A coupled wave-atmosphere RCM (RCA-WAM)

Anna Rutgersson
Alvaro Semedo
Björn Carlsson
Uppsala University

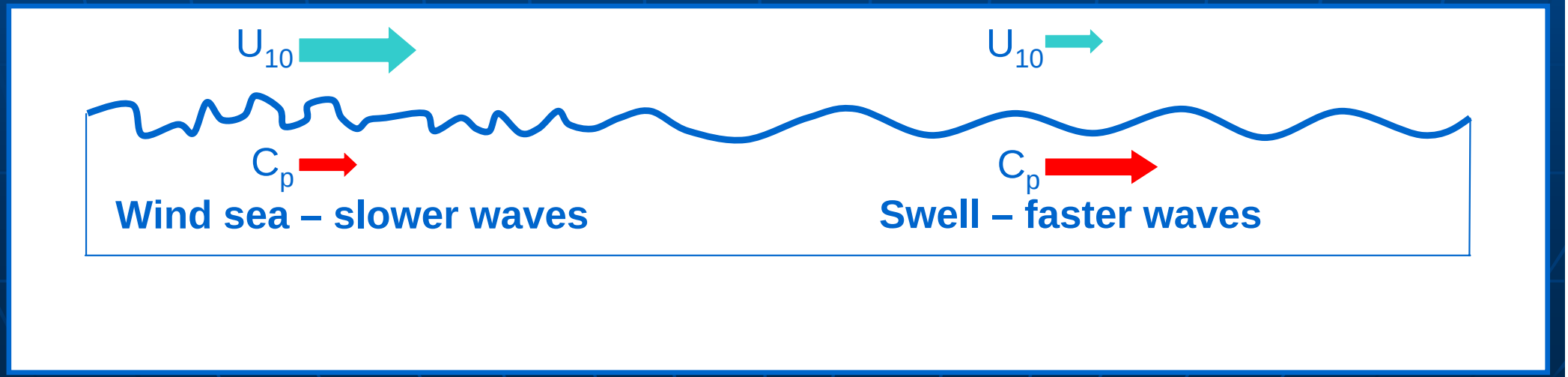
Ralf Döscher
Anders Ullerstig
Barry Broman
SMHI

Why introduce a wave model?

- We are interested in the waves.
  - Improved forecast/description of the waves.
- Waves influence the atmosphere and thus the RCM simulation.
  - Improved description of the atmosphere as well as air-sea exchange.

Two very different wave regimes:

- Growing waves (rough sea, slower waves).
- Decaying waves (swell, faster waves).



These situations influences the atmosphere differently

Growing waves, two-way coupling:

- Evolution of synoptic scale systems.
  - Improved forecast scores in the ECMWF-system (Jansen et al)
  - Improvement using a coupled system is larger for the waves than for the atmospheric parameters.
- Evolution of Polar lows:
  - More intense polar lows
  - Improved mean sea level pressure when including the wave model.
- Sea state dependent heat and humidity fluxes (scalars?).

ECMWF scores, atmosphere

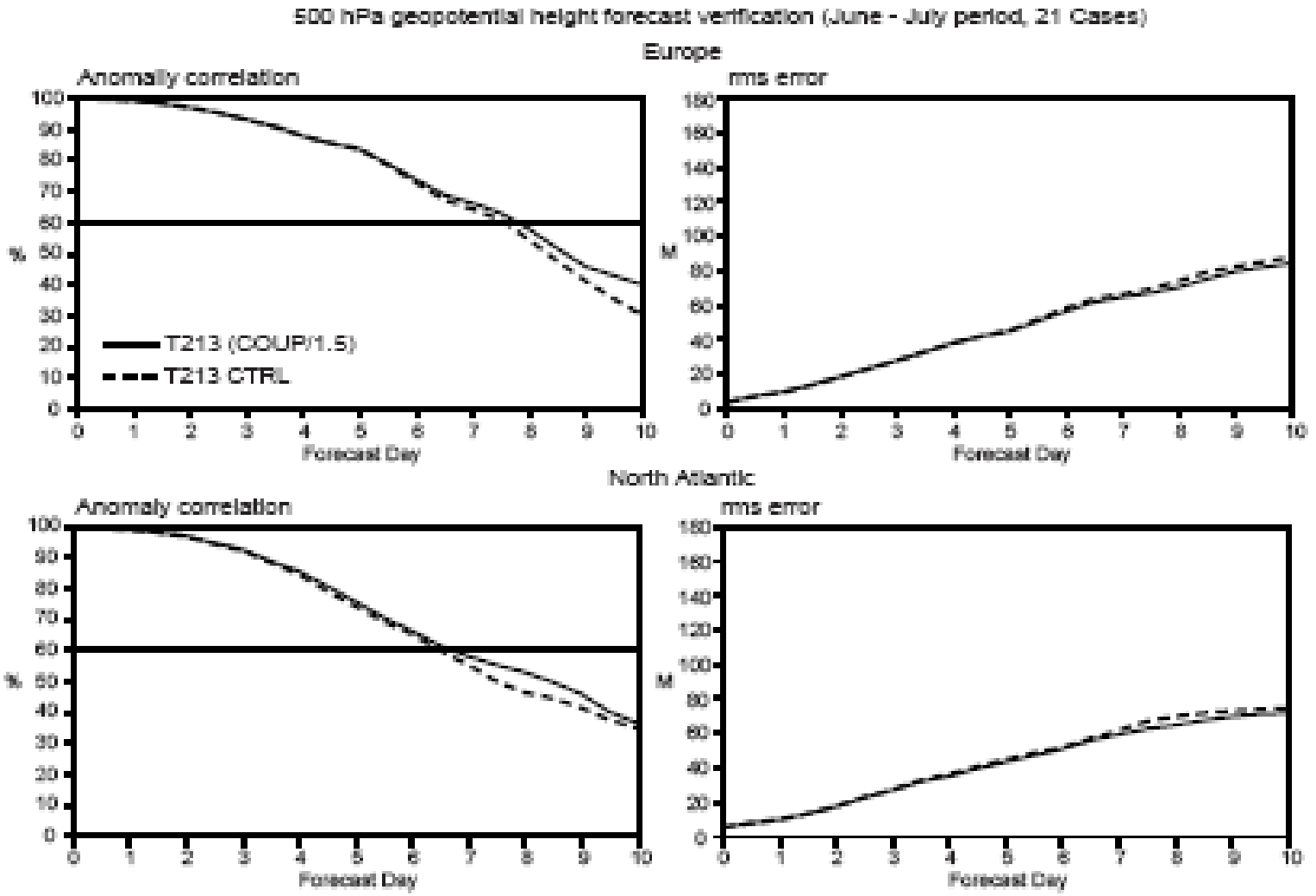


Figure 14: Scores of 500 mb height field for Europe and North Atlantic for the full June-July 1996 period.

