Oveshoot – проскок

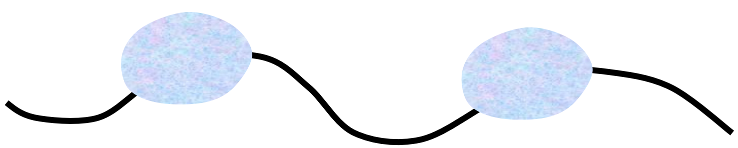
Lee side – подветренная сторона

Lenticular – линзобразный

Wake – волновой след

Undulatiform clouds

Wave-like motion in the atmosphere is rather often phenomena. This motion, at certain conditions, are responsible for ***undulatiform cloud*** **formation.**



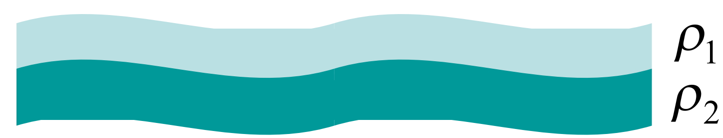
The undulatiform clouds are seen as long banks, bands, streets, and plates. The sizes of these formations are: 10^3-10^2 km in horizontal directions, and 10^1-10^2 meters in vertical, rarely up to 2 km.

Conditions for undulatiform clouds to arise

- *Wave-like motion*
- *Stable stratification of the atmosphere*
- *The air involved into the cloud formation should be humid enough to become saturated at a small ascent.*

Reasons for the wave-like motion to arise

- *Two layers (one above another) with different density and speed of motion.*



- *Inversion (barrier layer) must exist to prevent the layer to mix up.*

According to Helmholtz formula, the waves spread with the speed

$$C = \frac{T_2 u_1 + T_1 u_2}{T_1 + T_2} \pm \sqrt{\frac{g\lambda}{2\pi}\frac{T_2 - T_1}{T_2 + T_1} - T_1 \cdot T_2 \frac{(u_1 - u_2)^2}{(T_2 + T_1)^2}}$$

The wave can be stable or unstable. *Stable wave* → *amplitude does not change its value. Unstable wave* → *amplitude value increases.*

The wave stability depends on the wave length at a given conditions, i. e. on the radicand value in the Helmholtz' formula.

Setting this value to zero, we obtain

$$\frac{g\lambda^*}{2\pi}\frac{T_2 - T_1}{T_2 + T_1} = T_1 T_2 \frac{(u_1 - u_2)^2}{(T_2 + T_1)(T_2 + T_1)}$$

$$\lambda^* = \frac{2\pi}{g} T_1 T_2 \frac{(u_1 - u_2)^2}{(T_2 - T_1)(T_2 + T_1)} = \frac{2\pi}{g} T_1 T_2 \frac{(u_1 - u_2)^2}{(T_2^2 - T_1^2)}$$

Critical wavelength

Value λ^* ***varies from a few meter up to 8 km***

$\lambda > \lambda^*$ ***The waves are stable. Clouds may appear, but not develop***

$\lambda < \lambda^*$ ***The waves are unstable. Clouds appear and develop***

An example of the critical wavelength determination

$u_1 = 10 m/s$ $\qquad$ $T_1 = 273K$

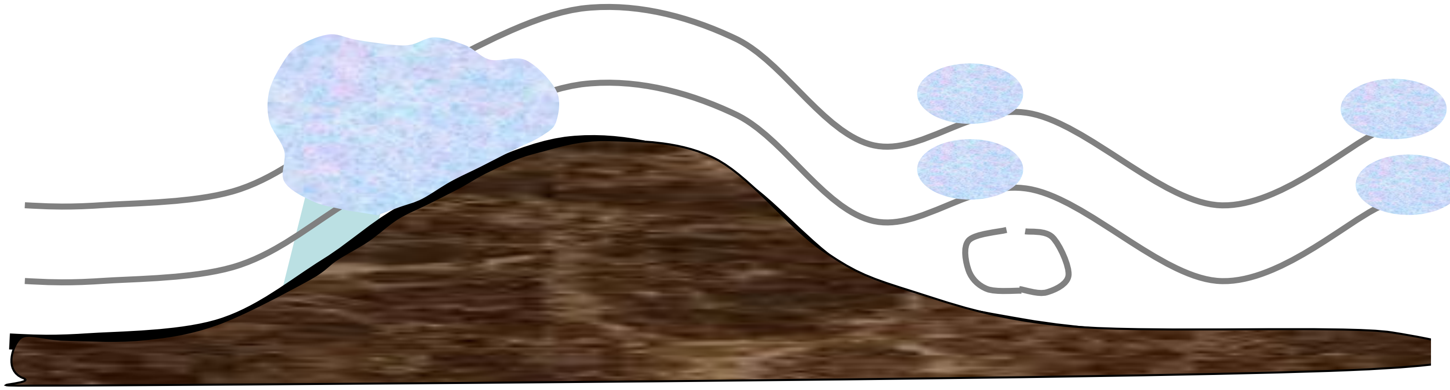
$u_2 = 15 m/s$ $\qquad$ $T_2 = 280K$

$$\lambda^* = \frac{6.28}{9.8} 280 \cdot 273 \frac{(15-10)^2}{280^2 - 273^2} = 316m$$

If at these conditions the observed wave $\lambda_1 > 316m$ *this wave is stable.*

If at these conditions the observed wave $\lambda_1 < 316m$ *this wave is unstable.*

Another reason for wave formation is air flowing over mountains. These wave arise on the lee side of mountains. That is why they are known as lee waves

