Atmospheric temperature structure

The atmosphere is conventionally subdivided, vertically, into four strata, called spheres, separated by discontinuity surfaces, called pauses. Spheres are characterized by inversions of the lapse rate $\partial T/\partial z$, where T denotes the temperature and z the height.

The lowest layer, in which the lapse rate is on average 6,5°C/km, is called troposphere. It is relatively well-mixed, often quite moist and it contains almost all the clouds and precipitation of the atmosphere. About 90% of the mass of the atmosphere and 75% of the water vapor is located there.

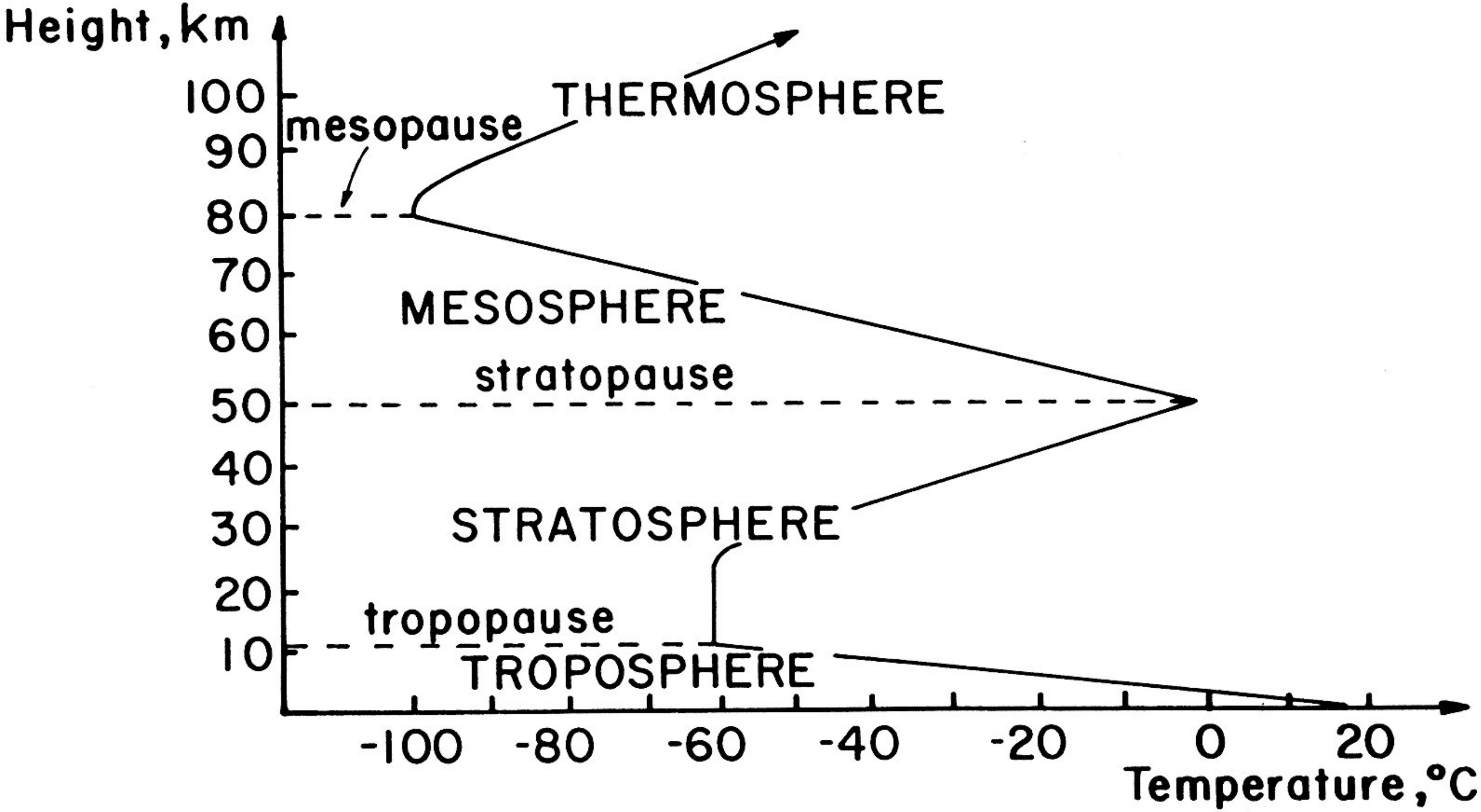
Atmospheric temperature structure

The layer between 10 and 50 km (on average) is called stratosphere. The surface that separates the troposphere from the stratosphere is called tropopause. The height of the tropopause varies from about 9 km at the poles to 16 km at the equator, with an average height of 11 km. In the lower stratosphere, the temperature is essentially constant with height, except near the equator, where it immediately increases upward. Higher up, the temperature generally increases with height. The stratosphere contains about 97% of the ozone in the atmosphere. It absorbs the ultra-violet solar radiation.

Atmospheric temperature structure

The stratopause, at about 50 km height, separates the stratosphere from the mesosphere, a region where the temperature again falls with the height. Here, the lapse rate $-\partial T/\partial z$ is positive. In this region, ionization is strong enough to reflect very long radio-waves sent up from the earth surface.

At the top of the mesosphere, above the mesopause, lies the thermosphere, where the temperature again increases upward, eventually reaching 1,000 °C. It has the fundamental role of protecting the earth from star radiations.



Atmospheric temperature profile

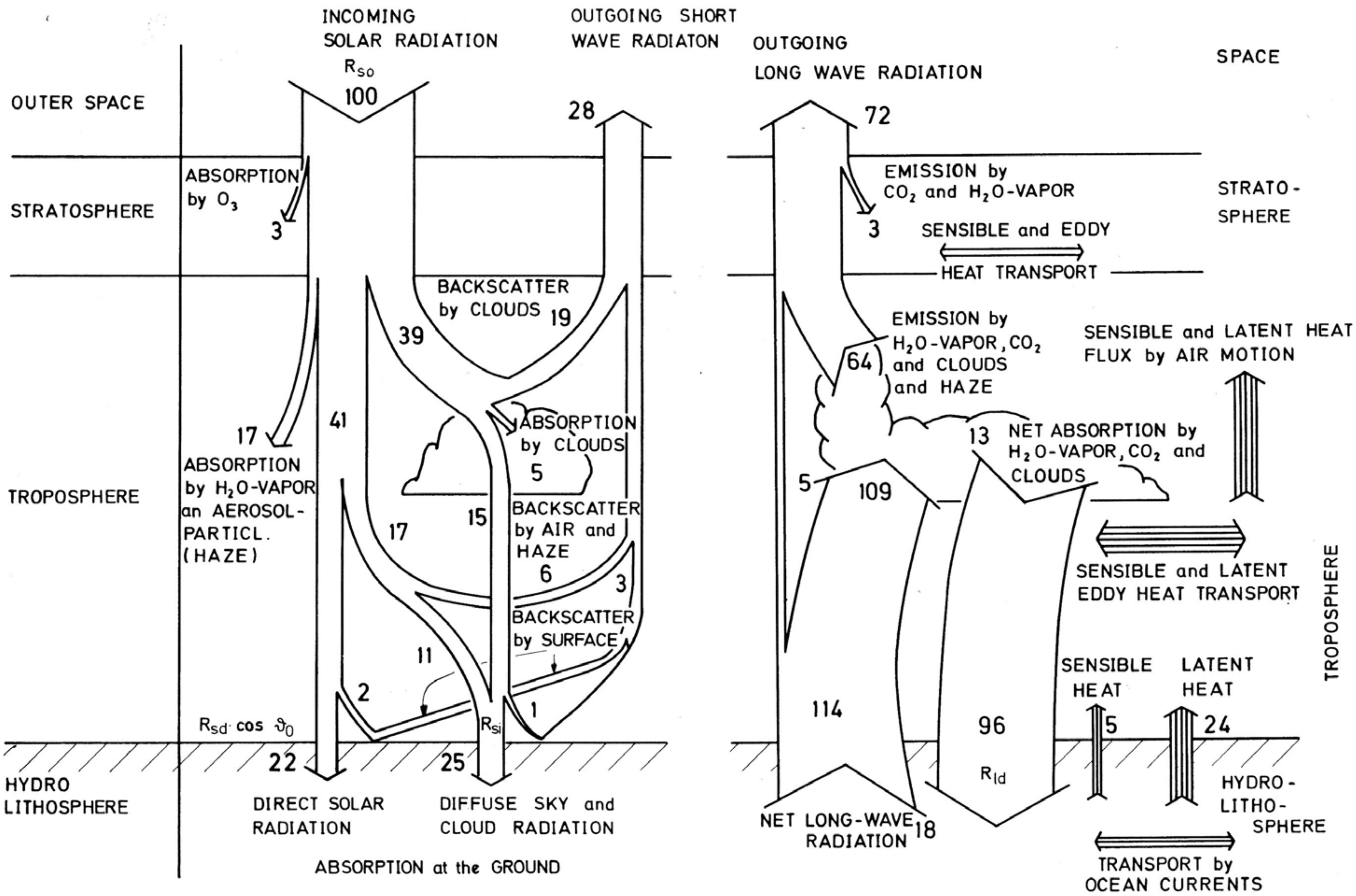
Atmospheric radiation

All the atmospheric phenomena are due to the solar radiation. This covers a wide range of the electromagnetic spectrum, with a dominant presence of high frequency (short wavelength) components from about 0.29 μm (micro-meter) to about 3 μm (solar infrared, visible, ultraviolet).

It is known that 28% of the incoming solar radiation is returned by means of a direct and diffuse reflection from the earth and the atmosphere back to the space (planetary albedo), 3% is absorbed by the ozone in the stratosphere, 22% is absorbed by the water vapor (17%) and by the clouds (5%) in the troposphere, 47% reaches the surface of the earth, partly as direct solar radiation (22%), partly as atmospheric diffusion and cloud radiation (25%).

Atmospheric radiation

The earth and the atmosphere, heated by the solar radiation, produce an outgoing radiation mainly characterized by low frequency (long wave-length) components from about 4 μm to about 100 μm (terrestrial infrared). More precisely, the surface of the earth produces radiations (114%), most of which (96%) is returned from the water vapor and the carbonic anhydride to the troposphere. Furthermore, wind contributes to subtract sensible heat from the ground (5%). Finally, latent heat (24%) enters the atmosphere, due to the condensation of the water vapor.



Atmospheric incoming and outcoming radiation

Atmospheric radiation

Since the earth and the atmosphere completely return the solar energy, the balance of the system is assured.

In other words, the sun sends the earth high frequency light radiations; the earth returns the space low frequency heat radiation.

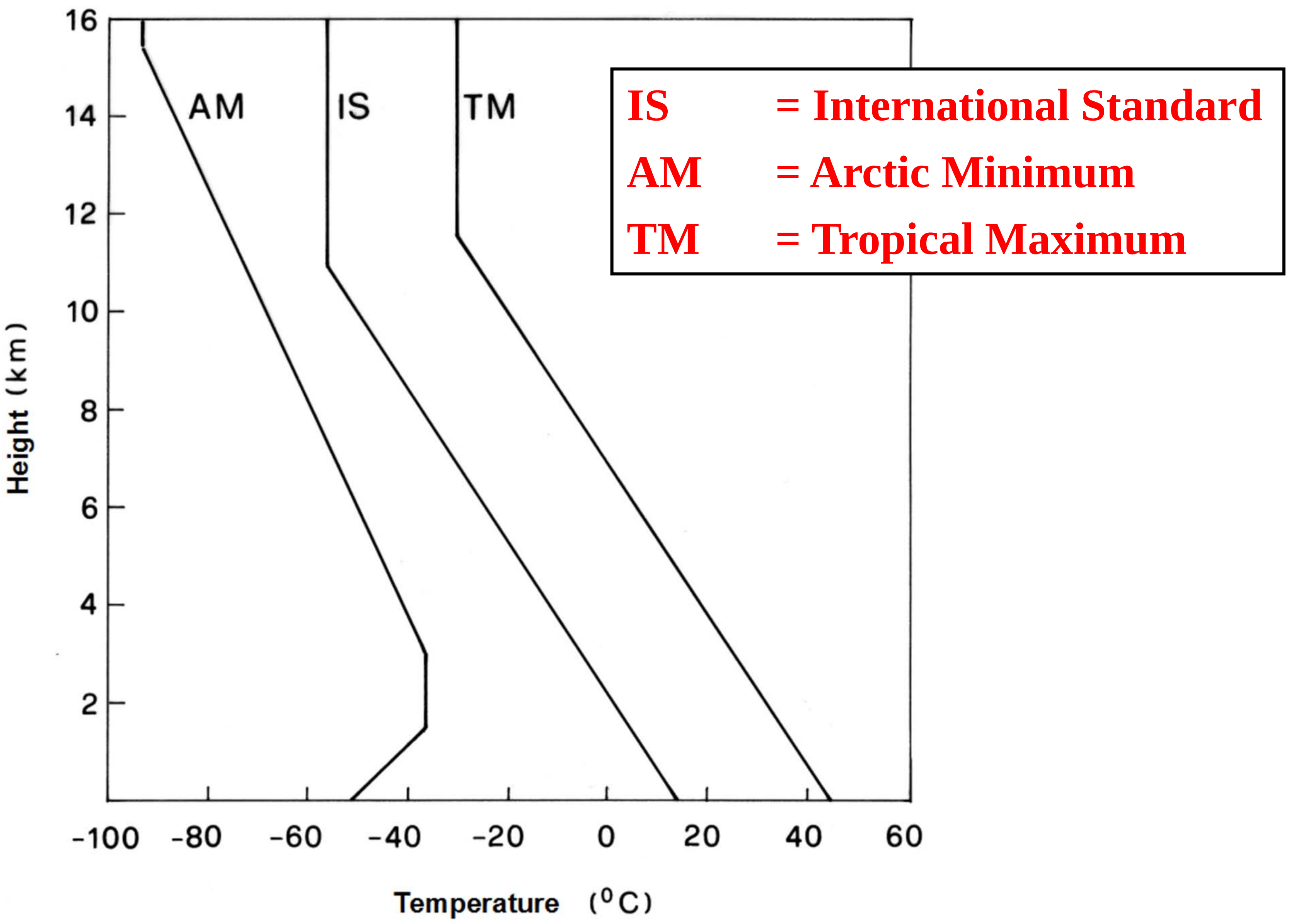
The atmosphere is, to a large extent, transparent to the solar radiation but not transparent to the terrestrial radiation (greenhouse effect).

The lower layers of the troposphere, close to the thermal source, are heater than the upper layers. This gives rise to the average lapse rate $-\partial T/\partial z = 6.5°C/km$ that characterizes the troposphere (IS, International Standard).

