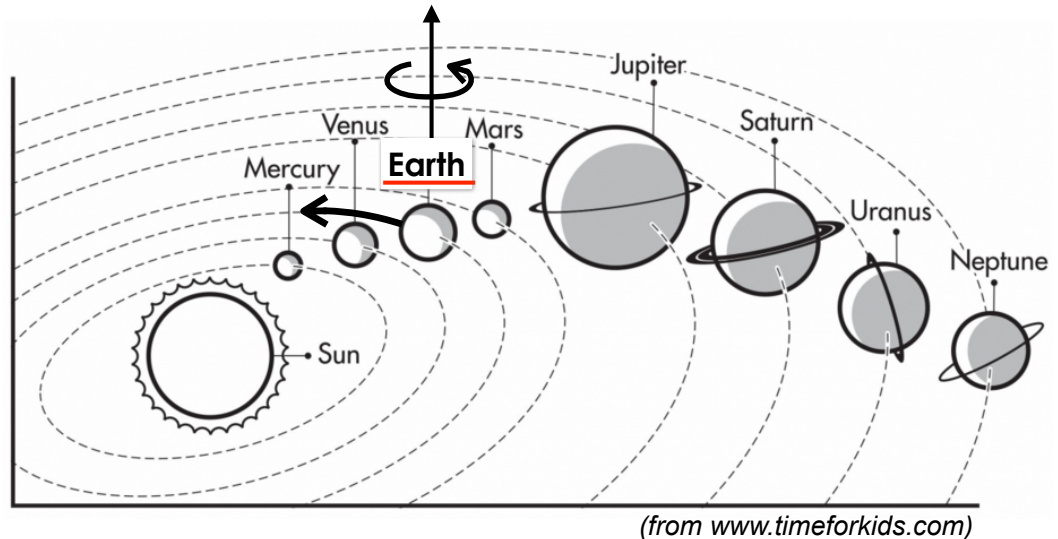# Earth's atmosphere

Things we understand, so far (we think…)

1. Composition
2. Structure
3. Processes (or phenomena)

(from www.timeforkids.com)

1. Composition

PERMANENT GASES						
Gas	Symbol	Percent Dry Air (by volume)	Parts per Million* ppm (by volume)	Atmospheric Sources	Atmospheric Sinks (removal mechanism)	Atmospheric Residence Time† (in years)
Nitrogen	N_2	78.084	780,840	decaying plants and animals combustion	nitrogen-f xing bacteria in soil and oceans lightning	14,000,000
Oxygen	O_2	20.946	209,460	photosynthesis water and nitrous oxide break-down by ultraviolet radiation in the stratosphere	plant and animal respiration decaying plants and animals chemical rock weathering growth of shellf sh	4,500
Argon	Ar	0.93	9,300	radioactive decay of potassium	no sinks	forever, gradually accumulating

| VARIABLE GASES						
Gas and Particles	Symbol	Percent Dry Air (by volume)	Parts per Million* ppm (by volume)	Atmospheric Sources	Atmospheric Sinks (removal mechanism)	Atmospheric Residence Time† (in years)
Water vapour	H_2O	0 to 4	0 to 40,000	evaporation transpiration	precipitation	0.026 or 9.5 days
Carbon dioxide	CO_2	0.0389	389	respiration combustion, (especially fossil fuels) industrial activity volcanoes oceans	absorbed by oceans photosynthesis burying organic material (landf lls)	5 to 200 plus, depending on source
Methane	CH_4	0.00018	1.8	wetlands growing rice agriculture	atmospheric oxidation (breaks down when it reacts with OH (hydroxyl) radicals)	8.4

(from Meteorology today)

1. Composition: Ideal Gas

a theoretical gas composed of

- many **randomly moving point particles** whose only
- interactions are perfectly **elastic collisions.**

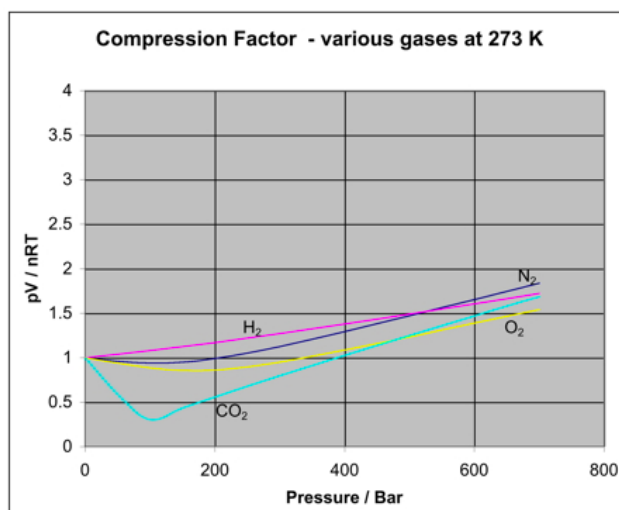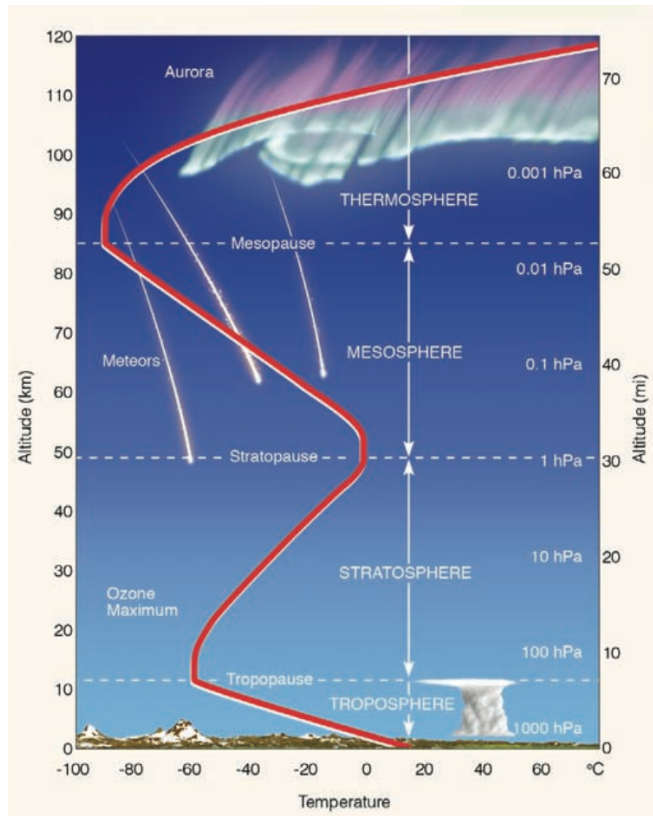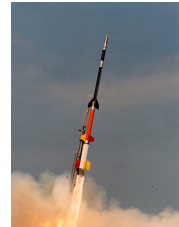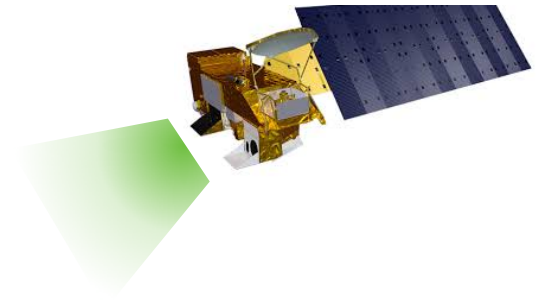(it obeys *the ideal gas law,* ***a equation of state, pv=nR*T***)
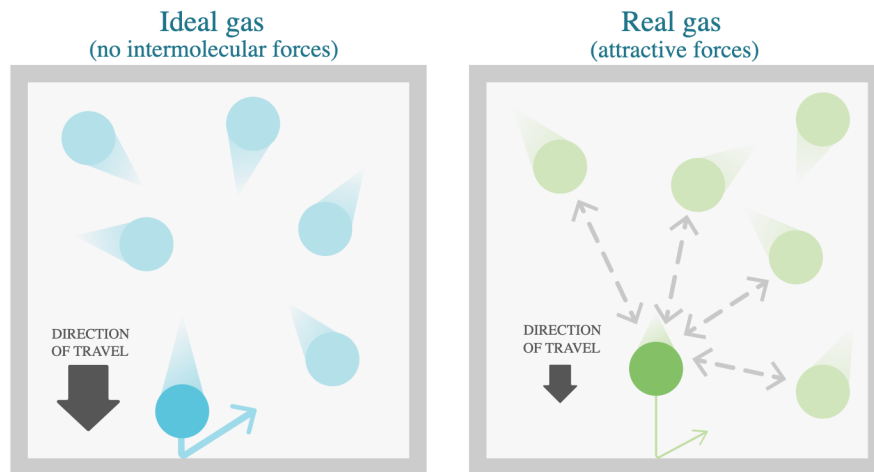
(from Khan Academy)

1. Composition: Ideal Gas

a theoretical gas composed of

- many **randomly moving point particles** whose only
- interactions are perfectly **elastic collisions.**

(it obeys *the ideal gas law,* ***a equation of state, pv=nR*T***)

