INTERPOLATION OF WIND VARIABLES USING THE MISH SYSTEM: A DATA-DRIVEN CLIMATOLOGICAL APPROACH

Kinga Bokros[1,2], Beatrix Izsák[1], Mónika Lakatos[1], Rita Pongrácz[3]

[1] HungaroMet Hungarian Meteorological Service, Department of Climate Research, Budapest, Hungary

[2] ELTE Eötvös Loránd University, Faculty of Science, Doctoral School of Earth Sciences, Budapest, Hungary

[3] ELTE Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Meteorology, Budapest, Hungary

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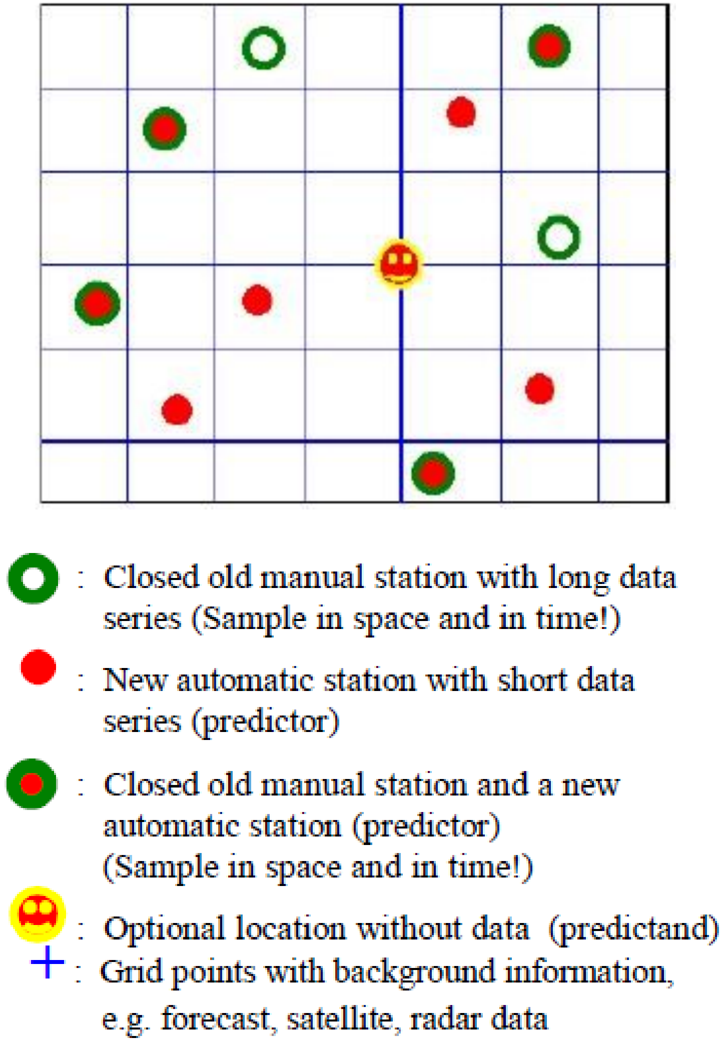
Introduction - why meteorological interpolation is needed

- Meteorological stations are sparse → no continuous coverage
- Gridded data must be derived from point observations
- Climate variables depend on terrain, elevation, and distance from sea
- Long-term data enable space–time statistical modelling
- Goal: spatially consistent and physically meaningful fields

Szentimrey & Bihari, 2014



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Limitations of traditional GIS-based interpolation methods

- Use only one moment in time → ignore temporal variability
- Climate information (mean, variance,...) is lost
- No distinction between additive (temperature) and multiplicative (precipitation) variables
- Cannot easily integrate background fields (e.g. models, radar, satellite)
- Often less accurate for meteorological applications

MISH (Meteorological Interpolation based on Surface Homogenized Data Basis, *Szentimrey* & *Bihari*, 2007, 2014)

Modeling subsystem:

- Based on long, homogenized time series and deterministic variables (e.g. topography, elevation)
- Additive or multiplicative model, depending on the variable type (e.g. temperature vs. precipitation)
- High-resolution grid (e.g. 0.5′ × 0.5′)

Interpolation subsystem:

- Uses the modeled parameters to estimate values at any location
- Allows integration of background information (e.g. radar, satellite, forecast data)
- Missing data completion (daily, monthly)

Why wind requires special attention

- The wind field has specific statistical and physical properties.
- Special modeling, interpolation, completion and gridding procedures were developed in MISH for wind speed and direction together.
- u and v components are interpolated separately, then recombined.
- Strongly influenced by surface roughness and orography.

