

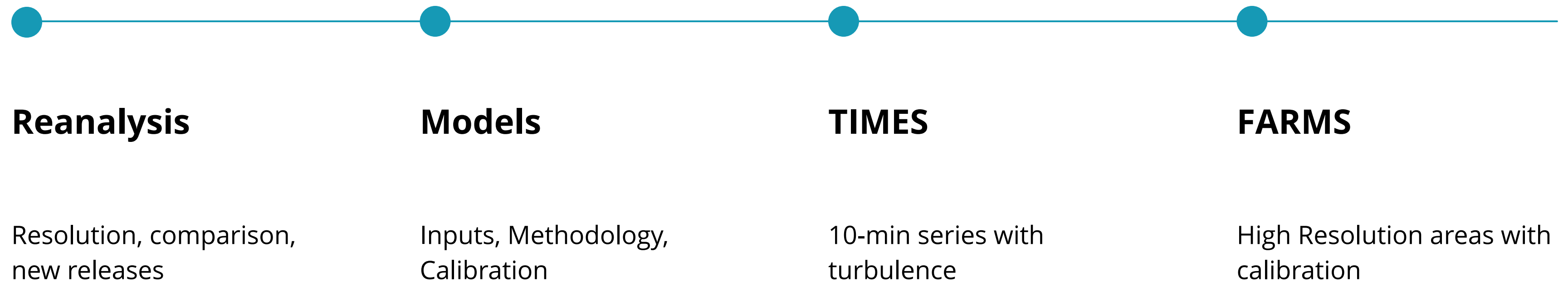
VORTEX TIMES + FARM

New Delhi, 6 Oct 2026

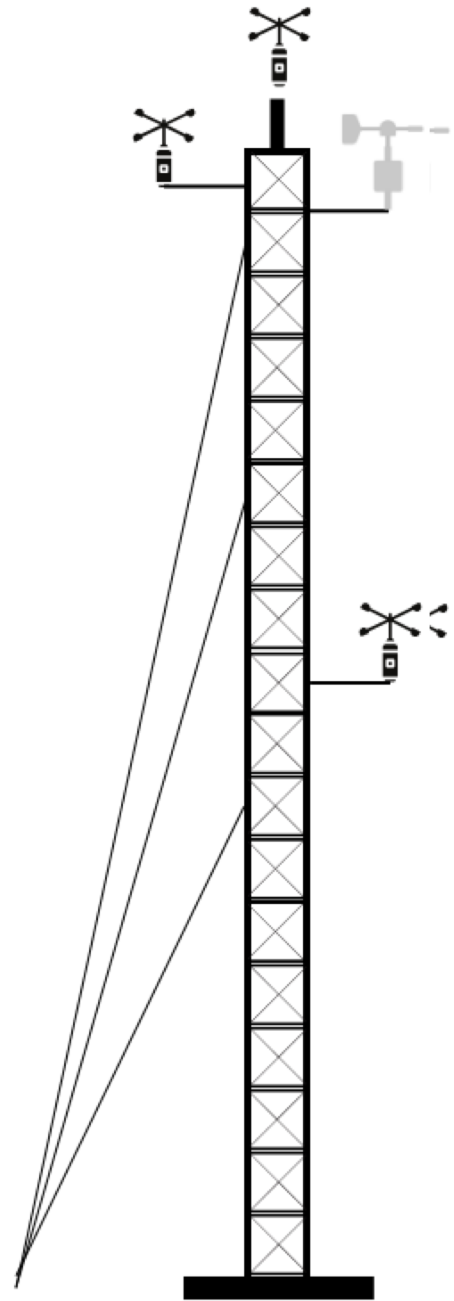
VORTEX TIMES + FARM

Chennai, 8 Oct 2026

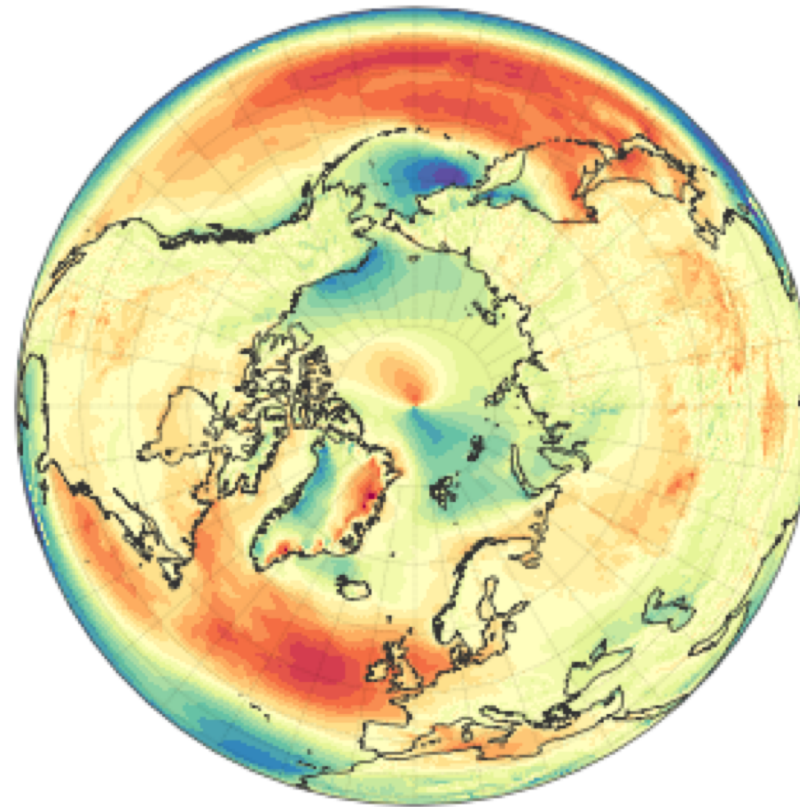
Outline



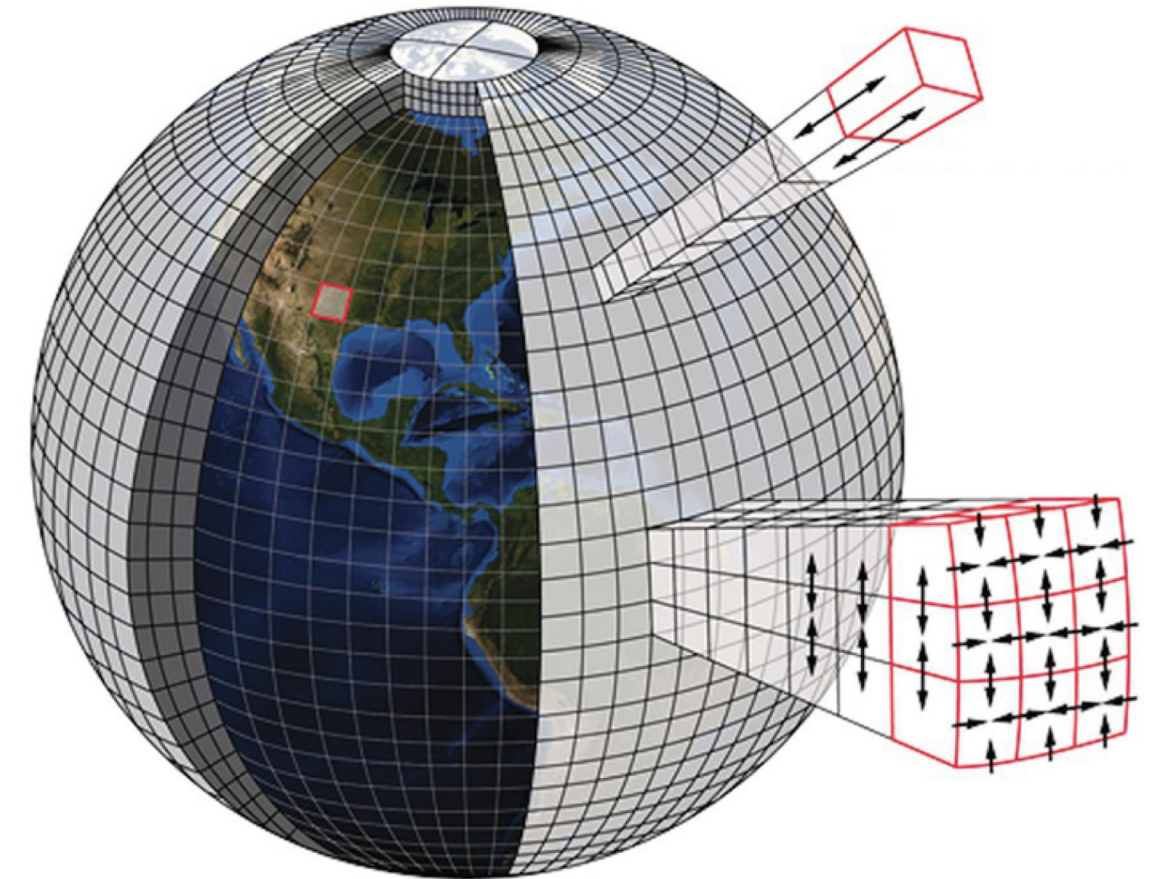
Estimating Wind



Measurements



Reanalysis



Models

Measurements



Accurate and characterizes local effects.



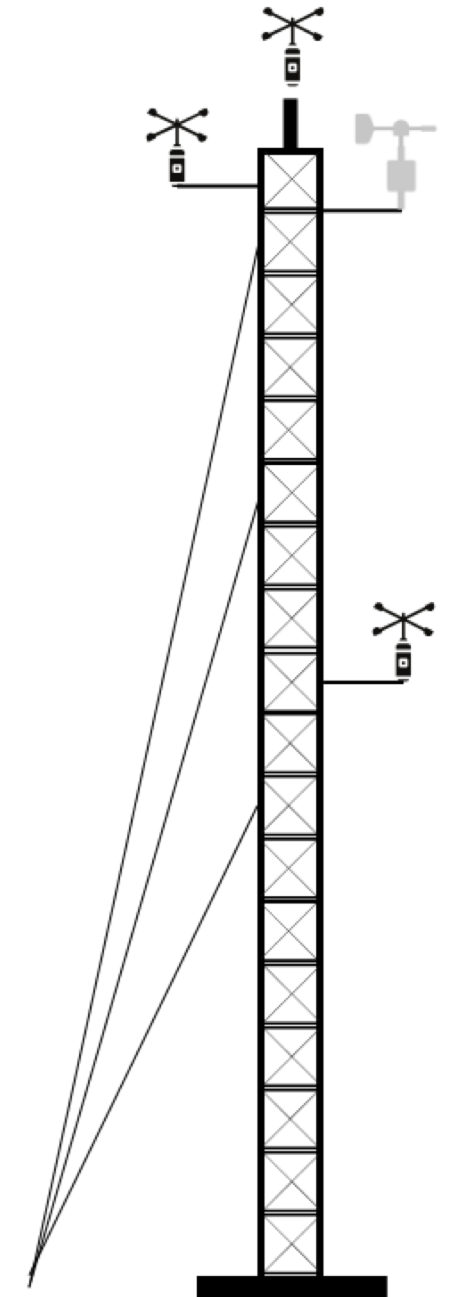
Multi-level meteorological towers and LIDARs estimate vertical profile.



Installation and maintenance is expensive



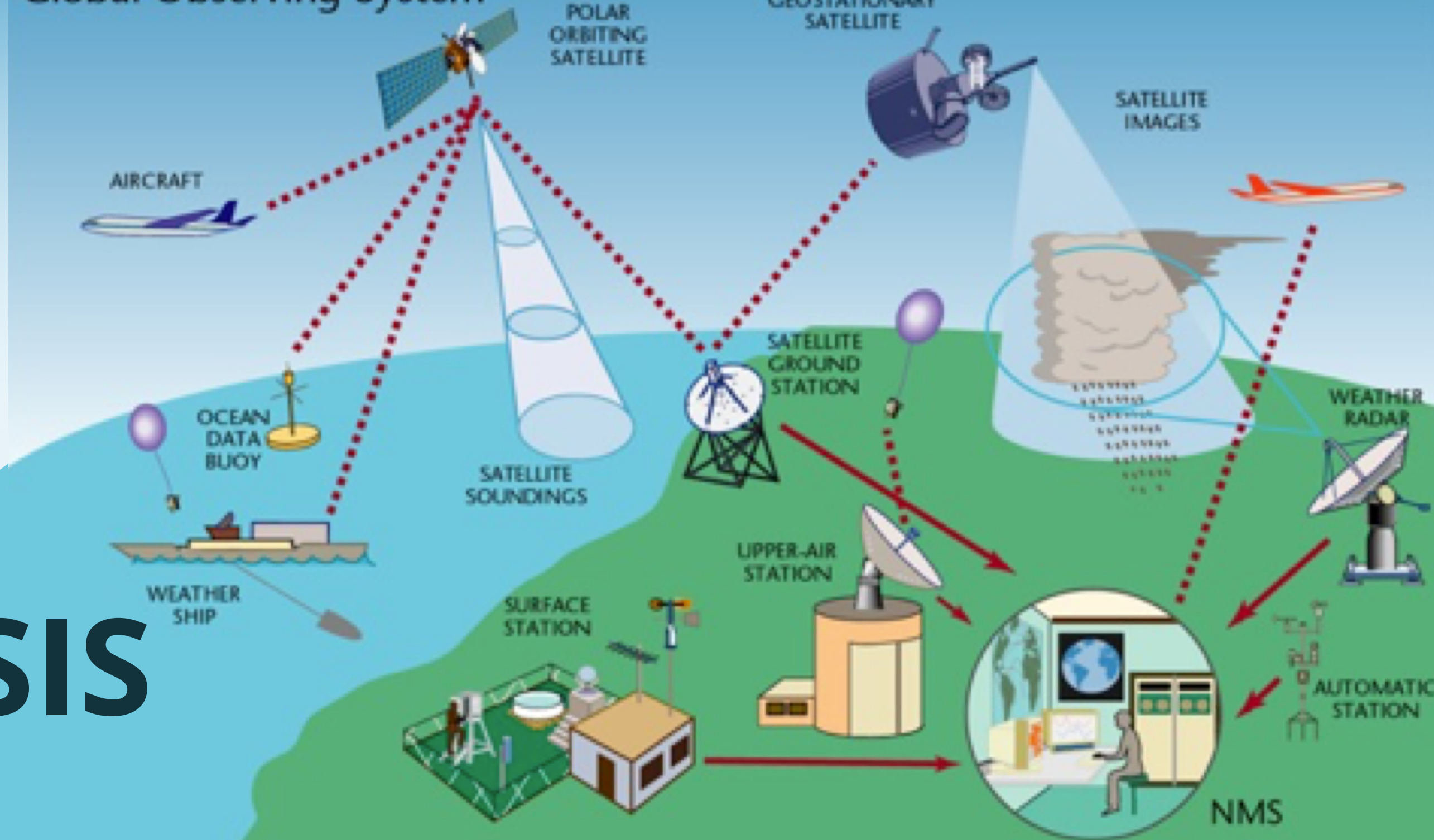
Long term datasets required



REANALYSIS

Observations are not evenly distributed around the globe

Global Observing System



METHODOLOGY

Back in time, there were fewer observations than in the present



MERRA2 Radiances by Instrument and Satellite

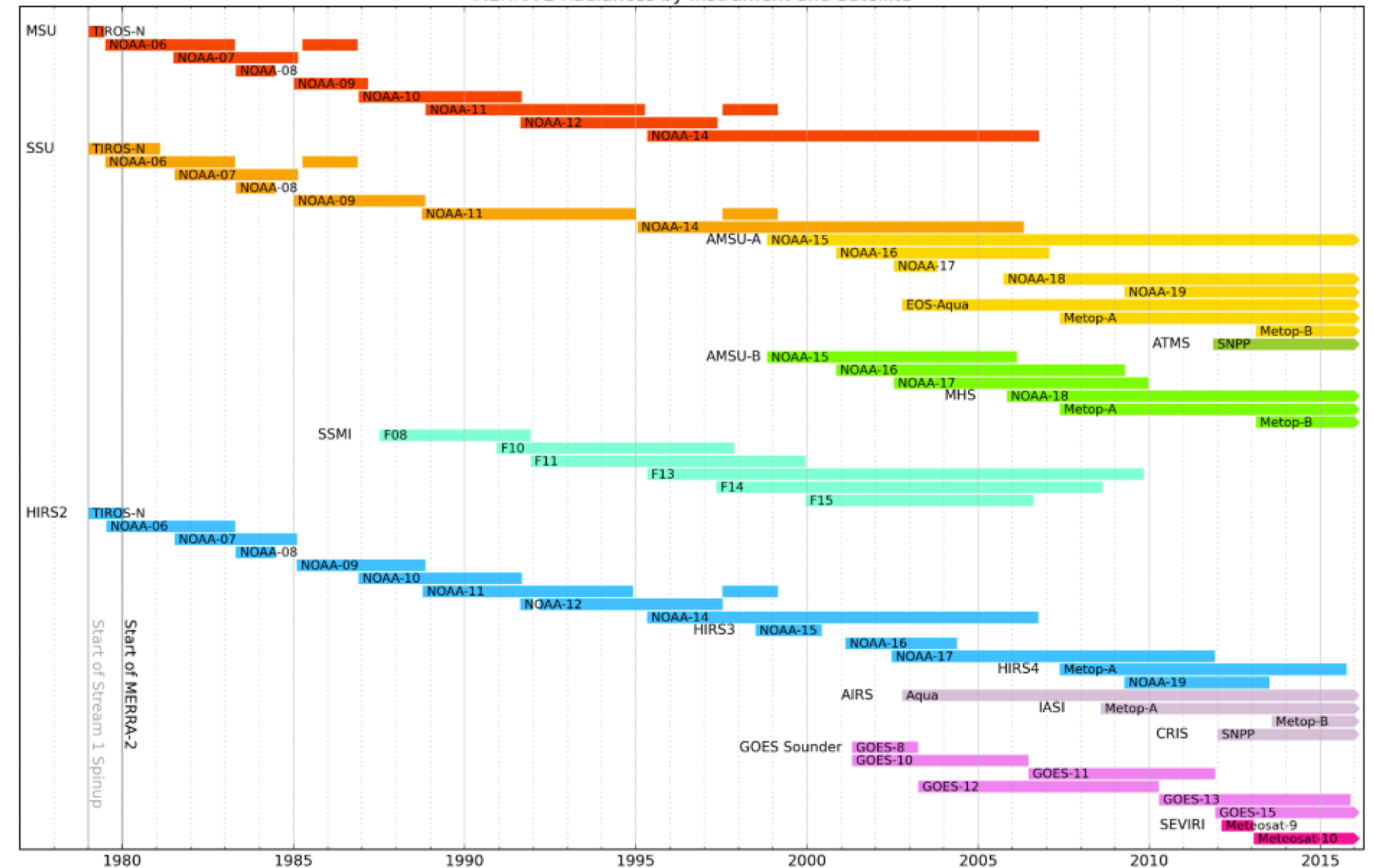


Image credit: NASA <https://gmao.gsfc.nasa.gov/pubs/docs/McCarty885.pdf>

METHODOLOGY

01

NWP model simulates the atmosphere

02

Observations are continuously assimilated

03

Assimilated observations correct the model prediction

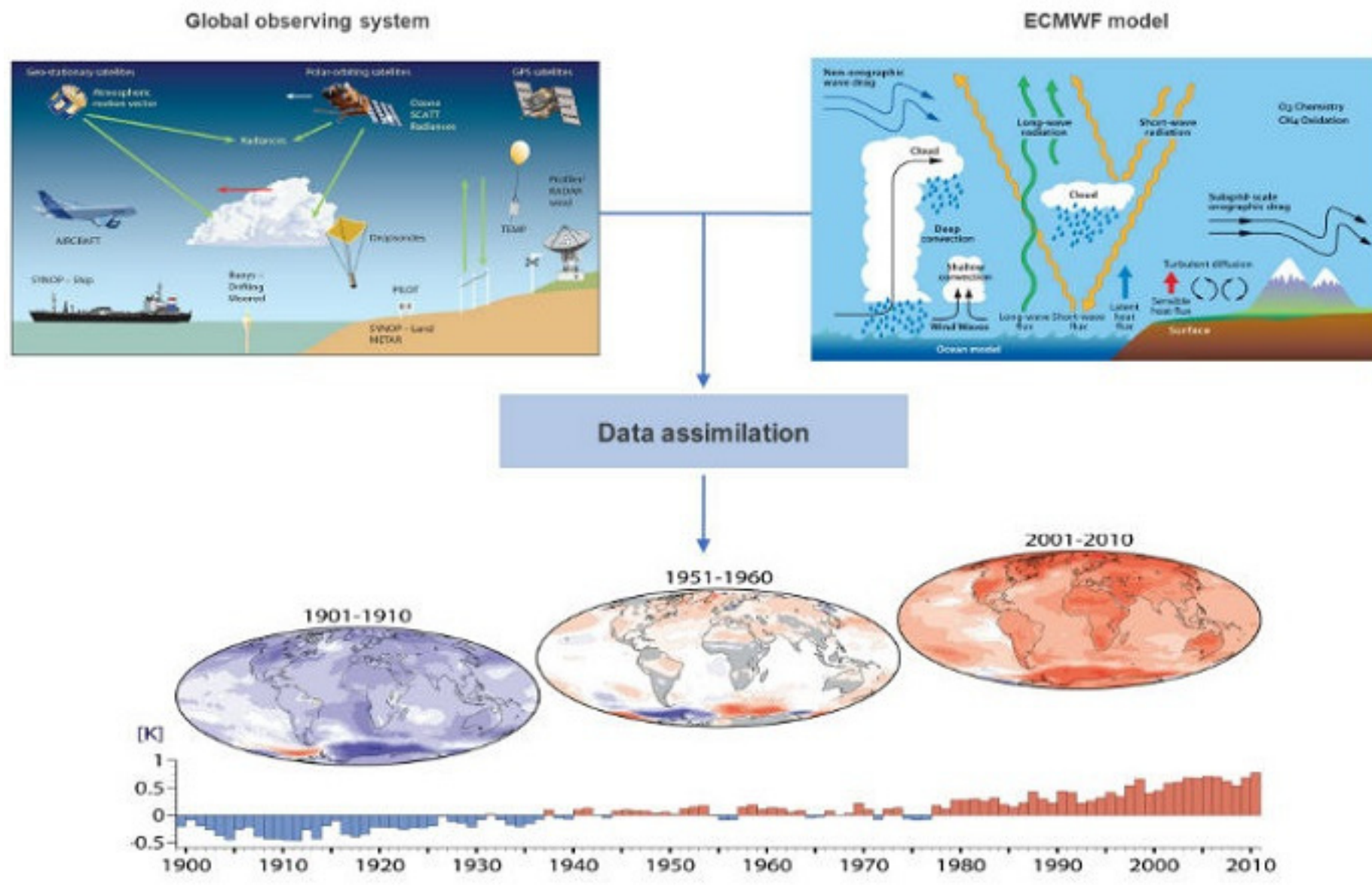
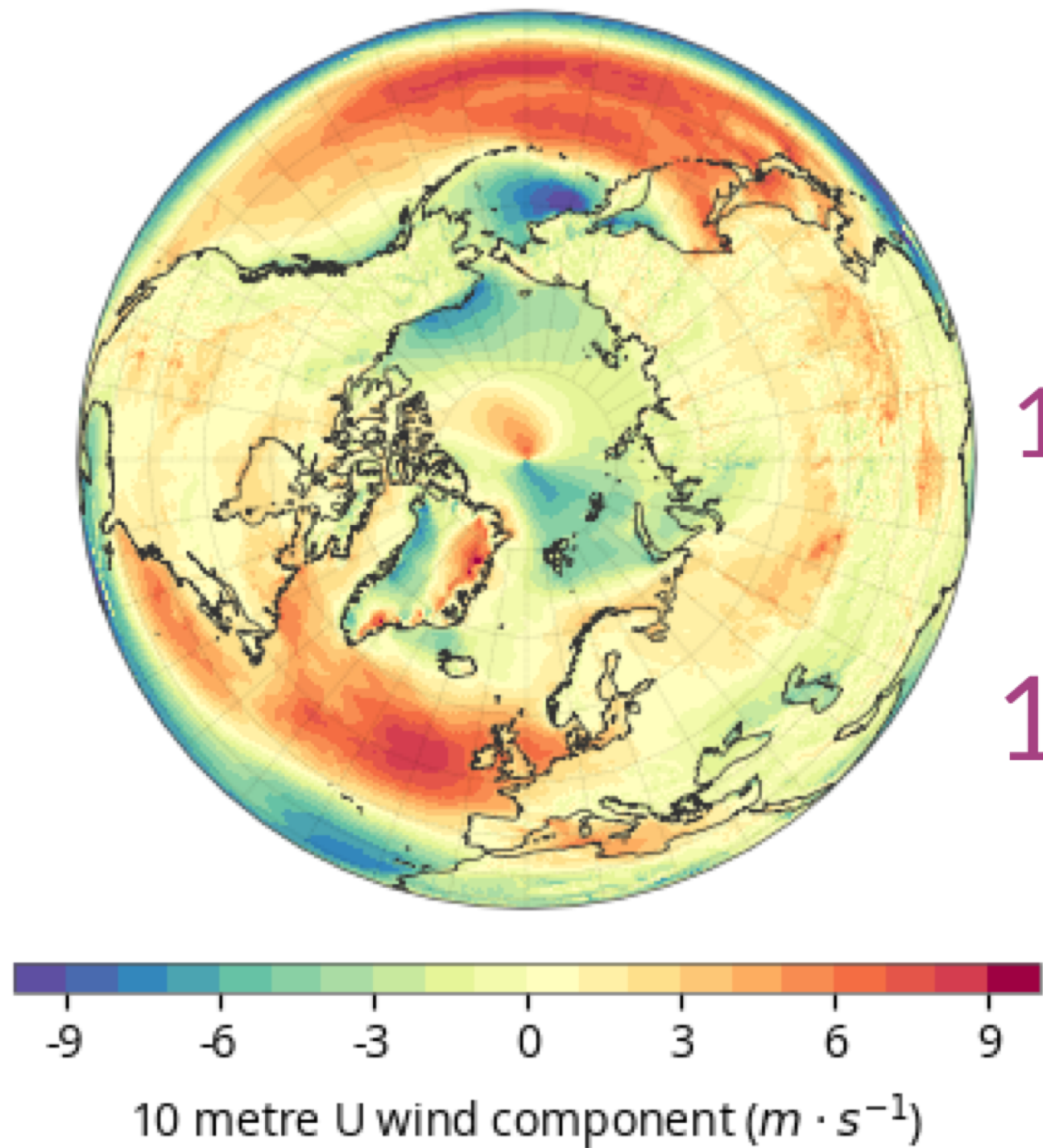


