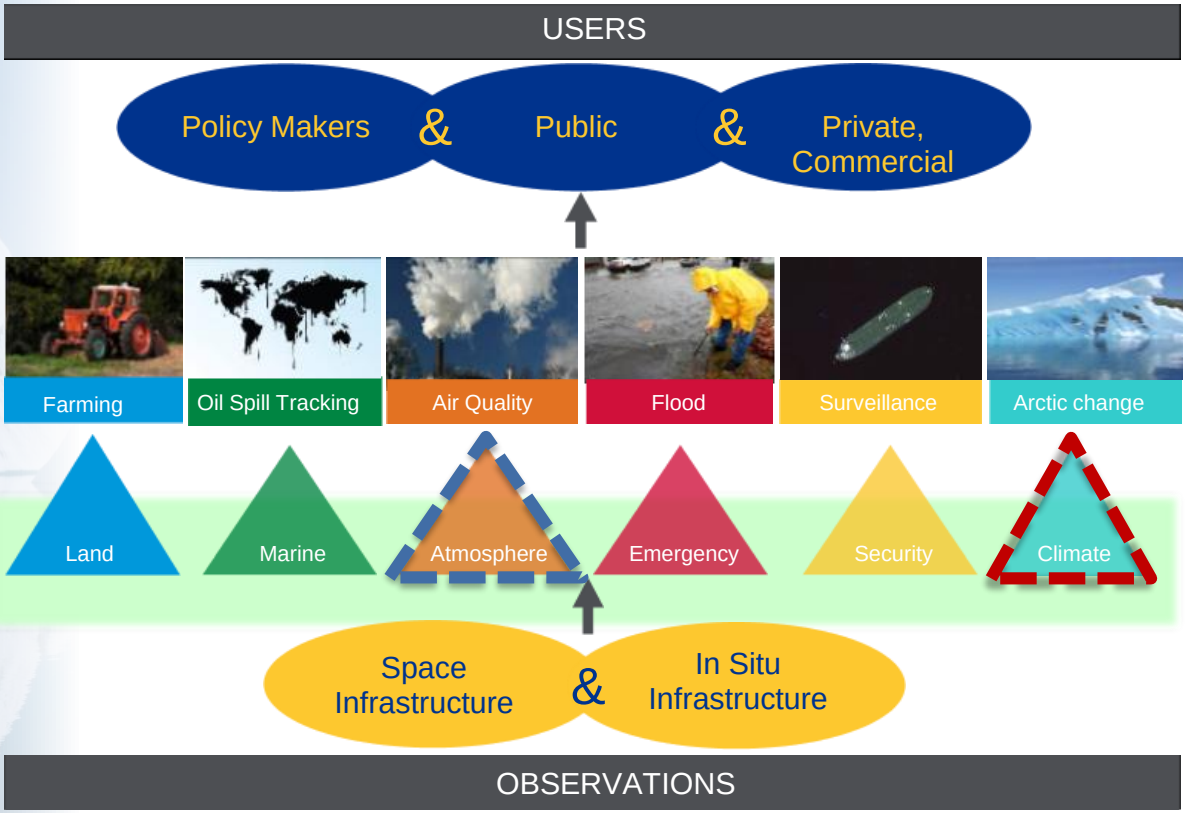
The Copernicus Climate Change Service



Different Needs

Examples of areas covered

6 Information Services

Sustainable observation capabilities

ECMWF operates the Copernicus Climate Change Service (C3S) and Copernicus Atmosphere Monitoring Service (CAMS) on behalf of the European Commission.

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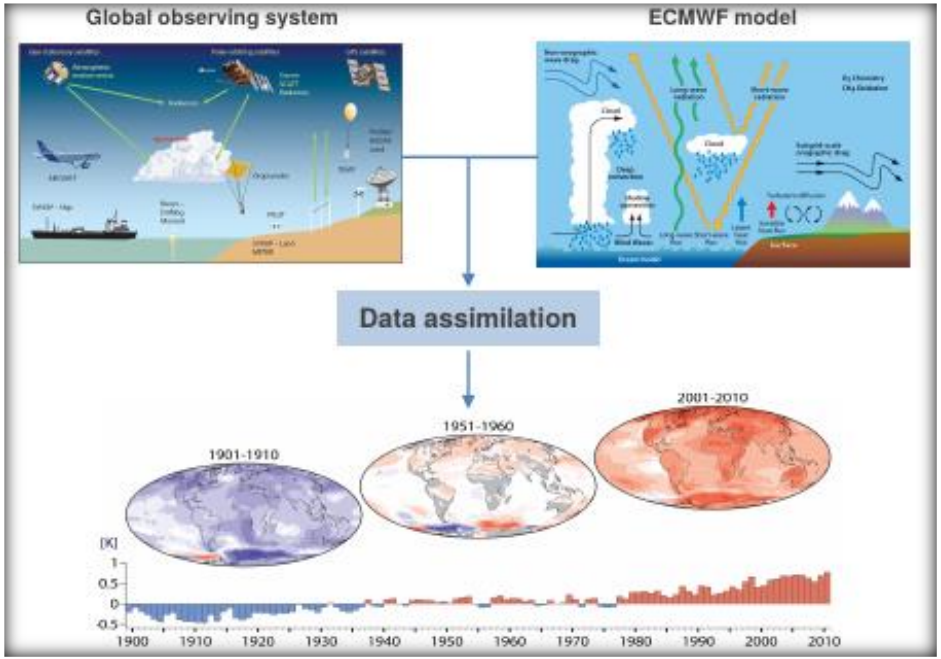
Why Reanalysis?

Atmospheric reanalysis offers a detailed overview of the past atmosphere, including ocean waves.

- **Complete**: combining vast amounts of observations into global fields
- **Consistent**: use the same physical model and DA system throughout
- **State-of-the-art**: use the best available observations and model at highest feasible resolution
- *Reanalysis allows for a close monitoring of the Earth's climate system also where direct observations are sparse*



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The ERA5 global reanalysis

ERA5 is in production at ECMWF for C3S

Atmosphere, land, and ocean waves

ERA5 has replaced ERA-Interim

(ERA-I was stopped end August 2019)

Improvements compared to ERA-Interim:

- Benefit from 10 years model development (2006 to 2016)
- Much higher resolution;
  - Atm: **31km** versus 80km
  - waves: **40km** versus 110km
- More and better input data
- **Hourly output**
- 10-member EDA-based **uncertainty estimate** (at 63km)
  - Perturbations to: SST, model tendencies & obs
- Will reach further back in time (1950 versus 1979)

Climate Data Store public release plan:

- **Published to date: Jan 1979– June 2019**
- **End 2019:** updates 2-5 days behind real time: **ERA5T**
- **Q2 2020: 1950-1978**.

