Global Ocean Wave Statistics from VOS: a new dataset and associated Atlas

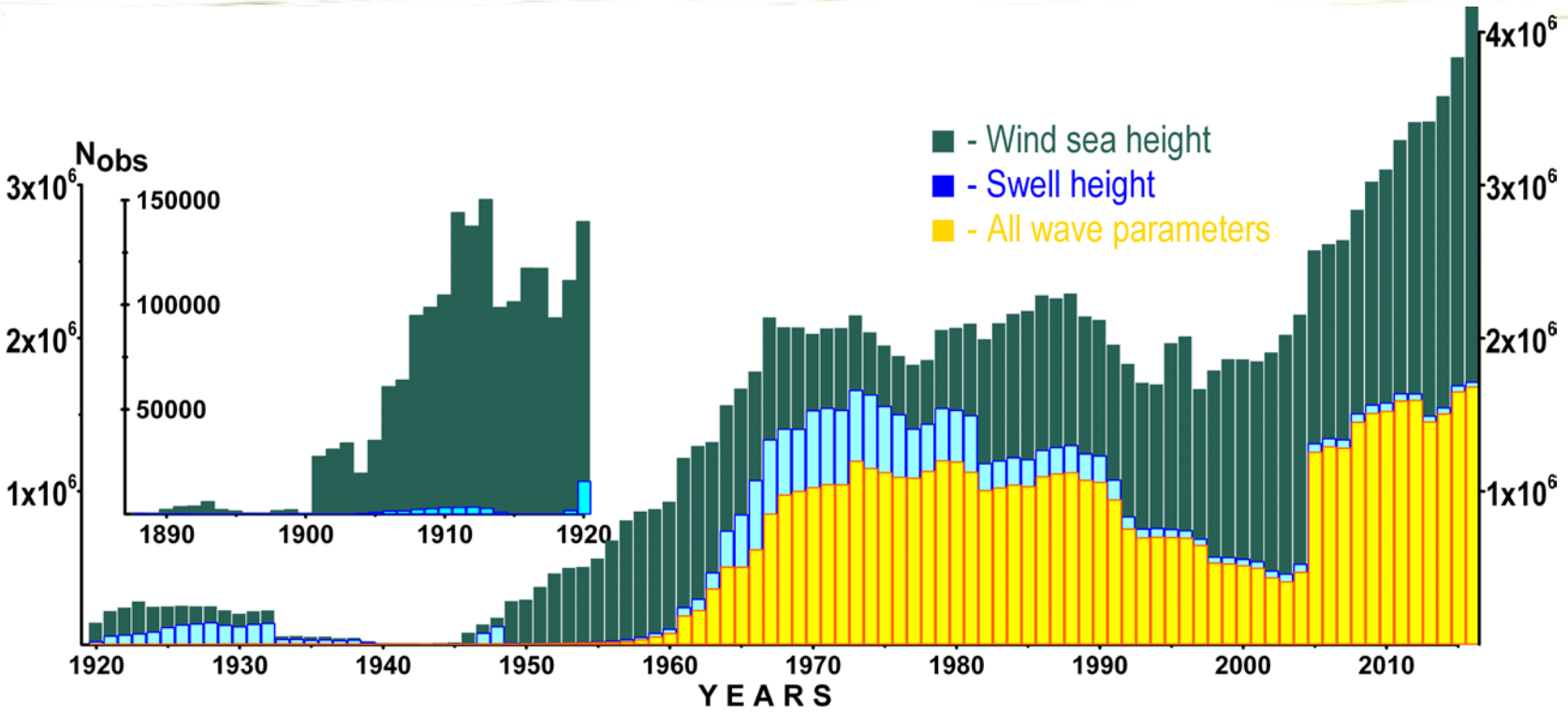
Vika Grigorieva and Sergey Gulev

Sea Atmosphere Interaction And Climate Laboratory P. P. Shirshov Institute of Oceanology, Russia

Outline:

- ICOADS version 3.0 Voluntary Observing Ship (VOS) data
- Global climatologies of wave characteristics: wind sea, swell, SWH
- Inhomogeneities associated with changes in the coding systems
- Long term trends and extremes

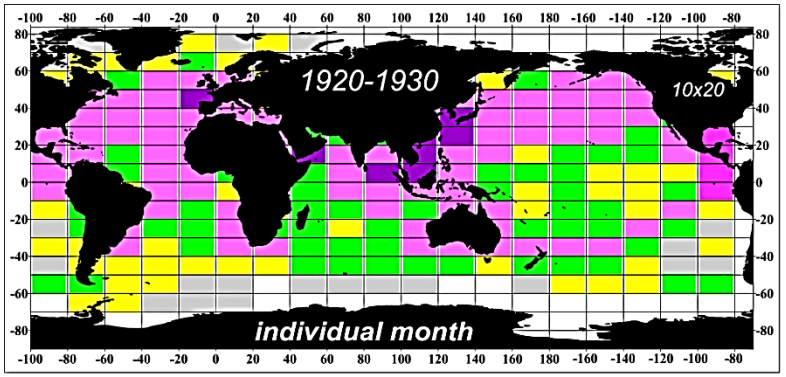
Waves in VOS : (1888-2016)

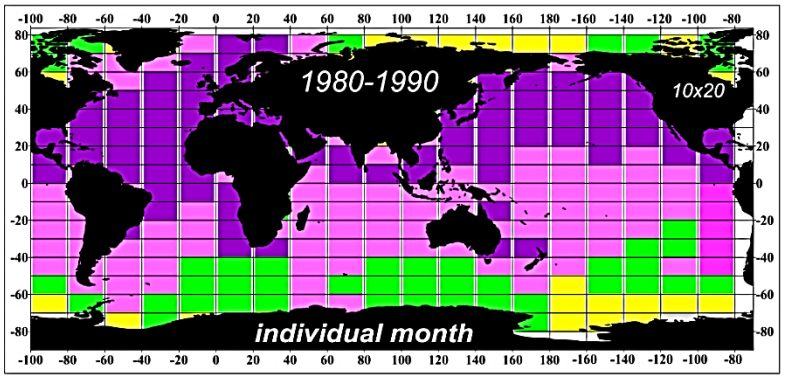


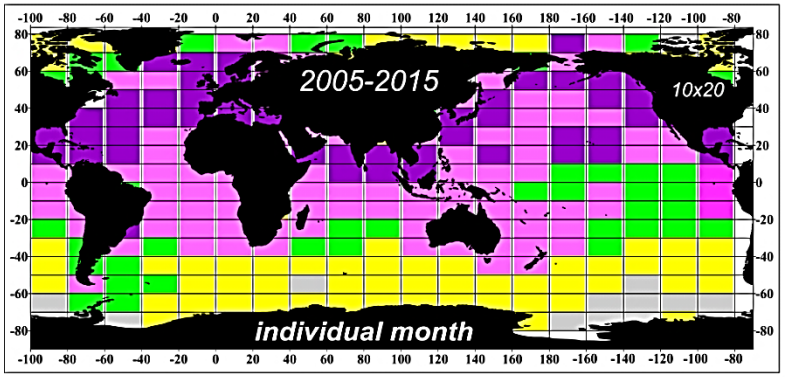
parameter	VOS	Altimetry	NDBC
Wave height	0.5 m	0.4 m (or 10%)	0.2 m (or 5%)
Wave period	1 s	–	≥1 s
Wind speed	1 m/s	1.5 m/s	1 m/s
Direction	10°	17-20°	10°

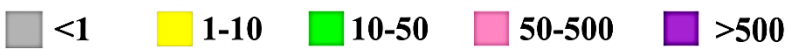
Observational density 1900-2015

WIND SEA









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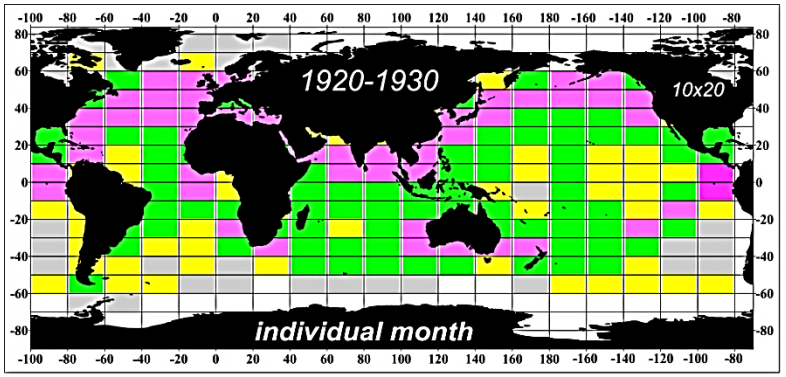
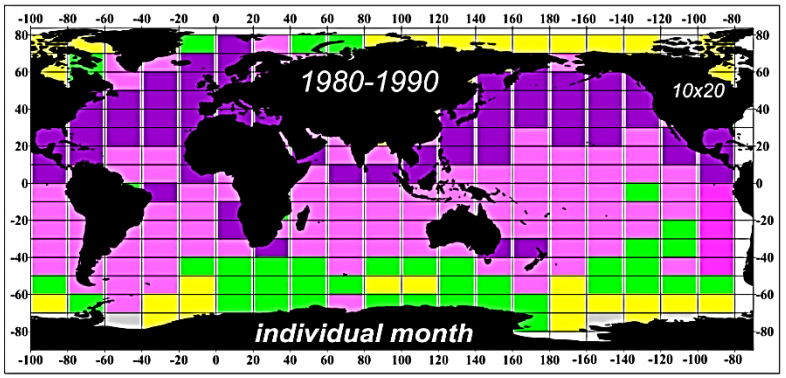
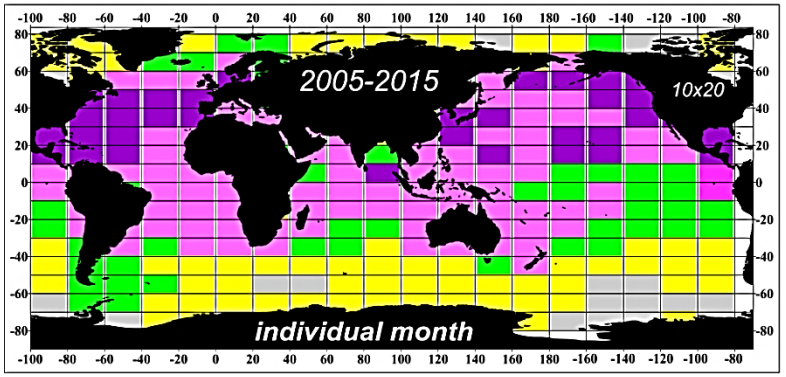
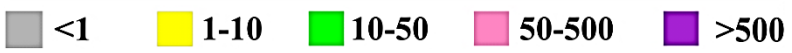
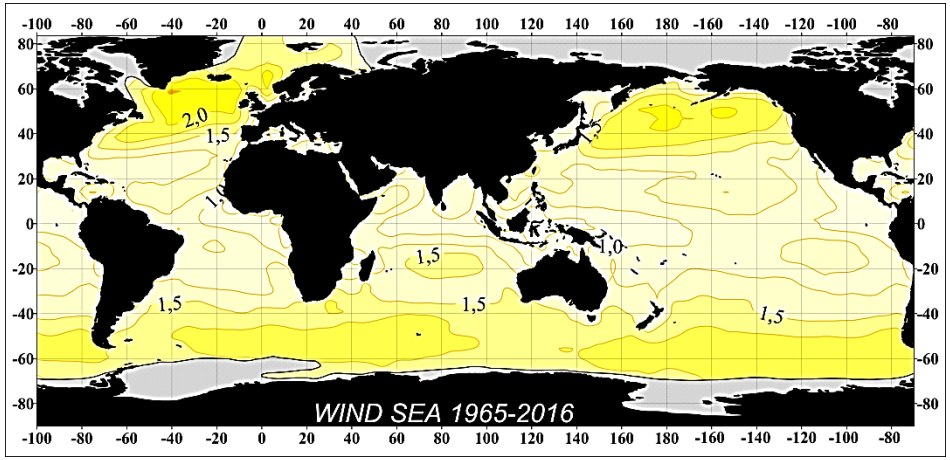


