EAS372 Open Book Final Exam 22 April, 2014

Professor: J.D. Wilson Time available: 2 hours Value: 30%

A. Multi-choice (16 x 1/2% → 8 %)

1. Contemporary operational NWP models have of the order of ____ vertical levels, and a finest horizontal resolution of the order of order ____ km
   (a) 100; 10
   (b) 1000; 10
   (c) 100; 100
   (d) 100; 1000
   (e) 1000; 1

2. Let (u, v) be the Cartesian components of the horizontal wind, let ρ_v be the absolute humidity, and let $\nabla = \hat{i}\,\partial/\partial x + \hat{j}\,\partial/\partial y$ be the (horizontal) gradient operator. Which expression for the convergence of the horizontal moisture flux is **false**?
   (a) $\nabla \cdot (\mathbf{u}\,\rho_v)$
   (b) $\partial(u\rho_v)/\partial x + \partial(v\rho_v)/\partial y$
   (c) $\rho_v\;(\partial u/\partial x + \partial v/\partial y)$
   (d) $\mathbf{u} \cdot \nabla\rho_v \;+\; \rho_v\,\nabla \cdot \mathbf{u}$

3. If the precipitation rate were given as 1.44 $[\mathrm{mm\,hr^{-1}}]$, what would be the equivalent value in the SI mass flux density unit $[\mathrm{kg\,s^{-1}\,m^{-2}}]$?
   (a) 4×10^{-4}
   (b) 1×10^{-2}
   (c) 0.04
   (d) 0.4
   (e) 1.0

4. Which statement regarding CMC's GEM-global NWP model is **false**?
   (a) formulated in the velocity components
   (b) terrain-following vertical coordinate η
   (c) non-hydrostatic
   (d) time step about 10 minutes
   (e) operational runs twice daily

5. Suppose $f(x)$ is the probability density function for a continuous random variable x defined on the range $a \le x \le b$. Which defines the median m of x?

   (a) $0.5 = \int_a^m f(x)\,dx$

   (b) $m = \int_a^b f(x)\,dx$

   (c) $m = \int_a^b x\, f(x)\,dx$

   (d) $1 = \int_a^b m\, f(x)\,dx$

   (e) $1 = \int_m^b x\, f(x)\,dx$

6. Suppose y is a continuous variable whose probability density function is

$$g(y) = \begin{cases} 0 & , |y| > 1/3 \\ \alpha & , -1/3 \le y \le 1/3 \; . \end{cases}$$

   What choice for α ensures that $g(y)$ is correctly normalized?

   (a) 1/3
   (b) 2/3
   (c) 1
   (d) 4/3
   (e) 3/2

7. Referring to the variable of Q6, if one wished to define (equiprobable) classes (below normal, normal, above normal) then what value defines the upper threshold of the "below normal" class?

   (a) - 2/6
   (b) -2/9
   (c) -1/6
   (d) -1/9
   (e) 1/9

Over the next few hours the temperature gradient in the region of **A** (Figure 1) will ____

8. (a) reverse
   (b) strengthen
   (c) decay
   (d) remain unchanged

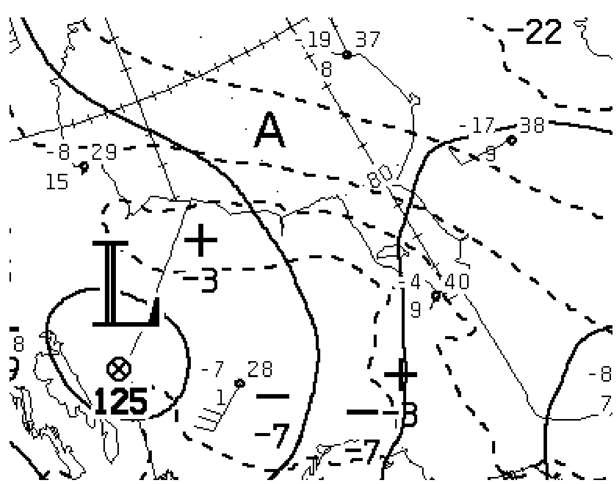


 Figure 1: 12 UTC 26 Jan. 2012 (850 hPa).

