Decadal to centennial changes in the global wave climate from VOS data: secular trends, leading modes and wave statistics

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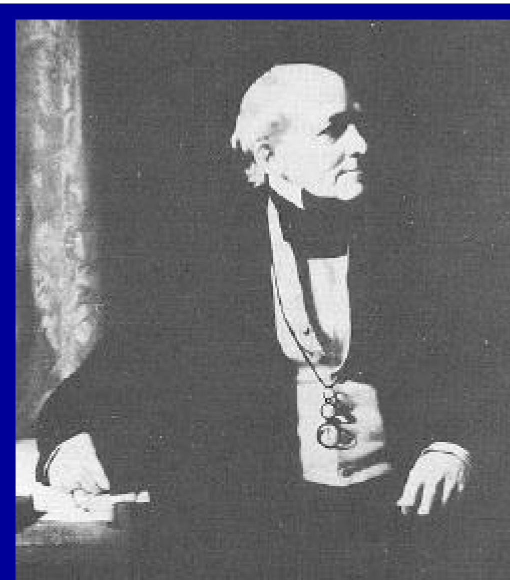
OUTLINE:

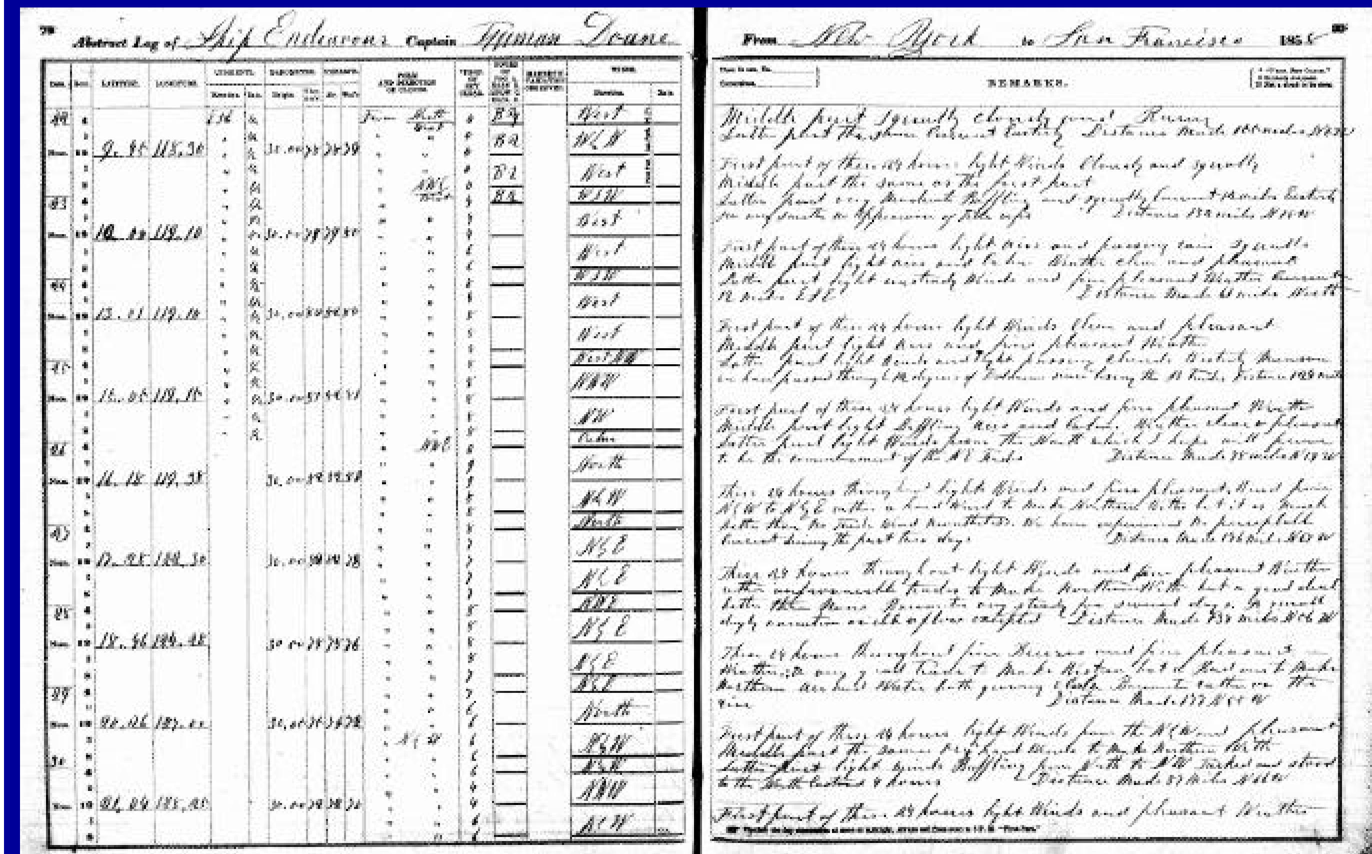
- Visual wave observations at sea: history, processing, uncertainties
- Centennial trends: do the waves grow?
- Interannual variability: mechanisms by which sea and swell are changed
- Wave statistics from VOS: decadal changes

The story

1838: the Beaufort wind force scale was made mandatory for log entries in all ships of the Royal Navy.



Rear-Admiral, Sir Francis Beaufort


Abstract Log of Ship Endeavour Captain
From New York to San Francisco 185
REMARKS.

Visual wave observations became a common practice after the Brussels Maritime Conference of 1953, convened by Lt. Matthew Fontaine Maury (US Navy)

CHANGES IN CODING SYSTEMS

1904 (Hydrographic Office No. 1190), 1906, and 1908
(US Weather Bureau "Circular M, 2nd edition"):

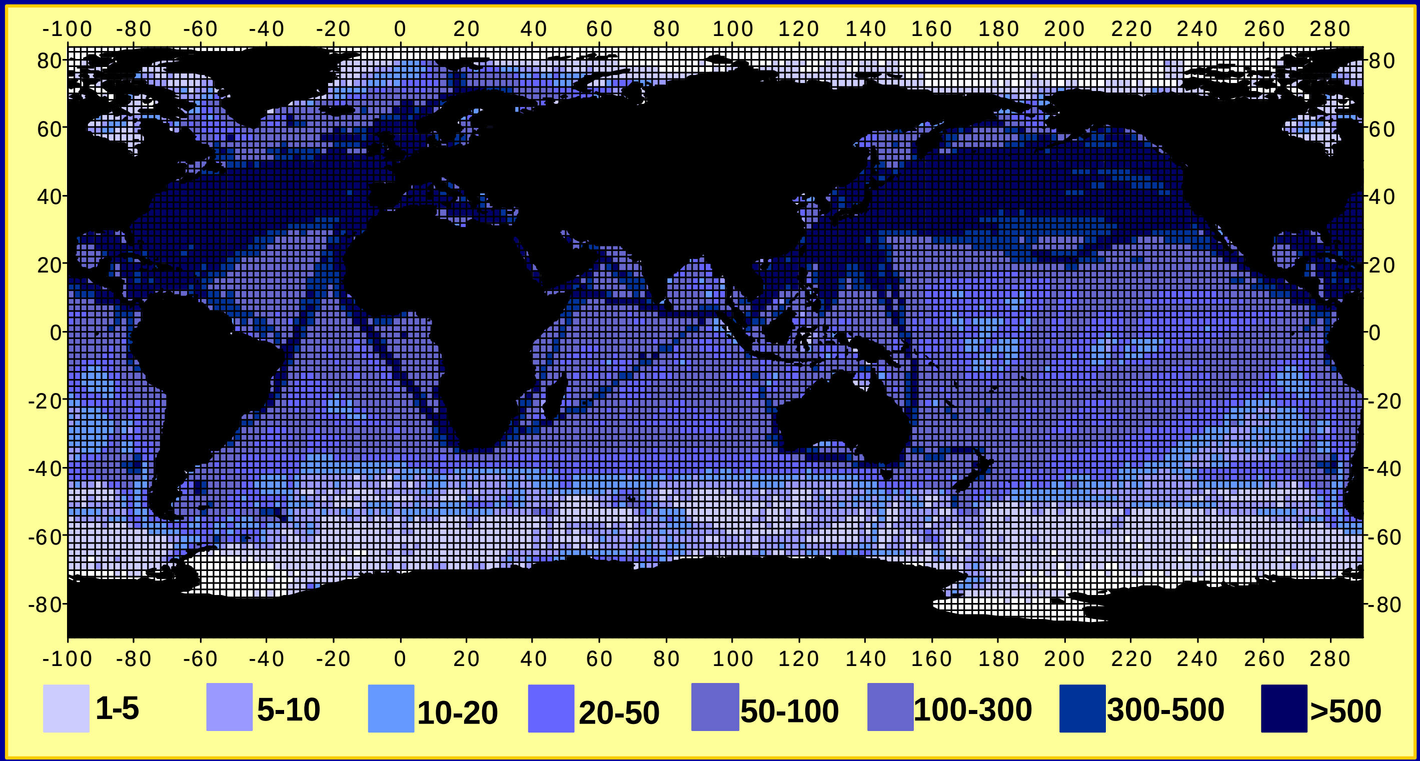
B.--Broken or irregular sea.
C.--Chopping, short, or cross sea.
G.--Ground swell.
H.--Heavy sea.
L.--Long rolling sea.
M.--Moderate sea or swell.
R.--Rough sea.
S.--Smooth sea.
T.--Tide rips.

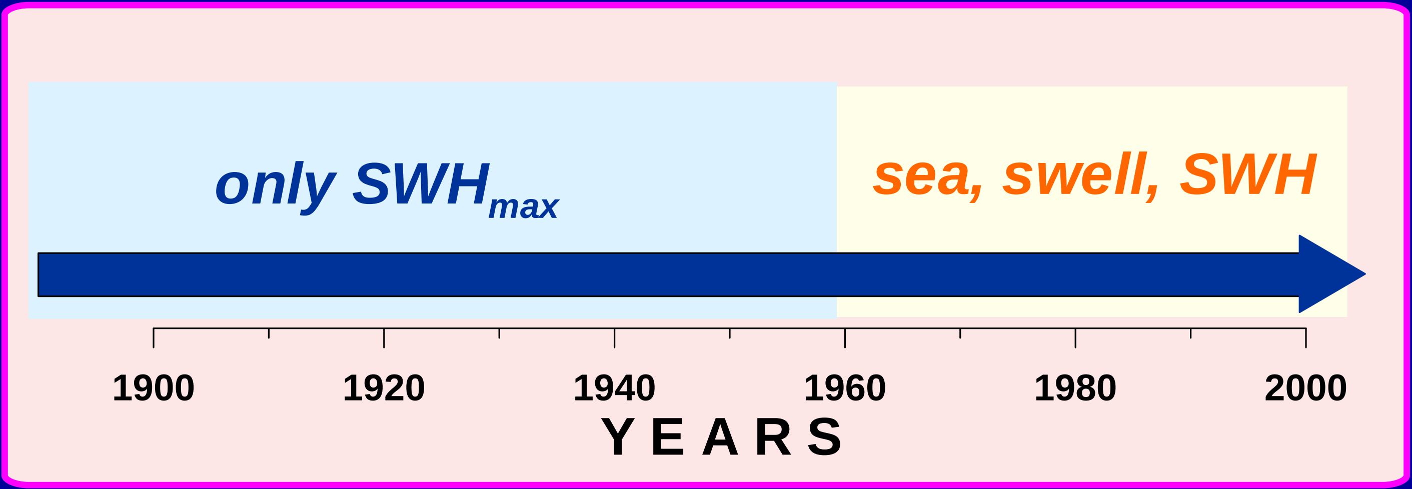
The Original Card Deck 193 Reference Manual of 1917:

