EAS270 "The Atmosphere" Final Exam 15 Dec., 2006

Professor: J.D. Wilson Time available: 120 mins Value: 40%

See back pages for equations and data you may need. You may keep the exam.

Multi-choice (60 x 1/2 → 30 % | 90 min)

1. The approximate percentages by volume of nitrogen (N_2), oxygen (O_2), and 'all other gases (AOG)' in the troposphere are N_2, O_2, AOG = ____ %

   (a) 78,21,1 ✓✓
   (b) 50,40,10
   (c) 33.3, 33.3, 33.3
   (d) 70,20,10
   (e) 10,20,70

2. Sunlit plants ____ the atmosphere

   (a) absorb O_2, CO_2 from
   (b) release O_2, CO_2 to
   (c) absorb O_2 from and release CO_2 to
   (d) absorb CO_2 from and release H_2O to ✓✓
   (e) exchange neither CO_2 nor H_2O with

3. Three modes of energy transport occur naturally in the atmosphere. That which depends on the existence of wind is called ____ and is ____ wind speed.

   (a) geostationary; proportional to
   (b) radiation; independent of
   (c) conduction; independent of
   (d) temperature inversion; related to
   (e) convection; proportional to ✓✓

4. At the times of the equinox, the subsolar point lies ____

   (a) on the tropic of Capricorn
   (b) on the tropic of Cancer
   (c) on the equator ✓✓
   (d) on the latitude line 23.5°N
   (e) on the latitude line 23.5°S

5. Suppose two (otherwise identical) surfaces are at temperatures T, $2T$ (Kelvin). The hotter surface radiates energy at a rate that is ____ times the rate of the cooler surface.

   (a) 1/2
   (b) 2
   (c) 1/4
   (d) 4
   (e) 16 ✓✓

6. Turbulent convective transport of momentum in the vertical direction is the mechanism for ____

   (a) redistribution of sensible heat in the atmospheric boundary-layer
   (b) friction in the atmospheric boundary-layer ✓✓
   (c) the Geostrophic wind
   (d) the hydrostatic balance of the atmosphere
   (e) evaporation from a wet soil

7. A characteristic value for air density (ρ) at sea-level is ____

   (a) $1\,\mathrm{kg\ m^{-3}}$ ✓✓
   (b) $1\,\mathrm{kg\ m^{-2}}$
   (c) 1000 mb
   (d) $1000\,\mathrm{mg\ m^{-3}}$
   (e) $1\,\mathrm{g\ m^{-3}}$

8. An atmospheric gas that selectively absorbs upwelling radiation in wavelength-band $\lambda_1 - \lambda_2$ will emit radiation ____

   (a) In the shortwave band
   (b) In the longwave band
   (c) At all wavelengths
   (d) Whose wavelength lies in the same band $\lambda_1 - \lambda_2$ ✓✓
   (e) Downwards towards ground but in no other direction

9. Suppose on a summer afternoon the net radiation was $Q^* = 500$ [W m^{-2}]. A patch of ground covering an area of 10 metres x 10 metres would be "capturing" radiant energy at a rate of ____

   (a) 500 [J sec^{-1}]
   (b) 500 [J]
   (c) 5 [J sec^{-1}]
   (d) 50,000 [J sec^{-1}] ✓✓
   (e) 50,000 [W sec^{-1}]

10. Consider a thermometer measuring air temperature 1.5 metres above a field of grass. Suppose that after a calm, clear night it reports the minimum temperature was +2°C, but yet, the grass is seen to be covered in frost. This explainable because ____

   (a) Under the stated conditions the ground can easily be several degrees cooler than air at the thermometer height ✓✓
   (b) Grass is "hygroscopic" and will draw vapor from the air, cooling in the process below the frostpoint
   (c) The soil heat flux Q_G has conducted heat away from the soil surface overnight, causing the ground surface and grass to freeze
   (d) The thermometer probably overestimated the true temperature, as it would have been receiving longwave radiation from the sky above
   (e) The thermometer probably overestimated the true temperature, as it would have been receiving longwave radiation from the grass below

11. Usually in summer, the base of the friction layer is absolutely unstable by day. Due to that instability vertical motion is ____ and turbulent convective transport carries sensible heat ____ the ground.

   (a) Enhanced; towards
   (b) Suppressed; towards
   (c) Enhanced; away from ✓✓
   (d) Suppressed; away from
   (e) None of the above

12. A deep layer of fog is more likely to form on a night with a very gentle wind, than during a night which is completely calm, because ____

   (a) longwave emission rate $L\uparrow$ is increased by wind
   (b) eddies carry heat down to the cooling surface from a deeper layer ✓✓
   (c) a light wind increases the rate of cooling of the ground
   (d) the ELR equals the DALR
   (e) none of the above

13. In reference to the surface energy balance, if Q_H, Q_G are both positive, then ____

    (a) the lower atmosphere must be warming, the upper soil cooling
    (b) the lower atmosphere must be cooling, the upper soil warming
    (c) both lower atmosphere and upper soil are cooling
    (d) both lower atmosphere and upper soil are warming ✓✓
    (e) the latent heat flux (Q_E) must be zero

14. In class we have seen satellite cloud photographs taken with a camera that 'sees' only radiation whose wavelength is $\lambda \approx 10.7\mu$m (micrometers). Such photographs exploit ____ and can be taken ____

    (a) Solar radiation in the atmospheric window; only by day
    (b) Terrestrial radiation in the atmospheric window; only by night
    (c) Terrestrial radiation in the atmospheric window; by day or night ✓✓
    (d) Solar radiation; by day
    (e) Radar; by day or night

15. We expect the wind near ground normally to diminish overnight because ____

    (a) Stable temperature stratification (inversion) suppresses vertical exchange of air parcels, decoupling the surface wind from stronger winds aloft ✓✓
    (b) Unstable temperature stratification suppresses vertical exchange of air parcels, decoupling the surface wind from stronger winds aloft
    (c) Stable temperature stratification (inversion) enhances vertical exchange of air parcels, decoupling the surface wind from stronger winds aloft
    (d) Unstable temperature stratification enhances vertical exchange of air parcels, decoupling the surface wind from stronger winds aloft
    (e) The air is loaded with dew, thus heavier, and so it slows down

