EAS270, "The Atmosphere" 2nd Mid-term Exam 2 Nov. 2016

Professor: J.D. Wilson Time available: 50 mins Value: 25%

No formula sheets; no use of tablet computers etc. or cell phones. **Formulae/data at back**.

Multi-choice (25 x 1 → 25 %)

1. Referring to Figure (1), which statement is **false**?
   (a) A,B,C lie in the shortwave radiation band
   (b) D,E lie in the longwave radiation band
   (c) The atmosphere is almost completely transparent at C
   (d) Waveband C would be ideal for nocturnal viewing of earth from satellites ✗✗
   (e) The high absorbtivity at $\lambda > 20\,\mu$m is due to greenhouse gases

2. Referring to Figure (2), select the correct pair of values for the temperature lapse rate ($\Delta T/\Delta z$) in respectively the lower and the upper layers. (Note: a temperature *change* of 1°C is the same as a change of 1 K).
   (a) $-0.01\ \mathrm{K\,m^{-1}}$, $-0.005\ \mathrm{K\,m^{-1}}$
   (b) $-0.01\ \mathrm{K\,m^{-1}}$, $-0.002\ \mathrm{K\,m^{-1}}$ ✓✓ Read $\Delta T/\Delta z$ off graph.
   (c) $-0.02\ \mathrm{K\,m^{-1}}$, $-0.002\ \mathrm{K\,m^{-1}}$
   (d) $-0.02\ \mathrm{K\,m^{-1}}$, $-0.005\ \mathrm{K\,m^{-1}}$
   (e) $-0.05\ \mathrm{K\,m^{-1}}$, $-0.005\ \mathrm{K\,m^{-1}}$

3. Referring to Figure 3, which option gives correct units for the vertical axis (spectral emission rate from a black body) and for the area under the curve (emitted radiant energy flux density)?
   (a) $\mathrm{W\,m^{-2}}$, $\mathrm{W\,m^{-2}}$
   (b) $\mathrm{W\,m^{-2}\,\mu m^{-1}}$, W
   (c) $\mathrm{W\,m^{-2}\,\mu m^{-1}}$, $\mathrm{W\,m^{-2}}$ ✓✓
   (d) $\mathrm{W\,m^{-2}\,\mu m^{-1}}$, $\mathrm{W}\,\mu m^{-1}$
   (e) $\mathrm{W\,\mu m^{-1}}$, $\mathrm{W}\,\mu m$

4. If a certain body has longwave emissivity $\epsilon = 0.96$ and its temperature is $T = 18$°C, which option most closely states the wavelength λ_{max} of the peak in its thermal emission spectrum and its full-spectrum rate of emission E of longwave radiation?
   (a) $10\,\mu$m, $390\ \mathrm{W\,m^{-2}}$ ✓✓
   (b) $10\,\mu$m, $6 \times 10^{-3}\ \mathrm{W\,m^{-2}}$
   (c) $100\,\mu$m, $390\ \mathrm{W\,m^{-2}}$
   (d) $1\,\mu$m, $410\ \mathrm{W\,m^{-2}}$
   (e) $0.1\,\mu$m, $410\ \mathrm{W\,m^{-2}}$

5. Which statement in regard to Figure (4) is **false**?
   (a) each of Q^*, Q_H, Q_E quantifies an energy flux density oriented along the *vertical* axis
   (b) it is implicit (assumed) horizontal energy flows are irrelevant
   (c) above the laminar sublayer on ground surfaces, the transport mechanism for sensible & latent heat (Q_H, Q_E) is convection
   (d) Q_G (sometimes symbolized ΔQ_S) is the rate at which energy is stored/released below the reference plane
   (e) times of sunrise & sunset coincide with sign changes in net radiation (Q^*) ✗✗

6. Suppose on a sunny summer afternoon the net radiation over a flat field of bare soil were $Q^* = 500$ W m^{-2}, and the sensible and latent heat fluxes were $Q_H = 180,\ Q_E = 300$ W m^{-2}. What was the soil heat flux Q_G?
   (a) 980 W m^{-2}
   (b) 480 W m^{-2}
   (c) 120 W m^{-2}
   (d) 20 W m^{-2} ✓✓
   (e) -980 W m^{-2}

7. Compute absolute humidity ρ_v if vapour pressure $e = 1.1$ kPa and temperature $T = 23^{\circ}$C.
   (a) 8×10^{-3} kg m^{-3} ✓✓
   (b) 8×10^{-6} kg m^{-3}
   (c) 0.1 kg m^{-3}
   (d) 1×10^{-4} kg m^{-3}
   (e) 8 g kg^{-1}

8. What is the RH of air with temperature $T = 6^{\circ}$C and vapour pressure $e = 7$ hPa?
   (a) 95%
   (b) 75% ✓✓
   (c) 65%
   (d) 55%
   (e) 45%

9. Which property is **not** constant, for an air parcel undergoing unsaturated, adiabatic vertical motion?
   (a) mixing ratio r
   (b) specific humidity q
   (c) potential temperature θ
   (d) vapour pressure e ✗✗

10. Suppose planet A at distance r_A from its star (or sun) has solar constant S_A. What is the solar constant ("S_B") for planet B, orbiting the same star at distance $r_B = 4\, r_A$?

