Global Circulation and Weather Systems

Outline:

- Overview/ review on global weather systems – primitive equations
- Mid-latitude weather and fronts
- A perfect storm example
- Modification by topography
- The End

Primitive Equations and Circulation Patterns

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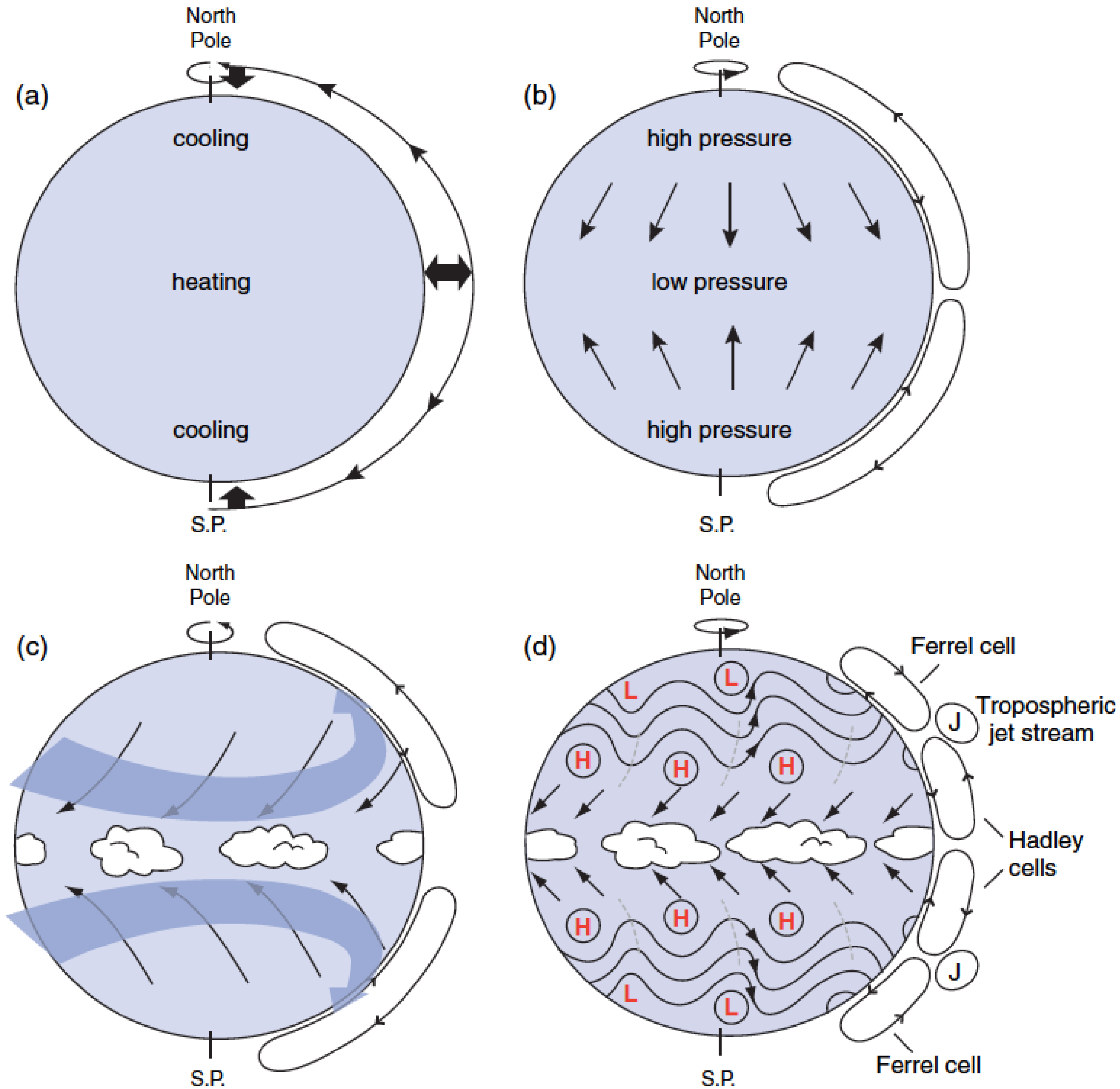
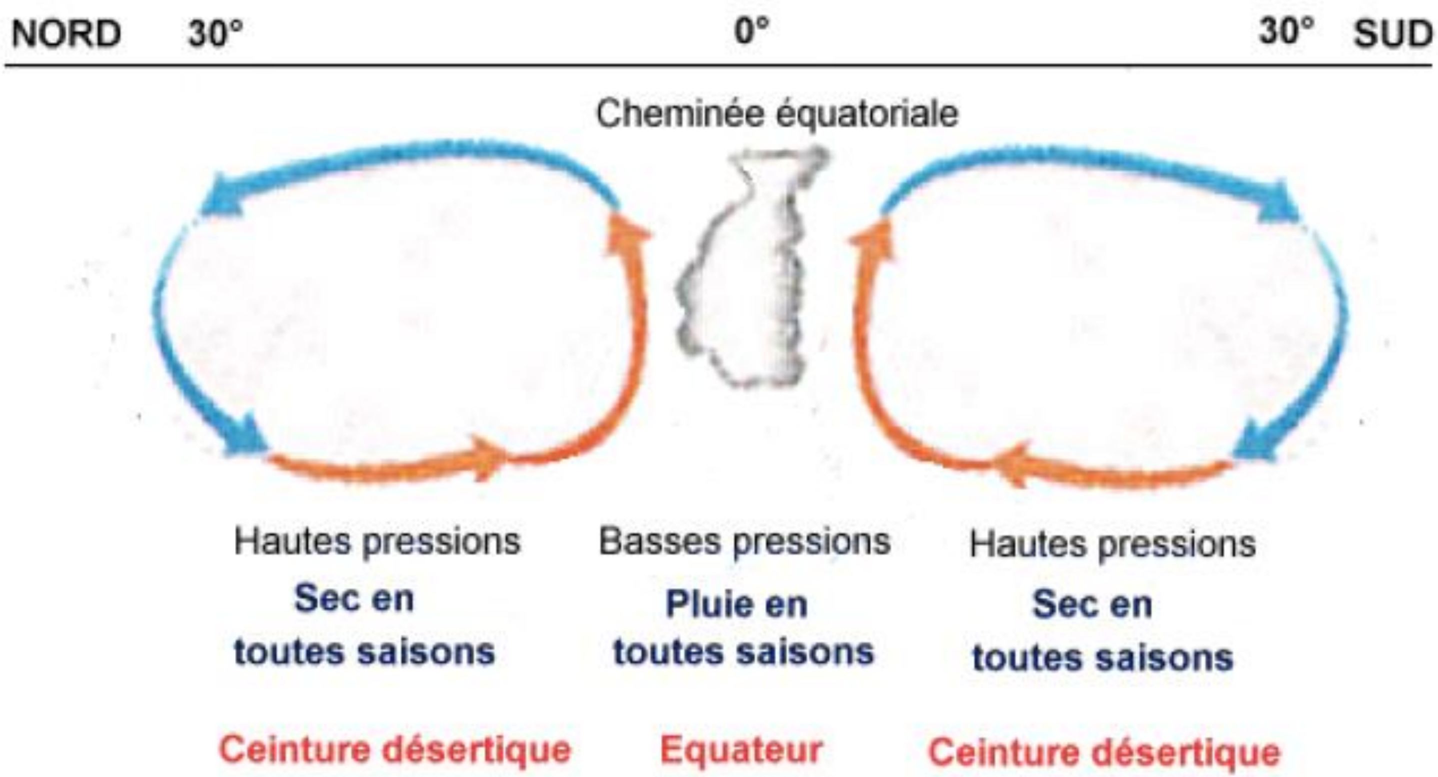


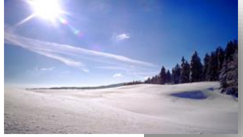
As already discussed in the Atmospheric Dynamics section, the set of “primitive” equations realistically shows the development of the major flow systems in the troposphere after starting the numerical integration. The Ferrel cell is a secondary meridional (north – south) circulation that is the net effect of mid-latitude weather patterns which are discussed in more detail below.

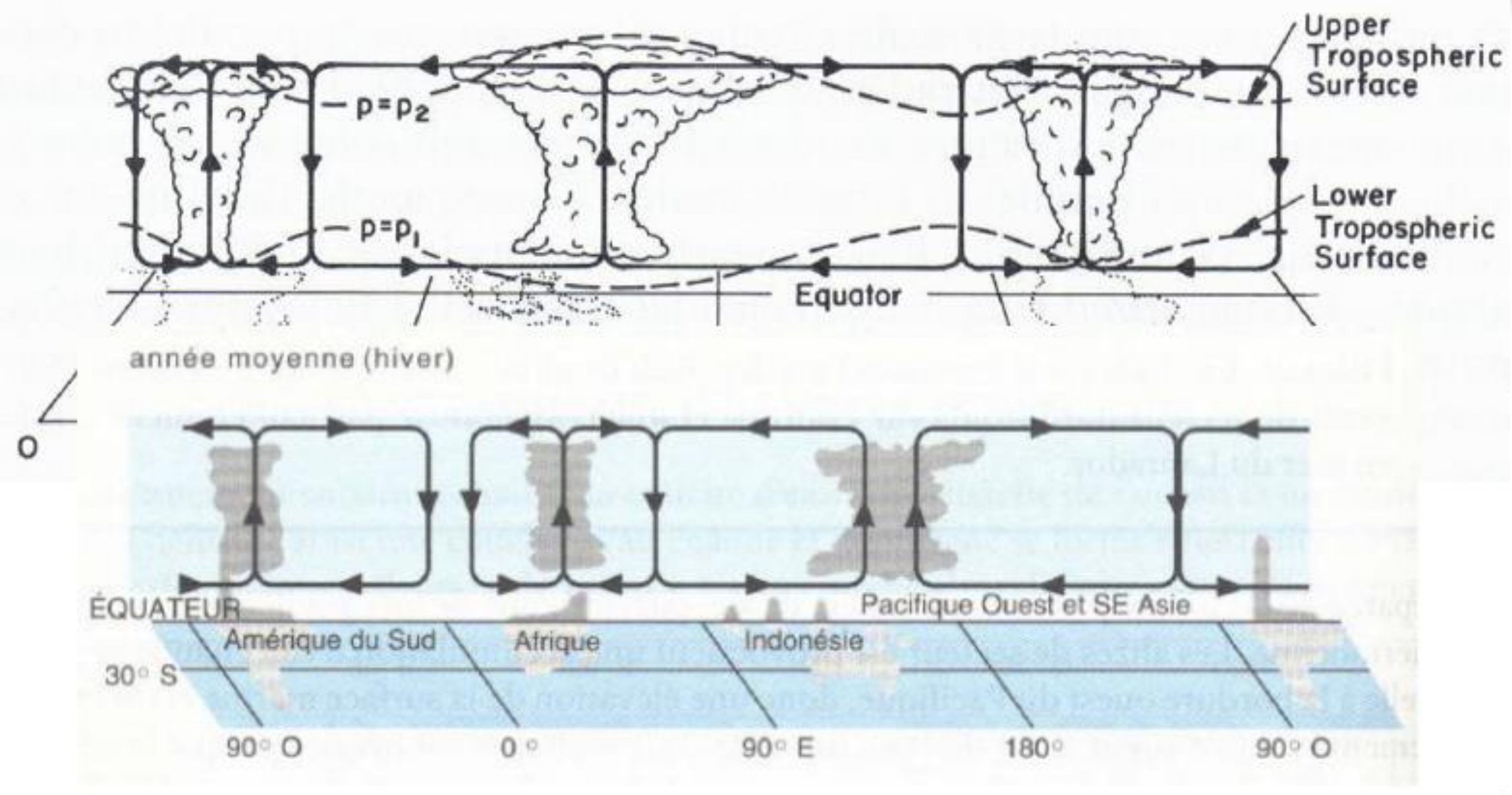
Hadley Cell



The Hadley cell describes the circulation that is initiated by hot and moist air rising near the equator in the so called inner tropical convergence zone (ITC). As a consequence air flows towards higher latitudes at height and back towards the equator close to the surface. This is the primary engine behind large-scale motions in the troposphere.

