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WASEDA University

MODELLING PARAMETERS AND IMPACTS OF FOUR EXTRATROPICAL CYCLONES UNDER FUTURE CLIMATE SCENARIOS

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~7200 km
Estonia
Baltimore
Google Earth

Motivation & Objectives

- Extratropical cyclones (winter storms)
- North Atlantic Oscillation (NAO)
- Northerly tracks

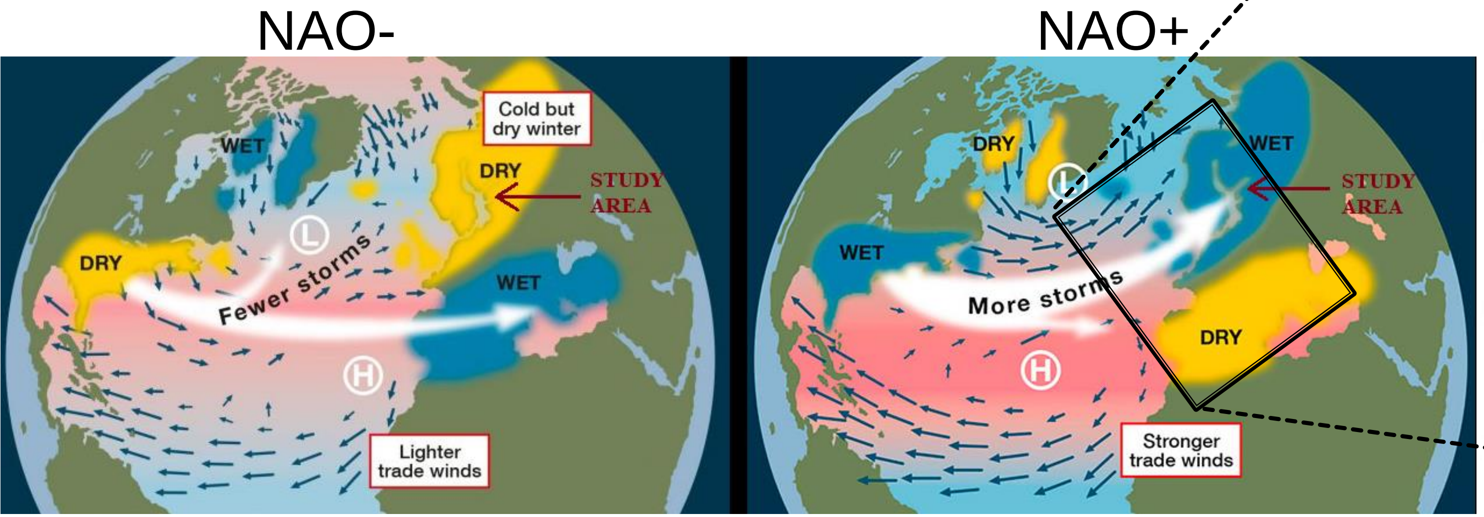

Fig 1. The effect of NAO phases to local weather patterns (image after: Maggie Nelson).

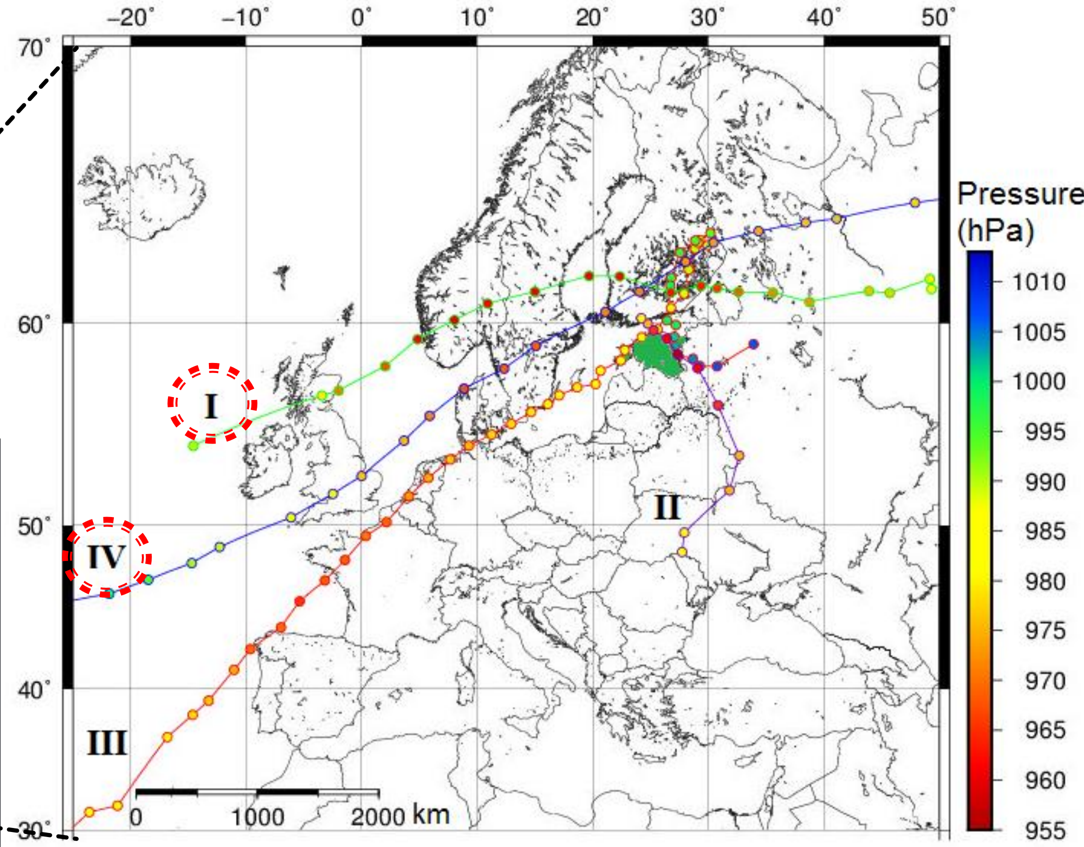

Fig 2. The tracks of 4 ETC's studied, where I - 2005-Jan; II – 2008-Nov; III – 2010-Feb; IV – 2013-Oct. Location of Estonia is coloured in green.

Baltic Sea:
semi-enclosed, tideless, shallow,
50-60N zone of Westerlies

Pärnu Bay:
small (20*25 km), tideless, max depth
14 m, SW exposed, storm-prone

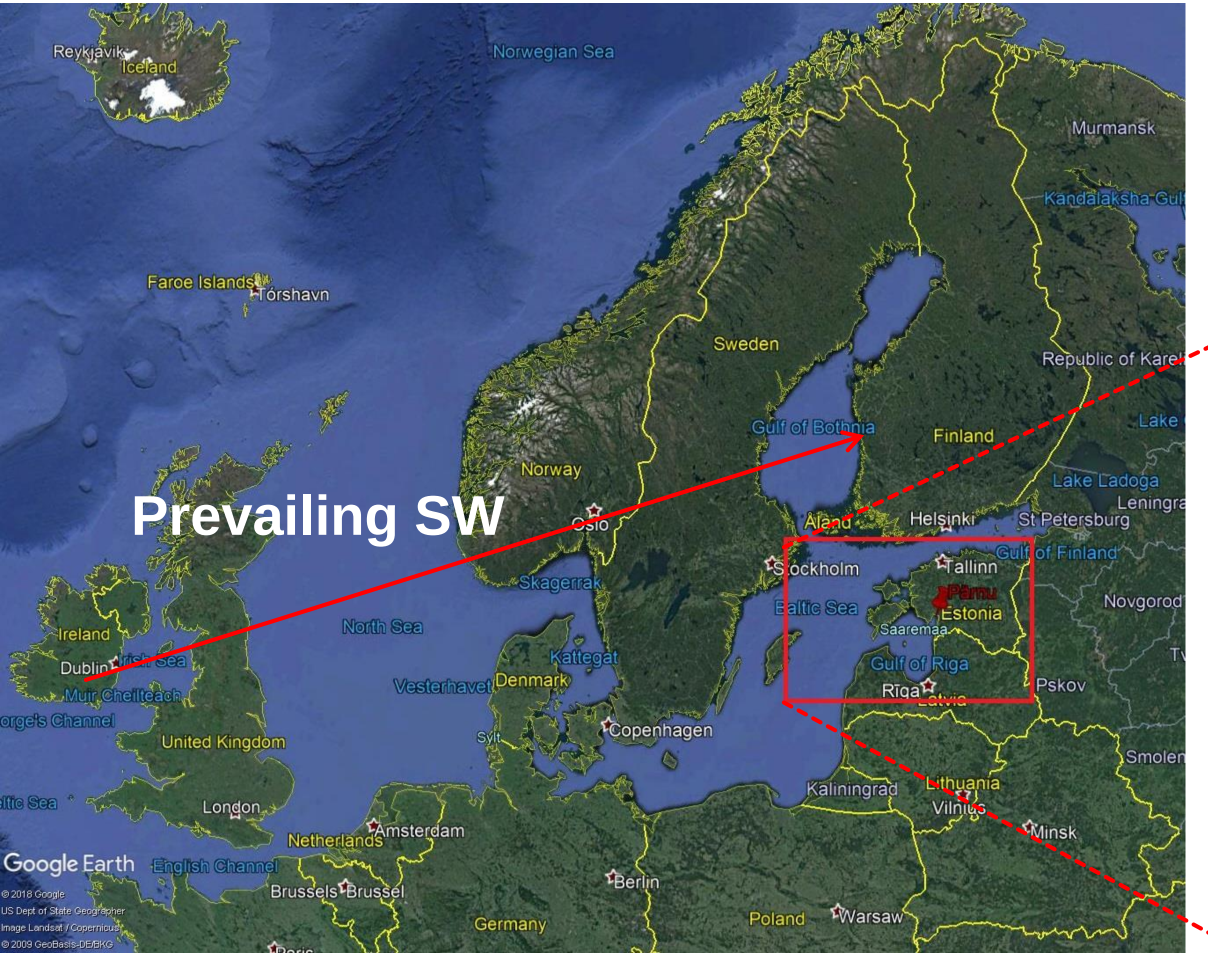

Fig 3. Snapshots showing the location of the study area (images: Google Earth).

Motivation & Objectives

- 2005 is the most extreme event on record (Fig 4 & 5).
- Mäll et al. (2017) studied the 2005 event under IPCC AR5 scenarios.
  - Storm did not get stronger
- Current study an extension to previous.

