EAS270, "The Atmosphere"   <u>Mid-term Exam</u>   28 Oct. 2011

<u>Professor</u>: J.D. Wilson   <u>Time available</u>: 50 mins   <u>Value</u>: 20%

Instructions: For each of the 30 multi-choice questions, choose the most logical option. Use a pencil to mark that choice on the answer form. **Data at back.** ***You may keep this exam.***

1. An order-of-magnitude value for air density (ρ) at sea-level is ____
   (a) 1000 mb
   (b) 1000 mg m^{-3}
   (c) 1 g m^{-3}
   (d) 1 kg m^{-2}
   (e) 1 kg m^{-3} ✓✓(p14, basic knowledge, used repeatedly)

2. To roughly estimate effective sea-level pressure from a reading P [hPa] made 1000 m above sea-level, one should ____
   (a) add 10 hPa
   (b) subtract 10 hPa
   (c) add 100 hPa ✓✓(use the hydrostatic law with $\rho \sim 1$ and $g \sim 10$ in MKS units)
   (d) subtract 100 hPa
   (e) add 1000 hPa

3. The occurrence of dew on vegetation indicates plant surfaces cooled to the ____ of the near surface air. Gentle mixing of the layer of air near ground would provide the moisture supply for continuing accumulation of dew by way of a ____ latent heat flux
   (a) temperature; positive (upward)
   (b) dewpoint; positive
   (c) temperature; negative (downward)
   (d) dewpoint; negative ✓✓(p157 & sign convention for vertical flux of water –same as sign convention for latent heat)
   (e) Environmental Lapse Rate; continuing

4. Conditions associated with a radiation frost are a strong ____ with a convective flow of sensible heat ____
   (a) temperature inversion; from ground to atmosphere
   (b) temperature inversion; from atmosphere to ground ✓✓(slides 6,7 lec. 8)
   (c) wind; from ground to atmosphere
   (d) wind; from atmosphere to ground
   (e) downward solar flux density $K\downarrow$; from air to nitrogen molecules

5. Noctural longwave radiative cooling of the ground tends to ____ a ground-based layer of the atmosphere, resulting in formation of a/n ____ layer
   (a) stabilize; inversion ✓✓(slides 6,7 lec. 8; p177, p181)
   (b) stabilize; statically neutral
   (c) destabilize; inversion
   (d) destabilize; statically neutral
   (e) destabilize; isothermal

6. Consider the magnitude of the atmospheric pressure decrease ΔP between sea-level (height $z = 0$), and a point overhead at a height of 1 kilometre above sea-level ($z = 1000$ m). In the northern hemisphere winter, ΔP is ____
   (a) larger at the north pole than at the equator ✓✓(implication of hydrostatic law)
   (b) smaller at the north pole than at the equator
   (c) the same at the north pole as at the equator
   (d) negative
   (e) zero

7. The Coriolis parameter f vanishes at the equator and is maximal at the poles. Which statement is **false**?
   (a) The Geostrophic wind equation is invalid at the equator
   (b) At the equator the horizontal force balance does not involve a "Coriolis force"
   (c) A non-accelerating wind at the equator would blow parallel to the pressure gradient
   (d) A preference for one's bathwater to drain anticlockwise (seen from above) is expected at the poles but not at the equator ✓✓(p115)
   (e) At mid latitudes the "Coriolis time scale" f^{-1} is of the order of several hours

8. According to the geostrophic model, the net force acting on air blowing at constant speed parallel to straight pressure (or height) contours is ____
   (a) zero ✓✓(p117)
   (b) non-zero, but constant
   (c) oriented in the direction of the wind
   (d) oriented perpendicular to the wind
   (e) oriented vertically

9. Which humidity variable is unchanged during adiabatic vertical motion of an unsaturated parcel?
   (a) relative humidity
   (b) dewpoint
   (c) vapour pressure
   (d) absolute humidity
   (e) specific humidity ✓✓(p138)

