DEPARTMENT OF METEOROLOGY
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Capabilities of current wildfire models when simulating topographical flow

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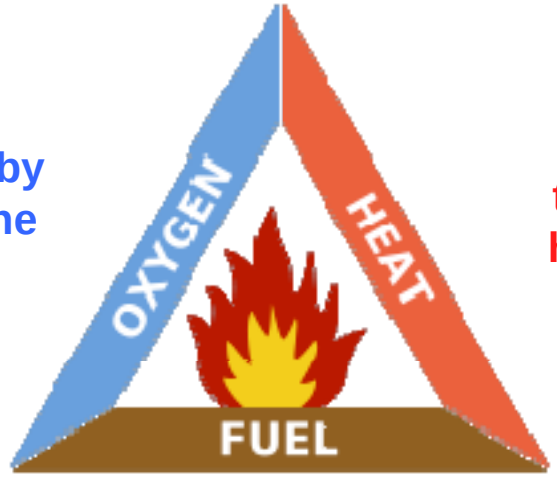
Photo from http://www.blazefire.com

Motivation

- Topographical obstacles strongly affect atmospheric flow
- Flow over the hill in general promotes eddies (turbulence)
- Generated turbulence:

Enhances transport of oxygen from the atmosphere to the fuel by reducing the depth of the laminar boundary layer formed during the flow around fuel elements



Intensifies heat transfer from the hot air to the fuel (pre-heating)

Increases rate of mass (moisture) transfer from fuel to the atmosphere (drying out of fuels)

- How well do the currently used models handle the topographical flow?

Simulation details - WRF and UU LES

WRF-LES:

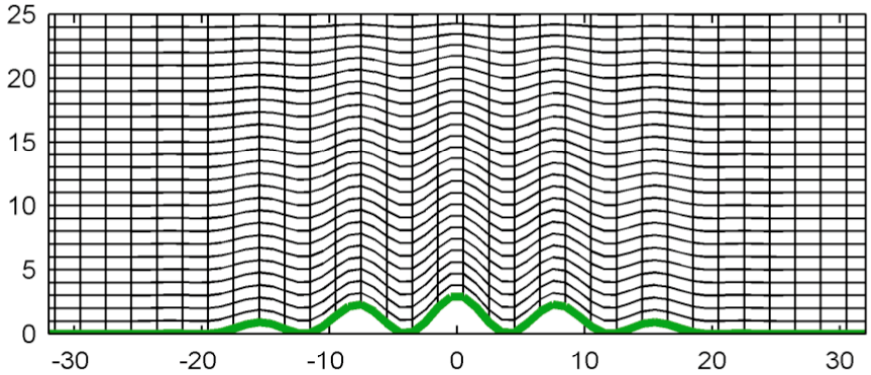
Analyzed domain:

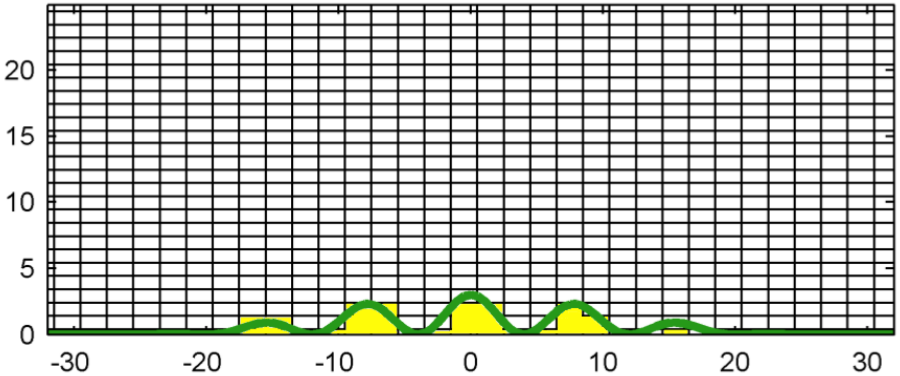
Grid: 256x256x200 (13,107,200 grid points)
Covered area: 5300 x 4960 x 600 m
Spatial resolution 20.7 x 19.3 x 3 m
Simulation length 1800s (30 min)
Time step 0.1 s, number of time steps 18,000
1.5 TKE sub-grid scale parameterization
Terrain-following coordinate system
Open boundary conditions
Wall clock simulation time on 8 CPU*: **206 h**
*restart files written each second

UU-LES:

Analyzed domain:

Grid: 256x256x200 (13,107,200 grid points)
Covered area: 5300 x 4960 x 600 m
Spatial resolution 20.7 x 19.3 x 3 m
Simulation length 1800s (30 min)
Time step 0.2 s, number of time steps 9,000
1.5 TKE sub-grid scale parameterization
Cartesian coordinate system
Cyclic boundary conditions
Wall clock simulation time on 8 CPU: **76h**





