BUILDING AERODYNAMICS

BME GEÁT MW08

Wind in the atmosphere

Dr. Goricsán István, 2008
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Wind in the atmosphere

1. Meteorological scales
2. Vertical structure of the atmosphere
3. Wind
4. Evolution of wind – acting forces
5. Global atmospheric circulation
6. Extratropical cyclones
7. Tropical cyclones
8. Local and regional winds

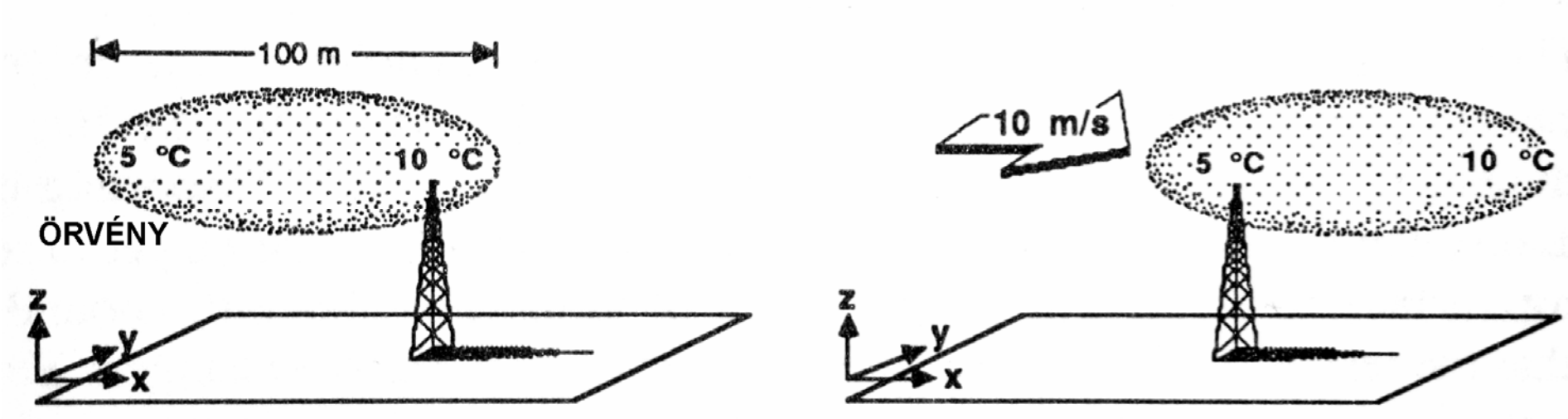
BOREAS (1902)
John William Waterhouse

**Bóreasz, az északi szél istene, Óreithüiá elrablója – a bóra névadója*

SCALES IN METEOROLOGY

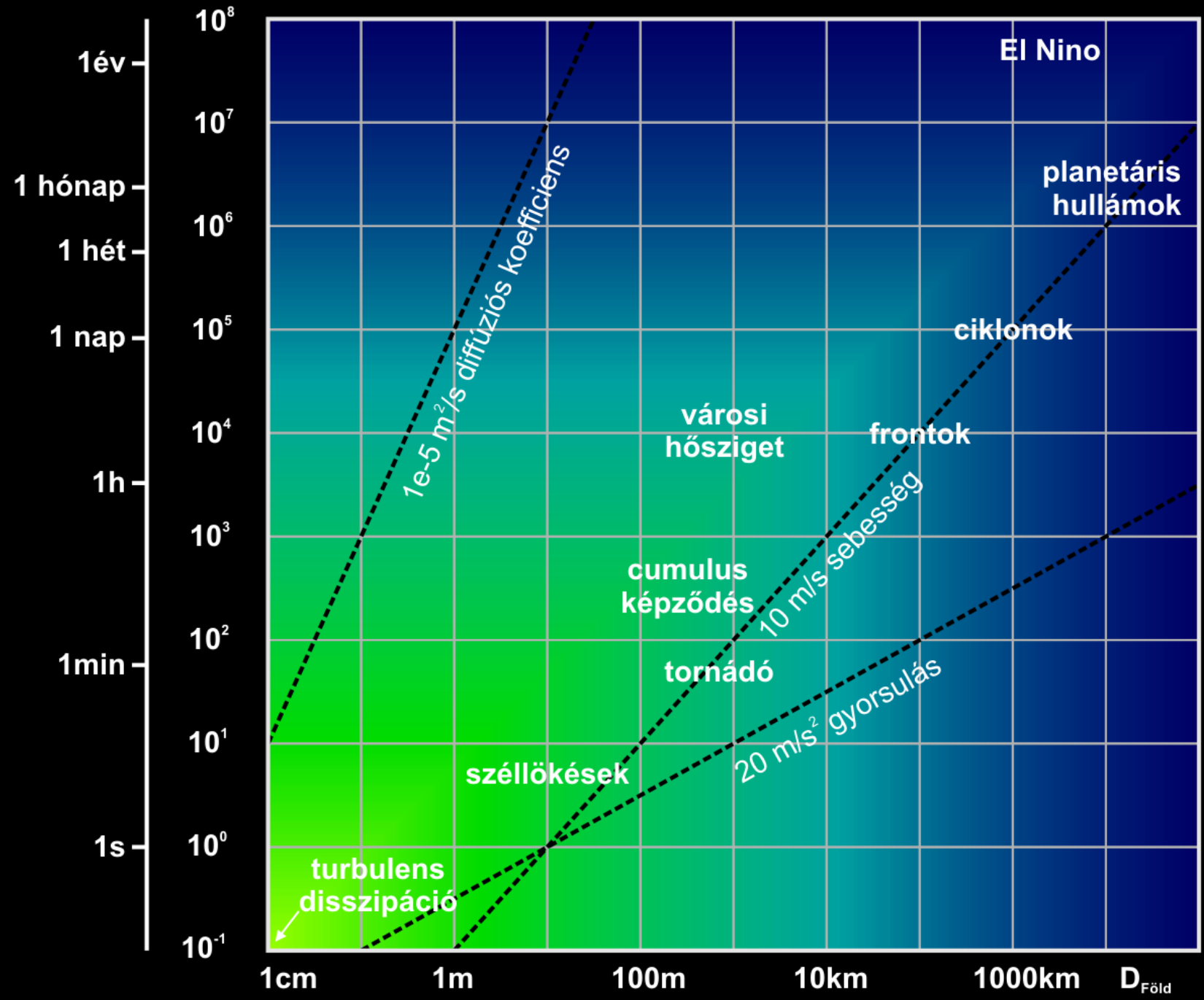
- SCALE: typical time and length of meteorological phenomena.
  - L : 10^{-3} m – 10^{7} m (10 nagyságrend)
  - T : 10^{-3} s – 10^{17} s (20 nagyságrend)

- Macroscale: L > 2000 km (global wind systems)
- Mezosscale: 2000 km > L > 2 km (extratropical and tropical cyclones urban heat island)
- Microscale: L < 2 km (tornadoes, orographic flows, flow around buildings)



Forrás: Roland B. Stull: Boundary Layer Meteorology

SCALES IN METEOROLOGY



SCALES IN METEOROLOGY

Size larger than	scale		Other naming	examples	időskála
20000 km	**macro**	α	global, planetary	Global winds	1 week
2000 km		β	synoptic, continental	Extratropical cyclones	100 hours
200 km	**meso**	α	regional	Tropical cyclones	10 – 100 hours
20 km		β		Weather fronts, terrain induced storms (mistral, phoen)	10 hours
2 km		γ	urban	Tornadoes, heat island,	10 – 60 min.
200 m	**micro**	α	local	Orographic flows	10 min
20 m		β		Wind gusts, flow in street canyons, around buildings	1sec – 1min.
2 m		γ		Flow around trees, masts, vehicles	
2 mm		δ		Viscous dissipation of turbulence	0.01sec.

VERTICAL STRUCTURE

Troposphere *(tropos: change)*

At the tropics: 16-18 km, in the polar regions ~10 km. Weather phenomena, greenhouse effect.

~80% of weight, ~98% of moisture

Temperature gradient: -6.5 K/km (average value, broad variation observable)

Tropopause (1-2 km thick)

Stratosphere *(stratos: layer) 12-50 km*

Tempearture constant up to ~ 20 km height, above that increasing. Ozonosphere above 20 km, T max at 20-30 km

Vertical mixing minimal due to positive temperature gradient !

Very dry (moisture entry only from below possible – T small).

Temperature rise caused by reactions of UV light and ozone (O_3).

Mesosphere *(meso: between) 50-90 km*

Isothermal followed by a decrease to ~180K at 79-80 km height

VERTICAL STRUCTURE

Termosphere (Ionoszféra) 95-120km -

Temperature around 220K at 100 km, UV rafdiation of the SUN ionizing N_2, O_2 .
Polar light. Sarki fény, Nemzetközi Űrállomás

Exosphere (250-500km – 1000km)

T ~ 1000 ºC

Components: H and He | Free trajectory of atoms: 100 km.

