Extrapolating Wind Speeds in the Vertical

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CALMET has several options including the Irwin profiles and Similarity Theory

Irwin Wind profiles

Irwin (1979) used the non dimensional wind shear

$$\phi_m = (k\, Z/\, u_*)\ \delta U/\delta Z$$

to obtain $p = (u_* /Uk)\ \phi_m$

where $p = \ln (U_2/U_1) / \ln(Z_2/Z_1)$

i.e. $U_2 = U_1 (Z_2/Z_1)^{\,p}$

For stable conditions Irwin used:

$$(u_* /Uk)^{-1} = \ln (Z/zo) + \beta\, Z/L$$

$$\phi_m = 1 + \beta\, Z/L$$

where Z was found to be best approximated as the average of the arithmetic and geometric mean of the two heights.

Irwin Wind profiles (contd.)

Used a linear form of ϕ_m which is now known to hold only for Z/L approx < 1.

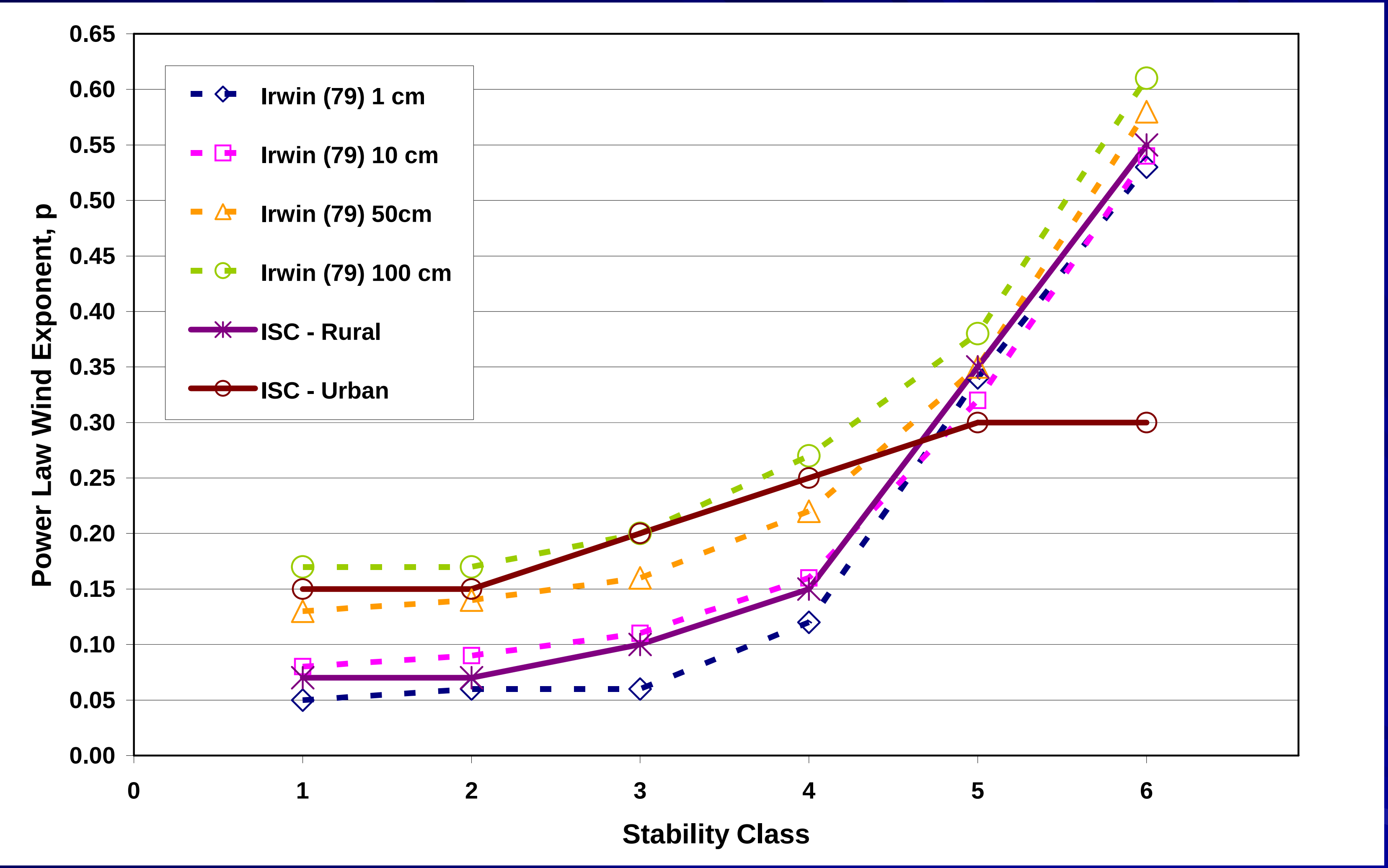
Comparing the estimates to three data sets, Irwin found the best agreement under stable conditions occurred with $\beta = 2$, instead of the normal 4.7 (see later).

