Mechanical mixing height

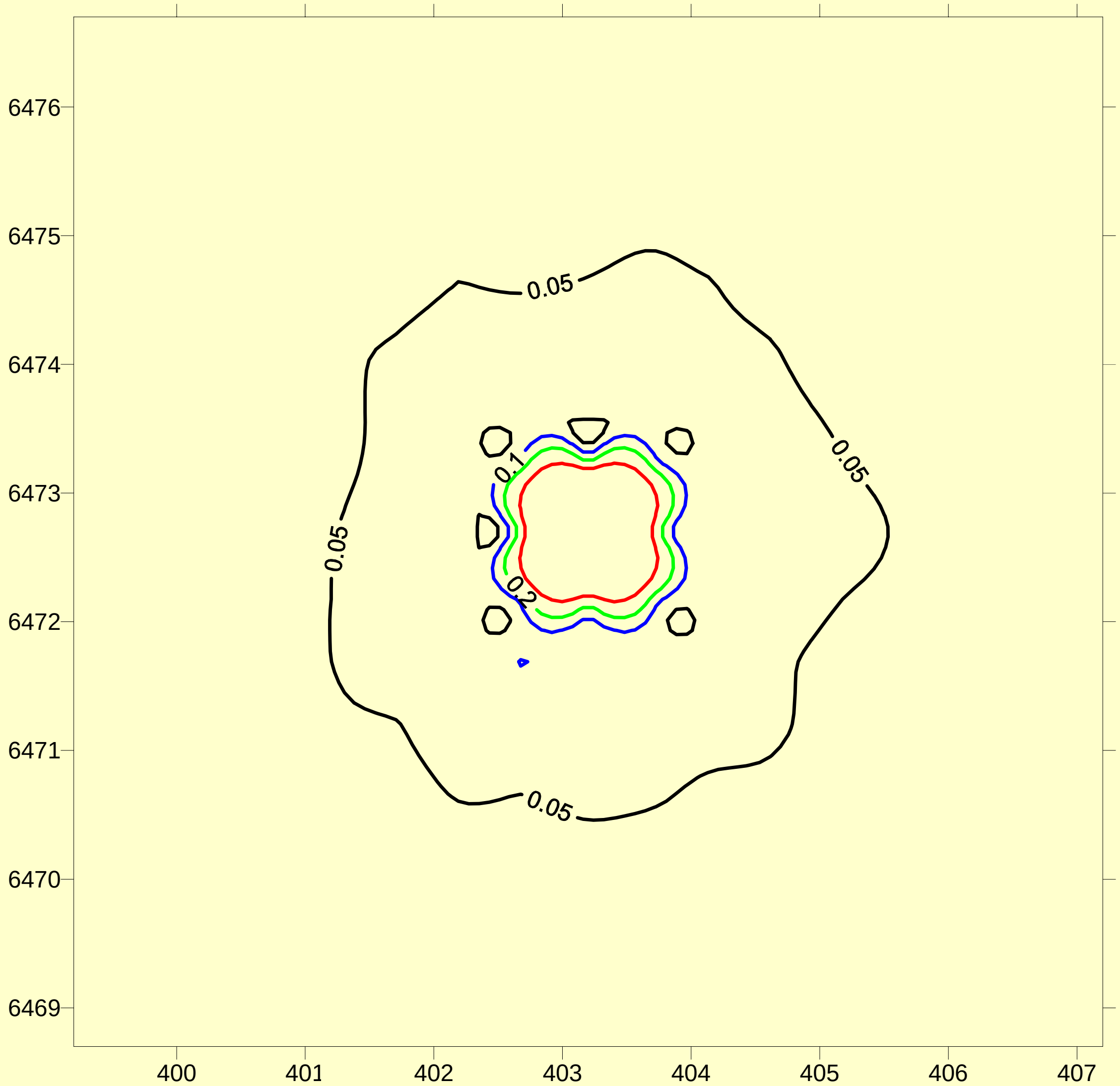
Part A: stable light wind conditions

Ken Rayner

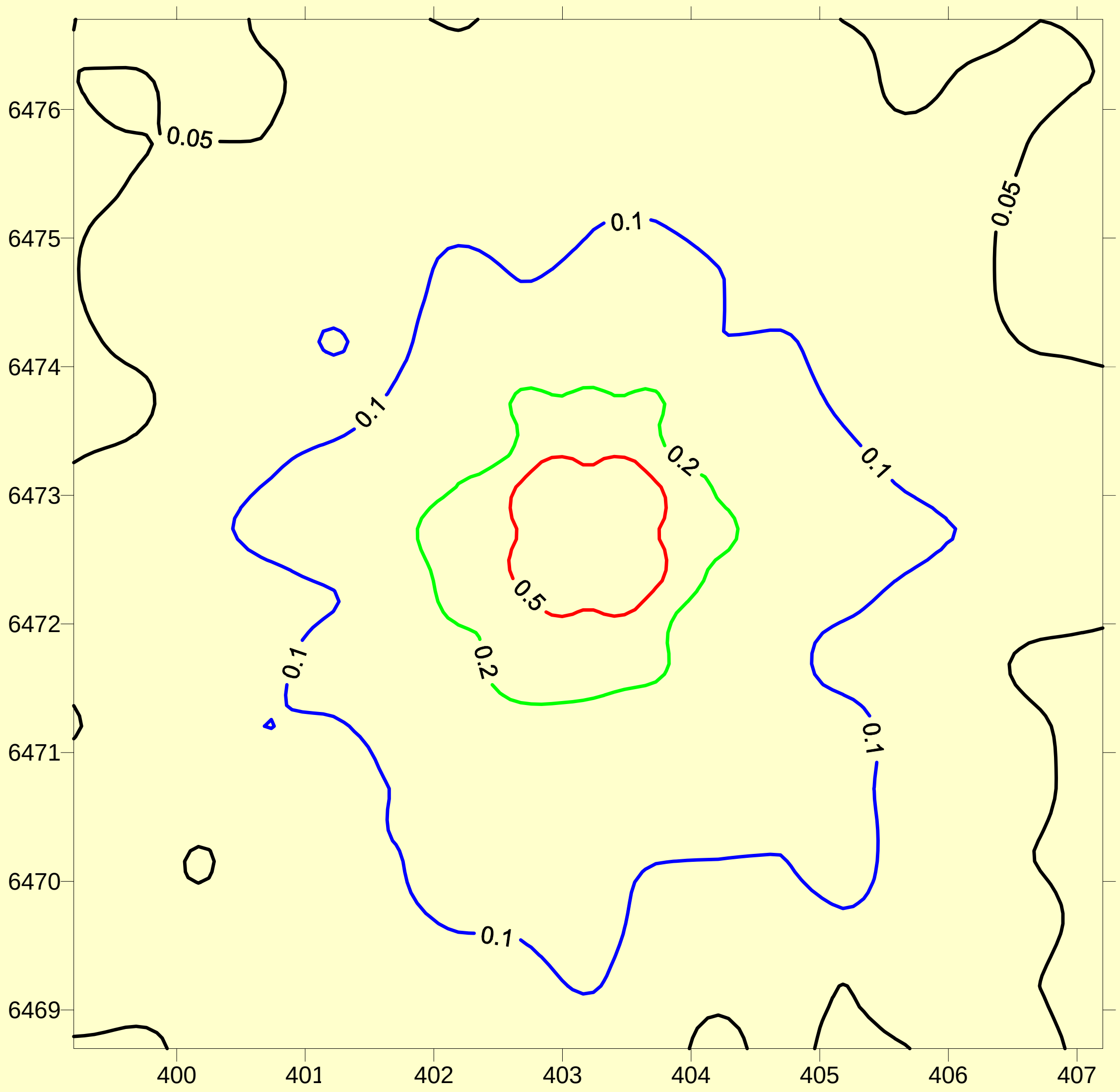
Department of Environment WA

Modelling of a simple volume source by Calpuff was extended to investigate Aermod performance.