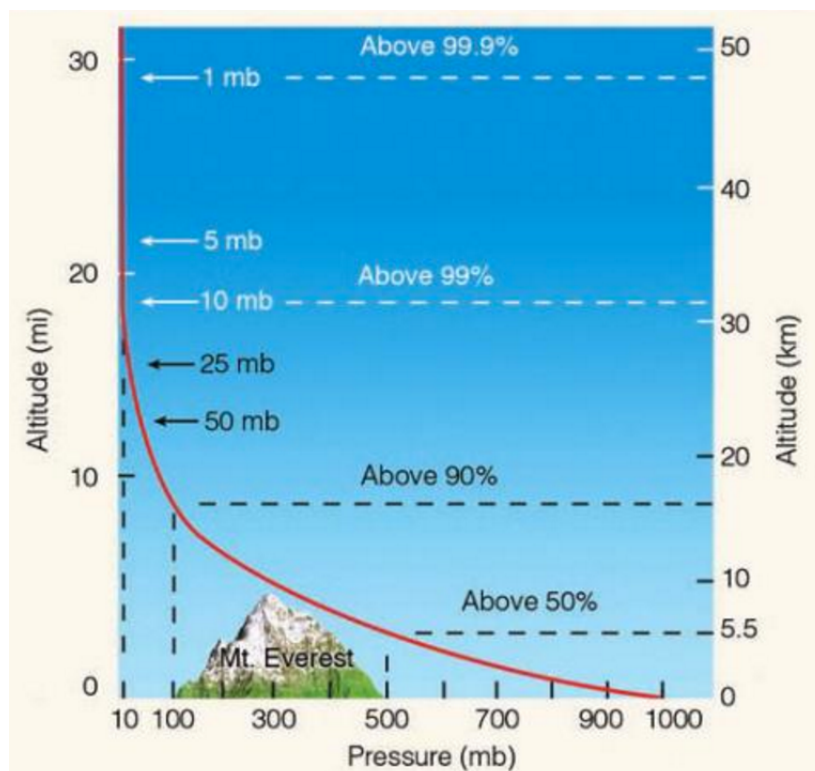(from Khan Academy)

2. Structure: Temperature

Rocketsonde
(~20-100 km)

Radiosonde
(~10-40 km)

(from Meteorology today)
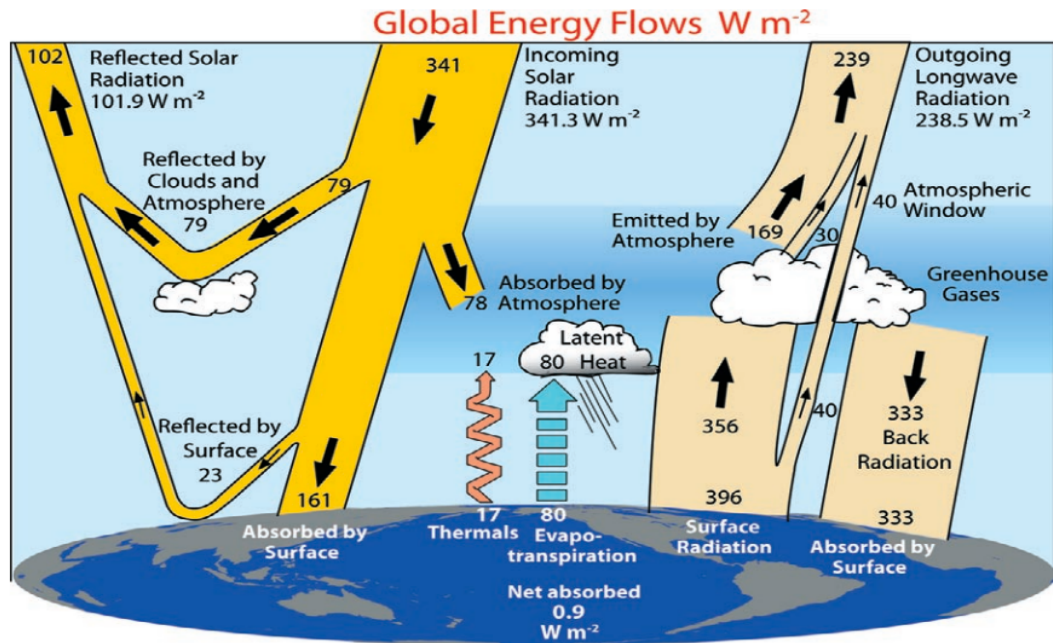
2. Structure: Pressure (as a function of altitude)

• Pressure decrease **exponentially** with increasing altitude

(from Meteorology today)
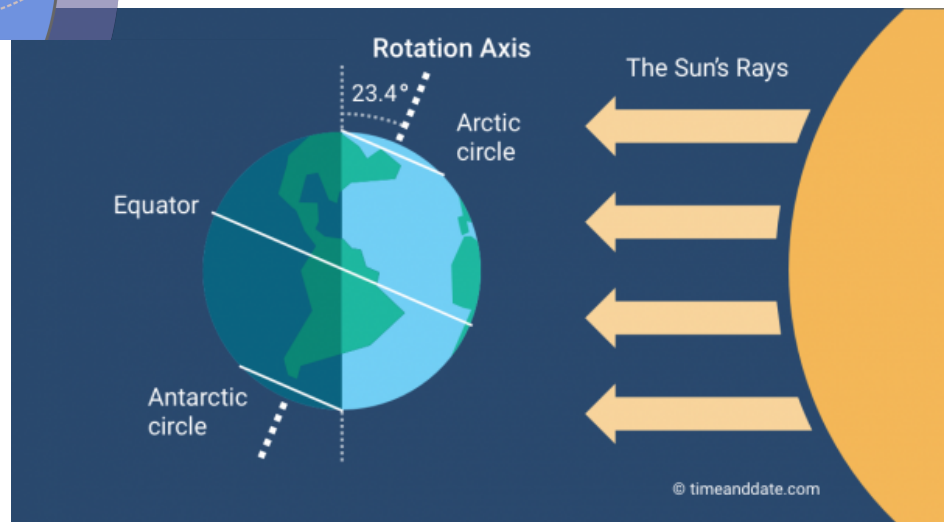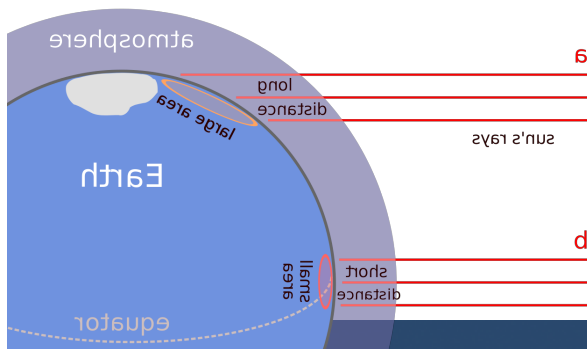
Earth's energy budget

Global Energy Flows W m⁻²

FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m⁻²). The broad arrows indicate the schematic flow of energy in proportion to their importance.