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

10. The quasi-geostrophic (QG) vorticity equation can be written

$$\frac{\partial \eta}{\partial t} + \mathbf{V}_g \cdot \nabla \eta = -f_0 \, D_p$$

   where η is the absolute vorticity, f_0 is the Coriolis parameter at the central latitude and $\mathbf{V}_g$ is the geostrophic wind. Here D_p is the ____ and it is evaluated using the ____
   (a) horizontal divergence; geostrophic wind
   (b) horizontal divergence; ageostrophic wind
   (c) thermal advection; vertical wind
   (d) thermal wind; ageostrophic wind
   (e) lapse rate; moist adiabatic rate

11. According to the QG paradigm, in mid-latitudes the evolution of the synoptic scale height field is primarily determined by ____ advection of ____
   (a) vertical; humidity and temperature
   (b) vertical; horizontal vorticity and temperature
   (c) horizontal; humidity and temperature
   (d) horizontal; vertical vorticity and temperature
   (e) geostrophic; earth vorticity

12. A qualitative diagnosis of ongoing or pending lower-tropospheric temperature advection is most reliably made on the basis of the ____ .
   (a) surface analysis
   (b) hodograph
   (c) infra-red satellite loop
   (d) configuration of 850 mb height contours and isotherms
   (e) configuration of 500 mb height contours and 1000-500 mb thickness contours

From Figure 2, estimate the potential temperature (referred to $p_0 = 1000$ hPa) of air at the 500 hPa level over The Pas (western Manitoba): $\theta = T(p_0/p)^{R/c_p}$

13. (a) 198 K
    (b) 234 K
    (c) 198 K
    (d) 241 K
    (e) 294 K

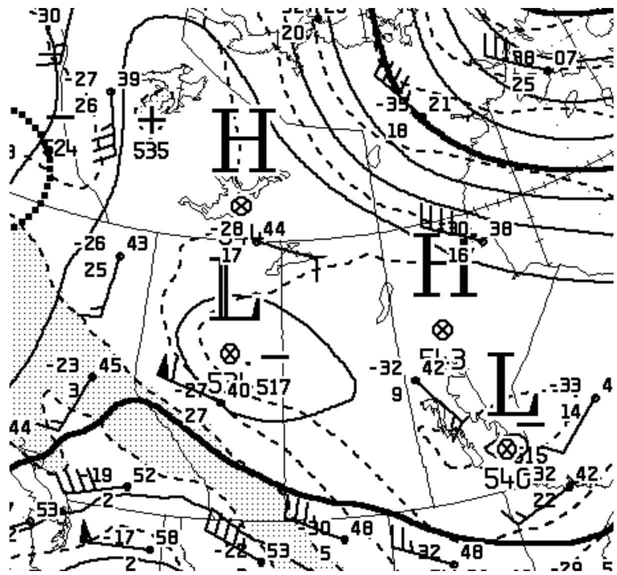


Figure 2: CMC 500 hPa analysis, 12 UTC Thurs. 17 April 2014. Stippling: 534-540 dam thickness band.

14. Through 15-18 April 2014, Edmonton experienced prolonged cool, cloudy conditions with accumulating light snowfall. Based on Fig.2, which conjecture is spurious (or **not** supported)?
    (a) arctic vortex in NE Canada injected cold air over the prairies
    (b) mid-troposphere conditionally unstable over C. Alberta
    (c) closed upper low over Alberta — likely to be slow moving
    (d) thickness trough extends into Alberta from the central prairies
    (e) based on thickness pattern, precip. (if any) would be snow

15. Suppose $y = \alpha\, x + \beta$ is a best least squares model for the relationship between variables x, y (where x is the "predictor"). Then if x_{oi}, y_{oi} $(i = 1...N)$ is a set of paired observations of the two variables, and if

$$SS = \sum_{1}^{N} \left[(\alpha\, x_{oi} + \beta) - y_{oi} \right]^2 \ ,$$

then the model's "slope" variable α is obtained by ____
    (a) minimizing $\sqrt{SS}$ with respect to α
    (b) minimizing $(SS)^2$ with respect to β
    (c) minimizing SS independently with respect to both α and β
    (d) maximizing $\sqrt{SS}$ with respect to α
    (e) maximizing SS independently with respect to both α and β

The vertical distribution of N. hemisphere winds depicted in Figure 3 implies

16. (a) warm advection
    (b) cold advection
    (c) isotherms are perpendicular to $\mathbf{V_T}$
    (d) thickness contours are perpendicular to $\mathbf{V_T}$
    (e) horizontal divergence