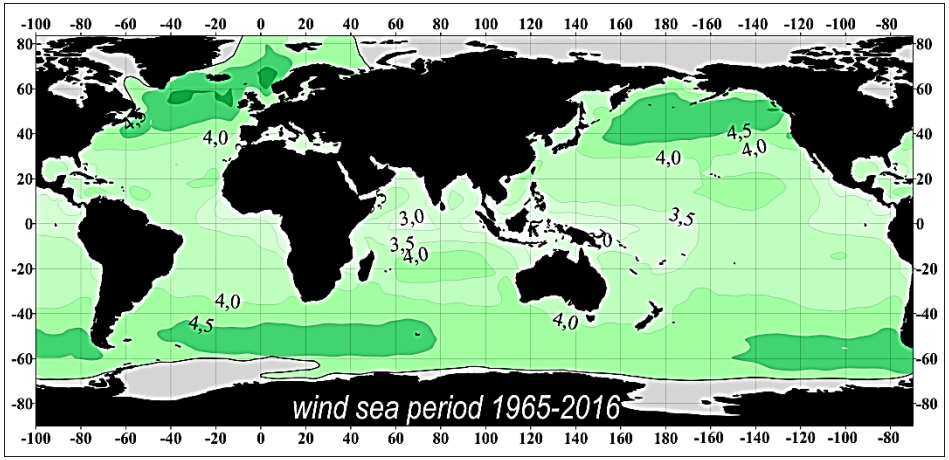


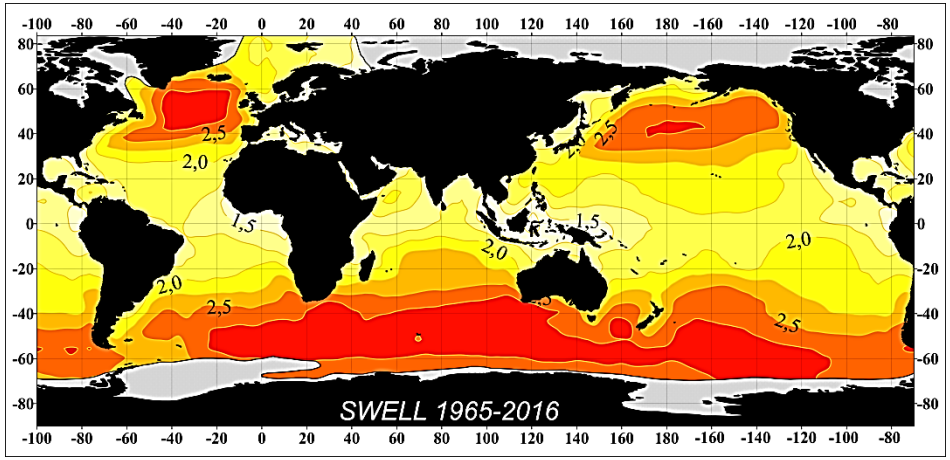


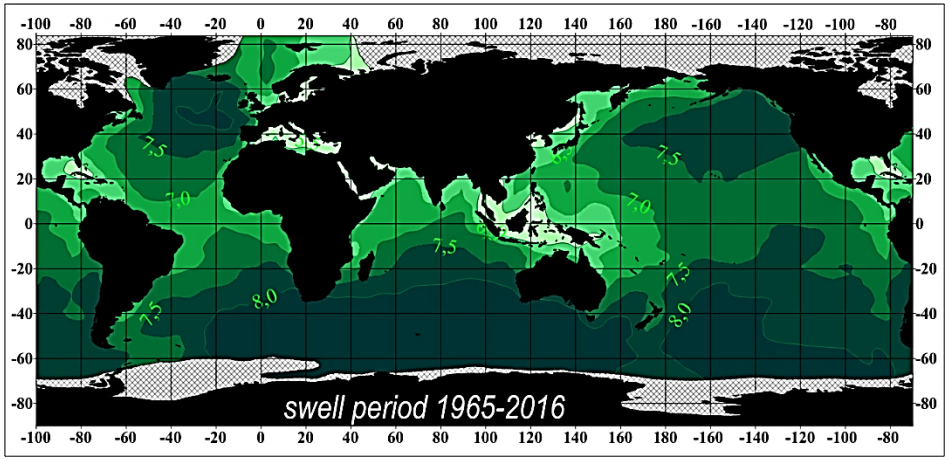


Global Wind Wave Climatology 1965-2016

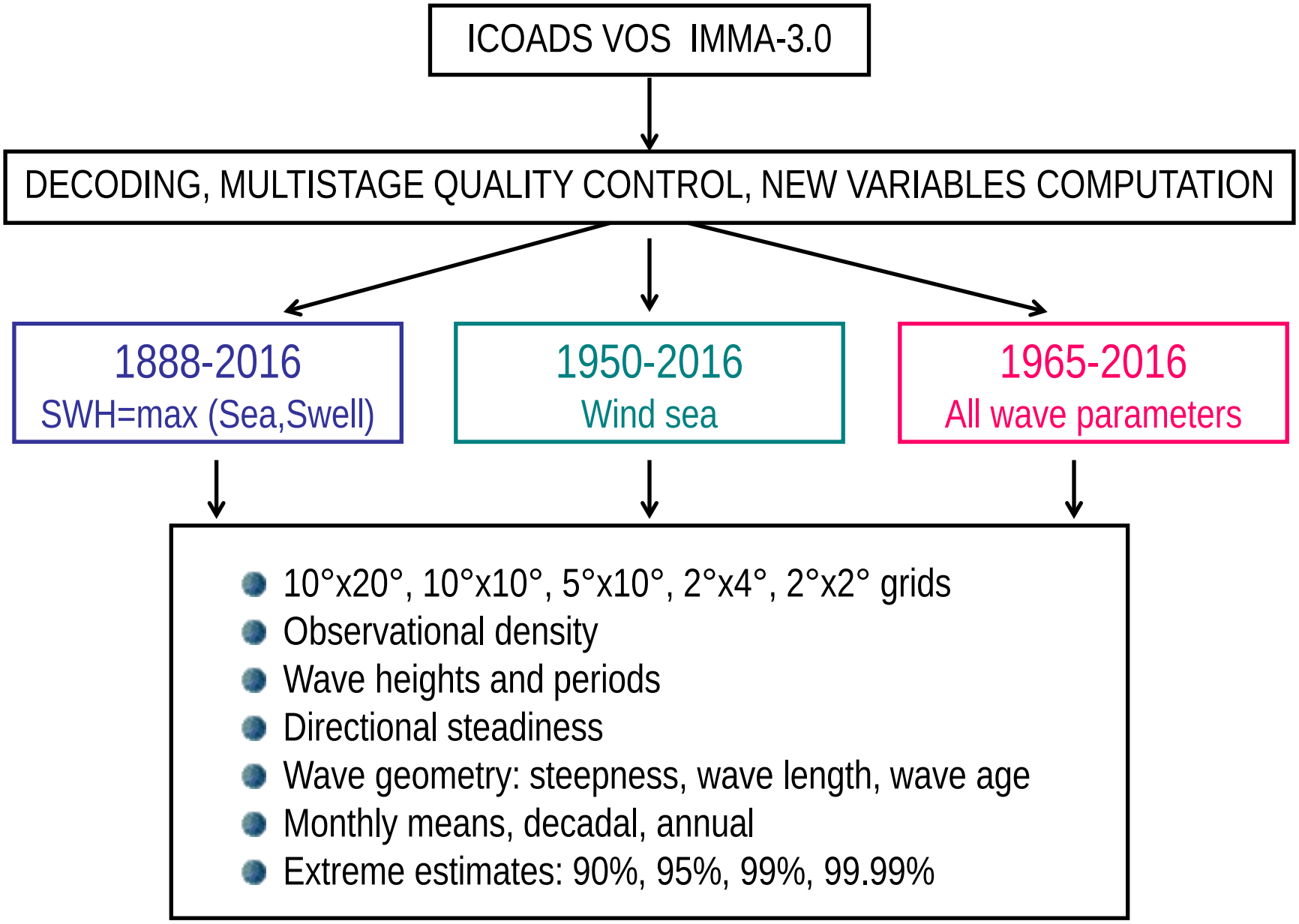




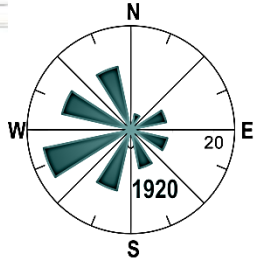


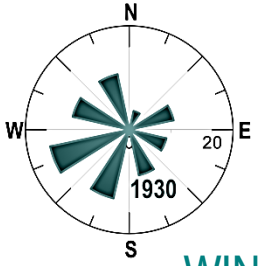


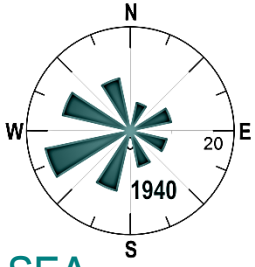
Multi-stream Wave Climatology 1888-2016

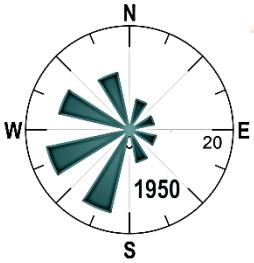


Wave directions (from where)

