EAS372 | Open book Mid-term Exam | 17 Mar., 2011

Professor: J.D. Wilson   Time available: 80 mins   Value: 15%

Please answer in the booklet provided. Equations and data given at back.

A. Web weather/climate data (6 x 1/2 → 3%)

To answer the following questions, please use whatever web resources best suit (e.g. CMC analyses, text data for Stony Plain sounding, etc).

1. At 00Z today the 850 hPa height at Edmonton was [**1332 m**] and the dewpoint at that level was [$-\mathbf{6.7}$°C]

2. Describe the 850 hPa thermal pattern over central Alberta at 00Z today

   A cold front extending west from a low in Saskatchewan crosses Alberta in the far south then runs northwestward along the mountains. North of that frontal zone temperature in Alberta is fairly uniform and below −5°C, with a pocket that is cooler than −10°C in the NW part of Alberta. Thus very little spatial variation in 850 hPa temperature over C. Alberta.

3. Describe the 700 hPa wind over central Alberta at 00Z today

   Very weak 700 hPa height gradient over Alberta, resulting in weak winds. No speed or direction provided on the Edmonton sounding, except at the lowest level (technical problem?). However on the basis of the Geostrophic equation we can be confident the 700 hPa wind had to be light over most of Alberta, which was covered by diffluent and far-separated height contours. There would have been a westerly component to such motion as existed.

4. Using the coded format, write down the METAR for Edmonton International Airport (CYEG) for 00Z today

   METAR CYEG 170000Z 02006KT 5SM -SN HZ OVC007 M04/M05 A2961 RMK ST8 CIG RAG SN VRY LGT SLP066

5. For the 71-2000 normals, the weather station titled "Lethbridge CDA" reported [**2300.6**] annual total hours of bright sunshine

6. The Stony Plain (Edmonton) sounding for 12Z on July 15th, 2010 reported that temperature and dewpoint at 500 hPa were [$-\mathbf{14.7}$°C] and [$-\mathbf{17.8}$°C]

B. Interpretation of weather charts. (1 x 4 → 4%)

During January 2011 Edmonton International Airport recorded a total of 63.7 cm of snow (only 8 of the 31 days did not register some snowfall). The highest daily total was 12.7 cm on January 8th. Referring to Figures (1 – 7), interpret the meteorological factors relevant to the snowfall event of January 8th.

This was the most challenging and open-ended question. With the luxury of not being under time pressure, one can compile a list of relevant factors:

1. a slow-moving, closed (and deepening) upper low affected the region throughout the day (associated with this, high 700 hPa humidity)
2. focusing on circumstances at 12Z, at that time the 700 hPa low coincided more or less with th elocation of a surface low pressure system centred (see 12Z charts for sfc and 850 hPa) in the SE of Alberta
3. the 12Z surface chart indicates upslope surface winds near C. Alberta
4. the 12Z Stony Plain sounding reports a stable atmosphere, that is saturated (or nearly so) from the surface to about 600 hPa. The sounding also indicates an easterly (upslope) component to the wind
5. a ridge of high values of precipitable water aligned NW-SE extending from the north-central U.S. up through Saskatchewan and eastern Alberta; 6-9 $\mathrm{kg\,m^{-2}}$ equates to a depth of about 1 mm (liquid) which (converting to snow in a cold atmosphere) suggests 10 mm or more of snow if all that water were precipitated
6. broad region of ascending motion over the region
7. uniformly overcast over C. Alberta and Saskatchewan
8. stable atmos. and weak ascent suggest the events can be interpreted as due to a modest rate of snowfall sustained for many hours
9. other points, almost too obvious to be stated: high humidity and ascending vertical motion conducive to cloud; temperature well below zero at all levels, so precip would have to be snow
10. speculative: the 850 hPa chart hints at the idea of relatively mild air to the southeast of the low (i.e. see station in eastern Montana) advecting northwestward over C. Alberta
11. noticeable but of unclear significance/relevance: the time sequence of 700 hPa charts shows initial 700 hPa warming over C. Alberta followed by steady cooling during 8-9 March