From Jansen et al (2001)

ECMWF scores, waves

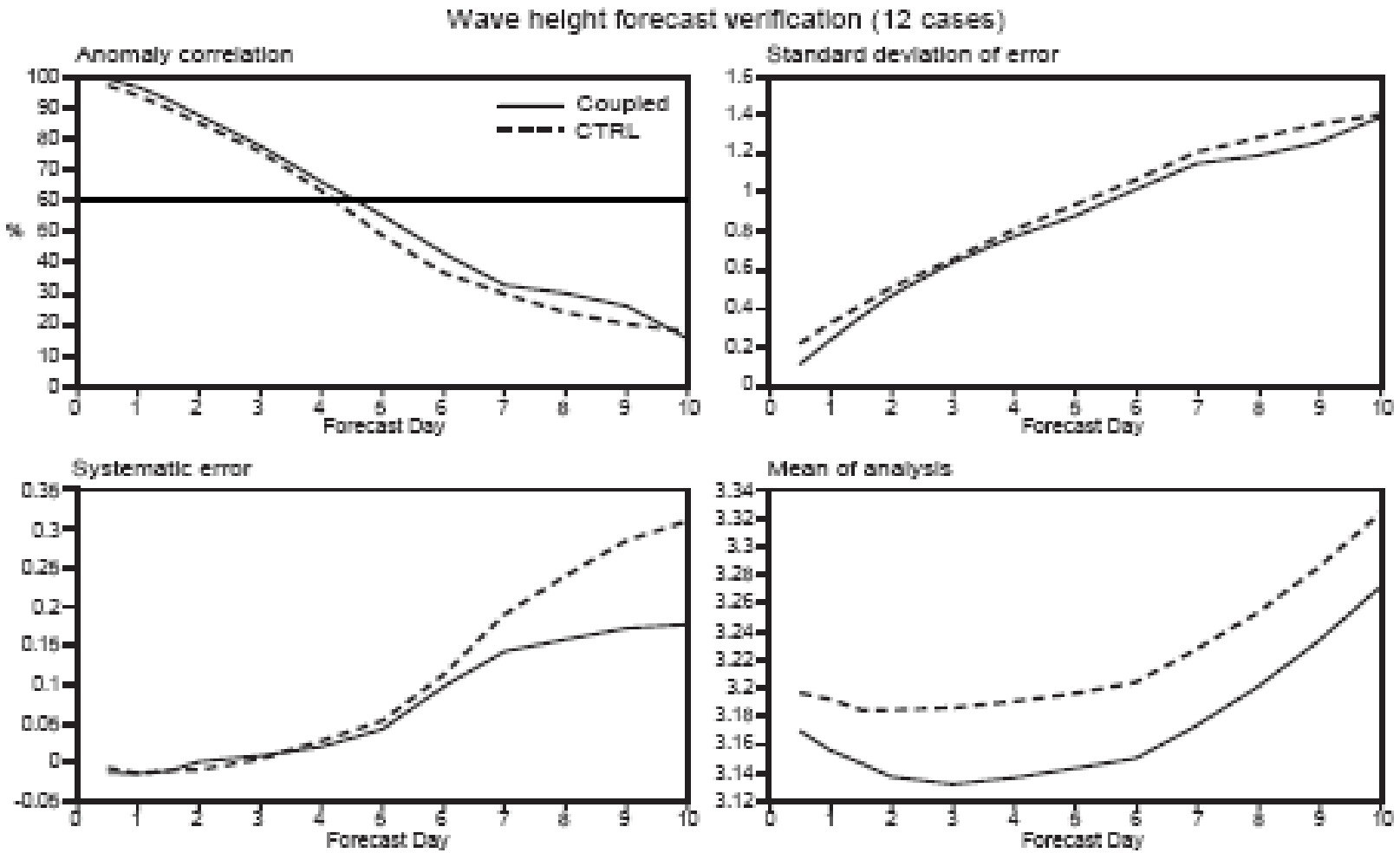
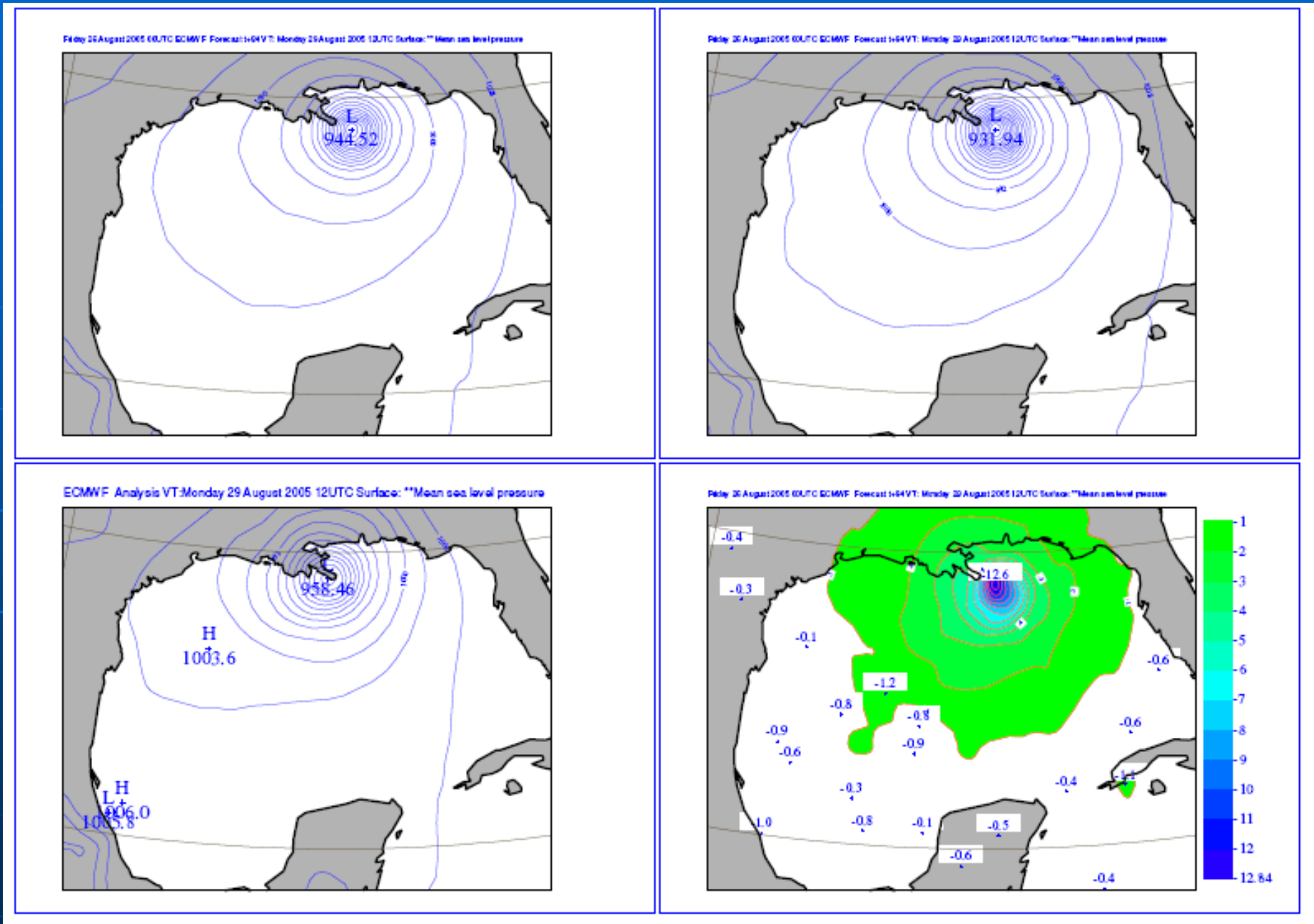


Figure 13: Wave height scores for June-July 1996 period in the Southern Hemisphere. Verification is against own analysis.

