EAS270, "The Atmosphere" 2$^{\text{nd}}$ Mid-term Exam 4 Nov. 2015

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**.

A. Multi-choice (30 x 5/6 → 25 %)

1. Referring to Figure (1), which statement is **false**? (recall Q_G is the storage term, i.e. heat added to the soil, air and vegetation below the reference plane).
   (a) $500 - 600\,\mathrm{W\,m^{-2}}$ is a plausible value for the maximum in Q^*
   (b) Time mark **A** denotes the time at which energy begins to go into storage
   (c) At time **B**, net radiation Q^* is balancing the sum of the latent and sensible heat fluxes
   (d) At time 24 h, net longwave radiation L^* is negative, and balanced by heat released from storage (negative Q_G)
   (e) Over the 24 h cycle, periods of positive and negative energy flux to storage (Q_G) partially or largely cancel

2. Which statement in regard to the type of local energy budget indicated by Figure (1) is **false**?
   (a) each of Q^*, Q_H, Q_E is a *vertical* energy flow
   (b) away from solid surfaces, the transport mechanism for sensible heat is convection
   (c) Q_G is the rate at which energy goes into storage below the reference plane
   (d) it is assumed that the site is horizontally uniform (horizontal energy flows are ignored)
   (e) times of sunrise & sunset coincide with sign changes in net radiation ($Q^* \equiv K^* + L^*$)

3. Referring to Figure (2), 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) Region C is known as the "atmospheric window"
   (e) The high absorbtivity at $\lambda > 20\,\mu$m is due to greenhouse gases

4. Again referring to Figure (2), in order for a radiometer on a satellite to "see" the ground at night, it should be sensitive to radiation at (or near) which wavelength?
   (a) A
   (b) B
   (c) C
   (d) D
   (e) E

5. Rayleigh scattering is ____ , while Mie scattering is ____ .
   (a) wavelength selective and caused by air molecules (versus) non-selective with respect to wavelength and caused by aerosols
   (b) non-selective with respect to wavelength and caused by aerosols (versus) wavelength selective and caused by air molecules
   (c) wavelength selective and caused by aerosols (versus) non-selective with respect to wavelength and caused by air molecules
   (d) responsible for the whiteness of sunlit clouds (versus) responsible for the blueness of diffuse sky light

6. At the time of the southern hemisphere summer solstice ($\delta = -23.5^o$), what is the noon solar elevation at latitude $\phi = +23.5^o$ (which is in the northern hemisphere)? (See given equation)
   (a) 90^o
   (b) 66.5^o
   (c) 43^o
   (d) 23.5^o
   (e) 0^o

7. At the time of the southern hemisphere winter solstice ($\delta = +23.5^o$), what is the noon solar elevation at latitude $\phi = -66.5^o$ (which is in the southern hemisphere)? (See given equation)
   (a) 90^o
   (b) 66.5^o
   (c) 43^o
   (d) 23.5^o
   (e) 0^o

8. If earth's average surface temperature were to increase, the amount of radiation energy emitted from its surface would ____ and the wavelength (λ_{max}) of peak emission would shift towards ____ wavelengths.
   (a) increase, longer
   (b) increase, shorter
   (c) decrease, longer
   (d) decrease, shorter
   (e) increase, redder

9. Suppose the atmosphere transmitted the solar beam, whose strength above the atmosphere is $S_0 = 1365\,[\mathrm{W\,m^{-2}}]$, without absorbtion or scattering. Under that assumption, what is incoming flux density of solar beam radiation across a *horizontal* reference plane at the surface ("S") at latitude 45° north (or south) at the time of the equinox? (See given equation)

   (a) 1365
   (b) 965
   (c) 683
   (d) 318
   (e) 0

10. To emphasize the climatic importance of the atmosphere, a hypothetical "radiative equilibrium temperature" T_{E} (= 255 K) can be calculated as the mean temperature of an isothermal earth (of radius R) that is devoid of (i.e., lacking, without) an atmosphere. T_{E} is computed by balancing 70% absorption of the solar beam over area πR^2 against longwave loss from area $4\pi R^2$. Which option correctly names the 70% factor?

