EAS270, "The Atmosphere" Final Exam 15 Dec. 2016

Professor: J.D. Wilson Time available: 120 mins Value: 50%

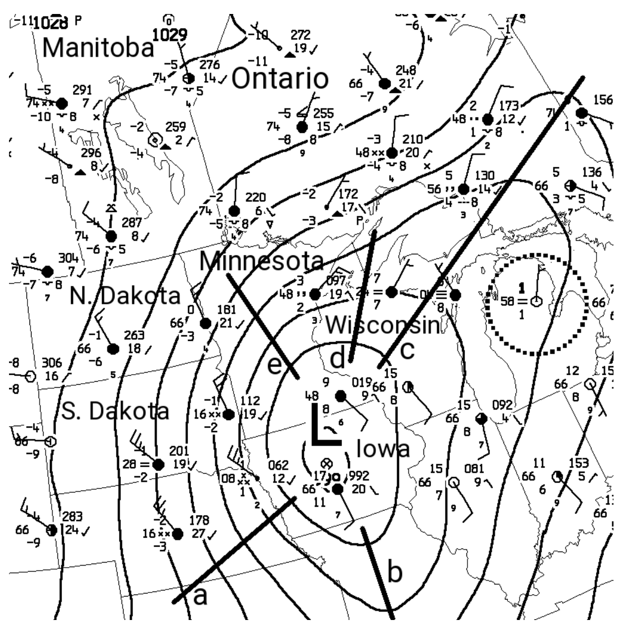
No formula sheets; no use of tablet computers etc. or cell phones. It is recommended you look at the provided **formulae/data** before starting the exam. Numbered figures are at the back of the exam; smaller figures, un-numbered are scattered through the exam.

Multi-choice (50 x 1 → 50 %) **(Added: % of responses correct)**

1. Which condition or process in relation to nocturnal radiation fog is wholly or partially **false**?
   - (a) light wind: warm air aloft is not efficiently mixed to the cooling surface
   - (b) air in contact with the ground is chilled by conduction
   - (c) ground cools radiatively ($L^* < 0$) and by loss of sensible heat to the air ($Q_H > 0$) ✗✗ 22%
   - (d) vapour condenses onto CCN (at humidities lower than 100%, if the CCN are hygroscopic)
   - (e) activated droplets grow slowly by diffusion to a diameter of order 10μm

2. A warm cloud may produce rain, but a warm fog layer does not: which explanation is **true**?
   - (a) the mechanism for cooling differs: adiabatic expansion (cloud case) cools air more effectively than chilling by contact with a cold surface (fog case)
   - (b) CCN in warm clouds are hygroscopic, whereas those near ground are not
   - (c) air distant from ground contains more numerous CCN than does air near ground
   - (d) activated droplets grow more rapidly by diffusion in cloud than in fog
   - (e) the (shallow) depth and near stillness of a radiation fog layer implies a "collector" droplet settles on ground before growing to any appreciable size ✓✓ 50%

3. Please interpret the heavy lines, identified by (a,b,c,d,e), as potential *approximate* locations for a cold front associated with the Iowa storm — bearing in mind that a cold front need not be linear, and would run in to the centre of low pressure. Which schematic location is *most* plausible?
   - (a) a
   - (b) b ✓✓ 42%
   - (c) c
   - (d) d
   - (e) e



4. For a small spherical cloud droplet of radius r and mass m falling with velocity w through still air of density ρ_a, the vertical force balance reads

$$m\frac{dw}{dt} = m\,g - \tfrac{1}{2}\,c_d\,A\,\rho_a\,w^2$$

where dw/dt denotes the rate of change of w (i.e. droplet acceleration) and c_d is a dimensionless "drag coefficient". Which interpretive statement is **false**? (Hint: think about units, noting that density times the square of velocity gives a pressure unit.)

(a) the "terminal velocity" can be computed by setting the left hand side (lhs) of the equation to zero, and solving for for w

(b) the second term on the right hand side (rhs) is an *upward* force, and opposes the downward force of gravity (mg)

(c) the quantity A is the volume $\frac{4}{3}\pi r^3$ of the droplet ✗✗ 47%

(d) the disparity between air density ρ_a and water density ρ_w affects droplet velocity via droplet mass $m = \rho_w\,\frac{4}{3}\pi r^3$

5. Which statement in relation to Cloud Condensation Nuclei (CCN), cloud droplets and Ice Nuclei (IN) is **false**?

(a) In a "cold" cloud, precipitation results from the transfer of water from the many ice crystals to the few cloud droplets ✗✗ 78%

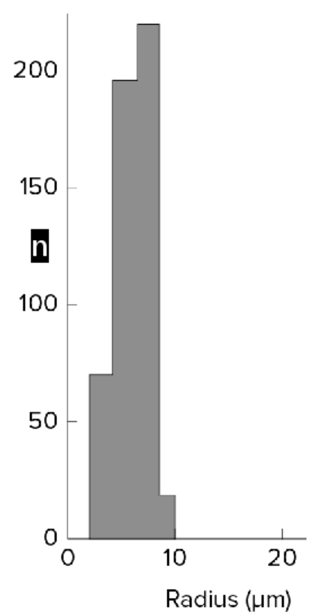
(b) The presence or absence of IN is irrelevant to the possibility of precipitation from a "warm" cloud

(c) There are generally more CCN per unit volume of air over land than over the ocean

(d) The presence of large, hygroscopic CCN permits cloud droplet formation at relative humidities below 100%

(e) Ice nuclei are particles whose crystal structure resembles that of ice

6. The adjacent figure represents the size distribution **n** of cloud condensation nuclei (CCN) in continental air, also known as the "size spectrum." The unit for **n** is [$\#\,\mathrm{cm}^{-3}\,\mu\mathrm{m}^{-1}$], where "#" denotes "number" and is dimensionless. Which best approximates the total number of CCN per unit volume in $\#\,\mathrm{cm}^{-3}$.



(a) 10

(b) 50

(c) 100

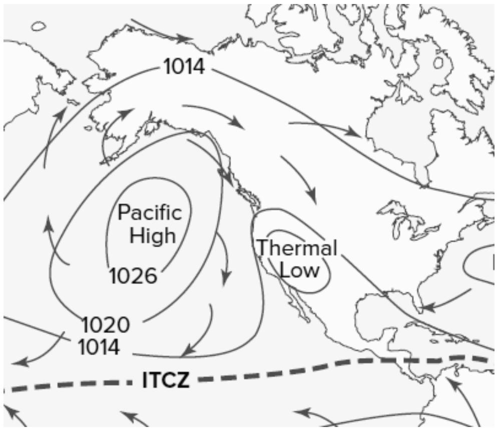
(d) 200

(e) 1200 ✓✓ 89%

7. In general at middle and high latitudes the *rate* of precipitation from a mid-winter synoptic scale storm is much lower than that from a typical mid-summer synoptic scale storm. Which explanatory factor is **least** pertinent?
   (a) the winter atmosphere is generally stable, limiting cloud depth
   (b) climatologically, midlatitude upper winds are stronger in winter than in summer ✗✗ 56%
   (c) the cold winter air holds less water vapour than warm summer air
   (d) winter storm cloud tends to be exclusively stratiform, and shallow
   (e) cumuliform clouds are typified by larger vertical velocities than stratiform clouds

