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Predicting large-scale recirculation using a hybrid lidar-LES approach

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Abstract

Flow recirculation and other complex flow phenomena occur frequently in complex terrain. These phenomena cause high turbulence, and can impose high loading and maintenance costs to exposed wind turbines. It is known that most flow modelling tools fails to predict the presence or behavior of these phenomena. Approximations such as the Reynolds Averaged Navier-Stokes approach used in most comercial CFD tools actually suppress these large scale turbulent fluctuations.

In order to better describe and predict recirculation and high-turbulent spots, a hybrid lidar-LES approach has been developed. The method has been tested in a full scale experiment in very complex terrain in a planned wind farm in Norway.

Background

The site studied is located in complex terrain near the coast in central Norway. Several wind turbines are planned on a plateau east of a dominant mountain with an escarpment on its western side. The lidar was deployed 1.3 km east of the escarpment, with a measurement mast located some hundred meters to the south.

The hybrid approach used in this study is made possible by the recent development of the StreamLine XR lidar. An initial benchmark study against measurements from a 3D sonic anemometer located at a distance of 350 meter showed that the lidar was capable of measuring at 1 Hz with a spatial resolution of 9-18 meters without lack of accuracy or data availability.

LES model

The flow model was developed using a high resolution digital terrain model obtained from a terrain lidar scan. The mesh was developed in the Pointwise mesher with an aim to provide a high quality mesh. The resolution obtained was approximately 10x10 meters in the horizontal plane, covering an area of 2x2 km. The resulting mesh passed all the checkMesh quality criteria:

- Aspect ratio < 5.1
- Mesh non-orthogonality < 67
- Skewness < 1.25

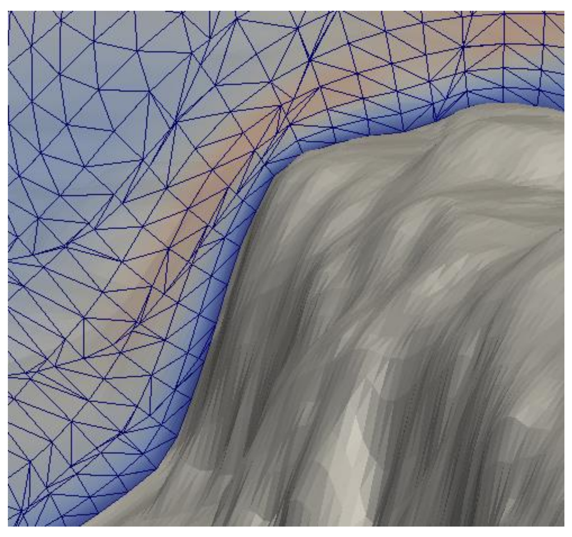

Figure 1 – Detail of grid near escarpment

The simulations were performed in OpenFOAM, using the pisoFoam solver together with a Smagorinsky sub grid turbulence model. Second order differencing was used and the solution was run for a total 20 minutes real time flow.

Simulations were performed for wind directions of 270 degree, and an inlet wind speed of 5 m/s with 15% turbulence intensity.

As seen in Figure 2, clear indications of flow detatchment were observed downwind the dominant escarpment. The extent of the resirculation bubble was found to vary with time, and detached vortices were advected downwind.

