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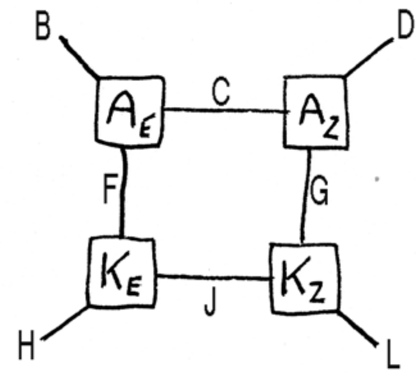
Comprehensive Final Exam — 2006

65 pts possible

1. (10 pts) Consider the energy box figure on this page. Use the letter labels provided.

a. (3 pts) Draw arrows to indicate the direction of energy flow for these quantities: D, F, and H.



b. (3 pts) Match these letters in the figure at left with the attached choices drawn from equations (4.62) through (4.69)

J in figure is eqn: ______

B in figure is eqn: _____ C in figure is eqn: ______

c. (4 pts) Fill in the correct letter. The energy conversion not directly measured in practice is _______. In contrast, the energy conversion _____, is estimated by an approximate formula that includes parts [u_g] and [v]. The energy conversion approximated as 'warm air rising or cold air sinking' is _____. The 'barotropic' conversion is letter ____.

2. (4 pts) Summary chart of momentum cycle in the atmosphere was presented on the web page and is duplicated below.

```
200 mb              < - 5 - - - <            < - 3 -
                     - 6 - >      4                           /\
                           |                                  2
                           7                                  |
                           \/                    1 - - >
                                                 |
Surface  ______|____ ____8 \/ ___________|______ ______/\____ _______|_____
               60N                   30N                          EQ
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Write the correct number to the left of each process that best matches the number on the diagram.

___ [u'v'] momentum flux ___ source of westerly momentum

___ ICZ convective transport of momentum ___ Ferrel cell momentum flux

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3. (2 pts) Write down the formula for the zonal average of T at 30 degrees north and 200 mb. Define all variables you introduce.

4. (6 pts) True (T) or false (F), continued.

T F The ICZ lies between 10S and 10N around the globe during June-August.

T F Western boundary currents are found along the west coasts of some continents.

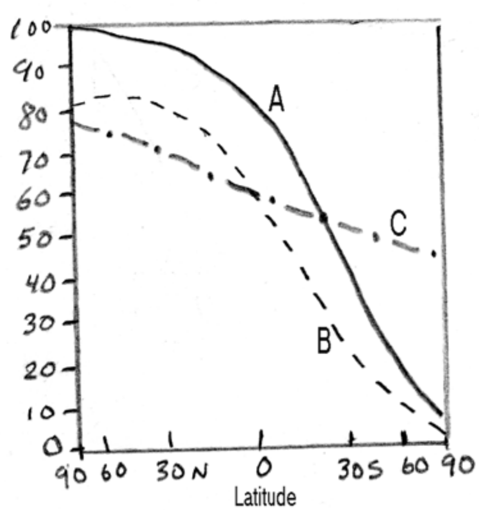
T F The radiosonde network has sufficient coverage (as judged by Table 2.2) over all the land areas, but not over the oceans.

T F The efficiency factor, ε, is mainly positive in the tropics.

T F The *range of latitudes* having surface westerlies is greater than the range of the latitudes having surface easterlies.

T F The rising branch of the Hadley cell mainly occurs in thunderstorms.

5. (6 pts) Radiative balance for Uranus. Uranus has a tilt of the rotation axis of > 80 degrees such that the north pole faces the sun far more than the south pole. A colleague at NASA asks you to help her interpret the radiation data plotted on the chart at right by answering the questions:



a. The albedo at the north pole is ________ percent.

b. (1.5 pts) Which curve is what? (Place the letter in the blank)

___ incoming solar radiation

___ outgoing IR radiation

___ absorbed solar radiation

c. Net radiation zero at latitude ______ degrees

d. The heat transport a maximum at latitude ______ degrees

e. (1.5 pts) There is something clearly wrong with the data. Explain why this data cannot be correct.

