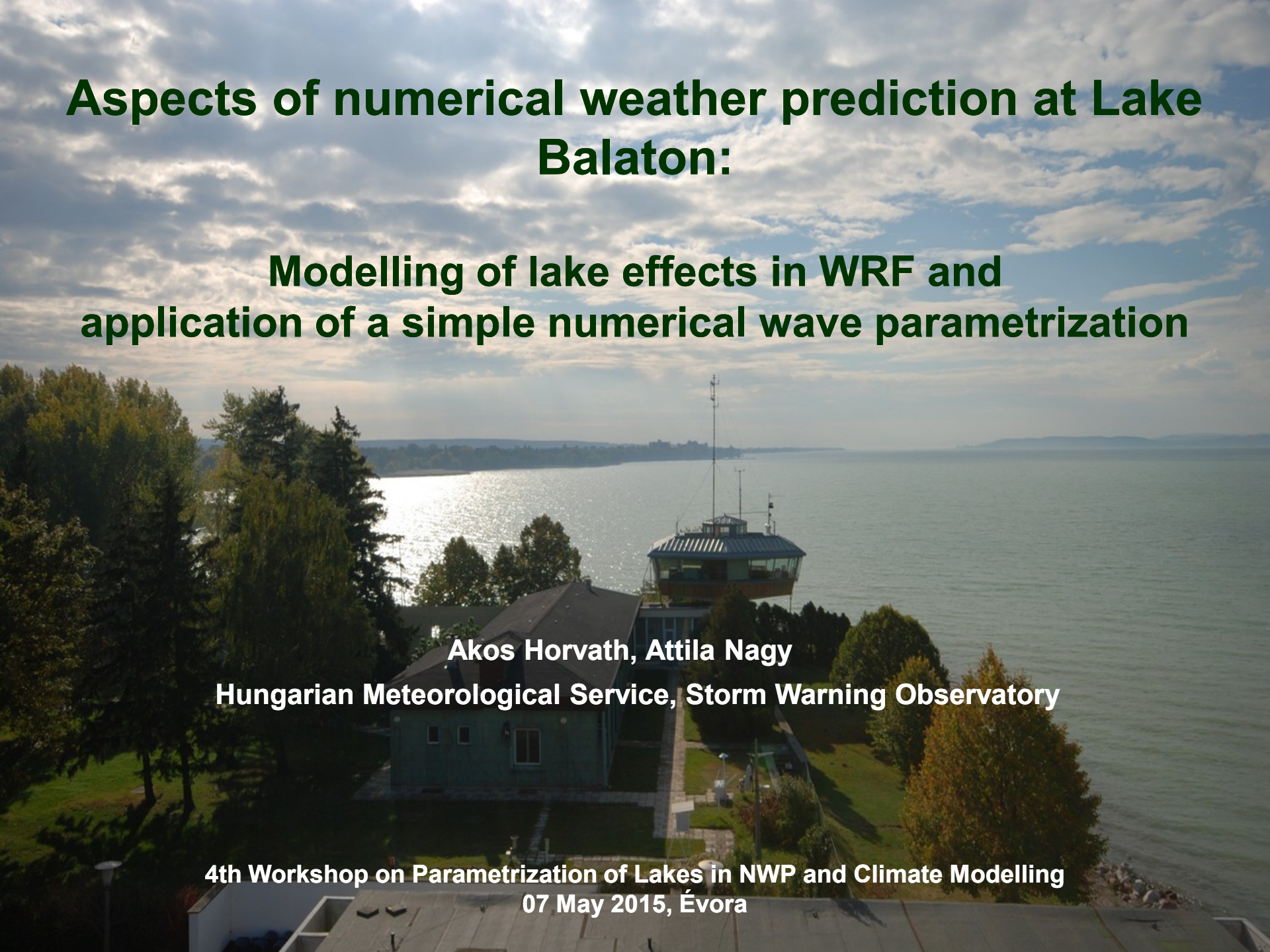
Aspects of numerical weather prediction at Lake Balaton:

Modelling of lake effects in WRF and application of a simple numerical wave parametrization



Akos Horvath, Attila Nagy

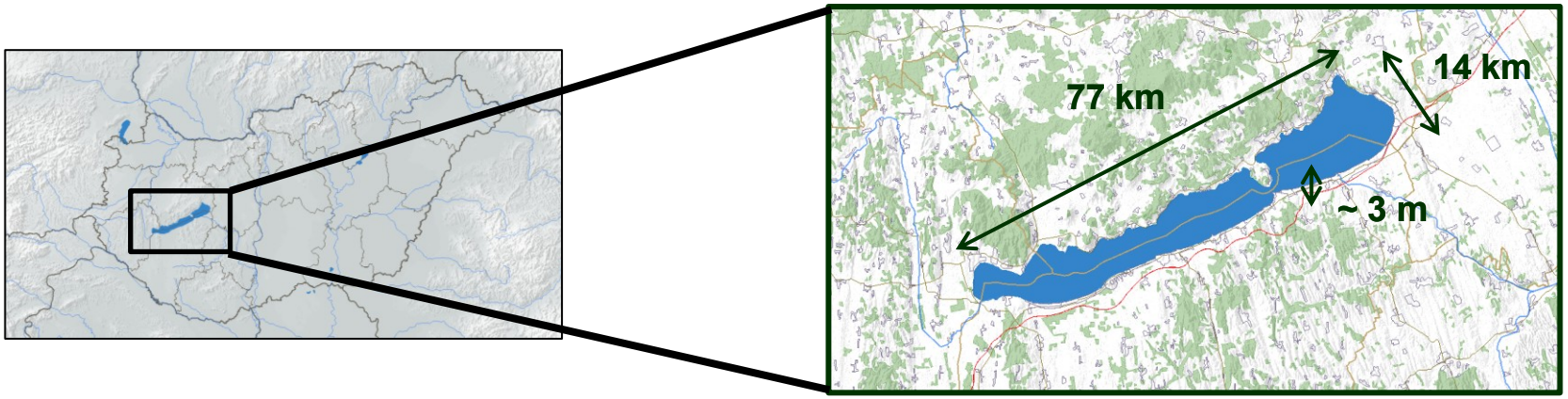
Hungarian Meteorological Service, Storm Warning Observatory

4th Workshop on Parametrization of Lakes in NWP and Climate Modelling
07 May 2015, Évora

Outline

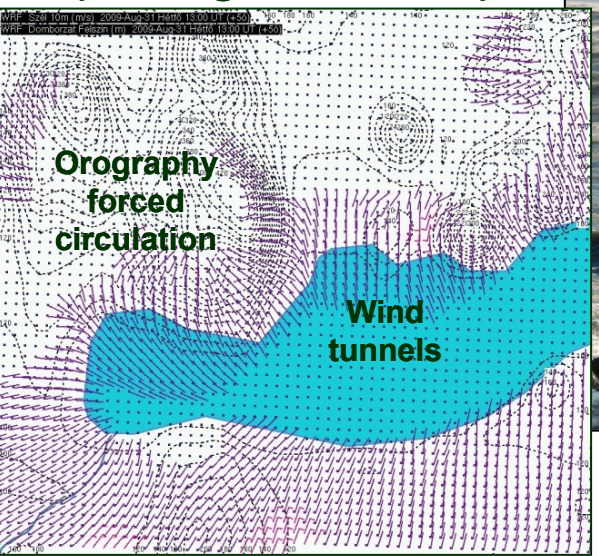
- Motivation and objectives
- Prediction of potentially dangerous phenomena at Lake Balaton
- Case studies and sensitivity tests to lake surface temperature
- Wave height parametrization and validation of results
- Summary, conclusions

Objective of better representation of Lake Balaton



To predict potentially dangerous phenomena by short range / nowcasting model

High resolution wind field (meso-gamma scale)

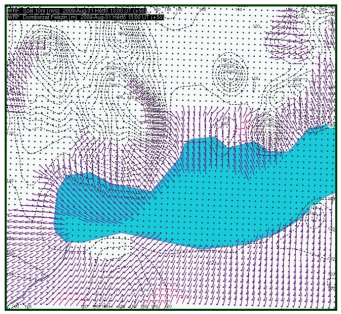


Wave height

Evaporation

Objective of better representation of Lake Balaton

To predict potentially dangerous phenomena by short range / nowcasting model



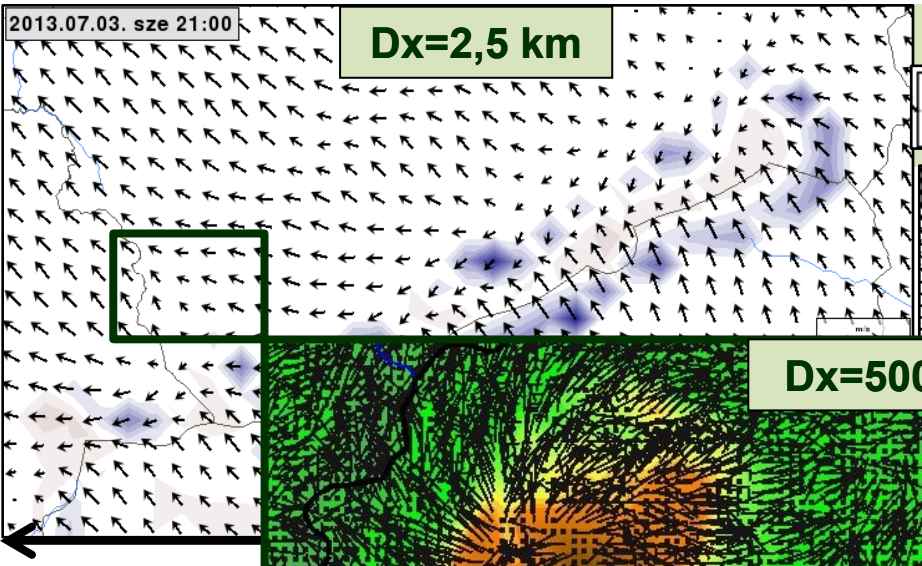
ISSUES

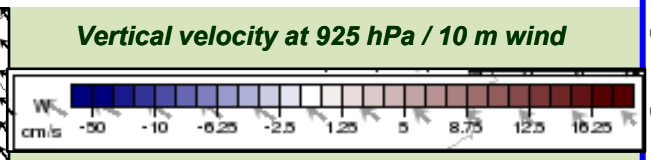
WRF downscaling

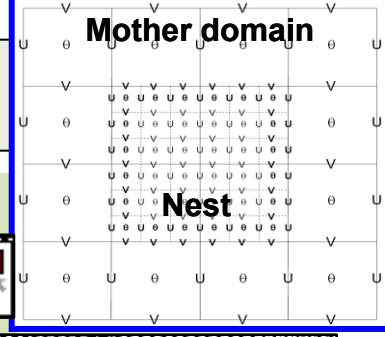
Wave parametrization

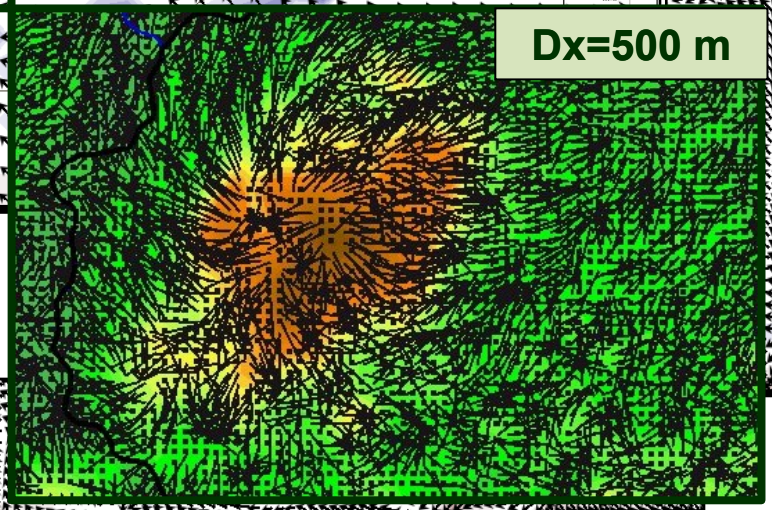
Evaporation
(Surface / Lake model in WRF)

