Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Verkeer en Waterstaat

Downscaling

and its use in ocean modelling

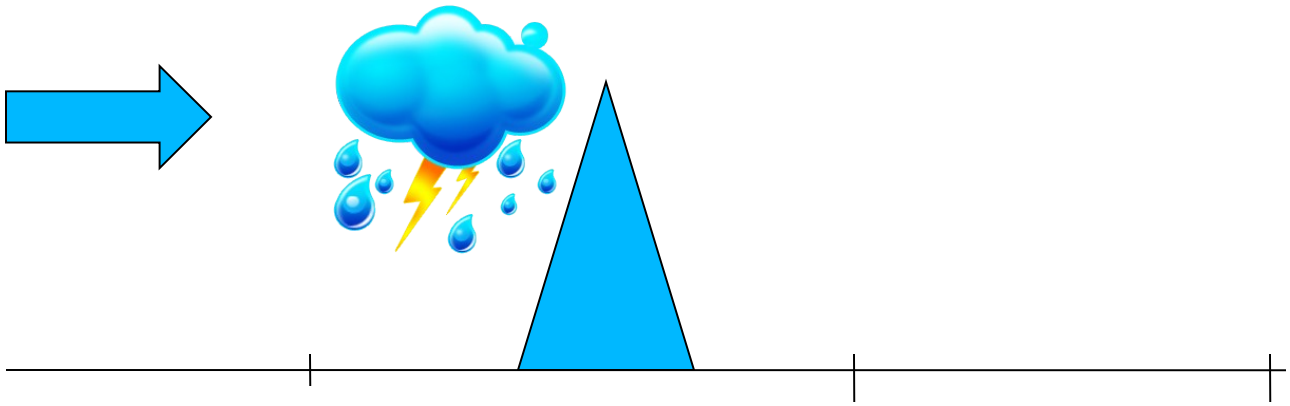
Andreas Sterl
KNMI

Definition

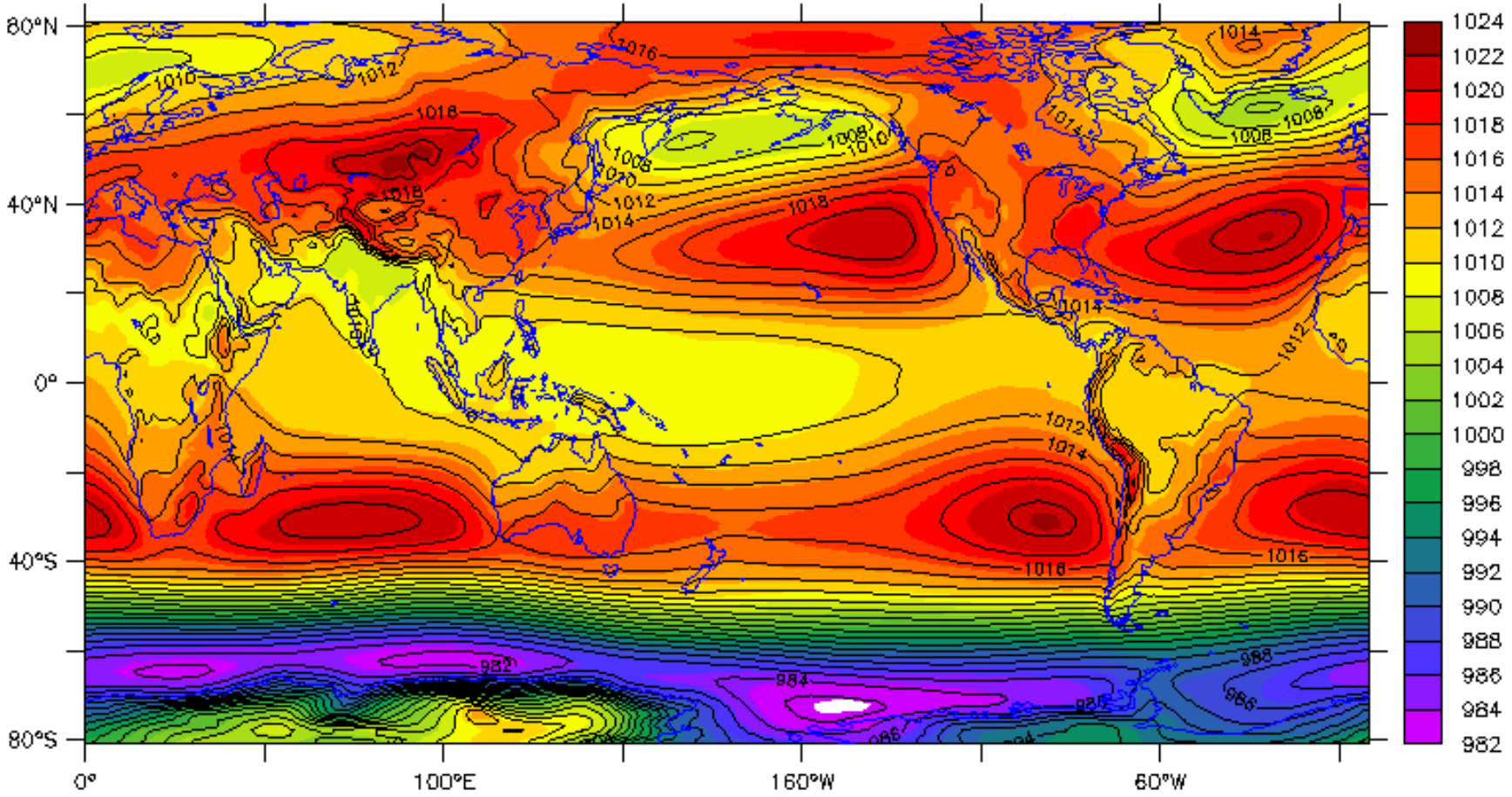
Infer information on small, non-resolved spatial scales from large-scale model output.

