INDIA METEOROLOGICAL DEPARTMENT

QUESTION BANK

OF

ADVANCED METEOROLOGICAL TRAINING COURSE (AMTC)

SEMESTER-II EXAMINATION

BASED ON 174-181 BATCHES

(2013-2021)

PAPER-I: GEOPHYSICAL FLUID DYNAMICS (GFD)

India Meteorological Department
Meteorological Training Institute
Advanced Meteorological Training Course

SEMESTER- II Final Examination (PAPER-I)

** *Geophysical Fluid Dynamics (GFD)* **

Q1. Fill in the blanks (any 10).

1. ---------- Gains westerly angular momentum due to friction.
2. ---------- is the source of all atmospheric energy.
3. ---------- is the source of horizontal KE.
4. ---------- loses westerly angular momentum due to orographic drag.
5. _____Region is the sink for horizontal K.E.
6. _____wave is an equatorially trapped wave.
7. A stably stratified boundary layer is parameterized using _____.
8. Critical wavelength of Rossby wave is _____ .
9. Ekman layer pumping is helpful for intensification when a cyclonic system is over_____ .
10. For a growing baroclinic wave thermal trough should _____ the Contour trough.
11. For a laminar flow flux Richardson number should be ----------.
12. For a turbulent flow flux Richardson number should be ----------.
13. Genesis of monsoon disturbances over Bay of Bengal is mainly due to _____ instability.
14. In a ---------- atmosphere, IE is proportional to PE.
15. In a stably stratified and hydrostatic mean flow, internal energy is proportional to _____ .
16. In a stably stratified PBL, turbulence is mainly _____ .
17. Long baroclinic waves are stabilized by _____ .
18. Monsoon trough is a region of----------instability.
19. Positive differential cyclonic vorticity advection results into _____.
20. Presence of mountain _____ zonal angular momentum in the tropics.
21. Rossby wave is a ----------wave.
22. Rossby wave transports energy ---------- of a mountain barrier.
23. Secondary circulation results into _____ .

24. Vertical transport of ---------- by IGW is opposite to each other.
25. Vertical transport of momentum and energy by IGW is _____ .
26. Warm advection results into _____ motion.
27. ----------wave is an equatorially trapped wave.

Q. 1 State with brief reasons whether the following statements are true or false

1. A zonal mean flow with cyclonic vorticity is inertially unstable.
2. Advection of cyclonic vorticity results into rising motion.
3. Any amount of Baroclinicity in the mean flow, ensures baroclinic instability.
4. CISK results from mutual competitive interaction between large scale flow and cumulus scale heating.
5. Divergent circulation converts IE to KE
6. Eddy PE of Baroclinic instability is maintained by $\overline{v'T'} > 0$.
7. In a barotropic atmosphere, APE is zero.
8. In a convective boundary layer θ_e increases with height.
9. In the atmospheric Ekmann layer mean wind veers with height.
10. In the Ekmann layer mean wind veers with height.
11. In the Ekmann layer mean wind veers with height.
12. Kelvin wave is westward propagating wave.
13. K-theory is applicable to parameterize an unstably stratified PBL.
14. Mean mixing length in PBL is analogous to the mean free path in kinetic theory of gas.
15. Mean mixing length is analogous to the mean free path in kinetic theory of gas.
16. Meridional transport of Ω is more during a strong zonal index.
17. Monsoon trough is a region of barolinic instability.
18. Mountain wave is a non-dispersive wave.
19. Perturbation technique is applicable for all types of disturbances.
20. Positive differential advection of cyclonic vorticity leads to sinking motion.
21. Positive differential cyclonic vorticity advection results into sinking motion.
22. Rising motion over a stable region leads to cooling.
23. Rossby wave transports energy downstream of a mountain barrier.
24. Shallow water gravity wave is a dispersive wave.
25. Shallow water gravity wave is a non-dispersive wave.
26. Stable stratification in PBL is favorable for mechanical turbulence.

27. Stable stratification in PBL is favorable for convective turbulence.
28. Tropics gain westerly angular momentum due to mountain torque.
29. Troughs in mid latitude baroclinic wave tilts southward with height.
30. Troughs in mid latitude growing baroclinic wave tilts eastward with height
31. Vertical transport of wave momentum & that of wave energy are unidirectional for IGW.

