New Generation of Wind and Wave Climate Handbooks

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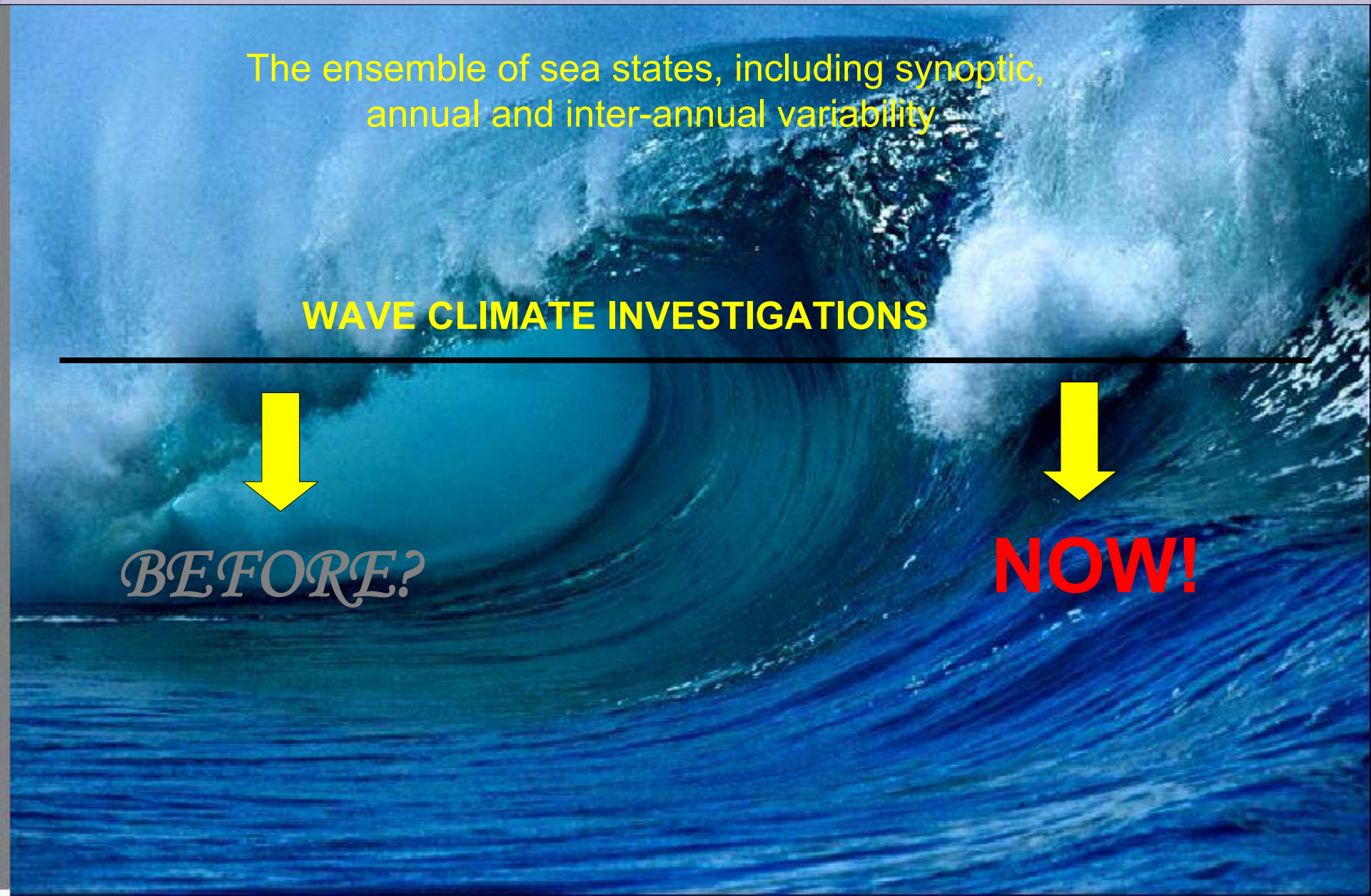
What is the Wave Climate?



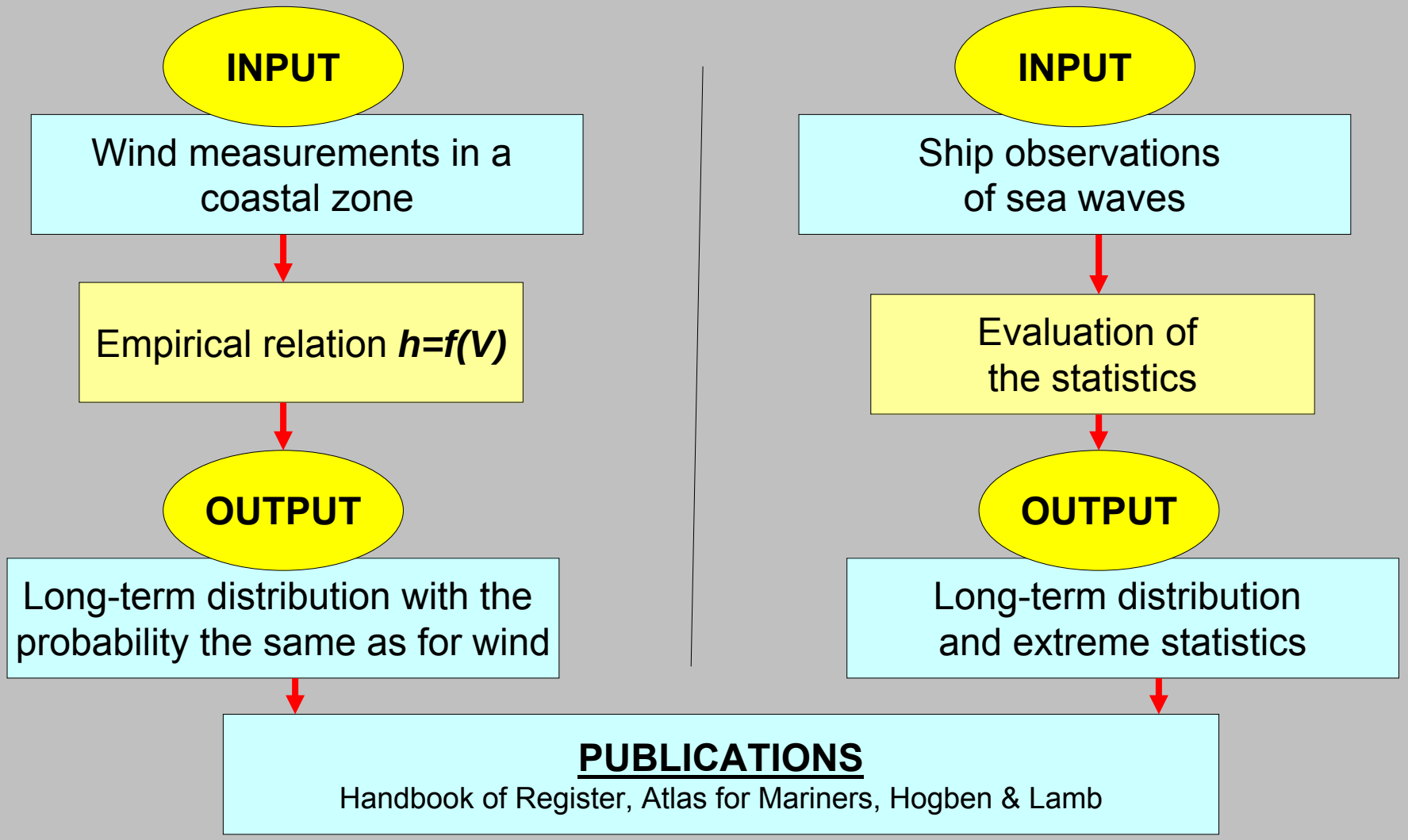
The ensemble of sea states, including synoptic, annual and inter-annual variability

WAVE CLIMATE INVESTIGATIONS

BEFORE?

NOW!

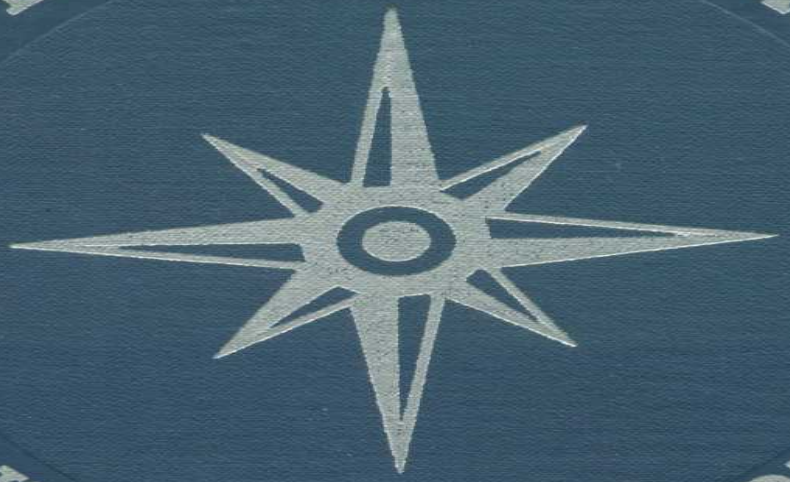
BEFORE…



THEREFORE: Wave climate is long-term distribution

РЕГИСТР СССР

ВЕТЕР И ВОЛНЫ В ОКЕАНАХ И МОРЯХ



СПРАВОЧНЫЕ ДАННЫЕ

1974

PART 1 (1974)

Methods of wind and wave climate calculations.

Includes:

- Visual observations vs wave measurements;
- Short-term statistics (distributions, spectra)
- Long-term distributions

PART 2 (1974)

Wind and wave climate statistics.

(All Oceans and seas.

Seasons, large regions, e.g., proper Baltic – one region, etc)

Operational statistics:

- **wind speed, wave heights distributions (one & omnidimensional),**
- **Wave heights, periods distributions**

Extreme statistics:

Only for whole the basin and for 30 years return period.

GLOBAL WAVE STATISTICS 1985

The last handbook, based on visual observations

Modern approach and Handbooks of new generation

- Advent of Reanalysis;
- Numerical (hydrodynamic models);
- High performance computing

The Wave Climate definition

The ensemble of states, including synoptic, annual and interannual variability

BEFORE

Visual wave observations

Instrumental observations in a point

Long-term distributions in a point (region)

Spectra

NOWADAYS

- Advent of reanalysis
- Numerical hydrodynamic spectral models
- High Performance computing

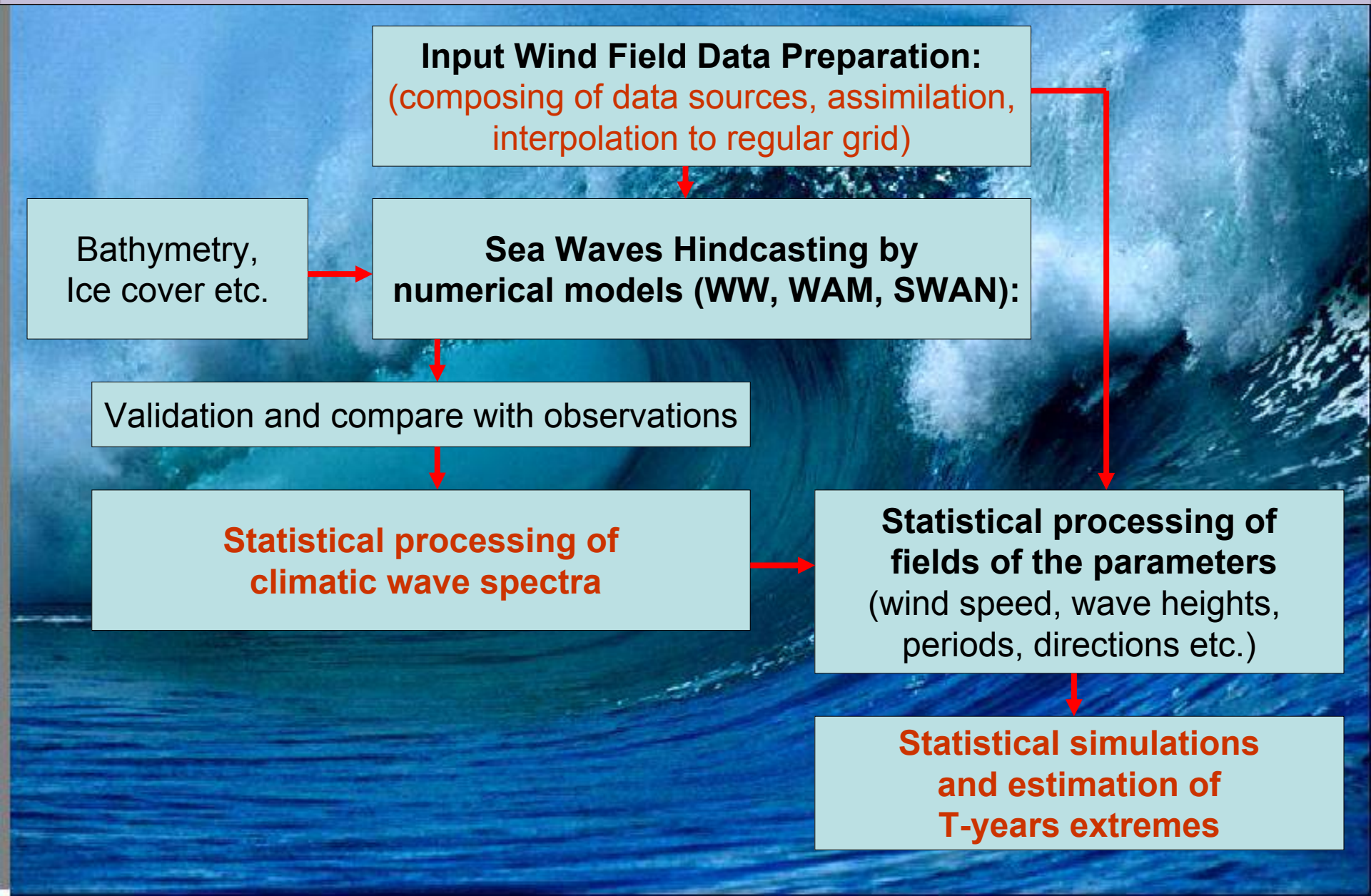
Statistics of the directional spectra
Multiscale statistical generalization
Field statistical generalization

MAIN CHALLENGE OF THE SPECTRAL STATISTICS:

The huge dimensionality of the data and their probabilistic characteristics $m_S(\bullet),\ K_S(\bullet,\bullet)$

HENCE, the special techniques of multivariate statistics are required for decreasing of dimensionality

Stages of wind and wave climate description



NOW!

