A study of the impact of very large wind farms on regional weather using the WRF model in high resolution

Simon Jacobsen

Supervisor: Aksel Walløe Hansen

Niels Bohr Institute

Information

A PDF reader with Java support is required for the animations to display correctly in this presentation, such as the Adobe Acrobat PDF Viewer.

Abstract 1/3

The Weather Research and Forecasting (WRF) model fitted with the Fitch et al. (2012) scheme for parameterization of the effect of wind energy extraction was used to study the effects of very large offshore wind farms on regional weather. Two real data cases have been run in a high spatial resolution (grid size 500m). Both cases are characterized by a convective flow. The inner model domain covers the North Sea and Denmark. The largest offshore wind farm consists of 202,500 wind turbines each with a capacity of 8MW. The remaining wind farm configurations are 50,176 and 12,544 wind turbines, all covering the same area in the North Sea, due to horizontal spacing changes between individual wind turbines. The model was run for up to 14 hours with and without the wind farm. The impact on the regional weather of these very large wind farms were studied and presented. Furthermore, the effect of horizontal spacing between wind turbines was investigated. Significant impact on the regional weather from the very large wind farms was found. Horizontal wind speed changes occurred up to 3500m above the surface.

Abstract 2/3

The precipitation pattern was greatly affected by the very large wind farms due to the enhanced mixing in the boundary layer. Increased precipitation occurs at the upstream area within the wind farm, thus leaving the airmass relatively dry downstream when reaching the Danish coast, resulting in a decrease in precipitation compared to the control run. The formation of a low level jet was found above the downstream area of the very large wind farm. Furthermore, wake effects from individual wind turbines decrease the total power production. The wind speed in the simulated cases were above the speed of maximum power production of the wind turbines. Yet most of the 202,500 wind turbines were producing only 1MW due the wake effects. The wind farm with 50,176 wind turbines was found to produce a similar amount of power as the 202,500 configuration.

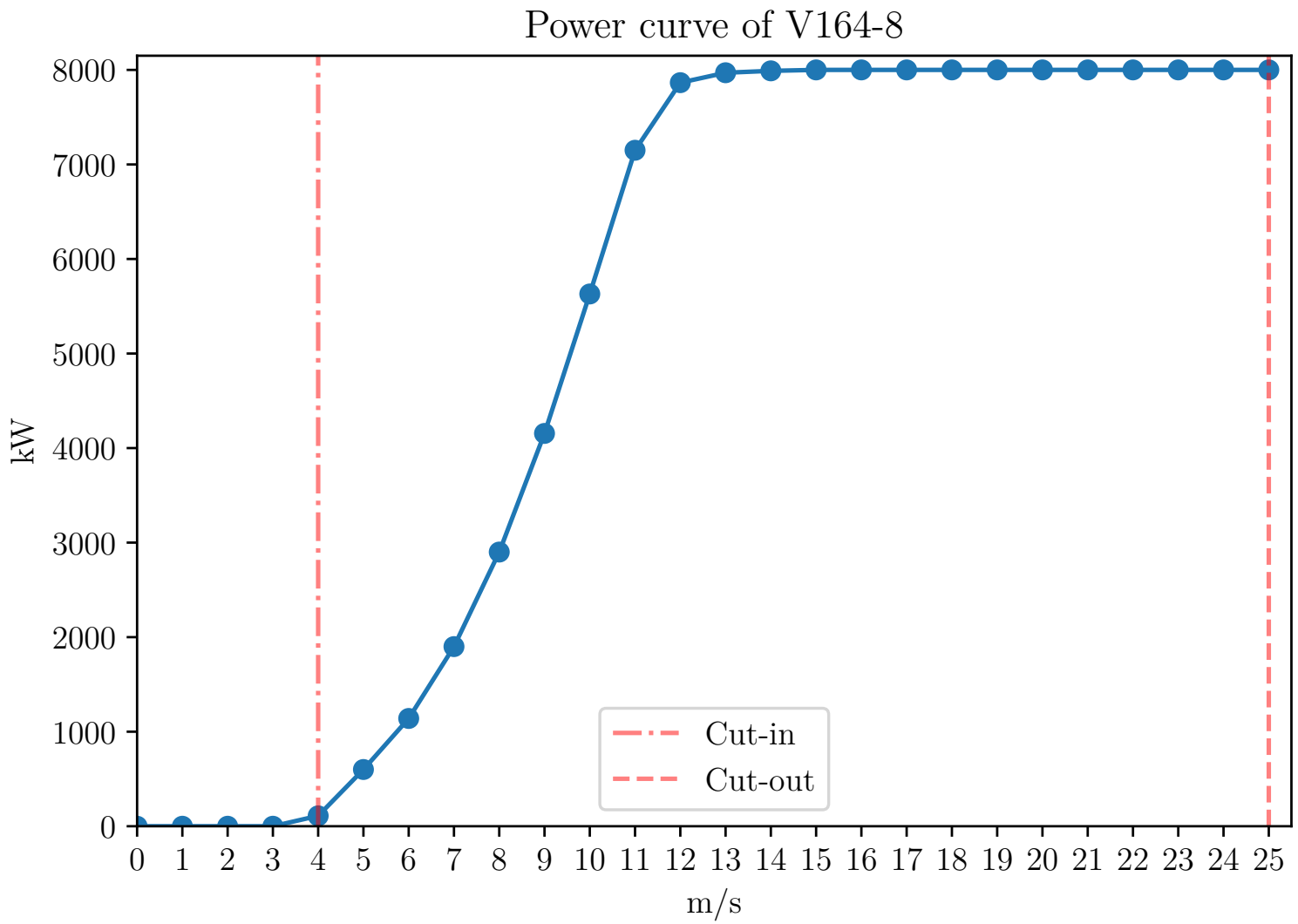
Abstract 3/3

Finally, the wind farm consisting of 12,544 wind turbines produced at maximum power through most of the simulations. Therefore, horizontal spacing of 2000m between wind turbines are optimal for minimal wake effect. Through the 14 hour simulations of the wind farm, consisting of 202,500 wind turbines, the maximum achieved $\mathrm{W/m^2}$ was 10.42 and maximum CF was 32.6%. For the 50,176 wind farm these values were 6.58 $\mathrm{W/m^2}$ and CF 82.3%. Finally, the wind farm consisting of 12,544 wind turbines achieved a peak of 1.99 $\mathrm{W/m^2}$ and a CF of 99.5%.

Wind turbine used: Vestas V164-8

Hub height	Wing span	Area swept	Nacelle weight	Cut in speed	Cut out speed
110m	80m	$21124m^2$	390 Ton	$4m/s$	$25m/s$

Vestas V164-8 Power Curve

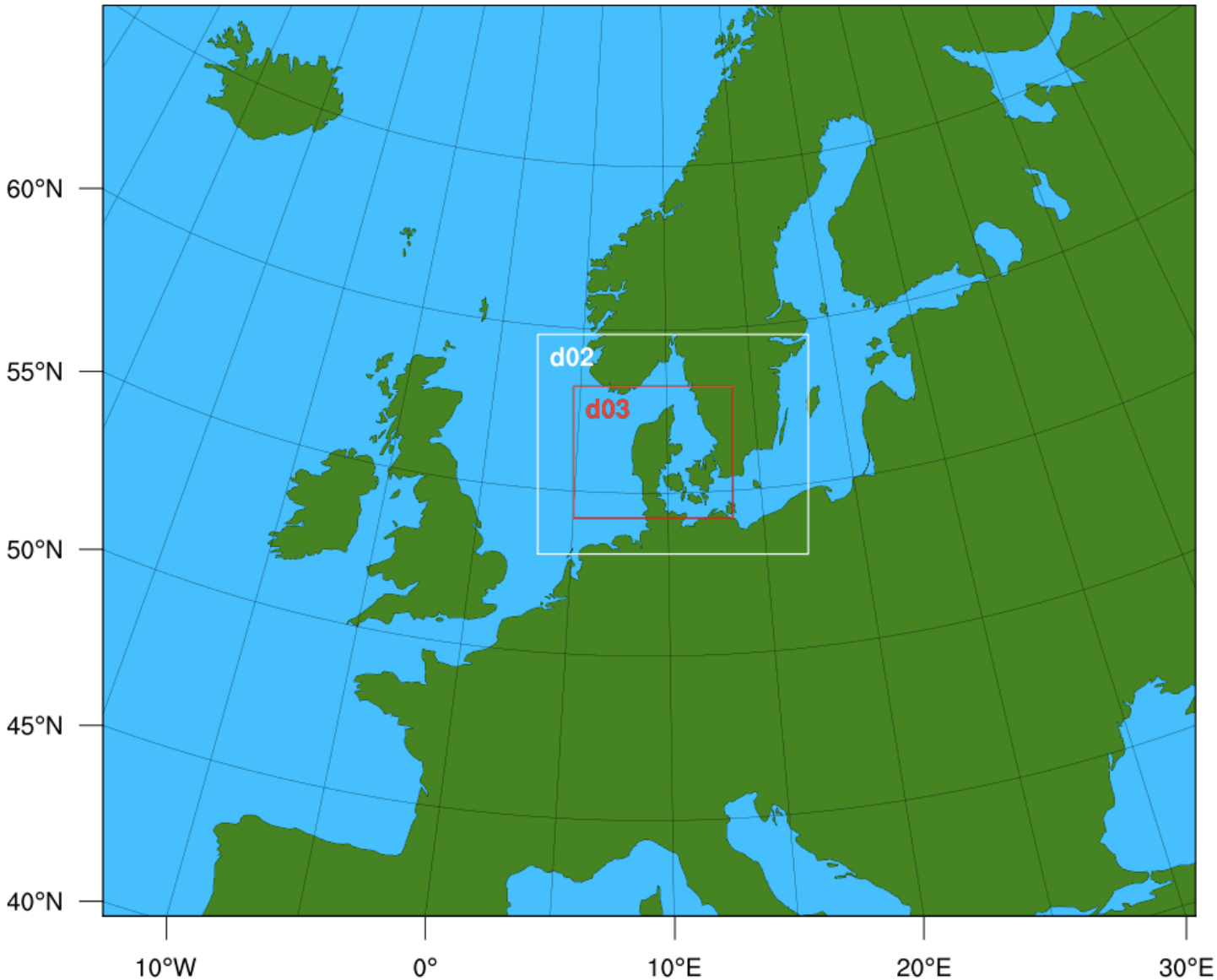


WRF - Setup

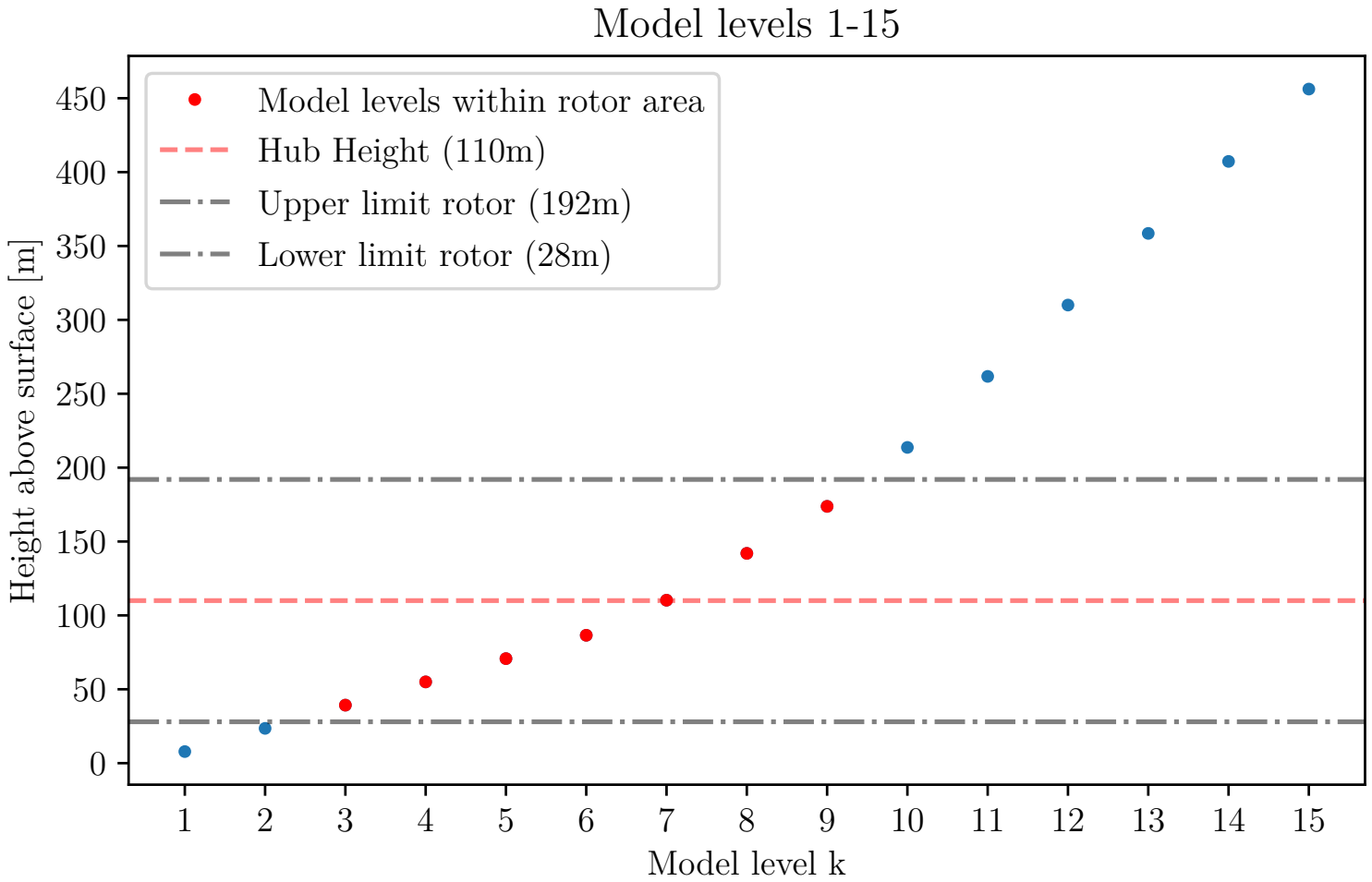
	Parent Domain	Nest 1	Nest 2
N/S Grid	300	371	1091
E/W Grid	250	301	901
Resolution	12500m	2500m	500m
Vertical Layers	61		
Model Top	50 hPa		

