INDIA METEOROLOGICAL DEPARTMENT

QUESTION BANK

OF

ADVANCED METEOROLOGICAL TRAINING COURSE (AMTC)

SEMESTER-I EXAMINATION

BASED ON 174-181 BATCHES

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PAPER-I: DYNAMIC METEOROLOGY

India Meteorological Department

Meteorological Training Institute

Advanced Meteorological Training Course

PAPER- I : Dynamic Meteorology

Q. 1.Fill in the blanks:

1. _________ principle is a direct corollary to mass conservation law
2. ____________________ gradient wind is super Geostrophic.
3. Cyclonic gradient wind is _________ Geostrophic.
4. For a _______________ flow Ertel's potential vorticity remains conserved.
5. For a frictionless barotropic flow -------------------- remains conserved.
6. For a frictionless isentropic flow -------------------- remains conserved.
7. For Geostrophic approximation to be valid, Rossby number should be ________
8. For pure deformation motion streamlines are family of _________________ .
9. For pure rotation streamlines are family of _________________
10. For solid body rotation vorticity is ______.
11. Heat low __________ with height.
12. If wind flows from source of a physical property to some other point, then advection of the physical property at that point is _________.
13. In a barotropic atmosphere number of ρ, p solenoids is _________________
14. In baroclinic atmosphere density is the function of ____________________.
15. In barotropic atmosphere isobaric and isothermal surfaces _________________ .
16. In southern hemisphere around a trough isobars turn in ____________ sense.
17. Net vertically integrated convergence in a column above a point leads to __________ of pressure at that point.
18. Rising motion at a point leads to __________ of pressure at that point.
19. Total change of a field variable is given by __________ derivative of that.

20. Transport of any physical quantity by horizontal wind is called ______________.
21. Vertical transport of any physical quantity by wind is called ______________.
22. Warm core anti-cyclone __________ with height.

Q. 1 State with brief reason whether following statements are true or false:

1. A circular isobaric low moves in an easterly direction.
2. A circular isobaric pattern moves towards west.
3. A pole ward moving vortex gains cyclonic vorticity.
4. A poleward moving vortex loses cyclonic vorticity.
5. Absolute circulation remains conserved following a frictionless isentropic flow.
6. Absolute circulation remains conserved in a baroclinic flow.
7. Ageostrophic wind is parallel to acceleration.
8. Ageostrophic wind is solely responsible for atmospheric divergence.
9. Ahead of an upper air westerly trough surface pressure falls.
10. All heat lows are shallow.
11. An incompressible fluid flow is always non-divergent.
12. Anomalous circulation is stronger than normal circulation.
13. Anomalous flow is stronger than normal flow.
14. Anomalous flow is weaker than normal flow.
15. Anomalous low or high is stronger than normal low or high.
16. Anticyclonic gradient wind is sub-geostrophic.
17. Baroclinicity has no role in changing vorticity.
18. Cold core low intensifies with height.
19. Curvature of earth's surface has no effect on the momentum budget of earth's atmosphere.
20. Cyclonic gradient flow is super-geostrophic.
21. Cyclostrophic balanced flow is frequent very near to Equator.
22. Dines compensation principle is a direct corollary to the Law of conservation of mass.
23. Divergence causes expansion.
24. Equatorial belt is favorable for cyclostrophic flow.

25. For an incompressible fluid vertical motion is solely due to horizontal Divergence /convergence.
26. Geostrophicwind with constant value of Coriolis parameter is a divergent wind.
27. In a baroclinic atmosphere, isotherms are parallel to isobars.
28. Incompressible flow is non-divergent.
29. Inertial flow is always cyclonic.
30. LND has nothing to do with day to day weather.
31. Monsoon trough tilts towards south as height increases.
32. Net lateral vertically integrated divergence in a column over a point, results in fall of pressure at that point.
33. Rising motion at a point results into fall of pressure there.
34. Sea breeze doesn’t occur in a barotropic atmosphere.
35. Stably stratified PBL is characterized by convective turbulence
36. Stretching of vortex intensifies cyclonic vorticity.
37. Surface low pressure forms at the left exit of STWJ.
38. Thermally direct circulation doesn’t occur in a barotropic atmosphere.
39. Veering of geostrophic wind is associated with cold air advection.
40. Warm core high intensifies with height.

