

Professor: J.D. WilsonTime available: 2 hours 20 minValue: 35%

*Please answer all questions in the Examination Booklet.*

**A. Multi-choice (20 x 1/2 → 10 %)**

1. In the N. hemisphere the thermal wind vector is oriented \_\_\_\_\_ the isotherms with cold air \_\_\_\_\_
  - (a) parallel to; on its right
  - (b) perpendicular to; on its right
  - (c) parallel to; on its left
  - (d) perpendicular to; on its left
  - (e) obliquely across; where it is pointing

2. The equation

$$Q_H = \rho c_p C_H U_{10} (T_0 - T_a)$$

is a bulk model for sensible heat exchange between the surface and the atmosphere ( $\rho$ , air density;  $c_p$ , specific heat of air at constant pressure;  $U_{10}$  the 10 m wind speed;  $T_0$ , surface temperature;  $T_a$ , air temperature). The units of  $C_H$  must be

- (a) m
  - (b) s
  - (c)  $\text{J m}^{-2} \text{s}^{-1}$
  - (d)  $\text{s m}^{-1}$
  - (e)  $C_H$  carries no units
3. The spatial resolution of the GOES infra-red image on the equator (instantaneous geographic field of view at nadir) is about
    - (a) 40m
    - (b) 400m
    - (c) 4km
    - (d) 40km
    - (e) 400km
  4. Brightness of each single pixel of the GOES visual image is determined by
    - (a) cloud top temperature
    - (b) shortwave reflectivity (albedo)
    - (c) sum of shortwave and longwave intensities incident at cloud top
    - (d) solar elevation and intensity, and shortwave reflectivity (albedo)
    - (e) roughness of the surface seen (cloud, ground or water)

5. If  $\phi$  is a conserved variable (i.e. does not change along trajectories) and  $\mathbf{U}$  is the 3D velocity vector, then

- (a)  $d\phi/dt = \partial\phi/\partial t$
- (b)  $\partial\phi/\partial t = -\mathbf{U} \cdot \nabla\phi$
- (c)  $\partial\phi/\partial t = \mathbf{U} \cdot \nabla\phi$
- (d)  $\partial\phi/\partial x = \partial\phi/\partial y = \partial\phi/\partial z = 0$
- (e)  $\mathbf{U} \cdot \nabla\phi = 0$

6. According to the quasi-geostrophic (QG) model, in mid-latitudes the evolution of the synoptic scale pressure 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) hydrostatic; earth vorticity

7. The velocity on a pressure surface may be partitioned into geostrophic and ageostrophic components ( $\mathbf{U}_g, \mathbf{U}_{ag}$ ), where  $\mathbf{U}_g$  is non-divergent. The QG vorticity equation, which associates a property of the vorticity and motion fields with horizontal divergence  $D_p$ , is

$$\frac{d_g\eta}{dt} = -f_0 D_p$$

where  $f_0$  is the Coriolis parameter evaluated at the reference latitude, and  $\eta = f_0 + \zeta_g$  is the absolute vorticity ( $\zeta_g$  is the relative vorticity evaluated using the geostrophic wind). The operator  $d_g/dt$  is

- (a) the local (Eulerian, or fixed-frame) tendency in time
- (b) the time derivative following the total wind  $\mathbf{U}_g + \mathbf{U}_{ag}$
- (c) the time derivative following the ageostrophic wind  $\mathbf{U}_{ag}$
- (d) the time derivative following the geostrophic wind  $\mathbf{U}_g$
- (e) the Laplacian

8. Referring again to the QG vorticity equation, the divergence  $D_p$  is evaluated using

- (a) the natural coordinate system
- (b) the hydrostatic approximation
- (c) a non-hydrostatic vertical momentum equation
- (d) the total wind  $\mathbf{U}_g + \mathbf{U}_{ag}$
- (e) the  $\beta$ -plane approximation  $f(y) = f_0 + \beta y$ ,  $y$  being the meridional coordinate

9. On a Graphical Area Forecast (e.g. Fig. 12) the symbol “P6SM” has what significance?
- (a) predicted visibility exceeds 6 statute miles
  - (b) probability 0.6 of snow
  - (c) precipitation 6 mm (snow depth)
  - (d) precipitation 6 mm (water equivalent)
  - (e) partial (6/8) cloud cover on synoptic and meso scales
10. Referring to Figures (1-2), surface analyses from the Australian Bureau of Meteorology, at a best guess the dashed blue lines represent
- (a) shortwave troughs
  - (b) shortwave ridges
  - (c) occluded fronts
  - (d) lee troughs
  - (e) storm tracks
11. The west coast of the South Island of New Zealand (NZ) is defined by a narrow chain of high mountains, while the east coast is substantially an erosion plain; the sea-level isobar pattern over the South Island often reflects the influence of that topography. Still in reference to Figures (1-2), westerly winds would have been occurring over the South Island of NZ on
- (a) 9 April and 11 April
  - (b) neither 9 April nor 11 April
  - (c) 9 April
  - (d) 11 April
12. On the basis of Fig. (3), what process or phenomenon might one expect to occur over east-central Manitoba?
- (a) cold advection
  - (b) cyclogenesis
  - (c) freezing rain
  - (d) frontogenesis
  - (e) severe convection
13. Again referring to Fig. (3), what temperature label attaches to the isotherm designated by an “X” in the Yukon at the top of the map? The heavy dashed ring, indicating suspicious data, probably refers to which variable?
- (a) -35; dewpoint
  - (b) -35; temperature
  - (c) -30; dewpoint
  - (d) -30; temperature
  - (e) -30; height of the 850 hPa surface

