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Application of Gaussian Processes to Dual-Doppler LiDAR scanning measurements for high frequency wind field reconstruction

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Abstract

Scanning LIght Detection And Ranging (LiDAR) instruments are capable of gathering wind measurements by scanning over wide spatial volumes, resulting in large amounts of information and thus incentivising the usage of data driven applications. Gaussian Processes (GPs), a machine learning regression technique, are here used to interpolate Radial Wind Speed (RWS) measurements from two scanning LiDARs deployed in an onshore measurement campaign in Bremerhaven, Germany. The GP model is trained using data from the scanning pattern and then used to interpolate measurements. The RWS estimates are validated using data from a cup anemometer placed at the cross section of the two LiDARs fields of view. In addition, planar radial wind speed estimates given by two independent GP models are combined and used for two dimensional horizontal wind speed reconstruction over a 300x300 meter horizontal plane. It has been demonstrated with this work that Gaussian Processes are able to provide accurate high frequency two dimensional wind field reconstructions using data from scanning LiDARs.

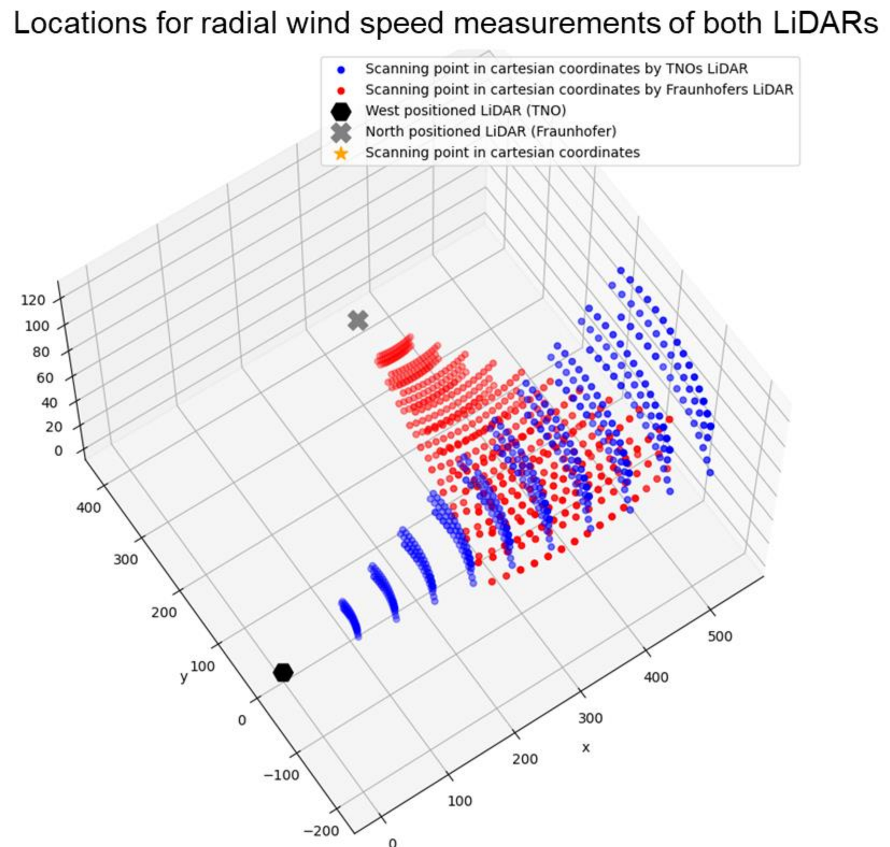
Objectives

There are two main objectives associated with this work: (1) validate the use of Gaussian Processes to interpolate radial wind speed measurements based on data from an onshore campaign (2) develop and validate a method to reconstruct two dimensional high frequency wind speeds based on data from 2 scanning LiDARs and 2 independent GP models.

Methodology: onshore campaign

The onshore campaign took place at the field of Bremerhaven from 14th March 2021 until 9th April 2021 in a collaboration effort with Fraunhofer Institute for Wind Energy Systems (IWES).