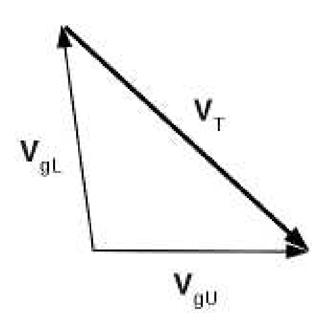
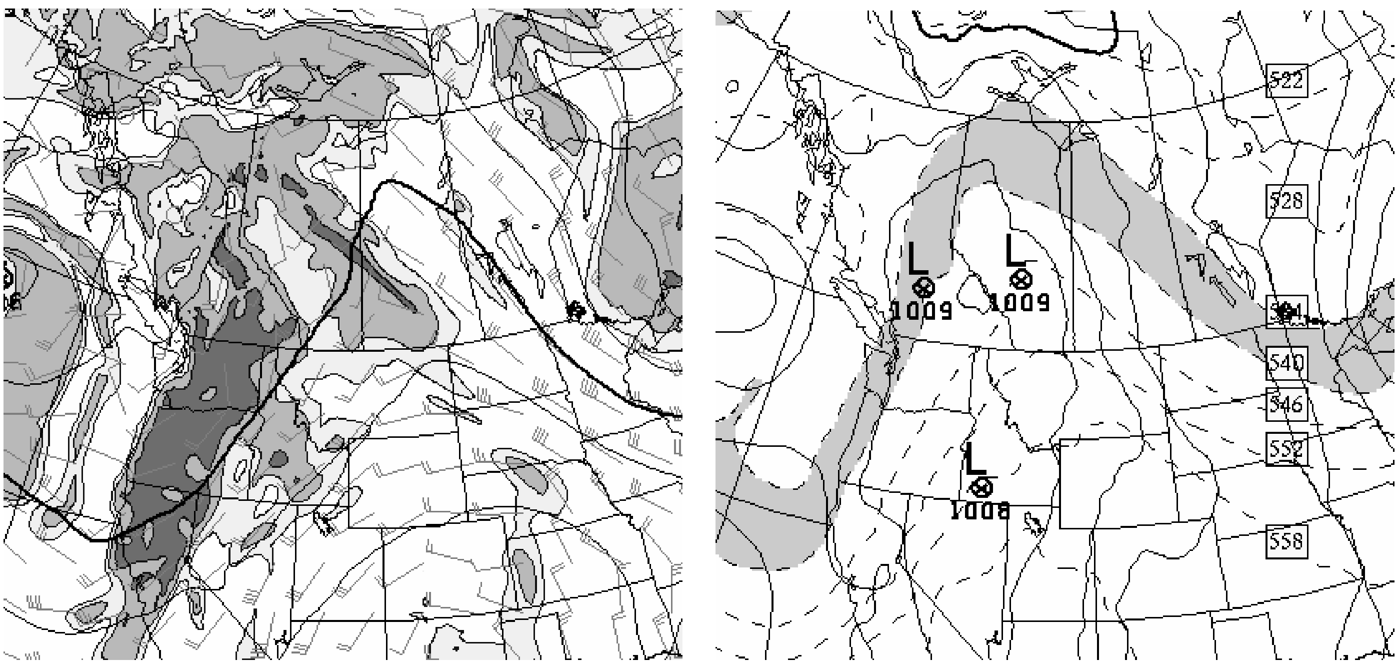


Figure 3: Wind vector at lower (L) and upper (U) levels.

B. "Live" web weather data (4 x 2 → 8%)

1. Briefly summarize the *actual* meteorological regime over Alberta as of 12Z today.
2. Briefly comment on the resemblance (or otherwise) between the analysed 700 hPa flow pattern and the GEM global 96h forecast (Fig.4a).
3. What is the 1000-500 hPa thickness over C. Alberta at 12Z today? What value had been forecast by the GEM global 96h prog (Fig.4b)?
4. Briefly comment on the resemblance (or otherwise) of the analysed and forecast MSLP patterns



(a) 700 hPa, 12Z Tues. 22 Apr. (dark shading: RH≥ 90%)   (b) MSLP & 1000-500 hPa Thickness, 12Z Tues. 22 Apr.

Figure 4: GEM glbl 96h prog, initialized 12Z Friday 18 April, valid 12Z Tuesday 22 April 2014.

C. Interpretation of weather situation. (1 x 5→ 5%)

Figures (5-9) depict the meteorology of a short spell of very cold weather in central Alberta at the end of February, 2014. Briefly give your interpretation of this cold snap, based on these figures: what message(s) about the event does each chart convey?

D. Short answer (3 x 3 % → 9 %)

Please answer any **three** of the following questions.