Wind exponents p where then derived for;

- The range from Z_1 =10m to Z_2 =100m with an “average” height of 43.3m
- $\beta = 2$
- The Monin Obukov length (L) for the six stabilities were obtained for various roughness lengths based on best fits to Golders (1972) curves.

The “urban” exponents were modified by the USEPA to account for the urban anthropogenic heat flux, by decreasing the exponents for stable conditions.

Irwin Wind Exponents



Irwin "Rural" exponent are generally approximated by a roughness length between 5cm and 15cm. Irwin "Urban" can be approximated by a roughness length of approximately 70cm to 90 cm, except for stable classes where E and particularly the F class exponent are significantly reduced.

Irwin Wind profiles (contd.)

Results

Wind exponents (p) are dependent on stability, the roughness length and the height range they were evaluated over.

The “urban” exponents were modified by the USEPA to account for the anthropogenic heat flux, by decreasing the exponents at night. Therefore they are only really applicable for urban areas with significant anthropogenic heat flux. Therefore, the use of urban exponents should be restricted to “urban”, as per the USEPA definition of urban.

The Irwin “rural” exponents are for a low roughness site, I.e rural grasslands and as such should not be applied for rougher rural sites. For B Class stability, the exponent Irwin rural exponent is 0.07, compared to that derived using the function in CALMET of 0.14 for zo =0.5m. When extrapolating 10m to 100m winds, the exponent of 0.07 will give a a multiplier of 1.175 compared to 1.38 for an exponent of 0.14. Therefore, use of Irwin rural curves for rougher rural areas will underestimate the extrapolated wind speeds for A to D class stabilities.

Similarity Theory

The wind speed (U) at height z_2 is estimated from the measurements at z_1 by:

$$U(z_2) = U(z_1) \; [\ln(z_2/z_o) - \psi_M(z_2/L)] / [\ln(z_1/z_o) - \psi_M(z_1/L)]$$

For stable conditions the Integral function (ψ_M) in CALMET (pre v6) was taken from van Ulden and Holstlag (1985).

$$\psi_M = -17(1 - \exp(-0.29z/L)$$

Van Ulden and Holstlag (1985) note that similarity theory for Z/L > 1 is not strictly applicable, but found that that the function “appears to predict the wind speed up to 200m without significant systematic errors even in cases which h is well below 200m. The scatter, however is not insignificant”.