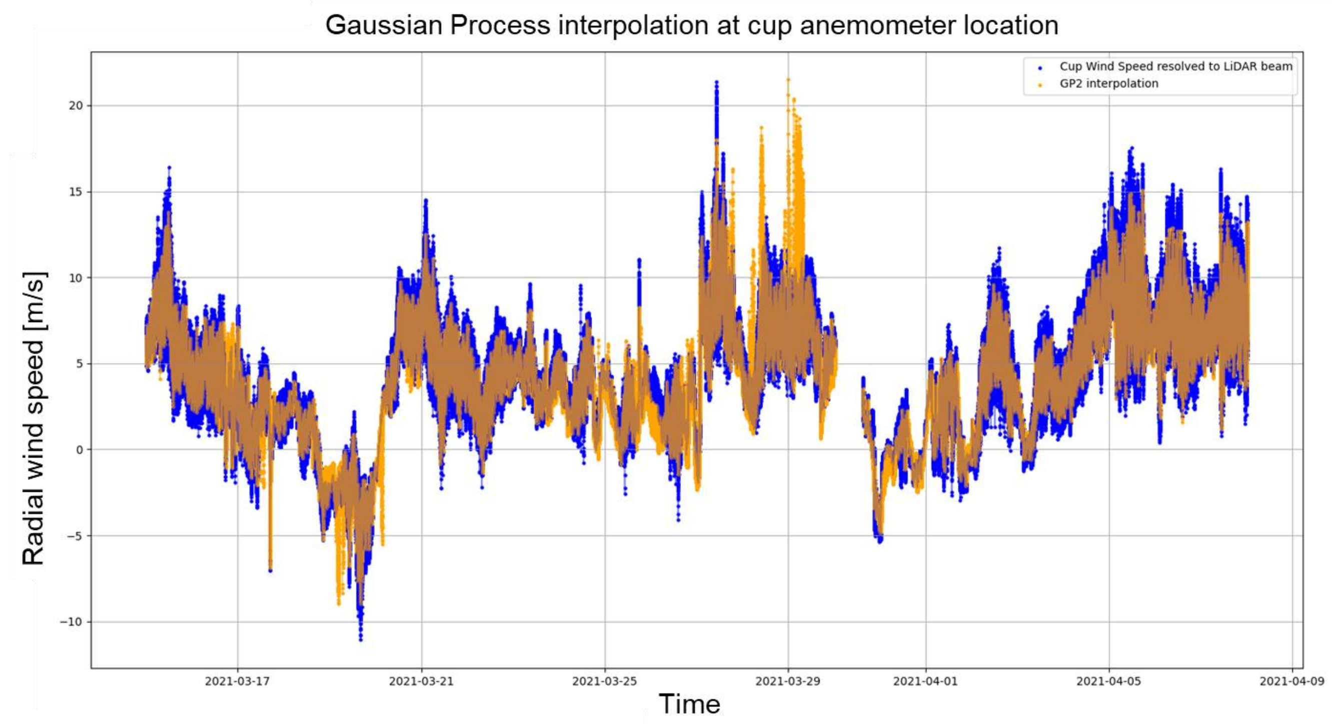
Available at the site were three WindCube 200s LiDARs (two scanning LiDARs functioning in dual-doppler mode and a Line of Sight (LOS) reference) and a 115m IEC compliant meteorological mast equipped with cup anemometers, sonic anemometers and wind vanes at different height levels. TNOs LiDAR (photo below, courtesy of Fraunhofer IWES) was located at the most western position and Fraunhofer's LiDAR at the most northern position. This is visible in the below figure.



