EAS372 Final Exam 19 April, 2010

Professor: J.D. Wilson Time available: 2 hours Value: 35%

Please answer all questions in the Examination Booklet.

A. Multi-choice (9 x 1 $\rightarrow$ 9 %)

1. The CMC (Canadian Meteorological Centre) "Global Environmental Multiscale" (GEM) model for Numerical Weather Prediction (NWP) ____
   (a) uses vorticity and divergence in lieu of the horizontal velocity components
   (b) is a "primitive equation" model, i.e. formulated explicitly in terms of the horizontal velocity components (and other necessary variables)
   (c) is coupled to a dynamical ocean model
   (d) resolves atmospheric motion on a range of scales from the global down to finer than one kilometer

2. For the regional run, GEM's timestep is ____
   (a) 6 hr
   (b) 3 hr
   (c) 15 min
   (d) 7.5 min

3. Suppose the potential temperature of an unsaturated parcel at 730 mb happened to be $\theta = 260$ K. If this parcel were to undergo an adiabatic motion that resulted in its descent to 930 mb, its potential temperature would be ____
   (a) 258 K
   (b) 260 K
   (c) 262 K
   (d) insufficient information is given to determine the answer

4. If ϕ is a conserved variable and $\vec{U}$ the 3D velocity vector, then ____
   (a) $d\phi/dt = \partial\phi/\partial t$
   (b) $\partial\phi/\partial t = -\vec{U} \cdot \nabla\phi$
   (c) $\partial\phi/\partial x = \partial\phi/\partial y = \partial\phi/\partial z = 0$
   (d) $\vec{U} \cdot \nabla\phi = 0$

5. In the N. hemisphere the thermal wind vector is oriented ____ to the isotherms with cold air on its ____

   (a) parallel; left
   (b) perpendicular; left
   (c) parallel; right
   (d) perpendicular; right

6. Which of the following properties is conserved by an unsaturated parcel undergoing adiabatic, non-entraining vertical motion?

   (a) temperature
   (b) dewpoint
   (c) density
   (d) water vapour mixing ratio

7. According to the quasi-geostrophic model, the evolution of mid-latitude, synoptic scale weather fields is primarily determined by ____ advection of ____

   (a) horizontal; vertical vorticity and temperature
   (b) horizontal; humidity and temperature
   (c) vertical; horizontal vorticity and temperature
   (d) vertical; humidity and temperature

8. The 'eddy diffusion paradigm' is applied in GEM to parameterize ____

   (a) deep convection
   (b) stratiform cloud
   (c) horizontal heat and vapour transport in the ABL by unresolved eddies
   (d) vertical heat and vapour transport in the ABL by unresolved eddies

9. If (over some region) a particular level p of the atmosphere is a 'level of non-divergence' (LND), then at that level ____

   (a) vertical velocity $\omega = 0$
   (b) the magnitude $|\omega|$ of the vertical velocity is a local maximum, i.e. $\partial|\omega|/\partial p = 0$
   (c) atmospheric stratification is unconditionally stable
   (d) relative vorticity $\zeta = 0$

B. "Live" web weather data (7 x 1 → 7%)

Please access the internet for today's 12Z data, i.e. sounding(s), analyses, etc.

1. At 12Z today the height (ASL) of the 850 hPa surface at The Pass (Manitoba, YQD) was ____
2. At 12Z today the 700 hPa wind direction at Fort Smith (YSM, located near the northern border of Alberta) was ____
3. At 12Z today the dominant meteorological feature(s) or weather system(s) affecting western Canada are ____
4. At 12Z today the true surface pressure at Kelowna (WLW, in southern British Columbia) was ____
5. At 12Z today the 1000-500 hPa thickness at Kelowna was ____
6. From the 0-hr GEM Regional forecast valid at 12Z today, the largest *magnitude* of the vertical velocity ω $[\mathrm{Pa\,s^{-1}}]$ at the 500 hPa level over Manitoba was ____ . This corresponds to ____ (ascent/descent?)
7. From a forecast sounding valid 00Z April 20, based on the NAM forecast initialized at 12Z today (April 19), the temperature and relative humidity at 650 hPa over Calgary (CYYC) are predicted to be ____

C. Interpretation of weather situation. (2 x 5 → 10%)

1. Contrast the two winter weather regimes summarized by Fig.(1).
2. Focusing on the extreme NE corner of Alberta and according to what is conveyed by Fig.(2), how has the weather evolved from 00Z to 12Z that day (11 Jan., 2010) — and by what mechanism?

