Mesoscale model based techniques for LiDAR wind speed measurement gap-filling

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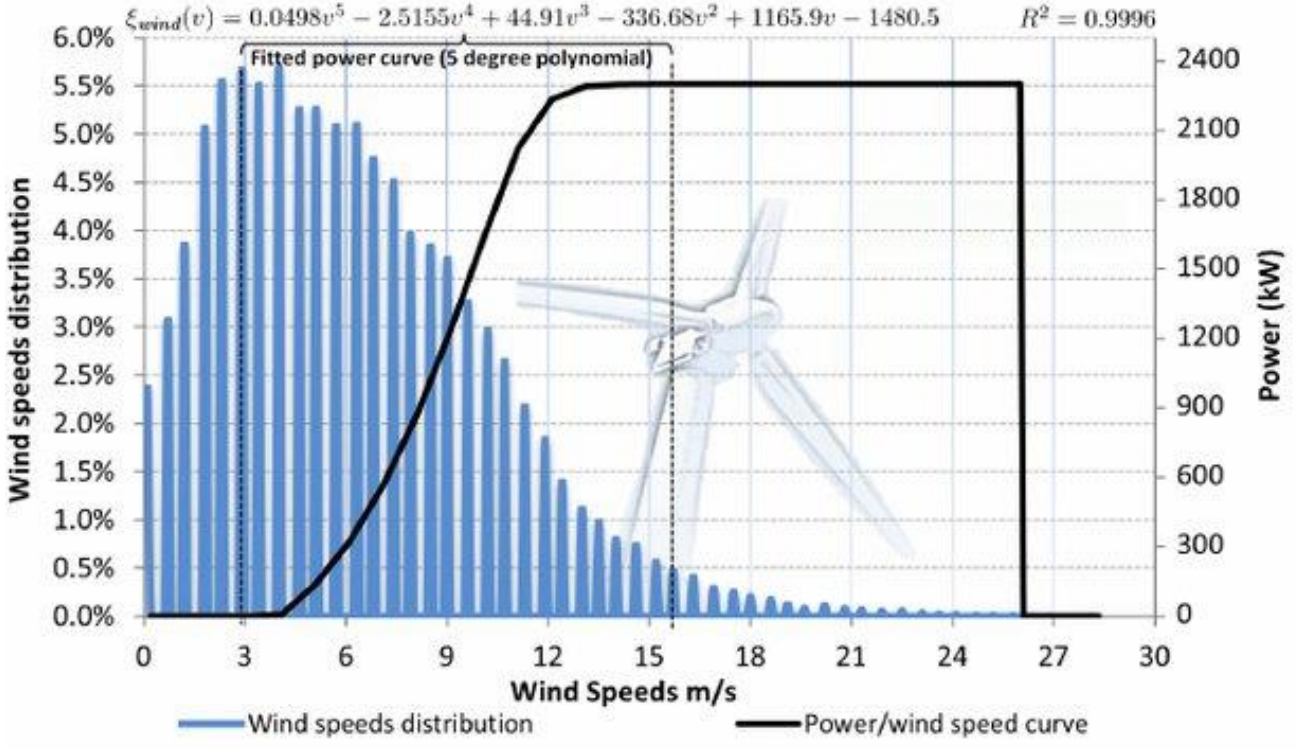
Wind resource assessment

- Turbine design
- Wind farm design
- Annual energy estimate
- Cost of electricity estimate

- Measurement outage
- Inaccessible device
- Data recovery



The impact of wind uncertainty on the strategic valuation of distributed electricity storage, Crespo Del Granado, Pedro & Wallace, Stein & Pang, Zhan. (2015)

LiDAR

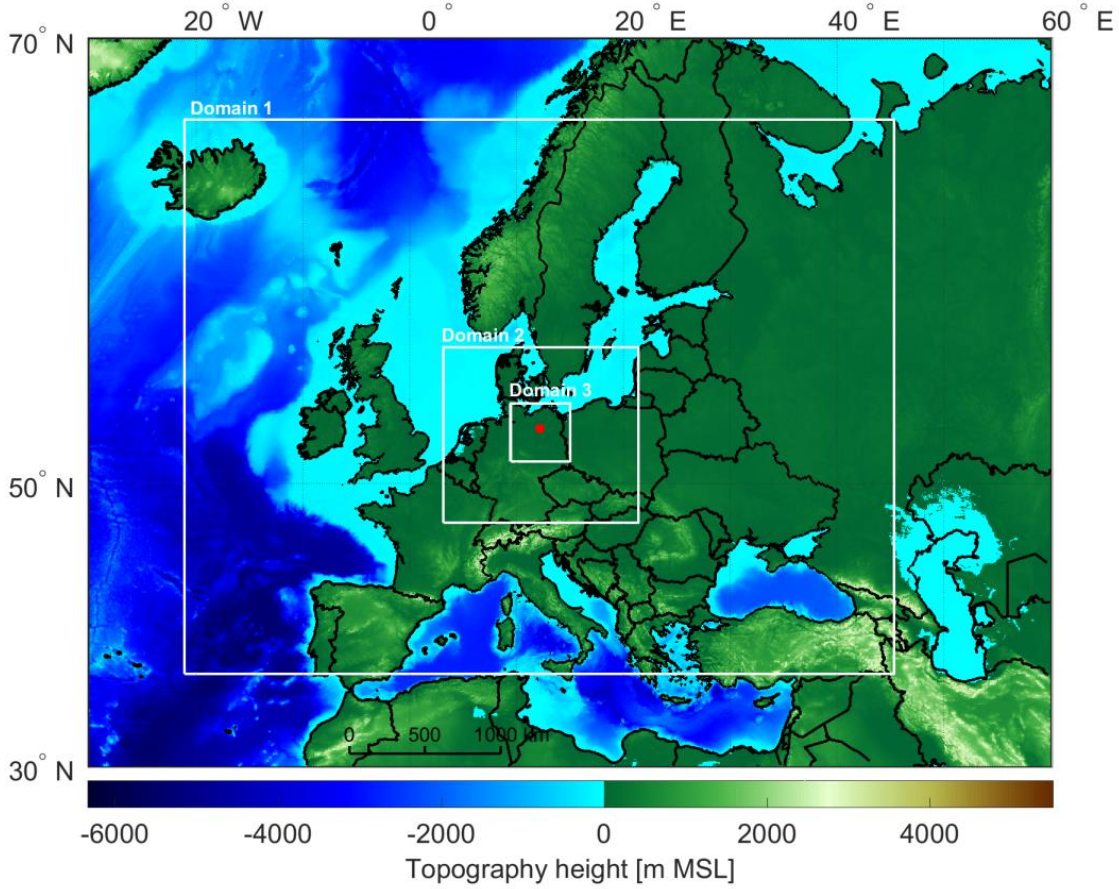
- Based on laser backscatter
- Limited by:
  - Aerosol content
  - Weather
  - Wind speed