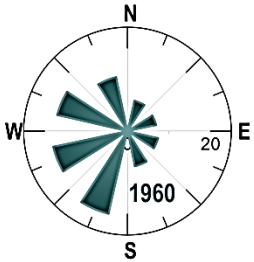


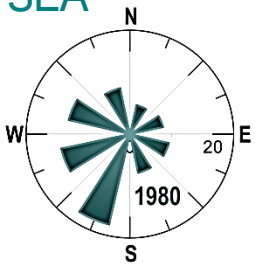


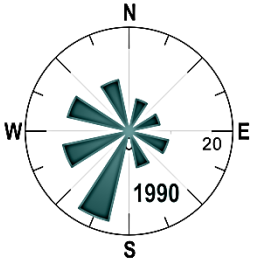


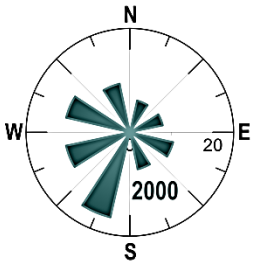


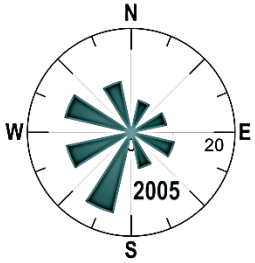
WIND SEA

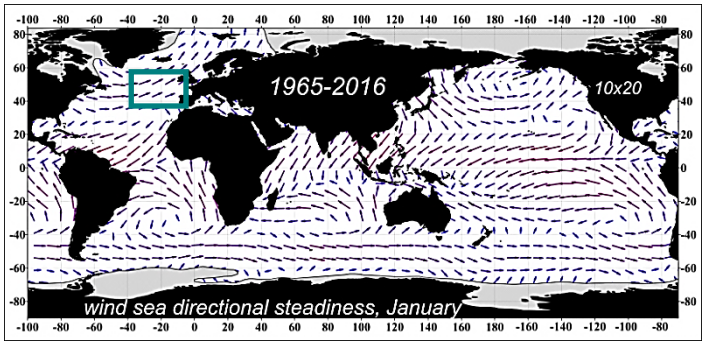


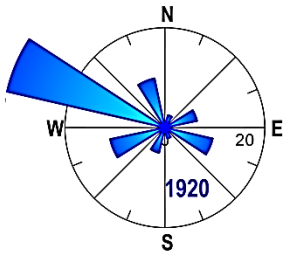


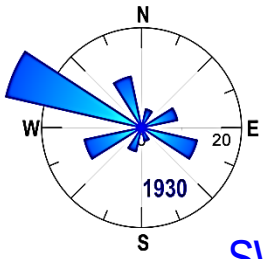


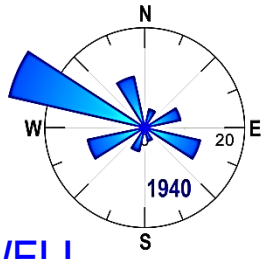


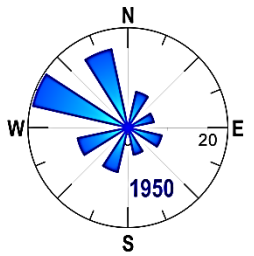




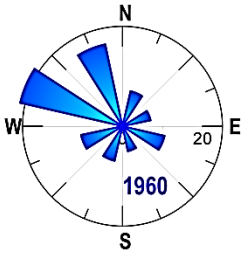


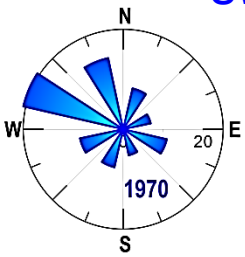


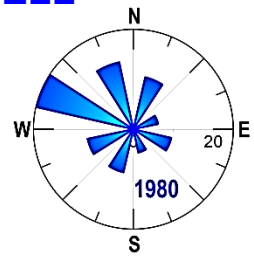


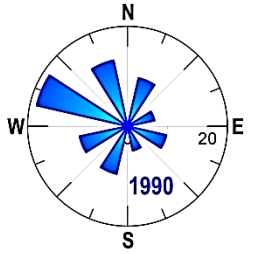


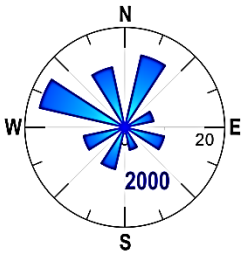
SWELL

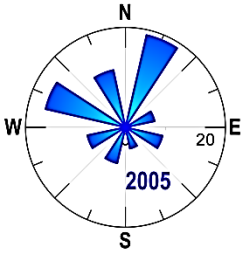


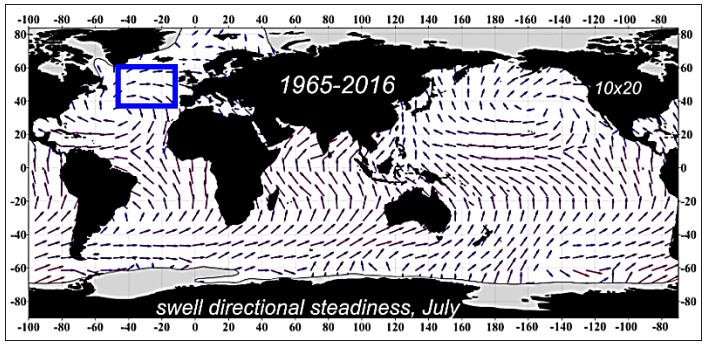






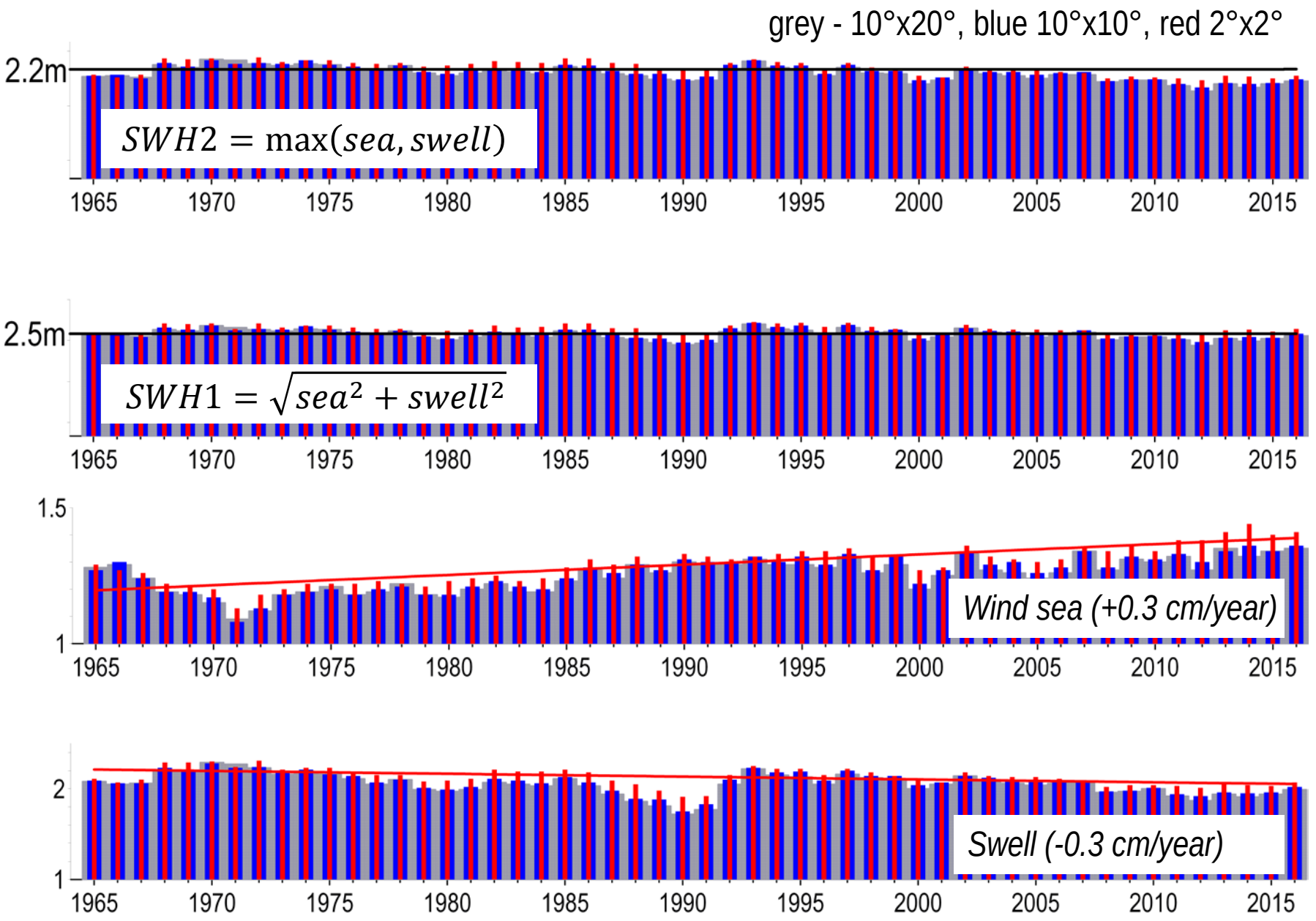




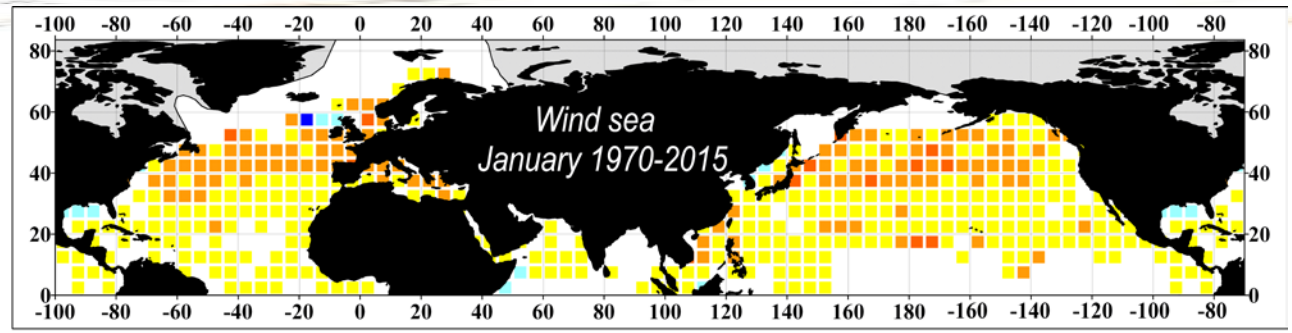


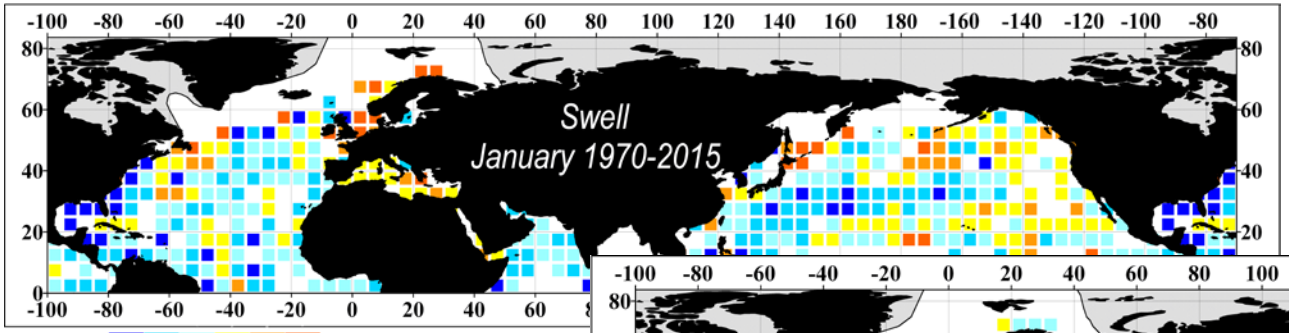
20°- 40° W
50°- 60° N

Global average 1965-2016

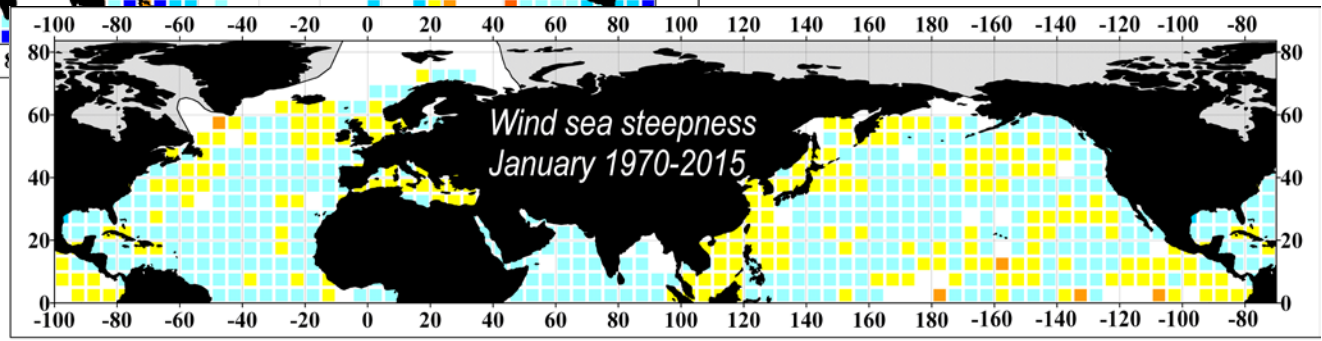


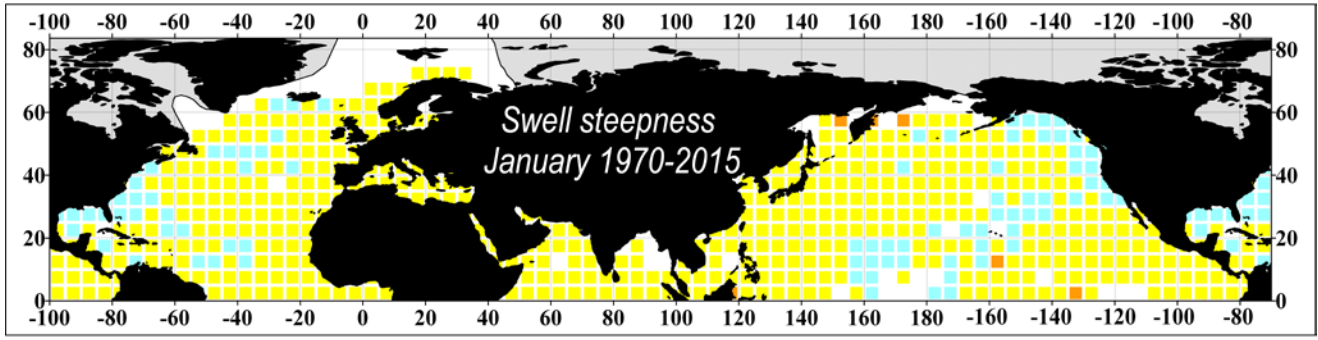
Long term trends





Wind sea are growing of about 0.1-0.4 cm/year in the Northern Hemisphere oceans but
swell is slightly decreasing (-0.1-0.6 cm/year)

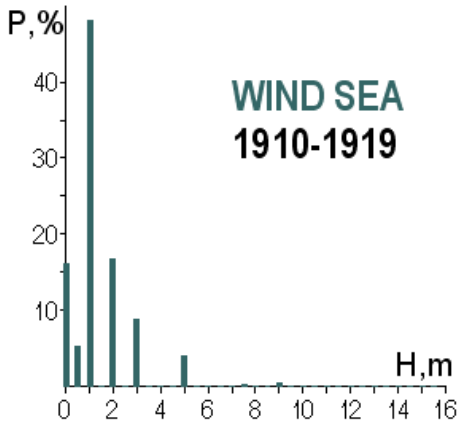


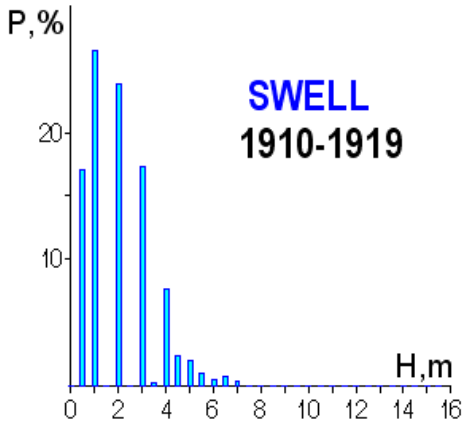


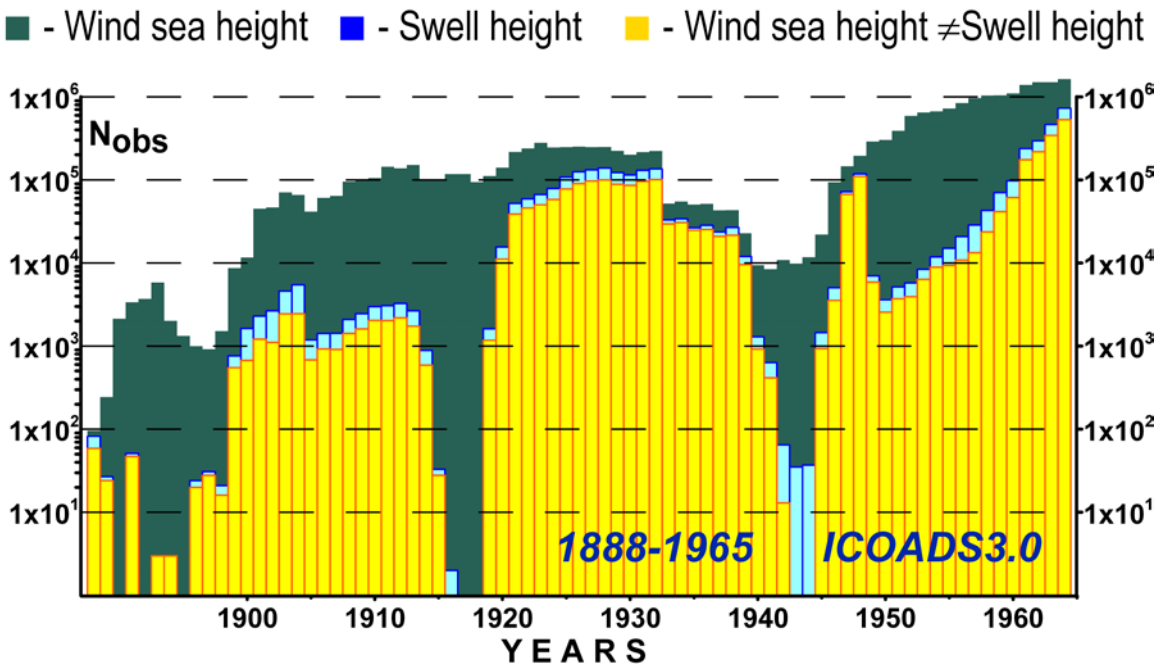
Wind sea are becoming less steeper and higher
while swell is becoming steeper but lower

Waves in VOS : (1888-1965)

IMMA: "*Prior to 1949 both sets of wave height (sea and swell) fields were apparently reported descriptively in the SHIP code, and thus are expected to be missing (and the swell fields are expected to be missing prior to 1 July 1963). Beginning 1 July 1963 both sea (i.e. wind wave) and swell were reported. Prior to that date only the higher of sea and swell was reported*"





