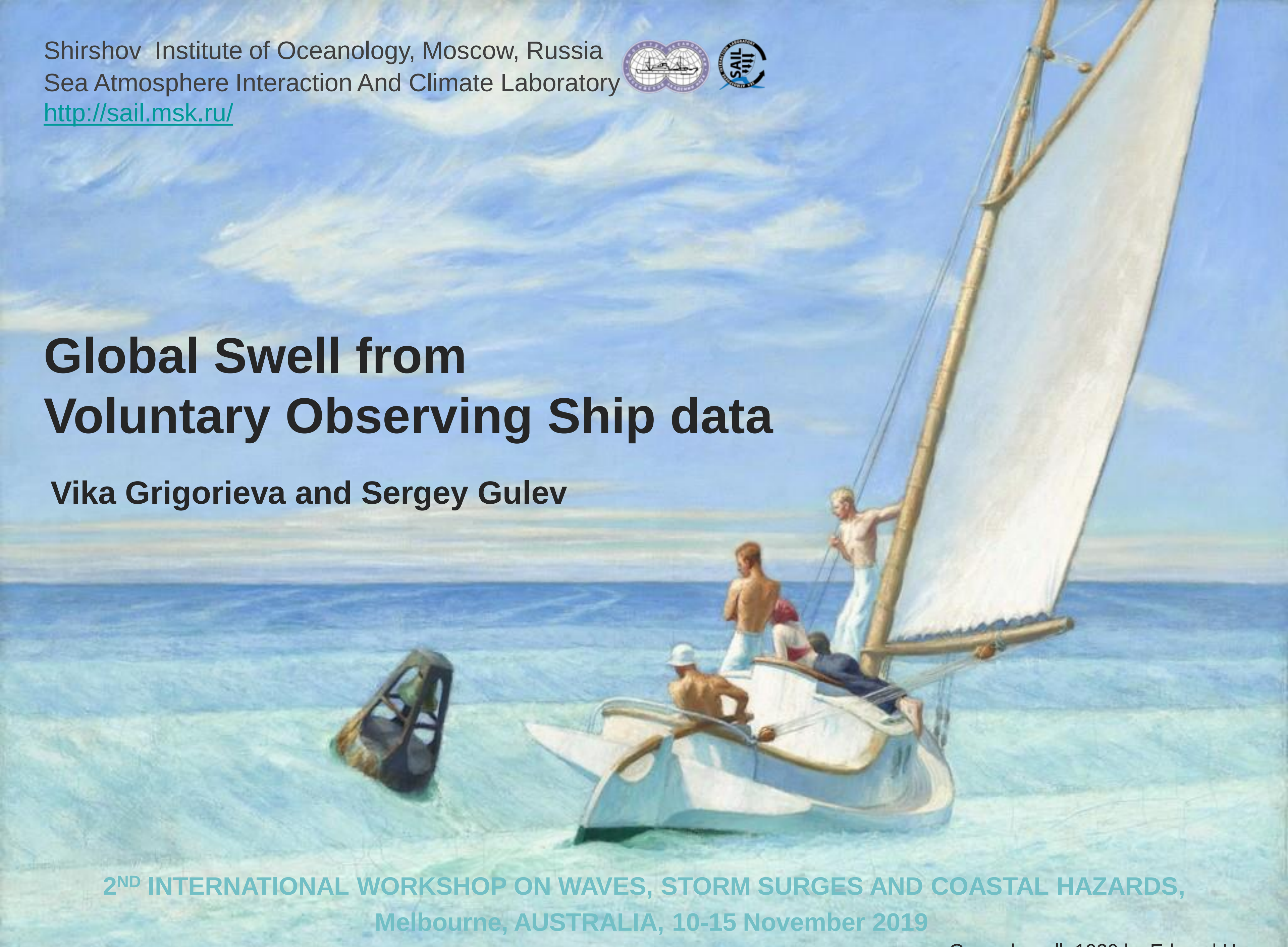
Shirshov Institute of Oceanology, Moscow, Russia
Sea Atmosphere Interaction And Climate Laboratory
http://sail.msk.ru/

Global Swell from Voluntary Observing Ship data

Vika Grigorieva and Sergey Gulev

2ND INTERNATIONAL WORKSHOP ON WAVES, STORM SURGES AND COASTAL HAZARDS, Melbourne, AUSTRALIA, 10-15 November 2019



Ground swell, 1939 by Edward Hopper

- a new approach to the correction of historical wave data
- comparison of visually observed and modeled swell (WW3-ERA5)
- a prototype of Swell Tracking System

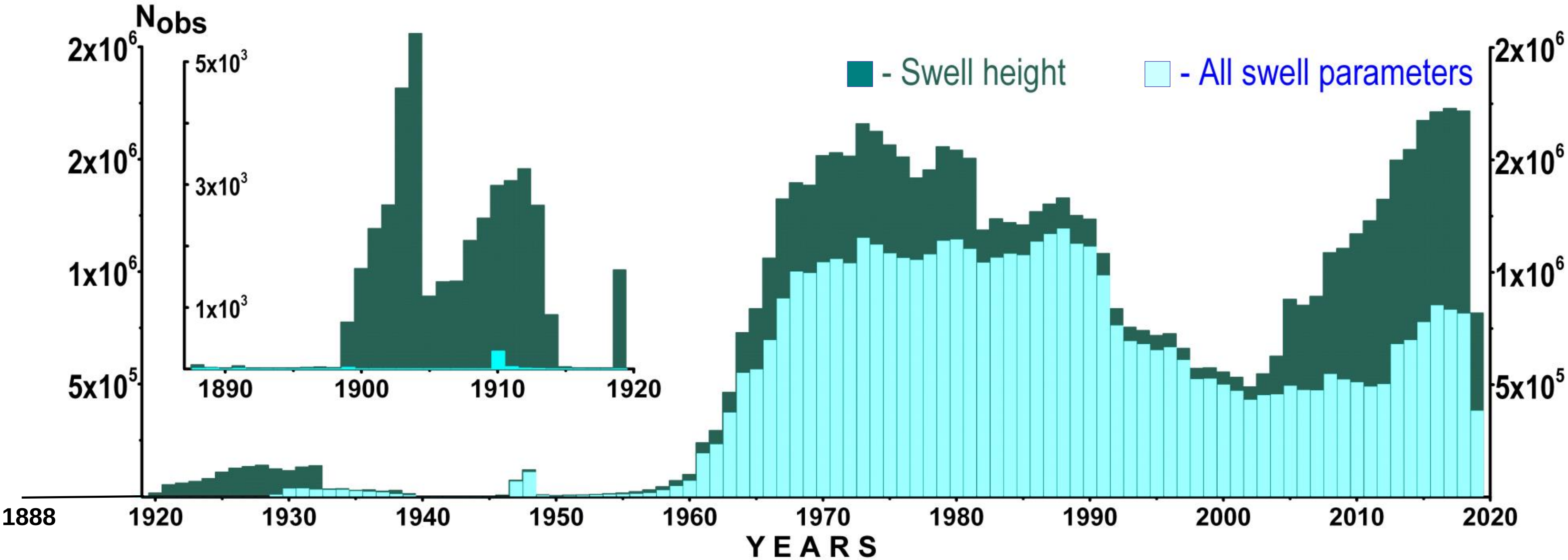
Ground swell, 1939 by Edward Hopper

Temporal distribution of swell characteristics in VOS

Continuity – more than 130 years with gaps (WW1,WW2)

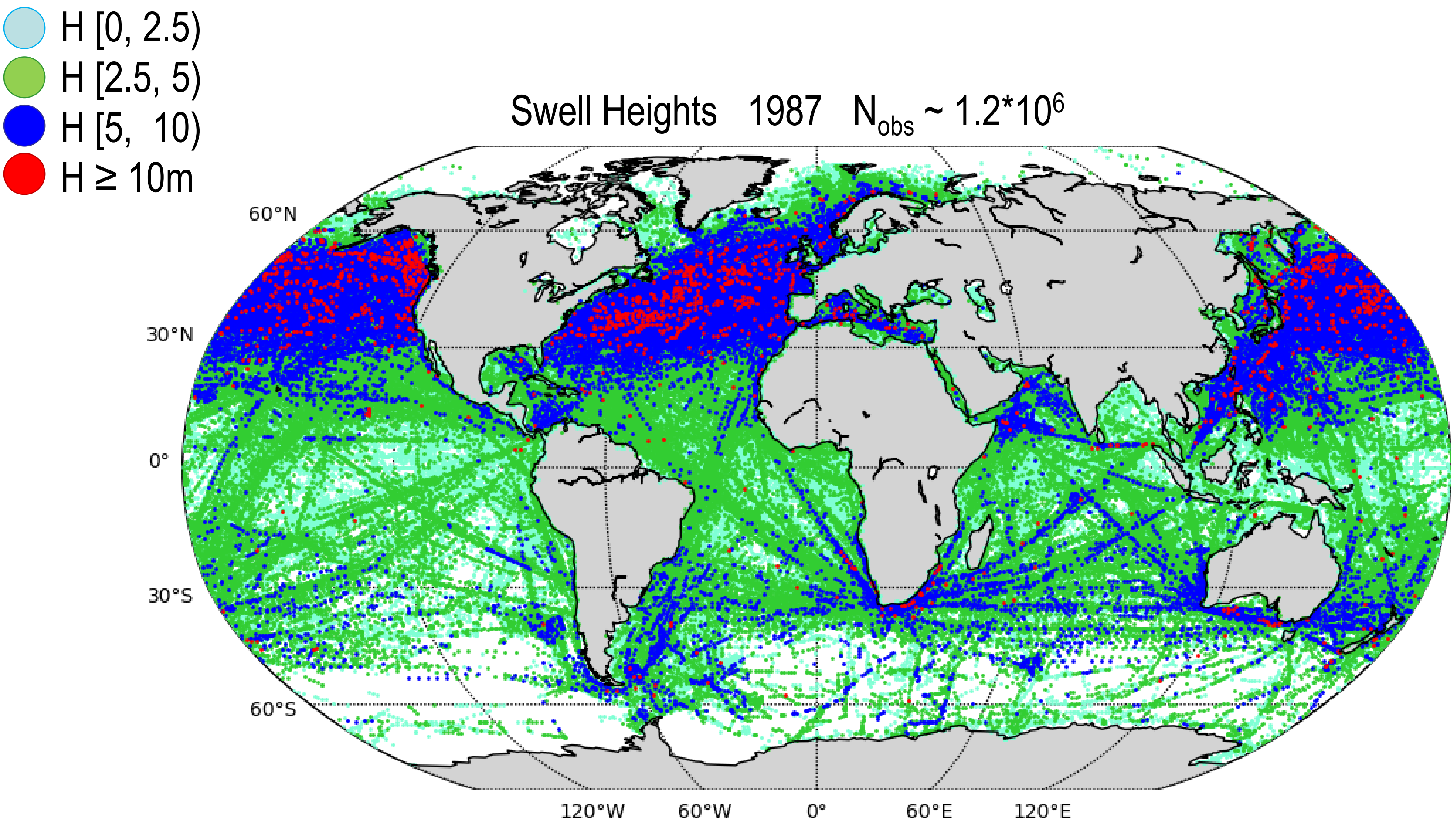
Consistency – observational practice has never been changed

Separate estimates of wind sea and swell characteristics in situ



Swell period is the rarest parameter in VOS collection which dramatically limits the number of complete records

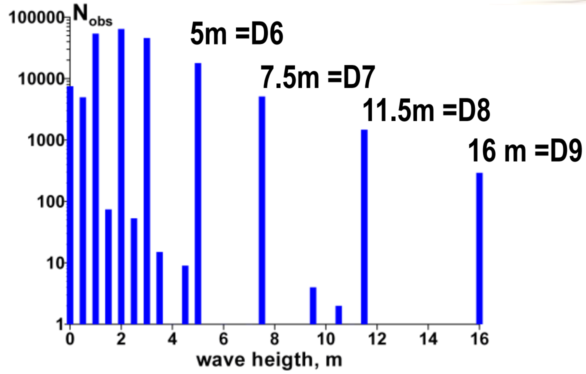
Spatial distribution of swell heights



Spatial and temporal inhomogeneity

Changes in the wave coding system

Douglas sea scale: wave codes prior to 1949



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	2.5–4.0	Rough
6	4.0–6.0	Very rough
7	6.0–9.0	High
8	9.0–14.0	Very high
9	14.0+	Phenomenal

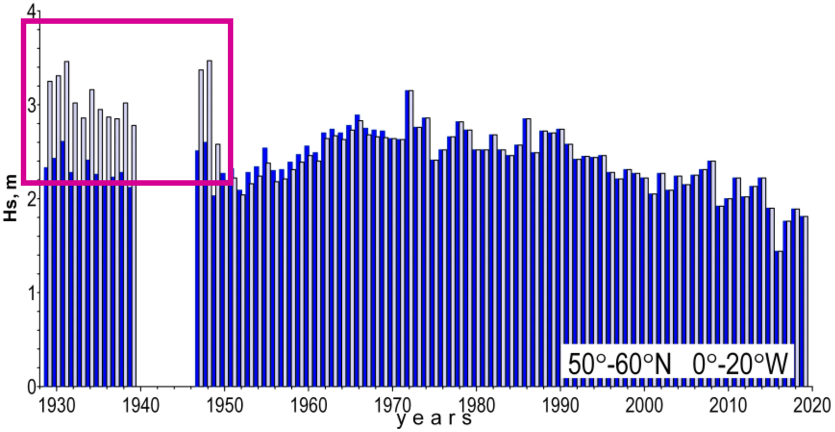
WIND SEA

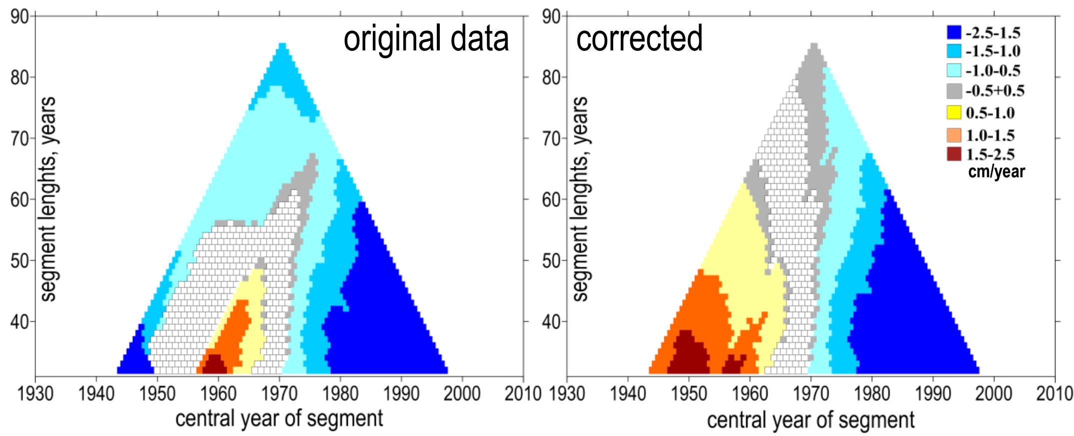
SWELL

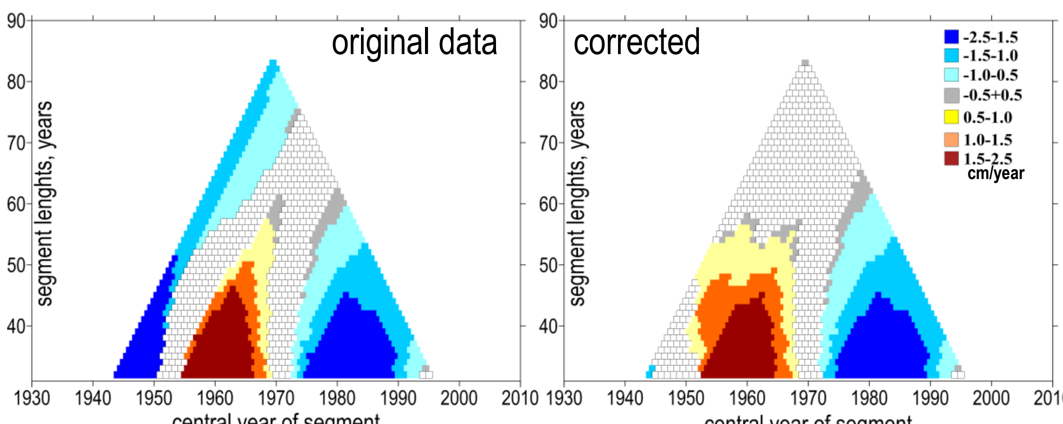
Degree	Description
0	No swell
1	The most probable value for each range estimated in every grid box (2ºx2º,4ºx5º,10ºx20º) for climatological months 1970-2019 (instead of average range value)
2	
3	
4	
5	
6	
7	
8	
9	

