EAS270, "The Atmosphere" Final Exam 15 Dec., 2014

Professor: J.D. Wilson Time available: 120 mins Value: 35%

No formula sheets or cell phones. **Formulae and data provided at the back**. Please record your multichoice answers on the scantron sheet. Note that in many cases you are looking for the *false* response, and that options may feature false or misleading statements or 'facts'.

Multi-choice (50 questions; all have equal value)

1. During cloudless, summertime "airmass weather," wind speed near ground tends to be highest in mid-afternoon and calm at night. Which aspect of the following explanation is **false**?
   (a) under such conditions the atmospheric surface layer is absolutely unstable by day and absolutely stable by night
   (b) vertical motion of air parcels "couples" the near surface wind to the "free winds" (that can be assumed unvarying) above the friction layer
   (c) turbulent vertical momentum exchange is strongest during strong winds in an unstably stratified boundary layer
   (d) descending parcels bring down a "momentum excess" (or velocity surplus) relative to average conditons at the surface
   (e) for each volume $\mathcal{V}\,[\mathrm{m}^3]$ of air that descends from height z_2 to z_1 ($< z_2$), a much larger volume $\sim 10^2\mathcal{V}\,[\mathrm{m}^3]$ ascends from z_1 to z_2

2. Which of the following statements about modern NWP models is **false**?
   (a) the grid resolves atmospheric motion on all scales of importance
   (b) a sparse observation network reduces accuracy of the initial state
   (c) equations are included to model heat and moisture exchange with the surface
   (d) some terms in the governing equations are neglected or simplified
   (e) long range forecasts from almost-identical initial states may be entirely different

3. What is meant by the "domain" of a Numerical Weather Prediction model?
   (a) the set of all variables predicted by the model (velocity, humidity,...)
   (b) the interval $t - t_0$ between initialization time (t_0) and valid time (t)
   (c) the region of space encompassed by the model's grid
   (d) the set of equations solved
   (e) the distance between neighbouring gridpoints

4. Compared to a medium-range NWP model initialized at the same time t_0, a short range model might
   (a) solve entirely different equations
   (b) commence from an entirely different initial state
   (c) use an entirely different set of parameterizations
   (d) cover a smaller region of the globe with finer space & time resolution
   (e) drop the Coriolis terms from the horizontal momentum equations

5. Which statement regarding the the GOES (geostationary) meteorological satellites is **false**?
   (a) they observe earth from a position on earth's equatorial plane about 36,000 km above the equator
   (b) they make two passes very day over every point on the earth's surface
   (c) the $\lambda = 10.7\,\mu$m ir (infrared) radiometer channel provides day-and-night cloud information
   (d) the utility of the $10.7\,\mu$m channel derives from its falling within the "atmospheric window"
   (e) GOES observations at 00, 06, 12, 18 UTC contribute to the definition of the initial state for NWP forecasts

6. Which of the following questions **cannot be answered** based on the given information?
   (a) If $T = 10^{\circ}$C, what is the equilibrium vapour pressure $e_*(T)$?
   (b) If equilibrium vapour pressure $e_* = 13.12$ Pa, what is the dewpoint?
   (c) If dewpoint $T_d = 10^{\circ}$C, what is the vapour pressure e?
   (d) If equilibrium vapour pressure $e_* = 13.12$ Pa, what is the temperature?
   (e) If vapour pressure $e = 13.12$ Pa, what is the dewpoint T_d?

7. 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) mixing results in uniform specific humidity and mixing ratio
   (e) mixing results in the lapse rate of potential temperature being $0.01\,\mathrm{K\,m^{-1}}$

8. Referring to Figure (1), which of the following qualitative statements about the layer below 700 hPa is **false**?

   (a) judged by its temperature profile (alone), the layer is *not* well mixed
   (b) potential temperature is approximately constant within the layer
   (c) lapse rate approximately equals the dry adiabatic lapse rate (ELR=DALR)
   (d) the layer is neutral with respect to unsaturated adiabatic motion
   (e) judged by its humidity profile (alone), the layer is *not* well mixed

9. If a sample of air at the 500 hPa level has temperature $T = -33^{\circ}\mathrm{C}$, what is its potential temperature θ (taking reference pressure $P_0 = 1000$ hPa)?

   (a) $-27^{\circ}\mathrm{C}$
   (b) $-40^{\circ}\mathrm{C}$
   (c) $-76^{\circ}\mathrm{C}$
   (d) $20^{\circ}\mathrm{C}$
   (e) 197K

10. Each member of a certain family of curves on a skew-T diagram (or tephigram) links all possible (P, T) states of a sample of air having a fixed potential temperature. With which of the following is that family of curves identified?

    (a) dewpoint lapse rate lines
    (b) saturated adiabats (SALR)
    (c) dry adiabats (DALR)
    (d) isothermal layers
    (e) inversion layers

11. The magnitude of the dewpoint lapse rate is about 0.2 K per 100 m of ascent. If the surface temperature and dewpoint are $(26, 18)^{\circ}$C, how high above the surface is the Lifting Condensation Level (LCL)?