(a) $4\, S_A$
(b) $16\, S_A$
(c) $S_A/4$
(d) $S_A/16$ ✓✓
(e) $S_A/64$

11. A hypothetical "radiative equilibrium temperature" T_{E} can be calculated as the mean temperature of an isothermal earth (of radius r_E) that has no atmosphere, based on an energy balance of form

$$\underset{I}{\frac{dT_E}{dt}} \;\propto\; \underset{II}{\pi\, r_E^2\, (1 - r_s)\, S_0} \;-\; \underset{III}{4\pi\, r_E^2\, \sigma\, T_E^4}$$

where the term on the left is the rate of warming or cooling (change in T_E per unit change in time t), r_s is the albedo (shortwave reflectivity), S_0 the solar constant, σ the Stefan-Boltzmann constant, and $\propto$ means "is proportional to". Which term(s) is/are set to zero in order to compute the radiative equilibrium temperature?

(a) I ✓✓ (b) I, II (c) I, III (d) I, II, III (e) III

12. Suppose a pilot, flying at midday through the middle of a deep cloud layer, observes a brighter region towards the sun. Which best describes the colour of this sunlight?

(a) reddish light
(b) bluish light
(c) milky white light ✓✓
(d) yellow-brown light

13. At the time of the southern hemisphere summer solstice (solar declination $\delta = -23.5^{\circ}$), what is the noon solar elevation at latitude $\phi = +23.5^{\circ}$ (which is in the northern hemisphere)? (See given equation)

(a) 90°
(b) 66.5°
(c) 43° ✓✓
(d) 23.5°
(e) 0°

14. Based on Figure (5), at what time did the daily maximum in surface temperature occur? (Note: Local Standard Time was UTC - 7).
    (a) 0/24 UTC
    (b) 21 UTC ✓✓
    (c) between 19 and 20 UTC
    (d) 13 UTC
    (e) 3 UTC

15. Assuming Figure (6) applies during a period of cloudless summer weather, which interpretive statement is **false**?
    (a) the layer identified as "free air" also classifies as being an inversion
    (b) the "Residual Layer" is well-mixed (i.e. neutral) with respect to unsaturated adiabatic motion
    (c) this diagram is characteristic of mid-afternoon conditions ✗✗
    (d) the "free air" is unconditionally stable
    (e) the sensible heat flux Q_H is negative in the surface inversion, and zero in the Residual Layer

16. Referring to Figure (7), over what interval of time was the atmospheric surface layer unstably stratified?
    (a) midnight to 07:00
    (b) 17:30 to midnight
    (c) midnight to 07:00 and 17:30 to midnight
    (d) 07:00 to 17:30 ✓✓
    (e) 05:30 to 20:00

17. Referring to Figure (8), what is the temperature T if the vapour pressure is $e = 4$ kPa?
    (a) $-20°$C
    (b) 0°C
    (c) 20°C
    (d) 29°C
    (e) T cannot be determined from the given information ✗✗

18. Referring to Figure (9), which statement is **true**?

   (a) the middle layer is neutral with respect to unsaturated adiabatic motion ✓✓
   (b) until it rose above level z, an unsaturated parcel rising from the surface would be subject to a downward buoyancy force F_B
   (c) in middle layer, potential temperature decreases with increasing height
   (d) the uppermost layer is absolutely unstable
   (e) the surface layer is an inversion

19. Using Figure (10), deduce an *approximate* value for the potential temperature of air with $(P, T) = (400\,\text{hPa}, -60°\text{C})$, taking the reference pressure as 1000 hPa.

   (a) $-22°$C
   (b) -22K
   (c) $-2°$C
   (d) $+4°$C ✓✓
   (e) $+22°$C

20. Again referring to Figure (10), suppose the surface pressure, temperature and dewpoint were respectively (1000hPa, 10°C, $-20°$C). Using Normand's Rule, estimate the pressure at the Lifting Condensation Level.

   (a) 510 hPa
   (b) 630 hPa ✓✓
   (c) 680 hPa
   (d) 850 hPa
   (e) 1000 hPa

21. If the Level of Free Convection is at height $z_{\text{LCL}} = 500\,\text{m}$ AGL (above ground level) and the surface temperature is $T = 23°$C, what is the surface dewpoint T_d?

   (a) $-4°$C
   (b) 4°C
   (c) 11.5°C
   (d) 19°C ✓✓
   (e) 27°C

22. What is signified by the heavy dashed line on Figure (11) that has been added by the instructor?
    (a) ridge in the 500 hPa height field
    (b) trough in the 500 hPa height field
    (c) thermal (thickness) ridge ✓✓
    (d) thermal trough
    (e) possibility of freezing rain

23. What is signified by the pattern of stippling on Figure (11)?
    (a) possibility of freezing rain
    (b) thickness lies in the interval $534 \leq \Delta Z \leq 540$ dam ✓✓
    (c) temperature-dewpoint spread $T_{\mathrm{dd}} \leq 2$ K
    (d) temperature below freezing
    (e) probable path for the upper low to follow

24. Based on Figure (11), which statement regarding the short term (say, 1 hour) weather trend at the point denoted "**X**" (north of "SASK.") is most plausible?
    (a) advective warming ✓✓
    (b) advective cooling
    (c) radiative cooling
    (d) frost
    (e) rain

25. Referring to Figure (12), which statement correctly distinguishes the expected 1-hour advective temperature trends at the points (A,B,C)?
    (a) A warming, B cooling, C cooling
    (b) A cooling, B warming, C cooling
    (c) A unchanging, B warming, C warming
    (d) A unchanging, B cooling, C warming ✓✓
    (e) A warming, B warming, C warming

Equations and Data.

