Multi-Scale high resolution flow modelling for local scale air quality assessment in complex terrain

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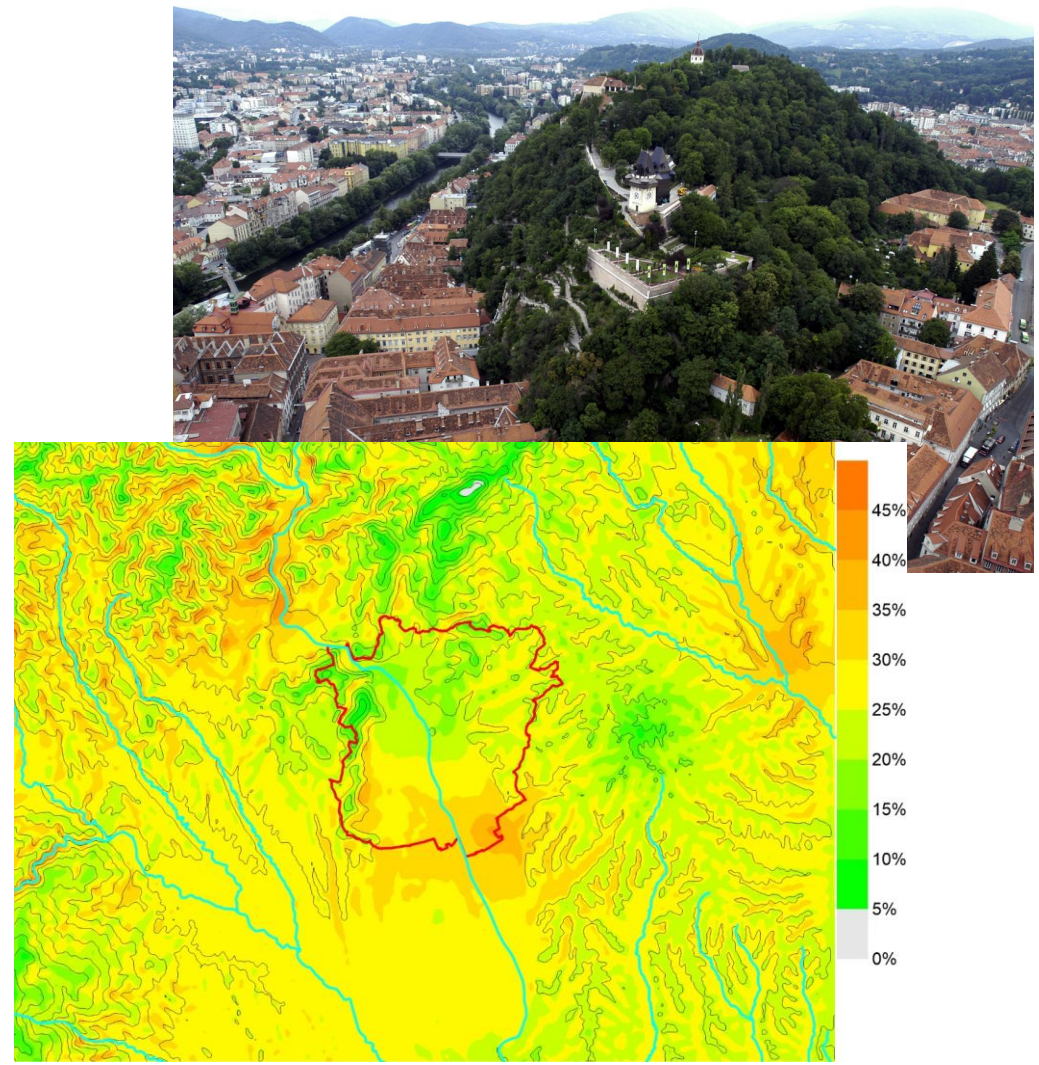
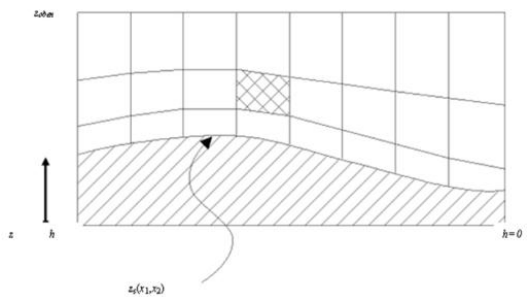
Background KIS Graz Project (Klima-Informations-System)

- Graz located at the southern foothills of the Alps & we encounter frequently calms
- KIS project climate driven & primary objective was the **analysis of ventilation** in Greater Graz area particularly by cold air drainage flows, slope winds, side valley winds and Mur valley wind system
  - In summer cold air drainage flows & slope winds are important for cooling
  - In winter interaction of wind systems is important concerning air quality
- Secondary objective producing a **flow field library capable** for air quality