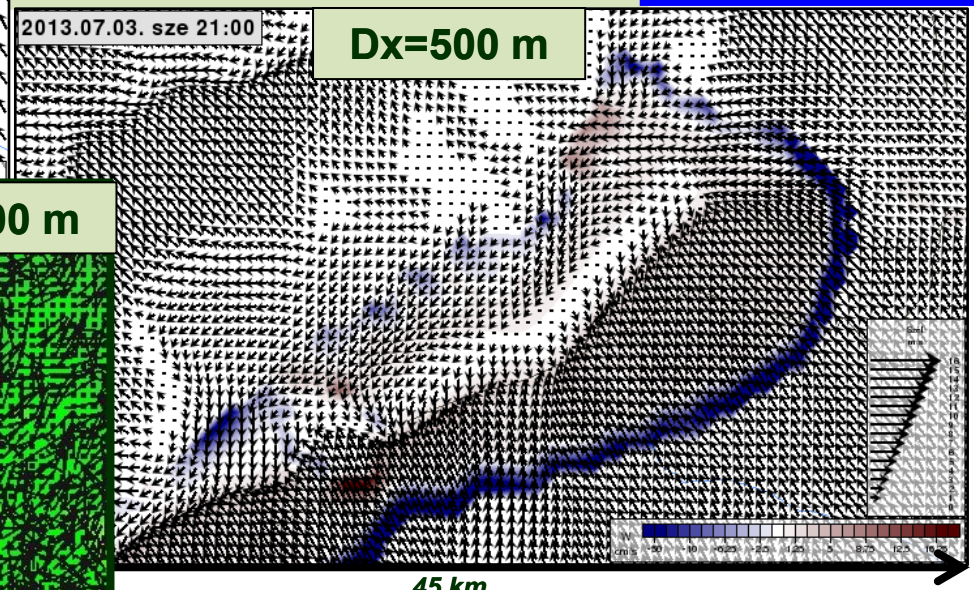
WRF downscaling

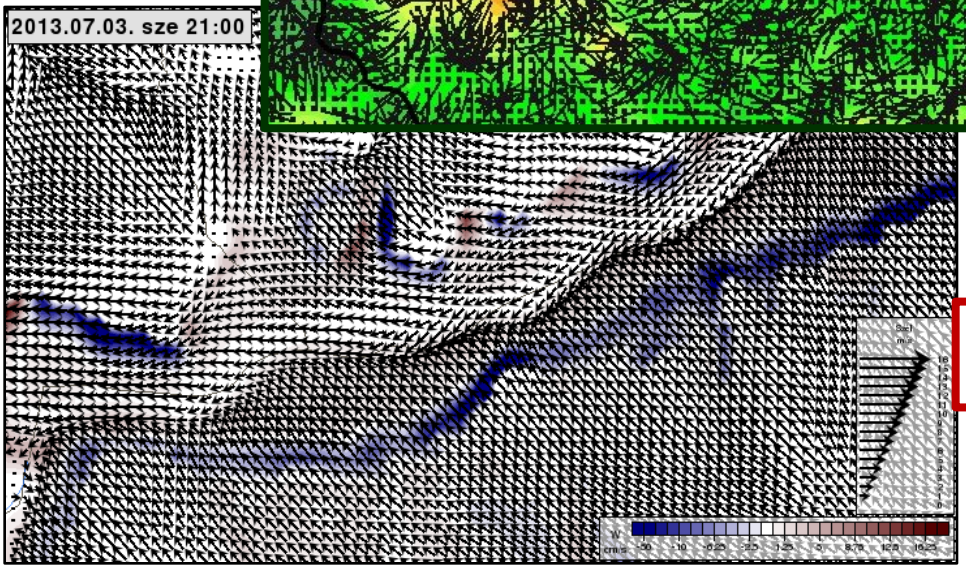












45 km

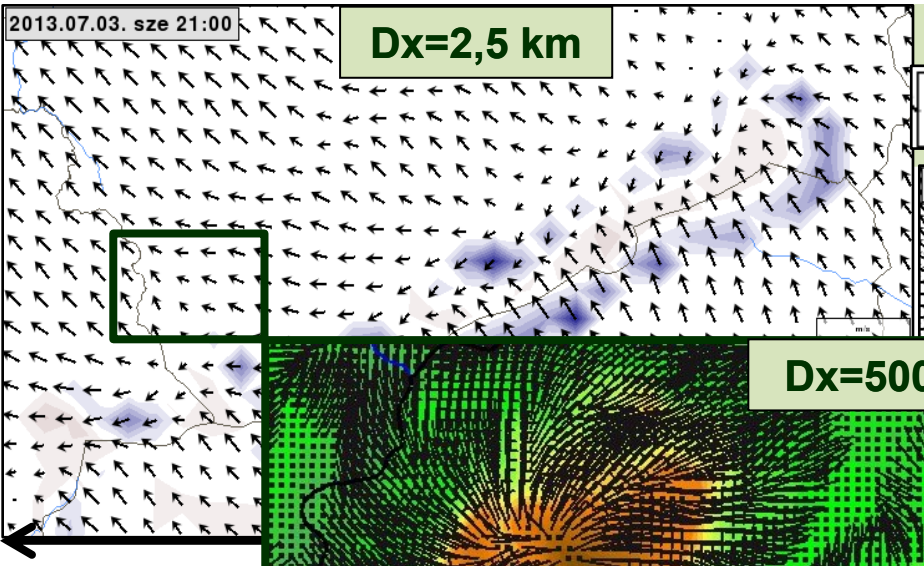
Downscaling practices

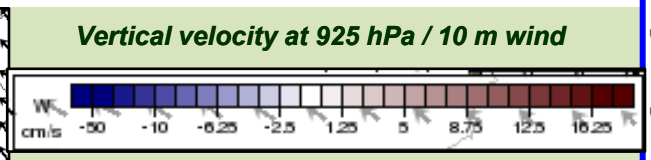
Lateral boundary conditions should not be overrelaxed

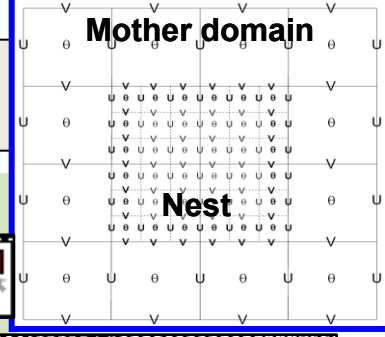
Dynamical diffusion may not be enough

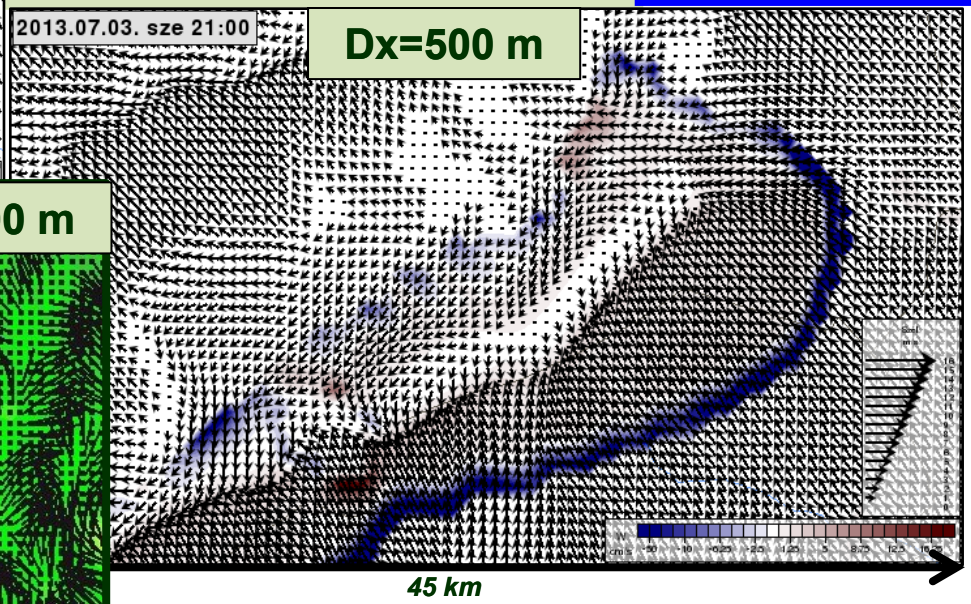
Use more accurate surface data

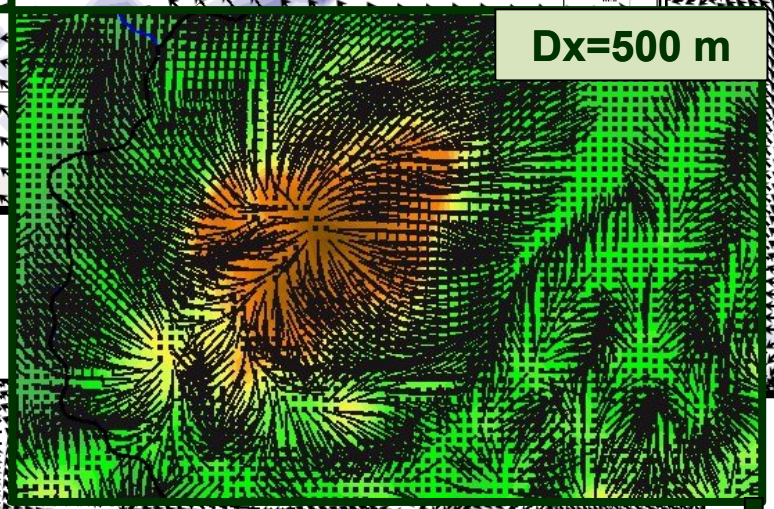
WRF downscaling

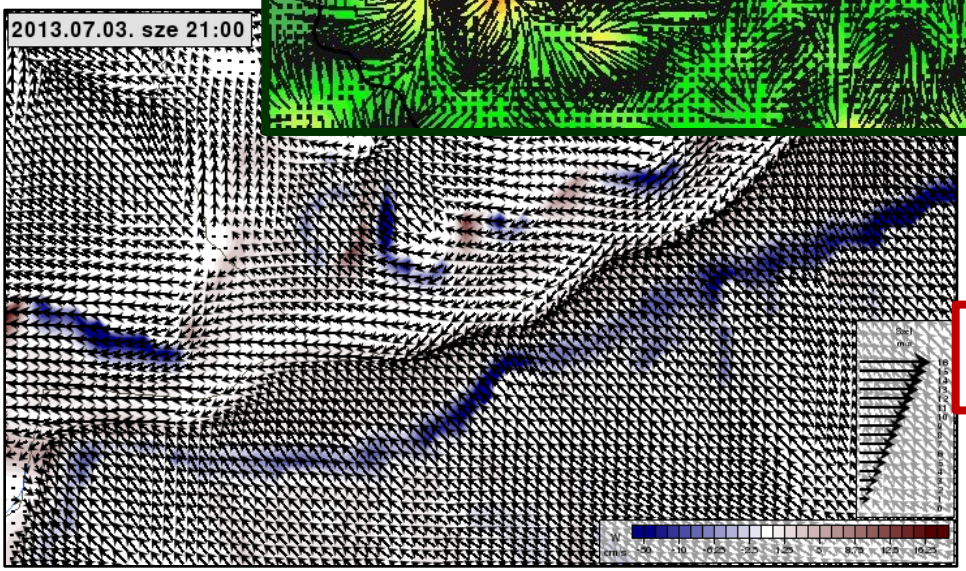












45 km

Downscaling practices

Lateral boundary conditions should not be overrelaxed

Use 6th order diffusion term

Use more accurate surface data

Lake processes in WRF model

CLM-based lake model
since the WRF version 3.6, taken from CLM version 4.5 (Subin et al., 2012., Oleson et al., 2013.) with some modifications by Gu et al., 2015.

- One-dimensional water and energy balance model (Hostetler et al., 1993; 1994)
- Vertical layers: 10 in lake, 10 in soil, 5 in snow on ice (if present)
- Lake temperature for each layer is computed based on a Crank-Nicholson thermal diffusion solution
- Surface heat and water fluxes are calculated assuming a freely varying (infinitesimal skin) surface temperature, with aerodynamic resistances computed as for nonvegetated surfaces.
- Energy transfer between lake layers -> dt, molecular (constant), eddy diffusion

General remarks:

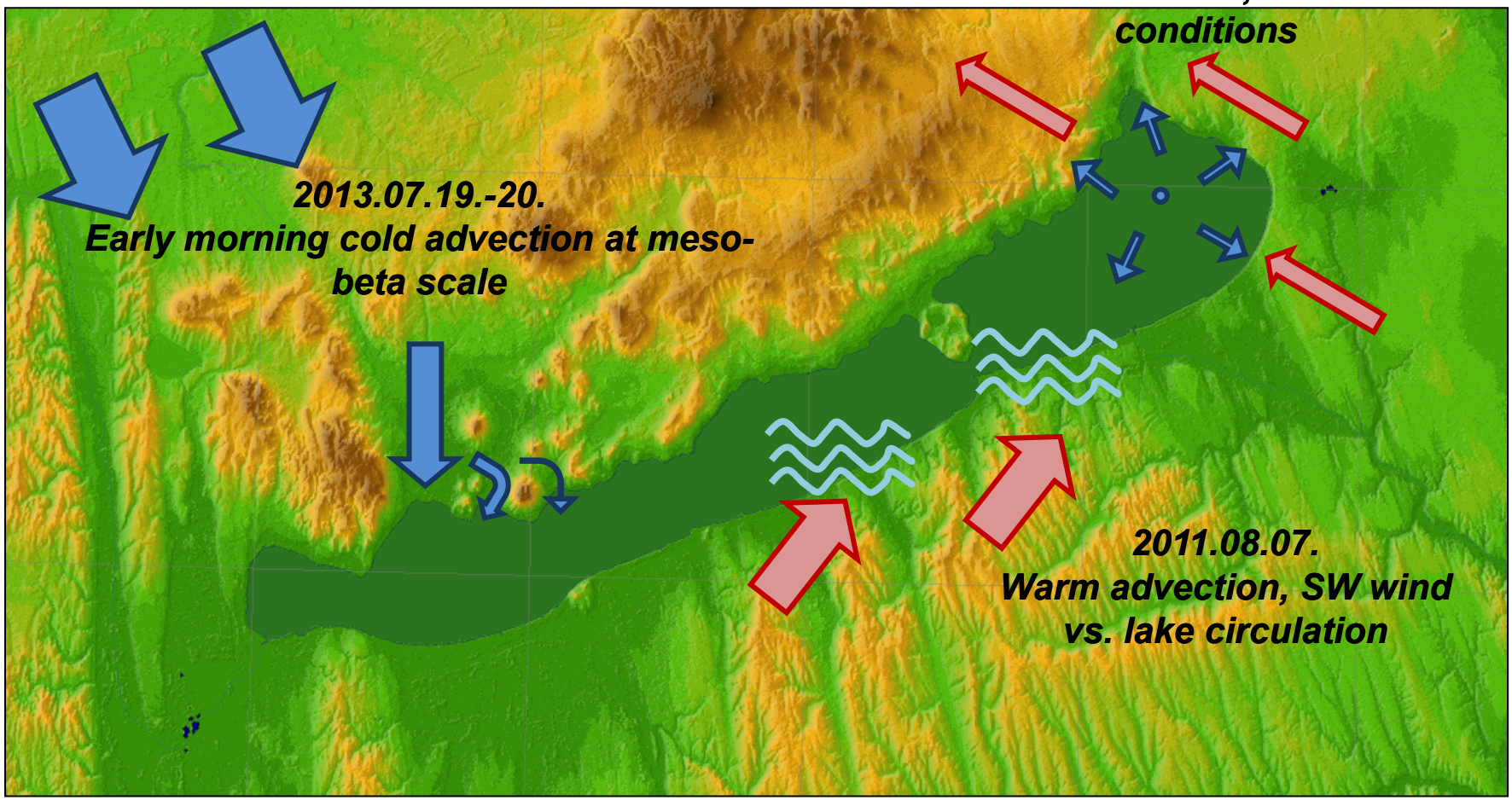
In short range NWP

only a few parameters might have an important role : LST, ice temperature/ snow depth