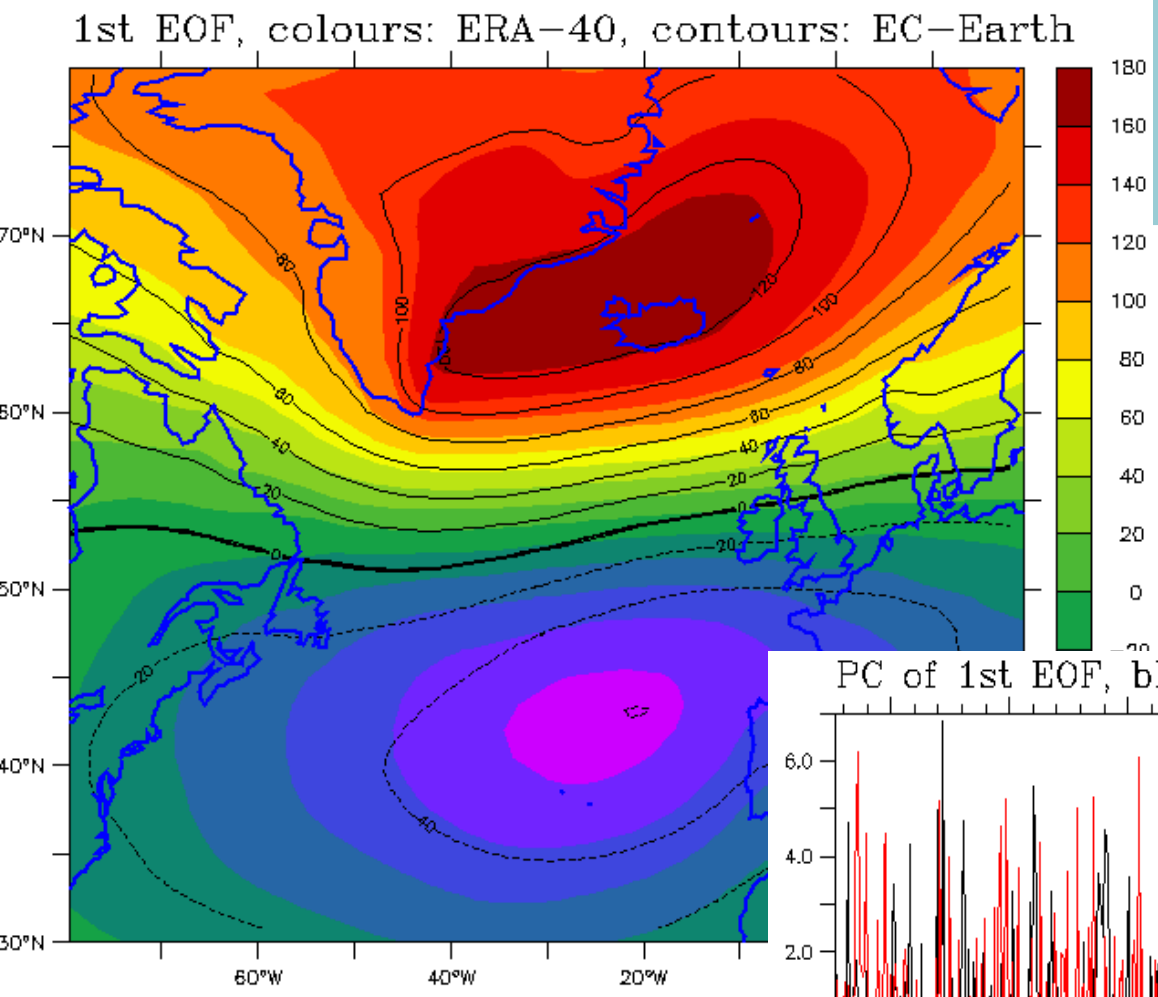
Example

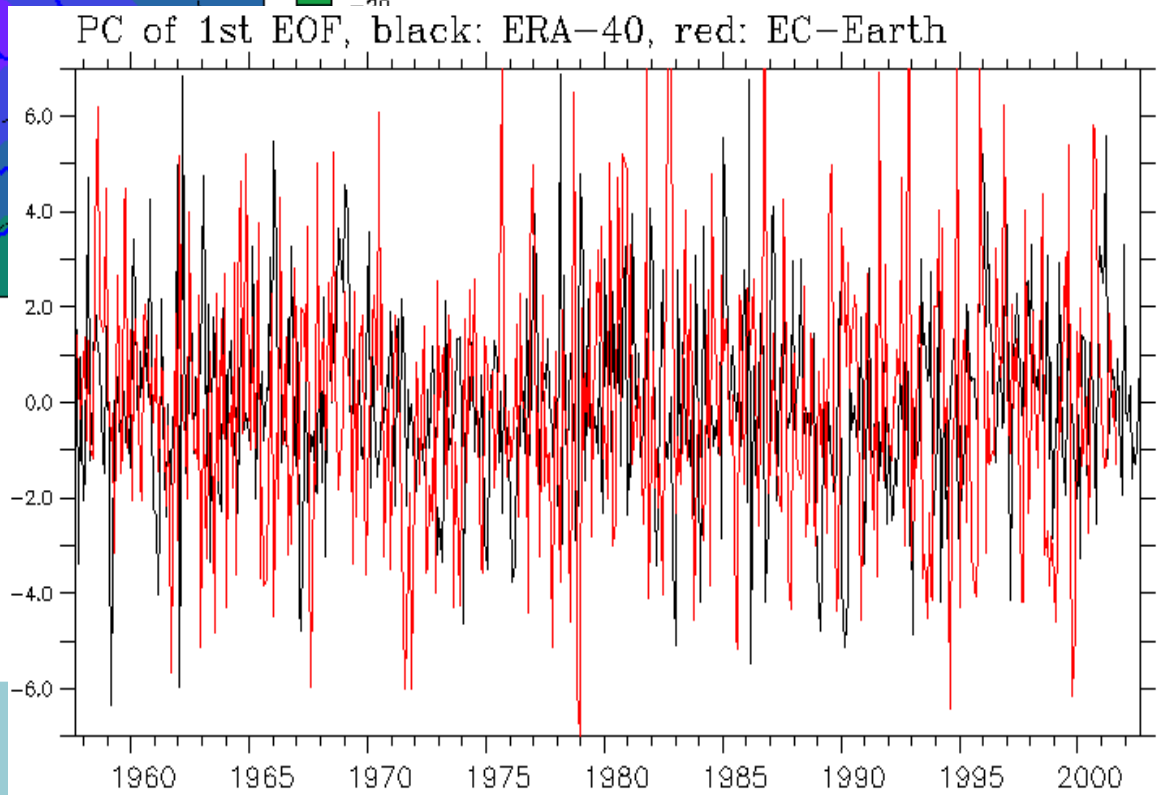
Rain in grid-cell with orography.



SLP from ERA40 (colour) and EC-Earth (contours)




1st EOF, colours: ERA−40, contours: EC−Earth
180
160
140
120
100
80
60
40
20
0
70°N
60°N
50°N
40°N
30°N
60°W
40°W
20°W

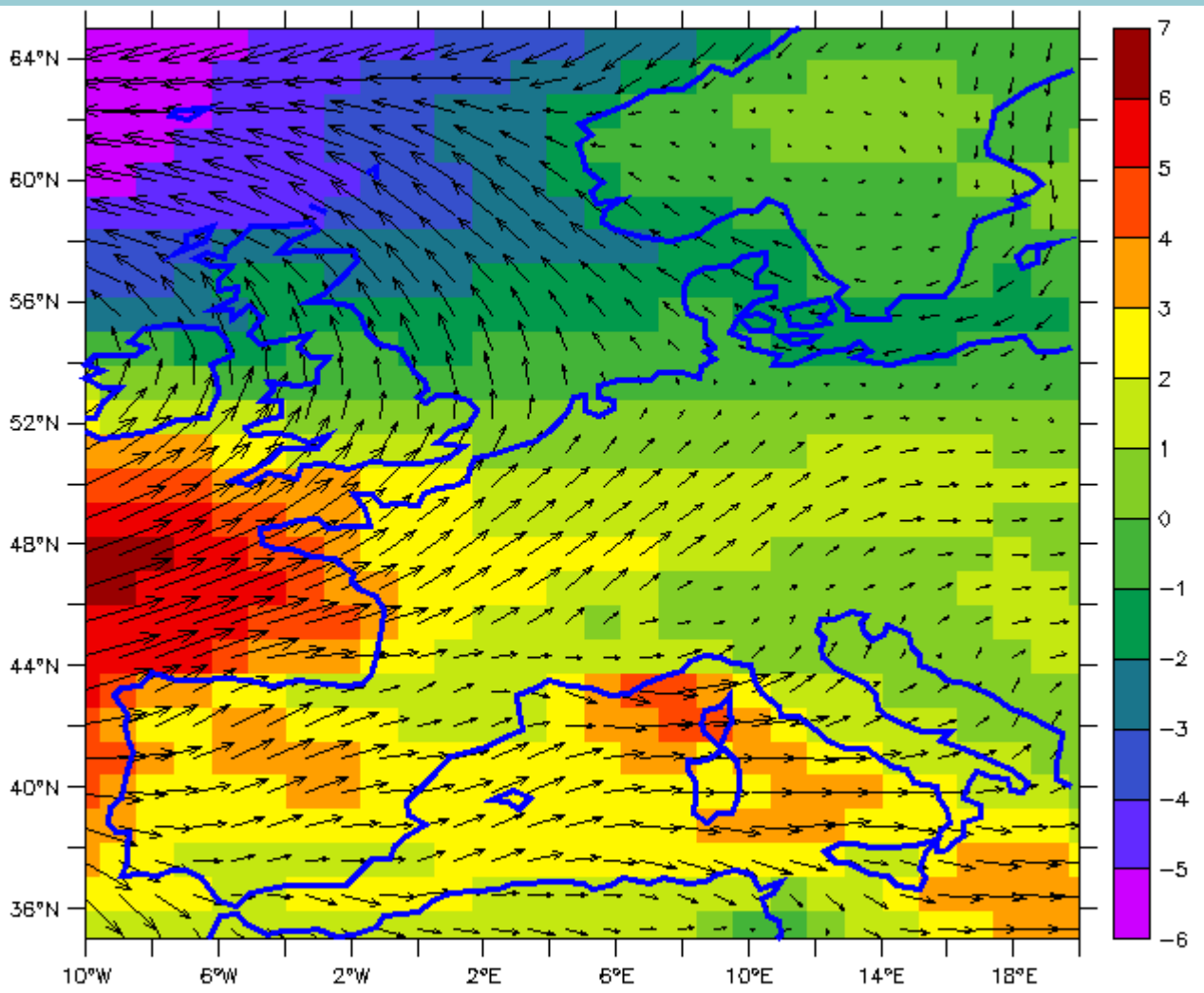

PC of 1st EOF, black: ERA−40, red: EC−Earth
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
1960
1965
1970
1975
1980
1985
1990
1995
2000