0 = calm (height of wave, crest to trough 0 feet)
1 = smooth (height of wave, crest to trough <1 foot)
2 = slight (height of wave, crest to trough 1-3 feet)
3 = moderate (height of wave, crest to trough 3-5 feet)
4 = rough (height of wave, crest to trough 5-8 feet)
5 = very rough (height of wave, crest to trough 8-12 feet)
6 = high (height of wave, crest to trough 12-20 feet)
7 = very high (height of wave, crest to trough 20-40 feet)
8 = precipitous (height of wave, crest to trough >40 feet)
9 = confused (see Reporting and coding practices

1925 US instructions (Circular M, 4th edition): a 0-9 scale is used
1963 WMO Manual on codes: 1-49 (0.5 meter increments)

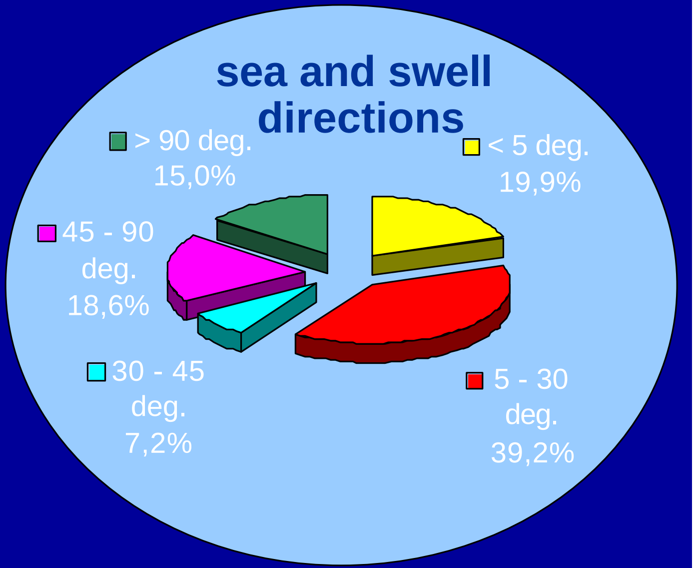
Visual VOS (ICOADS archive): 2 streams (1856-1948) and (1948-2003)

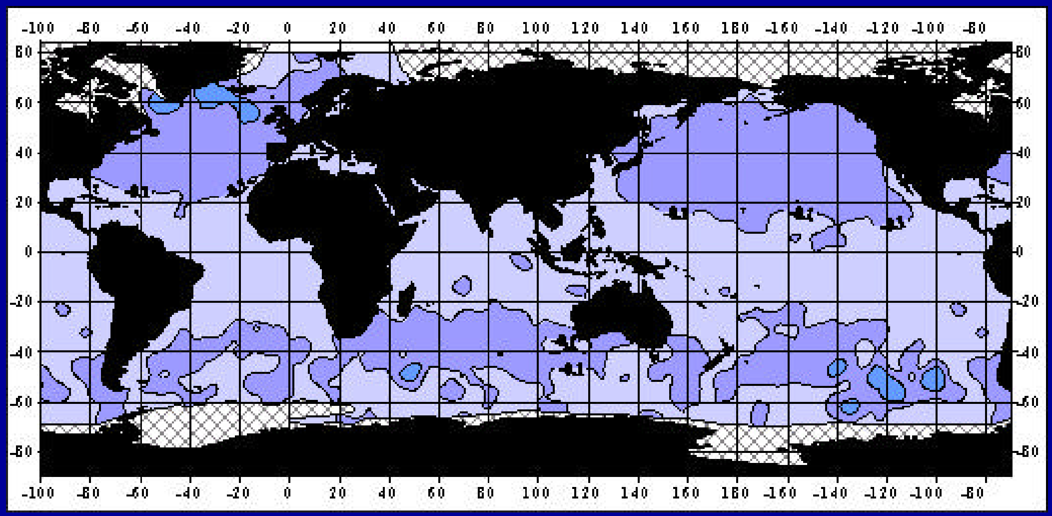




Pre-processing: SWH

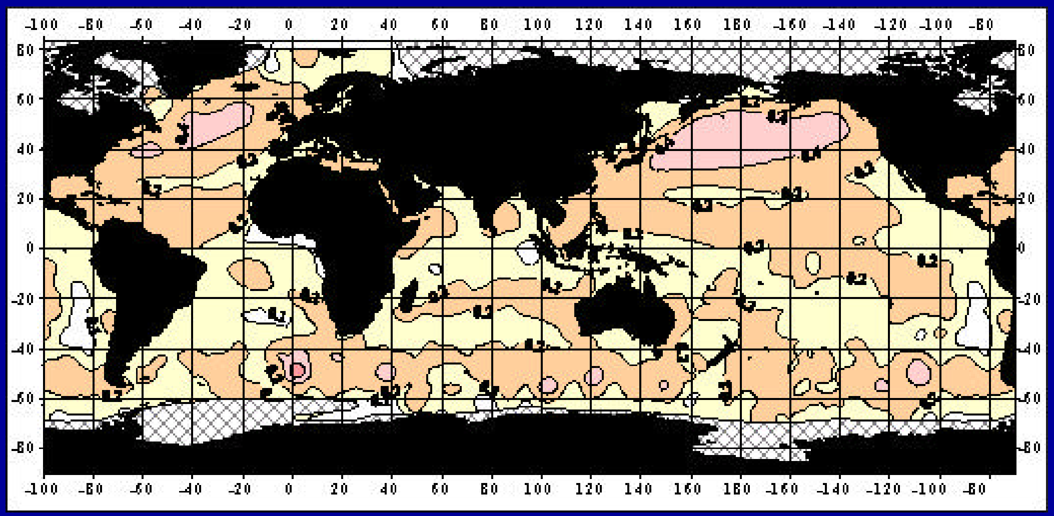
$$SWH = \begin{cases} (h_w^2 + h_s^2)^{1/2}, & [dir_{sea}, dir_{swell}] \in 30^o sector \\ max[h_w, h_s], & [dir_{sea}, dir_{swell}] \notin 30^o sector \end{cases} \quad \begin{matrix} (1) \\ (2) \end{matrix}$$





Our estimate minus (1)

Negative differences <0.3 m



Our estimate minus (2)

Positive deviations 0.2-0.45

Wave variable pre-processing and corrections

(for more details: Gulev et al. 2003, JGR)

1. General quality checks

2. Correction of small wave heights: code figure "01" problem (Gulev et al. 2002)

$$hs = 0.5 - \exp(-0.658V)$$

3. Separation of sea and swell in visual estimates (Carter 1988, Gulev and Hasse 1999)

Analysis of 2D wind-wave distributions with respect to JONSWAP curves for wind duration of 6 to 18 hours

4. Correction of the wave periods and computation of the dominant period (Gulev and Hasse 1998)

Fitting of the 2D wave-period distributions for sea and swell

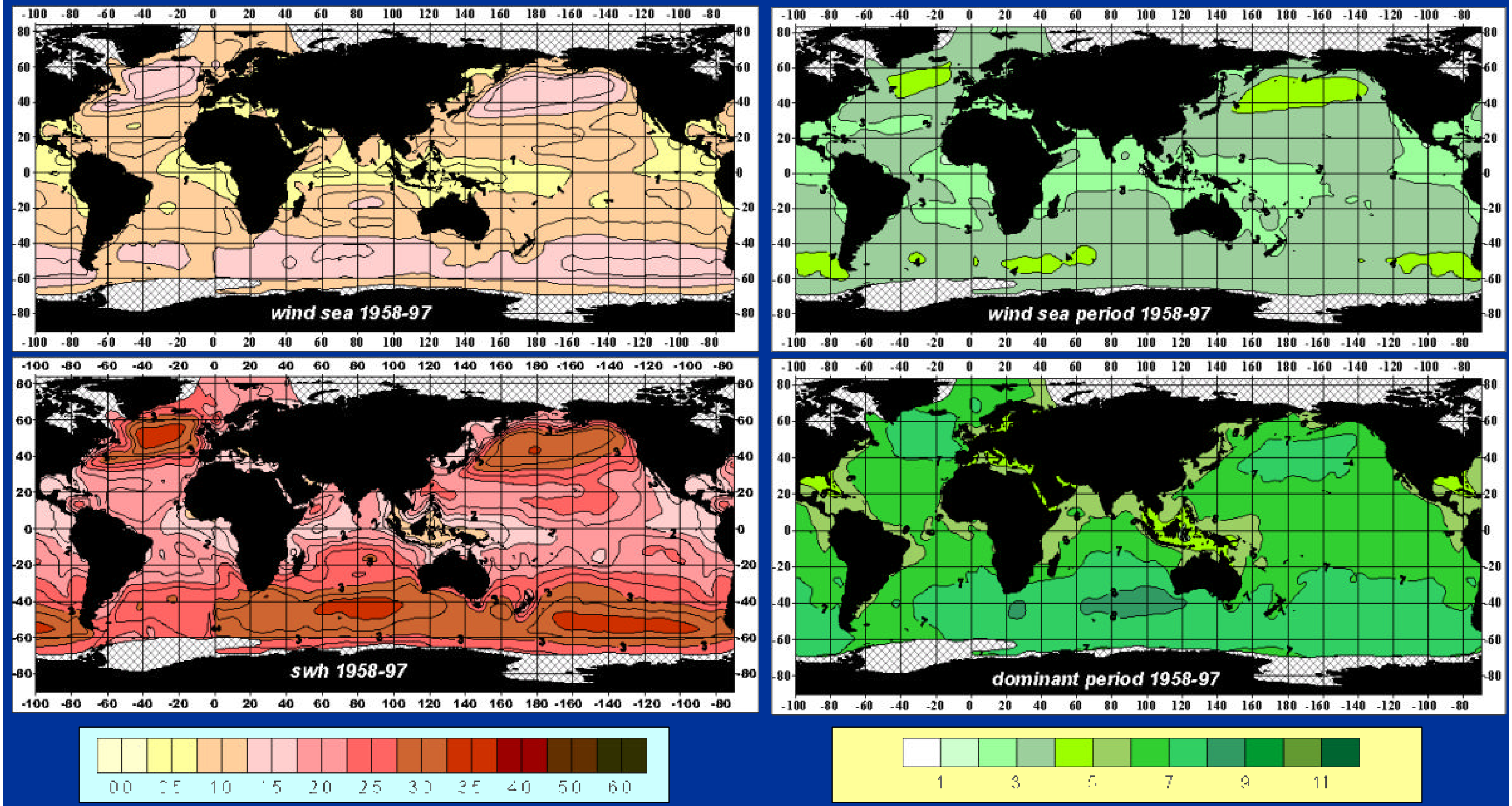
5. Uncertainty of the evaluation of the true wave direction and period from the relative direction (Grigorieva and Gulev 2004)