1. In the isobaric coordinate system, the "horizontal" velocity vector $\mathbf{V}_{\mathrm{H}} \equiv (U, V)$ obeys

$$\frac{\partial \mathbf{V}_{\mathrm{H}}}{\partial t} + (\mathbf{V}_{\mathrm{H}} \cdot \nabla_{\mathrm{H}})\, \mathbf{V}_{\mathrm{H}} + \omega \frac{\partial \mathbf{V}_{\mathrm{H}}}{\partial p} = -\, \nabla_{\mathrm{H}} \Phi \; - \; f\, \hat{k} \times \mathbf{V}_{\mathrm{H}}$$

where $\Phi \,(= g_0 Z)$ is the geopotential, $\nabla_{\mathrm{H}} = \hat{\imath}\, \partial/\partial x + \hat{\jmath}\, \partial/\partial y$ and f is the Coriolis parameter. Write down the implied equation for the zonal component (i.e. U). Note: to get the Coriolis term, pick the appropriate part of this determinant:

$$\begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 0 & 0 & 1 \\ fU & fV & 0 \end{vmatrix} .$$

2. For an unsaturated, horizontally-homogeneous and cloud free atmospheric boundary layer (ABL) of depth δ, the rate of change of potential temperature θ is (very) approximately

$$\frac{\partial \theta}{\partial t} = \frac{Q_{H0}}{\rho\, c_p\, \delta} ,$$

where Q_{H0} is the surface sensible heat flux density. If the boundary layer is 1000 m deep and the rate of warming is 1.8 $\mathrm{K\,hr^{-1}}$, estimate the implied sensible heat flux density Q_{H0}. (Note: $c_p \approx 10^3\,\mathrm{J\,kg^{-1}\,K^{-1}}$).

3. List at least four processes that are normally classified as belonging to the set of model "parameterizations" (or "grid point computations" or "model physics") in NWP models

4. Referring to Fig.6, the wind at The Pas (Manitoba) is a $10\,\mathrm{m\,s^{-1}}$ northerly. Give an approximate estimate for the rate of thermal advection in Saskatchewan, just west of The Pas.

5. If $Z_{\mathbf{P}}$ is the height of an isobaric surface at point $\mathbf{P}$ and $\overline{Z}_{\mathrm{nbrs}}$ the average height of the same isobaric surface in the neighbourhood of $\mathbf{P}$, a qualitative statement of the QG height tendency equation is:

$$\frac{\partial}{\partial t}\, \left[\overline{Z}_{\mathrm{nbrs}} - Z_{\mathbf{P}}\,\right] \;\propto\; \left[-\,\mathcal{U}_g\, \frac{\partial \eta}{\partial s}\right] \;+\; \beta\, \frac{\partial}{\partial z}\, \left[-\,\mathcal{U}_g\, \frac{\partial T}{\partial s}\right]$$

where η is the absolute vorticity, $\mathcal{U}_g$ is the magnitude of the Geostrophic wind, s is a coordinate parallel to height contours, and β is positive. Explain the implication of this expression.