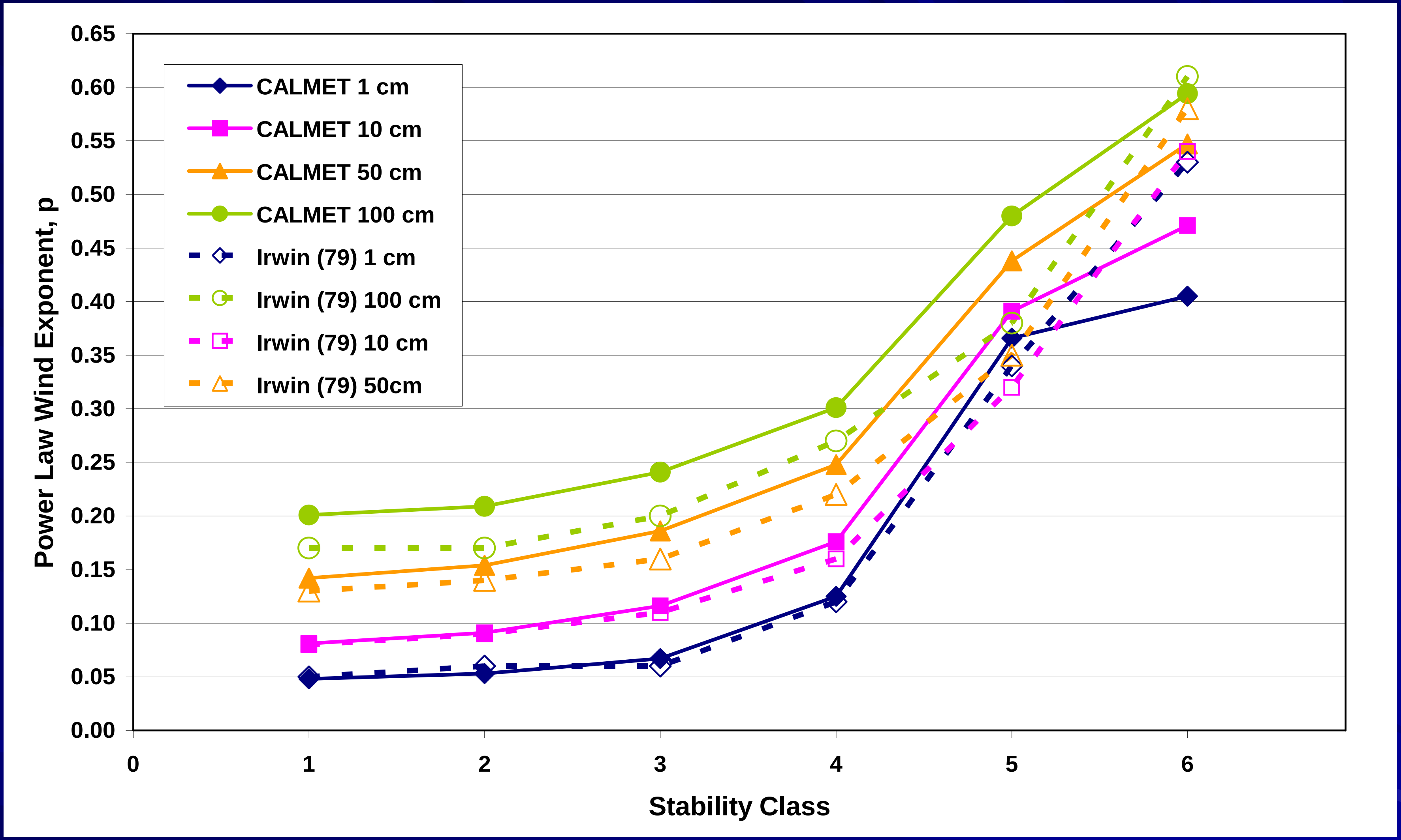
CALMET (v6) has replaced the above function with that from Beljaars and Holtslag (1991)