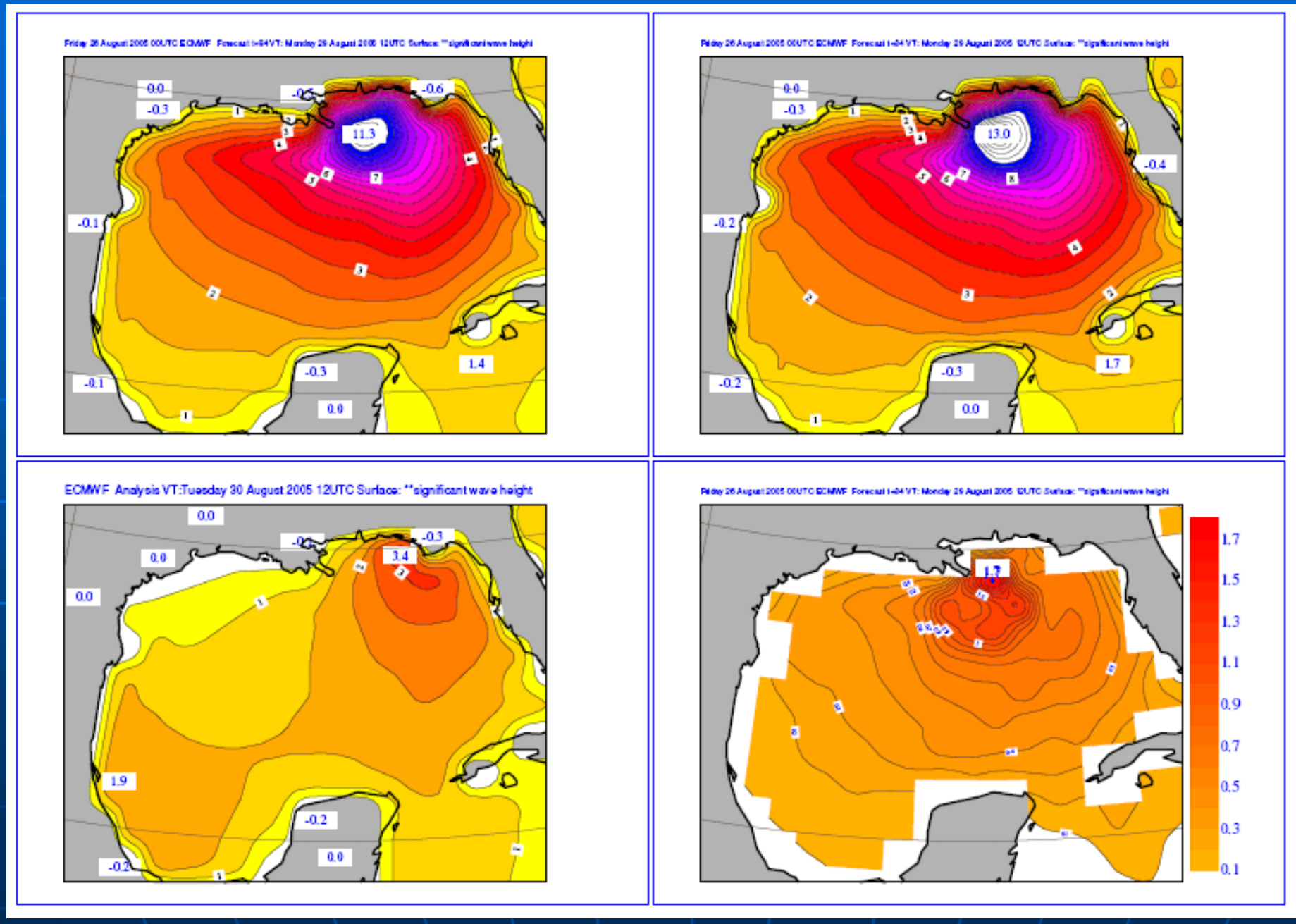
From Jansen et al (2001)

Evolution of a hurricane, ECMWF



From Jansen et al (2007)

