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Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

ATMOSPHERIC CHEMISTRY

Lecture No.: 4

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Organisation of study

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  building A, Dept. 216, door No.162
  e-learning:
  https://e-learning.vscht.cz/course/view.php?id=106
- Scale of subject: winter semester
  14 lectures, 14 weeks, 2 hours/week
- Classification: Exam - written + oral form (depending on result of the test)

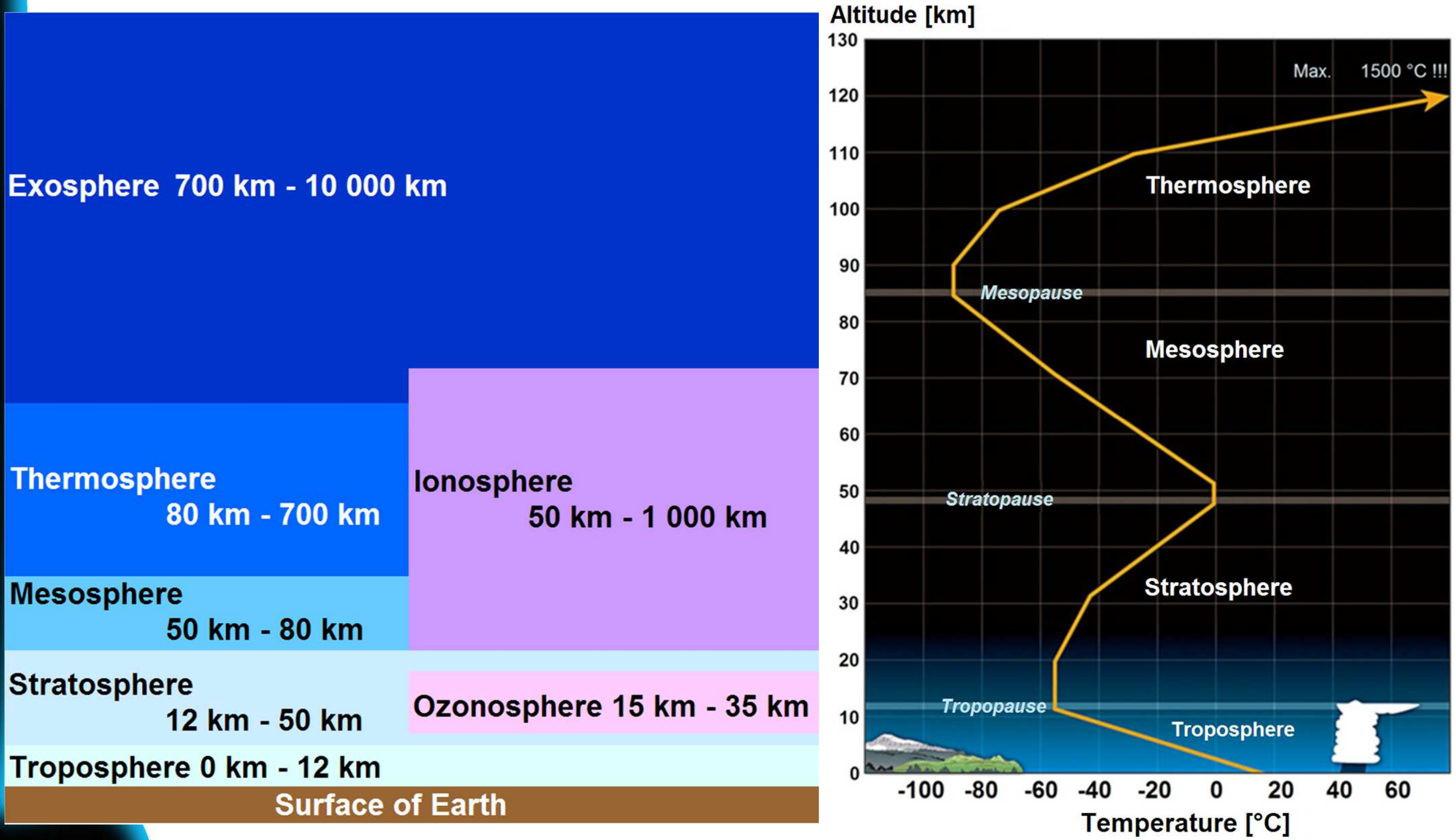
Scope of lecture 4

Physical rules in atmospheric processes

- Main forces contributing to movements of atmospheric masses
- Atmospheric circulation cells
- Tropospheric and stratospheric jet streams
- Wind speed and method of its subjective evaluation (wind scale)
- Local air flows – long range and short range winds
- Introduction to synoptic meteorology
- Preparation and evaluation of the synoptic maps
- Methods of data acquisition for weather forecasts
- Distribution of weather forecast according to time scale and available methods for their elaboration

Stratification of atmosphere (review)

Atmospheric layers and temperatures (by NASA and National Weather Service)