$$c = \min(50, 0.35\, z/L)$$

$$\psi_M = -[(1 + z/L) + 0.6667(z/L - 14.28) / \exp(c) + 8.525]$$

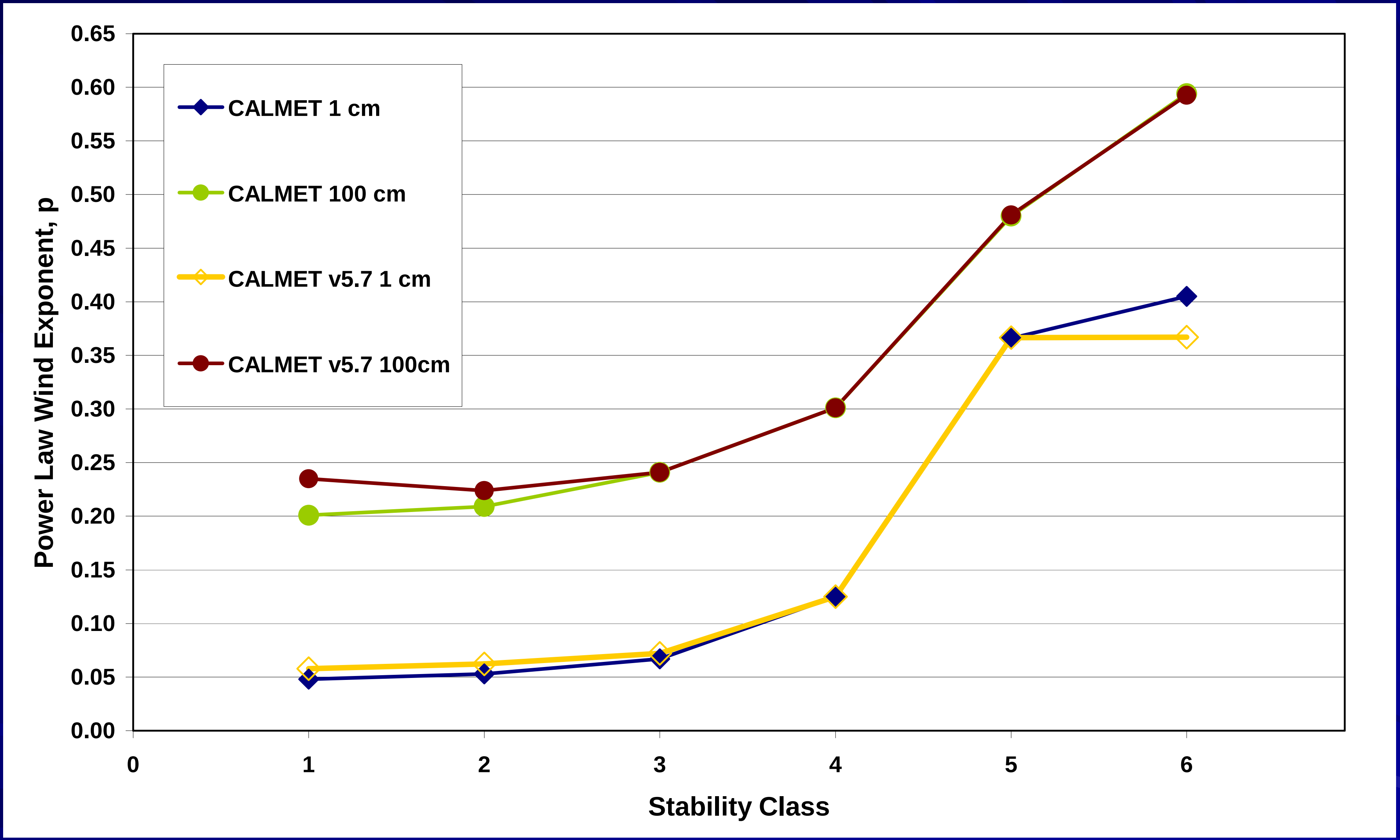
Likewise the unstable functions have been modified.

Wind Exponents Derived from CALMET (v6) for comparable conditions to Irwin (79)



- CALMET derived exponents are higher than that estimated in Irwin (1979) apart from F Class stability at lower surface roughness
- Note: The lower F class exponents are not due to the restrictions on L in the CALMET heat flux scheme where L is limited to 20m for z_o =1m decreasing to 6m at z_o = 0.01m

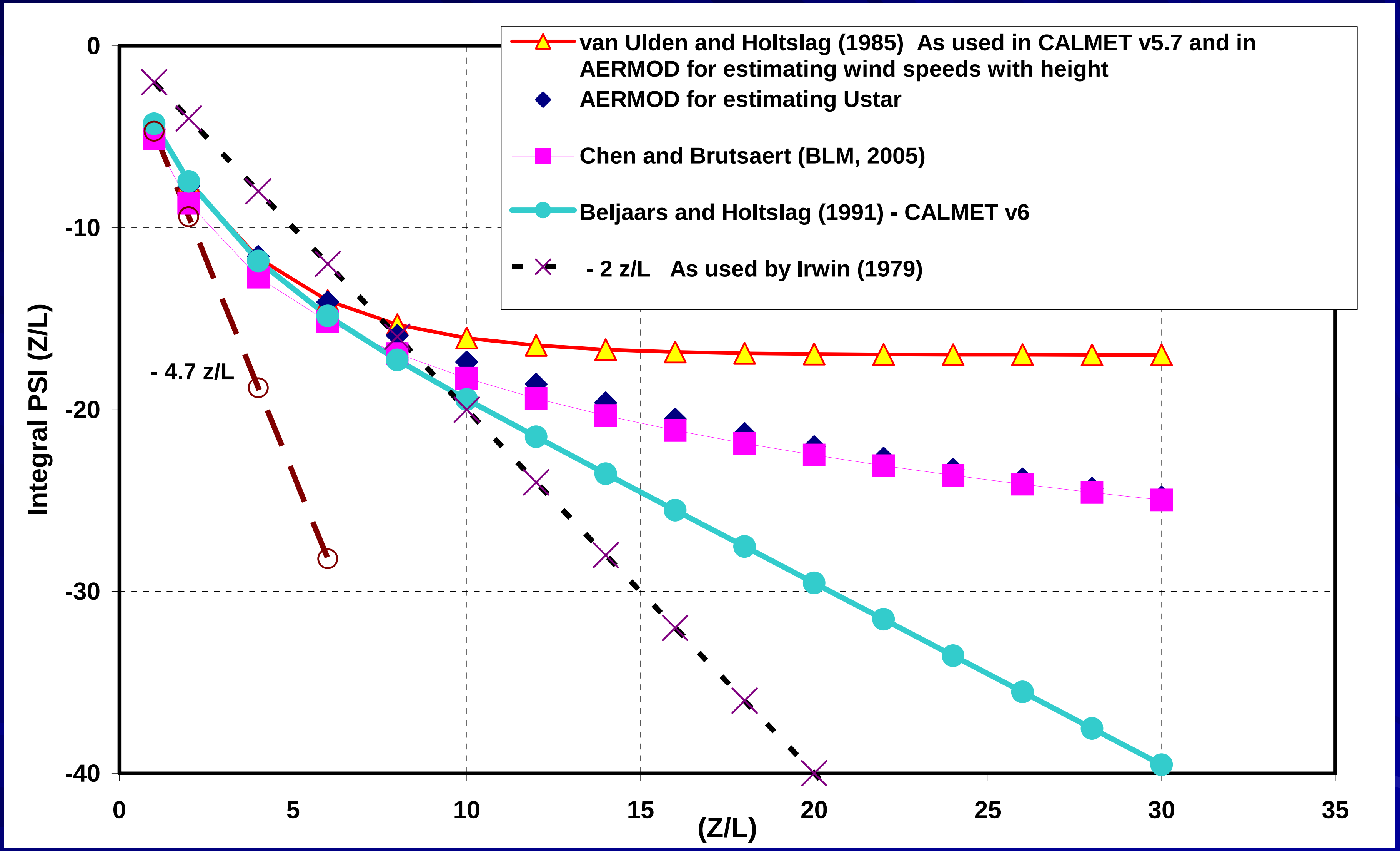
Comparison of Wind Exponents from CALMET (v5.7 and v6)