(Trenberth 2009, BAMS)
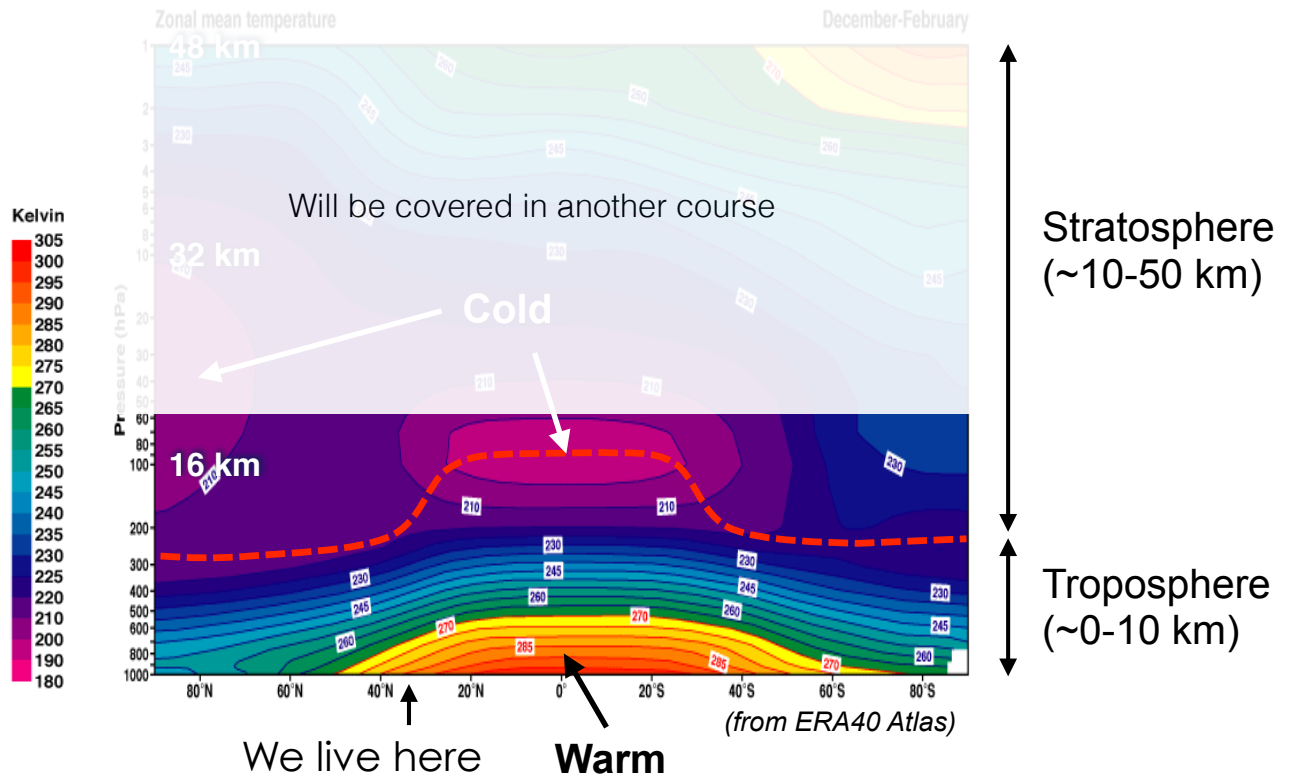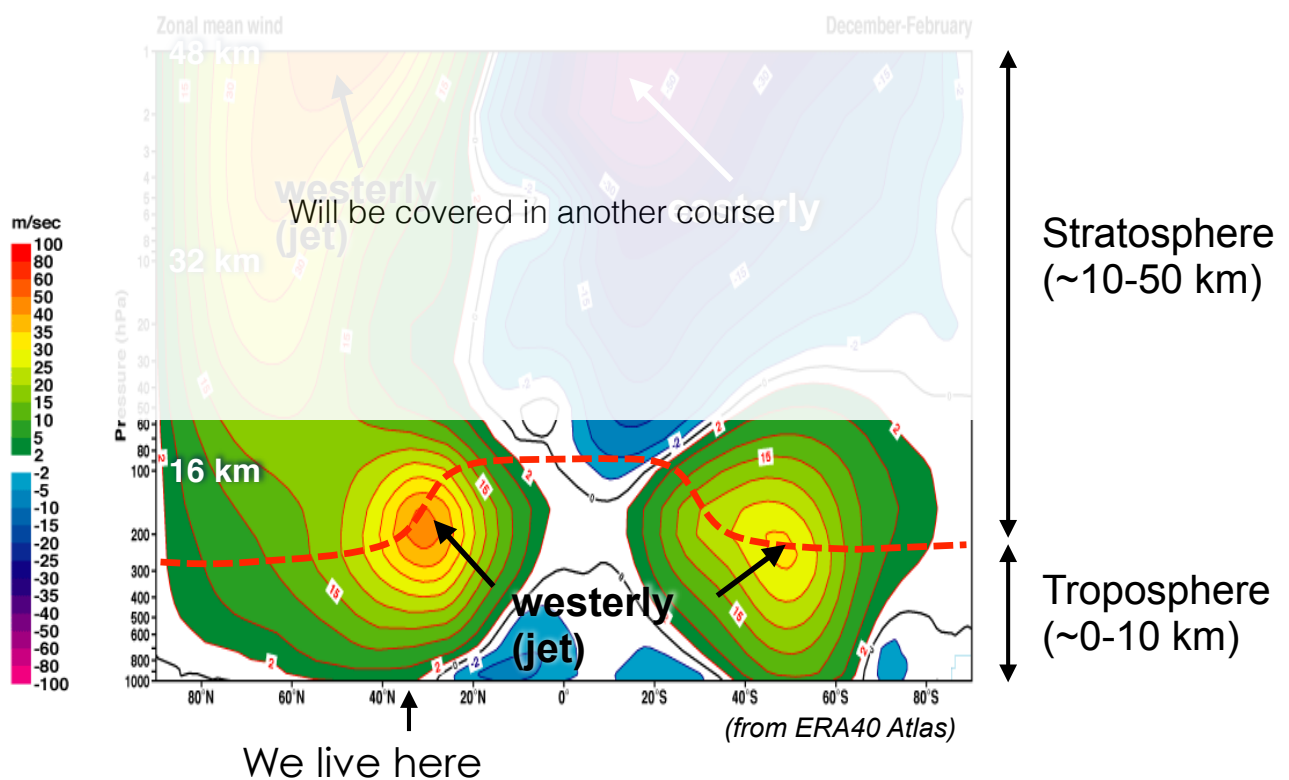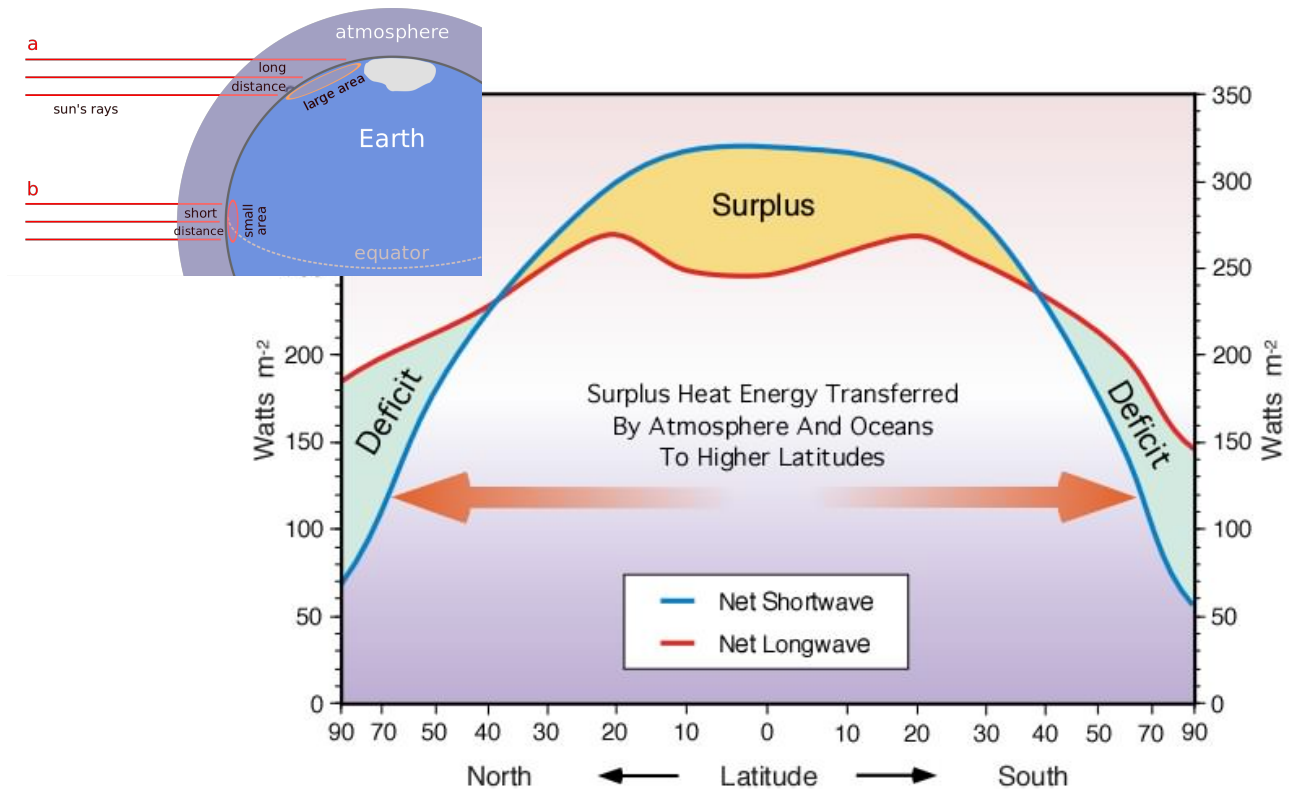
2. Structure: Sphere, tilted axis of rotation
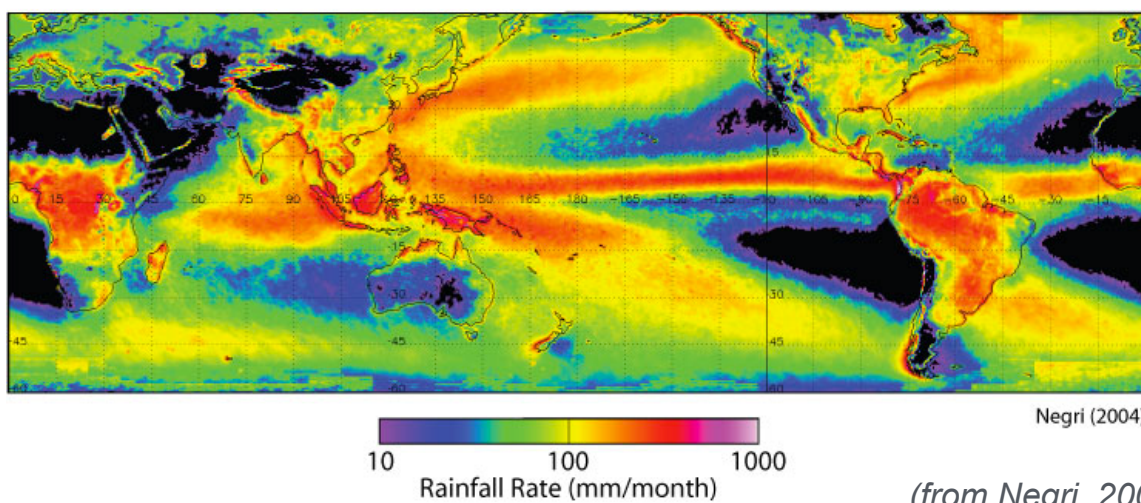
Meridional structure (temperature)

