# Applications of the dynamical and statistical downscaling techniques to the local multi-decade wave simulations

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9-th Wave Hindcasting and Forecasting workshop, Victoria, Canada, 26 September 2006

# Introduction and motivation

coastal zones:
coastal erosion, harbor protection, management, shipping, off-shore constructions

required wave data:
- high resolution in space and time
- homogeneity
- long-term (for statistical analysis)

✓ no adequate observations
✓ existed modelled data do not fulfil all the requirements

possible solution:
additional modelling (downscaling) for the areas of interest

# Objectives

- development and investigation of the methodology allowing the use of the existing medium-scale wave data for local coastal applications (downscaling methods)

### 1. dynamical modeling

existing coarse wave data → small-scale wave data

### 2. added value

existing coarse wave data ↔ small-scale wave data

**limited computational resources**

### 3. statistical-dynamical approach

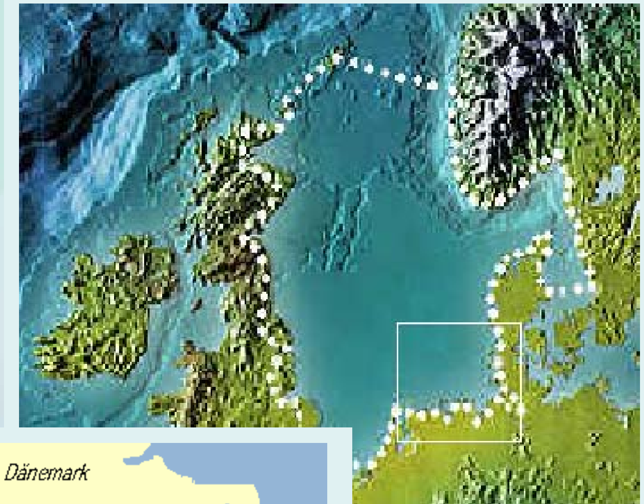
← statistical method

- application of the appropriate downscaling method to the long-term wave simulations and subsequent wave climate assessment for the Helgoland area

### 4. multi-decadal small-scale hindcast

- assessment of the local changes and trends
- evaluation of the extreme wave statistics

# Area description




<u>Helgoland</u>:

• need for coastal protection (has old protection constructions, is under the influence of the open sea waves)

• available observations

# Data description and experiment setup

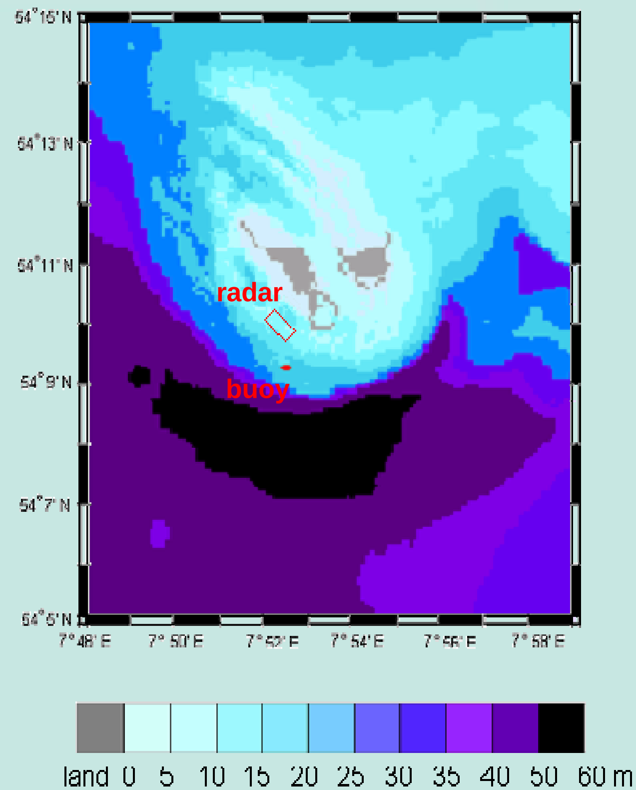
Available: wave statistics for the North Sea from HIPOCAS with 5x5km resolution
Required: wave statistics for the Helgoland near-shore zones with resolution of about tens to hundreds meters
Tool: K-model - spectral shallow water wave model
(wind energy input, refraction caused by currents and depth, bottom dissipation, non-linear dissipation)