    (a) shortwave absorbtivity
    (b) shortwave reflectivity (albedo)
    (c) shortwave transmissivity
    (d) longwave emissivity
    (e) shortwave emissivity

11. Suppose two (otherwise identical) blackbody surfaces are at Kelvin temperatures of respectively T, $2T$. The hotter surface radiates energy at a rate that is ____ times the rate of the cooler surface. [Hint: $(a\,b)^4 = a^4\,b^4$.]

    (a) 1/2
    (b) 2
    (c) 1/4
    (d) 4
    (e) 16

12. 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 (alternatively known as the "storage" term ΔQ_s)?

    (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}

13. Which set of properties are all constant in unsaturated, adiabatic motion of an air parcel?

(a) specific humidity q and potential temperature θ
(b) specific humidity q and temperature T
(c) mixing ratio r and virtual temperature T_v
(d) vapour pressure e and temperature T
(e) saturation vapour pressure $e_*(T)$ and temperature T

14. If vapour pressure $e = 1.1$ kPa and temperature $T = 23^oC$, give the absolute humidity ρ_v.

(a) $8 \times 10^{-3}\ \mathrm{kg\,m^{-3}}$
(b) $8 \times 10^{-6}\ \mathrm{kg\,m^{-3}}$
(c) $0.1\ \mathrm{kg\,m^{-3}}$
(d) $1 \times 10^{-4}\ \mathrm{kg\,m^{-3}}$
(e) $8\ \mathrm{g\,kg^{-1}}$

15. What is the relative humidity of air having temperature $T = 6^oC$ and vapour pressure $e = 7$ hPa?

(a) 95%
(b) 75%
(c) 65%
(d) 55%
(e) 45%

16. What option is closest to the dewpoint T_d of air whose temperature and relative humidity are $T = 19^oC$ and 65%?

(a) 28°C
(b) 23°C
(c) 19°C
(d) 12°C
(e) 4°C

17. Referring to Figure (3), what pressure and temperature correspond to the point of intersection of isotherms and isobars within the heavy circle **O**?

(a) 300 Pa, 18°C
(b) 300 hPa, 18°C
(c) 300 kPa, 18°C
(d) 300 hPa, −10°C
(e) 300 hPa, −25°C

18. Referring to Figure (3), what is the correct stability category for the layer below 700 hPa?
    (a) absolutely unstable
    (b) absolutely stable
    (c) conditionally unstable
    (d) neutral with respect to unsaturated adiabatic motion
    (e) neutral with respect to saturated adiabatic motion

19. Referring to Figure (3), which level is closest to the LCL for lifted surface parcels? (Hint: Use Normand's Rule).
    (a) 925 hPa
    (b) 850 hPa
    (c) 700 hPa
    (d) 500 hPa
    (e) 250 hPa

20. Referring to Figure (3), locate the dry adiabat labelled **a**: by definition, this is a line of constant potential temperature θ. If the reference pressure is taken as 1000 hPa, then what value for the potential temperature would you assign to dry adiabat **a**?
    (a) 5°C
    (b) 0°C
    (c) -5°C
    (d) -10°C
    (e) -20°C

21. Referring to Figure (4), which statement is **false** or **without justification**?
    (a) the LFC lies at the level marked "z"
    (b) this is an idealized summer daytime scenario
    (c) the middle layer is well mixed
    (d) the surface layer is absolutely unstable
    (e) the upper layer is an inversion

22. Referring to Figure (5), which option best describes the buoyancy force F_B that will act on a parcel of dry air that rises from the surface into the mixed layer?
    (a) $F_B = 0$, no buoyancy force
    (b) $F_B > 0$, downward buoyancy force
    (c) $F_B > 0$, upward buoyancy force
    (d) $F_B < 0$, downward buoyancy force
    (e) $F_B < 0$, upward buoyancy force

23. On a certain summer afternoon cumulus cloud base height (which identifies the Lifting Condensation Level, LCL) was rather low, at $z_{\mathrm{LCL}} = 375\,\mathrm{m}\,\mathrm{AGL}$. The surface dewpoint was $T_{\mathrm{d}} = 13^{\circ}\mathrm{C}$. What was the surface temperature T?