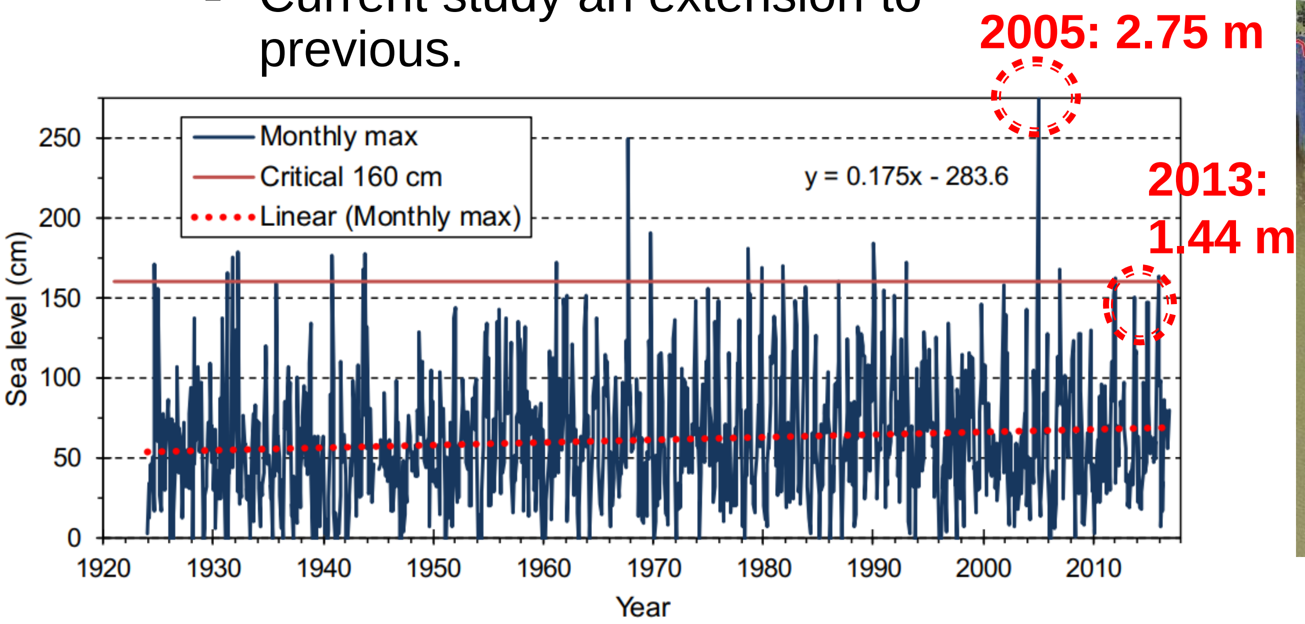

Fig 4. Variations in monthly maximum sea levels at Pärnu in 1923-2016. 160cm is the critical line for Pärnu.

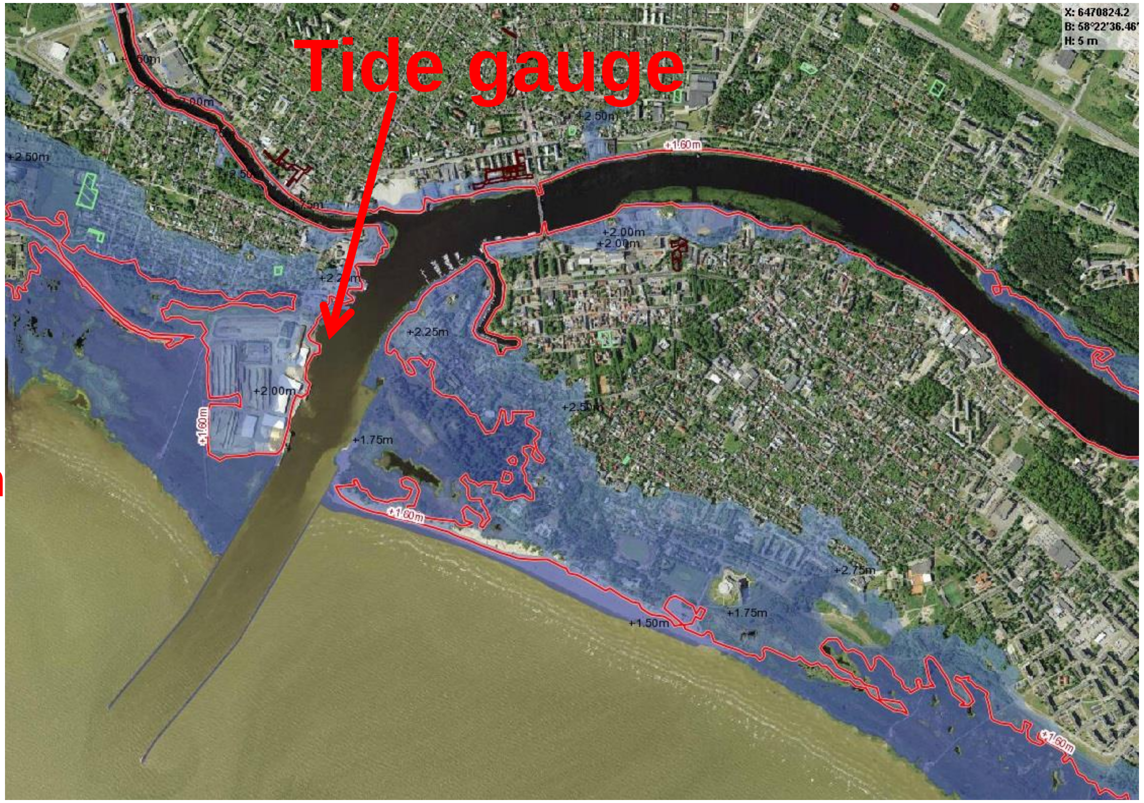

Fig 5. Pärnu city. The blue fill shows the inundation during 2005 storm, and red line marks the critical line of 160 cm. Images above are from the 2005 event (image credit: Estonian Land Board).

Methodology - Framework

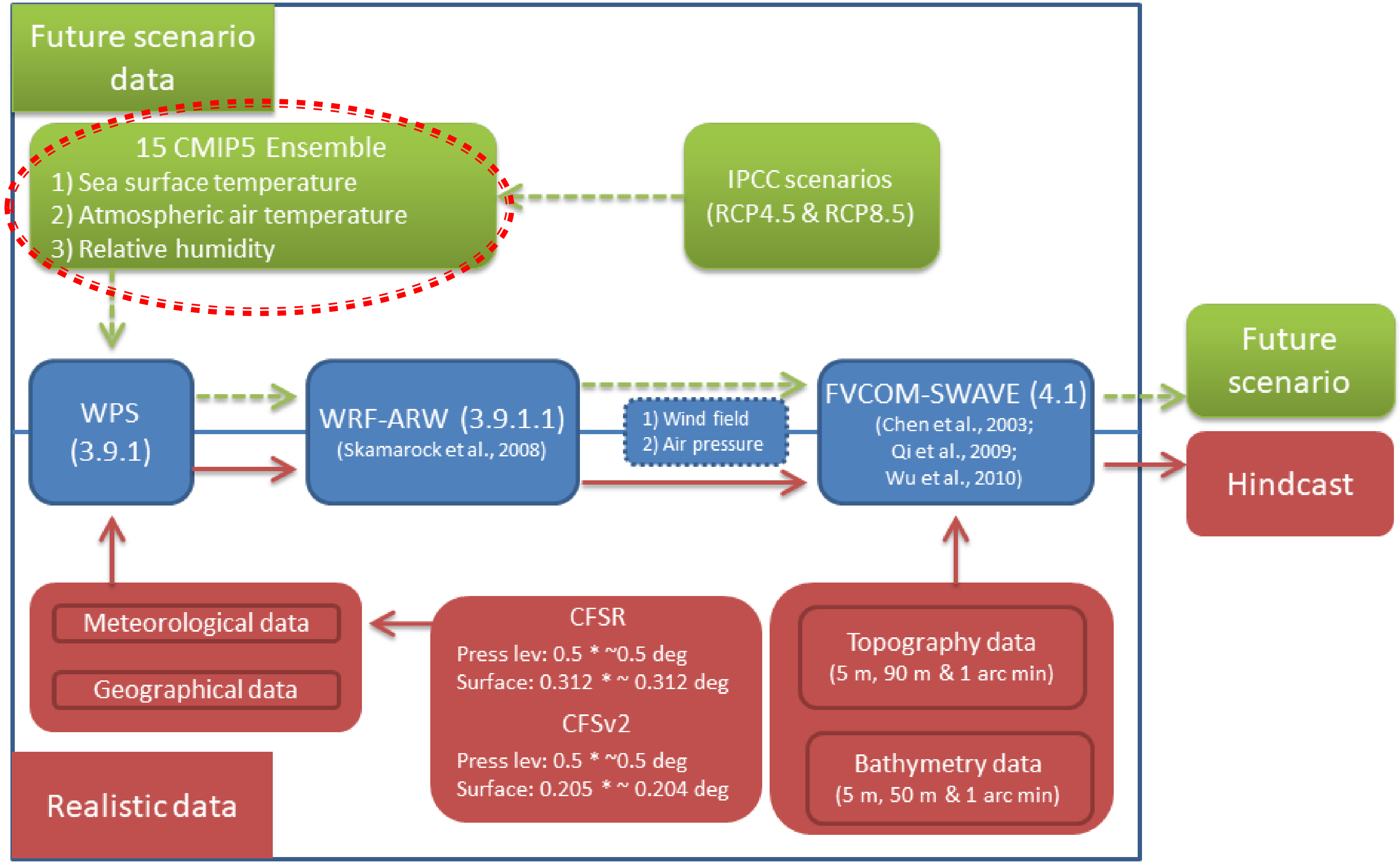

Fig 6. Flowchart of models and data used. **Blue** – the core models; **Red** – Initial data for hindcasting; **Green** – data for future simulations.

Methodology – WRF-ARW

Table 1. Initial and boundary conditions of WRF model.

