<u>Professor</u>: J.D. Wilson          <u>Time available</u>: 80 mins          <u>Value</u>: 20%

***Live web data, that were accessible during the exam, can be found in another file accompanying this one***

## A. Interpretation of weather charts (6%)

In Edmonton late on 24 February 2012 a prolonged period of snow commenced (roughly at 7 pm MST, i.e. 02Z Feb. 25th), with an accumulation exceeding 30 cm after months without significant snowfall. Figs. (1-7) provide a snapshot of the weather situation at 12Z on Saturday Februrary 25th, and Fig. (8) shows the 700 hPa pattern 12 hours later. Responding with (at most) *one tidy, legible, organized page*, identify significant meteorological factors associated with (or explaining) the storm. (You may use point or essay format).

*In this situation (of an exam) the idea is to respond by showing that you absorbed the evidence. Thus you want to list the things you "read" from the evidence. If you don't list it, the marker can't tell if you saw the significance in it... e.g. some people didn't remark the tongue of precipitable water or the analysed widespread vertical ascent.*

*Instructor's response:*

- upper trough at 500 hPa over B.C., closed 700 hPa low straddling BC/Ab

- the upper low moved relatively slowly

- high RH aloft (evident from 700 hPa stippling; from low $T-T_d$ spreads; and from sounding)

- north-south thickness gradient over Ab. (500 hPa chart). Decent $T_{700}$ and $T_{850}$ gradients over central to S. Ab. too

- sfc low in south of Ab. with tight surface pressure gradient; strong upslope surface wind over C. Ab.

- broad region of ascent at 700 hPa over c. Ab.

- tongue of precipitable water (5-7.5 mm) extends to c. Ab.

- sounding shows well sub-zero at all levels (implication for form of any precip); small $T-T_d$ spread to about 500 hPa, with saturation around the 850 hPa level

- strong inversion centred at about 850 hPa

- sounding shows wind shear – upper WSW wind over low level upslope E or SE

*From the ingredients perspective we have: direct evidence of moisture and ascent, and plenty of cause for the latter: upslope sfc wind, probable low-level convergence and possibly (though no direct evidence) upper level divergence. Temperature is such that any precip must be snow. Stability of the atmosphere suggests pace of precip will be slow. Low 700 hPa height still straddles the province 12 hrs later at 00Z 26 Feb. (prolonged light snowfall).*

# B. "Live" web weather data (2 x 3 → 6%)

1. According to this morning's (12Z) Stony Plain (wse) sounding, what was the height (AGL) of the 500 hPa surface over Edmonton and what was the 1000-500 hPa thickness? Write down a recent METAR for CYEG (Edmonton International Airport). State surface wind speed and direction, and the nature and base height of any reported cloud.

   *500 hPa surface was 5280-766=4514 m AGL. Thickness was 5280-97 = 5183 m, or 518 dam.*

2. Based on the GEM Global prog initialized 00Z Thurs 1 March, give a broad-brush summary of the anticipated meteorological "events" over central Alberta during the interval 12Z Sunday 4 March to 12Z Tuesday 6 March. You need not make specific predictions (e.g. of temperature or precipitation), but rather, focus on the gross trends. (*One page, max – brevity is good – use point format*)

   *Instructor's response:*

   - a **a midlatitude storm** will pass over Alberta, centred over N. Ab at 06Z Monday
   - the upper flow will induce a lee trough on Sunday (windy in SW Ab. and probably somewhat so in central Ab., too)
   - a warm sector, or thickness (thermal) ridge will accompany this storm, with warmest thickness over Edmonton also at about 06Z Monday
   - the arrival and departure of that thermal ridge implies **first warm then cold advection**
   - Monday is likely to be **windy**
   - surface **winds will switch** from being SE or S or SW to being N or NW some time on Monday (probably before 12Z)
   - there may be a noticeable cold frontal passage on Monday
   - **precipitation** will accompany the storm. Consecutive 12h (predicted) accumulations are of order 1 - 2.5 mm (water equiv.) for central Ab., thus not a heavy precip event
   - bulls-eye of precipitable water over Ab. at 00Z on Monday (10-15 mm)
   - not impossible we could see some freezing rain late on Sunday and/or early Monday, as the 534-540 dam thickness band will lie over central Ab. and sfc temp will be well above freezing (depending on which prog one selects, SpotWx gives some 2 -3 mm rain, total)
   - an upper trough (e.g. 700 hPa level) accompanies the storm, forming a closed upper low by 12Z Mon. Nevertheless a firm circulation is sustained over c. Ab., so weather is rapidly passing (expect cloud/precip to come and go, rather than be continuous)
   - generally RH>70% at 700 hPa with patches over 90%
   - plenty of 700 hPa vertical motion accompanying the storm, with sink after its passage
   - **surface temperature well above zero** early Monday, but the cooling phase returning the temperature to modestly sub-zero values

- intermittent cloud breaks over the period, with brief clearing by 00Z Tues (i.e. Monday afternoon) after the storm moves east
- however another low develops over N. Ab by 12Z Tues

# C. Calculations (8 x 1 → 8 %)

1. Compute the quantity

$$Q = \sum_{i=1}^{3} a_i' b_i'$$

where the prime indicates the deviation from average, and $a_i = (1, 3, -1)$, $b_i = (-1, 0, 1)$.