(1) Advent of reanalysis **(2)** Numerical models of sea waves **(3)** High Performance Computing

INPUT

Pressure and wind fields (reanalysis)

Data assimilation and verification

RESULTS

CONTINUOUS HINDCASTING
(30 and more years)

OUTPUT

Set of directional sea wave spectra

Climatic wave spectra
- Omnidirectional
- Directional

Persistence statistics
Storm and calm duration

Long-term distributions
- Operational
- Extreme

Univariate

Multivariate

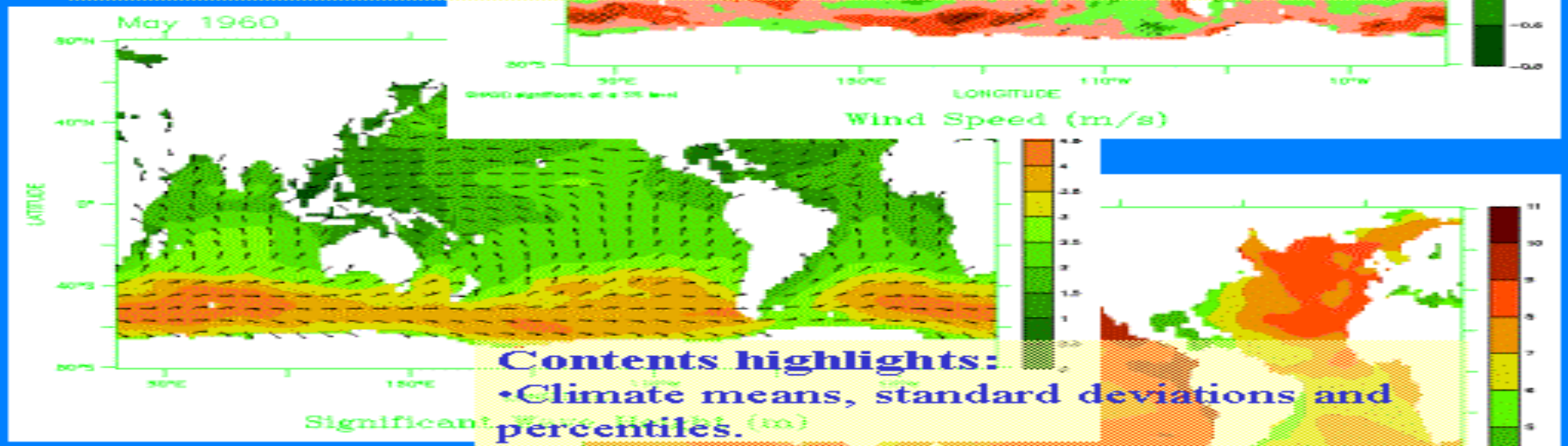
THEREFORE: Wave climate is a set of directional spectra and descended from them spatio-temporal statistics

Global Wave Climatology Atlas

derived from 45-years of ECMWF reanalysis data

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

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



Contents highlights:

- **Climate means, standard deviations and percentiles.**
- **Maps of extreme statistics.**
- **Wave height, period and direction tabular histograms.**
- **Description of wind and wave climate variability.**

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

Bookmark:
http://www.knmi.nl/waveatlas.

Wind and Waves Mediterranean Atlas

(Wind and wave atlas is the result of the Medatlas project led between 1999 and 2004 by a consortia of six companies located in France, Italy and Greece, that contributed to the project with own specific expertises and competence).

RUSSIAN MARITIME REGISTER OF SHIPPING

A classification society the Russian Register was established on 31 December 1913 as a result of the many years' experience in the sphere of technical supervision of ships. In 1923 the Russian Register was renamed the Register of the Soviet Union, thereafter - Russian Maritime Register of Shipping (RS). Since 1969 RS has been a member of International Association of Classification Societies (IACS).

www.rs-head.spb.ru

Russian Register of Shipping

WIND AND WAVE CLIMATE

Handbooks of new generation

Ed. by Russian Register of Shipping

(1974, 2003, 2006)

Authors: Lopatoukhin, Boukhanovsky, Rozhkov, Ivanov, et al.

Wave Climate Hindcasting in Seas around Russia

Sea	Years	Lat., N	Long.,E.	Model	Grid	
					Δx	Δy
Barents	1970–1999	60°-81°	30°W-60°N.	WW-III (1.18, 2.22)	0.5^0	1.5^0
Okhotsk	1970–1995	35°-65°	135°-165°	"	1.6^0	0.7^0
Caspian	1990–1995	36.5°-47.2°	48°-55.6°	"	0.2^0	0.2^0
Azov	1979-1998	45°-47.3°	34.7°-39.4°	"	9 nm, 3nm	
Baltic	1979–2000	53.8°-66.1°	9°-30°	"	10 nm	
North	1983–1998	50°-70°	5°W.-10°E.	WW-III (2.22)	15 nm	
Black	1974-2003	40.9^0-46.5^0	27.5^0-42.7^0	SWAN C.III. V.40.11	10 nm	
Ladoga lake	1994-2003	59.9^0-61.8^0	29.9^0-33.0^0	SWAN C.III. V.40.31	2 nm	

WIND DATA ASSIMILATION

¿ **Why only (as it is) reanalysis data are insufficient for wave climate investigations** ?

- Underestimation of extreme events
- Smoothing of the storm shapes
- Biasing of the climatic characteristic (in comparison with the measurements)
- “Losses” of rapid storms

The problem of wind data input: differences between climatic reanalysis and synoptic data

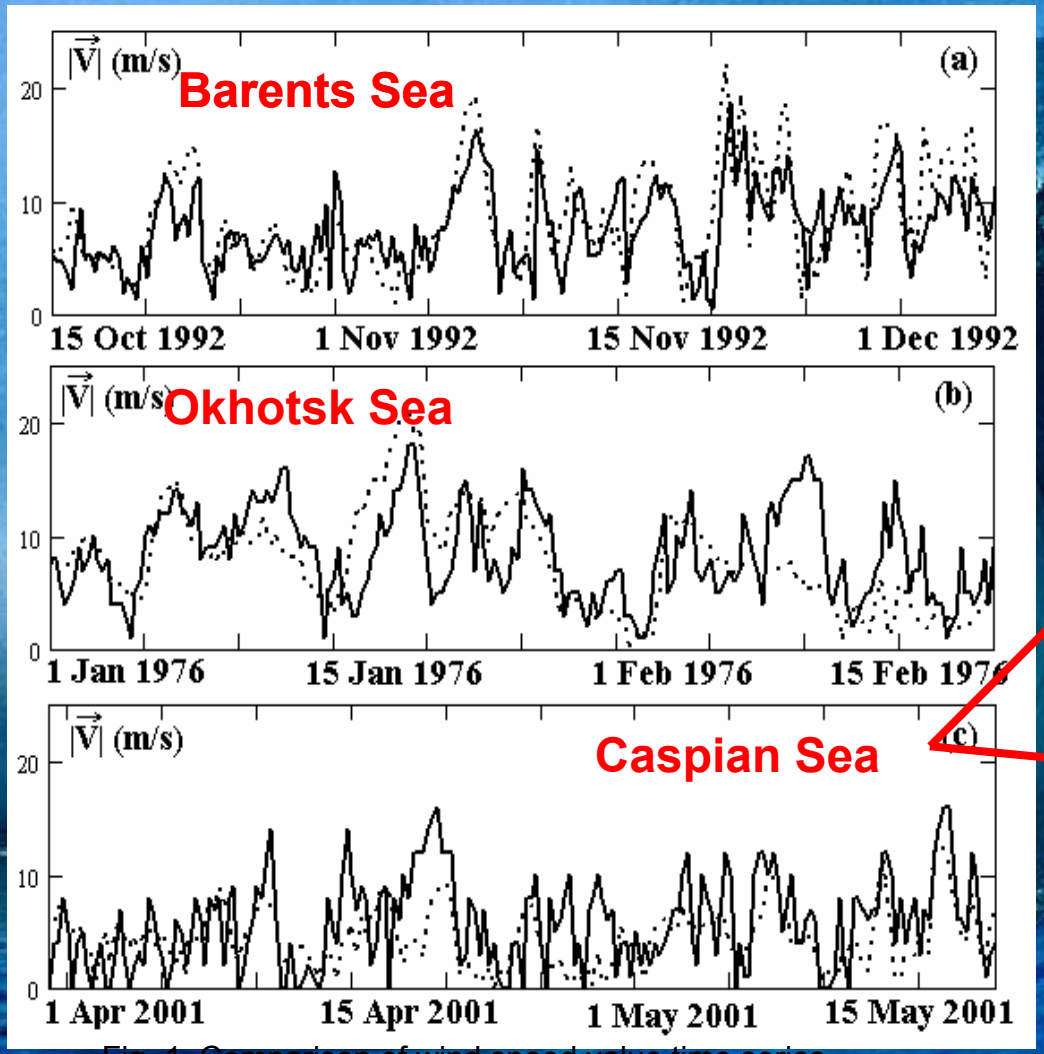
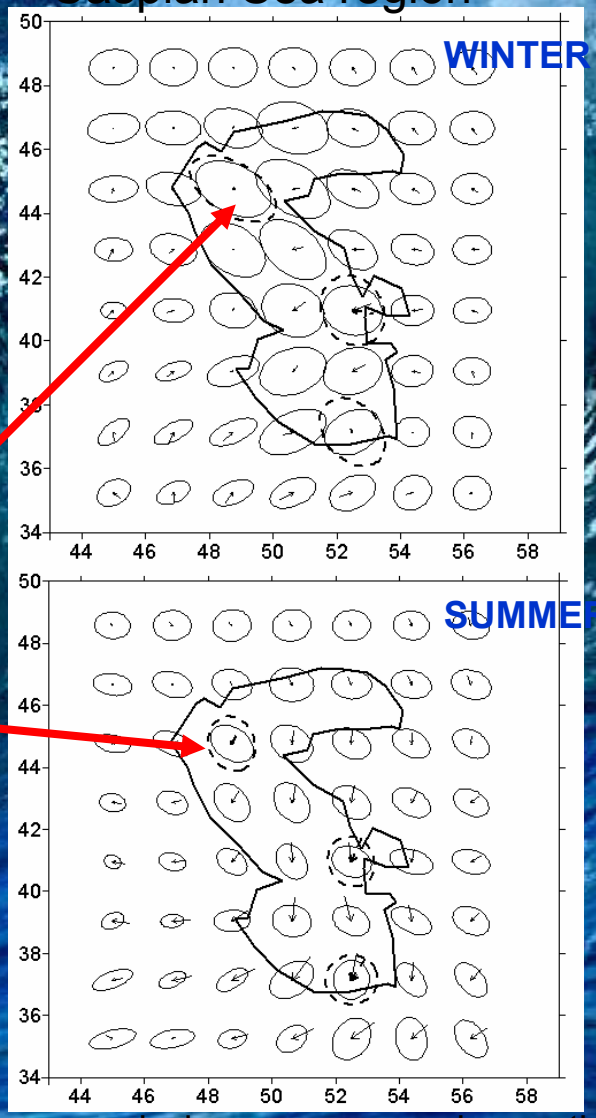


Fig. 1. Comparison of wind speed value time series.
Solid line – Measurements, *Dot line* – Reanalysis.
(a) – Barents Sea (Sental Banken, 740.5N–310.0E),
(b) – Okhotsk Sea (Odoptu, 58006'N, 143028' E.),
(c) – Caspian Sea (Tuleny island, 440 30N', 470 40'E)

