VERIFICATION

UDM APPENDIX A: AMBIENT PROFILES

DATE: December 2023

Reference to part of this report which may lead to misinterpretation is not permissible.

No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
1	1999	PHAST 6.0	Witlox & Holt		
2	May 2011	Phast 6.7; UDM v2	Harper		
3	May 2021	Apply new template	D. Vatier		

Date: December 2023

Prepared by: Digital Solutions at DNV

ABSTRACT

The vertical wind-speed, temperature and pressure profiles have been investigated in detail. These profiles are expressed in terms of the Monin-Obukhov length, power law exponent and friction velocity; these data have been evaluated for a given base case and compared with literature quoted values. A sensitivity analysis has been carried out on the base case with parameter variations in stability class and surface roughness length. Finally, comparison has been made between the logarithmic and power-law wind-speed profiles, and the logarithmic and linear temperature profiles.

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APPENDIX A. AMBIENT PROFILES

A.1 Introduction

The evaluation of the ambient data in the UDM is described in the UDM theory manual. This appendix documents the verification of the ambient profiles that are imposed in the dispersion model.

In section A.2 the parameters used in the ambient profile are considered. Model calculated values for Monin-Obukhov length, wind-speed power law exponent and friction velocity are considered and compared with literature quoted values.

In section A.3 a sensitivity analysis is carried out on a defined base-case in which wind-speed, temperature and pressure profiles are presented for variations in stability class and surface roughness length.

In section A.4 the power law approximation for the windspeed profile is compared with the logarithmic profile, and the linear temperature profile is compared with the logarithmic profile.

A.2 Parameters used in the ambient profiles

Figure A1 plots the Monin-Obukhov length as a function of both stability class and surface roughness length. These calculated values are in good agreement with the values quoted in the tables of Irwin[i]. Results for stability class D, where the Monin-Obukhov Length is set to 100,000 m, are not presented.

Figure A2 presents results for the power law exponent as a function of stability class and surface roughness length.[1] The following may be noted:

- There appears to be a discontinuity in the value for the power law exponent at the largest surface roughness length under stability class A.
- Under stable conditions the power law exponent contains a minimum for surface roughness lengths in the region 0.01 – 0.1 m [2]

Irwin presented results for surface roughness lengths in the region 0.01 – 1 m and the above observations may indicate that the wind-speed profiles are less reliable outside this range of validity.[3]

[1] The results are close, but not in exact agreement with the curves given in the UDM theory manual, which are taken from Irwin[i]

[2] Is this a physical phenomenon ?

[3] Further comparison is needed on the derivation of the UDM algorithm for the power law exponent with the theory in the paper by Irwin (1979). Note that Irwin refers to wind speeds for two levels, i.e. at 32 m (averaging between 10 and 100m) and 2 m (averaging at lower levels?).
Alternatively, the least-square approach of HGSYSTEM can be adopted, where a least-square fit is carried out between z_{ref} and $10z_{ref}$ (with wind speed u_{ref} specified at reference height z_{ref}).

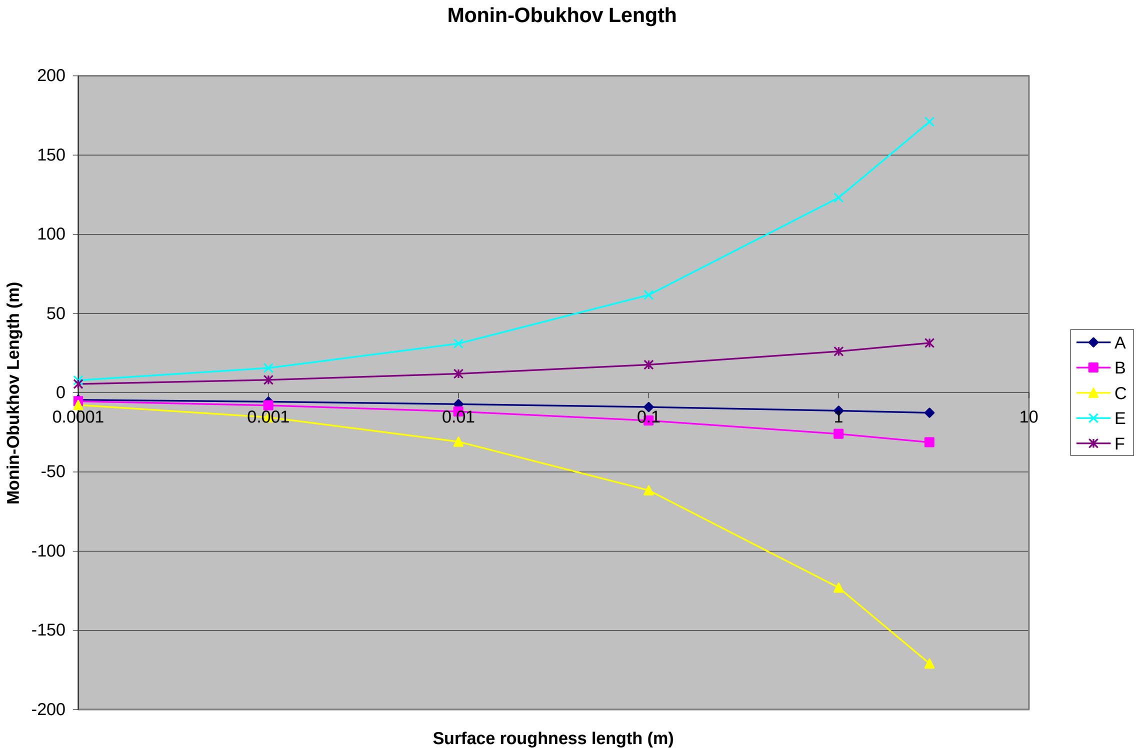


Figure A1 – Monin-Obukhov length for Stability class A-F and surface roughness lengths of 0.0001, 0.001, 0.01, 0.1, 1 and 3 m

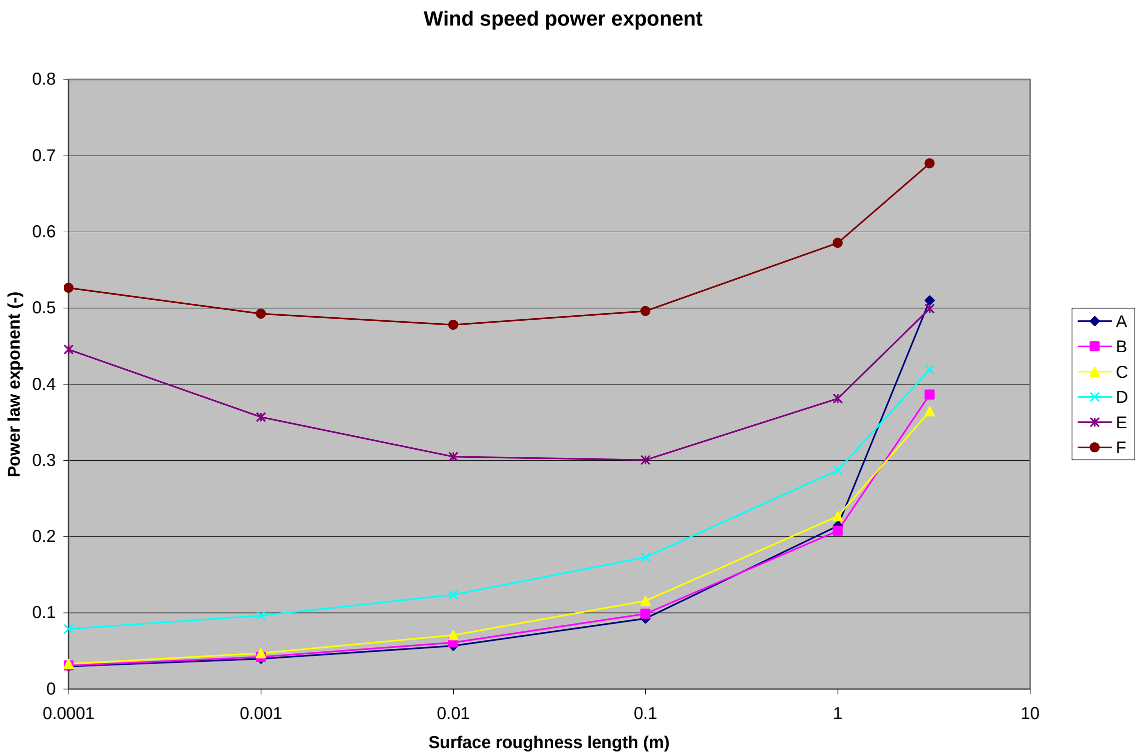


Figure A2 – Power law exponent for Stability class A-F and surface roughness lengths of 0.0001, 0.001, 0.01, 0.1, 1 and 3 m