Model area 10x15km with resolution 100m
Model integration period: 1990-2001

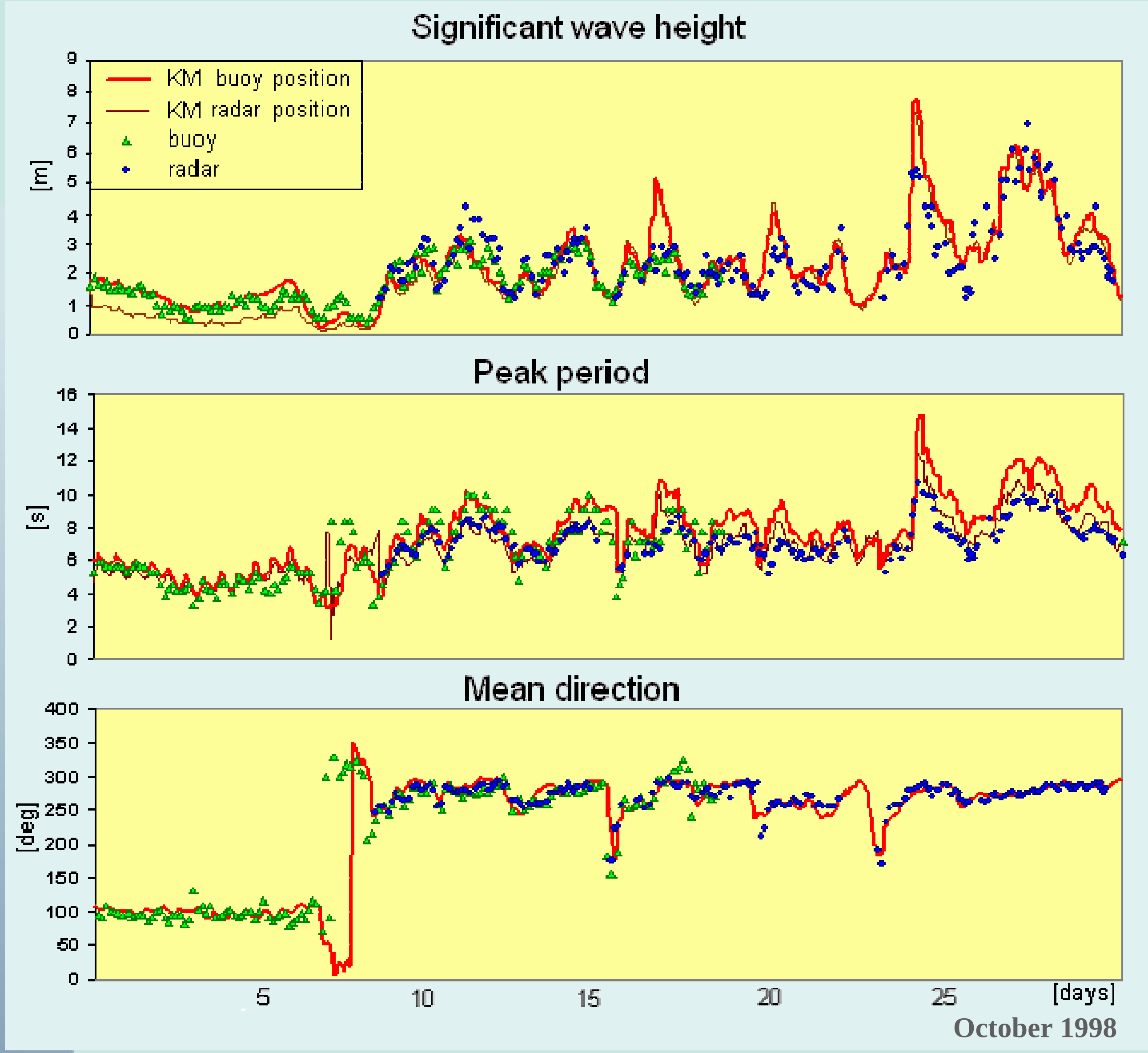
Input:
boundaries – HIPOCAS wave spectra (WAM) (5 km, 3 hour)
10m wind – REMO (50 km, 1 hour)
currents, water level variation – BAW (TELEMAC-2D) (200 m, 1 hour)

Output:
integrated wave parameters (1hour)

Observations:
Waverider buoy, WaMoS radar

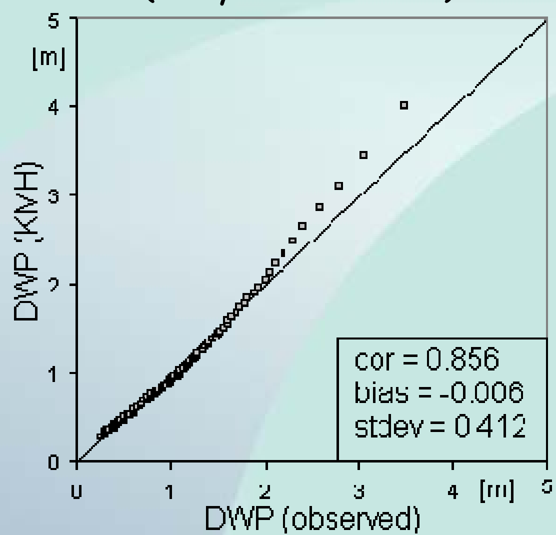


# K-model validation against observations

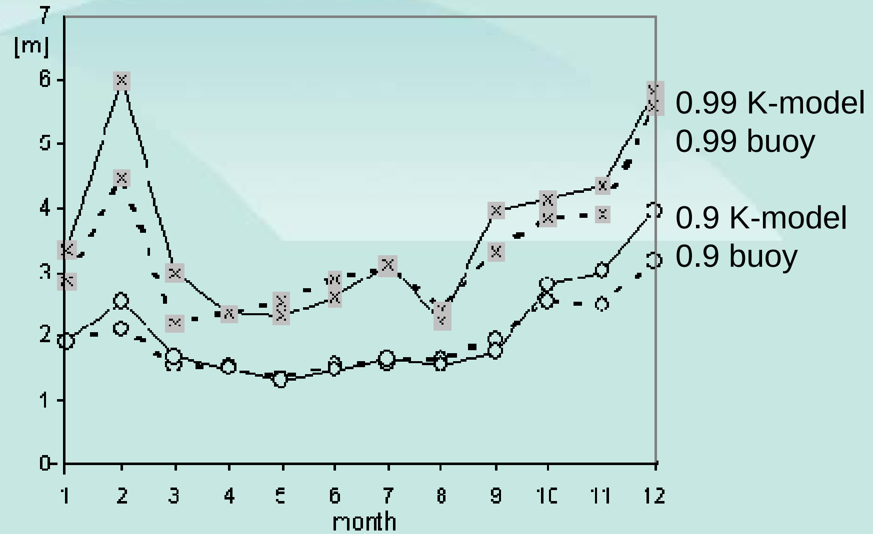


# K-model validation

Q-q plot of HS 1998-2001
(buoy vs. K-model)