(a) 10°C
(b) 13°C
(c) 16°C
(d) 19°C
(e) 21°C

24. Referring to Figure (6), assume that the vertical distance from the LCL to the crest of the mountain is $h = 500$ m, and that the SALR $= \Gamma_m = -0.004\,\mathrm{K\,m^{-1}}$. When the parcel arrives back at its starting level at the base of the lee slope, its final temperature (T_1) will differ from the temperature T_0 it had before it began its ascent. Choose the option correctly giving the temperature change $T_1 - T_0$, computed according to the formula

$$T_1 - T_0 = |\Gamma_d - \Gamma_m| \times h\ .$$

(a) −3 K
(b) +3 K
(c) −5 K
(d) +5 K
(e) +15 K

For the remaining questions, please refer to Figures (7, 8).

25. Referring to Figure (7), what is the heavy dotted line running from northwest B.C. into the Yukon?

(a) ridge
(b) trough
(c) dry adiabat
(d) moist adiabat
(e) ELR

26. Referring to Figure (7), what was the 1000-500 hPa thickness Δz in Edmonton (the station in central Alberta)?

(a) 571 m
(b) 571 dam
(c) 552 dam
(d) 558 dam
(e) 7.1°C

27. Referring to Figure (7), what is the meaning of the stippled band?

    (a) thickness in the range 534-540 dam
    (b) freezing rain likely to occur
    (c) extreme cold
    (d) extreme warmth

28. Referring to Figure (8), which statement regarding conditions at the station enclosed by the dotted square is **false**?

    (a) temperature-dewpoint spread $T_{\rm dd} = T - T_{\rm d} = 0$
    (b) wind is an ESE of about $5\,{\rm m\,s^{-1}}$
    (c) pressure is rising
    (d) sea-level corrected pressure is 1019.1 hPa
    (e) sky cover is 6/8

29. Referring to Figure (8), which would be your best guess as to surface wind conditions at point marked **X** (below and to the left of the **H** on the Alberta-B.C. border)?

    (a) clockwise
    (b) anticlockwise
    (c) gusty
    (d) strong easterly
    (e) calm

30. Referring to Figure (8), a station on the northern border of Alberta reports overcast sky conditions, and the "present weather" is designated by the two "dots" appearing to the left of the station symbol. What *was* the present weather?

    (a) gusting surface wind
    (b) snowing
    (c) lightning
    (d) raining
    (e) fog

Equations and Data.

- one full barb on the wind vector means 5 m s^{-1}, a solid triangle 25 m s^{-1}.
- $E = \epsilon\, \sigma\, T^4$. 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.

- $\alpha = 90^{\mathrm{o}} - |\phi - \delta|$. 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$^{\mathrm{o}}$).

- $S = S_i\ \sin\theta$. Intensity $S\,[\mathrm{W\,m^{-2}}]$ of beam radiation on a *horizontal* surface, as a function of the beam elevation angle θ above the horizontal. $S_i\,[\mathrm{W\,m^{-2}}]$ is the strength of the beam itself, i.e. the radiative flux density though a plane held perpendicular to the beam.

- $Q^* = Q_H + Q_E + \Delta Q_S$. 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.

- RH= 100 $e/e_*(T)$, $q = m_v/(m_v + m_d) = \rho_v/\rho$. Definitions of relative humidity and specific humidity, $e_*(T)$ being the "equilibrium vapour pressure" at temperature T; and ρ being the total air density.

- $\theta = T\ \left(\frac{P_{\mathrm{ref}}}{P}\right)^{R_d/c_p}$. Gives the potential temperature (θ, in K) of a parcel or air sample whose state is (P, T) with the reference pressure taken as P_{ref}. The sample temperature T is in Kelvin; $R_d = 287\,\mathrm{J\,kg^{-1}\,K^{-1}}$ is the specific gas constant for dry air; and $c_p \approx 10^3\,\mathrm{J\,kg^{-1}\,K^{-1}}$ is the specific heat capacity of air at constant pressure.

- $F_B = g\ \frac{T_p - T}{T} = g\ \frac{\theta_p - \theta}{\theta}$. 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.