10. The dewpoint of air whose vapour pressure is 17 hPa is about ____ °C
   (a) 0
   (b) 5
   (c) 10
   (d) 15 ✓✓(refer to saturation v.p. table given as data)
   (e) 20

11. The relative humidity of air whose temperature and dewpoint are respectively (18°C, 6°C) is about ____
   (a) 16%
   (b) 33%
   (c) 45% ✓✓(RH $= e/e_s(T) = e_s(T_d)/e_s(T)$)
   (d) 60%
   (e) 103%

12. A theoretical value for the dry adiabatic lapse rate (DALR) is obtained by combining which two laws?
    (a) Hydrostatic law & first law of thermodynamics ✓✓(p155; slides 10,11 lec. 13)
    (b) Geostrophic wind law & first law of thermodynamics
    (c) Geostrophic wind law & hydrostatic law
    (d) Hydrostatic law & ideal gas law
    (e) Ideal gas law & first law of thermodynamics

13. Which static stability classification *always* applies to the stratosphere?
    (a) Conditionally unstable
    (b) Conditionally stable
    (c) Absolutely stable ✓✓(p15 and definition of "absolute stability" class)
    (d) Absolutely unstable
    (e) Neutral with respect to dry adiabatic motion

14. Let $e_*(T)$ be the equilibrium vapour pressure over a plane surface of water. The environmental vapour pressure e required to assure the equilibrium of a droplet of pure water of radius $R \ll 1\,\mu$m in air of temperature T ____
    (a) is less than $e_*(T)$ due to the curvature effect
    (b) exceeds $e_*(T)$ due to the curvature effect ✓✓(p146-7)
    (c) is less than $e_*(T)$ due to the solute effect
    (d) exceeds $e_*(T)$ due to the solute effect
    (e) equals $e_*(T)$ due to the Bergeron effect

15. Consider two "air" parcels, each of equal volume and at equal pressure and temperature. Parcel A is dry (contains no water vapor), while parcel B is nearly saturated with water vapor. Then ____
    (a) parcels A and B have the same weight and density
    (b) parcel A is heavier than parcel B ✓✓(p106, Sec. 4-2. Molecular mass of H_2O less than that of N_2, O_2, so $\rho_A > \rho_B$)
    (c) parcel B is heavier than parcel A
    (d) parcels A and B have the same density but different weights
    (e) parcels A and B have the same weight but different densities

16. If a parcel of dry air had a temperature of 20°C when at height $z = 0$, then if lifted adiabatically to $z = 500$ m its temperature would be ____ °C
    (a) 30
    (b) 25
    (c) 20
    (d) 15 ✓✓(cooling by 1 degree Celcius per hundred metres of lift)
    (e) 10

17. In an conditionally unstable atmosphere a saturated air parcel initially at the same temperature as its environment but which is adiabatically displaced upward becomes ____ than the environmental air about it, and experiences a/an ____ buoyancy force.
    (a) cooler; downward
    (b) cooler; upward
    (c) drier; restoring
    (d) warmer; downward
    (e) warmer; upward ✓✓(p176)

18. If a very dry layer of the atmosphere remote from ground became absolutely unstable, ____ would promptly adjust that layer back towards ____
    (a) convective mixing; neutral stability (with respect to unsaturated adiabatic motion) ✓✓(final slide, lec. 14)
    (b) convective mixing; unconditionally stable stratification
    (c) molecular conduction; neutral stability
    (d) molecular conduction; unconditionally stable stratification
    (e) latent heat of condensation; an isothermal state

19. The clear air that typically lies between fairweather cumulus clouds is associated with
    (a) absolutely stable stratification of the layer
    (b) air that is so warm that its dewpoint depression remains positive
    (c) air that is so cold it can hold no vapour
    (d) air that is rising too rapidly to permit saturation
    (e) sinking air that compensates for the strong updraft under and within the Cu ✓✓(p190, Fig. 6-27)