14. Referring to Figure (4), the cut-off low in the United States might be termed
- (a) super-geostrophic
  - (b) a mesoscale low
  - (c) a cold core low
  - (d) a hurricane
  - (e) a tropical storm
15. If vectors  $\mathbf{P}$ ,  $\mathbf{Q}$  respectively have components  $(0, p_b, 0)$  and  $(1, q_b, 1)$  relative to a basis defined by orthogonal unit vectors  $(\hat{i}, \hat{j}, \hat{k})$  then the quantity  $\mathbf{P} \cdot \mathbf{Q}$  (ie. 'dot product' of the two vectors) is \_\_\_\_\_
- (a) 0
  - (b)  $(0, 0, 0)$
  - (c)  $p_b q_b$
  - (d)  $(1, p_b + q_b, 1)$
  - (e)  $p_b + q_b$
16. In a single spatial dimension  $x$ , and using a Cartesian coordinate, which is the correct representation of the operator  $\nabla^2$  ( $\equiv \nabla \cdot \nabla$ ), variously named the Laplacian/diffusion/curvature operator?
- (a)  $\partial/\partial x$
  - (b)  $\partial^2/\partial x^2$
  - (c)  $\partial/\partial t$
  - (d)  $\partial^2/\partial t^2$
  - (e)  $\partial/\partial t + U \partial/\partial x$
17. Suppose that  $f(x) = \alpha \exp(-x/x_0)$  is the probability density function (PDF) for a random non-negative real number  $x$ . For  $f$  to be an acceptable PDF, the constants  $x_0$  and  $\alpha$  must satisfy
- (a)  $\alpha = 1, x_0 < 0$
  - (b)  $\alpha = \exp(-1)$
  - (c)  $\alpha = x_0$
  - (d)  $\alpha = 1/x_0$
  - (e)  $\alpha^2 = \sqrt{x_0}$

18. The mean square value of  $x$  can be computed from the PDF as
- (a)  $\overline{x^2} = \int_0^\infty f(x) dx$
  - (b)  $\overline{x^2} = \int_0^\infty xf(x) dx$
  - (c)  $\overline{x^2} = \int_0^\infty xf^2(x) dx$
  - (d)  $\overline{x^2} = \int_0^\infty x^2 f(x) dx$
  - (e)  $\overline{x^2} = \int_0^\infty x^2 f^2(x) dx$
19. Assuming the 250 hPa wind speed  $|U|$  is the value reported for Fort Smith (YSM, on the northern border of Alberta) on Figure (9), the Courant number  $C = |U| \Delta t / \Delta x$  at a 250 hPa-level gridpoint of the GEM (regional config.) model (near Fort Smith) is about
- (a) 1000
  - (b) 100
  - (c) 10
  - (d) 1
  - (e) 0.1
20. The mean vertical sensible heat flux density carried by unresolved scales of motion, formally  $\overline{w'\theta'}$  (where  $w'$ ,  $\theta'$  are the fluctuations in vertical velocity and potential temperature), is typically parameterized in an NWP model, by analogy with Fourier's law of conduction, as

$$\overline{w'\theta'} = -K_h \frac{\partial \bar{\theta}}{\partial z}$$

where  $K_h$  [ $\text{m}^2 \text{s}^{-1}$ ] is the “eddy diffusivity for heat.” Then in a “neutral” (unstratified, i.e. thermally well-mixed) layer of the atmosphere the unresolved vertical heat flux

- (a) is positive
- (b) is zero
- (c) is negative
- (d) is indeterminate
- (e) is infinite

## B. “Live” web weather data (5 x 1 → 5%)

1. What was the total rainfall recording for Edmonton International Airport on 8 July 2011?
2. What was the CAPE at 00Z 3 April 2012 at Lamont Oklahoma (74646, LMN)?
3. Retrieve and write down the METAR for CYEG for 06Z today
4. According to the GEM reg run initialized at 06Z today, what was the 0h value (i.e. analysis) for the maximum value of the precipitable water anywhere over Western Canada (BC-Alberta-Saskatchewan-Manitoba)?
5. According to the MSC analysis valid at 06Z today, what is the maximum value over N. America of the absolute vorticity at the 500 hPa level?

## C. Interpretation of weather situation. (1 x 10 → 10%)

On 5 April 2012 Edmonton experienced a heavy snowfall, with a high rate of accumulation coinciding with morning rush hour traffic. This storm had been a feature of GEM model progs for at least the previous eight days. Figures (5-12) summarize the prevailing meteorology at 12Z (i.e. 06 MDT).

From the given information, **interpret the meteorological facts** relating to this event. Please present your analysis in point form.

## D. Short answer (2 x 5 % → 10 %)

Please answer **two** of the following questions.

1. Describe the scientific and operational features of Canada's NWP model "GEM"
2. In gridpoint computations the friction term  $F_u$  in the mean zonal momentum equation is simplified

$$\begin{aligned} F_u &\equiv -\frac{\partial \overline{u'^2}}{\partial x} - \frac{\partial \overline{u'v'}}{\partial y} - \frac{\partial \overline{u'w'}}{\partial z} \\ &\rightarrow -\frac{\partial \overline{u'w'}}{\partial z} \\ &\rightarrow -\frac{\partial}{\partial z} \left( -K \frac{\partial U}{\partial z} \right). \end{aligned}$$

Explain the logic and meaning of this simplification.

