EAS372 Open Book Final Exam 24 April, 2017

Professor: J.D. Wilson Time available: 2.5 hours Value: 30%

A. Multi-choice (20 x 1% → 20 %)

1. Suppose (q, ω) are respectively the specific humidity $[\text{kg kg}^{-1}]$ and the vertical velocity $[\text{Pa s}^{-1}]$. Which formula for the resolved vertical flux E of water vapour $[\text{kg m}^{-2}\,\text{s}^{-1}]$ is correct?

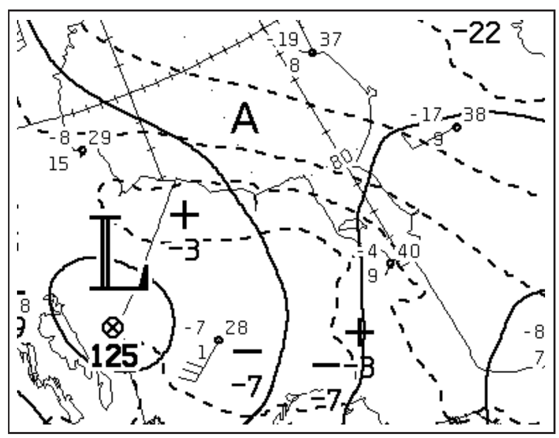
   (a) $E = -\omega\, q$
   (b) $E = \omega\, q$
   (c) $E = \omega\, q/g$
   (d) $E = -\omega\, q/g$ ✓✓

2. Let (u, v) be the Cartesian components of the horizontal wind, let ρ_v be the absolute humidity, and let $\nabla = \hat{\imath}\,\partial/\partial x + \hat{\jmath}\,\partial/\partial y$ 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. Referring to this 850 hPa analysis (valid 12 UTC 26 Jan. 2012), how will the temperature gradient in the region of **A** evolve over the next few hours?

   (a) reverse
   (b) strengthen ✓✓
   (c) decay
   (d) remain unchanged



4. If D/Dt represents the Lagrangian derivative, $\mathbf{u}$ is the 3D velocity vector and ϕ is a conserved variable, then which statement is **true**?

   (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) $\partial\phi/\partial t = \partial\phi/\partial x = \partial\phi/\partial y = \partial\phi/\partial z = 0$
   (e) $\mathbf{u}\cdot\nabla\phi = 0$

5. The turbulent kinetic energy (TKE) residing in unresolved scales of motion is defined as $k = \left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)/2$, and it is common to write the eddy diffusivity for unresolved transport as $K = \lambda\sqrt{k}$, where λ is a length scale (to be considered *known*) for the unresolved motion. Accordingly, many NWP models employ a simplified conservation equation for k, e.g.

$$\frac{\partial k}{\partial t} = \underbrace{K\left[\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2\right]}_{\text{I}} - \underbrace{\frac{g}{\theta_0} K \frac{\partial \overline{\theta}}{\partial z}}_{\text{II}} - \underbrace{\frac{k^{3/2}}{\lambda}}_{\text{III}} + \underbrace{\frac{\partial}{\partial z}\left(K \frac{\partial k}{\partial z}\right)}_{\text{IV}},$$

where (U, V) are the resolved horizontal velocities and $\overline{\theta}$ is resolved potential temperature (whose mean value for the planet is θ_0). Which interpretive statement is **false**?

(a) $\overline{w'^2}$ is the variance of the unresolved vertical velocity, $\overline{\theta}$ the resolved potential temperature
(b) term I reflects the tendency of strong winds to result in strong mixing
(c) term II shows that unstable stratification tends to reduce k ✗✗
(d) a solution for k implies a value for K, enabling flux computations like $\overline{w'\theta'} = -K\,\partial\overline{\theta}/\partial z$
(e) all terms on the r.h.s. vanish if there is no unresolved motion ($k = 0$)

6. Which formula expresses a well-defined (i.e. legitimate) action of the Laplacian operator ∇^2 on an argument? (ϕ is a scalar, and $\mathbf{A}$ a vector.)

