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On the measurement of wind gusts: from traditional anemometry to new methodologies applying Doppler lidar and research aircraft measurements

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Outline

- Motivation
- Definitions
- On the current techniques
- Something new: Doppler lidar and research aircraft
- Summary and future possibilities

Motivation


Solari et al. (2012)

- Extreme gusts cause damage and are a risk to safety: sea and land transport, aviation, construction, outdoor activities, etc
- Energy sector: power cuts, wind energy (design, siting, operation: unit commitment)
- Engineering: design of structures
- Insurance business
- Gusts can play a relevant role in many physical processes: sea ice drift, suspension of particles (dust, snow, sea spray)
- Despite of the high demand for gust information, gusts have received fairly little attention both from the modeling but also from the observational aspect.

What is meant by the gust?

- Wind gust is, by definition, a short duration wind speed maximum
- WMO recommendation is to measure 3 s maximum gust during each 10 min period
- Definitions:
  - U_{max} wind gust speed (maximum of the 3 s moving averages)
  - U mean wind speed (average wind speed during 10 min)
  - σ standard deviation of the wind speed (over 10 min)
- Measures of gustiness:

Gust factor:

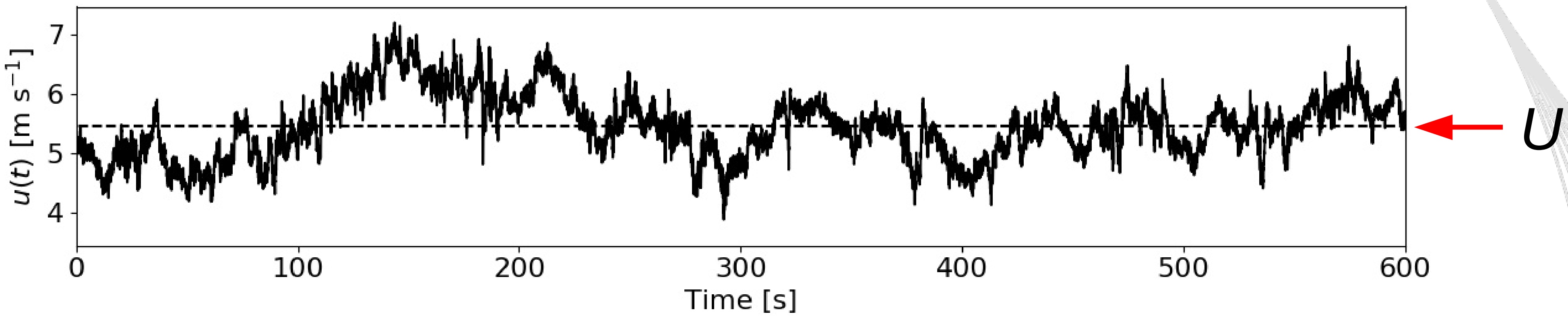
$$G = \frac{U_{max}}{U}$$

Peak factor:

$$g_x = \frac{U_{max} - U}{\sigma}$$

Example: gust from a time series

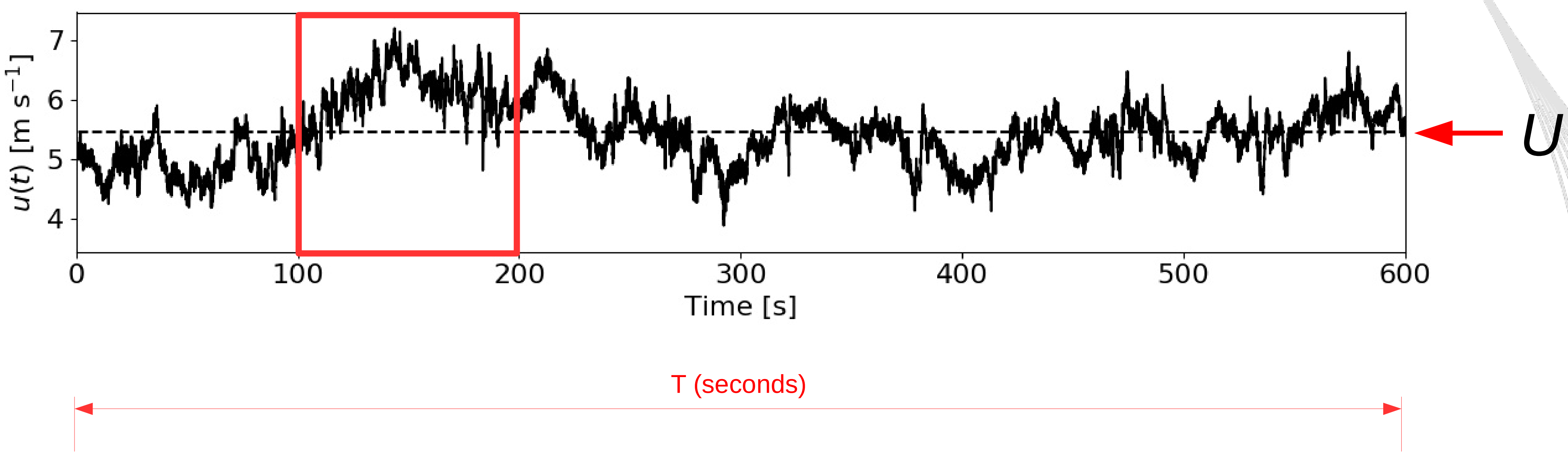
$$G = \frac{U_{max}}{U} \qquad g_x = \frac{U_{max} - U}{\sigma}$$