    (a) 100 m
    (b) 500 m
    (c) 1 km
    (d) 2 km
    (e) 8 km

12. Referring to Figure (2), based on the ELR which statement is **true**?

    (a) the lowest layer is superadiabatic (unconditionally unstable)
    (b) all three layers are conditionally unstable
    (c) the uppermost layer is an inversion
    (d) the lowest layer is saturated
    (e) all three layers are neutral with respect to unsaturated adiabatic motion

13. Which cloud type is able to produce large hail?

    (a) nimbostratus
    (b) cirrostratus
    (c) altocumulus
    (d) cumulonimbus
    (e) stratocumulus

14. Suppose the dewpoint near ground were $T_d = 7^{\circ}$C, and that overnight the ground cooled radiatively to or below that temperature but, the wind being calm, air temperature above the laminar sublayer remained warmer than T_d. What phenomenon is probable?

    (a) dew
    (b) a deep layer of haze
    (c) a deep layer of fog
    (d) frost
    (e) rain

15. Suppose that at 13:00 MST (20:00 Zulu) on 15 December in Edmonton you were asked to provide a forecast of the weather conditions to be expected locally in two hours' time, at 15:00 MST. Which of the following sources of information or forecast methods would you consider **least** useful or reliable?

    (a) weather radar images valid at 12:50 MST
    (b) persistence method
    (c) GOES satellite images valid at 12:30 MST
    (d) an NWP forecast initialized at 18:00 Zulu that day
    (e) Edmonton 30-year normals (climatology) for December

16. Suppose that on 15 December you were asked to forecast weather conditions for south-eastern Saskatchewan in four days' time (i.e. 4 day forecast range). Which of the following sources of information or forecast methods would you consider **most** useful?

    (a) 30-year normals for a station in SE Saskatchewan
    (b) the Environment Canada seasonal forecast for Dec-Jan-Feb produced on 30 November
    (c) the most recently initialized NWP forecast from Meteorological Service of Canada
    (d) the latest GOES satellite images
    (e) the latest weather radar image for SE Saskatchewan

17. Which of the following combinations produces the strongest Coriolis force?

    (a) fast winds and low latitude
    (b) fast winds and high latitude
    (c) slow winds and low latitude
    (d) slow winds and high latitude
    (e) complete calm on the equator

18. It is considered that areas enclosed by the 90 percent relative humidity contour (or $T - T_d \leq 2^{\circ}$C contour) on a 700 hPa NWP chart are liable to receive precipitation. Which of the following additional factors would you consider makes it even *more* likely precipitation will occur in such an area?

    (a) sinking vertical motion over the area
    (b) rising vertical motion over the area
    (c) strong winds over the area
    (d) sub-zero temperature below the 850 hPa level
    (e) an elevated temperature inversion over the area

19. "Model Output Statistics" refers to the use of an empirical equation to forecast a weather element (e.g. visibility V at an airport) from a subset of the gridded output variables (say $q_1, q_2, ...q_N$) of a NWP forecast valid at or about that time. How is an equation relating V to $(q_1, q_2, ...q_n)$ derived?

    (a) Future forecasts of $q_1...q_N$ are correlated with past observations of V
    (b) Future forecasts of $q_1...q_N$ are correlated with future observations of V
    (c) Past forecasts of $q_1...q_N$ are correlated with past observations of V
    (d) Past forecasts of $q_1...q_N$ are correlated with future observations of V

20. Suppose that on a windy day you observe the motion of middle layer clouds overhead, and orient yourself with your back to the winds aloft. Assuming you are in the northern hemisphere, in which direction does lower pressure lie?

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

21. What is the result of the ice-crystal (Bergeron) process, operating above the freezing level in a cloud?

    (a) transfers water from few ice crystals to many supercooled droplets
    (b) transfers water from few supercooled droplets to many ice crystals
    (c) transfers water from many ice crystals to few supercooled droplets
    (d) transfers water from many supercooled droplets to few ice crystals
    (e) "activates" hygroscopic cloud condensation nuclei

22. A formula for the speed of the wind above the friction layer, in a region of straight-line isobars (or height contours), is obtained by equating which quantities?

    (a) centripetal acceleration and the vertical pressure gradient force
    (b) centripetal acceleration and the horizontal pressure gradient force
    (c) vertical pressure gradient force and Coriolis force
    (d) gravitational acceleration and the vertical pressure gradient force
    (e) horizontal pressure gradient force and Coriolis force

23. During a period of fine summer weather with light synoptic scale winds, an alternating coastal seabreeze-landbreeze cycle may be observed. Which statement is **false**?