	2005	2008	2010	2013
Domain 1 UTC (res. 20 km)	01/06 00:00 – 01/10 12:00 (108 h)	11/19 18:00 – 11/26 00:00 (150 h)	02/26 00:00 – 03/03 18:00 (138 h)	10/26 00:00 – 10/31 00:00 (120 h)
Domain 2 UTC (res. 4 km)	01/07 06:00 – 01/10 12:00 (78 h)	11/20 06:00 – 11/25 12:00 (126 h)	02/28 12:00 – 03/03 18:00 (78 h)	10/27 12:00 – 10/31 00:00 (84 h)
Domain 3 UTC (res. 0.8 km)	01/08 06:00 – 01/10 12:00 (54 h)	11/21 12:00 – 11/25 06:00 (90 h)	03/01 12:00 – 03/03 18:00 (54 h)	10/28 06:00 – 10/30 12:00 (54 h)
Time step	D01 - 120 seconds, D02 – 24 seconds, D03 – 4.8 seconds			
Map projection	Lambert conformal			
Pressure top; vertical layers	1 hPa; 61			
Micro physics	WRF Single-moment 6-class scheme (Hong & Lim 2006)			
Planetary boundary layer	Yonsei University Scheme; YSU (Hong & Lim 2006)			
Cumulus parametarization	Grell-Freitas Ensemble Scheme (Grell & Freitas 2014)			
Shortwave and longwave	RRTMG Shortwave and Longwave Schemes (Iacono et al., 2008)			
Land surface option	Unified Noah Land Surface Model (Tewari et al., 2004)			
Surface Layer option	MM5 Similarity Scheme (Paulson 2017, Dyer & Hicks 1970, Webb 1970, Zhang & Anthes 1982, Beljaars 1994)			
Forcing data	Climate Forecast System Reanalysis (CFSR)			CFSv2
Forcing data res.	Pressure levels (1): 0.5 * 0.5 deg ; Surface (2): 0.312 * ~0.312 deg			(1): 0.5 * 0.5 deg (2): 0.205 * ~0.204 deg

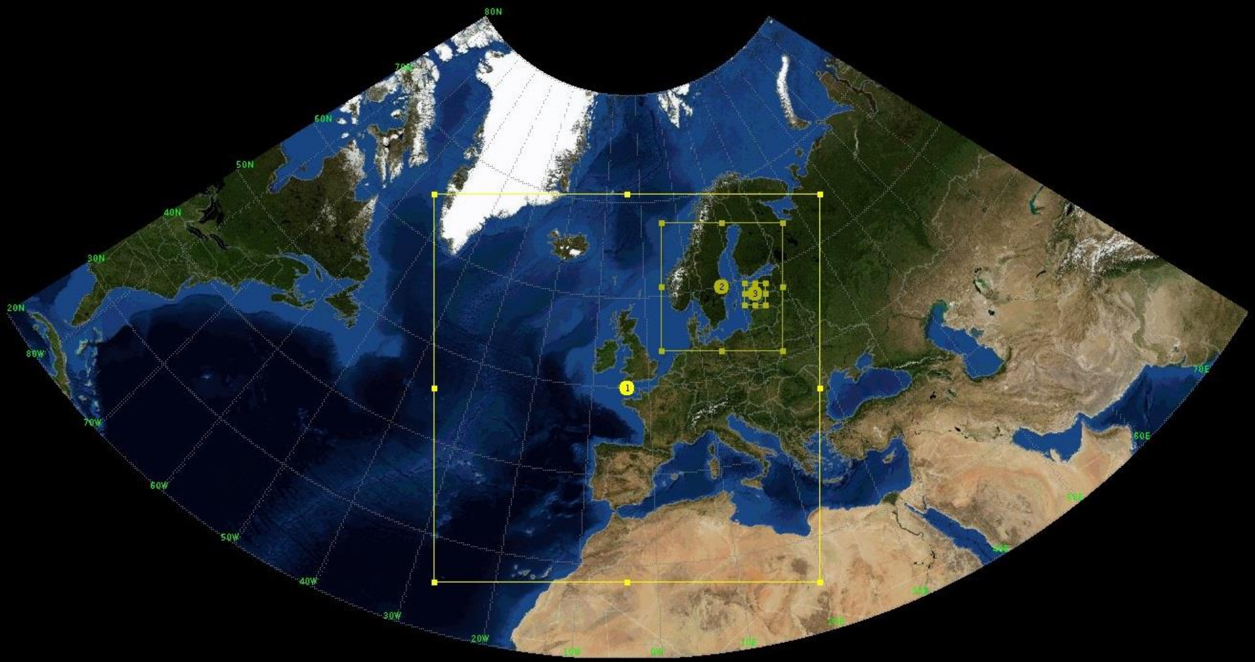

Fig 7. Simulation domains for the 2005, 2010 and 2013 cases.

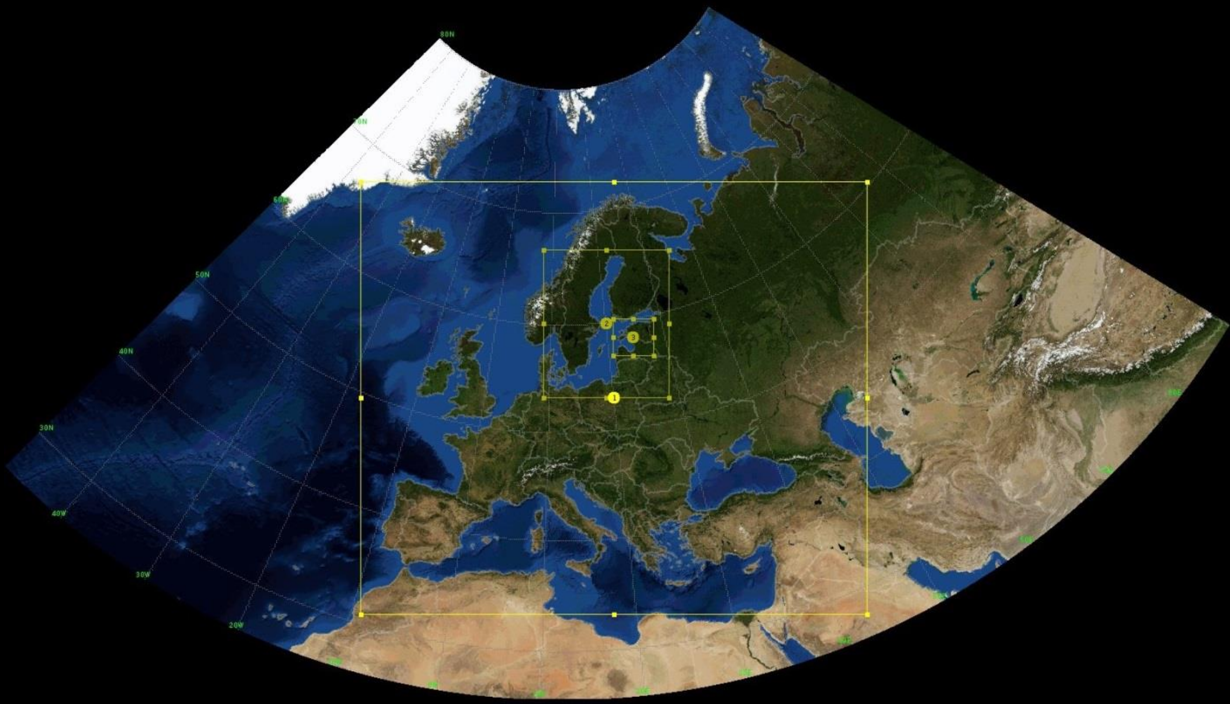

Fig 8. Simulation domains for the 2008 case.

Methodology – FVCOM-SWAVE

Table 2. Initial and boundary conditions of FVCOM-SWAVE model.

	2005	2013
Simulation time	01/08 06:00 – 01/10 12:00 UTC (54 h)	10/28 06:00 – 10/30 12:00 UTC (54 h)
Calculation time step	Sea level – 2 seconds; Significant wave height – 30 seconds	
Nodes	63 189	
Cells	123 533	
Mesh size	50 – 2000 m	
Coastline data (Estonian Land Board; SRTM90; ETOPO1)	Pärnu City – 5 m; Pärnu Bay – 90 m; Rest of the study area – 1 arc min.	
Bathymetry data (Estonian Maritime Administration; ETOPO1)	Pärnu Bay and Pärnu River – 5m; Gulf of Riga, Väinameri and Irbe Strait – 50 m; Rest of the study area 1 arc min.	
SWAVE parameters		
Frequency range (Hz)	0.05 -0.5	
Direction	Full circle	
Bottom friction	Madsen formulation (Madsen et al., 1988)	
Friction parameter	0.067	
Min water depth (m)	0.05	