To get all four marks one needed to mention (i) slow moving upper low over the region (ii) stable, nearly-saturated lower troposphere (iii) band of high precipitable water with widespread weak ascent (iv) an upslope component to the winds

C. Calculations (4 x 2 → 8 %)

1. Referring to the paired soundings of Figure (8), compute the effective rate of heat loss per unit ground area.

   An area of about 88 small squares separates the two profiles. Each square counts for $100\,\mathrm{m}\times 1\,\mathrm{K}$*. The density can be taken as unity and the specific heat as* 10^3*. Then we have*

$$\begin{aligned} Q &\approx \frac{88\times(1\times 100)\times 1\times 1000}{12\times 3600}\ \mathrm{K\,m}\,\frac{\mathrm{kg}}{\mathrm{m}^3}\,\frac{\mathrm{J}}{\mathrm{kg\,K}}\,\frac{1}{\mathrm{s}} \\ &\approx 200\,\frac{\mathrm{W}}{\mathrm{m}^2} \end{aligned}$$

2. Consider a snowpack of depth $D = 0.3$ m whose snow water equivalent ratio is $\alpha = 0.2$ and whose temperature is -10^{o}C. Compute the mass and volume of water per unit ground area. Compute the amount of energy E_1 [$\mathrm{J\,m^{-2}}$] required to bring the snowpack to the melting point. Compute the additional amount of energy E_2 [$\mathrm{J\,m^{-2}}$] required to convert the snowpack to water.

- volume per unit ground area $D \times \alpha = 0.06\,\mathrm{m^3\,m^{-2}}$
- mass per unit ground area $D \times \alpha \times \rho_w = 60\,\mathrm{kg\,m^{-2}}$
- $E_1 = D \times \alpha \times \rho_w \times c_w \times \Delta T = 2.5 \times 10^6\,\mathrm{J\,m^{-2}}$
- $E_2 = D \times \alpha \times L_f = 2.0 \times 10^7\,\mathrm{J\,m^{-2}}$

3. Consider the series x_i, $i = 1...4$ whose values are $1, 3, -4, 9$. Compute the standard deviation of this series, defined $\sigma_x = \sqrt{\overline{x'^2}}$. Please show your working.

$$\begin{aligned}
\overline{x} &= 9/4 \\
x'_i &= x_i - \overline{x} = -5/4, 3/4, -25/4, 27/4 \\
x'^2_i &= 25/16, 9/16, 625/16, 729/16 \\
\overline{x'^2_i} &= 1388/(16 \times 4) = 21.6875 \\
\sigma_x &= \sqrt{\overline{x'^2_i}} = 4.66\ .
\end{aligned}$$

The only remark to be made here is that several students substituted their own definition of σ_x for that given, and thus provided a value that is inconsistent with the instruction and with the notation, writing

$$\sigma_x^2 = \frac{4}{3}\,\overline{x'^2_i}\ .$$

Yes, this is commonly taken as the definition of σ_x, but it is not the definition given here. (No penalty was imposed for this).

4. Plot the hodograph corresponding to Table (1) on the hodograph blank (Figure 9). Suggest the orientation of the isotherms at 850 hPa and the location of colder air relative to this station.

Most students plotted the hodograph correctly. It would have been better to have asked for the orientation of the isotherms at a higher level than 850 hPa, because above 850 hPa the orientation of the thermal remained constant and the isotherms could be assessed to run WNW-ESE with cold air to the NE of the station.

Equations and Data.

- one full barb on the wind vector corresponds to 5 m $\mathrm{s^{-1}}$, and 1 degree of latitude corresponds to a distance of 111 km
- Properties of water: density $\rho_w = 1000\,\mathrm{kg\,m^{-3}}$, specific heat capacity $c_w = 4186\,\mathrm{J\,kg^{-1}\,K^{-1}}$, latent heat of freezing $L_f = 0.334 \times 10^6\,\mathrm{J\,kg^{-1}}$

Table 1: YQD sounding 00Z Mar. 11, 2011.

p,hPa	z,m ASL	dir	spd,knots
973.2	305	120	10
925.0	705	150	17
900.5	914	175	14
850.0	1368	175	10
801.7	1829	235	12
765.0	2198	256	16
700.0	2888	270	23

- $p = \rho\ R\ T$, 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.

