

# The ERA-40 wind and wave data

**Andreas Sterl and Sofia Caires**

KNMI, De Bilt, Netherlands

- What is ERA-40?
- The quality of the ERA-40 waves
- The 100 year return wave height
- Statistical correction of wave heights
- The KNMI/ERA-40 Wave Atlas

....

# ERA-40 = ECMWF 40 year reanalysis

**E** uropean **40**: length of reanalysis  
**C** entre for  
**M** edium Range  
**W** eather  
**F** orecasts

Produces twice daily a 10-day weather forecast for the member states

# How to Make a Weather Forecast?

forecast = initial value problem

or

today's weather,

tomorrow's one

know

calculate

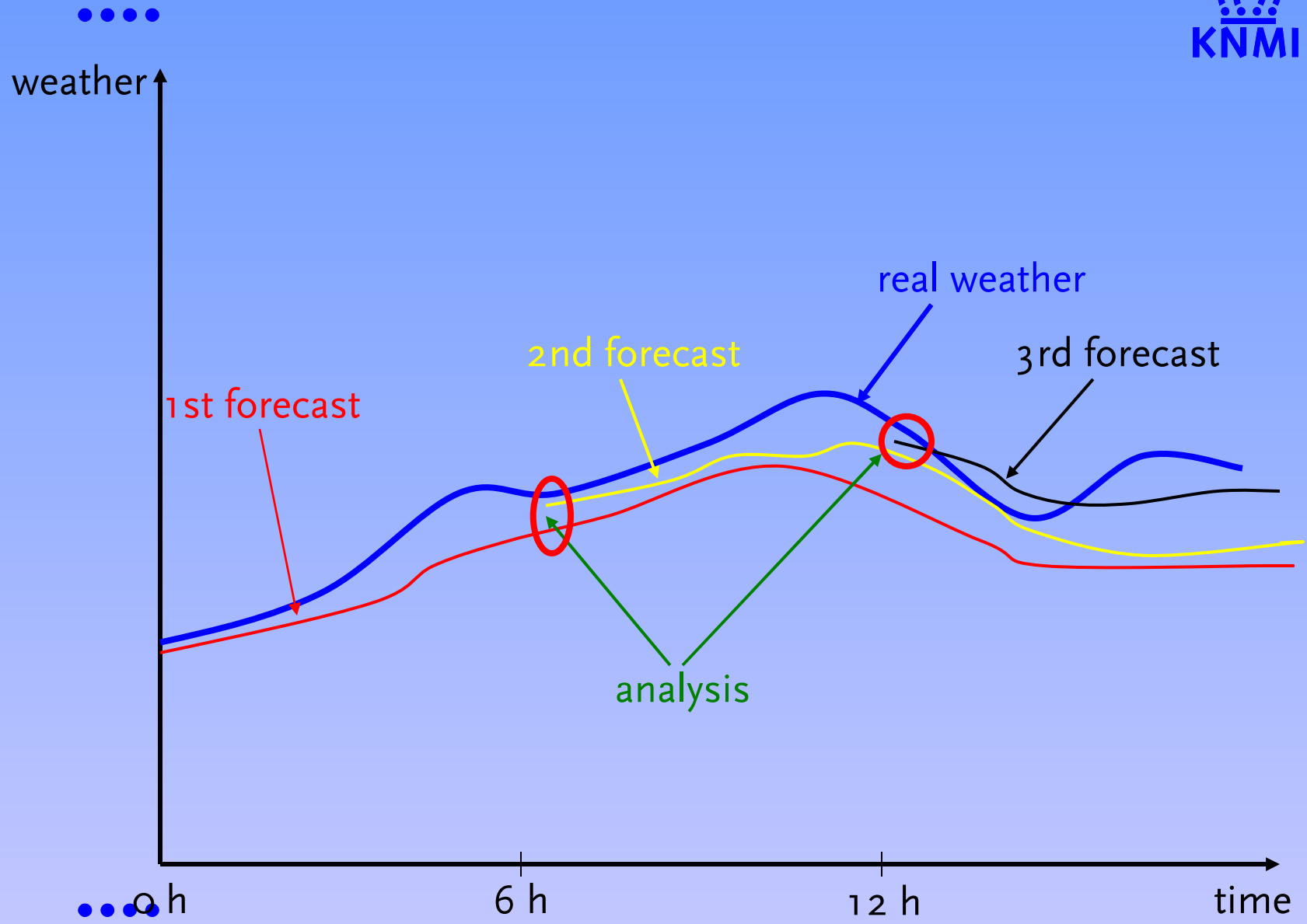
**PROBLEM**

you do not know today's weather

Solution

**Analysis**

= optimal combination of **observations**  
and **latest forecast** (first guess)





## Result of analysis

Complete description of atmosphere 4 times a day

## Drawback

Inhomogeneous over time due to model changes



## Reanalysis

Repeat analysis process for the past using a fixed, state-of-the-art analysis system.

## Result

Long-term description of atmosphere free of *model* inhomogeneities.

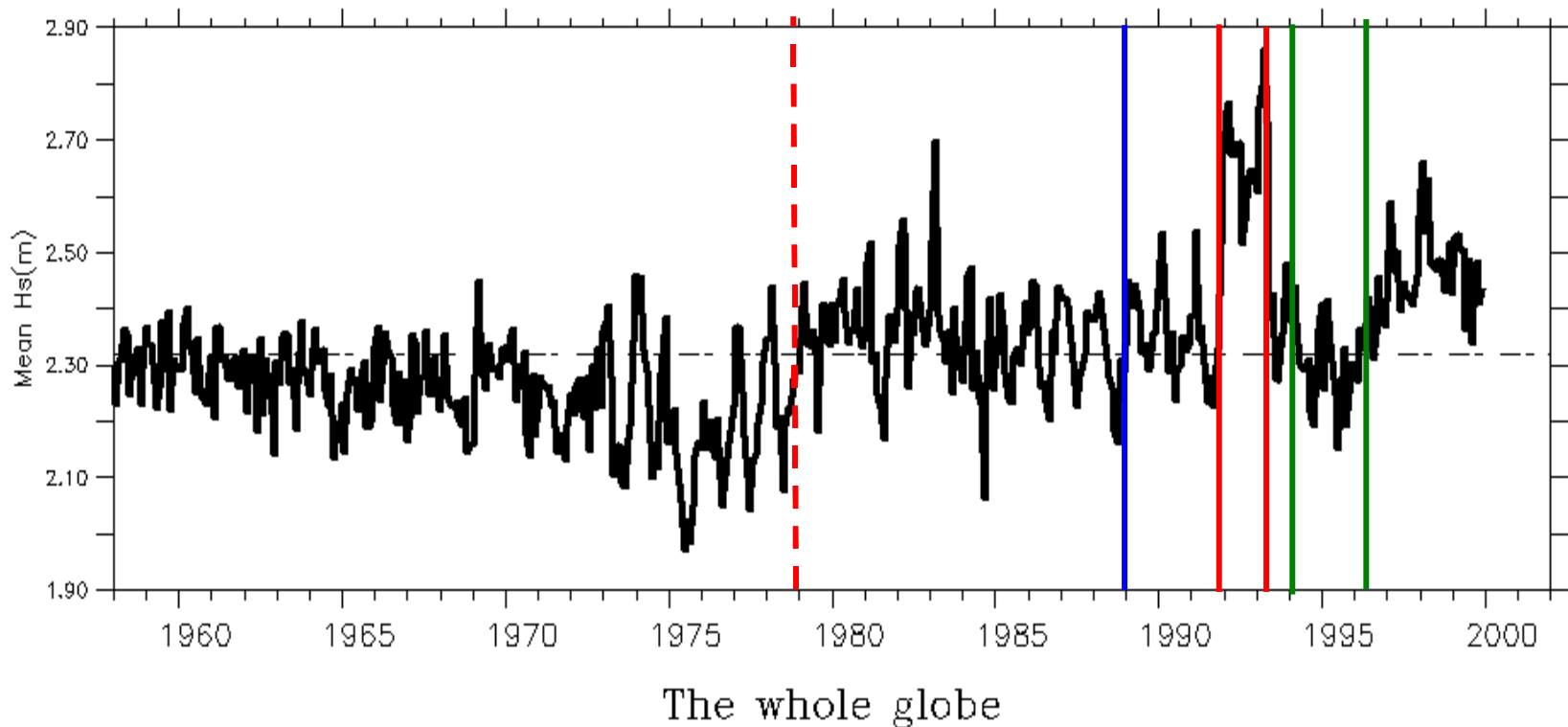
## The ERA-40 system

- Operational ECMWF system (IFS)
- $T_L 159$ , 60 layers
- 3DVAR:
- COADS, GTS, satellites, hist. data, ....
- interactive determination of Charnock Parameter (= sea surface roughness)
- coupled to WAM ( $1.5^\circ$ )
- => **Waves**

## Possible inhomogeneities

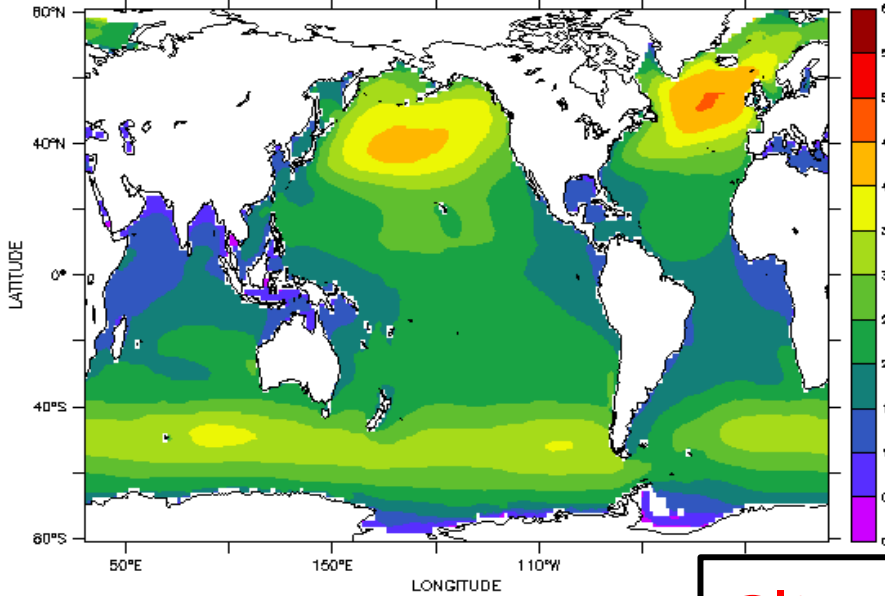
- Assimilation of TOVS radiances in 1979
- Assimilation of SSM/I winds in 1989
- Assimilation of ERS-1 altimeter data
  - **faulty**: 12/1991-05/1993
  - **none**: 06/1993-12/1993
  - **correct**: 01/1994-05/1996
- assimilation of ERS-2 altimeter data since 06/1996