8. Let $W_{\mathrm{FA}}, W_{\mathrm{CB}}, W_{\mathrm{T}}$ represent the "order of magnitude" (ie. "scale," or "typical size") of the vertical velocity in the free atmosphere (FA), in a cumulonimbus cloud (CB), and in the turbulent friction layer (T). Pick the most reasonable statement concerning the relative sizes of these "scales" (units are $\mathrm{m\,s^{-1}}$; the symbol $\sim$ means "approximately equal to")
   (a) $W_{\mathrm{FA}} \sim W_{\mathrm{T}} \sim W_{\mathrm{CB}} \sim 1$
   (b) $W_{\mathrm{FA}} \sim W_{\mathrm{T}} \sim W_{\mathrm{CB}} \sim 10$
   (c) $W_{\mathrm{FA}} << W_{\mathrm{T}} \sim W_{\mathrm{CB}} \sim 1$
   (d) $W_{\mathrm{FA}} << 1$; $W_{\mathrm{T}} \sim 1$; $W_{\mathrm{CB}} >> 1$ ✓✓ 56%

9. Which option correctly identifies the contours and winds on this map?



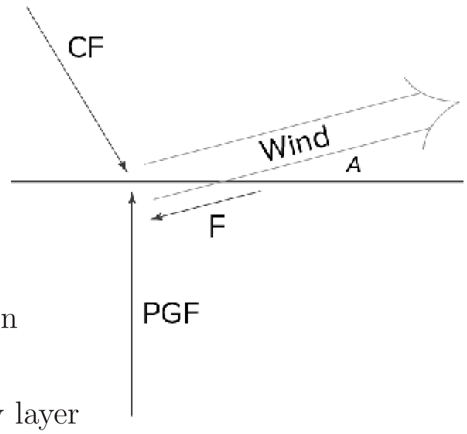
   (a) January mean 850 hPa height [m] and wind
   (b) January mean sea level pressure [hPa] and surface wind
   (c) July mean 250 hPa height [dam] and wind
   (d) July mean sea level pressure [hPa] and surface wind ✓✓ 50%
   (e) sea-level pressure and surface wind distribution characteristic of Alberta lee trough & Chinook conditions

10. Referring to Figure (1), suppose the relative humidity of the air were sustained at 100.5%. Which droplets will be activated?
   (a) A,B,C,D
   (b) C,D
   (c) A,B ✓✓ 92%
   (d) B,C
   (e) D

11. Again referring to Figure (1), which option correctly gives the fate of droplets of type A assuming the relative humidity of the air were sustained at 100.05%?

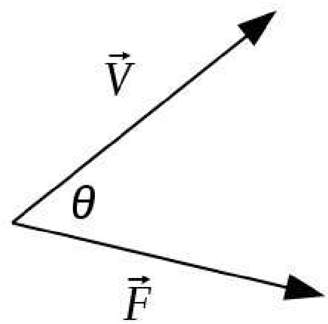
    (a) complete evaporation
    (b) continuous growth
    (c) survival with equilibrium radius 0.2 μm
    (d) survival with equilibrium radius 0.3 μm
    (e) survival with equilibrium radius 0.4 μm ✓✓ 81%

12. Referring to the adjacent force balance for the horizontal wind, which statement is **false**?



    (a) the solid horizontal line is an isobar
    (b) "F" denotes a friction force
    (c) the cross-isobar wind angle "A" is smaller over rougher surfaces ✗✗ 56%
    (d) the Coriolis force vector "CF" *should* have been drawn perpendicular to the wind
    (e) this balance applies within the atmospheric boundary layer (i.e. friction layer)

13. The diagram shows a force $\vec{F}$ [N] acting obliquely on a body of mass m whose velocity is $\vec{V}$. If (F, V) are the magnitudes of the force and the velocity, which correctly gives the rate W [J s^{-1}] of working by the force?

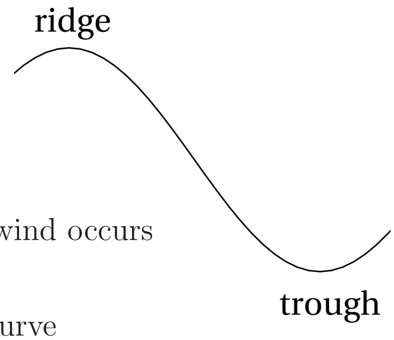


    (a) $m\,F\,V$
    (b) $m\,F\,V^2$
    (c) $V\,\vec{F}$
    (d) $F\,V\,\cos\theta$ ✓✓ 67%
    (e) $m\,F\,V\,\sin\theta$

14. Consider a point in the free troposphere (i.e. above the friction layer), and let $\vec{F_c}$ be the Coriolis force vector, $\vec{V}$ the wind velocity vector and θ the angle between these two vectors. Which statement is true? (Note: $|\vec{a}|$ denotes the *magnitude* of vector $\vec{a}$, and $|b|$ the magnitude of an ordinary number b).

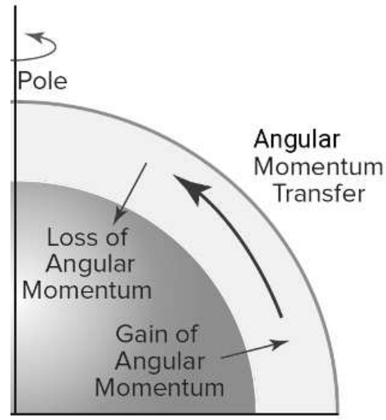
    (a) $\theta = 0$
    (b) $|\theta| = 90°$ ✓✓ 78%
    (c) $|\vec{F_c}| = 0$
    (d) $|\vec{F_c}| = \theta$
    (e) $\theta \leq \vec{F_c}$

15. The diagram shows a single 500 hPa height contour in the N. hemisphere. Which statement is **false**?



   (a) according to the gradient wind model, the wind blows parallel to the height contour
   (b) midway between the ridge and the trough, a "northwest" wind occurs
   (c) at every point along the contour, the height gradient (and pressure gradient) are oriented *perpendicular* to the curve
   (d) according to the gradient wind model, if the *strength* of the pressure gradient is constant along the contour the wind speed is larger in the trough than in the ridge ✗✗ 53%
   (e) moving away from the contour towards the top of the page, the isobaric height gets lower

16. If the combined angular momentum of the earth and oceans (E+O) is counted as positive, which planetary component *on average*, i.e. given the climatological distribution of surface winds, **gains** angular momentum due to surface-atmosphere momentum exchange (i.e. wind drag) at low latitudes?