EC-Earth:

U10 (colour; grid-size)

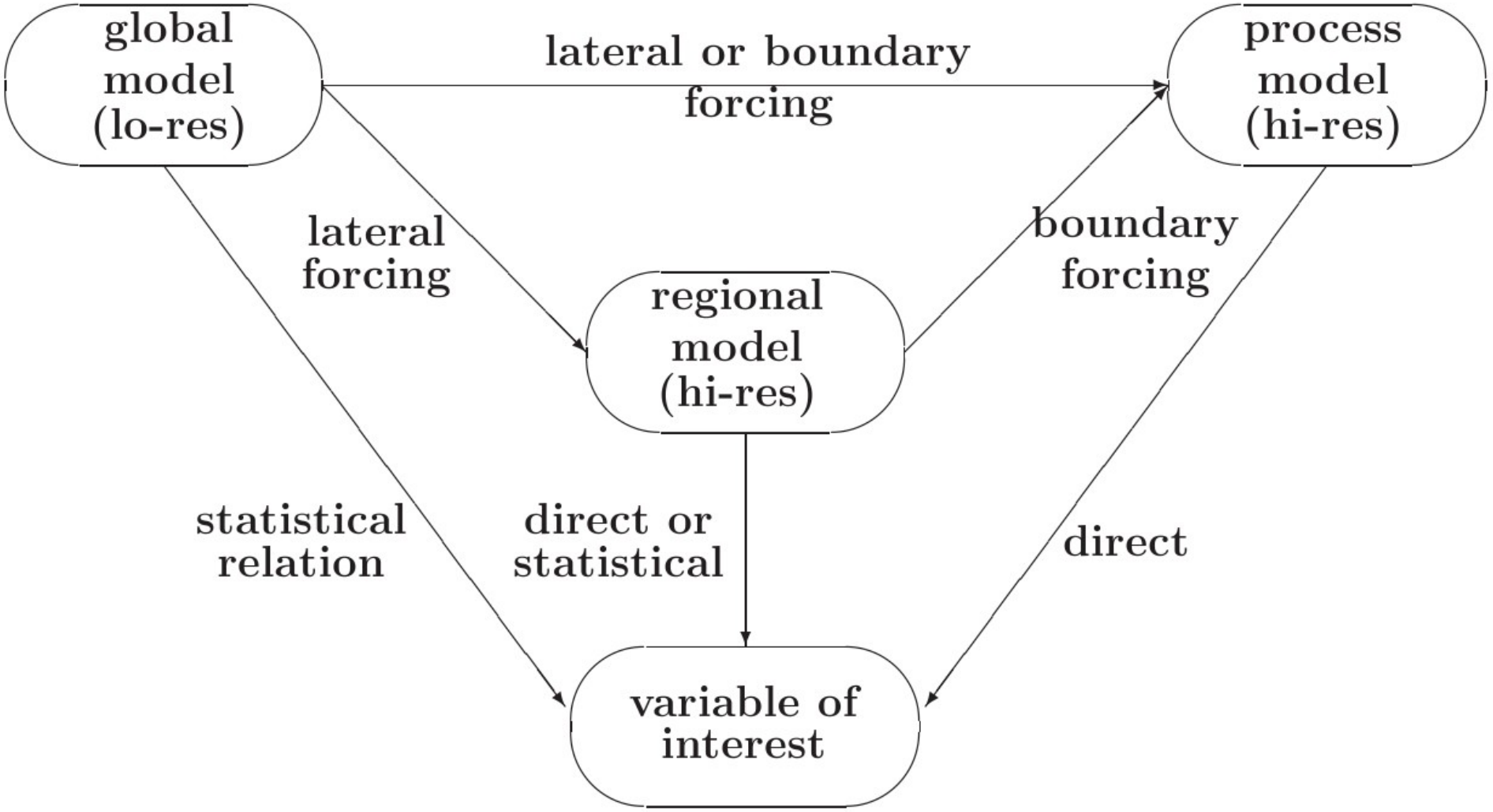
Wind (vectors)

One month



Three methods

- **Statistical** A statistical relation between large-scale and small-scale phenomena is derived and assumed to also hold in a changing climate.
- **Dynamic** Output from a coarse-resolution model is used to force a high-resolution model over a limited domain. Can be coupled (atm-oce) or uncoupled. Usually done off-line, no feedback from the high-resolution model to the large-scale.
- **Nested** A high-resolution limited-area model is nested into a coarse-resolution global model

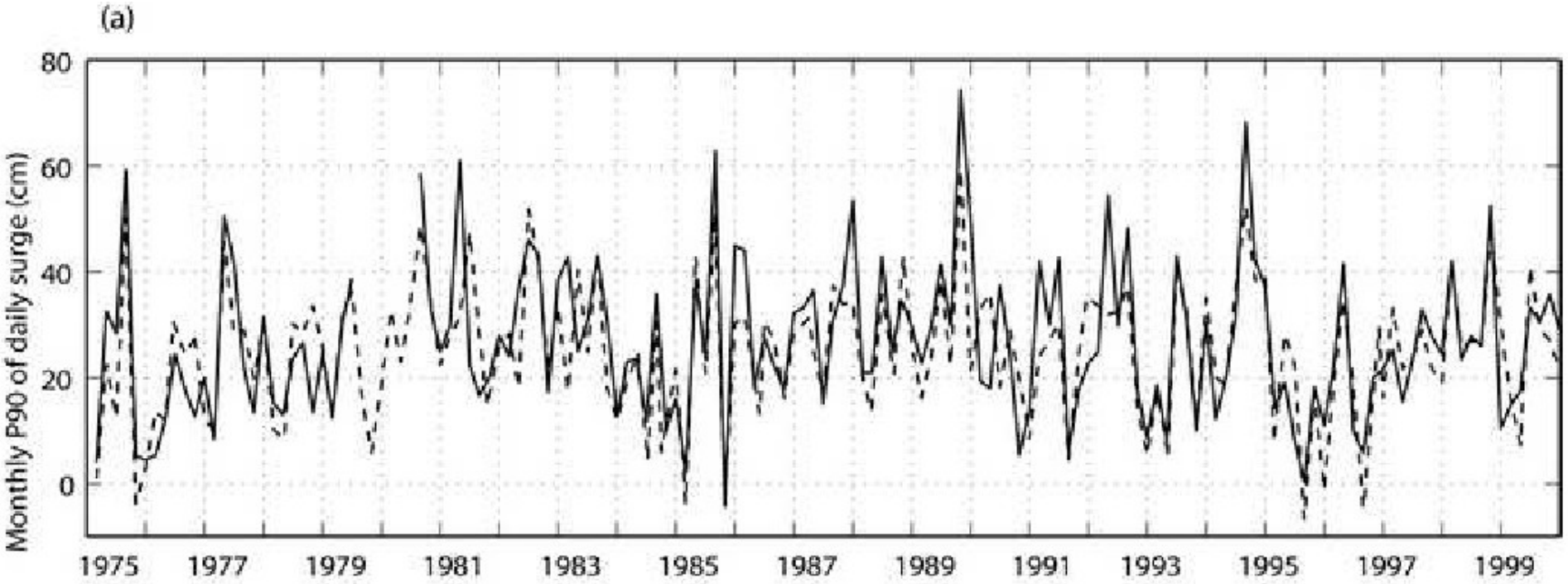

global model (lo-res)
lateral or boundary forcing
process model (hi-res)
lateral forcing
regional model (hi-res)
boundary forcing
statistical relation
direct or statistical
direct
variable of interest

Examples of “variable of interest”

- winds
- currents
- surges
- waves
- sediment transport
- ecosystem
- ...