# Global Mean Significant Wave Height



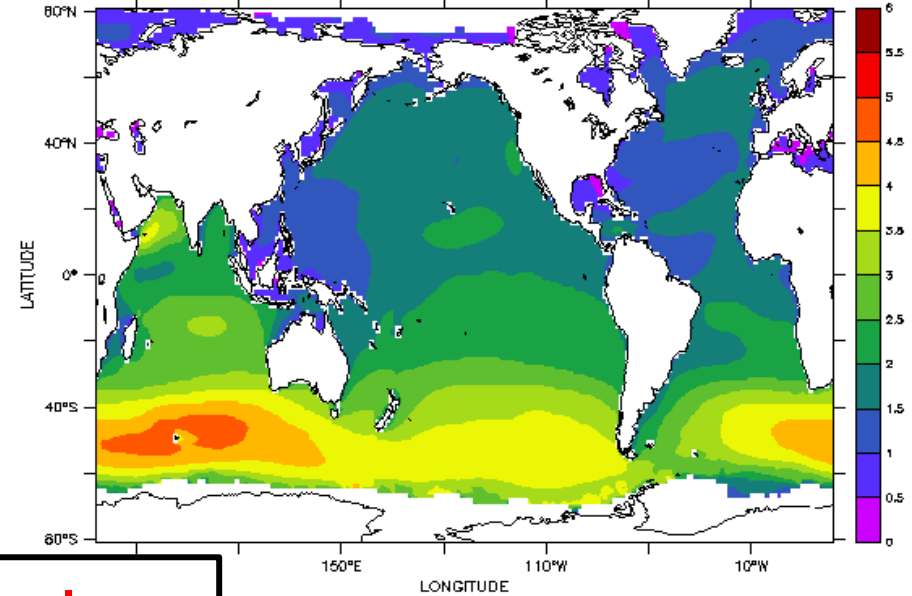
ERA-40 (1971-2000)

January



ERA-40 (1971-2000)

July

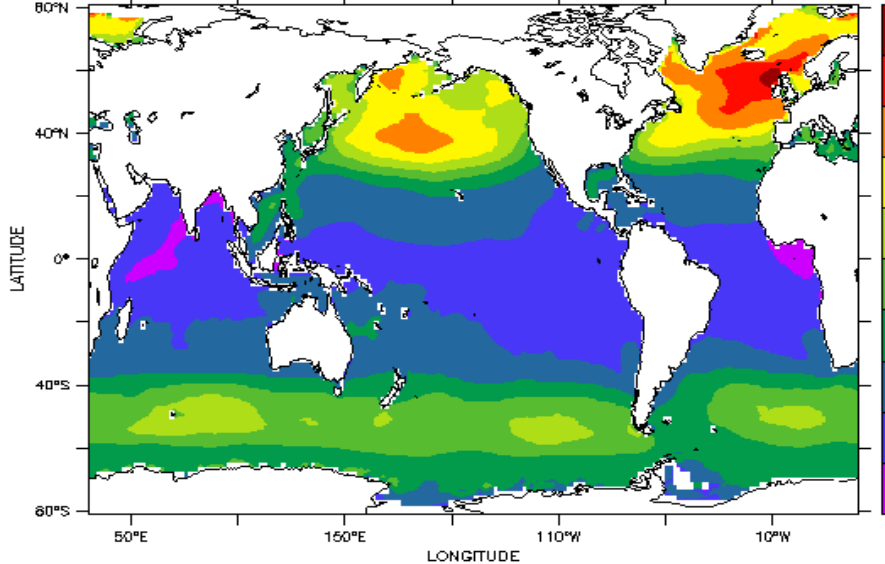


Significant wave height mean (m)

# Climatology

Significant wave height mean (m)

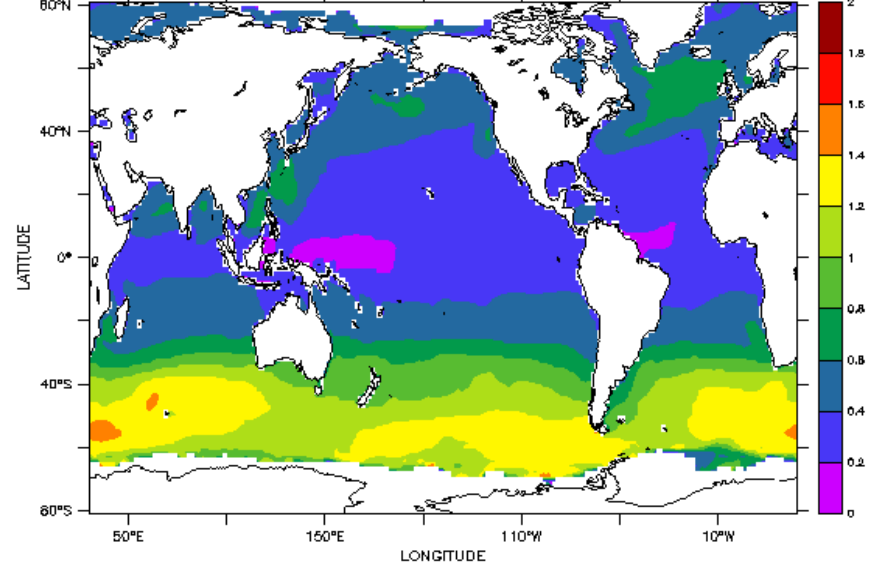
ERA-40 (1971-2000)



Significant wave height standard deviation (m)

ERA-40 (1971-2000)

July

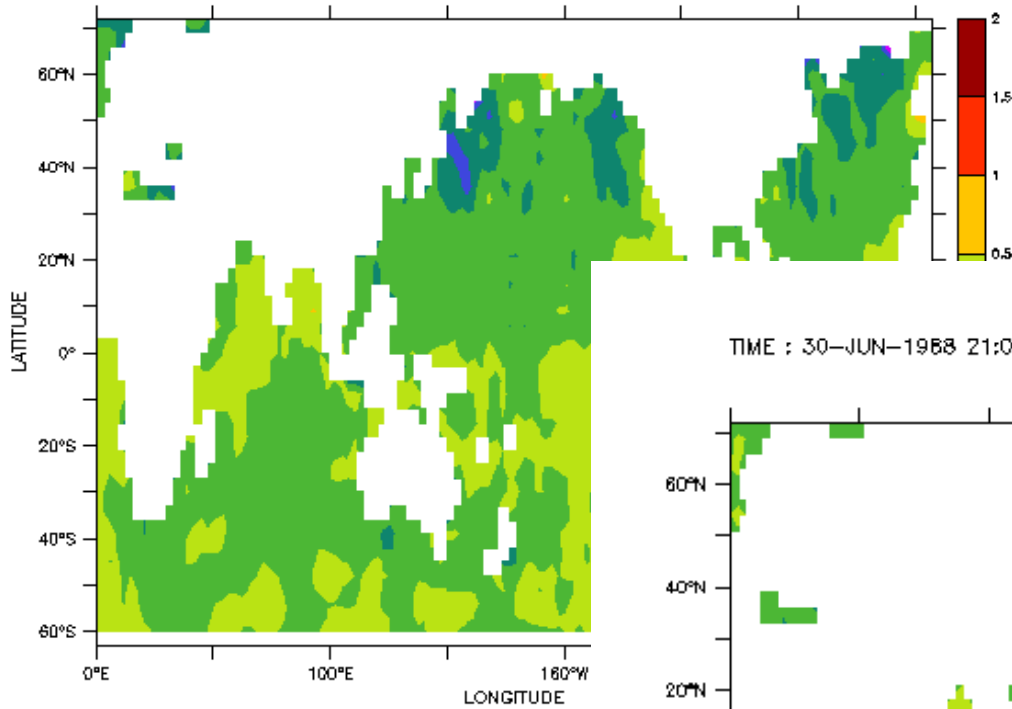


Significant wave height standard deviation (m)

## Assessment of ERA-40 waves

- other modelling efforts
- buoys (since 1978)
- altimeters (satellites)
  - Geosat (1987-1989)
  - ERS-1 (1991-1996)
  - ERS-2 (since 1996)
  - TOPEX/POSEIDON (since 1992)

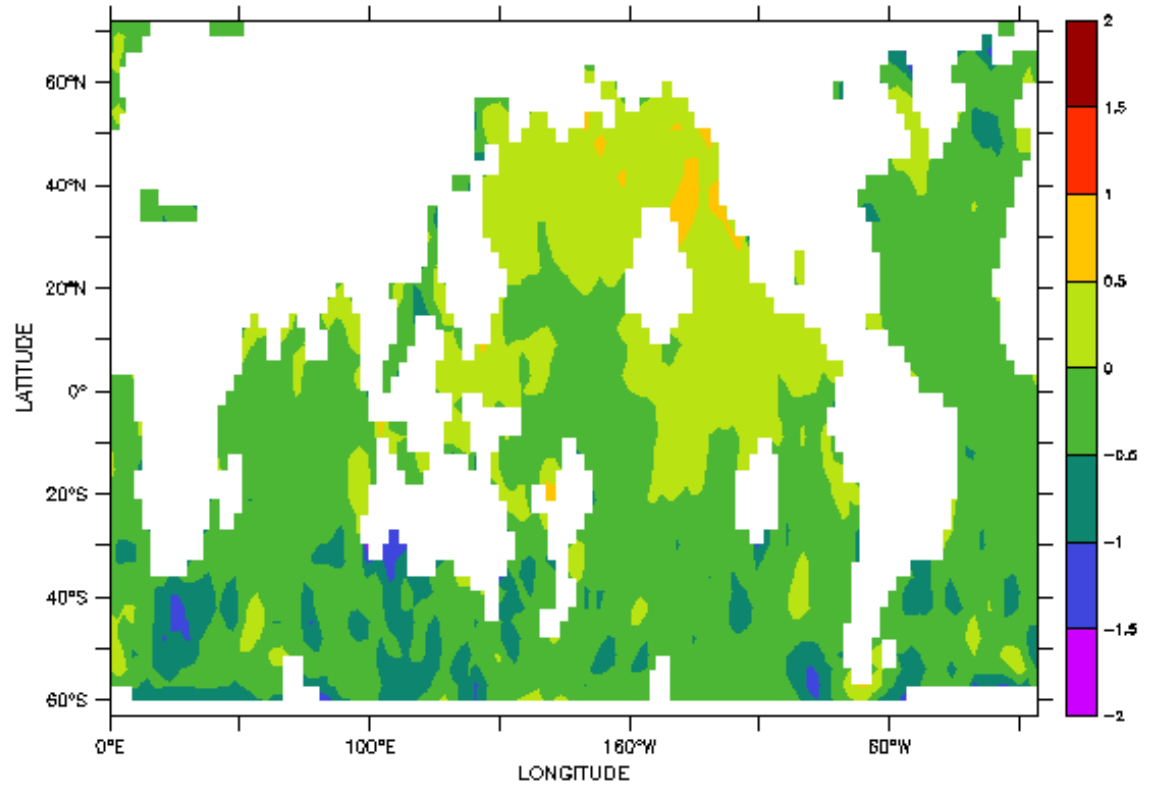
TIME : 31-DEC-1987 21:00 to 31-JAN-1988 21:00