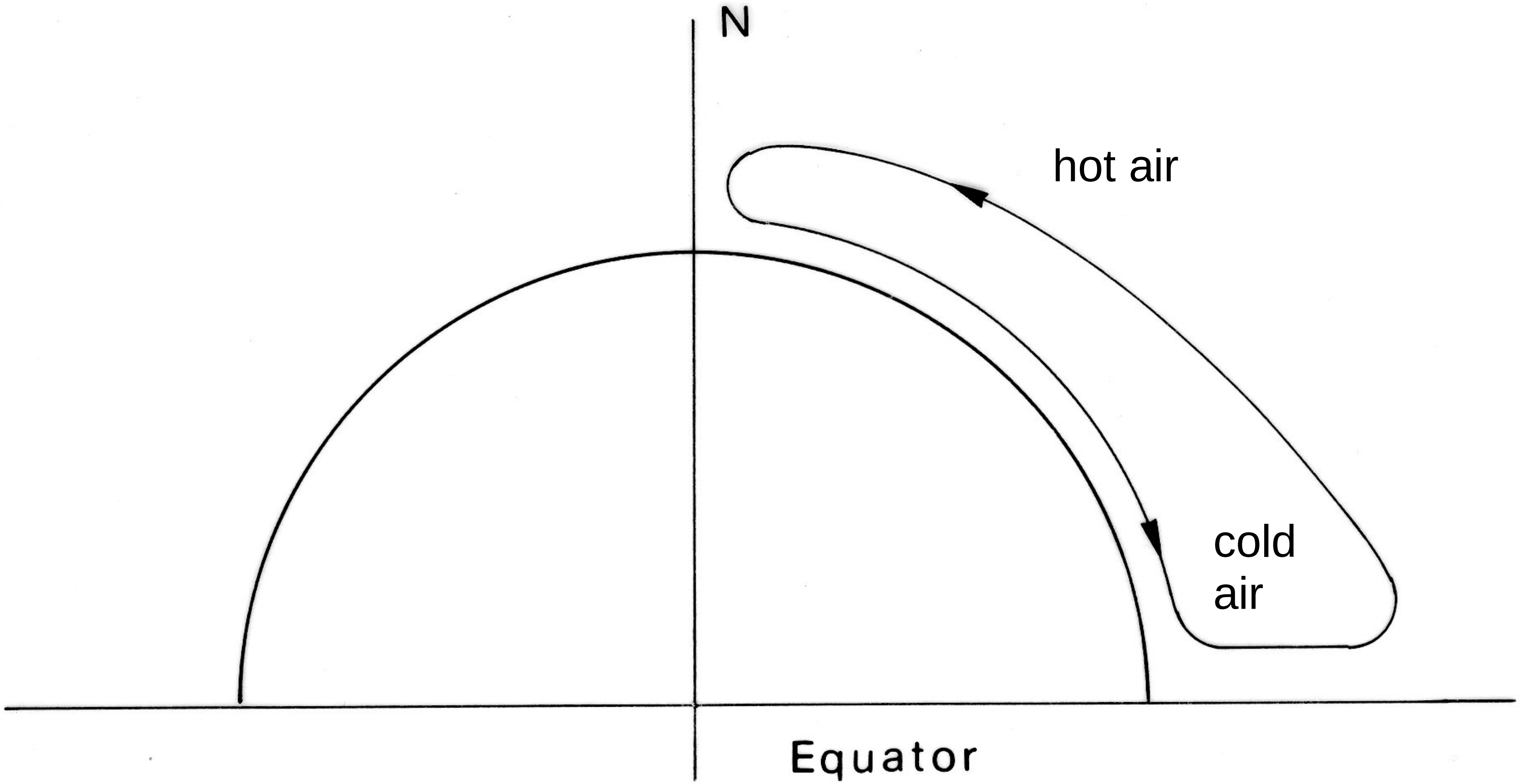
Atmospheric temperature and pressure

The local situation deeply varies from region to region due to the different inclination of the sun over the horizon and to the non uniform distribution of clouds. This causes a maximum insulation of the equatorial and tropical zones (TM, Tropical Maximum) and a minimum insulation of the polar zones (AM, Arctic Minimum). It follows that the pressure is maximum in the polar zones (polar high pressure), and it is minimum close to the equator (equatorial low pressure).

This gives rise to a gradient force that, in principle, moves the cold air from the pole to the equator. In turn, this creates a so-called mono-cellular circulation phenomenon, first explained by Hadley (1735).



Troposphere temperature profiles

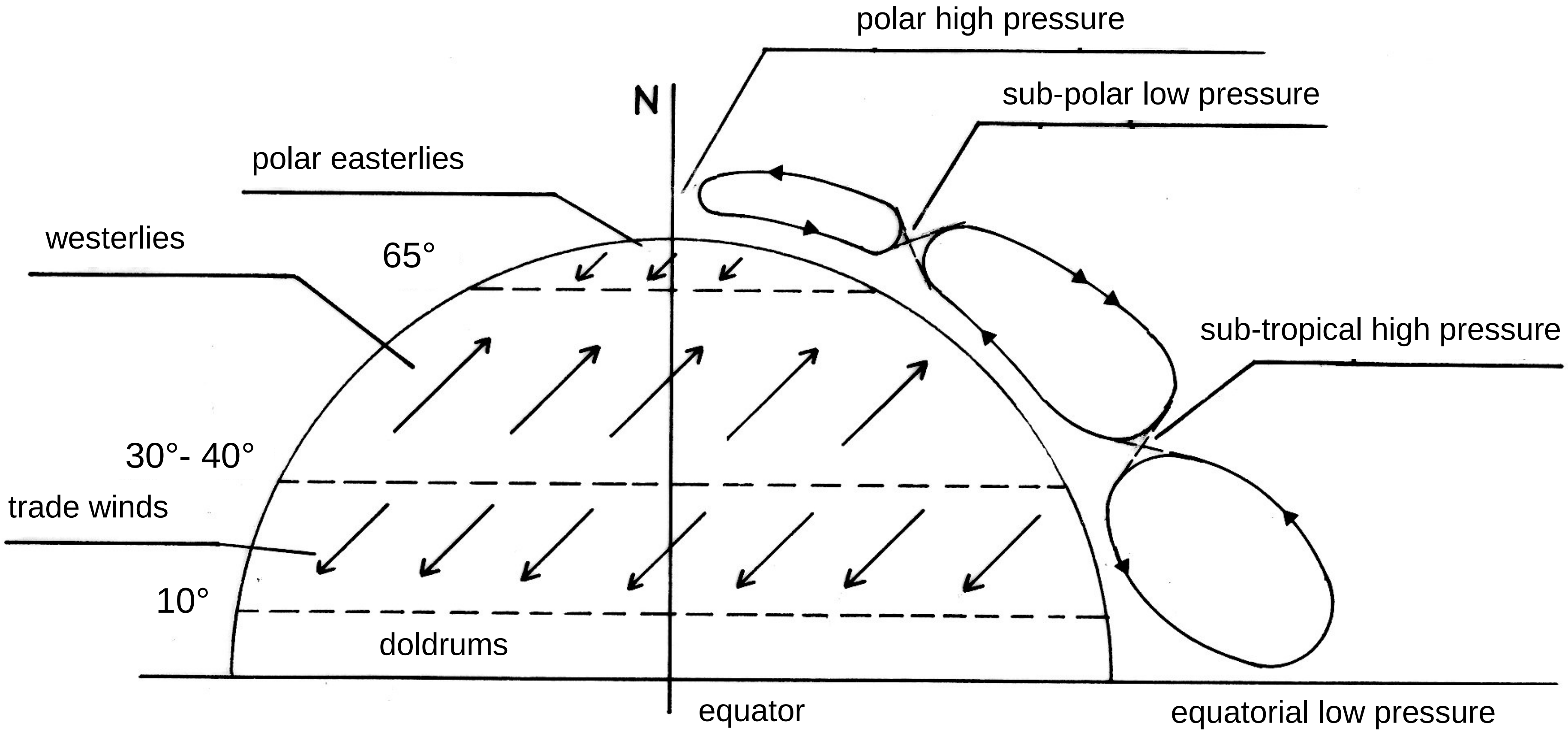


Hadley mono-cellular circulation

Atmospheric temperature and pressure

In reality, the mono-cellular circulation model is an idealization.

The non-uniform distribution of the oceans, of the continents and of the clouds creates a sub-polar low pressure belt at about 65 degrees latitude, and a sub-tropical high pressure belt at about 30-40 degrees latitude. Therefore, on each hemisphere, a three-cellular circulation system arises, first explained by Ferrel (1856). The horizontal motion of the air close to the ground is called wind.



Farrel three-cellular circulation

Wind classification

The atmospheric motions that derive from the three-cellular circulation system may be described as the superimposition of interdependent flows characterized by length scales ranging from approximately one millimeter to thousands of kilometers. It is convenient to classify them according to their horizontal scale.

Using this criterion, the atmospheric circulation can be classified into a primary circulation, at the planetary scale, a secondary circulations, at the synoptic scale, and local circulations, at the mesoscale.

Primary circulation

The primary circulation can be explained in the framework of the three-cellular model. It comprehends the atmospheric motions that occur on monthly or seasonal periods, over areas of several thousands of kilometers. As such, it determines the climatology of the earth.

The primary circulation includes three types of wind: the polar easterlies (from polar high pressure to sub-polar low pressure), the westerlies (from sub-tropical high pressure to sub-polar low-pressure) and the trade winds (from sub-tropical high pressure to equatorial low pressure). The terms easterlies and westerlies are associated with the deviating action produced by the Coriolis force.

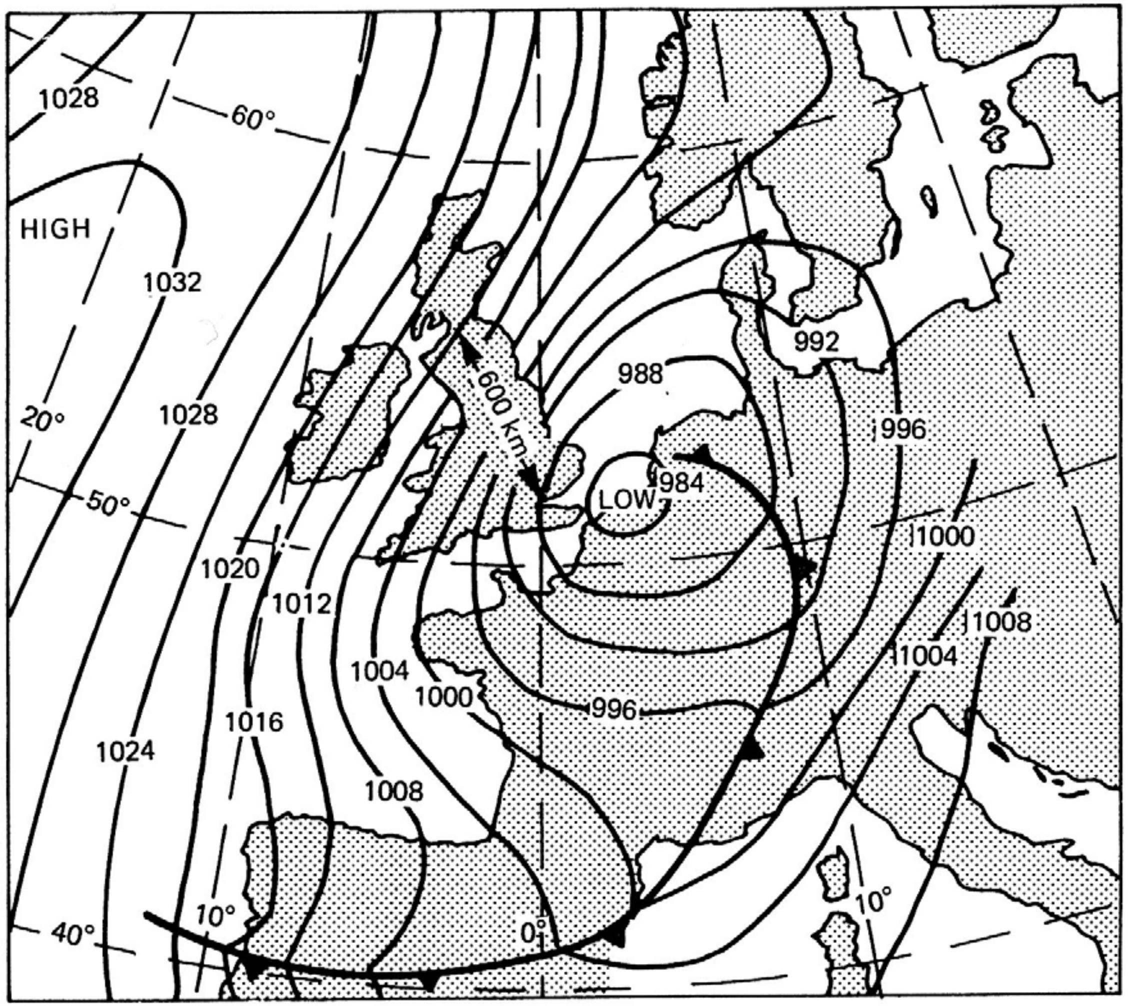
All the winds belonging to the primary circulation have low velocity.

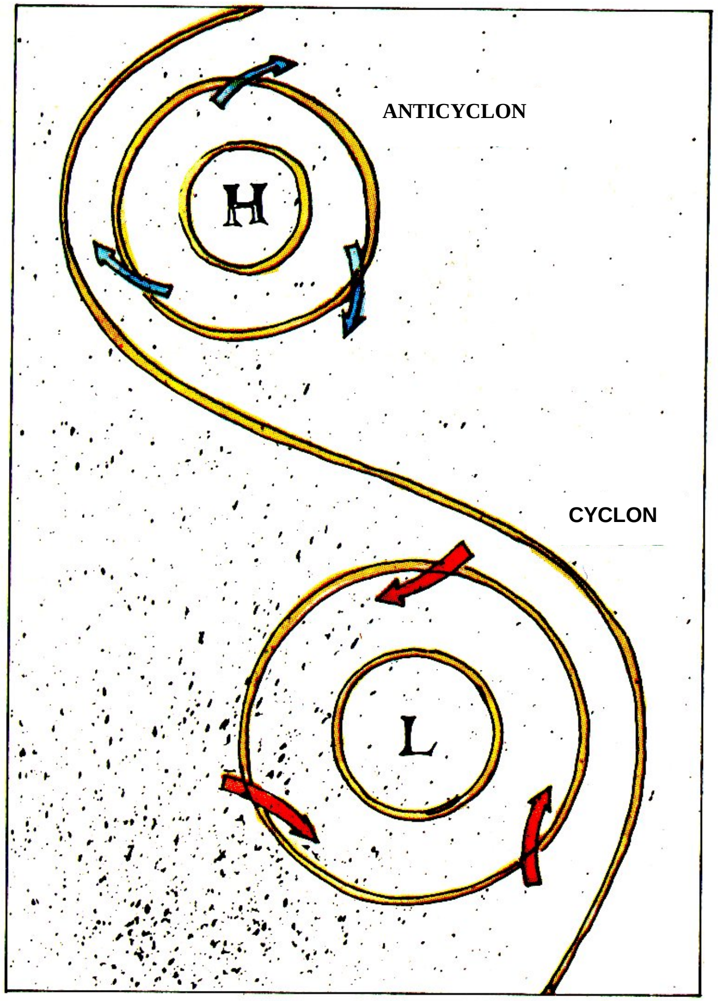
Secondary circulation

The secondary circulation is the set of the winds that arise in low and high pressure zones, due to the local heating or cooling of the lower atmospheric layers. While the primary circulation is associated with the earth climatology, the secondary circulation causes the local weather.

The winds that blow parallel to isobars concentric with high pressure areas are called anticyclones. They cause good weather and relatively moderate wind velocities. Their structure is yet not so well known.

The winds that blow parallel to isobars concentric with low pressure areas are called cyclones. Their diameter is usually in the order of several hundred kilometers. They are subdivided into extra-tropical cyclones and tropical cyclones according to the area in which they form.



