Ocean Wave Analysis and use of surface wind observations over the oceans

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ECMWF

Outline :

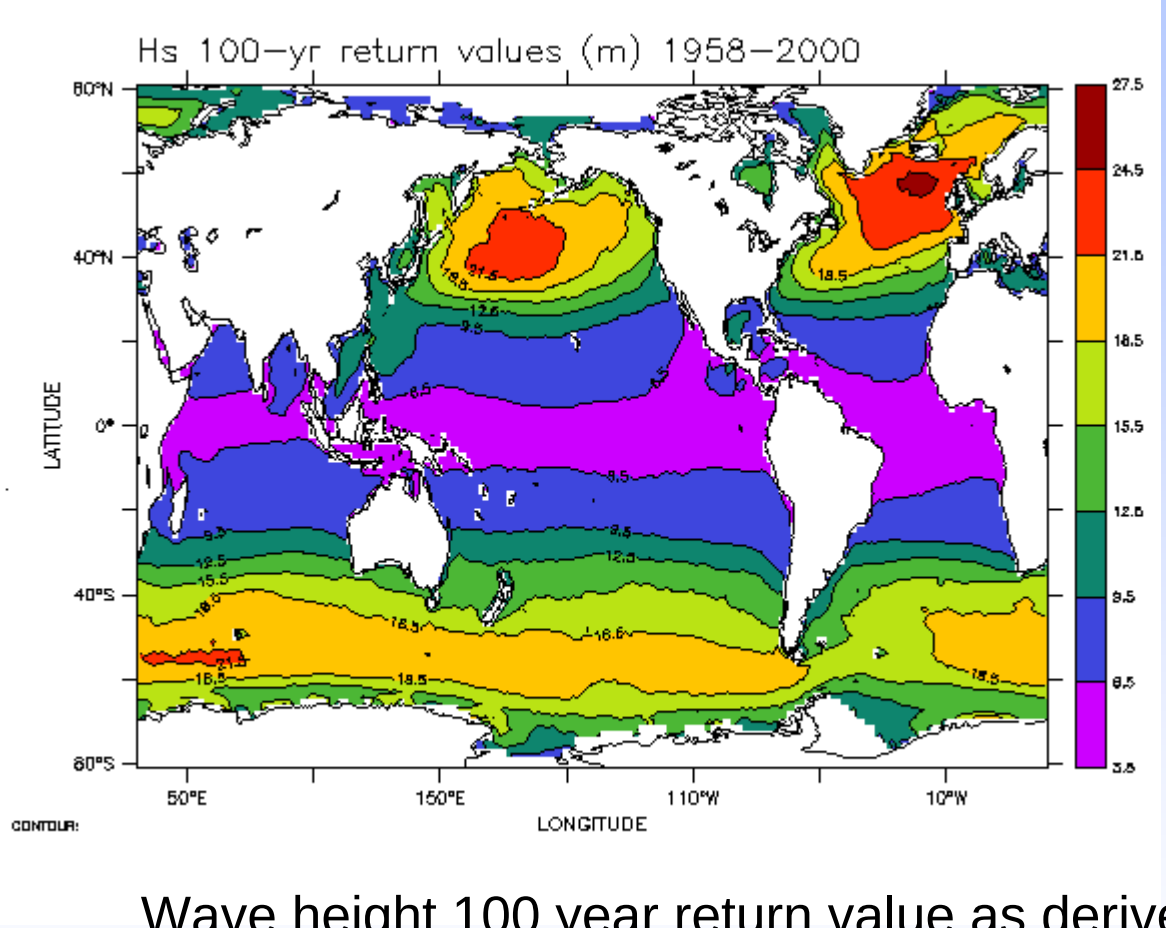
- **Background.**
- **Wave data available for reanalysis.**
- **Wave data analysis at ECMWF.**
- **ERA-40 wave data problem.**
- **Wave model for the interim reanalysis.**
- **Wave data for the interim reanalysis.**

- **A few comments on in-situ surface wind.**

Background :

- **ECMWF has been running operational wave models since June 1992.**
- **Two-way coupling between the wave model and the atmospheric model was introduced in June 1998 with benefits for both wave model (*via high temporal wind field resolution*) and atmospheric model (*via wave dependent surface roughness*).**
- **More than just winds are now exchanged between the two models and more wave dependent processes could be added (i.e. sea-state dependent satellite retrievals, wave-current interactions).**
- **Reanalysis wave data and wind data have many applications, quite often in coastal areas, hence the need for an increase in horizontal resolution.**

Reanalysis wave data :



Wave height 100 year return value as derived from ERA-40 as available in the KNMI wave and wind atlas: http://www.knmi.nl/waveatlas

Reanalysis wave data :

Tabular wave height and mean period bivariate histogram for an area west of Ireland as derived from ERA-40: http://www.knmi.nl/waveatlas

Lon: 342-351

Lat: 54N-45N

Dir: 0.- 45.

Total of: 67718. observations, 4.%

Tm \ Hs	0.- 1.	1.- 2.	2.- 3.	3.- 4.	4.- 5.	5.- 6.	6.- 7.	7.- 8.	8.- 9.	9.- 10.	10.- 11.	11.- 12.	12.- 13.	13.- 14.	14.- 33.	sum
0.- 3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.- 4.	2.	15.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	17.
4.- 5.	24.	883.	122.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1029.
5.- 6.	36.	1016.	1625.	172.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	2849.
6.- 7.	3.	647.	1013.	960.	242.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	2868.
7.- 8.	0.	259.	697.	432.	379.	166.	13.	0.	0.	0.	0.	0.	0.	0.	0.	1946.
8.- 9.	0.	43.	355.	223.	92.	92.	74.	21.	1.	0.	0.	0.	0.	0.	0.	901.
9.- 10.	0.	1.	69.	148.	38.	19.	12.	18.	12.	2.	0.	0.	0.	0.	0.	319.
10.- 11.	0.	0.	1.	16.	27.	14.	3.	1.	1.	2.	1.	0.	0.	0.	0.	67.
11.- 12.	0.	0.	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.
12.- 13.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13.- 33.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
sum	65.	2864.	3882.	1952.	779.	296.	102.	41.	14.	3.	1.	0.	0.	0.	0.	10000.