20. A halo around the sun or moon is associated with ____ cloud
    (a) nimbostratus
    (b) stratocumulus
    (c) altocumulus
    (d) cirrostratus ✓✓(p187, Fig. 6-19)
    (e) altostratus

21. The "lifting condensation level" (LCL) is the level to which a parcel must be lifted to ____ ; whereas the "level of free convection" (LFC) is the level to which a parcel must be lifted to experience a/an ____ buoyancy force
    (a) become saturated; upward ✓✓(p175-6)
    (b) become unsaturated; upward
    (c) become saturated; downward
    (d) become unsaturated; downward
    (e) become buoyant; oscillating

22. Lake effect snowfalls occur on the ____ shores of an open body of water, where moistened air rises due to ____ and ____
    (a) leeward (downwind); downslope onshore flow; frictional divergence
    (b) windward (upwind); downslope onshore flow; frictional convergence
    (c) windward (upwind); upslope onshore flow; frictional divergence
    (d) leeward (downwind); upslope onshore flow; frictional convergence ✓✓(Fig. 7-13)
    (e) leeward (downwind); hydrostatic compression; warm advection

23. A climatology of sea-level pressure is obtained by averaging the observed pressure over many months, and may be displayed as a pattern of isobars. In which region of the globe do those isobars circle the globe running (almost) parallel to lines of latitude?
    (a) The arctic circle (66.5°N)
    (b) Northern mid-latitudes (40 – 60°N)
    (c) The equator
    (d) Southern mid-latitudes (40 – 60°C) ✓✓(p234, Fig. 8-5)
    (e) The Intertropical Convergence Zone (ITCZ)

24. The kinetic energy KE $= \frac{1}{2}mV^2$ of a spherical hailstone (mass m, velocity V) varies with its radius r according to KE $\propto r^4$. This implies that the fall speed (terminal velocity) of the hailstone varies as ____

  (a) $V \propto r^{1/3}$
  (b) $V \propto r^{1/2}$ ✓✓(p214, slide 7 lec. 16)
  (c) $V \propto r^1$
  (d) $V \propto r^2$
  (e) $V \propto r^3$

25. Formation of water droplets by "homogeneous nucleation" requires the presence of ____

  (a) hygroscopic aerosols
  (b) supersaturation ✓✓(p147)
  (c) cloud condensation nuclei
  (d) ice nuclei
  (e) supercooled droplets

26. As had Hadley and Ferrel before him, Rossby ignored some of the complexity of earth's geography – and of atmospheric dynamics – when he attempted to explain the spontaneously-developing free tropospheric wind pattern we know as the "Rossby wave." Which element below is incompatible with Rossby's paradigm?

  (a) Time scale of the wave motion is long with respect to the Coriolis time scale f^{-1}
  (b) Coriolis parameter f treated as zero (non-rotating planet) ✓✓[all answers treated as correct – outside promised scope of exam]
  (c) Atmospheric heating rate varies with latitude but independent of longitude
  (d) Atmosphere treated as dry
  (e) Atmosphere treated as being in hydrostatic balance

For the remaining questions, please refer to the attached charts.

27. Figure (1) evidences a ground based layer (extending to an elevation of about 730 hPa) that is neutral with respect to unsaturated adiabatic vertical motion. In that layer the Environmental Lapse Rate (ELR) equals the ____ and the dewpoint ____ with increasing elevation

  (a) DALR; decreases ✓✓
  (b) MALR; increases
  (c) MALR; decreases
  (d) DALR; increases

28. The 700 hPa analysis (Figure 2) evidences a ring of polar lows at latitudes of about 50 – 60°N, and a ring of subtropical highs at about 30°N. The farthest equatorward outbreak of subfreezing air at the 700 hPa level is associated with ____

  (a) the low over eastern Canada (central height 260 dam)
  (b) the eastern Pacific low (central height 301 dam) ✓✓(look for the bolded isotherm)
  (c) the north Atlantic low (central height 270 dam)
  (d) the longwave trough over eastern North America