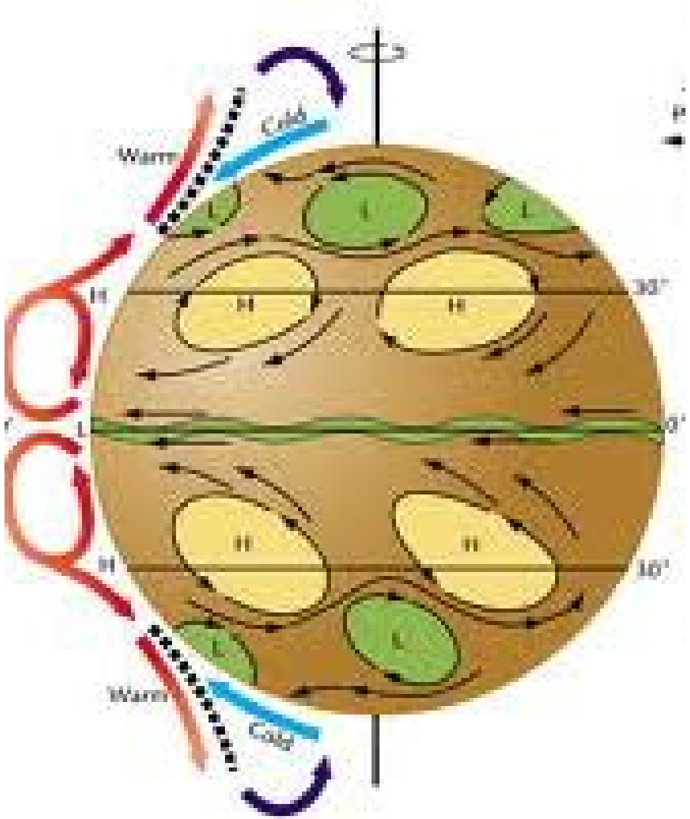


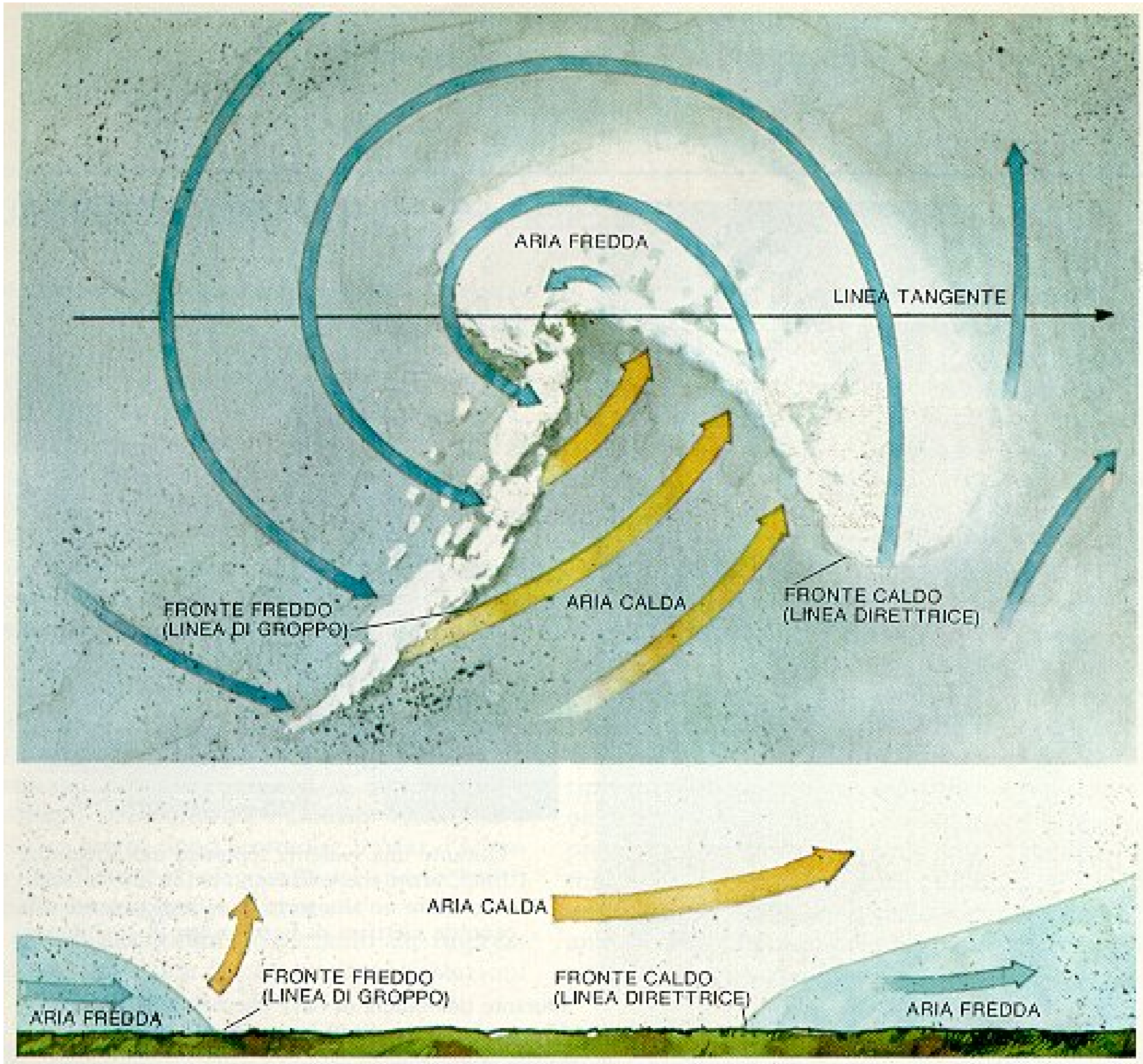
Antyciclone and cyclone

Secondary circulation

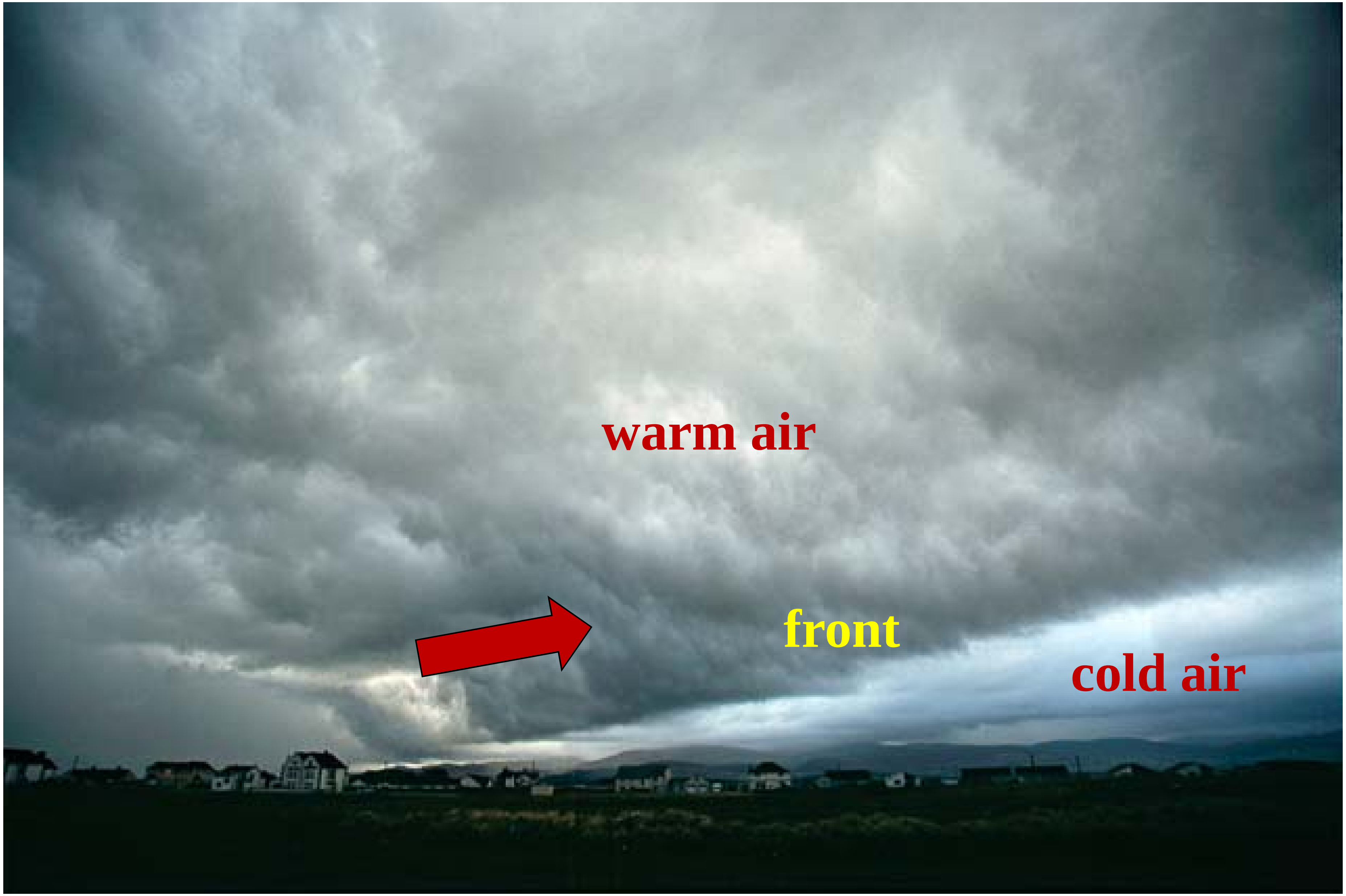
The extra-tropical cyclones originate from the meeting, in the sub-polar belt, of the cold polar air, driven by the easterlies, with the hot tropical air, driven by the westerlies. The transition zones between the two masses at different temperature is called front. The evolutionary mechanism of this phenomenon is explained by the cyclogenetic theory formulated by Bjerknes and Solberg (1921).

The extra-tropical cyclones represent the most typical wind that determine the design wind velocity of structures for the European mid-latitude areas and in particular for Italy.

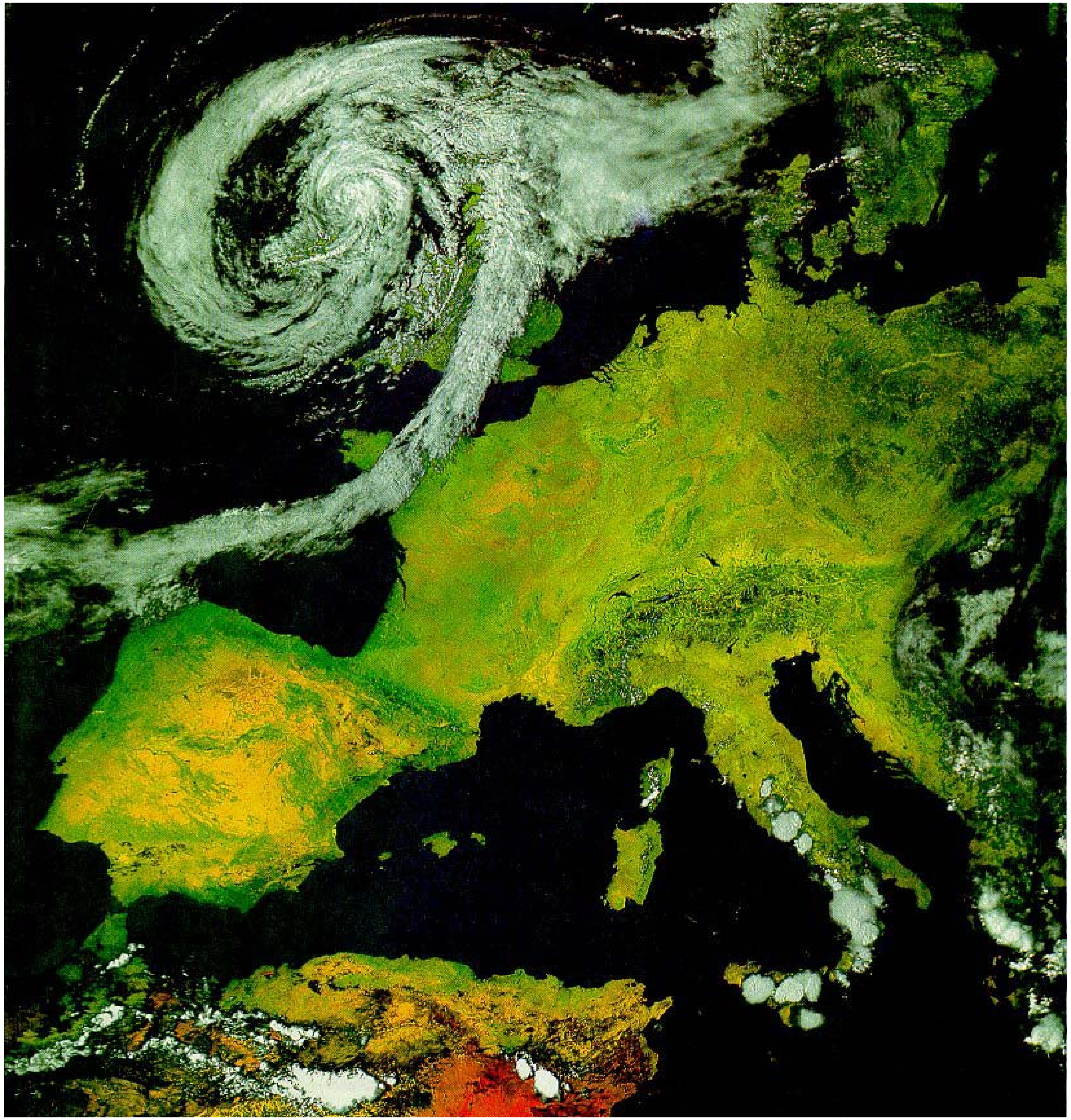




Bjerknes and Solberg cyclogenetic model



Gust front



Satellite image of an extra-tropical cyclone

Grade	Description	Wind speed (km/h)	Land conditions
0	Calm	< 1	Calm. Smoke rises vertically.
1	Light air	1.1–5.5	Smoke drift indicates wind direction and wind vanes cease moving.
2	Light breeze	5.6–11	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.
3	Gentle breeze	12–19	Leaves and small twigs constantly moving, light flags extended.
4	Moderate breeze	20–28	Dust and loose paper raised. Small branches begin to move.
5	Fresh breeze	29–38	Branches of a moderate size move. Small trees in leaf begin to sway.
6	Strong breeze	39–49	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.
7	High wind, Moderate gale, Near gale	50–61	Whole trees in motion. Effort needed to walk against the wind.

Beaufort scale

Grade	Description	Wind speed (km/h)	Land conditions
8	Gale, Fresh gale	62–74	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
9	Strong gale	75–88	Some branches break off trees, and some small trees blow over. Construction/ temporary signs and barricades blow over.
10	Storm, Whole gale	89–102	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
11	Violent storm	103–117	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
12	Hurricane force	≥ 118	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.

Beaufort scale (continuation)

Secondary circulation

The tropical cyclones are storms that derive their energy from the heat released by the condensation of the water vapor and originate, usually, between the 5 and 20 latitude circles.

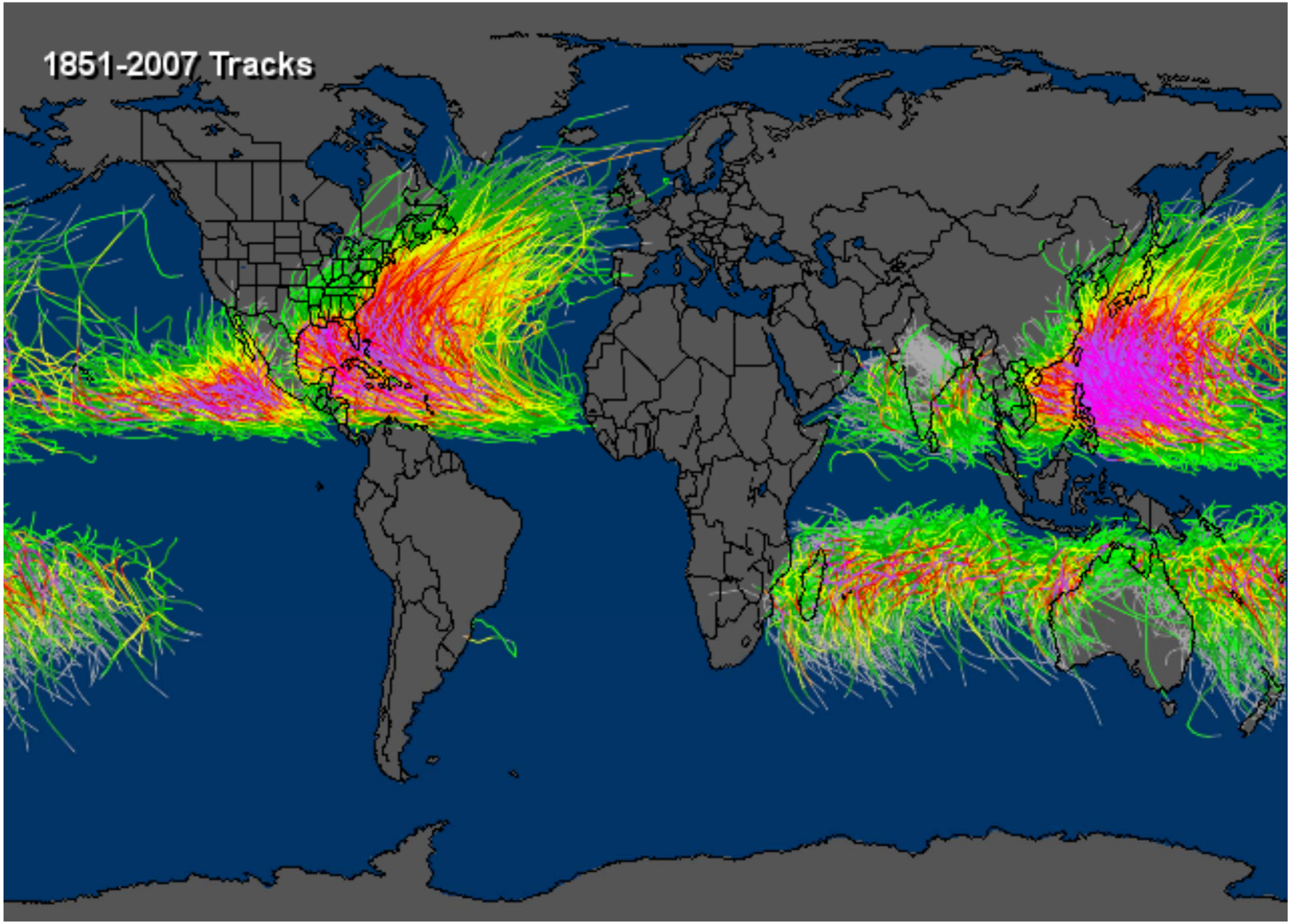
Tropical cyclones often produce surface wind velocities exceeding 120 km/hour. In these cases, they are called hurricanes in America, typhoons in the Far East and cyclones in Australia and in the Indian Ocean. These winds may reach velocities higher than 200 km/hour.

