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# The NEWA Mesoscale Wind Atlas: WRF production and ensemble runs

**Björn Witha**<sup>1</sup>, Andrea Hahmann<sup>2</sup>, Tija Sīle<sup>3</sup>, Jordi Barcons<sup>4</sup>, Neil Davis<sup>2</sup>, Martin Dörenkämper<sup>5</sup>, Yasemin Ezber<sup>6</sup>, Elena Garcia Bustamante<sup>7</sup>, Fidel González-Rouco<sup>8</sup>, Grégoire Leroy<sup>9</sup>, Jorge Navarro<sup>7</sup>, Bjarke Tobias Olsen<sup>2</sup>, Mariano Sastre<sup>8</sup>, Stefan Söderberg<sup>10</sup>, Wilke Trei<sup>1</sup>



<sup>1</sup>**ForWind, Carl von Ossietzky University Oldenburg, Germany**

<sup>2</sup>Technical University of Denmark, Roskilde, Denmark

<sup>3</sup>University of Latvia, Riga, Latvia

<sup>4</sup>Barcelona Supercomputing Center, Spain

<sup>5</sup>Fraunhofer IWES, Oldenburg, Germany

<sup>6</sup>Istanbul Technical University, Turkey

<sup>7</sup>CIEMAT, Madrid, Spain

<sup>8</sup>Universidad Complutense de Madrid, Spain

<sup>9</sup>3E, Brussels, Belgium

<sup>10</sup>DNV GL / WeatherTech Scandinavia AB, Sweden

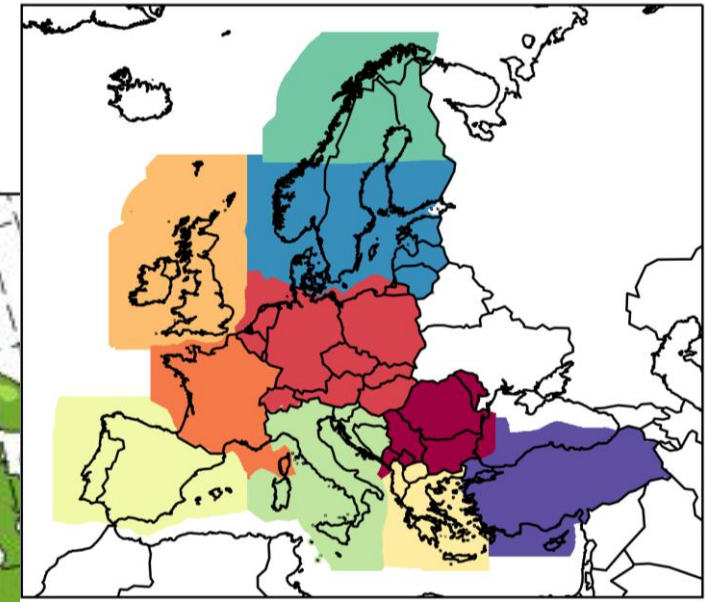
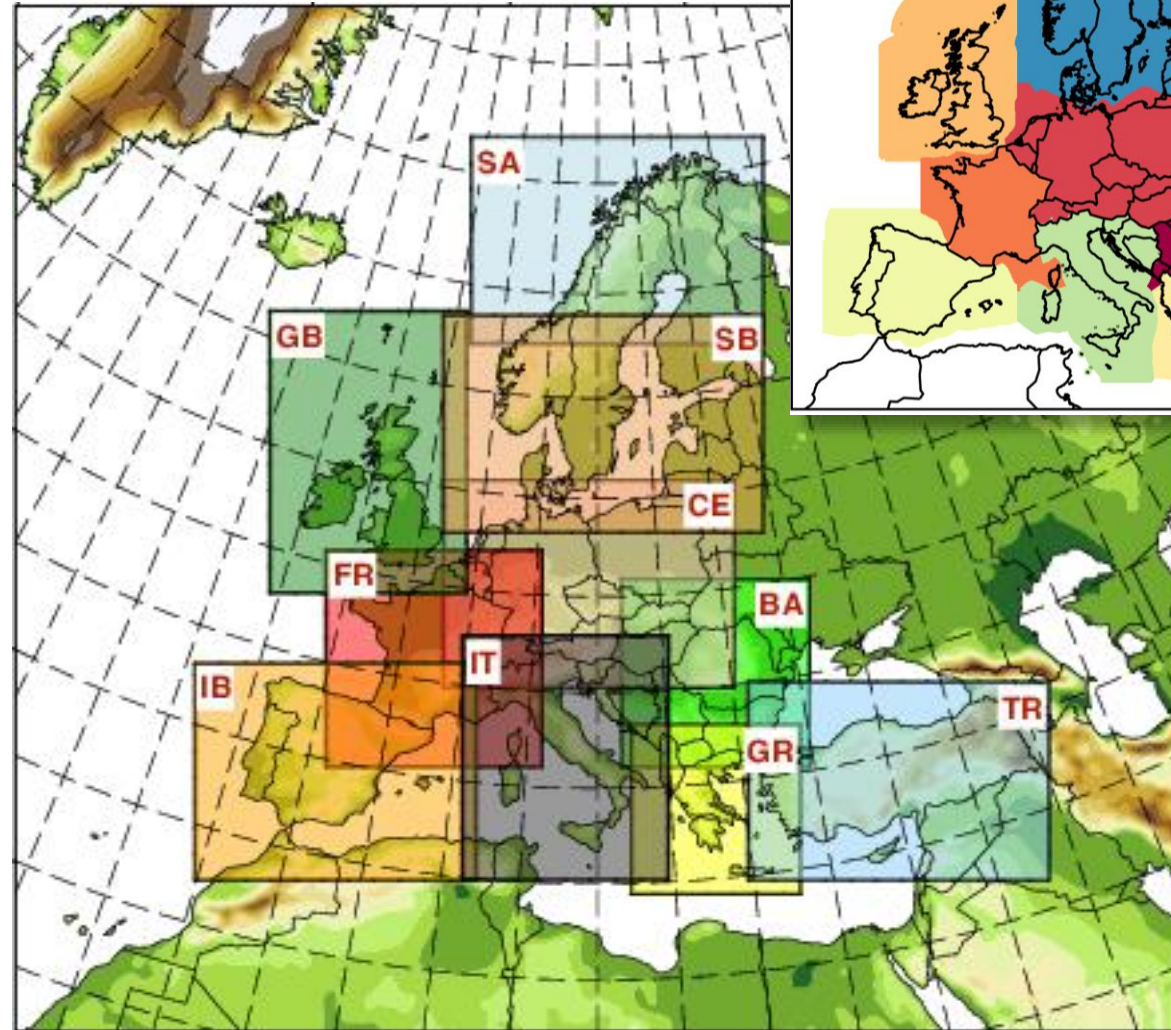
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WindEurope Conference 2019 – NEWA Side Event

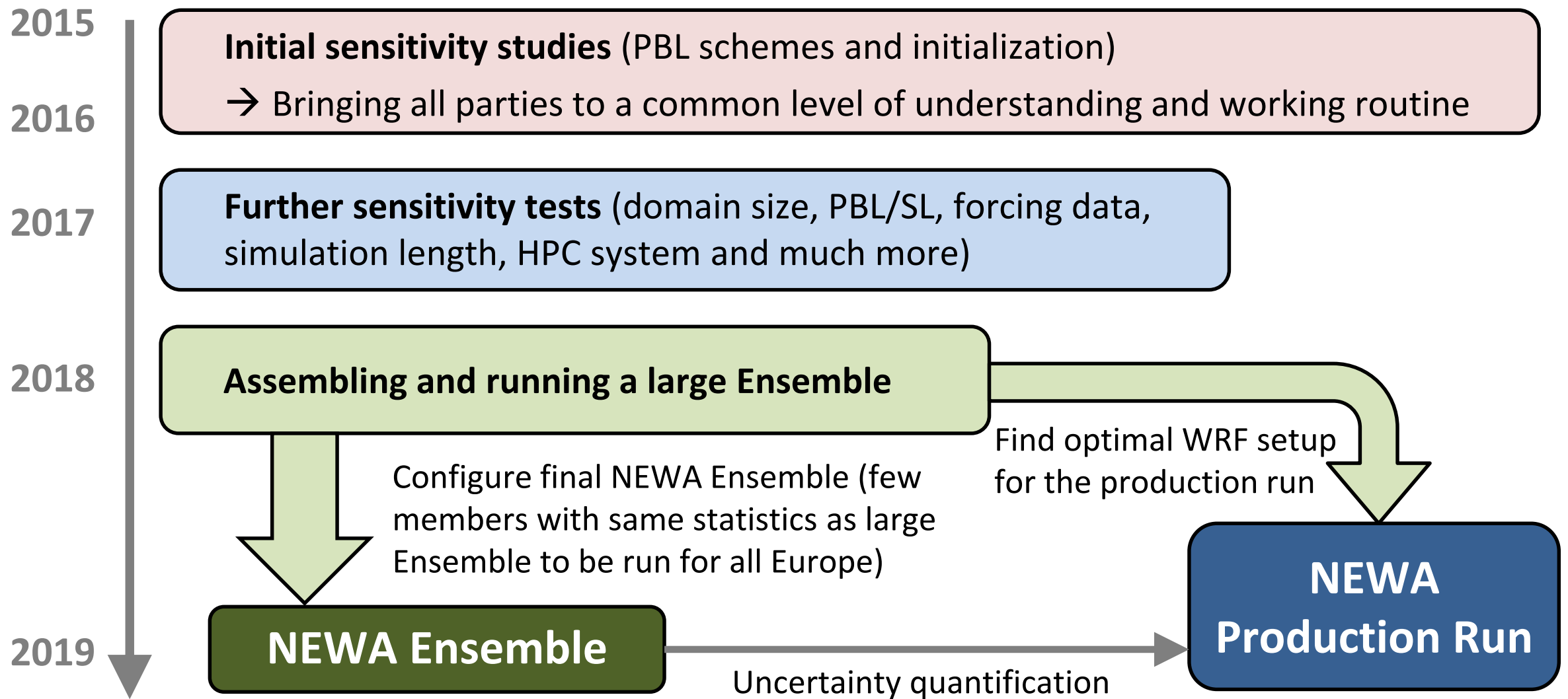
2 April 2019 - Bilbao

# NEWA: The mesoscale wind atlas

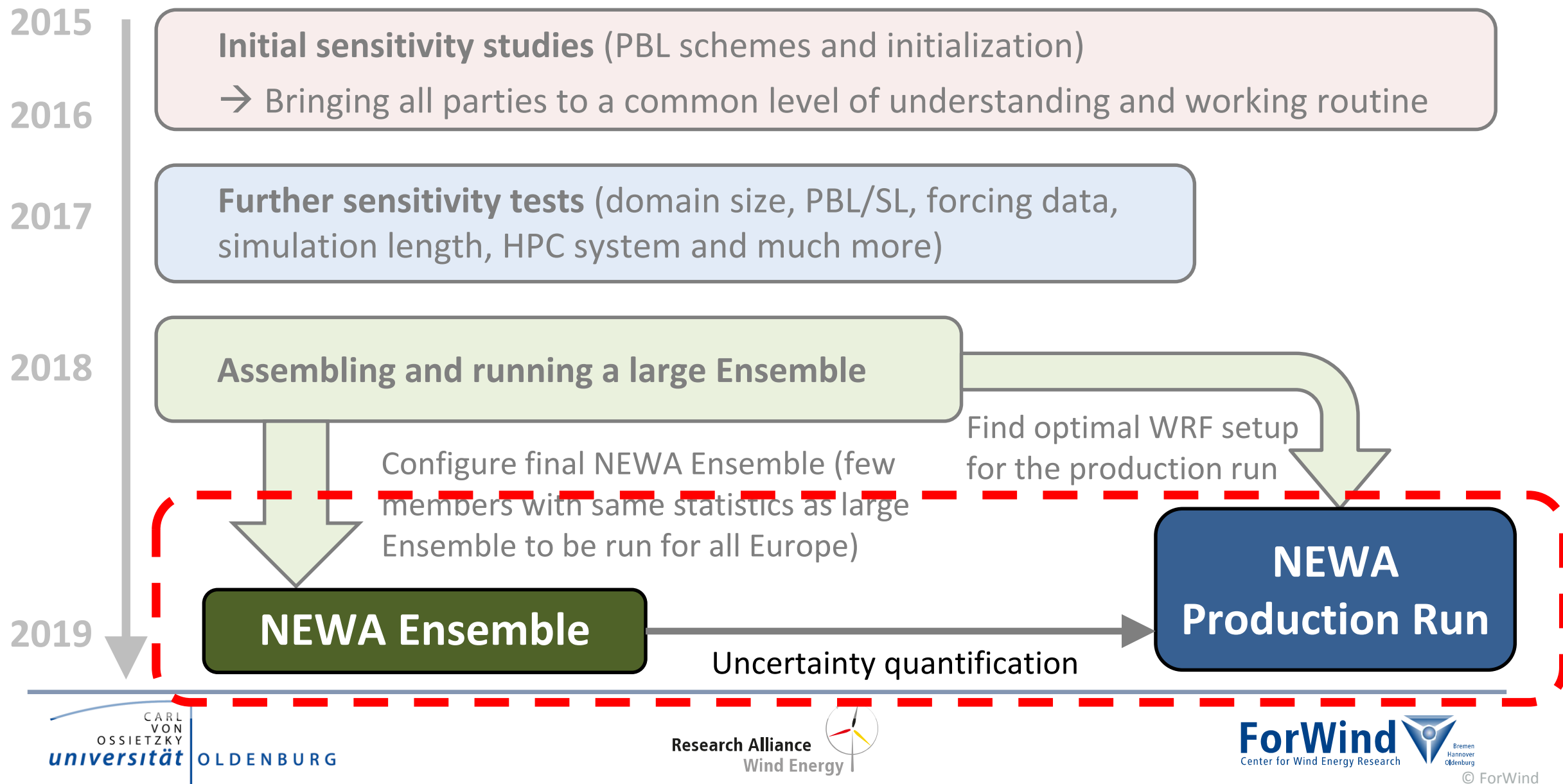
- Spatial coverage:
  - **entire EU + 100 km offshore**
  - + Turkey (project partner)
  - Complete North and Baltic Seas
- Simulated with the model WRF
  - **3 km grid spacing**
  - **30 years (1989-2018)**
- Furthermore: **1 year WRF Ensemble runs** to assess model uncertainties