Cpuff: micromet



Cpuff: micromet – reduced limits σ_v=0.2, σ_w =0.02

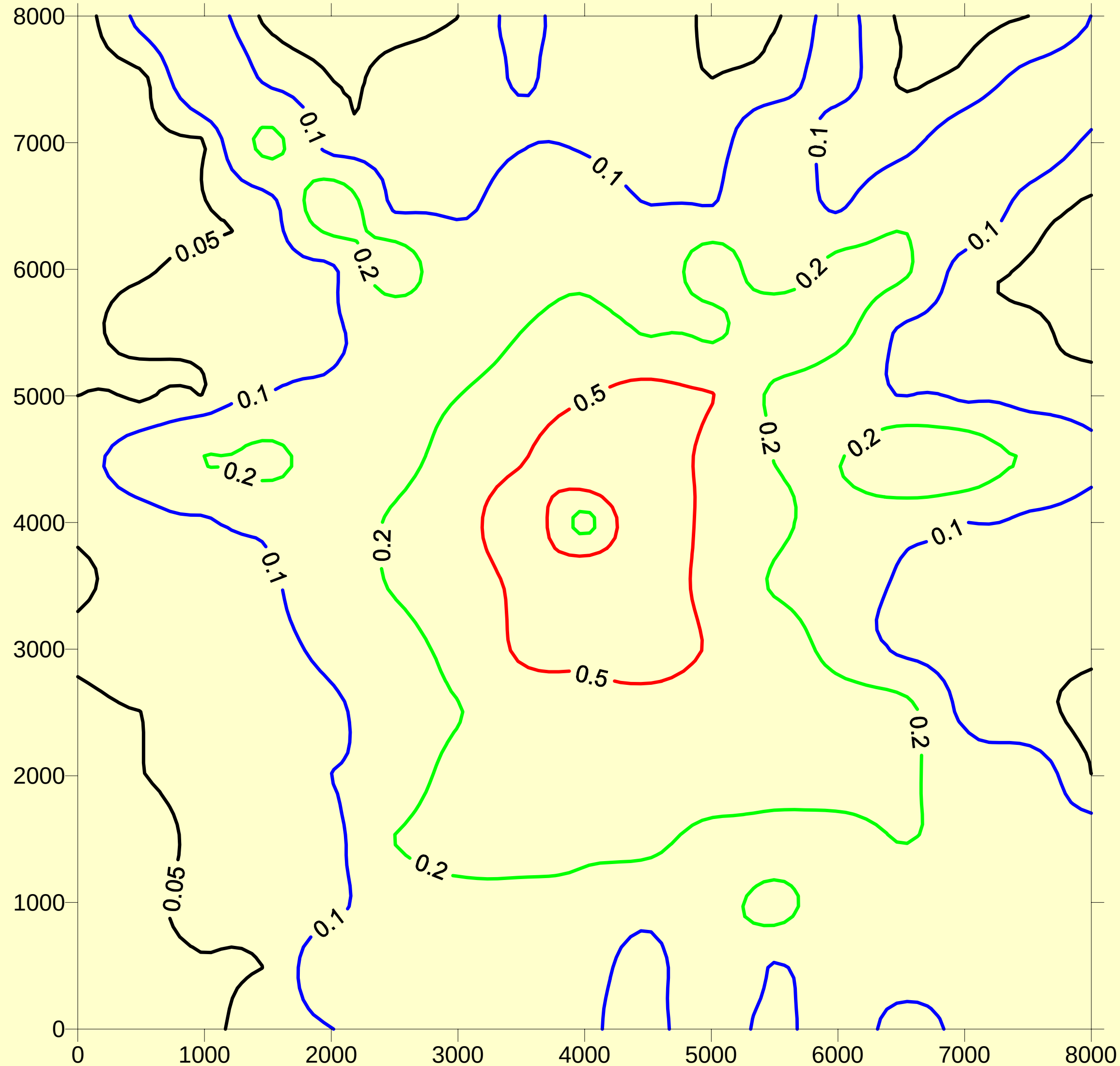


Aermod was run with an Aermet met file produced as per Calmet methodology (calculated solar radiation, cloud amount for stable conditions). Does not have Calmet limits on u_* and L (insignificant difference).

Results were found to be sensitive to Aermod's allowance of small mechanical mixing height Zim. This was determined by resetting Zim < 50 to Zim = 50 in the aermet file.