3. The geostrophic wind is

$$\mathbf{U}_g = \frac{g}{f} \hat{k} \times \nabla_p Z$$

where  $Z$  is the height of a constant pressure surface. Derive an expression for the geostrophic shear  $\partial \mathbf{U}_g / \partial p$  in terms of the two components  $\partial T / \partial x, \partial T / \partial y$  of the temperature gradient  $\nabla_p T$  on the constant pressure surface. (Assume a hydrostatic atmosphere).

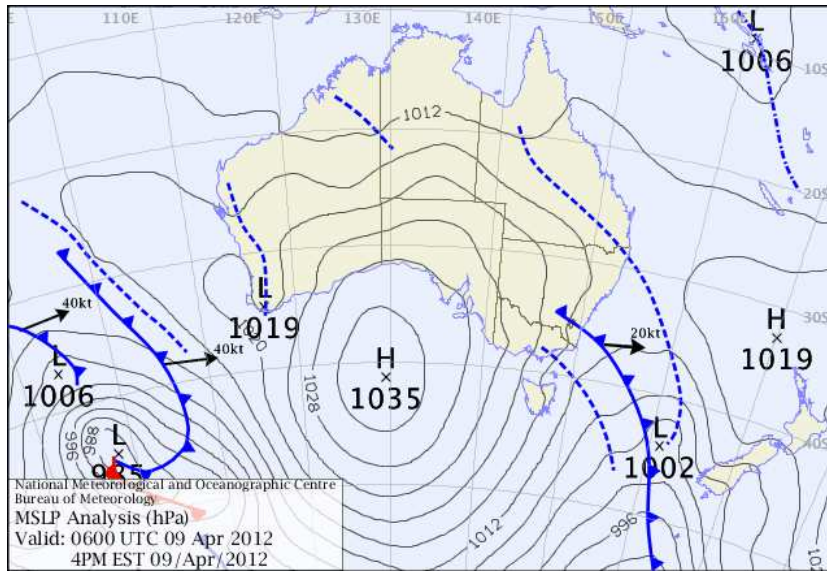


Figure 1: Bureau of Meteorology (Australia) surface analysis, 06Z April 9, 2012.

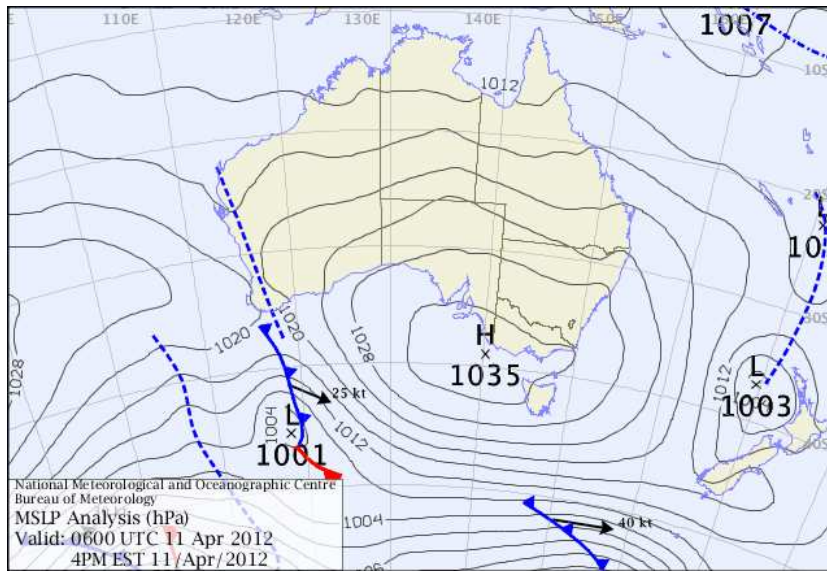


Figure 2: Bureau of Meteorology (Australia) surface analysis, 06Z April 11, 2012.