- the saturation vapour pressure at temperature T is given by

$$
\begin{aligned}
e_*(T) &\approx 610.78\ \exp\ \frac{19.8\ T}{273 + T}\ \text{(over water)}\ , \\
&\approx 610.78\ \exp\ \frac{22.5\ T}{273 + T}\ \text{(over ice)}\ ,
\end{aligned}
$$

  where T is to be entered in degrees Celcius and e is in [Pa].

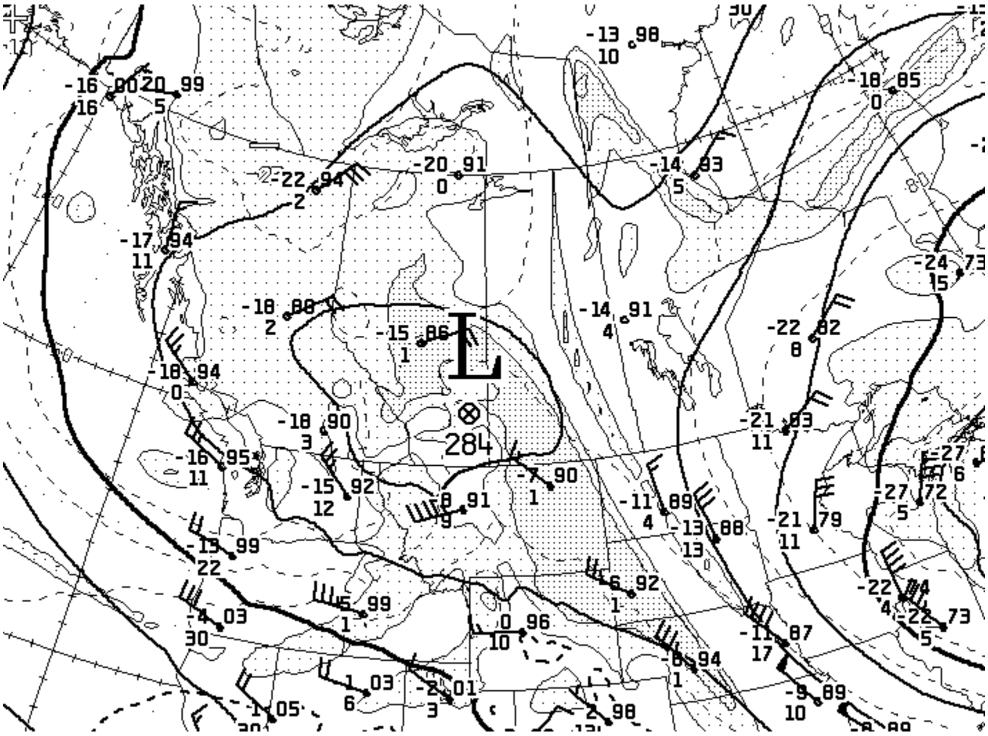

Figure 1: CMC 700 hPa analysis for 12Z Jan. 8th, 2011.