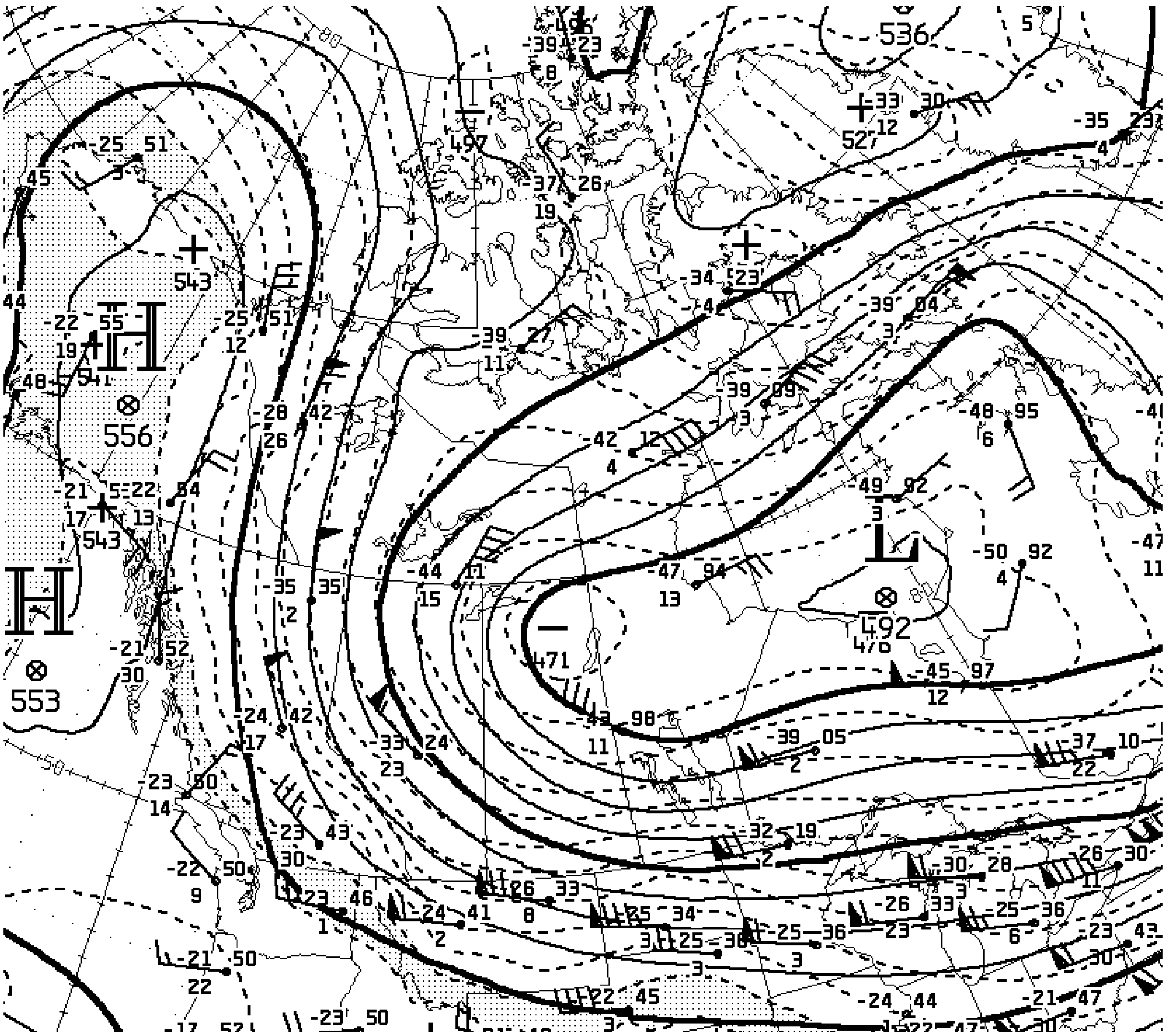


Figure 5: CMC 500 hPa analysis 12 UTC **Friday** February 28, 2014.