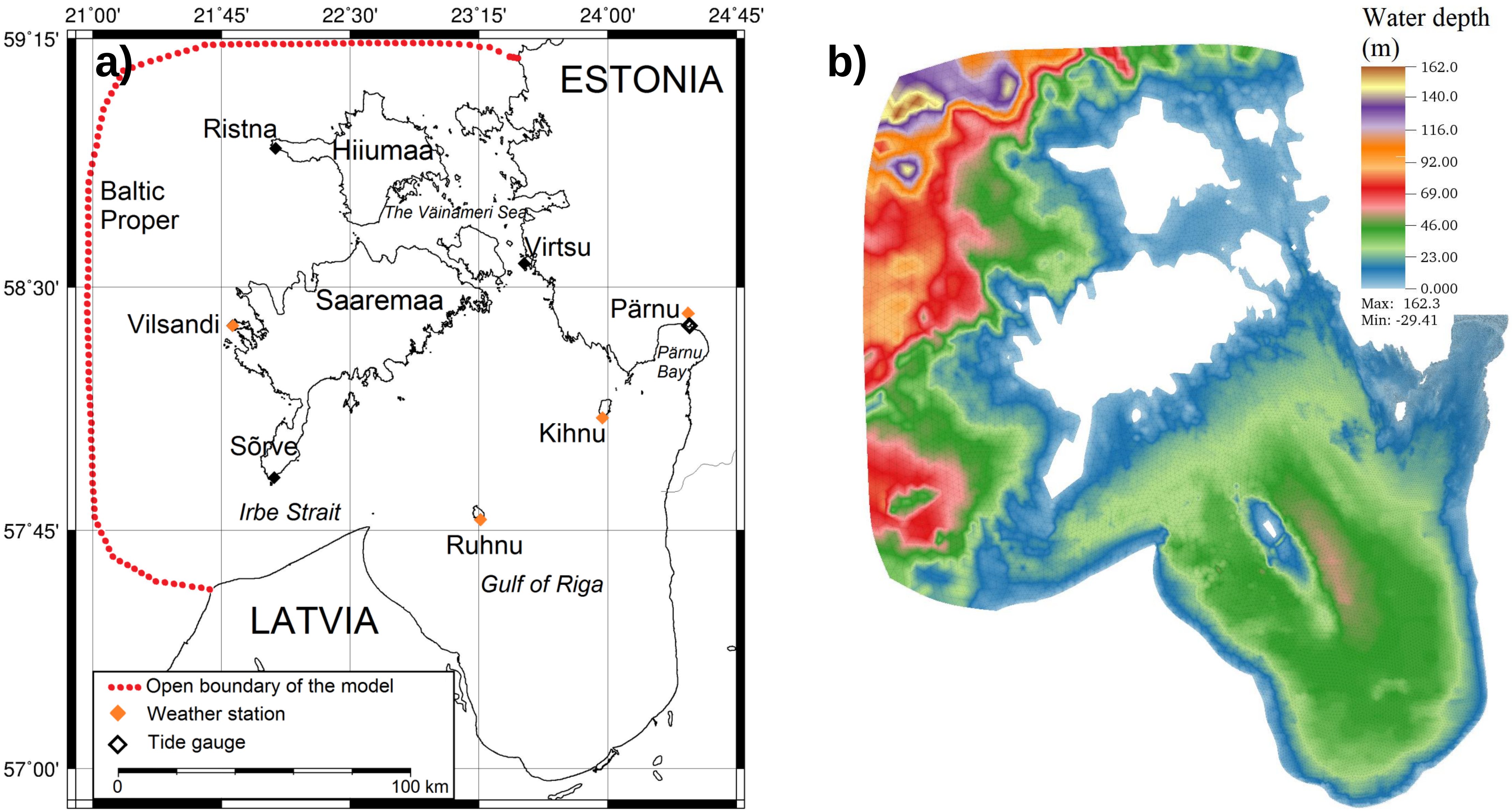

Fig 9. The simulation domain of FVCOM-SWAVE, where a) shows the open boundary and location of station used for hindcasting and b) shows the water depth plotted over bathymetry mesh.

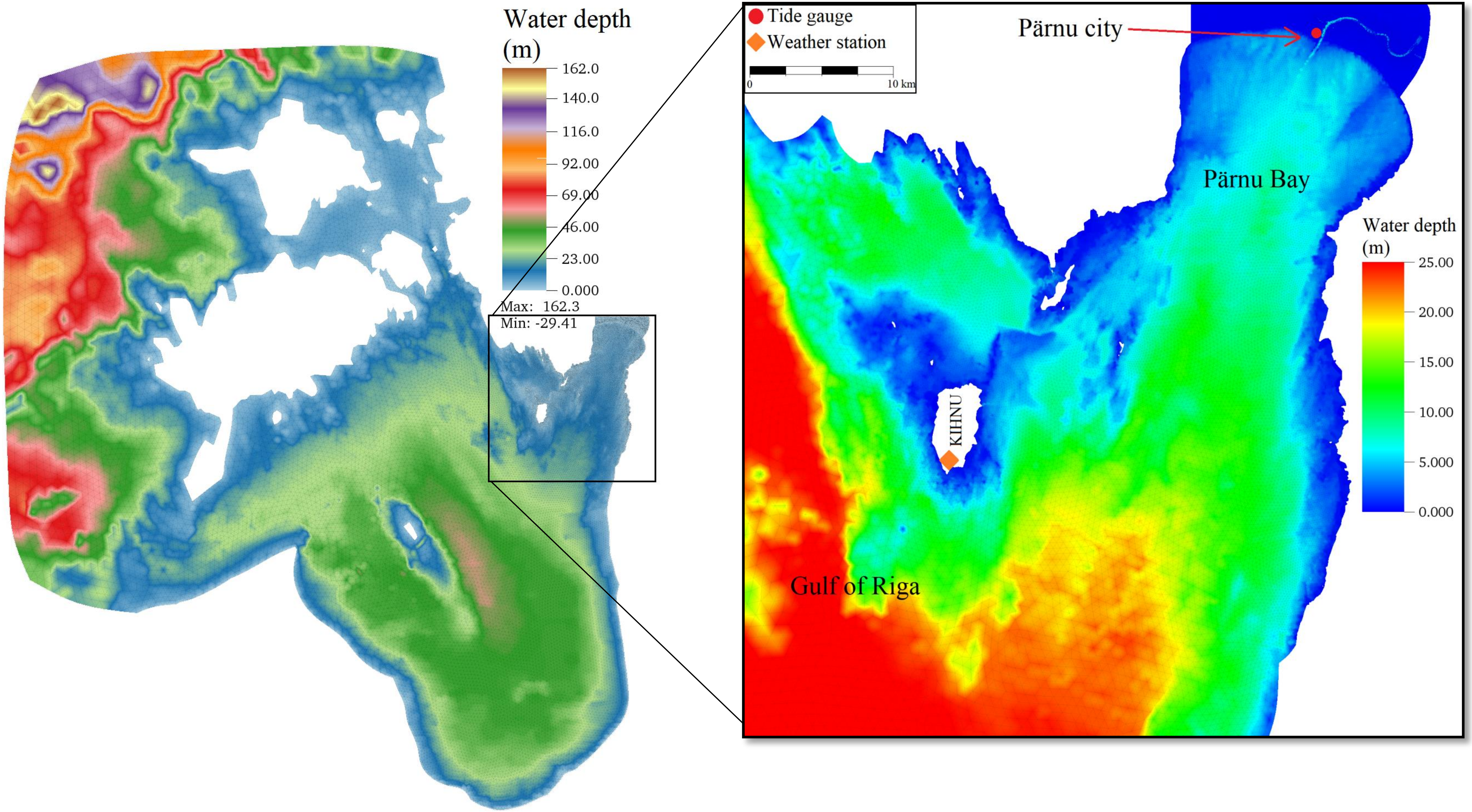

Fig 10. The bathymetry of FVCOM-SWAVE. Right hand image shows locations of measurement stations.

Methodology – Future scenarios (CMIP5)

- 15 selected GCM
  - RCP8.5
  - RCP4.5 (14 GCM)
- Future period
  - 2081-2099
- Control period
  - 2006-2015
- Interpolation
  - Future-Control difference

Table 3. Selected GCM's for future scenario calculations.

Model name	Model Institution	Atmospheric resolution: Horizontal	Atmospheric resolution: Vertical levels	Ensemble number	Ensemble name
ACCESS1.0	Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	192 x 145 (N96)	38	1	r1i1p1
ACCESS1.3				1	r1i1p1
BCC-CSM1.1 (m)	Beijing Climate Center, China Meteorological Administration	T106	26	1	r1i1p1
CCSM4	National Centre for Atmospheric Research	0.9 x 1.25 deg	27	6	r1i1p1, r2i1p1, r3i1p1, r4i1p1, r5i1p1, r6i1p1
CESM1(BGC)	NFS-DOE-NCAR	0.9 x 1.25 deg	27	1	r1i1p1
CESM1(CAM5)				3	r1i1p1, r2i1p1, r3i1p1
CMCC-CM	Centre Euro-Mediterraneo per I Cambiamenti Climatici	0.75 x 0.75 (T159)	31	1	r1i1p1
EC-EARTH	EC-EARTH consortium	1.125 long. Spacing, T159L62	62	4	r1i1p1, r6i1p1, r8i1p1, r12i1p1
GISS-E2-H-CC	NASA Goddard Institute for Space Studies	Nominally 1 deg	40	1	r1i1p1
GISS-E2-R-CC				1	r1i1p1
HadGEM2-AO	National Institute of Meteorological Research/Korea Meteorological Administration	1.875long x 1.25lat (N96)	60	1	r1i1p1
HadGEM2-CC	UK Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	1.875long x 1.25lat (N96)	60	3	r1i1p1, r2i1p1, r3i1p1
HadGEM2-ES			38	4	r1i1p1, r2i1p1, r3i1p1, r4i1p1
MRI-CGCM3	Meteorological Research Institute	320 x 160 (TL159)	48	1	r1i1p1
MRI-ESM1				1	r1i1p1

Results – Hindcast 2005 (Wind and sea level)

- Observed surge max: 2.75 m at 9 January 04:00 UTC
- Simulated surge max: 2.41 m at 9 January 00:20 UTC

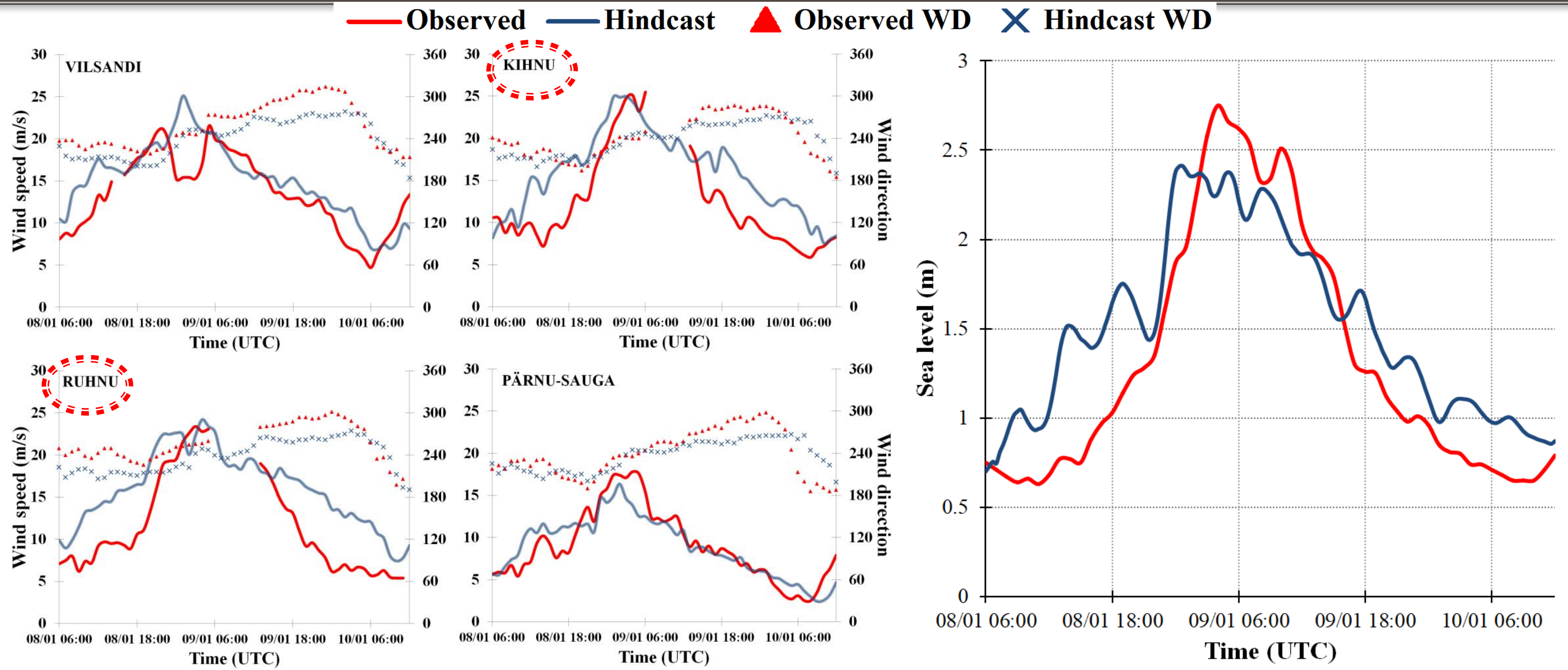

Fig 11. Hindcast results for 2005 wind (four left) and surge (right).

