General PhD Qualifying Exam Question - from General Meteorology (Ruscher)

This question is designed to be completed in 90 minutes. It is a test of comprehensive meteorology material that all students in Meteorology should have a good grasp of. It will be rescaled to the Laseur grading scale, after scoring on a 105 point basis for this exam.

I. Multiple Guess – circle the response which best answers the question posed. 8 questions this part, each worth 2 points, for a total of 16 points.

1. The temperature to which air must be cooled at constant water vapor content and constant pressure is the _____ ?

   a) dew point b) frost point c) triple point d) wet bulb

2. Which temperature has the greatest relationship to the human body's ability to cool down on a hot, sunny day?

   a) dew point b) frost point c) triple point d) wet bulb

3. What happens to air density as water vapor content increases?

   a) nothing b) density increases c) density decreases
   d) none of the above

4. Which of the following provides an example of how clouds form?

   a) low level convergence
   b) orographic uplift
   c) uplift over frontal boundaries
   d) convection
   e) all of the above

5. In order for cloud drops to form at a relative humidity near 100%, what must be present?

   a) CCN b) CNN c) CFCs d) good karma

6. For small drop sizes, the solute effect may be explained by the following statement: _________ .

   a) the equilibrium relative humidity for pure water drops is lower than drops in solution
   b) the equilibrium relative humidity for pure water drops is greater than drops in solution
   c) only salt can produce condensation at relative humidities below 100%
   d) large drops are less likely to contain some solute than small drops

7. For cloud drops, the curvature effect may be explained by the following statement: _________ .

   a) large drops are less likely to contain some solute than small drops
   b) large drops have an increased likelihood of being heavy enough to fall out of clouds
   c) large drops have a lower equilibrium relative humidity than small drops
   d) large drops have a smaller equilibrium relative humidity than small drops

8. The constant fall speed at which raindrops fall out of clouds is called the __________.

   a) gravity b) gradient c) pressure effect d) terminal velocity

Part II. Matching/Combo questions. Each question in this section is worth 1 point. Total this section: 35 points

Use the following answers for questions (9) through (13).

a) cirrus b) cumulus c) cumulonimbus d) stratus e) cirrostratus

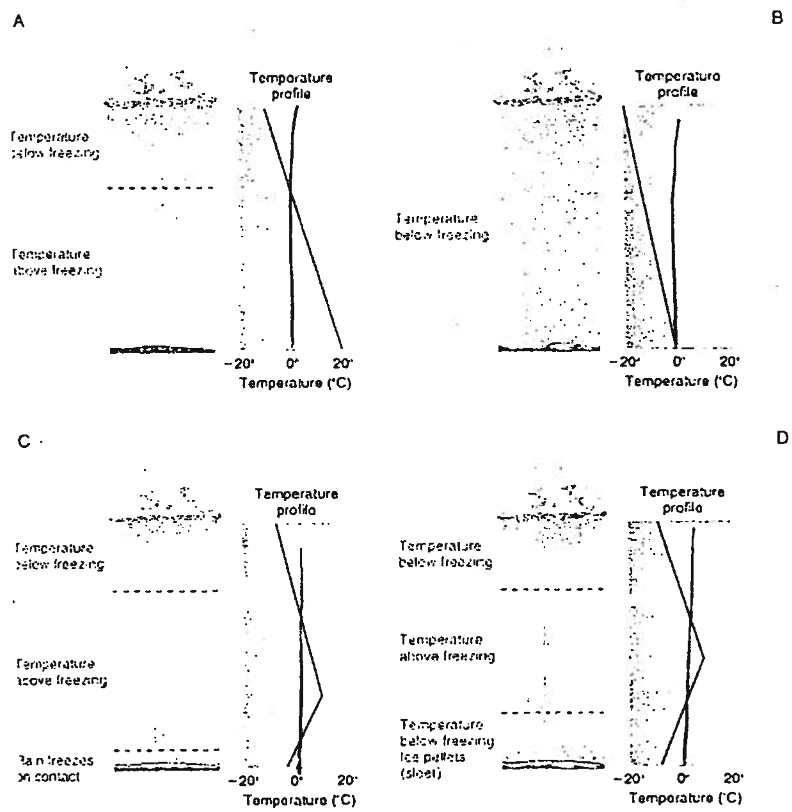
9. Which cloud type is most generally associated with rainbows? __c__
10. Which cloud type is most generally described as being lumpy or puffy? __b__
11. Which cloud type is most generally associated with halos? __a__
12. Which cloud type is most generally associated with precipitation? __c__
13. Which cloud type is most generally associated with fog? __d__

Use the following answers for questions (14) through (18).

a) altostratus b) altocumulus c) cirrocumulus d) nimbostratus e) stratocumulus

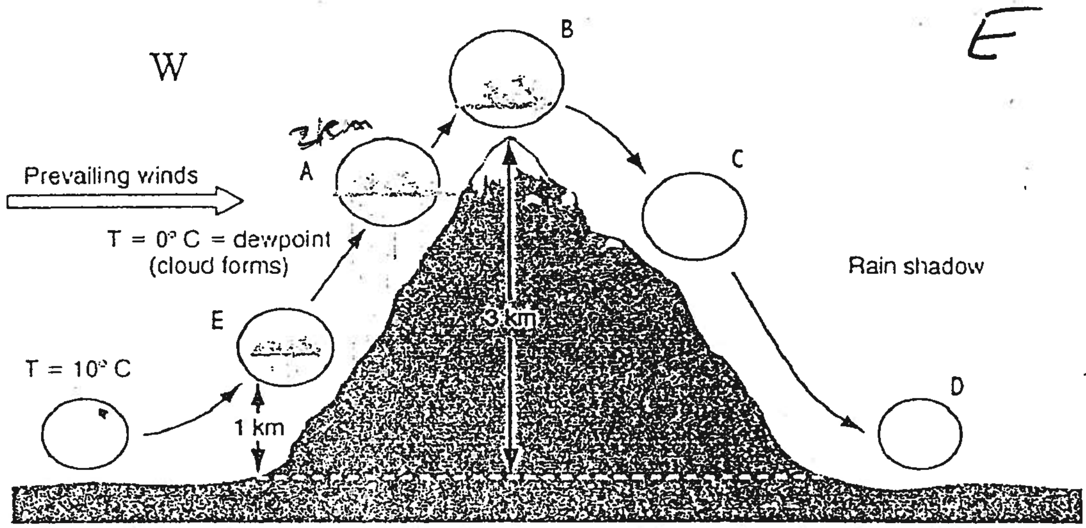
14. Which cloud type is most generally described as being a mid-level flat cloud? __a__
15. Which cloud type is most generally described as being a mid-level puffy cloud? __b__
16. Which cloud type is most generally described as being a low level cloud with an identity crisis? __e__
17. Which cloud type is most generally associated with frontal rain or snow? __d__
18. Which cloud type is most generally likely present if you see tiny spots in the sky? __b__