ERA40 Hs(m) - Geosat Hs(m)



TIME : 30-JUN-1988 21:00 to 31-JUL-1988 21:00



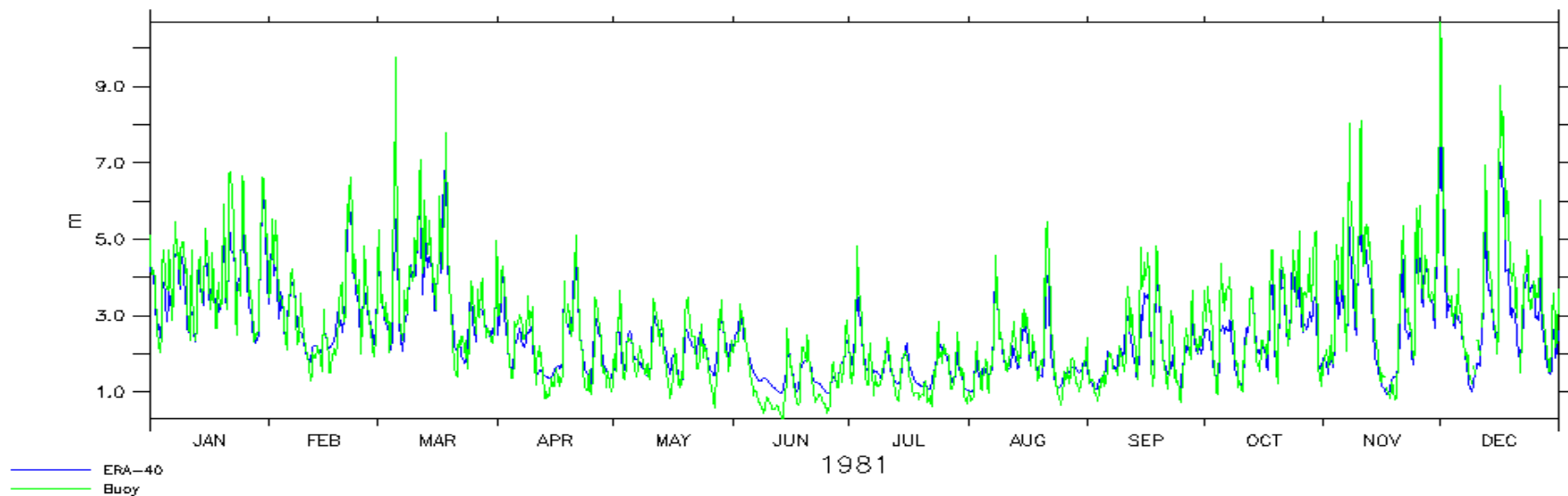
ERA40 Hs(m) - Geosat Hs(m)

# Monthly Means

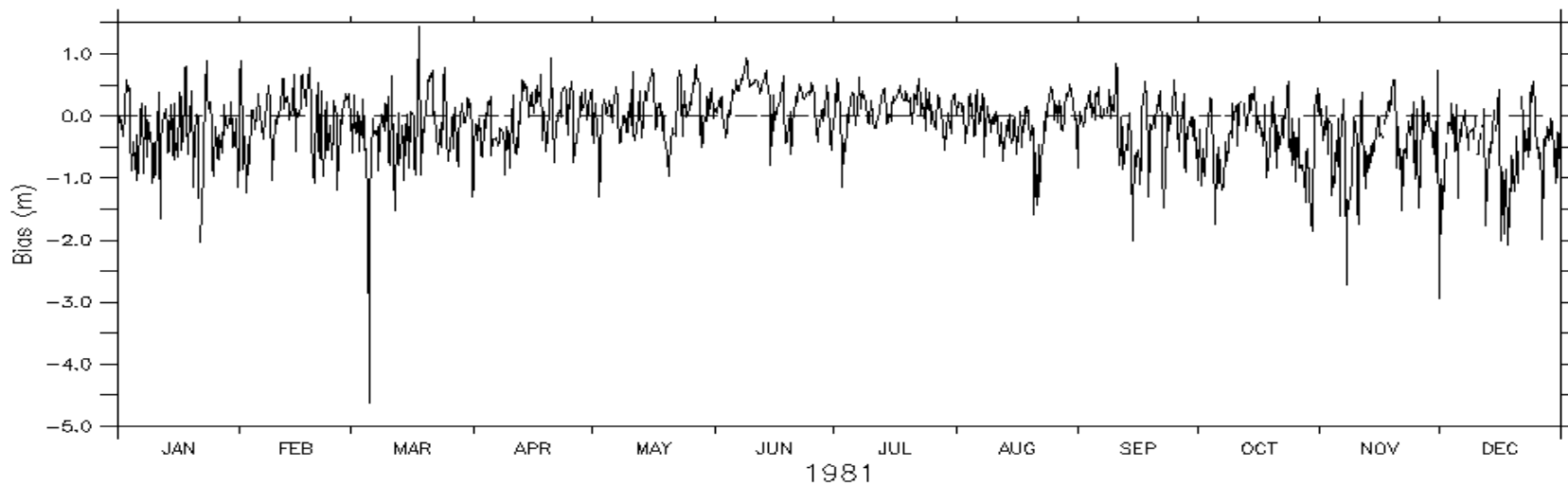


X (count) : 1

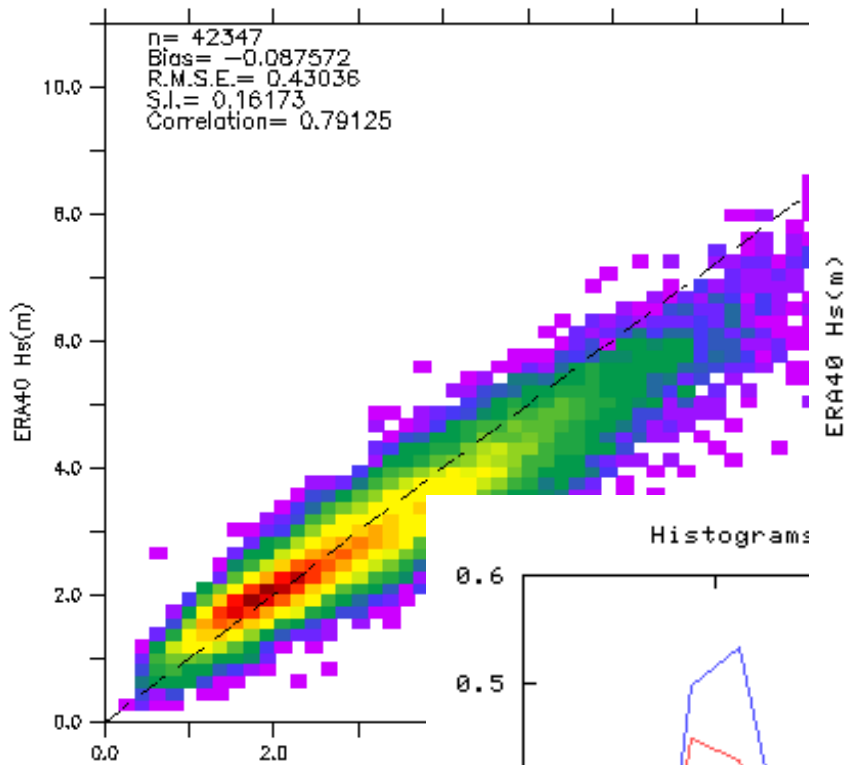
DATA SET: 46001



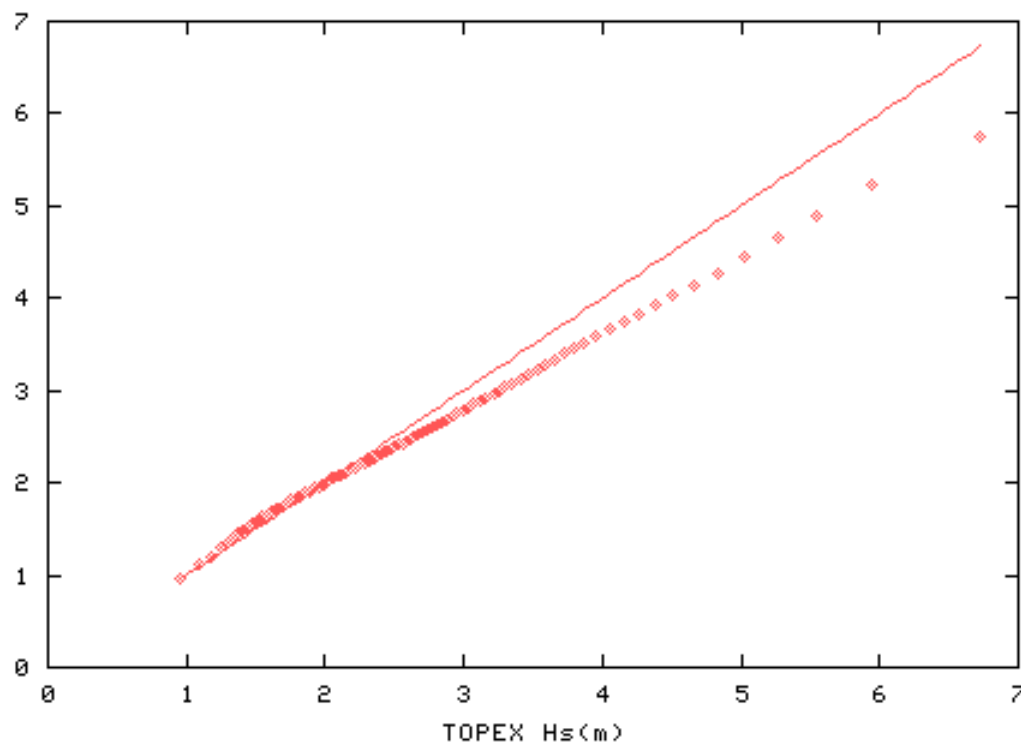
LATITUDE : 56N



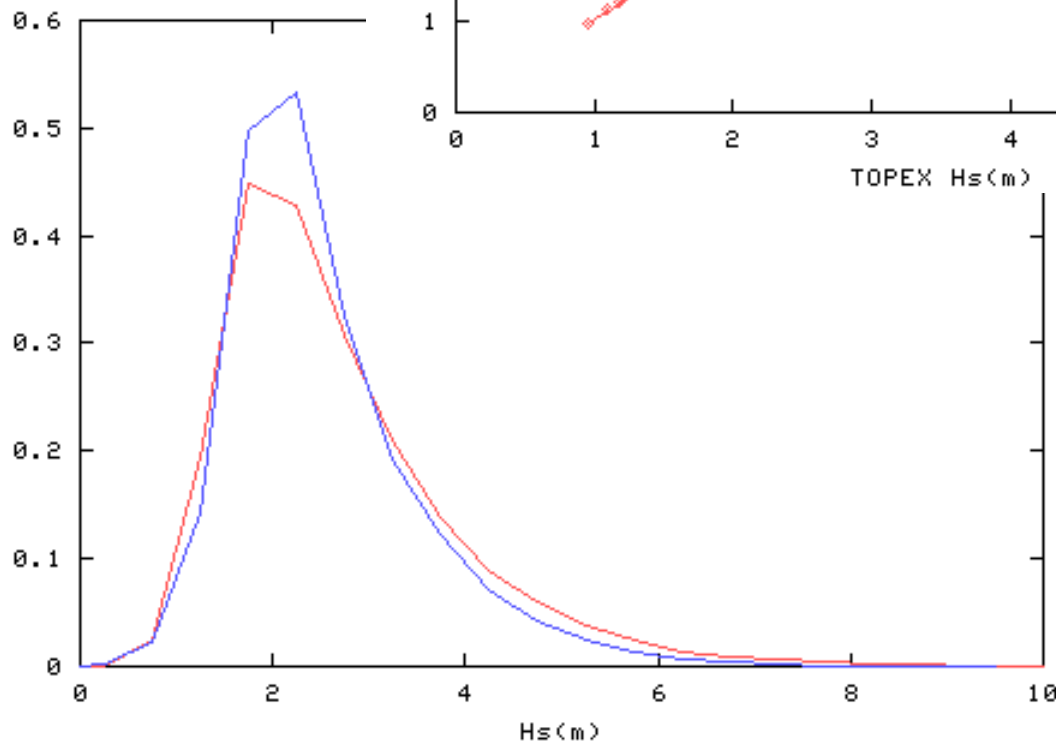
Significant Wave Height data at buoy 46001 location