Use of the actual ship course and velocity

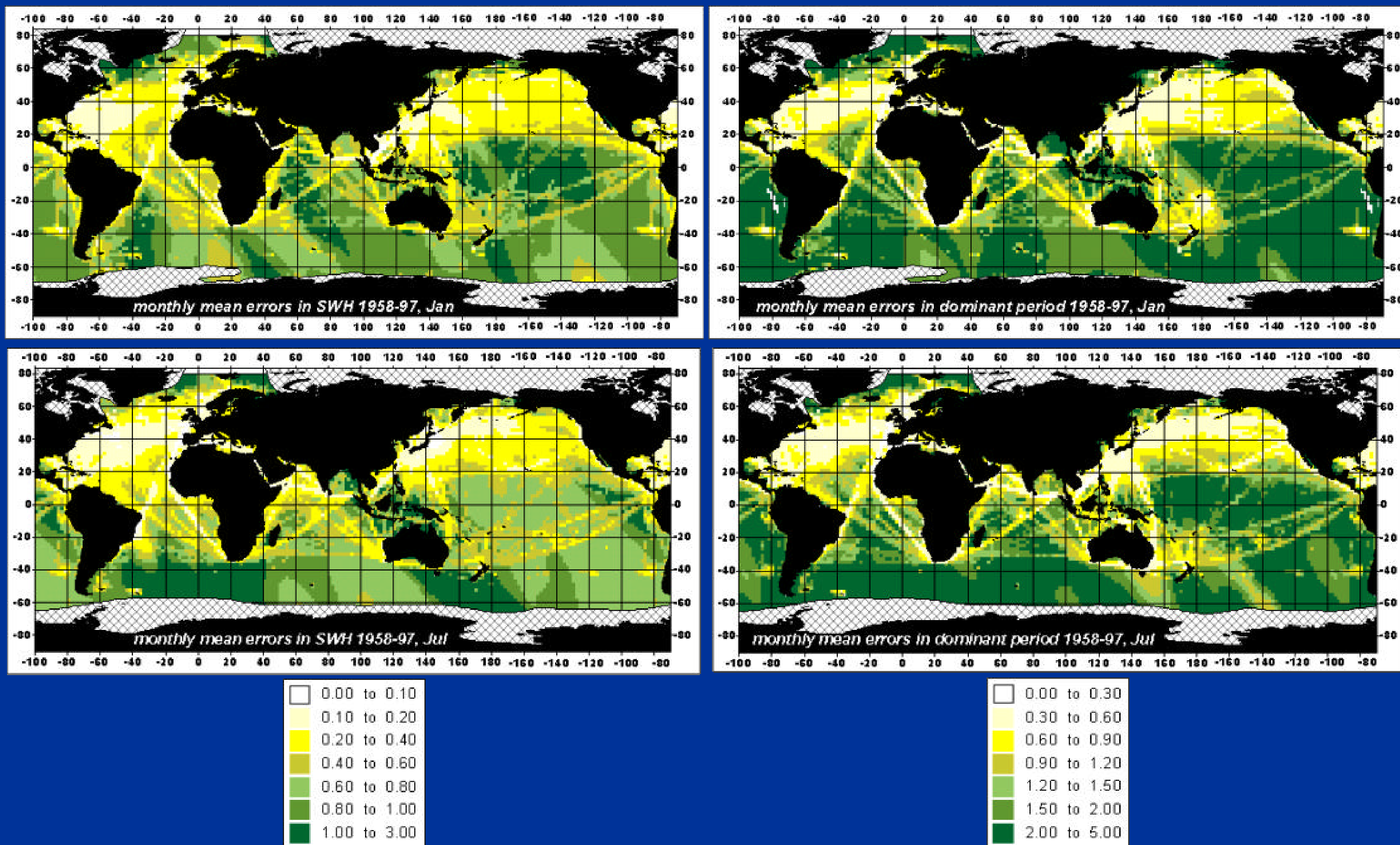
6. Day-time minus night-time biases (Grigorieva and Gulev 2004)

A global VOS waves climatology (1958-2002):

http://www.sail.msk.ru/atlas/index.htm

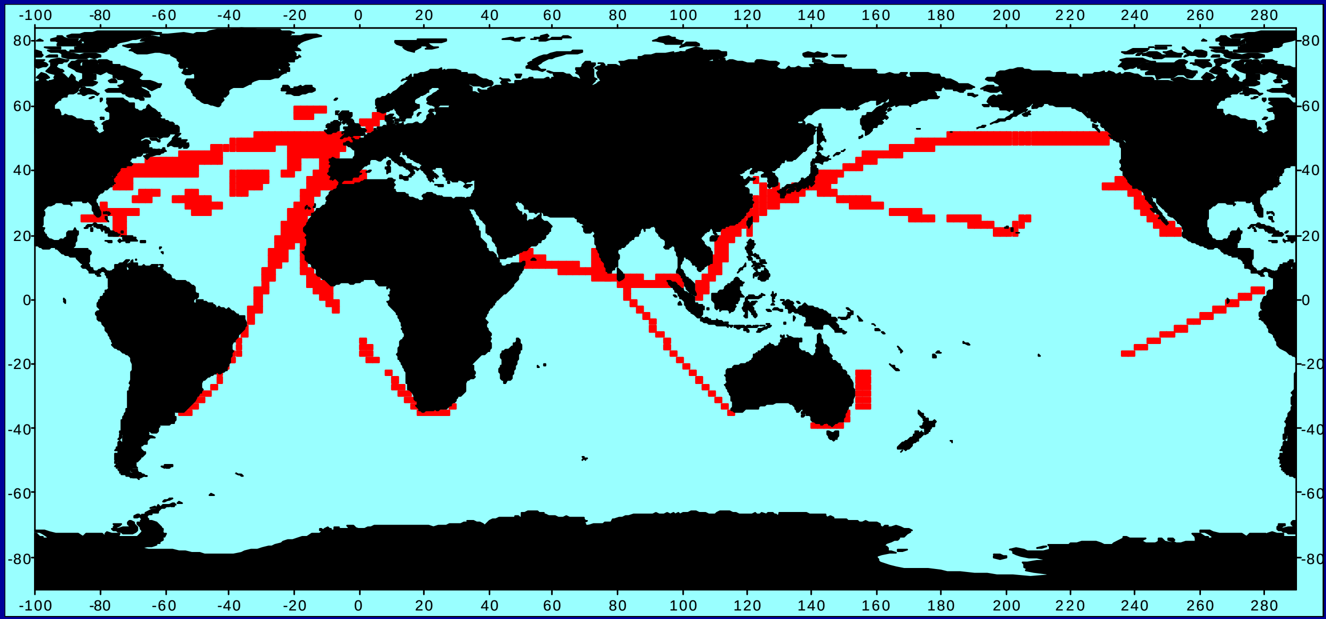


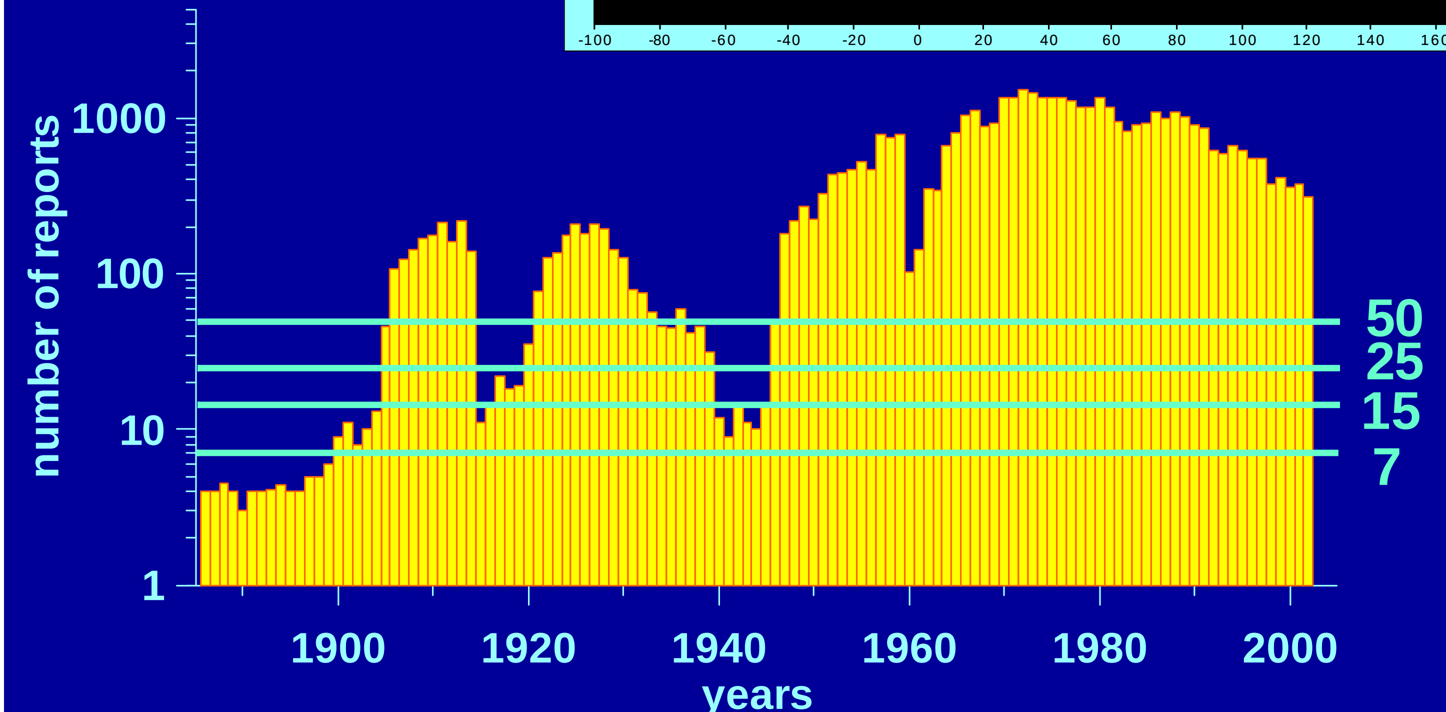
Total random (observational + sampling) errors



Very long-term changes along the major ship routes

65 regions with high sampling during 1885-2002

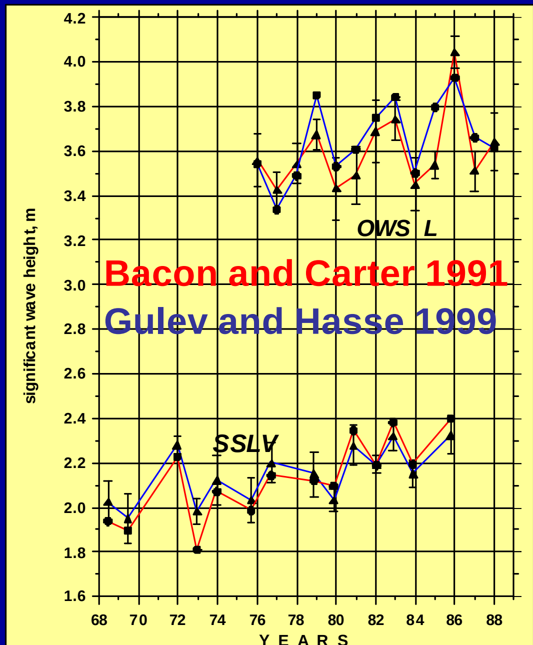


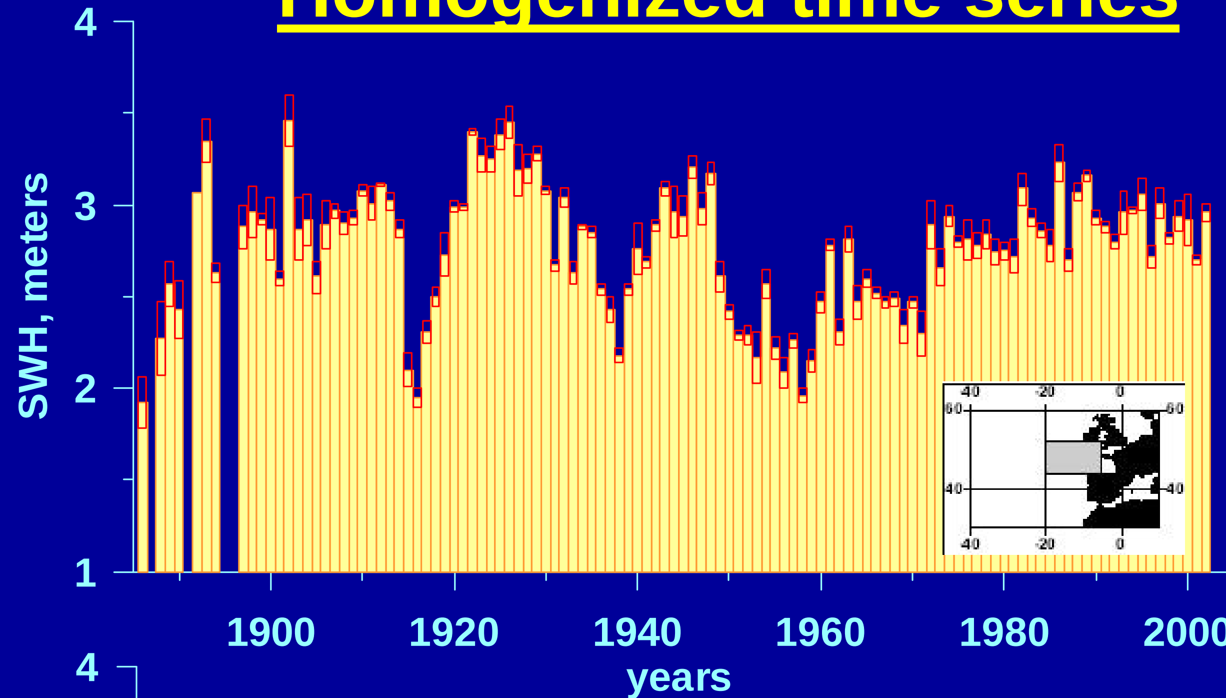


Homogenization:

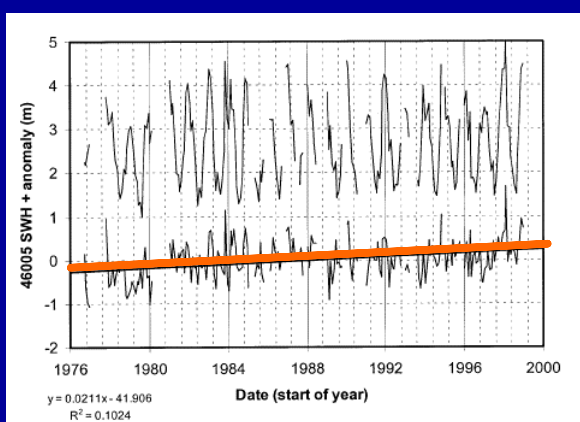
sub-sampling for 7,15,25,50 reports per region per month

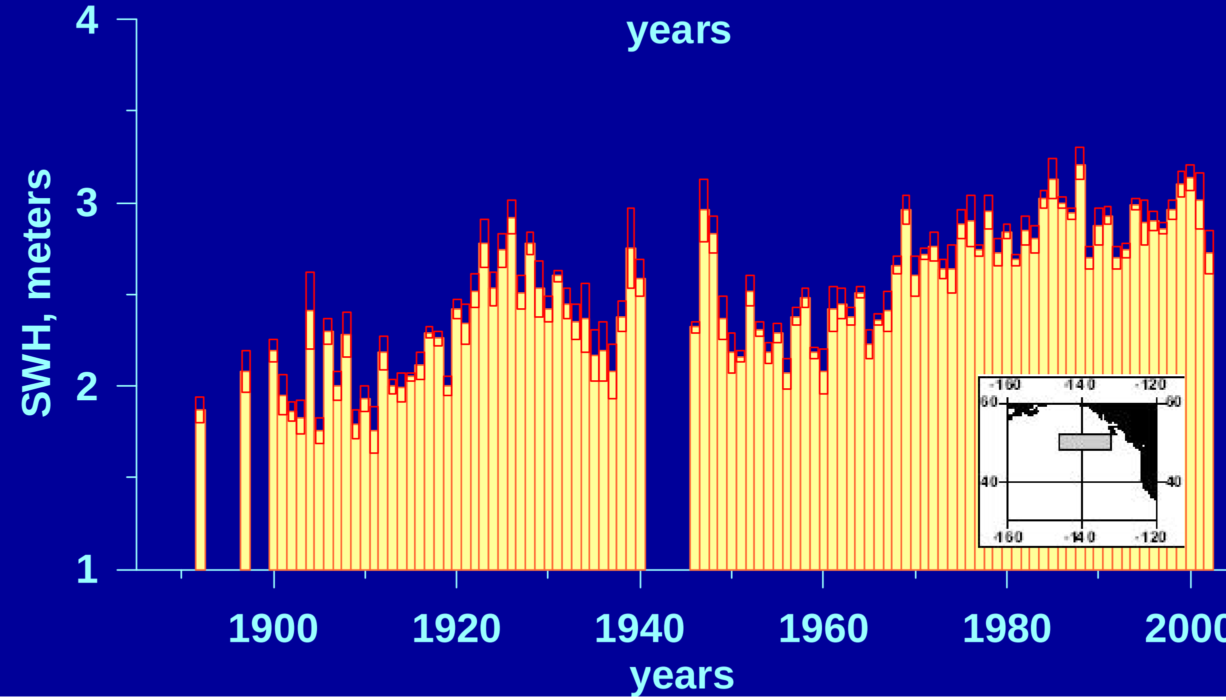
Homogenized time series





Buoys: Gower 2002:



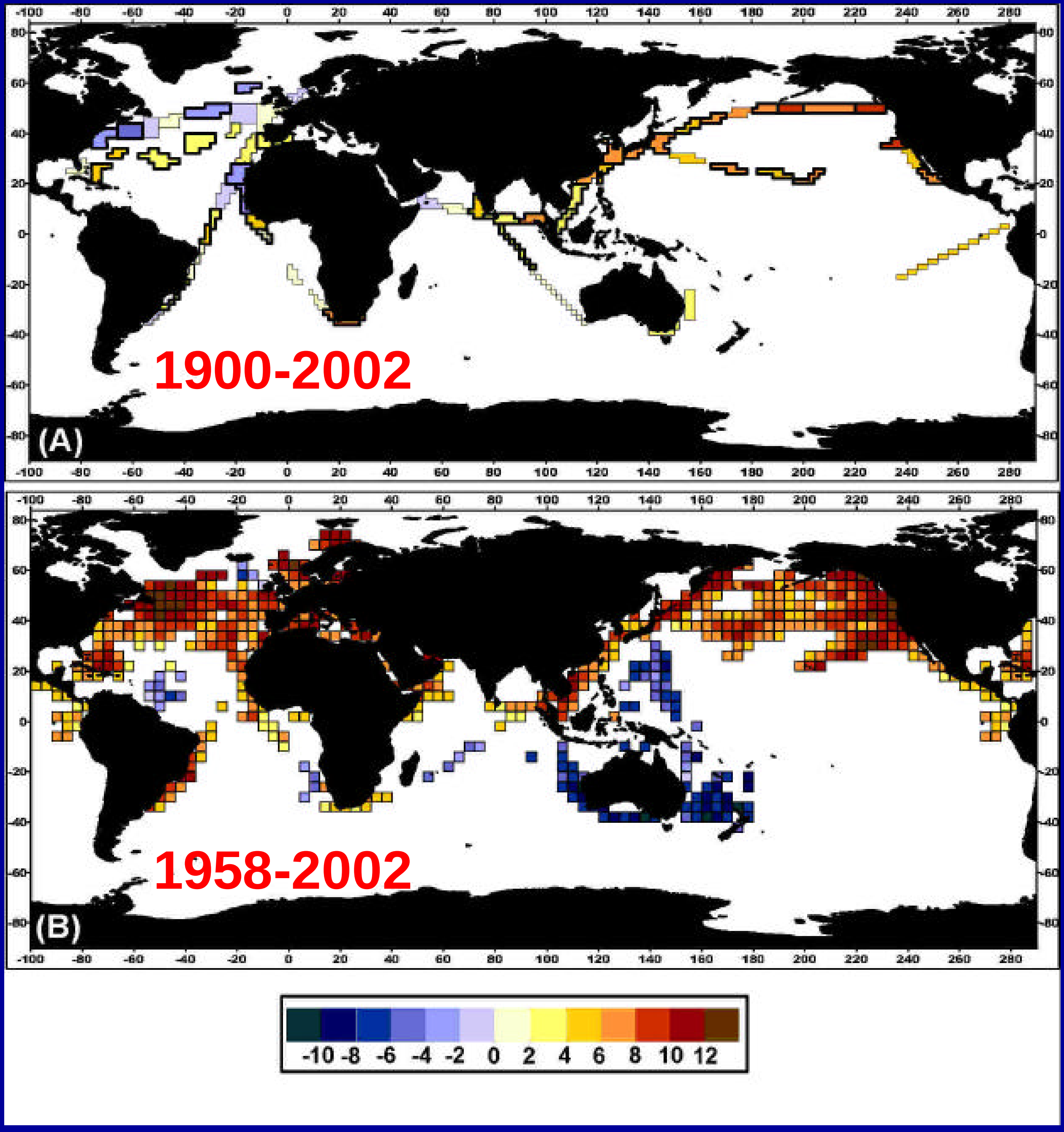


Linear trends:

Significance:

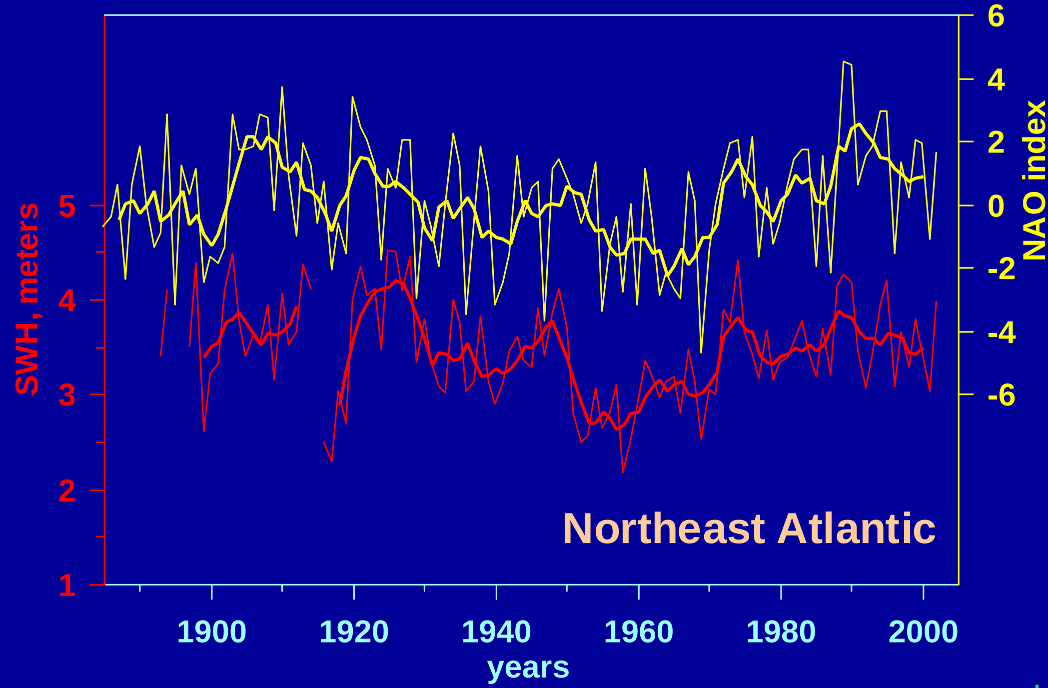
1. Student *t*-test
2. Hayashi ratio
3. Wilcoxon test
4. No difference between sub-sampled time series