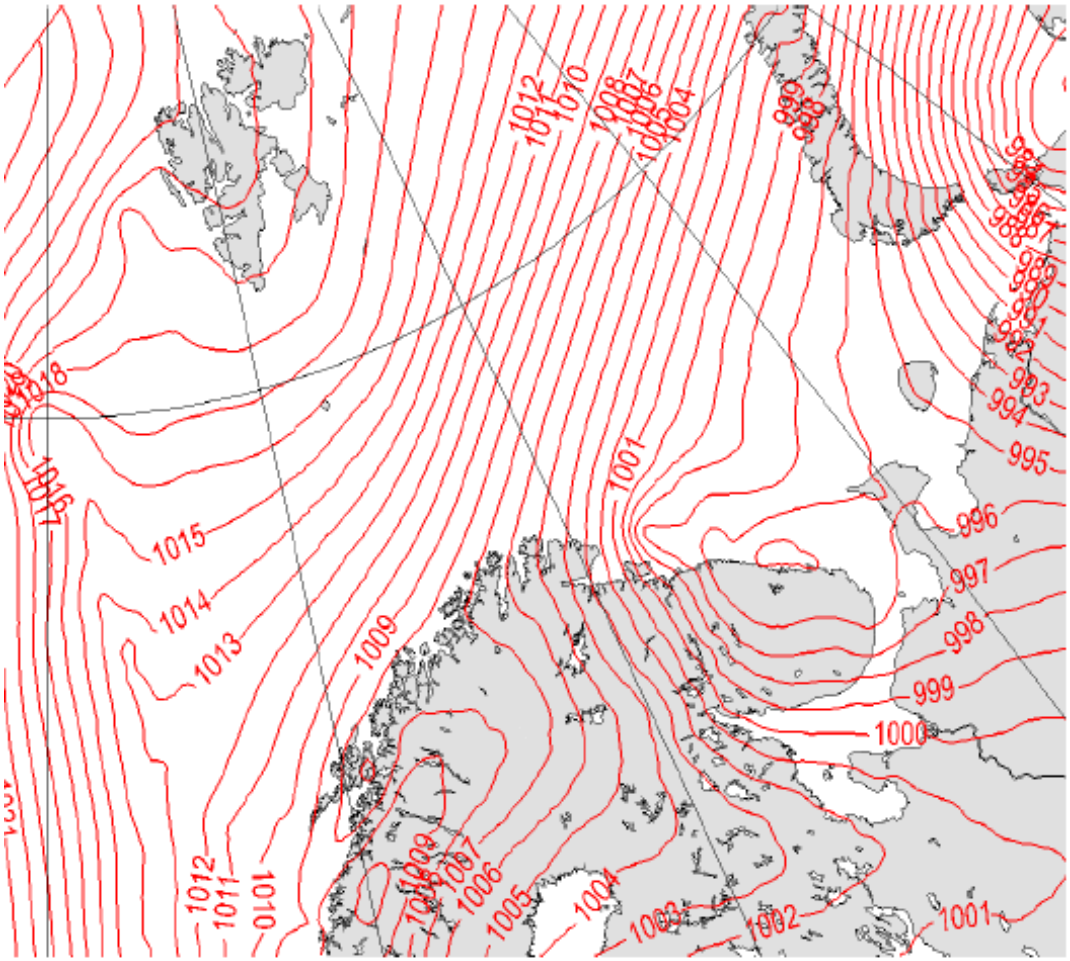
Evolution of a hurricane, ECMWF



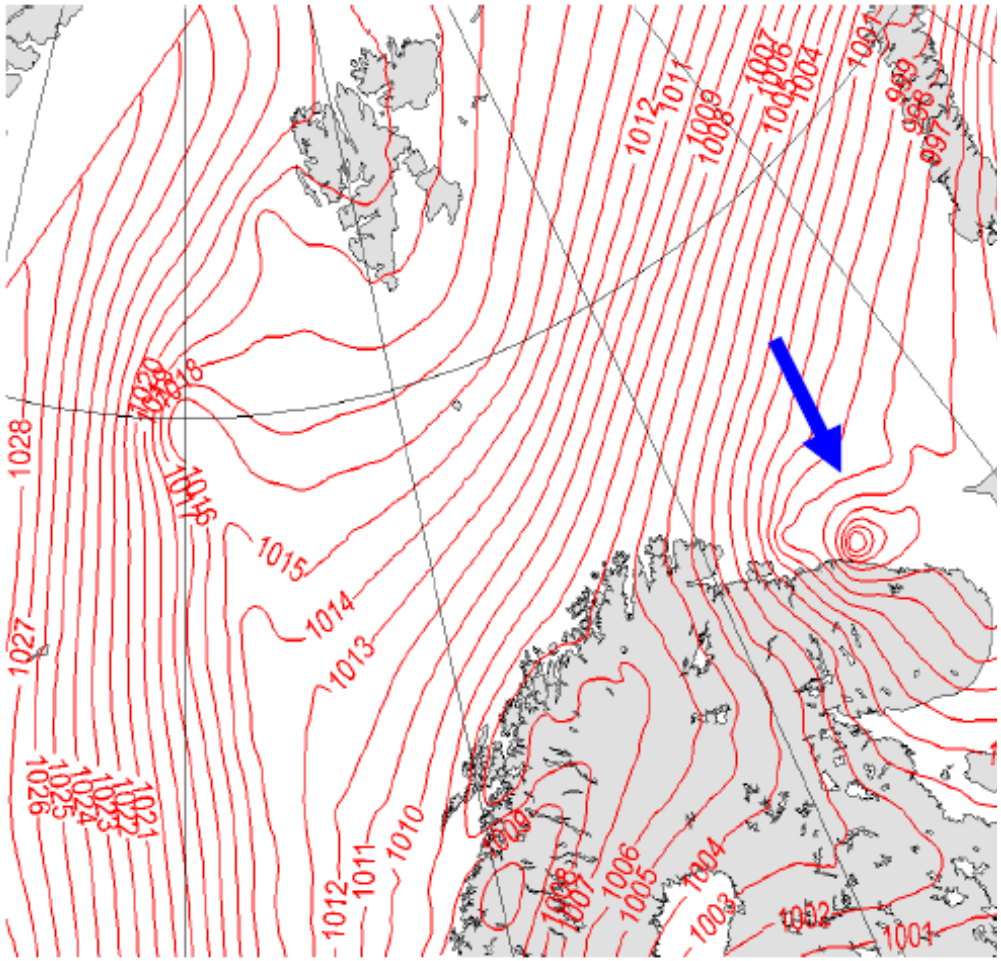
From Jansen et al (2007)

Polar lows

Uncoupled



Coupled



From Kolzow and Saetre (2007)

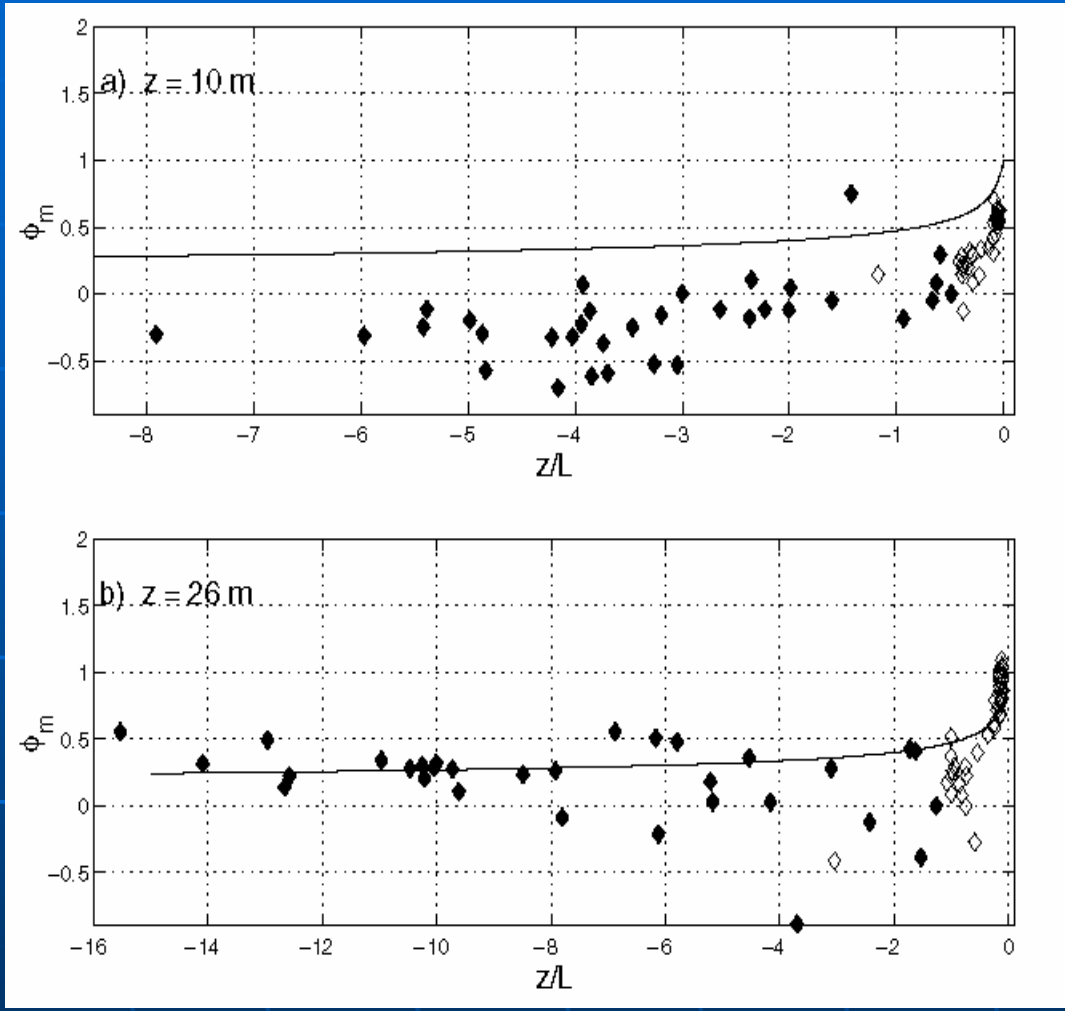
Important

- Impact of waves (improvement when including the waves). Larger the higher resolution we have. Of special interest for higher resulution RCM.
- Impact on extreme events significant – impact of overall scores limited.

