Meteorology

Lecture 2

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Meteorological Dynamics

Introduction

definition of dynamical meteorology

➔research on the nature and cause of atmospheric motions

two fields:

➔kinematics ⇨ study on nature and phenomena of air motion

➔dynamics ⇨ study of causes of air motions

We will mainly concentrate on the second part (dynamics)

Forces and equation of motion

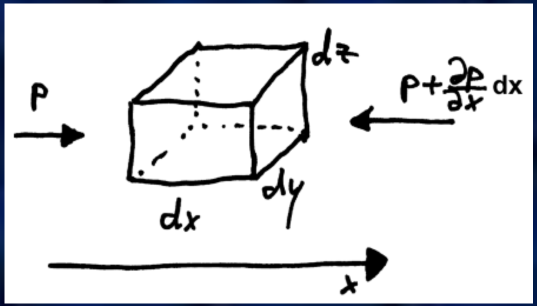
Newton's law: $\vec{F} = \sum_i \vec{F}_i = m \cdot \frac{d\vec{v}}{dt}$

Following atmospheric forces are important:

- ➔pressure gradient force (PGF)
- ➔gravity force
- ➔friction
- ➔Coriolis force

Pressure gradient force

Pressure=force/area



Force from left $F_{left} = p \cdot dy \cdot dz$

$$F_{right} = -\left(p + \frac{\partial p}{\partial x} dx \right) dy \cdot dz$$

sum of forces: $F_{p_x} = F_{left} + F_{right} = -\frac{\partial p}{\partial x} \cdot dx \cdot dy \cdot dz = -\frac{\partial p}{\partial x} \cdot dV$

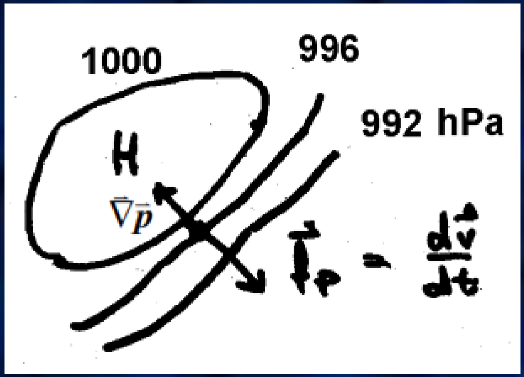
Force per unit mass: $-\frac{\partial p}{\partial x} \cdot \frac{dV}{dm} = -\frac{1}{\rho_m} \cdot \frac{\partial p}{\partial x}$ $\quad \boxed{\rho_m = m/V}$

General: $\vec{f}_p = -\frac{1}{\rho_m} \vec{\nabla} p = -\frac{1}{\rho_m} \cdot grad\ \ p$

Note: unit is N/kg

Pressure gradient force

$$\vec{f}_p = -\frac{1}{\rho_m}\vec{\nabla}p = -\frac{1}{\rho_m}\cdot grad\ \ p$$



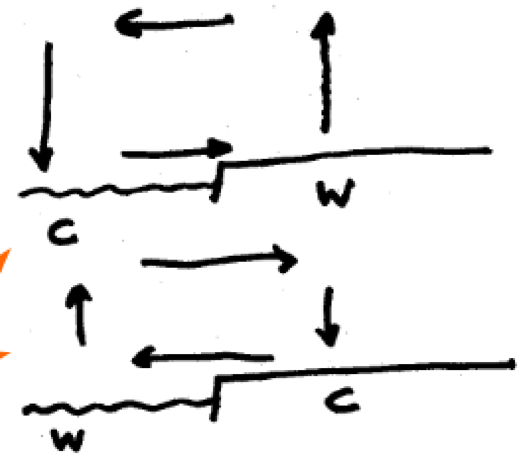
pressure gradient force acts „downhill“ of the pressure gradient

wind formed from pressure gradient force is called Eulerian wind

this type of winds are found:

- ➔at the equator (no Coriolis force)
- ➔small scale thermal circulation (100-200km)

- Thermal circulation is caused by a horizontal temperature gradient
  - ➔ Examples:
    - oven (warm) and window (cold)
    - open field (warm) and forrest (cold)
    - cold lake and warm shore
    - urban region (warm) and green surroundings (cold)
    - cool ocean and warm land (see breeze)
    - warm ocean and cold land (night, winter)



- in some cases thermal circulation also plays an important role at larger scales
  - ➔ trade winds (equator and cool sub-tropics)
  - ➔ monsoon (Indian Ocean and Indian sub-continent)
    - but note, that Coriolis force also contribute to these types of circulation

Gravity force

Newton law: $\vec{F}_g = m \cdot \vec{g}$

Note: unit is N/kg

surfaces of equal geopotential height (*z*) experience the same gravitational force

→geopotential height: $z = \frac{1}{g_o}\int_{h'=0}^{h} dh' \; g(\varphi, h') \approx \frac{g(\varphi, h)}{g_o} \cdot h$