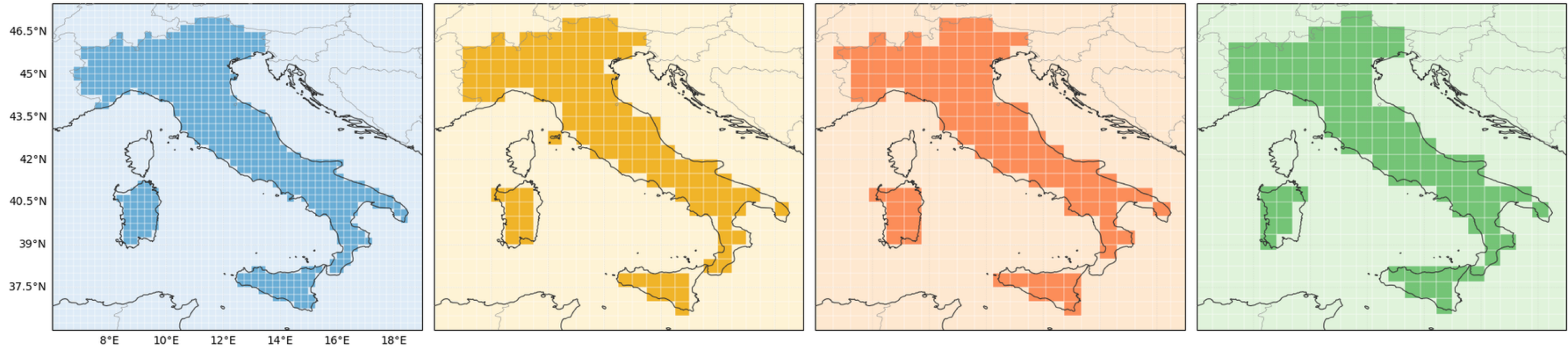
Image credit: Copernicus

REANALYSIS VARIABLES

[illegible]

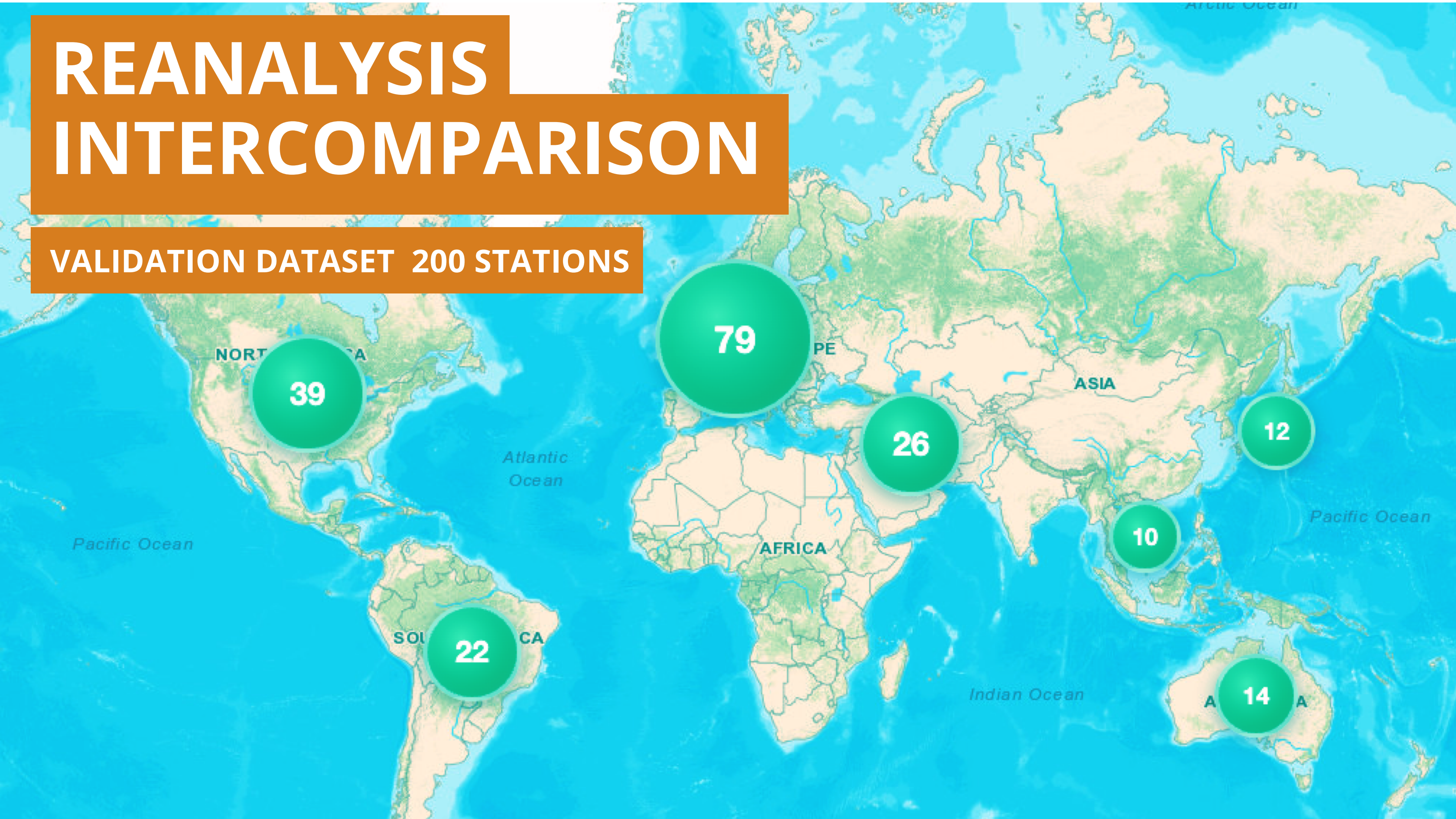
GLOBAL DATASETS

DATASET	ERA5	CFSR	MERRA2	JRA-3Q
INSTITUTION	ECMWF	NOAA	NASA	JMA
SINCE	1940	2011	1980	1947
SURFACE	10m, 100m	10m, 100m	10m, 50m	10m
TIME RES.	1h	6h	6h	6h
SPATIAL RES.	0.25°x0.25°	0.5°x0.5°	0.5°x0.625°	0.5625°x0.5625°



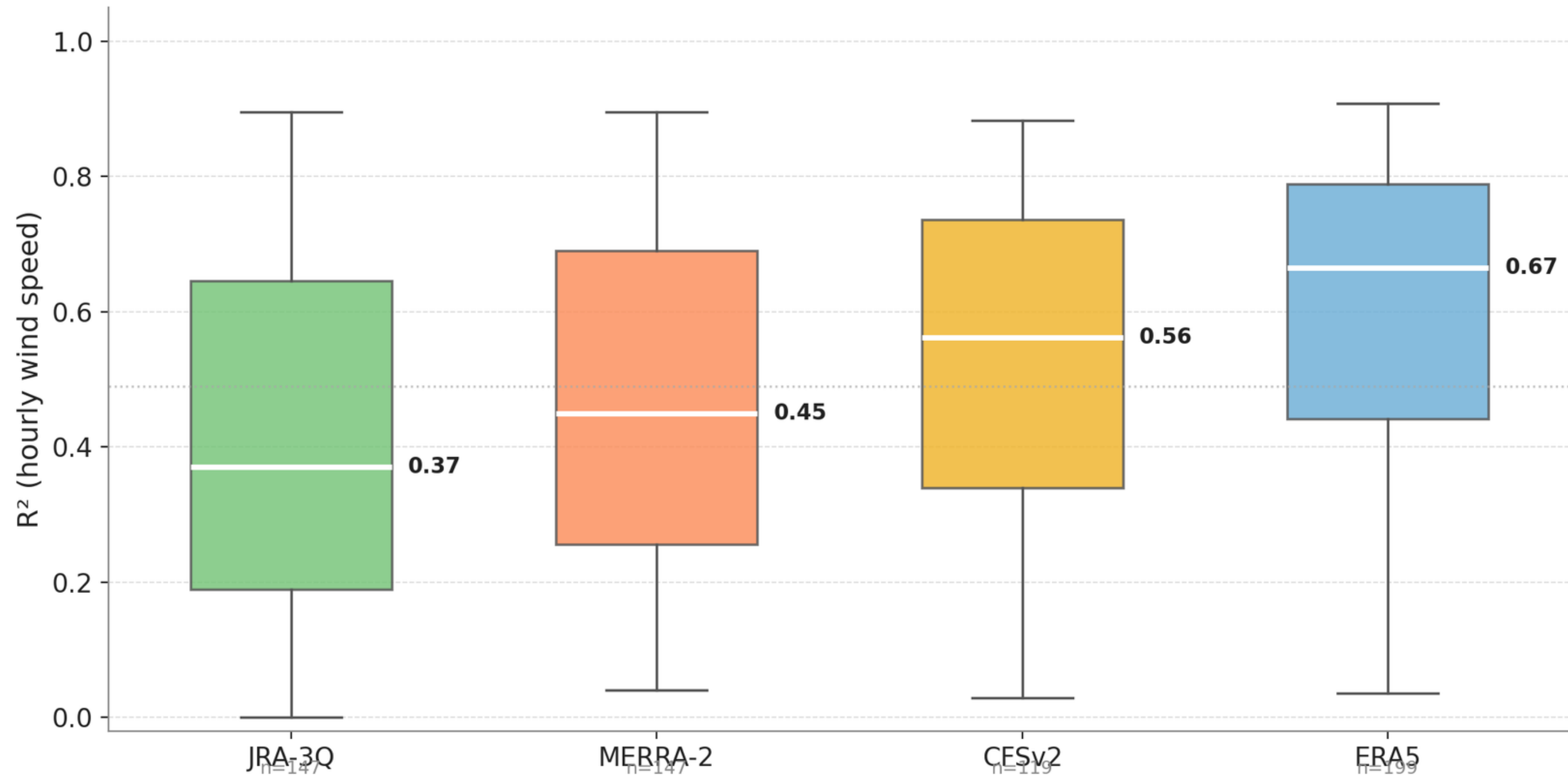
REANALYSIS INTERCOMPARISON

VALIDATION DATASET 200 STATIONS



REANALYSIS COMPARISON

Global — all stations (n=201)
 R^2 of hourly wind speed vs met-mast observations



ERA6 REANALYSIS

- Expected end of 2027
- Two test batches released:
 - June to August 2022 (3 months)
 - Oct 2019 to April 2020 (7 months)

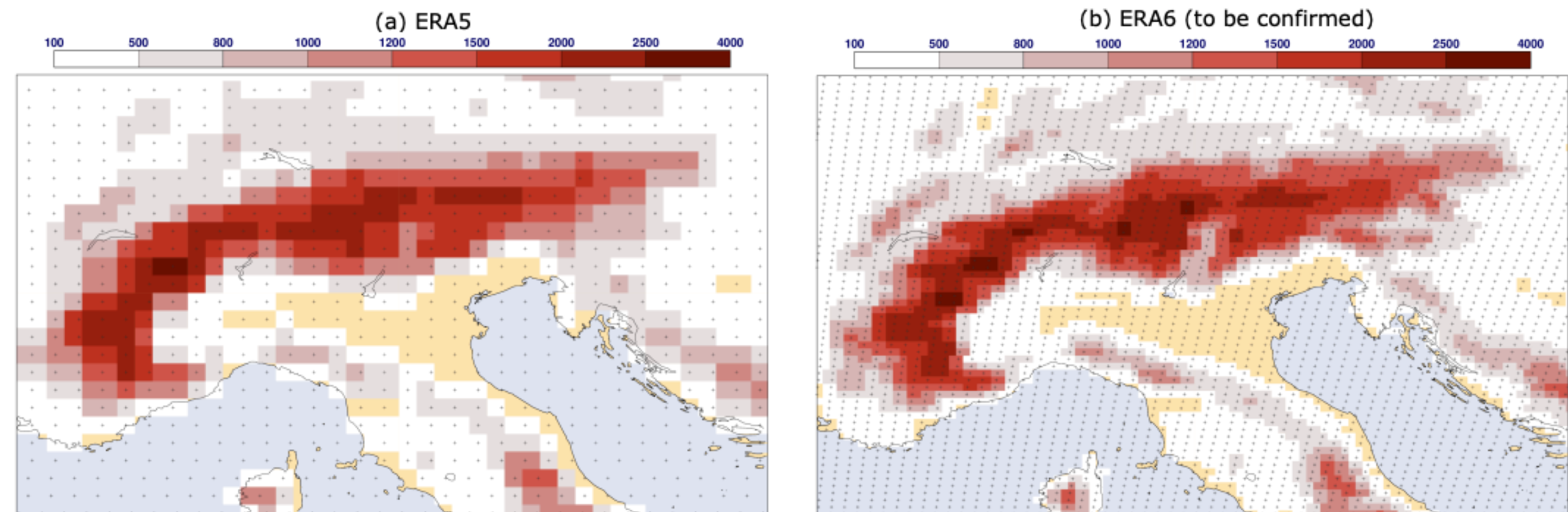
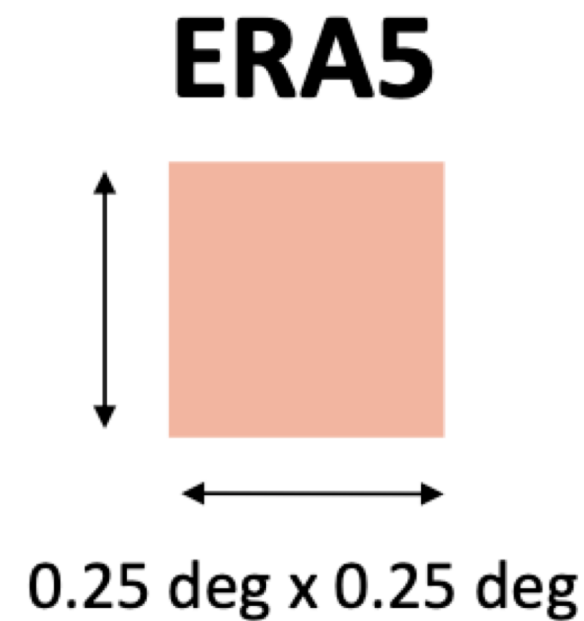
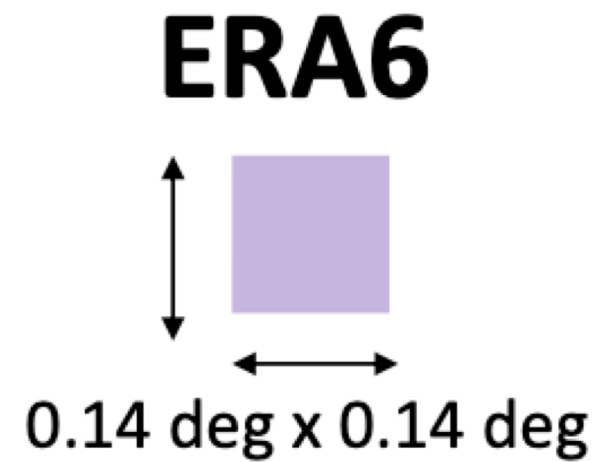
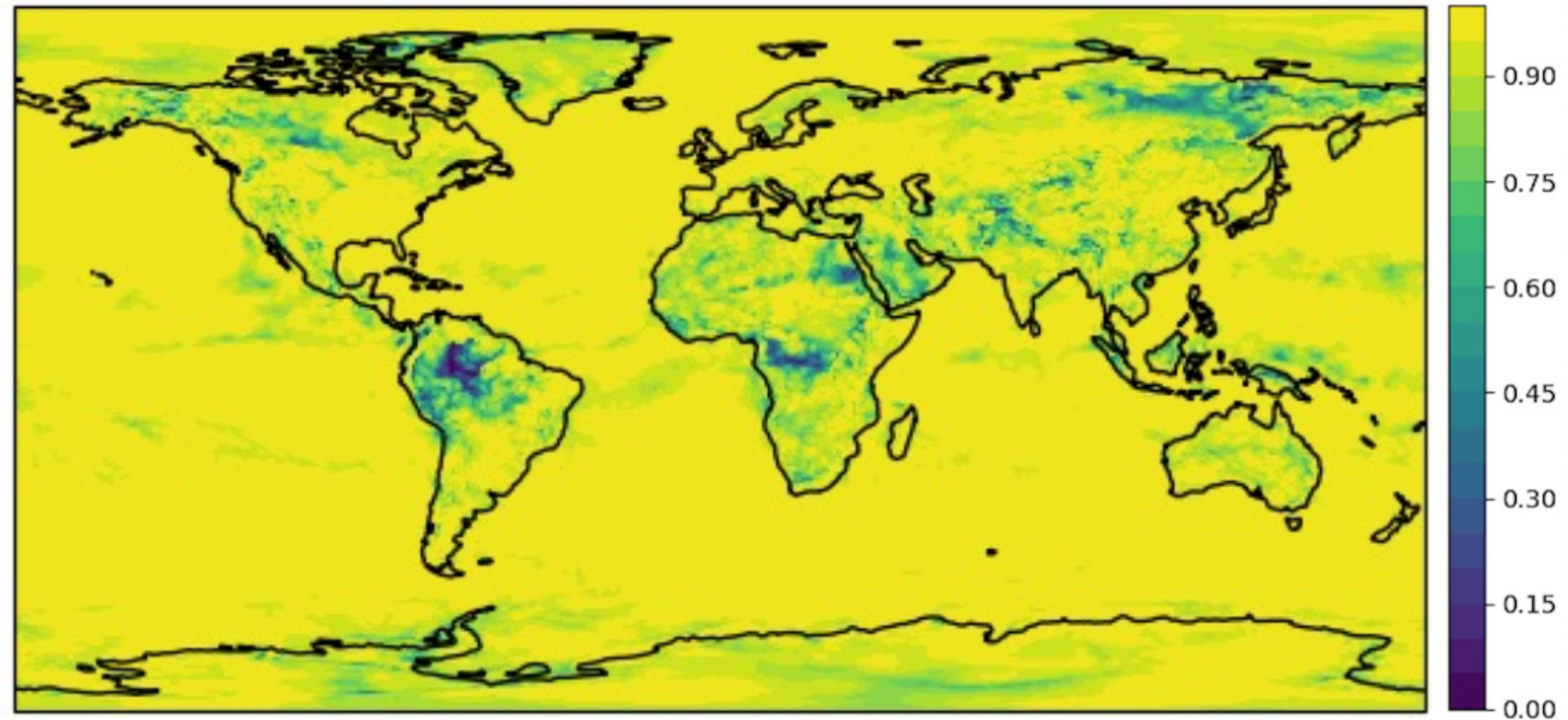
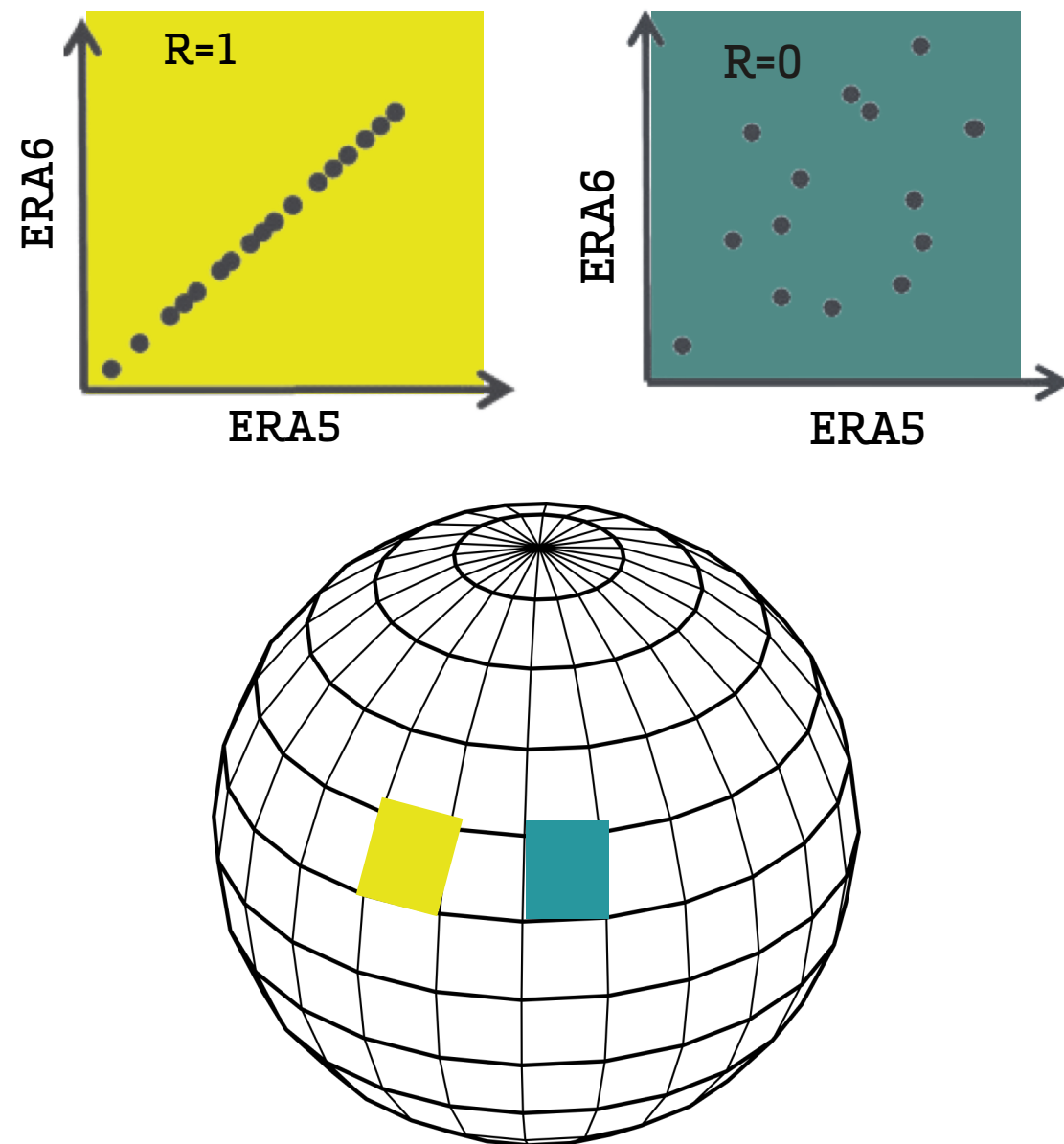


Image credit: European Center for Medium-Range Weather Forecast
(ECMWF))