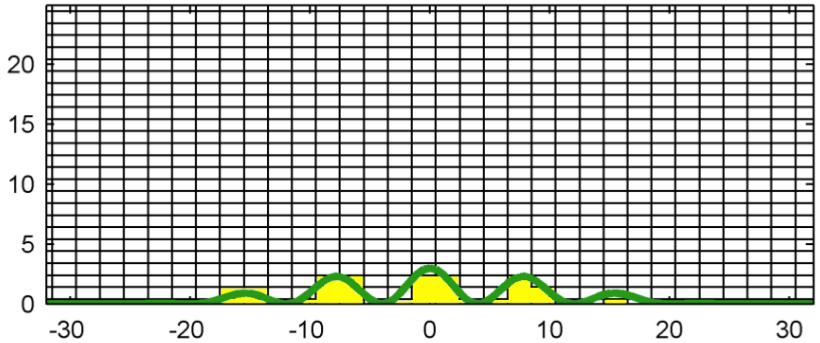
Graphs from Lundquist et al. 2008

Simulation details – WindNinja and FDS

FDS:

Analyzed domain:

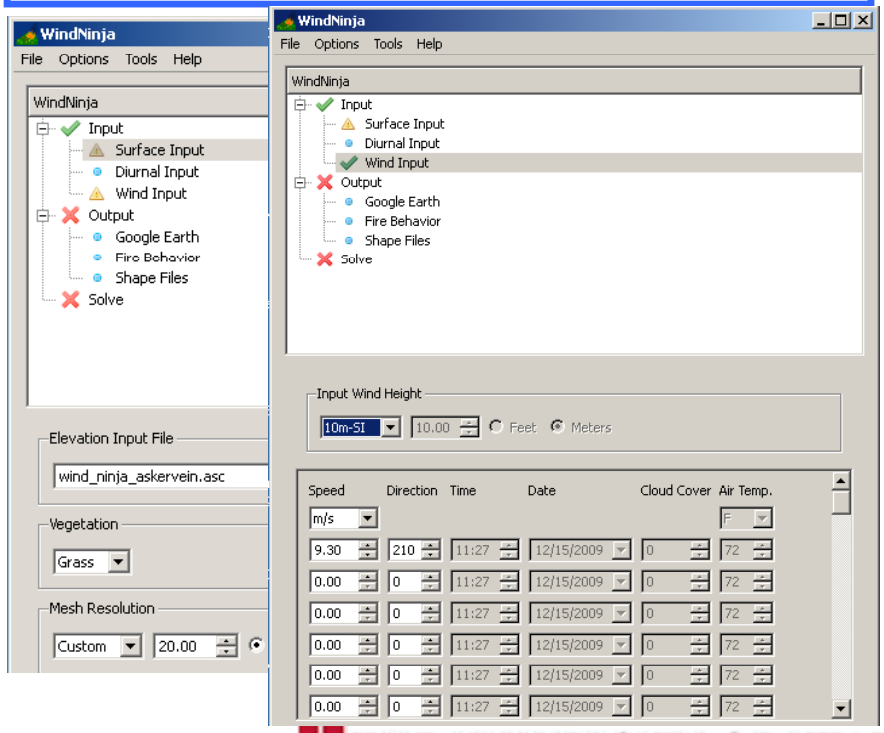
Grid: 128x128x100 (1,638,400 grid points)
Covered area: 2650 x 2480 x 500 m
Spatial resolution 20 x 20 x 5 m
Simulation length 3600s (1 hr)
Smagorinsky (dynamical) sub-grid scale parameterization
Cartesian coordinate system
Cyclic horizontal boundary conditions
No flux top boundary conditions
Wall clock simulation time on 8 CPU: **12h**
Expected 30 min simulation for WRF domain 48h



WindNinja 2.0.1 (mass-consistent model)