T (seconds)

Example: gust from a time series

$$G = \frac{U_{max}}{U} \qquad g_x = \frac{U_{max} - U}{\sigma}$$



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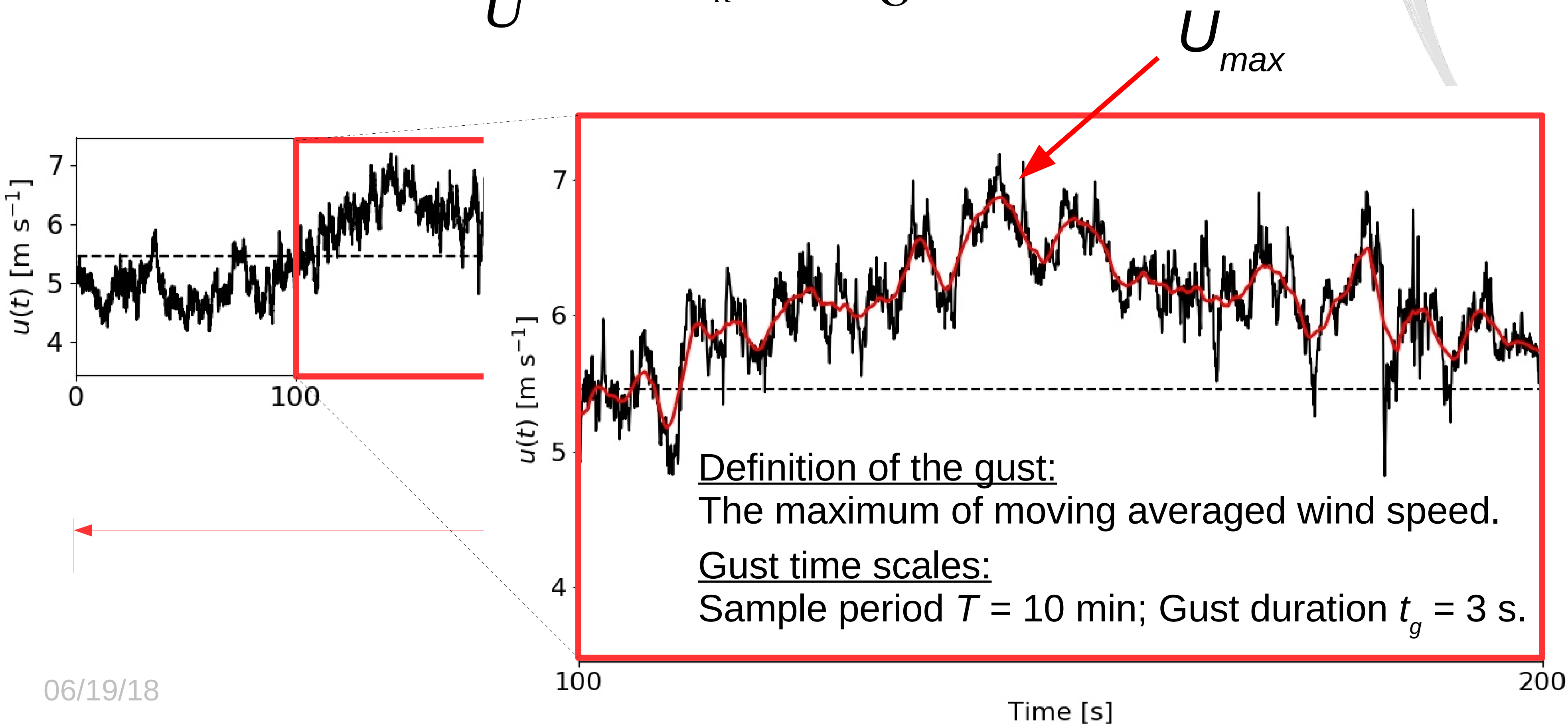


Definition of the gust:
The maximum of moving averaged wind speed.

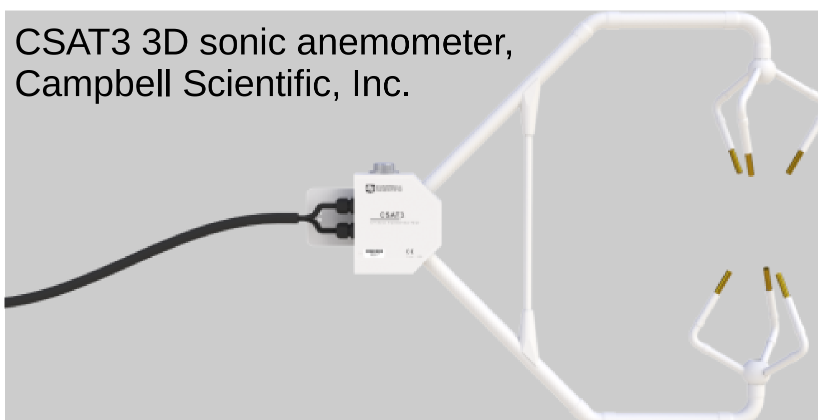
Gust time scales:
Sample period T = 10 min; Gust duration t_g = 3 s.