- Our dataset
  - 6 mon measurement campaign
  - Onshore, flat land Northern Germany
  - Focus on higher altitudes
  - **Gaps in data**

Weather Research and Forecasting (WRF)

- Numerical weather prediction (NWP)
- Mesoscale model

- 3 nested domains
- Inner domain:
  - 3x3 km grid size
  - 120 x 120 elements
  - Reanalysis data: ERA-Interim



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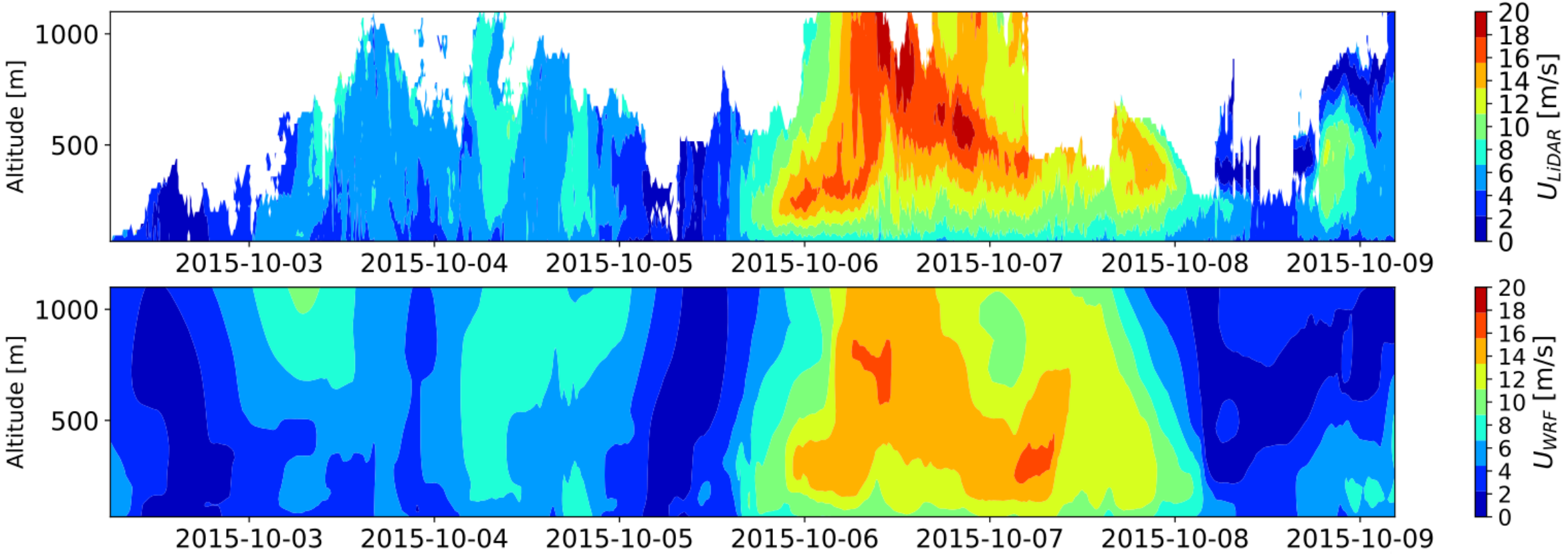
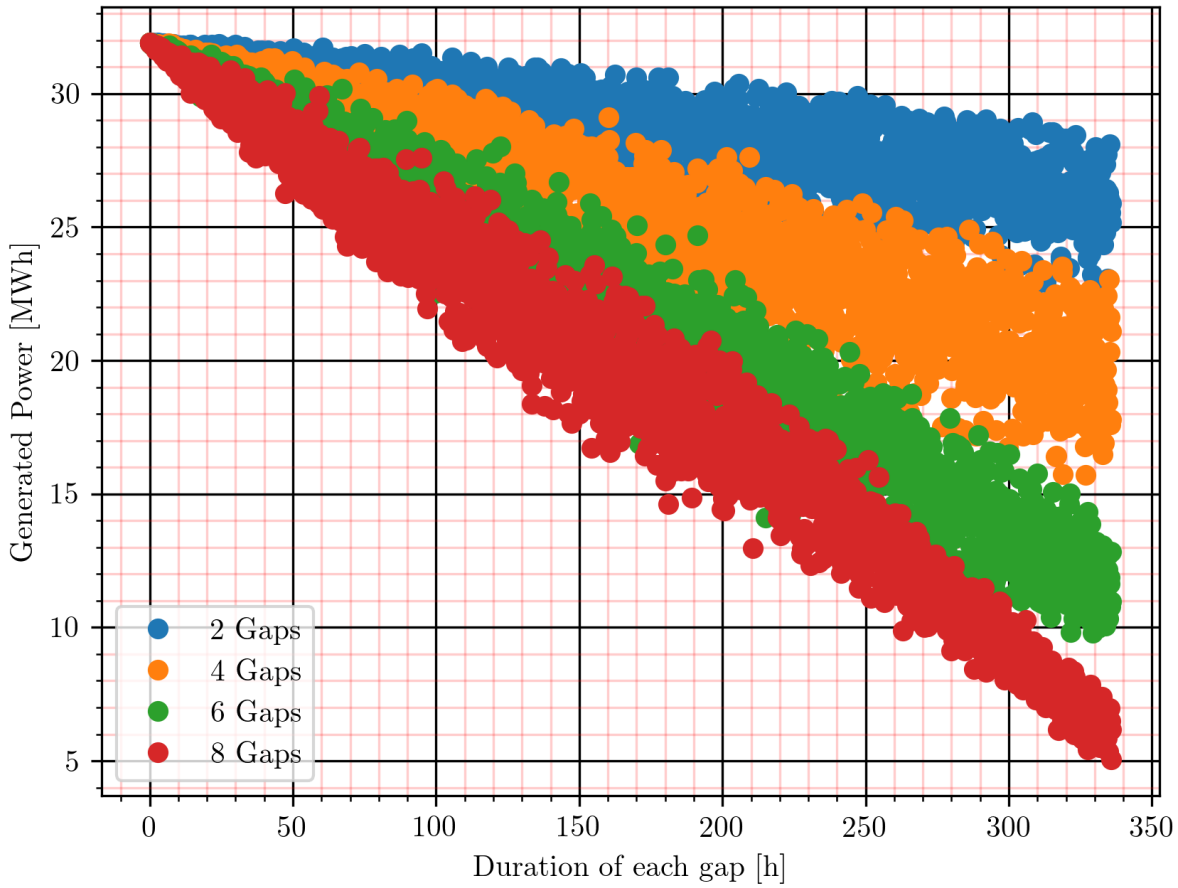
Improving mesoscale wind speed forecasts using LiDAR-based observation nudging for Airborne Wind Energy Systems, Markus So Curran Crawford, Gerald Steinfeld, and Martin Dörenkämper, 2019