*The averages $\bar{a} = 1$ and $\bar{b} = 0$. Thus $Q = (1 - 1) \times -1 + (3 - 1) \times 0 + (-1 - 1) \times 1 = -2$.*

2. Evaluate $\nabla \times \vec{a}$, where $\vec{a} = \hat{i} \, x^2 y - \hat{j} \, e^{y^2} + \hat{k} \, \ln z$

   *Evaluate the determinant*

$$\nabla \times \vec{a} = \begin{pmatrix} \hat{i} & \hat{j} & \hat{k} \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ x^2 y & -e^{y^2} & \ln z \end{pmatrix} = 0\,\hat{i} - 0\,\hat{j} + \hat{k} \times \left( 0 - \frac{\partial x^2 y}{\partial y} \right) = -x^2 \, \hat{k} \ .$$

3. A standardized Gaussian random variate $x$ has probability density function

$$f(x) = \frac{1}{\sqrt{2\pi}} \, \exp\left( \frac{-x^2}{2} \right) \ ,$$

   that is, with probability $f(x_1)dx$ a random sample lies in the range $x_1 - dx/2 \leq x \leq x_1 + dx/2$. Give an approximate value for the probability that single, randomly chosen sample value for $x$ lies in the range $-0.005 \leq x \leq 0.005$.

   *Probability $P = f(0) \times dx = \frac{1}{\sqrt{2\pi}} \, 0.01 = 0.04$*

4. Referring to Fig. (1), compute the Geostrophic 500 hPa windspeed at The Pas, Manitoba (YQD, the station in west-central Manitoba near the Saskatchwan border; latitude 53.96°N implying $f = 1.18 \times 10^{-4} \, \mathrm{s}^{-1}$) and compare with the reported speed.

   *Separation between adjacent height contours was about $\Delta n = 8/44 \times 11 \times 111{,}000 \, \mathrm{m} = 2.22 \times 10^5$ m. Then $\Delta h / \Delta n \approx 60/2.22 \times 10^{-5}$ and $V \approx 23 \, \mathrm{m\,s}^{-1}$ (or bearing in mind the inaccuracy of the calculation, roughly $20 - 25 \mathrm{m\,s}^{-1}$).*

5. Referring to Fig. (3), calculate an approximate value for the rate of temperature advection $A_T$ at Glasgow, Montana (GGW, the northern-most station in the U.S. just south of Saskatchewan). Give your answer in $\mathrm{K\,hr}^{-1}$, and state whether your result corresponds to warming or cooling.

   *Isotherm separation along the direction of the wind is $\Delta s \approx 6/46 \times 11 \times 111{,}000 \, \mathrm{m} = 1.6 \times 10^5$ m. Wind speed $U_{850} \approx 20 \, \mathrm{m\,s}^{-1}$. Thus the rate of temperature advection is $-U_{850} \times \Delta T/\Delta s \approx -20 \, -5/1.6 \times 10^{-5} \approx +6.3 \times 10^{-4} \, \mathrm{K\,s}^{-1} = +2.3 \, \mathrm{K\,hr}^{-1}$ (legitimate range of answers, i.e. uncertainty on this, is at least 25%). This of course corresponds to warming.*

3

6. From the sounding data of Fig. (9), compute the air density $\rho$ at ground level ($p = 915.0$ hPa, $z = 766$ m ASL). Based on the listed value for the potential temperature at ground level ("THTA=268.6 K") deduce what reference pressure $p_0$ must have been used to define THTA.

$$\rho = \frac{91500}{287 \times (273.16 - 11.3)} = 1.2\,\mathrm{kg\,m^{-3}}$$

*The reference pressure is obtained as:*

$$\theta = 268.6 = (273.16 - 11.3)\left(\frac{p_0}{915}\right)^{287/1000}$$

$$\left(\frac{p_0}{915}\right)^{0.287} = 1.026$$

$$\frac{p_0}{915} = 1.026^{1/0.287} = 1.0935$$

$$p_0 = 1000\mathrm{hPa}\,.$$

7. On the hodograph blank (Fig. 10) plot the sounding data of Fig. (9) at the mandatory levels up to 500 hPa. Add a vector designating the thermal wind between the 850 hPa and 700 hPa levels, and comment on the implied location of colder air.