Q. 2 Answer the following questions:

1. Define and obtain an expression of atmospheric pressure at a point. Derive pressure tendency equation. (3+4=7)
2. Define circulation and vorticity along with their mathematical expressions. Write down Stoke’s theorem. Using this or otherwise, obtain relation between circulation and vorticity. Define Jacobian between pressure and temperature. Discuss the physical interpretation of the same. Derive Bjerkness circulation theorem. Discuss different mechanisms for change of relative circulation. (2+1+2+1+2+3+3=14)
3. Define circulation and vorticity. Obtain relation between them. Derive vorticity equation in (x,y,Θ,t) co-ordinate. Hence or otherwise obtain Ertel’s potential vorticity equation. Explain formation of trough on the lee side of a mountain for a westerly flow using above equation.

4. Define circulation and vorticity. Obtain relation between them. Obtain expression of vorticity for a solid body rotation. Hence or otherwise derive the expression for planetary vorticity.
5. Define circulation, Derive Bjerknes circulation theorem. Discuss the latitudinal and tipping effect in the change of relative circulation. (1+3+3=7)
6. Define divergence. Show that divergence is fractional rate of change of volume/area. Mention different dynamical approaches, followed, in establishing conservation laws. Following either of these approaches, derive mass continuity equation in (x, y, p, t) co-ordinate. Hence or otherwise moisture continuity equation.
7. Define geopotential at a point. Define One GPM. Derive Hypsometric equation. (1+1+5=7)
8. Define Geostrophic wind & write down its vector equation in isobaric co-ordinate. Explain, how horizontal temperature gradient can lead to the vertical shear of Geostrophic wind. Define thermal wind & derive its expression. Discuss the properties of thermal wind. Discuss stability analysis using wind shear hodograph. (2+2+4+2+4 =14)
9. Define isallobars. Show that a strong low pressure system, with circular symmetry, moves in a direction parallel to isallobaric gradient. Derive pressure tendency equation. Using this equation, discuss the importance of divergence and vertical motion in changing pressure at a point. Hence discuss the movement of a Sinusoidal isobaric pattern in westerly flow.
10. Define natural co-ordinate. Obtain horizontal equation of motion in natural co-ordinate. Hence or otherwise obtain the gradient wind equation. Discuss in detail all the feasible gradient flow. Show that inertial flow is always anticyclonic.
11. Define natural co-ordinate. Obtain horizontal equation of motion in natural co-ordinate. Hence or otherwise obtain the gradient wind equation. Discuss different physically possible solution of gradient equation and corresponding gradient flow. Show that inertial flow is always anti cyclonic, irrespective of the hemisphere. (1+4+2+4+3=14)
12. Define potential vorticity. Show that potential vorticity always remains conserved. Using conservation of potential vorticity, explain the formation of trough on the lee side of a large-scale mountain, for a westerly mean flow. (1+2½+3½ =7)

13. Define scale of atmospheric motion. What is scale analysis? What are the steps to be followed to perform scale analysis? Perform scale analysis on vorticity equation for mid latitude synoptic scale system. Hence or otherwise discuss the mechanisms of vorticity change at a place for such motion.
14. Define scale of atmospheric motion. Mention different scales of atmospheric motions with examples. What is scale analysis? What are the steps to be followed to perform scale analysis? Perform scale analysis on vertical momentum equation for mid latitude synoptic scale systems. Interpret physically the result. (1+2+1+2+6+2=14)
15. Define stream line & trajectory and write down their equations. Show that horizontal wind field at a point consists of pure translation, divergence, rotation and deformation. Obtain the stream line equations and pattern for pure rotation and divergence. Using Helmholtz's equation, obtain the expressions for divergent & rotational parts of horizontal wind vector.Define Velocity potential (χ) & stream function (ψ) (2+3+3+4+2=14)
16. Define stream line & trajectory and write down their equations. Show that horizontal wind field at a point consists of pure translation, divergence, rotation and deformation. Obtain the stream line equations and pattern for pure rotation and divergence. Using Helmholtz's equation, obtain the expressions for divergent & rotational parts of horizontal wind vector. Define Velocity potential (χ) & stream function (ψ) (2+3+3+4+2=14)
17. Define vorticity along with its mathematical expression. Derive vorticity equation in rectangular Cartesian co-ordinate. Explain physical interpretations for the Solenoidal & tilting term. Explain why surface LOPAR forms ahead of an upper air westerly trough. (2+5+4+3=14)
18. Derive continuity equation in isobaric co-ordinate. Hence discuss the kinematic method for computation of vertical velocity at different levels.
19. Derive expression for geostrophic wind. State its properties.
20. Derive pressure tendency equation. Discuss the different mechanisms of pressure fall. Hence or otherwise discuss the movement of a surface circular low under the influence of an upper air trough in westerlies.

