EAS372 | Mid-term Exam | 16 Feb., 2017

Professor: J.D. Wilson | Time available: 75 mins | Value: 15%

Open book exam. Please answer in the booklet provided.

A. Theory & calculation (2 x 3 → 6%)

Answer any **two** questions in this section:

1. Imagine a region over which the temperature was uniform in space and time ($T = 20°C$) while wind was zonal, and independent of latitude, longitude and elevation: $\vec{u} = (u, 0, 0)$, with $u = \text{const.} = 5\,\text{m}\,\text{s}^{-1}$. Suppose however that over the domain of interest there were a constant longitudinal gradient in the relative humidity ($0 \leq \text{RH} \leq 1$) such that $\partial \text{RH}/\partial x = 0.0005\,\text{km}^{-1}$. Compute the advective tendency

$$\frac{\partial \rho_v}{\partial t} = -\,u\,\frac{\partial \rho_v}{\partial x} \tag{1}$$

in the absolute humidity, given that (under the stated restriction of a uniform temperature)

$$\frac{\partial \rho_v}{\partial x} = \frac{\partial}{\partial x}\,\frac{e}{R_v\,T} = \frac{1}{R_v T}\,\frac{\partial e}{\partial x} = \frac{1}{R_v T}\,\frac{\partial}{\partial x}\,[\,e_*(T)\;\text{RH}(x)] = \frac{e_*(T)}{R_v T}\,\frac{\partial \text{RH}}{\partial x}\,. \tag{2}$$

Express your answer in $\text{kg}\,\text{m}^{-3}\,\text{hr}^{-1}$.

Answer:

This question really entailed no more than a substitution, although ideally one would have understood the validity of Eq. (2). The RH gradient is

$$\frac{\partial \text{RH}}{\partial x} = \frac{5\,\times\,10^{-4}}{1000} = 5\,\times\,10^{-7}\;[\text{m}^{-1}]$$

and the needed saturation vapour pressure is $e_*(20°\text{C}) = 23.373$ hPa (from the chart on the class home page). Thus the gradient in absolute humidity is

$$\frac{\partial \rho_v}{\partial x} = \frac{2337}{462 \times 293.15}\;\times\;5 \times 10^{-7}\;=\;8.63\,\times\,10^{-9}\,\text{kg}\,\text{m}^{-3}\,\text{m}^{-1}$$

and the advective tendency is

$$\frac{\partial \rho_v}{\partial t}\,[\text{kg}\,\text{m}^{-3}\,\text{hr}^{-1}] = 3600\,[\text{s}\,\text{hr}^{-1}]\;\times(-5)\times\;8.63\times10^{-9}\;=\;-1.55\times10^{-4}\,\text{kg}\,\text{m}^{-3}\,\text{hr}^{-1}.$$

2. It is common in meteorological models to use the "sigma coordinate" $\sigma = p/p_{\rm sfc}$, which has the advantage of being "flat" (constant) both at the base ($\sigma = 1$) and at the top ($\sigma = 0$) of the atmosphere: for earth's atmosphere, $\sigma = 1/2$ would be close to the 500 hPa level. Suppose that at a certain time and place the horizontal divergence $D_p \equiv \partial u/\partial x + \partial v/\partial y$ were given by the formula

$$D_p(\sigma) = A \sin \left[2\pi \left(\sigma - \frac{1}{2}\right) \right] . \tag{3}$$

Roughly sketch the pattern of D_p versus σ, with σ as your vertical axis. Identify any level(s) of non-divergence (LND) and use an arrow to indicate the sign of the vertical motion (up or down) at that (those) levels. Does this idealized scenario correspond to a cyclonic or an anticyclonic weather system?

Answer: see Figure 8. The $\sigma = 1/2$ level is a level of non-divergence (LND), with positive divergence below and negative above. Thus this corresponds to the simplest paradigm of a surface anticyclone, with convergence above the LND, an extremum of vertical velocity at the LND (sink), and divergence below the LND.

3. Refer to Figure (1), and assume this is a northern hemisphere case.

   (a) Specify the wind vectors $\vec{U}_{\rm L}$, $\vec{U}_{\rm U}$ at the lower and upper levels based on the given thermal wind vector. Please give the speed, direction in degrees, and categorical direction (N, NNE, NE, ENE, E, ESE, SE, SSE, S... etc). Recall the convention that a "NE" wind *comes* from the NE and has compass direction in the neighbourhood of 45°, etc.

   (b) What deduction are you able to make regarding thermal advection at the hodograph's location?

Answer: At the lower level the wind vector (added in blue on Figure 1) was a $25\,{\rm m\,s^{-1}}$ NW wind with compass direction $\sim 315°$. At the upper level (added in red) the wind was a $40\,{\rm m\,s^{-1}}$ ESE wind with compass direction $\sim 105°$.

The thermal wind blows from the ESE, so cold air lies to the SSW. At both the lower and the upper levels, thus throughout the layer, the wind is blowing across the thickness contours from the warm side towards the cold: warm advection is occurring.

B. "Live" web weather data (4 x 1 $\rightarrow$ 4%)

1. Retrieve and record the CYEG METAR for 12Z Wednesday 15 February 2017 (note: yesterday!). Decode the cloud type(s) and base height(s). Speculate on any relationship with Figures (6, 7).

   Answer: The METAR reads "CYEG 151200Z 17009KT 15SM SCT140 OVC240 03/M02 A2950 RMK AC3CI5 SLP014". The cloud: 3 oktas altocumulus based at 14000 feet AGL, overcast at 24000 feet AGL with 5 oktas (5/8 cover) of cirrus.

2. Retrieve the record of past weather data for Calgary International Airport (hourly, January 15th 2017). What were the reported temperature and dewpoint for 12:00 LST (Local Standard Time)?

   Answer: $(T, T_{\rm d}) = (+9.6, -0.6)$°C (see Figure 9 added after the exam).

3. What was the 1000-500 hPa thickness in the NE corner of Alberta at Fort Smith (YSM sounding) at 12Z on 15 January 2017?

   Answer: thickness =5290 - (-32) = 5322 m = 532 dam (see Figure 10).

4. Based on today's CMC 850 hPa analysis for 12Z, what was the temperature T_{850} at 60°N on the Saskatchewan-Manitoba border (interpolate or give a temperature range, if necessary)? What value (or range) for T_{850} had been *forecast* for that time and place by the GEM GDPS run that was initialized at 12Z on February 11?

   Answer: The analysis (see Figure 11) indicates a value between 0°C and +5°C. Interpolating linearly, +2°C seems about right. This is very consistent with the prog (see Figure 12), which gave between +1.5°C and +5°C.

C. Interpretation of Weather Charts (5%)

Using "point form", please give your interpretation of the meteorological cause of the mild weather conditions that were observed (Figure 2) in Edmonton on Wednesday 15 February 2017, based on the information provided by Figures (3 – 7).

Elements of an Answer:

- Figure 3, the 0h prog, shows a thermal (i.e. thickness) ridge with its axis running through Alberta, the very cold (510-516 dam) air being displaced far to the north and even the more moderate 534-540 dam thickness band well north of 60°N.