Walker Circulation





The Walker circulation is zonal, i.e. air flows in east – west direction. This (weaker) circulation is caused by the uneven land – sea distribution. The ITC is stronger over land than over sea and therefore zonal differences generate this weaker Walker circulation.

Why is the ITC stronger over land than over water?

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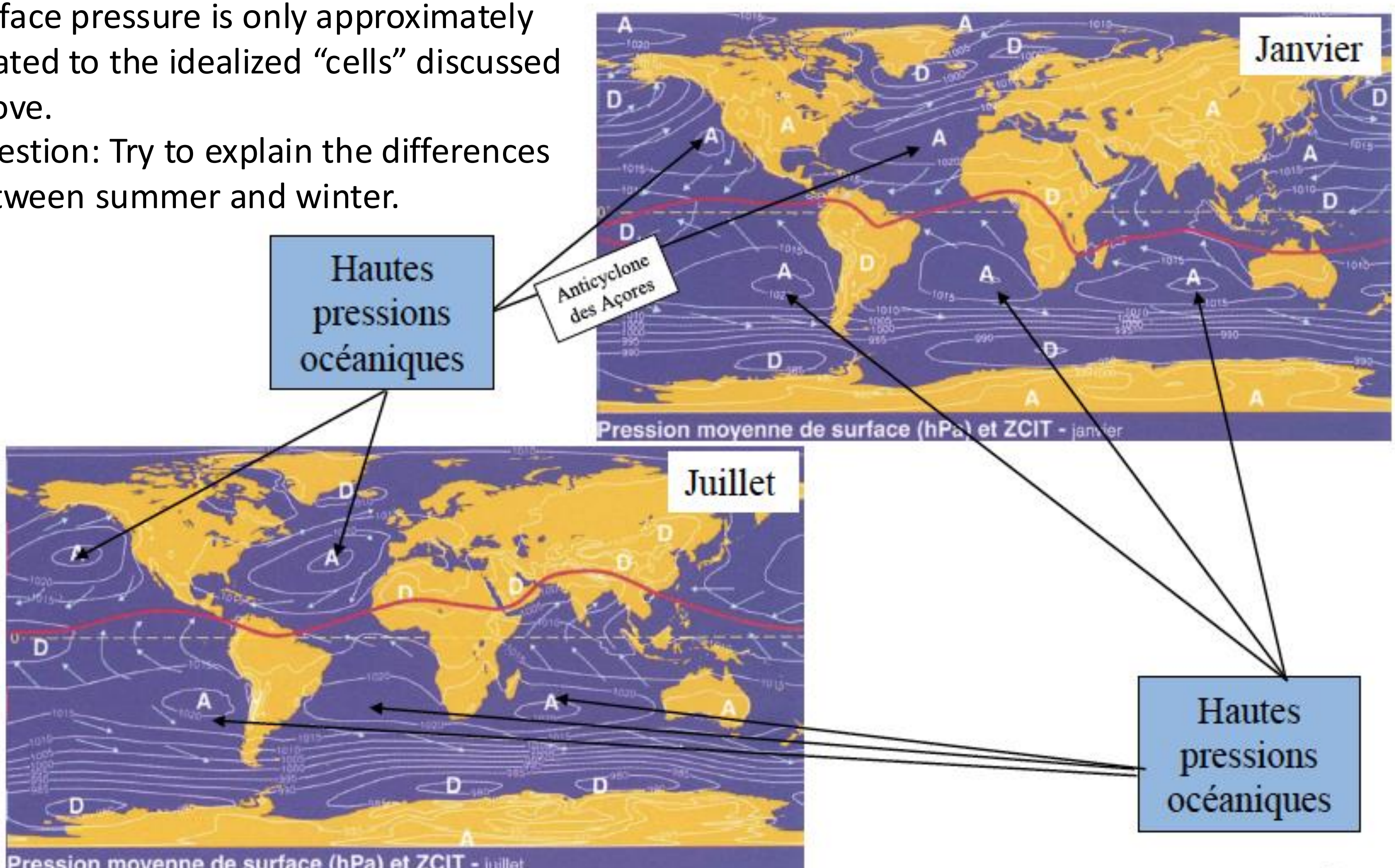
A. The albedo over land is higher
B. Water mixes and transports heat away
C. Land is on average at higher elevation and has therefore lower pressure
D. There are more clouds over land

Observed (real) surface pressure distribution

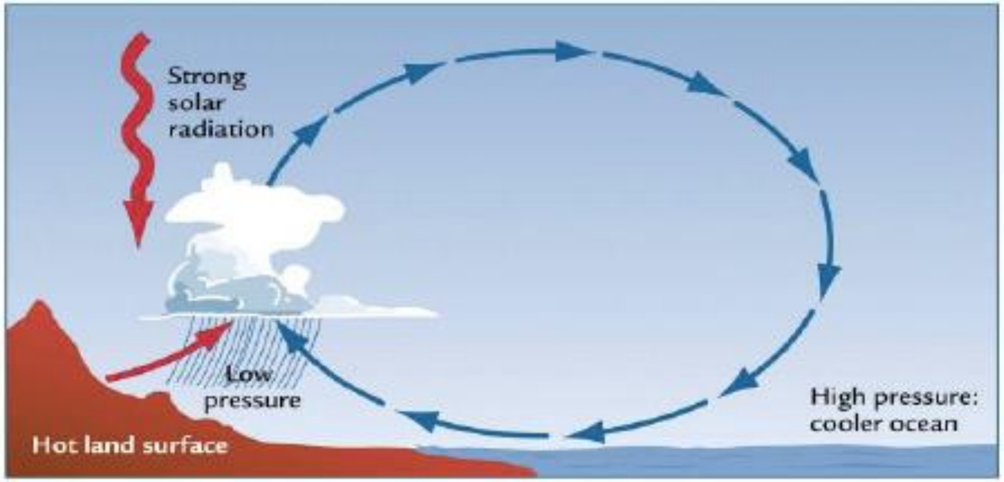
Mostly shaped by the irregular distribution of the continents, the real surface pressure is only approximately related to the idealized “cells” discussed above.

Question: Try to explain the differences between summer and winter.

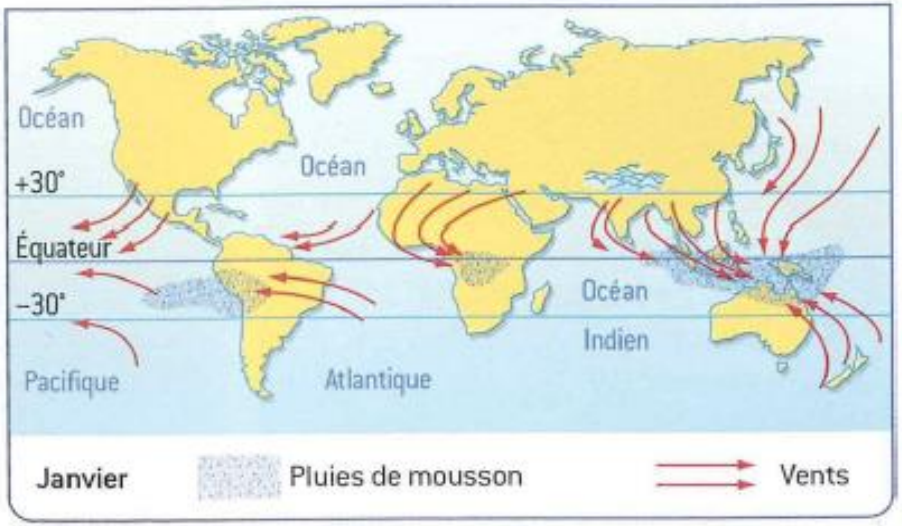


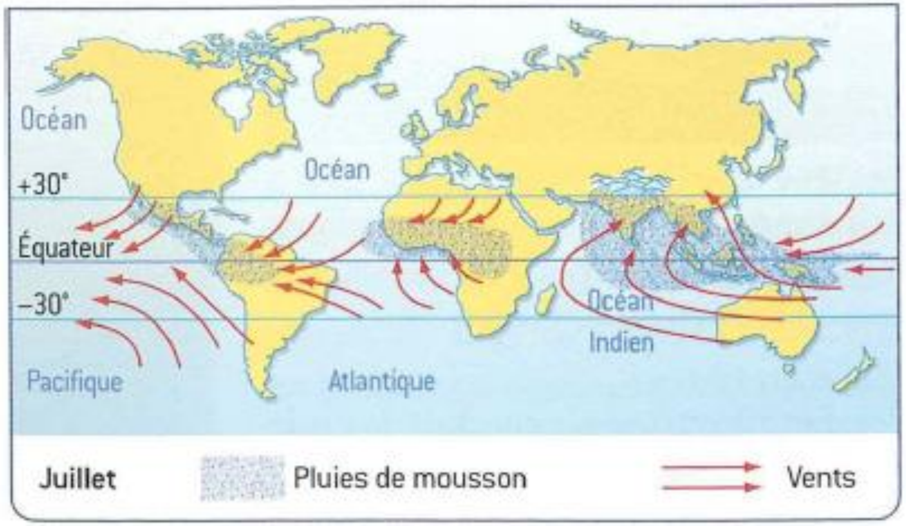
Monsoons

The pressure and circulation patterns as given by the land – sea distribution are further modified by mountain ranges such as the Himalayas. Recurring seasonal weather cycles such as strong precipitation in India are called monsoons.



A Summer monsoon





Why do the wind patterns show the greatest deviations from the normal trade wind patterns caused by Coriolis in Indonesia?