Use the following diagram for questions 19-23; answers A through D are in the figure; answer E if the selection is not shown.



19. Which vertical temperature profile is most likely to be associated with freezing rain? __C__
20. Which vertical temperature profile is most likely to be associated with hail? __A__
21. Which vertical temperature profile is most likely to be associated with ice pellets? __D__
22. Which vertical temperature profile is most likely to be associated with rain? __A__
23. Which vertical temperature profile is most likely to be associated with snow? __B__

Questions 24-27 refer to the diagram below. Winds are blowing from left (west, the W) to right (east). At an altitude of 1 km (E), the air parcel first becomes saturated and precipitation begins, after cooling at the dry adiabatic lapse rate (9.8 K/km) to (approx.) 0°C. We will revisit this picture in the bonus portion of the test.



24. The wind direction in this situation is called _____.

a) west b) east c) north d) south

25. Suppose the moist adiabatic lapse rate is 6°C/km. What will be the temperature of the parcel at 2 km (point A), where it is raining?

a) 0°C b) -4°C c) -6°C d) -10°C e) -12°C

26. Suppose the parcel keeps rising to the summit, where the parcel remains in a cloud but precipitation has ended. What will be the temperature there (at point B)?

a) 0°C b) -4°C c) -6°C d) -10°C e) -12°C

27. The temperature upon descent will ______ .

a) continue to decrease at the moist adiabatic lapse rate
b) continue to decrease, but at the dry adiabatic lapse rate
c) start to increase upon descent, at the moist adiabatic lapse rate
d) start to increase, but at the dry adiabatic lapse rate
e) remain the same until it reaches its equilibrium level (near the surface again)

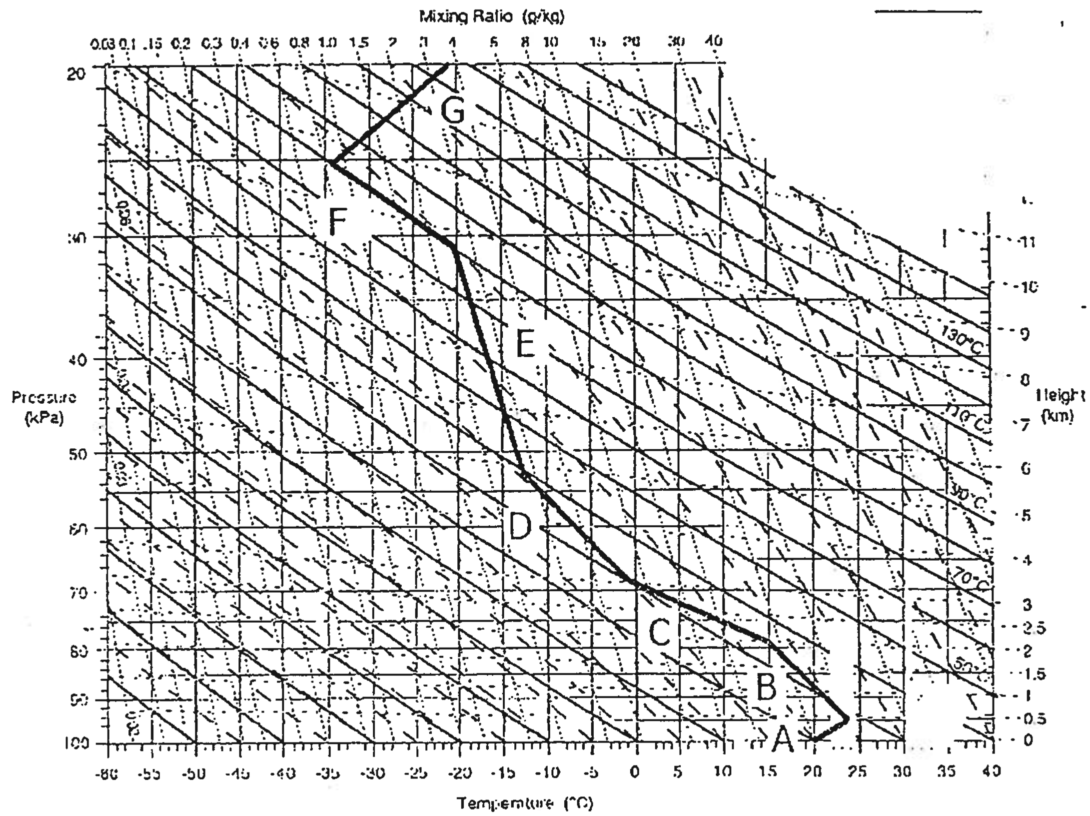
28. A water drop, an ice crystal, and an egg are present in a ~~bar~~ cloud with a relative humidity of 100%. The egg leaves. What will happen to the ice crystal and the water drop?

a) the water drop will evaporate while the ice crystal grows
b) the water drop will evaporate and the ice crystal will shrink
c) the water drop will grow while the ice crystal shrinks
d) the water drop will grow while the ice crystal also grows
e) the ice crystal will end up picking up the tab

29. What is the process described by your answer in #28 called?

a) the collision-coalescence process
b) the ice crystal process
c) the Bergeron-Findeisen process
d) both (a) and (b) are true
e) both (b) and (c) are true

Questions (30) – (35) refer to the thermodynamic diagram shown below. The diagram shows a temperature sounding in a heavy line, with 7 distinct layers, each with a different slope.