*See Fig. 10. Colder air lies, in principle, towards the NE — the thermal wind blows parallel to isotherms with cold air on its left (in the N. hemisphere). This concurs qualitatively with the analyses.*

8. Use the hypsometric equation (given as data) to compute the $(p^{-1})$-weighted mean temperature of the $850 - 700$ hPa layer for the sounding of Fig. (9)

*The result is:*

$$\overline{T} = \frac{g}{R}\frac{z_{700} - z_{850}}{\ln 850/700}$$

$$= \frac{9.81}{287}\frac{2817 - 1330}{0.194}$$

$$= 262\,\mathrm{K}$$

## Equations and Data.

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

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

- $\theta = T\left(\frac{p_0}{p}\right)^{R/c_p}$, the potential temperature $\theta$ [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.

- $A_T \equiv \left(\frac{\partial T}{\partial t}\right)_{adv} = -V \frac{\partial T}{\partial s}$

  Advective contribution to the rate of change of temperature, expressed in natural coordinates. The unit vector $\hat{s}$ for the $s$ axis points downstream and parallel to the flow contours (eg. height contours), and $V$ is the wind *speed*.

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

  The Geostrophic wind equation. $\Delta h$ [m], the change in height of a constant pressure surface over distance $\Delta n$ [m] normal to the height contours; $f = 2\Omega \sin\phi$ [s$^{-1}$] the Coriolis parameter (where $\Omega \approx 2\pi/(24 \times 3600)$ s$^{-1}$ is the angular velocity of the earth, and $\phi$ is latitude); $g$ acceleration due to gravity.

- $z_2 - z_1 = \frac{R}{g} \overline{T} \ln \frac{p_1}{p_2}$

  The hypsometric equation (where $z_2 > z_1$). The left hand side is the ($z_2$ to $z_1$ hPa) thickness, and $\overline{T}$ is the weighted mean temperature [K] of the layer (weighting factor is $p^{-1}$).

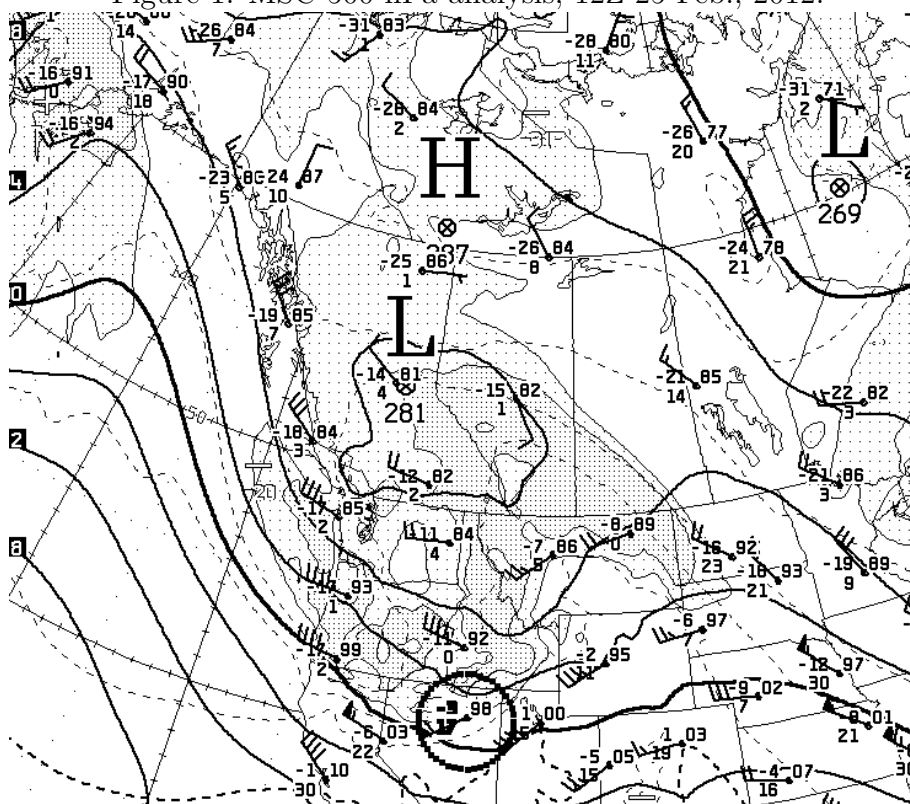Figure 1: MSC 500 hPa analysis, 12Z 25 Feb., 2012.