ECMWF

Wave data for reanalysis : from satellites

- **Radar altimeter wave height observations:**

  - **Seasat (1978), Geosat (1985-1986), ERS-1* (1991-1996), Topex (1992-2002),**

  - **ERS-2* (1995-), GFO (2000-), Jason* (2002-), ENVISAT* (2002-)**

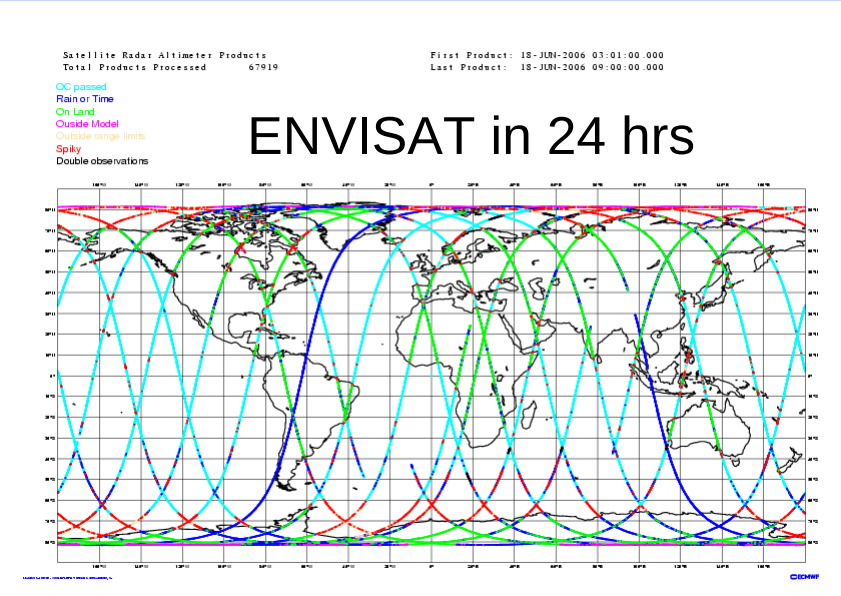
  Note: ***the wave model predicts the evolution of the wave spectrum. Wave height is connected to the total energy, which is proportional to the integral of the wave spectrum. Hence some assumptions are required to go from analysed wave height to analysed spectrum.***

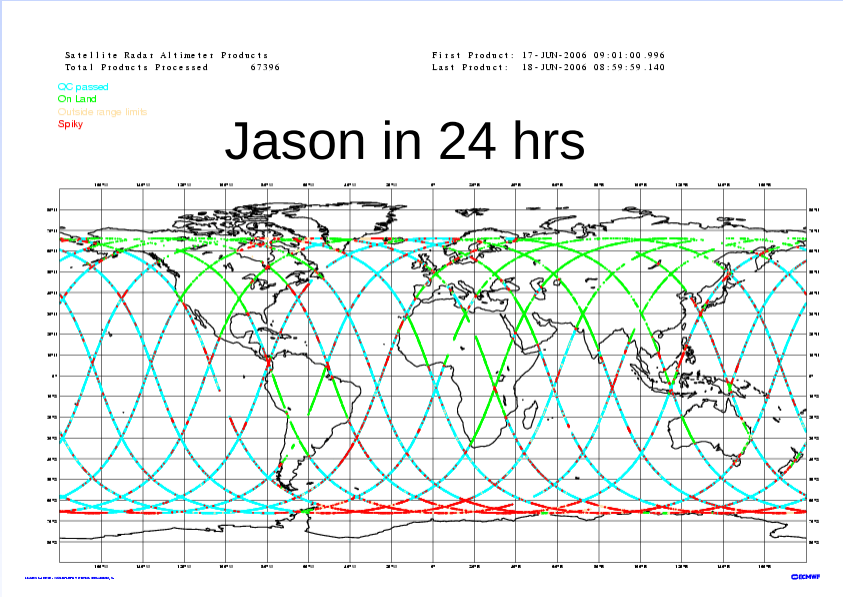
* Currently available in the ECMWF archives

Wave data for reanalysis : from satellites

Note: radar altimeter are nadir looking instrument, with a very narrow swath.

Their global coverage is therefore limited.





Wave data for reanalysis : from satellites

- **SAR/ASAR ocean mode data:**
  - **ERS-1* and 2* SAR**
  - **ENVISAT* ASAR**

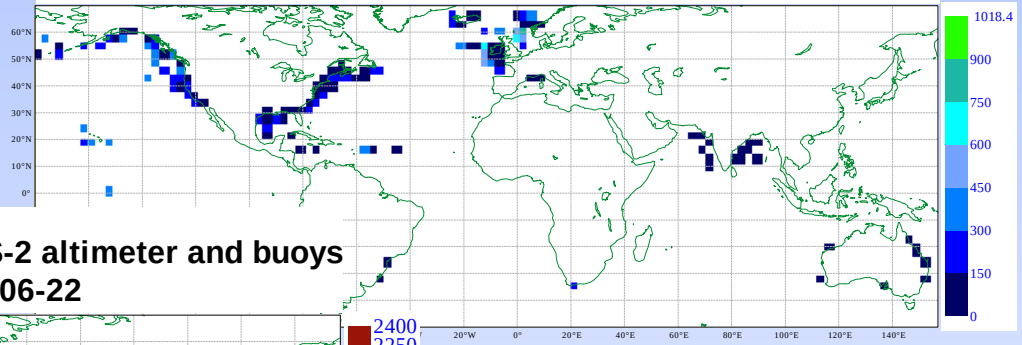
  Note: *SAR does not unfortunately observe the full two-dimensional wave spectrum. In practice SAR wave spectra are retrieved using a model first guess. For these reasons, the impact of SAR assimilation is much reduced than originally hoped.*

* Currently available in the ECMWF archives

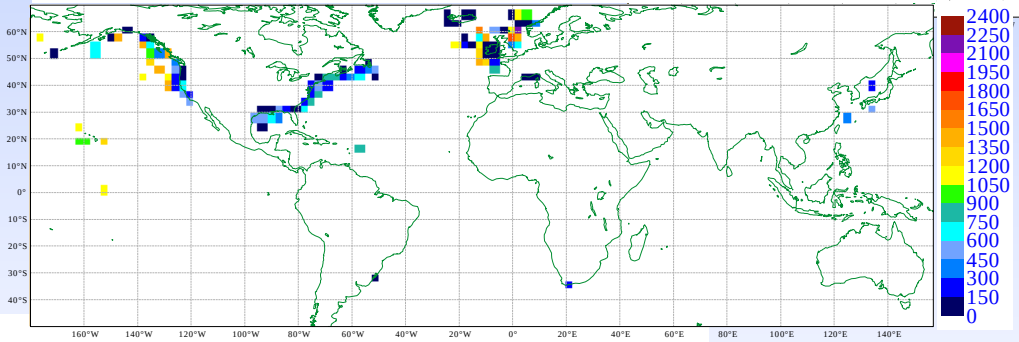
Wave data for reanalysis verification: in-situ

Buoy reporting wave observations have a relatively limited geographical coverage.
They are used for verification only.

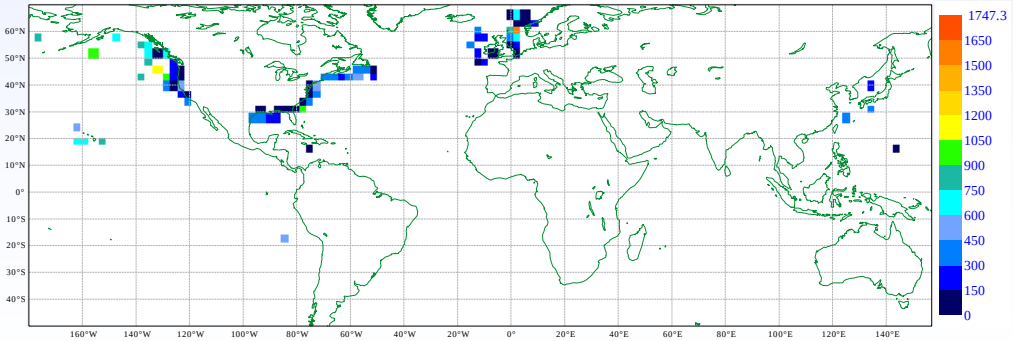
Number of collocations between ENVISAT altimeter and buoys
2003-07-21 to 2006-05-13