Zonal mean temperature — December-February

Will be covered in another course

48 km
32 km
16 km

Cold

Warm

We live here

Kelvin: 305 300 295 290 285 280 275 270 265 260 255 250 245 240 235 230 225 220 215 210 200 190 180

Stratosphere (~10-50 km)

Troposphere (~0-10 km)

(from ERA40 Atlas)

Meridional structure (zonal wind)

Zonal mean wind — December-February

Will be covered in another course

48 km
32 km
16 km

westerly (jet)

westerly (jet)

We live here

m/sec: 100 80 60 40 35 30 25 20 15 10 5 2 -2 -5 -10 -15 -20 -25 -30 -35 -40 -50 -60 -80 -100

Stratosphere (~10-50 km)

Troposphere (~0-10 km)

(from ERA40 Atlas)

3. Processes: Energy transport

(from wikibooks and http://www.physicalgeography.net)

3. Processes: Convection

(from Negri, 2004)

3. Processes: Meridional circulation
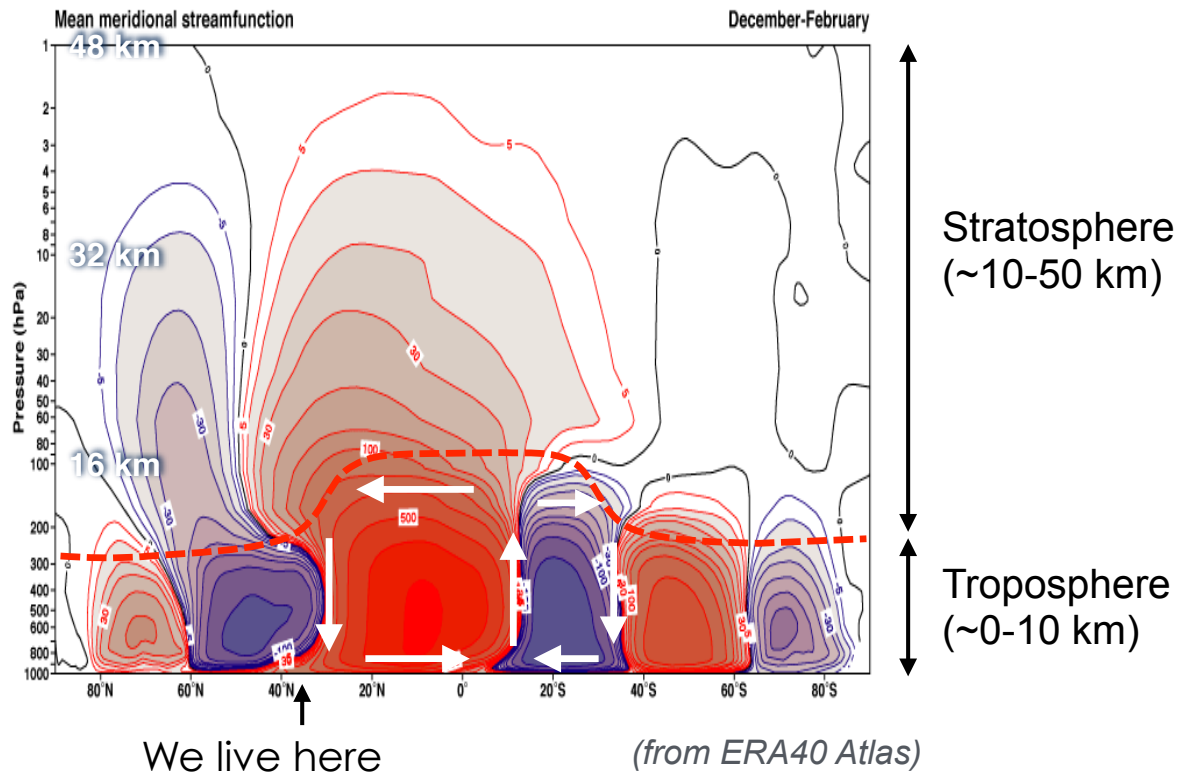
Mean meridional streamfunction   December–February

We live here   *(from ERA40 Atlas)*

Stratosphere (~10-50 km)

Troposphere (~0-10 km)

3. Processes: Synoptic waves

January 2013   EUMETSAT   NOAA   気象庁 Japan Meteorological Agency

3. Processes: Synoptic waves

(Ullrich and Guerra, 2015)
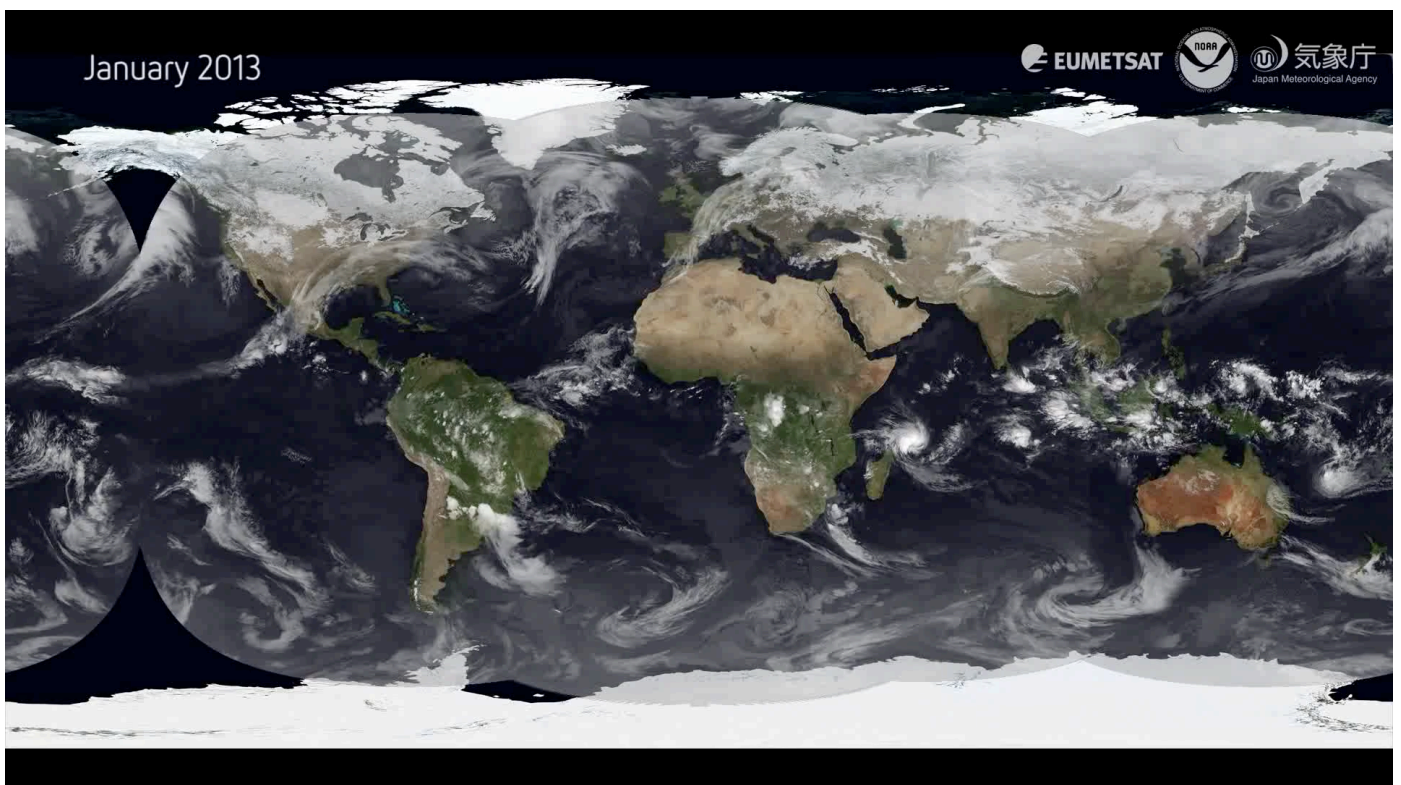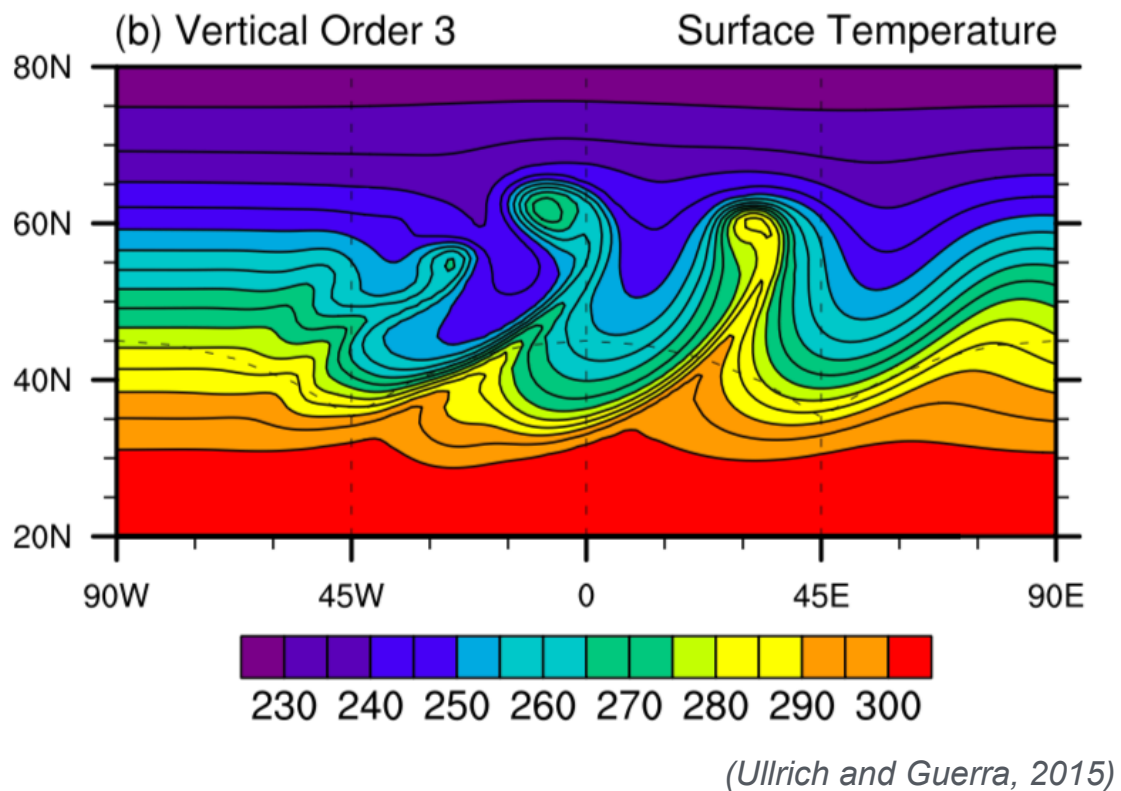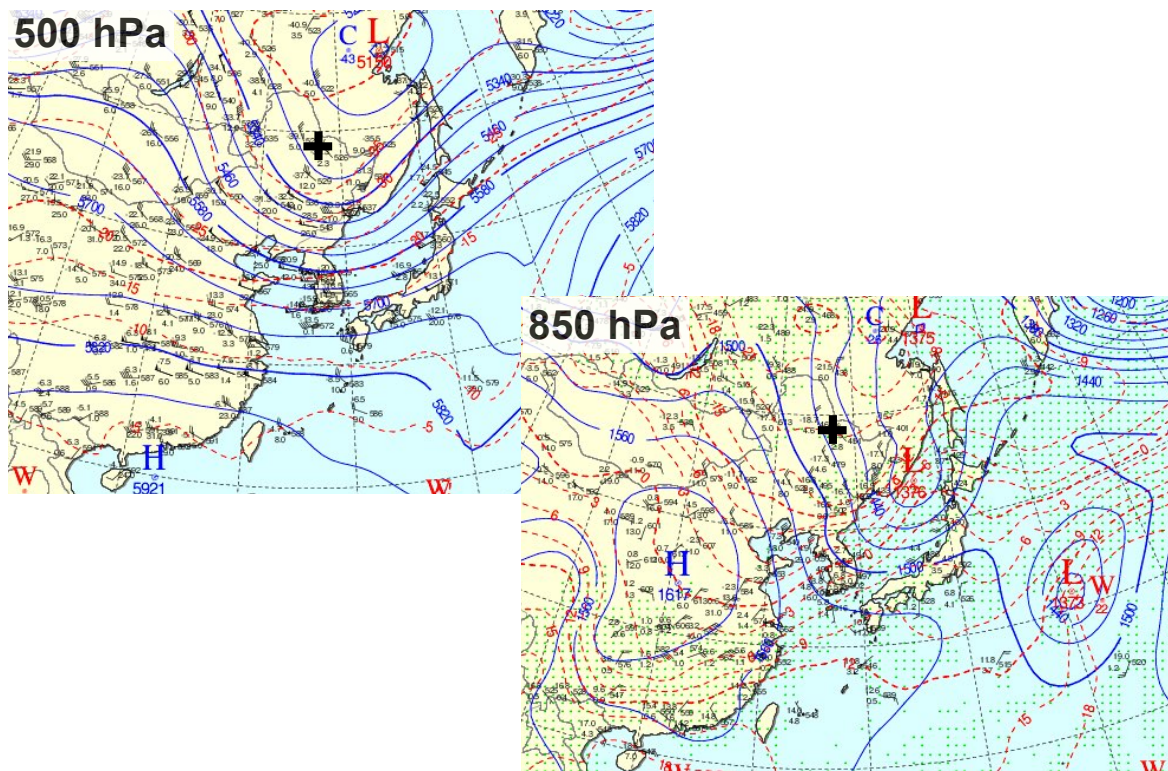
3. Processes: Synoptic waves