Representative data set



Gap-Filling methods

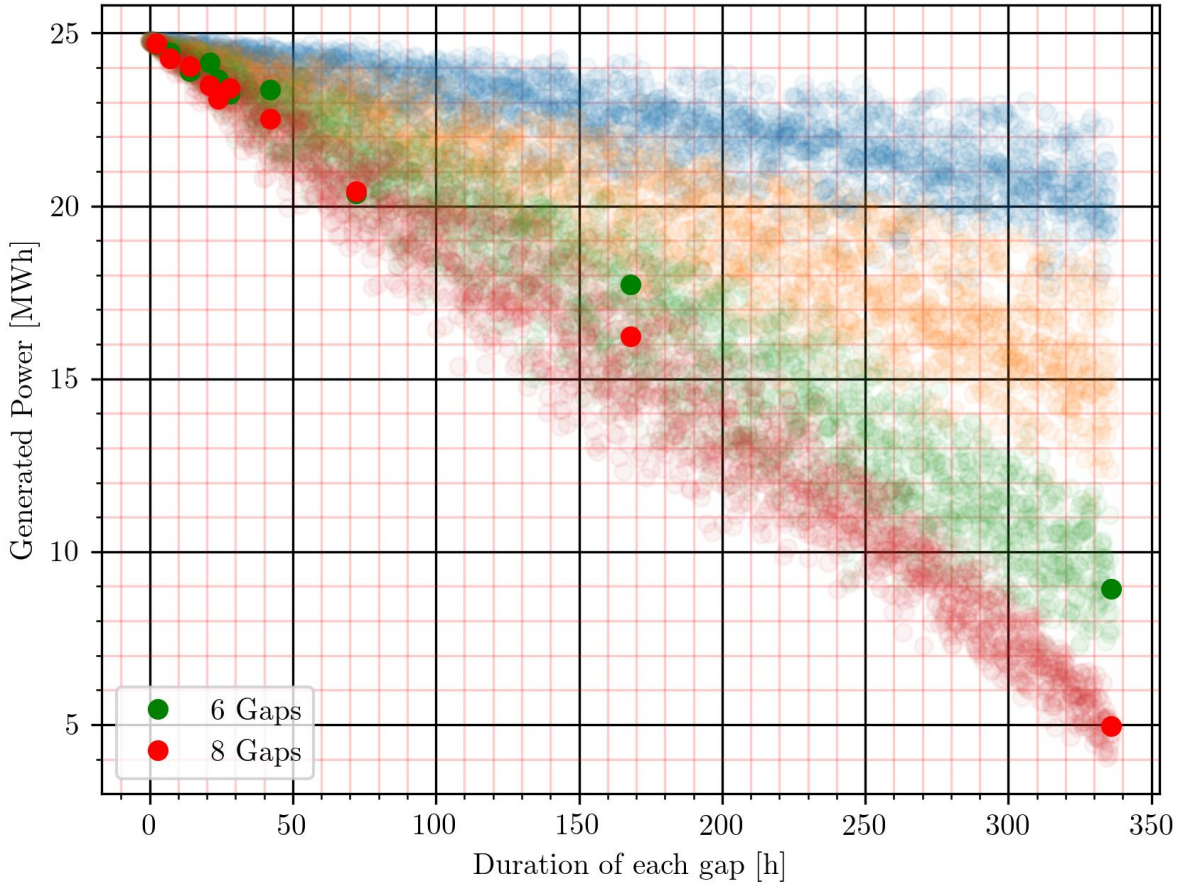
- Filling data:
  - (linear) interpolation
  - WRF
  - WRF + Gaussian process
  - WRF + K-means clustered profiles



Impact of data gaps on wind data statistics, with a special focus on offshore measurement data from a floating LIDAR system, B. Engelbrecht, J. Gottschall 2016

Gap-Filling methods

- Filling data:
  - (linear) interpolation
  - WRF
  - WRF + Gaussian process
  - WRF + K-means clustered profiles
- Removing data:
  - Duration: 10 min – 2 weeks
  - Frequency: 1-8 times in 6 months
  - Random uniform



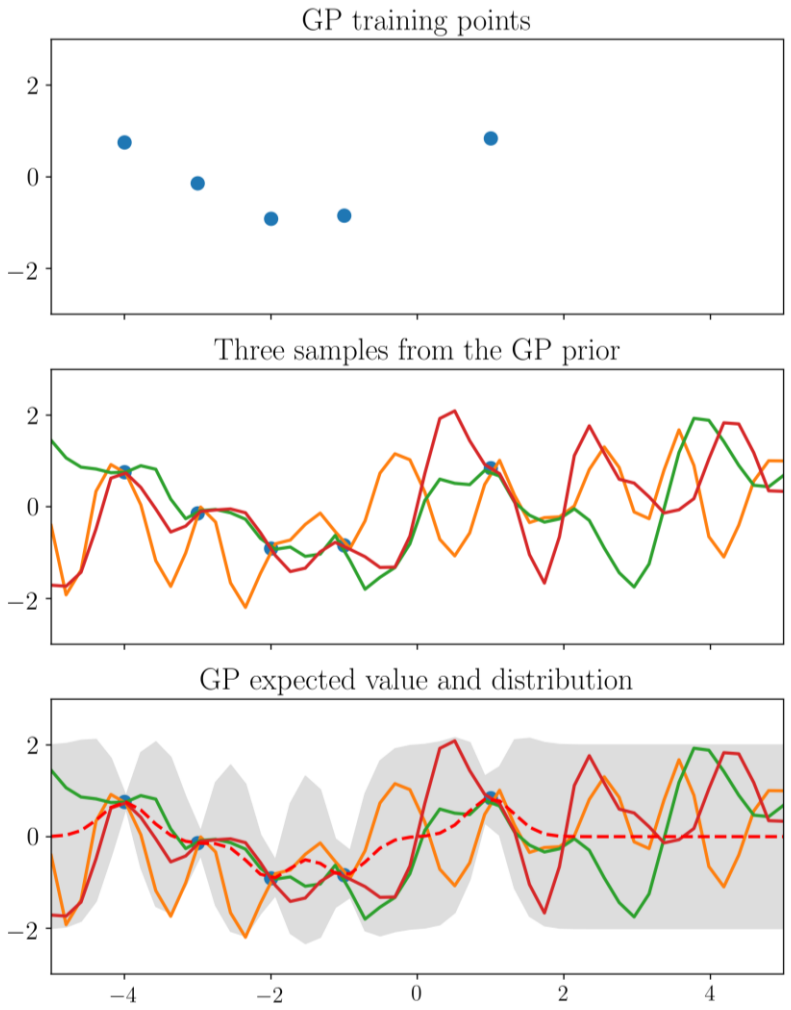
Impact of data gaps on wind data statistics, with a special focus on offshore measurement data from a floating LIDAR system, B. Engelbrecht, J. Gottschall 2016