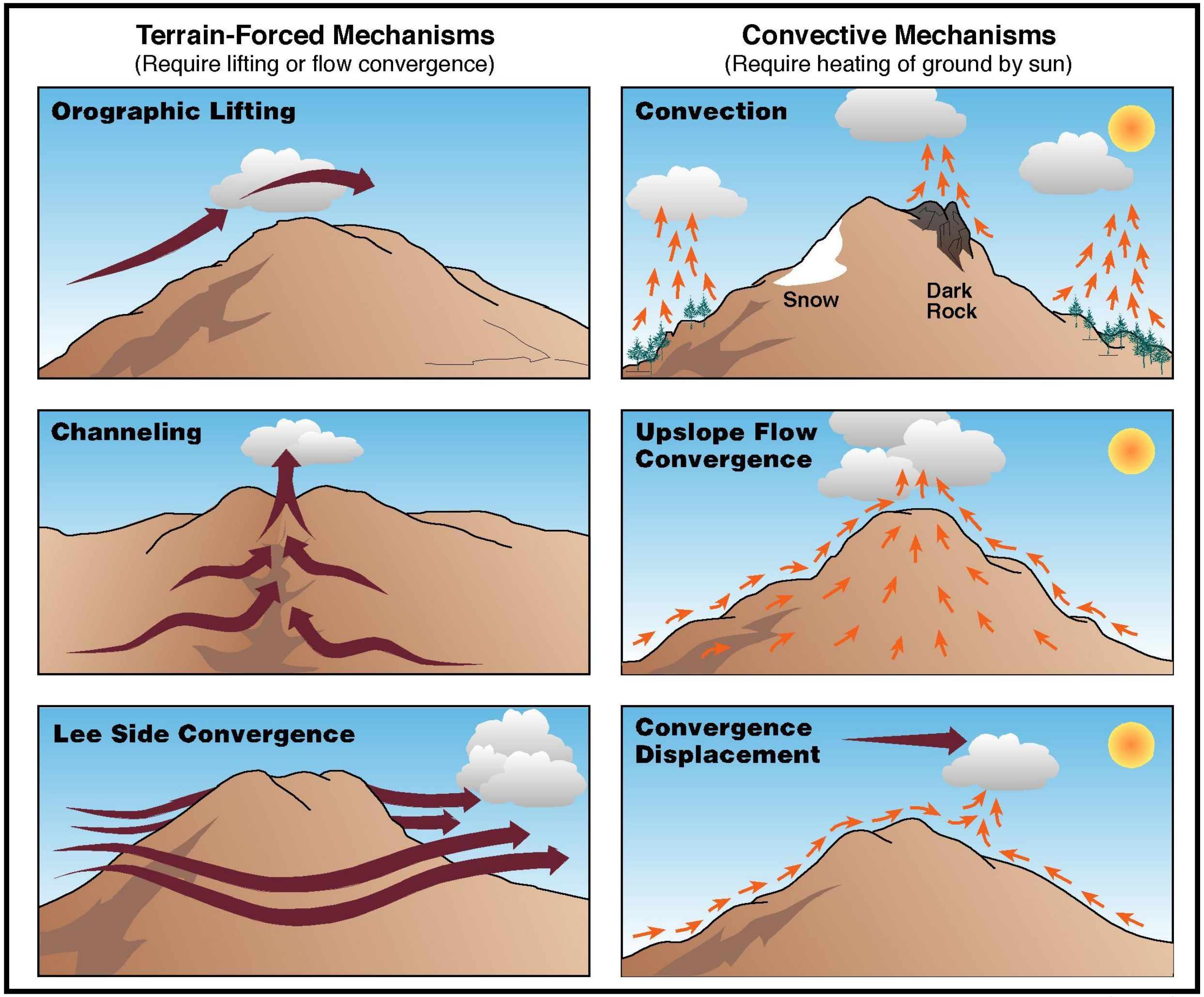


Lee wave structure depends on:

- *Velocity of air currents*
- *Stratification of the atmosphere (unstable stratification results in formation of lee vortexes and chaotic cloudiness appearance)*
- *Size of the mountains.*

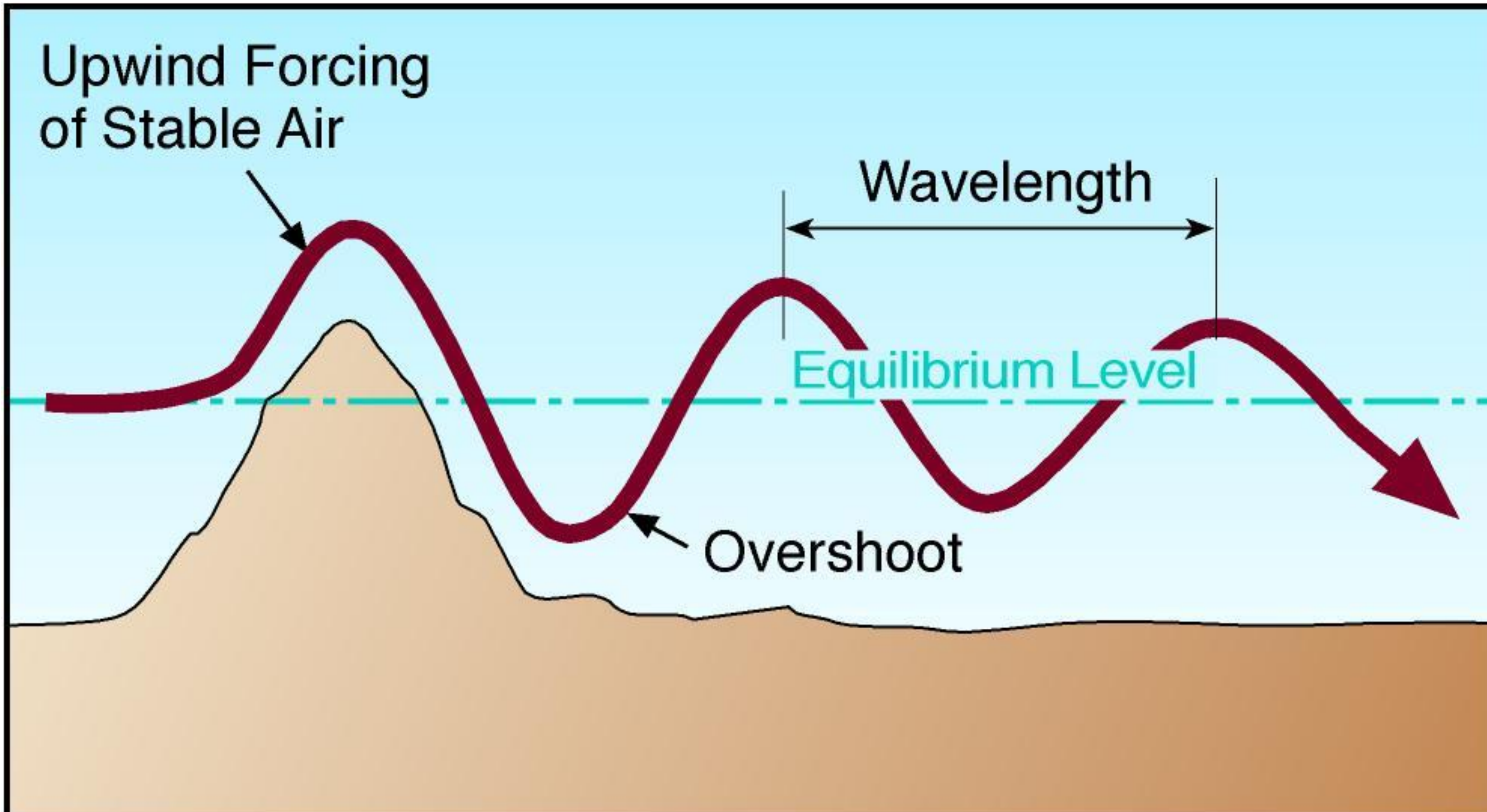
Terrain-related lifting mechanisms

(Whiteman ppt)