D. Calculations (3 x 3 → 9 %)

1. Estimate the height above ground of the GEM model's $\eta = 0.995$ surface, given that at the surface $p = p_S = 910$ hPa and $T = 20°$C. Compute also the density ρ at $\eta = 0.995$, assuming the $1 \leq \eta \leq 0.995$ layer is neutrally stratified
2. Referring to Fig.(2), compute the rate of temperature advection at 12Z on the 850 hPa surface at the extreme NE corner of Alberta
3. Referring to Fig.(3), and taking the reference pressure as being 1000 hPa, determine the potential temperatures of parcels of air at the 700 hPa and the 500 hPa level. Compute the absolute humidity and the relative humidity of surface parcels.

Equations and Data.

- one full barb on the wind vector corresponds to about 5 m s^{-1}, and 1 degree of latitude corresponds to a distance of 111 km

- $v = \frac{g}{f} \frac{\Delta h}{\Delta n}$

  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 Ω is the angular velocity of the earth, and ϕ is latitude); g acceleration due to gravity.

- $\frac{dA}{dt}$ and $\frac{\partial A}{\partial t}$

  Respectively the Lagrangian (or "material") time derivative (time derivative following the motion) and the local (fixed-point) time derivative ("local tendency") of an arbitrary atmospheric property A. The two time derivatives are related by the equation

  $$\frac{dA}{dt} \equiv \frac{\partial A}{\partial t} + \vec{U} \cdot \nabla A \equiv \frac{\partial A}{\partial t} + U \frac{\partial A}{\partial x} + V \frac{\partial A}{\partial y} + W \frac{\partial A}{\partial z}$$

  where U, V, W are the three velocity components in a Cartesian coordinate frame

- $D_p \equiv \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$

  The horizontal divergence, expressed in Cartesian coordinates (x parallel to lines of latitude, increasing towards the east; y parallel to lines of longitude).

- $D_p \equiv \frac{\partial v}{\partial s} + v \frac{\partial \beta}{\partial n}$

  The horizontal divergence, expressed in natural coordinates. The unit vector $\hat{s}$ points downstream, i.e. it is parallel to height contours in the free atmosphere. The unit vector $\hat{n}$ is normal to $\hat{s}$ and points to its left. The angle β is the inclination of flow relative to lines of latitude, with $\beta = 0^o$ being a zonal flow and $\beta = 90^o$ being a meridional flow. The first term is the stretching term. The second term is the diffluence term, and is positive if the channel widens downstream (ie. widens with increasing s).

- $\frac{\partial p}{\partial z} = -\rho g$

  The hydrostatic law, giving the rate of change of pressure p [Pascals] with height; ρ [kg m^{-3}] the density; $g = 9.81$ [m s^{-2}] acceleration due to gravity.

- $p = \rho R T$

  The ideal gas law. p [Pascals], pressure; ρ, [kg m^{-3}] the density; T [Kelvin], the temperature; and $R = 287$ [J kg^{-1} K^{-1}], the specific gas constant for air.

- $e = \rho_v R_v T$

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

- $\theta = T \left(\frac{p_0}{p}\right)^{R/c_p}$

  The potential temperature θ [K] of air whose actual pressure and temperature are (p, T), ie. the temperature that air would have if compressed adiabatically to pressure p_0. The exponent involves the gas constant for air ($R = 287$ J kg^{-1} K^{-1}) and the specific heat of air at constant pressure ($c_p \approx 1000$ J kg^{-1} K^{-1}). Temperatures must be expressed in the Kelvin unit.

- $\eta = \frac{p - p_T}{p_S - p_T}$

  Terrain following coordinate used in the GEM model, where $p_T = 10$ hPa is pressure at the top of the model domain, p_S is the pressure at ground-level (n.b. not sea-level corrected), and p is the pressure at the η level.

