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Effects of Stability on Wind Gusts

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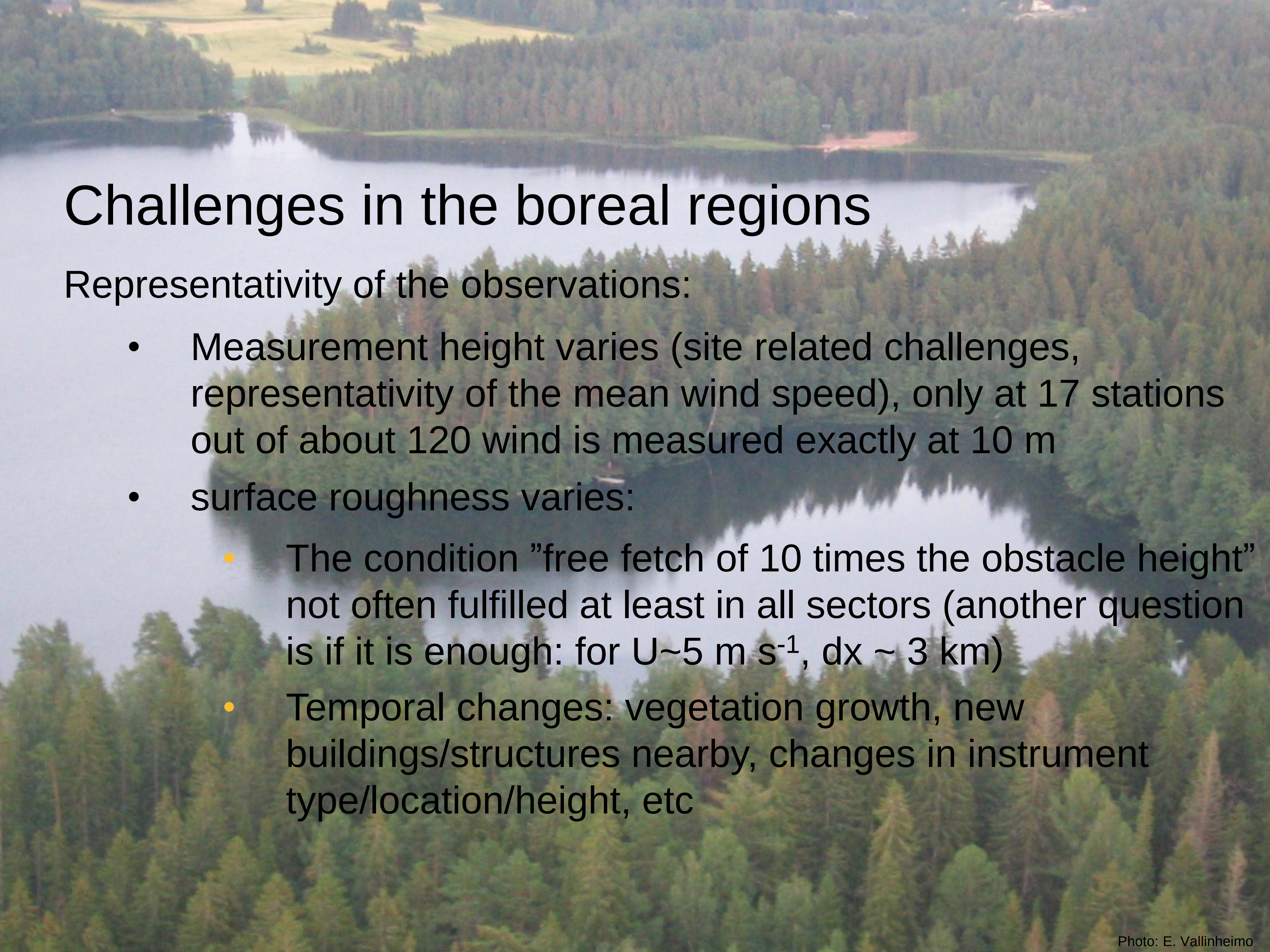
Why gusts?

- Strong gusts cause damage: forest cuts, wide-ranging power cuts, etc

Other applications:

- air quality / air pollution diffusion, wind energy, aviation
- Finnish wind warning system is based on gusts
- Gusts can be used for roughness length estimation and exposure corrections

Photo: E. Vallinheimo



Challenges in the boreal regions

Representativity of the observations:

- Measurement height varies (site related challenges, representativity of the mean wind speed), only at 17 stations out of about 120 wind is measured exactly at 10 m
- surface roughness varies:
    - The condition ”free fetch of 10 times the obstacle height” not often fulfilled at least in all sectors (another question is if it is enough: for U~5 m s^{-1}, dx ~ 3 km)
    - Temporal changes: vegetation growth, new buildings/structures nearby, changes in instrument type/location/height, etc

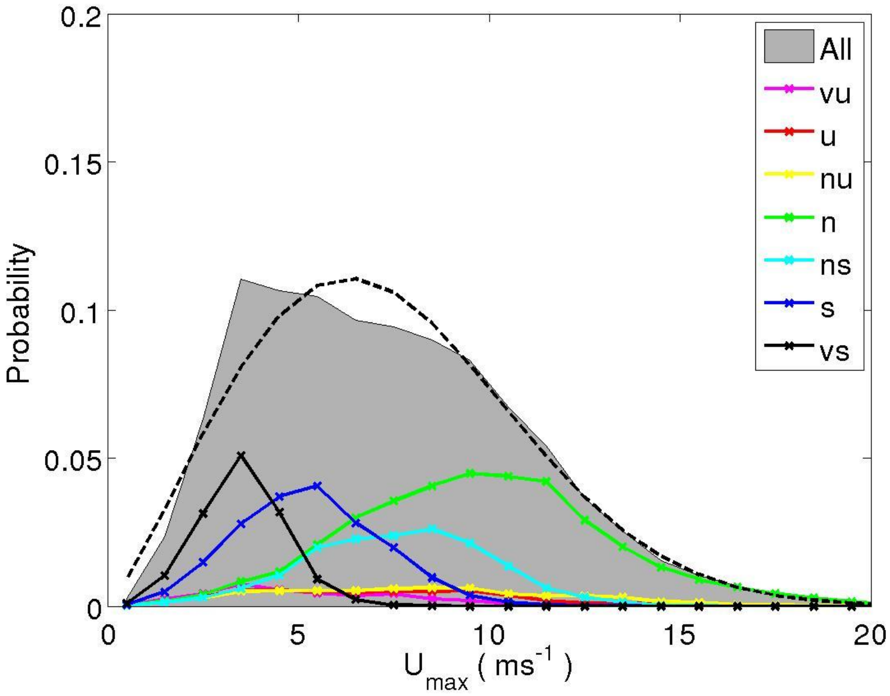
Photo: E. Vallinheimo

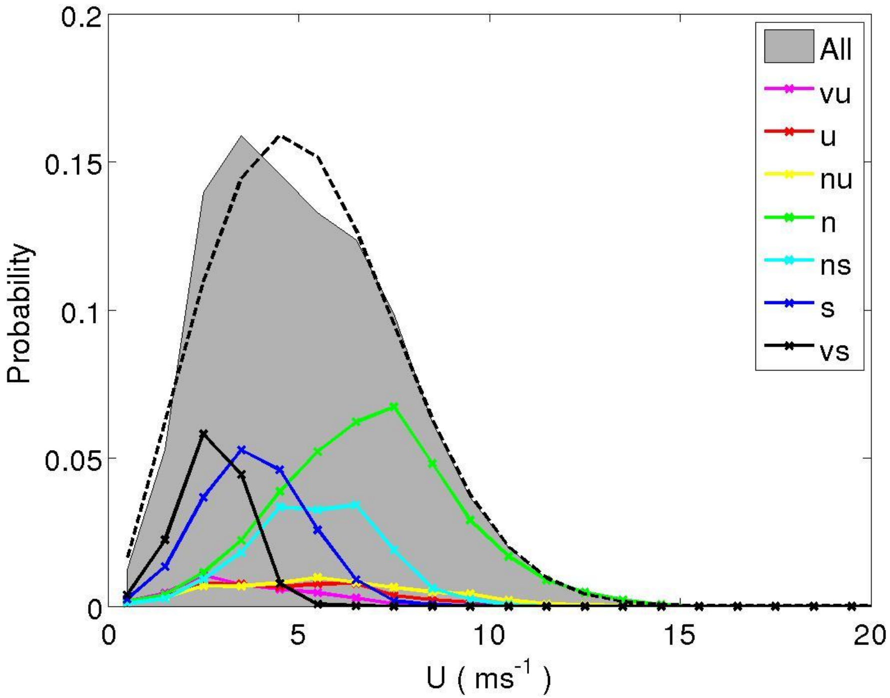
Definitions

- Gusts at Finnish AWS stations are recorded as a maximum of 3 s averages during a 10 min sampling period (WMO standard)
- Mean wind speed is an average over 10 min period
- Gustiness is a measure of how much the gust wind speed differs from the mean wind speed

- Gust factor: $G = \frac{U_{\max}}{U}$
- Peak factor: $g_{t,T} = \frac{U_{\max} - U}{\sigma_U}$

Gusts and stability?





Gust and mean wind speeds in near neutral conditions (green) are larger than in stable conditions (black/blue), unstable conditions (red) are spread over a large interval.