ERA6 vs ERA5 COMPARISON



R^2 correlation between ERA5 and ERA6 surface daily averages



REANALYSIS FEATURES

Global coverage including remote regions and oceans

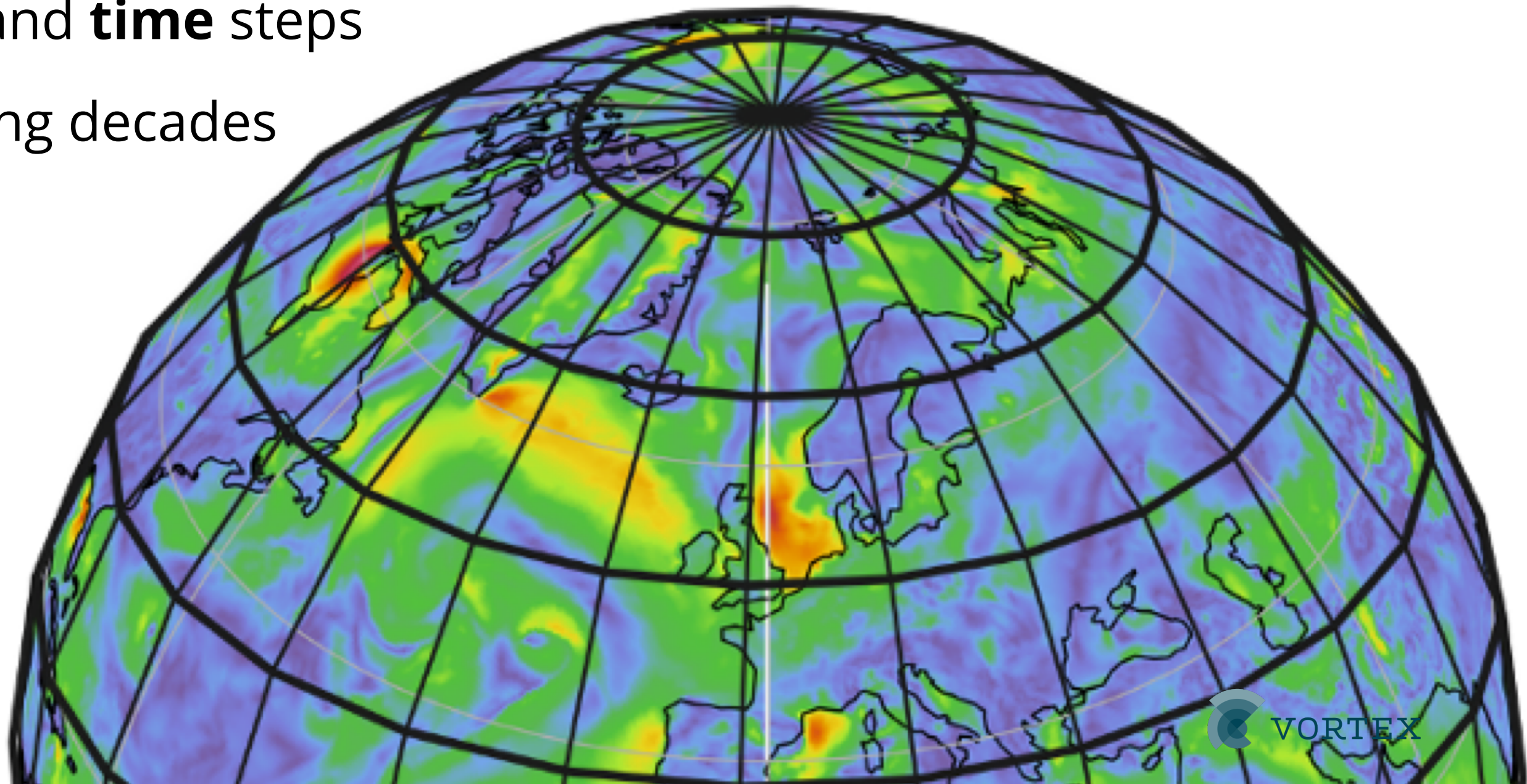
Available at different **heights** and **time** steps

Consistent **time series** spanning decades



Low Resolution

Limited for local effects

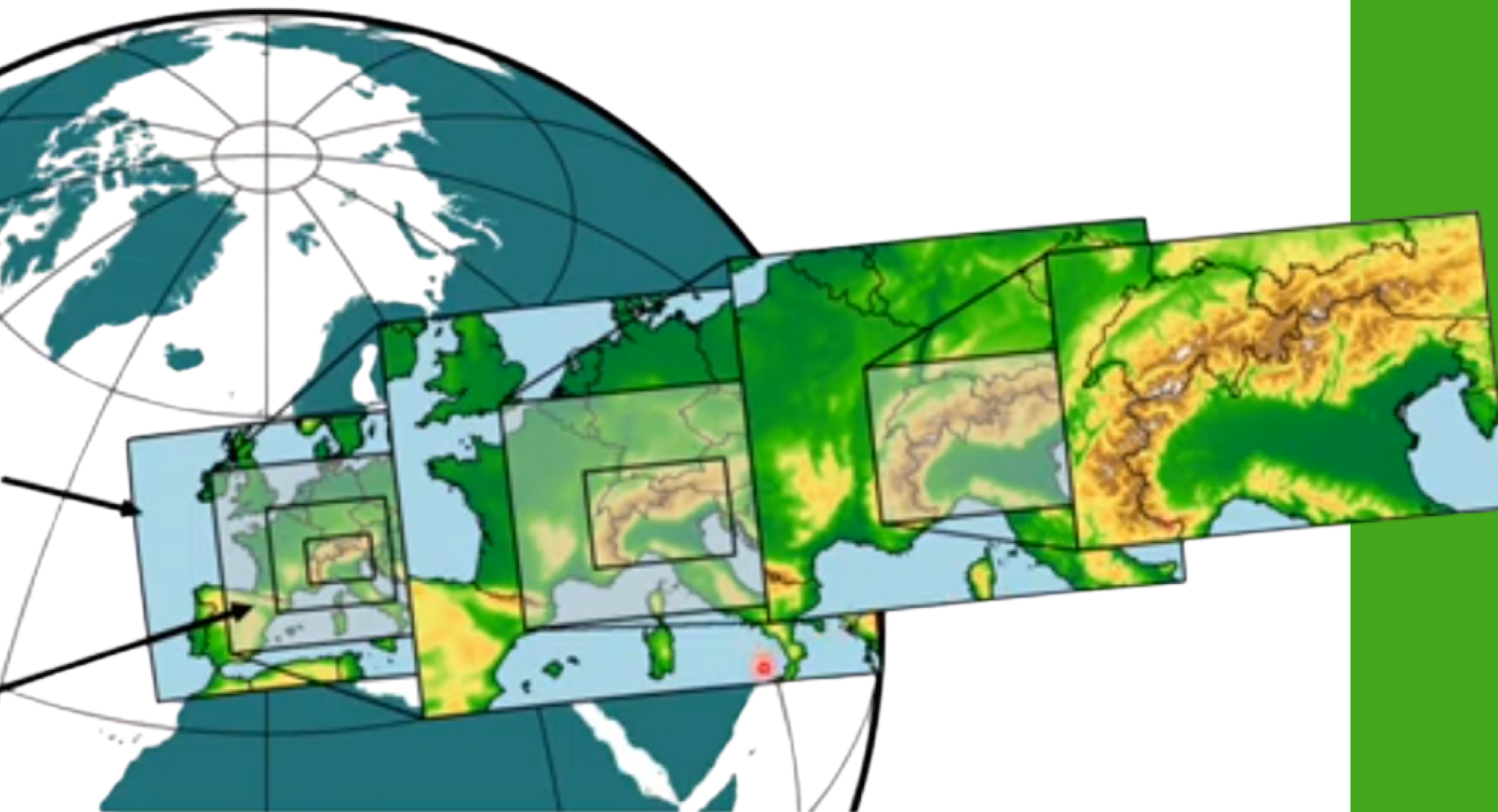


NUMERICAL WEATHER PREDICTION MODELS

Models solve **dynamically** the equations of the atmosphere

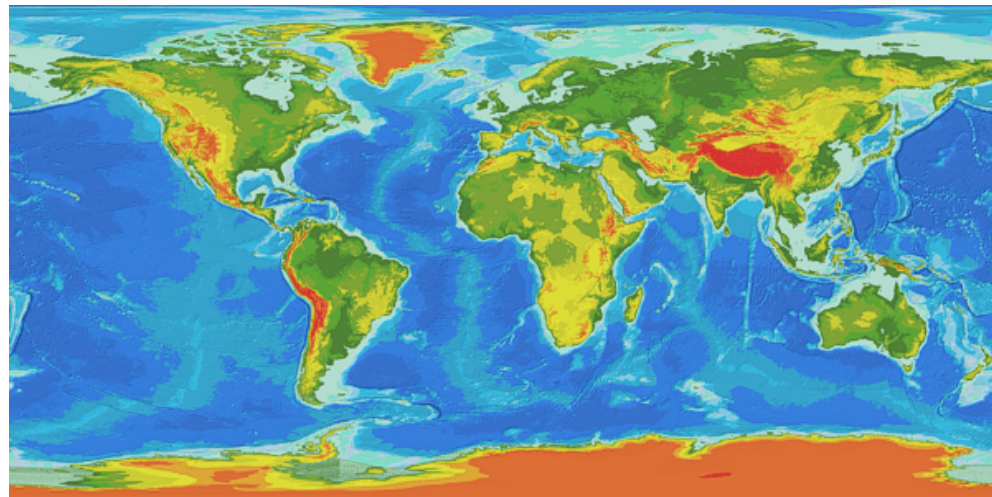
Models allow to obtain **high resolution** data (100m)

Outputs spanning **decades** and covering **large** areas



WRF MODEL INPUTS

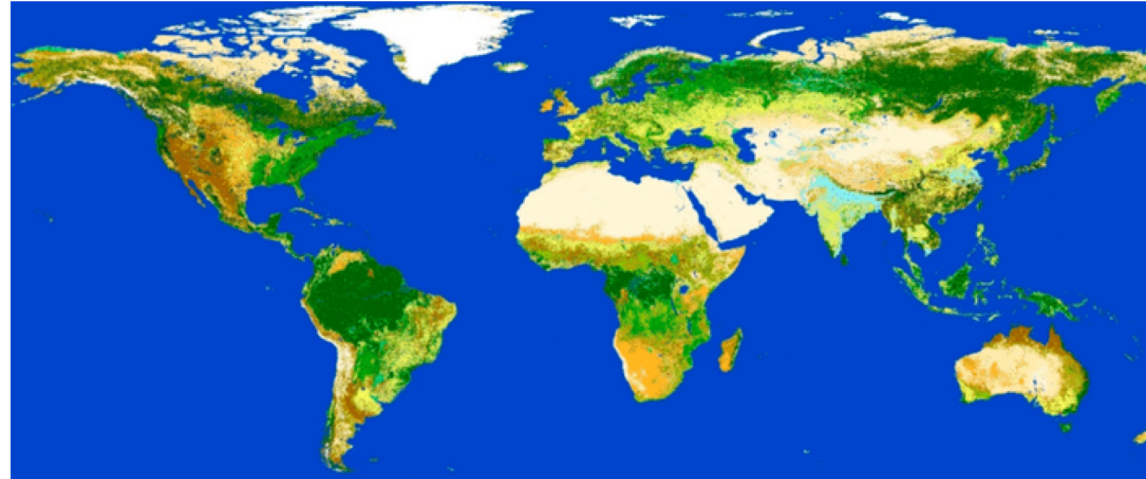
1



Topography

SRTM by NASA
90m resolution

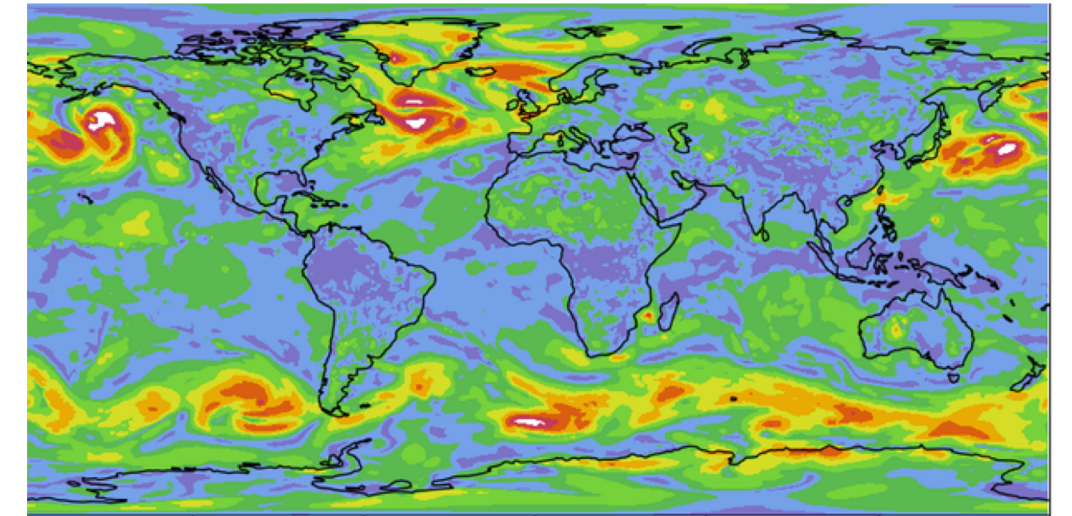
2



Land Use

GlobCover by ESA
22 different classes
300m resolution

3

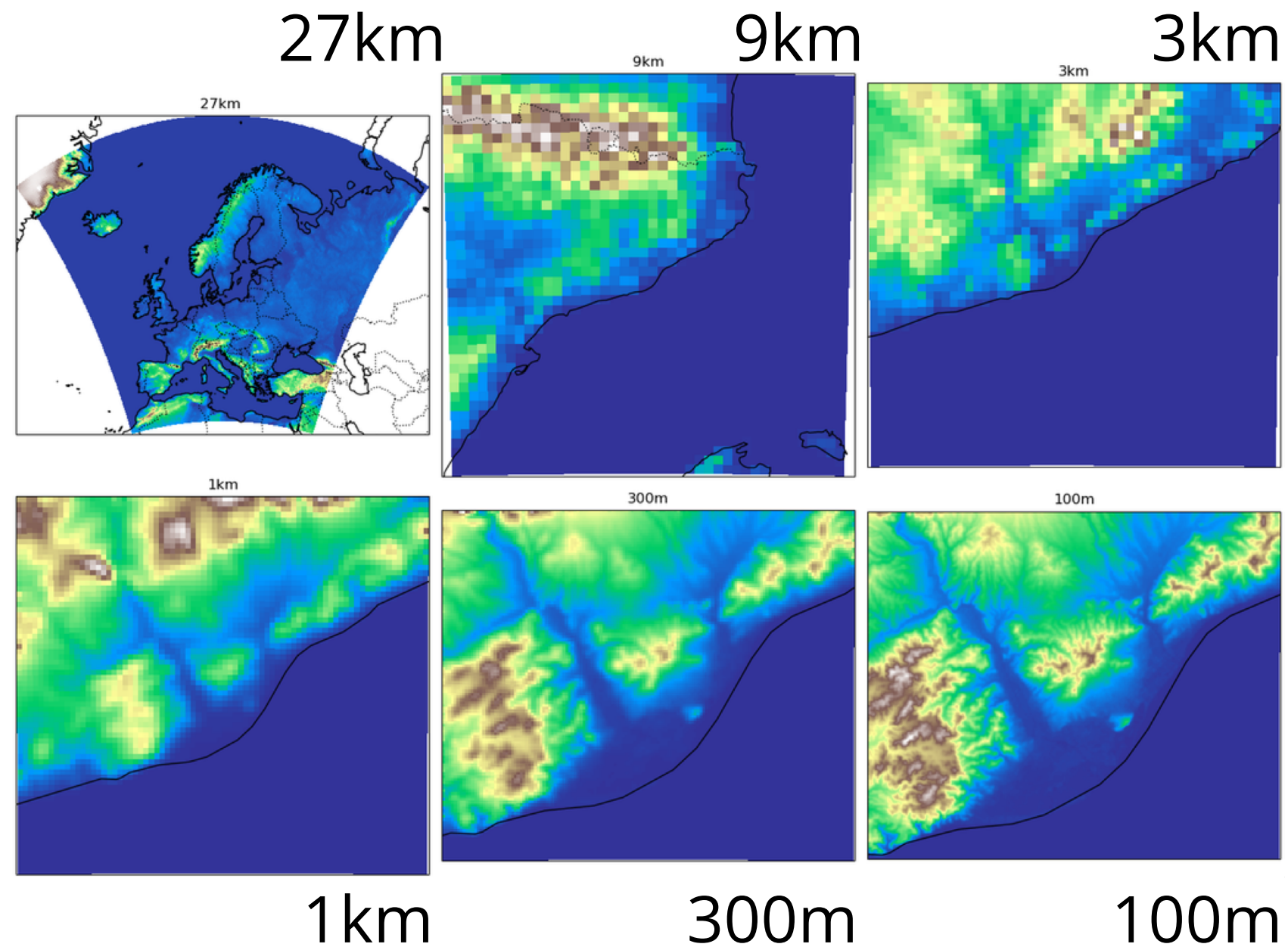


Reanalysis

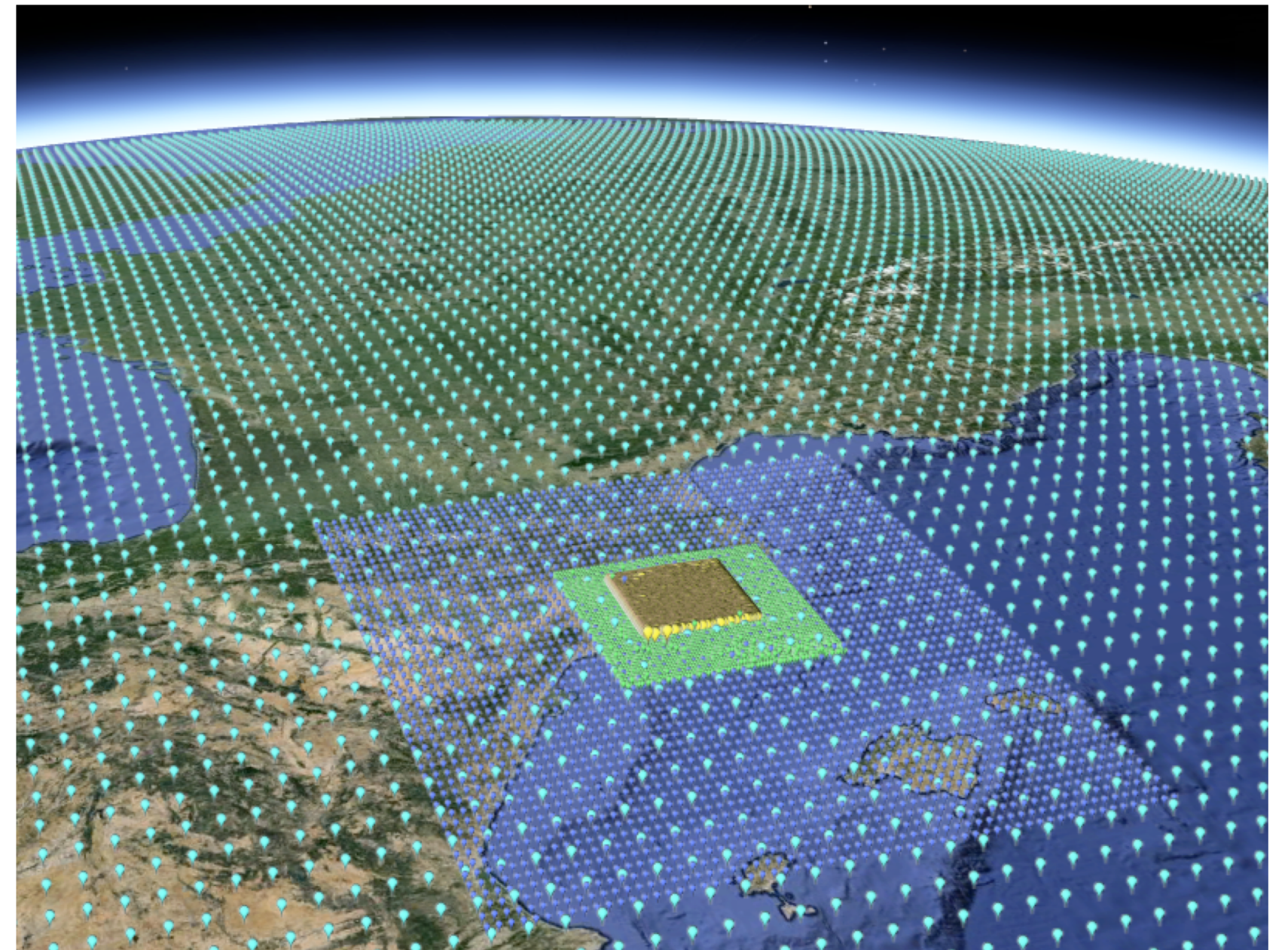
ERA5: $0.25^\circ \times 0.25^\circ$, 37 levels, hourly
MERRA2: $0.625^\circ \times 0.5^\circ$, 42 levels, 6h
CFSR: $0.5^\circ \times 0.5^\circ$, 37 levels, 6h

WRF MODEL METHODOLOGY

3:1 nesting ratio



Dynamical downscaling not interpolation



MESOSCALE

- 1 - 3 km resolution
- Simulates storms, Sea/land breezes
- Turbulence is parametrized in the PBL scheme

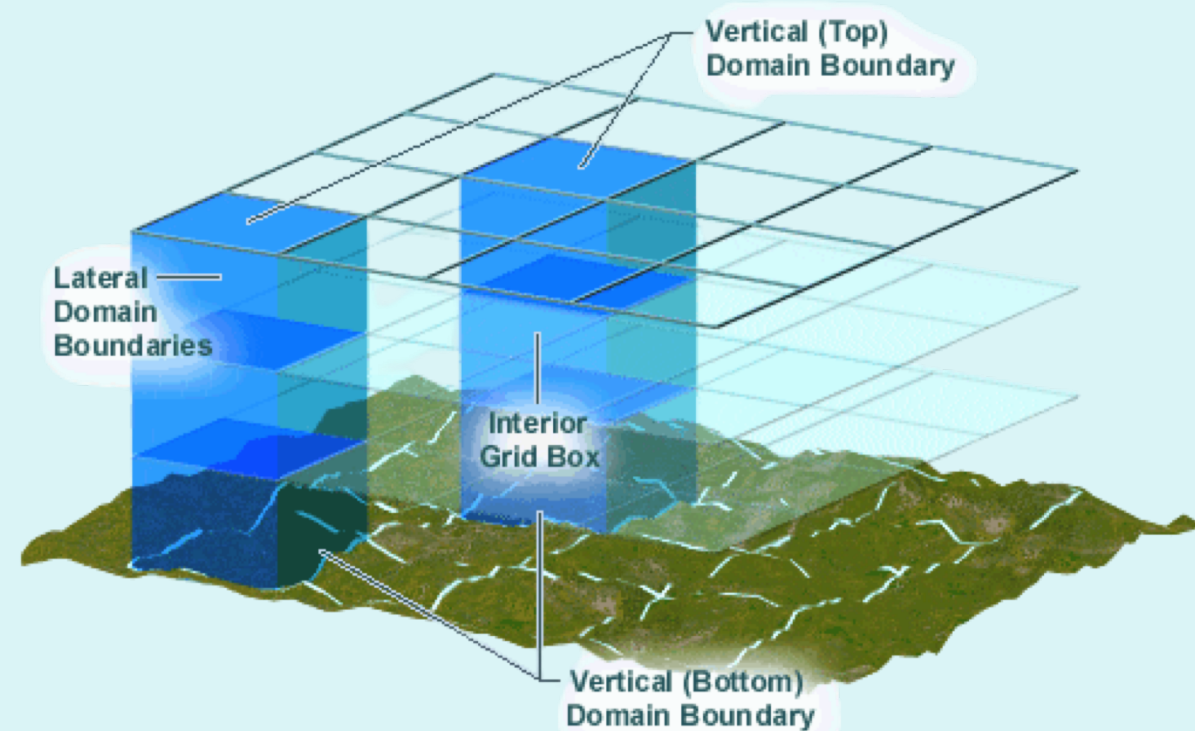
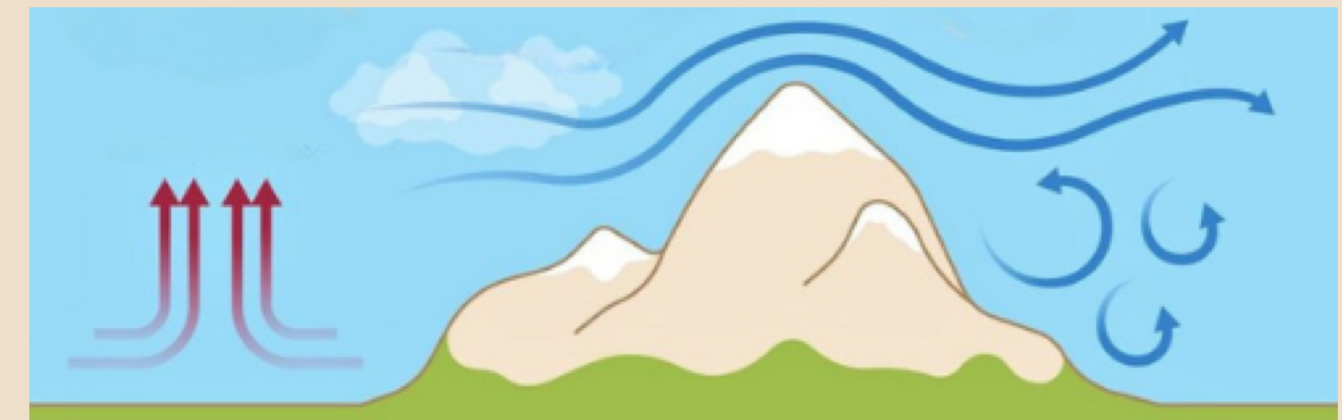


Image credit: University Corporation for Atmospheric Research (UCAR)

MICROSCALE

- 100 - 300 m resolution
- Turbulence is explicitly solved using LES
- Subgrid eddies are parametrized