(from web.kma.go.kr)

3. Processes: Synoptic waves

500 hPa

850 hPa

(~4000 km)
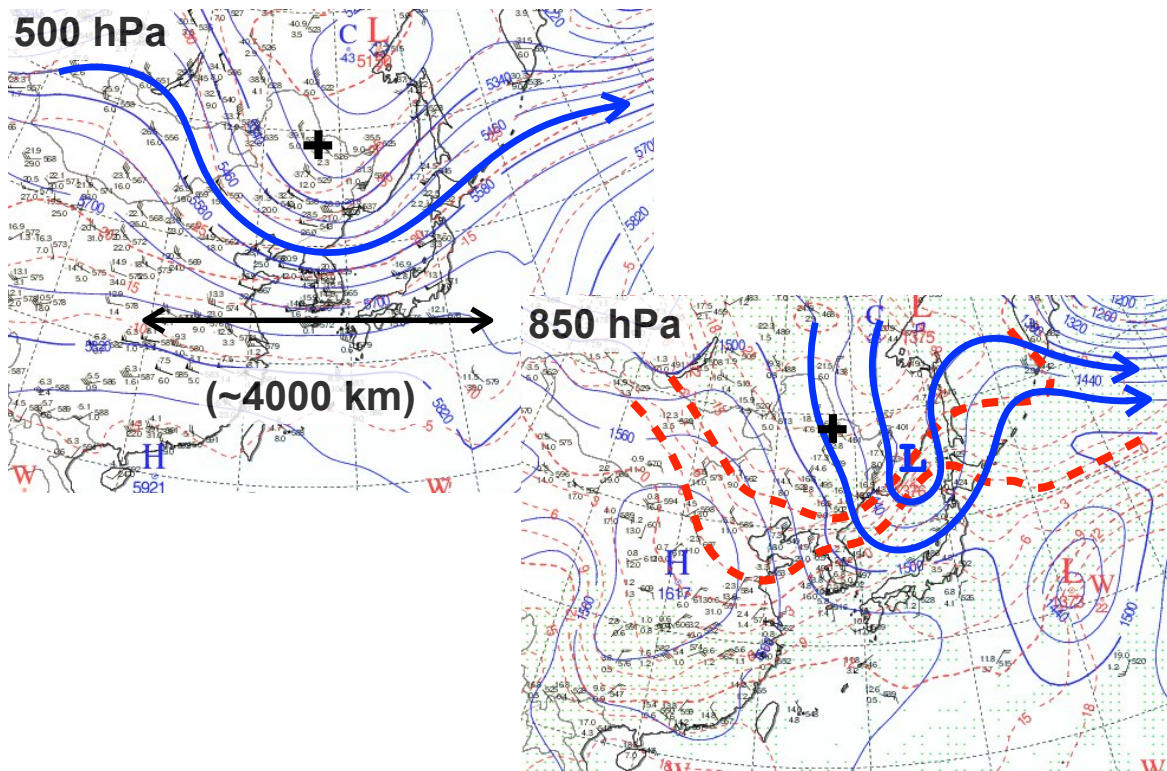
(from web.kma.go.kr)

Atmospheric phenomena (and their scale)

Orlanski (1975)	micro γ scale	micro β scale	micro α scale	meso γ scale	meso β scale	meso α scale	macro β scale	macro α scale
Fujita (1981)		moso α scale	miso β scale	miso α scale	meso β scale	meso α scale	maso β scale	maso α scale