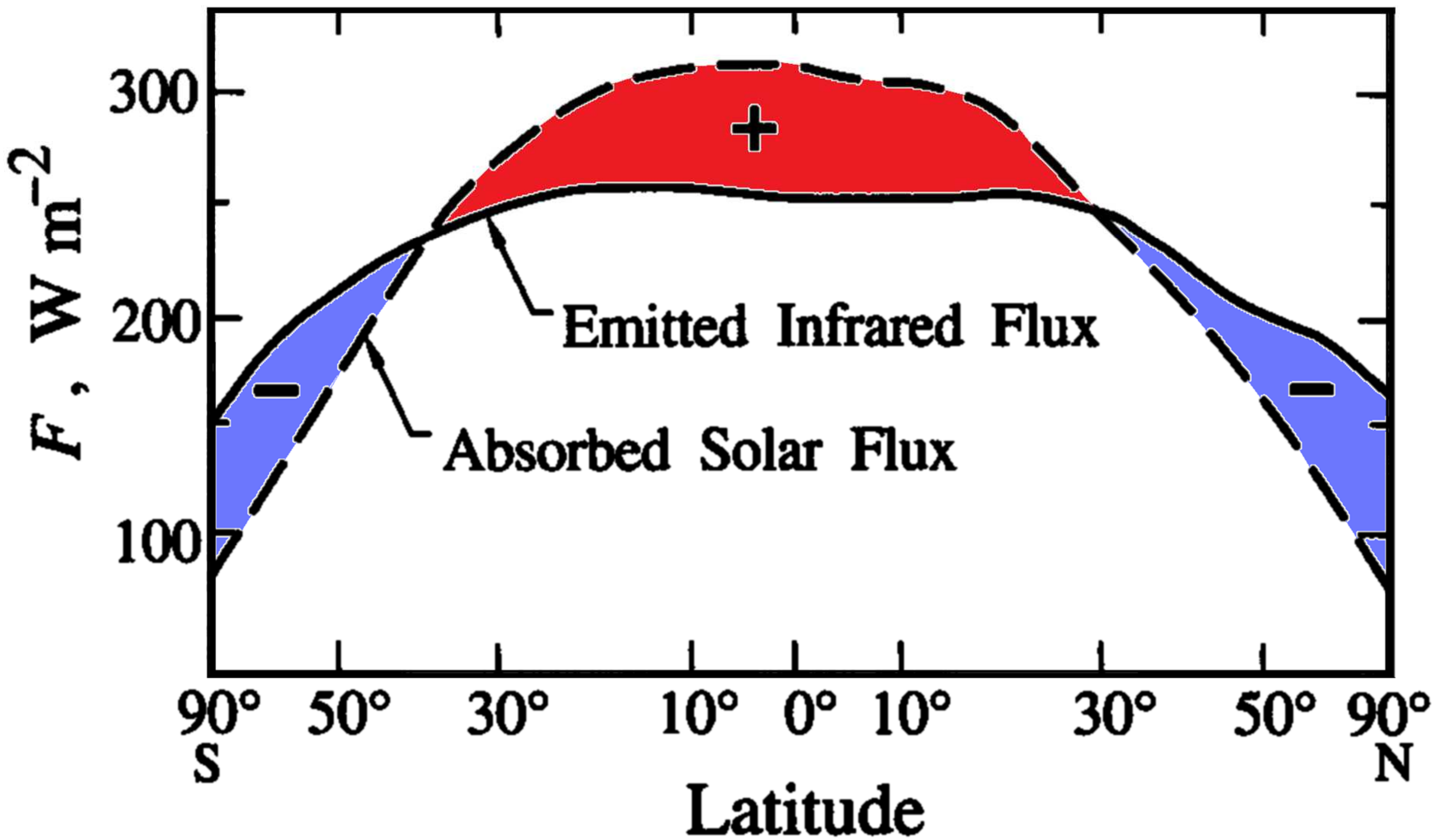


General rules for air circulation

- Driving forces for air movement
  - Basic force = uneven heating of different parts of the planet by sunlight;
  - Tropical regions receive more energy than is reflected back;
  - Polar regions receive significantly less energy than is reflected;
  - Surplus energy (absorption – radiation) between 40° north and 40° south latitude;
  - Approximately 60% of the circulation is driven by the aforementioned mechanism;
  - Approximately 40% of the circulation is due to ocean mechanism;
  - Movement in Hadley cell (described in 1735) is given by the principle of rising warm air with lower density and descending air with higher density.
  - Another significant force - the Coriolis force is caused by rotation of the Earth (see below).

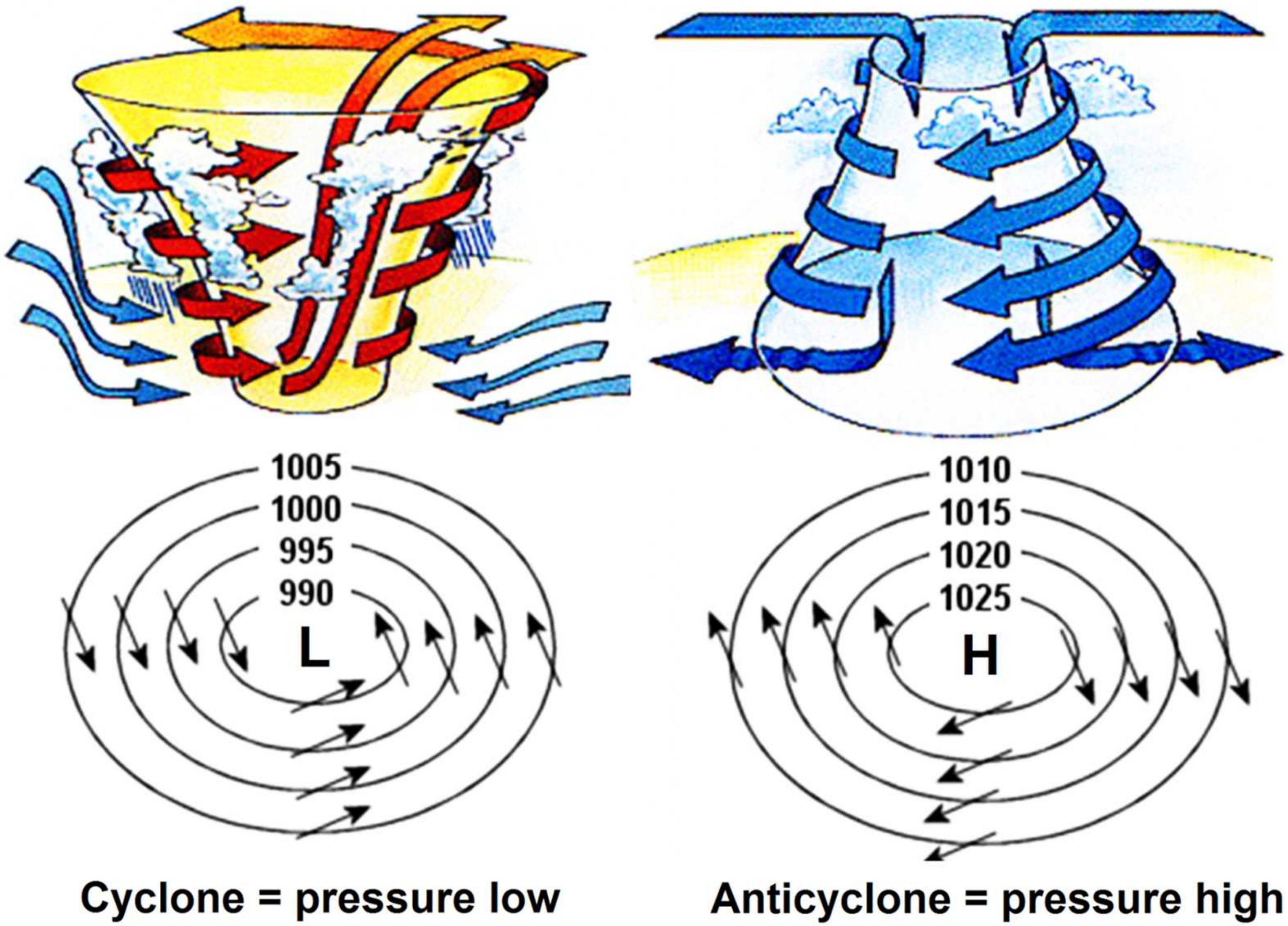
General rules for air circulation

- Differences in absorbed and emitted solar energy (Source: Seinfeld, J., H., Pandis, S., N.: Atmospheric Chemistry and Physics)



General rules for air circulation

- Local changes in pressure = main moving force for wind (Source: Seinfeld, J., H., Pandis, S., N.: Atmospheric Chemistry and Physics)



General rules for air circulation

- Other factors that influence air movements
  - Coriolis force = inertial force caused by the rotation of the Earth:

    In the northern hemisphere, it causes moving masses to rotate to the right, and in the southern hemisphere to the left, i.e. from the direction of movement;

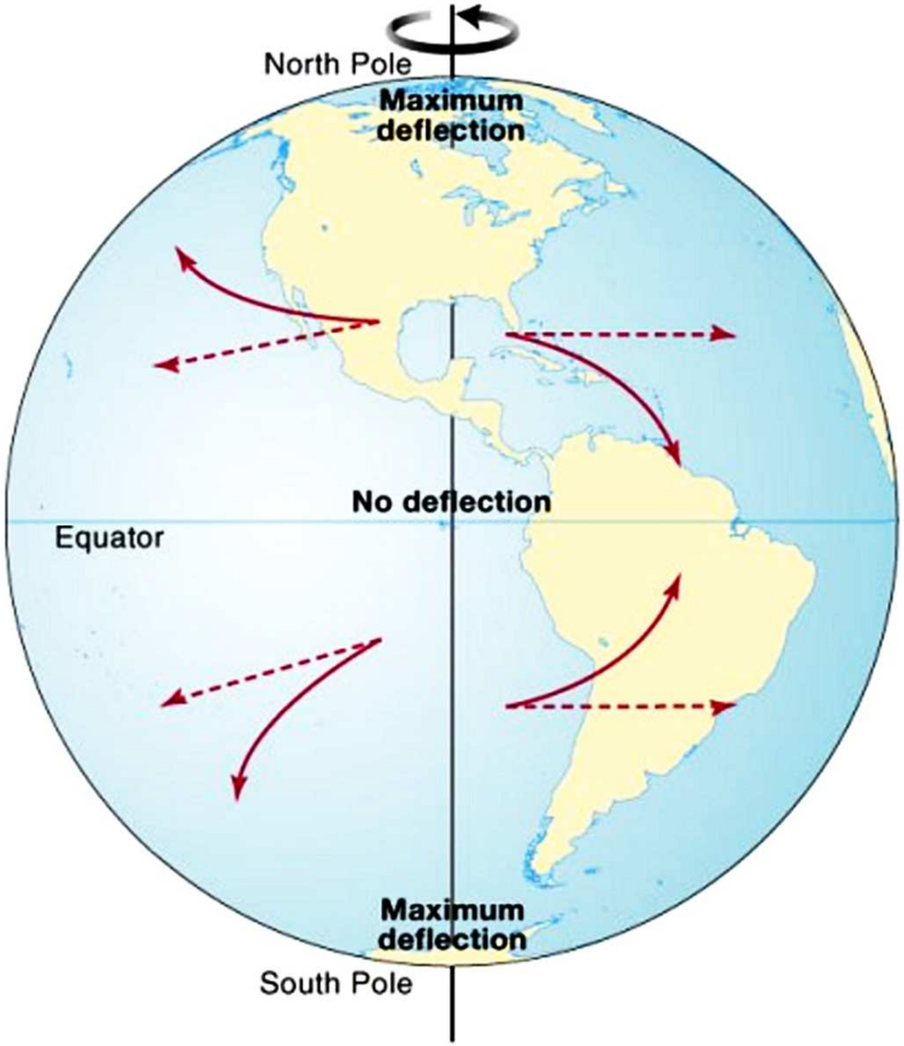
    CF has zero value at the equator and increases with latitude;