Wave code correction

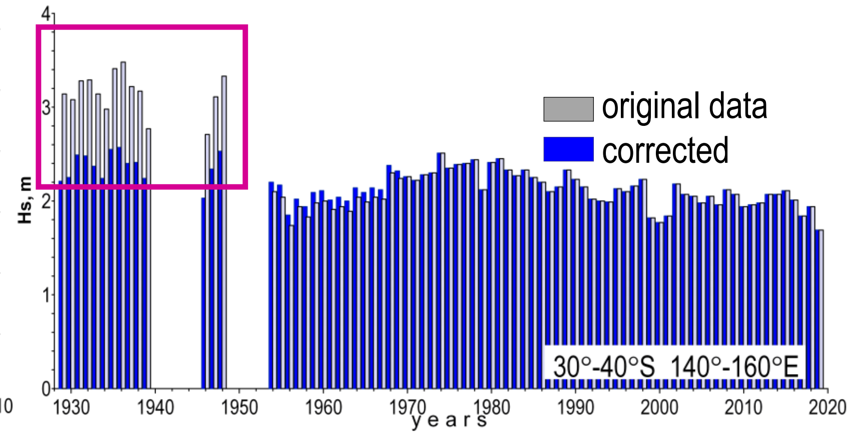
The regularization removes spurious trends over the whole period





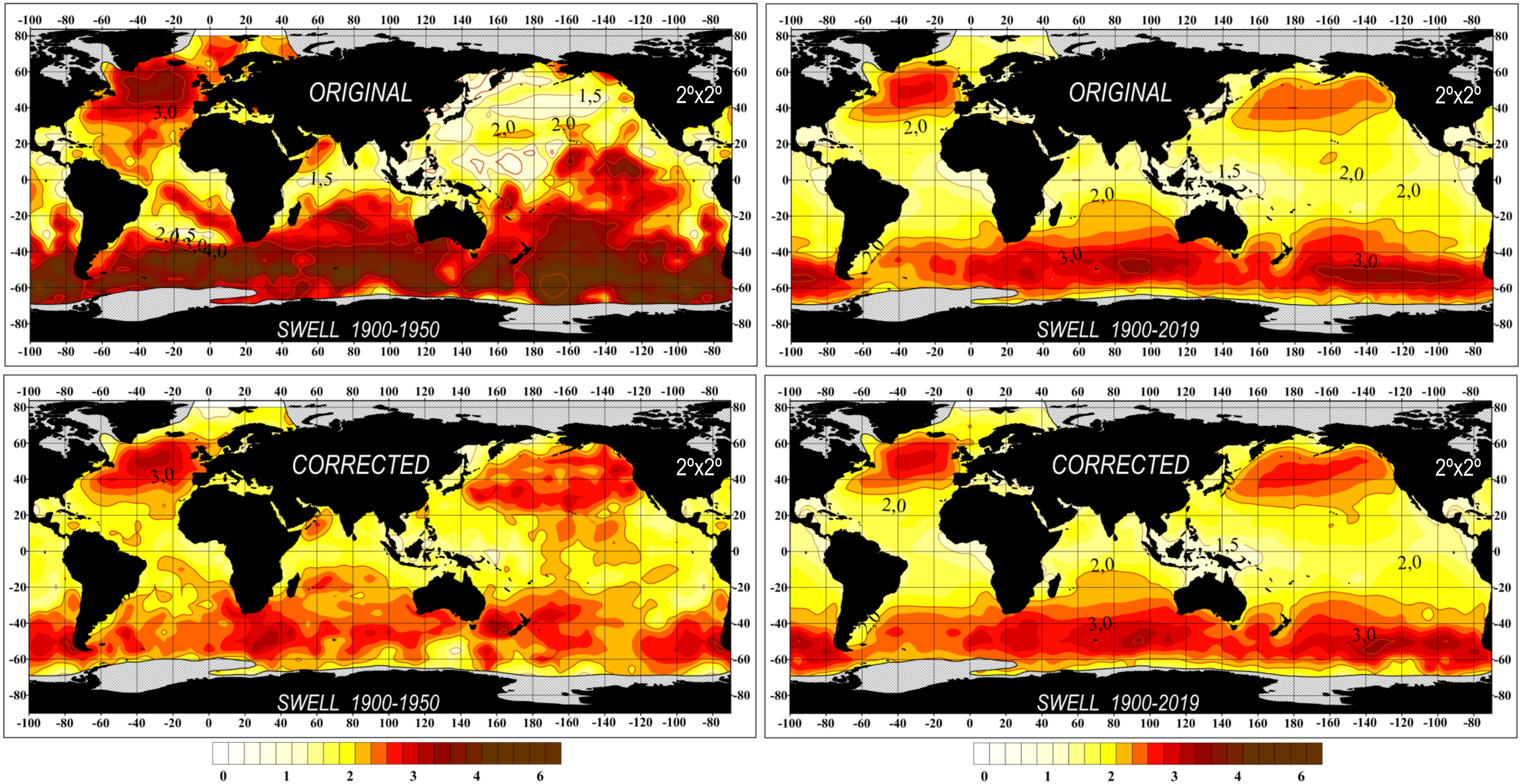


95% significance level t-test

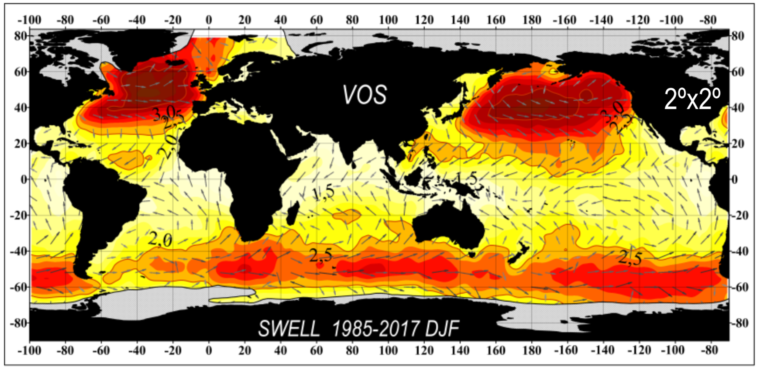


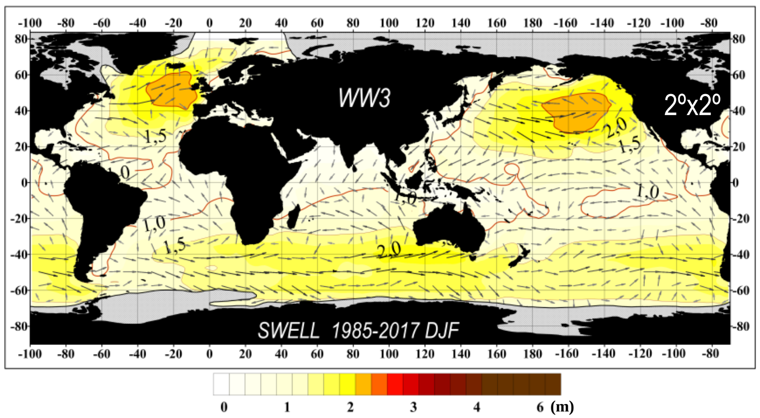
Wave code correction

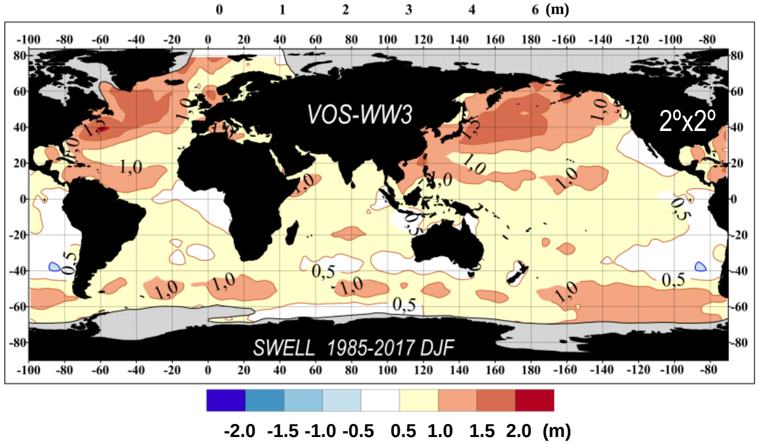
- does not change the number of observations
- takes the geographical and seasonal variability into account
- is done separately for wind sea and swell



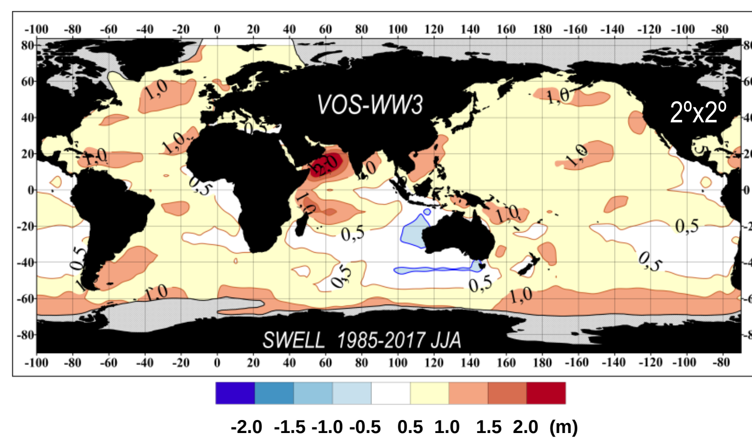
VOS vs WW3 (ERA5) 1985-2017 DJF



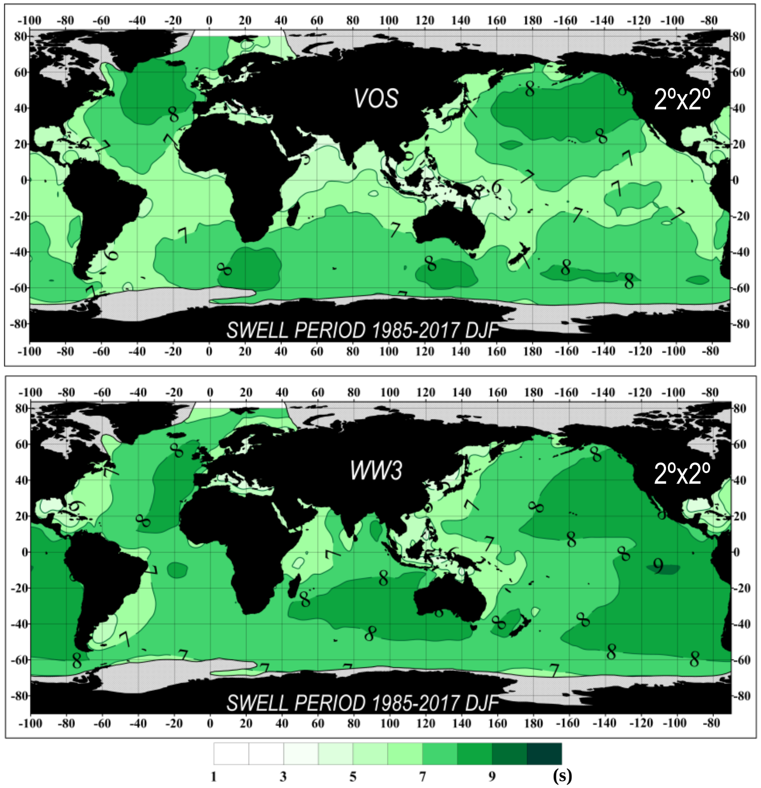


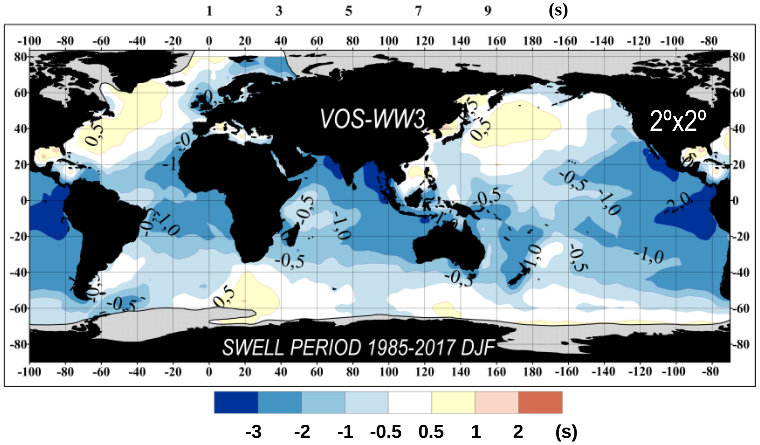


- Swell in WW3 is substantially underestimated
- Good agreement in swell pools for all seasons and months
- Perfect match in directional steadiness
- The biggest differences in summer are in the Arabian Sea (up to 2 m)



VOS vs WW3 (ERA5) 1985-2017 DJF





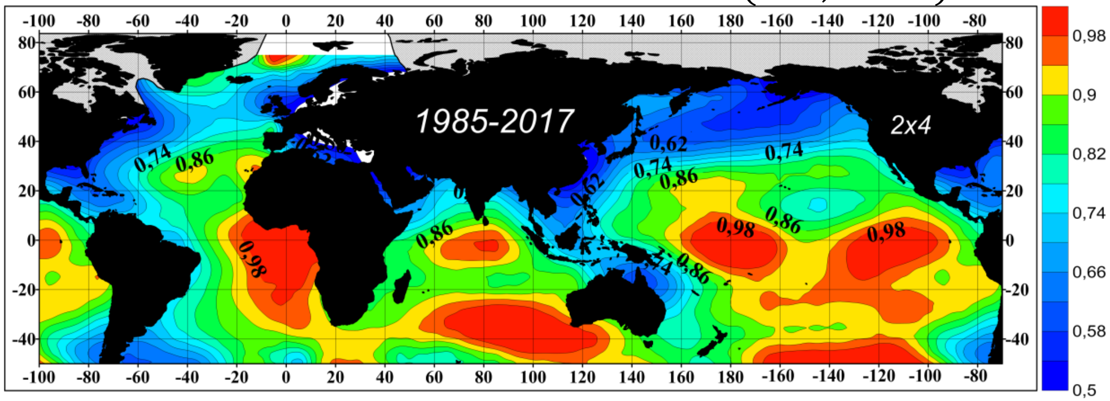
- WW3 peak periods have been corrected according to the relationship from Pierson-Moskowitz spectrum

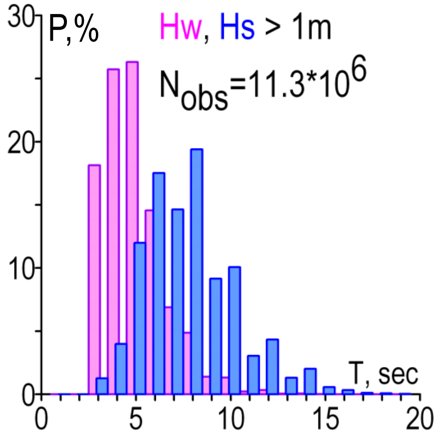
- WW3 swell periods are lower in the NW Atlantic, NW Pacific and partly in the SO (up to 1 sec)
- VOS swell periods are lower in swell pools (up to 3 sec)
- Good agreement in the central Atlantic, central Pacific, and in the SO
- Similar differences for monthly, seasonal, annual, and climatological means

Identification of wind sea and swell

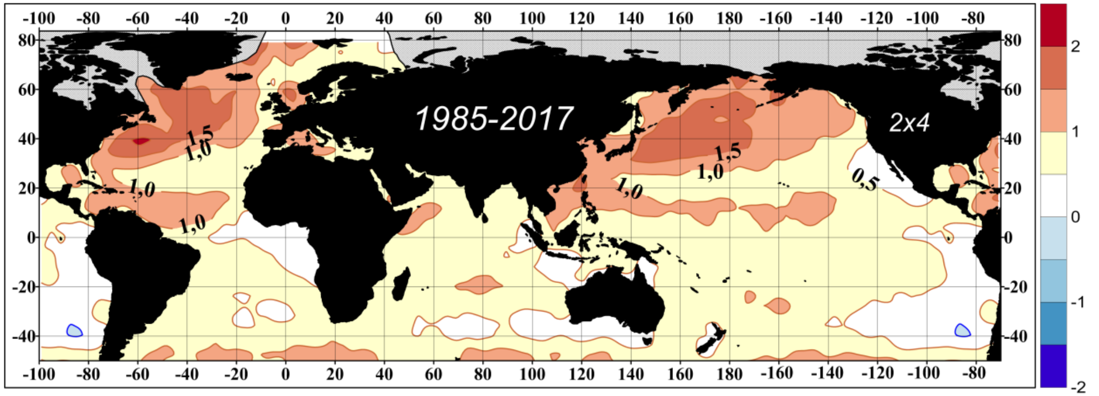
- The biggest differences match the areas where wind sea and swell contribution are equal
- Good agreement in the swell pools where wind sea and swell are clearly separated