- The cause of this is a strong SW upper flow over B.C. (Figure 4) that, impeded by the Rockies, is resulting in a lee trough. The airstream aloft is largely dried out in passing across B.C. At the 700 hPa level, the wind over C. Alberta is weak.

- The lee trough is seen also at 850 hPa (Figure 5), with a centre of warm air aloft in Alberta (+14°C at Edmonton) and a cold centre on the west side of the Rockies. This is the Chinook effect, associated with the strong SW wintertime winds and the lee trough. At the 850 hPa level the freezing contour (0°C isotherm) has been pushed way north of 60°N.

- The Stony Plain sounding (Figure 6) shows the super mild air aloft. (There is a surface inversion, but this can't be said to be the "cause" of the mild day in Alberta – the cause is that mild air has blown in aloft.)

- A thin saturated layer just below 500 hPa (see the Stony Plain sounding, Figure 6) correlates with the high cloud seen on the GOES image (Figure 7).

- Also evident on the GOES image, a clear(-ish) slot in the lee of the Rockies, due to a sinking airstream.

- (Though not included on the exam, Figure 13 gives the CMC surface analysis contemporaneous with the given charts, and shows the trough at the surface.)

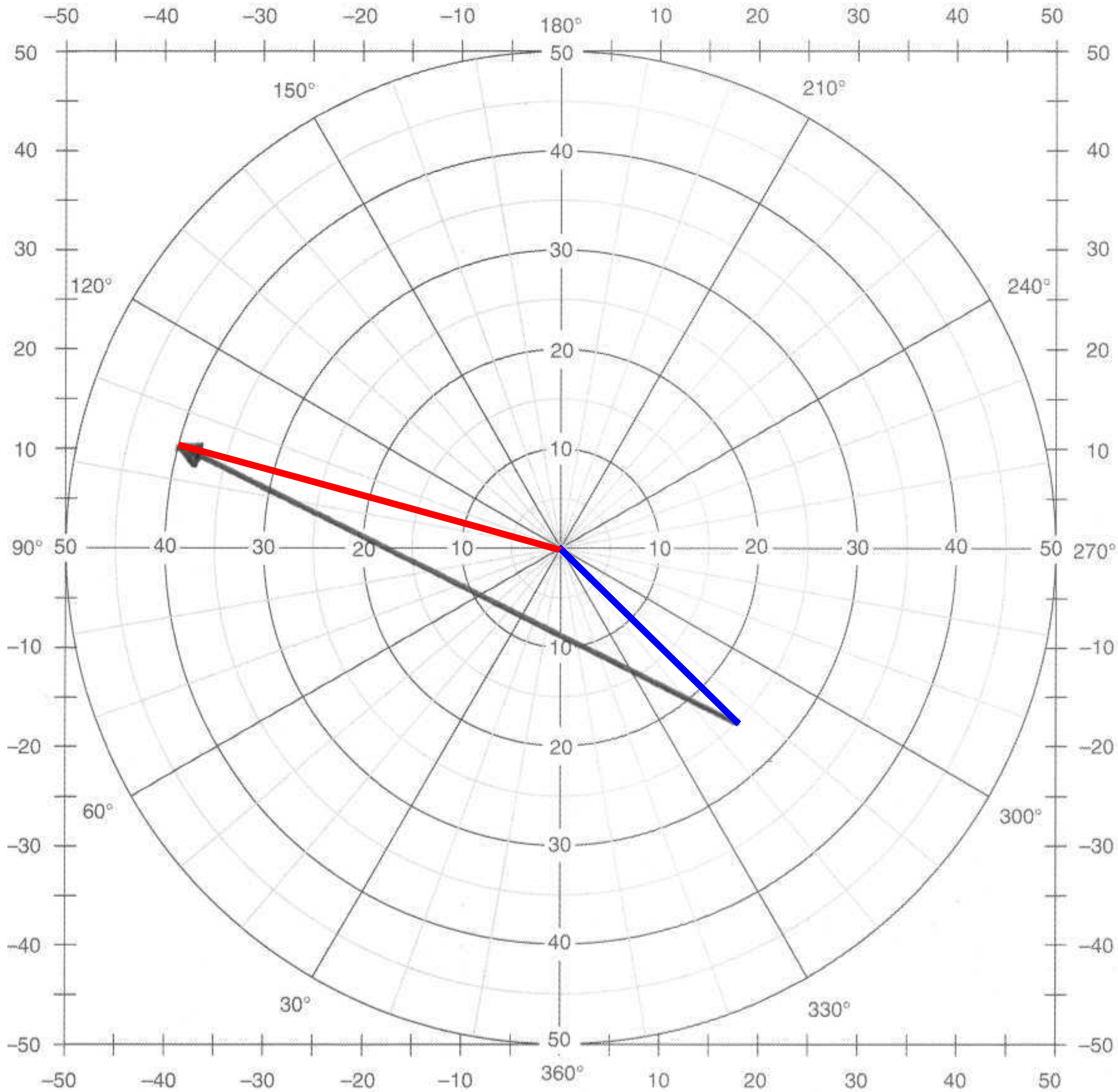

Figure 1: Hodograph. Assume the speed scale is in $\mathrm{m\,s^{-1}}$. The arrow represents a thermal wind vector. The red and blue lines, representing the wind vector at the upper and lower levels, were added after the exam.

Date / Time (MST)	Conditions	Temperature (°C)	Wind (km/h)	Wind chill	Relative humidity (%)	Dew point (°C)
15 February 2017						
16:00	Mainly Sunny	9 (9.0)	S 11	*	55	1
15:00	Mainly Sunny	11 (11.2) ↑	calm	*	45	0
14:00	Partly Cloudy	11 (10.9)	SSE 3	*	47	0
13:00	Mostly Cloudy	9 (8.9)	ESE 9	*	59	1
12:00	Mostly Cloudy	7 (7.0)	N 5	*	59	-1
11:00	Mostly Cloudy	5 (4.6)	SE 16	*	66	-1
10:00	Mostly Cloudy	6 (5.5)	SSE 3	*	57	-2
09:00	Mostly Cloudy	5 (5.2)	SSE 15	*	59	-2
08:00	Mostly Cloudy	3 (3.4)	S 13	*	68	-2
07:00	Mostly Cloudy	3 (3.1)	S 12	*	67	-2
06:00	Mostly Cloudy	4 (4.3)	SSE 20	*	59	-3
05:00	Mostly Cloudy	3 (3.4)	S 17	*	67	-2
04:00	Mostly Cloudy	2 (2.4)	S 17	*	65	-4
03:00	Mostly Cloudy	2 (1.9)	SE 12	*	68	-3
02:00	Cloudy	1 (1.4)	S 12	*	67	-4
01:00	Mostly Cloudy	0 (0.3)	SSE 13	*	73	-4
00:00	Mostly Cloudy	-1 (-0.9)	S 8	-4	79	-4

Figure 2: Observed conditions at Edmonton International Airport (CYEG), Wednesday 15th February 2017.