- $E = \epsilon \, \sigma \, T^4$. Stefan-Boltzmann law. E [W m^{-2}], the emitted longwave energy flux density; ϵ, the emissivity of the surface (dimensionless); $\sigma = 5.67 \times 10^{-8}$ [W m^{-2} K^{-4}], the Stefan-Boltzmann constant; T [K], the surface temperature.

- $\lambda_{\max} = \frac{2897}{T}$. Wien's displacement law. $\lambda_{\max}$ [μm], the wavelength at which the peak in the emission spectrum occurs; T [K], the temperature of the emitting surface.

- $\alpha = 90^o - |\phi - \delta|$. Solar elevation α at local solar noon time, at a location having latitude ϕ (negative in the S. hemisphere), at the time of year when solar declination is δ (δ is negative during northern hemisphere winter, and at the time of the solstices its *magnitude* is 23.5^o).

- $Q^* = Q_H + Q_E + \Delta Q_S$. Surface energy balance on a reference plane at the base of the atmosphere. Q^* the net radiation, positive if directed towards the surface; Q_H, Q_E the sensible and latent heat fluxes, positive if directed from the surface towards the atmosphere; ΔQ_S (sometimes denoted Q_G) the storage term, positive if directed from the surface into ground/lake/ocean.

- $e = \rho_v \; R_v \; T$. The ideal gas law for water vapor. e [Pa], vapour pressure; ρ_v, [kg m^{-3}] the absolute humidity (ie. vapor density); T [Kelvin], the temperature; and $R_v = 462$ [J kg^{-1} K^{-1}], the specific gas constant for water vapor.

- $F_B = g \, \frac{T_p - T}{T} = g \, \frac{\theta_p - \theta}{\theta}$. The buoyancy force on a parcel whose temperature is T_p (and potential tempertaure is θ_p) at a level where the environmental temperature and potential temperature are T, θ. The denominator must be in Kelvin unit. F_B is positive for an upward force.

- $z_{\rm LCL} = 125 \; (T_{\rm sfc} - T_{\rm d,sfc})$. Gives the height of the LCL in metres AGL, given the difference between surface temperature and surface dewpoint.

Table 1: Equilibrium vapour pressure $e_s(T)$ [hPa] versus temperature T [^{o}C]. Figure cited applies to equilibrium over a plane surface of water where $T \geq 0^o$C, or of ice where $T < 0^o$C.

T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$
-10	2.60	-5	4.02	0	6.11	5	8.72	10	12.27	15	17.04	20	23.37	25	31.67
-9	2.84	-4	4.37	1	6.57	6	9.35	11	13.12	16	18.17	21	24.86	26	33.61
-8	3.10	-3	4.76	2	7.05	7	10.01	12	14.02	17	19.37	22	26.43	27	35.65
-7	3.38	-2	5.17	3	7.58	8	10.72	13	14.97	18	20.63	23	28.09	28	37.80
-6	3.69	-1	5.62	4	8.13	9	11.47	14	15.98	19	21.96	24	29.83	29	40.06

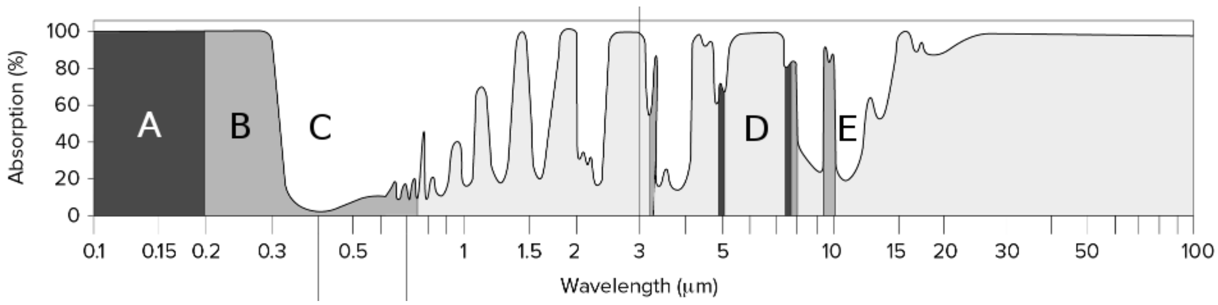

Figure 1: Radiative absorptivity of the earth's atmosphere, versus wavelength ("λ"): if, at a given wavelength, the absorptivity is 100%, then light of that wavelength is absorbed completely on a vertical path through the (whole) atmosphere. Labels (A,B,...E) each denote a characteristic region of the absorption spectrum.