# The long road towards the NEWA Mesoscale Wind Atlas...



# The long road towards the **NEWA Mesoscale Wind Atlas**...



# Large Mesoscale WRF Ensemble (1 sub-domain, 1 year)

- 62 members defined/tested
  - Based on previous tests/experience + suggestions from external reviewers
- 47 members successfully completed (1 year)

## Sensitivity experiments

Nudging options  
2-way nesting  
Forcing (reanalysis)  
WRF version  
Roughness (annual cycle, aggregated z0)  
SST data  
Radiation time step (for timing)

## Multi-physics runs

PBL scheme  
Surface layer scheme  
Land surface model  
various combinations of the above

## Other model physics

Icing  
Microphysics  
Radiation scheme  
Convection scheme



# Ensemble members that change the results

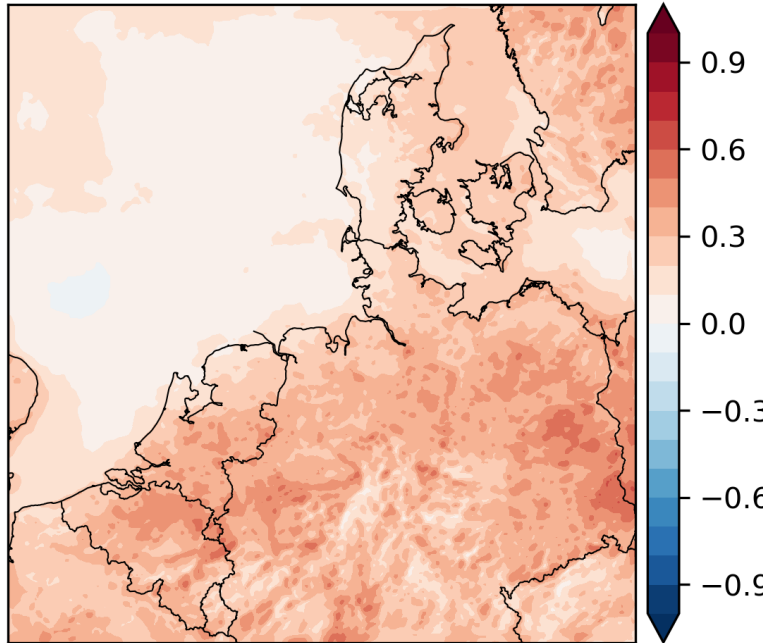
- 13 “sensitivity” runs:
  - Reanalysis data
  - Roughness coefficient changes
  - Changes in nudging
  - Radiation scheme
  - WRF version
- 20 (=all) “multi-physics” runs

Type	No.	Ensemble member	Code	Sensitivity
sensitivity experiments	1	base	EES81_2551040004	
	2	xw_36_yw_36	EES81_2551040004_A	not sensitive
	3	large_relax	EES81_2551040004_B	not sensitive
	4	2-way-nest	EES81_2551040004_C	not sensitive
	5	grid-nudging-D3	EES81_2551040004_H	sensitive
	6	grid-nudging-D1	EES81_2551040004_I	sensitive
	7	spec-nudging-D3	EES81_2551040004_J	sensitive
	8	ERA1	IIS81_2551040004	sensitive
	9	MERRA2	MMS81_2551040004	sensitive
	10	FNL	FFS81_2551040004	not sensitive
	11	Vers-361	EES61_2550040004	sensitive
	12	MYNN-unmod	EES81_2550040004	sensitive
	13	Z0-cycle	EES82_2551040004	sensitive
	14	Z0-cycle-NCAR	EES82_2551040004_A	sensitive
	15	Z0-aggr	EES83_2551040004	sensitive
	16	Z0-aggr-COR	EES84_2551040004	sensitive
	17	HRSST	EEH81_2551040004	not sensitive
	18	OISST	EEO81_2551040004	sensitive
	19	SST_ERA5	EEE81_2551040004	not sensitive
	20	radt_3	EES81_2551040004_D	not sensitive
	21	radt_12	EES81_2551040004_E	not sensitive
	22	cam	EES81_2551040003	sensitive
land surface / model physics	23	MYNN-MM5	EES81_2511040004	sensitive
	24	MYNN-MO	EES81_2521040004	sensitive
	25	MYJ-MO	EES81_2220040004	sensitive
	26	YSU-MM5	EES81_2110040004	sensitive
	27	RUC	EES81_3551040004	sensitive
	28	RUC-VEG	EES81_3551040004_A	sensitive
	29	RUC-MYNN-MO	EES81_3521040004	sensitive
	30	RUC-YSU-MM5	EES81_3110040004	sensitive
	31	RUC-ACM2-PX	EES81_3770040004	sensitive
	32	PXLSM-ACM2-PX	EES81_7770040004	sensitive
	33	PXLSM-ACM2-MM5	EES81_7710040004	sensitive
	34	SLAB	EES81_1551040004	sensitive
	35	SLAB-MYJ-MO	EES81_1220040004	sensitive
	36	SLAB-YSU-MM5	EES81_1110040004	sensitive
	37	SLAB-ACM2-PX	EES81_1770040004	sensitive
	38	NOAHMP	EES81_4550040004	sensitive
	39	NOAHMP-MYNN-origMP	EES81_4550040004_A	sensitive
	40	NOAHMP-MYNN-optsfc2	EES81_4550040004_B	sensitive
	41	NOAHMP-MYJ-MO	EES81_4220040004	sensitive
	42	NOAHMP-YSU-MM5	EES81_4110040004	sensitive
other	43	wms05_icing	EES81_2551040004_F	not sensitive
	44	wms05_icing2	EES81_2551040004_G	not sensitive
	45	thomps_icing	EES81_2551080004	not sensitive
	46	grell-freitas	EES81_2551040304	not sensitive
	47	rrtmg	EES81_2551040024	not sensitive

# Ensemble members that change the results

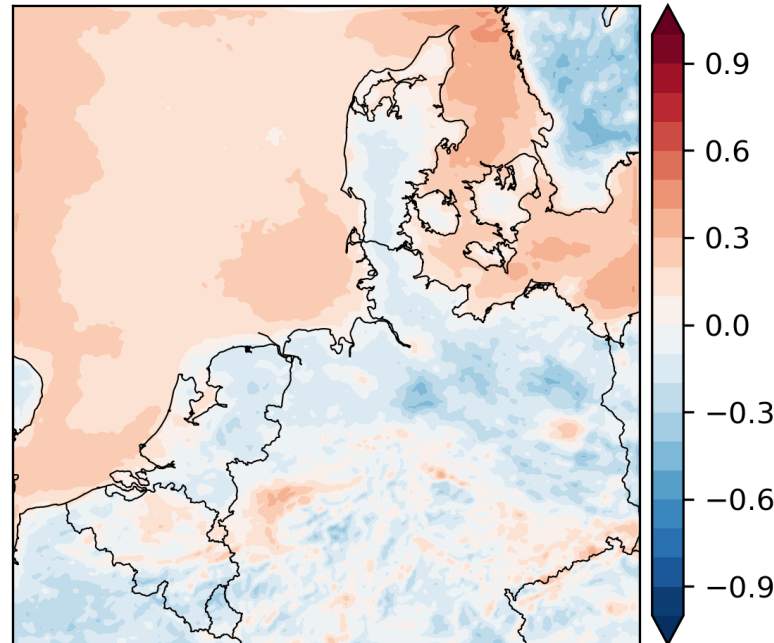
## Differences in annual mean wind speed