H reaching first cosmic velocity – H leaving Earth

Some air drag observable on satellites

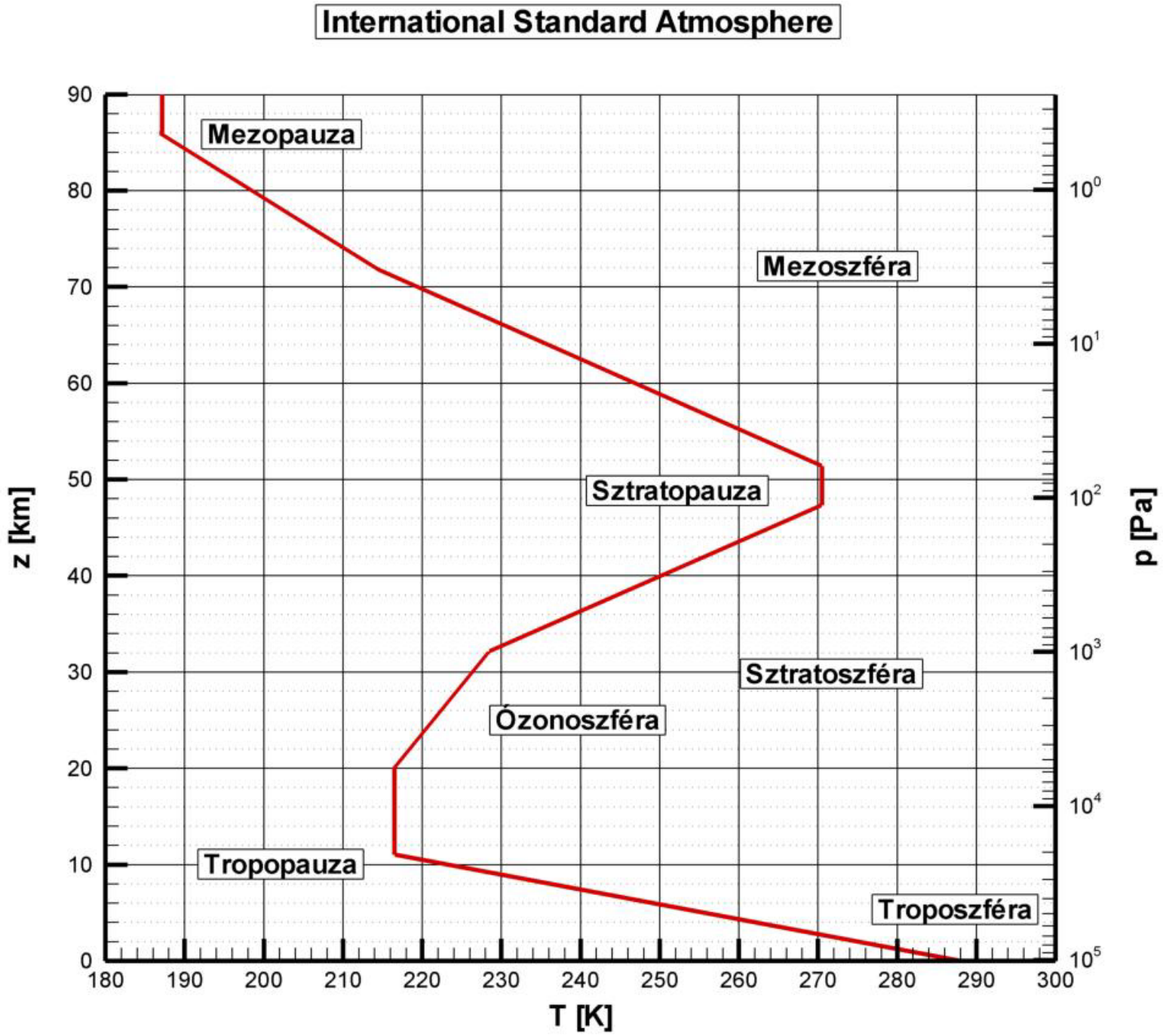
(Magnetosphere)

Where is the limit of atmosphere and space?

Von Kármán-line: **100km**: upper limit of aerodynamic flight (in practice, above 30-40 km steering surfaces do not work)

Consequence: there is no sharp limit. At 1000km-en the number os particles coming from the Sun and from the atmosphere is approx. equal.

VERTICAL STRUCTURE



WIND

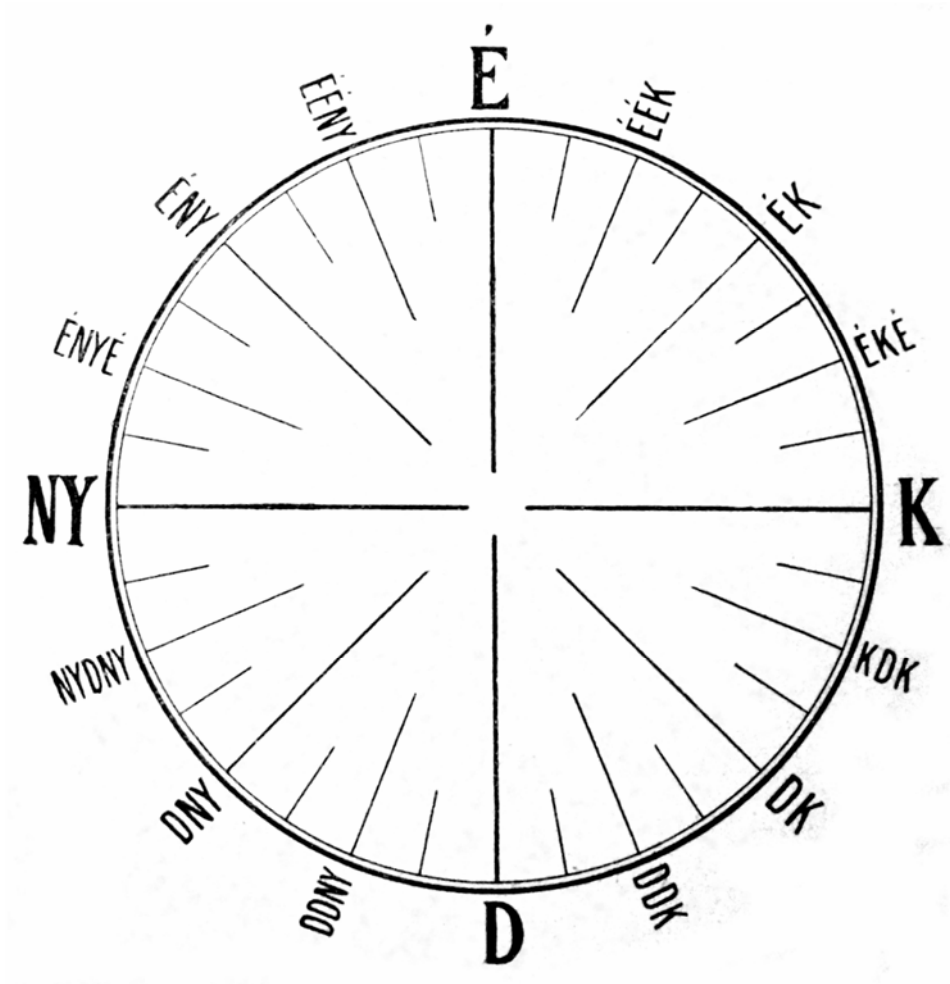
Moving air

- Inhomogenius in space and time

$$\underline{V}(\underline{r},t)=\begin{bmatrix} u \\ v \\ w \end{bmatrix}(\underline{r},t)$$

N (North): 0°

E (East): 90°



Direction : where it blows from

- 4 main wind directions
- 12 mellékirány

Wind speed:

- m/s
- km/h
- (English) miles/h = 1.609 km/h
- knots

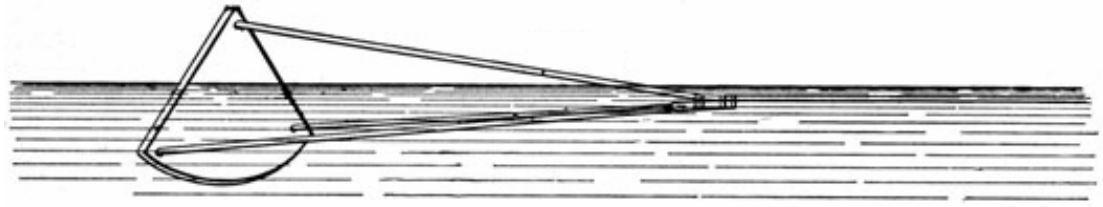
Measuring a ship's speed: the ship log

Tengerészeti sebességmérés

- 1 nautical mile/hour = 1.852 km/h = 1 minute of latitude/h
- Measuring 28 sec. - knot distance: 47 feet 3 inch ⇨ 1 knot = 1 n. miles/hour

The full rigged ship 'Danmark'

LOGG! (MENET-GYORSASÁG MÉRÉSE.)



The ship log : wwoden bord attached to a line with knots

Source: Dr. Gáspár Ferencz:
Hét év a tengeren. Budapest,1903.