(a) $\nabla^2\phi = \nabla\cdot(\nabla\phi)$ ✓✓
(b) $\nabla^2\mathbf{A} = \nabla\cdot(\nabla\mathbf{A})$
(c) $\nabla^2\phi = 2\nabla\phi$
(d) $\nabla^2\phi = \nabla\cdot(\nabla\cdot\phi)$
(e) $\nabla^2\mathbf{A} = \nabla\mathbf{A}\times\nabla\mathbf{A}$

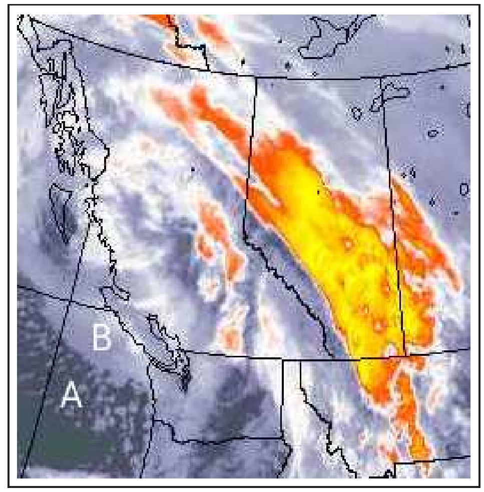
7. The "heat equation" in one space dimension reads

$$\frac{\partial T}{\partial t} = \kappa\,\frac{\partial^2 T}{\partial x^2}$$

where κ, a constant, is a thermal diffusivity. Which statement is false?

(a) κ has the unit $[\mathrm{m^2\,s^{-1}}]$
(b) the right hand side could equivalently be written $= \kappa\,\nabla T$, $\nabla \equiv \partial/\partial x$ being the gradient operator appropriate to a one-dimensional Cartesian (x-) coordinate ✗✗
(c) the right hand side could also be written $= -\partial F/\partial x$ where $F = -\kappa\,\partial T/\partial x$ is the (kinematic) heat flux along the x-axis
(d) if κ is a molecular diffusivity, the heat transport process is conduction (as per Fourier's equation)
(e) if κ is an *eddy* diffusivity, the transport process is (in truth) unresolved convection for which the heat equation is serving as a *model* (i.e. "*parameterization*")

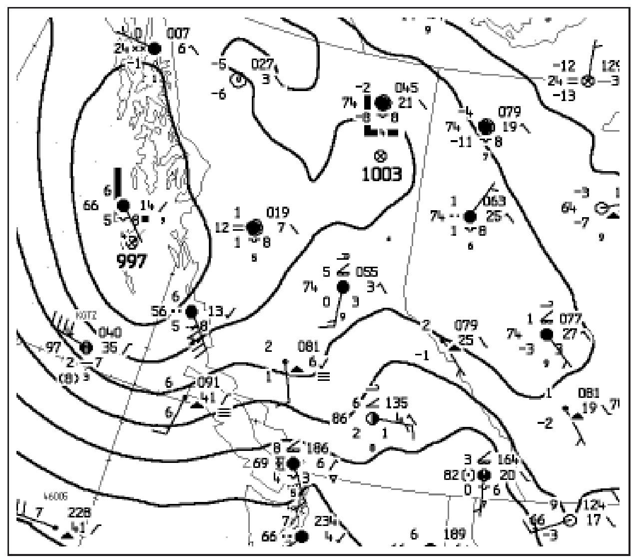
8. This GOES ir image was taken at 12Z, 11 March 2008. Given that the wind at 700 hPa over B.C. and W. Alberta was a south-westerly, what name might one appropriately give to the shield of high cloud over Alberta?



   (a) Chinook arch ✓✓
   (b) trowal
   (c) lee trough
   (d) stratocumulus
   (e) nimbostratus

9. Which option is the best guess for the feature at location B?
   (a) cumulus
   (b) cumulonimbus
   (c) stratocumulus ✓✓
   (d) cirrostratus
   (e) snowpack

10. This cropped CMC surface analysis coincides with the GOES ir image above. What is the surface feature over Alberta?



   (a) arctic ridge
   (b) warm front
   (c) cold front
   (d) trowal
   (e) lee trough ✓✓

11. Which statement in regard to dry adiabats on a thermodynamic chart is **untrue** or **illogical**?
   (a) every point along a dry adiabat has the same potential temperature
   (b) in an unsaturated atmosphere, dry adiabats are parallel with moist adiabats ✗✗
   (c) if an unsaturated parcel's ascent is such that the $T(p)$ curve it traces on the chart is parallel to a dry adiabat, the environment has constant potential temperature
   (d) if a parcel's ascent is such that the $T(p)$ curve it traces on the chart is parallel to a dry adiabat, the parcel is cooling at a rate of g/c_p degrees Celcius per metre of ascent
   (e) if a parcel's ascent is such that the $T(p)$ curve it traces on the chart is parallel to a dry adiabat, the atmosphere may be said to be neutrally stratified (and, well mixed) with respect to unsaturated adiabatic motion