Q-Q plot (from 1 to 99%) of collocated data from 01/1994



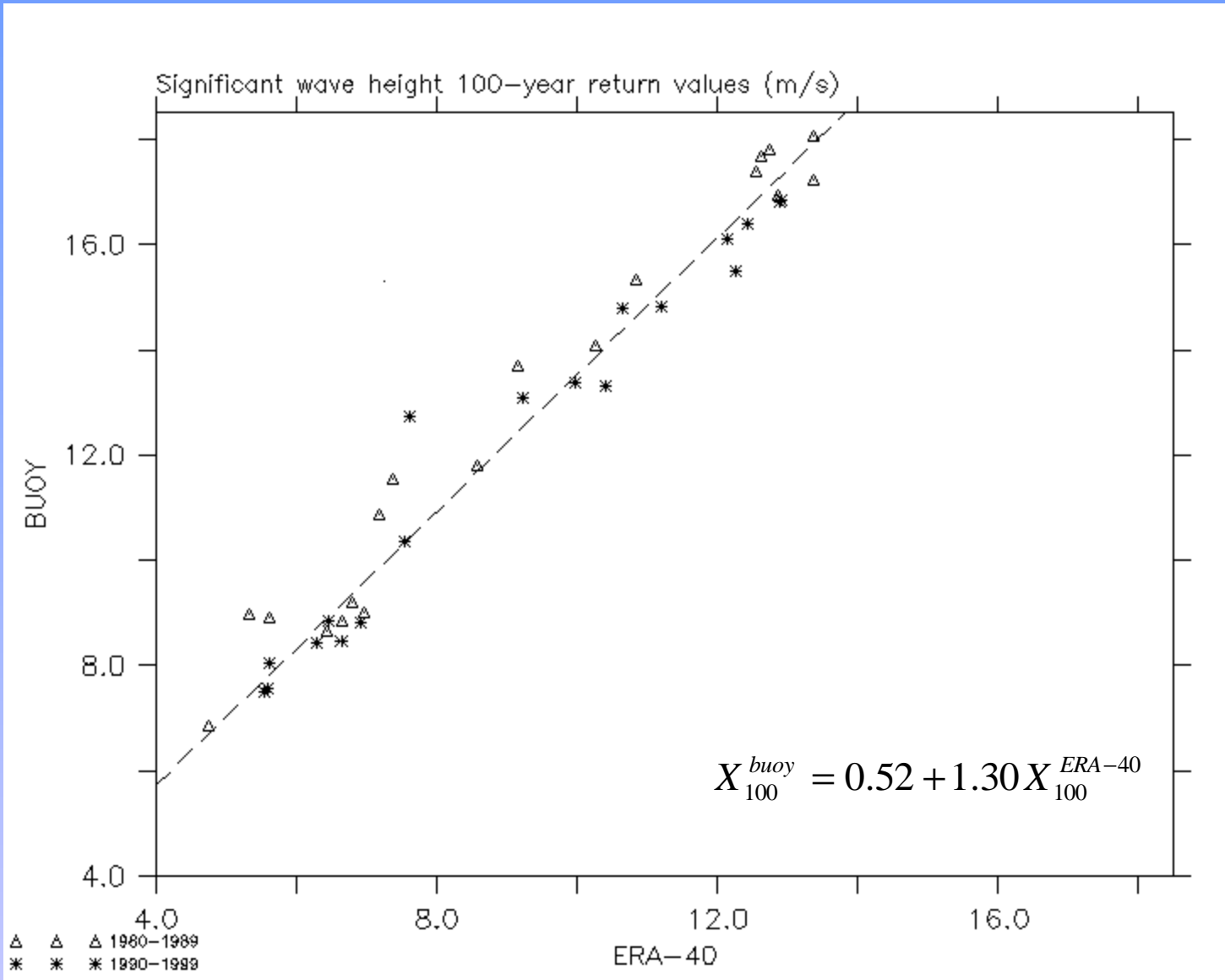
Histograms



## The “100 year return” wave height

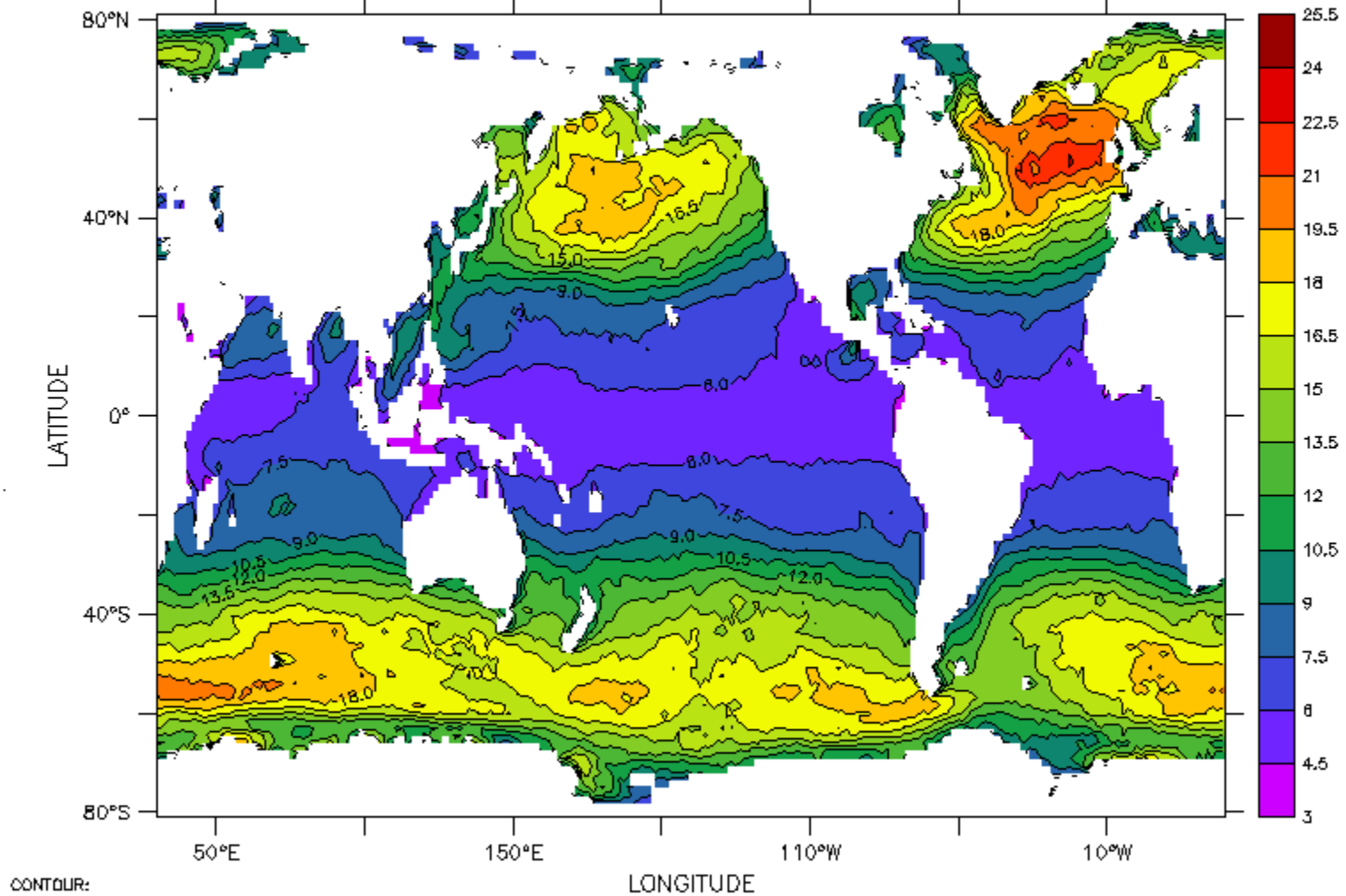
- Peak-Over-Threshold (POT) method:
- $\{H_s: H_s > T\}$  – exponential PDF (or GPD)
- $T = H_s(Q_{93})$
- Estimate parameter(s) of PDF
- $\Rightarrow H_{100}$
- Both for ERA-40 and buoy