30. Which layers illustrate temperature inversions?

a) A and B b) B and D c) A & E d) D and F e) A and G

31. Which layers illustrate absolutely stable layers?

a) A, B, and E b) A, B, and G c) A, E, and G d) B, E, and G e) B, D, and G

32. Which layer is conditionally unstable? a) A b) B c) C d) D e) E

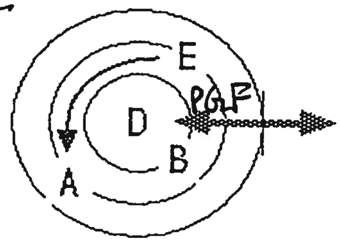
33. Which layer is absolutely unstable? a) A b) B c) C d) D e) E

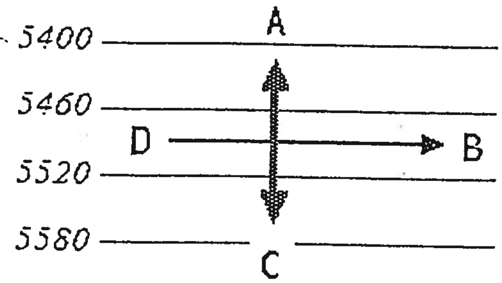
34. Which layer is conditionally neutral?

a) B b) C c) D d) E e) F

35. Which layer is (absolutely) neutral?

Questions 36-39 refer to the figure on the *left* below. Questions 40-43 refer to the diagram on the *right* below. Both diagrams depict flow and forces near the mid-troposphere.





36. Suppose the pressure gradient force is indicated by arrow B. What type of pressure system would you say is present at point D?

a) high b) low

37. What would you call the arrow pointing in the opposite direction to point B?

a) pressure gradient b) Coriolis c) gravity d) friction e) wind

38. What would you call the arrow pointing in the direction of arrow A?

a) pressure gradient b) Coriolis c) gravity d) friction e) wind

39. Suppose we brought this pressure system down to the boundary layer or near the surface. What label would you give E (opposite A)?

a) pressure gradient b) Coriolis c) gravity d) friction e) wind

40. (diagram on the right now) What pressure level is depicted on this isohypse (constant height) chart?

a) 850 hPa b) 700 hPa c) 500 hPa d) 300 hPa e) 150 hPa

41. What is the orientation of the pressure gradient force? a) A b) B c) C d) D
42. What is the orientation of the Coriolis force? a) A b) B c) C d) D
43. What is the direction of the wind? a) A b) B c) C d) D

III. Short answer. (54). Each question is worth 9 points – answer in the area provided, please!

44. For a pressure of 1015 mb and a temperature of 77°F and a vapor pressure of 12 mb, find the virtual temperature [$T_v = T(1+0.61r]$. State all assumptions used, show all work, set up the problem, and express an estimate for T_v in degrees Celsius. [T (°C) = 5/9 {T (°F)-32}] Use only the information given, or other materials that you can recall; no additional formulas will be given.

45. Explain why the moist adiabatic lapse rate is (a) different from the dry adiabatic lapse rate; and (b) why it changes its magnitude as you move upwards in the troposphere. (c) Name a variable that is conserved for moist adiabatic processes.

46. (a) Explain the difference between the "warm cloud" and "cold cloud" processes for creating precipitation.
(b) Which is generally regarded as more efficient and why?

47. In general, a vertical force balance between two forces. (a) What are they? (b) What is this equilibrium called? (c) Give an example of a situation where these forces go way out of whack and tell what happens to the motion in such a situation.

48. Sketch a few ***parallel*** isobars. Label them with appropriate values of sea level pressure (all must be different). Place the appropriate symbol for a low pressure system in the northern hemisphere. Now draw the surface wind direction and the appropriate force balance for this situation.

49. Suppose we have a simple heat balance situation, where $dq = c_p \Delta T + L_v \Delta r$. Given the following values, *estimate* the amount of heat given off in this situation (for condensation of a rising air parcel). Show all of your work! I need an order of magnitude estimate at least, for the final answer.

General Question for MS/PhD Examinations (Climate/Chemistry)

Ruscher (1 hour)

Discuss the radiative properties of ozone with respect to shortwave radiation (insolation). How do these relate to the development and annual variation of the so-called ozone hole?

General Question for MS/PhD Examinations (Climate/Chemistry)

Ruscher (1 hour)

Discuss the radiative properties of ozone, water vapor, carbon dioxide, and ozone depleting substances (provide some specific examples of these) with respect to longwave radiation in the atmosphere. How are these radiative properties related to potential to exacerbate the so-called greenhouse effect?

Here are some initial questions for the Fall 2005 exam.

1. [General - Ruscher - 60 min.] It has been said that the primary reason why we observe westerly winds that increase with height in the troposphere in the midlatitudes is because it is warmer in the tropics than in high latitudes. Explain (with diagrams) how this relates to the hydrostatic nature of the atmosphere, and how it relates to jet streams.

2. [General - Ruscher - 90 min.] Atmospheric composition is dominated by nitrogen and oxygen, yet it is the effects of several so-called minor, trace, and variable gases that dominate most discussion of weather and climate phenomena by the general public and popular press. Discuss (at a level appropriate for a scientist without much training in meteorology) the radiative/physical properties of each of these gases, and the ramifications that they have on weather and/or climate, if any. ***Note*** - several of these gases are multi-faceted in their impacts, so don't limit your responses to one per gas, in general.