(a) the sea breeze may penetrate tens of kilometers inland
(b) the Coriolis force plays no role in the sea breeze circulation
(c) differences in the surface energy budget over land and water drive this type of circulation
(d) the sea breeze circulation is shallow, i.e. only of the order of 1 km deep
(e) during the sea breeze a thermal low forms over the land surface

24. According to the three-cell model of the general circulation, where do the sub-tropical highs occur?

(a) along the intertropical convergence zone (ITCZ)
(b) where the NE trade winds and the SE trade winds converge
(c) at the boundary of the Hadley cell and the Polar cell
(d) at the boundary of the Hadley cell and the Ferrel cell
(e) at the boundary of the Ferrel cell and the Polar cell

The next three questions refer to Fig. (3). Assume you are situated at ground at the point marked **P** *and observe a sequence of events in time (first → last) as the storm moves from the WSW towards the ENE parallel to the indicated straight line.*

25. When your position at **P** relative to the storm is as shown by Fig. (3), the two lowest layers of the air column above **P** would represent ____

(a) the cold conveyor belt riding over the warm conveyor belt
(b) the warm conveyor belt riding over the cold conveyor belt
(c) the dry conveyor belt riding over the cold conveyor belt
(d) the warm conveyor belt riding over the dry conveyor belt

26. As time progresses, the thermometer at **P** will show these phases ____

(a) cold-to-warm transition followed by warm-to-cold transition
(b) cold-to-warm transition followed by warm-to-warmer transition
(c) warm-to-cold transition followed by cold-to-warm transition
(d) warm-to-cold transition followed by cold-to-colder transition

27. Which statement correctly describes events as the cold front passes **P**?

    (a) pressure will reach a minimum then begin to rise, winds will become south-easterlies
    (b) pressure will reach a maximum then begin to fall, winds will become south-easterlies
    (c) pressure will reach a minimum then begin to rise, winds will become north-westerlies
    (d) pressure will reach a maximum then begin to fall, winds will become north-westerlies

28. The Polar Front Theory for the life cycle of a mid-latitude cyclone originated at a time when measurements high aloft in the troposphere were rarely made. According Bjerknes' model, cyclogenesis takes place on a stationary polar front. Which further factor is now considered to initiate the storm?

    (a) subsidence in the lee of mountains
    (b) an upslope surface wind
    (c) a dryline (boundary between air masses with very different dewpoints)
    (d) a cold front overtaking a warm front, resulting in an occlusion
    (e) arrival of a shortwave trough over the front

29. Which association, referring to conditions on an isobaric chart in the free troposphere, is **incorrect**?

    (a) barotropic atmosphere – no thermal advection
    (b) baroclinic atmosphere – isotherms intersect height contours
    (c) trough exit region – divergence
    (d) warm advection – ascent
    (e) vorticity maximum – shortwave ridge

30. Which option best approximates the horizontal gridlength of the GEM model over North America for the Regional Deterministic Prediction System?

    (a) 1000 km
    (b) 100 km
    (c) 10 km
    (d) 1 km
    (e) 0.1 km

31. Which statement best describes the criterion according to which an NWP model may be termed "skillful"?

    (a) forecast must predict more weather elements than any other method
    (b) forecast must (on average) outperform forecasts based on climatology or persistence
    (c) range must exceed that of a forecast based on climatology
    (d) range must exceed that of a forecast based on persistence
    (e) spatial resolution of the forecast must be finer than 100 km

32. The modest skill of CMC's deterministic 3-month seasonal forecast (i.e. ensemble forecasts based on coupled dynamical ocean-atmosphere models) is attributed to which factor?

    (a) teleconnections – adjustment of the atmosphere-ocean to slowly changing anomalies in sea surface temperature (e.g. El-Nino)
    (b) insensitivity of NWP forecasts to errors in the initial state
    (c) perfect "parameterization" of all unresolved processes (such as cumulus convection) in the NWP models
    (d) use of the hydrostatic equation in lieu of a more complete vertical momentum equation
    (e) adoption of the ensemble method

33. In most NWP models the atmospheric variables are represented at gridpoints distributed in space around the region of interest, e.g. the "gridded field of temperature." The gridpoints are ordered and referred to by their "indices," often denoted I, J, K (for example $T_{I,J,K}$ means "temperature at the gridpoint whose indices are I, J, K). What name is given to the distance between neighbouring gridpoints, e.g. between (I, J, K) and $(I, J+1, K)$?

    (a) grid spacing along the direction indexed by J
    (b) contour interval
    (c) thickness
    (d) forecast range
    (e) height of the isobaric surface

34. Suppose $T_{I,J,K}$ represents the gridded field of temperature in an 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)
(d) surface analysis (contour map of MSLP)
(e) precipitation map

35. Which option correctly states the treatment of cumulus clouds by CMC's Global Environmental Multiscale (GEM) model?

(a) the role of cumulus is neglected
(b) the fields of velocity, temperature, humidity etc. are resolved by the model grid on a scale sufficiently fine to explicitly represent (i.e. model) cumulus
(c) the role of cumulus, which constitute a "subgrid" feature, is represented by a "parameterization"
(d) a climatology of cumulus clouds (i.e. their 30-year average distribution in space and time) is used

36. A "lee trough" in the MSLP pressure field over Alberta appears under which circumstance?

(a) during a winter-time period of strong, sustained north winds
(b) during an arctic outbreak
(c) when strong SW winds aloft are impeded by the Rocky Mountains
(d) during intervals of very light upper winds
(e) on winter mornings after a cloud free night

37. Which association is false?

(a) left exit of jet core — divergence
(b) cold advection — sink
(c) ridge exit — divergence
(d) trough of warm air aloft — occluded front
(e) stratiform cloud types — warm front

38. Heavy short-dashed lines on Figure (4) identify several families of reference curves. Which line represents the family of dry adiabats?

