A Nested Micro-Scale Simulation of a Lake Michigan Land-Breeze Front

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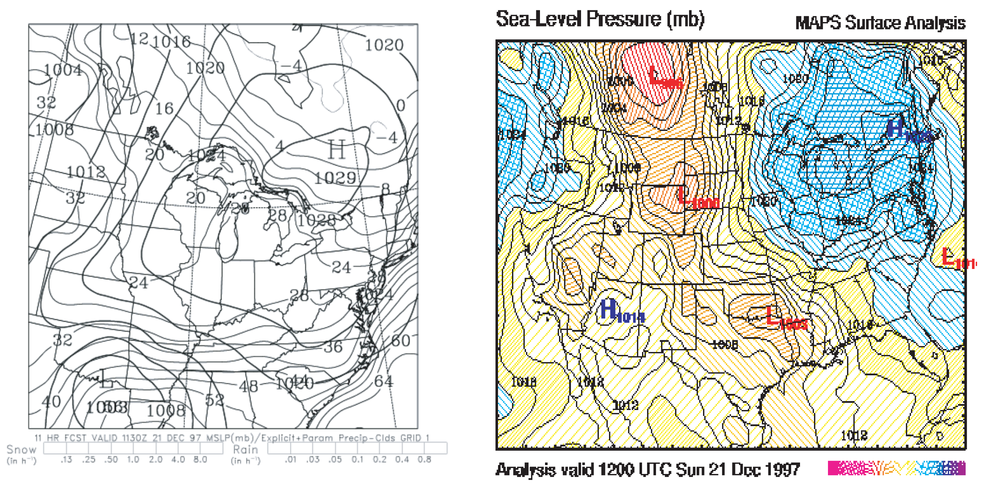
Introduction

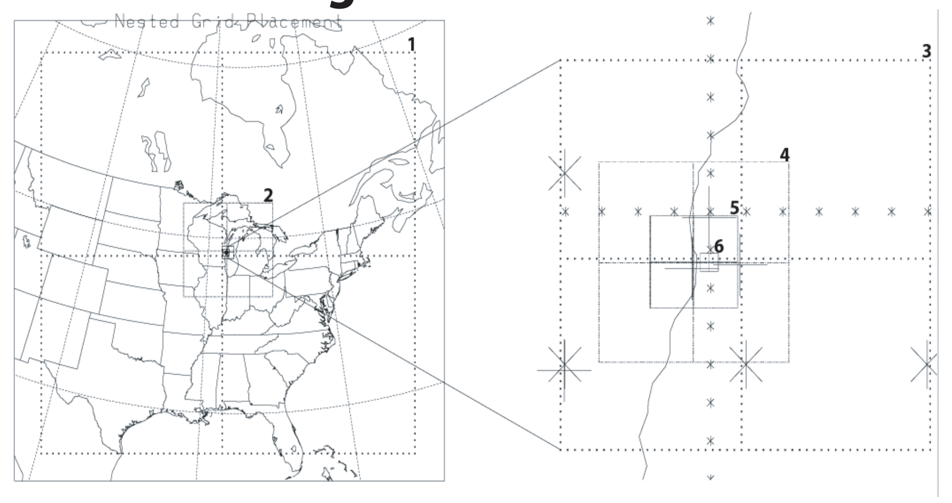
As part of the Lake Induced Convection Experiments (LAKE-ICE) on 21 December 1997, the University of Wisconsin Volume Imaging Lidar (UW-VIL) observed a visually intriguing, very shallow (100m) land breeze front undulating off the Lake Michigan shoreline at Sheboygan (Wisconsin) Point. Backscattering returns revealed pollutants trapped within the cold air extending offshore from the mainland. Eventually, as snow showers moved in from the east, the front withdrew across the shoreline into Wisconsin, clearing the air of pollutants as it moved westward. It was hypothesized that these small scale undulations and movements were actually deterministic and predictable in the 24 hour time frame because it was a localization of the synoptic system, modulated by the mesoscale effects of the land/lake thermal and moisture contrast. To investigate this hypothesis, we attempted to simulate the observed structure at the micro-scale by simply downscaling a regional synoptic scale simulation of the day's weather to resolve microscale topographical features that are believed to have created the observed frontal behavior in response to synoptic scale movements. For this we employed the University of Wisconsin Nonhydrostatic Modeling System (UW-NMS), initialized from standard NCEP EDAS (Etad Data Assimilation System) analysis. Previous efforts to simulate such microscale phenomena have largely focused around so called Large Eddy Simulations. Those studies seek to understand the structure and evolution of small scale turbulence, and its connection to local topographical and land use structures or regional scale atmospheric structures. Since turbulence structures evolve over hours, and turbulent eddies have lifetimes of only a couple of minutes, LES seeks to simulate the statistics of turbulence and structure types, rather than deterministically predicting a particular weather state. Moreover, LES typically employs periodic boundary conditions so that turbulence can evolve as naturally as possible, without obvious boundary influences. In the present study, the motivation is not to simulate the evolution of turbulence, but to examine to what extent the complex behavior of microscale flow is simply a localization of a more easily predictable large scale pattern. Compared to mesoscale simulations, which often nest down to around 1 km resolution using two or three grids, this simulation uses a larger number of two-way nested grids in order to achieve resolutions in the range of 10s of meters. To localize the synoptic scale prediction, our simulation includes very high resolution shoreline geometry of the Wisconsin coastline where the observations were taken, as well as specific land-use and topographical features derived from high-resolution topographical databases in order to more accurately represent the Sheboygan area. A simple down-gradient turbulence closure is used to represent the smoothing effects of turbulence. With this simple setup, the non-hydrostatic model was able to simulate the observed local behavior of the land breeze front with striking accuracy. These results imply that a great deal of the variance of small scale flow behavior may actually feature large scale flow-like predictability, and also have very interesting implications on the merits of forecasting at the microscale in the 24-48 hour time frame.

