Exploring Cold-Climate Wind-Energy Modelling and Ice-Mapping with the New Copernicus Regional Reanalysis for Europe (CERRA) Dataset

Morten Lybech Thøgersen, mlt@emd.dk [presenter]
Marie Cecilie Pedersen, mcp@emd.dk
Lasse Svenningsen, ls@emd.dk
Thorkild Guldager Sørensen, tgs@emd.dk

2023-03-13; 1.0

Why this study and presentation on CERRA: Copernicus Regional Reanalysis for Europe? (1/2)

KNOWN KNOWNS

- High-Resolution Regional Reanalysis (5.5km)
- Part of the EU Copernicus System
  (Open and free; thus very cost-efficient to use)
- Developed by SMHI
  (Meteo-France & MET-Norway as subcontractors)
- Data assimilation used (3D-Var Scheme)
- Data from 1984-04 to 2021-06
- Delivers all parameters needed for ice-losses
- HARMONIE-ALADIN model instead of WRF
- Heights 25m to 500m above ground level

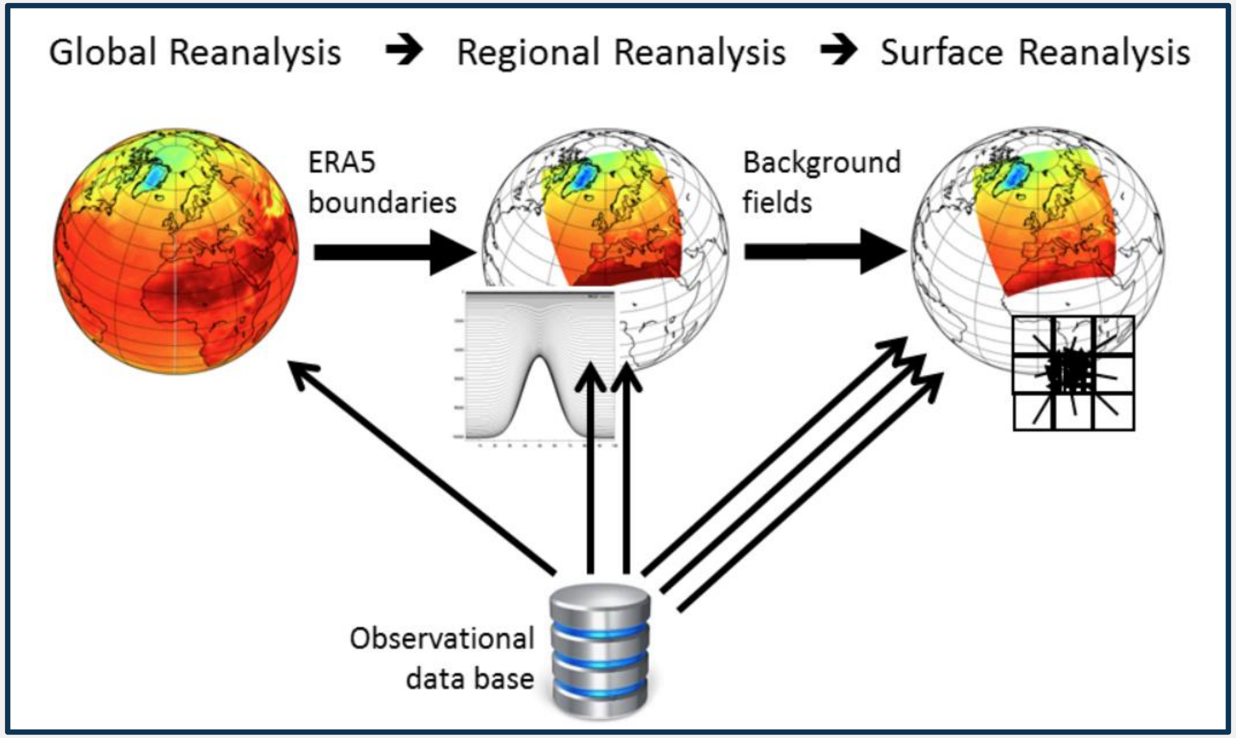


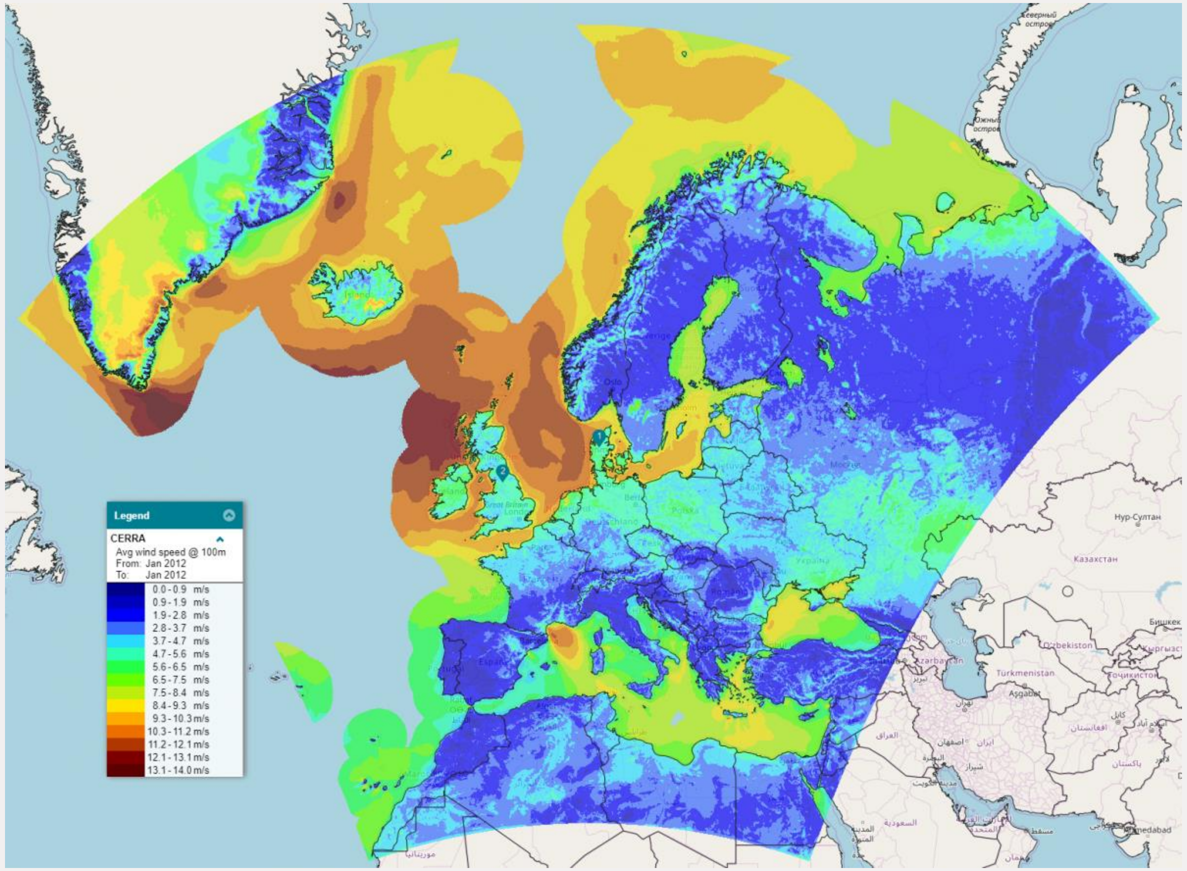
Image Credit: Copernicus

KNOWN UNKNOWNS

- Not-So High-Resolution Regional Reanalysis (5.5km)
- No near real-time updates
- Unknown release schedule for new data? 2023, 2024?
- ERA5 is replaced by ERA6 (2024?)

windPRO

Why this study and presentation on CERRA: Copernicus Regional Reanalysis for Europe? (2/2)



Spatial domain for the CERRA mesoscale data in windPRO and EMD-API, coverage approx. 300km from the coastline)

PARAMETERS FROM DATASET

- Wind Speed and Direction at heights
- TKE at heights
- Pressure at heights
- Temperatures at heights
- Relative humidity
- Cloud Water + Cloud Ice at heights
- Cloud Cover
- Gusts
- Precipitation
- Solar irradiation
- Roughness lengths & orography

(80 in total in windPRO and EMD-API, more at the Copernicus Data Store)

windPRO

How is the CERRA data performing for general wind-energy use-cases?

Statistics 194 masts	Dataset CERRA	 EMD-WRF EUR+	 ERA5
Wind speed, 10 min, R^2 mean(R^2) ± std(R^2)	0.73 ± 0.10	0.73 ± 0.09	0.70 ± 0.14