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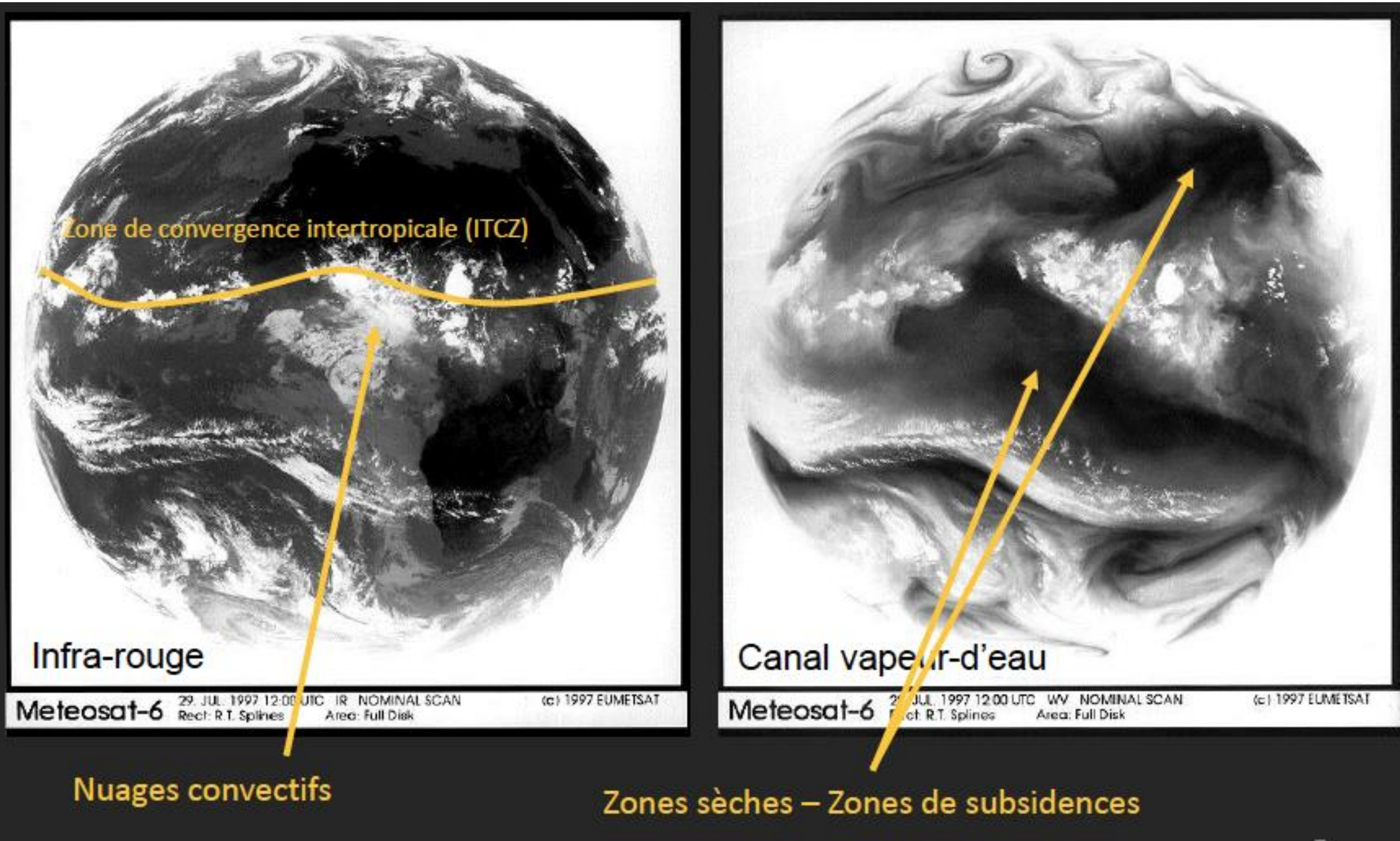
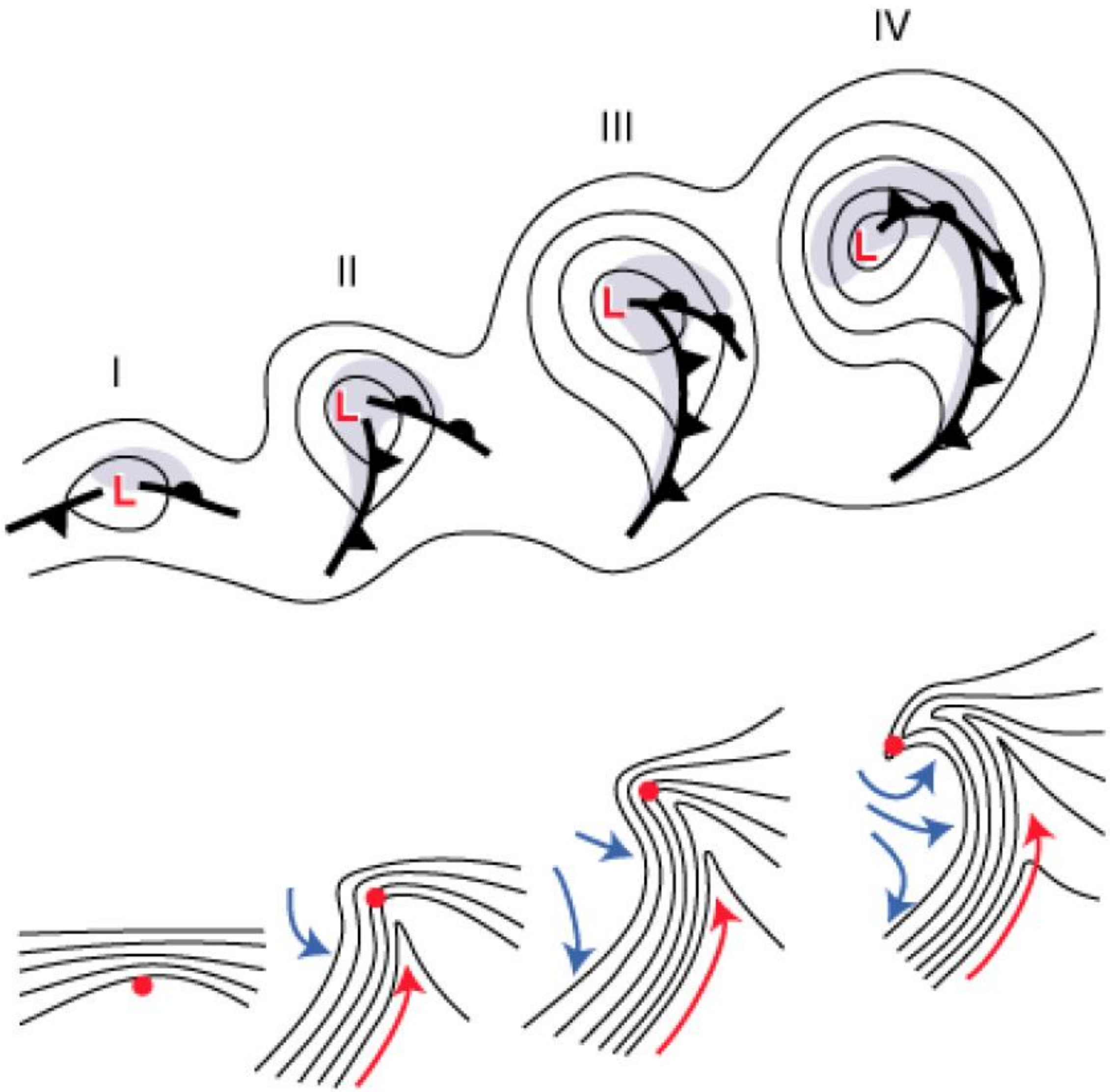
A. Coriolis is weaker there
B. The free atmosphere is in thermal equilibrium
C. Monsoon effects are strongest there
D. Indonesia has the highest fraction of rain forests
E. The ITC moves asymmetrically
F. Australia has lots of desserts

IR, V – Picture of Weather Systems

A lot of knowledge on weather and atmospheric motions is provided by satellite images.

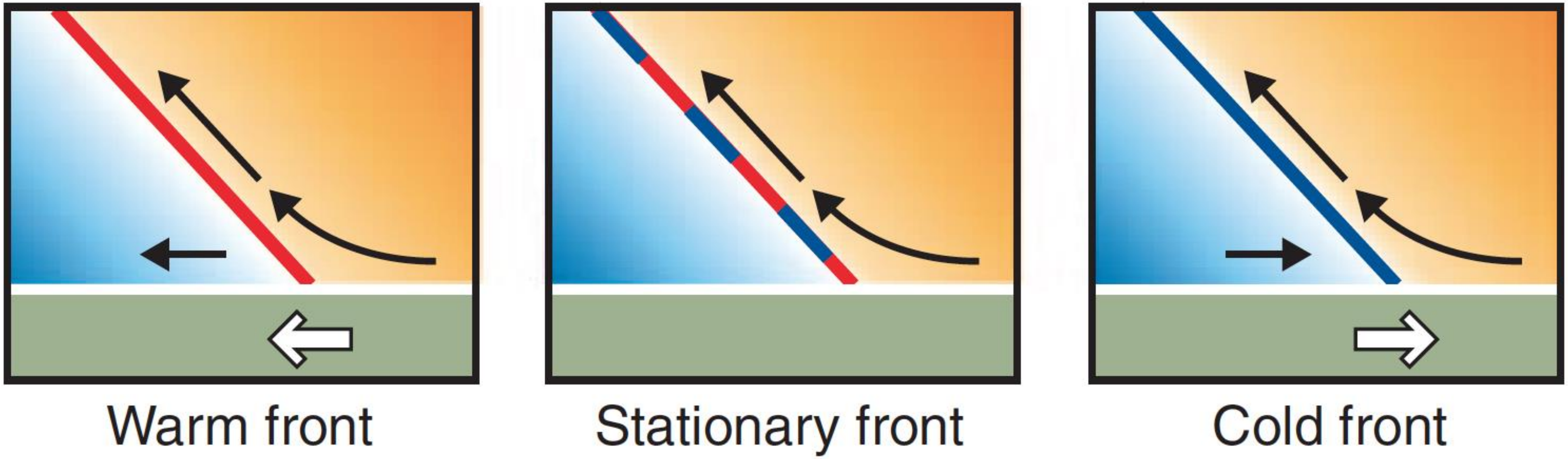


Cyclogenesis



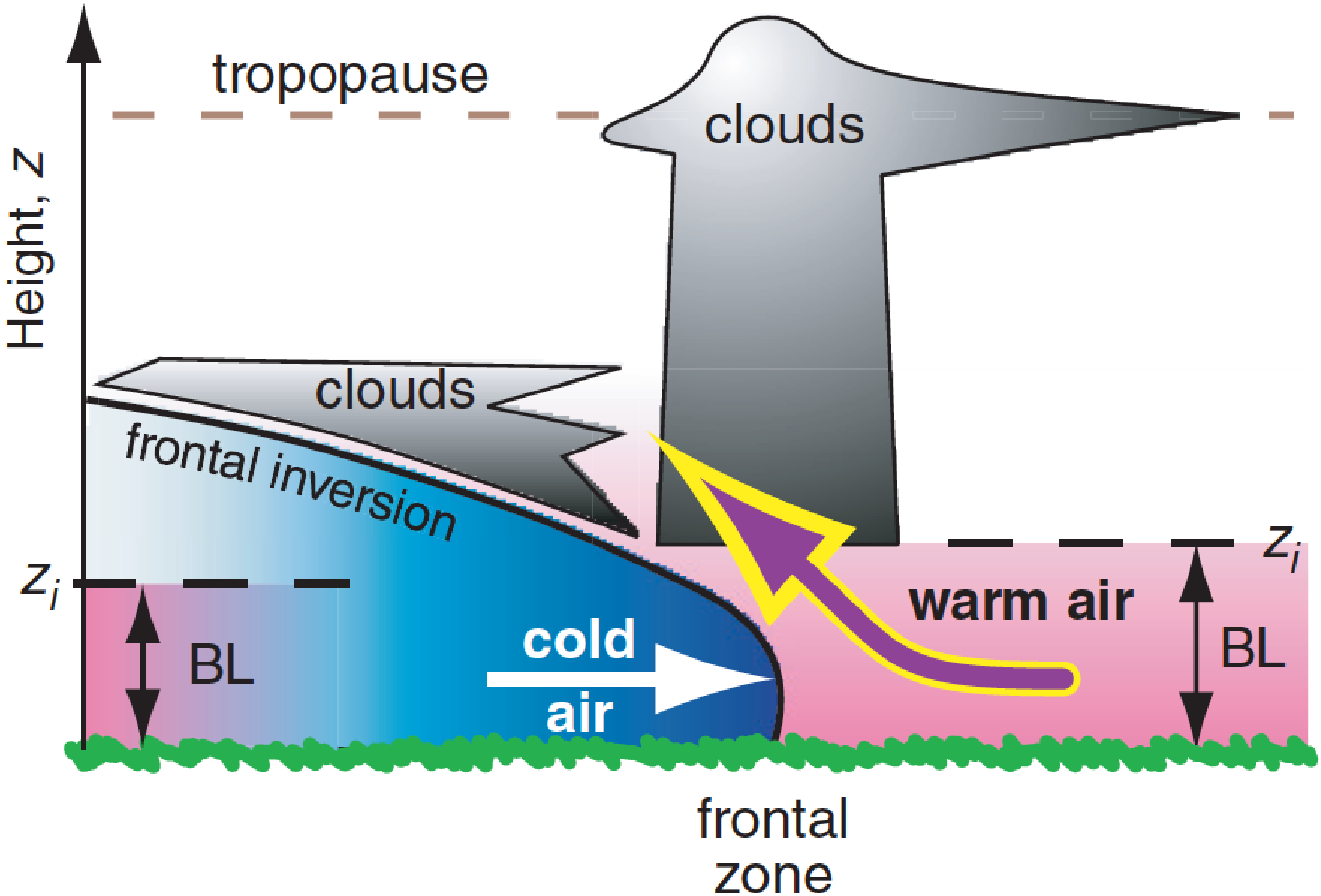
Idealized picture of cyclogenesis in four stages. Shown are (a) isobars, fronts and the area with precipitation (shaded); (b) isotherms, the center of low pressure (red dots) and winds in the warm (red) respectively cold sector (blue). Since the warm front is slower than the cold front, an occluded front develops.