horizontal length scale
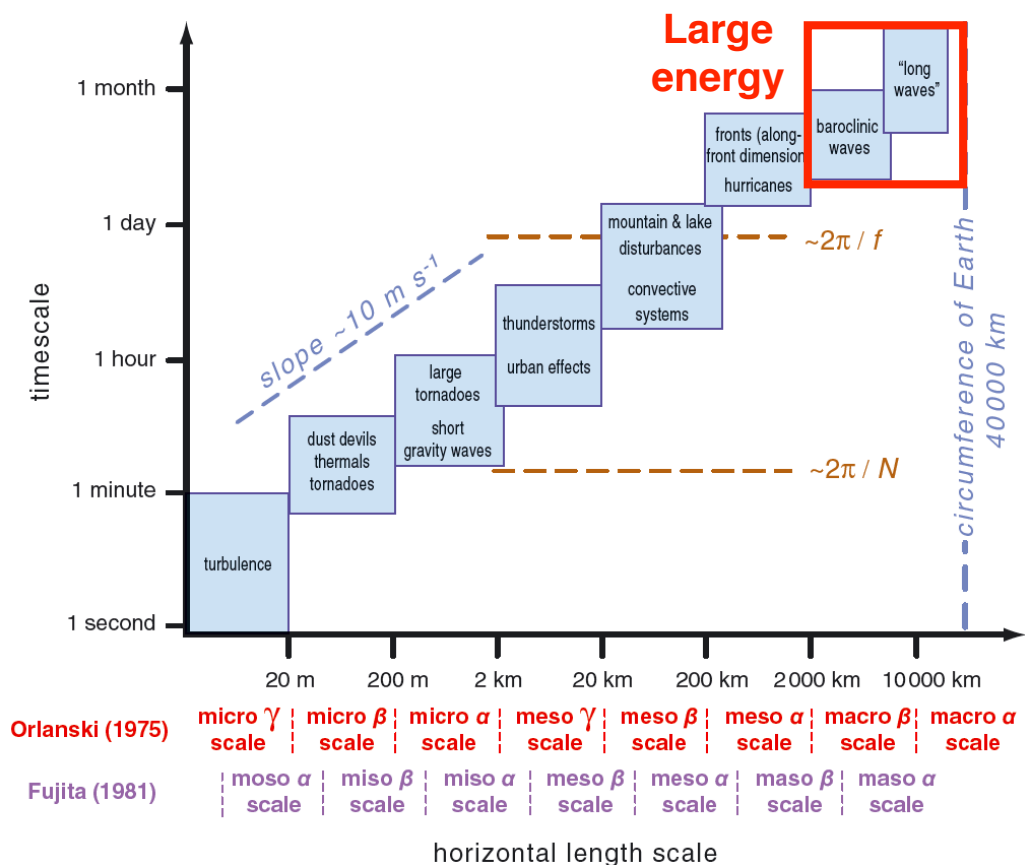
Atmospheric phenomena (and their scale)
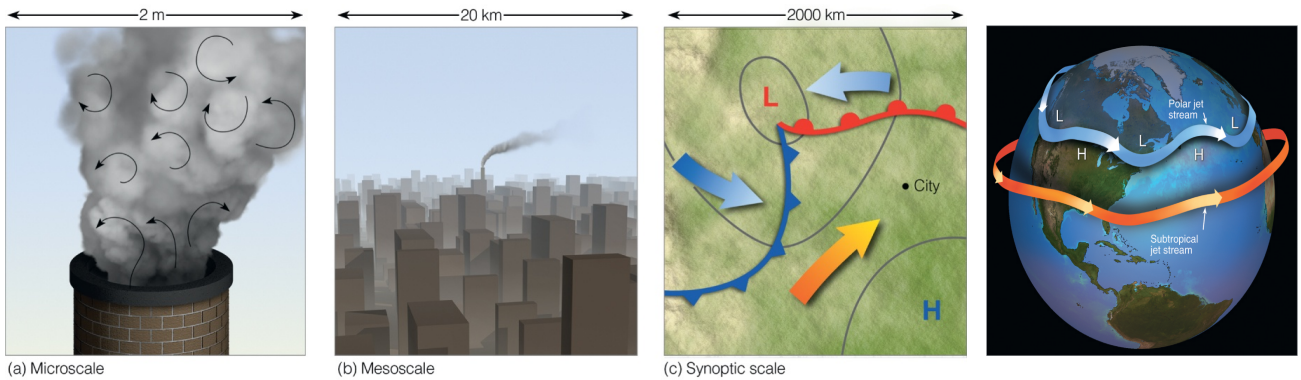
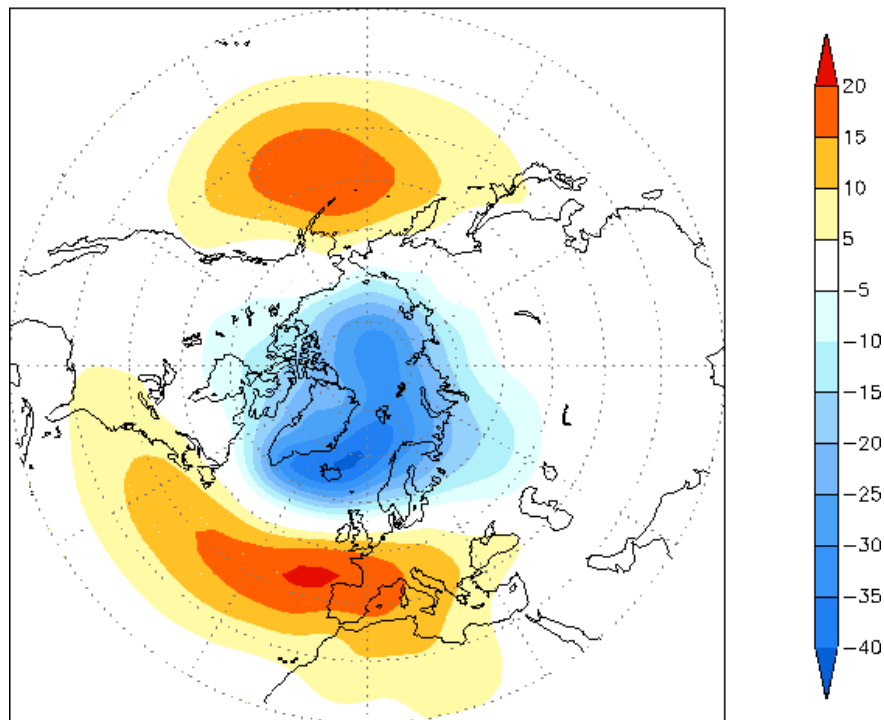| 미규모 (micro-scale) | 중규모 (meso-scale) | 종관규모 (synoptic-scale) | 행성규모 (planetary-scale) |

Rossby waves
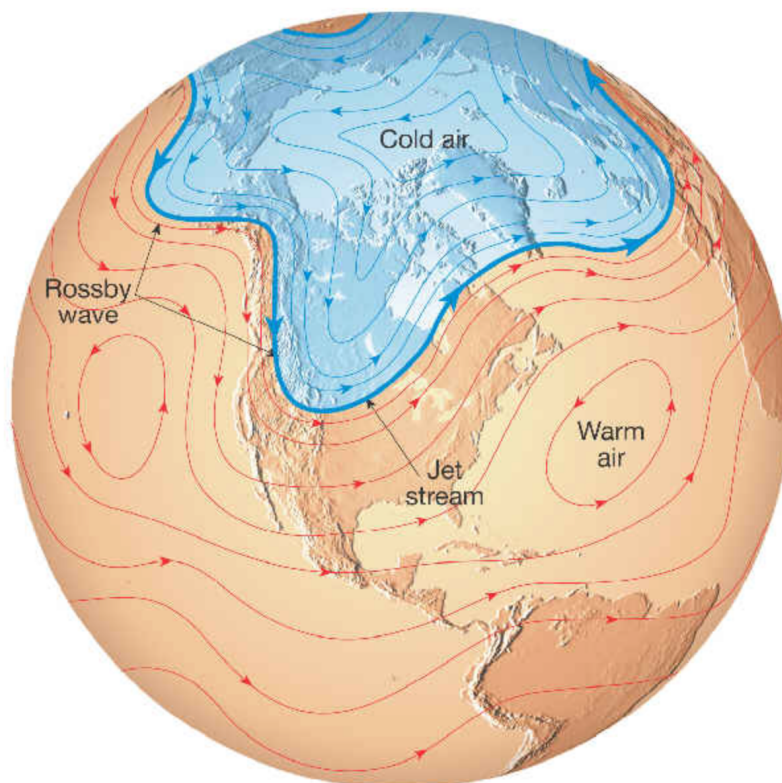
(from www.geography.hunter.cuny.edu)
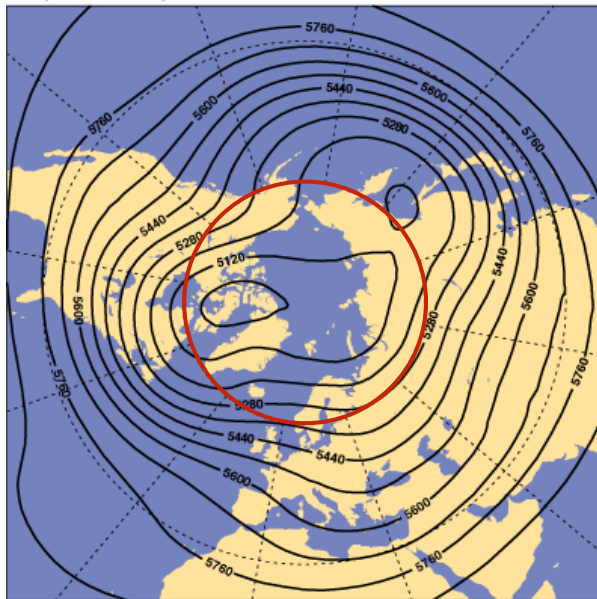
Arctic Oscillation (high latitude)

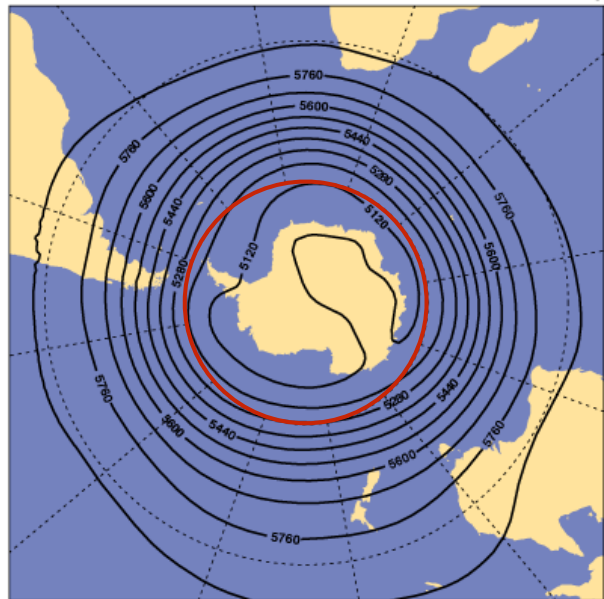Leading EOF (19%) shown as
regression map of 1000mb height (m)