- $z_{\mathrm{LCL}} = 125\ (T_{\mathrm{sfc}} - T_{\mathrm{d,sfc}})$. 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 [°C]. Figure cited applies to equilibrium over a plane surface of water where $T \geq 0$°C, or of ice where $T < 0$°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

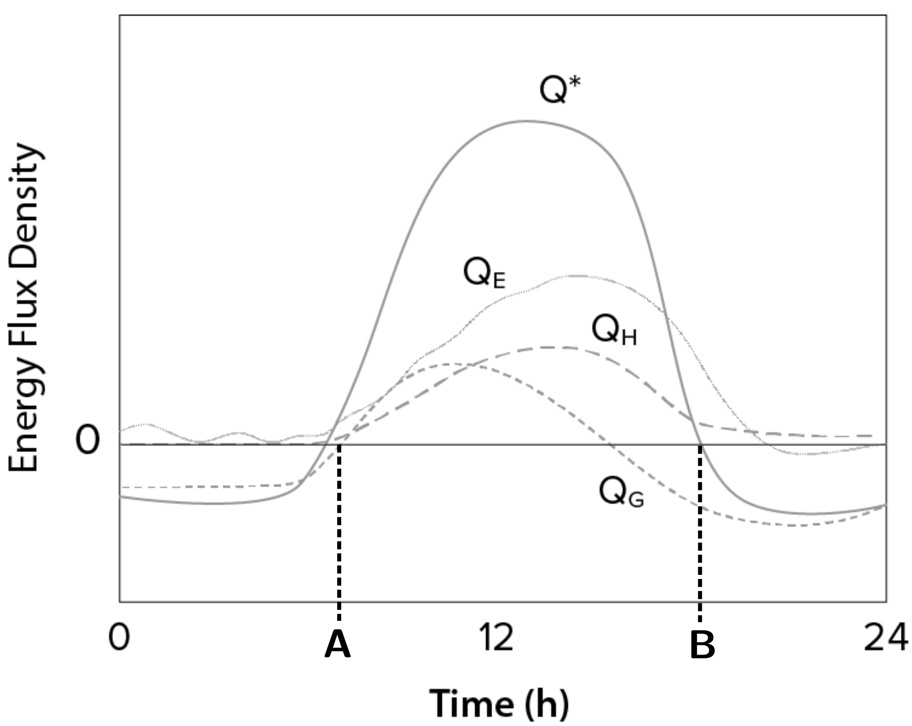

Figure 1: Idealized daily cycle in the components of the surface energy balance "for a moist, vegetated surface on a clear day in summer" (Figure 6.19 from Ross's *Weather & Climate*). Symbols are Q^* the net radiation ($= K^* + L^*$, sum of net shortwave plus net longwave radiation), positive for downward 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.

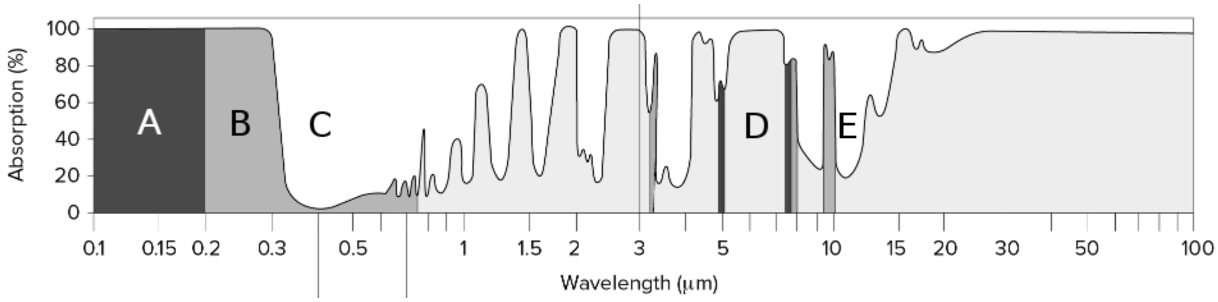

Figure 2: Radiative absorptivity of the earth's atmosphere, versus wavelength ("λ"): if, at a given wavelength, the absorptivity is 100%, then light of that wavelength is absorbed completely on a vertical path through the (whole) atmosphere. Labels (A,B,...E) each denote a characteristic region of the absorption spectrum.

