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1st virtual EXCELSIOR International Technical Workshop

15 July 2020

Offshore Wind Power Assessment around Cyprus using Sentinel-1 Data

@excelsior2020eu

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Cyprus University of Technology / Eratosthenes Centre of Excellence

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 857510

This project has received funding from the Government of the Republic of Cyprus through the Directorate General of the European's Programmes, Coordination and Development

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Geospatial Analytics Laboratory @ CUT

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Big Earth Data Analytics @ Eratosthenes CoE

Basic Research

- Geostatistics & Spatial Analysis
- Geographic Information Science & Systems
- Geocomputation & Geoinformatics

Application Domains

- Earth and environmental sciences
- Energy and mineral resources
- Hydrology and water resources
- Archaeology and cultural heritage
- Public health
- Urban and regional planning

http://geospatialanalytics.cut.ac.cy/

WELCOME RESEARCH PERSONNEL PROJECTS PUBLICATIONS PRESENTATIONS LINKS

The **Geospatial Analytics** research lab – **geospatial_analytics@CUT** – conducts basic and applied research on spatial analysis, geostatistics, geocomputation and geoinformatics, focusing on geographic information science (GIScience) and systems (GIS), as well as relevant applications in engineering, earth and environmental sciences, and archaeology/cultural heritage. The lab is housed in the Department of Civil Engineering and Geomatics of the Cyprus University of Technology (CUT), in Lemesos (Limassol), Cyprus.

geospatial_analytics@CUT already maintains strong ties with research and academic institutions locally and internationally (Europe, USA, Asia), yet is actively seeking to further expand its collaboration network. The lab's mission is to foster the development of novel methods of geospatial information analysis & modeling, as well as to promote innovative applications of geospatial technologies towards geography-enabled problem-solving and decision-support.

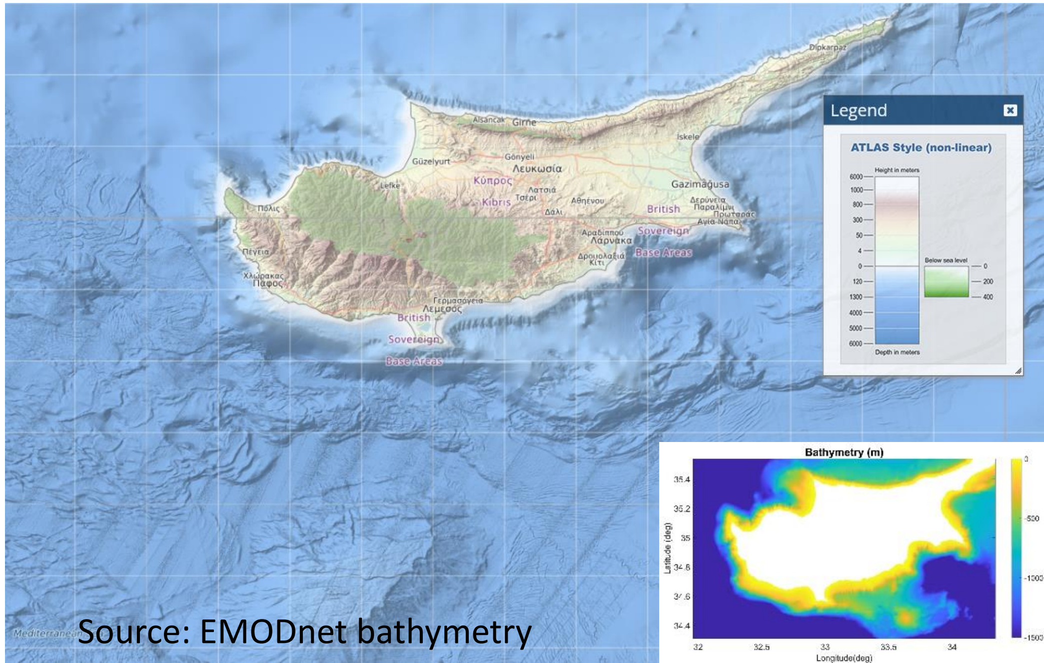
Introduction

Offshore wind offers an excellent opportunity for domestic renewable energy production with a vast potential for future energy systems.

The **offshore wind industry** has grown enormously in recent years, surpassing 25 GW of global cumulative wind capacity as of September 2019.

Cyprus, however, **lags behind this global trend**, as very limited efforts have been made towards the assessment of its offshore wind potential, let alone the undertaking of offshore wind farm installation projects.

Cyprus's **steep bathymetry gradient** implies that any offshore wind farm installation endeavour would be economically viable at relatively small distances from the coast, even in the case of floating wind turbines.



Source: EMODnet bathymetry

Project GeoWindSat

Geostatistical downscaling of wind field predictions using high resolution satellite data

Researchers: Phaedon Kyriakidis (PI), Stylianos Hadjipetrou, Stelios Liodakis, Anastasia Sykioti, Evangelos Akylas, Prof. No-Wook Park (Inha Univ., South Korea)

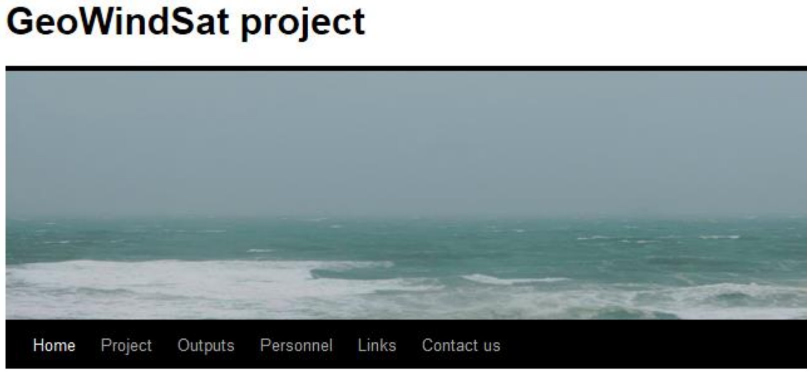
Project **GeoWindSat** aims to refine the relatively coarse **wind** information available for **offshore areas of Cyprus** through numerical weather prediction models, contributing towards a more detailed offshore wind resource assessment for the region

Downscaling of UERRA (Harmonie) reanalysis data is accomplished using satellite data (Sentinel 1A and B) and advanced geostatistical methods for data integration

GeoWindSat also seeks to establish a research collaboration between the Cyprus University of Technology (CUT-Lead Partner-Cyprus) and **Inha University, South Korea**

GeoWindSat is **funded** by the Restart 2016-2020 “International Collaboration – Dual Targeting” Programme of Cyprus’s Research and Innovation Foundation

http://geowindsat.cut.ac.cy/



European Union
European Regional Development Fund

Republic of Cyprus

Structural Funds of the European Union in Cyprus

geoWindsat

Cyprus University of Technology

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Sentinel 1A&B data

Sentinel-1 is a Synthetic Aperture Radar (SAR) constellation of EU's Copernicus Earth Observation program, consisting of two polar orbiting satellites, Sentinel-1A&B, with the same orbital plane operating in the C-band 24 hours daily.

Sentinel-1A launched on 3 April 2014 and **Sentinel-1B on 25 April 2016.** Each satellite has a near-polar, sub-synchronous orbit with a 12-day repeat cycle and 175 orbits per cycle. Since the two satellites share the same orbit with a 180^{o} orbital phasing difference, the repeat cycle is reduced to 6 days.

The **high spatial resolution** of Sentinel provides detailed information on the spatial variability of offshore wind. Sentinel 1A&B data are used for offshore wind resource assessment, as well as for the long-term validation of wind speed measurements from other sources.

Spatial resolutions depend on the **acquisition mode** and the **level of processing**. In particular, there are three levels of processing: Level-1 SLC (Single Look Complex), Level-1 GRD (Ground Range Detected), **Level-2 OCN** (Ocean).