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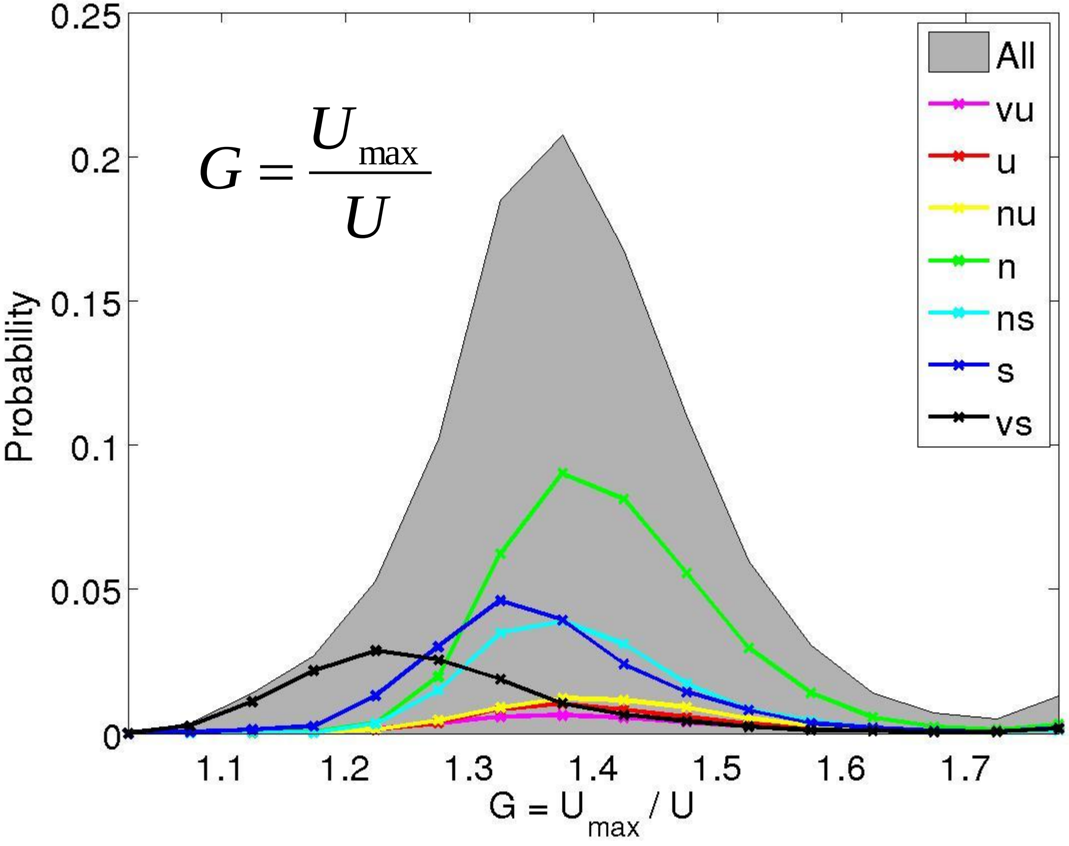
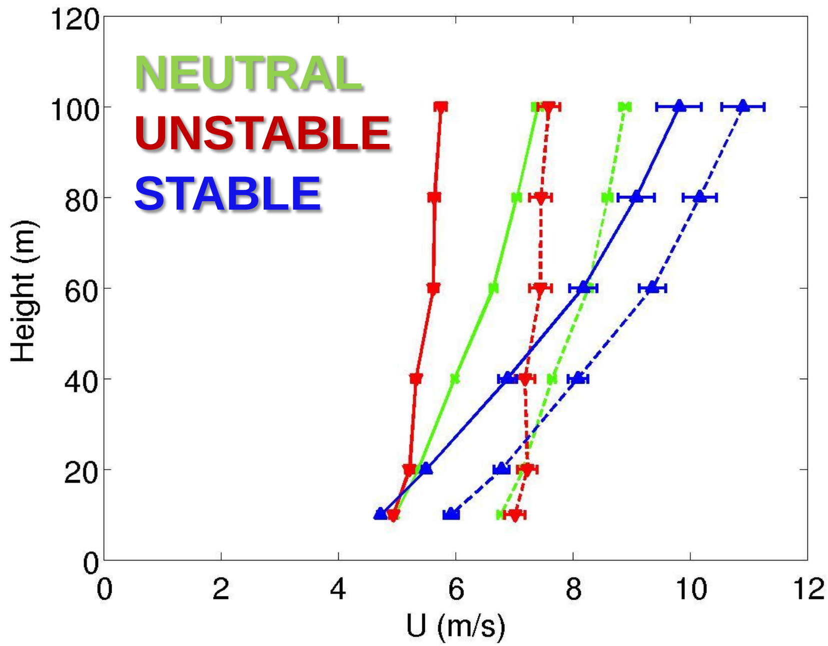
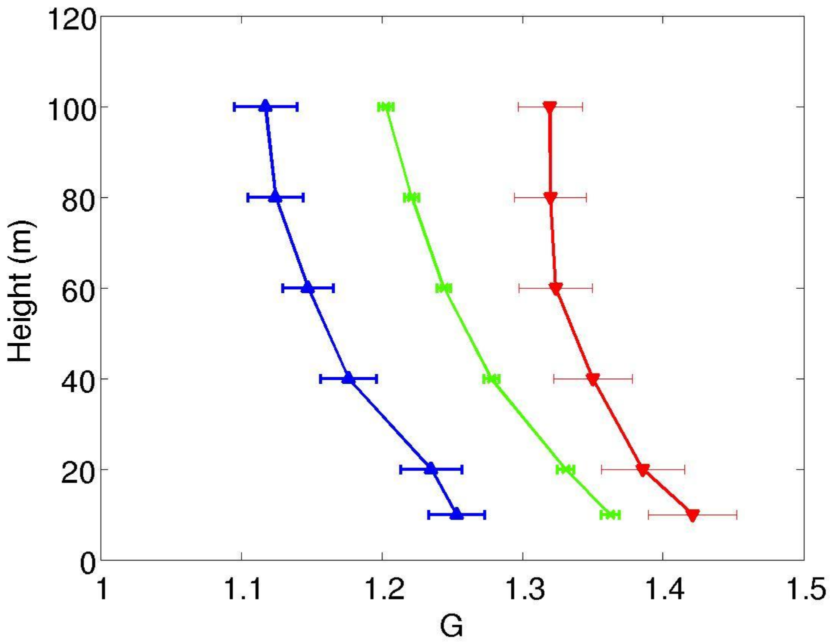
Gust factor and stability?



- In stable conditions, gust factors are smaller than in neutral/unstable
- Large values (>1.7) originate from very low wind speeds

Gust profiles over a grassland...





$$G = \frac{U_{\max}}{U}$$

These cases include profiles for which the 10 m level mean wind speed is within the range 4.5 - 5.5 m s^{-1}

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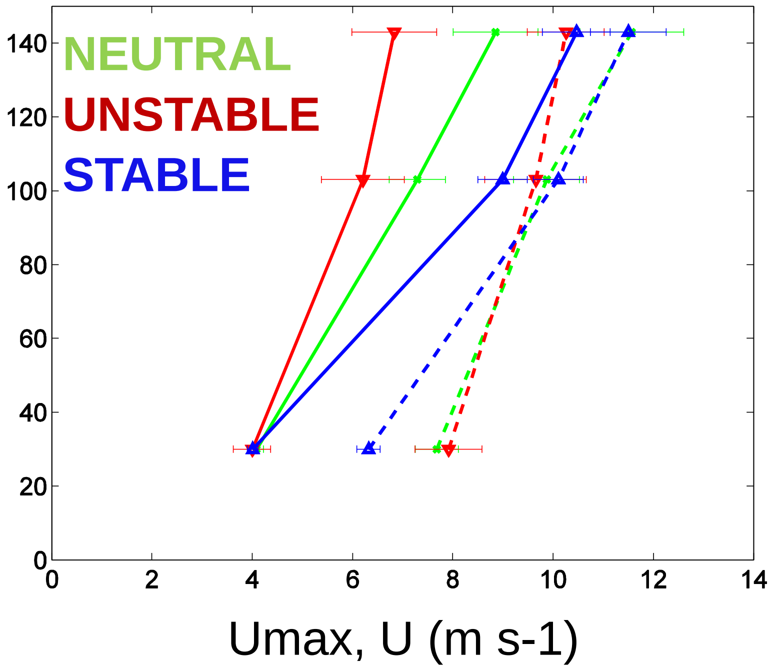
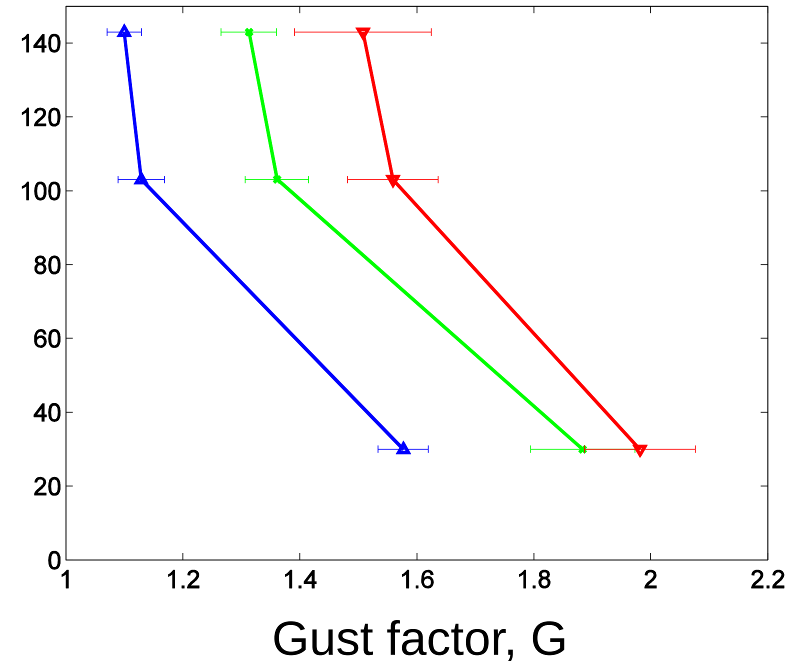
...and over a forest



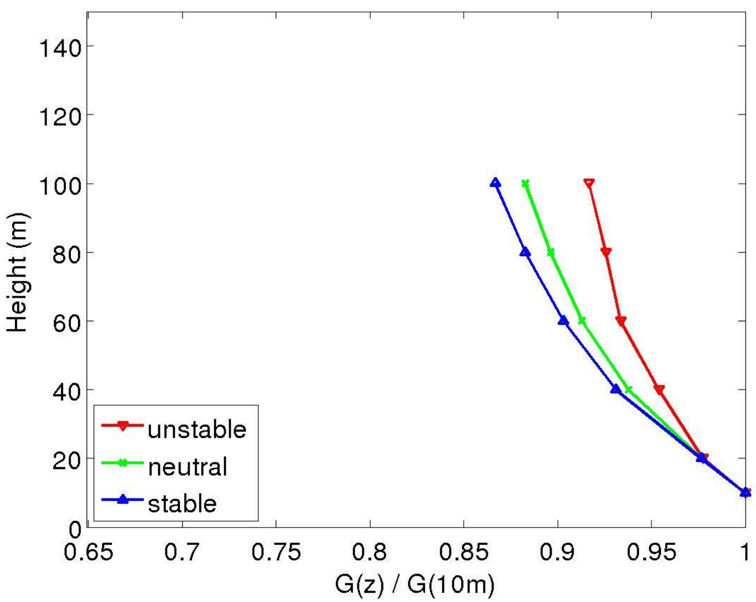


These cases include profiles for which the lowest level (30 m) mean wind speed is wit