16. Atmospheric pressure varies ____

    (a) more rapidly in the horizontal direction than in the vertical
    (b) more rapidly in the vertical direction than in the horizontal ✓✓
    (c) at the same rate in the horizontal and vertical directions
    (d) more rapidly in the vertical over land than over the ocean
    (e) in the horizontal at a rate [Pa m^{-1}] given by the hydrostatic equation

17. Consider the magnitude of the atmospheric pressure decrease ΔP between sea-level (height $z = 0$), and a point overhead at a height of 1 kilometre above sea-level ($z = 1000$ m). In the northern hemisphere winter, ΔP is ____

    (a) larger at the north pole than at the equator ✓✓
    (b) smaller at the north pole than at the equator
    (c) the same at the north pole as at the equator
    (d) negative
    (e) zero

18. If the air temperature at the 500 mb level is -20°C, the air density ρ [kg m^{-3}] at that level is ____ (use the ideal gas law)

    (a) 1.0
    (b) 500.0
    (c) -0.087
    (d) 0.0069
    (e) 0.69 ✓✓

19. "Cross-isobar flow" occurs in the ____ layer of the atmosphere. That flow is oriented ____ a center of Low pressure, and results in ____ vertical motion.

    (a) Geostrophic; away from; descending
    (b) Geostrophic; into; ascending
    (c) Friction; into; descending
    (d) Friction; into; ascending ✓✓
    (e) Tropospheric; away from; ascending

20. The "Geostrophic wind" results from a balance of the ____ and ____ forces. In the northern hemisphere, if you stand with your back to the Geostrophic wind, low pressure lies to your ____ hand.

    (a) Coriolis; pressure-gradient; left ✓✓
    (b) Coriolis; pressure-gradient; right
    (c) friction; pressure-gradient; right
    (d) friction; pressure-gradient; left
    (e) Gravity; pressure-gradient; left

21. According to the geostrophic model, the net force acting on air blowing at constant speed parallel to straight pressure (or height) contours is ____

    (a) Oriented in the direction of the wind
    (b) Oriented perpendicular to the wind
    (c) Oriented vertically
    (d) Zero ✓✓
    (e) Non-zero but constant

22. If height contours are NOT straight, parallel lines, the Pressure-gradient and Coriolis forces are ____ and the winds in the free atmosphere are called ____ winds.

    (a) unequal; adiabatic
    (b) in balance; Geostrophic
    (c) in balance; Gradient
    (d) unequal; Geostrophic
    (e) unequal; Gradient ✓✓

23. A parcel of air has pressure P, temperature T, vapor pressure e, and dewpoint temperature T_d. You could determine its relative humidity (RH) given which two factors?

    (a) T, e
    (b) T, P
    (c) T, T_d
    (d) T_d, e
    (e) Both option (a) and option (c) are correct ✓✓

24. A parcel of air with temperature $T = 15$°C and dewpoint $T_d = 10$°C has absolute humidity ρ_v [kg m^{-3}] ____

    (a) 9.2 x 10^{-5}
    (b) 1.8 x 10^{-3}
    (c) 9.2 x 10^{-3} ✓✓
    (d) 0.18
    (e) 1

25. Which of the following statements concerning the water vapor density (ie. 'absolute humidity', ρ_v) in the atmosphere and the air density (ρ) is false?

    (a) ρ_v and ρ have the same units

    (b) ρ_v (or ρ) can be related to vapor pressure (or total pressure) and temperature by means of the ideal gas law

    (c) $\rho_v \gg \rho$ ($\gg$ means "is very much greater than") ✓✓

    (d) $\rho_v \ll \rho$

    (e) there can be no convective transport of latent heat across a layer of air in which $\rho_v = 0$

26. If a parcel of dry air had a temperature of 20°C when at height $z = 0$, then if it was lifted adiabatically to $z = 500$ m, its temperature would be ____ °C

    (a) 10

    (b) 15 ✓✓

    (c) 20

    (d) 25

    (e) 30

27. In an absolutely stable atmosphere an air parcel initially at the same temperature as its environment but which is adiabatically displaced upward becomes ____ than the environmental air about it, and experiences a ____ buoyancy force.

    (a) cooler; downward ✓✓

    (b) warmer; upward

    (c) wetter; upward

    (d) drier; restoring

    (e) none of the above

28. An atmospheric layer is said to be "conditionally unstable" if ____

    (a) Environmental temperature drops faster with increasing height than the moist adiabatic lapse rate

    (b) Environmental temperature drops slower with increasing height than the dry adiabatic lapse rate

    (c) Environmental temperature does not change with height

    (d) Environmental temperature drops slower with increasing height than the moist adiabatic lapse rate

    (e) Environmental temperature drops with increasing height at a rate intermediate between the dry and moist adiabatic lapse rates ✓✓

29. The actual (environmental) temperature profile in the friction layer is most likely to run parallel to a dry adiabat under conditions of ____

    (a) night-time calm under clear skies
    (b) heavy cloud cover with strong wind ✓✓
    (c) daytime calm under sunny skies
    (d) positive thickness advection at 500 mb
    (e) an inversion

30. A lumpy, non-precipitating cloud layer below a height of about 2 kilometers is called ____ . If the layer is unbroken, then vertical velocities in the cloud are probably ____

    (a) stratocumulus; weak ✓✓
    (b) stratocumulus; strong
    (c) cirrostratus; strong
    (d) cirrostratus; weak
    (e) nimbus; strong

31. The "lifting condensation level" (LCL) is the level to which a parcel must be lifted to ____ ; whereas the "level of free convection" (LFC) is the level to which a parcel must be lifted to experience a/n ____ buoyancy force

    (a) become saturated; upward ✓✓
    (b) become unsaturated; upward
    (c) become saturated; downward
    (d) become unsaturated; downward
    (e) become buoyant; oscillating

