Methodological aspects of orographic winds analysis and modelling in the Arctic

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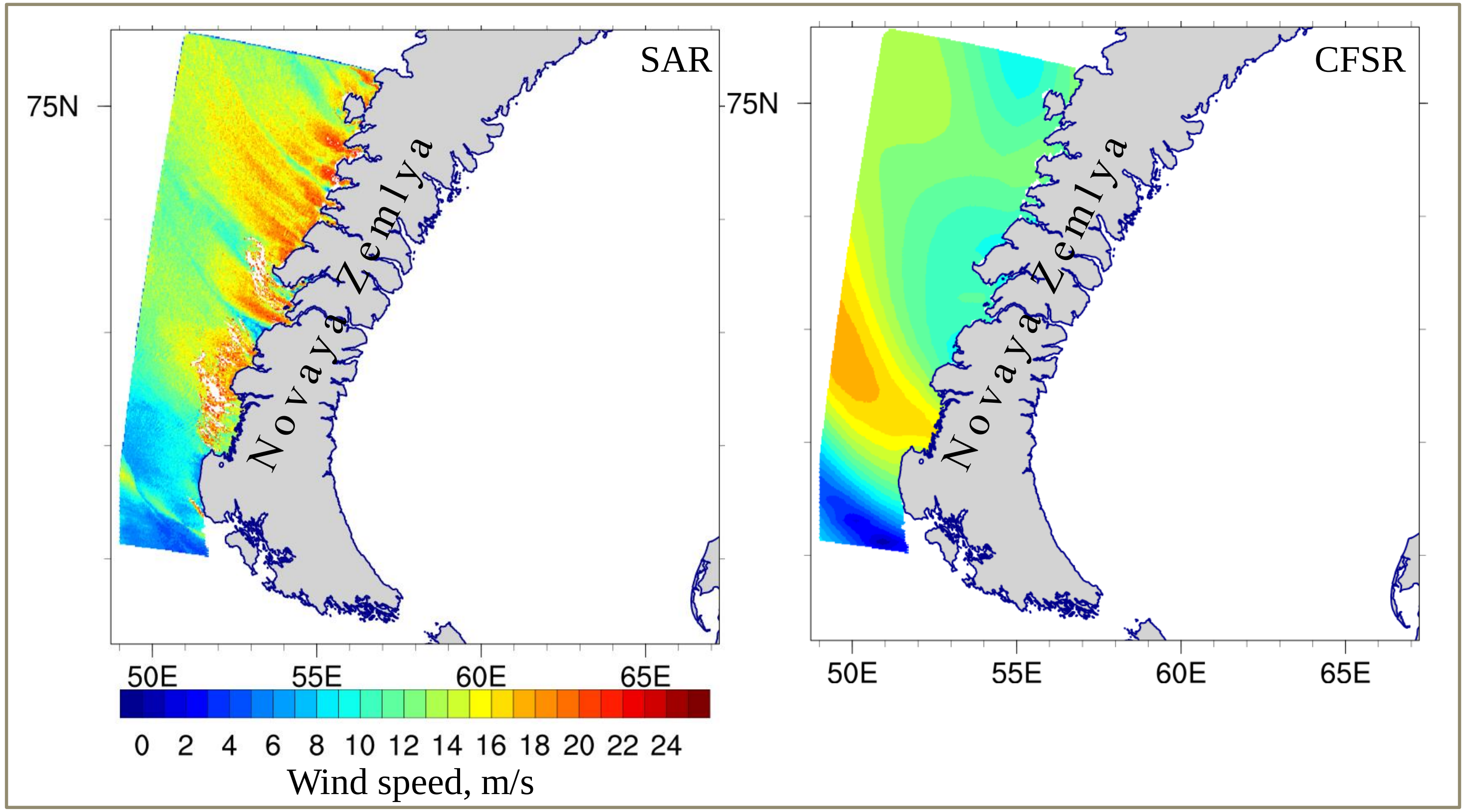
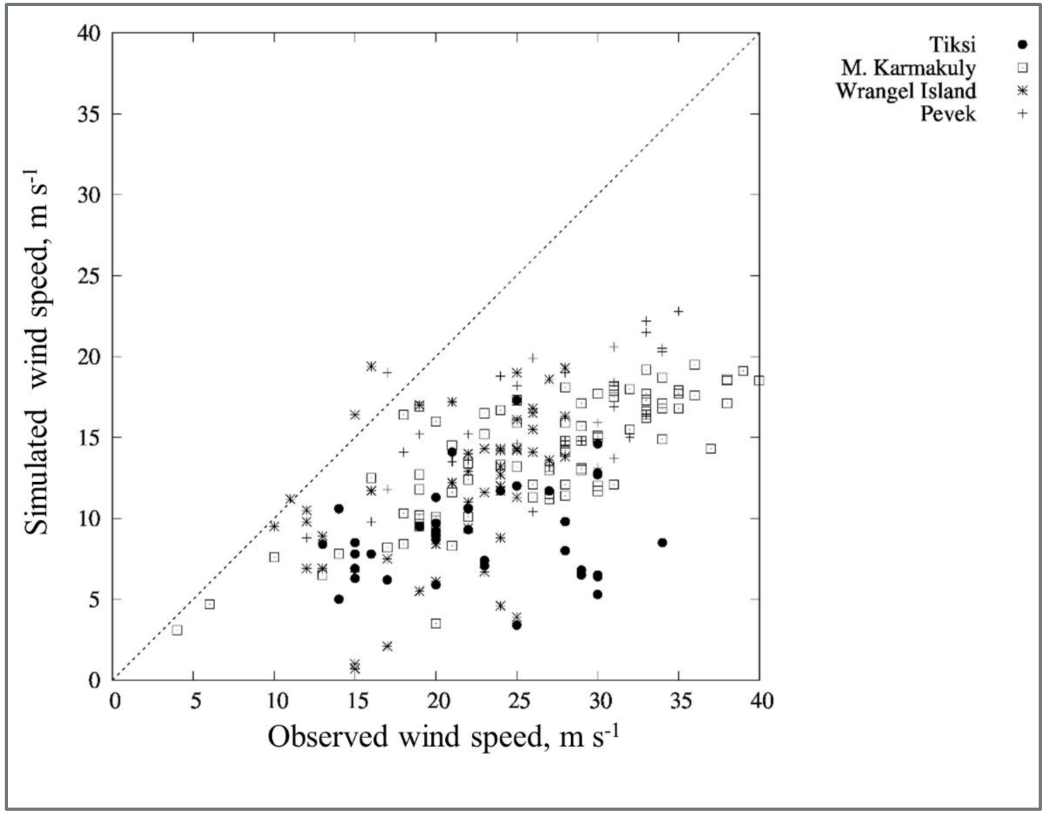
MOTIVATION

- Mesoscale effects, including orographic winds, are usually poorly reproduced in reanalyses and high-resolution simulations (not to mention low-resolution simulations)



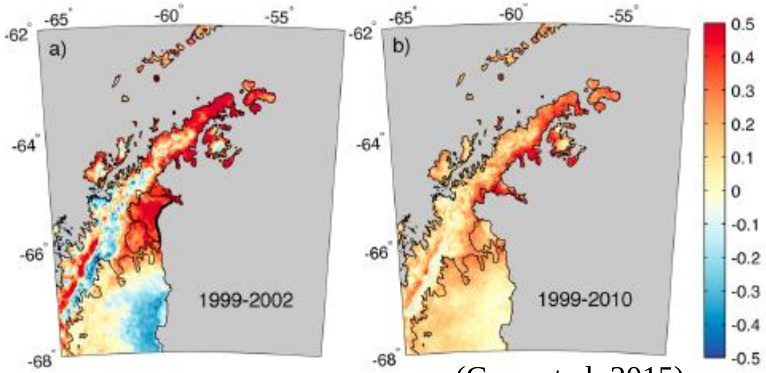


MOTIVATION

- Mesoscale effects, including orographic winds, are usually poorly reproduced in reanalyses and high-resolution simulations (not to mention low-resolution simulations)

- Orographic winds are a) hazardous weather events (severe wind, ship icing, reduced visibility, low-tropospheric air turbulence etc.) and b) affect other processes (surface-atmosphere heat transfer, ocean waves, glacier melting, ice drift etc.)