Settings applied in the namelist.input			
Domain	D01	D02	D03
PBL Scheme	5	5	5
Surface Layer Scheme	5	5	5
Cumulus Parameterization	1	1	0
Wind farm setting	0	0	1
Wind farm ij			1
MYNN 2.5 TKE Budget	1	1	1
MYNN 2.5 TKE Advection	.true.	.true.	.true.
Time Step	75s	15s	3s

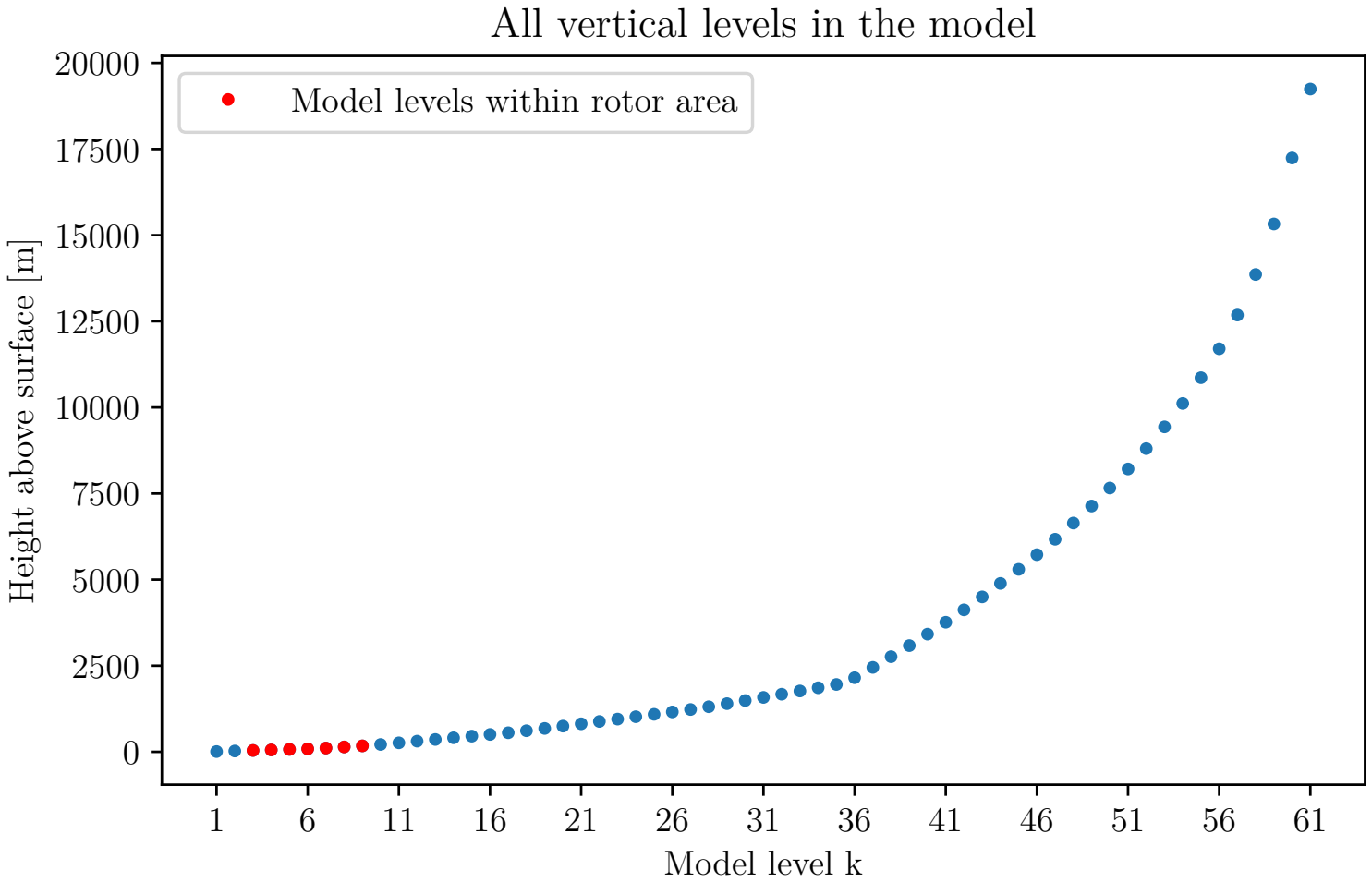
WRF - Setup



WRF - Setup

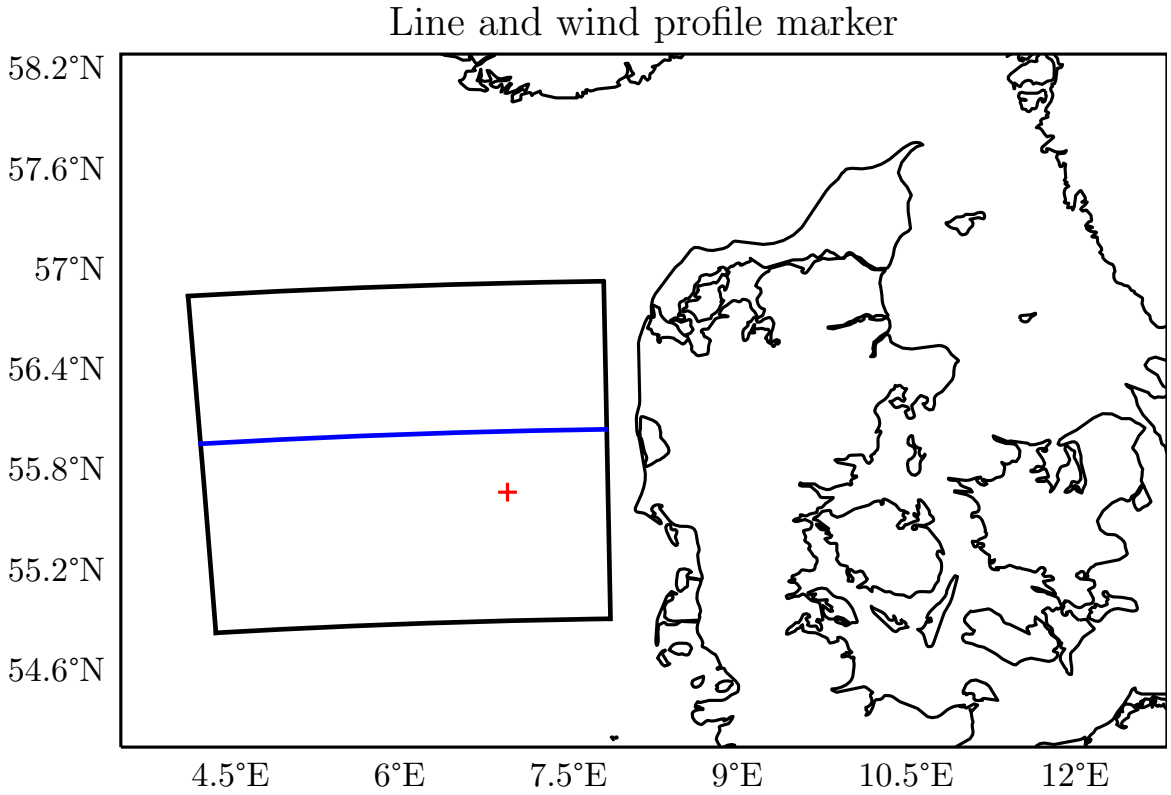

Model levels 1-15
Model levels within rotor area
Hub Height (110m)
Upper limit rotor (192m)
Lower limit rotor (28m)
Height above surface [m]
0
50
100
150
200
250
300
350
400
450
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Model level k

WRF - Setup


All vertical levels in the model
Model levels within rotor area
Height above surface [m]
20000
17500
15000
12500
10000
7500
5000
2500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
Model level k

WRF - Setup

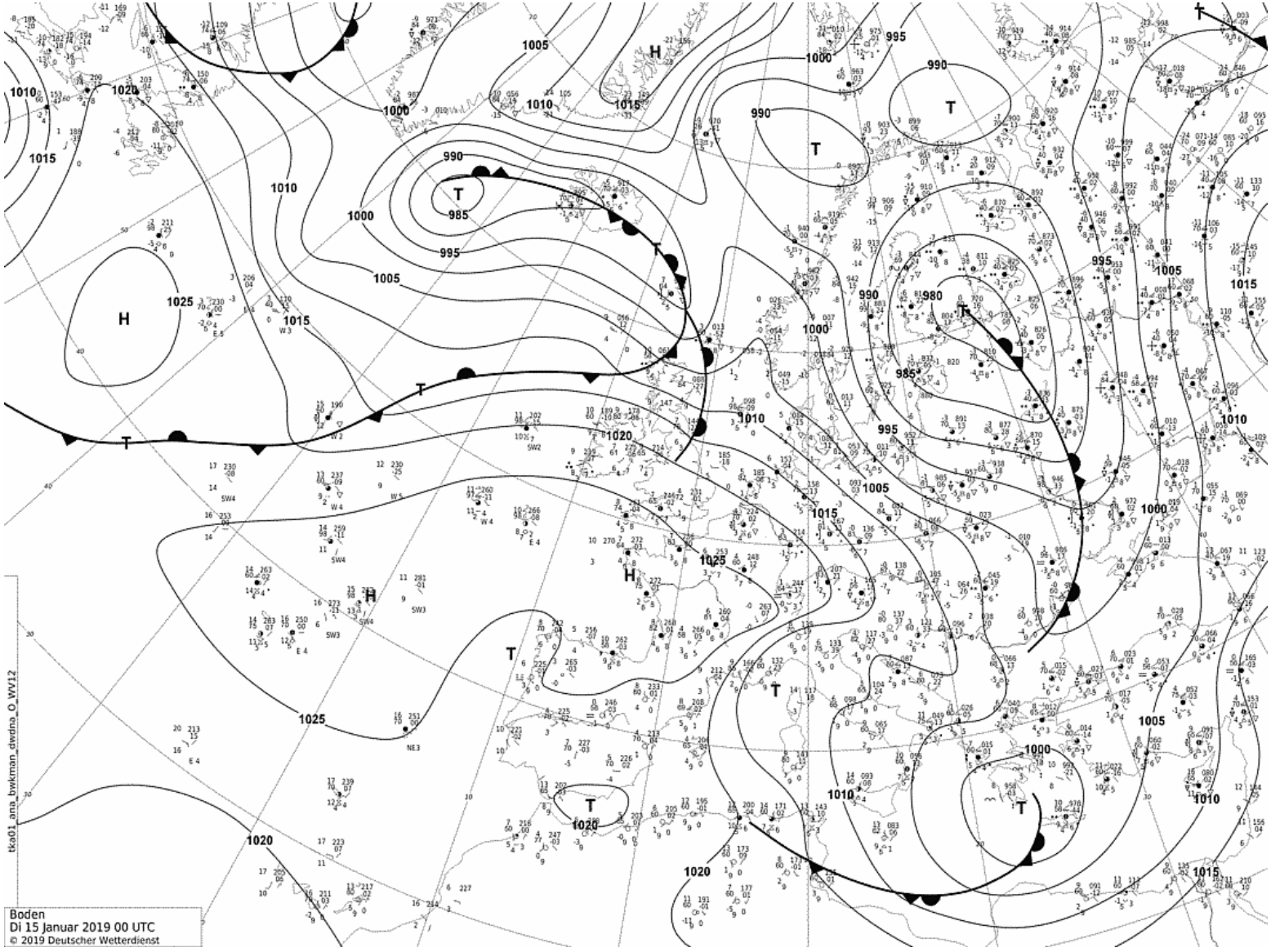
- Black square represents the area of the wind farm.
- Blue line represents the line plots showed later in the presentation.
- Red cross is the location of the wind profile included in the presentation.