(a) A
(b) B
(c) C
(d) D
(e) E

39. Concerning the layer L1 on Figure (4), which statement is **false**?

(a) layer L1 is well mixed
(b) layer L1 is neutral with respect to unsaturated adiabatic motion
(c) layer L1 is unsaturated
(d) layer L1 is conditionally unstable
(e) layer L1 is capped by a stable layer

40. Referring to Figure (5), let the x-axis increase towards the east and the y-axis towards the north. Which statement is **false**?

(a) in (**A**) the thermal wind is zero
(b) in (**A**) the thermal wind is a southerly
(c) in (**B**) the thermal wind is a southerly, parallel to the geostrophic wind
(d) in both cases, thickness lines run parallel to the y-axis
(e) in neither case is thermal advection occurring

41. Referring to Figure (6), what weather event seems a possibility?

(a) strong winds
(b) snow
(c) freezing rain or wet snow
(d) clearing skies
(e) a frontal passage

42. Again referring to Figure (6), what *upper limit* would you suggest for the magnitude of the temperature lapse rate above the warm layer?

(a) $10\ \mathrm{K\,m^{-1}}$
(b) $1\ \mathrm{K\,m^{-1}}$
(c) $0.1\ \mathrm{K\,m^{-1}}$
(d) $0.01\ \mathrm{K\,m^{-1}}$
(e) $0.001\ \mathrm{K\,m^{-1}}$

43. Which forecast range is considered the "short range"?

(a) 2 weeks and longer
(b) 3 – 10 days
(c) 12 hours – 3 days
(d) 0–6 hours

44. Referring to Figure (7), compute an approximate value for the geostrophic wind speed corresponding to the height gradient $\Delta h/\Delta n$ implied by the smaller arrow. (For simplicity, assume the Coriolis parameter $f_c = 10^{-4}\,\mathrm{s}^{-1}$).

(a) $1\,\mathrm{m\,s}^{-1}$
(b) $15\,\mathrm{m\,s}^{-1}$
(c) $30\,\mathrm{m\,s}^{-1}$
(d) $60\,\mathrm{m\,s}^{-1}$
(e) $150\,\mathrm{m\,s}^{-1}$

45. Which statement is **false**?

(a) the relative vorticity ζ_r of a parcel with horizontal velocities U, V along axes (x, y) is given by the Coriolis parameter f_c
(b) climatologically, the polar front jetstream lies closer to the pole in summer than it does in winter
(c) a simple paradigm for the Rossby waves is that, as air parcels move eastward, the meridional component of their motion is arranged such that absolute vorticity is conserved
(d) the force balance in the friction layer is such that the pressure gradient force is *not* perpendicular to the direction of the wind
(e) one may find the LCL graphically as the intersection of the isohume that runs through surface dewpoint with the dry adiabat that runs through surface temperature

46. During winter, Alberta is most liable to experience which airmass(es)?

(a) cA air and modified mP air
(b) cA air and cT air
(c) mP and mT air
(d) cA air
(e) mP air

47. Concerning climatological pressure systems in the N. hemisphere, which association is **false**?

(a) Aleutian low — winter feature
(b) Canadian high — summer feature
(c) Siberian high — winter feature
(d) Aleutian and Icelandic lows — polar lows
(e) Pacific and Bermuda highs — subtropical highs

48. Referring to Fig.(8), at the locations respectively designated (**A**, **B**) ____ advection is occurring

(a) warm; warm
(b) cold; cold
(c) warm; cold
(d) cold; warm
(e) horizontal; vertical

49. Referring to Fig.(8), what height corresponds to the innermost contour about the low pressure centre southeast of Manitoba?

(a) 114 dam
(b) 120 dam
(c) 124 dam
(d) 126 dam
(e) 150 dam

50. The "analog method" of weather forecasting relies on the recognition of patterns in past observations, and one of the analog methods exploits a set of "map types" that characterize different weather regimes. Referring to Figure (9), which association is false?

(a) 26 November – mild spell in Alberta
(b) 26 November – Chinook wind
(c) 26 November – Alberta lee trough
(d) 6 December – cold advection in N. Alberta
(e) 6 December – steady and mild weather on the Canadian prairies

Equations, Data & Figures.

A. The dry adiabatic lapse rate (DALR) is

$$\frac{\Delta T}{\Delta z} = -g/c_p\,,$$

where g is the gravitational acceleration and c_p [J kg^{-1} K^{-1}] is the specific heat at constant pressure. Our textbook defines the DALR as the *magnitude*, DALR= $|\Delta T/\Delta z|$, often rounded to DALR=1°C (100 m)$^{-1}$.