They produce devastating effects through three main causes: 1) wind velocity; 2) storm surge; and, 3) torrential rain.

Tropical cyclone

Category	**Wind speed (km/h)**	**Effects**
1	120-153	No real damage to building structures. Damage primarly to unanchored mobile homes, shrubbery, and trees. Also, some coastal road flooding and minor pier damage
2	154-177	Some roofing material, door, and window damage to buildings. Considerable damage to vegetation, mobile homes, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of center. Small craft in unprotected anchorages break moorings.
3	178-209	Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain continuously lower than 5 feet ASL may be flooded inland 8 miles or more.
4	210-249	More extensive curtainwall failures with some complete roof strucutre failure on small residences. Major erosion of beach. Major damage to lower floors of structures near the shore. Terrain continuously lower than 10 feet ASL may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.
5	≥ 250	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Major damage to lower floors of all structures located less than 15 feet ASL and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5 to 10 miles of the shoreline may be required.

Saffir-Simpson scale



Hurricane tracks

Hurricane Katrina

Hurricane damage due to wind velocity

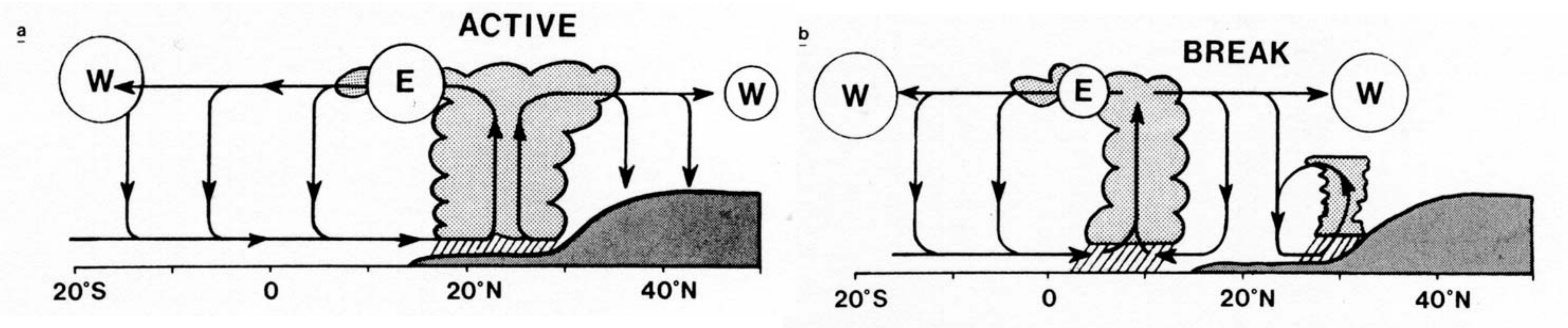
Hurricane damage due to storm surge

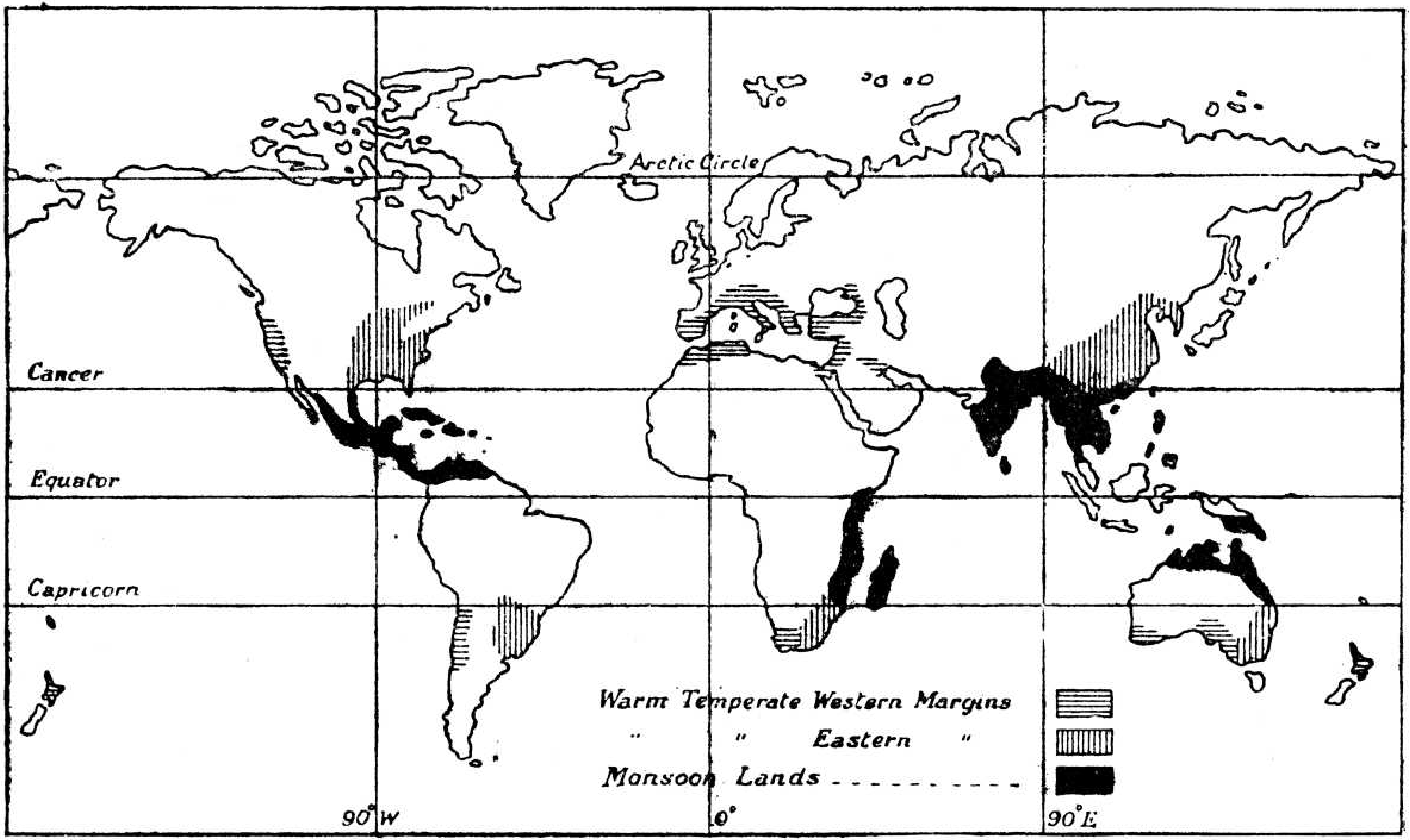
Hurricane damage due to torrential rain

Secondary circulation

The seasonal winds due to the thermal contrast between the oceans and the continents require special considerations.

These phenomena prevailingly occur on the Asiatic Continent and the Indian Ocean. Though they conceptually belong to local circulation phenomena, in these areas they assume such relevant properties as to produce flows usually dealt with as part of the secondary circulation. These winds are called monsoons.





World map of monsoons

Damage caused by monsoons

Damage caused by monsoons

Local circulation

The local circulation consists of local winds represented by air movements that do not modify the properties of the secondary circulation. In spite of their limited extent, they can reach exceptional velocities. They are usually separated into two categories associated with, respectively, particular geographic conditions and particular atmospheric conditions.

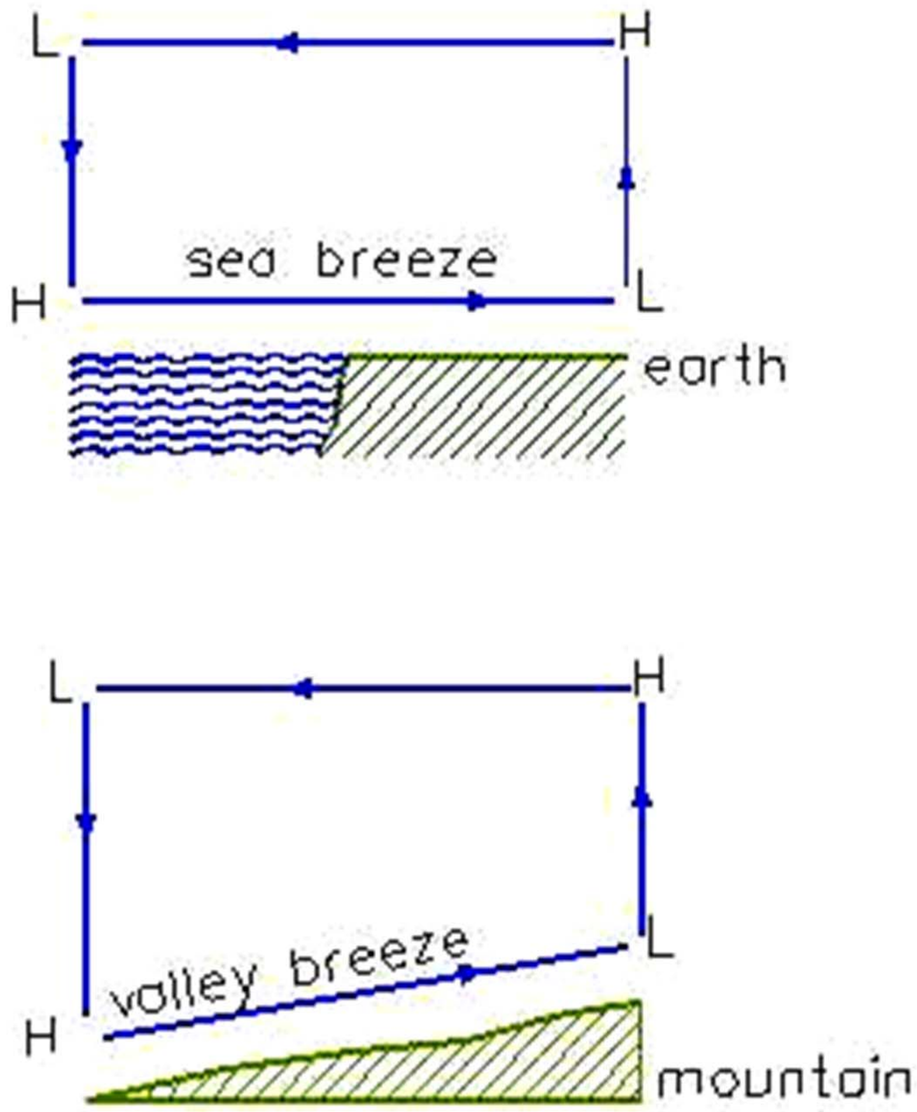
Local circulation

The local winds associated with particular geographic conditions include the breezes, the foehn winds and the katabatic winds.

The breezes are winds usually endowed with moderate velocity, which arise from the thermal contrast between the earth and the sea or a valley and a mountain.

A cold mass of air that has passed over a mountain barrier or a plateau gives rise to foehn winds when the adiabatic compression results in high temperatures of the dry descending air.

Differently from foehn winds, when the adiabatic heating is not sufficient to change a cold mass of air into a warm wind, but the potential energy of the air is converted into kinetic energy, this causes the katabatic winds, with gusts often exceeding 150-200 km/h. The bora is the most well known Italian katabatic wind.


L
H
sea breeze
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earth
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earth breeze
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sea
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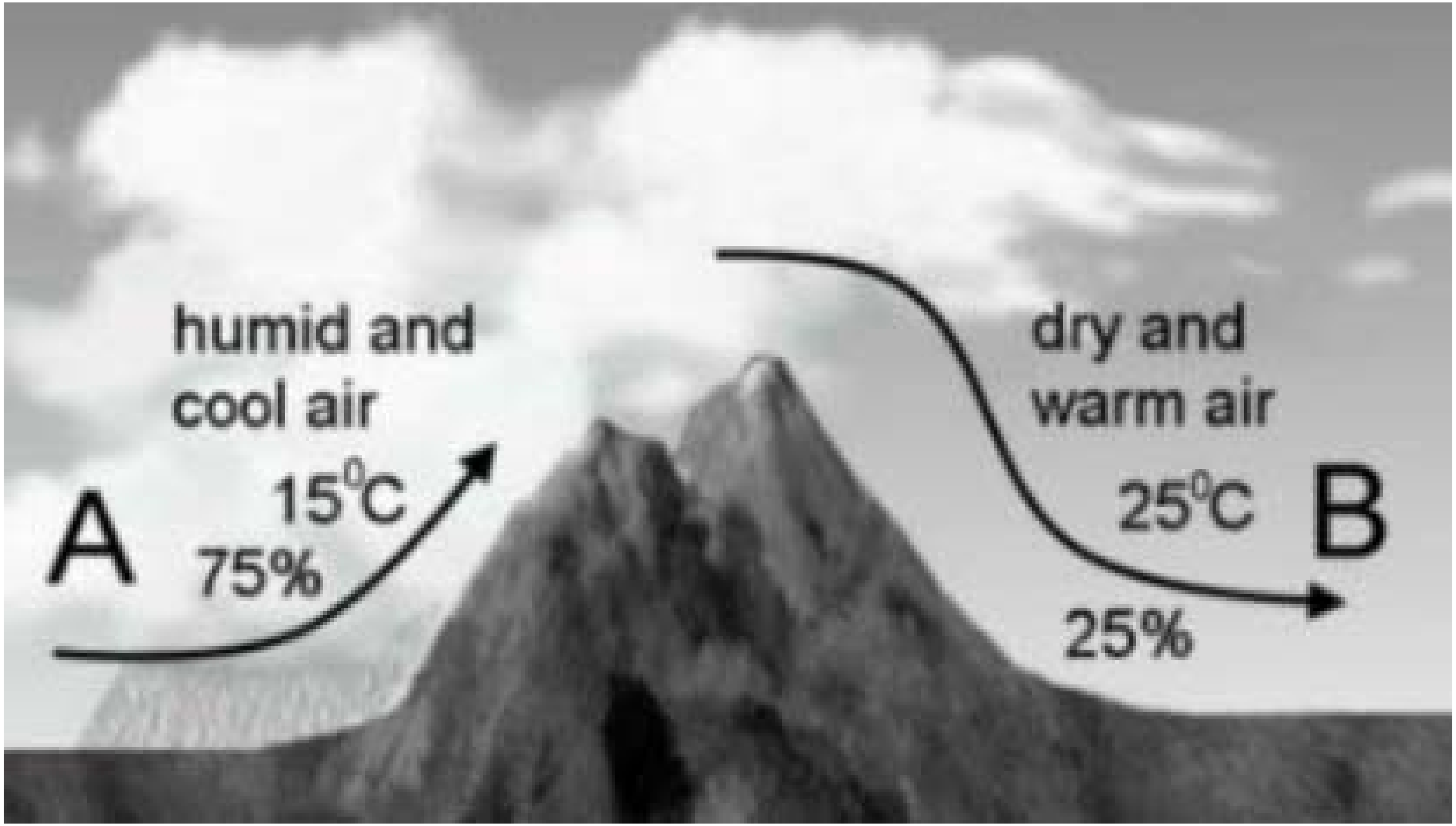
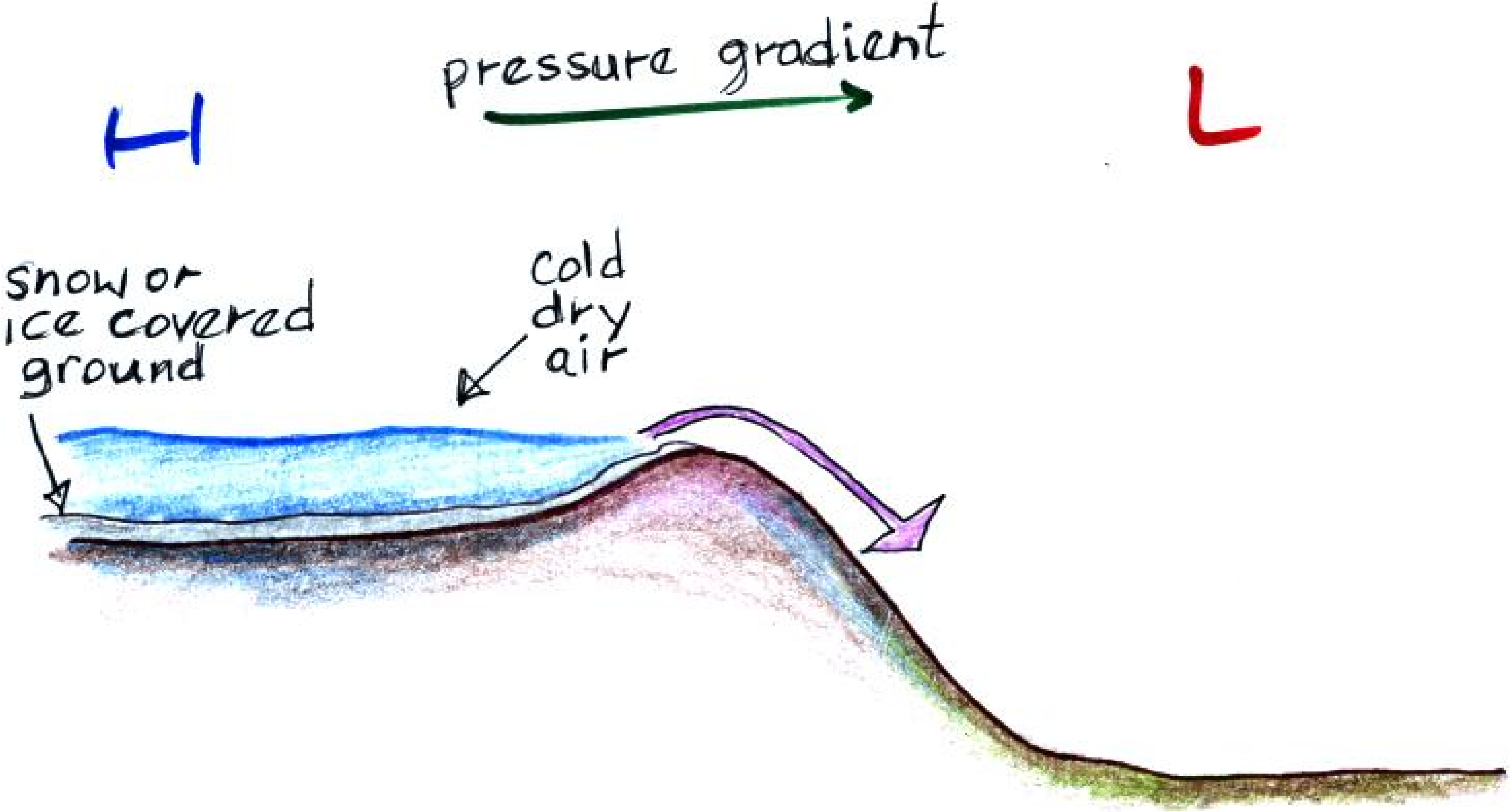
H
valley breeze
L
H
mountain
H
L
mountain breeze
H
L
valley