(from CPC, NOAA)

Stationary waves (mid-latitudes)
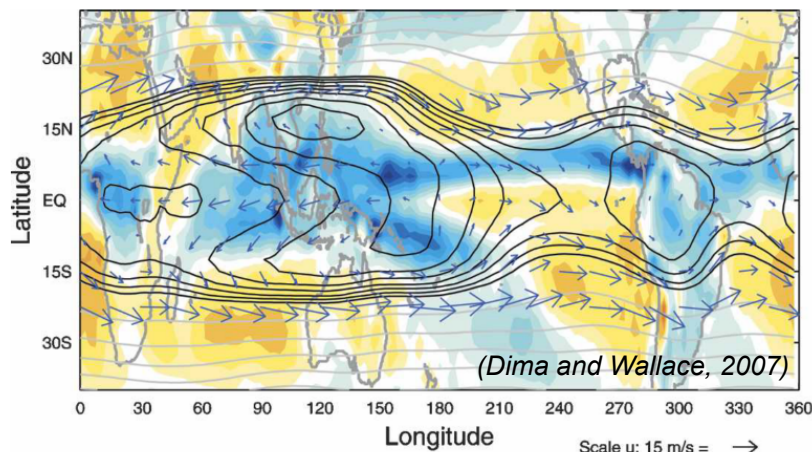

Geopotential height at 500 hPa

December-February

(from ERA40 Atlas)

- Effects of topography and land-sea contrast
  (N. Hemisphere)

Gill-type response (tropics)

(Dima and Wallace, 2007)

(Gill, 1980)

From basic equations set

$$\frac{\partial u}{\partial t} - \tfrac{1}{2}yv = -\frac{\partial p}{\partial x},$$

$$\frac{\partial v}{\partial t} + \tfrac{1}{2}yu = -\frac{\partial p}{\partial y},$$

$$\frac{\partial p}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = -Q.$$
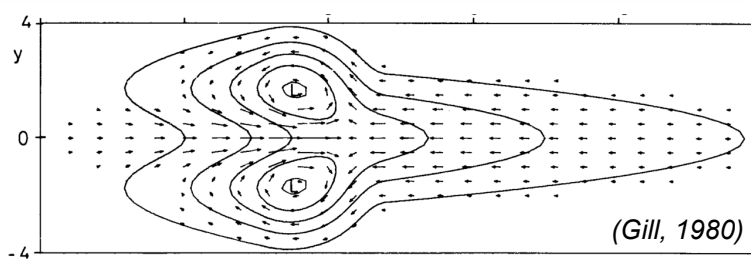
Simplify and solve

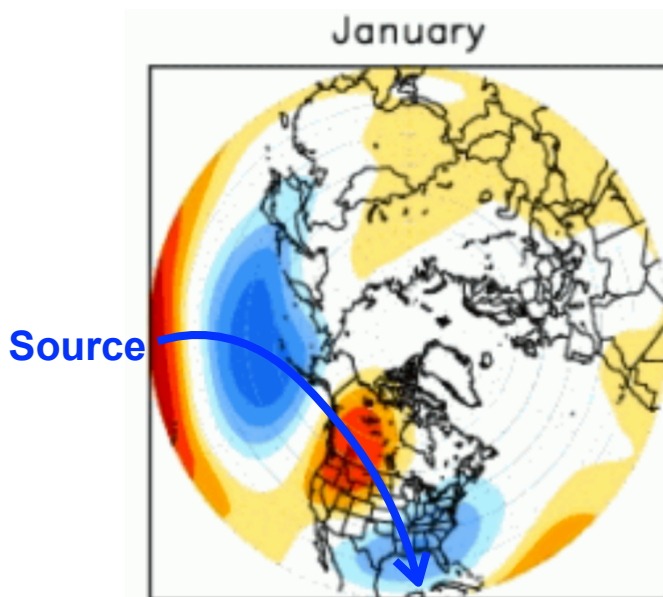$$\varepsilon u - \tfrac{1}{2}yv = -\frac{\partial p}{\partial x},$$

$$\varepsilon v + \tfrac{1}{2}yu = -\frac{\partial p}{\partial y},$$

$$\varepsilon p + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = -Q,$$

$$w = \varepsilon p + Q.$$

Rossby waves (from tropics)

Source

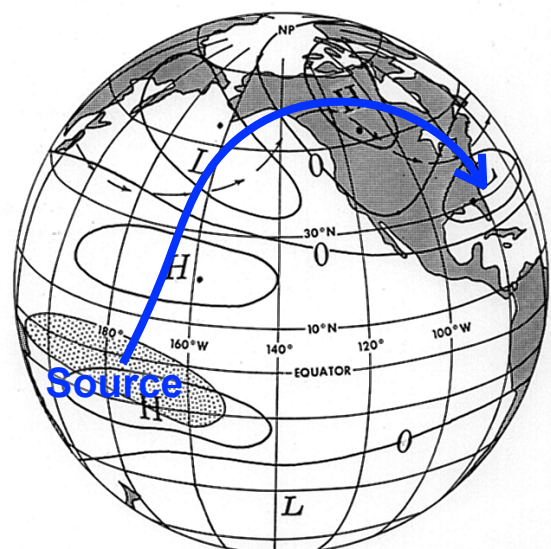*Pacific/North American Pattern (PNA)*
(from CPC, NOAA)