Wind speed, daily average, R^2 mean(R^2) ± std(R^2)	0.88 ± 0.07	0.89 ± 0.06	0.85 ± 0.11
Wind direction, MAE [deg] mean(MAE) ± std(MAE)	36 ± 11	36 ± 11	38 ± 12
Bias - Avg. wind speed [m/s] mean(BiasWS) ± std(BiasWS)	-1.0 ± 0.8	0.2 ± 0.7	-1.3 ± 1.2
Wind distribution, CV error [%] mean(CV error) ± std(CV error)	-0.8 ± 6.6	0.5 ± 6.6	-1.0 ± 8.5

Legend: green – best performance, blue = second-best, red – worst performance


Niels Jernes Vej 10 | DK-9220 Aalborg Ø
tel: +45 6916 4850 | e-mail: emd@emd.dk

Memo: Accuracy of Wind Speeds in Copernicus Regional Reanalysis for Europe, CERRA

Authors: Morten Thøgersen (mlt@emd.dk), Lasse Svenningsen (ls@emd.dk), Thorkild G. Sørensen (tgs@emd.dk), 2022-12-28

Introduction

How accurate is the CERRA data when used for renewable energy modelling? How does it benchmark against other widely used mesoscale datasets? This note gives a hint by analysing some important metrics, R^2 correlation and distribution-bias, from almost 200 tall and high-quality meteorological masts from within the Pan-European area.

Approach

Wind speeds obtained from CERRA data have been evaluated by comparing against mast-measurements. The approach is to:

- Limit to masts with 100m wind speed > 5.50 m/s (from GASP)
- Wind speeds taken from top anemometer with limitation on mast-heights to the range from 80m to 120m
- Statistics (mean, std) on important metrics for all masts and all 3 datasets (CERRA, EMD-WRF EUR+ & ERA5):
  - *Wind speed correlation, 10 min + day, R2:* Correlation on 10-minute wind speeds and daily averaged values
  - *Wind direction, MAE:* Sample statistics on wind direction error (in degrees)
  - *Bias - Avg. wind speed:* Bias in annual average mean wind speed (in m/s)
  - *Wind distribution – CV-error:* Error in coefficient of variation (in percent)

KDE probability density of 10min R^2 correlations for wind speed. Based on almost 200 masts.