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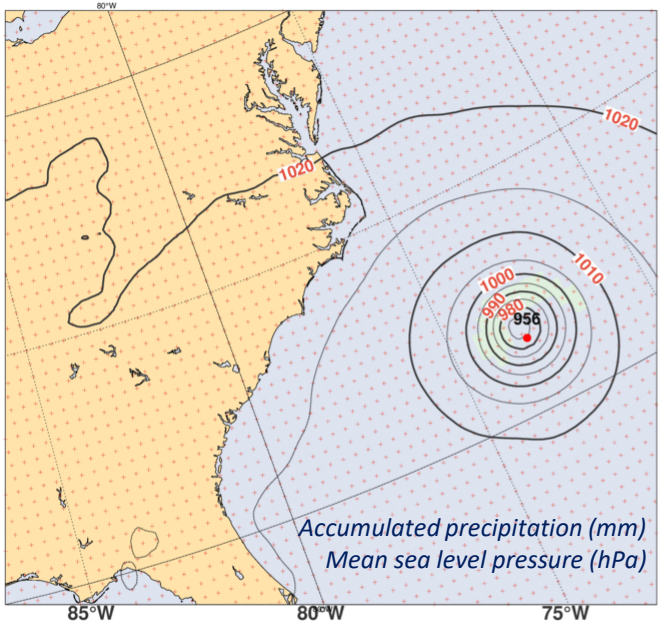
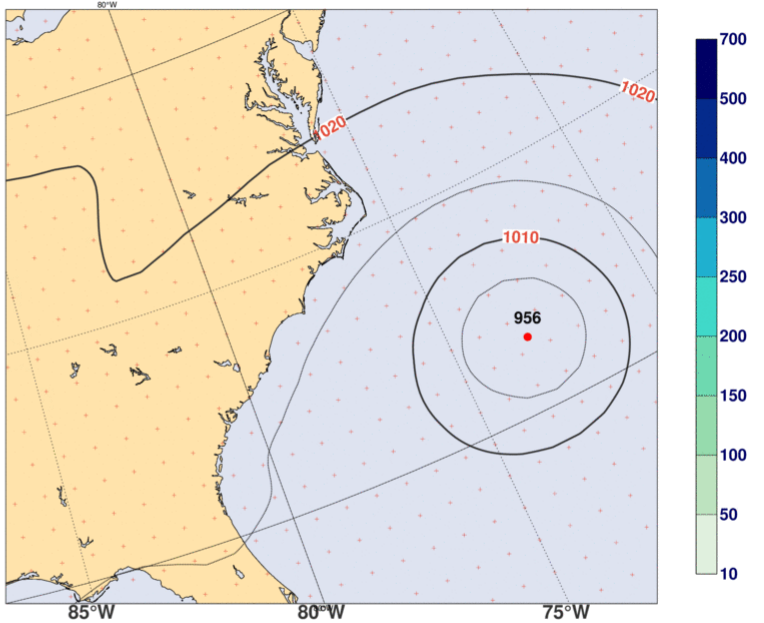
Better model, more and better observations, higher resolution, hourly output



ERA5



ERA-Interim

Freja Vamborg, Hans H

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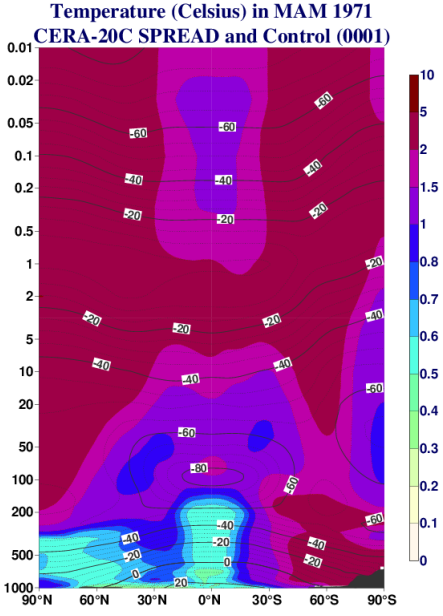
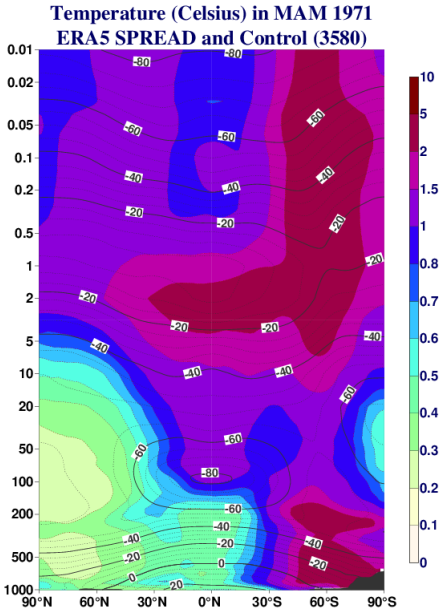
Climate Change Service climate.copernicus.eu

IMPLEMENTED BY ECMWF

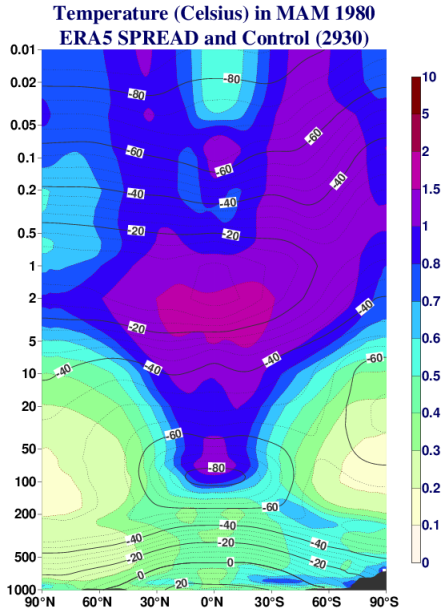
New: Ensemble spread as a measure for the ERA5 uncertainty



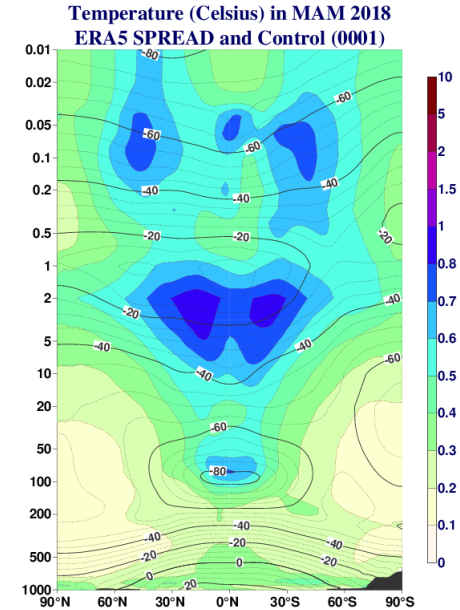
1971 CERA-20C:
Surface pressure, marine wind, only



1971 ERA5:
Upper-air data



1980 ERA5:
Early-satellite era



2018 ERA5:
Current observing system

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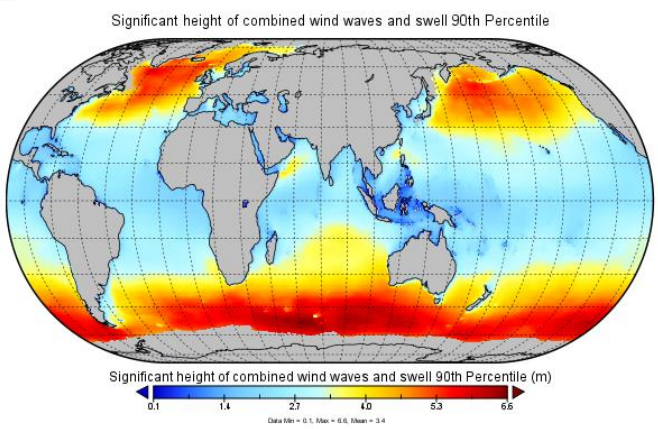
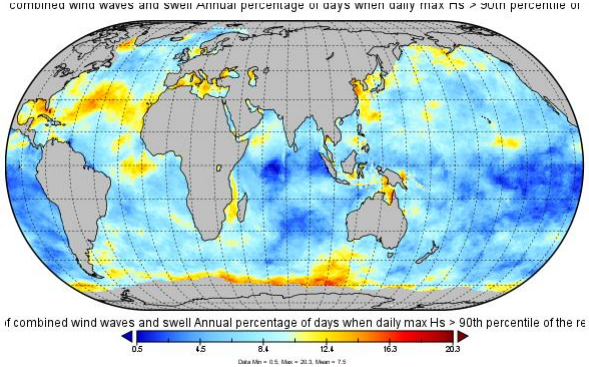
Example of products that can be derived from ERA5