12. In an NWP model whose vertical coordinate is "η", and with the "dot" representing the Lagrangian derivative d/dt, the term representing vertical advection of resolved zonal momentum has which form?
   (a) $W\, \partial U/\partial z$
   (b) $\dot{\eta}\, \partial U/\partial z$
   (c) $\dot{\eta}\, \partial U/\partial \eta$ ✓✓
   (d) $\eta\, U$
   (e) $\dot{\eta}\, U$

13. Which statement is **true** regarding the vertical advection of resolved zonal momentum, under the approximations inherent to the quasi-geostrophic paradigm?
   (a) neglected ✓✓
   (b) computed using the ageostrophic wind
   (c) computed using the geostrophic wind
   (d) computed assuming the Coriolis parameter $f = f_0 + \beta\, y$ (f_0, value at reference latitude; β, a constant; y, the north-south coord.)
   (e) computed using the vertical component of the **Q**-vector

14. Most NWP models compute the part of the temperature tendency that is due to unresolved convective heat transport and radiative transport according to

$$\rho\, c_p \left(\frac{\partial \overline{\theta}}{\partial t}\right)_{\text{phys}} = -\,\rho\, c_p\, \frac{\partial \overline{w'\theta'}}{\partial z} - \frac{\partial K^*}{\partial z} - \frac{\partial L^*}{\partial z}$$

where $\overline{\theta}$ is the resolved potential temperature and K^*, L^* [$\mathrm{W\,m^{-2}}$] are respectively the net vertical shortwave and longwave radiative energy flux densities. Which simplification(s) would seem most acceptable for windy, clear-sky, summer conditions and very dry air?
   (a) steady state ($\partial\overline{\theta}/\partial t = 0$)
   (b) steady state ($\partial\overline{\theta}/\partial t = 0$) and $\partial\overline{w'\theta'}/\partial z = 0$
   (c) $\partial\overline{w'\theta'}/\partial z = 0$
   (d) $\partial\overline{w'\theta'}/\partial z = 0$ and $\partial L^*/\partial z = 0$
   (e) $\partial K^*/\partial z = 0$ and $\partial L^*/\partial z = 0$ ✓✓

15. Referring to Figure (1) below, what is your best guess as to the near-surface wind direction on the west coast of the South Island at a point defined by the intersection of the central longitude line (170°E) and the 1020 hPa isobar?
   (a) S
   (b) SE
   (c) E
   (d) NE
   (e) W or NW ✓✓

16. Which statement in regard to contemporary operational Canadian (GEM GDPS) and American (GFS) global NWP models is **true**?
    (a) both hydrostatic
    (b) both formulated in U, V and (generalized) vertical velocity ("primitive equations")
    (c) both use terrain-following coordinate ✓✓
    (d) both use a time step exceeding 30 minutes
    (e) both use spectral representation of horizontal structure

17. Which option is a correct re-expression of the infinitesimal quantity d $\ln(p)$?
    (a) dp
    (b) p dp
    (c) p d(ln$p$)
    (d) dp/p ✓✓
    (e) $1/p$

18. Let Z be isobaric height, z height ASL and p pressure. If "s" and "n" are the "alongstream" and "normal" coordinates of the "natural coordinate system," then which option is a correct statement in relation to the geostrophic wind speed V?
    (a) $V \propto \partial Z/\partial n$ ✓✓
    (b) $V \propto \partial Z/\partial s$
    (c) $V \propto \partial Z/\partial p$
    (d) $V \propto \partial Z/\partial z$

19. Referring to Figure (3) below, one might see evidence that cold air was "ponding" at the valley floor. Which statement is false or misleading?
    (a) the ground-based downslope current presumably was driven by the alongslope component of the reduced gravity force, i.e. $(\Delta\overline{\theta}/\theta_0)\, g\, \sin\alpha$.
    (b) the return current aloft was probably driven by a reduced gravity force *of opposite sign*
    (c) the downslope current appears to "lift off" on approaching the valley floor, hypothetically running over an accumulating (deepening) pond of cold air
    (d) the slope wind's speed is largest at the lowest model gridpoint, and near the base of the hill
    (e) it is a normal feature of surface layer meteorology that wind speed be largest near ground, and decrease with increasing height AGL ✗✗

20. Between about 00Z and 12Z on Sunday 23 April 2017 not only did the Edmonton Oilers chance to defeat the San Hose Sharks, but more to the point, Edmonton received a blanket of damp, heavy snow. To answer the following question, please consult the 0h RDPS prog. valid at 06Z Sunday 23 April 2017. Which statement, bearing on this precipitation event, is **false**?