YSU-MM5 - base, bias, m/s at 100m



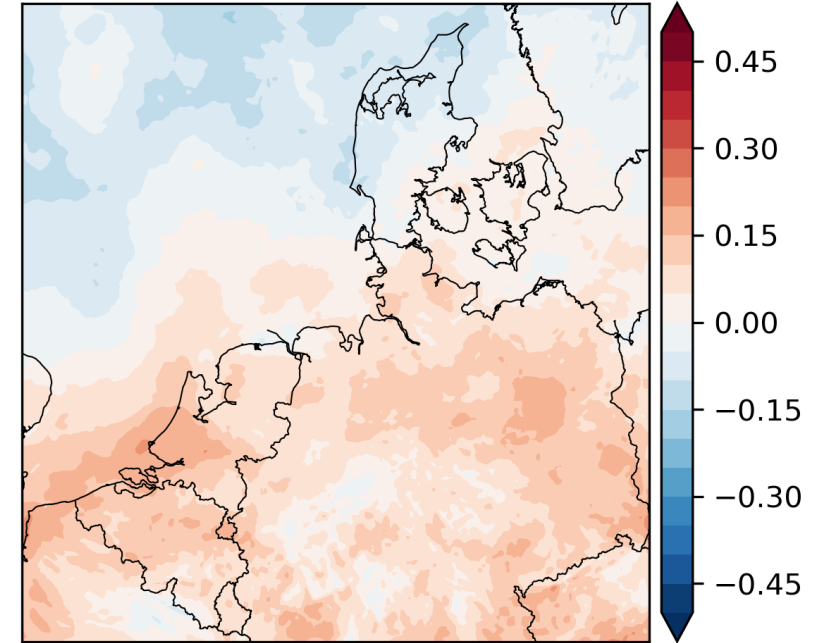
NOAH/YSU/MM5 –  
NOAH/MYNN/MYNN

SLAB-MYJ-MO - base, bias, m/s at 100m



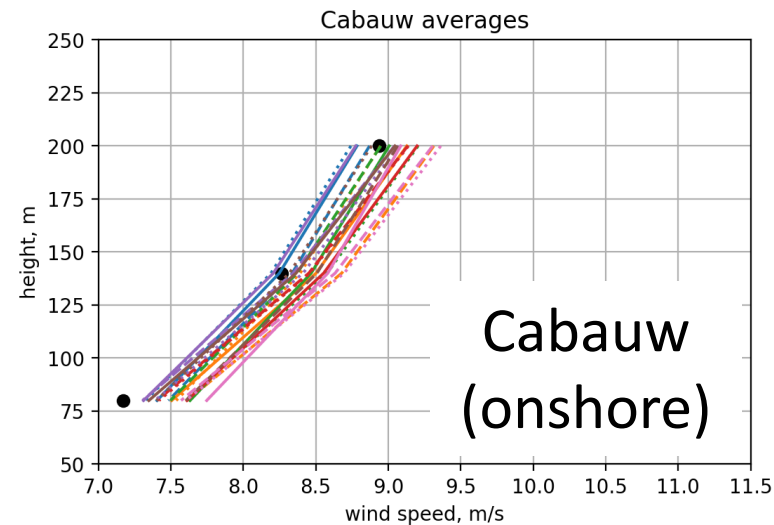
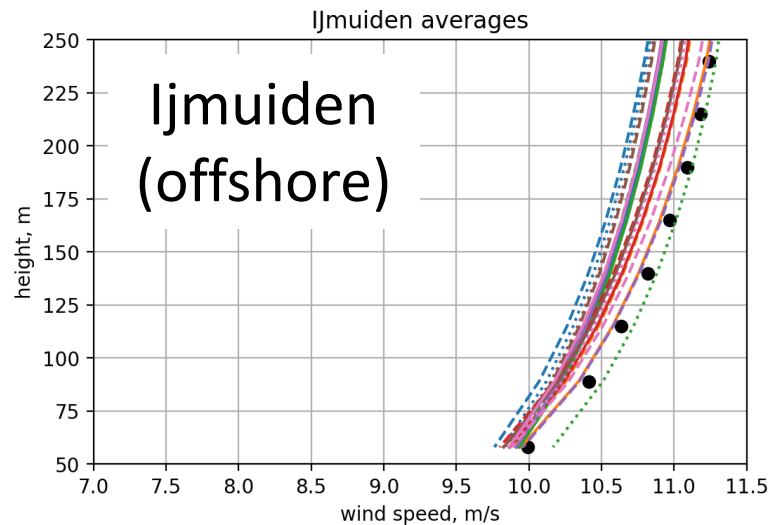
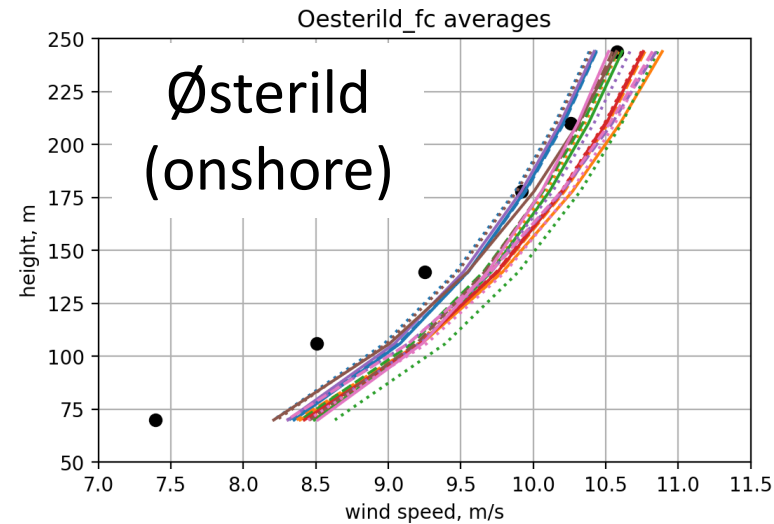
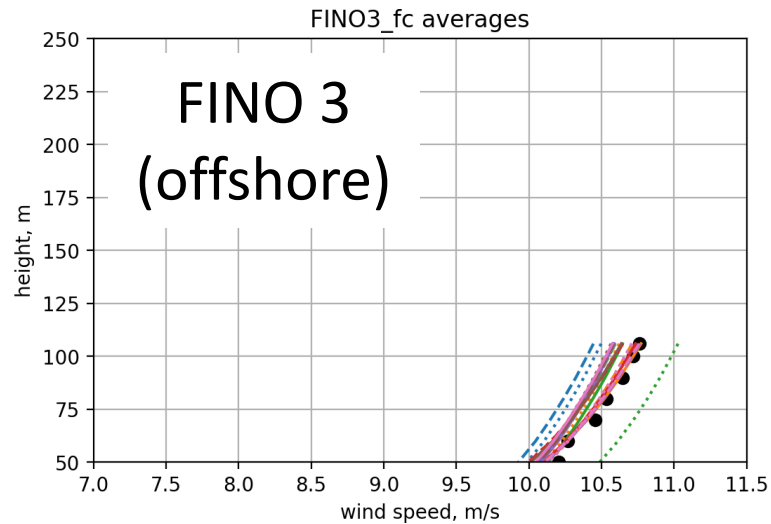
SLAB/MYJ/MO –  
NOAH/MYNN/MYNN

MERRA2 - base, bias, m/s at 100m



MERRA2 - ERA5

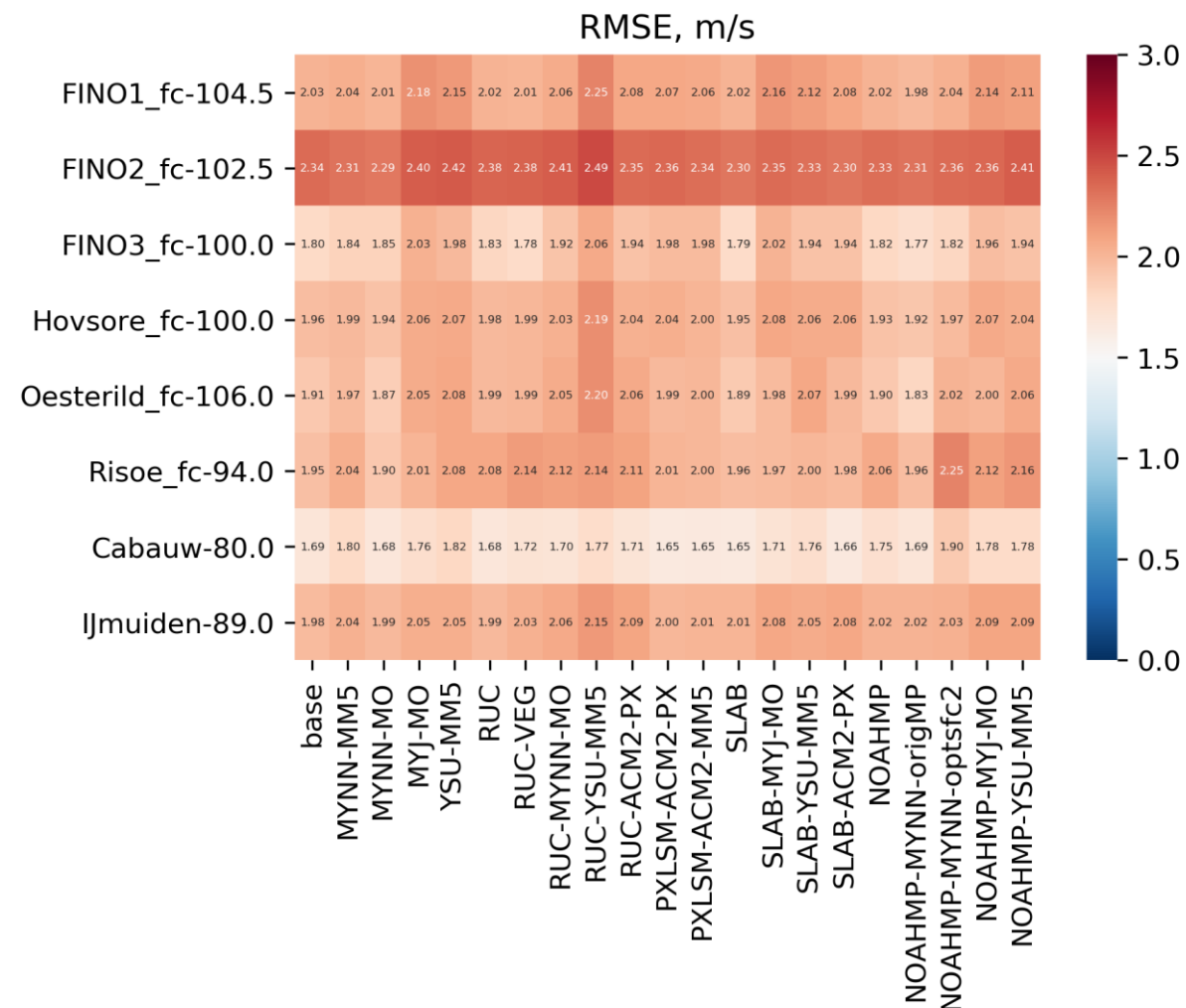
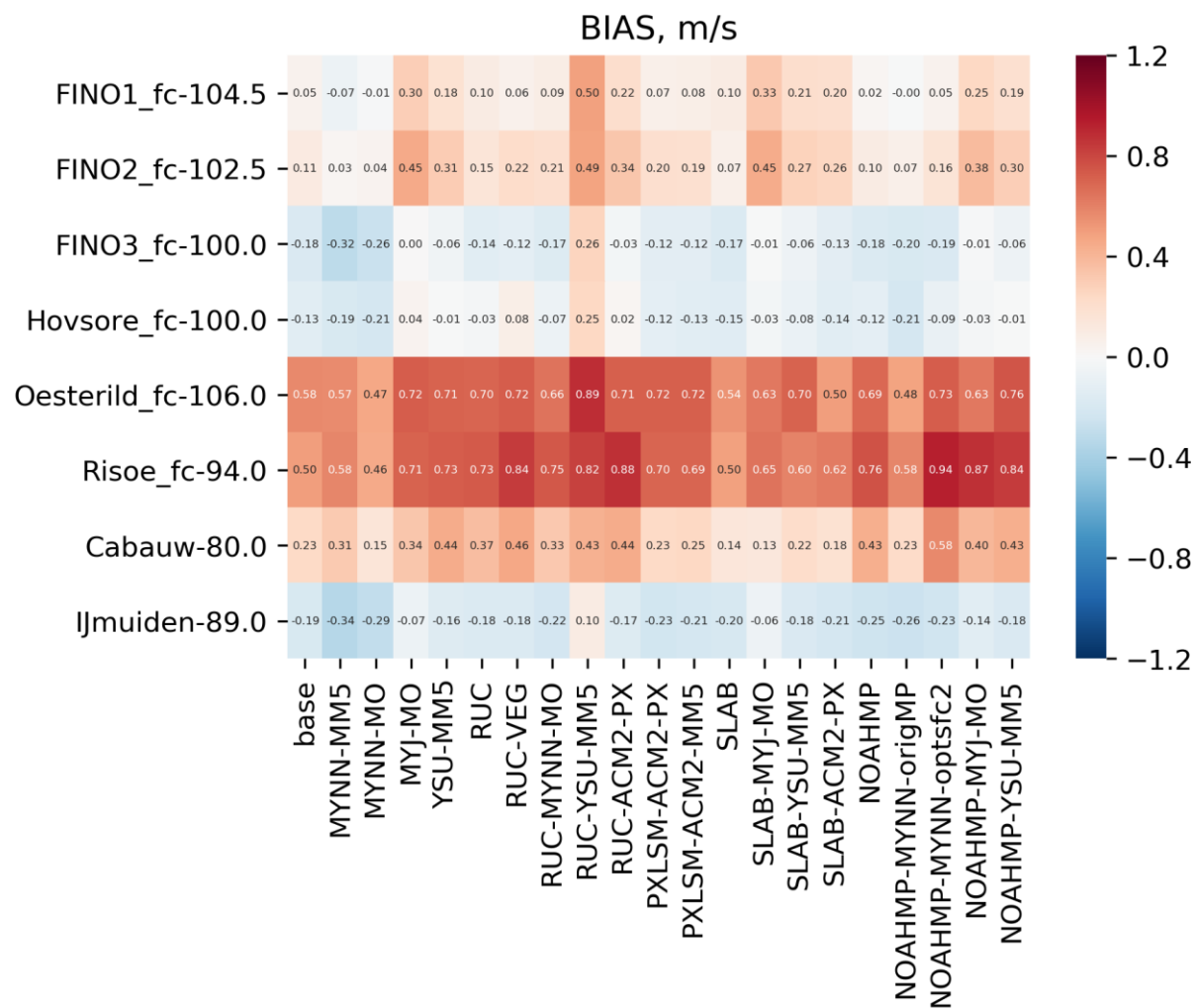
# Comparison with observations from tall masts



- base
- - MYNN-MM5
- ... MYNN-MO
- MYJ-MO
- - YSU-MM5
- ... RUC
- RUC-VEG
- - RUC-MYNN-MO
- ... RUC-YSU-MM5
- RUC-ACM2-PX
- - PXLISM-ACM2-PX
- ... PXLISM-ACM2-MM5
- SLAB
- - SLAB-MYJ-MO
- ... SLAB-YSU-MM5
- SLAB-ACM2-PX
- - NOAHMP
- ... NOAHMP-MYNN-origMP
- NOAHMP-MYNN-optsfc2
- - NOAHMP-MYJ-MO
- ... NOAHMP-YSU-MM5