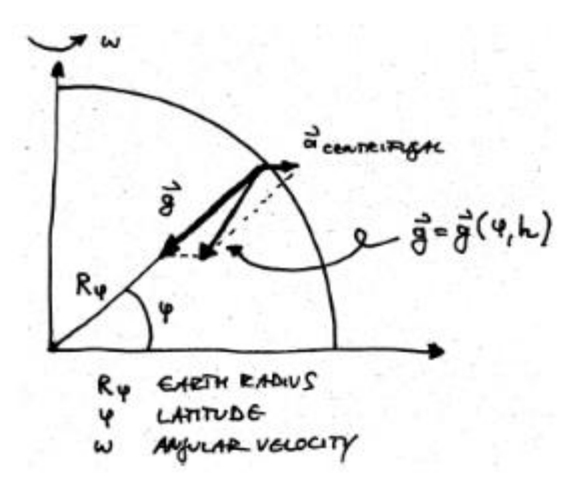
Geopotential is the potential of the Earth's gravity field. For convenience it is often **defined** as minus the potential energy per unit mass, so that the gravity vector is obtained as the gradient of this potential, without the minus. For geophysical applications, gravity is distinguished from gravitation.

Geopotential:

$$\phi = g_o \cdot z = g(\varphi, h) \cdot h$$

$$\vec{f}_g = -\vec{\nabla}_z \cdot \vec{\phi} = -\vec{\nabla}_h \cdot \vec{\phi}$$

$$\vec{\phi} = \begin{pmatrix} 0 \\ 0 \\ g_o \cdot z \end{pmatrix}$$



Newton's law is only valid in a system which is at rest or is in uniform motion (constant velocity, e.g. constant speed and constant direction)

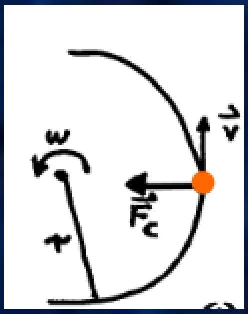
Earth is rotating around its axis and, therefore, is an accelarating system

→ We have to take into account earth's rotation if Newton´s law of motion is applied

Example 1: Roundabout $$m\frac{dv}{dt} = m \cdot \omega^2 \cdot r = m \cdot v^2 / r$$

→ External viewer sees a force acting towards the center

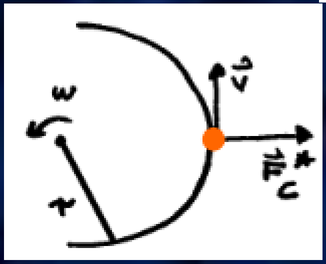
- Centripedal force $\vec{F}_c$



$\omega = 2\pi / T$

→ Person on the roundabout feels the moment of inertia

- Centrifugal force $\vec{F}_c^{\,*}$



→ Coriolis force is a virtual force: $\vec{F}_c + \vec{F}_c^{\,*} = 0$

Geopotential height approximates the actual height of a pressure surface above mean sea-level.

Geopotential is the potential energy acquired by unit mass on being raised through unit distance in a field of gravitational force of unit strength. The Geopotential meter is related to the Dynamic meter by the expression one geopotential meter=0.98 dynamic meter. It is roughly the height of a pressure surface in the atmosphere above mean sea level.

The equation which defines the relationship between *geopotential* height (Z) and *geometric* height (z) is $Z=gz/980$.