Why wind requires special attention

Wind vector series: $\mathbf{v}(t) = [u(t), v(t)]^{\mathrm{T}} \quad (t = 1,..,n)$

$u(t)$: components towards east,

$v(t)$: components towards north.

The components can be expressed by the wind speed $z(t) = \|\mathbf{v}(t)\|$ (m/s) and meteorological wind direction $\phi_{MET}(t)$ in degree, according to the following formulas:

$$u(t) = -z(t) \cdot \sin\left[\frac{\pi}{180} \cdot \phi_{MET}(t)\right], \quad v(t) = -z(t) \cdot \cos\left[\frac{\pi}{180} \cdot \phi_{MET}(t)\right]$$

$$z(t) = \sqrt{u^2(t) + v^2(t)}, \quad \phi_{MET}(t) = \frac{180}{\pi} \cdot \mathrm{atan2}[-u(t), -v(t)] \qquad (\text{if } \mathbf{v}(t) \neq \mathbf{0})$$

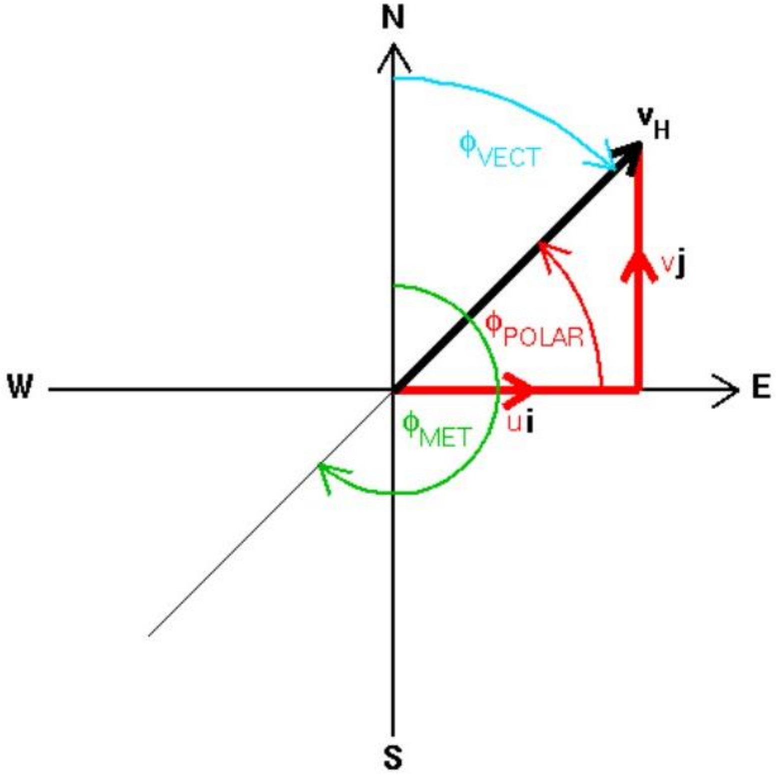
Then, the mean wind speed: $\bar{z} = \frac{1}{n}\sum_{t=1}^{n} z(t)$

The mean wind vector: $\bar{\mathbf{v}} = \frac{1}{n}\sum_{t=1}^{n} \mathbf{v}(t) = [\bar{u}, \bar{v}]^{\mathrm{T}}$,

where $\bar{u} = \frac{1}{n}\sum_{t=1}^{n} u(t)$, $\quad \bar{v} = \frac{1}{n}\sum_{t=1}^{n} v(t)$.