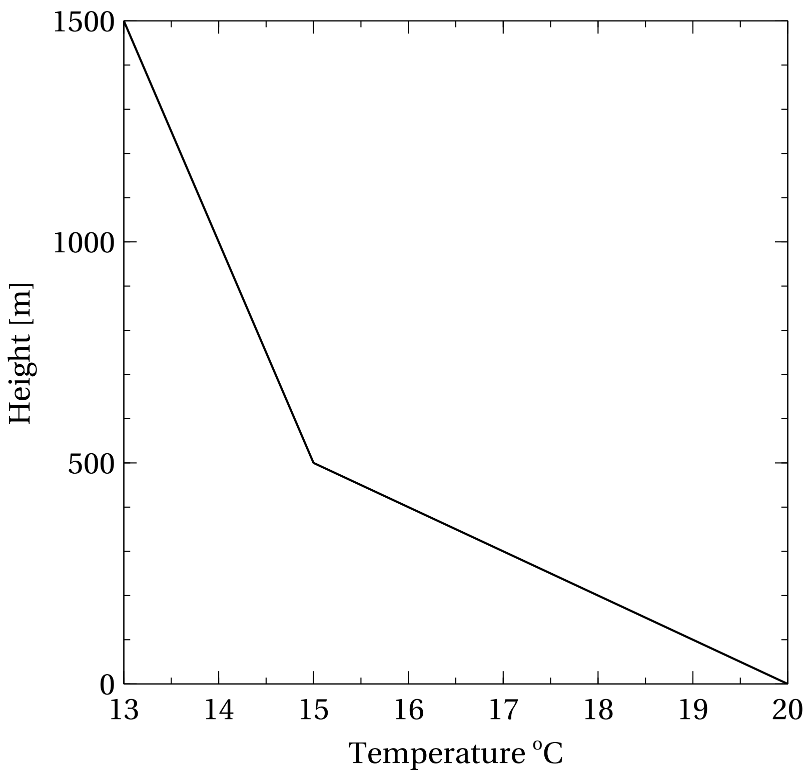

Figure 2: Idealized profile of temperature in the lowest 1500 m of the atmosphere. The "elbow" is at $(z, T) = (500\,\text{m}, 15^o\text{C})$. (Note: a temperature *change* of 1°C is the same as a change of 1 K.)

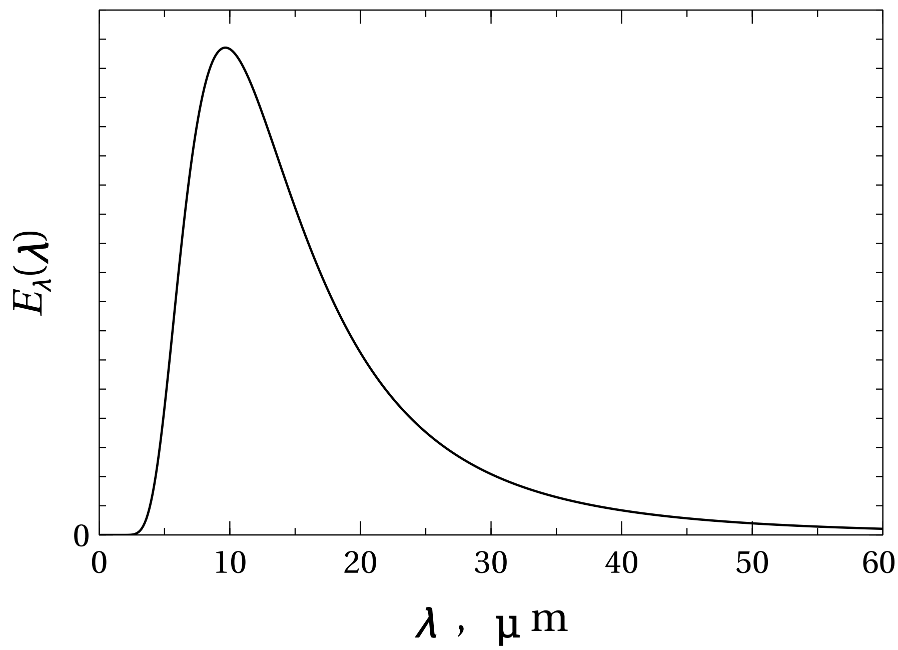

Figure 3: Planck curve for the spectral emission rate from a blackbody with temperature 300 K.

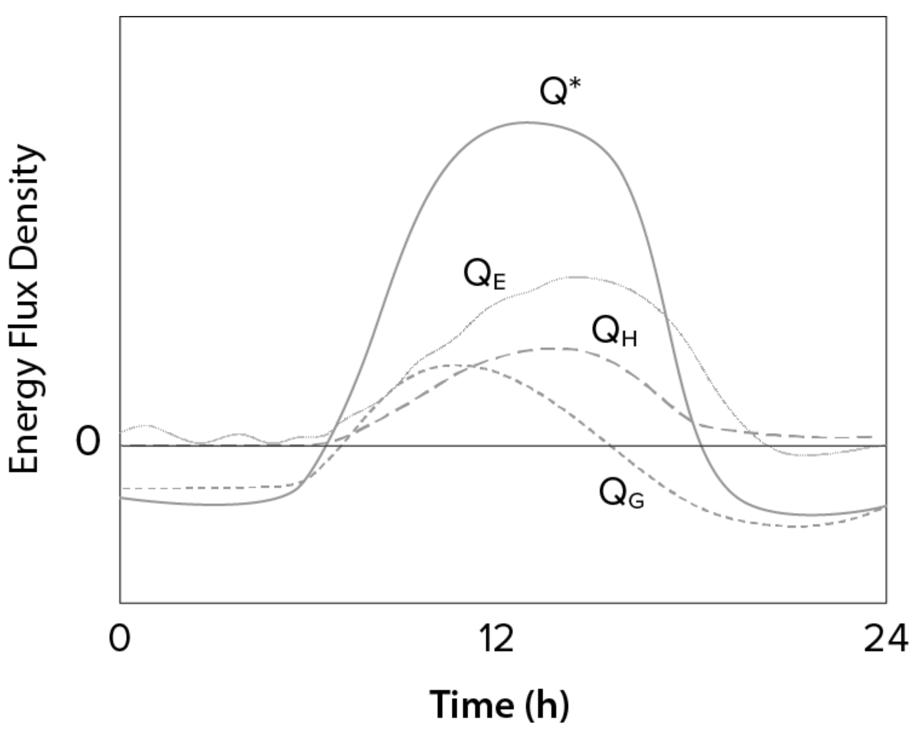

Figure 4: Idealized daily cycle in the components of the surface energy balance "for a moist, vegetated surface on a clear day in summer" (Figure 6.19 from Ross's *Weather & Climate*). Symbols are Q^* the net radiation ($= K^* + L^*$, sum of net shortwave plus net longwave radiation), positive for downward flow towards the surface; Q_H, Q_E the sensible and latent heat fluxes, positive for upward flow away from the surface; and Q_G the energy flux into storage, sometimes labelled ΔQ_s.