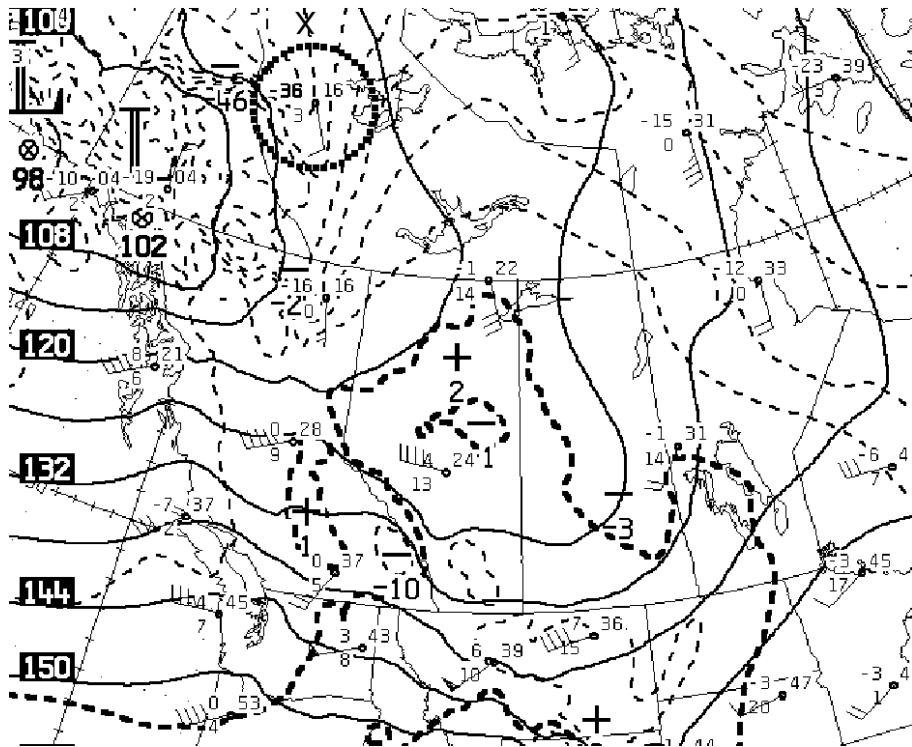


Figure 3: MSC 850 hPa analysis, 12Z January 25, 2012.

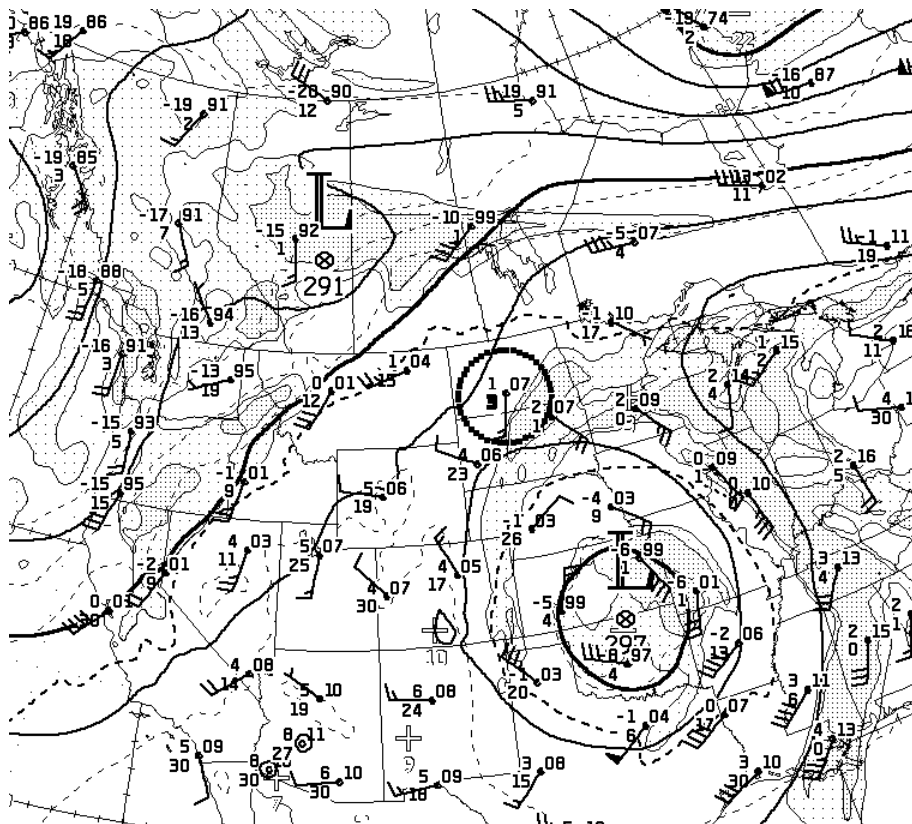


Figure 4: MSC 700 hPa analysis, 00Z March 23, 2012.



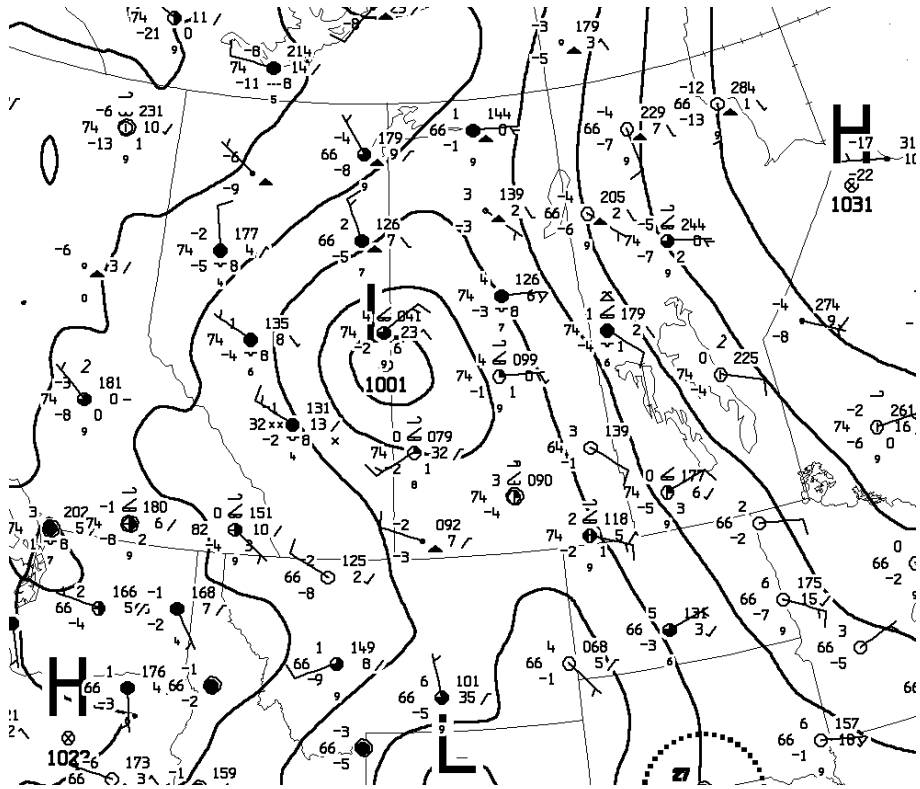


Figure 5: MSC surface analysis, 12Z Thurs 5 April 2012.