OCN OWI Sentinel data around Cyprus

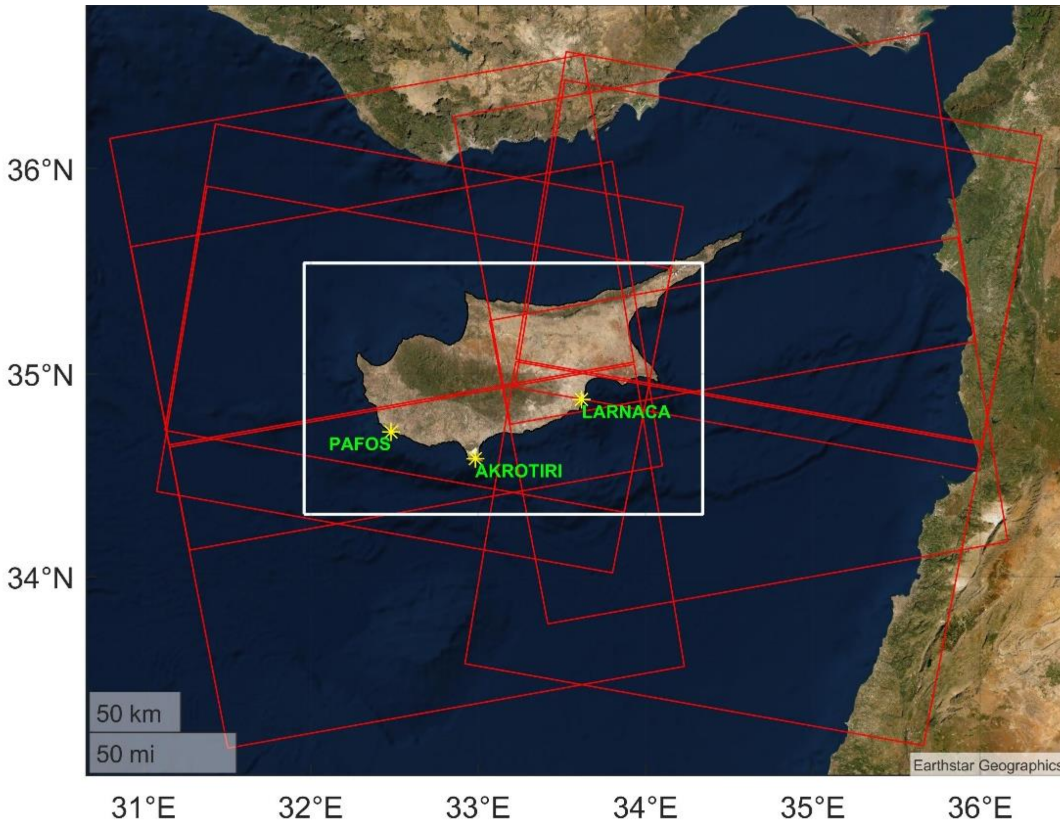
Sentinel wind field (OWI) data from **475** OCN products in Interferometric Wide Swath mode (VV+VH polarization) with a **spatial resolution of 1km** and a time frame from **June 2017 until June 2019**.

Both Sentinel satellites – 1A and 1B – record scenes in the broader offshore Cyprus area approximately at 3:45UTC and 15:45UTC, leading to a (spatially partial) coverage of 1 to 2 scenes per day within a 4-day run, leaving 3 days in between without a scene.

The **tiles/scenes** used along with the location of 3 coastal weather monitoring stations (validation data) are depicted with red outline in the Figure.

Tiles tilting to the right occur when both satellites are **descending**, while tiles tilting to the left occur when satellites are **ascending**.

The **white polygon** corresponds to the outline of the **study area**.



Data pre-processing

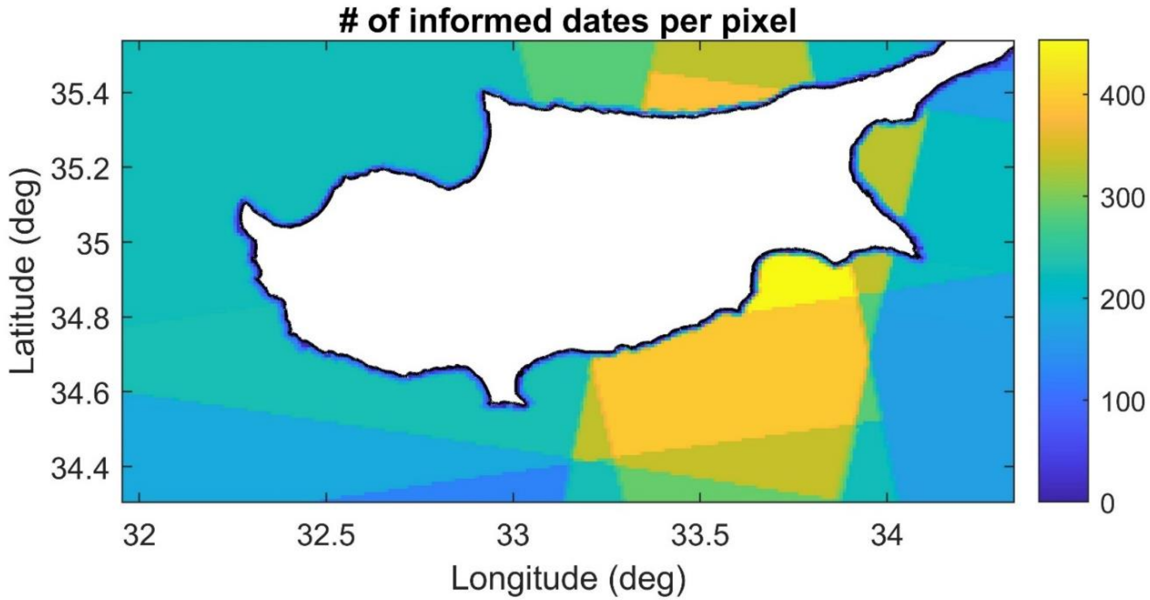
Sentinel-1 Level 2 OCN wind fields are associated with a quality flag at the pixel level, ranging between 0-3 (high quality to bad quality); this is related to the inversion quality, as well as the geophysical and the NRCS quality estimated. *Pixels with quality flag values of 3 (bad quality) were completely discarded from each image.*

Sentinel-1 SAR images exhibit border noise, resulting in artefacts like 0 or extremely low values at pixels lying along the east and west image edges. *Problematic image rows/columns were completely removed from these images.*

Sentinel data correspond to different pseudo-grids almost for each tile. In order to bring all the information to a common basis, all values were **resampled to a regular square grid** by assigning Sentinel pixel values to the closest grid node within a 1km radius.

All tiles partially overlap in space, resulting in different number of values for each node of the resampled grid.