Temporal **correlation** between the monthly **foehn anomaly** time series **and** total monthly backscatter-derived **melt days** over the ice sheet



(Cape et al. 2015)

OBJECTIVES

Our two main goals are:

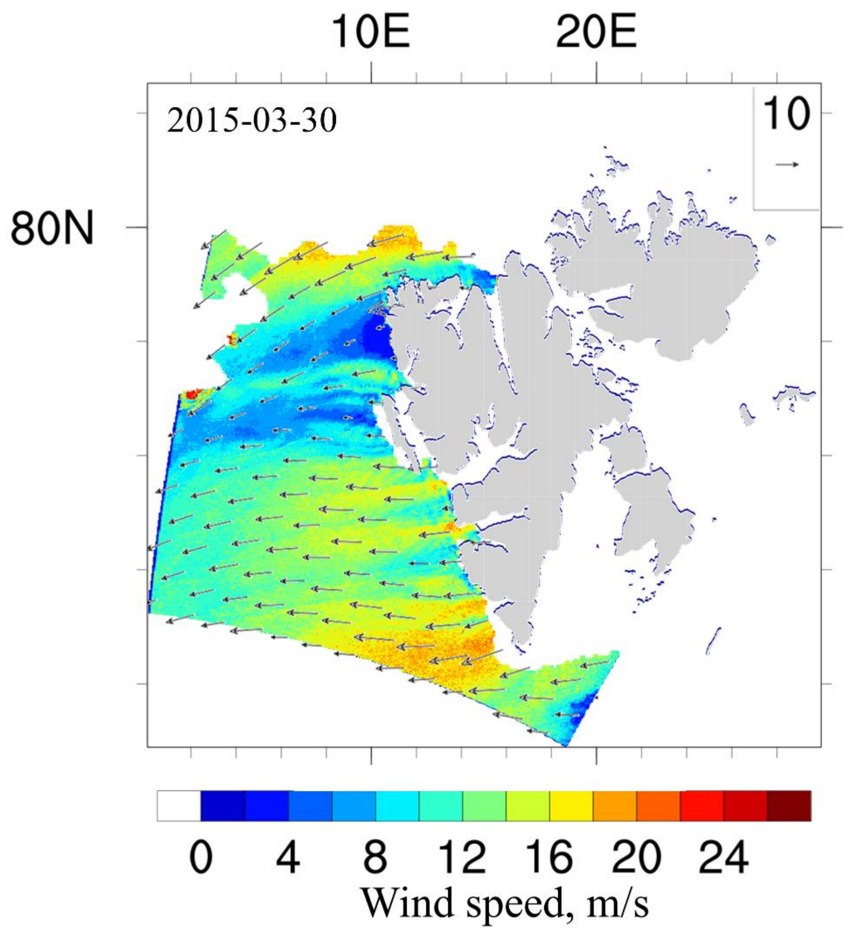
a) to estimate the quality of Arctic orographic winds reproducibility in various reanalyses and numerical simulations with different spatial resolution

b) to understand the sources of error when modelling orographic winds with high resolution

1. ARCTIC OROGRAPHIC WINDS IN VARIOUS REANALYSES AND NUMERICAL SIMULATIONS WITH DIFFERENT SPATIAL RESOLUTION

Data

- The most suitable source of data on the spatial structure of the wind speed during orographic winds is high-resolution synthetic aperture radar (SAR) satellite imagery



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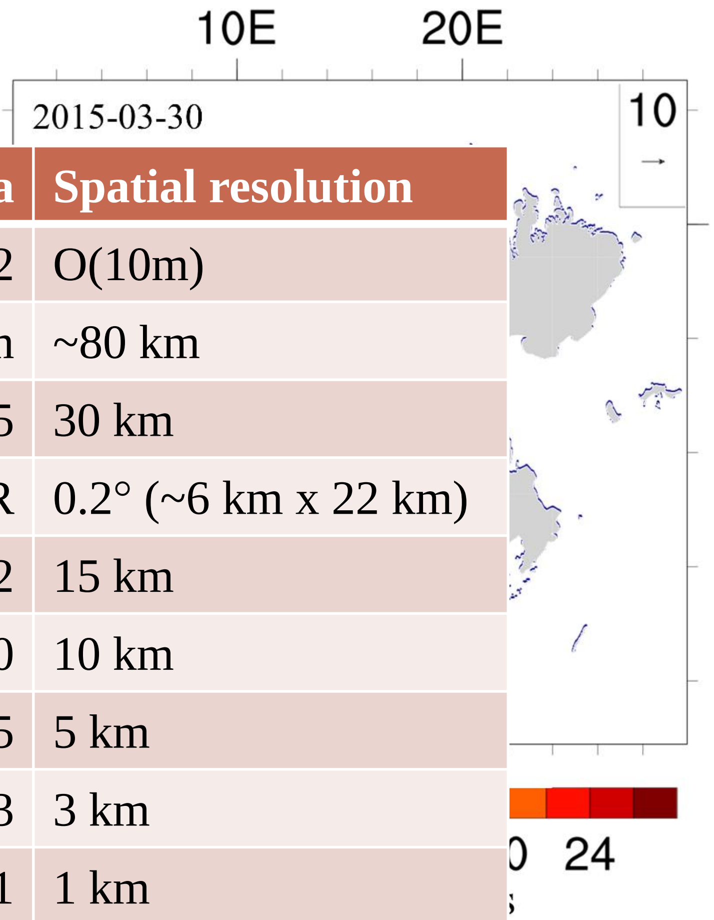
- Widely used reanalyses were compared with SAR data

- …as well as numerical simulations with WRF-ARW v.4 model with various resolution.

Model was initialized from the ASR v.2 data

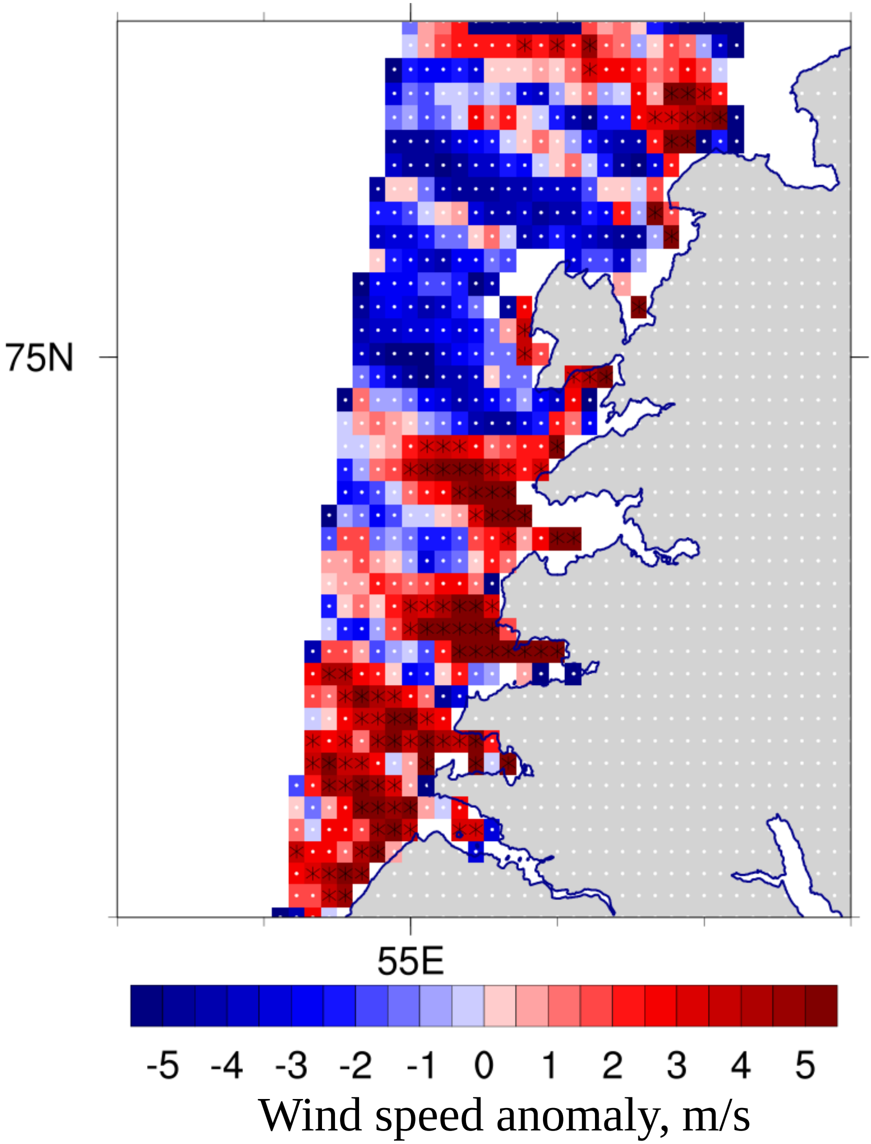


Data	Spatial resolution
SAR Radarsat-2	O(10m)
ERA-Interim	~80 km
ERA 5	30 km
CFSR	0.2° (~6 km x 22 km)
ASR v.2	15 km
WRF10	10 km
WRF5	5 km
WRF3	3 km
WRF1	1 km

1. ARCTIC OROGRAPHIC WINDS IN VARIOUS REANALYSES AND NUMERICAL SIMULATIONS WITH DIFFERENT SPATIAL RESOLUTION

Methods

- We estimated errors in spatial average $\bar{U}$, minimum U_{min}, maximum U_{max}, 95, 99 and 99.9 percentile (U_{95}, U_{99}, U_{999}) wind speed and wind speed range U_r
- All data were bilinear interpolated to SAR grid
- Pattern correlation coefficient R was calculated to estimate spatial similarity between wind fields
- Since the correlation coefficient was not very indicative, we used an object-based method of assessing "similarity". We applied **SAL** (**S** - structure, **A** - amplitude, **L** - location) method developed by Wernli et al. (2008, 2009) to assess the quality of precipitation forecasting.