lake profil initialization is important

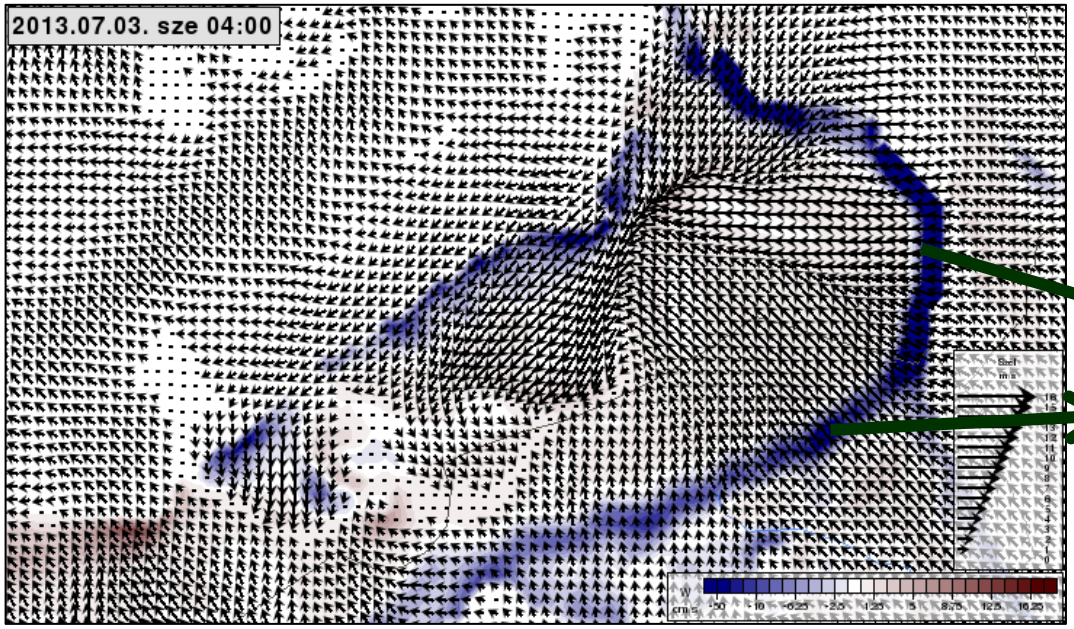
Evaporation shows a particular sensitivity to lake surface properties

Case studies



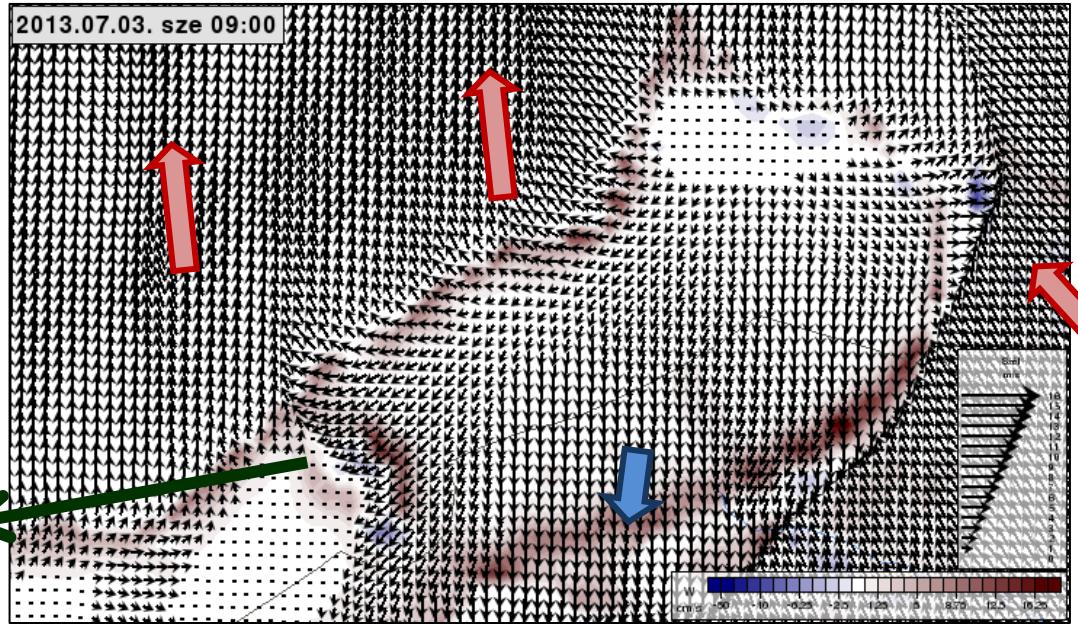
Lake circulation 1. (night / day)

Nighttime regime



Orography forced downdraft at lowest levels

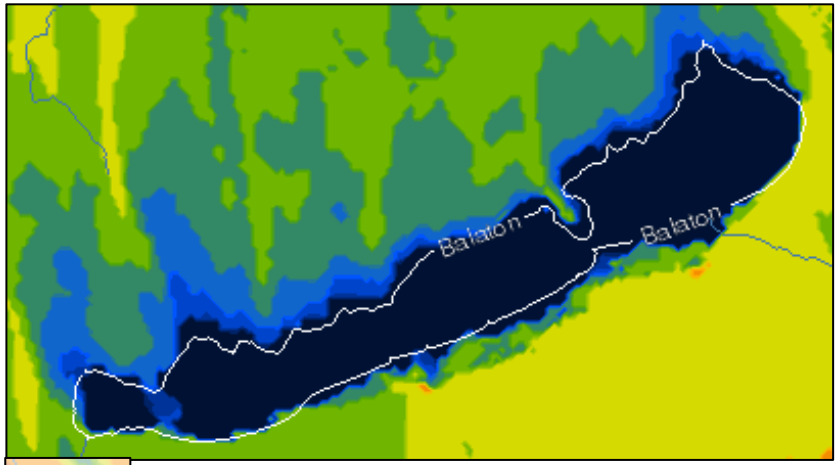
Daytime regime

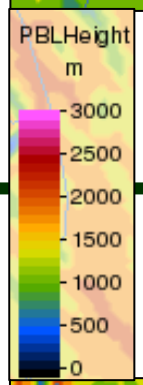


Convergence over the peninsula

Weak / moderate SE wind

Lake circulation 2. (transition period, aspects of PBL)



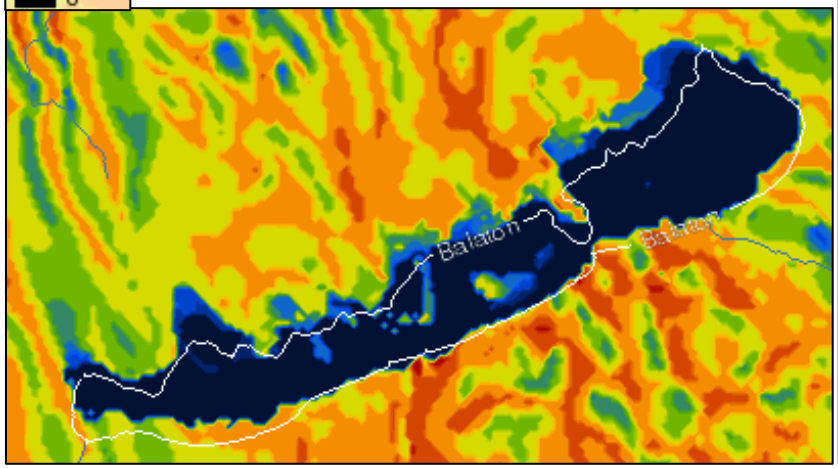


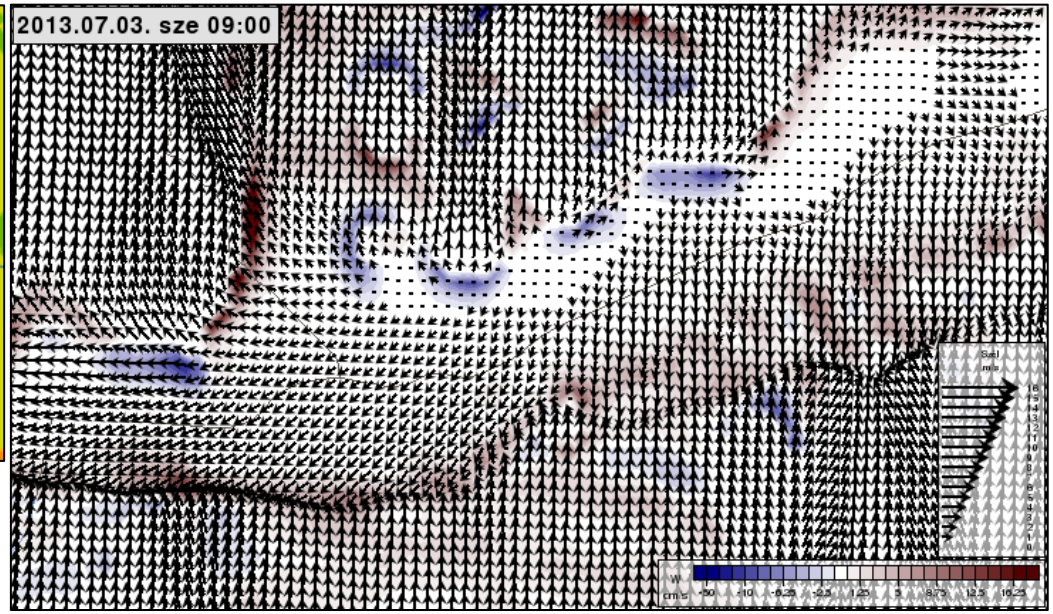
Daytime

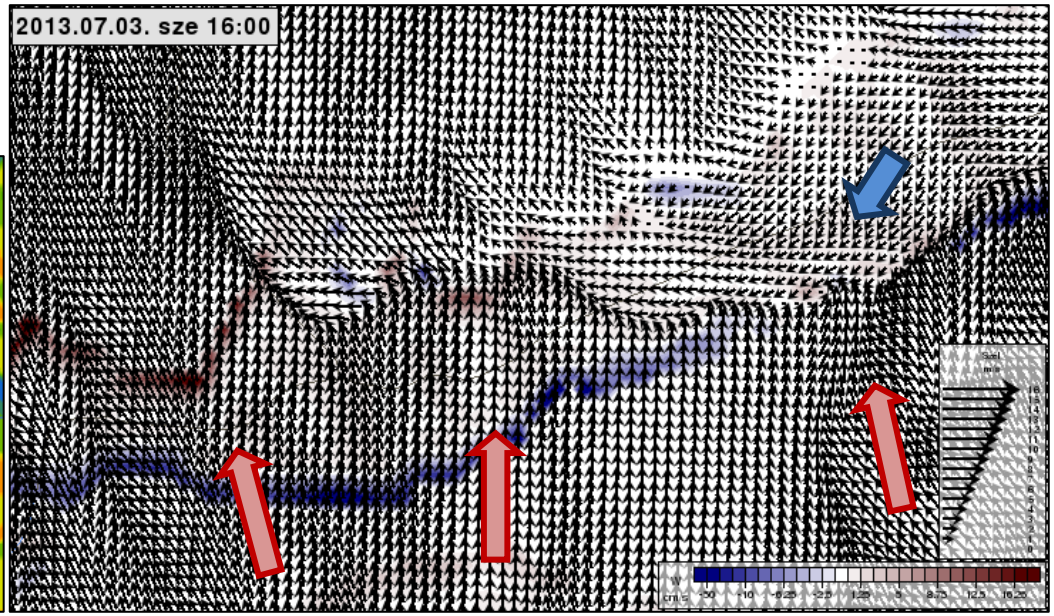
Lake breeze front at coastline or over land