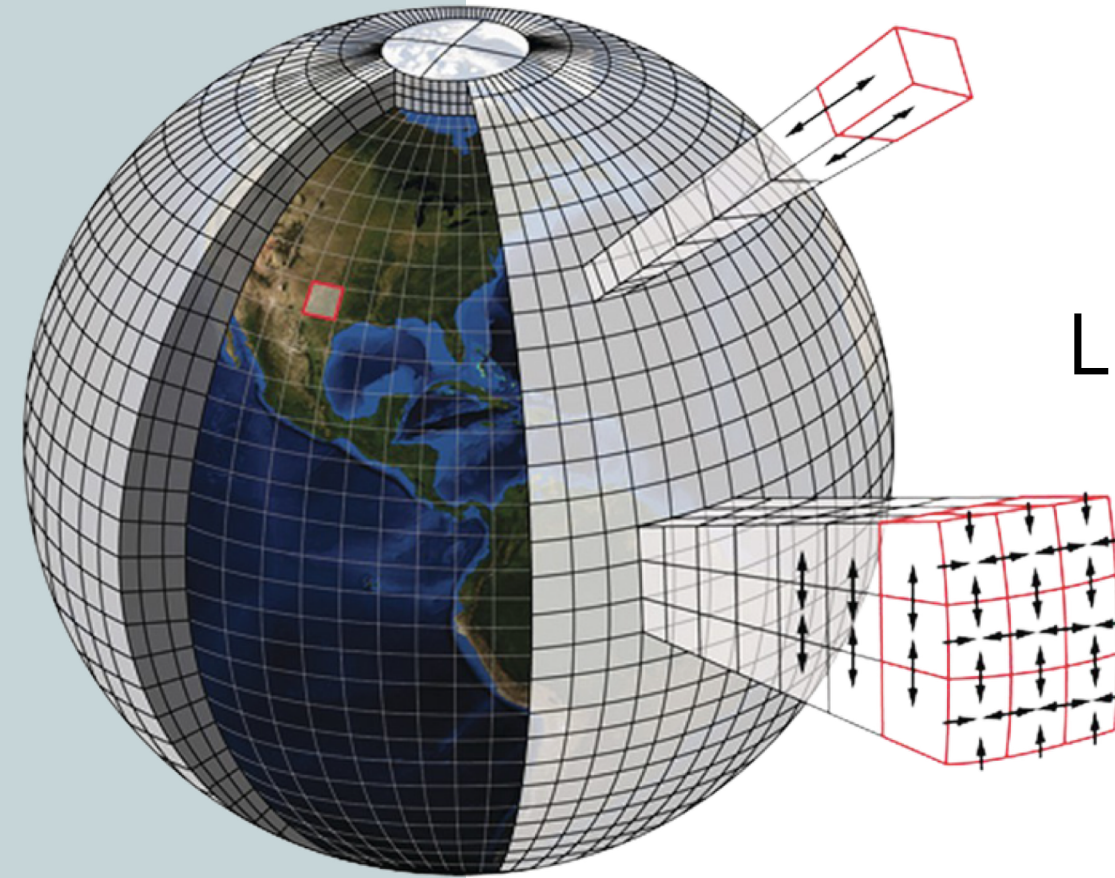


Thermal and mechanical turbulence. **Image credit:** Shutterstock

NWP MODELS



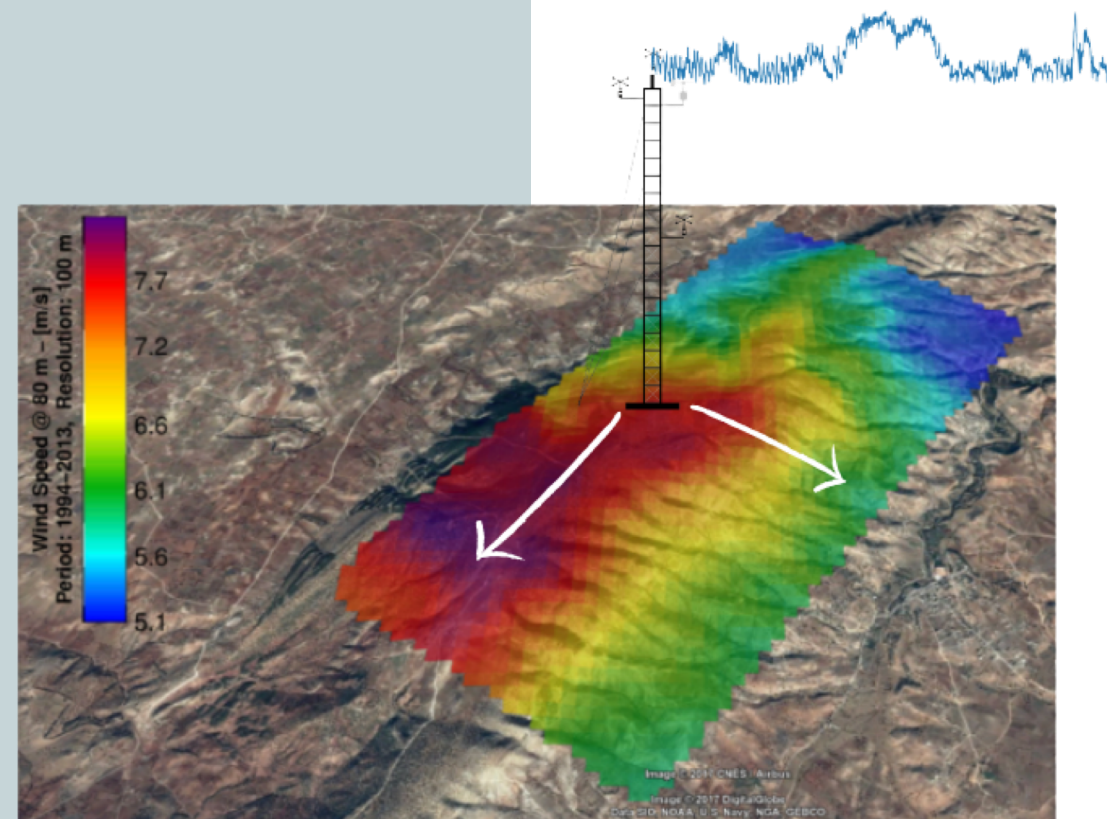
- High resolution
- Local effects represented
- Long term datasets



Low accuracy in complex sites?

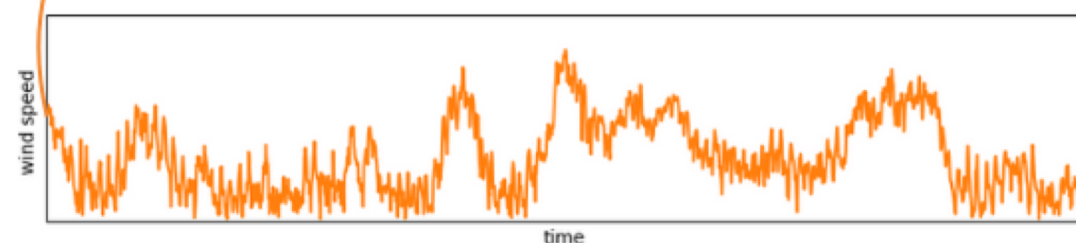
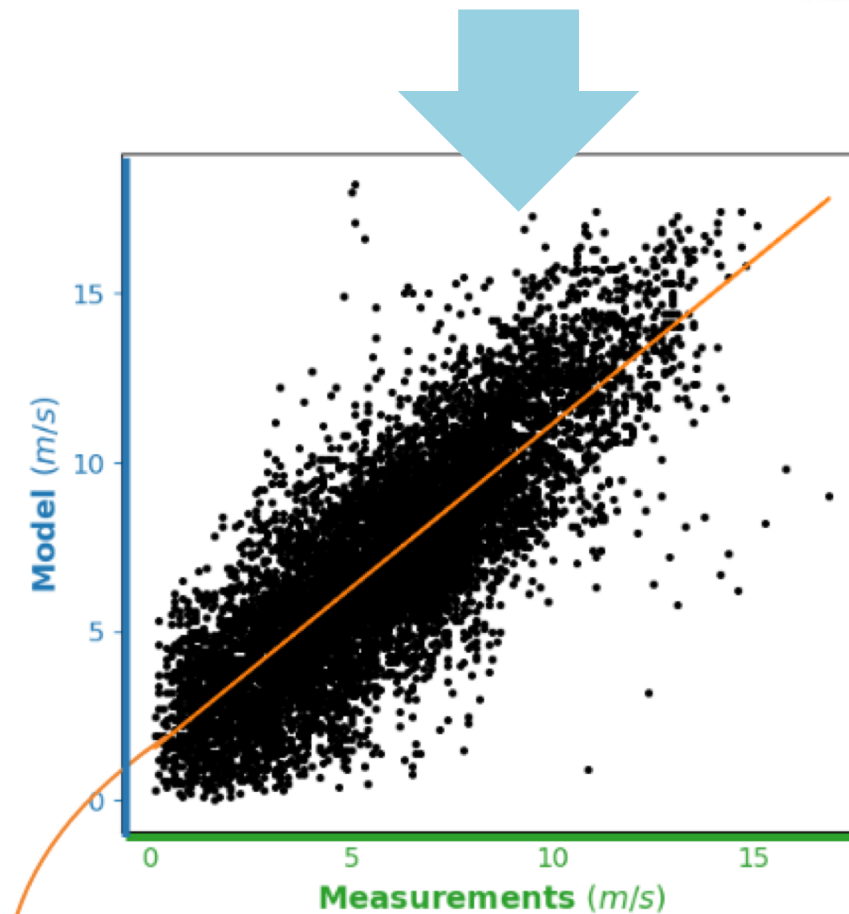
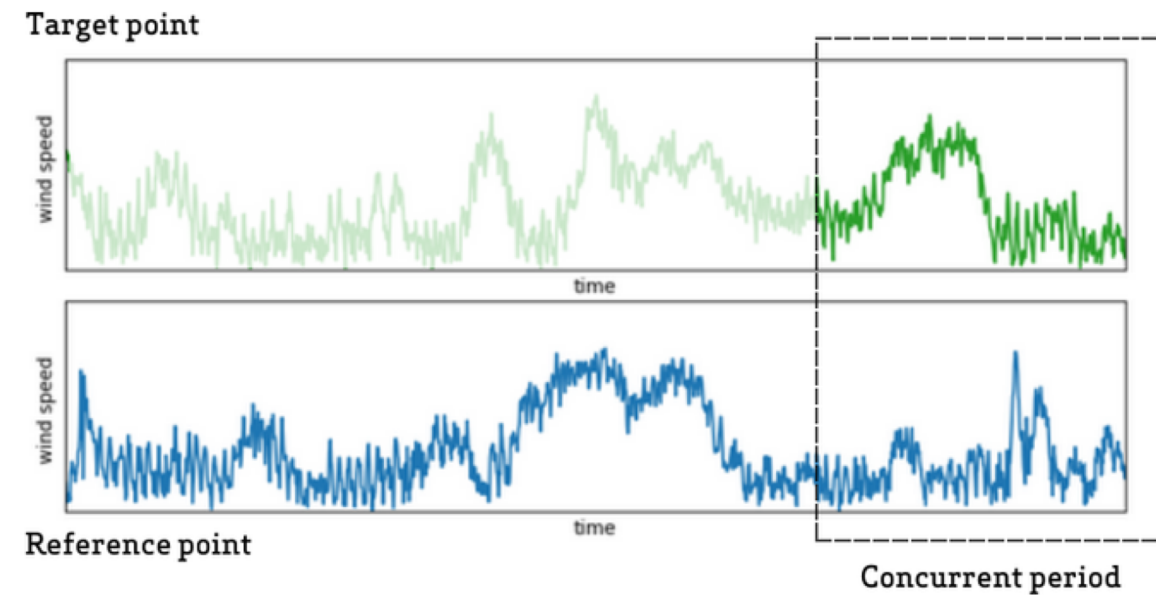


Calibration with measurements



Higher accuracy

Measure, Correlate, Predict



01

MCP does not correct wind rose

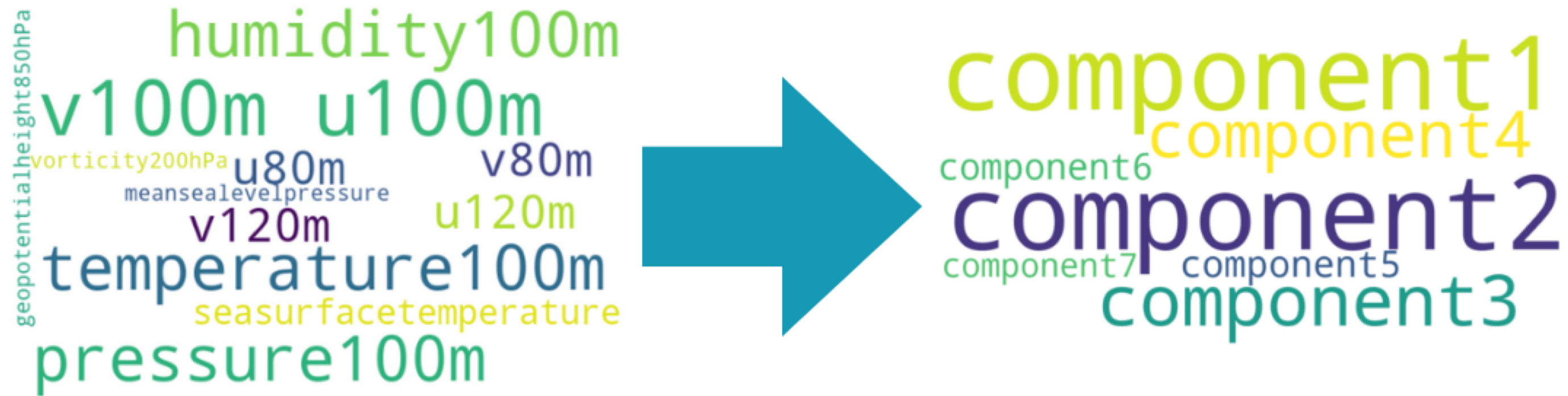
02

Metrics degrade out of training

03

MCP does not improves all parameters

VORTEX CALIBRATION



Non-linear Principal Component Analysis

1

Corrects the Wind Rose

2

Reduces out of training
degradation

3

Improves all attributes
(M, A and K weibull)

VORTEX MICROSCALE



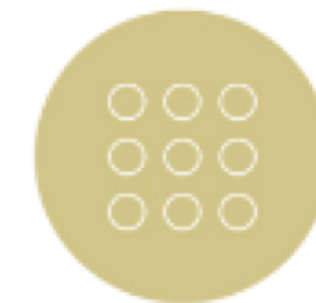
TIMES

- 300m high resolution
- 10-min up to 30-years
- Any height between 10 - 300m
- Turbulence
- Extremes and vref reports

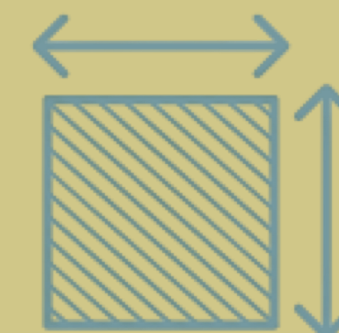


FOR A POINT?

FARM

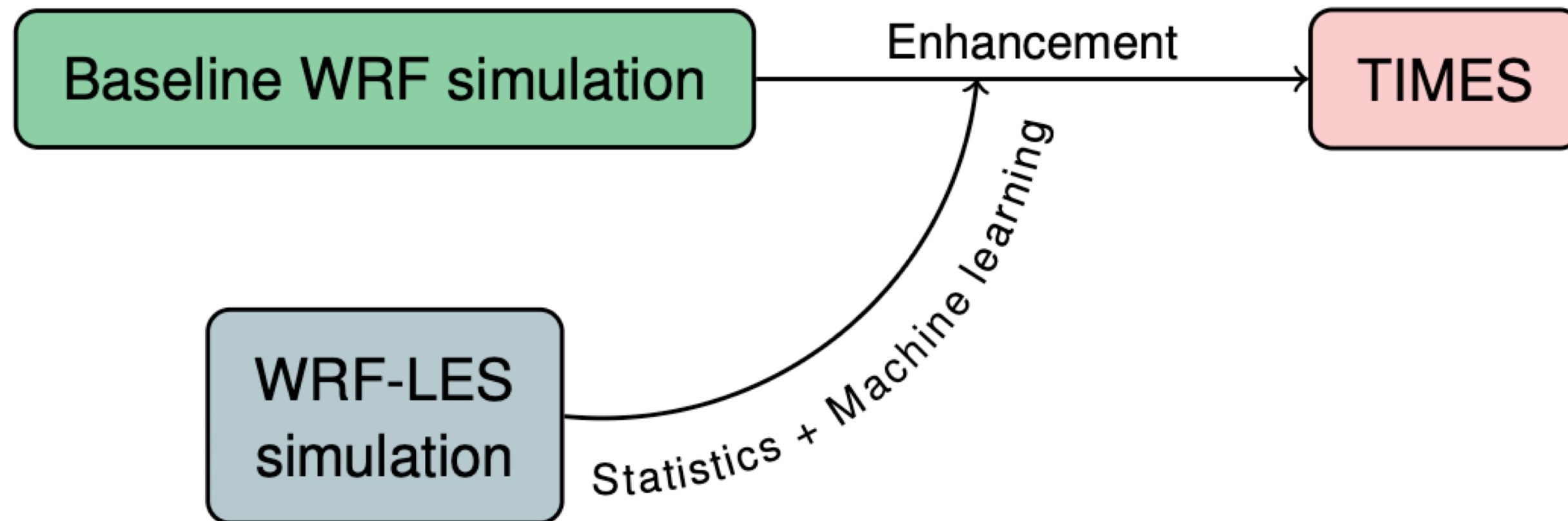


- Up to 4000km²
- 100m high resolution
- Layers and TAB 30 - 300m
- Turbulence
- Extremes and vref reports



FOR AN AREA?