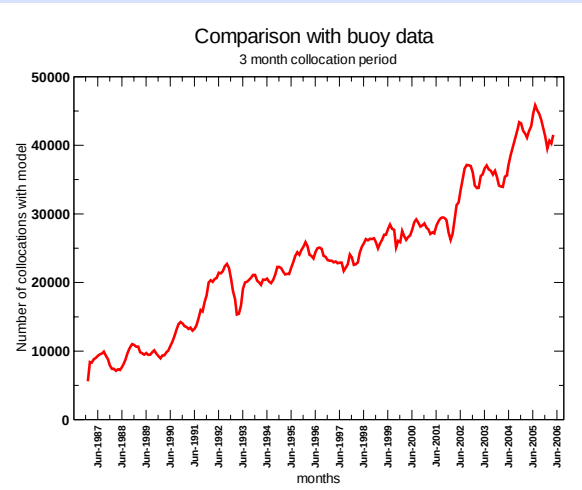


Number of collocations between ERS-2 altimeter and buoys
1996-06-03 to 2003-06-22



Number of collocations between ERS-1 altimeter and buoys
1991-08-01 to 1996-06-03





1987 **2006**

The number of wave buoys available on the GTS has steadily increased over the years.

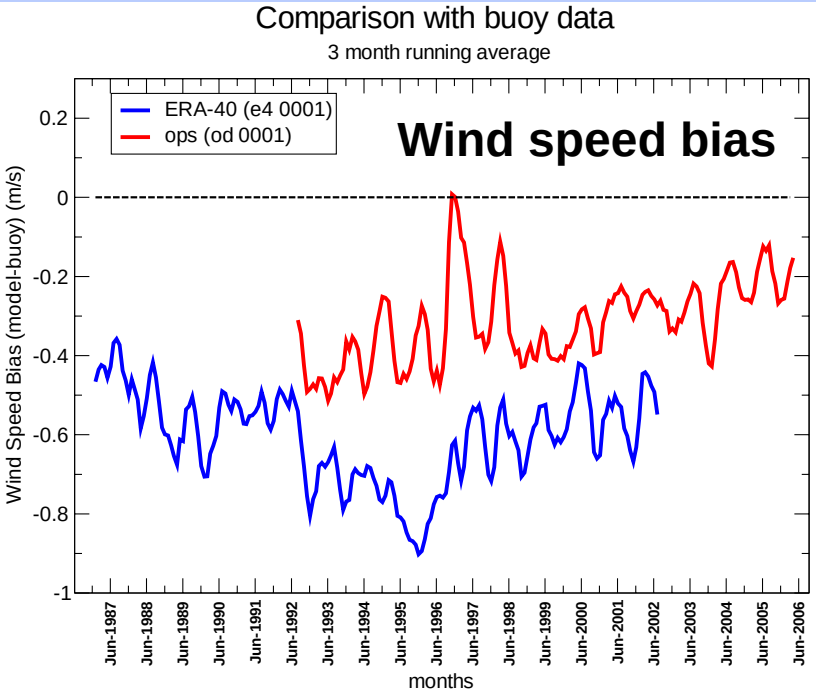
Wave data analysis:

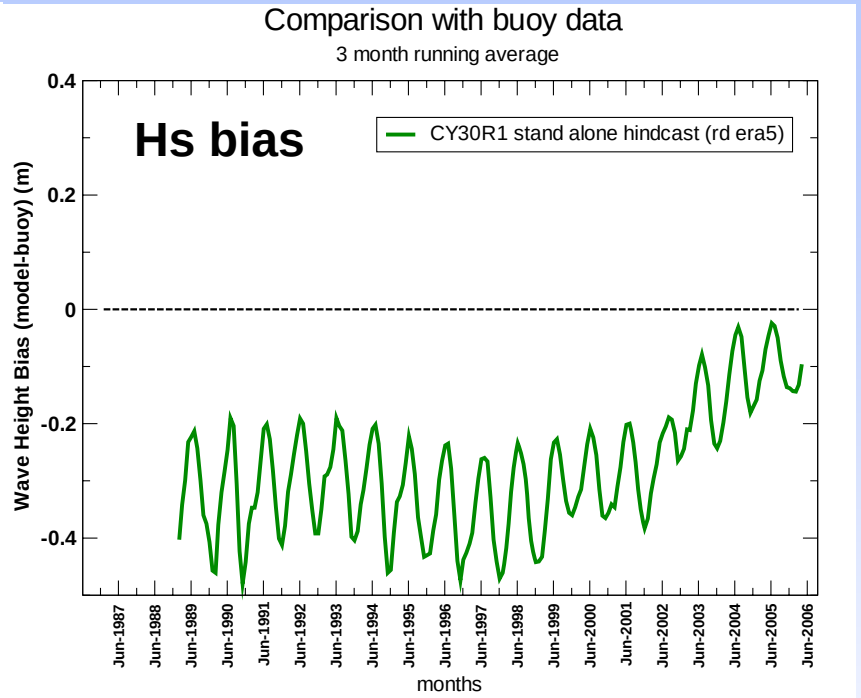
- **The wave model data analysis is based on an optimal interpolation scheme for wave height as originally developed by Lionello et al. 1992.**
- **The scheme was extended to assimilate wave systems as derived from SAR wave spectra.**
- **It is not yet directly coupled to the atmospheric scheme.**

ERA-40 :

- **1.5ºx1.5º wave model coupled to T159 atmospheric model.**
- **Only deep water physics.**
- **Wave spectra discretised with 12 directions and 25 frequencies.**
- **Near-real time operationally obtained ERS-1 (1991-1996) and ERS-2 (1996-2002) altimeter data were used.**
- **An extensive comparison with buoy data and Topex altimeter data was carried by a KNMI team** http://www.knmi.nl/waveatlas

Too low wind in ERA-40 :