   - water vapor (35% weight for this question)
   - ozone (35%)
   - chlorofluorocarbons (20%)
   - methane (or pick on other gas, 10%)

Turbulence Question for PhD prelim exam - Ruscher

Describe the importance of the Richardson number for the classification of turbulent shear flow. Include how it is related to both development and scaling of the turbulence kinetic energy equation.

Synoptic Question for PhD prelim exam - Ruscher

Look up

Describe in some detail how the following five methods of determining vertical motion are developed:

a) kinematic method
b) kinematic method with O'Brien correction
c) adiabatic method
d) QG method
e) Q vectors

Include comparisons that allow the judgment of each methods strengths and weaknesses.

General Question for PhD prelim exam - Ruscher

What is a surface energy balance? Write down the components of a surface energy balance and explain the Bowen Ratio, and the various flux and radiative components.

Draw a simple energy balance (appropriately scaled) for a middle latitude grass field on a sunny midday afternoon and in the middle of a clear night.

Synoptic/Dynamic Question (Ruscher – 1.5 hour)

Consider a flow situation at 300 hPa where a straight westerly jet has superimposed upon it a straight jet streak.

a. describe the force balance in the entrance and exit regions of the jet streak. Describe the evolution of these forces.
b. Describe and sketch the horizontal and vertical ageostrophic balances that would occur for this situation
c. How would such ageostrophic forcings produce perturbations in the pressure field? In particular, how would the sea level pressure pattern evolve under such a flow situation?
d. Provide one example of how one might obtain measurements or estimates of the vertical motion field in the vicinity of this flow situation, using standard available observations, in an effort to document the existence of such perturbations in the flow field.
e. Consider a similar flow situation under cyclonic curvature. How would the geometry of the ageostrophic circulations change?

Physical Question for All Students who have had PBL or Turbulence courses (1.5 hour; Ruscher)

a) Define the atmospheric boundary layer.
b) Describe the evolution of the height of the boundary layer over a typical diurnal cycle, under synoptic scale anticyclone conditions.
c) Describe the growth mechanisms for such a boundary layer, and a quantitative discussion of the importance of the Richardson number on boundary layer studies and stability classification.
d) Discuss the role of variations of cloud cover, wind speed, and soil moisture on diurnal boundary layer evolution.
e) Discuss a simple representative surface energy balance, including all radiative inputs and outputs, and distribution of net radiation into various fluxes for any time along your time evolution above (in part b).

(approx. 1.5 hour) – Ruscher

Explain the utility of Q-vectors in the diagnosis of (a) mid-latitude synoptic scale cyclones and (b) development of frontal systems. Your discussion should include definitions of the Q-vector in a form of your choice, using the equation below, if you wish. You should also include a discussion and definition of frontogenesis. Under what conditions might such a diagnostic approach for estimation of vertical motion in the vicinity of a frontal system or extratropical cyclone *not* be valid?

Q-G Omega Eq.

$$\left(\nabla^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = \frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[\vec{V}_g \cdot \vec{\nabla}\left(\frac{1}{f_0}\nabla^2\Phi + f\right)\right] + \frac{1}{\sigma}\nabla^2\left[\vec{V}_g \cdot \vec{\nabla}\left(-\frac{\partial \Phi}{\partial p}\right)\right]$$

$L = F_V$ - if cycl. ↑ w/height PVA $\omega < 0$ $+ F_T$ If WA OV, $\omega < 0$ veering wind

$L = -2\nabla_p \cdot \vec{Q}$

Physical / PBL Question (Ruscher - 1.5 hour)

A. Consider a surface energy balance over a healthy short grass field under sunny skies in springtime at midday, in the middle latitudes. Write down the surface energy balance, including all radiative forcing terms. Explain all terms. Indicate the sign of each term in the equation, and the relative magnitudes of terms.

B. Now consider the same situation under high pressure at night, for a nominally dry atmosphere. How does the energy balance change, compared to (A)?

C. Now discuss the effects of the following on the daytime balance discussed in (A):

- change the active grass to one of dead vegetation
- change the season from spring to winter, with a 10 cm, 2 day old snow pack
- discuss the effects of stratus clouds (also consider the effects of stratus clouds for the nighttime situation)
- discuss the changes produced if this energy balance is for an underlying ocean surface at 40 N, for both the east Pacific Ocean and the western Atlantic Ocean, just offshore

The diagnosis of vertical motion is one of the difficult problems which synoptic meteorologists must deal with in research and operational settings. This question deals with aspects of such diagnosis in the context of a very specific example. You must answer all three parts; weights are given for each part. [One hour]

(a) [20%] One of the types of imagery available to meteorologists for the purpose of satellite interpretation is so-called "water vapor imagery". Discuss briefly the characteristics of the radiation involved, the meteorological variable and part of the atmosphere involved in the radiation, and the characteristics of the imagery (relationship of gray-scale to the weather element). Also, contrast water vapor imagery to visible and conventional infrared imagery in your answer.

(b) [60%] Water vapor imagery is widely used by meteorologists all over the world for various purposes. Some controversy about its use has been noted, however, regarding the inference of vertical motion just upstream of the mature middle-latitude cyclone; there is often a marked contrast in radiation intensity on the imagery in this region. Discuss how you would go about attempting to evaluate vertical motion (*without* the use of a numerical model) in this region of sharp gray-scale contrast (what kinds of analyses and calculations would be most useful?). In your answer, include some background on the problem (what are the expectations for vertical motion in this region based on observations and theory of synoptic scale cyclones?) and include at least one sketch.

(c) [20%] Discuss how a numerical model simulation might assist in the diagnosis of vertical motion upstream of the cyclone for individual cases of interest.