Monthly 0.9 and 0.99 quantiles of HS

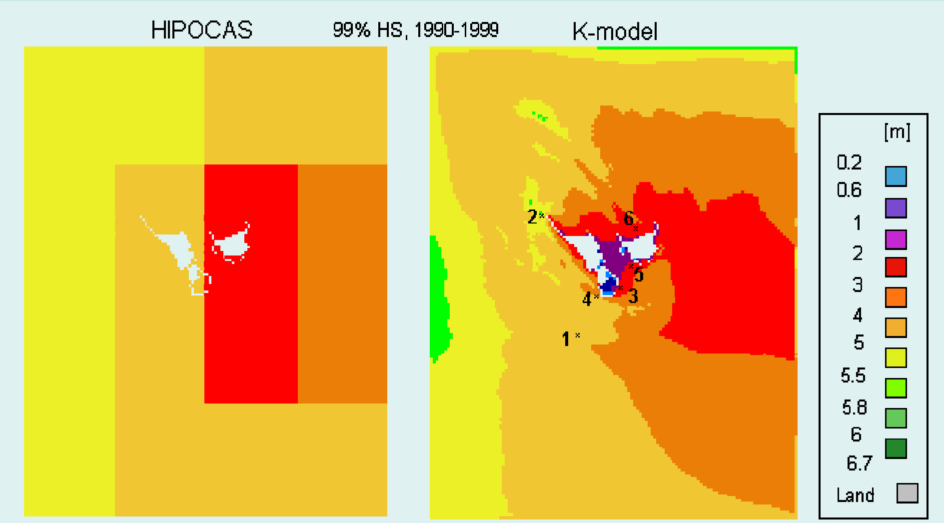



good agreement for the major part of the wave heights

overestimation for highest 10% of modeled waves

similar results for boundary conditions (HIPOCAS)

# Wave data modeled on different scales



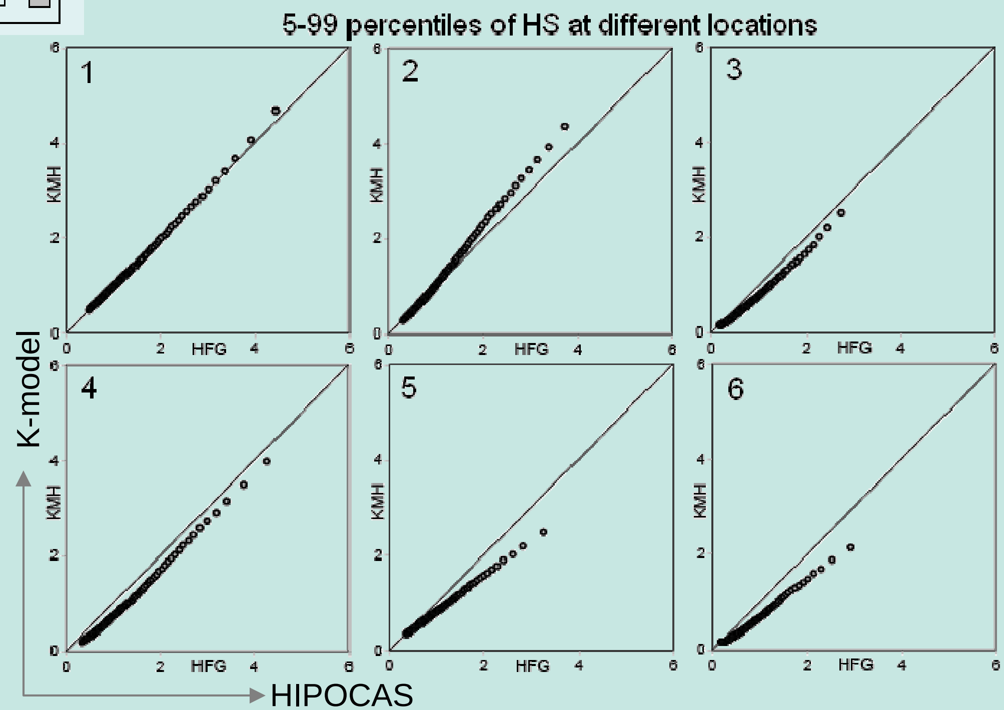

similar large-scale pattern

small-scale differences

for deep water (1) there is a strong influence of boundaries

for the west coast (2, 4) the bathymetry and shallow water effects are more important