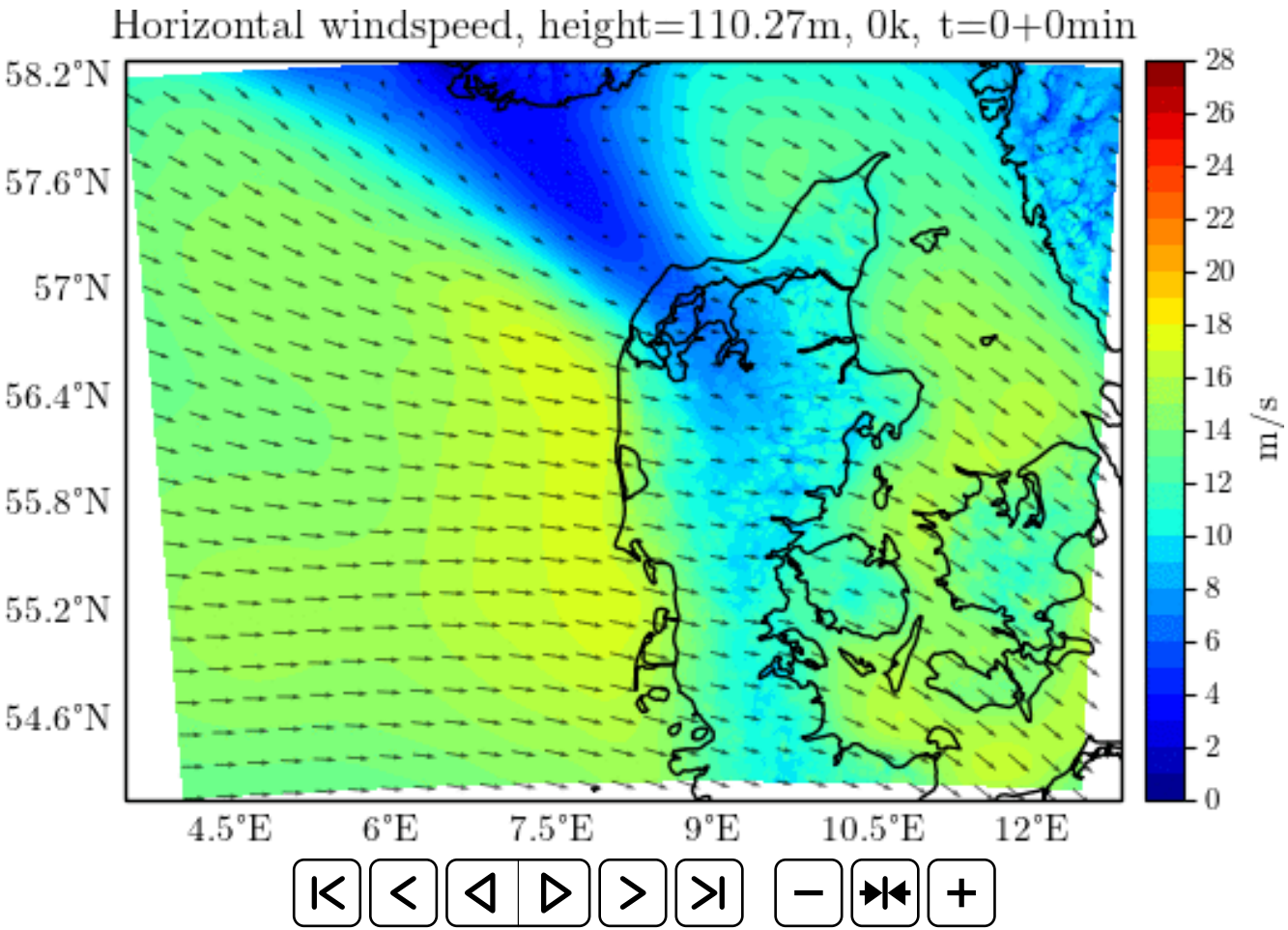
WRF - Setup

Wind turbine configurations				
Setup	Amount	Grid	Spacing	Capacity
1	202,500	450*450	500m	1620 GW
2	50,176	224*224	1000m	401.4 GW
3	12,544	112*112	2000m	100.3 GW

