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WindSim User Meeting, Orlando, FL 4 Dec 2014

Turbulence Modeling Comparison in Complex Terrain

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Introduction

Turbulence modeling comparison in complex terrain

- Why is turbulence modeling important?
- Turbulence models – which one?
- Experiment Setup
- Results
- Conclusions

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Why is turbulence modeling important?

if $\min\{d_i\} \geq 10\,D$:

$$I_{\text{eff}} = \frac{\hat{\sigma}}{V_{\text{hub}}} \qquad \text{(D.2)}$$

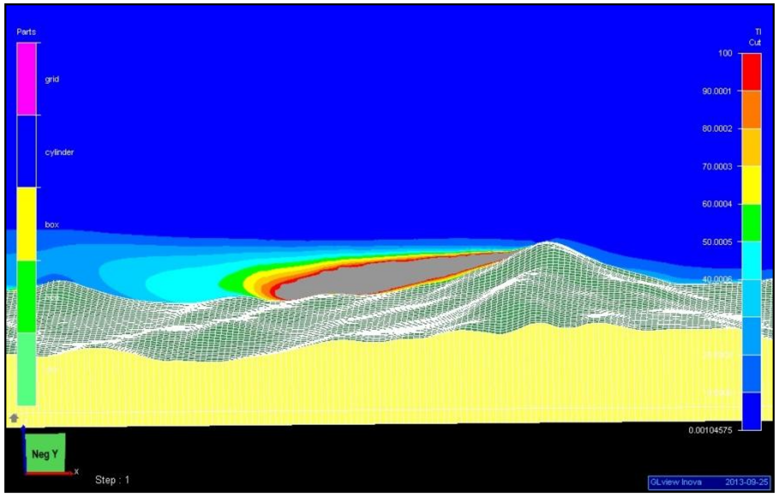
if $\min\{d_i\} < 10\,D$:

$$I_{\text{eff}} = \frac{\hat{\sigma}_{\text{eff}}}{V_{\text{hub}}} = \frac{1}{V_{\text{hub}}}\left[(1-N\,p_{\text{w}})\hat{\sigma}^{m} + p_{\text{w}}\sum_{i=1}^{N}\hat{\sigma}_{\text{T}}^{m}(d_i)\right]^{\frac{1}{m}}; p_{\text{w}} = 0{,}06 \qquad \text{(D.3)}$$

where

$\hat{\sigma}$ is the ambient estimated turbulence standard deviation;

$\hat{\sigma}_{\text{T}} = \sqrt{\dfrac{0{,}9V_{\text{hub}}^2}{(1{,}5+0{,}3d_i\sqrt{V_{\text{hub}}/c})^2} + \hat{\sigma}^2}$ is the maximum centre-wake, hub height turbulence standard deviation;



Loads, e.g. DLC 1.2

Turbulence drives the fatigue load calculations

Avoid potential performance issues

We need to see the areas of extreme high TI, shear, veer associated with recirculation

Which turbulence model should I use?

Many options available in WindSim

- K-epsilon – 4 variants (http://www.cham.co.uk/phoenics/d_polis/d_lecs/general/turb.htm)
  - Standard k-e
  - Modified k-e
  - Yap k-e
  - RNG k-e
- K-omega (Wilcox) (http://www.cham.co.uk/phoenics/d_polis/d_enc/turmod/enc_t346.htm)

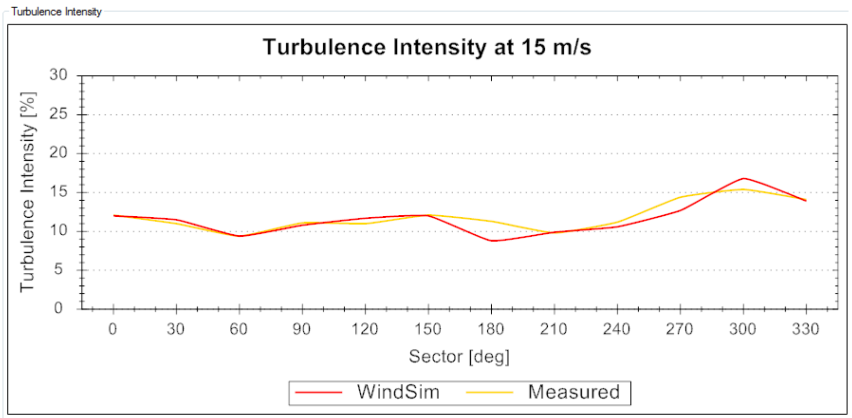
Which turbulence model should I use?

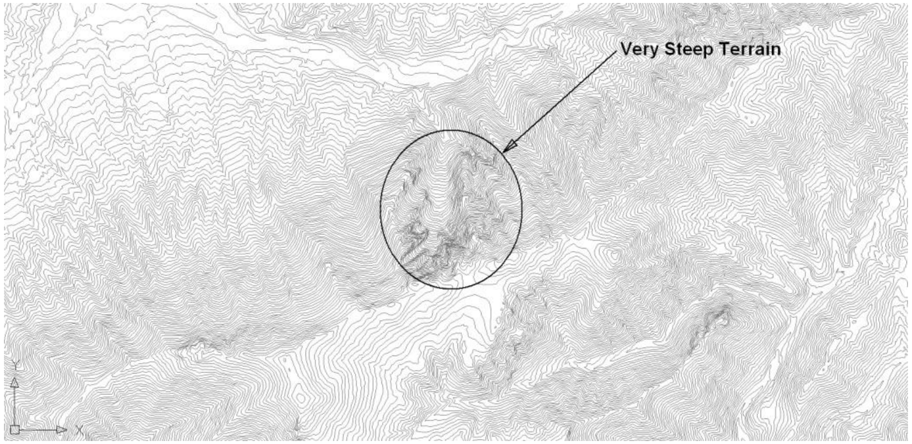
The NoKFoS Principle
Nobody knows for sure, so….

Which model gives the best result – Good match to the real world at the place(s) where we have real data?

Which model gives reasonable results at places where we do not have data?

Having an idea how the different models may behave can help getting more accurate results quicker.





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Experiment setup

An investigation was performed to see how the various turbulence models available in WindSim behave with respect to modeling turbulence in terrain of various steepness.

- Four Gaussian Hills were generated using Weng, converted to.gws:
  - Hill1: 115m height, 200m major axis and minor axis half-width, = 24deg max
  - Hill2: 167m height, 200m major axis and minor axis half-width, = 33deg max
  - Hill3: 238m height, 200m major axis and minor axis half-width, = 42deg max
  - Hill4: 346m height, 200m major axis and minor axis half-width, = 52deg max

- Windsim settings (WS 6.1):
  - Roughness uniform 0.10, or Forestry (p=0.3,C1=0,C2=0.0005, 20m x 4 cells)
  - Geometric 0.05 z dist, 28 cells z, 1000 m max. model height
  - <1M cells
  - 5m x 5m x-y cell size
  - Default windfield settings, coupled solver, unless noted

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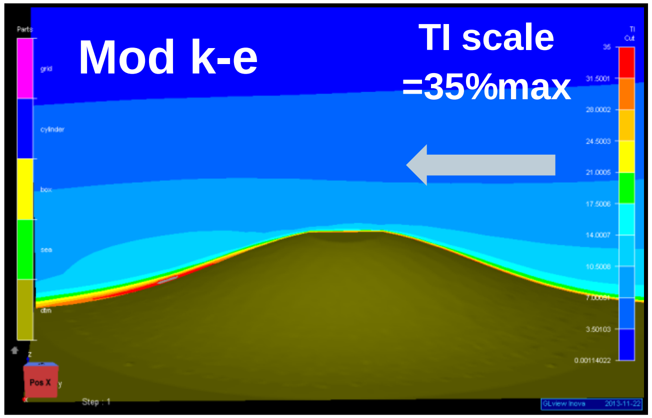
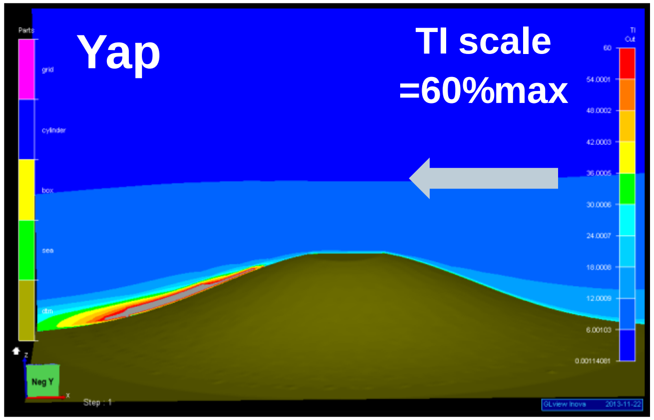
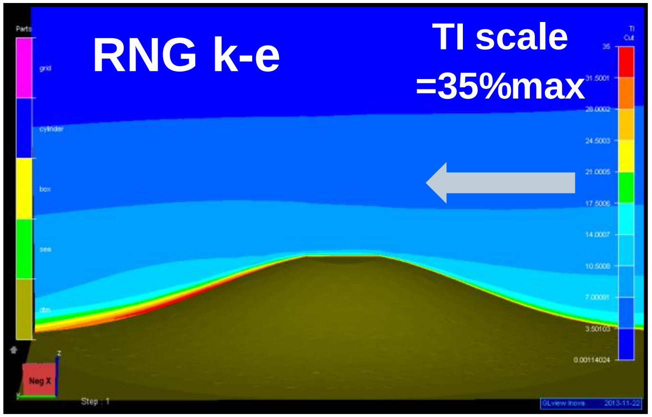
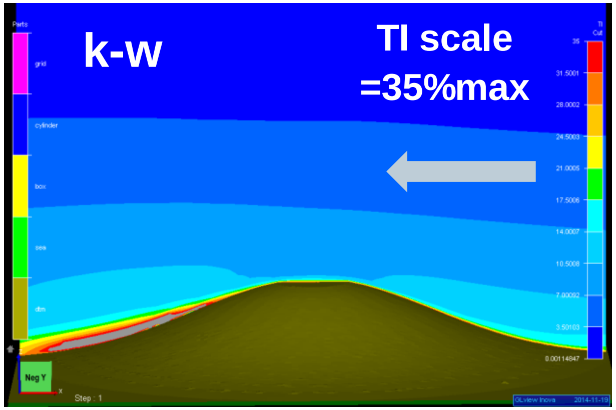
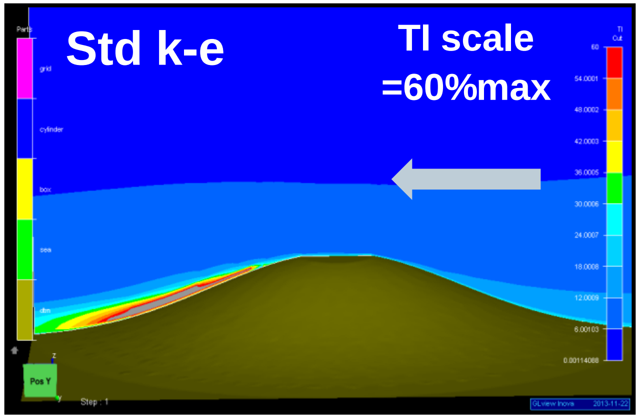
Hill1 – 24 deg max inclination