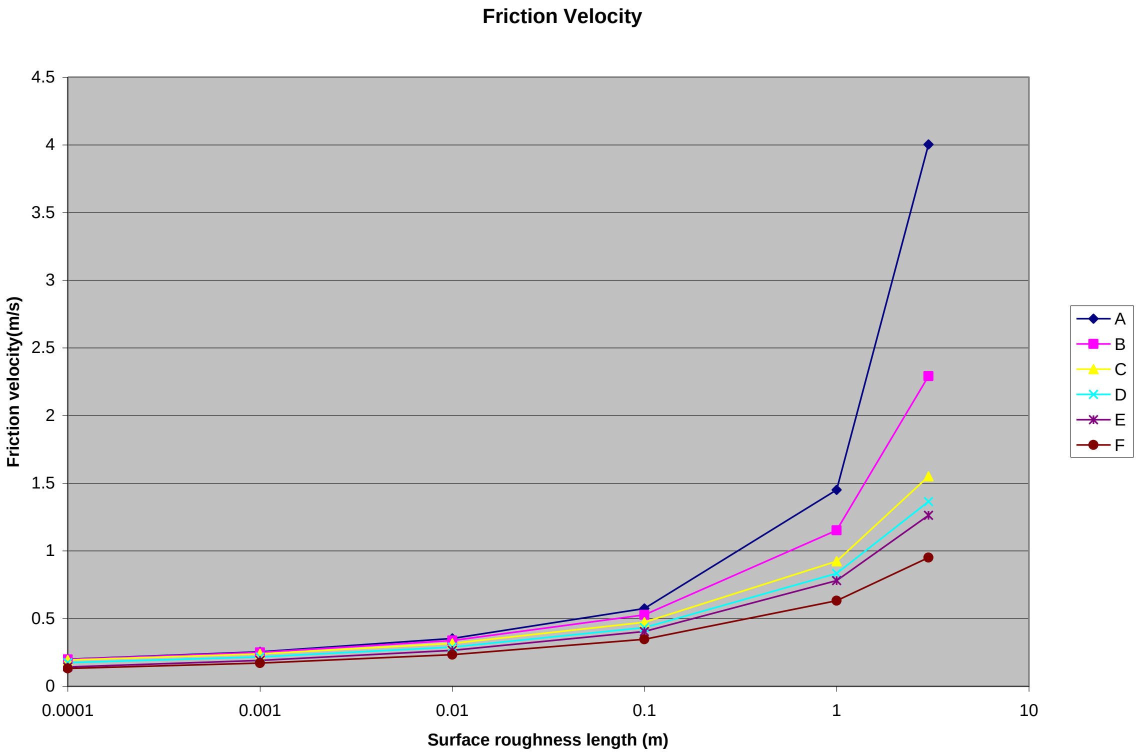


Figure A3 – Friction velocity for Stability class A-F and surface roughness lengths of 0.0001, 0.001, 0.01, 0.1, 1 and 3 m

Figure A3 plots the friction velocity for the base case including parameter variations in stability class and surface roughness length. As can be seen the expected trends are observed.

A.3 Sensitivity Analysis

This verification and sensitivity exercise is concerned with the power law wind-speed profile and logarithmic temperature and linear pressure profiles. The base case is defined by the following remaining ambient properties:

- Reference height for temperature and pressure = 0 m
- Temperature at reference height = 283 K
- Pressure at reference height = 101325 N/m^2
- Reference height for wind-speed = 10 m
- Wind-speed at reference height = 5 m/s
- Atmospheric humidity = 0.7
- Surface roughness length = 0.1 m
- Atmospheric specific heat = 1004 J/kg K
- Atmospheric molecular weight = 28.966 g/mol
- Cut off height for power law wind profile = 1 m

Figures A4 – A9 present wind-speed, and temperature profiles for the base case as a function of stability class and surface roughness length. The following observations can be made:

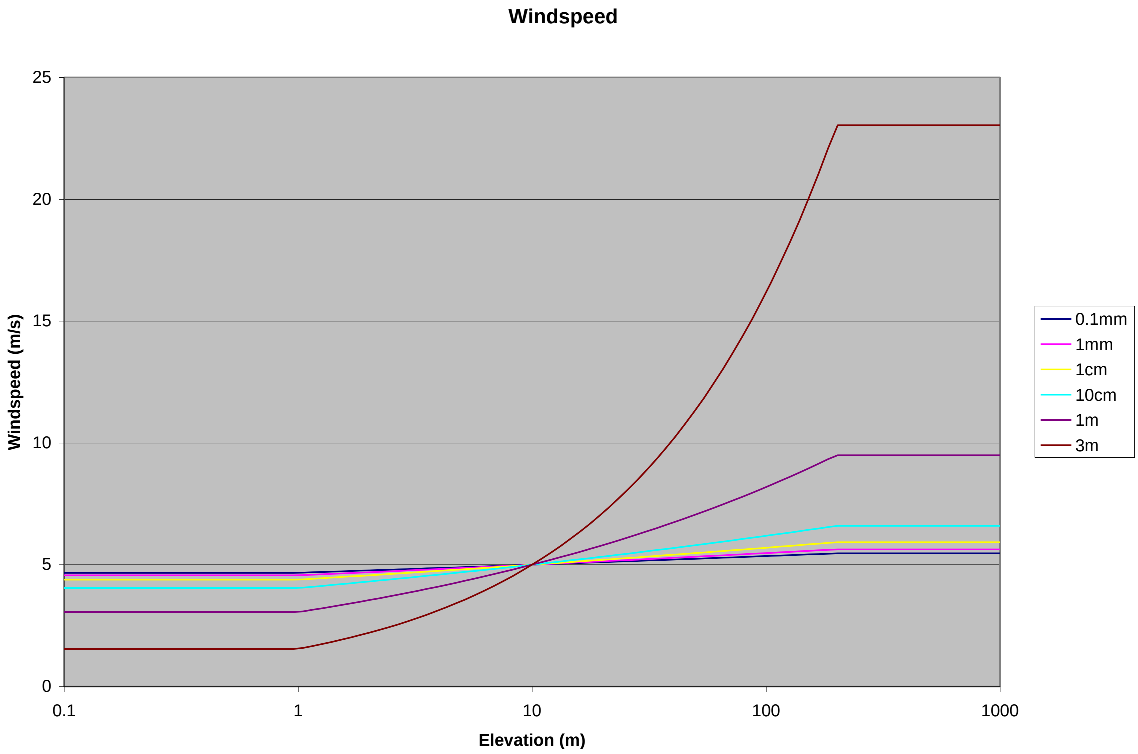
1) For all weather conditions the wind-speed is cut-off below 1m and above 200 m. i.e. the wind-speed is constant below 1 m and is constant above 200m elevation.