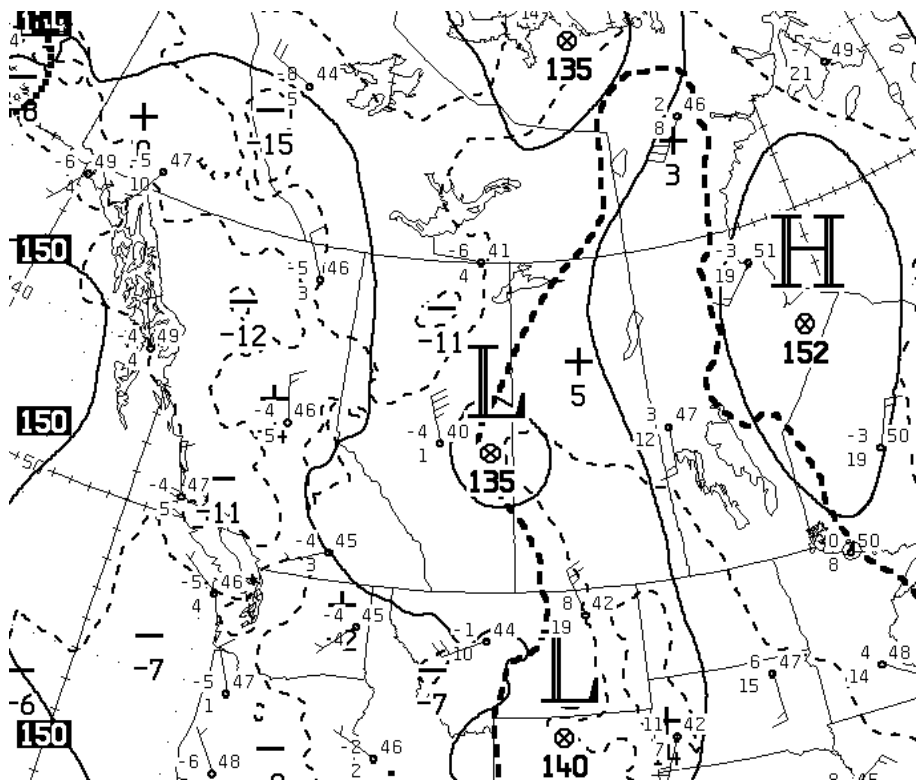


Figure 6: MSC 850 hPa analysis, 12Z Thurs 5 April 2012.

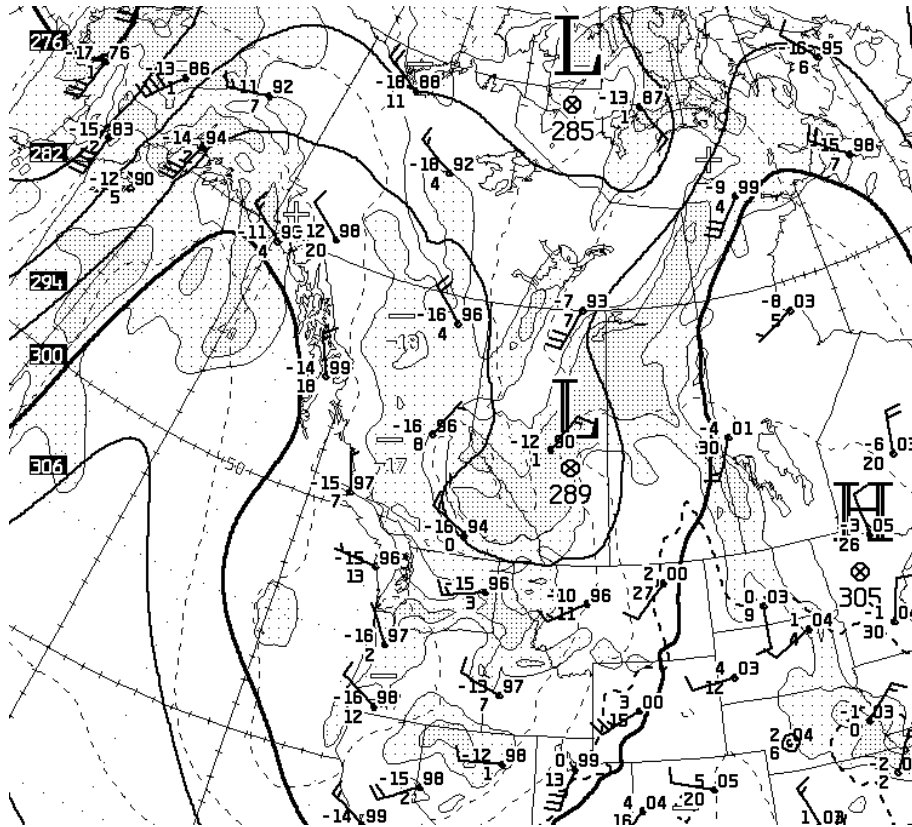


Figure 7: MSC 700 hPa analysis, 12Z Thurs 5 April 2012.