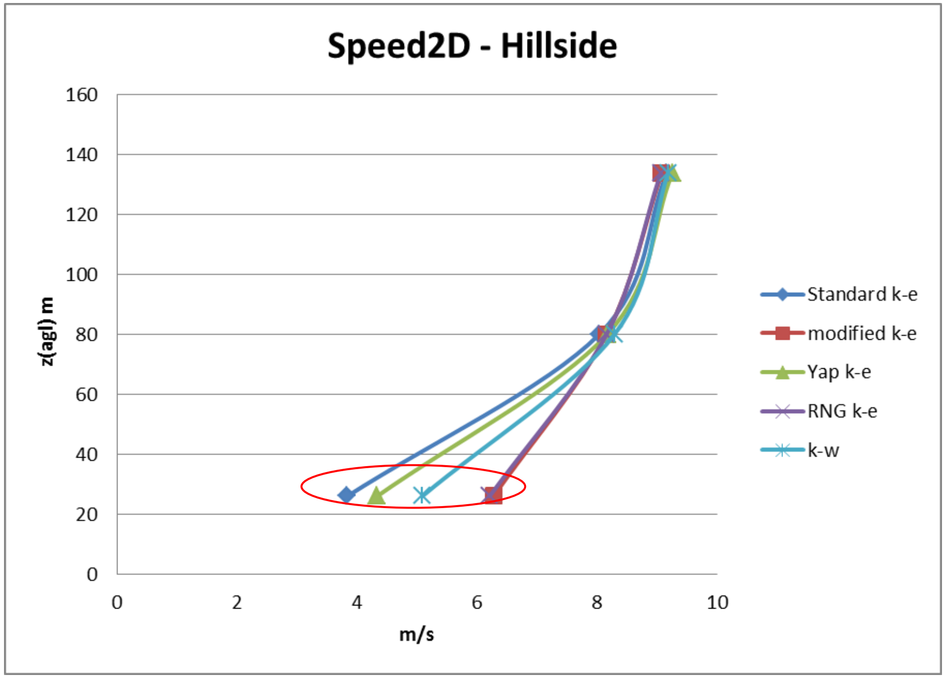


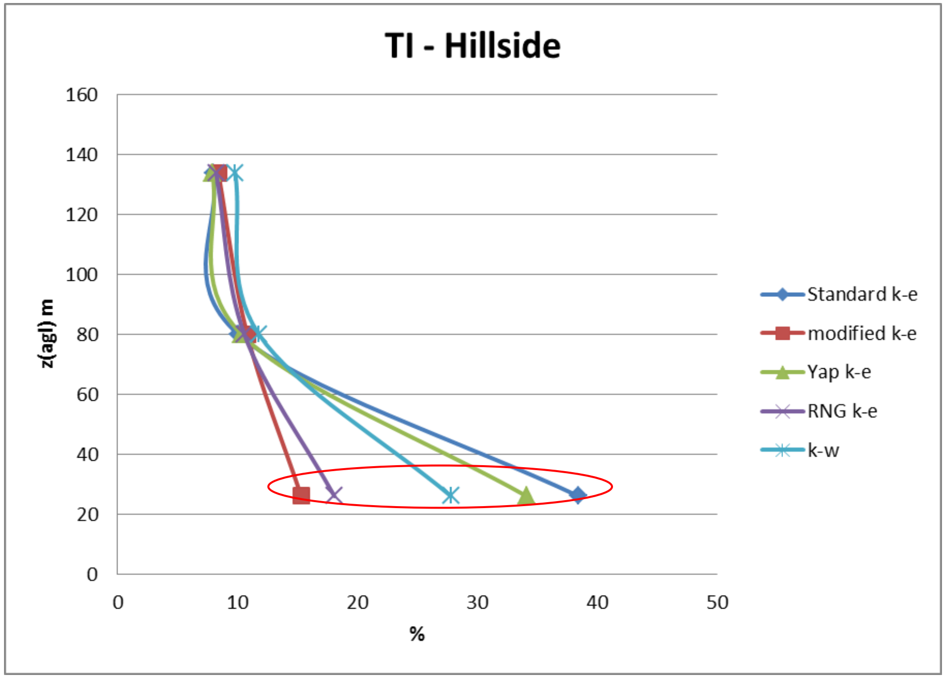




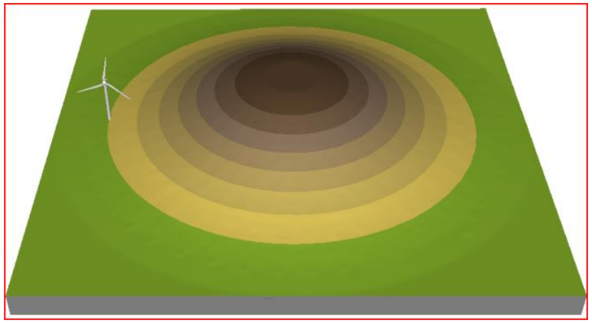


Hill1 – 24 deg max inclination





Vertical profile results, rotor plane, downstream of hill, 100m inside boundary



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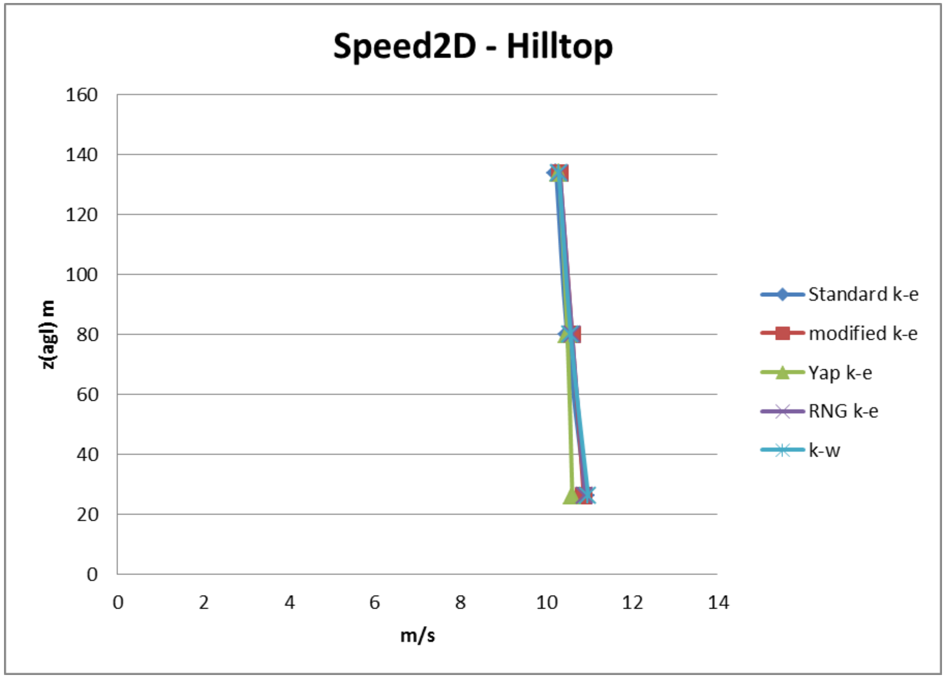
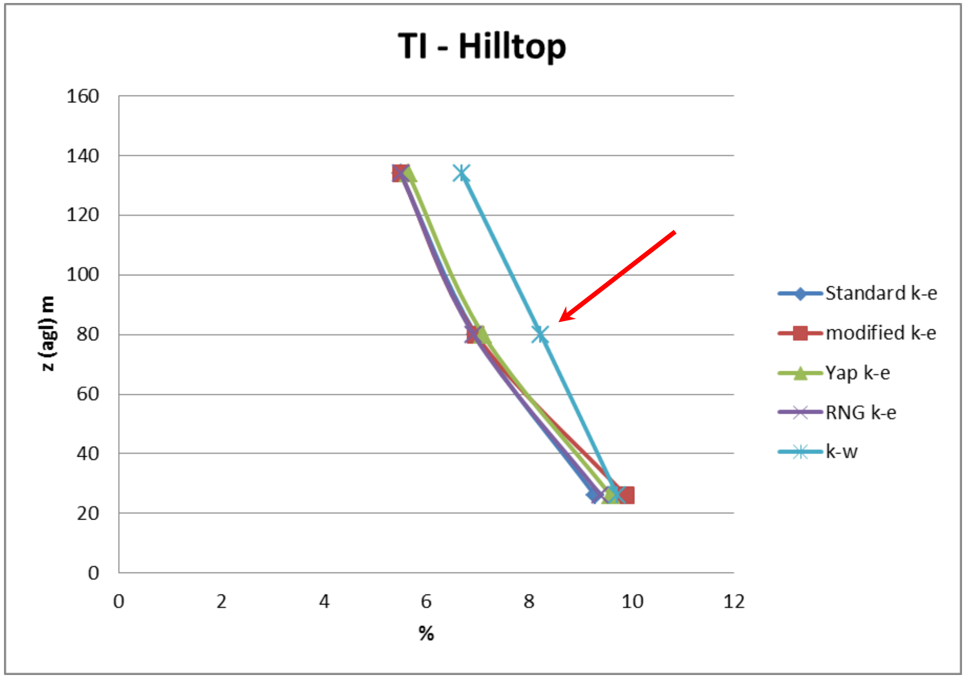
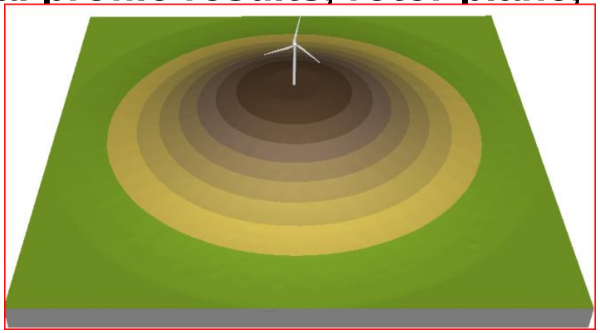
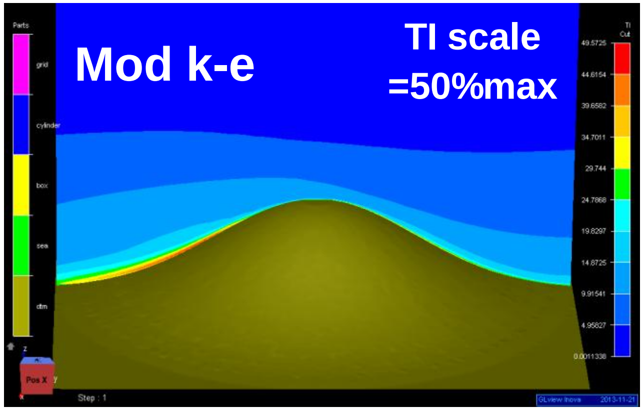