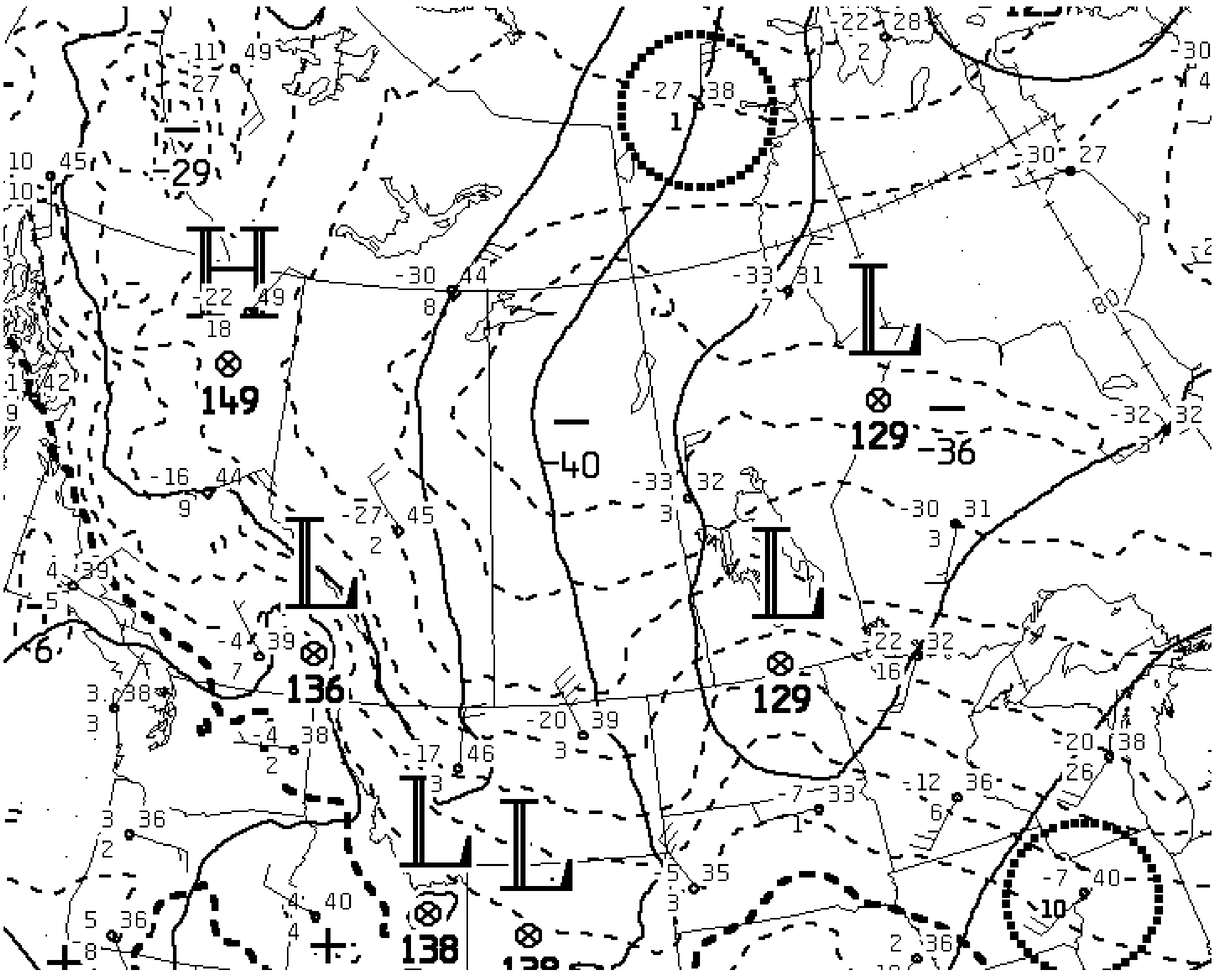


Figure 6: CMC 850 hPa analysis 12 UTC **Friday** February 28, 2014.