Whiteman (2000)

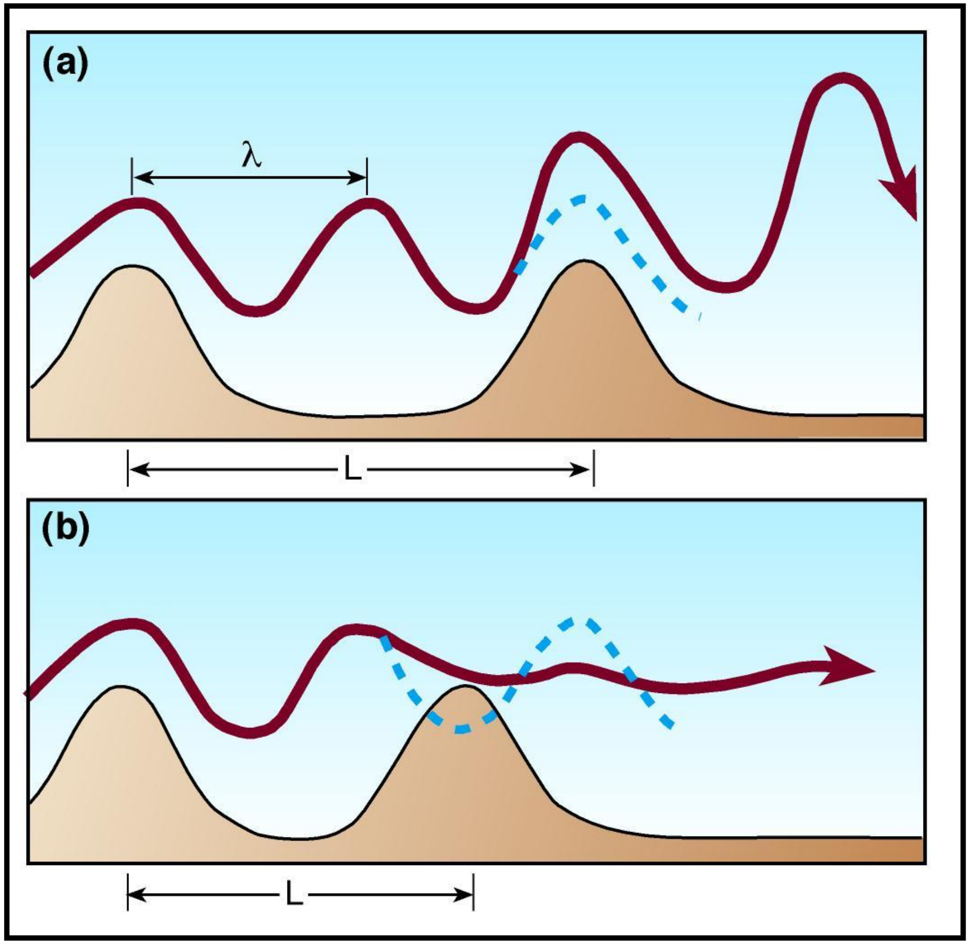
Lee waves (Whiteman ppt)



Stull (1995)

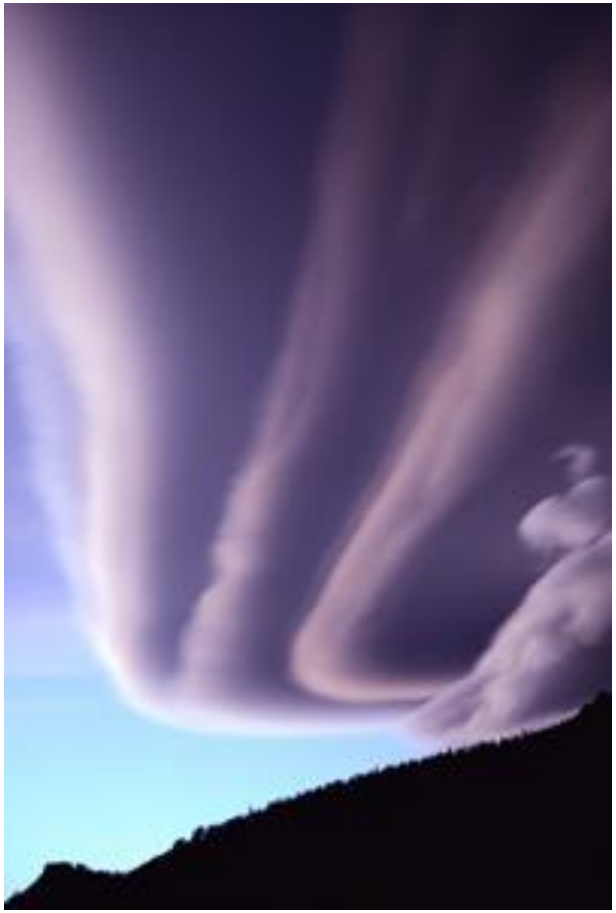
Lift

Amplification and cancellation of lee waves (Whiteman ppt)



Bérenger & Gerbier (1956)

Lenticular clouds (Whiteman ppt)