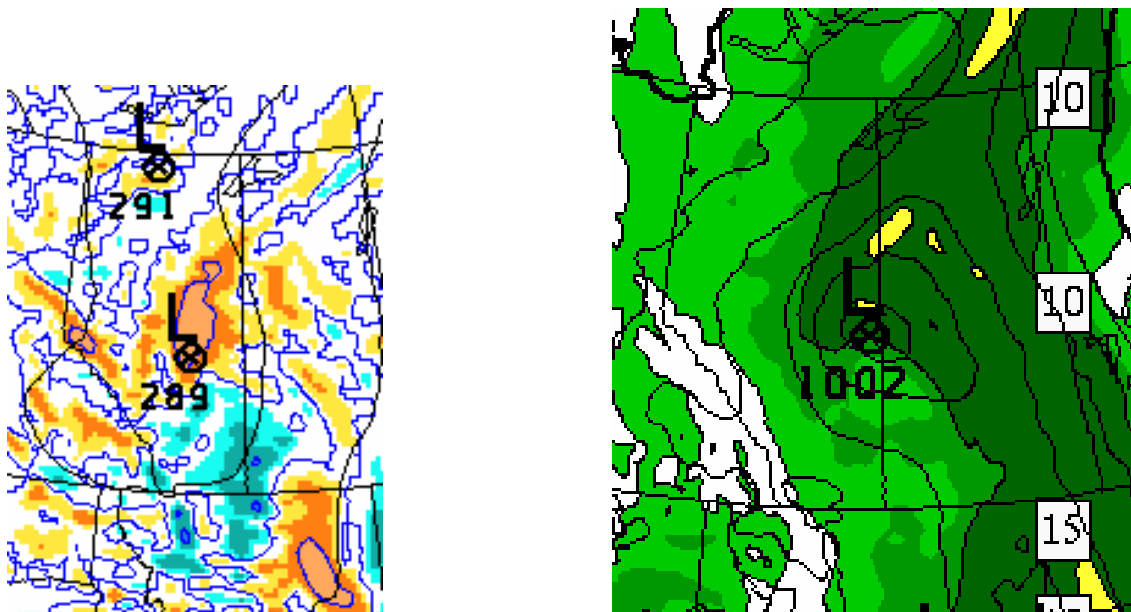


Figure 8: Left panel: Omega at 700 hPa (light orange,  $-1 \rightarrow -2 \text{ Pas}^{-1}$ ). Right panel: precipitable water (yellow/green boundary, 15 mm). From GEM 0h prog valid 12Z, Thurs 5 April 2012

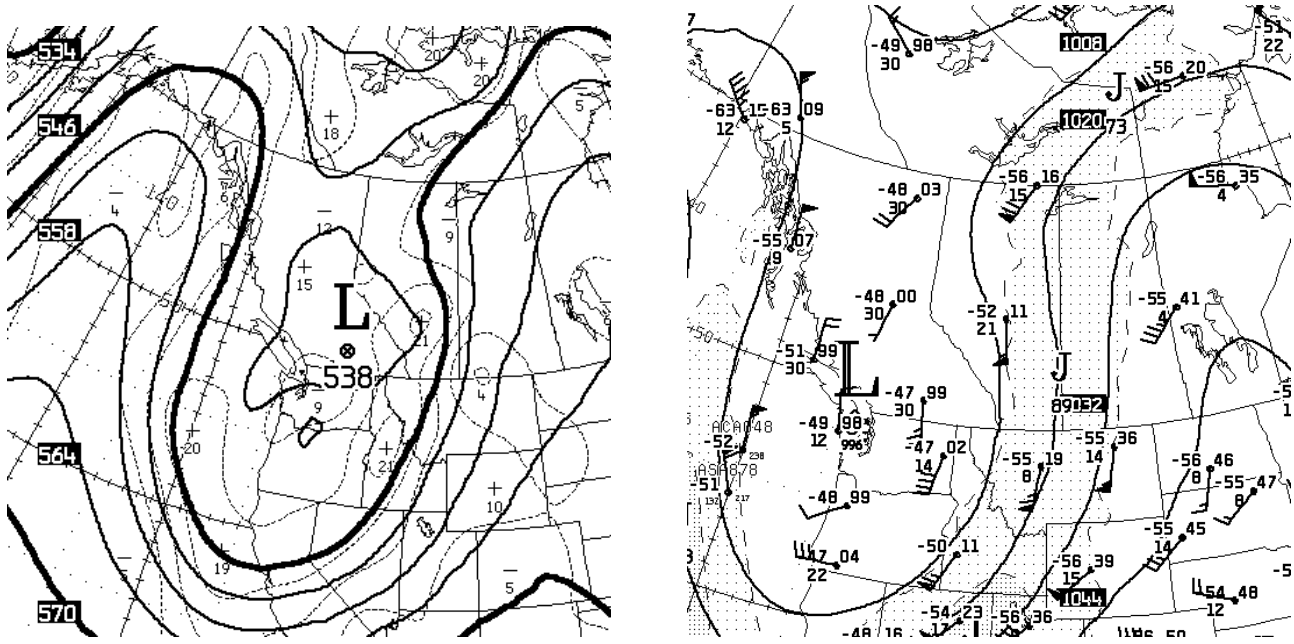


Figure 9: Left panel: 500 hPa height and absolute vorticity( GEM reg 0h prog). Right panel: MSC 250 hPa analysis. Valid 12Z Thurs 5 April 2012.



