Detection of turbulence aloft by wind noise measurements at ground level

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Summary

Wind turbines can be damaged by the inflow of high amplitude wind turbulence. The goal of this project is to determine if potentially damaging turbulent structures at hub height can be detected by infrasonic wind noise measurements at the ground. A large eddy simulation is used to model the atmospheric turbulence structures of interest and the resulting pressure fluctuations on the ground. Preliminary studies of the relationship between the time development of the pressure structures on the ground and the velocity fluctuations in the atmosphere are described. If elevated turbulent structures can be detected on the ground, the predictions will be used to design an optimized pressure sensing array for experimental tests.

LES Code

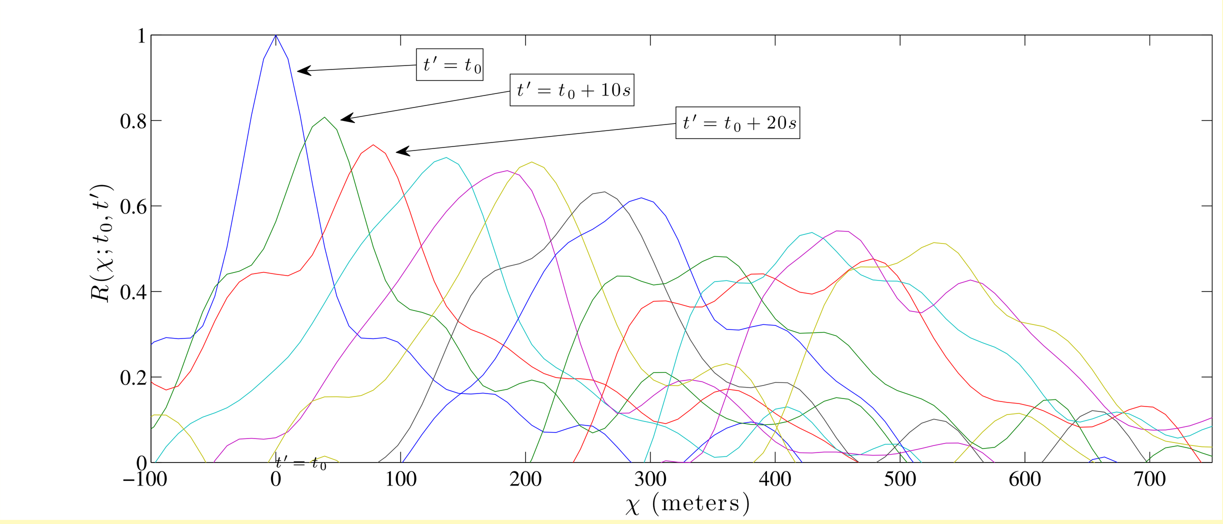
- Chin-Hoh Moeng LES code modified by Martin Otte to incorporate the Kosevic SGS model (energy backscatter) and parallelization.[1],[3],[4]
- Periodic boundary conditions in the horizontal directions.
- Pseudospectral method evaluates horizontal derivatives and centered finite-differences of 2nd order accuracy evaluates vertical derivatives.
- The time development is solved using the Adams-Bashforth scheme.
- Numerical integration of the Poisson pressure equation computed using a tridiagonal matrix method yielding the pressure field for each time step.