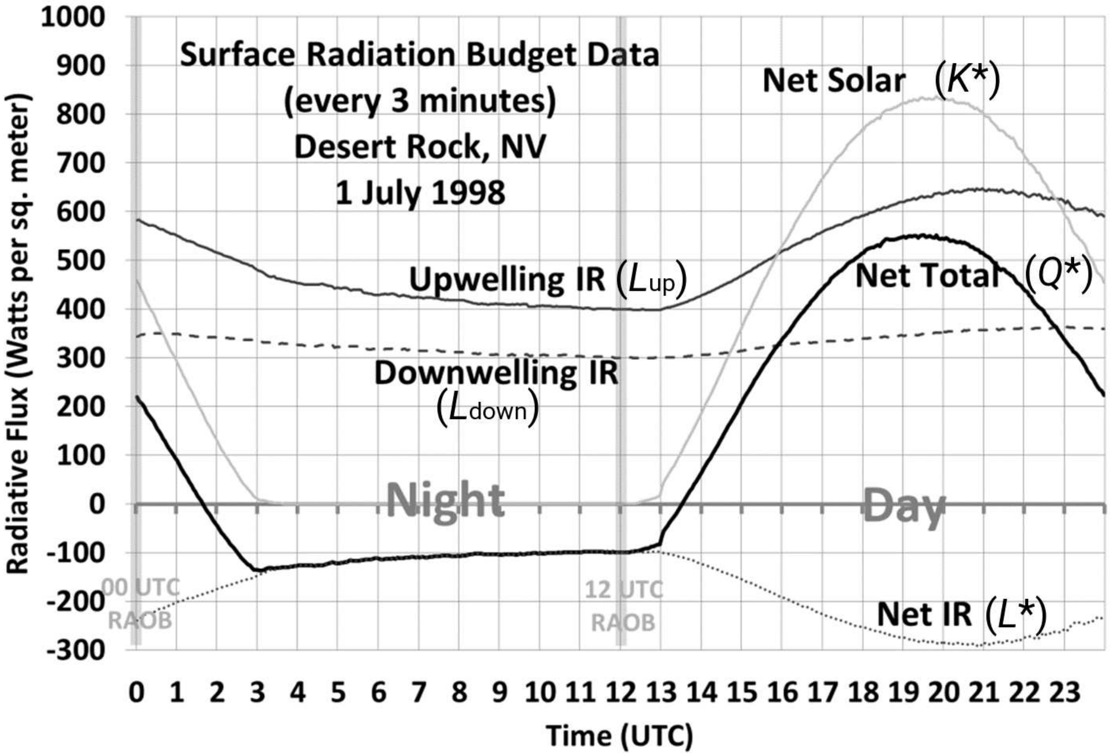

Figure 5: Variation with time of the components of the near-surface radiation budget, measured in Nevada.

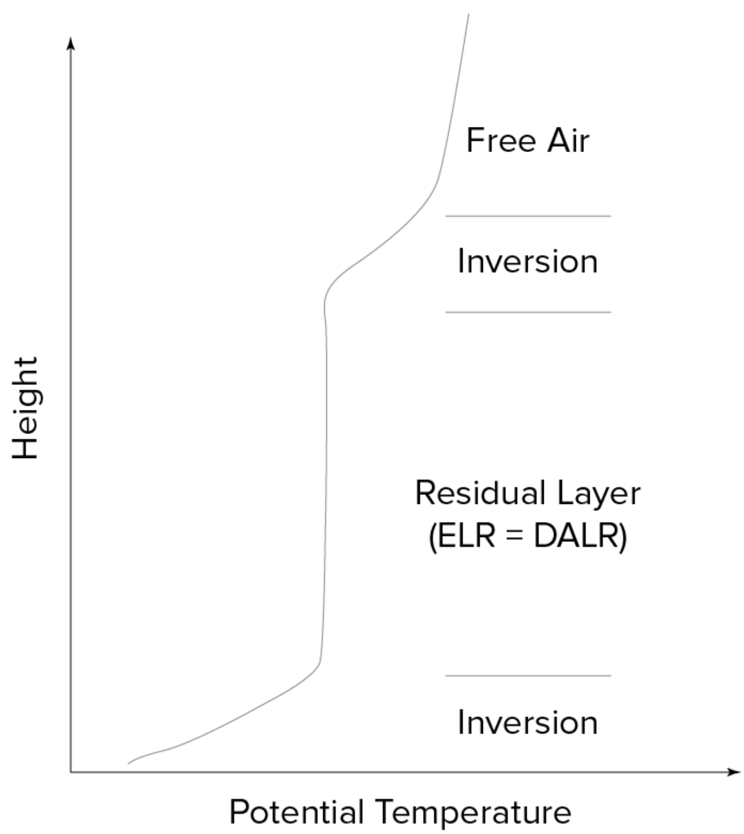

Figure 6: Idealised profile of potential temperature $\theta(z)$.