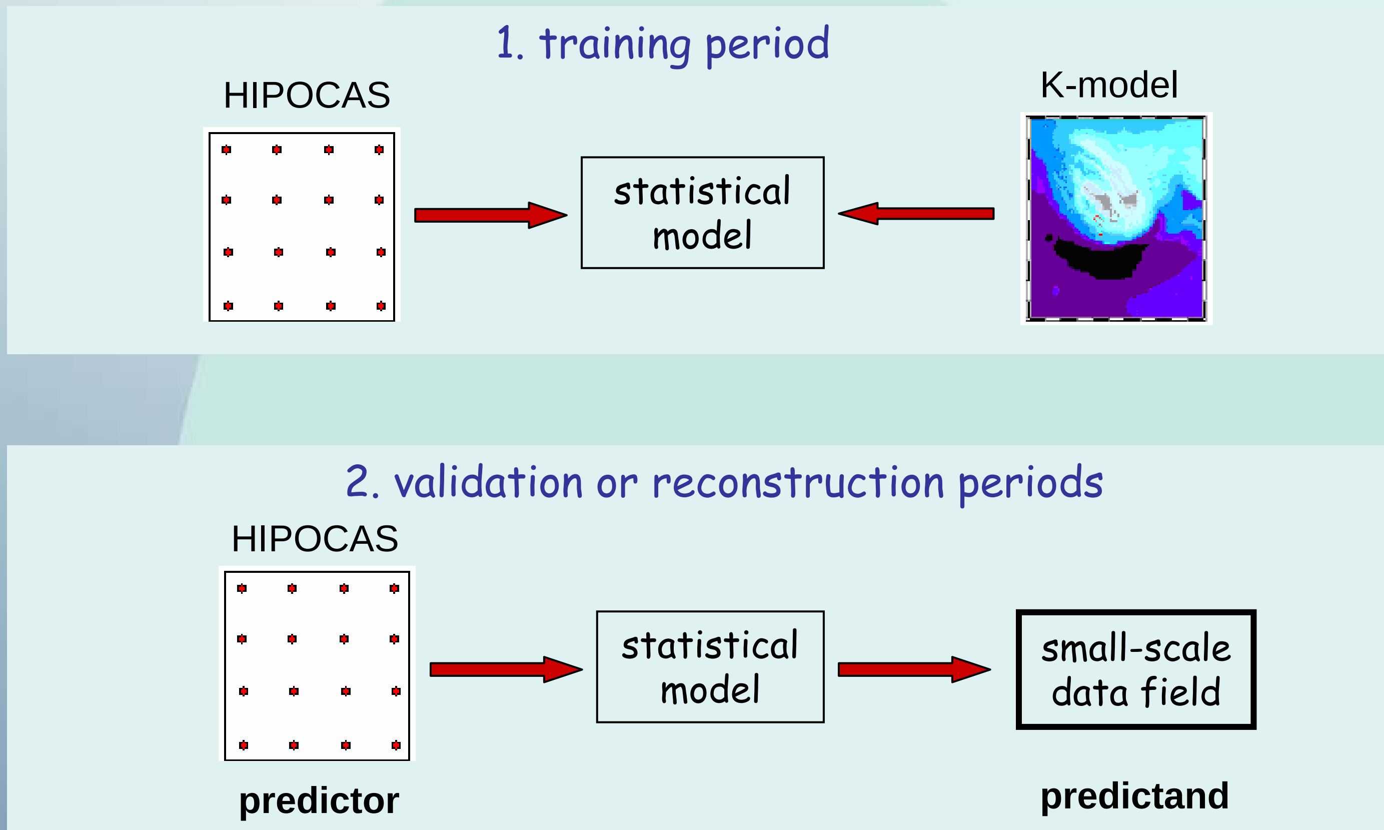
for eastern points (3, 5, 6) the lee effect plays a significant role



# Statistical-dynamical approach

for an adequate assessment of the near-shore wave statistics the medium-scale wave data needs additional processing or downscaling

computational costs for dynamical long-term simulations are enormously high



# Statistical-dynamical approach

Predictor: HIPOCAS wave field with 5km resolution
Predictand: high-resolution HS-field with 3 hour time-step
Procedure: training period 1990-1994, validation period 1995-2001

**Linear regression**

$$y_{i,t} = a_{i,j}x_i + b_{i,j}$$

where $y_{i,t}$ is K-model HS for time *t* at point *i*, $x_t$ is HIPOCAS HS for time *t*, *j* – wind direction sectors starting from [-22.5,22.5]

**Canonical Correlation Analysis**

1,2 EOFs of HIPOCAS HS anomalies explain 99.1% of total variability
1,2 EOFs of K-model HS anomalies explain 98.3% of total variability
Canonical correlation patterns are built basing on both pairs.