29. Figure (3) is a 48 hour numerical weather forecast. On the basis of this forecast expected surface winds in northern Manitoba would be ____

  (a) strong easterly
  (b) strong southerly
  (c) strong southwesterly
  (d) strong northwesterly ✓✓

30. At the 500 hPa level (Figure 4) meridional heat transport is occurring due to the winds around the eastern Canadian low (central height 519 dam). Focusing on that region of the map, it is evident that ____

(a) mild air has been wrapped clockwise around the W and SW flanks of the low, through eastern Saskatchewan and southern Manitoba
(b) cold air has been wrapped anticlockwise around the W and SW flanks of the low, through eastern Saskatchewan and southern Manitoba ✓✓
(c) freezing rain was occurring south of the low
(d) the analyzed thickness pattern was poorly predicted by the 48-hour numerical weather forecast (Figure 3)

Equations and Data.

- The volume and surface area of a sphere of radius R are respectively $V = \frac{4}{3}\pi R^3$, $A = 4\pi R^2$
- 1 hPa $=$ 100 Pa
- $Q^* = K^* + L^* = K\downarrow - K\uparrow + L\downarrow - L\uparrow$. The radiation balance on a horizontal reference plane surface. All fluxes are in [W m^{-2}]. $K\downarrow, K\uparrow$, the incoming and outgoing solar fluxes (net solar, $K^* = K\downarrow - K\uparrow$); and $L\downarrow, L\uparrow$, the incoming and outgoing longwave fluxes (net longwave, $L^* = L\downarrow - L\uparrow$). Any quantity carrying the arrow ($\downarrow$ or $\uparrow$) is non-negative by definition.
- $Q^* = Q_H + Q_E + Q_G$. Surface energy balance on a reference plane at the base of the atmosphere, all fluxes in [W m^{-2}]. Q^* the net radiation, positive if directed towards the surface; Q_H, Q_E the sensible and the latent heat fluxes, positive if directed from the surface towards the atmosphere; Q_G the 'soil' heat flux, positive if directed from the surface into ground/lake/ocean. The latent heat flux is related to the vertical flux of water vapour E by the relationship $Q_E = L_v E$, where L_v [J kg^{-1}] is the latent heat of vapourization.
- $V = \frac{g}{f}\frac{\Delta h}{\Delta n}$. The Geostrophic wind equation. Δh [m], 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 $\Omega \approx 2\pi/(24 \times 60 \times 60) = 7.27 \times 10^{-5}$ s^{-1} is the angular velocity of the earth, and ϕ is latitude); $g = 9.81$ [m s^{-2}] acceleration due to gravity. The Geostophic wind is oriented *parallel* to the height contours.
- $\frac{\Delta T}{\Delta z} = -\frac{g}{c_p}$, the dry adiabatic lapse rate DALR (textbook gives as the DALR the magnitude, DALR$= |\Delta T/\Delta z|$). Here $g = 9.81$ [m s^{-2}] is the gravitational acceleration and $c_p \approx 10^3$ [J kg^{-1} K^{-1}] is the specific heat at constant pressure. Magnitude of the moist adiabatic lapse rate $|\text{MALR}| < |\text{DALR}|$

Table 1: Equilibrium vapour pressure $e_s(T)$ [hPa] versus temperature T [°C].