Current wind gust measurement techniques

P2546-OPR,
WindSensor

WA25 Wind Set, Vaisala

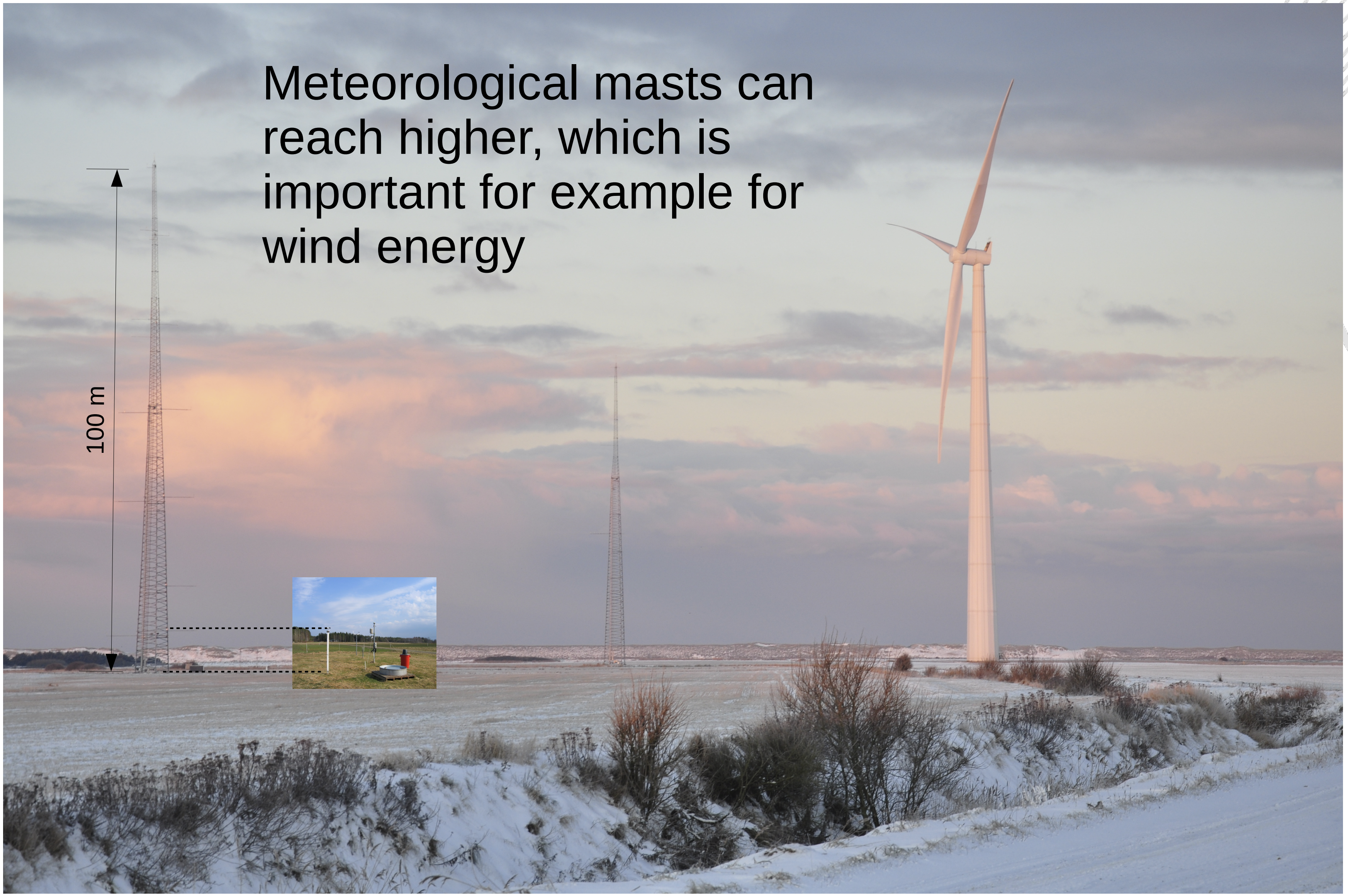
CSAT3 3D sonic anemometer,
Campbell Scientific, Inc.



Ultrasonic Anemometer 2D,
Thies Clima

Recommended conditions

- These instruments are used at weather stations, where the standard measurement height is 10 m (WMO)