**Analog method**

principal components of 1-st EOF of HIPOCAS HS anomalies

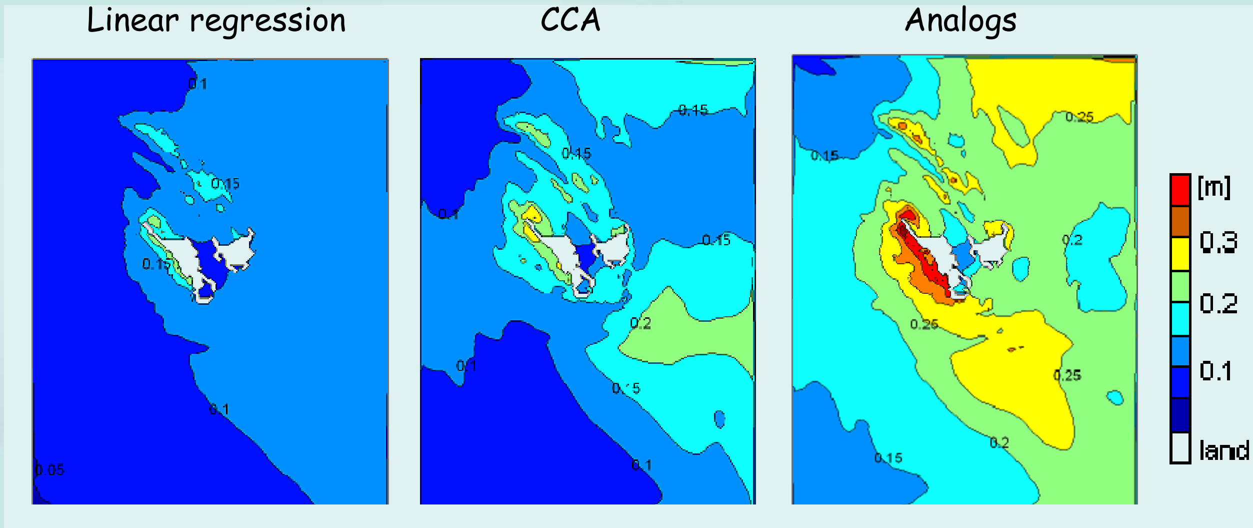
$\updownarrow$

K-model HS

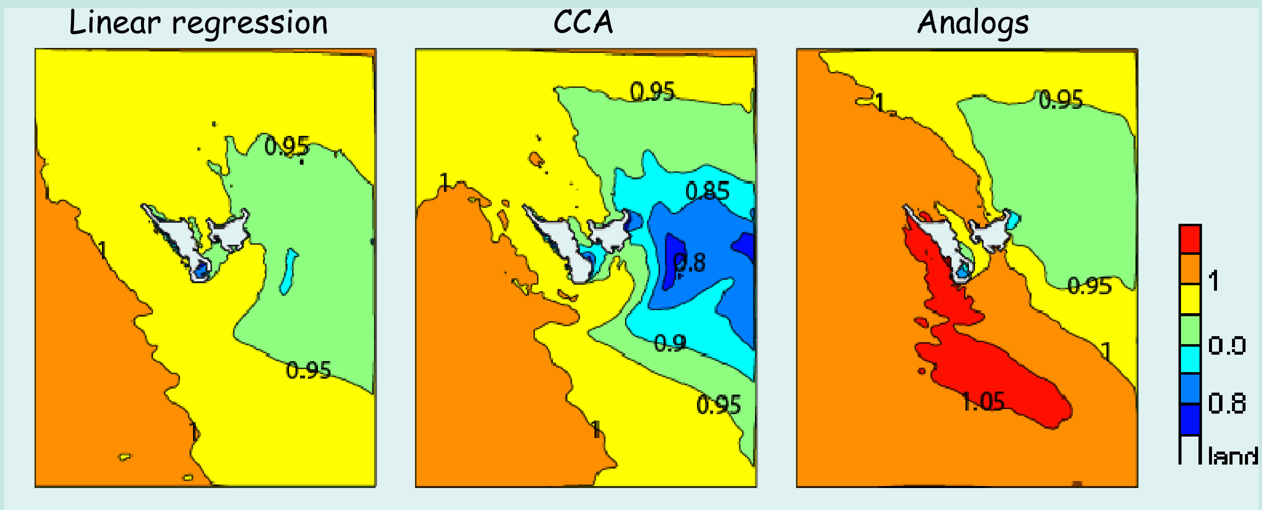
# Comparison of the statistical models

Instantaneous significant wave height values (hourly) simulated for validation period 1995-2001

Root mean square error in meters between instantaneous HS from K-model and statistical methods




Variance ratio of HS from statistical methods with respect to K-model



# Performance of the statistical models

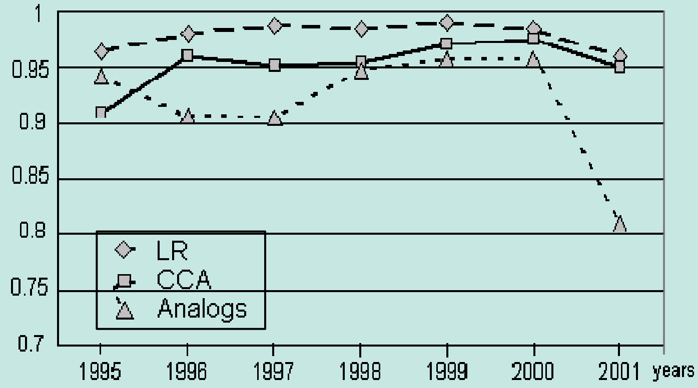
Quality assessment of the representation of the wave statistics by different statistical models with respect to regional and dynamical data

**Brier skill score**:

F – forecast (downscaling results)
P – observations (K-model)
R – reference (HIPOCAS)