# ERA-40 vs buoy data



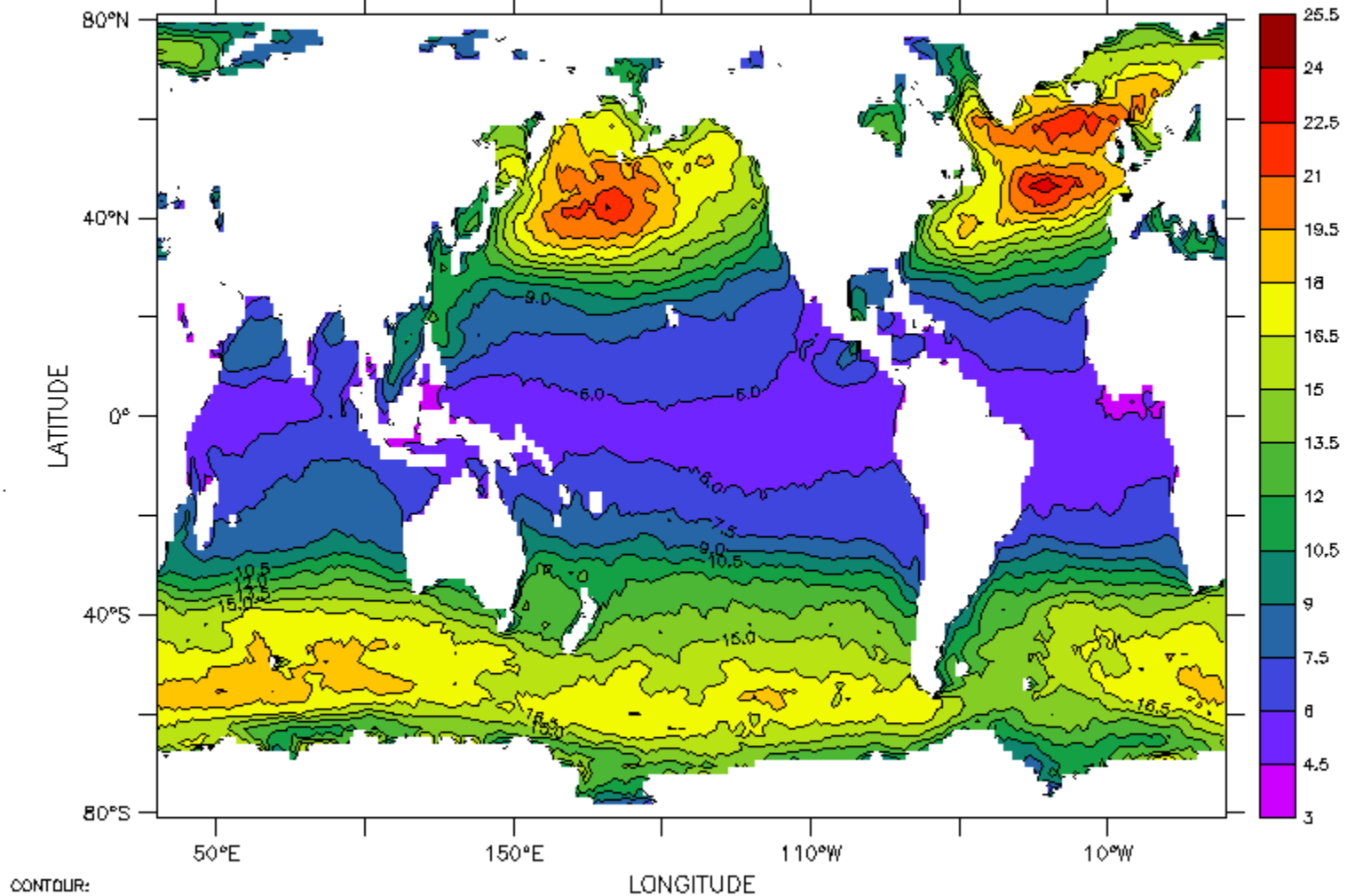
TIME : 01-SEP-1968 00:00

Hs 100-yr return values (m) 1958-1967



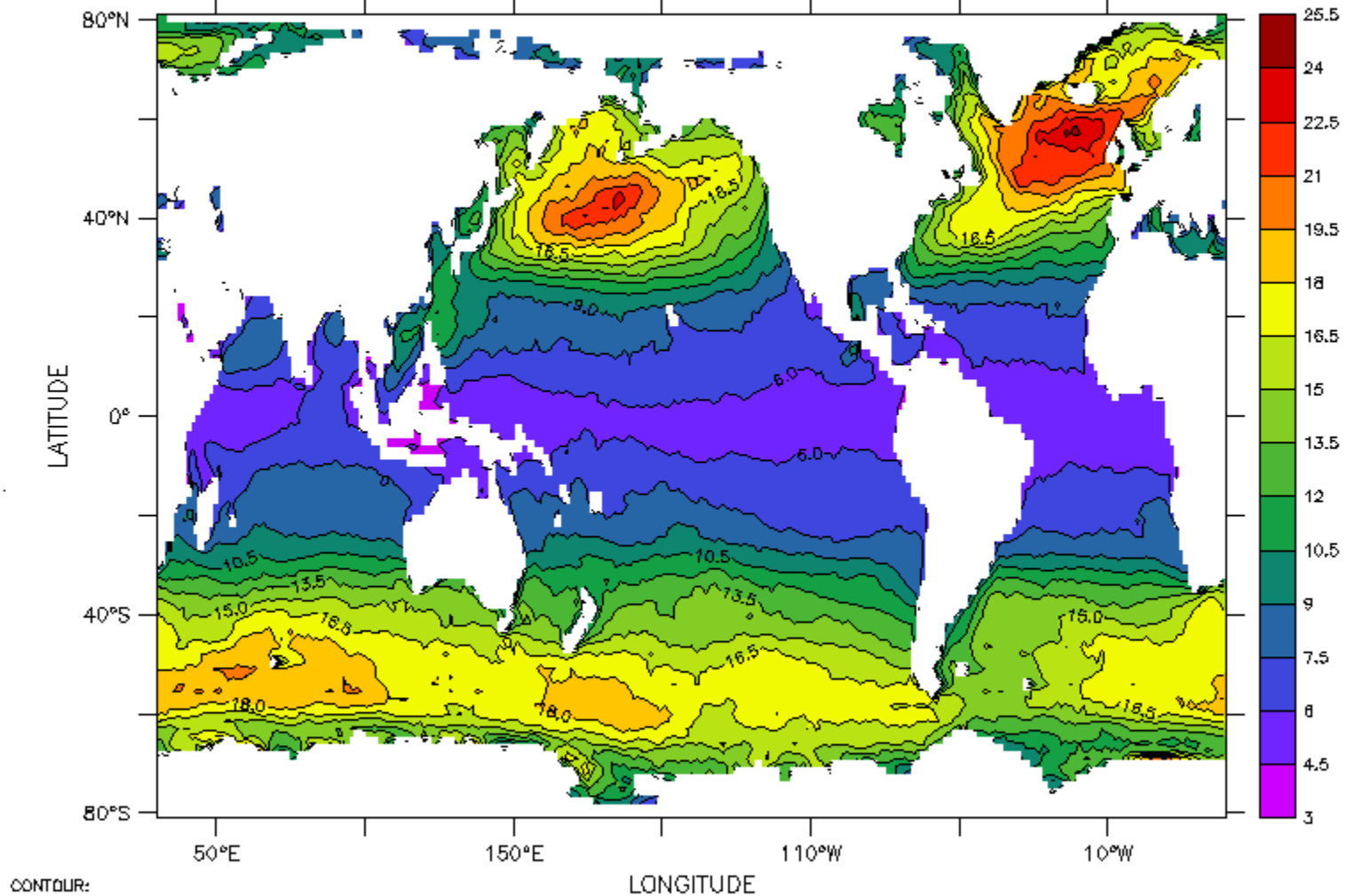
TIME : 01-AUG-1982 00:00

Hs 100-yr return values (m) 1972-1981



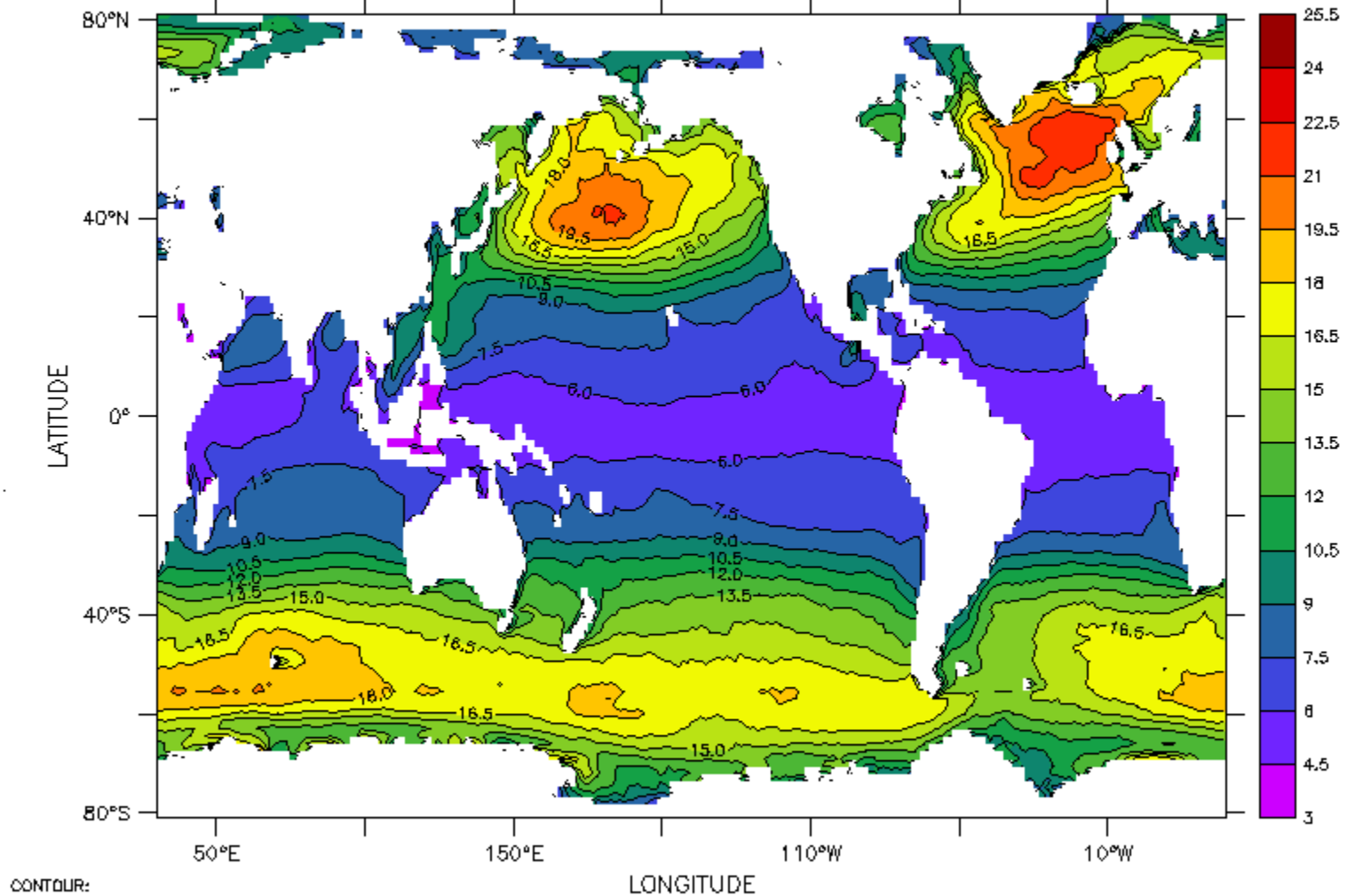
TIME : 01-SEP-1996 00:00

Hs 100-yr return values (m) 1986-1995



TIME : 01-SEP-2001 00:00

Hs 100-yr return values (m) 1958-2000



## Statistical correction of wave heights

- bias = bias ( $H_s$ , swell, ... )
- => no simple parametric correction
- **hope:** bias similar in similar situations
- **then:**
- identify “similar” situations (“analogues”)
- learn from known biases (“learning data”)

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## Analogue

Last three  $H_s$ -values close together:

$$|H_s^1(t_0 - i \Delta t) - H_s^2(t_0 - i \Delta t)| < \varepsilon, i = 0, 1, 2$$

Or:

The development of the waves must be similar.