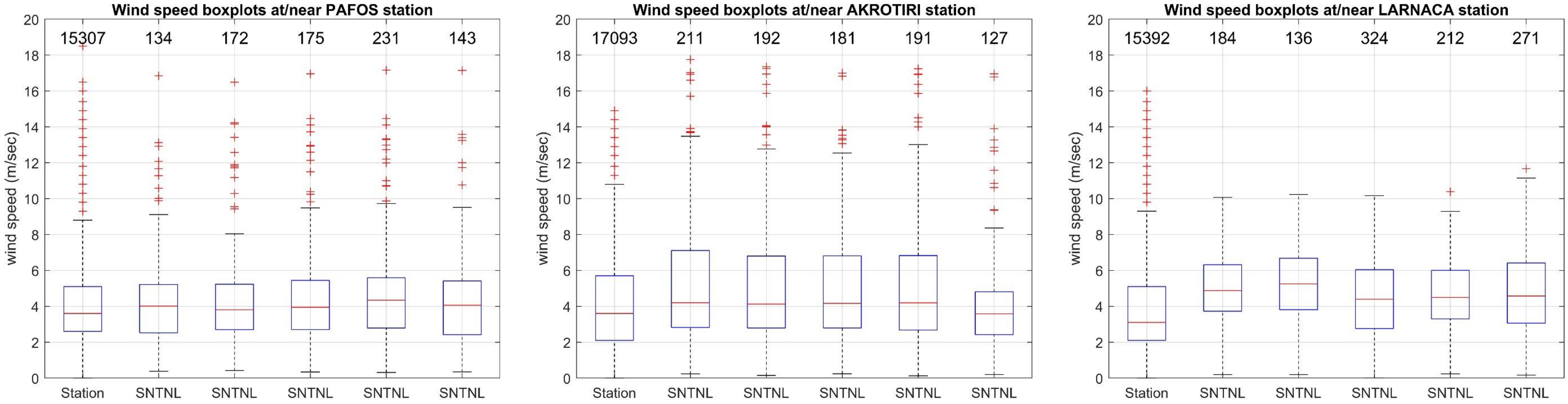
Nodes with many values (~475) lie close to Larnaca, while nodes with fewer values (~250) lie close to Pafos and Akrotiri. *Data at nodes with <65 values, mainly near Cyprus's coastline, were discarded.*



Comparison with station data

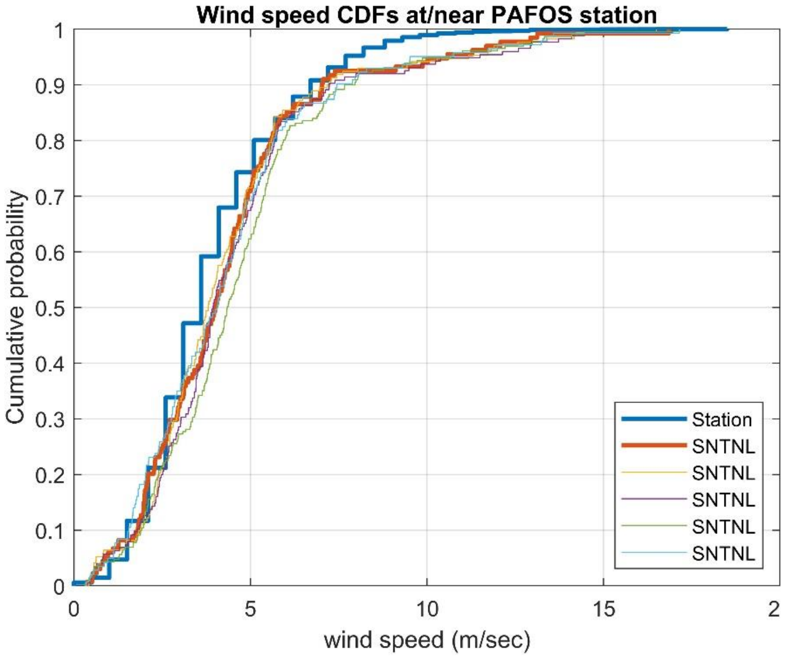
After adjustment of SENTINEL data to station height…

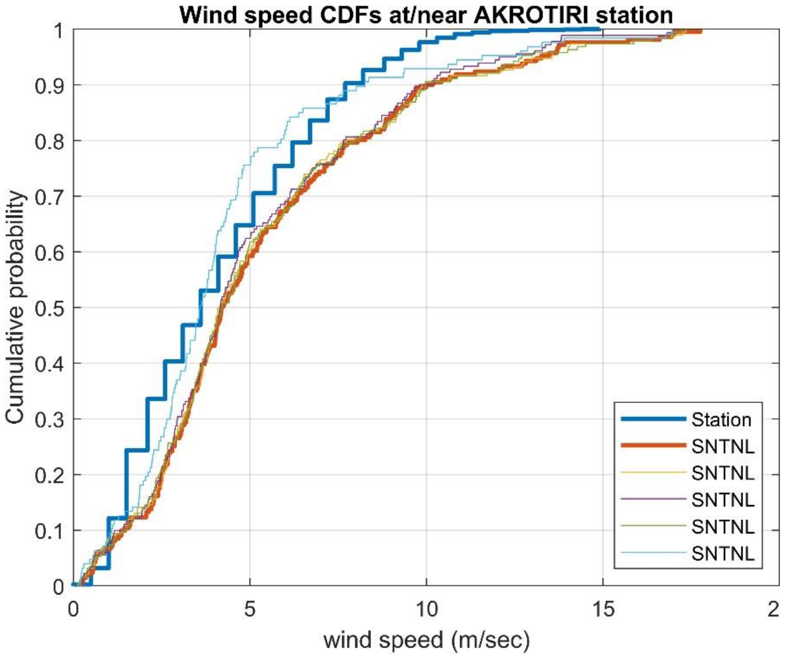
Box plots of **hourly** data at 3 stations and Sentinel values from **5 nearest nodes**
for Pafos (left), Akrotiri (center) and Larnaca (right)

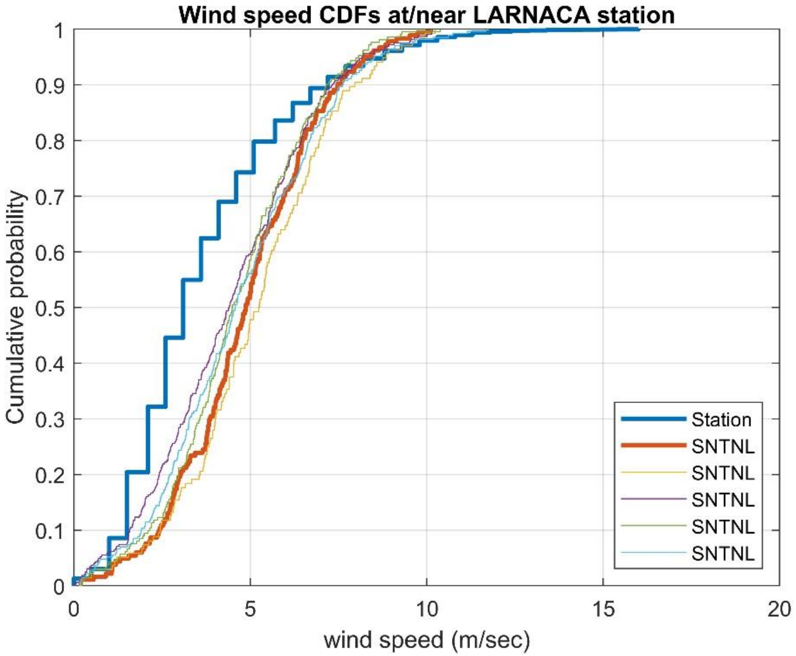


Comparison with station data *After adjustment of SENTINEL data to station height…*

Sample cumulative distribution functions (CDFs) from **hourly** station data and Sentinel values for **5 nearest nod**es for Pafos (left), Akrotiri (center) and Larnaca (right)