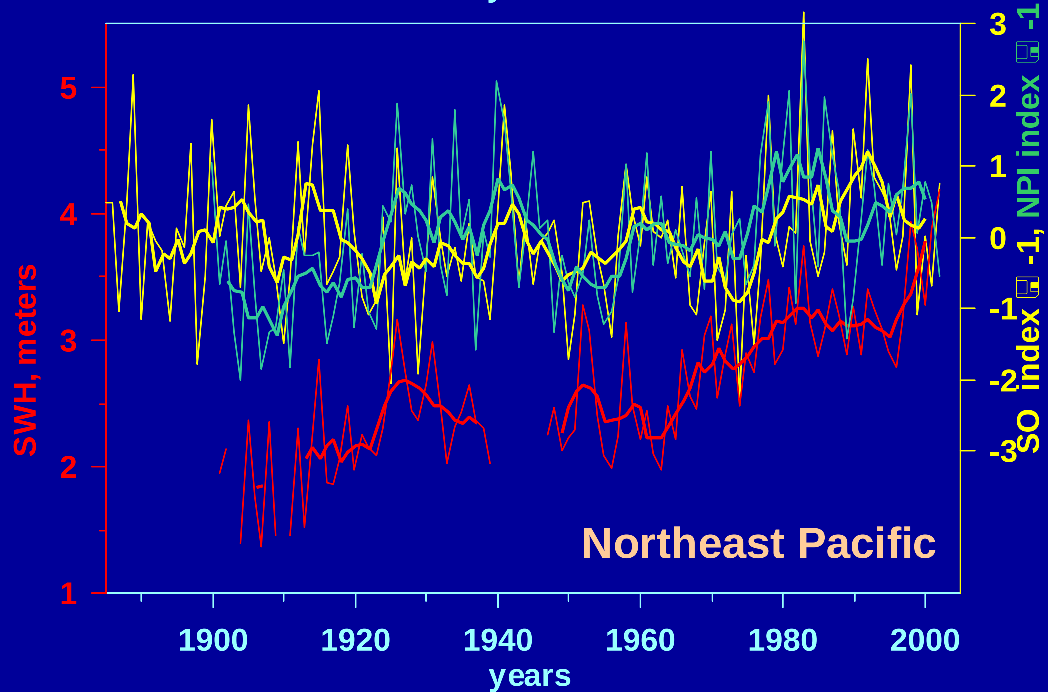
(1)+ (2) + (3) + (4)
95% >3 95% 90%



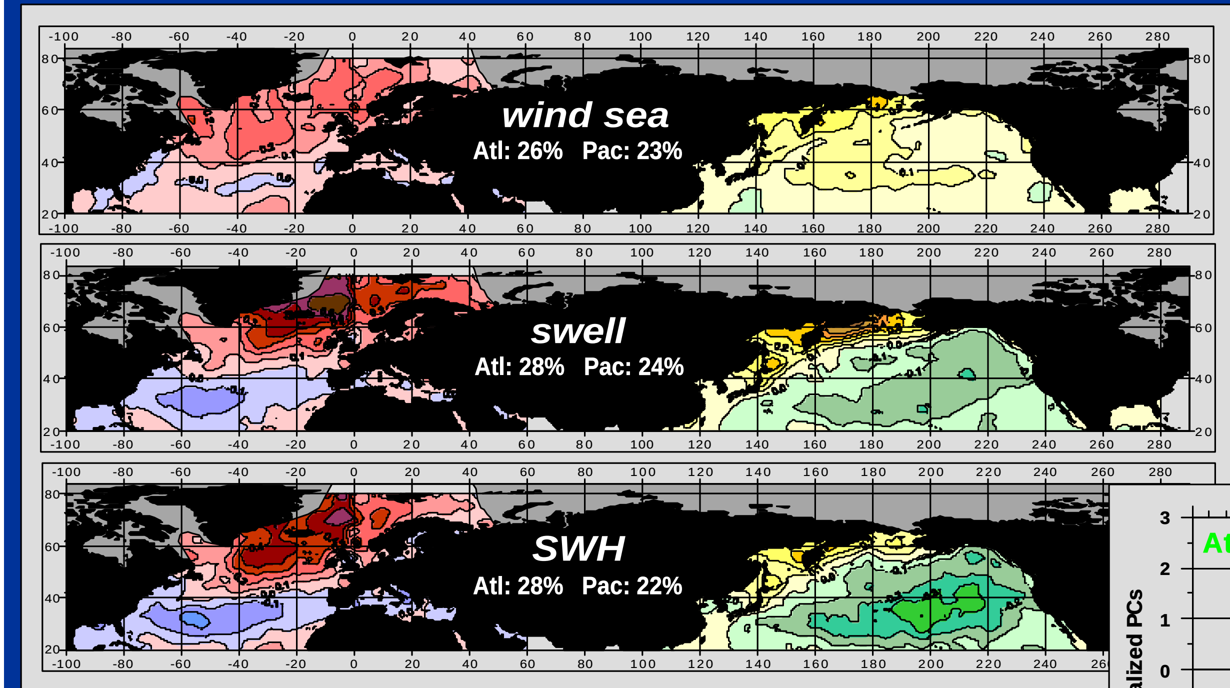
Link of the winter variability in SWH

- to the NAO index in the Atlantic (r=0.68)
- NPI (r=0.66) and SOI (r=0.47) in the Pacific

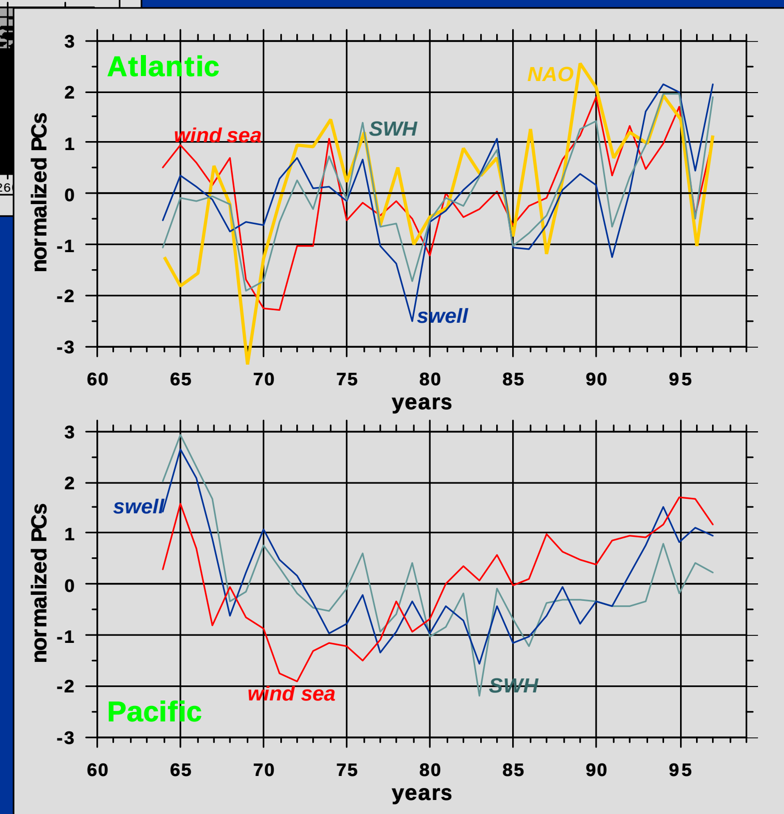




Variability of wave heights: winter (JFM) EOFs

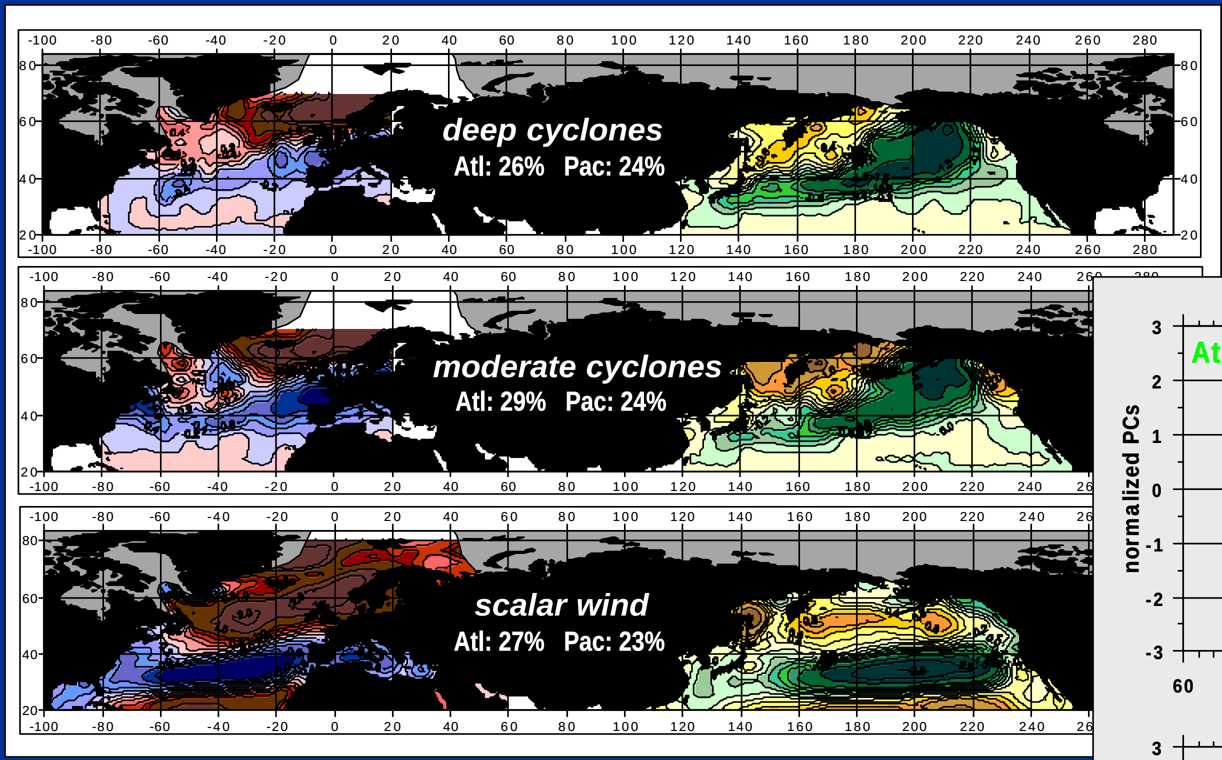


Sea and swell demonstrate different patterns of variability, especially in the Pacific.

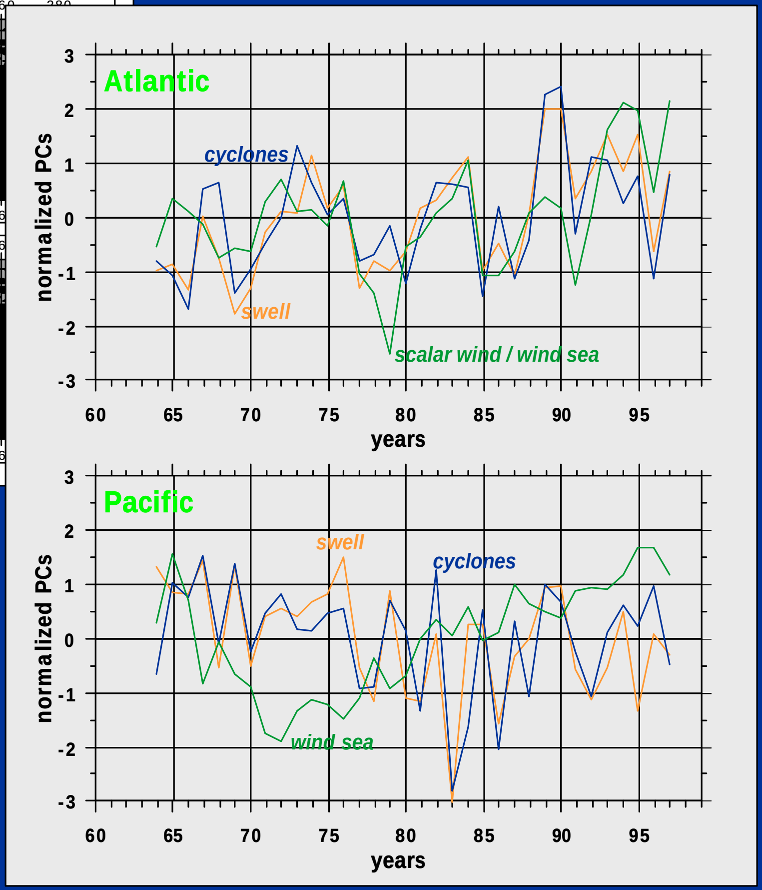


The leading PCs are also different for sea, swell and SWH.