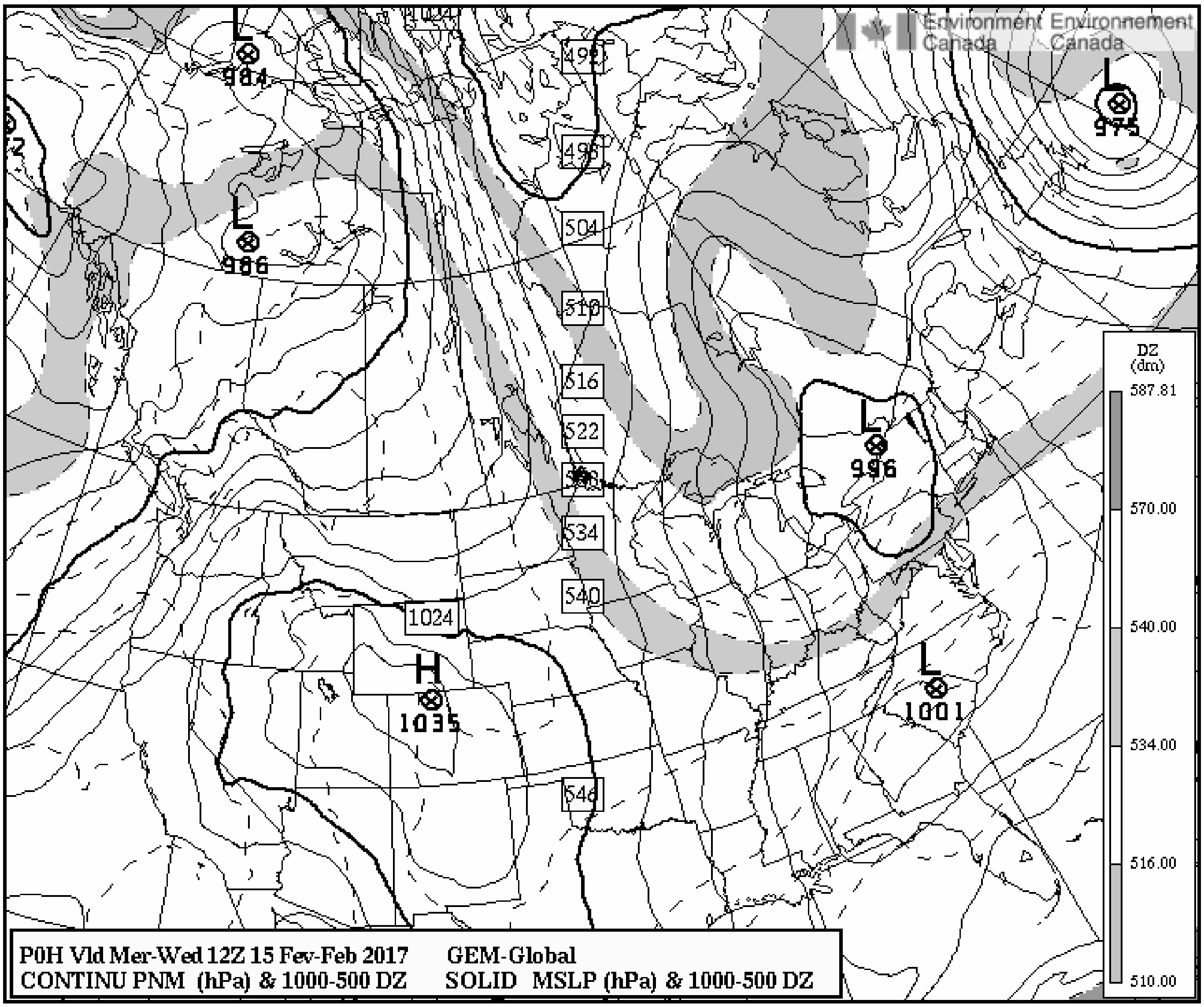

Figure 3: MSLP and thickness, GEM GDPS 0h prog valid 12Z Wednesday 15th February 2017.

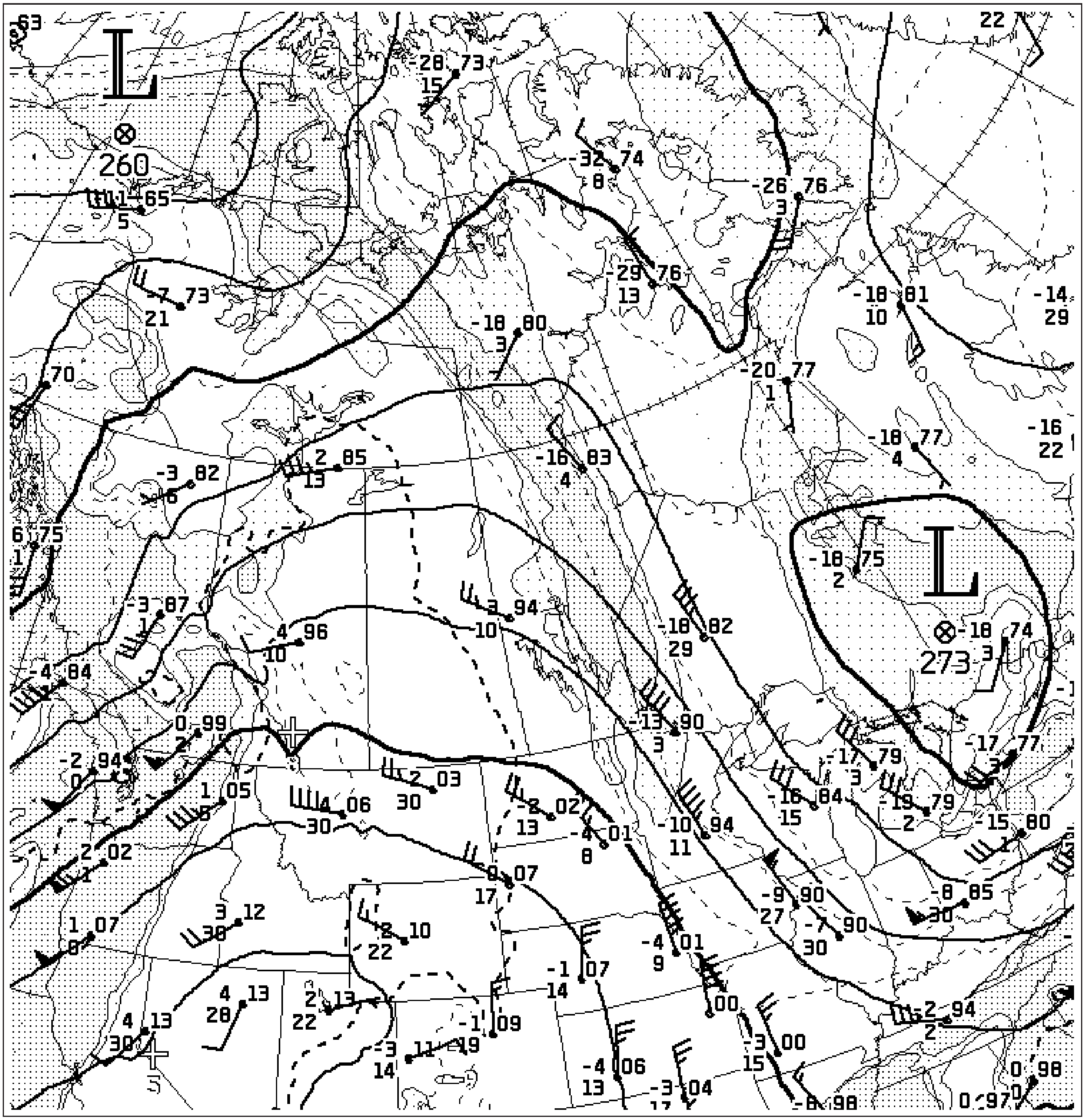

Figure 4: CMC 700 hPa analysis, 12Z Wednesday 15th February 2017.