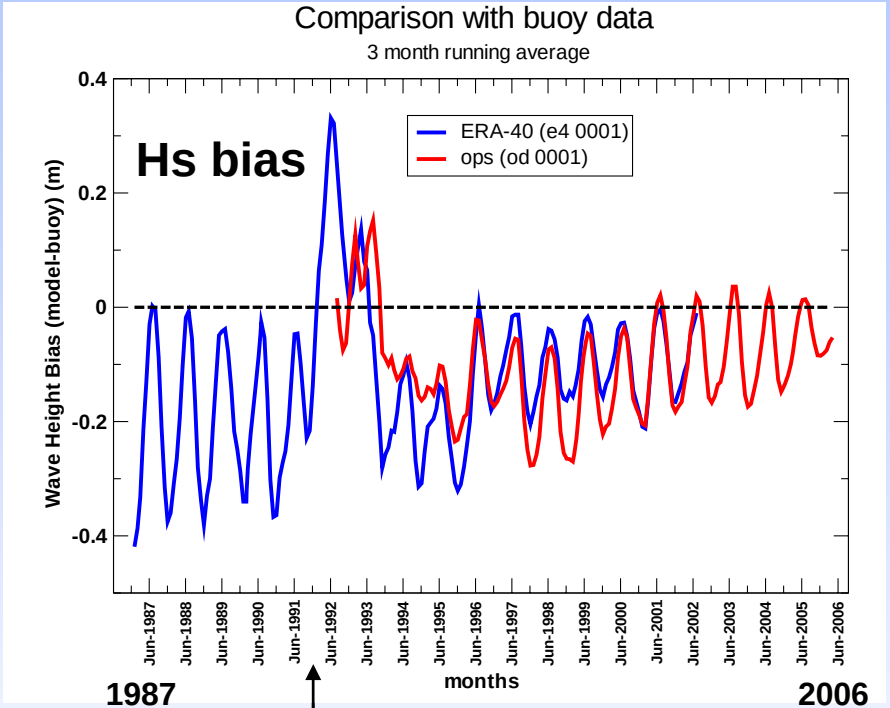


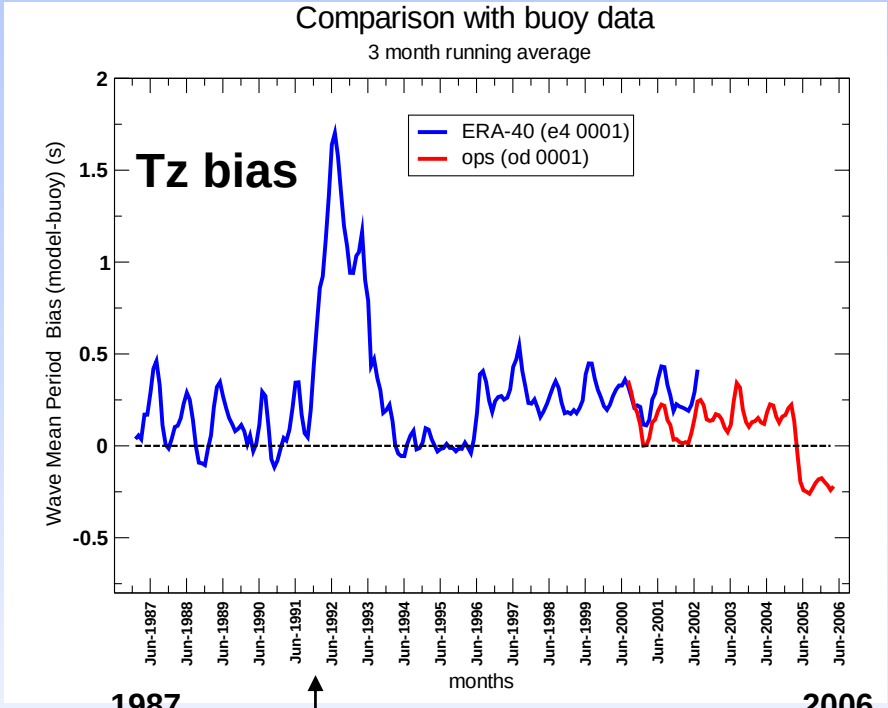


1987 **2006** **1987** **2006**

Results from a wave model hindcast run (uncoupled, no data assimilation), with the latest operational model version (CY30R1), forced by ERA-40 winds until August 2002, then operational analysis winds.

Problem with wave data in ERA-40 :



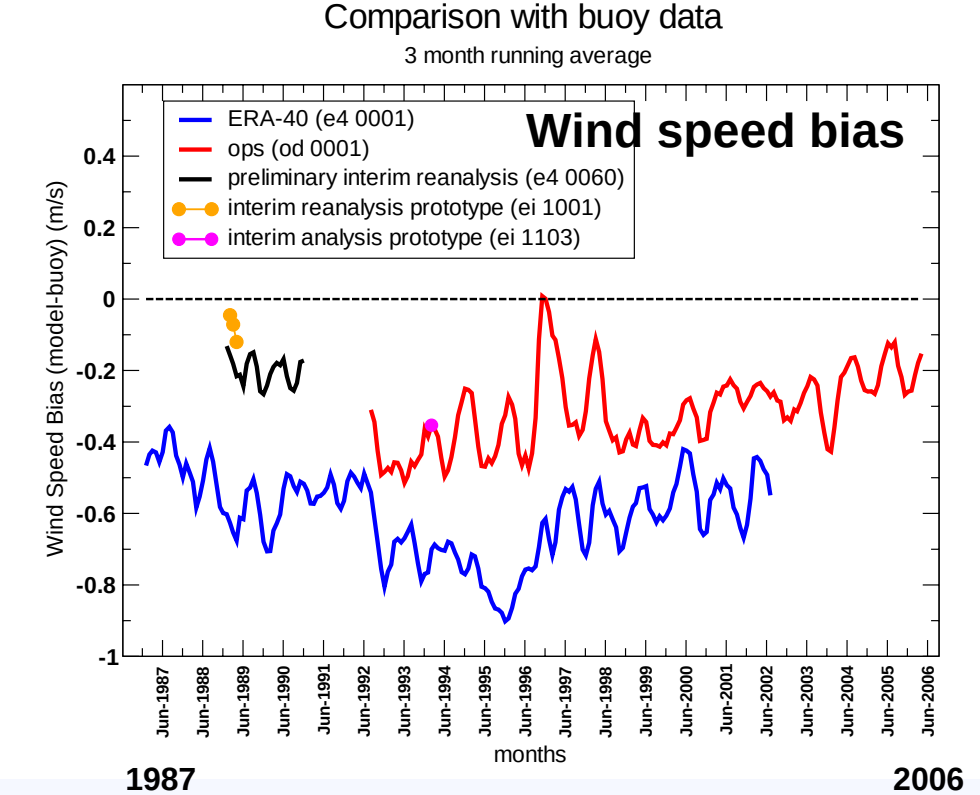


Between Dec. 1991 and May 1993 low quality ERS-1 altimeter data were wrongly assimilated.

Between Dec. 1991 and May 1993 low quality ERS-1 altimeter data were wrongly assimilated.

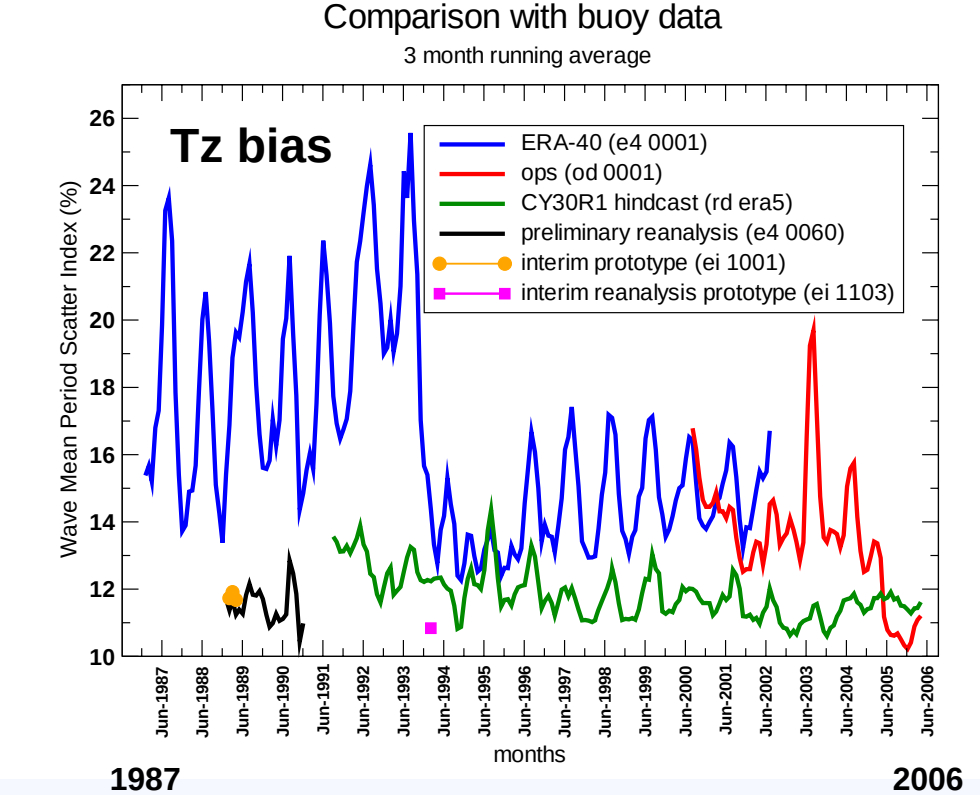
Note: this problem was originally spotted by KNMI. This emphasises the need for ‘in-house’ monitoring tools.