Comparison with station data

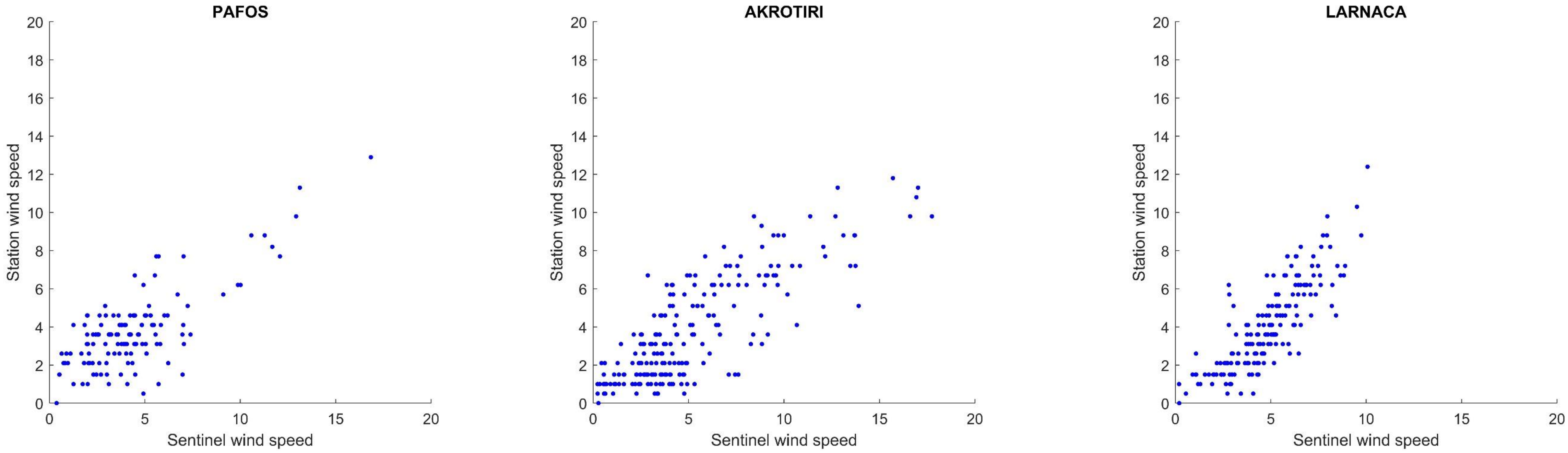
After adjustment of SENTINEL data to station height…

Mismatch statistics between hourly station data and Sentinel values from **nearest node** for Pafos (left), Akrotiri (center) and Larnaca (right)

	Station							SENTINEL						
	N	Mean	Median	Q75	Q90	Std dev	IQR	N	Mean	Median	Q75	Q90	Std dev	IQR
Pafos	15307	3.90	3.60	5.10	6.70	2.07	2.50	134	4.34	4.01	5.22	7.03	2.72	2.69
Akrotiri	17093	4.10	3.60	5.70	7.70	2.65	3.60	211	5.32	4.2	7.11	10.07	3.64	4.29
Larnaca	15392	3.72	3.10	5.10	7.20	2.37	3.00	184	4.89	4.87	6.32	7.49	1.99	2.59

Comparison with station data *After adjustment of SENTINEL data to station height…*

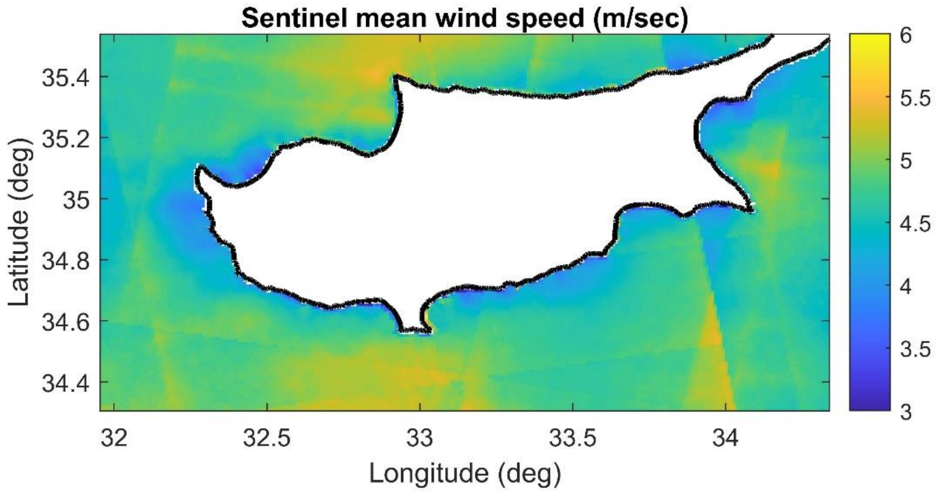
Scatter plots between station data and Sentinel values from **nearest node** for Pafos (left), Akrotiri (center) and Larnaca (right)

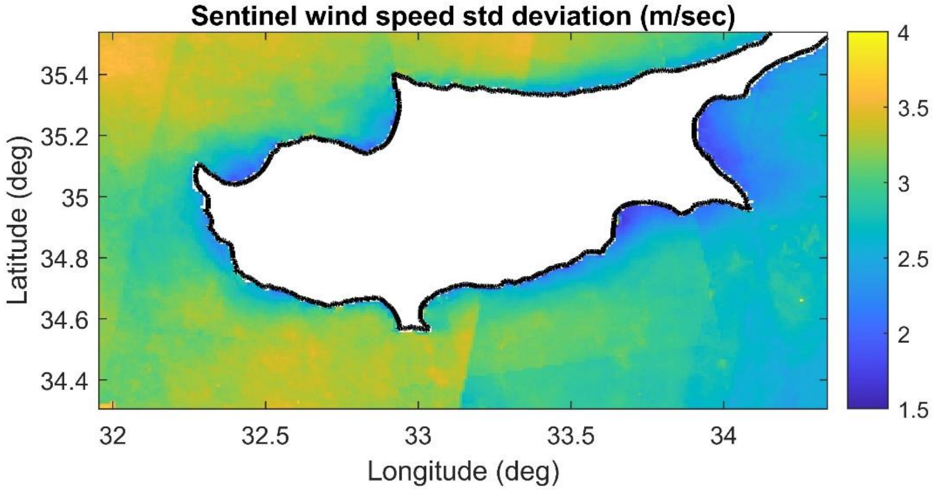


	SENTINEL vs Stations				
	N	Correlation	Bias	RMSE	MAE
Pafos	131	0.76	0.64	1.88	1.48
Akrotiri	206	0.82	1.42	2.54	1.89
Larnaca	177	0.83	0.79	1.50	1.23

Sentinel-1 offshore wind speed statistics per grid node

Sample (Sentinel-1 Level 2 OCN) statistics of wind speed values (at 10m from sea surface) at each grid node mean (left) and standard deviation (right)