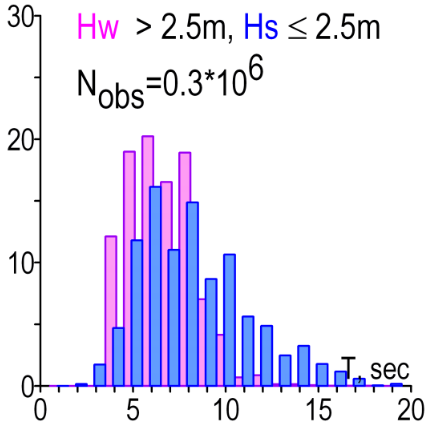
Swell contribution into $SWH = max(Sea, Swell)$





Swell heights differences: VOS minus WW3

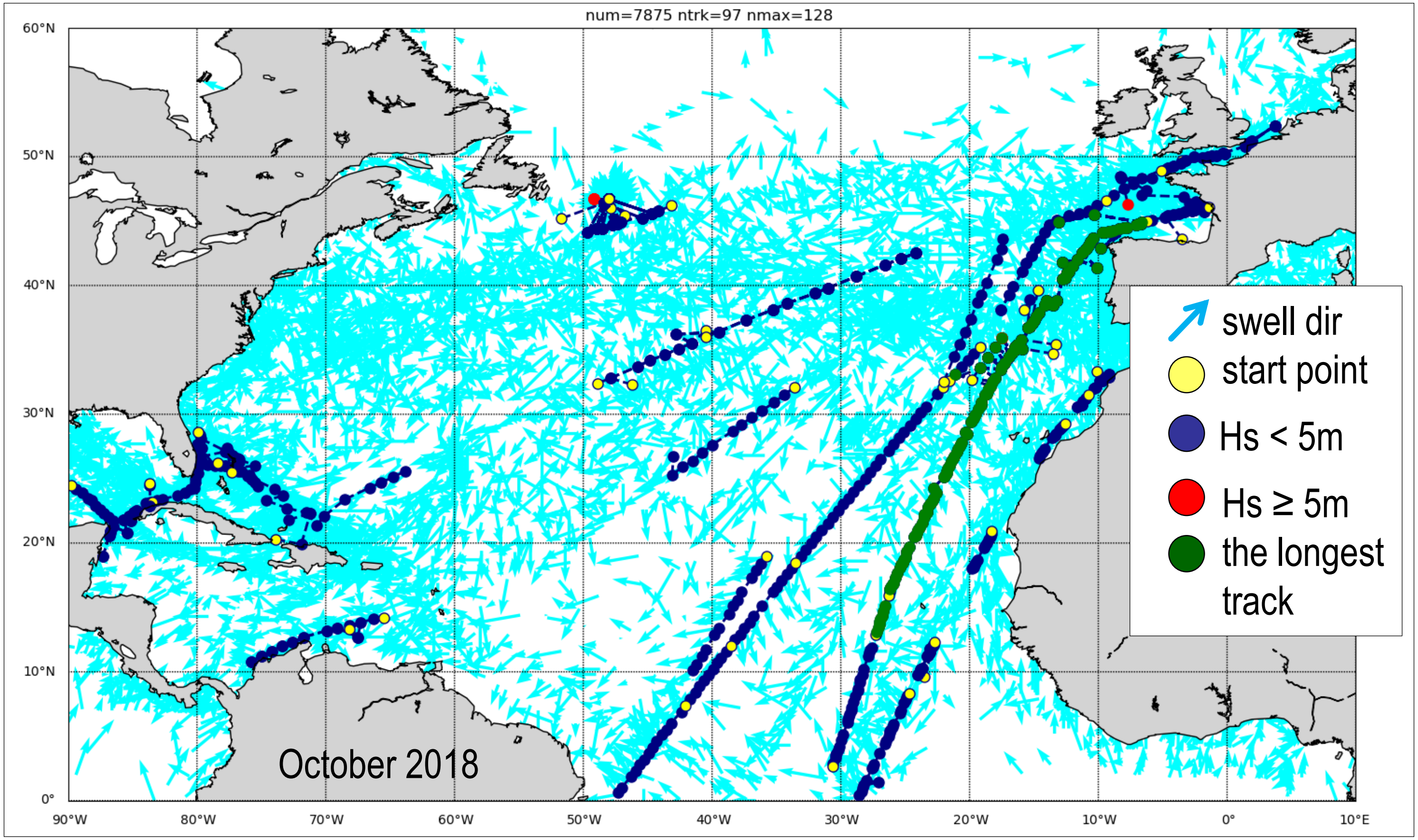




Could it be possible to find an ultimate underlying criterion
to discriminate wave systems?

Swell Tracking Algorithm

- Only the records with complete swell characteristics passed the QC
- Only ships for homogeneity reasons (~90% of the number of observations)
- No restrictions on swell heights, periods, steepness, wave age
- No limitations on the distance to the coast



