

GFD I AOS 610

Study Guide for the Third Quiz

(* indicates that the material will not be on this exam)

1. *Contrast the following types of waves*

free versus forced

internal versus external

stationary versus travelling

steady versus transient

linear versus nonlinear

dispersive versus nondispersive

2. *Wave definitions*

Define phase for a 3D plane wave.

Be able to determine the sign of m or l from the phase axis orientation.

Define wavenumber, frequency, phase velocity, trace velocity, and group velocity.

What is the difference between the x-component of c_p and c_t ?

Be able to describe in words what a dispersion relation is.

Know the main procedures of the linear perturbation method for obtaining a dispersion relation.

How fast do sound waves travel and are they dispersive?

3. *Shallow water gravity waves*

Why is the hydrostatic approximation associated with shallow water waves?

How does the horizontal pressure gradient force arise in such a wave?

What is the vertically averaged continuity equation?

What are the linearized shallow water equations with no Coriolis term?

What is a tsunami and how fast do they travel?

Are tsunamis dispersive?

4. *Deep water gravity waves*

What boundary conditions did Laplace use to obtain a general solution for water waves?

Be able to obtain the two limits from the dispersion relation corresponding to shallow and deep water waves, by taking appropriate 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 the Stokes drift and what is it due to?

Write an equation relating the Lagrangian velocity, Eulerian velocity, and Stokes drift.

What happens to the wave momentum when it reaches the beach?

5. *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?

Be able to calculate the phase speeds given the equivalent depths.

6. *Internal gravity waves*

Write down the dispersion relation for internal gravity waves.
What is the physical basis for upper and lower limits on their frequencies?
What similarity with hydrostatic internal gravity waves exists with shallow water waves?
Know the dispersion relation for hydrostatic internal gravity waves and be able to calculate the trace and group velocities.
What are three primary mechanisms of exciting internal gravity waves?
In which direction do orographic gravity waves tilt and what is the sign of the momentum flux?
What assumptions in linear theory are violated in a Boulder windstorm?
When the momentum flux associated with the gravity wave is absorbed by the mean flow in the upper troposphere, what happens to the mean flow?

7. *The Rossby adjustment problem*

What does the Rossby adjustment problem seek to solve?
What are the basic elements of this classical problem?
What are the key contributions of Kelvin and Rossby?
Why is the steady state shallow water system called degenerate?
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.
Be able to define shallow water potential vorticity, Ertel's PV, and quasi-geostrophic PV.
What is the mathematical definition of the Rossby radius of deformation, L_R ?
Contrast L_R with the Rossby number, Ro .
Give two physical interpretations of the Rossby radius.
What are typical values of L_R in the atmosphere and ocean?
Why is L_R 10 times larger in the atmosphere?
What is Prandtl's ratio and why is it a useful estimator of the aspect ratio of circulations?
Describe some typical situations where you might expect to see gravity waves radiating from an adjusting geostrophic flow.

8. *Rossby waves*

What is the Rossby number?
What is the beta effect?
Give a qualitative description of the Rossby wave propagation mechanism.
Give a qualitative description of downstream energy dispersion.
Write down the linear dispersion relation for Rossby waves.
Be able to derive the zonal trace speed and zonal group speed from the dispersion relation.
Describe how synoptic scale Rossby waves move relative to the midlatitude westerlies and relative to the surface.
Describe how long planetary scale Rossby waves move relative to the midlatitude westerlies and to the surface.
Describe how Rossby wave energy moves relative to the mean flow.
What is a Hovmöller diagram?
Know typical values for the Coriolis parameter in midlatitudes and for Beta at the equator.

9. *Baroclinic instability*

What is the basic principle underlying baroclinic instability?
How is the earth's rotation important for this instability?
From geostrophic and thickness arguments, explain why growing systems tilt westward with altitude.
What are the primary air mass motions in baroclinic instability?
What is the energy pathway for baroclinic instability?
Using a displaced parcel argument, describe how sloping convection works and what the short-wave cutoff is.
What is the final result of a poleward heat flux?

10. *Eady and Charney problems*

Contrast the fundamental assumptions underlying these two solutions.
Give a physical interpretation of the Rossby height, H_R .
What is the growth rate proportional to?
What are typical scales for the fastest growing modes?
What are typical e-folding growth time scales in the atmosphere and ocean?
What primary advection process underlies the explanation for the long-wave cutoff in the Charney problem?
In the real atmosphere, what additional physical processes will affect how synoptic systems develop and decay?

11. *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 jet?
Why is the baroclinic growth rate fastest near the jet maxima over the east coasts of continents in winter?

12. *Instability.*

What characterizes 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 a nonlinear instability?

*13. *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 conclusion about Taylor's 1923 viscous solution do some people make regarding the Navier-Stokes equations?
What method is used to obtain the criterion for inertial instability?
Express the inertial instability criterion 3 ways, using the Coriolis parameter and relative vorticity, angular momentum, and potential vorticity.
What general regions will have $P \sim 0$?
What general regions will have P opposite in sign to f ?

In what physical situations is inertial instability important?
If an overturning cell arises from inertial instability, what is implied about convective instability?

*14. *Kelvin-Helmholtz instability.*

What is the energy pathway for this instability?

What is the final result of this instability?

How is this energetics pathway similar to that for barotropic instability?

How do those two instabilities differ from baroclinic instability regarding the energy pathway and final result?

Where is KH instability occurring?

What is its role in the general circulation?

What is a critical surface?

What method is used to obtain the Richardson number instability criterion?

Describe this criterion mathematically and give a physical interpretation.

What is a Kelvin's Cats Eye pattern?

*15. *Barotropic instability.*

Write down the meridional structure equation and give a physical interpretation of $c-U$ and U_{yy} .

What is Fjortoft's modification of Rayleigh's barotropic instability criterion?

What is Kuo's modification of this criterion?

What is the effect of beta on this instability?

What do you think the effect of friction would be on this instability?

Contrast a necessary and a sufficient condition.

Where would you expect barotropic instability to be relevant in the earth system?

*16. *Energy conversion and eddy fluxes.*

How can a wave be stationary but transport momentum?

What is the expression for energy conversion between zonal mean kinetic energy and eddy kinetic energy?

Sketch a situation where the wave is growing off of 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?