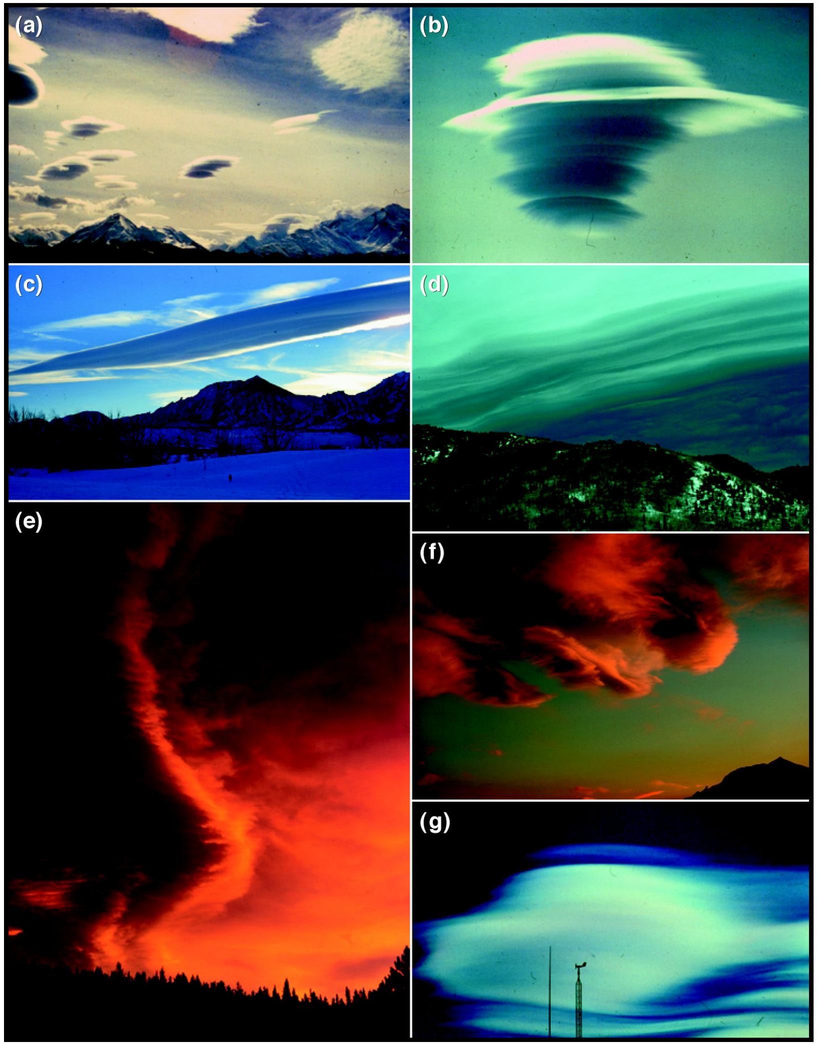


© Jeff Grandy

www.pbs.org/wgbh/nova/ denali/extremes/speak.html

Lenticular and wave clouds

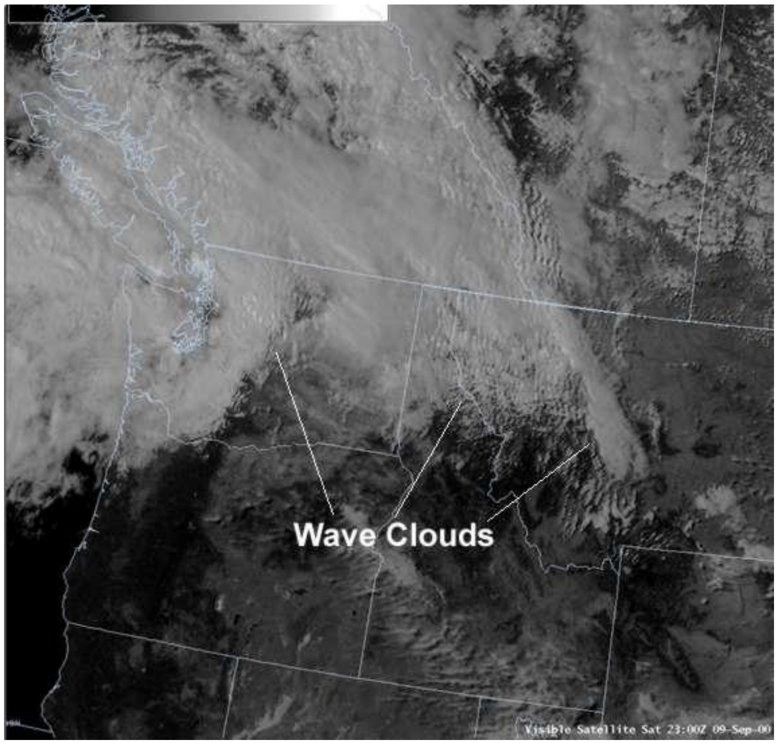
(Whiteman ppt)



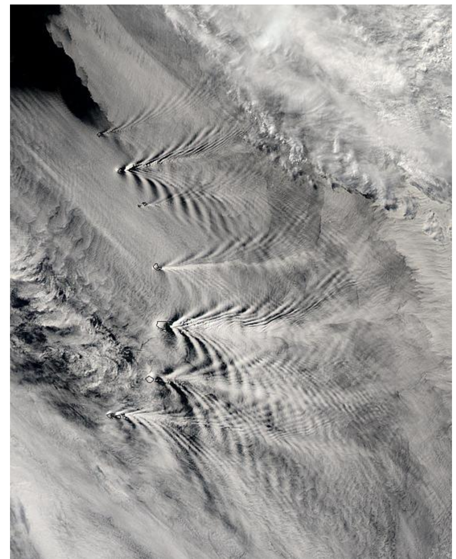
a, b, & g:
Brooks Martner photos

Whiteman (2000)

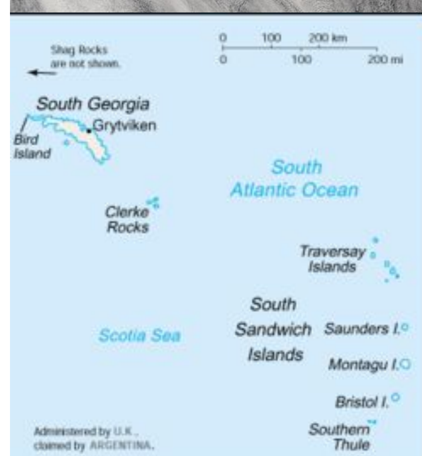
Leewave clouds, wakes (Whiteman ppt)