32. The majority of meteorologists consider cloud seeding as ____

    (a) verified unambiguously as being effective
    (b) a sure means to reduce hail damage
    (c) the reliable scientific recipe for rain-making
    (d) more effective in the tropics than at mid-latitudes
    (e) of unproven value, and most likely ineffective ✓✓

33. As a climatological generalization, and on the global scale, sharpest 500 mb height gradients are seen ____

    (a) over Lake Superior
    (b) at the edge of the Boreal Forest
    (c) in the winter hemisphere ✓✓
    (d) in the summer hemisphere
    (e) in the stratosphere

34. Which of the following names a semi-permanent, sub-tropical high?

    (a) Hadley
    (b) Siberian
    (c) Hawaiian ✓✓
    (d) Aleutian
    (e) Tibetan

35. Factors tending to deepen a storm are ____ aloft, which often occur in the outlet region of an upper ____

    (a) convergence and warm advection; ridge
    (b) divergence and cold advection; trough
    (c) convergence and cold advection; ridge
    (d) divergence and warm advection; trough ✓✓
    (e) divergence and warm advection; ridge

36. Which of the following conditions should minimize the ground-level concentration of locally-emitted pollutants?

    (a) light surface winds
    (b) a deep mixing layer ✓✓
    (c) strong subsidence inversion
    (d) a large, slow-moving anticyclone
    (e) heavily overcast skies

37. Advection and turbulent mixing ('turbulent diffusion') of urban air pollutants by the wind

(a) remains a fundamental mystery because it occurs on a scale far smaller than the grid length (order $10 - 100$ km) of weather models

(b) can be computed with some degree of usefulness by mathematical-numerical models having an appropriately finer grid ✓✓

(c) can be computed almost exactly on a fine grid by mathematical-numerical models, taking into account all aspects of the problem

(d) is a process fundamentally different from the transport of heat, water vapour, etc.

(e) is unimportant relative to much larger fluxes due to molecular diffusion

38. A certain variety of canola requires 1100 growing degree days above a base temperature of +5°C (Celcius), in order to reach maturity. The units of a "growing degree day" are

(a) degrees Celcius

(b) degrees Kelvin

(c) hours

(d) days

(e) (degrees Celcius) x (days) ✓✓

39. On a summer afternoon, sitting in an urban back yard, surrounded by fences, garages, houses, trees etc., the temperature is liable to be more uniform (on the "local" scale, ie, over horizontal distances of order 1 - 100 m) under which conditions?

(a) Strong sunshine, light wind

(b) Strong sunshine, strong wind

(c) Sun obscured by heavy cloud, wind light

(d) Sun obscured by heavy cloud, wind strong ✓✓

(e) Light wind, sun intermittently obscured by fairweather Cu

40. Which of the following statements about modern NWP models is NOT true?

(a) gridpoint spacing is fine enough to pick up even the smallest microscale motions ✓✓

(b) in some regions sparsity of observations reduces accuracy of the initial state

(c) treatment of interactions with the surface (land, lake or ocean) is imperfect

(d) they solve detailed (though not 100% complete or exact) mathematical statements of the relevant laws of physics

(e) after several weeks the initial conditions are "forgotten," meaning long range weather forecasts from almost-identical initial states may be entirely different.

41. A common technical phrase that denotes "the minimum size below which explicit representation is impossible" in a numerical weather model is ____

    (a) model domain
    (b) model range
    (c) synoptic scale
    (d) sub-scale
    (e) spatial resolution ✓✓

42. Spacing between adjacent radiosonde stations across Canada is roughly of order ____

    (a) 1000 km ✓✓
    (b) 100 km
    (c) 10 km
    (d) 6 dam
    (e) 1000 mb

43. Match forecast type (climatology; numerical model; persistence) with appropriate range (short=less than six hours; medium= $1/2 - 15$ days; long= more than 15 days):

    (a) persistence-long, numerical-medium, climatology-short
    (b) persistence-short, numerical-medium, climatology-long ✓✓
    (c) persistence-medium, numerical-long, climatology-short
    (d) persistence-short, numerical-long, climatology-medium
    (e) persistence-long, numerical-short, climatology-long

44. In the context of the science of weather and weather forecasting, 'MOS' refers to ____

    (a) A type of ice nucleus used in cloud seeding
    (b) Metal Oxide Semiconductors
    (c) Mid Oceanic Services
    (d) Model Output Statistics ✓✓
    (e) Meso-Orographic Stability

45. Koeppen's climate classification is broadly based on ____

    (a) growing degree days
    (b) Penman's formula for potential evapotranspiration
    (c) mean monthly temperature and precipitation taken as indicative of natural vegetation types ✓✓
    (d) latitude and elevation
    (e) climate simulations using a modern Global Climate Model

46. The concept of the 'potential evapotranspiration' in a given climate region is best conveyed by which statement?

(a) the evapotransiration that would occur if the relative humidity were zero

(b) the evapotransiration that would occur if the windspeed were very large

(c) actual evaporation occurring in a situation where energy is conserved and the rate of transport of water vapour between two points A,B is proportional to the difference in vapour pressure at the two points

(d) the annual water transpired by a sample area (say 1 square kilometer) of naturally-occurring vegetation in that region

(e) actual evaporation from a wetted surface into an atmosphere with the given climatic parameters (radiation, humidity, windspeed, etc.) ✓✓

47. As of 2006, the global climatic record as inferred from analysis of ice cores stretches back for over ____ years

(a) 4 billion

(b) 6.5 million

(c) more than 650 thousand (but less than 1 million) ✓✓

(d) 65 thousand (but less than 100 thousand)

(e) 650 (but less than 1000)

48. For most of its 4.5 billion year history the climate on earth has been ____ than the present. The slow climate variations over hundreds of millions of years are believed best explained by ____

(a) cooler; varying solar energy output

(b) cooler; the D-O (Dansgaard-Oeschger) cycles thought to arise from changes in North-Atlantic oceanic circulation

(c) warmer; the Milankovitch cycles in sun-earth geometry

(d) warmer; plate tectonics and resultant changes in atmospheric composition ✓✓

(e) warmer; varying solar energy output

49. Which of the following statements in regard to the atmospheric role of aerosols is untrue?

(a) they suppress transpiration by plants and thereby influence the surface energy budget ✓✓

(b) as cloud condensation nuclei they play a vital role in cloud formation

(c) depending on their size, they may reduce incoming solar radiation and/or outgoing (longwave) radiation

(d) they impact on air quality (eg. visibility)

(e) precipitation is the main agency for their removal

50. The atmospheric layer that is well-stirred by the vertical motions associated with weather systems and clouds has a height of about ____ , and is seasonally deeper in ____ and at ____ latitudes.