THE BEAUFORT WIND FORCE SCALE

- an empirical measure for describing wind speed based mainly on observed sea conditions
- 0-12 forces, later extended by 13-17
- 1805 /1832, Sir Francis Beaufort, Rear-Admiral of the Royal Navy, hydrographer.
- Fastest observed winds on Earth can reach Beaufort scale 23 in tropical cyclones

BEAUFORT FORCE 1
WIND SPEED: 1-3 KNOTS

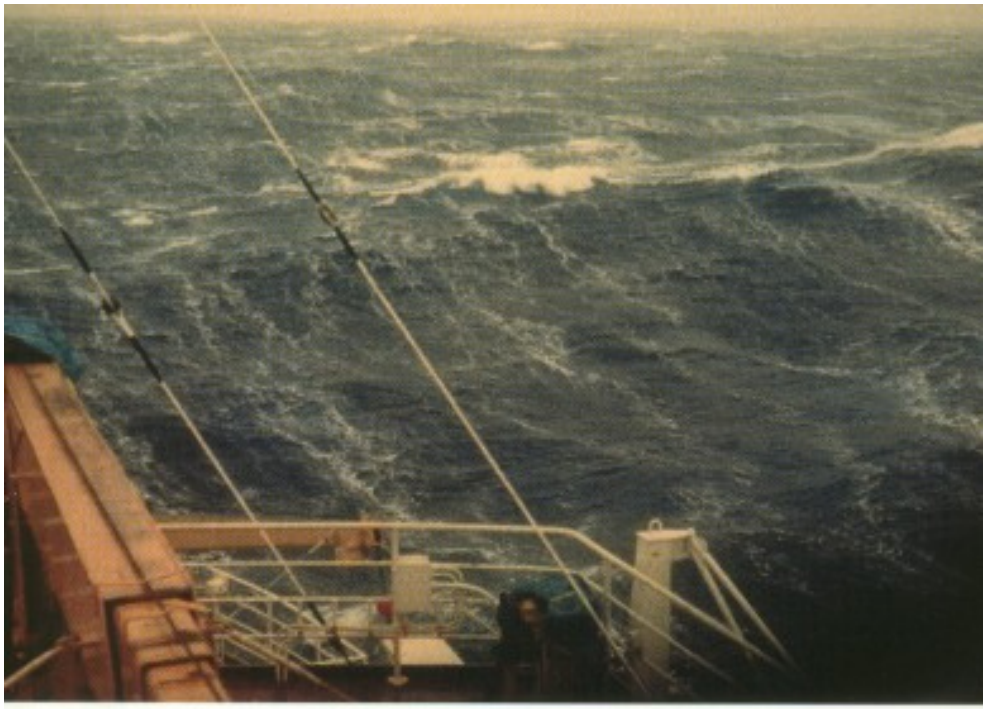
SEA: WAVE HEIGHT .1M (.25FT), RIPPLES WITH THE APPEARANCE OF SCALES, BUT WITHOUT FOAM CRESTS

BEAUFORT FORCE 5
WIND SPEED: 17-21 KNOTS

SEA: WAVE HEIGHT 2-2.5M (6-8FT), MODERATE WAVES TAKING MORE PRONOUNCED LONG FORM, MANY WHITE HORSES, CHANCE OF SOME SPRAY

THE BEAUFORT WIND FORCE SCALE

Category 1 storm warning at Balaton Lake = BWFS 6 (12m/s),
Category 2 = BWFS 8 (17m/s)



BEAUFORT FORCE 8
WIND SPEED: 34-40 KNOTS

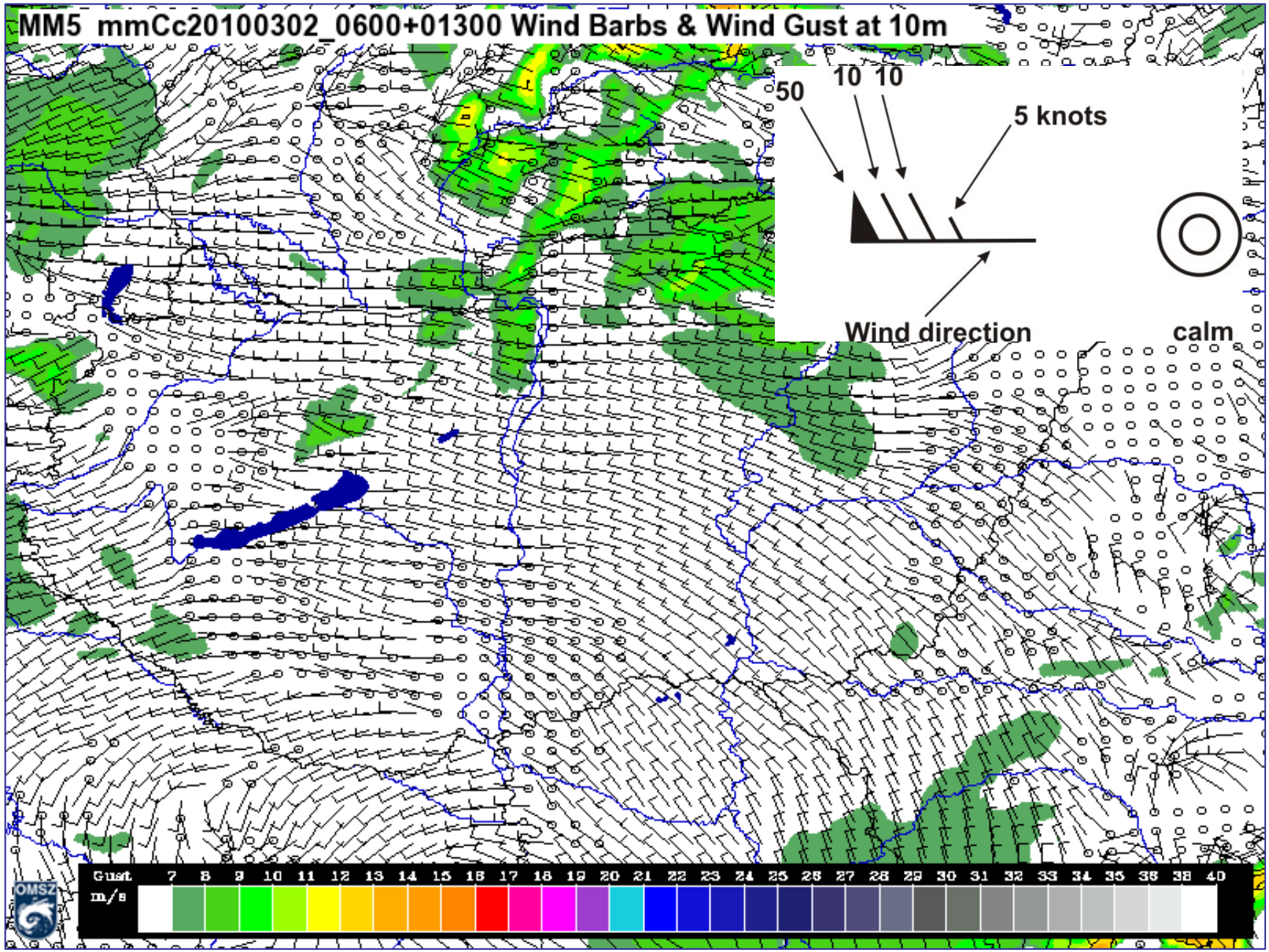
SEA: WAVE HEIGHT 5.5-7.5M (18-25FT), MODERATELY HIGH WAVES OF GREATER LENGTH, EDGES OF CREST BEGIN TO BREAK INTO THE SPINDRIFT, FOAM BLOWN IN WELL MARKED STREAKS ALONG WIND DIRECTION.

Forrás: wikipedia.org

BEAUFORT FORCE 12
WIND SPEED: 64 KNOTS

SEA: SEA COMPLETELY WHITE WITH DRIVING SPRAY, VISIBILITY VERY SERIOUSLY AFFECTED. THE AIR IS FILLED WITH FOAM AND SPRAY

WIND MAPS



Source: www.met.hu

MM5 numerical weather prediction model's wind output for 10 m height

EVOLUTION OF WIND

Atmospheric flows are induced by:

- Inhomogenious warming above Earth surface causing differences in air density and » pressure)
- Earth's gravity
- Coriolis force from the Earth's rotation

Other acting forces:

- Friction with the surface and air packages themseves (viscosity) influence of surface recognizable up to 1.5-2 km height. Above this limit : the frree atmosphere
- Centripetal force – needed when movement trajectories are curved.

$$\underline{g} \qquad -\frac{1}{\rho}\frac{\partial p}{\partial r} \qquad \underbrace{\frac{V_{gr}^2}{r} \qquad 2V\omega}_{\text{fictitious forces}}$$

EXPLANATION OF CORIOLIS FORCE

Fotó: Balczó M.