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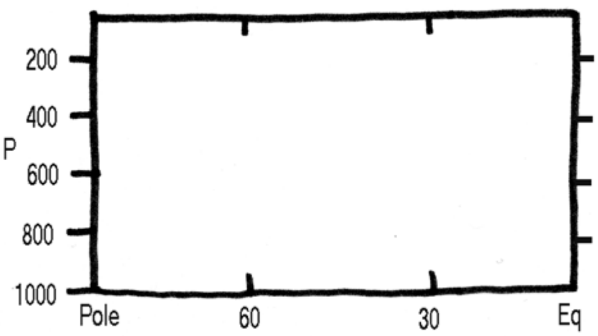
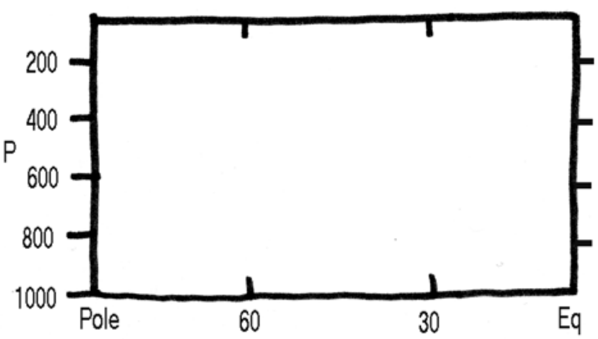
6. The Kuo-Eliassen equation.

a. (4 pts) Explain how a Ferrel cell maintains thermal wind balance. Discuss eddy and Ferrel cell properties.

b. (3 pts) On the diagram at right, draw meridional cross sections of the observed eddy meridional potential temperature heat fluxes: $[\Theta'v']$. Be sure to define the convention you use to represent the fluxes.



c. (3 pts) Let the Kuo-Eliassen equation be approximated by: $-\Psi = -\partial^2[\Theta'v']/\partial y^2$. Using your answer in part b., deduce the streamfunction field (Ψ). Draw the Ψ field on the chart at right being consistent with what you drew above. Be sure to indicate clearly the sign(s) in your answer.



d. (4 pts) Assume that the meridional circulation: velocities (v, ω), moves <u>clockwise</u> around your chart. Write down the correct formulas (including correct sign) to define v and ω from your Ψ field.

7. (5 pts) Life-cycles of extra-tropical cyclones

a. (3 pts) Most *observed* frontal cyclones appear to grow by the baro-__________ mechanism as judged by sector averages of *observations*. Those observations show _________-ward eddy __________ fluxes.

b. (2 pts) What is the principal structural difference between nonlinear and linear *simulations* of these cyclones?

8. (12 pts) The latent heat flux at 10N is -10^{15} W. Assume that the meridional velocity field is specified by $v = A*(0.5 - P/P_0)$ and the specific humidity field by: $q = Q (P/P_0)^3$ where A is 2 m/s and Q is to be determined in gm of water vapor per kg of air. P is the pressure elevation which ranges from 0 to P_0 where $P_0 = 10^5$ Pa. Some helpful information is on the attached sheet.

a. (6 pts) Find Q such that the specified latent heat flux is obtained.

b. (5 pts) Find the annual rainfall for the area 0 to 10 N assuming that: all the flux across 10 N falls out as rain and is spread evenly over this area. Express your answer in cm/yr. (Hint: first obtain the rain rate, expressed as m of water depth per second.)

c. (1 pt) Briefly explain why your answer to part b is (and *should be*) much less than the observed rainfall.

9. (6 pts) Perform/answer the specific task/question for the indicated figure.

a. Fig. (1) In the Southern Hemisphere moisture transport is a maximum *north*ward at latitude______S.

c. Fig. (2) Are the highs and lows shown here amplifying or decaying? _________________

d. Fig. (3) Is 500 mb u'v'. The figure implies that troughs at 40N, 40W are usually oriented from _________ to ________ (using compass directions)

b. Fig. (4) What 3-month season is most likely shown here? ____________.

c. Fig. (4) Place an 'H' inside each Hadley cell and an 'F' inside each Ferrel cell shown in the figure.

