On discriminating swell and wind-driven seas in Voluntary Observing Ship data

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QUANTITY MAKES QUALITY !

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Outline

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ICOADS – International Comprehensive Ocean-Atmosphere Data Set

- Spans the past three centuries;
- Contains observations from many different observing systems encompassing the evolution of measurement technology over hundreds of years;
- ICOADS is probably the most complete and heterogeneous collection of surface marine data in existence (http://icoads.noaa.gov)

VOS – Voluntary Observed Ship

Definition

Voluntary Observing Ship – wave estimates taken visually by marine officers over many years - assimilated in ICOADS

Measured parameters

wind sea height, swell height, wind sea period, swell period, wind sea direction, swell direction, wind direction, wind speed, SLP, SST *et cet.* $>$30 parameters

The coding precisions are

0.5 m for heights,
1 sec for periods,
10° for directions

Visual wave observations: 1870 - onwards

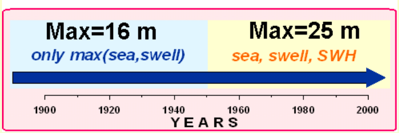
Two streams of data: (1870-1949) and (1950-2007)
$>$ 2.000.000.000 telegrams

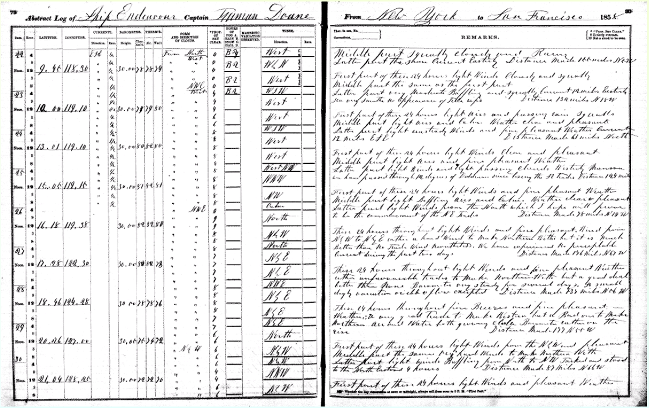
Cutty Sark (1869)

Noname (today)

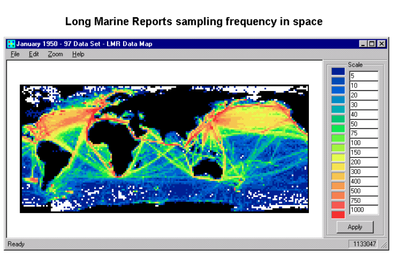
Observational practice has never been changed
Coding systems have been changed several times

VOS wave data: since 1950 WW sea and swell are filed separately

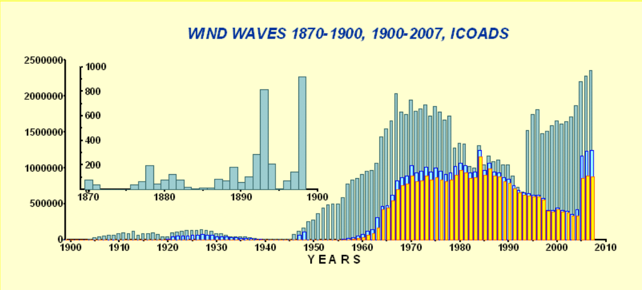




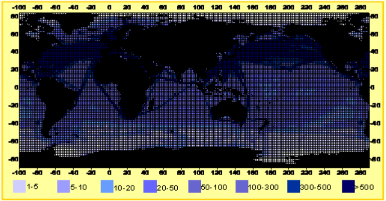
Spatial and temporal data distributions



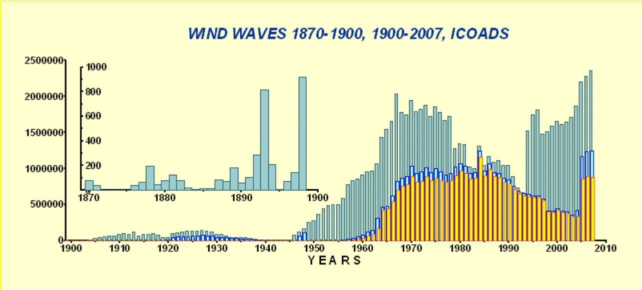
- increase in the total number during the last decade
- no the actual increase of reports containing all wave parameters (yellow)
- 1970-1990 – the best sampled period