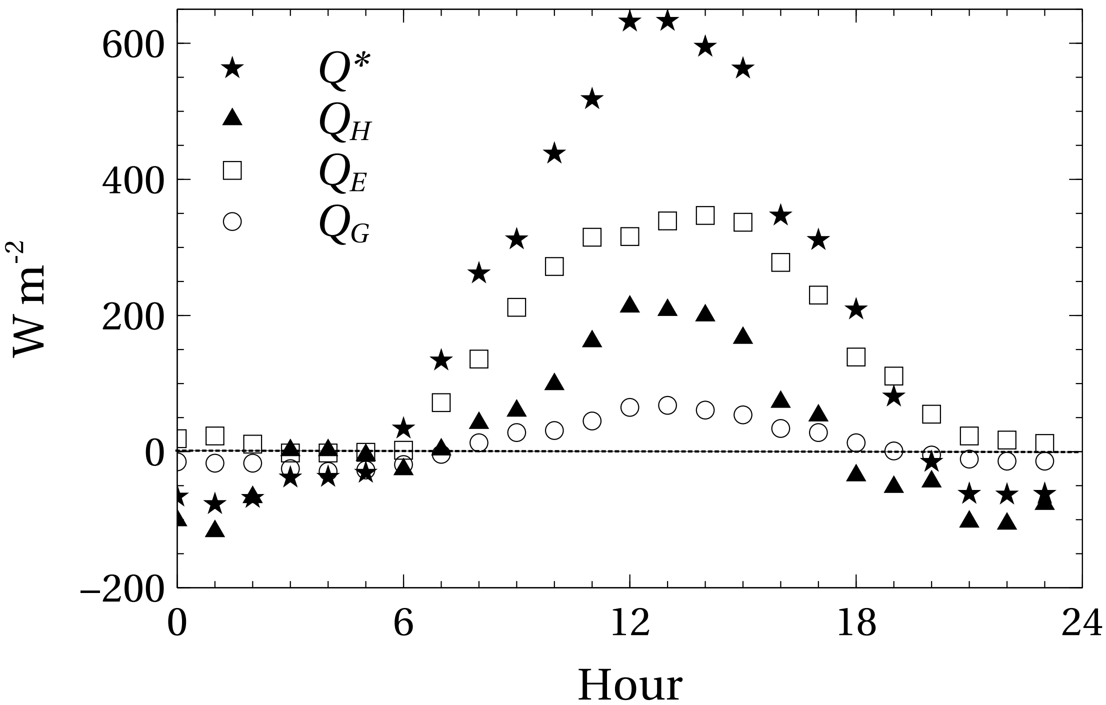

Figure 7: Variation with time of the components of the surface energy budget over grassland in Alberta (1 July 2003; courtesy of L. Flanagan).

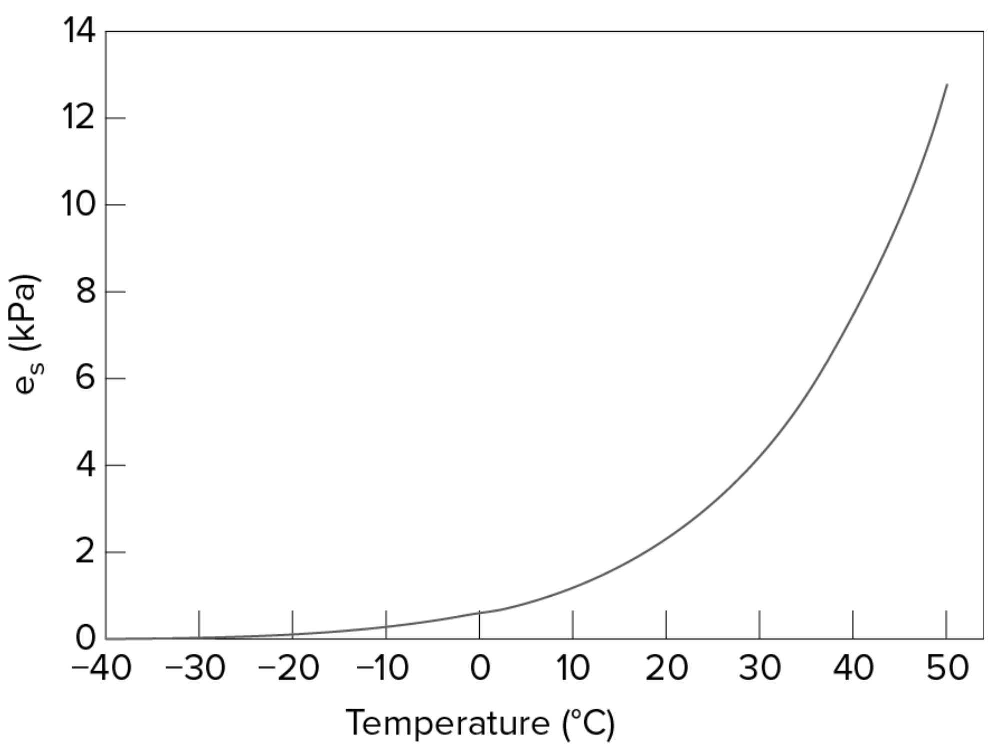

Figure 8: Curve giving equilibrium vapour pressure versus temperature. (Ross, Fig 7.4.)