Comparison of the surface types

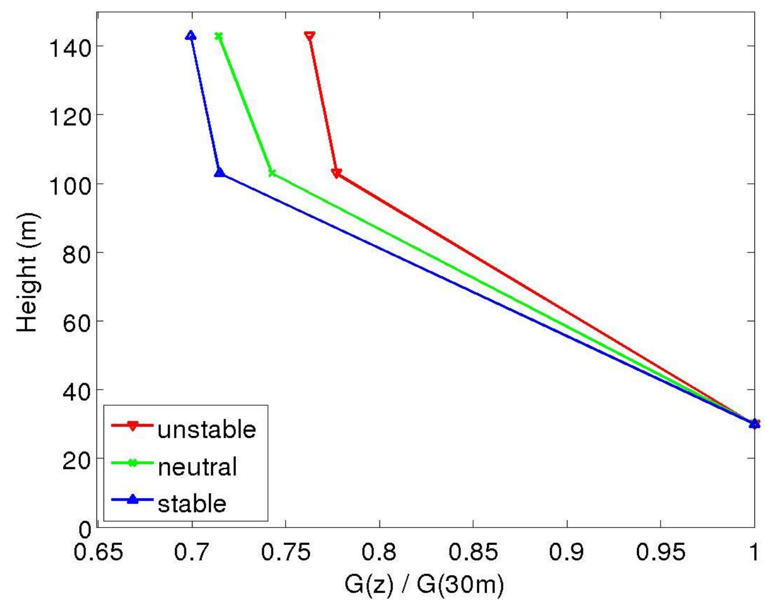
$$G = \frac{U_{\max}}{U}$$

Over a flat grassland



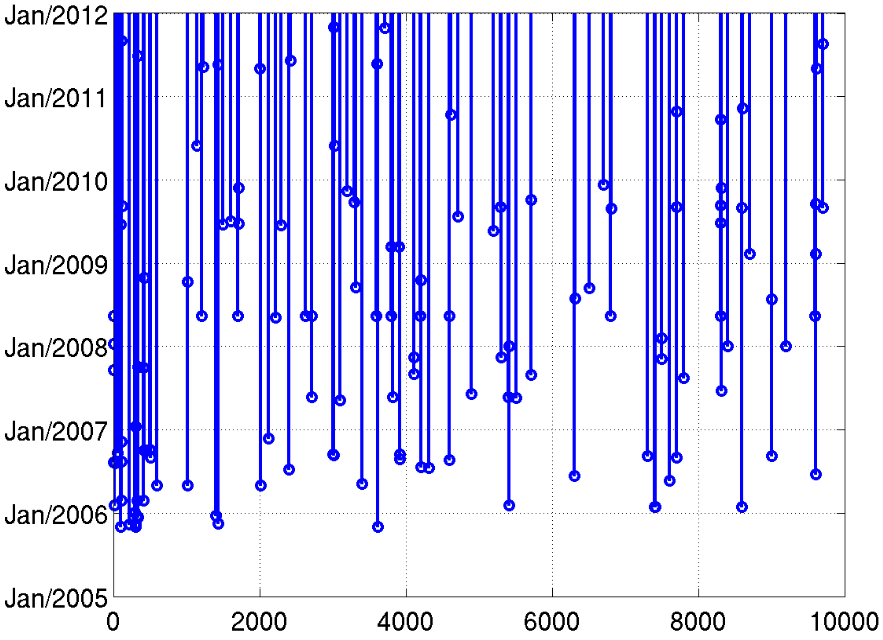
15 %

Over a forest

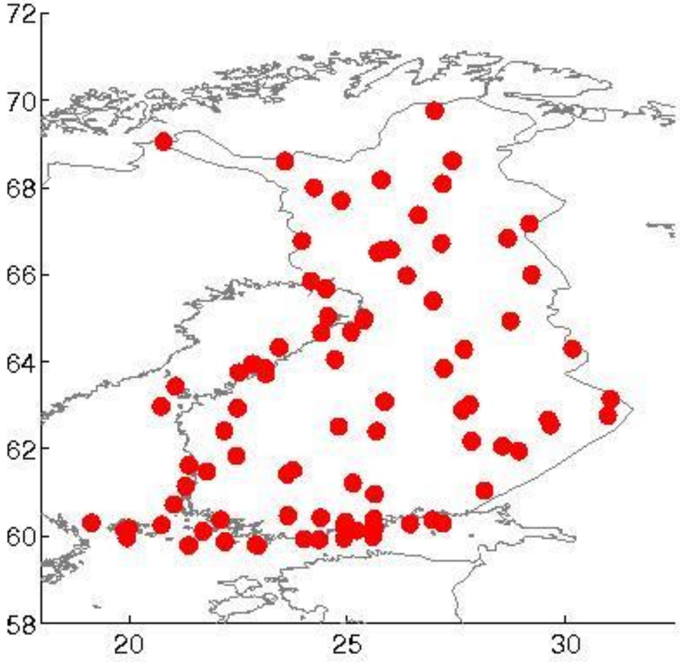


30 %

Gust stations in Finland



Jan 2009

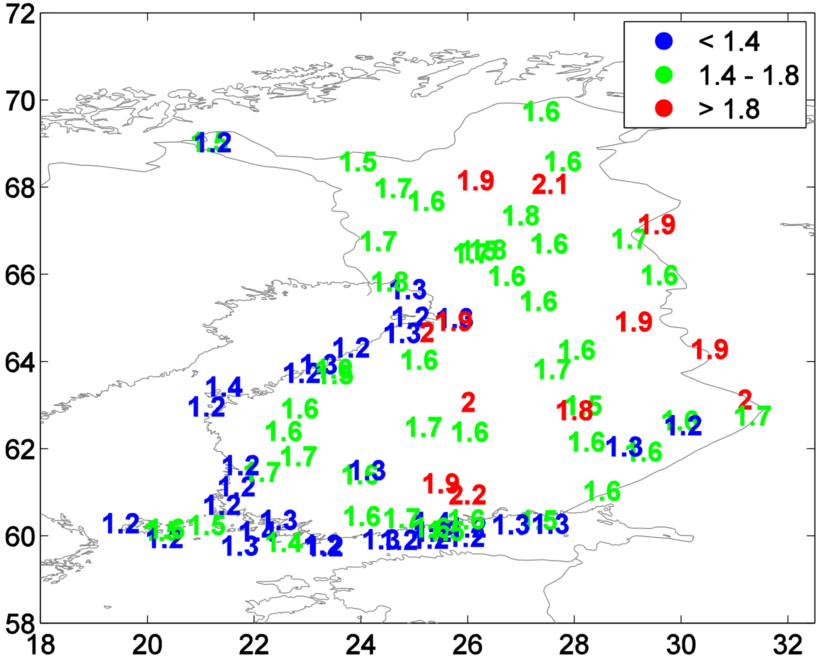


10 min data mainly available from 2006 onwards, except Helsinki Kaisaniemi (from 2001)

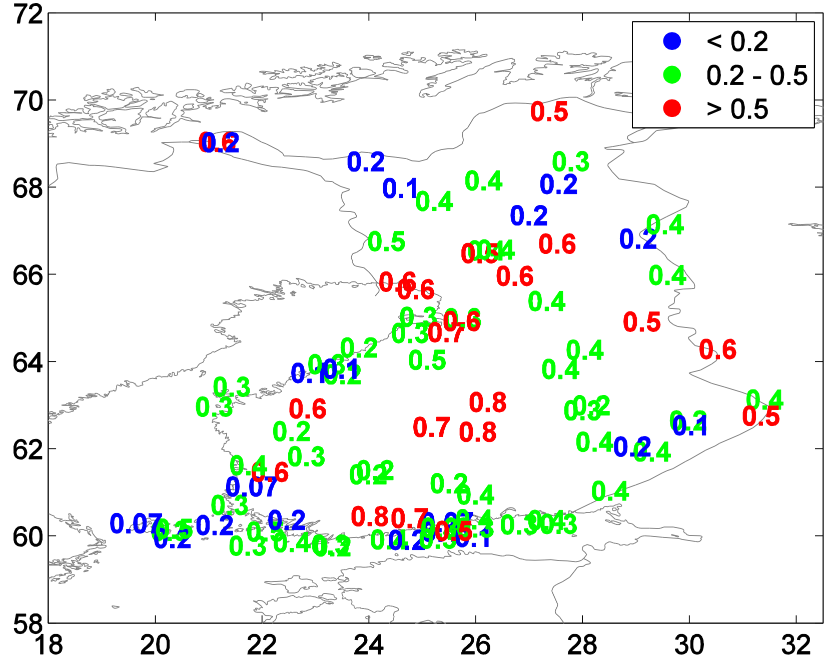
Gust factors, differences between stations

