Wind Turbine

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Wind Turbine

- Wind Turbine
  - Background

- Wave effects
  - Swells

- Complex terrain
  - Hills
Wind Turbine

- **Wind Energy**
  - \( P \propto U_{\text{hub}}^3 \)
Wind Turbine

- Wind Farm
  - Optimum distance \( h_x \)
Wind Turbine

- Wind Farm
  - Optimum distance $h_x$
Wind Turbine

- Wind Farm
  - Optimum distance $h_x$

- WT wake
  - Wind velocity
  - Wind shear
  - Wind veer

- ABL turbulence
- ABL stability
- ABL depth
- Surface roughness
Wind Turbine

- Wind Velocity & Direction
  - Long term statistics
  - Short term statistics
- Are available for some heights
  - Logharitmic profile
Wind Turbine

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  - Swells

- Complex terrain
  - Multiply hills
Wave Effects

- **Swell**
  - Nonlocal waves generated remotely by storms.
  - Uniform long waves that can propagate for a relatively long distance with little attenuation.
  - May have any direction and velocity, independent of the local wind.
Wave Effects

- The solver
  - OpenFOAM 2.1.3
  - Buoyant solver, Boussinesq approximation
  - Fixed driving pressure force (from the geostrophic balance)
  - Coriolis force is added
  - Modified GenEddyVisc, with a variable length scale $f$(stability)
  - Modified oneEqEddy: buoyant term, and variable Prt are added
  - A new BC for velocity
Wave Effects

- **BCs**
  - Periodic in horizontal directions
  - No slip at upper boundary
  - The ABL height is controlled by temperature profile
  - Wall shear stress at lower boundary, $f(\text{stability})$

- **Moving reference of frame**
  - Wave length 100m
  - Swell attenuation is neglected
  - Unresolved waves are modeled as roughness height

- **Neutral ABL**
Wave Effects

Resolution

- 1200m 1200m 800m
- \( N_x = N_y = 250, N_z = 100 \)
- 2nd order spatial and temporal schemes
Wave Effects
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Summary

- The swell-induced stress has an opposite sign to that of the turbulent stress.
- The magnitude of the swell-induced stress is increased with the wave-age and wave steepness.
- The increase in wave-induced stress normalized by the geostrophic wind is found to be quadratic with the wave-age and linear with the wave steepness.
- The swell-induced stress decays exponentially above the surface.
- The decaying rate shows no significant variation with the swell parameters and can be scaled with the wavelength and the height above the surface.
- At high swell wave-age and wave steepness, the swell-induced stress increases and exceeds the turbulent stress which results in a negative wind drag, i.e. a thrust.
Wave Effects

Summary

- The wind velocity accelerated to a velocity larger than its geostrophic wind and forms the super-geostrophic wind jet.
- The size and the intensity of the jet increase, while the height of the maximum wind velocity decreases, with wave-age and wave-steepness.
- Above the Umax, the velocity is reduced with a negative wind gradient to match its geostrophic wind at the top of the BL, while the velocity decreases below it to its surface value.
- At higher wave-age and wave steepness, the negative stress accelerates the wind and the wind gradient between the super-geostrophic wind jet and the rest of the MABL, therefore the turbulent intensity and shear stress increases again.
Wave Effects

Wave statistics

- <=0.5
- >0.5 - 1
- >1 - 1.5
- >1.5 - 2
- >2

Wave climatology

HANLEY ET AL.

Fig. 6. Inverse wave age calculated using the ERA-40 wind and wave data averaged over 1958-2001.
Wave Effects

Wave induced stress  Velocity profile
Wave Effects

Without waves

With waves
Wave Effects

Without waves

With waves
Wave Effects

Without waves

With waves
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Complex Terrain
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