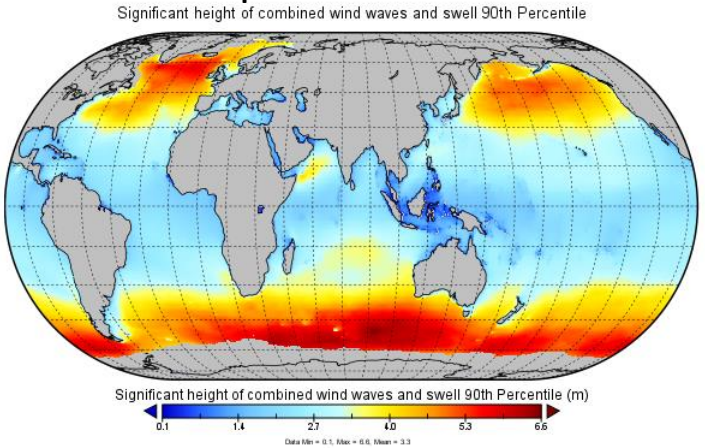
e.g. for COWCLIP

Hs 90th percentile for 1979





Hs 90th percentile for 2017



Percentage of days when Hs > 90th percentile

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ERA5 ensemble

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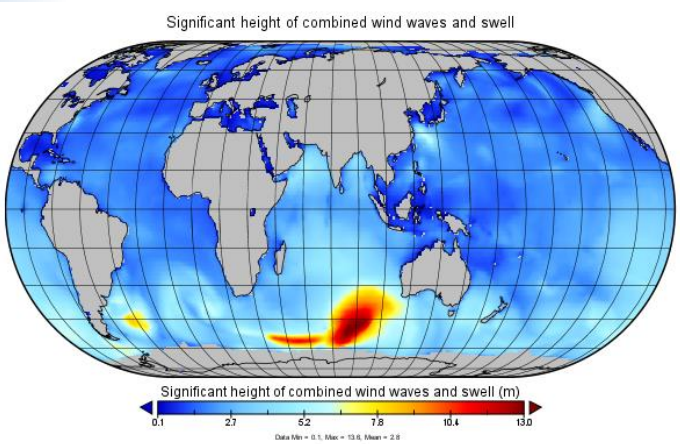
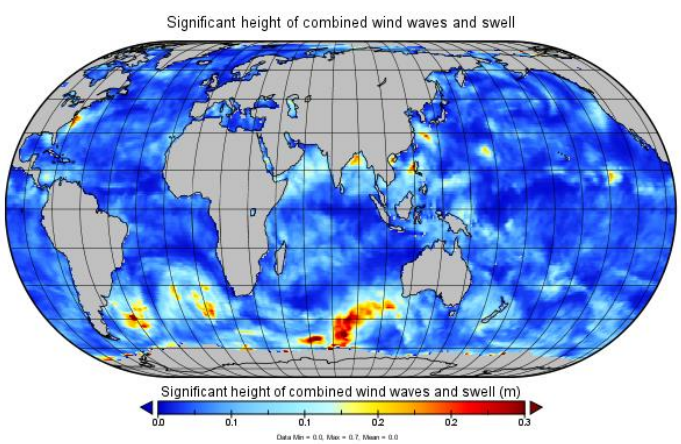
Hs ensemble mean



Hs ensemble spread



The potential of these type of data is there to be explored!

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ERA5 based wave hindcast (ERA5 HIND)

- Based on a more recent version (CY46R1, June 2019):
  - Sinput and Sdiss based of Ardhuin et al. (2010) in ECWAM (ST4-like*).
- 14 km (ECMWF HRES configuration)
- Forced by hourly ERA5 neutral 10m winds, gustiness, air density and sea ice cover.
- NO altimeter data assimilation!
- Bug fix to output of partitioned parameters.
- Revised and new output parameters.
- Hourly output (except 2d spectra, 12 hourly)

ERA5 based hindcast

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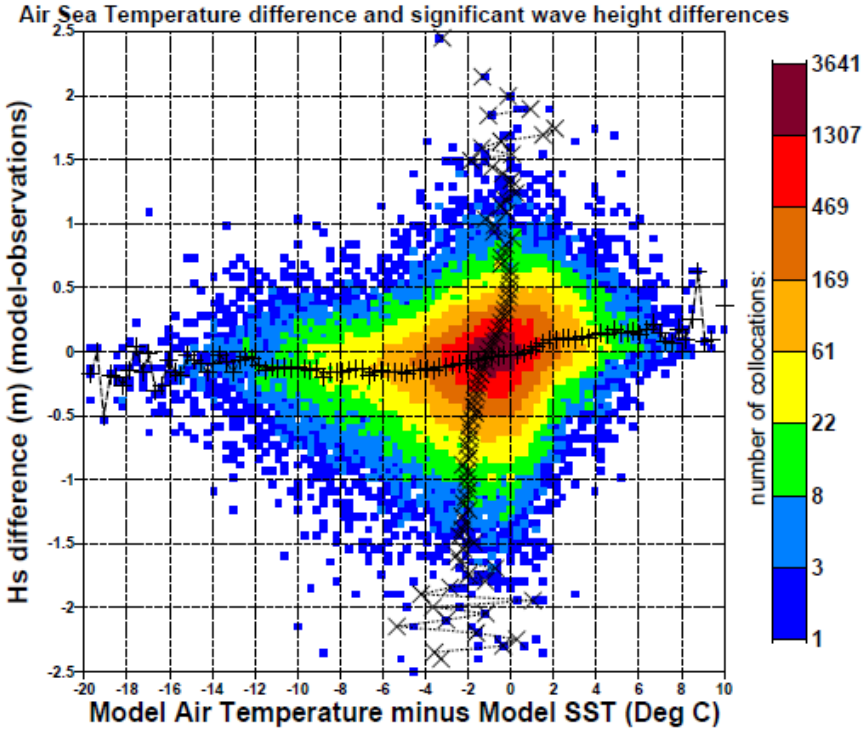

ECMWF ERA5 hindcast data (h7g6), January to December 2015
Comparison to in-situ Hs observations from all selected locations

Hindcast forced by 10m winds.