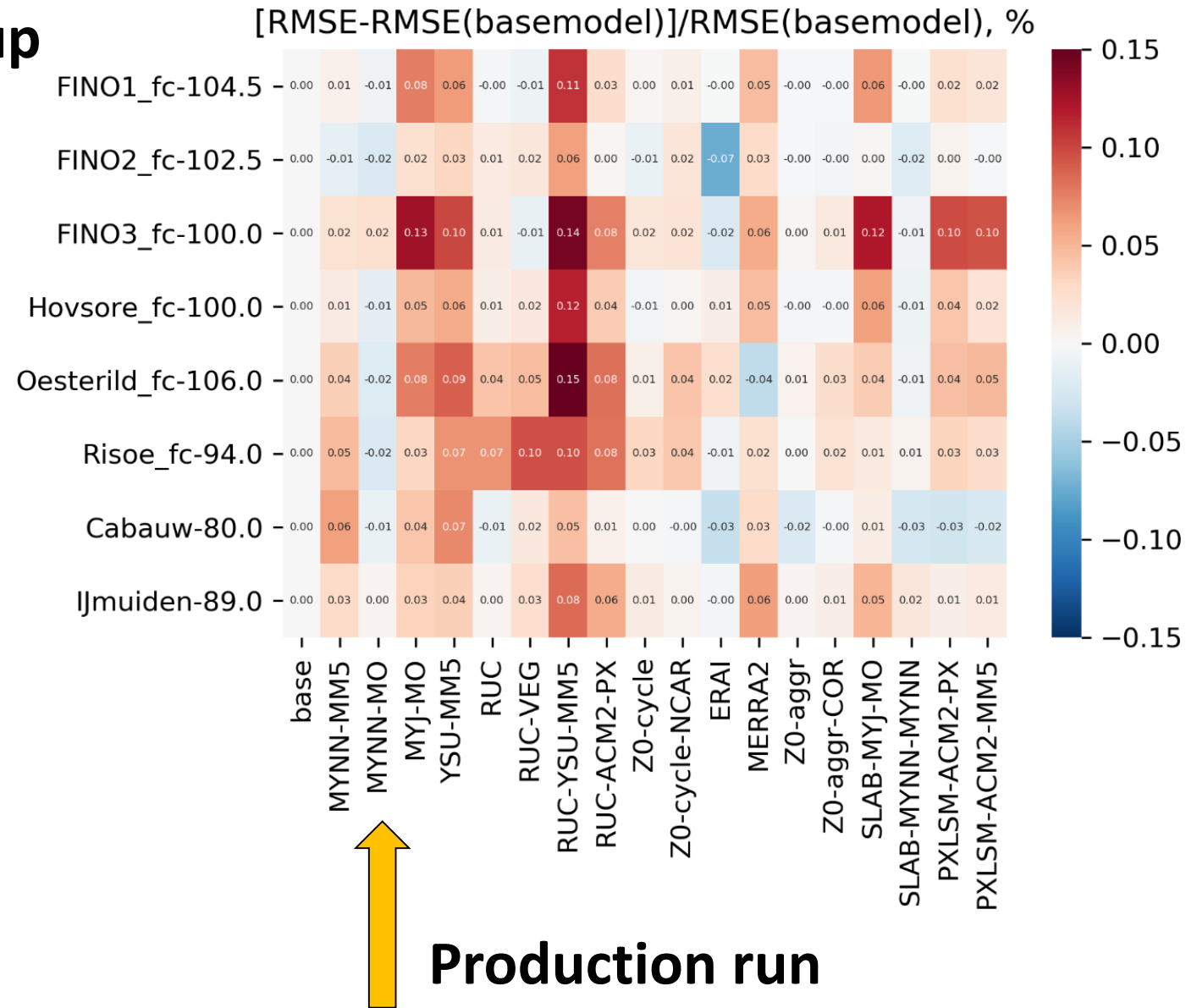


# Comparison with observations from tall masts



# Finding the production run setup

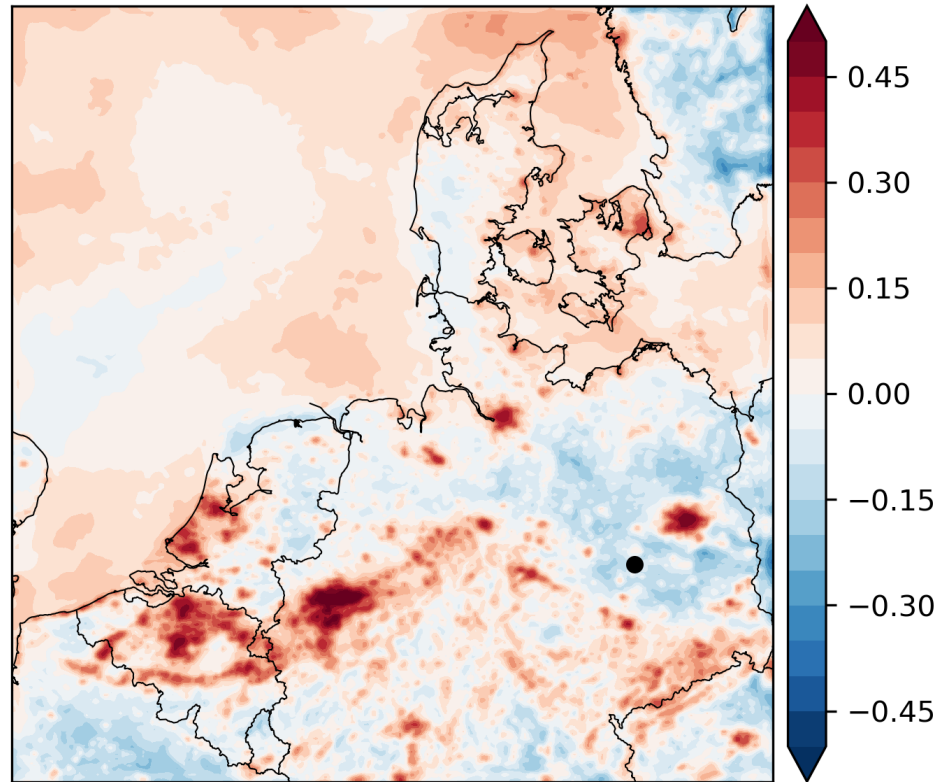
- Ratio of RMSE ensemble member vs. base run
- No single simulation performs best at all sites
- MYNN-MO slightly better at 2-3 sites, so it was chosen as production run



# Towards the configuration of the final NEWA Ensemble:

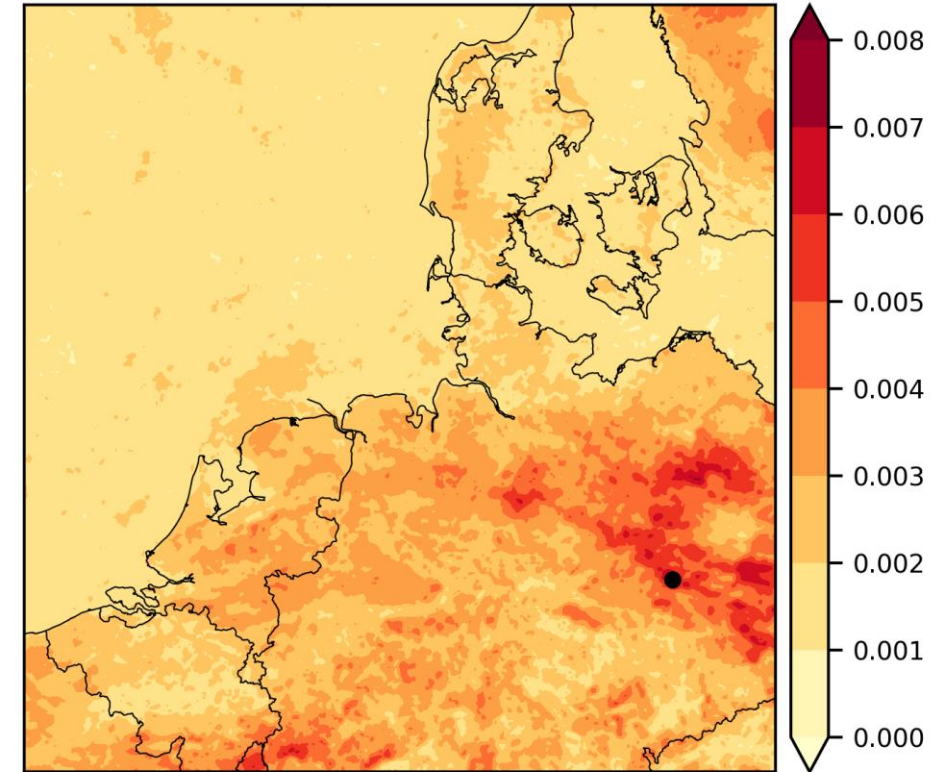
## Comparison of means vs. comparison of distributions

SLAB-YSU-MM5 - base, bias, m/s at 100m



Bias of one member against the base run (annual mean wind speed)

EMD metric wind\_speed SLAB-YSU-MM5



EMD metric: Difference in the wind speed distribution

## Further information on poster PO.160:

# Are mesoscale ensembles useful for estimating the uncertainty of wind resource atlases?



PO.160

## Are mesoscale ensembles useful for estimating the uncertainty of wind resource atlases?

Björn Witha<sup>1</sup>, Andrea Hahmann<sup>2</sup>, Tija Sile<sup>3</sup>, Fidel González-Rouco<sup>4</sup>, Elena García-Bustamante<sup>4,5</sup>, Jorge Navarro<sup>6</sup>, Martin Dörenkämper<sup>6</sup>, Yasemin Ezber<sup>7</sup>, Mariano Sastre<sup>4</sup>

<sup>1</sup>ForWind, University of Oldenburg, Germany, <sup>2</sup>DTU Wind Energy, Denmark, <sup>3</sup>Department of Physics, University of Latvia, <sup>4</sup>Opto. Física de la Tierra, Universidad Complutense de Madrid, <sup>5</sup>Renewable Energy Division, CIEMAT, Spain, <sup>6</sup>Fraunhofer IWES, Germany, <sup>7</sup>Istanbul Technical University, Turkey



### The New European Wind Atlas

- New European Wind Atlas (NEWA) ERA-NET+ project running from 2015-2019 [1,2]
- 30 partners in 8 countries



#### Objectives of NEWA:

- Generate mesoscale wind atlas (3 km resolution) based on the WRF model [3]
- Microscale climatological downscaling to 50 m
- Quantify uncertainties through ensemble simulations → focus of this poster
- Field experiments to validate models and wind atlas
- NEWA atlas will be launched in June 2019 – data freely available

### Mesoscale WRF Ensemble

Two objectives:

- Find the best WRF setup for the wind atlas production run
- Try to quantify uncertainty in the wind atlas resulting from the choices made in the model setup

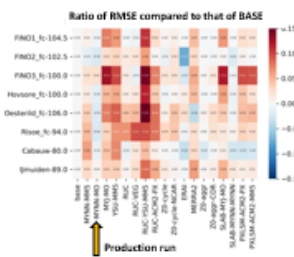
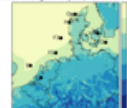
1<sup>st</sup> step: Define and run a large Ensemble based on many different configuration options for a small model domain.

2<sup>nd</sup> step: Generate a reduced ensemble that has the same ensemble statistics (e.g. spread) as the large ensemble and run it for the complete NEWA domain.

→ Main question: How to choose these members?