2) For neutral and unstable conditions the wind-speed gradient increases for increasing surface roughness. For stable conditions, however, the wind-speed gradient gives peculiar trends for increasing surface roughness length. This seems to be attributed to the parabolic behaviour for the power-law exponent with varying surface roughness length, see figure A2.

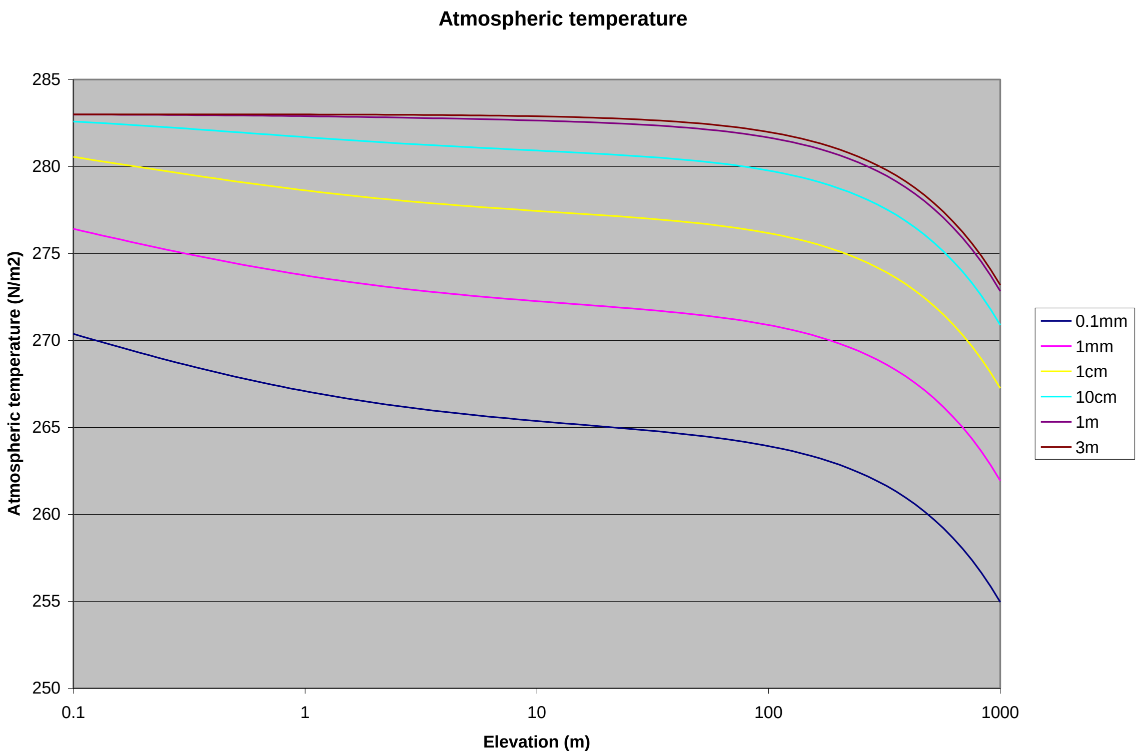
3) Extremes in temperature at moderate elevations are possible for very low surface roughness length's (0.0001 m). This is exaggerated at lower wind-speeds.

4) For stable conditions the temperature can increase with elevation up to the mixing layer height. Above the mixing layer height, the temperature decreases in proportion to the adiabatic lapse rate.

Figure A10 plots the pressure profile for the base case, which is independent of both stability class and surface roughness length.