Comparison with in-situ data for 2015

number of data = 227488
x mean = 1.848 stdev = 1.254
y mean = 1.801 stdev = 1.191
BIAS = -0.048
R.M.S.E. = 0.249
Scatter Index = 0.132
corr. coef. = 0.981
symmetric slope = 0.967
lsq fit: slope = 0.933 intr = 0.077

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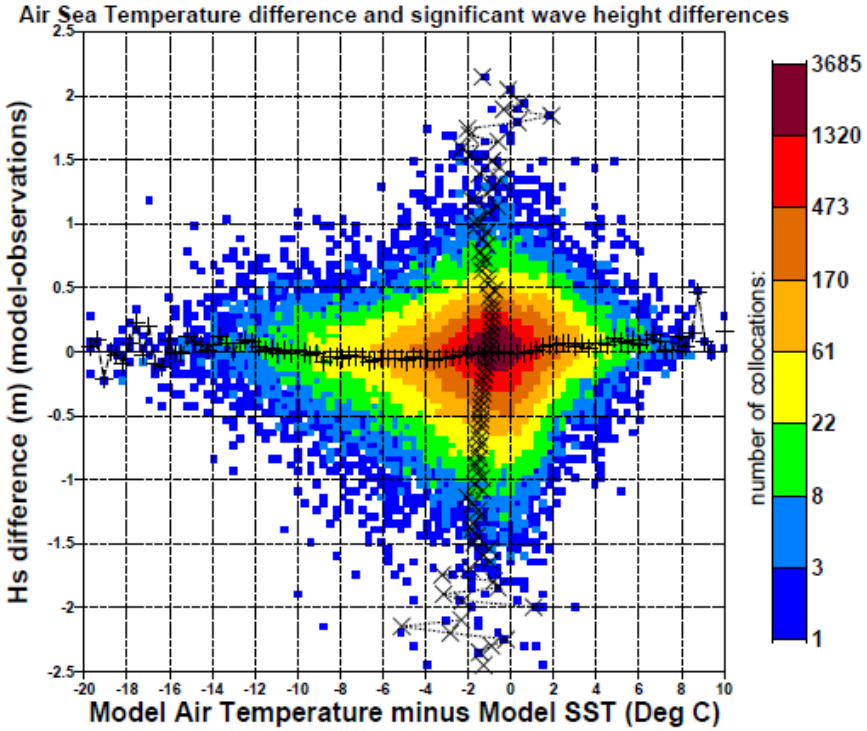
ERA5 based hindcast



ECMWF ERA5 hindcast data (h7ci), January to December 2015
Comparison to in-situ Hs observations from all selected locations

Hindcast forced by <u>neutral</u> 10m winds.

Comparison with in-situ data for 2015

number of data = 227488
x mean = 1.848 stdev = 1.253
y mean = 1.836 stdev = 1.205
BIAS = -0.012
R.M.S.E. = 0.234
Scatter Index = 0.127
corr. coef. = 0.983
symmetric slope = 0.983
lsq fit: slope = 0.945 intr = 0.090

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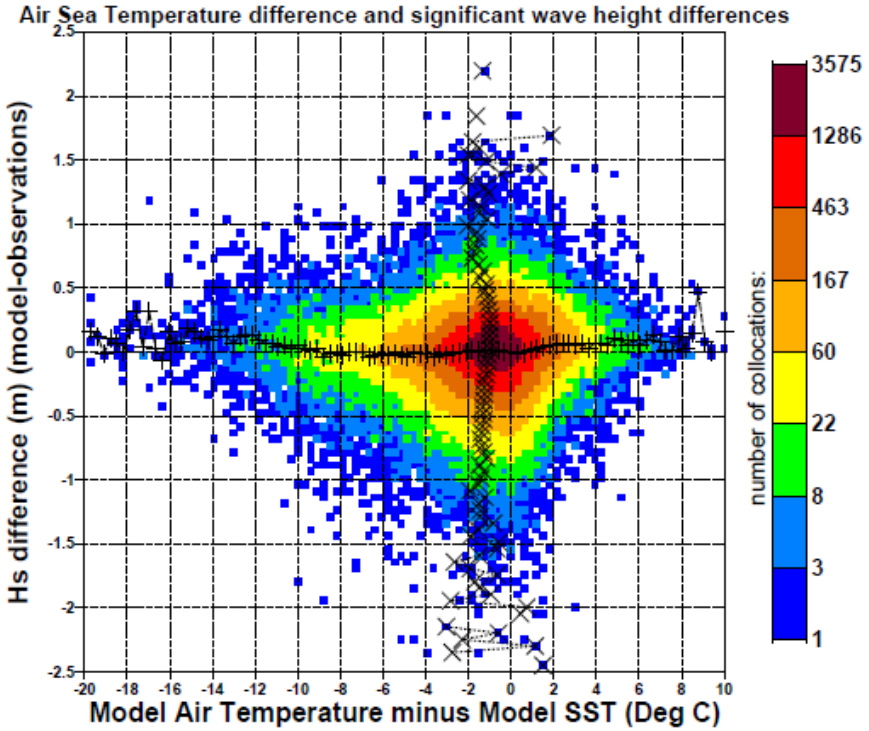
ERA5 based hindcast (ERA5 HIND)



ECMWF ERA5 hindcast data (h1pe), January to December 2015
Comparison to in-situ Hs observations from all selected locations

Hindcast forced by <u>neutral</u> 10m winds and gustiness and air density

Comparison with in-situ data for 2015

number of data = 227488
x mean = 1.848 stdev = 1.253
y mean = 1.853 stdev = 1.213
BIAS = 0.005
R.M.S.E. = 0.233
Scatter Index = 0.126
corr. coef. = 0.983
symmetric slope = 0.992
lsq fit: slope = 0.951 intr = 0.095

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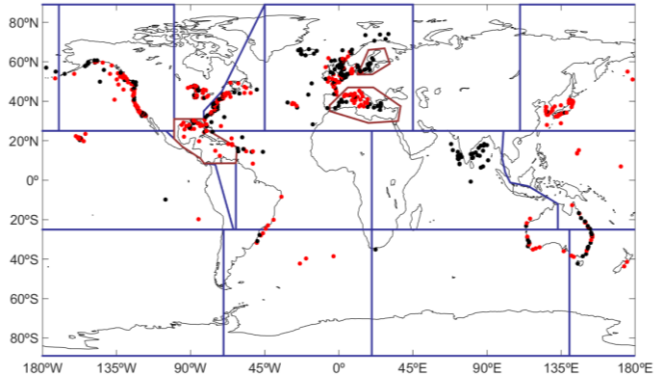
Comprehensive comparison with in-situ data 1979-2018

'ECMWF' dataset (buoys and platform data)

- GTS (ECMWF operational archive),
- NODC (NCEI) (US), CDIP(US), MEDS (Canada)
- CEFAS(UK), Faroe Island buoys, German buoys (BSH), Dutch buoys (SEADATANET)
- From JCOMM wave forecast verification project
  - NIWA buoys (NZ)
  - Japanese buoys via JMA
  - Danish buoys via DMI
  - Norwegian platforms via Met.no



Locations with Significant wave height observations

- **Australia (from IMOS – Integrated Marine Observing System)**
- **The Azores archipelago (from the CLIMAAT)**
- **The Baltic Sea (from CMEMS – Copernicus Marine Environment Monitoring System)**
- **Brazil (from PNBOIA – Programa Nacional de Bóias).**

Gil has produced a comprehensive quality controlled data set

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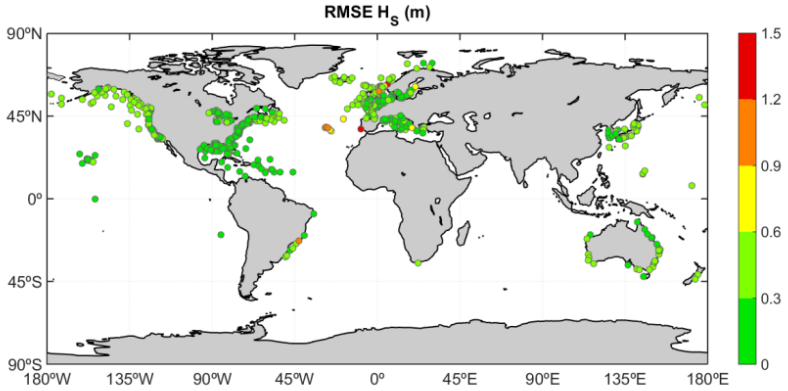
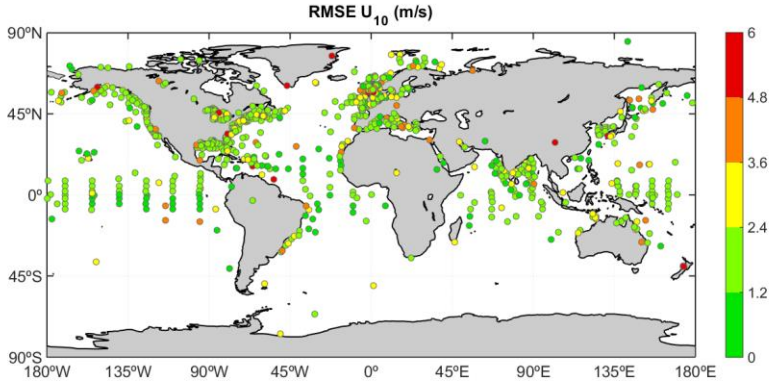
Comparison with buoy data: hindcast RMSE 1979-2018