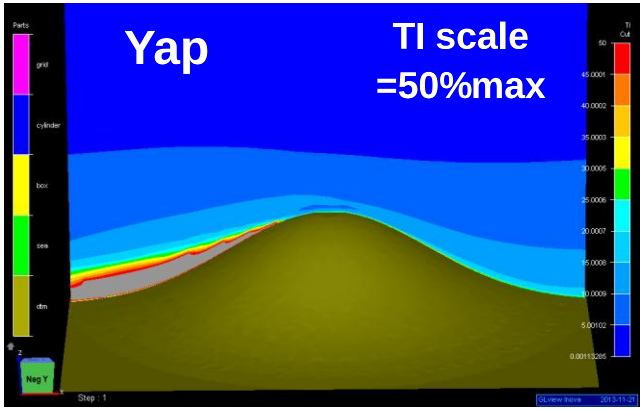


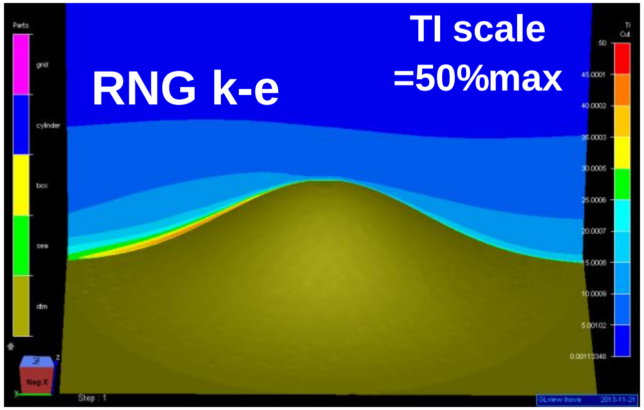
Vertical profile results, rotor plane, top of hill

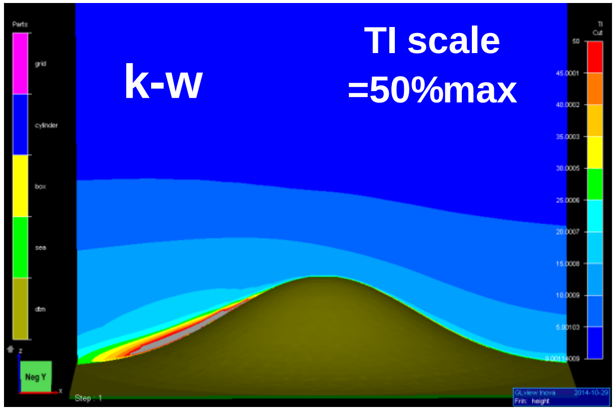


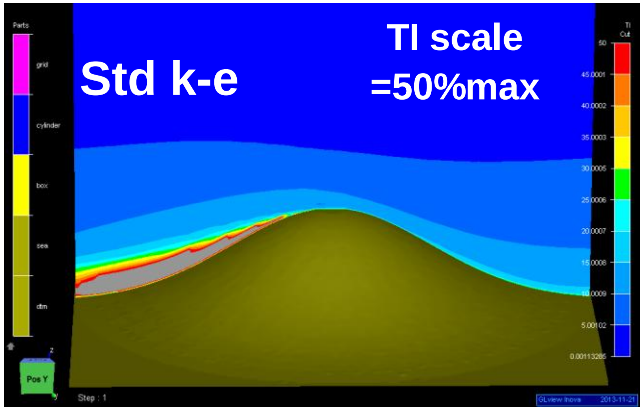
Hill2 – 33 deg max inclination











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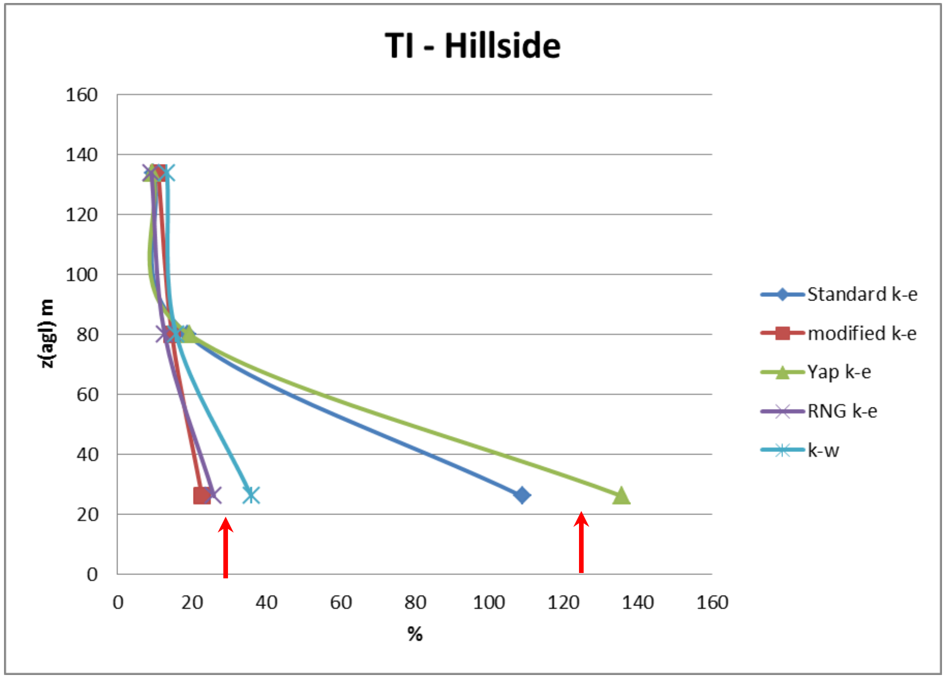