Results – Hindcast 2013 (Wind and sea level)

- Observed surge max: 1.44 m at 29-Oct 07:00 UTC
- Simulated surge max: 1.19 m at 29-Oct 05:00 UTC

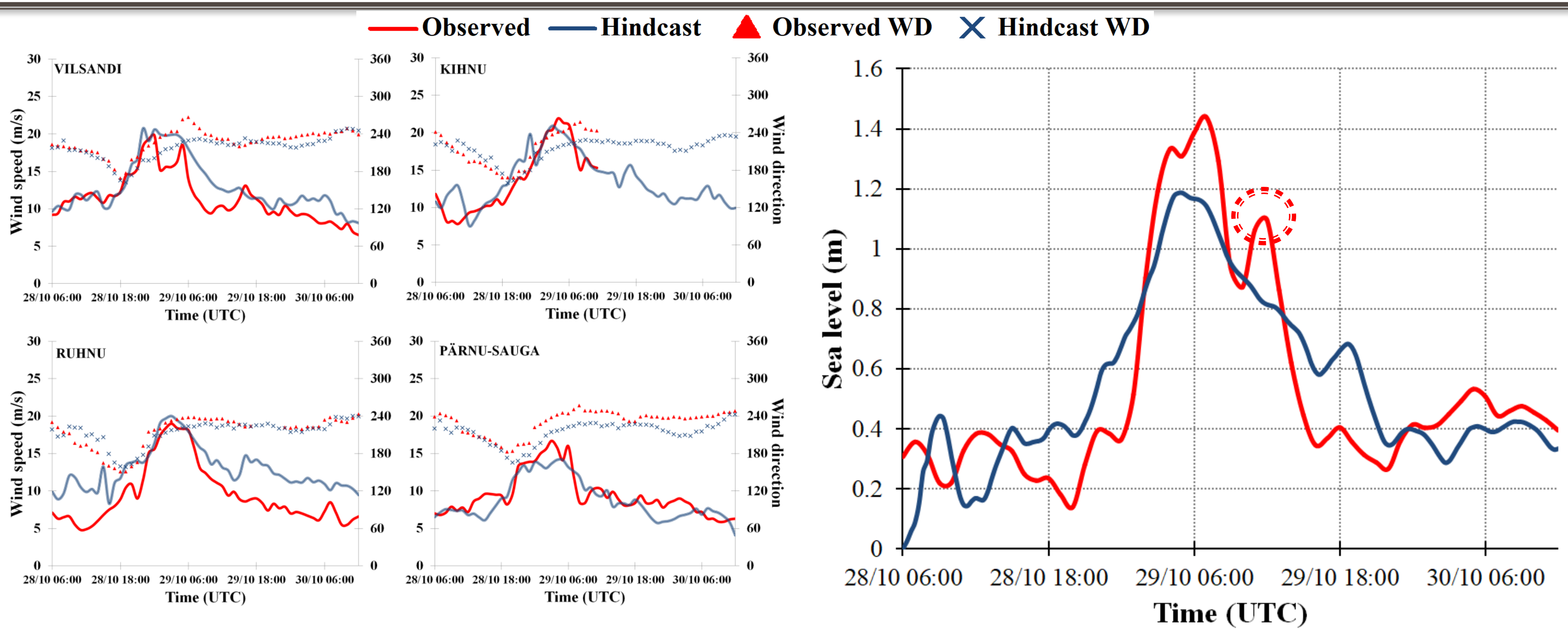

Fig 12. Hindcast results for 2013 wind (four left) and surge (right).

Results – GCM output

- SST
  - Twofold increase between scenarios
- AAT
  - ~ 2 K increase for RCP4.5
  - ~ 4 K increase for RCP8.5
- RH
  - More mixed
  - Negative up to 300 hPa
  - Positive up from 350-250 hPa

Table 4. Sea surface temperature (K) GCM ensemble mean increase over WRF d01.

Scenario	2005	2008	2010	2013
RCP 4.5	1.10	1.47	1.07	1.35
RCP 8.5	2.24	3.03	2.15	2.79

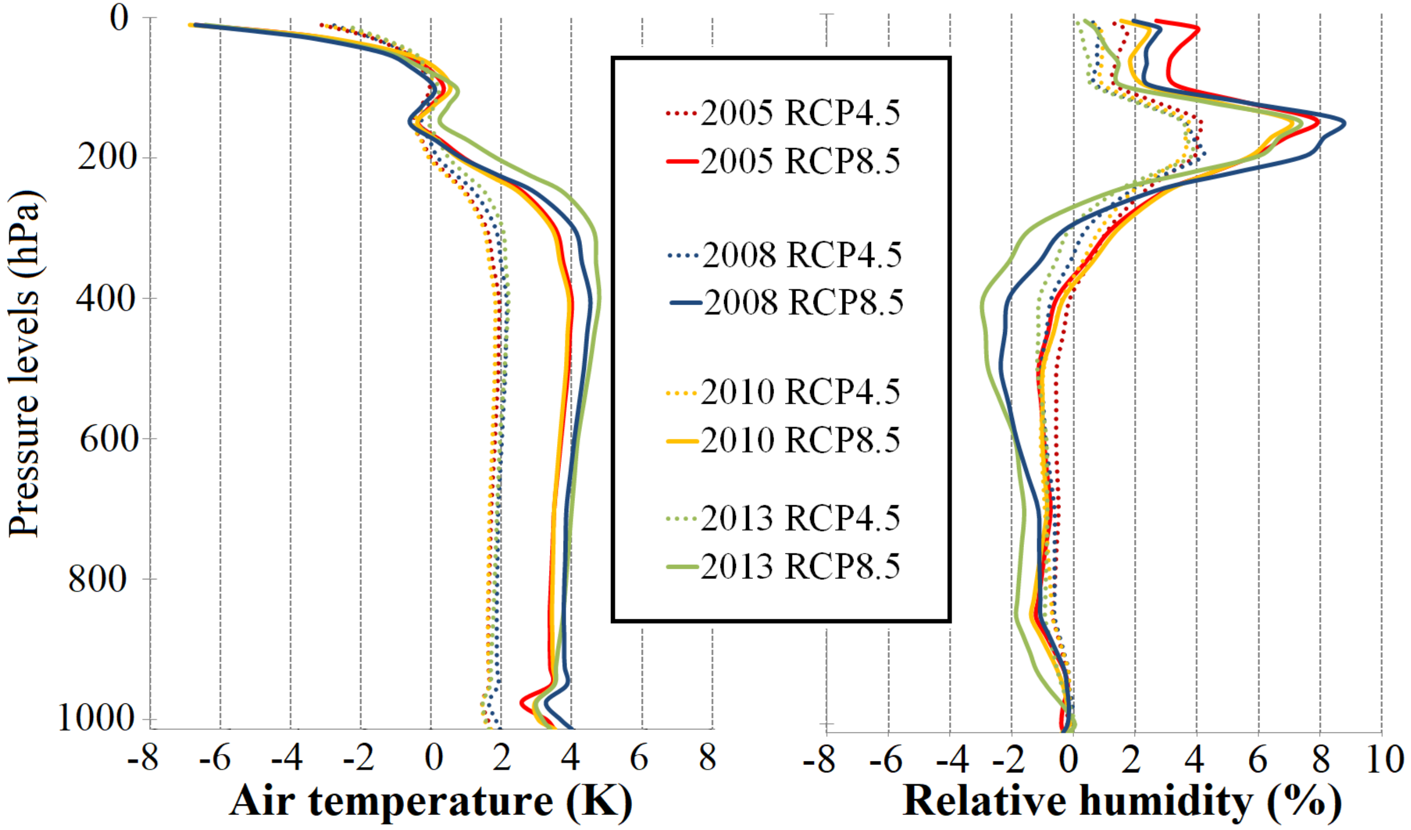

Fig 13. AAT (left) and RH (right) GCM ensemble means over WRF D01.