$$G = \frac{U_{max}}{U}$$

Mean G

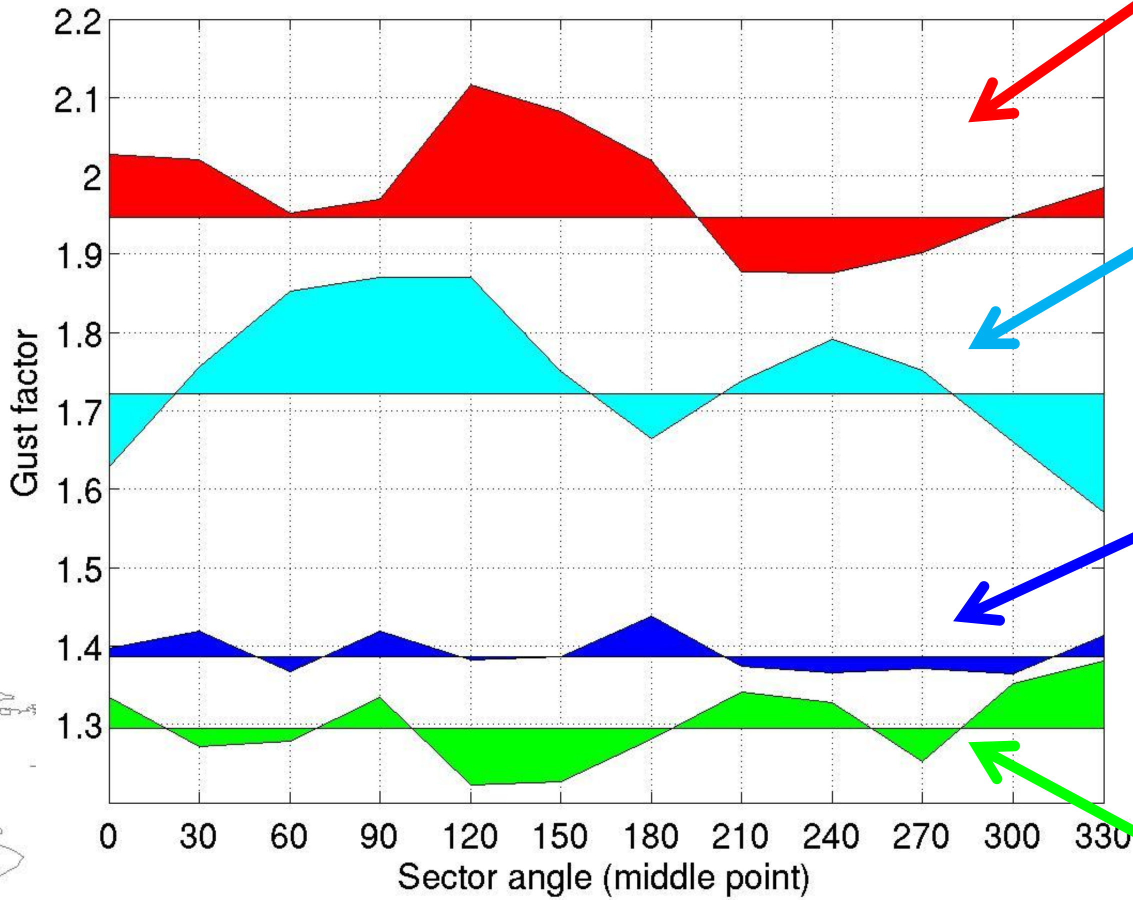


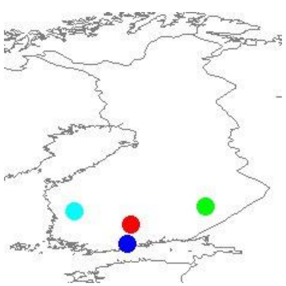
Sector mean G: max – min



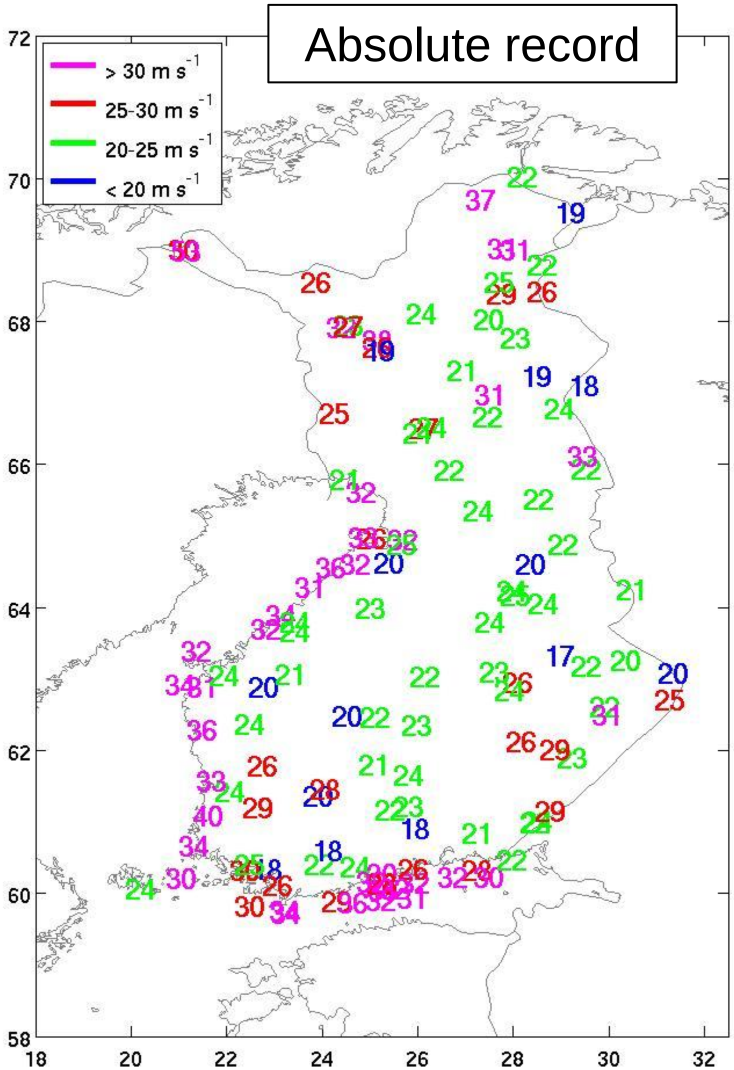
Gust factor: differences between stations

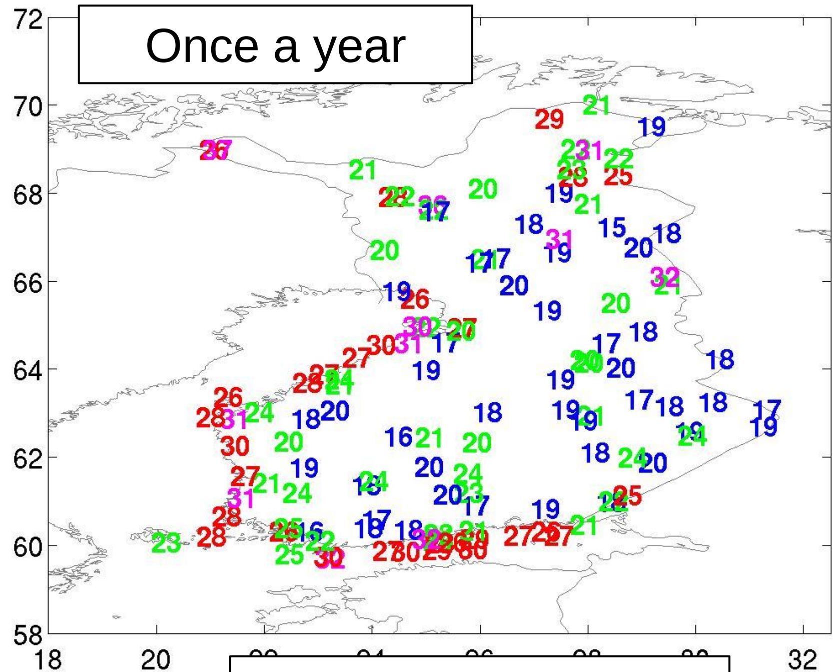
$$G = \frac{U_{max}}{U}$$

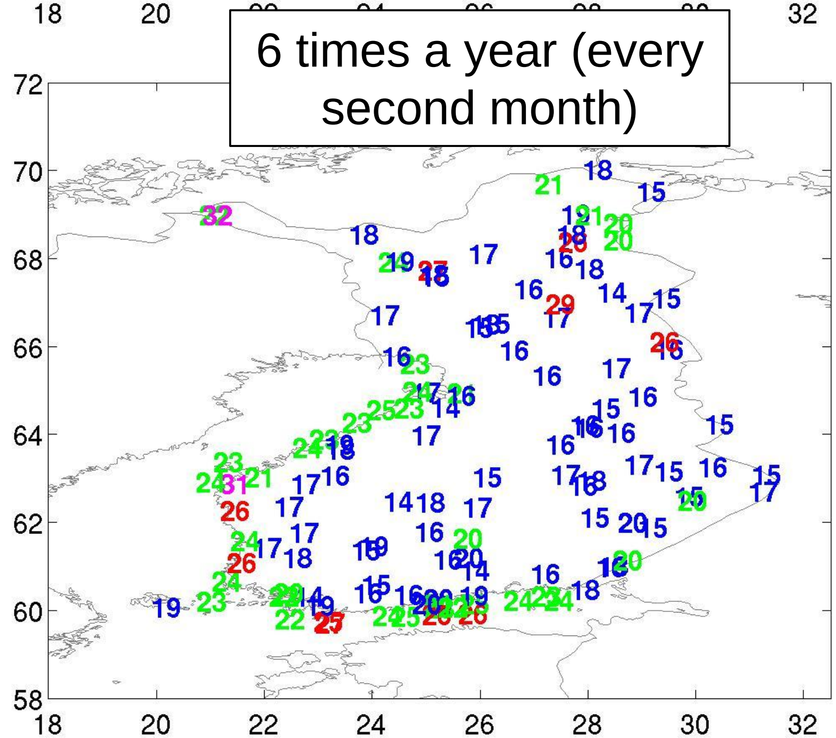




Daily extreme gusts







Two types of parametrizations for gusts

A) Surface methods

- Wieringa (1973)
- Woetmann Nielsen ja Petersen (2001)
- Wischer Schreur ja Geertsema (2008) – (in operational HIRLAM)
- Suomi et al. (2012)
- Operational ECMWF/IFS method

B) Profile method(s)

- Brasseur (2001)
- (Operational ECMWF/IFS method)

Gust parametrizations: surface methods

Main idea: $U_{\max} = U + u' = U + g_{t,T}\sigma_U$

Same as derived from the definition of a gust factor:

$$G = \frac{U_{\max}}{U} = 1 + \frac{U_{\max} - U}{U} = 1 + \frac{U_{\max} - U}{\sigma_U}\frac{\sigma_U}{U} = 1 + g_{t,T}\frac{\sigma_U}{U}$$

Two parameters needed:

1) $g_{t,T} = \frac{U_{\max} - U}{\sigma_U}$ 2) σ_U

A) Surface method used in HIRLAM

$$G = 1 + g_{t,T} r_\sigma \frac{\sigma_U}{U}$$

$$g_{t,T} = \frac{U_{\max} - U}{\sigma_U}$$

Assumptions

- $\sigma_U = \sqrt{2E}$ where E is the turbulent kinetic energy from the model
- Coefficient for the ratio of observed and model standard deviation

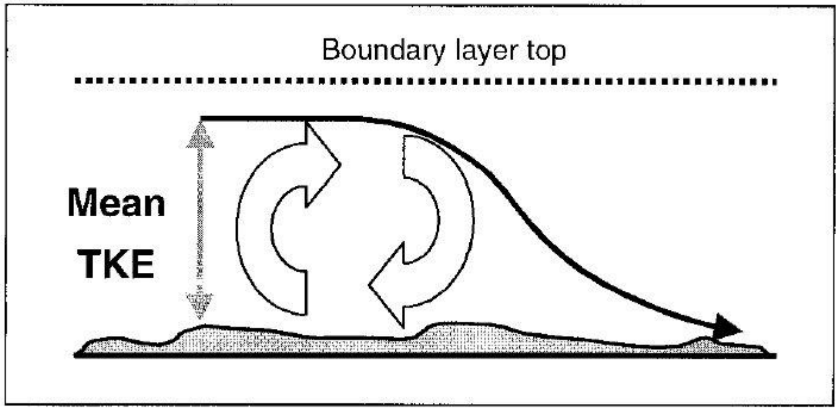
$$r_\sigma = \left(1 - 0.069 \cdot \exp\left(-2.3 \cdot \frac{U \cdot t}{z}\right)\right) \cdot \exp\left(-0.116 \cdot \left(\frac{U \cdot t}{z}\right)^{0.555}\right)$$

- Peak factor is derived from probabilistic considerations and turbulence spectra

$$g = \left[2 * \ln\left\{\frac{T}{\tau} \frac{1}{\sqrt{2\pi} \ln\left(\frac{1}{P}\right)}\right\}\right]^{1/2}$$

$$\tau = \left[\frac{\int_0^\infty S(f)\, df}{2\pi \int_0^\infty f^2 S(f)\, df}\right]^{1/2}$$

B) Profile method: Brasseur (2001)



$$\frac{1}{z_p}\int_0^{z_p} E(z)\,dz \geq \int_0^{z_p} g\frac{\Delta\theta_v(z)}{\Theta_v(z)}\,dz,$$