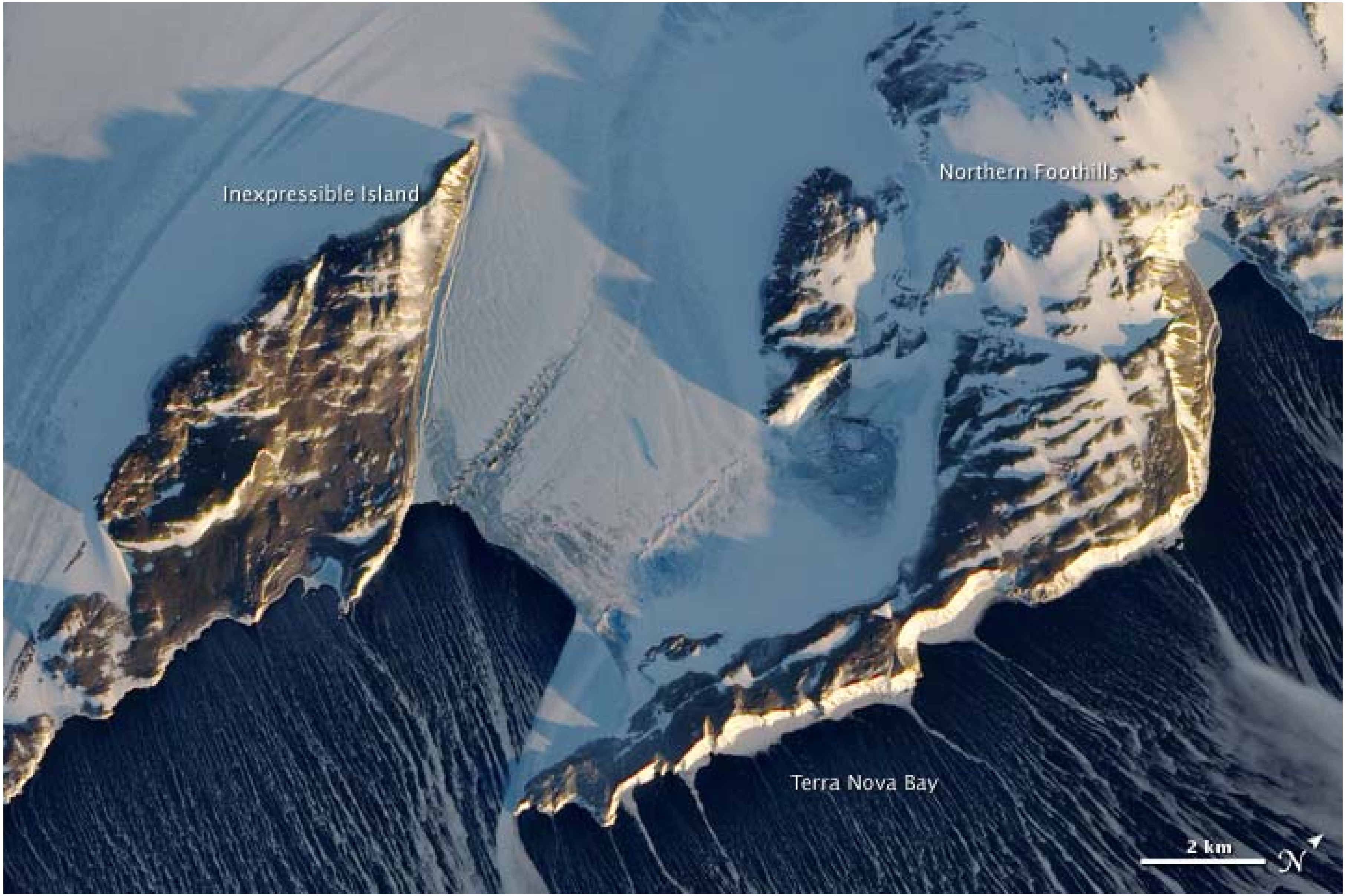
Breeze



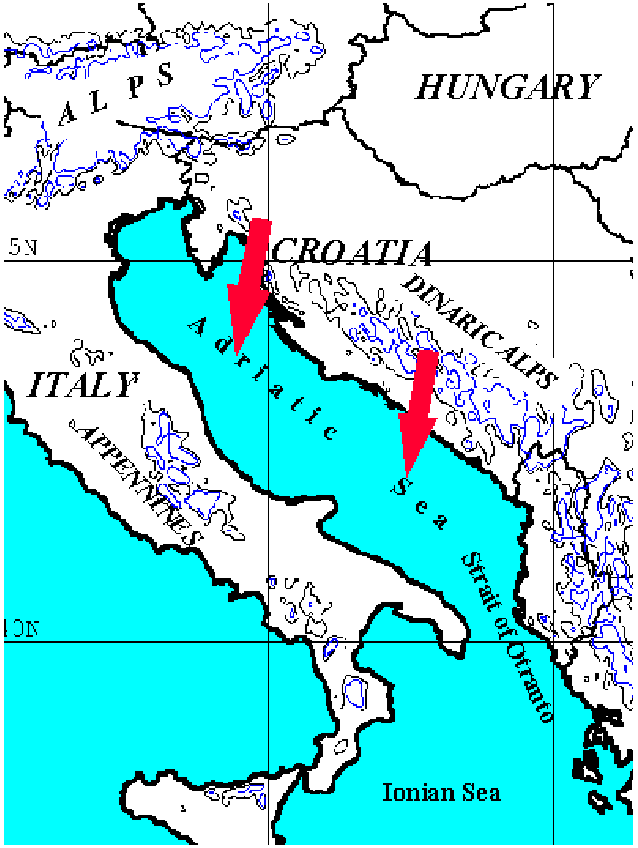
Foehn



Katabatic wind



Antarctic katabatic wind



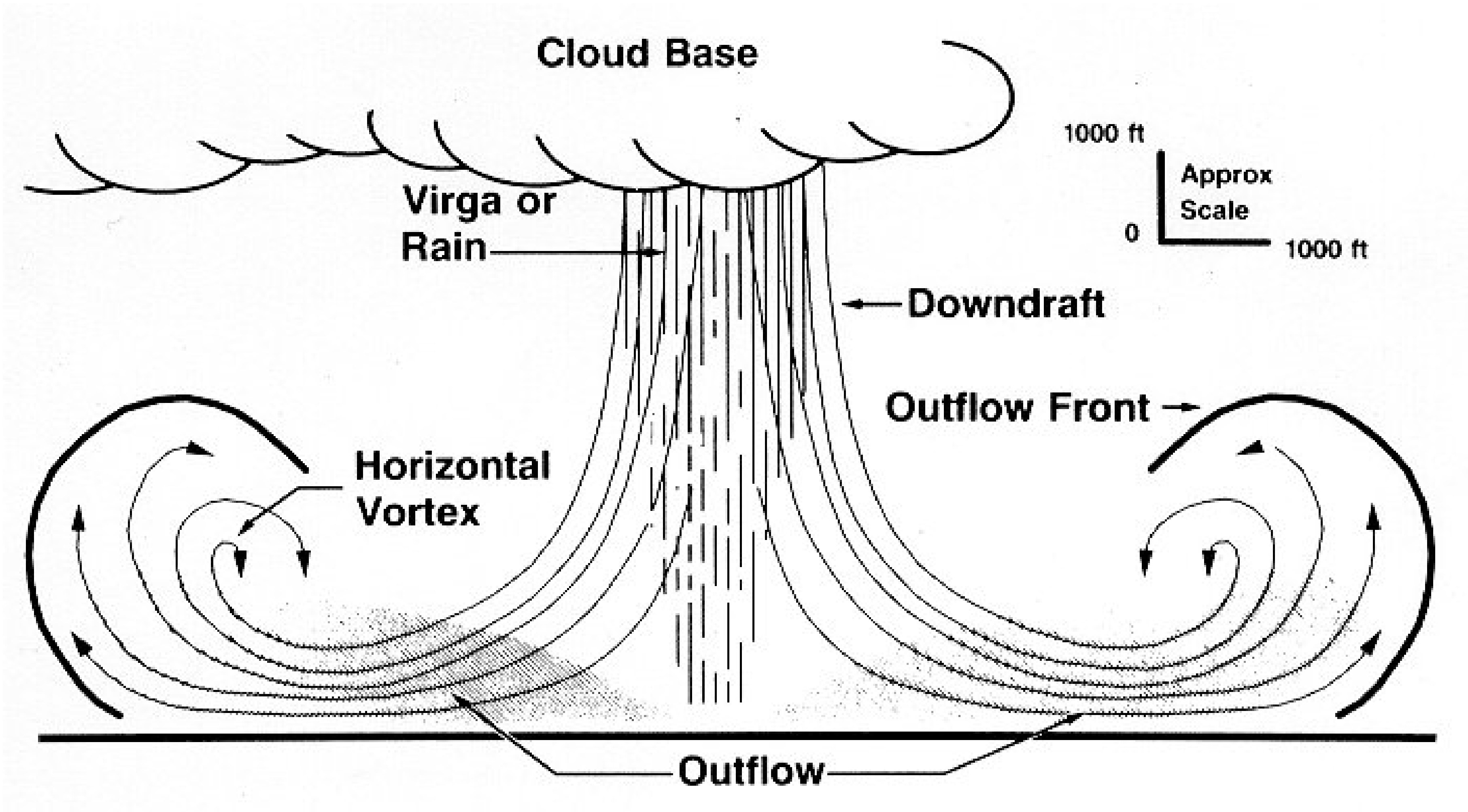
Katabatic winds in Istria: Bora in Trieste

Local circulation

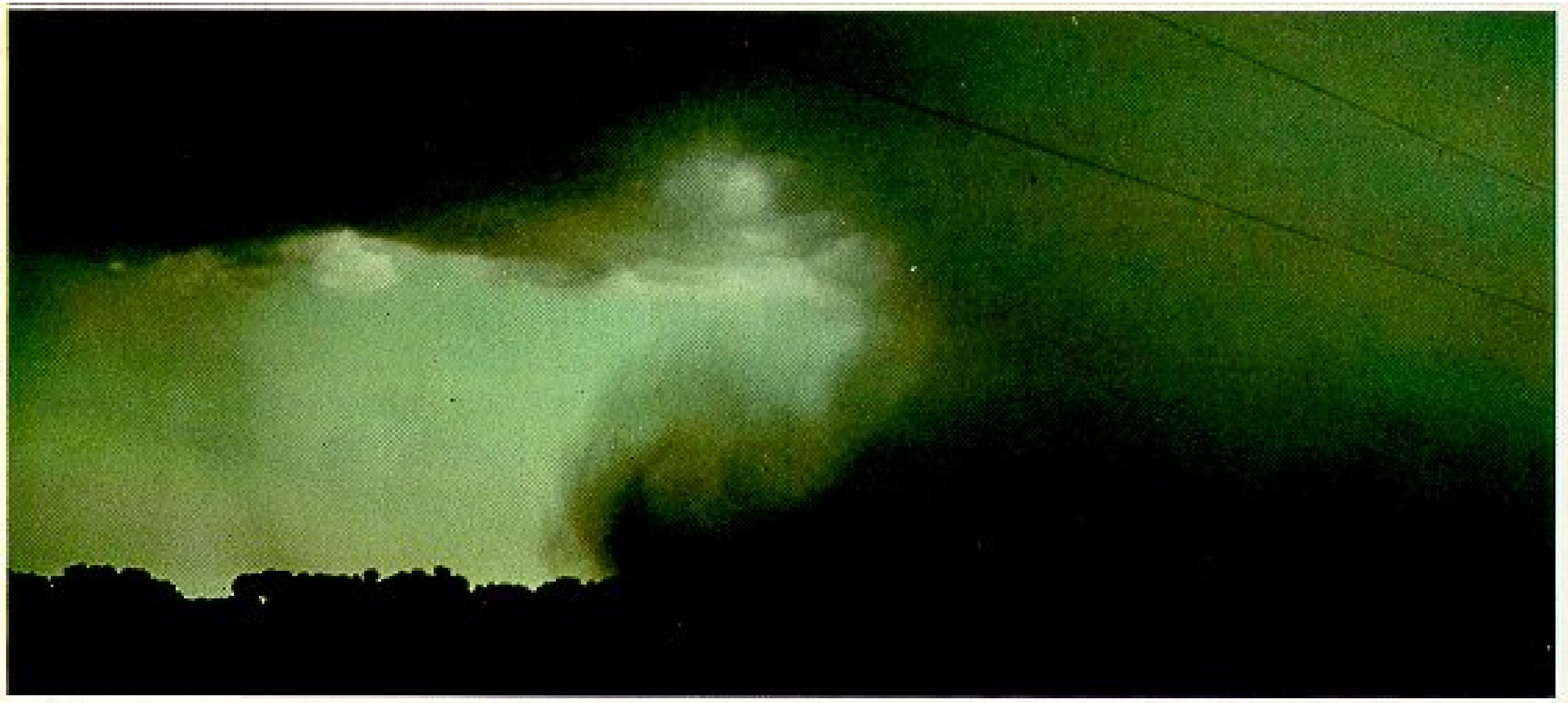
The local winds associated with particular atmospheric conditions include the thunderstorm winds and the tornadoes.

The thunderstorm winds can occur when tall convective clouds are produced by the upward motion of warm and moist air. Depending on whether this motion is determined by mountain slopes, gust fronts or thermal instability, they are classified as slope winds, frontal winds or downbursts.

The tornado is the most powerful of all the wind types. It is a vortex of air of about 300 m in diameter, which develops in severe thunderstorms and moves with respect to the ground with speeds of about 30-100 km/h in a path approximately 15 km long. The tangential speed in the tornadoes has been estimated up to 700 km/h.