SE wind extends over lake due to change of the PBL regime

Evening

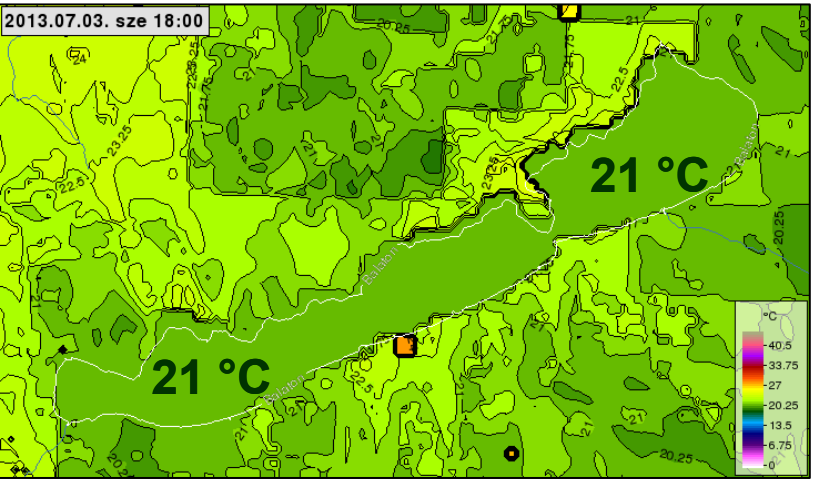


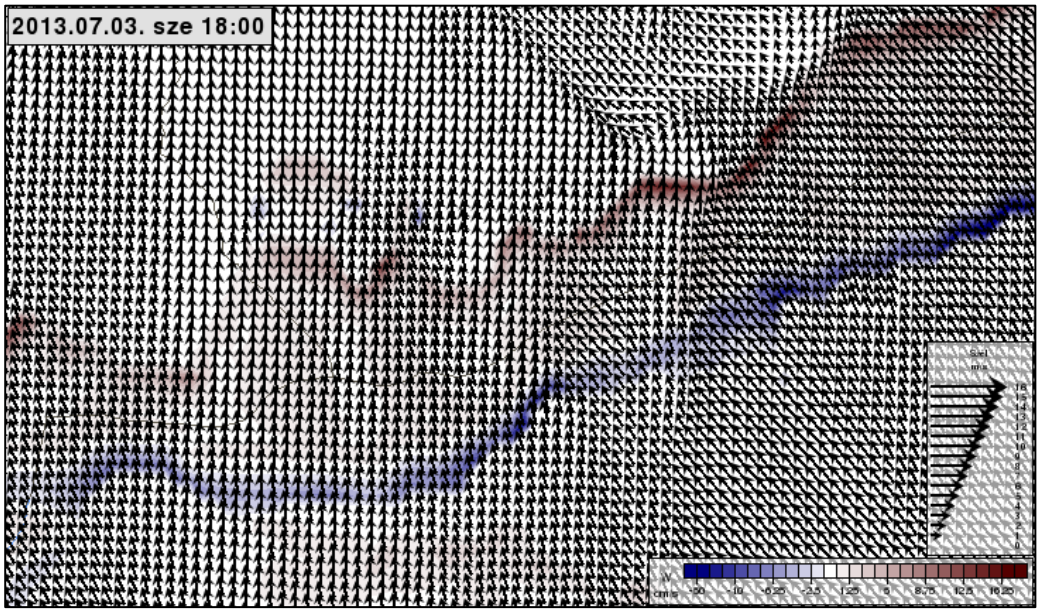




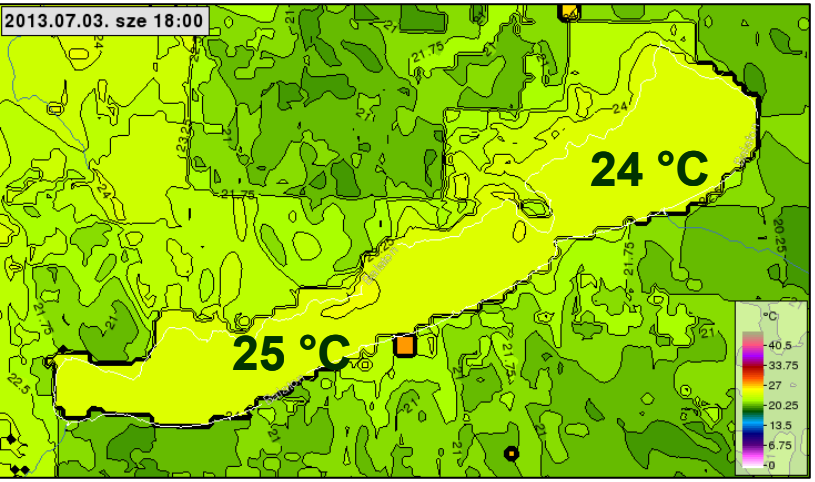
Lake circulation (sensitivity)

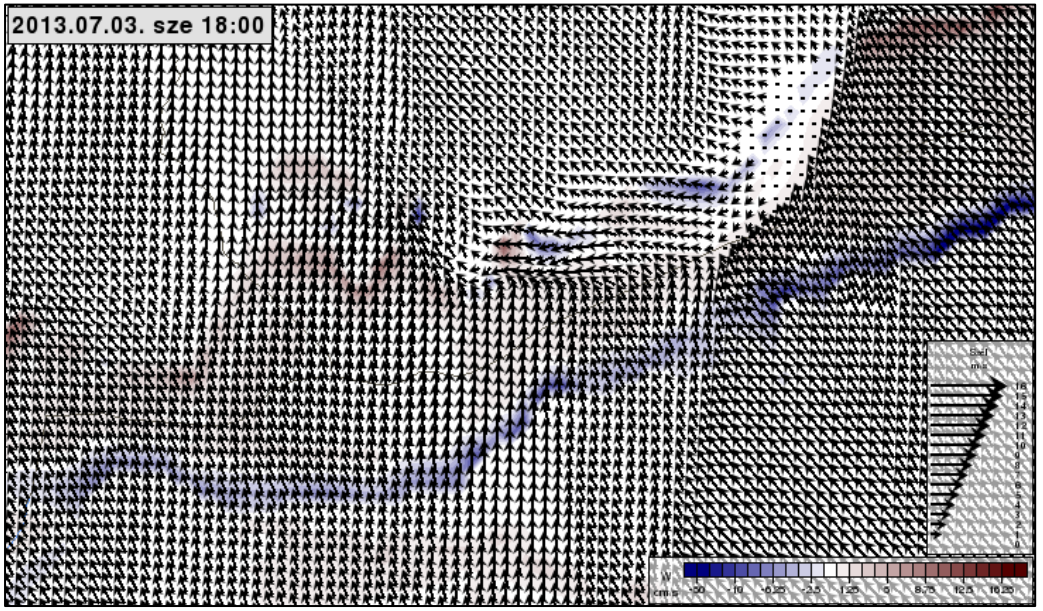
Constant LST over all integration period





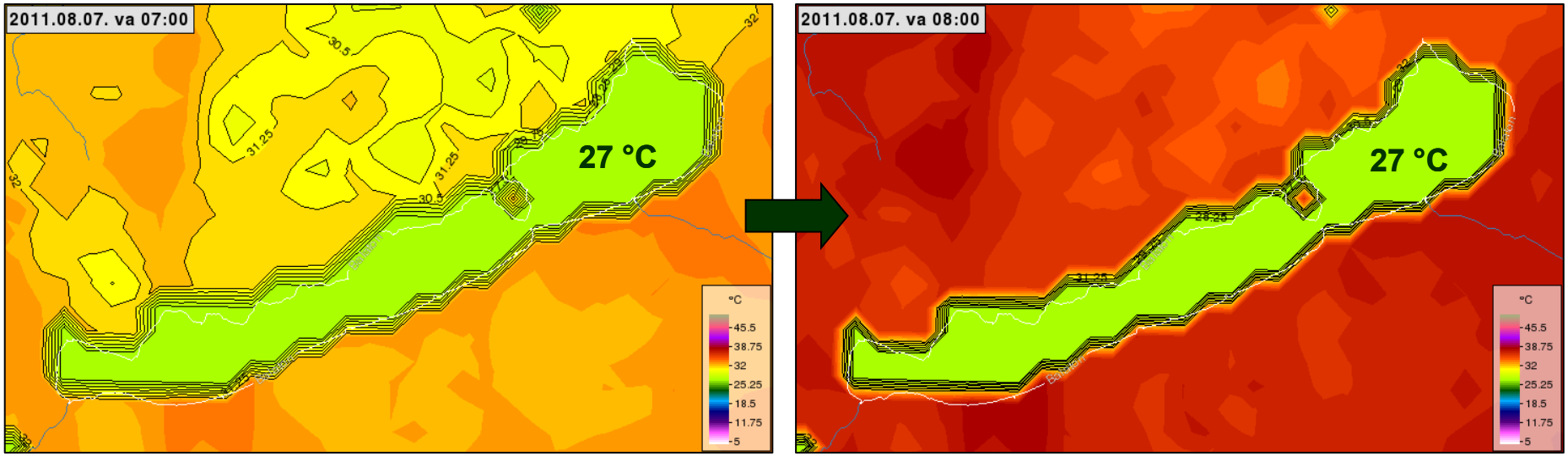
LST calculated by lake model





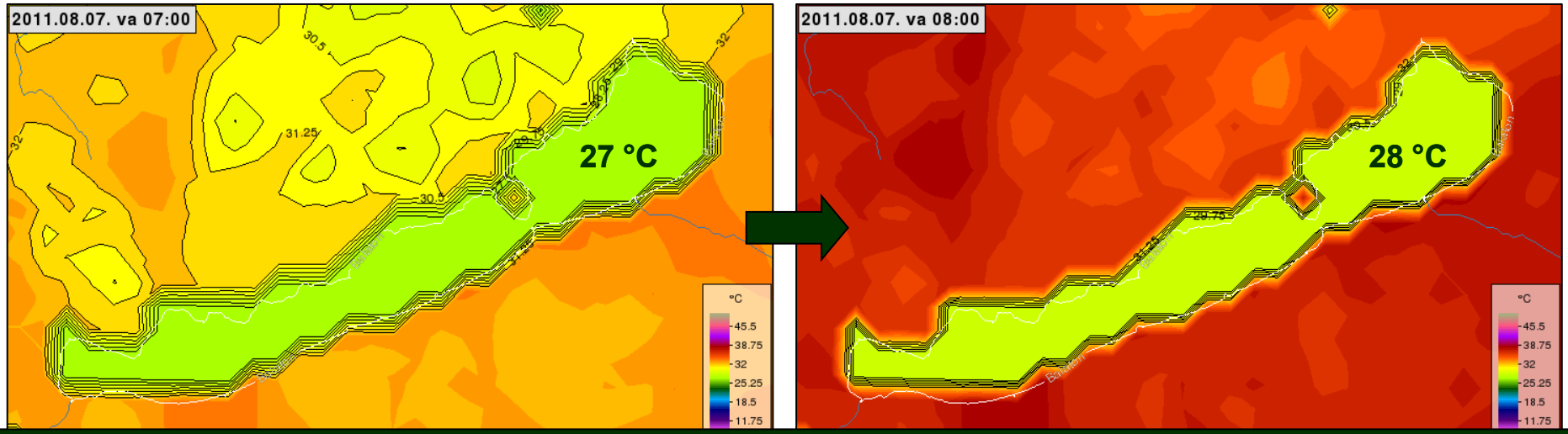
Warm advection (SW wind extending over lake)

Constant LST over full integration period



07 UTC **08 UTC**

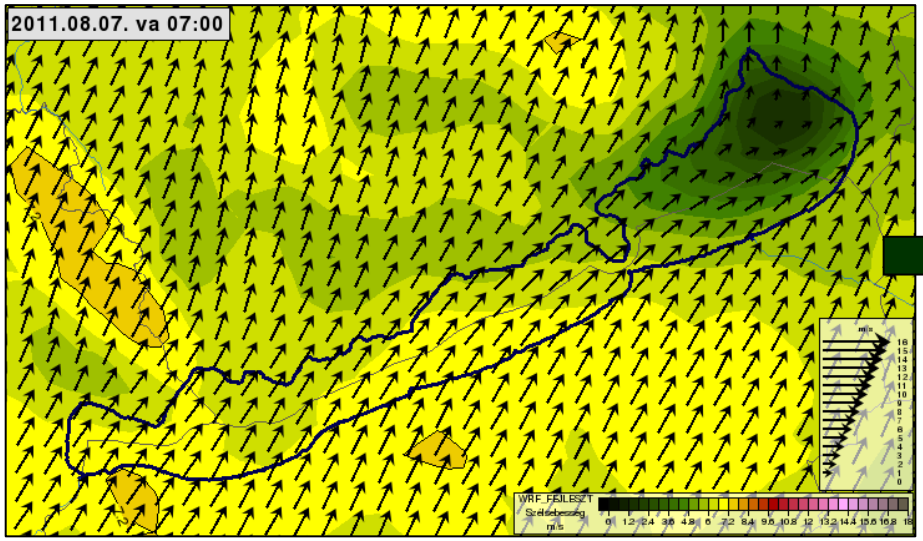
LST calculated by lake parametrization

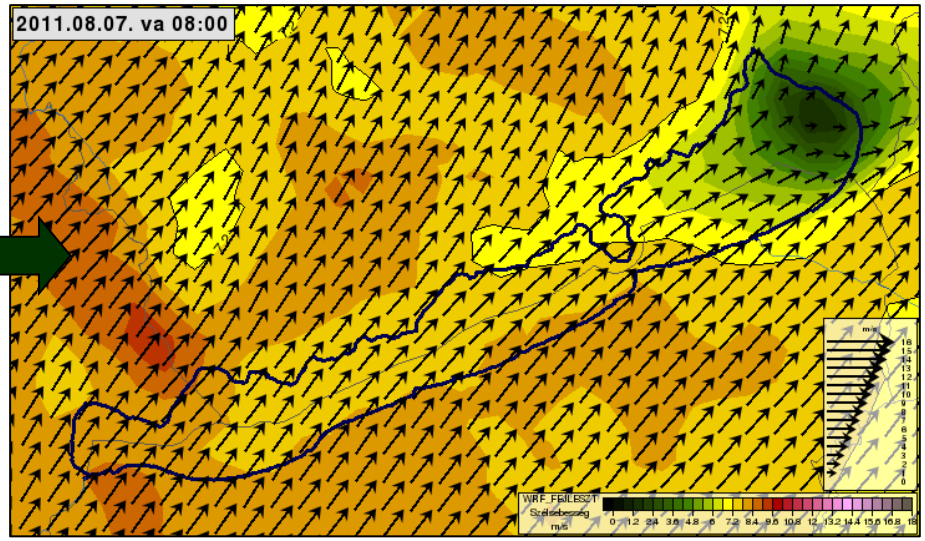


Small difference in LST, …

Warm advection (SW wind extending over lake)