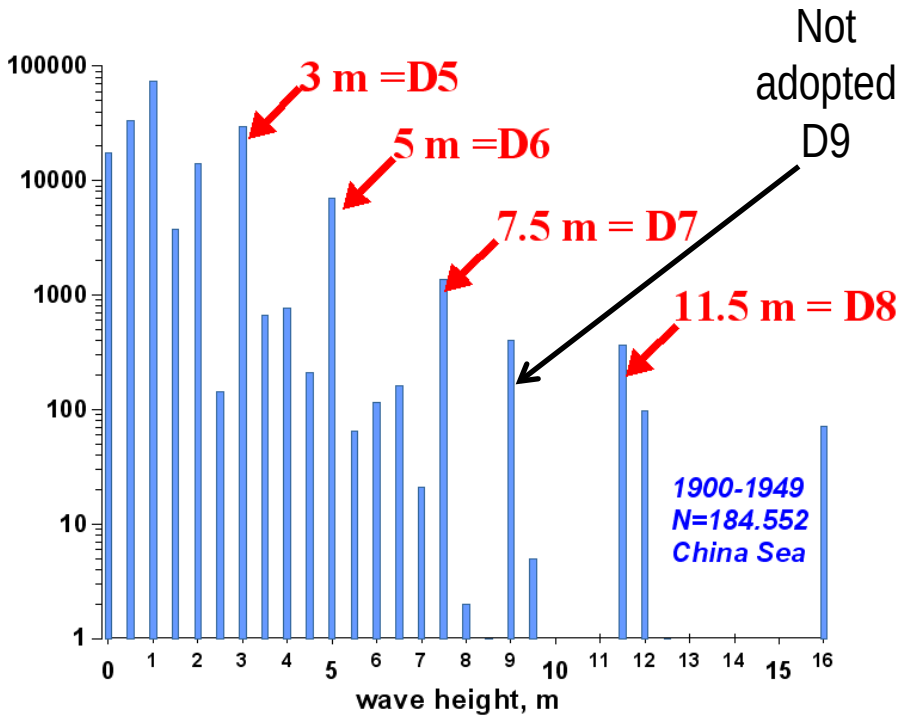


Ship code: prior to 1949

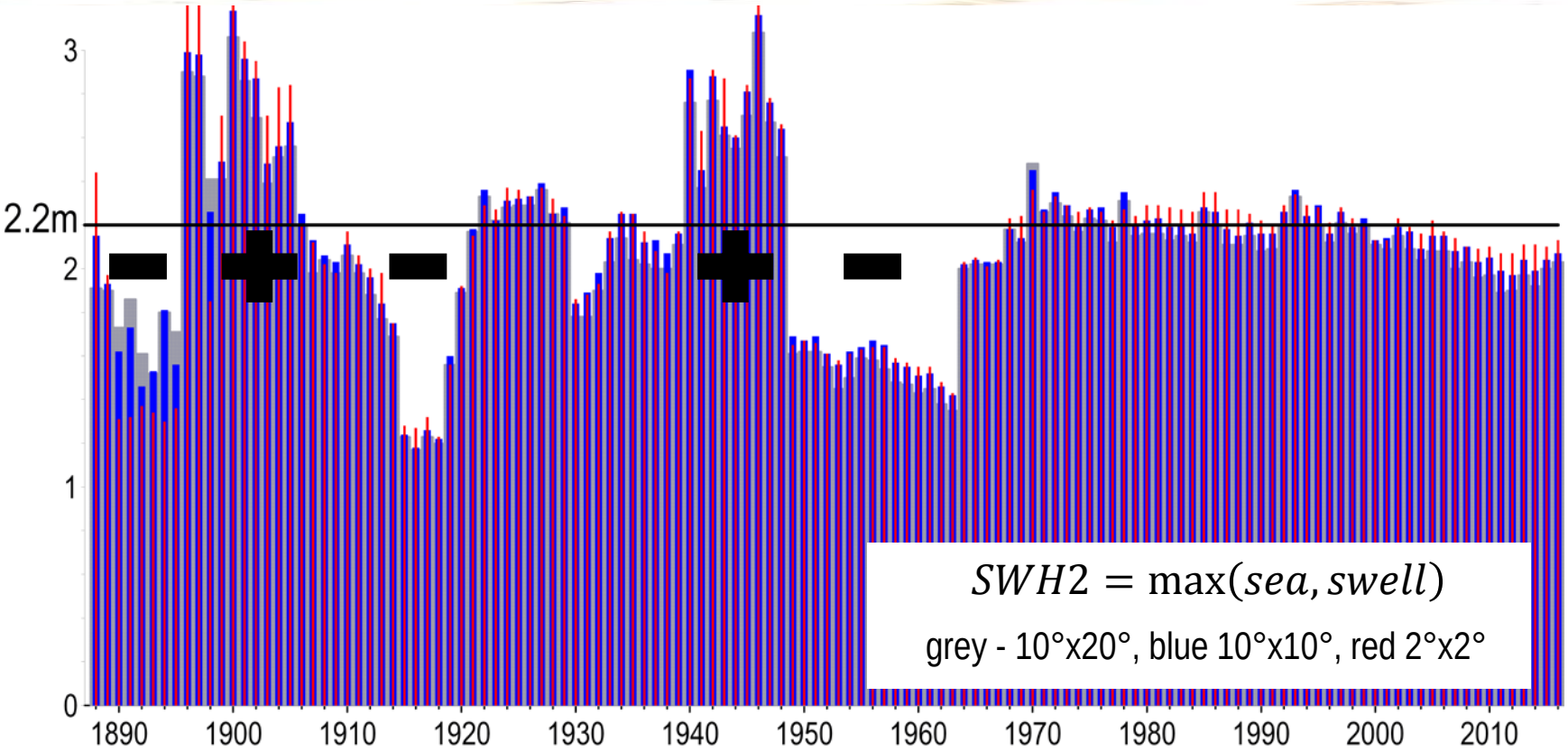
The WMO sea state code largely adopts the 'wind sea' definition of the Douglas Sea Scale. The Degree (D) value is almost linearly dependent to the square root of the average wave Height (H) above, i.e., $D \cong b + a\sqrt{H}$

Sir Percy Douglas

Degree	Height (m)	Description
0	no wave	Calm (Glassy)
1	0–0.10	Calm (rippled)
2	0.10–0.50	Smooth
3	0.50–1.25	Slight
4	1.25–2.50	Moderate
5	2.50–4.00	Rough
6	4.00–6.00	Very rough
7	6.00–9.00	High
8	9.00–14.00	Very high
9	14.00+	Phenomenal



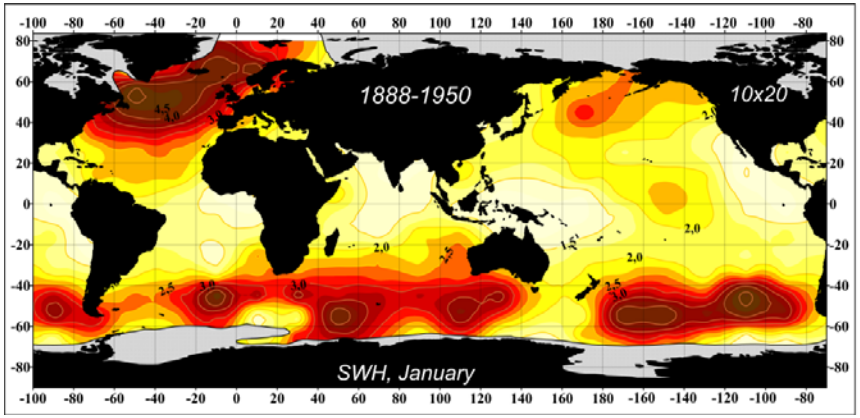
Global average 1888-2016

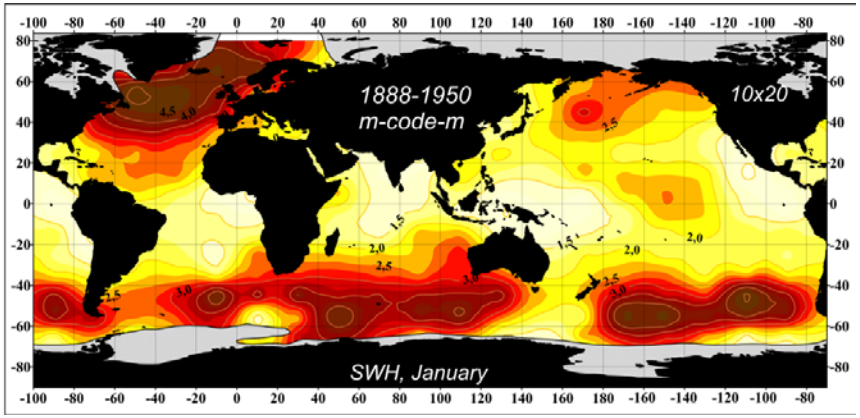


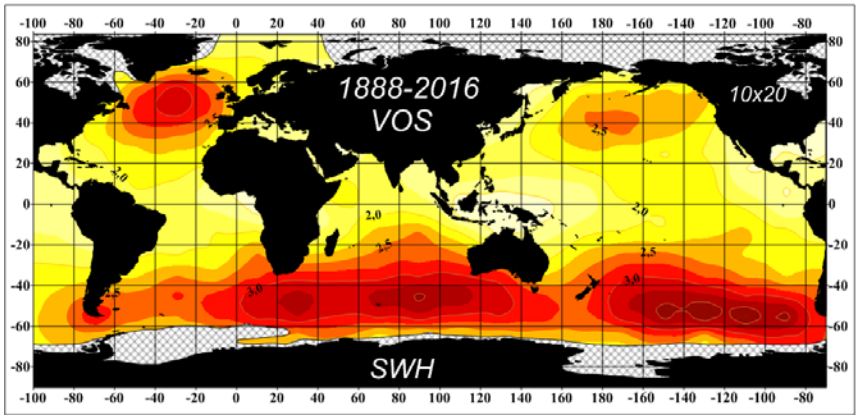
Wave height was converted from the ship code: 11.5 and 7.5m waves influence

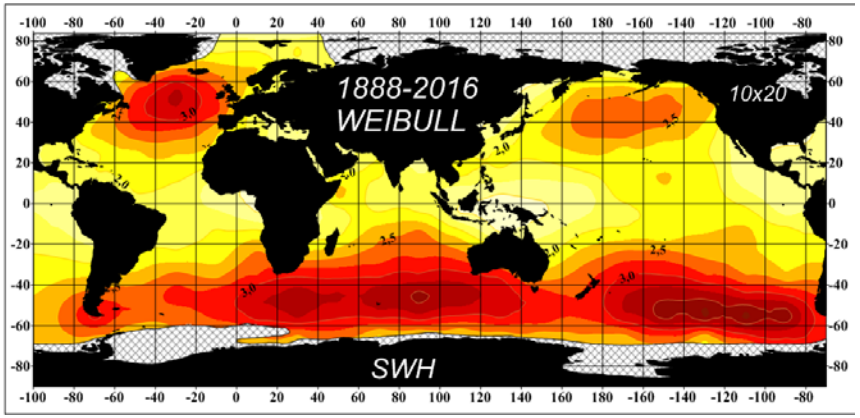
Actual sea or swell were wrongly reported as SWH (maximum of the 2 components), both components are available starting from 1949 (not 1963, as reported by IMMA)

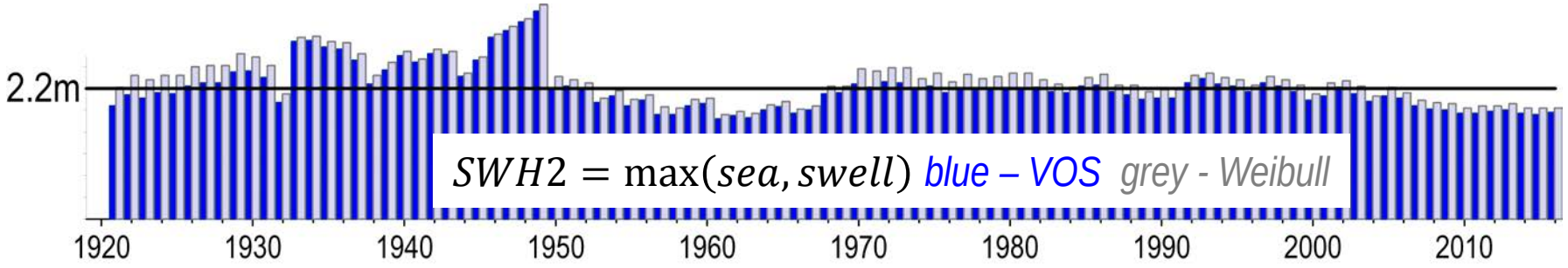
Is there a solution?