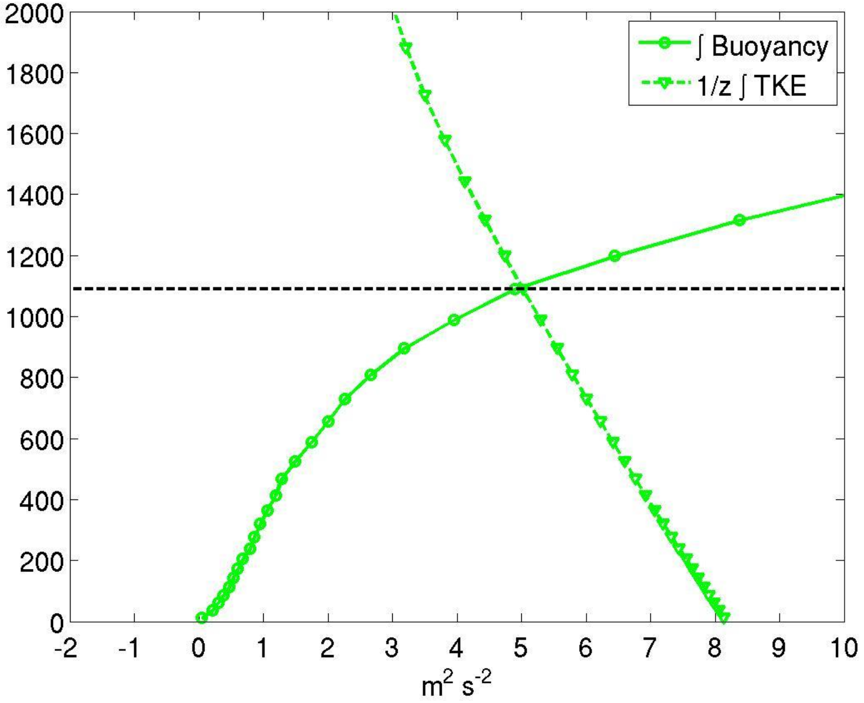
$$Wg_{\text{estimate}} = \max[\sqrt{U^2(z_p) + V_p^2(z_p)}]$$

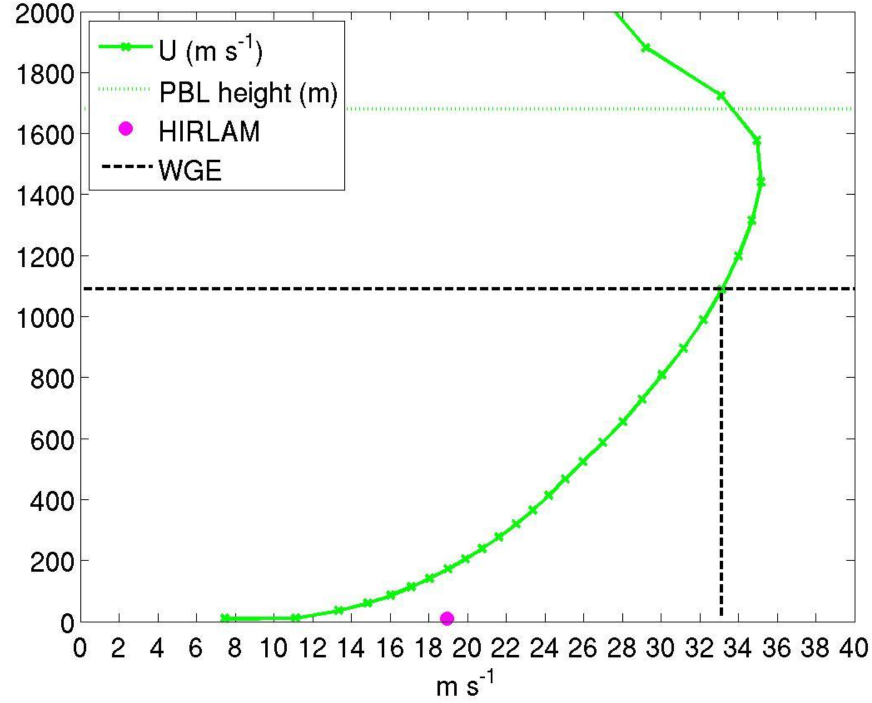
Basic idea:

Surface gusts are formed by turbulent eddies which deviate air parcels moving at some height within the boundary layer down to the surface so that they retain their original wind speed and form the gust at the surface.

Hence, the wind gust estimate (WGE) is the maximum wind speed of the layer where the mean turbulent kinetic energy is larger than the integral of the buoyancy flux.

Example: neutral case





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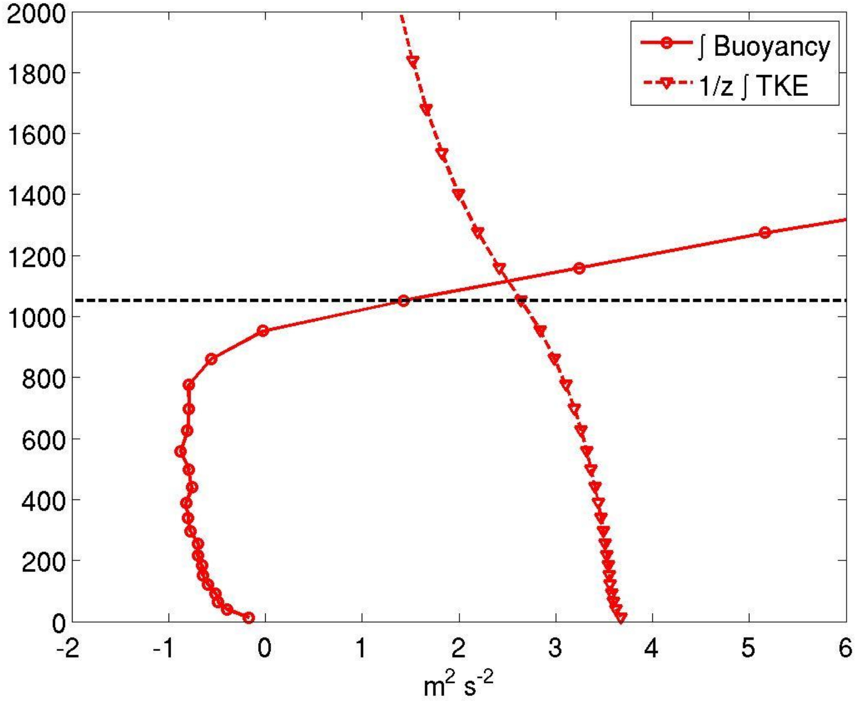
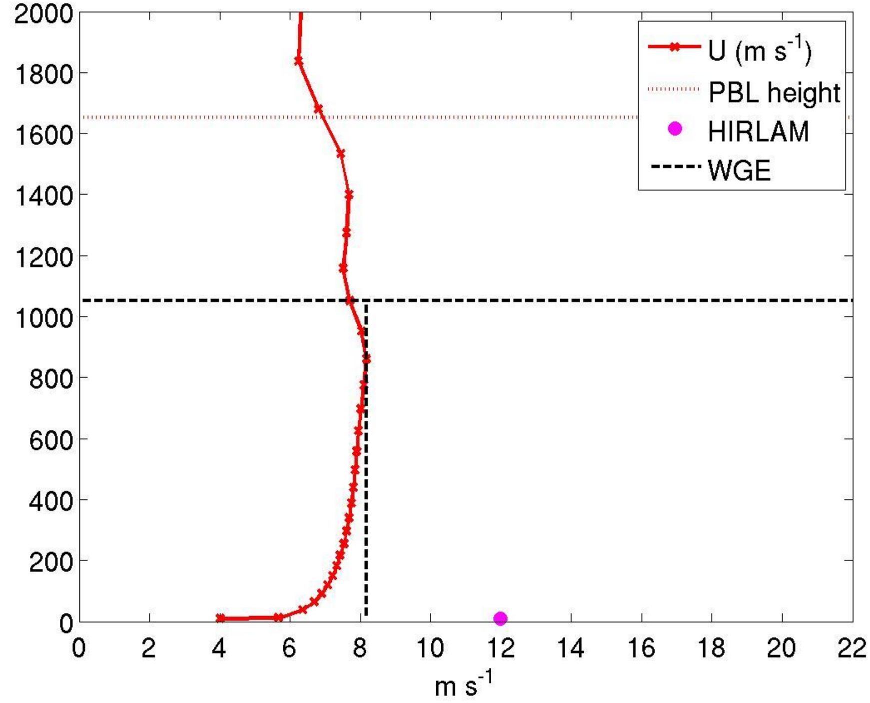
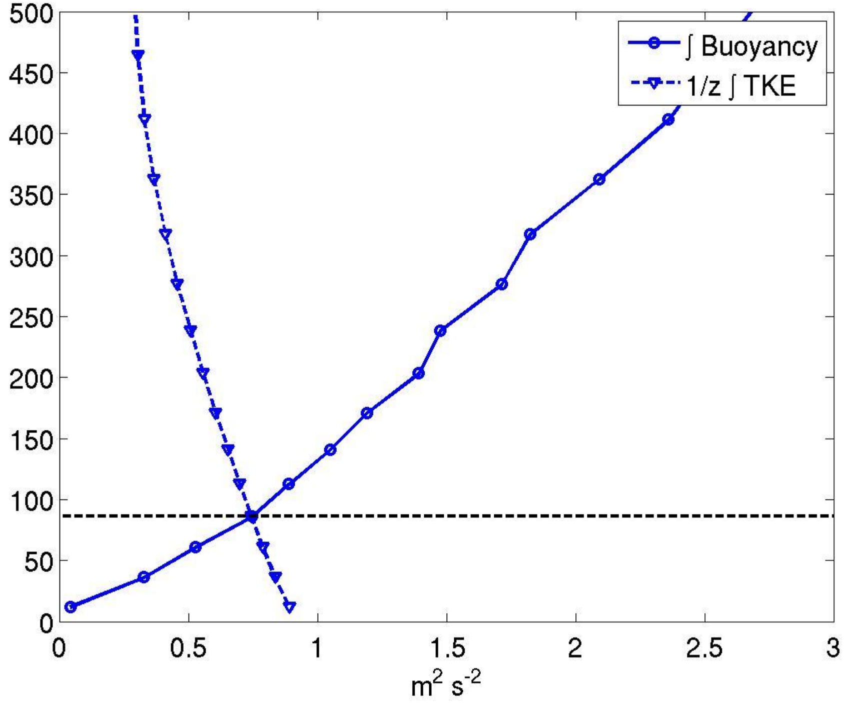
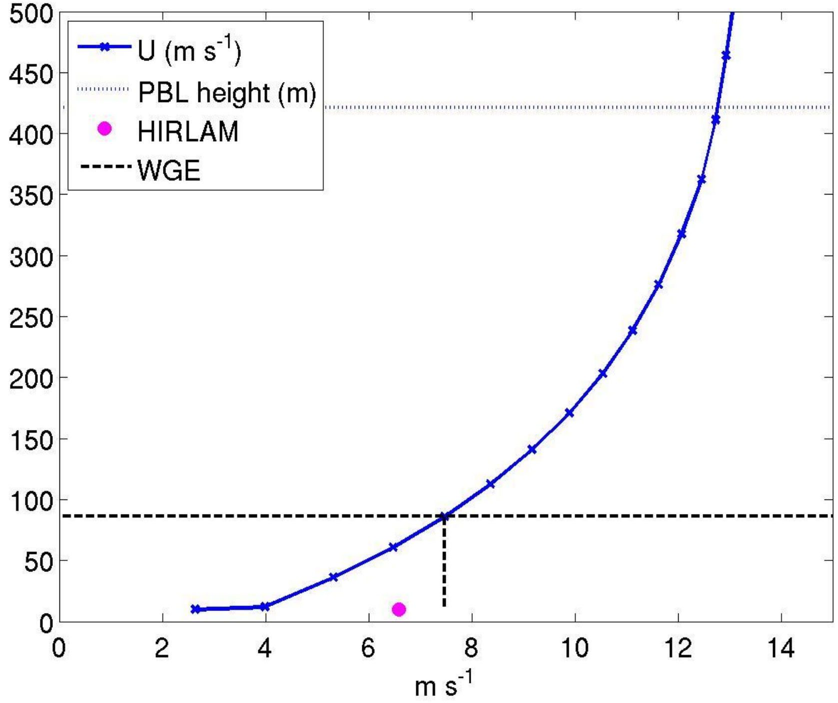
Example: unstable case