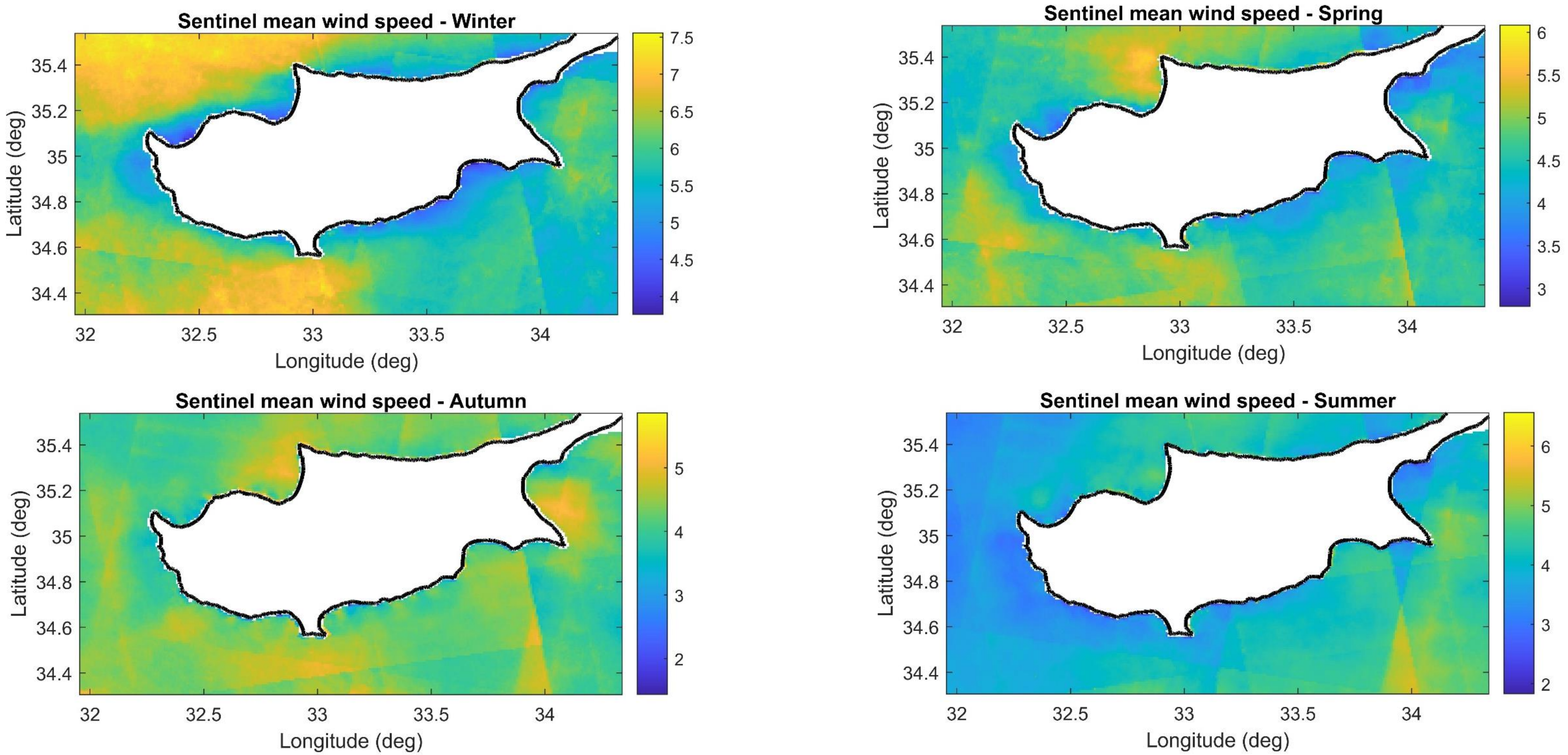




Other sample statistics include the median, interquartile range, coefficient of variation, etc…

All statistics can also be computed for smaller time periods, e.g., on a monthly or seasonal basis…

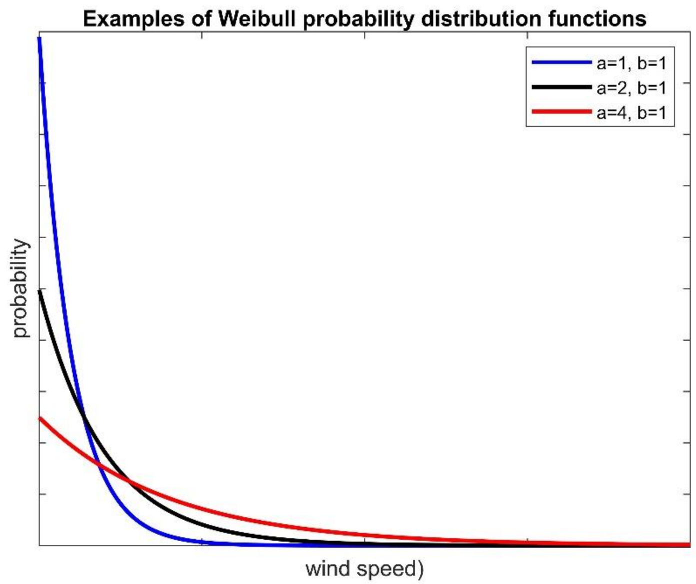
Sentinel-1 average wind speed per grid node – per season

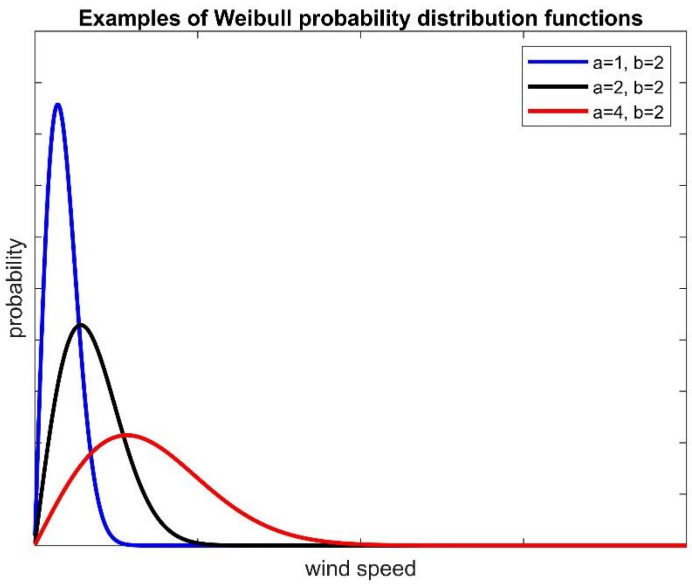


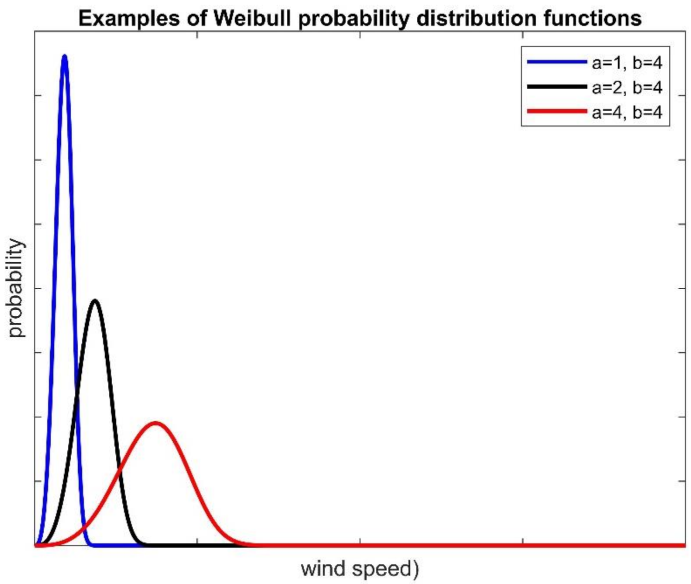
Weibull distribution

$$f(s;a,b)=\left(\frac{b}{a}\right)\left(\frac{s}{a}\right)^{b-1}\exp\left(-\left(\frac{s}{a}\right)^{b}\right),\quad s,a,b>0$$

The statistical distribution of (sample) wind speed values (*s*) over time is usually modeled using a theoretical **Weibull probability distribution function** (PDF); other distribution models, e.g., Rayleigh, have also been used…







a is the **Weibull scale parameter** in m/sec; a measure of how windy a site is.