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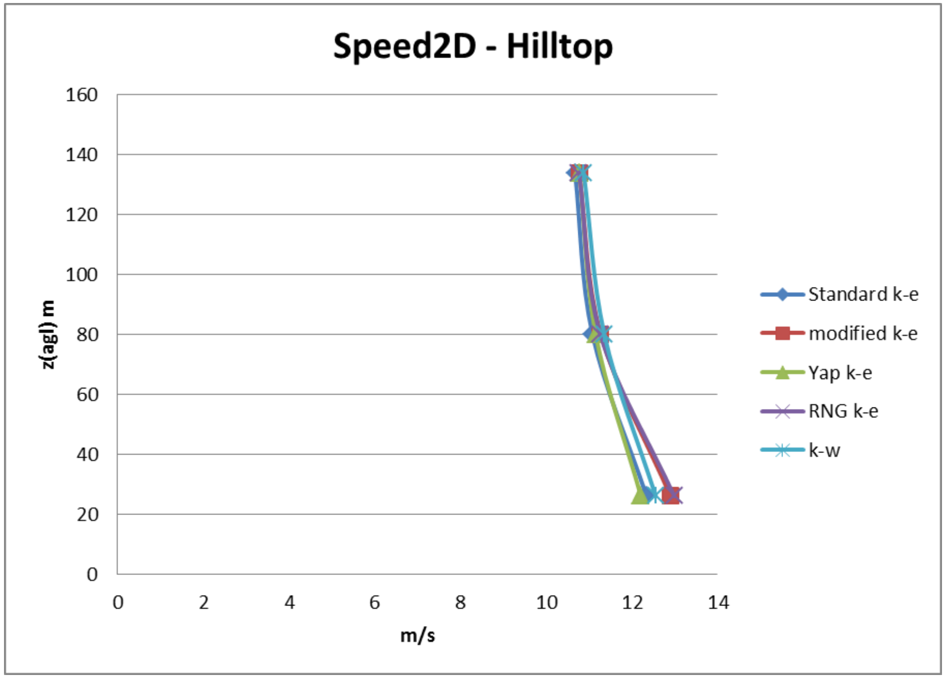
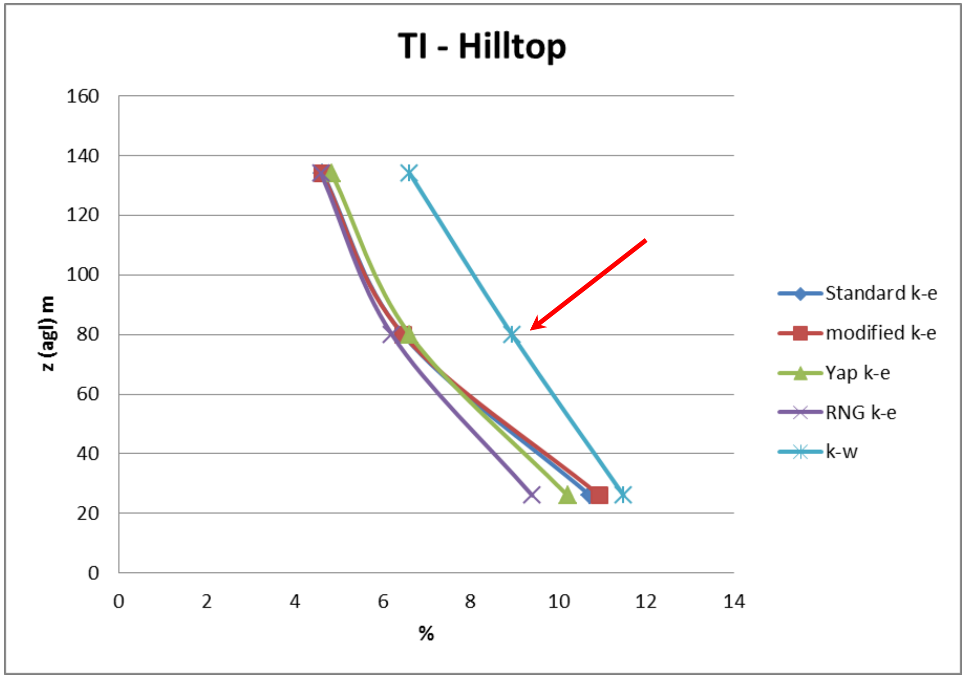
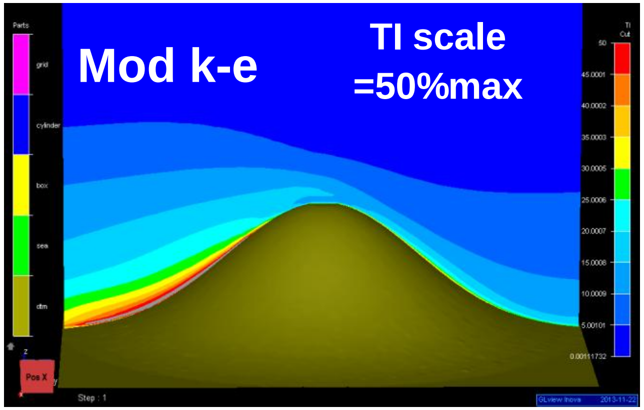
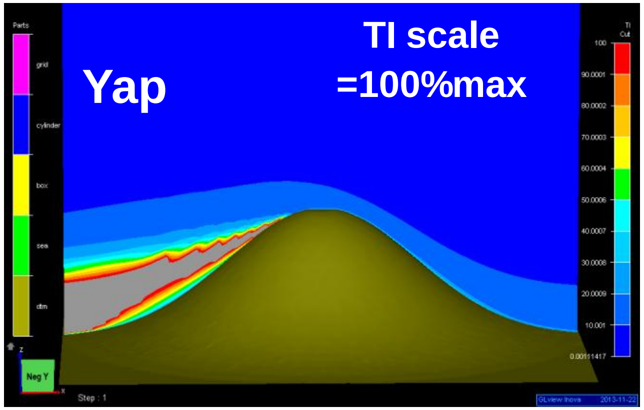
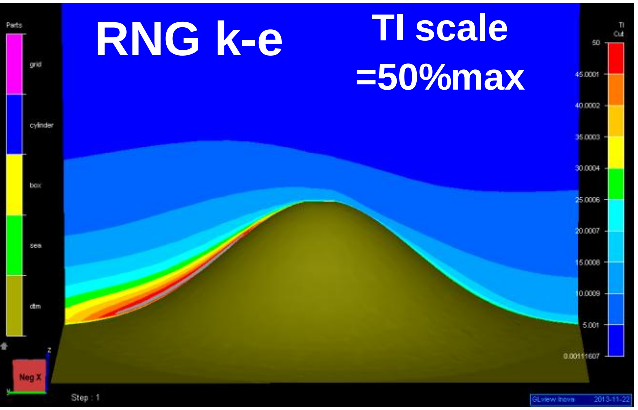