Results – 2005 Future (Wind & sea level)

Hindcast max: 2.41 m; RCP4.5 max: 2.7 m; RCP8.5 max: 2.88 m

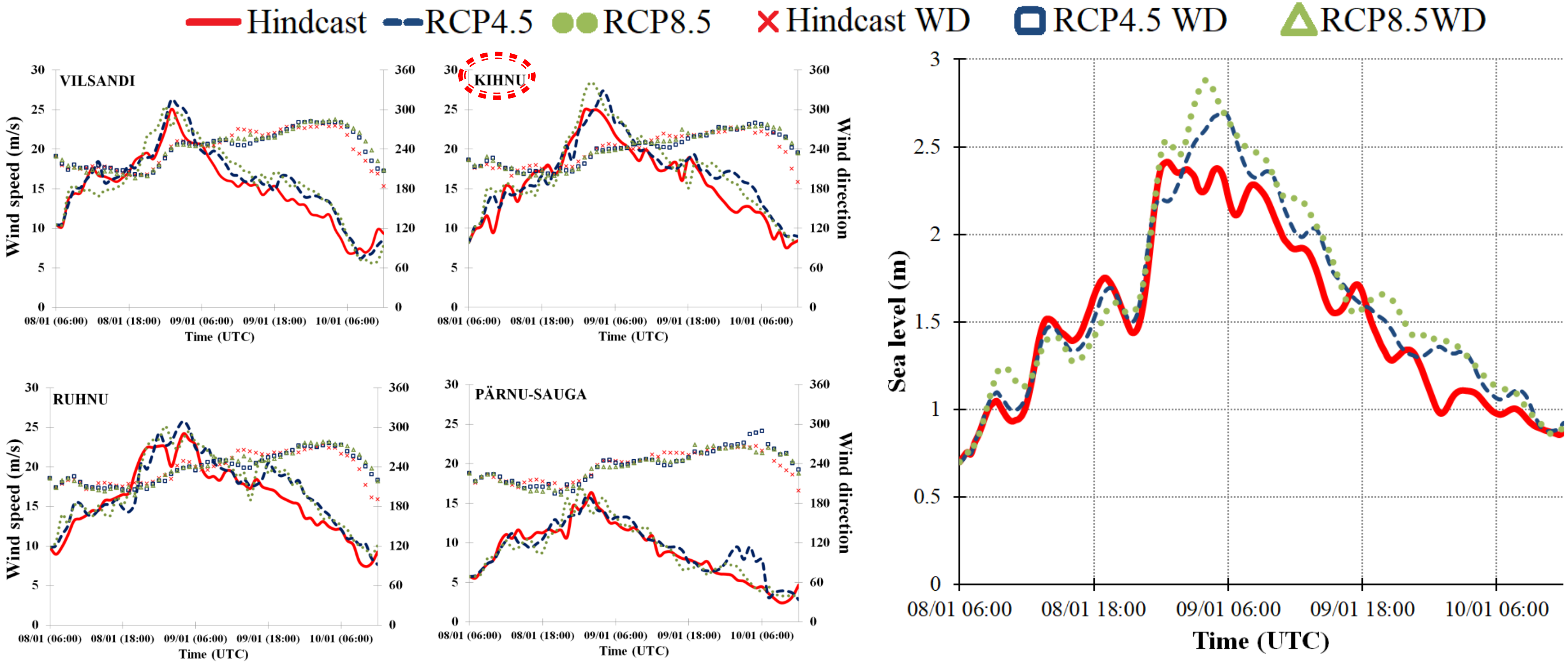

Fig 14. Hindcast and future wind speed, direction and surge comparison.

Results – 2013 Future (Wind & sea level)

Hindcast max: 1.19 m; RCP4.5 max: 1.25 m; RCP8.5 max: 1.5 m

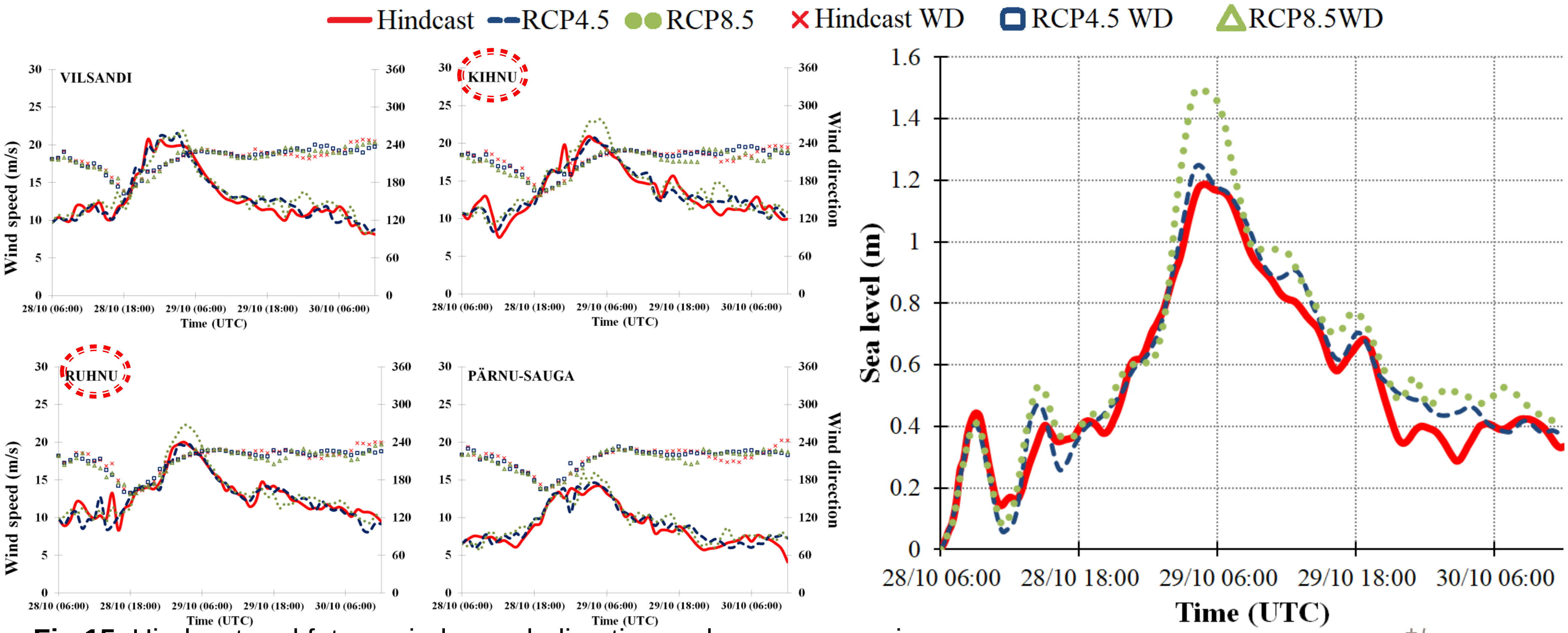

Fig 15. Hindcast and future wind speed, direction and surge comparison.

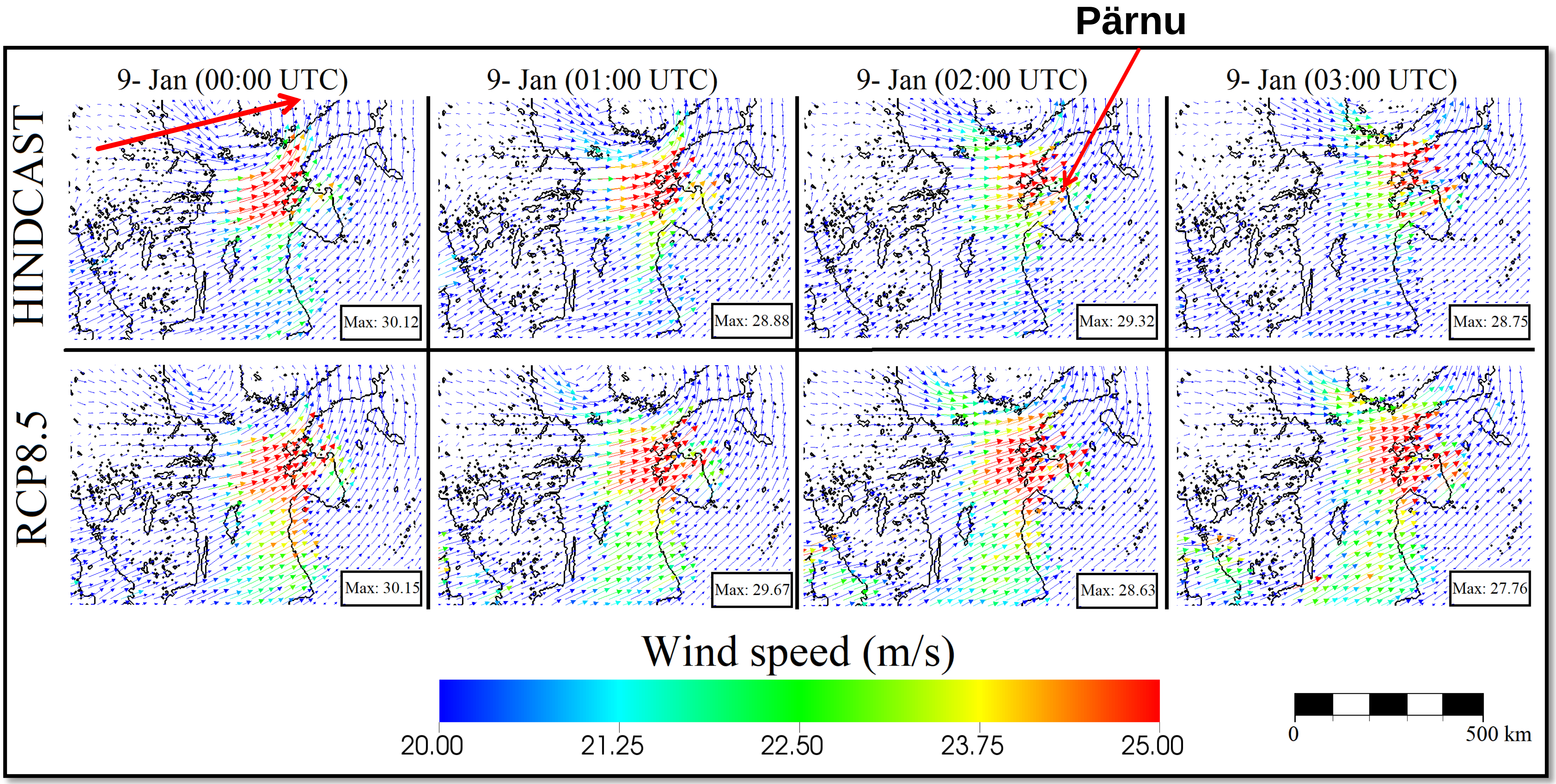

Fig 16. Wind field comparison between Hindcast and RCP8.5 simulation for the 2005 event. The four time-steps represent the hours leading to the maximum surge at Pärnu.