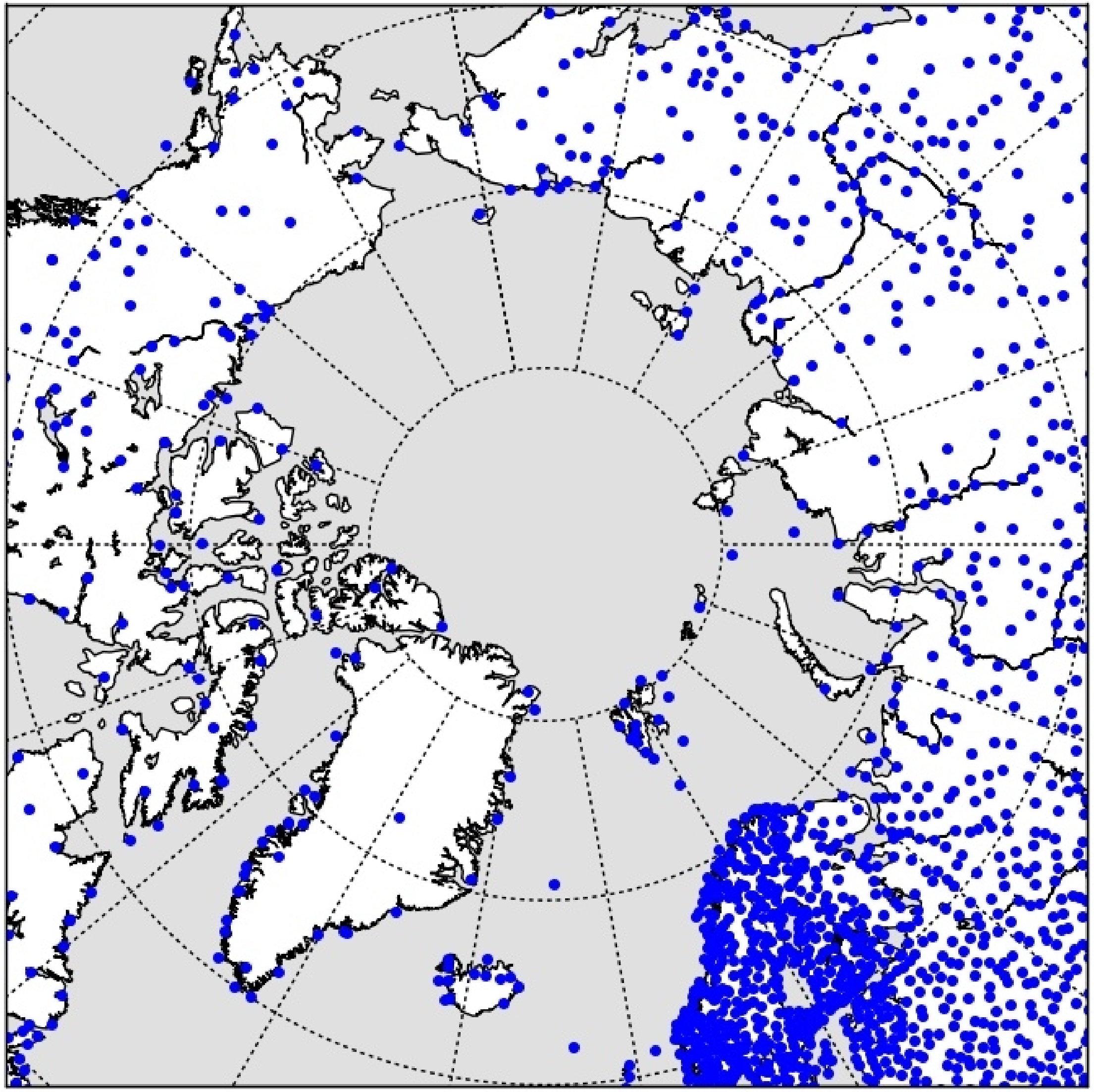

Meteorological masts can reach higher, which is important for example for wind energy
100 m

Challenges of existing measurements

- Limited range of measurement heights:
  - Only one height at weather stations: representativity?
  - Deployment of tall meteorological masts costly

Challenges of existing measurements

- Sparse network of observations in remote locations, such as the marine Arctic, where most of the weather stations are located at coastal regions.