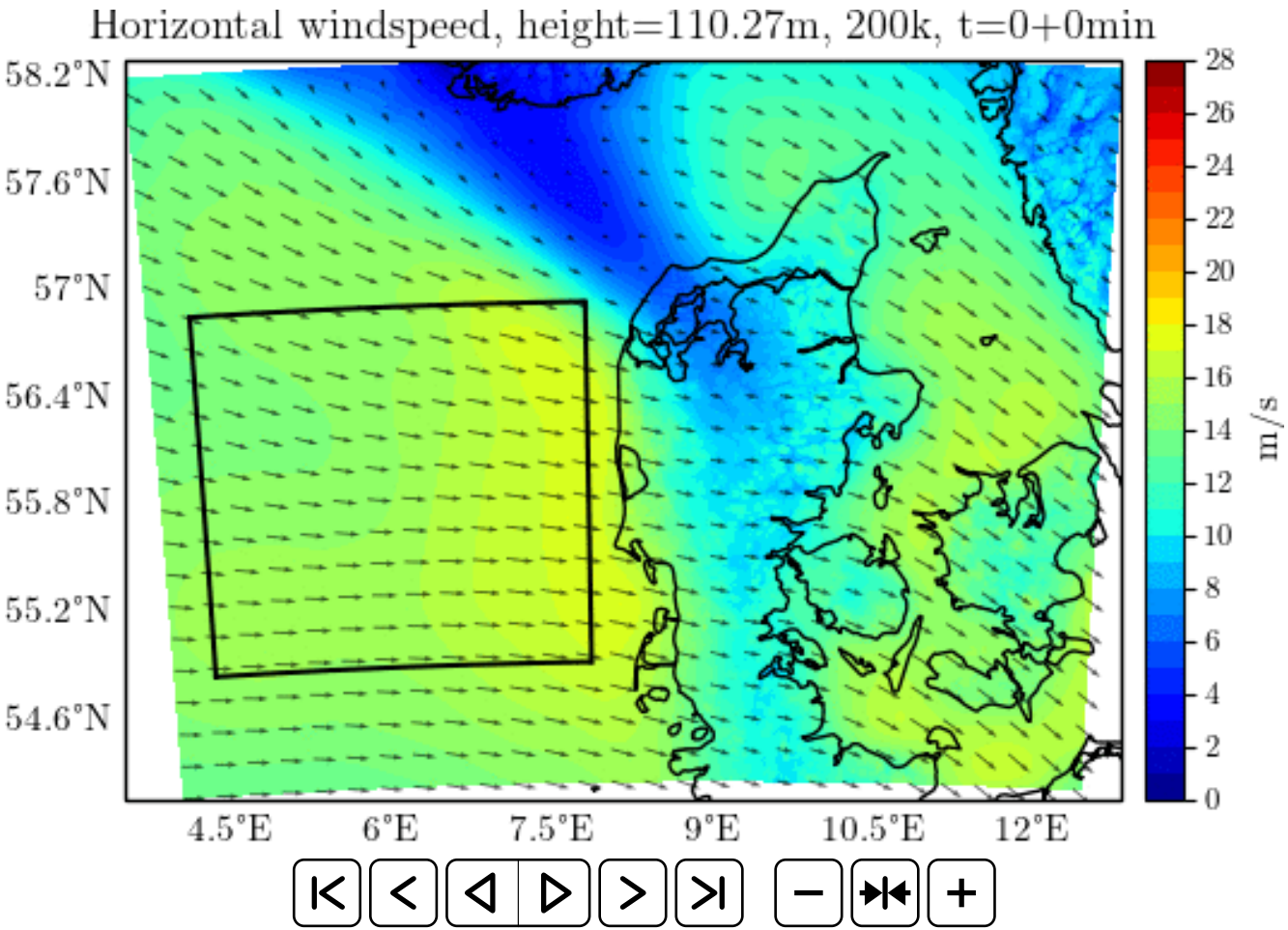
Weather - 00 UTC 15/01/2019



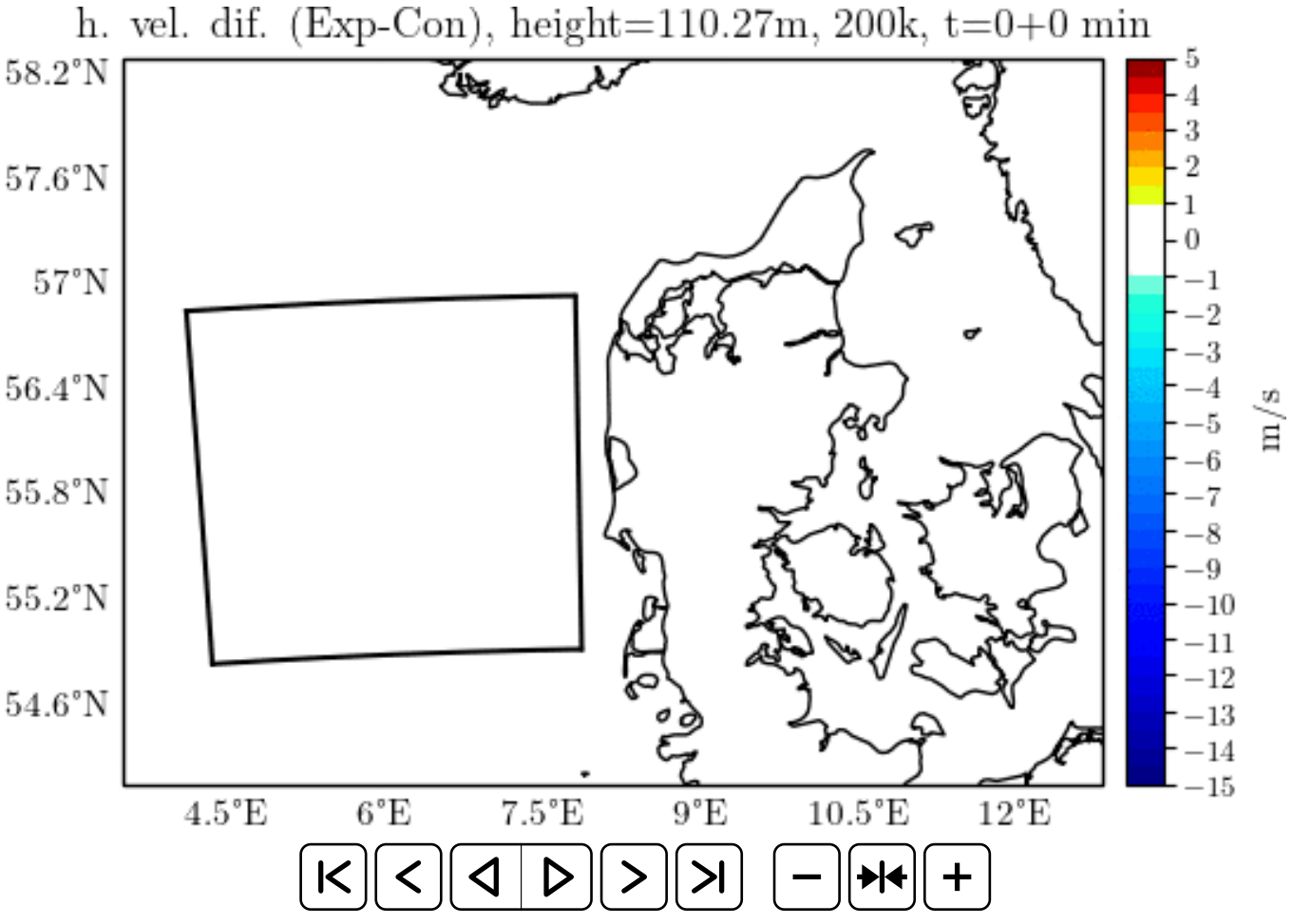
Results - Control run 110m



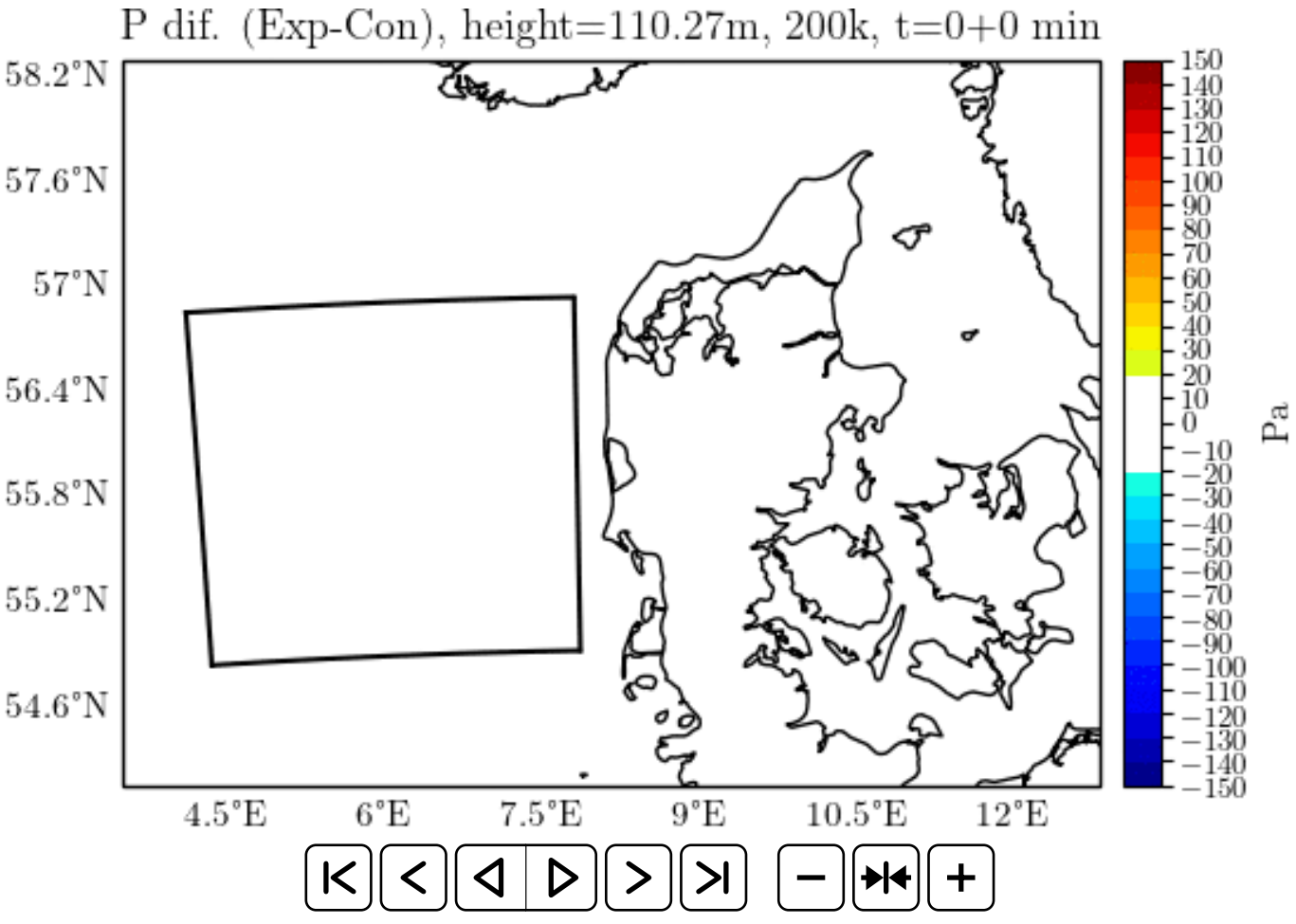
Results - 200k 110m



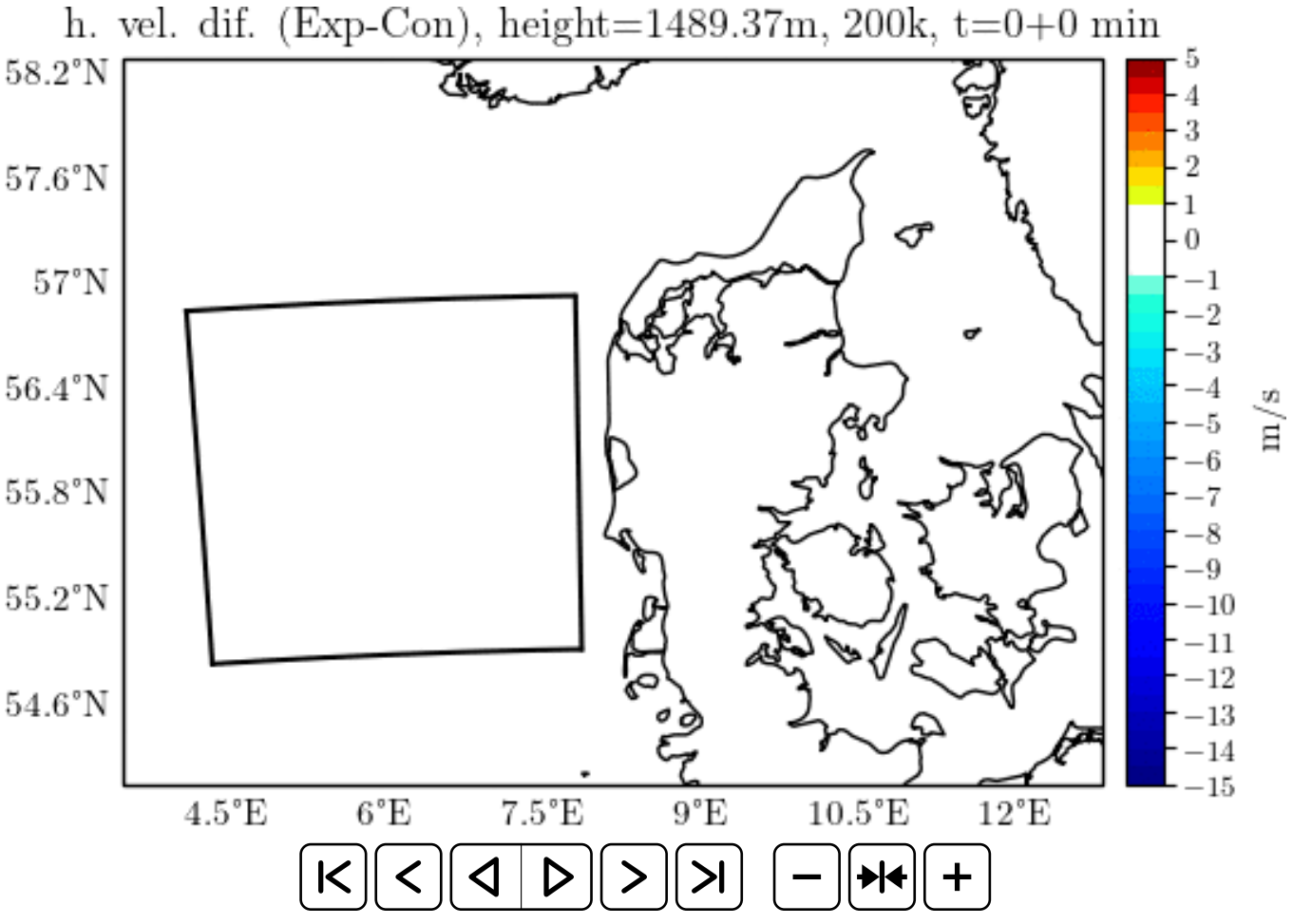
Results - 200k 110m horizontal wind speed difference.



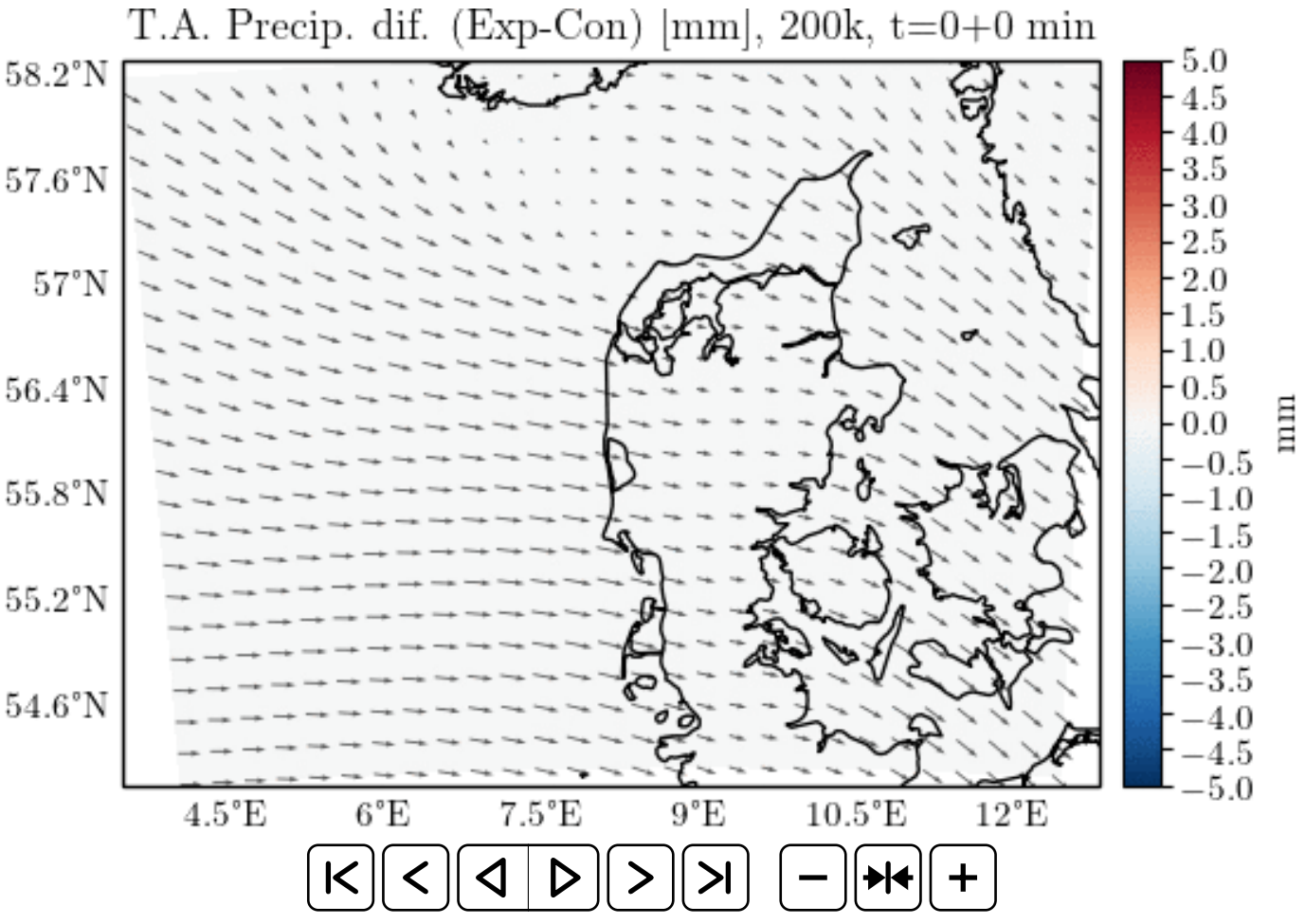
Results - 200k 110m pressure difference



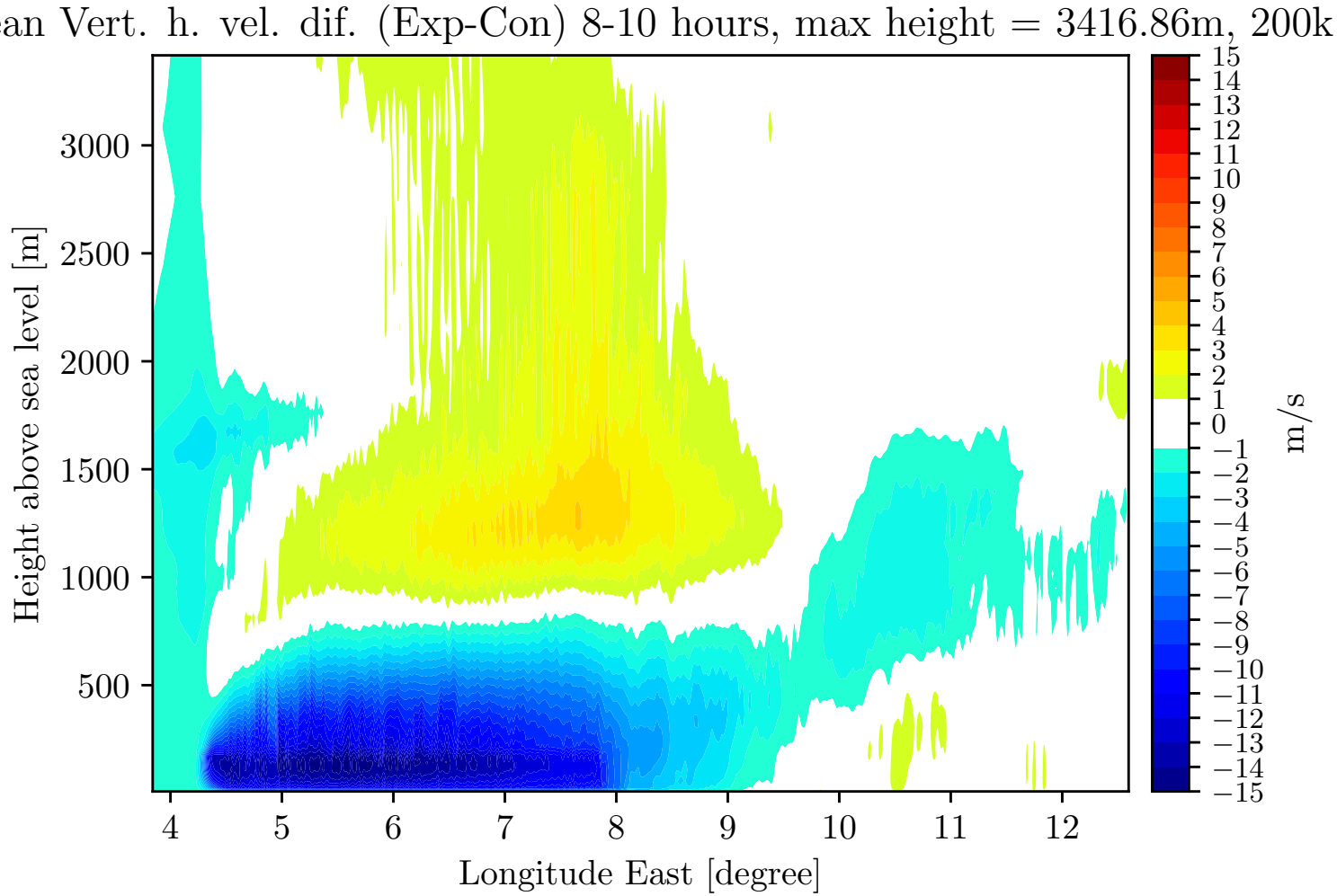
Results - 200k 1489m horizontal wind speed difference.