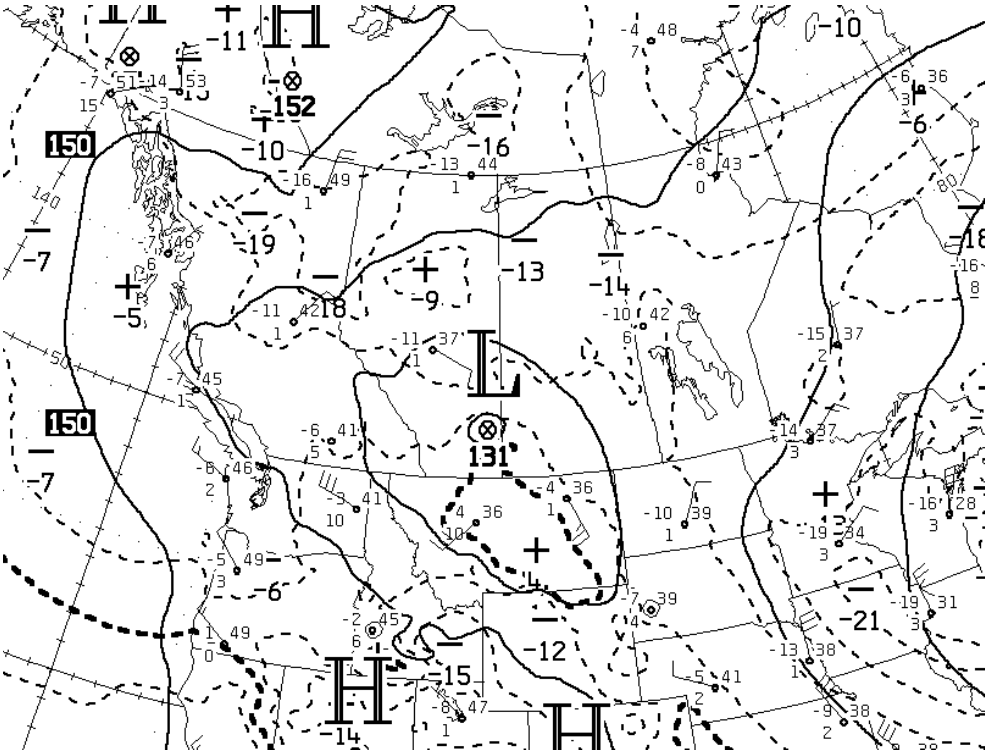

Figure 2: CMC 850 hPa analyses for 12Z Jan. 8th, 2011.

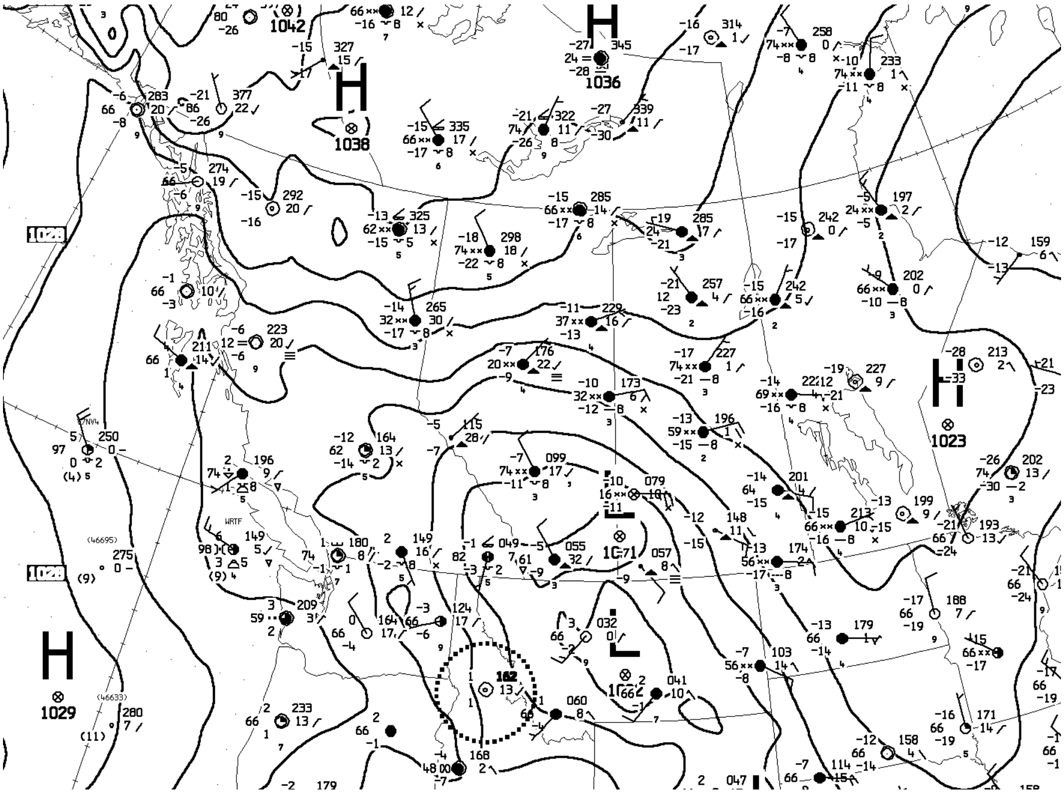

Figure 3: CMC sfc analysis for 12Z Jan. 8th, 2011.