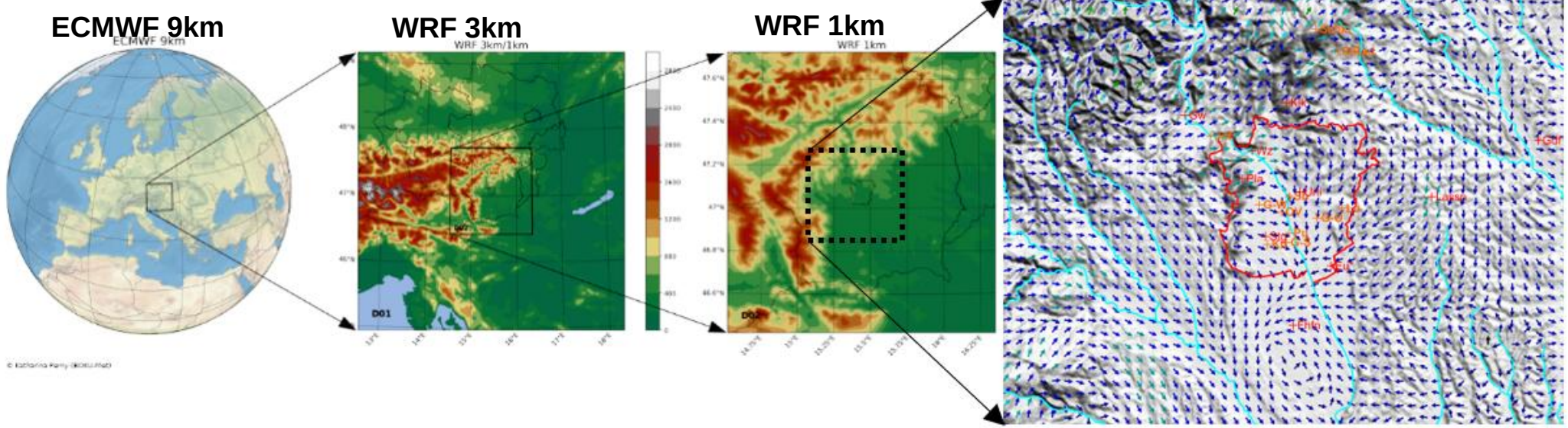


Modelling KIS Graz

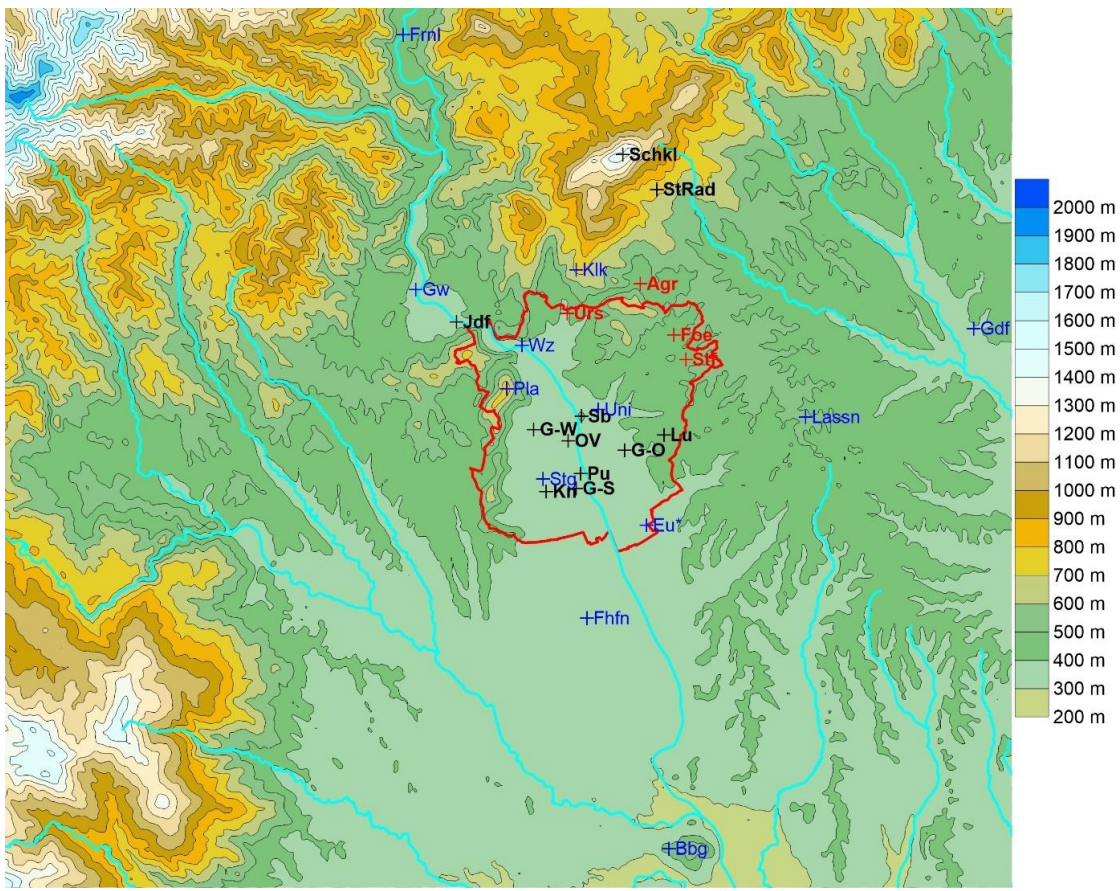
- GRAMM GRAz Mesoscale Model
  - Prognostic non-hydrostatic
  - Δx,y 50 m – 300 m
  - SIMPLE algorithm (Patankar & Spalding, 1972)



- WRF run by BOKU Vienna



Local Model Set-Up & Monitoring Data



++ Locations of monitoring stations + free flow +SOP

- Greater Graz flow modelling
  - 54 km x 48 km Greater Graz Domain
  - $\Delta x,y=100m$ resolution, lowest $\Delta z=10m$
  - Hourly 06/2021-05/2022
- Represent:
  - Synoptic flow at mountain/hill stations
  - Orographically forced flow/channeling
  - Interaction of mountain wind systems

  particularly drainage flows
- Want to make use of KIS monitoring network
- **Major Challenges → Initialisation** & **boundary conditions ↔ Computational efforts** & **Efficiency**

Two Initialisation Approaches for Flow Field Modelling Complex Terrain

Coupling & use of measurements

- Interpolation of regional *u,v, p*, *Φ*, *θ, q* → local scale model grid
  - Synoptic flow near mountain tops & flow forced by orography well represented
  - Mountain wind systems & drainage flow sub-grid at regional scale
- Use local wind & T measurements for Init as well:

$$|(u_{sim} - u_{mon})/u_{mon}| > crit$$
$$OR \quad |(v_{sim} - v_{mon})/v_{mon}| > crit$$

- Weighting

$zwgt_{i,j,k} = 1 -$
$\Delta z_{i,j,k}/\left(Z_{\mathrm{w}\,max} - AH_{i,j}\right)$ $Z_{\mathrm{w}\,max}$=1500m
W-E/N-S inverse distance weighting

WS < 0.5 m/s Crit 0.35; 0.2

Simple “synthetic” approach

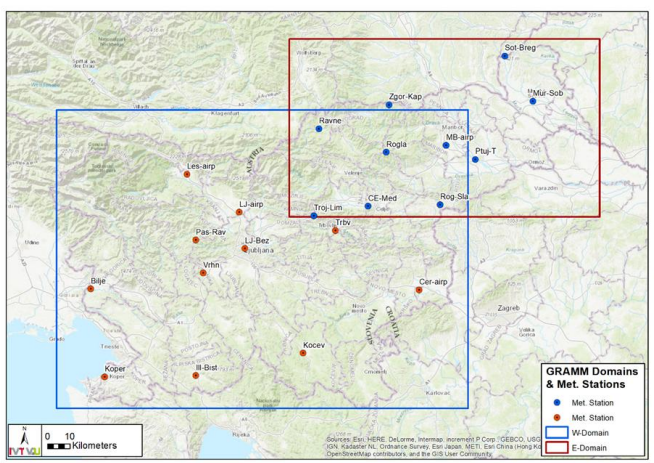
- Pre-compute flow fields with “artificial” triples of wind speed categories, wind direction sectors & stability class; use standard wind profiles to initialize & B.C.
- Thereafter, for multiple monitored timeseries of WS, WD & SC class a match-to-observation (MtO) procedure is applied, minimize: $err_h =$

$$\sum_{h(tMon)=1}^{ntim} \sum_{i=1}^{kmon} \sqrt{\left[\left(u_{S,j} - u_{hM,i}\right)^2 + \left(v_{S,j} - v_{hM,i}\right)^2\right]}$$