Better surface winds for the interim reanalysis :



- T159 → T255 better (ideally more)
- Benefit from using 4dvar.
- Improved atmospheric model physics.
- The latest physics changes (CY31R1) should be even better.

Improved wave model for the interim analysis :



- 1.5º → 1.0º
- 24 directions and 30 freq.
- Shallow water physics.
- Improved wave model.
  - -Unresolved bathymetry scheme.
  - -New dissipation source term.
  - -…

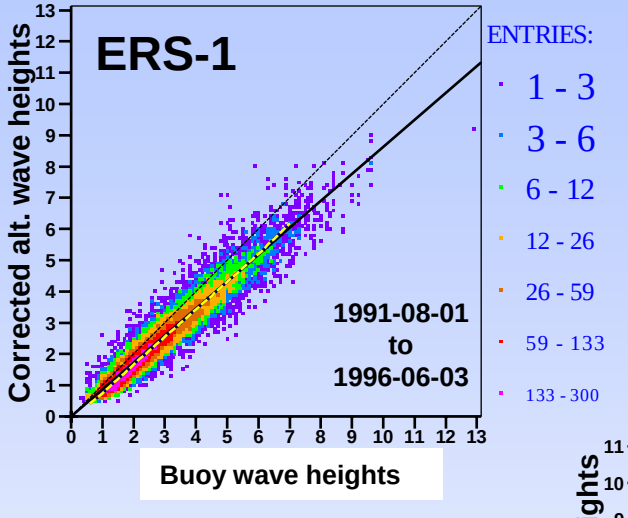
Wave data for the interim reanalysis :

- **Because of the inhomogeneity of the ERS-1 and also some other known problems with the NRT ERS data, we have obtained OPR ERS-1 and 2 data from ESA.**
- **Some works was necessary to convert the data from CD's into data in a format more compatible with ECMWF system (i.e BUFR)!**
- **NRT ENVISAT altimeter data are already of good quality. Note that some orbits are missing, especially in early days of the mission due to NRT transmission problems. Access to off-lin data could prove useful.**
- **NRT Jason altimeter data are also available.**
- **SAR data from ERS-2 and ASAR data from ENVISAT will also be used.**

Wave data for the interim reanalysis :

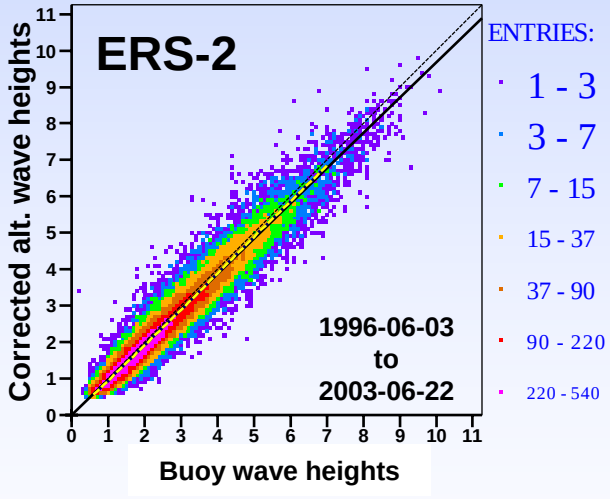
- **Because the OPR ERS-1 and 2 have never been used by our data assimilation system, we have run passively the altimeter data through a long wave model hindcast with the latest operational wave model version (CY30R1) using ERA-40 and operational winds.**
- **A comprehensive buoy data set was generated by merging NDBC (US) and MEDS (Canada) data sets with GTS data from the ECMWF archives.**
- **This comprehensive buoy data set was collocated with the altimeter data and the model counterparts.**
- **Triple collocation techniques can be used to infer relative biases and error estimates for each data set.**

Wave data for the interim reanalysis :

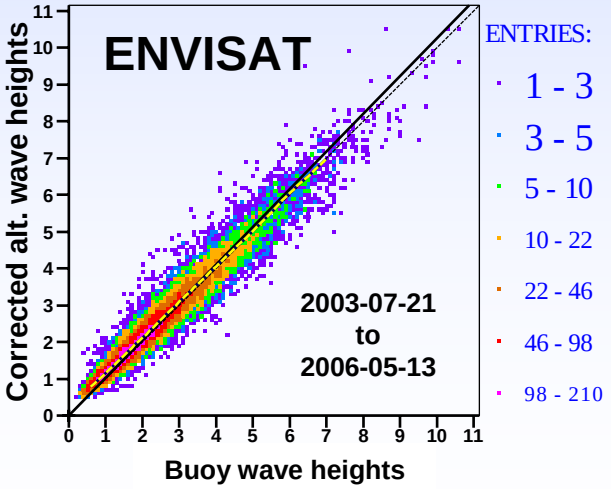


ERS-1 OPR wave heights are still biased low when compared to buoys

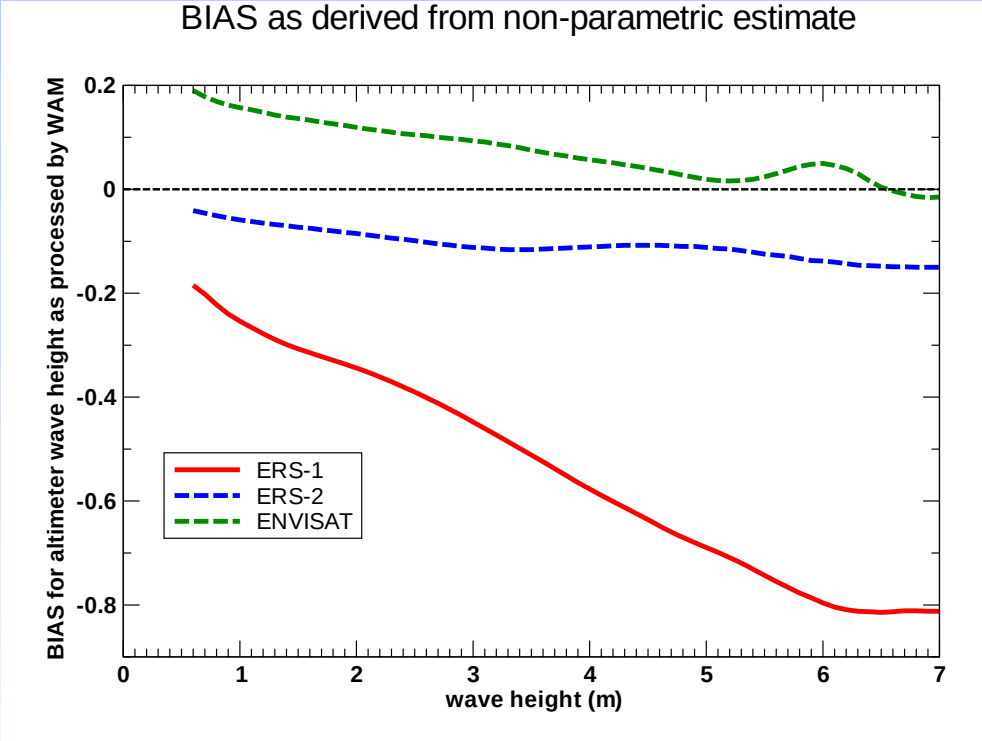
ERS-2 OPR wave heights are slightly biased low when compared to buoys