Results – Selected Metrics – almost 200 masts in all terrains

The table below summarizes the statistics for the R2-correlation histogram shown in the figure above and the other metrics.

Statistics 194 masts	Dataset CERRA	 EMD-WRF EUR+	 ERA5
Wind speed, 10 min, R^2 mean(R^2) ± std(R^2)	0.73 ± 0.10	0.73 ± 0.09	0.70 ± 0.14
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Legend: green – best performance, blue = second-best, red – worst performance

Findings

- *R^2-correlation:* The two mesoscale datasets CERRA and EMD-WRF EUR+ performs equally well. ERA5 has a lower R^2-correlation than the other 2 datasets.
- *Wind direction:* The CERRA, EMD-WRF EUR+ and ERA5 datasets have an equal performance – and are very similar.
- *Bias in annual wind speed:* CERRA and ERA5 has a quite large average by bias' in mean wind speeds. The ERA5 bias can be explained (large negative bias) due to the missing mesoscale-effects. The negative bias in CERRA is likely due to a coarser model spatial resolution 5.5km in CERRA vs 3km in the EMD-WRF EUR+.
- *Wind distribution, CV error:* EMD-WRF EUR+ is best performing (coefficient of variation is closely linked to Weibull k).
- *Generally:* The CERRA mesoscale data has a satisfactory performance and is suitable for renewable energy applications.

Endnotes

Read more on the CERRA and the other datasets at the windPRO wiki and knowledge-base:
- CERRA: https://help.emd.dk/mediawiki/index.php?title=CERRA
- Other datasets: https://help.emd.dk/mediawiki/index.php?title=Category%3AWind_Data

KNOWN KNOWNS

- Not used so much – only 2% of downloads in windPRO
- Validation one-pager paper freely available at:
  https://help.emd.dk/mediawiki/index.php/CERRA

The Idea:
Use the existing technology with new CERRA data (1/3)

The EMD-WRF On-Demand icing modelling chain relies on industry proven standards.

Atmospheric Data:

WRF + Thompson microphysics

Resolution: 3x3 km, 1 h

ERA5 global boundary conditions
or other reanalysis data

→

Ice Model:

Standard cylinder-based ice model (ISO 12494)

- Ice growth rate,
  ice load and instru. + meteo. icing hours

→

Production Loss Estimations:

Production loss estimates using:

IEA Ice Class system

(by IEA Task 19)

↓

Downscaling to 30m using **CopernicusDEM**

Sketch of EMD-WRF OD Icing modelling chain.

The Idea:
Use the existing technology with new CERRA data (2/3)

EXISTING EMD-WRF ICING

Model Setup
- Model: WRF
- Resolution : 3 km
- Time Span: 1993-present
- Land Use: GlobCover (300m)

Parameterization Schemes
- Microphysics: Ferrier or Thompson
- Surface layer: Janjic
- Planetary boundary layer: Mellor-Yamada-Janjic
- Land-surface model: Noah
- Radiation: GFDL

Global Boundary Data
- ERA5 (default setup)
- ERA-Interim
- MERRA2
- CFSR

NEW EMD-CERRA ICING

Model Setup
- Model: HARMONIE-ALADIN
- Resolution : 5.5 km
- Time Span: 1984-01 to 2021-06
- Land Use: ? SURFEX V8.1

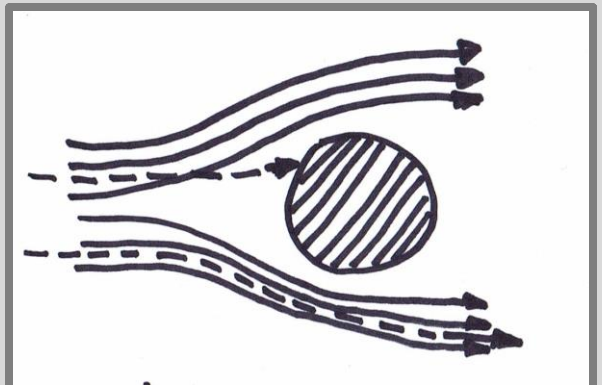
Parameterization Schemes
- Microphysics: ? ICE3 mixed phase
- Surface layer: ?
- Planetary boundary layer: ?
- Land-surface model: ?
- Radiation: ?

Boundary Data
- ERA5
- 3D-Var data assimilation

? = Model not explicitly stated

EMD ICING MODEL SETUP

- Makkonen / ISO 12494
- In cloud icing cylinder
- Downscaled mesoscale-model data
- Pressure, temp, cloud water, winds
- dm/dt > 10g/h
- Heights: Up to 500m / 1000m
- 10 winters for seasonal analysis



$$\frac{dm}{dt} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot w \cdot A \cdot v$$

The Idea:
Use the existing technology with new CERRA data (3/3)

Results: Stor Rotliden Case (1/4)
Some side-by-side model comparisons

IEA ICE-CLASS	DURATION OF METEOROLIGICAL ICING [% OF YEAR]	DURATION OF INSTRUMENTAL ICING [% OF YEAR]	PRODUCTION LOSS [% OF AEP]
5	> 10.0	> 20.0	> 20.0
4	5.0 – 10.0	10.0 – 30.0	10.0 – 25.0
3	3.0 – 5.0	6.0 – 15.0	3.0 – 12.0
2	0.5 – 3.0	1.0 – 9.0	0.5 – 5.0
1	0.0 – 0.5	< 1.5	0.0 – 0.5