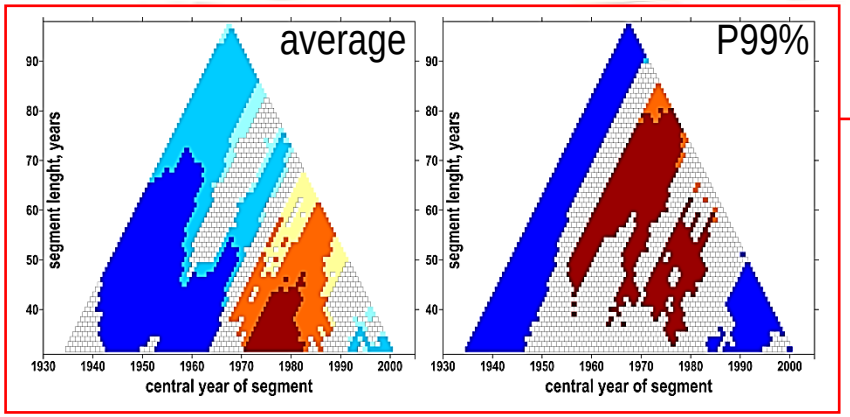


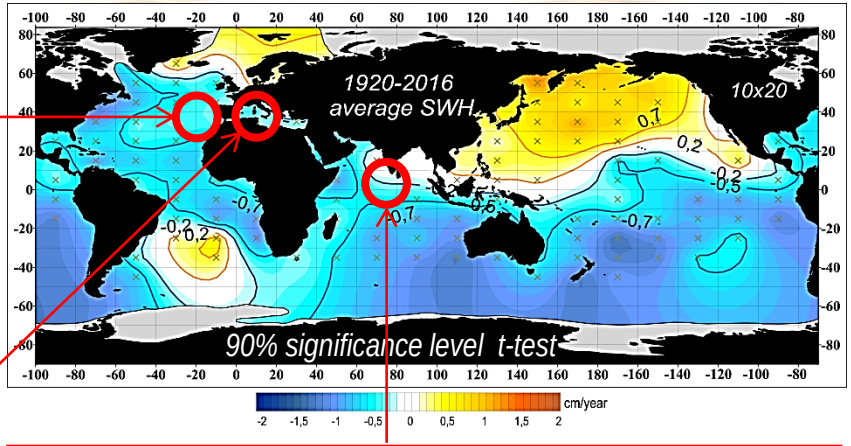


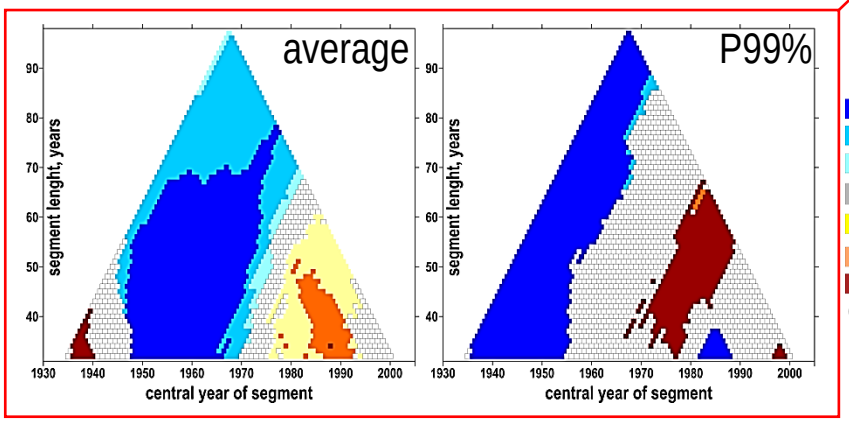




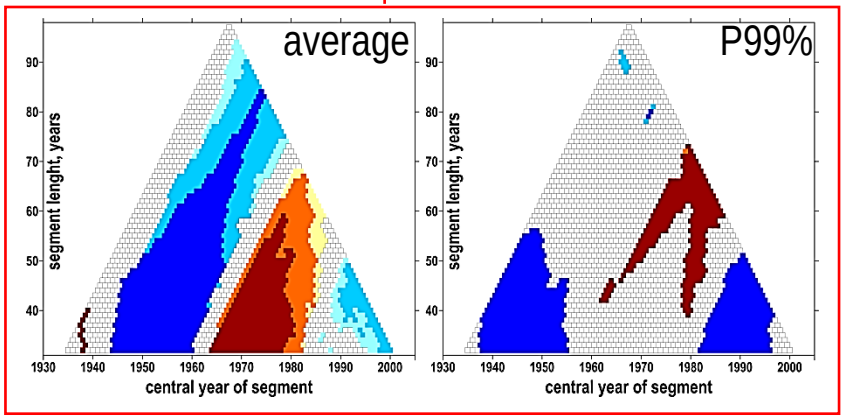
Trends 1920-2016

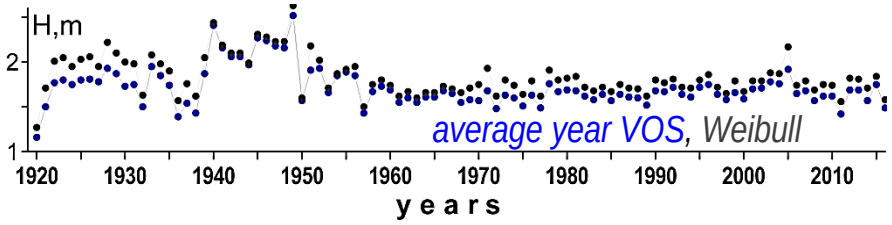






-0.50
-0.25
-0.05
0
0.05
0.25
0.50
cm/year

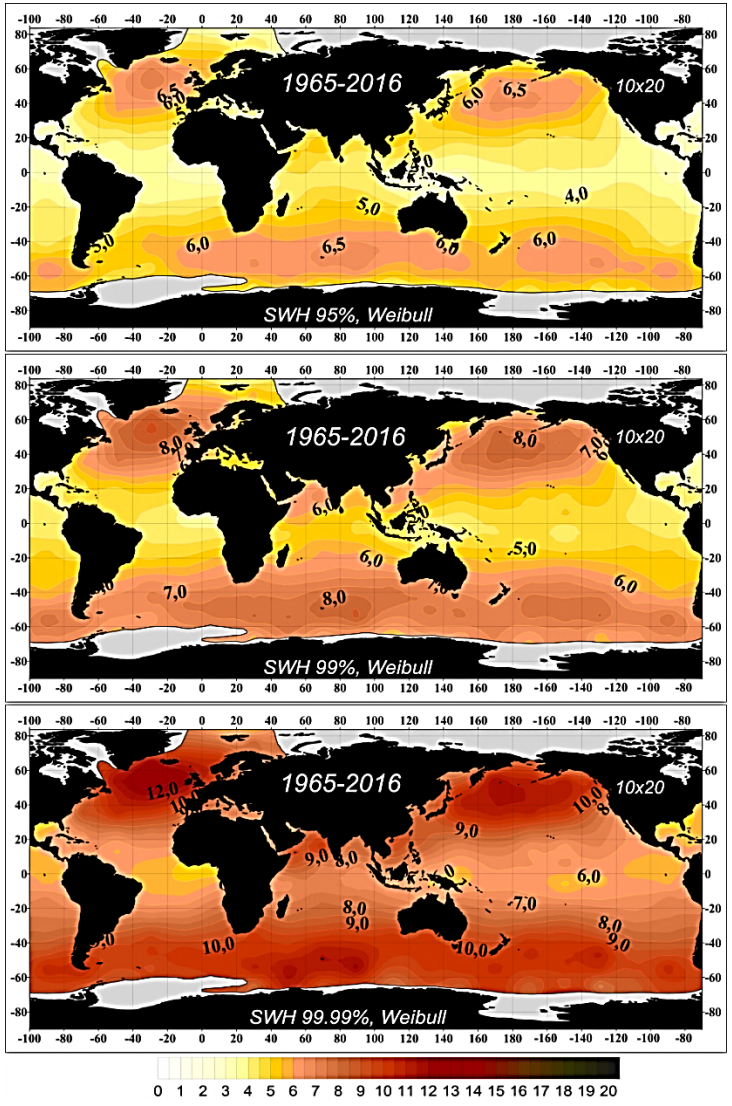


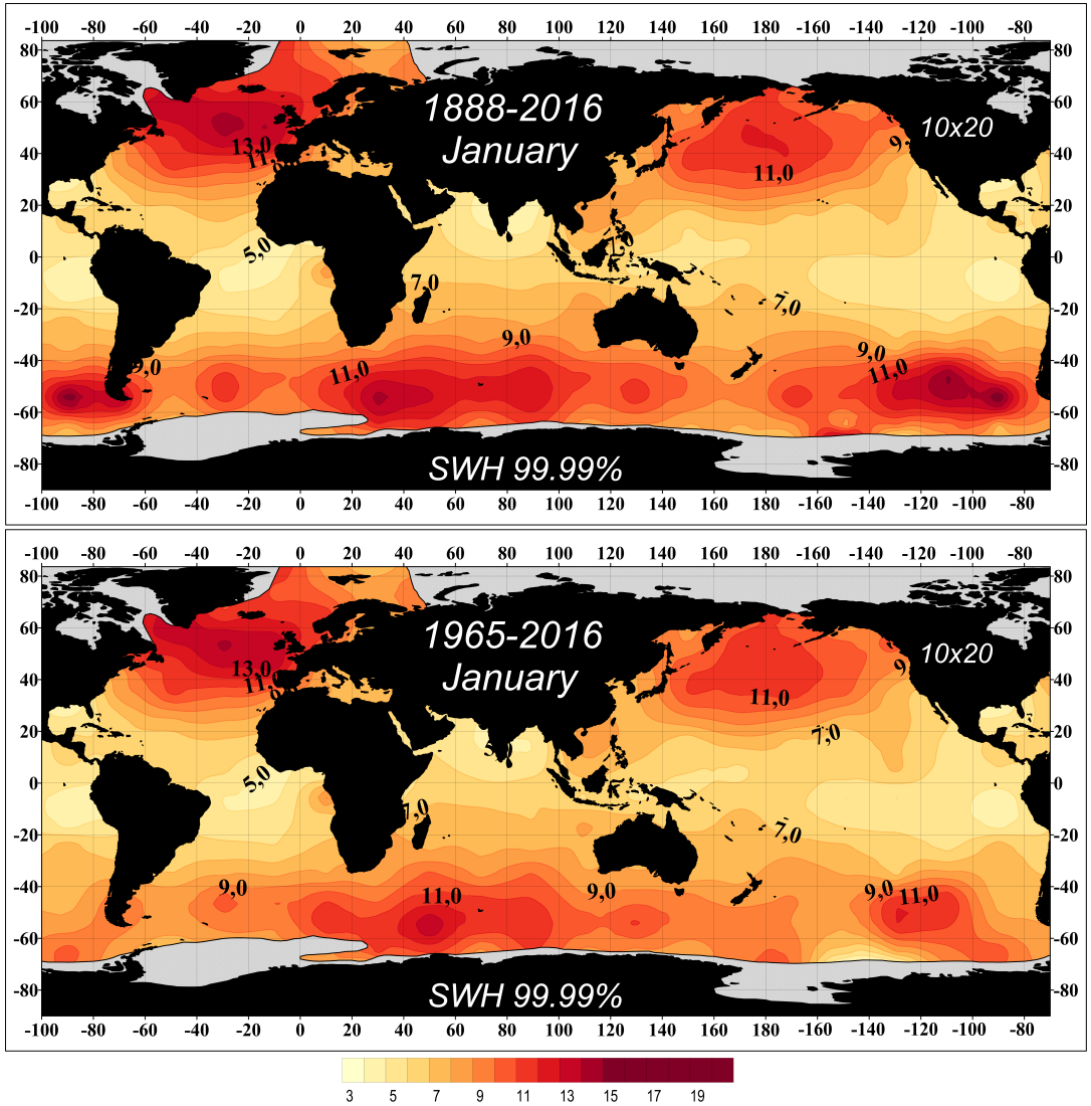


Global trend estimates for 1920-2016 demonstrate rather data inhomogeneity then the change in the wave climate

Trends computed over different time windows trace the character of temporal changes

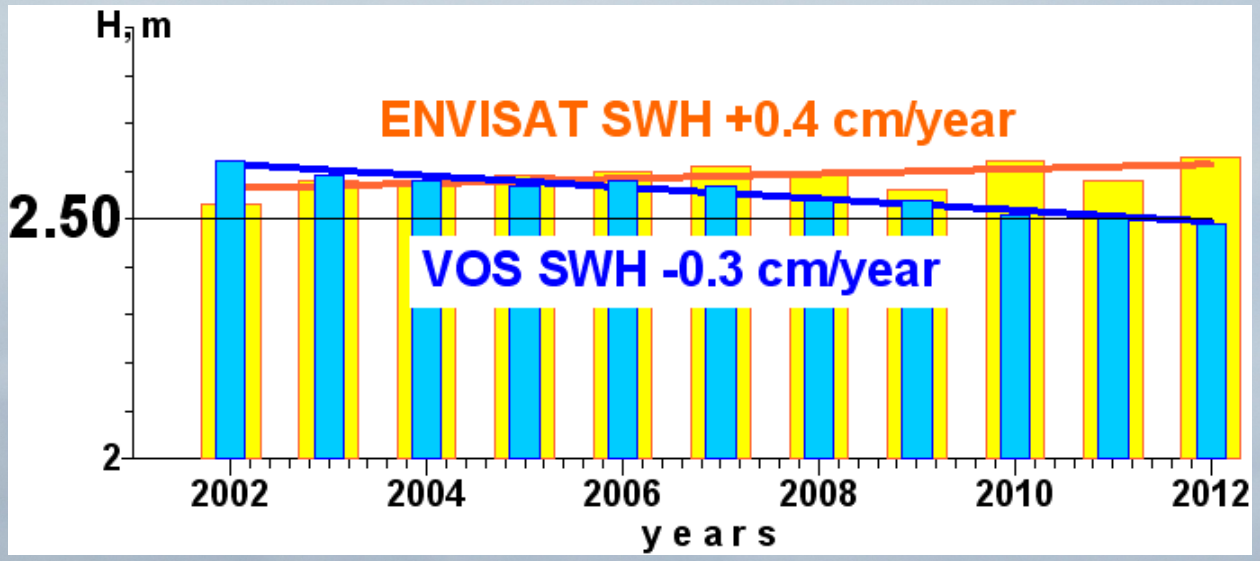
Extreme waves 1888-2016, 1965-2016





Conclusions

- New update of the Global Wind Wave Atlas based upon ICOADS version 3.0 release has been presented: different grids and new wave variables
- Statistical modeling with Weibull PDF allows for minimizing the impact of sampling onto wave probability distributions
- Centennial time series of homogenized wave data allow for estimating trends and extremes for different time periods
- Trends are influenced by the discontinuities associated with changes in the coding systems



- Blue bars - VOS SWH

$SWH1 = (h_w^2 + h_s^2)^{1/2}$

- Yellow bars

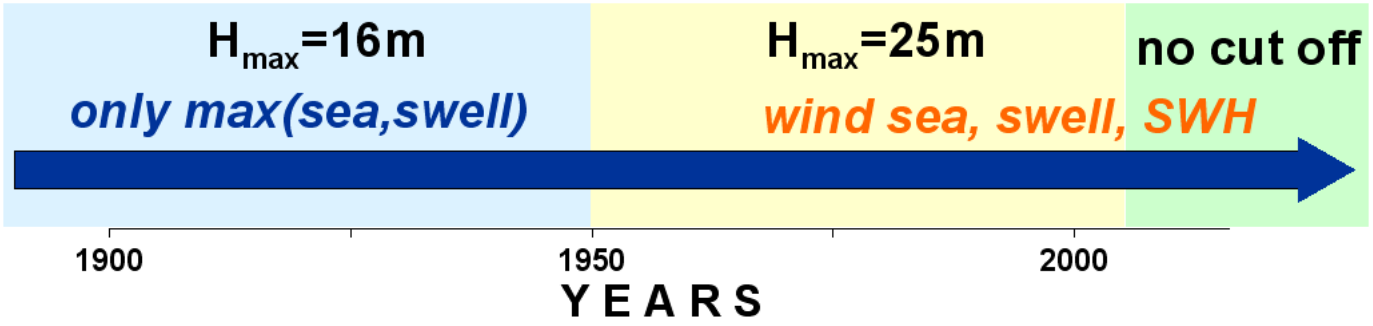
SWH – Envisat 2002-2012

Cabo da Roca

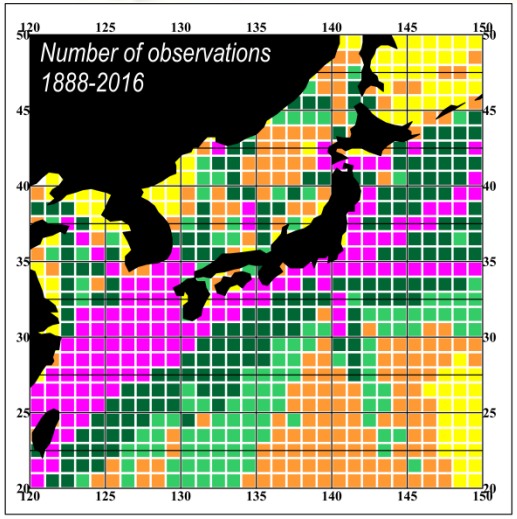
Voluntary Observing Ship (VOS): 1888 - 2016

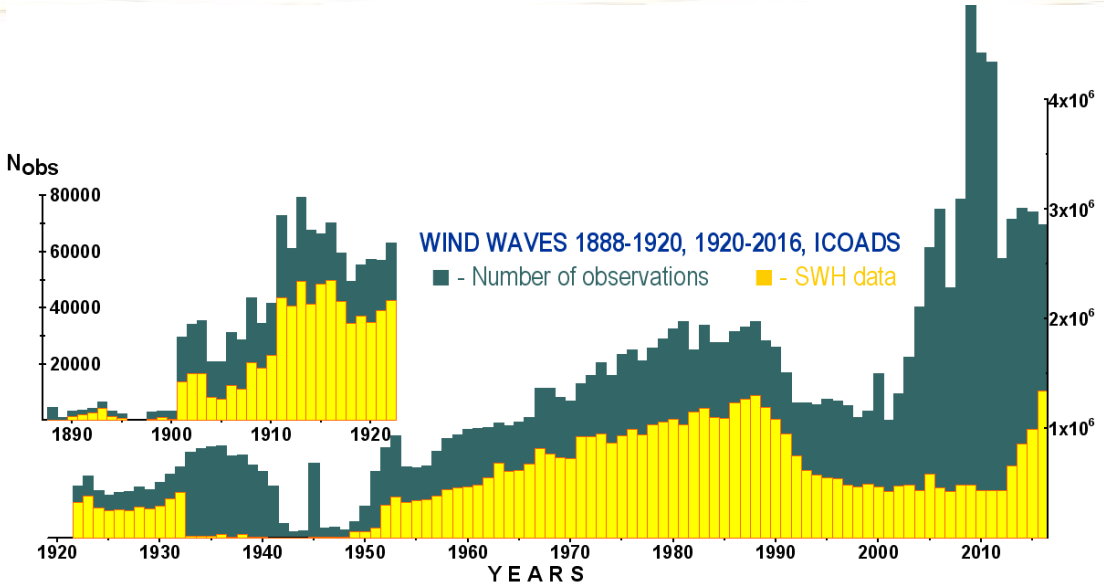
- The longest global observations taken visually by marine officers
- Separate estimates of wind sea and swell
- Observational practice has never been changed
- Coding systems have been changed several times, while documented
- Code precision is 0.5m for heights and 1 sec for periods
- Assimilated in ICOADS (http://icoads.noaa.gov)
- New IMMA-formatted data are available nearly operationally