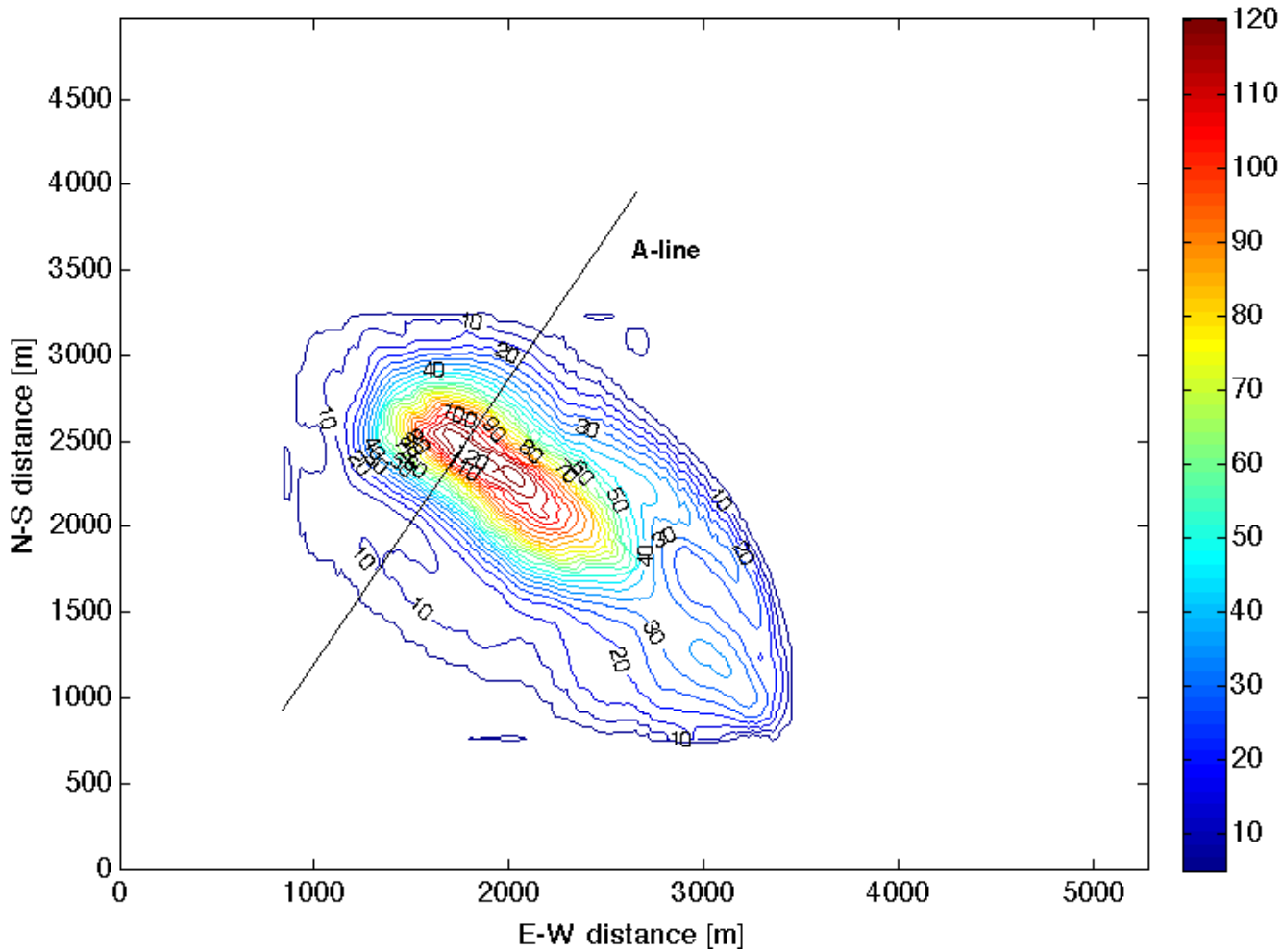
Analyzed domain:

Grid: 261x 261 2D (68,121 grid points)
Covered area: 5220 x 5220
Spatial resolution: 20 m
Simulation time: **< 1 minute**



Simulation details

Topography of the analyzed area (Askevein Hill, Scotland)
4960 m (N-S)
5300 m (E-W)
Max height 126 m



WRF and UU LES initialization

Both the WRF and UU LES were initialized using the measurement data collected during the Askervein ’83 experiment (Taylor and Tunissen 1983) on the third of October 1983:

- Kite wind profiles up to 600 m
- Rawisond data (temperature humidity)
- Tower wind profile data (up to 30 m)

The FDS was initialized using:

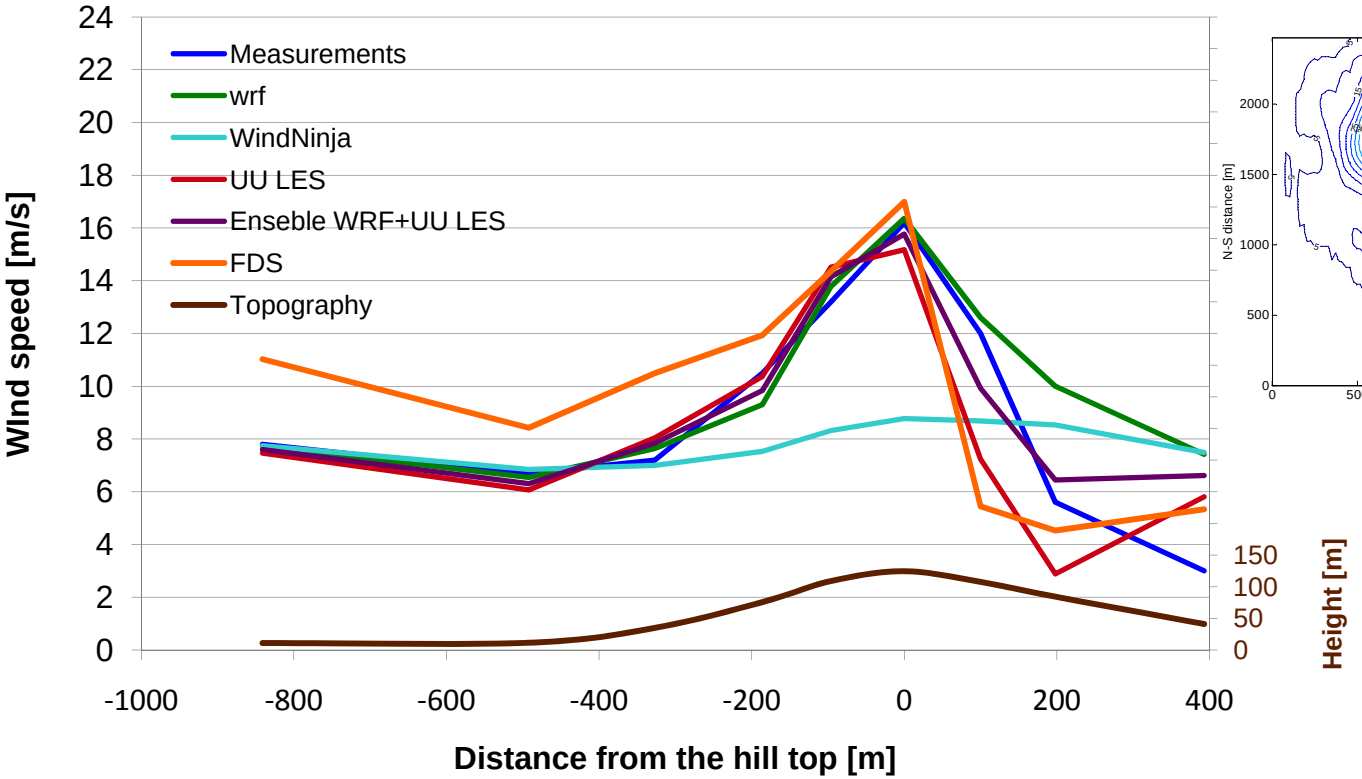
- Tower wind profile data (up to 30 m)
- Kite wind profiles up to 600 m
- Constant lapse rate -0.01^{o}C/m, and constant RH=95%

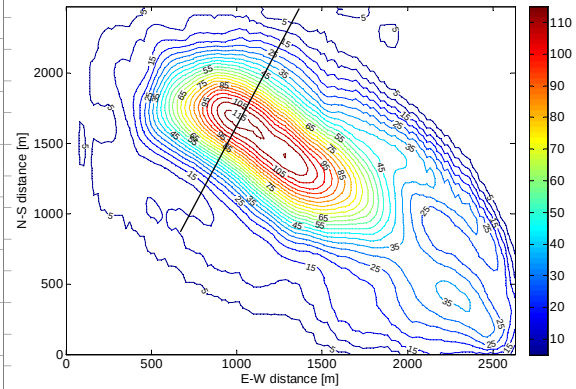
WindNinja was initialized using:

- The wind speed at the reference station (10 m AGL)

Models validation (cross-hill)

- Comparison between the wind speed simulated by the WRF-LES, WindNinja, UU LES, FDS and measured during Askervein ’83 experiment along the short hill axis ‘A’.

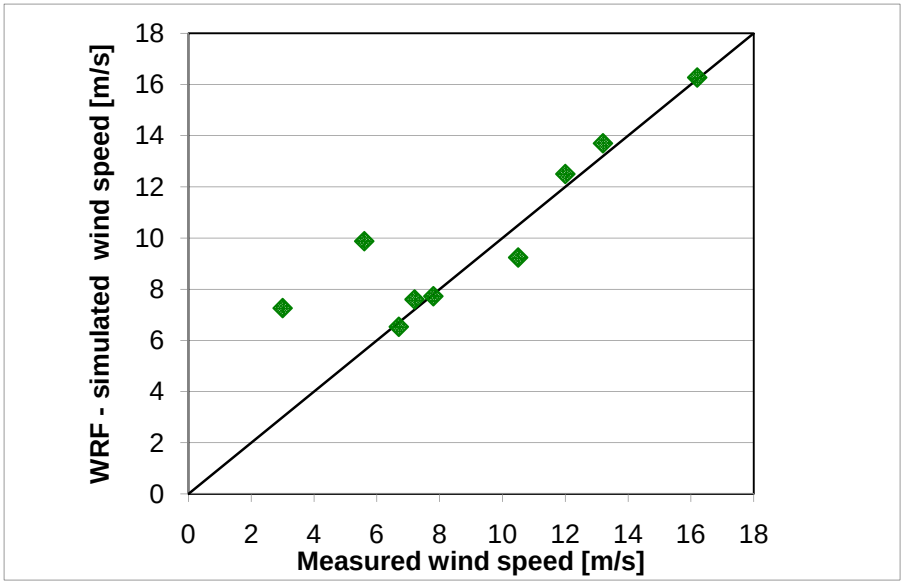




Models validation (WRF and UU LES)