(a) 50 km; winter; higher

(b) 5 km; winter; lower

(c) 10 km; summer; lower ✓✓

(d) 10 km; winter; lower

(e) 10 km; winter; higher

The remaining questions relate to weather conditions as inferred from the attached analyses and sounding for 12Z on 27 Oct 2003.

51. The innermost isobar of the cyclone in northern Saskatchewan (not Manitoba!) could be labelled ____ mb

(a) 992

(b) 996 ✓✓

(c) 1000

(d) 1004

(e) 1008

52. Present weather, at the station just east of the border of Saskatchewan and Manitoba where sea-level pressure was 998.8 mb, was ____ (Instructor's slip - two right answers - both will be scored correct)

(a) steady snow, 100% relative humidity ✓✓

(b) steady snow, winds gusting to 51 kph

(c) overcast with steady snow ✓✓

(d) overcast with drizzle

(e) overcast with steady rain

53. Pressure tendency, at the station just east of the border of Saskatchewan and Manitoba where sea-level pressure was 998.8 mb, was ____

(a) 51 mb fall in past 24 hr

(b) 51 mb fall in past 3 hr

(c) 5.1 mb fall in past 24 hr

(d) 5.1 mb fall in past 3 hr ✓✓

(e) 5.1 mb rise in past 3 hr

54. Based on the surface chart, winds in the lee of the SW Alberta Rockies are likely to be

(a) weak northwesterlies
(b) strong easterlies
(c) strong southerlies
(d) weak northeasterlies
(e) strong, from northwest or west or southwest ✓✓

55. It may be reasonable to associate the surface trough that extends from Northern Saskatchewan southward into the United States with ____

(a) a lee trough
(b) a cold front
(c) a warm front ✓✓
(d) an occluded front
(e) a stationary front

56. Referring to the 850 mb chart, at Edmonton at 850 mb the height was ____ and the dewpoint was ____ °C

(a) 543 dam; 9
(b) 543 dam; -3
(c) 143 dam; 9
(d) 143 dam; -3 ✓✓
(e) 943.0 mb; 9

57. Referring to the 850 mb chart, at location **a** ____ was occurring while at location **b** ____ was occurring

(a) cold advection; warm advection ✓✓
(b) warm advection; cold advection
(c) calm wind; strong wind
(d) a northwesterly wind; southerly wind
(e) cyclogenesis; occlusion

58. Referring to the 850 mb chart, the atmosphere at locations **a** and **b** is said to be ____

(a) hydrostatic
(b) cyclogenic
(c) anticyclonic
(d) baroclinic ✓✓
(e) quasi-static

59. Referring to the given sounding (Stony Plain), the environmental temperature profile below 700 mb is the consequence of the atmosphere over central Alberta being ____ (as inferred from all the given evidence)

    (a) windy, overcast and dry ✓✓
    (b) overcast with light winds
    (c) overcast with a saturated atmosphere
    (d) sunny with light winds
    (e) in an Omega high (Omega block) configuration

60. Referring to the 700 mb chart, what feature(s) is/are consistent with the hypothesis of there being over-running on top of a warm front aligned roughly north-south and lying in the general vicinity of the Saskatchewan-Manitoba border?

    (a) low temperature-dewpoint spread in this region
    (b) warm advection over south-central Manitoba
    (c) westerly wind at The Pass (Le Pas), ie. the radiosonde station in west-central Manitoba
    (d) colder air at 700 mb in eastern Manitoba (-13, -15) than in western Manitoba (-7)
    (e) all of the above ✓✓

Short answer (5% | 15 min)

Instruction: Answer question tidily on this side (only) of this page. Tear off, and hand in at end of exam.

"Causal" (ie. mechanistic) numerical models are used both for Weather Prediction and for Climate Analysis. In **point format**, convey similarities and differences between global weather and global climate simulations, identifying how the models may (appropriately) differ.

Name: ID#:

Schematic Response

The instructor's response has not been limited to a single page - this is to permit a comprehensive listing of possible points that could have been made (no doubt there are others not listed below). It was not expected that students under the time-pressure of an exam would cover all these points. Note also that some of the points listed below may not have been specifically made by the textbook or instructor in 2006; they are included here partly because of the future (educational) role of this exam for later students, and also because they are reasonable inferences *from material taught in the course. The instructor spent roughly one hour to record the list below - realistically, students could not have been expected to capture all these points, nor would space have allowed.*

Marking scheme: Legibility/Organization assigned up to 3 x (1/2)%. Each specific, valid, relevant and reasonably important technical point was scored (1/2)%.