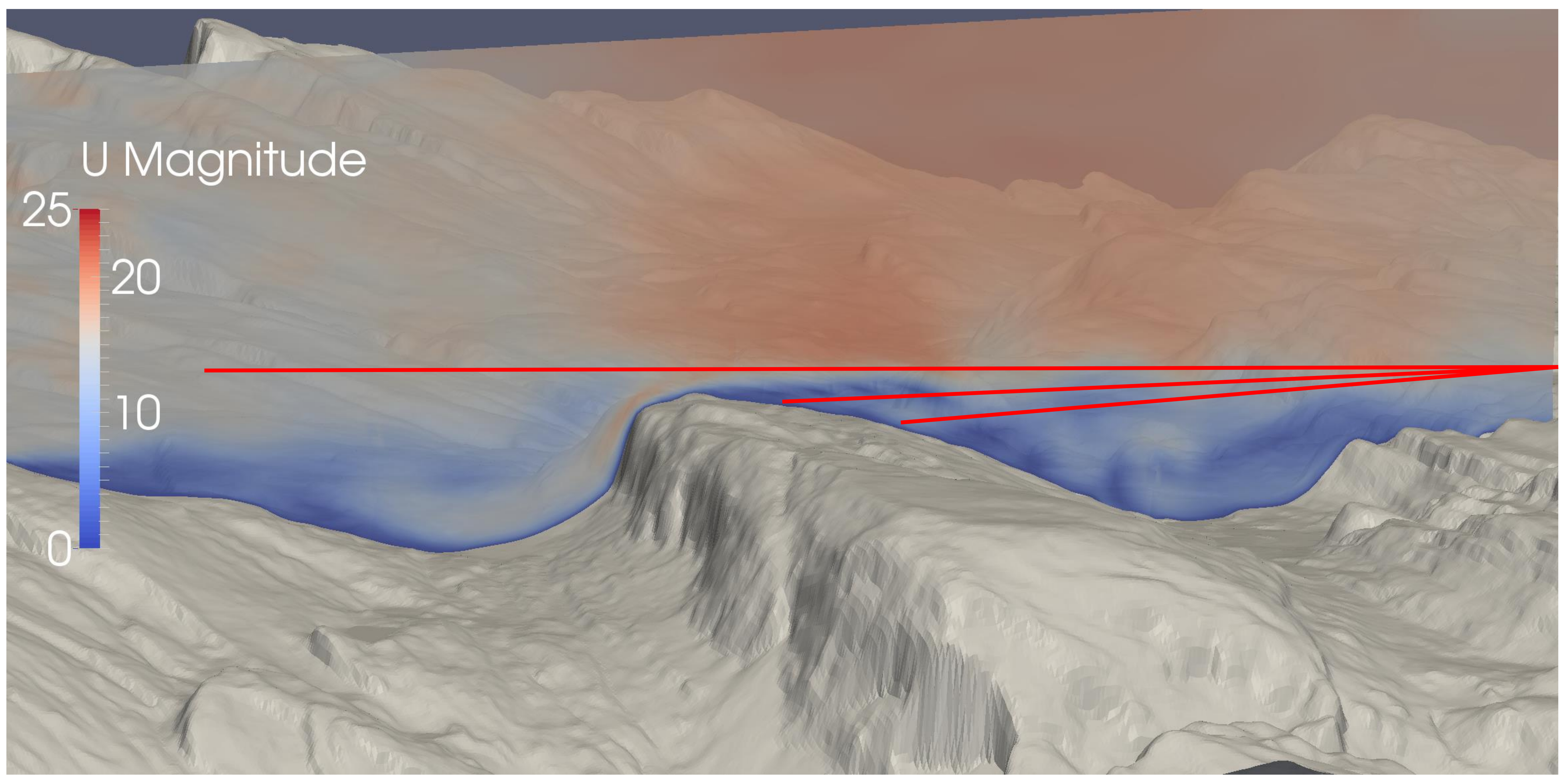

Figure 2 – Terrain model with LES results described in the same plane that the lidar was scanning. Lidar trajectory is indicated by a red line. Measurements were performed at three different elevations (0º, 1º and 2º) all with similar azimuth angle (262º)

Lidar measurements

Using wind data from the measurement mast periods of near-constant wind speed and wind direction were identified. A period with winds of approximately 7 m/s blowing from west (260º - 290º) was selected for the future investigations.

The full scale experiment was conducted with lidar measurements taken at 1Hz and range gates of 18 meters. A constant elevation was retained for periods of 10 minutes in order to describe the temporal changes in the flow field. Measurements confirmed the presence of large recirculation predicted by the LES model..

