Development and Evaluation of a RANS-based CFD solve in WindNinja

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November 21, 2022

Abstract

WindNinja is a high-resolution diagnostic wind model developed for use by operational wildland fire management. The original version of WindNinja employed a numerical solver to enforce conservation of mass (COM). Because the COM solver is fast-running, requires little technical experience to run, and predicts ridgetop speed up and channeling effects well, it is widely used by the operational fire community. The COM solver has limitations, however, in regions where momentum effects dominate the flow, such as in regions of flow separation, which can occur on the lee-side of terrain obstacles. Recently, a second solver has been incorporated into WindNinja which enforces conservation of mass and momentum using computational fluid dynamics (CFD) techniques based on the Reynolds-Averaged Navier-Stokes (RANS) equations. In this work we compare simulations from the CFD solver to measurements made during three field campaigns (Askervein Hill, Bolund Hill, and Big Southern Butte) as well as to simulations from the COM solver and an LES model. Evaluations focus on near-surface winds during high-wind periods, which are of particular interest to wildland fire managers.

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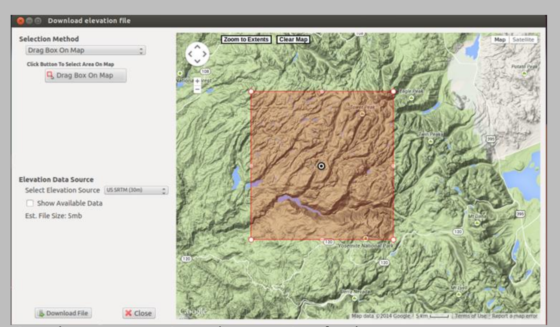
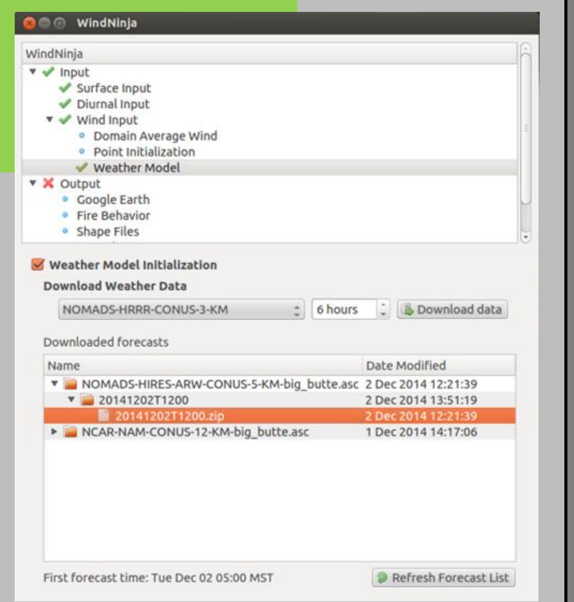
Introduction

Microscale wind forecasts are important for wildland fire behavior prediction, particularly in complex terrain where mechanical and thermal effects of the terrain can induce large gradients in the near-surface flow. Computational fluid dynamics (CFD) models are increasingly being used to simulate atmospheric boundary layer (ABL) flows, especially for wind energy applications. A CFD model was recently incorporated into WindNinja, a wind modeling framework developed specifically for operational wildland fire managers. The model is optimized for computational efficiency and ease of use by emergency response personnel. Here we investigate two important numerical settings used in the model: the turbulence model and the discretization scheme used for advection. We compare surface wind predictions against observations from two well-known field campaigns.