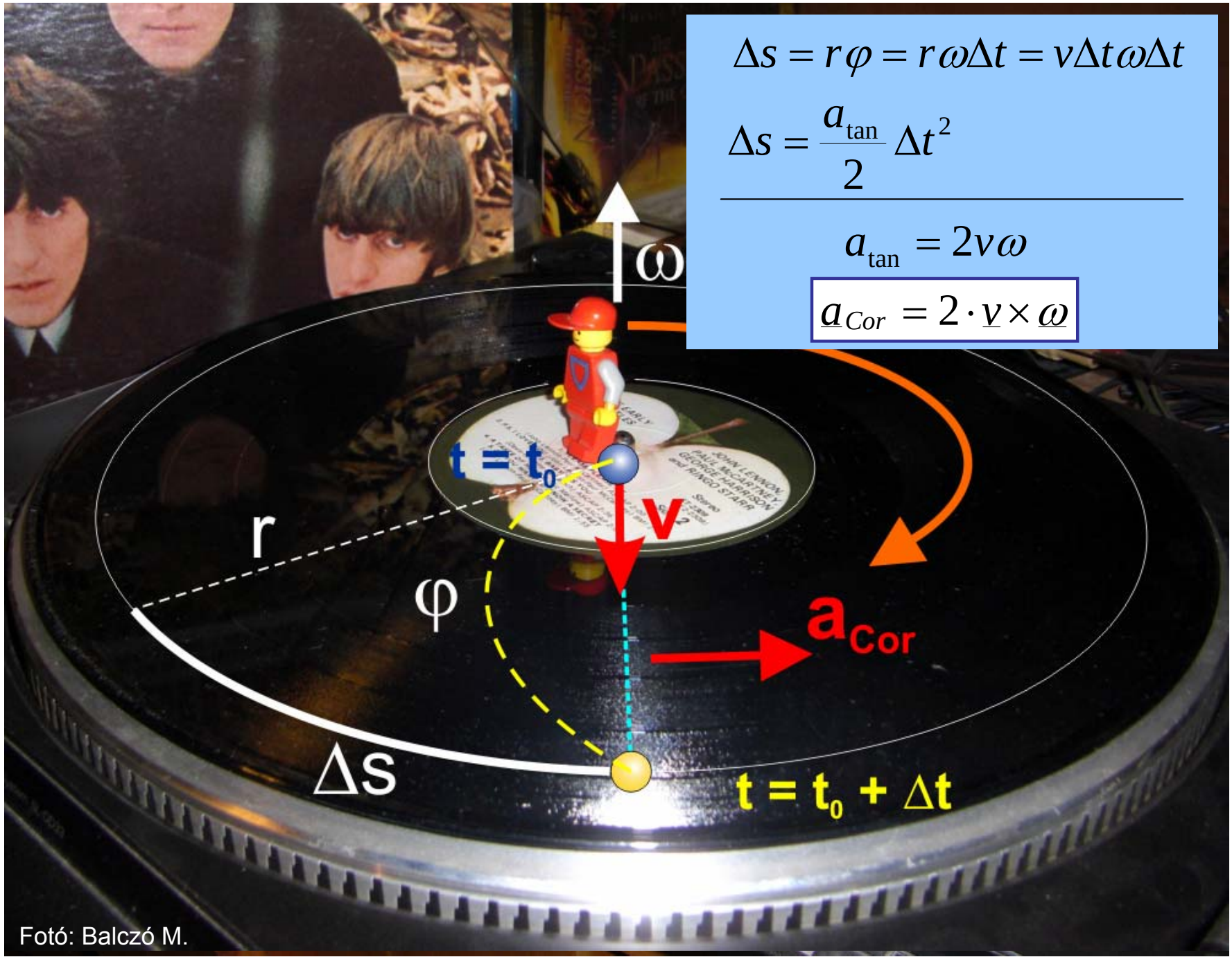
EXPLANATION OF CORIOLIS FORCE

$$\Delta s = r\varphi = r\omega\Delta t = v\Delta t\omega\Delta t$$

$$\Delta s = \frac{a_{\tan}}{2}\Delta t^2$$

$$a_{\tan} = 2v\omega$$

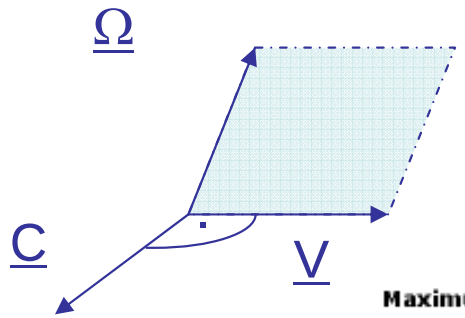
$$\underline{a}_{Cor} = 2 \cdot \underline{v} \times \underline{\omega}$$



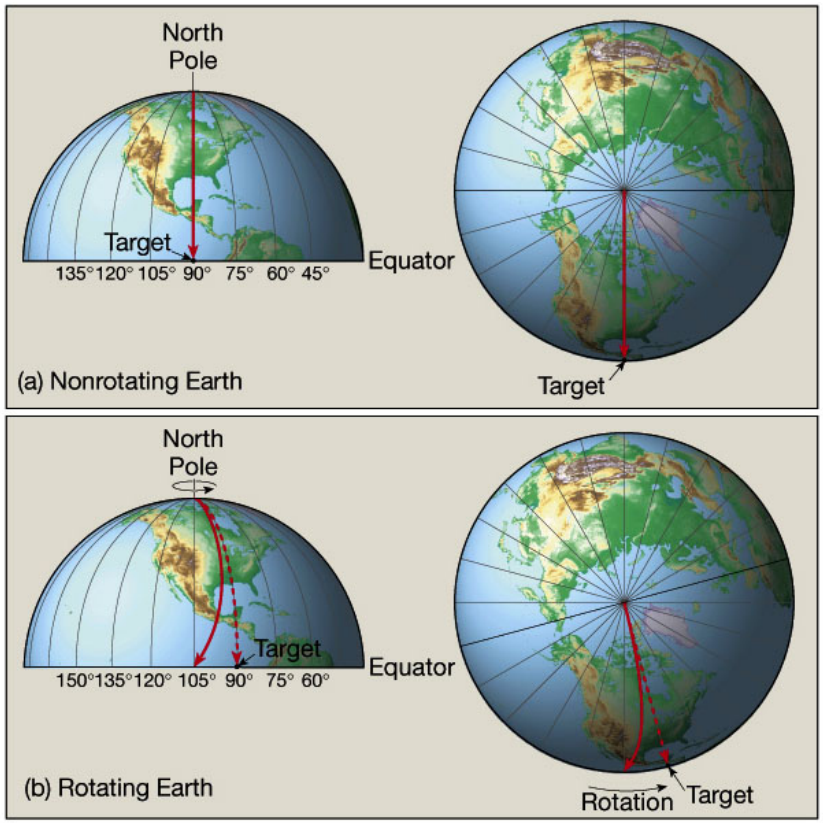
Fotó: Balczó M.

CORIOLIS FORCE ACTING ON EARTH

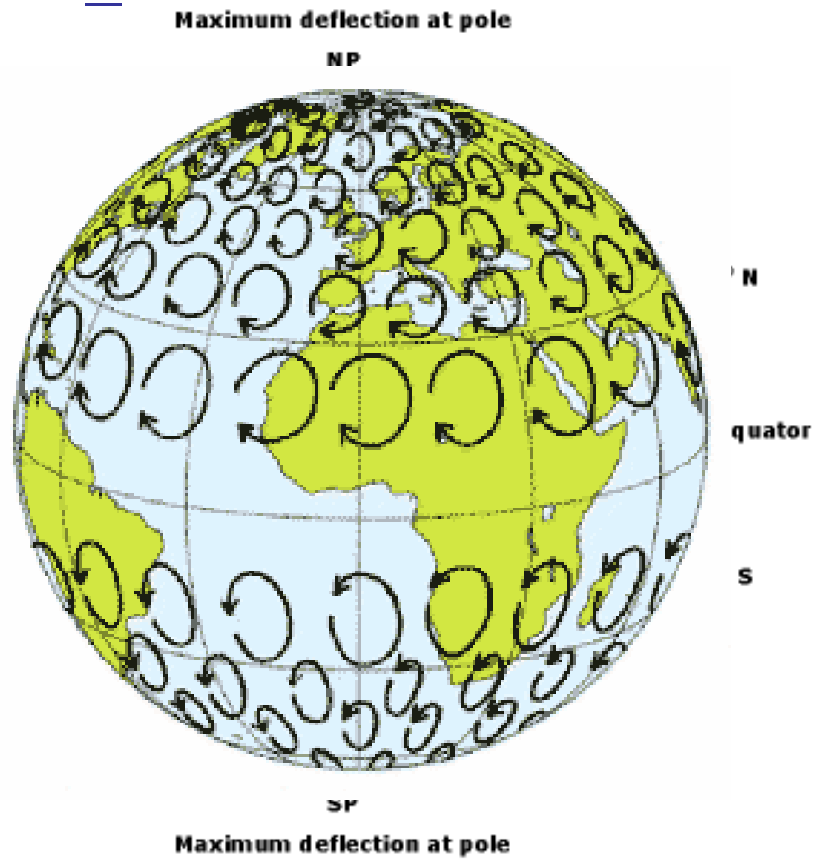
$$\underline{C} = -2\underline{\Omega} \times \underline{V}$$