    (a) at 700 hPa the strongest of the updrafts in the Edmonton region exceeded $-1\,\mathrm{Pa\,s^{-1}}$

    (b) at 700 hPa over (or near) the Edmonton region the relative humidity exceeded 90%

    (c) over Edmonton the atmosphere contained 10 – 15 mm of precipitable water

    (d) surface wind direction in the Edmonton region was NW (meaning downslope) ✗✗

B. Weather chart interpretation. (4% + 6% → 10%)

B1 (4%). Figure (1) is a New Zealand Met. Service surface analysis, and Figure (2) is an NCEP reanalysis (2.5 degree spatial resolution) valid at the same time (extremely high winds were occurring over the South Island). Bearing in mind that the west coast of the South Island is defined by a continuous high mountain barrier (oriented roughly SW-NE), explain why the pattern of the isobars (e.g. the highlighted 1020 hPa contour) differs so markedly between the analysis and the reanalysis. Speculate as to what might be the outcome of "downscaling" the NCEP reanalysis onto higher-resolution nested grids. If that were done, what factor(s) might be decisive in terms of producing better fidelity with respect to the actual meteorology of the time (which is presumably well represented by the NZMS analysis).

Schematic response

- the 2.5° spatial resolution of the reanalysis corresponds to a very coarse latitudinal grid length, $\Delta y \approx 280$ km, and a comparably coarse (large) longitudinal gridlength Δx
- the discrepancy between the analysis and the reanalysis has to do with the impact of the mountainous topography: in its reality, versus, as modelled by the low resolution reanalysis
- the low spatial resolution of the reanalysis means that it does not properly represent the topography
- "downscaling" the reanalysis onto higher resolution nested grids would improve the fidelity of the modelled topography
- better representation of the topography should be a decisive improvement

B2 (6%). Figures (4, 5, 6) are CMC analyses depicting weather conditions over Canada at 12Z on 11 March 2017. Using either point form or essay form according to your preference, contrast weather conditions on the prairies versus those on the east coast, including Newfoundland.

Schematic response

Table 1: Contrasting weather conditions.

Level	**Prairies**	**East coast**
surface	arctic high (> 1044 hPa) calm & very cold over Central prairies	deep storm (966 hPa) near Newfoundland very windy, some stations reporting snowfall
850 hPa	relatively uniform temperature	strongly variable temperature (cold core onshore, milder offshore)
	light wind (distant contour spacing)	windy (tight contours), especially near storm centre
	negligible temperature advection	strong temperature advection in many areas
700 hPa	roughly NW flow, modest strength	closed upper low, generally tighter contour packing
	southern prairies in stream rounding ridge axis in Montana/Alberta.	eastern Canada (& N. Manitoba) in cold northerly stream induced by the Newfoundland storm (arctic outbreak)
	$T - T_d$ exceeds 5° over prairies (even drier to NE)	wrap-around shield of humid air ($T - T_d \leq 2°$) over Newfoundland

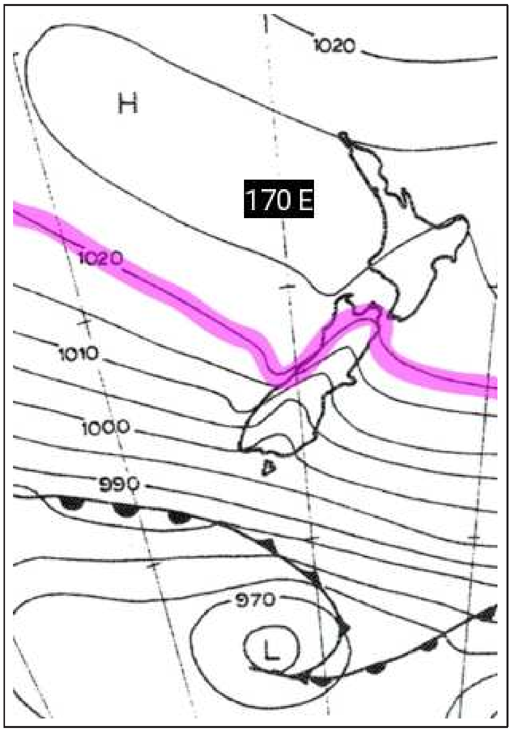


Figure 1: NZMS surface analysis, valid 31 July 1975 at 12 NZST . Isobars of MSLP (hPa). The west coast of the South Island is defined by a mountain chain oriented SW-NE.