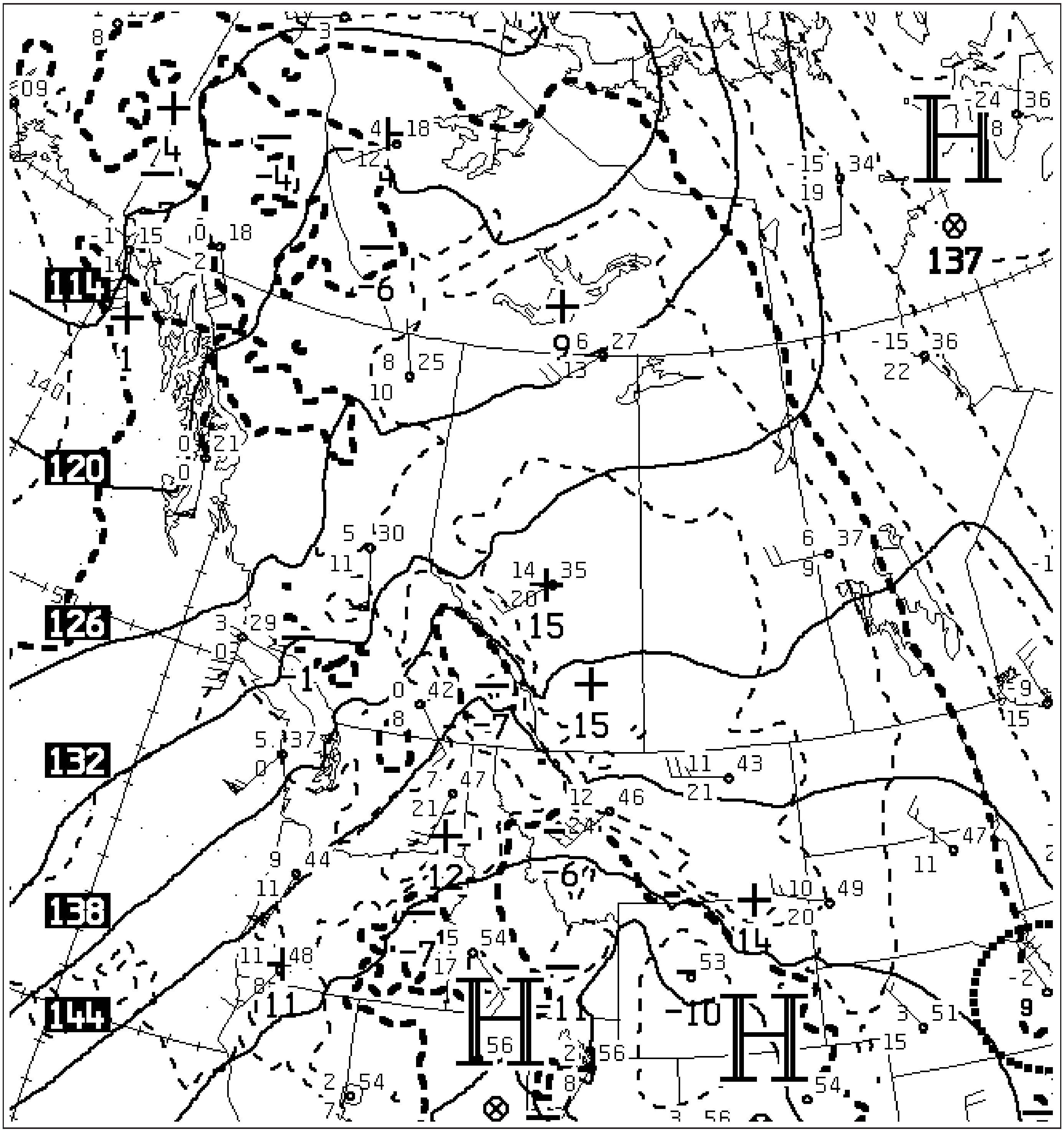

Figure 5: CMC 850 hPa analysis, 12Z Wednesday 15th February 2017.