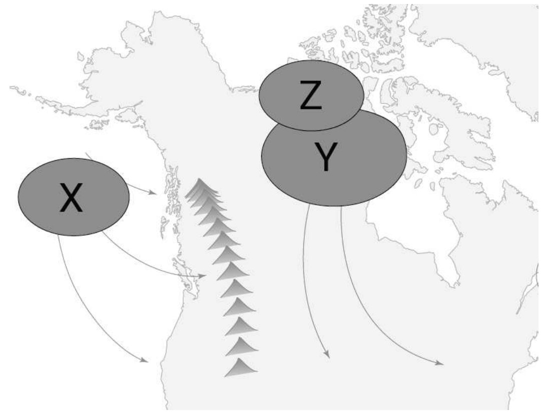


   (a) the atmosphere (A) ✓✓ 75%
   (b) the earth & oceans (E+O)
   (c) neither A nor E+O
   (d) both A and E+O

17. During fair summertime weather, wind speed in the atmospheric surface layer (ASL) tends to be highest in mid-afternoon and calm at night — and this is true even if the winds aloft, say at 850 hPa, are steady through day and night. Which aspect of the following explanation is **false**?

   (a) in such conditions the ASL is absolutely unstable by day and absolutely stable by night
   (b) turbulent vertical motion of air parcels "couples" the wind in the ASL to the winds aloft
   (c) on average, for each cubic metre of air that descends from height z_2 to z_1 ($< z_2$), a much larger volume (> 100 cubic metres) ascends from z_1 to z_2 ✗✗ 78%
   (d) turbulent vertical momentum exchange is strongest during strong winds in an unstably stratified boundary layer
   (e) descending parcels bring down a "momentum excess" (or velocity surplus) relative to that of the average parcel at the surface, while ascending parcels transport velocity deficit

18. Which is the appropriate label for airmass "X"?

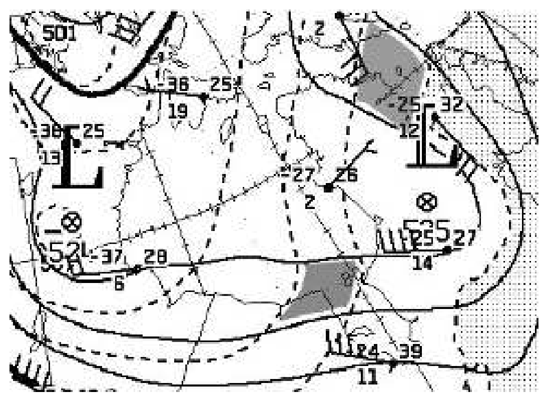


(a) mA
(b) cP
(c) cA
(d) mP ✓✓ 69%
(e) mT

19. Which statement regarding the effect of sustained vertical mixing of an *unsaturated* atmospheric layer is **false**?

(a) lapse rate of a superadiabatic layer adjusts back towards the DALR
(b) lapse rate of an isothermal layer adjusts back towards the DALR
(c) lapse rate of an inversion layer adjusts back towards the DALR
(d) the mixing results in uniform specific humidity and mixing ratio
(e) the mixing results in the lapse rate of potential temperature being $0.01\,\mathrm{K\,m^{-1}}$ ✗✗ 53%

20. The diagram is cropped from a CMC 500 hPa analysis. Which statement is **false**?



(a) over this region, and near 500 hPa, geostrophic wind speed & direction are height-independent ✗✗ 44%
(b) over this region the atmosphere is baroclinic
(c) plotted wind vectors are radiosonde data
(d) dark shading signifies thickness advection, while stippling signifies the 534-540 dam thickness band
(e) the thermal wind runs parallel to the dashed lines

21. Referring to Figure (2), what is the surface dewpoint? (Hint: first, deduce the height z_{LCL} of the LCL based on the adiabatic lapse rate.)

(a) 21.6°C
(b) 23.0°C
(c) 24.4°C ✓✓ 92%
(d) 30.0°C
(e) 35.6°C

22. Again referring to Figure (2), how would you classify the static stability of the surface layer?

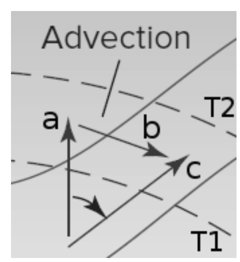
(a) neutral with respect to unsaturated adiabatic motion
(b) neutral with respect to saturated adiabatic motion
(c) absolutely stable
(d) conditionally unstable
(e) absolutely unstable ✓✓ 75%

23. Again referring to Figure (2), how would you classify the static stability of the mixed layer?

(a) neutral with respect to unsaturated adiabatic motion ✓✓ 44%
(b) neutral with respect to saturated adiabatic motion
(c) absolutely stable
(d) conditionally unstable
(e) absolutely unstable

24. Again referring to Figure (2), which would be your estimate for the height of the LNB (Level of Neutral Buoyancy)?

(a) same height as the LCL
(b) at the top of the surface layer (about 300 m)
(c) at the base of the inversion (about 1300 m)
(d) at around 1600 m (level of cloud top) ✓✓ 61%
(e) at the surface



25. In the figure solid lines are N. hemisphere 500 hPa height contours and dashed lines are thickness contours for the 700-500 hPa layer. Assuming thickness contour T1 is "warmer" than contour T2, which option is correct?

(a) thermal wind is the vector labelled **a**
(b) thermal wind is the vector labelled **b** ✓✓ 86%
(c) thermal wind is the vector labelled **c**
(d) cold advection is occurring

26. On the CMC 850 mb analysis, which feature that can be taken to signify a classical "front"?

(a) an occlusion
(b) a belt (linear region) of very strong winds
(c) a warm sector
(d) thunderstorms
(e) a belt of closely-spaced isotherms ✓✓ 56%

27. Referring to Figure (3), suppose the mean windspeed 30 m upwind from the shelter and 2 m AGL (above ground level) was $10\,\mathrm{m\,s^{-1}}$. Which option best approximates the mean wind speed 50 m downwind from the shelterbelt at 2 m AGL?

(a) $10\,\mathrm{m\,s^{-1}}$
(b) $8\,\mathrm{m\,s^{-1}}$
(c) $5\,\mathrm{m\,s^{-1}}$
(d) $3\,\mathrm{m\,s^{-1}}$ ✓✓ 53%
(e) $1\,\mathrm{m\,s^{-1}}$

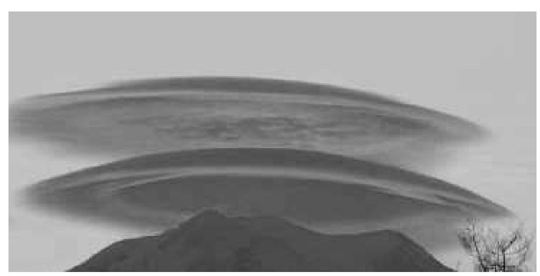
28. Dim sunlight seen through a blanket of middle layer cloud is the diagnostic for which cloud type?

(a) altostratus ✓✓ 86%
(b) stratocumulus
(c) cirrostratus
(d) nimbostratus
(e) altonimbus

29. Which association is incorrect?

(a) cumulus — puffy convective cloud
(b) cirrostratus — high layer cloud
(c) nimbostratus — fair weather cloud ✗✗ 86%
(d) broken stratocumulus — patchy layer of cumulus clouds
(e) cumulonimbus — thunderstorm

30. Which of the inferences below is illegitimate (wrong), supposing one had observed a smooth, thin, saucer-shaped lenticular cloud over hills or mountains?