IEA Task 19 Ice Classes

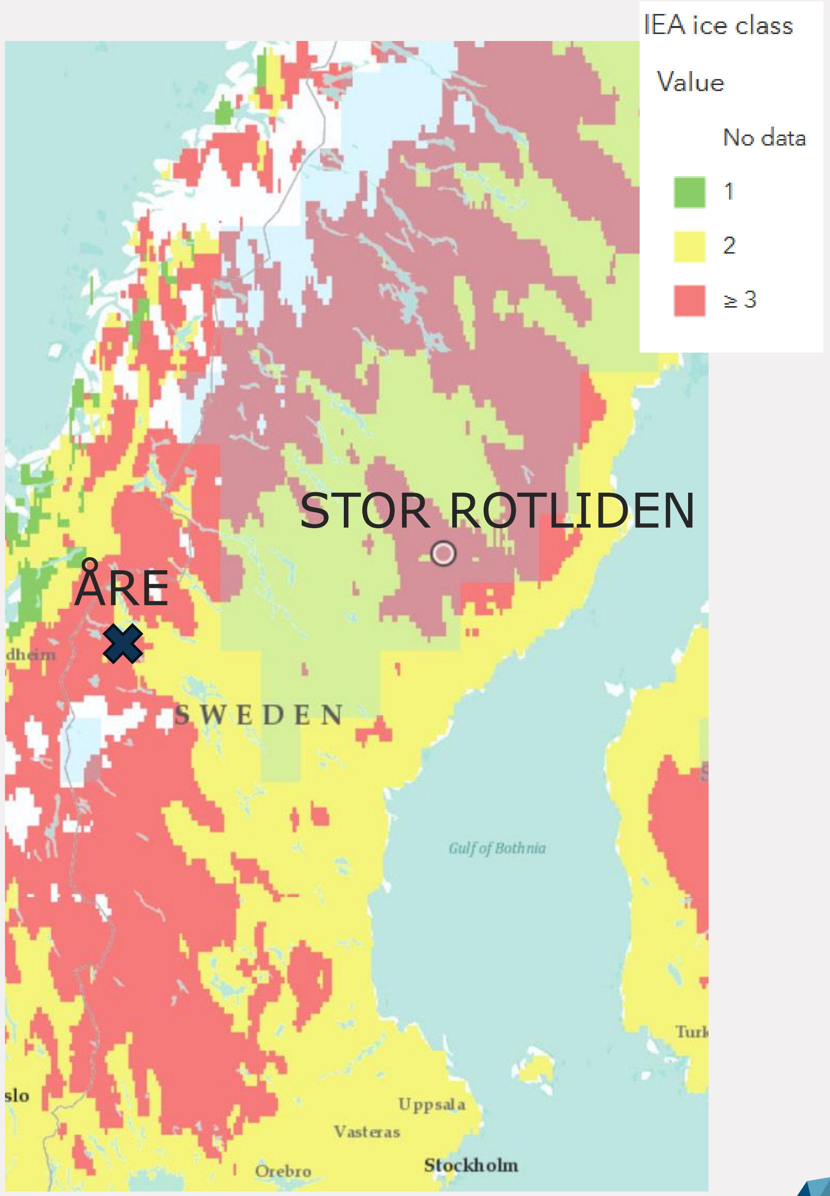