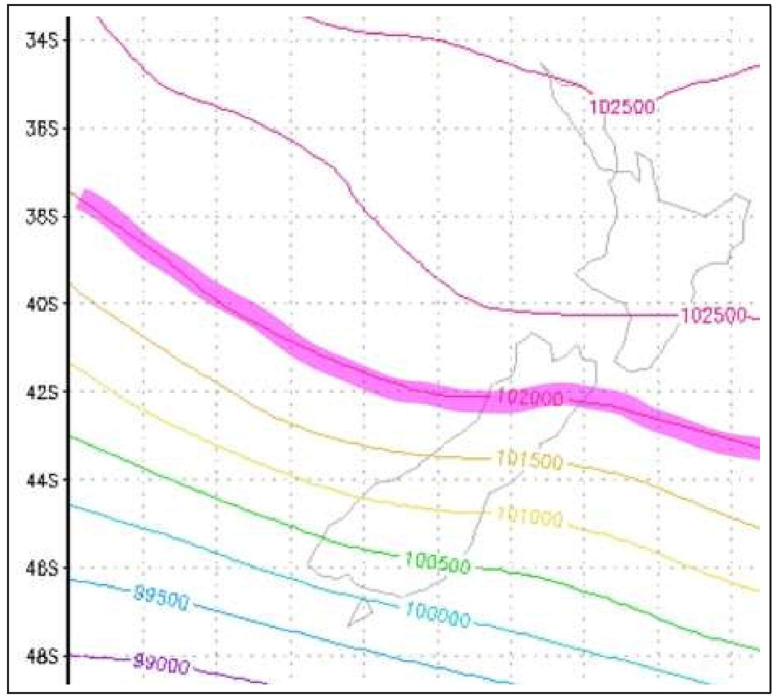


Figure 2: NCEP 1 reanalysis, 31 July 1975 at 12 NZST. Isobar label [Pa]. The spatial resolution of the meteorological fields of the reanalysis is 2.5°.