(a) the airstream has been lifted sufficiently to produce saturation
(b) the layer within which the cloud occurs is unconditionally stable
(c) the airstream has been *forced* to ascend, doing work against gravity
(d) air parcels traversing the highest point (apex) of the (lenticular) cloud are subject to a downward buoyancy force
(e) since the cloud is stationary (fixed to the landscape), winds aloft are calm ✗✗ 42%

31. What cloud type does Figure 4 illustrate? (Note: the sun was not visible, nor was it raining or snowing at the time.)
    (a) stratocumulus ✓✓ 69%
    (b) cirrostratus
    (c) nimbostratus
    (d) altonimbus
    (e) altostratus

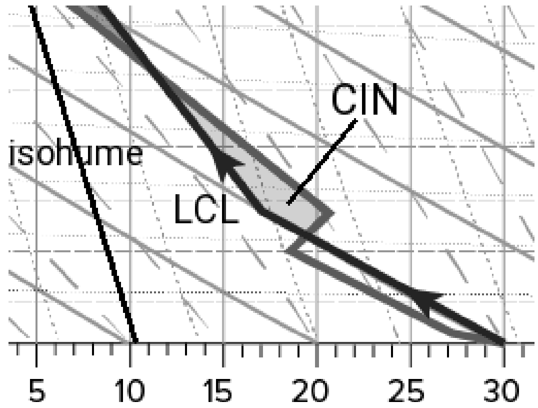
32. Referring to Figure (5), which of the following qualitative statements about the layer below 700 hPa is **false**?
    (a) potential temperature is approximately constant within the layer
    (b) lapse rate approximately equals the dry adiabatic lapse rate (ELR=DALR)
    (c) the layer is neutral with respect to unsaturated adiabatic motion
    (d) judged by its humidity profile (alone), the layer is *not* well mixed
    (e) judged by its stratification alone (i.e. profile of TEMP and/or THTA), the layer is *not* well mixed ✗✗ 47%

33. Again referring to Figure (5), what was the thickness of the layer bounded by the 850 hPa and 700 hPa isobaric surfaces?
    (a) 228 dam
    (b) 159 dam ✓✓ 75%
    (c) 1413 m
    (d) 2998 m
    (e) 333 dam

34. Which of the following **is not** a valid condition or precursor for the formation of hurricanes?
    (a) ocean temperature exceeds about 26°C in a layer some 60 metres deep
    (b) presence of very strong vertical wind shear ✗✗ 31%
    (c) latitude lies in the range of about $5 - 20^o$
    (d) conditional instability throughout the troposphere
    (e) late summer or early autumn

35. What is the (immediate) energy source for a hurricane?
    (a) gravitational potential energy due to horizontal temperature contrast
    (b) kinetic energy of the strong winds
    (c) shortwave (solar) radiative heating within cloud updrafts
    (d) sensible and latent heat drawn from the warm ocean ✓✓ 83%
    (e) Coriolis potential energy

36. The dark path (with arrows) on this emagram (i.e. plot of temperature on x-axis versus pressure on y) gives the (p, T) trajectory for a parcel rising adiabatically from the surface, and the LCL is identified by the change in slope of that path. Which best estimates the surface dewpoint?

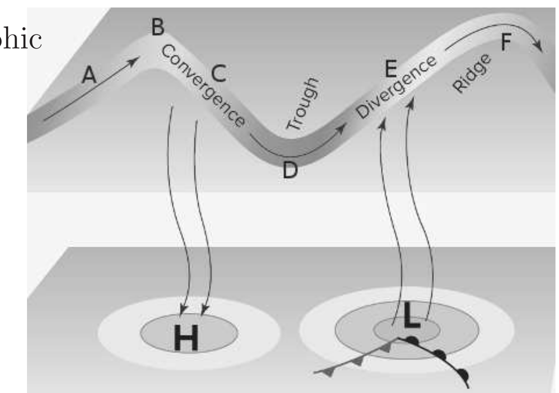


a) 30°C b) 19°C ✓✓ 58% c) 15°C d) 10°C

37. Three-dimensionality in space is an essential feature of many types of atmospheric circulation. Which of the following circulations could most plausibly be represented by a numerical model that carried only *two* space coordinates, radius (r) and height (z)?

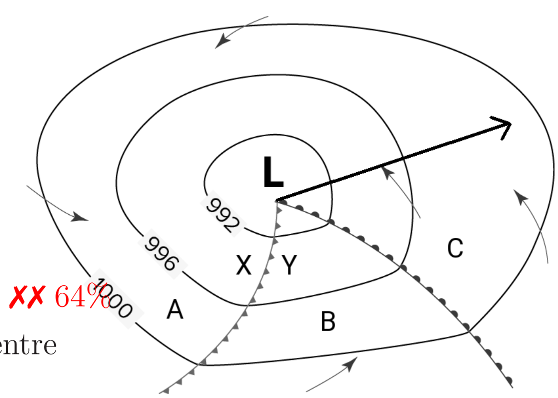
(a) severe thunderstorm
(b) mid-latitude cyclone
(c) individual fair-weather cumulus cloud ✓✓ 31%
(d) hurricane

38. At which location(s) on the wave aloft is the geostrophic wind model less accurate than the gradient wind model?



(a) A,C
(b) A,C,E
(c) C,E
(d) B,D,F ✓✓ 58%
(e) E

39. The heavy straight arrow shows the direction of storm motion, and light arrows are surface winds. Which statement is **false**?



(a) this is a N. hemisphere low
(b) temperatures $T_A < T_C < T_B$
(c) pressure at **X** is falling, pressure at **Y** is rising ✗✗ 64%
(d) ascending vertical motion must occur at the centre of the system
(e) as the cold front moves through location **Y**, the wind will turn from being a SW wind to being a NW wind

40. Suppose that on a windy day you observe the direction of motion of middle layer (say, 700 hPa level) clouds overhead, and you orient yourself with your back to that wind aloft. Assuming you are in the northern hemisphere, towards which direction does the 700 hPa isobaric surface slope downward? (Hint: assume the 700 hPa wind is geostrophic.)

   (a) to your left ✓✓ 69%
   (b) to your right
   (c) behind your back
   (d) to your front
   (e) the stated observations don't provide sufficient basis to judge

41. Suppose $T_{I,J,K}$ represents the gridded field of temperature in a Numerical Weather Prediction (NWP) model at a particular "valid time," and that $TD_{I,J,K}$ is the dewpoint field at that same time. Let the third index (K) order gridpoints along the local vertical axis. Which type of meteorological diagram could be constructed from the set of all values of these two gridded fields at *fixed* (I, J), but including all values of K?