Figure 10: Left panel: Horizontal divergence at 900 hPa (deep purple,  $< -1 \times 10^{-4} \text{ s}^{-1}$ ). Right panel: temperature advection at 850 hPa (orange,  $> 3 \text{ K hr}^{-1}$ ). From NAM 0h prog valid 12Z, Thurs 5 April 2012

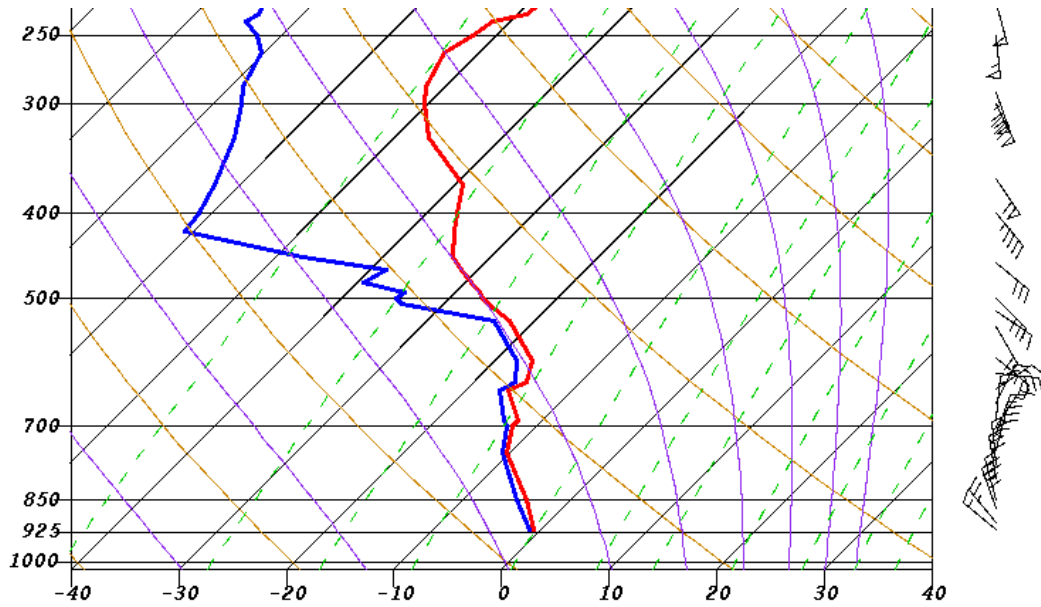


Figure 11: Stony Plain sounding, 12Z Thurs 5 April 2012 (data below).

PRES	HGHT	TEMP	DWPT	RELH	MIXR	DRCT	SKNT	THTA	THTE	THTV
hPa	m	C	C	%	g/kg	deg	knot	K	K	K
1000.0	92									
925.0	725									
920.0	766	-0.7	-1.0	98	3.88	310	16	279.0	289.9	279.7
903.1	914	-1.5	-1.9	97	3.69	320	25	279.7	290.1	280.3
869.2	1219	-3.1	-3.9	95	3.32	340	42	281.0	290.5	281.6
850.0	1397	-4.1	-5.0	93	3.12	345	34	281.8	290.8	282.4
804.2	1829	-6.9	-7.6	95	2.70	350	30	283.4	291.2	283.8
773.4	2134	-8.9	-9.4	96	2.44	355	25	284.4	291.6	284.8
752.0	2353	-10.3	-10.7	97	2.26	9	32	285.1	291.9	285.5
743.7	2438	-10.6	-11.0	97	2.23	15	35	285.7	292.4	286.1
714.7	2743	-11.7	-12.2	96	2.11	20	15	287.8	294.1	288.1
700.0	2903	-12.3	-12.8	96	2.05	35	15	288.8	295.1	289.2
690.0	3013	-12.3	-13.5	91	1.97	12	13	290.0	296.1	290.4
686.8	3048	-12.5	-13.7	91	1.94	5	13	290.2	296.1	290.5
659.8	3353	-14.4	-15.3	93	1.77	25	16	291.4	296.9	291.7
636.0	3632	-16.1	-16.8	94	1.62	52	17	292.5	297.6	292.8
633.8	3658	-15.9	-16.7	94	1.64	55	17	293.0	298.2	293.3
623.0	3788	-15.1	-16.1	92	1.76	72	22	295.4	300.9	295.7
608.8	3962	-15.7	-16.9	91	1.69	95	28	296.7	302.0	297.0
590.0	4198	-16.5	-17.9	89	1.59	122	27	298.4	303.5	298.7
584.6	4267	-17.0	-18.4	89	1.54	130	27	298.6	303.6	298.9
538.5	4877	-21.5	-22.9	88	1.13	150	19	300.3	304.0	300.5
531.0	4982	-22.3	-23.7	88	1.07	142	18	300.6	304.1	300.8
516.6	5182	-24.4	-29.7	61	0.63	125	17	300.4	302.5	300.5
507.0	5320	-25.9	-33.9	47	0.43	131	24	300.2	301.7	300.3
500.0	5420	-26.9	-34.9	47	0.40	135	30	300.2	301.6	300.2
492.0	5536	-27.7	-34.7	51	0.41	134	30	300.6	302.0	300.7
479.0	5728	-29.5	-39.5	37	0.26	133	31	300.7	301.6	300.7
464.0	5954	-31.5	-38.5	50	0.30	131	32	300.9	302.0	301.0
454.7	6096	-32.6	-43.7	32	0.18	130	32	301.2	301.9	301.3
448.0	6201	-33.5	-47.5	23	0.12	131	34	301.4	301.9	301.5
420.0	6652	-35.7	-60.7	6	0.03	136	41	304.2	304.3	304.2
400.0	6990	-37.1	-61.1	6	0.03	140	46	306.7	306.8	306.7
371.0	7509	-39.3	-62.3	7	0.02	144	56	310.4	310.5	310.4
365.0	7620	-40.3	-62.6	7	0.02	145	58	310.6	310.7	310.6
327.0	8362	-46.9	-64.9	11	0.02	151	69	311.4	311.5	311.4
300.0	8930	-50.3	-67.3	12	0.01	155	78	314.3	314.4	314.4
290.3	9144	-51.4	-68.4	11	0.01	160	77	315.8	315.8	315.8
286.0	9241	-51.9	-68.9	11	0.01	162	75	316.4	316.4	316.4
262.0	9807	-53.3	-70.3	11	0.01	175	64	322.4	322.4	322.4
250.0	10110	-52.3	-72.3	7	0.01	175	54	328.2	328.2	328.2