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INTRODUCTION

In my response I refer to a typical modern "Weather Prediction"
(NWP) model whose domain is global, and compare and contrast relative to a
"GCM". I shall assume the "forcing" for a GCM includes: sun-earth geometry,
solar constant, positions of continents, atmospheric composition

SIMILARITIES

o both entail numerical solution of equations representing the earth-ice-atmos-ocean
     system
o equations solved are "conservation equations" (heat, mass, momentum) as well as
     equations of state (gas laws), radiation laws and others
o essence of both is to compute the property distribution (eg. temperature) arising
     as consequence of existing "sources and sinks" (eg. solar heating) and
     "transport processes" (convection & radiation - diffusion/conduction unimportant)
o both entail initialization (less important for GCM) and prediction (integration)
     phases
o global domain
o discrete representation of properties (ie. grid)
o predictive variables include gridded: wind velocity, pressure, temperature,
     humidity,...
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o both must deal with a system undergoing motion on vast range of scales
o resolution limits solution accuracy
o trade-offs in speed and complexity must be made
o necessity to parameterize sub-grid scales of motion, eg. cumulus clouds
o necessity to simplify many processes
o necessity to simplify terrain
o conceptual basis and enabling technology integrates all human knowledge, and came to fruition about mid-1900's (basic elements in place; refinements continue)

DIFFERENCES

o NWP an "initial value problem", GCM seeks equilibrium climate response to specified forcing (in view of its importance, I gave 1% for this one)
o NWP very sensitive to initial conditions (and error in their specification) whereas GCM predictions are independent of (or "forget") init. conds. (very similar to above - I gave it 1%)
o NWP has 3 space dimensions, some GCM's have an atmos. with fewer dimensions (eg. latitude-elevation, or lat-long.)
o NWP demands expensive global data collection network
o NWP integrates for 1-2 weeks, GCM for months/years/centuries or longer
o some "fast" processes important to weather may not be important in GCM (eg. a GCM designed to predict climate variation on a timescale of millions of years might not resolve the diurnal cycle)
o some slow processes (eg. CO2 flux to oceans, uptake by marine organisms) must be represented in, GCM but not in NWP
o GCM may require more sophisticated parameterization of plants, possibly including their adaptation
o NWP timestep order minutes, GCM probably much longer
o NWP may have higher spatial resolution
o GCM must couple dynamic atmos. & ocean models, whereas NWP models atmos. only, with ocean surface temperatures fixed
o NWP forecast timeliness is a practical issue (computation must be rapid), whereas laborious GCM calculations limited more by cost
o GCM's not presently considered capable to diagnose regional climate change whereas NWP routinely makes useful predictions of (eg.) location of fronts

What cannot be read, cannot be marked!... before anything else, pay attention to (i) Legibility and (ii) Organization of ideas

In view of space limitations, avoid the trivially obvious (eg. both NWP & GCM both consider intensity of insolation).

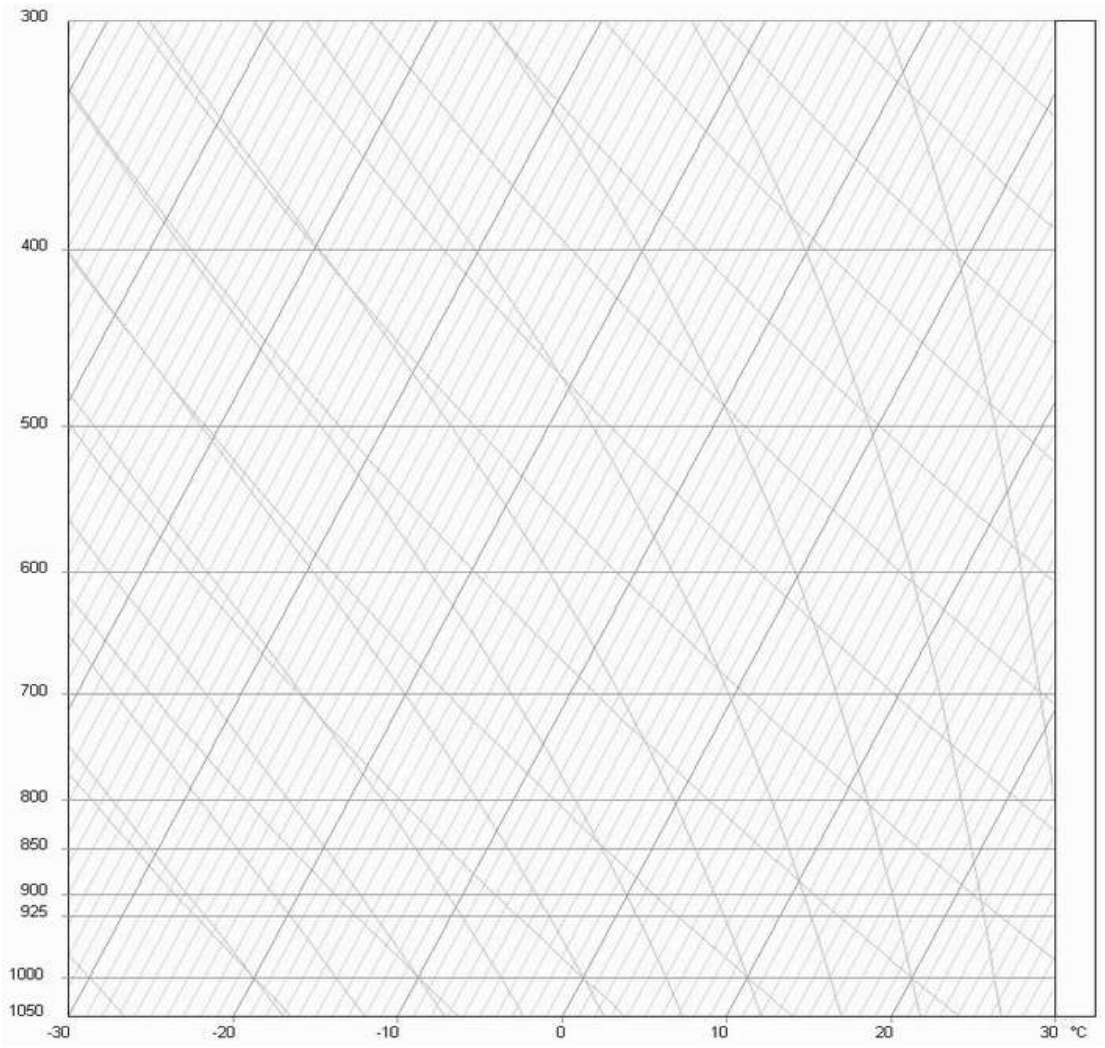
Don't give irrelevant information, eg. the degree of global warming that GCM's are predicting.

