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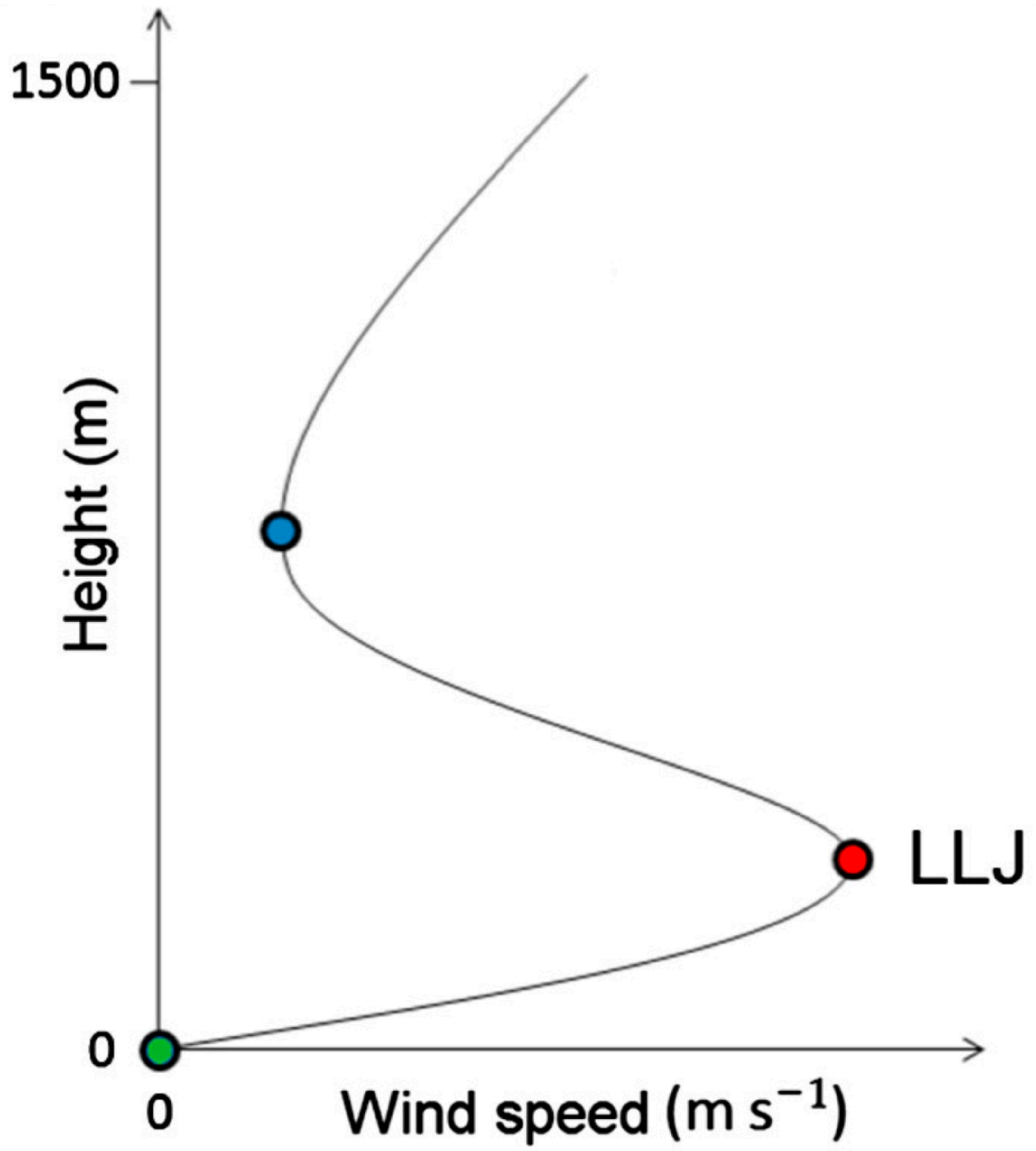
Climatology of low-level jets in Scandinavia for offshore wind applications and a variety of datasets

Clio Michel, Birgitte Rugaard Furevik, and Øyvind Breivik

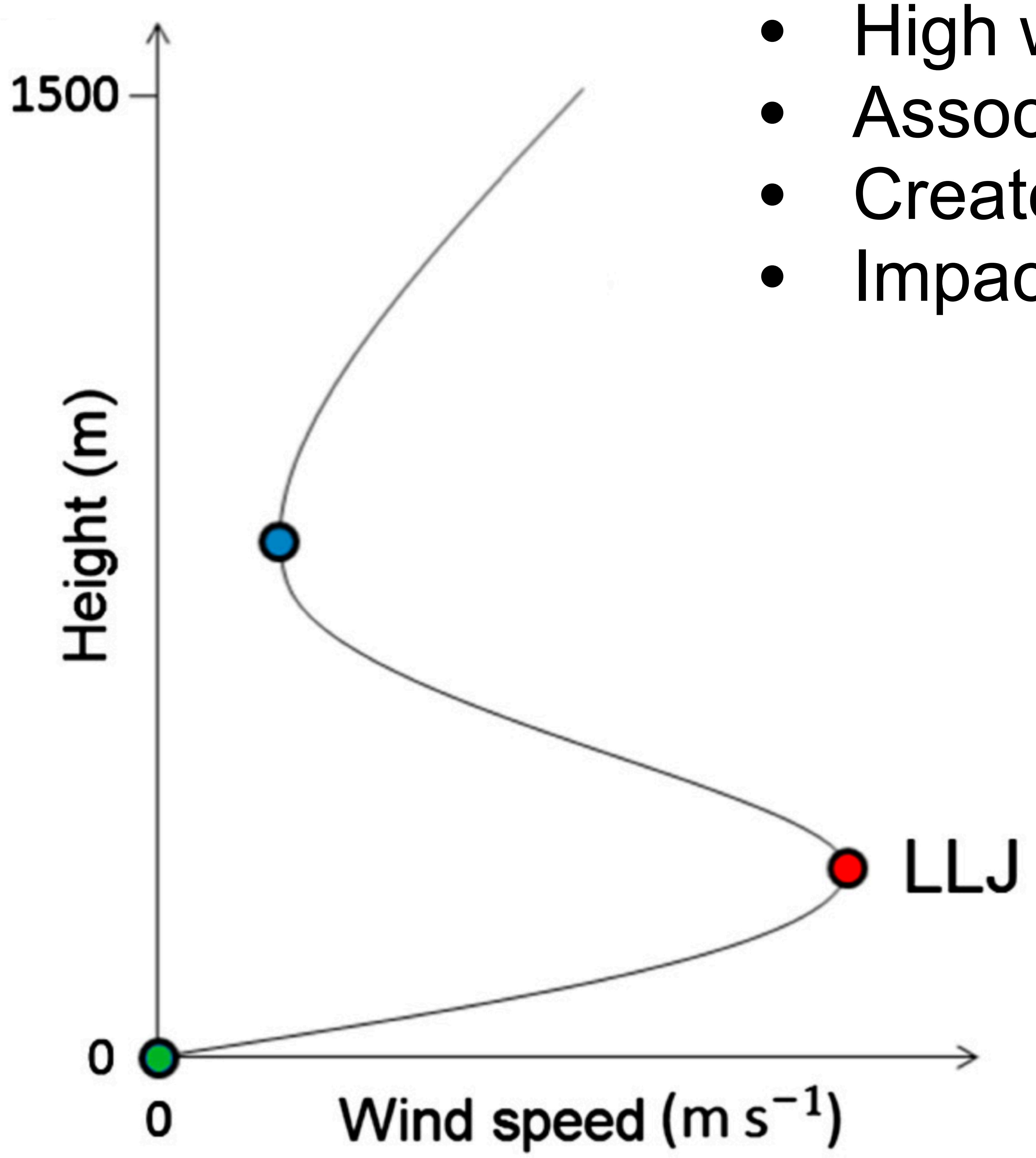
EERA DeepWind conference, 17-19 January 2024

Low-level jets (LLJ) and impact on wind energy



Tuononen et al. (2015)

Low-level jets (LLJ) and impact on wind energy



Tuononen et al. (2015)

- High winds to be harvested
- Associated with wind shear above and below the jet
- Creates loads on the turbine (mast, nacelle, blades)
- Impacts the wind production, accelerates the fatigue of the structure

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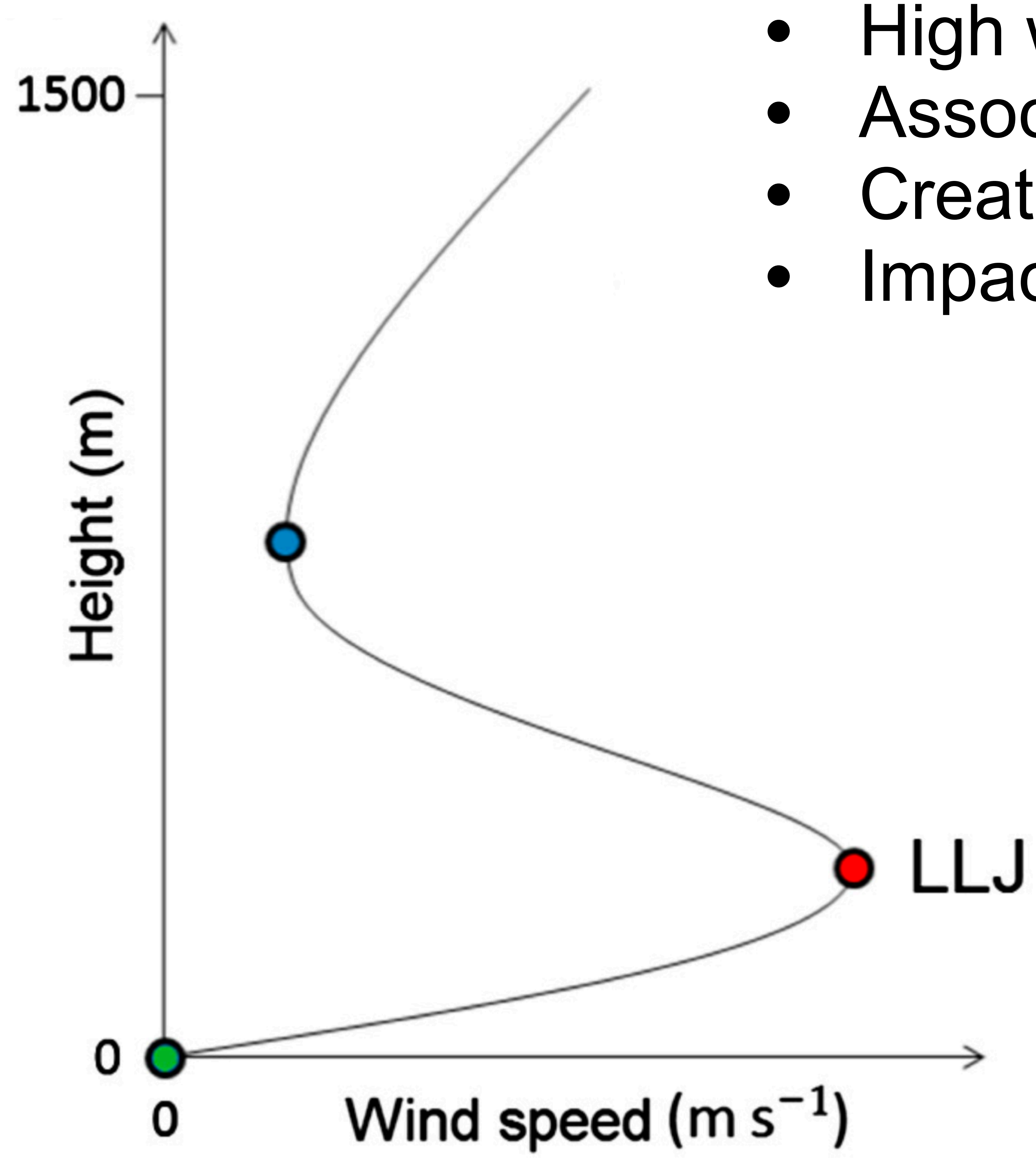

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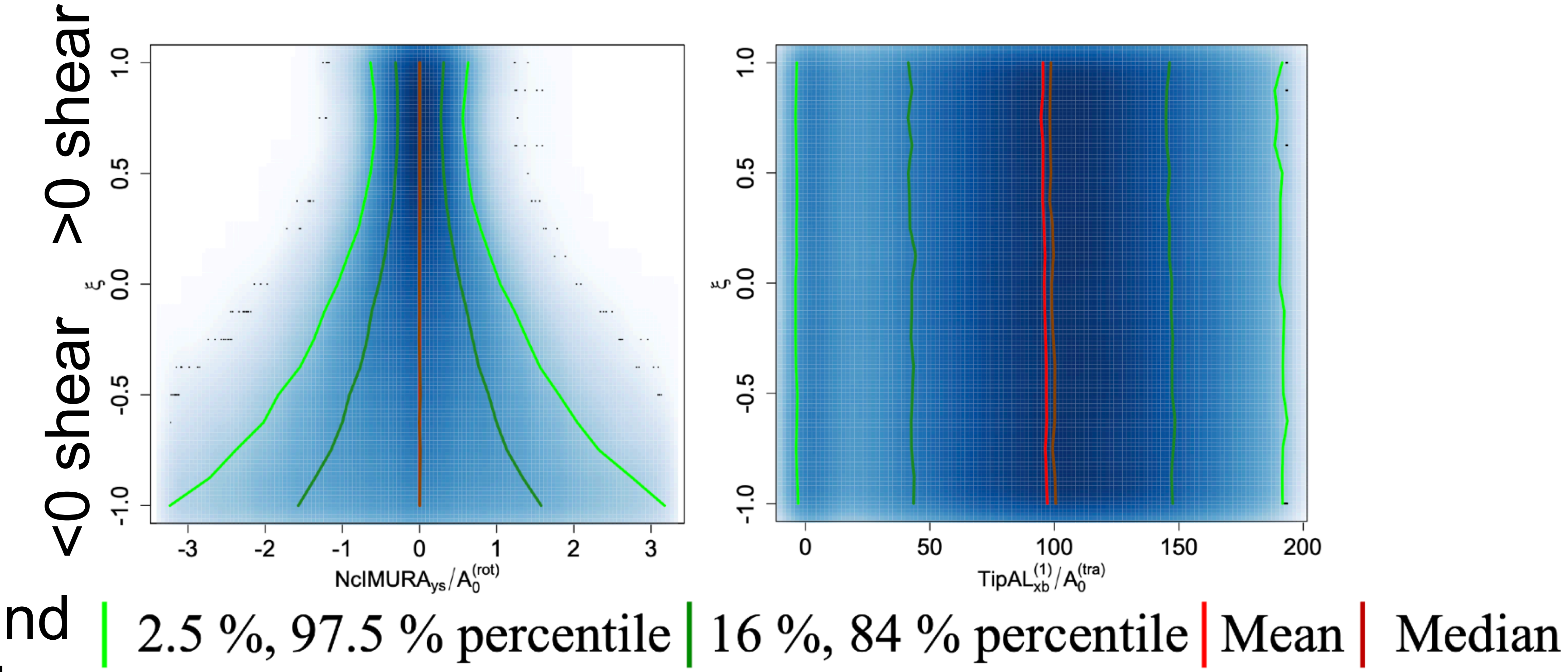
Nacelle's angular acceleration around cross axis