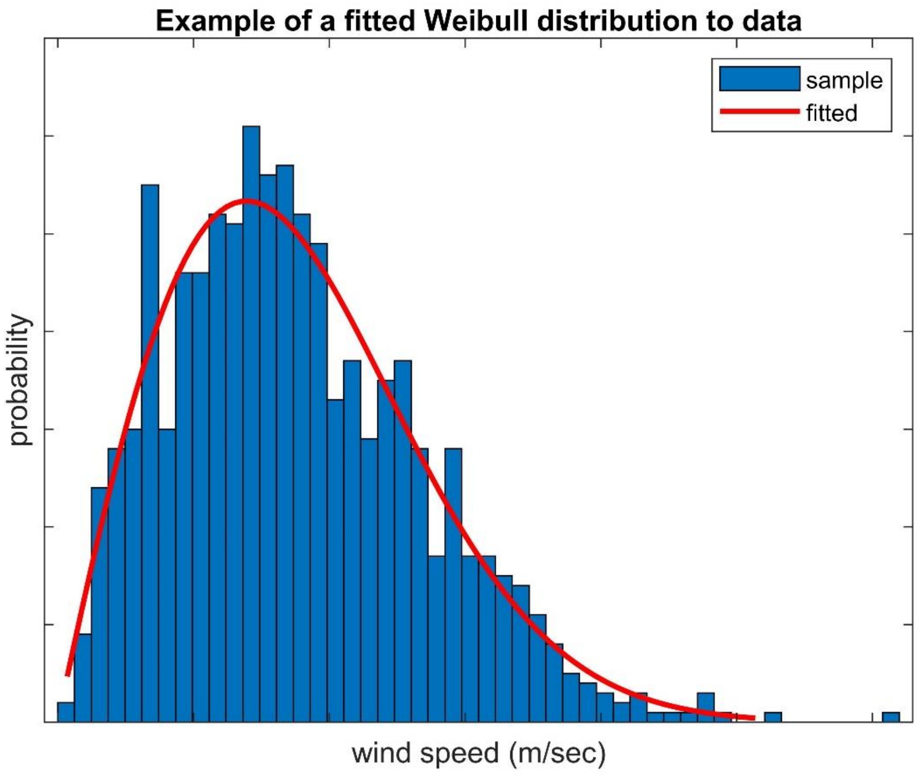
b is the **Weibull shape parameter**. It specifies how peaked the Weibull distribution is.
A small value for b signifies very variable wind speed values, while near constant wind speeds are characterized by a larger b.

Weibull distribution fitting

The theoretical PDF is **fitted** to the sample wind speed data by **estimating the parameters** (a and b of the Weibull distribution), so that some **measure of agreement** between the model-derived and the sample statistics (or quantiles and/or probabilities) is maximized

Parameter estimation procedures include least-squares, method of moments, maximum likelihood, and variations thereof; in this study, the **maximum likelihood** method was adopted.

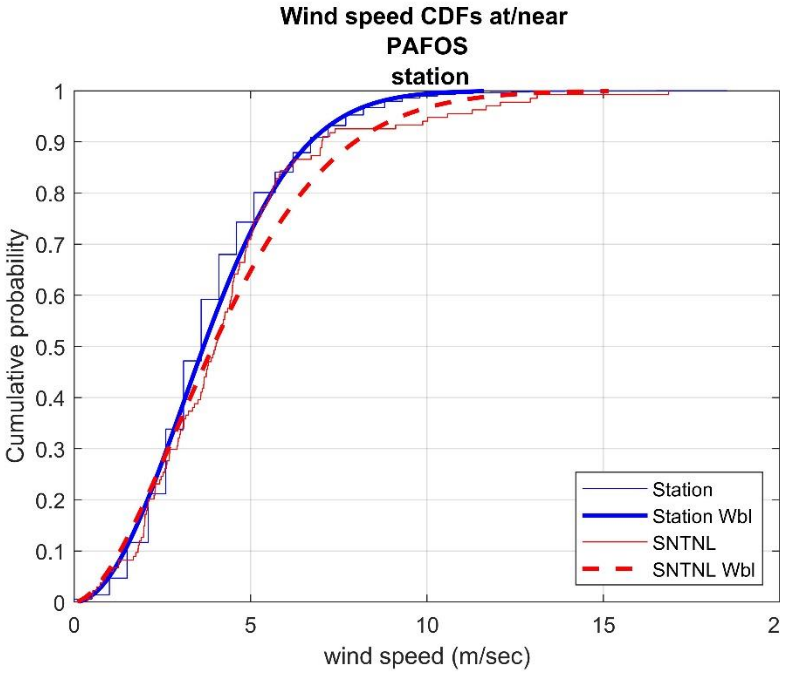
Goodness-of-fit statistical tests can also be used (albeit with caution) for deciding on the adoption of alternative PDF models

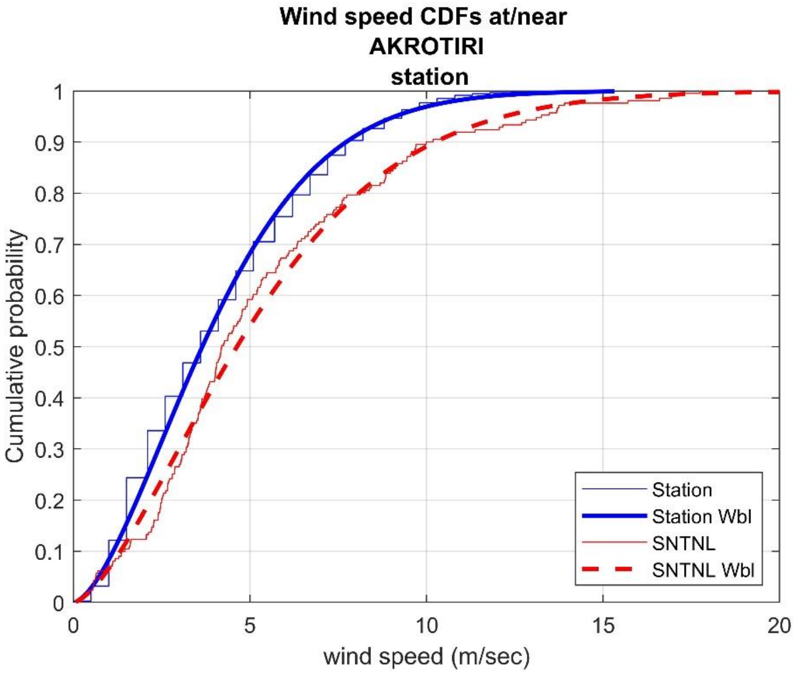


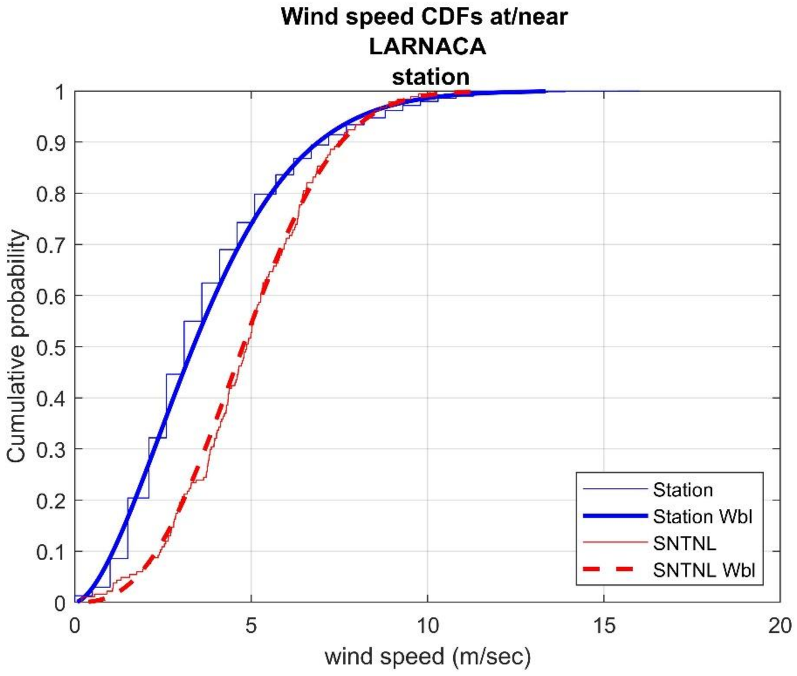
Comparison with station data

After adjustment of SENTINEL data to station height…

Sample and fitted Weibull CDFs for station data and Sentinel values from **nearest node** for Pafos (left), Akrotiri (center) and Larnaca (right)