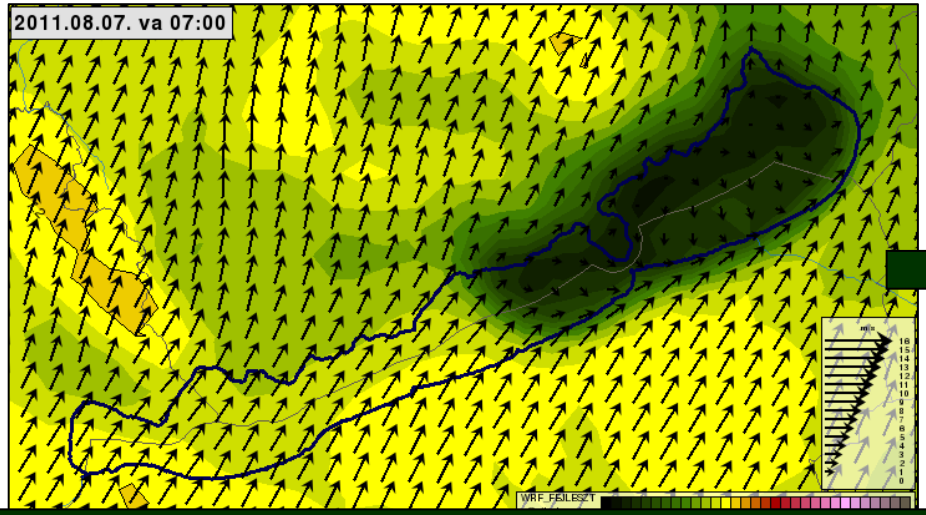
Constant LST over full integration period

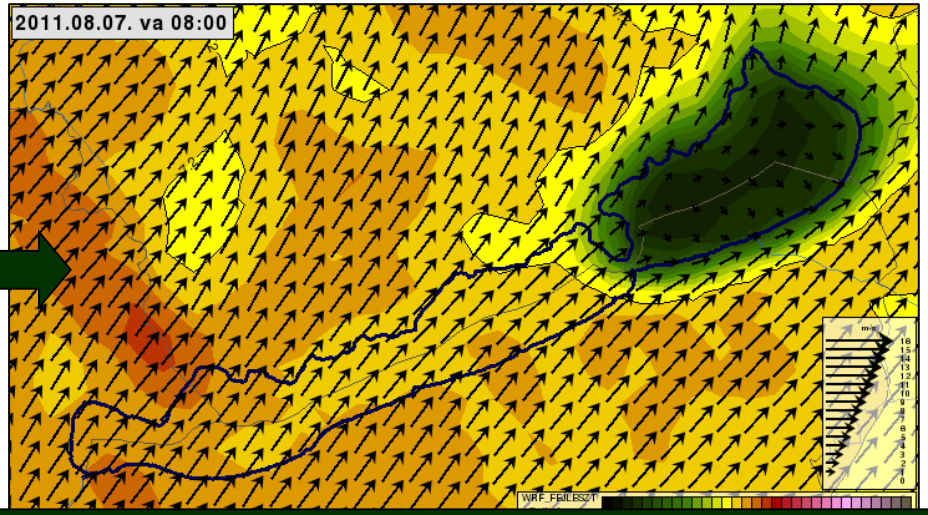




07 UTC **08 UTC**

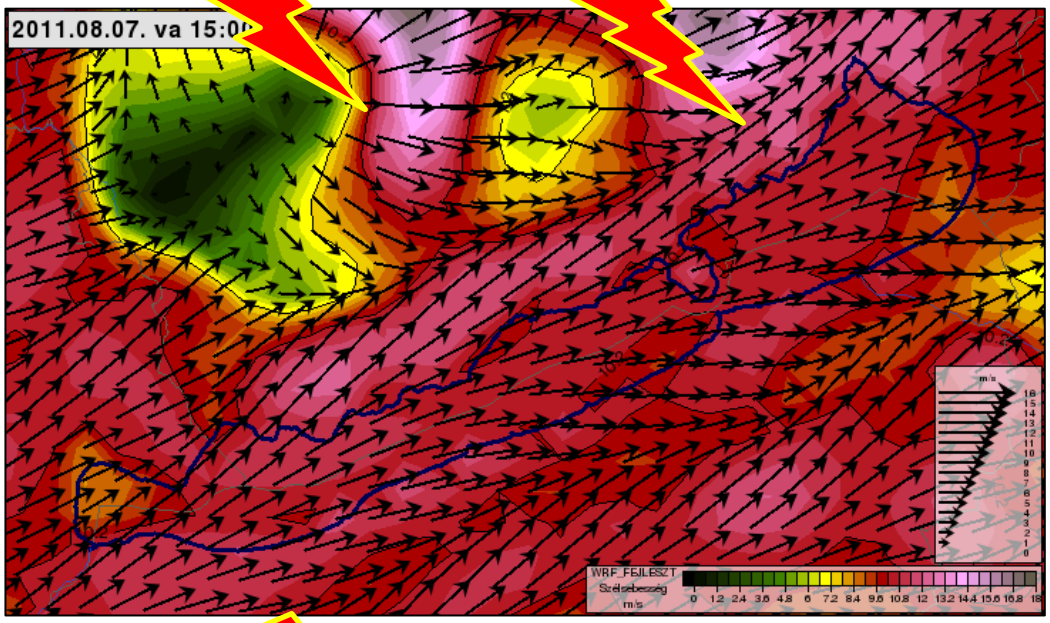
LST calculated by lake parametrization



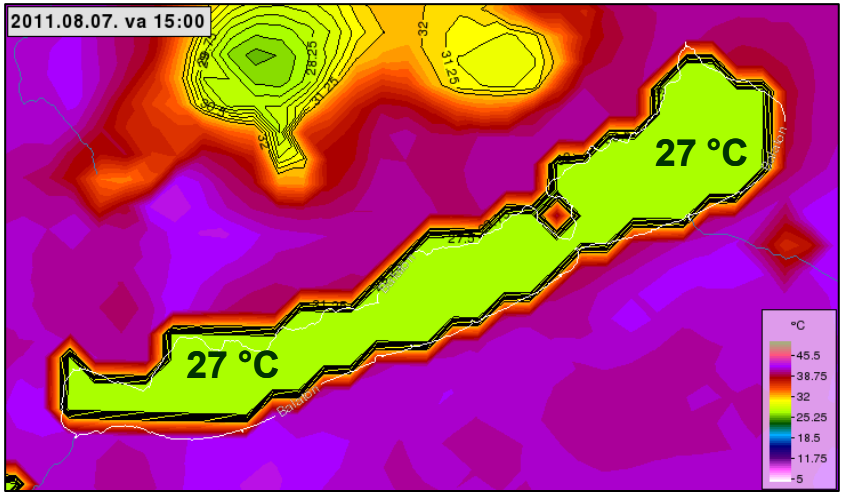


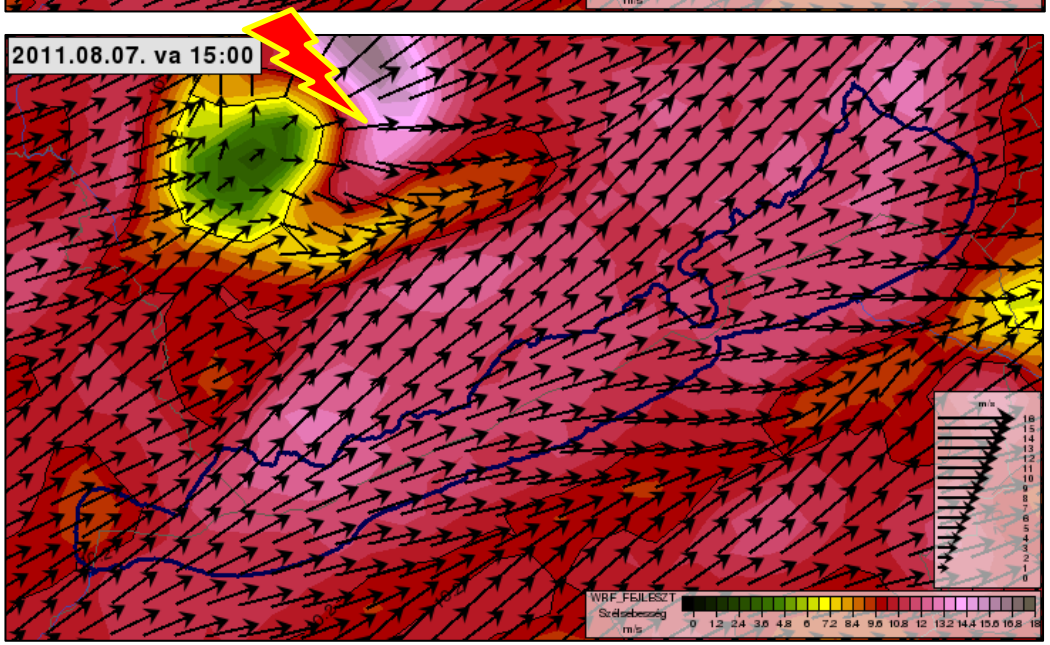
…big difference in wind field.

Warm advection, SW wind

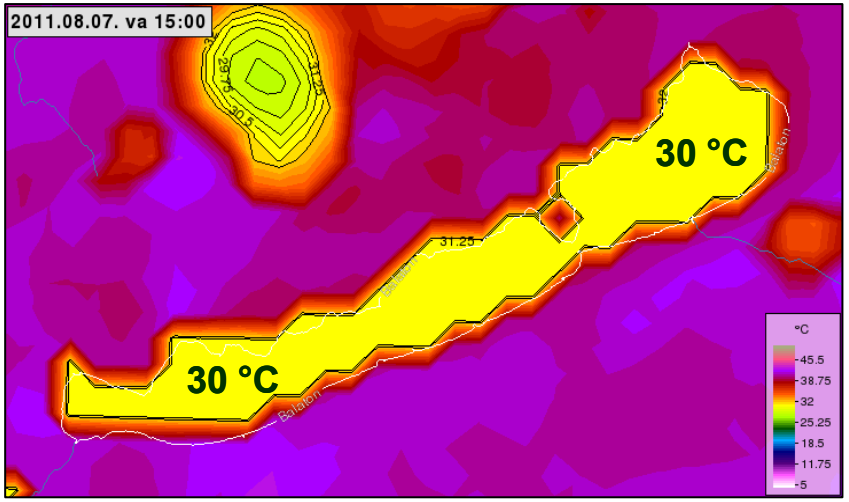


Constant LST over full integration period



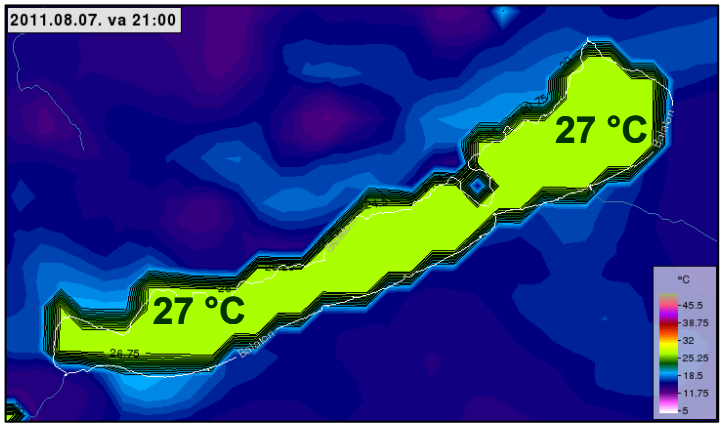


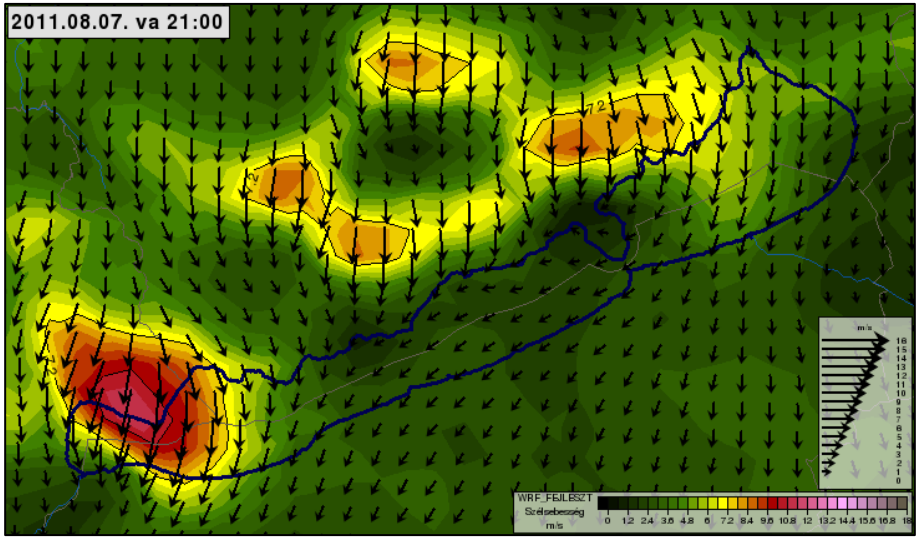
LST calculated by lake parametrization



Weak cold advection at late evening

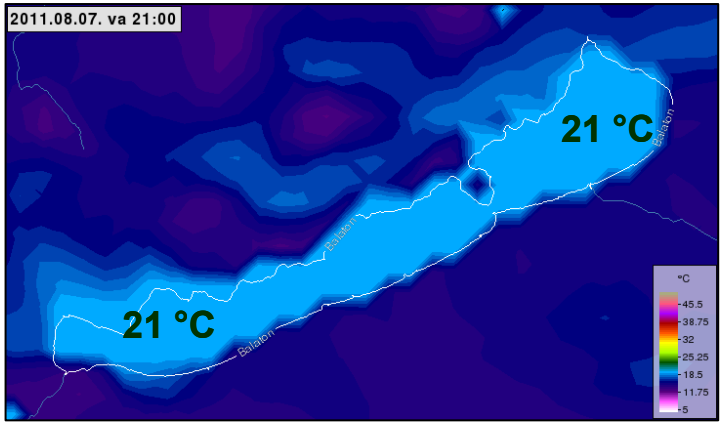
Constant LST over full integration period