Examples: Statistical Downscaling

- SLP - surge (Albin et al., 2009)
- Wind - surge (van den Brink et al., 2004)



90%-ile of surge in Oostende from observations (black) and reconstructed from SLP over Baltic Sea and pressure gradient between Baltic Sea and Azores (dashed)

(Albin et. al, submitted)

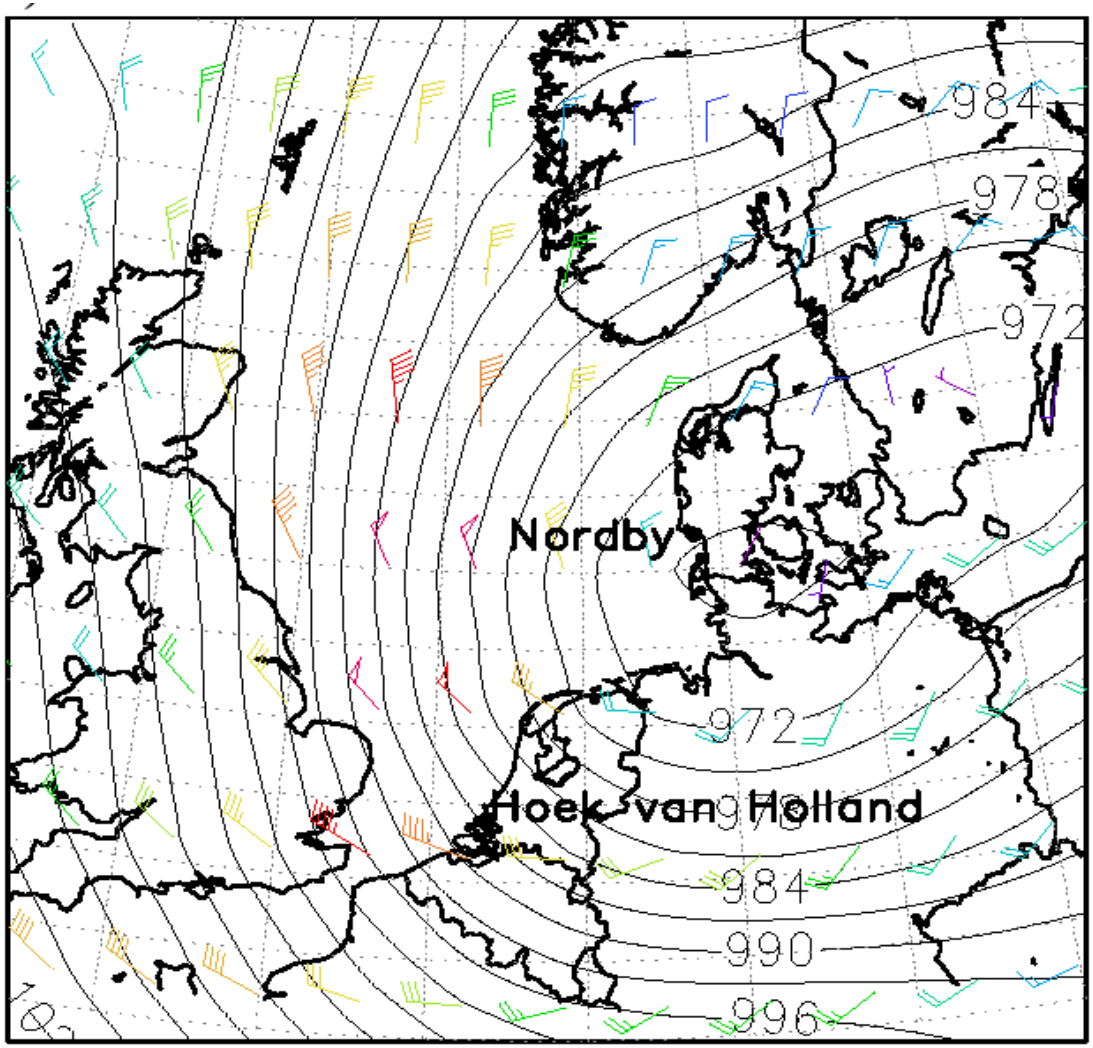
Surge in Hoek van Holland

Idea: surge results from integral of forcing over North Sea

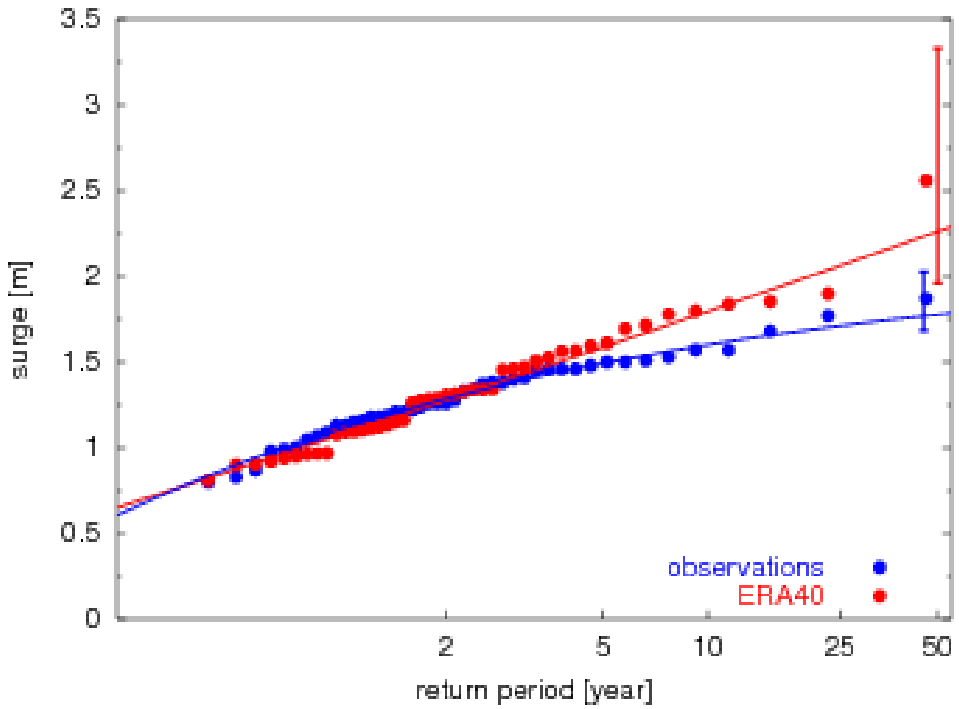
$$\text{Surge} = A\, C_d\, u_{10}^2\, \sin(\phi - \beta) + \frac{1015 - \text{SLP}}{100.5} \quad [\text{m}]$$

C_d: drag coefficient
u_{10}: 10-m wind speed in central North Sea (12 h ave)
Φ: wind direction
A, β: empirical constants

(Van den Brink et al. (2004), GRL 31, L17210)



(Sterl et al. (2009), Ocean Sci. 5, 369-378)



annual-maximum surges in HvH:
observed and according to simple formula and observed winds (ERA-40)