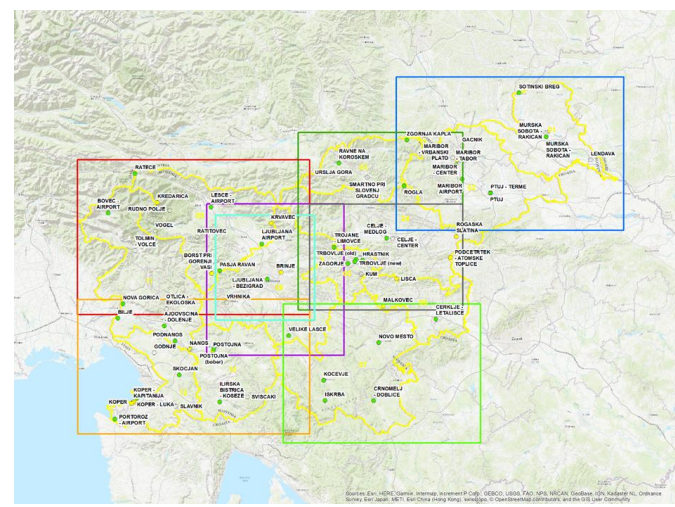
Coupling & use of measurements vs Synthetic MtO Approach

- + For CTM-GRAL(t) coupling
- + T, q → climate indices for KIS
- Challenge use appropriate “representative” monitoring stations for initialisation to avoid a nudging procedure & reduce integration times
- - Standard regulatory AQ application – huge data volume & stability classes are needed

- + suited typical local scale AQ applications
- + Practical & effective, low CPU/data burden
- + **MtO can reduce data volume**
- - Missing horizontal & vertical variability
- - in practice MtO works for up to 3 monitoring stations → split in sub-domains

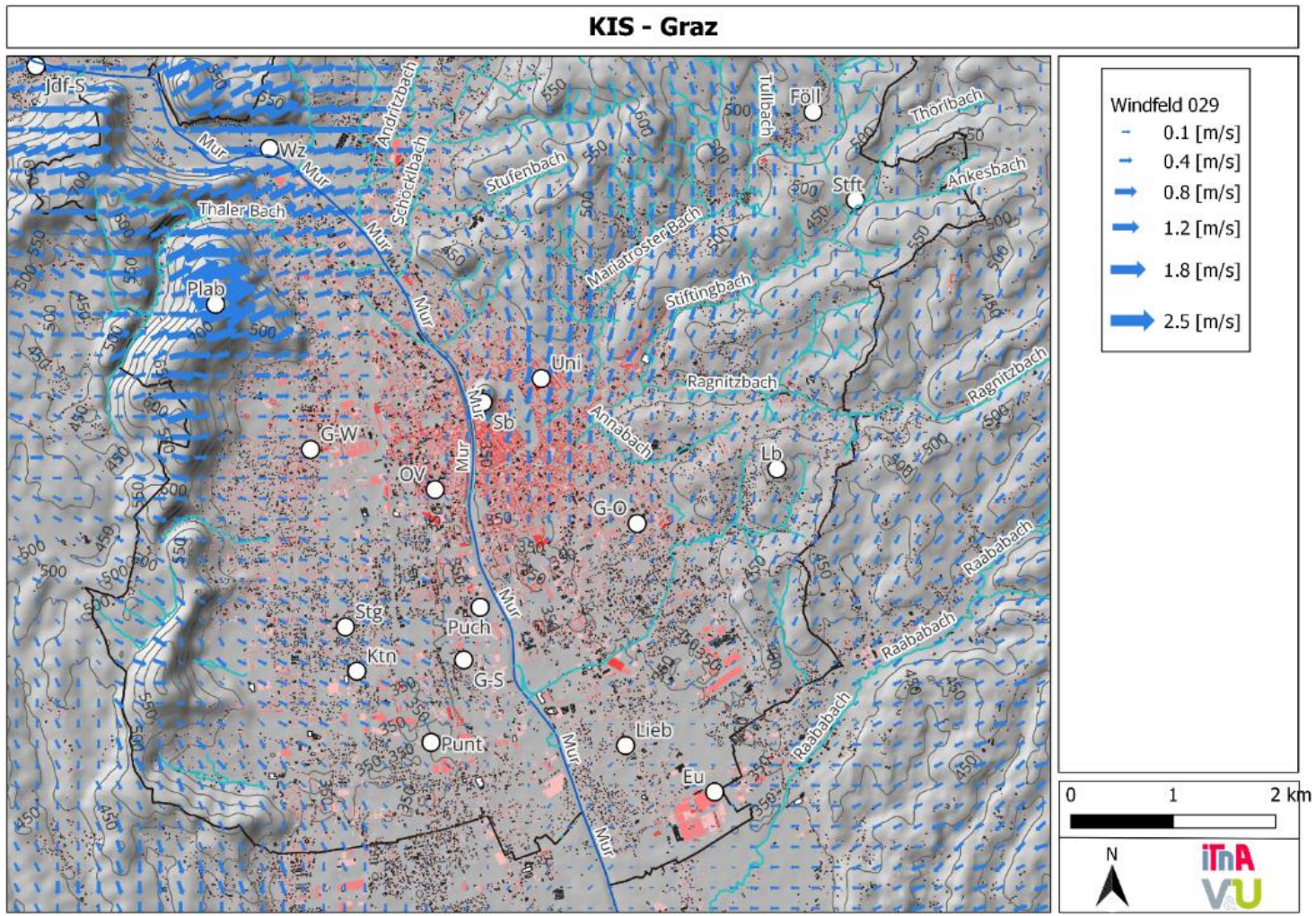


→ Can we produce reduced flow field library with sufficient quality? by categorizing flow from multi-scale approach & using the MtO for data reduction?