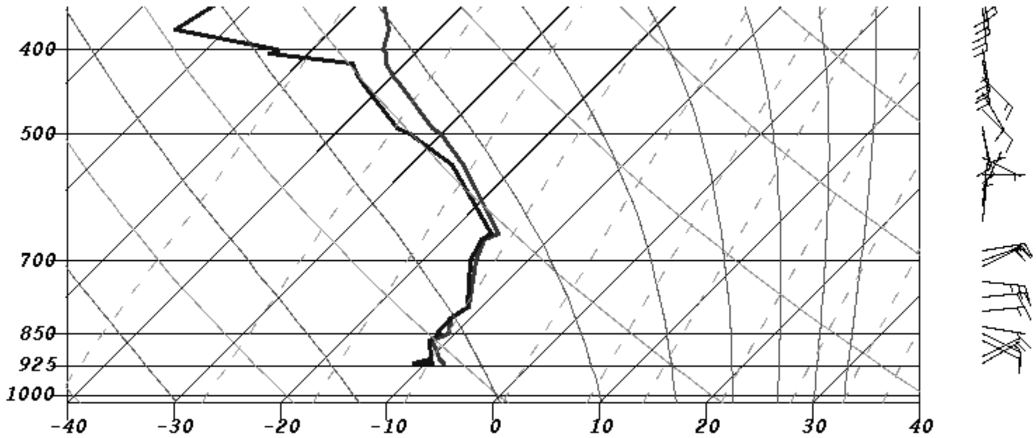

Figure 4: Edmonton sounding, for 12Z Jan. 8th, 2011.

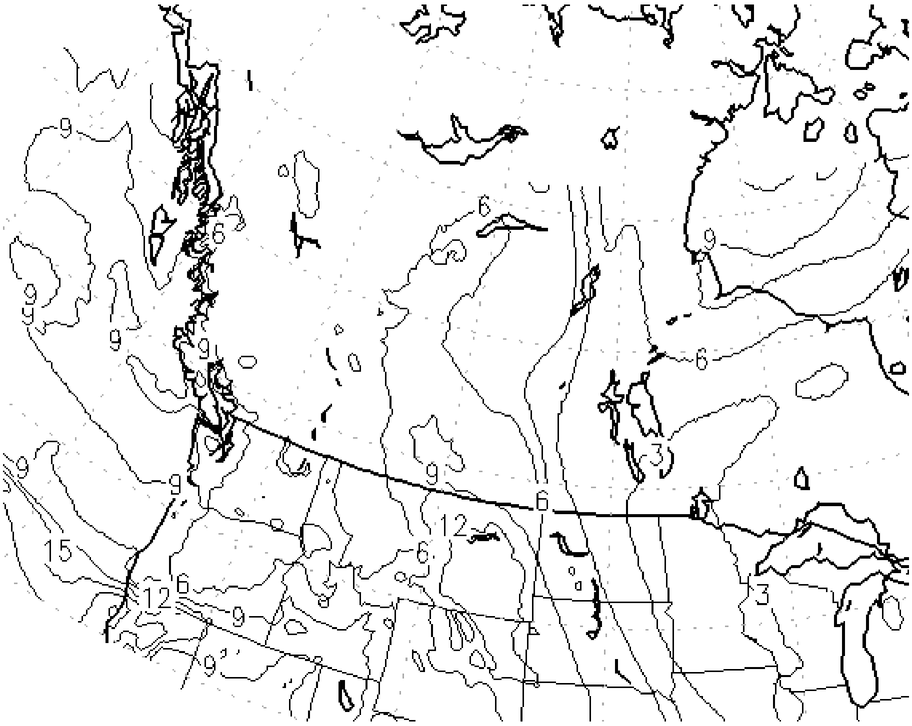

Figure 5: Reconstructed NAM analysis: precipitable water ($kg\,m^{-2}$), 12Z Jan 8th, 2011.