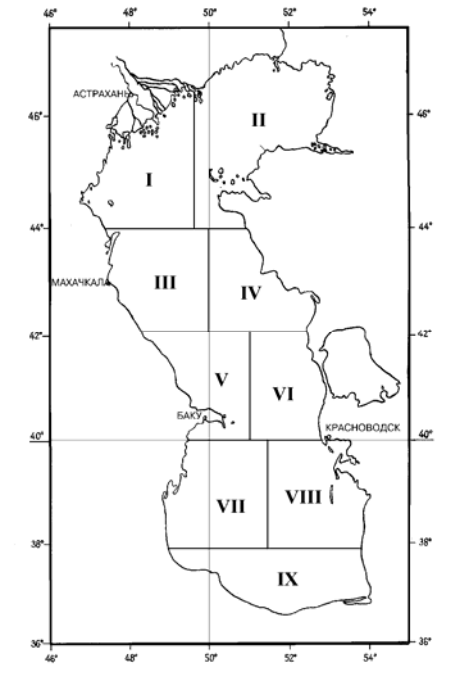
Caspian Sea region



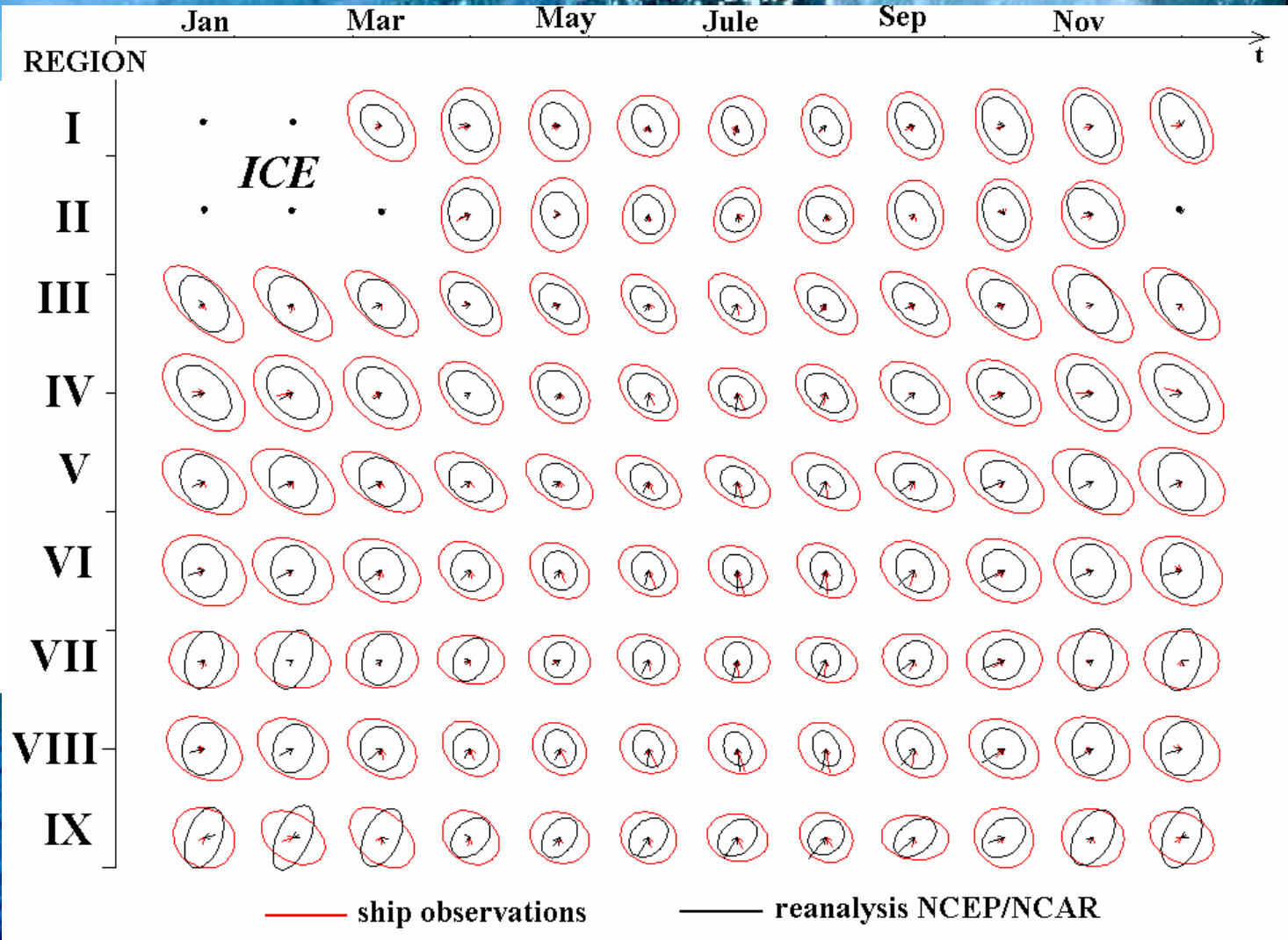
reanalysis observations

Caspian sea: differences between reanalysis and observations

REGIONS of the Caspian sea



Comparison of monthly mean wind speed and tensor of r.m.s.

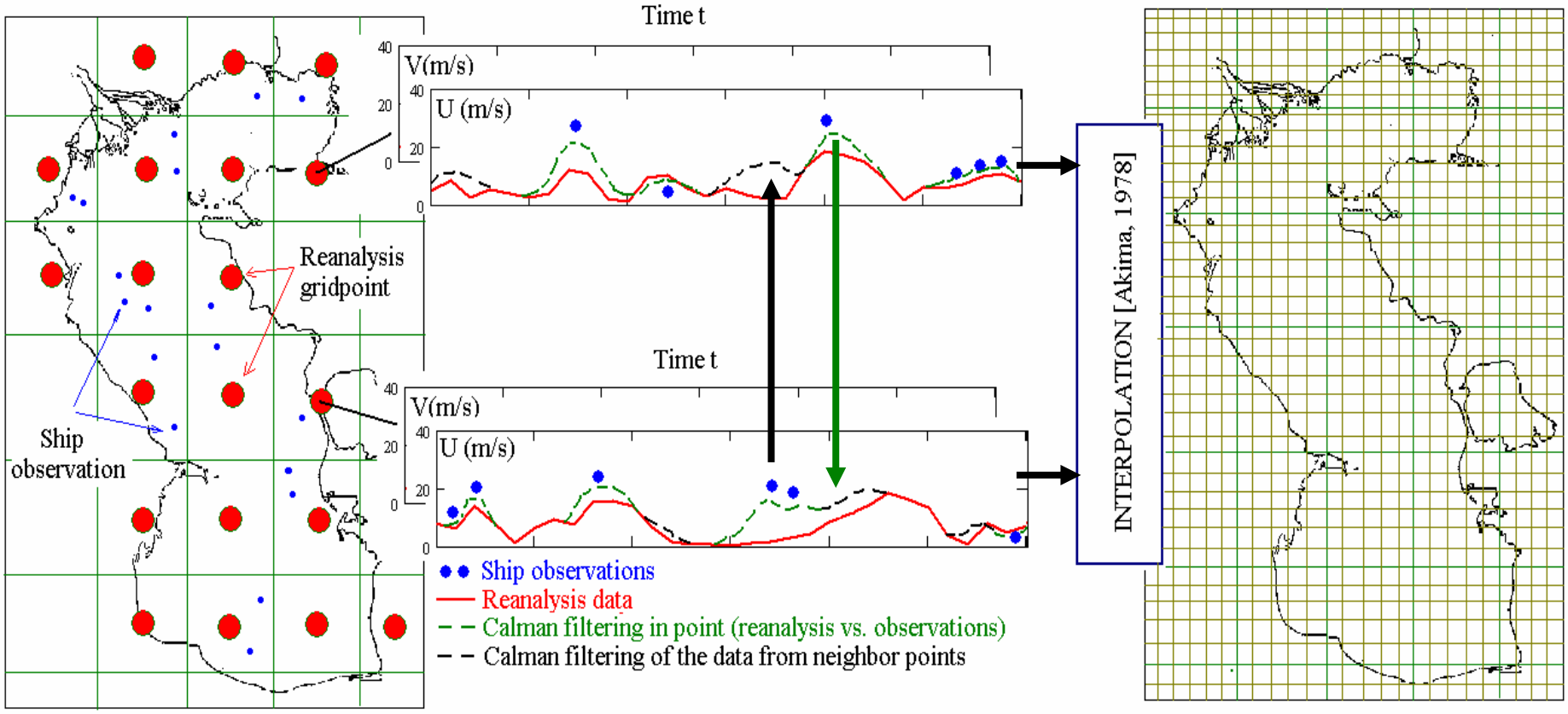


Procedure of Data Assimilation and Interpolation

$$\vec{V}(\vec{r},t)=\sum_{j=1}^{R}\Psi_{t,j}(\vec{r})\vec{V}(\vec{r},t-j)+\Sigma(\vec{r},t)\vec{\varepsilon}(\vec{r},t)$$ - Stochastic model of reanalysis data (with noise $\vec{\varepsilon}$)

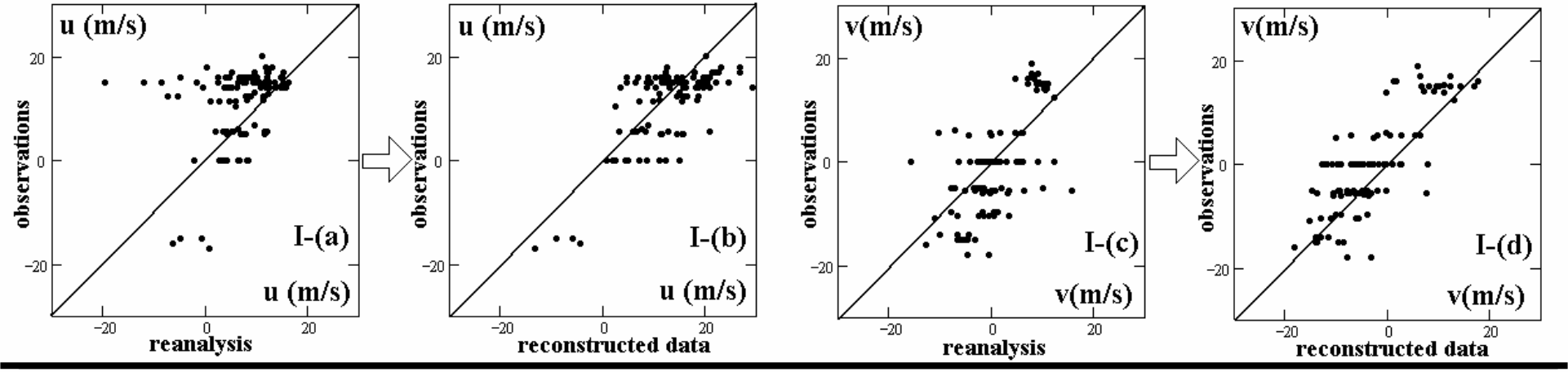
$$\vec{V}_s=\mathrm{H}\vec{V}(\vec{r}_k,t_0)+\vec{\delta}$$ - Equation of measurements (with noise $\vec{\delta}$)

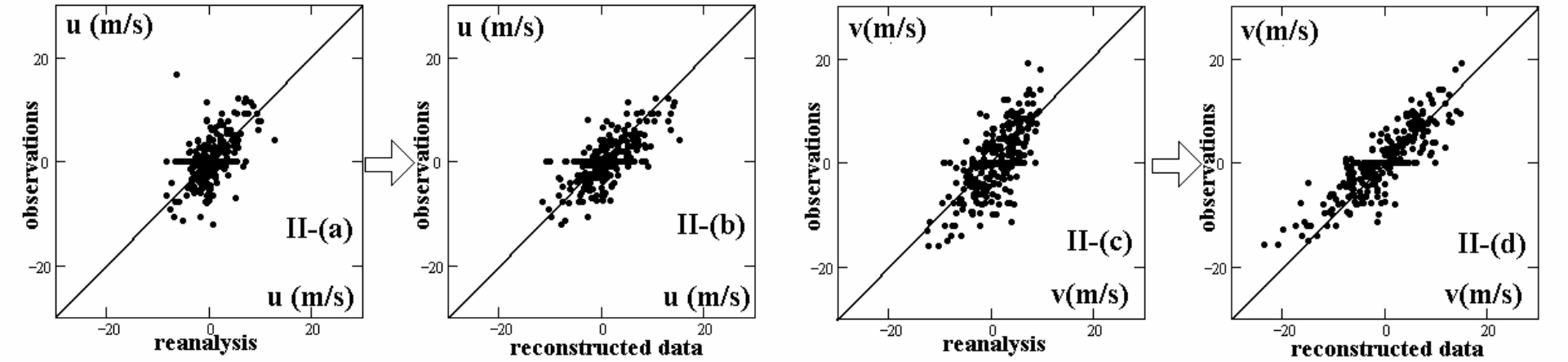
$$\vec{V}^*(\vec{r}_k,t_0)=\vec{V}(\vec{r}_k,t_0)+\Re_{\vec{V}}(\vec{r}_k,t_0)(\vec{V}(\vec{r}_k,t_0)-\vec{V}_s)$$ - Kalman filter equation