Figure 2: MSC 700 hPa analysis, 12Z 25 Feb., 2012 (see Fig. 8 for the 700 hPa chart 12 hrs later, at 00Z 26 Feb).
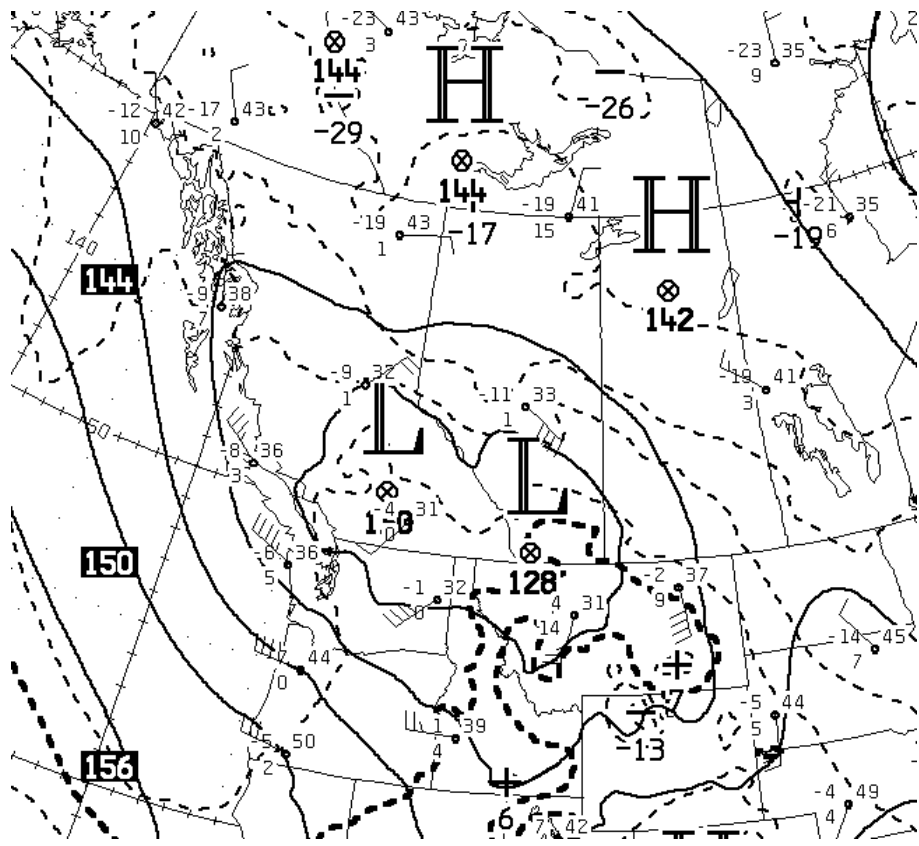
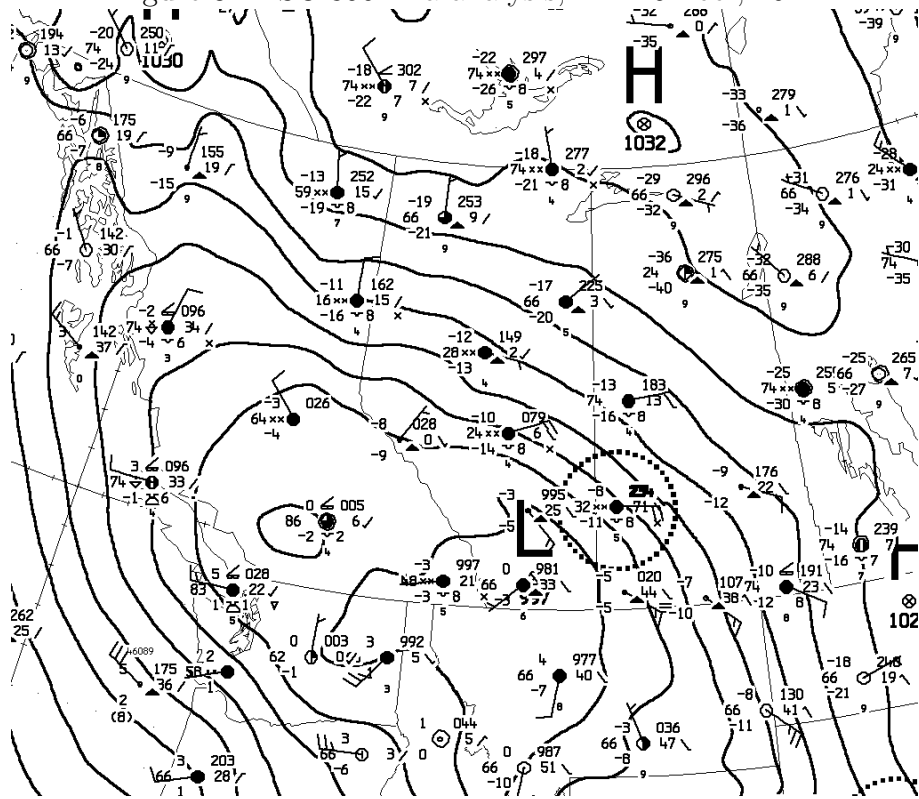Figure 3: MSC 850 hPa analysis, 12Z 25 Feb., 2012.