Blade tip's translational acceleration streamwise



Guttierez et al. (2017)
Recommend to build wind turbine high enough to be in the negative shear

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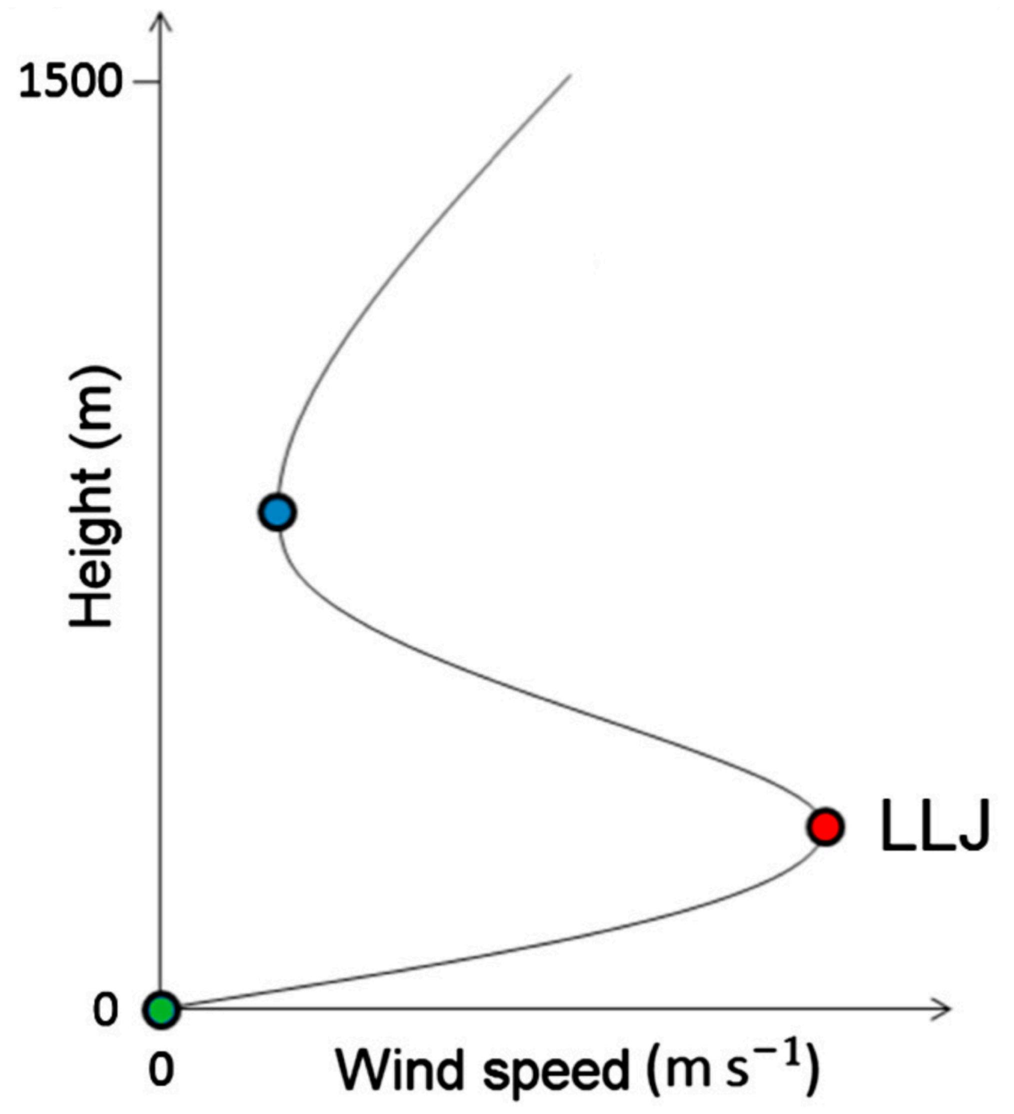
Detection of low-level jets

Following the method of *Tuononen et al. (2015)*:

- Differences:
  1) Lowest model level as surface,
  2) if no local minimum above and/or below the jet, the lowest model level or the level 1500 m are considered as minima.

- Additions:
  1) Polynomial fit (parabolic) around the maximum to define the height and speed,
  2) Direction of the wind taken at the jet height on model levels



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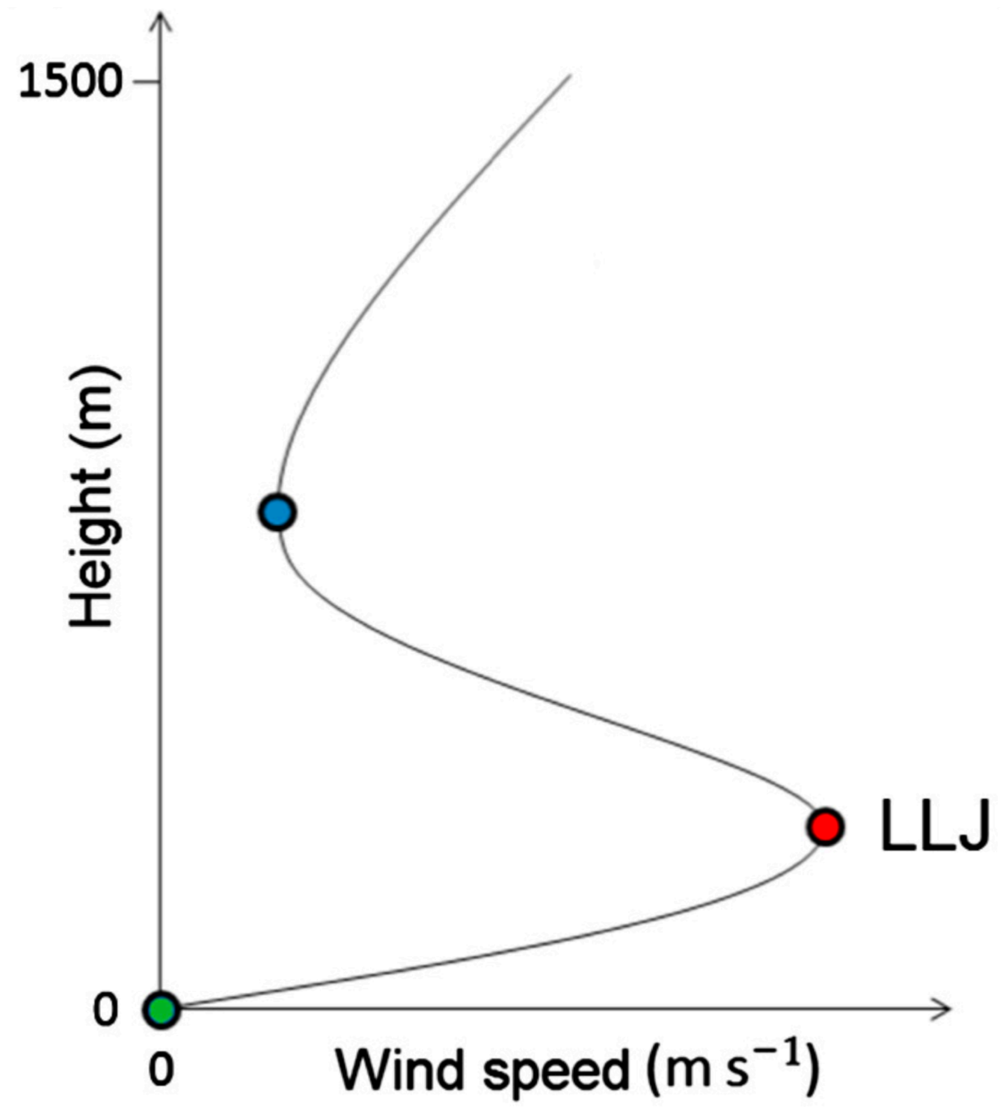


Tuononen et al. (2015)

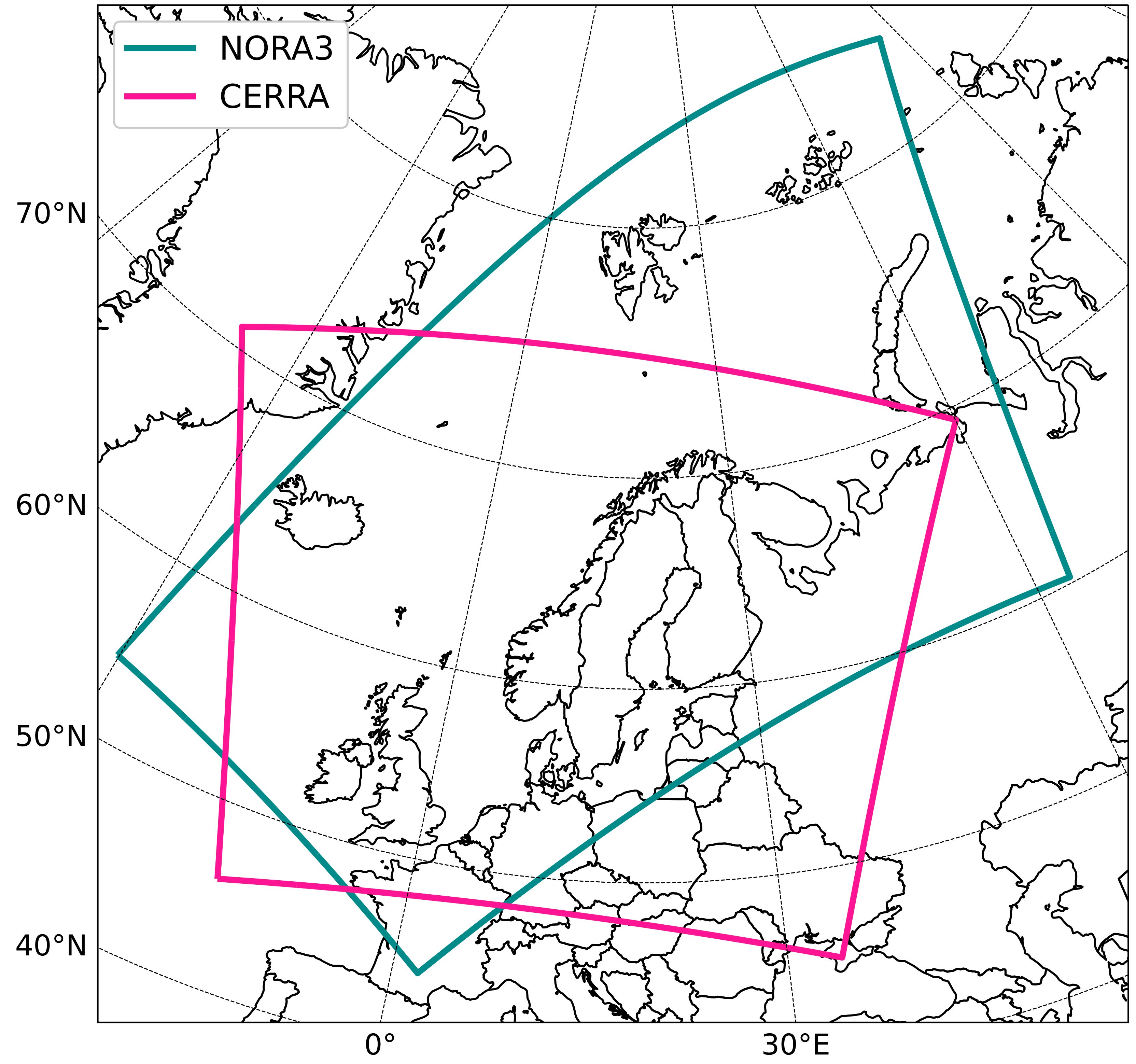
→ 3(6)-hourly maps with height, speed and direction of low-level jets

Three different datasets

- **ERA5** (ECMWF, *Hersbach et al. 2020*)
  - Global reanalysis
  - 0.25° spatial resolution
  - 6-hourly

Model levels

2000-2009



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  - Regional hindcast (aggregation of short-range forecasts)
  - 3-km spatial resolution
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→ Model levels

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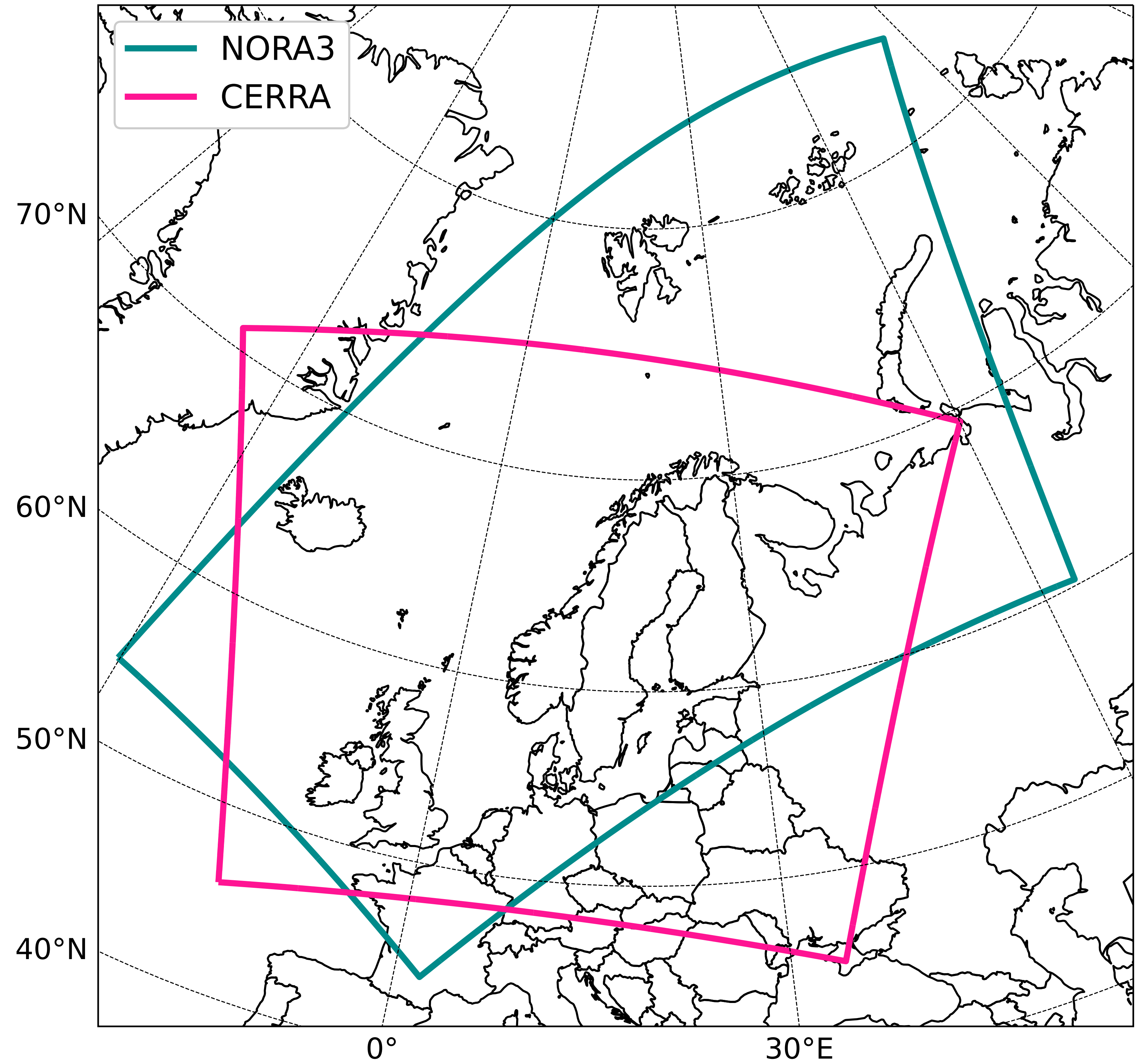