B. Poisson's law

$$\frac{T}{T_1} = \left(\frac{P}{P_1}\right)^{R/c_p}$$

links two states (P, T) and (P_1, T_1) of a sample of ideal gas, assuming the process connecting the two states is adiabatic ($R/c_p = 2/7 = 0.286$).

C. The potential temperature is defined

$$\theta = T\,\left(\frac{P_0}{P}\right)^{R/c_p}\,,$$

and amounts to a restatement of Poisson's law. The potential temperature θ of a sample of air whose pressure and temperature are (P, T) is the temperature it *would* have if its pressure were changed adiabatically to the reference pressure P_0 ($R/c_p = 2/7 = 0.286$).

D. The Geostrophic wind equation

$$V = \frac{g}{f}\,\frac{\Delta h}{\Delta n}$$

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

71119 WSE Edmonton Stony Plain Observations at 00Z 19 Oct 2014

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 1: Stony Plain sounding 00Z 19 Oct. 2014.

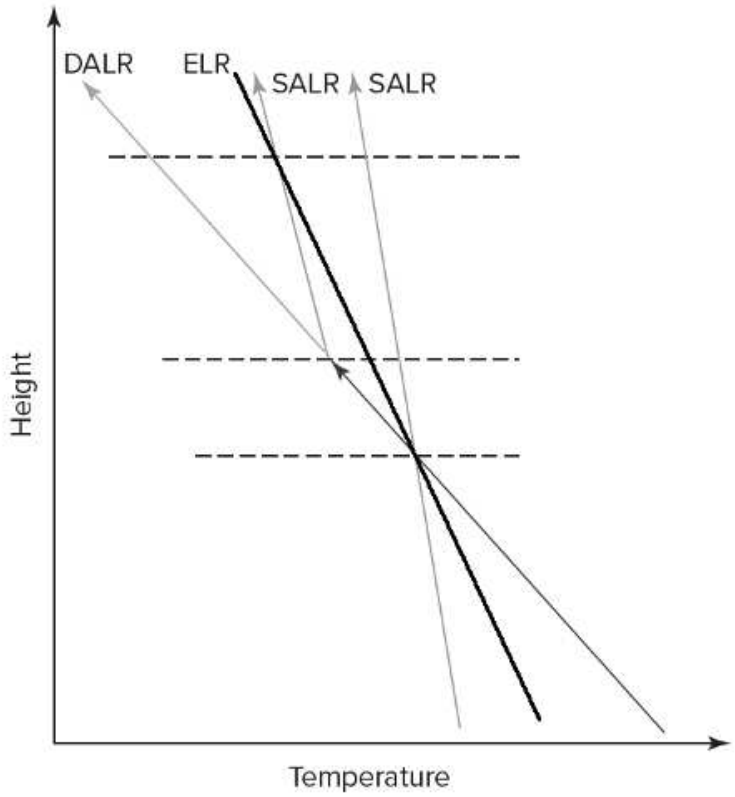

Figure 2: Idealized temperature profile (Ross's Fig. 8.19), compared with benchmark profiles (heavy line gives the ELR; consider the two lines labelled 'SALR' as being parallel).

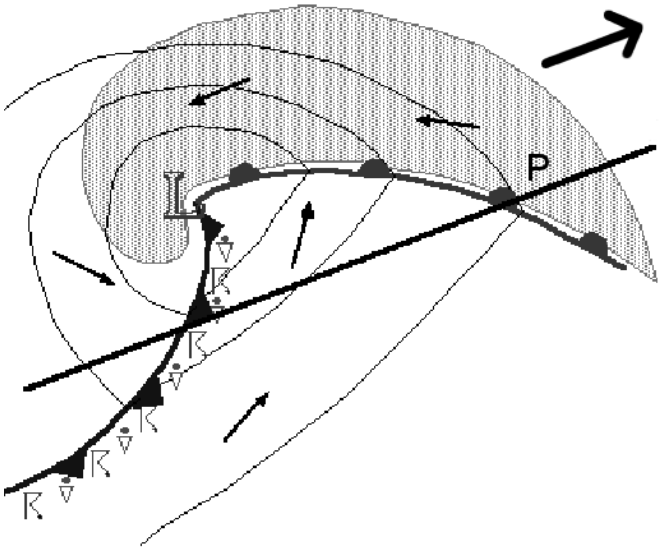

Figure 3: Northern hemisphere middle-latitude cyclone (north to the top of the diagram). Arrows give the wind direction in the friction layer, and the single heavy arrow shows the direction of motion of the system as a whole. The "R" symbols designate thunderstorms, the "dot over triangle" symbols designate rain showers, and the shading denotes precipitating stratiform cloud (with possibility of embedded deep convection). Questions concern the sequence of events or conditions at the point denoted **P** as the storm moves to the ENE parallel to the indicated line. (Adapted from Doswell & Maddox 1986, 11th Conference on Weather Forecasting and Analysis, Kansas City, American Meteorological Society.)