The "vectorial mean" meteorological wind direction in degree:

$$\bar{\phi}_{MET} = \frac{180}{\pi} \cdot \mathrm{atan2}[-\bar{u}, -\bar{v}] \qquad (\text{if } \bar{\mathbf{v}} \neq \mathbf{0})$$



David Hooper: http://mst.nerc.ac.uk/wind_vect_convs.html

Steps of modeling in case of wind speed (z) and direction (Φ)

- Calculation of wind components u, v data from z and Φ data.
- Wind speed (z) is modeled in MISH using a **multiplicative** model.

  The modeling includes special predictors related to observation height (wh) and surface roughness (r).
  The procedure outputs monthly wind-profile parameters (α and γ).
- The u and v components are converted to standard reference conditions (wh = 10 m, r = 0.1) by applying the wind-profile parameters → u_0, v_0.
- The transformed components u_0 and v_0 are then modeled in MISH using an **additive** model.

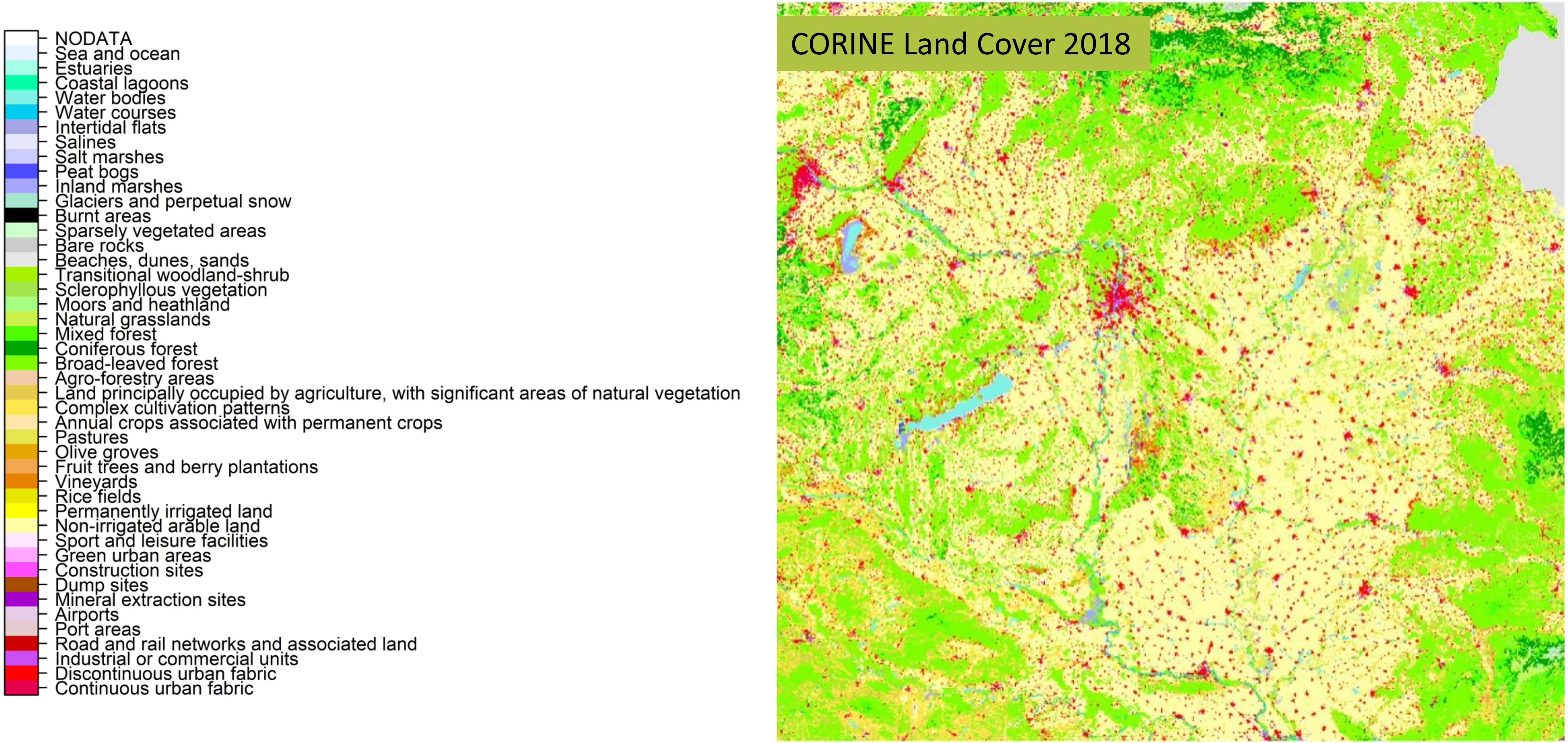
Steps of interpolation in case of wind speed (z) and direction (Φ)