Source

Figure 1.26. A schematic diagram of the Pacific North American (PNA) pattern of middle- and upper-tropospheric geopotential height anomalies during a Northern Hemisphere winter that coincides with El Niño conditions in the tropical Pacific. The arrows depict a midtropo- spheric streamline as distorted by the anomaly pattern, with pronounced "troughing" over the central Pacific and "ridging" over western Canada. Cloudiness and rainfall are enhanced over the shaded area. The dots indicate the stations used in the time series mentioned in Table 1.1. [From Horel and Wallace (1981).]
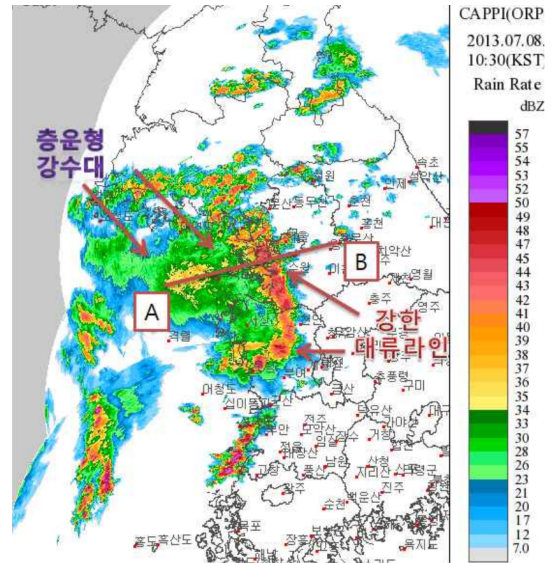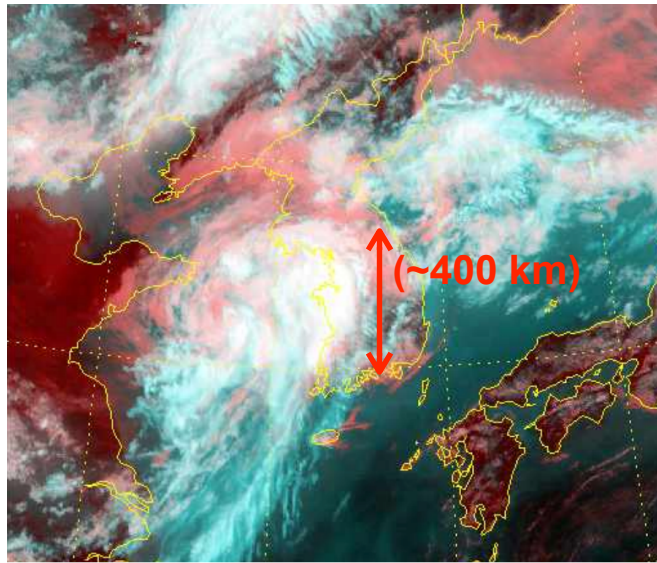
Mid-latitude cyclone (synoptic waves)
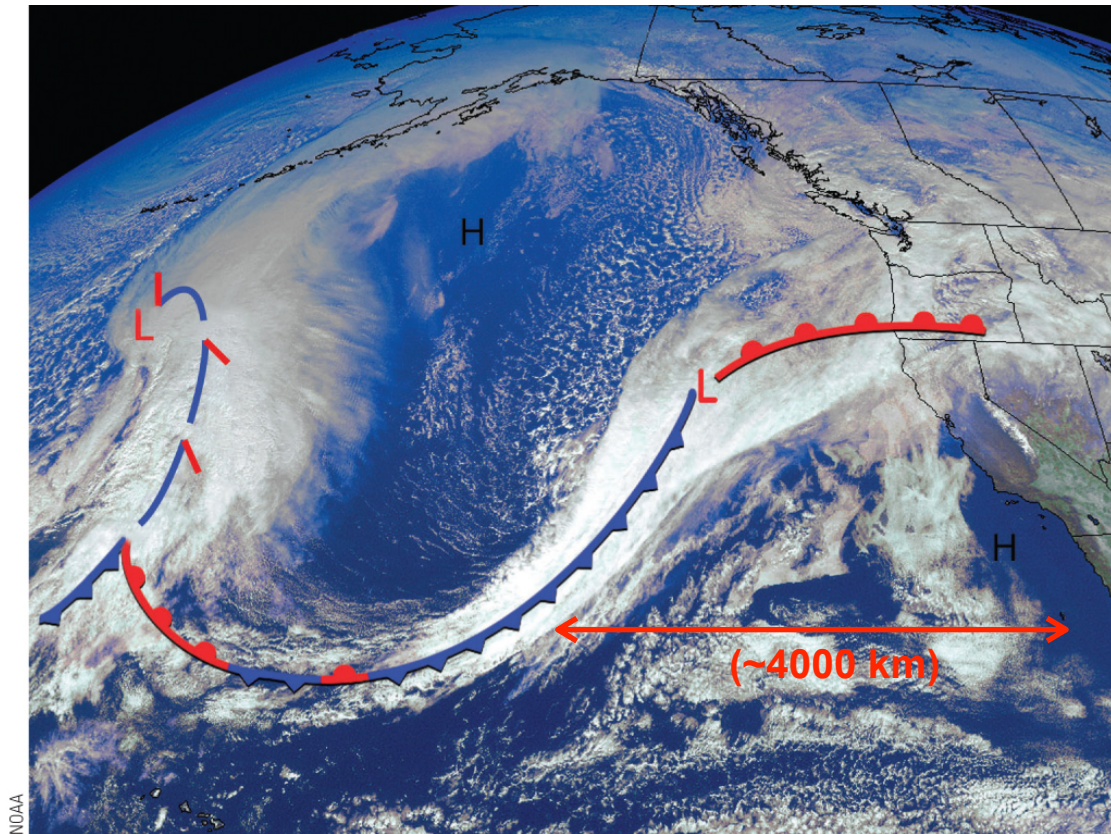
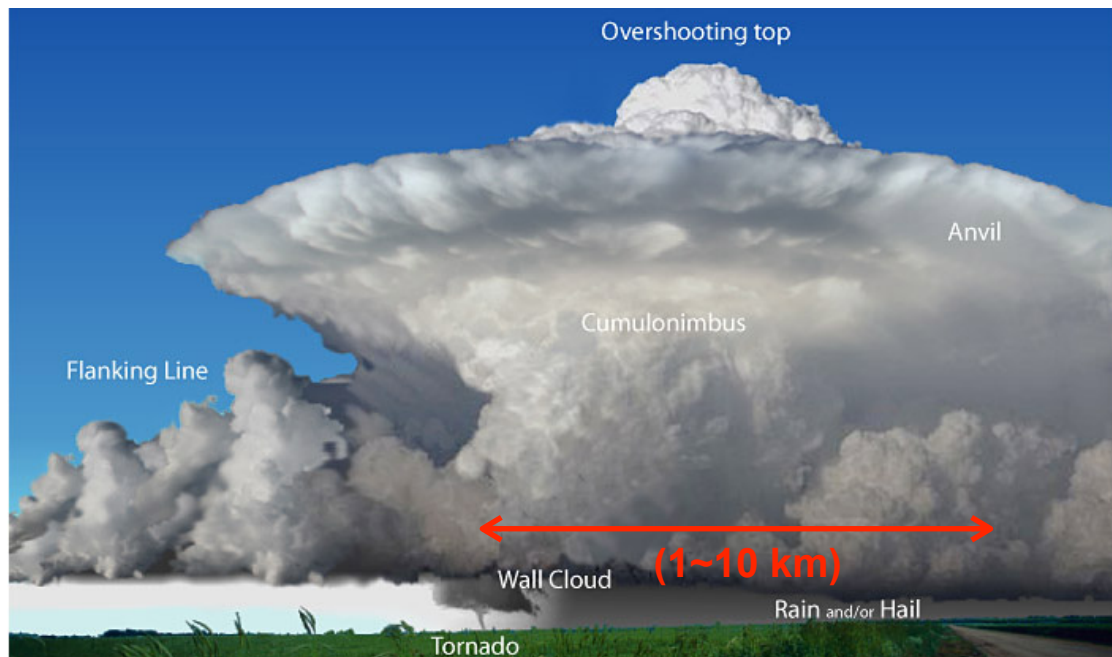# Tropical cyclone (typhoon, hurricane)
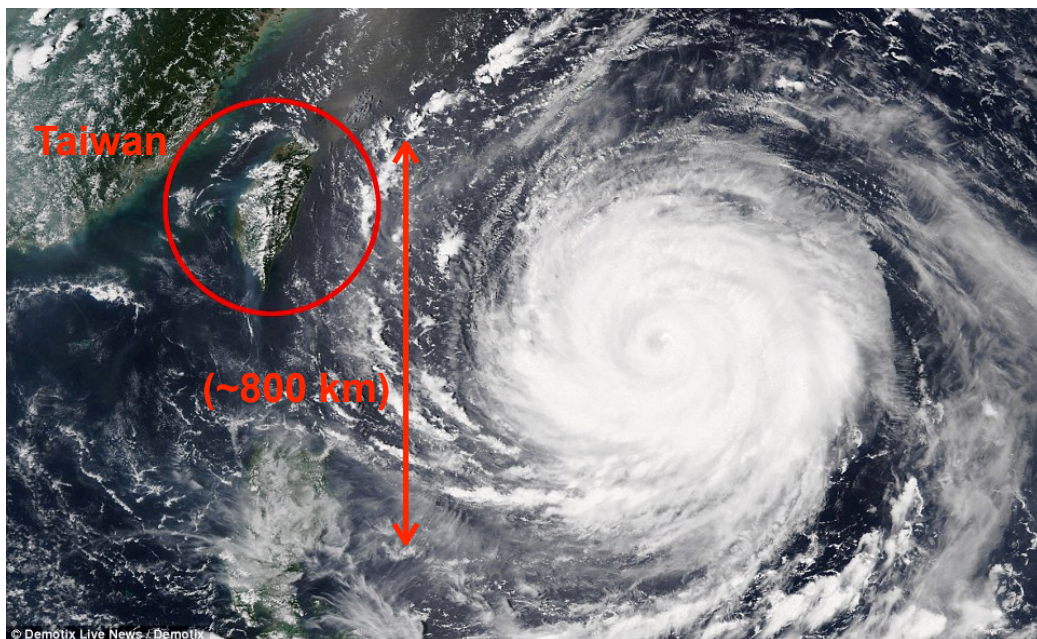
(Typhoon Soudelor, NASA)

Mesoscale Convective System

(~400 km)

(기상청: 손에잡히는 예보기술)

Thunderstorm

(Thomas A. Horne, http://aopa.org)
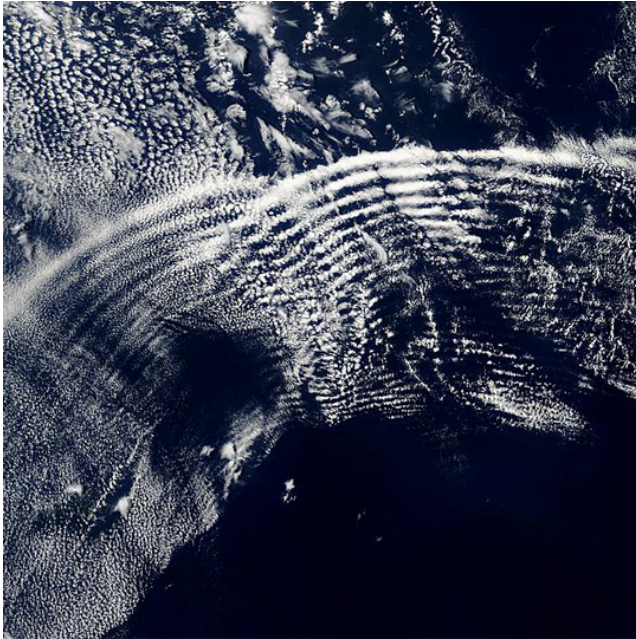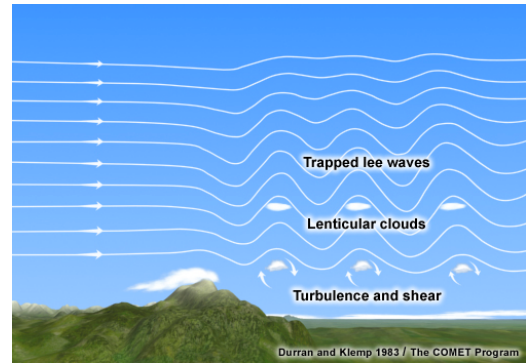
Gravity waves

(Gravity waves near Australia, NASA)

(from MetEd)

Tornado

Rossby wave