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

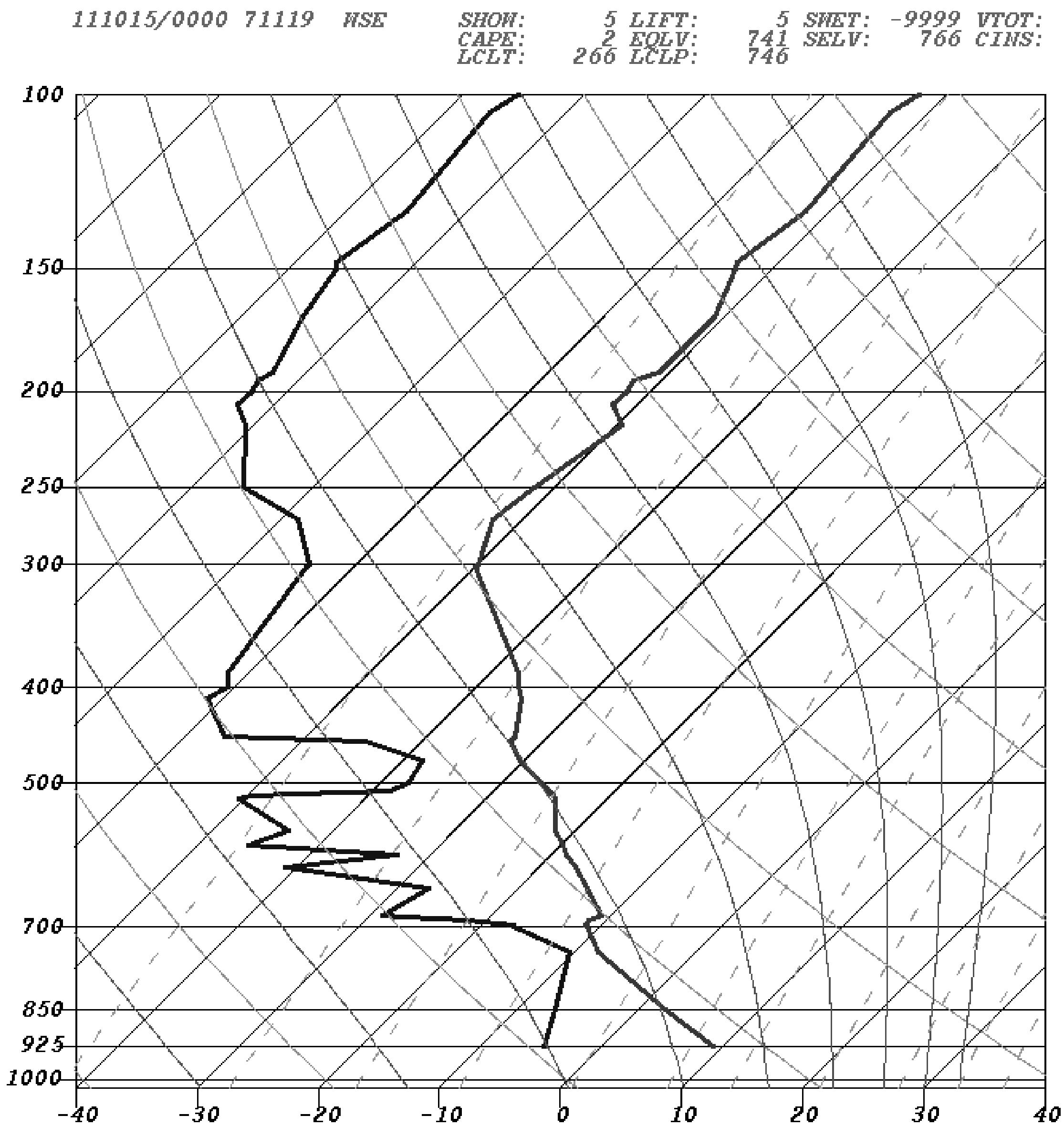

Figure 1: Skew-T/Log-P diagram for Stony Plain sounding at 00Z Oct. 15, 2011. The heavy black lines give T and T_d in Celcius.