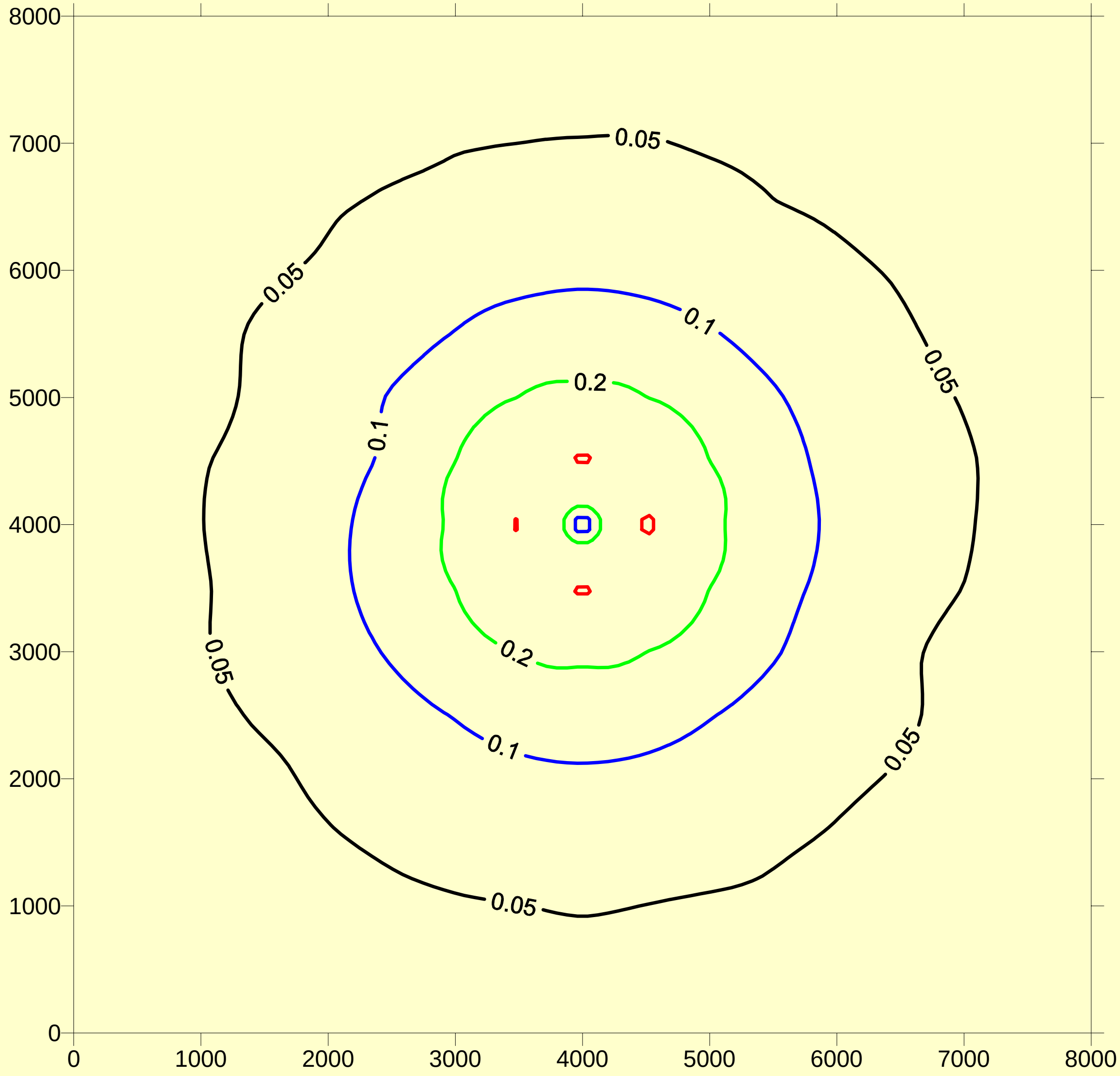
Aermod

Highest glcs for u < .5, L < 2m, **Zim < 10m**



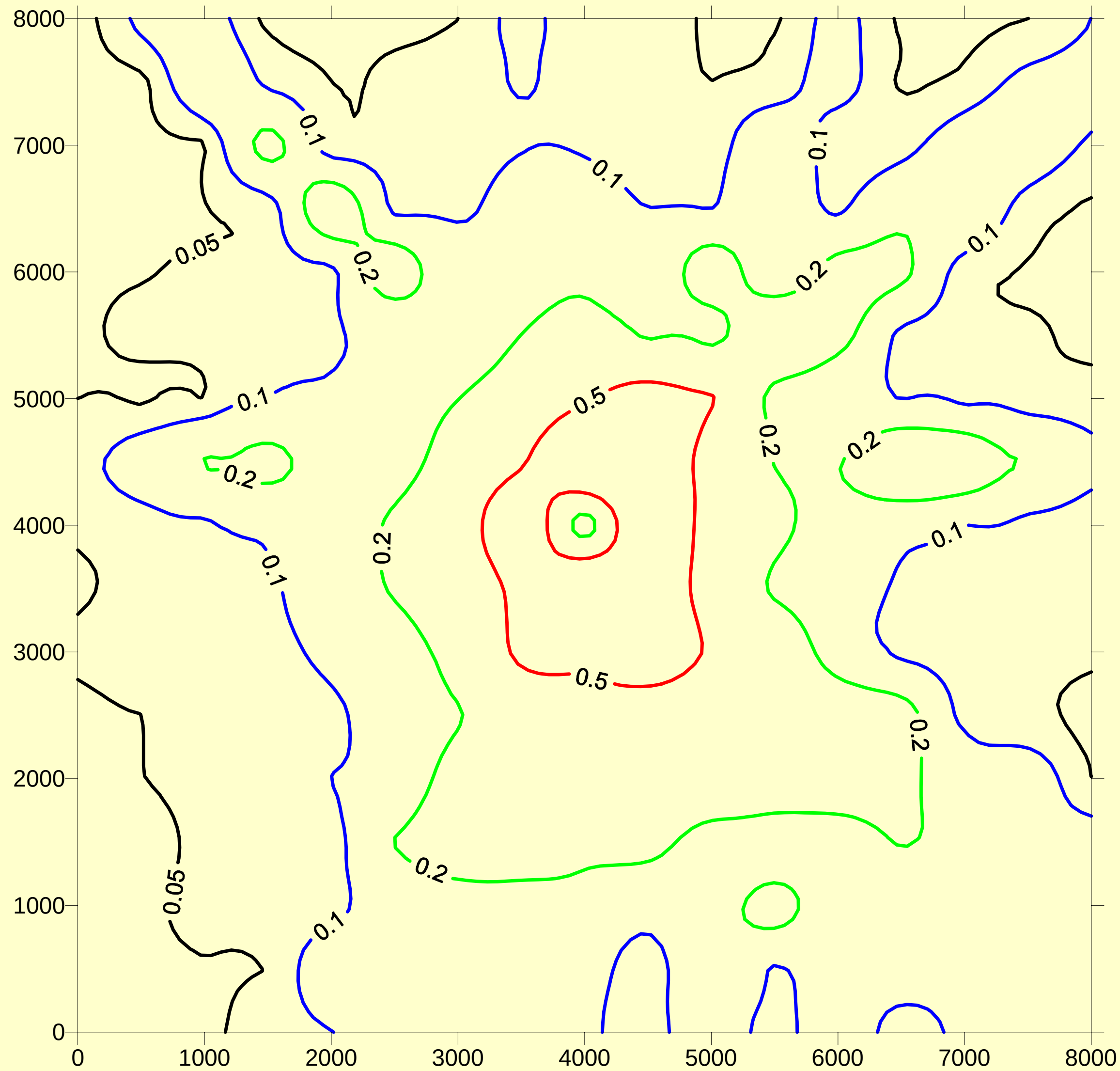
Aermod

Zim lower limit of 50m set in met. input file

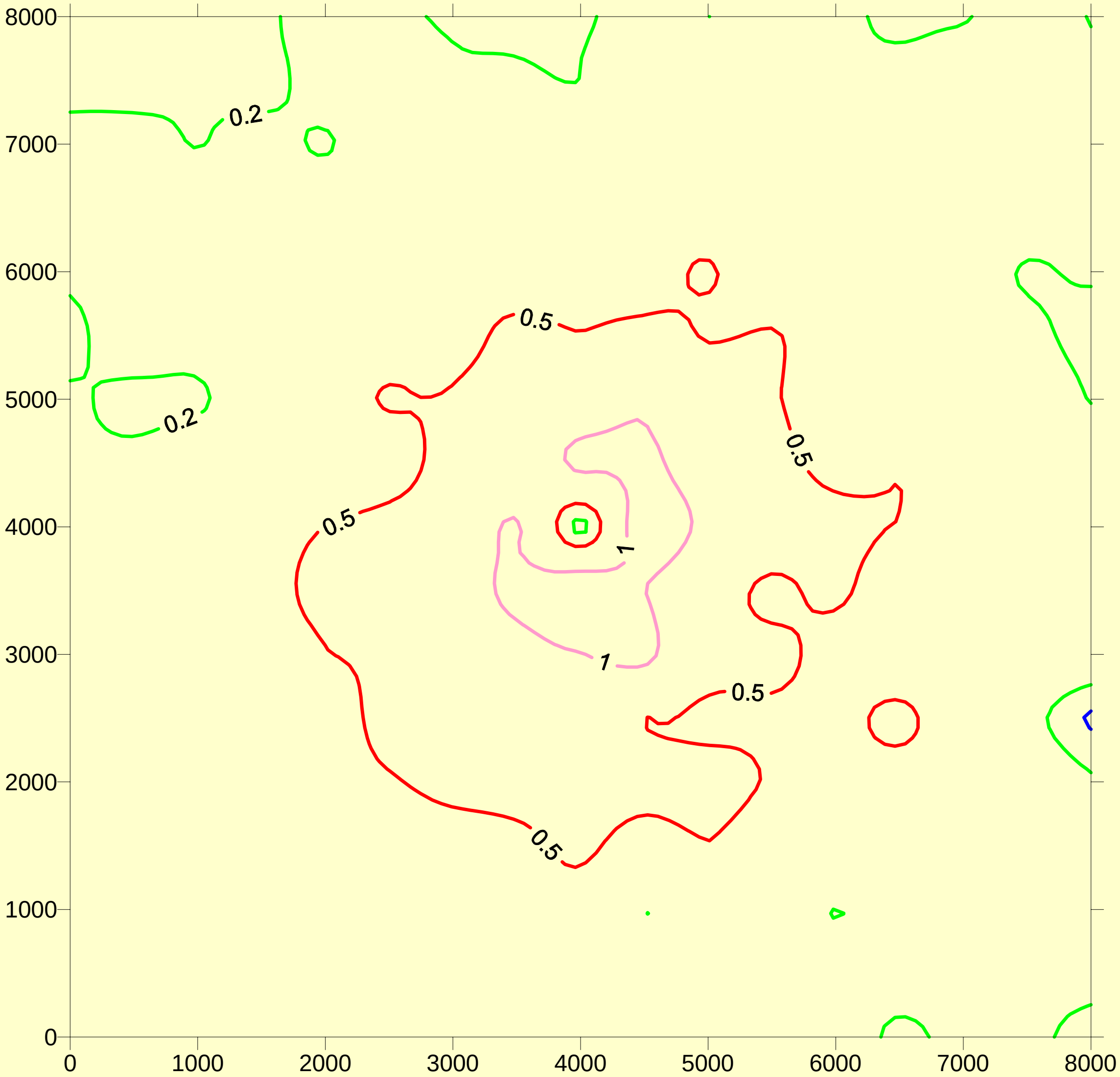


Aermod was re-run to compare results obtained by using the new Ri_B scheme instead of cloud data for stable condition.