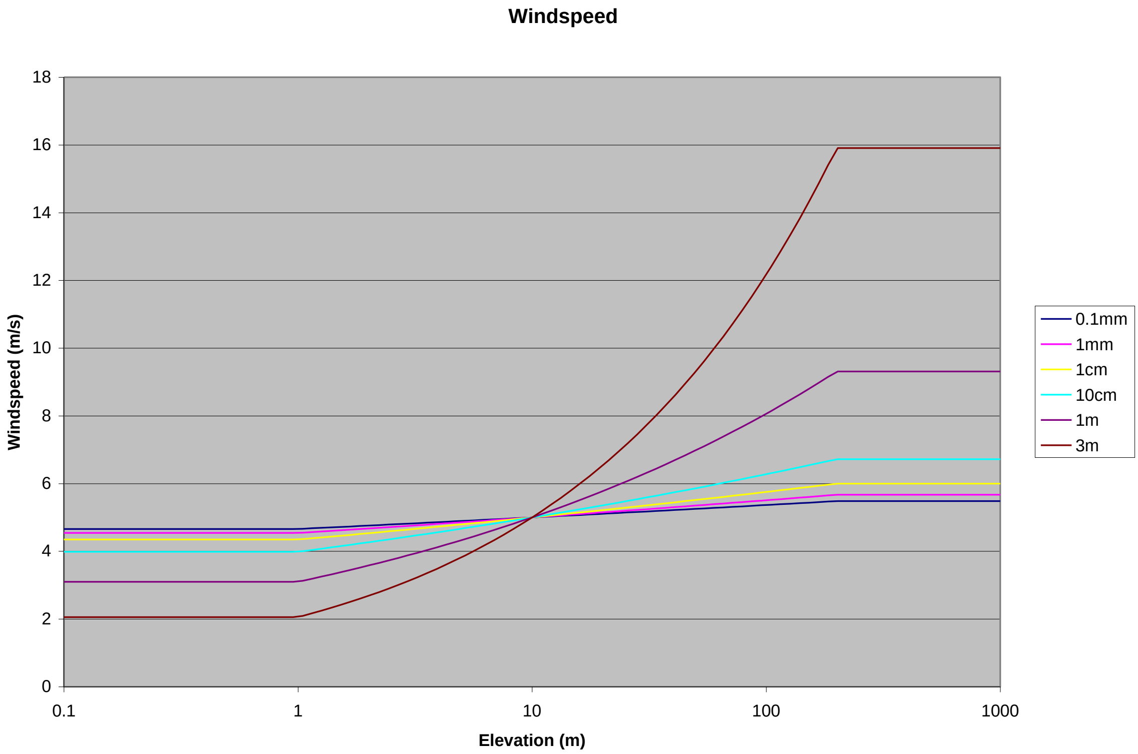


(a) Wind-speed Profile

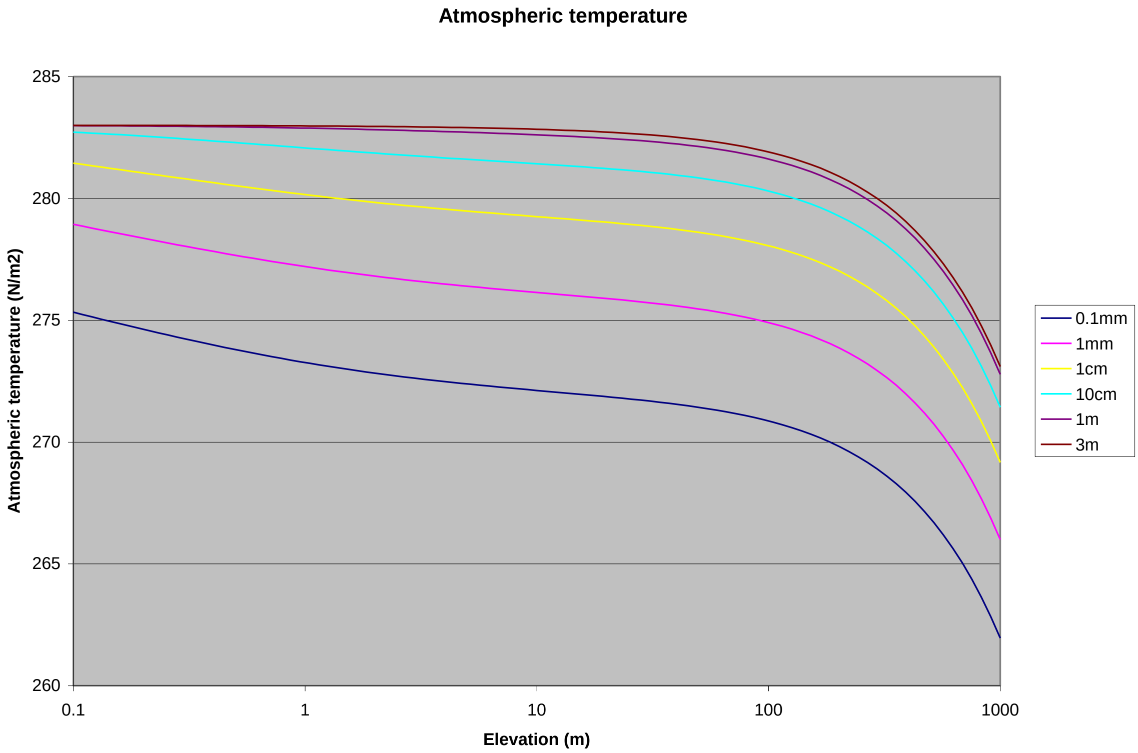


(b) Temperature Profile

Figure A4 – Temperature and wind-speed profile for the base case under stability class A

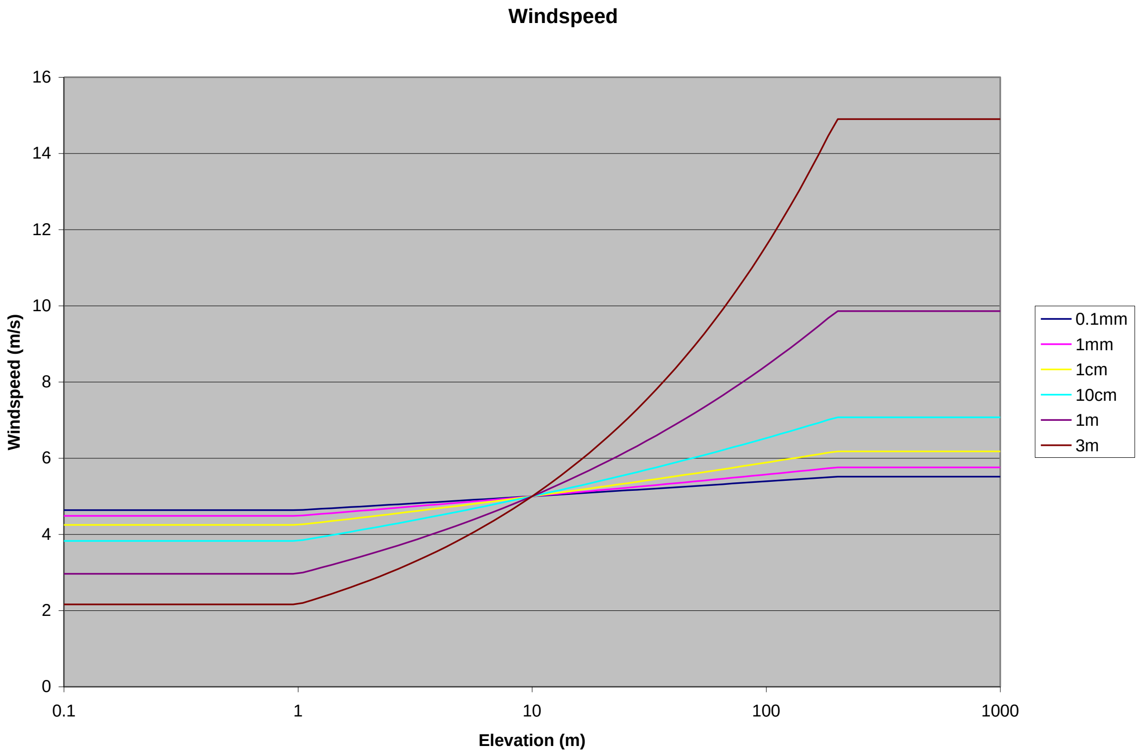


(a) Wind-speed Profile

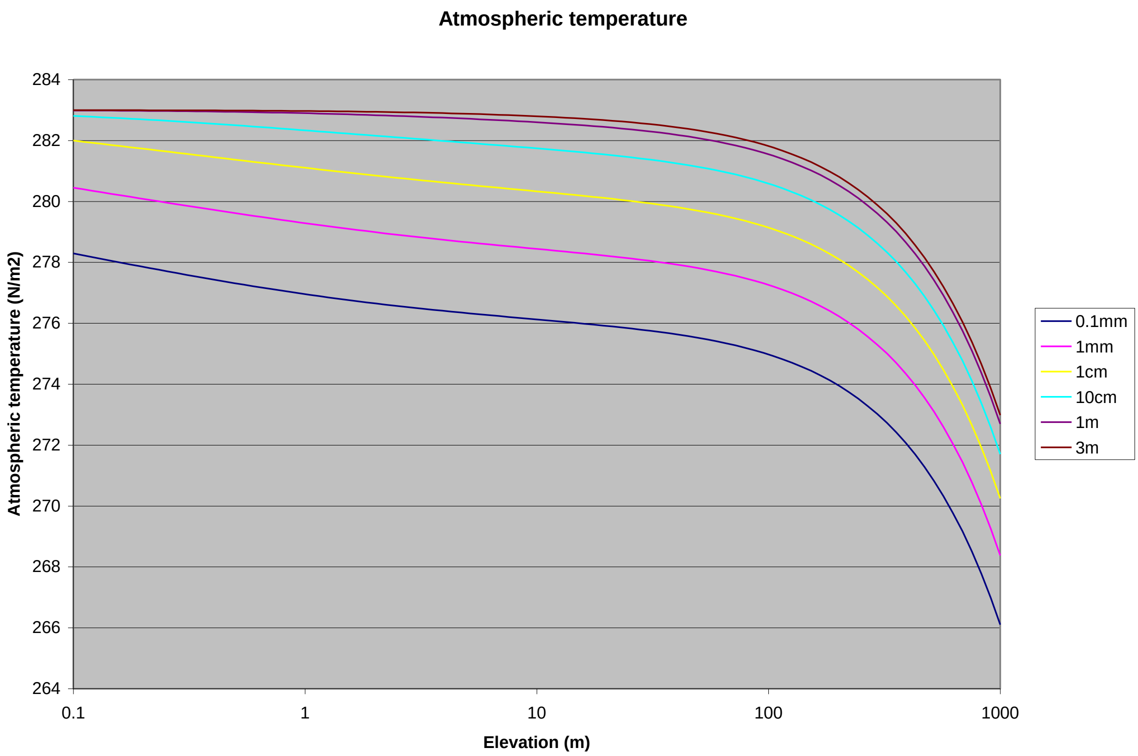


(b) Temperature Profile

Figure A5 – Temperature and wind-speed profile for the base case under stability class B