ENVISAT wave heights are slightly biased high when compared to buoys

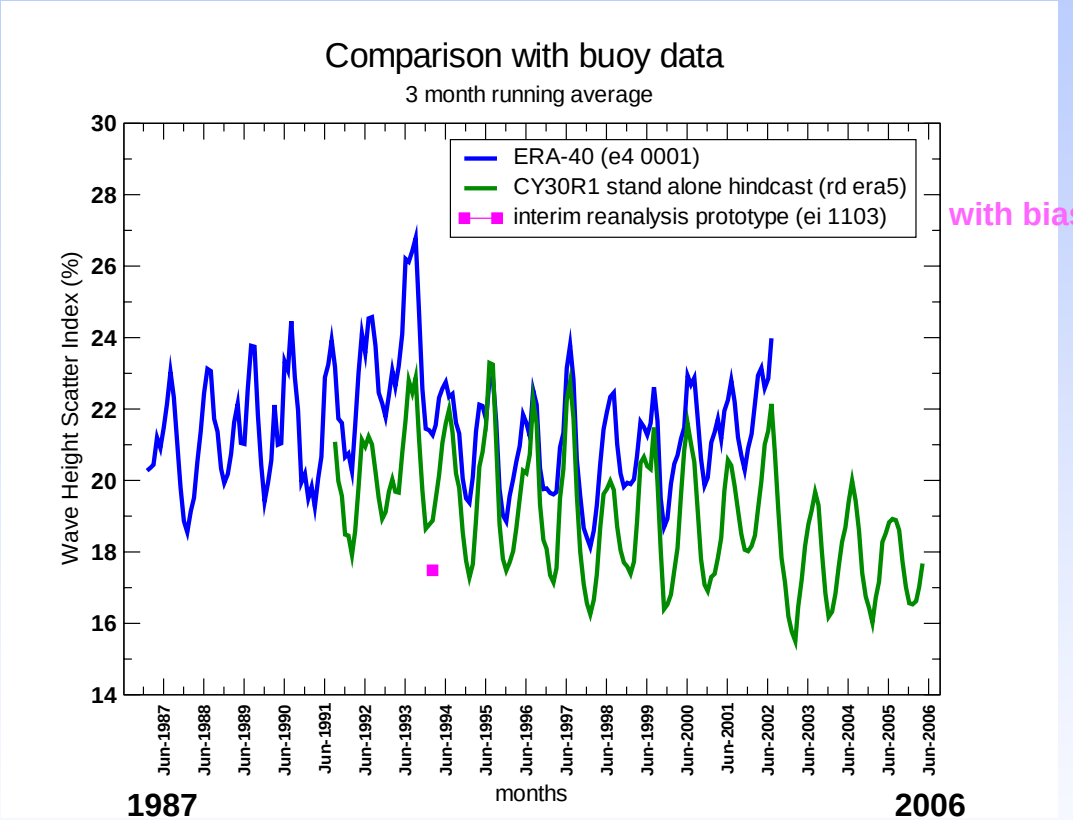


Wave data for the interim reanalysis :



- **Using a non-parametric bias estimation technique, we have determined the relative bias with respect to the buoys (work still under way).**
- **Initial results are quite satisfactory. More test will follow.**

Wave data for interim reanalysis :



with bias corrected ERS-1 data

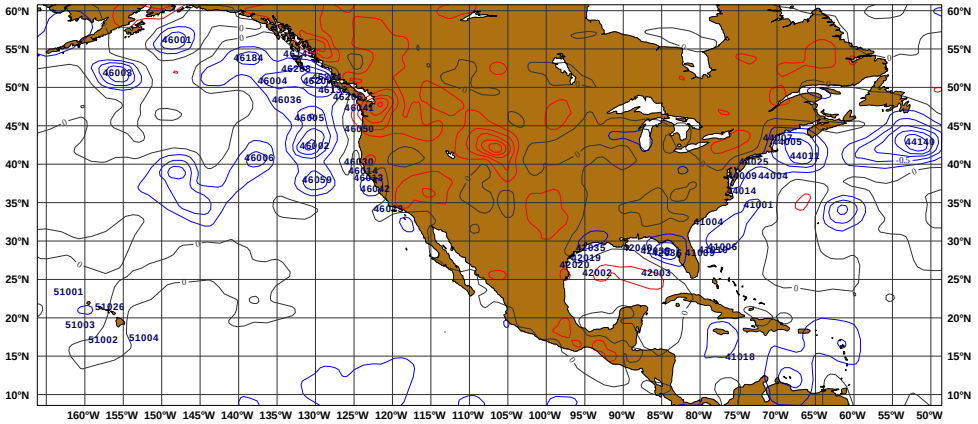
In-situ surface wind data over the ocean :

- **The quality of any wave reanalysis is largely determined by the quality of the wind fields used to force the model.**

- **More emphasis should be put on making a better use of wind observations over the oceans.**

In-situ surface wind data over the ocean :

Mean analysed minus forecast 10m wind speed for expver:18
from 19960201 to 19960229



Mean analysed minus forecast 10m wind speed for expver:18
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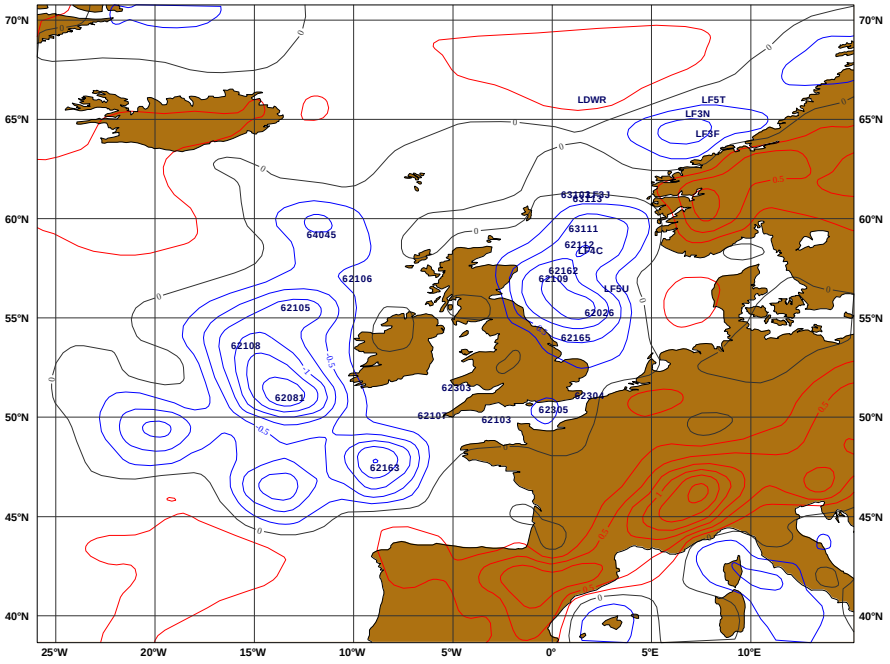
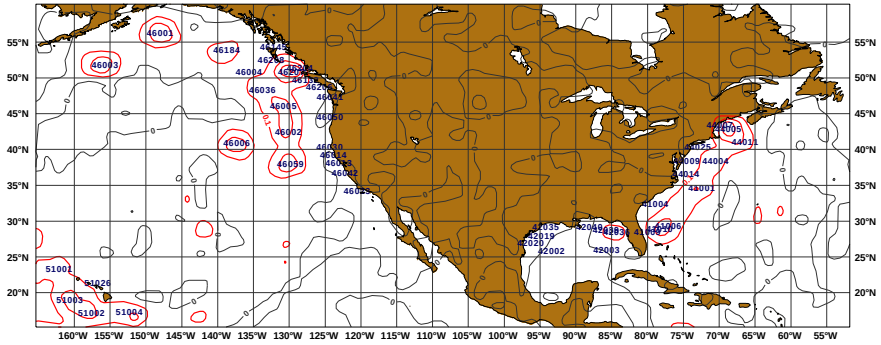