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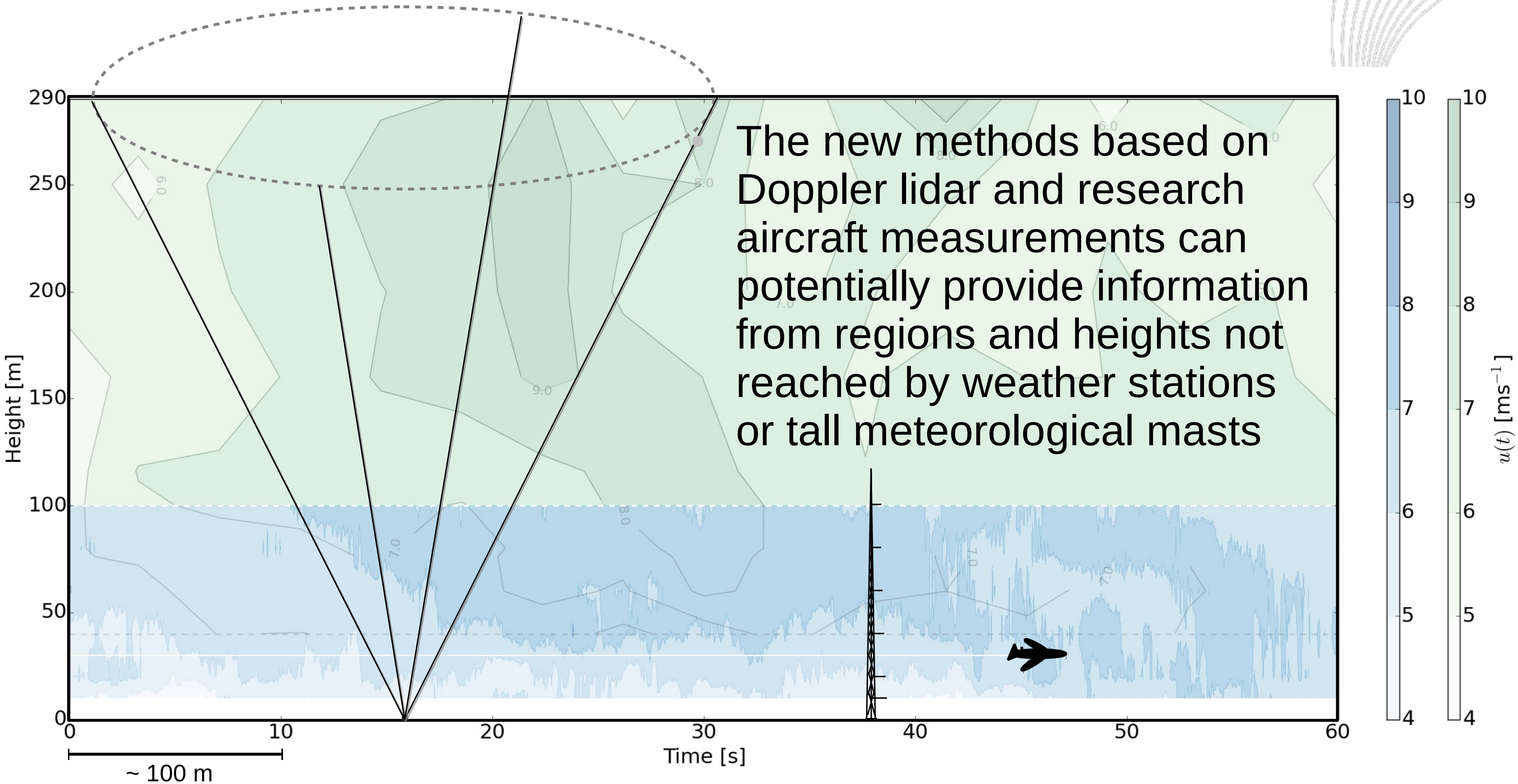
Recent developments

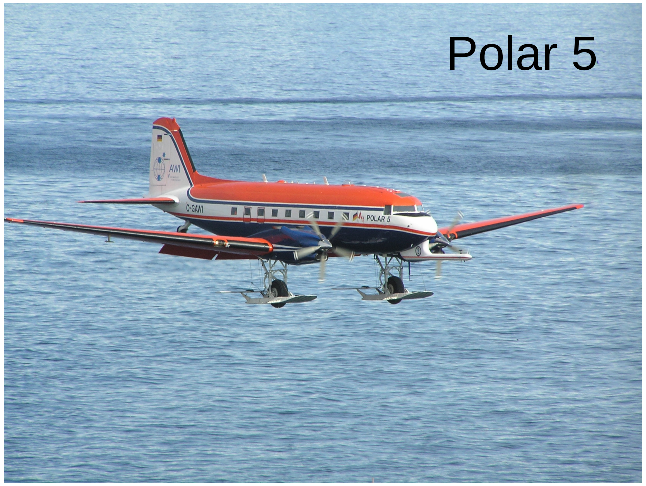


The new methods based on Doppler lidar and research aircraft measurements can potentially provide information from regions and heights not reached by weather stations or tall meteorological masts