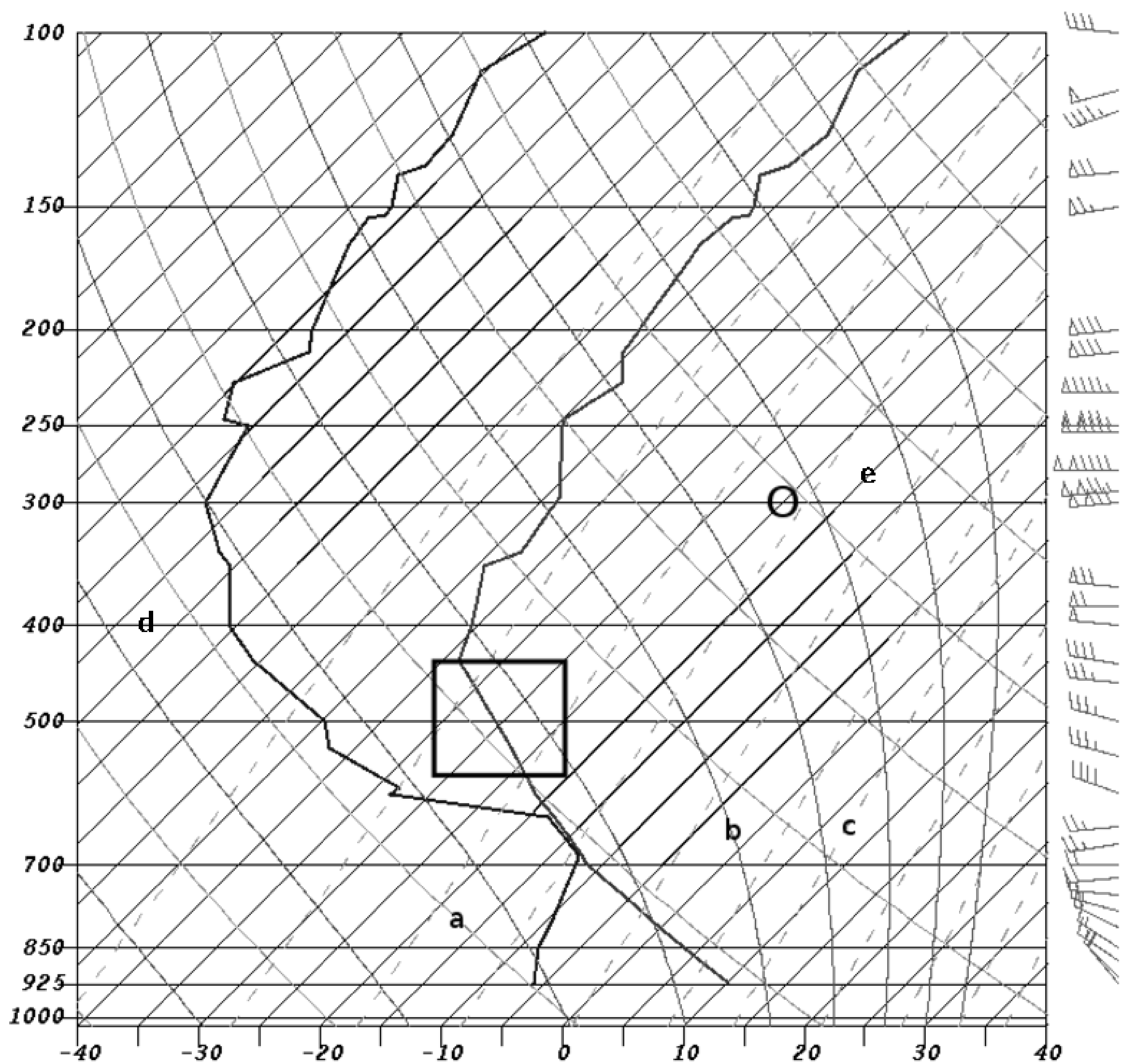

Figure 3: Stony Plain sounding, 00 UTC 25 October 2014, plotted on the skew-T diagram. Dry adiabats (e.g. **a**), moist adiabats (e.g. **b**), isobars (e.g. **d**) and isotherms (e.g. **e**) are all solid lines; isohumes (e.g. **c**) are dashed lines.