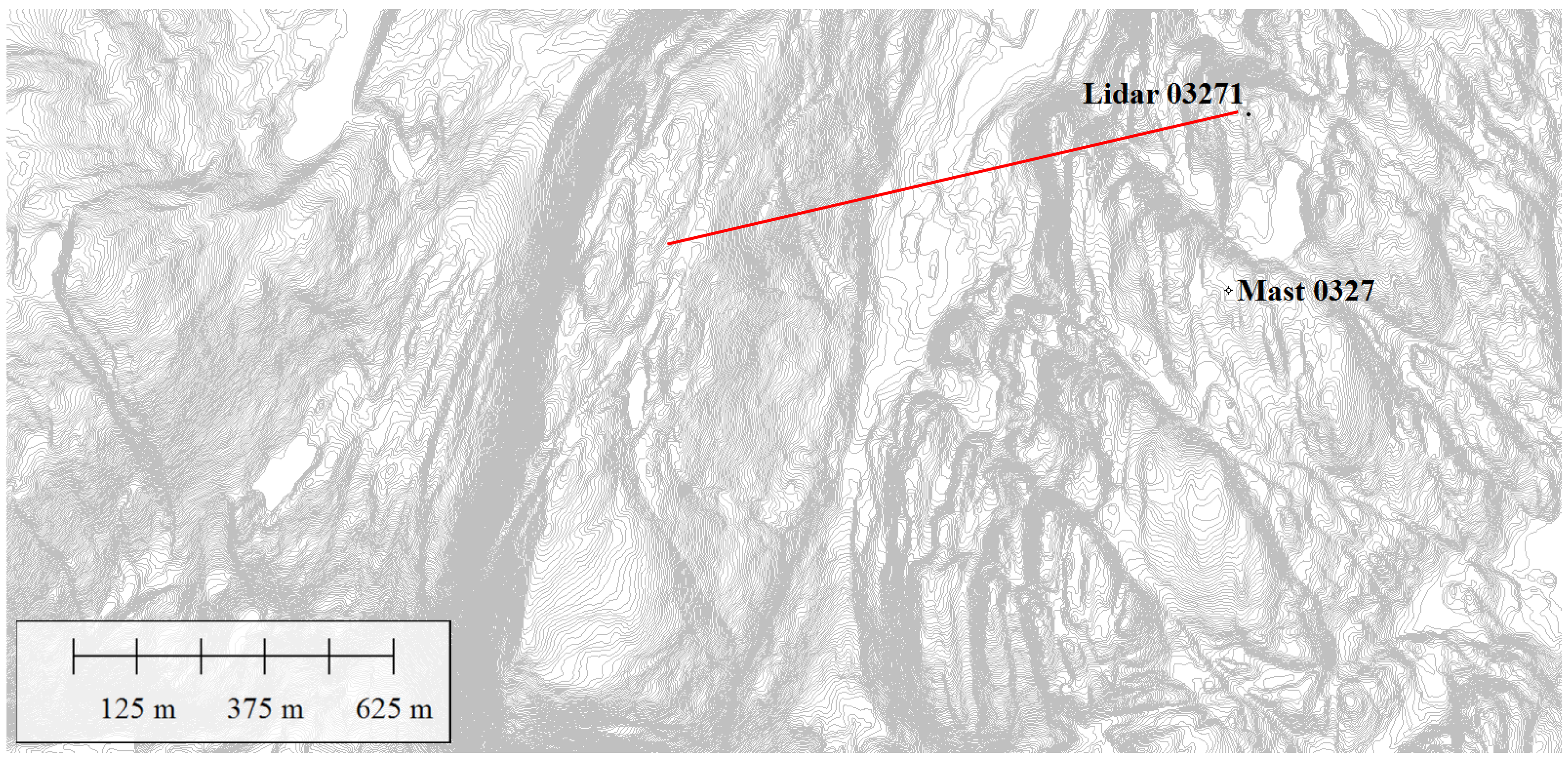

Figure 3 – Map showing the lidar and mast location, as well as the direction of the lidar measurements.

Results

The comparison between the lidar measurements and LES model results show that the model inlet velocity is slightly lower than it should be. The standard deviation is however clearly within the range of observed values, indicating that the variations in wind speed occurring behind the escarpment are well described.

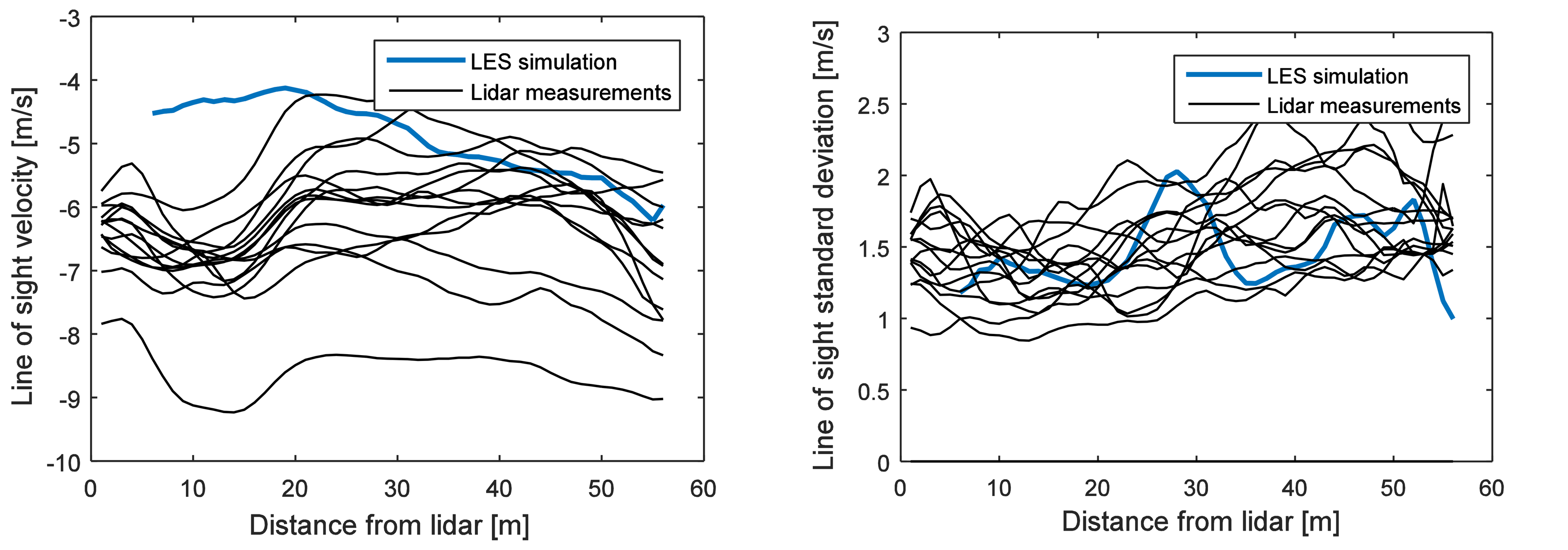

Figure 4 – Comparison of lidar measurements from different 10 minute periods, compared to the LES simulation results