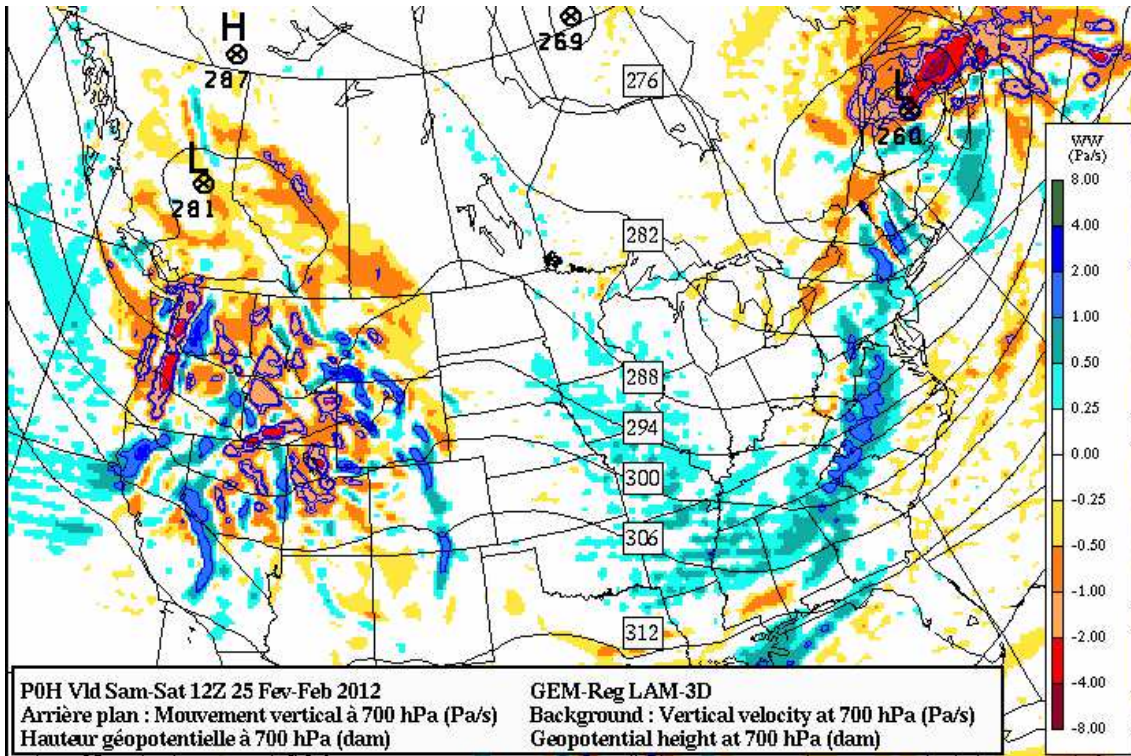Figure 4: MSC surface analysis, 12Z 25 Feb., 2012.

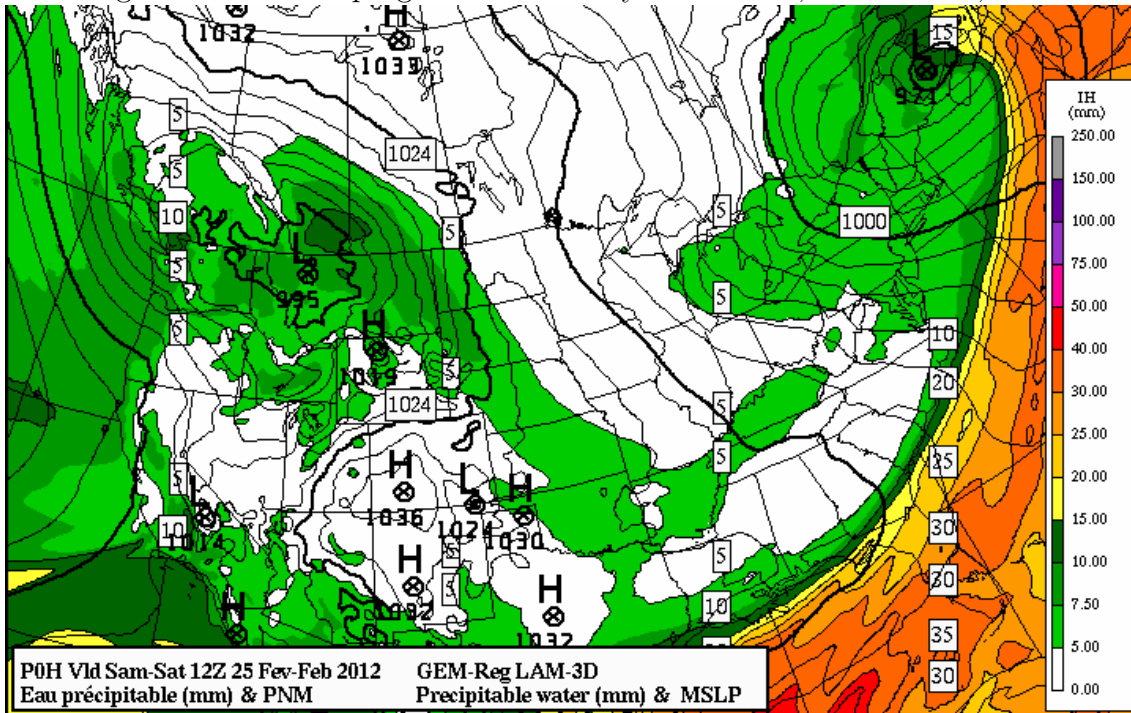Figure 5: GEM 0h prog vertical velocity at 700 hPa, 12Z 25 Feb., 2012.