Validation of Assimilation Procedure

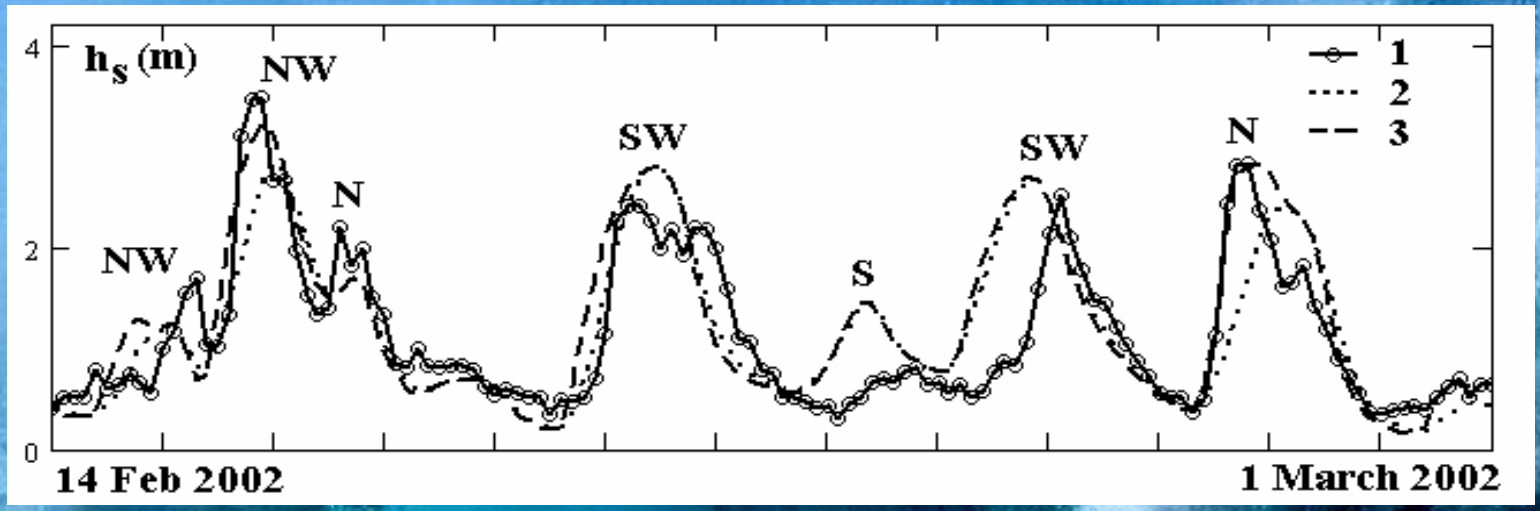
Krasnovodsk GMS (SE-Caspian), 1954-1990, severe storms only



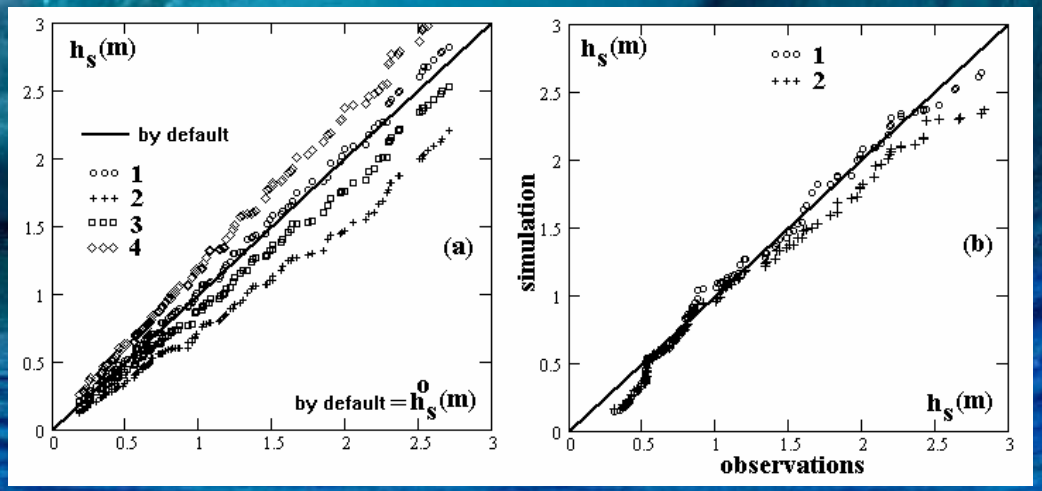


Tuleny Island GMS (N-Caspian), March-May 2001 (each 3 hours)

Validation of Hindcasting Procedure with Assimilated Wind Data



Parts of significant wave height time series. North Caspian, point 44.10N, 48.49E (depth 24 m).
1 – measurements. 2 - SWAN with step 1 hour. 3 – SWAN with step 15 minutes.

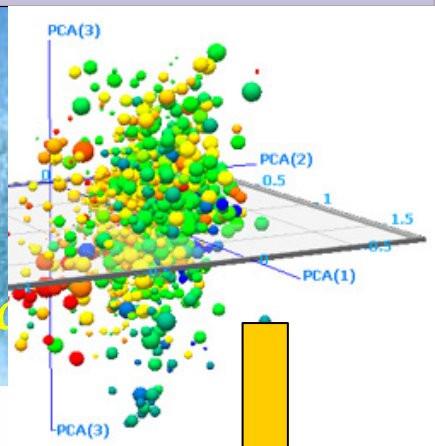


Variants	C_{ds}	S_{pm}
By default	2.36	3.02
1	2.85	3.62
2	2.85	2.42
3	1.86	2.42
4	1.86	3.62

Q-Q plots of SWAN calculations for N. Caspian (February, 2002).
(a) – values from table, (1-4 – the same as in table), (b) – different time steps; 1- 15 minutes, 2 – 1 hour.

Methods and set of Stochastic Models

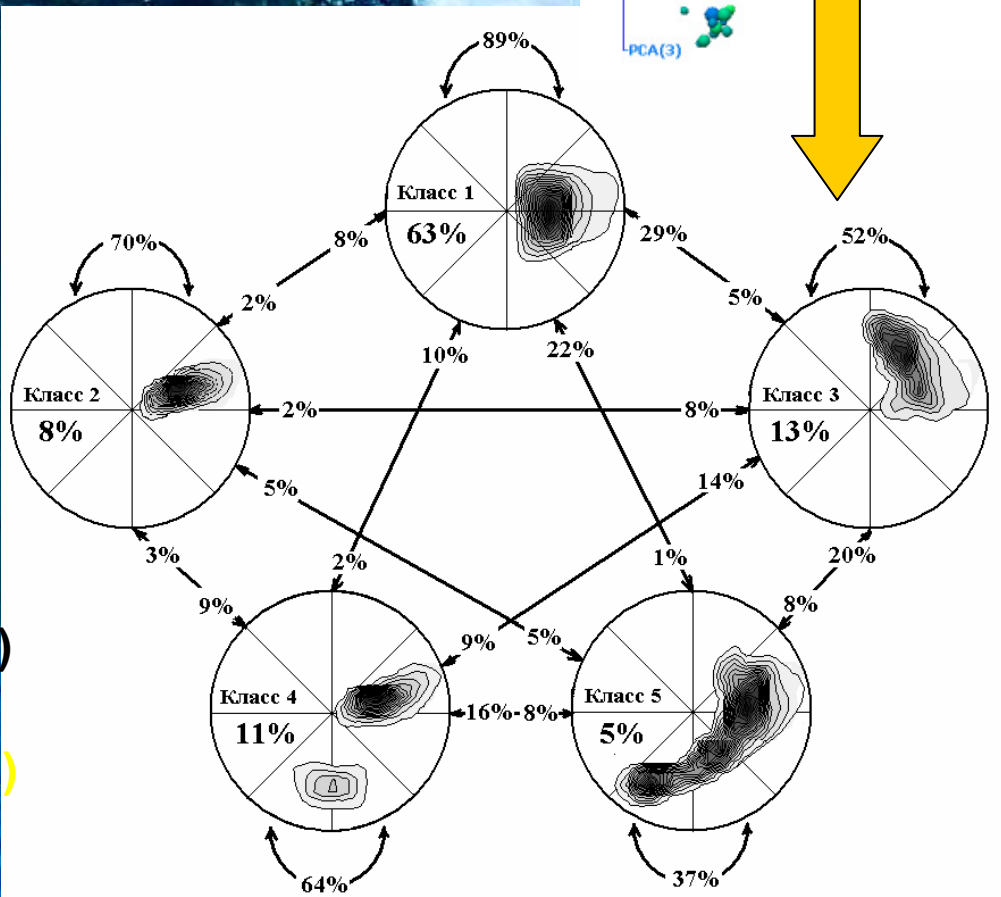
Multidimensional statistical analysis of spatiotemporal wave fields



Consideration of multiscale variability by mean of a set of inserted models…

- **Models AR, ARMA**
  (small scale variability)
- **Impulse models**
  (synoptic variability)
- **Markov models**
  (intermittency of spectra)
- **PCSP-models**
  (annual and year-to-year variability)

Extremes may be estimated (inter alia)




“Wind and wave climate of Barents, Okhotsk and Caspian Seas”. Handbook
Russian Register of Shipping
Saint-Petersburg, 2003. 213p.

PART 1 (2003)

Background, including main approaches

- Numerical models (short description)
- Short-term statistics:

(wave heights, periods, lengths, crests distributions), frequency and directional spectra;

- Long-term statistics:

Operational statistics: distributions, persistence, climatic spectra

Extreme statistics:

(based on WMO publication (www.wmo.ch JCOMM Publications)

Approach to wave heights with return period of 1000 and 10000 years.

PART 2 (2003)

Reference data (monthly, detailed by regions)

Extreme statistics

- *Extreme winds with return periods 1, 5, 10, 25, 50 and 100 years. (Omnidirectional and for 8 directions)*
- *Wave heights, periods, lengths (mean, significant, 3%, 1%, 0.1%) and wave crests with return periods1, 5, 10, 25, 50 and 100 years*

Operational statistics

- *One-dimensional distributions (winds, waves)*
- *Persistence statistics (mean, rms, max) for wind and waves .*
- *. Wave heights: Monthly storm and weather windows durations.*
- *Monthly probabilities of wave heights and direction.*
- *Joint probability of wave heights and periods*

WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO)

ESTIMATION OF EXTREME WIND WAVE HEIGHTS

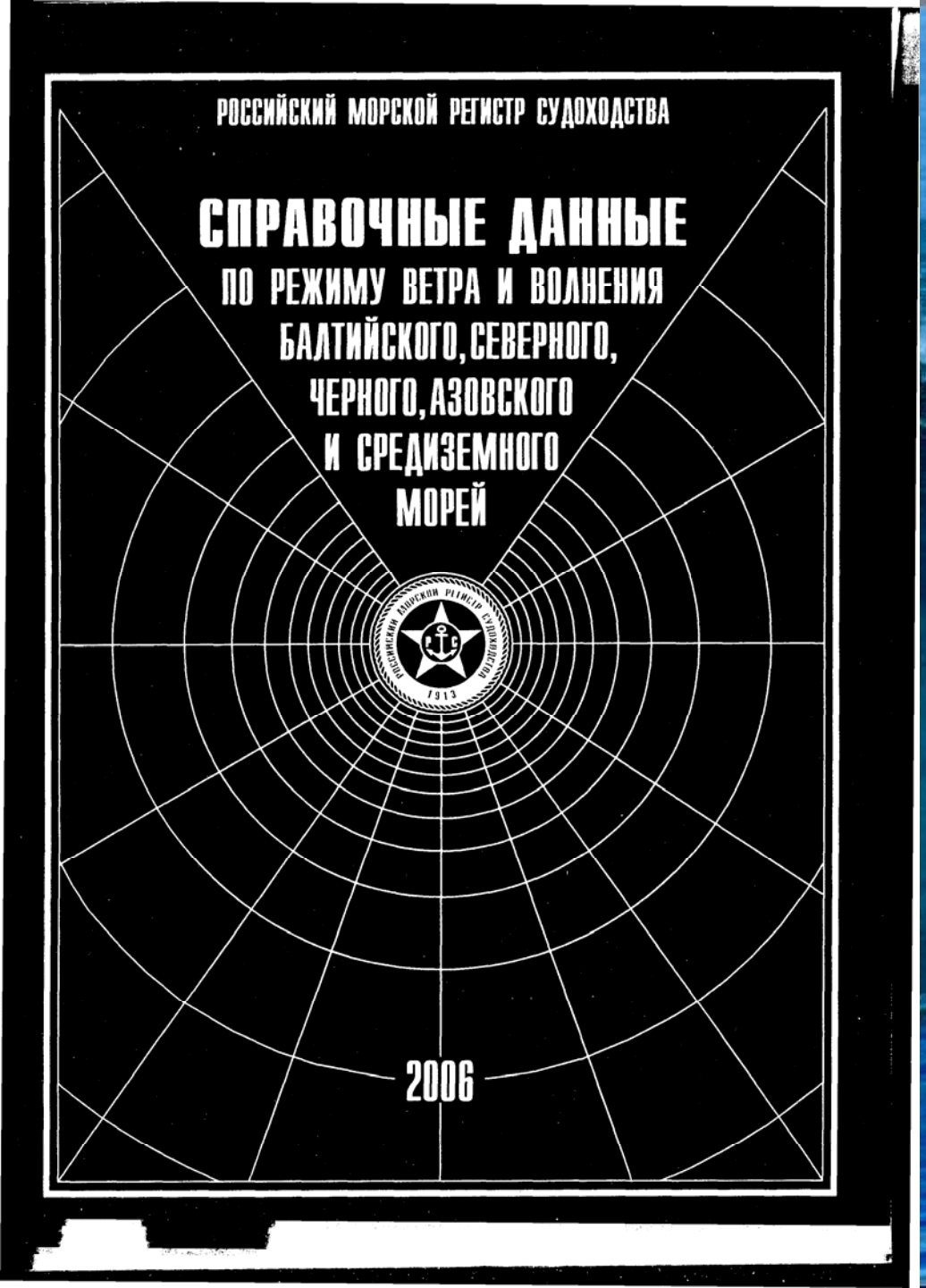
by

L.J. Lopatoukhin, V.A. Rozhkov, V.E. Ryabinin, V.R. Swail, A.V. Boukhanovsky and A. B. Degtyarev

WMO/TD-No. 1041

2000

JCOMM Technical Report No. 9



HANDBOOK 2006

"Wind and wave climate of Baltic, North, Black, Azov and Mediterranean Seas". Handbook.