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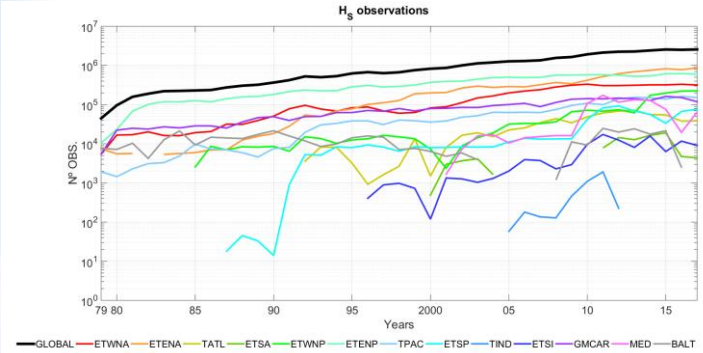
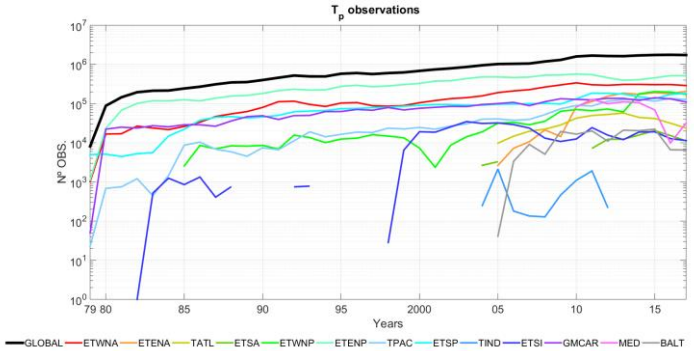
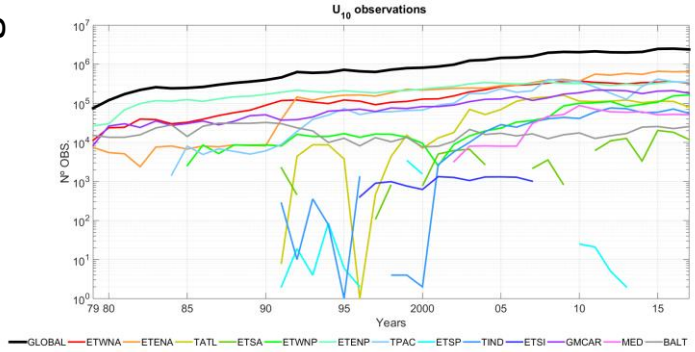
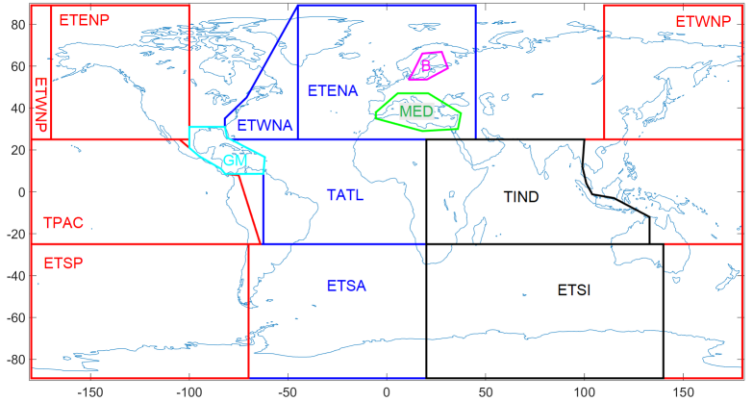
Comparison with buoy data: data coverage 1979-2018

Number of observations on a log scale !









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Comparison with buoy data1979-2018 QQ plots

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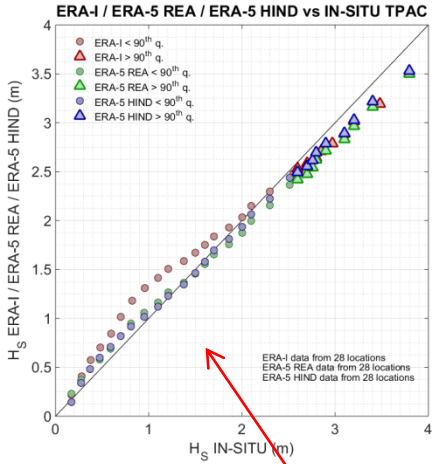
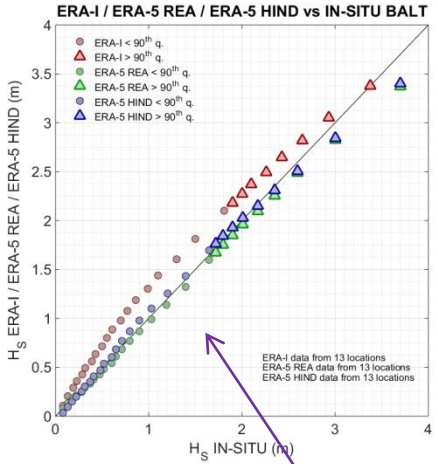
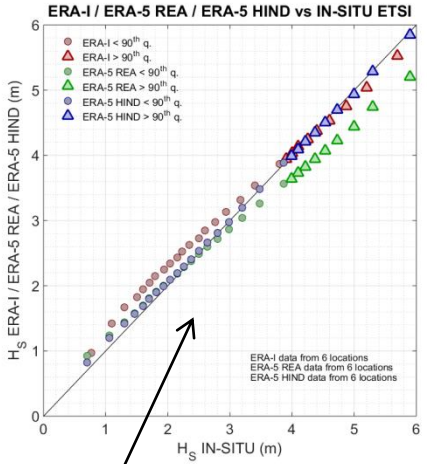
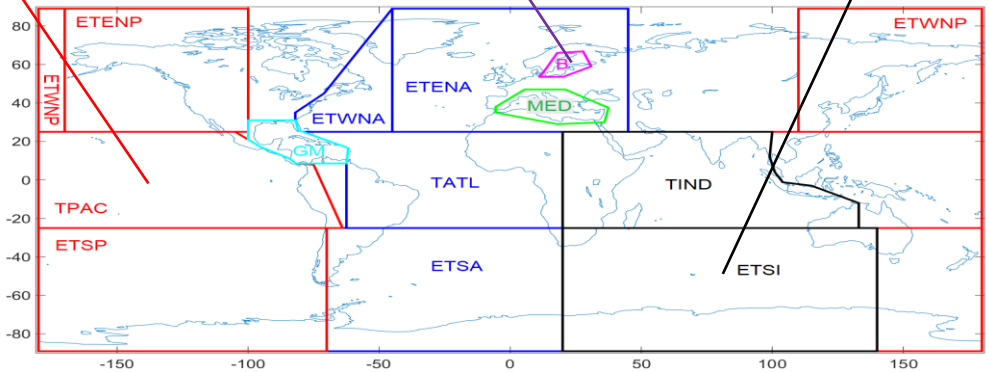






ERA-I < 90th q.
ERA-I > 90th q.
ERA-5 REA < 90th q.
ERA-5 REA > 90th q.
ERA-5 HIND < 90th q.
ERA-5 HIND > 90th q.