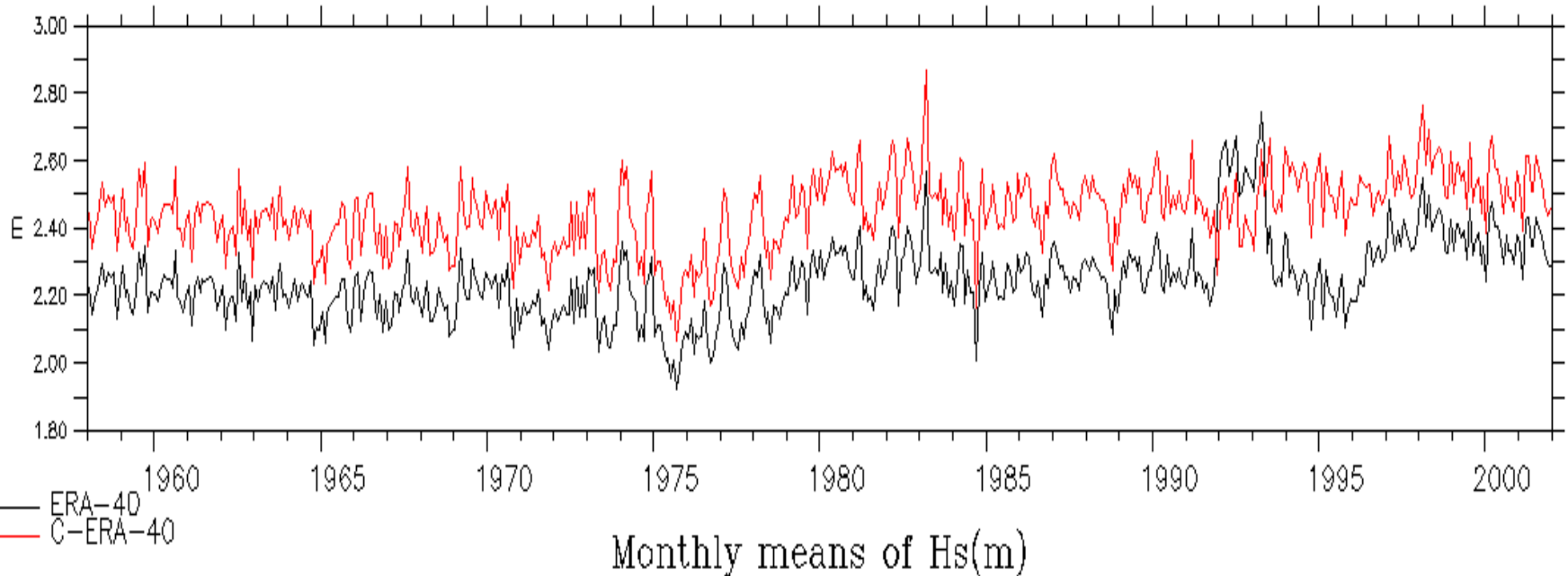
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## How to do it

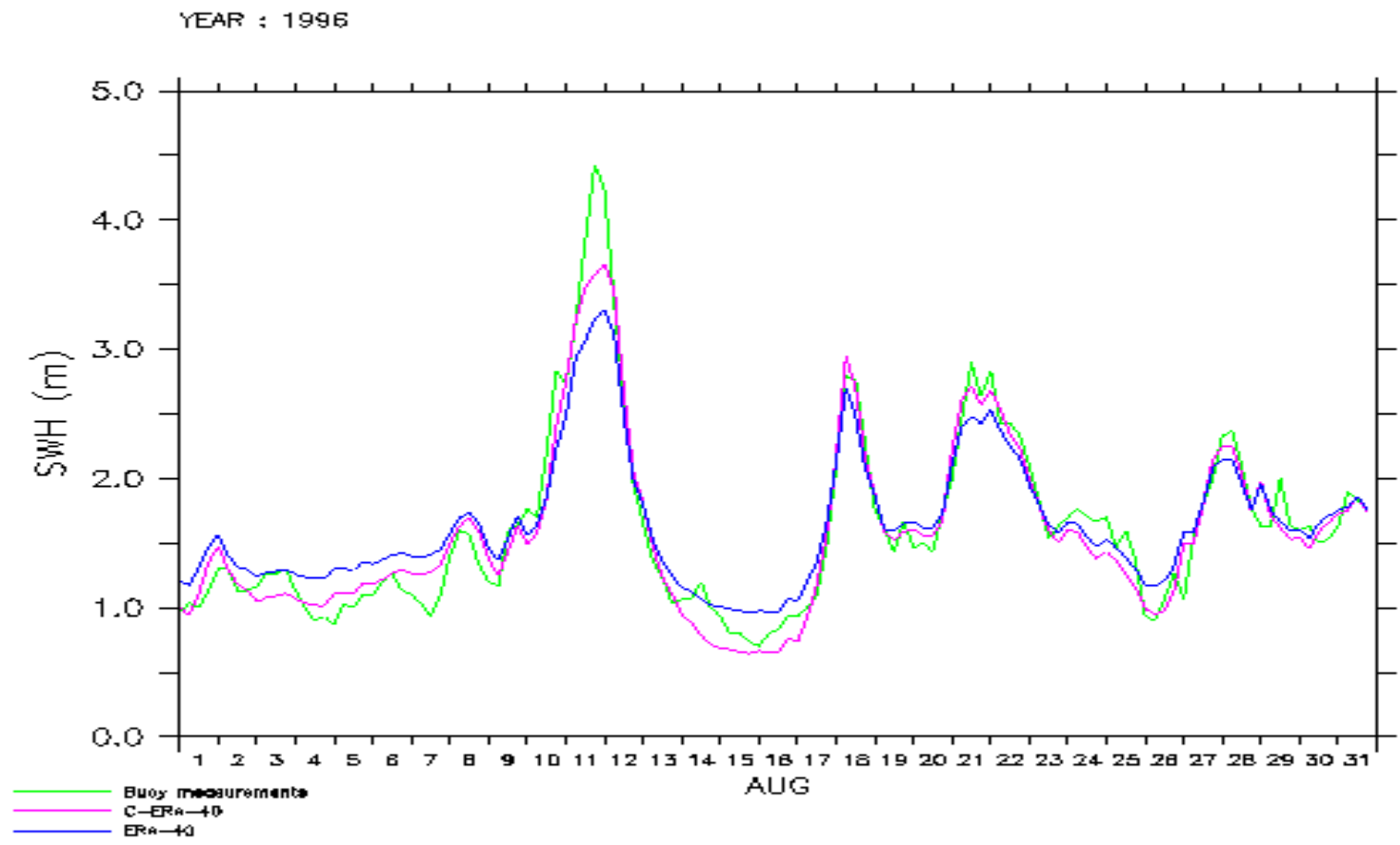
- Divide ERA-40 into periods according to inhomogeneities
- “Truth” from TOPEX
- Build learning dataset for each period
- Identify analogues and correct data
- Calculate confidence intervals
- Validate (buoy, Geosat, ERS-2)

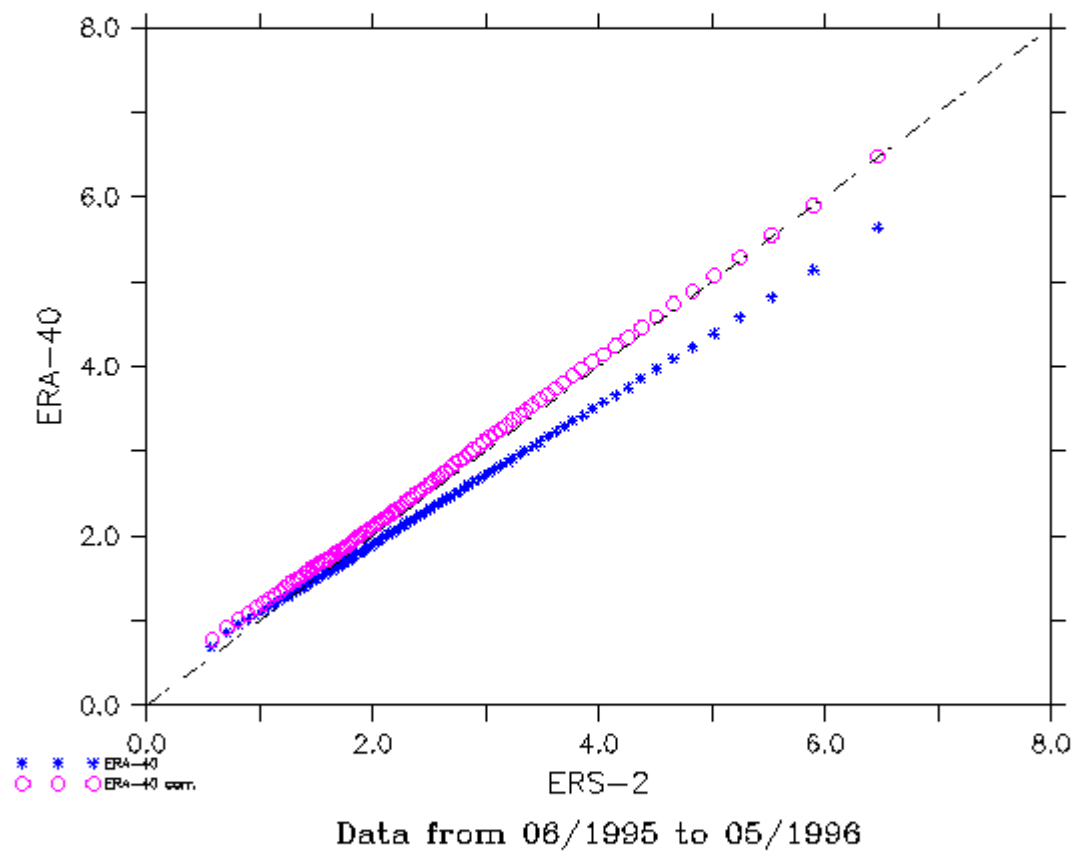
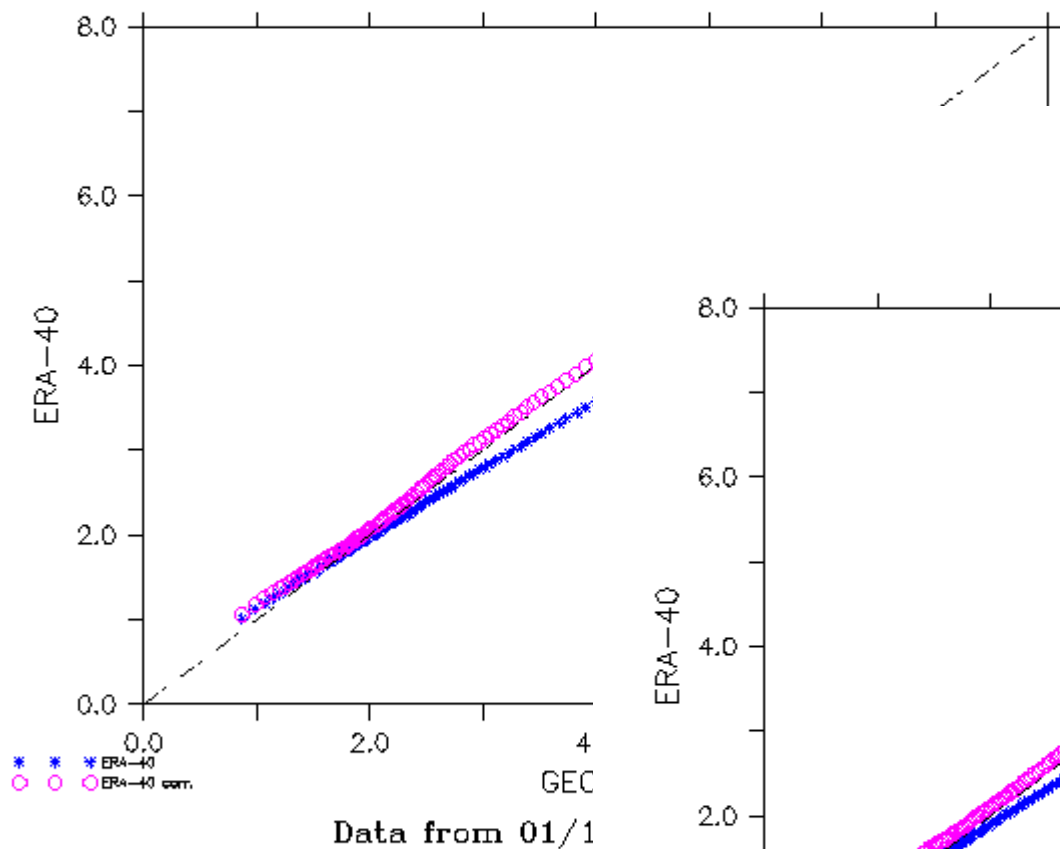