Russian Register of Shipping Saint-Petersburg, 2006. 450p.

PART 1 (2006)

As in 2003 edition, but with more details for:

- assimilation data in reananlysis;
- persistence statistics;
- Climatic wave spectra;
- Freak waves (with example of the loss of ship “Aurelia” in February 2005)

PART 2 (2006)

The same as in 2003 edition, but for the first time in the World practice:

Climatic wave spectra for every area

CLIMATIC WAVE SPECTRA

Genetic classification as a tool for wave spectra modeling

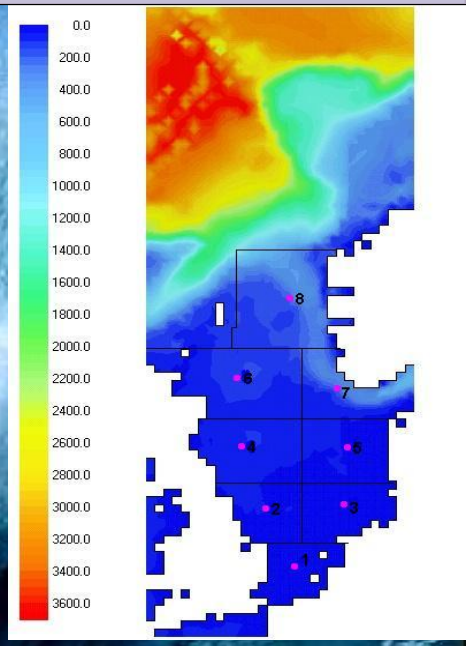
The techniques for decreasing of data dimensionality

- Formal orthogonal expansions
- Clustering
- Classification with learning

INITIAL DATA:

North Sea Region
Directional wave spectra
(24 directions x 25 frequencies each)

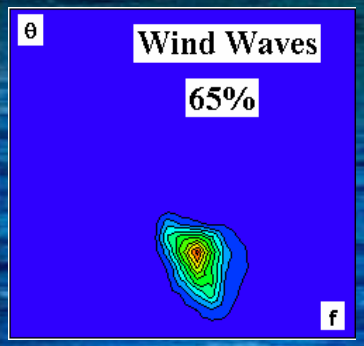
Continuous hindcasting: WW 2.22, 3 hours, 1983-1998

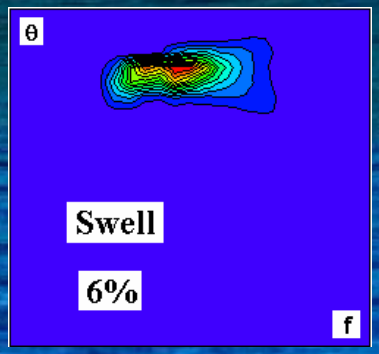


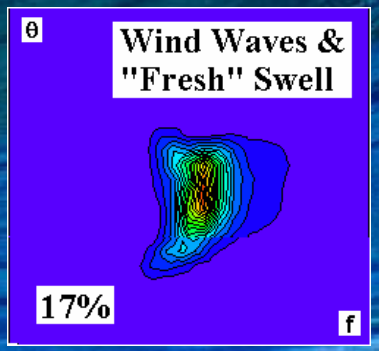
Genetic systems of classes

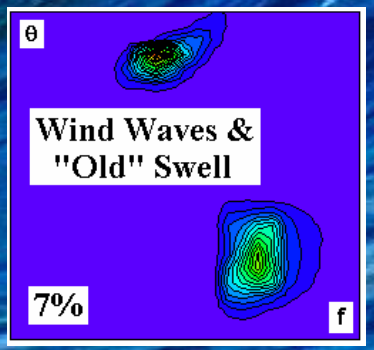
Classification of climatic spectra (probabilities for point 2)

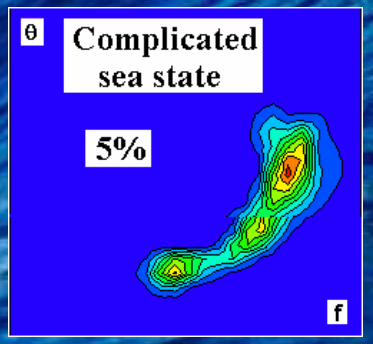
I II III IV V



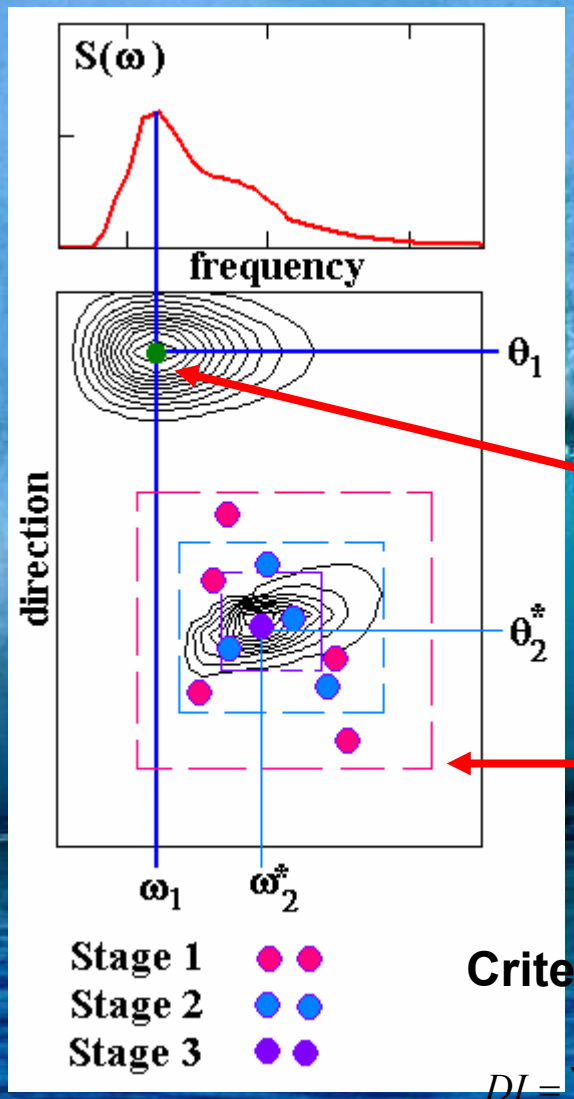








How to construct the classification rules? Parameterization technique for directional spectra



Dataset of Initial Spectra

Smoothing

Model of multipeaked spectrum

$$S(\omega,\theta)=\sum_p \gamma_p S_p(\omega,\theta\,|\,\Xi_p)$$

Approximation

$$S(\omega,\theta)\equiv S(\omega)G(\omega,\theta)$$

$$S(\omega)=\alpha g^2\omega^{-k}\exp\left[-B\omega^{-n}\right]\gamma^{\beta(\omega)}$$

$$G(\omega,\theta)=C_m(\omega)\cos^{2m(\omega)}(\theta/2)$$

Estimation of prevailed peak position on the data sheet directly

Estimation of secondary peaks positions and other parameters γ_p, Ξ_p by means of multistage Monte-Carlo optimization

Control of significance of the peaks has been obtained

Set of spectral parameters for classification

Criterion of optimization:

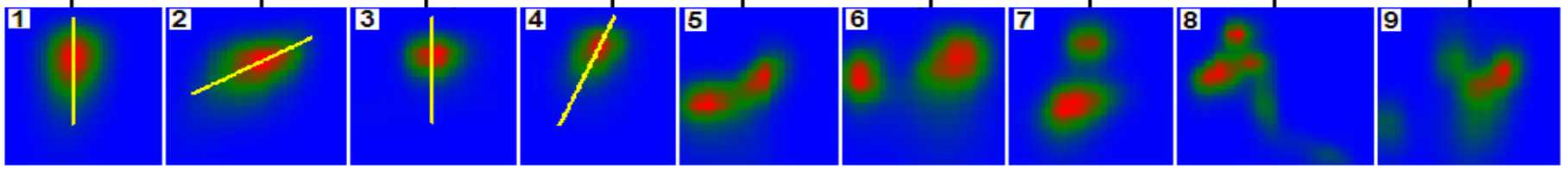
$$DI=\sum_i\sum_j \frac{\left|S(\omega_i,\theta_j)-S_{ij}^*\right|}{S_{ij}^* m_{00}} \rightarrow \min_{\left\langle \gamma_k,\omega_m^{(k)},\theta_{\max}^{(k)},n_{fields}\right\rangle}$$

Hierarchical classification of climatic wave spectra

North Atlantic
(near Azores)

54.8% 1
35.5% 2
9.7% n

16.9% W
37.9% S
25.8% W
9.7% S
8.1% W
1.6% S

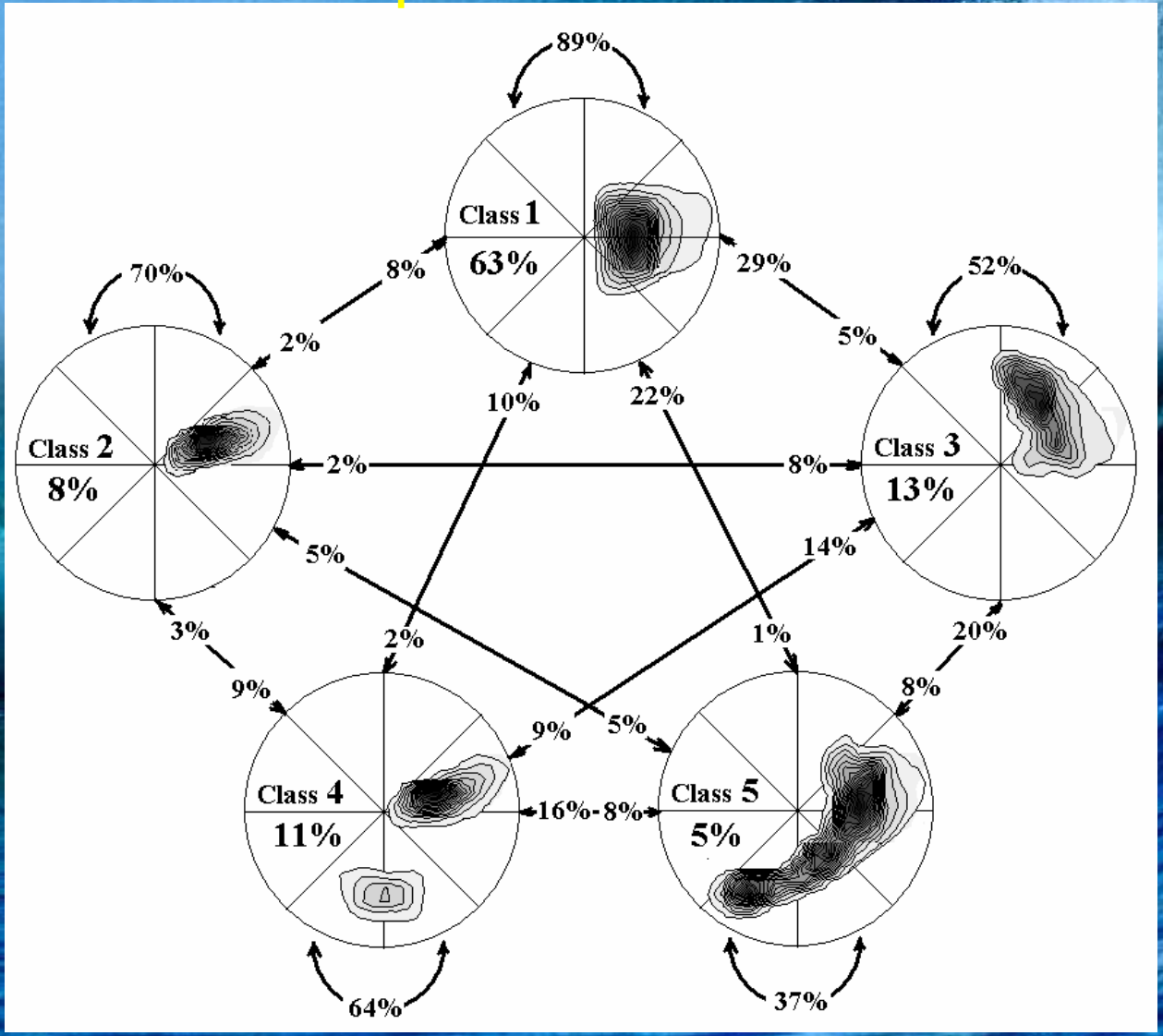


6.5% WIND SEA
10.5% T. WIND SEA
29.8% SWELL
8.1% T.SWEEL
8.1% W. + FRESH SWELL
17.7% W. + OLD SWELL
9.7% 2 SWELLS
8.1% W. + MANY SWELLS
1.6% MANY SWELLS