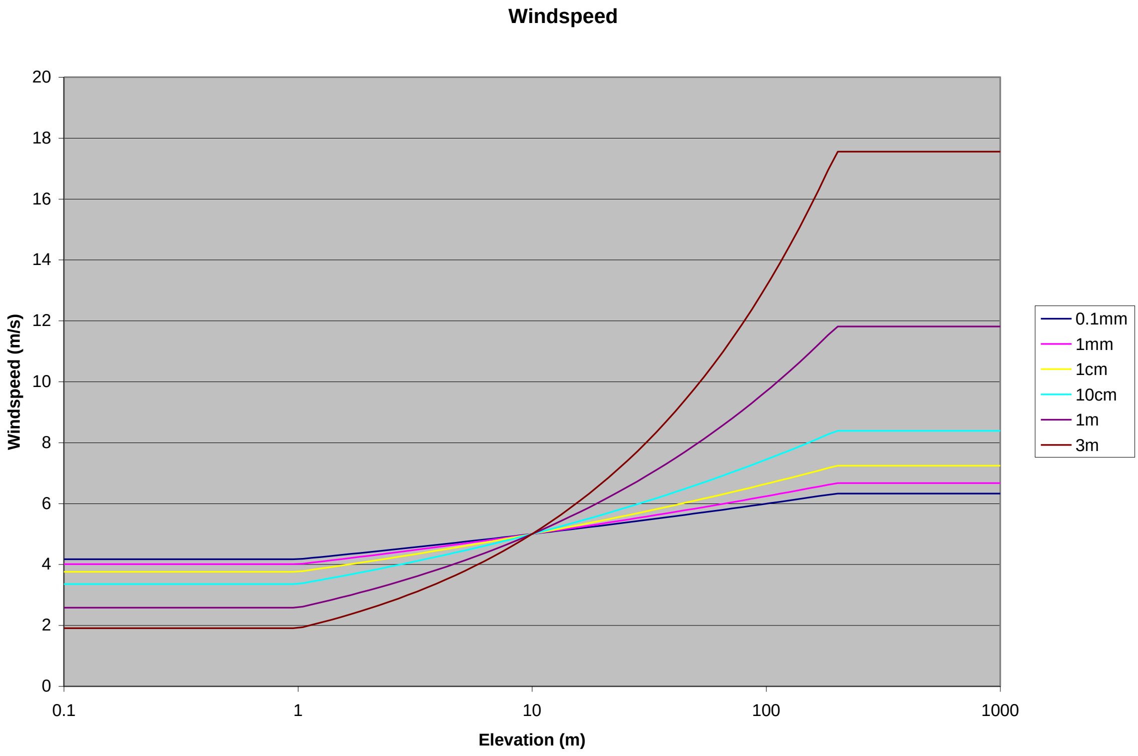


(a) Wind-speed Profile

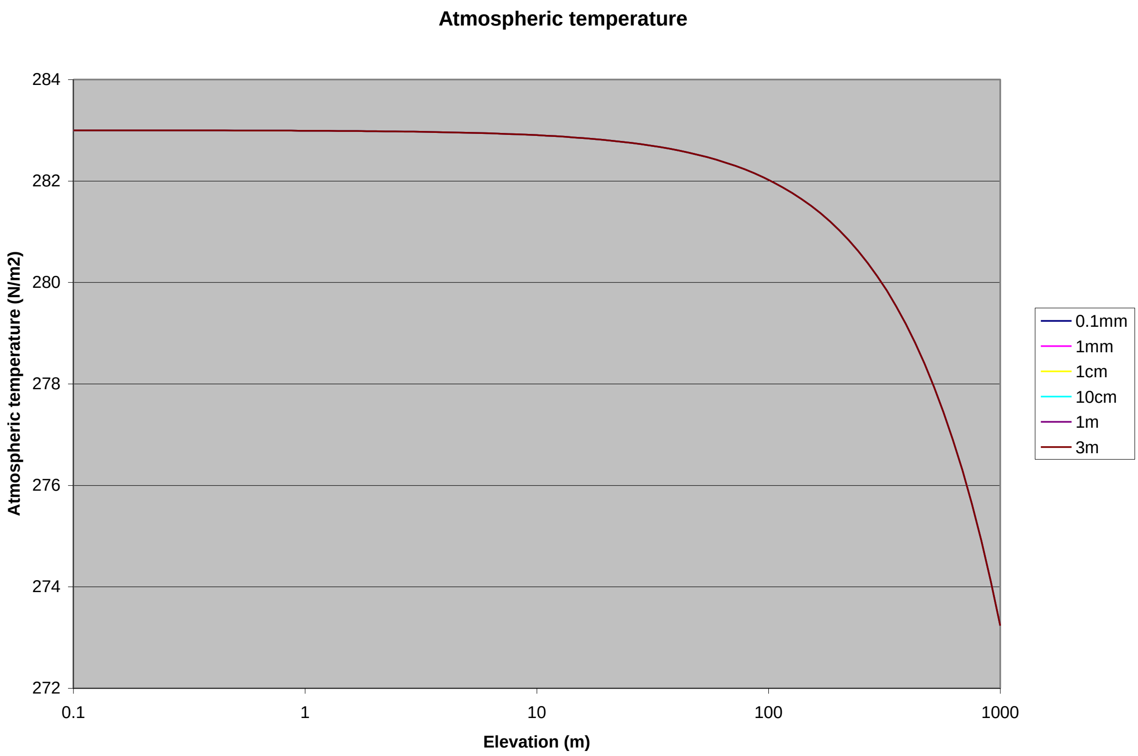


(b) Temperature Profile

Figure A6 – Temperature and wind-speed profile for the base case under stability class C