   (a) isobaric chart for each of the elevations
   (b) ensemble forecast chart (spaghetti plot)
   (c) skew-T diagram (thermodynamic chart) ✓✓ 79%
   (d) surface analysis (contour map of MSLP)
   (e) precipitation map

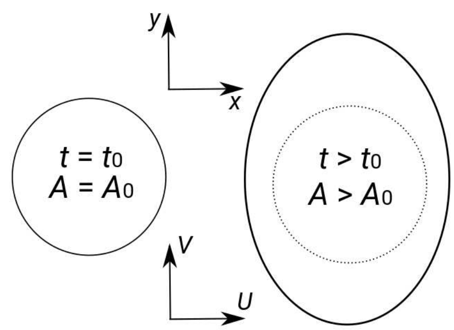
42. For every location (I, J) within its domain, an NWP model provides the vertical profiles $T_{I,J,K}$ and $TD_{I,J,K}$ of (model) temperature and dewpoint versus height z_K, including values at ground ($K = 1$). Which inference is **false**?

   (a) this is sufficient information to estimate the height of the LCL at each location (I, J)
   (b) this is sufficient information to assign a stability classification to each layer of the model atmosphere over each location (I, J)
   (c) this is sufficient information to assign an LFC and an LNB over each location (I, J)
   (d) this is sufficient information to assign values for CIN and CAPE over each location (I, J)
   (e) none of this information has any bearing on the likelihood that a real atmosphere characterized by the same vertical profiles of (T, T_d) would develop a layer of cumulus clouds ✗✗ 61%

43. Which claim in relation to the CMC's (i.e. the Canadian Meteorological Centre's) NWP models (GEM-RDPS, $\Delta x \sim 10$ km; and global GEM-GDPS, $\Delta x \sim 25$ km) is **false**?

(a) even the regional model, with $\Delta x \approx \Delta y \approx 10$ km, fails to "resolve" fairweather cumulus
(b) the collective (statistical) effect of fairweather cumulus (i.e. vertical mixing of heat and vapour by cloud updrafts and downdrafts) is *entirely neglected* ✗✗ 69%
(c) the initial state (at time t_0) is based in part on a *forecast* for atmospheric state at time t_0 that had been initialized at $t_0 - 6$hr
(d) refining model resolution (reducing $\Delta x, \Delta y, \Delta z, \Delta t$) enhances model accuracy, but increases computational burden
(e) a meteorological process is termed "subgrid" if it cannot be explicitly represented on the given grid $(\Delta x, \Delta y, \Delta z)$

44. An initially circular patch of air (time $t = t_0$) lying on an isobaric surface is distorted by the divergence of the velocity field, $D = \Delta U/\Delta x + \Delta V/\Delta y$ where U is the zonal (i.e. x-) velocity component and V the meridional. Which option correctly describes the divergence and the individual velocity gradients? (Note: the dashed circle, congruent with the inital patch, represents the outcome if the velocity field were uniform, with $U =$ const. > 0 and $V =$ const. ≈ 0.)



(a) $D > 0$, $\Delta U/\Delta x > 0$, $\Delta V/\Delta y > 0$ ✓✓ 78%
(b) $D \approx 0$, $\Delta U/\Delta x < 0$, $\Delta V/\Delta y > 0$
(c) $D < 0$, $\Delta U/\Delta x < 0$, $\Delta V/\Delta y < 0$
(d) $D \approx 0$, $\Delta U/\Delta x > 0$, $\Delta V/\Delta y < 0$

The final 6 questions refer to Figures (6 – 15), and compare the meteorological regimes over Western Canada on 20 October and 5 December 2016.

45. Which statement is **false**? (Assume the reference level for potential temperatures is 925 hPa, i.e. surface pressure.)

(a) the surface feature in Alberta on 20 Oct. is a lee trough
(b) the surface feature in Alberta on 5 Dec. is an arctic high
(c) on 20 Oct. at Edmonton, both the actual and the potential temperatures (T_{850}, θ_{850}) of air at the 850 hPa level greatly exceed the temperature at ground
(d) on 5 Dec. at Edmonton potential temperature θ_{850} at the 850 hPa level was about the same as actual surface temperature
(e) on 5 Dec. the 850 hPa analysis suggests warm temperature advection is occurring ✗✗ 47%

46. Which statement is **true**?

(a) on both occasions, the sounding exhibits a ground-based temperature inversion
(b) at 850 hPa temperature-dewpoint spread $T - T_d$ was greater on 5 Dec. than on 20 Oct.
(c) at 850 hPa the vapour pressure was greater on 20 Oct. than on 5 Dec. ✓✓ 33%
(d) dewpoint T_d at 700 hPa on 20 Oct. was 18°C
(e) on both occasions the upper flow over Western Canada could be described as "zonal"

47. What is the surface pressure feature (as defined by the surface isobar pattern, Figure 10) in south-eastern B.C. on 20 October?

(a) an upper-level Rossby wave ridge
(b) a sea-breeze circulation
(c) an Omega-block
(d) a low pressure trough, due to the SW upper wind being impeded by the Rockies
(e) a high pressure ridge, due to the SW upper wind being impeded by the Rockies ✓✓ 67%

48. Referring to Figure (12), what is implied or defined by the pattern of thickness contours over Western Canada?

(a) a thermal ridge, whose axis runs through Alberta ✓✓ 69%
(b) a thermal trough, whose axis runs through Alberta
(c) freezing rain occurring in N. Alberta
(d) at the 500 hPa level, air in Alberta was colder than in B.C. and Saskatchewan
(e) a shortwave trough has overtaken a longwave trough

49. Referring to Figure (15), what was the height (above sea level) of the 850 hPa surface at Stony Plain (Edmonton)?

(a) 41 dam
(b) 941 dam
(c) 941 hPa
(d) 141 dam ✓✓ 75%
(e) 1041 hPa

50. Which correctly describes the surface pressure trend in C. Alberta on the two occasions?

(a) 20 Oct., falling; 5 Dec., rising ✓✓ 56%
(b) 20 Oct., rising; 5 Dec., rising
(c) 20 Oct., falling; 5 Dec., falling
(d) 20 Oct., rising; 5 Dec., falling

Equations and Data.

Notation for vectors: $\vec{A}$ or $\mathbf{A}$. One full barb on the wind vector means 5 m s^{-1}, while a solid triangle means 25 m s^{-1}. The dewpoint lapse rate is $\Gamma_{T_d} \approx -0.002\,\mathrm{K\,m^{-1}}$ (i.e. -0.2 K per 100 m).

A. Height of the LCL in metres AGL

$$z_{\mathrm{LCL}} = 125\ (T_{\mathrm{sfc}} - T_{\mathrm{d,sfc}})$$

is proportional to the difference between surface temperature and surface dewpoint.

B. The potential temperature θ of a sample of air whose pressure and temperature are (P, T) is $\theta = T\ \ (P_0/P)^{R/c_p}$, and gives the temperature the temperature the sample *would* have if its pressure were changed adiabatically to the reference pressure P_0 (where $R/c_p = 2/7 = 0.286$).

C. The Geostrophic wind speed is given by

$$V_g = \frac{g}{f_c} \left| \frac{\Delta Z}{\Delta x} \right| = \frac{1}{\rho\, f_c} \left| \frac{\Delta P}{\Delta x} \right|$$

where ΔZ [m] is the change in height of a constant pressure surface over distance Δx [m] normal to the height contours; $f_c = 2\Omega\ \sin\phi$ [s^{-1}] is the Coriolis parameter (where $\Omega \approx 2\pi/(24\mathrm{x}60\mathrm{x}60) = 7.27\mathrm{x}10^{-5}\ s^{-1}$ is the angular velocity of the earth, and ϕ is latitude); $g = 9.81$ [m s^{-2}] acceleration due to gravity; ρ is the air density. The Geostrophic wind is oriented *parallel* to the height contours.