Q. 2 Answer the following questions

1. Derive the KE & PE equations for baroclinic instability in a zonal meanflow. And hence discuss the energetics of a growing baroclinic instability, using a schematic diagram.
2. Obtain the vertical profile for mean horizontal wind in an atmospheric Ekman layer. Obtain the depth of atmospheric Ekman layer. Discuss secondary circulation and spindown.
3. Obtain the angular momentum budget equation. Discuss in detail about the roles of mountain and waves in the westerly mean flow in the above budget.
4. Define gravity wave. Discuss in detail about their classification. Derive the dispersion equation of any one of them and discuss the dispersion relation.
5. Discuss the turbulent kinetic energy equation in detail (without derivation).
6. Show that in the oceanic Ekman layer mass transport is perpendicular to the surface wind stress and it is to the right of surface wind stress in the N.H.
7. Drive the energy equations and hence discuss the importance of divergent circulation.
8. Derive the relation between I.E. and K.E. in a stably stratified and hydrostatic atmosphere. Discuss in brief about available potential energy.
9. Obtain the criteria for barotropic instability.
10. Show that in a barotropic non-divergent flow K.E. remains conserved
11. What is meant by the term ‘Atmospheric Energetics’? Obtain the expressions for their global internal energy, potential energy & kinetic energy. Derive the equations for global kinetic, potential & internal energy. Discuss the mechanisms for conversions among themselves.

    (1+3+6+4)
12. Mention the sub-grid scale physical process in PBL. Discuss how it is parameterized in a stably stratified PBL. Obtain the Ekman layer profile in an oceanic boundary layer.

Derive the expression of wind driven mass transport in an Oceanic Ekman layer. Show that in Northern hemisphere, wind driven mass transport in an oceanic Ekman layer is at right angle with surface wind stress & it is to the right of surface wind stress. Hence or otherwise offer a plausible explanation for El-Nino. (1+2+5+4+2)

13. Define Hydrodynamic instability. Discuss the categorization of Hydrodynamic instabilities, with examples. Derive the criteria for inertial instability. Discuss, schematically with a diagram, the energetics of a growing mid-latitude baroclinic instability. (1+2+5+6)
14. Define circulation & vorticity, along with their mathematical expressions. Using Stoke's theorem or otherwise, obtain their relationship.Derive vorticity equation in any co-ordinate system. Discuss the physical interpretations of the terms. (2.5+2.5+5+4)
15. Define wave number, phase velocity & group velocity of wave. What is meant by dispersion relationship of a wave. Discuss the dispersion relationship of Rossby wave and movement of shorter & longer Rossby wave. (1.5+1.5+2+2)
16. What is a β-plane & β-plane approximation? What is its importance? Write down quasi geostrophic vorticity equation. Discuss the physical importance of vortex stretching term. (2+1.5+1.5+2)
17. Write down the diagnostic omega equation. Discuss in detail the different mechanisms for rising motion. (1+6)
18. Write down the turbulent kinetic energy equation. Discuss the energetics of turbulent eddies in a stably & unstably stratified PBL. Define flux Richardson number and its significance.
19. Derive the expression for vertical profile of mean horizontal wind in an atmospheric Ekman layer. Show analytically that the hodograph of mean horizontal wind is an equiangular spiral. Show that wind driven mass transport in Oceanic Ekman layer is perpendicular to surface wind stress and is to the right of surface wind stress in northern hemisphere. (5+3+6=14)

20. What is beta plane and beta plane approximation? What is the importance of this approximation? Write down the assumptions in quasi geostrophic theory. Using this theory discuss the importance of ageostrophic part of horizontal wind. Derive quasi geostrophic vorticity equation. Discuss physical interpretations of different terms. (1+1+3+2+4+3=14)
21. Define hydrodynamic instability. Discuss its categorization. Obtain the necessary condition for a westerly baroclinic mean flow, to have baroclinic instability. Discuss it for the special non rotational case. Hence discuss the importance of atmospheric static stability on baroclinic instability. (1+2+7+4)
22. Derive global internal energy, kinetic energy and potential energy equations. Discuss the mechanisms for conversion among themselves. Using a neat diagram, discuss schematically, the energetics of a growing baroclinic instability embedded in a westerly mean flow. (6+3+5)
23. Define gravity wave. Discuss its categorization. Derive the dispersion relation of an internal gravity wave. Show that for an internal gravity wave group velocity vector and phase velocity are perpendicular to each other. Hence discuss vertical momentum and energy propagation by this wave for different combinations of wave numbers. (1+2+6+3+2=14)
24. Mention the sub-grid scale physical process in PBL. Discuss how it is parameterized in a stably stratified PBL. Obtain the Ekman layer profile in an oceanic boundary layer. Derive the expression of wind driven mass transport in an Oceanic Ekman layer. Show that in Northern hemisphere, wind driven mass transport in an oceanic Ekman layer is at right angle with surface wind stress & it is to the right of surface wind stress. Hence or otherwise offer a plausible explanation for El-Nino. (1+2+5+4+2=14) What is beta plane approximation? What is the importance of this approximation? Write down the assumptions in quasi geostrophic theory. Derive the diagnostic omega equation. Hence, discuss in detail different dynamical processes leading to rising motion. (1+1+3+5+4=14)
25. Define hydrodynamic instability. Discuss its categorization. Derive the KE & PE equations for baroclinic instability in a zonal mean flow. And hence discuss the energetics of a growing baroclinic instability, using a schematic diagram. (1+2+7+4=14)
26. Derive global kinetic energy equation for horizontal motion in a closed isolated system. Explain why belt of sub-tropical anticyclone is the source of horizontal kinetic