Spatial and temporal distributions: swings and roundabouts



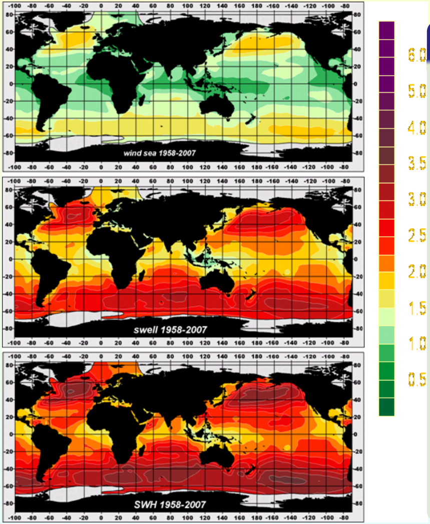
- ⊕ the longest records, separate estimates of wind sea and swell
- ⊖ inhomogeneous in space and in time sampling, “human factor” – subjectivity



Data control and preprocessing of VOS wave data

- Presence of all wave-related variables – 80% of total number of reports eliminated;
- Observational artifacts
  - unrealistic reporting date;
  - reported zero periods for nonzero heights $\approx$ 3 % out
- Computation of significant wave height;
- Sea and swell separation – up to 10% of all reports out;
- Correction of small waves and periods $\approx$ 5 %
- Steepness control (unrealistic steepness)
  - Wind sea steepness $\mu > 0.2 \approx$ 30 % !!! – problem of "1 s" period
  - Swell steepness $\mu > 0.15 \approx$ 10 %
- Wave age control for wind waves $a = C_p/V_{ef}$ $a > 1.2$ up to 3 % of all data are eliminated

Global Wind Wave Climatology from VOS data
http://www.sail.msk.ru/atlas



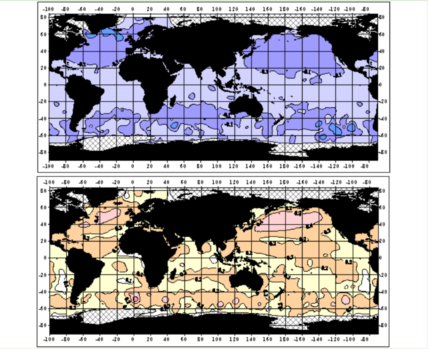
http://www.sail.msk.ru/atlas

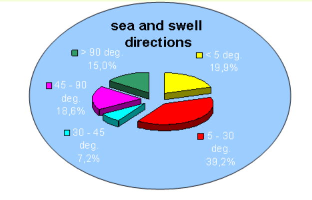
- monthly 1958-2007 (updated);
- 2-degree resolution;
- separate estimates of sea, swell, SWH;
- raw and processed data upon your request;
- observational errors;
- day-night biases;
- sampling errors;
- fair weather bias

Computation of significant wave height

$$SWH = \begin{cases} (h_w^2 + h_s^2)^{1/2}, & \Delta\Theta_{ws} \leq 30^\circ \quad (1) \\ \max(h_w, h_s), & \Delta\Theta_{ws} > 30^\circ \quad (2) \end{cases}$$