f. Fig. (5) What is the most likely variable plotted here? _____________

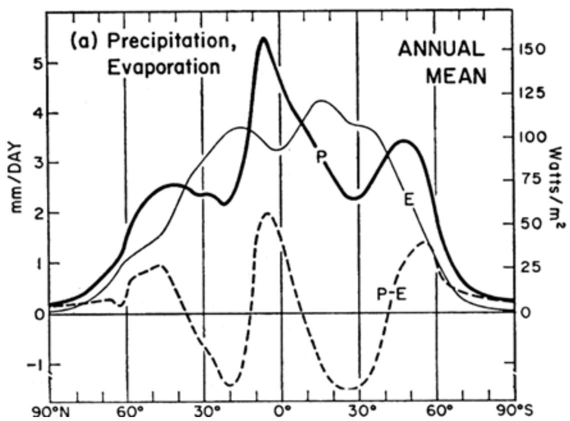


Fig.1

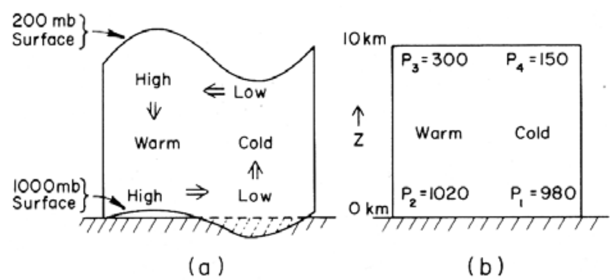


Fig. 2 (above)

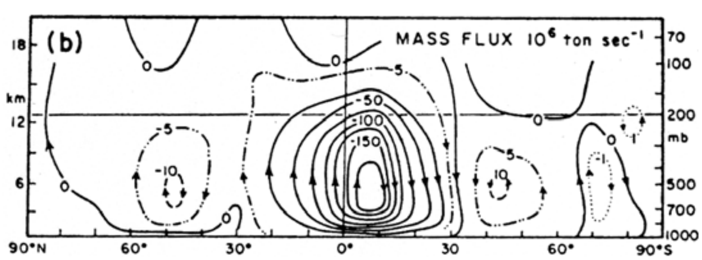


Fig. 3

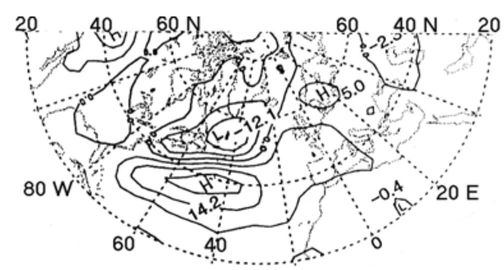
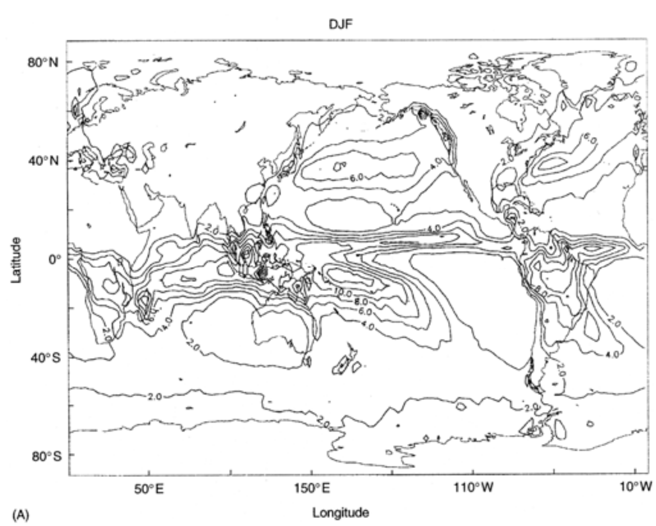


Fig. 4

Fig 5



Some helpful information:

$\sin(0) = 0.$	$\cos(0) = 1$
$\sin(10) = 0.17365$	$\cos(10) = 0.98481$
$\sin(30) = 0.5$	$\cos(30) = 0.86603$
$\sin(38) = 0.61566$	$\cos(38) = 0.78801$
$\sin(90) = 1.$	$\cos(90)= 0$

density of water: $\rho_w = 10^3$ kg/m^3

latent heat of vaporization at 20C: $L = 2.4\text{x}10^6$ J/kg

acceleration of gravity: $g = 9.81$ m/s^2

radius of earth: $r = 6.37 \text{ x } 10^6$ m

gas constant: $R = 287$ J/(K kg)

specific heat at constant pressure: $C_p = 1004$ J/(K kg) $\kappa = R/C_p = 0.28585657$

angular velocity of rotation: $\Omega = 7.292\text{x}10^{-5}$ s^{-1}

$\pi = 3.14159$

conversions:

1 W = 1 J/s 1 J = 1 N-m 1 N = kg m/s^2 1 Pa = N/m^2 = J/m^3

useful formulas:

$$E_i = \frac{C_1}{\lambda^5[exp(\frac{C_2}{\lambda T}) - 1]} \quad (3.1)$$

$$\text{heat transport} = \frac{2\pi a \cos\phi}{g} \int \overline{[v(C_p\text{T} + \Phi + Lq)]} dP \quad (3.3)$$

$$\psi = \frac{2\pi R}{g} \int_P^{P_0} [v] dP \quad (3.4)$$

$$[v] = \frac{g}{2\pi R} \frac{\partial \psi}{\partial p} \quad \text{and} \quad [\omega] = \frac{-g}{2\pi r^2 \cos\phi} \frac{\partial \psi}{\partial \phi} \quad (3.5)$$

$$\text{MSE} = \Phi + C_p T + Lq \quad (3.6)$$

$$p\alpha = RT \quad or \quad p = \rho RT \tag{1.17}$$

$$dp/dz = -\rho g \tag{1.18}$$

$$\mathbf{V}_g \equiv \mathbf{k} \times \frac{1}{\rho f}\nabla p \tag{2.23}$$

$$\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)_p + \frac{\partial \omega}{\partial p} = 0 \tag{3.5}$$

$$\frac{\partial A_Z}{\partial t} = GZ - CZ - CA$$
$$\frac{\partial A_E}{\partial t} = GE - CE + CA \qquad (4.57)$$