Gaussian Process (GP) in one slide!

- Remember regression:

$$y = f(x) + \varepsilon \Rightarrow y = \theta_0 + \theta_1 x + \ldots + \theta_n x^n + \varepsilon$$

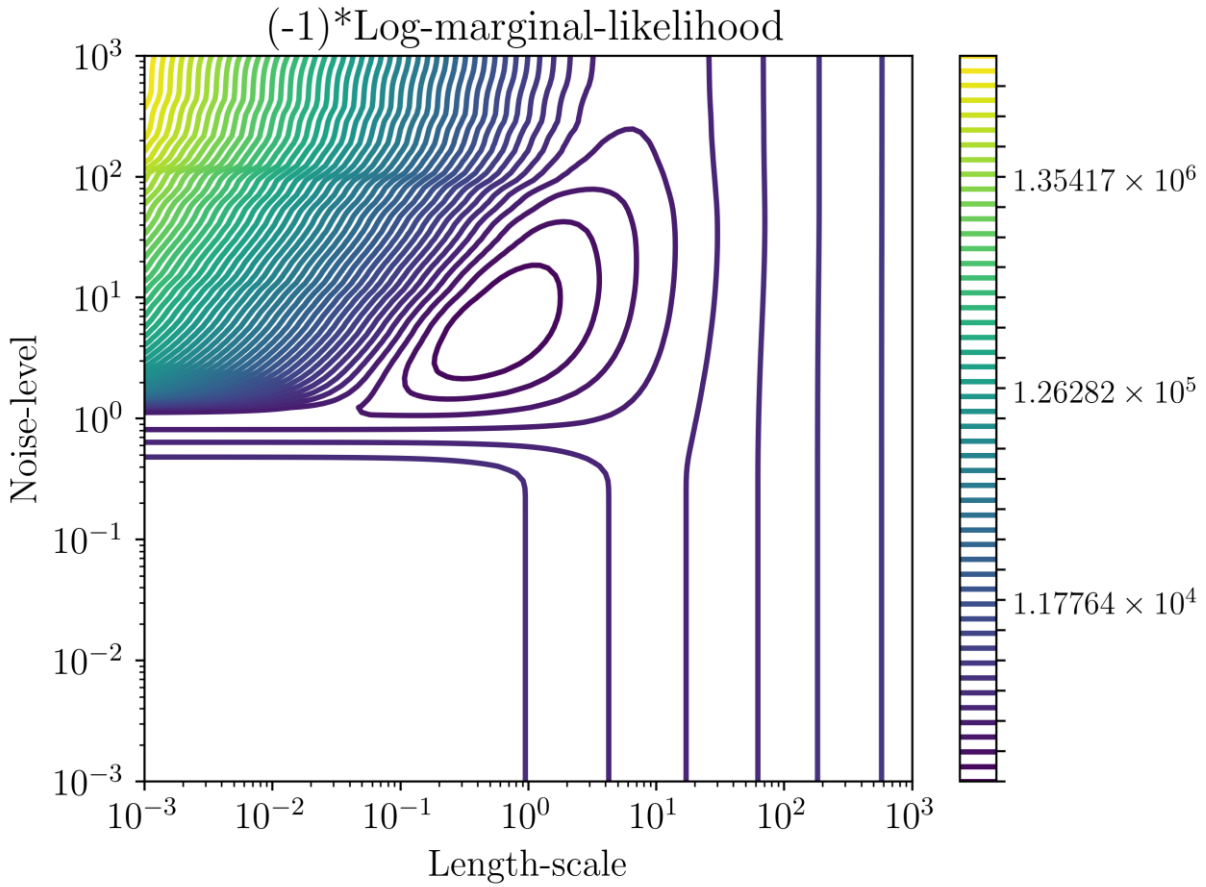
- GP: find the distribution for the possible f(x) functions, which are passing thorough the observations.