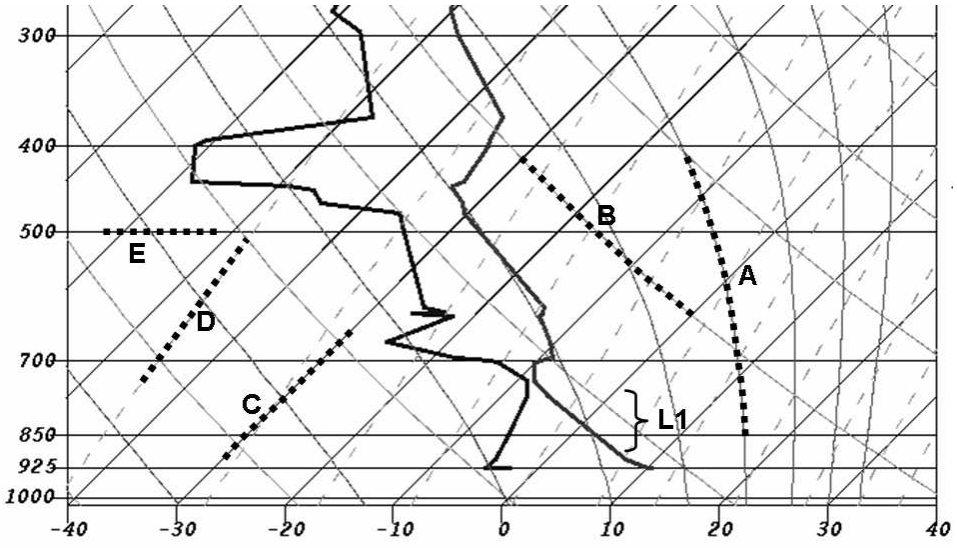

Figure 4: Thermodynamic chart (skew-T log-P diagram).

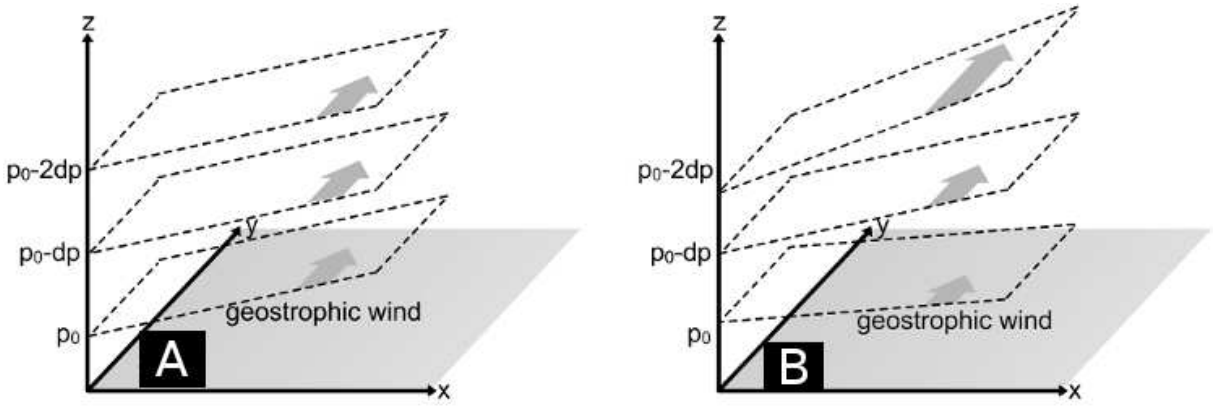

Figure 5: Sloping isobaric surfaces (Wikipedia). Arrows designate the geostrophic wind. (In A, the isobaric surfaces are all parallel and geostrophic wind is not changing with height).