SWH for mixed seas



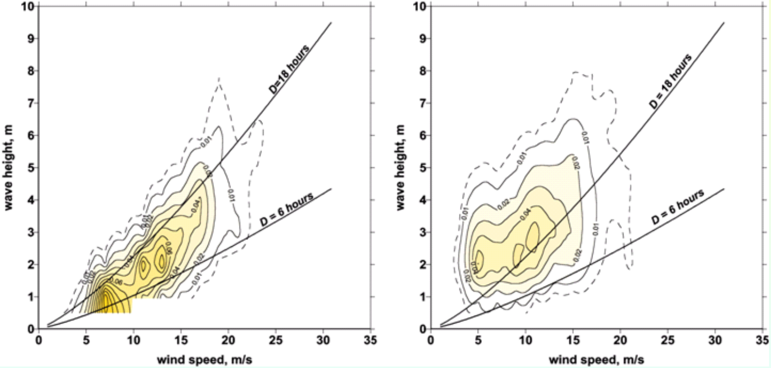


UP Our estimate minus (1)
Negative < 0.3 m

DN Our estimate minus (2)
Positive $< 0.2 - 0.45$ m

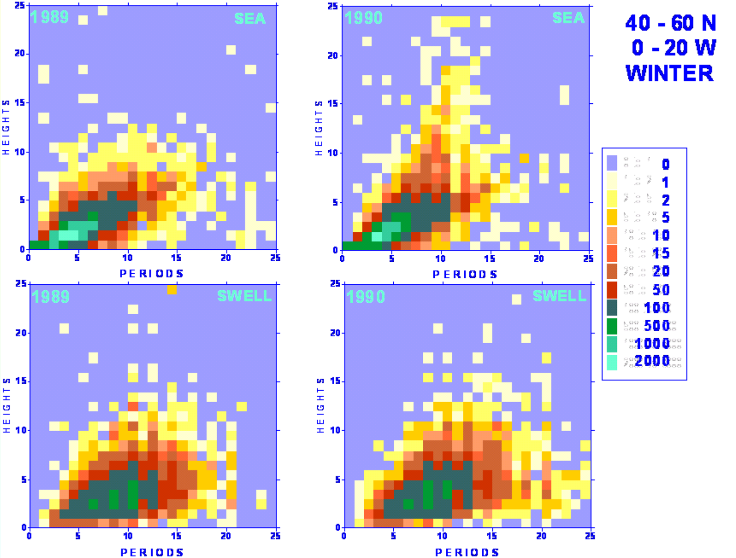
Wind sea and swell discriminating

Analysis of 2D wind-wave distributions with respect to the JONSWAP curves (Carter 1988), durations of 6 to 24 hrs: elimination of 0.1 to 3% of reports



Wind speed scaling is quite questionable

Sea and swell discriminating in VOS data



VOS wave data – where we are?

Our vision of sea waves
is mostly empirical,
not theoretically based

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Wind speed scaling of wave data continues to play a key role in the analysis of wave data

Simple theory of self-similar seas for VOS data

- Nonlinear transfer (nonlinear relaxation) is a governing mechanism of sea wave evolution (is not a hypothesis yet, cf. Zakharov & Badulin at this conference);
- Dominating nonlinearity determines a strong tendency to self-similarity of wave spectra;
- Energy balance of sea waves is determined by total external forcing (energy flux) in spirit of Kolmogorov's theory of strong hydrodynamical turbulence

NB

Wind speed is not a perfect scale of wind wave growth

Conventional power-law fits and families of self-similar solutions of the KE

Following Kitaigorodsky (1962)

Dependencies on non-dimensional fetch

$$\chi = xg/U_h^2$$

$$\tilde{E} = E_0 \chi^{p_\chi}; \qquad \tilde{\omega}_p = \omega_0 \chi^{-q_\chi}$$

or non-dimensional duration

$$\tau = tg/U_h$$

$$\tilde{E} = E_0 \tau^{p_\tau}; \qquad \tilde{\omega}_p = \omega_0 \tau^{-q_\tau}$$

FOUR FREE PARAMETERS!!!

IS IT OUR FORTUNE?

Following weakly turbulent scaling by Badulin, Babanin, Zakharov & Resio, 2007

Fetch-limited growth

$$p_\chi = \frac{10 q_\chi - 1}{2}$$

Duration-limited growth

$$p_\tau = \frac{9 q_\tau - 1}{2}$$

Energy-to-flux

$$\frac{E\omega_p^4}{g^2} = \alpha_{ss} \left(\frac{\omega_p^3 \mathrm{d}E/\mathrm{d}t}{g^2} \right)^{1/3}$$

TWO FREE PARAMETERS ONLY (p and E_0 or ω_0) !!!

Simple theory in simple relationships
ABC and D of wind-wave growth (WISE-2010)

One parametric dependencies $H_s(T_s)$ (wave height to wave period) provides information on spatio-temporal rates of wave growth, i.e.

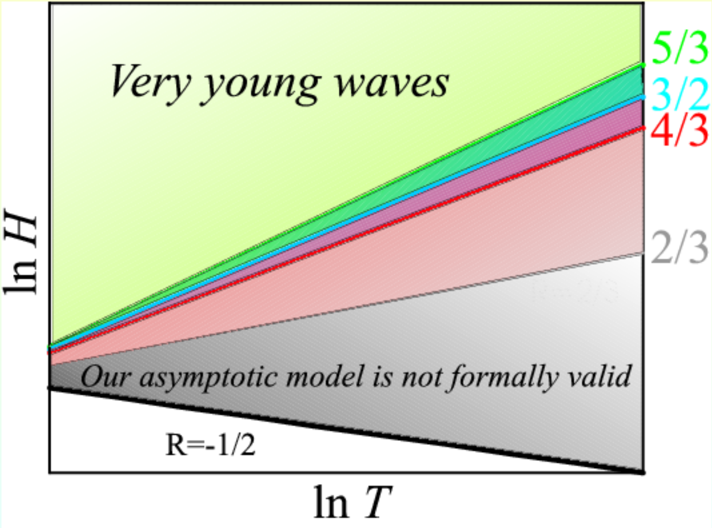
One-parametric dependencies is a key tool of our approach