https://katbailey.github.io/post/gaussian-processes-for-dummies/

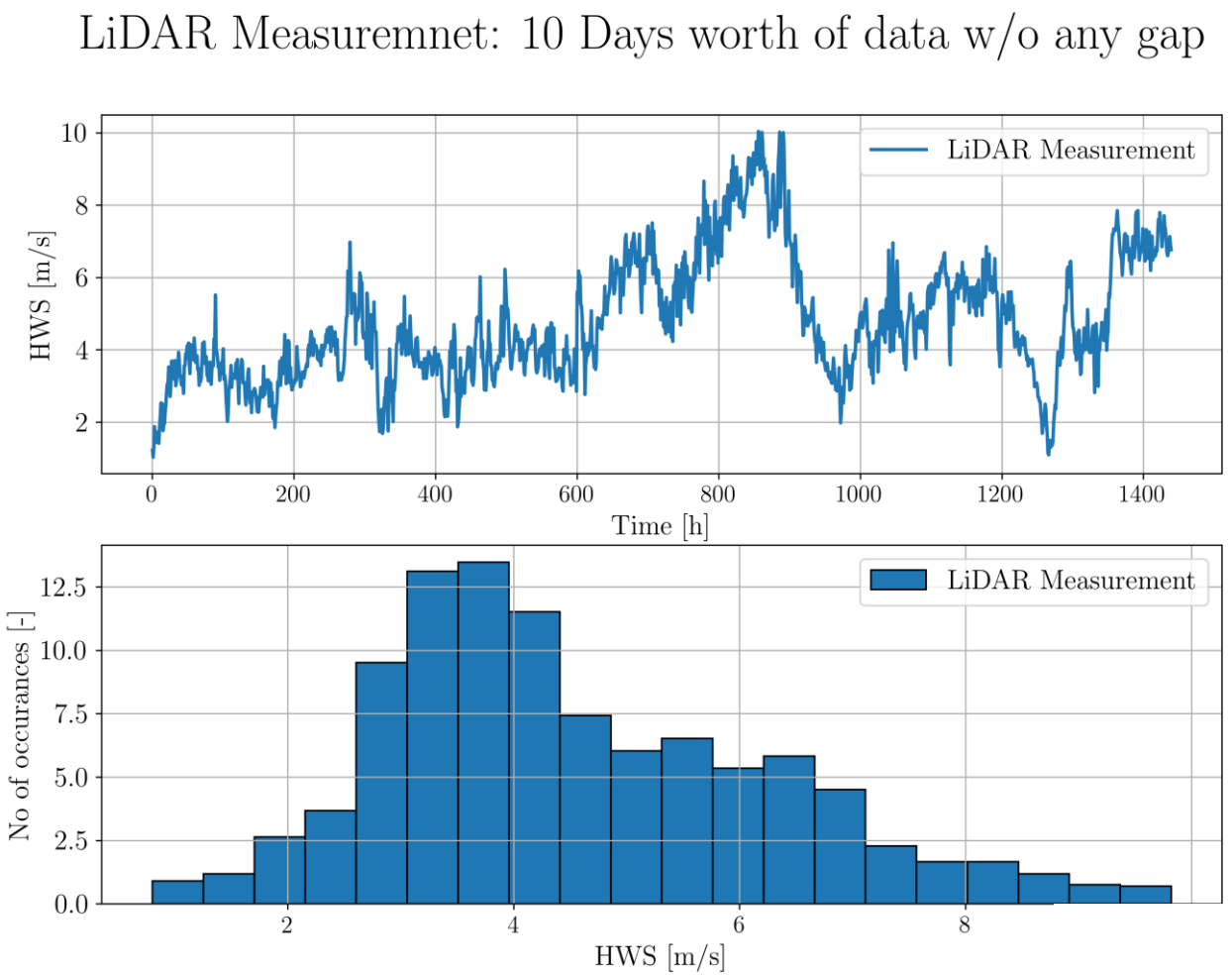
GP for LiDAR gap filling

- Discrepancy function is the input to GP $\Delta = U_{WRF} - U_{LiDAR}$
- GP library in sklrean used
- Normalize Discrepancy function
- GP Kernel: Radial Base Function (RBF) + White Kernel
- Optimized length scale, noise level for max Log-marginal likelihood