FIG 4

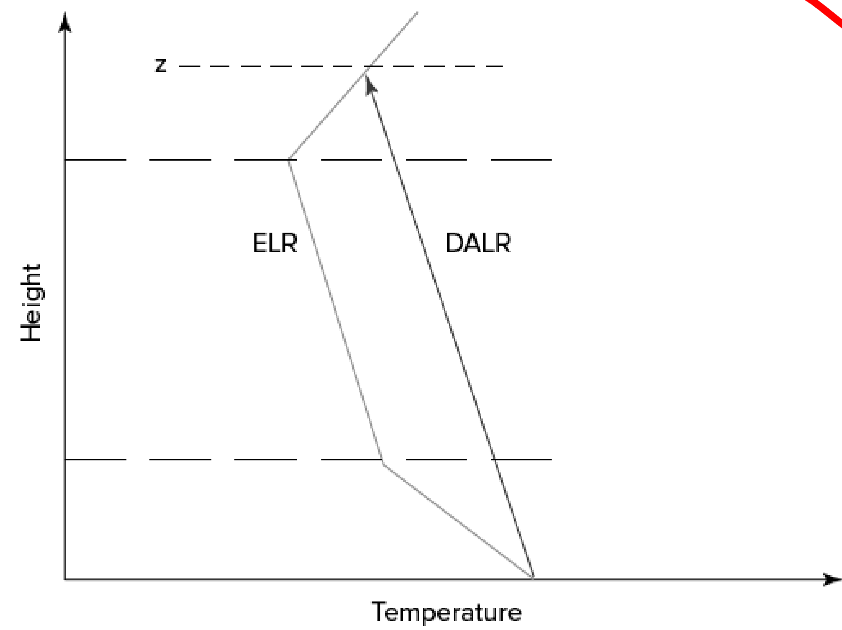

Figure 4: Idealized three-layer temperature profile. (Ross's Figure 8.21).

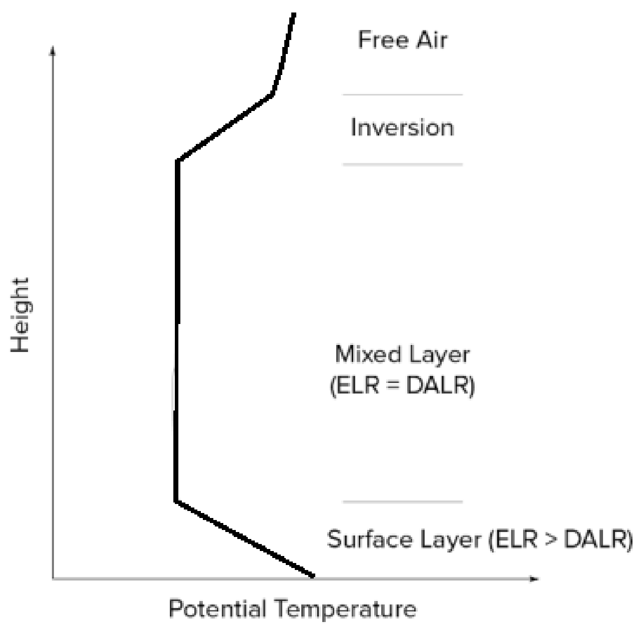

Figure 5: Idealized summer daytime profile of potential temperature θ. (Ross's Figure 8.29).

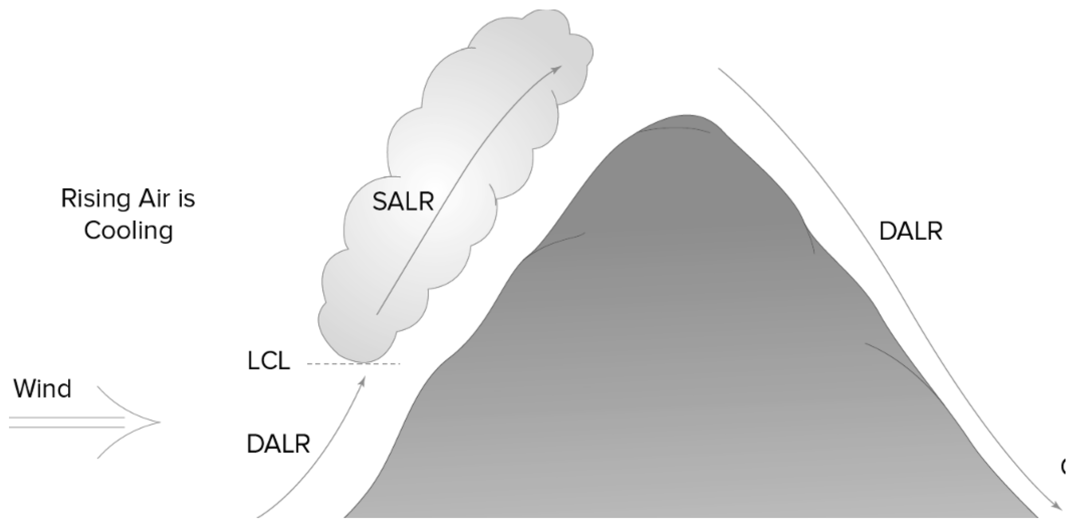

Figure 6: Idealized parcel evolution in flow over a mountain, assuming all vapour that condenses during the ascent is precipitated out of the parcel (Ross's Figure 8.8a).