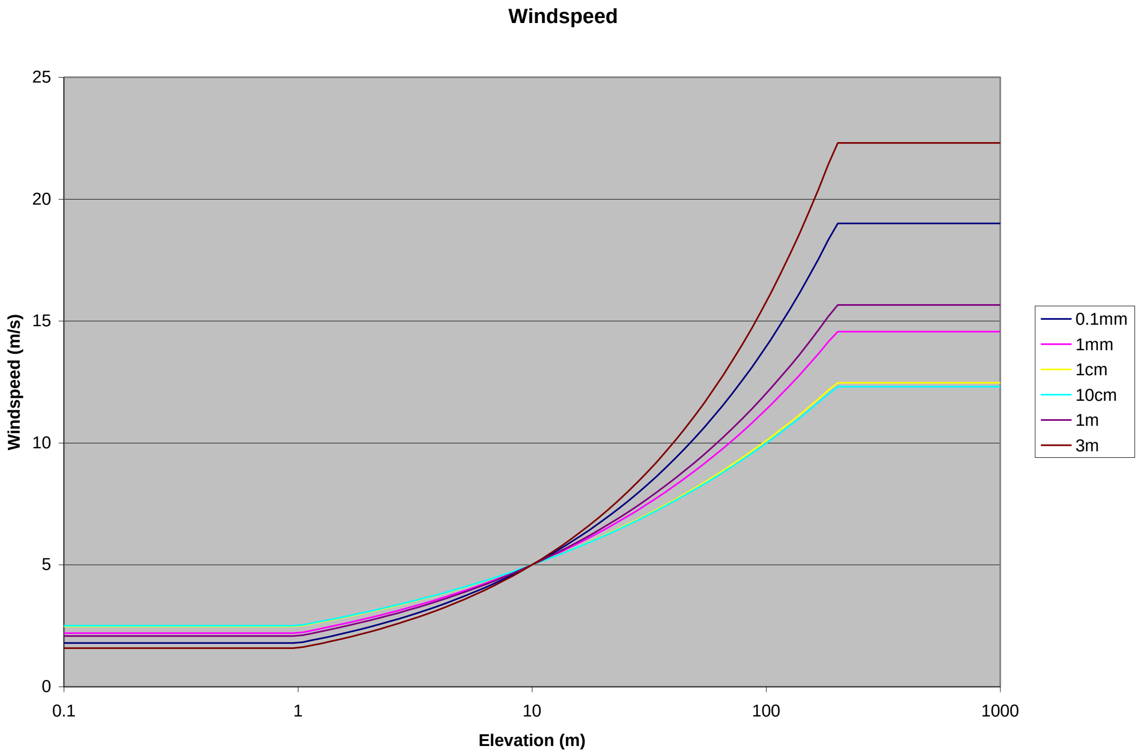


(a) Wind-speed Profile

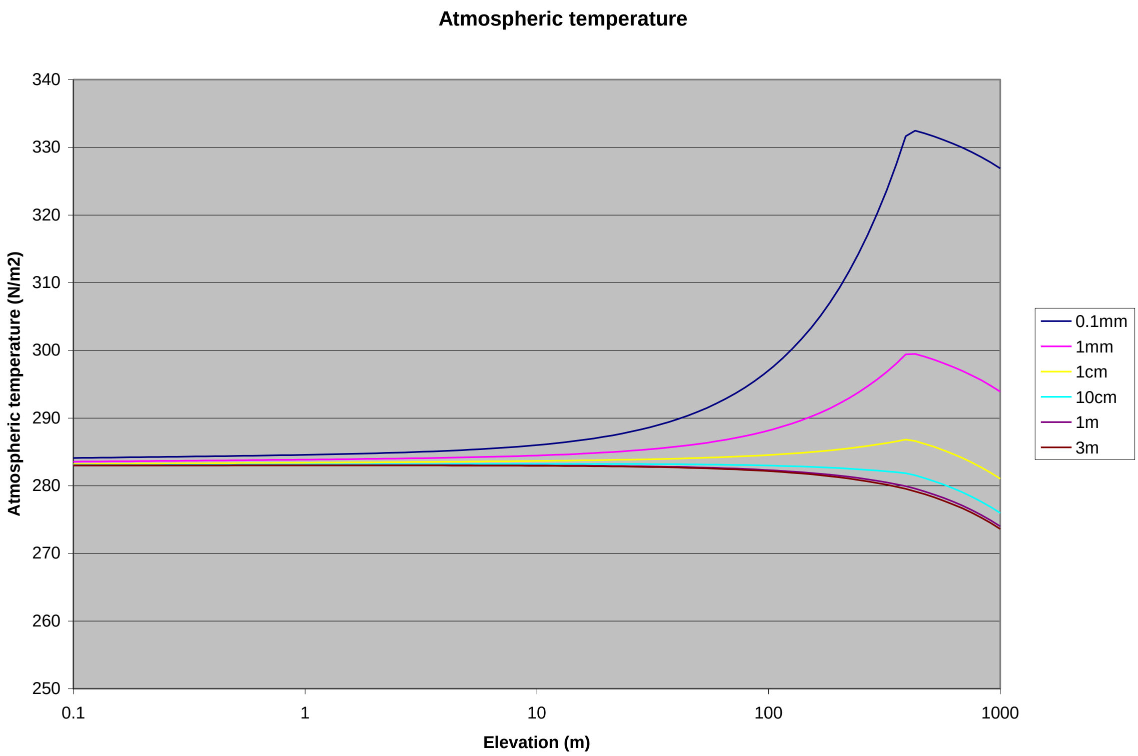


(b) Temperature Profile

Figure A7 – Temperature and wind-speed profile for the base case under stability class D



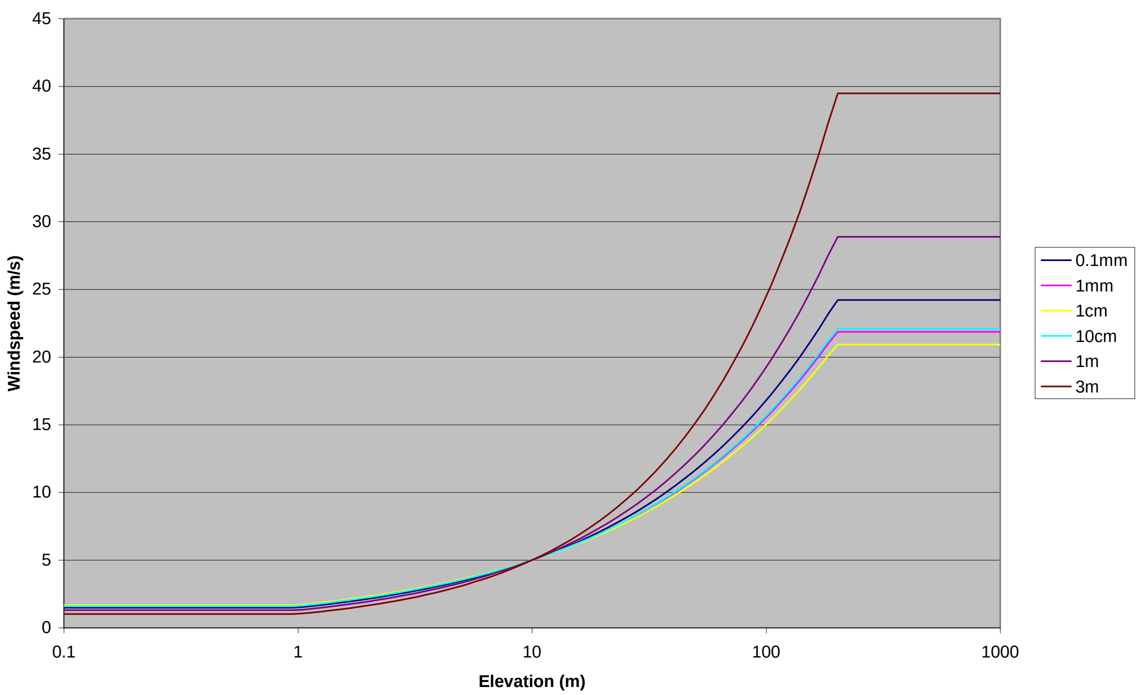
(a) Wind-speed Profile



(b) Temperature Profile

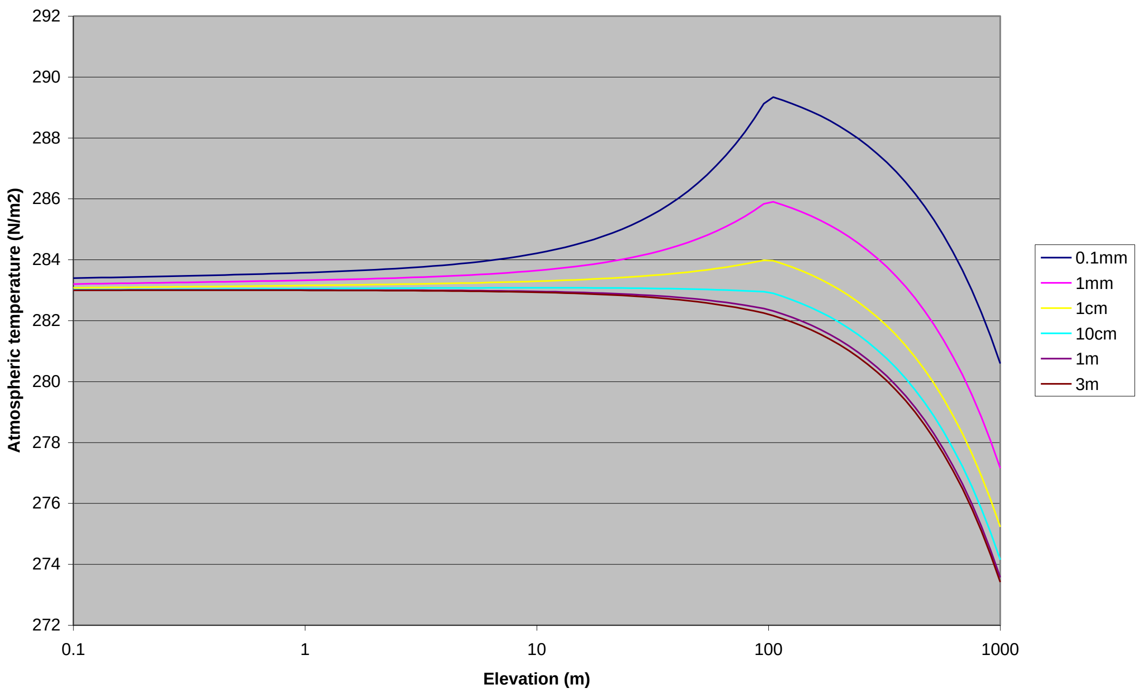
Figure A8 – Temperature and wind-speed profile for the base case under stability class E