- Calculation of wind components u , v data from z and Φ data.
- Interpolation applications for wind speed z by MISH.

Special input is the modeled wind profile parameters α and γ by months.

- Transformation of the components u , v data for wh=10m, r=0.1 by using the wind profile parameters α and γ: u_0, v_0.
- Interpolation applications for components u_0 and v_0 by MISH.
- Calculation of interpolated wind direction Φ data from the interpolated components u_0 and v_0 data.

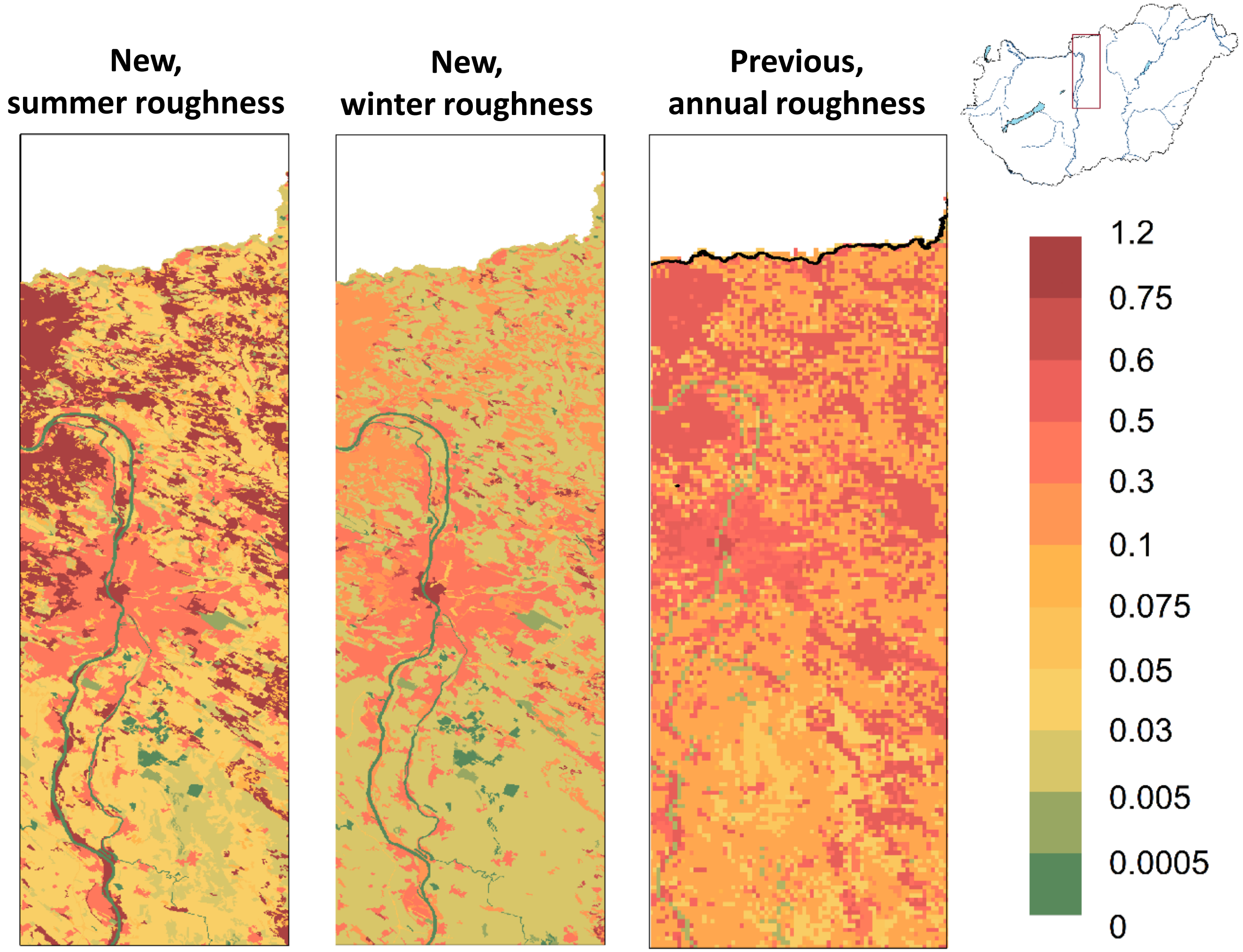
Renewal of the surface roughness database