### Verification

Comparison against observations for 8 sites offshore or over "simple" terrain to find the best setup for the NEWA production run:



- No single simulation performs best at all sites, RMSE is mainly site depending
- MYNN-MO slightly better at 2-3 sites, so it was chosen as production run

### Ensemble members

- 60 ensemble members defined, only 47 were successfully computed
- 1 year simulated (2015), 900 x 900 km<sup>2</sup> domain
- Majority of members showed sensitivity

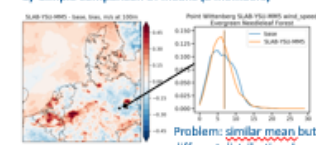
Line	No.	Ensemble member	Code	Sensitivity
1	1	base	ERA1_255040000_A	not sensitive
2	2	era_36_yr_36	ERA1_255040000_A	not sensitive
3	3	large_nires	ERA1_255040000_A	not sensitive
4	4	2-way-nires	ERA1_255040000_A	not sensitive
5	5	grid-nudging CD	ERA1_255040000_A	sensitive
6	6	grid-nudging D1	ERA1_255040000_A	sensitive
7	7	grid-nudging D3	ERA1_255040000_A	sensitive
8	8	ERA1	ERA1_255040000_A	sensitive
9	9	MYNN-MO	MYNN_255040000_A	sensitive
10	10	MYNN-MO	MYNN_255040000_A	sensitive
11	11	MYNN-MO	MYNN_255040000_A	sensitive
12	12	MYNN-MO	MYNN_255040000_A	sensitive
13	13	MYNN-MO	MYNN_255040000_A	sensitive
14	14	MYNN-MO	MYNN_255040000_A	sensitive
15	15	MYNN-MO	MYNN_255040000_A	sensitive
16	16	MYNN-MO	MYNN_255040000_A	sensitive
17	17	MYNN-MO	MYNN_255040000_A	sensitive
18	18	MYNN-MO	MYNN_255040000_A	sensitive
19	19	MYNN-MO	MYNN_255040000_A	sensitive
20	20	MYNN-MO	MYNN_255040000_A	sensitive
21	21	MYNN-MO	MYNN_255040000_A	sensitive
22	22	MYNN-MO	MYNN_255040000_A	sensitive

23	23	MYNN-MO	MYNN_255040000_A	sensitive
24	24	MYNN-MO	MYNN_255040000_A	sensitive
25	25	MYNN-MO	MYNN_255040000_A	sensitive
26	26	MYNN-MO	MYNN_255040000_A	sensitive
27	27	MYNN-MO	MYNN_255040000_A	sensitive
28	28	MYNN-MO	MYNN_255040000_A	sensitive
29	29	MYNN-MO	MYNN_255040000_A	sensitive
30	30	MYNN-MO	MYNN_255040000_A	sensitive
31	31	MYNN-MO	MYNN_255040000_A	sensitive
32	32	MYNN-MO	MYNN_255040000_A	sensitive
33	33	MYNN-MO	MYNN_255040000_A	sensitive
34	34	MYNN-MO	MYNN_255040000_A	sensitive
35	35	MYNN-MO	MYNN_255040000_A	sensitive
36	36	MYNN-MO	MYNN_255040000_A	sensitive
37	37	MYNN-MO	MYNN_255040000_A	sensitive
38	38	MYNN-MO	MYNN_255040000_A	sensitive
39	39	MYNN-MO	MYNN_255040000_A	sensitive
40	40	MYNN-MO	MYNN_255040000_A	sensitive
41	41	MYNN-MO	MYNN_255040000_A	sensitive
42	42	MYNN-MO	MYNN_255040000_A	sensitive

### Metrics

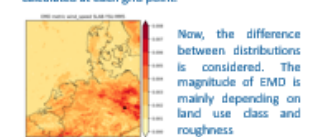
How to characterize and quantify the ensemble properties of wind speed distributions both at a single grid point and in the whole computational domain?

#### 1) Simple comparison of means (2 members)



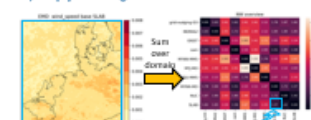
#### 2) Earth Mover's Distance (EMD)

Amount of work that is required to change one distribution into another, calculated at each grid point.



### How to compare many members in many grid points?

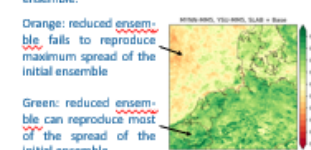
#### 1) Simply summing the EMD values over the domain



Problem: How can we be sure that the result is robust and does not depend on the specific domain?

#### 2) Maximum fulfillment approach

Ratio of maximum possible spread in each grid point between reduced four-member-ensemble and full ensemble:



### Conclusions and next steps

- A robust method of ensemble member selection has been found based on EMD and maximum fulfillment approach
- Ensemble simulations (2-5) will be run for all NEWA domains
- The spread may quantify the model configuration "uncertainty", but possibly not the wind atlas uncertainty
- Quantification of the WRF error based on the ensemble spread is still under investigation, main constraint is lack of observations

### Acknowledgements

We acknowledge PRACE for awarding us access to MareNostrum at Barcelona Supercomputing Center (BSC), Spain.



### References

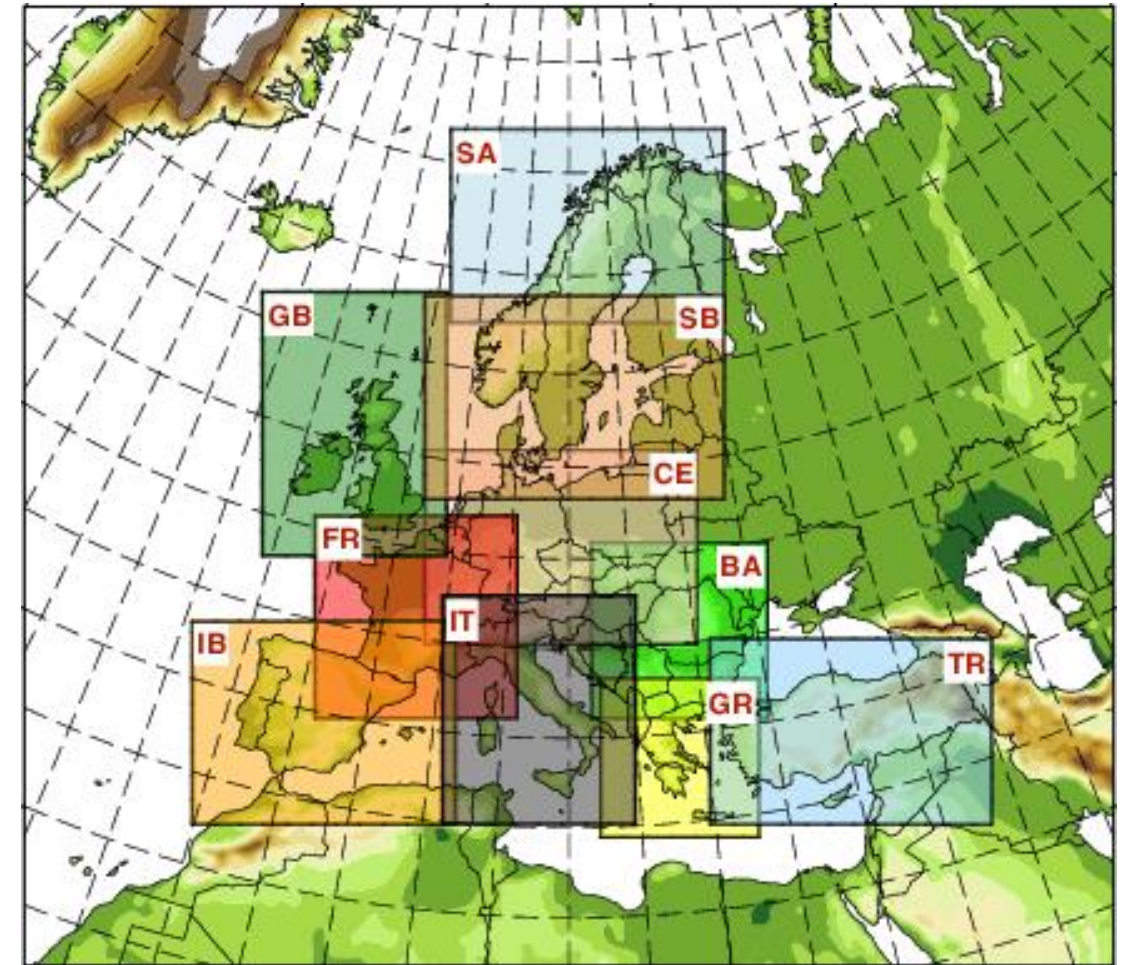
- <http://www.newa.eu/newa/era-net-plus>
- Petersen et al. (2013): An local wind power resources well estimated? *Energy*, Res. Lett., 8, 011005, doi: 10.1088/1748-0226/8/1/011005
- Skanavrock et al. (2008): A Description of the Advanced Weather Research and Forecasting Version 3, Technical Report NCAR/TN-475+STR, NCAR





# Mesoscale Production Runs – Final Setup

- WRF version: **modified v3.8.1** (PBL, icing)
- Grid: 27 km → 9 km → 3 km; 61 vertical levels
- **10 regions**
- **8-day runs** incl. 24 h spin-up, spectral nudging in D1
- **MYNN PBL scheme** (modified) + MO surface layer
- Forcing: **ERA5** reanalysis (0.3°)
- **OSTIA SST** and sea-ice (1/12°)
- Adaptive time step (where working)
- **CORINE 100 m land use data**, USGS where CORINE not available
- NOAH land surface model
- Icing (WSM5 + icing code + sum of qcloud and qice)
- Radiation time step = 12 minutes
- 480 cores, IO Quilting (1 node used for output)





# Managing the Mesoscale Production Runs

- **57 million core hours on the supercomputer MareNostrum4** in Barcelona granted by PRACE consortium (peer-reviewed proposal)
  - from 01 April 2018 – 31 March 2019
- **30 years x 52 weekly simulations x 10 domains; 30 min output**
- Each weekly simulation took 6-8 hours on 480 cores (plus considerable queueing time)
- **6 Petabytes of raw data produced**
  - impossible to store, immediate postprocessing required
- Bottleneck: “only” 100 TB disk space
  - only 3-4 runs could be active at the same time

# Managing the Mesoscale Production Runs

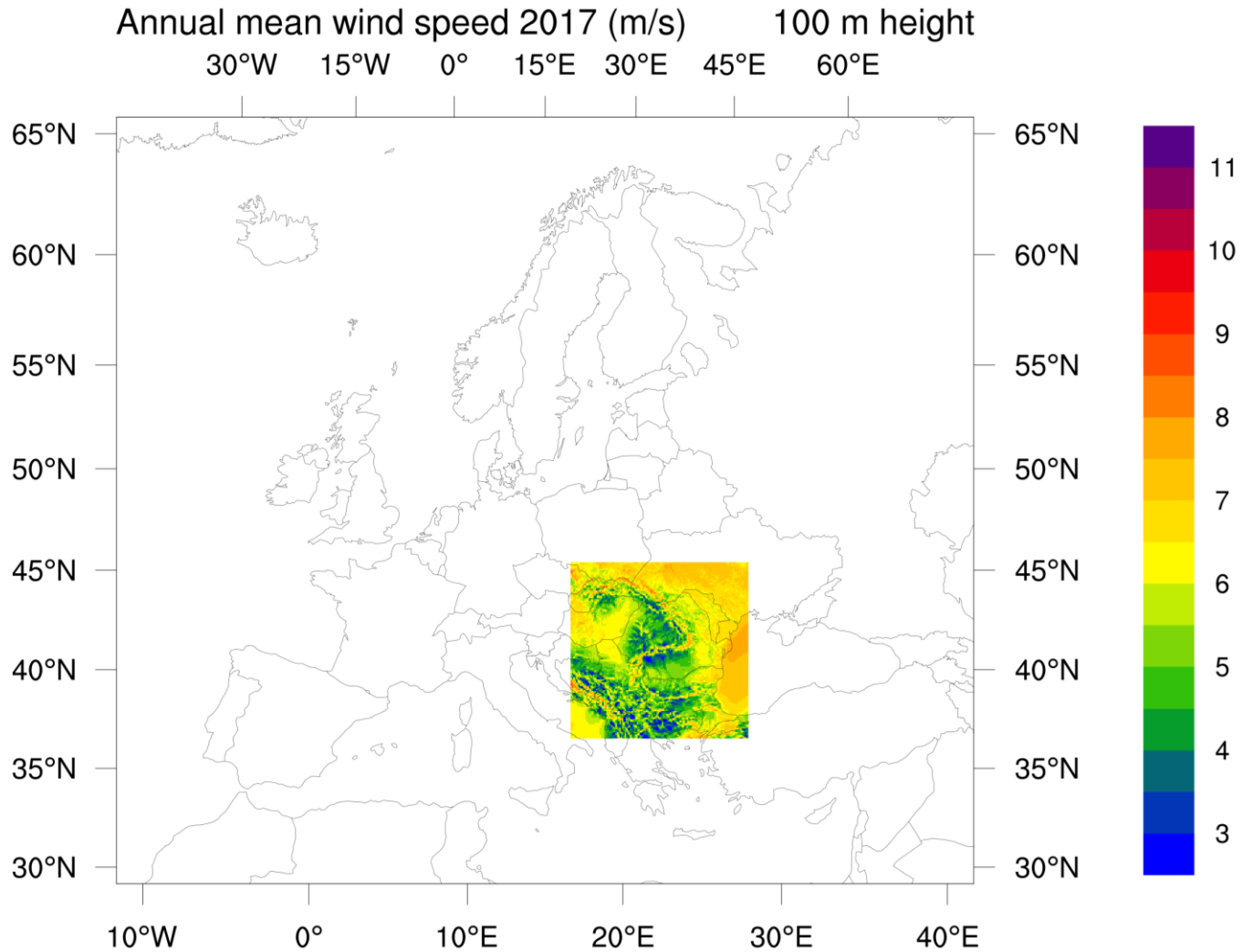
- Largely automated and easy to handle procedures (python and bash scripts)
- 1 main responsible person per week (including evenings and weekends!) + 1 assistant
- A lot of communication in an online project forum (Slack)