The Synoptic Picture



The 1130Z surface analysis from the UW-NMS run is shown on the left, while the 1200Z surface analysis for the 21st of December, 1997 is shown on the right. Both analyses feature high pressure over south-eastern Canada, as well as an area of low pressure over south-eastern Oklahoma. The model appears to be in good agreement with the analysis as far as the strengths and positions of these systems.

Positioning of the 6 Nested Grids

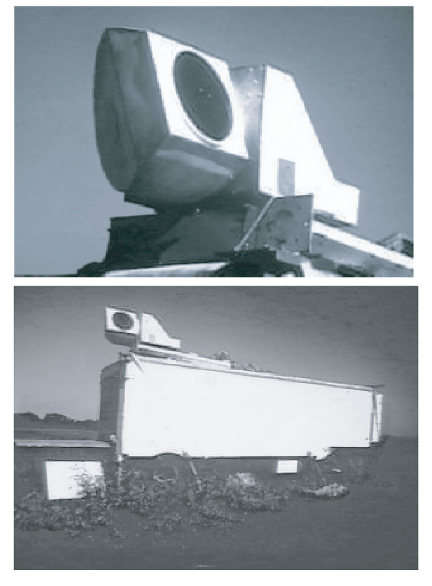


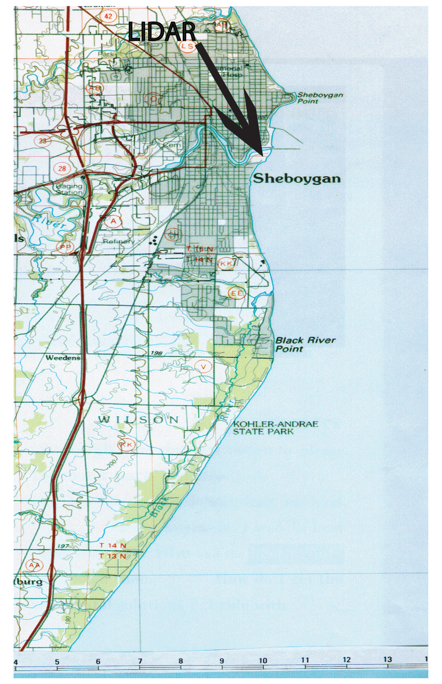
The grid positions of the six grids used in this simulation. The left image shows the outer domains, with the right image being an enlarged view of the the third, fourth, fifth and sixth grids. The Wisconsin shoreline can be seen in the right image, with grid number six being completely offshore.

The University Of Wisconsin Volume Imaging Lidar (UW-VIL)

The VIL uses a Nd:YAG laser to transmit 400 mJ pulses at 1.064-micron wavelength at 100 Hz. The VIL resides in a semi-trailer van, employs 0.5 m optics, a beam steering unit, log-amplifier, and real-time displays. Data are stored on write once optical disks.