WindNinja

- GUI and command line versions
- Windows, Linux
- Open source, free
- User-friendly


Google maps terrain and vegetation fetcher


WindNinja graphical user interface

Inputs
- Terrain
- Vegetation
- Initial wind

Built-in fetching:
- SRTM data
- LANDFIRE data
- NOMADS weather model forecasts

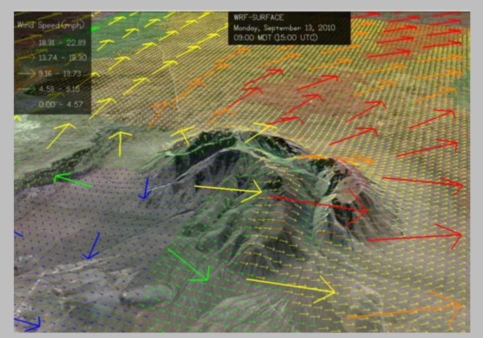
Solvers

Native solver
- Conservation of mass
- Steady-state

CFD solver
- Conservation of mass and momentum
- OpenFOAM devkit
- Steady-state
- RANS with k-ε turbulence closure

Options
- Diurnal slope winds
- Non-neutral stability

Gridded winds
- KMZ
- Shapefiles
- Rasters
- VTK (3D)


WindNinja KMZ output viewed in Google Earth

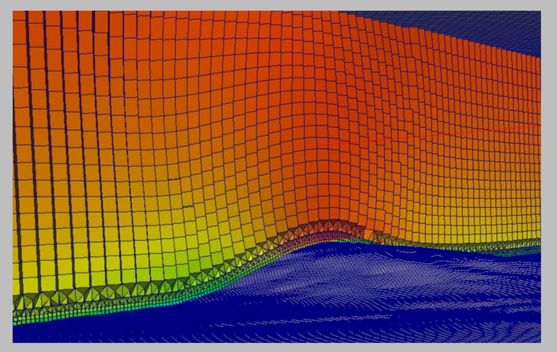
https://weather.firelab.org/windninja

CFD Settings

Boundary conditions:
ground: U = fixed value (0 0 0), υ_t, k, ε = wall functions
top: zero gradient
sides: zero gradient
inlet profiles: $U = \frac{u_*}{\kappa_{k-\varepsilon}} ln\left(\frac{z}{z_0}\right)$, $k = \frac{u_*^2}{\sqrt{C_\mu}}$, $\varepsilon = \frac{u_*^3}{\kappa_{k-\varepsilon} z}$

Turbulence Model:
k-ε vs. modified k-ε

Discretization Schemes:
advection: Linear upwind vs. QUICK
other terms: Linear



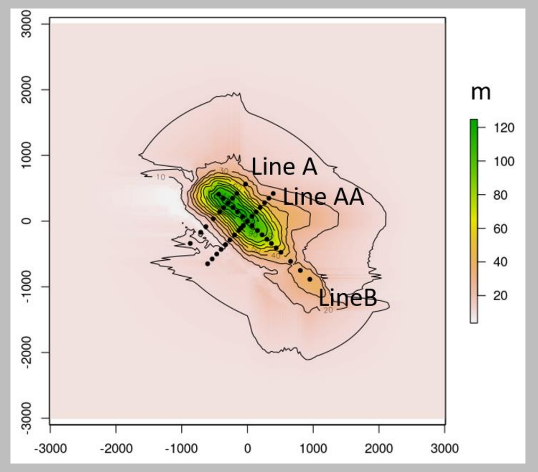
Mesh:
terrain-following, hexahedral mesh with refinement at surface
100K cells ("fine" mesh setting in WindNinja)