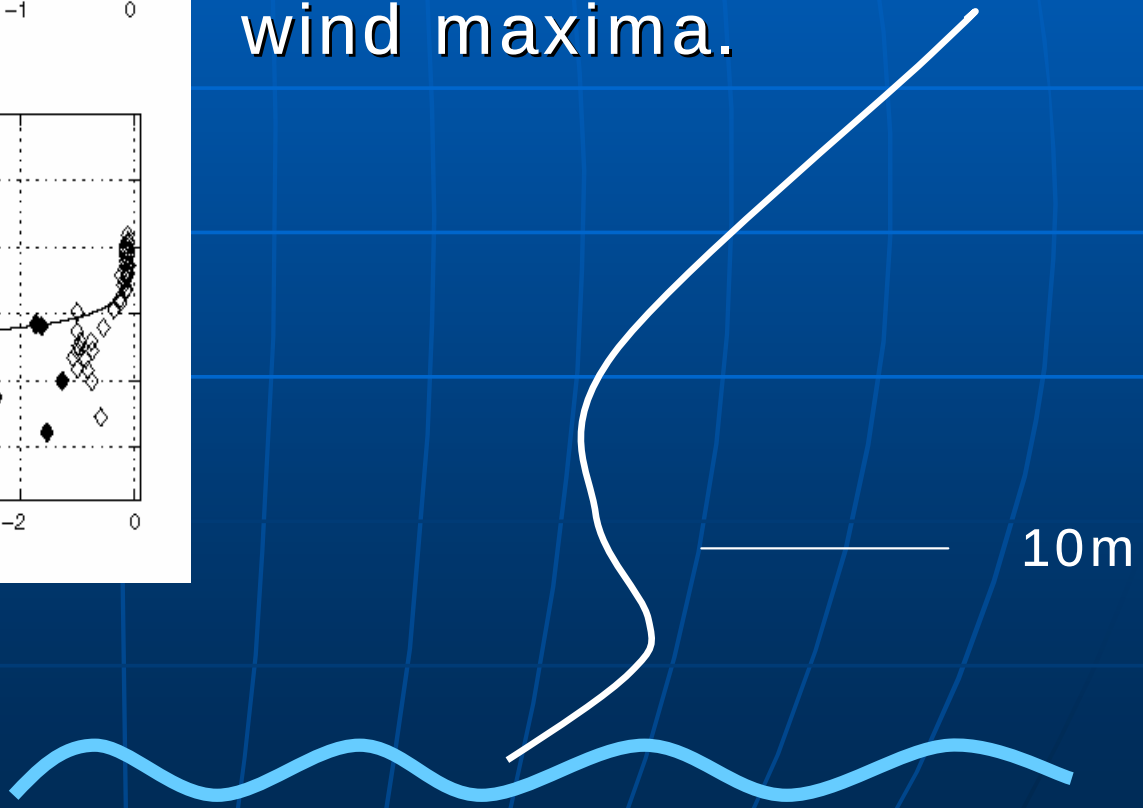
Swell waves new effects:

- Decaying waves (swell, faster waves). Strongly influences the atmosphere.
  - Lower drag – less mixing.
  - Wind gradient changed.
  - Structure of turbulence changed.
- IPCC indicates that swell waves increases in a changes climate.

Non-dimensional wind gradient

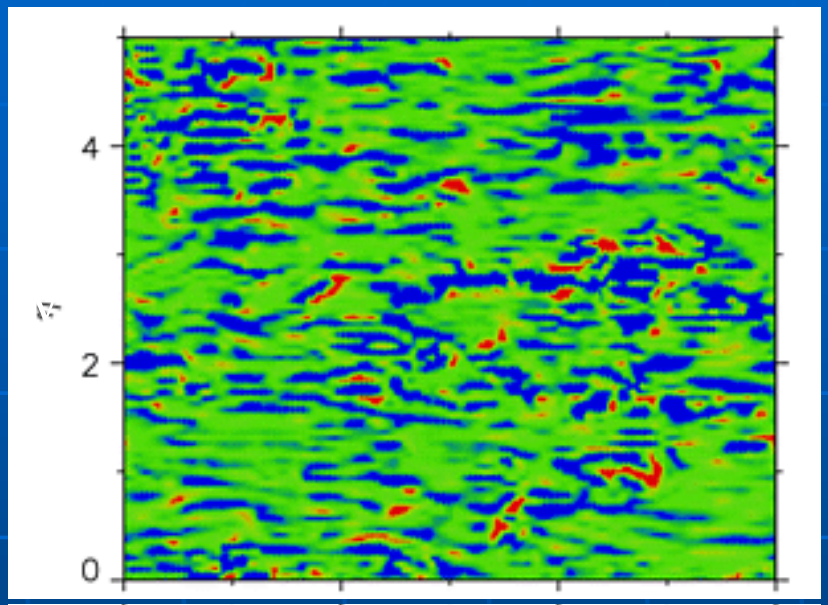


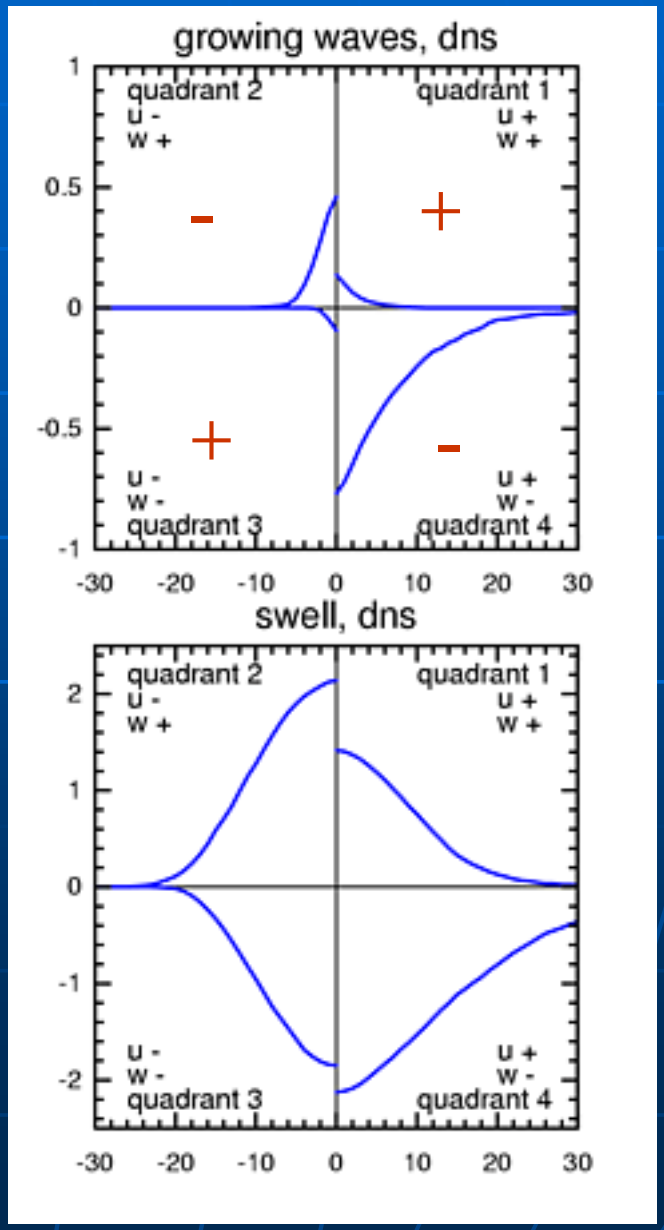
Negative wind gradient at 10 m indicate a low level wind maxima.