VORTEX TIMES



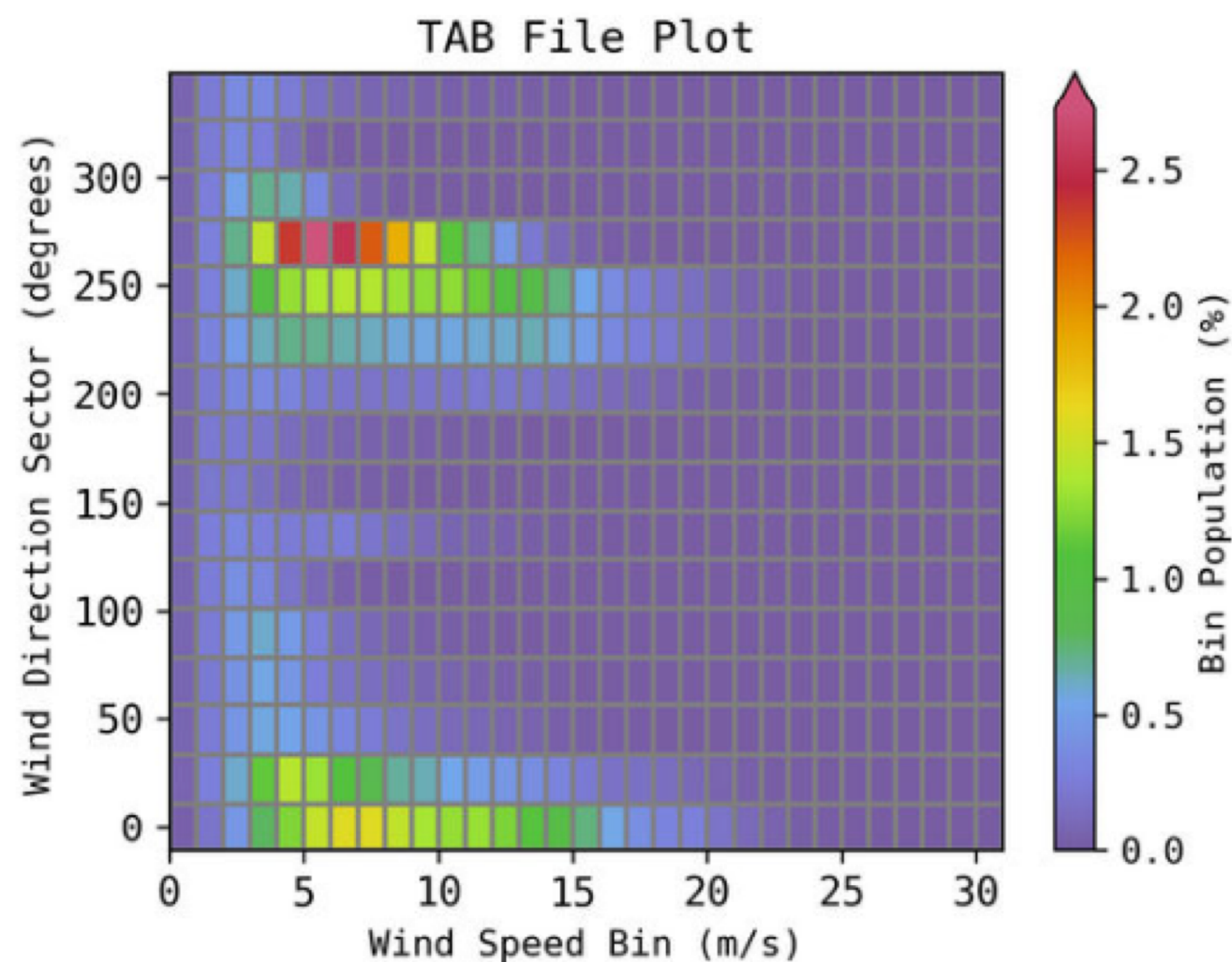
Resolution: 300m

Period: 30 years

Output frequency: 10min

Turbulence and Extremes

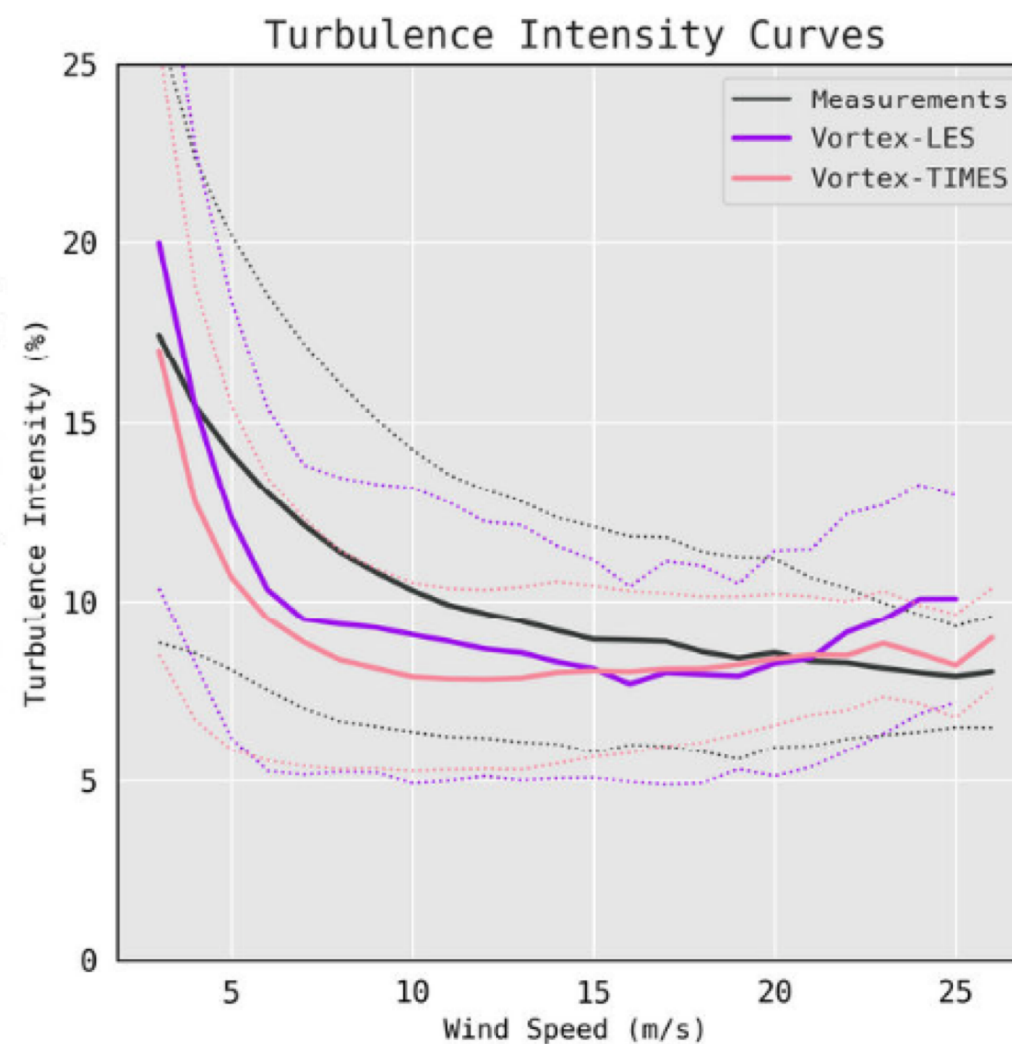
TIMES METHODOLOGY



1

Wind Distribution

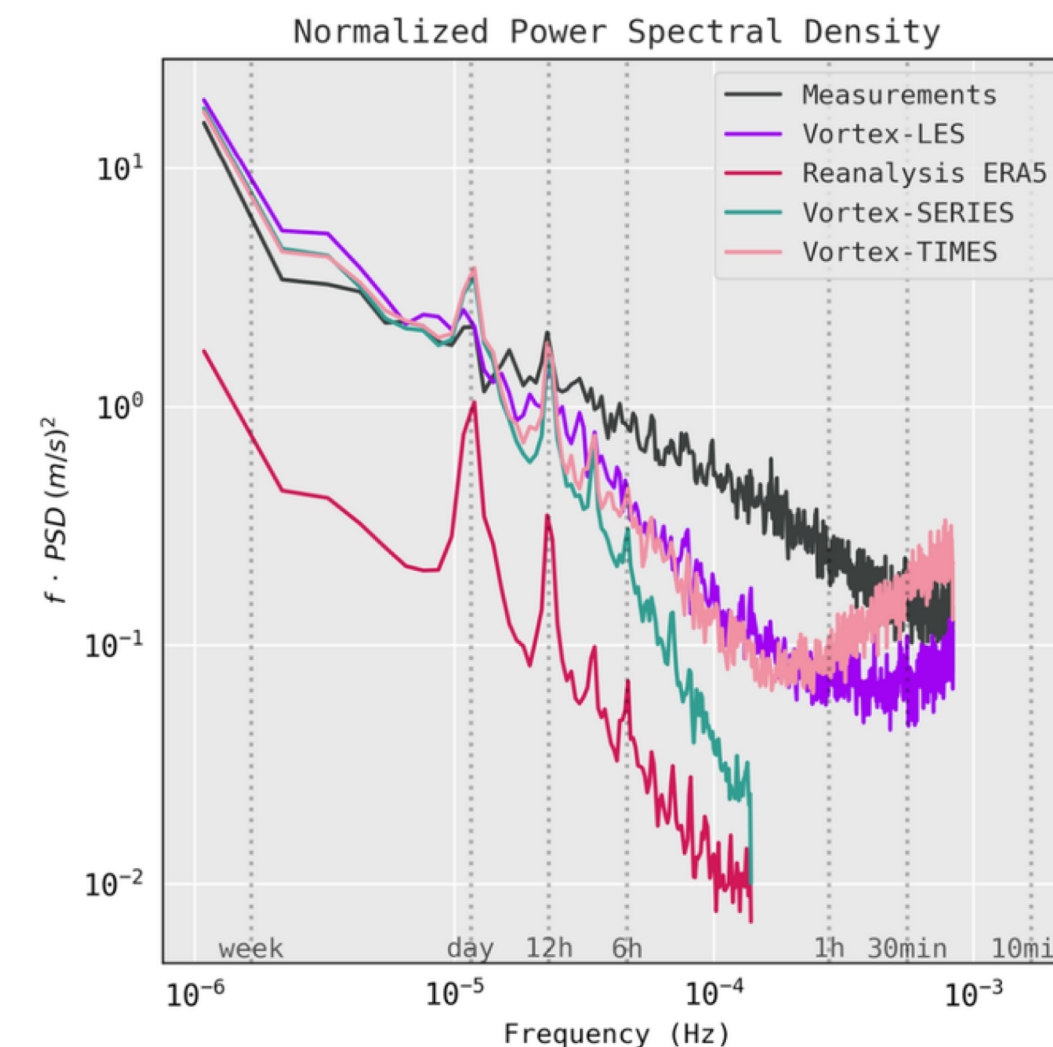
Improve speeds and directions using LES



2

Turbulence

Parametrized from TKE
turbulence improved
with explicit LES Ti

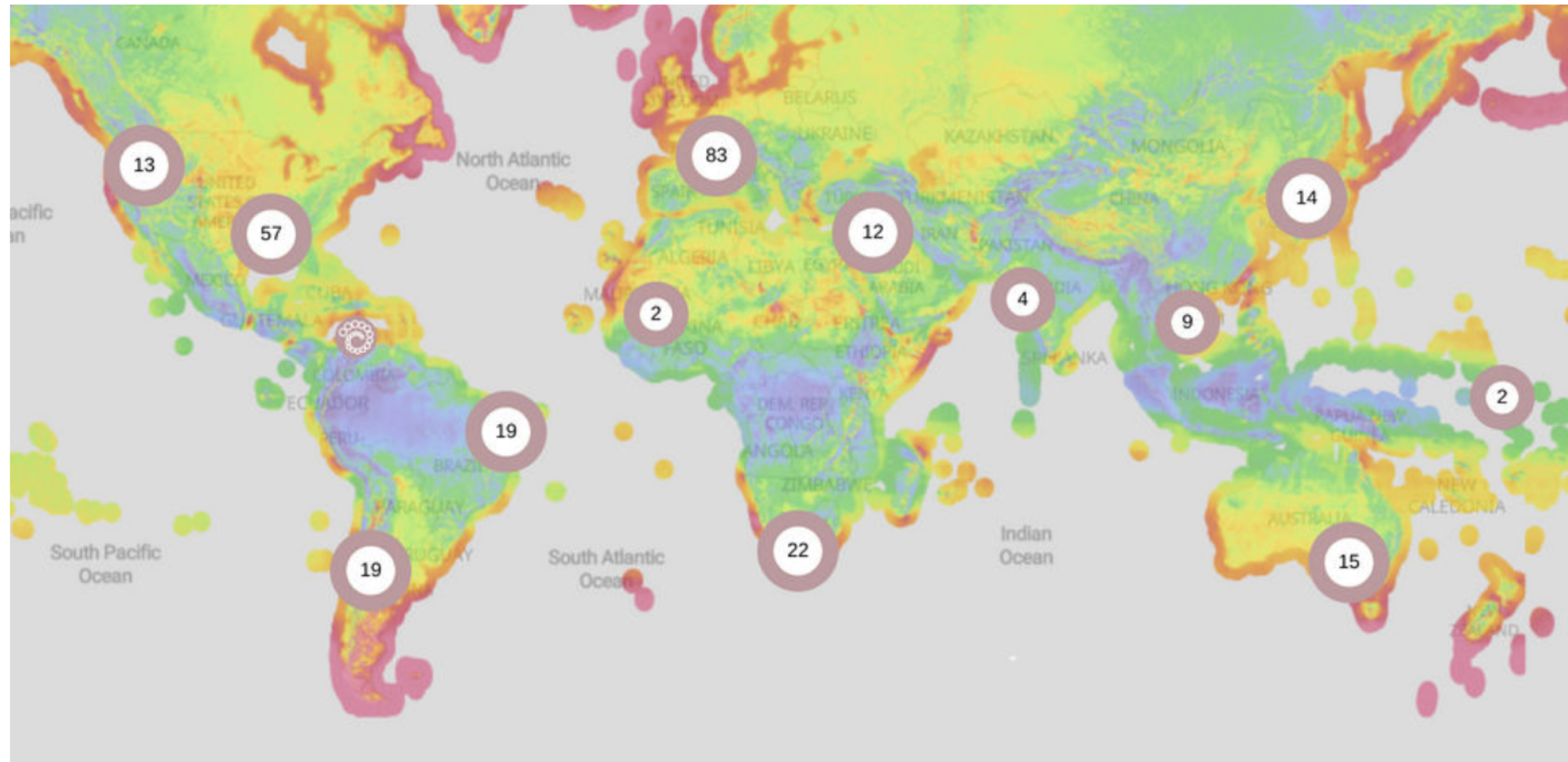


3

Sub-hour Variability

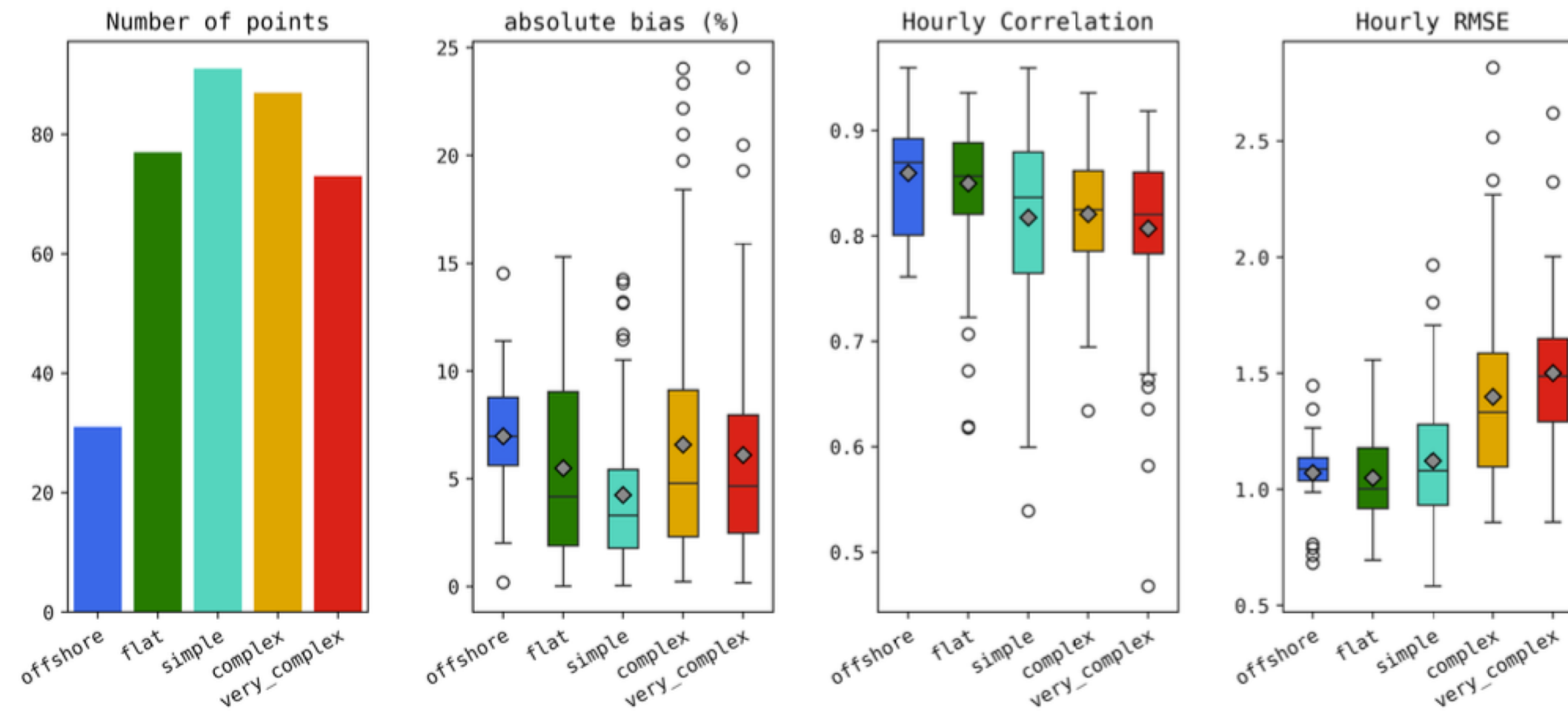
Power Density Spectral
Analysis to improve
variability

TIMES VALIDATION



- **272** locations
- Different **terrain** complexities on each continent
- **Offshore** sites located more than 10km from the coast
- 22 locations with **multiple levels**

TIMES VALIDATION



Mean Wind Speed Absolute Bias (%)	5.71 ± 4.72
Mean Wind Speed Bias (%)	0.003 ± 7.393
10-min RMSE (m/s)	2.04 ± 0.47
10-min Correlation	0.70 ± 0.09

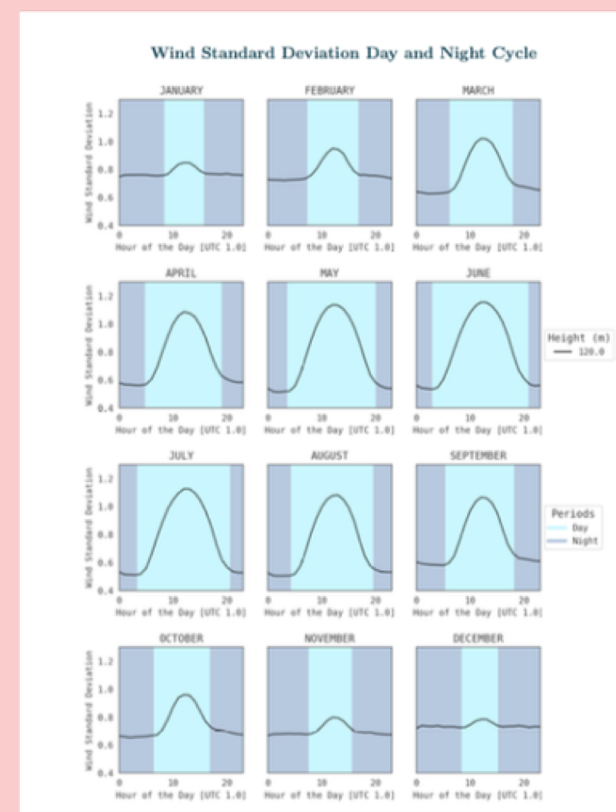
TIMES DELIVERABLES

Lat=55.191 Lon=7.152 Hub-Height=101 Timezone=00.0 Terrain-Height=0.0 (file requested on 2023-02-14 13:12:35)
VORTEX (www.vortex.es) - Computed at 100 m resolution WRF-LES based on ERA5 data

YYYYMMDD HHMM	M(m/s)	D(deg)	SD(m/s)	DSD(deg)	Gust3s(m/s)	T(C)	PRE(hPa)	RiNumber	VertM(m/s)
20110101 0000	20.38	275.0	2.16	0.7	20.78	4.9	999.7	0.87	-0.28
20110101 0010	19.94	276.1	1.11	0.5	20.80	5.6	999.5	-0.29	0.03
20110101 0020	19.84	276.9	0.97	0.6	20.33	5.5	999.2	-0.11	-0.03
20110101 0030	19.68	278.2	0.78	0.3	20.02	5.3	999.0	0.39	0.05
20110101 0040	19.68	279.1	1.91	0.5	20.07	5.4	998.9	0.14	0.09
20110101 0050	19.56	280.6	0.79	0.6	19.76	5.3	998.7	-0.01	0.06
20110101 0100	19.55	282.3	0.75	0.8	19.99	5.4	998.7	-0.04	-0.04
20110101 0110	19.46	284.6	0.75	0.6	19.98	5.5	998.6	-0.22	-0.17
20110101 0120	18.65	287.2	0.69	1.1	18.98	5.7	998.7	0.14	0.09
20110101 0130	18.55	290.3	0.73	1.1	18.82	6.2	998.7	0.47	0.28
20110101 0140	18.43	293.8	0.87	0.9	18.69	5.3	998.8	1.11	-0.07
20110101 0150	18.25	296.9	0.83	1.3	18.62	5.6	998.9	1.10	-0.15
20110101 0200	17.88	300.1	0.66	0.7	18.31	5.6	999.0	0.74	-0.00
20110101 0210	17.34	304.1	0.68	2.1	17.75	5.7	999.1	0.91	0.20
20110101 0220	17.55	307.0	1.13	0.9	18.91	5.3	999.2	1.53	-0.10
20110101 0230	17.97	305.1	1.32	0.7	18.98	5.4	999.3	0.31	-0.15
20110101 0240	16.37	307.3	1.24	1.5	17.45	5.1	999.3	1.65	0.64
20110101 0250	16.82	309.1	0.76	1.7	17.62	5.1	999.4	0.19	-0.02

Data:

- Plain txt/csv
- NetCDF
- WindPRO mesores
- OpenWind csv
- WAsP TAB



1 Interannual Variability

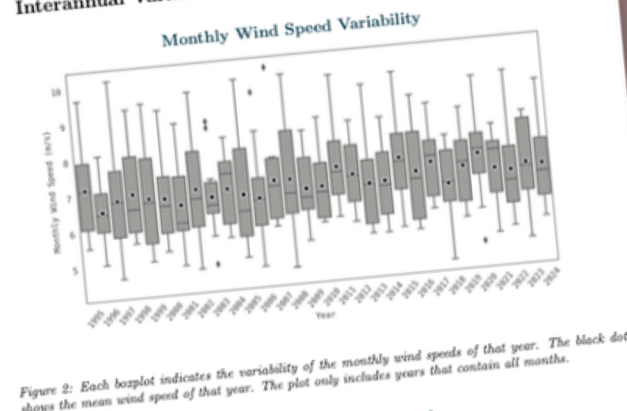
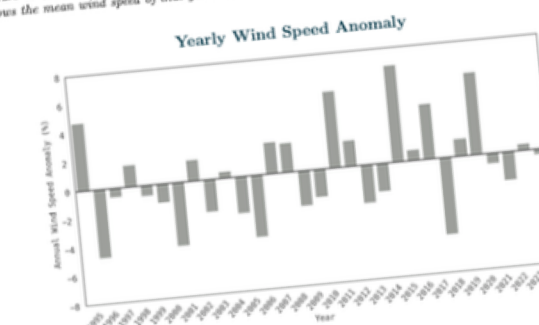


Figure 2: Each boxplot indicates the variability of the monthly wind speeds of that year. The black dot shows the mean wind speed of that year. The plot only includes years that contain all months.



1 Temporal Patterns of Extreme Events

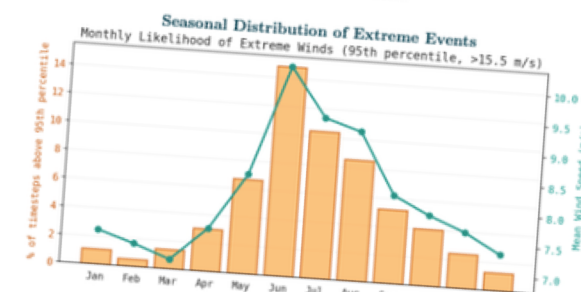


Figure 3: Monthly distribution of extreme wind events (defined as timesteps above the 95th percentile). Orange bars show the percentage of timesteps in each month that exceed the threshold, while the teal line shows the mean wind speed for context.

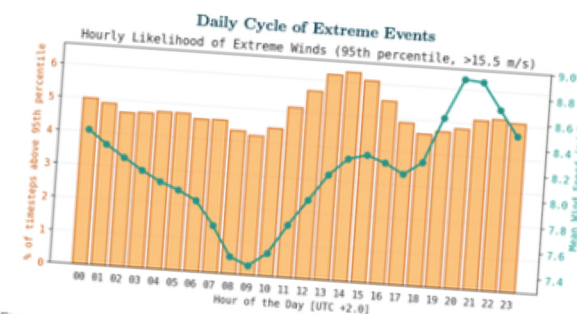


Figure 4: Hourly distribution of extreme wind events (defined as timesteps above the 95th percentile). Orange bars show the percentage of timesteps in each hour that exceed the threshold, while the teal line shows the mean wind speed for context.

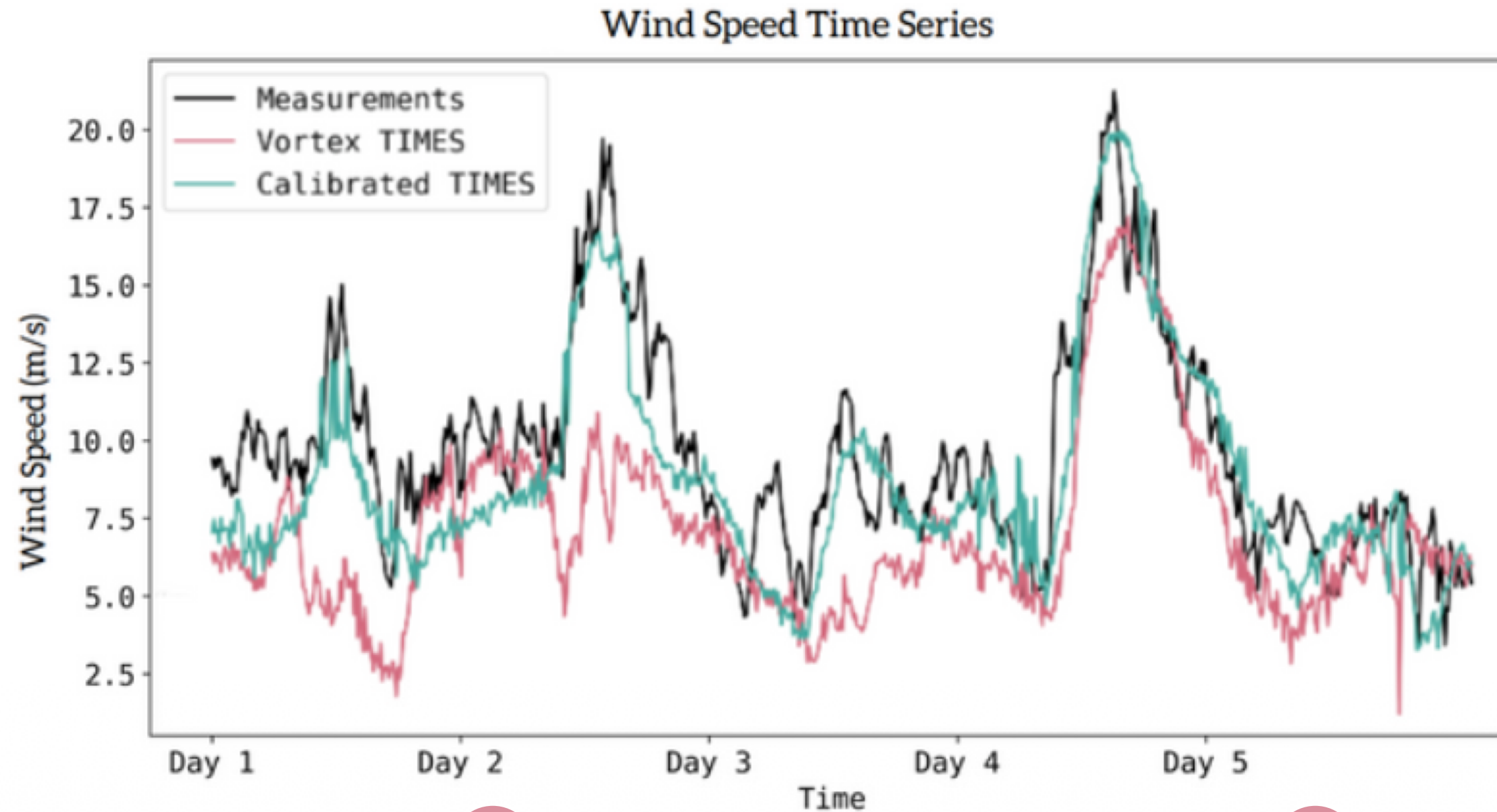
2 Weibull Analysis by Sector

	Mean Wind (m/s)	Weibull A (m/s)	Weibull k	Weibull r ²	Events (%)
Global	6.85	7.71	2.43	0.99	100.00
Sector 0	6.75	7.59	2.43	0.96	4.71
Sector 1	6.75	7.60	2.29	0.97	4.13
Sector 2	6.38	7.19	2.43	0.99	5.74
Sector 3	5.62	6.35	2.20	0.97	4.40
Sector 4	5.43	6.13	2.14	0.98	3.50
Sector 5	5.56	6.27	2.19	0.98	3.63
Sector 6	5.74	6.48	2.28	0.98	4.61
Sector 7	6.04	6.81	2.41	0.99	5.23
Sector 8	6.61	7.43	2.53	0.99	5.78
Sector 9	7.25	8.14	2.67	0.97	7.18
Sector 10	7.66	8.57	2.85	0.98	9.73
Sector 11	7.79	8.72	2.74	0.97	11.24
Sector 12	7.74	8.69	2.61	0.97	10.94
Sector 13	6.96	7.82	2.55	0.98	7.87
Sector 14	6.67	7.49	2.50	0.97	6.05
Sector 15	6.57	7.39	2.43	0.96	5.27

Reports:

- Extremes
- Vertical structure
- Weibull
- Wind Speed
- Wind Direction
- Overview