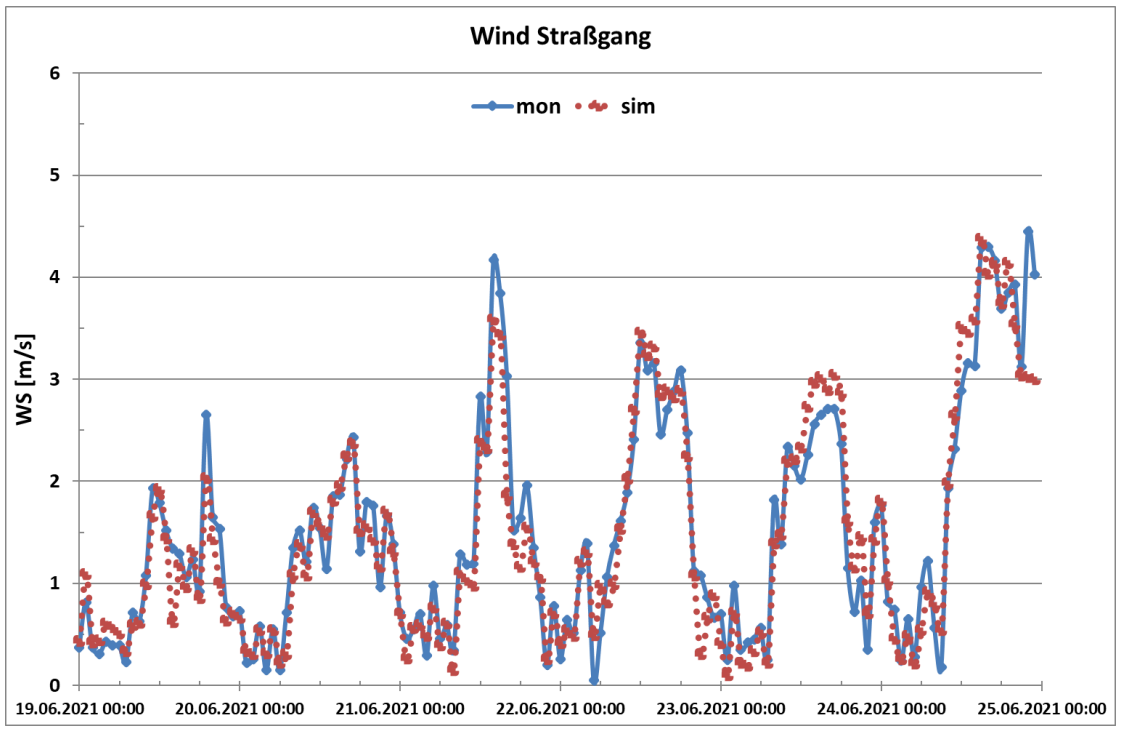


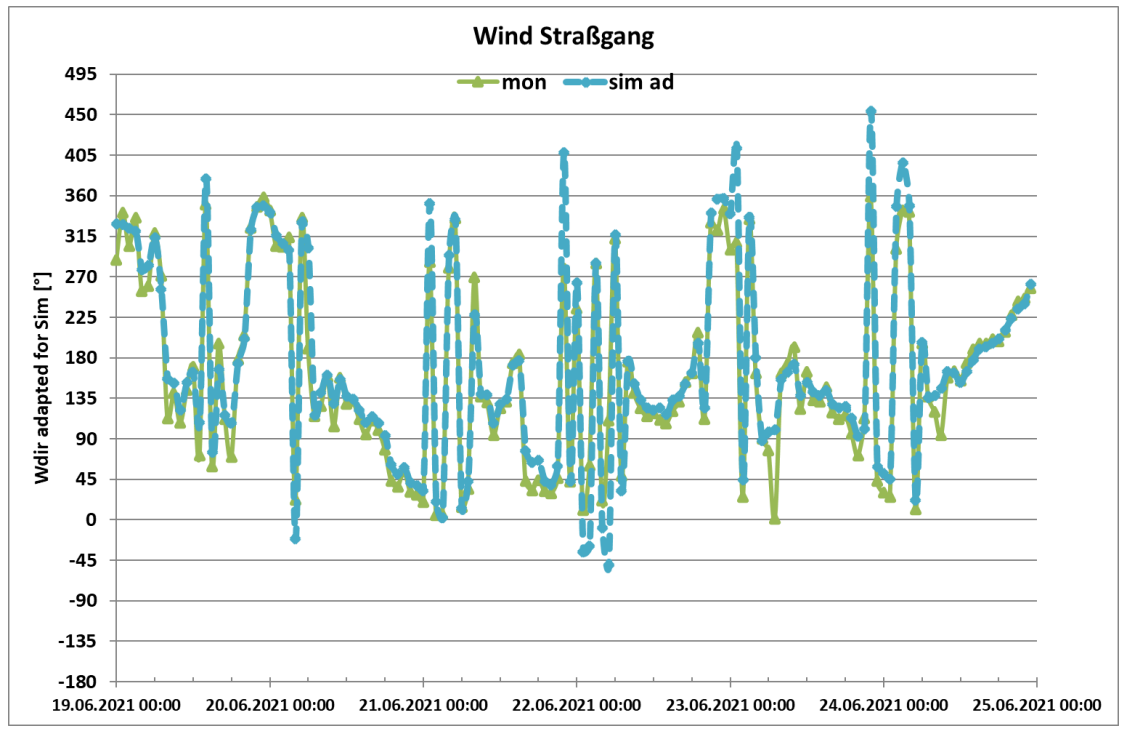
Results coupled approach using monitoring data for initialization