Doppler lidar

Research aircraft

Aircraft measurements from the marine Arctic

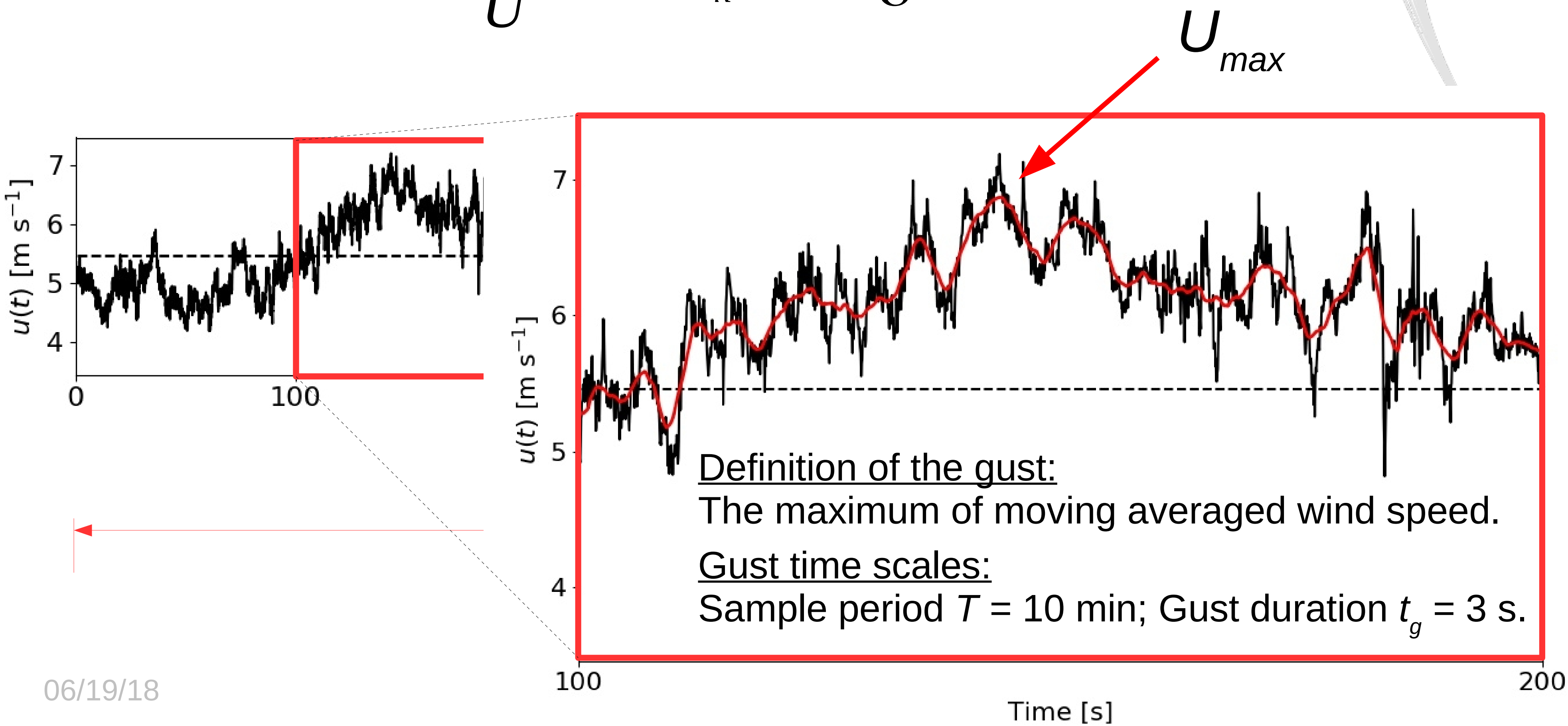


Research aircraft of the Alfred Wegener Institute (AWI), Germany

Research aircraft has been used to measure turbulence already for decades, but gusts have not yet been assessed based on these data.

Example: gust from a time series

$$G = \frac{U_{max}}{U} \qquad g_x = \frac{U_{max} - U}{\sigma}$$



Definition of the gust:
The maximum of moving averaged wind speed.

Gust time scales:
Sample period T = 10 min; Gust duration t_g = 3 s.

But: a moving aircraft...

- As the research aircraft moves (flight speeds typically 50 – 100 m/s) when measuring the wind speed time series, the measurements do not represent the wind speed fluctuations as a function of time but instead as a function of flight distance.

What are the gust length scales?

~~t_g = 3 s~~
~~T = 10 min~~

⇒

x_g = ?
X = ?

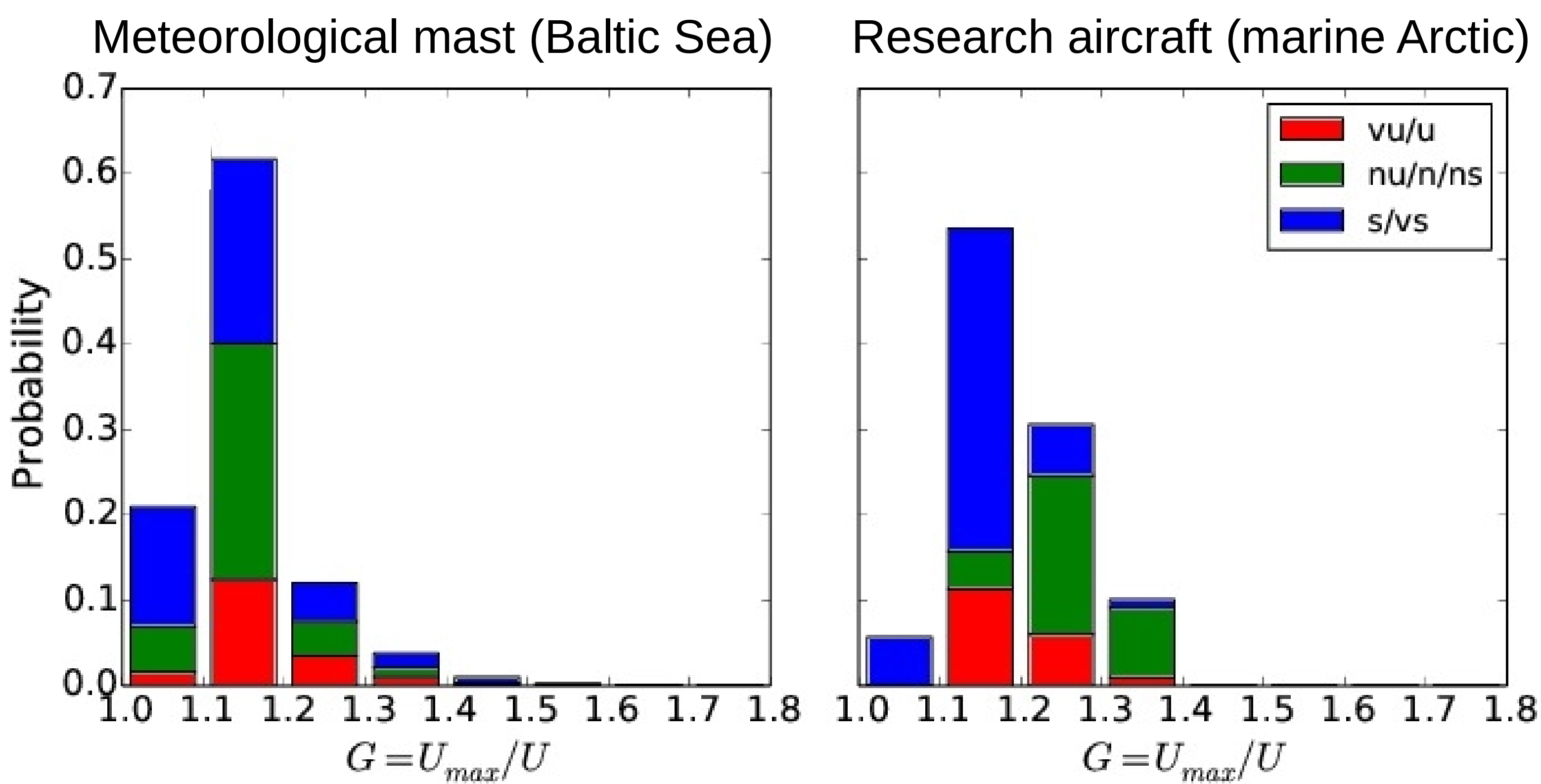
What are the gust length scales?