    It affects the airflow and movement of ocean currents;

    CF is visibly manifested only in larger wind systems ⇒ deflection from the horizontal pressure gradient (see previous slide);
  - Friction = force against the direction of air movement;
  - Centrifugal force - affecting the flow, if this takes place along a curvilinear trajectory;
- Result: air flows to the lower pressure side and is deflected at a certain angle from the direction of the horizontal pressure gradient.

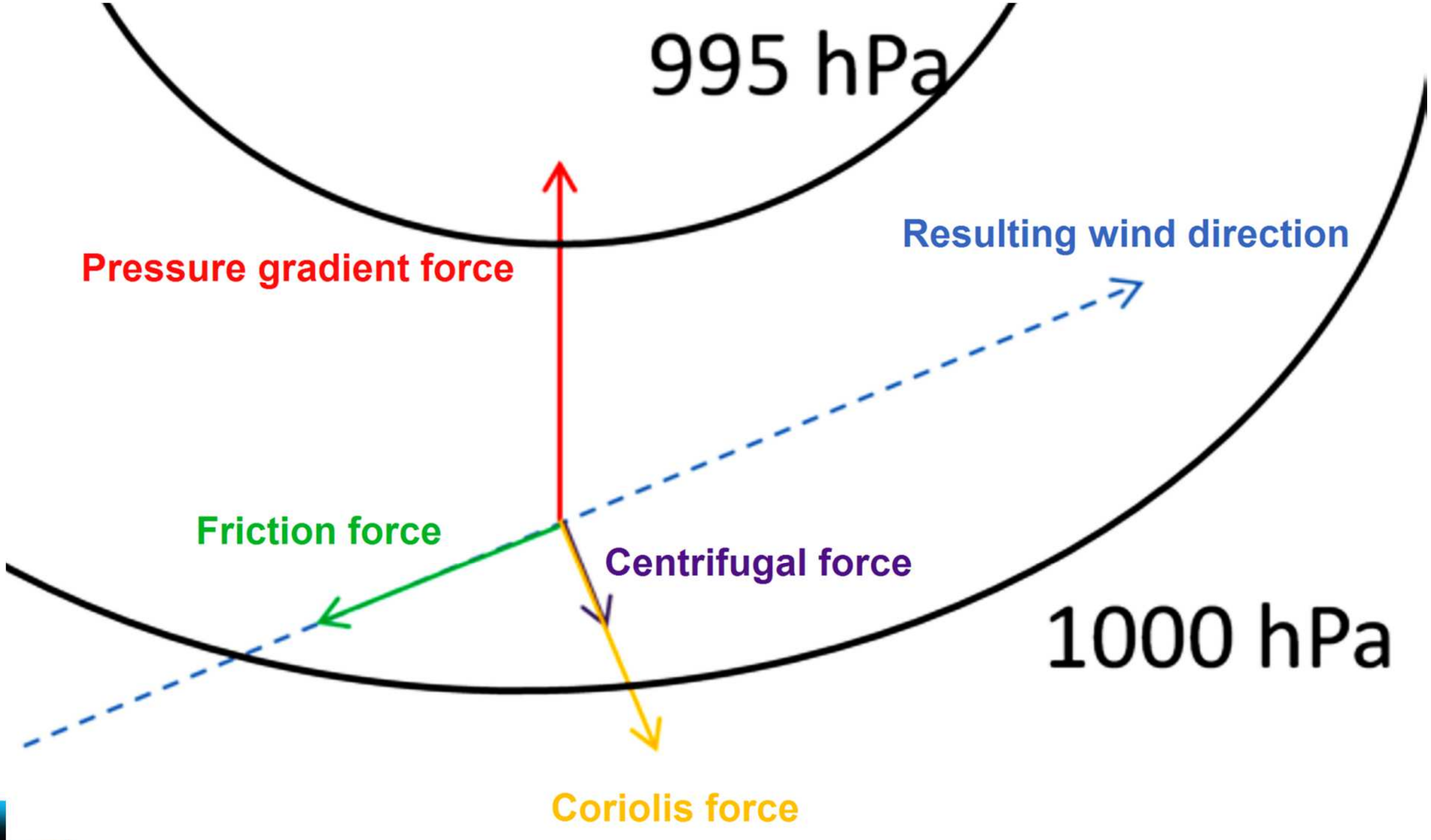
General rules for air circulation

- Demonstration of deflections from the straight trajectory, caused by Coriolis force



General rules for air circulation

- Example of vector determining the wind direction, taking into account the above mentioned factors (Source: In-počasí.cz):



General rules for air circulation

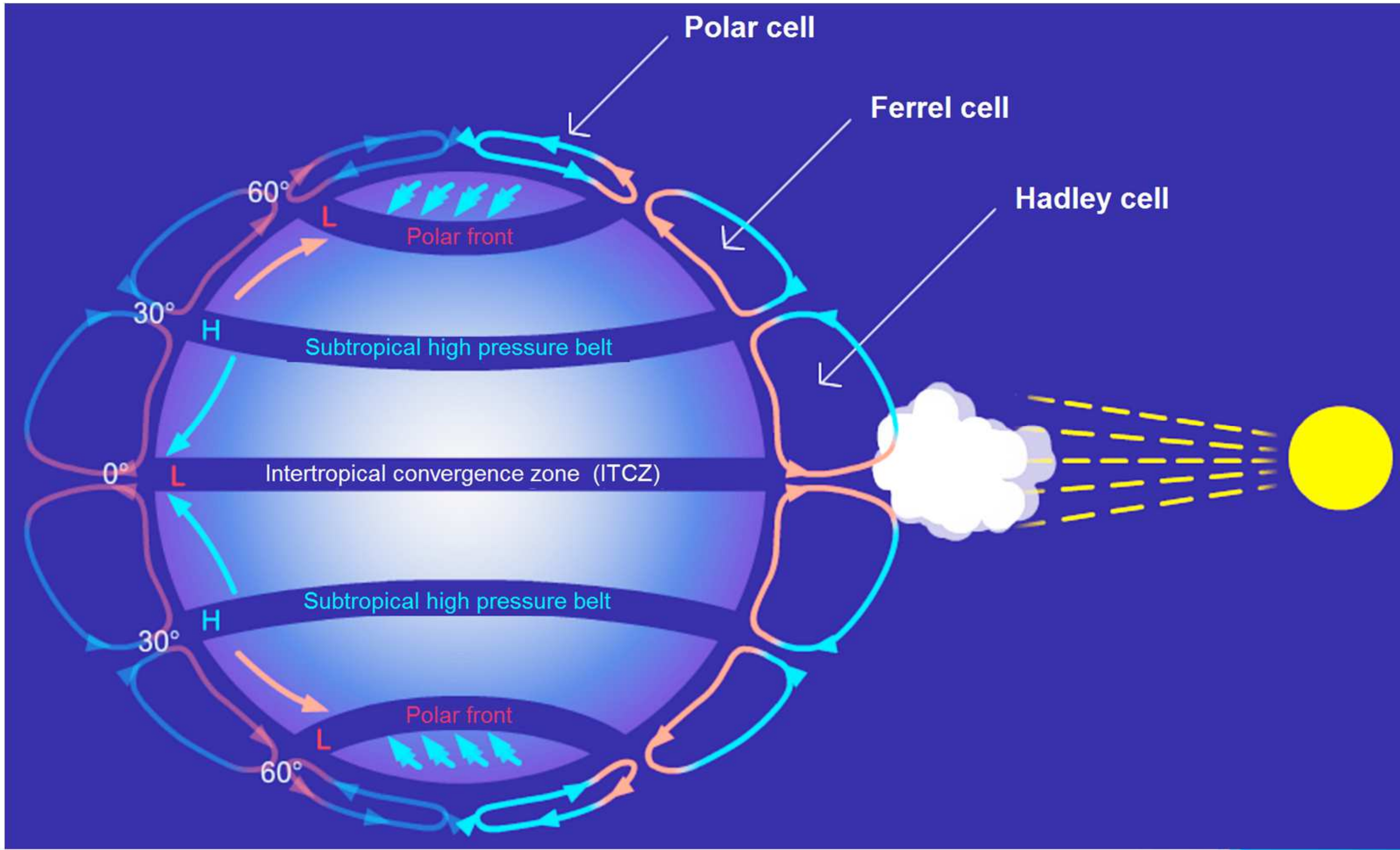
- Global circulation of the atmosphere has following properties:

  (Source: http://is.muni.cz/do/rect/el/estud/pedf/ps14/fyz_geogr/web/pages/04-cirkulace.html)

  – Mostly vortex (circulating) character of air movement (e.g. cyclonic flow);
  – Predominance of horizontal movements over the vertical ones;
  – Predominance of zonal winds (along parallel lines) over movements along the meridian;
  – Variability of atmospheric circulation and its components;
  – Changes in direction and velocity of the flow from layer to layer;
  – Prevailing westerly transfer of air in the troposphere and lower stratosphere in moderate latitudes.

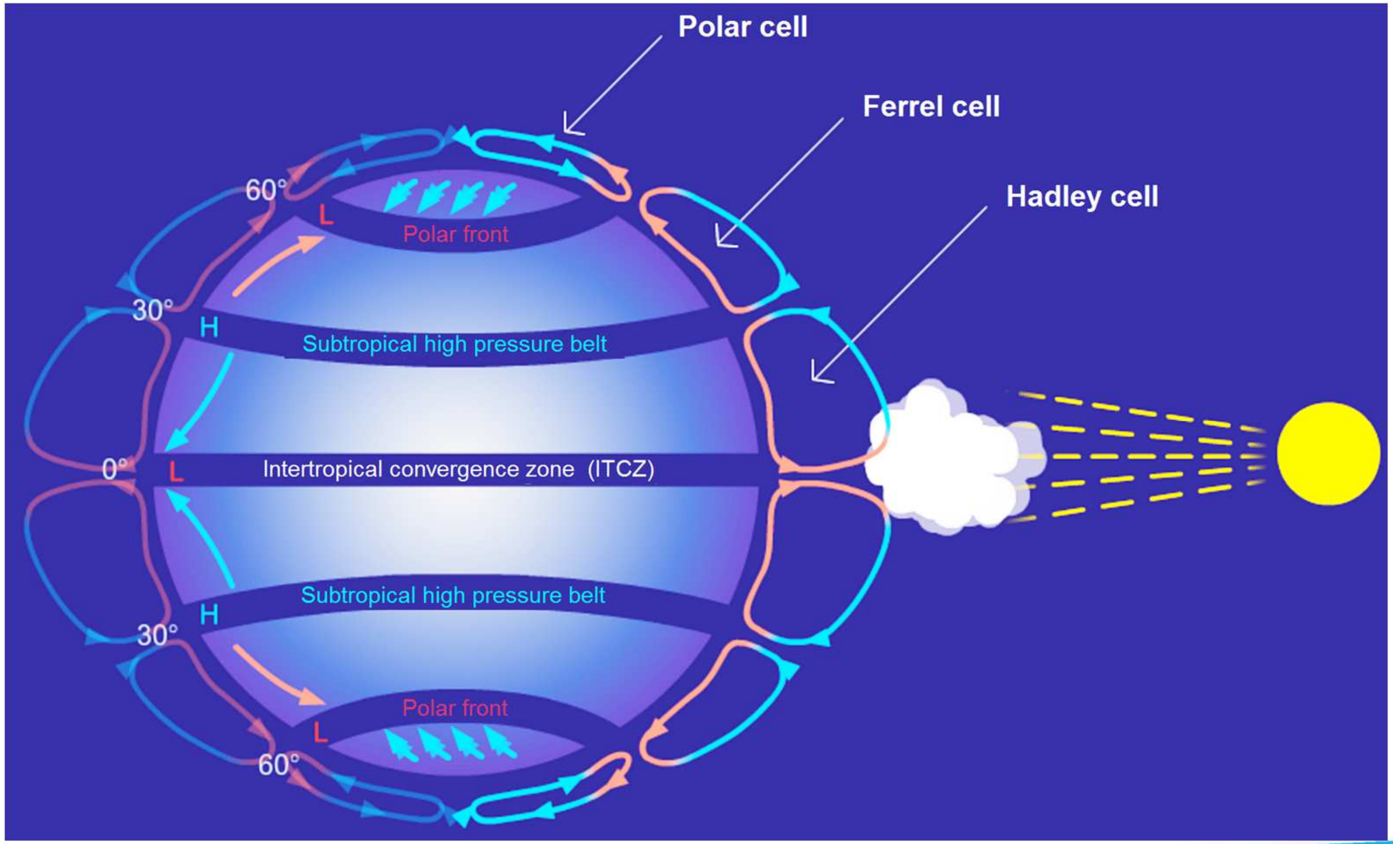
Movement of air in atmosphere

- Hadley cell – the air in the low pressure area along the equator (ITCZ) rises up to the upper border of Troposphere, after that, it flows simultaneously to the North and South; after reaching 30 °of latitude, dry air descends and forms high pressure belts (desert areas); after that, it either returns to the equator or it is pushed to moderate temperature latitudes.



Movement of air in atmosphere

- Polar cell – at 60° of North and South latitude, warm air rises to the upper border line of Troposphere, then, it is cooled down close to the poles and descends in polar areas ⇒ area of high pressures.
- Ferrel cell – dominating West air flows due to circulation between Hadley and polar cell.