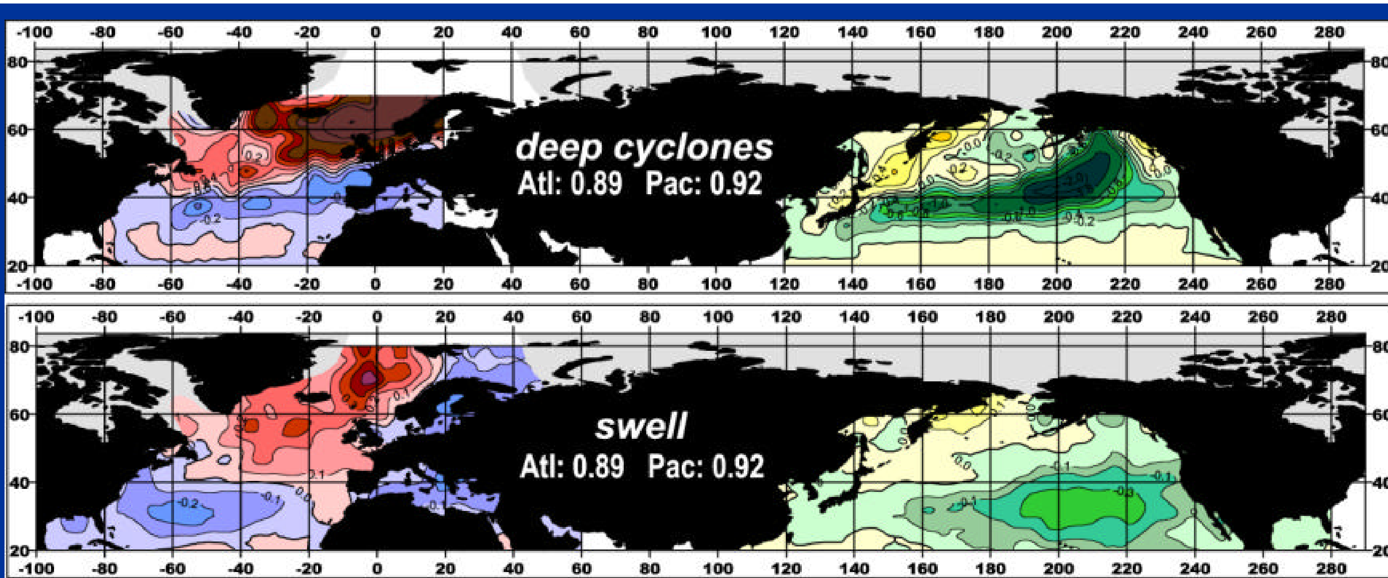
Interannual variability of cyclone frequency and scalar wind 1st EOFs