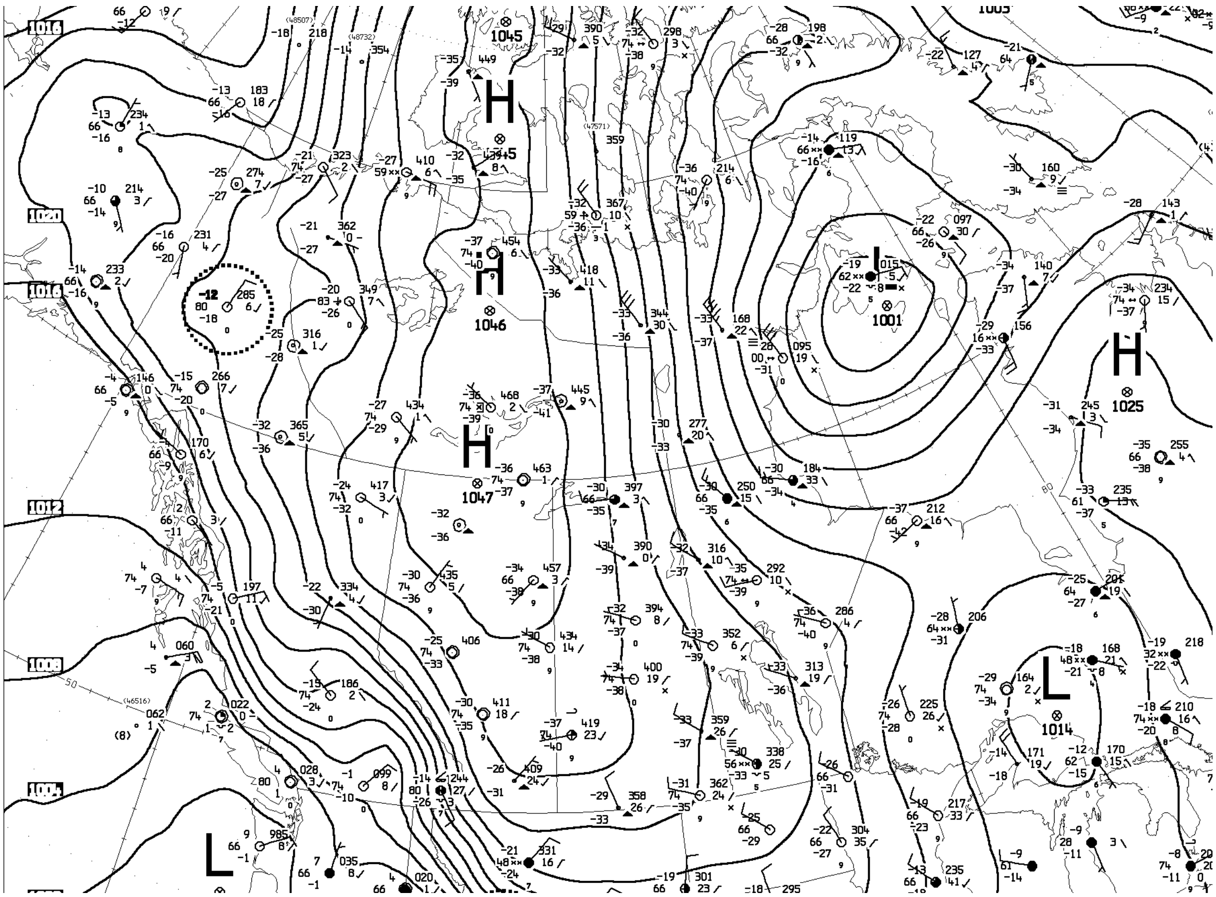


Figure 7: CMC surface analysis 06 UTC **Saturday** March 1, 2014.

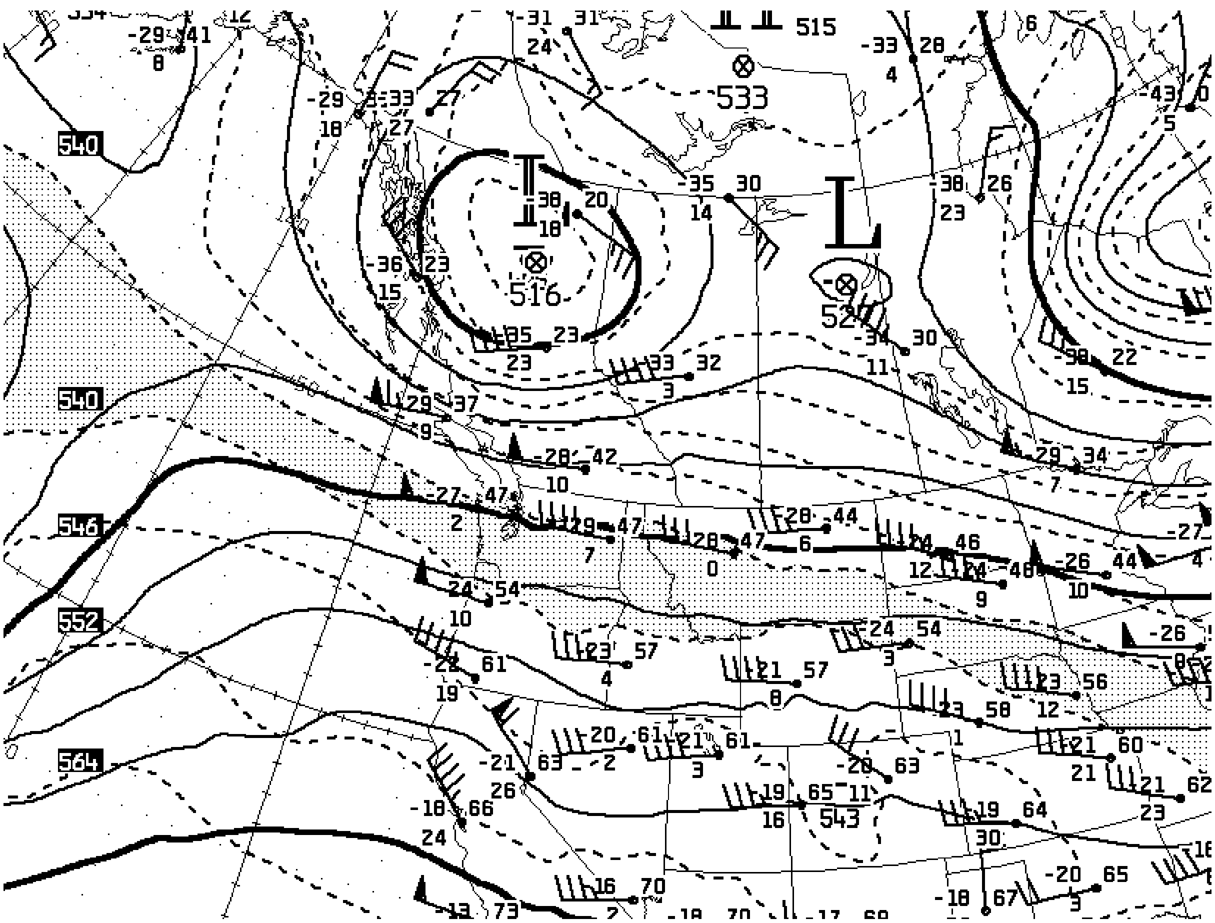


Figure 8: CMC 500 hPa analysis 12 UTC **Tuesday** March 4, 2014.