Development of wind modeling

Innovations:

- Higher spatial resolution
- **Seasonal** roughness maps
- **Summer** (May–October) and **Winter** (November–April) roughness
- Considering vegetation conditions following *MacArthur & Haines* (1982)
- Expected outcome: **more accurate wind estimation**



Wind profile model in MISH

- derived from the power law and logarithmic profile models.

$$z_{2j} = \left(\frac{\ln\left(\frac{wh_2}{r}\right) * \ln\left(\frac{wh_1}{0.1}\right)}{\ln\left(\frac{wh_2}{0.1}\right) * \ln\left(\frac{wh_1}{r}\right)} \right)^{\gamma} * \left(\frac{wh_2}{wh_1}\right)^{\alpha} * z_{1j}$$

wh_1 : original height of the measurement
wh_2 : target height for conversion, e.g. 10 m, 30 m, etc.
r: surface roughness at station z_j
z_{1j} : wind speed measured at height wh_1
z_{2j} : wind speed converted to height wh_2
α,γ: modeled parameters, depending on month and variable — i.e., modeled separately for wind maxima, wind averages or wind direction

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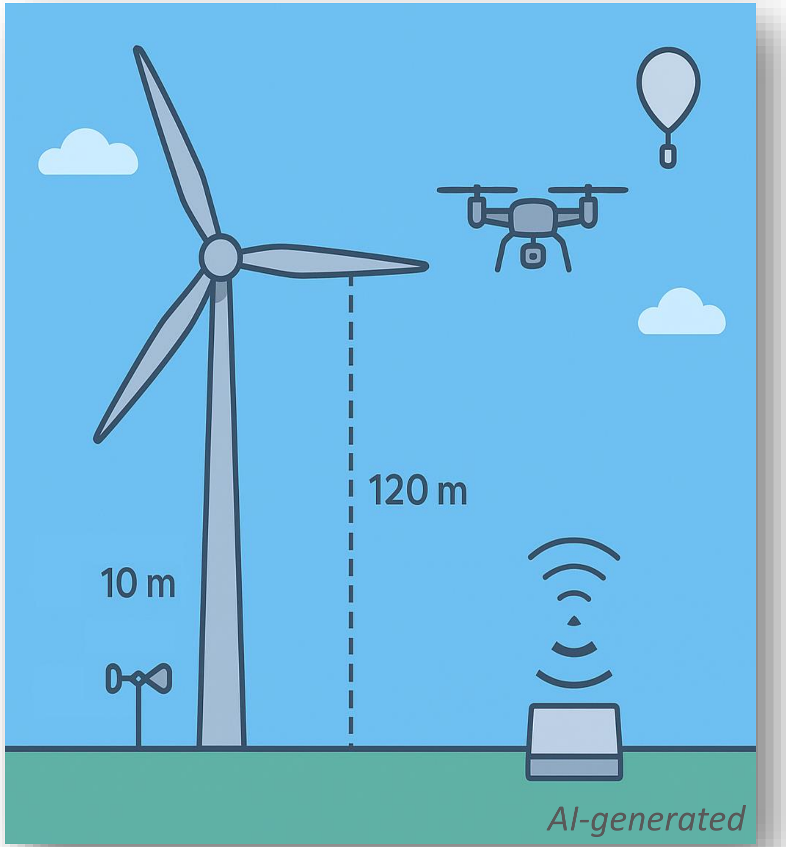
Wind profile model in MISH