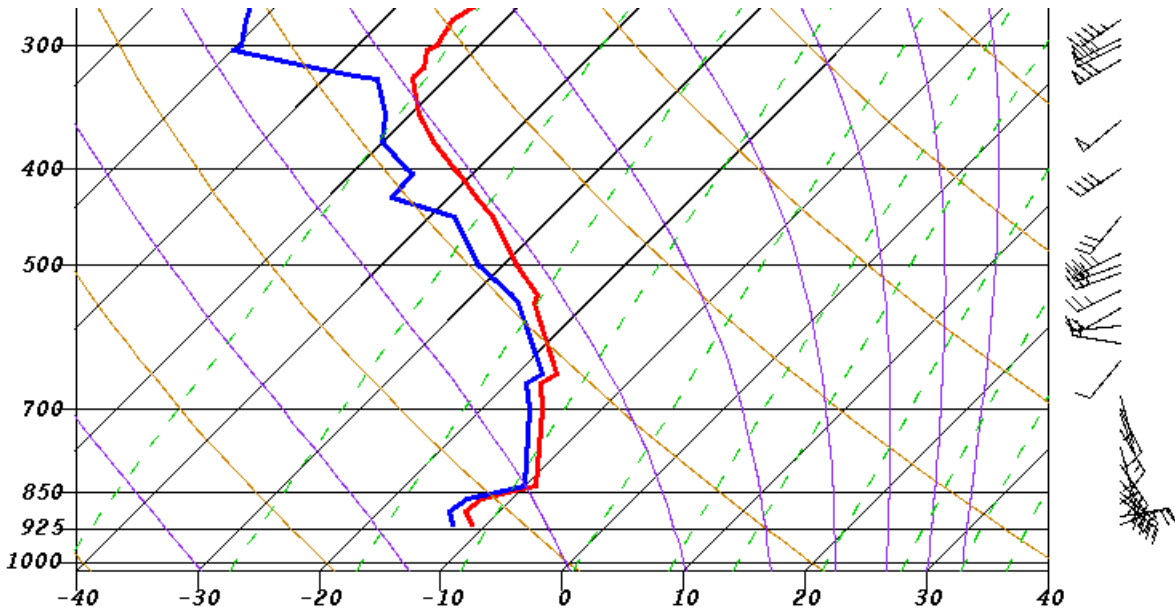Figure 6: GEM 0h prog precipitable water, valid 12Z 25 Feb., 2012.

8

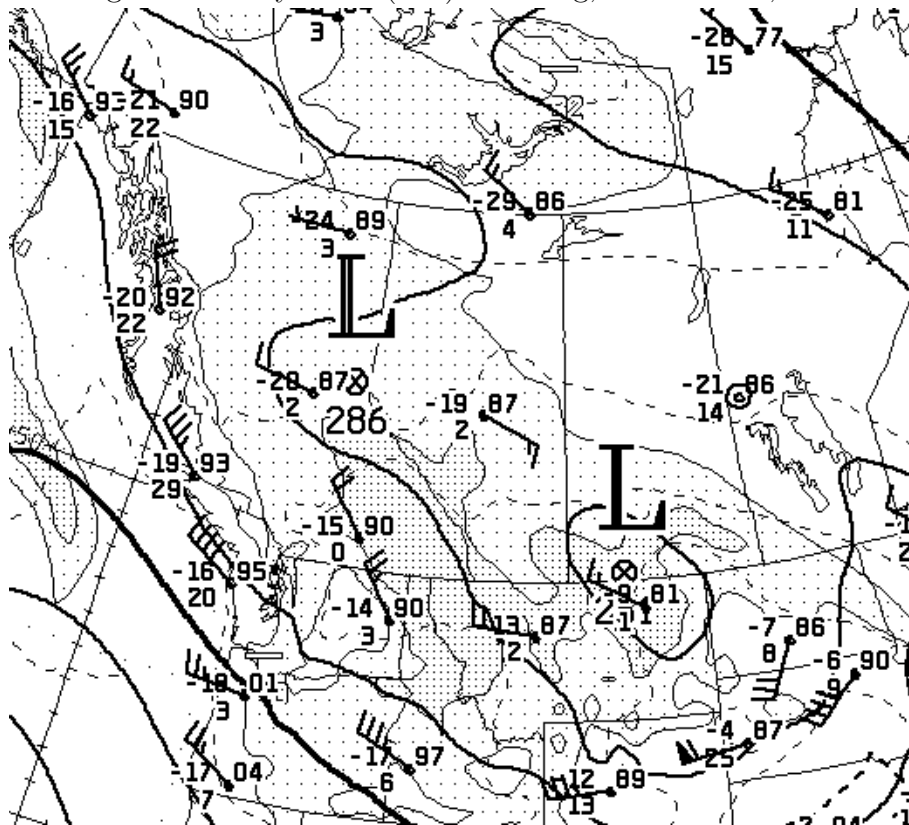Figure 7: Stony Plain (wse) sounding, 12Z 25 Feb., 2012.