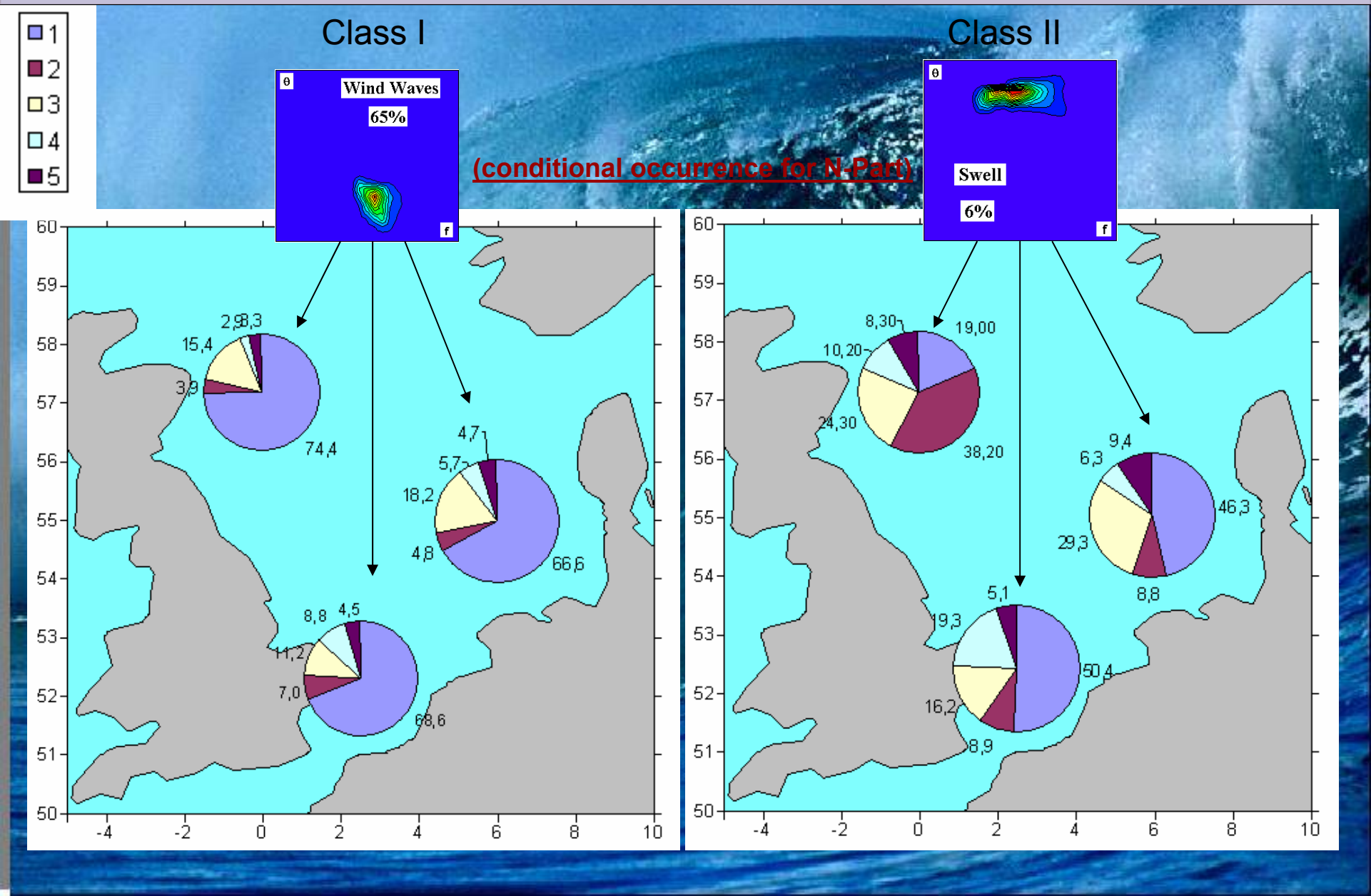
ONE PEAK
TWO PEAKS
MANY PEAKS

“Star” representation of Markov probability model of the variability of directional spectra

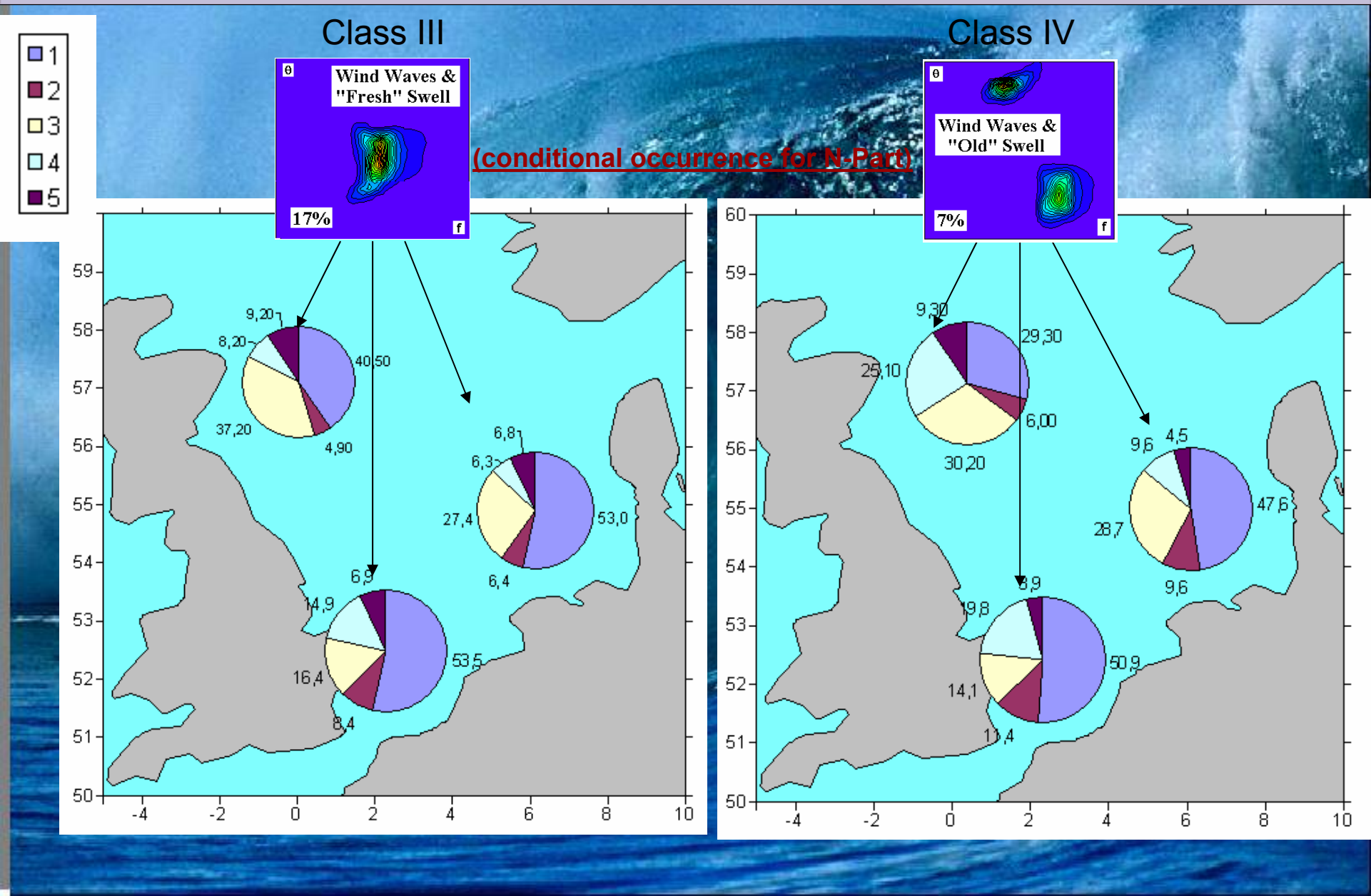
SW-part of the North Sea



Conditional Spatial Distribution of Sea Wave Spectra

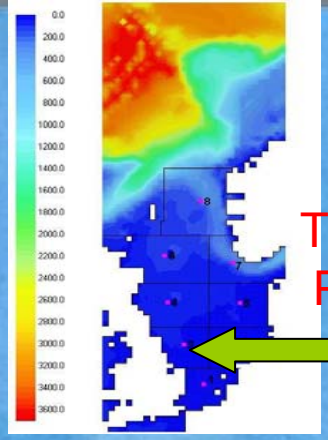


Joint Spatial Distribution of Sea Wave Spectra

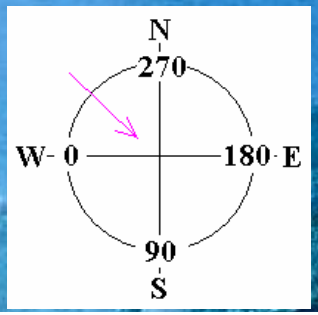


Approximation of ensemble of the climatic spectra

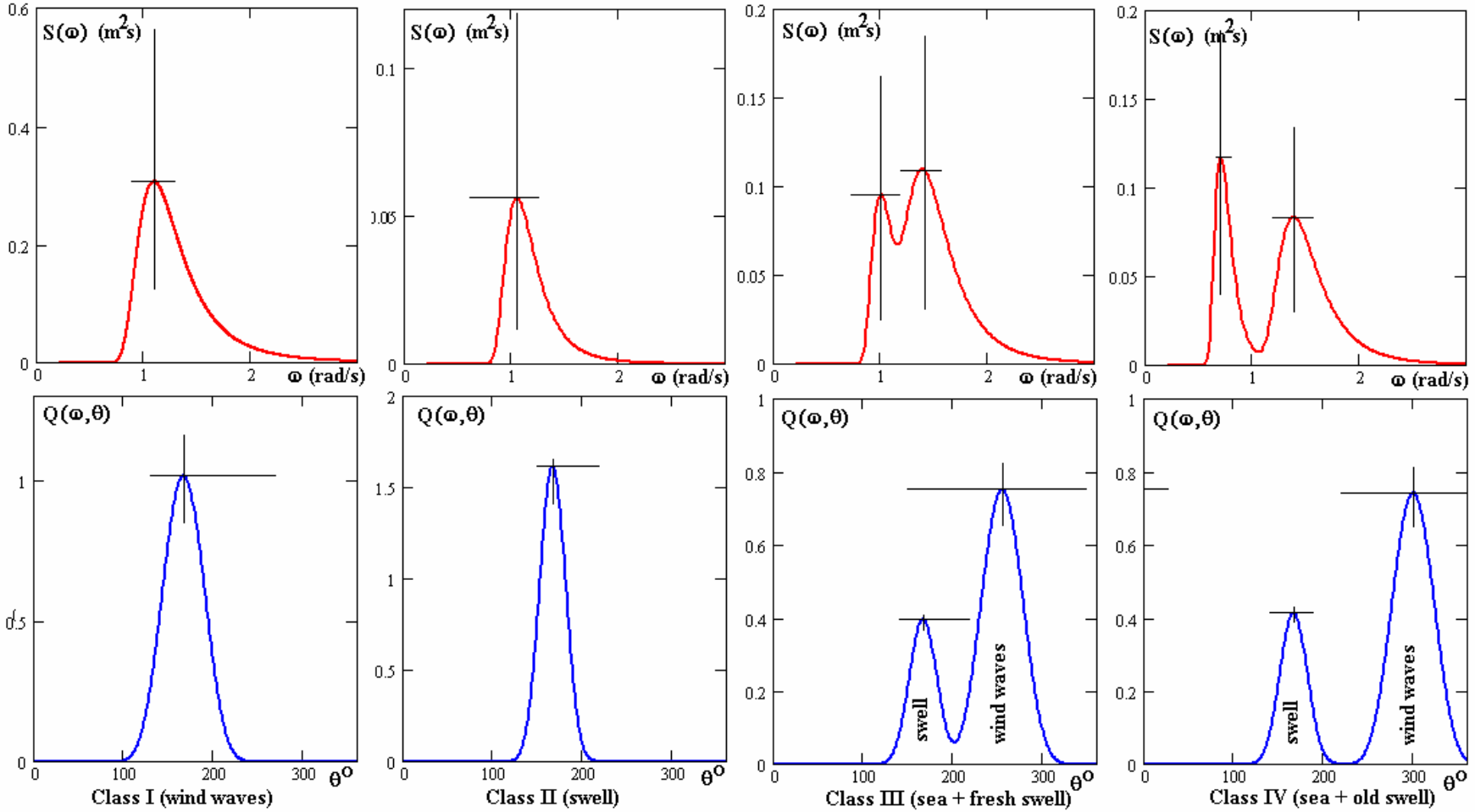
(statistical linearization technique)