Optional general synoptic question for anyone (30 minutes; Ruscher):

Discuss how jet stream dynamics can play a role in intensifying and/or weakening surface cyclones. In particular, discuss the importance of the placement of a jet streak with respect to the surface cyclone and its development. Include a discussion of front- and rear-quadrant jet dynamics and secondary horizontal circulations and associated

This question is in 3 parts. Parts (a)-(c) will be given equal weight. Given the turbulence kinetic energy equation below,

$$\frac{\partial \bar{e}}{\partial t} = -(\overline{u'w'})\frac{\partial \bar{u}}{\partial z} + \frac{g}{\bar{\theta}}(\overline{w'\theta'}) - \frac{1}{\rho}\frac{\partial}{\partial z}(\overline{w'p'}) - \frac{\partial}{\partial z}(\overline{ew'}) - \epsilon$$

(a)

(i) Give the expression for the Richardson number and show how it is determined.

(ii) Explain two different ways in which turbulence can be created, and illustrate them through the TKE equation which terms are involved.

(iii) How is turbulence destroyed (use the equation to elaborate)

(b) Illustrate the diurnal cycle of h, the boundary layer height, for a middle-latitude overland location on the vernal equinox, which was dominated by high pressure overnight. Skies were clear overnight, but about 3 hours after sunrise, some stratocumulus clouds formed, breaking up about 3 hours later. Plot a curve for h as a function of t, beginning and ending at local midnight. You may make assumptions if you must to work through this problem, to add information (not change it!), but state them clearly. You may include text here to elaborate on your thought process.

(c)

(i) When are the processes you identified in part a working on your diagram, if at all? Illustrate them.

(ii) Add a plot of Richardson number to your plot of h vs. t, by using a new scale for the ordinate axis. You should comment about your rationale here, as well.

A very "hot" issue in Tallahassee right now involves the construction of small-scale medical waste incinerators. These incinerators burn waste around the clock at a temperature of approximately 1500°F. Some in state and local government have concerns about the prospects for local and regional impacts on air quality. Suppose that the county's emergency planning office wants to evaluate the impacts on air quality at the present incinerator site, off Springhill Road, and a possible additional site, near Lake Jackson. Discuss in detail the procedures you would recommend to accomplish this, considering likely sources of data. How much confidence do you feel should be ascribed to the results of the evaluation you describe and why?

Discuss, starting with hydrostatics, the gas law, and Newton's second law, why there are westerlies in the middle latitudes in the troposphere. Also, discuss why the speed of the westerly current increases with height in the troposphere. Also, why do we find easterlies in the stratosphere?

Provide the basic assumptions embodied within the quasi-geostrophic approximation. Next discuss, using QG-theory, why, when looking at a satellite picture of a mature extratropical cyclone, one sees a "comma"-shaped head, with a large expanse of cloudiness near and to the northeast of the low pressure system. In addition, cloudiness typically is confined to somewhat narrower bands to the southwest of the low center; explain why.

Discuss each of the following controversial ideas as related to the notion of antropogenic factors influencing atmospheric changes. You do not have to present your own point of view, rather, I am interest here in seeing what the scientific arguments are related to each topic:

a) nuclear winter
b) global warming
c) acid rain
d) the ozone hole

Doppler radar observations of squall line structure have led to a conceptual model of a squall line as proposed by Houze et al., (1989). Draw this conceptual model in a vertical cross section and discuss the mechanisms for:

a) the trailing stratiform region

b) descending rear inflow

c) ascending rear outflow

d) the 'bright band' as depicted on radar imagery

Using hydrostatics and basic arguments related to Newton's Laws of Motion, explain why winds aloft are westerly in the troposphere and why these westerly wind speeds increases with height in the troposphere. Include diagrams/sketches in your response.

Explain and contrast barotropic and baroclinic instability as they pertain to synoptic scale disturbances. Be sure to include information about both the theoretical and practical aspects of these instability mechanisms. Also, describe the difference between a barotropic and baroclinic atmosphere.

(Ruscher; 1 hour).

Please read each part of the question and answer each part separately in your blue book.

The quasi-geostrophic system of equations includes the following equation:

$$\left(\nabla^2 + \frac{f_o^{\,2}}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = \frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[\vec{V}_g\cdot\vec{\nabla}\left(\frac{1}{f_0}\nabla^2\Phi + f\right)\right] + \frac{1}{\sigma}\nabla^2\left[\vec{V}_g\cdot\vec{\nabla}\left(-\frac{\partial\Phi}{\partial p}\right)\right]$$

A B C

$L = F_V + F_T$

(1) What is the name of this equation and at what vertical level is it applicable?

Q-G Omega → appr. at 500mb b/c

(2) According to this equation, vertical motion is related to two physical processes; what are they and which terms do they correspond to? vertical deriv. of Geost. Vort. Adv (B) + Advection of Thickness by Geostrophic Wind (C)

(3) When does term **A** represent *upward* vertical motion (assume a wave-like solution here)? [Hint: it might be easier to define upward motion first, using the symbols above.] when F_V ↑ w/height, ω<0 PVA & when F_T shows WAOV, ω<0

(4) What is required for terms **B** and **C** to be indicating *upward* vertical motion? Discuss the process and illustrate graphically the appropriate fields.

$L = -2\nabla_p \cdot Q$ → when conv. Q : ω<0 rising

Eee (5) What kinds of assumptions are invoked to develop this equation from the primitive equation set? Give two atmospheric situations where use of this equation would not seem appropriate based on these assumptions.

Eep (6) Name the other three primary equations in the quasi-geostrophic set and tell as much as you can about them (for example: prognostic or diagnostic; processes involved, etc.).