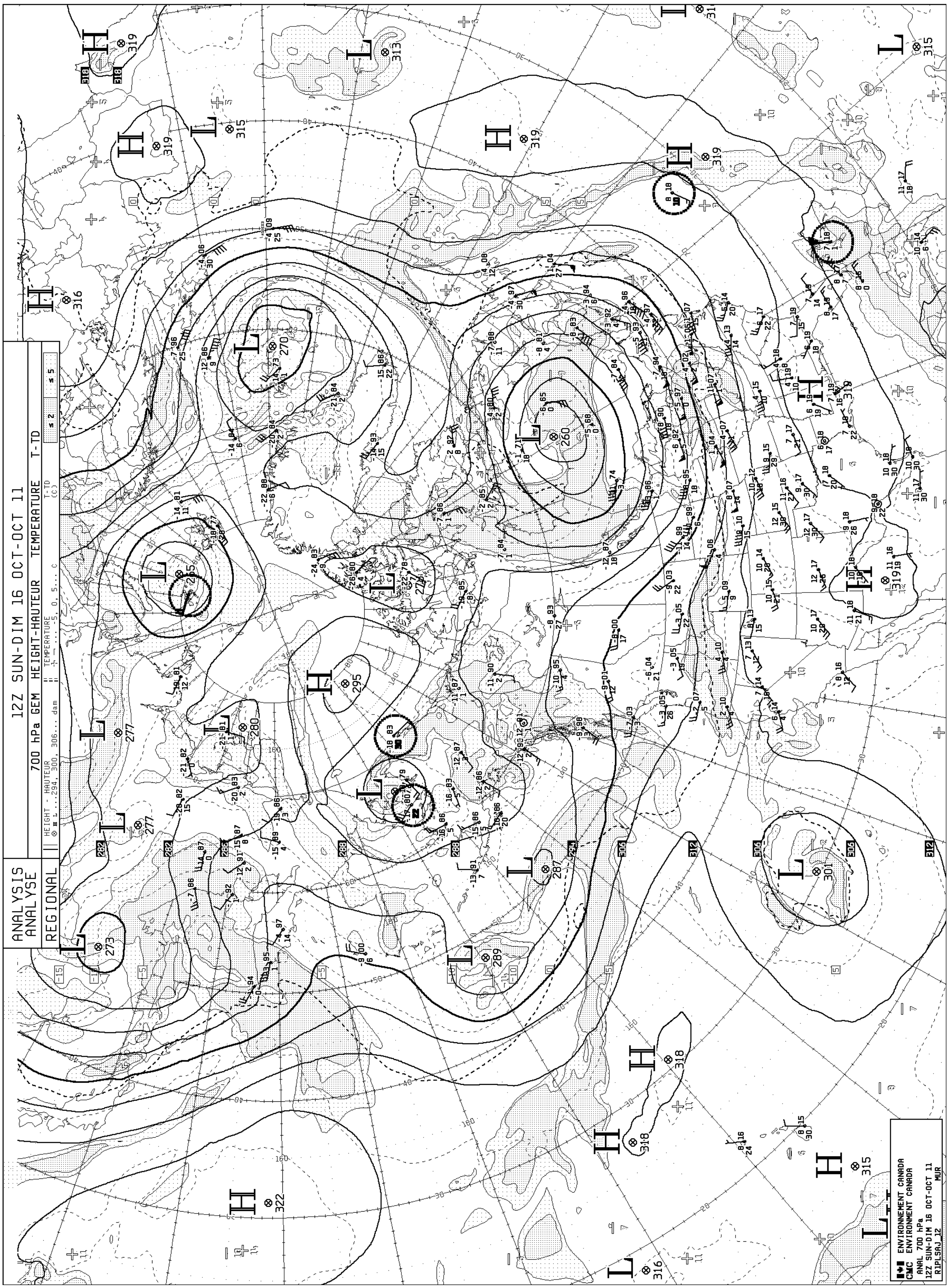

Figure 2: MSC 700 hPa analysis 12Z 16 Oct. 2011: 700 hPa height (solid lines) and temperature (dashed lines).