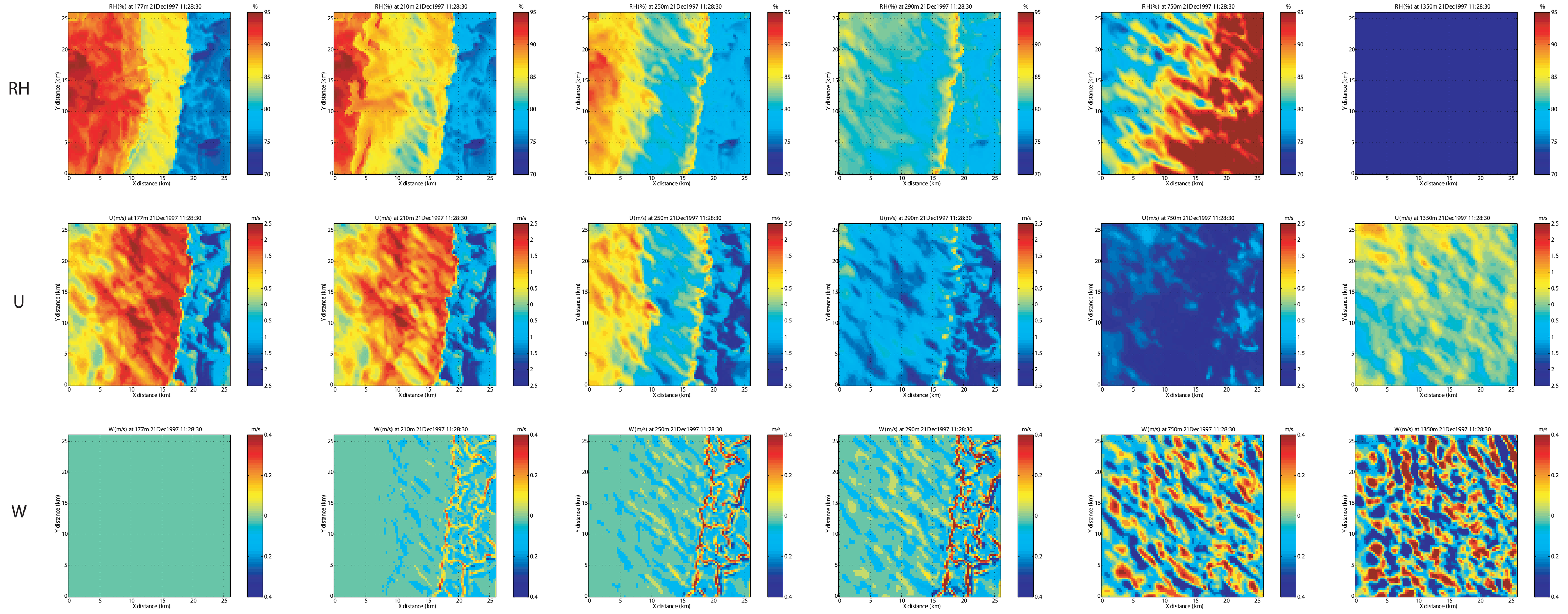
Transmitter	
Wavelength	1064 nm (Nd:YAG)
Average Power	20 W
Repetition Rate	30 Hz
Receiver	
Telescope Diameter	50 cm
Optical Bandwidth	1 nm
Detector Quantum Efficiency	~35%
Range Resolution	15 m
Maximum Scan Rate	20 degrees/second
Data Acquisition	
Data Rate	~500 MB/h
Length of Data Buffer	16K x 16 bit
Data Acquisition Computer	Heurikon i960
Controlling Computer & Real-time Graphics	SGI
Optical Data Storage	Hitatchi 7 GB Disk





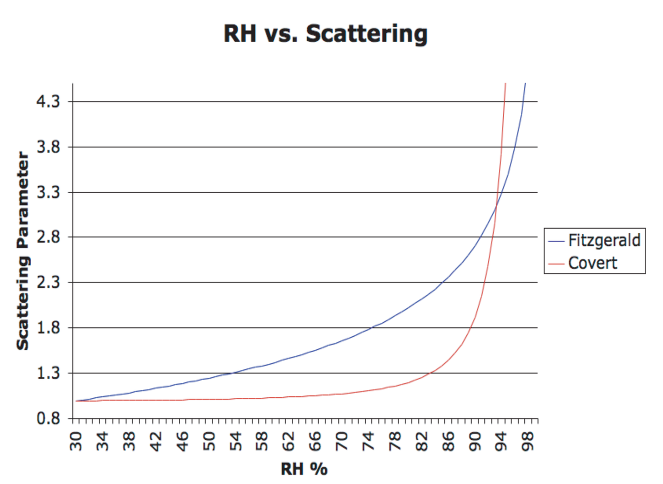
On the left is a map of the Sheboygan area, with an indication as to where the lidar was situated during the experiments. The VIL trailer, as well as the beam-steering unit can be seen in the above images. Below are some photos taken from Sheboygan Point during the Lake-ICE experiments. The right two photographs show the trailer sitting on the Lake Michigan shoreline.