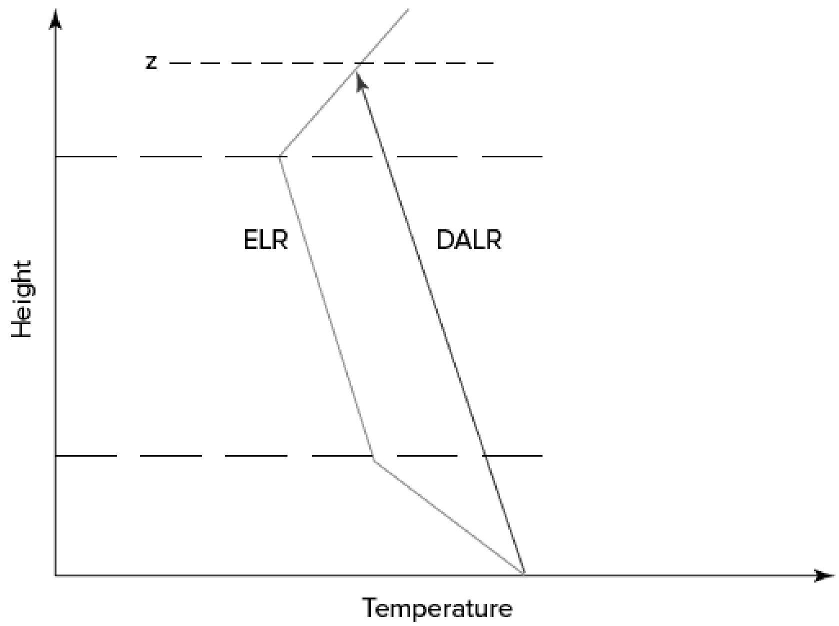

Figure 9: Idealized three-layer summer, daytime temperature profile. (Ross's Figure 8.21).

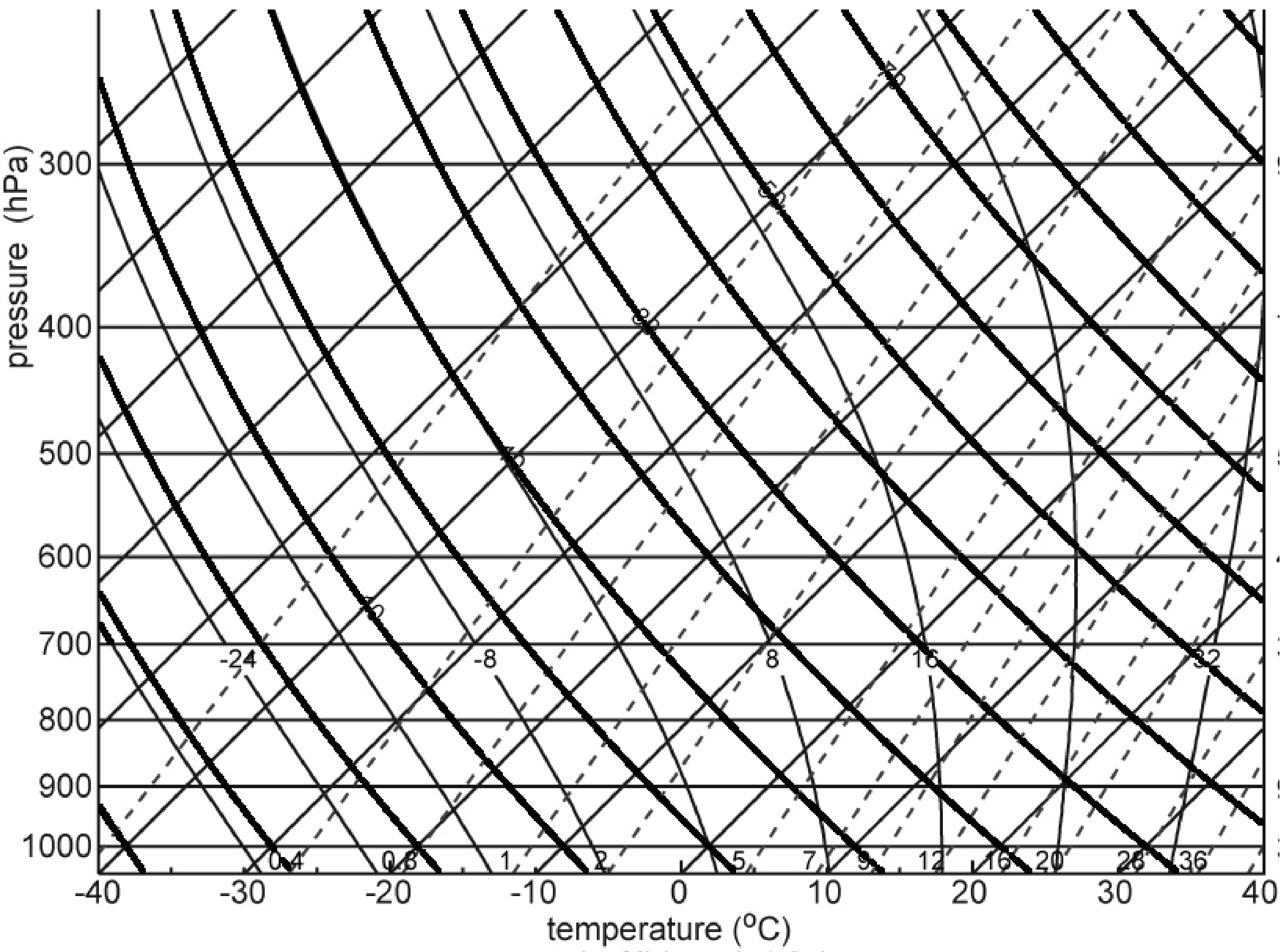

Figure 10: Blank skew-T/log-P diagram. Heavy solid curves are dry adiabats, lighter solid curves are moist adiabats, dashed lines are isohumes, and straight lines are isobars or isotherms..