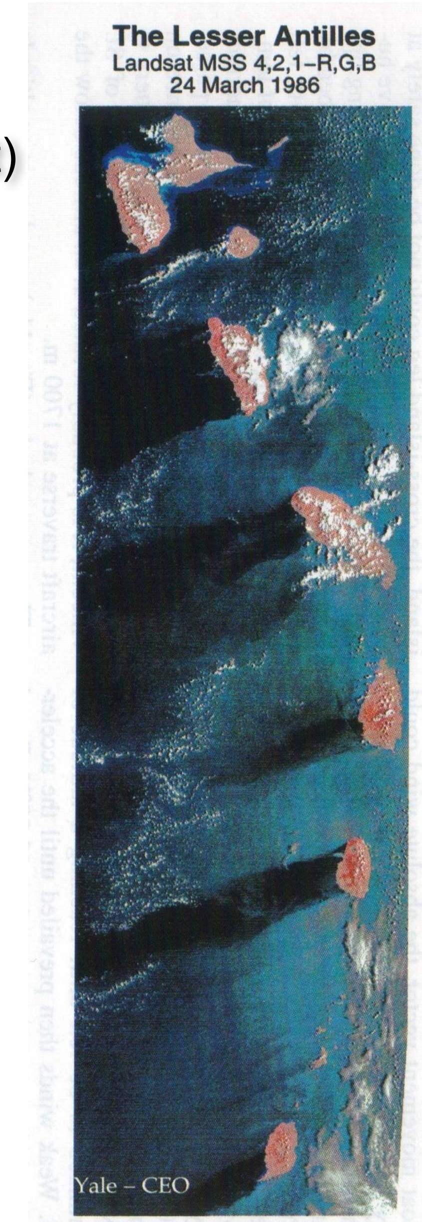


http://www.wrh.noaa.gov/spokane/pix_month/waves.htm



MODIS satellite





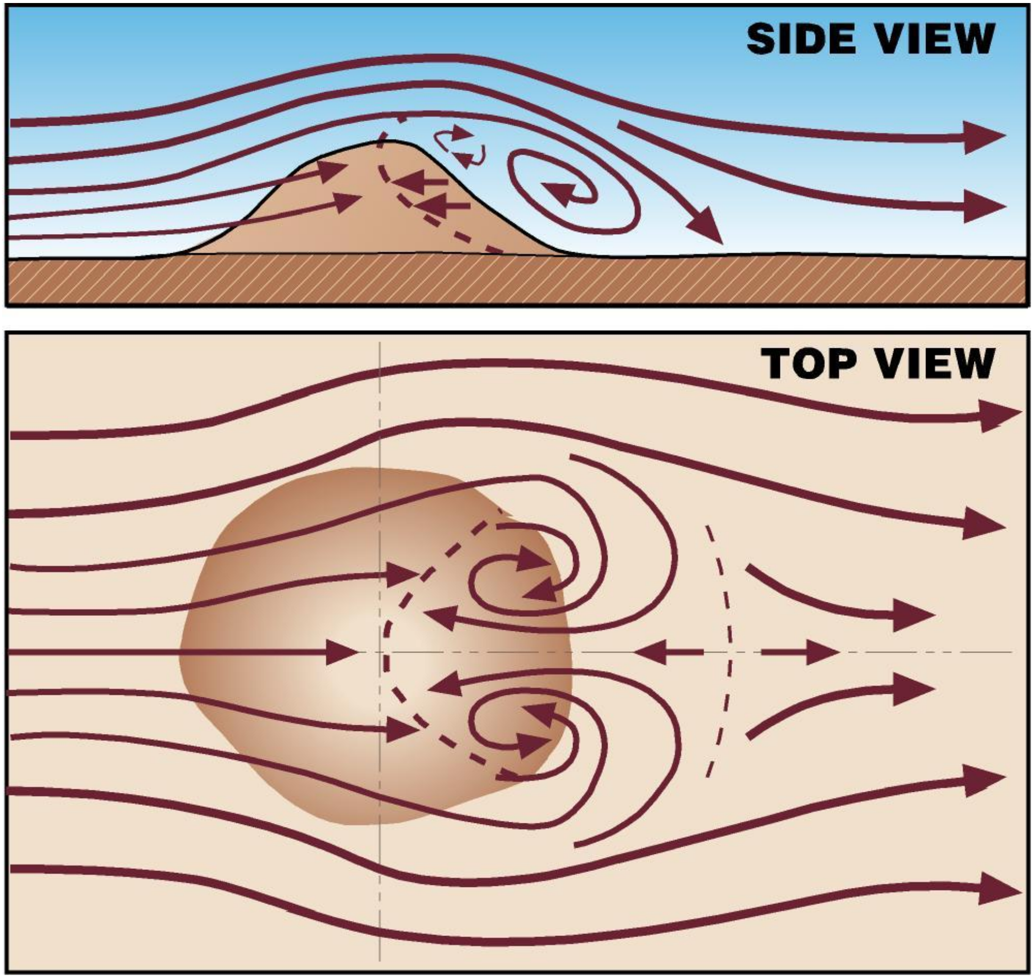
Smith et al. (1997)

Wave clouds over Cascades and Rocky Mtns of MT and Alberta

Wave clouds induced by South Sandwich Islands on 27 January 2004, MODIS satellite