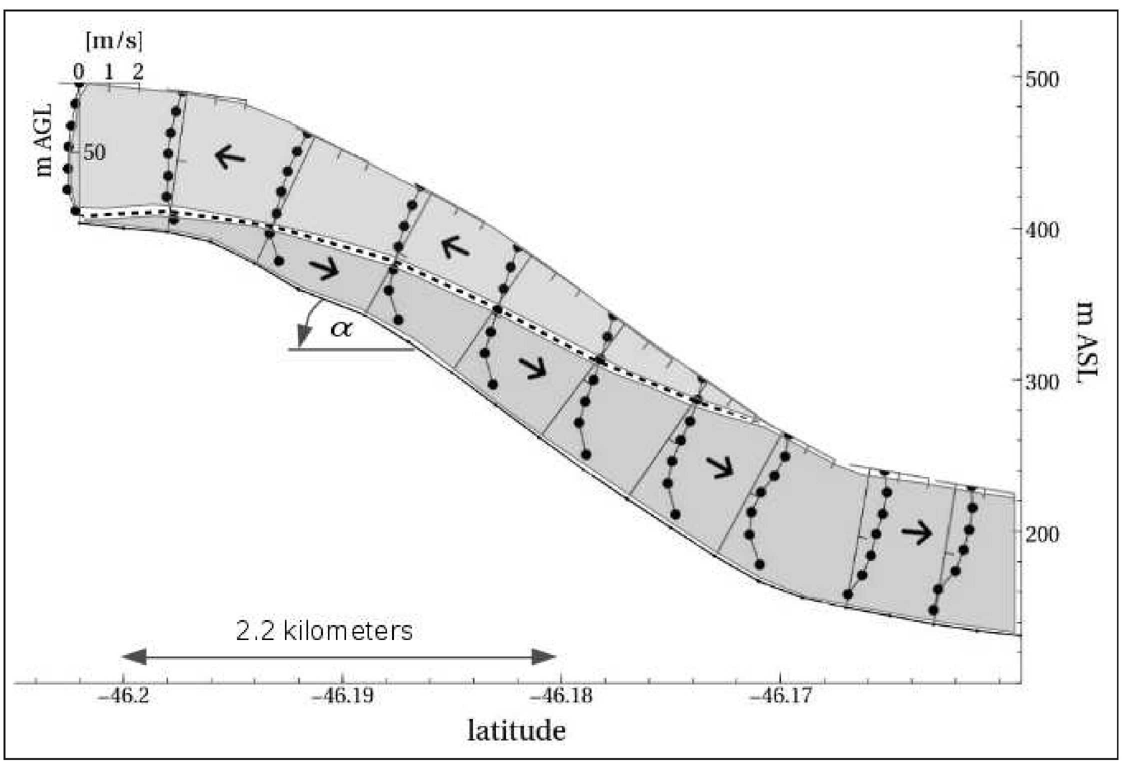


Figure 3: Slope winds diagnosed by downscaling an NCEP reanalysis, for dawn conditions during a period of calm, anticyclonic, winter-time weather in southern New Zealand (6 am, NZST 4 July 1996). Model: WRF. Spin-up time: 12 hrs.