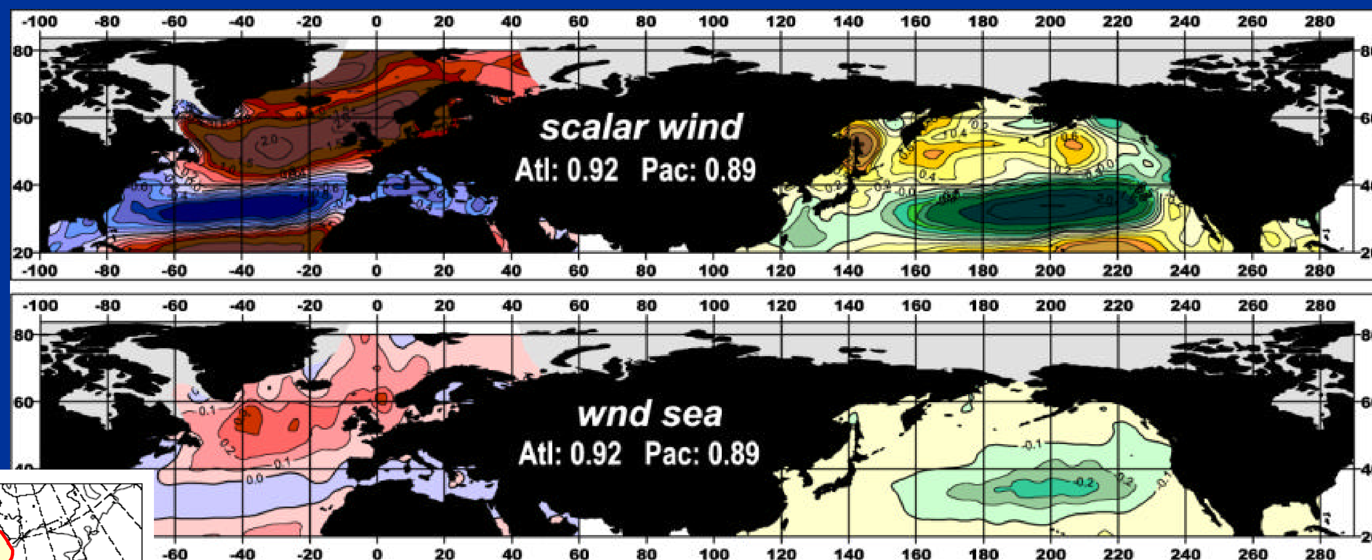
1st EOFs

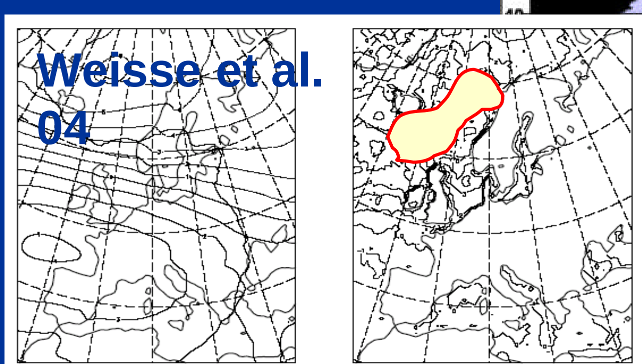


Normalized PCs

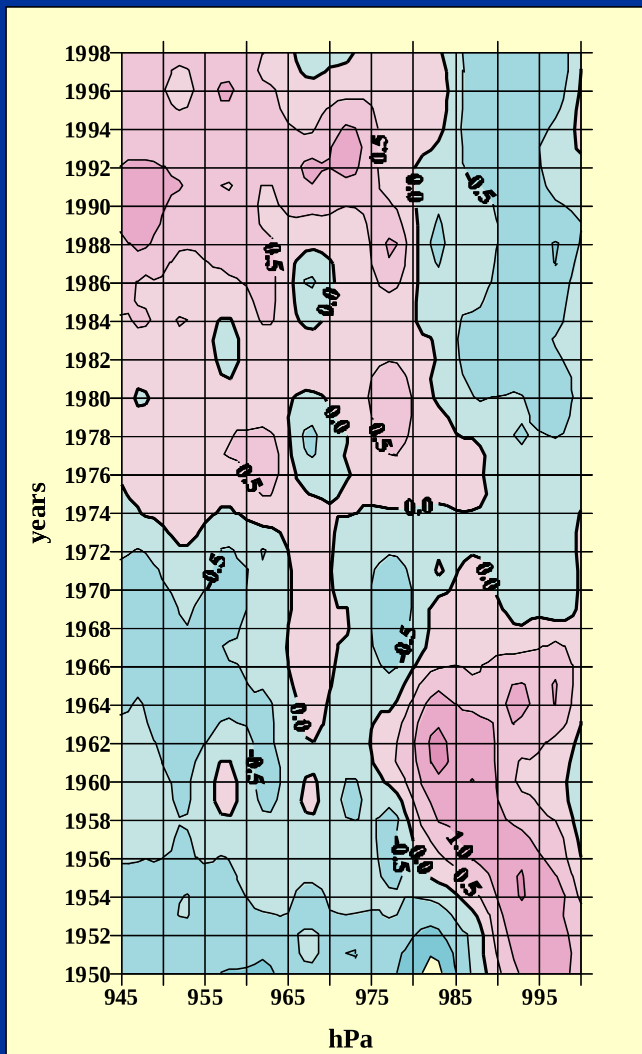


Canonical patterns

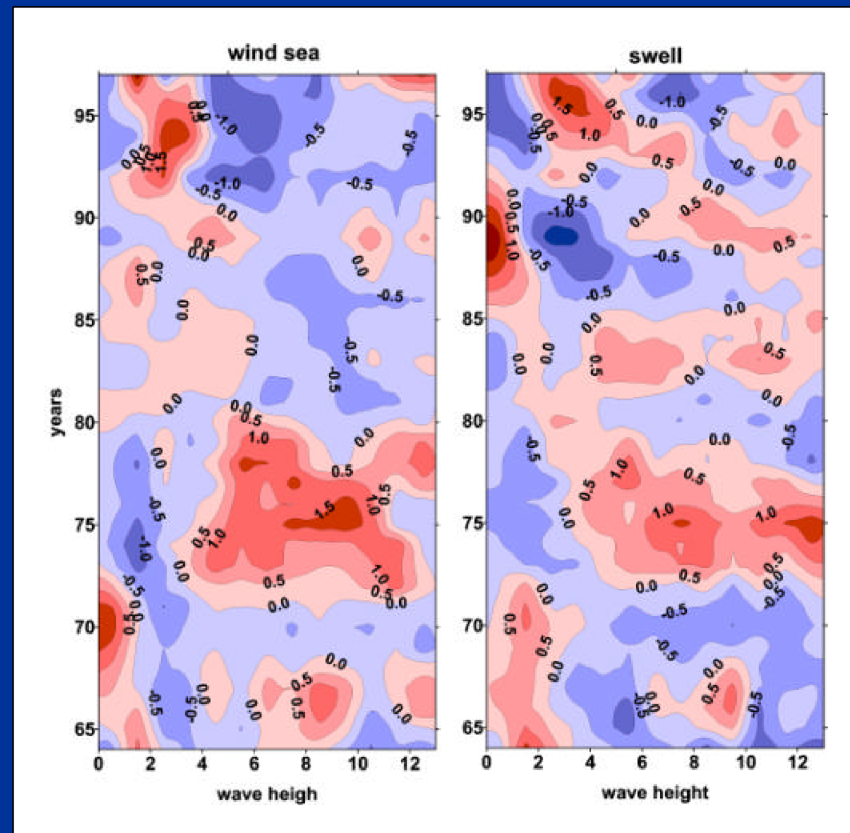


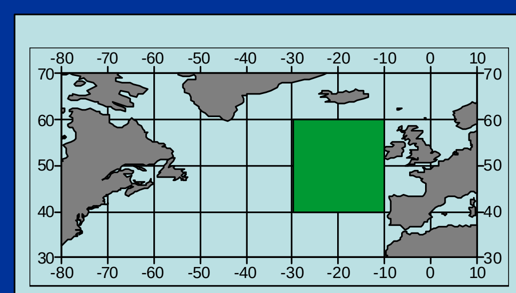


Changes in statistical properties of sea, swell, SWH and cyclone intensity



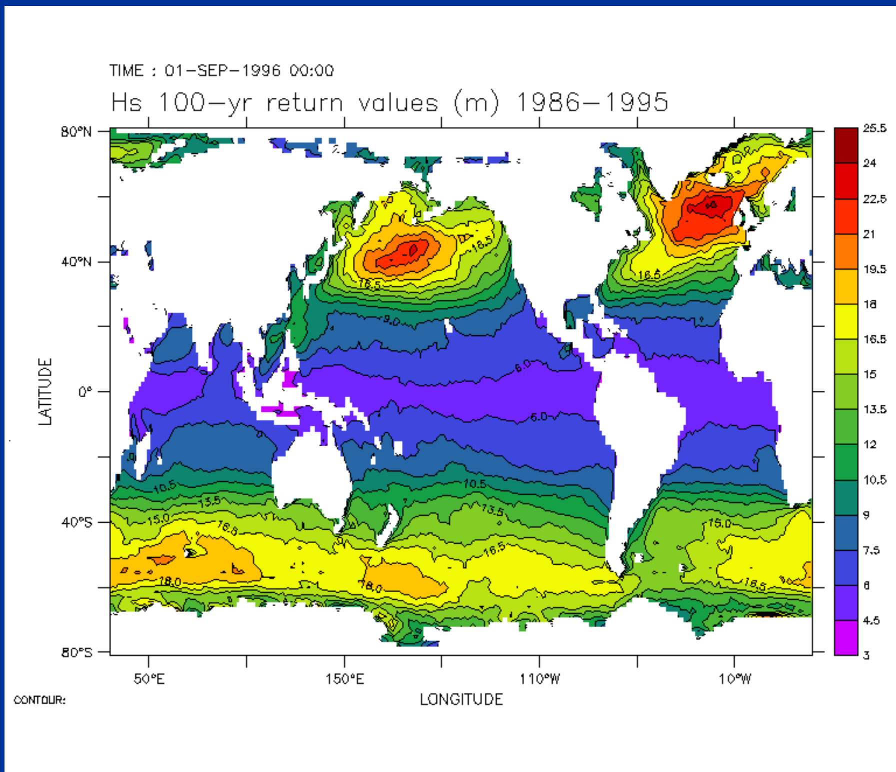
Cyclone frequency: NE Atlantic





100-yr returns from WAM and altimetry: POT/GPD

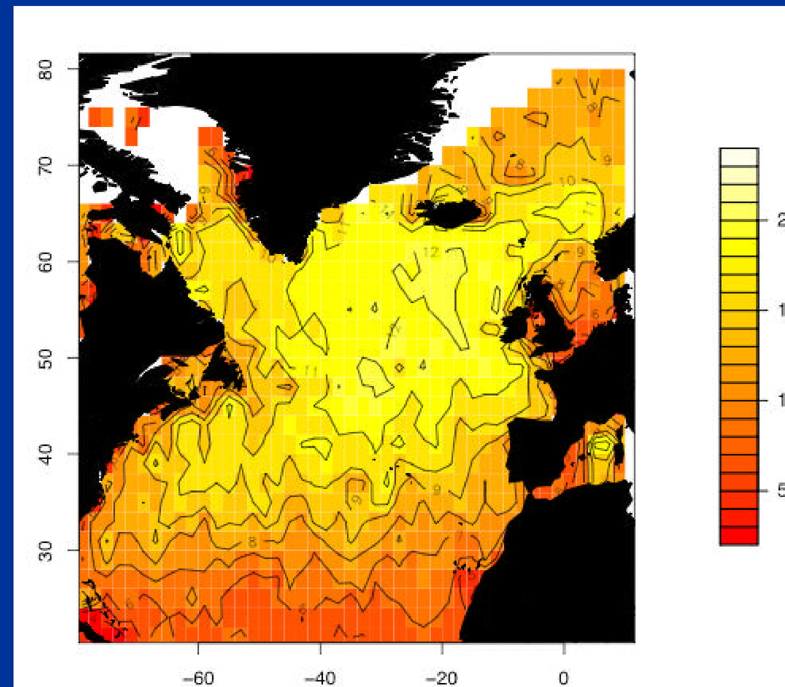
ERA-40-WAM



Caires and Sterl 2004

Grid-point time series: easy to deal with

TOPEX/POSEIDON altimeter



Challenor et al. 2004

Take medians of satellite tracks, 12-hourly virtual storm time is assigned for each

Extreme waves from VOS: problem of estimation

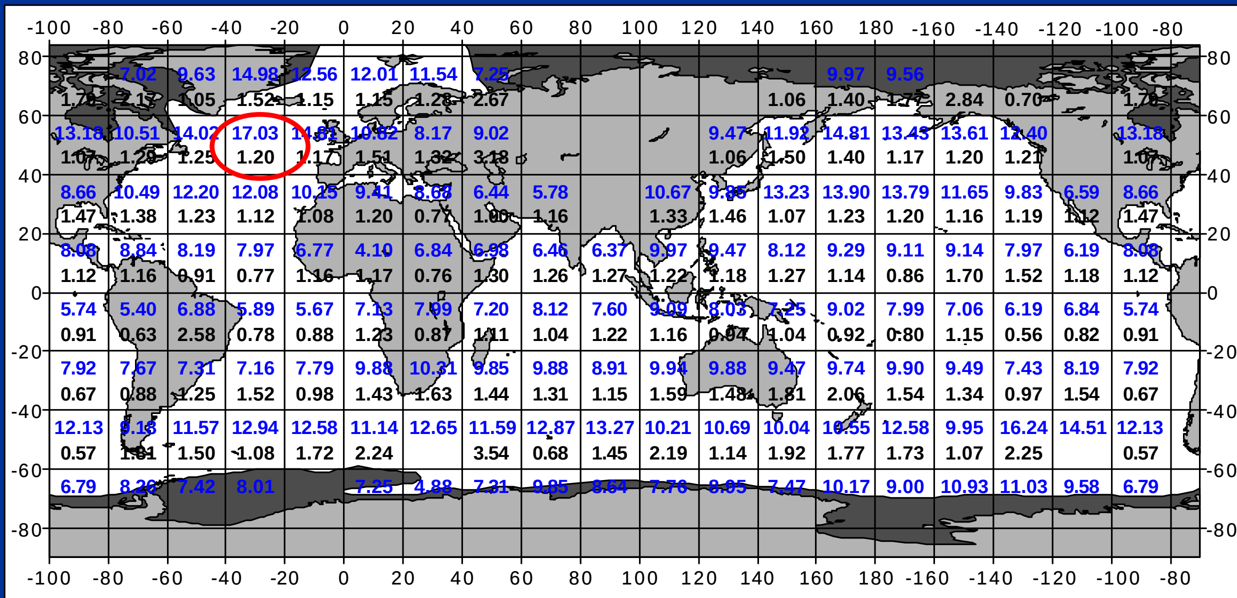
IDM – initial distribution method –

methodologically, most relevant for VOS, but does not allow for reliable estimation of extreme waves

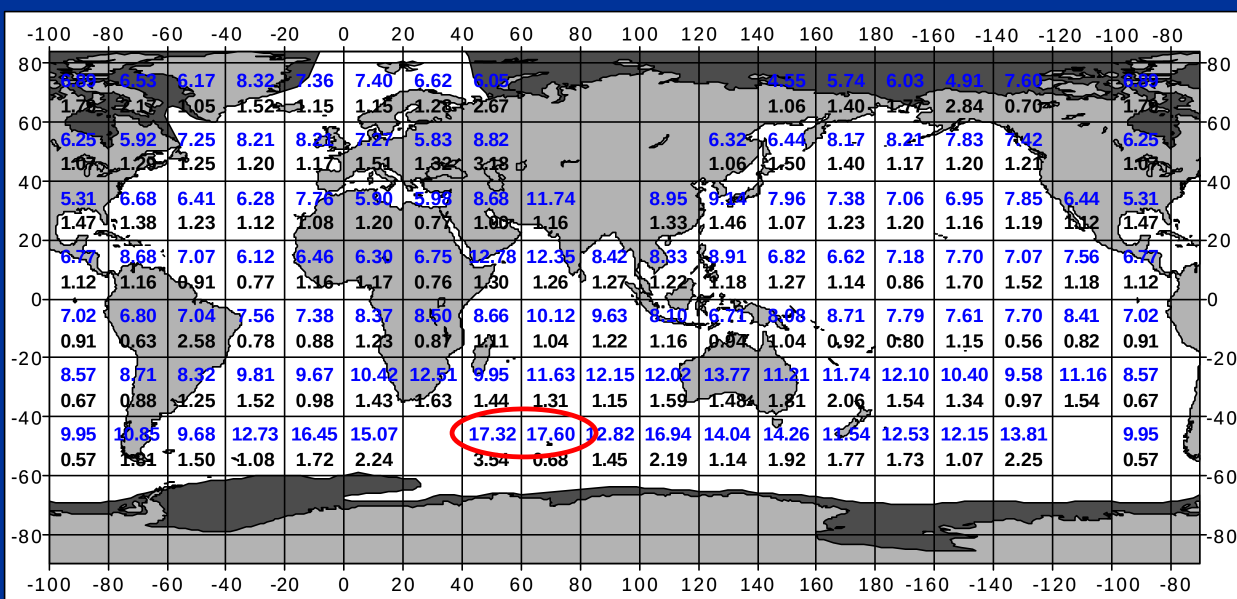
POT – peak over threshold –

requires estimation of the virtual storm duration

VOS 100-yr returns: IDM

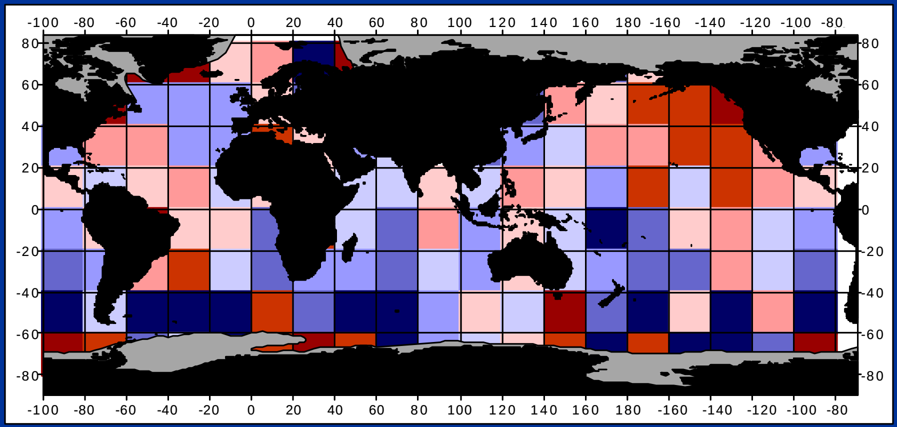


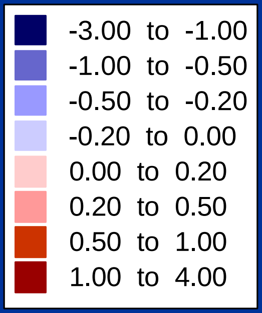
Winter 100-yr SWH return (best estimate from tails)



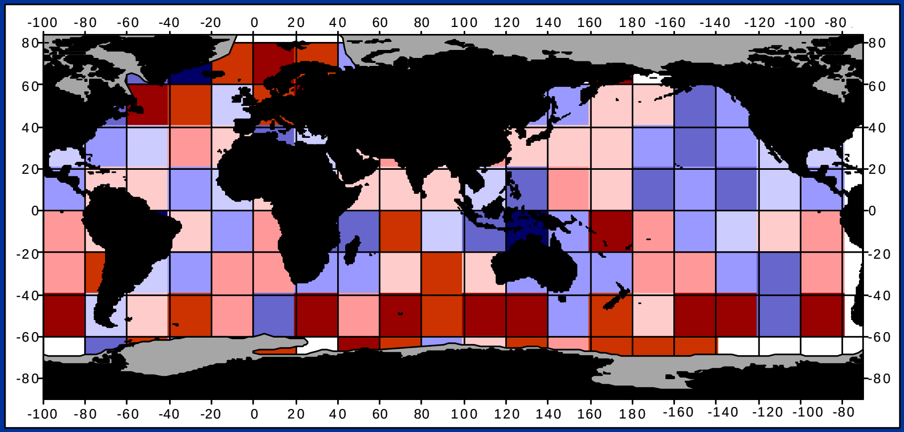
Summer 100-yr SWH return (best estimate from tails)