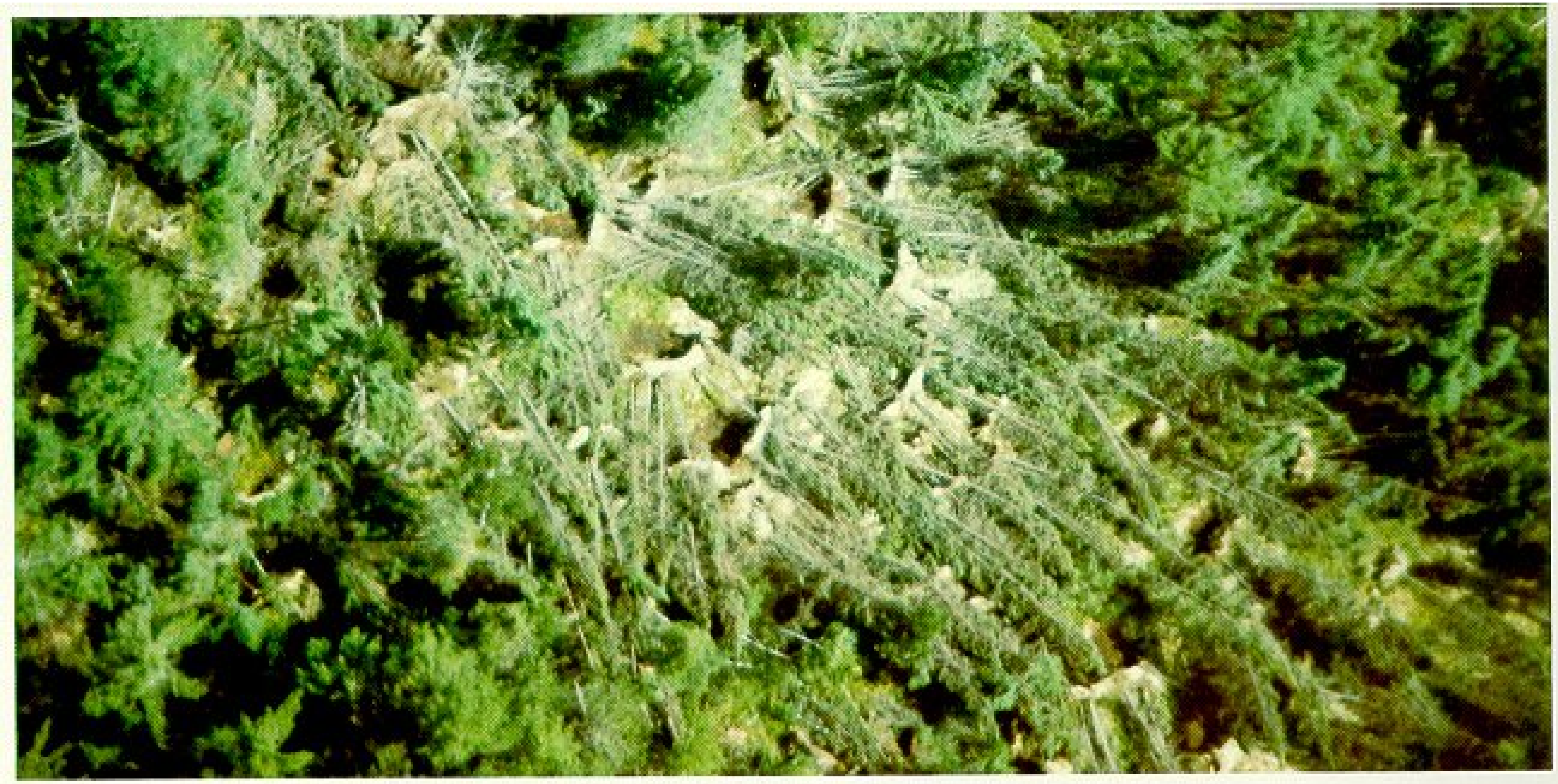

Cloud Base
1000 ft
Approx
Scale
0
1000 ft
Virga or
Rain
Downdraft
Outflow Front
Horizontal
Vortex
Outflow

Downburst

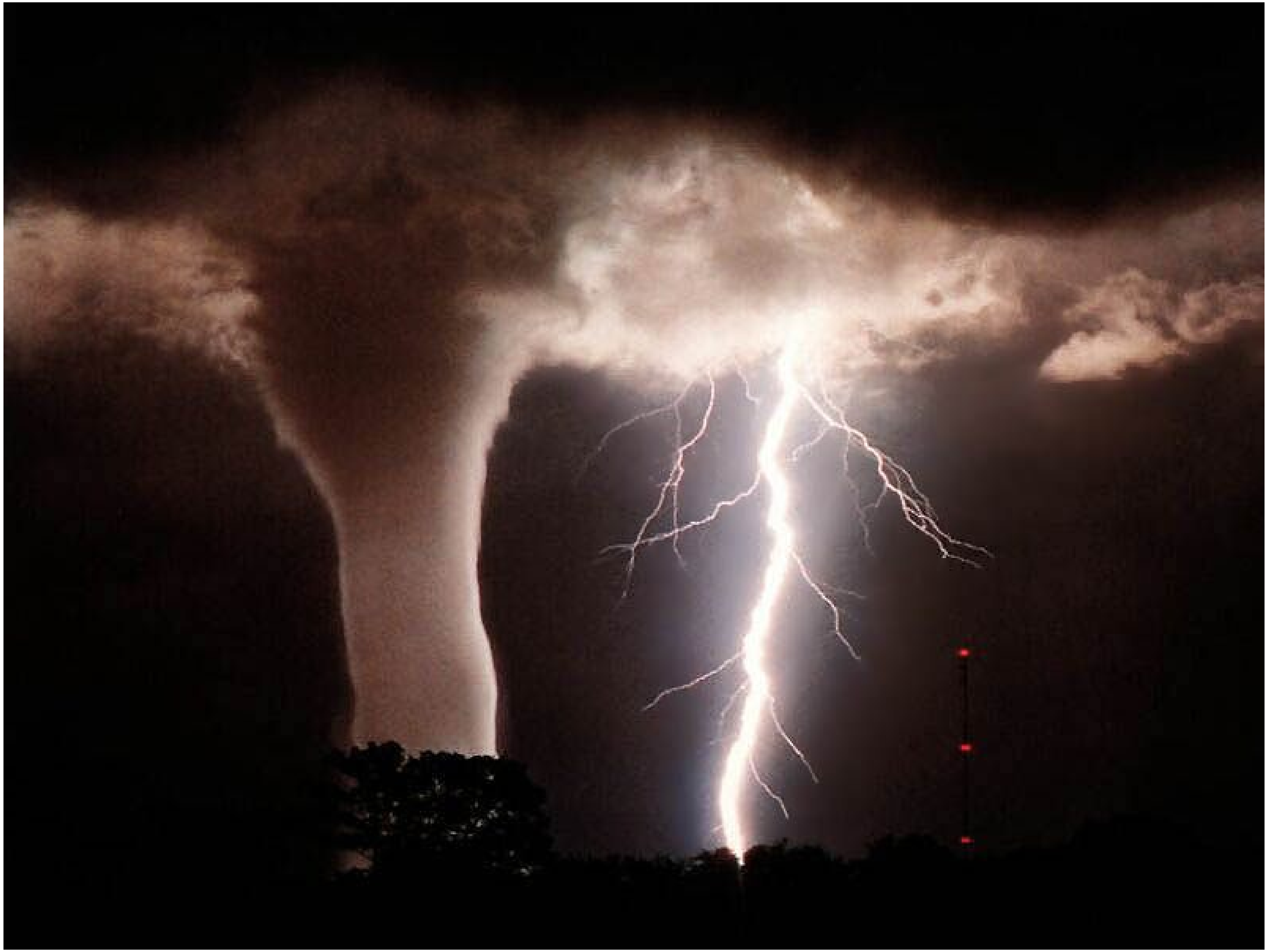


Downburst

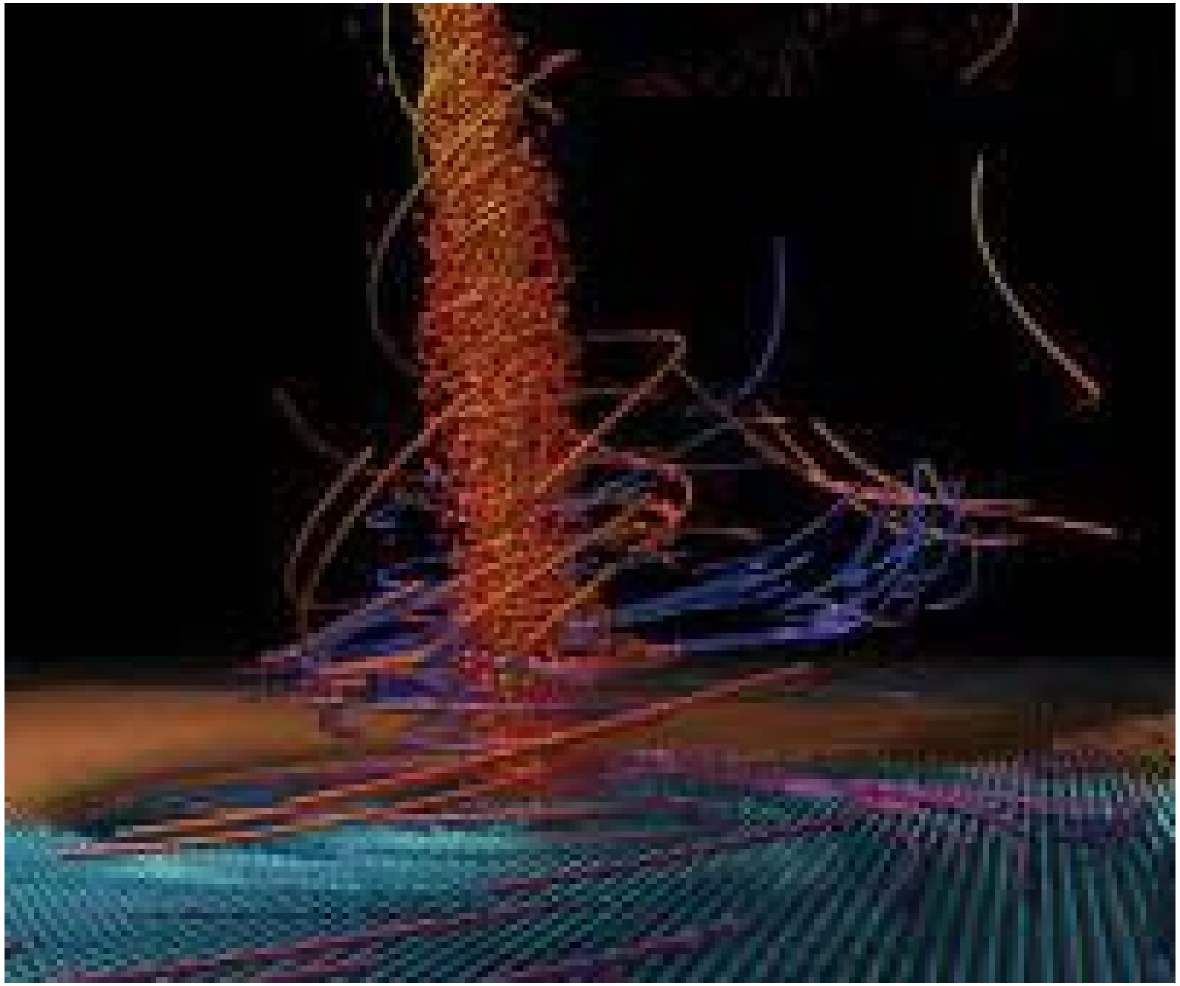
Downburst signature



Downburst signature



Tornado

Tornado

Tornado signature

Tornado signature

Grade	Velocity (km/h)	Effects
F0	64–116	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	117–180	Moderate damage. The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	181–253	Significant damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; high-rise windows broken and blown in; light-object missiles generated.
F3	254–332	Severe damage. Roofs and some walls torn off well-constructed houses; most trees in forest uprooted; skyscrapers twisted and deformed with massive destruction of exteriors; heavy cars lifted off the ground and thrown.
F4	333–418	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; trains overturned; cars thrown and large missiles generated. Skyscrapers and highrises toppled and destroyed.
F5	419–512	Catastrophic damage. Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 m (109 yd); trees debarked; steel reinforced concrete structures badly damaged.

Fujita scale

Fujita scale F0

Fujita scale F1

Fujita scale F2

Fujita scale F3

Fujita scale F4

Fujita scale F5

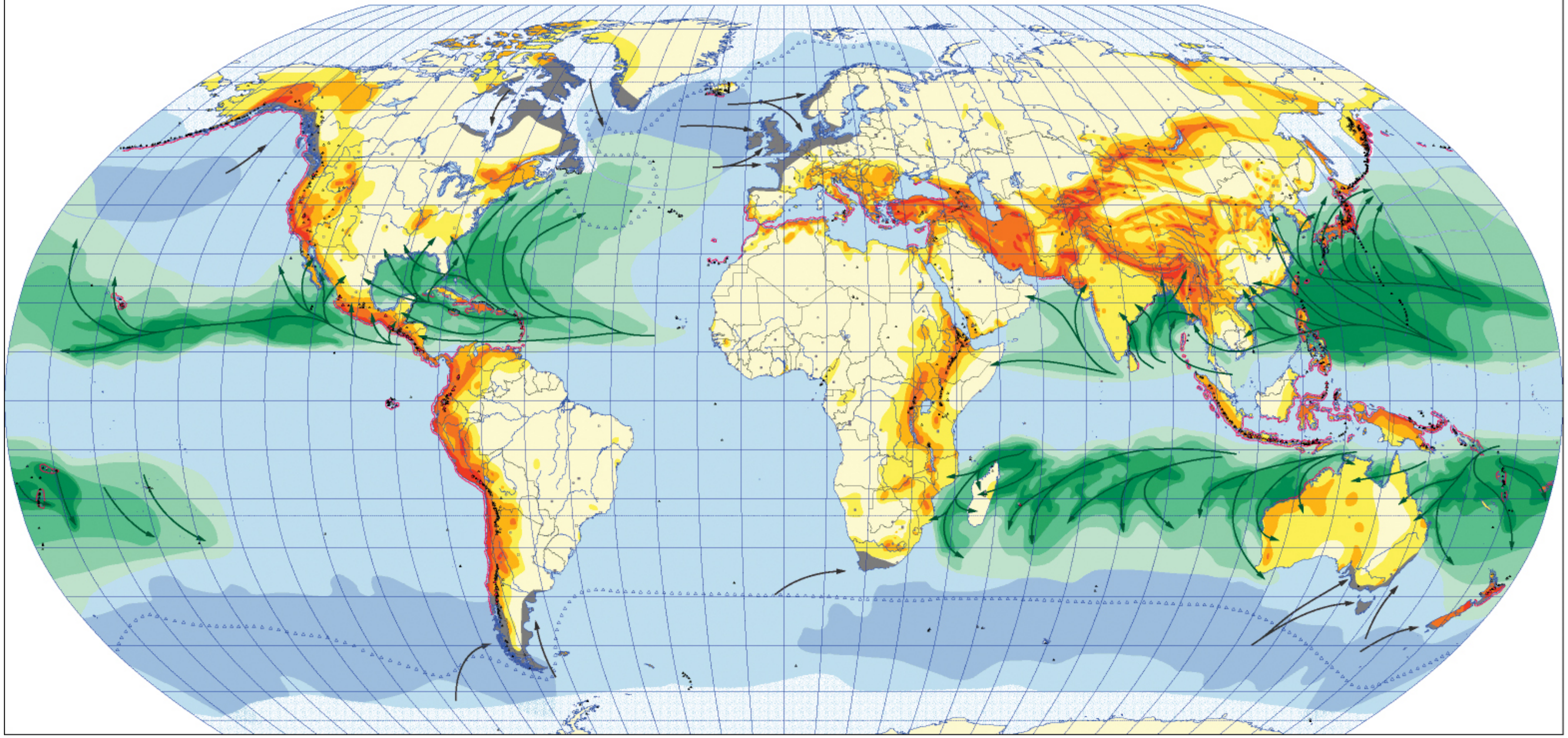
Fujita scale F5

Tornado debris

Tornado debris

World Map of Natural Hazards

Münchener Rück
Munich Re



Earthquakes

- Zone 0: MM V and below
- Zone 1: MM VI
- Zone 2: MM VII
- Zone 3: MM VIII
- Zone 4: MM IX and above

Probable maximum intensity (MM: modified Mercalli scale) with an exceedance probability of 10% in 50 years (equivalent to "return period" of 475 years) for medium subsoil conditions

Seattle — Large city with "Mexico City effect"

Volcanoes

- Last eruption before 1800 AD
- Last eruption after 1800 AD
- Particularly hazardous volcanoes