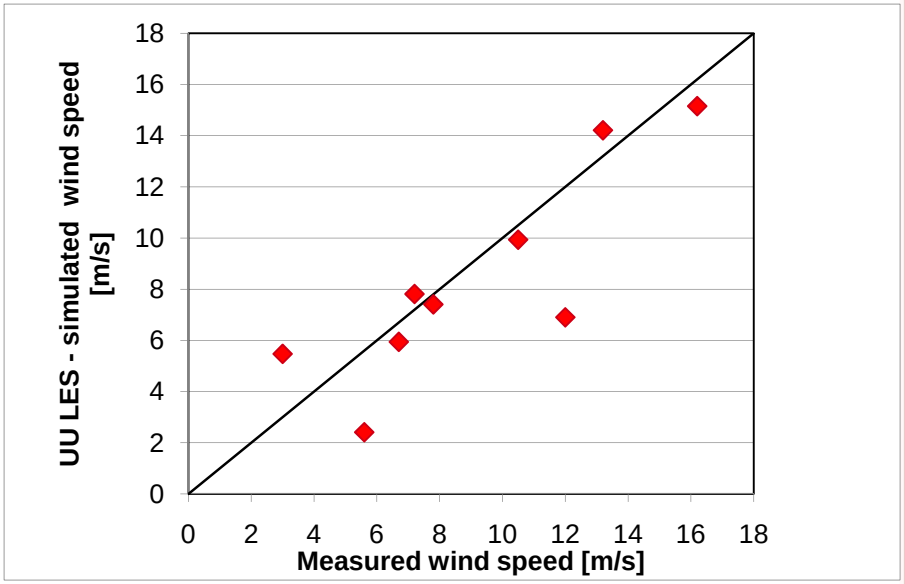
- Scatter plots of measured and simulated wind speeds across the hill (along ‘A’ axis), for the WRF-LES and UU LES.

WRF-LES



Correlation coefficient: R=0.88
Mean Absolute Error: MAE=1.34 m/s

UU LES

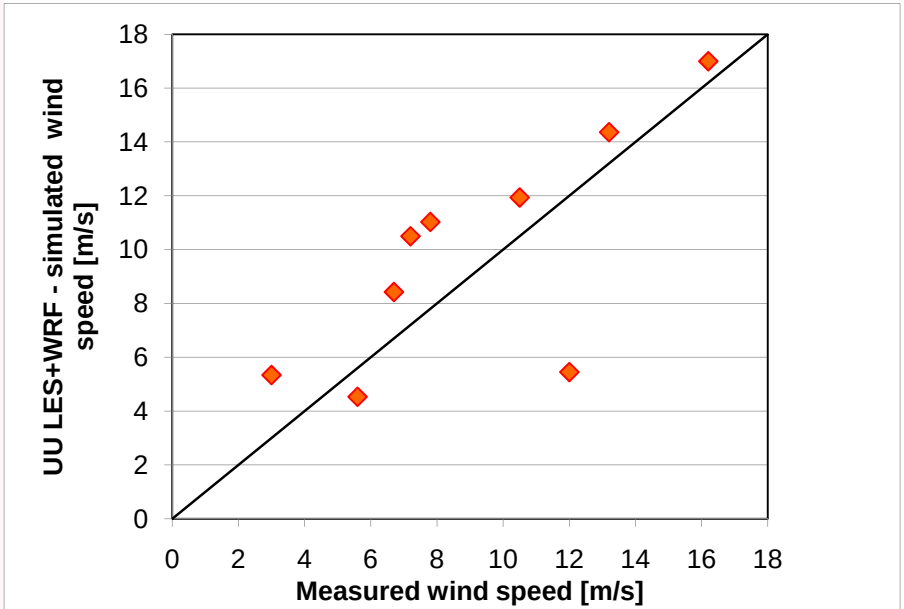


Correlation coefficient: R=0.85
Mean Absolute Error: MAE=1.62 m/s

Models validation (FDS and WindNinja)