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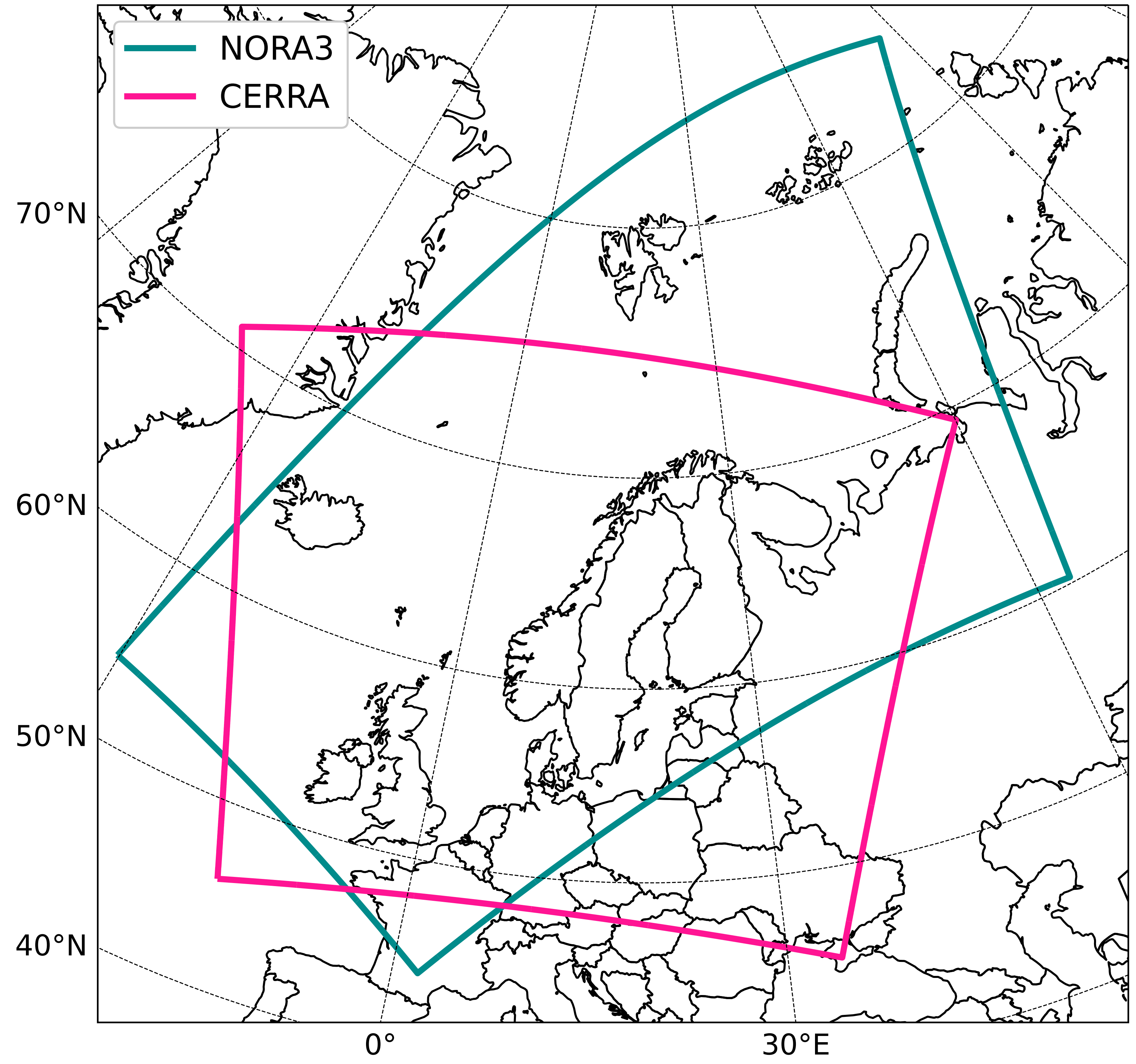
- **CERRA** (SMHI / Copernicus, *Schimanke et al. 2021*)
  - Regional reanalysis
  - 5.5-km spatial resolution
  - 3-hourly

→ Model levels
2000-2009



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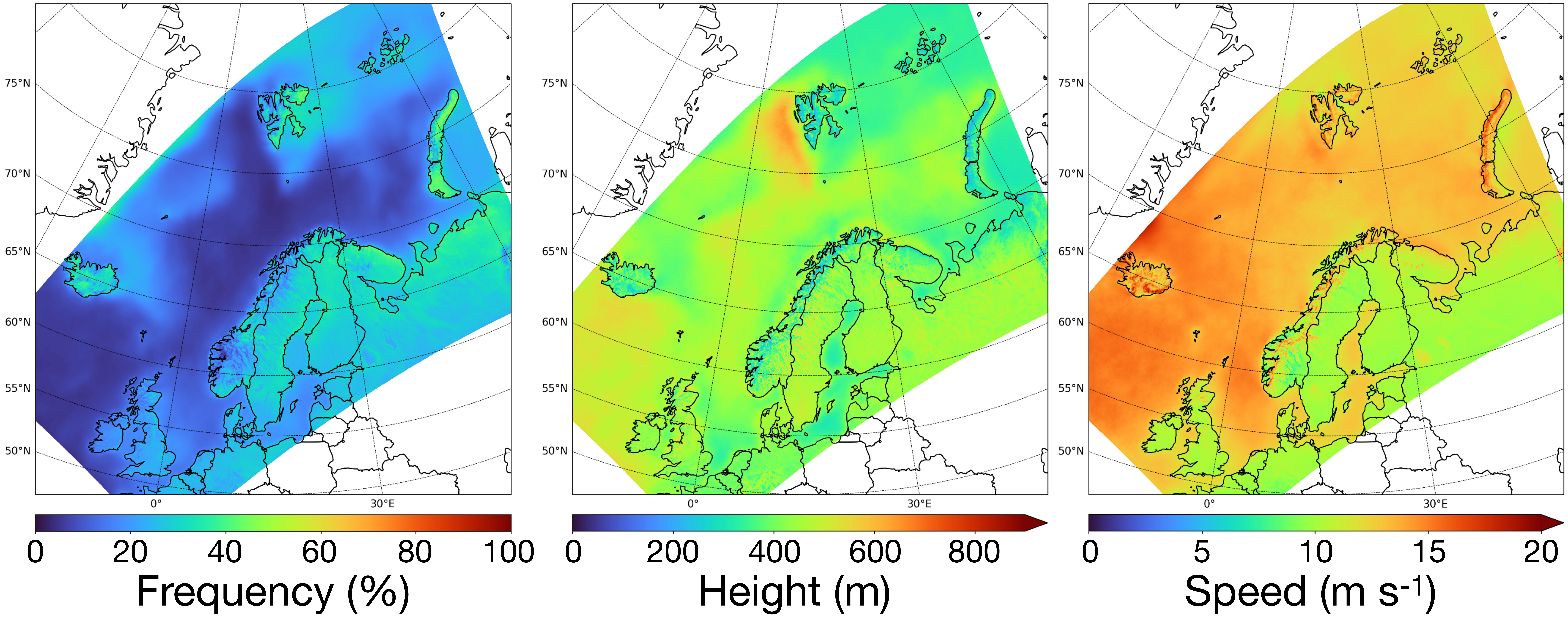
Climatologies (2000-2009) for NORA3



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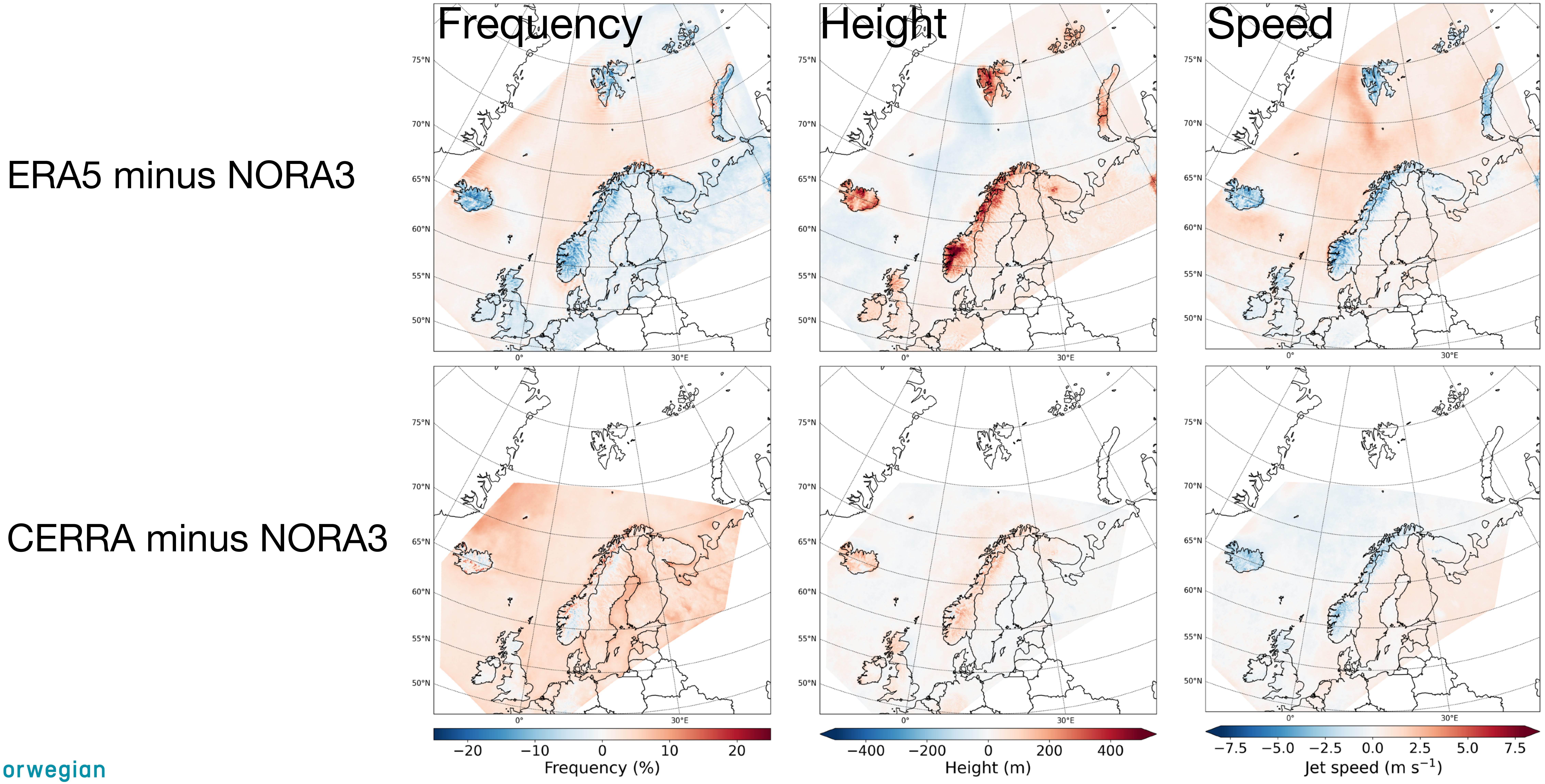
Differences from NORA3



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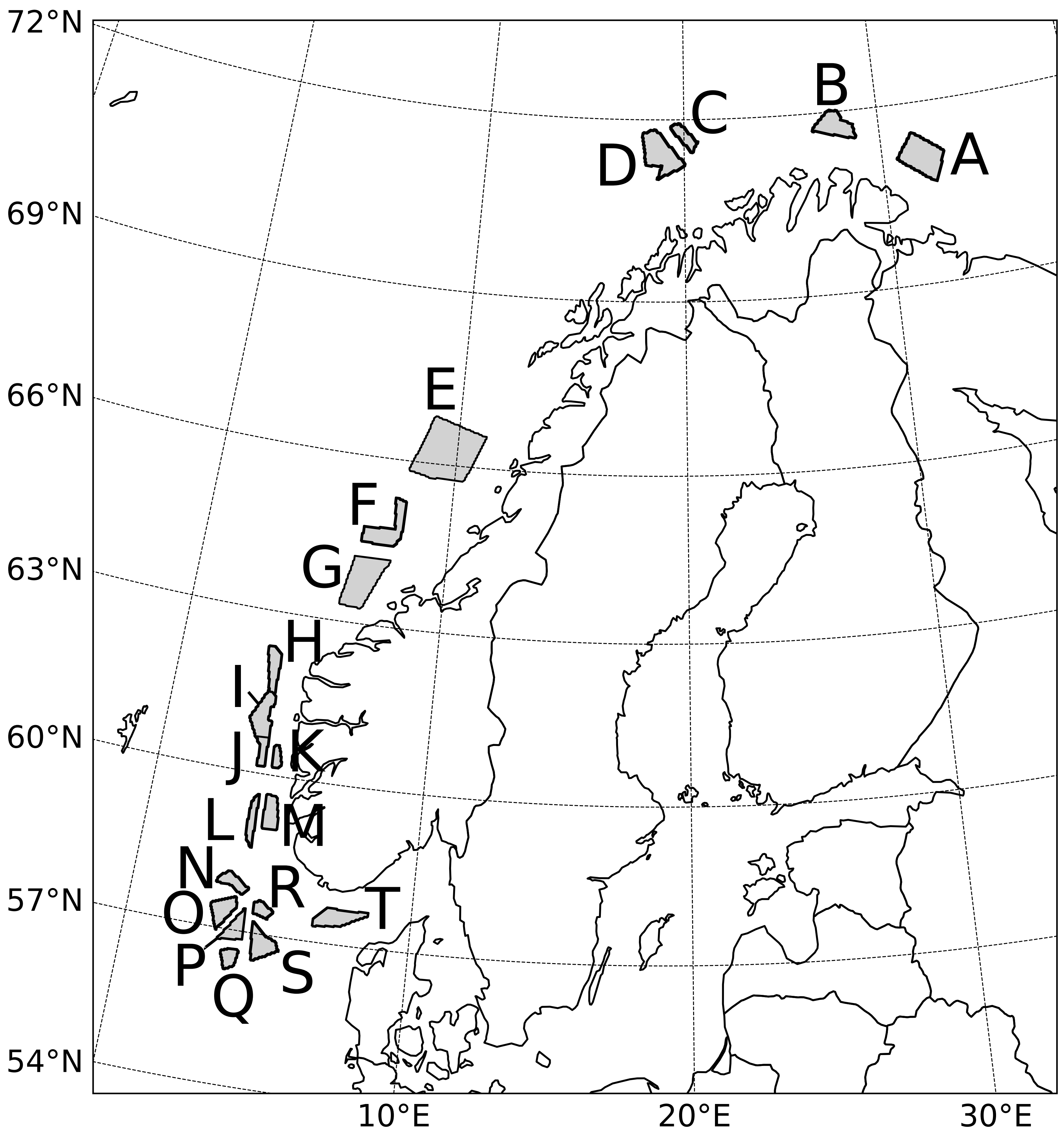
Potential offshore wind farms locations