$$\frac{\partial K_Z}{\partial t} = -DZ + CZ - CK$$
$$\frac{\partial K_E}{\partial t} = -DE + CE + CK$$

$$A_Z = C_p \int [\epsilon][\overline{T}]dM \tag{4.58}$$

$$A_E = \frac{C_p}{2} \int \gamma[(\overline{T'})^2 + \overline{(T'')^2}]dM \tag{4.59}$$

$$K_Z = \frac{1}{2}\int [\overline{u}]^2 + [\overline{v}]^2 dM \tag{4.60}$$

$$K_E = \frac{1}{2}\int [(\overline{u'})^2 + (\overline{v'})^2] + [\overline{(u'')^2} + \overline{(v'')^2}]dM \tag{4.61}$$

where

$$\gamma = -\left(\frac{\theta}{T}\right)\left(\frac{P_r}{P}\right)^{\kappa}\left(\frac{\kappa}{P_r}\frac{\partial P_r}{\partial \theta}\right)$$

$$GZ = \int [\epsilon][\overline{Q}]dM \tag{4.62}$$

$$GE = \int \gamma[\overline{Q'}\,\overline{T'}]dM \tag{4.63}$$

$$CZ = -\int (\overline{\omega})_{\sigma}(\overline{\alpha})_{\sigma} dM \tag{4.64}$$

$$CE = -\int [\overline{\omega'}\,\overline{\alpha'} + \overline{\omega''\alpha''}]dM \tag{4.65}$$

$$CK = -\int [\overline{u'}\,\overline{v'} + \overline{u''v''}]\frac{\cos\phi}{r}\frac{\partial}{\partial \phi}\left(\frac{[\overline{u}]}{\cos\phi}\right)dM \tag{4.66}$$
$$- \int [\overline{u'}\,\overline{\omega'} + \overline{u''\omega''}]\frac{\partial}{\partial P}([\overline{u}])dM$$

$$CA = -C_p \int \left(\frac{\theta}{T}\right)[\overline{v'}\,\overline{T'} + \overline{v''T''}]\frac{1}{r}\frac{\partial}{\partial \phi}\left(\frac{[\epsilon][\overline{T}]}{[\overline{\theta}]}\right)dM \tag{4.67}$$
$$- C_p \int \left(\frac{\theta}{T}\right)[\overline{\omega'}\,\overline{T'} + \overline{\omega''T''}]\frac{\partial}{\partial P}\left(\frac{[\epsilon][\overline{T}]}{[\overline{\theta}]}\right)dM$$

$$DZ = -\int ([\overline{u}][\overline{F_x}] + [\overline{v}][\overline{F_y}])dM \tag{4.68}$$

$$DE = -\int [\overline{u'}\,\overline{F'_x} + \overline{v'}\,\overline{F'_y} + \overline{u''F''_x} + \overline{v''F''_y}]dM \tag{4.69}$$

where r is the earth's radius, $dM = r^2(\cos\phi/g)d\phi d\lambda dP$, λ is longitude, ϕ latitude.