$$H \sim T^R, \qquad R = \frac{p}{2q} = \frac{9p}{4p+2}$$

An alphabet of evolution of wind-wave spectra

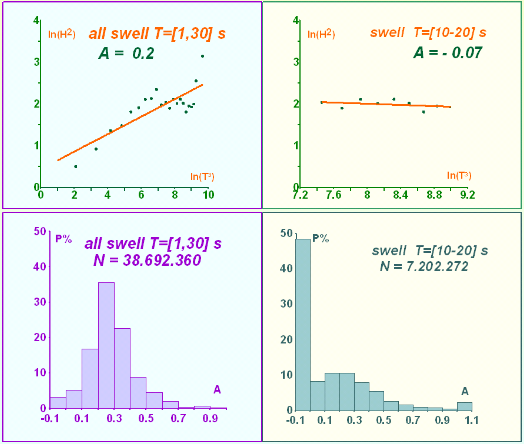
- **A** R=5/3 – Hasselmann et al., 1976 – young waves
- **B** R=3/2 – Toba, 1972 – growing waves
- **C** R=4/3 – Zakharov, Zaslavskii, 1983 – pre-saturated waves
- **D** R=-1/2 – swell, e.g. Badulin et al. 2005

ABC and now D on $H - T$ plots



$H - T$ dependencies for swell. All data
Long swell is consistent with D case !

$A = -1$ – case B (Toba); $A = -1/3$ – case D (swell)

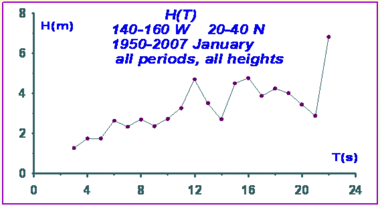


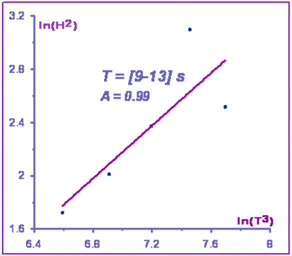
The last graph – swell never decays (!?) – $A > -1/3$

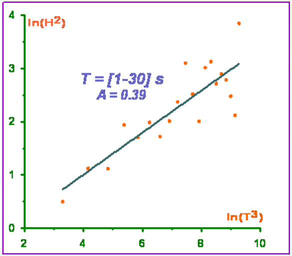
$H - T$ dependencies for wind waves East Pacifica (not too short, not too long)

$A = 1$ – case B (Toba);

$A = 8/9$ – case C (Zakharov, Zaslavskii, 1983)