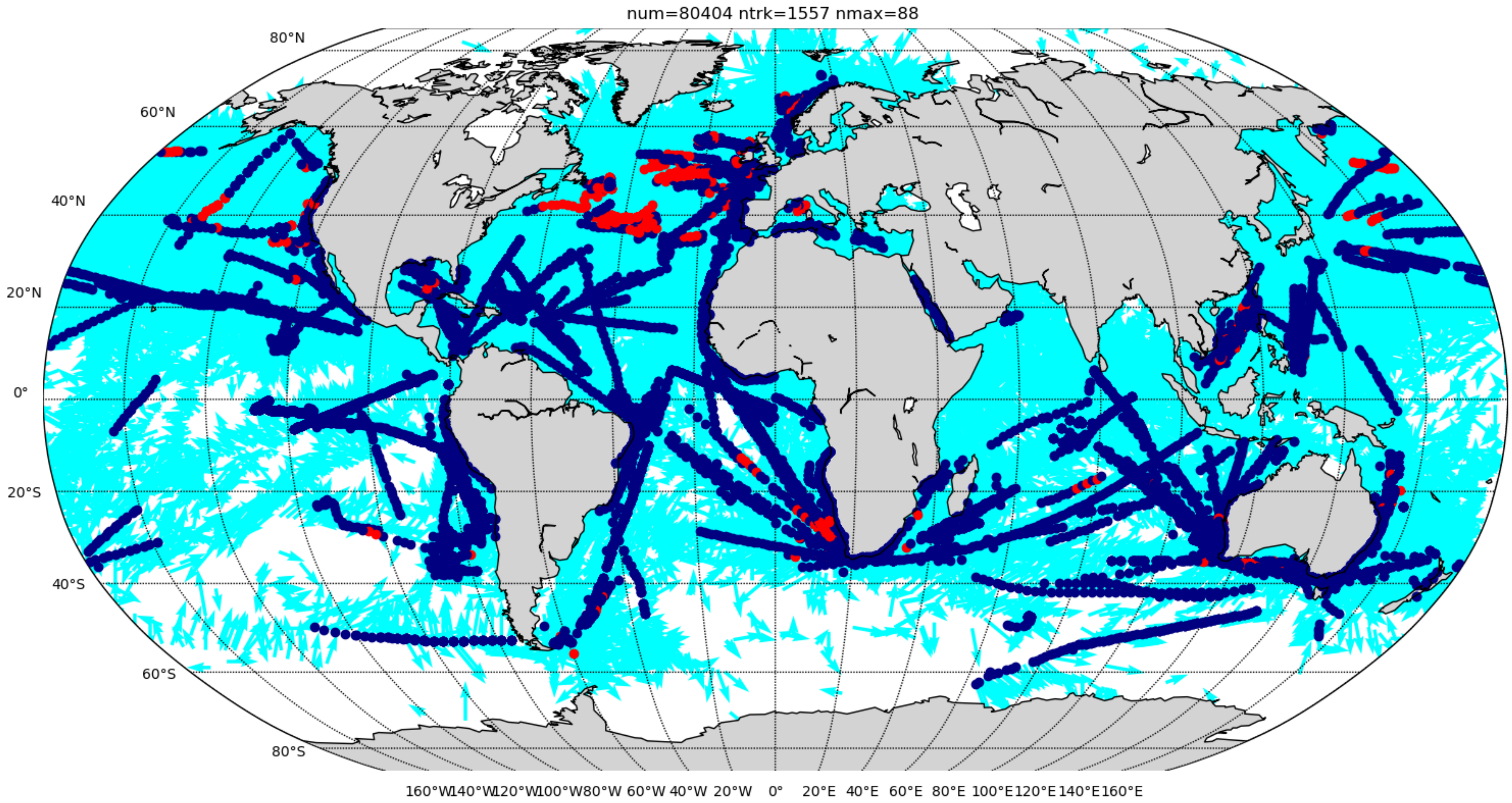
Swell tracking criteria

$\Delta T \leq$ 3 -12 h

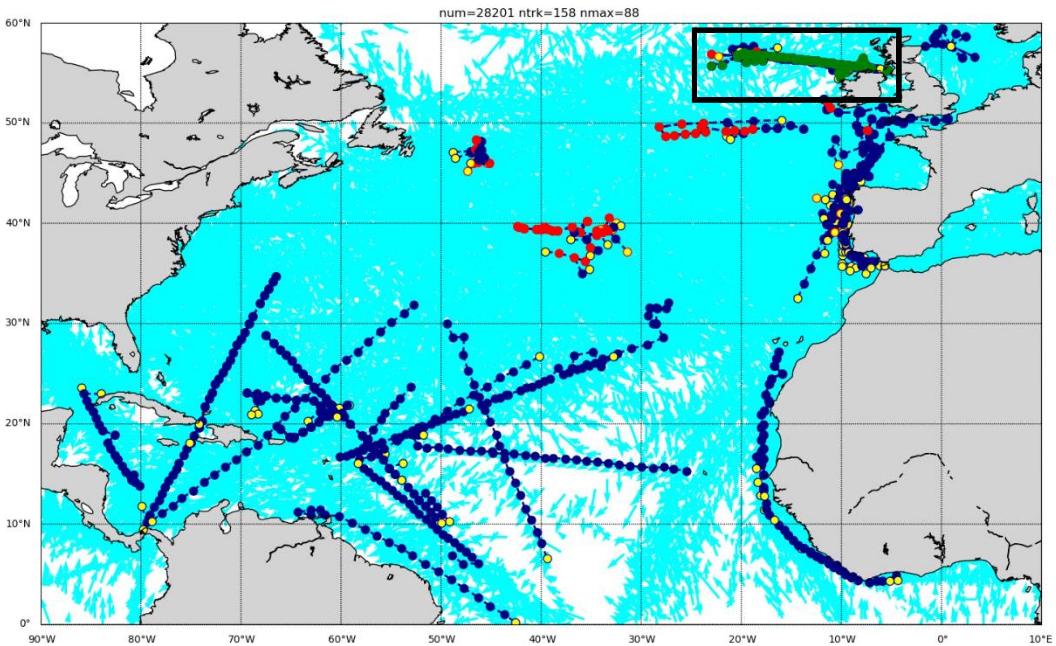
$\Delta R \leq$ 100 - 400 km

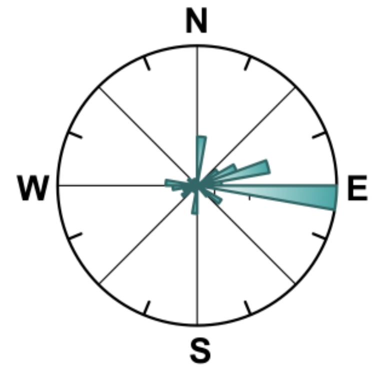
$\Delta D \leq \pm 20°$

$N \geq 15$

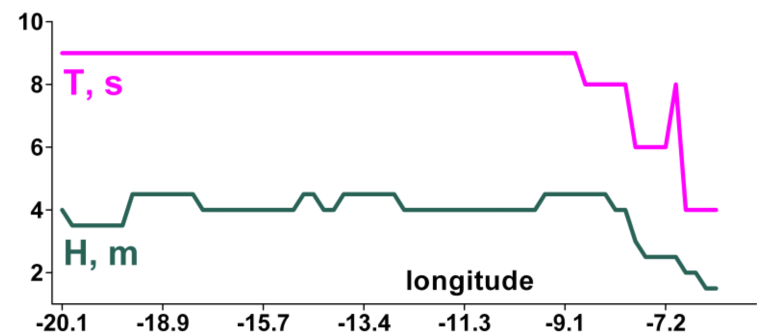


North Atlantic November 1988

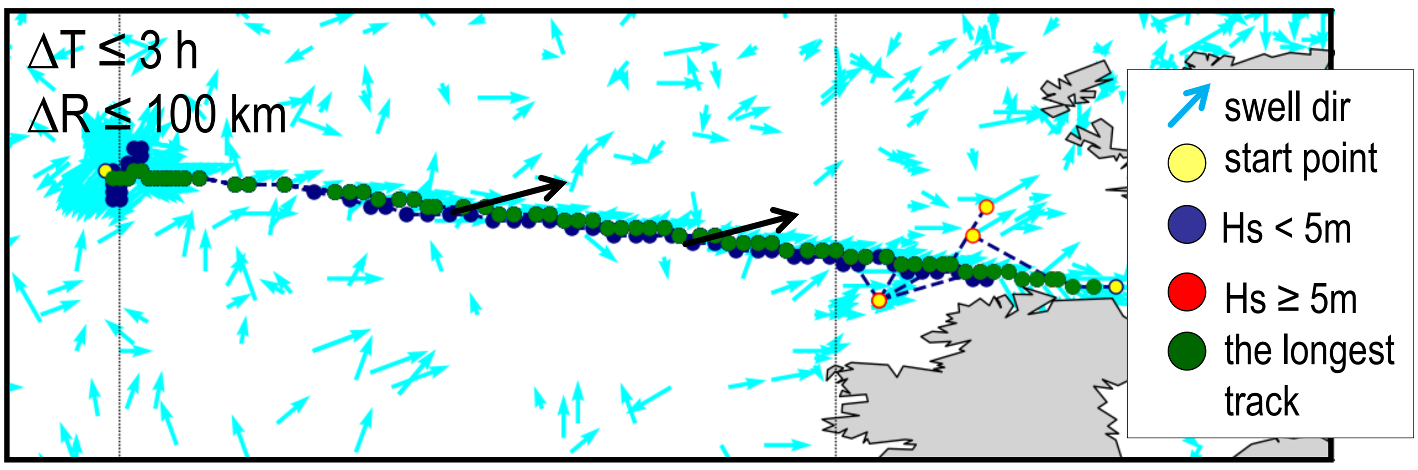




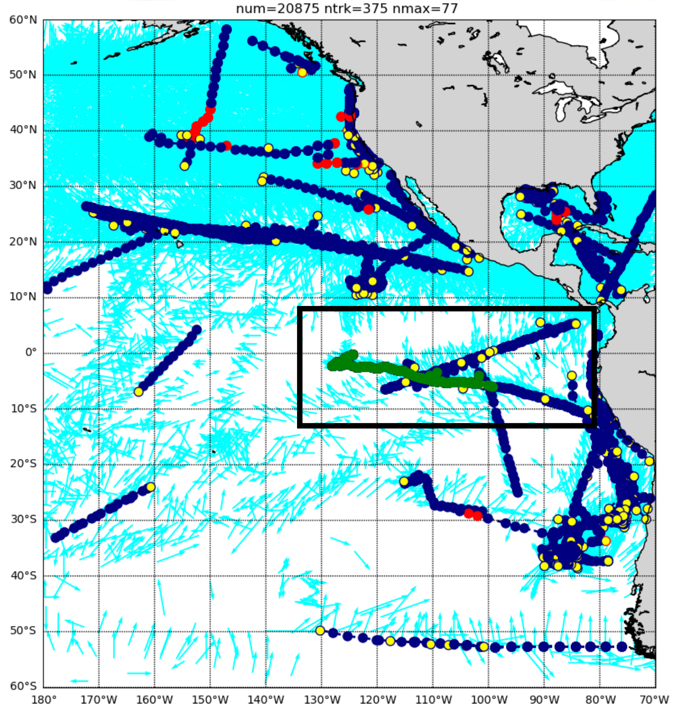
ΔT ≤ 6 h
ΔR ≤ 200 km
N ≥ 20

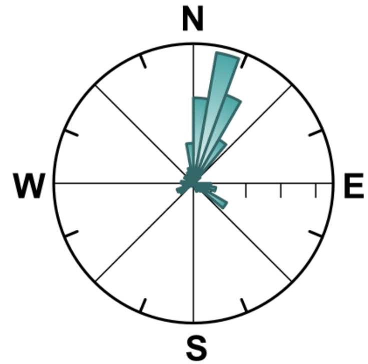


the longest track:
N = 67
T = 80 h
L = 950 km

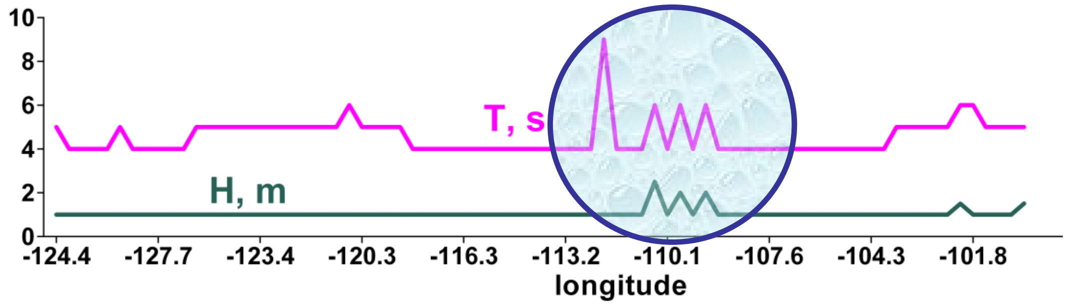


East Pacific November 1988

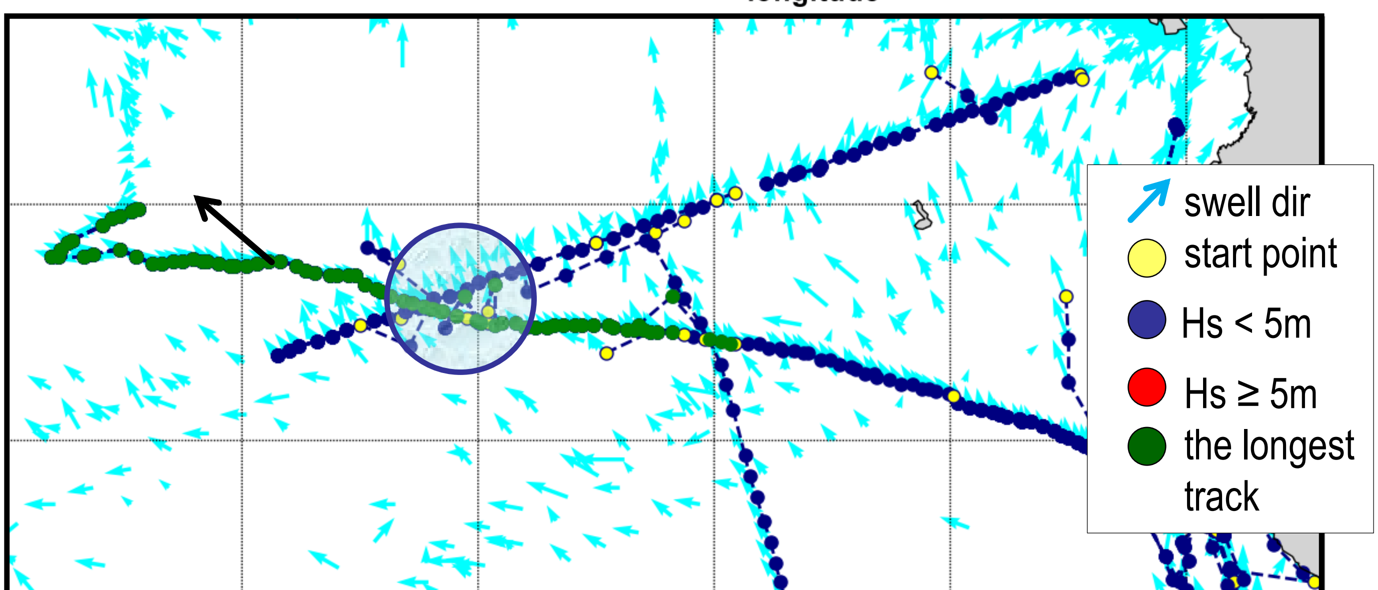




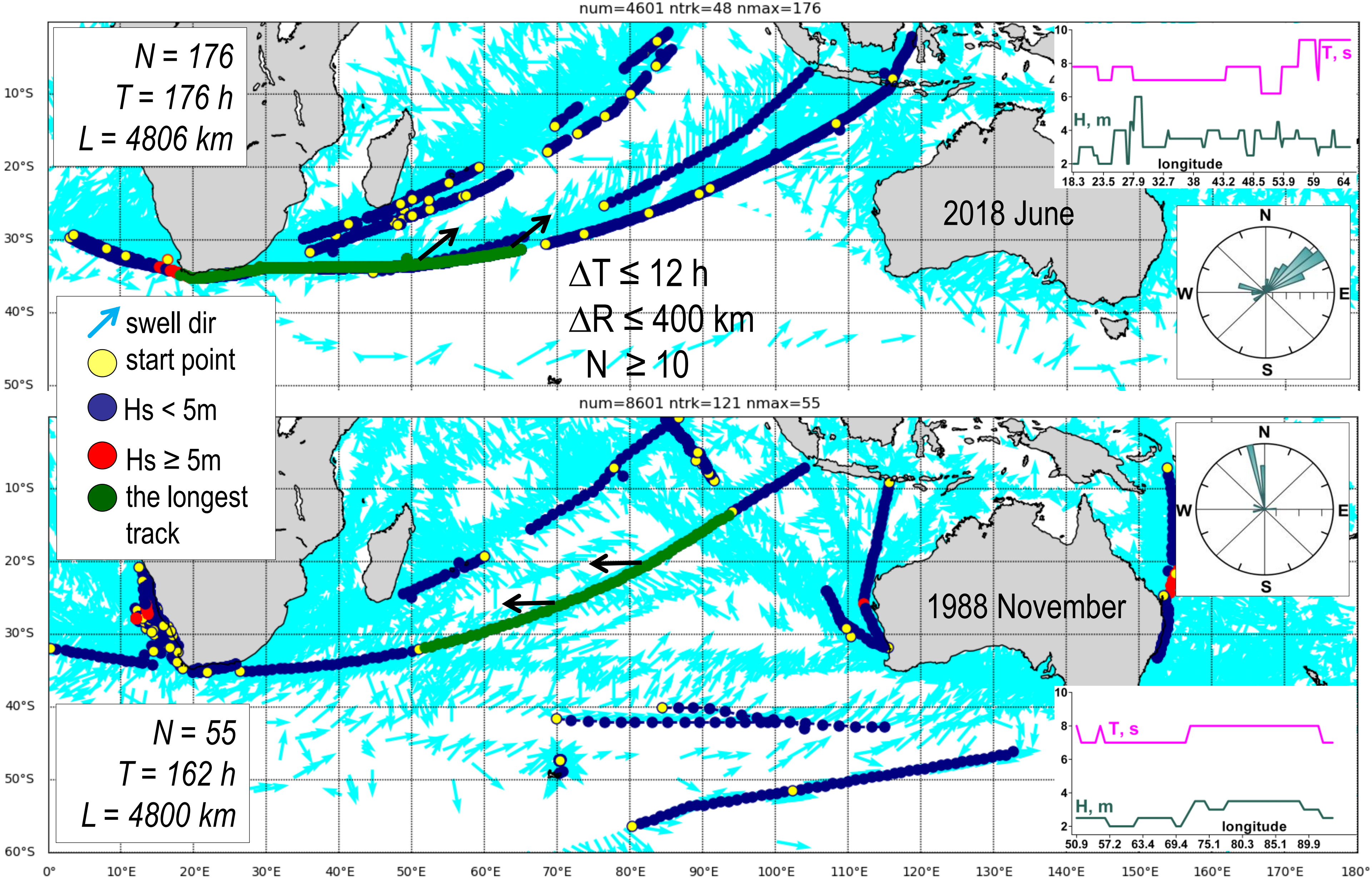
$\Delta T \leq 6$ h
$\Delta R \leq 200$ km
$N \geq 15$



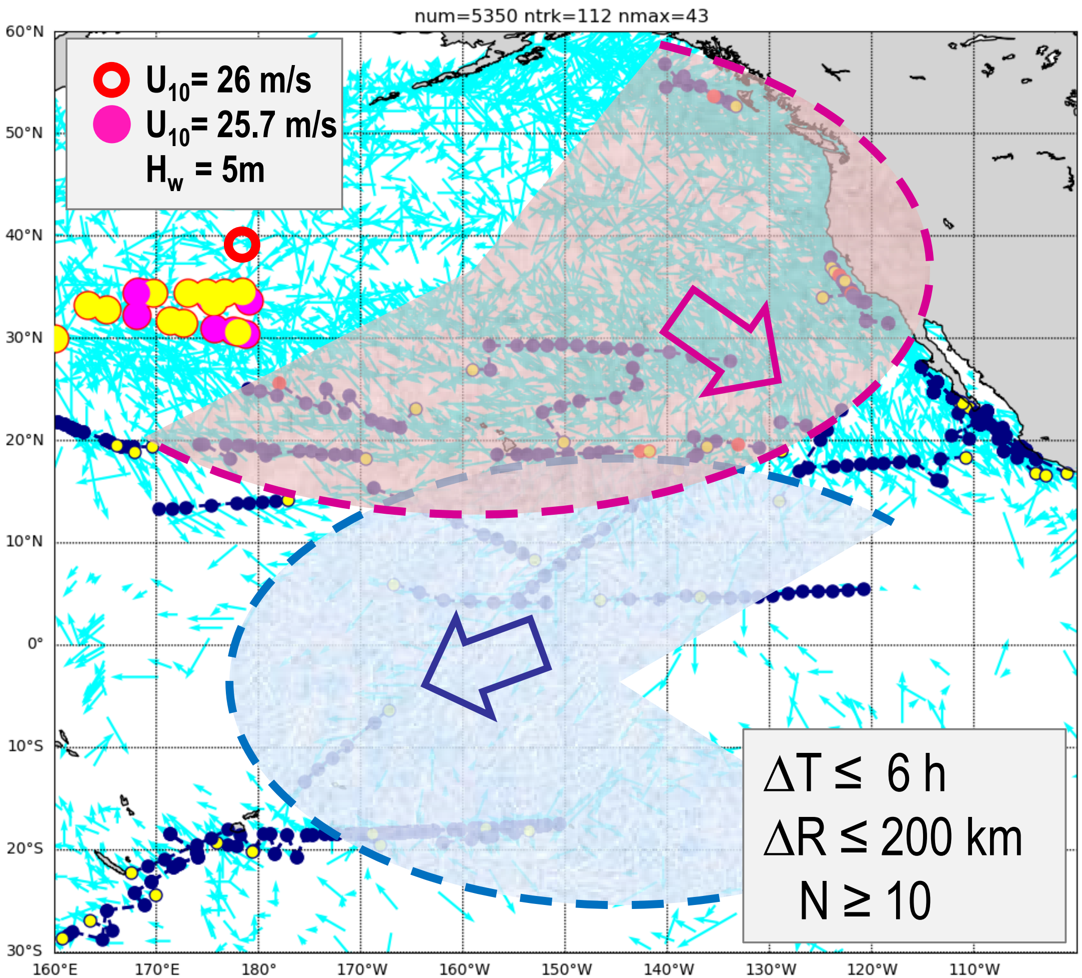
the longest track:
N = 77
T = 255 h
L = 3100 km

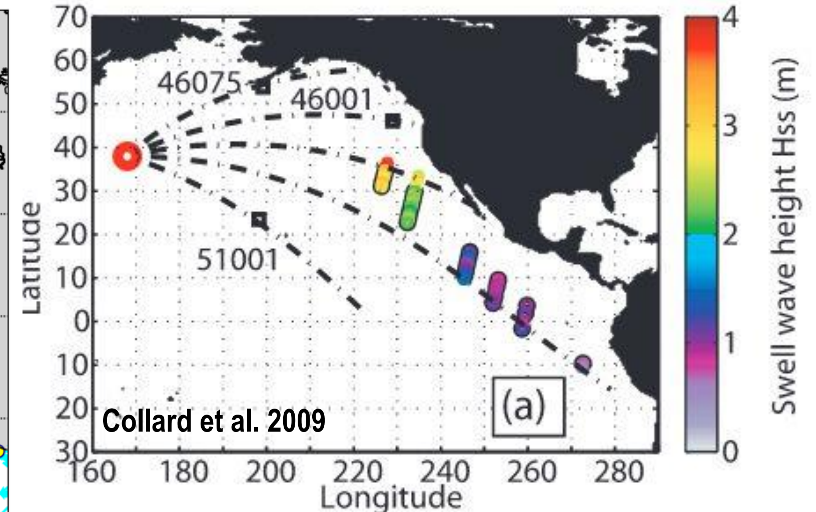


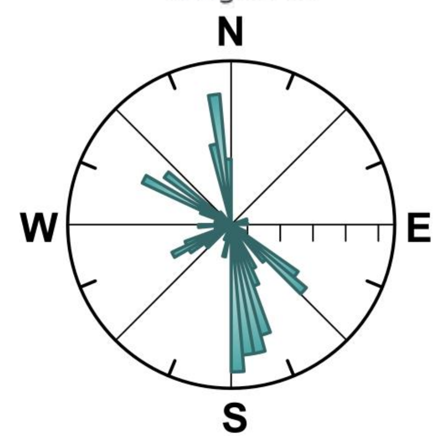
Southern Ocean

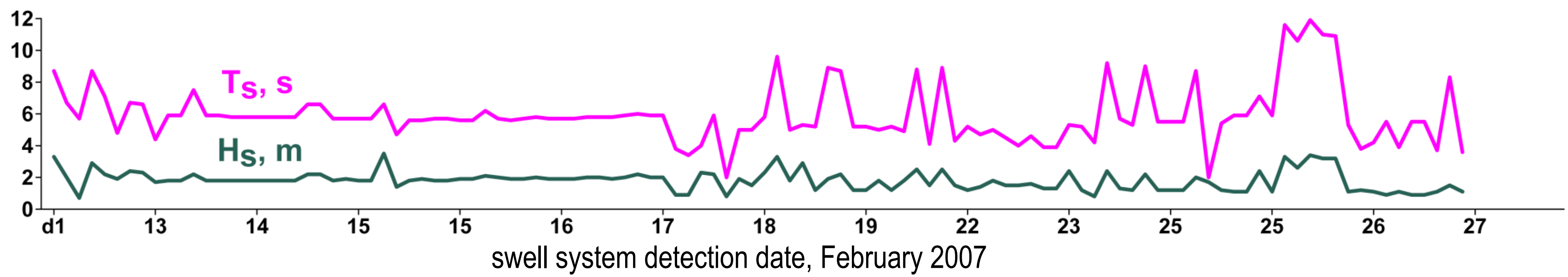


Case Study: 12 February 2007 (storm)









Conclusions

- Homogeneous centennial time series of swell heights based on visual wave observations were developed with the corrected data for the early XXth century

- For the last three decades WW3 hindcast agree well with VOS for the directions but demonstrates underestimation of swell heights almost everywhere likely due to the chosen methodology of identification of swells

- A simplified swell tracking algorithm based on visual wave data is tested for a number of swell trains over the Global Ocean