Related Work

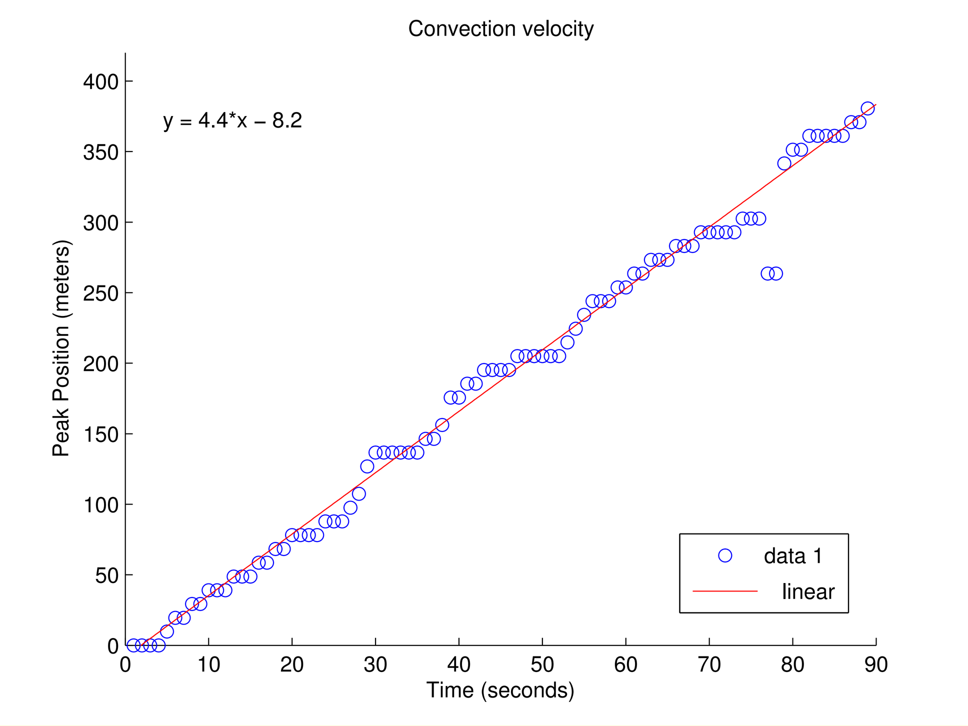
In Dr. Priestly's thesis, he assumes that the dominant influence of an eddy extends a distance proportional to eddy size or frequency.[2] This suggest that low frequency pressure fluctuations are caused by large eddies at high altitudes. This was confirmed in separate experiments by Priestly and Shields using pressure sensing arrays on the ground coupled with anemometer data from towers.[5]

Preliminary Results: Daytime Run

To check if LES can recover results by Priestly and Shields, a spatial cross correlation of a pressure string near the ground for a characteristic time difference that grows larger on each iteration was performed as shown in the plot below. This broadband plot of correlation amplitude versus spatial lag represents the time evolution of the spatial correlation of pressure.

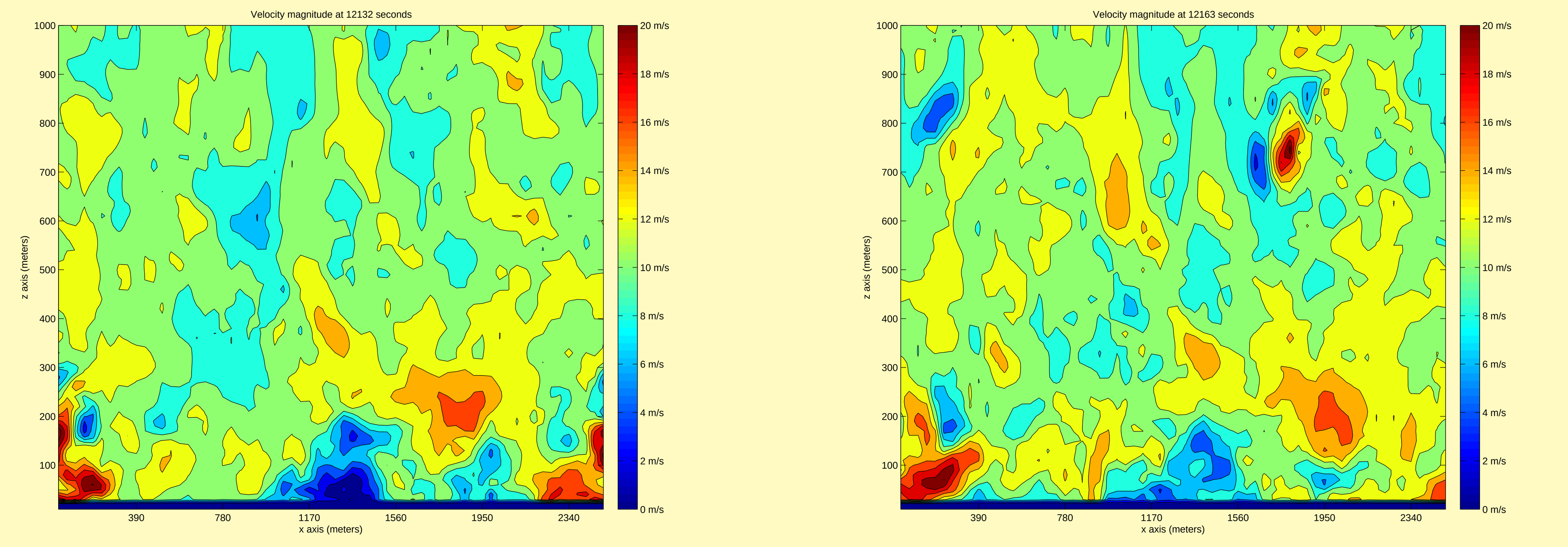


The positions where the peaks occurred were plotted against the times that they registered on the simulated array. A linear fit yields the convection velocity of the pressure signal to be 4.4 m/s. The mean flow velocity near the ground was 1.6 m/s. This preliminary result is in agreement with Priestly and Shields.