TIMES CALIBRATION



1

Temporal correlation

Neural Network
ensemble trained with
Speed and Turbulence

2

Daily and Seasonal Cycles

Quantile mapping is used to
adjust the daily and seasonal
patterns

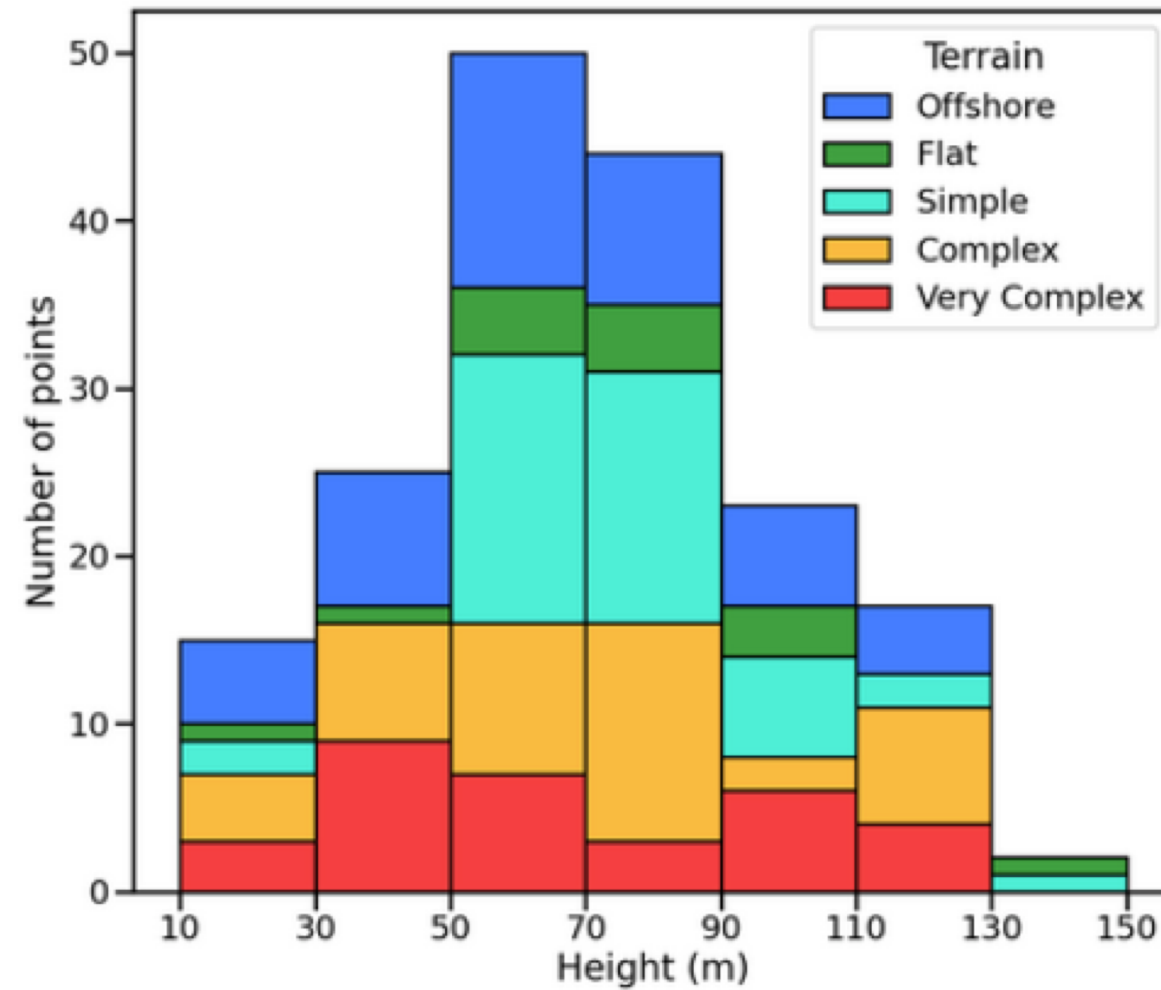
3

Sub-hour Variability

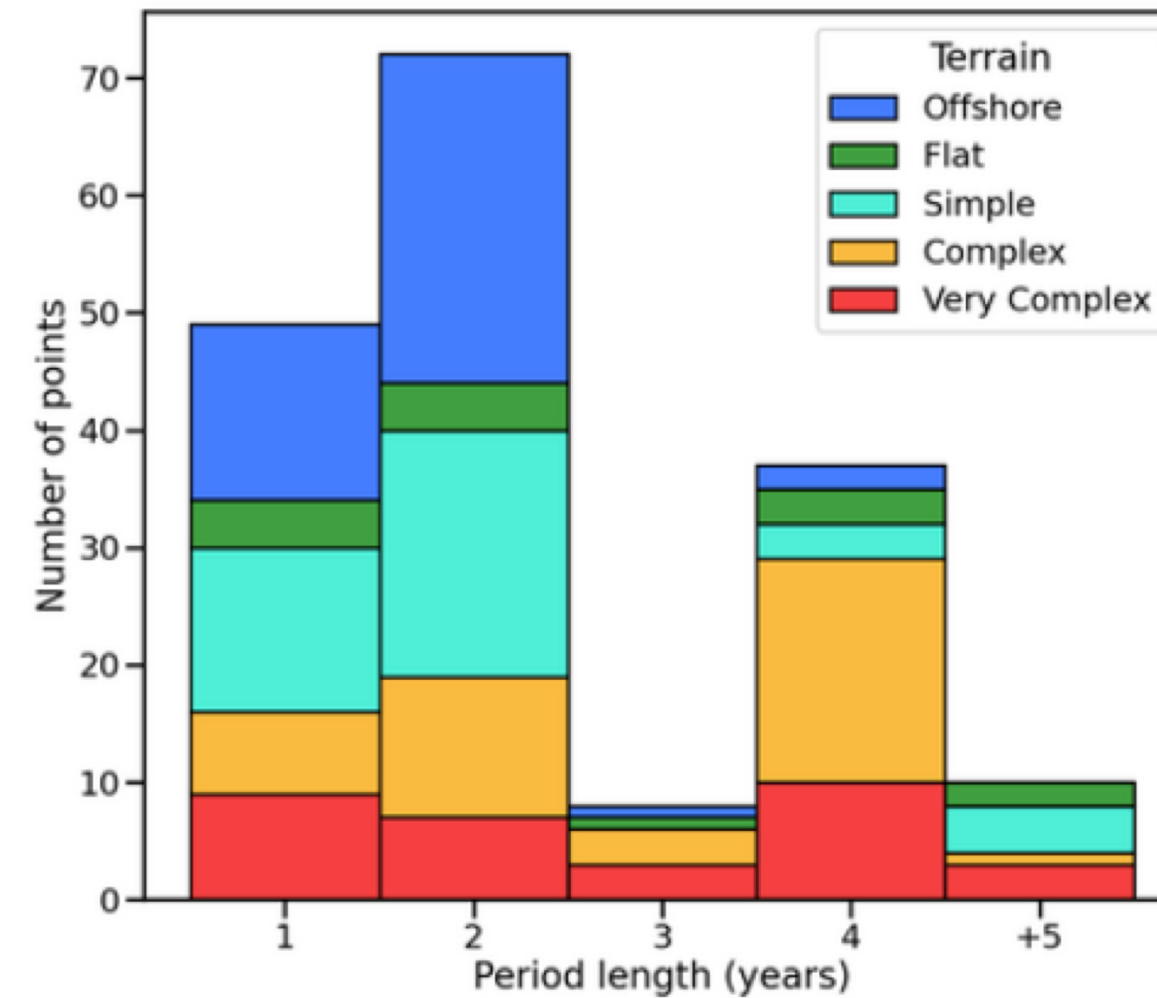
Short-term fluctuations
adjusted based on non-calibrated
values and measurements

TIMES CALIBRATION VALIDATION

Number of points per measurement height



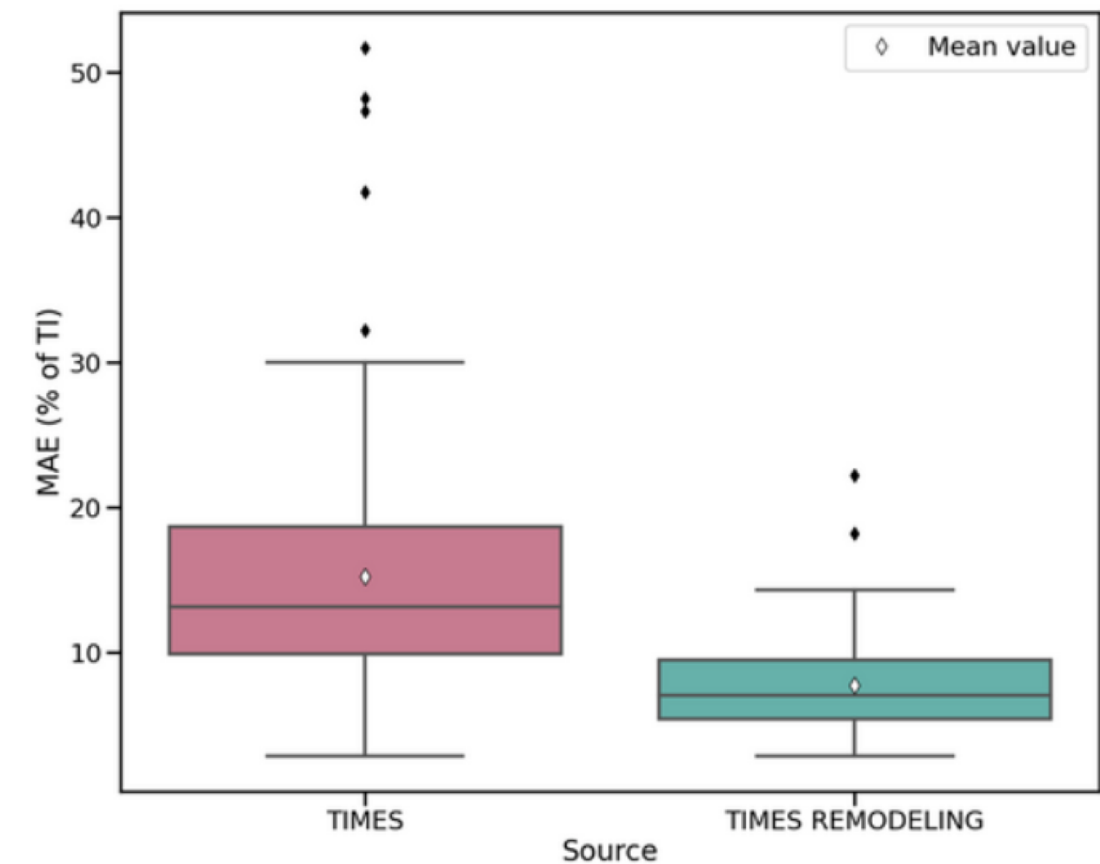
Training and validation period length



- 143 locations worldwide
- 37 with 10-min std dev
- 176 measurements

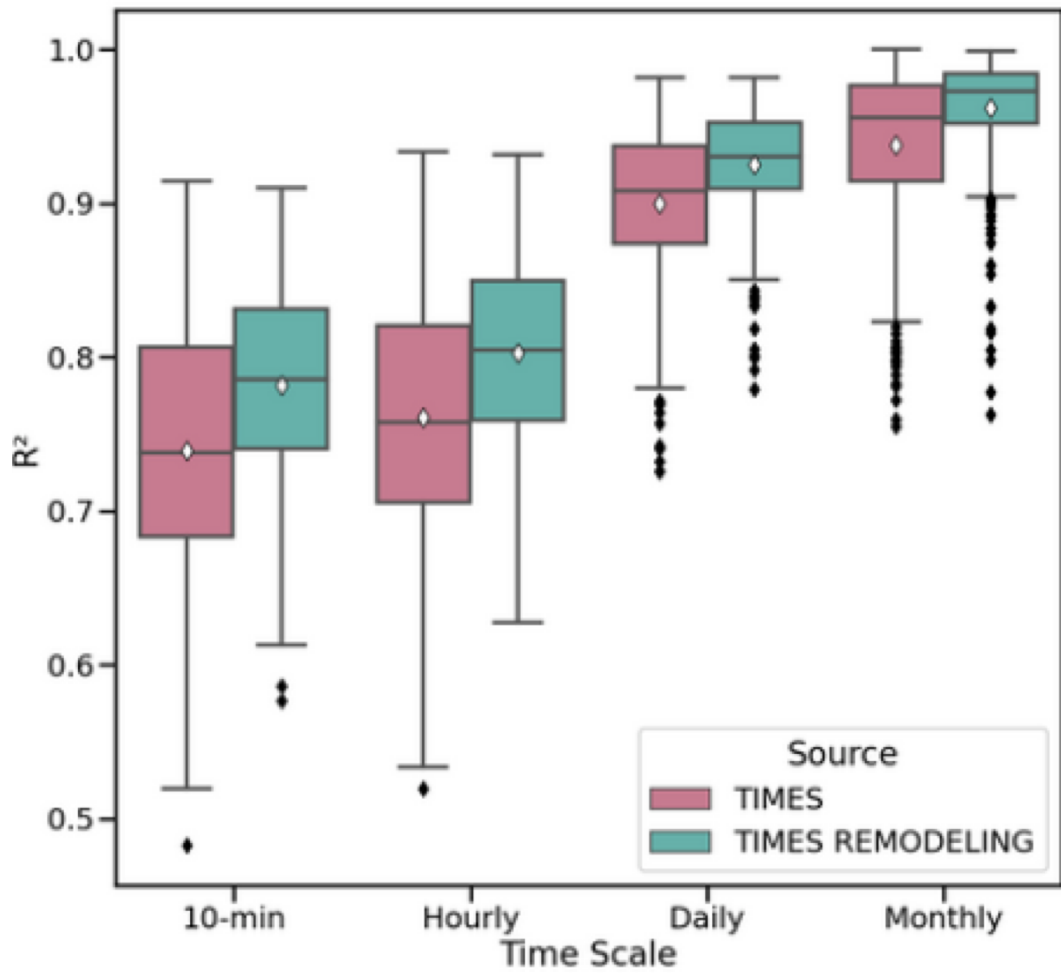


TIMES CALIBRATION VALIDATION



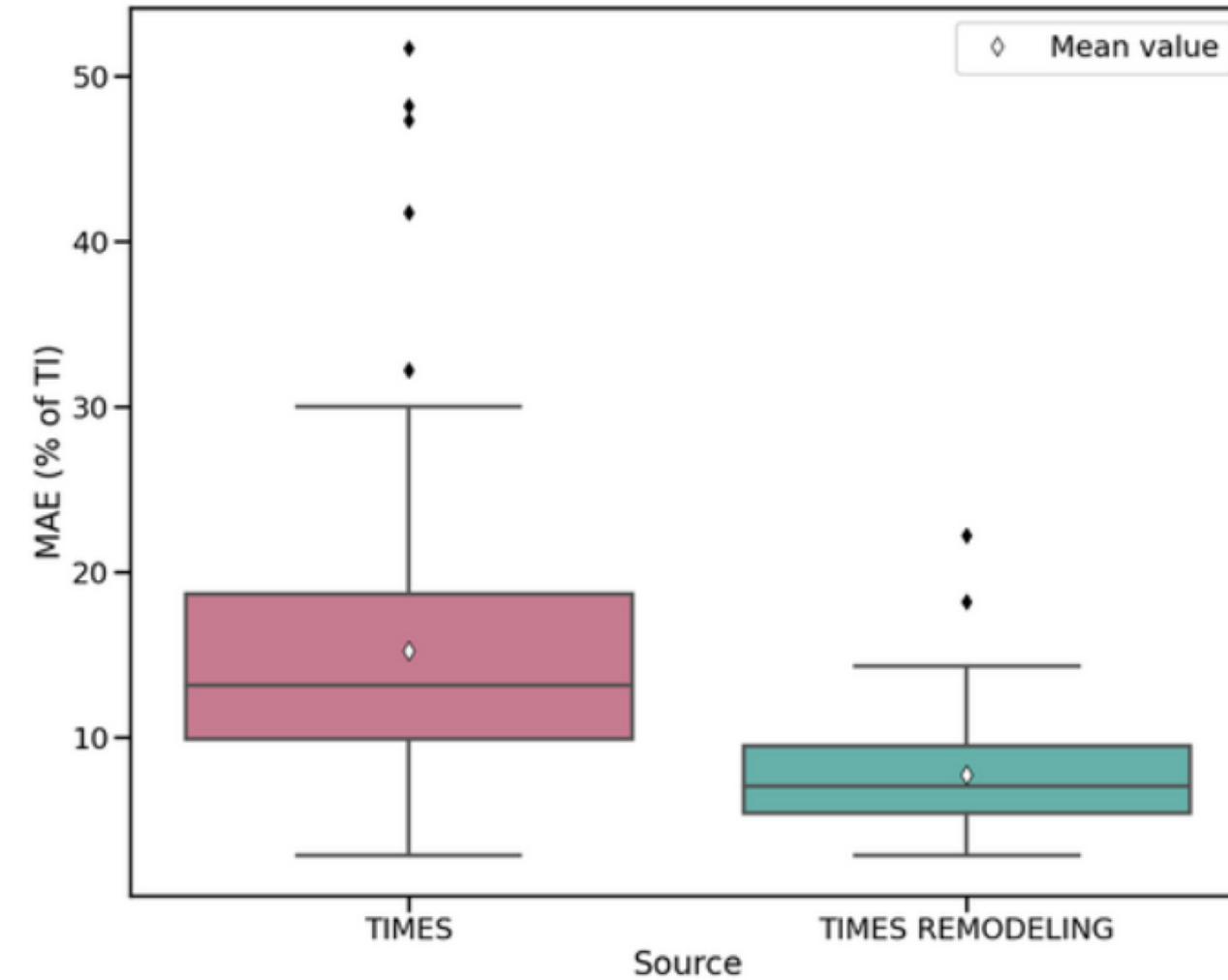
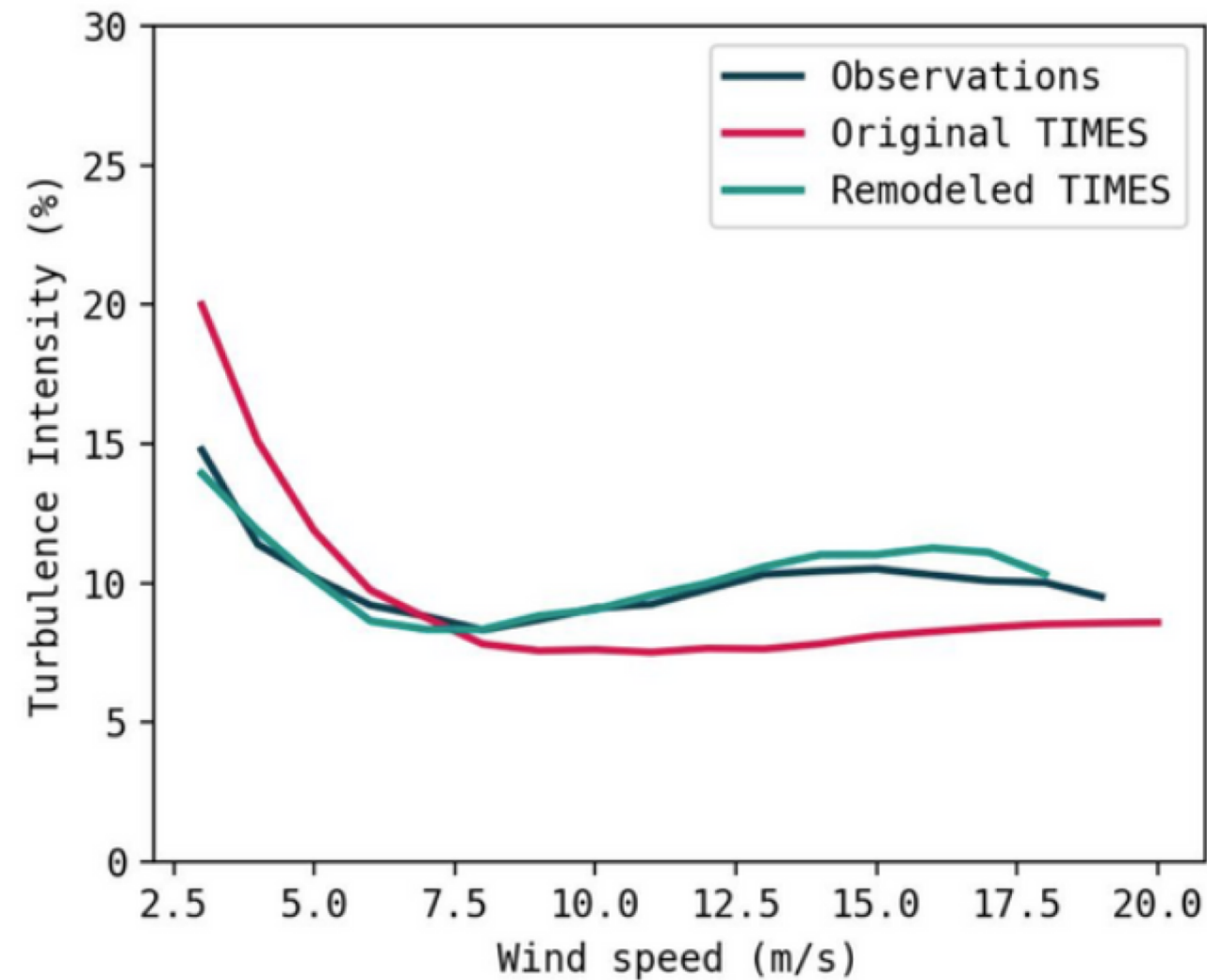
Mean Wind Speed Absolute Bias (%)

TIMES	5.07 ± 4.63
Remodeling	1.59 ± 2.08



	R² 10-min	R² monthly
TIMES	0.739 ± 0.086	0.938 ± 0.052
Remodeling	0.781 ± 0.063	0.962 ± 0.036

TIMES CALIBRATION VALIDATION



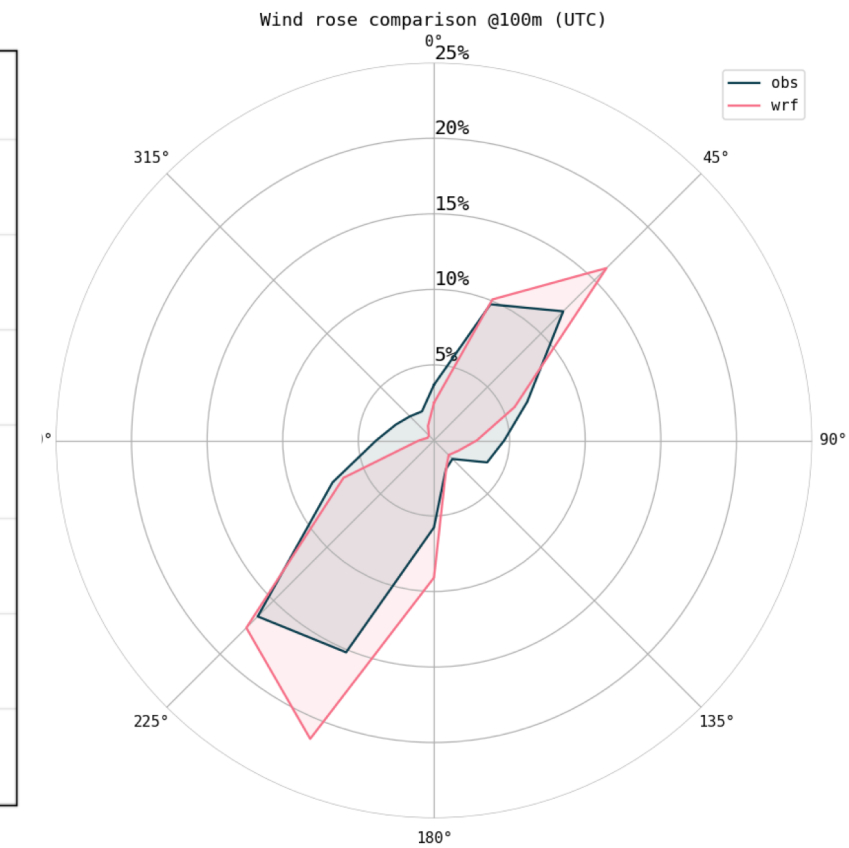
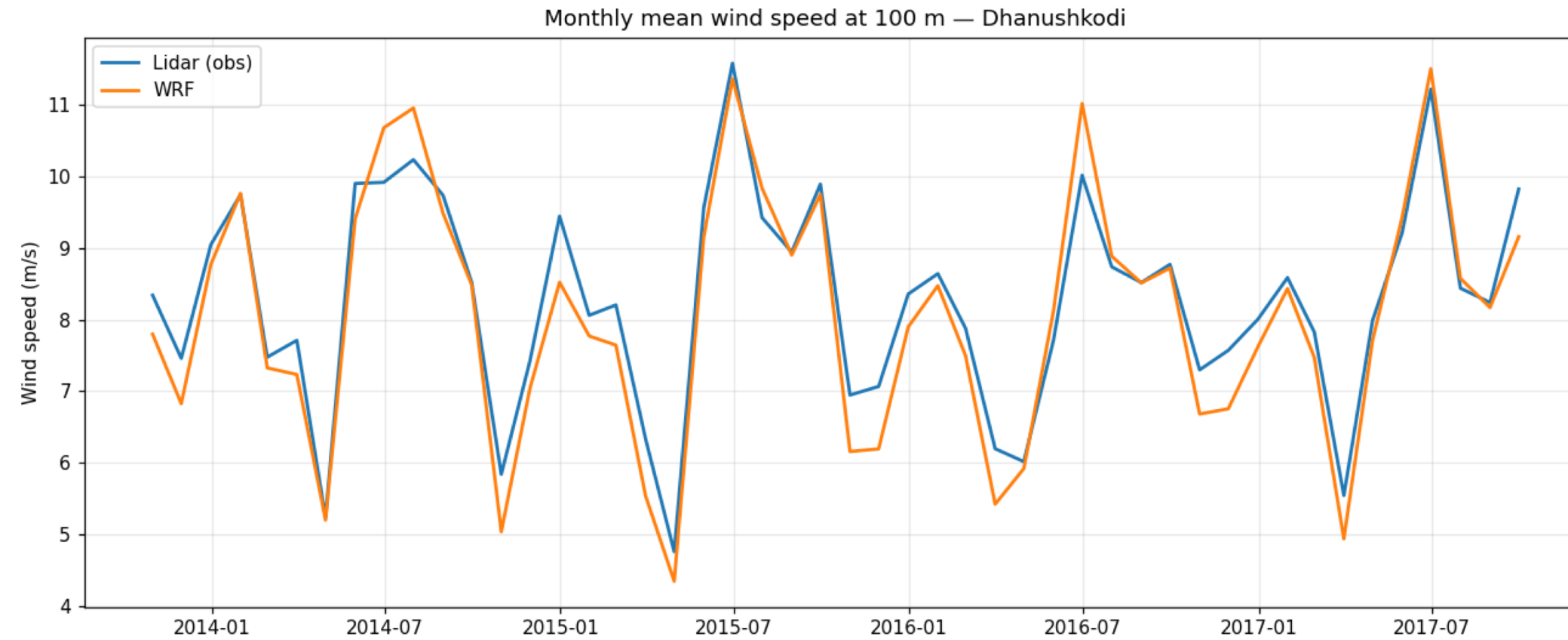
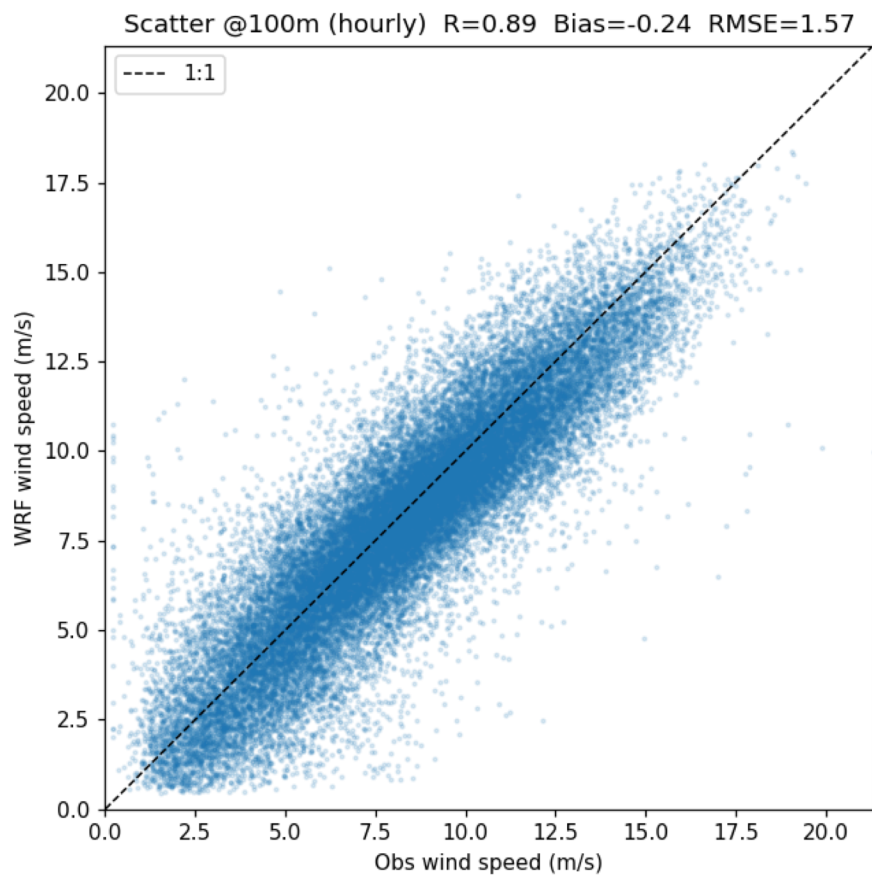
Turbulence Intensity Curve. Example of TI curves for measurements, TIMES and TIMES *Remodeling*.