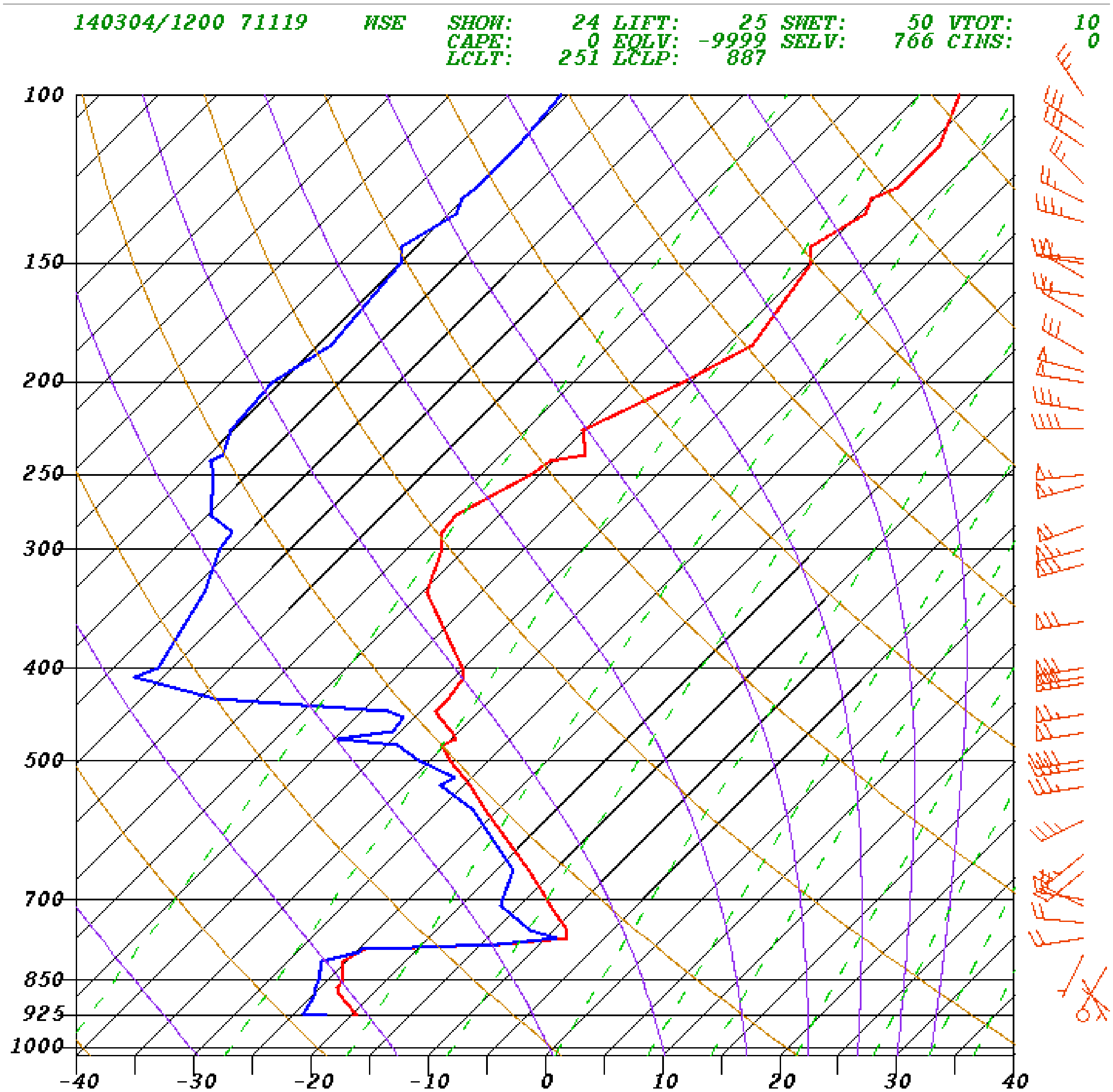


Figure 9: Stony Plain (CWSE) sounding, 12 UTC **Tuesday** March 4, 2014.