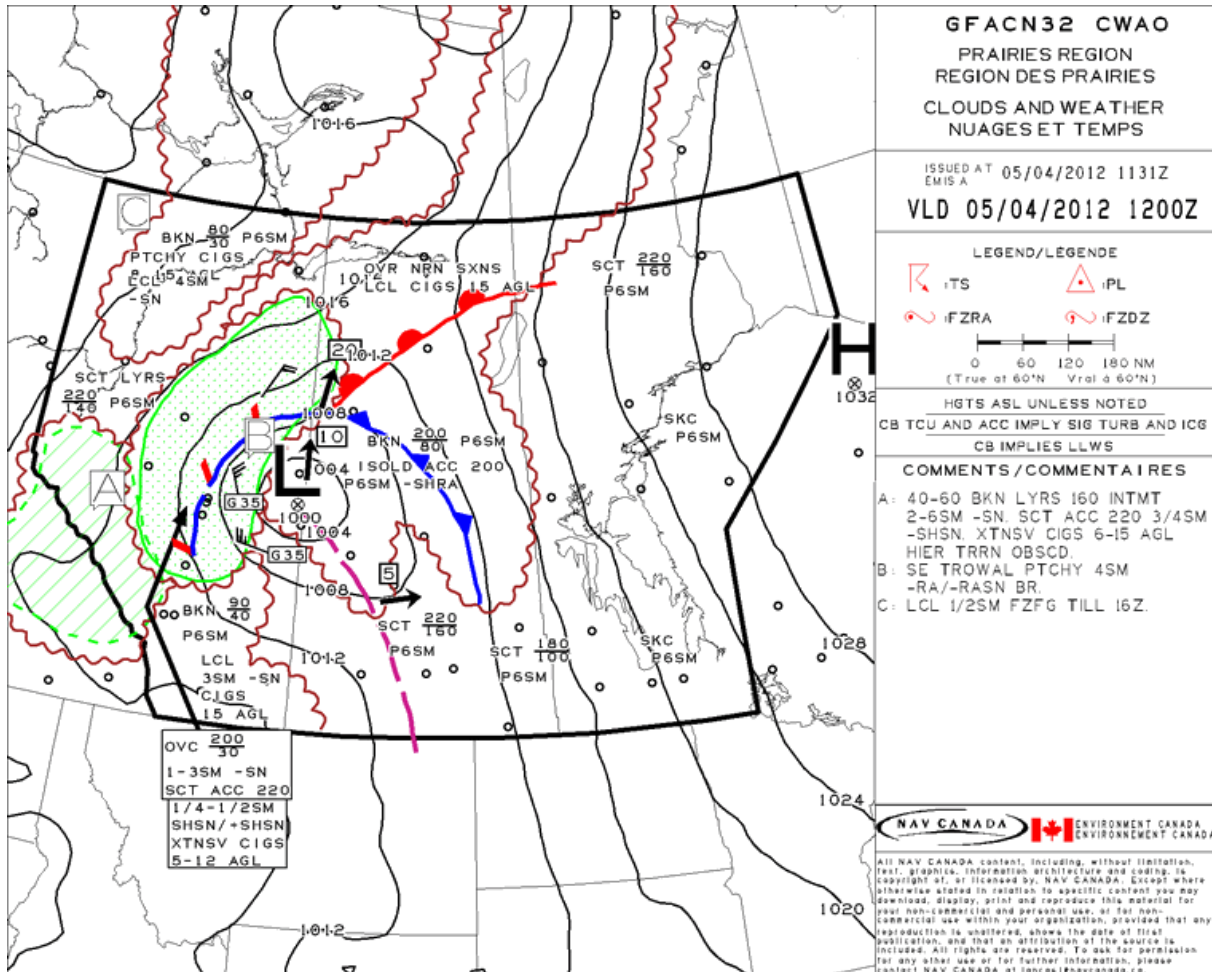


Figure 12: GFA valid 12Z Thurs 5 April 2012.