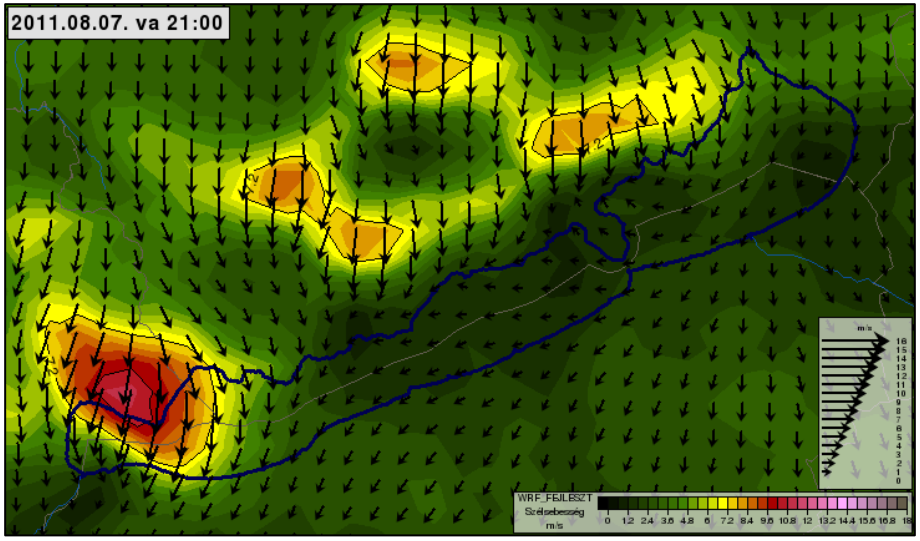




Big difference in LST, smaller difference in wind field.

LST updated at every hours (values correspond nearly to land surface skin temperature)

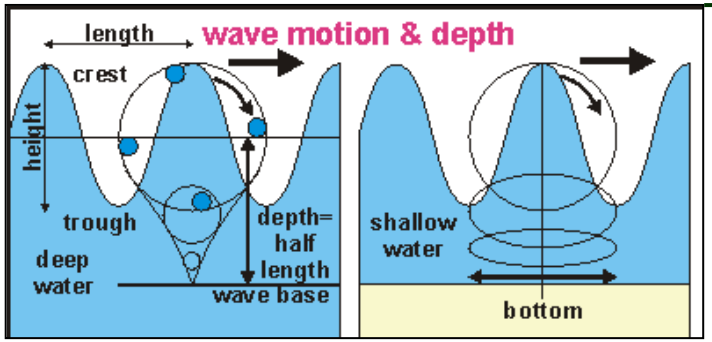




Wave parametrization method

Waves on surface of still water

- ⬅ Surface tensions **U**
- ⬅ Water depth **H**
- ⬅ Fetch lenght (coastline caracteristics) **F**



Shallow water ➡ **U ~ H ~ F**

In shallow water
wave action does not decrease with depth

Simplified method to describe waves =

Statistical assumption:

Individual wave characteristics
No development
Fetch-limited and duration-limited conditions

H_s significant wave height

$$\frac{gH_s}{u_A^2} = 0{,}283 \cdot \tanh\left(0{,}530\left(\frac{gh}{u_A^2}\right)^{0{,}75}\right) \tanh\left[\frac{0{,}00565\left(\frac{gF}{u_A^2}\right)^{0{,}5}}{\tanh\left(0{,}530\left(\frac{gh}{u_A^2}\right)^{0{,}75}\right)}\right],$$

F fetch lenght

u_A wind-stress factor derived from wind speed near water surface (=0,71*$u^{1,23}$)

h water depth

Detailed description: Shore Protection Manual, 1984. Vol. III.

Wave parametrization method

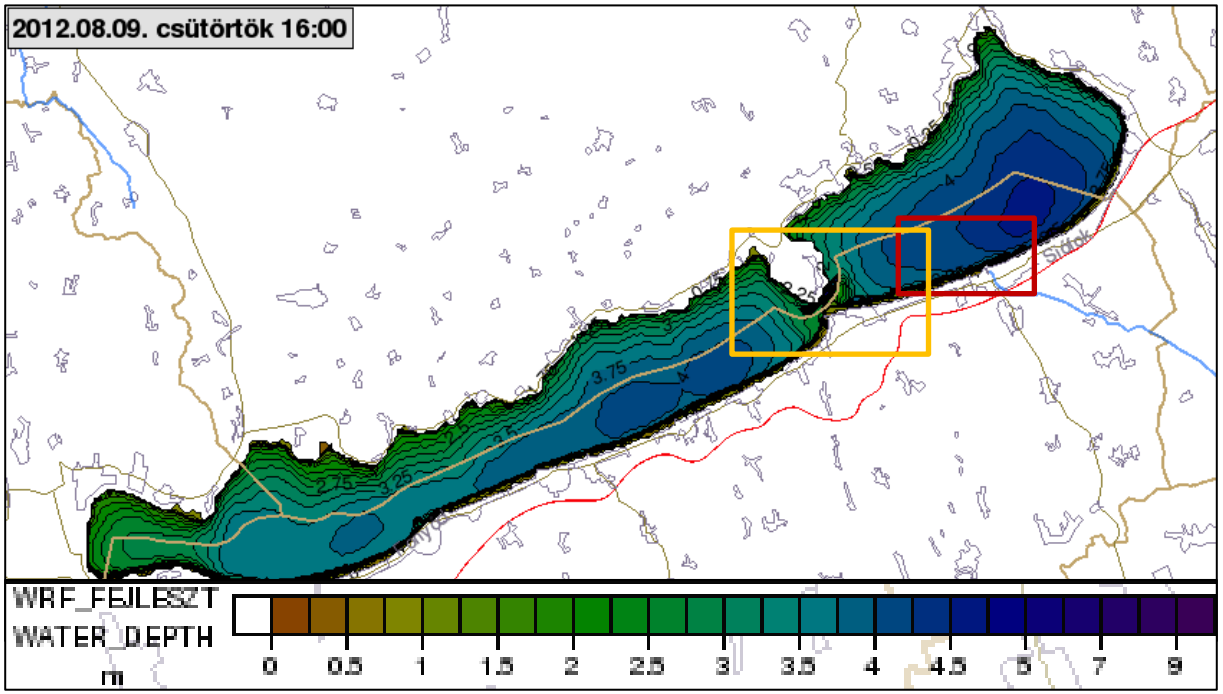
$$\frac{gH_s}{u_A^2} = 0{,}283 \cdot \tanh\left(0{,}530\left(\frac{gh}{u_A^2}\right)^{0{,}75}\right)\tanh\left[\frac{0{,}00565\left(\frac{gF}{u_A^2}\right)^{0{,}5}}{\tanh\left(0{,}530\left(\frac{gh}{u_A^2}\right)^{0{,}75}\right)}\right],$$

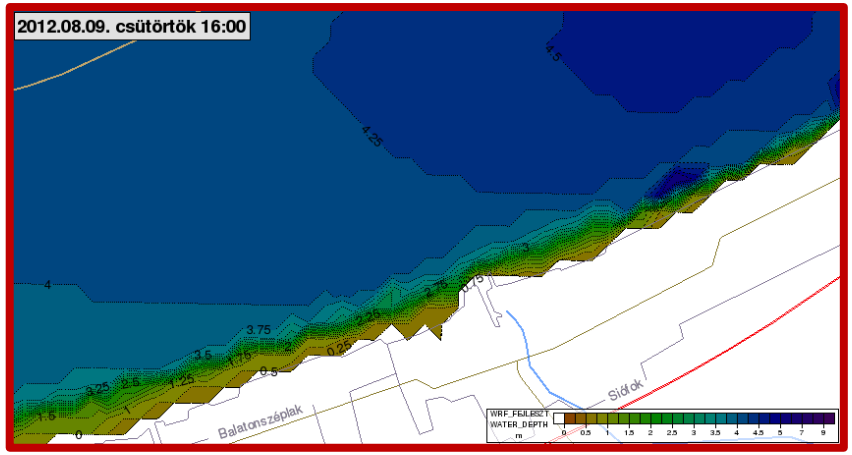
significant wave height = Average height of the one-third highest waves at given place and time (Munk, 1944.)

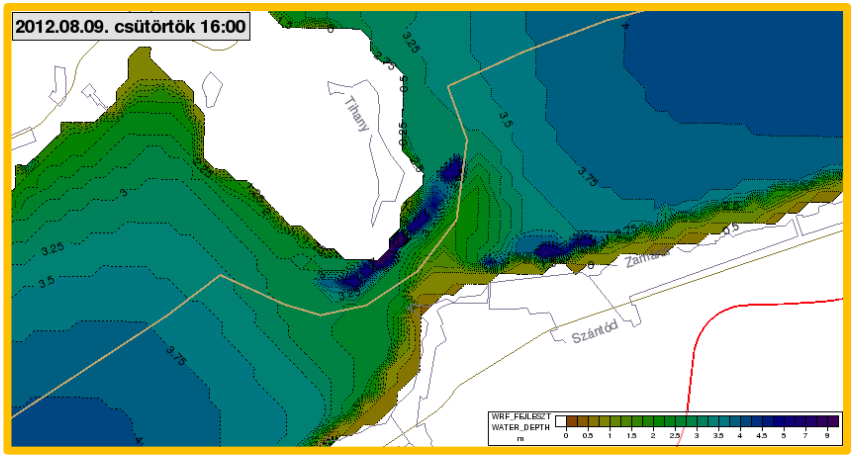
Neglected interactions

Input: lake depth database

First step of work: Preparation of coastline and lake depth data on 200 m resolution grid





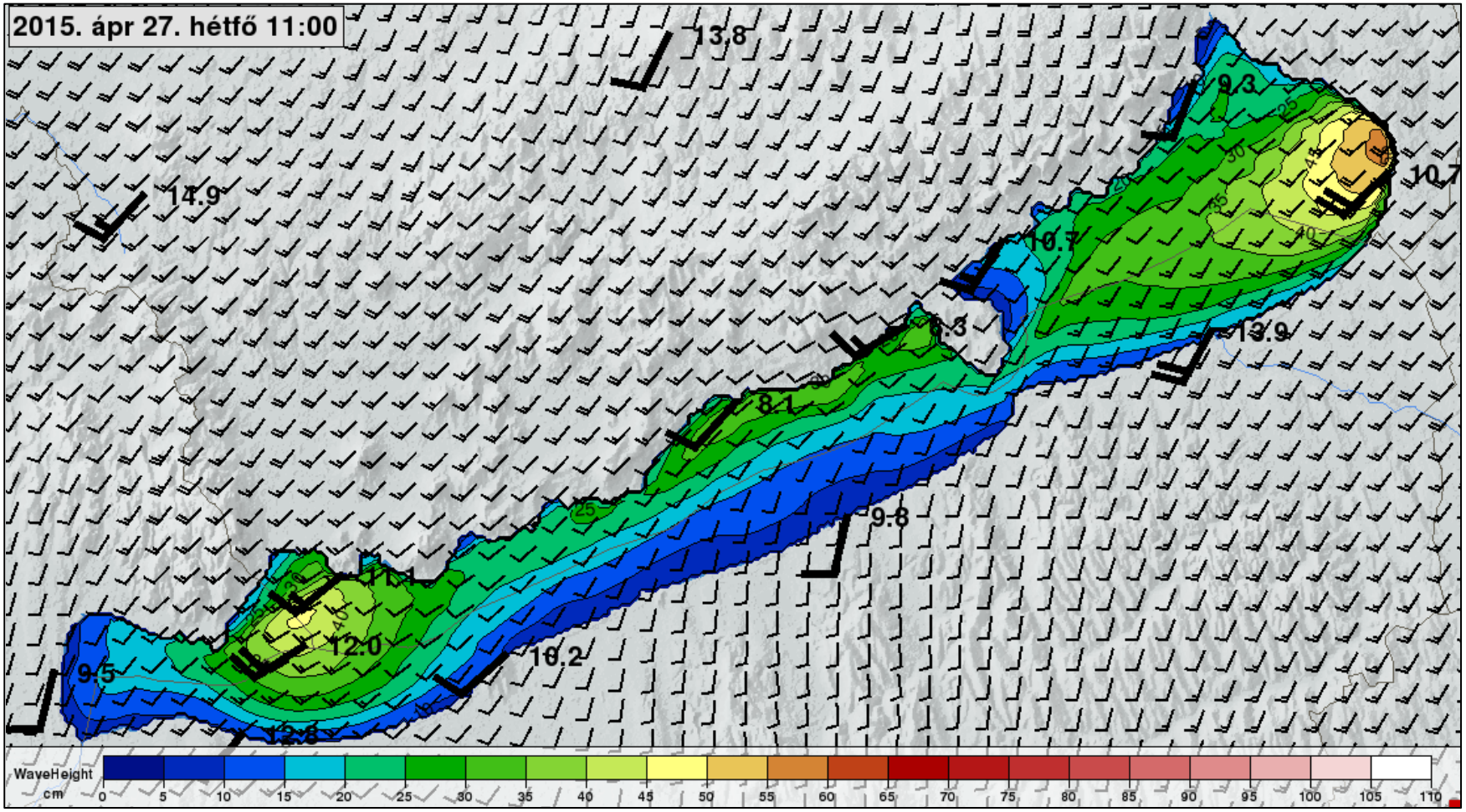


Input: wind fields

MEANDER (nowcasting system, analysis fields at every 10 minutes)