5th Grid (160 m Resolution) Output

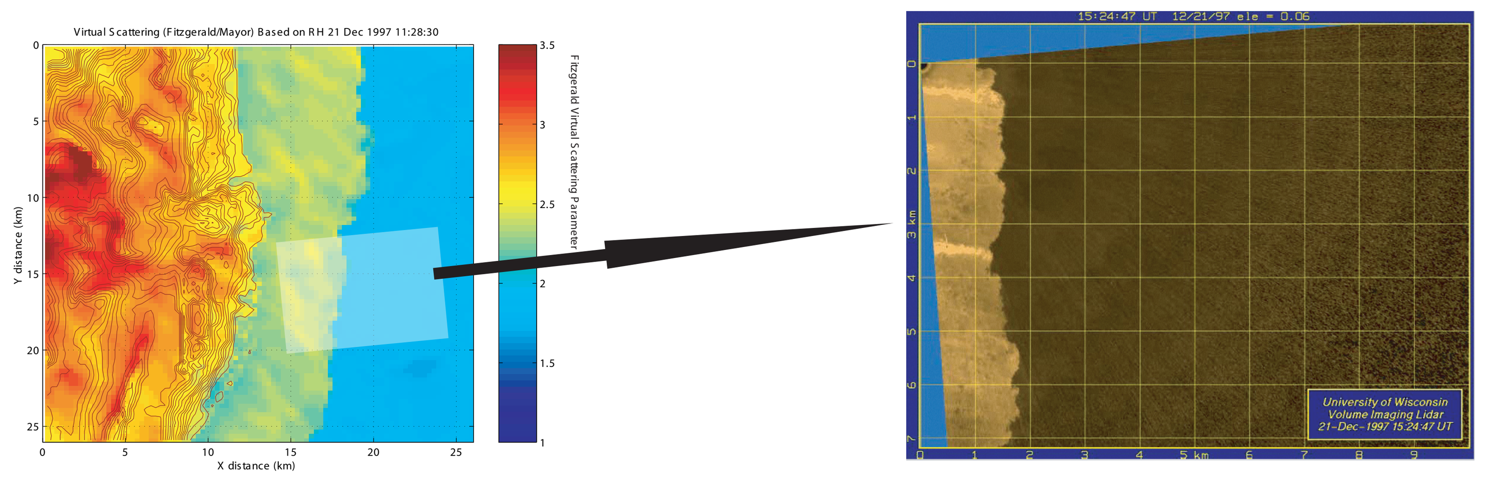


Lake Level (177 m) | 33 m above Lake Level | 73 m above Lake Level | 113 m above Lake Level | 573 m above Lake Level | 1173 m above Lake Level