Windspeed



(a) Wind-speed Profile

Atmospheric temperature



(b) Temperature Profile

Figure A9 – Temperature and wind-speed profile for the base case under stability class F

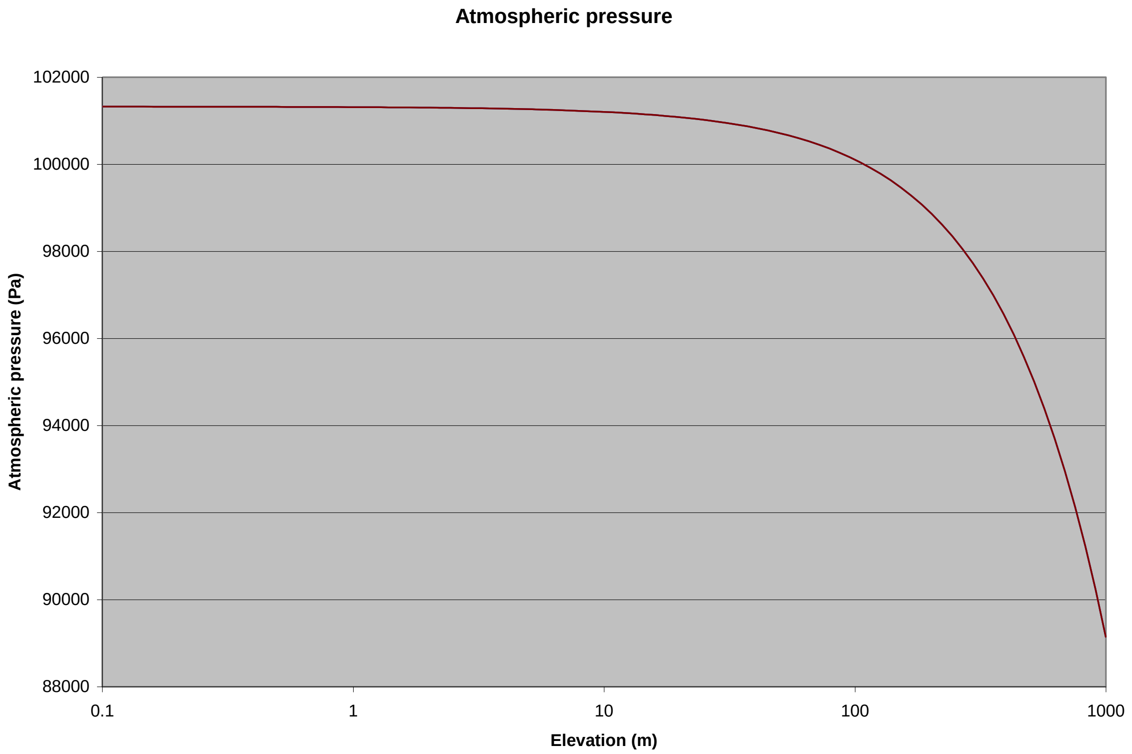


Figure A10 – Atmospheric Pressure profile

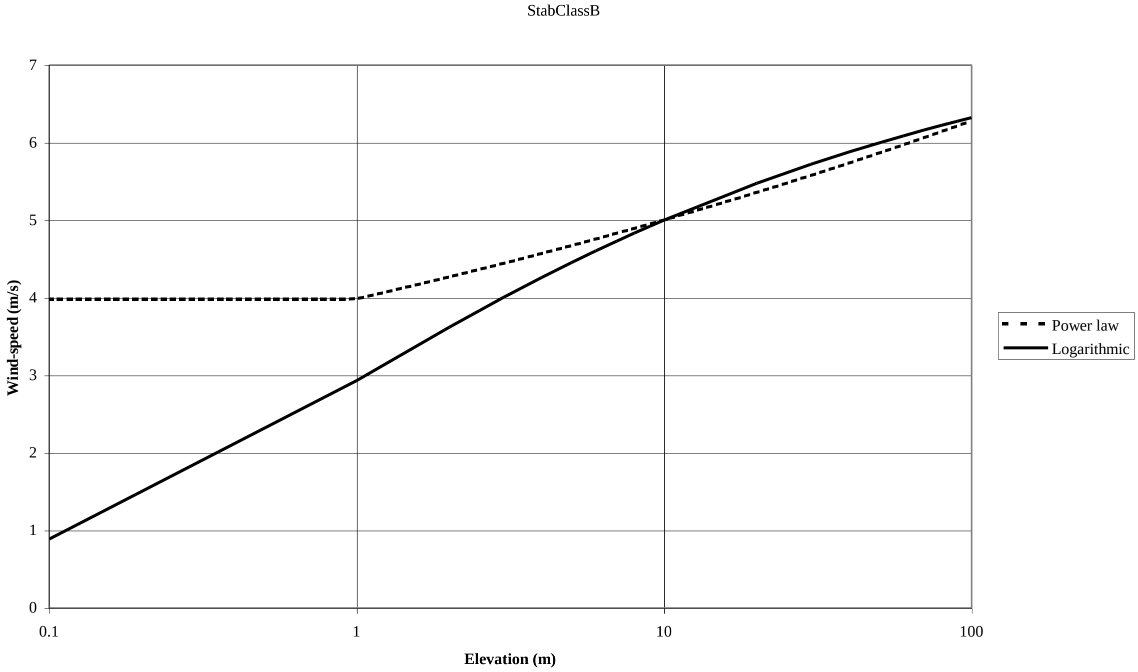
A.4 Comparison differing wind-speed and temperature profiles

Figure A11 compares the logarithmic and power law wind-speed profiles for the basecase, using stability classes B, D and F. The wind-speeds are in close agreement except in the region below the lower cut-off height (default value 1 m). This difference will be seen to have greatest effect on heavy shallow clouds.

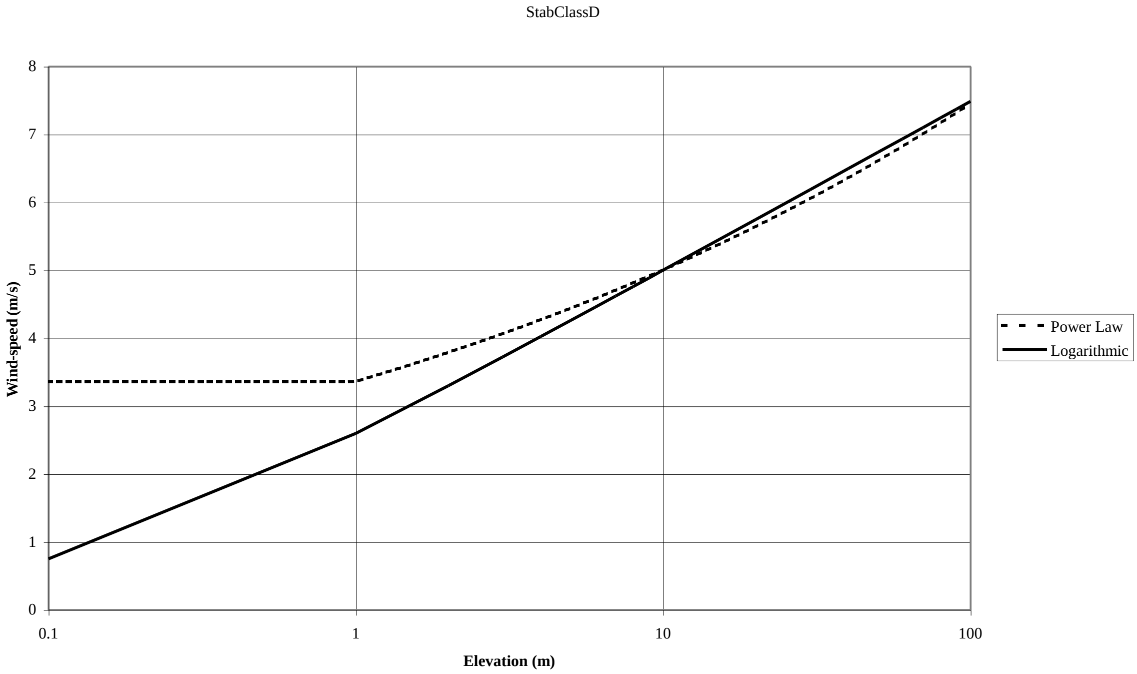
Figure A12 compares the logarithmic and linear temperature profiles for the base case under stability classes B, D and F. For stable and unstable conditions, the logarithmic and linear profiles give differing results but similar trends. For neutral conditions, identical results are obtained since both profiles give temperature gradients equal to the adiabatic lapse rate.