Measurements → downscaling → **~ 1 km resolution wind field** ← downscaling ← WRF model runs

Nesting at 900 m resolution



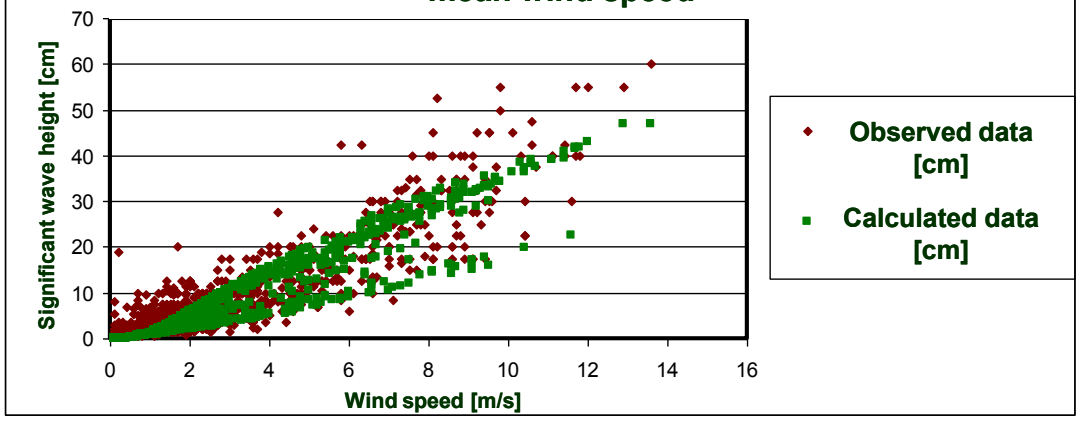
The third parameter, fetch lenght can be calculated

Objective validation

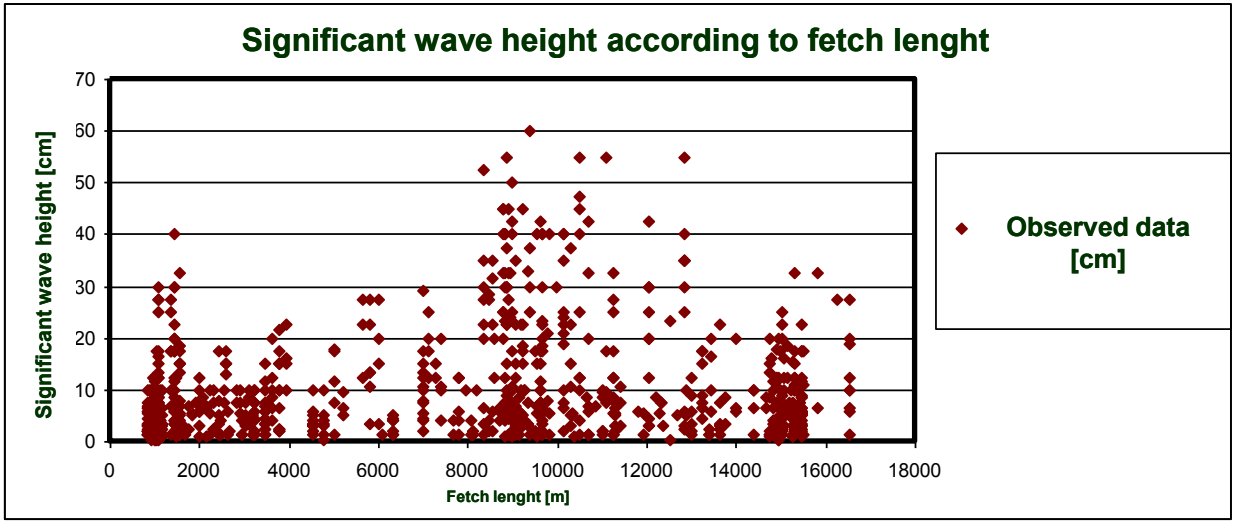
Measurements between

16 September 2013

27 November 2013

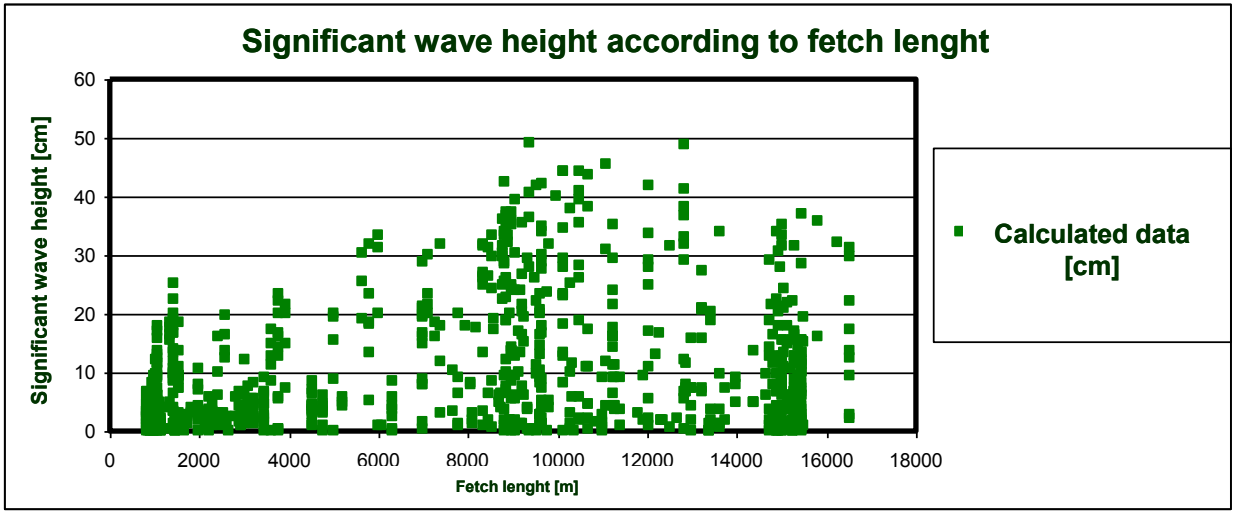


Objective validation



$$e = \frac{\sum_{i=0}^{N} \left| x^{i}_{calculated} - x^{i}_{observed} \right|}{N}$$

N: number of observed data
x: wave height values

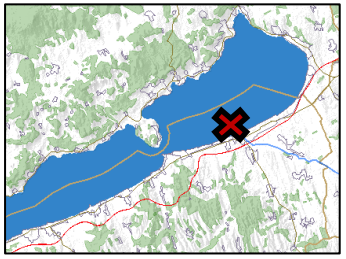


all data

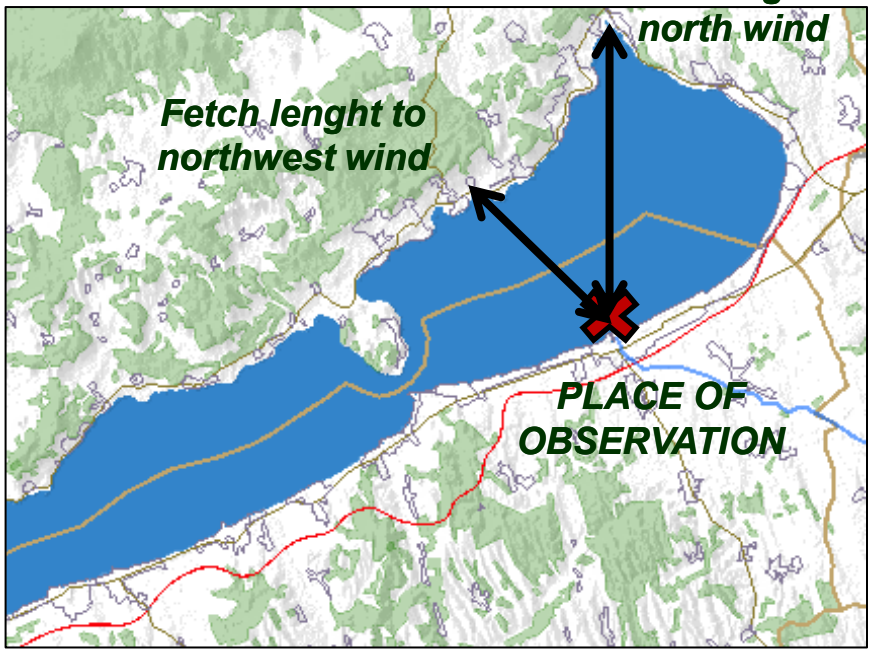
$e = 3{,}64cm$

NW, N wind directions

$e = 4{,}62cm$



Objective validation



$$\frac{gH_s}{u_A^2} = 0{,}283 \cdot \tanh\left(0{,}530\left(\frac{gh}{u_A^2}\right)^{0{,}75}\right) \tanh\left[\frac{0{,}00565\left(\frac{gF}{u_A^2}\right)^{0{,}5}}{\tanh\left(0{,}530\left(\frac{gh}{u_A^2}\right)^{0{,}75}\right)}\right],$$

If F is large

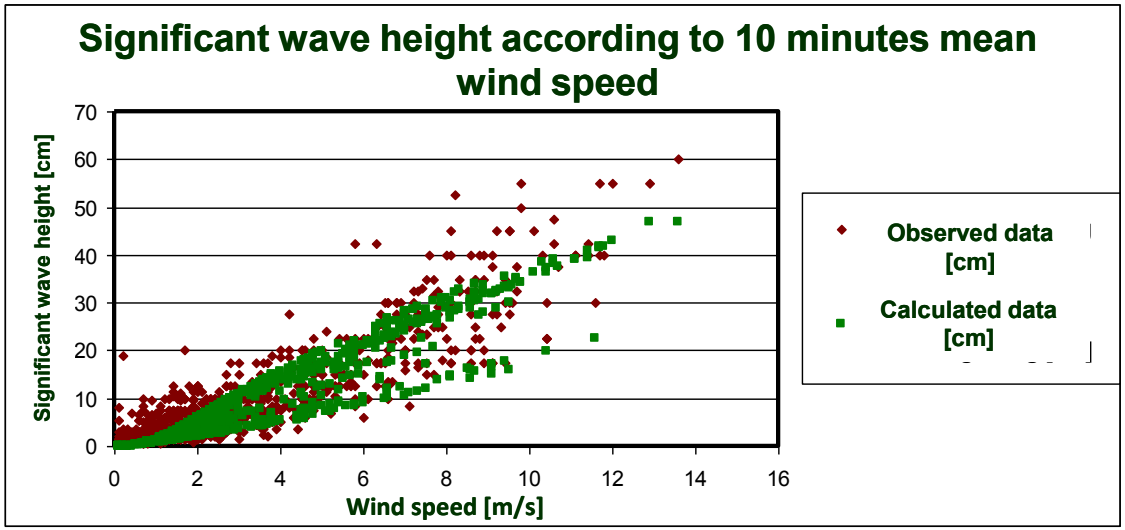
$$\frac{gH_s}{u_A^2} = 0{,}283 \cdot \tanh\left(0{,}530\left(\frac{gh}{u_A^2}\right)^{0{,}75}\right)$$

Validation of the formula based on measurements of wave heights on Great Lakes

Balaton is more shallow (~ 3 m)

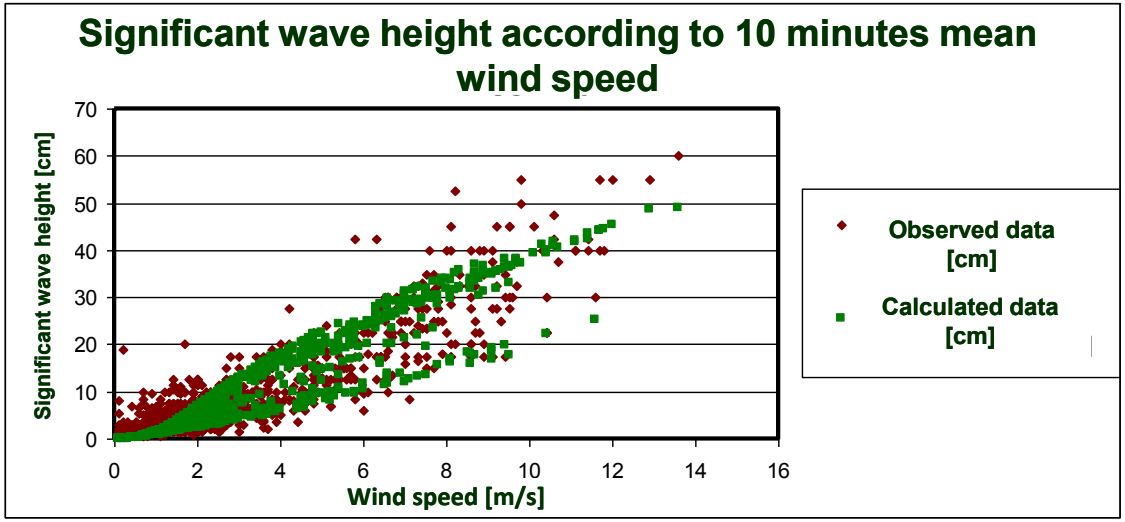
Original constants	**0,283**	**0,530**	**0,750**
Modified constants	**0,260**	**0,510**	**0,710**