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$$\boldsymbol{A} = \frac{\bar{U}_{mod} - \bar{U}_{obs}}{0.5(\bar{U}_{mod} + \bar{U}_{obs})}$$

$$\boldsymbol{S} = \frac{V(U_{mod}) - V(U_{obs})}{0.5(V(U_{mod}) + V(U_{obs}))}$$

$$V(U) = \frac{\sum_{n=1}^{N} U_n V_n}{\sum_{n=1}^{N} U_n}$$

$$V_n = \sum_{ij} \frac{U(i,j)}{U_n^{max}}$$

U_n – sum of wind speed anomaly for each of N objects

U_n^{max} – maximal U anomaly within the object

$$\boldsymbol{L} = \frac{|x(U_{mod}) - x(U_{obs})|}{d} + 2\frac{|r(U_{mod}) - r(U_{obs})|}{d}$$

$$r(U) = \frac{\sum_{n=1}^{N} U_n |x - x_n|}{\sum_{n=1}^{N} U_n}$$

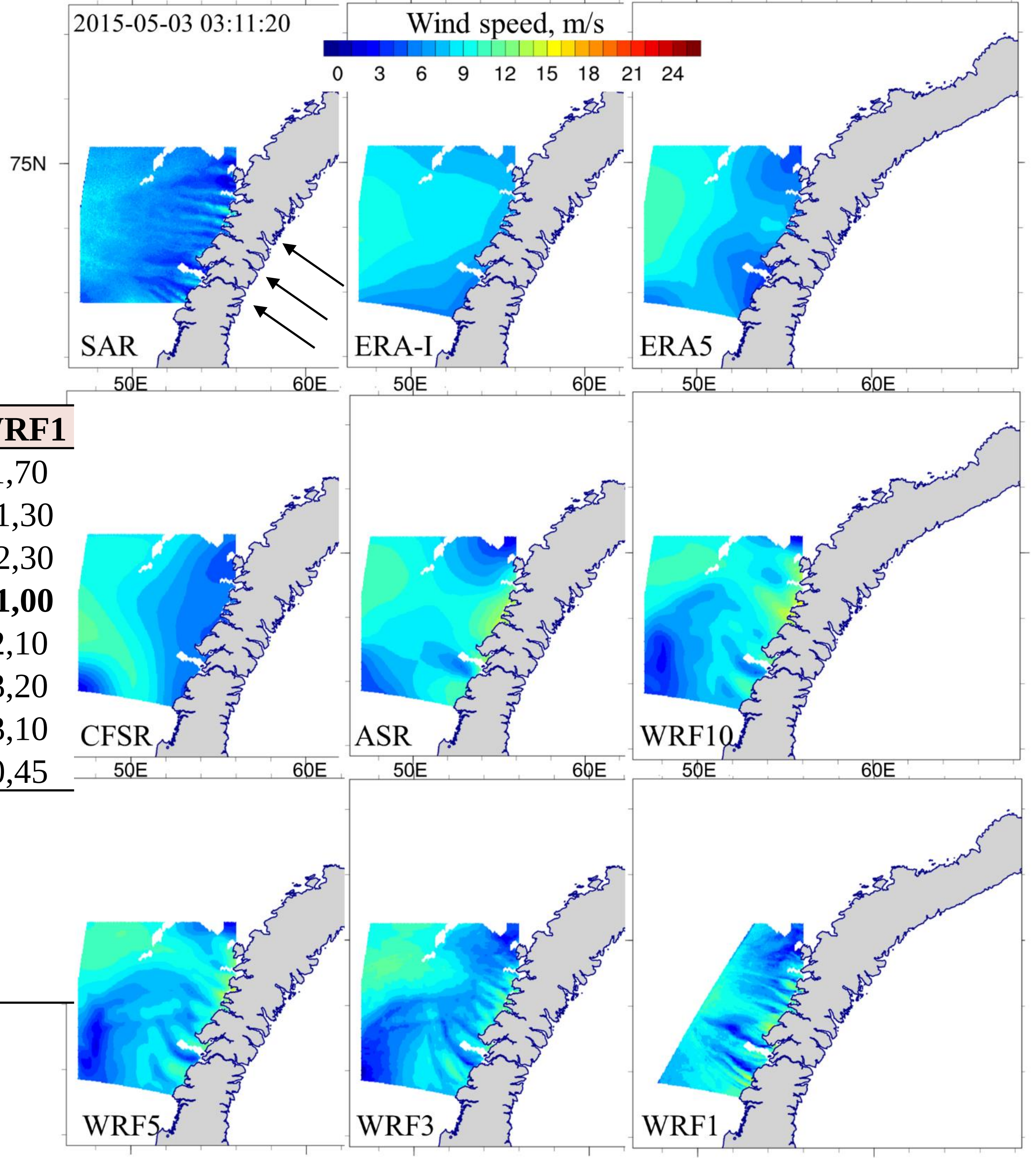
d – maximal distance between points

x – general center of mass, x_n – center of mass for each of N objects

Results

	ERA-I	ERA5	CFSR	ASR	WRF10	WRF5	WRF3	WRF1
bias $\bar{U}$	1,90	1,70	1,60	2,40	1,90	1,60	**1,40**	1,70
bias U_{min}	3,80	1,80	0,50	0,20	-0,20	**-0,10**	-1,20	-1,30
bias U_{max}	-7,70	-6,90	-6,20	-3,90	**-2,10**	-2,40	-4,40	-2,30
bias U_r	-11,50	-8,70	-6,70	-4,10	-1,90	-2,30	-3,20	**-1,00**
bias U_{95}	**1,10**	2,00	2,10	2,50	2,60	2,30	2,40	2,10
bias U_{99}	**0,60**	1,60	2,10	3,70	3,80	2,50	2,00	3,20
bias U_{999}	-1,10	**-0,20**	0,50	2,40	3,50	2,40	1,20	3,10
R	0,28	**0,63**	0,59	0,25	-0,14	-0,08	0,20	0,45

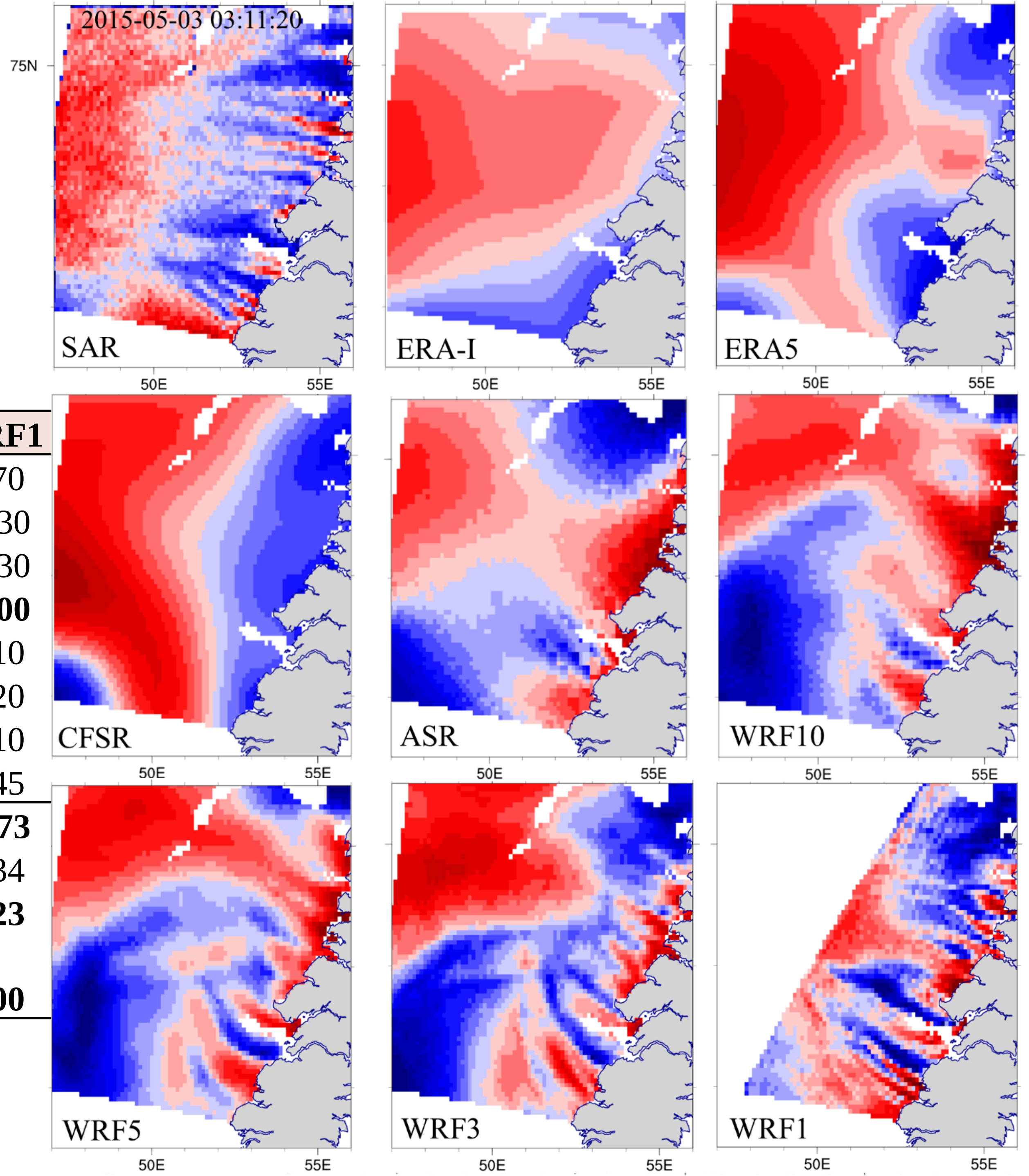
*N – number of selected objects



Results

	ERA-I	ERA5	CFSR	ASR	WRF10	WRF5	WRF3	WRF1
bias $\overline{U}$	1,90	1,70	1,60	2,40	1,90	1,60	**1,40**	1,70
bias U_{min}	3,80	1,80	0,50	0,20	-0,20	**-0,10**	-1,20	-1,30
bias U_{max}	-7,70	-6,90	-6,20	-3,90	**-2,10**	-2,40	-4,40	-2,30
bias U_r	-11,50	-8,70	-6,70	-4,10	-1,90	-2,30	-3,20	**-1,00**
bias U_{95}	**1,10**	2,00	2,10	2,50	2,60	2,30	2,40	2,10
bias U_{99}	**0,60**	1,60	2,10	3,70	3,80	2,50	2,00	3,20
bias U_{999}	-1,10	**-0,20**	0,50	2,40	3,50	2,40	1,20	3,10
R	0,28	**0,63**	0,59	0,25	-0,14	-0,08	0,20	0,45
S	1,57	1,90	1,90	1,33	1,52	1,71	1,81	**-0,73**
A	0,27	0,24	0,23	0,34	0,27	0,24	**0,20**	0,34
L	0,97	1,01	0,87	0,59	0,57	0,63	0,71	**0,23**
N(mod)-N(obs)	-22,00	-22,00	-22,00	-15,00	-19,00	-16,00	-14,00	**2,00**