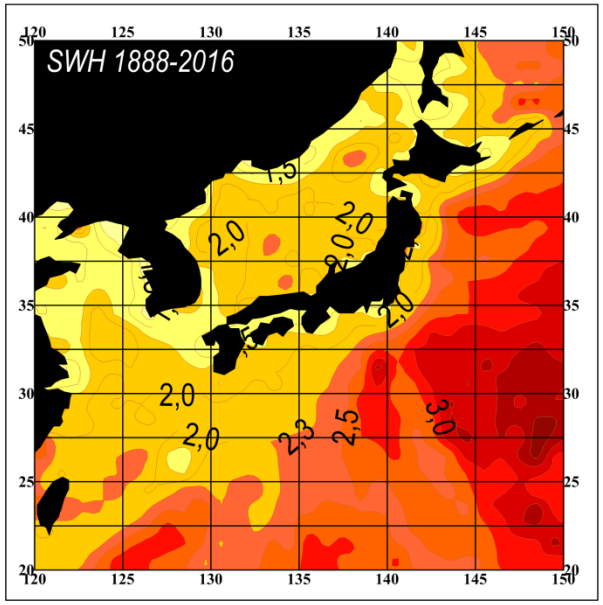
3 streams of data:
(1870-1949) and (1950-2006) and (2006-onwards)
> 2.000.000.000 telegrams

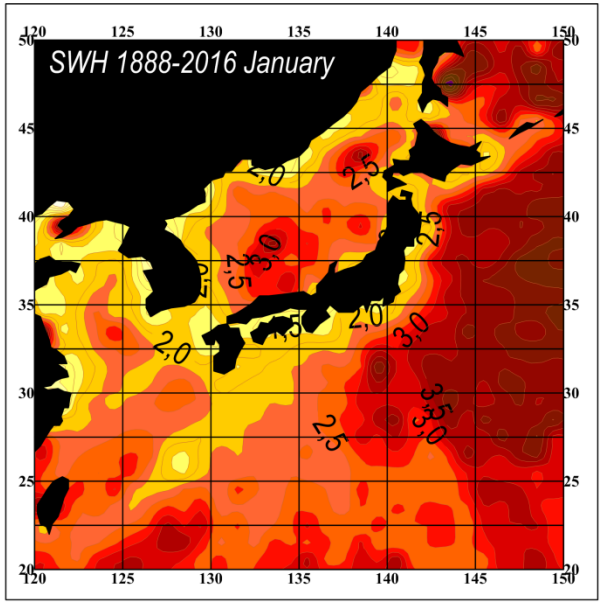


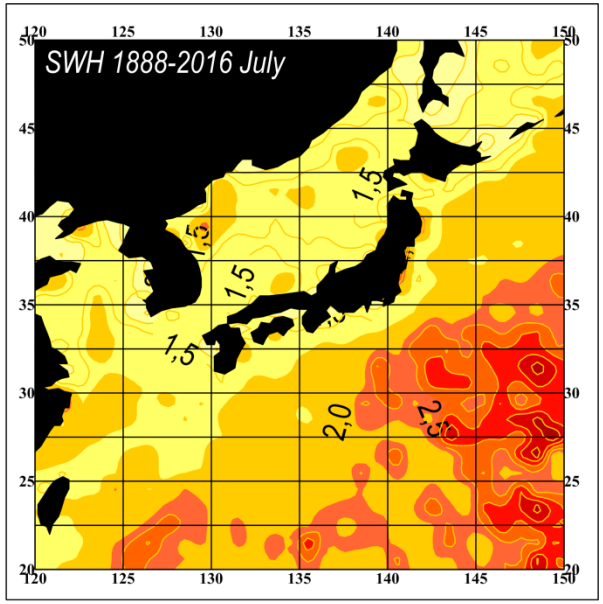
Regional climatology 1°x1° (1888-2016)



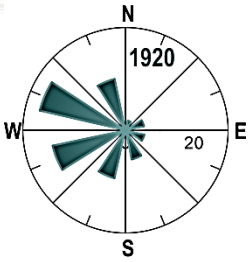


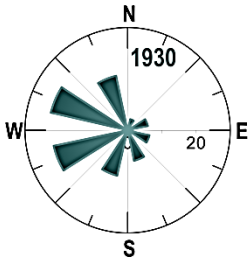


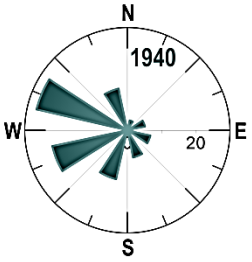


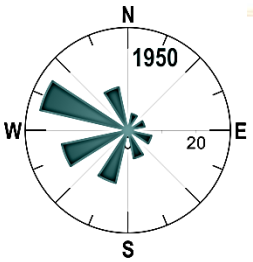


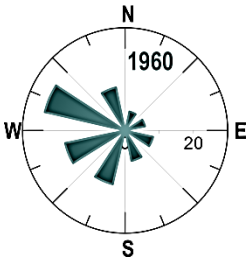
Wave directions

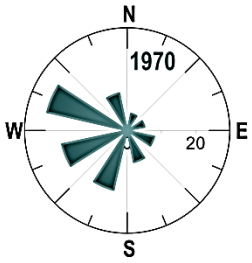


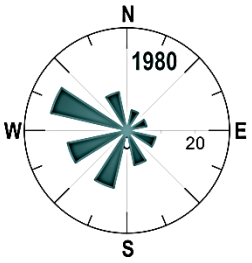


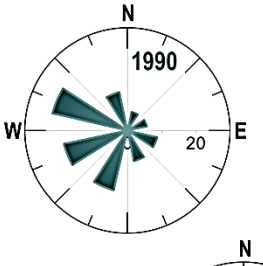


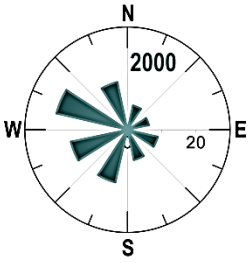


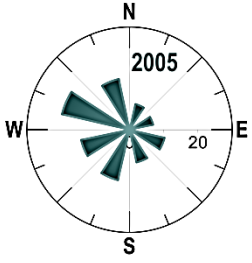


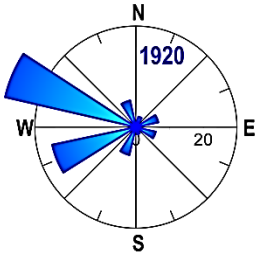


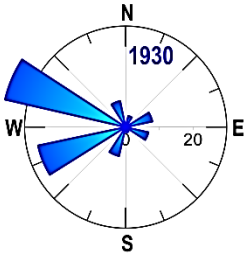


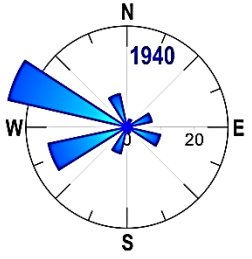


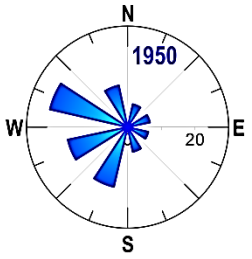


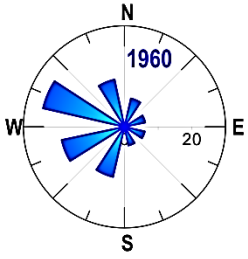


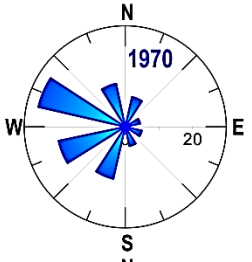


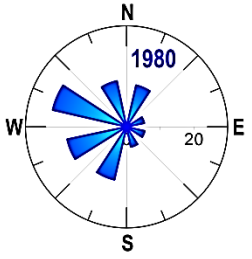


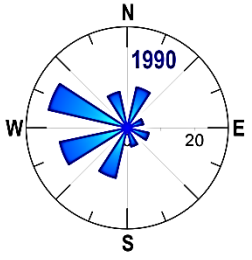


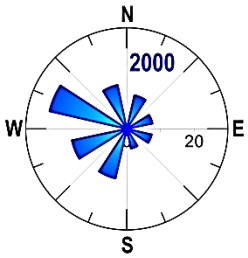


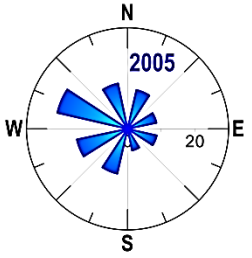






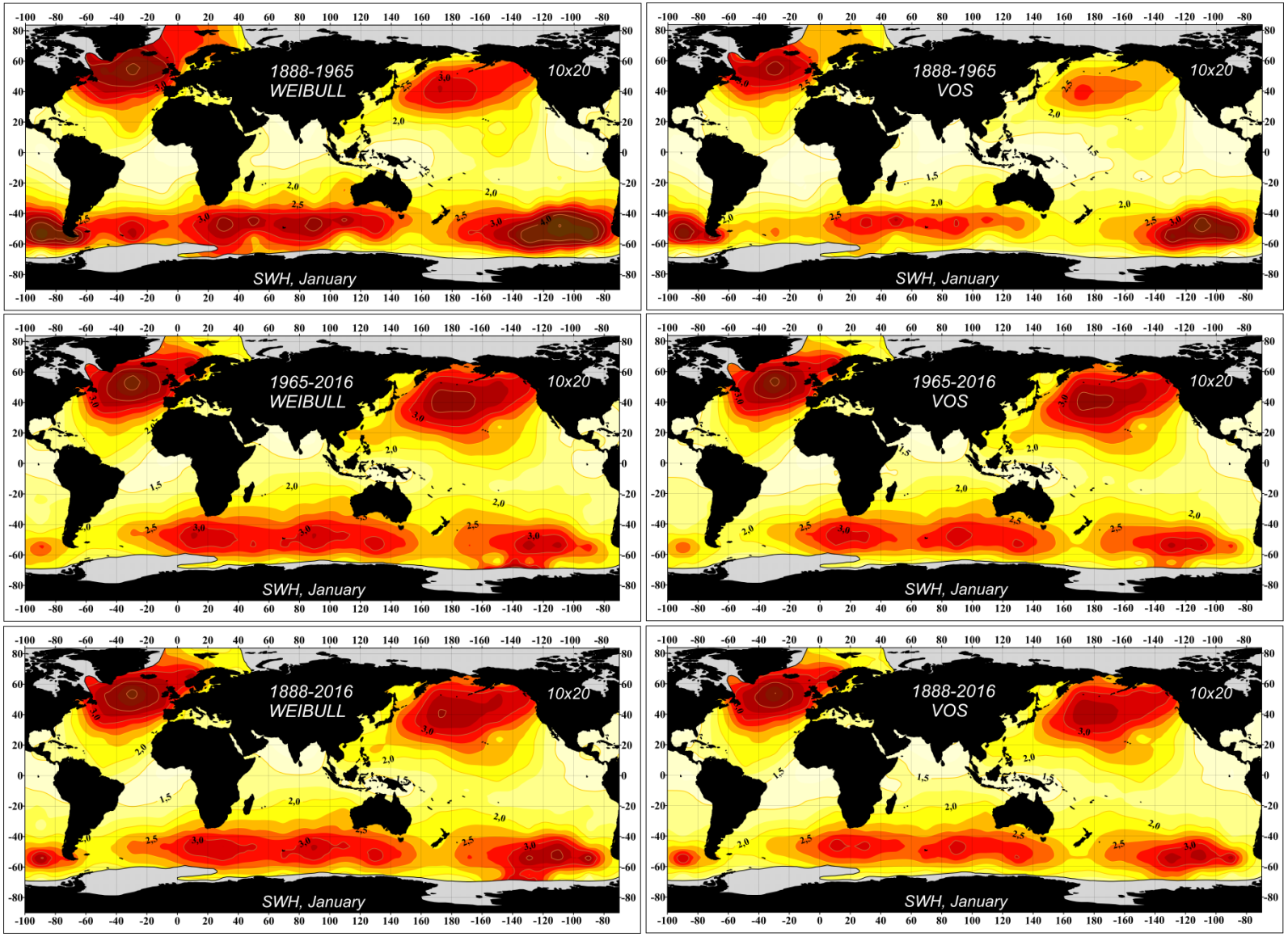




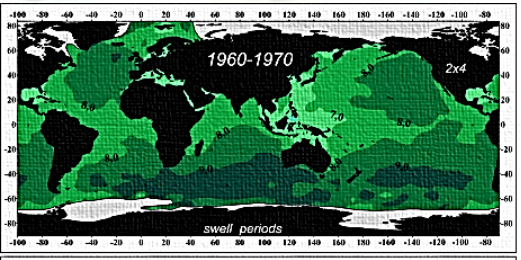


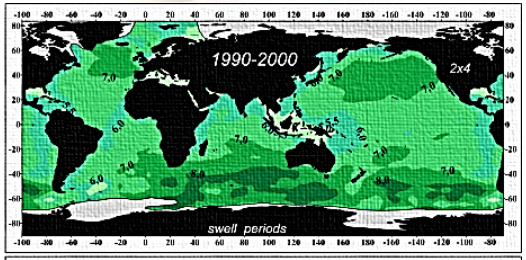
swell directions (from where)
20-40 W
50-60 N