Movement of fronts



The warm front is bringing warm air to an area, which had previously colder air. This leads to the warmer and moister air rising and producing precipitation. A cold front is the opposite: the cold air moves into the warm sector of the system. Warm air is pushed up and this can happen faster, i.e. the cold front moves faster than the warm front. As the cold front hits a previous warm front, a stationary front my occur, which does not show any pronounced progression.

Capping Inversion Dynamics and Fronts



The passage of a front can also temporarily wipe out the upper boundary of the BL. This is shown here for the example of a cold front.

Weather between fronts – vertical cross section

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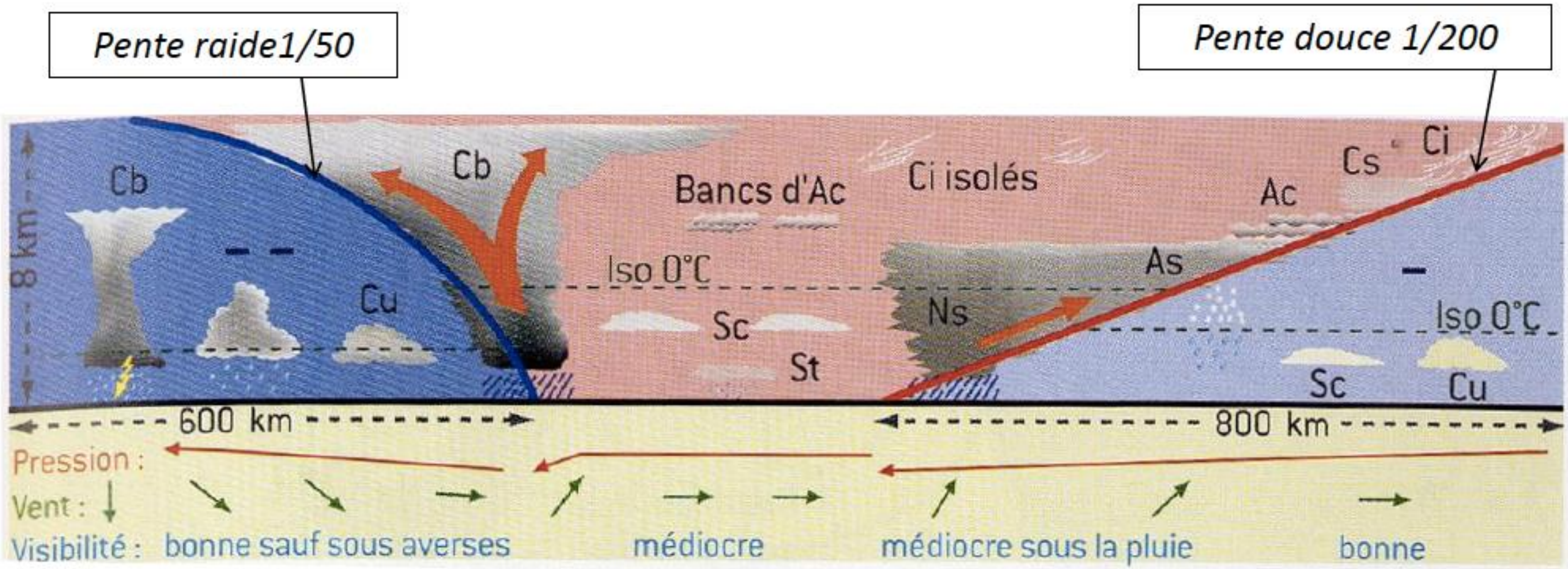
Coupe A-B:



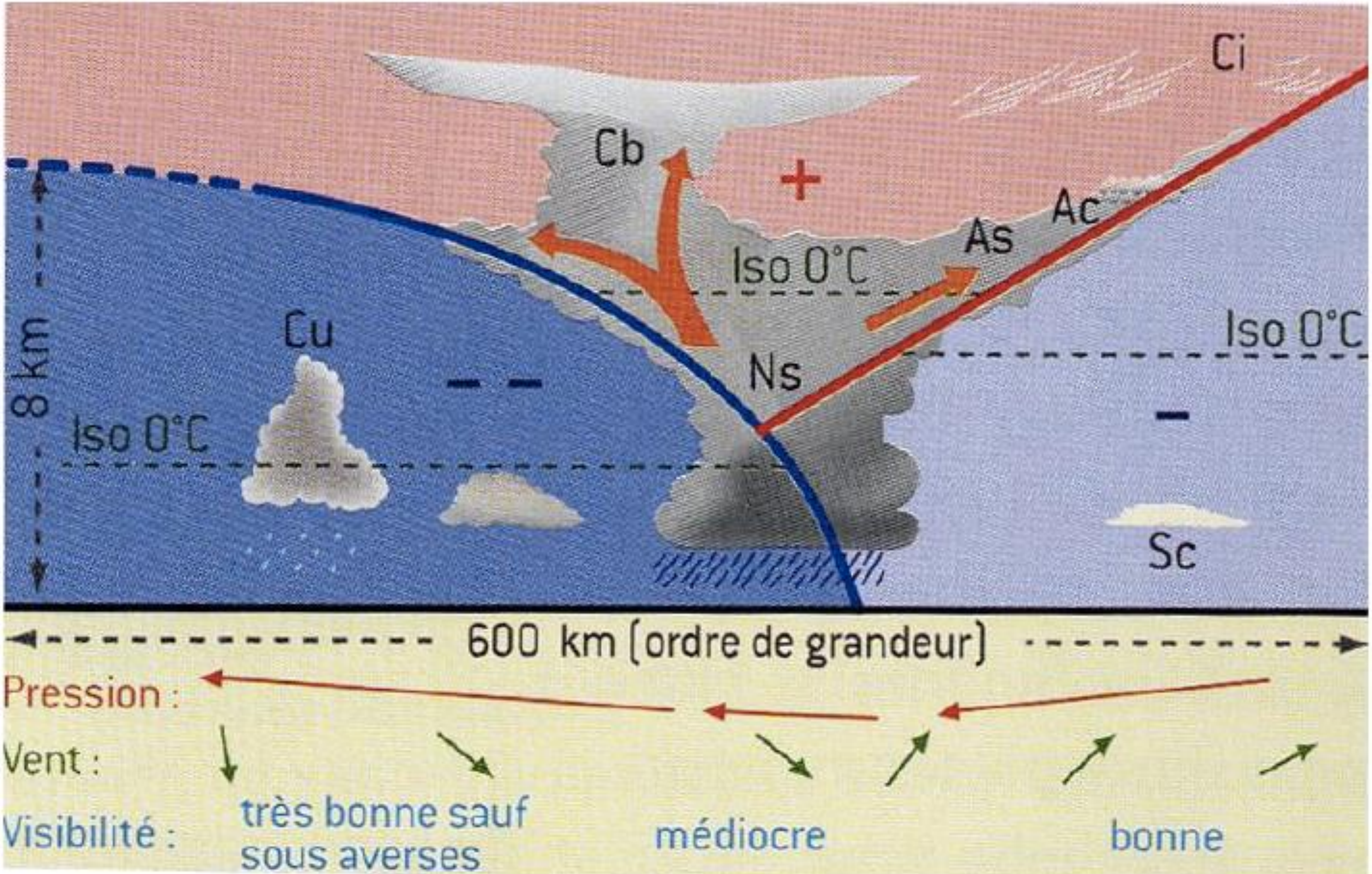
Front froid:
Orages violents

Front chaud:
Précipitations tranquilles, continues et durables

La traine:
Développement de nuages cumuliformes, averses.

Secteur chaud:
Accalmie

Occlusion Weather



Why is there typically more severe weather with cold fronts compared to warm fronts?