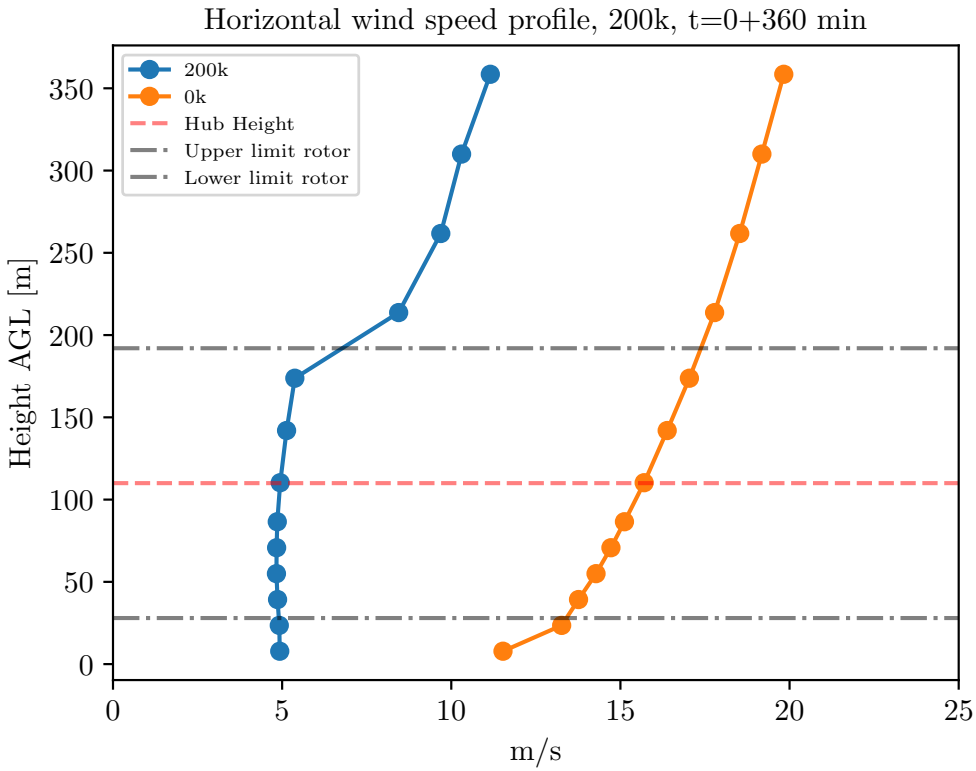
Results - 200k precipitation difference.

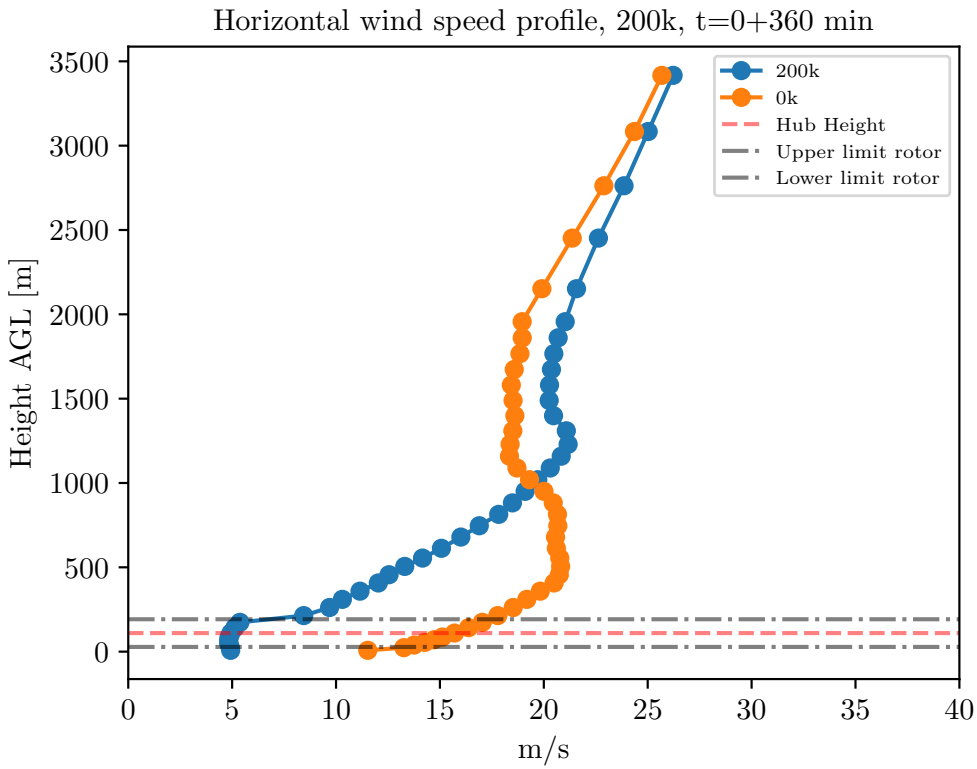


Results - 200k mean vertical horizontal wind speed difference (Blue line plot, slide 12)

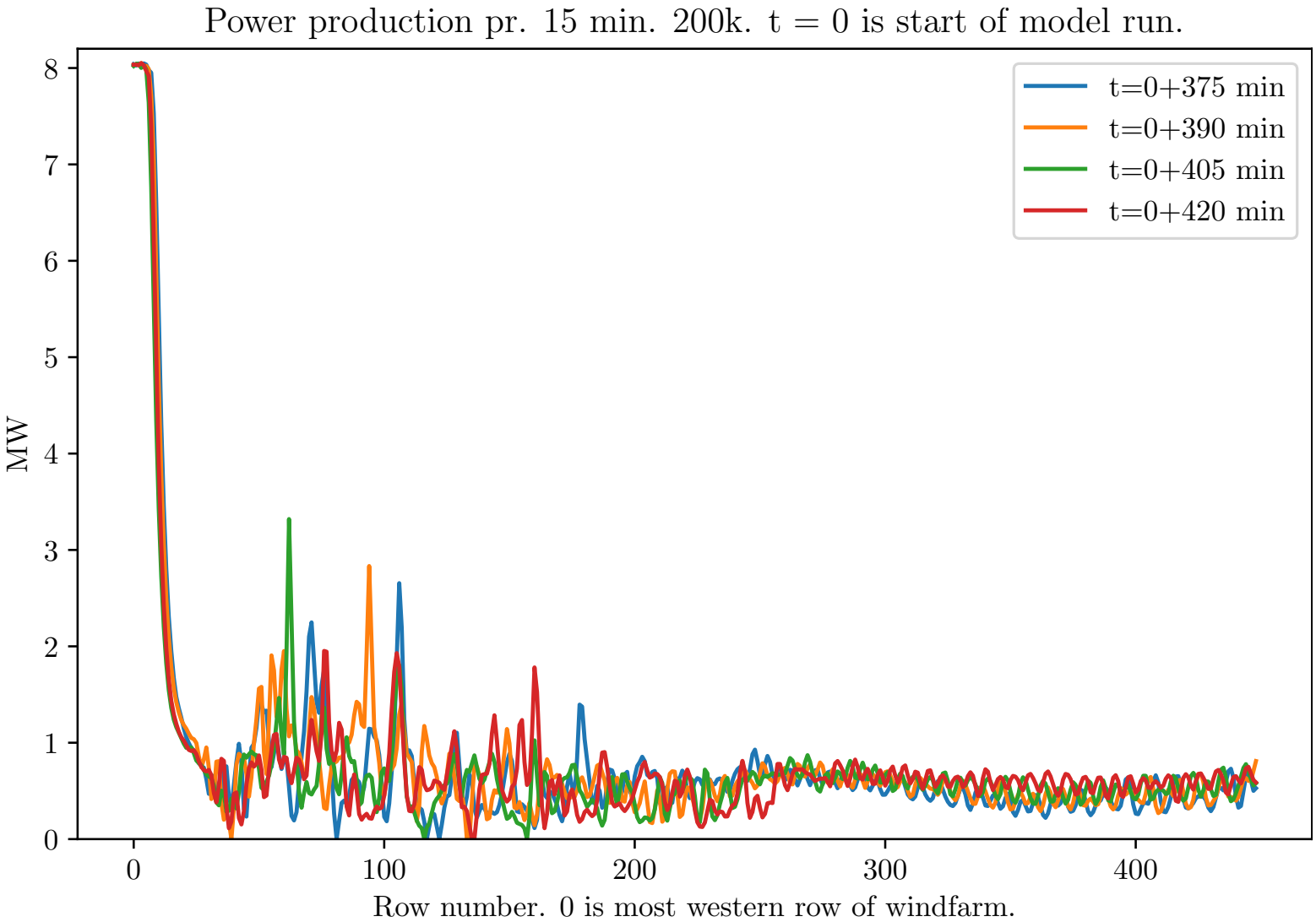


Results - 200k wind profile (Red Cross, slide 12)