Outlook

- Coupling swell tracks in VOS data and models

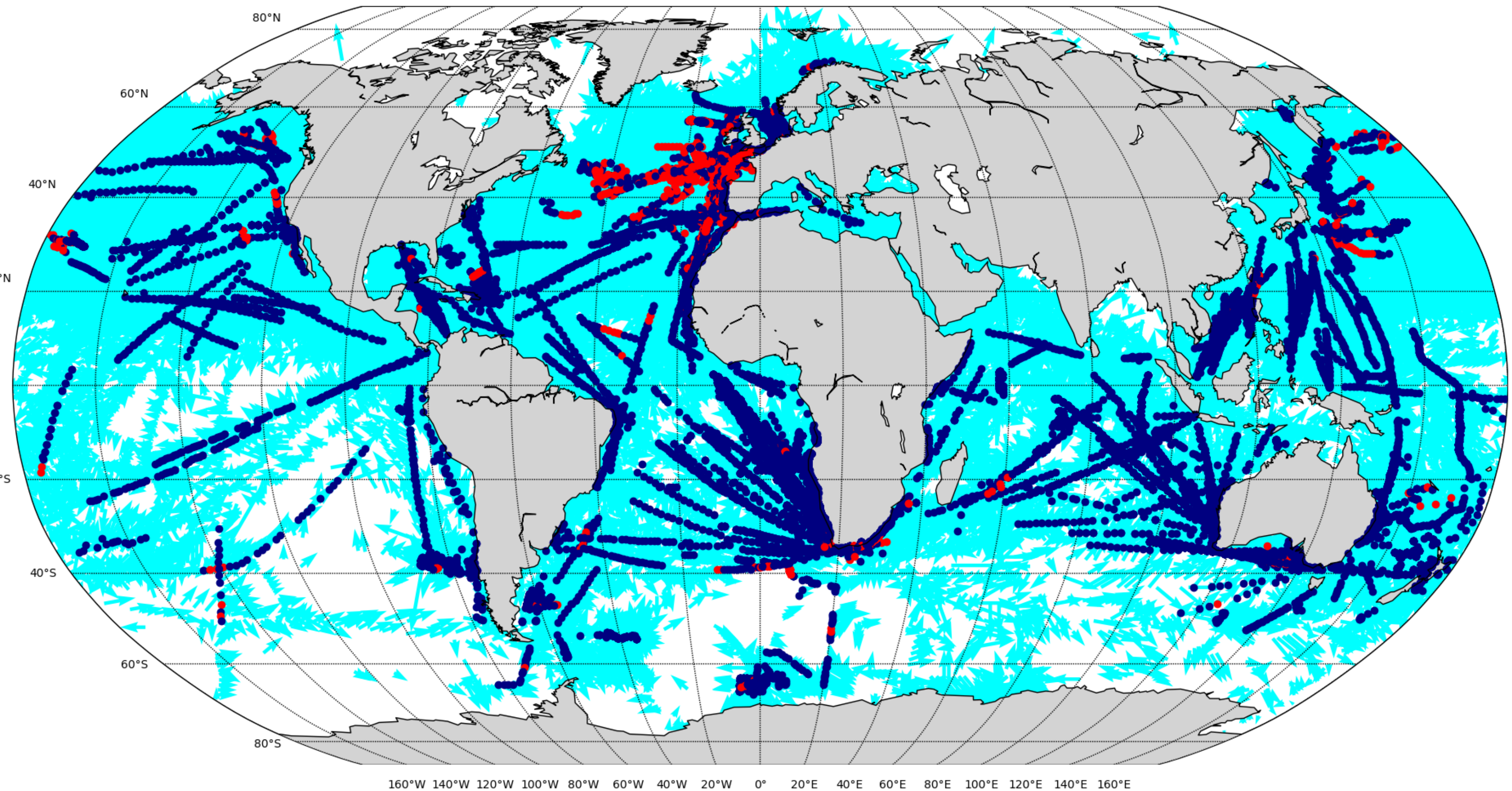
- A joint analysis of swell propagation using spatial model data with high resolution and EOF-based approach

- Linking propagating swell systems with atmospheric transients

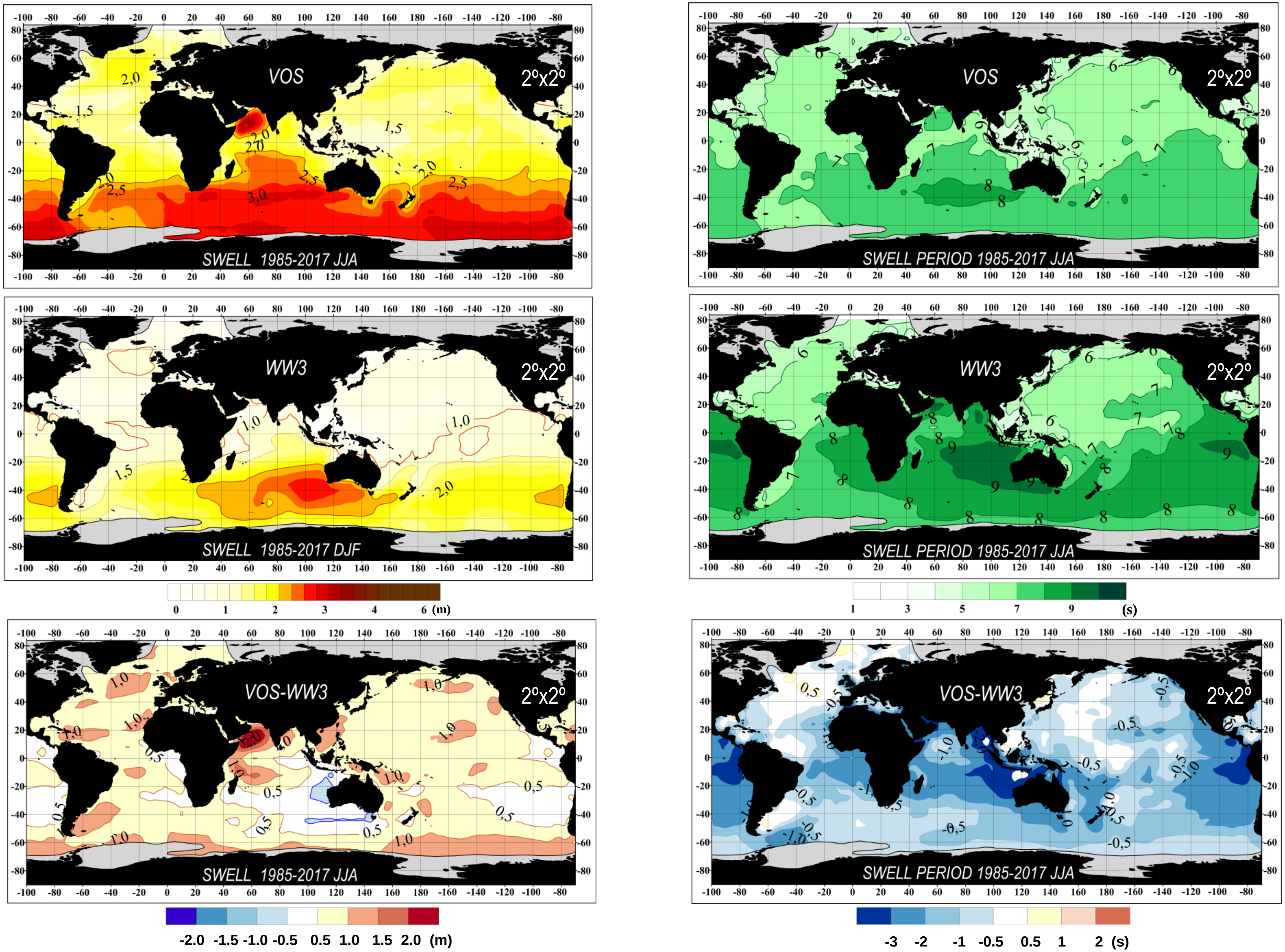
Swell tracking

- $\Delta T \leq$ 3 -12 h
- $\Delta R \leq$ 100 - 400 km
- $\Delta D \leq \pm$ 20°
- Number of track points >15

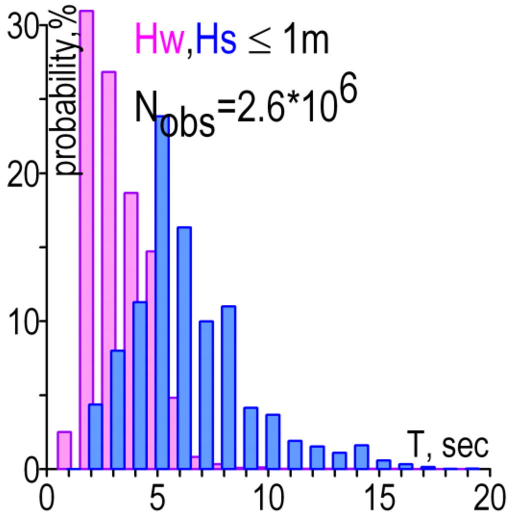
Swell Tracks 1988 Jan $N_{obs} \sim 9*10^5$, $N_{track} = 1952$



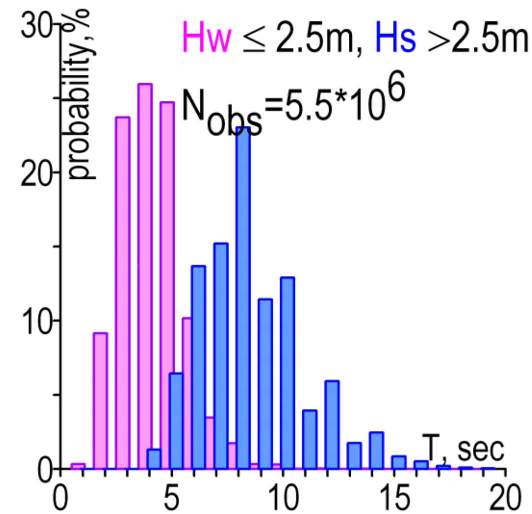
VOS vs WW3-ERA5 1985-2017 JJA

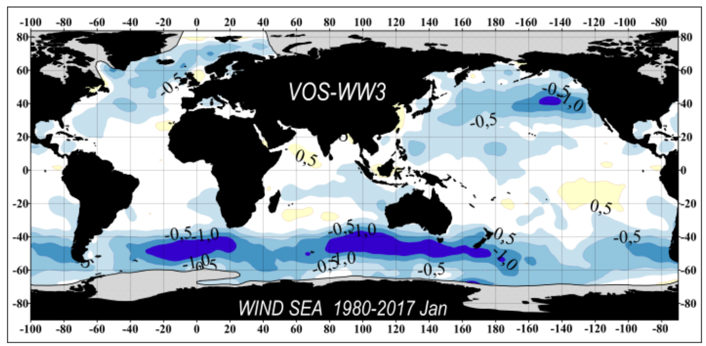


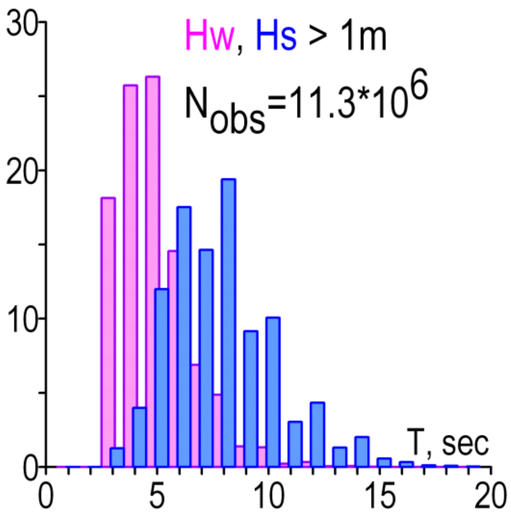
Identification of wind sea and swell

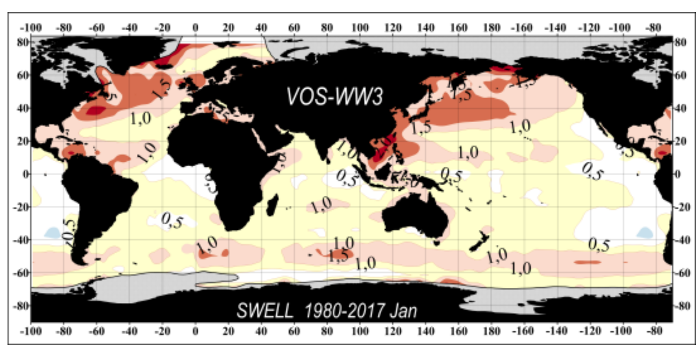


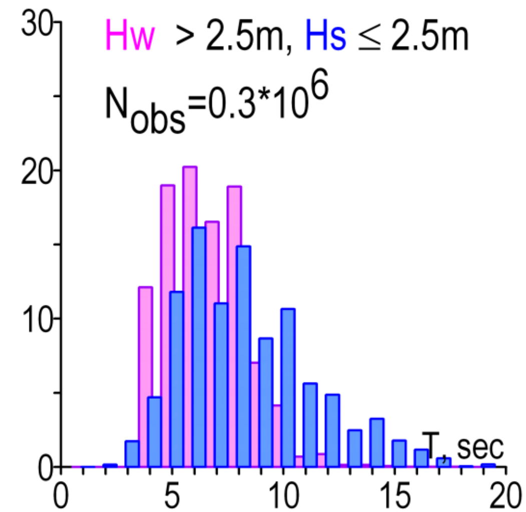
Joint analysis of wind sea and swell distributions in VOS allows for explaining the nature of differences between modelled and observed waves





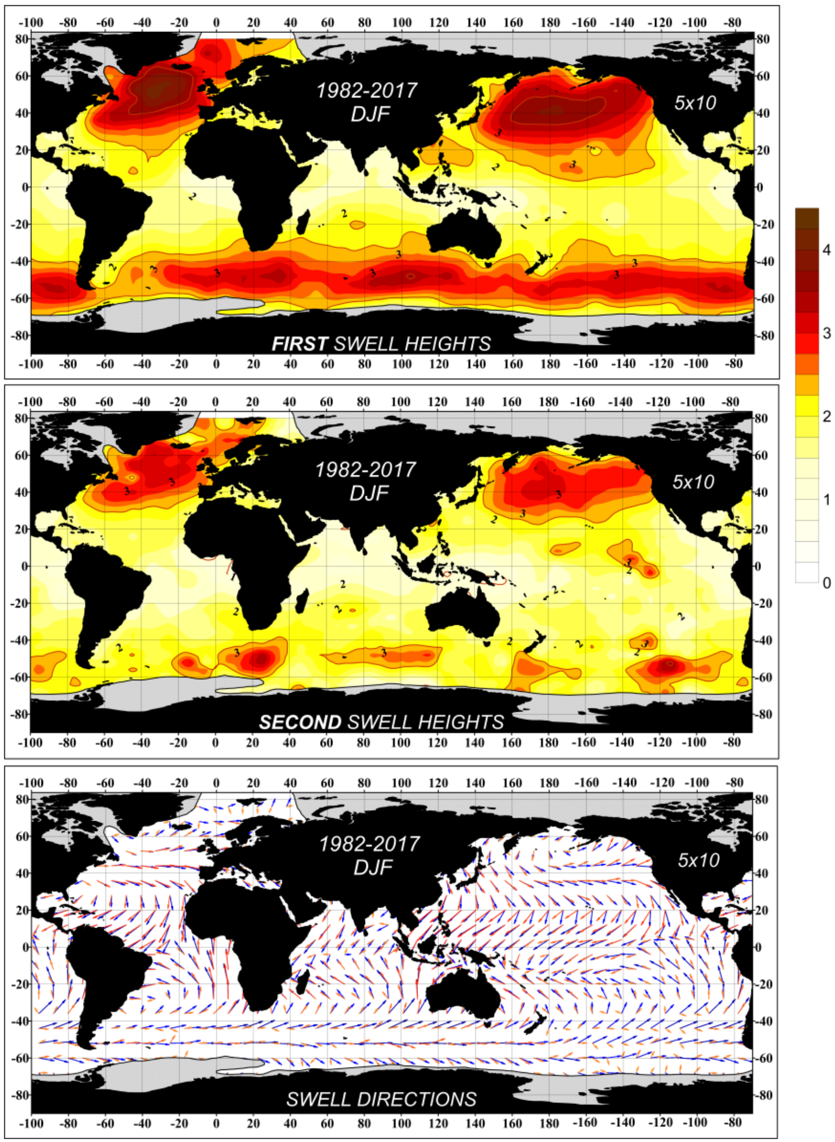




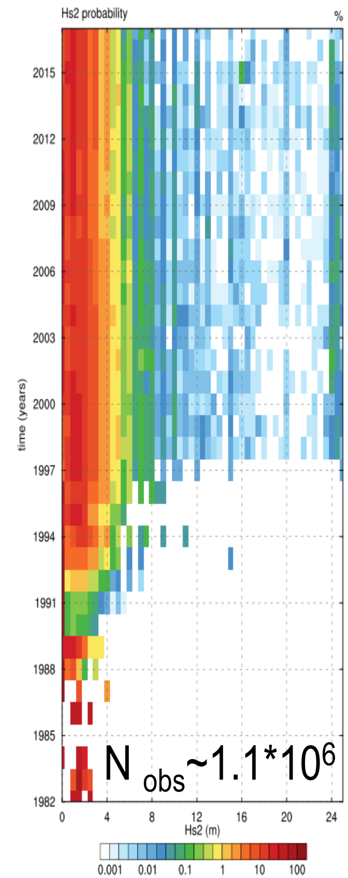


VOS vs WW3

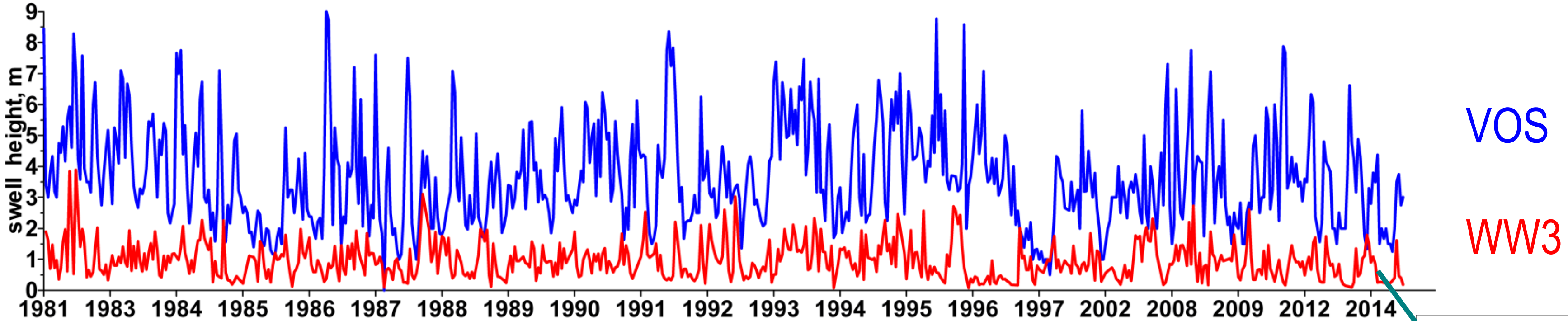
Secondary swell (1982+)