# Global mean $H_s$



- wave height generally increased (bias  $\approx 0$ )
- no more inhomogeneities





## Summary

- Inhomogeneities due to changing data
- Good monthly means
- Low waves (slightly) too high
- High waves (much) too low
- Possibility of statistical correction
- **Wave Atlas**, freely accessible via <http://www.knmi.nl/waveatlas>



Click [here](#) for a no frames version of this page.

# ATLAS derived from 45-years of ECMWF reanalysis data

S. Caires, A. Sterl, G. Komen and V. Swail

Thanks to  
  
for the raw ERA-40 data..



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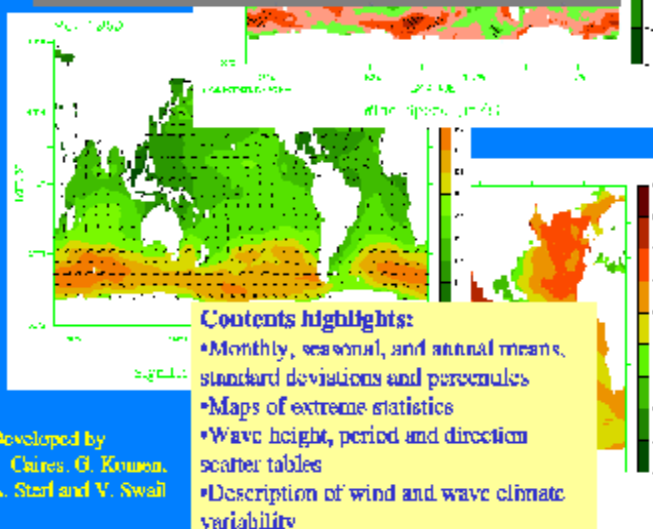
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    - Significant wave height: 3 m, 6 m, 9 m.
    - Wind speed: 12 m/s, 18 m/s, 24 m/s.
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  - 4.4 Maps of extreme statistics
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  - 5.1 Plots of interannual and decadal variability of the statistics in Chapter 4
  - 5.2 Maps of variability of extremes
  - 5.3 Variability patterns
    - Significant wave height

## Global Wave Climatology Atlas

derived from 45-years of ECMWF reanalysis data

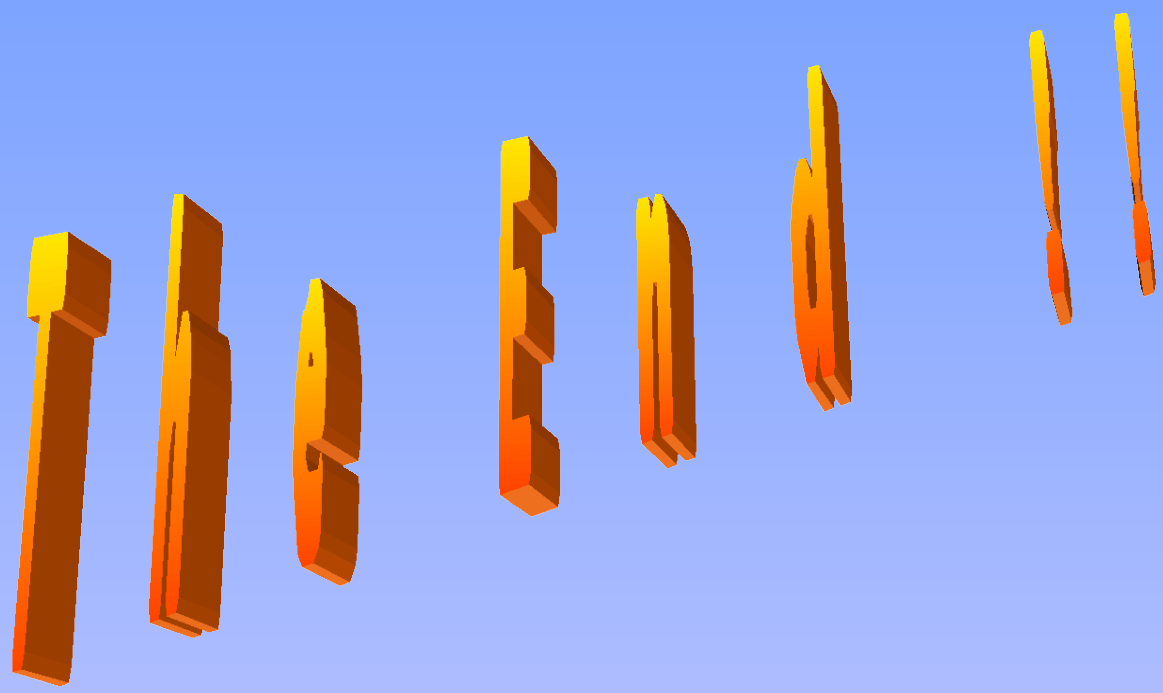
This web-based book describes wave climate and variability for use in

- Ocean engineering applications
- Detailed strategic planning of shipping routes
- Scientific areas such as climate research