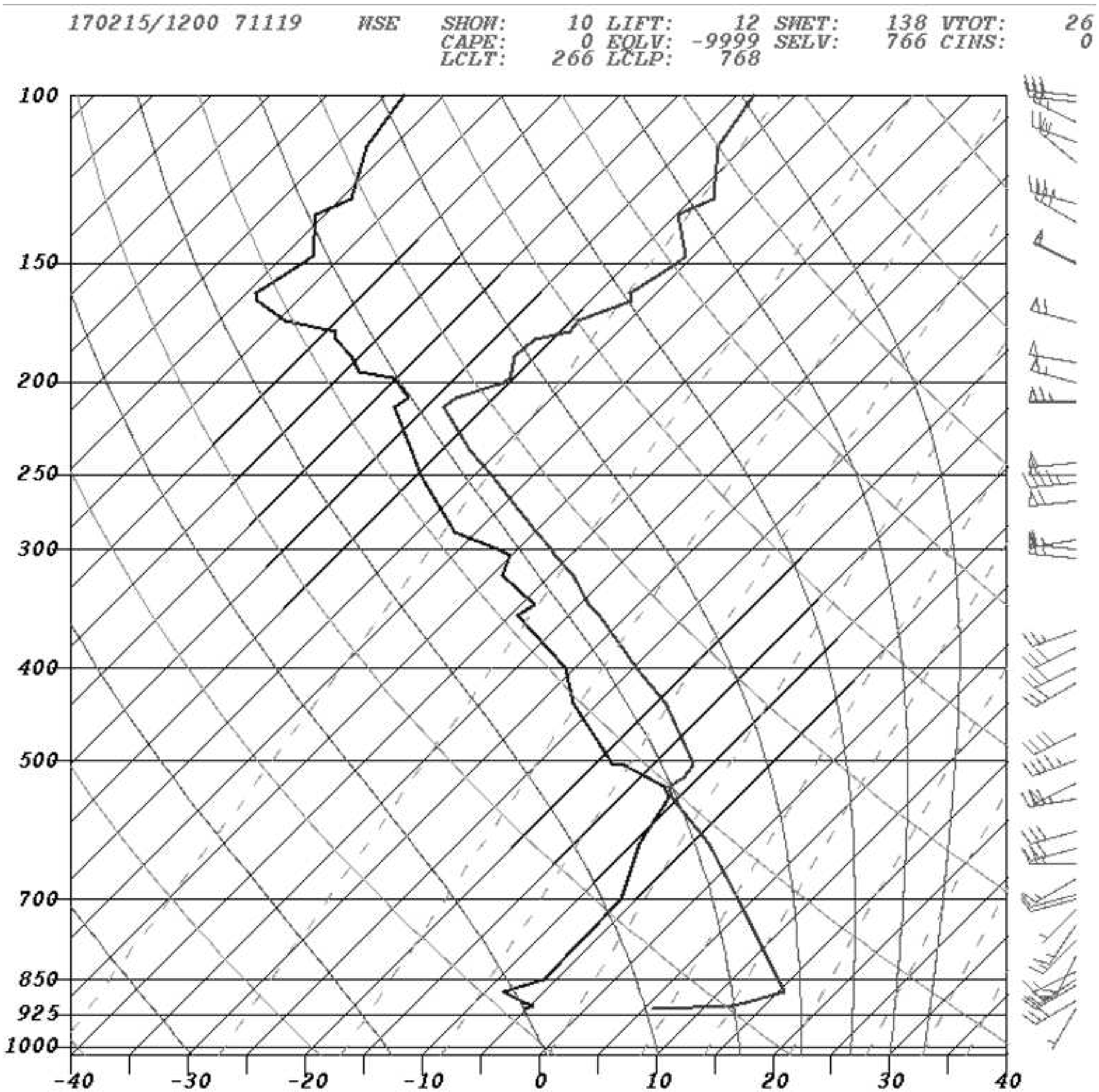

Figure 6: Edmonton (Stony Plain, wse) sounding, 12Z Wednesday 15th February 2017.

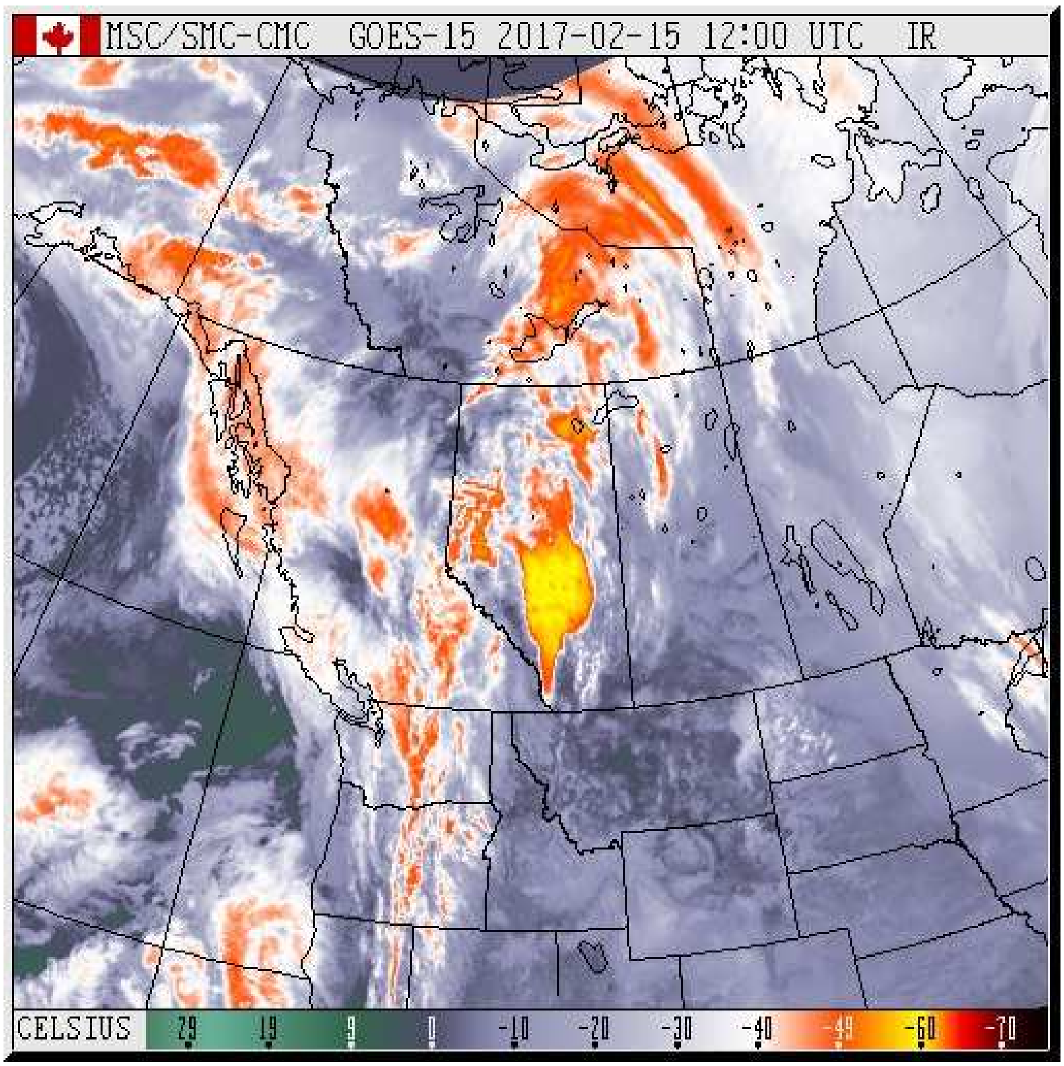

Figure 7: GOES West infra-red image, 12Z Wednesday 15th February 2017.