$$\underline{C} \perp \underline{V}$$



Source: http://www.ux1.eiu.edu/~jpstimac/1400/FIG06_011.jpg



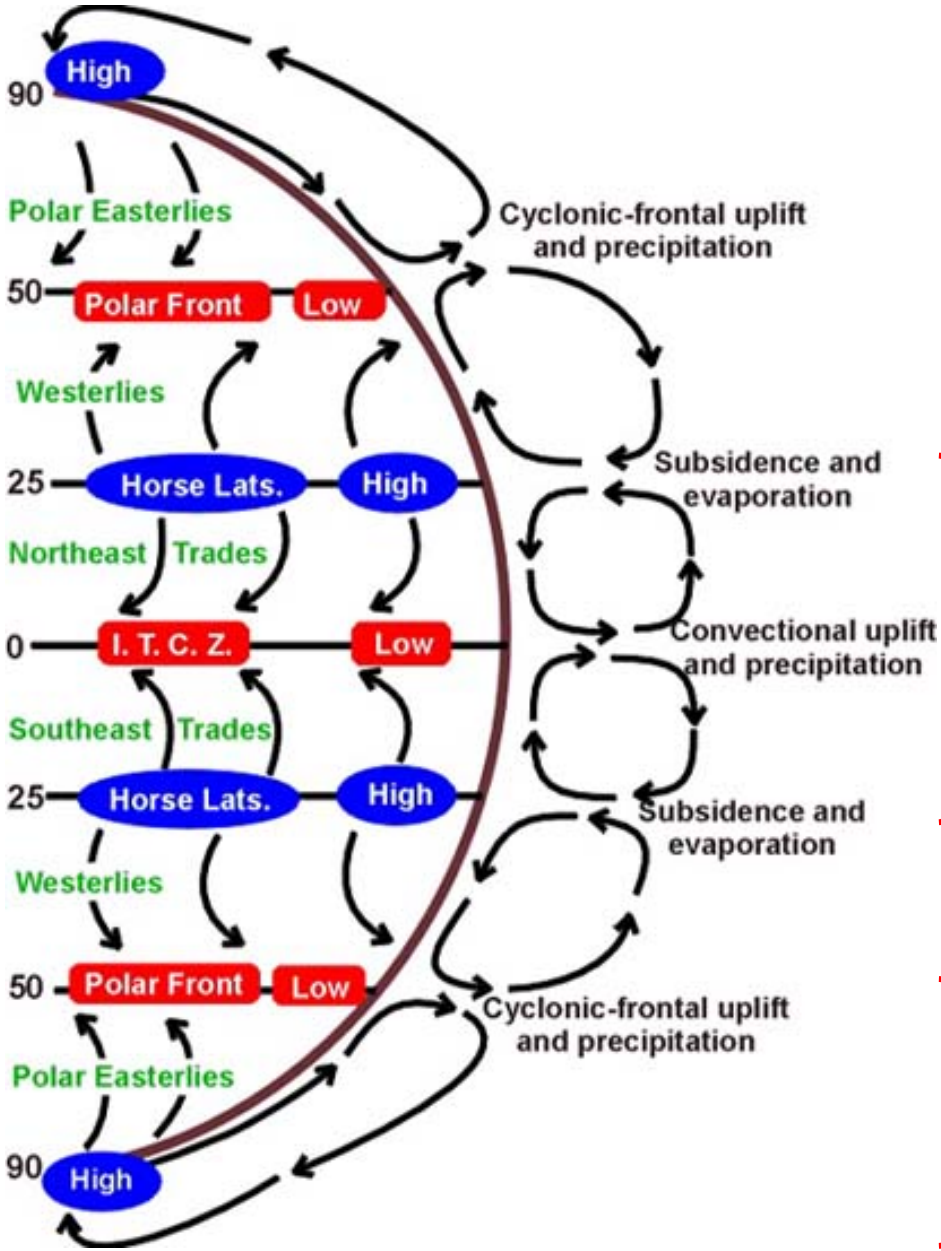
Source:http://nsidc.org/arcticmet/images/factors/coriolis.gif

$$\underline{V} = u \cdot \underline{i} + v \cdot \underline{j} + w \cdot \underline{k}$$

$$C_{horizontal} = \sqrt{u^2 + v^2} \cdot \underbrace{2\Omega \sin\phi}_{f} = V_{horizontal} \cdot f$$

f - Coriolis parameter

PLANETARY CIRCULATION



Forrás:http://www.atmosphere.mpg.de/media/archive/3318.jpg

Different solar heating at low and high latitudes:

- Low pressure at Equator
- intertropical Convergence Zone
- A 30° latitude pressure grows (+ 4-8mbar) – ***subtropical high pressure zones***
- Winds towards the equator in lowe heights

HADLEY CELL

- heat transport to the poles

High pressure cold air at the poles

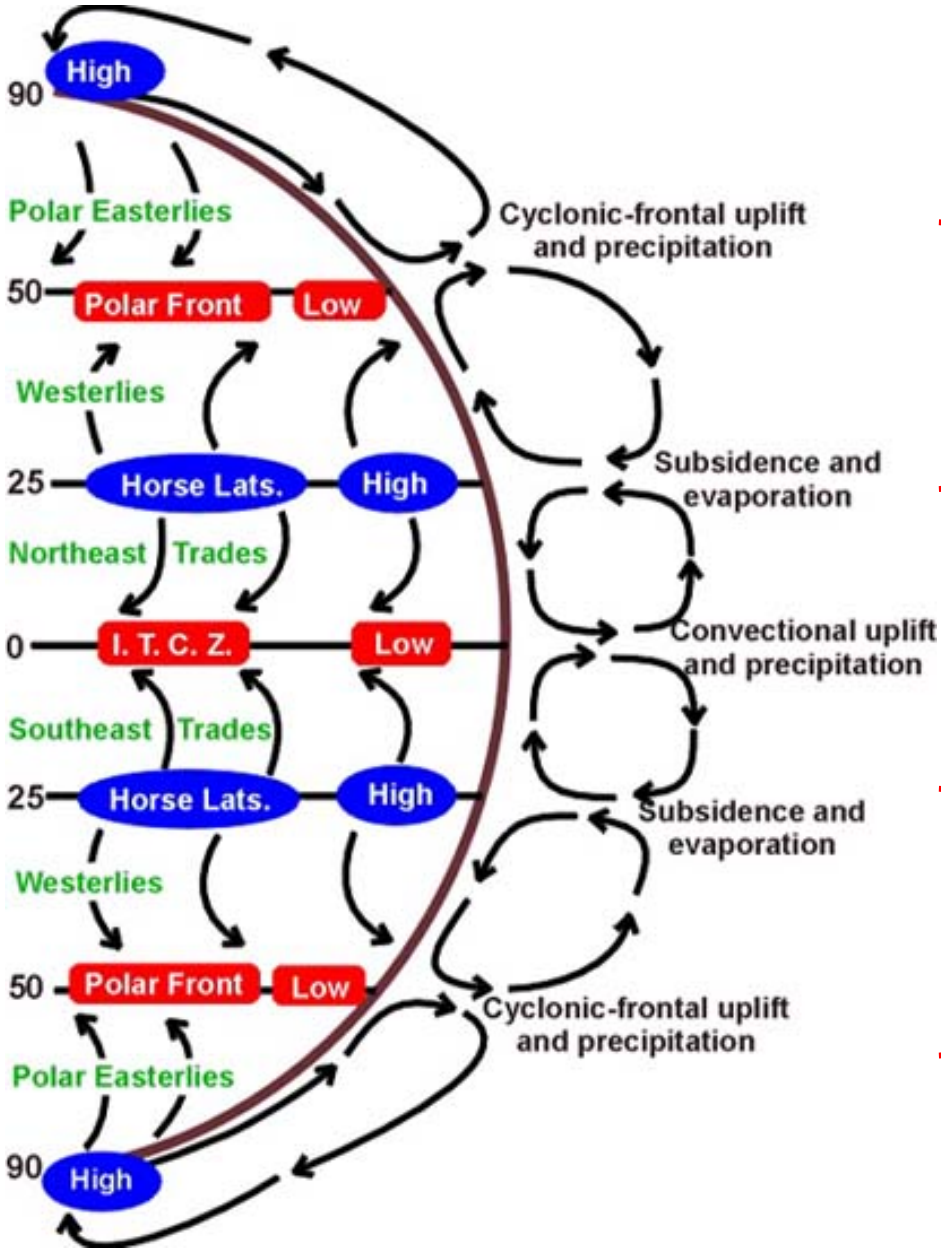
- Flow towards the ***polar front*** (at. 60°, lower pressure)
- Warms up, elevating to the tropopause and transported to the poles