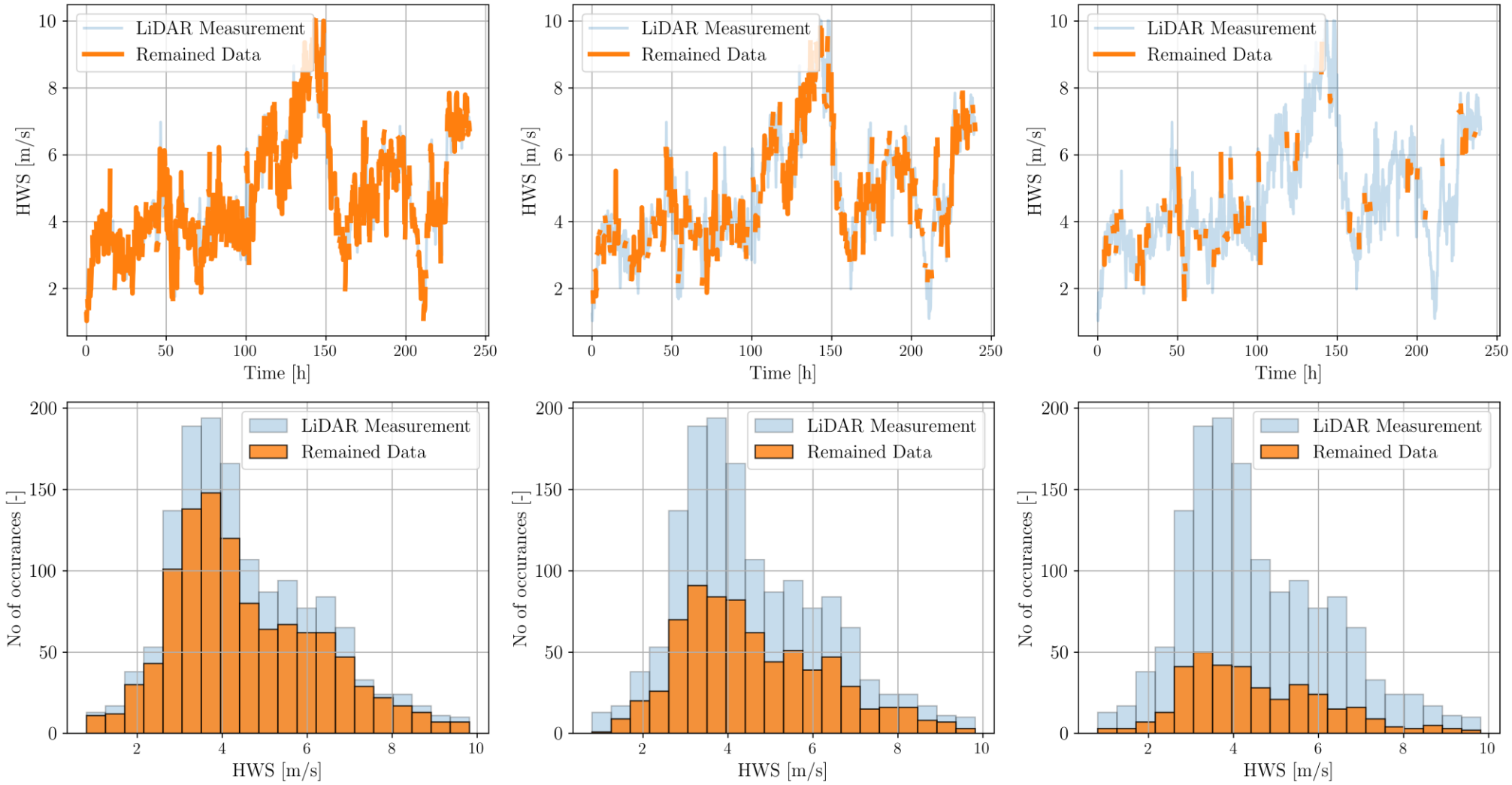


Proof of concept

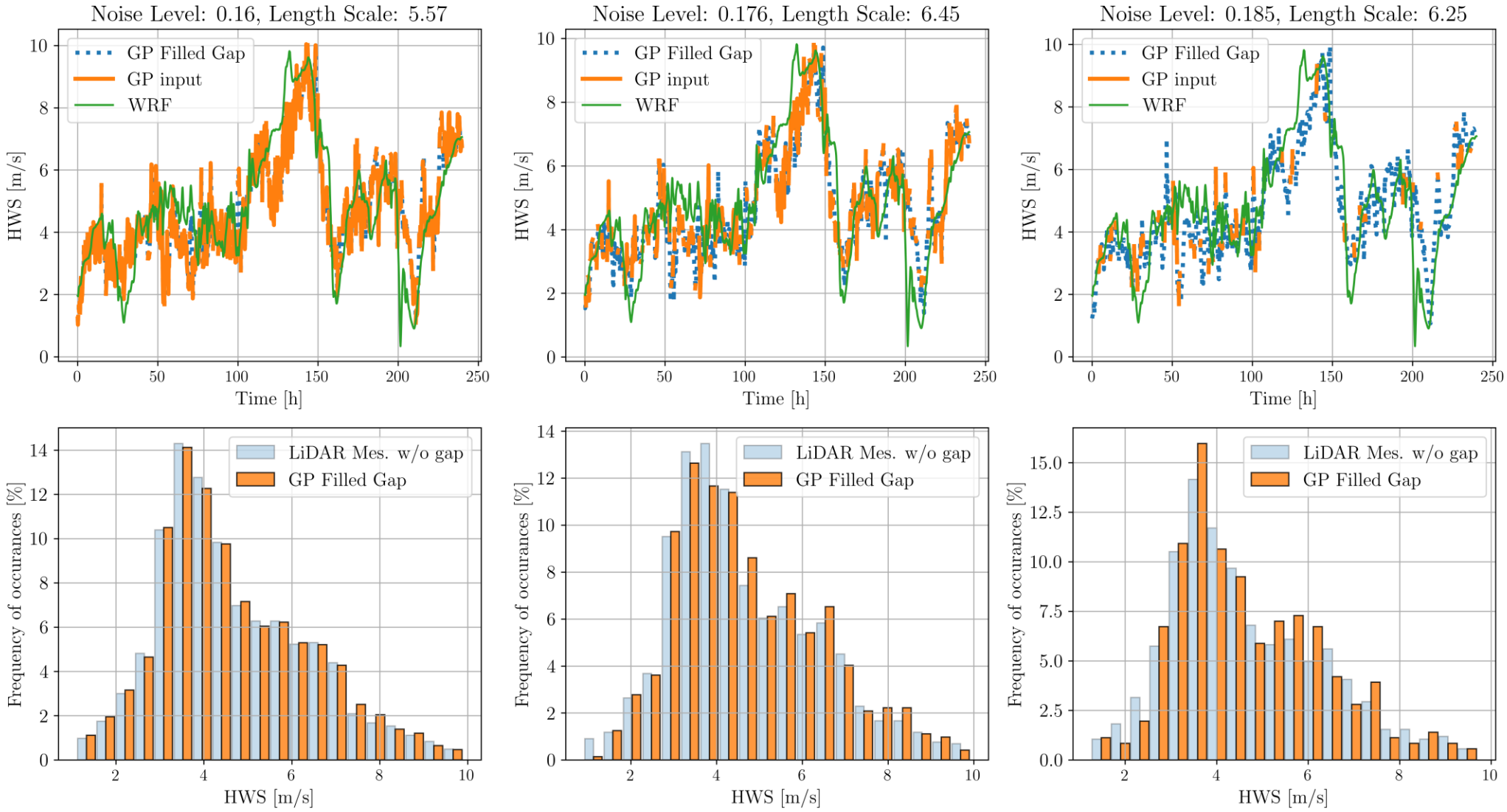
- 10 days worth of LiDAR data without any gap
- Artificial gaps: 25%, 50%, 75% removed
- GP predicted the descrapency function
- GP predicted mean used