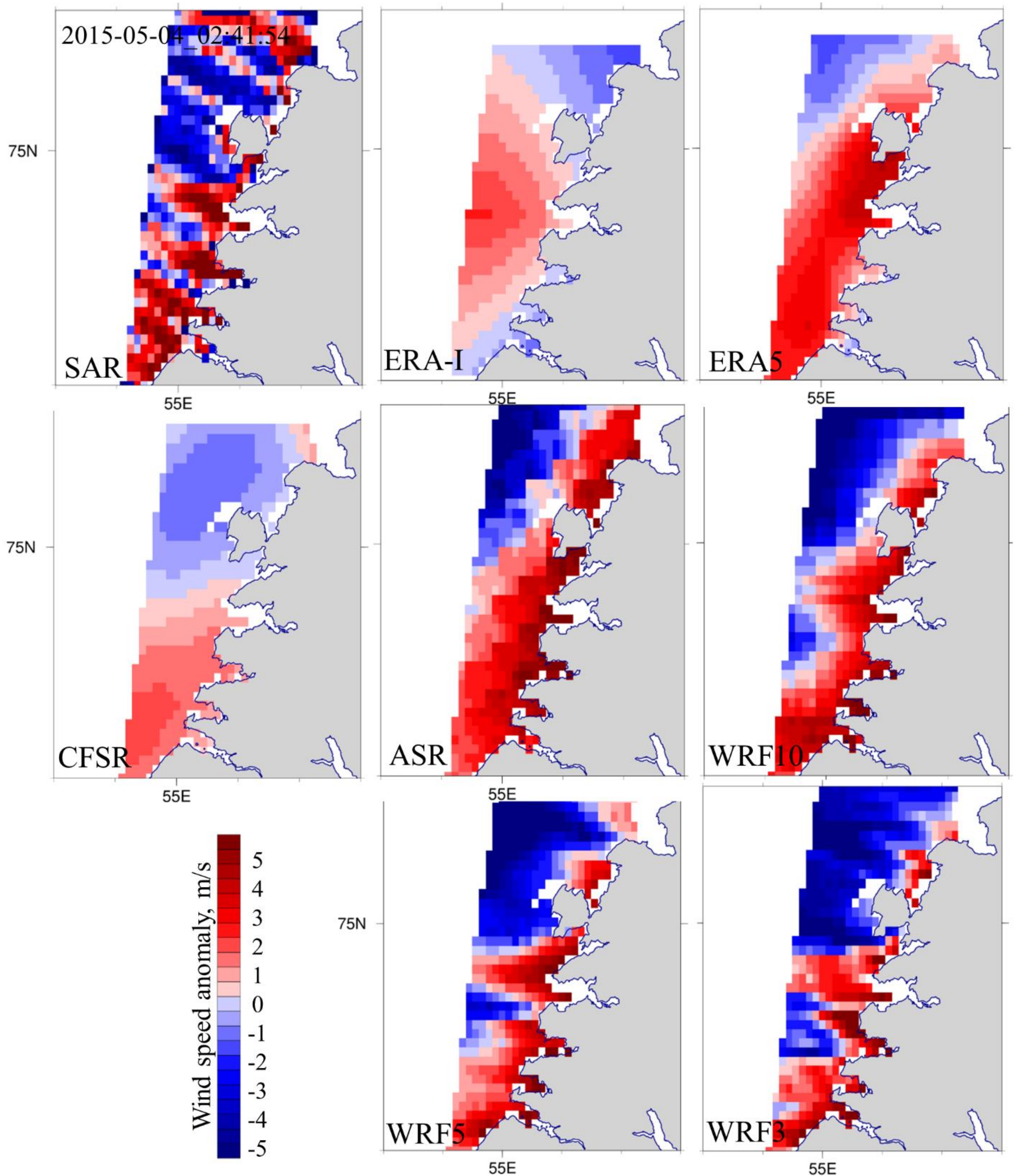
*N – number of selected objects



Results

	ERA-I	ERA5	CFSR	ASR	WRF10	WRF5	WRF3
bias $\bar{U}$	2,50	**0,40**	-2,20	6,20	5,40	4,00	2,10
bias U_{min}	8,90	6,20	4,90	5,70	6,70	5,80	**4,10**
bias U_{max}	-6,90	-7,70	-11,70	0,70	0,70	**0,30**	2,30
bias U_r	-15,80	-13,90	-16,60	-5,00	-6,00	-5,50	**-1,80**
bias U_{95}	**-1,50**	-2,70	-6,10	5,10	4,60	3,70	1,90
bias U_{99}	-3,20	-4,20	-8,00	3,90	3,30	3,10	**2,00**
bias U_{999}	-5,20	-6,10	-10,00	2,30	1,80	**1,60**	2,50
R	-0,05	0,37	0,57	0,50	0,50	0,57	**0,62**
S	-	0,73	-	1,17	0,64	**-0,06**	-0,60
A	0,28	**0,11**	-0,18	0,53	0,46	0,37	0,23
L	-	0,59	-	0,18	**0,09**	**0,09**	0,17
N(mod)-N(obs)	-11,00	-10,00	-11,00	-9,00	-8,00	-6,00	**-5,00**

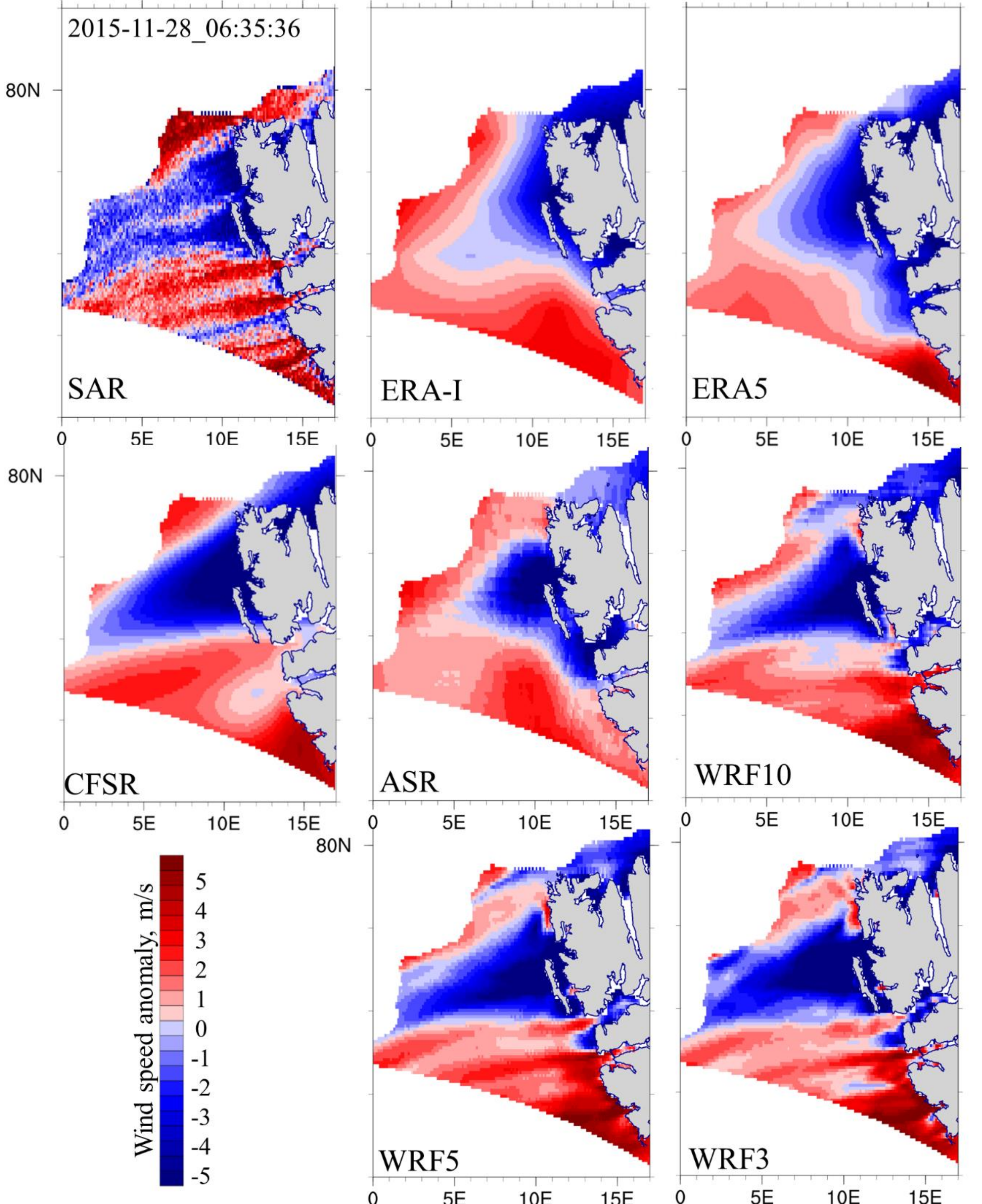
*N – number of selected objects



Results

	ERA-I	ERA5	CFSR	ASR	WRF10	WRF5	WRF3
bias $\overline{U}$	3,50	**2,10**	3,90	4,10	4,00	3,90	3,50
bias U_{min}	6,70	3,90	4,50	4,40	2,80	2,00	**0,30**
bias U_{max}	-8,80	-7,80	-6,40	-7,40	-3,90	-2,60	**-1,60**
bias U_r	-15,50	-11,70	-10,90	-11,80	-6,70	-4,60	**-1,90**
bias U_{95}	1,70	**1,40**	3,70	2,50	4,20	4,10	4,20
bias U_{99}	**0,30**	1,10	2,60	1,20	3,30	3,60	3,90
bias U_{999}	-1,50	-0,60	0,90	**-0,30**	3,10	3,30	4,40
R	0,42	0,51	**0,63**	0,33	0,54	0,57	0,58
S	1,43	**0,81**	1,03	1,06	1,09	1,17	1,04
A	0,37	**0,27**	0,40	0,41	0,40	0,40	0,37
L	0,58	0,98	**0,25**	0,49	0,81	0,73	0,76
N(mod)-N(obs)	-31,00	-33,00	-31,00	-27,00	-27,00	-26,00	**-24,00**