Comparison of CALMET v6 to v5.7 formulas indicates that:

- Under unstable conditions V6 predicts lower wind exponents than v5.7; and
- Under stable conditions, v6 appears to produce better estimates for F class stability.

Comparison of ψ_M Functions



Integral functions (ψ_M) used in CALMET (v5.7 and 6) differ markedly above a z/L of approximately 6. Indicates the approximate nature of the function Irwin (1979) used to approximate ψ_M to better match the data.

In extrapolating winds to heights of 50 to 200m, Z/L of 10, 20, 30 are common. Eg. a Z/L of 20 is obtained for L =10m and Z =200m or with L =5m and Z=100m. Therefore, for wind extrapolation, how ψ_M varies at high Z/L is important.

Note, similarity theory is not really applicable for Z/L >1 but there are no ready alternatives.

Therefore extrapolating winds in stable conditions above z/L >1 is approximate and though we may have better functions now, do they really estimate the wind profiles at high Z/L better than the old profile of van Ulden and Holtslag, which was found to provide good agreement? Note, AERMOD uses the older van Ulden and Holstlag formula.

The comparison indicates that the function used in v6, may over-estimate at high Z/L in comparison to other forms.

The comparison indicates the reason why Irwin (79) had to adjust the coefficient of β to 2, as when extrapolating winds to heights of 100m, Z/L can be well above the now accepted range at which the linear function for (ψ_M) is applicable. Therefore, this indicates that the Irwin exponents for stable conditions may be to a degree uncertain.

Indicates the approximate nature of wind extrapolations and the need for wind measurements near stack height for stable light wind conditions?

Conclusions and Recommendations

1) Wind exponents are a function of stability and surface roughness.

2) The Irwin “rural” and “urban” exponents are two approximations to the continuum of profiles possible. The Irwin “rural” exponents for roughness in the range of 5 to 15cm, whilst, Irwin “urban” exponents are for urban areas with significant heat island affect.

Suggest that if wind exponents are to be used, then there is the need for at least another category for higher roughness lengths without heat island affects. For example, we could develop exponents for cases for 7cm, 50 cm and 100 cm and no heat island affects. The changes that would result would be most significant during A to D class.

3) Preferable to use similarity theory to capture the roughness, stability and height range variation.

4) Note similarity theory is however not really applicable above Z/L > 1 and as such F class extrapolation to “large” heights may be approximate. For example extrapolating 10m winds to 100m in moderately stable conditions and even as low as 30 to 50 m in very stable conditions. Therefore the need for measurements at or near plume height (esp. at night) as per the recommendations of the USEPA.