- MISH allows wind speed scaling to arbitrary heights
  - energy, infrastructure!
- However: above ~100–120 m
  - Dynamic processes dominate (not purely statistical behaviour) (*Dobi*, 2006)
  - Requires dedicated validation (LIDAR, SODAR, drone, weather balloon measurements)
  - Ongoing research direction



Integration of background information

Predictand: $Z(\boldsymbol{s}_0, t)$, Predictors: $Z(\boldsymbol{s}_i, t), (i = 1, \dots M)$

Interpolation without background information (multiplicative interpolation formula):

$$\hat{Z}(\boldsymbol{s}_0, t) = \vartheta \left(\prod_{q_i Z(\boldsymbol{s}_i, t) \geq \vartheta} \frac{q_i Z(\boldsymbol{s}_i, t)^{\lambda_i}}{\vartheta} \right) \left(\sum_{q_i Z(\boldsymbol{s}_i, t) \geq \vartheta} \lambda_i + \sum_{q_i Z(\boldsymbol{s}_i, t) \geq \vartheta} \lambda_i \frac{q_i Z(\boldsymbol{s}_i, t)}{\vartheta} \right)$$

where $\vartheta > 0, q_i > 0, \lambda_i \geq 0$ *and* $\sum_{i=1}^{M} \lambda_i = 1$ (interpolation parameters)

Background information (e.g. radar, forcast, satellitite data etc.) on a dense grid:

$$\boldsymbol{B} = \{B(\boldsymbol{s}, t) \mid \boldsymbol{s} \in \boldsymbol{D}\}$$ ($\boldsymbol{D}$: space domain)

Interpolation with background information:

$$\hat{Z}_B(\boldsymbol{s}_0, t) = \hat{Z}(\boldsymbol{s}_0, t) + \beta_1(t) \cdot \left(B(\boldsymbol{s}_0, t) - \hat{B}(\boldsymbol{s}_0, t) \right)$$, where

$\beta_1(t)$ is the estimated regression coefficient,

$\hat{B}(\boldsymbol{s}_0, t) = F_M(B(\boldsymbol{s}_1, t), \dots, B(\boldsymbol{s}_M, t); q_1, .., q_M, \lambda_1, .., \lambda_M)$ is the interpolation formula for the background information

Integration of background information

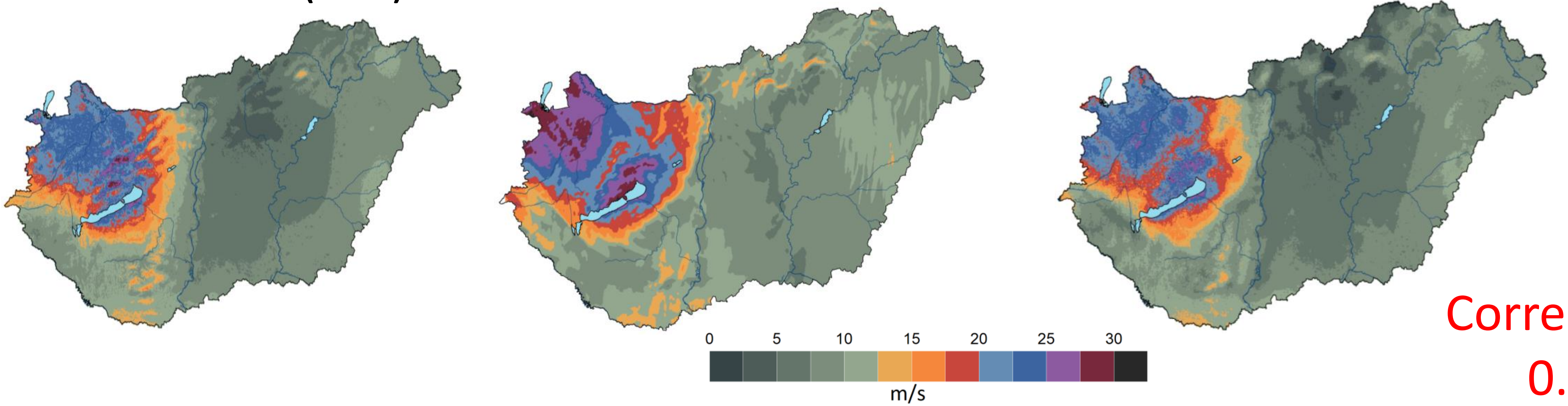
Case study: September 14, 2024, Storm *Boris* with heavy rains, stormy wind gusts