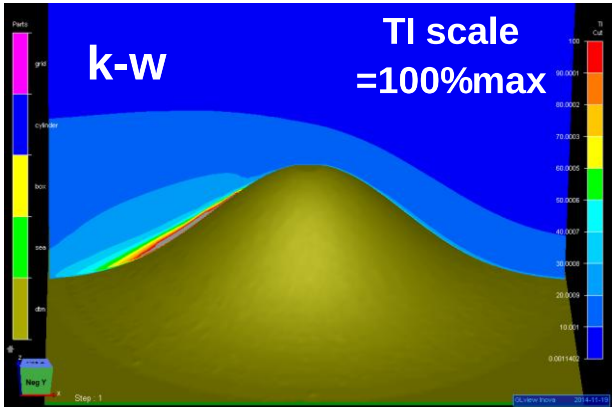


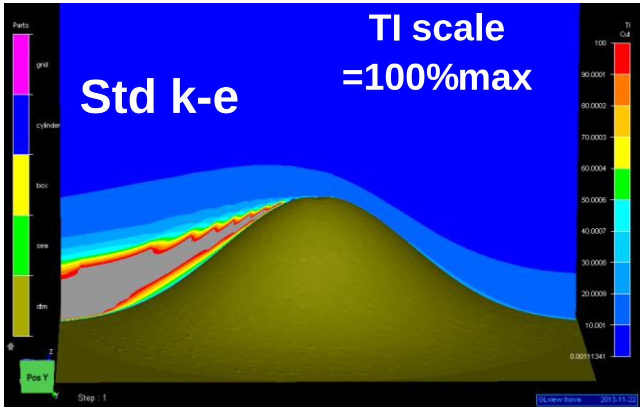
Hill3 – 42 deg max inclination



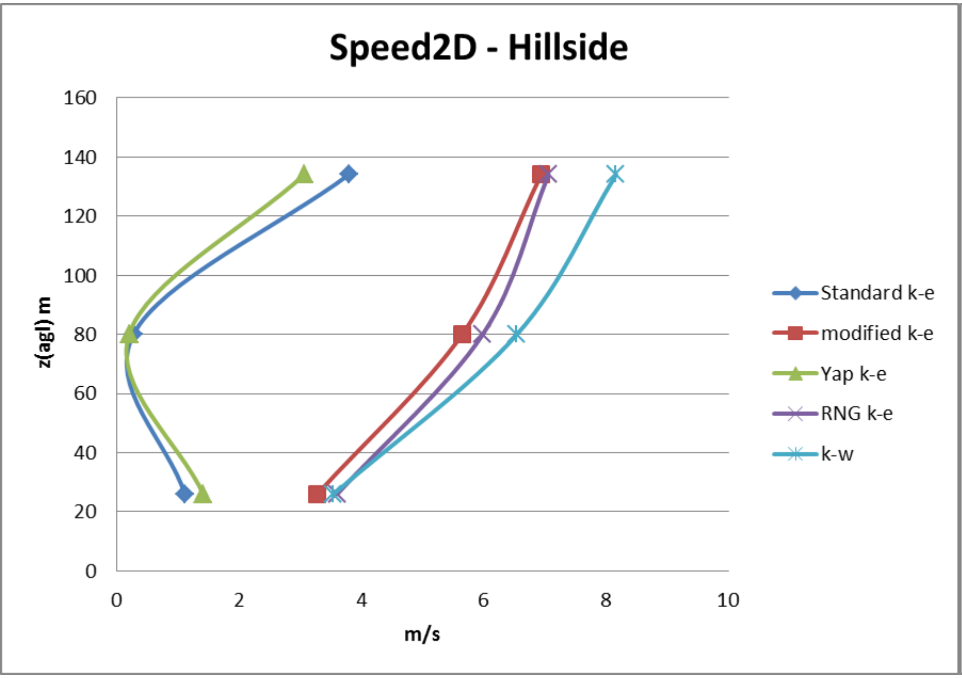


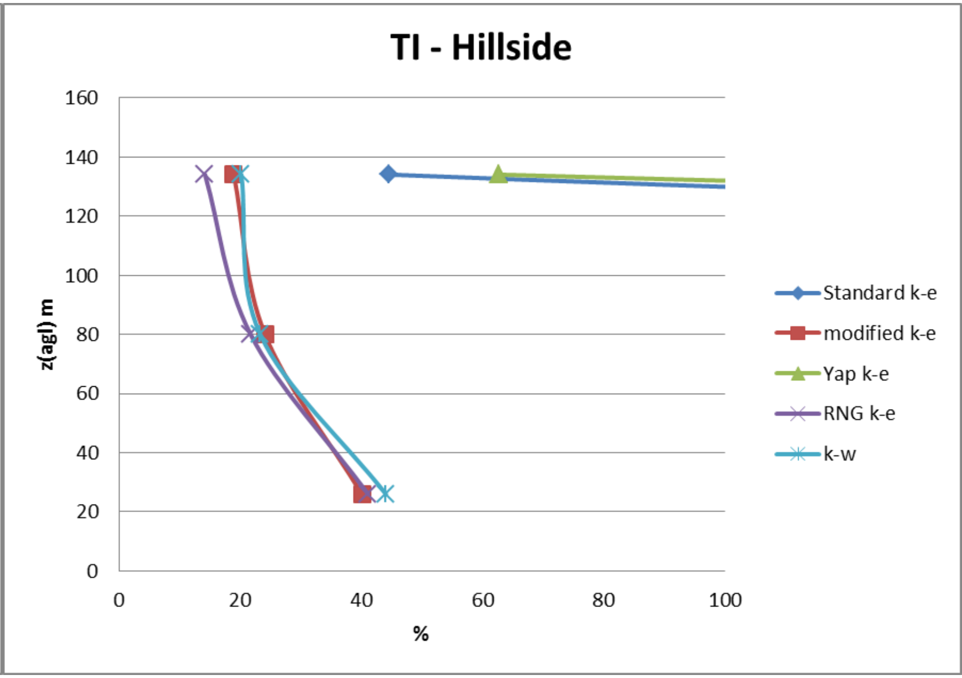






Hill3 – 42 deg max inclination





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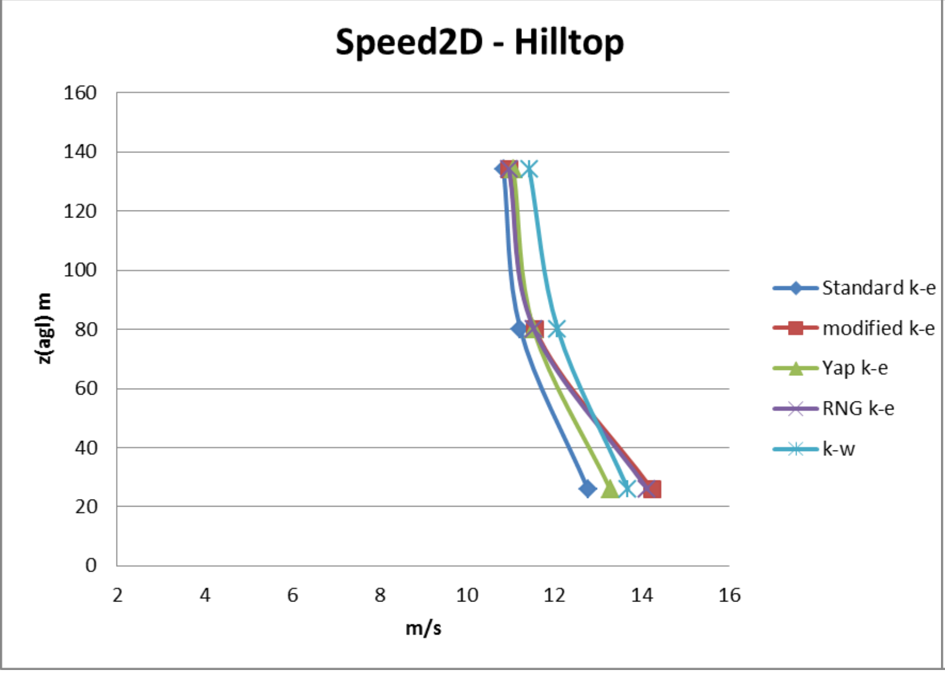
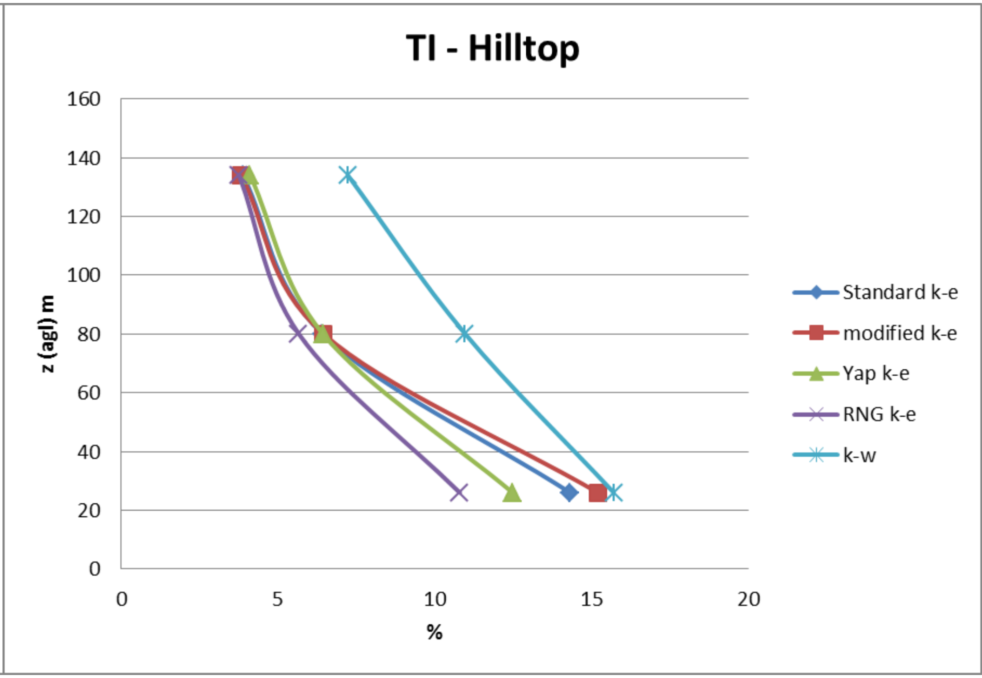
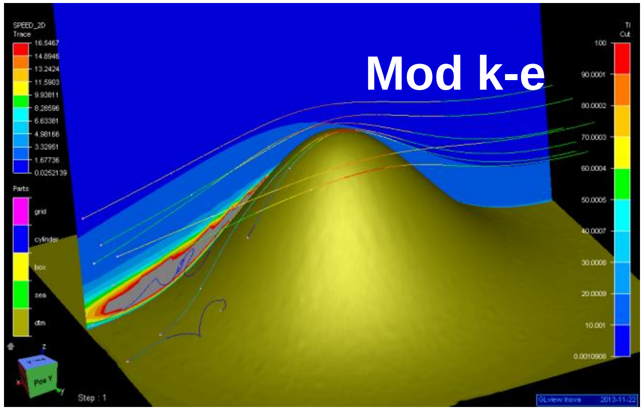
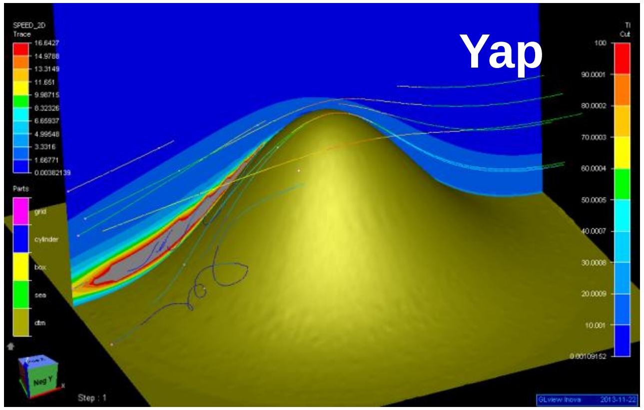