- Static stability eq.
- vorticity eq.
- Tendency eq. - eq. w/ χ in it

Synoptic question (general) - one hour

The two equations below form the basis of a particular set of equations often used in synoptic and dynamic meteorology. Discuss the complete system of equations, their appropriate use and limitations, and relevant assumptions for their application. Discuss the details of each of the two equations below for diagnosis of weather systems.

$$\left(\nabla^2 + \frac{f_o^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = \frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[\vec{V}_g \bullet \vec{\nabla}\left(\frac{1}{f_0}\nabla^2\Phi + f_0\right)\right] + \frac{1}{\sigma}\nabla^2\left[\vec{V}_g \bullet \vec{\nabla}\left(-\frac{\partial\Phi}{\partial p}\right)\right]$$

A B C

$$\left(\nabla^2 + \frac{f_o^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\chi = -f_o\,\vec{V}_g \bullet \vec{\nabla}\left(\frac{1}{f_o}\nabla^2\Phi + f\right) + \frac{f_o^2}{\sigma}\frac{\partial}{\partial p}\left(-\vec{V}_g \bullet \vec{\nabla}\frac{\partial\Phi}{\partial p}\right)$$

A B C

Question #5

Turbulence Question (one hour)

Derive the kinetic energy equation starting with the equation of motion (written as a local tendency of the zonal wind). Show how the Richardson number can be derived from terms of this equation, and give an interpretation for laminar, turbulent, and transitional flows in terms of the Richardson number.

Two fundamental relationships of quasi-geostrophic theory are shown in the following two equations —

$$\left(\nabla^2 + \frac{f_o^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = \frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[\vec{V}_g \cdot \vec{\nabla}\left(\frac{1}{f_0}\nabla^2\Phi + f_0\right)\right] + \frac{1}{\sigma}\nabla^2\left[\vec{V}_g \cdot \vec{\nabla}\left(-\frac{\partial\Phi}{\partial p}\right)\right] \qquad (1)$$

A B C

and

$$\left(\nabla^2 + \frac{f_o^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\chi = -f_o\,\vec{V}_g \cdot \vec{\nabla}\left(\frac{1}{f_o}\nabla^2\Phi + f\right) + \frac{f_o^2}{\sigma}\frac{\partial}{\partial p}\left(-\vec{V}_g \cdot \vec{\nabla}\frac{\partial\Phi}{\partial p}\right) \qquad (2)$$

A B C

(**a**) Name these two equations and give complete physical interpretations for each term, including the level at which they are valid. (**b**) What assumptions are made in order to develop this set of diagnostic equations? That is to say, can we apply this equation to any synoptic situation and does it cover the importance of any and all physical processes which could have an influence on the terms on the left hand side? (**c**) Suppose we were interested in a situation of a developing wave cyclone. Show how each of the terms in each equation would be related in order that maximum intensification is likely. Include sketches or diagrams in your response.

Question for Rick Sluben for M. S. Comprehensive Exam (Ruscher; 1 hour)

One form of the Petterssen development equation is given by:

$$\frac{\partial Z_0}{\partial t} = A_Z - \frac{R}{f}\nabla^2\left(\frac{g}{R}A_{\Delta z} + S + H\right) - V_0 \cdot \nabla Z_0 - Z(\nabla \cdot V) \qquad (1)$$

where

$$A_Z \equiv -V \cdot \nabla Z$$

$$A_{\Delta z} \equiv -V \cdot \nabla(\Delta z)$$

$$S \equiv \ln\left(\frac{p_0}{p}\right)\overline{\omega\,(\Gamma_a - \Gamma)}$$

$$H \equiv \ln\left(\frac{p_0}{p}\right)\frac{1}{C_p}\frac{\overline{dW}}{dt}$$

and a subscript 0 refers to the surface and non-subscripted terms refer to some upper level in the troposphere.

(1) How is cyclogenesis defined with this equation?

(2) At what level in the troposphere do we evaluate the terms on the right-hand side of Eq. 1? One term in (1) can immediately be eliminated. Which one is it?

(3) Which other term in (1) is normally ignored for most synoptic scale situations?

(4) Discuss each of the remaining terms of the development equation, and give an illustration of how each term may contribute to cyclogenesis. Include sketches or descriptions of processes which would lead to cyclogenesis.

The quasi-geostrophic system of equations include a static stability equation, a vorticity equation, a tendency equation, and the following equation:

$$\left(\nabla^2 + \frac{f_o^{\,2}}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = \frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[\vec{V}_g \cdot \vec{\nabla}\left(\frac{1}{f_0}\nabla^2\Phi + f\right)\right] + \frac{1}{\sigma}\nabla^2\left[\vec{V}_g \cdot \vec{\nabla}\left(-\frac{\partial\Phi}{\partial p}\right)\right]$$

A B C

(1) What is the name of this equation and at what vertical level is it applicable?

(2) According to this equation, vertical motion is related to two physical processes; what are they and which terms do they correspond to?

(3) When does term A represent *upward* vertical motion (assume a wave-like solution here)? (Hint: it might be easier to define upward motion first, using the symbols above.)

(4) What is required for terms B and C to be indicating *upward* vertical motion? Discuss the process and illustrate graphically the appropriate fields.

(5) What kinds of assumptions are invoked to develop this equation from the primitive equation set? Give two atmospheric situations where use of this equation would not seem appropriate based on these assumptions.

Question for M. S. Comprehensive and Ph.D. Qualifying Exam (Ruscher; 1 hour)

A prognostic equation often used in synoptic meteorology is given by:

$$\frac{\partial Z_0}{\partial t} = A_Z - \frac{R}{f}\nabla^2\left(\frac{g}{R}A_{\Delta z} + S + H\right) - \boldsymbol{V}_0 \cdot \nabla Z_0 - Z(\nabla \cdot \boldsymbol{V}) \qquad (1)$$

where

$$A_Z \equiv -\boldsymbol{V} \cdot \nabla Z$$

$$A_{\Delta z} \equiv -\boldsymbol{V} \cdot \nabla(\Delta z)$$

$$S \equiv \ln\left(\frac{p_0}{p}\right)\overline{\omega\,(\Gamma_a - \Gamma)}$$

$$H \equiv \ln\left(\frac{p_0}{p}\right)\frac{1}{C_p}\overline{\frac{dW}{dt}}$$

and a subscript 0 refers to the surface and non-subscripted terms refer to some upper level in the troposphere.