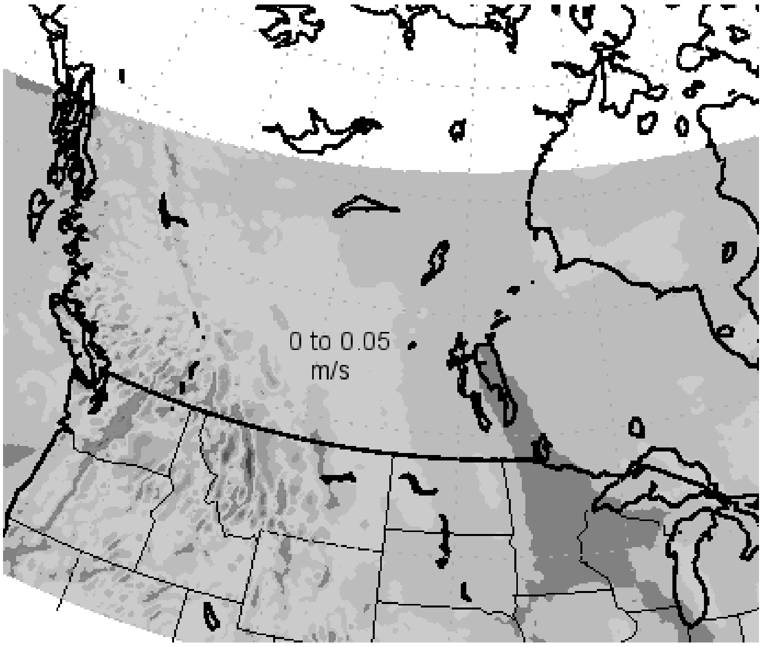

Figure 6: Reconstructed NAM analysis: vertical velocity ($m\,s^{-1}$), 12Z Jan 8th, 2011. (Note added after the exam: caption ought to have specified the analysis level, which is 700 hPa.)