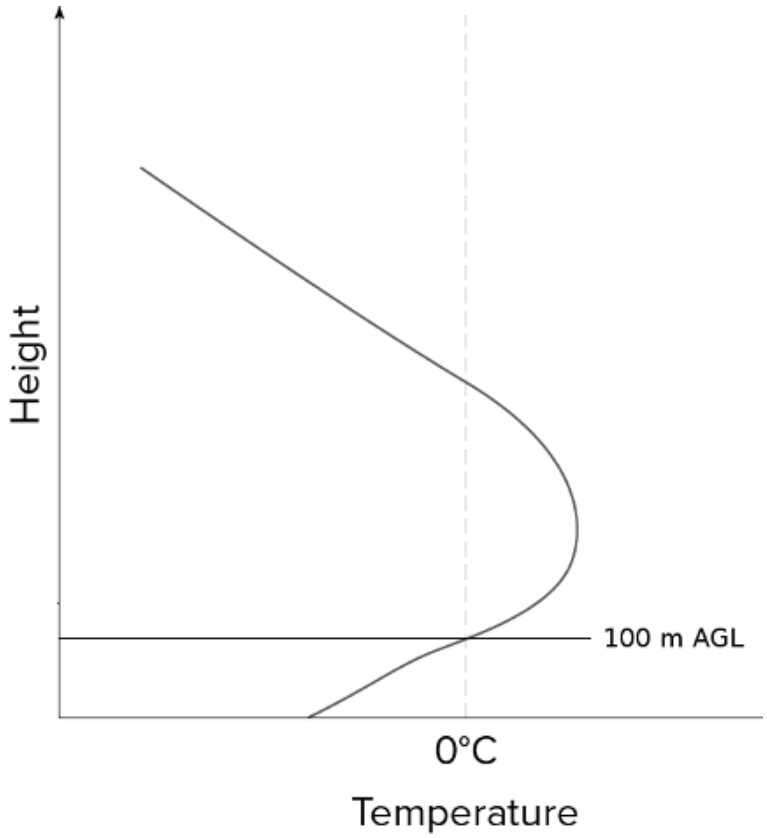

Figure 6: Hypothetical environmental temperature profile near ground (Ross's Figure 10.11b, modified).

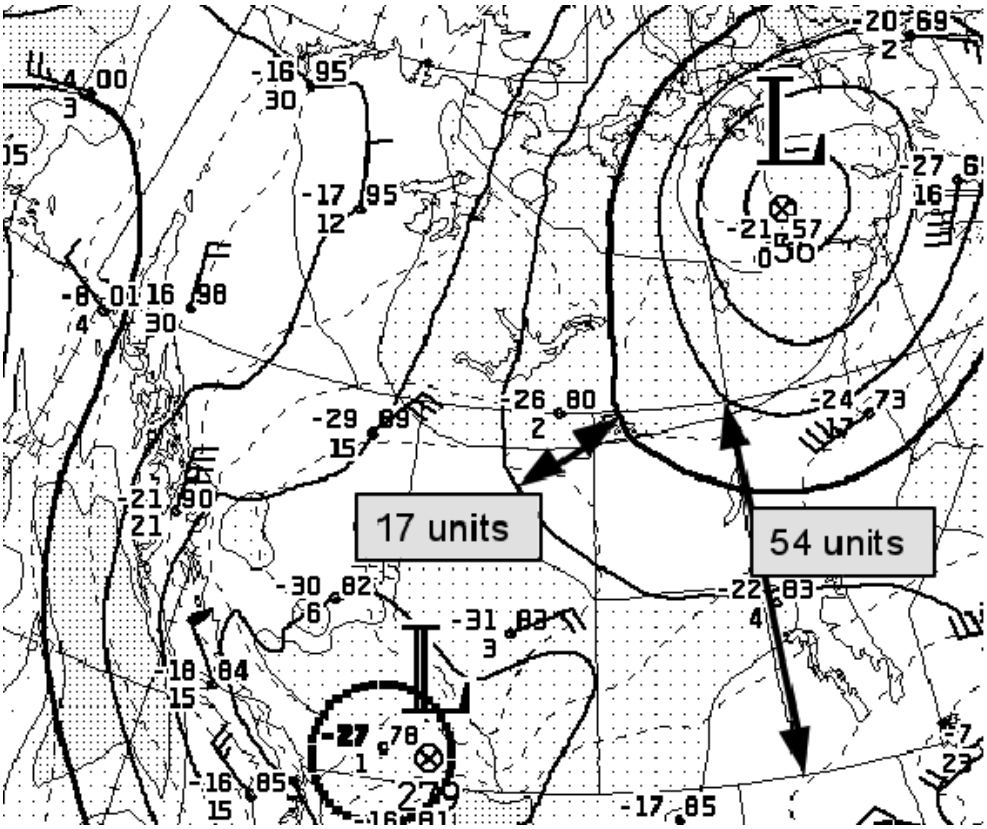

Figure 7: MSC 700 hPa analysis, 12Z 22 Nov., 2010. The numbers in boxes refer to the lengths of the two heavy arrows, in arbitrary units. The height interval between adjacent height contours is 6 dam (60 m). The long arrow corresponds to a true distance of 11×111 km.