21. Derive pressure tendency equation. Discuss in detail different mechanisms of pressure change. What is isallobars? Show that the centre of a circular isobaric pattern moves in a direction parallel to the isallobaric gradient. (6+4+1+3=14)
22. Derive pressure tendency equation. Hence, discuss different mechanisms of surface pressure fall.
23. Derive the gradient wind equation. Discuss with flow diagram for all feasible gradient flow. (3 + 4=7)
24. Derive vector equation of motion in a rotating frame of reference.
25. Derive vorticity equation in theta (θ) co-ordinate. Hence or otherwise show that for isentropic frictionless flow Ertel's potential vorticity remains conserved.
26. Derive vorticity equation. Discuss the physical interpretation of any two terms of the equation. Define Potential vorticity (PV). Show that in a frictionless flow it remains conserved. (5+4+1+4=14)
27. Explain how horizontal temperature gradient may lead to vertical shear of geostrophic wind. Hence or otherwise define thermal wind. Derive vector equation for thermal wind. Discuss salient features of thermal wind.
28. Explain how horizontal temperature gradient may lead to vertical shear of geostrophic wind. Define thermal wind. Derive the thermal wind equation. (3+1+3=7)
29. Explain schematically how horizontal temperature gradient can lead to vertical shear of geostrophic wind. Hence or otherwise define thermal wind. Derive thermal wind equation.
30. Explain, schematically using a neat diagram, how horizontal temperature gradient can lead to the vertical shear of Geostrophic wind. Define thermal wind & derive its expression. Discuss the properties of thermal wind. Define barotropic atmosphere in terms of pressure and density. Explain whether in such an atmosphere, thermal wind can exist or not.(3+4+2+2+3 =14)
31. Mention the dynamical approaches followed to establish conservation laws. Following any approach derive continuity equation in velocity divergence form in (x,y,z,t) co-ordinate. State & establish Dines compensation principle. Define level of non-divergence and explain its importance in day to day weather forecasting. (1+6+4+3 =14)

32. Show that a center of low-pressure system, with circular symmetry, moves in a direction parallel to gradient of pressure fall. Hence or otherwise, show that such pressure system tends to move westward in northern hemisphere. (4+3=7)
33. State Helmholtz's theorem for splitting a vector into rotational and divergent part. Hence or otherwise obtain the expressions for rotational and divergent wind.
34. State Helmhotz's theorem. Define rotational and divergent wind. Derive expressions for them. Define velocity potential and stream function. Obtain the stream lines for pure rotational and divergent motion.
35. What is meant by Scale analysis? What are the different steps, followed, in performing scale analysis? Write down horizontal momentum equations in spherical polar co-ordinate. Perform scale analysis on above equations. Hence or otherwise obtain and discuss geostrophic balance. (1+3+2+4+4=14)
36. what is scale analysis? What are the necessary steps to be taken during scale analysis? Perform scale analysis on vertical momentum equation for mid latitude synoptic scale system (1+2+4=7)

Q. 3 Solve the following numerical problems:

1. Geostrophic wind at 900hPa, 700hPa and at 500hPa are respectively wly 10m/s, swly 20m/s and wly 20m/s. Find out GTA in the layers 900-700 hPa and 700-500hPa. If the atmospheric column between 900 & 700 hPa was initially isothermal, then how long the above GTA pattern should continue to establish DALR in the column. Average height between 600hPa & 800hPa may be taken as 2.25 Km.
2. Show that for a given pressure gradient, $V_g < V_{gr} < 2V_g$, where V_{gr} is gradient wind and V_g is geostrophic wind.
3. An atmospheric column at 45^0N while crossing a mountain deflects towards north by 5^0. Given westerly flow at 45^0N decreases east ward at a rate 5m/s per 100km. If the mountain top and bottom are at 700hPa & 1000hPa, then find out the vorticity at mountaintop. If the wind speed at top of the mountain is 20m/s, then find out the curvature there. Top of the atmosphere may be taken at 200hPa.
4. The mean temperature in the layer between 750 and 500 hPA decreases eastward @ 3°C per 100 km. IF the 750 hPa geostrophic wind is from southeast at 20 m/s, what is the

geostrophic wind speed and direction at 500 hPa and what is the mean temperature advection in the 750 to 500 hPa layer? Assume $f=10^{-4}S^{-1}$

5. An air column at 60°N with S=0 initially, stretches from the surface to a fixed tropopause at 10 km height. If the air column moves until it is over a mountain barrier 2.5 km high at 45°N, what is its absolute and relative vorticity as it passes the mountain top? Also find out curvature of flow.
6. The divergence of horizontal wind at various pressure levels above a given station is shown in the following table. Compute vertical velocity in Pa/sec at different level. Assume at 1000 hPa there is no vertical motion.