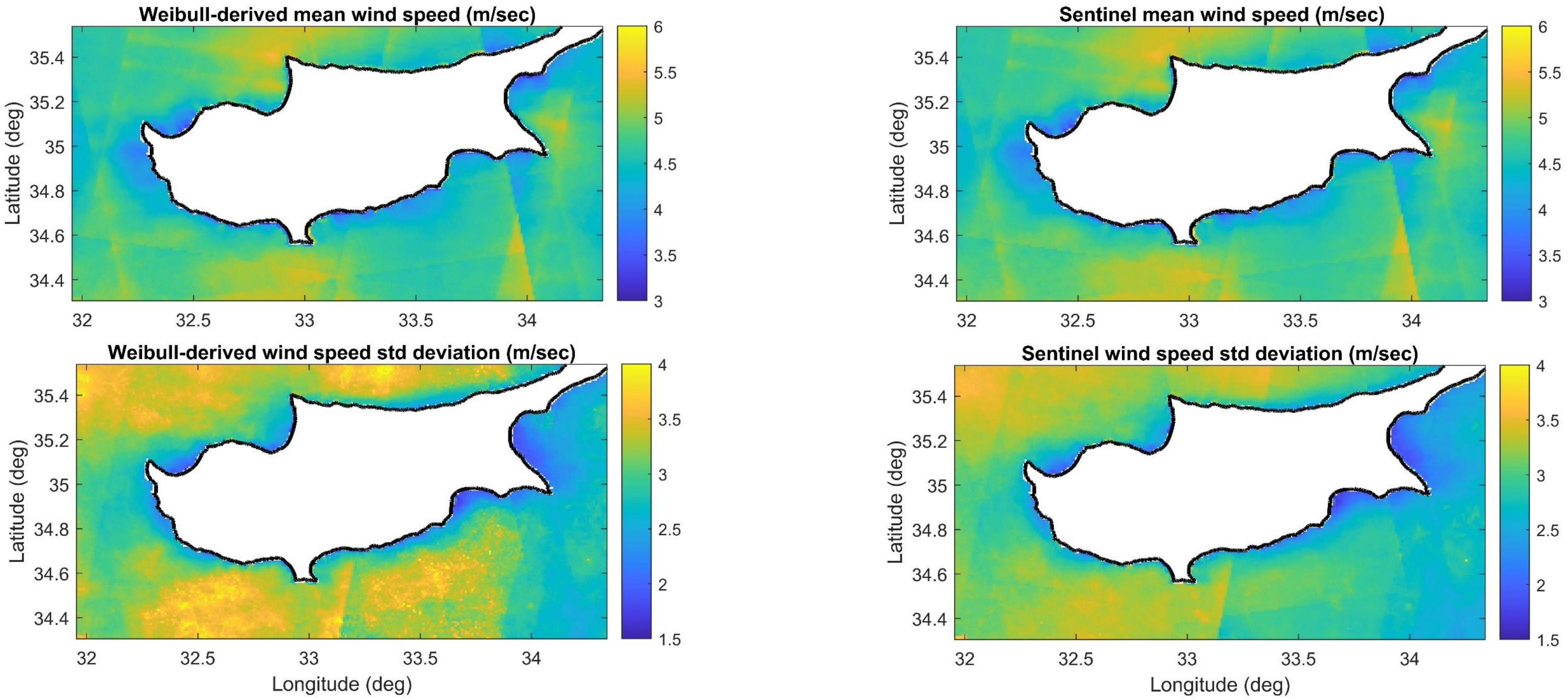






Weibull-derived offshore wind speed statistics per grid node

Weibull-derived (Sentinel-1 Level 2 OCN) statistics – mean and std deviation of wind speed values at each grid node (left) and corresponding sample statistics (right).



Wind power density

The **average wind power density** *P* in (W/m²), is the average kinetic energy passing through a unit of surface per unit of time, and represents a key quantity in **wind resource assessment studies**.

When **wind speed time series are available**, P can be estimated directly from the data as: $P_S = 0.5\rho \frac{1}{N}\sum_{i=1}^{N} s_i^3$

where ρ is the air density (1.225 g/m^3 at 15°C) and s_i is the wind speed value.

When a **Weibull distribution** is fitted to sample data, the average wind power density is expressed in terms of the Weibull PDF parameters (a and b) as:

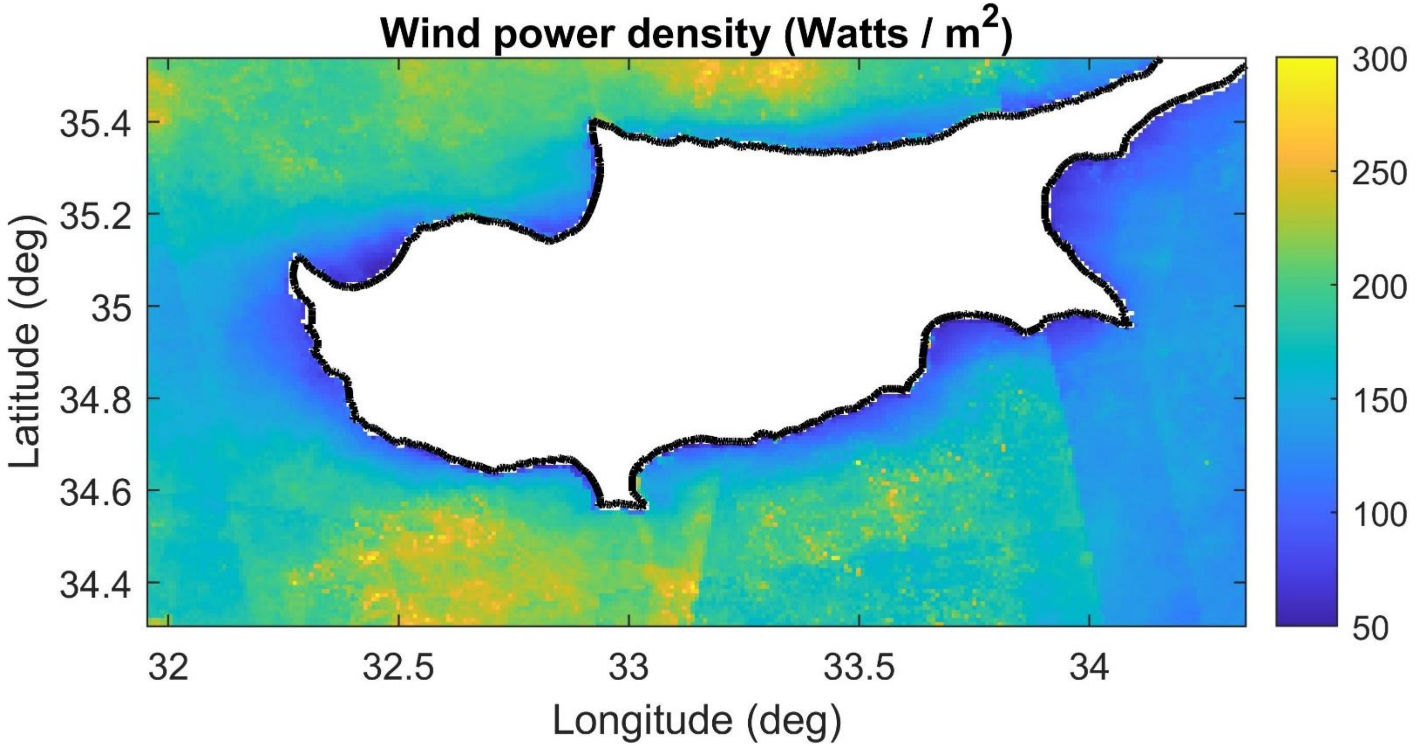
$$P_W = 0.5\rho a^3 \Gamma\left(1 + \frac{3}{b}\right)$$

where $\Gamma(\ )$ is the Gamma function.