(1) What is the name of this equation? (5%)

(2) How is cyclogenesis defined with this equation? (10%)

(3) At what level in the troposphere do we evaluate the terms on the right-hand side of Eq. 1? (10%)

(4) What is the form of the equation which is used most typically? That is, show which terms are normally important and discuss why one or more other terms are not evaluated routinely. (20%)

$A_{\Delta z}$ – WAA for cycl. → S & H

(5) Define and discuss each of the remaining terms, and give an illustration of how each term may contribute to cyclogenesis, including the stage or part of the life cycle of the cyclone at which each term becomes involved typically. Include sketches or descriptions of processes which would lead to cyclogenesis. (55%)

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There are many ways in which vertical motion may be diagnosed in the troposphere. Some of the methods include the (a) kinematic method, (b) the adiabatic/isentropic method(s), (c) the vorticity method, (d) the infrared satellite photograph method, and (e) use of quasi-geostrophic theory.

(Part I) Pick one of the methods from (a) - (d) and give a **full** description of the method and how it can be used to estimate/diagnose vertical motion. (30%)

(Part II) A convenient method for determining the quasi-geostrophic forcing effects on vertical motion is to use so-called $\boldsymbol{Q}$-vectors, where $\boldsymbol{Q}$ is defined as follows:

$$\boldsymbol{Q} \equiv -\frac{R}{\sigma p}\begin{bmatrix} \dfrac{\partial \boldsymbol{V}_g}{\partial x} \bullet \nabla_p T \\ \dfrac{\partial \boldsymbol{V}_g}{\partial y} \bullet \nabla_p T \end{bmatrix} = \begin{bmatrix} Q_x \\ Q_y \end{bmatrix} \qquad (1)$$

Then the quasi-geostrophic omega equation becomes:

$$\left(\nabla_p^2 + \frac{f_0^2}{\sigma} \frac{\partial^2}{\partial p^2} \right) \omega = -2 \nabla_p \bullet \boldsymbol{Q} - \frac{R}{\sigma p} \beta \frac{\partial T}{\partial x} \qquad (2)$$

Discuss each term in this equation and discuss how this equation can be used to diagnose vertical motion. (70%)

- Using basic principles such as the ideal gas law and the hydrostatic balance, tell why

There exist westerly winds in the middle latitude tropospheric circulation
There is an increase in westerly wind speed with altitude
The westerly wind speed decreases with altitude in the stratosphere, and may become easterly

If you consider any forces or force balances in your explanation, you must explain the evolution of these forces; in any case, please keep your discussion basic, but comprehensive!

- **Synoptic/Dynamic Question** (Ruscher – 1.5 hour)

Consider a flow situation at 300 hPa where a straight westerly jet has superimposed upon it a straight jet streak.

a. describe the force balance in the entrance and exit regions of the jet streak. Describe the evolution of these forces.
b. Describe and sketch the horizontal and vertical ageostrophic balances that would occur for this situation
c. How would such ageostrophic forcings produce perturbations in the pressure field? In particular, how would the sea level pressure pattern evolve under such a flow situation?
d. Provide one example of how one might obtain measurements or estimates of the vertical motion field in the vicinity of this flow situation, using standard available observations, in an effort to document the existence of such perturbations in the flow field.
e. Consider a similar flow situation under cyclonic curvature. How would the geometry of the ageostrophic circulations change?

Physical – PBL Question (Ruscher – 1.5 hour)

A. Consider a surface energy balance over a healthy short grass field under sunny skies in springtime, in the middle latitudes. Write down the surface energy balance, including all radiative forcing terms. Explain all terms. Indicate the sign of each term in the equation.

B. Now consider the same situation under high pressure at night, for a nominally dry atmosphere. How does the energy balance change, compared to (A)?

C. Now discuss the effects of the following on the daytime balance discussed in (A):

- change the active grass to one of dead vegetation
- change the season from spring to winter, with a 10 cm, 2 day old snow pack

Petterssen speaks of cyclogenesis in terms of his well-known "development equation" —

$$\frac{\partial Z_0}{\partial t} \doteq A_Z - \frac{R}{f}\nabla^2\left(\frac{g}{R}A_{\Delta z} + S + H\right)$$

where the following definitions are used:

vorticity advection:	$A_Z \equiv -V \cdot \nabla Z$
thickness advection:	$A_{\Delta z} \equiv -V \cdot \nabla(\Delta z)$
stratification:	$S \equiv \ln\left(\frac{p_0}{p}\right)\overline{\omega\,(\Gamma_a - \Gamma)}$
heating	$H \equiv \ln\left(\frac{p_0}{p}\right)\frac{1}{C_p}\overline{\frac{dW}{dt}}$

(**a**) Define each of the terms separately, including symbols used, and including the level at which each term is valid. (**b**) How would you define cyclogenesis, based on the equation above? (**c**) Give a thorough physical explanation of each term in the development equation, and give an example of a situation where cyclogenesis is supported. Include diagrams or sketches of appropriate variables.

Suppose you were given the code for a three-dimensional numerical weather prediction model of the atmosphere (e.g., the FSU global spectral model). Your task is to adapt the model for use in atmospheric chemical studies. (**a**) What chemical species (or families) would you consider to be most important to include in short- and medium-range forecast (out to 10 days) runs. Discuss very briefly the significance of each species/family. (**b**) How would you like to parameterize boundary layer processes involving these chemical species, given that the current model uses standard K-theory? If using the existing K-theory, what assumptions would need to be made? If you would use a different method, describe it. (**c**) Describe in a paragraph or two a scientific problem which might be suitable for investigation with such a model. What kind of hypothesis would you be testing and what kinds of experiments might you devise?