$$\phi_m\left(\frac{z}{L}\right) = \frac{\partial U}{\partial z}\frac{kz}{u_*}$$

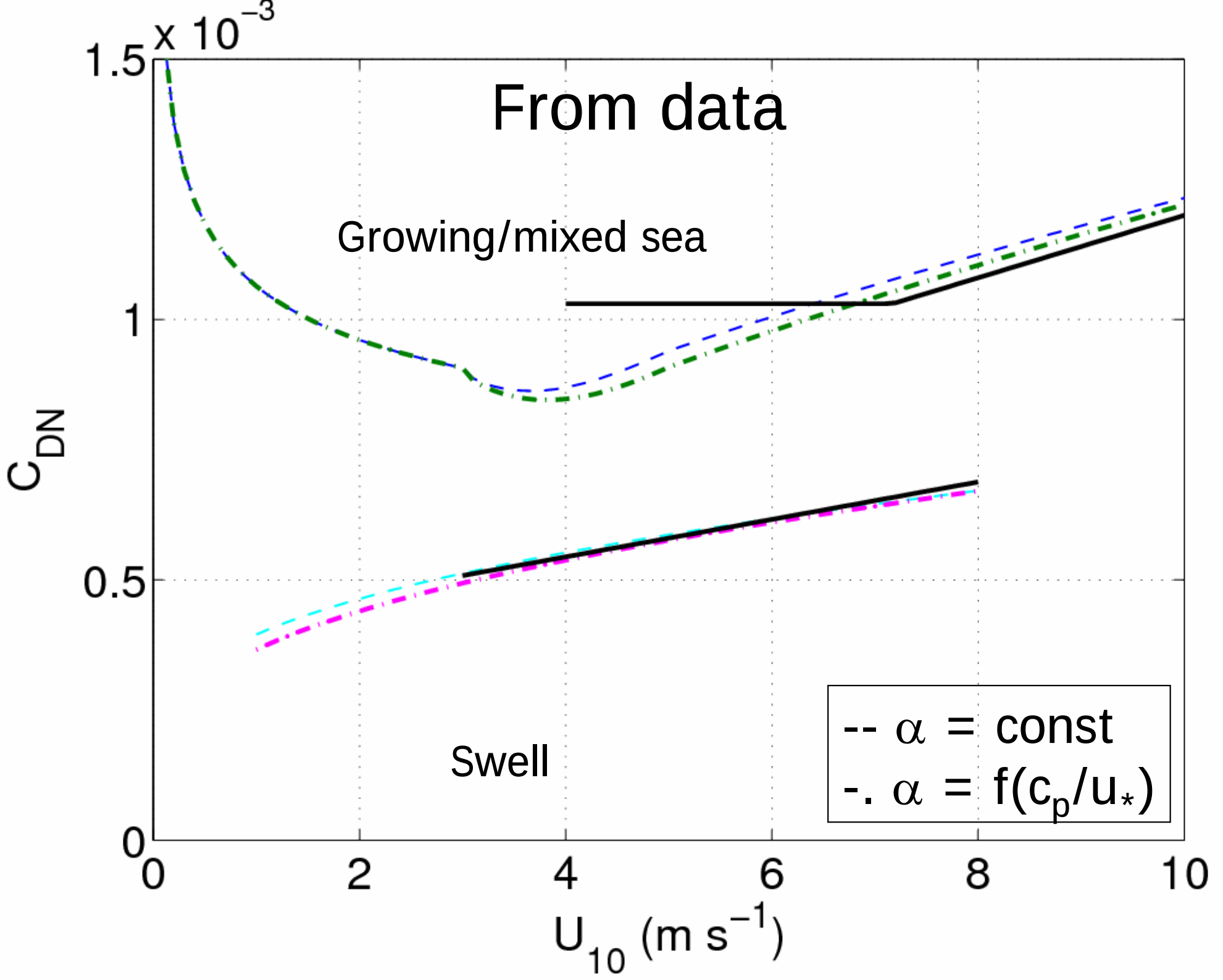
Momentum flux near lower boundary, $u'w'/u_*^2$



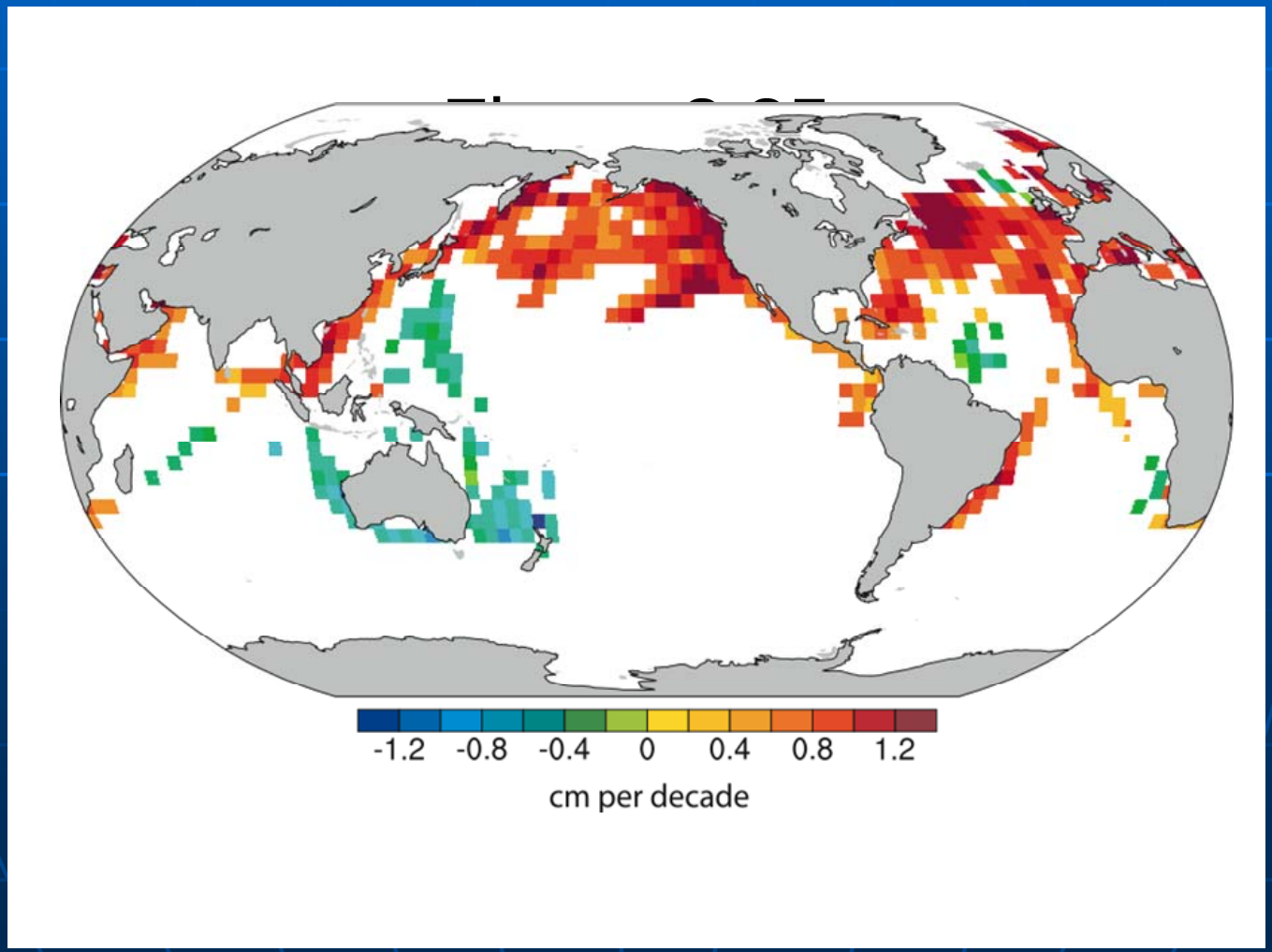


growing waves

old waves


From data
Growing/mixed sea
Swell
x 10^-3
1.5
1
0.5
0
0
2
4
6
8
10
C_DN
U_10 (m s^-1)
-- α = const
-. α = f(c_p/u_*)