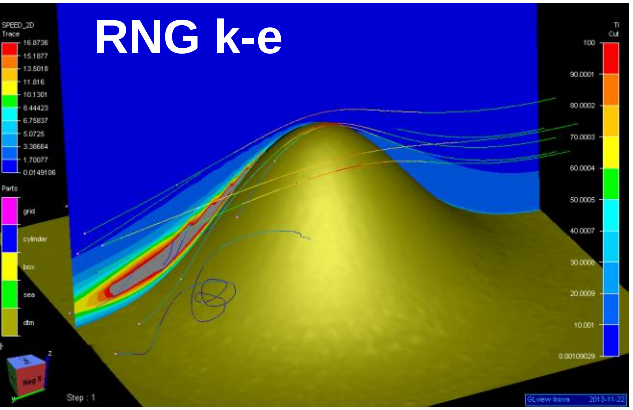


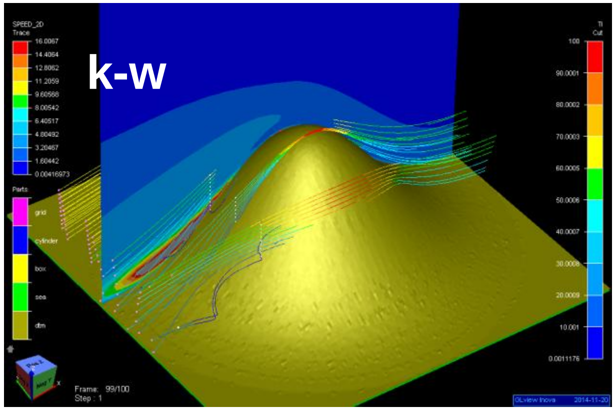
Hill4 – 52 deg max inclination

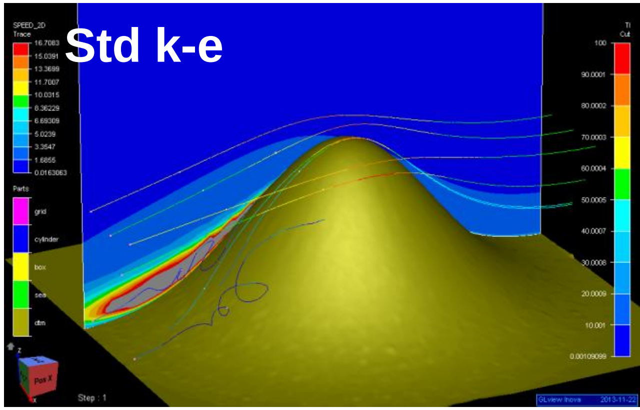




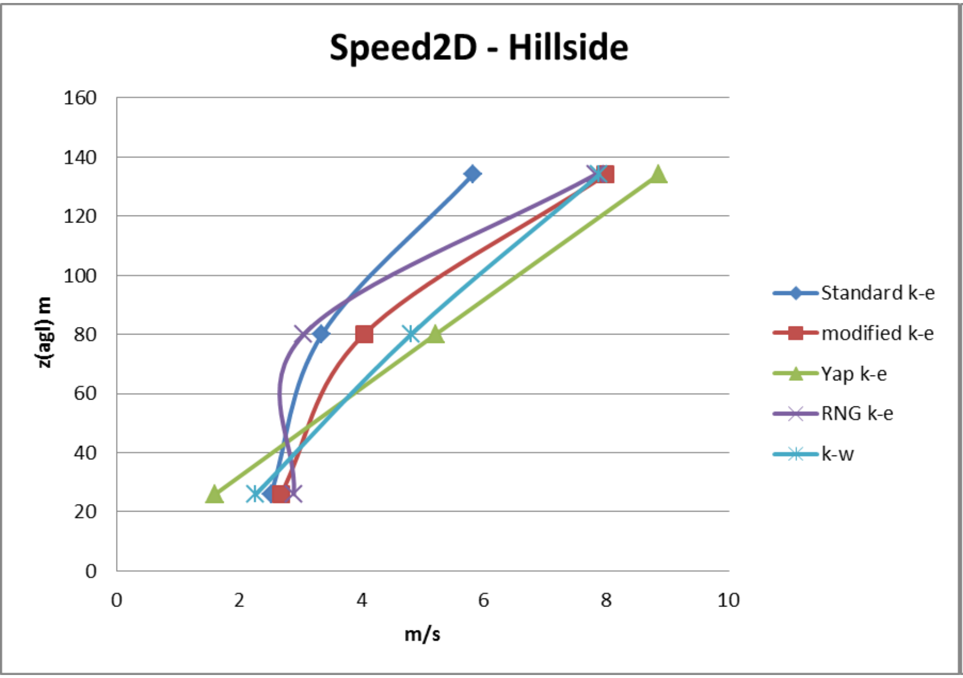
GCV solver used for these

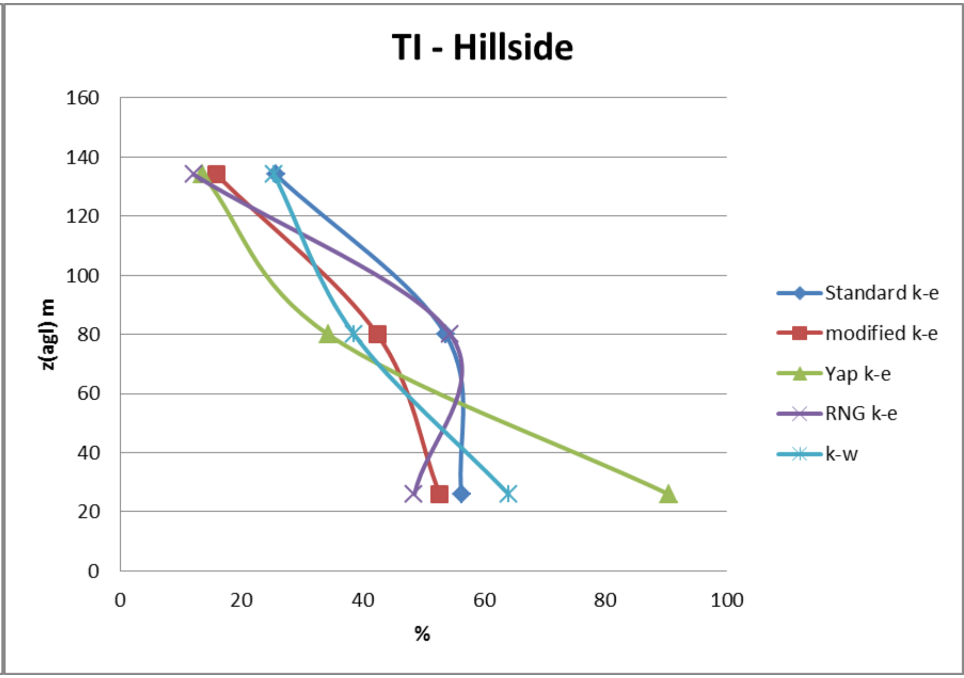




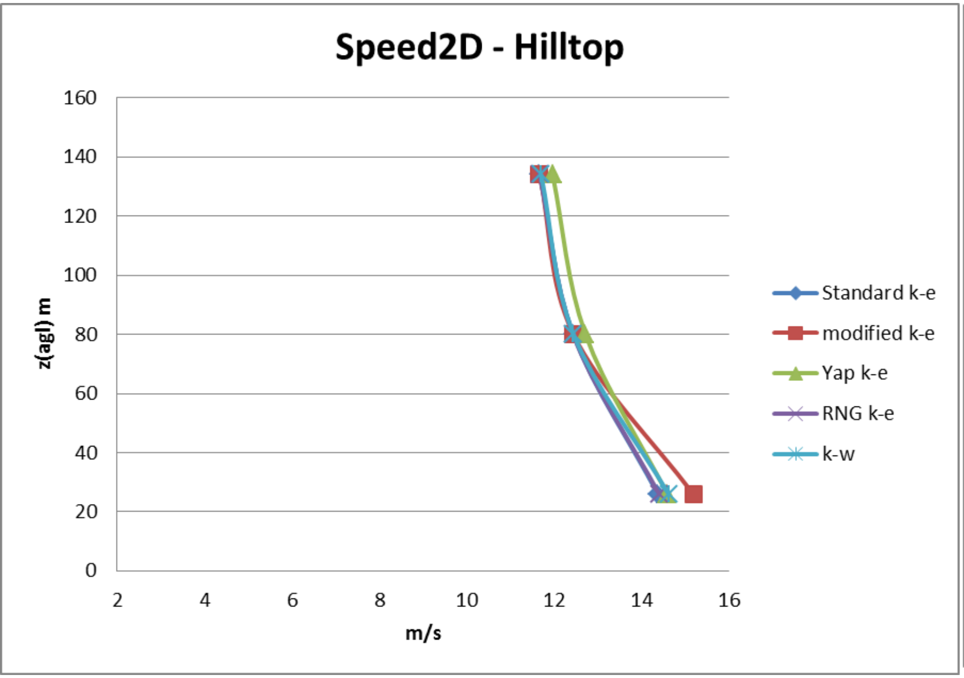


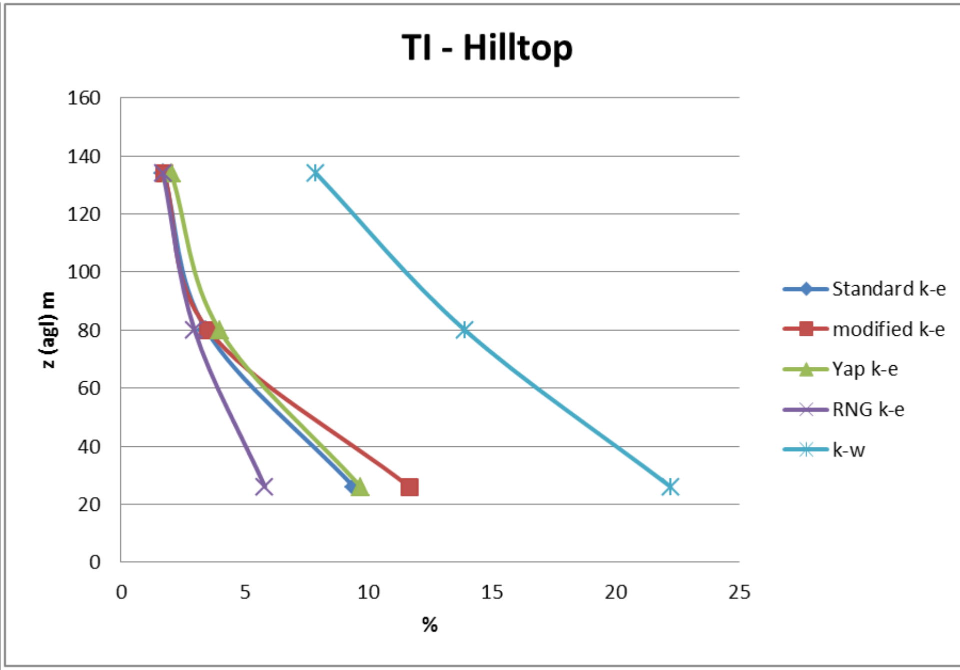
Hill4 – 52 deg max inclination



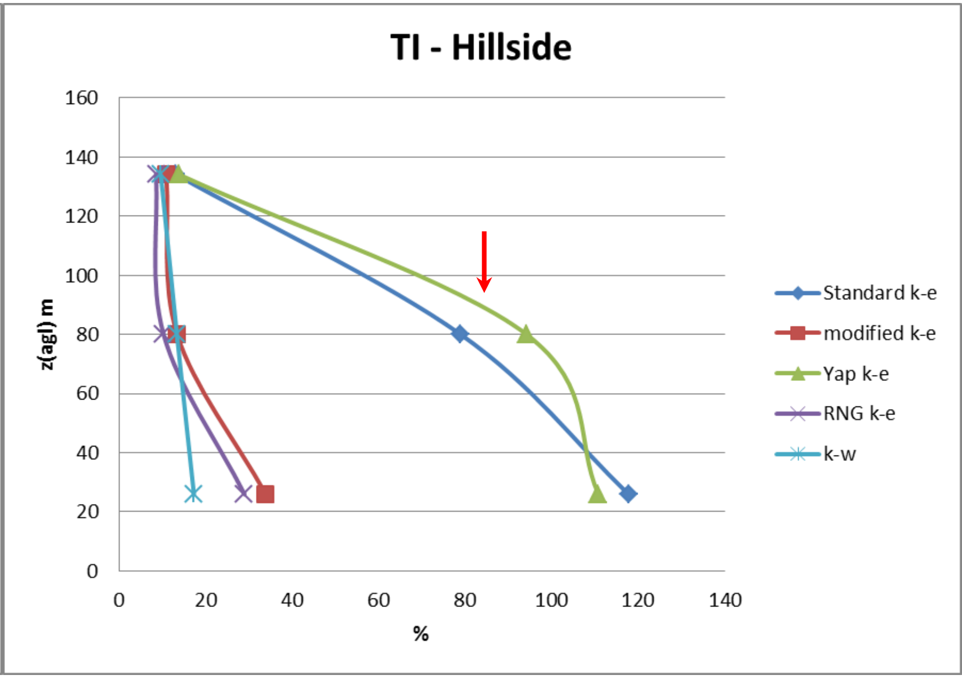