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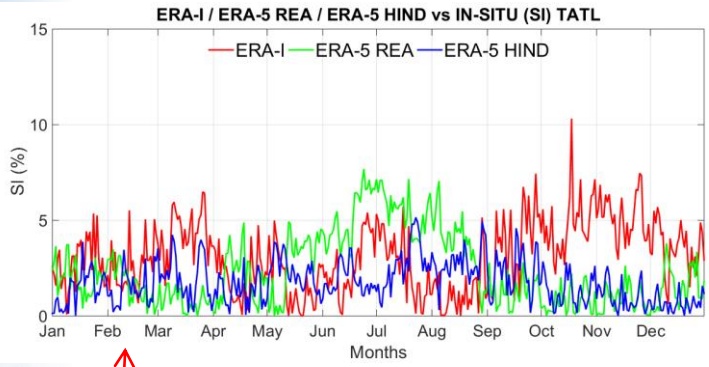
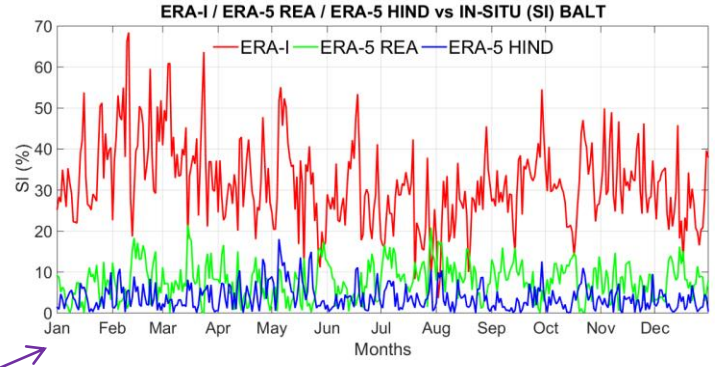
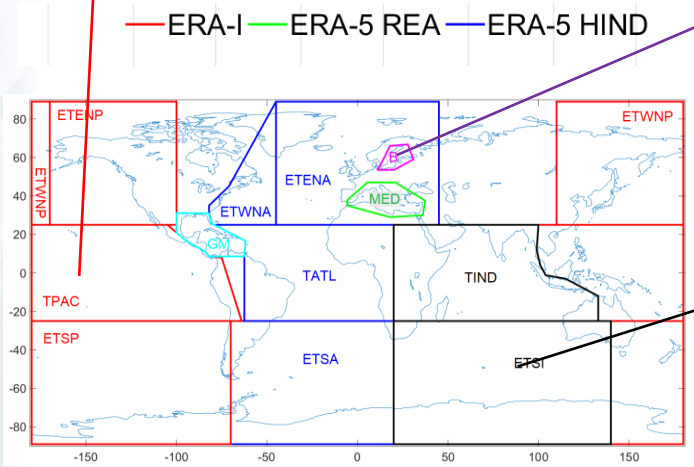
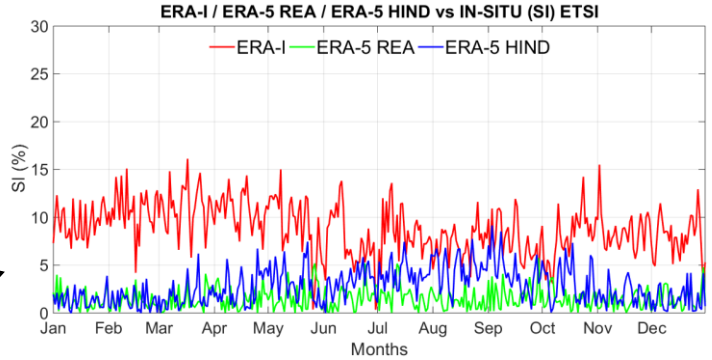
Comparison with buoy data: intra-annual scatter index









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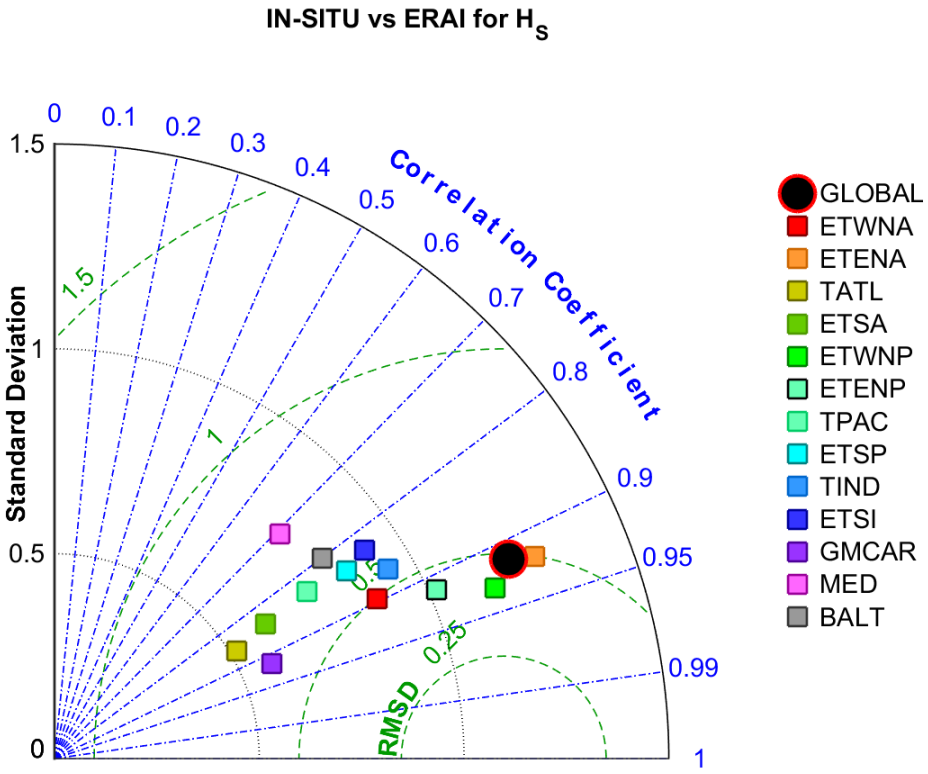
Comparison with buoy data: Taylor diagram