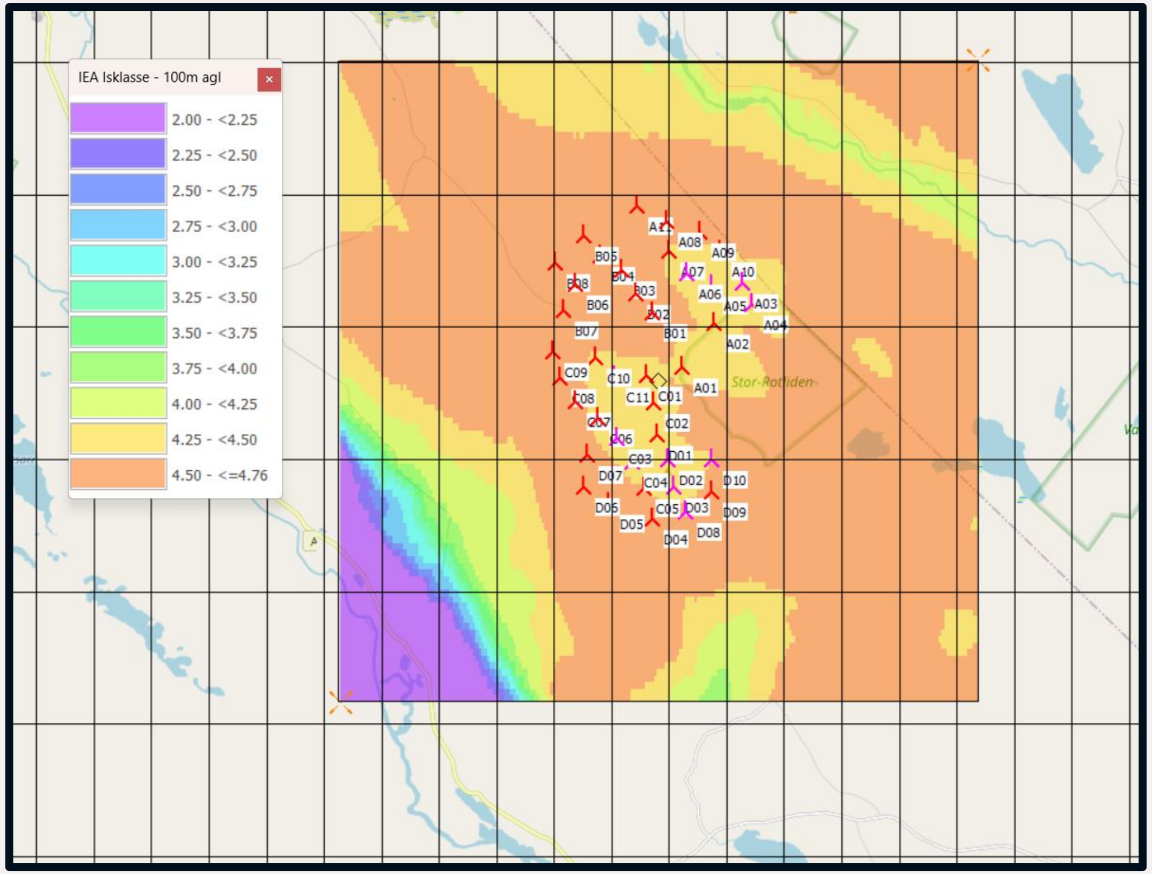
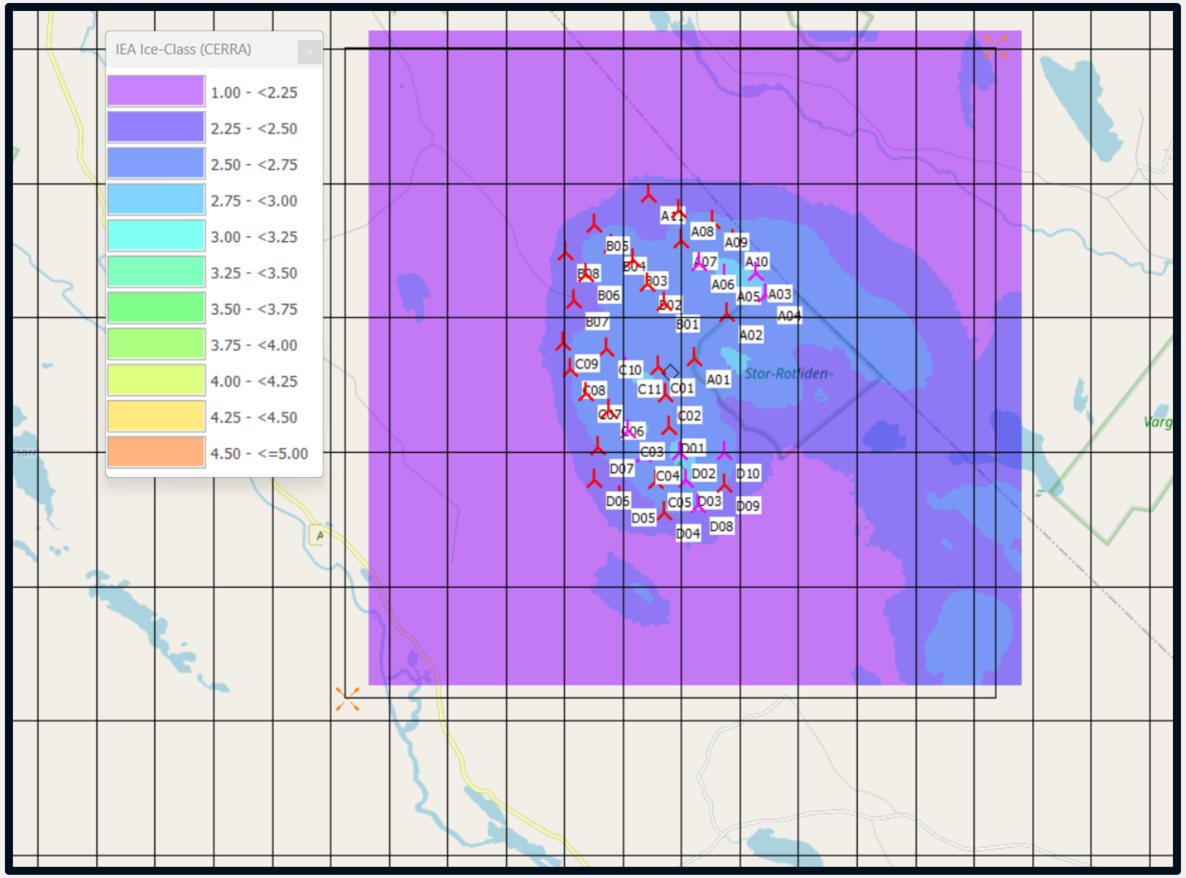