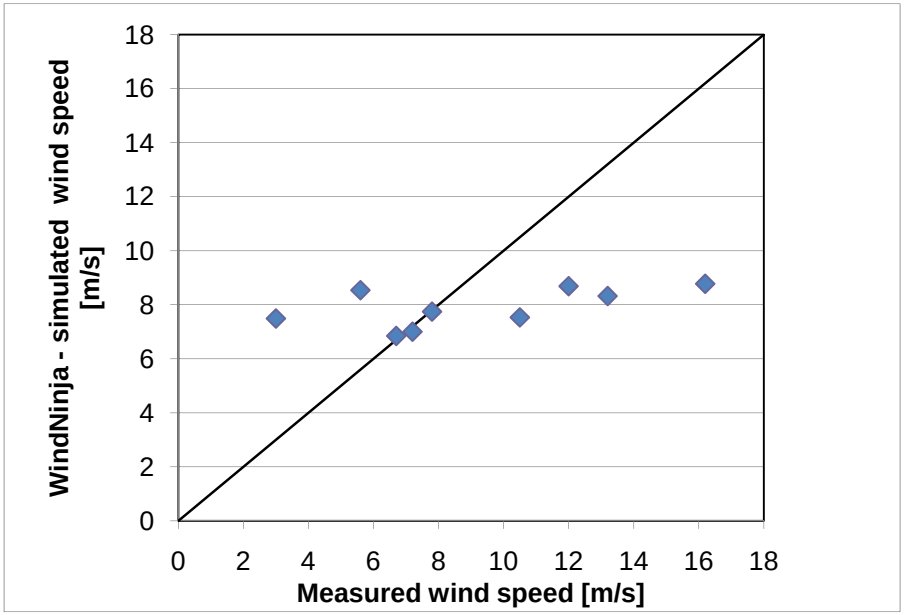
- Scatter plots of measured and simulated wind speeds across the hill (along 'A' axis), for the WindNinja and the FDS