fx

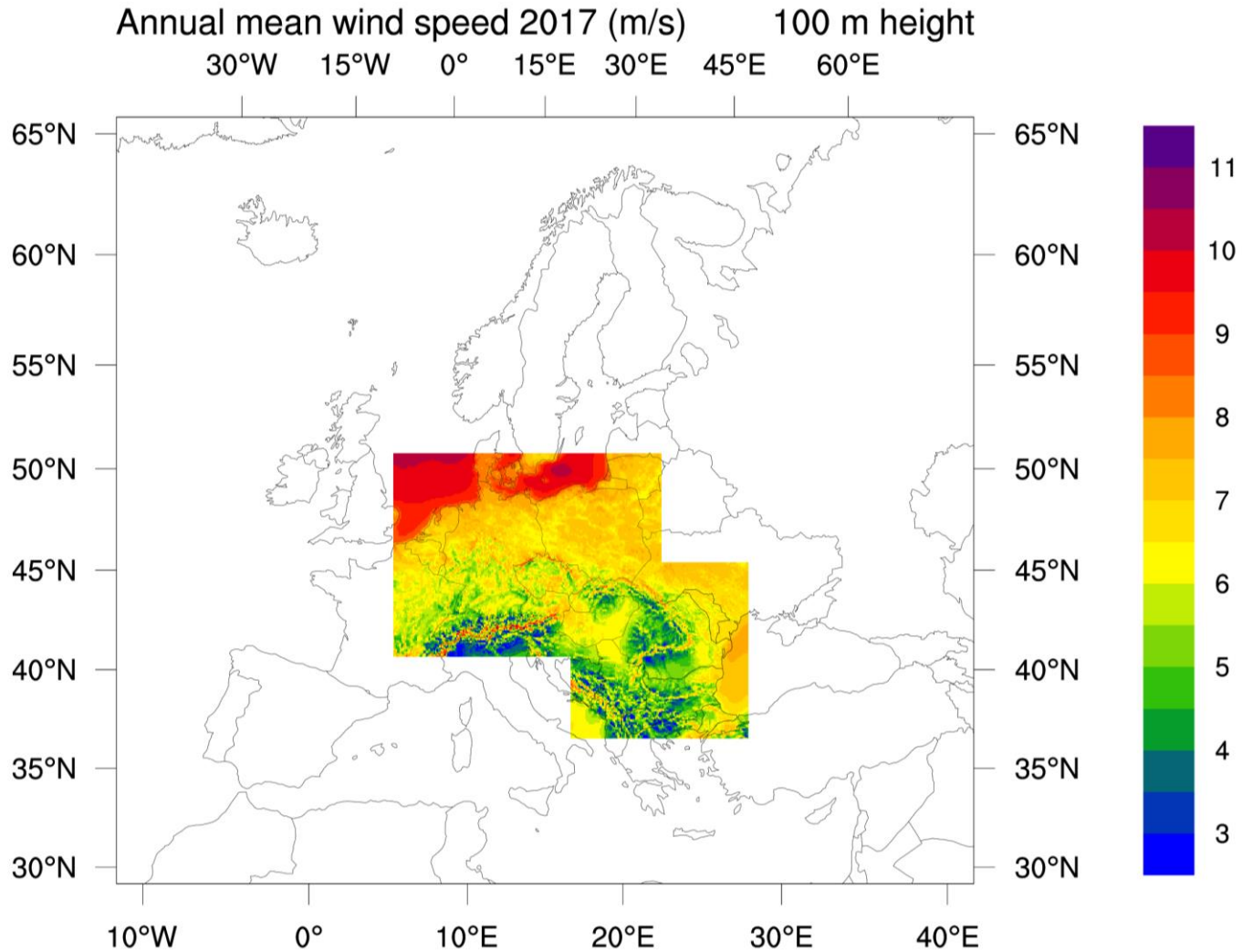
NEWA Production Run:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF												
1	NEWA Production Run:																																											
2	region / year	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988												
3	BA		BW	BW	JB	JB	TS	WT	WT	AH	BO	AH	MD	YE	MD	MS	JN	JN	JB	JB*	BW	BW	MD	MD	MD	MD																		
4	CE		BW	AH	JB	JB	TS	WT	WT	AH	BO	AH	BW	YE	MS	MS	JN	JN	JB	JB*	BW	BW	MD	MD	MD																			
5	FR		BW	AH	JB	JB	TS	BW	WT	AH	EG	AH	MD	YE	MS	MS	JN	JN	JB	JB*	BW	BW	MD	MD	MD																			
6	GB		BW	BW	JB	JB	TS	TS	WT	AH	EG	AH	MD	YE	MS	MS	JN	JN	JB	JB*	BW	BW	MD	MD	MD																			
7	GR		BW	BW	BW	JB	BW	TS	WT	AH	EG	YE	MD	YE	MS	MS	JN	JN	JB	BW*	BW	BW	MD	MD	MD																			
8	IB		BW	JB	BW	JB	TS	TS	WT	AH	EG	YE	MD	YE	MS	MS	JN	JN	JB	BW*	BW	BW	MD	MD	MD																			
9	IT		BW	TS	BW	TS	BW	WT	WT	AH	EG	YE	MD	YE	MS	MS	JN	JN	JB	BW*	BW	BW	MD	MD	MD																			
10	SA		BW	JB	JB	TS	TS	BW	WT	AH	EG	YE	MD	YE	MS	JN	JN	JN	JB	BW*	BW	BW	MD	MD	MD																			
11	SB		BW	JB	JB	TS	TS	WT	WT	AH	EG	YE	MD	YE	MS	JN	JN	JN	JB	BW*	BW	BW	MD	MD	MD																			
12	TR		BW	JB	JB	TS	TS	WT	AH	BO	EG	YE	MD	YE	MS	JN	JN	JN	JB	BW*	BW	BW	MD	MD	MD																			
13																				* week 000 only																								
14		Transfer by hand; no remove											Main run done; some weeks failed; waiting to run																															
15		Run completed and data transferred											Run completed; transfer initiated																	ERA5 data not yet available/downloaded														
16		Job submitted; running or waiting to run											WPS done, WRF failed/was canceled																															
17		Run completed; waiting postprocess											Test																															