Aermod using cloud data *(repeated)*
Highest glcs for u < .5, L < 2m, Zim < 10m

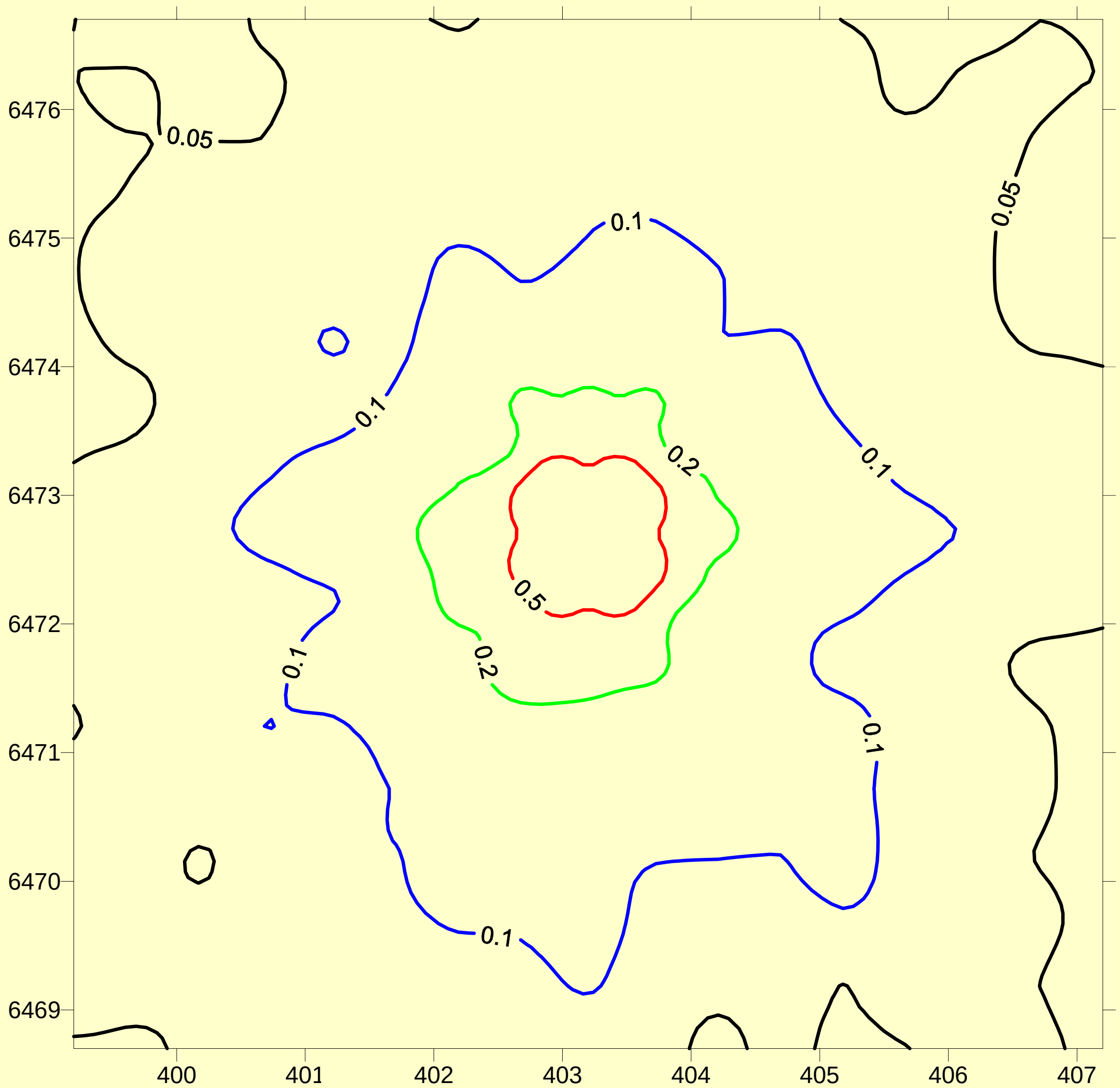


Aermod using new Ri_B scheme
Highest glcs for u < .5, L < 2m, Zim < 10m

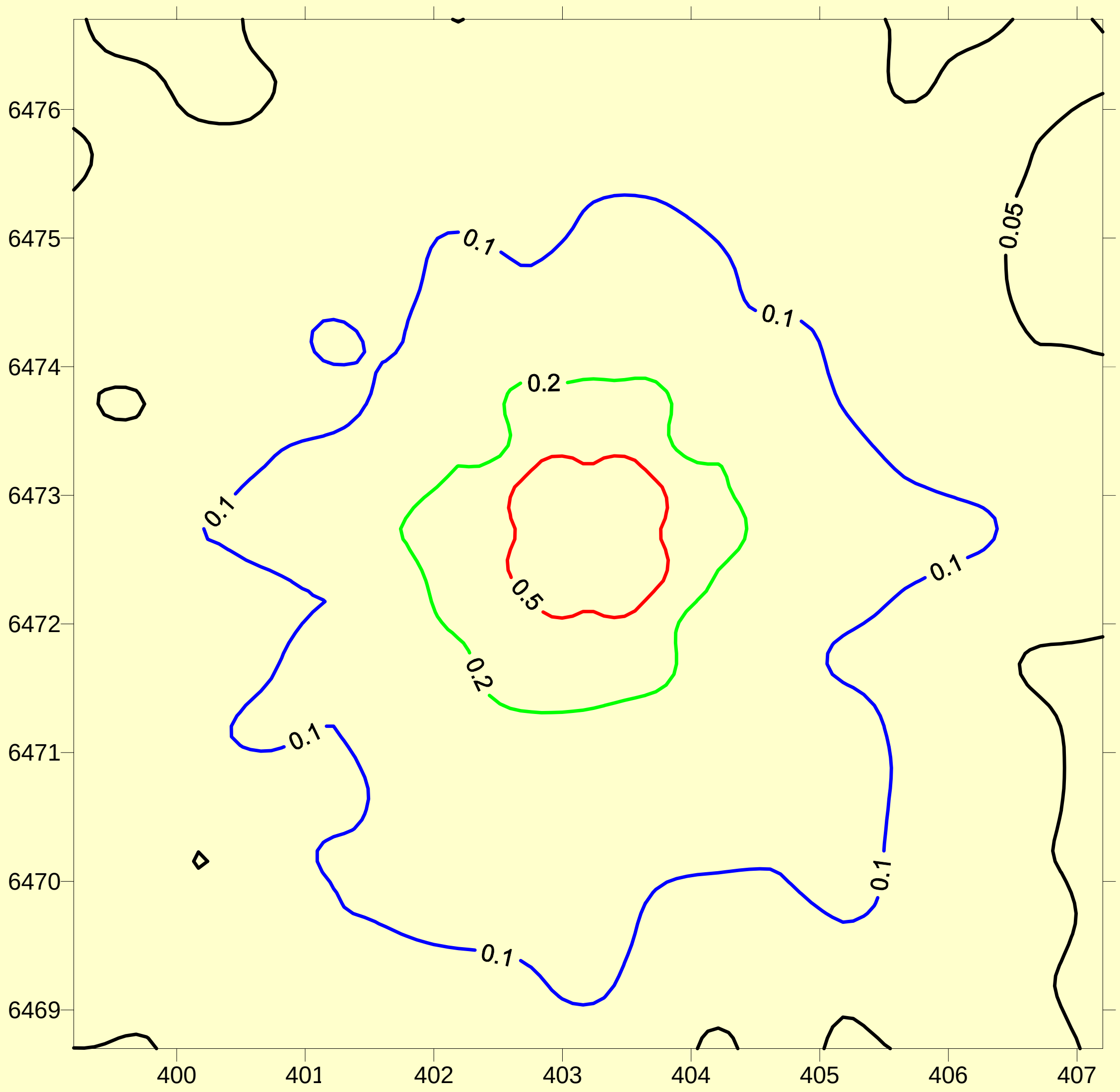


Calpuff concentration results were checked for sensitivity to lower limit on mixing height in Calmet/Calpuff