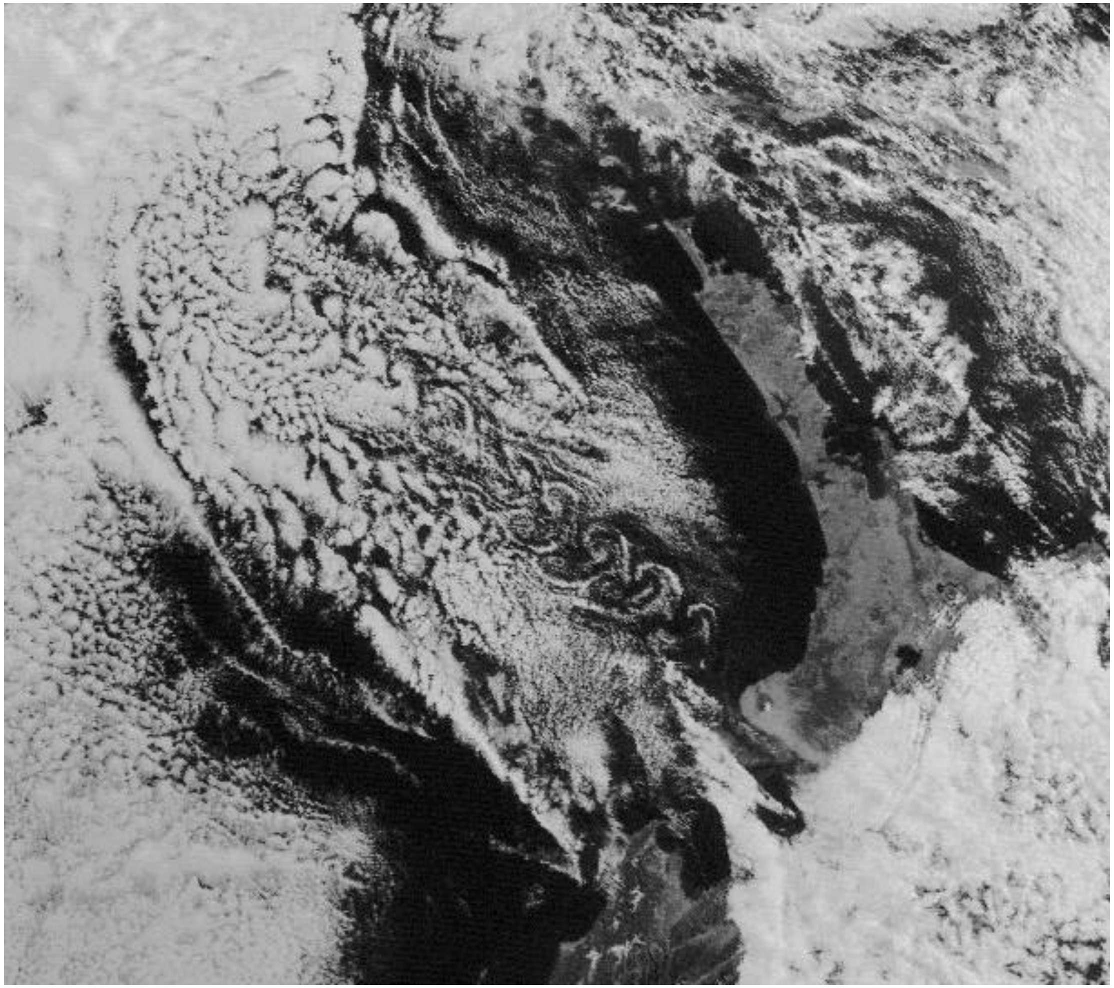
Wakes -турбулентный след

(Whiteman ppt)



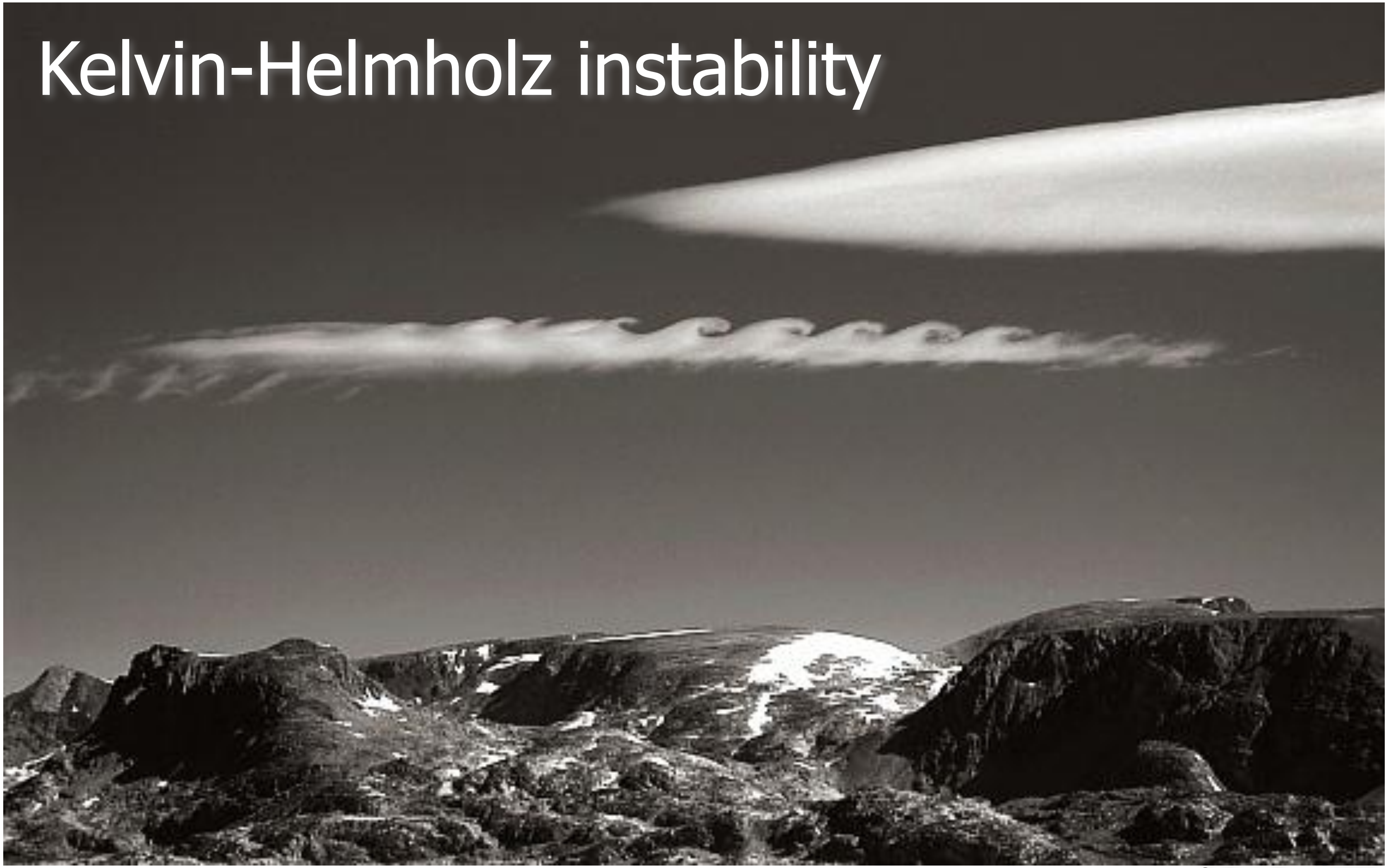
Orgill (1981)

Wake (Whiteman ppt)



From Erick Brenstrum

(Whiteman ppt)



© Amy Flygare

(Whiteman ppt)

Matterhorn banner cloud (Whiteman ppt)

Whiteman (2000)

Blocked flow - New Zealand

(Whiteman ppt)

Whiteman photo

Notion on cloud cells

Observation (including satellite ones) show that clouds often exist in form of mesoscale objects that are called *cloud cells.* These cells have a form of not fully regular systems – *hexagons.* The cells are not the only systems; there are also bands and banks of clouds.