*N – number of selected objects



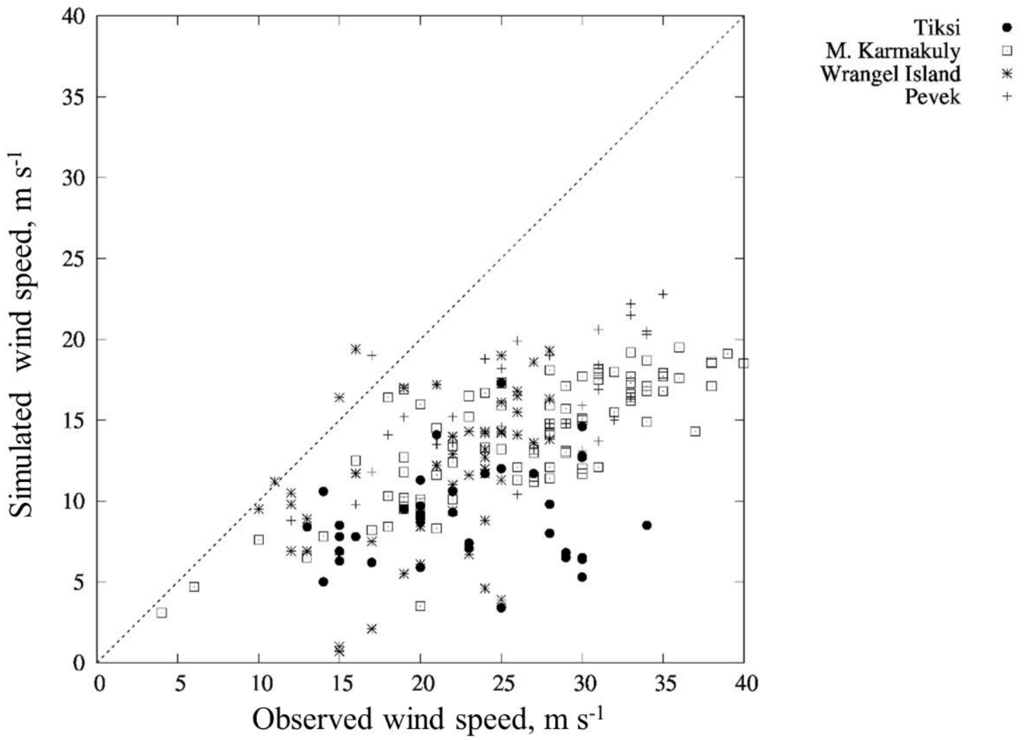
1. ARCTIC OROGRAPHIC WINDS IN VARIOUS REANALYSES AND NUMERICAL SIMULATIONS WITH DIFFERENT SPATIAL RESOLUTION

Conclusions

- Estimation made by eye is still the best! The SAL method in the form in which we used it for the analyzed individual cases sometimes gives adequate results, sometimes not. Perhaps the method needs to be improved, or other methods must be looked for.
- Systematically, the smallest error in wind speed range (maximum minus minimum) is observed at the highest resolution, because orographic winds are characterized by the presence of jets and wakes, both of which are absent or smoothed at low resolution. We also see that the structure and position of objects (i.e., jets) are best reproduced at the highest resolution (1-3 km), which in some cases is confirmed by the SAL method.
- At the same time, biases of the spatially average wind speed and even the upper percentiles of wind speed are not clearly related to the resolution. The ERA5 and CFSR reanalyses, on average, reproduce the average wind speed better than others, while in numerical simulations using the WRF model and in the ASR v2 reanalysis, the average wind speed is systematically overestimated.

2. SOURCES OF ERROR WHEN MODELLING OROGRAPHIC WINDS WITH HIGH RESOLUTION

Data and methods



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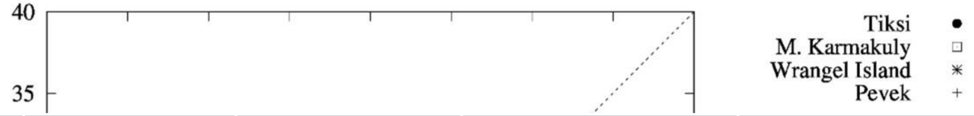
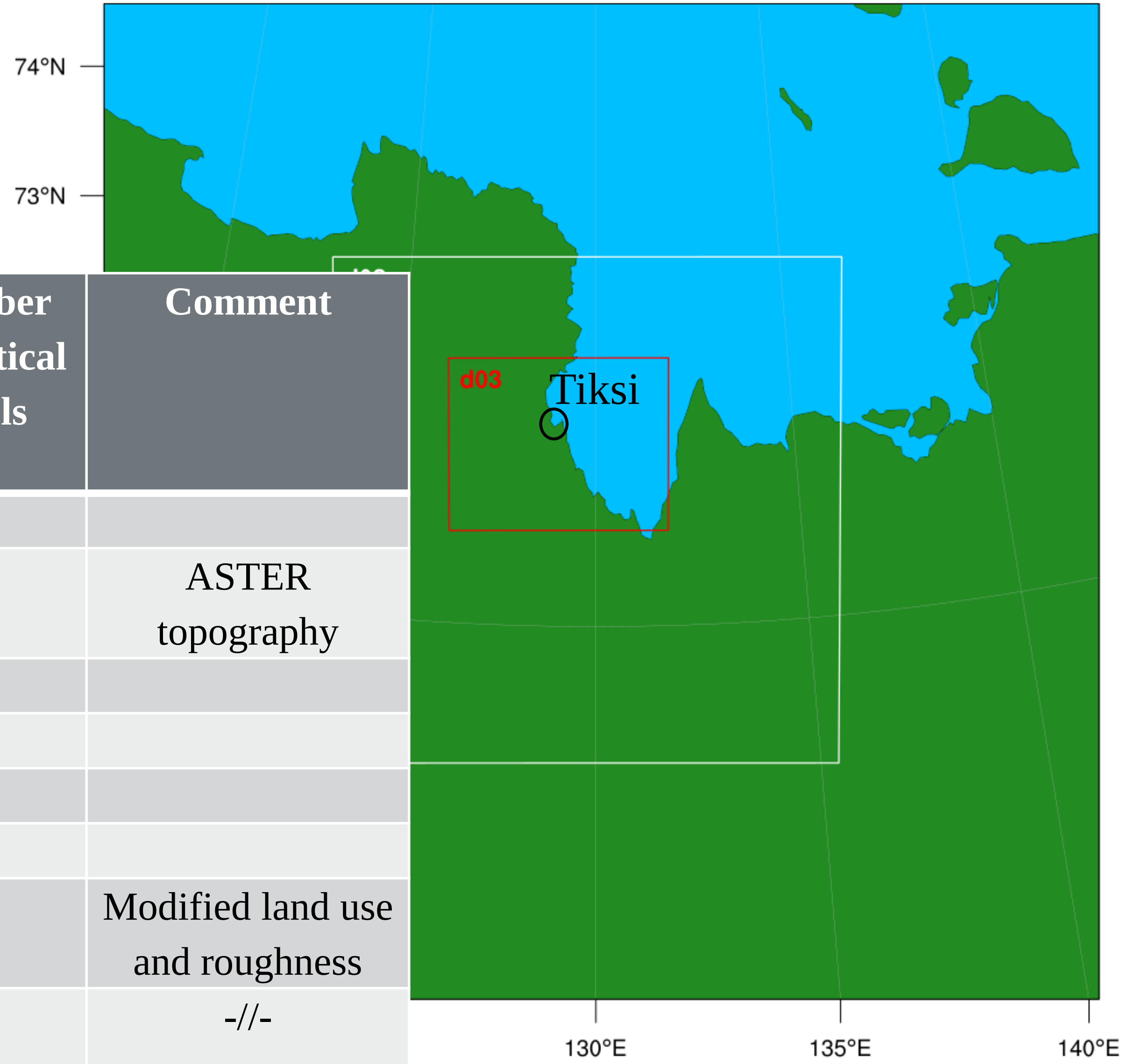
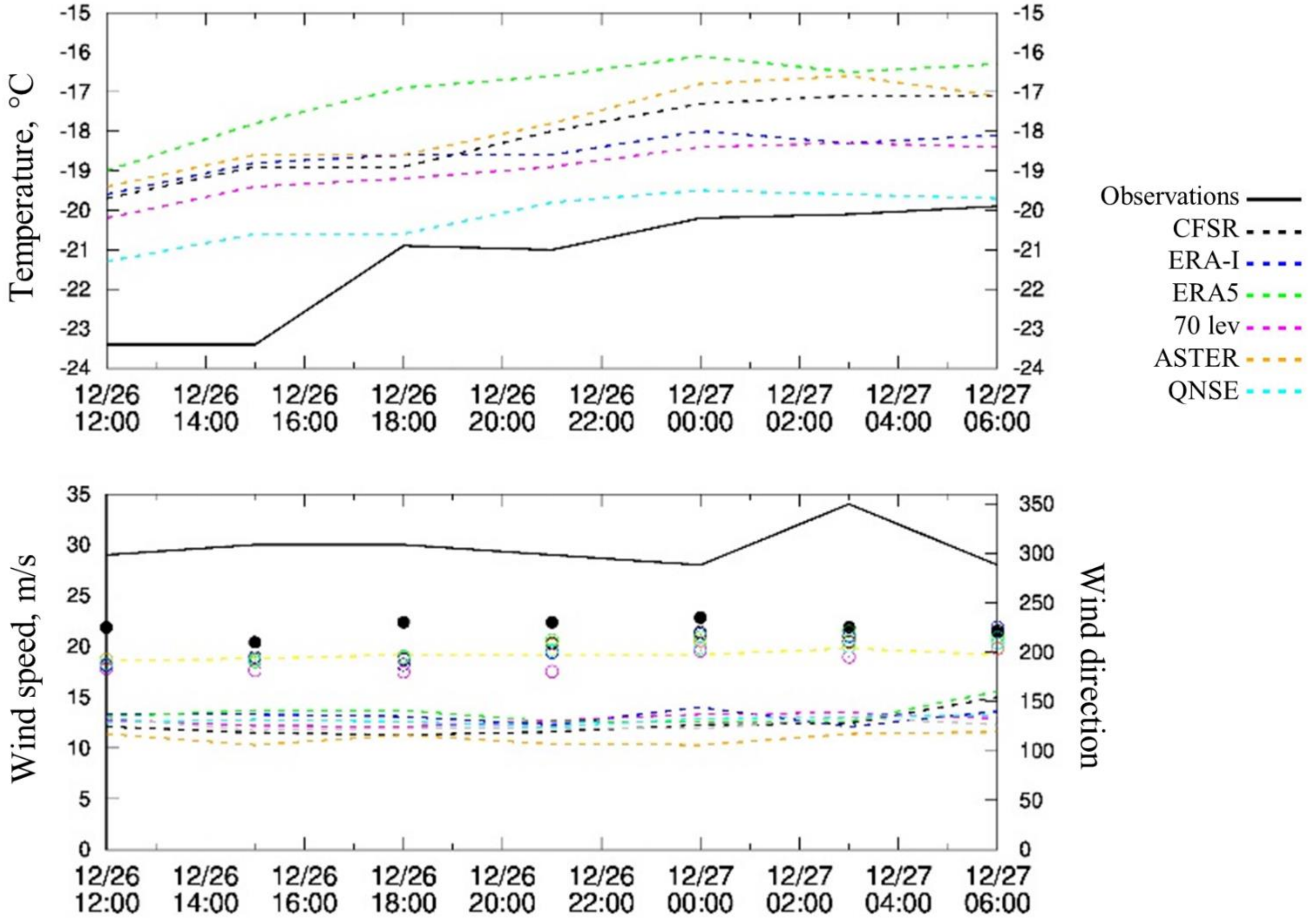