Tsunamis and Storm Surges

- Tsunami hazard (seismic sea-wave)
- Storm surge hazard
- Tsunami and storm surge hazard

Tropical Storms and Cyclones

- Zone 1: SS 1 (118–153 km/h)
- Zone 2: SS 2 (154–177 km/h)
- Zone 3: SS 3 (178–209 km/h)
- Zone 4: SS 4 (210–249 km/h)
- Zone 5: SS 5 (>= 250 km/h)

Probable maximum intensity (SS: Saffir-Simpson hurricane scale) with an exceedance probability of 10% in 10 years (equivalent to a "return period" of 100 years)

- Principal tracks of tropical storms

Extratropical Storms/Winter Storms

- High extratropical storm hazard, mainly in winter
- Principal tracks of extratropical storms

Other Natural Hazards

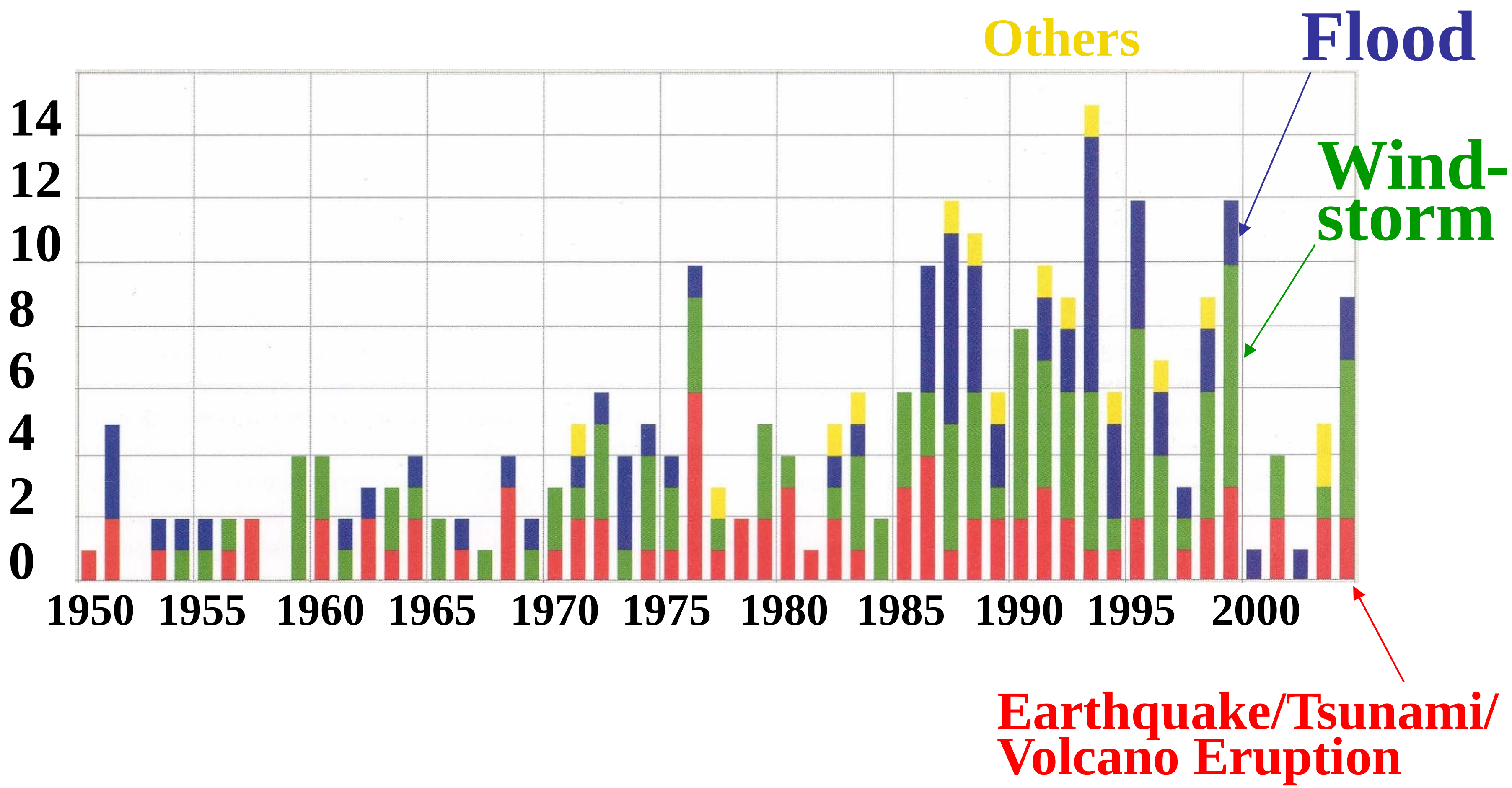
- Limit of iceberg drift
- Pack ice (winter maximum)
- High seas with wave heights > 5 metres, exceedance probability 10% per year ("10-year wave")

Cities

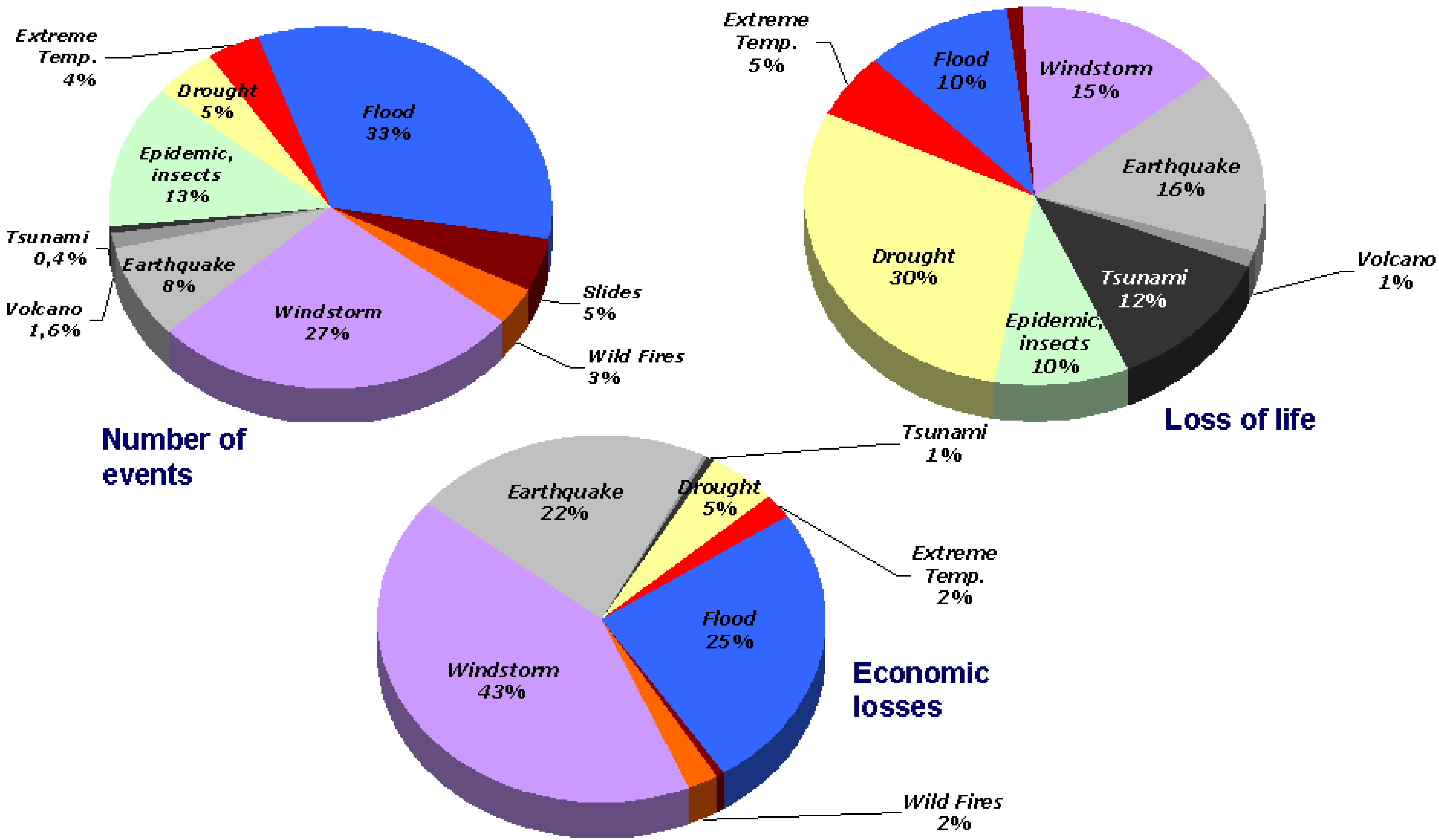
- Denver — > 1 million inhabitants
- San Juan — 100,000 to 1 million inhabitants
- Maun — < 100,000 inhabitants
- Berlin — Capital city
- Melbourne — Munich Re office

Political Borders/Inland Waters

- State border
- State border, controversial (political borders not binding)
- River
- Lake
- Previous extent of lake



Number of devasting natural disasters



Statistics of devasting natural disasters

Equations of motion

Conservation of mass (continuity equation)

$$\boxed{-\left(\nabla \bullet \rho \mathbf{V}\right) = \frac{\partial \rho}{\partial t}}$$

Conservation of motion (Navier-Stokes equation)

$$\boxed{\frac{\partial \mathbf{V}}{\partial t} = -\mathbf{V} \bullet \nabla \mathbf{V} - \frac{1}{\rho} \nabla p + \mathbf{g} - 2\Omega \times \mathbf{V}}$$

ρ = density of air
$\mathbf{V}$ **=** velocity vector
t = time
p = pressure
g = gravity acceleration
Ω = angular velocity of rotation of earth

Equations of motion

Conservation of heat (first thermodynamic principle)

$$\boxed{\frac{\partial\theta}{\partial t} = -\mathbf{V}\bullet\nabla\theta + S_\theta}$$

Using the ideal gas law:

$$\theta = T_v (p_0 / p)^{R_d / C_p}$$

$$p = \rho R_d T_v$$

$$T_v = T(1 + 0.61 q_3)$$

S_θ	= source and skin term of heat
θ	= potential temperature
p_0	= reference pressure (p_0 = 1000 hPa)
T_v	= virtual temperature
R_d	= gas constant in dry air
C_p	= specific heat at constant temperature
T	= temperature
q_3	= specific humidity of air

Equations of motion

Conservation of water

$$\boxed{\frac{\partial q_n}{\partial t} = -\mathbf{V}\bullet\nabla q_n + S_{q_n} \qquad (n = 1, 2, 3)}$$

Conservation of other gaseous and aerosol materials

$$\boxed{\frac{\partial \chi_\kappa}{\partial t} = -\mathbf{V}\bullet\nabla \chi_\kappa + S_{\chi_\kappa} \qquad (\kappa = 1, 2, ..m)}$$

q_n = ratios of the mass of the solid, liquid and vapor forms of water, respectively, to the mass of air in the same volume

S_{qn} = source and skin term of water

χ_k = ratio of the mass of a gas or of any other aerosol material to the mass of air in the same volume

$S_{\chi k}$ = source and skin term of gases and any other aerosol materials

Equations of motion

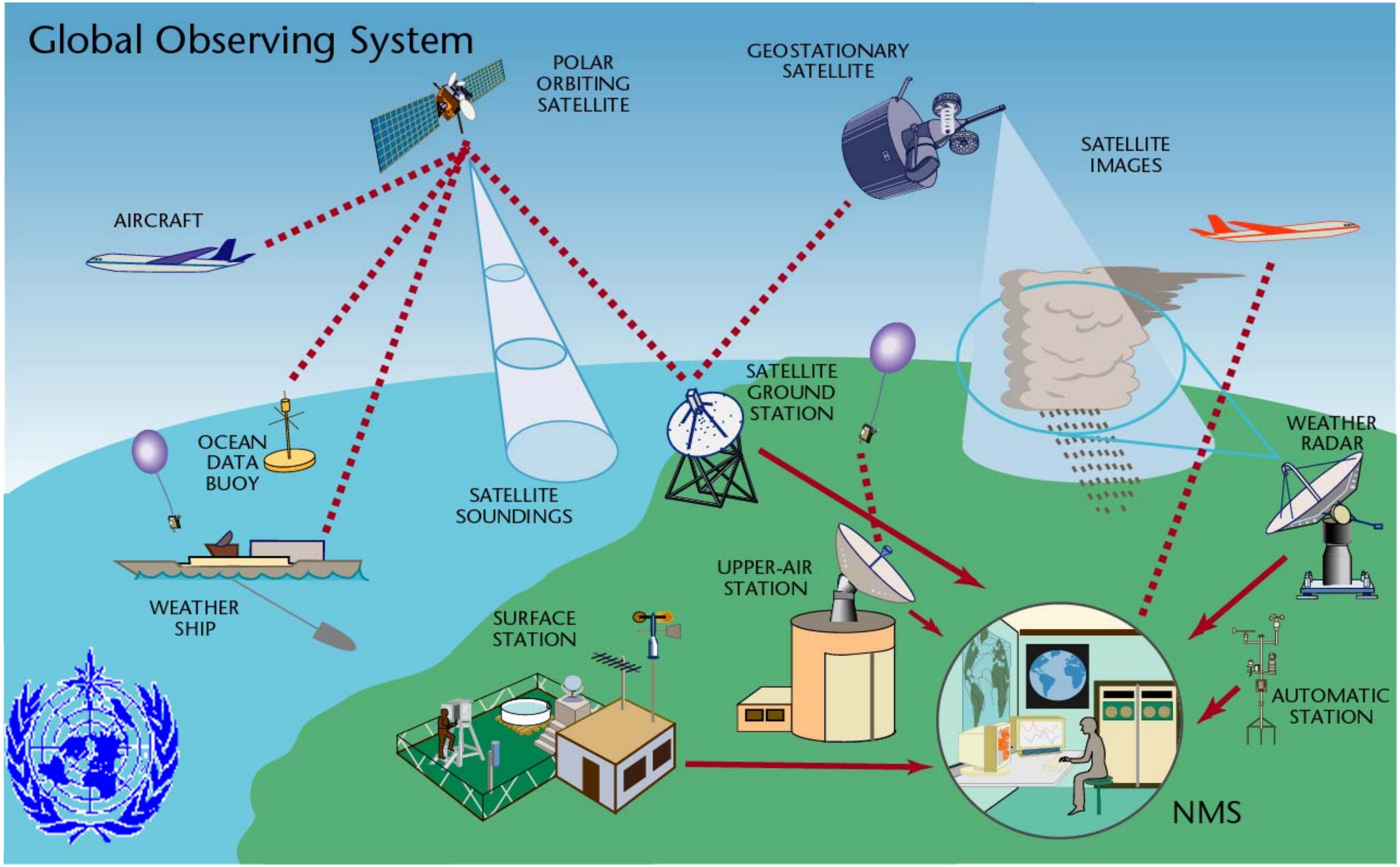
Motion is governed by a set of 8+m non-linear partial differential equations in 8+m dependent variables - ρ, V_x, V_y, V_z, θ, q_1, q_2, q_3, χ_1, χ_2, χ_m – functions of time t and space x, y, z.