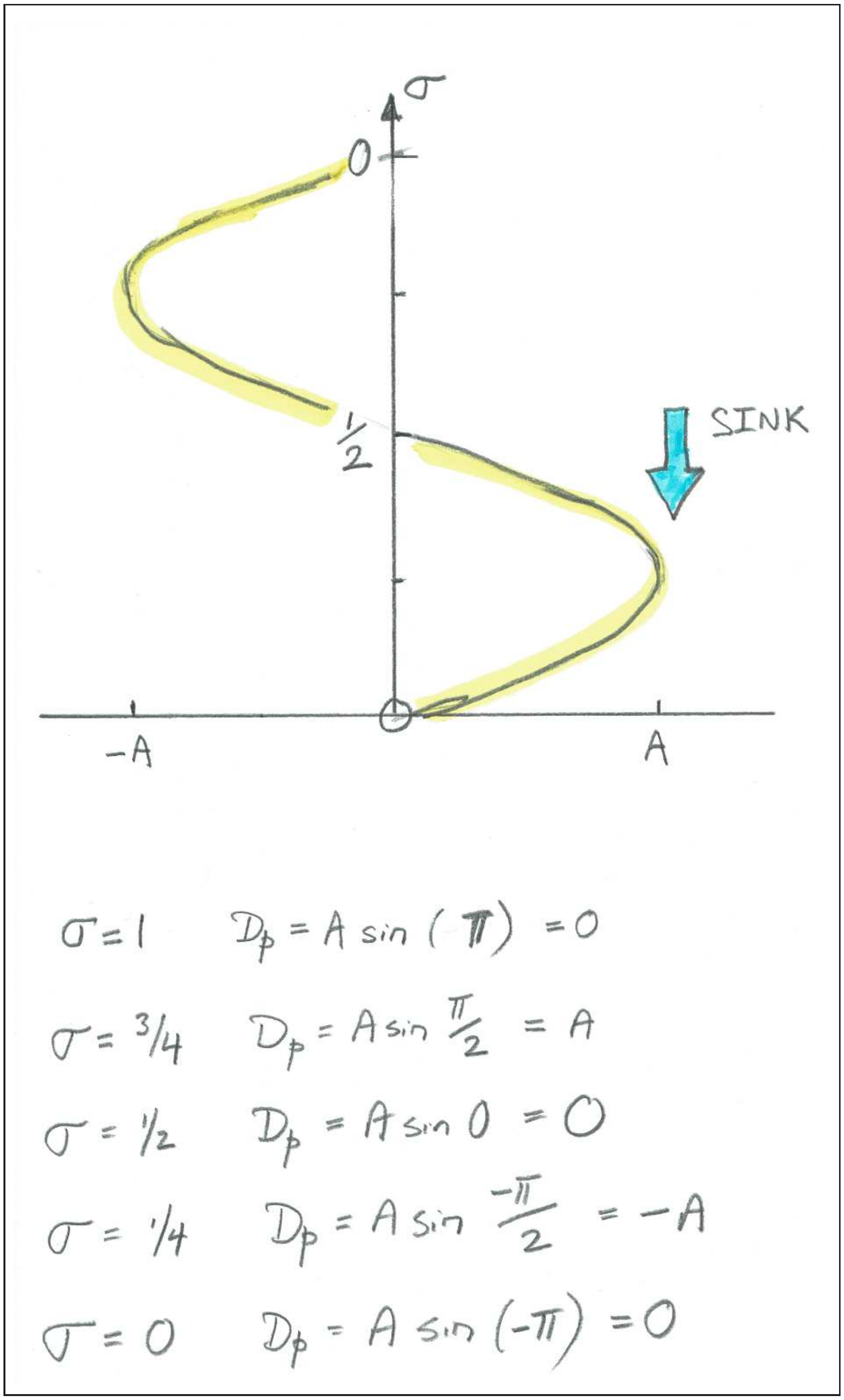

Figure 8: Added after the exam: the stated (idealistic) profile of horizontal divergence D_p versus $\sigma = p/p_{\text{sfc}}$. The $\sigma = 1/2$ level is a level of non-divergence (LND), with positive divergence below and negative above. Thus this corresponds to the simplest paradigm of a surface anticyclone, with convergence above the LND and divergence below.

	Temp °C	Dew Point Temp °C	Rel Hum %	Wind Dir 10's deg	Wind Spd km/h	Visibility km	Stn Press kPa
Hourly Data Report for February 15, 2017							
TIME							
00:00 ‡	2.5	-3.8	63	15	4	24.1	88.20
01:00 ‡	-0.5	-3.9	78	31	3	24.1	88.18
02:00 ‡	-0.5	-4.6	74	8	3	24.1	88.11
03:00 ‡	-1.1	-4.6	77	36	3	24.1	88.07
04:00 ‡	-1.6	-4.3	82	2	3	24.1	87.96
05:00 ‡	0.0	-2.9	81	36	2	24.1	87.90
06:00 ‡	0.8	-3.0	76	20	3	24.1	87.82
07:00 ‡	1.8	-3.3	69	19	6	24.1	87.76
08:00 ‡	3.6	-3.5	60	18	7	64.4	87.68
09:00 ‡	3.5	-2.9	63	21	7	64.4	87.65
10:00 ‡	4.5	-3.1	58	22	5	64.4	87.61
11:00 ‡	7.0	-1.9	53	20	5	64.4	87.56
12:00 ‡	9.6	-0.6	49	35	6	64.4	87.52
13:00 ‡	13.4	-0.9	37	19	5	64.4	87.49
14:00 ‡	16.1	-0.5	32	29	9	64.4	87.54
15:00 ‡	14.5	-0.3	36	30	30	64.4	87.57
16:00 ‡	14.3	-0.5	36	27	18	64.4	87.57
17:00 ‡	11.7	-0.1	44	28	23	64.4	87.58
18:00 ‡	11.1	-0.3	45	26	19	64.4	87.56
19:00 ‡	9.5	-0.1	51	23	10	24.1	87.55
20:00 ‡	6.9	0.1	62	11	14	24.1	87.48
21:00 ‡	3.2	-0.6	76	8	16	24.1	87.43
22:00 ‡	5.3	0.5	71	23	3	24.1	87.34
23:00 ‡	2.7	-0.6	79	35	9	24.1	87.31

Figure 9: Added after the exam: Observations at Calgary Airport (CYYC) on Wednesday 15th February 2017. (Environment Canada).

71934 YSM Fort Smith Observations at 12Z 15 Jan 2017

PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K	THTE K	THTV K
1000.0	-32									
971.0	204	-7.9	-9.3	90	1.96	140	2	267.5	272.9	267.8
969.0	220	-2.9	-3.3	97	3.11	165	6	272.7	281.3	273.2
958.8	305	0.4	-3.4	76	3.12	295	24	276.8	285.6	277.4
955.0	337	1.6	-3.4	69	3.13	295	24	278.4	287.3	278.9
949.0	388	1.8	-4.2	64	2.96	295	23	279.1	287.6	279.6
925.0	595	1.0	-5.0	64	2.86	295	22	280.3	288.6	280.8
923.3	610	1.0	-5.1	64	2.85	295	21	280.4	288.7	280.9
889.0	914	0.2	-6.3	62	2.70	285	15	282.7	290.6	283.2
855.8	1219	-0.6	-7.5	60	2.56	265	18	285.0	292.6	285.4
850.0	1274	-0.7	-7.7	59	2.53	270	18	285.4	292.9	285.8
845.0	1321	-0.7	-7.7	59	2.55	272	19	285.9	293.4	286.3
823.4	1524	-2.5	-8.4	64	2.47	280	25	286.1	293.4	286.5
791.9	1829	-5.3	-9.5	73	2.37	275	28	286.3	293.4	286.7
761.6	2134	-8.1	-10.5	83	2.26	275	29	286.5	293.3	286.9
732.6	2438	-10.9	-11.6	94	2.16	280	35	286.7	293.2	287.1
724.0	2531	-11.7	-11.9	98	2.13	285	34	286.7	293.1	287.1
704.2	2743	-11.9	-15.5	75	1.64	295	33	288.8	293.8	289.1
704.0	2745	-11.9	-15.5	75	1.63	295	33	288.8	293.8	289.1
700.0	2789	-12.3	-15.9	75	1.59	300	34	288.8	293.7	289.1
649.8	3353	-16.1	-17.0	93	1.56	315	29	290.8	295.6	291.0
642.0	3444	-16.7	-17.2	96	1.55	305	27	291.1	295.9	291.3
638.0	3491	-16.5	-17.9	89	1.47	299	25	291.8	296.4	292.1
632.0	3563	-15.9	-23.9	50	0.88	291	24	293.3	296.2	293.4
624.0	3658	-16.5	-25.9	44	0.75	280	21	293.7	296.2	293.9
599.1	3962	-18.3	-32.2	28	0.43	270	28	295.1	296.5	295.1
575.1	4267	-20.1	-38.5	18	0.24	285	29	296.4	297.3	296.5
567.0	4372	-20.7	-40.7	15	0.19	288	30	296.9	297.6	296.9
542.0	4704	-22.7	-39.7	20	0.23	296	31	298.4	299.2	298.4
529.4	4877	-24.1	-40.2	21	0.22	300	32	298.8	299.5	298.8
527.0	4909	-24.3	-40.3	21	0.22	301	32	298.8	299.6	298.9
517.0	5049	-25.5	-34.5	43	0.40	304	31	299.0	300.4	299.1
507.0	5190	-26.9	-37.9	35	0.29	308	30	299.0	300.0	299.0
501.0	5276	-27.5	-34.5	51	0.41	310	30	299.3	300.7	299.4
500.0	5290	-27.7	-34.7	51	0.40	310	30	299.2	300.6	299.3
487.0	5478	-29.3	-34.2	62	0.44	311	28	299.5	301.0	299.6
446.0	6096	-34.4	-37.3	74	0.35	315	23	300.7	301.9	300.8
439.0	6208	-35.3	-37.9	77	0.33	311	22	300.9	302.1	301.0
434.0	6287	-35.7	-41.7	54	0.23	309	22	301.4	302.2	301.4
426.9	6401	-36.2	-45.0	40	0.16	305	21	302.2	302.8	302.2
412.0	6647	-37.3	-52.3	19	0.07	329	20	303.9	304.1	303.9
409.0	6697	-37.1	-52.1	20	0.08	334	20	304.8	305.0	304.8
408.5	6706	-37.2	-52.0	20	0.08	335	20	304.8	305.1	304.8
400.0	6850	-38.3	-51.3	24	0.09	335	19	305.1	305.5	305.1
382.0	7166	-40.7	-50.7	33	0.10	318	19	306.0	306.4	306.0
373.7	7315	-41.7	-53.0	28	0.07	310	19	306.6	306.9	306.6