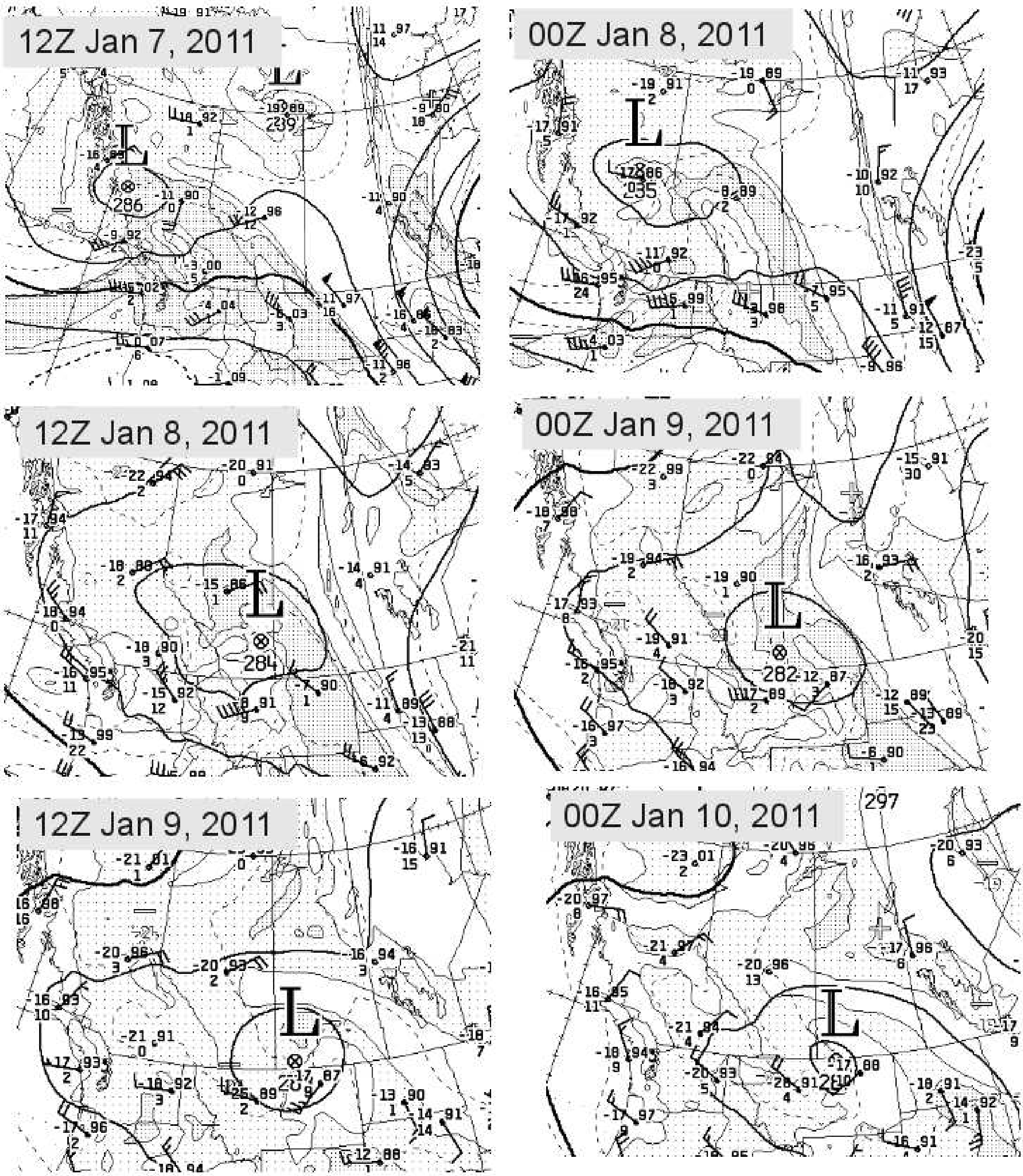

Figure 7: Sequence of CMC 700 hPa analyses, January 2011.

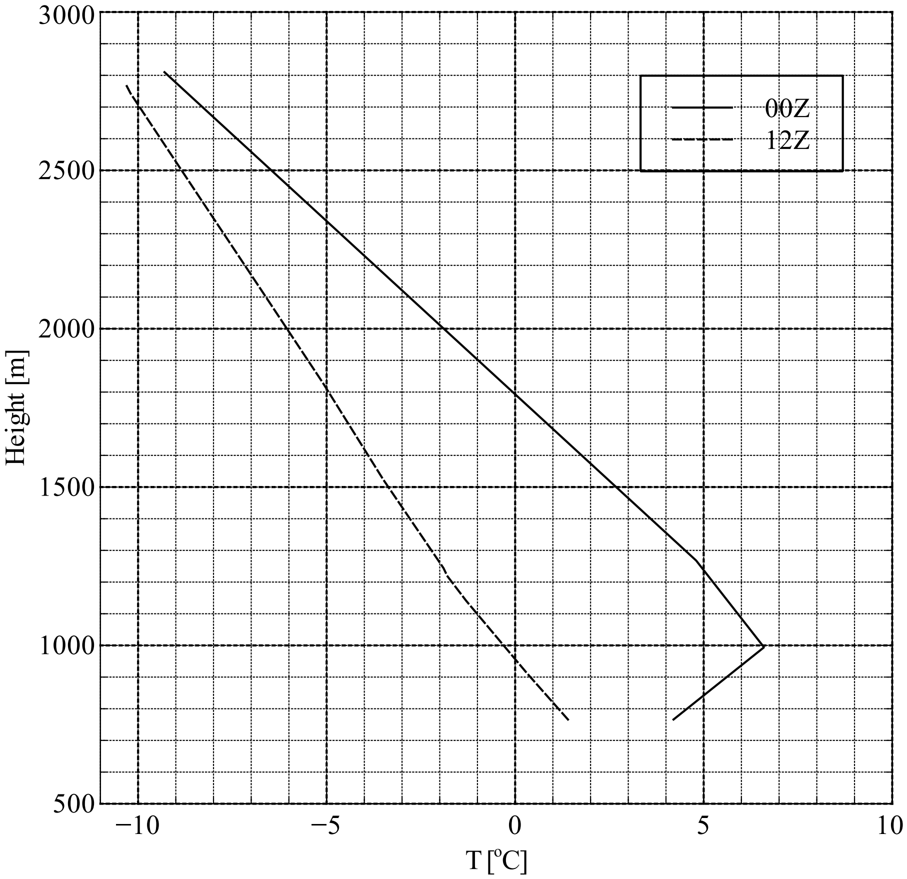

Figure 8: Edmonton soundings for 00Z & 12Z on Feb. 13th, 2011.