A - Nordavind A
B - Nordavind B
C - Nordavind C
D - Nordavind D
E - Nordvest A
F - Nordvest B
G - Nordvest C
H - Vestavind A
I - Vestavind B
J - Vestavind C
K - Vestavind D
L - Vestavind E
M - Vestavind F
N - Sørvest A
O - Sørvest B
P - Sørvest C
Q - Sørvest D
R - Sørvest E
S - Sørvest F
T - Sønnavind A

NVE
https://nedlasting.nve.no/gis/
Havvind / Identifiserte områder for havvind - 2023

Frequencies

Probability to get a LLJ at one grid point of the region (in %):

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
NORA3	9.1	7.5	6.0	5.6	8.3	8.2	9.9	9.2	9.7	10.9	11.1	11.4	12.6	11.4	12.0	12.5	13.0	12.1	12.4	13.4	10.3
CERRA	12.5	11.5	8.9	8.2	10.9	11.4	13.8	13.7	14.4	15.2	15.1	16.2	17.6	15.4	16.4	16.7	17.4	16.3	17.0	18.0	14.3
Difference	3.4	3.9	2.9	2.7	2.6	3.2	3.9	4.5	4.7	4.4	4.1	4.8	5.0	4.0	4.4	4.2	4.4	4.2	4.6	4.6	

Frequencies

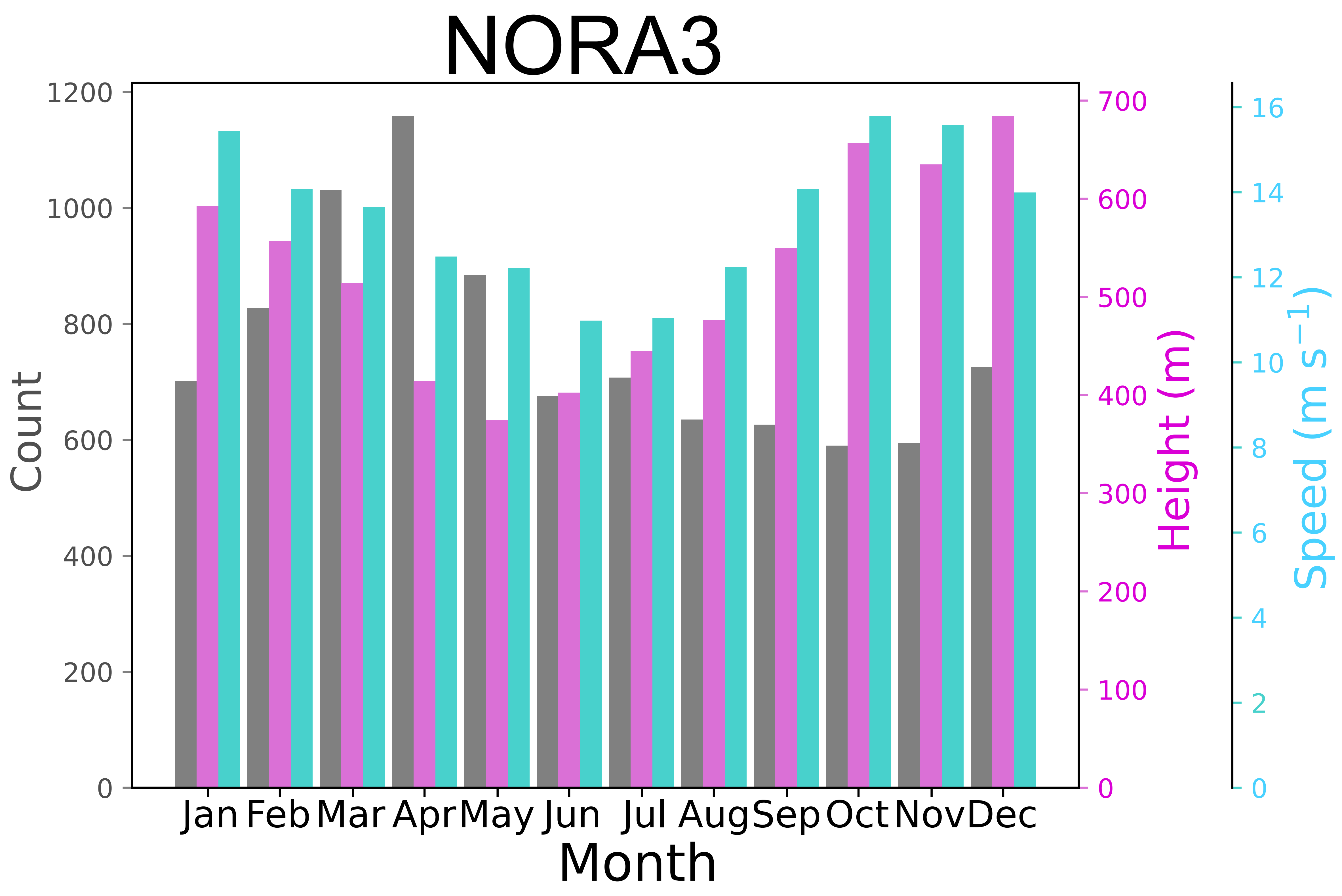
Probability to get a LLJ at one grid point of the region (in %):

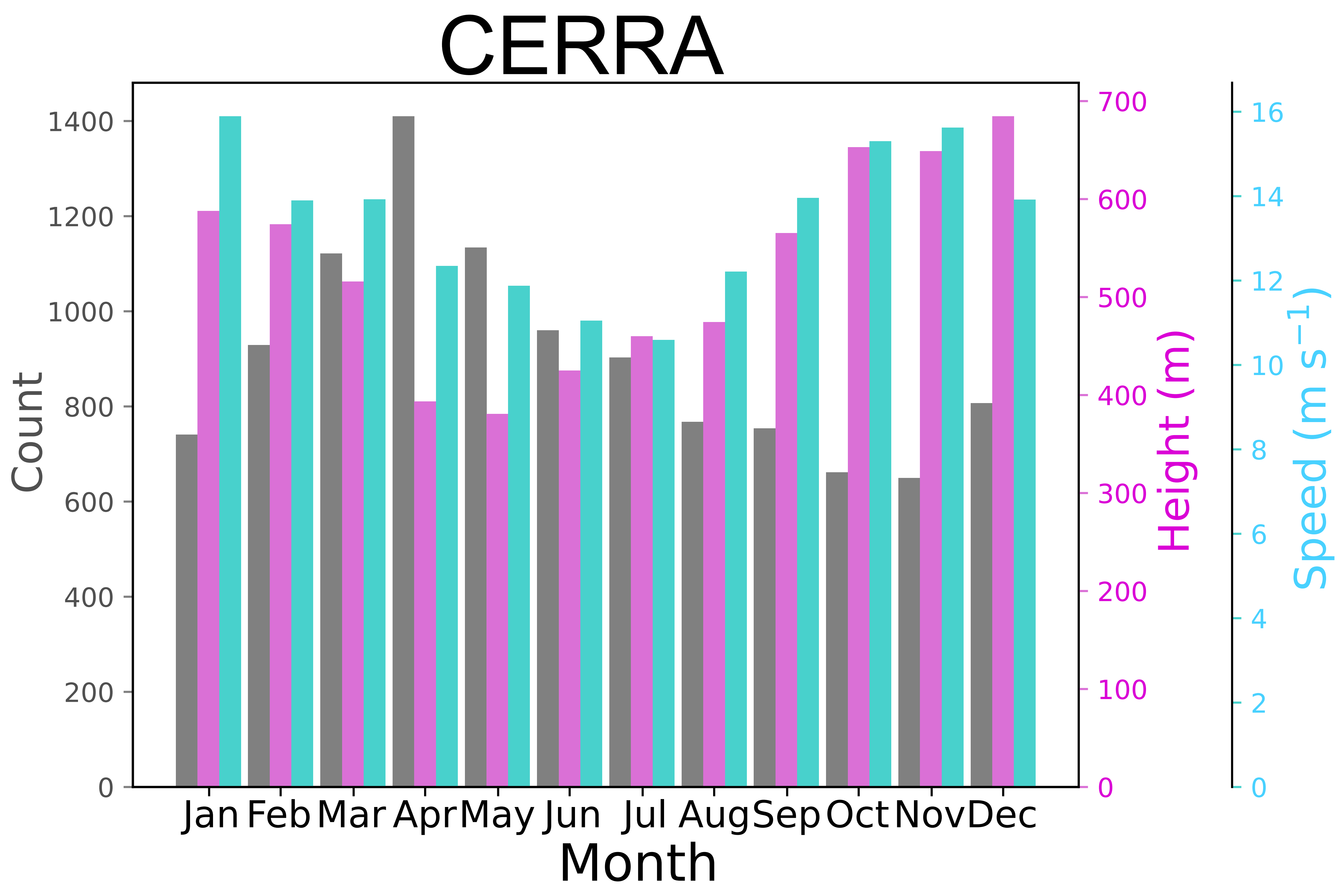
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
NORA3	9.1	7.5	6.0	5.6	8.3	8.2	9.9	9.2	9.7	10.9	11.1	11.4	12.6	11.4	12.0	12.5	13.0	12.1	12.4	13.4	10.3
CERRA	12.5	11.5	8.9	8.2	10.9	11.4	13.8	13.7	14.4	15.2	15.1	16.2	17.6	15.4	16.4	16.7	17.4	16.3	17.0	18.0	14.3
Difference	3.4	3.9	2.9	2.7	2.6	3.2	3.9	4.5	4.7	4.4	4.1	4.8	5.0	4.0	4.4	4.2	4.4	4.2	4.6	4.6	

Probability to get a LLJ within the region (in %):

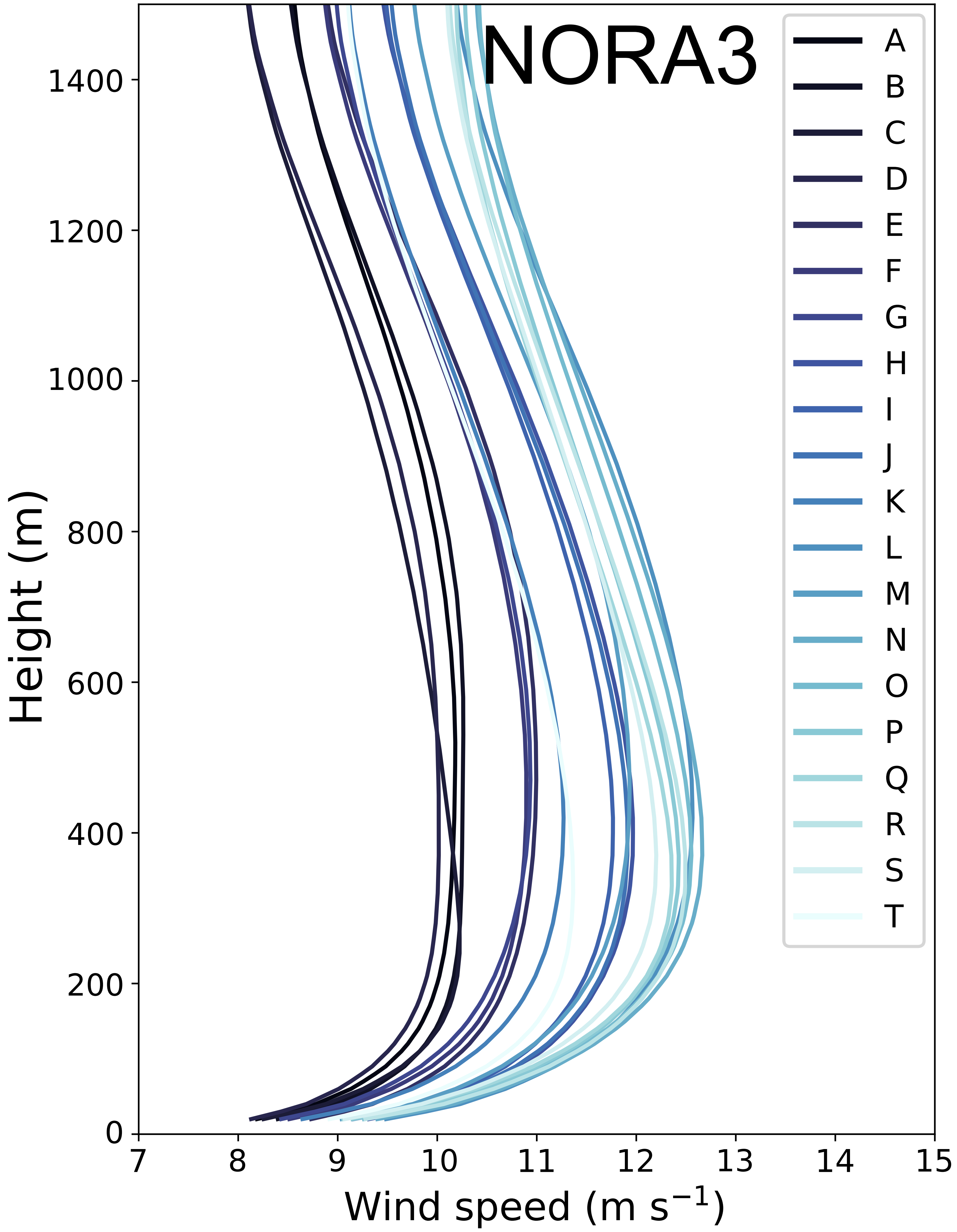
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
NORA3	32.5	25.5	15.8	23.6	39.6	28.0	37.3	26.7	30.7	24.4	22.9	28.1	31.3	26.1	28.8	28.8	25.1	23.4	30.9	40.3	28.5
CERRA	37.8	31.4	19.8	27.6	42.2	33.2	42.3	32.4	36.7	29.5	27.2	34.9	37.1	31.9	36.4	35.7	31.5	29.7	39.5	47.5	34.2
Difference	5.3	6.0	4.0	4.0	2.5	5.1	5.0	5.7	6.0	5.1	4.3	6.8	5.8	5.8	7.6	6.8	6.5	6.3	8.5	7.2	