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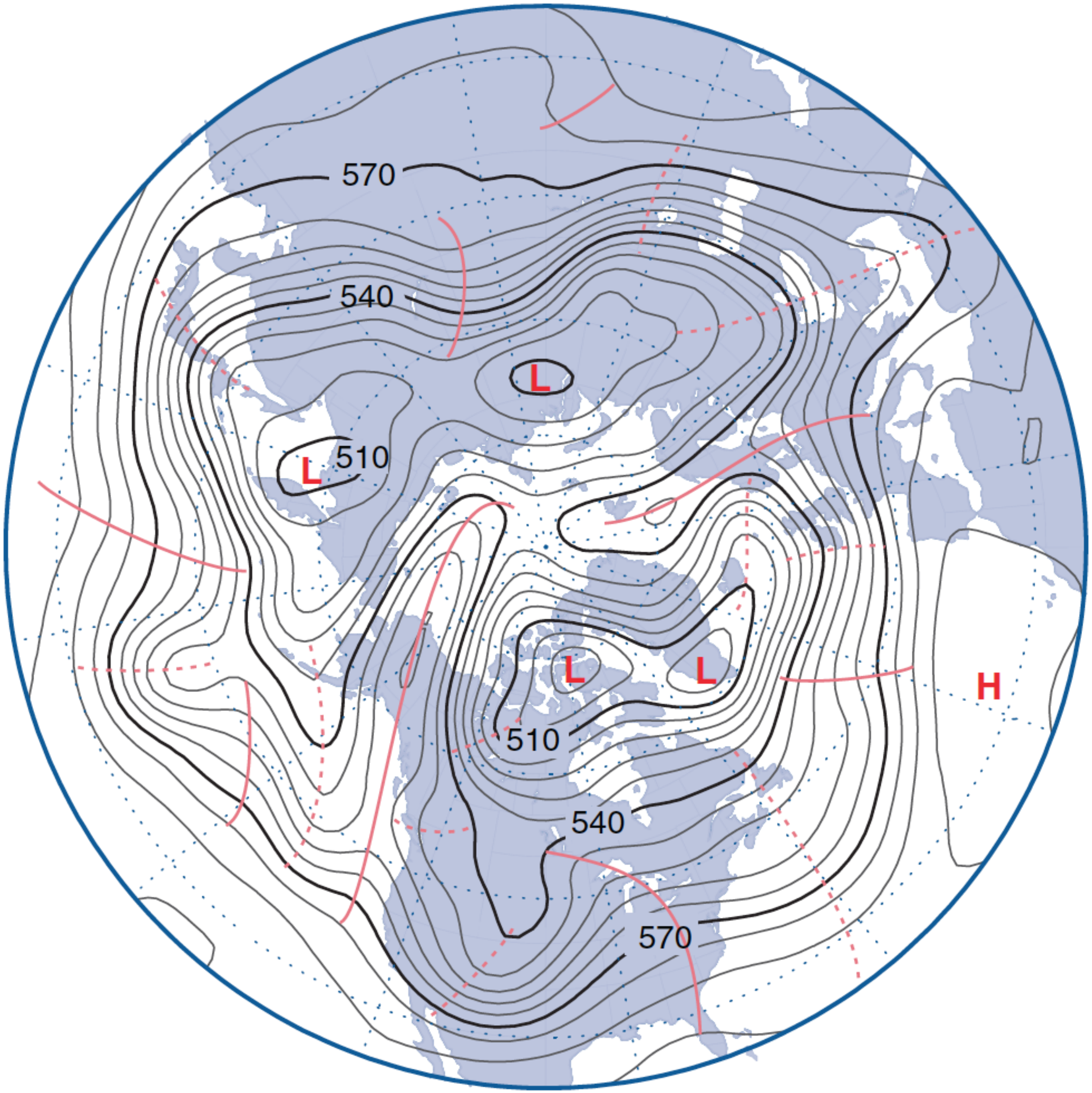
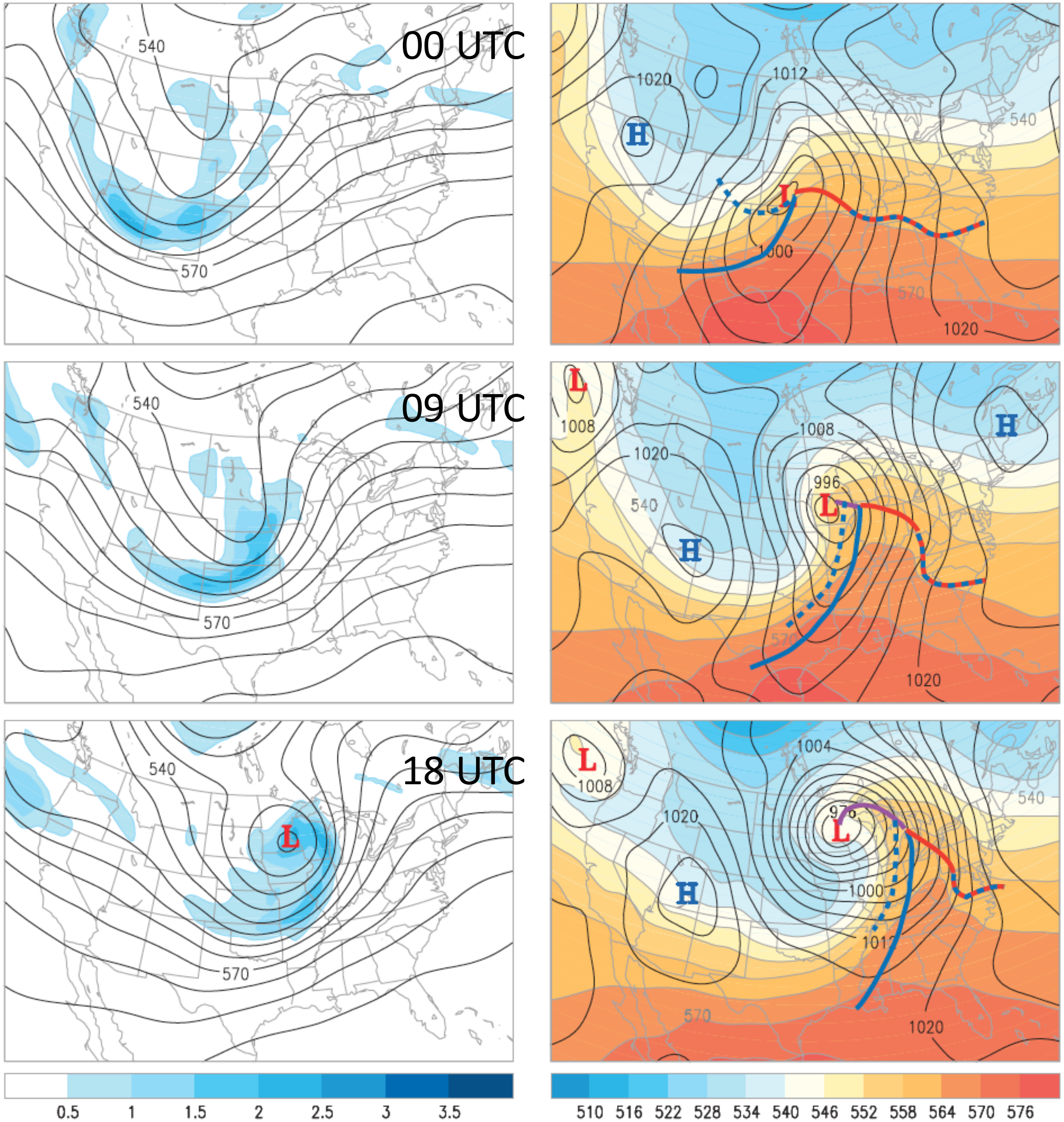
A. Cold fronts lead to faster and deeper lifting
B. Warm fronts have more energy
C. Cold fronts advect polar air
D. Cold fronts are less frequent than warm fronts

Analysis of a real case (500 hPa) Nov. 10 1998



Series of low-pressure systems (shown as height of the 500 hPa pressure level) at high latitudes of the northern hemisphere. Shown are also high-pressure “ridges” (solid red) and low pressure “troughs” (dashed red). From a pronounced trough over North America, a significant storm develops and will be analysed in the following. Baroclinic waves move on average eastward with 10 m/s, which is approximately the mean wind speed at the 700 hPa level. Distance between troughs is approximately 4000 km.

Synoptic Development over North America

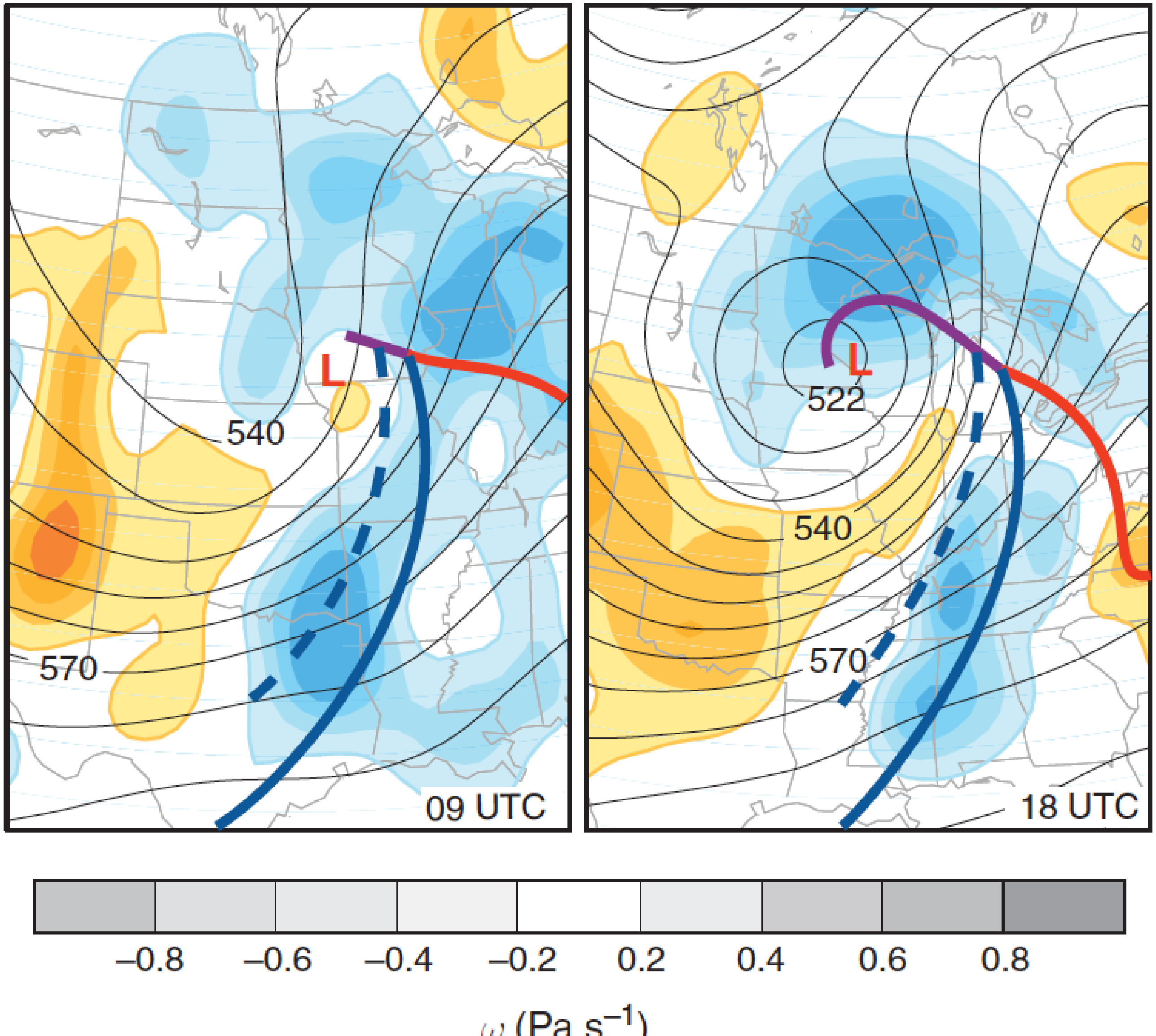


500 hPa height and vorticity   sea-level pressure, 1000 to 500 hPa thickness and fronts

Intensification of the trough (a) and formation of a cutoff low (isolated low in the geopotential height field), which suggests an almost circular wind pattern. The small spacing between the 500 hPa contours shows dramatic increase in geostrophic wind speed. An extratropical cyclone has formed.

At the surface (b), the low pressure intensifies and the thickness between 1000 and 500 hPa becomes larger in the area of the fronts (temperature gradient intensifies). This is associated with the formation of surface fronts. Warm front is drawn in red, cold front is drawn in blue.