During the ERA-40 production, the following mean analysis increments in surface winds were found.
For a large part, they collocated with locations where meteorological buoys were deployed !

NB: maps of mean analysis increments are powerful tools

In-situ surface wind data over the ocean :

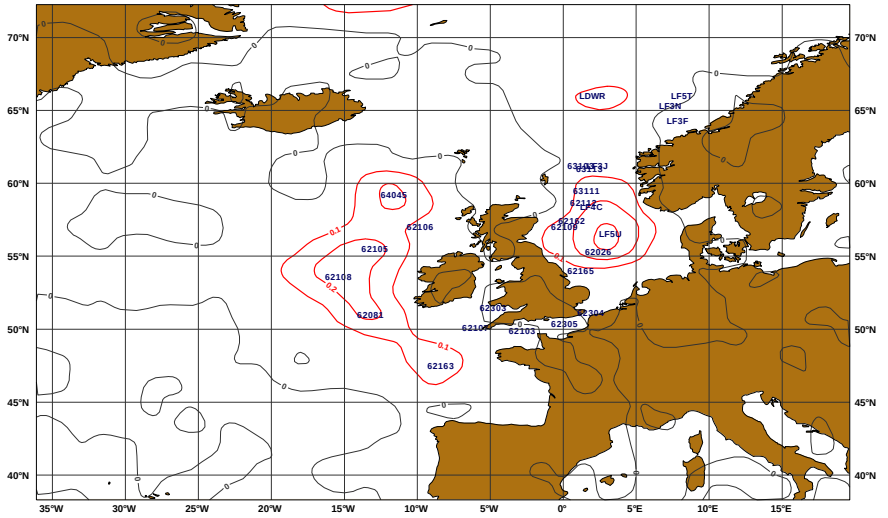
Mean analysis difference in 10m wind speed: 314 - 315
from 19960201 to 19960228



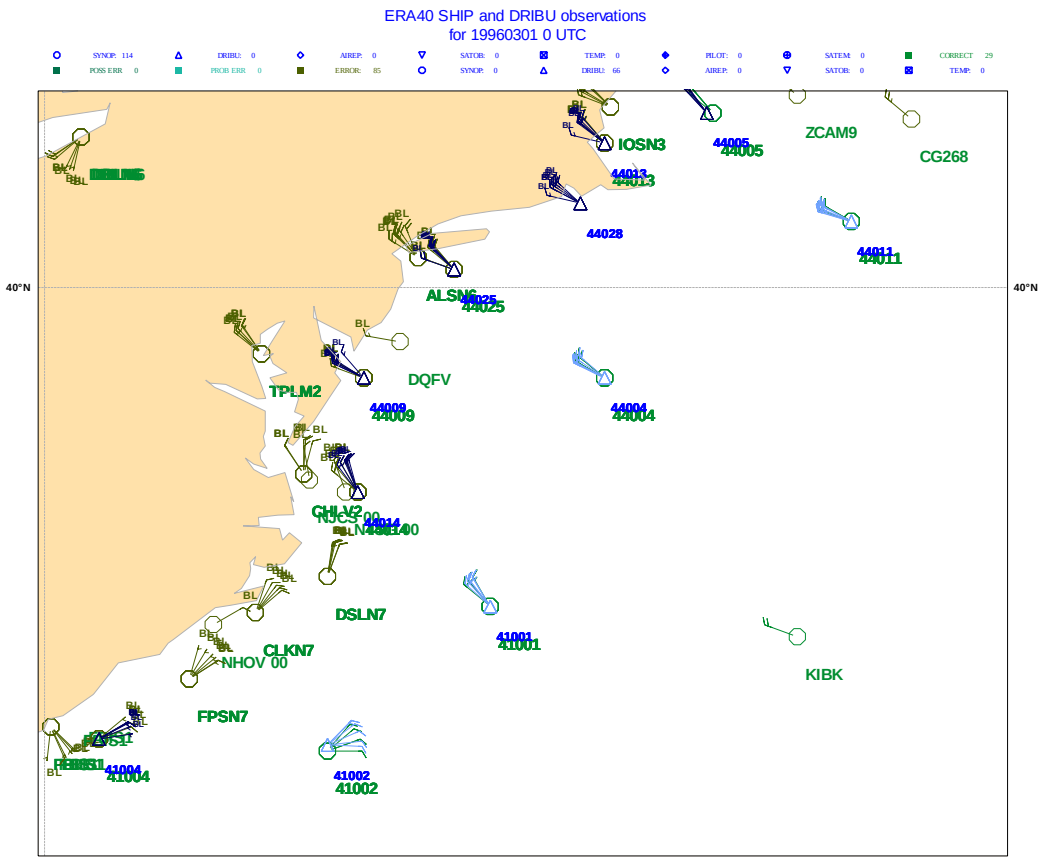
Most buoys observes winds at height ~4-5 m. By default the analysis assumes a height of 10m (25m for ships).
Once corrected, the expected impact was visible (ERA-40 was modified ~1997).
Is it the end of it ?

Further analysis, indicated that the scheme used to provide the data analysis with the actual height of the anemometer did not work !

Mean analysis difference in 10m wind speed: 314 - 315
from 19960201 to 19960228



In-situ surface wind data over the ocean :



It was not realised then that some buoy data are available both as SHIP and DRIBU, because of the blend of ECMWF (SHIP) and NCEP (DRIBU) data sets.

The anemometer height scheme only worked on SHIP data !