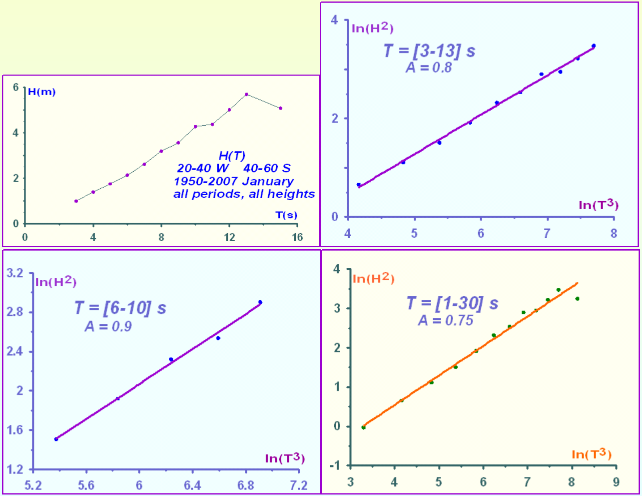




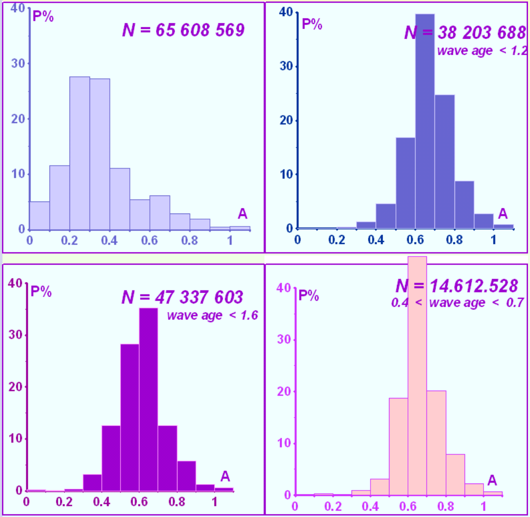
$H - T$ dependencies for wind waves South Atlantica (not too short, not too long)

$A = 1$ – case B (Toba);

$A = 8/9$ – case C (Zakharov, Zaslavskii, 1983)



Distribution of $H - T$ slopes
Wave age control. All data

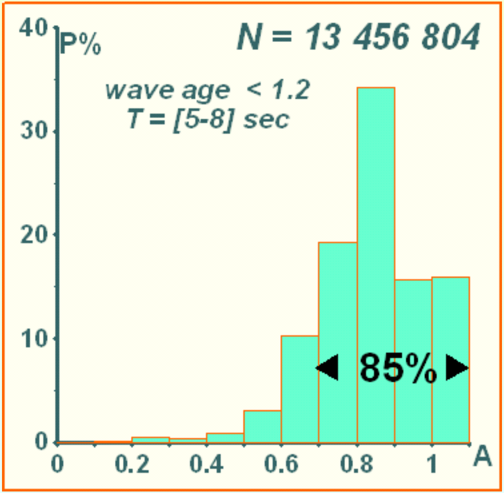


$A = 1$ – case B (Toba)

Distribution of $H - T$ slopes. All data
Double control – Wave age + Periods

$A = 1$ – case B (Toba);

$A = 8/9$ – case C (Zakharov, Zaslavskii, 1983)



Summary

- VOS data is a valuable but very special source of information on wind-driven seas;
- VOS data can be related to “weakly turbulent vision” of wind-wave spectra evolution, especially, in discriminating wind and swell seas;
- Wave scale (frequency) control emphasizes dramatically the basic scenarios of the evolution (say, $T = 6 \div 13$ sec for wind sea and $10 < T < 30$ sec for swell), the effect of wave age is less critical;
- Wind speed does not affect essentially our results due to features of its sampling

References

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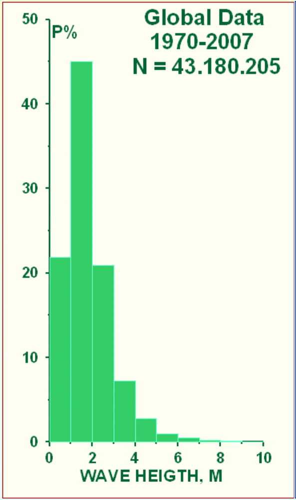
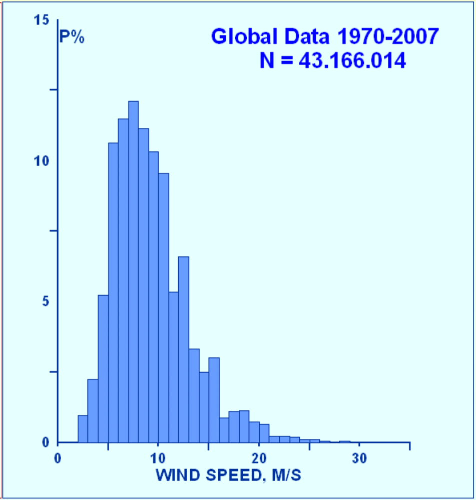
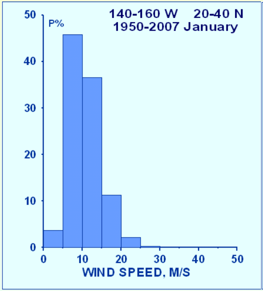
Slides for possible discussion
Global wind-wave statistics



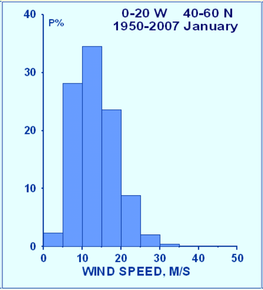


Slides for possible discussion Regional wind-wave statistics

North Pac.



North Atl.



South Atl.