Artificial Gaps: 25%, 50% and 75% of data removed

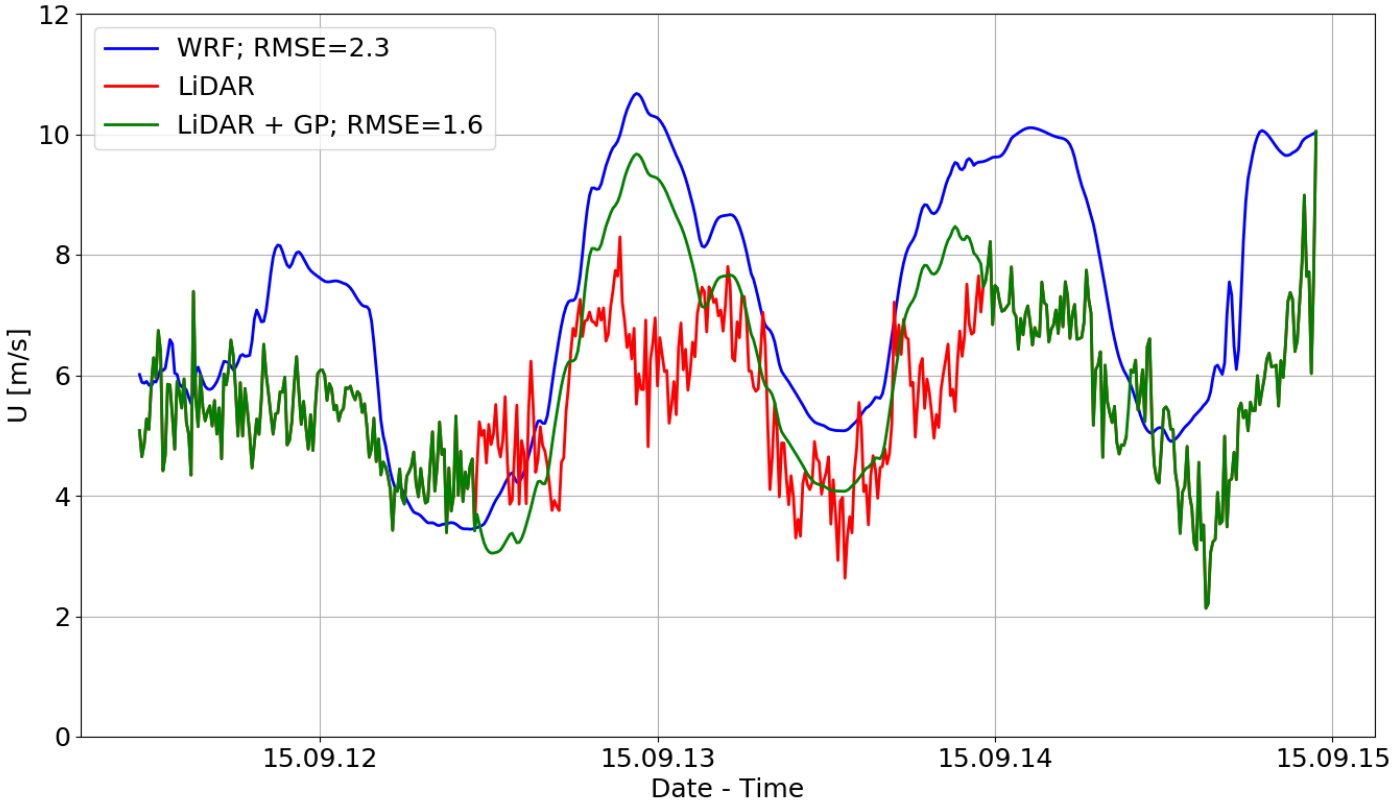


Artificial Gaps Filled by GP: Time series and effect on statistics



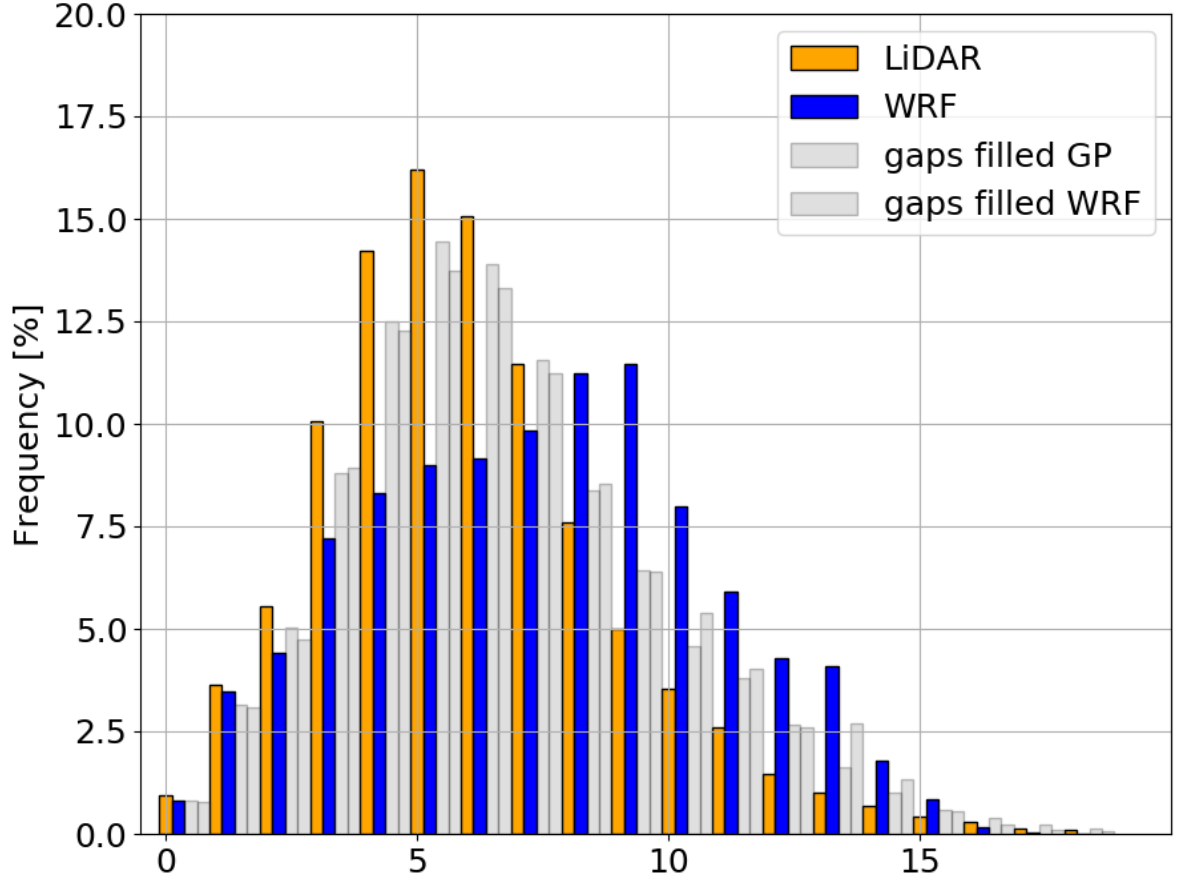
Representative time series

- Artificial data-gap:
  - Measurement height 66m
  - 8 gaps
  - Duration of 36h
- Fill-in with Gaussian Process
- Comparison with WRF