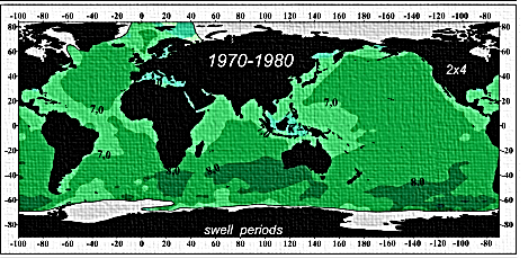
Weibull average + observations

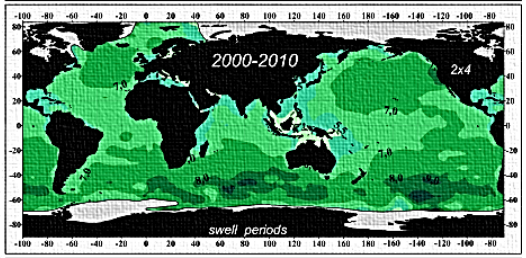


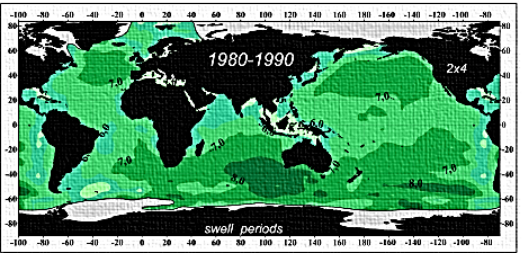
Global Wind Wave Climatology

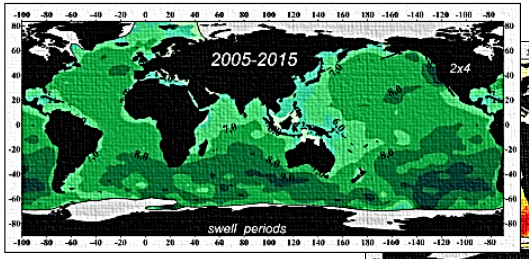


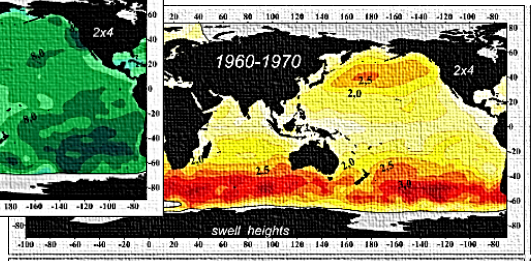


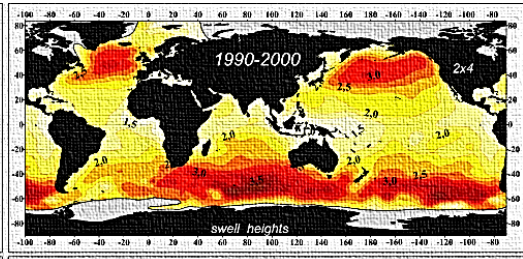


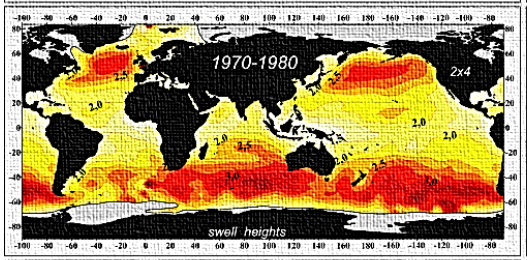


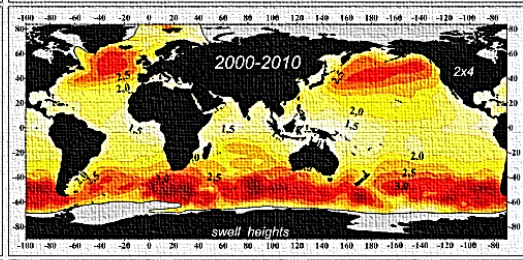


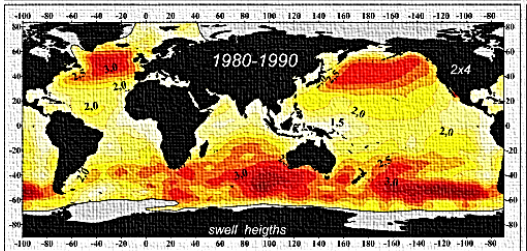


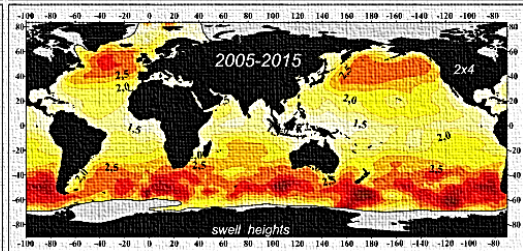




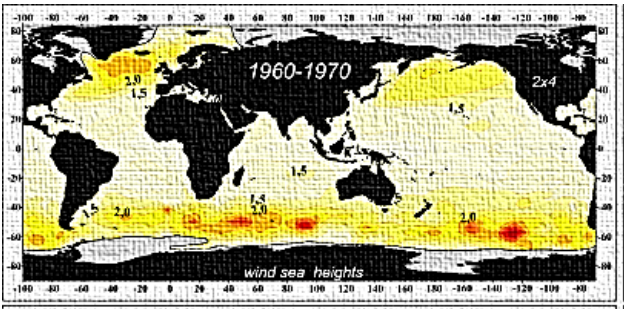


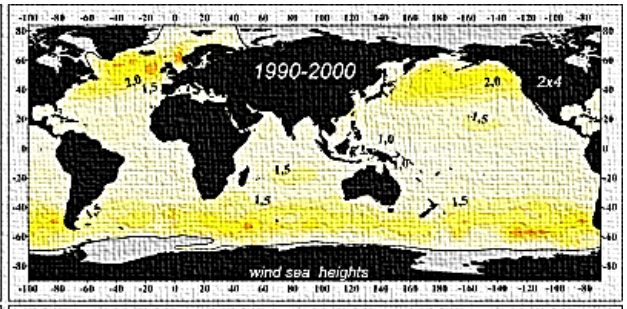


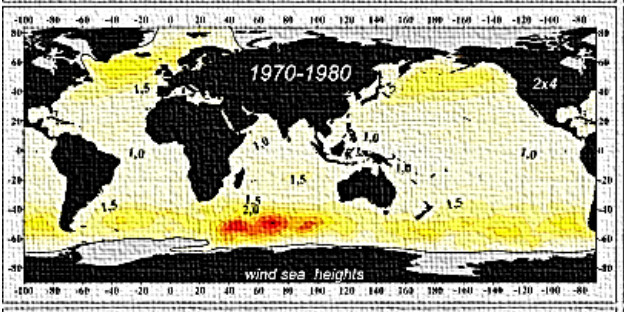


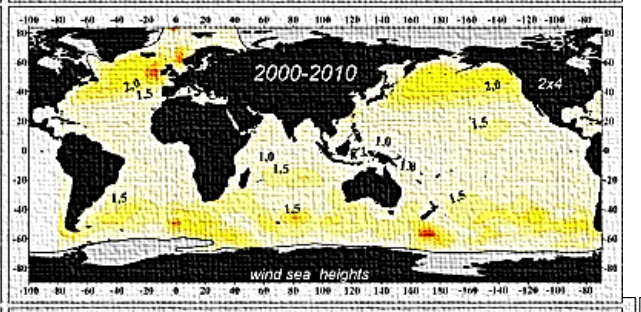


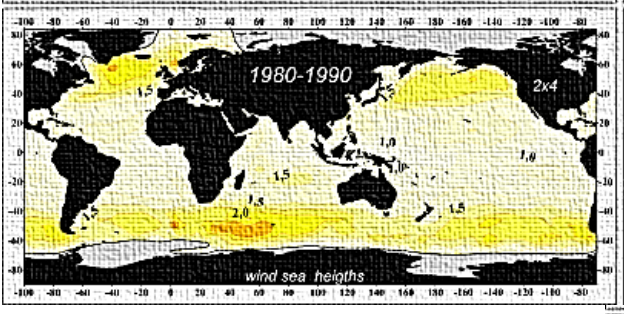
Global Wind Wave Climatology

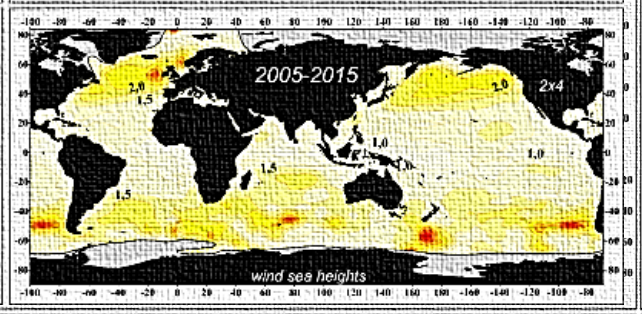


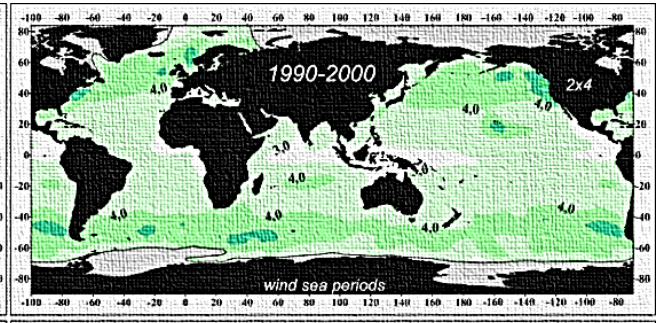


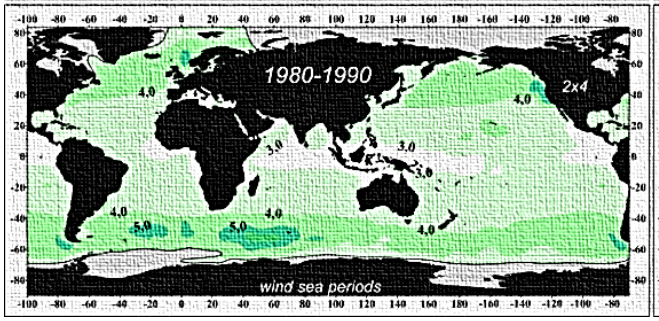


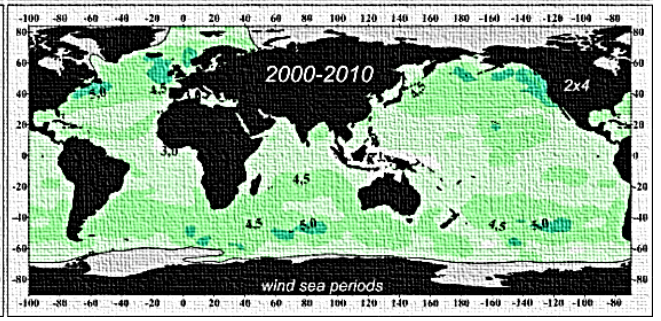






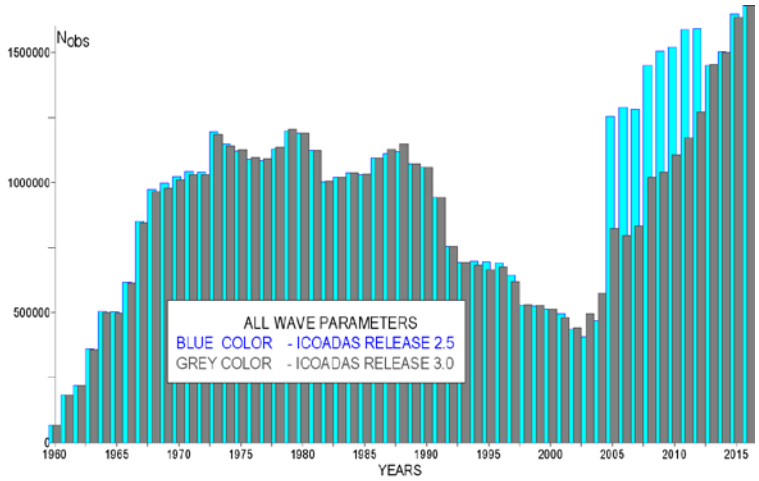




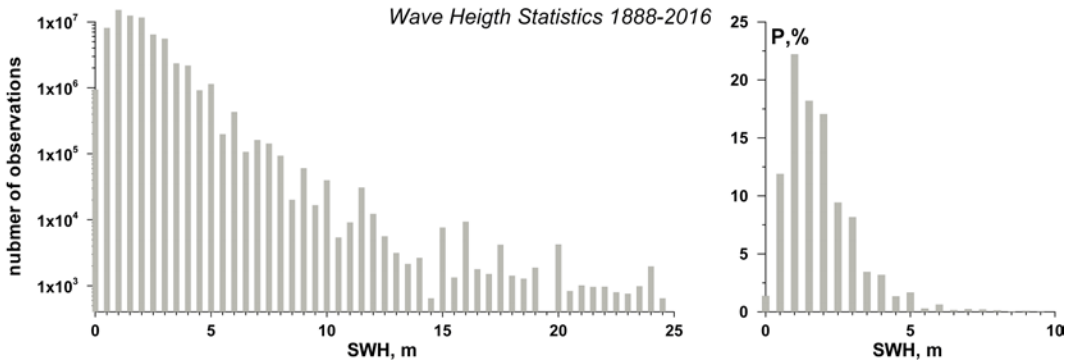


Numbers: ICOADS 2.5 vs ICOADS 3.0 (1960-2014)

	ICOADS 3.0, *10^6	ICOADS 2.5, *10^6	Difference, *10^6
Number of records	**447.4**	**424.3**	**+23.1**
Wind sea height ≥0	**143.8**	**128.4**	**+15.4**
Swell height ≥0	**60.6**	**63.8**	**- 3.2**
Wind sea ≠ swell	**46.4**	**48.6**	**-2.2**
All wave parameters	**48**	**51.3**	**-3.3**



- No difference in wave information before 1960
- Whole number of reports is growing (jumping)
- Wind sea height number is growing (huge leap)
- Swell height number is decreasing
- Sea+swell number is decreasing
- Number of all wave parameters is decreasing



Common problems with known cures

- Unrealistic dates and mistakes in attribution of coordinates of reports («± error» North vs South, East vs West) → confuse in wave characteristics

- Predominantly integer figures for wave height estimates (often rounded to the nearest multiple of 5)
- Extreme waves (>25 m)
- Different thresholds before and after 1950 and 2006

} influence on extreme and long term estimates

- Wind sea and swell separation
- Inconsistency of wave parameters (zero height with the period > 0)
- Small wave periods («1 sec problem»)
- Zero wave heights: calm or data missing?