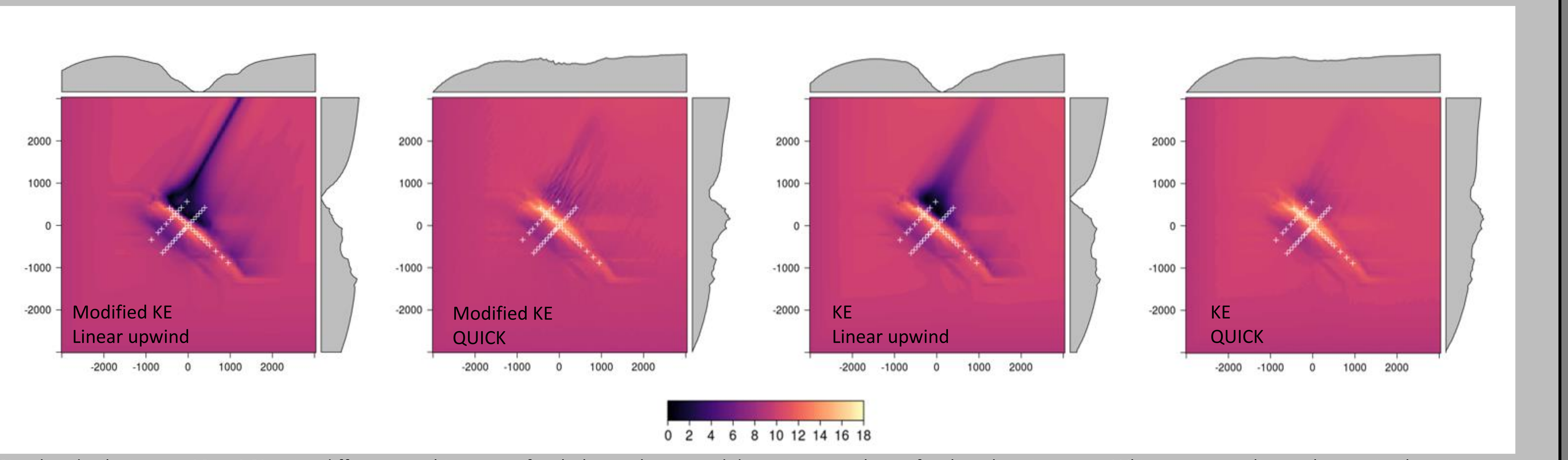
Askervein Hill

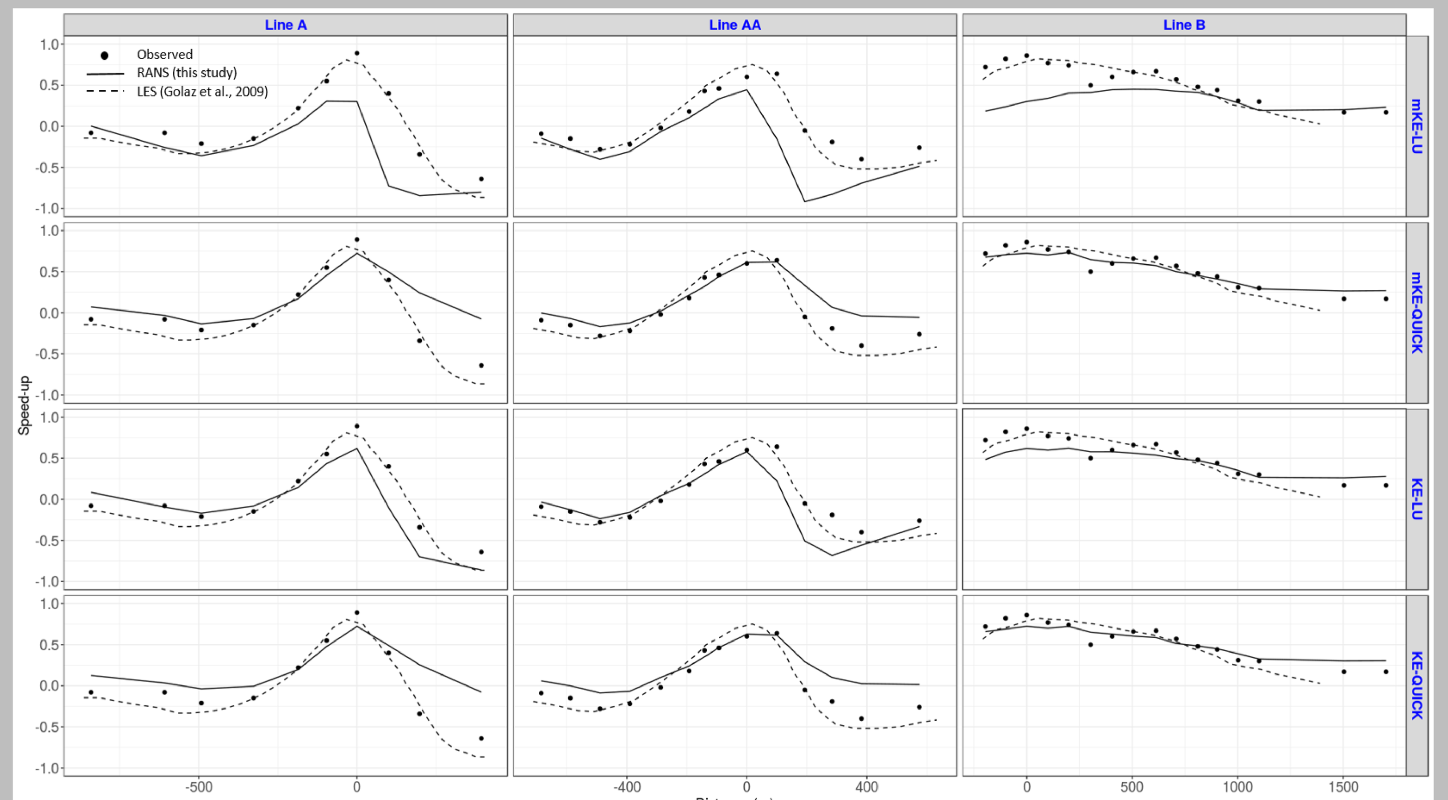
- 116 m tall
- 10-m wind 8.9 m/s from 210°
- Slightly stable conditions upwind