Image Credit: VTT Public WIce Map
From https://projectsites.vtt.fi/sites/wiceatlas

Results: Stor Rotliden Case (2/4)
Icing Losses – by EMD-WRF On-Demand Icing and EMD-CERRA Icing



EMD-WRF On-Demand ICING



EMD-CERRA ICING

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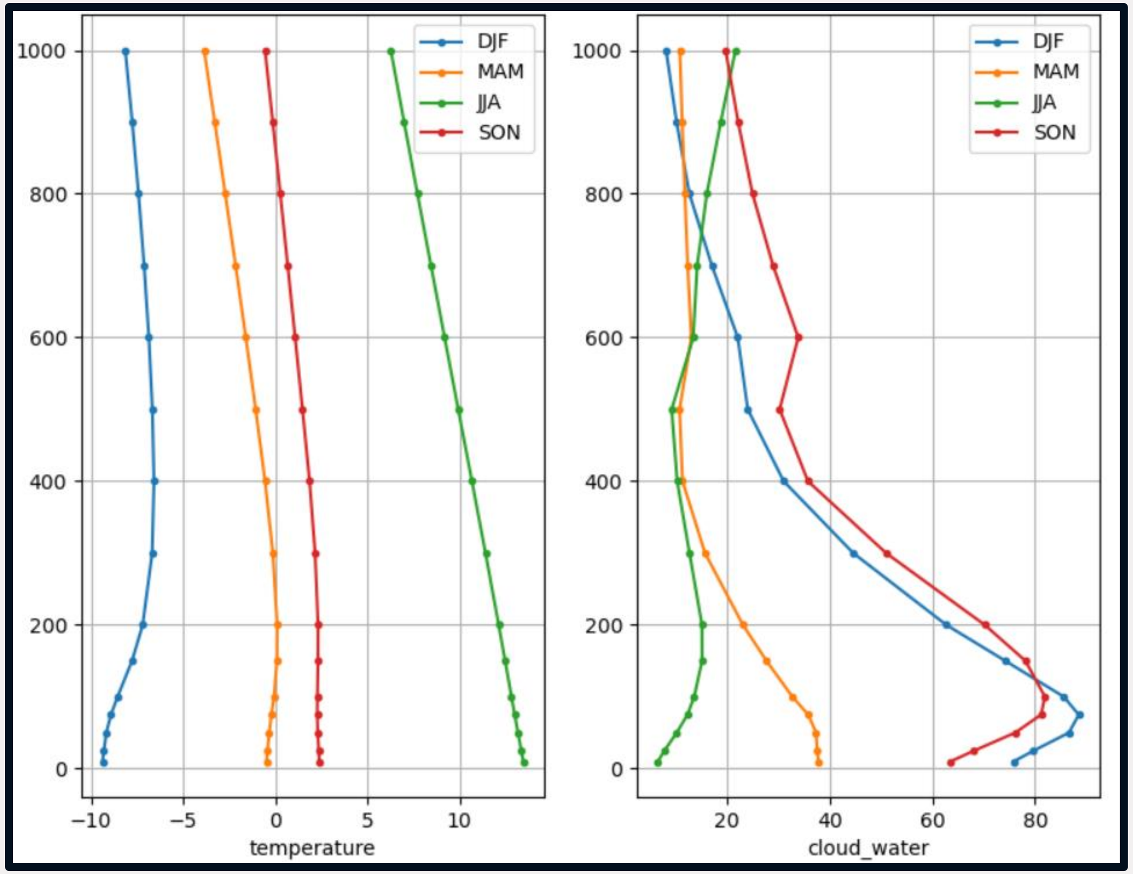
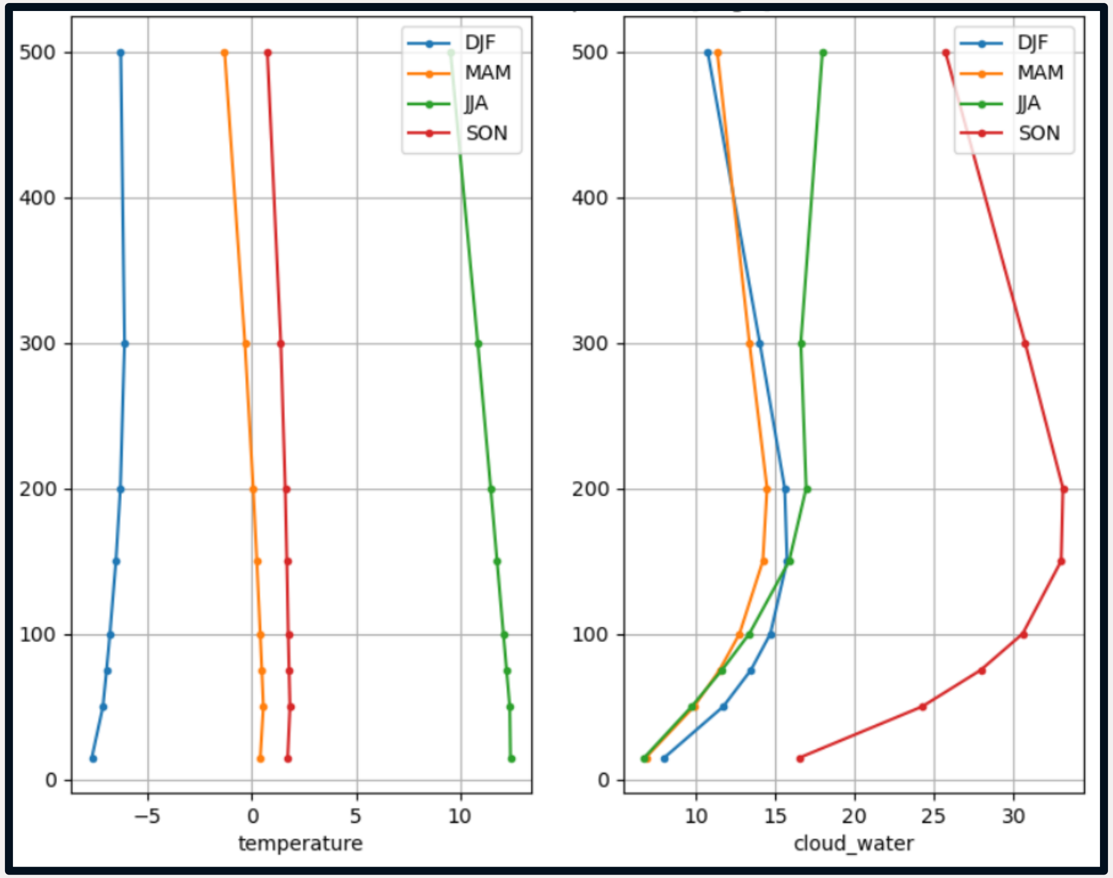
Units:
Temperature [degC]
Cloud-Water [µg/kg]