FDS – preliminary results



Correlation coefficient: R=0.74
Mean Absolute Error: MAE=2.07 m/s

WindNinja

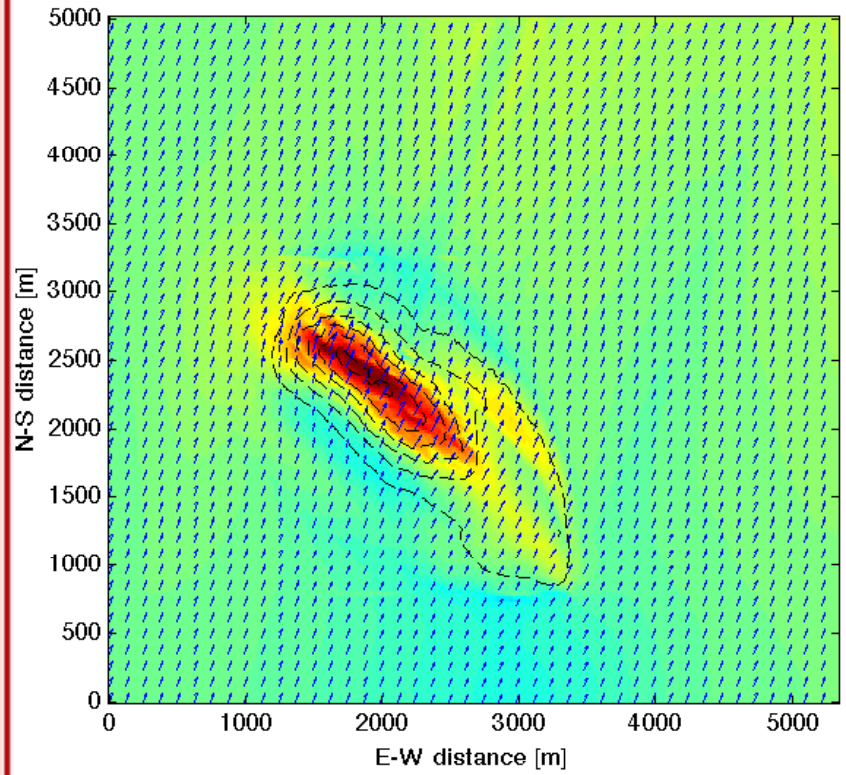


Correlation coefficient: R=0.60
Mean Absolute Error: MAE=2.93 m/s

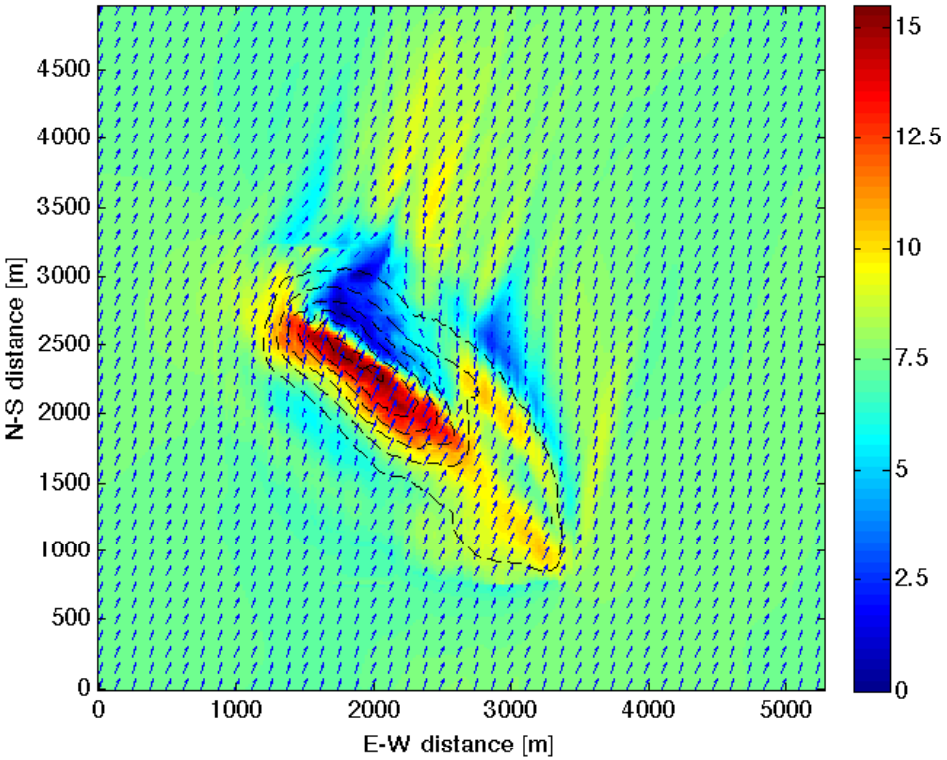
Simulated mean surface flow for WRF-LES and UU-LES

- Mean wind vectors at 10 m above the ground level with color coded wind speed [m/s], and topography contour for WRF-LES and UU LES

WRF-LES

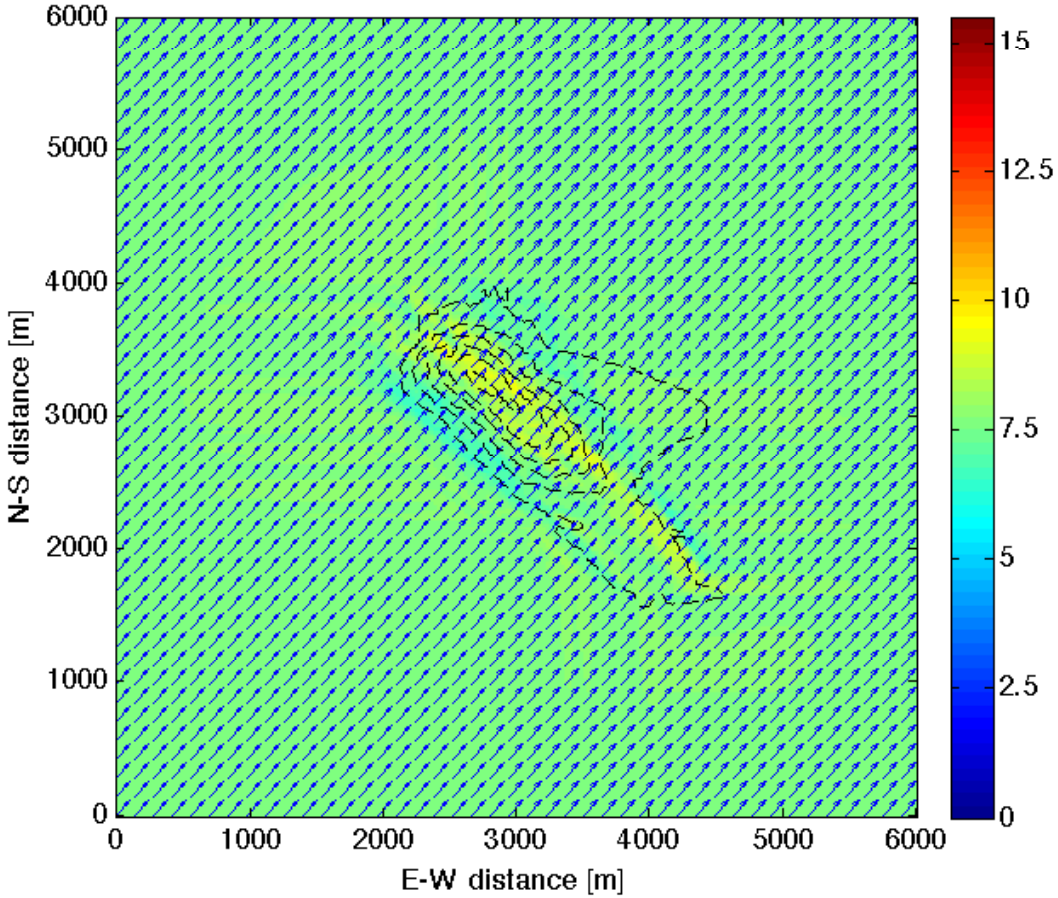


UU LES



Simulated mean surface flow for WindNinja

- Mean wind vectors at 10 m above the ground level with color-coded wind speed [m/s]