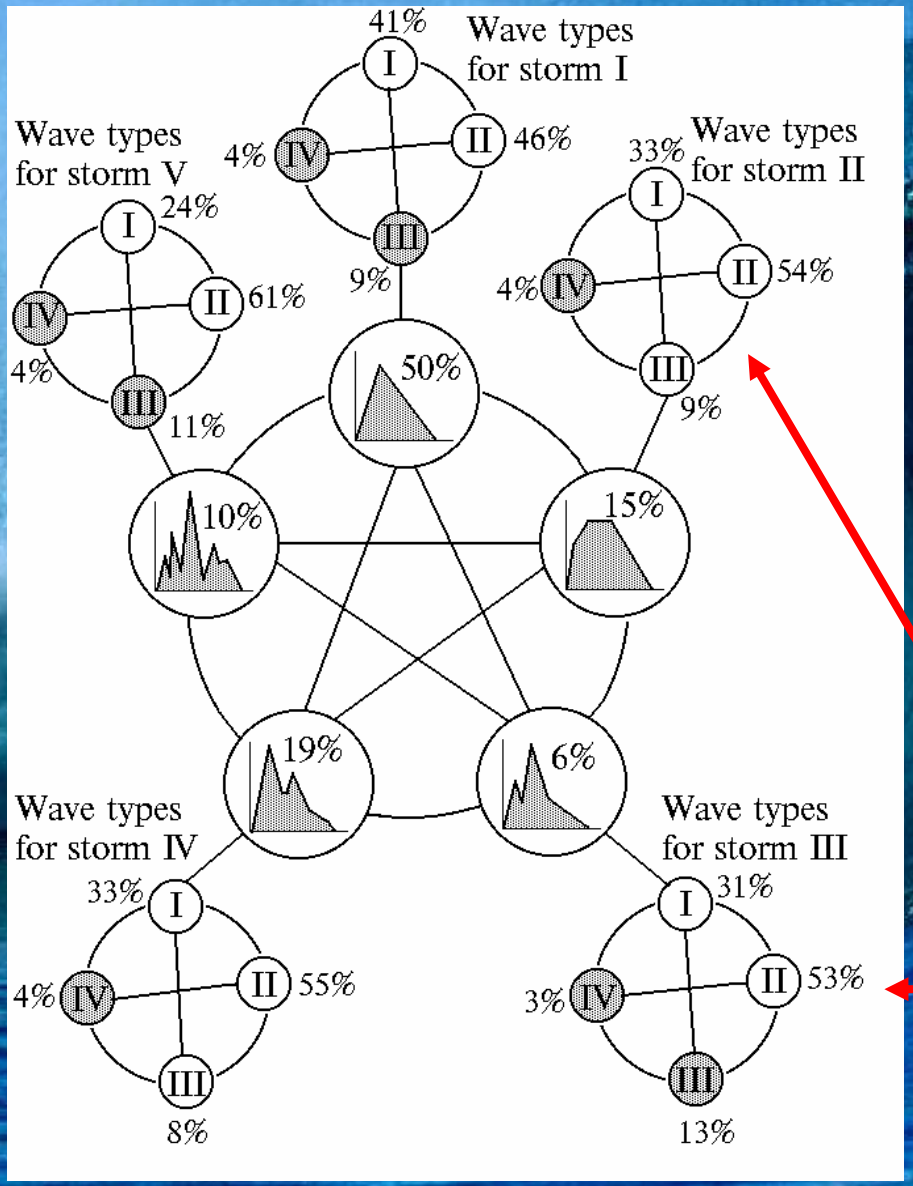
Target Point

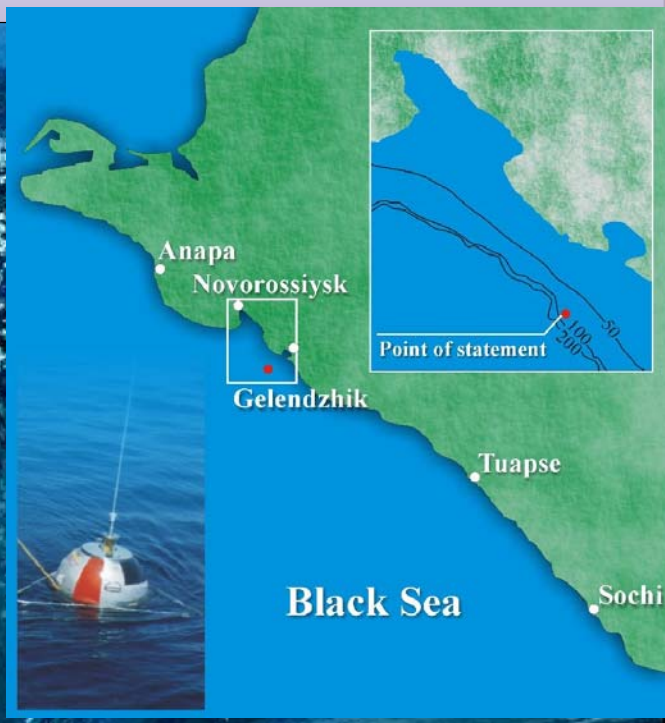


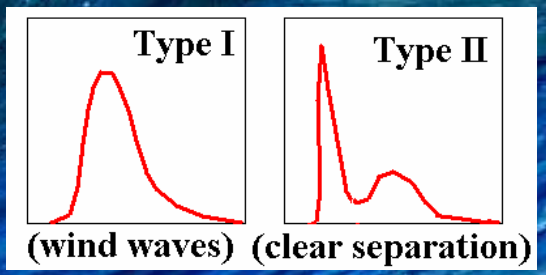
Notation of the directions - WW 2.22

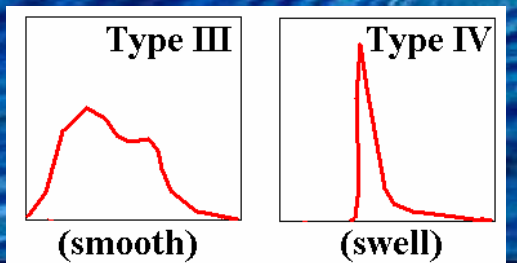


Comparison with measured data: climatic spectra and storms in a Black Sea









HANDBOOKS OF NEW GENERATION

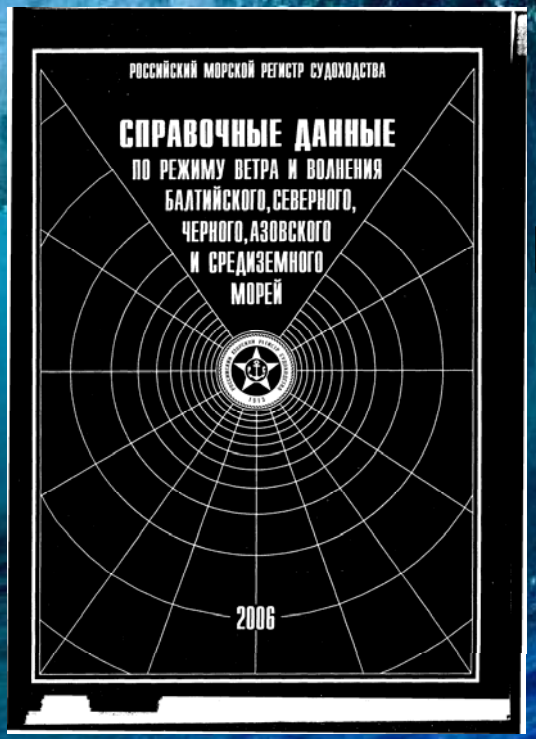
2003

REGISTER

Barents, Caspian and Okhotsk seas

2006

REGISTER



Baltic, North, Black, Azov, Mediterranean

2008

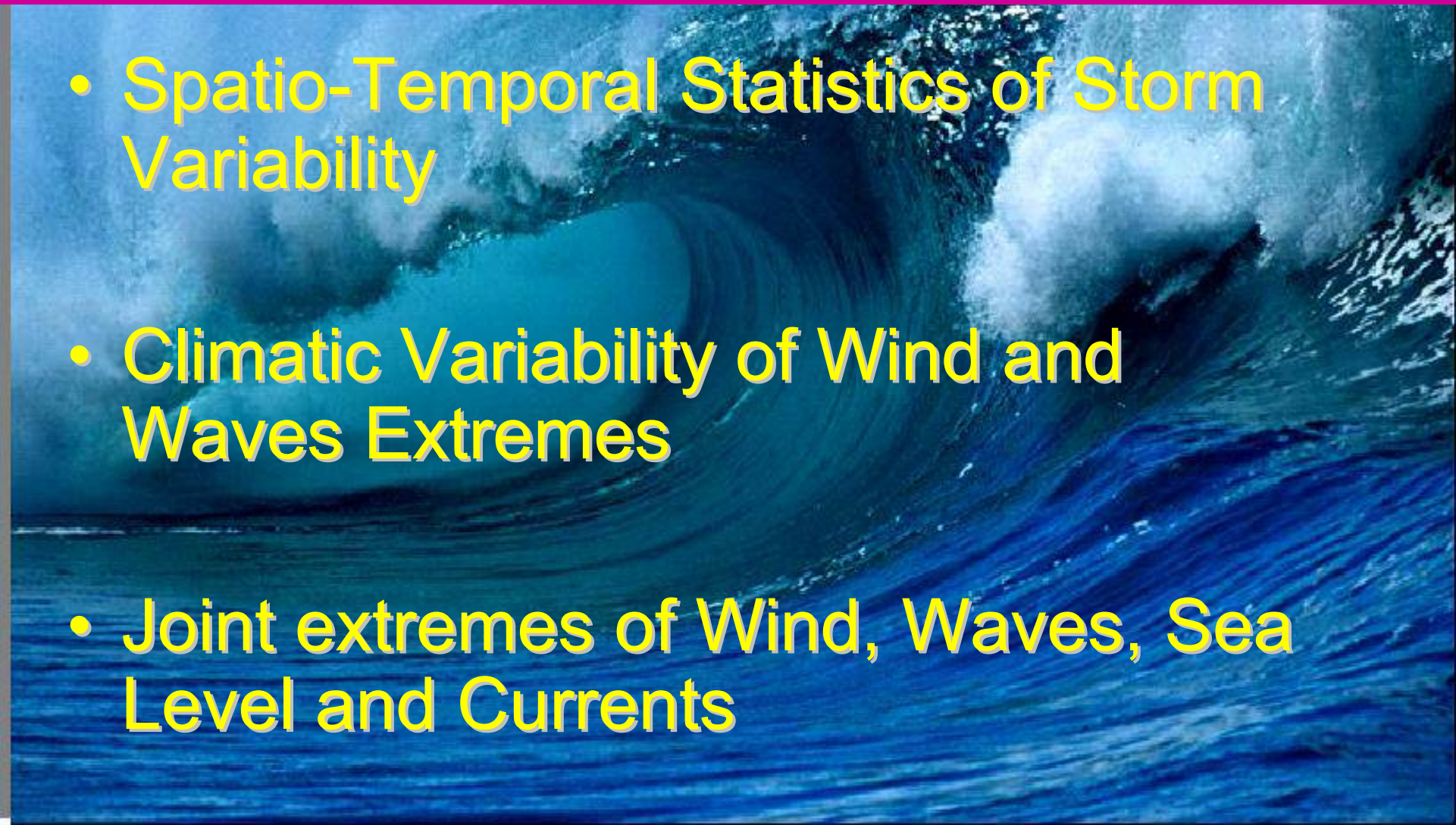
Russian Federal Agency on Science & Innovations

(TO BE PUBLISHED)

Atlas of Metocean Extremes.

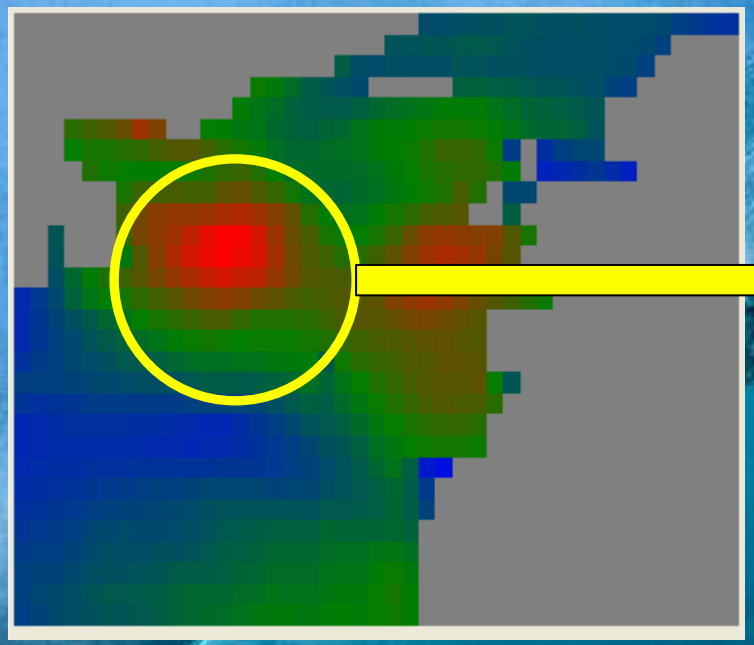
Caspian Sea

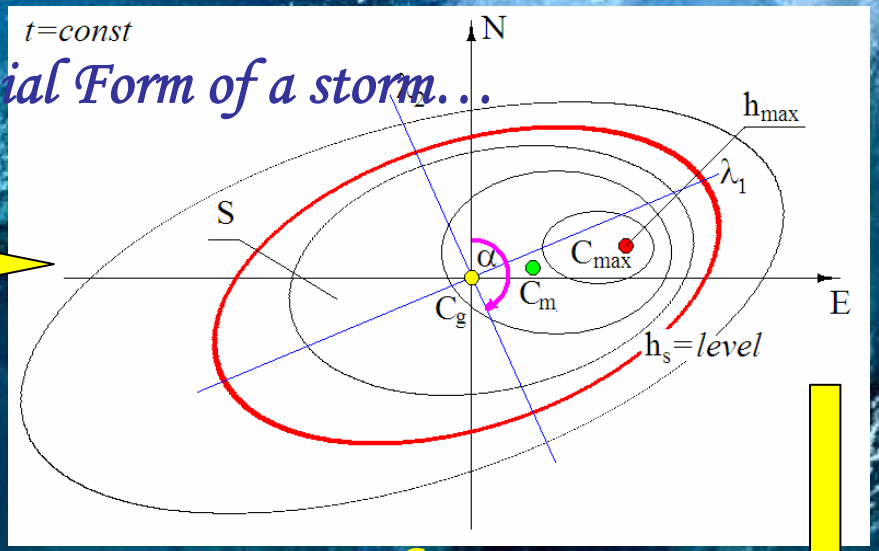
?☺ What will be in the next handbook ☻?