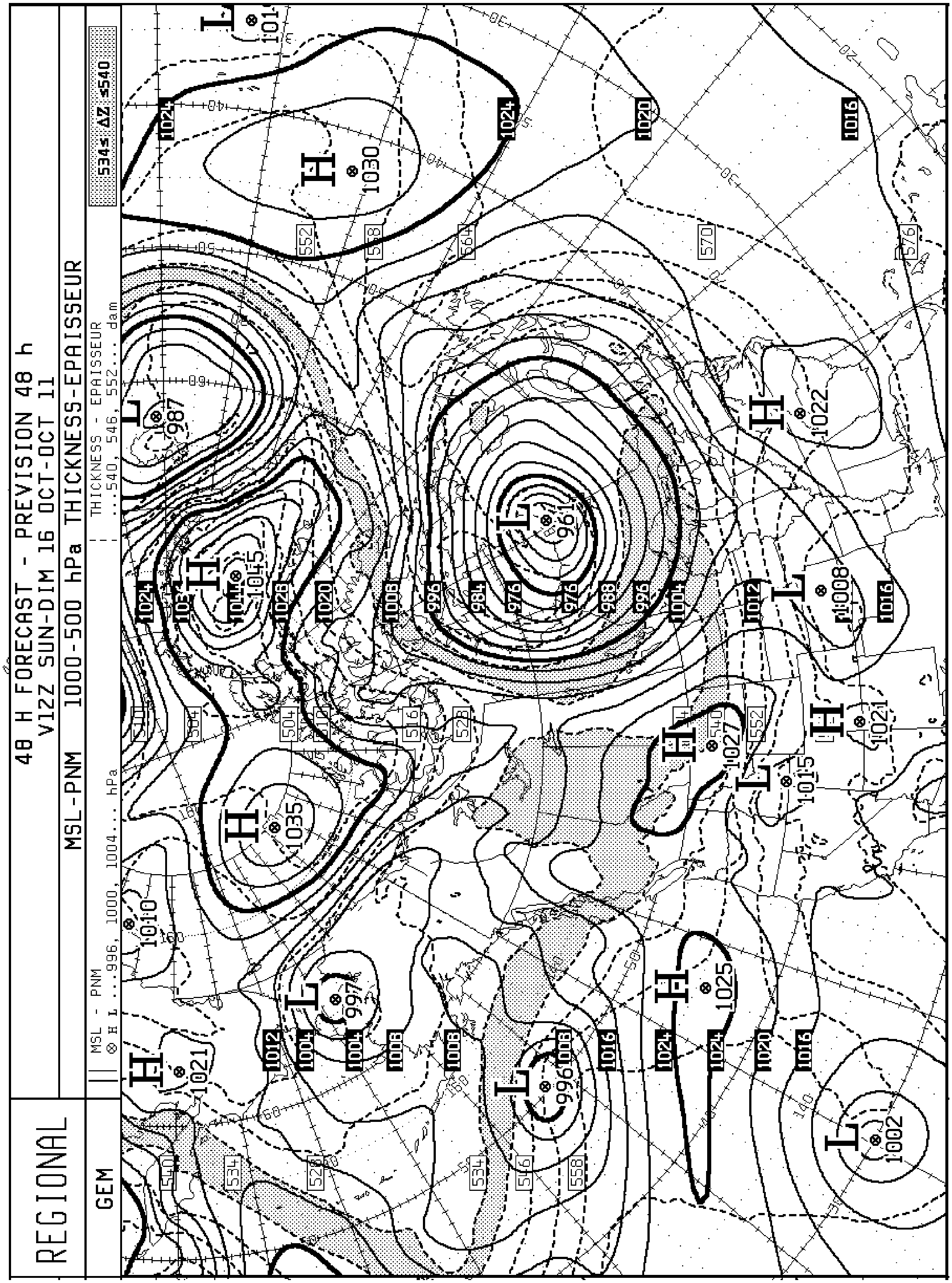

Figure 3: MSC 48 hour forecast, valid 12Z 16 Oct. 2011. Sea-level pressure (solid lines) and 1000-500 hPa thickness (dashed lines).