[Synoptic/Dynamic – Ruscher – 1 hr] The Sutcliffe development equation (sometimes known as the Petterssen-Sutcliffe equation), now more than 60 years old, still has some relevance in cyclogenesis research, primarily through the more recent work of Smith, Zwack, and Okossi. In its original form, sea level absolute vorticity tendency is predicted using:

$$\frac{\partial(\zeta+f)_0}{\partial t} = -\vec{V}\bullet\vec{\nabla}(\zeta+f) - \frac{R_d}{f}\nabla^2\left(\frac{g}{R_d}A_{\Delta z} + S + H\right),$$

where the three terms inside the Laplacian operator correspond to thickness advection, stratification, and heating, respectively, e.g.,

$$A_{\Delta z} \equiv -\vec{V}\bullet\vec{\nabla}(\Delta z),$$

$$S \equiv \ln\left(\frac{p_0}{p}\right)\overline{\omega(\Gamma_a - \Gamma)}, \; and$$

$$H \equiv \ln\left(\frac{p_0}{p}\right)\frac{1}{c_p}\overline{\frac{dW}{dt}}.$$

[Synoptic – Ruscher – 1 hr] Describe in some detail how the following five methods of determining vertical motion are developed:

a) kinematic method
b) kinematic method with O'Brien correction
c) adiabatic method
d) QG method
e) Q vectors

Include comparisons that allow the judgment of each of the method's strengths and weaknesses.

Numerical Weather Prediction (Ruscher)

Answer ONE of the following two questions:

(1) Compare and contrast finite difference and spectral techniques for numerical weather prediction. Include the advantages and disadvantages of each method, as well as common problems that modelers face regardless of which method they adopt. Take a few minutes to outline your answer before you start to write.

(2) Discuss the following concepts related to numerical weather prediction.

(a) Courant-Friedrichs-Lewy (CFL) condition
(b) subgrid-scale parameterization
(c) truncation error
(d) time step
(e) semi-implicit time difference schemes

Synoptic/Dynamic Meteorology (Ruscher – 1 hr)

(a) 20% of problem: Define mathematically the words cyclogenesis and cyclolysis, using the term $\partial/\partial t\,(\zeta + f)$. Explain the full physical meaning of this term.

(b) 80% of problem: The question appears below, but is prefaced by the following. Using (a), you can define cyclogenesis using the Sutcliffe development equation (sometimes known as the Petterssen-Sutcliffe equation),

$$\frac{\partial(\zeta + f)_0}{\partial t} = -\vec{V} \bullet \vec{\nabla}(\zeta + f) - \frac{R_d}{f}\nabla^2\left(\frac{g}{R_d}A_{\Delta z} + S + H\right), \qquad (1)$$

now more than 60 years old. It still has some relevance in cyclogenesis research, primarily through the more recent work of Smith, Zwack, and Okossi. In (1), the three terms inside the Laplacian operator correspond to thickness (Δz) advection (nominally from the surface to some upper tropospheric level), stratification, and heating, respectively, e.g.,

$$A_{\Delta z} \equiv -\vec{V} \bullet \vec{\nabla}(\Delta z),$$

$$S \equiv \ln\left(\frac{p_0}{p}\right)\overline{\omega(\Gamma_a - \Gamma)}, \textit{ and}$$

$$H \equiv \ln\left(\frac{p_0}{p}\right)\frac{1}{c_p}\overline{\frac{dW}{dt}}.$$

Here an overbar represents a layer average. In the other terms, a subscript 0 (on the left-hand side) represents a calculation at sea level, and the advection term is evaluated in the upper troposphere.
Question: What are sufficient conditions for cyclogenesis for each of the terms on the right hand side of (1)? Give mathematical expressions, physical interpretations, and a sketch or diagram for each of the four terms.

General Meteorology (Ruscher)

It is common practice in meteorology to make estimates when precise measurements of a quantity are not known. Please comment on the veracity of the following common observations, and the statements that follow them. In each case, use a physical basis and discuss what the observer should do, if at all possible, to provide more precise measurements than just looking up the "handbook" version of how to do this. Or, provide a scientific rationale that can explain how an observer might quantify error associated with the reported measurement.

a. Today's precipitation is 0.35", which translates to 3.5" of new snow. Yesterday we received 0.67", or 6.7" of snow. It was very cold and windy yesterday, but was near freezing today.
b. The satellite retrieved a brightness temperature of 285 K, making the surface temperature 12°C.
c. Today's cloud cover is broken cirrus at 25,000 ft. However, upon reflection, whenever we have cirrus clouds at the TLH airport, they are *always* reported at 25,000 ft. Are there never cirrus clouds at altitudes other than 25,000 ft?
d. It is raining; therefore the relative humidity is 100%. [Perhaps the observer does not wish to take a sling psychrometer measurement in the rain, thus getting wet in the process!]

Quasi-geostrophic Omega and Tendency Equations (Ruscher)

Discuss the limitations of the quasi-geostrophic set of equations for diagnosis of vertical motion (ω= dp/dt) and geopotential tendency ($\chi = \partial\Phi/\partial t$) following the form presented by Holton, Bluestein, and most other authors who write about quasi-geostrophic theory.

$$S\nabla^2\omega + f_0^2\frac{\partial^2\omega}{\partial p^2} = -f_0\frac{\partial}{\partial p}\left[-\vec{V}_g \bullet \vec{\nabla}(\zeta_g + f)\right] + \nabla^2\left(\vec{V}_g \bullet \vec{\nabla}\alpha\right)$$

$$S\nabla^2\chi + f_0^2\frac{\partial^2\chi}{\partial p^2} = -f_0\left[\vec{V}_g \bullet \vec{\nabla}(\zeta_g + f)\right] - \frac{f_0^2}{S}\frac{\partial}{\partial p}\left(-\vec{V}_g \bullet \vec{\nabla}\alpha\right)$$

Here, S is the static stability parameter, taken to be a constant, and α = RT/p is the specific volume. In particular, what processes are not considered, and what assumptions are made that prevent routine diagnosis of vertical motion and geopotential tendency during most typical interesting weather events?