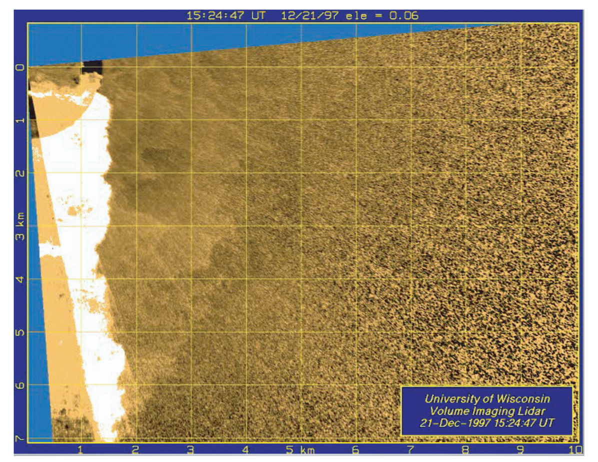
Comparison With Lidar Imagery



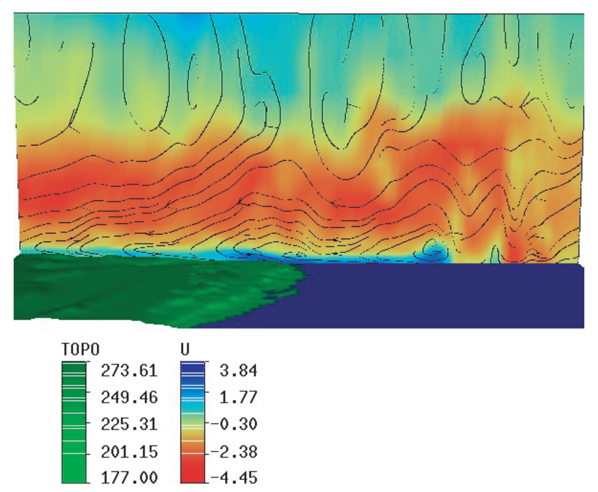
Fitzgerald: Scattering Parameter=-2.6+8.41/(100-RH)^0.2
Covert: Scattering Parameter =0.98+117.92/(100-RH)^2.1
Best fit curves to data thanks to Shane Mayor.

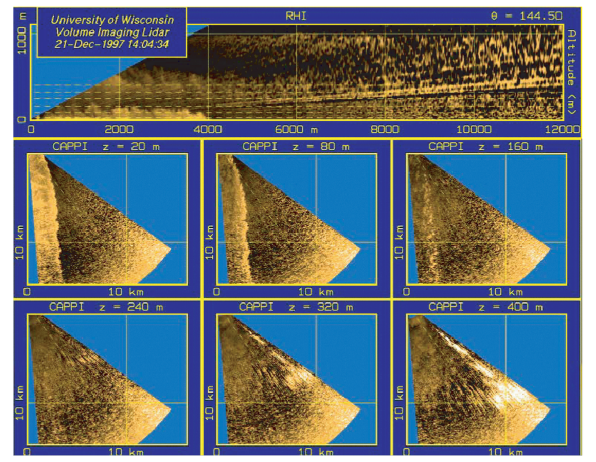


The best fit curve to the Fitzgerald data was used on the RH output of the model to create a virtual scattering parameter. Above, the resulting parameter is compared to the lidar returns. The model appears to have the front further offshore when compared to the lidar data, though the front's position did fluctuate in both the lidar imagery as well as the model output. Topography is contoured.



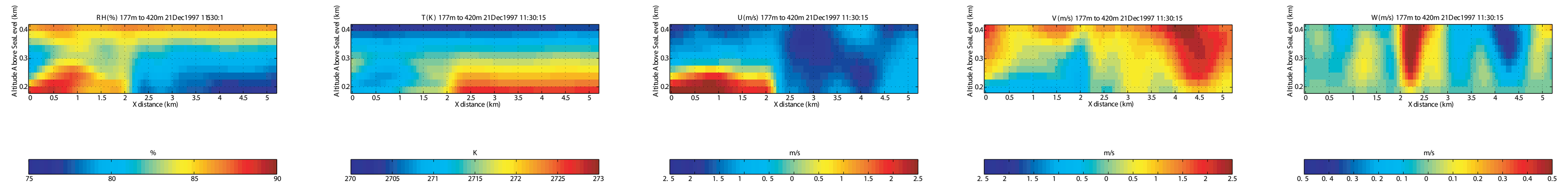
A filter was applied to this lidar data in order to reveal some of the structure of the cleaner onshore flow to the right of the front. Some of this structure can also be seen in the model output.