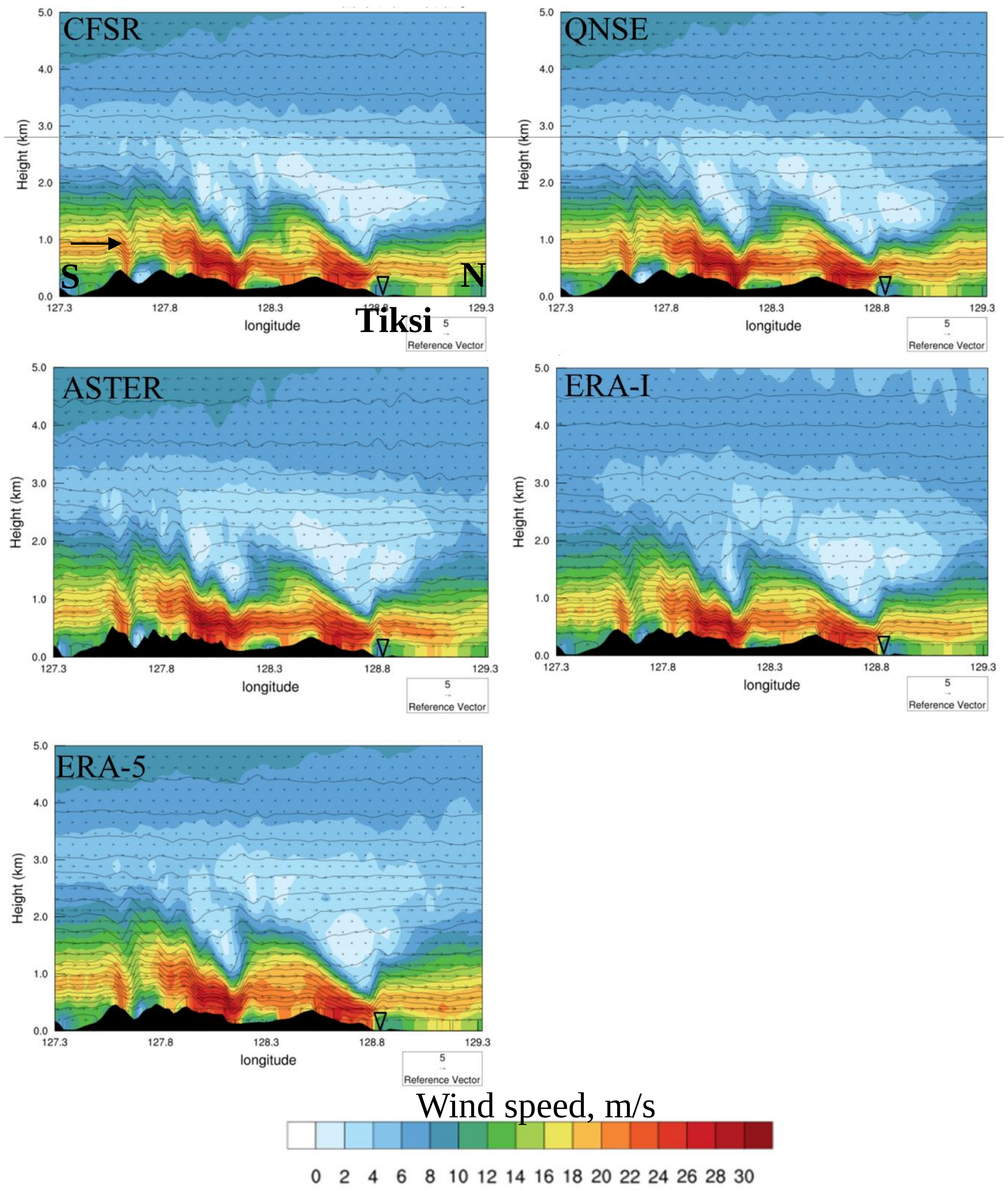
№	Name of experiment	Resolution of the inner domain	Initial and boundary conditions	Boundary-layer scheme	Number of vertical levels	Comment
1	CFSR	1 km	CFSR	YSU	50	
2	ASTER	600 m	CFSR	YSU	50	ASTER topography
3	70 lev	1 km	CFSR	YSU	70	
4	QNSE	1 km	CFSR	QNSE	50	
5	ERA-I	1 km	ERA-Interim	YSU	50	
6	ERA5	1 km	ERA5	YSU	50	
7	Low_z0	1 km	ERA5	YSU	50	Modified land use and roughness
8	Low_z0 + QNSE	1 km	ERA5	QNSE	50	-//-



Results



Temperature, °C
Wind speed, m/s
Wind direction
Observations
CFSR
ERA-I
ERA5
70 lev
ASTER
QNSE
12/26 12:00
12/26 14:00
12/26 16:00
12/26 18:00
12/26 20:00
12/26 22:00
12/27 00:00
12/27 02:00
12/27 04:00
12/27 06:00



CFSR
QNSE
ASTER
ERA-I
ERA-5
S
N
Tiksi
Height (km)
longitude
Reference Vector
Wind speed, m/s
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