- $$\frac{\partial \eta}{\partial t} + \vec{V} \cdot \nabla_p \eta + \omega \frac{\partial \eta}{\partial p} = -D_p \eta + \hat{k} \cdot \left(\frac{\partial \vec{v}}{\partial p} \times \nabla_p \omega \right)$$

  The vorticity equation in isobaric coordinates; η is the vertical component of the absolute vorticity; D_p is the horizontal divergence; ∇_p is the grad operator in a constant pressure surface; $\vec{V} = (U, V)$ is the 'horizontal' wind vector (strictly, the component in the constant pressure surface); $\omega \equiv dp/dt$ the vertical 'velocity'; $\hat{k}$ the unit vector normal to the constant pressure plane.

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

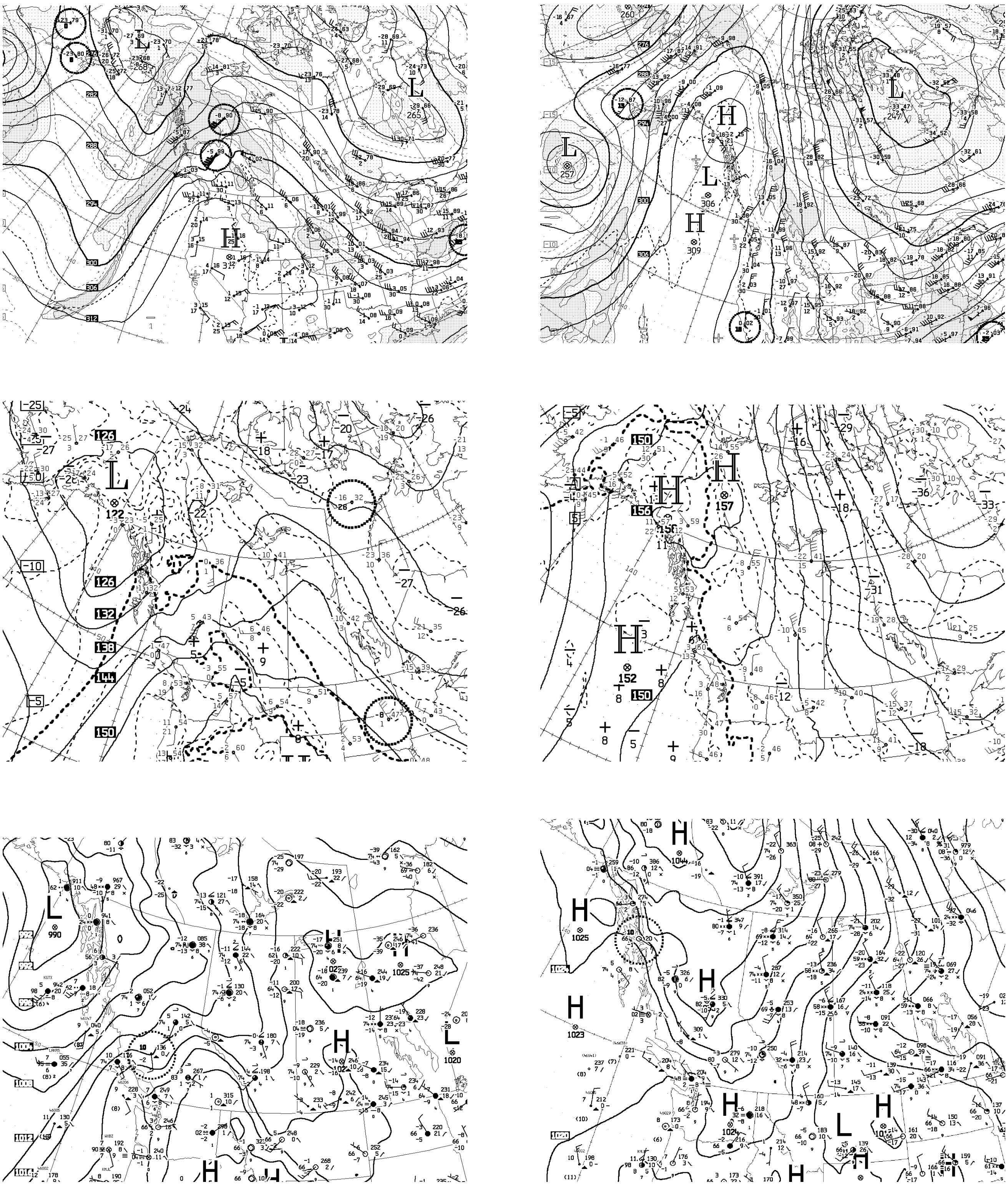

Figure 1: 700 hPa, 850 hPa and surface analyses for: 12Z 24 Jan (left) & 00Z 1 Feb (right), 2007.