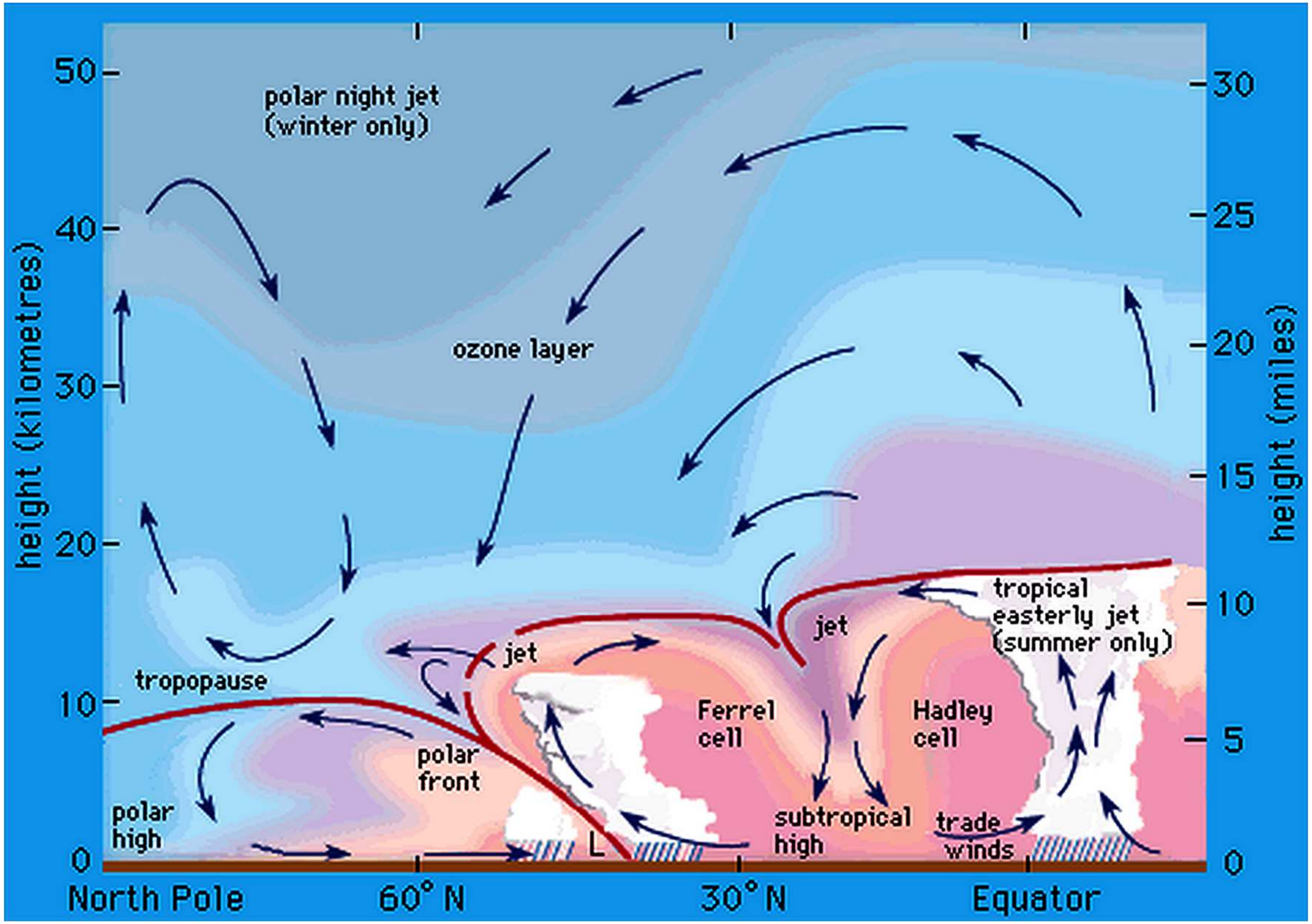


Atmospheric Jet Streams

- Types of atmospheric jet streams (Source: In-počasí.cz)
  - Tropospheric jet stream;
    - Polar Jet Stream (localization ca. 60°, between polar and Ferrel cell)
    - Subtropical Jet Stream (in winter ca. 30°, in summer shift to ca. 40°, between Ferrel and Hadley cell)
    - Equatorial Jet Stream (over the equator)
  - Stratospheric jet stream;
  - Low level jet stream;

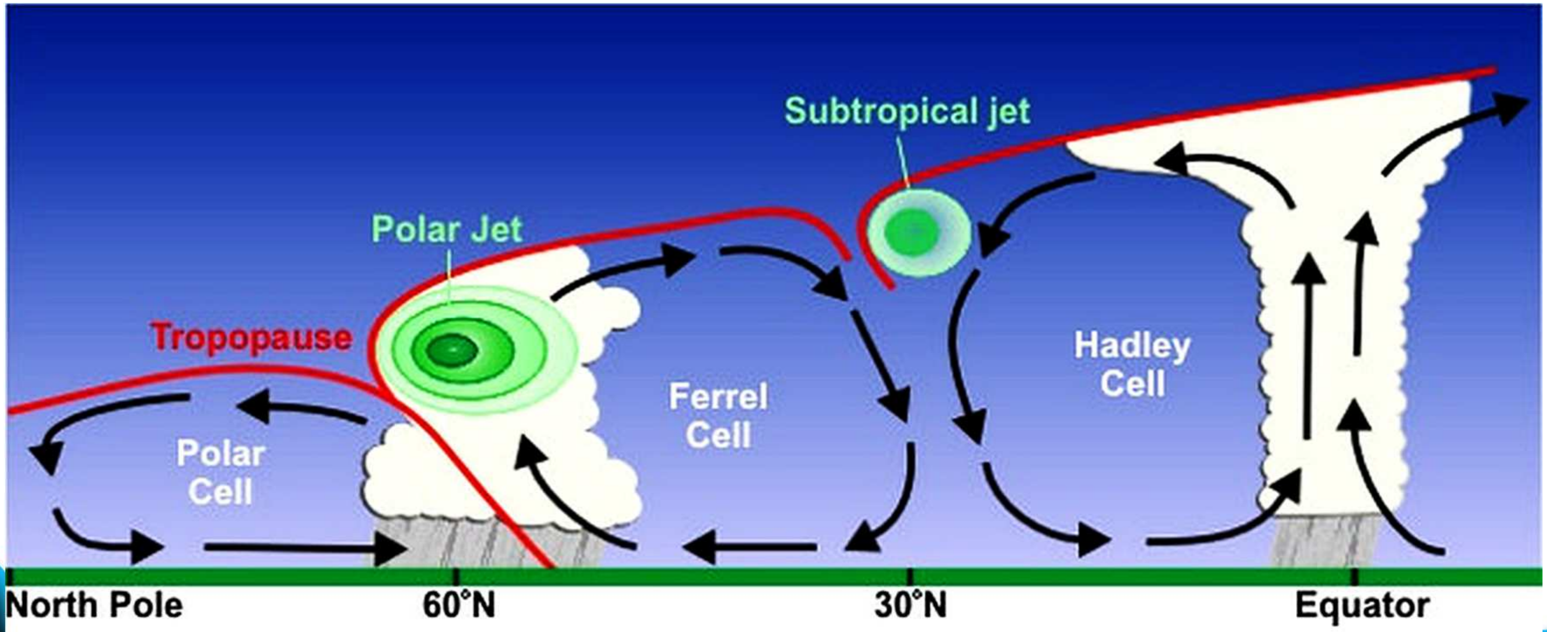
Atmospheric Jet Streams

- Vertical localisation of jet streams (for north hemisphere)