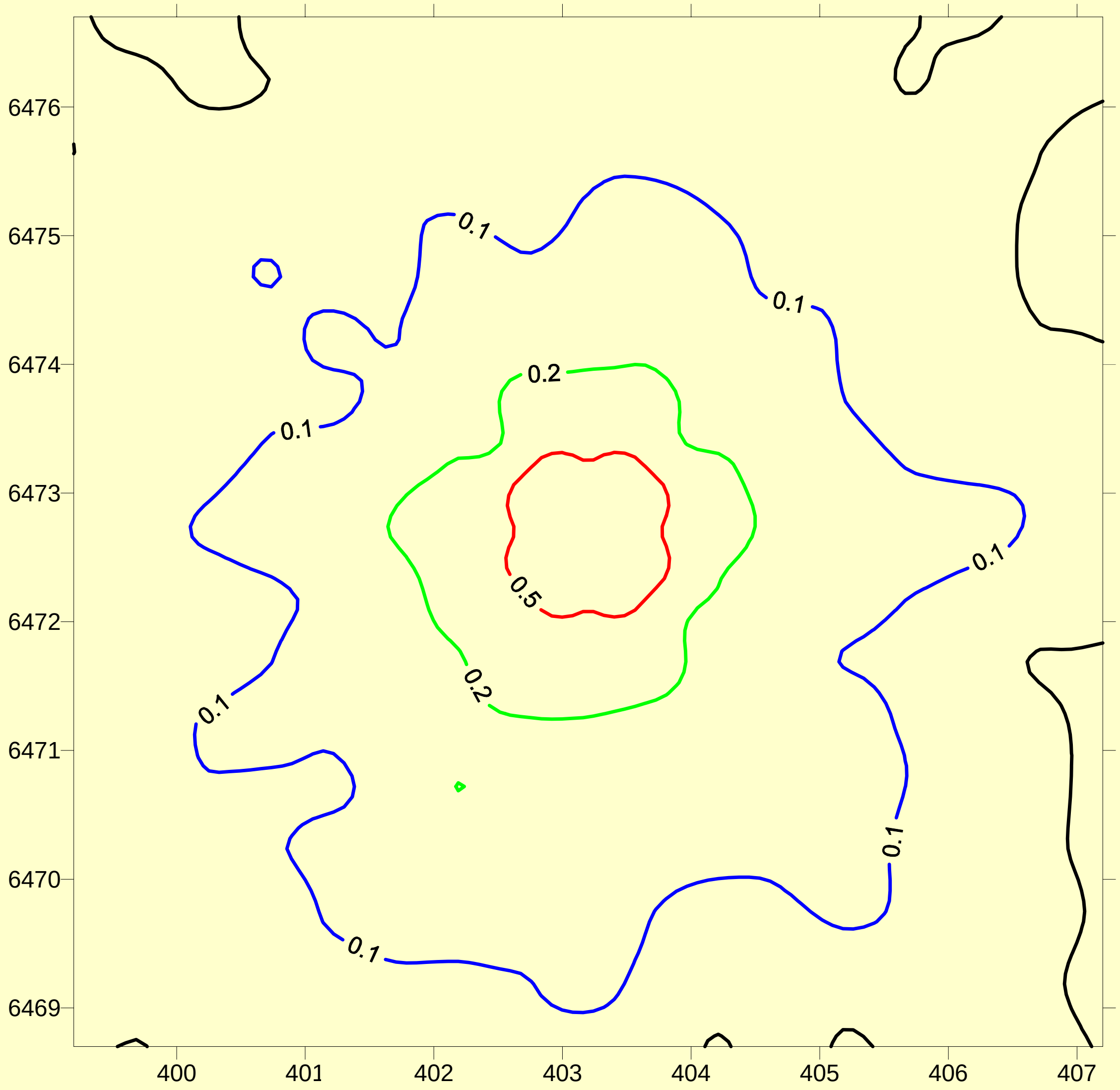
Cpuff: micromet, Zi limit = **500m** *(repeated)*



Cpuff: micromet, Zi limit = **50m**



Cpuff: micromet, Zi limit = **10m**



Summary

- reasons for Aermod's greater sensitivity to small Zim c.f. Calpuff not clear.
- USEPA contacted. Roger Brode responded – he is not convinced there is a problem.
- results very different to Ausplume which sets Zi = 9999 in stable conditions (no "reflection"). Aermod's vertical turbulence parameterisation is relatively sophisticated, but are the high concentrations realistic?
- What is the rationale for setting a lower limit like 50 metres in Calpuff?

Mechanical mixing height

Part B: daytime formulae

Are there problems with Aermet / Aermod and does Calmet / Calpuff do better?

Aermod formula

Aermod (page 22, 2004) calculates Zim from Venkatram's 1980 formula:

$$Zie = 2300\, u_*^{3/2} \qquad (1)$$

which is stated to be an empirical representation, in mid latitudes, of Zilitinkevich (1972)

$$Zie = 0.4(u^*L/f)^{1/2} \qquad (2)$$

although the Aermod document missed the ½ exponent.

A smoothing formula is applied to derive Zim. It gives rapid growth, slower decline – realistic??

Review Venkatram (1980)

He analysed data for **stable conditions** from three field studies and determined that the relationship:

$$L = 1.1x10^3\ u_*^2 \qquad (3)$$

was a good fit to observations.

He expressed L as $L = T_0\, u_*^2 / (g\, k\, \mathbf{T_*})$ (4)

Comparing the above relations, it is apparent that

$$T_* \sim 0.08C \qquad (5)$$

(i.e. T_* has to be ~ constant if L is proportional to u_*^2).

Venkatram accepted the form of Zilitinkevich (1972) (equation 2), so by substitution for L he derived

$$h = B\, u_*^{3/2} \qquad (6)$$

where the constant B ~ 2400 (from field data??)

Comments on $h = 2400\, u_*^{3/2}$

T_* is dependent on cloud cover. Aermod uses:

$$T_* = 0.09(1 - 0.5\, n^2)$$

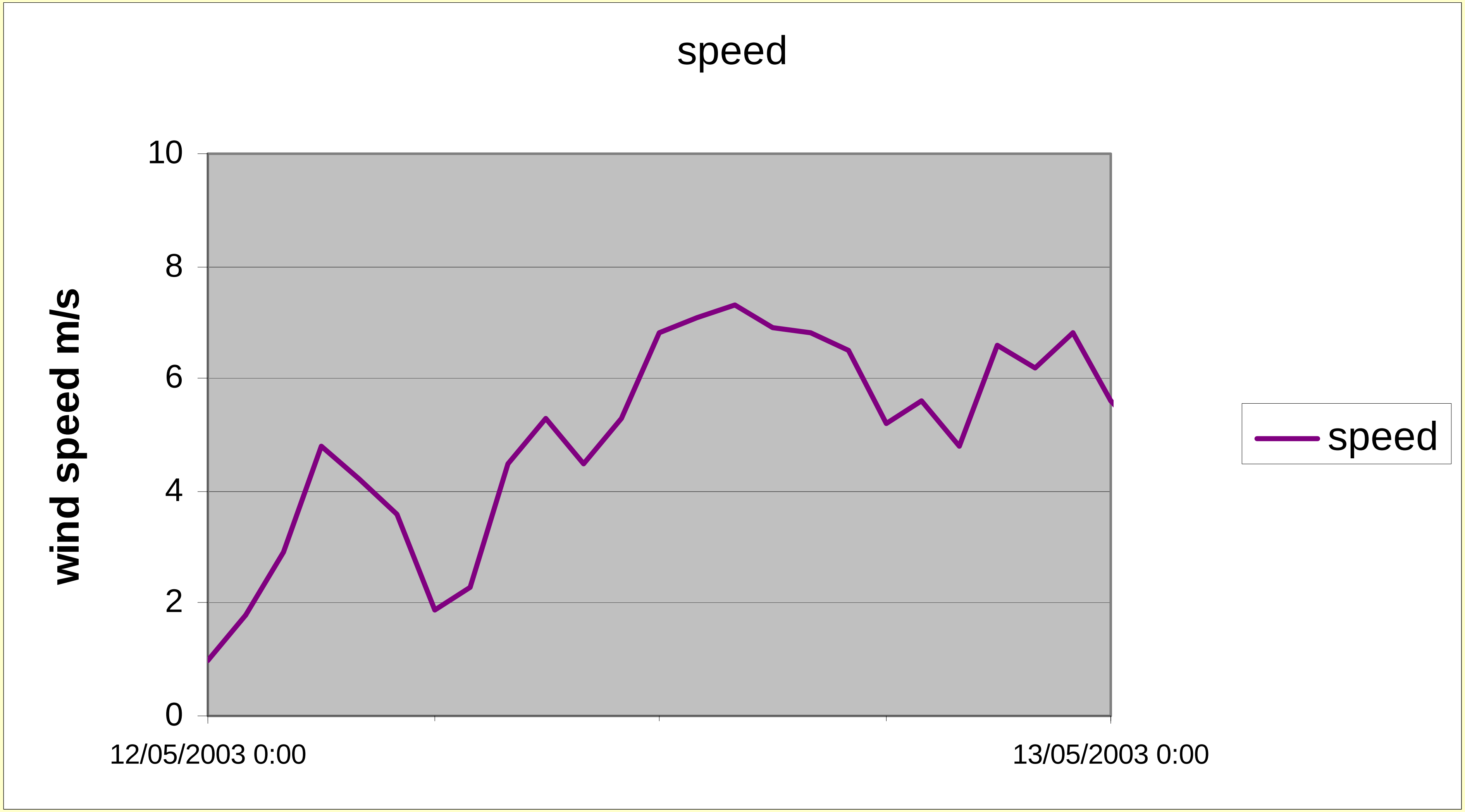
where n is cloud cover, so $0.04 < T_* < 0.09$. So how can B be constant (2400) for varying cloud amounts?