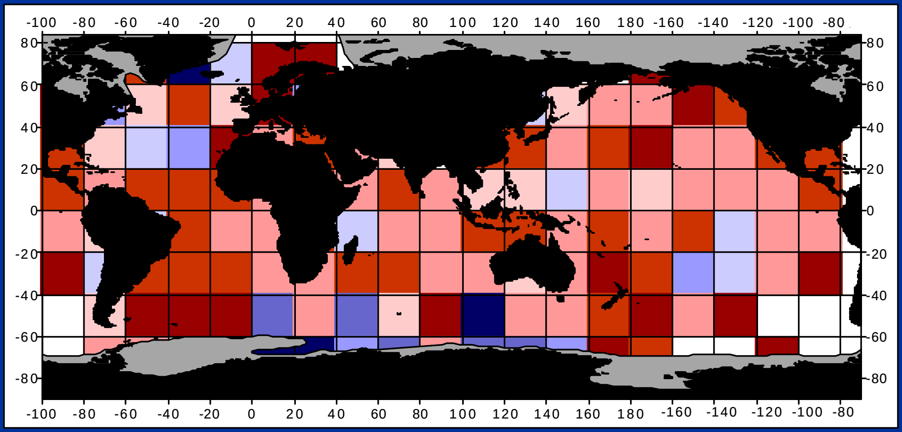
Changes in extreme wave heights: 100-yr returns





Winter 100-yr SWH difference between the best estimates from 1980s and 1970s

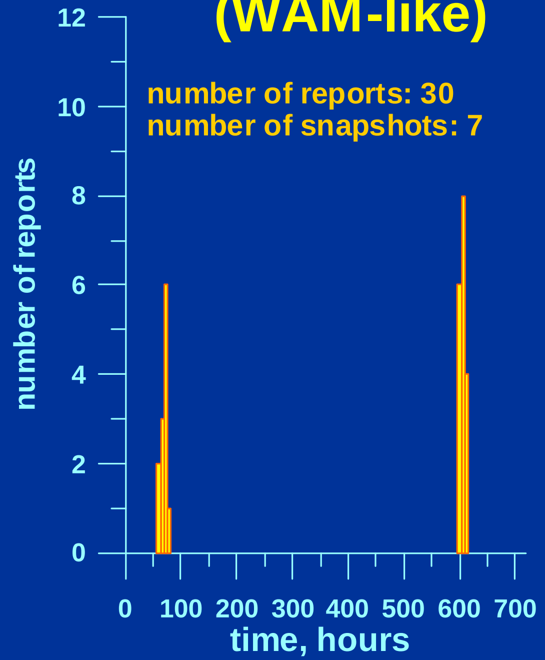


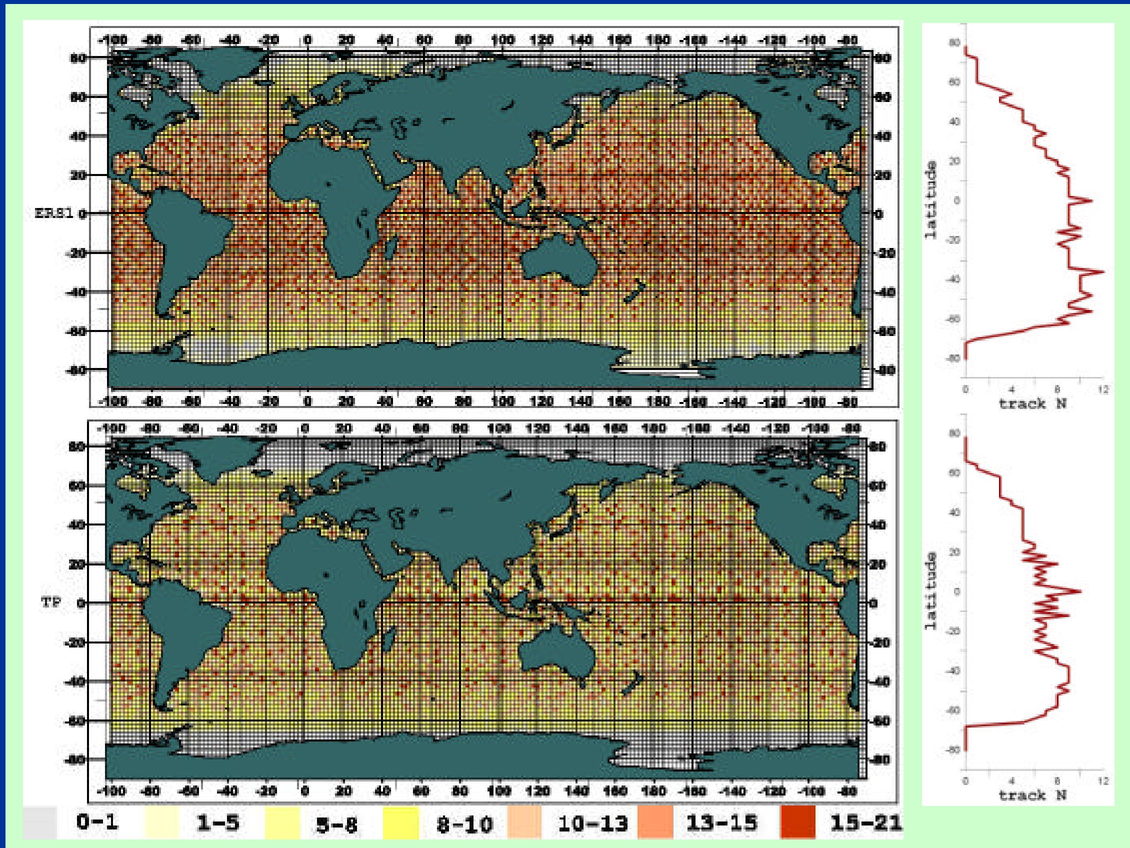


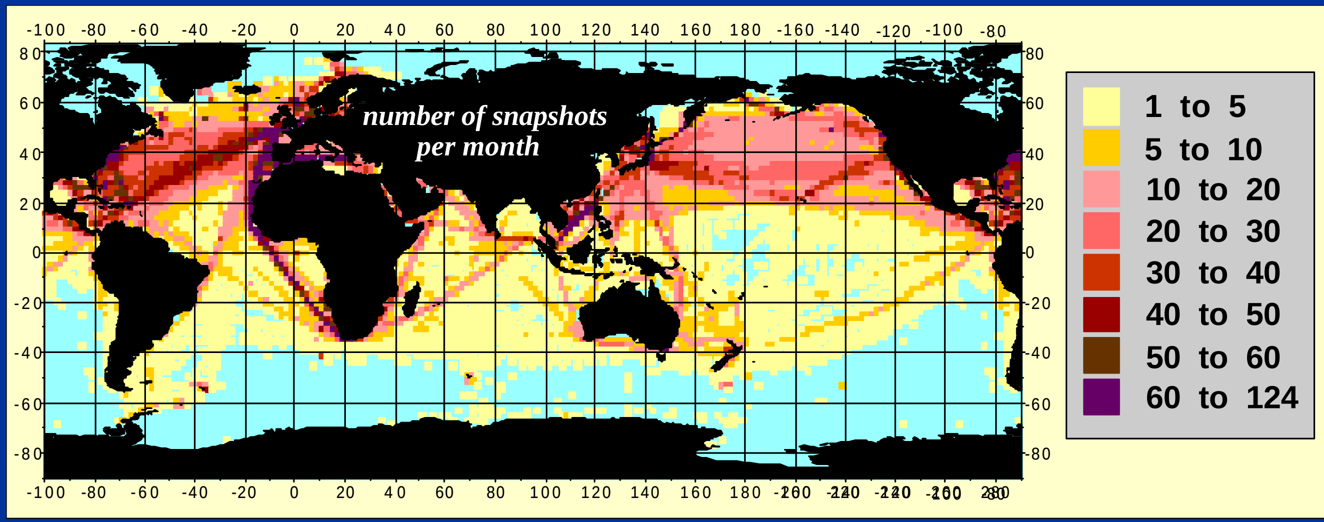
Winter 100-yr SWH difference between the best estimates from 1990s and 1980s

Winter 100-yr SWH difference between the best estimates from 1990s and 1960s

The number of 6-hourly snapshots in VOS data (WAM-like)



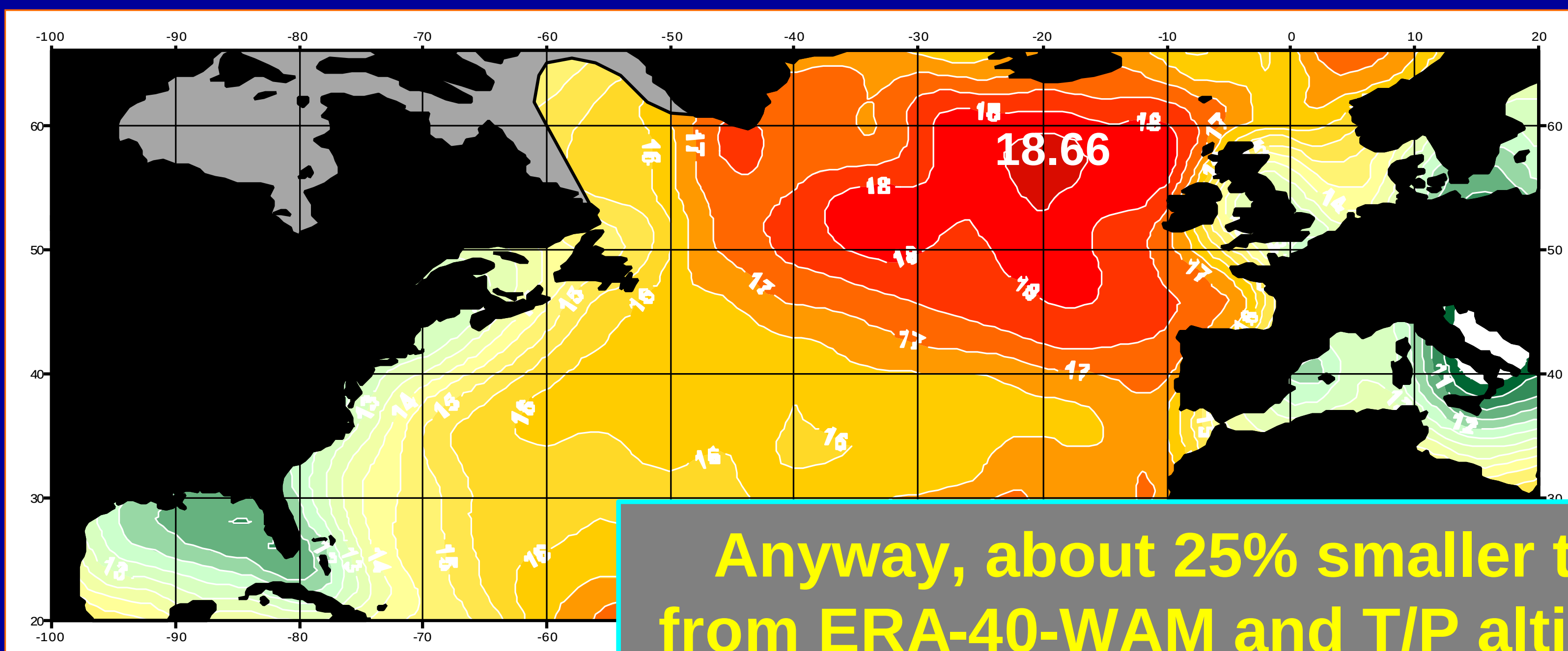




Estimation of 100-yr returns from POT/GPD based on the simulation of 6-hourly snapshots

Problems:

- threshold is assigned to 90% exceedance,
- virtual storm duration was estimated from WAM (see another talk) and was changeable from year to year



Anyway, about 25% smaller than from ERA-40-WAM and T/P altimeter

Conclusions:

To the extent that it is possible to make physical inferences from the VOS visual data:

- ***Visual wave data allow for the analysis of centennial-scale variability of ocean wind wave characteristics: linear trends in the North Atlantic and North Pacific may amount to 1.2 m per century.***

- ***Interannual variability is different for sea and well, forcing frequency (e.g. cyclones) matters.***

- ***Extreme wave statistics from VOS are biased in comparison to those derived from model hindcasts and altimetry, however show quate comparable with WAM decadal variability***