D. Surface energy balance on a reference plane at the base of the atmosphere,

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

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. The thermal wind is the vector difference $\vec{V}_{T21} = \vec{V}_2 - \vec{V}_1$ between the wind vectors at two levels (Z_1 the lower level and Z_2 the upper level). Its magnitude is related to the gradient in the thickness $h = Z_2 - Z_1$ of the layer, viz.

$$|V_{T21}| = \frac{g}{f_c} \left| \frac{\Delta h}{\Delta x} \right|$$

where the thickness gradient is evaluated with x pointing perpendicular to thickness contours ($f_c = 2\Omega \sin\phi$ is the Coriolis parameter, Ω being the angular velocity of the earth and ϕ the latitude). The thermal wind is oriented parallel to thickness contours, with cold air on its left (in the N. hemisphere).

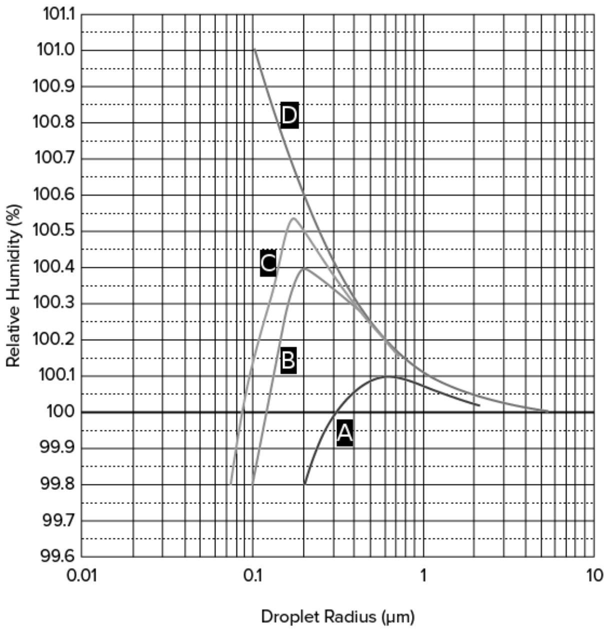


Figure 1: Relative humidity required to assure the equilibrium of a droplet of pure water (D, "Kelvin curve") or containing various types and masses of solute ("Kohler curves" for droplets A,B,C).

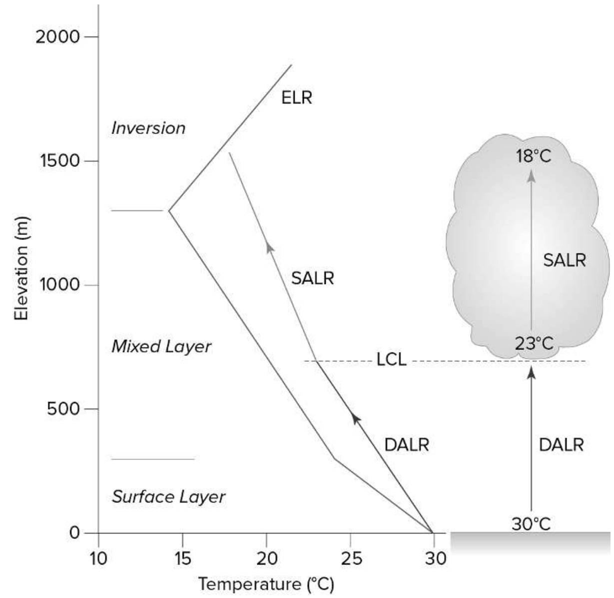


Figure 2: Simplified three-layer scenario for the temperature profile in the ABL (ELR constant within each layer).

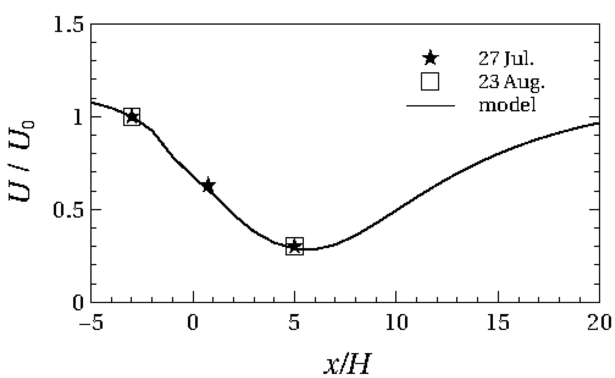


Figure 3: Transect (at height $z = 2$ m above ground) of the normalized mean horizontal wind speed U/U_0 for a wind blowing along the x-axis perpendicular to a shelterbelt (long row of trees) of height $H = 10$ m . Measurements are compared with a numerical model that solves the equations expressing conservation of momentum.

Figure 4: Cloud over UA campus, 15 Nov. 2016.

PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K
1000.0	22							
925.0	696							
918.0	766	19.2	2.2	32	4.91	320	3	299.6
902.0	914	17.6	1.3	33	4.69	335	5	299.5
869.8	1219	14.4	-0.5	36	4.27	255	12	299.3
850.0	1413	12.4	-1.6	38	4.02	260	13	299.1
838.7	1524	11.3	-1.8	40	4.03	275	13	299.2
808.3	1829	8.5	-2.2	47	4.05	275	18	299.3
779.0	2134	5.6	-2.6	56	4.08	275	21	299.4
765.0	2284	4.2	-2.8	60	4.09	275	23	299.4
750.5	2438	2.8	-3.8	62	3.87	275	25	299.5
722.5	2743	0.0	-5.7	65	3.48	265	26	299.8
700.0	2998	-2.3	-7.3	69	3.17	260	29	299.9
671.0	3333	-5.3	-8.1	81	3.11	260	31	300.2

Figure 5: Stony Plain (WSE) sounding 00Z 19 Oct. 2014. “HGHT” is height of an isobaric surface (identified by “PRES”, hPa) above sea level, and “THTA” is the potential temperature on that surface.

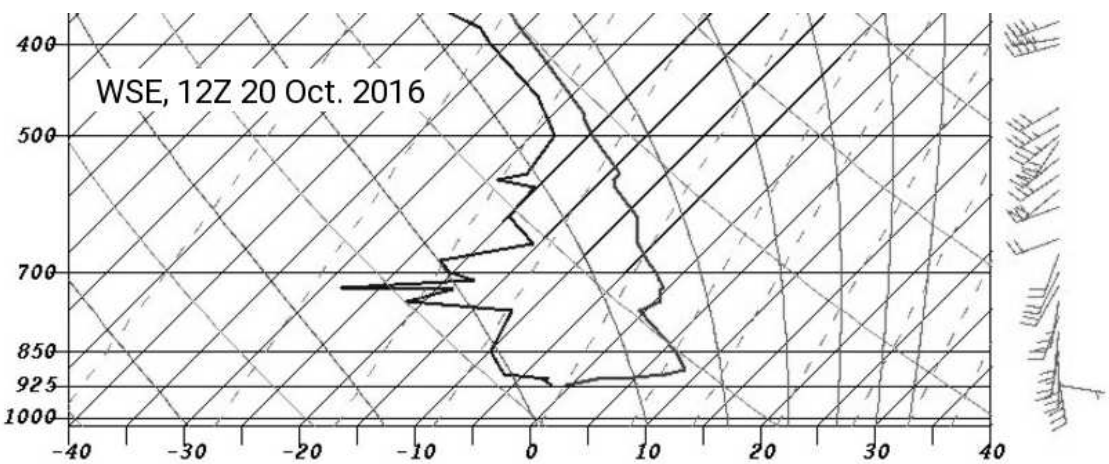


Figure 6: Stony Plain (WSE) sounding 12Z 20 Oct. 2016.