POLAR CELL

- heat transport towards the poles

- in summer weak, in winter strong

PLANETARY CIRCULATION

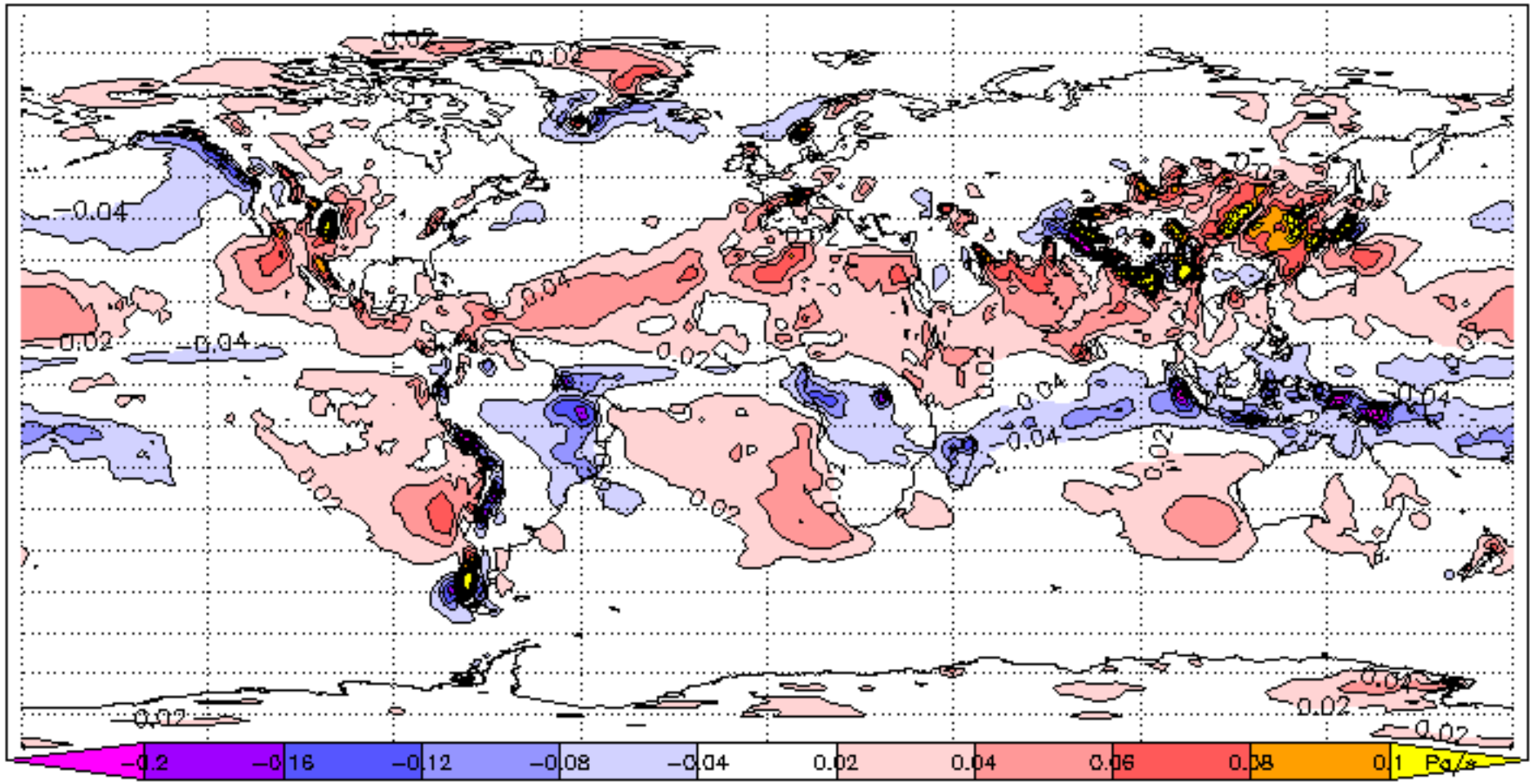


- The Hadley cell and the polar cell induce an indirect circulation at mid ***(30-60°) called FERREL CELL***
- Secondary forces have larger influence in these cells: sea-continent temperature differences
- Secondary cells are more variable and not as stable as primary cells.

- much weaker circulation
- Extratropical cyclones determining the weather

Forrás:http://www.atmosphere.mpg.de/media/archive/3318.jpg

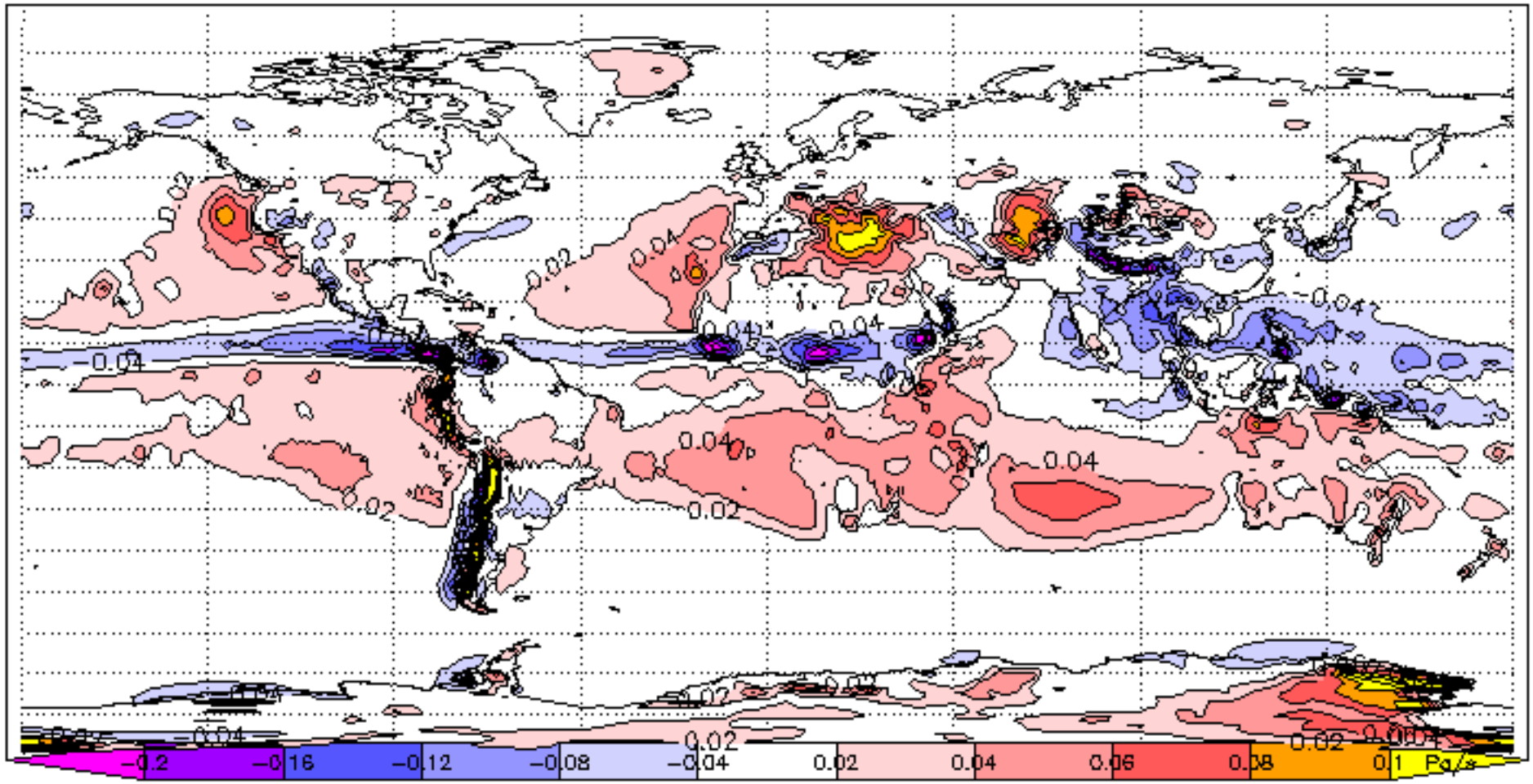
PLANETARY CIRCULATION



Forrás: William M. Connolley, wikipedia.org

Vertical mean wind speed in January (1979-2001)