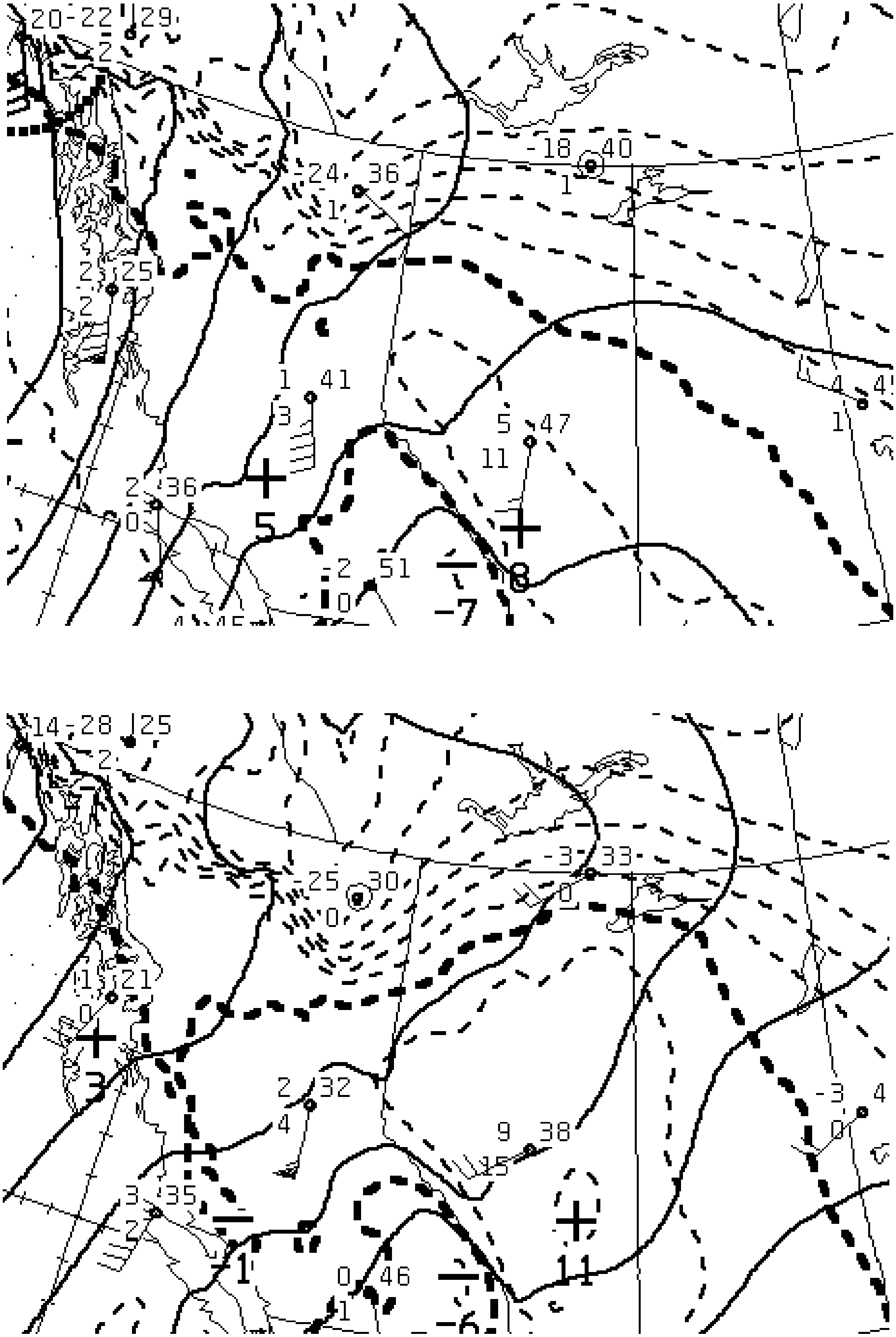

Figure 2: CMC 850 hPa analyses for 00Z (top) and 12Z on 11 Jan., 2010.