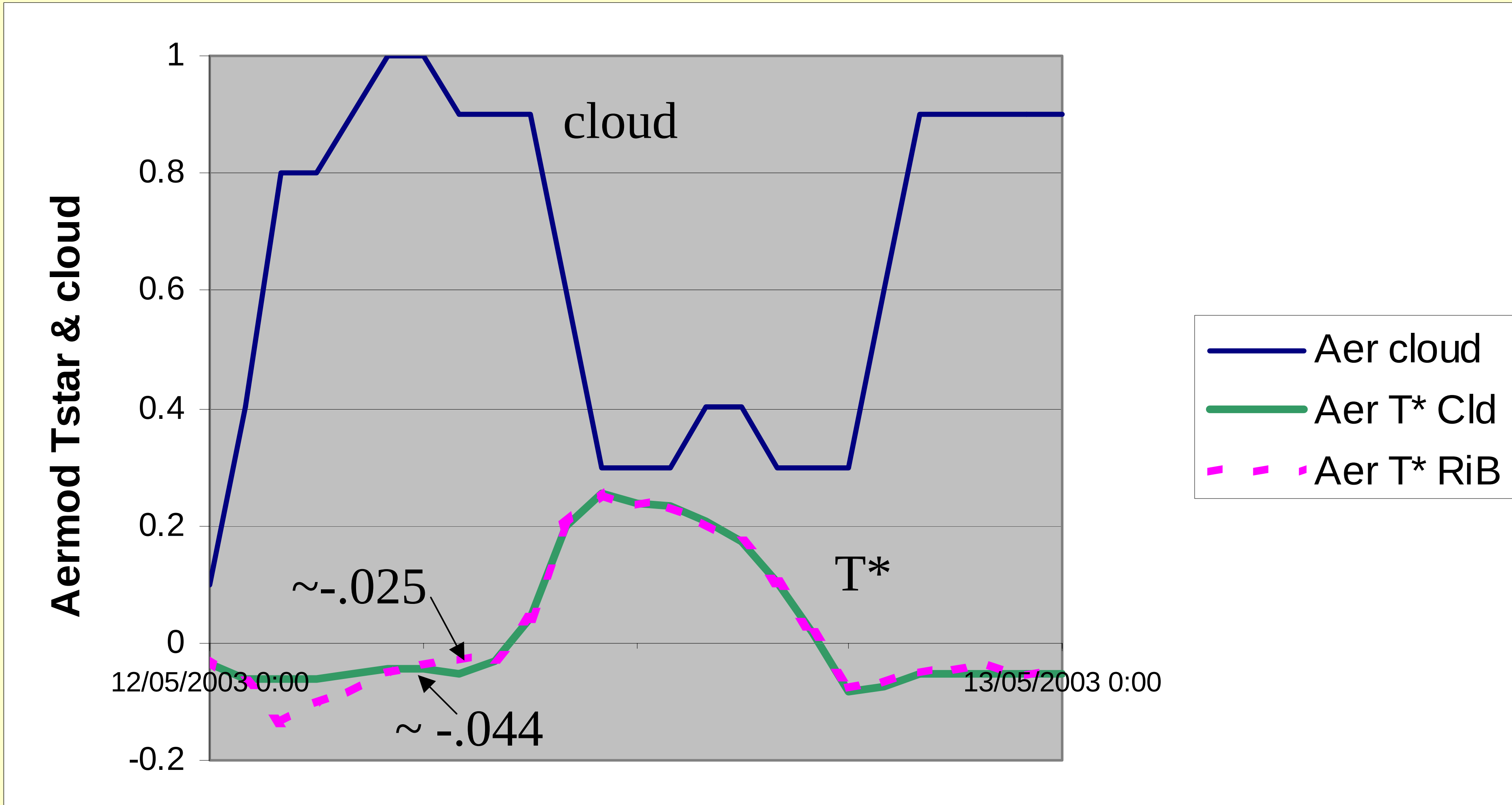
Venkatram gives no indication that his formula is valid in unstable conditions.

T_* changes sign and magnitude in daytime, so equations 2 and 3 are invalid, hence Aermod's use of $h = 2400\, u_*^{3/2}$ in unstable conditions seems highly dubious.

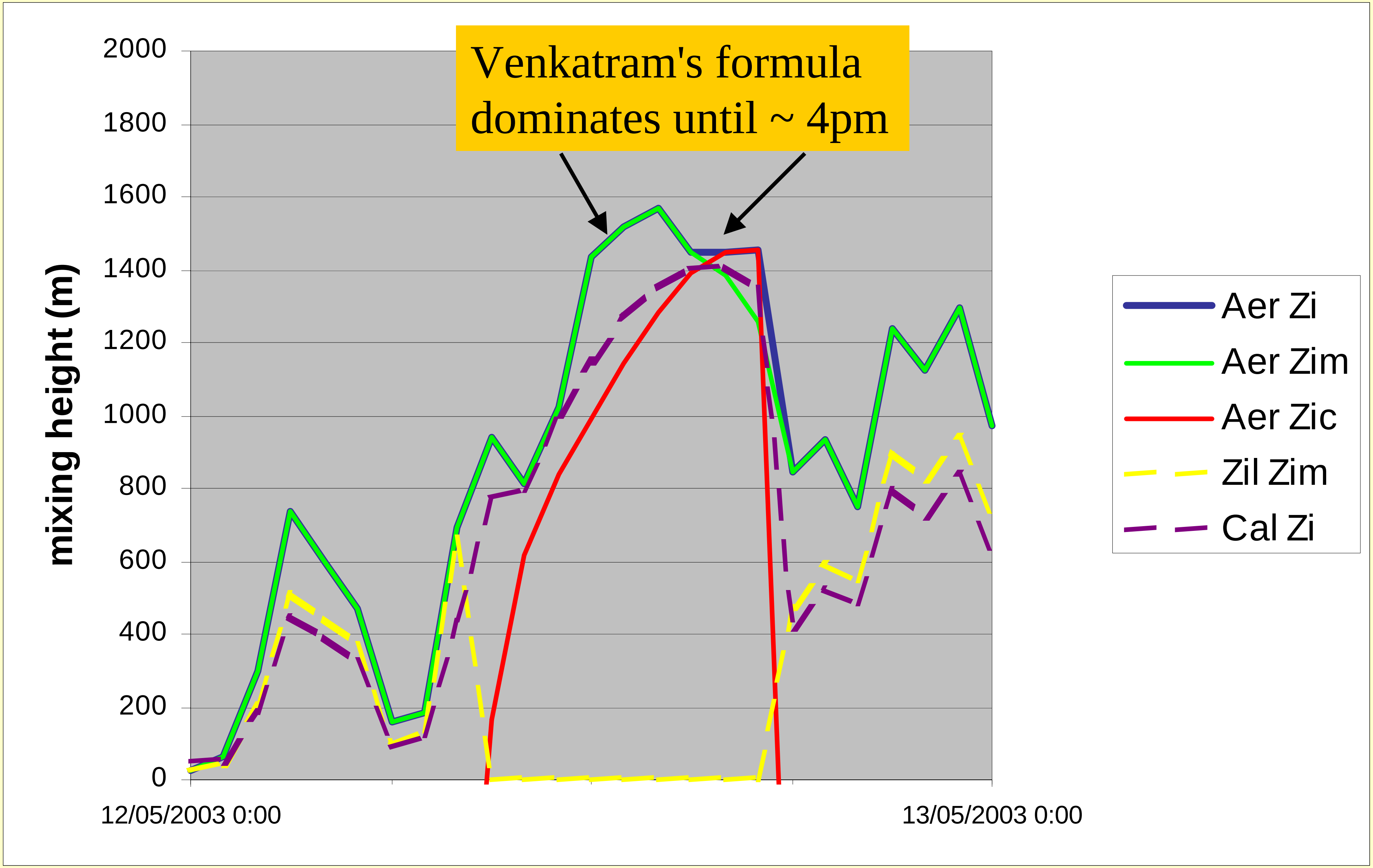
Example calculations

- 13 May 2003
- Caversham meteorological station
- Aermet and Calmet run with measured cloud (nearby Perth Airport)
- cloudy night and day, reasonably windy day


speed
wind speed m/s
10
8
6
4
2
0
12/05/2003 0:00
13/05/2003 0:00
speed



sorry folks, I have used the wrong sign convention for T*, but note the change of sign and magnitude in daytime



Venkatram's formula dominates until ~ 4pm
mixing height (m)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
12/05/2003 0:00
13/05/2003 0:00
Aer Zi
Aer Zim
Aer Zic
Zil Zim
Cal Zi