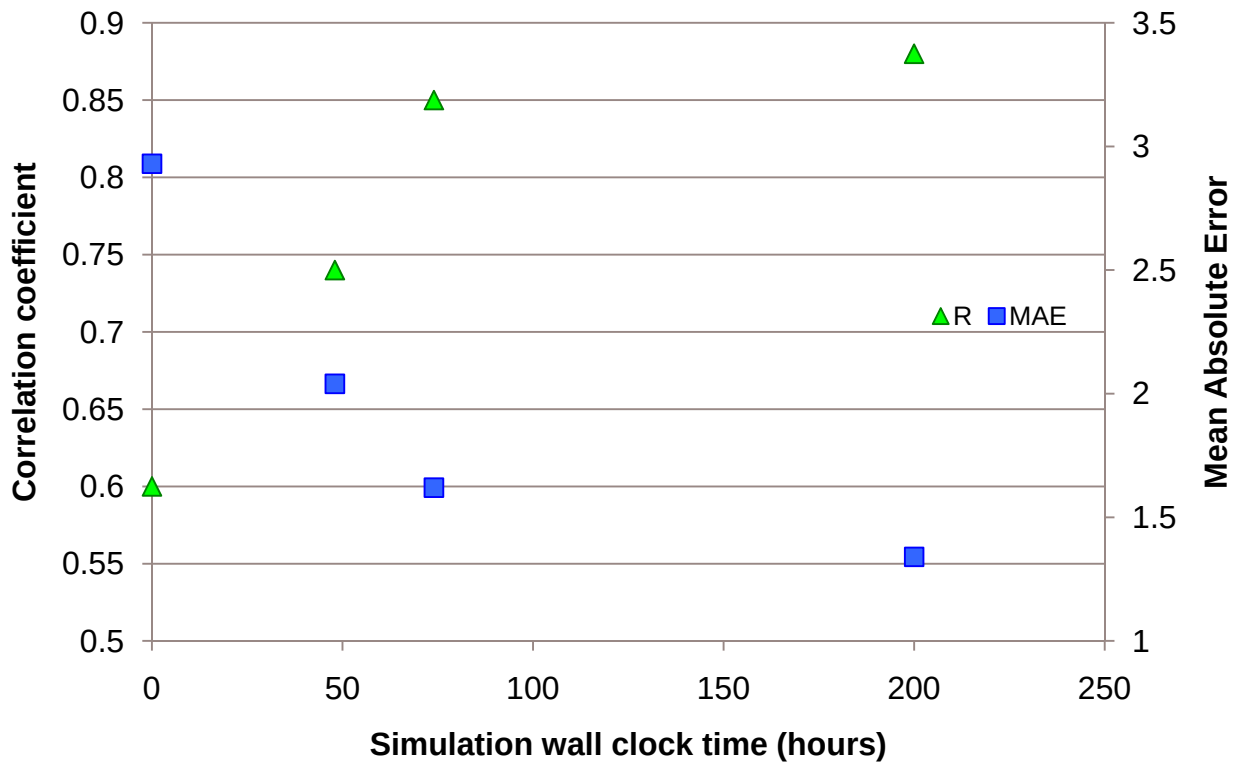


Summary

- All the CFD-based models (WRF-LES, UU LES, FDS) showed characteristic wind speed up on the windward slope and deceleration on the leeward side of the hill
- The WindNinja wasn't able to capture adequately the wind speed variation across the hill
- Among the four analyzed models the WRF-LES showed the best agreement with measurements, with R=0.88, and MAE=1.34 m/s, the UU LES showed very similar performance, with R=0.85, and MAE 1.63 m/s, the FDS showed slightly worse performance with R=0.74 and MAE=2.04 m/s, and the WindNinja showed the lowest correlation coefficient (R=0.6) and highest MAE=2.93 m/s
- The WRF-LES overestimated the wind speed on the leeward side, while the UU LES and FDS underestimated it, as a consequence the ensemble average of WRF-LES and UU LES gives the best wind speed prediction with R=0.93 and MAE=1.09 m/s
- The deceleration on the leeward side of the hill is more rapid for the UU LES and FDS, than for the WRF-LES. One of possible reasons for that may be the Cartesian coordinate system used in UU LES and FDS vs. smooth, terrain following coordinate system implemented in WRF.
- Different lateral boundary conditions used by the WRF-LES and the UU LES and FDS, may also affect the simulation. Open boundary conditions used by the WRF-LES evidently reduces the turbulence in vicinity of inflow boundaries (south and west).
- 'You get what you pay for', the more computational time the better results.
- We are on a good track, tested CFD-based models performs well in complex terrain, however problems with simulation of the leeward flow requires further investigations

Thank you!

- Questions?

Model performance vs. simulation wall clock time

- Correlation coefficient (R) and Mean Absolute Error (MAE) as a function of the wall clock simulation time