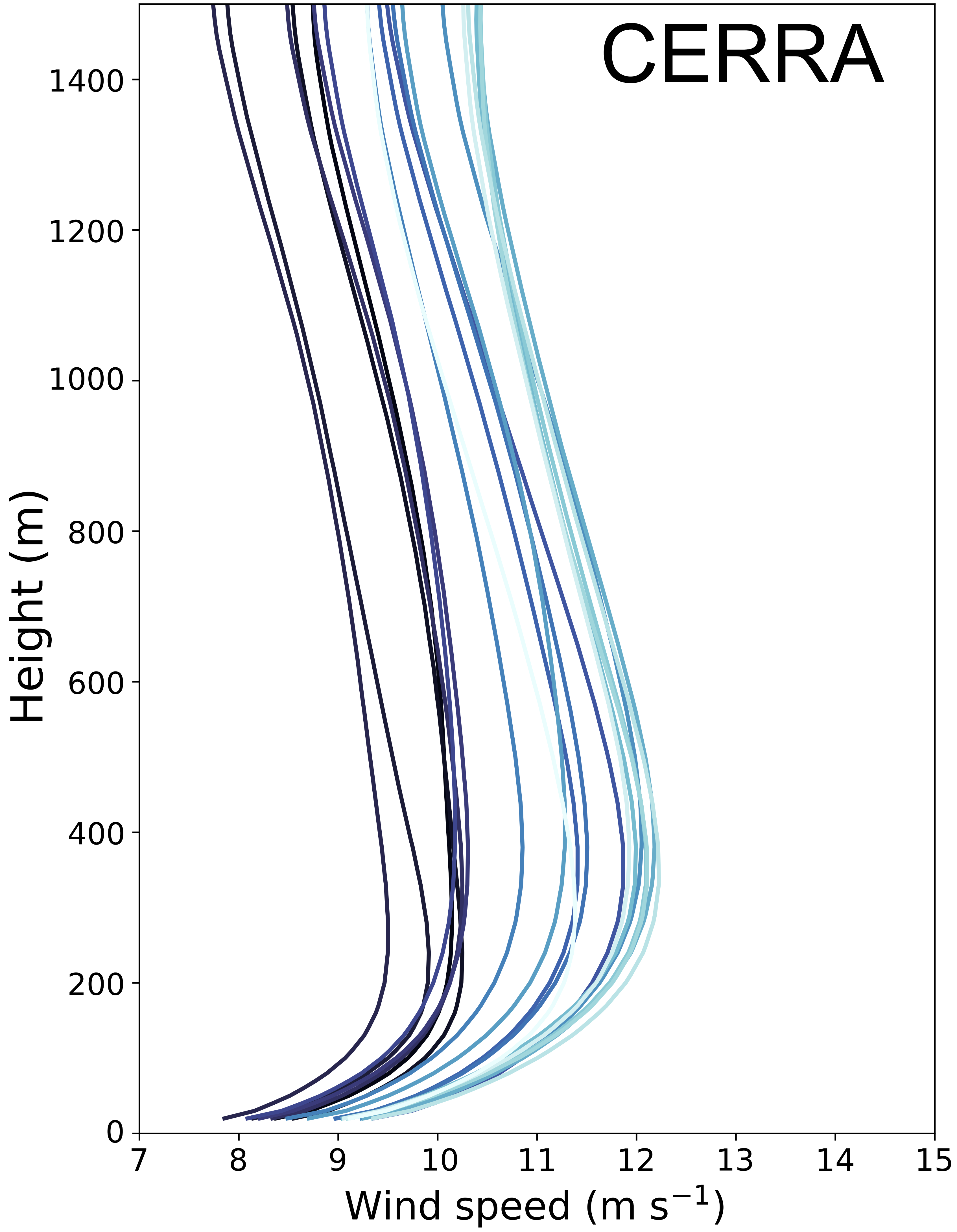
Temporal variability for Vestavind F





Mean low-level jet

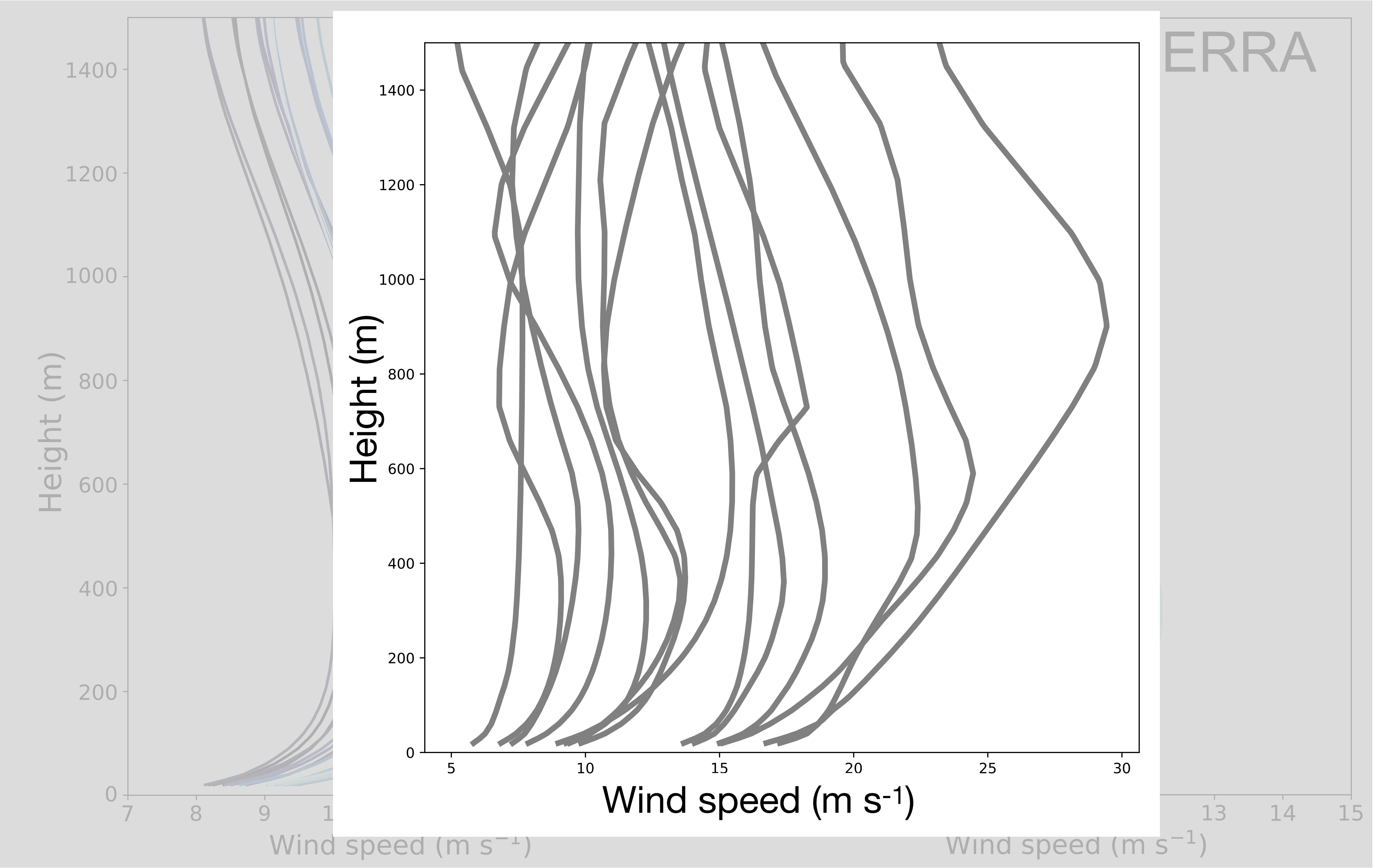




Many different profiles in the mean

=> does not reflect the instantaneous wind profile

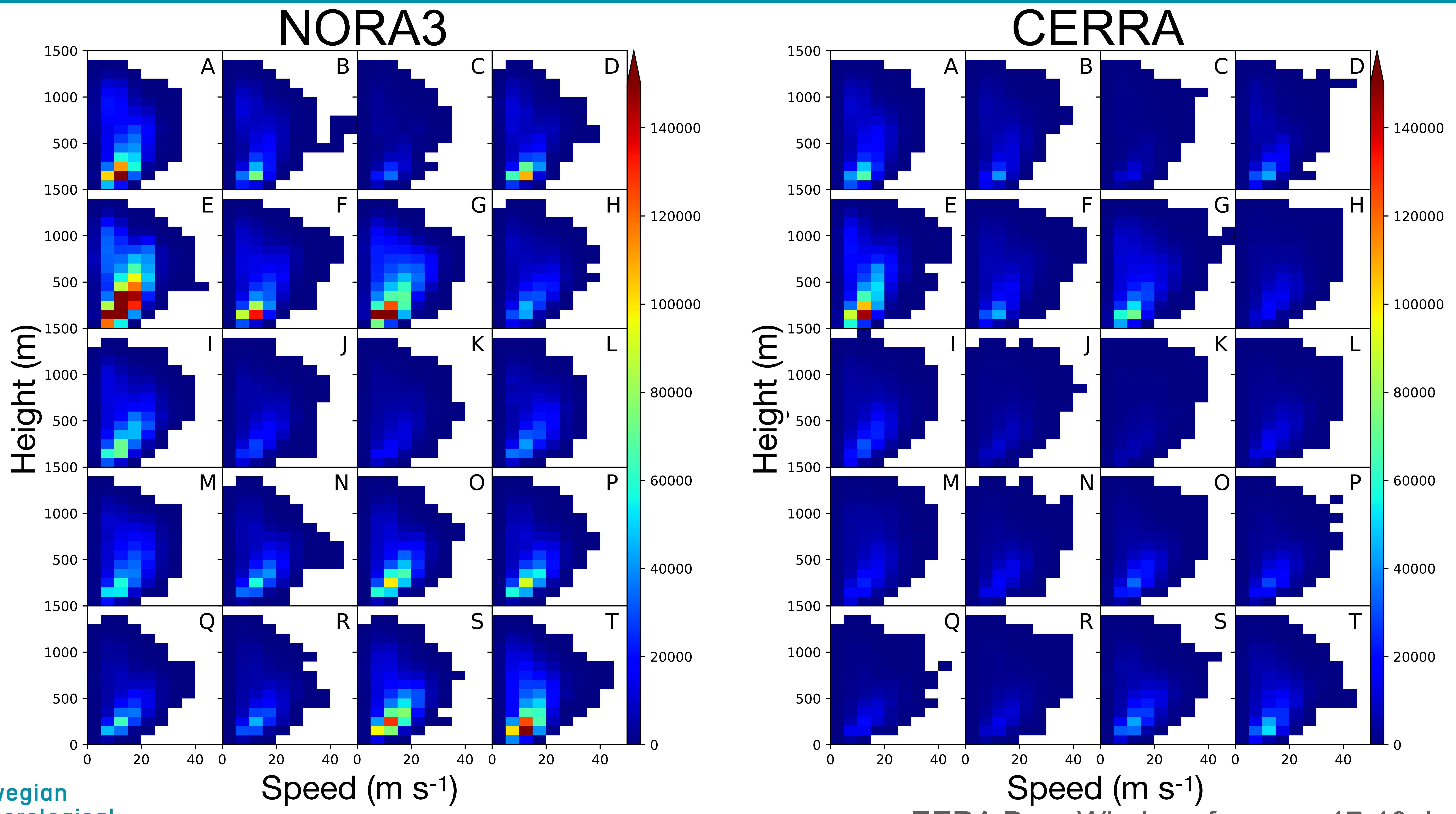
Mean low-level jet



Many different profiles in the mean
=> does not reflect the instantaneous wind profile