Vertical Motion associated with Storm



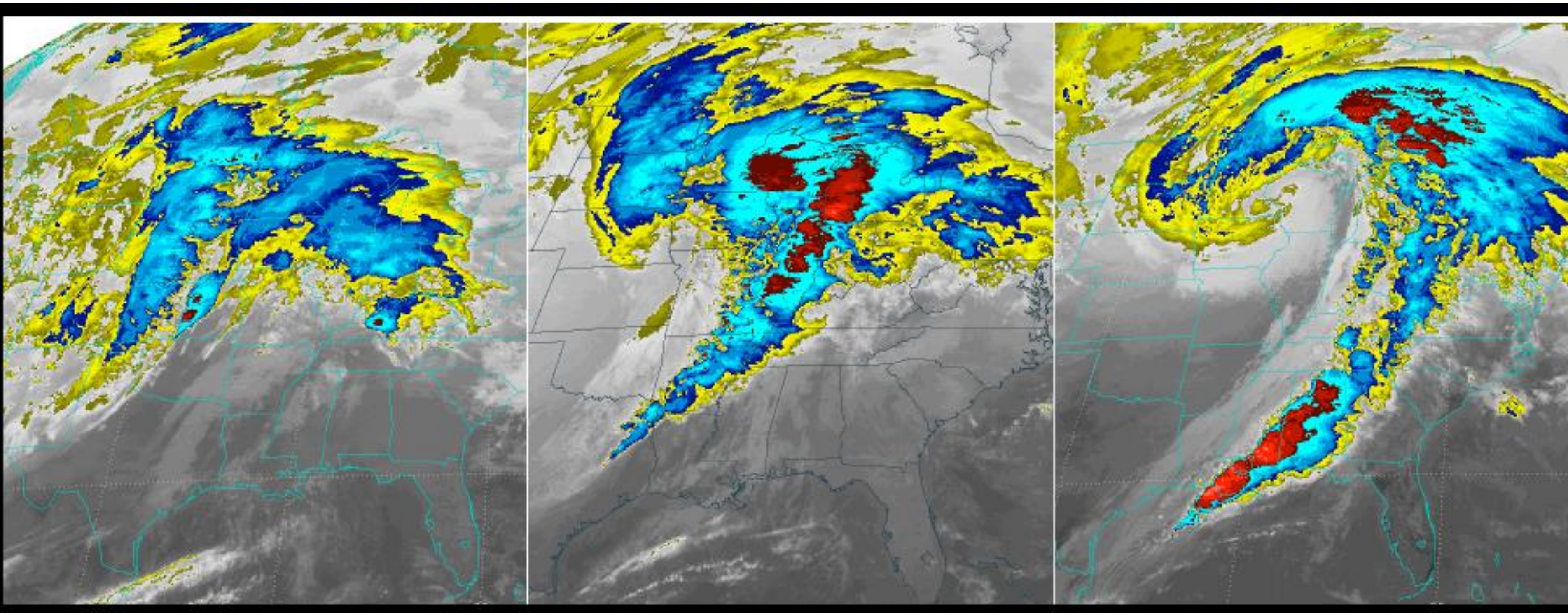
Ascent (upward) motion (blue, negative ω) is associated with the frontal passage and behind the front subsidence prevails (tan / orange) because of colder air moving in. Often clouds clear after the passage of the cold front. The vertical motion is given for the 700 hPa level.

Blue

Tan

Satellite Image of the Same Front

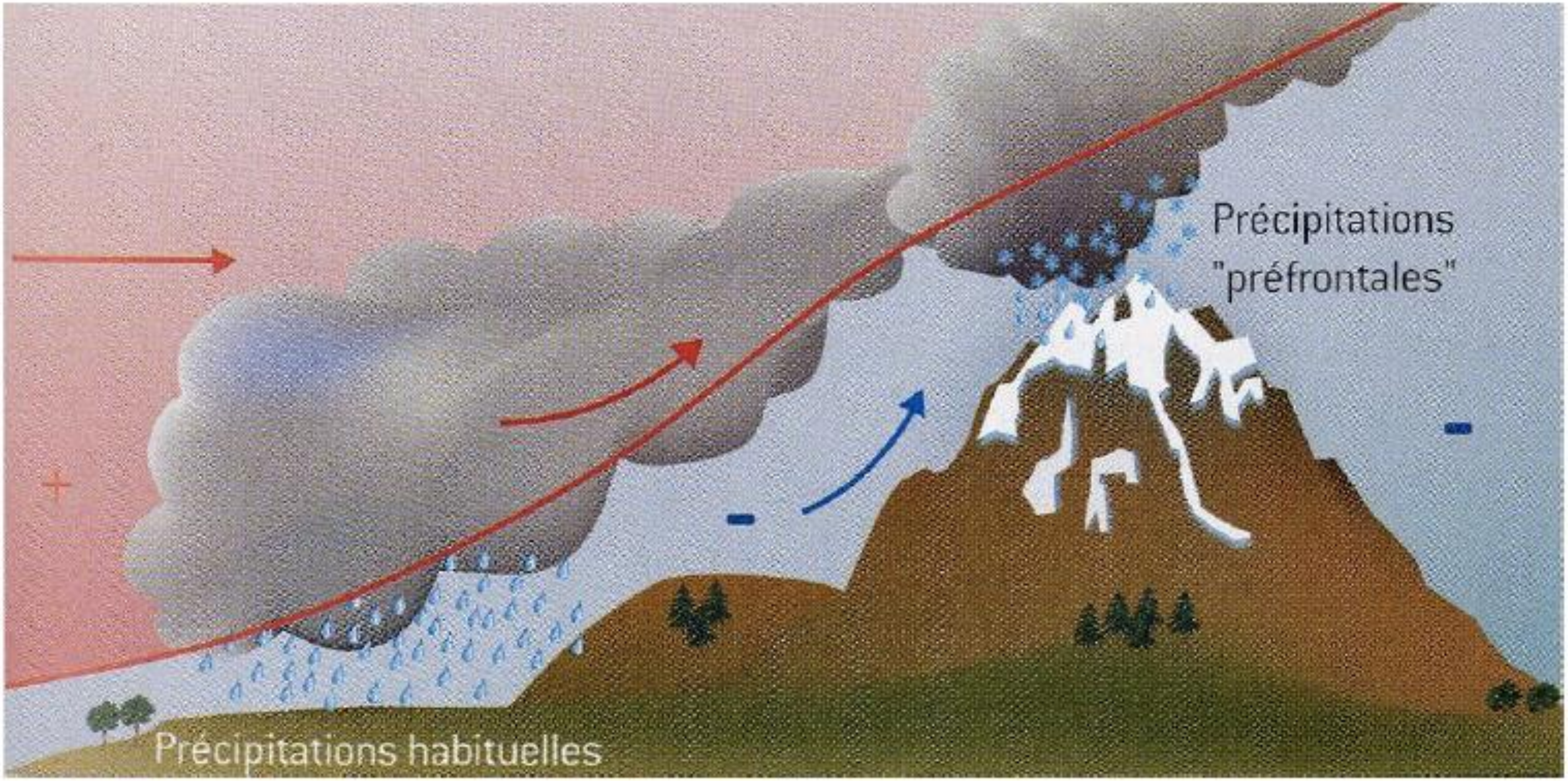
00 UTC 09 UTC 19 UTC



Sequence of satellite (10.7 μm) showing temperatures at the earth's surface in greyscale (the darker the warmer) and from cloud tops in color (red - coldest). The cloud pattern matches the vertical velocity pattern from the slide before and shows warm and cold fronts.

Topographic Effects

Topographic lifting leads to precipitation maxima over mountain tops. In addition to the lifting, microphysical effects contribute to this precipitation maximum: “Seeding” the air below the cloud collects additional moisture onto the droplets or snow crystals. The air in the lee of the mountain is then dried out and more pleasant to live in (Föhn).

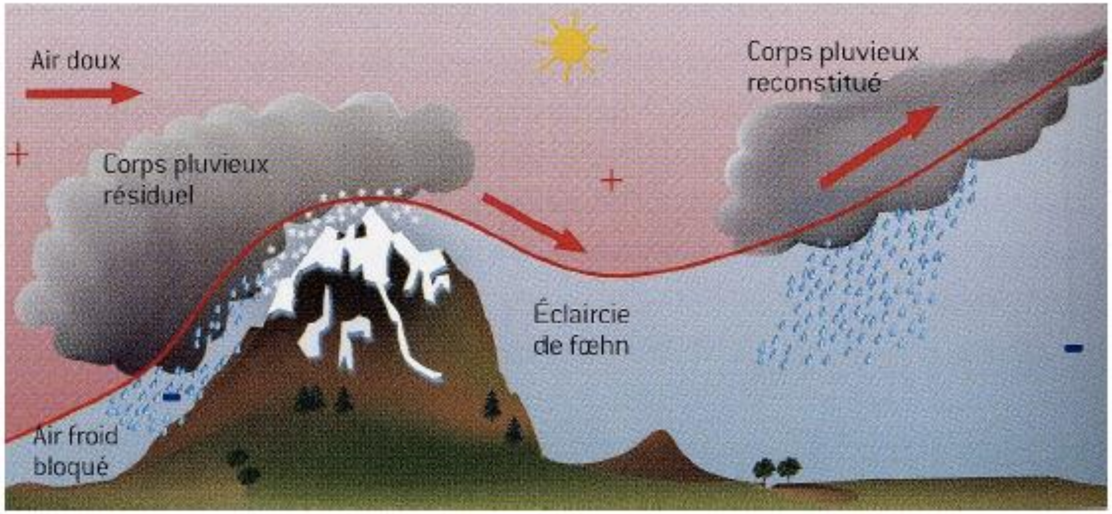


Topographic Effects

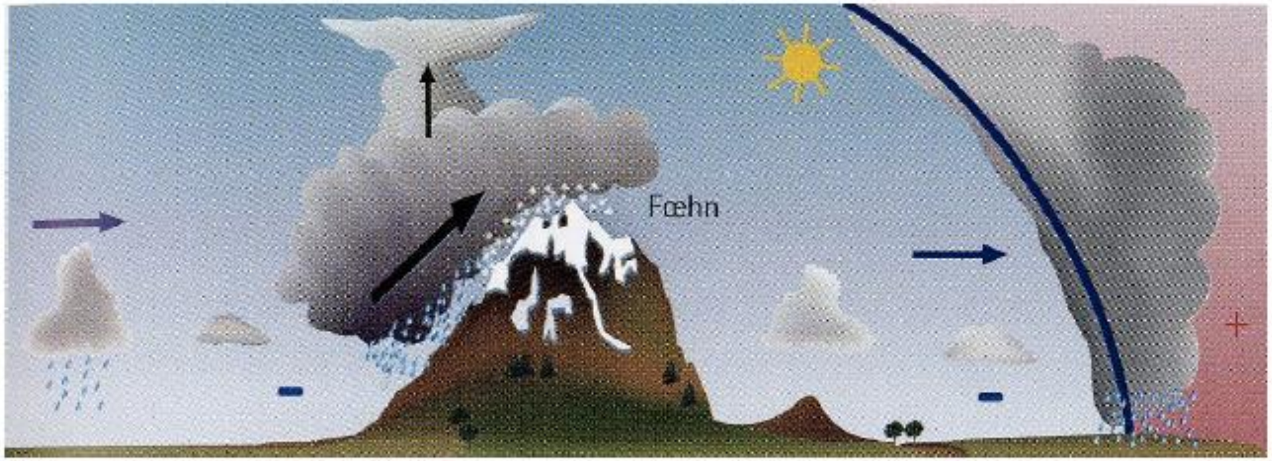
There is also a temporal effect of the mountains: The bad weather tends to stick around longer around the mountain tops and at the windward side because of the lifting.

La montagne retient les perturbations

Front chaud



This does not bother you if you are on the right side of the mountain and enjoying the Föhn window.