Calmet

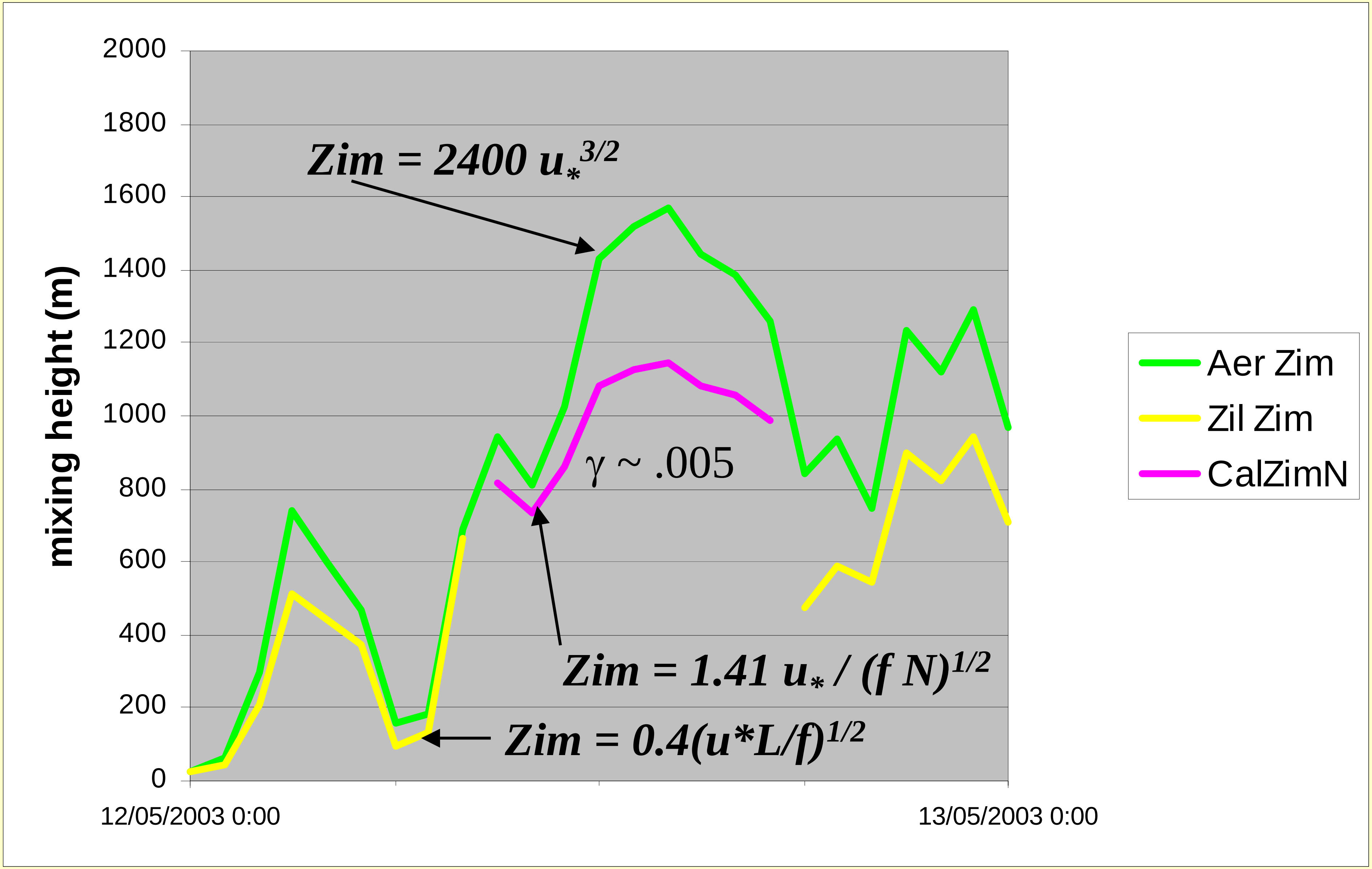
Stable: Zim taken as the lesser of the values from equations (1) and (2)

Neutral: $Zim = 1.41\, u_* / (f\, N)^{1/2}$ (7)

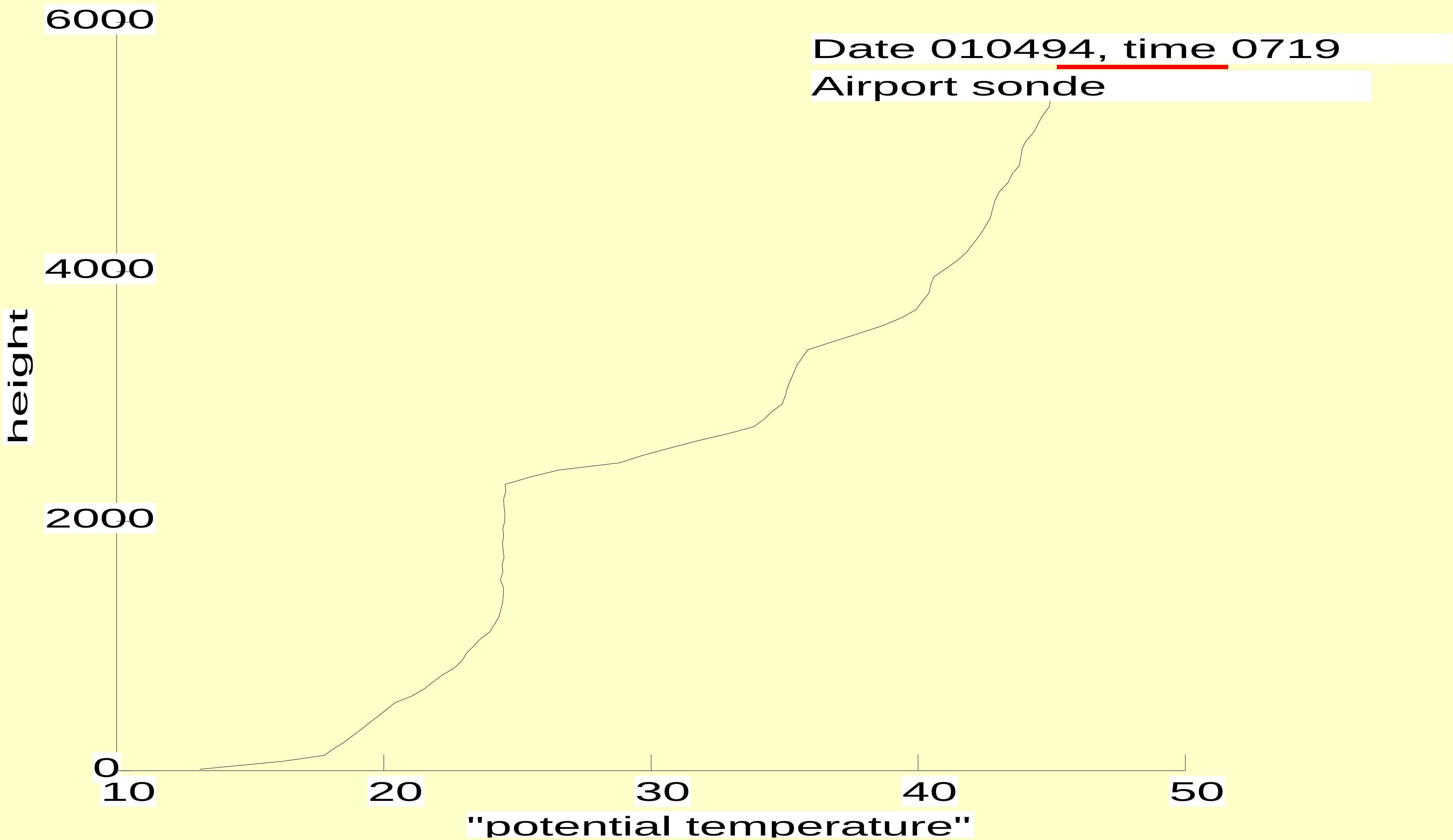
where N is the B-V frequency aloft.

During daytime, Zi is taken as the maximum of equation 7 and the computed convective mixed layer height.