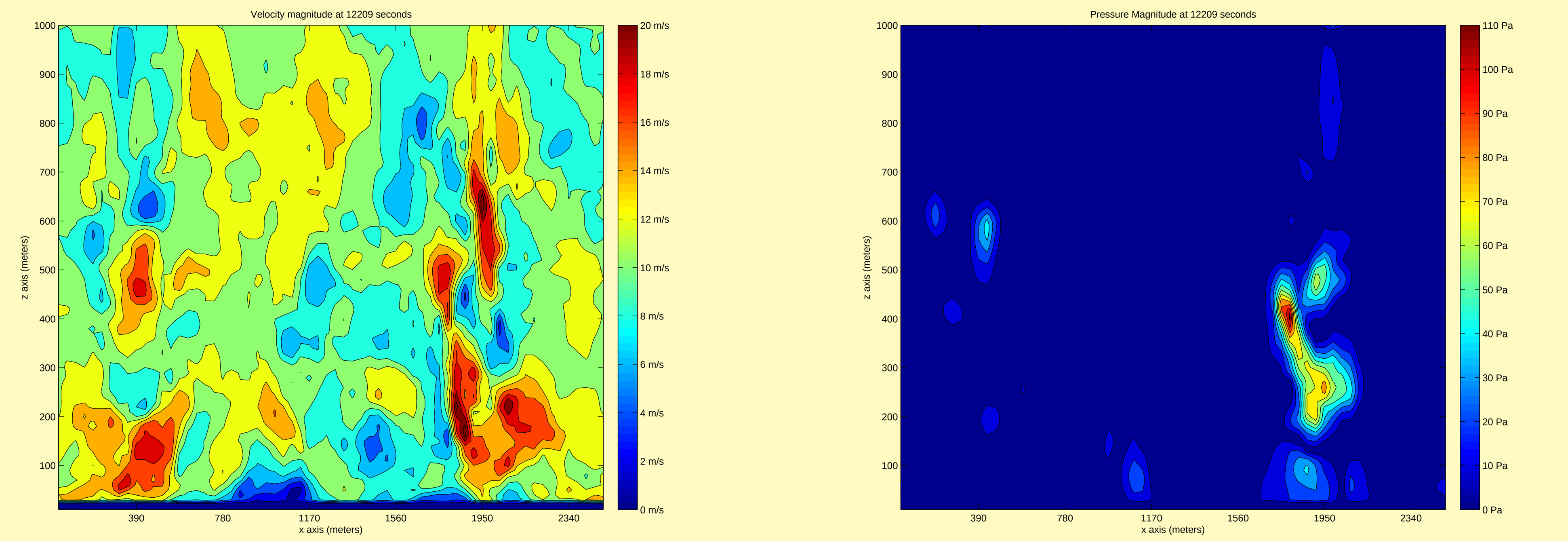


Current Work

Altitude vs. flow direction slices of the velocity magnitude field were extracted for each time slice. Contour plots were created so that visual identification of turbulent structures of interest could be performed.



The first three contour plots show large sigma events (red) that evolve rapidly with time. These events are possible gust candidates. The fourth plot shows the corresponding pressure magnitude for $t = 12169$ s.



Currently, high resolution daytime and nightime runs are being planned so that wavelet cross correlation studies can be used on gusts candidates to associate them with low frequency fluctuations in the pressure spectrum on the ground.

Additional Questions

There is evidence that nightime gusts often arise from the formation, propagation, and decay of Kelvin-Helmholtz instabilities and that these gusts are thought to be the primary source of wind turbine damage. LES has been used in the past to produce KHIs.[6] One major goal of this project is to investigate whether gusts formed by KHIs can be detected with infrasonic pressure sensors on the ground.

Aknowledgements

Martin Otte, Jeremy Webster, Greg Lyons

References

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