A qualitative investigation of the lidar and LES results indicate that the model is capable of describing the recirculation occurring behind the escarpment. However, additional refinement of the model is required to enhance the accuracy of the model, so the three-dimensional information can be utilized. It is also clearly seen how the lower slope of the features in the model show wind speed underprediction.

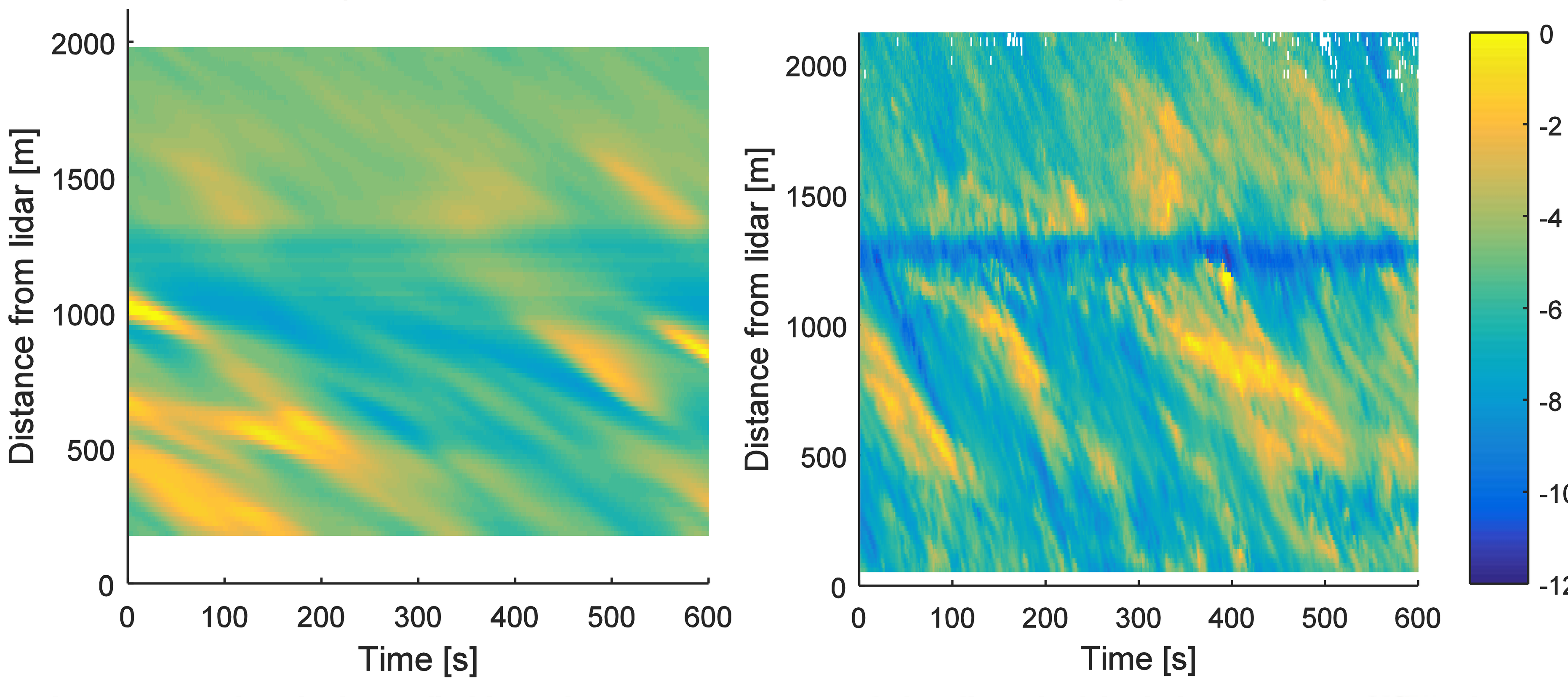

Figure 6 – Simulations (left) and measurements of the flow behind the escarpment. The colormap indicates line of sight velocity. Line of sight is directed at az=262º and el=2º

Conclusion

The results show that both high resolution lidar measurements and LES flow models can be used to describe large scale recirculation in complex terrain. In regions where the scales of the main turbulent fluctuations are significantly larger than the spatial resolution of the lidar and the flow model, accurate descriptions of the flow behavior can be made.