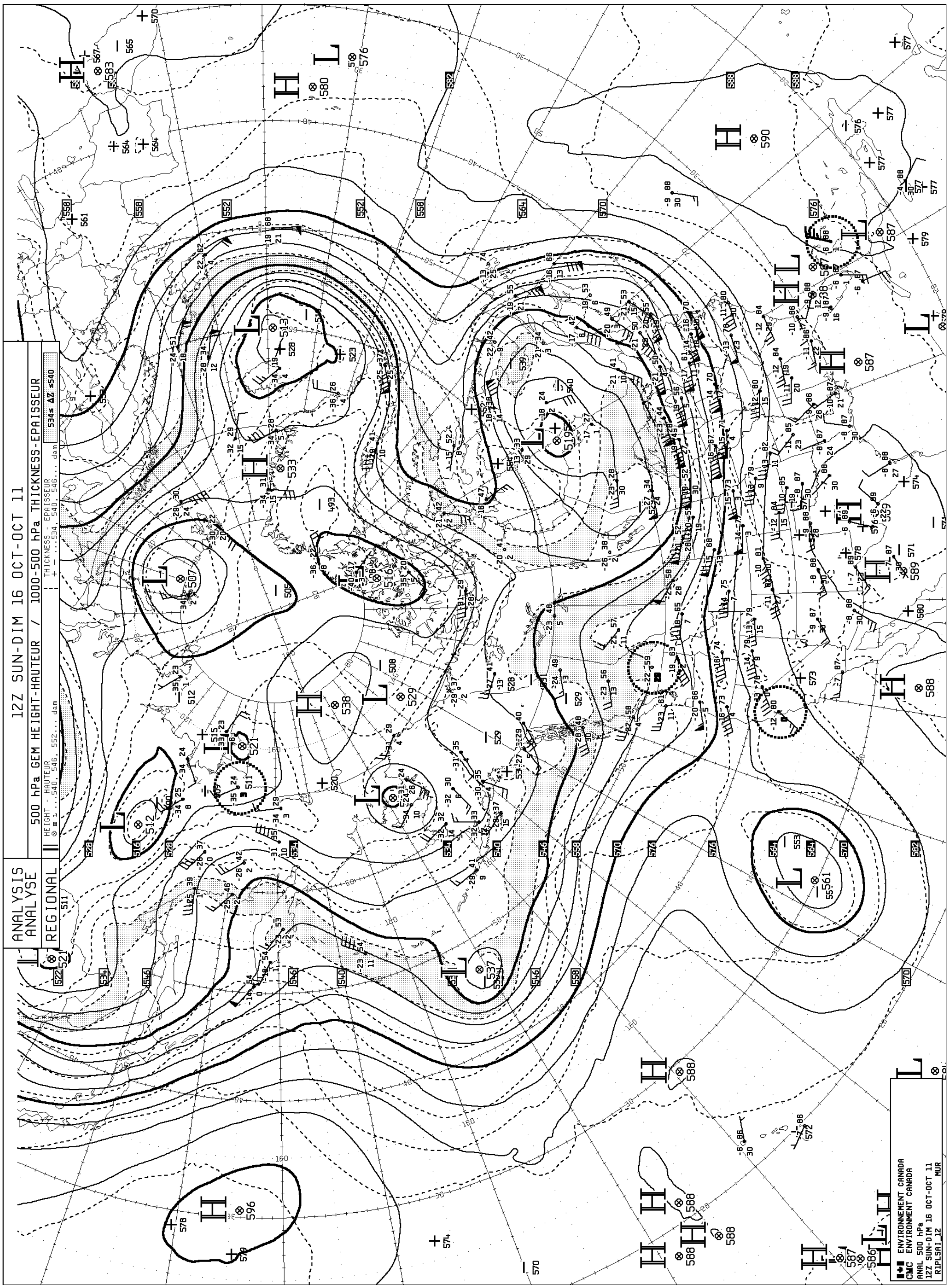

Figure 4: MSC 500 hPa analysis 12Z 16 Oct. 2011: 500 hPa height (solid lines) and 1000-500 hPa thickness (dashed).