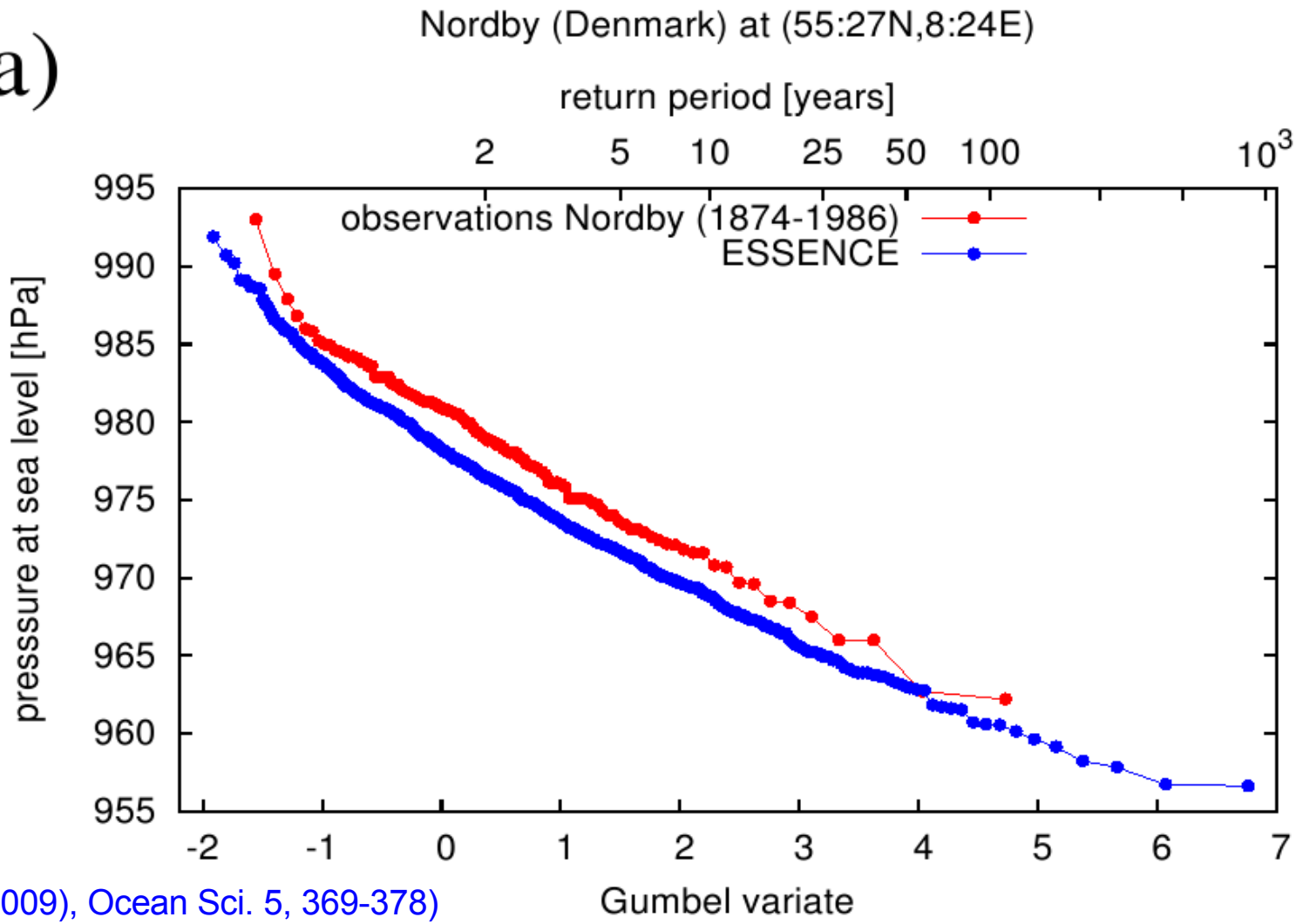
(Van den Brink et al. (2004), GRL 31, L17210)

Example: Process Model

ESSENCE – Dutch Delta Committee

- climate change runs with coarse resolution (≈ 2^{o})
- large-scale forcing enough for surges
- model is capable of producing very low pressure
- force a surge model directly with output from climate model

a)



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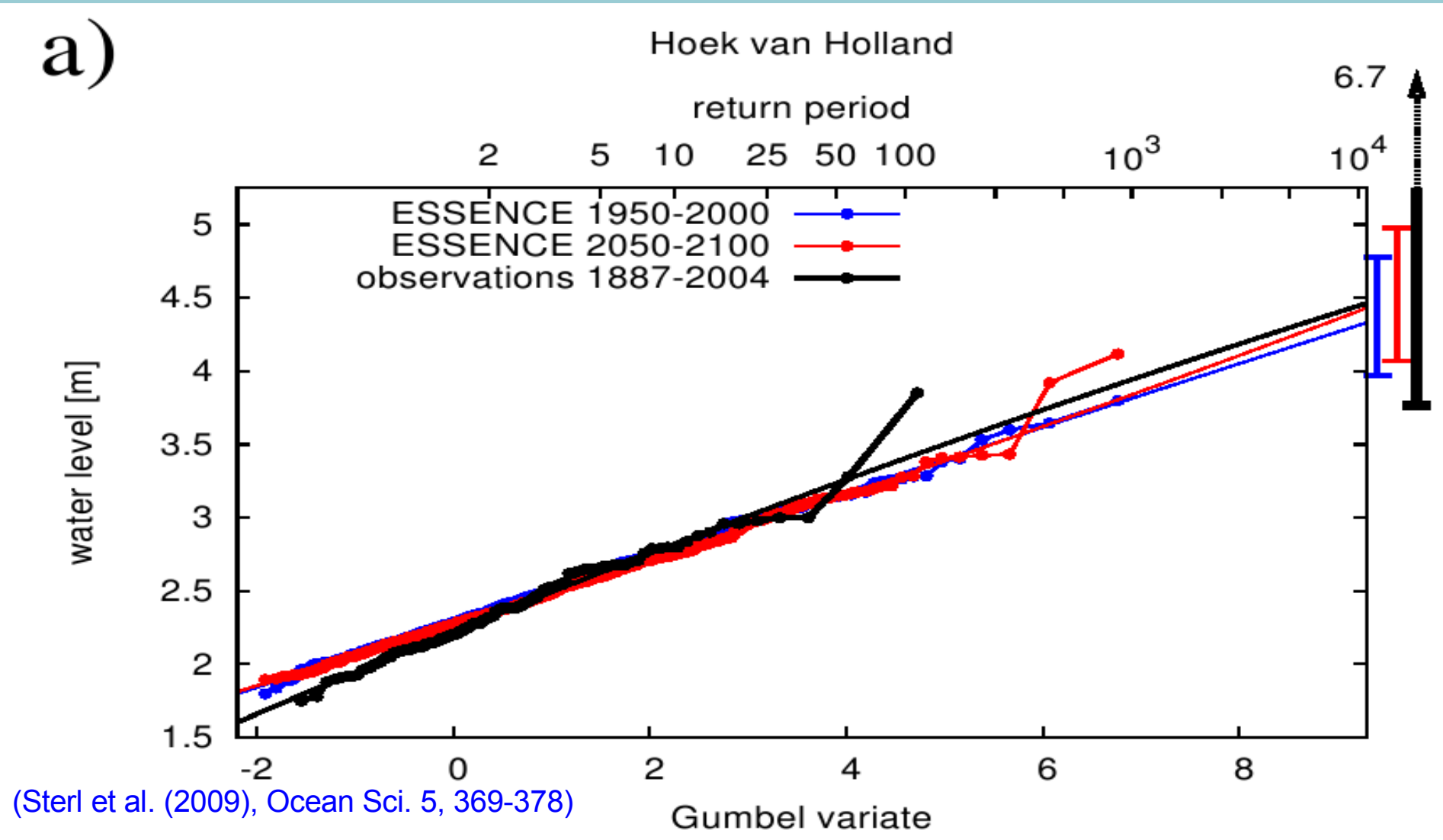
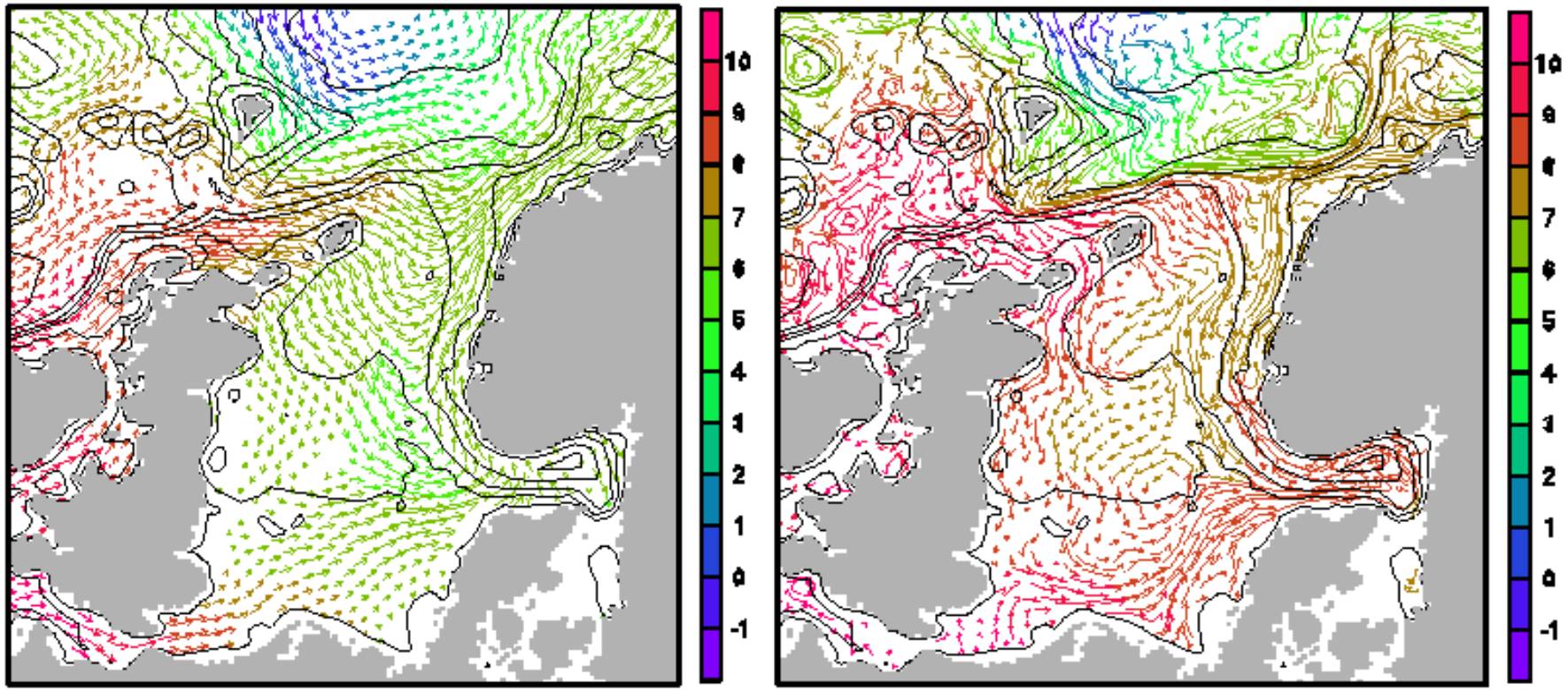