Surface wind
02.06.2021
5:00

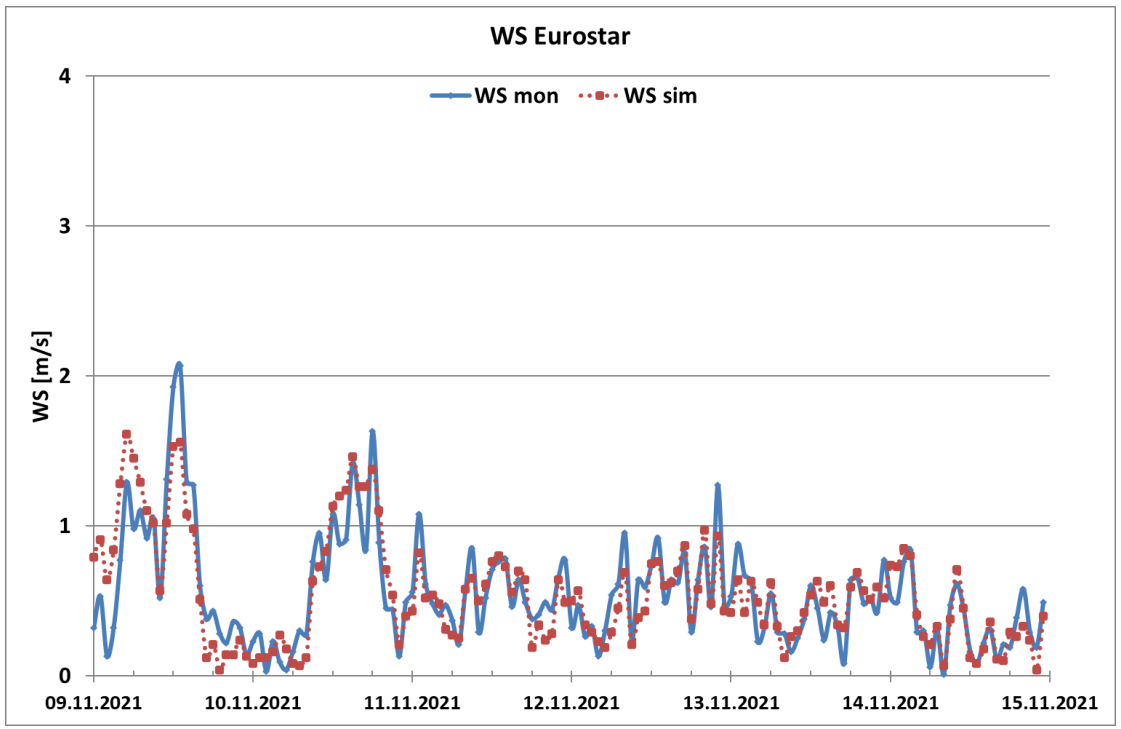


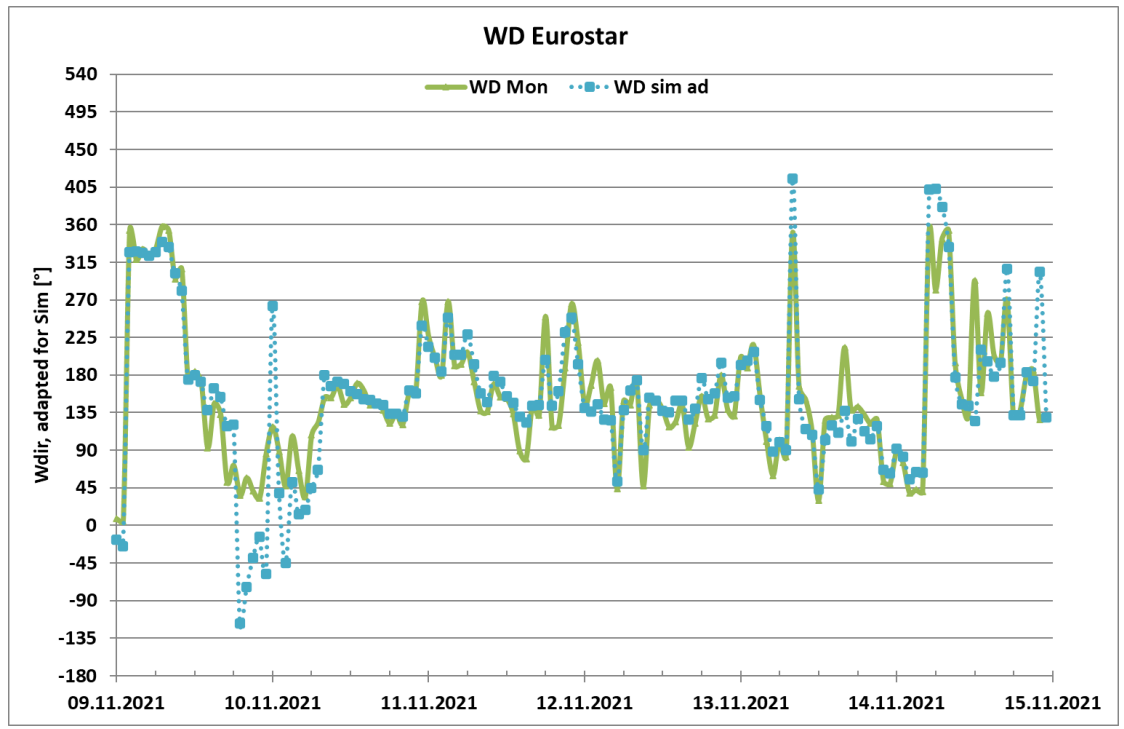
Monitored vs simulated WS & Wdir Straßgang during Heat Wave





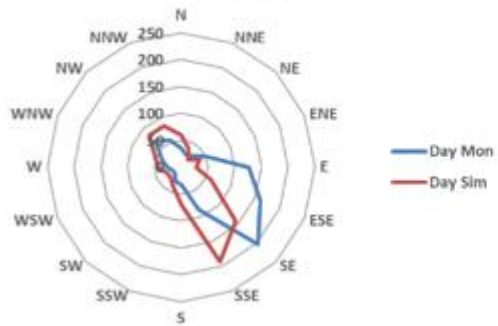
Monitored vs simulated WS & Wdir South of Graz during Inversion period