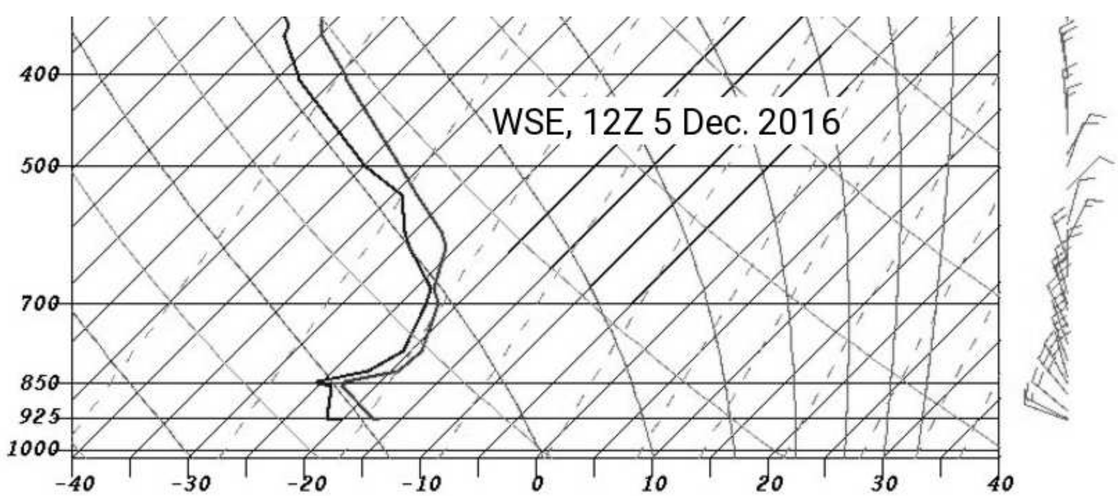
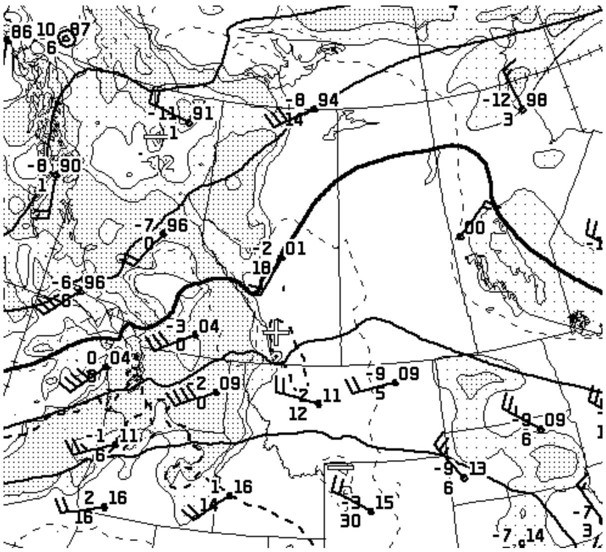


Figure 7: Stony Plain (WSE) sounding 12Z 5 Dec. 2016.



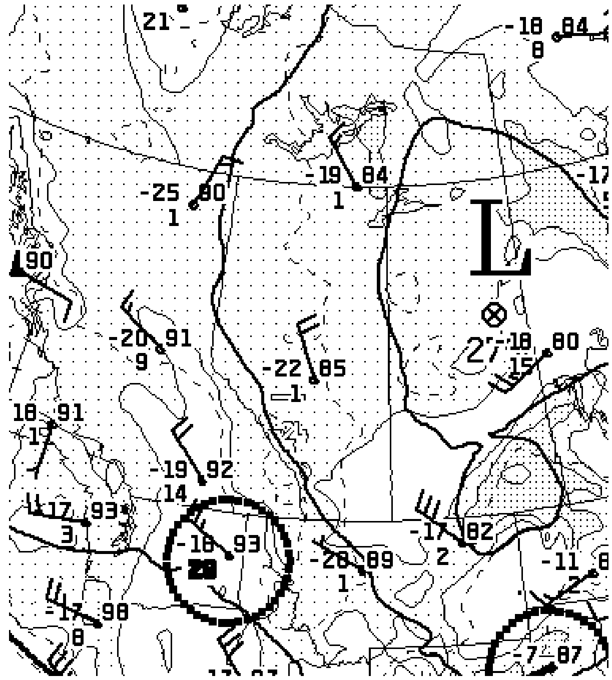
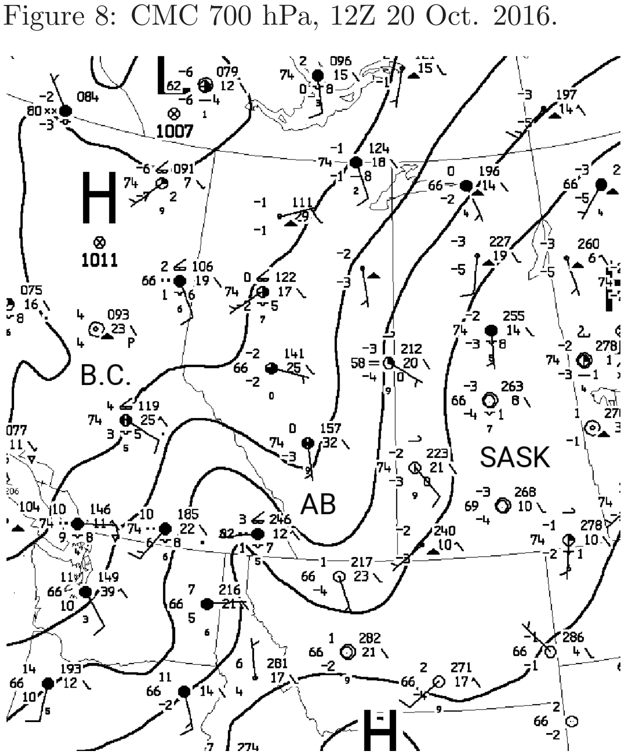


Figure 8: CMC 700 hPa, 12Z 20 Oct. 2016.

Figure 9: CMC 700 hPa, 12Z 5 Dec. 2016.