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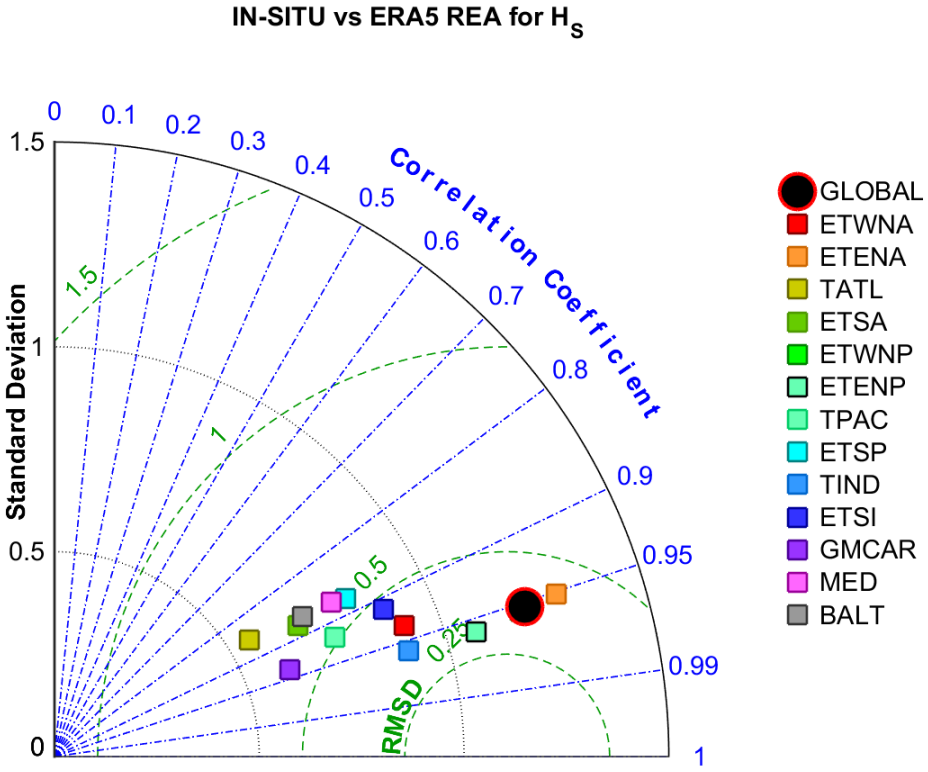
Comparison with buoy data : Taylor diagram



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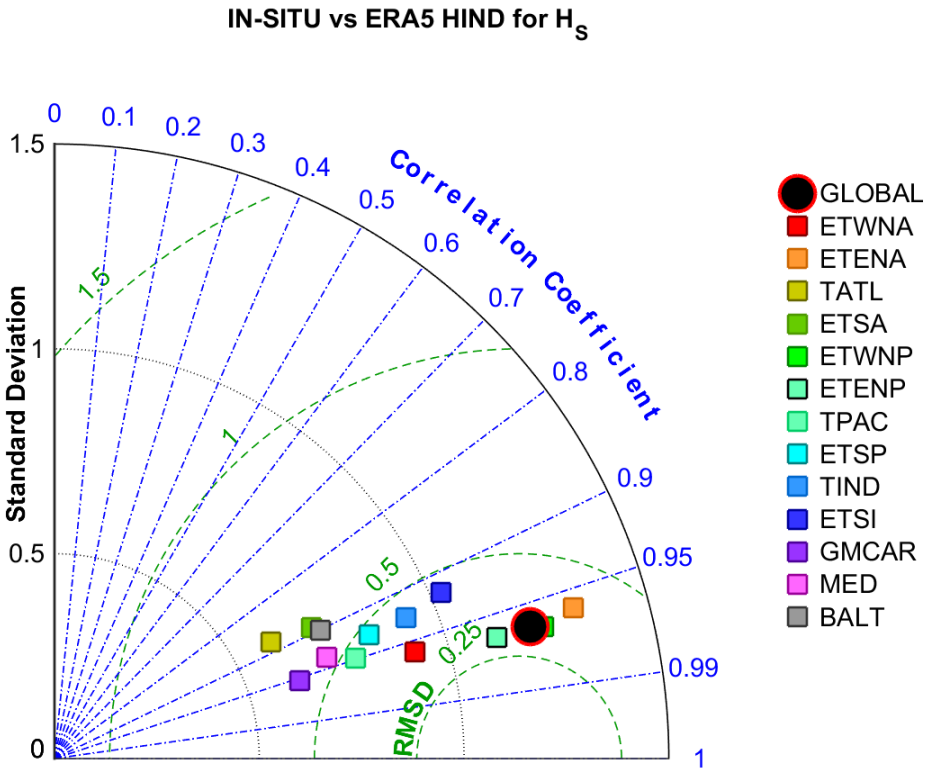
Comparison with buoy data : Taylor diagram



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Comparison with buoy data and ERA-Interim: summary

- U10 agreement with observations has improved for ERA5.
- U10 upper quantiles agreement with observations has improved for ERA5.
- In comparison with ERA-Interim, for U10, the ERA-5 show lower biases along the entire distribution (bias per bin of 1 m/s).
- U10 ERA5 intra-annual variability agreement with observations has improved for the ERA5.
- GLOBAL and regional U10 inter-annual variability (monthly means) has improved for the ERA-5.

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Comparison with buoy data and ERA-Interim: summary

- Significant wave height (Hs) agreement with observations has improved for ERA5 and ERA5 hind, compared to ERA-Interim.
- Hs intra-annual variability (multi-annual daily means) agreement with observations has improved for the ERA-5 and ERA-5h
- Hs inter-annual variability (monthly means) agreement with observations has improved for the ERA-5 and ERA-5h.

- Peak wave period (Tp) agreement with observations has improved in several areas (more in the extratropical areas), and the agreement is better for the ERA-5 than for the ERA-5h, especially in the tropical areas.
- Tp inter-annual variability (monthly means) agreement with observations has improved for both the ERA-5 and ERA-5h, however, the agreement is better for the ERA-5 in most areas

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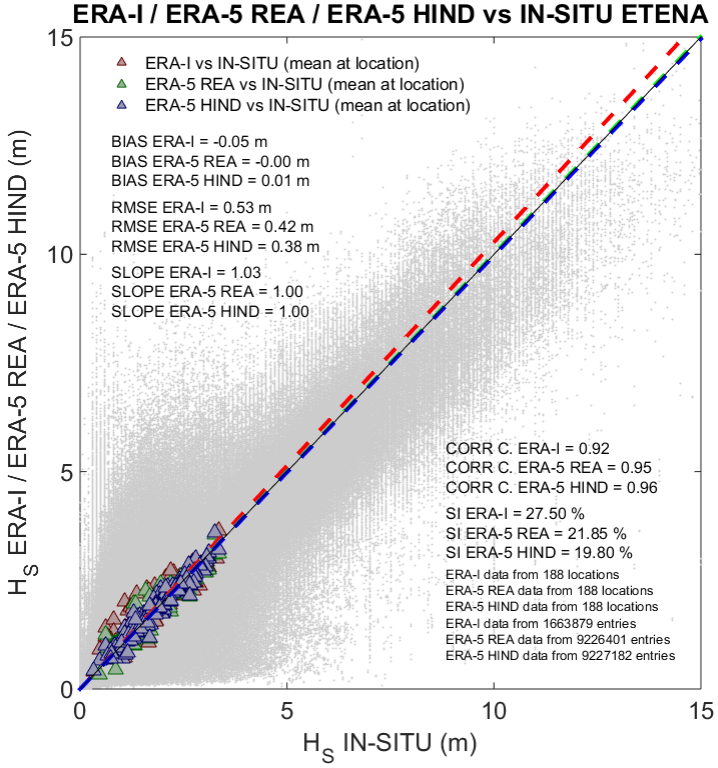
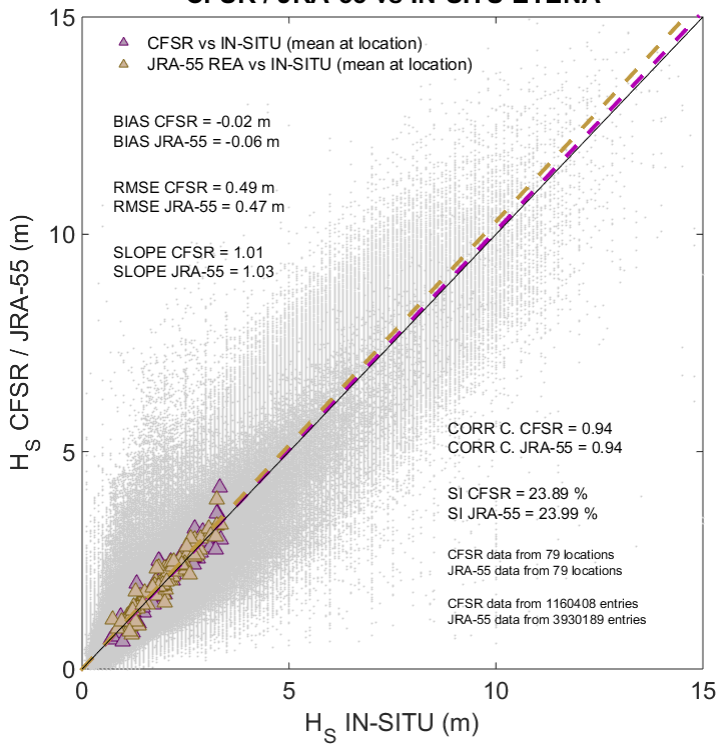
Comparison with buoy data: other reanalyses (ongoing)