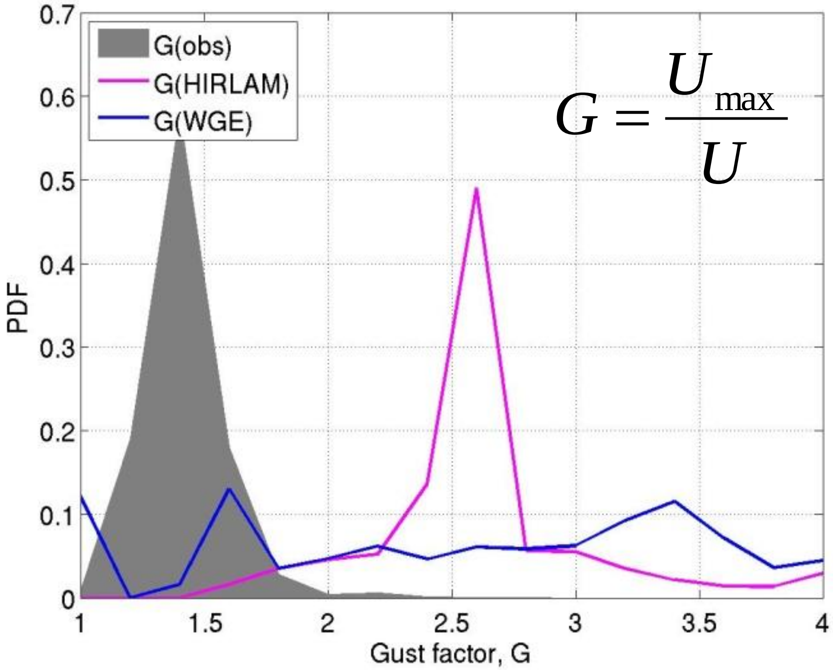
Example: stable case





Comparison of model results: Helsinki-Vantaa airport

HKI-Vantaa, z = 16 m



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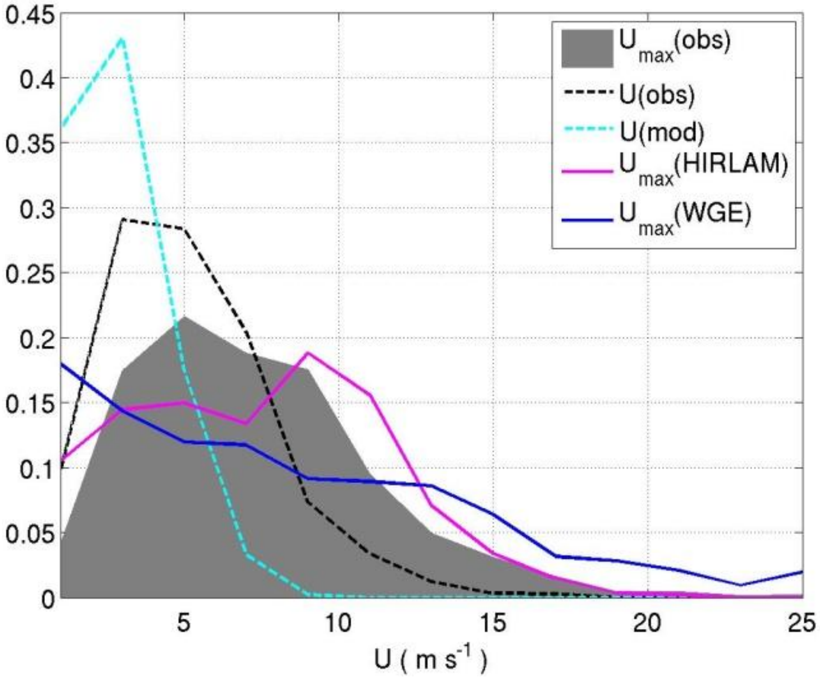

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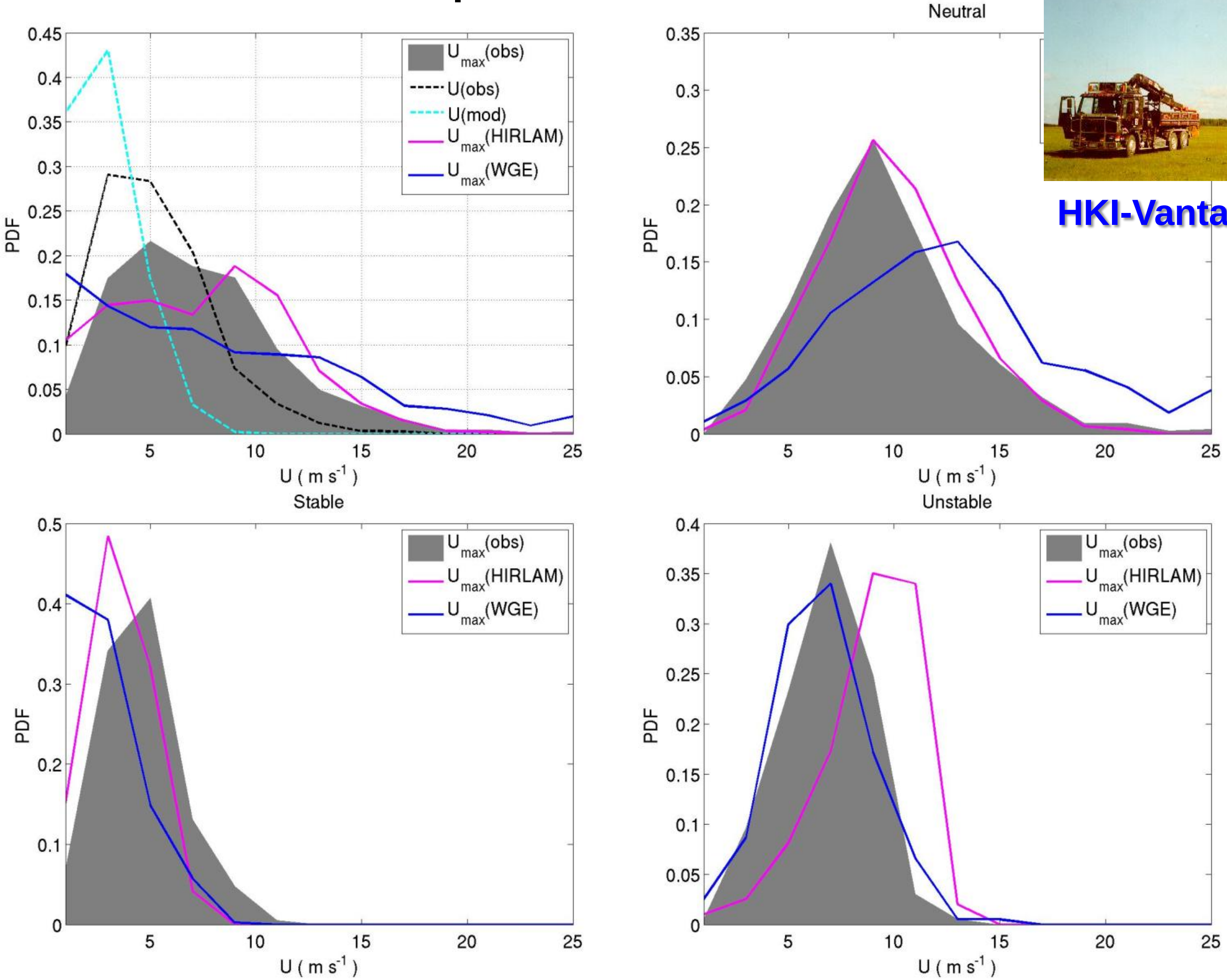

HKI-Vantaa, z = 16 m

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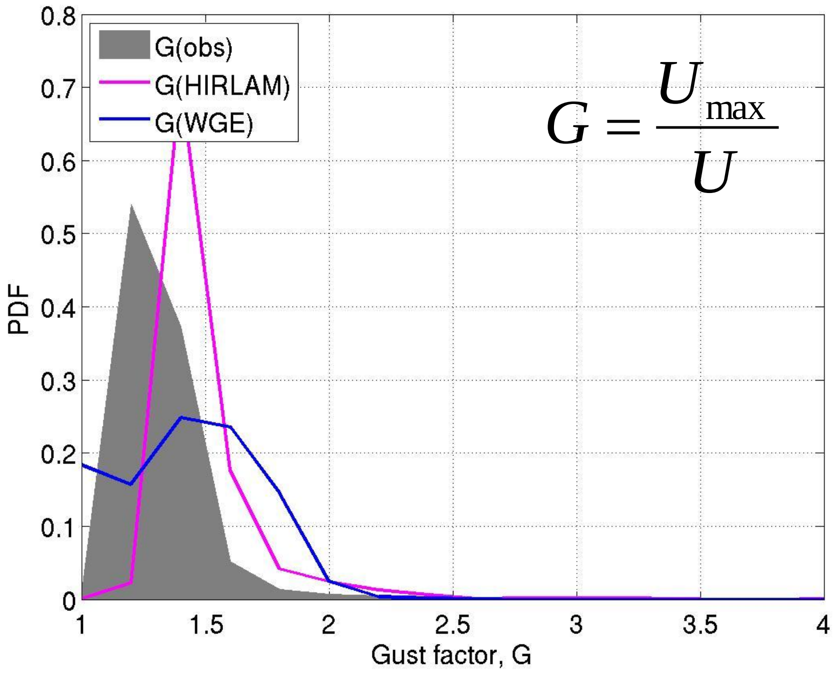
Comparison of model results: Rantasalmi (lake)