t_g = 3 s
T = 10 min

⇒

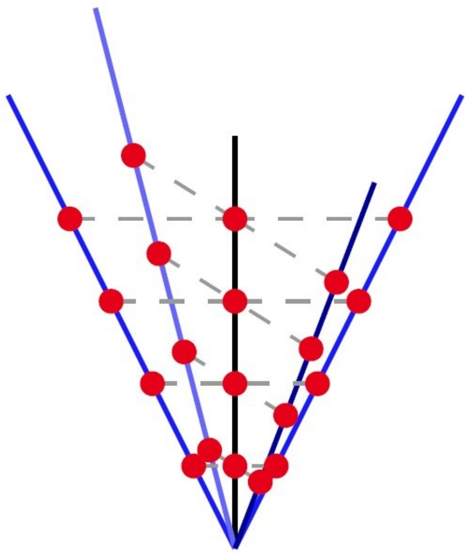
x_g = 30 m
X = 6 km

Comparison with independent data



- Range of values very similar → gust length scales were determined successfully
- Result: research aircraft can be used to measure wind gusts!

Doppler lidar

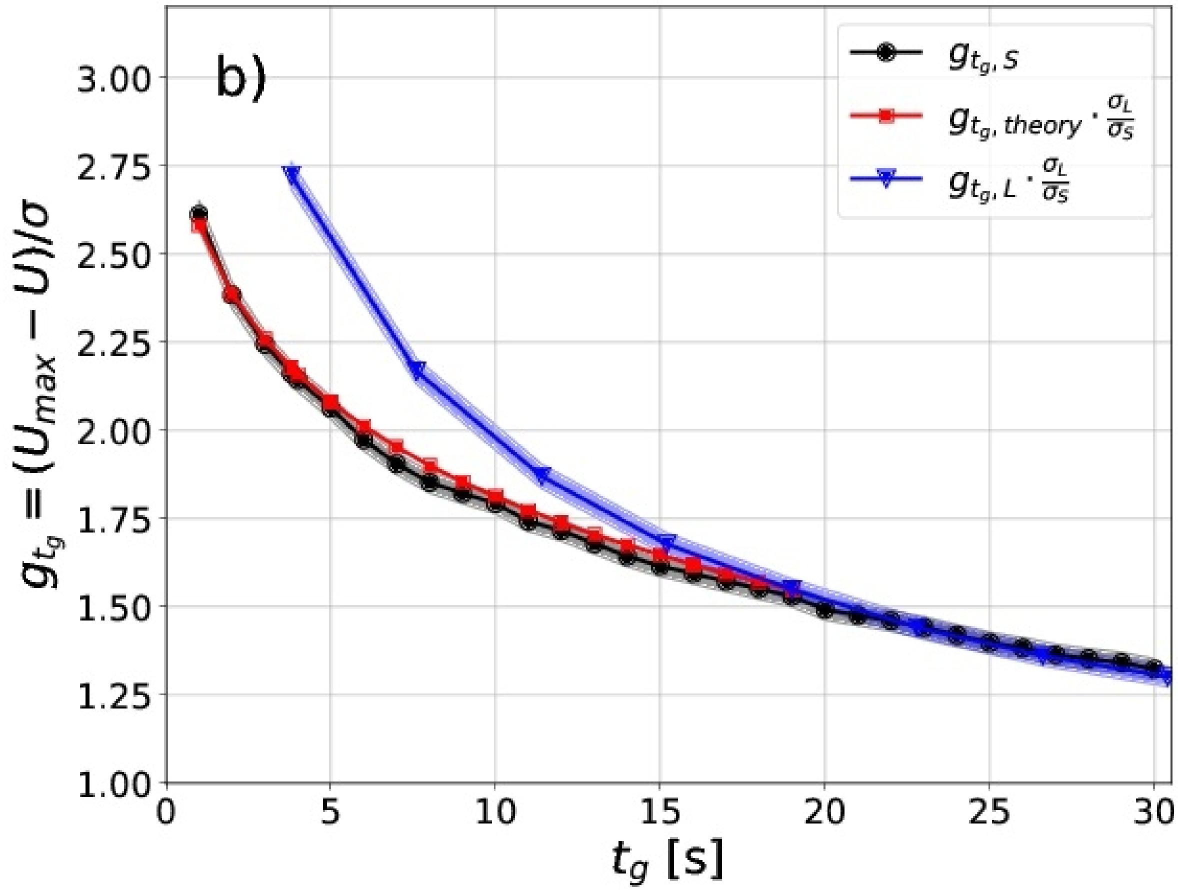


Windcube V2 Doppler lidar by Leosphere

- In this study we used a Doppler lidar, which has been designed for wind energy applications
- Lidar characteristics:
  - Five lines of sight: 1 vertical, 4 inclined (28º zenith angle)
  - Measurement range 40-300 m
  - Temporal resolution: 3.8 s (including all 5 beams)
- To obtain the 3D wind vector, information from all 5 beams are combined
- This involves:
  - temporal and
  - spatial averaging

➔ Doppler lidar wind speed maxima higher than the corresponding gusts from the nearby meteorological mast

A new scaling method to reduce the positive bias



meteorological mast
scaling method
Doppler lidar

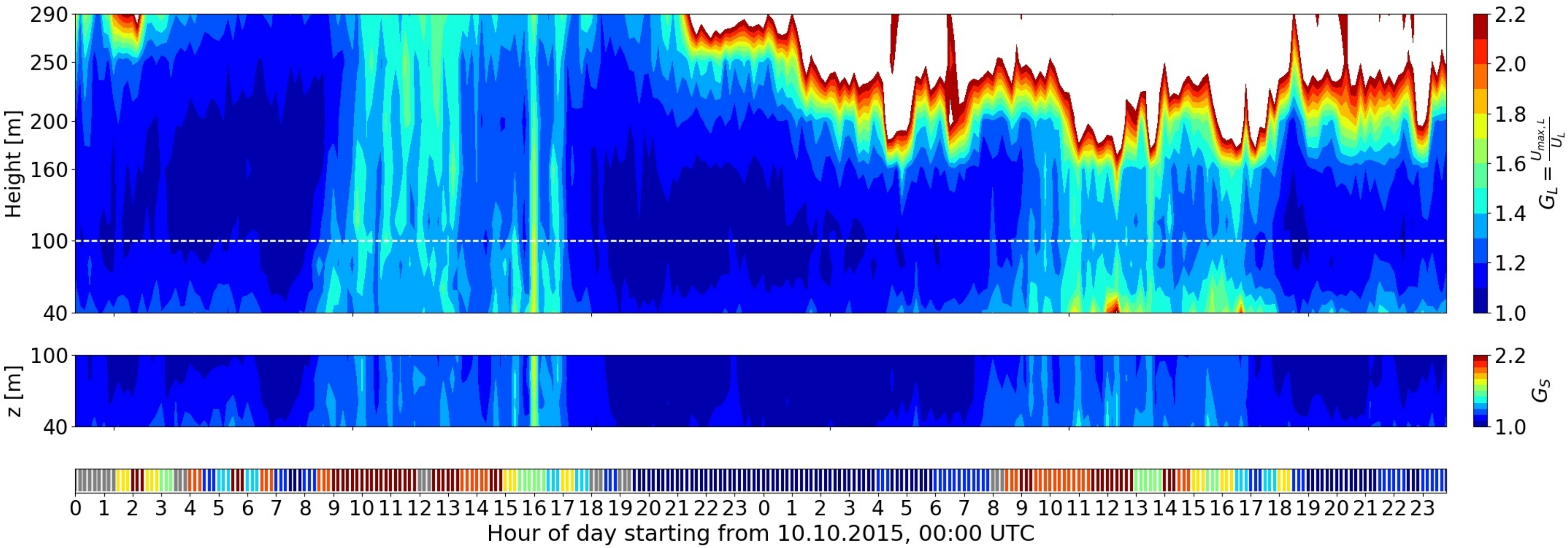
- Peak factors agree at long gust durations (>19 s)
- By using the theoretical behavior of peak factors as a function of gust duration it is possible to reduce the bias between the mast measurements and the Doppler lidar.

Doppler lidar: results

Color scale: the gust factor $G = \frac{U_{max}}{U}$

Doppler lidar

Mast



<u>2-day period:</u>

1st day: ideal conditions for lidar measurements

2nd day: low clouds and rain: challenges for lidar measurements (values partly out of range)

Summary

- New methods to obtain wind gusts were developed based on
  - Research aircraft measurements
  - Doppler lidar measurements
- New measurement methods
  - enable measurements of wind gusts from heights and regions were traditional measurement techniques cannot reach
  - potentially allow better understanding of the physical processes leading to extreme gust events
  - may lead to further improvements of gust forecasting methods
- Future?
  - Testing of the scaling method for Doppler lidar measurements: other types of lidars and scanning techniques
  - Unmanned Aircraft Systems (UAS) – can those be used to measure gusts?

References

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