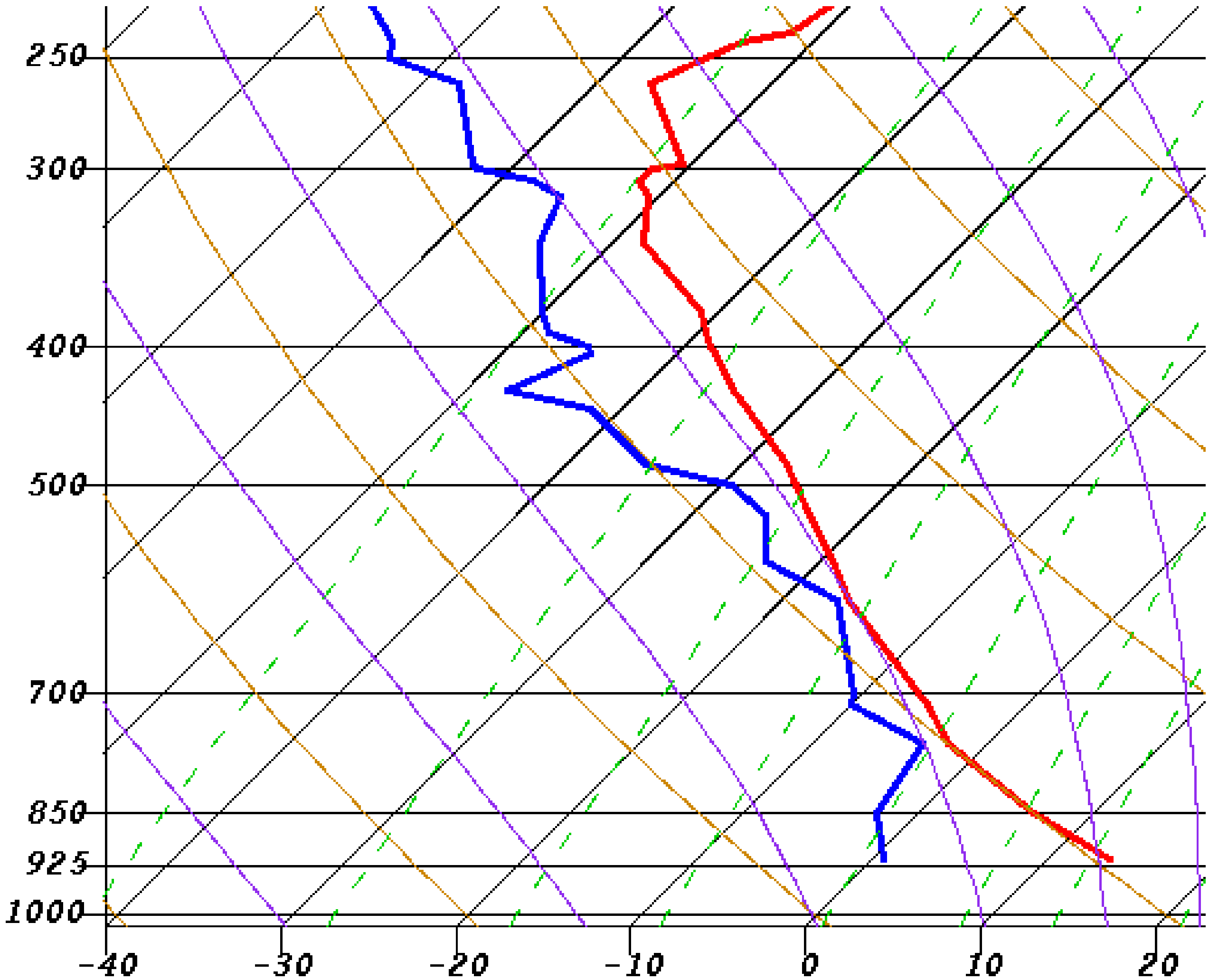

Figure 3: 00Z sounding at Edmonton (wse) on 7 May, 2009.