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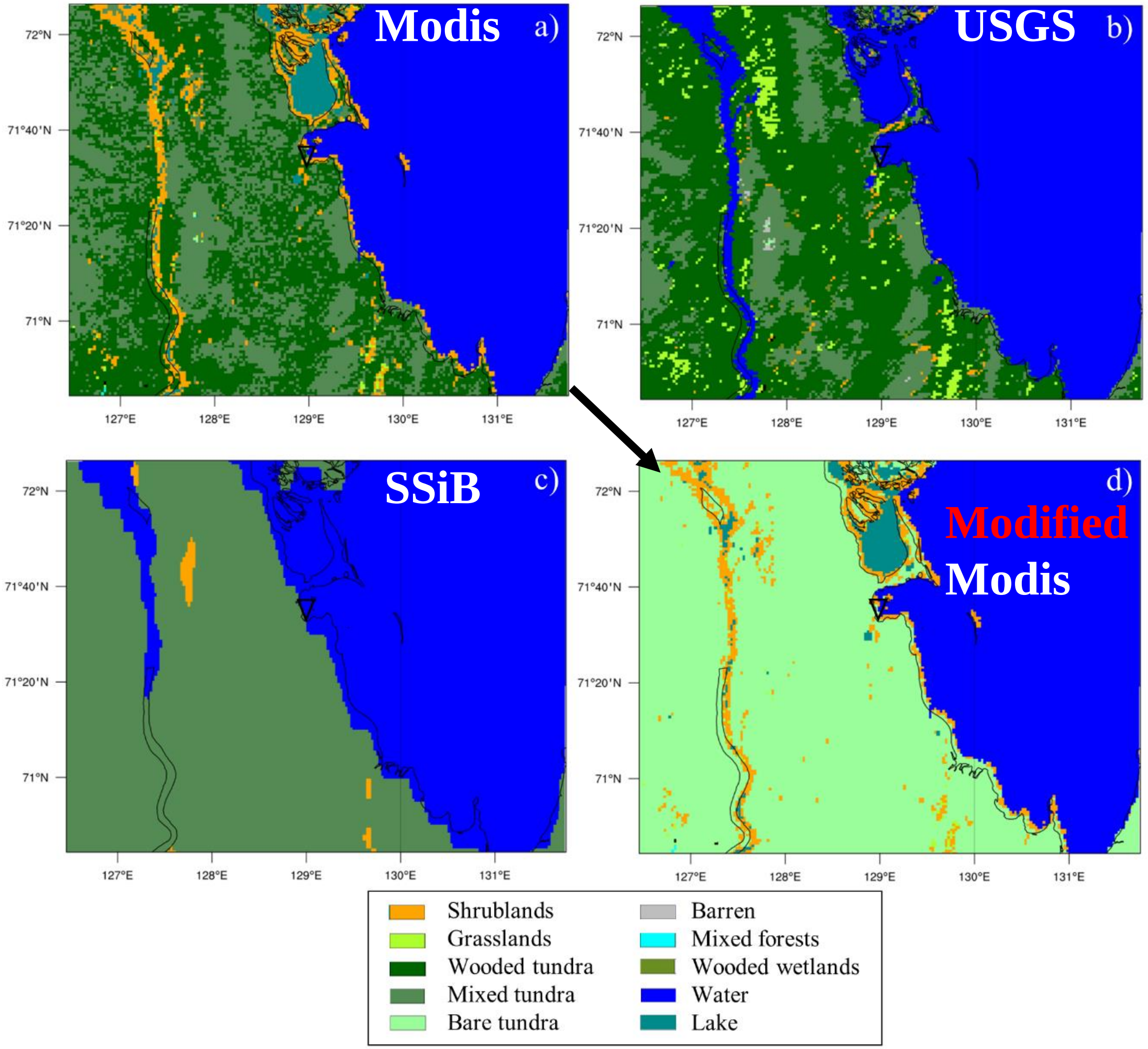
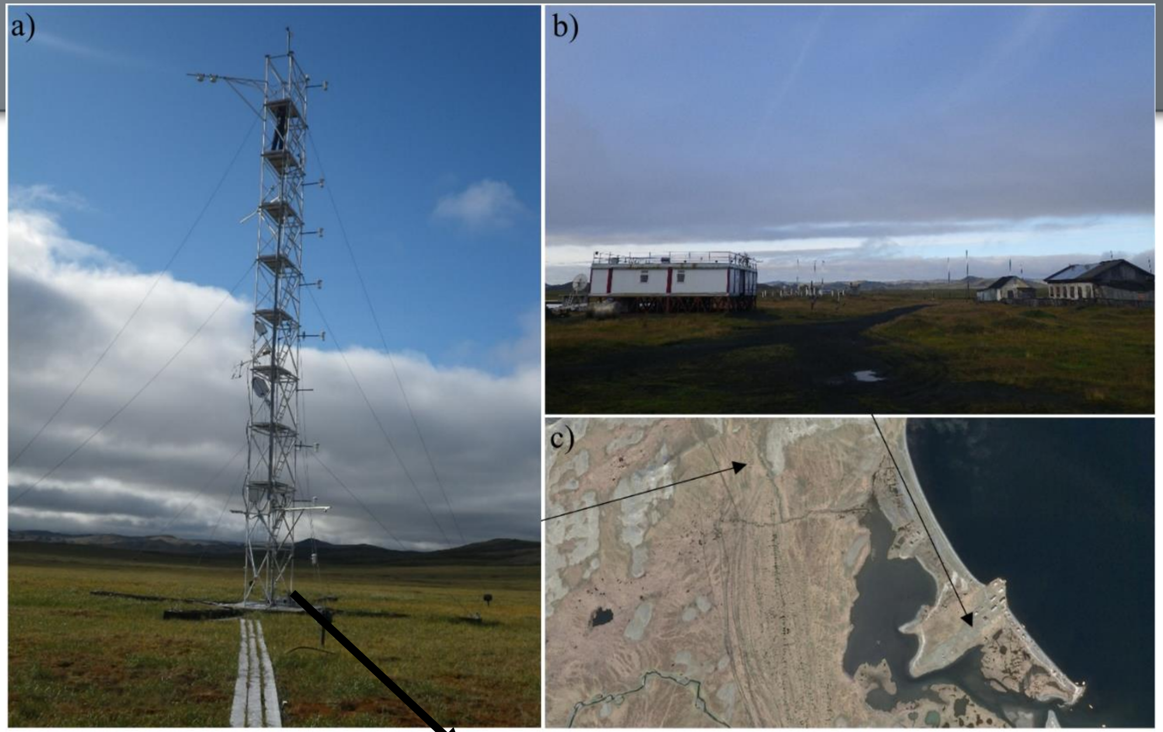
Results

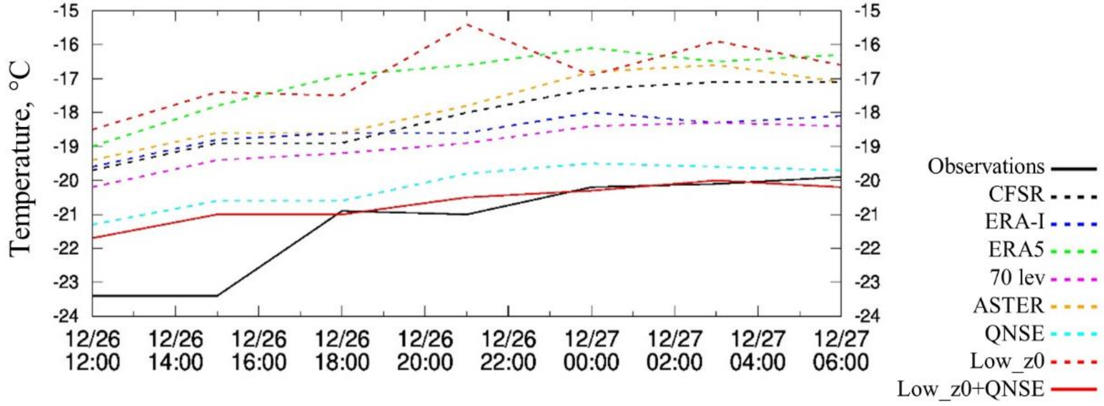


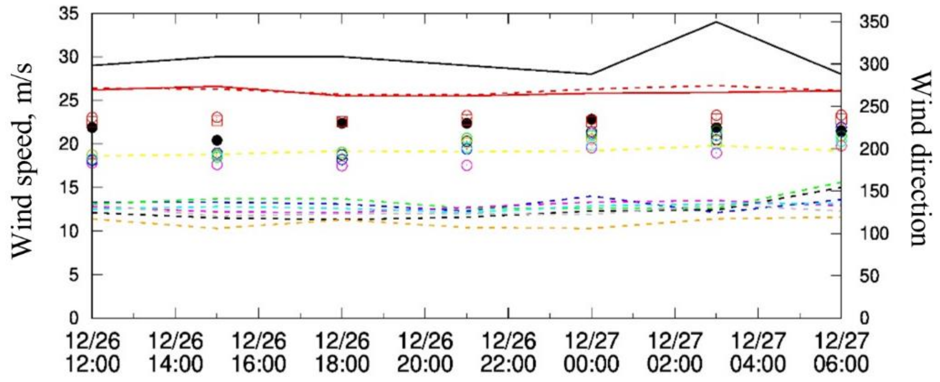


observed z_0	Winter	Summer
U>15 m/s	$2*10^{-3}$ m	$4.3*10^{-3}$ m
U>10 m/s	$2.9*10^{-3}$ m	$1.2*10^{-2}$ m