Figure 10: Added after the exam: Fort Smith (YSM) sounding at 12Z on Wednesday 15th February 2017.

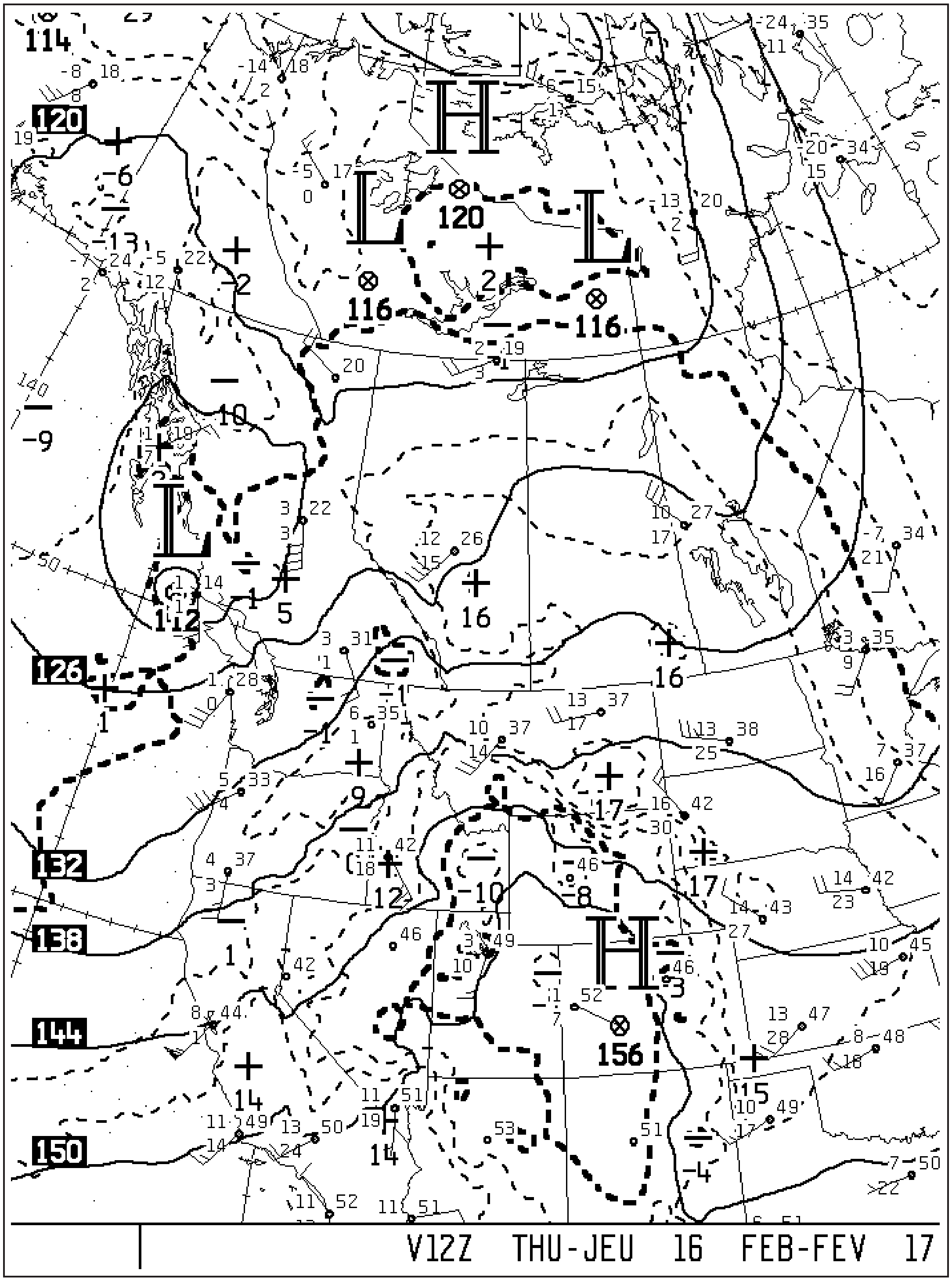

Figure 11: Added after the exam: CMC 850 hPa analysis (cropped) for 12Z Thursday 16 February 2017. Note the Alberta lee trough (persisting from the previous day).