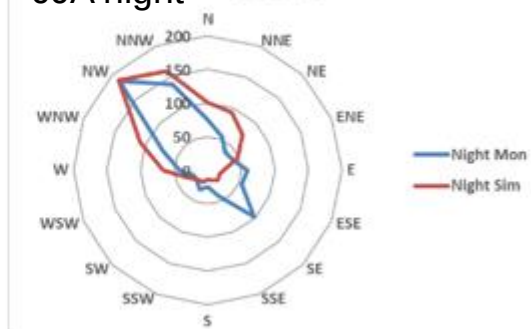


Examples analysis day/night, DJF/JJA

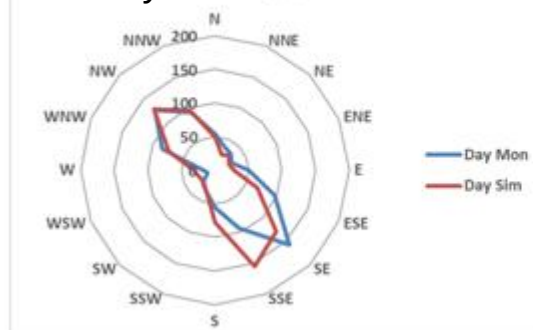
JJA day



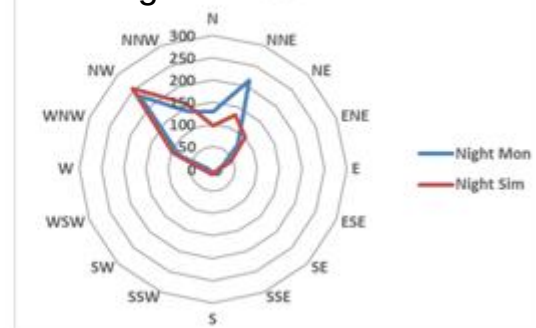
JJA night



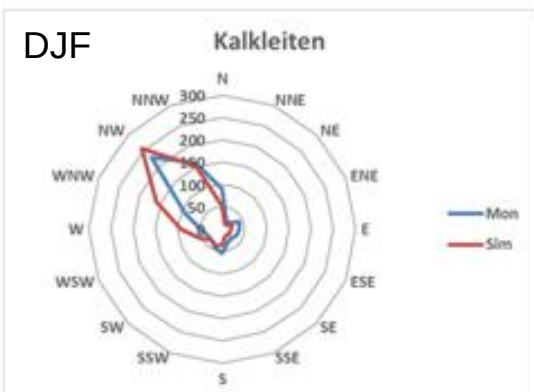
JJA day



JJA night



DJF



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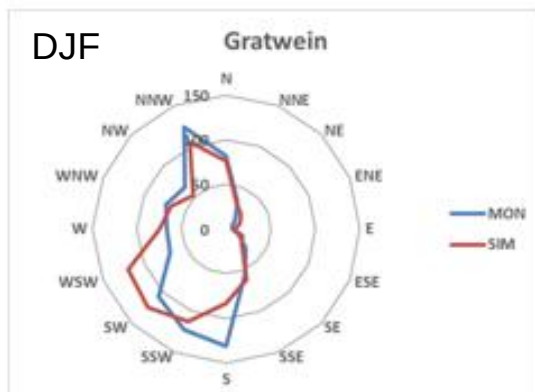

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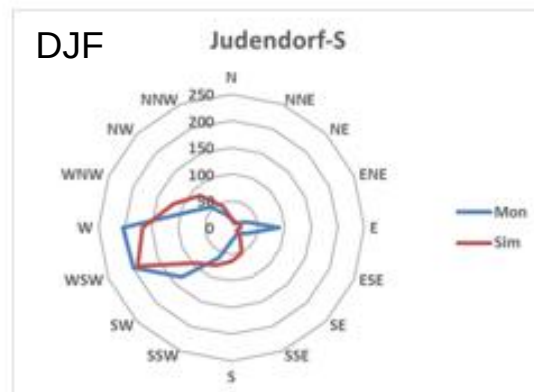
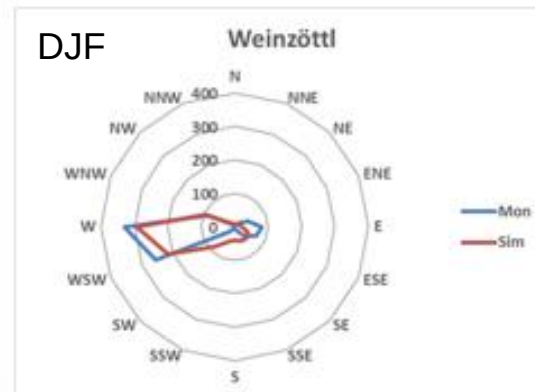
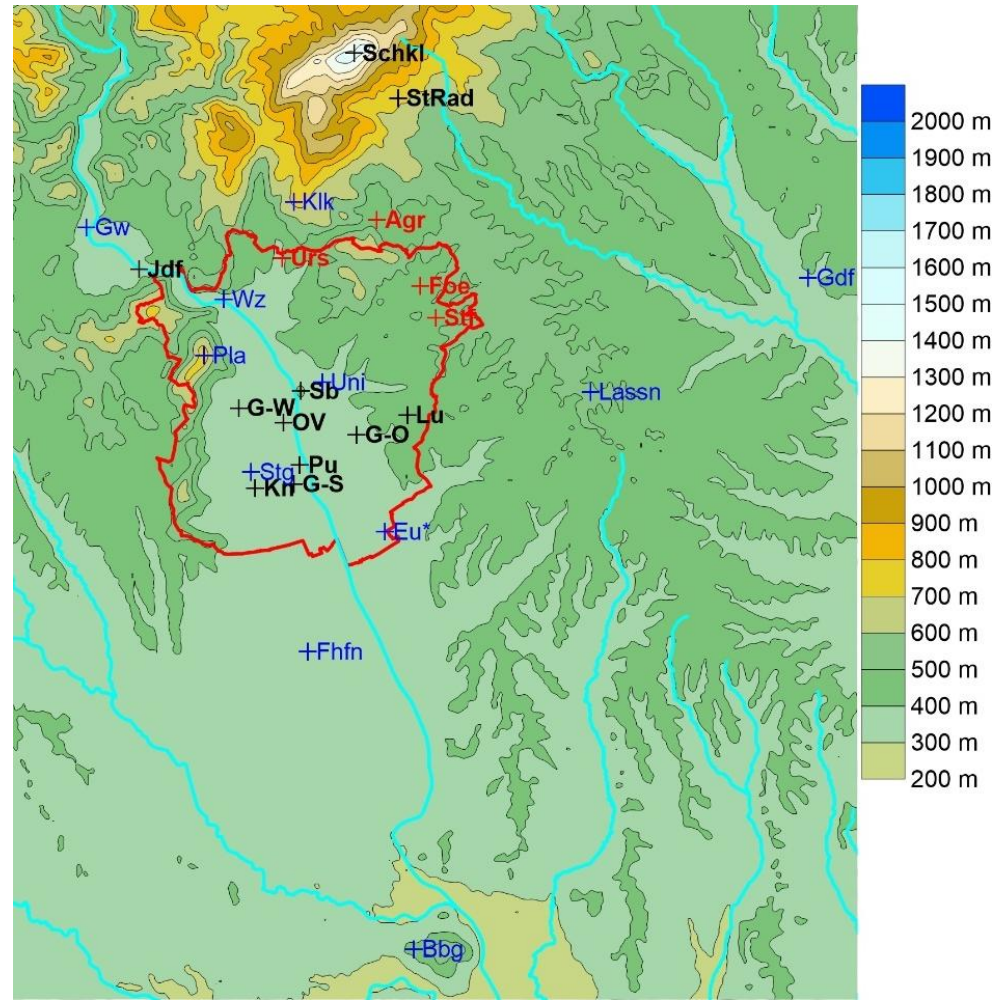


