GFD I AOS 610 Fall 2024
Study Guide for the Third Quiz

1. *Shallow water gravity waves*
Why are shallow water waves called "hydrostatic"?
How does the horizontal pressure gradient force arise in such a wave?
How does one obtain the vertically averaged continuity equation?
Write down the linearized shallow water equations in the absence of rotation.
What is a tsunami and how fast do they travel?
Are tsunamis dispersive?

2. *Deep water gravity waves*
What boundary conditions did Laplace use to obtain a dispersion relation for water waves?
From the general dispersion relation, show how to obtain the two limits corresponding to shallow and deep water waves, by taking limits of tanh(kH).
What is the relationship between phase velocity and group velocity for shallow water waves and for deep water waves?
What is Stokes drift and what causes it?
Write an equation relating the Lagrangian velocity, Eulerian velocity, and Stokes drift.
What happens to wave momentum when it reaches the beach?

3. *Normal modes in a two-layer system*
What assumption is made to solve for oscillations in a system with more than one layer?
Which travels faster, the barotropic mode or baroclinic mode?
What is an equivalent depth?
Write down the mathematical expression for the baroclinic mode.

4. *Internal gravity waves*
Write down the dispersion relation for internal gravity waves propagating in (x, z).
What is the physical basis for upper and lower limits on their frequencies?
Know the dispersion relation for hydrostatic internal gravity waves and be able to calculate the phase and group velocities.
What are three primary mechanisms of exciting internal gravity waves?
In which direction do orographic gravity waves tilt, what is the sign of their momentum flux, and what is the sign of their group velocity?
What assumption in linear theory is violated in a Boulder windstorm?
When the momentum flux associated with orographic gravity waves is absorbed by the mean flow in the upper troposphere, what happens to the mean flow?

5. *The Rossby adjustment problem*
What does the Rossby adjustment problem seek to solve?
What are the basic elements of this classical problem?
Why is the steady state shallow water system called degenerate?
What are the key contributions of Kelvin and Rossby?
Why can only some of the available potential energy be used?
Where does the kinetic energy of the final geostrophic flow come from?

What are Poincare waves?
Define the geostrophic streamfunction, velocity components and vorticity.
Define shallow water PV, Ertel's PV, and quasi-geostrophic PV.
Write down the mathematical definition of the Rossby radius of deformation, L_R.
How does L_R differ from the Rossby number, Ro?
Provide two physical interpretations of the Rossby radius of deformation.
What are typical values of L_R in the atmosphere and ocean?
Why is L_R about 10 times larger in the atmosphere than in the ocean?
What is Prandtl's ratio and why is it useful for describing the aspect ratio of circulations?
Where would you expect to see gravity waves radiating from adjusting large-scale flow?

8. *Rossby waves*
What is the beta effect?
Provide a qualitative description or sketch of the Rossby wave propagation mechanism.
Provide a qualitative description or sketch of downstream energy dispersion.
Be able to derive the 1-D linearized dispersion relation for Rossby waves from conservation of absolute vorticity.
For Rossby waves propagating zonally (l, $m = 0$) in constant zonal mean flow, derive the zonal phase and group velocities.
How do synoptic scale Rossby wave troughs and ridges move relative to the zonal mean flow and relative to the surface?
How do planetary scale Rossby waves move relative to the zonal mean flow and to the surface?
What is Charney-Devore resonance?
What is a Hovmöller diagram?
What are typical values of f in midlatitudes and β at the equator?
What conservation principle is used to obtain a 3D linear Rossby wave dispersion relation?
What is a critical surface and what happens to wavenumber m or l at a critical surface?
What happens to wavenumber m or l at a turning surface?

9. *Momentum fluxes*
What is a flux? What are Reynolds stresses?
What results from a momentum flux convergence?
Using linear mixing length theory, represent vertical momentum flux convergence in the form of diffusion.
Can turbulence transport momentum up-gradient?
Sketch a wave streamline pattern in (x, y) that transports westerly momentum northward.
Sketch a wave streamline pattern in (x, z) that transports westerly momentum downward.

10. *Baroclinic instability*
What causes baroclinic instability?
What role does earth's rotation play in this instability?
Using geostrophic and thickness concepts, explain why growing baroclinic synoptic waves tilt westward with height.
What are the primary air mass motions in baroclinic instability?
What is the energy pathway for baroclinic instability?
Describe how sloping convection works and what the short-wave cutoff is.

What does a poleward heat flux accomplish?

11. *Eady and Charney problems*
What are two fundamental assumptions that differ for these two classical solutions?
Give a physical interpretation of the Rossby height, H_R.
What primary physical quantity does the growth rate depend on?
What is a typical horizontal scale for the fastest growing mode?
What are typical e-folding growth time scales in the atmosphere and in the ocean?
What primary advection process underlies the long-wave cutoff in the Charney problem?
In the real atmosphere, what additional physical processes affect how synoptic systems develop and decay?

12. *Baroclinic Life Cycles*.
How well does a linear solution represent poleward heat fluxes and momentum fluxes?
What is the observed pattern of momentum fluxes and what is their net effect on the location of the subtropical westerly jet?
Why is the baroclinic growth rate faster near the jet maxima over the east coasts of continents in winter?

13. *Instability*.
What distinguishes linear from nonlinear instability?
What mathematical condition for frequency or phase speed is required for growth?
What mathematical condition on wavenumber is compatible with spatial evanescence?
When could a perturbation grow faster than the fastest growing normal mode?
What is generally required to calculate the solution for nonlinear instability?

14. *Parcel Instabilities*.
Describe the method of evaluating parcel instabilities.
Compare static and inertial instability.
What is Rayleigh's 1888 inviscid criterion for inertial instability?
What doesTaylor's 1923 viscous solution imply about the Navier-Stokes equations?
What method is used to obtain the criterion for inertial instability for zonal mean flow?
Express the inertial instability criterion 3 ways, using the Coriolis parameter and relative vorticity, angular momentum, and Ertel's PV.
What two main regions in the global atmosphere have PV ~ 0?
What do we call PV that is opposite in sign to f?
In which physical situations is inertial instability important?

15. *Kelvin-Helmholtz instability*.
What is the energy pathway for KH instability?
What is the final result of KH instability?
How does this differ from baroclinic instability?
Where is KH instability occurring?
What is its role in the general circulation?
How does the critical surface function in KH instability?
What method is used to obtain the Richardson number instability criterion?

Describe the *Ri* criterion mathematically and give a physical interpretation.
What is a Kelvin's Cats Eye pattern?

16. *Barotropic instability*.
Write down the meridional structure equation and give an interpretation of c-U and Uyy.
What is Fjortoft's modification of Rayleigh's barotropic instability criterion?
What is Kuo's modification of Rayleigh's barotropic instability criterion?
What is the effect of β on this instability?
Contrast a necessary and a sufficient condition.
Where would you expect barotropic instability to be relevant in the atmosphere?

17. *Energy conversion and eddy fluxes*.
Can a wave be stationary but still transport momentum?
What is the expression for energy conversion between zonal mean kinetic energy and eddy kinetic energy ($\overline{K} \rightarrow K'$)?
Sketch a situation where the wave is growing from the mean flow and a situation where the wave is decaying, feeding energy into the mean flow.
During what phase of a baroclinic wave life cycle is barotropic conversion to mean kinetic energy most likely?