$$\frac{\partial}{\partial t}\underbrace{\int \left(\frac{[u]^2}{2}\right)dm}_{(A)} + \int \underbrace{\left(\frac{[u]}{R}\right)}_{(B)} \underbrace{\left(\frac{1}{R}\frac{\partial R^2[uv]}{\partial y} + \frac{\partial R[u\omega]}{\partial P}\right)}_{(C)} dm$$
$$- \int f[u][v]dm + \int [u][F_x]dm = 0 \tag{4.12}$$

$$\frac{\partial A_j}{\partial t} = \underbrace{\frac{1}{g}\int_S \int_{P_2}^{P_1}\{\epsilon q\}dPdS}_{(A)} + \underbrace{\frac{1}{g}\int_S \int_{P_2}^{P_1}\{\epsilon\omega\alpha\}dPdS}_{(B)}$$
$$- \underbrace{\frac{C_p}{g}\int_S \int_{P_2}^{P_1}\epsilon\left\{\nabla_P \cdot (T\mathbf{V}_P) + \frac{\partial}{\partial P}(\omega T)\right\}dPdS}_{(C)} \tag{4.31}$$

$$[v] = \frac{\partial \psi}{\partial p} \quad \text{and} \quad [\omega] = -\frac{\partial \psi}{\partial y} \tag{6.46}$$

$$\frac{\partial [u_g]}{\partial p} = \frac{Rp^{\kappa-1}}{fP_{00}^{\kappa}}\frac{\partial[\theta]}{\partial y} \equiv \Upsilon\frac{\partial[\theta]}{\partial y} \tag{6.49}$$

$$A\frac{\partial^2 \psi}{\partial y^2} + 2B\frac{\partial^2 \psi}{\partial y \partial p} + C\frac{\partial^2 \psi}{\partial p^2} + D\frac{\partial \psi}{\partial y} + E\frac{\partial \psi}{\partial p} = \Upsilon\frac{\partial H}{\partial y} + \frac{\partial \chi}{\partial p} \tag{6.50}$$

$$A = -\Upsilon\frac{\partial[\theta]}{\partial p} \qquad B = \frac{\partial[u]}{\partial p} = \Upsilon\frac{\partial[\theta]}{\partial y} \qquad C = f - \frac{\partial[u]}{\partial y}$$

$$E = -\frac{\partial \Upsilon}{\partial y}\frac{\partial[\theta]}{\partial y} \qquad D = \frac{\partial \Upsilon}{\partial p}\frac{\partial[\theta]}{\partial y}$$

$$\chi = [F_x] + \frac{\partial[u'v']}{\partial y} + \frac{\partial[u'\omega']}{\partial p} \qquad H = -\left(\frac{\partial[\theta'v']}{\partial y} + \frac{\partial[\theta'\omega']}{\partial p}\right) + \frac{[Q][\theta]}{[T]}$$

$$\frac{\partial \zeta_a}{\partial t} + \mathbf{V}_{\psi}\cdot\nabla\zeta_a = -\mathbf{V}_{\chi}\cdot\nabla\zeta_a - \zeta_a D \equiv S$$