Hill4 – 52 deg max inclination



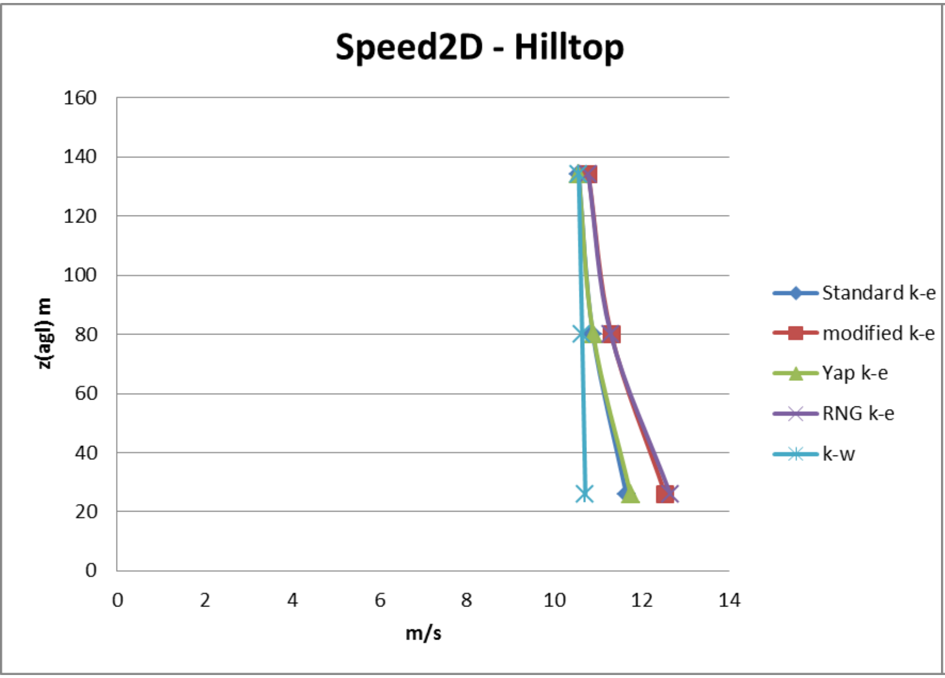


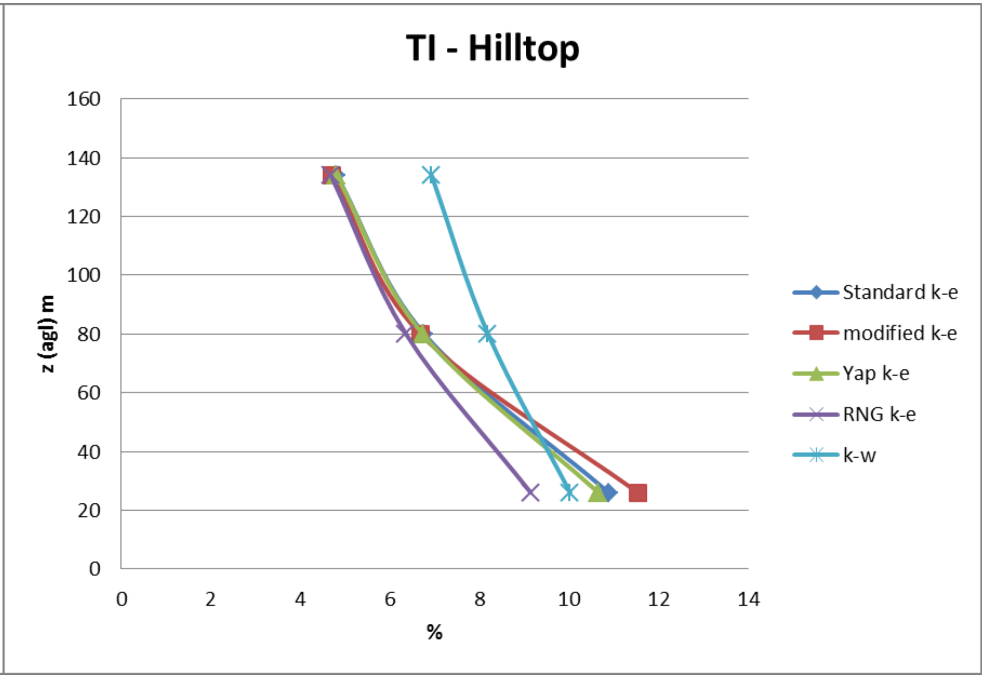
Hill2 – 33 deg, + Forestry



Forestry:P=0.3, C1=0, C2=0.0005, 20m. Coupled solver except segregated used for k-w

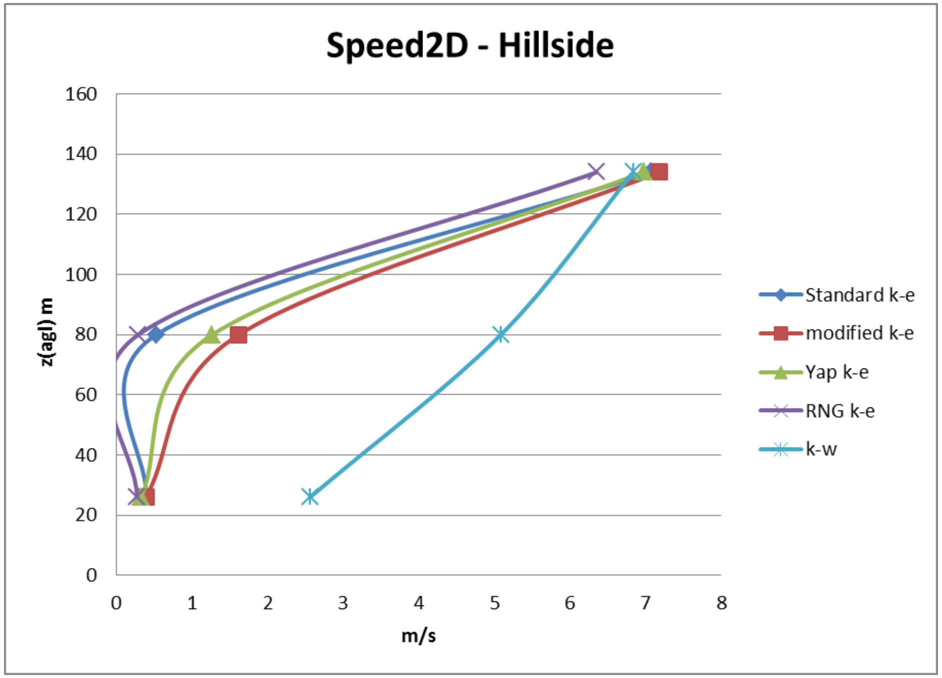
Hill2 – 33 deg, + Forestry

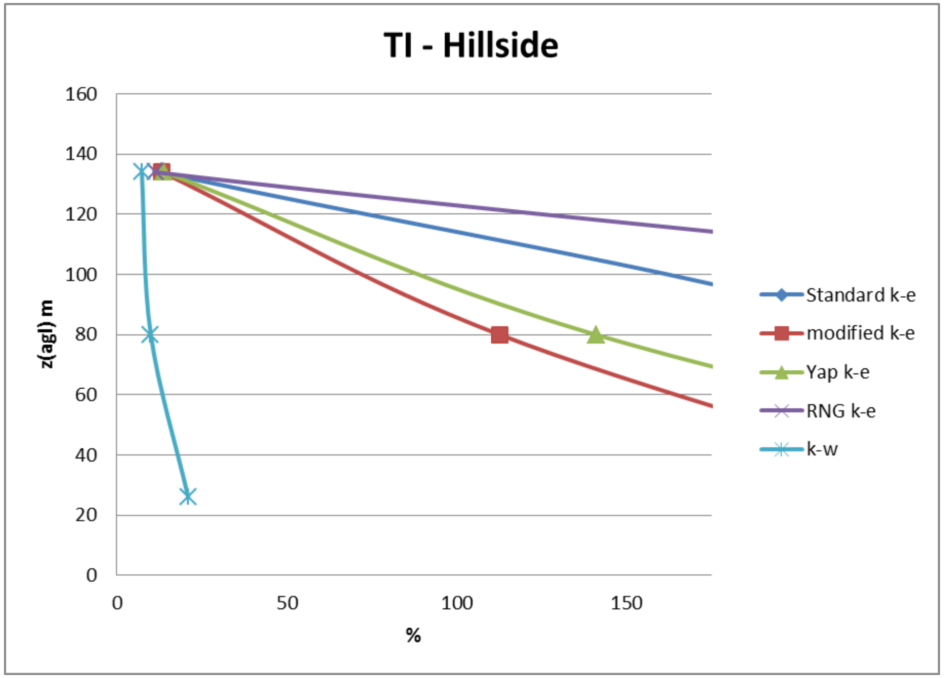




Forestry:P=0.3, C1=0, C2=0.0005, 20m.   Coupled solver except segregated used for k-w