Mean TI Curve MAE (% of TI)

Mean TI Curve Absolute Bias
at 15 m/s (% of TI)

TIMES	15.87 ± 7.67	13.23 ± 7.85
Remodeling	7.70 ± 2.95	7.77 ± 5.03

TIMES DHANUSHKODI LIDAR

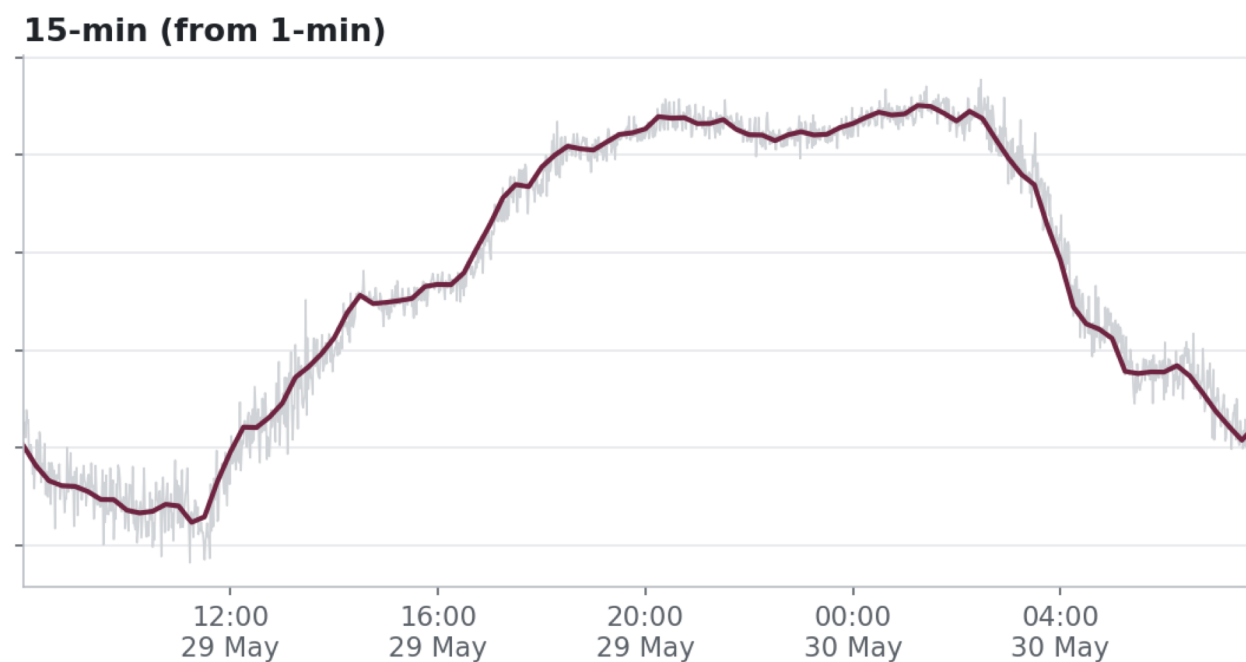
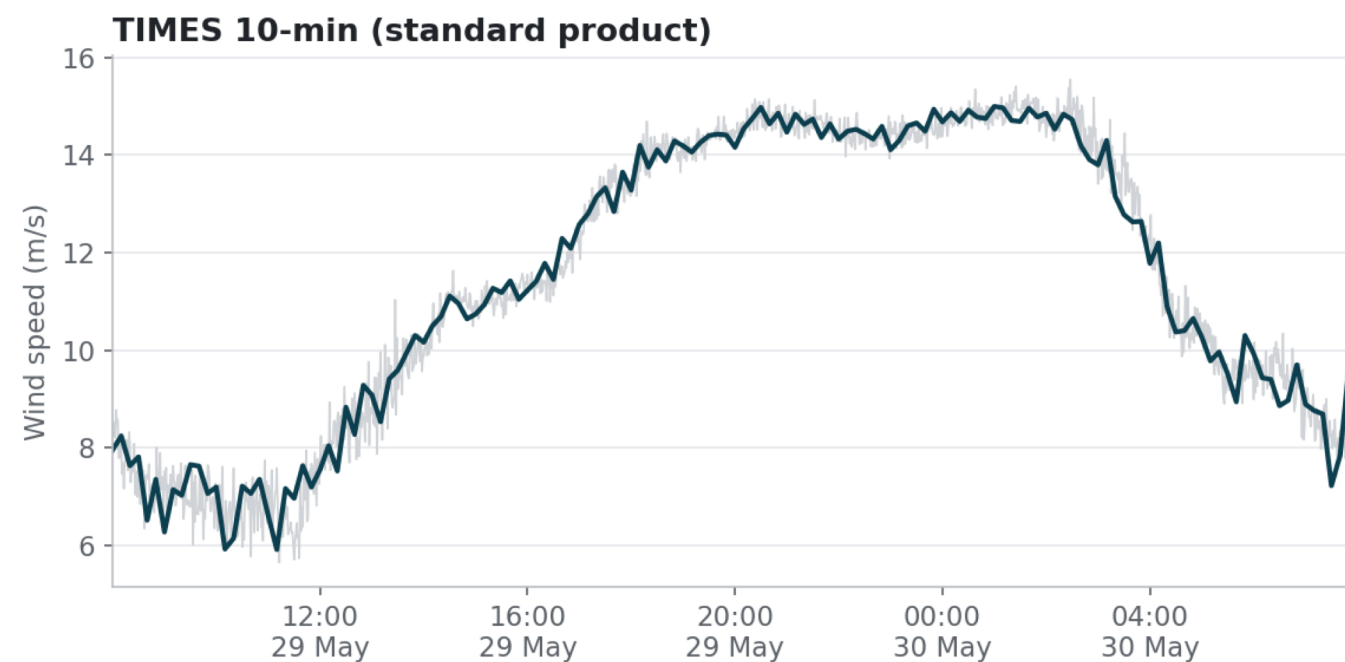
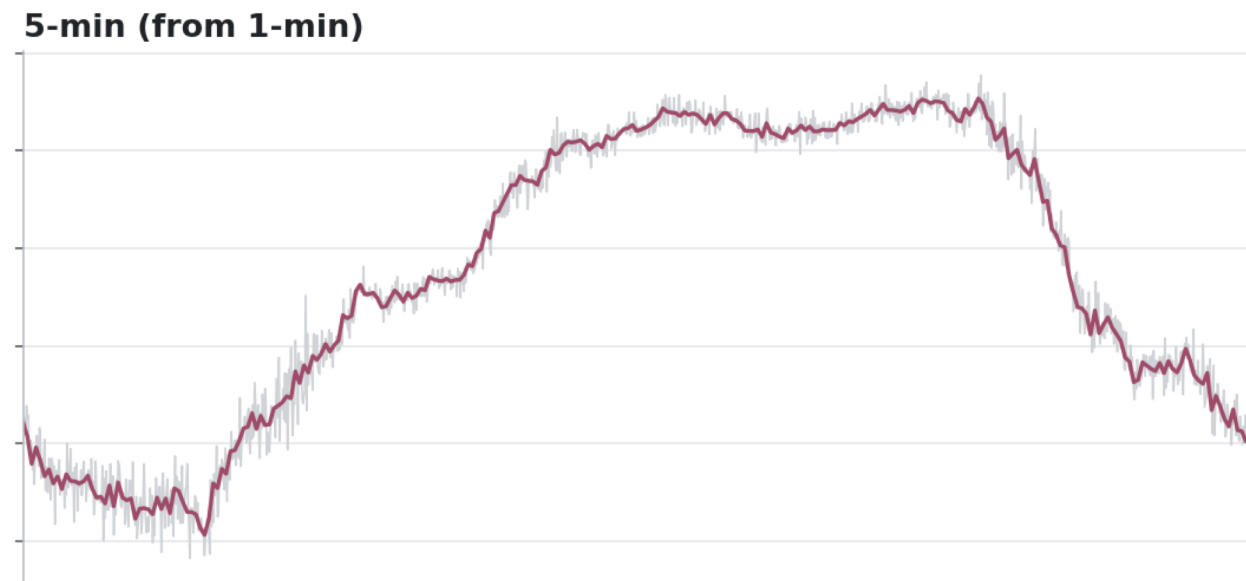
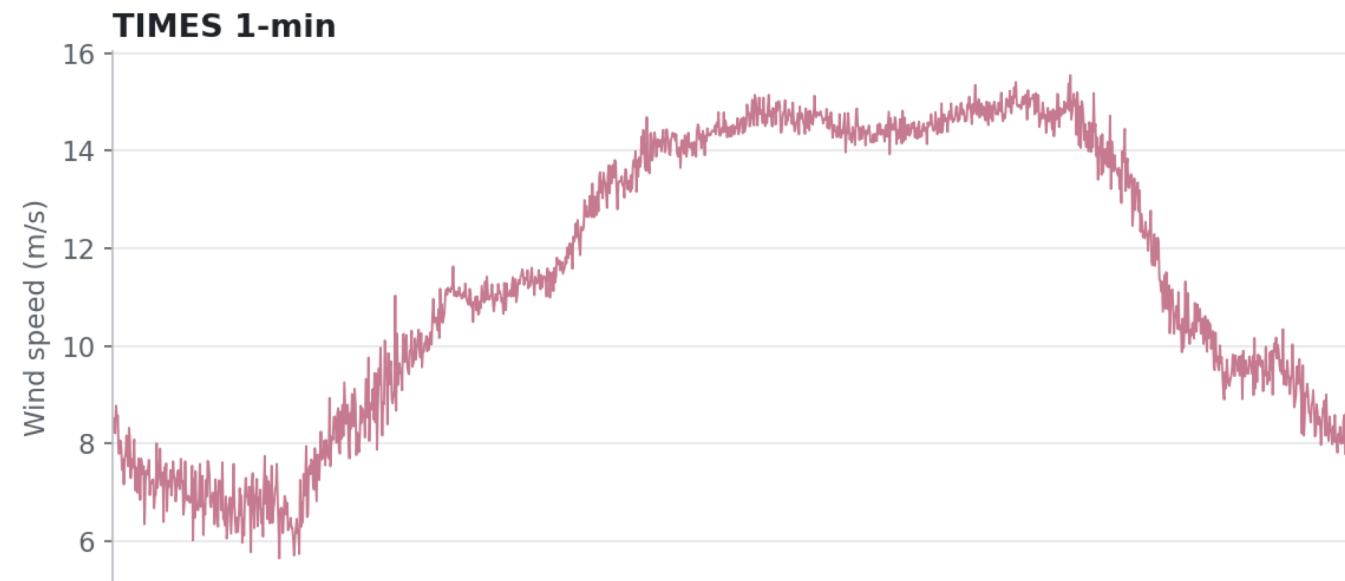


1-min RESOLUTION TIMES

TIMES at 1, 5, 10 and 15-minute resolution

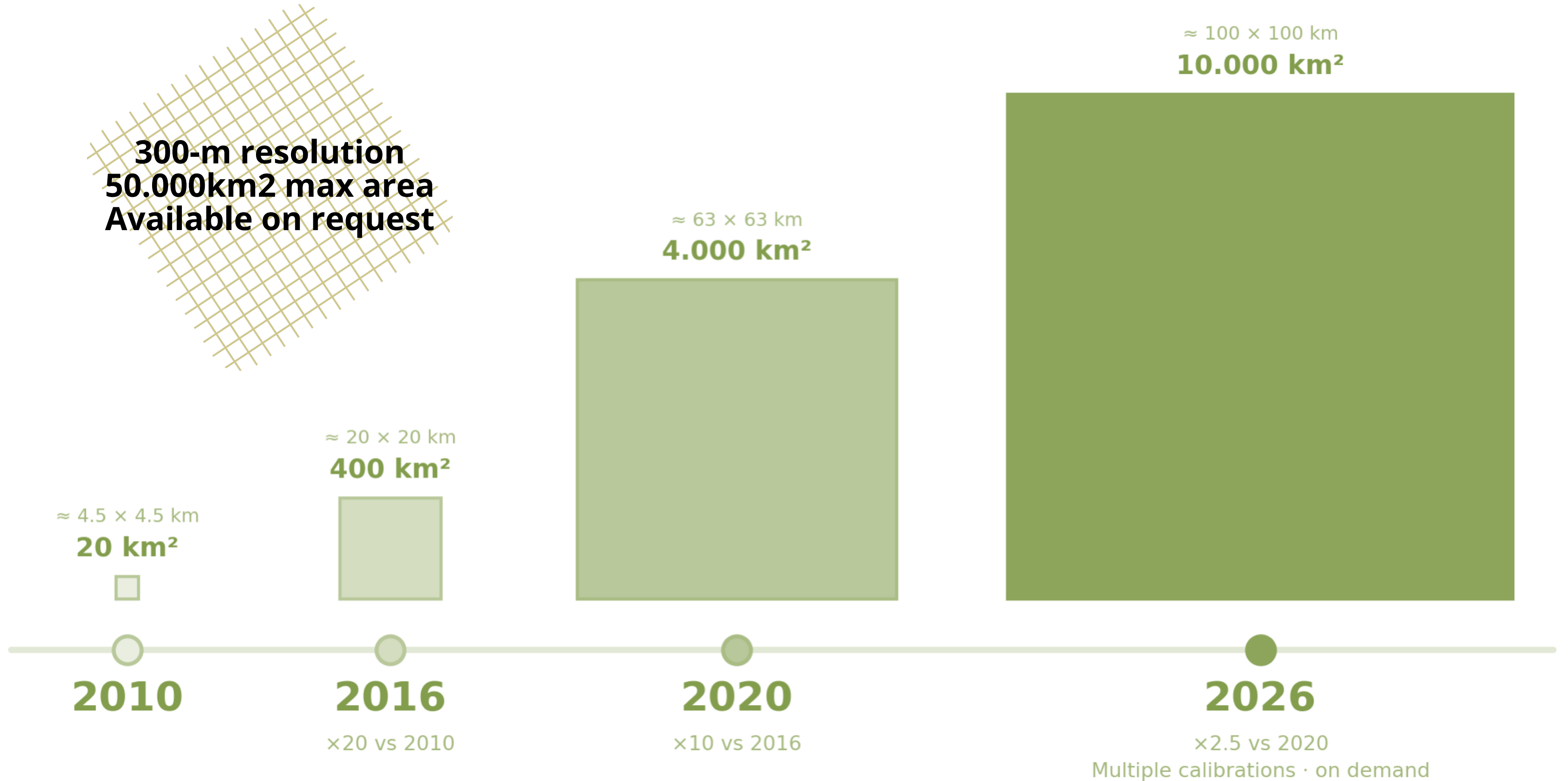
Wind speed at 124 m · times in UTC · 10-min is the standard product; 5 and 15-min are means of the 1-min series

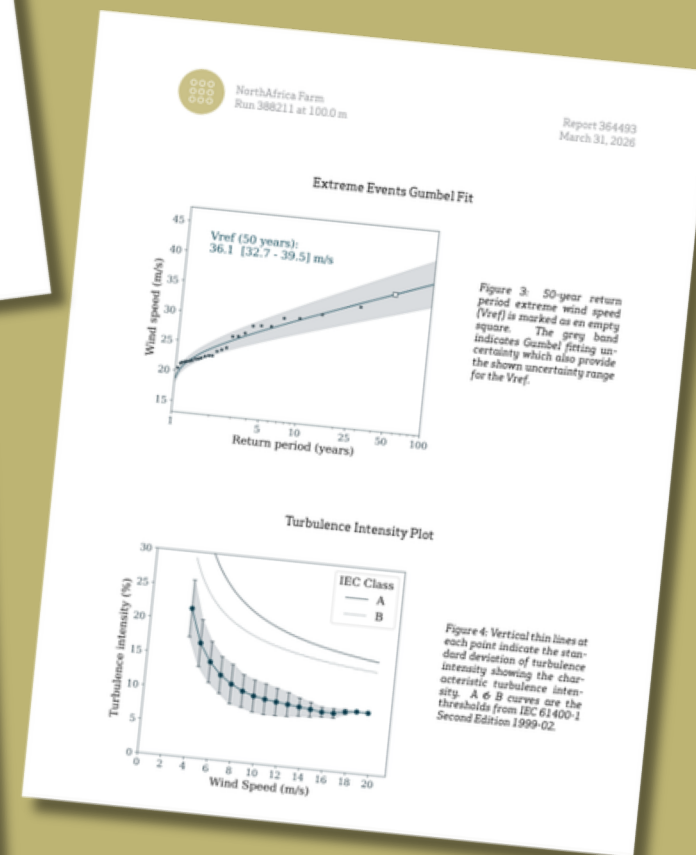
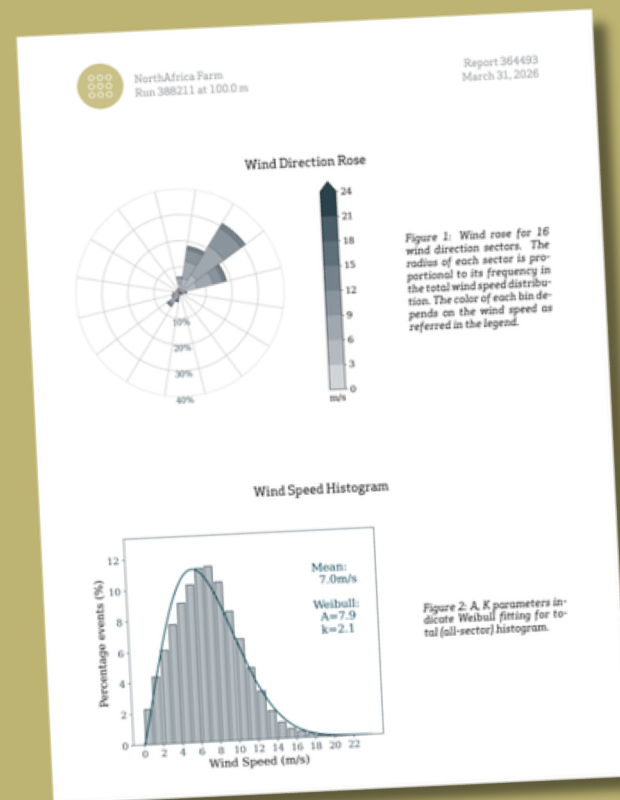
grey = 1-min



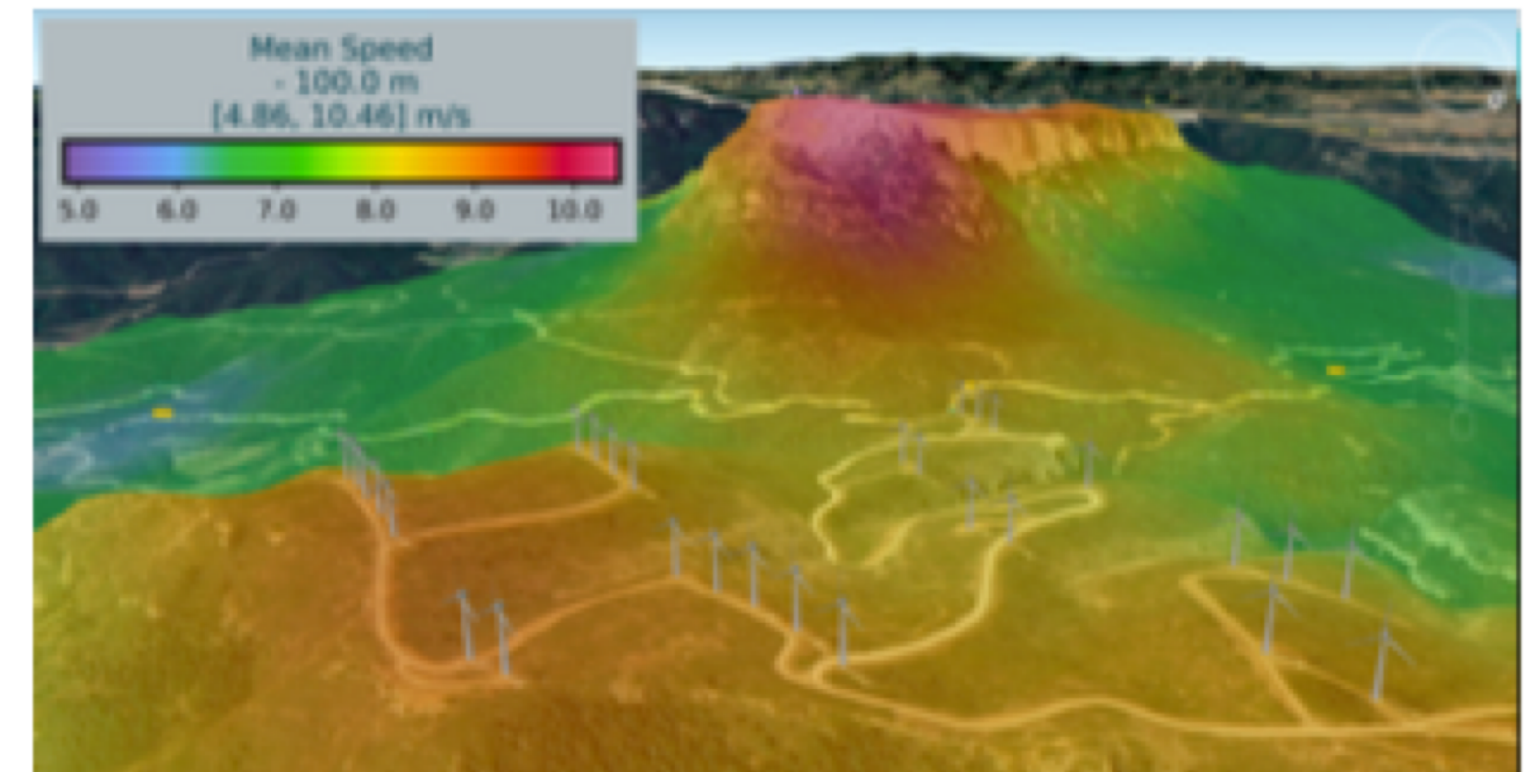
- Upon request
- Hybrid projects
- Resample to
5-min 15-min