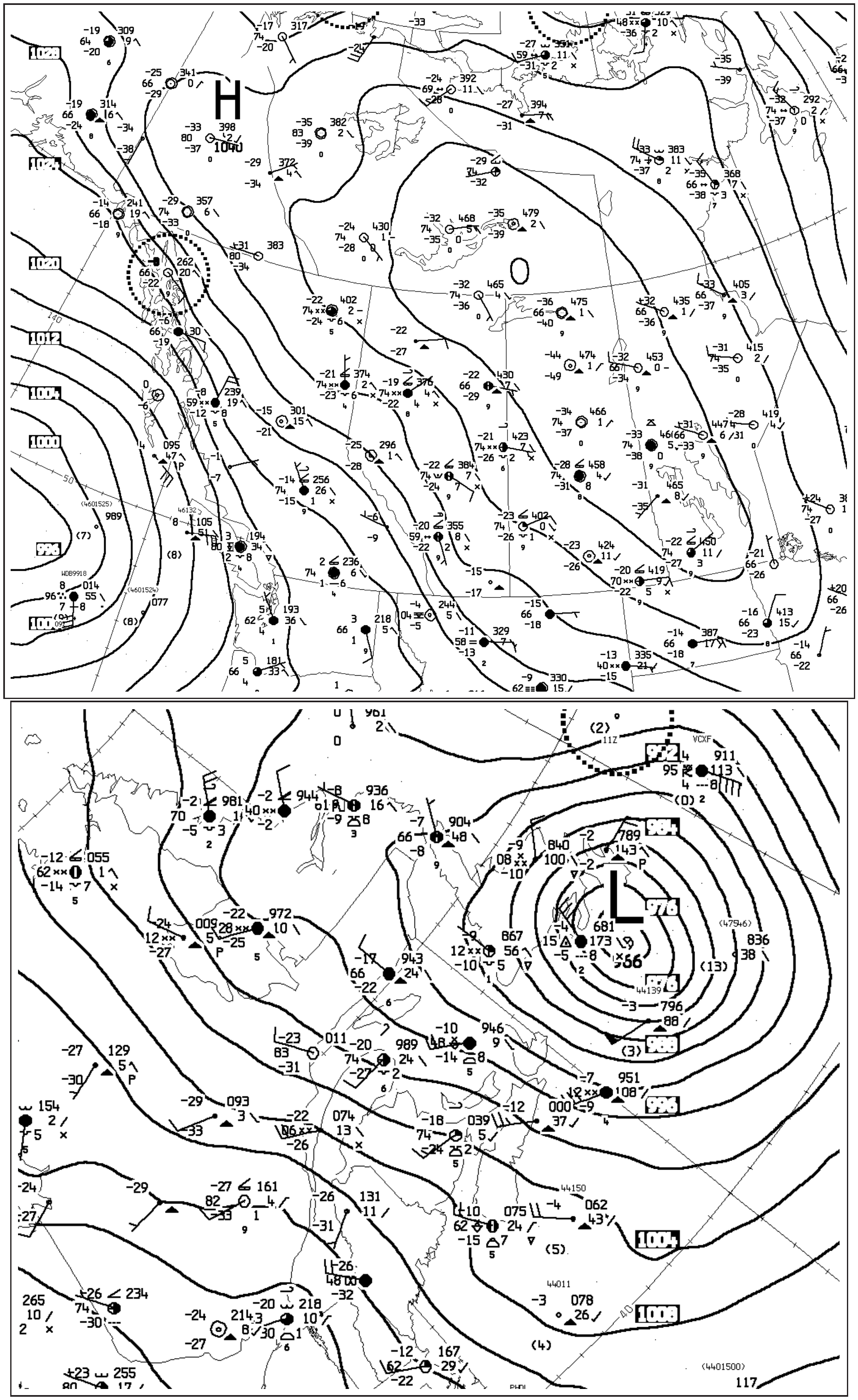


Figure 4: CMC surface analysis (cropped) for 12Z 11 March, 2017. Upper: western Canada. Lower: coastal eastern Canada

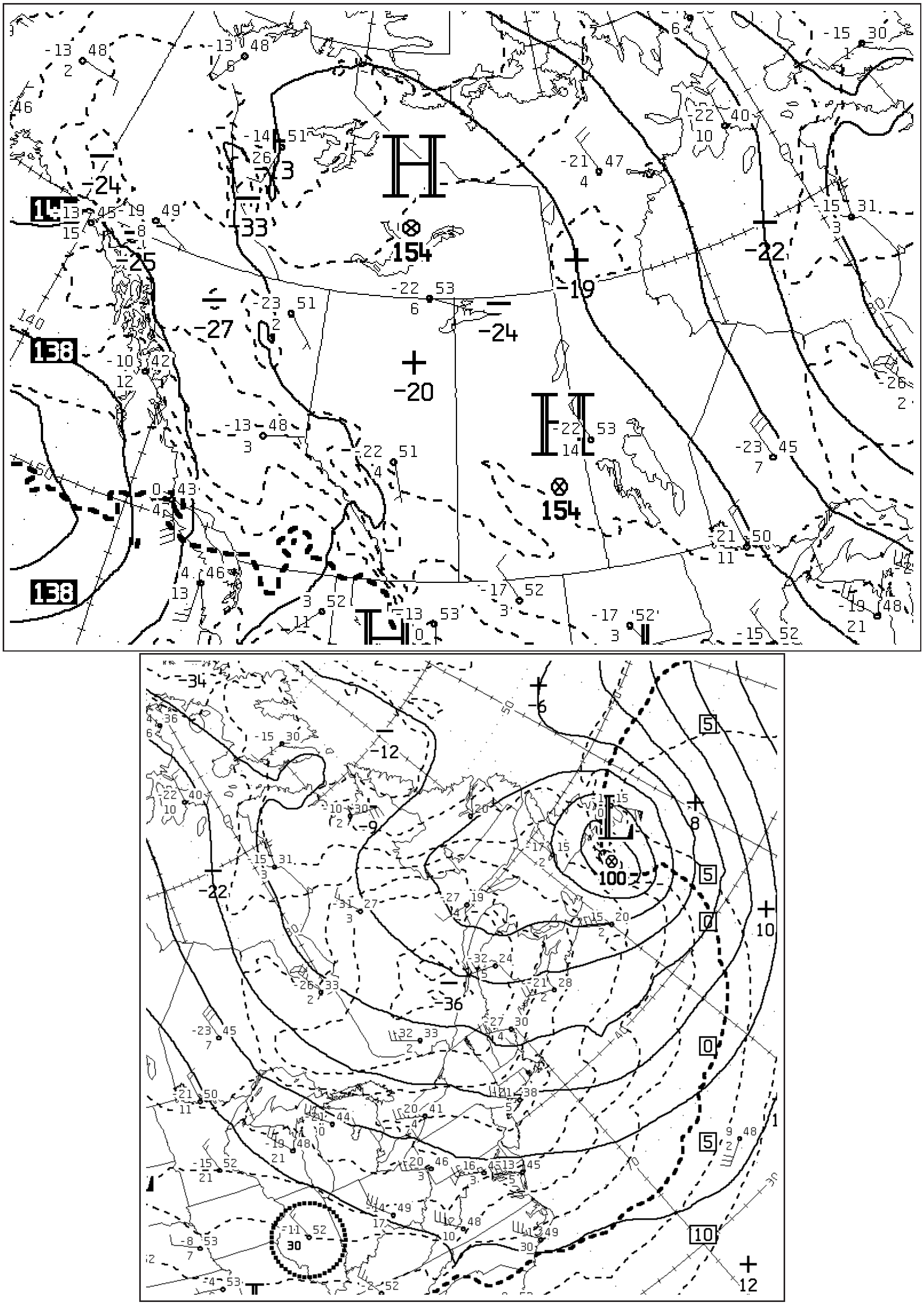


Figure 5: CMC 850 hPa analysis (cropped) for 12Z 11 March, 2017. Upper: western Canada. Lower: central & eastern Canada