(Sterl et al. (2009), Ocean Sci. 5, 369-378)

Examples: Dynamical Downscaling

- Regional ocean model (Ådlandsvik & Bentsen, 2007)
  - **ROMS** (= Regional Ocean Modelling System):
    - ocean circulation model
    - driven at lateral boundaries by global model
    - can have extra processes
- combined atmosphere/wave downscaling + statistical downscaling (Breivik et al., 2009)



a BCM

b ROMS

Current fields at 25-m depth averaged over January 1979. a Interpolated from BCM, b downscaled by ROMS. Colours denote temperature.
6-10 km, 32 levels, timestep: 6 min/6 s

(Ådlandsvik, Bentsen, Ocean Dyn. 57 (2007), 453-466)

problems

lateral boundary - relaxation

surface forcing – from coarse model

Breivik et al. (2009):

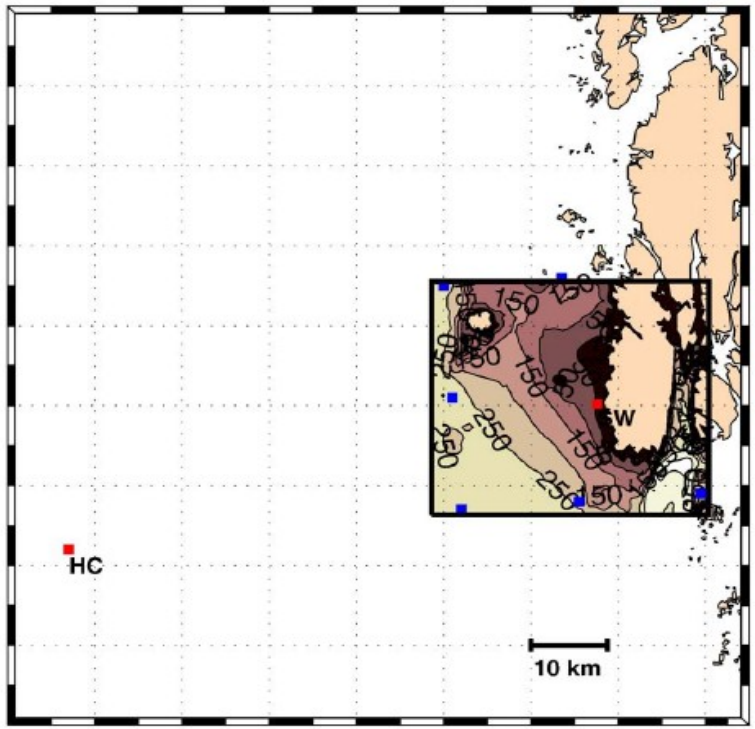
dynamical approach:

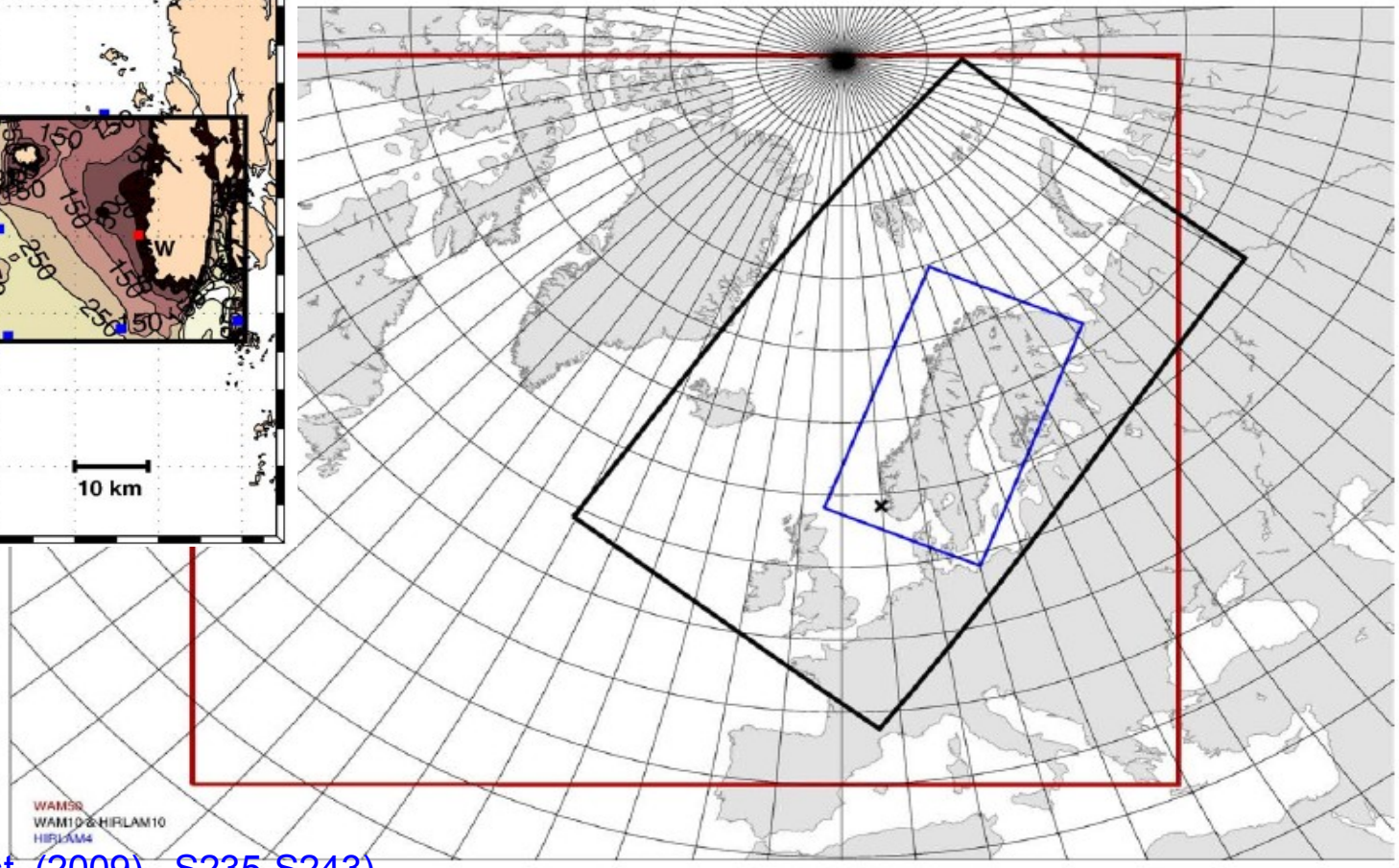
- drive SWAN at 500 m res. with WAM at 10 km resolution, driven with WAM at 50 km resol.
- forcing from HIRLAM at 4 (5) km resol., nested into HIRLAM at 10 km resol.