Jet height vs speed

All grid points in a region included



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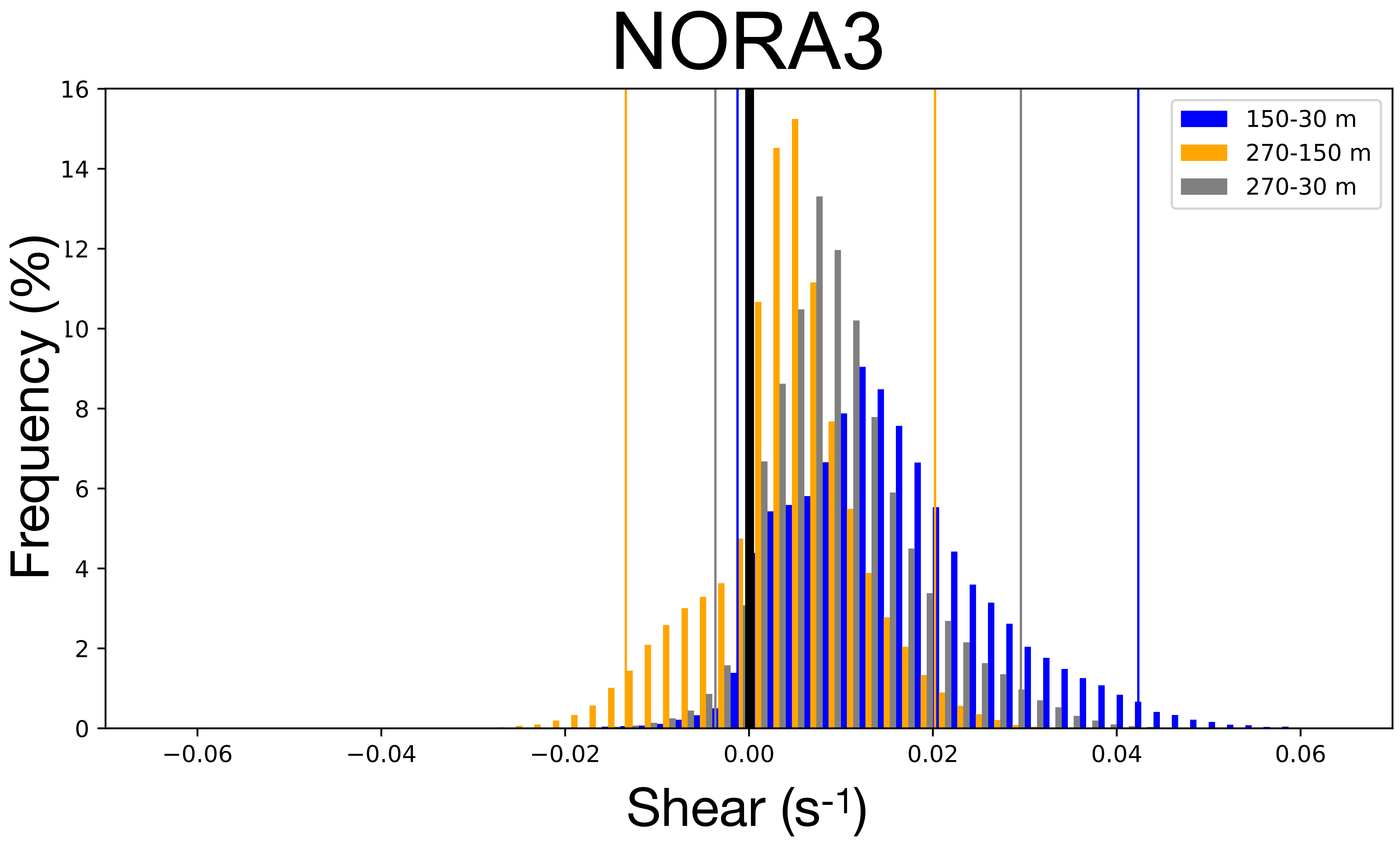
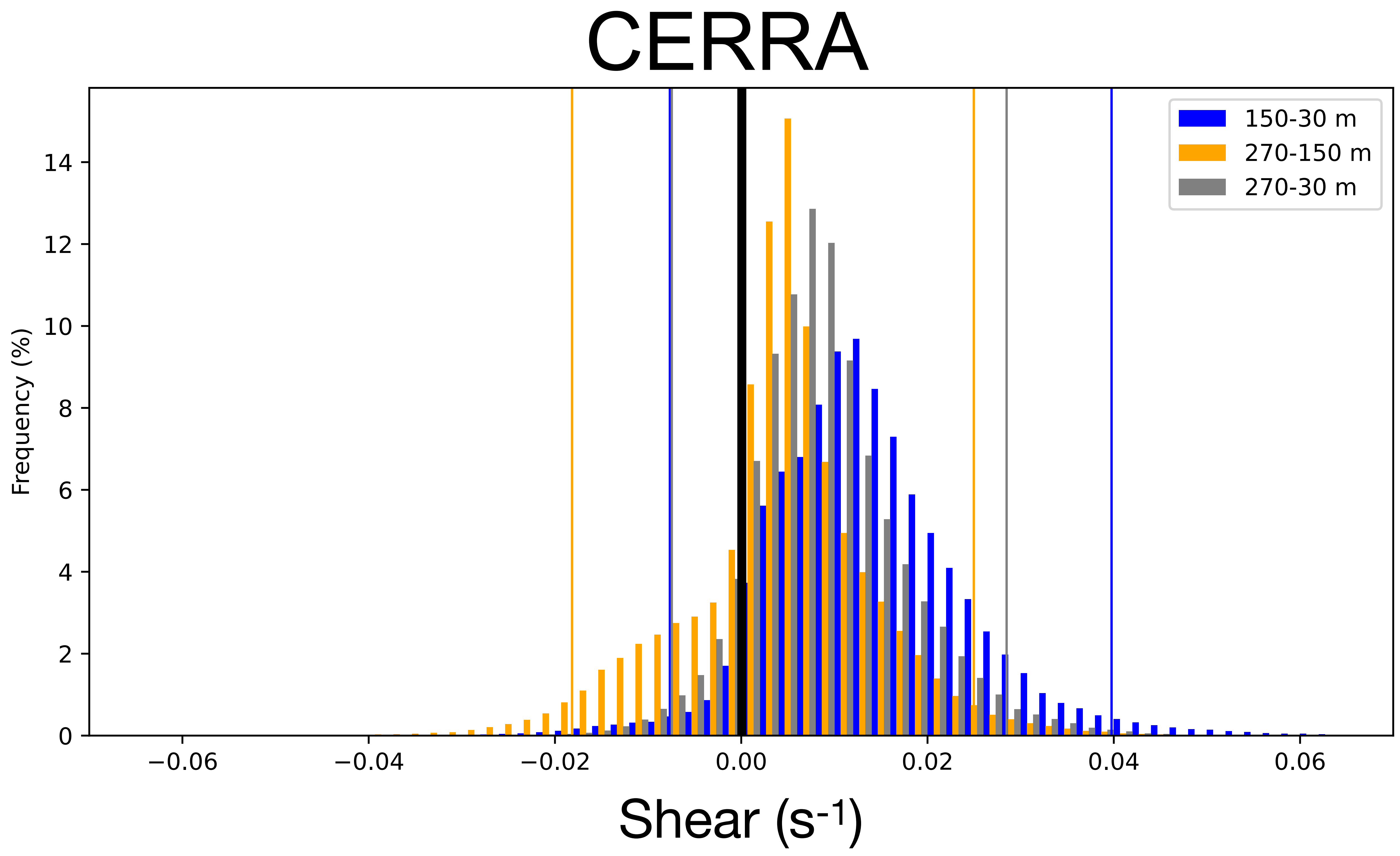
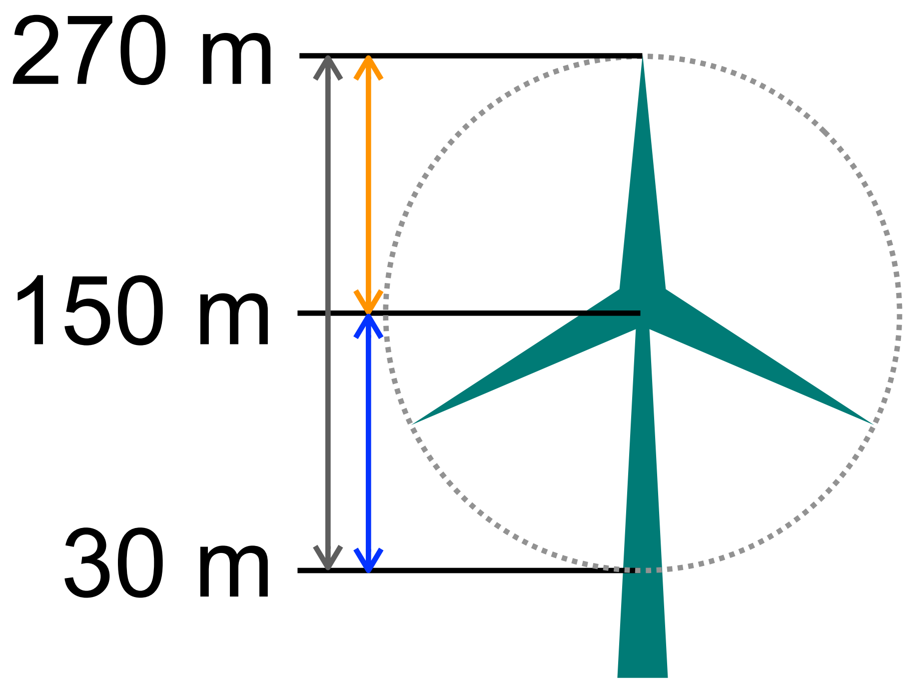
Wind shear at Vestavind F





Vertical colored lines: 2nd and 98th percentiles



IEA Wind
15-Megawatt Offshore Reference Wind Turbine
(*Gaertner et al. 2020*)

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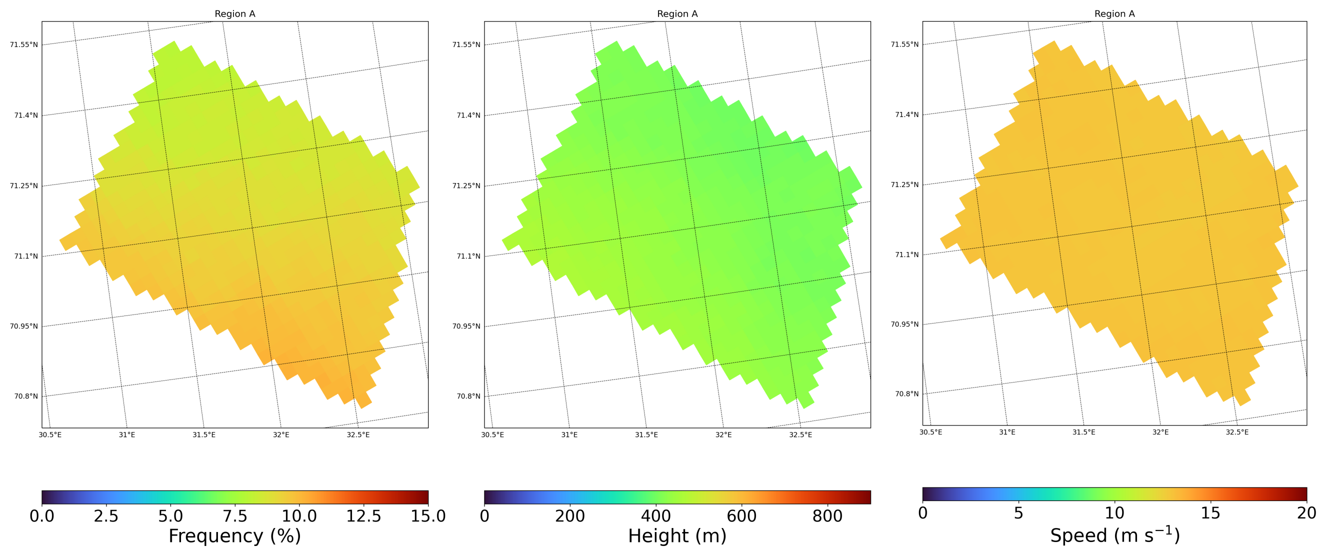
Low-level jet feature card for each region

NORA3

Region A

1



1 Mean frequency, height, speed

Low-level jet feature card for each region

NORA3

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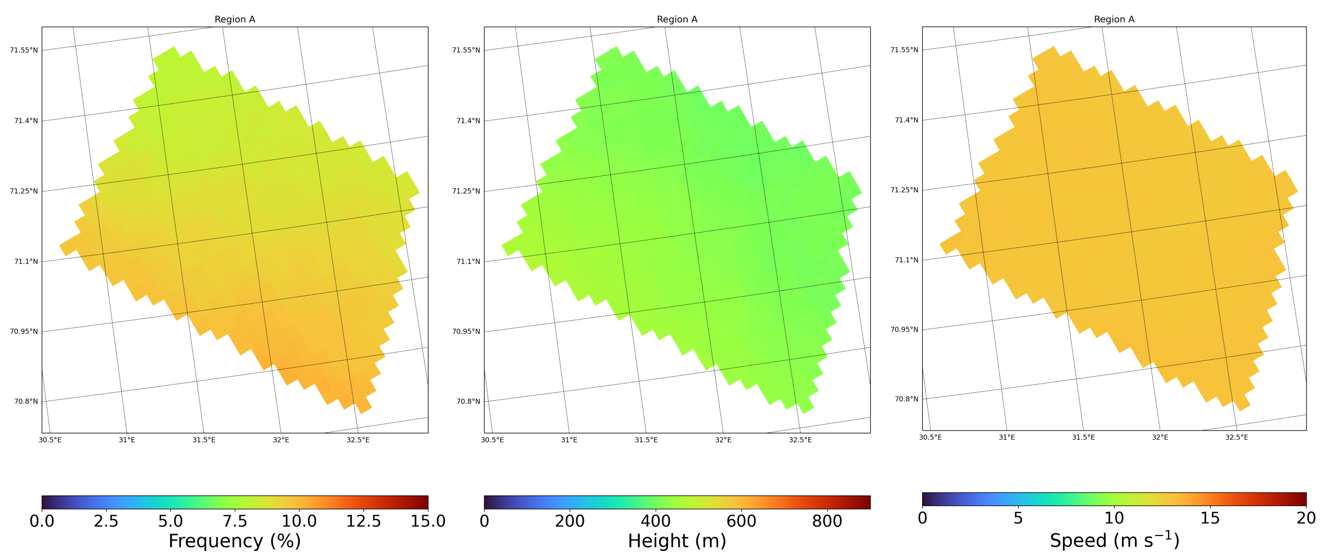

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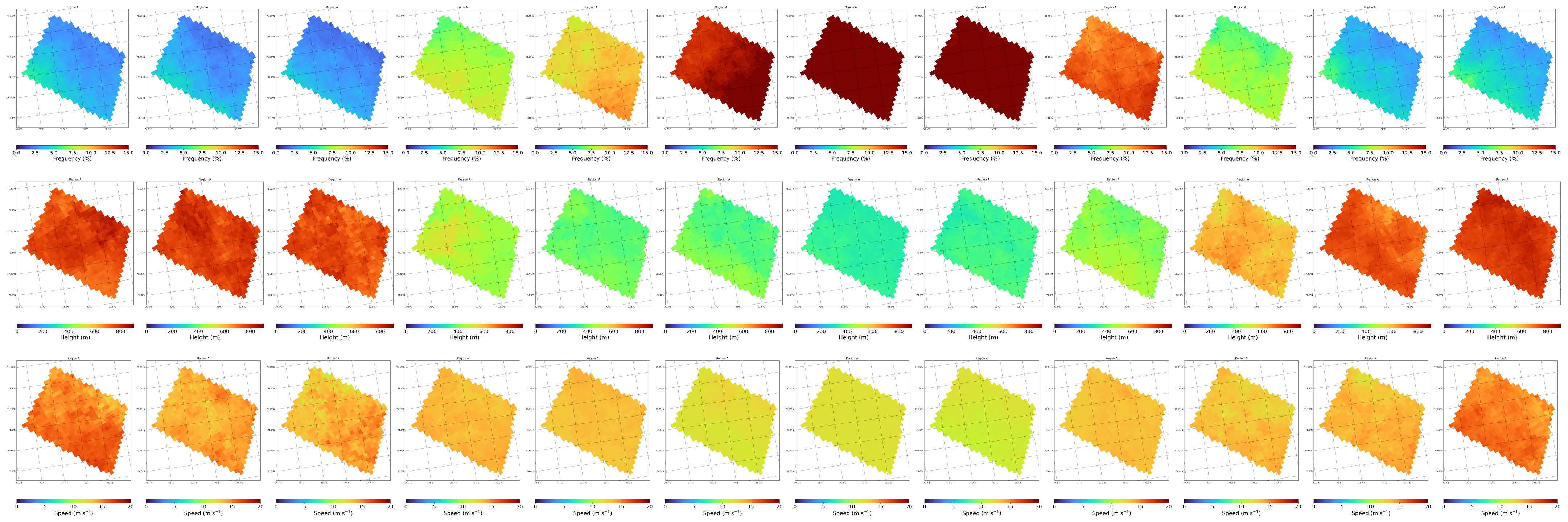