PLANETARY CIRCULATION



Forrás: William M. Connolley, wikipedia.org

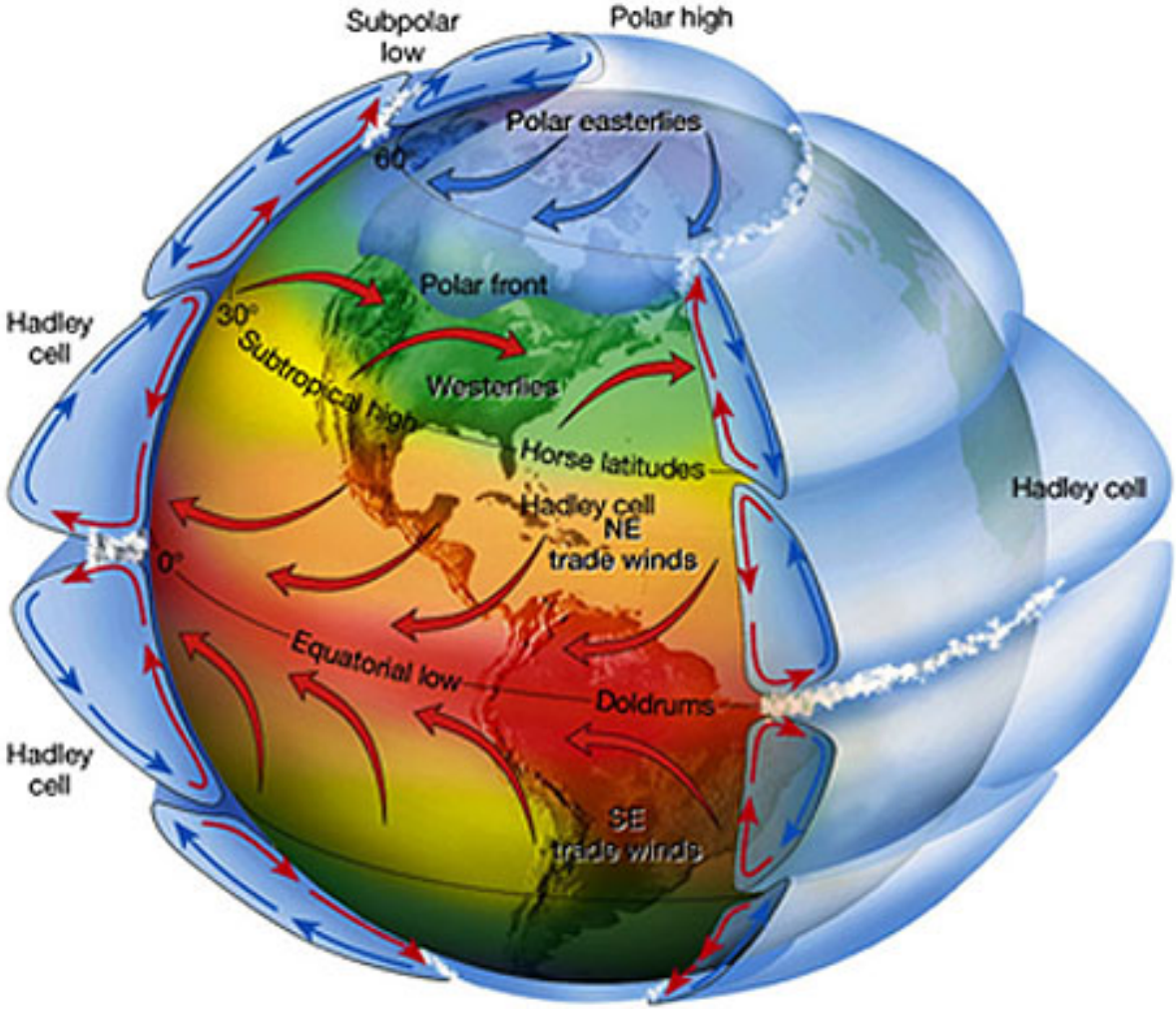
Vertical mean wind speed in July (1979-2001)

PLANETARY CIRCULATION

Earth seen from Apollo–17
(Dec. 1972)

Source: NASA

PLANETARY CIRCULATION – WIND DIRECTIONS



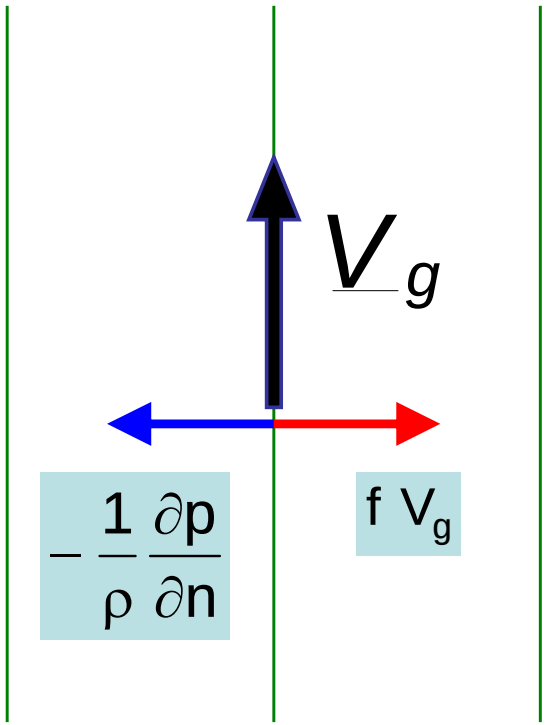
- Polar easterlies
- Mid-latitude westerlies
- NE - trade winds
- Equatorial calms (‘doldrums’)
- SE trade winds
- …

Coriolis force lagrest at the pole, and zero at the equator. In the Ferrel cell cyclones induced by Coriolis force are mainly responsible for the heat transfer between the adjacent two cells.

Source: http://www.fas.org/irp/imint/docs/rst/Sect14/FIG07_006.jpg

GEOSTROPHIC WIND

Moving air is deflected by the Coriolis force to move parallel with isobars.



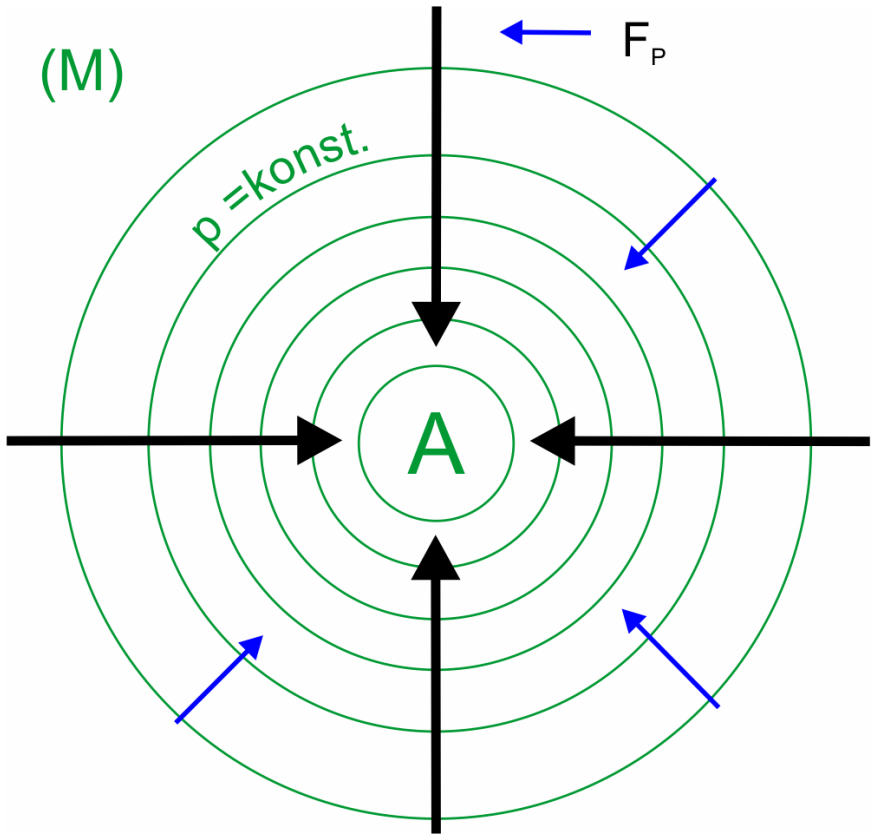
Pressure gradient force and Coriolis force holding balance:

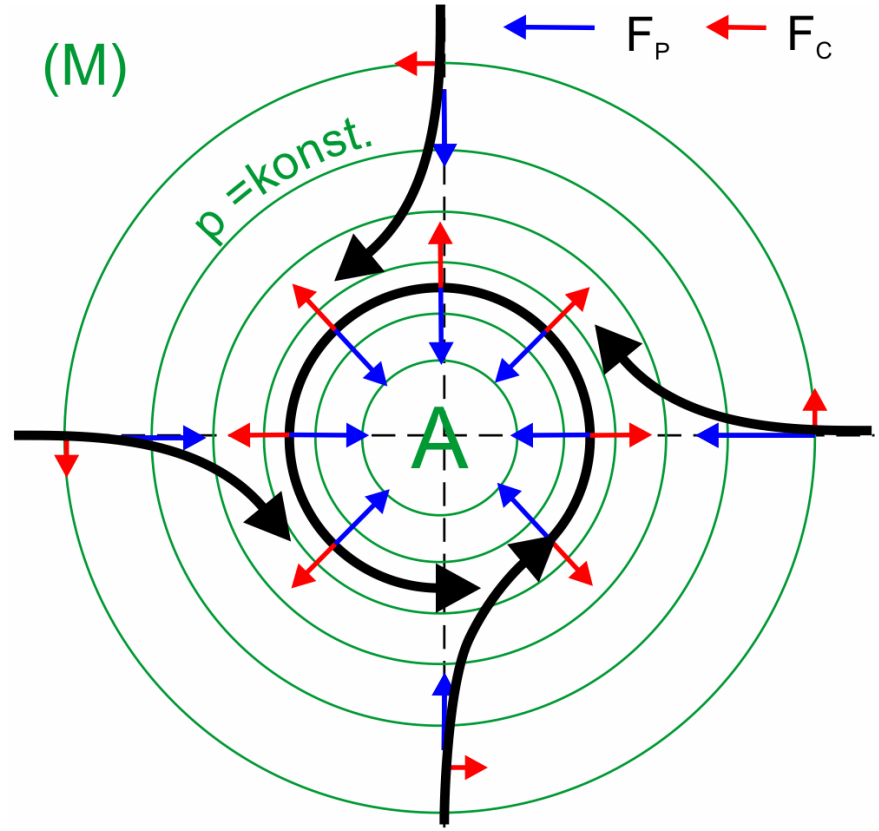
$$fV_g - \frac{1}{\rho}\frac{\partial p}{\partial n} = 0$$

- The higher the pressure gradient, the higher V_g
- Pressure difference remains!