	RANS-"fine"	RANS-"coarse"
Simulation Time	4.2 minutes	26 seconds
Number of cells	100K	25K
Number of processors	4	4

Golaz et al., 2009 did not report simulation times


Askervein terrain and measurement locations.


Simulated velocities at 10 m AGL using different combinations of turbulence closure and discretization scheme for the advection term. White crosses indicate observation locations.

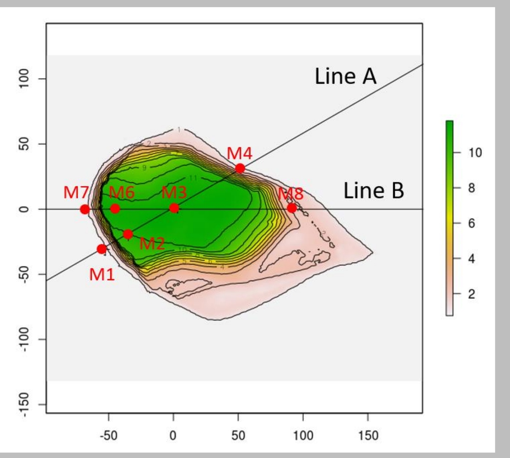

Observed and simulated speed-up along three transects at Askervein Hill. All RANS simulations used the "fine" mesh setting in WindNinja. LES curves reproduced from Golaz et al., 2009.