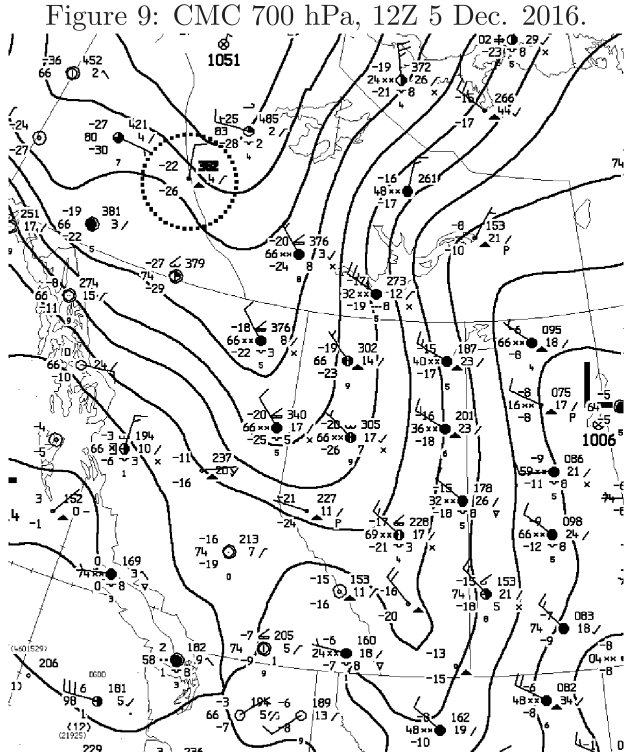


Figure 10: CMC surface, 12Z 20 Oct. 2016.

Figure 11: CMC surface, 12Z 5 Dec. 2016.

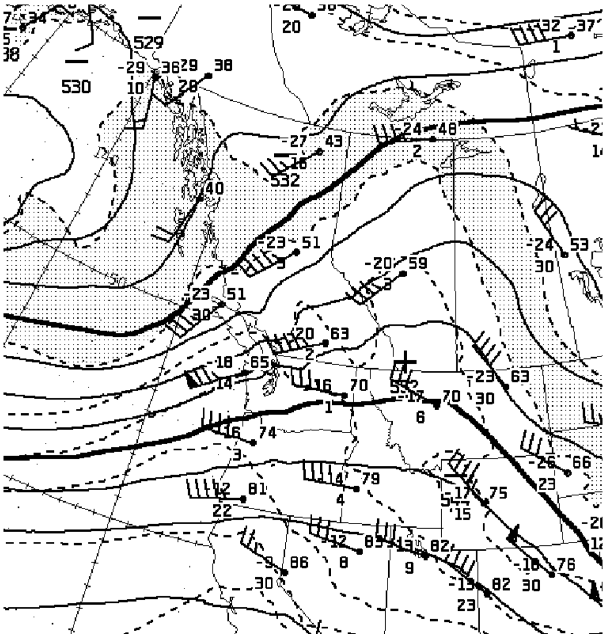


Figure 12: 500 hPa analysis, 12Z 20 Oct. 2016. (Stippling, the 534-540 hPa thickness band.)

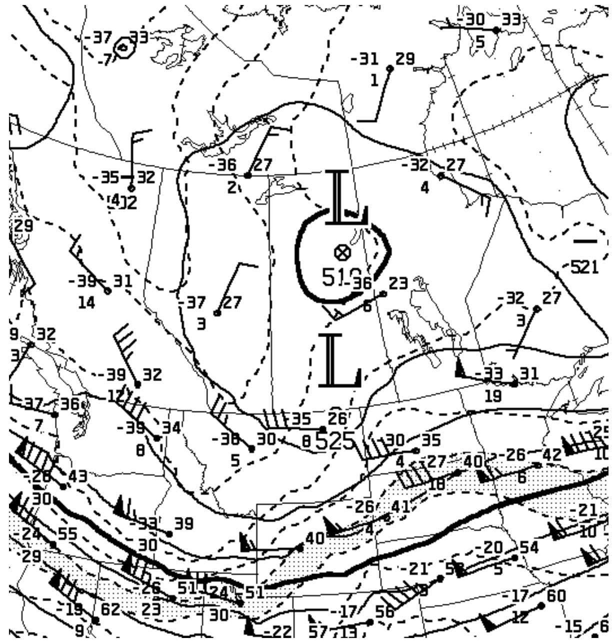


Figure 13: 500 hPa analysis, 12Z 5 Dec. 2016.

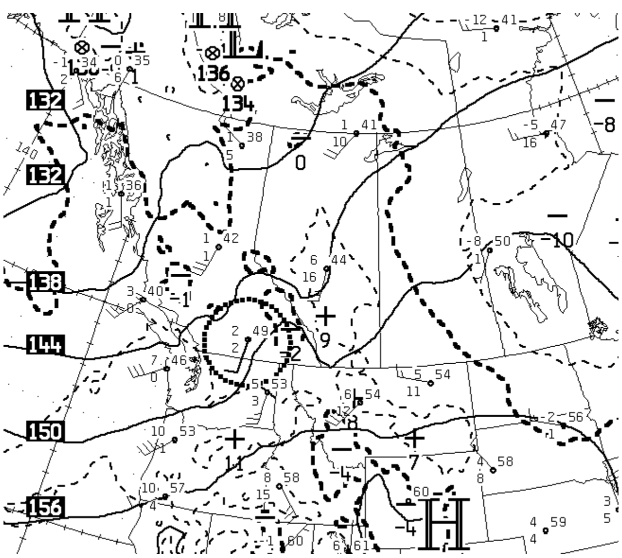


Figure 14: 850 hPa analysis, 12Z 20 Oct. 2016. (Heavy dashed line, the 0°C isotherm.)

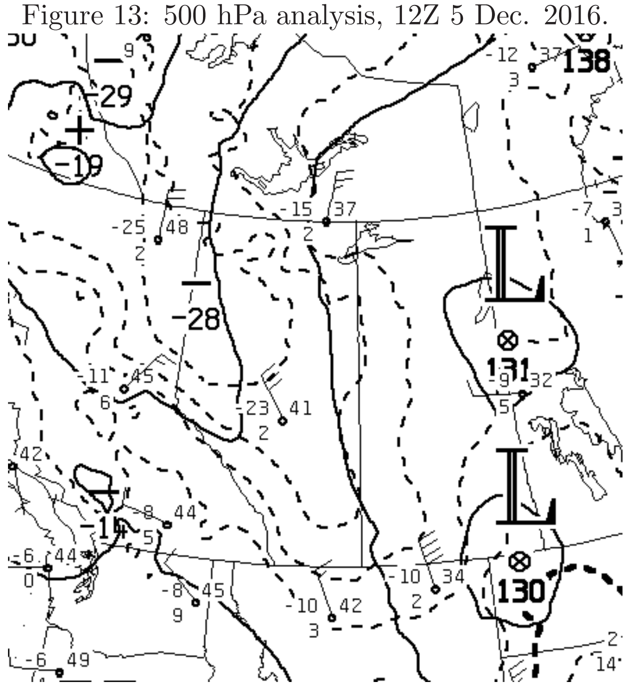


Figure 15: 850 hPa analysis, 12Z 5 Dec. 2016.