DJF

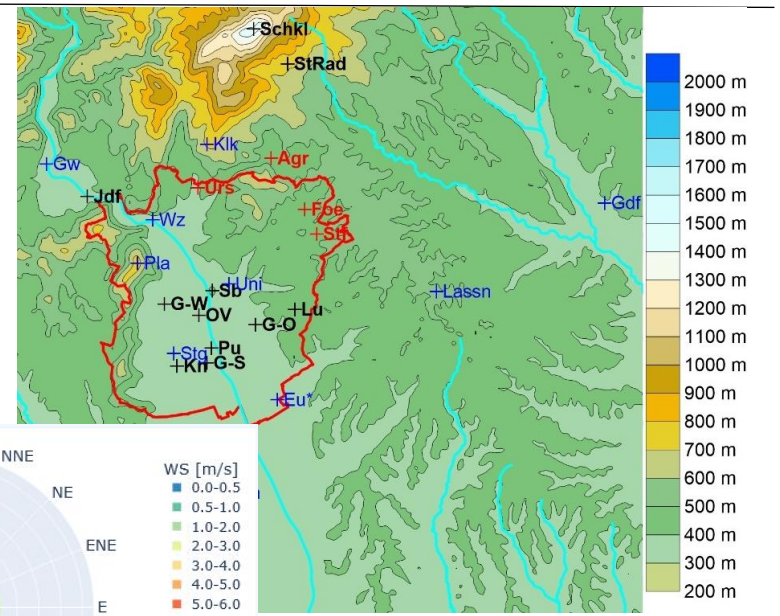


Application of the Match-to-Observation Algorithm

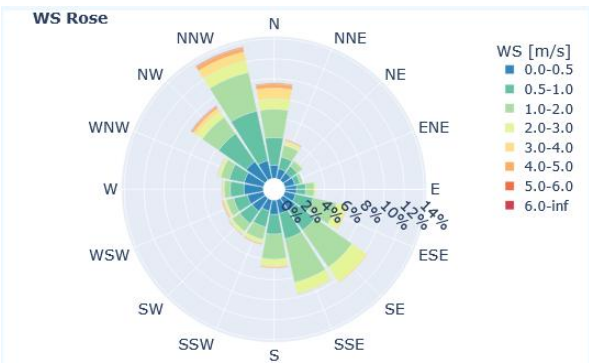
- Local stability class fields calculated for all flow fields (8760)
- Monitored data from 6 stations were used
  - University Uni
  - Straßgang Stg
  - Plabutsch Pla
  - Kalkleiten Klk
  - Lassnitzhöhe Lassn
  - Bockberg
- To be matched with 8760 flow fields



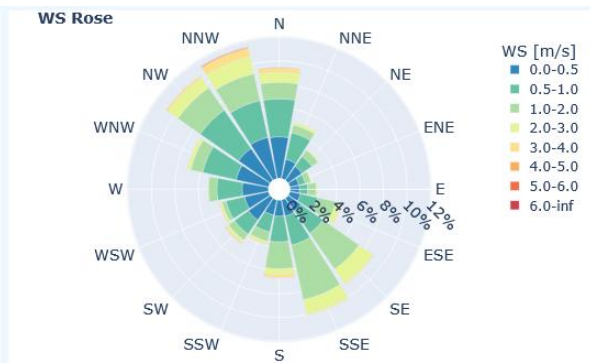
Comparison monitored vs 1-year Sim vs MtO reduced/classified Windrose