Figure 8: MSC 700 hPa analysis, 00Z 26 Feb., 2012.

9

# 71119 WSE Edmonton Stony Plain Observations at 12Z 25 Feb 2012

| PRES hPa | HGHT m | TEMP C | DWPT C | RELH % | MIXR g/kg | DRCT deg | SKNT knot | THTA K | THTE K | THTV K |
|---|---|---|---|---|---|---|---|---|---|---|
| 1000.0 | 69 | | | | | | | | | |
| 925.0 | 683 | | | | | | | | | |
| 915.0 | 766 | -11.3 | -12.8 | 89 | 1.57 | 70 | 12 | 268.6 | 273.0 | 268.8 |
| 897.5 | 914 | -12.3 | -13.7 | 89 | 1.49 | 80 | 23 | 269.0 | 273.2 | 269.2 |
| 888.0 | 995 | -12.9 | -14.2 | 90 | 1.44 | 93 | 28 | 269.2 | 273.4 | 269.5 |
| 864.0 | 1205 | -12.5 | -13.7 | 91 | 1.54 | 128 | 39 | 271.8 | 276.2 | 272.0 |
| 862.4 | 1219 | -12.3 | -13.5 | 91 | 1.57 | 130 | 40 | 272.1 | 276.6 | 272.4 |
| 850.0 | 1330 | -10.9 | -11.8 | 93 | 1.83 | 130 | 40 | 274.7 | 280.0 | 275.0 |
| 837.0 | 1449 | -9.1 | -10.1 | 92 | 2.13 | 136 | 41 | 277.8 | 284.0 | 278.2 |
| 828.8 | 1524 | -9.4 | -10.4 | 92 | 2.10 | 140 | 41 | 278.3 | 284.4 | 278.6 |
| 796.5 | 1829 | -10.7 | -11.7 | 92 | 1.96 | 145 | 36 | 280.1 | 285.8 | 280.4 |
| 765.3 | 2134 | -12.0 | -13.1 | 92 | 1.84 | 165 | 16 | 281.9 | 287.3 | 282.2 |
| 735.5 | 2438 | -13.3 | -14.4 | 92 | 1.72 | 150 | 13 | 283.7 | 288.9 | 284.0 |
| 706.8 | 2743 | -14.6 | -15.7 | 91 | 1.60 | 160 | 12 | 285.5 | 290.4 | 285.8 |
| 700.0 | 2817 | -14.9 | -16.0 | 91 | 1.58 | 155 | 8 | 286.0 | 290.8 | 286.2 |
| 678.8 | 3048 | -16.0 | -17.2 | 90 | 1.47 | 165 | 3 | 287.2 | 291.8 | 287.5 |
| 659.0 | 3271 | -17.1 | -18.4 | 90 | 1.37 | 185 | 6 | 288.4 | 292.7 | 288.7 |
| 644.0 | 3444 | -16.7 | -17.8 | 91 | 1.47 | 201 | 8 | 290.8 | 295.4 | 291.1 |
| 625.6 | 3658 | -18.0 | -19.2 | 91 | 1.35 | 220 | 10 | 291.7 | 296.0 | 291.9 |
| 600.4 | 3962 | -19.9 | -21.1 | 90 | 1.19 | 280 | 13 | 293.0 | 296.8 | 293.2 |
| 576.2 | 4267 | -21.8 | -23.1 | 90 | 1.04 | 265 | 16 | 294.2 | 297.6 | 294.4 |
| 552.9 | 4572 | -23.7 | -25.0 | 89 | 0.91 | 240 | 19 | 295.4 | 298.4 | 295.6 |
| 546.0 | 4665 | -24.3 | -25.6 | 89 | 0.88 | 242 | 20 | 295.8 | 298.7 | 296.0 |
| 537.0 | 4785 | -24.7 | -26.7 | 83 | 0.81 | 243 | 22 | 296.8 | 299.4 | 296.9 |
| 530.2 | 4877 | -25.4 | -27.7 | 82 | 0.75 | 245 | 23 | 296.9 | 299.4 | 297.1 |
| 508.2 | 5182 | -27.9 | -30.9 | 76 | 0.58 | 250 | 31 | 297.5 | 299.5 | 297.6 |
| 500.0 | 5300 | -28.9 | -32.1 | 74 | 0.52 | 250 | 31 | 297.7 | 299.5 | 297.8 |
| 487.0 | 5486 | -30.3 | -33.5 | 74 | 0.47 | 245 | 35 | 298.3 | 299.9 | 298.4 |
| 446.9 | 6096 | -34.8 | -37.9 | 73 | 0.33 | 220 | 29 | 300.0 | 301.2 | 300.1 |
| 446.0 | 6110 | -34.9 | -38.0 | 73 | 0.33 | 220 | 29 | 300.1 | 301.2 | 300.1 |
| 427.0 | 6412 | -37.7 | -44.7 | 48 | 0.17 | 226 | 33 | 300.3 | 300.9 | 300.3 |
| 404.0 | 6792 | -41.1 | -45.0 | 66 | 0.17 | 234 | 38 | 300.6 | 301.3 | 300.7 |
| 400.0 | 6860 | -41.9 | -45.9 | 65 | 0.16 | 235 | 39 | 300.4 | 301.0 | 300.5 |