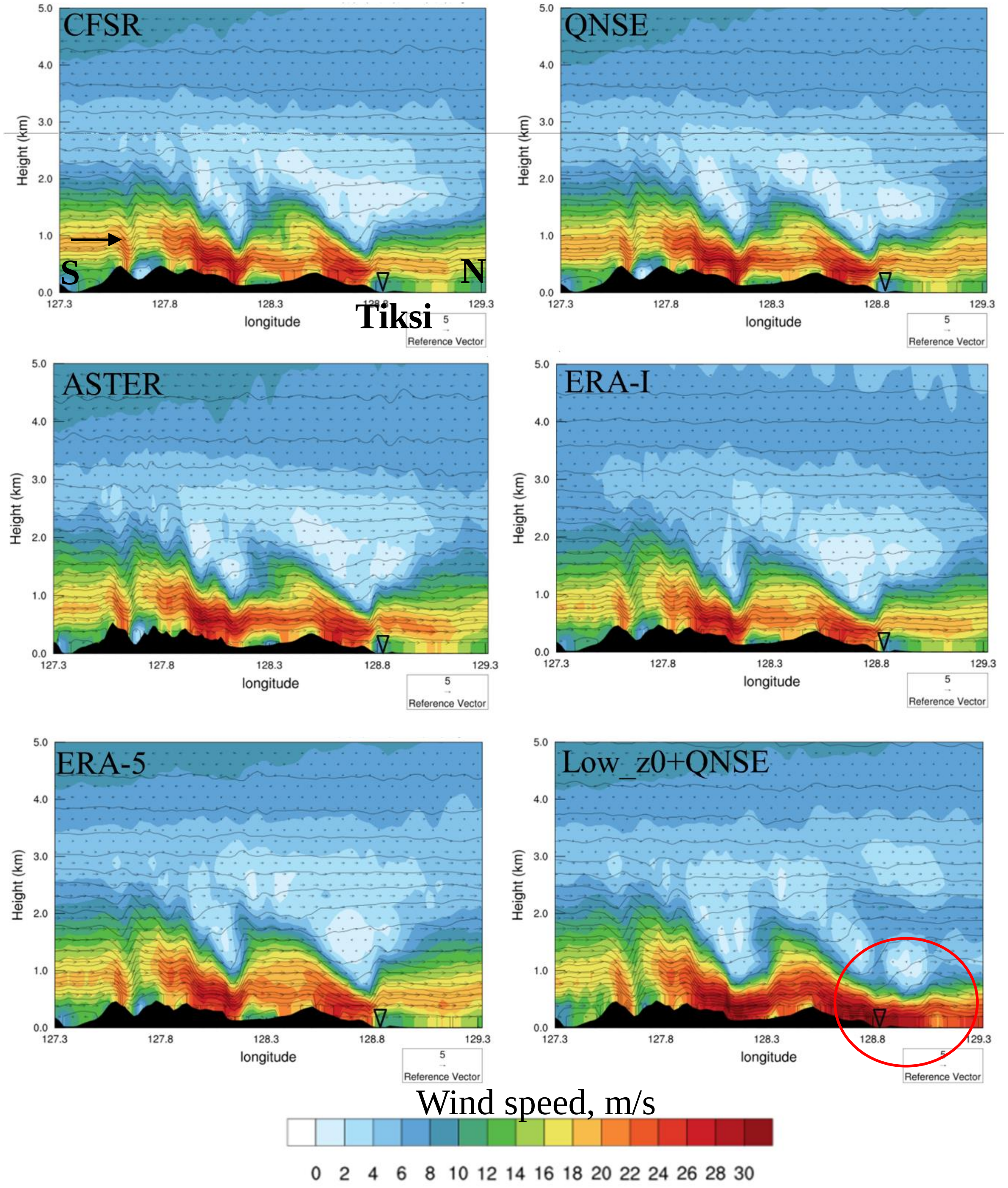
Modis Land use	z_0	Modified z_0
Wooded tundra	0.3 m	0.3 m
Mixed tundra	0.15 m	0.15 m
Bare tundra	0.05 m	0.01 m

Results



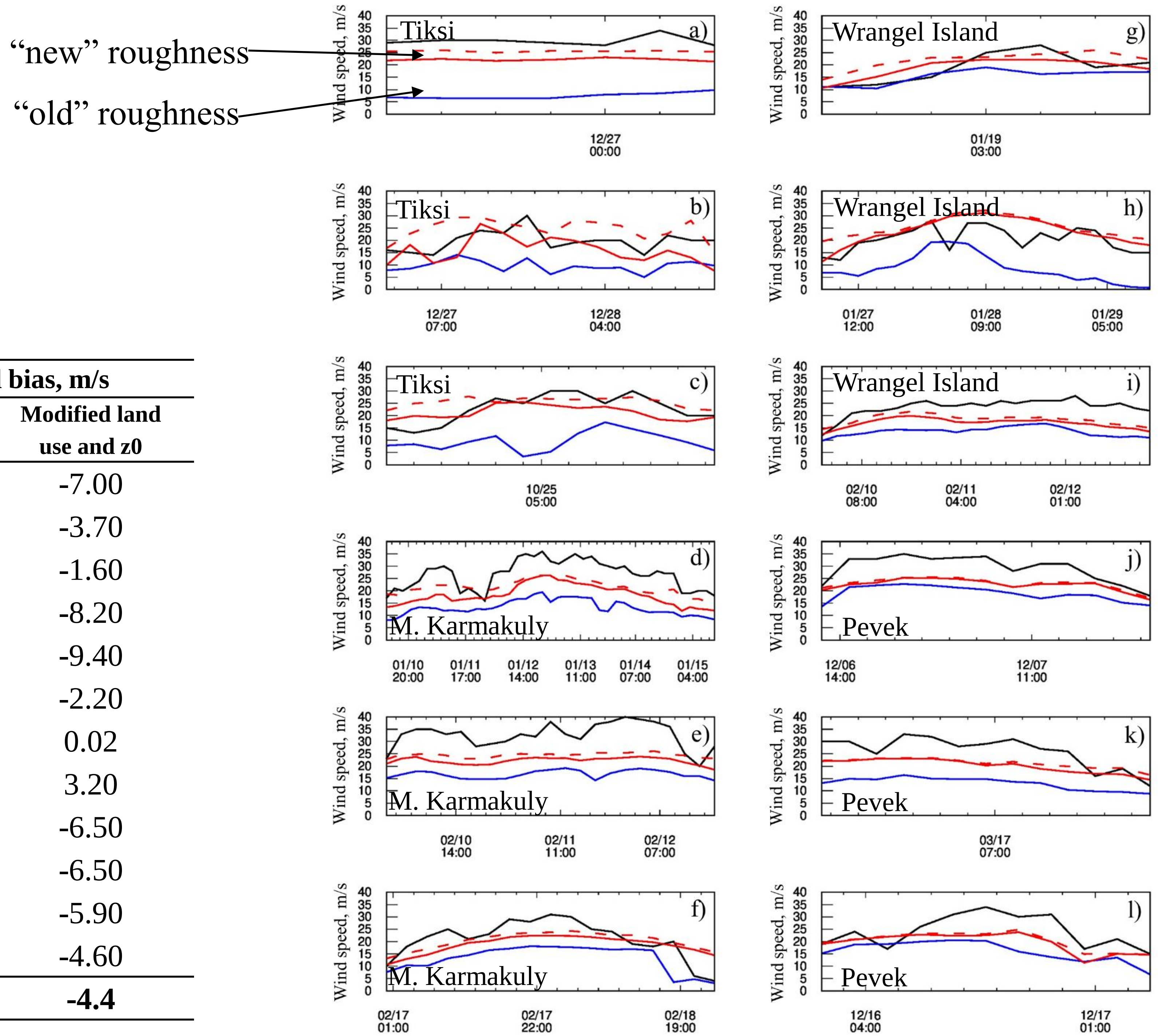


№	bias, m/s
1	-22.2
2	-22.2
3	-22.7
4	-21.9
5	-21.9
6	-22
7	**-7.9**
8	**-7**



Results

Region	Episodes	Wind speed bias, m/s	
		“Old” land use and z0	Modified land use and z0
Tiksi	26-27.12.1980	-22.20	-7.00
	27-28.12.1995	-10.10	-3.70
	24-25.10.2002	-13.10	-1.60
Novaya Zemlya	10-15.01.2006	-13.40	-8.20
	9-12.02.2009	-14.60	-9.40
	16-18.02.2014	-7.70	-2.20
Wrangel Island	18-19.01.1980	-3.10	0.02
	27-29.01.2000	-11.90	3.20
	9-12.02.2004	-9.90	-6.50
Pevek	6-7.12.2008	-10.00	-6.50
	16-17.03.2009	-13.00	-5.90
	16-17.12.2015	-8.10	-4.60
Mean:		**-11.4**	**-4.4**



2. SOURCES OF ERROR WHEN MODELLING OROGRAPHIC WINDS WITH HIGH RESOLUTION

Conclusions

- Our sensitivity experiments aimed to find the reason for the total underestimation of the wind speed during orographic winds (downslope windstorms) by the WRF model at weather stations. We found that the land use data, used in WRF, was incorrect for some areas in the Russian Arctic. For this reason the roughness length was greatly overestimated.
- When the average roughness length obtained from the observation data in Tiksi was substituted into the model, the simulation results improved significantly, not only in Tiksi, but also in other areas (Wrangel Island, Novaya Zemlya, Pevek) where the landscape is very similar.
- Improvement of the simulation results is not only due to a general increase in wind speed in the boundary layer with a decrease in roughness, but primarily due to an improved reproduction of the flow dynamics.
- Even with the corrected roughness length, the error in modeling the wind speed remains, and is quite large (on average for our case studies, it was -4.4 m/s). And this is a subject for further research.

MAIN CONCLUSIONS

- For tasks related to the analysis of spatially averaged wind, high resolution is not necessary and even worsens the results.
- For tasks related to the analysis of the structure of orographic winds, high resolution (at least 3 km) is recommended. For that reason none of the reanalyses can be recommended for such purposes.
- Methods for estimation of the wind structure reproducibility should be improved.
- When modeling orographic winds with high resolution, it is very important to ensure that the surface roughness is correct. All land use databases used in the WRF model are not correct in the Arctic region, which lead to erroneous roughness length.

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THANK YOU FOR YOUR ATTENTION!