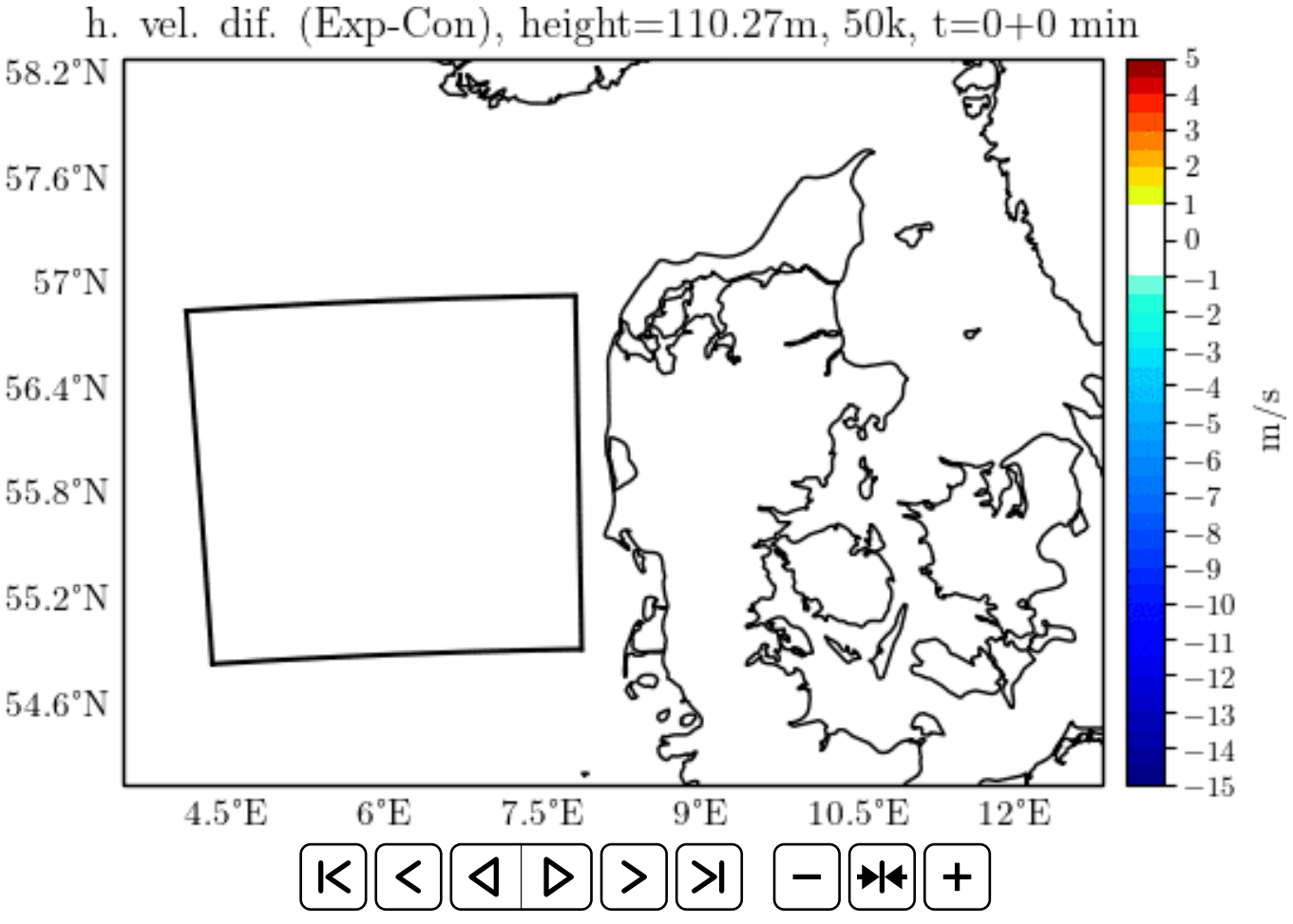




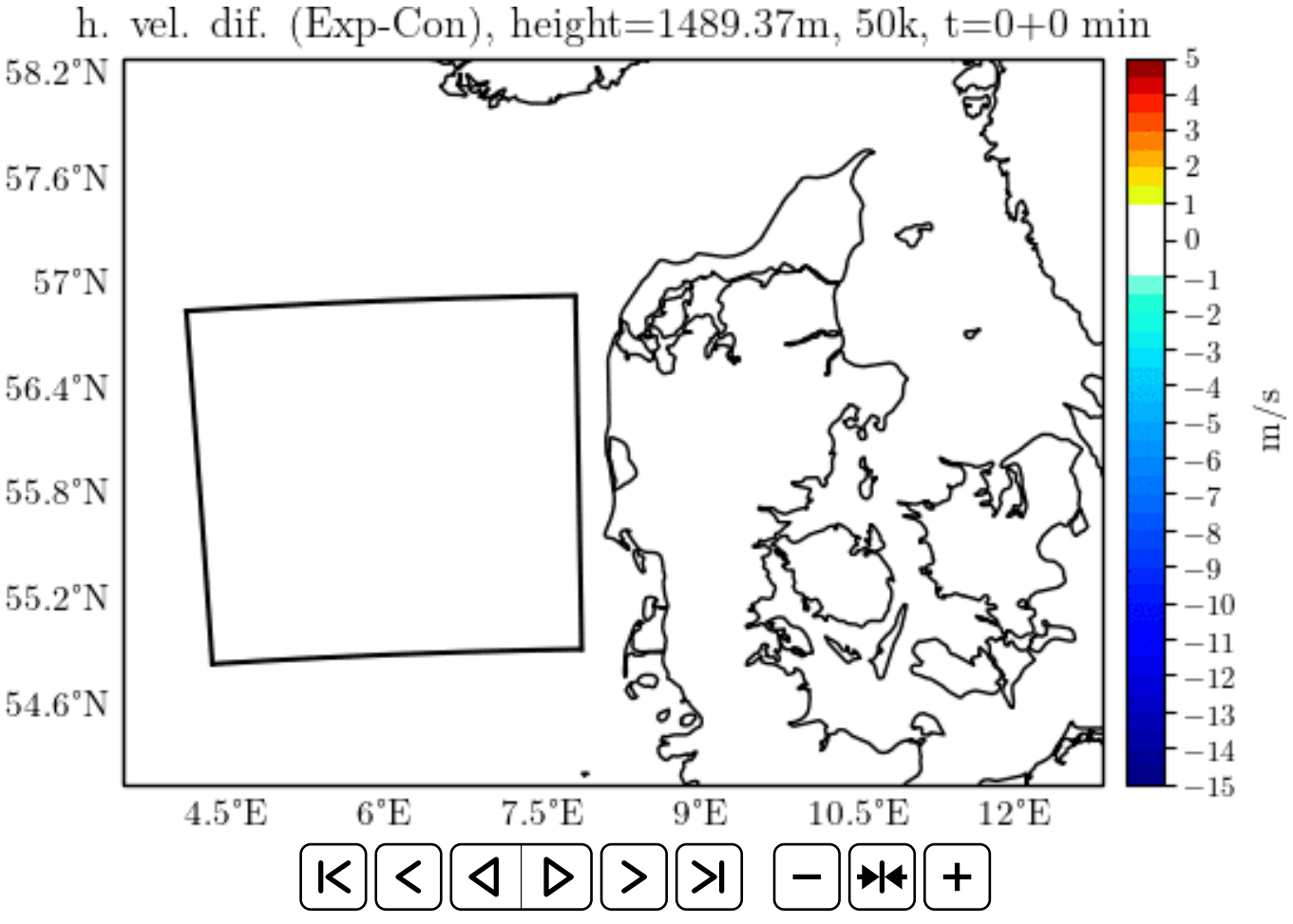
Results - 200k energy line plot



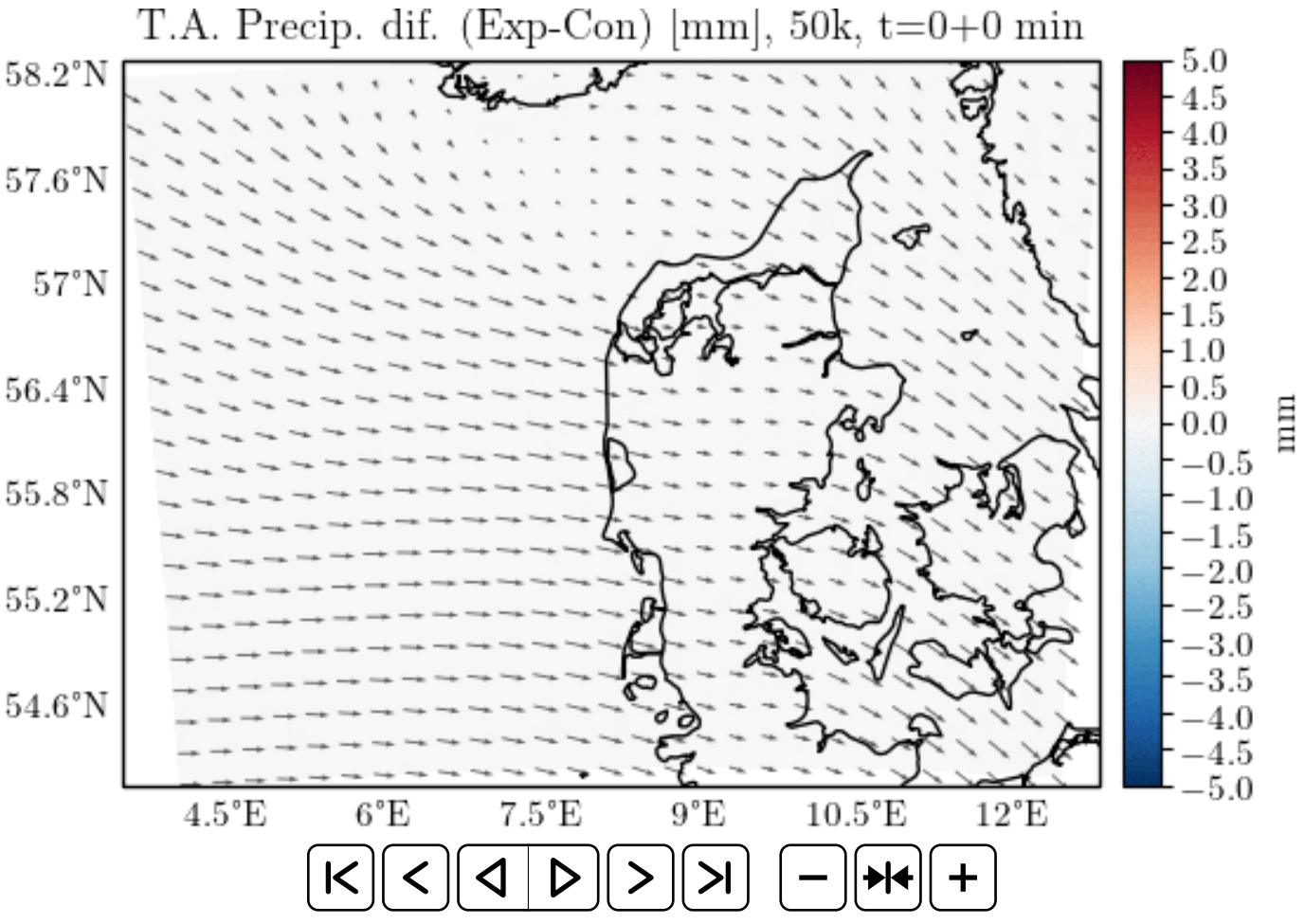
Results - 50k 110m horizontal wind speed difference.



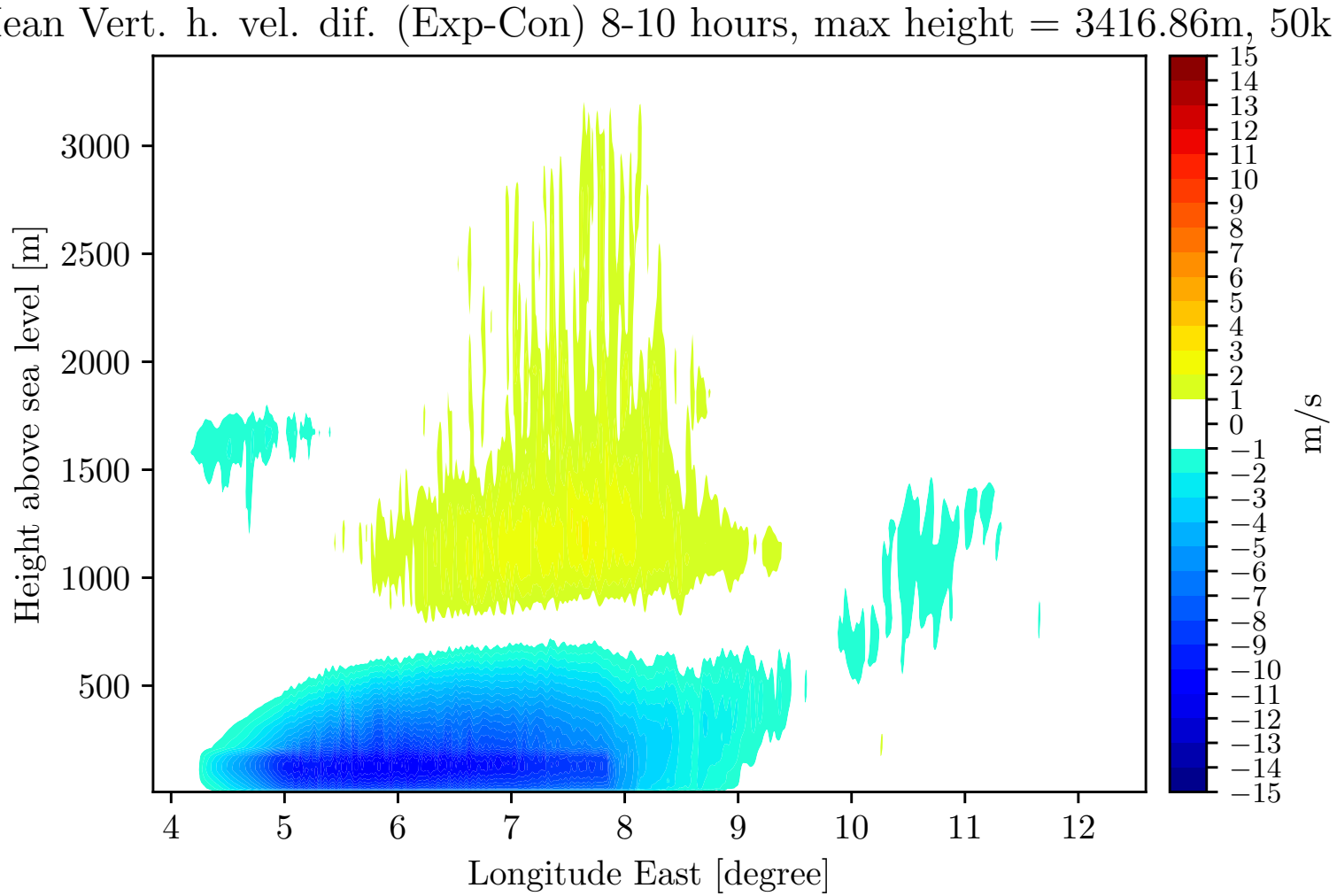
Results - 50k 1489m horizontal wind speed difference.