Results: Stor Rotliden Case (4/4) Vertical Profiles for Four Seasons



EMD-WRF On-Demand ICING
Yearly Precipitation = 788 mm



EMD-CERRA ICING
Yearly Precipitation = 877 mm

windPRO

Results: Stor Rotliden Case (4/4)
Microphysics Model and Cloud Ice

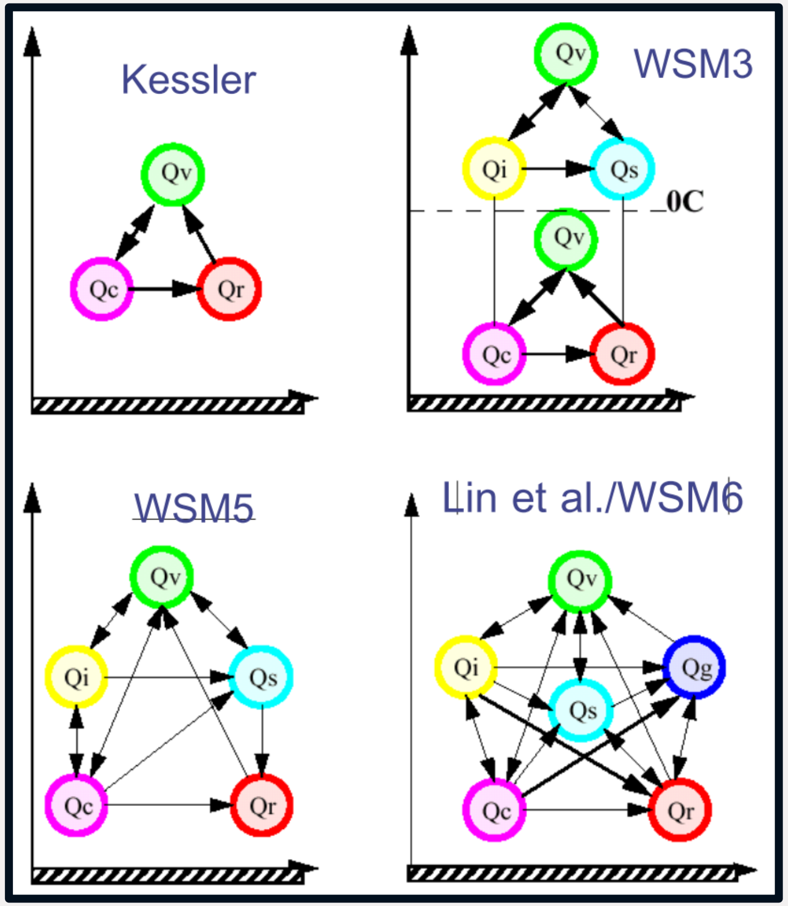
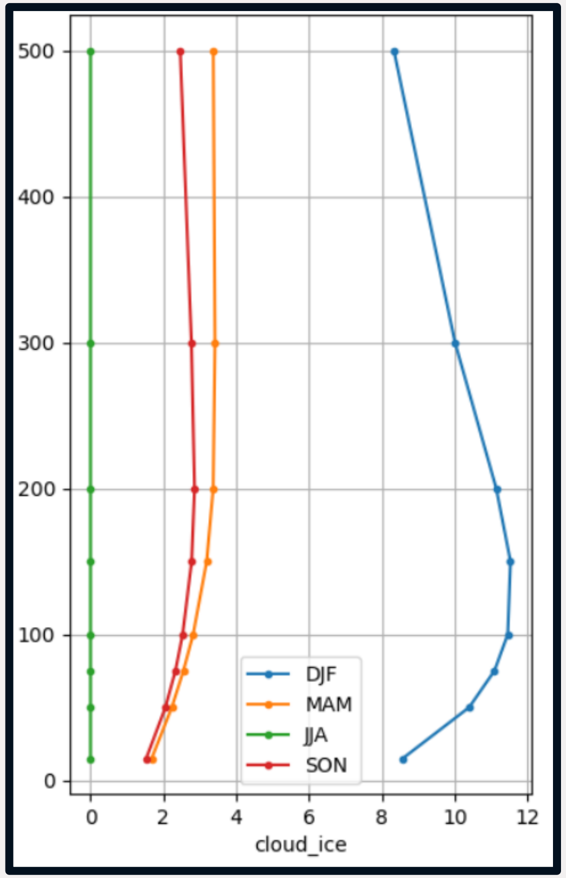


Image Credit:
Jimy Dudhia,
WRF Physics Options

Where has the water gone – and should we include it?
(cloud: water, rain, ice, snow, graupel)



Units:
Temperature [degC]
Cloud-Water [μg/kg]

EMD-CERRA ICING: Cloud Ice

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Learnings and Outlook

LEARNINGS

- EMD-Icing model is suitable to run with same input from EMD-WRF and CERRA
- Plenty of water present (we think), but surely distributed differently on the hydrometeors;
  so, a 1:1 setup from EMD-WRF to EMD-CERRA is not possible
- Download from the Copernicus Climate Data Store is pretty "slow"
- Using the right level of "standard tools" – including .mesores format
- Could also be a "scaling" issue, 3km vs. 5.5km
- So, maybe not so easy-peasy!
  Remember the Rumsfeld Matrix and also consider the Unknown Knowns