- Data: surface measuements of **wind gust** and AROME-RUC high-resolution numerical weather prediction model wind gust data
- Method: MISH interpolation software

Interpolation of surface measurements (MISH)

AROME-RUC

MISH + AROME-RUC



Correlation: 0.89

Bokros, Izsák, Sz. Gáspár, Lancz, Lakatos, Pongrácz (2025): Improving wind hazard assessment using high-resolution numerical weather prediction models and interpolation techniques in Hungary, 2nd Natural Hazard and Climate Change Conference (21-23, May, 2025, Szeged)

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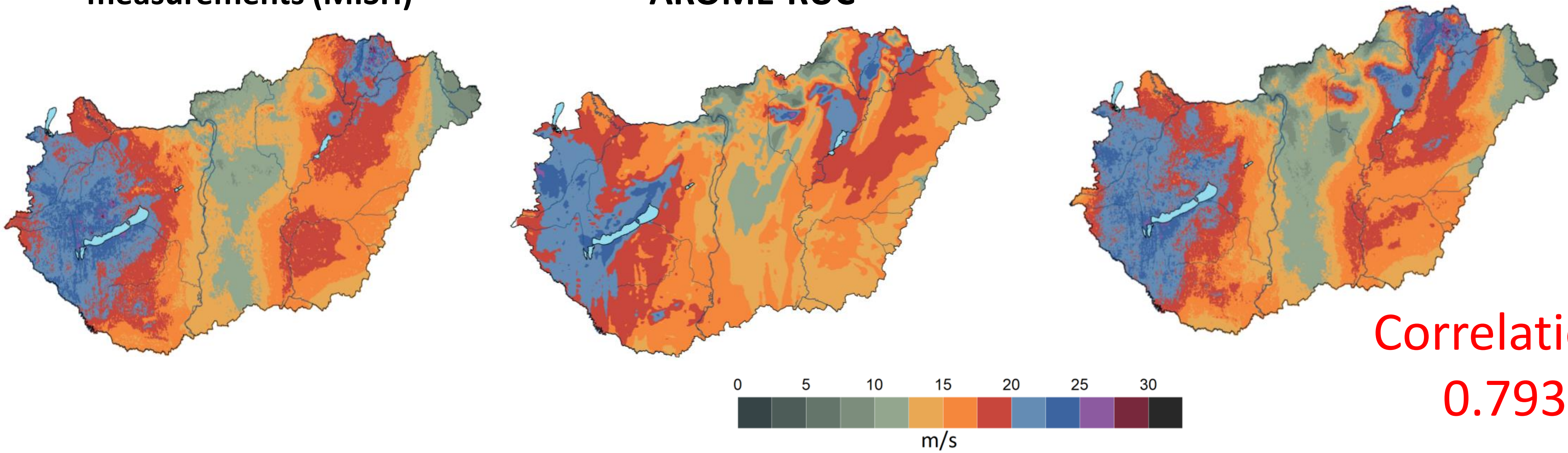
Integration of background information

Case study: December 24, 2024, Mediterranean Cyclone

Interpolation of surface measurements (MISH) | **AROME-RUC** | **MISH + AROME-RUC**