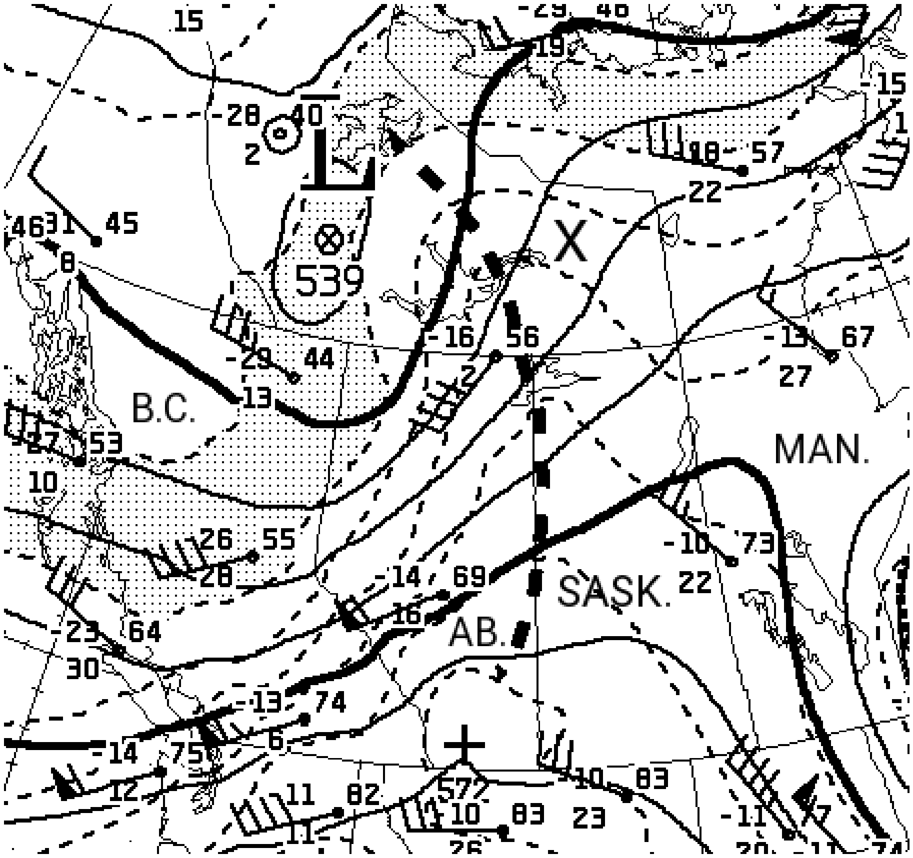

Figure 11: CMC 500 hPa analysis (cropped) for 12Z on 27 Sept. 2016. Secondary field is the 1000-500 hPa thickness, and the contour on the "warm side" of the stippled zone is the 540 dam thickness contour.

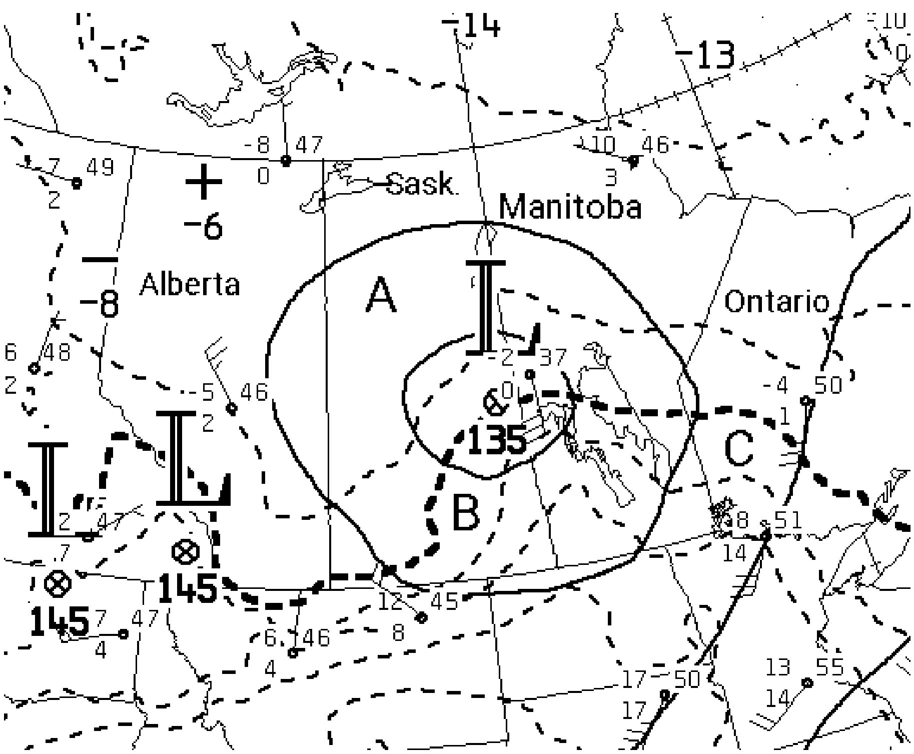

Figure 12: CMC 850 hPa analysis (cropped) for 00Z on 10 Oct. 2016.