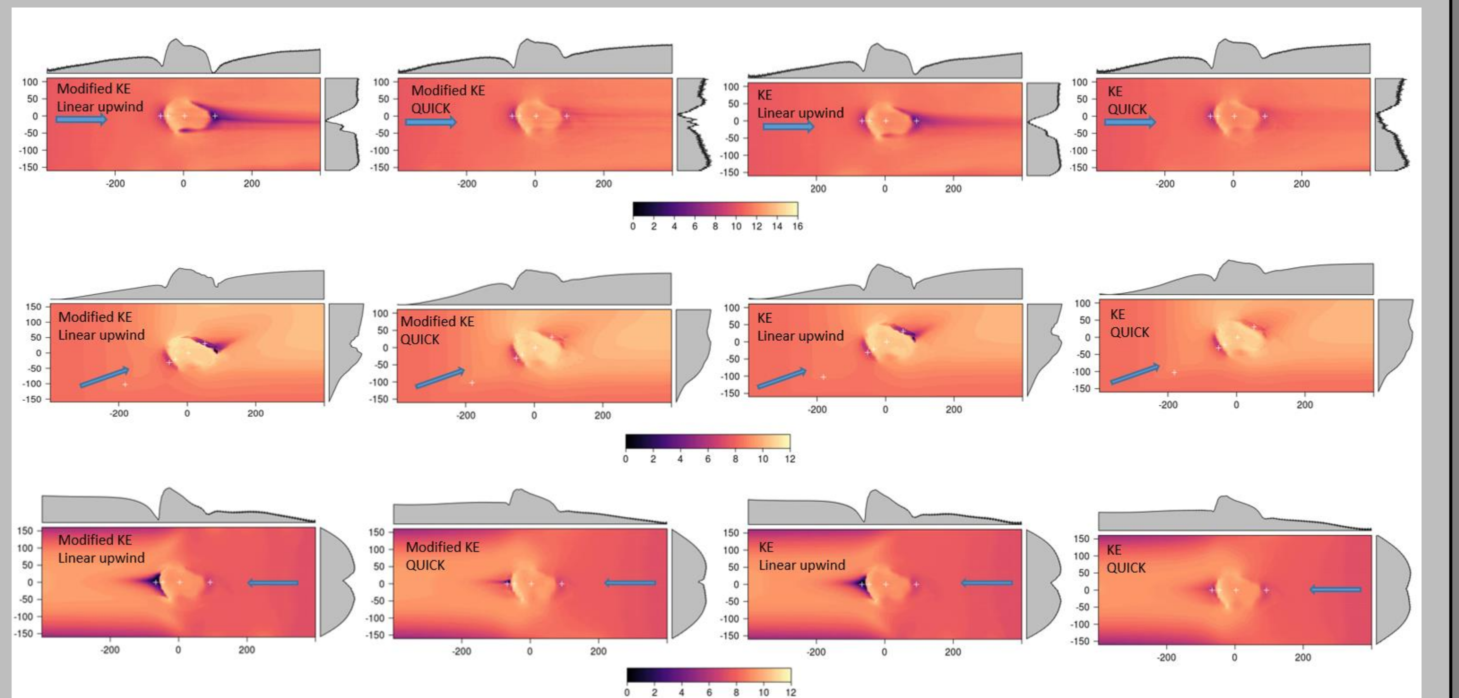
Bolund Hill

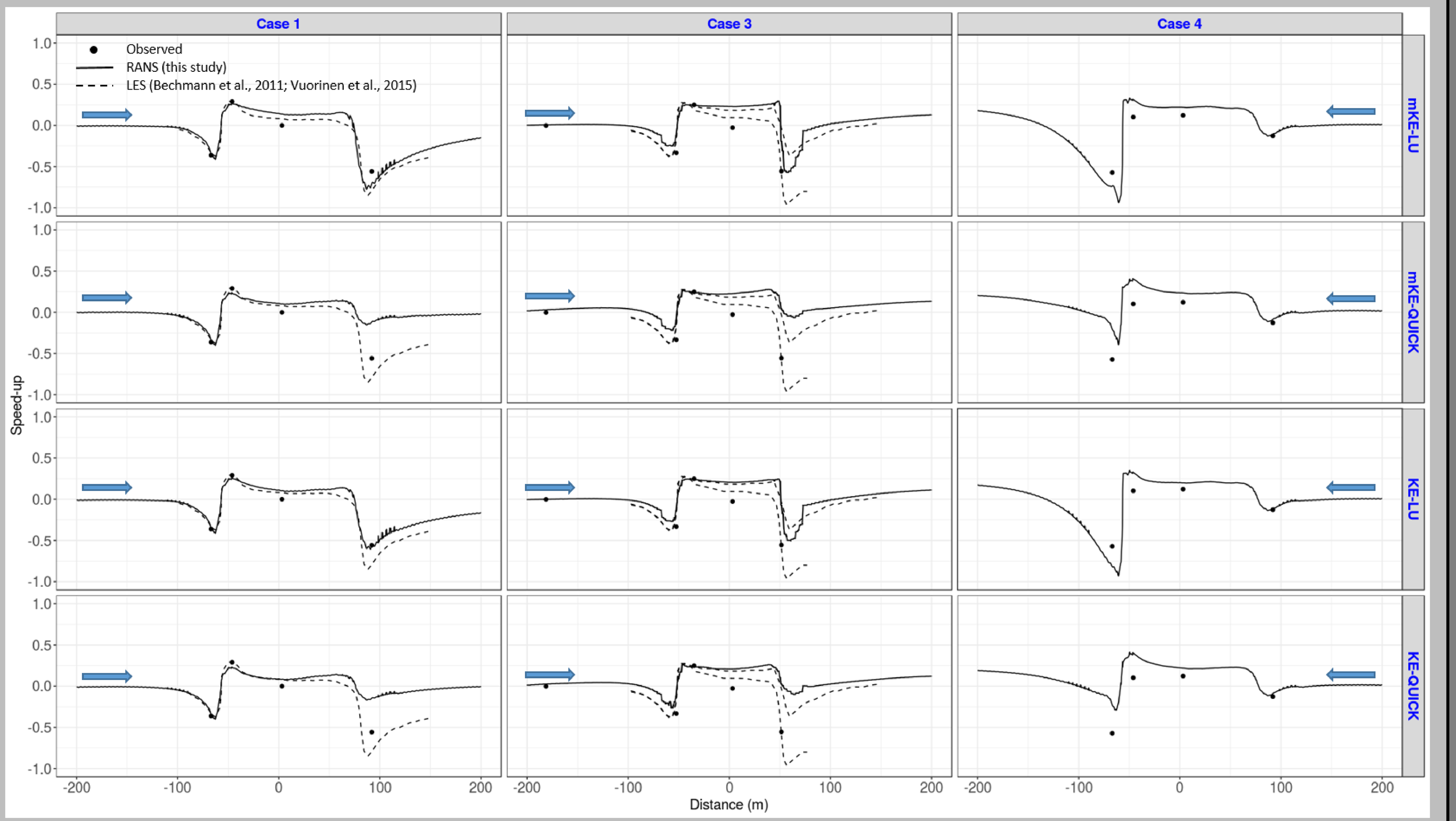
- 12 m tall
- Very steep west face
- Case 1: 10.9 m/s from 270°
- Case 3: 8.7 m/s from 239°
- Case 4: 7.6 m/s from 90°

	RANS-"fine"	RANS-"coarse"	LES
Simulation Time	7.3 minutes	4.7 minutes	40 days
Number of cells	100K	25K	2.9M
Number of processors	4	4	512

LES numbers reported by Vuorinen et al., 2015


Bolund Hill terrain and measurement locations.


Simulated velocities at 5 m AGL using different combinations of turbulence closure and discretization scheme for the advection term. White crosses indicate observation locations.


Observed and simulated speed-up for three cases at Bolund Hill. All RANS simulations used the "fine" mesh setting in WindNinja. LES curves reproduced from Bechmann et al., 2011 (Case 3) and Vuorinen et al., 2015 (Case 1).

Conclusions

- The choice of turbulence model and discretization scheme for advection impact the simulated surface winds
- The main features of the surface flow are captured with all of the tested combinations
- k-ε with linear upwind discretization gives the best results for the cases investigated
- Simulated speeds in the ballpark of those from LES studies
- Evaluations are being conducted with observed data from recent field campaigns in more rugged terrain