dynamical downscaling not feasible for more than 1 year or so

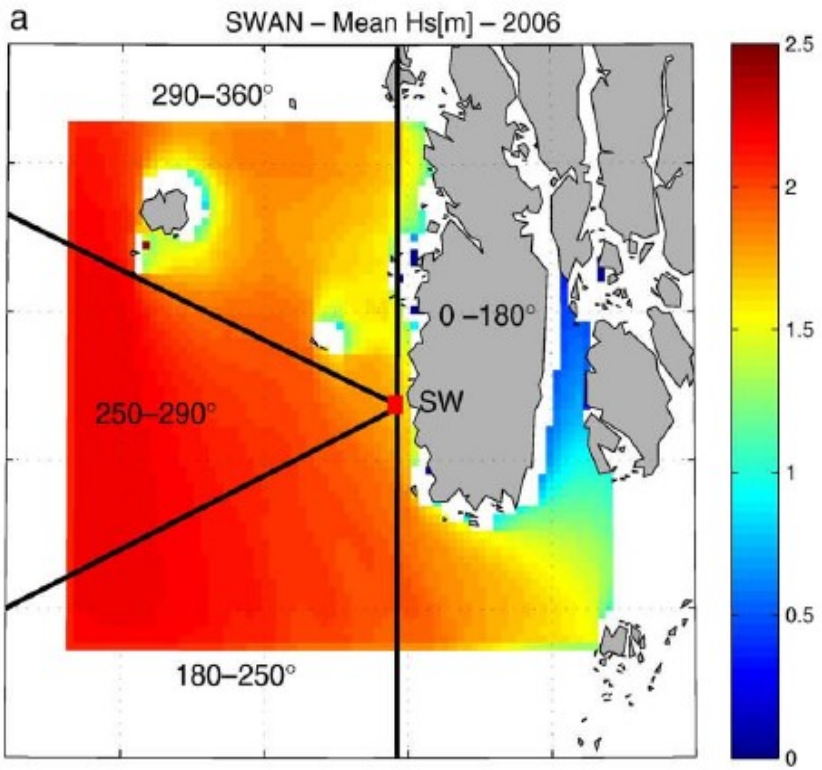
statistical approach:

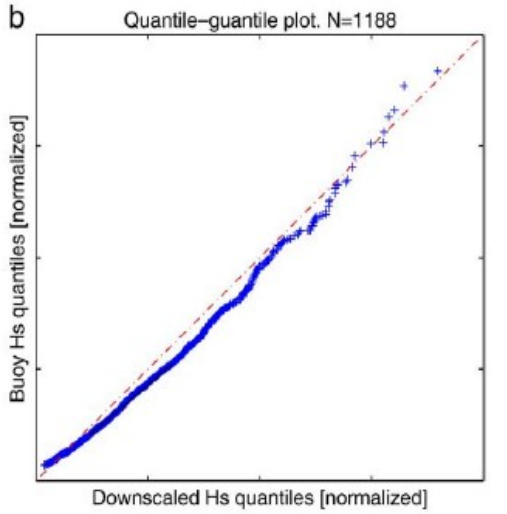
- derive linear relation between offshore hindcast from coarse model and near-shore SWAN result for four wave direction sectors
- validate against buoy measurement
- extend to full length of coarse resolution hindcast
- use as input to extreme-value analysis

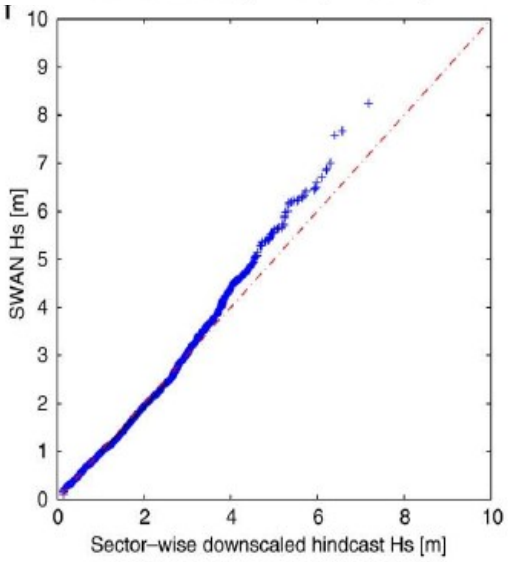




(Breivik et al., J. Mar. Syst. (2009), S235-S243)





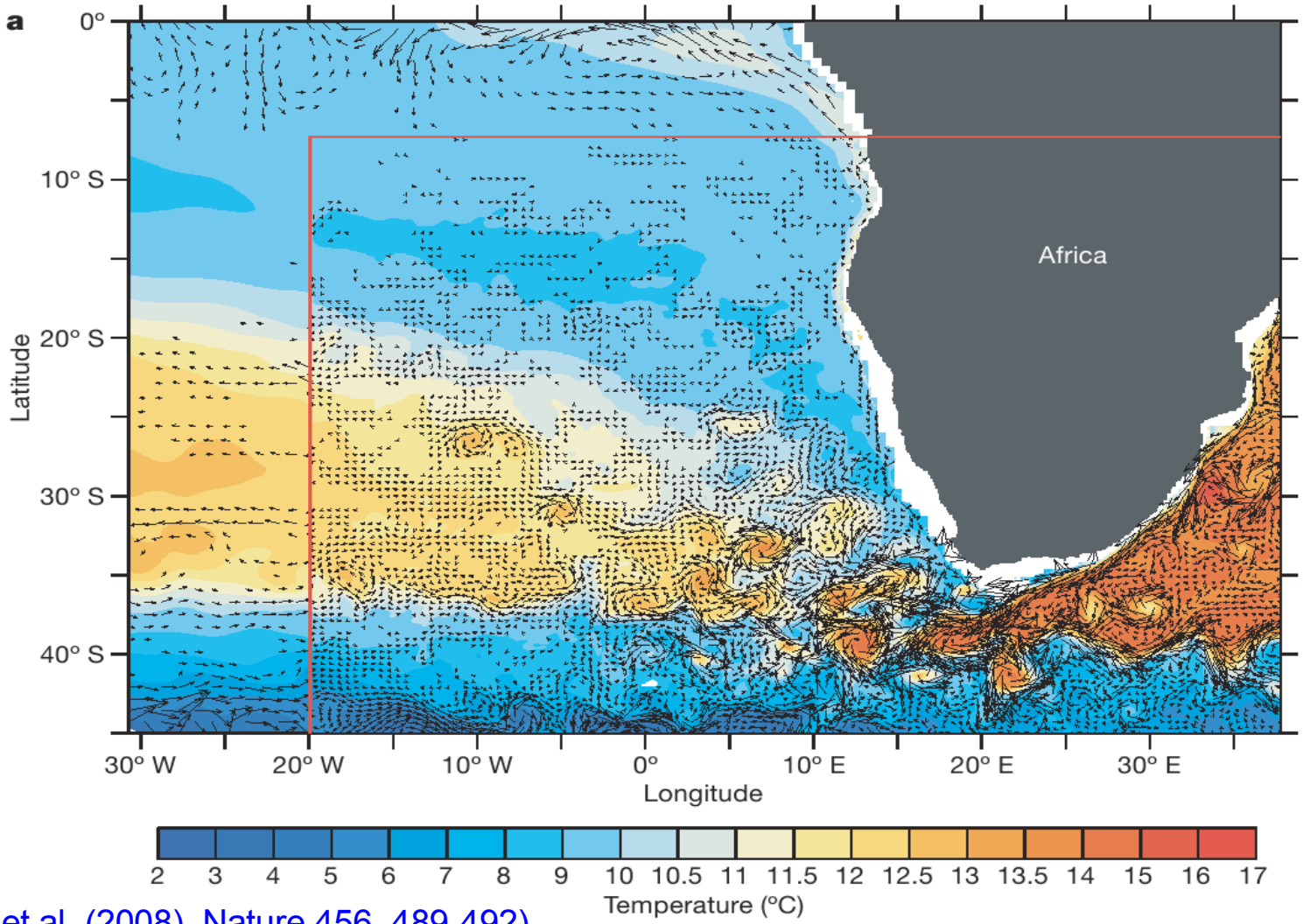


(Breivik et al., J. Mar. Syst. (2009), S235-S243)