This is a shortcut to the estimation of wind power density via integration as: $P_W = 0.5\rho \int s^3 f(s;a,b)\,ds$

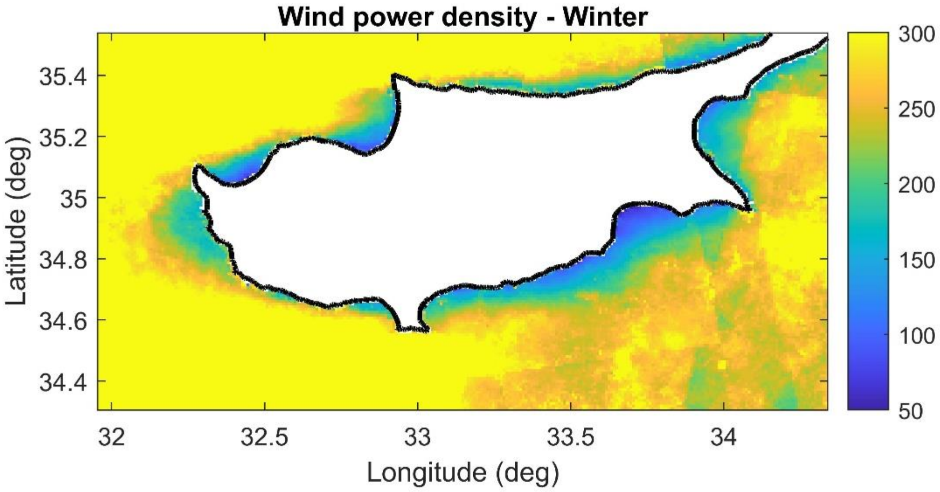
Wind power density per grid node

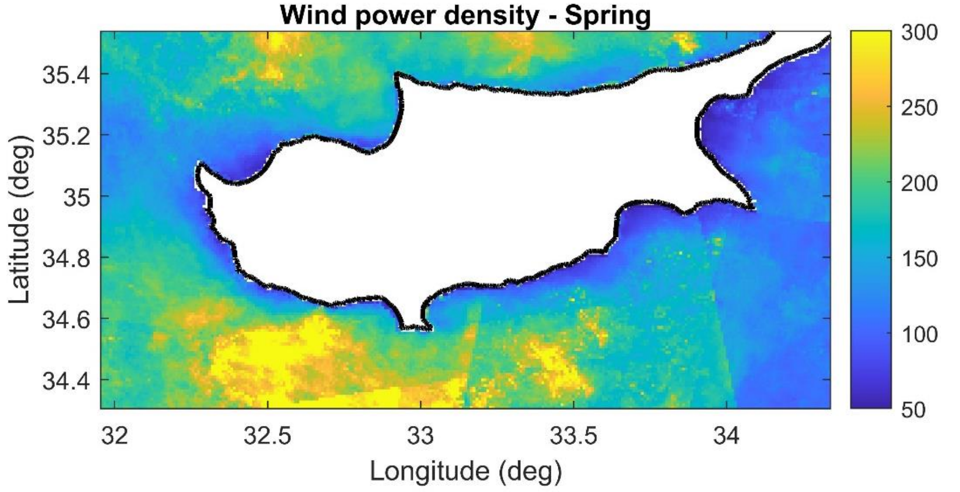
Over the 2-year period of interest



Rating	Wind Power Class*	10 m (33 ft) Wind Power Density (W/m²)	Speed[b] m/s (mph)
		0	0
Poor	1		
		100	4.4 (9.8)
Marginal	2		
		150	5.1 (11.5)
Fair	3		
		200	5.6 (12.5)
Good	4		
		250	6.0 (13.4)
Excellent	5		
		300	6.4 (14.3)
Outstanding	6		
		400	7.0 (15.7)
Superb	7		

Wind power density per grid node – per season





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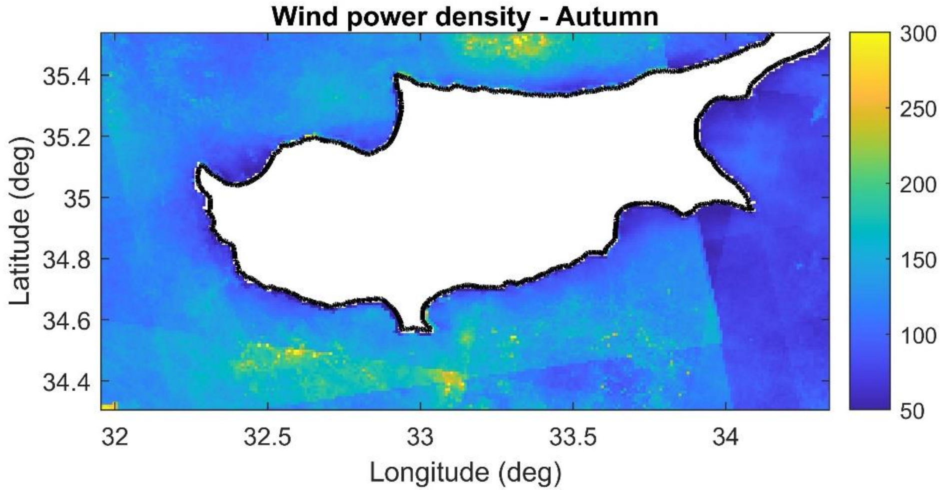

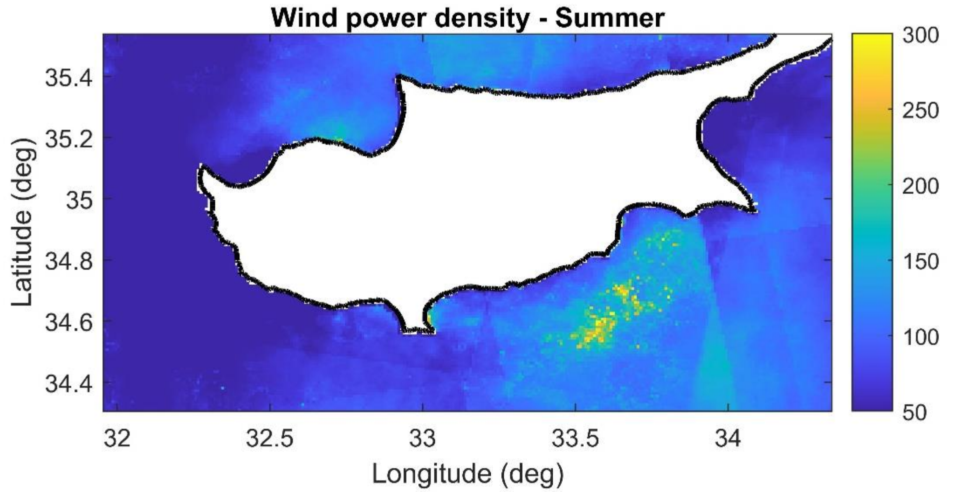

Ongoing and future work

Extension of SENTINEL time series by incorporating processed GRD data from 2016 to 2017 from DTU's service, and **comparison with data from more coastal stations** in Cyprus.

Integration of coarse spatial resolution (11km) and high frequency (6hour) **reanalysis data** (UERRA Harmonie) with Sentinel 1A&B data for improved characterization of wind speed distributions at a fine spatial resolution (1km).

Integration can be achieved via different means, such as conflation of distributions, regression models developed at each grid node linking coarse (reanalysis) and fine (Sentinel) resolution data, or geostatistical downscaling of the parameters of Weibull distributions derived from different data sources at each node.

Comparison with and integration of **other data sources**, such as: COSMO-REA6 (6km), New European Wind Atlas (3km), CERRA (5.5km)…

Assessment of the uncertainty in wind power density estimation and implications for the selection of sites for potential offshore windfarm installation.

Offshore Wind Power Assessment around Cyprus using Sentinel-1 Data

THANK YOU FOR YOUR ATTENTION

Phaedon Kyriakidis

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Proposal acronym: EXCELSIOR

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