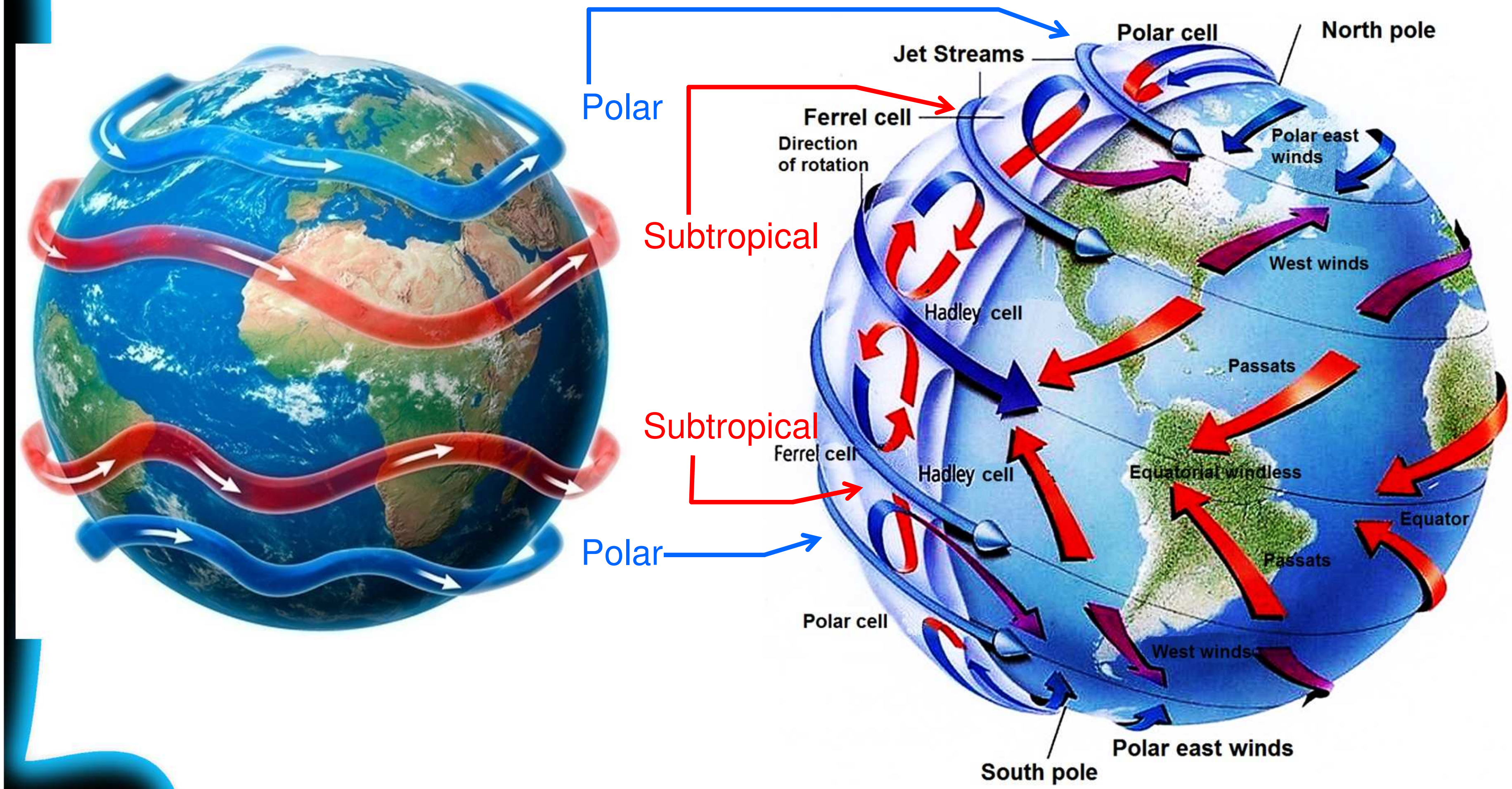
Tropospheric Jet Stream

- Shape, driving force and direction of Jet Stream
  - Direction: from west to east except equatorial j.s.;
  - Shape: approximate shape of wave hose or pipe, leading alongside parallels of latitude;
  - Driving force: generated by temperature differences at various latitudes;
- Speed of Jet Stream
  - average velocity > 30 m·s^{-1} (108 km/h), maximum speed > 700 km/h



Tropospheric Jet Stream

- Horizontal direction of Jet Stream locomotion + tropospheric cells



Tropospheric Jet Stream

- Importance of Jet Stream (for northern hemisphere)
  - influencing weather in Europe and Asia;
  - north-south waving caused by so-called Rossby's waves, which make additional pressure to the west side;
  - The force of jet streams is usually bigger than Rossby's waves ⇒ waves of jet streams move from west to east;
  - Sometimes, the power of Rossby's waves is equal to the jet stream ⇒ stopping of jet stream movement ⇒ long-term uniform pressure distribution ⇒ extremes in weather:

    meanders bent to the north attract warm air from the south latitudes

    meanders bent to the south attract cold air from north latitudes.
  - Jet stream transports huge air masses to long distances (including pollutants).

Tropospheric Jet Stream

- Appearance and properties of Jet Stream
  - The shape similar to the hose-like channels with a significantly higher flow rate – defined by isotachs;

  Note: Isotach = imaginary line connecting points with the same wind speeds, water and the movement of certain meteorological phenomena

  - Margins of jet streams are characterized by a sharp increase (gradient) of wind speed - about 10 $m \cdot s^{-1}$ (36 km/h) per 1 km of lateral distance.
  - Vertical location: typically 1-2 km below the tropopause (on the border of neighbouring air masses with significantly different temperatures);
  - Beware! Jet Stream is potentially dangerous for aircrafts. However, when flying in the direction of the jet stream, significant fuel savings are achieved.

Tropospheric Jet Stream

- Particular streams of the tropospheric Jet Stream (Source: In-počasí.cz)
  - Polar Jet Stream

    Collision of cooler air from the north and the southern warm air from warmer areas, localised between Polar and Ferrel cells.

    PJS does not entirely form a continuous belt around the Earth, but it is represented by sub-bodies moving alongside the longitude and latitude as well.

    The intensity of PJS increases with the onset of winter.

    A stronger polar jet stream is localised around 60-50° latitude, but due to the effect of waving it extends well below 30°;

    Vertical localization 7-12 km

Tropospheric Jet Stream

- Particular streams of the tropospheric Jet Stream (Source: In-počasí.cz)
  - Subtropical Jet Stream

    Average localisation 30°, between Ferrel and Hadley cells; on the border line between tropical and cooler air;

    Vertical localisation 10 to 16 km (see the changes of Tropopause height according to the latitude);

    SJS is more stable than the Polar Jet Stream and it is in fact continuous (unbroken into parts).

    Summer shift by 10° to poles, in average (above the continent more significant than above the seas);

    Velocity higher than Polar Jet Stream: > 50 $m.s^{-1}$ (180 km/h).
  - Equatorial Jet Stream

    Above the equator, on the border between north and south Hadley cells; Vertical localisation 15 to 20 km;
    Opposite flow than other Jet Streams (from the east)!

Other Jet Streams

- Characterisation of the stratospheric Jet Stream (Source: In-počasí.cz)
  - Vertically localised over the tropospheric Jet Streams (ca. 30 – 50 km);
  - Very fast stream with isotach about 60 $m.s^{-1}$ (216 km/h);
  - During winter, it descends down to the edge of Tropopause = 12 km;
  - Direction of flow changes during the calendar year: In winter, it flows from the west; in summer from the east.

    In summer time, the stratospheric Jet Stream loses the velocity and typical character of jet streams;
  - The most significant stratospheric Jet Stream is in winter and around 70° latitude.

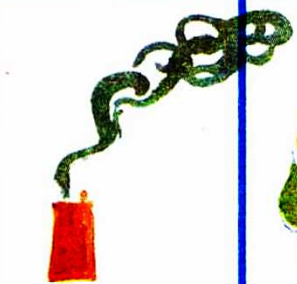
Other Jet Streams

- Properties of low level Jet Stream (Source: In-počasí.cz)
  - More types of powerful wind at low altitudes;
  - In fact, pipe of very fast air, moving alongside (and before) the cold front;
  - Night low level Jet Stream is formed due to night temperature inversion;
  - The so-called sting jet, moving along quickly growing cyclones with a rapid pressure decrease, is very dangerous ⇒ It may damage building roofs, break trees etc.
  - Climatological low level Jet Stream exists only on the north hemisphere.

    For example: Somalian Jet Stream removes humidity from the Somalian region and transfers it to form Asian monsoons.

Local flux in troposphere

- Beautofort wind force scale (Source: http://www.rmets.org/weather-and-climate/observing/beaufort-scale)
  - Author sir Francis Beaufort, British Rear Admiral (1774 – 1857),
  - originally for naval purposes (the table is „continental version“)

Number	0	1	2	3	4	5
Wind speed (m/s)	0–0.2	0.3–1.5	1.6–3.3	3.4–5.4	5.5–7.9	8.0–10.7
Description	Calm	Light air	Light breeze	Gentle breeze	Moderate breeze	Fresh breeze
	 Calm. Smoke rises vertically	 Smoke drift indicates wind direction. Leaves and wind vanes are stationary	 Wind felt on exposed skin. Leaves rustle. Wind vanes begin to move	 Leaves and small twigs constantly moving, light flags extended	 Dust and loose paper raised. Small branches begin to move	 Branches of a moderate size move. Small trees in leaf begin to sway

Local flux in troposphere

- Beaufort wind force scale (Source: http://www.rmets.org/weather-and-climate/observing/beaufort-scale)
  - Author sir Francis Beaufort, British Rear Admiral (1774 – 1857),
  - originally for naval purposes (the table is „continental version“)