Objective validation



$e = 3{,}64$

$e = 4{,}62$



$e = 3{,}38$

$e = 4{,}12$

Correlation between calculated wave height and wind speed / fetch lenght is similar to the correlation between the observed wave height and ws / Fl

Big differences – neglected interactions (adaptation time, wave relaxation…)

Summary

- The main objective of the short range weather modelling at Lake Balaton mainly consist of predicting dangerous phenomena over lake

- Downscaling method works well at ~500 m resolution applying special dynamical, physical (and numerical) model settings

- Case dependent, but generally weak sensitivity to LST in wind fields

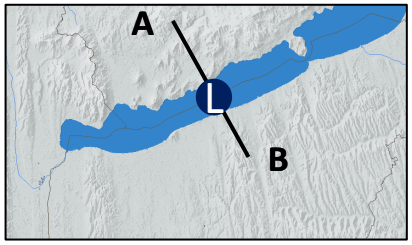
- The applied wave model is
  simple in point of calculation costs
  such as effective in making of warnings and special forecasts

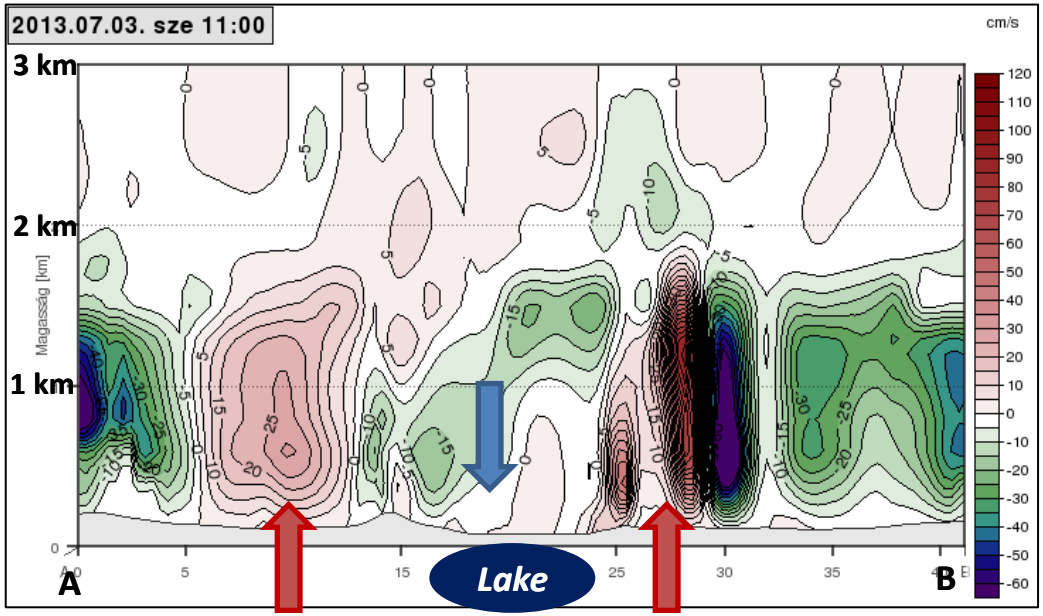
- Correlation between *calculated* wave height and wind speed / fetch lenght is similar to the
  correlation between *observed* wave height and wind speed / fetch lenght


Thank you for your attention!

Lake circulation – downscaling

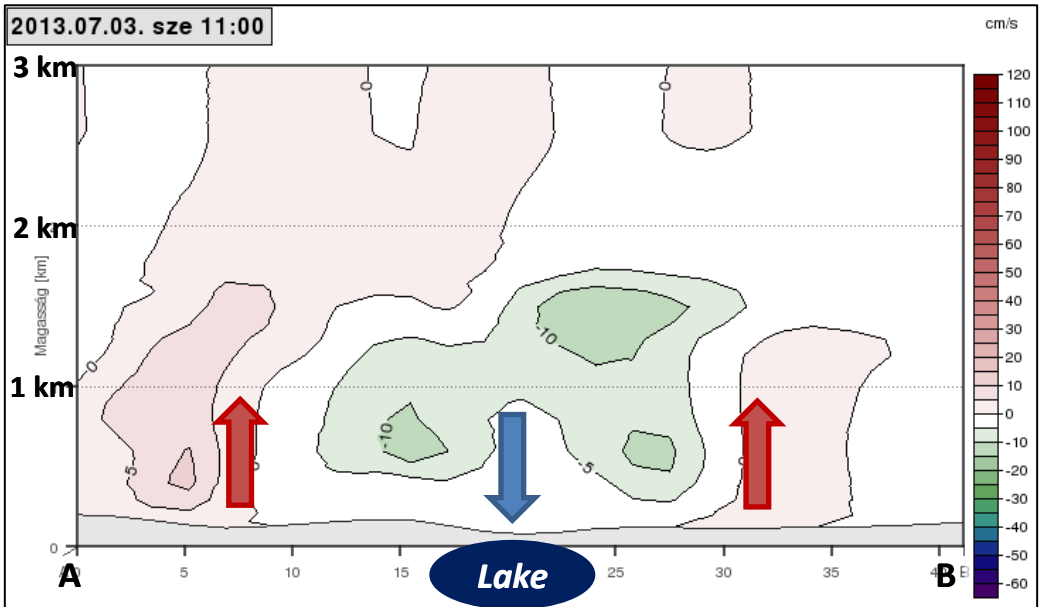
DX = 500 m





Motions on small scale

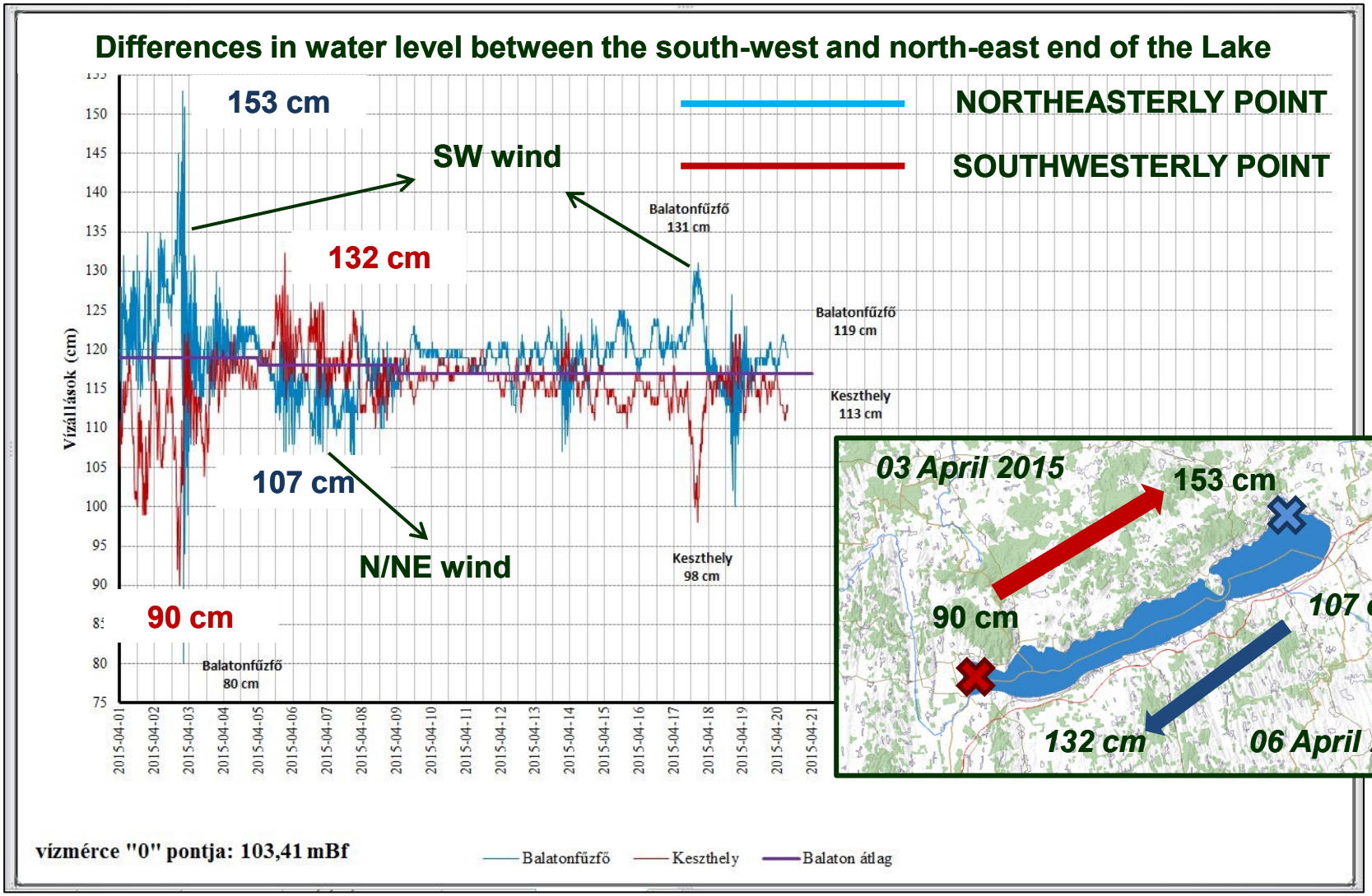
correspond to



DX = 2500 m

circulation at larger scale.
(not instabilities)

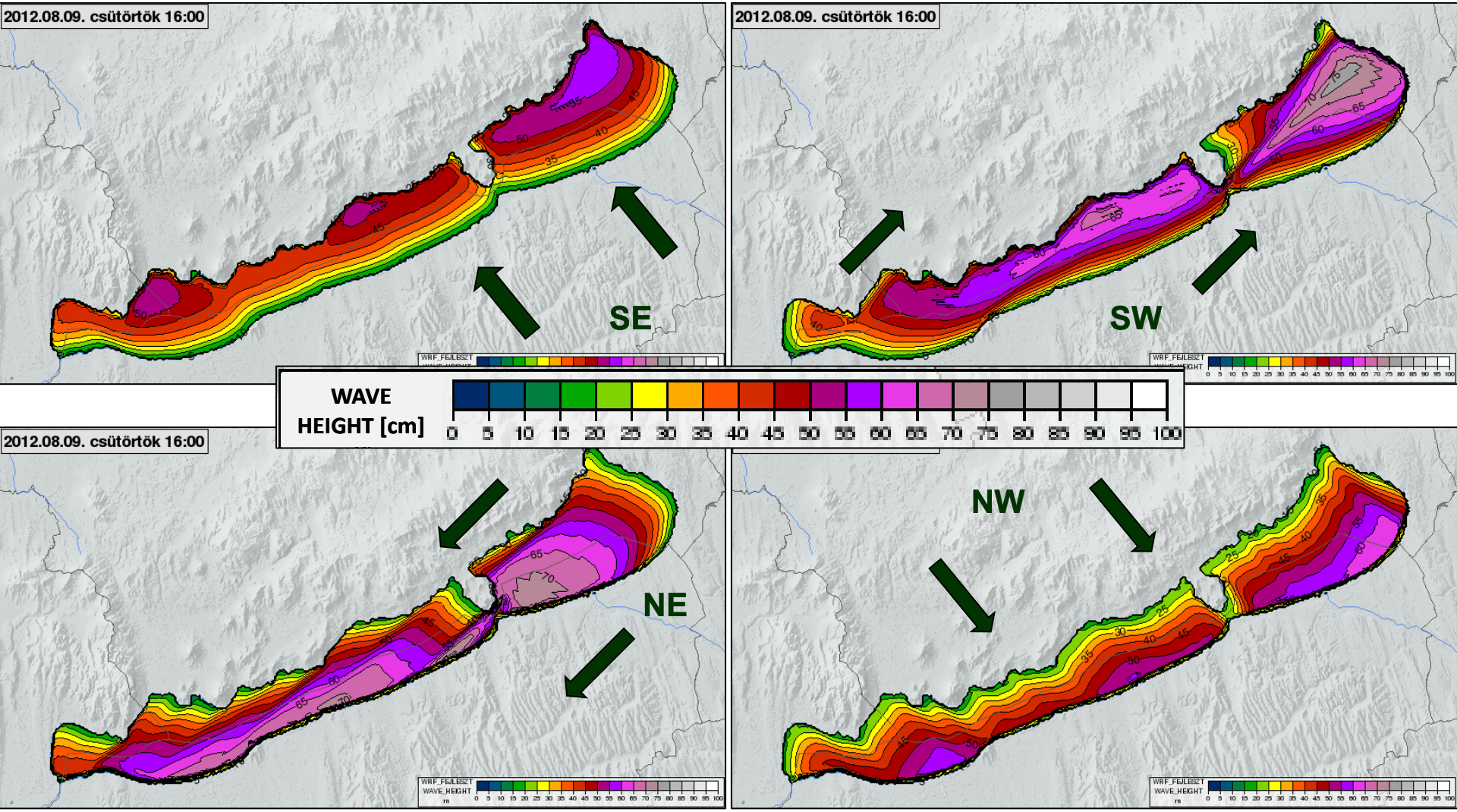
Effects on water level due to wind along lake axis



Subjective validation

Homogeneous wind speed and direction

*(**8 m/s** mean wind speed)*



Cold advection at meso-beta scale

Local increase of wind speed in west basin of Balaton