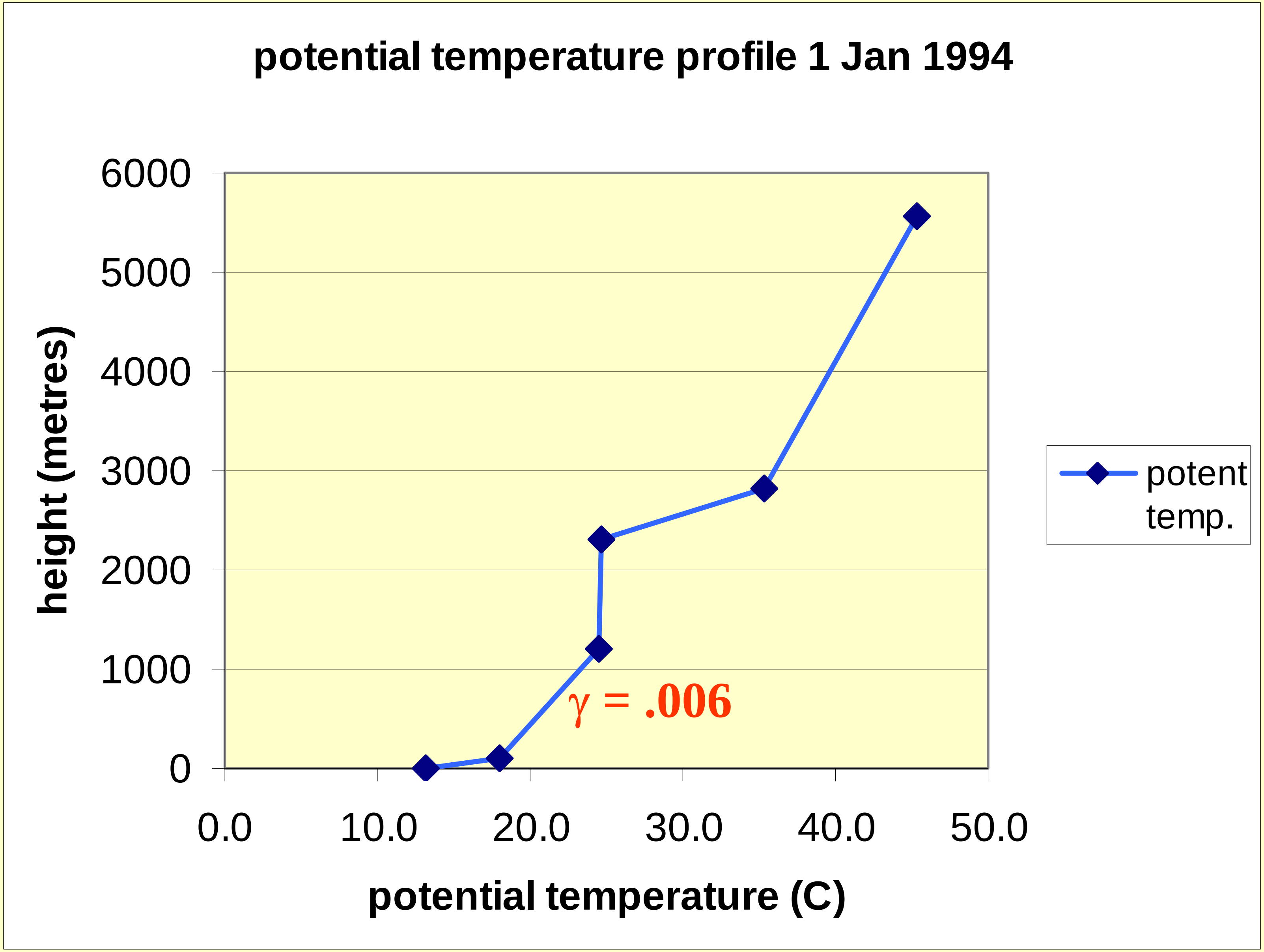
(user-selected minimum and maximum values ignored here)



mixing height (m)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
12/05/2003 0:00
13/05/2003 0:00
Zim = 2400 u*^3/2
γ ~ .005
Zim = 1.41 u* / (f N)^1/2
Zim = 0.4(u*L/f)^1/2
Aer Zim
Zil Zim
CalZimN

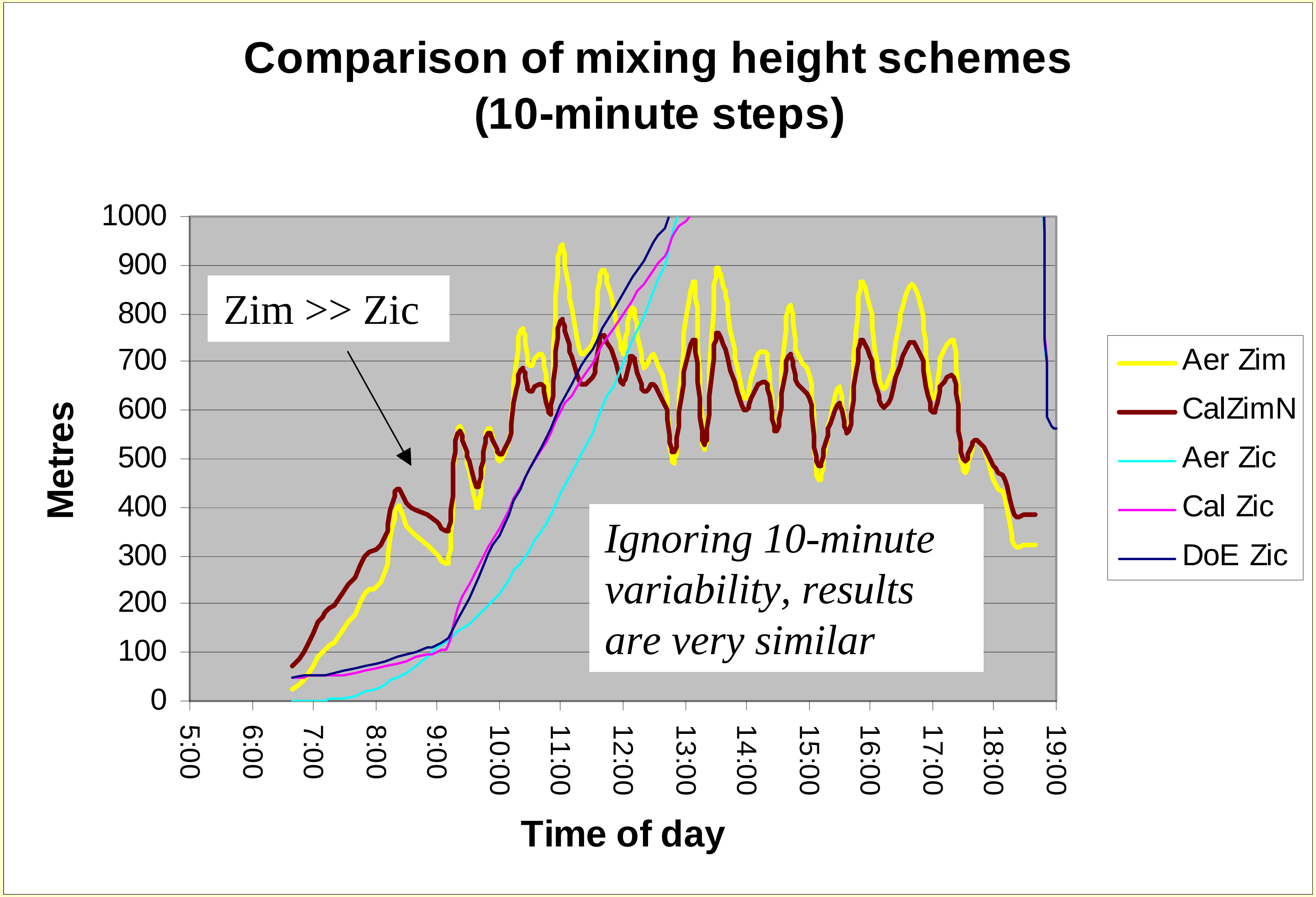


Date 010494, time 0719
Airport sonde
6000
4000
2000
0
height
10
20
30
40
50
"potential temperature"



potential temperature profile 1 Jan 1994
6000
5000
4000
3000
2000
1000
0
height (metres)
γ = .006
0.0
10.0
20.0
30.0
40.0
50.0
potential temperature (C)
potent temp.

Compare daytime Zim formula from Aermod and Calpuff



Why use Zi = max(Zim, Zic) in unstable conditions?

- If the lapse rate below Zim is clearly stable, as on 1 Jan 1994, how can it be correct to set Zi = Zim and use this for calculating turbulence profiles, w_*, etc? In reality wouldn't large-scale mixing be limited to Zic, with the vertical dispersion of any plume penetrating the lid ($\Delta\theta$) at Zic being considerably reduced?
- Isn't Zi = max(Zim, Zic) superfluous if Zic has been calculated by combining mechanical and convective contributions to d(Zic)/dt , i.e. $c_1(w_*^3 + c_2 u_*^3)$ as per BG, DoE?

Summary

- Use of $Zim = 2400\, u_*^{3/2}$ in daytime seems dubious. Has there been any work to demonstrate that this formula gives reliable results in unstable conditions?
- The formula used by Calpuff,

  $$Zim = 1.41\, u_* / (f\, N)^{1/2}$$

  may or may not give different results to that above, presumably depending on values of u_* and temperature lapse rate.
- Is Zi = max(Zim, Zic) rigorous?