6	7	8	9	10	11	12
10.8 – 13.8	13.9 – 17.1	17.2 – 20.7	20.8 – 24.4	24.5 – 28.4	28.5 – 32.6	over 32.7
Strong breeze	High wind, near -moderate gale	Gale, fresh gale	Strong / severe gale	Storm, whole gale	Violent storm	Hurricane force
Large branches in motion. Whistling heard in overhead wires. Umbrella becomes difficult. Empty plastic bins tip over.	Whole trees in motion. Effort needed to walk against the wind.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over	Trees are broken off or uprooted, structural damage likely.	Widespread vegetation and structural damage likely.	Severe widespread damage to vegetation and structures. Debris and unsecured objects are hurled about

Local flux in troposphere

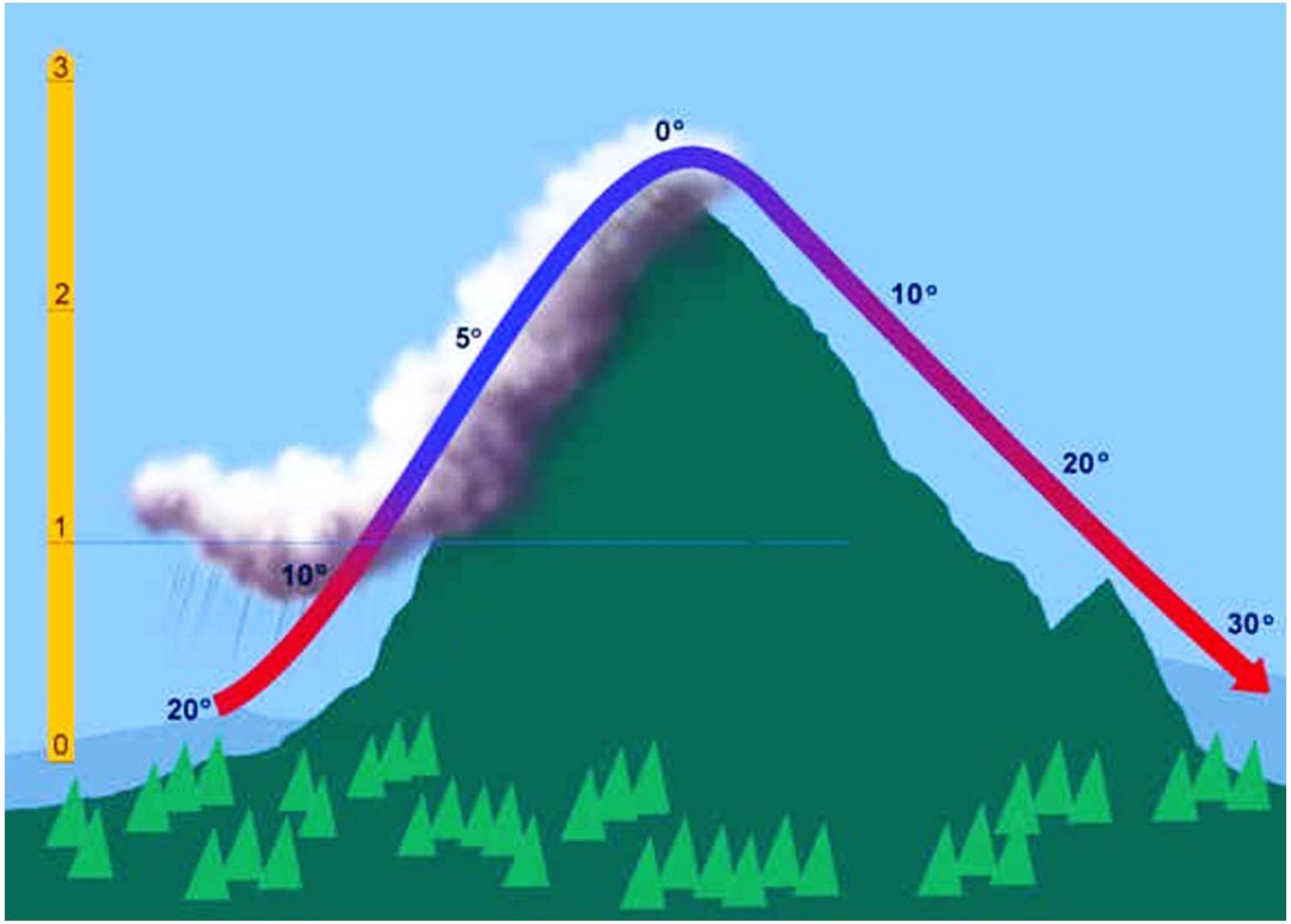
- Long-distance winds
  - Trade winds: (passats) Tropical winds resulting from circulation in Hadley cells. They flow from areas of high pressures at subtropical latitudes (30 - 40 °) to the low pressure area above the equator.

    In the area between 30 - 40° north and south latitudes passats draw moisture and transmit it to the equatorial rainforests. In the north hemisphere passats flow from the northeast, and in the south hemisphere from the southeast.
  - Monsoon: Regular seasonal winds providing rainfall in South and Southeast Asia.

Summer monsoons created by higher heating of the land compared to the ocean. Pressure low formed over continent ⇒ wet air from the ocean flows to high mountains over where it cools and forms rainfalls.
Winter monsoon is dependent on uneven cooling, when dry air blowing over the ocean carries snowstorms over Japan.

Local flux in troposphere

- Local winds – influenced by effect of high relief upon air circulation
  - Foehn (föhn): dry, warm wind flowing down over the leeward side of the mountain slopes.



Local flux in troposphere

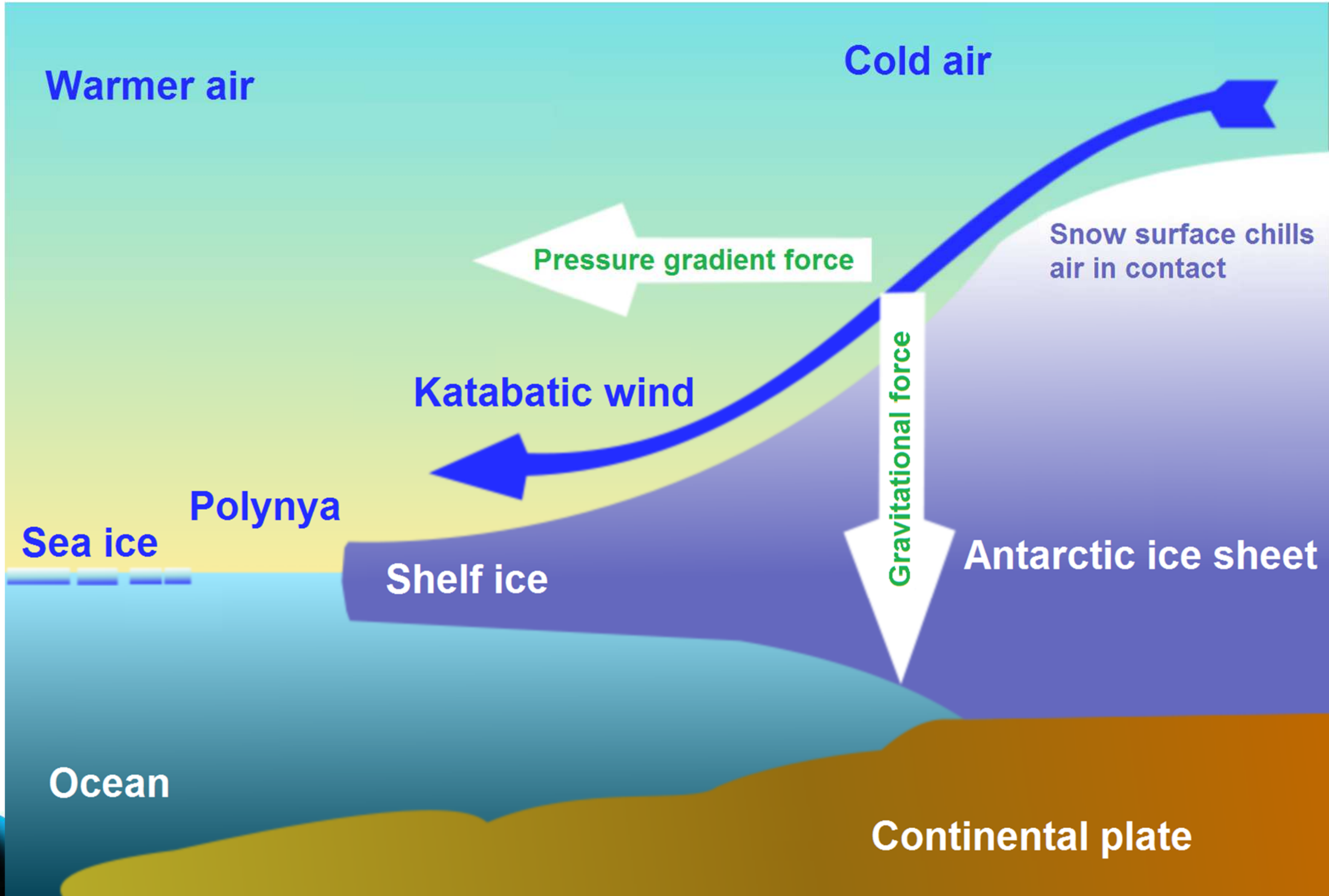
- Local winds – influenced by effect of high relief upon air circulation
  - Breeze: Coastal wind that blows between the sea and the coast in summer as a result of uneven heating of water and land, changing the direction of the pressure gradient.