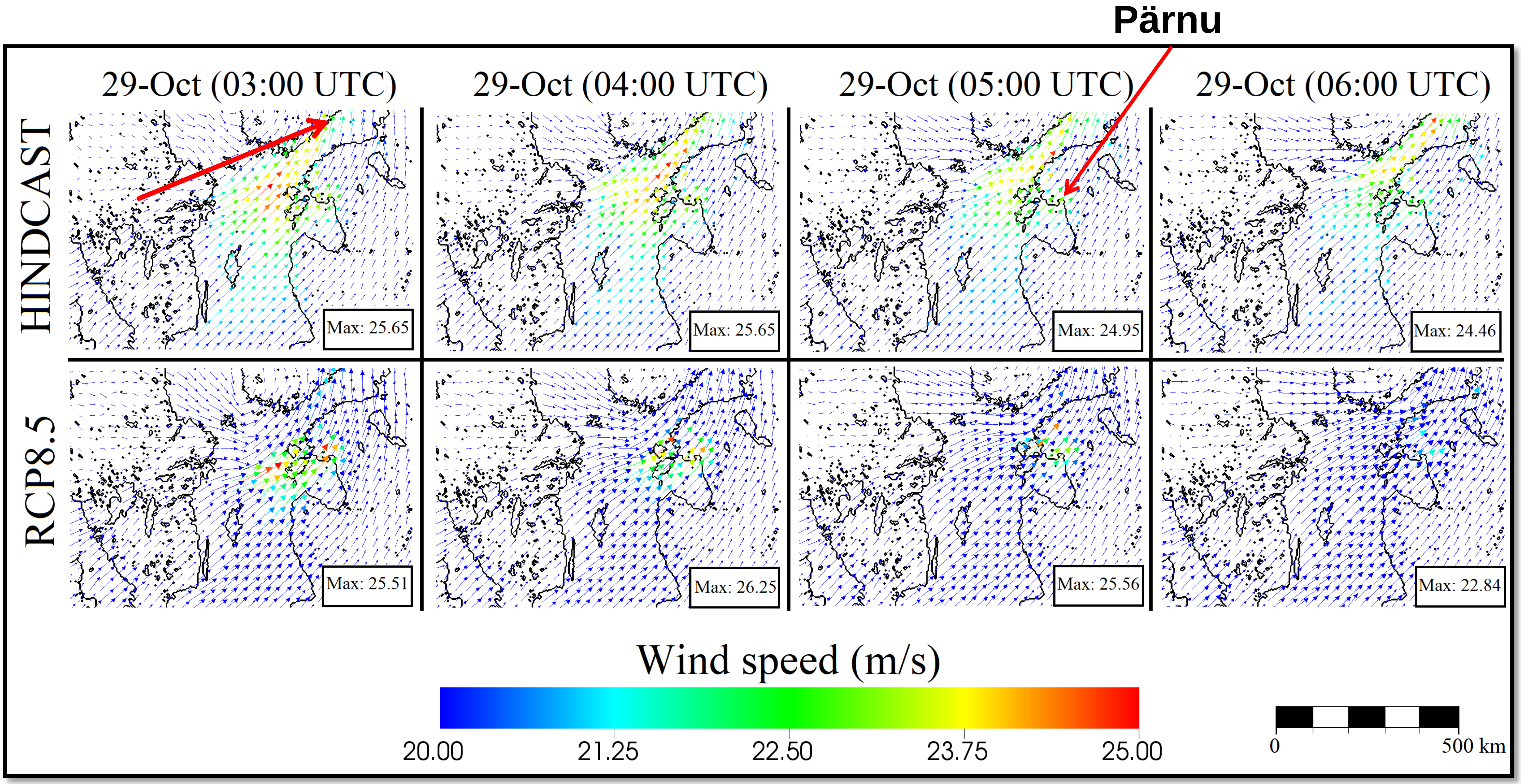

Fig 17. Wind field comparison between Hindcast and RCP8.5 simulation for the 2013 event. The four time-steps represent the hours leading to the maximum surge at Pärnu.

Coastal zone management in Pärnu

- Different storm surge related adaptation and response measures have been widely discussed (Fig. 18).
- Currently relied on soft measures / smart solutions.

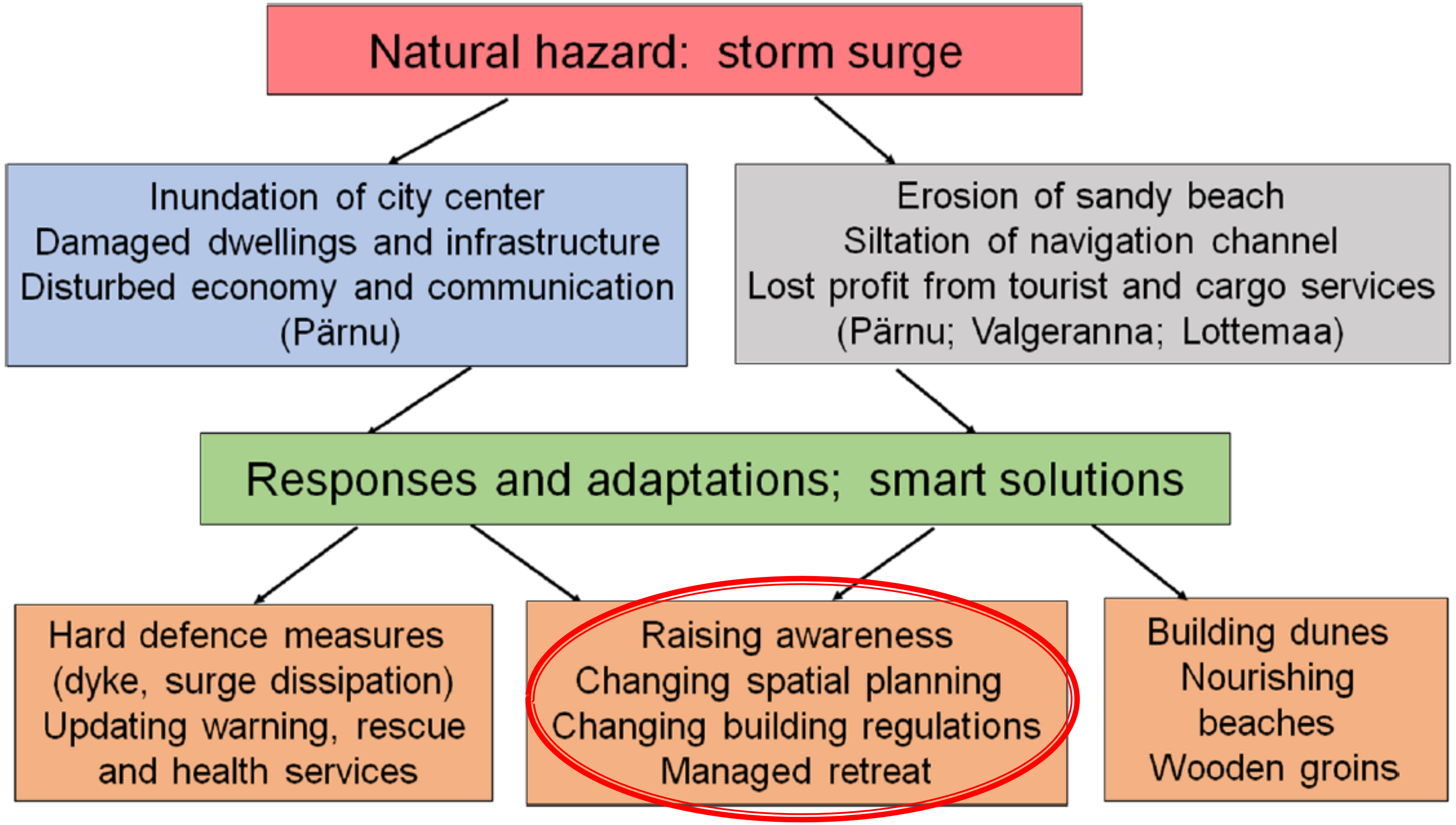

Fig 18. Conceptual model of Pärnu Bay study area. **Grey** boxes – problems related to erosion and siltation, **Blue** boxes – inundation problems, **Brown** boxes – the most suitable response (after Tõnisson et al., 2018).

Conclusions

- Two storm surge inducing extratropical cyclones (ETC) in Estonian waters were studied under future climate change scenarios (2100 RCP4.5/RCP8.5)

- Numerical models (WRF, FVCOM-SWAVE) were able to capture these events with relatively good accuracy.
  - Wind peaks were well captured, however with some time lag. Mid-level values at some locations overestimated.
  - Surge heights were underestimated for both 2005 and 2013 ETCs.

- Future simulations showed some mixed results for wind speed (almost no change in direction):
  - Maximum wind speed values (against hindcast) had minor changes
  - 2005: increase in strong wind (≥ 20 m/s) area coverage, with southward extension.
  - 2013: area coverage of strong winds (≥ 20 m/s) decreased, however stronger concentrated area.

- Future sea level values showed increase for both ETC cases:
  - 2005: 16.7% increase, from 2.41 m to 2.88 m
  - 2013: 20.7% increase, from 1.19 m to 1.5 m

Thank you for your attention!