Increase in swell waves since 1950:



WAM – a wave spectral model

- The sea state is described by a 2D wave energy spectrum (*25 frequencies vs 24 direction bins*) by solving the **spectral energy-balance equation**:

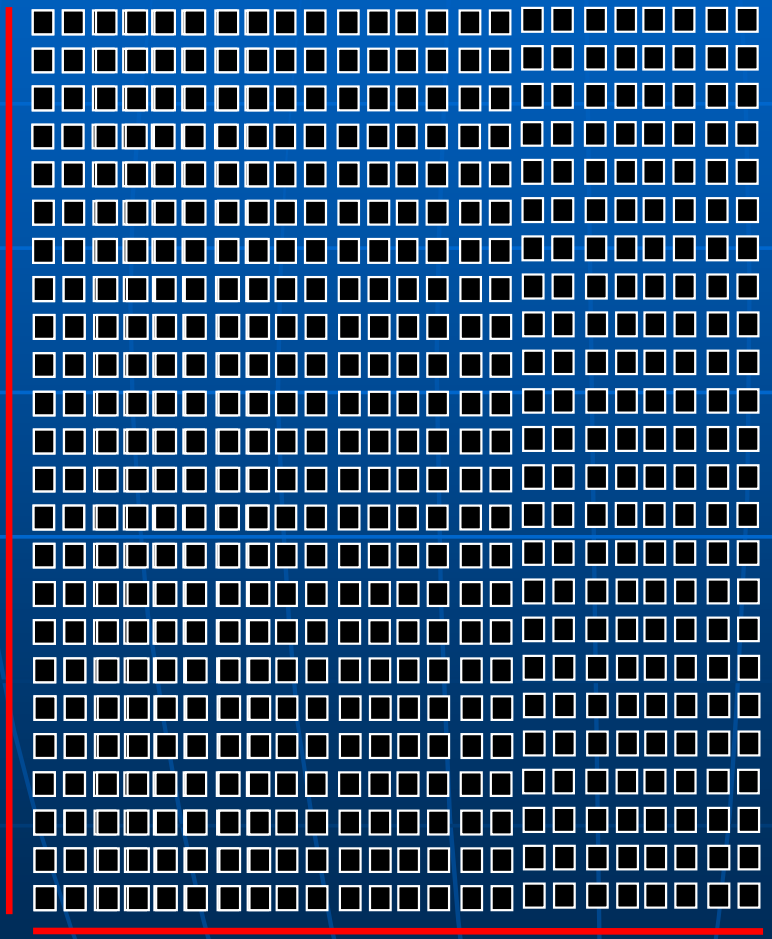
$$F(f,\theta,\varphi,\lambda) = S_{in} + S_{nl} + S_d$$

- First order up wind finite difference scheme
- Global or regional
- Forced by 10 m wind field
- Deep or shallow waters

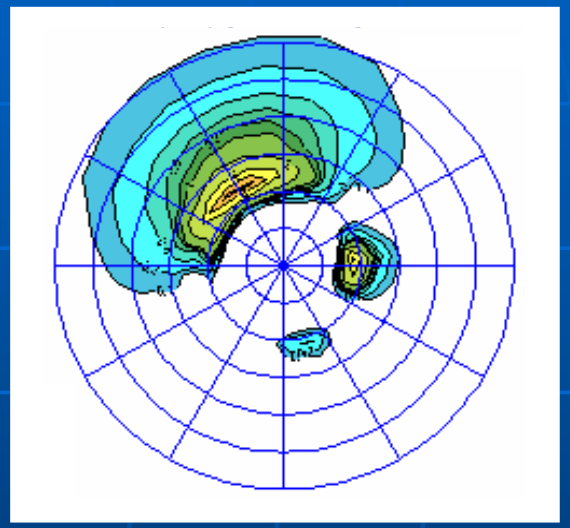
WAM – model output

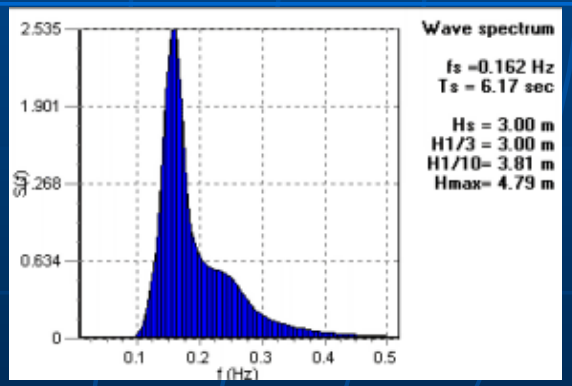
2D spectra at each (chosen) grid point

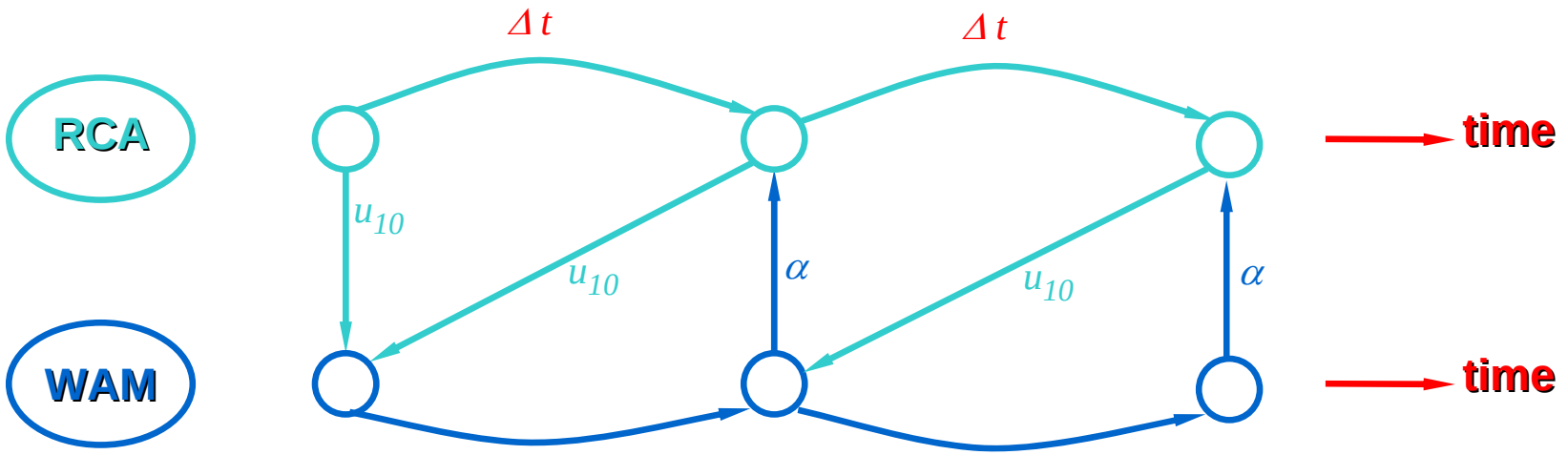
25 freq. (log)