Benar (1900) and Rayleigh (1916) were the first to discover this kind of cloud field structure. According to Rayleigh's investigations, *regime of motion causing waves and cloud formation depends on non-dimensional number (*Rayleigh's number)

$$Ra = \frac{g}{T}\frac{\gamma - \gamma_a}{\nu K} h^4$$

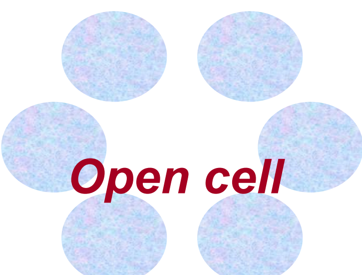
Depth of convective layer (h)

Temperature conductivity (K)

Molecular viscosity (ν)

$$Ra \geq Ra_{cr} \rightarrow$$ ***Wavelike motion of the cell type; unstable waves***

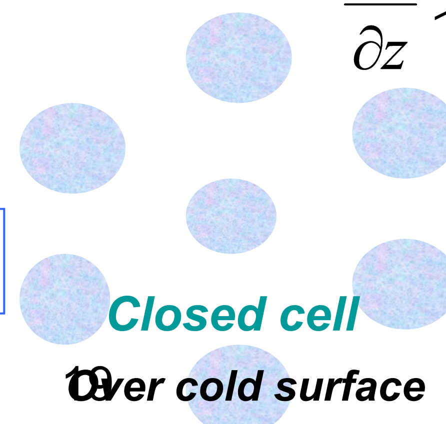
$$Ra < Ra_{cr} \rightarrow$$ ***Any type of motion; waves (if any) are stable***