    Direction: afternoon colder air from sea to land; in the night it flows from the coast to the sea;
  - Bora: Overflowing cold air over the mountain barriers lining the coast. First accumulated, then overflows passes and saddles with a sharp drop in temperatures (underflows the warm air and causes waves).
  - Mistral: Synonym for bora used in south France.
  - Katabatic winds:

    Cold air flows down by gravity from the upper position into the lower (e.g. iceberg wind); In fact, it is the polar form of Bora.

Local flux in troposphere

- Katabatic winds – gravitation underflow of the cold wind underneath the warm air (with lower density)



Local flux in troposphere

- Local winds – influenced by effect of high relief upon air circulation
  - Mountain and valley winds:

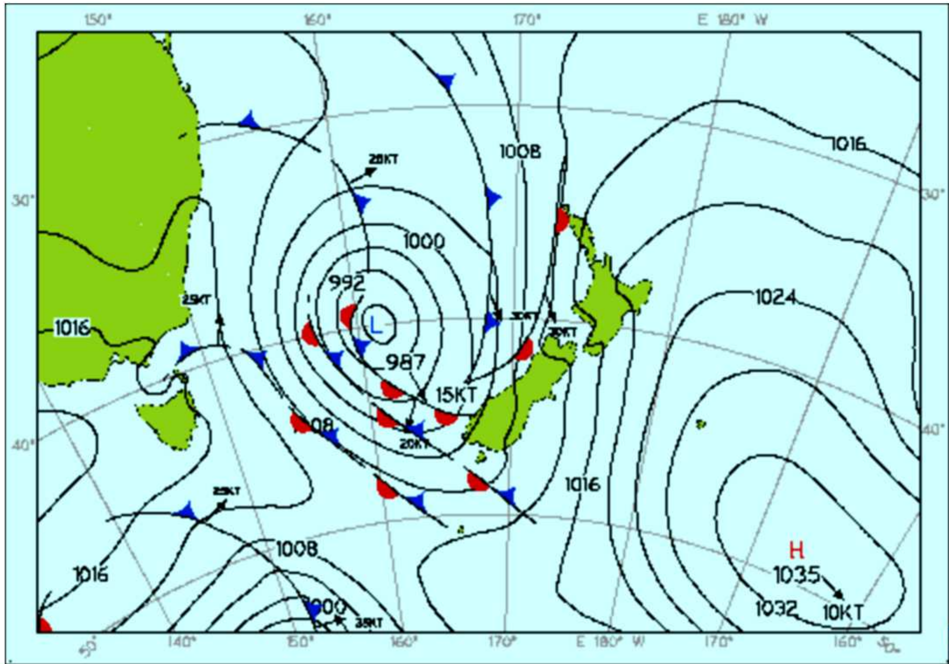
    Warm air rises up from valleys during the day (valley wind). In the night, however, cold air descends the same way back from the mountains to the valleys (mountain wind). The above mentioned flux is combined with transverse circulation on the hillsides (rising warm air during the day, descending cold air during a night).
  - Blizzard:

    Wet circulation flowing from the sea to the land transporting mainly snow precipitation. Normally it appears at northern latitudes. Wind speed ca. 15 $m.s^{-1}$ (54 km/h).
  - Tornado:

    Very quickly ascending spiral air flow, created during unequal temperature and pressure distribution nearby the surface. Wind speed may exceed 200 km/h.

Issues of meteorology

- **Synoptic meteorology (SM)**
  - SM studies atmospheric phenomena and processes on the macroscopic scale.
  - Obtained information is periodically inscribed into synoptic (weather) maps.
  - Analysis of information in the map enables to forecast the weather, which is based on the observation of appearance, evolution and movement of cyclones, anticyclones, air masses and atmospheric square areas.
  - Synoptic maps visualize data, both in horizontal and vertical directions (so-called isobaric levels).
  - Data acquired using:
    - aerological measurement
    - meteorological radars
    - meteorological satellites



Issues of meteorology

- **Synoptic meteorology**
- Synoptic analysis = comparison of values measured and drawn into synoptic maps. Synoptic analyses are based on following principles:

– Complexity

= Weather characteristics are mutually interconnected and conditioned each other.

Values of one characteristic are compared in different locations, in different altitudes and during certain times.

– Three-dimensional behaviour

Observations and detections of values of meteorological characteristics are realised simultaneously (concurrently) at several altitude levels.

– Time consecution

Comparison of measured meteorological characteristics is realised in more subsequent time intervals ⇒ observation of weather evolution during time.

Issues of meteorology

- **Synoptic meteorology**
- Working procedure for synoptic map analysis:
  - Determination of stable and unstable air masses, based on type of clouds and form of precipitations (rainfall), localisation and identification of frontal fractures;
  - Plotting of lines expressing hourly trends of air pressure (isobaric lines);
  - Determination of geographic location of warm, cold and occluded fronts;
  - Determination of front type and direction of movement of isobars in case of gradient wind (changes of vectors of winds);
  - Comparison of the above listed data with height maps of absolute and relative baric topography;
- Condition for successful forecasts:

  Knowledge of precise values about current state of atmosphere.

Issues of meteorology

- **Synoptic meteorology**
- Acquisition of precise values about current state of atmosphere:
  – Every 1 or 6 hours, a network of terrestrial stations transmits an encoded message with data about: clouds, range of vision, relative humidity, precipitations, snow coverage, air temperature, dew point temperature, direction and speed of wind, air pressure and its trend;
  – Aerological stations (4 times per day at the same time around the world) release meteorological balloons with analytical aeroprobes, e.g. Czech Republic stations: Prague-Libuš and Prostějov;

  Altitude range ca. 32 km

  Data acquisition:

After reaching the limit altitude, the balloons crack and the probes fall down using a parachute; following parameters are measured each 5 s: temperature, pressure, humidity, dew point, direction and speed of wind + several times per year additional data about O_3 and radioactivity.

– Long distance detection: meteorological satellites, radars, flash detections systems, etc.

Issues of meteorology

- Aerological station – release of aeroprobe using meteorological balloon = weather balloon (Source: CHMI)

Issues of meteorology

- **Synoptic meteorology**
- Classification of weather prognoses:

– Very short term	0–12 hours	synoptic evaluation
→ Nowcasting	0–2 hours	synoptic evaluation
– Short term	1–3 days	numerical models
– Medium term	4–8 days	numerical models + models of deterministic chaos theory
– Long term	months	knowledge of relations among parts of climatic system (e.g. Asia – beginning of monsoon period and so on)
– Prognosis of climate	decades, centuries	very complicated