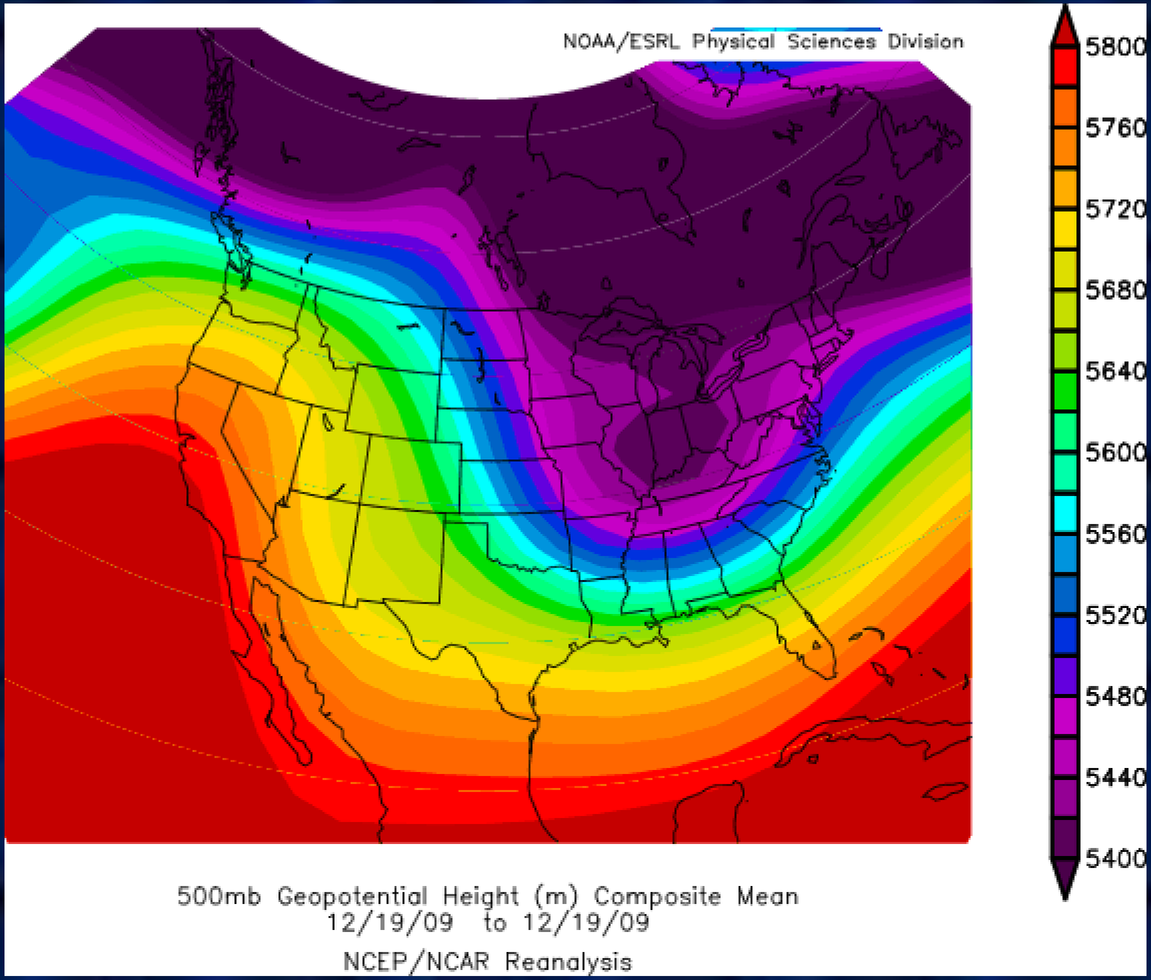
Thus when gravity *g* has its near average value of 980 cm/sec^2, heights in geopotential meters and and geometric meters are the same; for $g < 980$ cm/sec^2 the height in geopotential meters is the smaller, for $g > 980$ cm/sec^2 it is bigger.

Geopotential (from the dynamic point of view) is a better measure of height in the atmosphere than is *geometric* height since energy is in general lost or gained when air moves along a geometrically level surface but not when it moves along an equigeopotential surface.

Geopotential height approximates the actual height of a pressure surface above mean sea-level. Therefore, a geopotential height observation represents the height of the pressure surface on which the observation was taken.

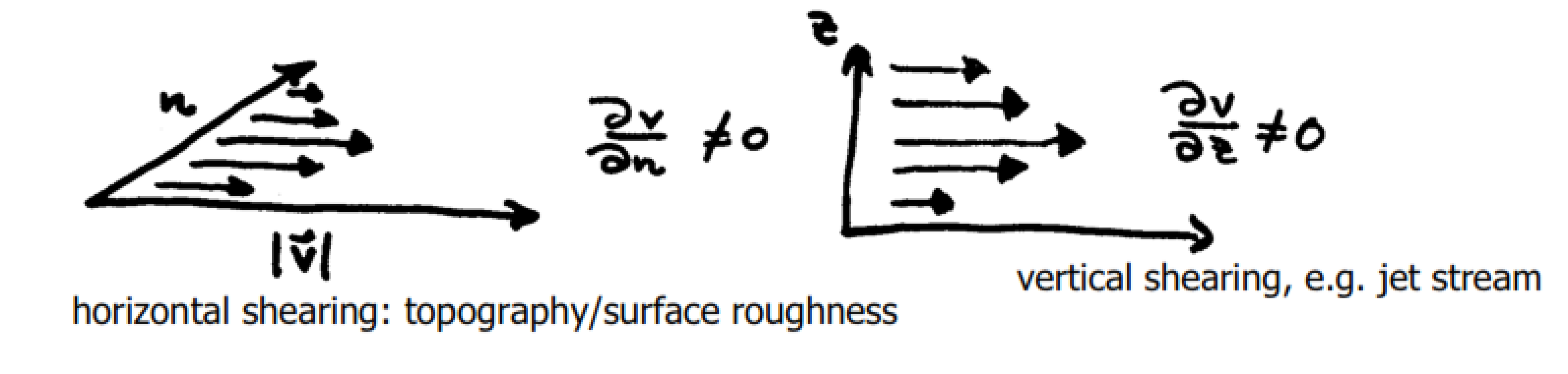
Since cold air is more dense than warm air, it causes pressure surfaces to be lower in colder air masses, while less dense, warmer air allows the pressure surfaces to be higher.
Thus, heights are *lower* in cold air masses, and *higher* in warm air masses.

A line drawn on a weather map connecting points of equal height (in meters) is called a height contour. That means, at every point along a given contour, the values of geopotential height are the same. An image depicting the geopotential height field is given below.



Friction

Friction forces appear when the wind field is sheared



Slowing down of air parcel due to turbulences perpendicular to the main wind direction

Slow air parcel decelerate faster moving air parcels (collisions!) and so on introducing a shearing in the wind field