Pressure (hPa)	Divergence ($x10^{-5}S^{-1}$)
1000	+0.8
850	+0.5
700	+0.2
500	0.0
300	-0.5
100	-1.0

7. The area of a large CB anvil, between 300 hPa & 100 hPa, is observed to increase by 20% in 10 minutes time. Calculate vertical velocity at 300 hPa, given it is zero at 100hPa.
8. Show that the height $Z(r)$ of the free surface of a cylindrical tank of liquid, in solid body rotation about the cylinder axis with angular velocity $'\Omega'$, at distance $'r'$ from the axis of the cylinder is given by $Z(r) = Z_0 + \frac{\Omega^2 r^2}{2g}$, where Z_0 is the height of free surface at the axis of rotation.
9. Suppose that a vertical column of the atmosphere at 45°N is initially isothermal below 700hPa. The geostrophic wind is 10 ms^{-1} from the south at 950 hPa, 14.14 ms^{-1} from the south west at 850 hPa, and 10 ms^{-1} from the west at 750 hPa. Calculate the mean Geostrophic temperature advection in the layers 950-850 hPa & 850-750hPa. Estimate the lapse rate created between those layers after 1 day.

10. The surface motion beneath a cyclone is described by the Stream function (ψ) and Velocitypotential (χ), $\psi(x,y) = \Psi\left\{1 - exp\left[-\frac{(x^2+y^2)}{L^2}\right]\right\}$ & $\chi(x,y) = Xexp\left[-\frac{(x^2+y^2)}{L^2}\right]$, where, Ψ & X are constants. Find out horizontal velocity and horizontal divergence.
11. Geostrophic wind at 700hPa, 500hPa and at 300hPa are respectively Swly 10m/s, Wly 20m/s and Nwly 20m/s. Find out GTA in the layers 700-500 hPa and 500-300hPa.
12. An atmospheric column at 45^0N while crossing a mountain deflects towards north by 5^0. Given westerly flow at 45^0N decreases east ward at a rate 5m/s per 100km. If the Mountain top and bottom are at 700hPa & 1000hPa, then find out the vorticity at mountain top.
13. Show that for gradient wind, V_{gr}, we have, $V_g \le V_{gr} \le 2V_g$.
14. Suppose that a vertical column of the atmosphere at 45°N is initially isothermal from 900 to 500 hPa. The geostrophic wind is 10 m s^{-1} from the south at 900 hPa, 10 m s^{-1} from the west at 700 hPa, and 20 m s−1 from the west at 500 hPa. Calculate the mean horizontal temperature gradients in the two layers 900-700 hPa and 700-500 hPa. Compute the rate of advective temperature change in each layer. How long would this advection pattern have to persist in order to establish a dry adiabatic lapse rate between 600 and 800 hPa? (Assume that the lapse rate is constant between 900 and 500 hPa and that the 800- to 600-hPa layer thickness is 2.25 km.)
15. The divergence of the horizontal wind at various pressure levels above a given station is shown in the following table. Compute the vertical velocity

Pressure (hPa)	$D_h (\times 10^{-5}\ s^{-1})$
1000	+0.9
850	+0.6
700	+0.3
500	0.0
300	-0.6
100	−1.0

at each level assuming an isothermal atmosphere with temperature 260 K and letting w = 0 ms^{-1} at 1000 hPa.

16. A tornado rotates with constant angular velocity ω. Show that the surface pressure at the center of the tornado is given by, $p = p_0 \exp(-\omega^2 r_0^2 / 2RT)$, where p_0 is the surface pressure at a distance r_0 from the center and T is the temperature (assumed constant). If the temperature is 288 K and pressure and wind speed at 100 m from the center are 1000 hPa and 100 m s^{-1}, respectively, what is the central pressure?
17. The divergence of the horizontal wind at various pressure levels above a given station is shown in the following table. Compute the vertical velocity

Pressure (hPa)	$D_h(\times 10^{-5}\ s^{-1})$
1000	+0.9
850	+0.6
700	+0.3
500	0.0
300	-0.6
100	−1.0

at each level assuming $\omega = 0$ hPa/s at 1000 hPa.

18. Show that PGF in isentropic co-ordinate is $\overrightarrow{\nabla_\theta}(C_P T + gZ)$

Q. 4 Write short notes on the following topics:

1. Ageostrophic wind.
2. Bjerkness circulation theorem
3. Blaton's equation
4. Continuity equation
5. Dines compensation principle
6. Kelvin's circulation theorem
7. Planetary boundary layer.
8. Potential vorticity
9. Pressure tendency equation.
10. Scale analysis of vorticity equation.
11. Scale analysis.

12. Streamline and trajectory
13. Thermal wind.
14. Wind shear hodograph for stability analysis.