energy. Show that in a stably stratified and hydrostatically stable atmosphere internal energy is proportional to potential energy. Hence, or otherwise discuss (No derivation) in brief on Available potential energy (4+2+4+4=14)

27. Mention a few equatorial tropospheric waves. Discuss their categorization. Define Kelvin wave. Derive the dispersion relation of an equatorially trapped atmospheric Kelvin wave. Show that equatorially trapped atmospheric Kelvin wave is eastward propagating wave. (2+2+2+5+3=14)
28. Derive the expression for vertical profile of mean horizontal wind in an atmospheric Ekman layer. Show analytically that the hodograph of mean horizontal wind is an equiangular spiral. Show that wind driven mass transport in Oceanic Ekman layer is perpendicular to surface wind stress and is to the right of surface wind stress in northern hemisphere. (5+3+6=14)
29. What is beta plane and beta plane approximation? What is the importance of this approximation? Write down the assumptions in quasi geostrophic theory. Using this theory discuss the importance of ageostrophic part of horizontal wind. Derive quasi geostrophic vorticity equation. Discuss physical interpretations of different terms. (1+1+3+2+4+3=14)
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34. What is beta plane approximation? What is the importance of this approximation? Write down the assumptions in quasi geostrophic theory. Derive the diagnostic omega equation. Hence, discuss in detail different dynamical processes leading to rising motion. (1+1+3+5+4=14)
35. Define hydrodynamic instability. Discuss its categorization. Derive the KE & PE equations for baroclinic instability in a zonal mean flow. And hence discuss the energetics of a growing baroclinic instability, using a schematic diagram. (1+2+7+4=14)
36. Derive global kinetic energy equation for horizontal motion in a closed isolated system. Explain why belt of sub-tropical anticyclone is the source of horizontal kinetic energy. Show that in a stably stratified and hydrostatically stable atmosphere internal energy is proportional to potential energy. Hence, or otherwise discuss (No derivation) in brief on Available potential energy (4+2+4+4=14)
37. Mention a few equatorial tropospheric waves. Discuss their categorization. Define Kelvin wave. Derive the dispersion relation of an equatorially trapped atmospheric Kelvin wave. Show that equatorially trapped atmospheric Kelvin wave is eastward propagating wave. (2+2+2+5+3=14)

Q. 3 Solve the following problem

1. Assuming that the dispersion relation for an IGW is
   $(\nu - \bar{U}k)^2 (k^2 + m^2) - N^2 k^2 = ,$ show that when
   $\bar{U} = 0$, the wave number vector $(\hat{\imath}\, k + \hat{k}\, m)$ is perpendicular to the group velocity vector.

2. Assume that the linearised form of QGVE is
   $$\left(\frac{\partial}{\partial t} + \bar{u}\ \frac{\partial}{\partial x}\right)\nabla^2\ \psi' + \beta\ \frac{\partial \psi'}{\partial x} = -f_0\ \underset{\nabla}{\rightarrow} \cdot \underset{V}{\rightarrow} \quad ,$$

   Find a solution for relative vorticity field (ζ') if the horizontal divergence field (D') is given by

   $$D' = \underset{\nabla}{\rightarrow} . \underset{V}{\rightarrow} = A\cos[k(x - ct)]$$

   What is the phase relationship between D' and ζ' ? For what value of C, ζ' will be infinite?

$\boldsymbol{\psi' = \frac{\Phi'}{f_o}}$ perturbation geostrophic stream function. $f_o = 10^{-4}\ Sec^{-1}$

Q. 4 Write short notes on the following

1. Bjerkness circulation theorem
2. CISK
3. External gravity wave
4. Global angular momentum budget
5. Internal & Potential energy in a stably stratified atmosphere and the concept of APE.
6. Mixing length theory
7. Perturbation technique
8. Perturbation theory
9. Rossby wave
10. Shallow water gravity wave
11. Turbulent kinetic energy equation