Open cell

$$\frac{\partial \gamma}{\partial z} < 0$$

Over warm surface

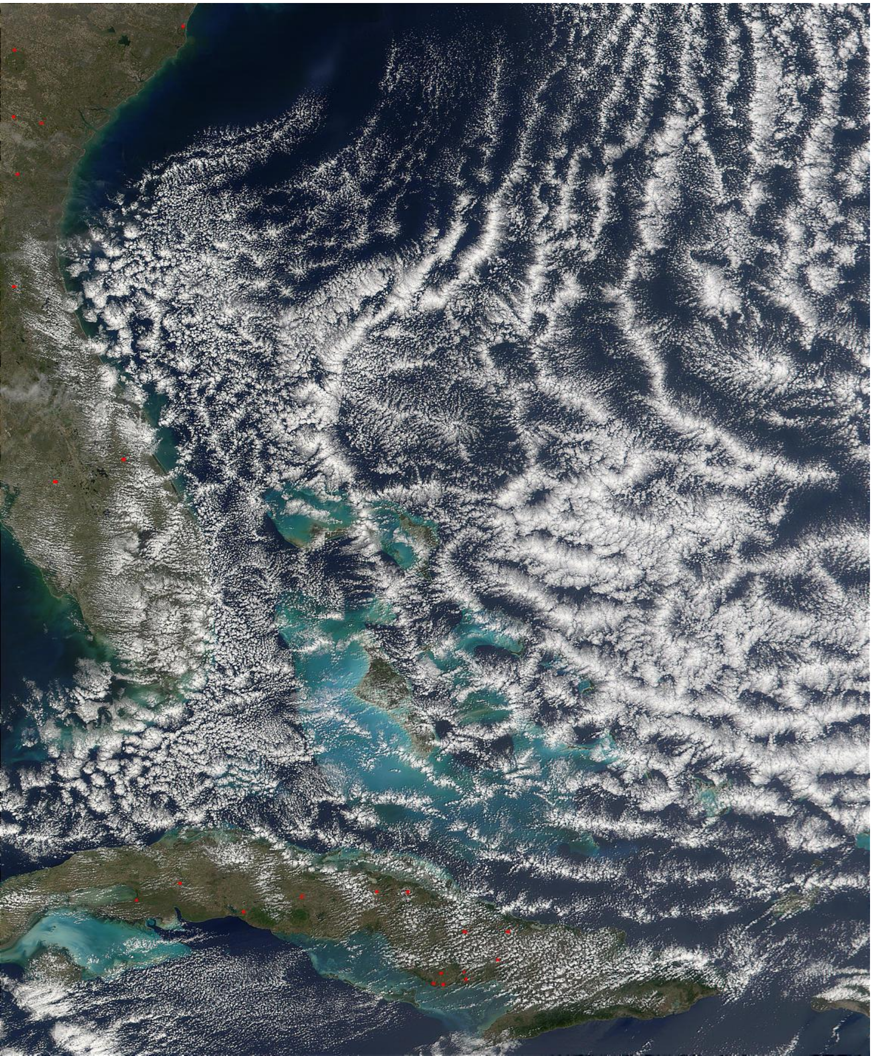


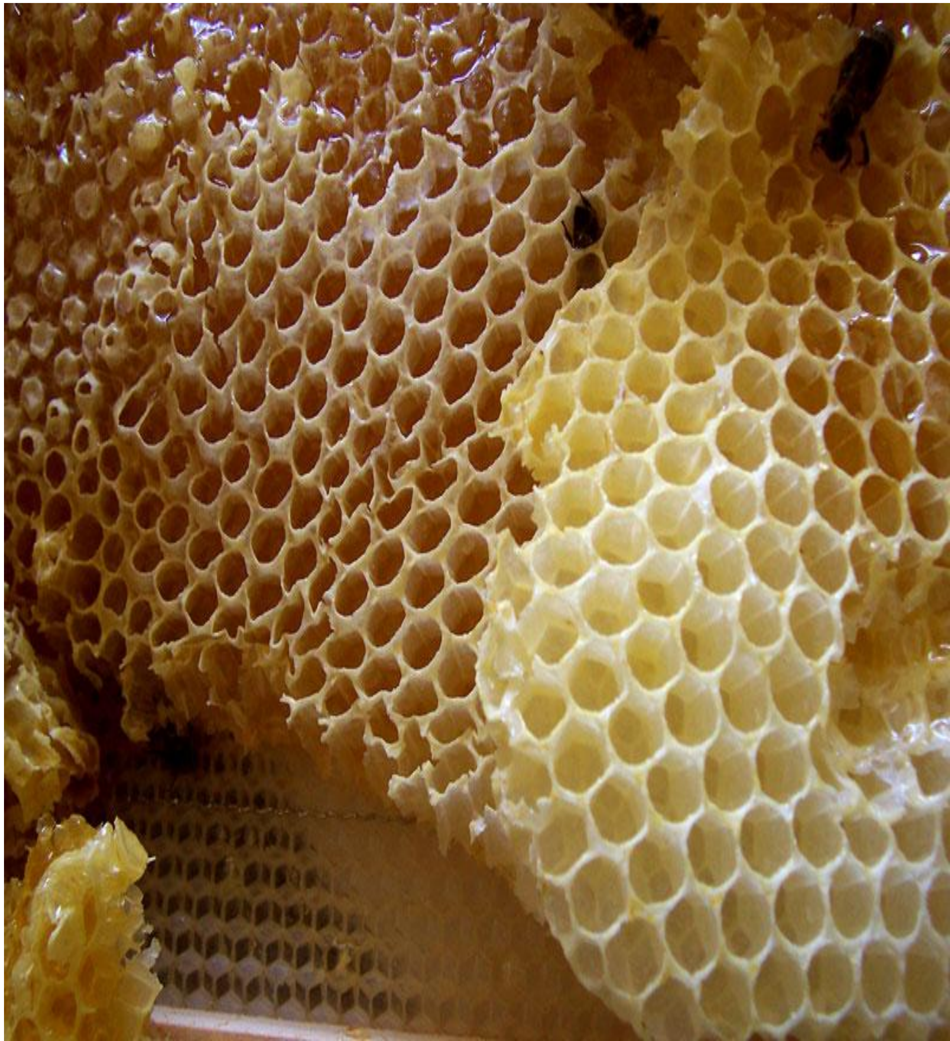
$$\frac{\partial \gamma}{\partial z} > 0$$

Closed cell

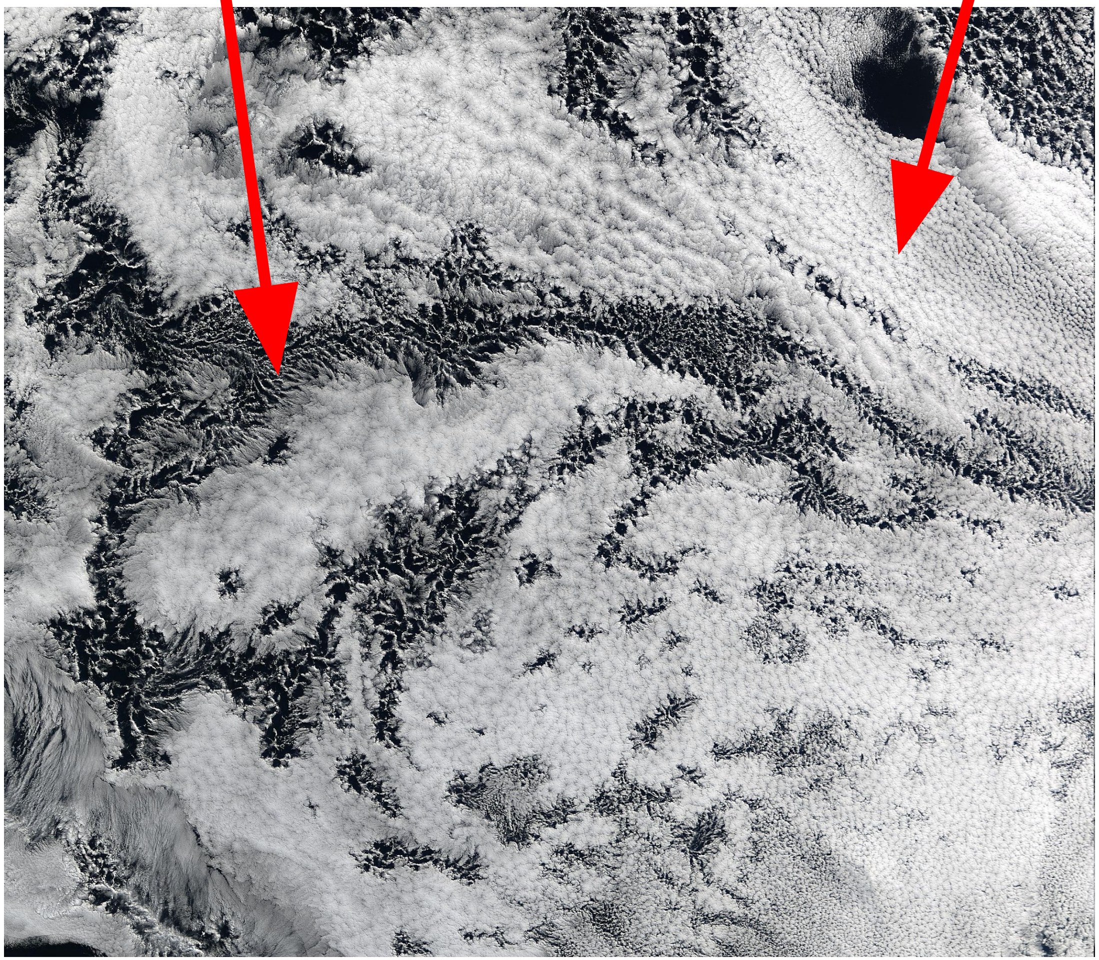
Over cold surface

Open cells which resembles a honeycomb





open- and closed-cell in South Atlantic



In "closed" cells, seen primarily in the top right corner of the image, warm air is rising in the center, and sinking around the edges, so clouds appear in cell centers, but evaporate around cell edges.

Closed and open cell convection represent two stable atmospheric configurations—two sides of the convection coin.

Credit Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC
http://visibleearth.nasa.gov/view_rec.php?id=6394

Closed Cell Convection near the Azores (NASA MODIS Terra Satellite – 12 April 2006

12:30 UTC - resolution 1 km; Image courtesy of MODIS Rapid Response Project at NASA/GSFC,
[Van Delden, A., 1998, On the flow-pattern of shallow atmospheric convection,
Beitr.Phys.Atmos., **61**, 169-186**])**

Cloud band (street)