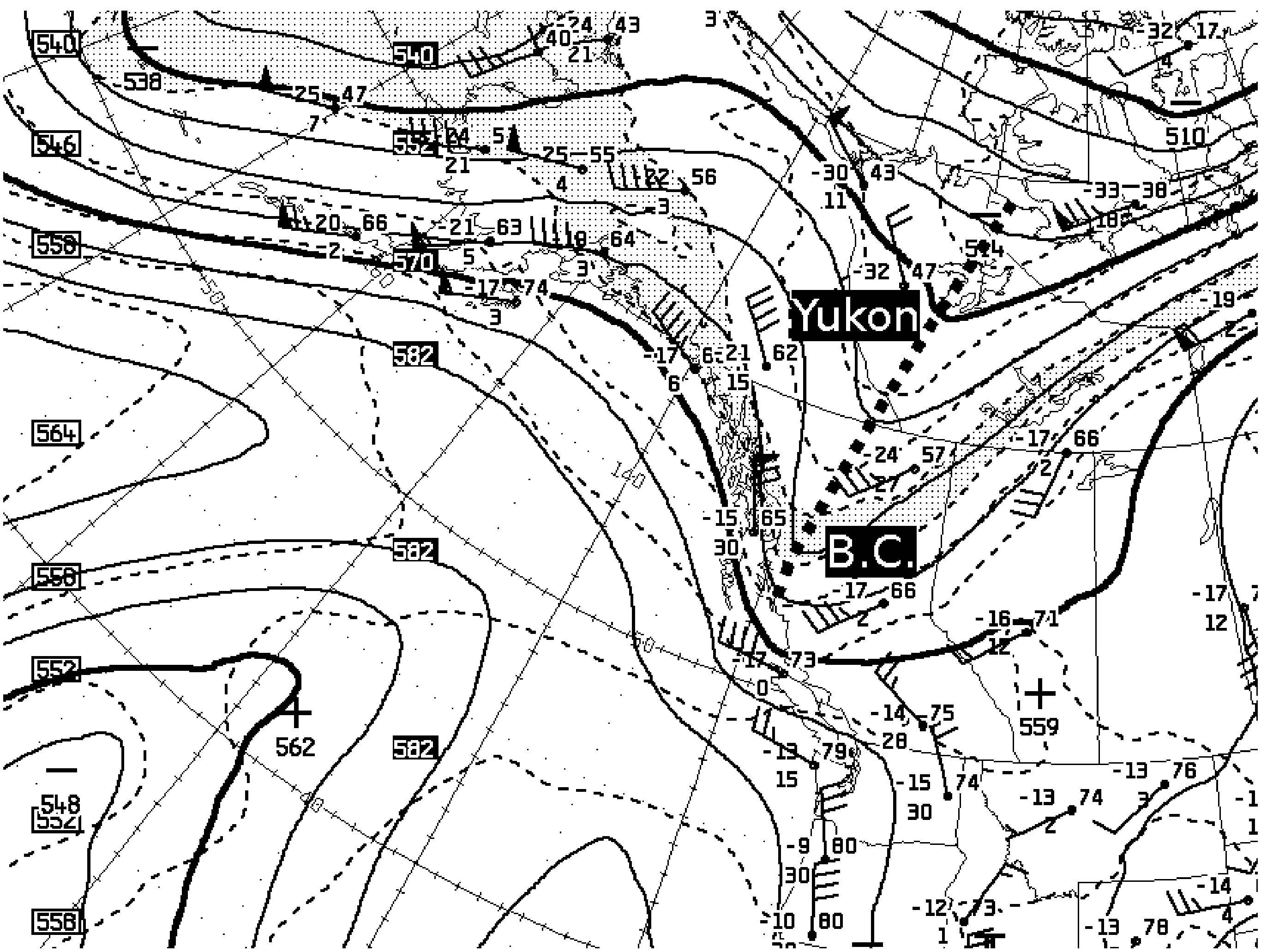

Figure 7: Environment Canada 500 hPa analysis (cropped) for 12 UTC 2 October 2015.