References

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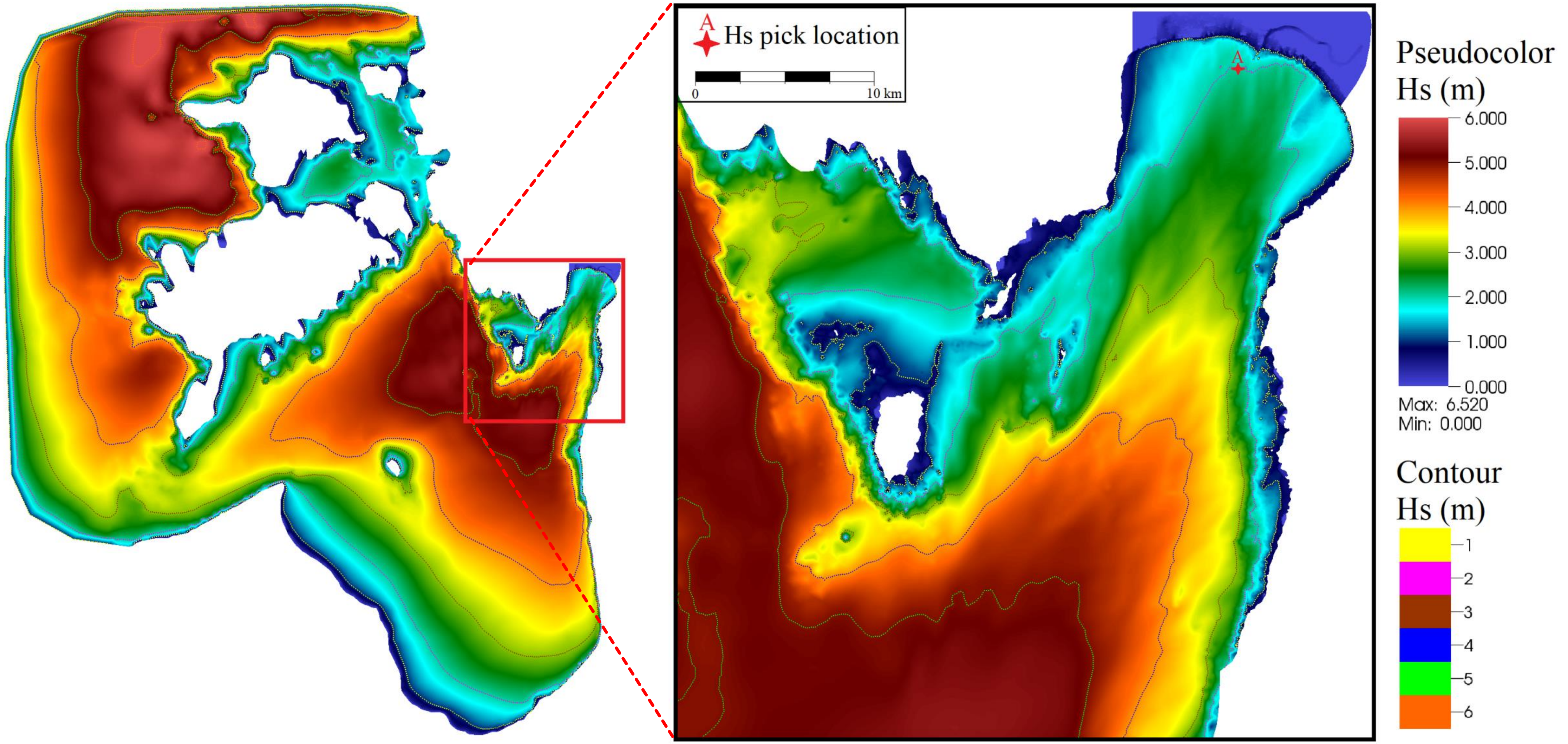
- Wu , L., Chen, C., Guo, P. et al. J Ocean Univ. China (2011). DOI 10.1007/s11802-011-1788-3

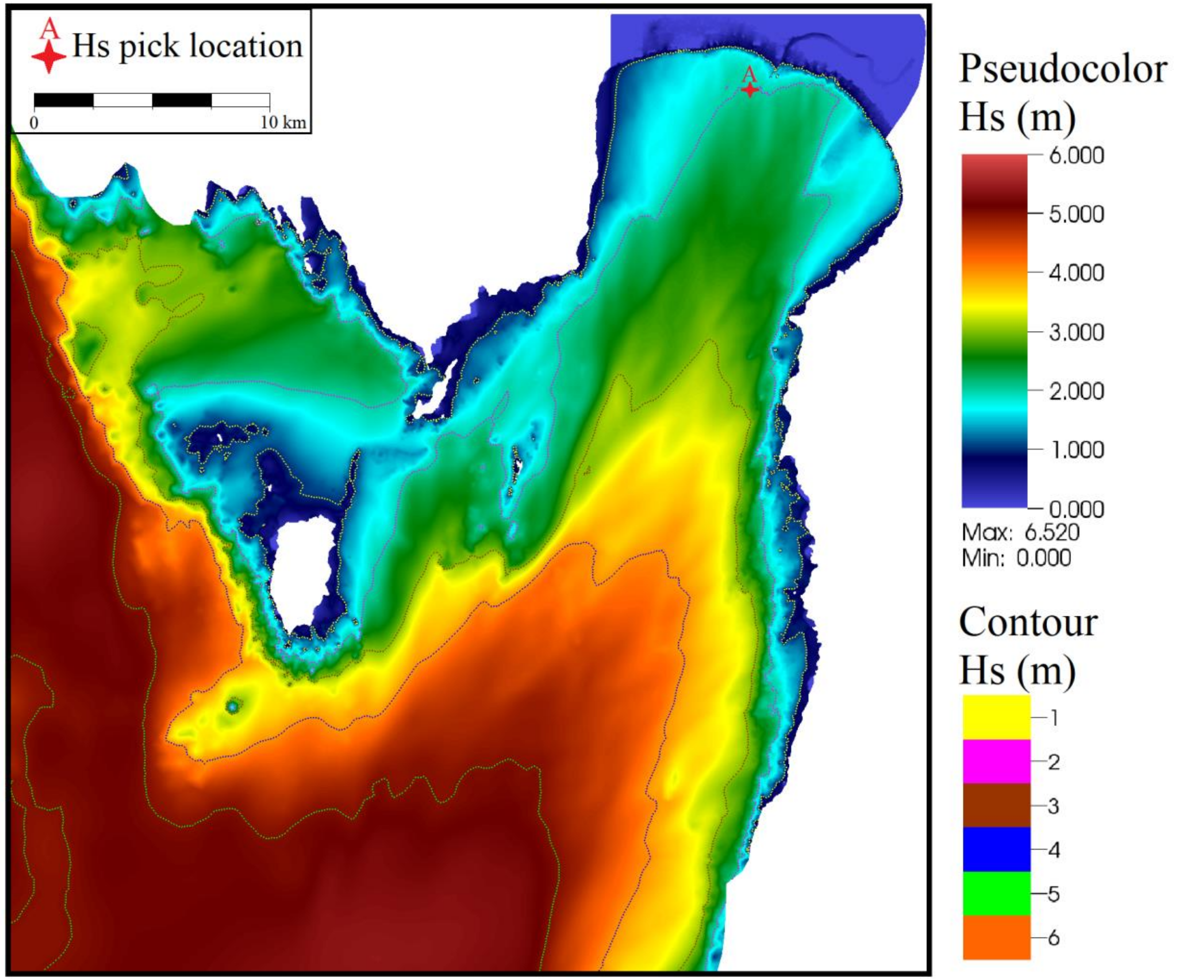
Appendix

Results - Significant wave height *(no validation data)*

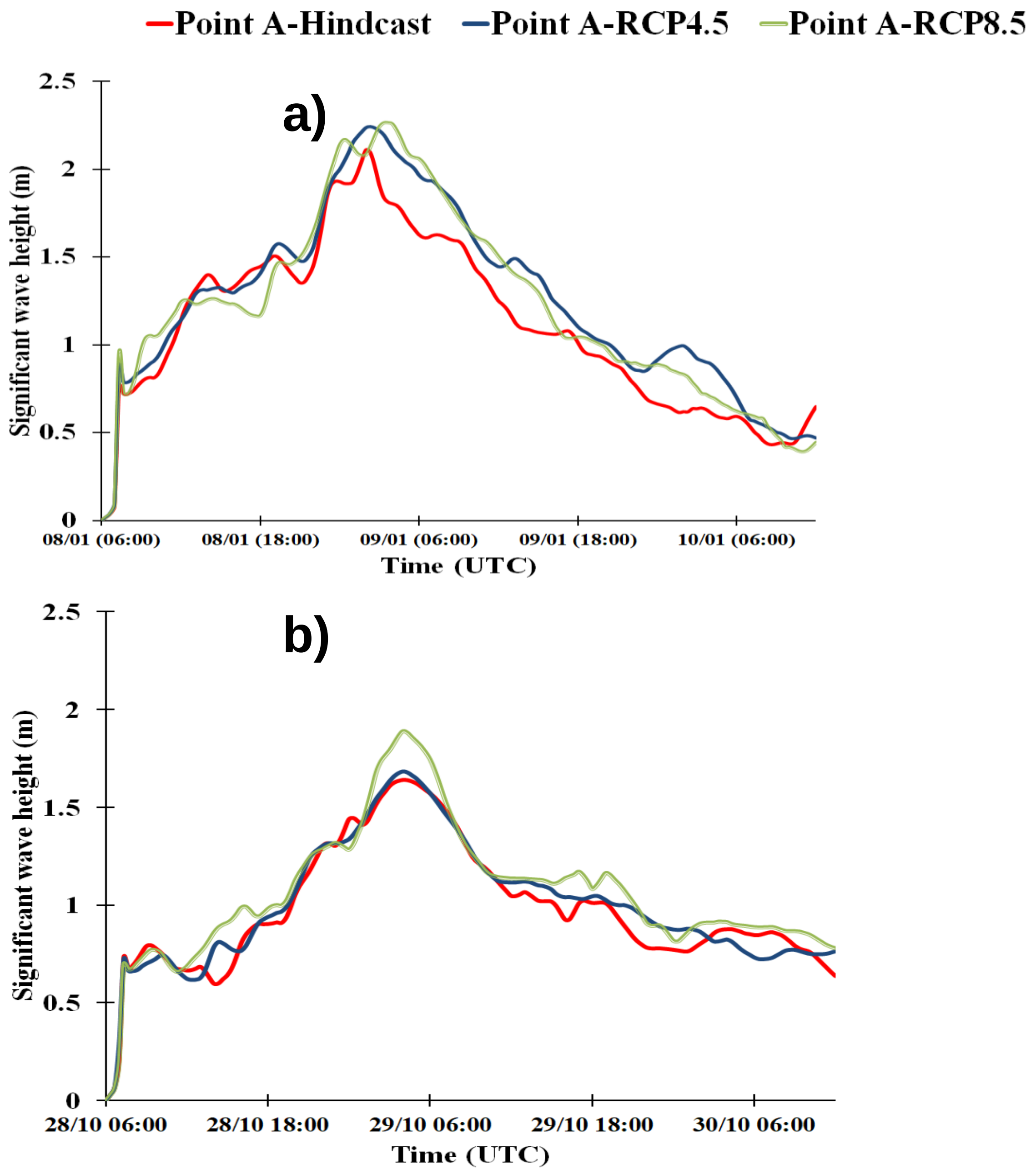


Appendix 1. Simulated significant wave height spatial distribution for 2005 case during highest wave occurrence at 9-Jan 02:00 UTC.

Hs – Future simulations



Appendix 2. Simulated significant wave height spatial distribution for 2005 case during highest wave occurrence at 9-Jan 02:00 UTC.



Appendix 3. Significant wave height for Hindcast and future simulation at “point A” for a) 2005 and b) 2013 cases.