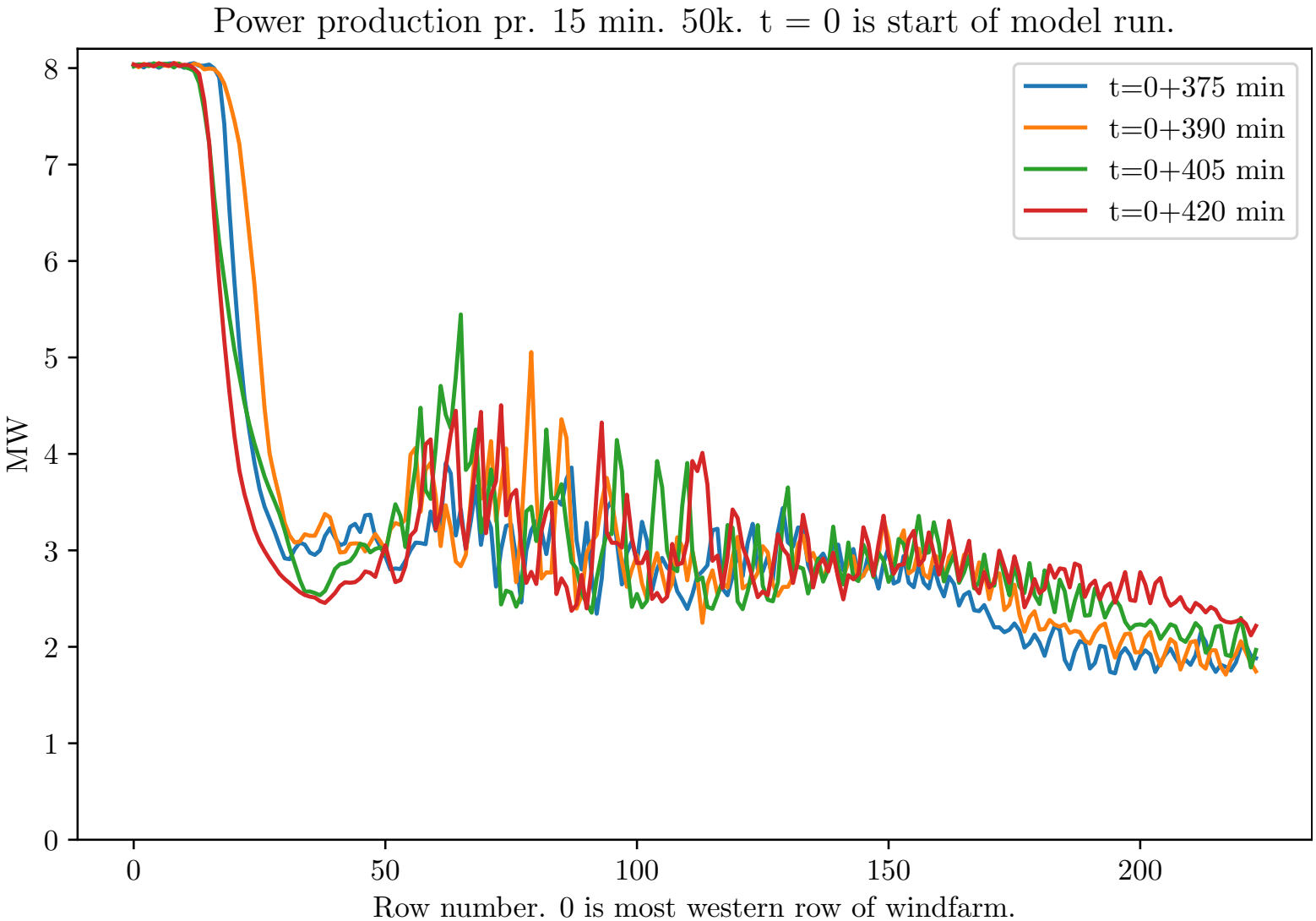
Results - 50k precipitation difference.



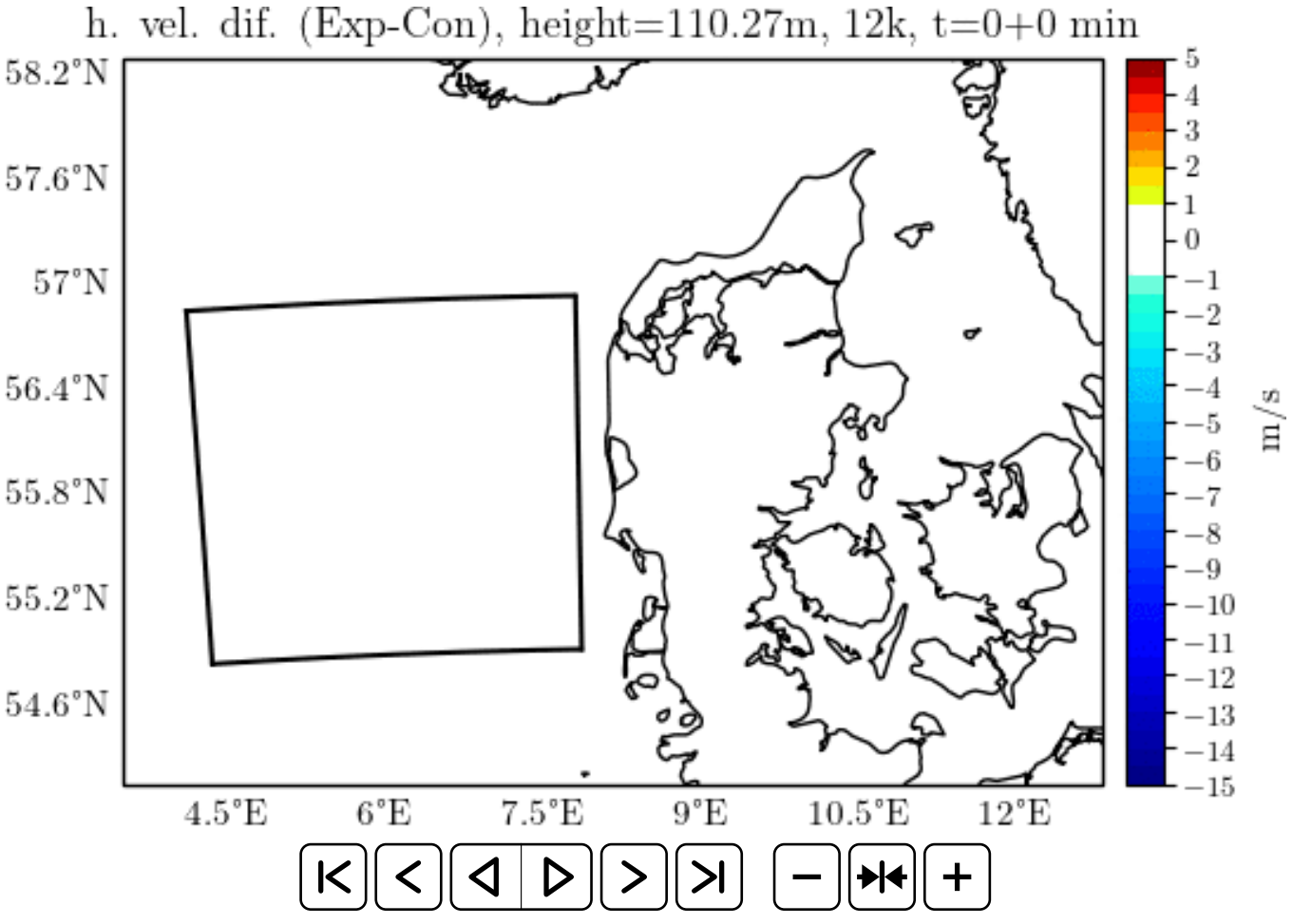
Results - 50k mean vertical horizontal wind speed difference (Blue line plot, slide 12)



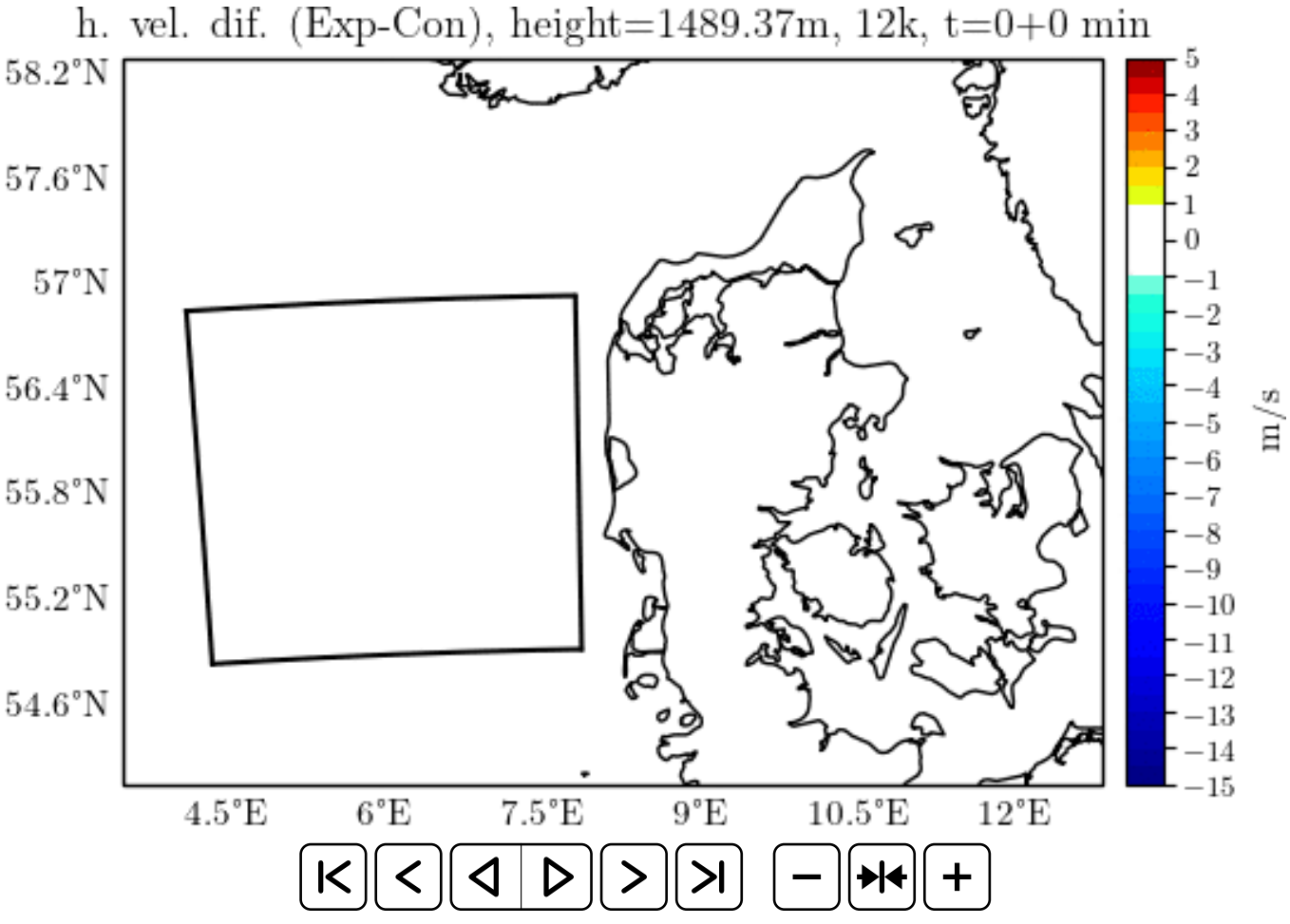
Results - 50k energy line plot



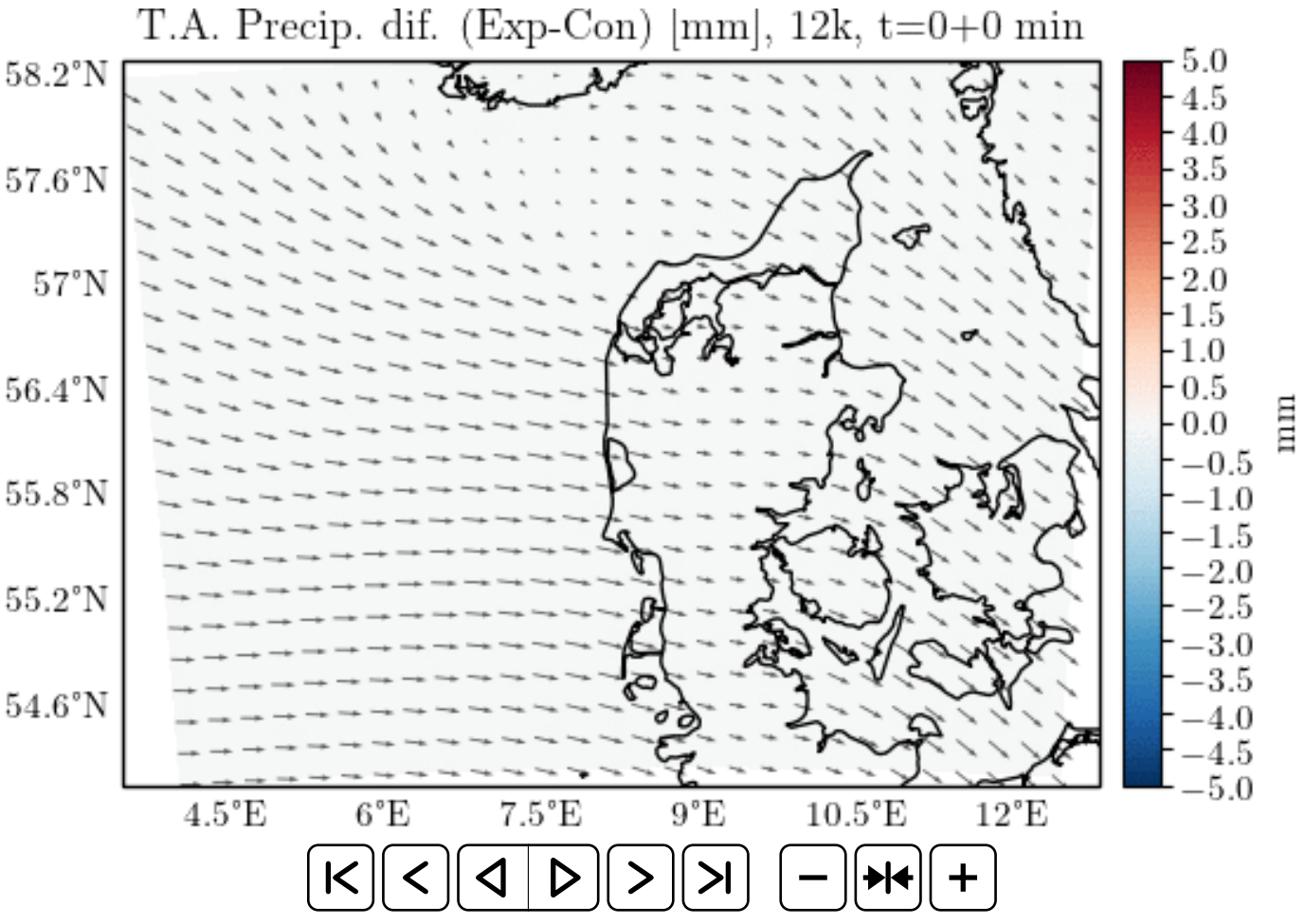
Results - 12k 110m horizontal wind speed difference.