Short answer (5% | 15 min)

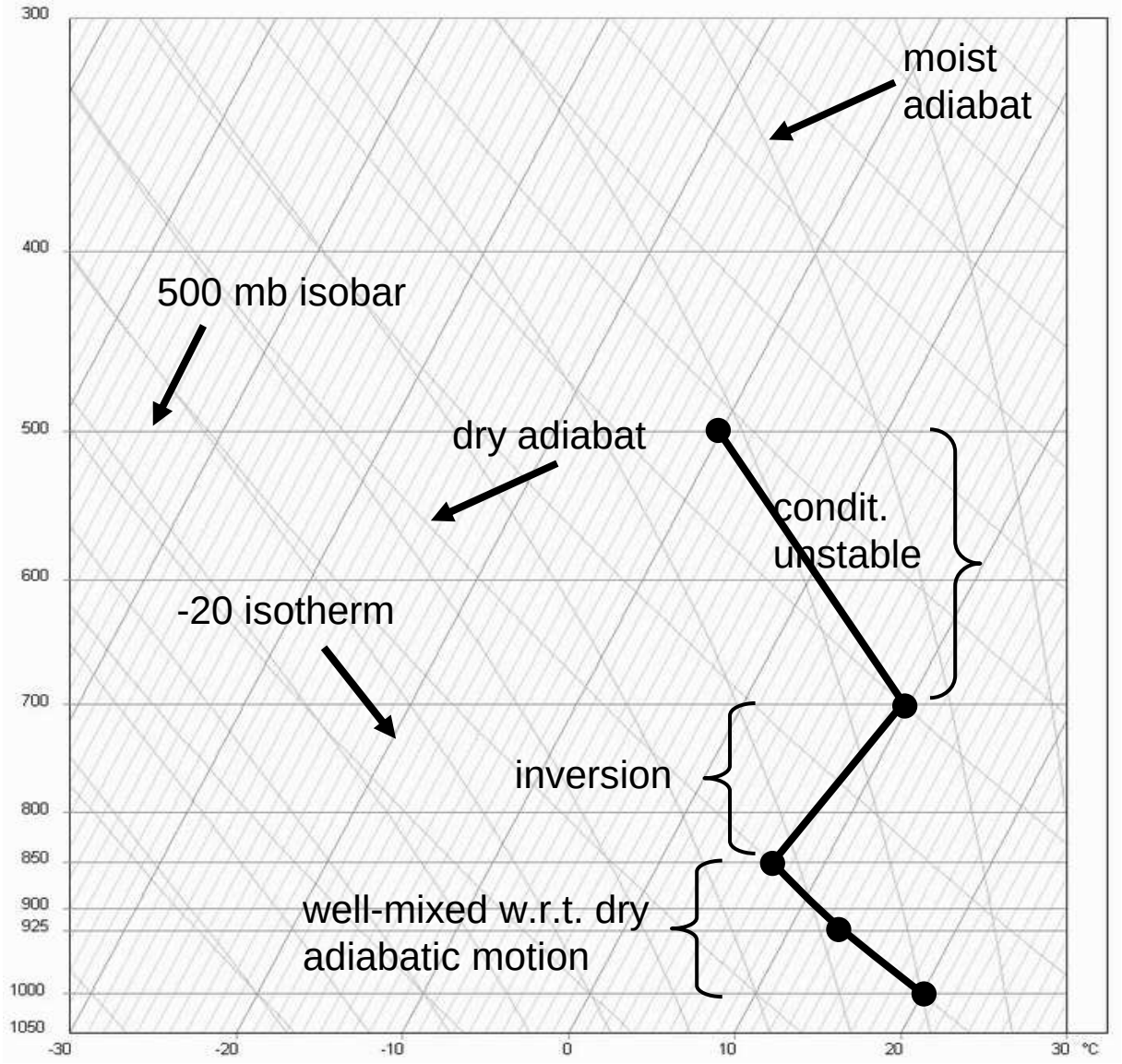
Name: ID#:

Plot the given sounding. Identify one member of each of these families or reference curves/lines: isobars, isotherms, dry adiabats, moist adiabats. Identify a layer that is well-mixed with respect to dry adiabatic motion; an inversion layer; and a conditionally unstable layer.

Height (mb)	T °C
1000	20
925	13
850	7
700	10
500	-10



Marking scheme: 1/2% for correct identification of a member of each of the four families. 1% for correct identification of each layer. Penalty of 1/2% if the data were mis-plotted due to the student not recognizing isotherms are not vertical on the Skew-T diagram.



Equations and Data.

- $\frac{\Delta P}{\Delta z} = -\rho\, g$

  The hydrostatic law. ΔP [Pascals], the change in pressure as one ascends a distance Δz [m]; ρ [kg m^{-3}] the density; $g \sim 10$ [m s^{-2}] acceleration due to gravity.

- $P = \rho\, R\, T$

  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 vapor. e [Pascals], pressure; ρ_v, [kg m^{-3}] the absolute humidity (ie. vapor density); T [Kelvin], the temperature; and $R_v = 462$ [J kg^{-1} K^{-1}], the specific gas constant for water vapor).