VORTEX FARM





- Up to 4000km² areas
- 100m high resolution
- Heights 30 - 300m
- WRG, kmz, GeoTiff, ESRI layers
- Extremes and 50y Vref



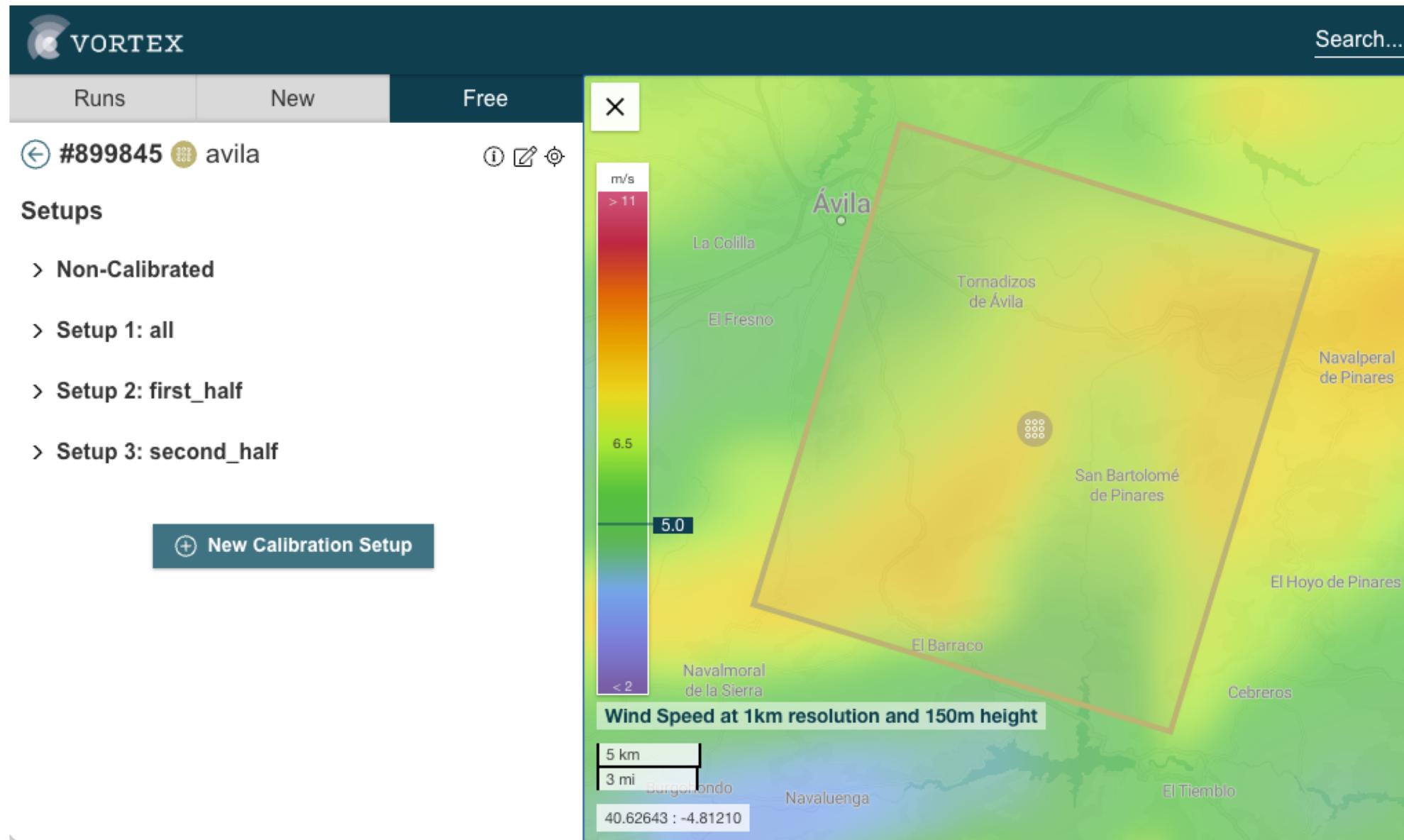
FARM VALIDATION

Mean Wind Speed Absolute Bias (%)	5.18 ± 4.99
Mean Wind Speed Bias (%)	1.47 ± 7.04

- Mean wind speed
- 422 locations worldwide
- Heights from 40 to 200 m
- Minimum one year.

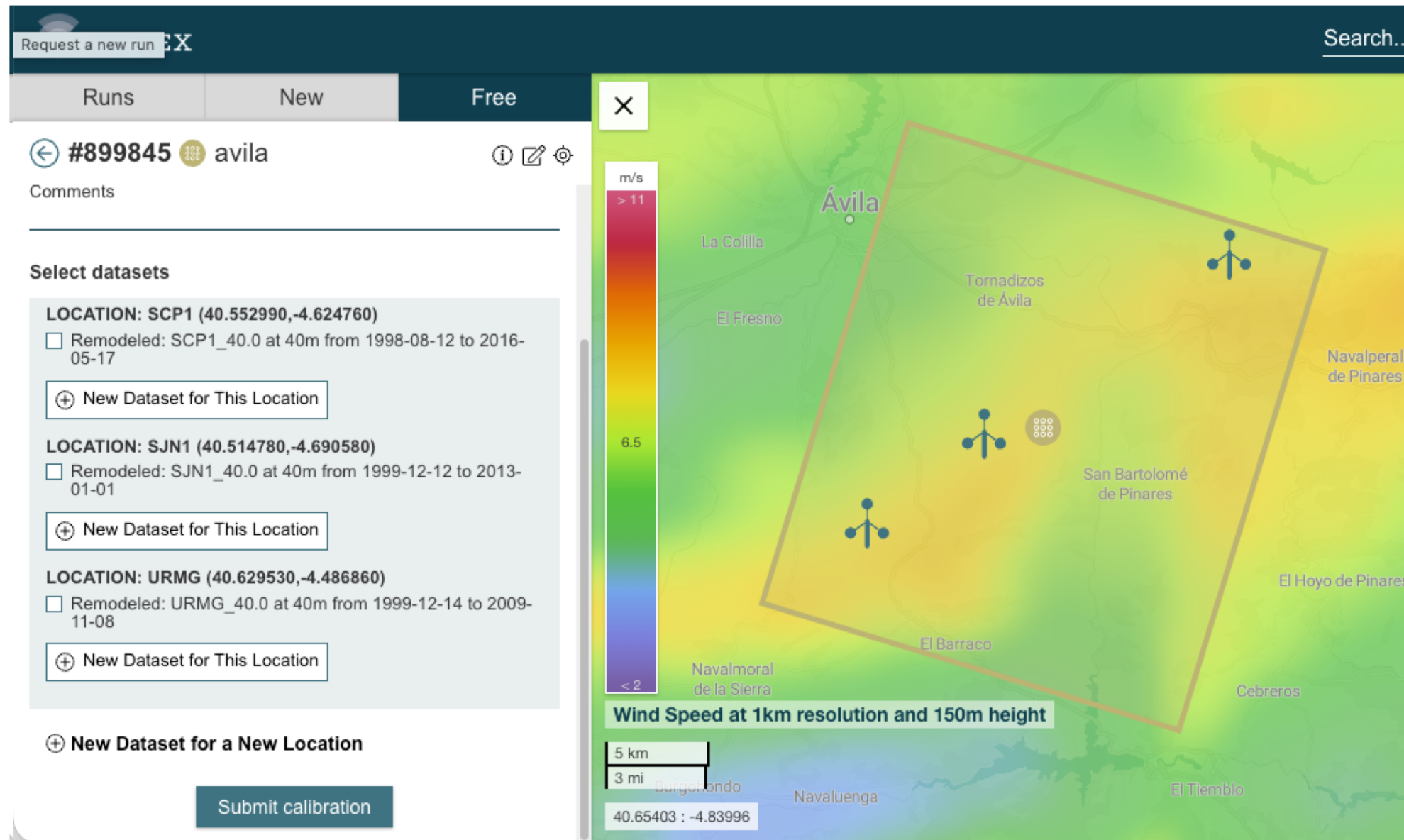


FARM CALIBRATION



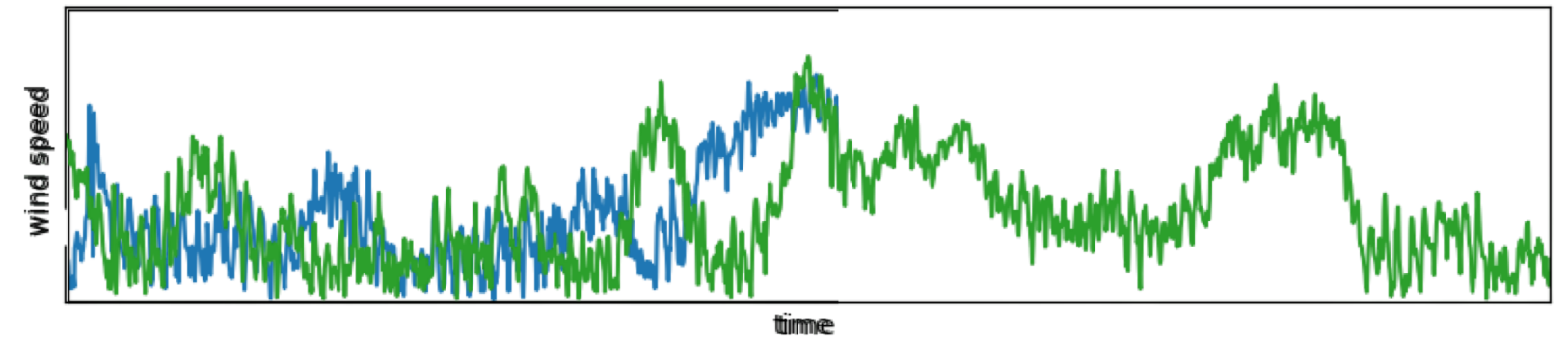
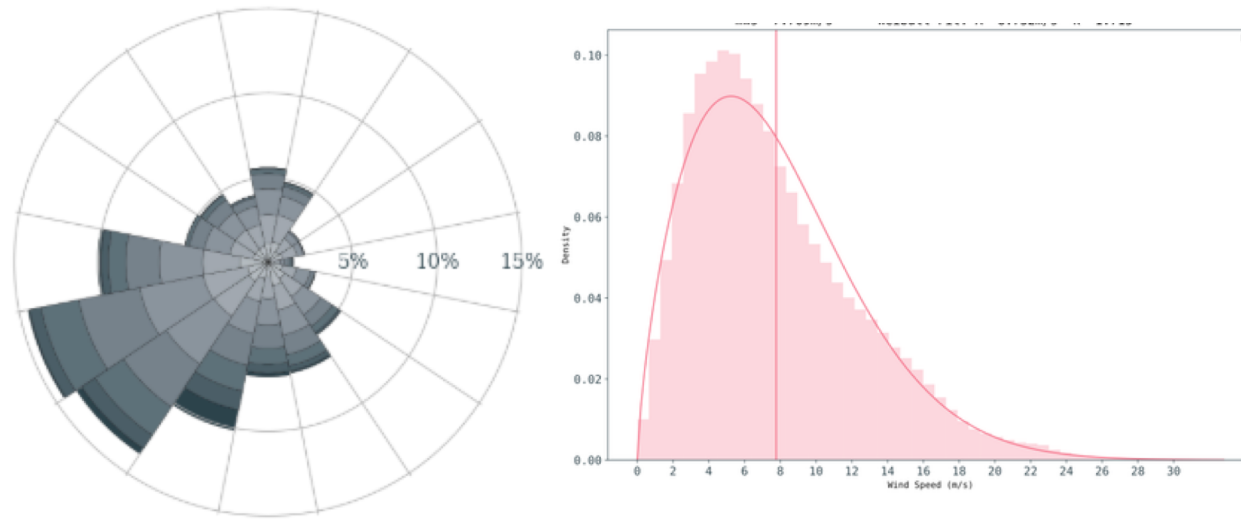
- Multiple calibrations setups in a single FARM
- Incorporate new measurement periods as campaigns progress
- Add new heights and locations

FARM CALIBRATION



- Multiple calibrations setups in a single FARM
- Incorporate new measurement periods as campaigns progress
- Add new heights and locations

FARM CALIBRATION METHODOLOGY



Wind distribution

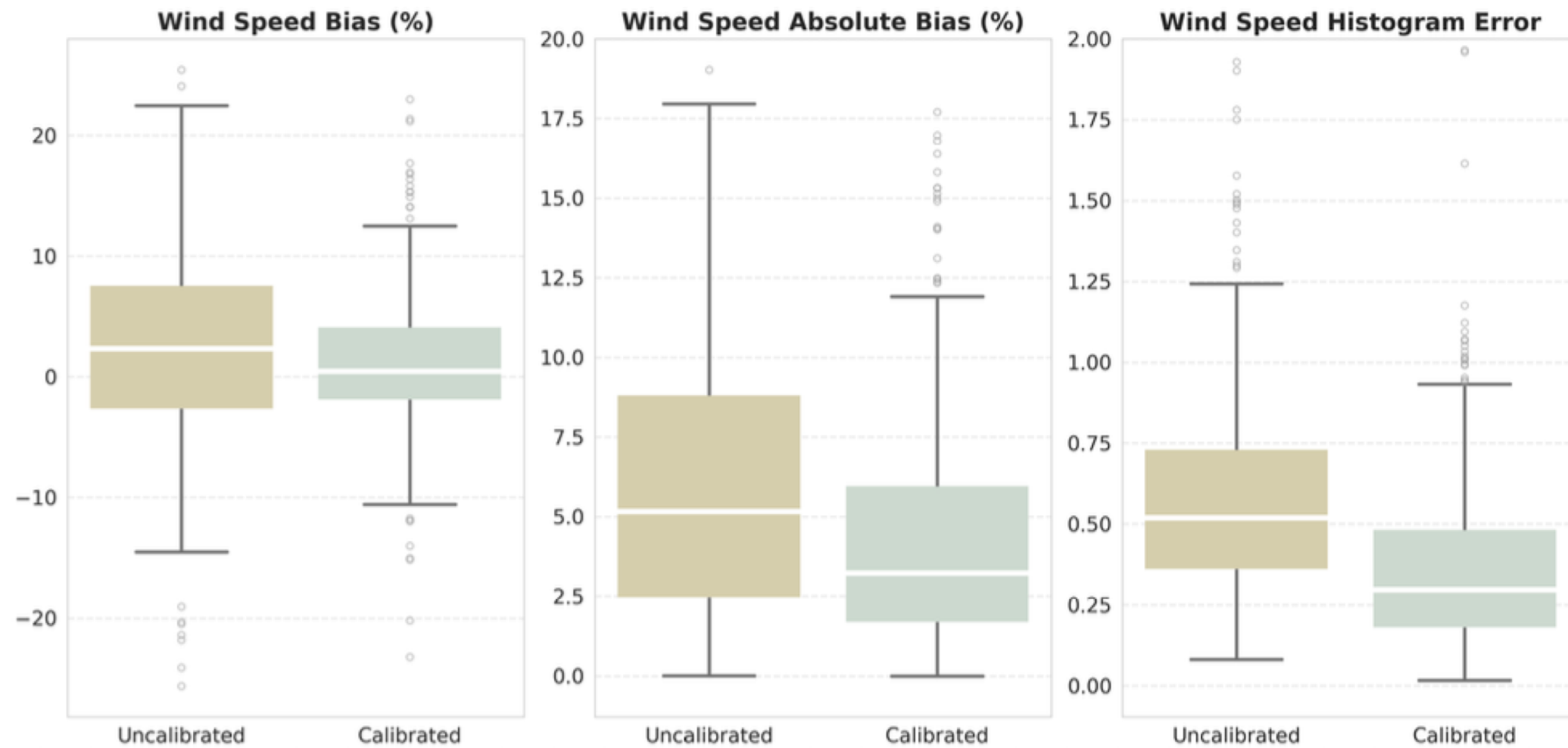
- Sectors and Bins collapse information
- Weibull not appropriate for all situations



Time series

- Match events for every time step, preserving causality.
- Multiple heights and locations

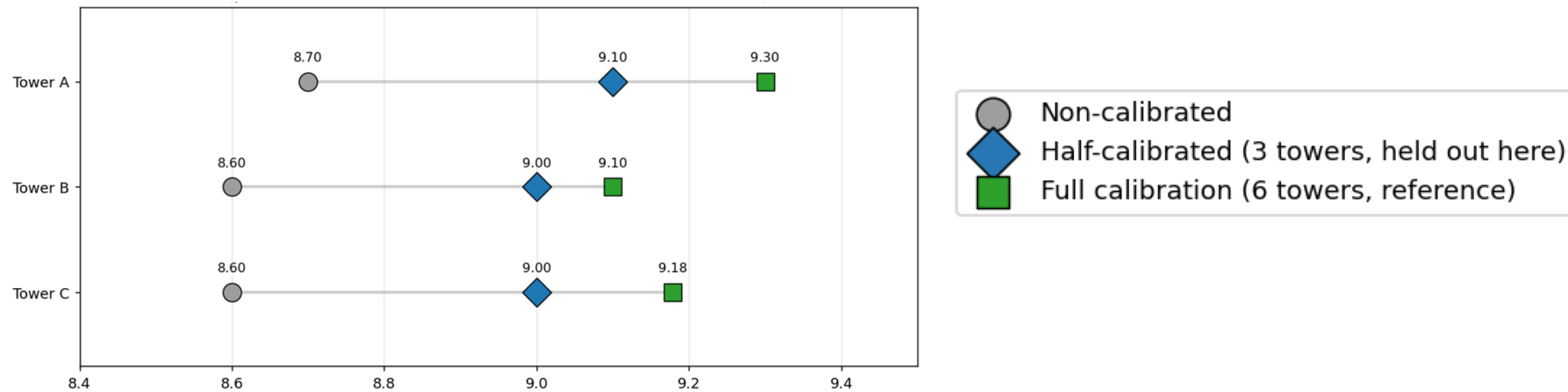
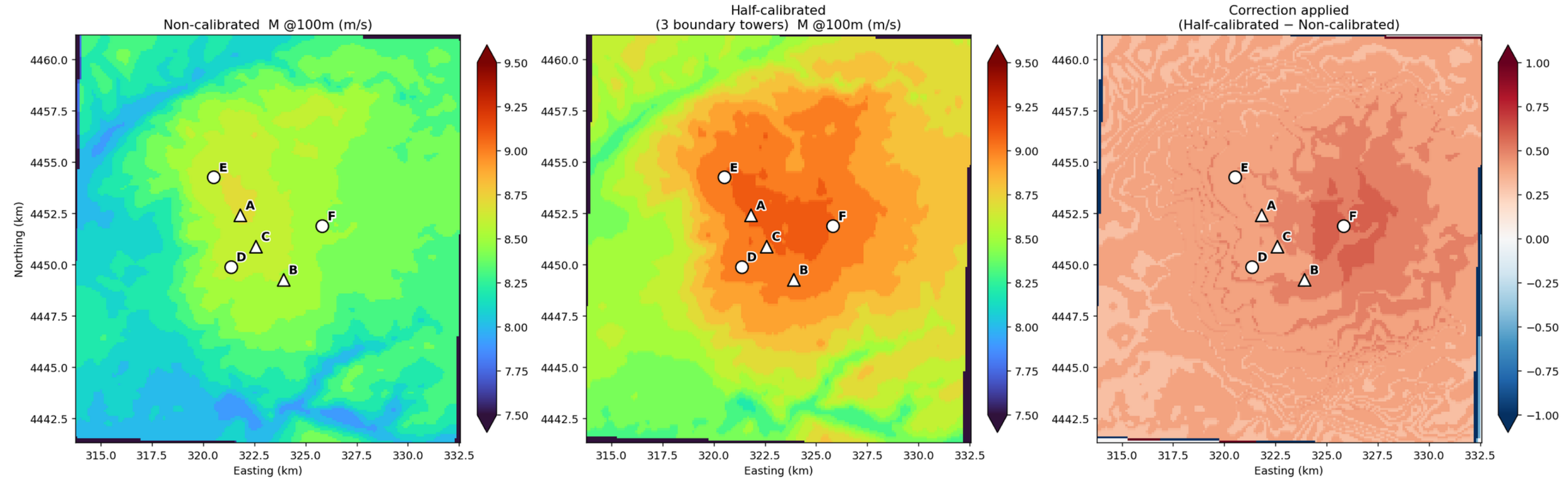
FARM CALIBRATION VALIDATION



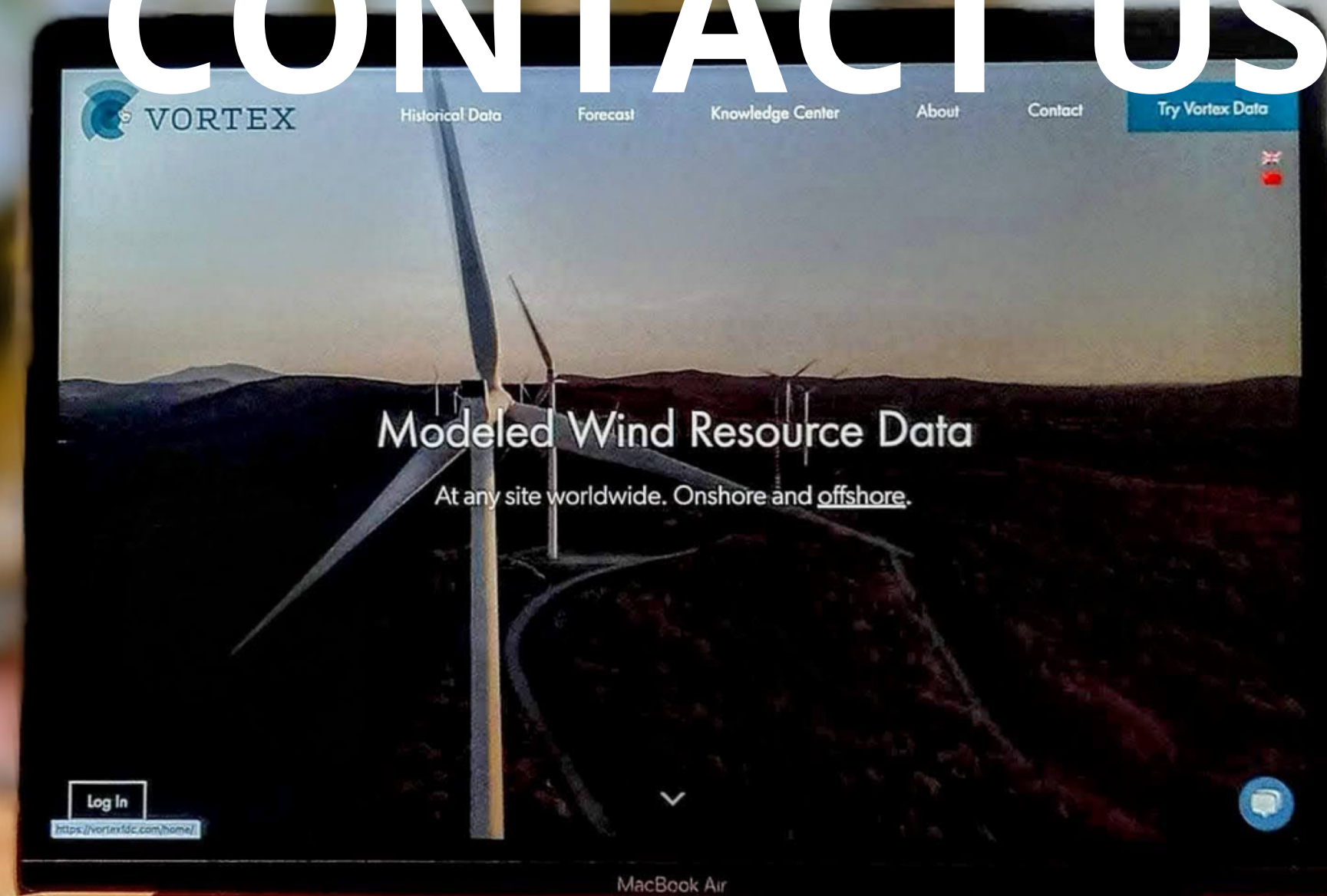
- Leave-one-out cross-validation framework
- Mean wind speed
- 45 wind farm sites
- 138 met towers
- Heights at least 50 m
- Distance at most 50 km

	Non-Calibrated	Calibrated (out-of-training)	Calibrated (in-training)
Mean Wind Speed Bias (%)	2.11 ± 7.53	1.10 ± 5.73	0.01 ± 0.39
Mean Wind Speed Absolute Bias (%)	6.15 ± 4.81	4.45 ± 4.00	0.08 ± 0.38
Wind Histogram Error - EMD	0.58 ± 0.32	0.36 ± 0.26	0.01 ± 0.03
Weibull k Parameter Absolute Bias (%)	12.42 ± 9.48	6.97 ± 6.41	0.16 ± 0.93
TAB rmse	0.26 ± 0.17	0.20 ± 0.14	0.01 ± 0.02

FARM CALIBRATION



CONTACT US



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