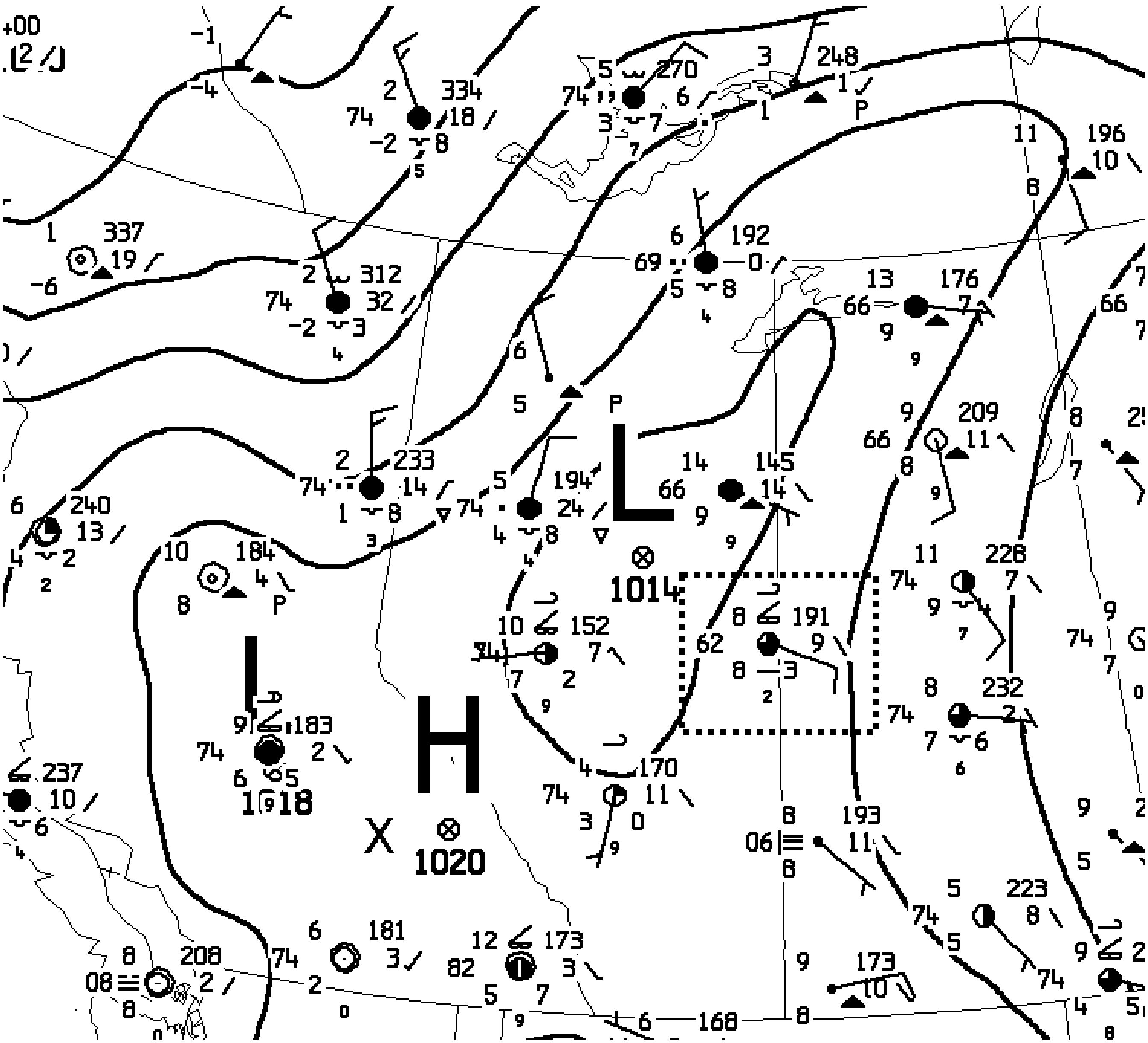

Figure 8: Environment Canada surface analysis (cropped) for 12 UTC 2 October 2015.