- Theoretical wind, neglecting friction – in the free atmosphere above 2km
- trade winds, polar easterlies etc. are geostrpohic winds

EXTRATROPICAL CYCLONES AND ANTICYCLONES





- Synoptic sacle phenomena (~ 1000km diameter) .
- Streamlines almost paralell to isobars
- Pressure force ensuring Coriolis force and centripetal force.
- Also called **gradient wind**.

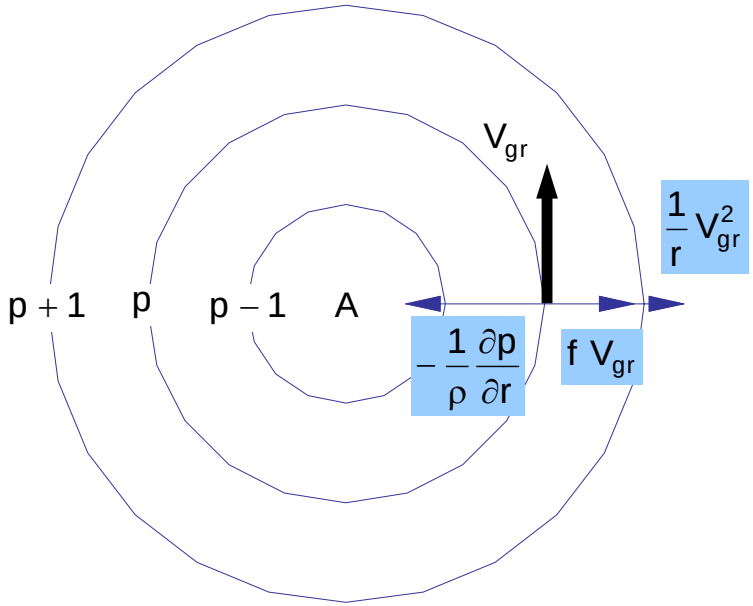
EXTRATROPICAL CYCLONES AND ANTICYCLONES

Written forthe northern hemisphere

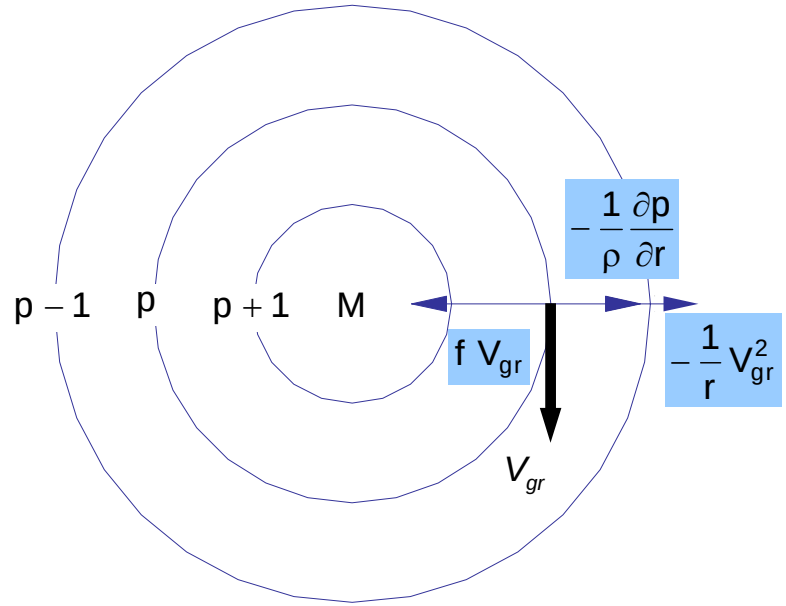
$$\pm \frac{V_{gr}^2}{r} + fV_{gr} - \frac{1}{\rho}\frac{\partial p}{\partial r} = 0$$

$$\frac{\partial p}{\partial r} = 0 \Rightarrow V_{gr} = 0$$

cyclone



Anticyclone



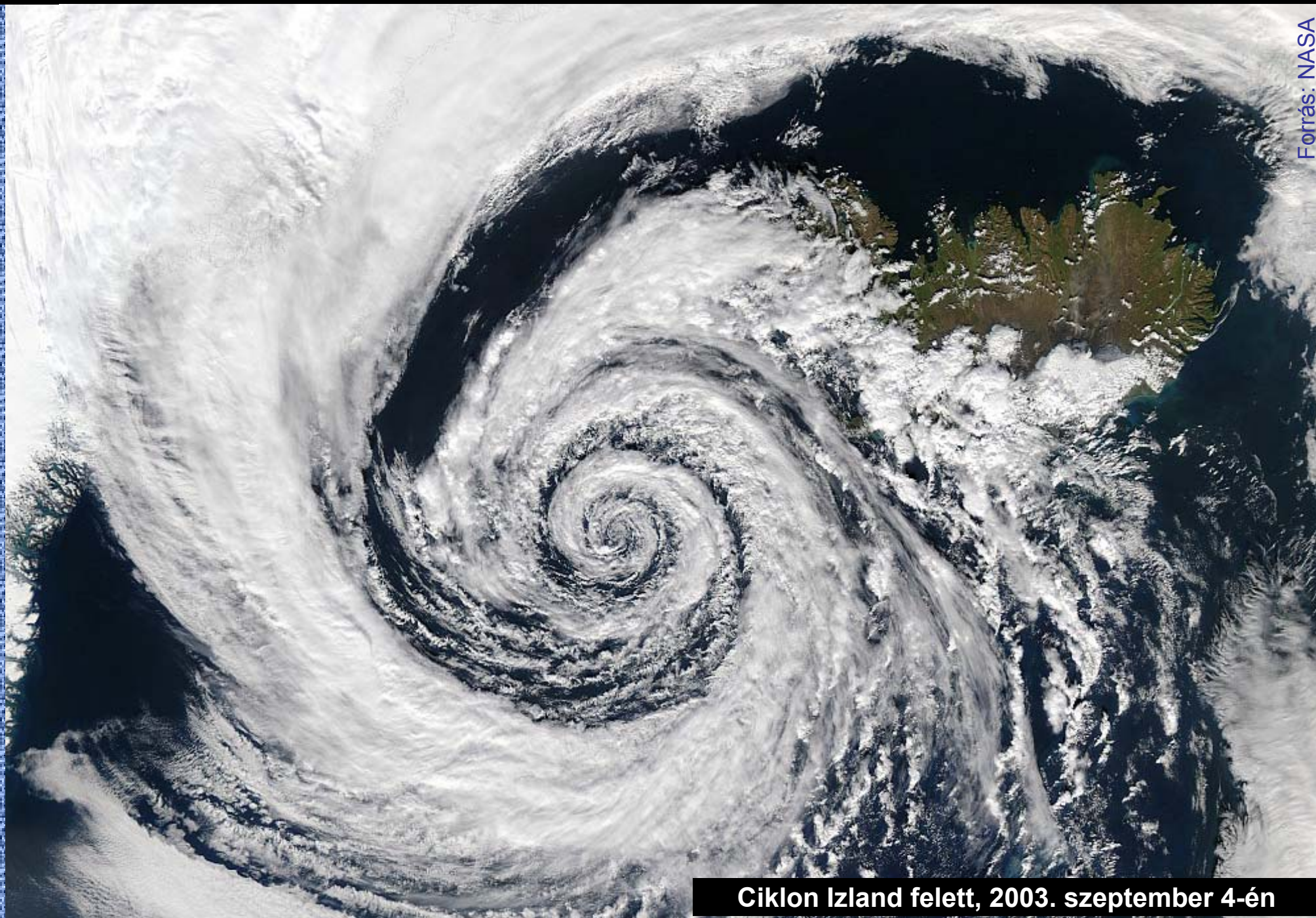
$$V_{gr} = -\frac{fr}{2} + \sqrt{\frac{f^2r^2}{4} + \frac{r}{\rho}\frac{\partial p}{\partial r}}$$

counterclockwise

$$V_{gr} = \frac{fr}{2} - \sqrt{\frac{f^2r^2}{4} - \frac{r}{\rho}\frac{\partial p}{\partial r}}$$

clockwise

EXTRATROPICAL CYCLONES AND ANTICYCLONES



Forrás: NASA

Ciklon Izland felett, 2003. szeptember 4-én