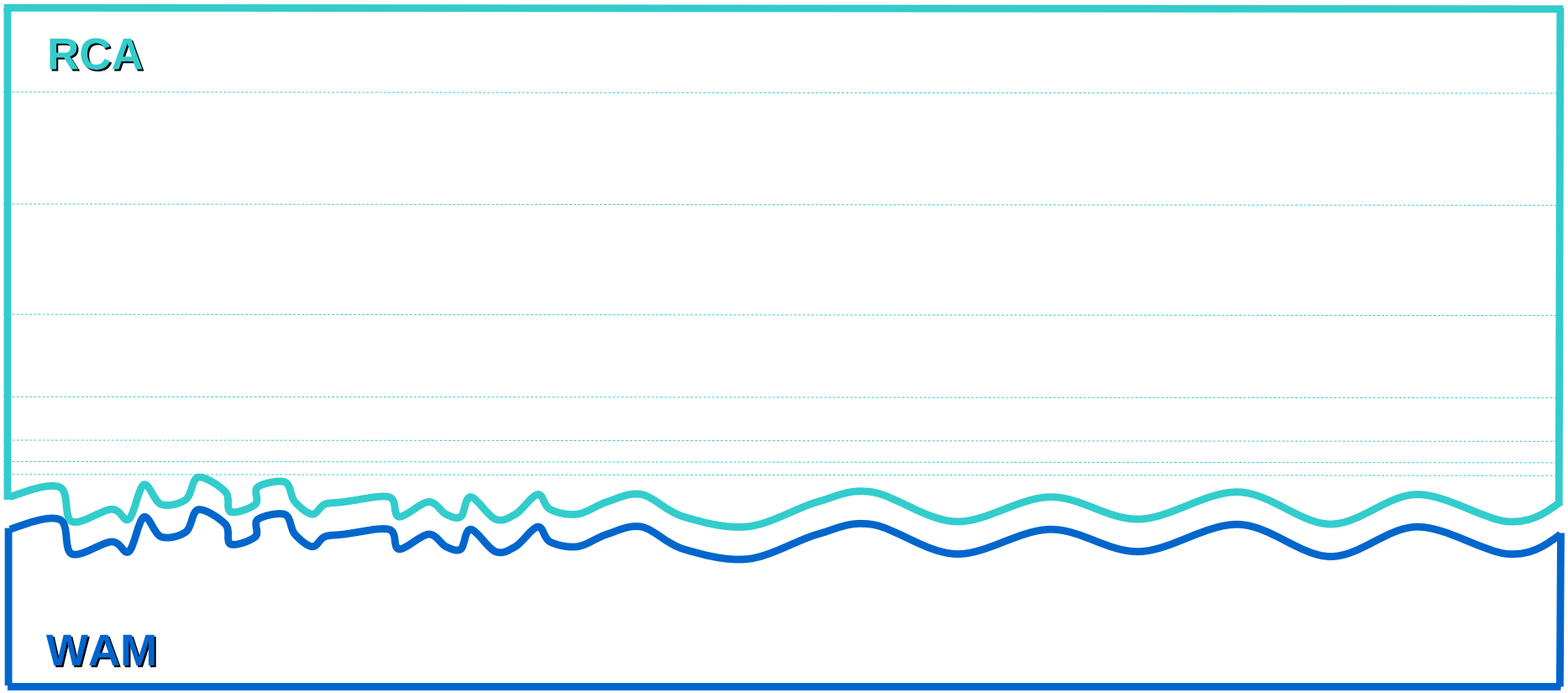


24 direction bins



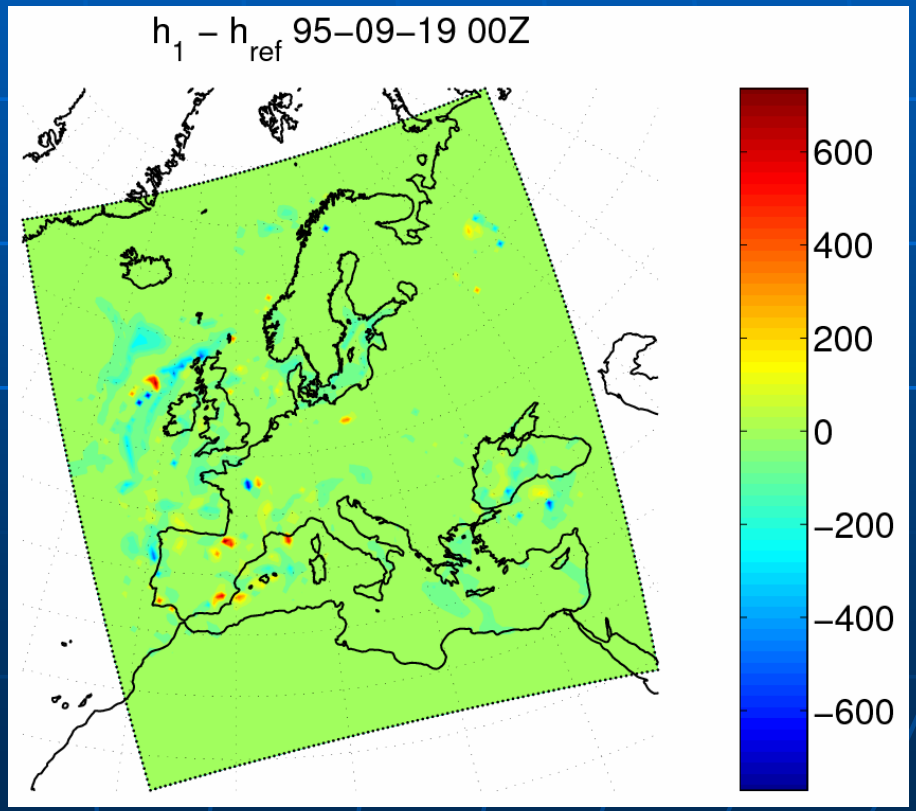



Δ t
Δ t
RCA
WAM
u_{10}
u_{10}
u_{10}
α
α
time
time


RCA
WAM

Preliminary swell results RCA-WAM

- increased wind speed
- reduced surface friction
- reduced boundary layer height



Other RCM-wave coupled projects:

- FMI: HIRLAM-WAM
  - Improved surface winds
  - Improved wave forecast
- Met.no: HIRLAM-WAM
  - Polar lows
- RCA-WAM-RCO

Conclude:

- Growing sea effect:
  - Well documented improvement in two-way coupled systems, especially for relatively high resolution.

- Swell effect
  - New theories should be included in coupled systems, have the potential impact on atmospheric mixing and secondary parameters as well as air-sea exchange.

Östergarnsholm swell influences - results

Variable *roughness lenght* (z_0) and sea drag (drag coeficient C_D) as a function of wave age (Jansen 1989, 1991), under swell conditions (Larsén 2004)