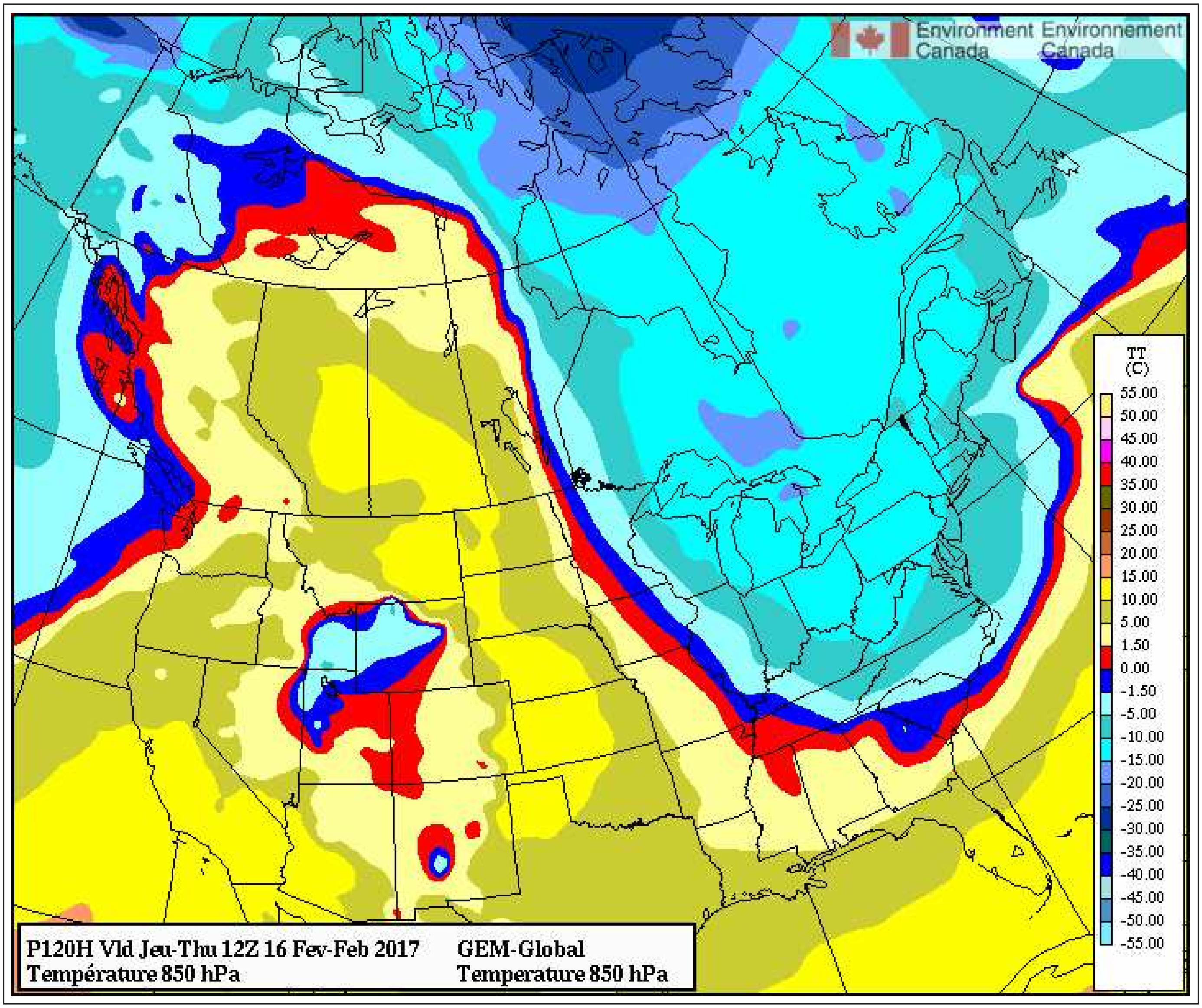

Figure 12: Added after the exam: GEM GDPS 120h prog valid 12Z Thursday 16 February 2017.

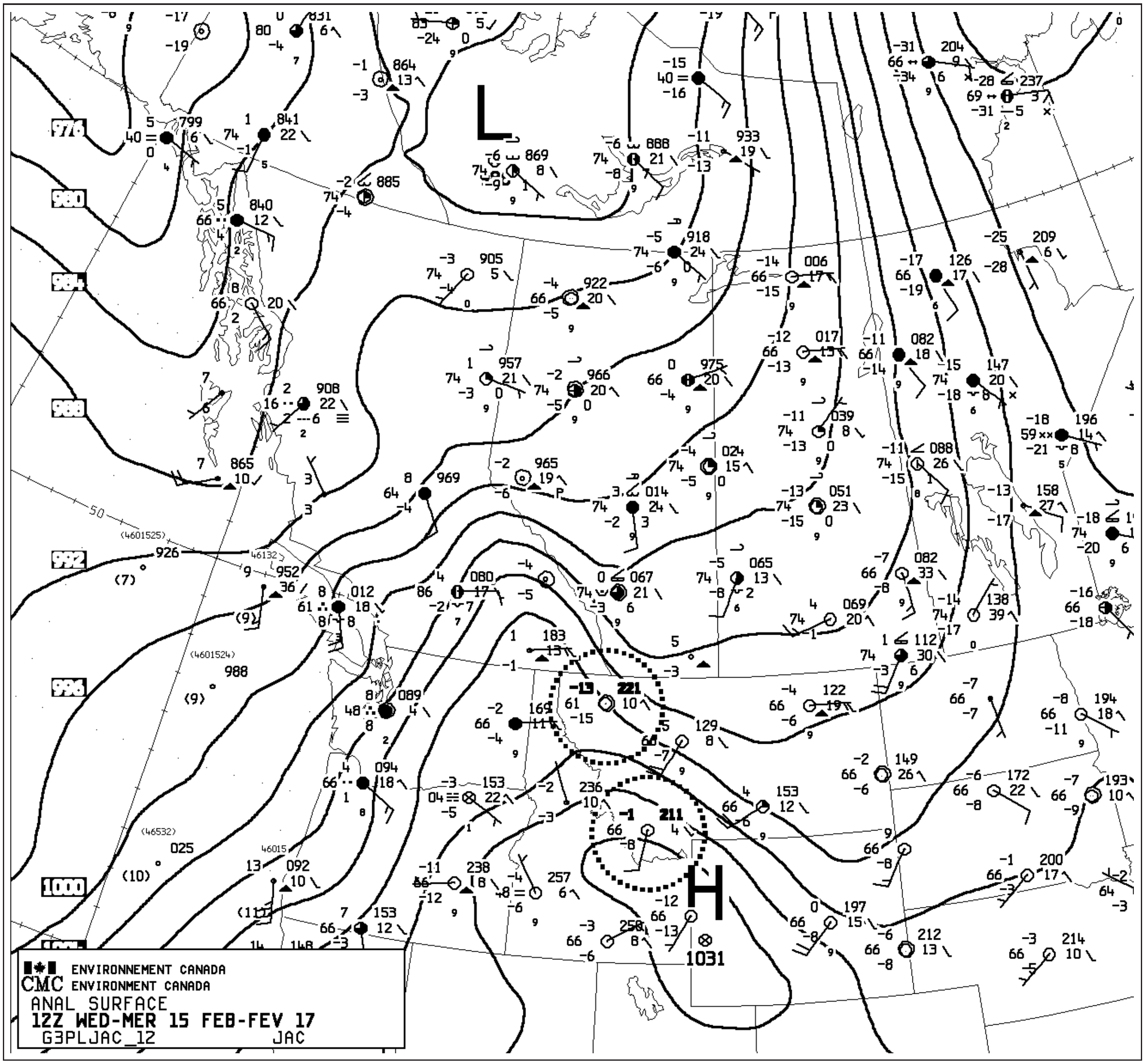

Figure 13: Added after the exam: CMC surface analysis for 12Z Wednesday 15 February 2017, showing the surface lee trough. Note the strong MSLP pressure gradient across the Rockies in SE B.C/SW Alberta.