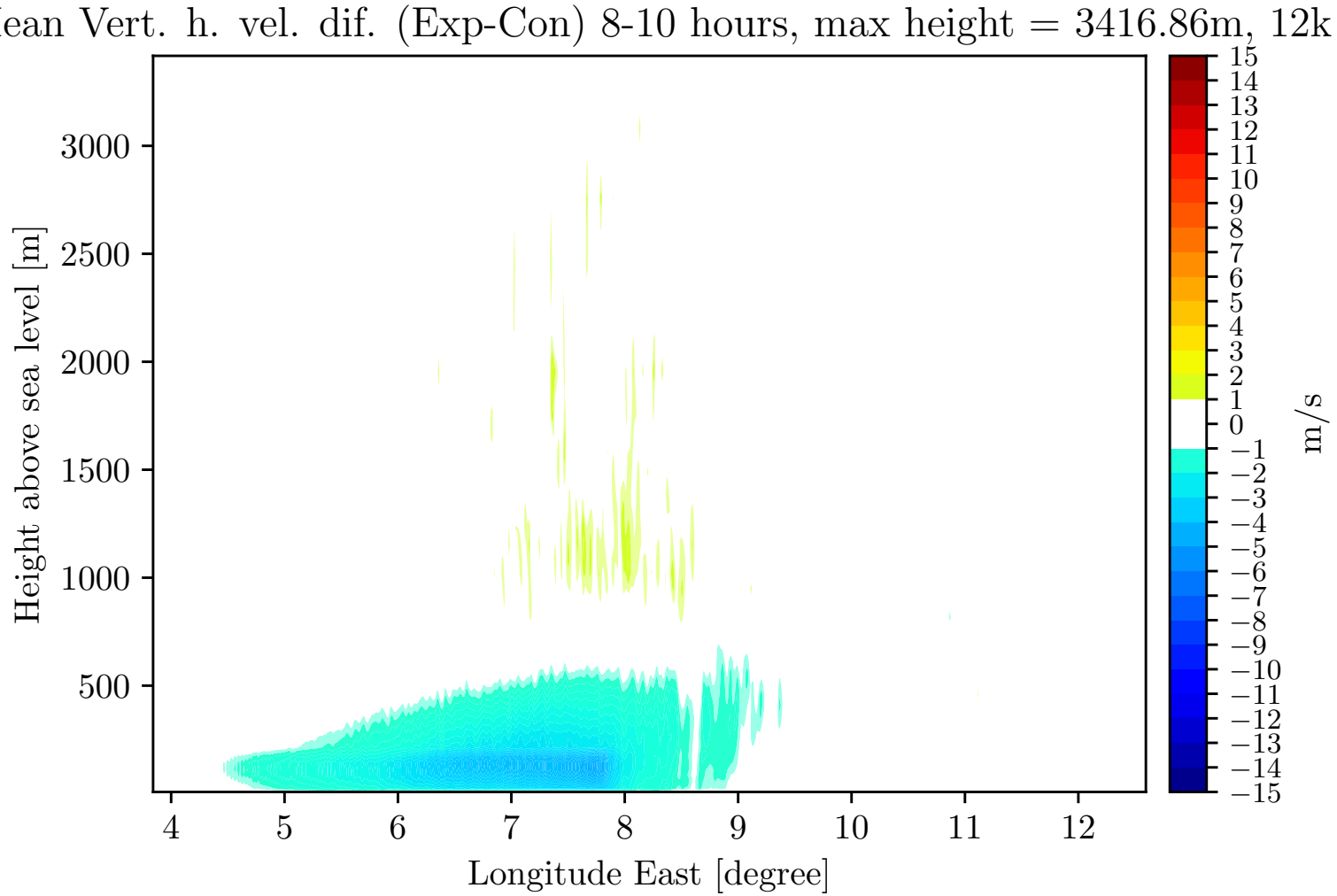
Results - 12k 1489m horizontal wind speed difference.



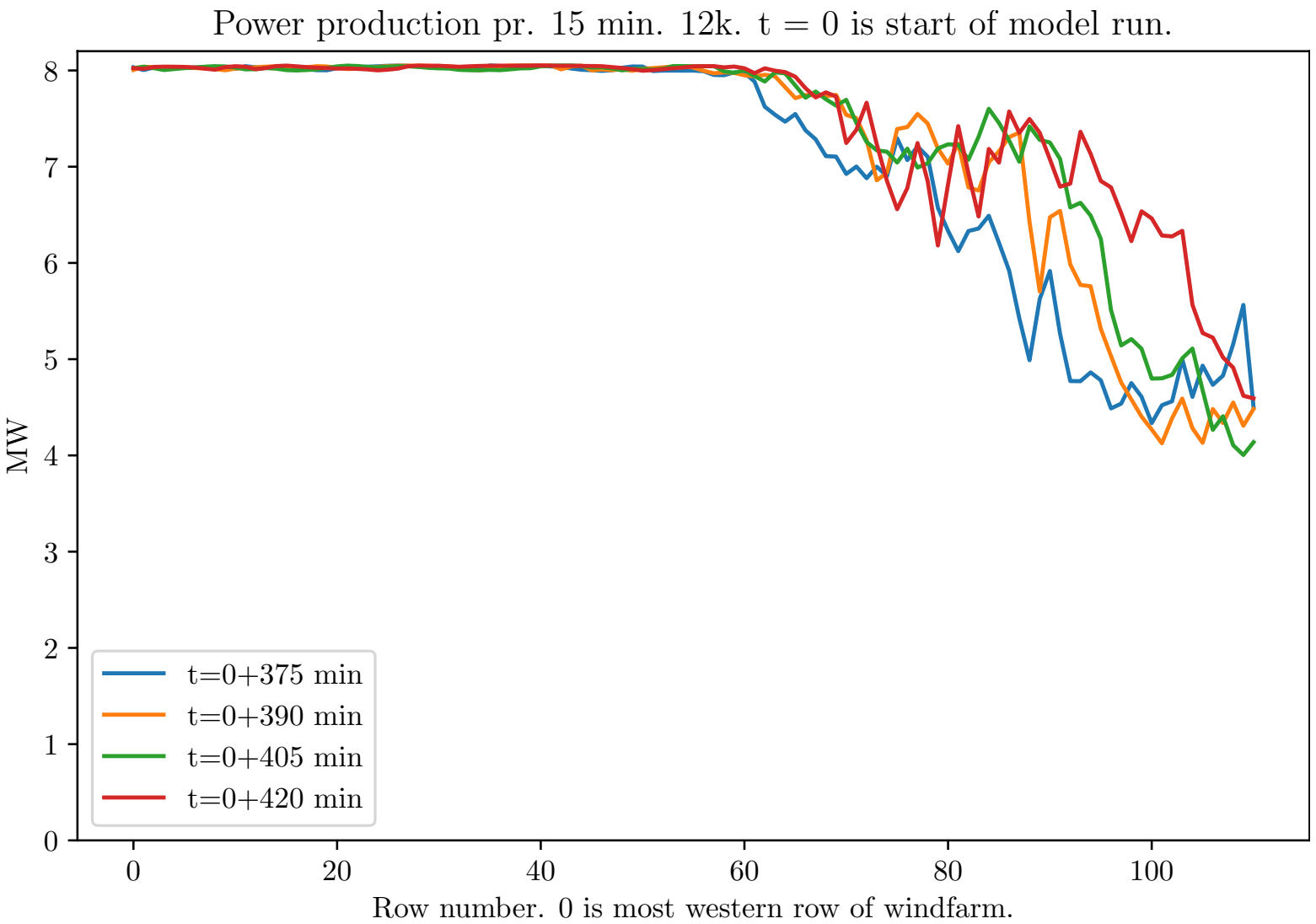
Results - 12k precipitation difference.



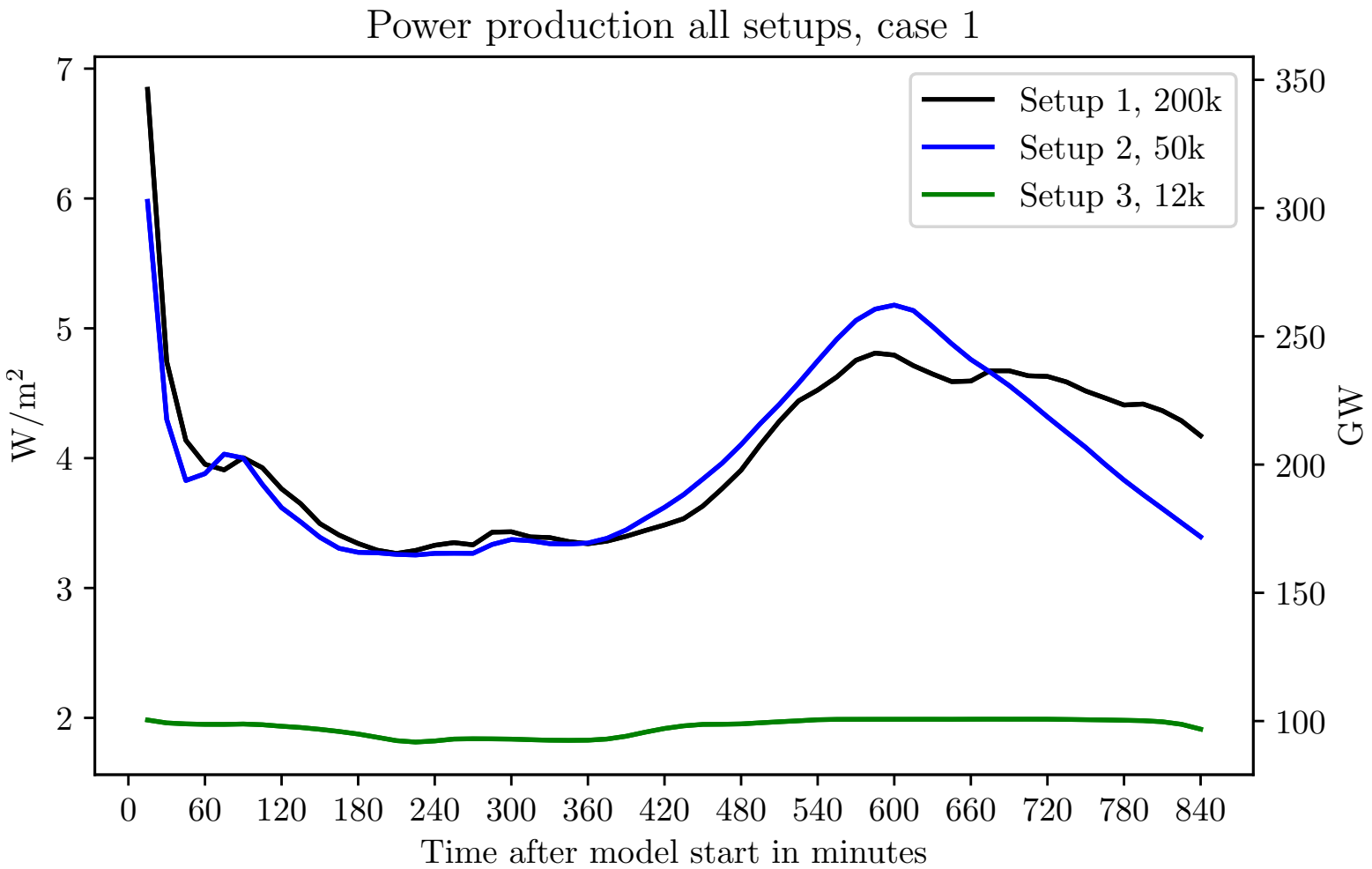
Results - 12k mean vertical horizontal wind speed difference (Blue line plot, slide 12)



Results - 12k energy line plot



Results - Production of Energy



Results - Production of Energy

Case 1	Setup 1, 200k		Setup 2, 50k		Setup 3, 12k	
Hour	Mean W/m^2	CF %	Mean W/m^2	CF %	Mean W/m^2	CF %
0-2	4.41	13.8	4.17	52.1	1.95	97.5
2-4	3.38	10.6	3.32	41.5	1.86	93.0
4-6	3.38	10.6	3.33	41.6	1.83	91.5
6-8	3.57	11.2	3.70	46.3	1.91	95.5
8-10	4.54	14.2	4.79	59.9	1.98	99.0
10-12	4.64	14.5	4.72	59.0	1.99	99.5
12-14	4.40	13.8	3.79	47.4	1.97	98.5

Conclusion

- The atmospheric flow reacts to very large wind farms in a similar way to a mountain. (Foehn wind)
- Horizontal spacing should be above 1000m for the V164-8
- 4.000.000 km^2 is required for setup 3 in order to cover entire EU energy consumption
- 1.000.000 km^2 is required for setup 2 in order to cover entire EU energy consumption
- Changes in wave heights and wind driven ocean circulation
- Issues for ship traffic