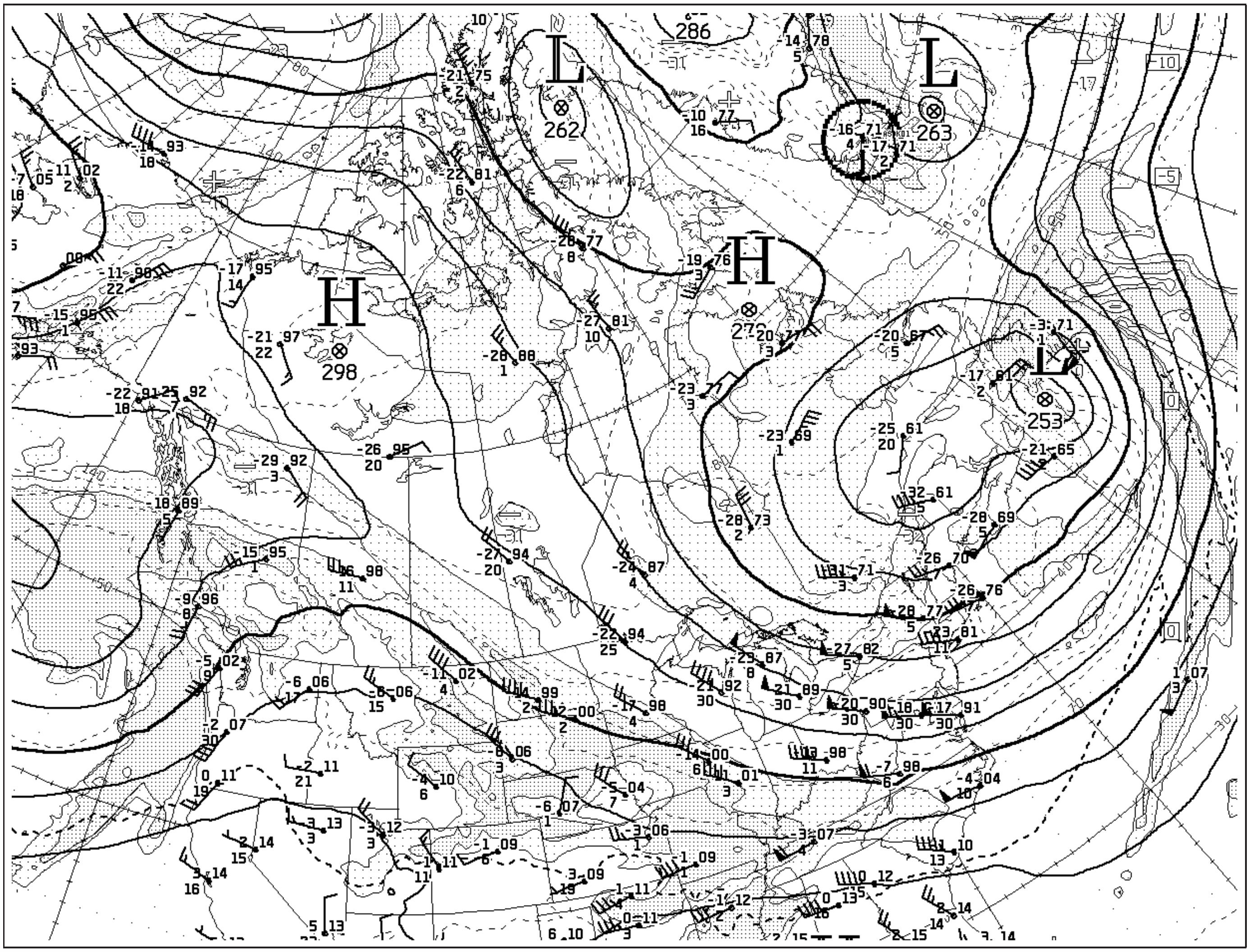


Figure 6: CMC 700 hPa analysis (cropped) for 12Z 11 March, 2017.