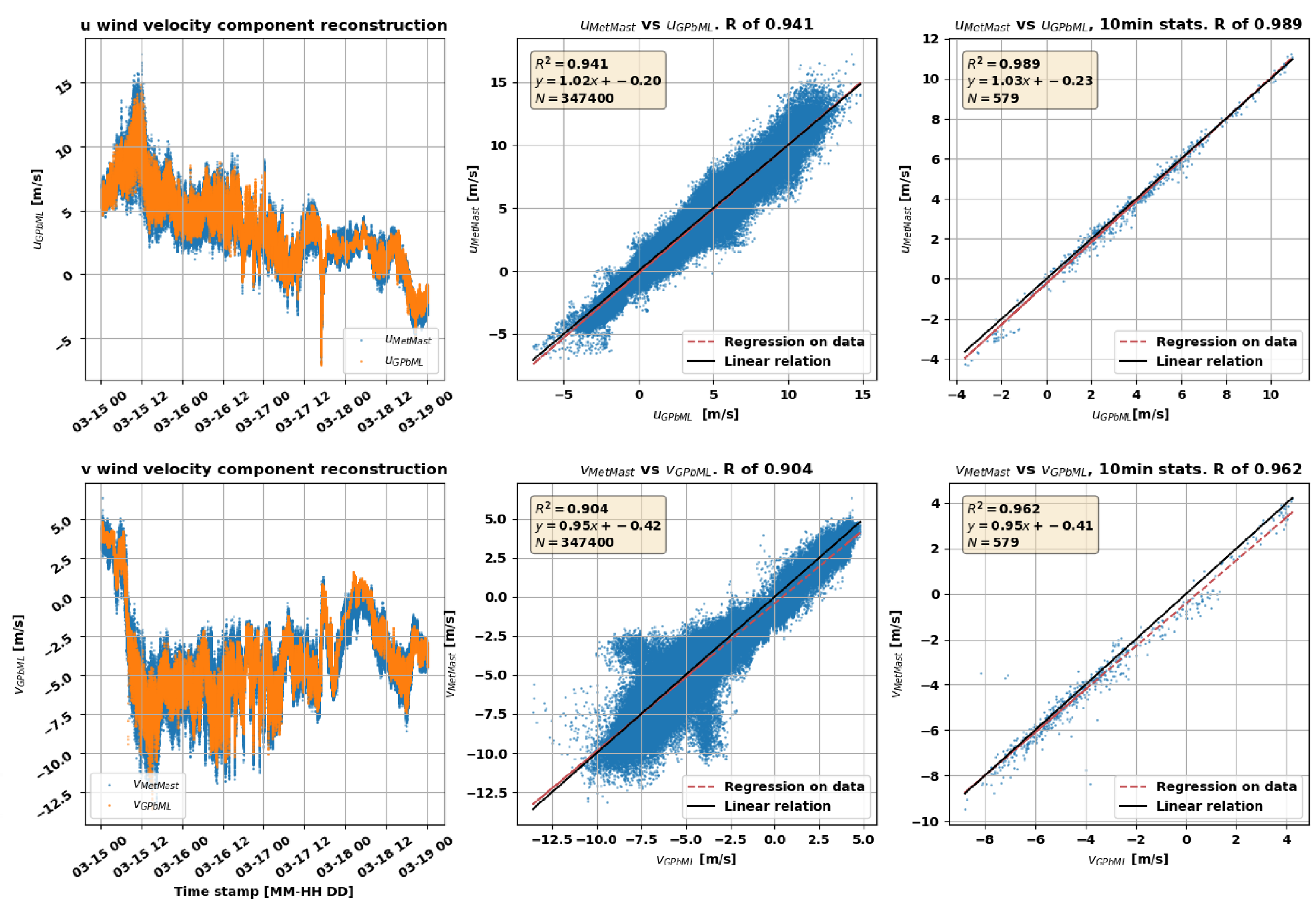
TNOs LiDAR was set to measure three PPI scans at the elevations of 9, 11 and 13 degrees, covering a range in azimuth from 82 to 112 degrees with a speed of 2 deg/s. The points are represented in a cartesian grid in blue. Fraunhofer's LiDAR was set to measure three PPI scans at the elevations of 6, 8 and 10 degrees, covering a range in azimuth from 165 and 195 degrees with a speed of 2 deg/s. The points are represented in a cartesian grid in red. For the purposes of this work, measurements from the cup anemometer at 55 meters and wind vane at 110 meters are used.

Results

A GP model is trained with data from TNO's scanning LiDAR and predictions at the cup locations by the model are compared to 1Hz measurements from the cup. The wind vane is used to project the wind speed onto the LiDAR's LOS (referred to as resolved to LiDAR beam). A comparison for the complete campaign, shown below for both time series, shows a R^2 value of 0.934 and a linear fit of y=1.01x+0.08.



Two GP models are then trained with data from each scanning LiDAR. Estimations of RWS from both models are provided for the same locations in space-time. A Hampel filter is used to remove outliers from the RWS time series. The u and v components can then be reconstructed. Using a time window of 4 days, the comparison of measured and estimated for the u components yields a R^2 of 0.937 and linear fit of y=1.02x-0.19. For the v the comparison yields a R^2 value of 0.892 and a linear fit of y= 0.96x-0.45.



Conclusions

The results from this work suggest that Gaussian Processes are a suitable machine learning technique to accurately interpolate radial wind speed measurements from scanning LiDAR measurements. Following this work, the wind field reconstruction method will be applied to an offshore campaign with the goal of reconstructing wind speed over a spatial grid and extracting more value from LiDAR measurements for identification of global blockage effects.

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