Rantasalmi, z = 12 m



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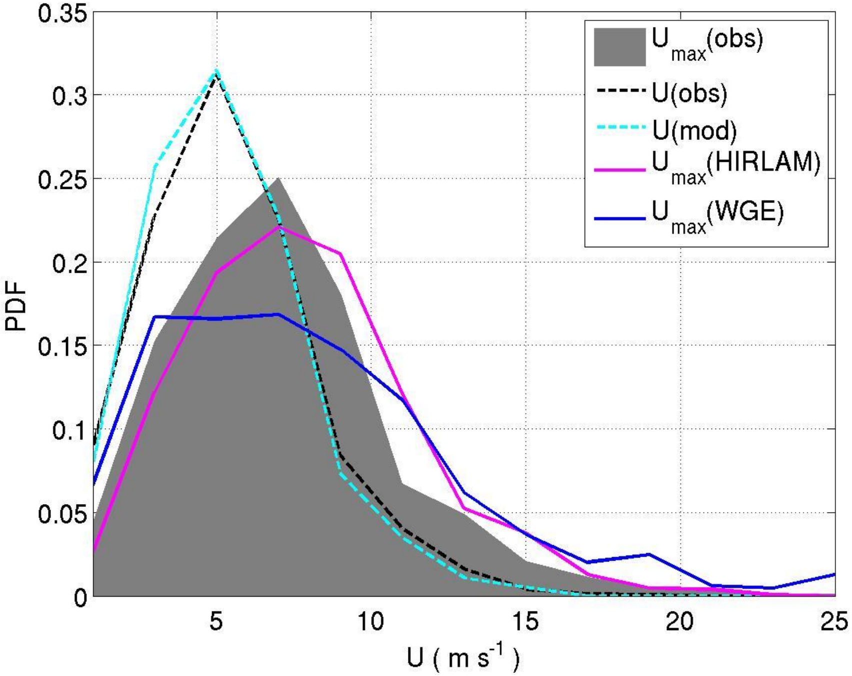

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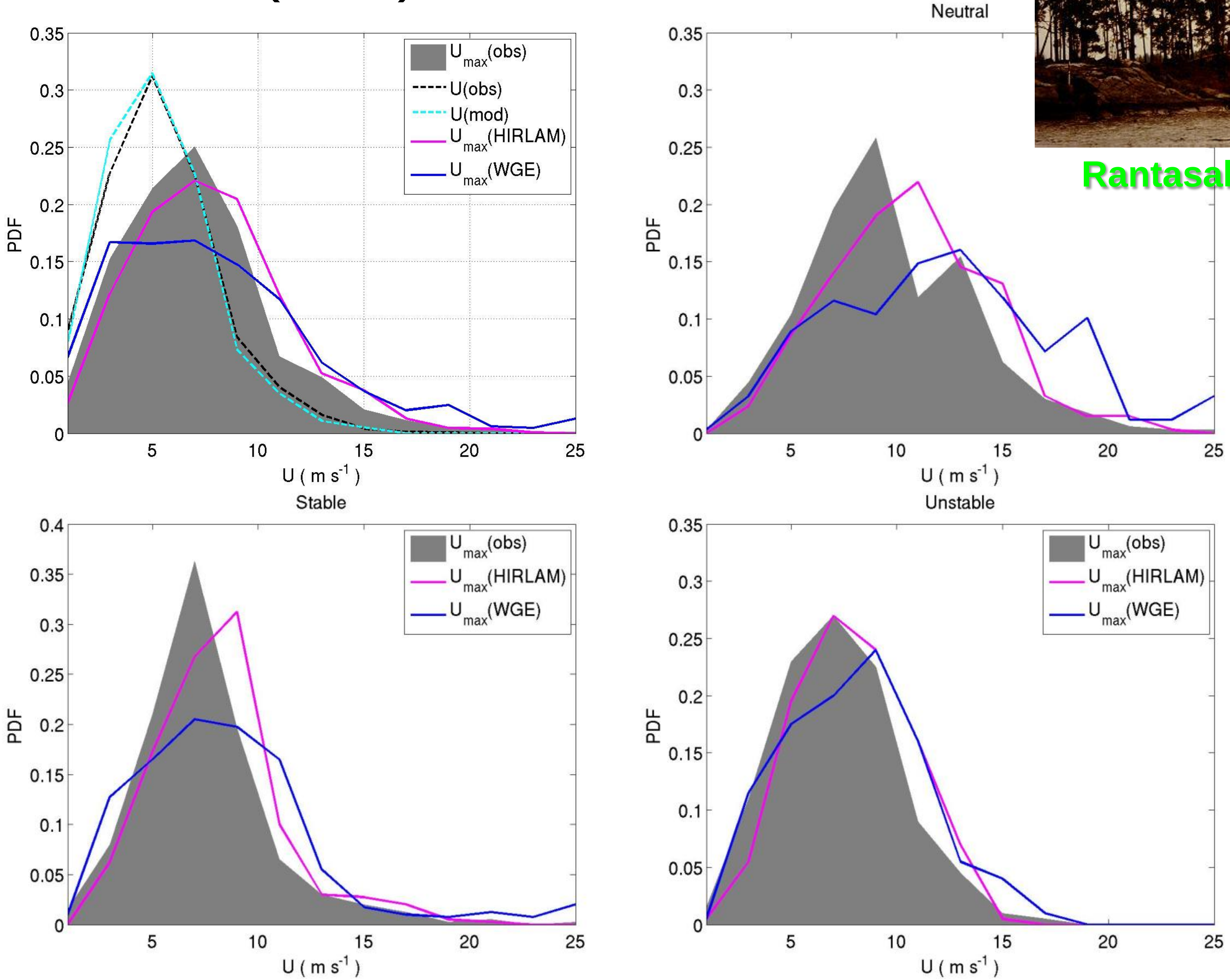
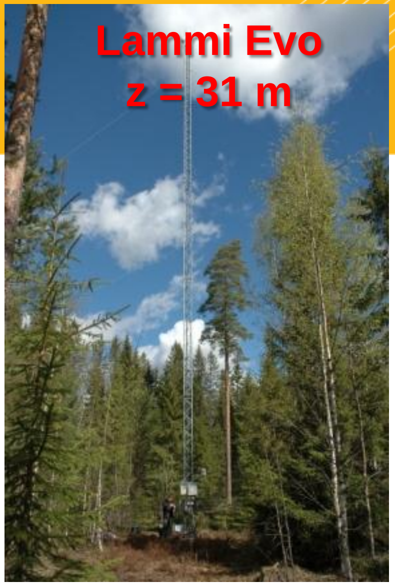
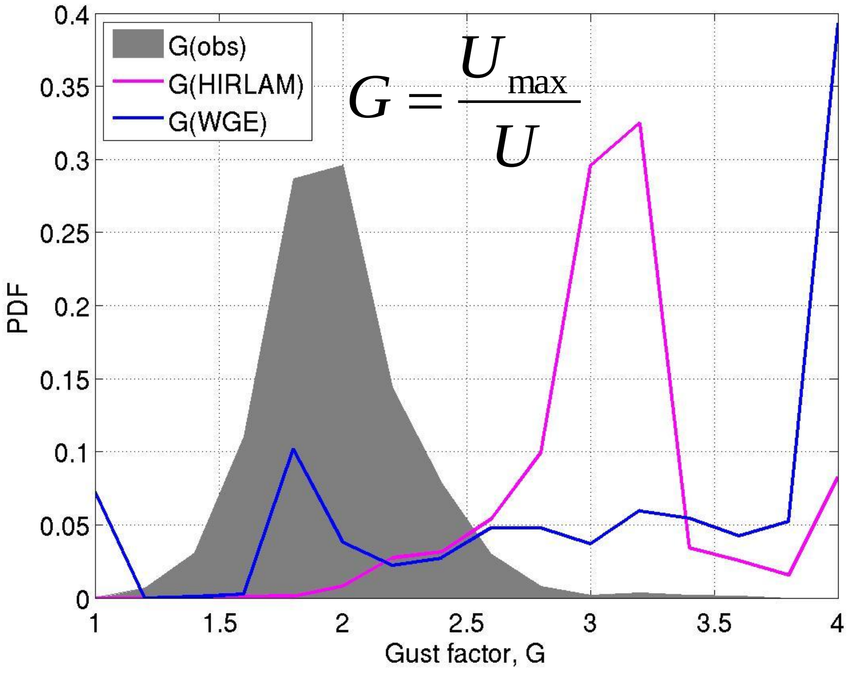
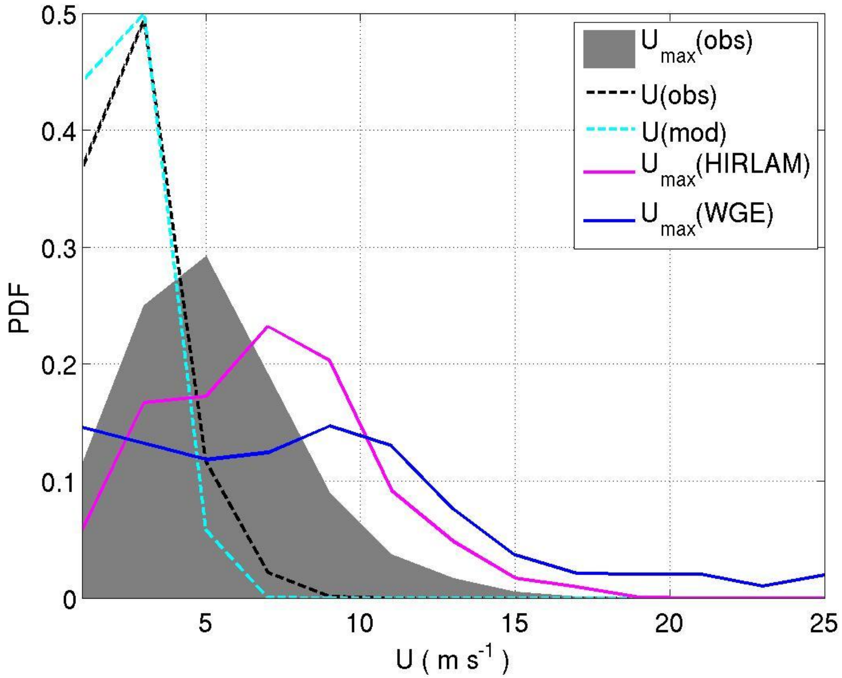


Rantasalmi, z = 12 m

Comparison of model results: Lammi Evo (forest)