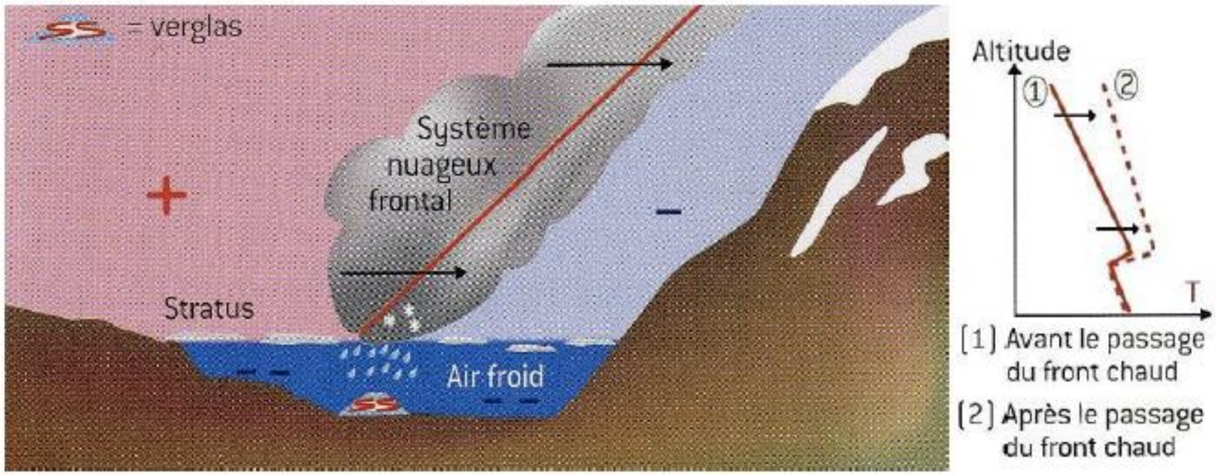


Traîne

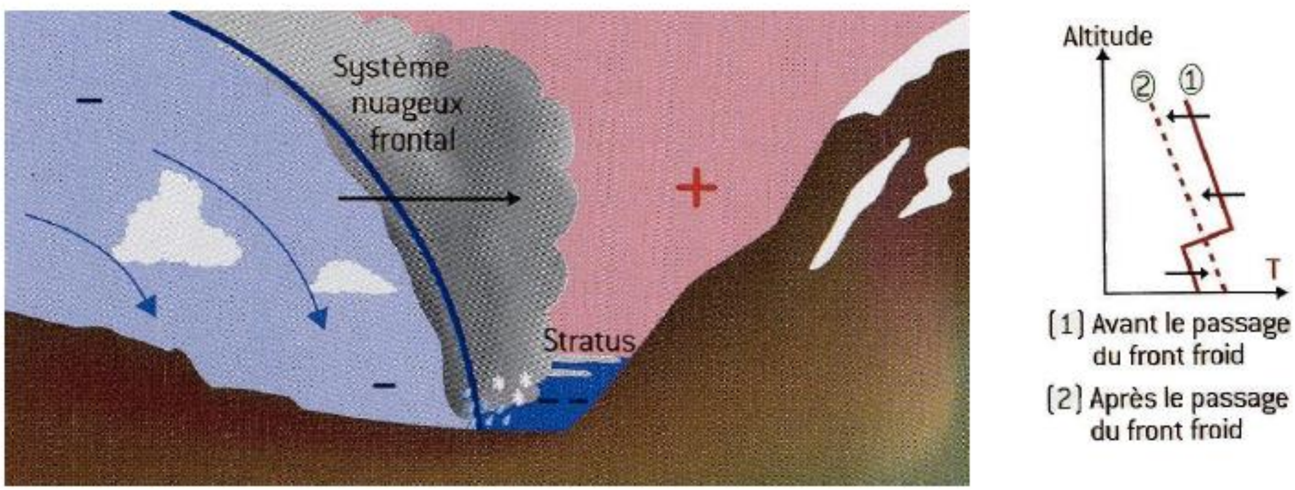
Topographic Effects

The specific setting of the Swiss Plateau: The warm front may not be able to penetrate into the cold air pool and will pass leaving the lower air masses unchanged.

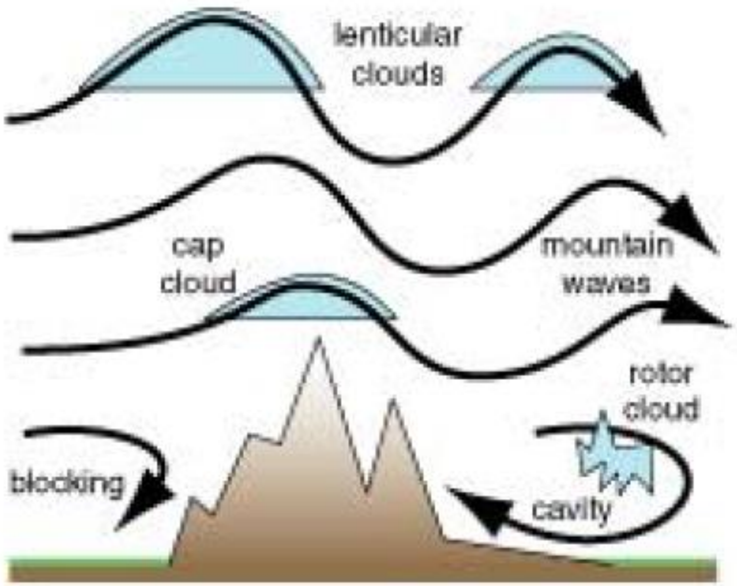
Fronts masqués

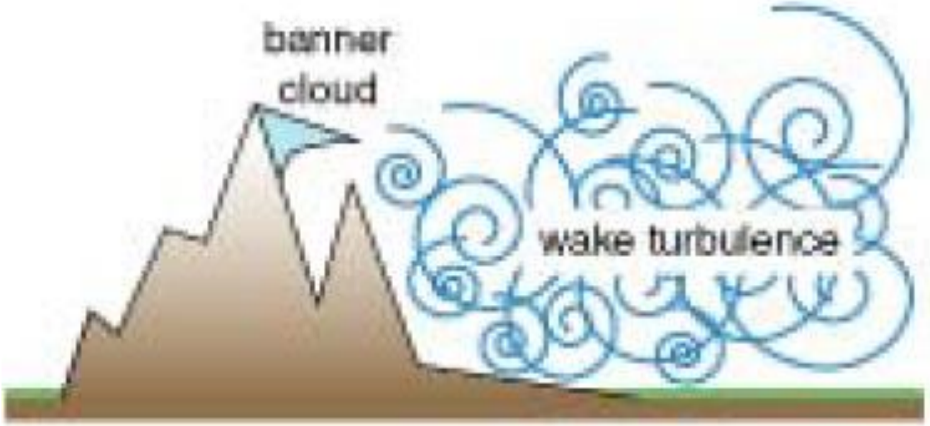


The cold front with much more vigorous mixing is likely to erode the cold air pool and may even lead to a surface warming