} influence on mean values

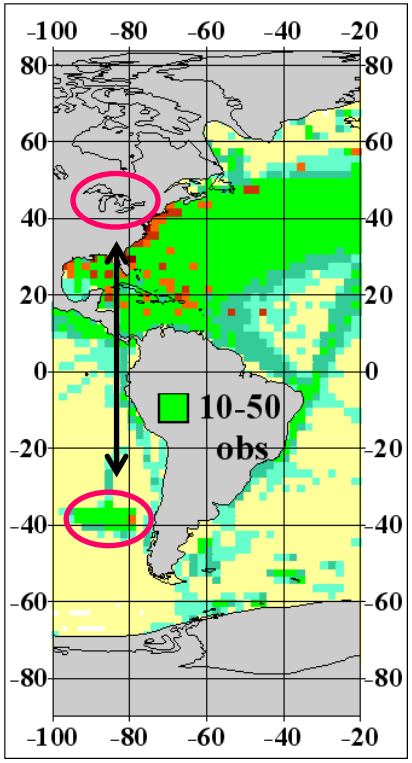
$$SWH = \begin{cases} (h_w^2 + h_s^2)^{1/2}, & [dir_{sea}, dir_{swell}] \in 30^\circ sector \\ max[h_w, h_s], & [dir_{sea}, dir_{swell}] \notin 30^\circ sector \end{cases}$$

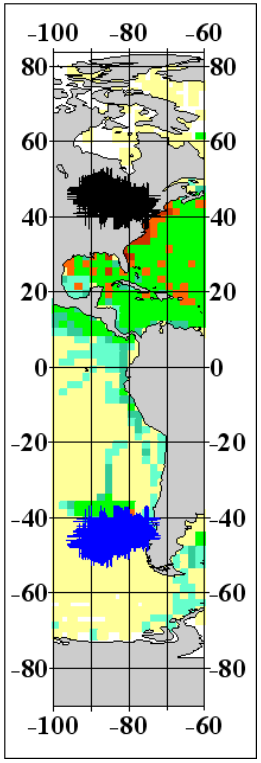
Artefacts

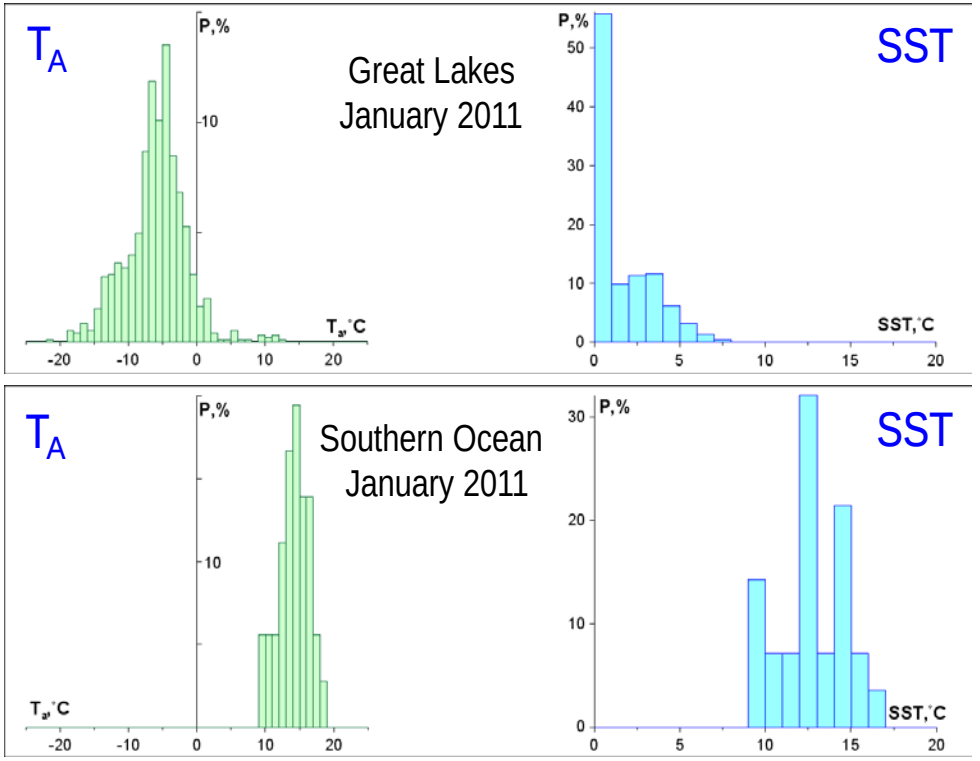
- Unrealistic dates

  1855-1949 31 days almost in every month
  1893-1949 each year is leap year
  1950-2016 problems are fixed

- Wrong attribution of S/N and E/W coordinates of reports



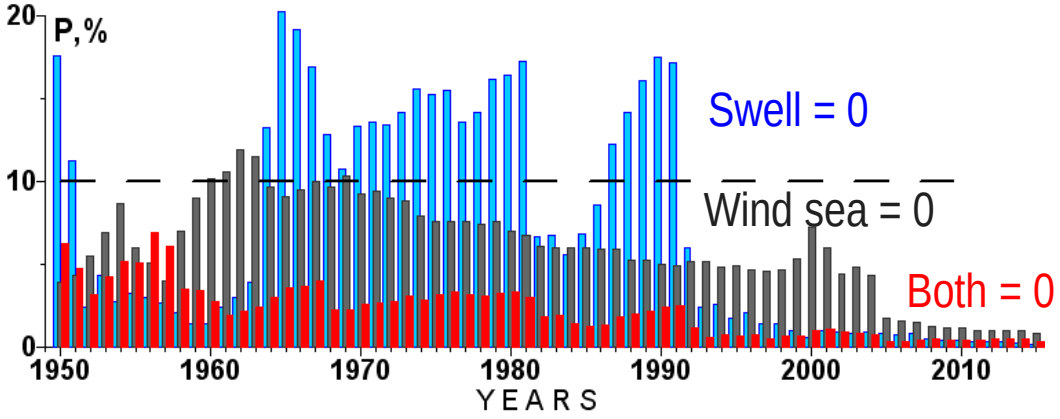


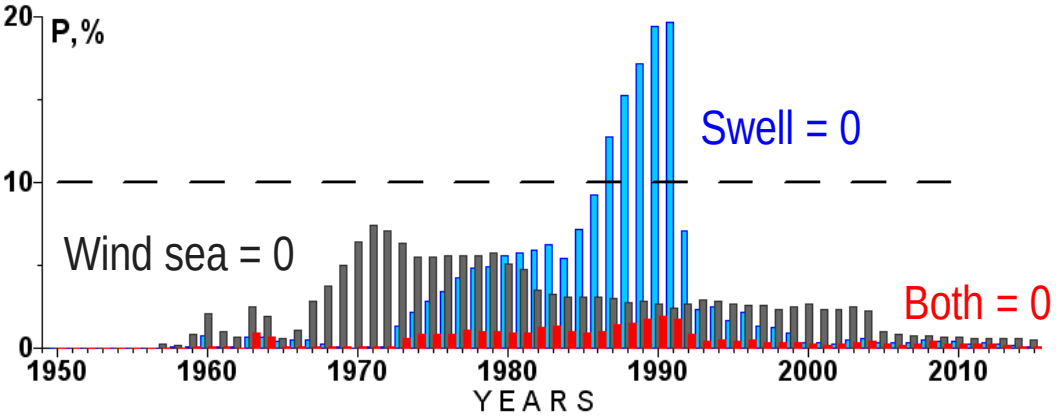


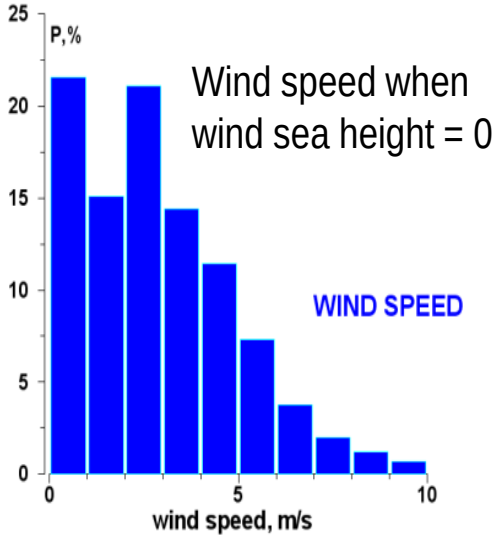
Zero wave heights: calm or data missing

Most observations are located in the areas dominated by wind sea with a little occurrence of swell (likely NH)

Beaufort scale, buoy and satellite wind-wave analysis allow zero wind waves (or less than 0.5m) when wind speed is less than 5 m/s



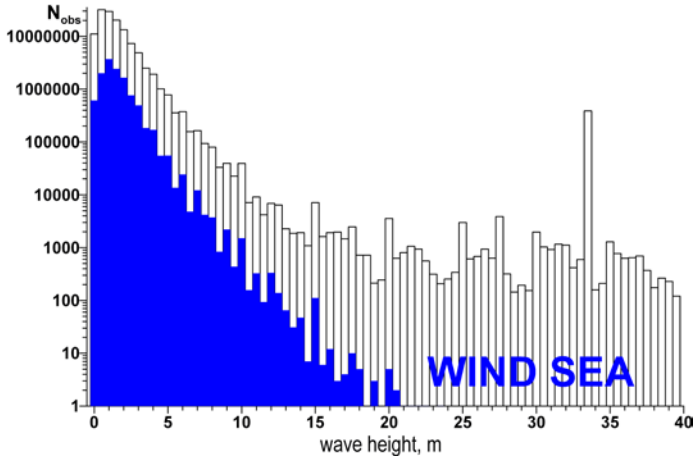


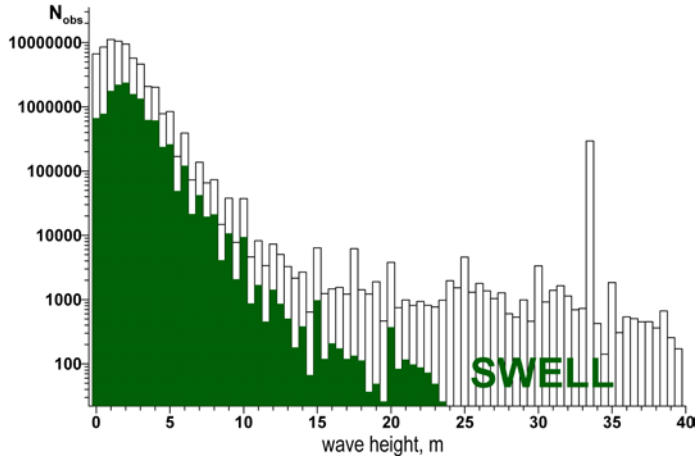


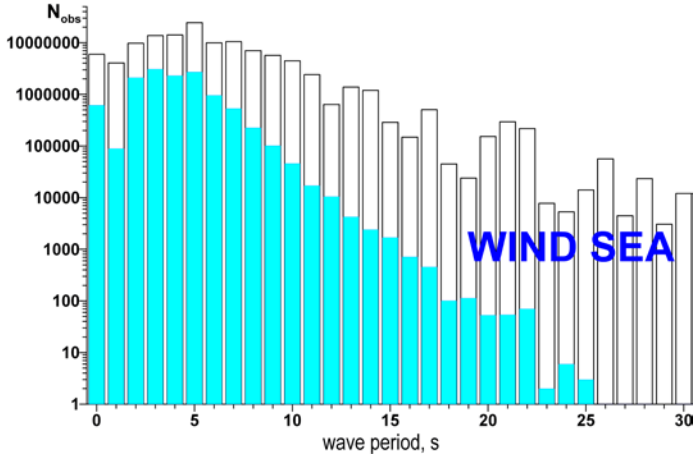
Wave heights and periods

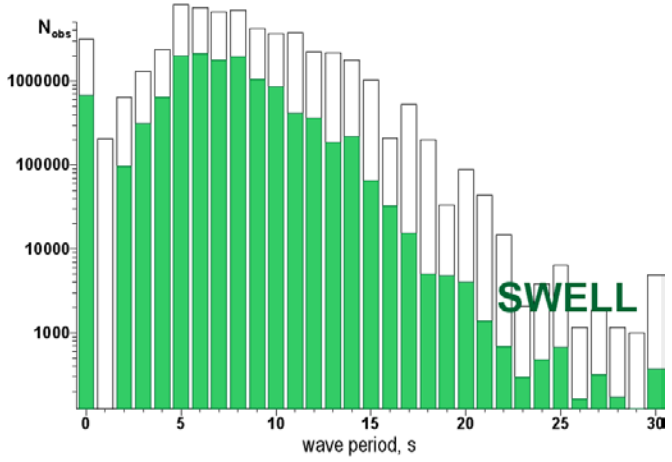
After all QC procedures – from 700 000 reports (27%,1970) to 550 000 (2%, 2015)

Open questions: H=11.5m – the real value or not converted feet? (11.5 Ft = 3.5 m)
H=33.5m – ?
1950-1959 – no swell higher than 10 m
1968-1979 – swell periods range within 5-15 sec

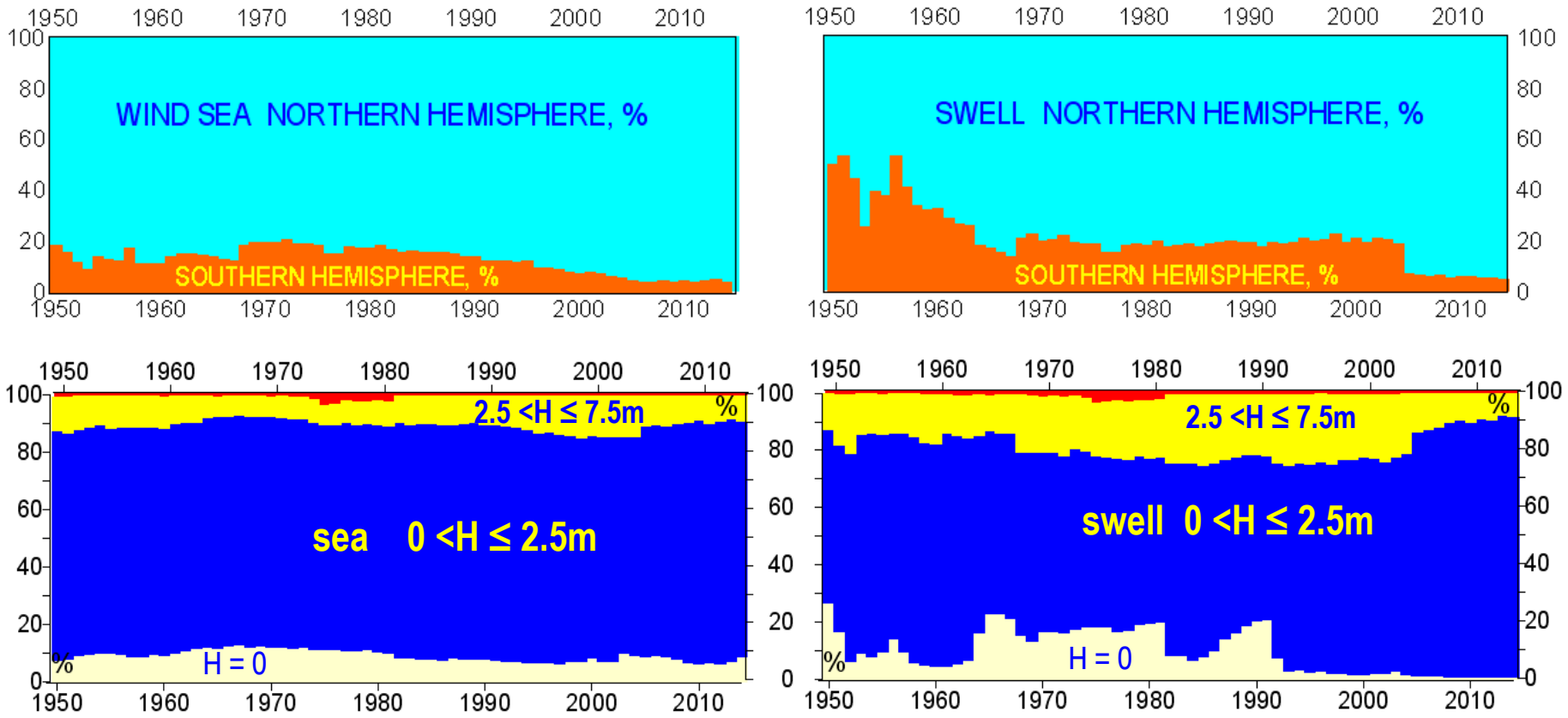








What happened in 2004?



- Significant decrease of the number of observations in the Southern Hemisphere: from 20% to 5%
- 99% of all reported wave heights are smaller than 7.5 m
- Significant (~10%) decrease of the number of reported moderate waves during the last decade