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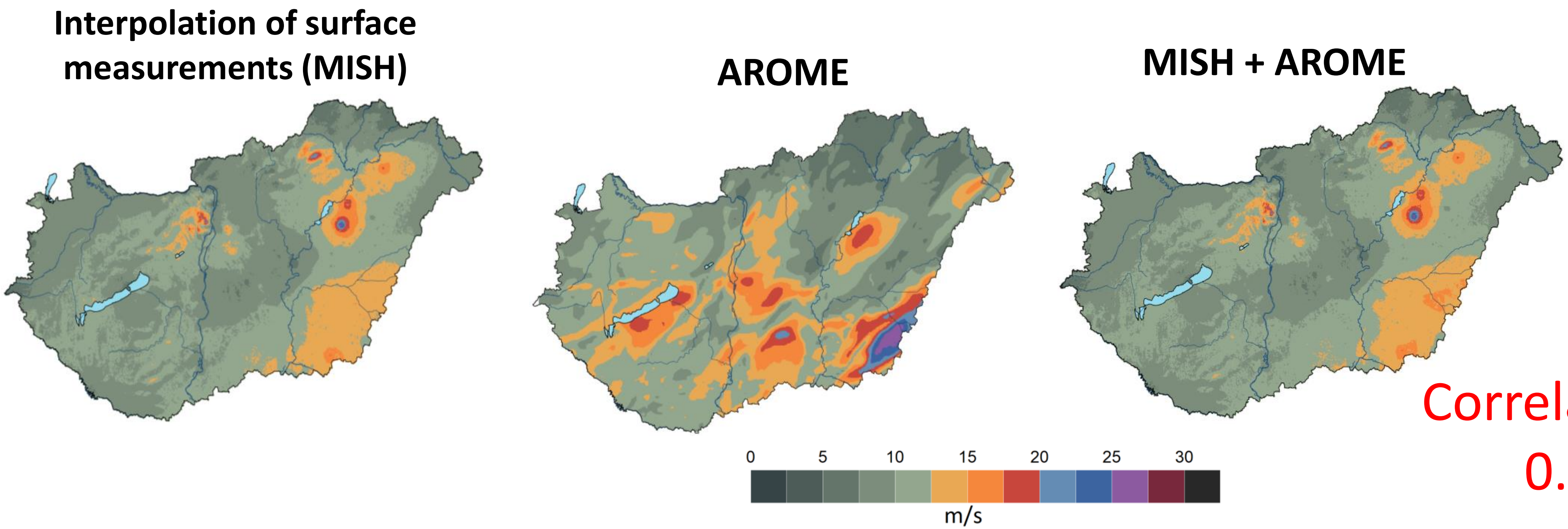
Bokros, Izsák, Sz. Gáspár, Lancz, Lakatos, Pongrácz (2025): Improving wind hazard assessment using high-resolution numerical weather prediction models and interpolation techniques in Hungary, 2nd Natural Hazard and Climate Change Conference (21-23, May, 2025, Szeged)

Integration of background information

Case study: June 10, 2024 (Only AROME):

- Summer storms cause local strong gusts —background is crucial for interpolation.
- Low correlation between observations and model fields in case of convective events.



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Bokros, Izsák, Sz. Gáspár, Lancz, Lakatos, Pongrácz (2025): Improving wind hazard assessment using high-resolution numerical weather prediction models and interpolation techniques in Hungary, 2nd Natural Hazard and Climate Change Conference (21-23, May, 2025, Szeged)

Summary

- MISH provides a climatologically based, data-driven interpolation framework.
- Wind is treated with dedicated procedures due to its vector nature.
- We renewed the surface roughness database, including seasonal values.
- The wind-profile model enables height scaling using modeled α and γ. Upcoming sodar and drone data will support real-height validation and future development.
- Background fields further enhance interpolation performance.

Thank you for your kind attention!

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References

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Dobi I. (szerk.) (2006). Magyarországi szél és napenergia kutatás eredményei. Országos Meteorológiai. Szolgálat

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Szentimrey, T., Bihari, Z., 2007: Mathematical background of the spatial interpolation methods and the software MISH (Meteorological Interpolation based on Surface Homogenized Data Basis), Proceedings of the Conference on Spatial Interpolation in Climatology and Meteorology, Budapest, Hungary, 2004, COST Action 719, COST Office, 2007, pp. 17–27.

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