$$B = 1 - \frac{E((F-P)^2)}{E((R-P)^2)}, \quad B \in [0,1]$$

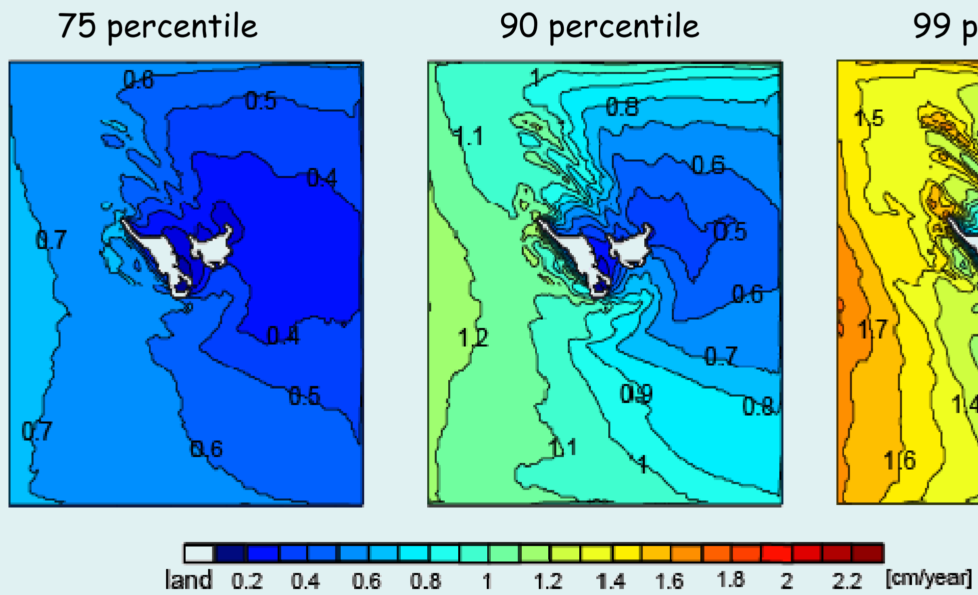
Brier skill score for the 99 percentiles of yearly HS

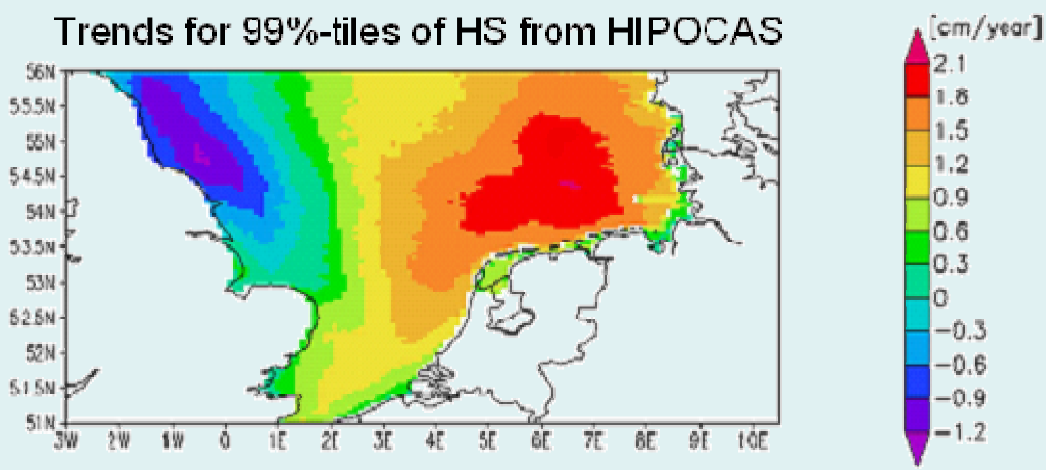



Based on a balance between the quality of simulated data and required computational resources linear regression was chosen as an appropriate method for further downscaling experiments and obtaining of the long-term wave statistics.

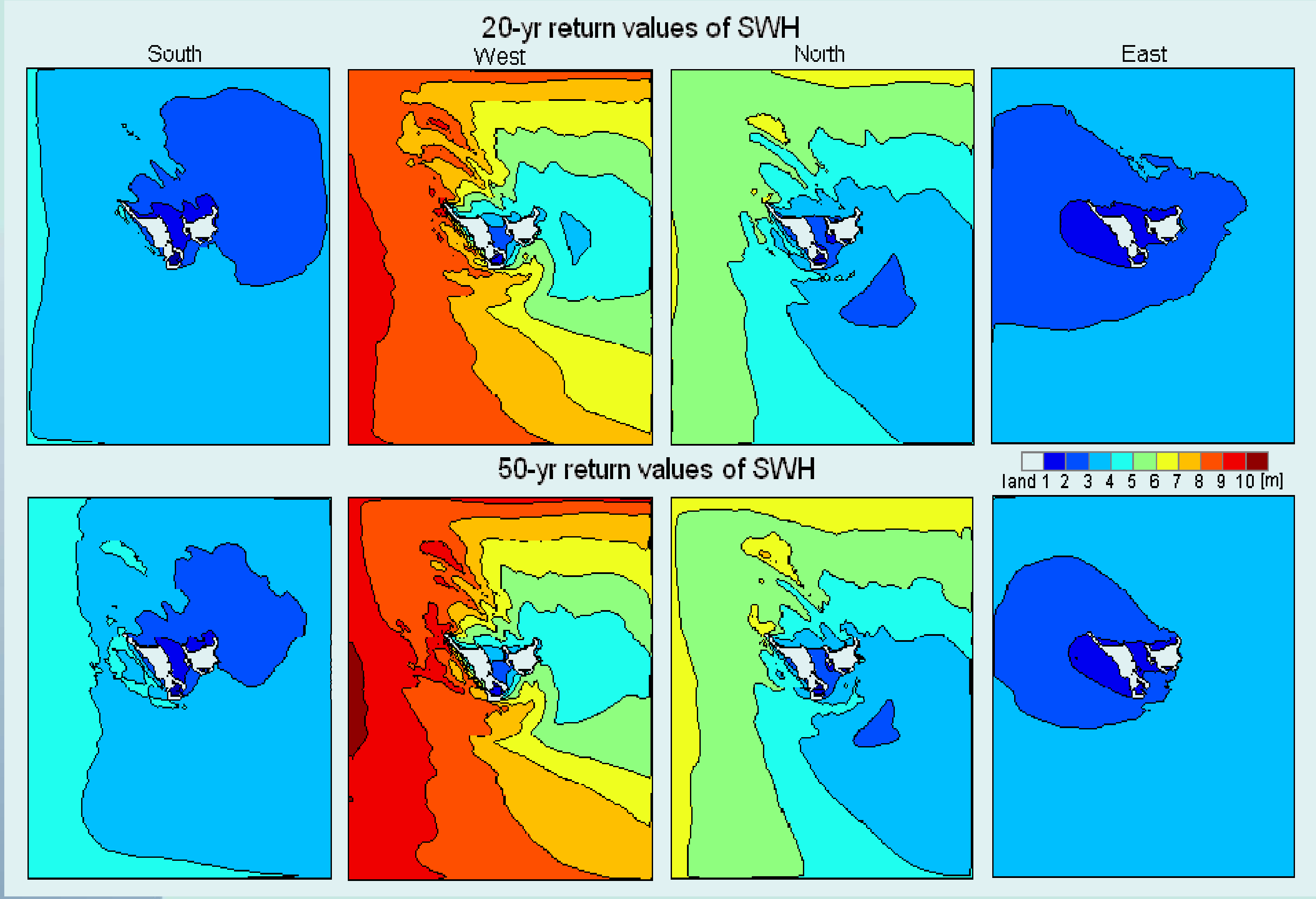
# Intra-annual trends for the wave heights