- RH$= e/e_s(T)$, $q = m_v/(m_v + m_d) = \rho_v/\rho$

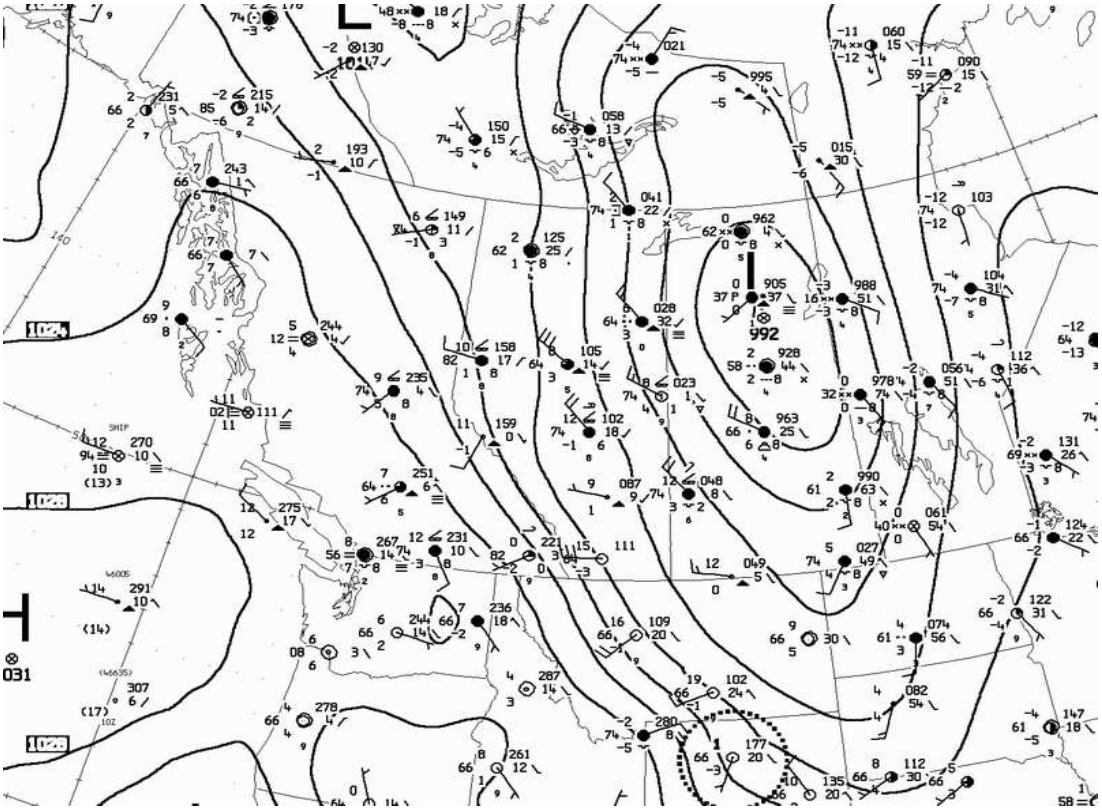
  Other common humidity variables: the relative humidity (RH) and the specific humidity (q). In the definition of the latter, m_v, m_d are respectively the mass of vapour and the mass of all else but vapour (ie. of the "dry air") in a sample

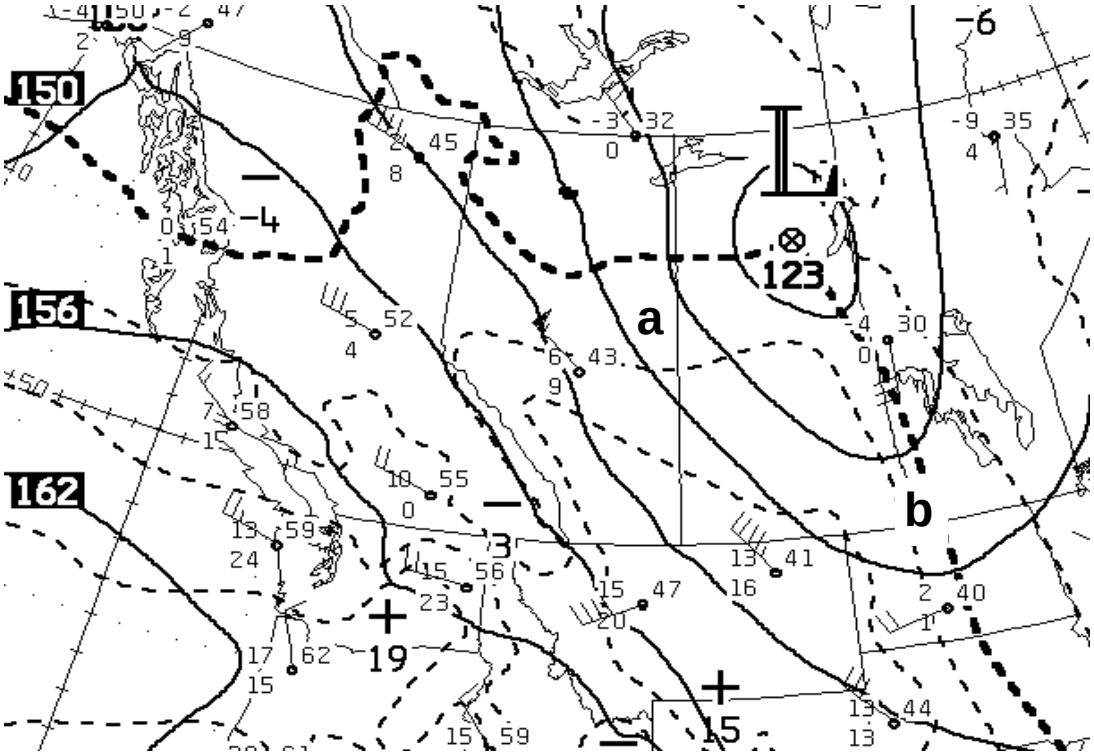
- $Q^* = Q_H + Q_E + Q_G$

  Surface energy balance on a reference plane at the base of the atmosphere, all fluxes in [W m^{-2}]. Q^* the net radiation, positive if directed towards the surface; Q_H, Q_E the sensible and the latent heat fluxes, positive if directed from the surface towards the atmosphere; Q_G the 'soil' heat flux, positive if directed from the surface into ground/lake/ocean.

Table 1: Equilibrium vapour pressure $e_s(T)$ [mb] versus temperature T [C].