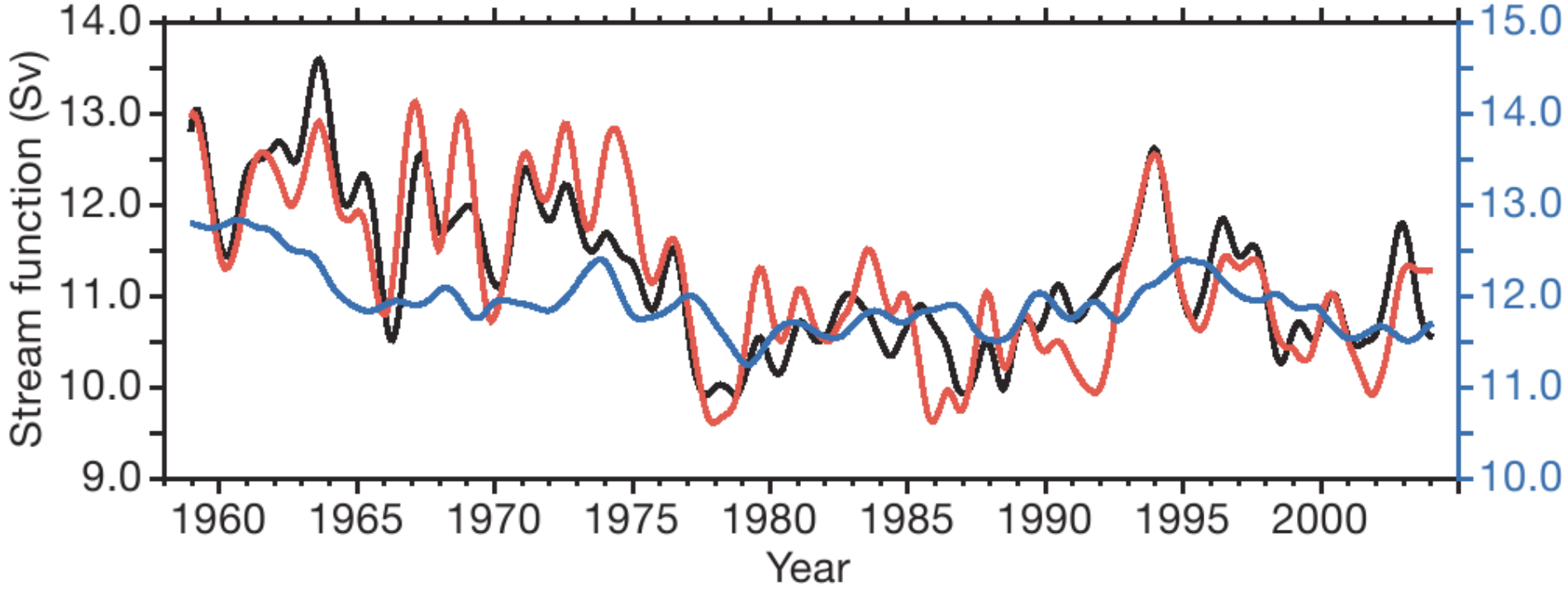
Example: Nested Model

Impact of Agulhas on Atlantic overturning (Biastoch et al., 2008)

- regionally increased (5-fold) resolution
- nested into global model
- two-way interaction (feedback)



(Biastoch et al. (2008), Nature 456, 489-492)



Atlantic MOC with/without nesting in Agulhas region.

(Biastoch et al. (2008), Nature 456, 489-492)

(Dis-)Advantages of methods - statistical

- there should be a physical and statistically significant relation between predictor and predictant
- predictor well-represented in coarse model
- needs long observational time series to calibrate model

- easy to apply
- systematic model error can be accounted for

- results only for one (or a few) points
- only one variable
- relation between predictor and predictant invariant
- extrapolation?
- no feedback

(Dis-)Advantages of methods - dynamical

- availability of boundary forcing

- independent of observational records
- results for whole area
- more than just one variable
- feedback possible (nesting)

- complex & time-consuming to apply
- outflow may not be compatible with boundary condition => careful choice of boundaries needed
- errors from global model may propagate into LAM-domain

Conclusions

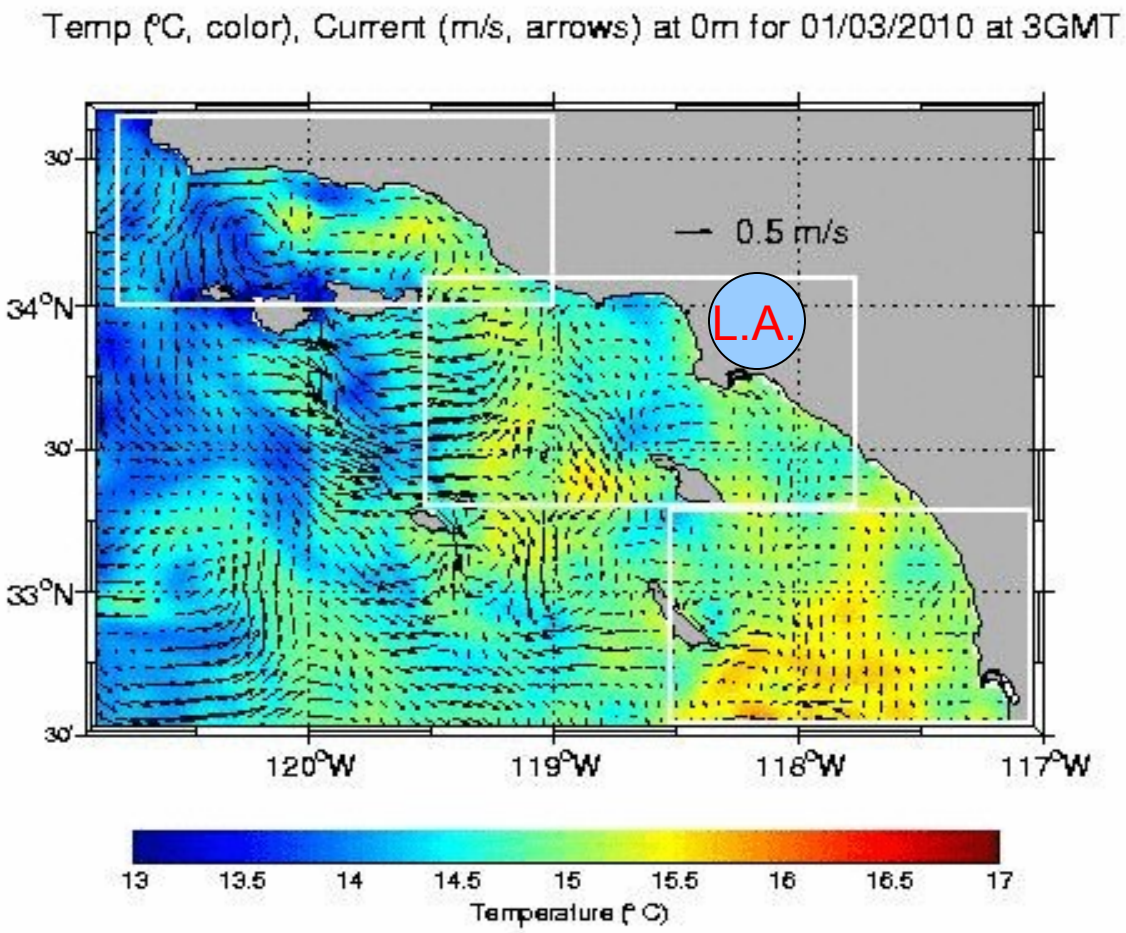
- **statistical *vs.* dynamical:** clearly define your needs
- **coarse model:** concentrate on variables well represented & physically relevant
- **hi-res model:** must be large enough for details of interest not being influenced by boundary
- **process models:** investigate whether downscaling is needed
- **dynamical model:** choose boundaries carefully

- **no downscaled variable can be "better" than large-scale input!**

1 km resolution

ROMS (= Regional Ocean Modelling System):

- ocean circulation model
- driven at lateral boundaries by global model
- can have extra processes



(http://ourocean.jpl.nasa.gov/)