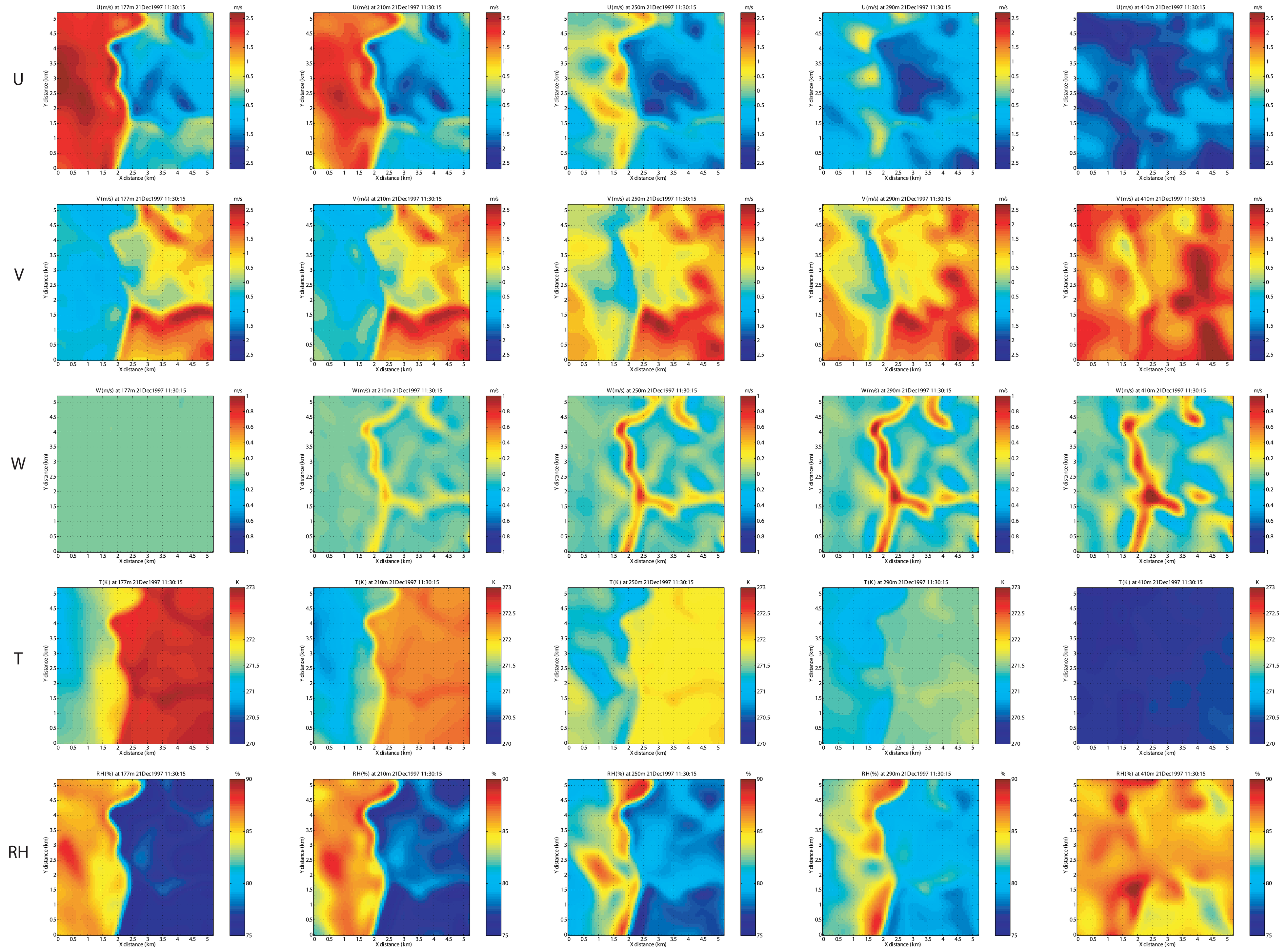
The u-component of the model winds, together with the streamlines, show the offshore flow coming off of the shoreline. A similar current shows up in the lidar data on the right, with the most intense backscatter coming off of the "dirty" air flowing offshore. Also, both the model and the lidar data show a wavy structure to the top of the boundary layer at around 900-1000m. Both the model output and top lidar image are viewed from the south, looking up the Wisconsin shoreline, with the left side of the image being west.

6th Grid (32 m Resolution) Output



RH X-Z Cross Section | Temperature X-Z Cross Section | U X-Z Cross Section | V X-Z Cross Section | W X-Z Cross Section

These cross sections through the offshore front show the shallow nature of the structure, with the vertical portion shown only representing around 240 m. The land breeze circulation only appears to be around 50 m deep, with some waves reaching a bit higher. Note the strong vertical motions at the intersection of the land-breeze and the prevailing winds. The entire domain of the sixth grid is located offshore.



Lake Level (177m) | 33 m Above Lake Level | 73 m Above Lake Level | 113 m Above Lake Level | 233 m Above Lake Level

Above are shown relative humidity, temperature, and wind (horizontal and vertical components) plots for five elevations in the 6th grid. The intersection of the offshore land-breeze and the onshore prevailing flow can be seen very clearly throughout. Since the entire grid is offshore, there is no influence on the data from points that would fall underground when the domain is viewed at a constant elevation, unlike on the fifth grid, where these underground points show up clearly on the relative humidity plot, for one.

Acknowledgements

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