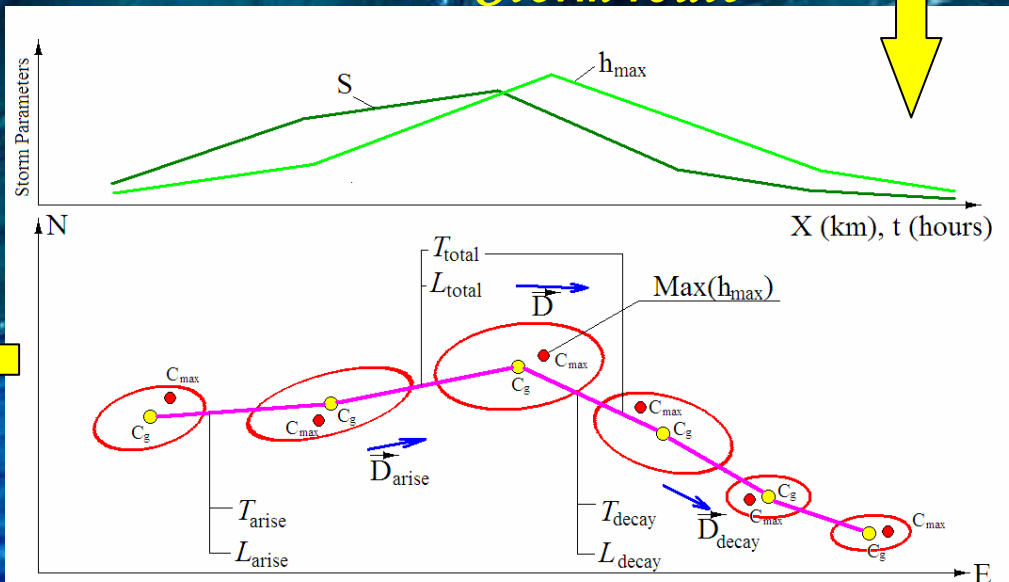
- Spatio-Temporal Statistics of Storm Variability
- Climatic Variability of Wind and Waves Extremes
- Joint extremes of Wind, Waves, Sea Level and Currents

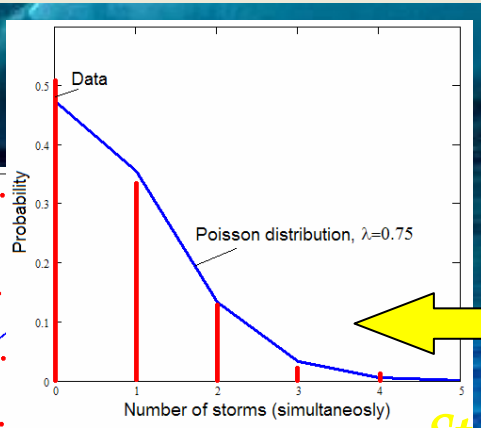
NEW TYPES OF CLIMATIC DATA
(1): Spatial-temporal variability of storms

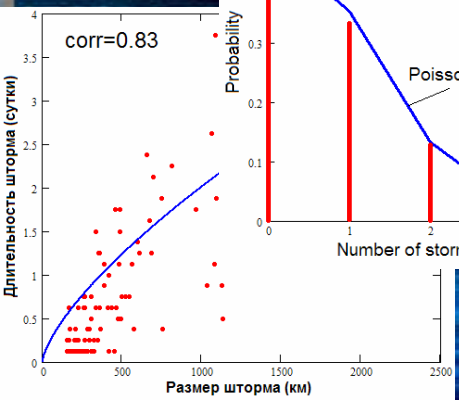




Storm route



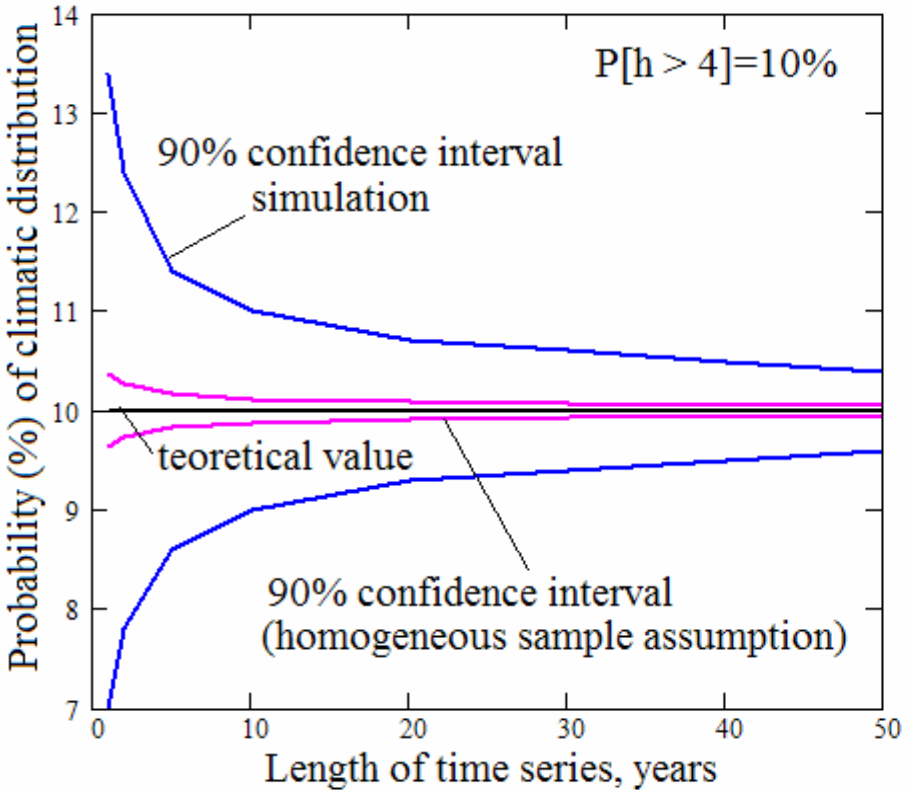


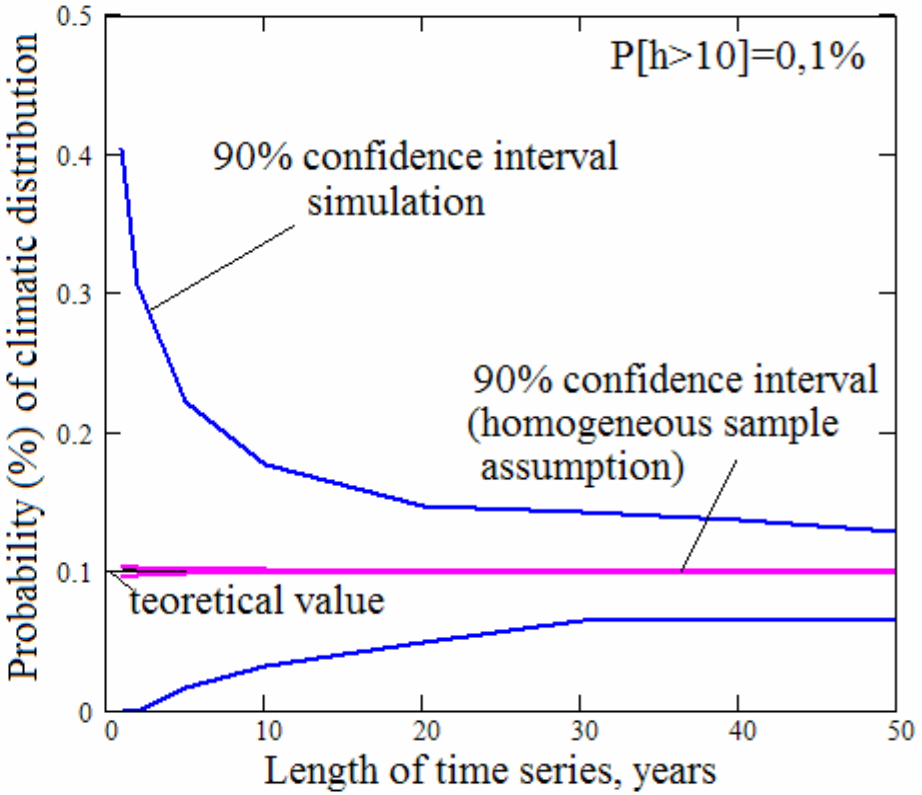


Storm statistics

NEW TYPES OF CLIMATIC DATA

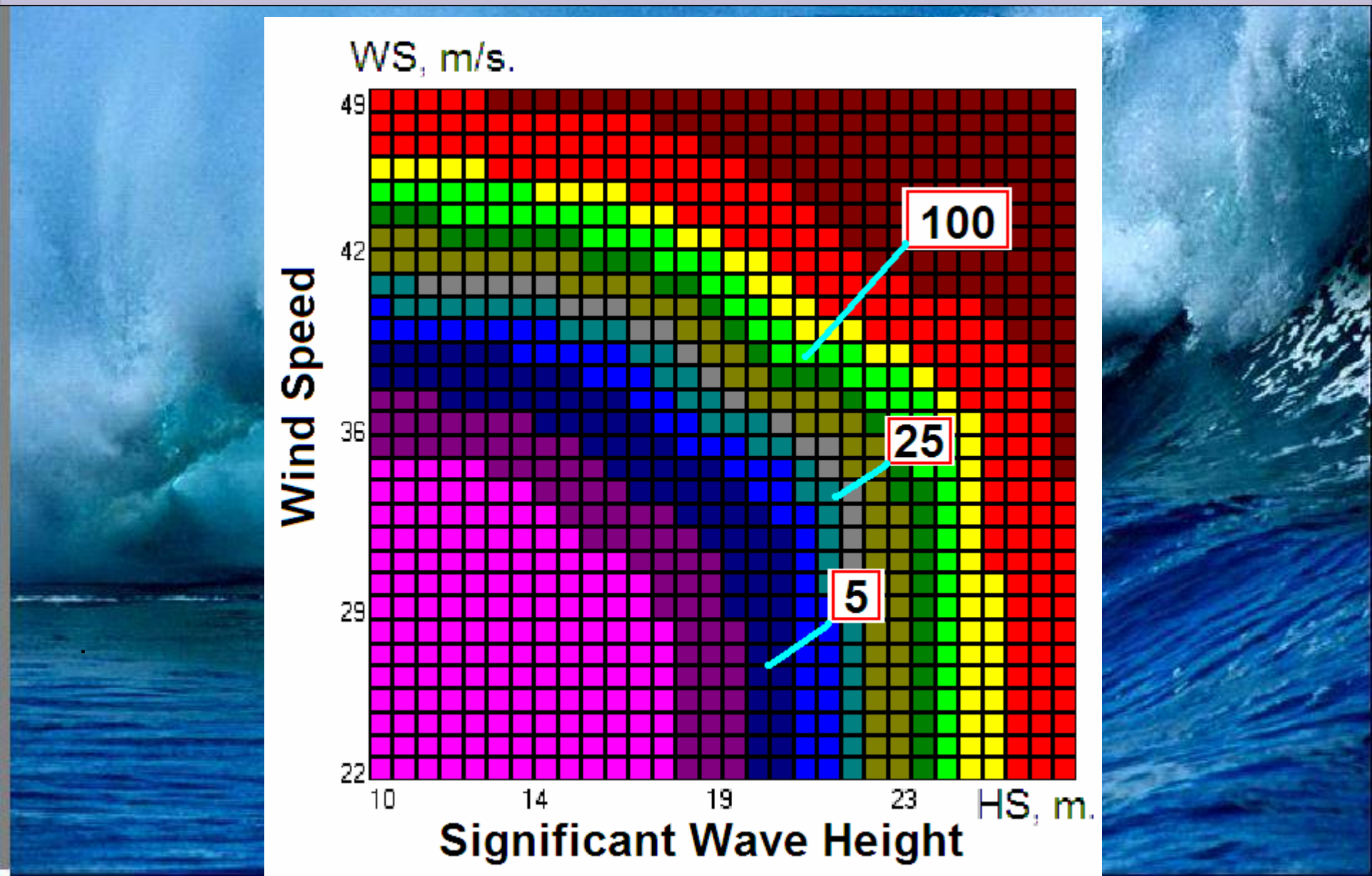
(2): Climatic Variability of Wind and Waves Extremes





NEW TYPES OF CLIMATIC DATA

(3): Joint extremes of metocean events



SUMMARY

- Hindcasting is the main tool for wave climate investigations.
- Confidence of wind reanalysis is quite different for various basins and even their parts.
- Ship data assimilation is a useful approach for improvement of wind data input.
- Continuous 30 years (and sometimes more) hindcasting was performed for a lot of seas near Russia.
- Wave climate is a set two-dimensional spectra and descended from them spatiotemporal statistics.
- Genetic classification of two-dimensional climatic wave spectra performed.
- Markov probability model
  is used for investigation of the variability of directional climatic spectra.
- Approach to calculations of wave extremes on a point and field is elaborated.
- New Handbooks of Wind and wave climate of Barents, Caspian, Okhotsk, Baltic, North, Black, Azov, Mediterranean seas are based on hindcasting, and published by Russian Register of shipping in 2003, 2006.
- Two-dimensional metocean extreme Handbook is in preparation.

St. Petersburg