1 Mean frequency, height, speed

2 Monthly mean frequency, height, speed

Low-level jet feature card for each region

NORA3

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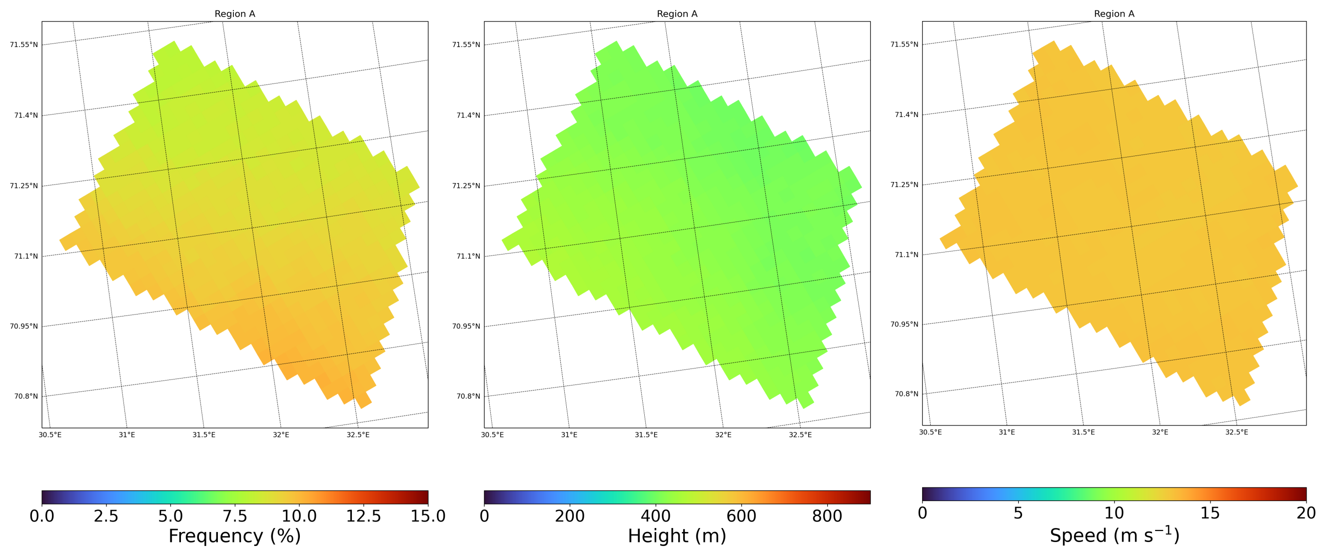

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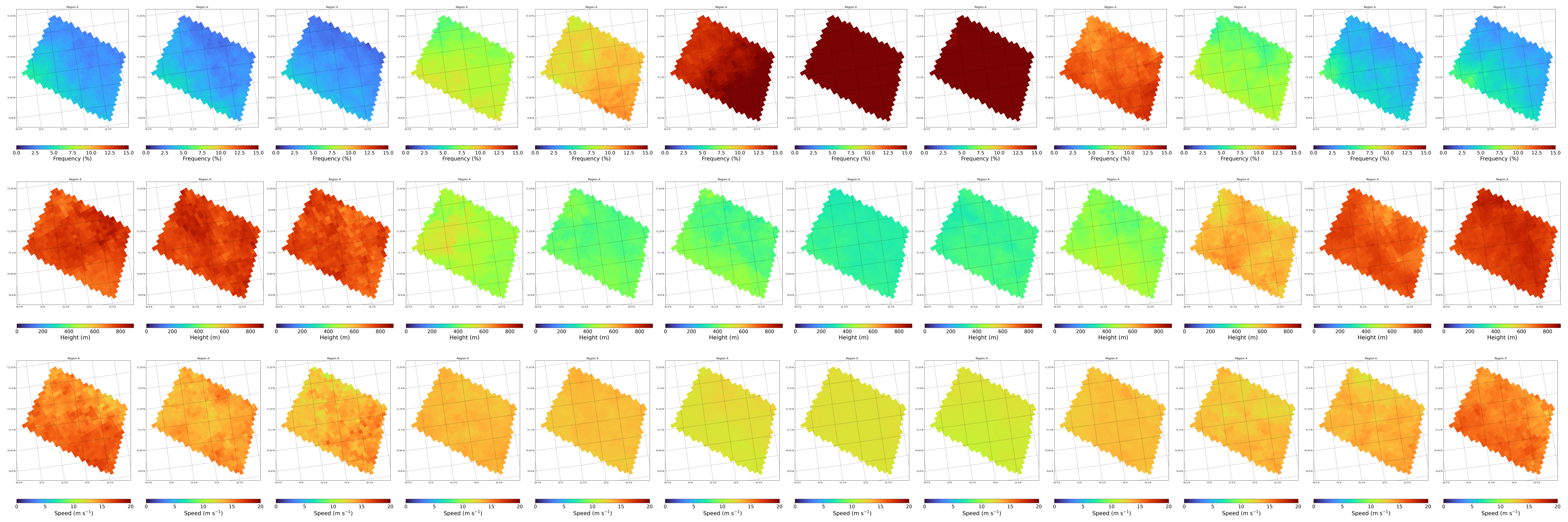

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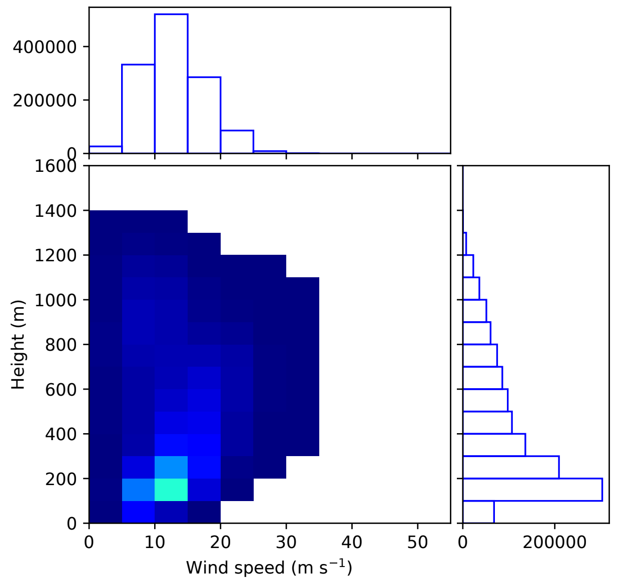

1 Mean frequency, height, speed

2 Monthly mean frequency, height, speed

3 LLJ height and speed variability

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Low-level jet feature card for each region

NORA3

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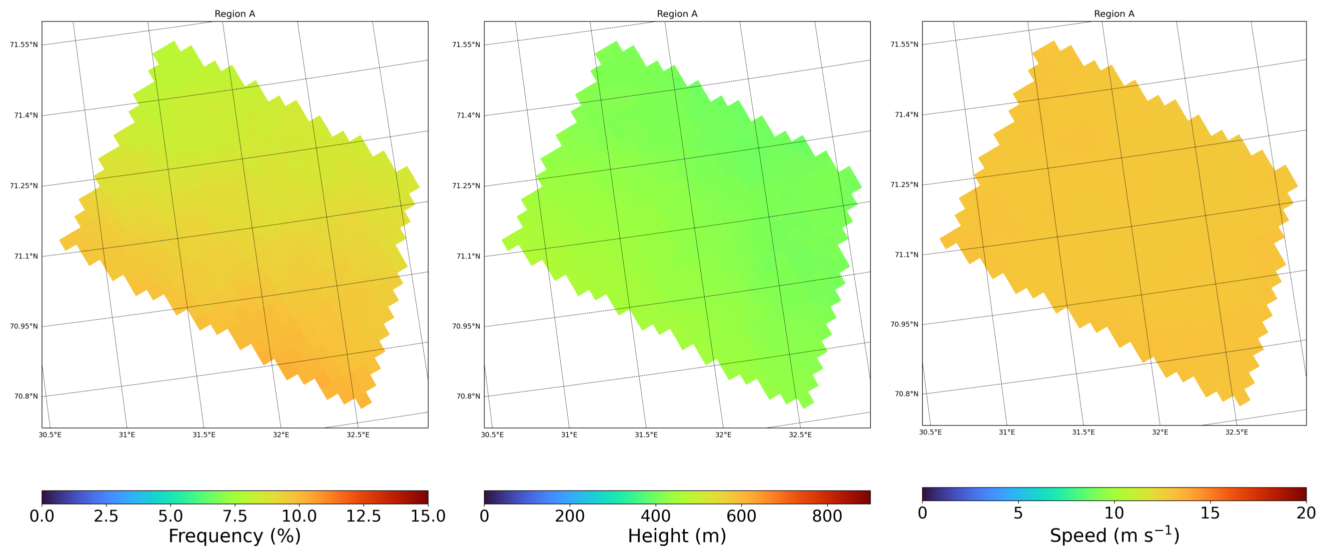

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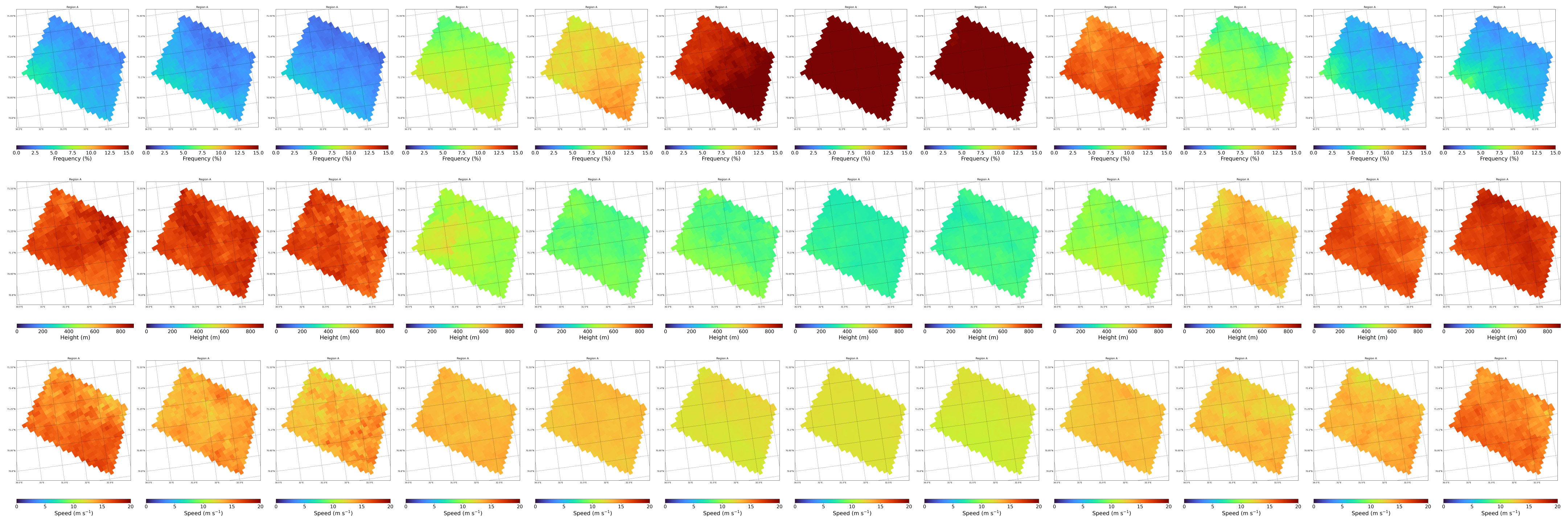

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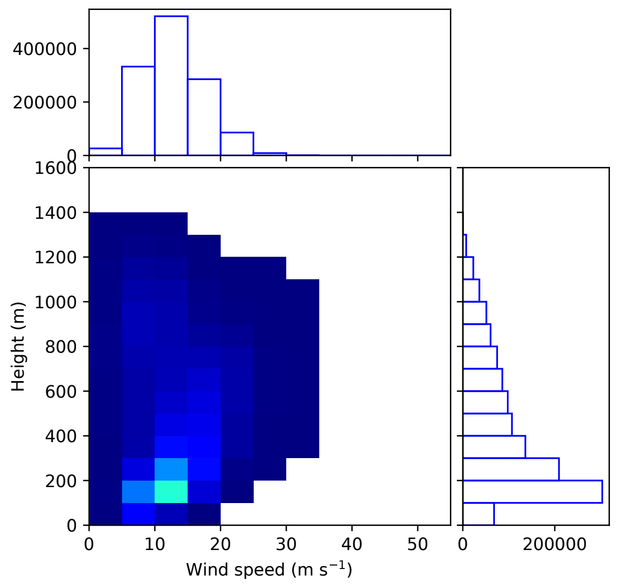

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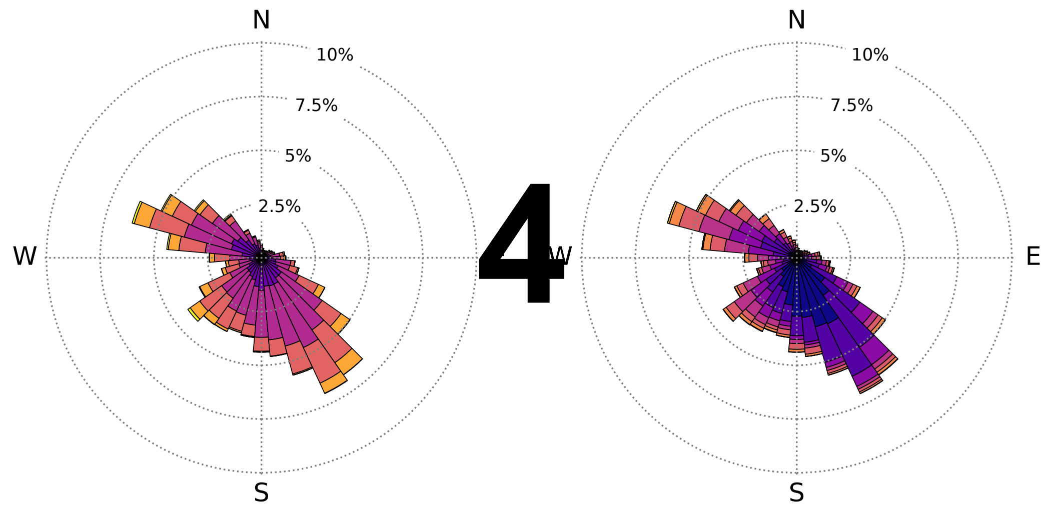

1 Mean frequency, height, speed

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3 LLJ height and speed variability