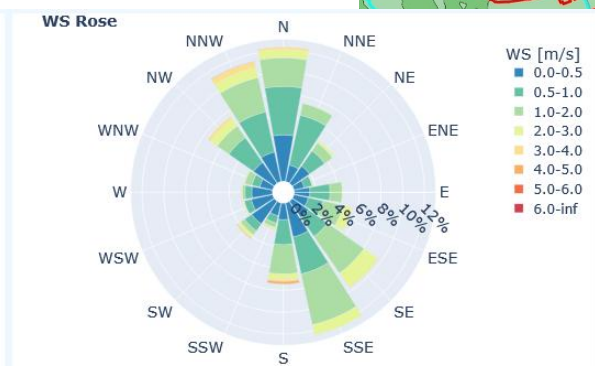
Straßgang (Stg) monit



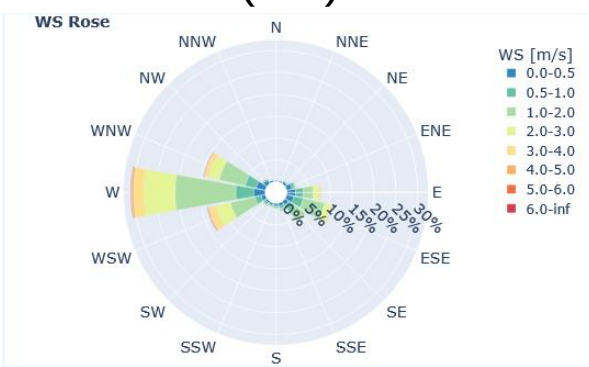
Stg Sim-all



Stg Sim-reduc

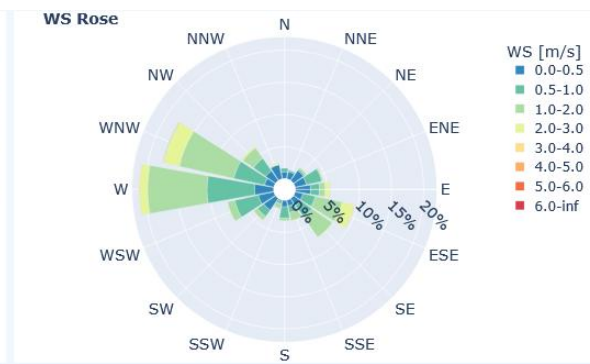


Weinzöttl (Wz) monit



Wz Sim-all

Wz Sim-reduc



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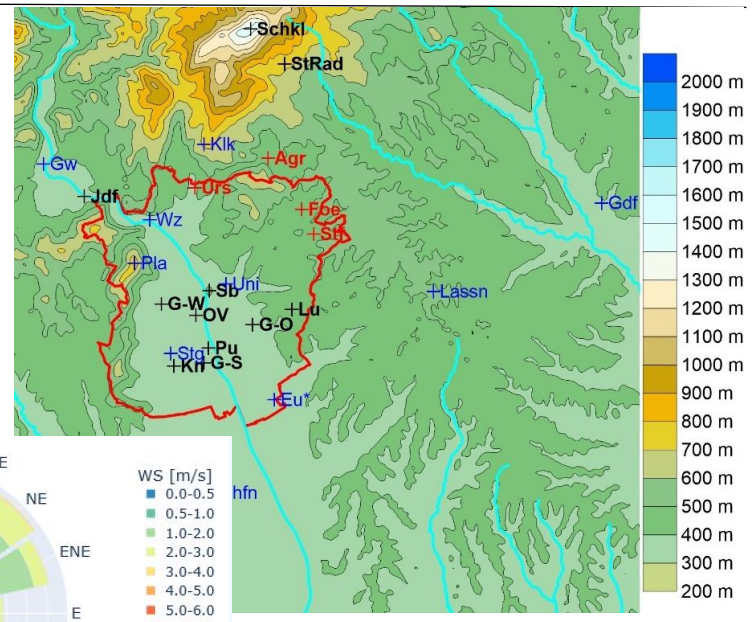
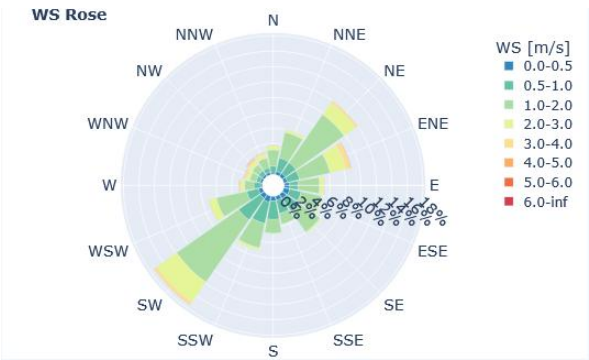
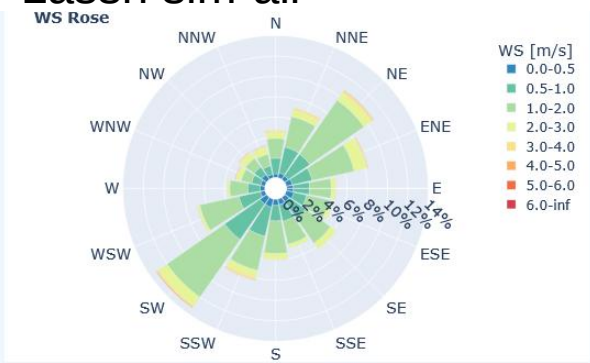


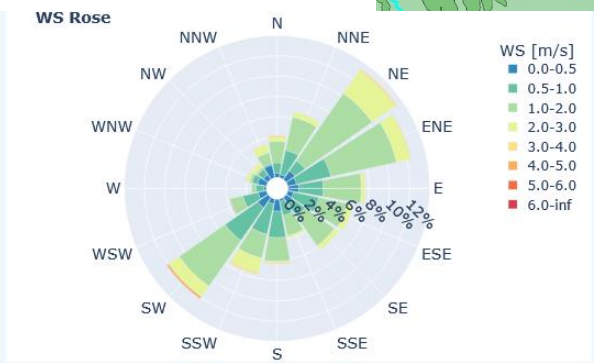
Lassnitzhöhe monit



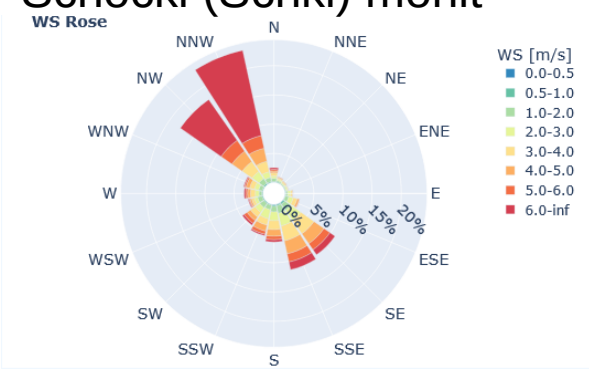
Lassn sim-all



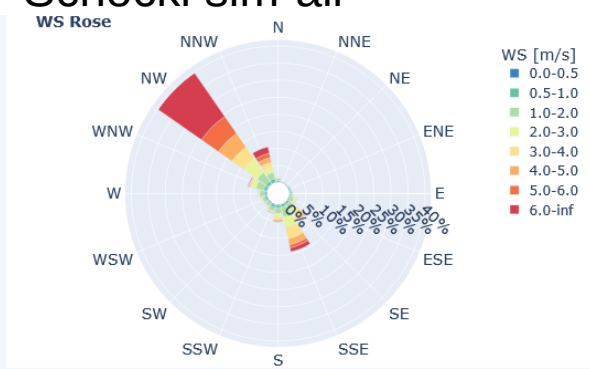
Lassn Sim-reduc



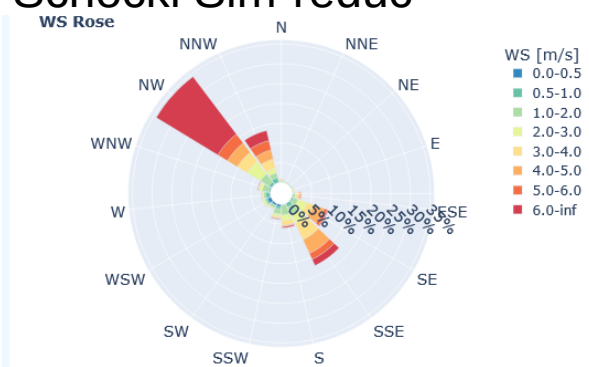
Schöckl (Schkl) monit



Schöckl sim-all



Schöckl Sim-reduc



Summary

- An efficient multi-scale high resolution (Δx,y=100m) flow modelling system was developed & validated
- The modelling system successfully captures complex local terrain flow features
- The large 1-year flow field library is dedicated
  - Climate & Energy related applications
  - Seamless coupled CTM – Local Dispersion Modelling
- By categorizing wind data and using the GRAMM MtO approach a second reduced flow field library was created and validated
  - Quality remains on high level
  - Data volume is reduced by a factor of 8
  - Suitable for effective local scale environmental assessment

Thank you for your attention!

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