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Future work

- Comparison with altimeter data: started
- Paper
- Make the ERA5 hindcast data available.

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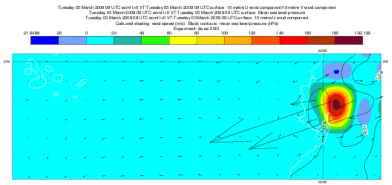
Some known issues:

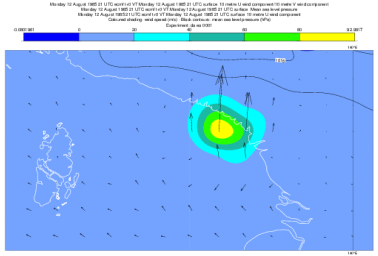
https://confluence.ecmwf.int/display/CKB/ERA5+data+documentation#ERA5datadocumentation-Knownissues

- Analysis low level winds (u or v atm. variables) too large (very localised effect) for few dates every year (see link above).

U10 > 120 m/s !



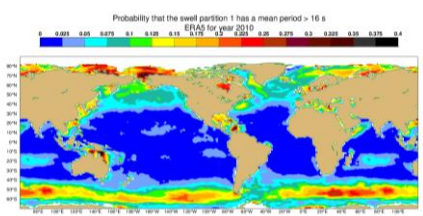
U10 > 80 m/s !



- Analysis surface instantaneous stresses tends to be too low.

- ERA5 swell partitions parameters are erroneous (bug in the partitioning scheme). ERA5 hindcast is OK.

Probability that swell1 partition has mean period > 16 s



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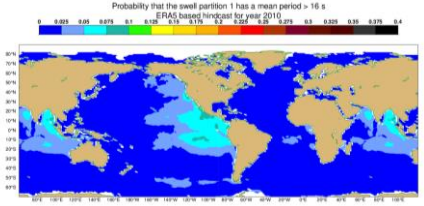

ERA5 hindcast

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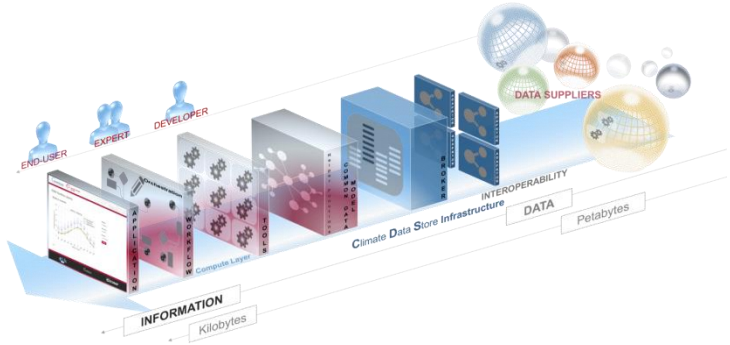
Summary and Final remarks

As part of the Copernicus Climate Service, at ECMWF, the production of ERA5 is well underway:

- 31km global resolution, from 1950, hourly output, uncertainty estimate.
- To date ERA5 1979-2016 is publicly available
- Data access via the **Climate Data Store** .
- C3S User service Desk, Knowledge Base, FAQ's, user support



https://cds.climate.copernicus.eu/#!/home

The performance of ERA5 is very promising in the troposphere.

- Winds and Ocean waves
- improved global hydrological and mass balance
- reduced biases in precipitation,
- refinement of the variability and trends of surface air temperature.

ERA5 is freely available and a timely product will be available one week behind real time

Quarterly Journal of the Royal Meteorological Society
A journal of the atmospheric sciences and physical oceanography
RMetS

In review

The ERA5 Global Reanalysis

Journal:	QJRMS
Manuscript ID	QJ-19-0273
Wiley - Manuscript type:	Research Article
Date Submitted by the Author:	03-Sep-2019

ECMWF Copernicus Europe's eyes on Earth European Commission

Climate Change

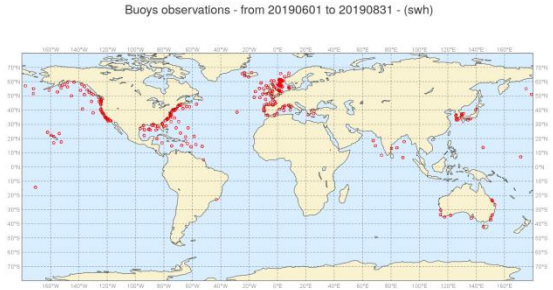
WMO Lead Centre for Wave Forecast Verification LC-WFV

https://confluence.ecmwf.int/display/WLW/WMO+Lead+Centre+for+Wave+Forecast+Verification+LC-WFV

ECMWF has been designated as the Lead Centre for Wave Forecast Verification (LC-WFV) by the World Meteorological Organisation (WMO) Commission for Basic Systems (CBS-2016)

Acronym	Centre	Country
BoM	Bureau of Meteorology	Australia
DMI	Danmarks Meteorologiske Institut	Denmark
DWD	Deutscher Wetterdienst	Germany
ECCC	Environment and Climate Change Canada	Canada
ECMWF	European Centre for Medium-Range Weather Forecasts	Europe
FNMOC *	Fleet Numerical Meteorology and Oceanography Center	USA
JMA	Japan Meteorological Agency	Japan
KMA	Korea Meteorological Administration	Korea
LOPS *	Laboratoire D'Océanographie Physique et Spatiale	France
METEOAM	Servizio Meteorologico dell'Aeronautica Militare	Italy
METNO *	Norwegian Meteorological Institute	Norway
METFR	Météo-France	France
NCEP	National Centers for Environmental Prediction	USA
NIWA	National Institute of Water & Atmospheric Research	New Zealand
NZMS *	New Zealand MetService	New Zealand
PRTOS	Puertos del Estado	Spain
SHNSM	Department of Meteorology of the Naval Hydrographic Service	Argentina
UKMO	UK Met Office	UK

Contributing Centres. As of October 2019, 14 wave forecast centres regularly provide model fields to the Lead Centre. Data from another four centres, marked by an asterisk, are in preparation.



https://www.ecmwf.int/en/newsletter/161/news/wmo-lead-centre-wave-forecast-verification-established-ecmwf

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