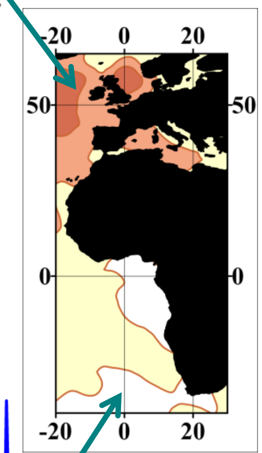
- global coverage since 1995
- Good agreement in directions with SAR and WW3
- The highest differences in heights are observed in the NA Ocean with VOS waves twice higher than model ones
- Allowing for the analysis of crossing swell

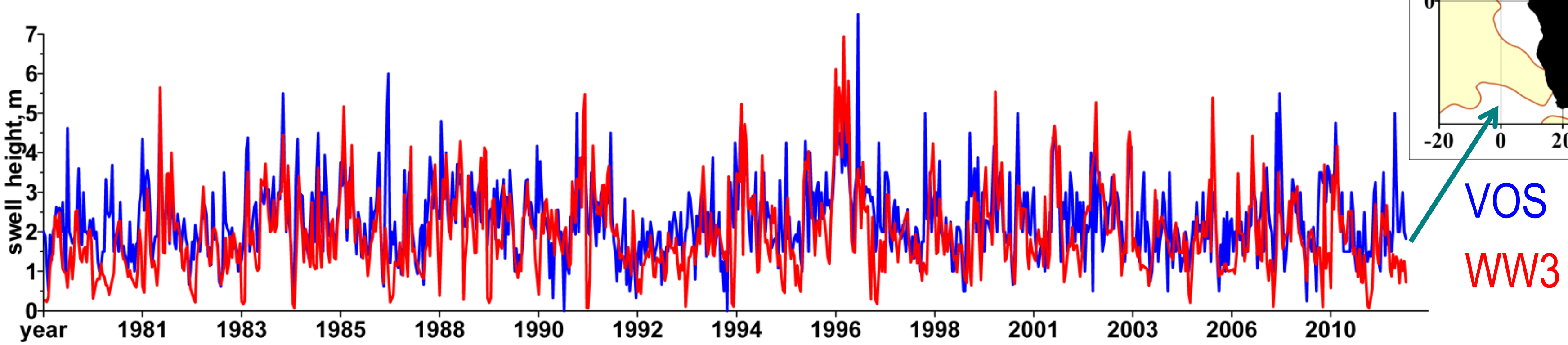


Swell heights daily series 1980-2017



Bias in magnitudes and uncorrelated variability



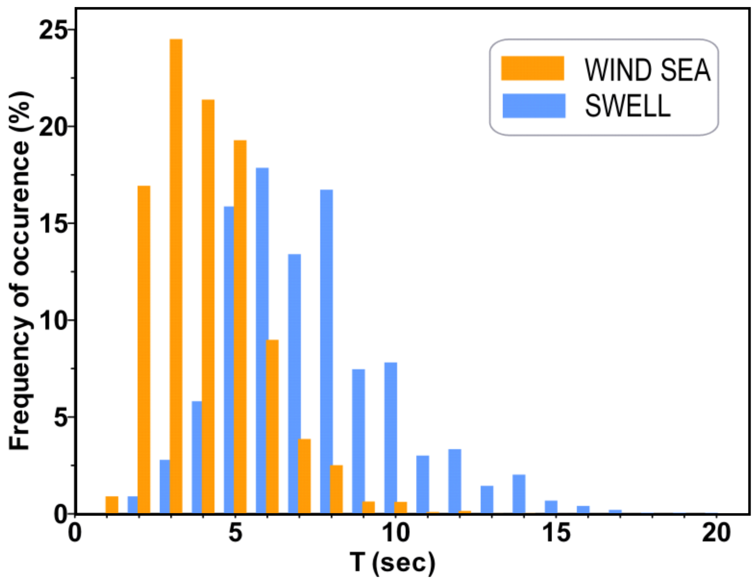


Consistency in magnitudes and in variability

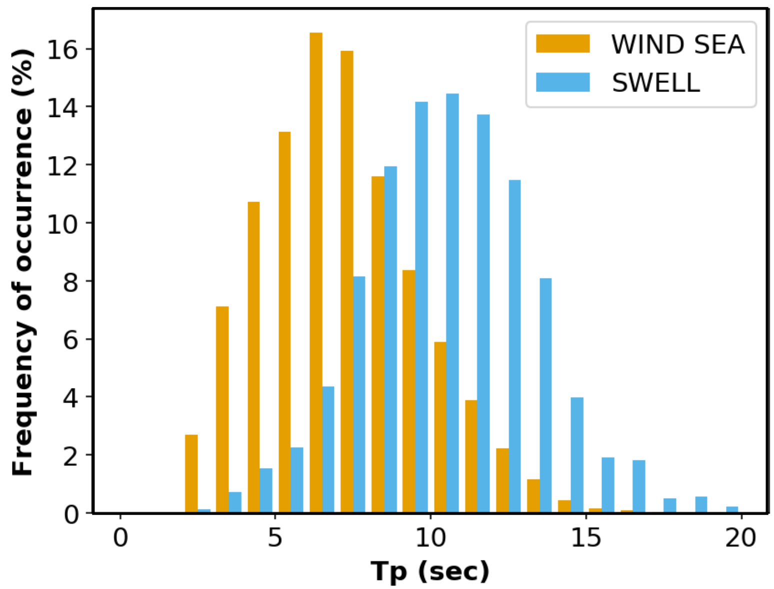
Identification of wind sea and swell

Could it be possible to find an ultimate underlying criterion
to discriminate wave systems?

VOS

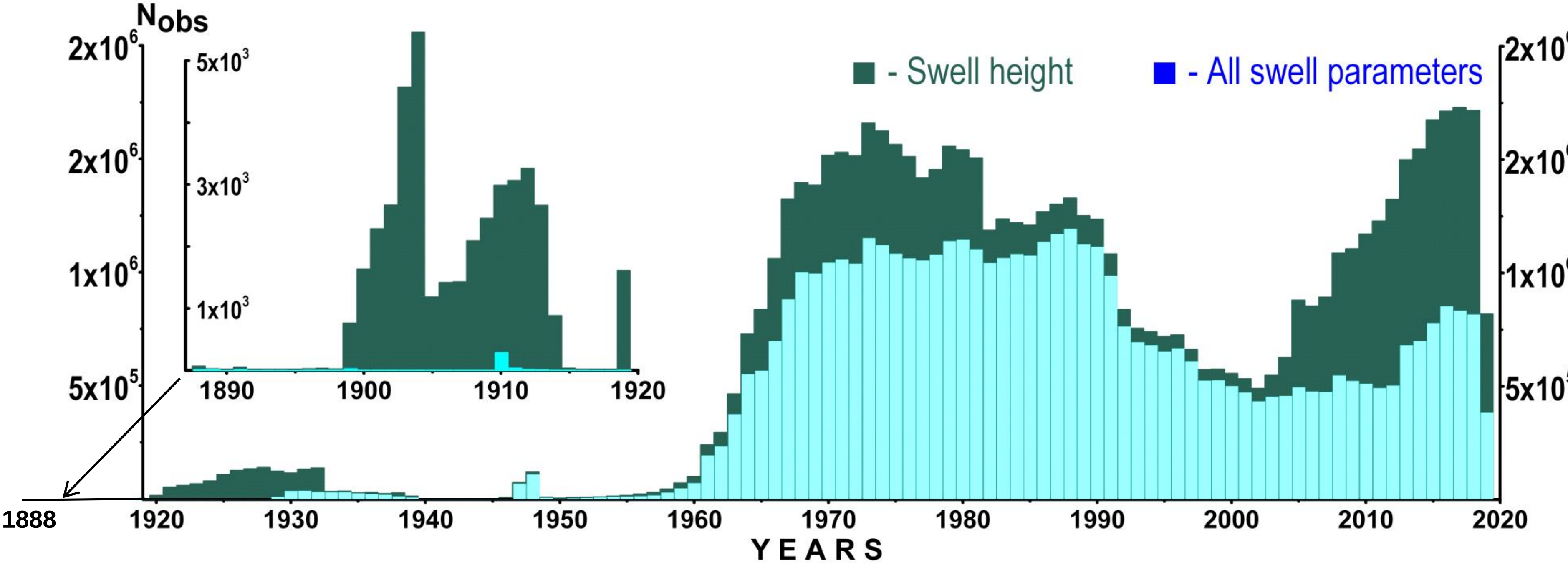


WW3



Temporal distribution of the number of swell (1888-2019)

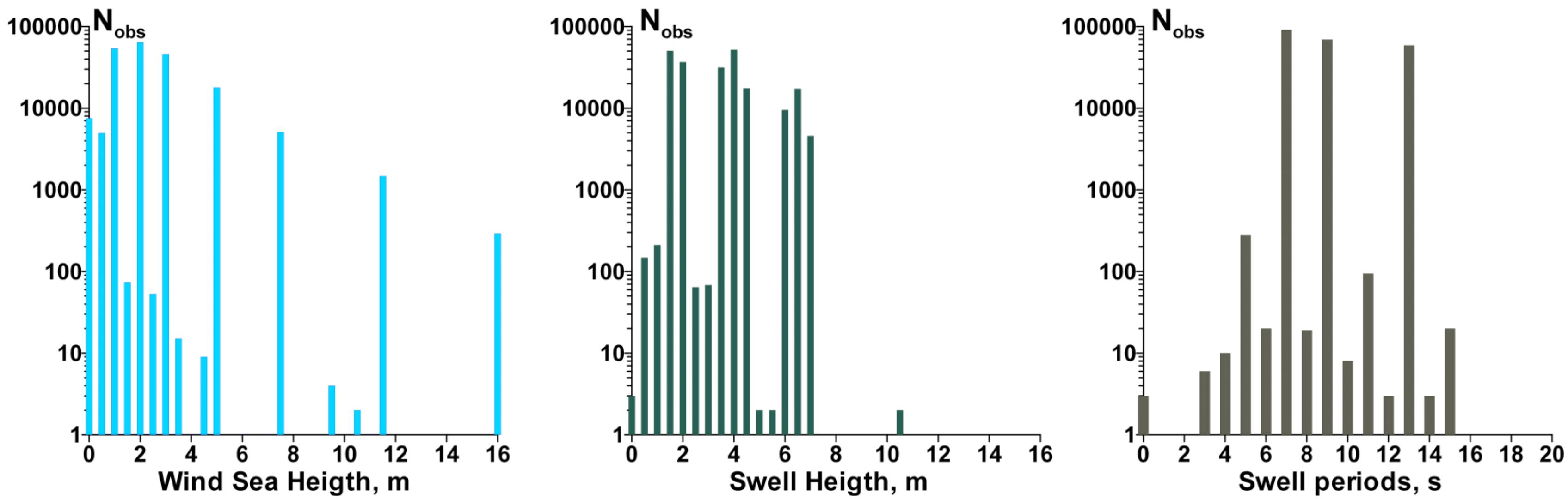
Number of all VOS records ~ $658*10^6$
Number of swell heights ~ $68*10^6$ ~ 10.3%
Number of all swell parameters ~ $47*10^6$ ~ 7.1%



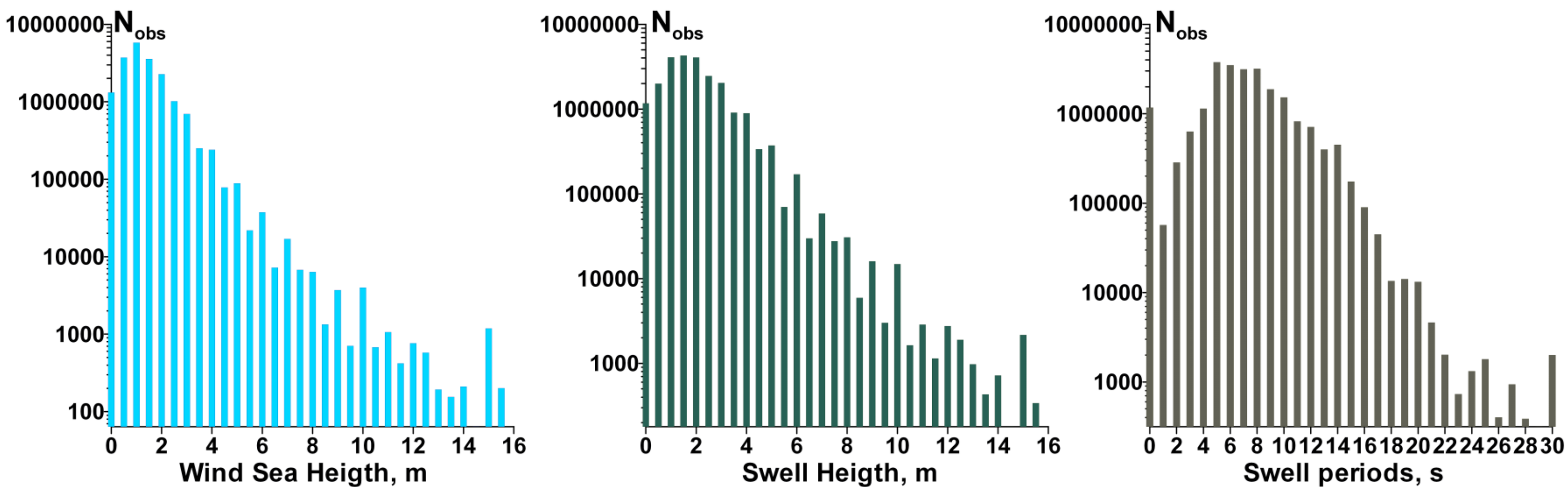
Swell period is the rarest parameter in VOS collection which dramatically limits the number of complete records