Histogram impact of gap-filling

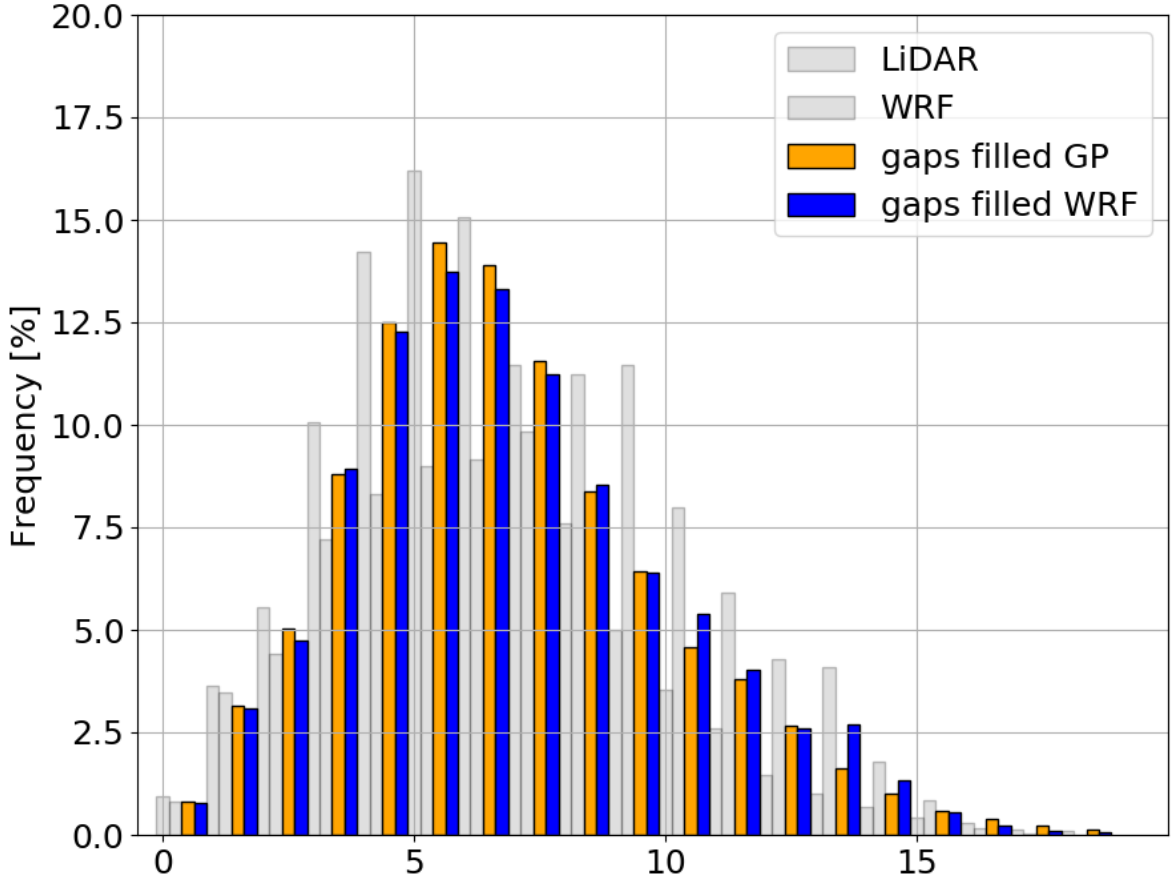
- WRF overly high wind speeds
- Model overpredicts low altitude wind speeds



Histogram gap-filling

- Both gap-filling methods reduce difference between histograms
- Shift towards higher wind speeds

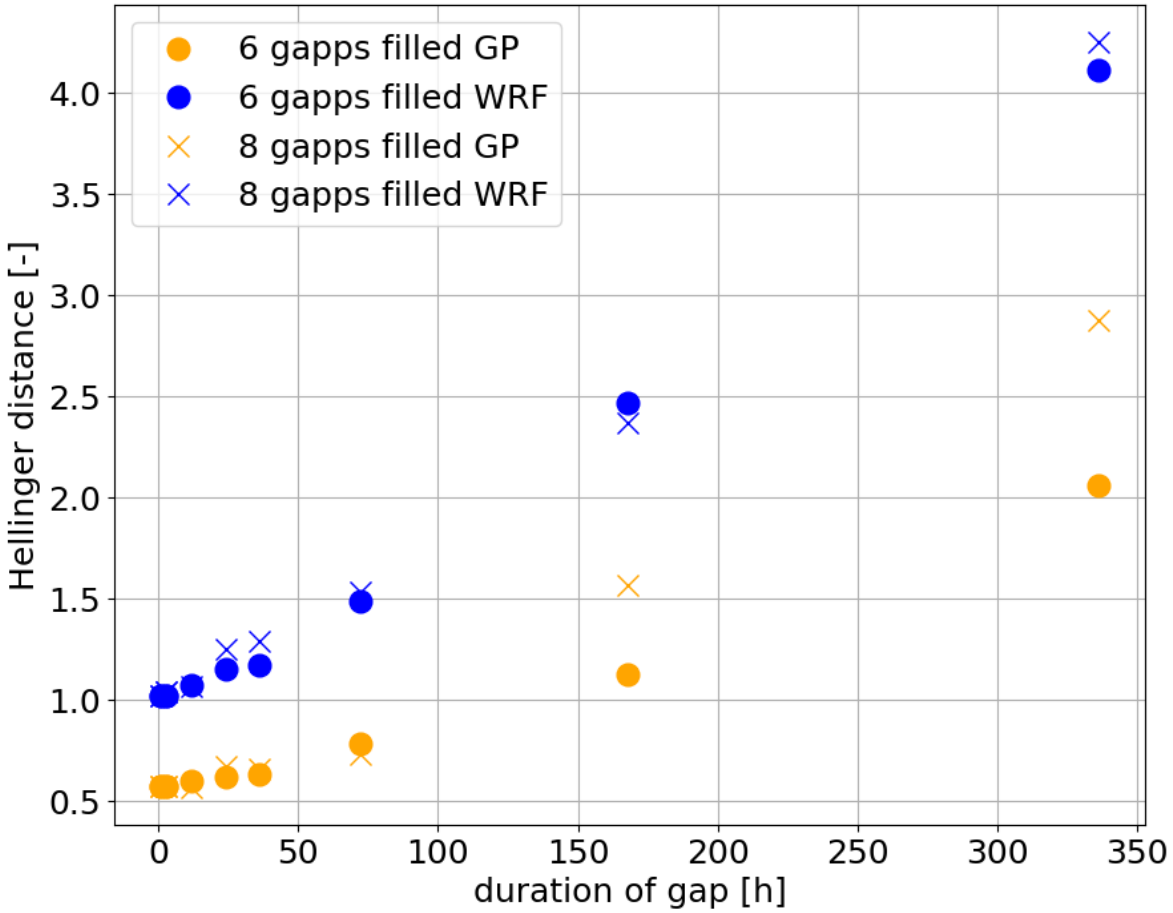
- WRF
  - overpredicts high wind speeds
  - Underpredicts low wind speeds



Quantifying histogram differences

- Hellinger distance
  - Measures quality of distribution match

- Data-gaps:
  - 6 & 8 gaps
  - Durations of 1h to 3 weeks



Conclusion & Future work

- Gap filling is worth it
  - especially during longer data outage
- GP delivers better results
  - Especially for smaller gaps
  - Corrected WRF best guess

- Need to quantify relative errors
  - Reanalysis data (ERA5)
  - GP + WRF
  - 2D GP (time + altitude)
  - GP STD to add high frequency fluctuation
- **WRF correction factor**
- K means clustering
  - Based on wind profile shape
  - Higher altitudes

Questions ?

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