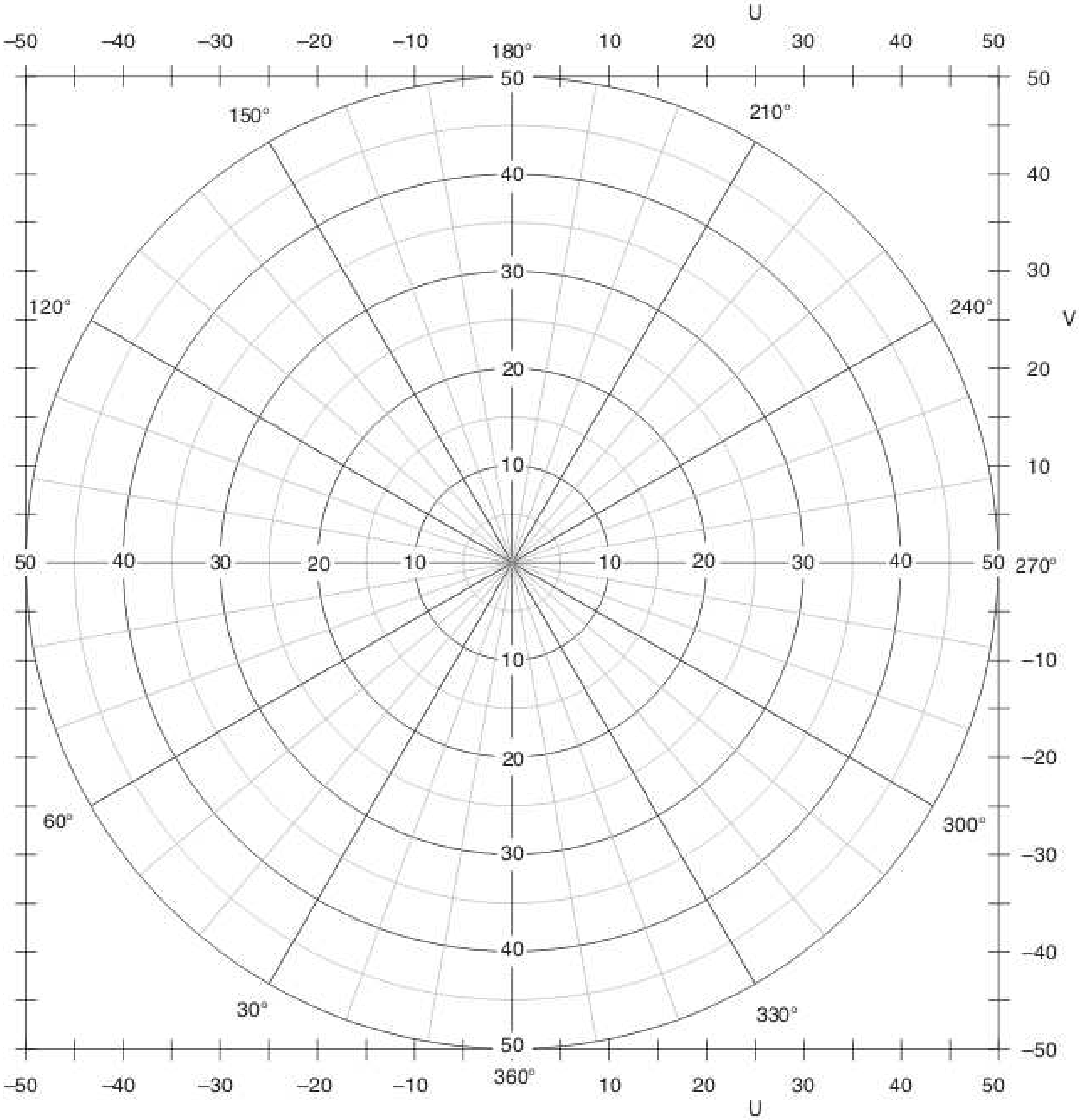

Figure 9: Blank hodograph (courtesy R. Stull).