Probability distributions

Wave Statistics 1888-1949

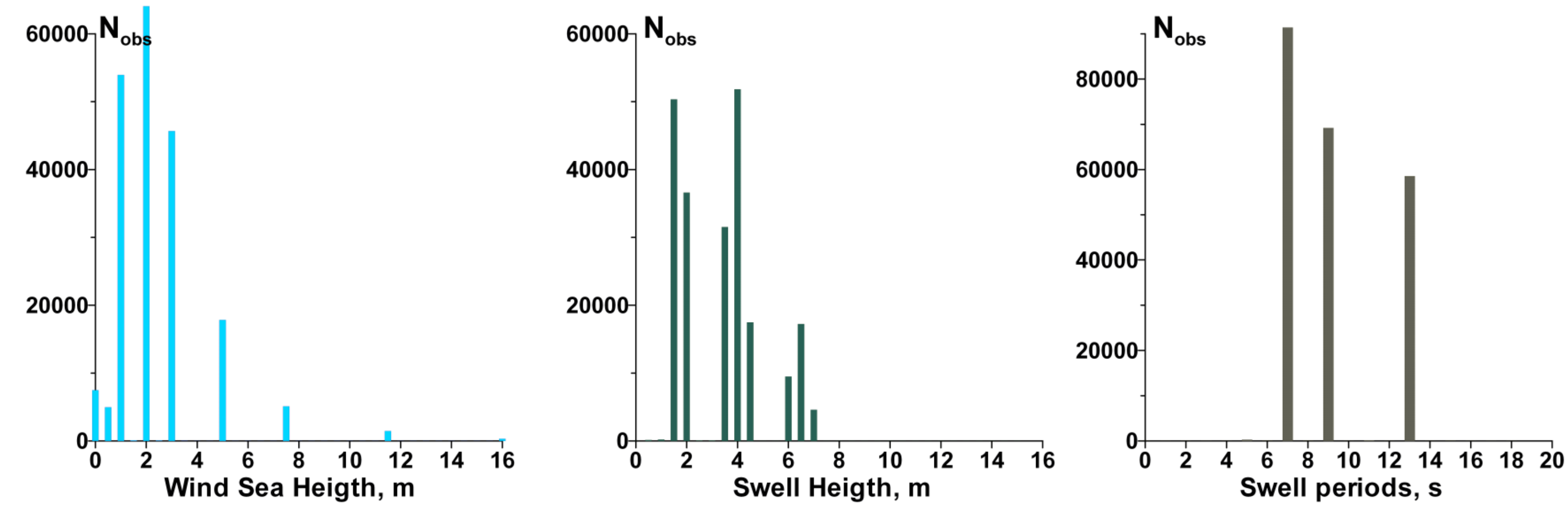


Wave Statistics 1950-2019

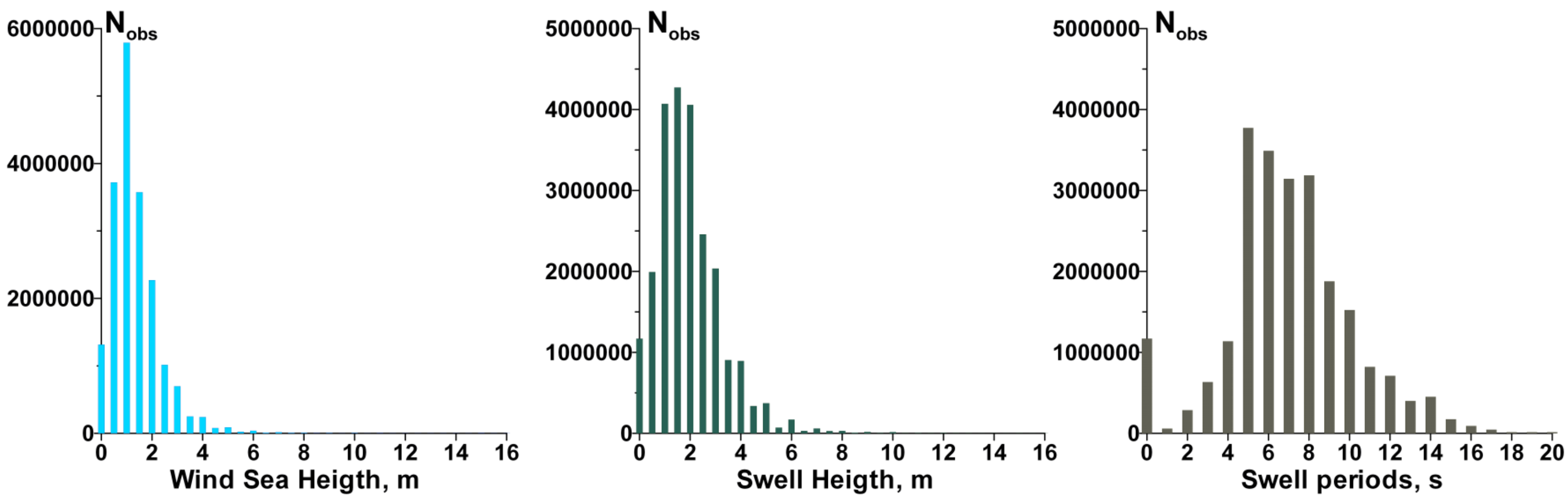


Probability distributions

Wave Statistics 1888-1949



Wave Statistics 1950-2019



Spectral Wave Model WAVEWATCH III: (v5.16)

Boundary conditions:

6-hr winds and ice concentrations from ERA5

Horizontal resolution:

0.25°(lat)x0.25°(lon)

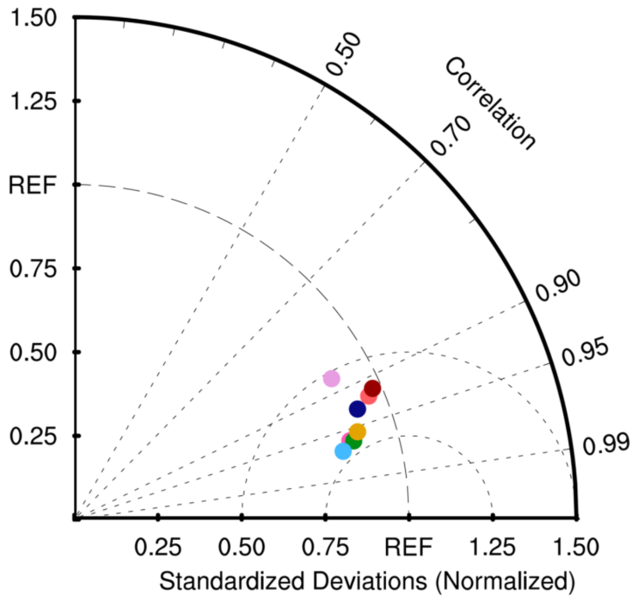
Spectral resolution:

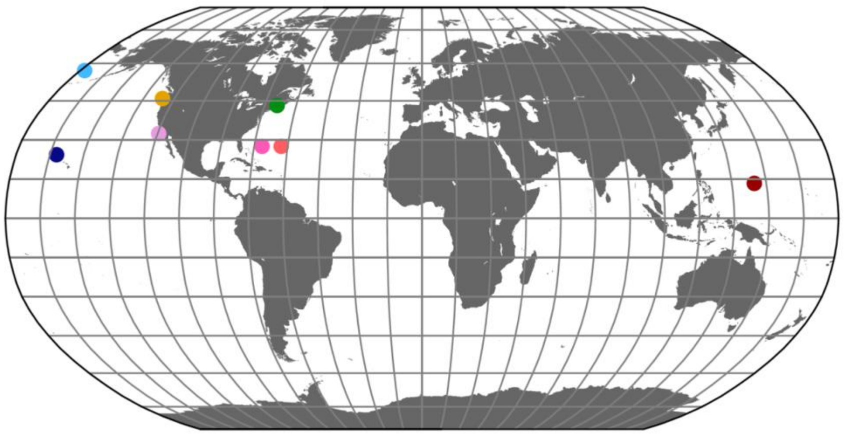
32 frequencies and 24 directions

Parameterization of energy input and dissipation: ST4

Wave-ice interactions: IC0

Non-linear interactions: DIA



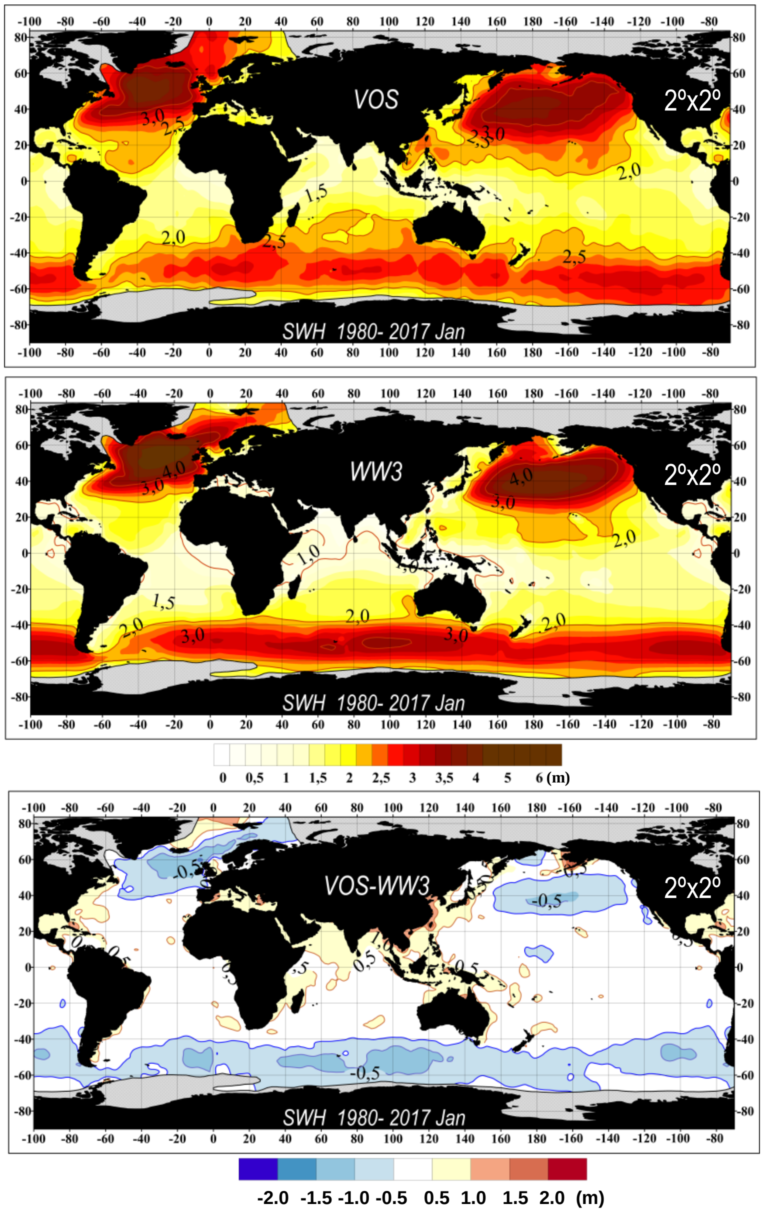


Taylor diagram for SWH in MERRA2-WW3 in comparison to NDBC buoys (JFM 2010)

VOS vs WW3

Climatological SWH: VOS vs WW3

$$SWH2 = \max(Sea, Swell)$$



Apparent agreement between model and visually observed SWH:

- Within the performance of the third generation models (5-10%)
- within VOS code figures (±0.5m)

for monthly, seasonal, annual and climatological means

CHALLENGES:

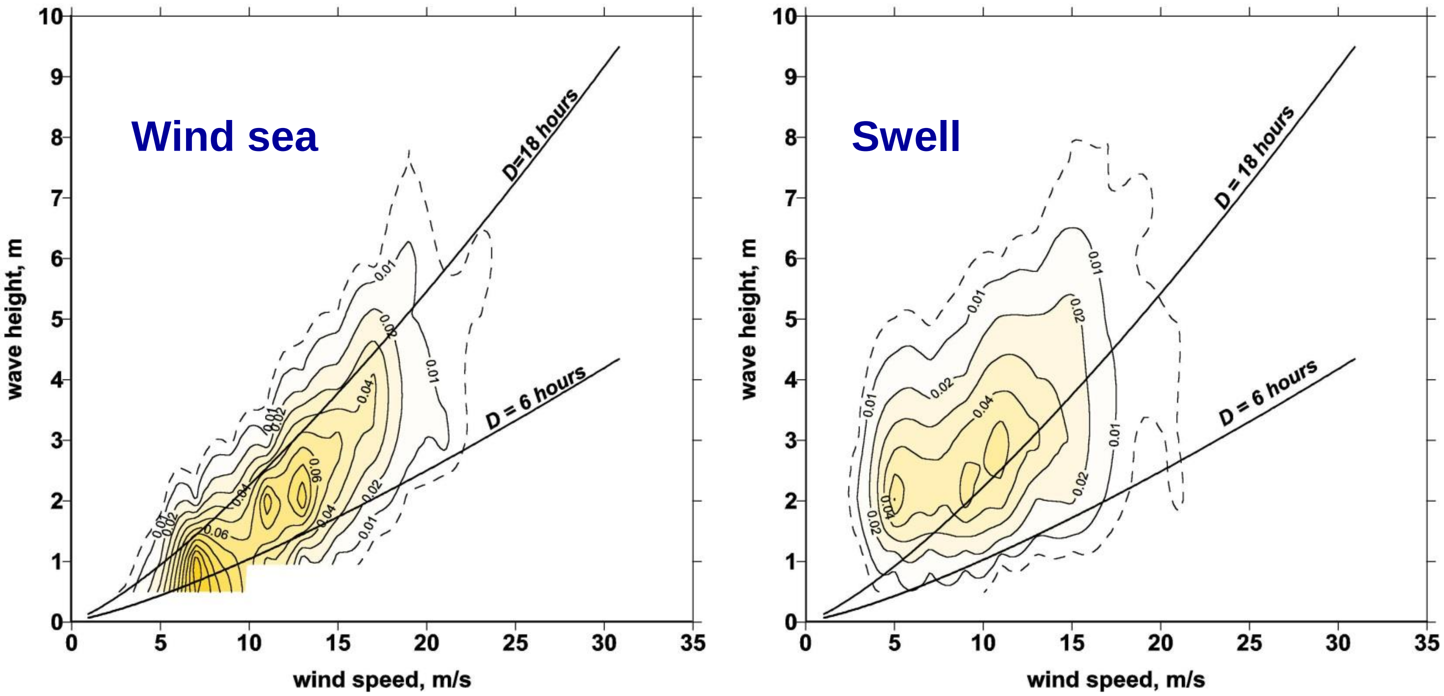
- Uncertainties in MERRA-2 input winds
- Wave height bias for ST4 parameterization
- Systematic errors in visual wave observations
- Space-time inhomogeneity in VOS – sampling errors

Sea and swell separation

1st step:

Analysis of 2D wind-wave distributions with respect to the JONSWAP curves (Carter 1988) for wind durations of 6 to 24 hours:

elimination of 0.1 to 3% of reports



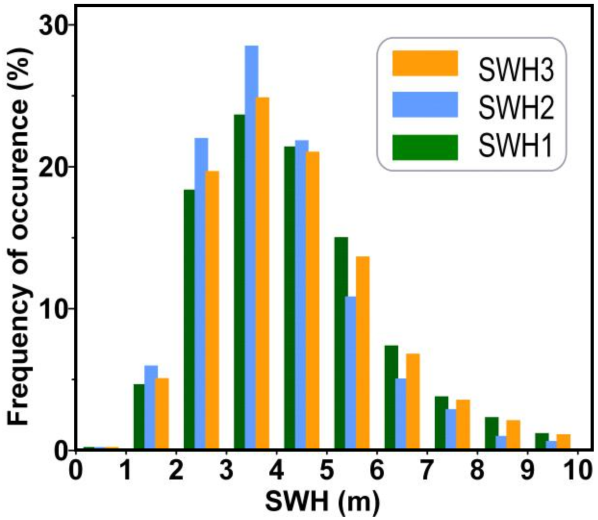
2nd step:

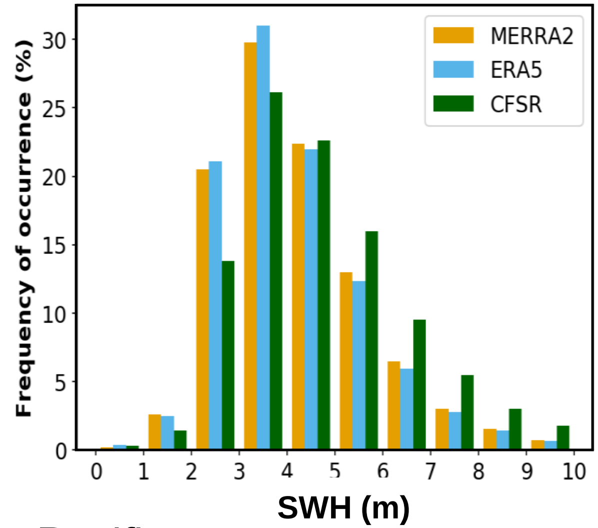
Analysis of wave age $a = C_p / V_{ef,}$ *where* $C_p = (g/2p)p_w$ *is the deep water phase speed: waves with* a < 1.2 are attributed to sea, otherwise to swell:

elimination of 0.05 to 1.5% of reports

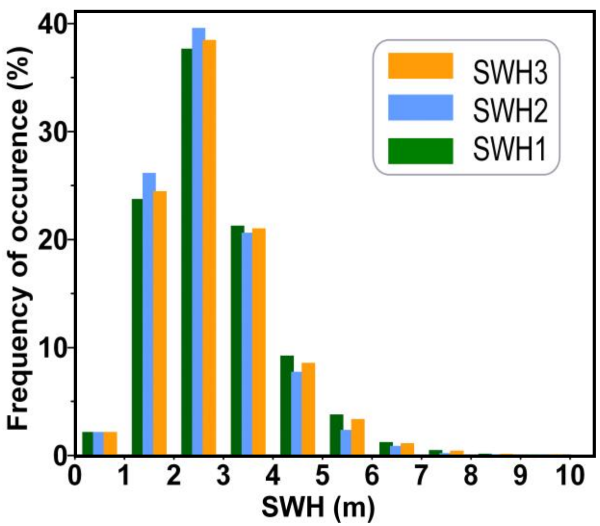
DJF climatological histograms for SWH

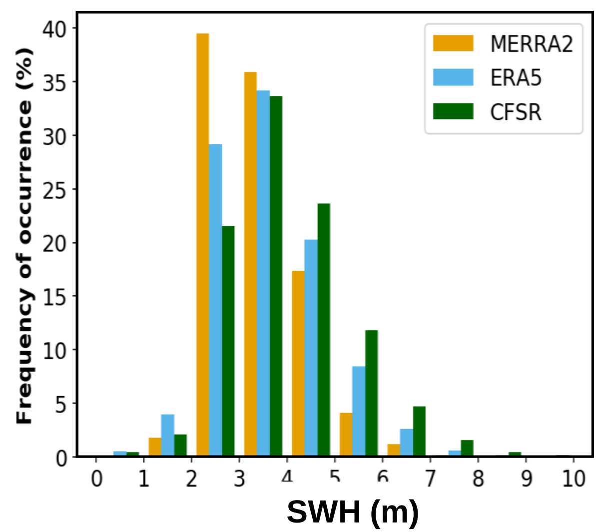
North Pacific Ocean





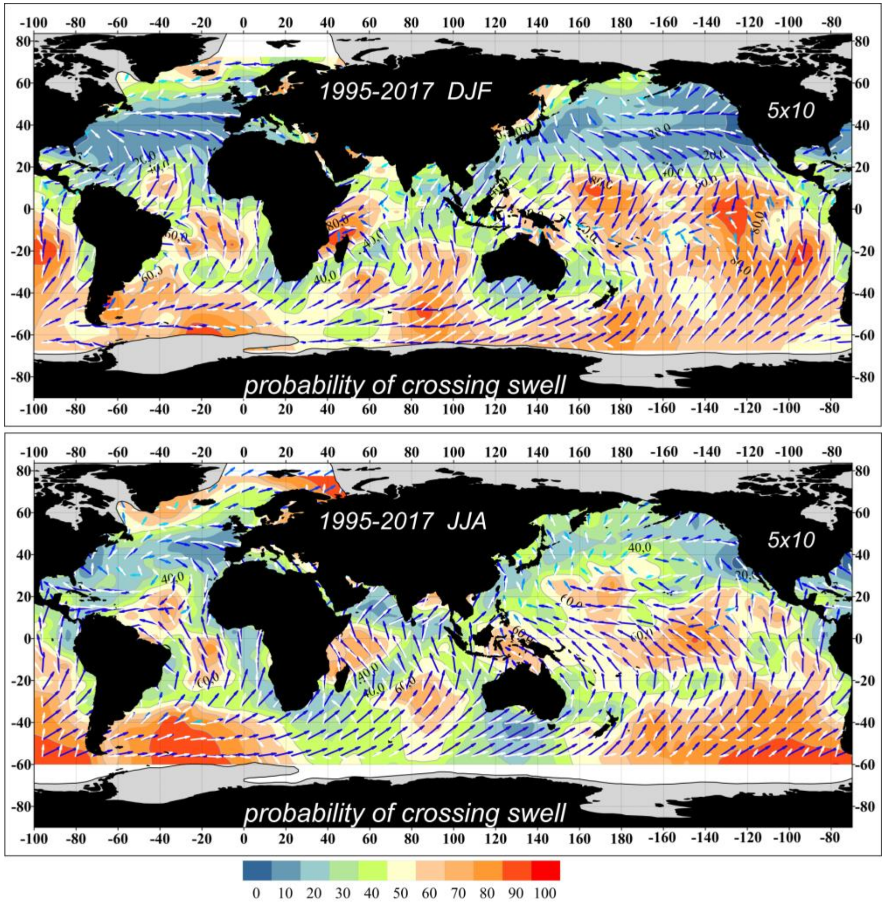
Southern Ocean Pacific

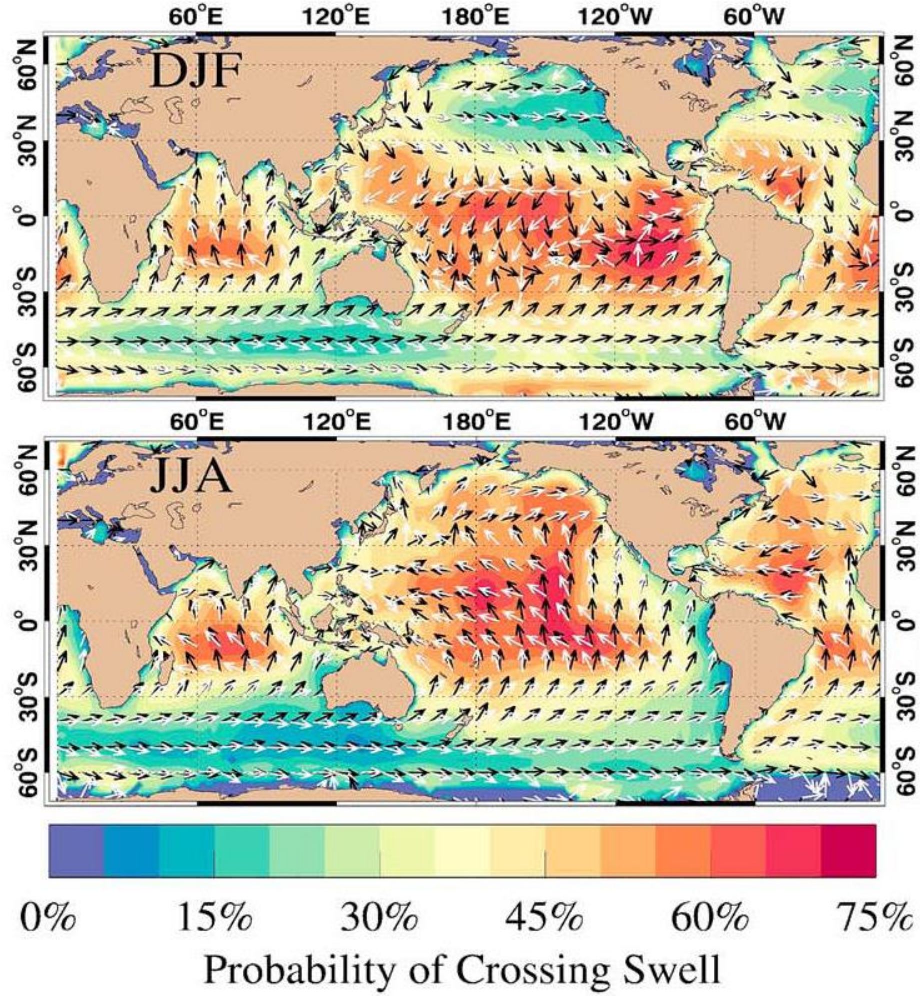




$$SWH1 = \sqrt{Sea^2 + Swell^2}\ ;\ SWH2 = \max(Sea, Swell)\ ;\ SWH3 = combined$$

Second Swell from VOS 1982-2017 $N_{obs} > 10^6$

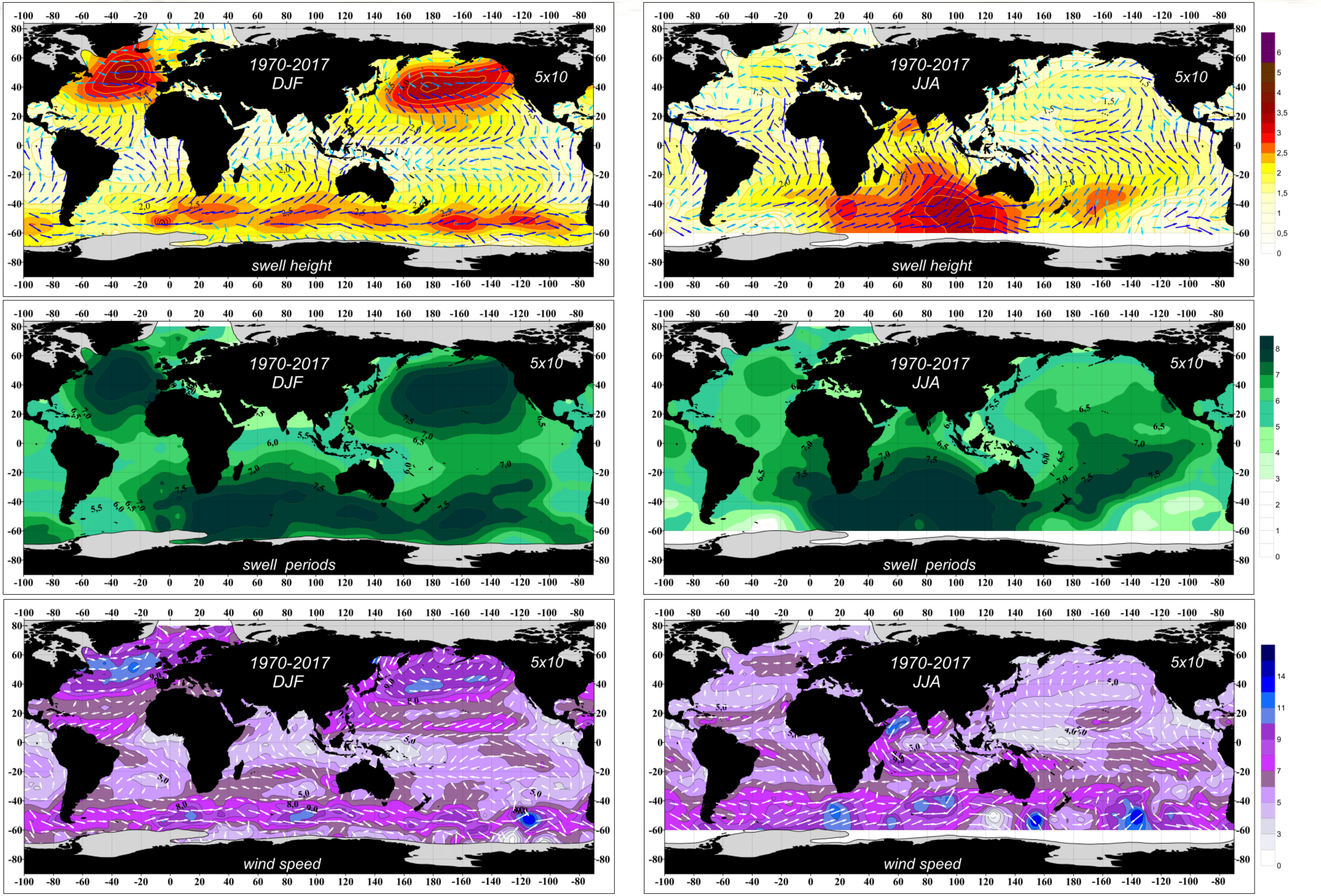




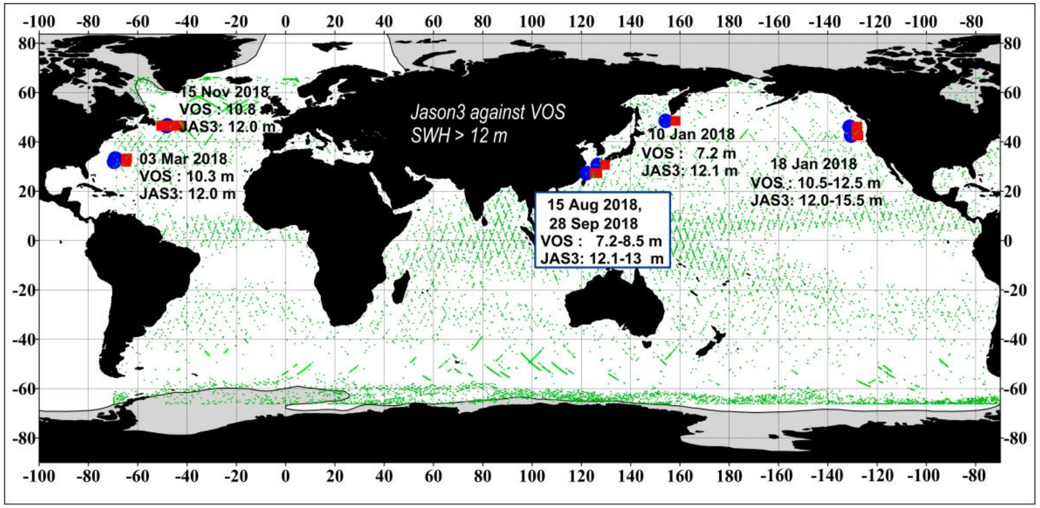
similar space patterns being diverted in numbers

The probability value from VOS varies depending on the chosen range of the first swell periods. Directional steadiness maps for both swell systems show a good agreement.

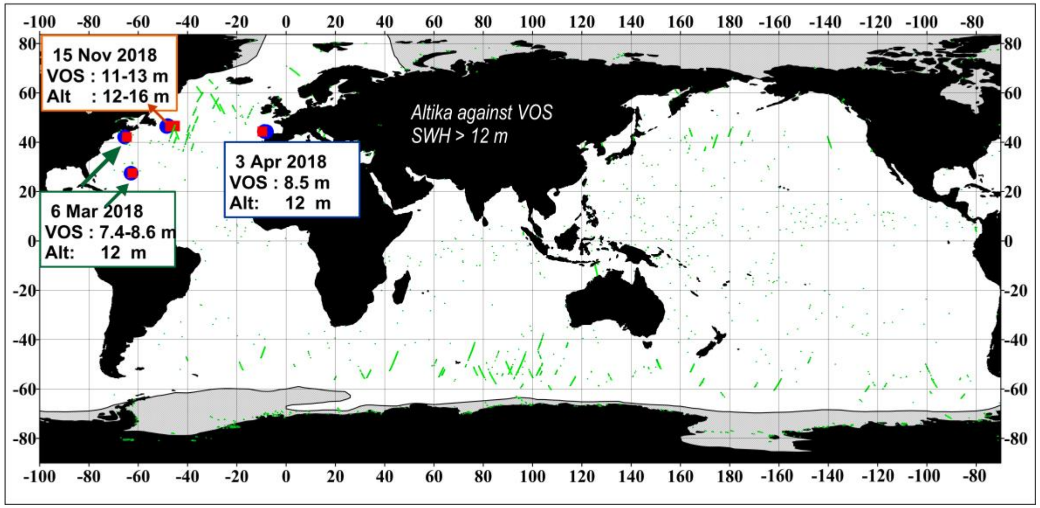
Marginal Swell from VOS



Extremes



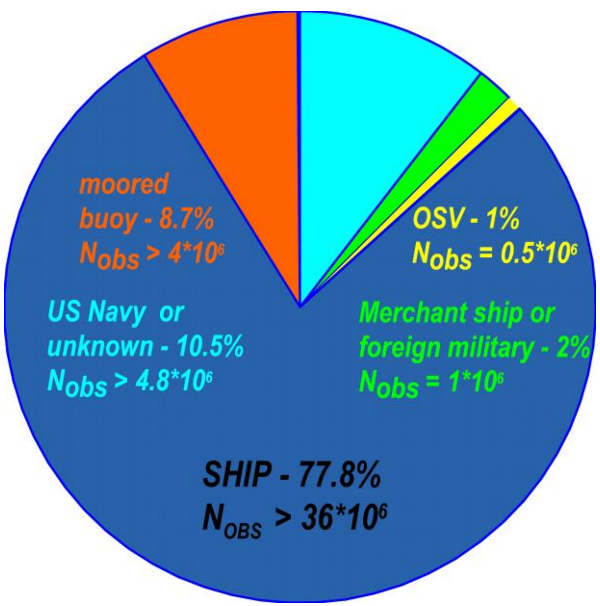
Jason3 against VOS
SWH > 12 m
15 Nov 2018
VOS : 10.8
JAS3: 12.0 m
03 Mar 2018
VOS : 10.3 m
JAS3: 12.0 m
10 Jan 2018
VOS : 7.2 m
JAS3: 12.1 m
18 Jan 2018
VOS : 10.5-12.5 m
JAS3: 12.0-15.5 m
15 Aug 2018,
28 Sep 2018
VOS : 7.2-8.5 m
JAS3: 12.1-13 m



Altika against VOS
SWH > 12 m
15 Nov 2018
VOS : 11-13 m
Alt : 12-16 m
6 Mar 2018
VOS : 7.4-8.6 m
Alt: 12 m
3 Apr 2018
VOS : 8.5 m
Alt: 12 m

Swell tracking

- relatively stable number of observations since 1970
- completed changes in the coding system
- all swell characteristics passed the QC
- Other VOS parameters are optional
- ships only for homogeneity reasons



Identification/ Callsign

0 @:
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+:
#-#
&& &
??
-/-/
#%

20% - empty
4% - not assigned to a particular vessel
1% - MasksID