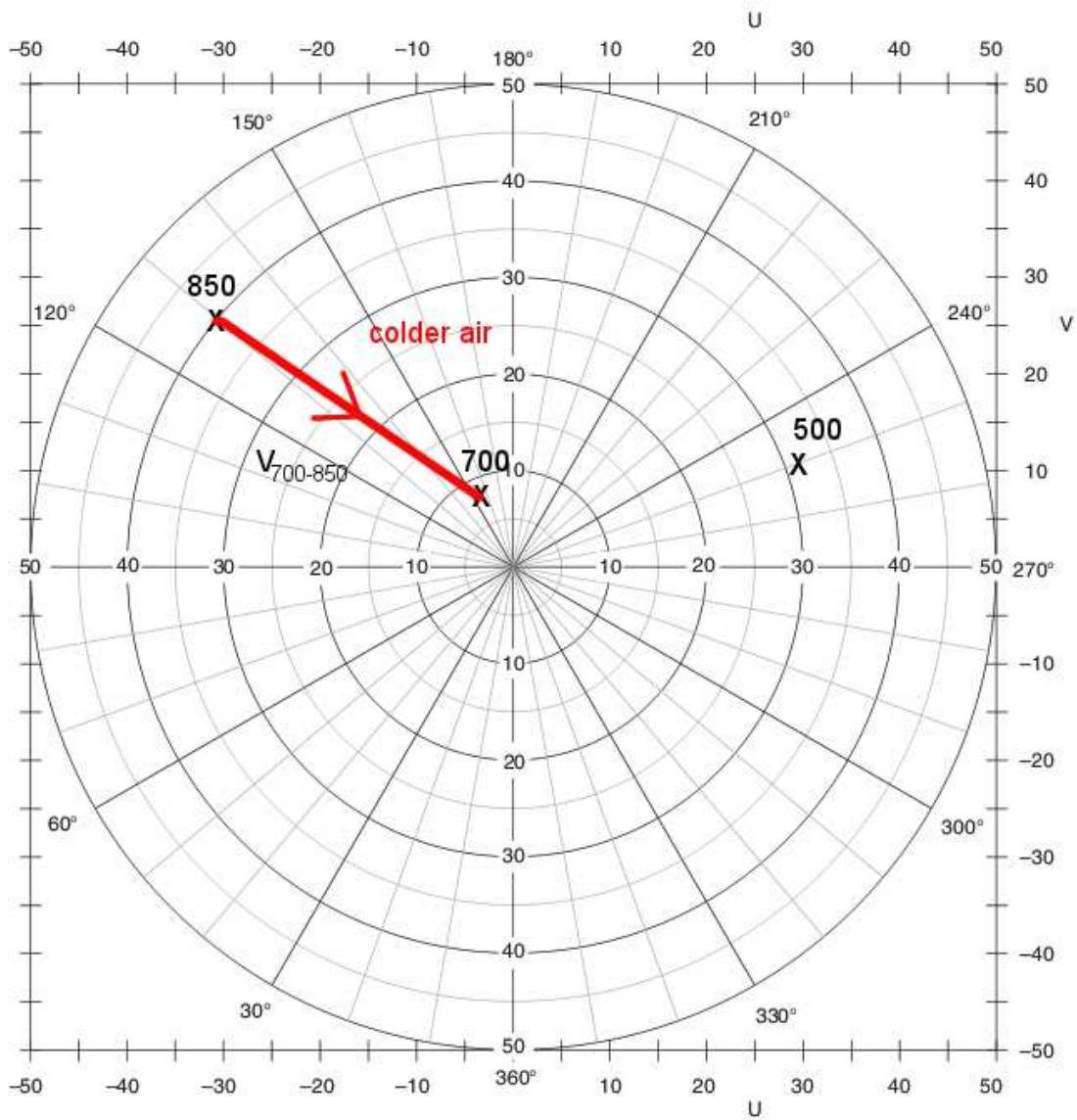Figure 9: Stony Plain (wse) sounding data, 12Z 25 Feb., 2012.

Figure 10: Hodograph corresponding to Fig. 9, i.e. Stony Plain 12Z 25 Feb. 2012. (Hodograph blank courtesy of Prof. R. Stull, 2007).