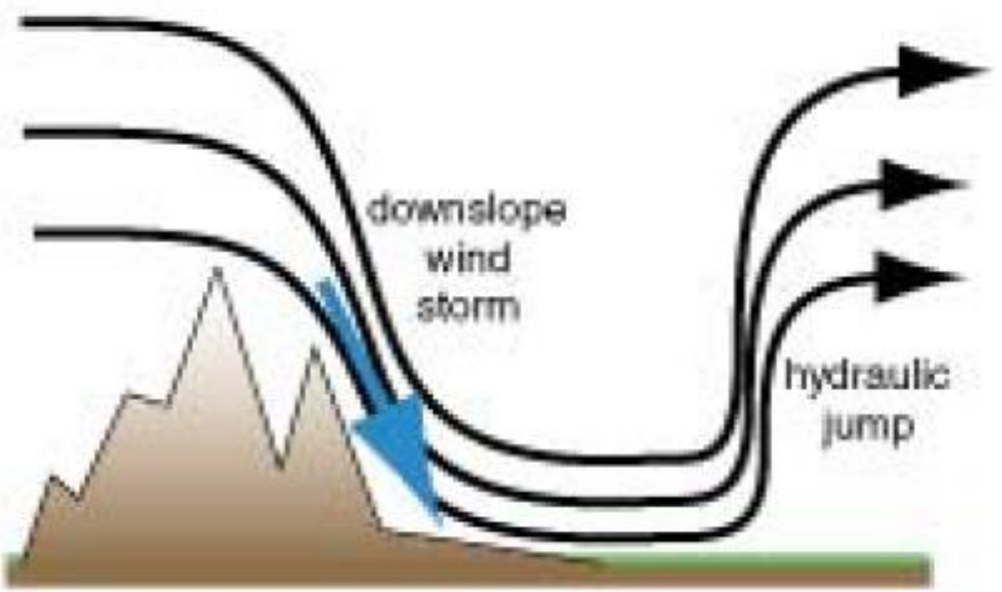


Flow Mountain Interactions

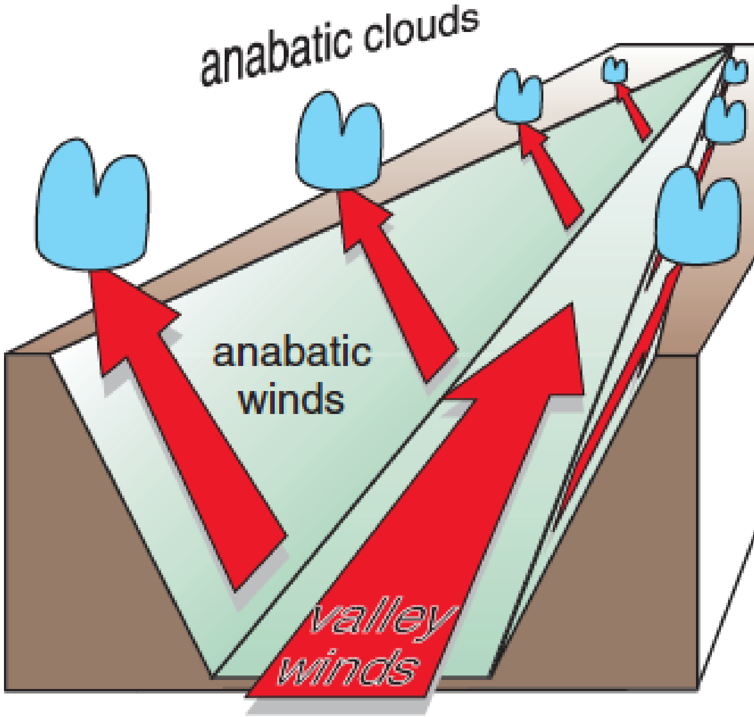




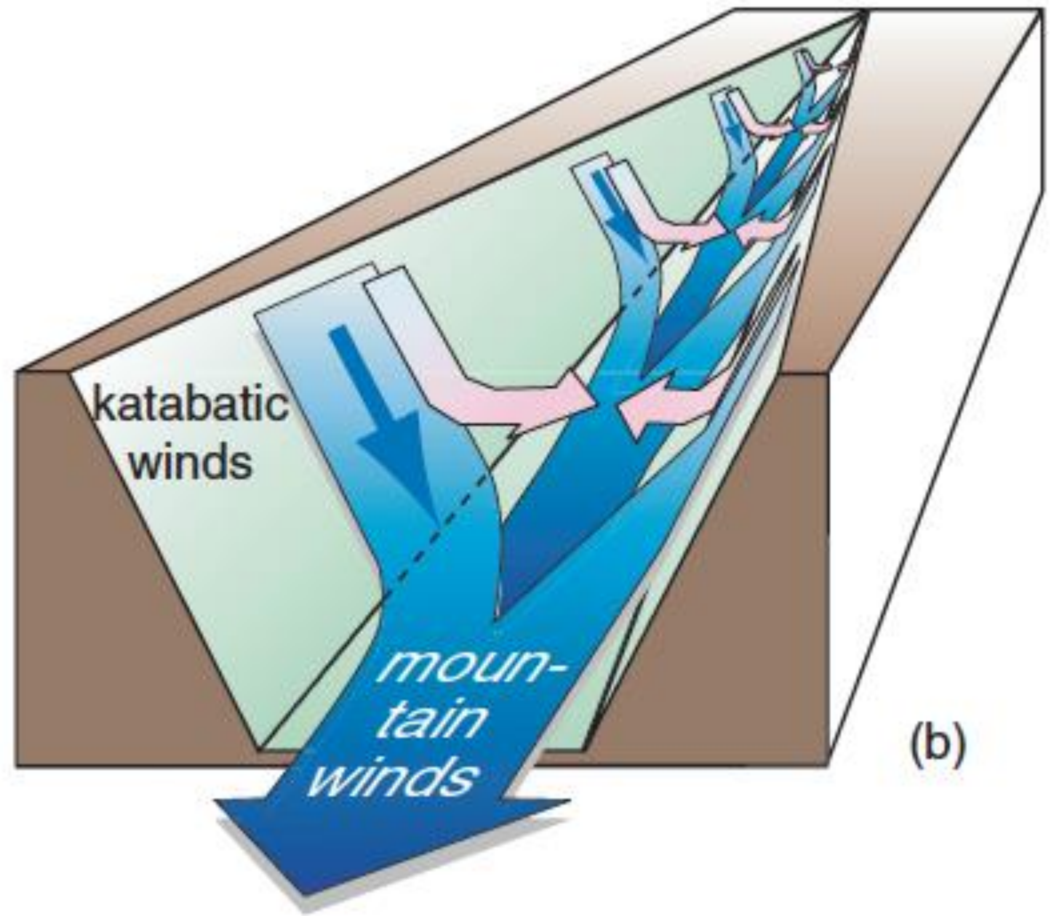
When flow is hitting topography, many different features are possible. The relative magnitude depends on parameters such as (again) stability, moisture, and of course the driving forces e.g. pressure differences. Flow features associated with the lee of mountains are (gravity) waves, wake turbulence and separation, downslope wind storms and hydraulic jumps. Upstream you may find speed-up or blocking. Cloud systems associated with waves are lenticular clouds and cap clouds. Rotor clouds are found in the wake.



Mountain – Valley Winds



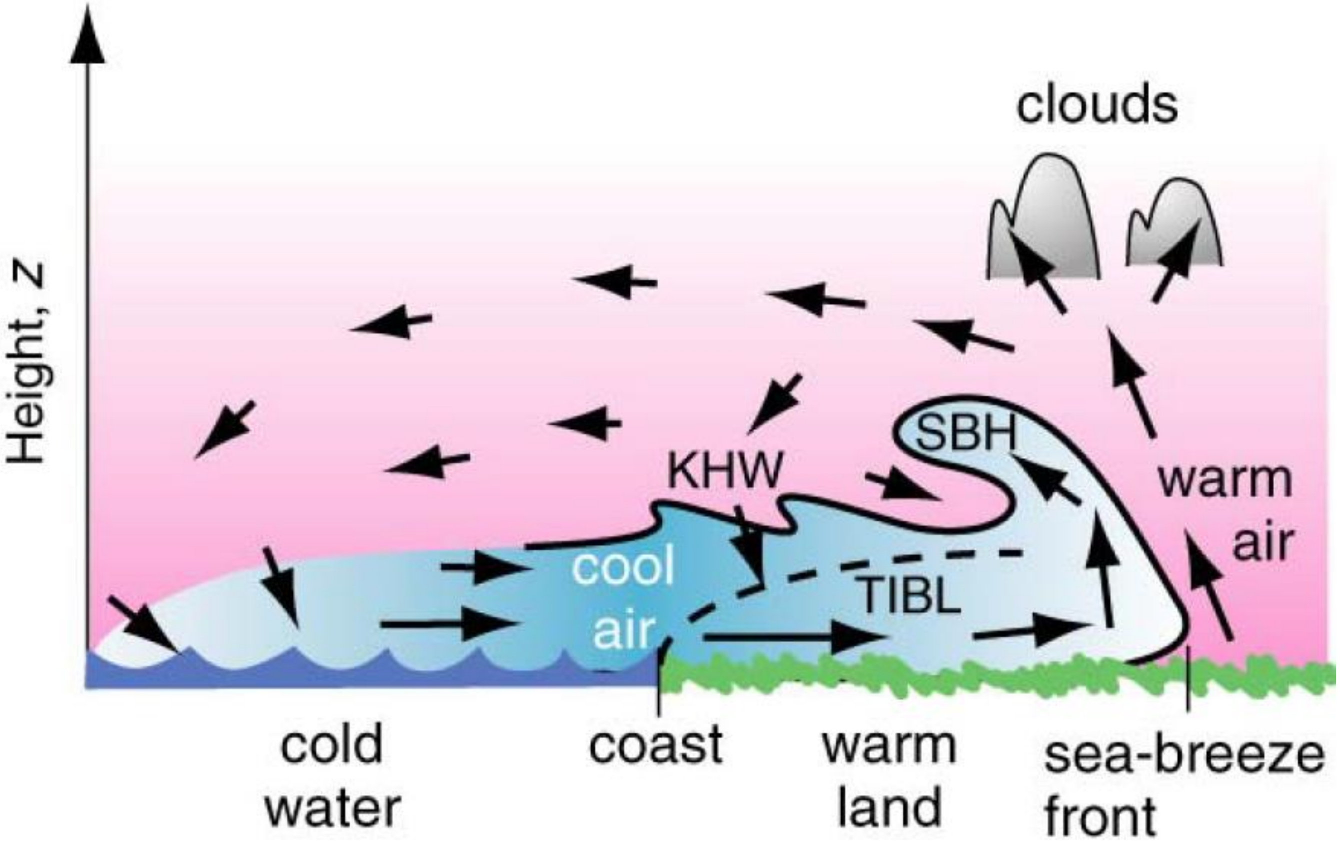
(a)



(b)

Over sloping terrain heating generates up-slope motions, which are called anabatic or valley winds. Cooling generates down-slope motions, which are called katabatic or mountain winds.

Water – Land Interactions



Sea (or lake) – land differences in heating or cooling generate circulation patterns. At daytime, warmer air over the land surface rises and sucks colder air onto the coast. A Thermal Internal Boundary Layer (TIBL) is formed. The head of the cold air may be forced to rise with the warm air forming a Sea Breeze Head (SBH). In the shear layer between the cold and the warm air, Kelvin-Helmholtz Waves (KHW) may develop.

Take Home Messages

- The global circulation is characterized by a pattern of high- and low pressure distributions, which is statistically stable but complex. The complexity comes from 1) land – sea distributions and 2) topography. Minor factors are vegetation and snow cover. The temporal variability is caused by the seasons.

- Mid latitude weather is particularly complex because initial pressure differences tend to become larger in the first phase of a storm (cyclogenesis). Fronts develop because gradients (differences) in temperature become larger as well. The cold front moves faster then the warm front and this leads to an occlusion and finally the end of the intensification.

- Both fronts have lifting of warm air masses and therefore precipitation. Vertical mixing and thunderstorms are more vigorous at the cold front.

- Mountains get more precipitation because of extra lifting and generate the Föhn effect in the lee. Passage of weather systems is slowed down.

Overview on Course – Physics Part

Atmospheric Processes

Atmospheric Radiation

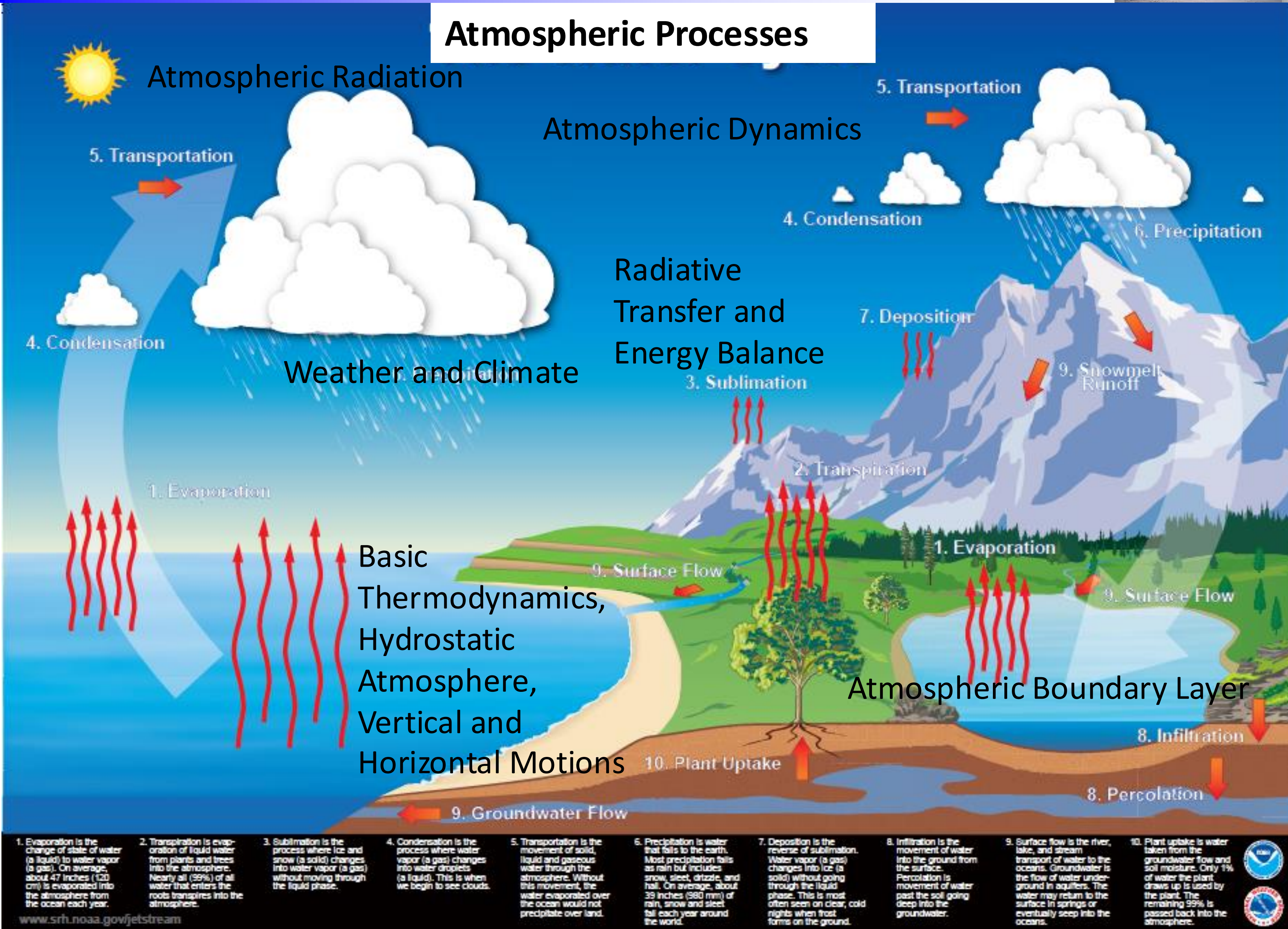
Atmospheric Dynamics

Radiative Transfer and Energy Balance

Weather and Climate

Basic Thermodynamics, Hydrostatic Atmosphere, Vertical and Horizontal Motions

Atmospheric Boundary Layer



Hurricane Floyd
1999 on Florida

The End