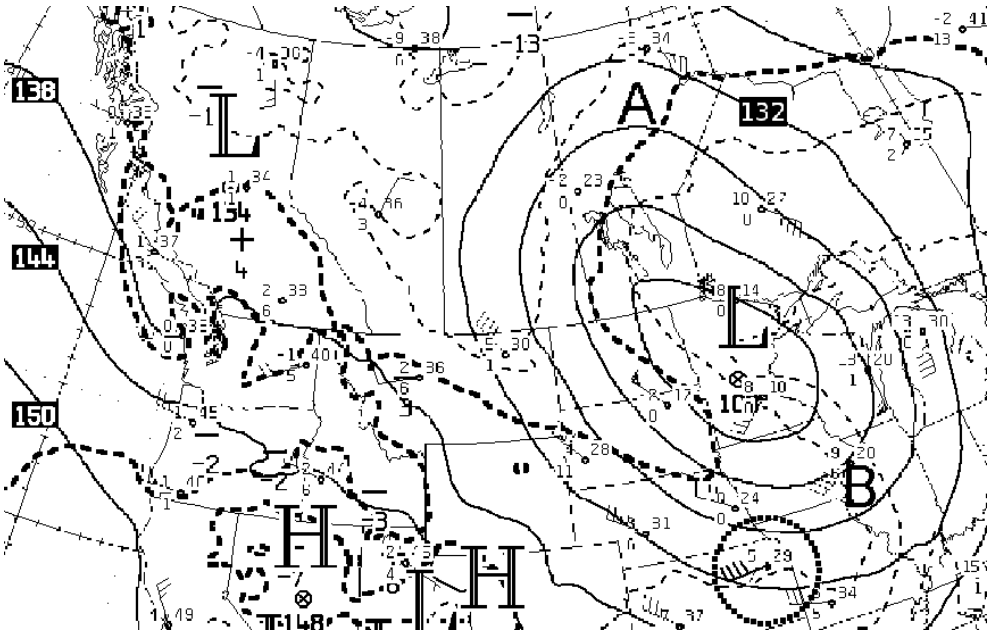

Figure 8: CMC 850 hPa analysis, 12Z Oct. 26, 2010.

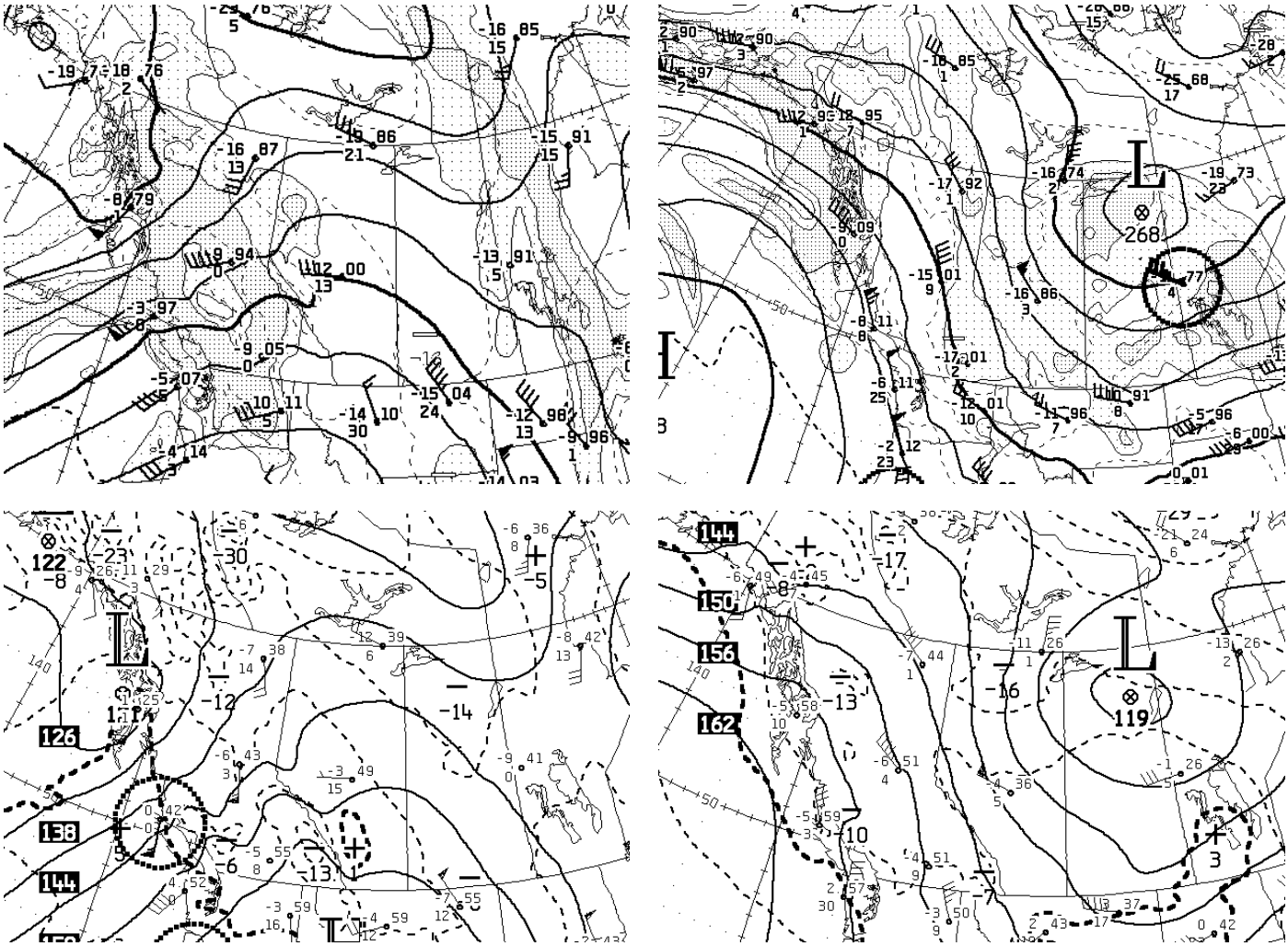

Figure 9: MSC 850 hPa and 700 hPa analyses for 12Z 26 Nov. (left side) and 12Z 2 Dec. (right side), 2011.