An AI impression on "Learnings and Outlook"

OUTLOOK

- We will try to re- and fine-tune the model to adapt to water and ice in CERRA
- Our aim is to utilize our big-data and high-performance computing cluster to create a map for in-cloud icing for the CERRA domain

windPRO

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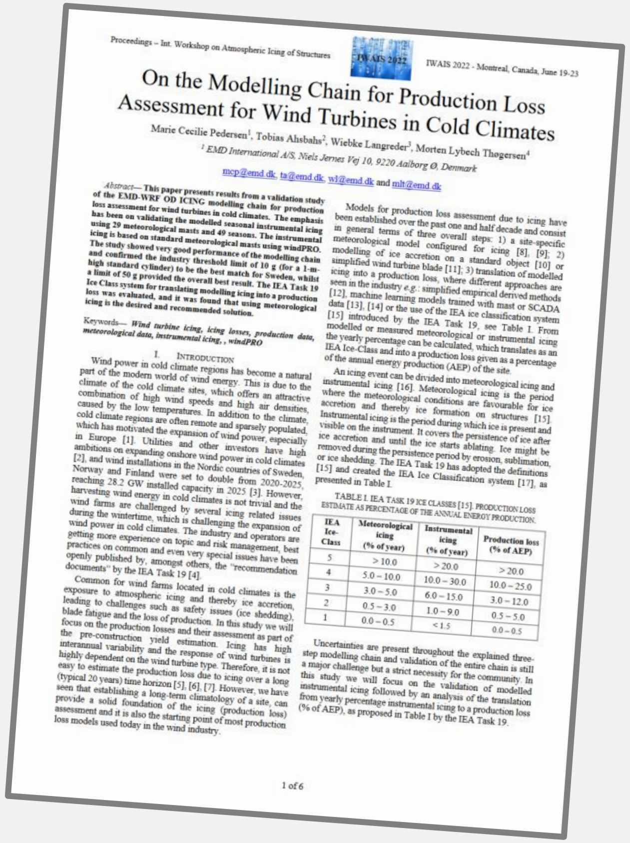
Lasse Svenningsen, ls@emd.dk
Thorkild Guldager Sørensen, tgs@emd.dk

EMD International A/S
Niels Jernes Vej 10
DK-9220 Aalborg East
Denmark
Phone: +45 69164850
E-mail: emd@emd.dk

More information and validation paper
https://help.emd.dk/mediawiki/index.php/EMD-WRF_On-Demand_ICING


Proceedings – Int. Workshop on Atmospheric Icing of Structures   IWAIS 2022 - Montreal, Canada, June 19-23

On the Modelling Chain for Production Loss Assessment for Wind Turbines in Cold Climates

Marie Cecilie Pedersen[1], Tobias Ahsbahs[2], Wiebke Langreder[3], Morten Lybech Thøgersen[4]
[1] EMD International A/S, Niels Jernes Vej 10, 9220 Aalborg Ø, Denmark
mcp@emd.dk, ta@emd.dk, wl@emd.dk and mlt@emd.dk

TABLE I. IEA TASK 19 ICE CLASSES [15]. PRODUCTION LOSS ESTIMATE AS PERCENTAGE OF THE ANNUAL ENERGY PRODUCTION.

IEA Ice-Class	Meteorological icing (% of year)	Instrumental icing (% of year)	Production loss (% of AEP)
5	> 10.0	> 20.0	> 20.0
4	5.0 – 10.0	10.0 – 30.0	10.0 – 25.0
3	3.0 – 5.0	6.0 – 15.0	3.0 – 12.0
2	0.5 – 3.0	1.0 – 9.0	0.5 – 5.0
1	0.0 – 0.5	< 1.5	0.0 – 0.5

1 of 6

References

[1] I. Baring-Gould, R. Cattin, M. Durstewitz, M. Hulkkonen, A. Krenn, T. Laakso, A. Lacroix, E. Peltola, G. Ronsten, L. Tallhaug and W. T., "*13 Wind Energy Projects in Cold Climate,*" IEA Wind, http://ieawind.org, 2011.

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[3] G. Thompson, P. R. Field, R. M. Rasmussen and W. D. Hall, "Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part II: Implementation of a New Snow Parameterization," American Meteorological Society, vol. 136, no. Monthly Weather review, pp. 5095-5115, 2008.

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[7] K. Hämäläinen and S. Niemelä, "Production of a Numerical Icing Atlas for Finland," Wind Energy, vol. 20, pp. 171-189, 2017.

[8] https://iea-wind.org/task19/t19icelossmethod/

Acknowledgements

CERRA:
The Copernicus Regional Reanalysis for Europe. Distribution through EMD and windPRO - EMD International A/S, 2022. This study uses CERRA which is being developed through the Copernicus Climate Change Service (C3S). Data processing for CERRA is carried out by SMHI and distribution by ECMWF.

ERA5
ERA5(T) Rectangular Grid and ERA5 Gaussian Grid. Distribution through EMD and windPRO - EMD International A/S, 2020. This dataset uses ERA5 and ERA5(T) which is being developed through the Copernicus Climate Change Service (C3S). Data processing and distribution for ERA5 is carried out by ECMWF.

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Rumsfeld Matrix

	Knowns	Unknowns
Knowns	**Known Knowns** Things we are aware of and understand.	**Known Unknowns** Things we are aware of but don't understand.
Unknowns	**Unknown Knowns** Things we understand but are not aware of.	**Unknown Unknowns** Things we are neither aware of nor understand.