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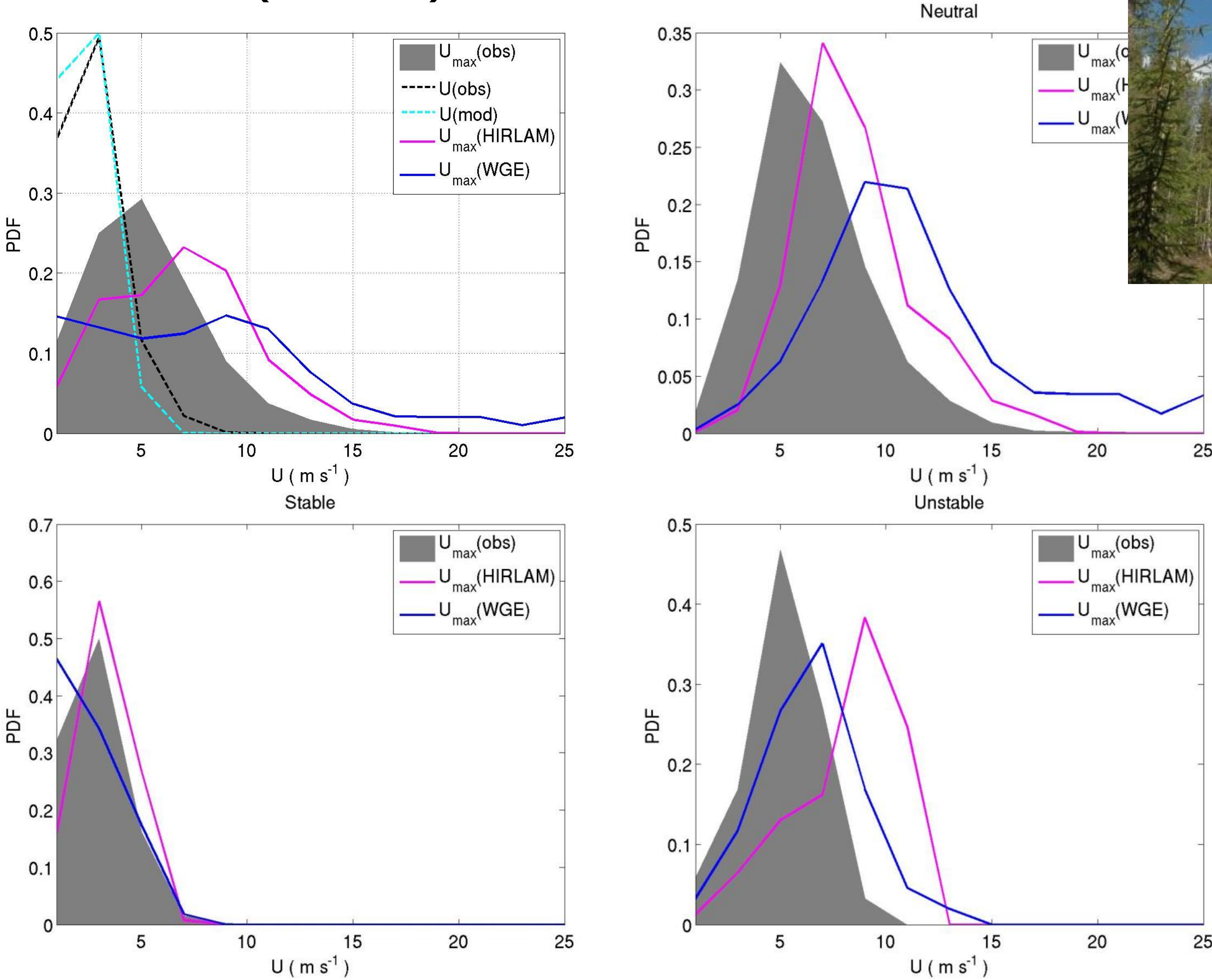
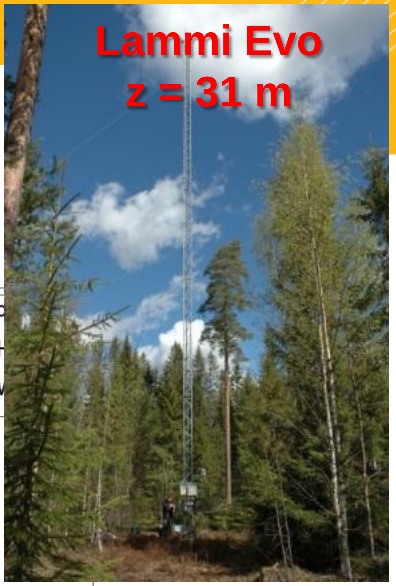
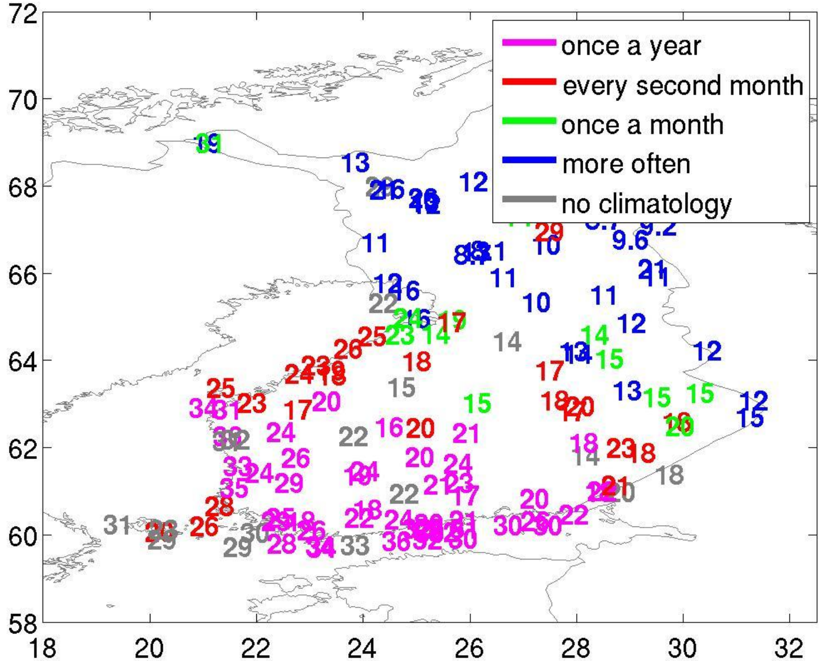


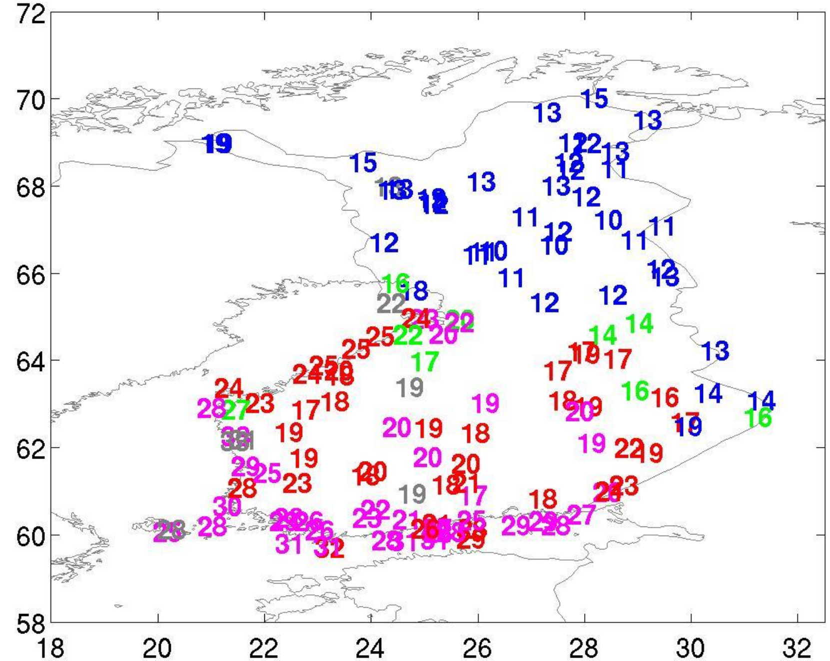


Example case: Tapani storm 26 December 2011

Observations



Hirlam surface method



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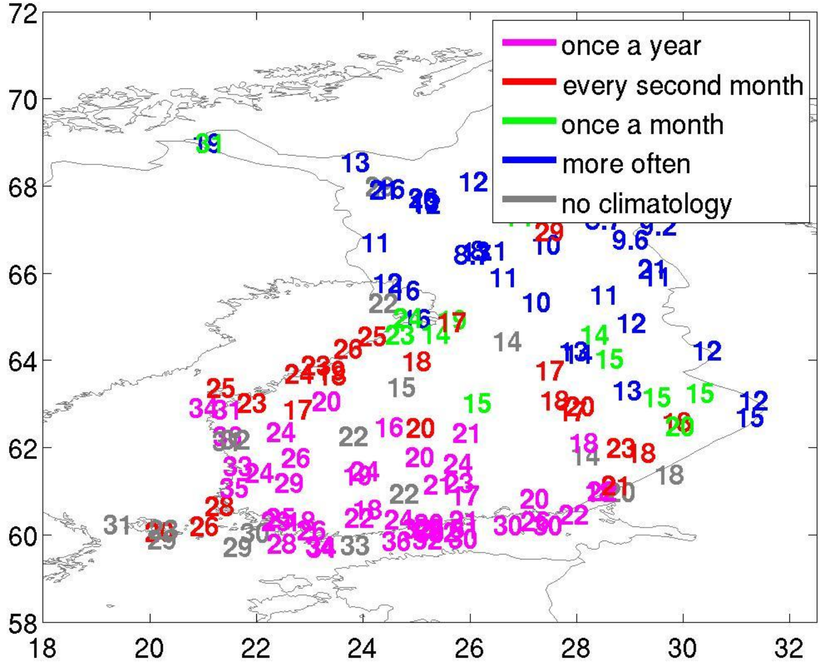
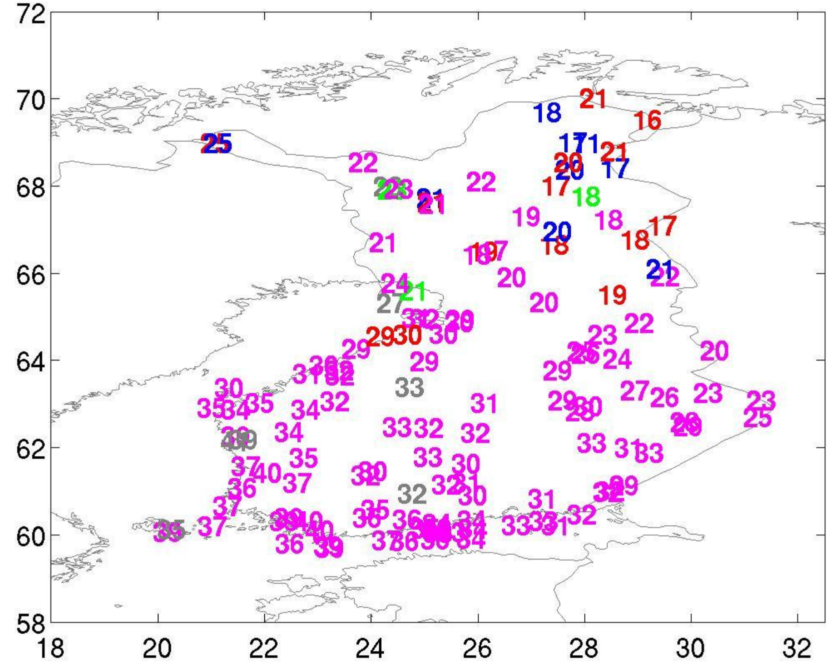


Brasseur profile method



Summary

- The largest factor determining the gust factor is surface roughness
- Gustiness conditions at Finnish AWS stations are highly variable
- Gust factor forecast is good over lake (and coastal regions), but has large differences over land: model turbulence (the gust factor) is estimated too large in the example cases
- Gust wind speed forecast can be good even though the gust factor is overestimated and/or the mean wind speed is too small in the model
- Effect of stability is included in (some of) the gust parametrizations. Over boreal regions this signal can, however, be hidden by the effects of surface roughness.

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