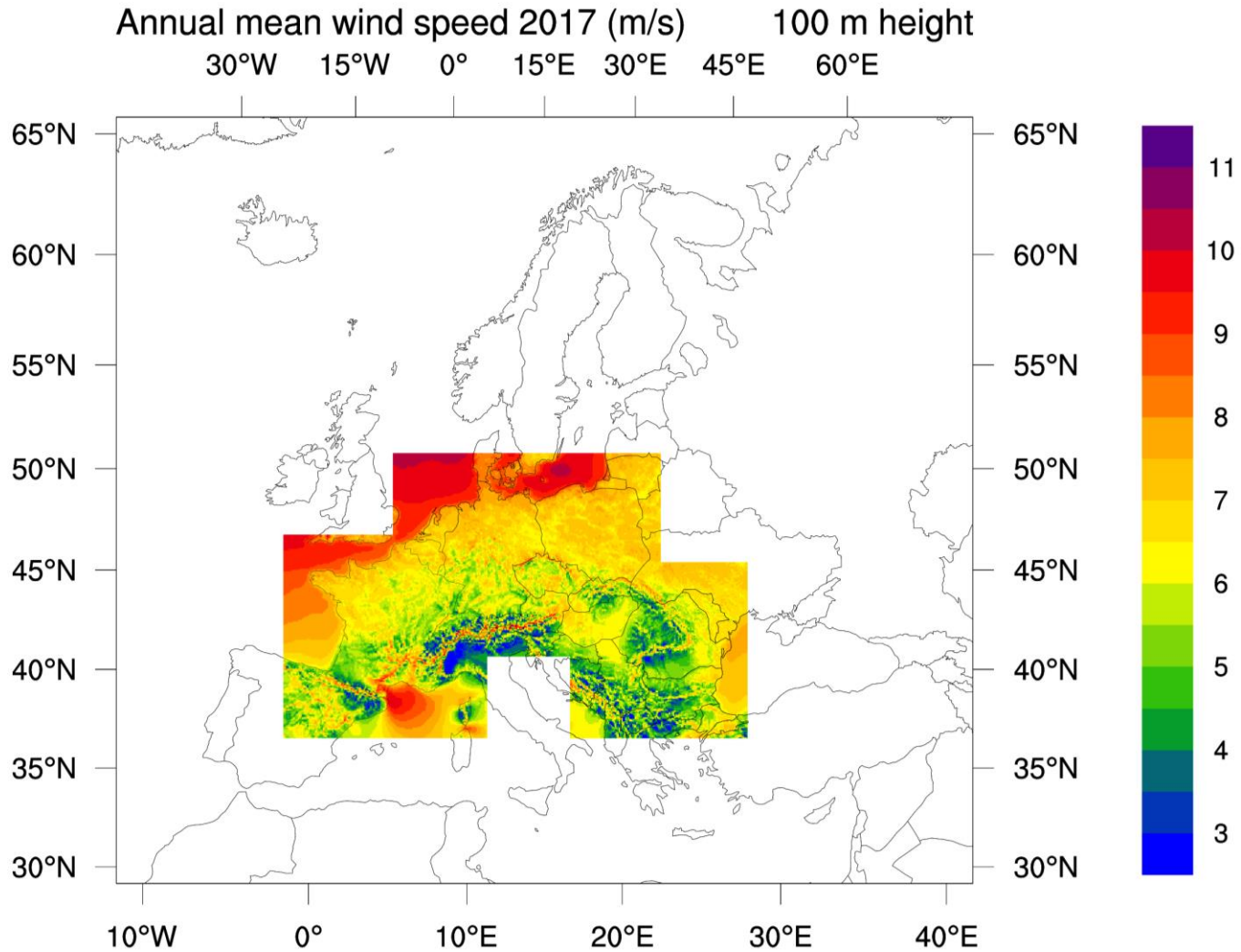
# Results from the production runs



# Results from the production runs

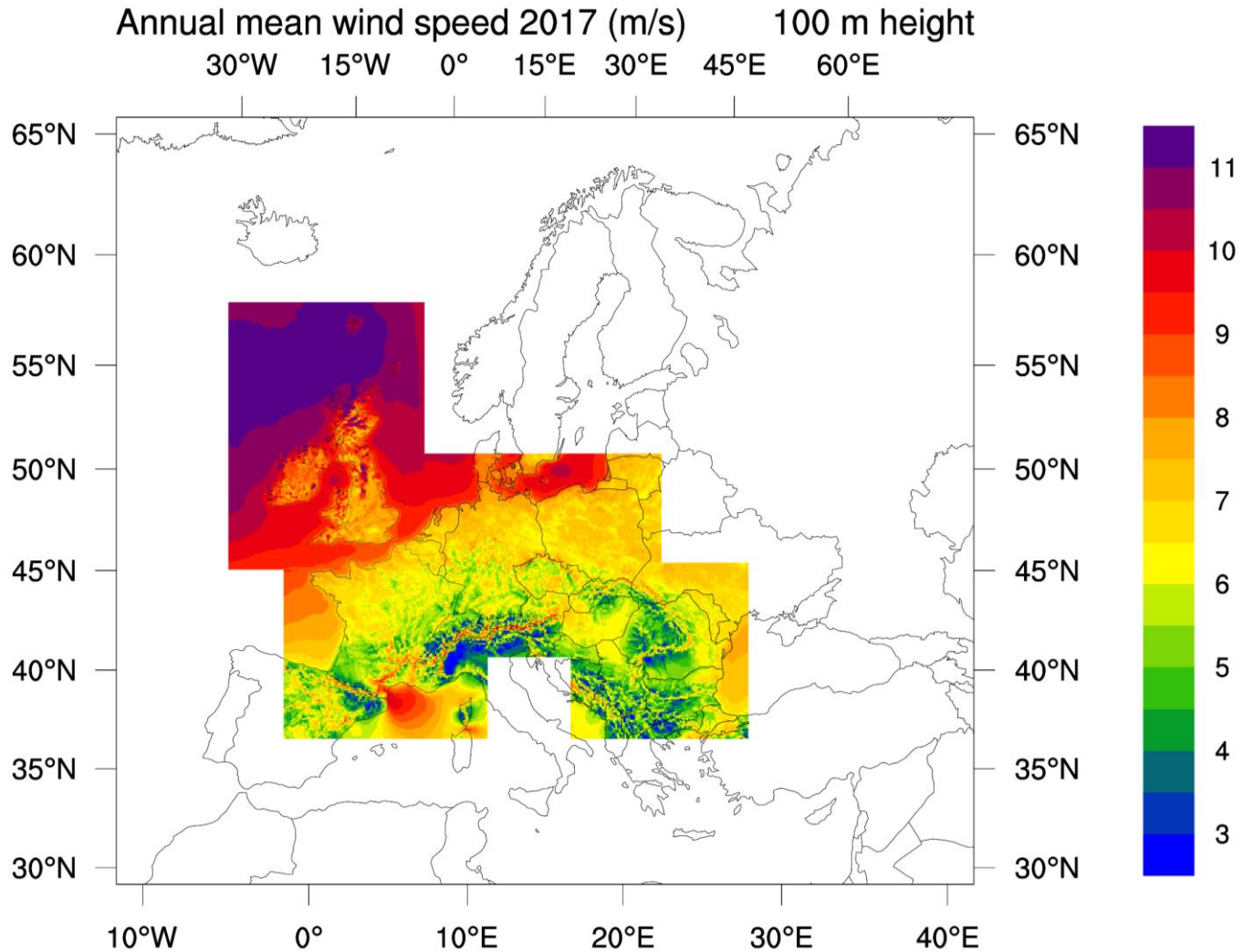


# Results from the production runs

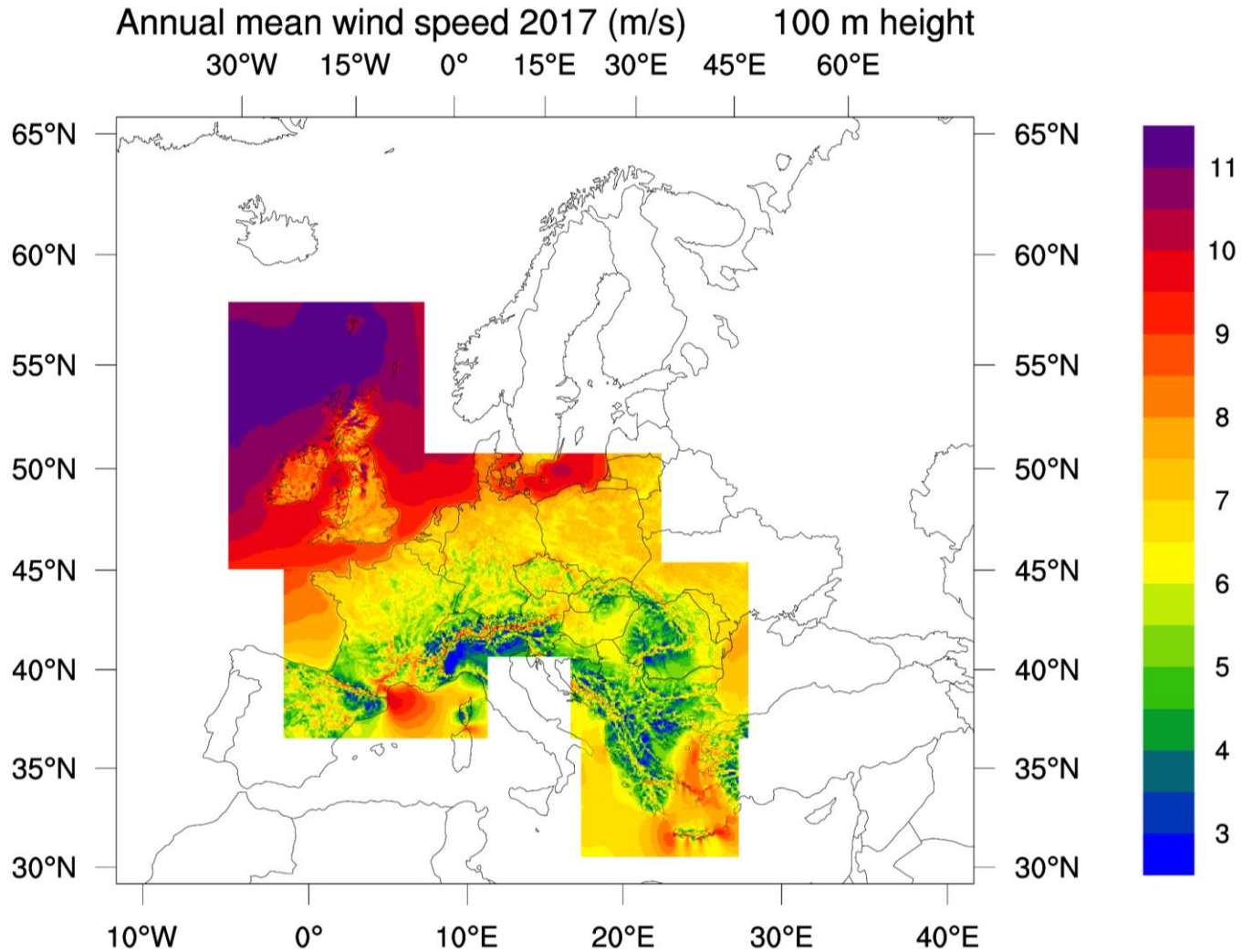




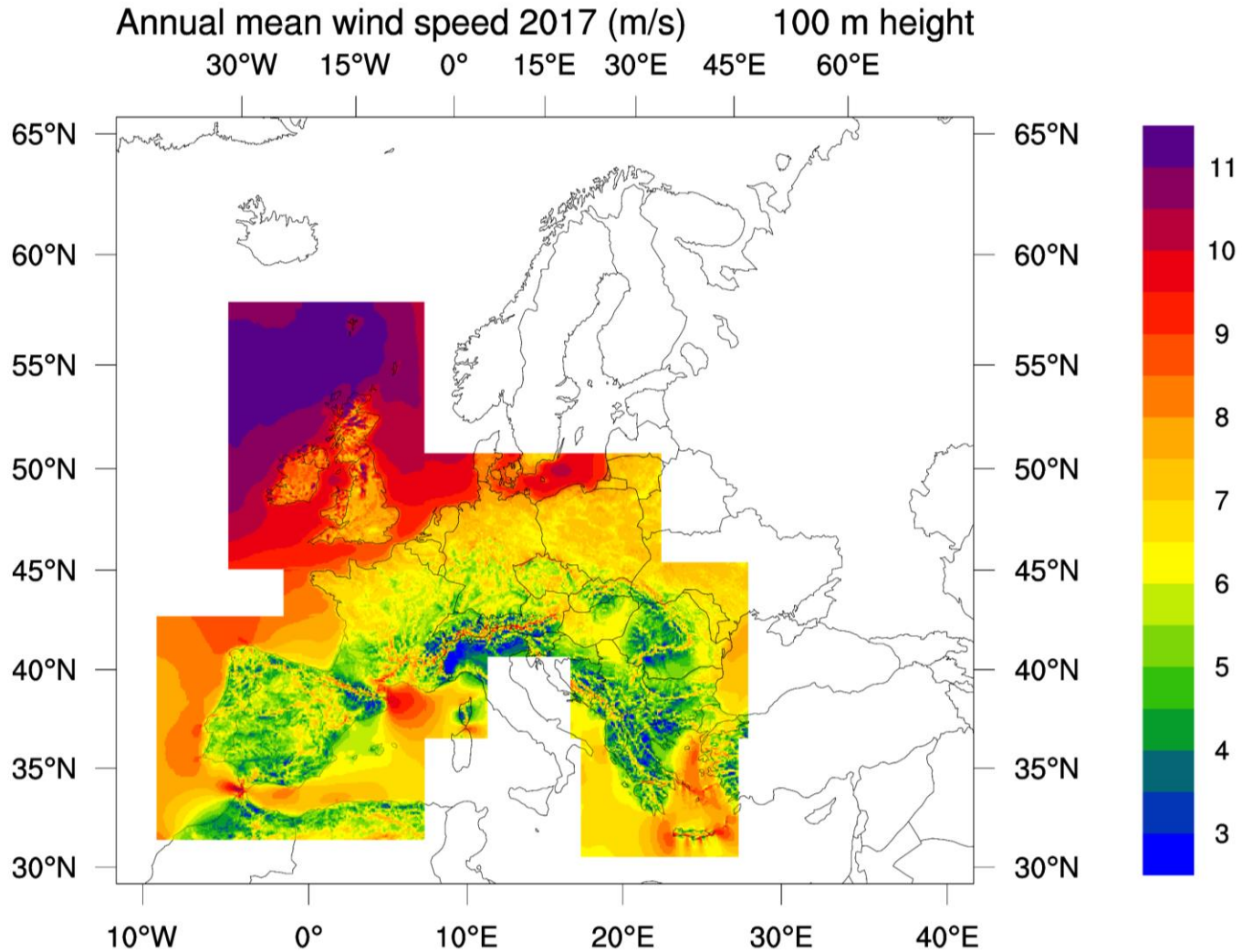
# Results from the production runs



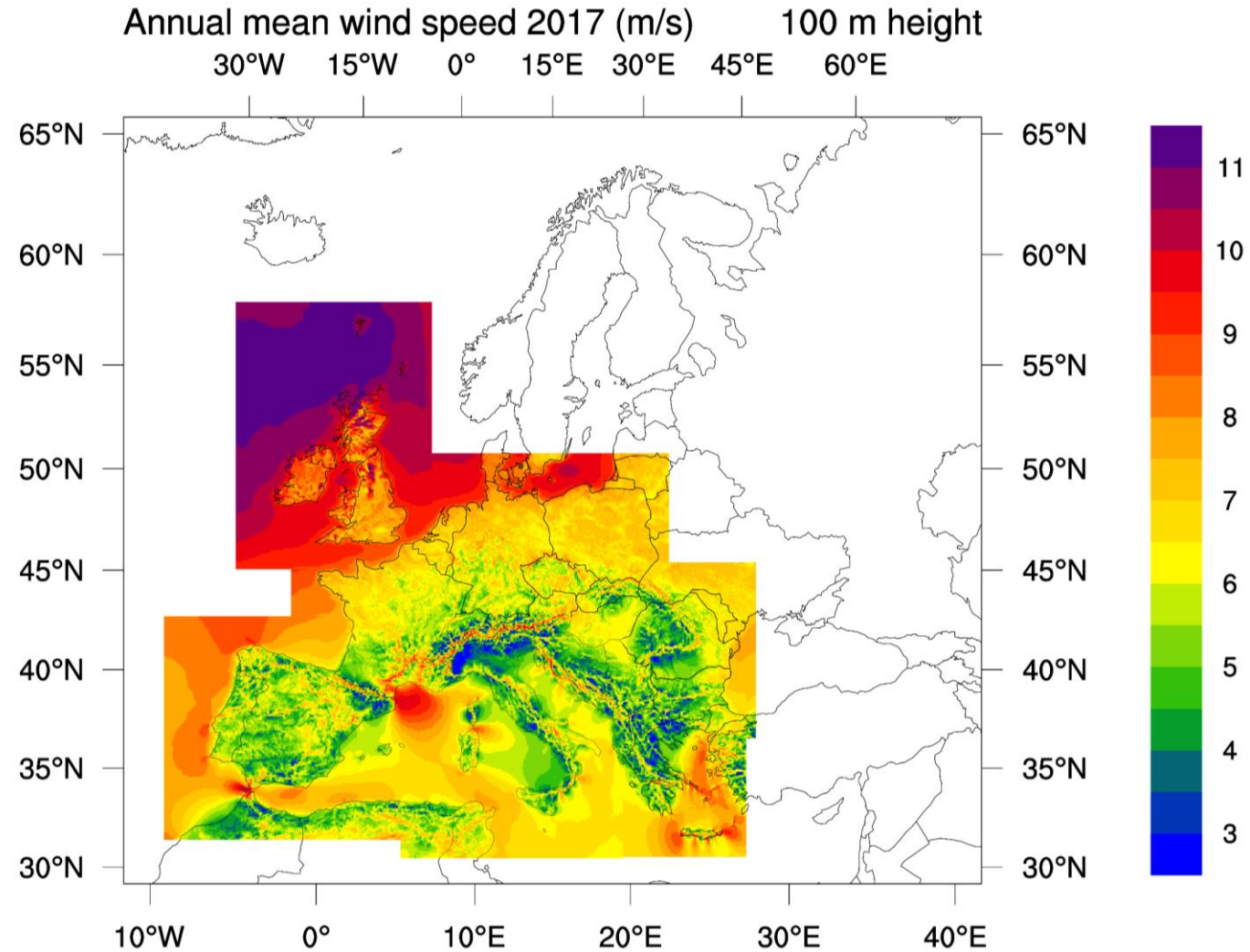
# Results from the production runs



# Results from the production runs

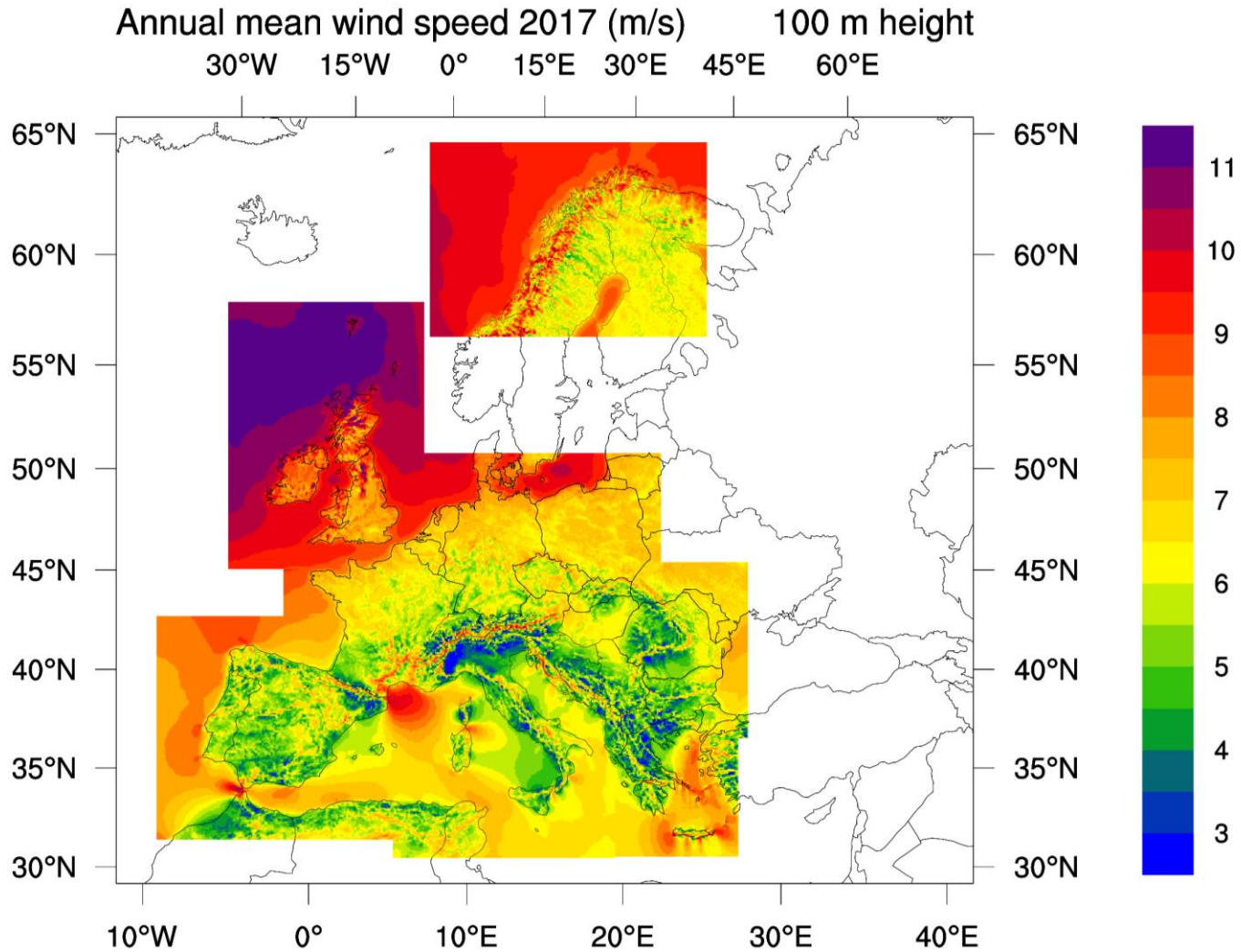


# Results from the production runs



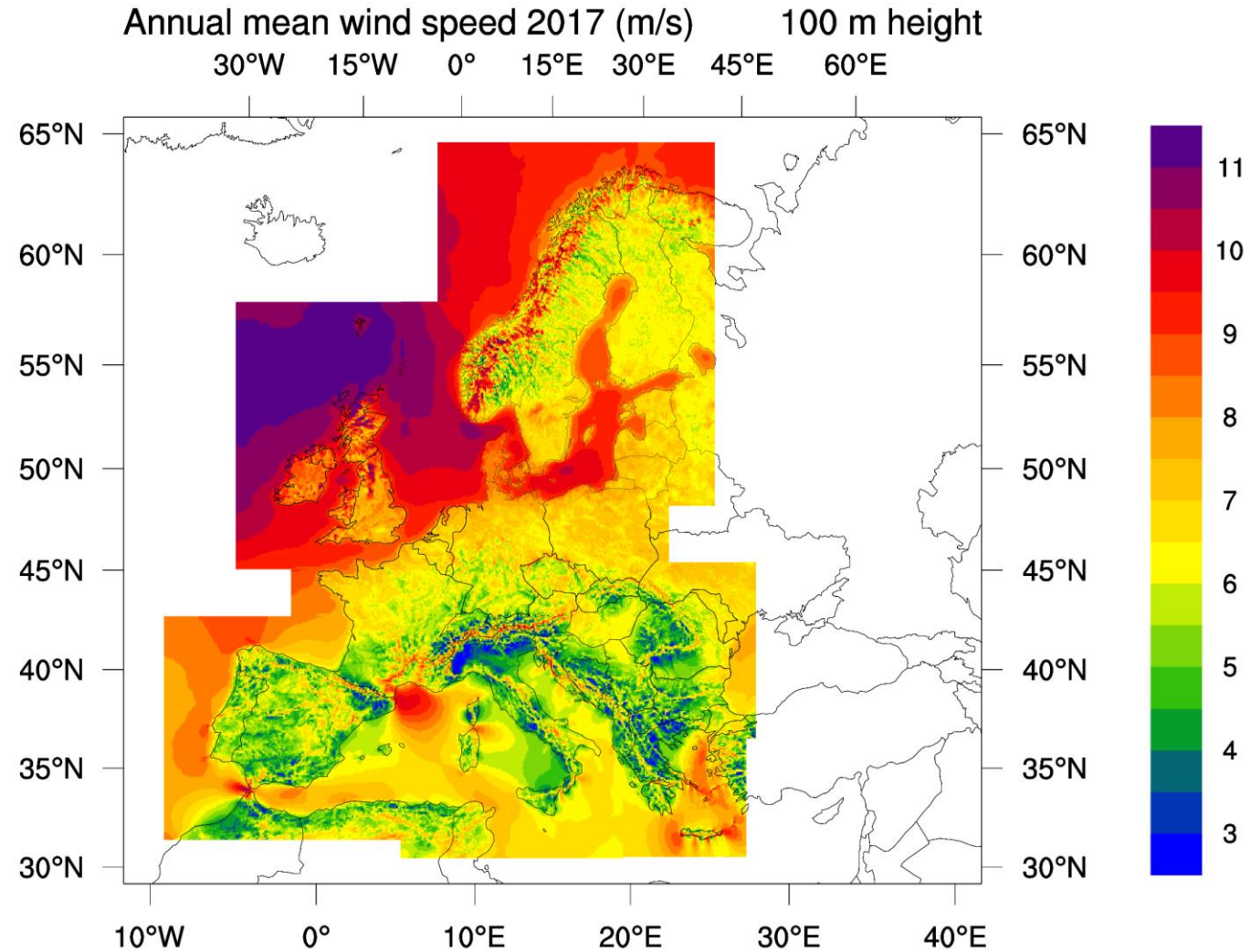


# Results from the production runs

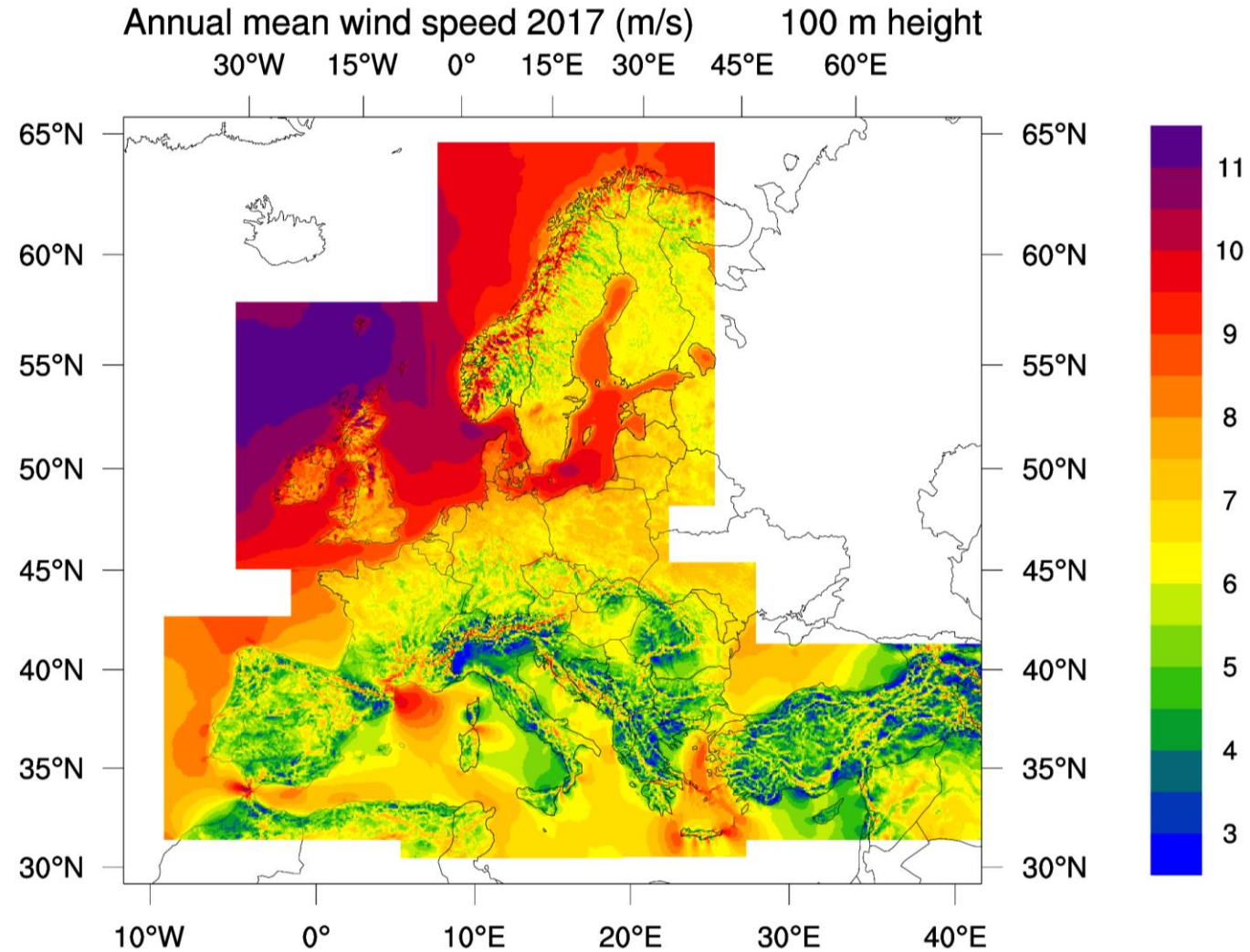




# Results from the production runs



# Results from the production runs



# Conclusions

- Mesoscale wind atlas = core of NEWA
- Massive amount of WRF simulations: 30 years time series for Europe in 3 km resolution
- Not only wind atlas production but a lot of testing, sensitivity studies and validation behind it!
- Great team effort!
- Uncertainty assessment based on a WRF Ensemble:
  - Quantifies the model configuration uncertainty, not the complete wind atlas uncertainty

# Acknowledgements



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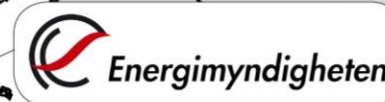
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