Trends in cm/year for annual percentiles of HS obtained with Linear regression model driven by HIPOCAS



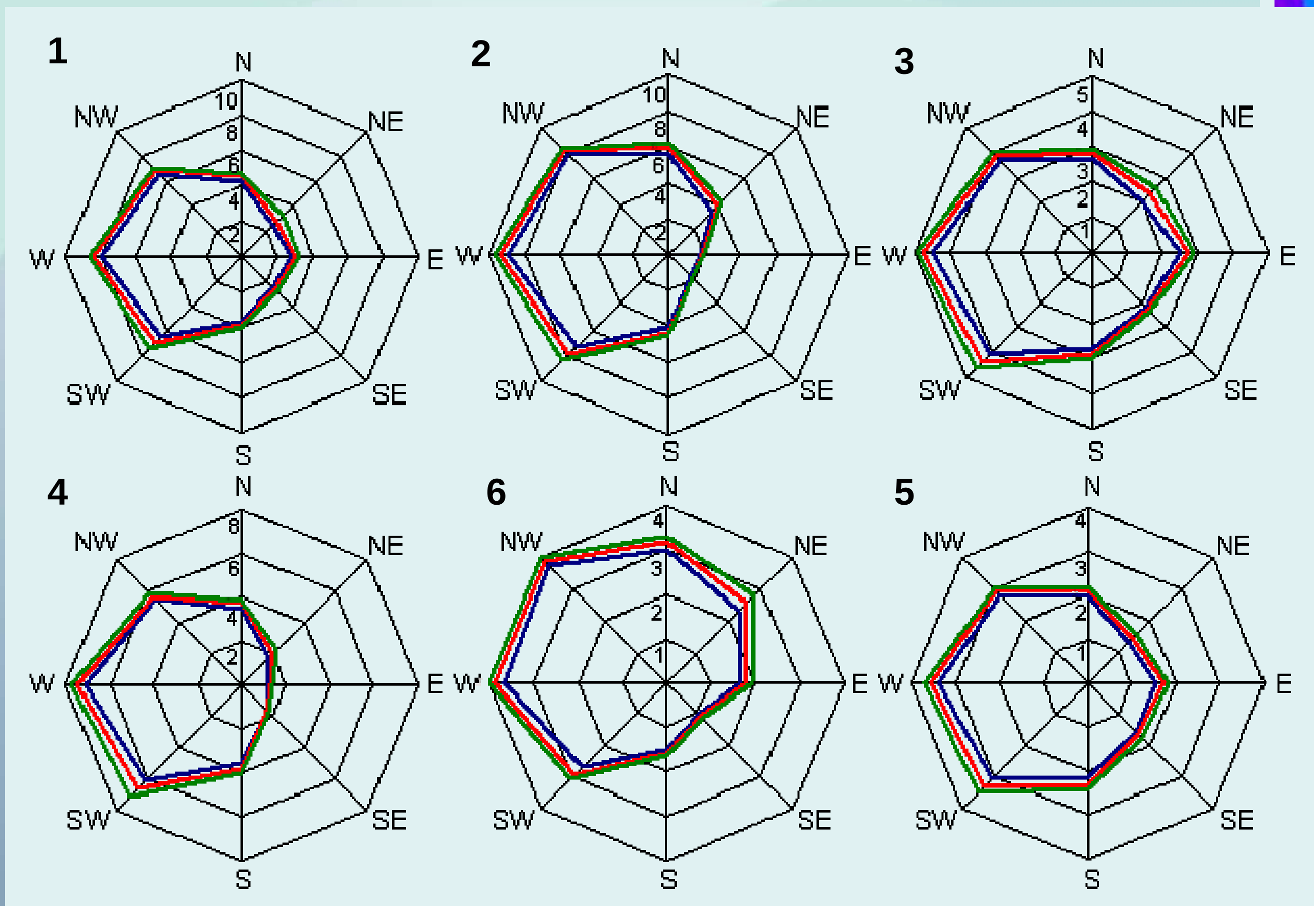



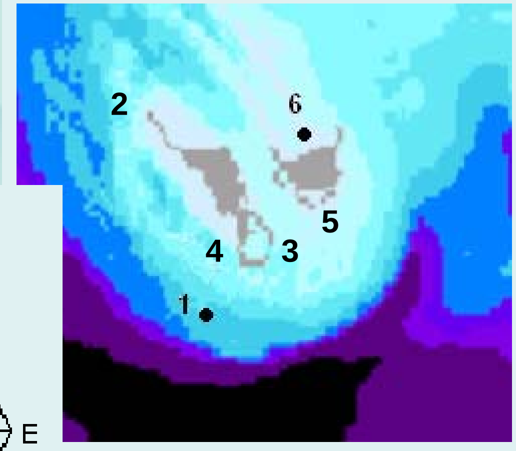
# Extreme value analysis



# Extreme value analysis

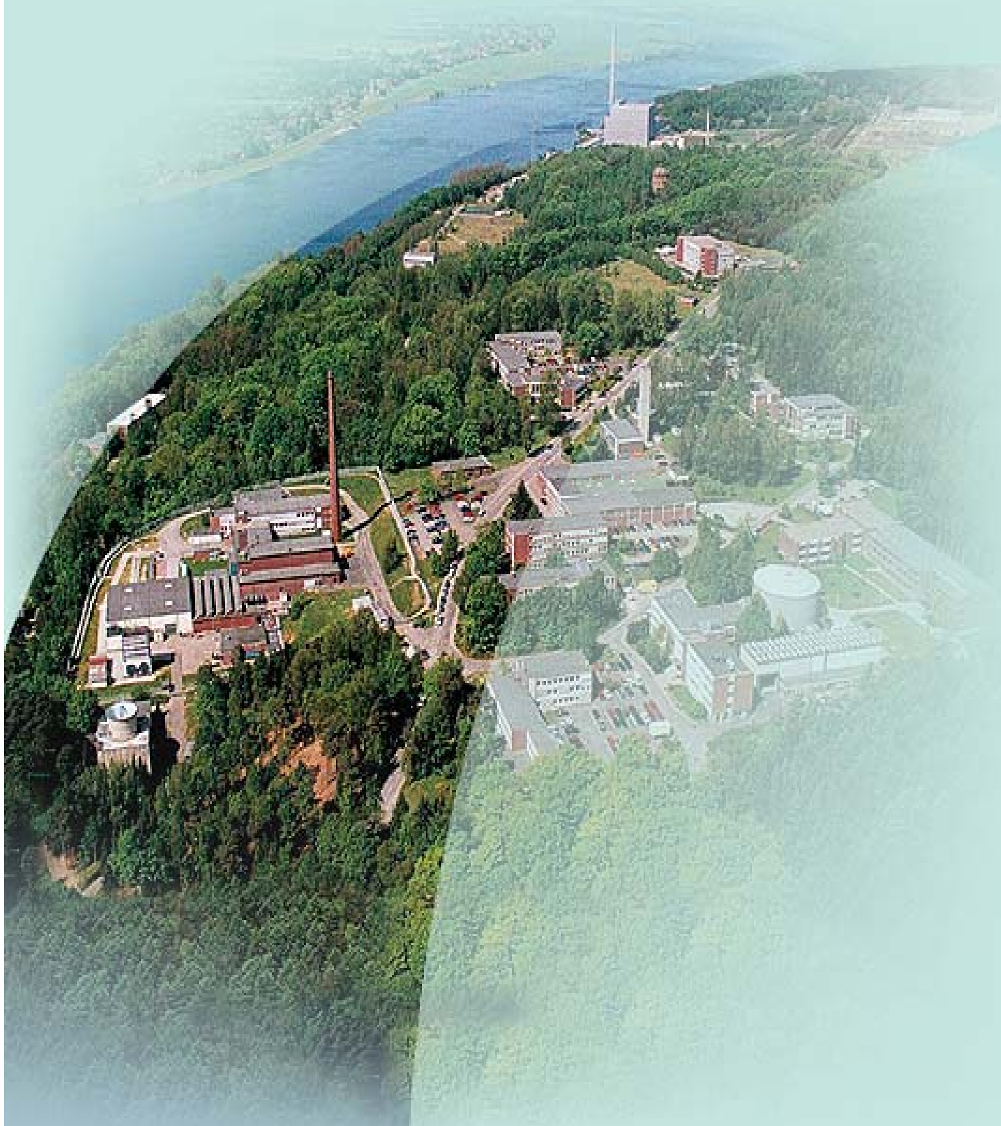
20, 50 and 100-year return values of HS



# Summary

- shallow water dynamical wave model was applied to the downscaling of the regional wave data from HIPOCAS
- modeled wave parameters showed resemblance with observational data
- dynamically obtained wave data improved the representation of wave statistics with respect to HIPOCAS data (spatial resolution and shallow water effect may have significant impact on the wave frequency distribution)
- statistical techniques were proposed as the complimentary downscaling tool in the case of limited computational resources
- combination of dynamical modeling and statistical method has good skills in working out the wave parameters in detail and allow to produce long-term wave simulations



Thank you