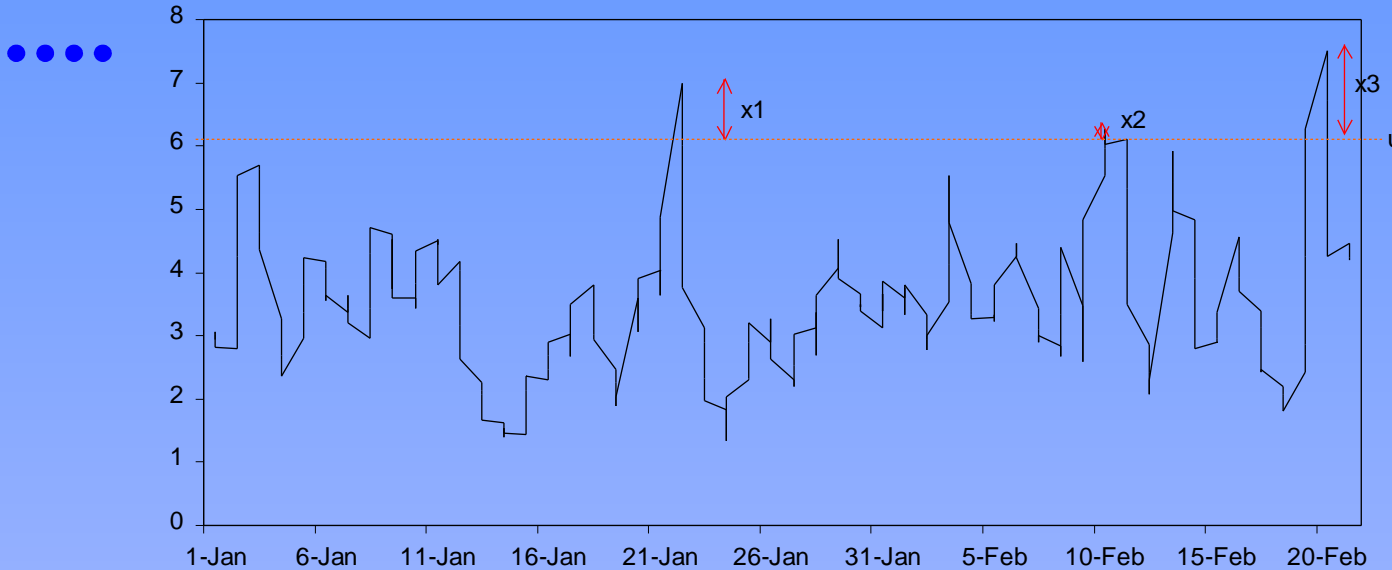


Developed by  
S. Caires, G. Komen,  
A. Sterl and V. Swail

**Bookmark**  
<http://www.knmi.nl/onderz/oceaan/wave/era40/atlas.html>



# Peaks-over-threshold method



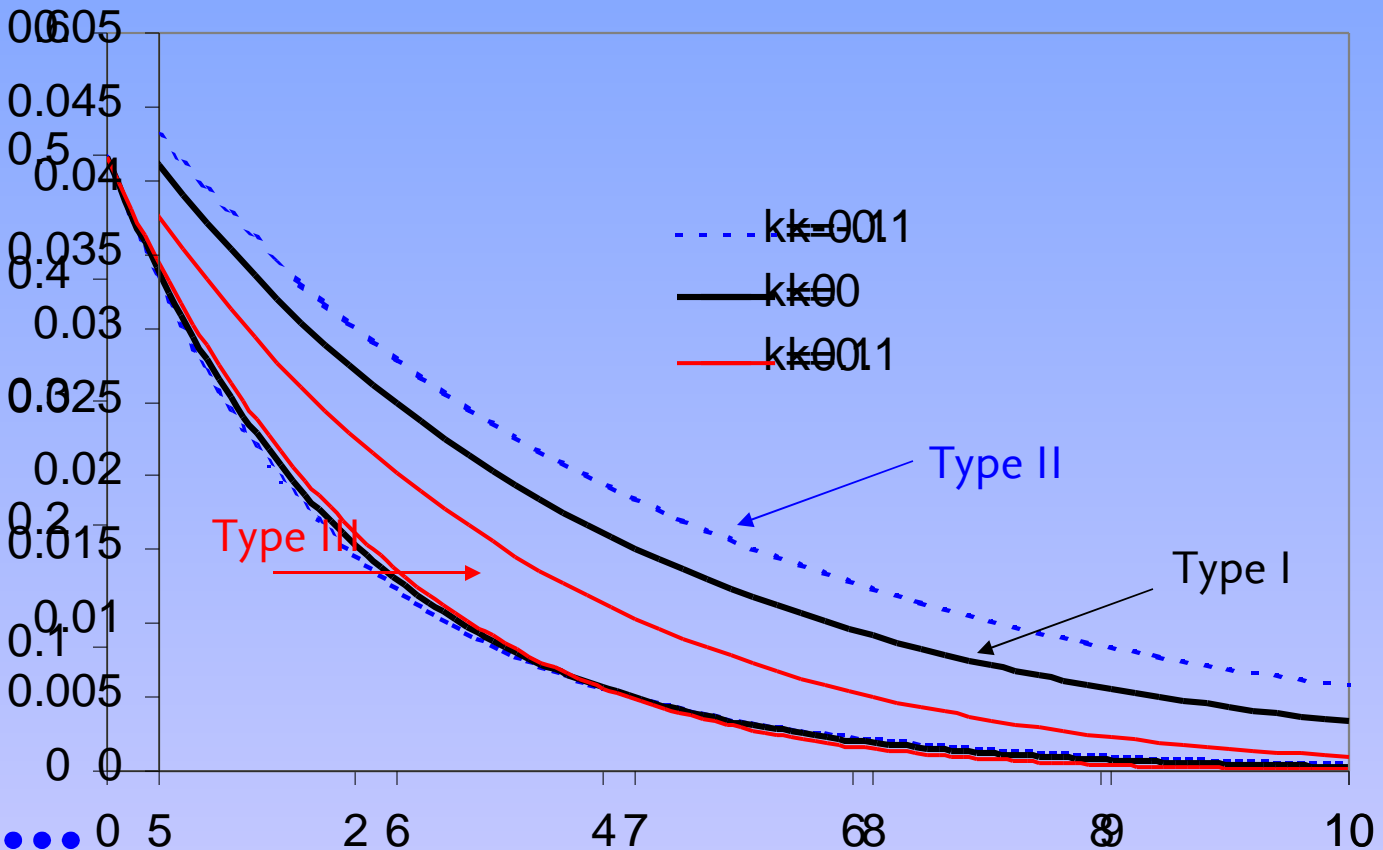
Peak excesses over a high threshold  $u$  occur according to a Poisson process with rate  $\lambda_u$  and are independently distributed with a **Generalized Pareto Distribution**

$$F_u(x) = \begin{cases} 1 - (1 - \kappa x / \alpha)^{1/\kappa} & \kappa \neq 0 \\ 1 - \exp(-x / \alpha) & \kappa = 0 \end{cases}$$

**m-year return value**

$$x_m^{(u)} = \begin{cases} u + \alpha / \kappa \log(1 - (\lambda_u m)^{-\kappa}) & \kappa \neq 0 \\ u + \alpha \log(\lambda_u m) & \kappa = 0 \end{cases}$$

Theoretically, most data conform to 1 of the 3 tails of the GPD



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Estimation method: maximum likelihood

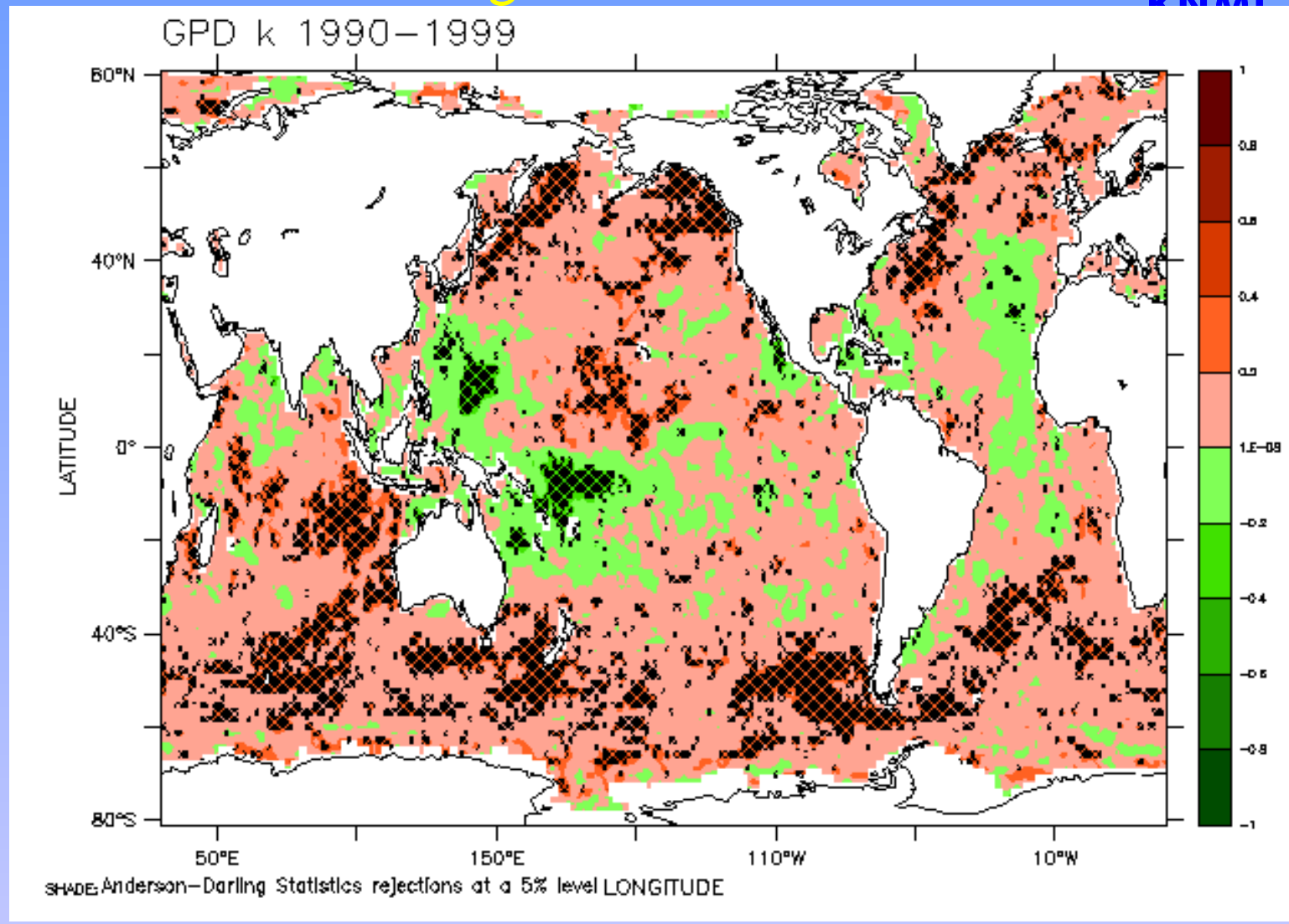
Unknowns:  $u, \lambda, \alpha, \kappa$

## Assumptions

- $\kappa = 0$  (data is exponential)
- $u = h_{0.93}$

••••

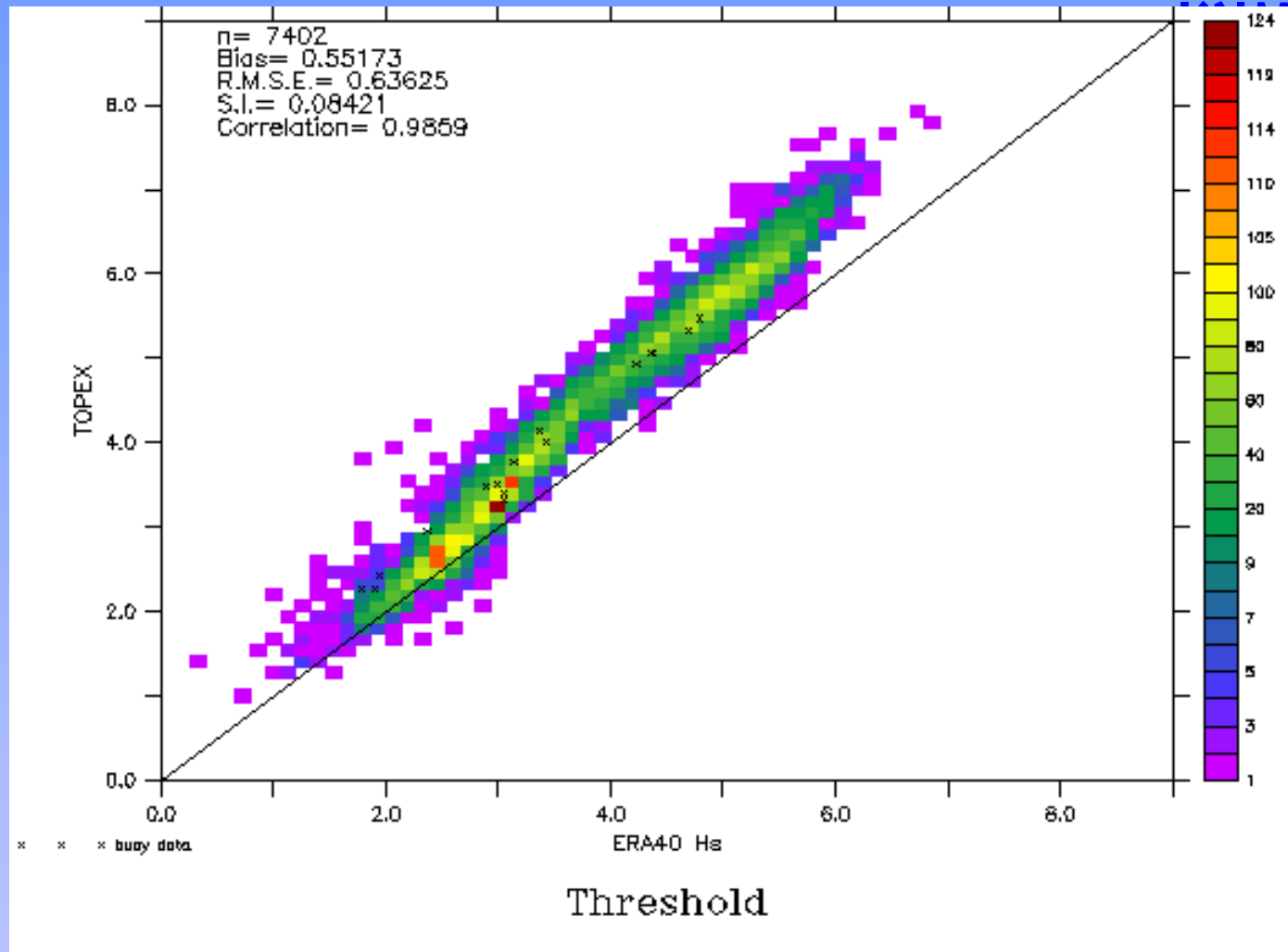
- The exponentiality of the data was tested using the Anderson-Darling statistic



A. Sterl, SEAMOC, Toulouse, 16-02-2009

Rejection rate = 20%

# Assessment against Topex data



$$x_m^{(u)} = u + \alpha \log(\lambda m)$$

A. Steri, SEAMOCS, Toulouse, 16.02.2006

# Learning