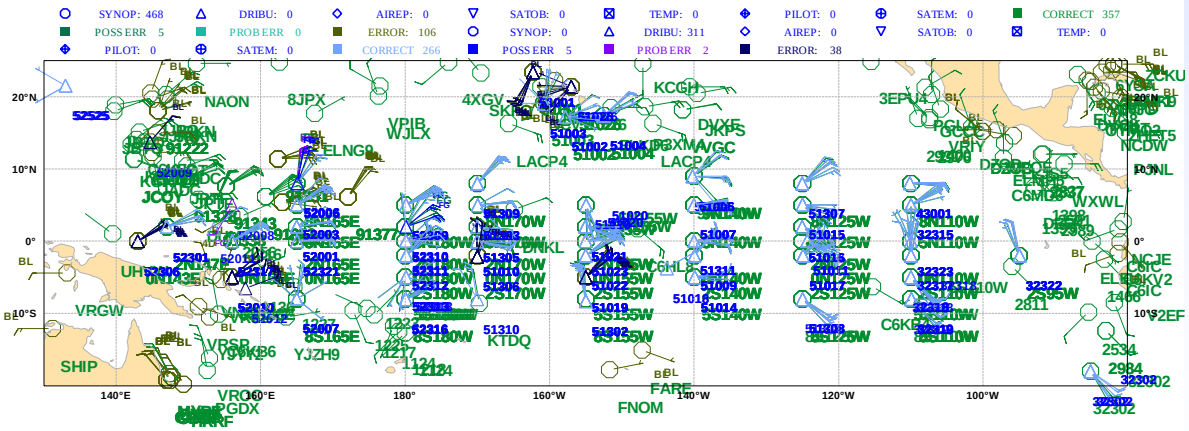
It now works for DRIBU data as well (since end of August 2005 in operations) and in the interim reruns (finally)!

In-situ surface wind data over the ocean :

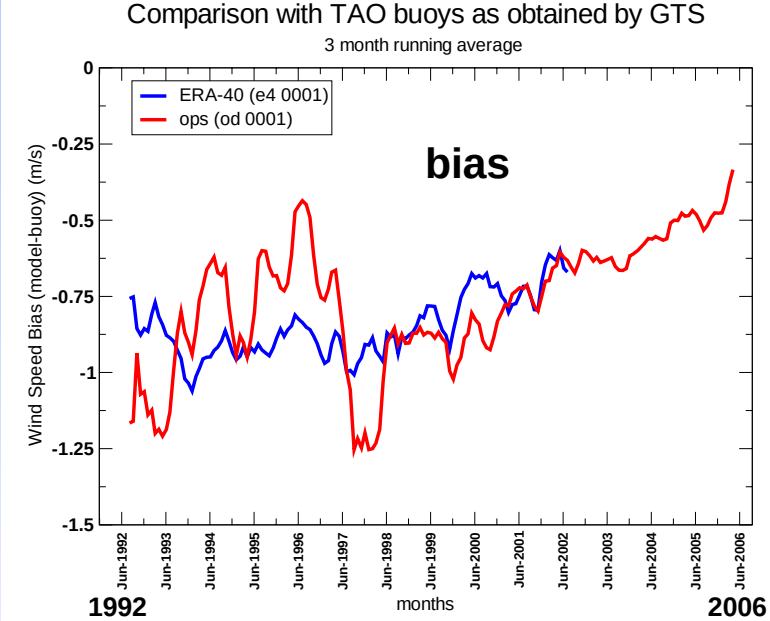
The anemometer height scheme relies on a list connecting the station identifier (buoys, ship and platforms) with the height of the anemometer. It has been built by gathering information from different sources. It will requires more effort for older data sets.

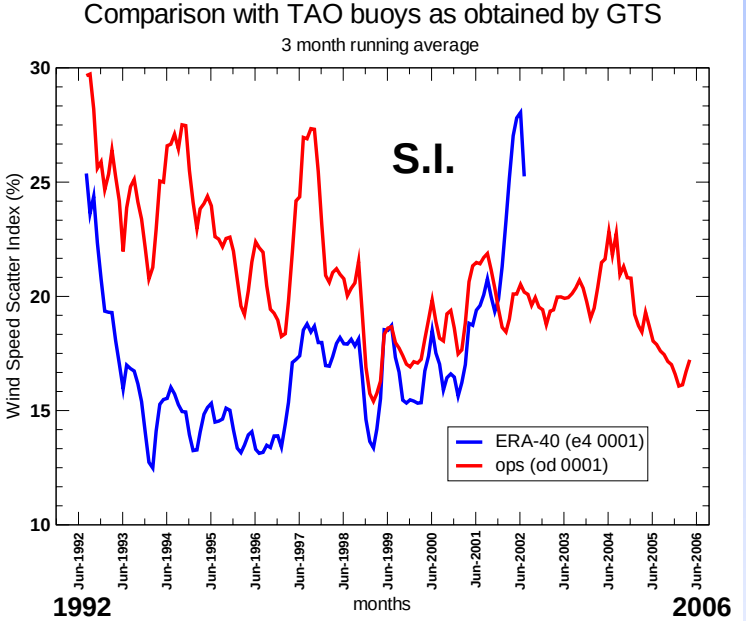
e.g. earlier TAO data both appear as SHIP and DRBU but with different station identifier:
e.g.
51014 <=> 5S140W

ERA40 SHIP and DRIBU observations for 19940301 18 UTC

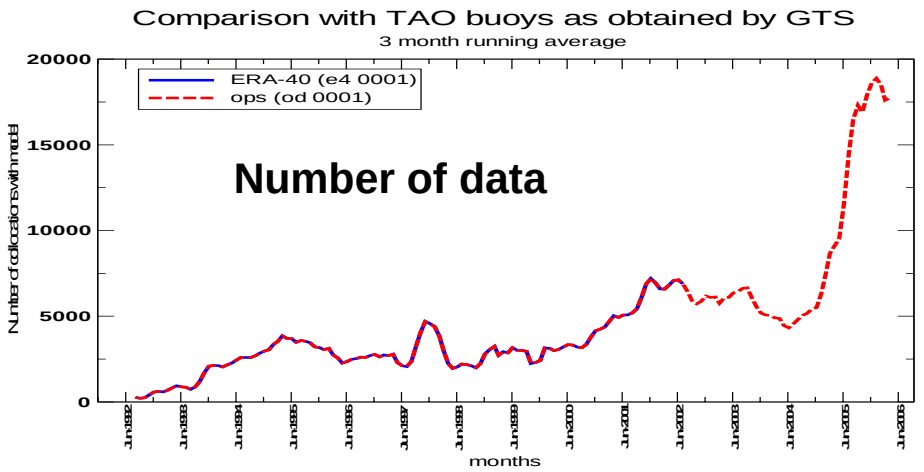


In-situ surface wind data over the ocean :





Limited past GTS dissimination of certain data should be complemented by off-line data as they are very useful data.
e.g. TAO data for more recent years before the upgrade in earlier 2005.



In-situ surface wind data over the ocean :

- **There is a need to sort out in-situ observations over the oceans to avoid unnecessary duplications.**
- **It is unfortunate that potentially very valuable data from moored buoys are mixed with other type of data of the same nature (e.g. with ship and fixed platforms (SHIP) or with drifting buoys (DRIBU)). This is reflected by the relatively large error assigned to these data. A separate data type should be created (moored buoys) and bit of data mining should take place to bring the data to ECMWF.**

Conclusions :

- **Wind and waves should be better analysed in the interim analysis following improvements in both atmospheric and wave models.**
- **A more consistent altimeter wave height data base has been created with the acquisition of OPR ERS data and the homogenization of the data following bias estimation from a triple collocated data set.**
- **A bit more work (coordination) on a surface wind data base could be beneficial to any future reanalysis.**