4 LLJ direction as a function of height and speed

Low-level jet feature card for each region

NORA3

Region A

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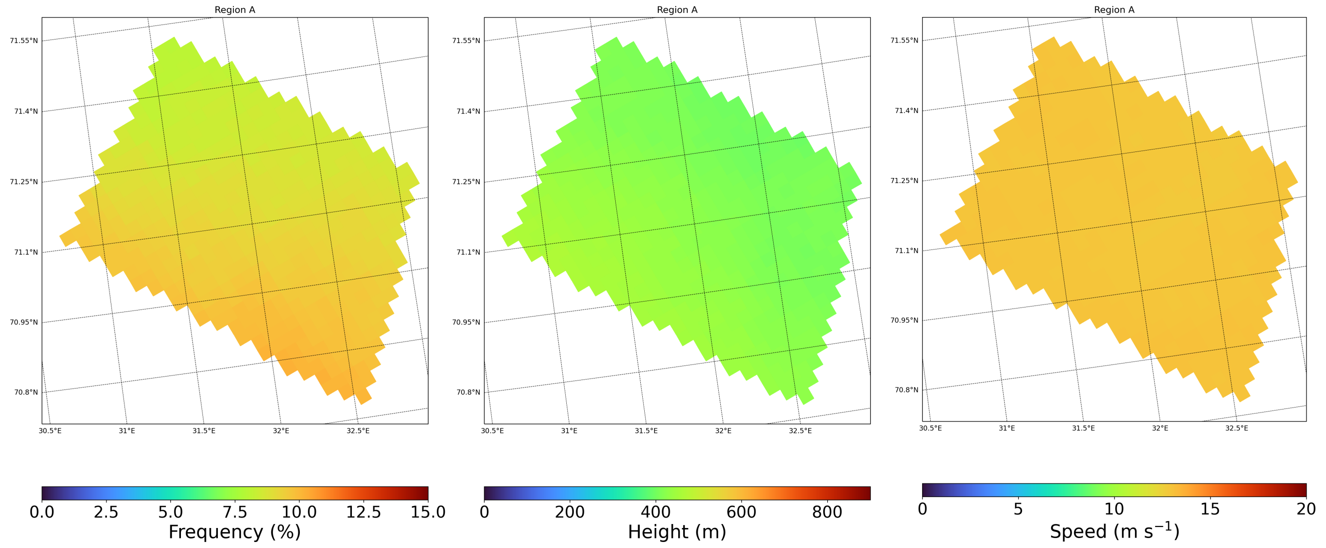

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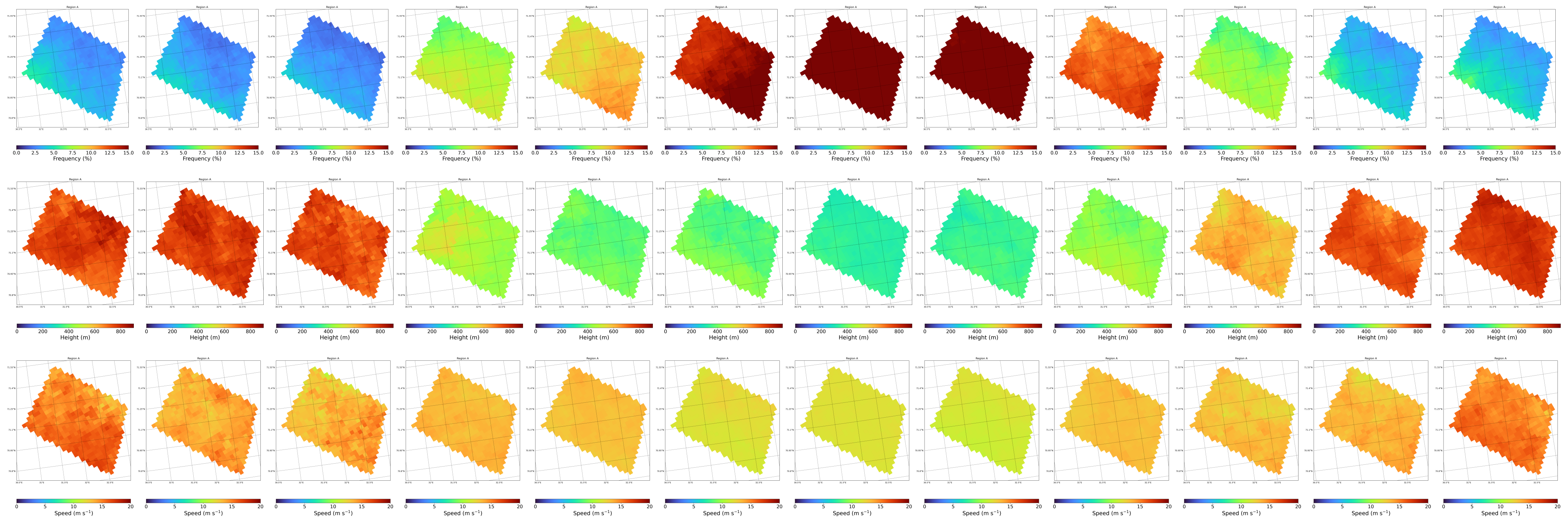

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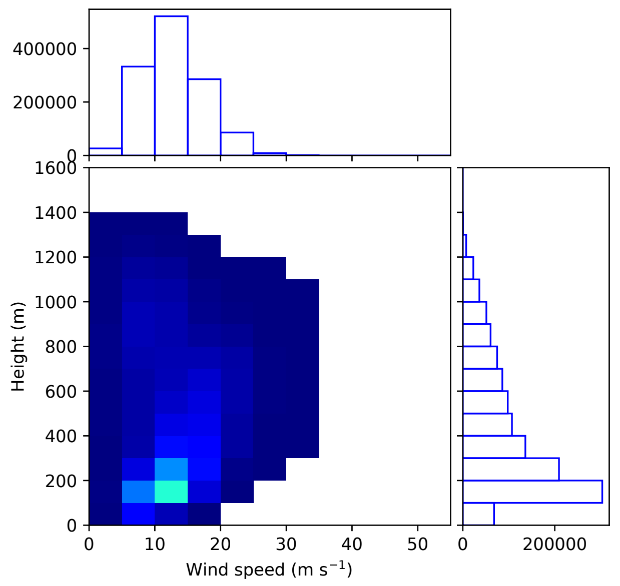

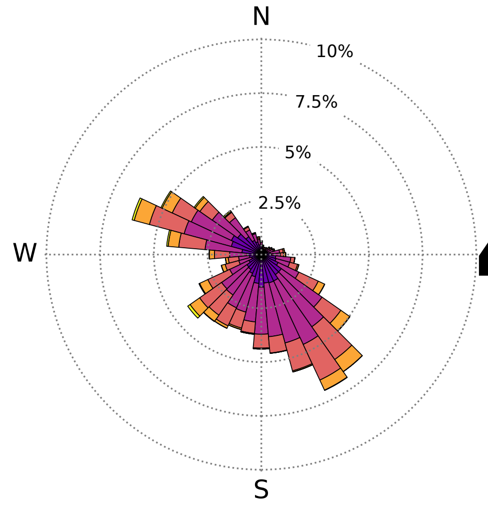

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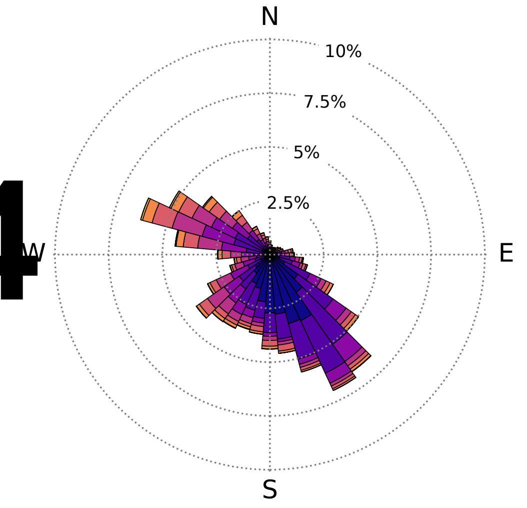

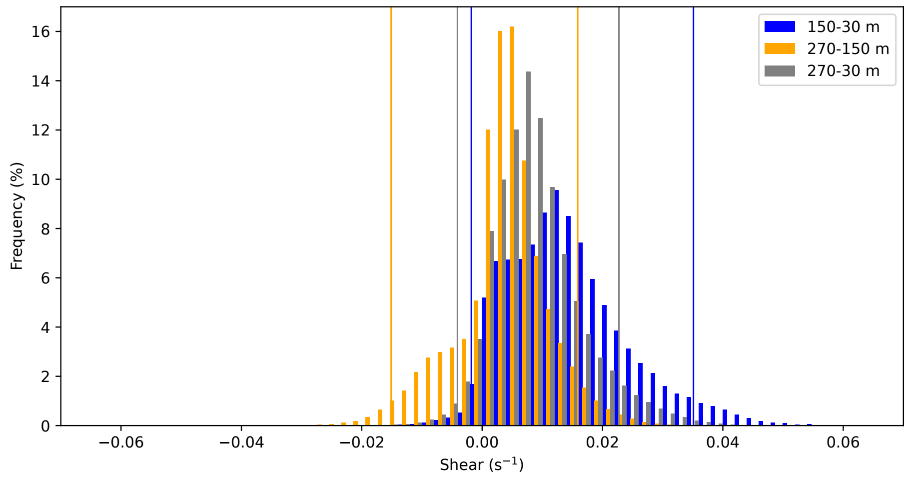

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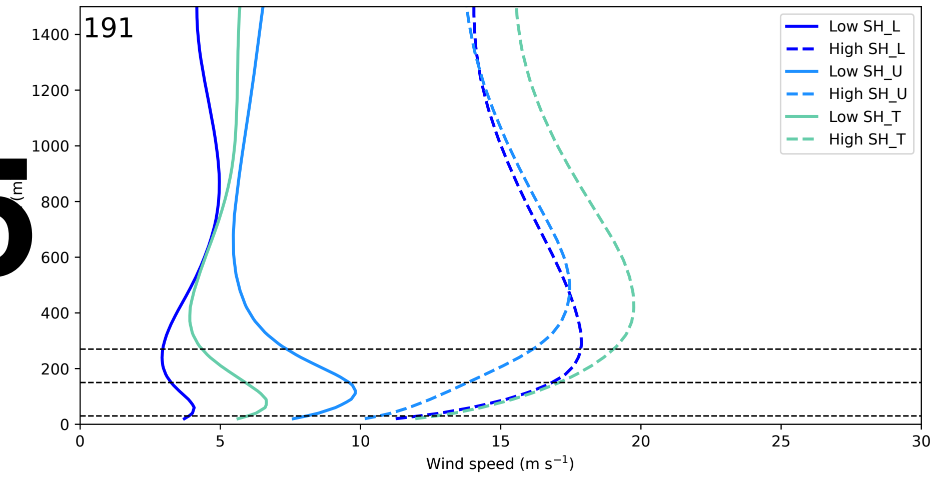

1 Mean frequency, height, speed

2 Monthly mean frequency, height, speed

3 LLJ height and speed variability

4 LLJ direction as a function of height and speed

5 Vertical wind shear around the IEA reference wind turbine (*Gaertner et al. 2020*)

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Future work

- Detect cases with only decreasing wind (negative wind shear)
- Extend the analysis to 3-hourly ERA5
- Validate the analysis with rawinsonde data
- Origin of the low-level jet

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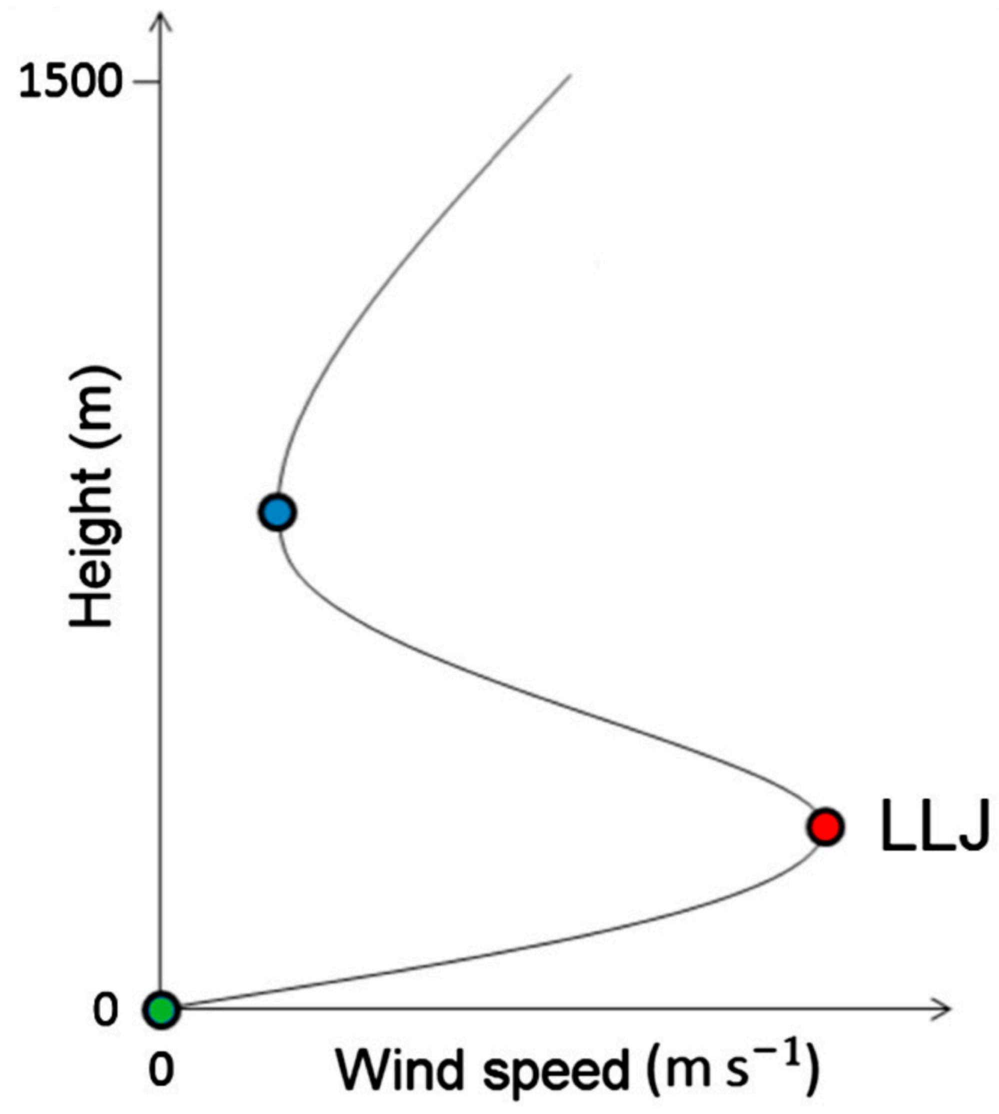
Thank you for your attention !

Additional slide

Detection of low-level jets

Following the method of *Tuononen et al. (2015)*:

- Absolute criterion: wind speed maximum at least 2 m s^{-1} stronger than the two surrounding minima
- Relative criterion: wind speed maximum at least 25% stronger than the two surrounding minima
- Jets below 1500 m
- If multiple, lowest jet selected
- Differences: 1) Lowest model level as surface, 2) if no local minimum above and/or below the jet, the lowest model level or the level 1500 m are considered as minima.
- Additions: 1) Polynomial fit (parabolic) around the maximum to define the height and speed, 2) Direction of the wind taken at the jet height on model levels



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