T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$	T	$e_s(T)$
0	6.11	5	8.72	10	12.27	15	17.04	20	23.37	25	31.67
1	6.57	6	9.35	11	13.12	16	18.17	21	24.86	26	33.61
2	7.05	7	10.01	12	14.02	17	19.37	22	26.43	27	35.65
3	7.58	8	10.72	13	14.97	18	20.63	23	28.09	28	37.80
4	8.13	9	11.47	14	15.98	19	21.96	24	29.83	29	40.06

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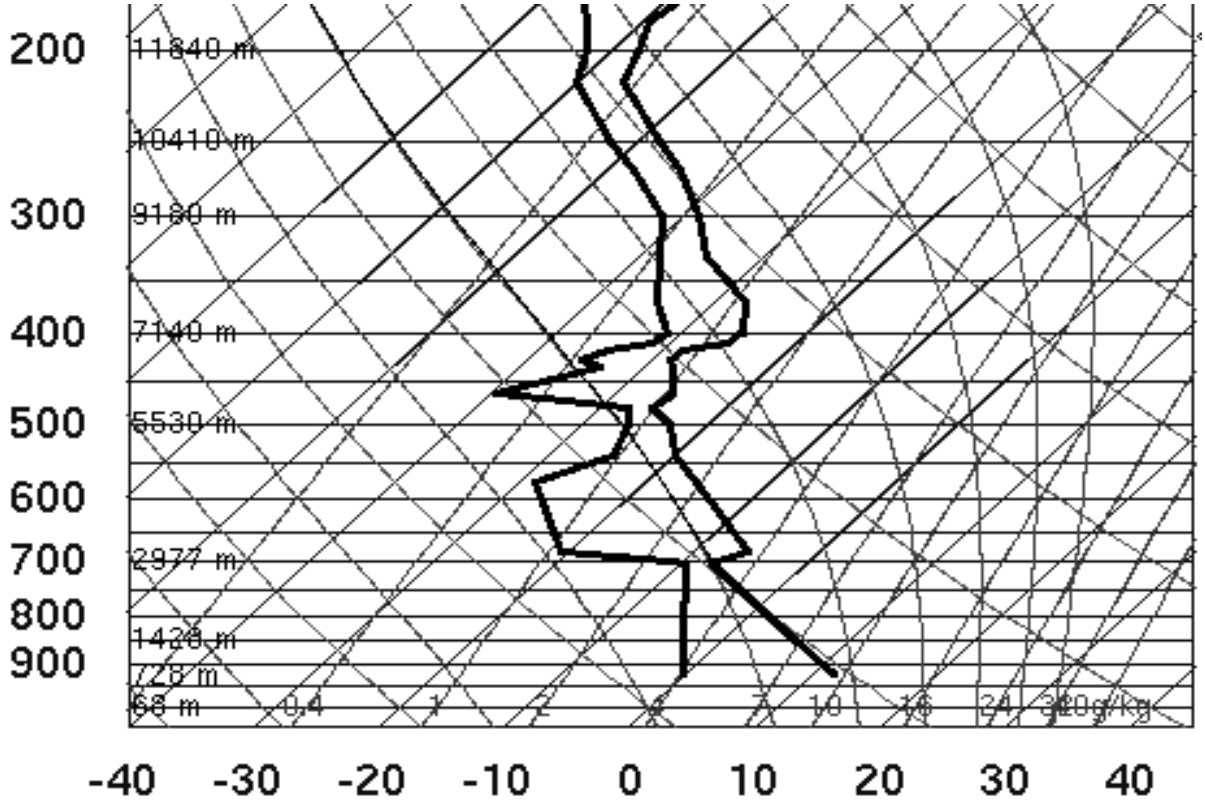
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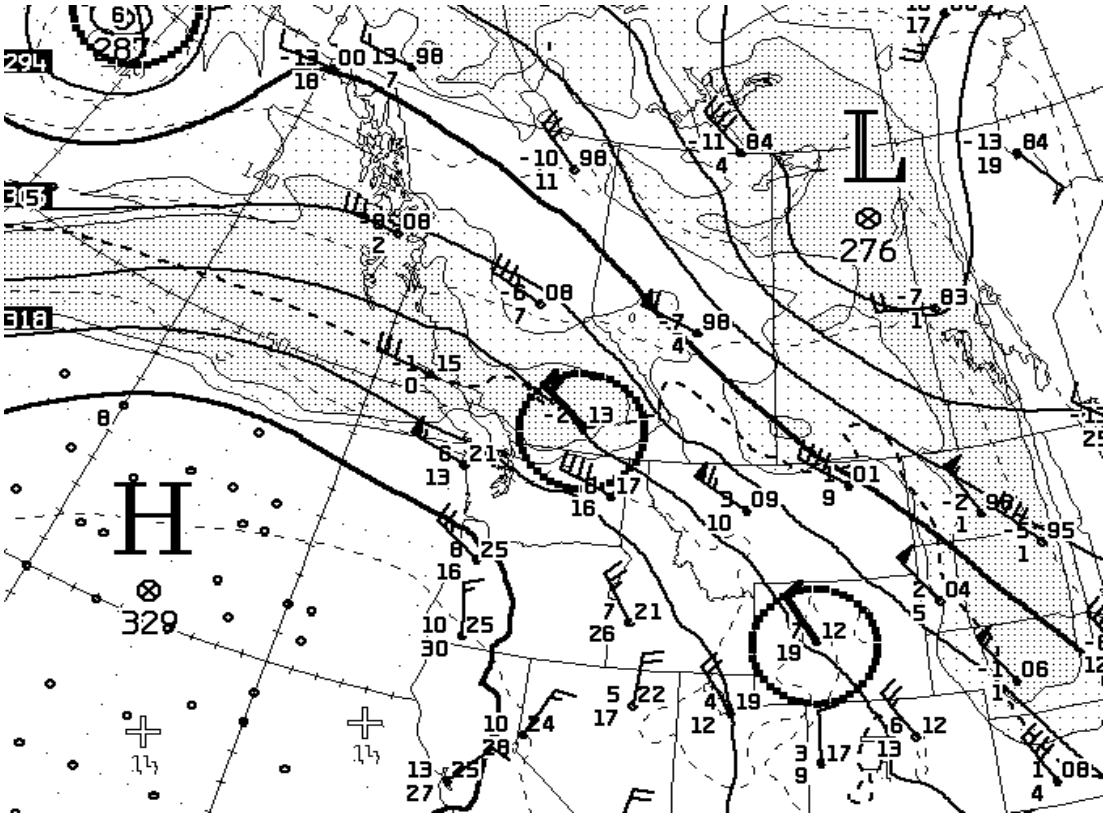
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