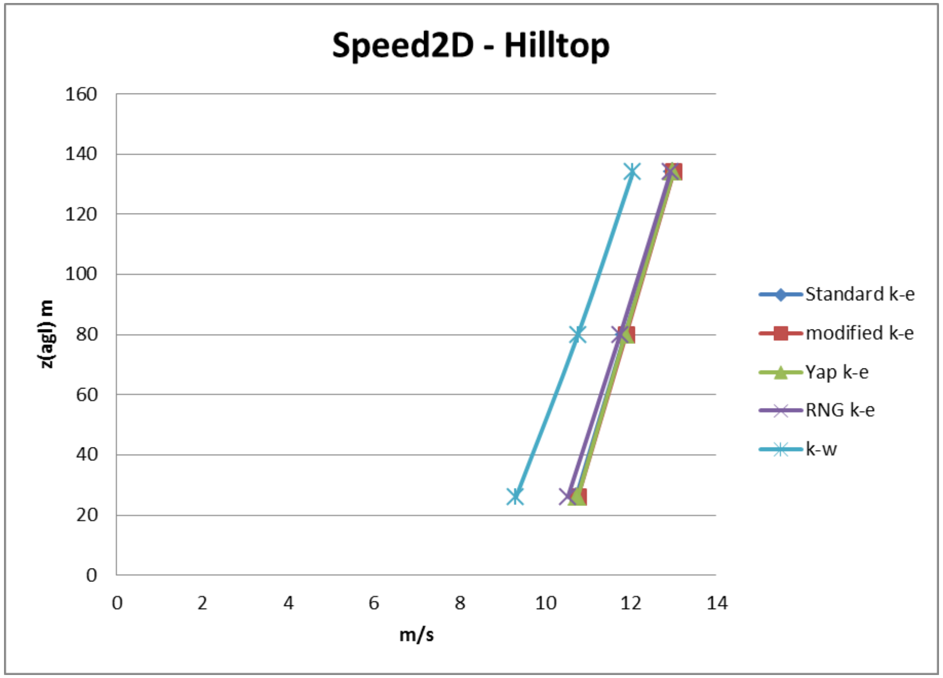
Hill2 – 33 deg, + Forestry + Stability

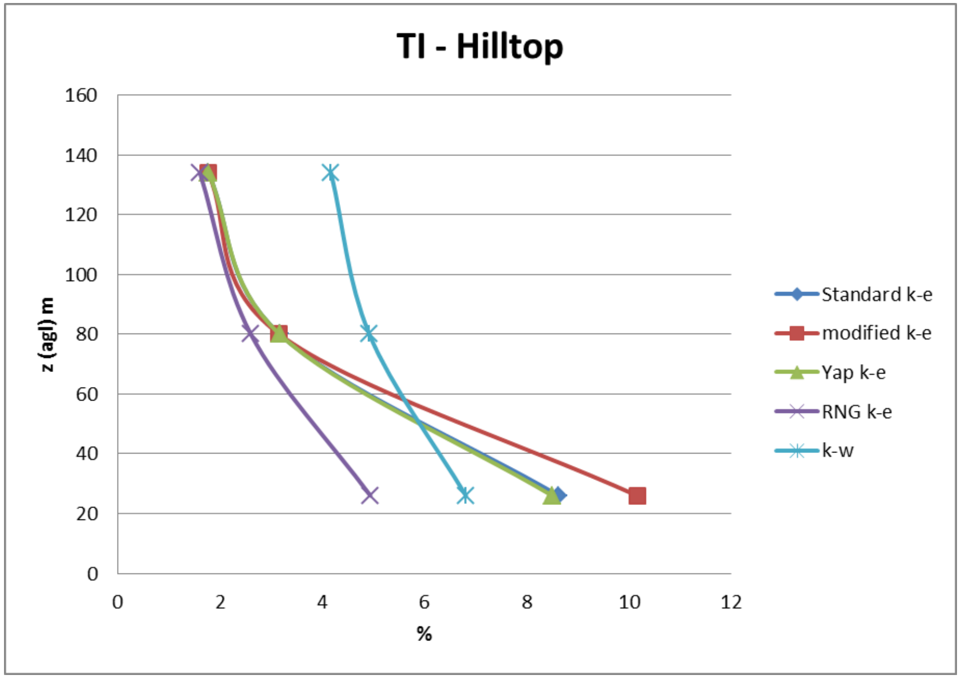




Forestry:P=0.3, C1=0, C2=0.0005, 20m. Coupled solver except segregated used for k-w Stable, MOL=100

Hill2 – 33 deg, + Forestry + Stability

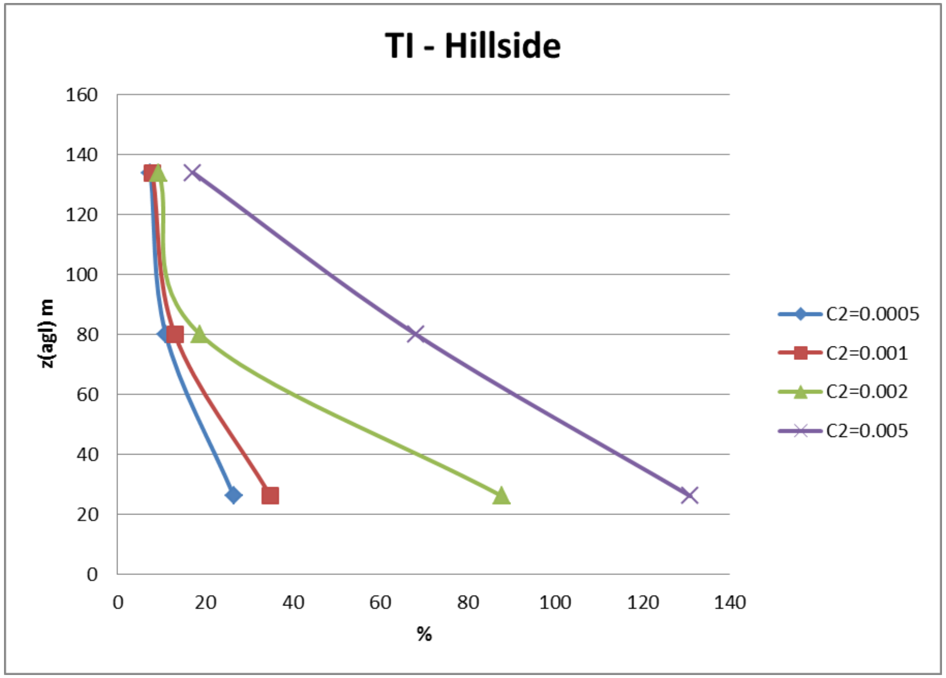




Forestry:P=0.3, C1=0, C2=0.0005, 20m. Coupled solver except segregated used for k-w

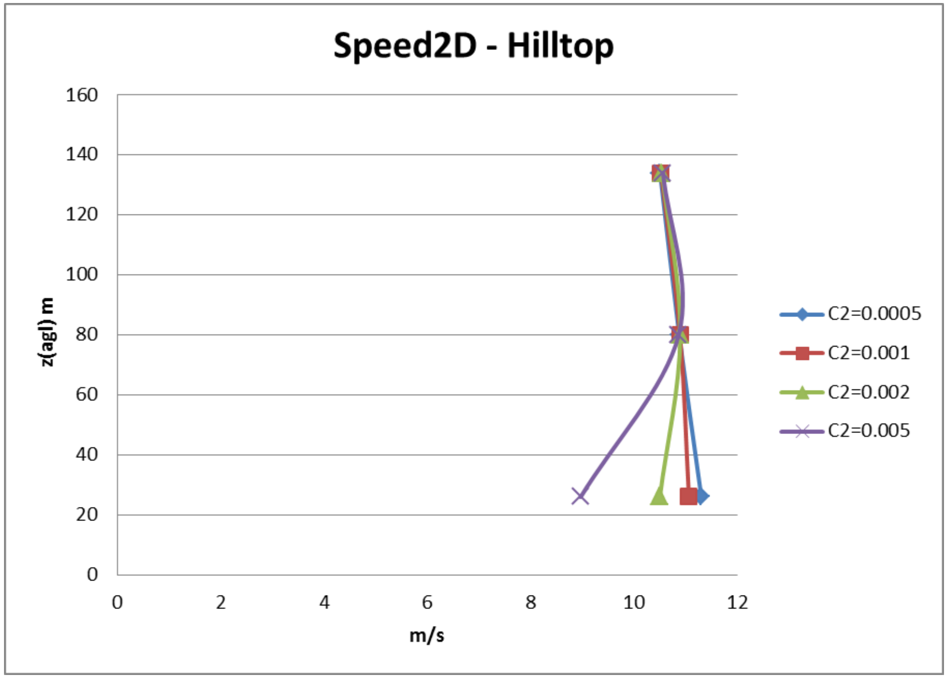
Stable, MOL=100

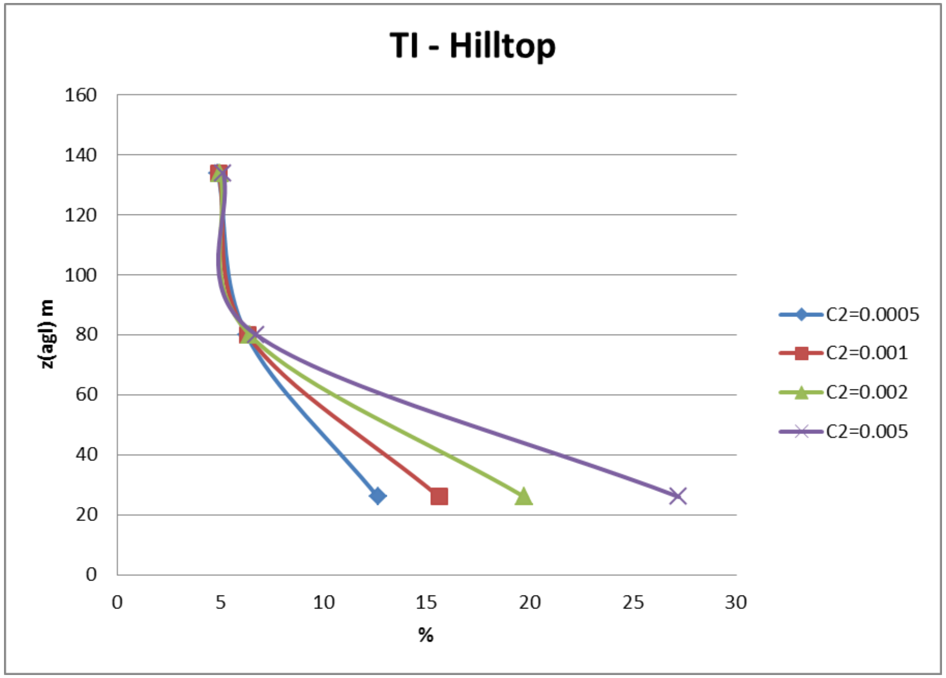
Hill1 – 24 deg, + Forestry with Turbulence Source



Forestry: Activate Turbulence source, P=0.3, C1=0, C2=0.0005 to 0.005, 20m.
GCV solver. Neutral setting. All models except k-w.
No significant differences between the turbulence models – only varying C2

Hill1 – 24 deg, + Forestry with Turbulence Source





Forestry: Activate Turbulence source, P=0.3, C1=0, C2=0.0005 to 0.005, 20m.
GCV solver. Neutral setting. All models except k-w.
No significant differences between the turbulence models – only varying C2

Conclusions

Be careful making any sweeping generalized conclusions based on these simple test cases

Standard k-epsilon or Yap correction should be considered if the area of interest includes turbines near steep terrain features where extreme high shear/TI/recirculation might be expected.

Anecdotally, standard k-e usually gives good all around results, but k-omega model is worth trying if your model shows unrealistically low TI at hill top locations. Convergence is much more difficult with k-omega though – especially with forestry.

When using Forestry with turbulence source, turbulence model selection may not matter so much (at least at ~20 deg inclination, others not tested). Recommend varying C2 parameter, <0.005.

Results will be sensitive to real life terrain variations, roughness, forestry, stability, etc.

Contact

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