A.5 Further Work

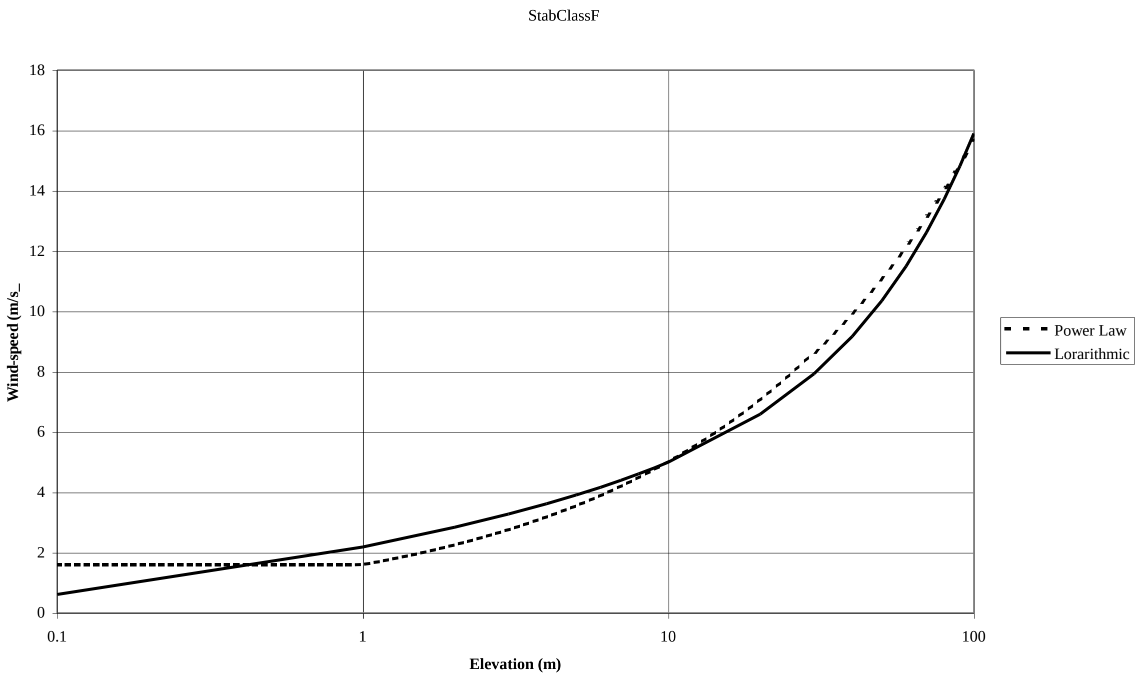
- Further check the value of β that is used in the wind-speed profile for stable weather conditions.
- Check and justify the default cut-off values for windspeed at 1 m and 200 m.
- Values for surface heat flux H_o need further checking against Clarke's paper.
- To further check the validity of the ambient profiles for low surface roughness length and stable conditions.



(a) Stability class B



(b) Stability class D



(c) Stability class F

Figure A11 Comparison of logarithmic and power law wind-speed profiles

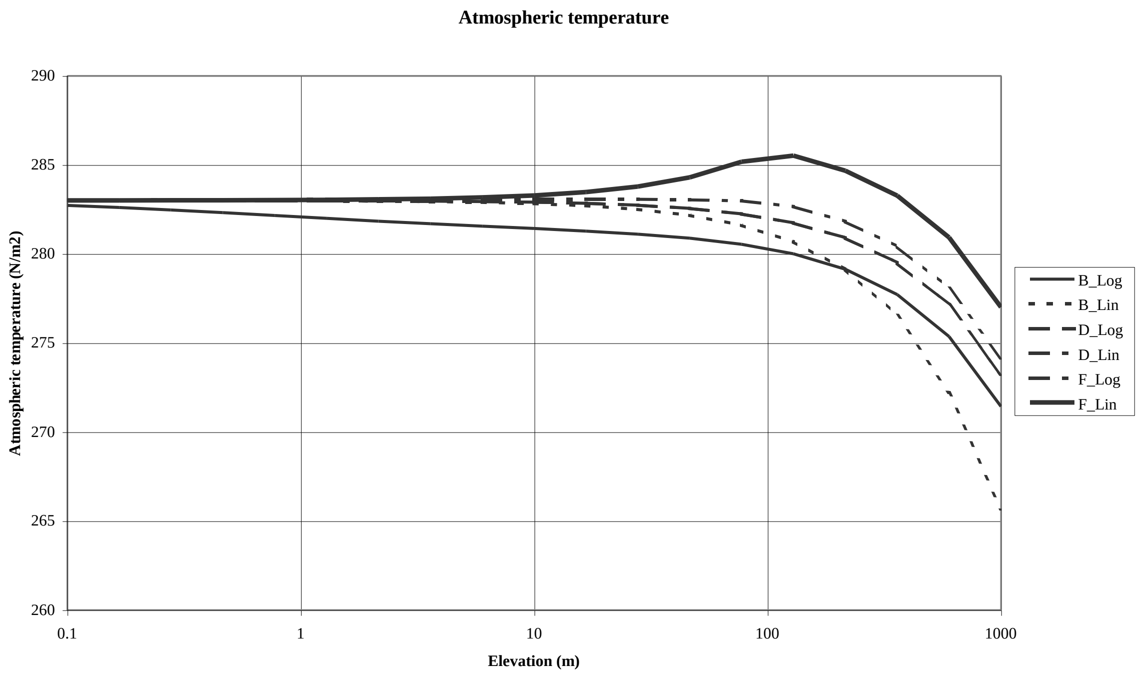


Figure A12 Comparison of logarithmic and linear temperature profiles for the base case under stabilities B, D and F

SPREADSHEETS

Figure A1, A2, A3 – From spreadsheets for A4 – A9 below
Figure A4 – AMBI_Vary_SR_A.xls
Figure A5 – AMBI_Vary_SR_B.xls
Figure A6 – AMBI_Vary_SR_C.xls
Figure A7 – AMBI_Vary_SR_D.xls
Figure A8 – AMBI_Vary_SR_E.xls
Figure A9 – AMBI_Vary_SR_F.xls
Figure A10 - AMBI_Vary_SR_D.xls
Figure A11 – B_D_F_Log_PowerLaw_Profile.xls (log profile not allowed)
Figure A12 – B_D_F_Log_Lin_Temp_Profile.xls (log profile not allowed)

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REFERENCES

[i] Irwin, J. S., “A Theoretical Variation of the Wind Profile Power Law Exponent as a Function of Surface Roughness and Stability”, Atmos. Environment 13, pp. 191-194 (1979)