This set of equations can be solved deterministically by means of two classes of numerical models:

Prognostic models solve the set of the equations of motion on varying the time, by assigning initial and boundary conditions; they are mainly used for meteorological forecasts;

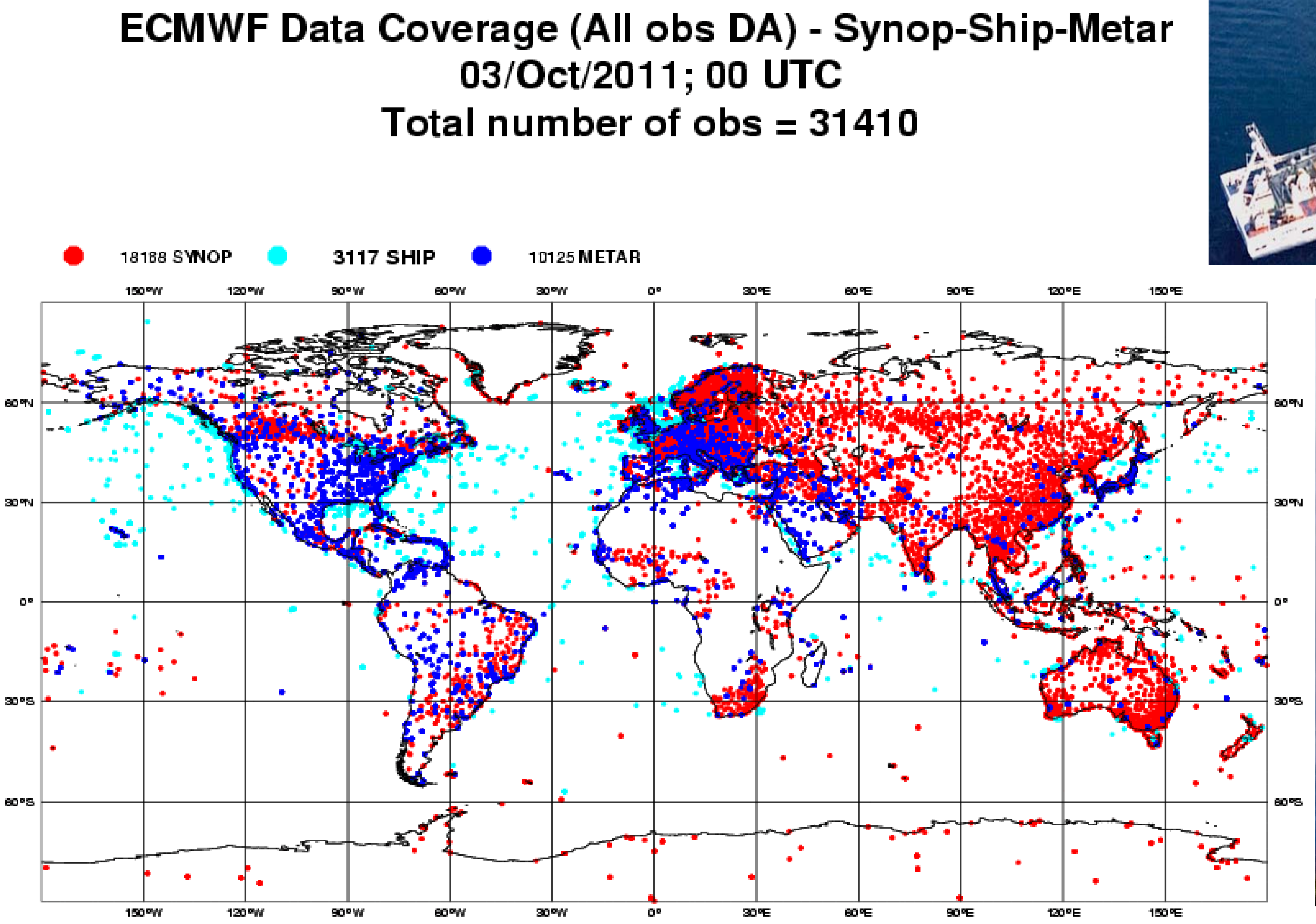
Diagnostic models solve the set of the equations of motion as independent of time, by assigning initial boundary conditions; they are mainly used to reconstruct atmospheric fields and, in particular, wind velocity fields.

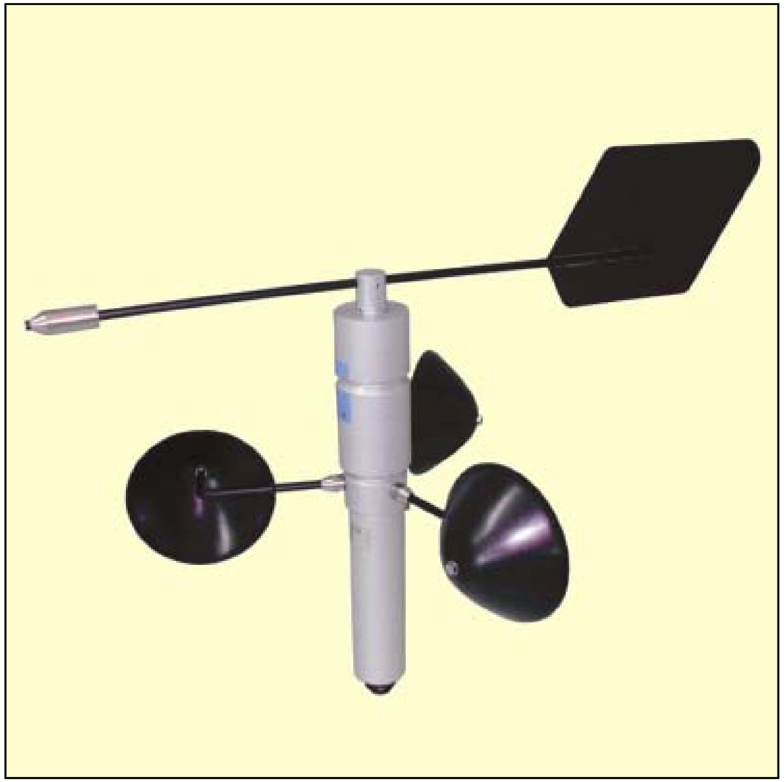
Global Observing System (GOS)



World Meteorological Organization

Global Observing System (GOS)



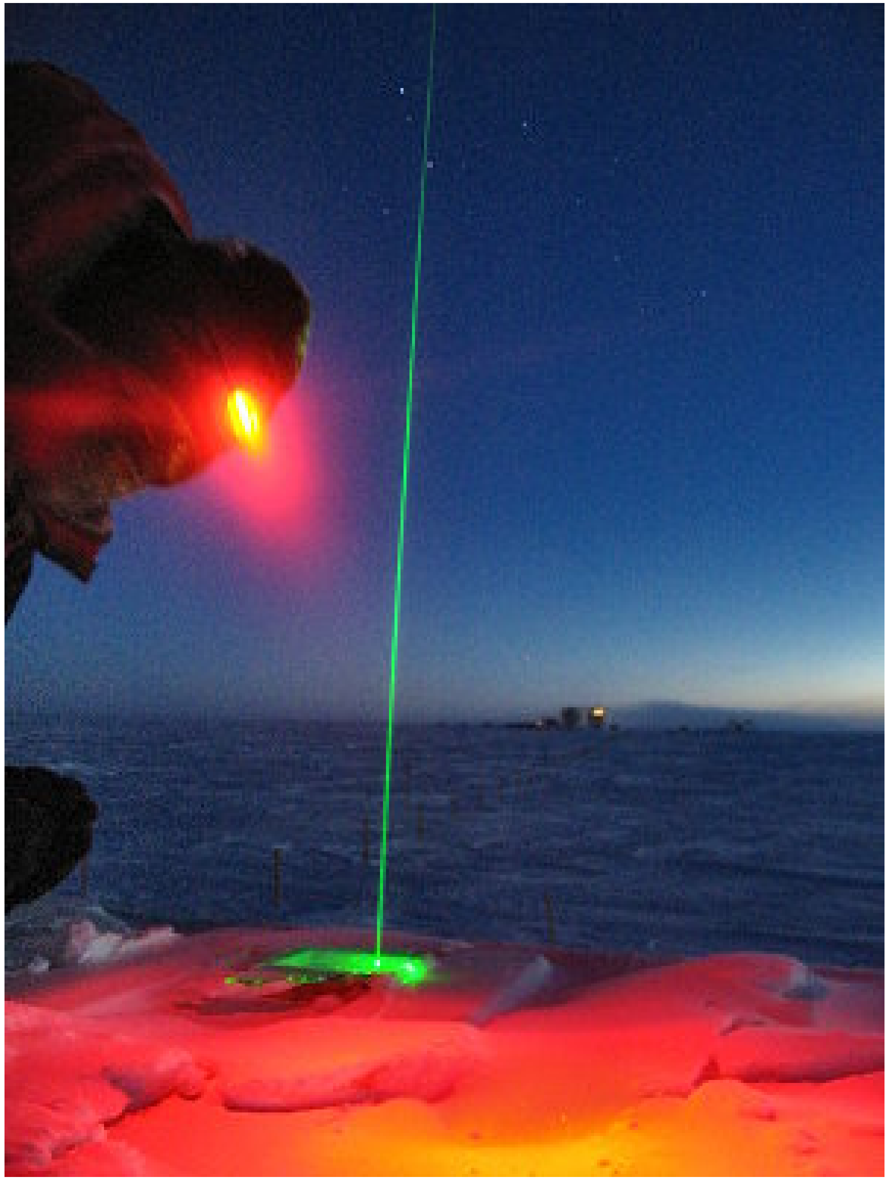


Cup Anemometer and Vane

Propeller Anemometer

Bi-axial and Tri-axial Sonic Anemometers

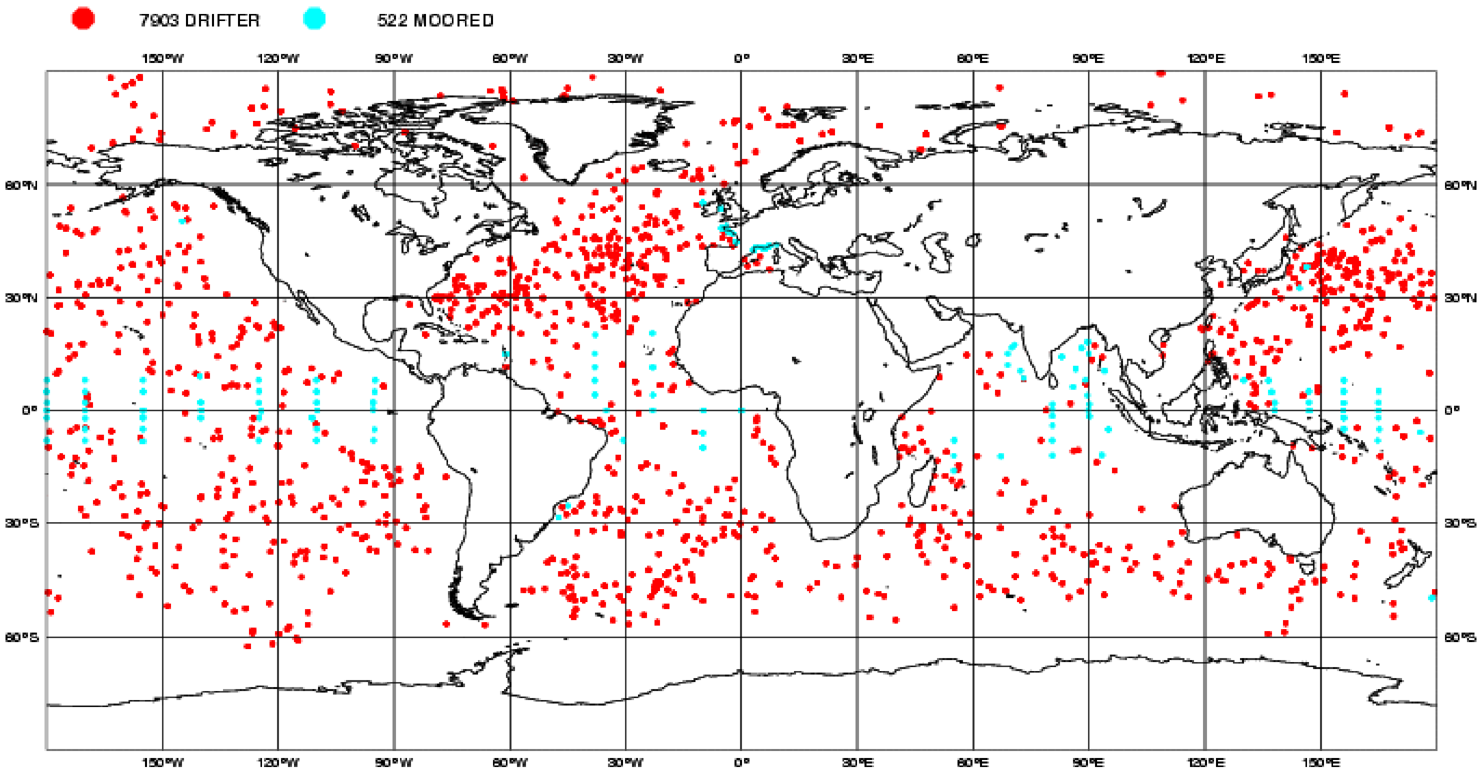
Sodar



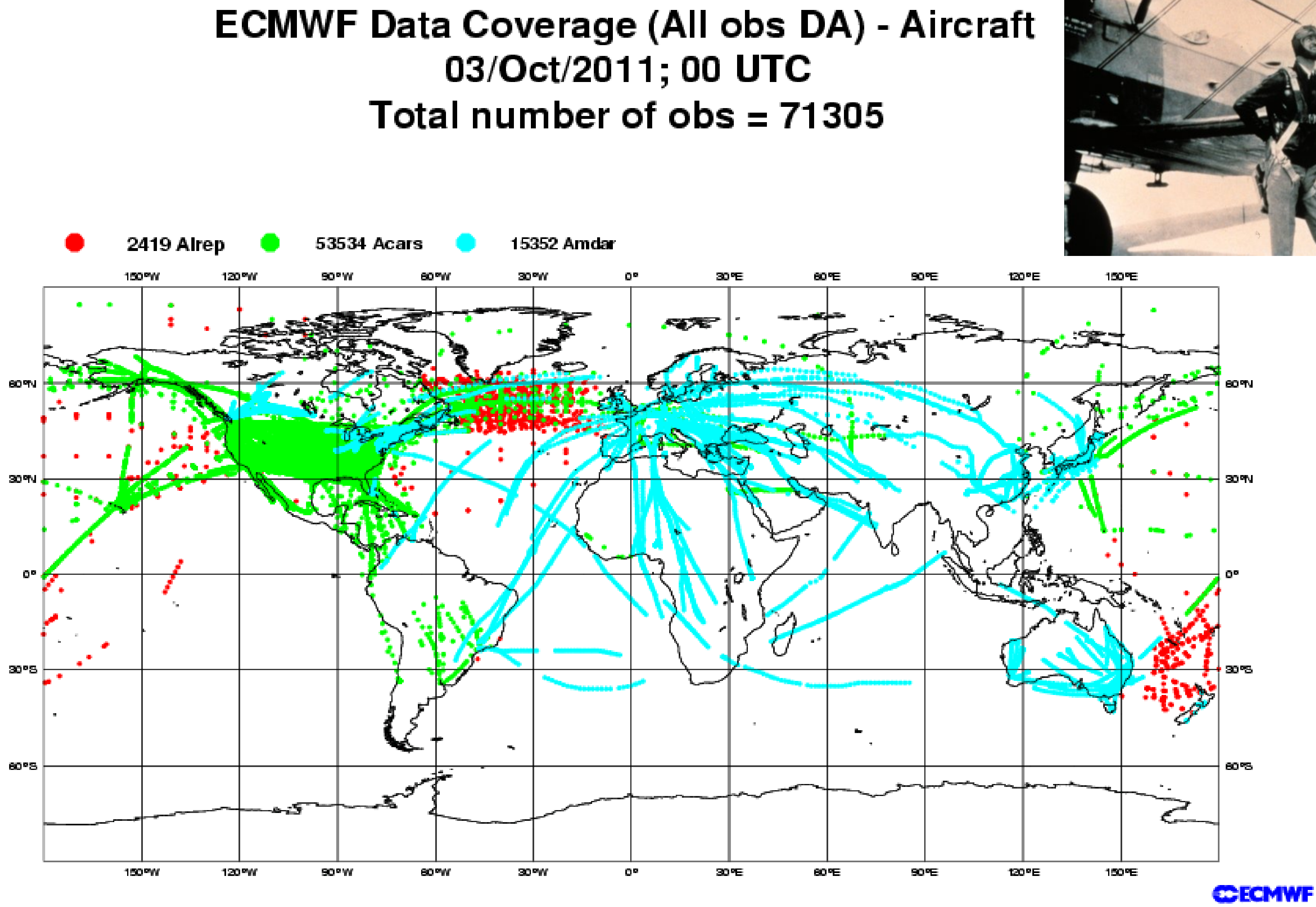
Lidar

Global Observing System (GOS)

ECMWF Data Coverage (All obs DA) - Buoy
03/Oct/2011; 00 UTC
Total number of obs = 8425

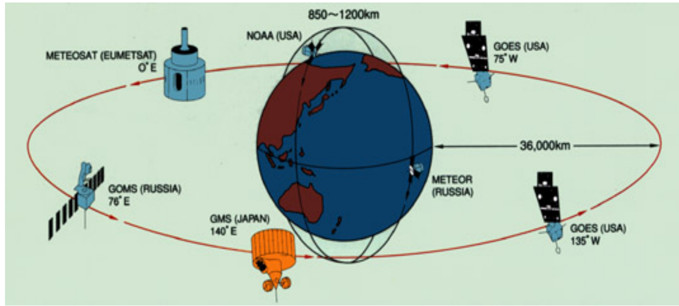


Global Observing System (GOS)

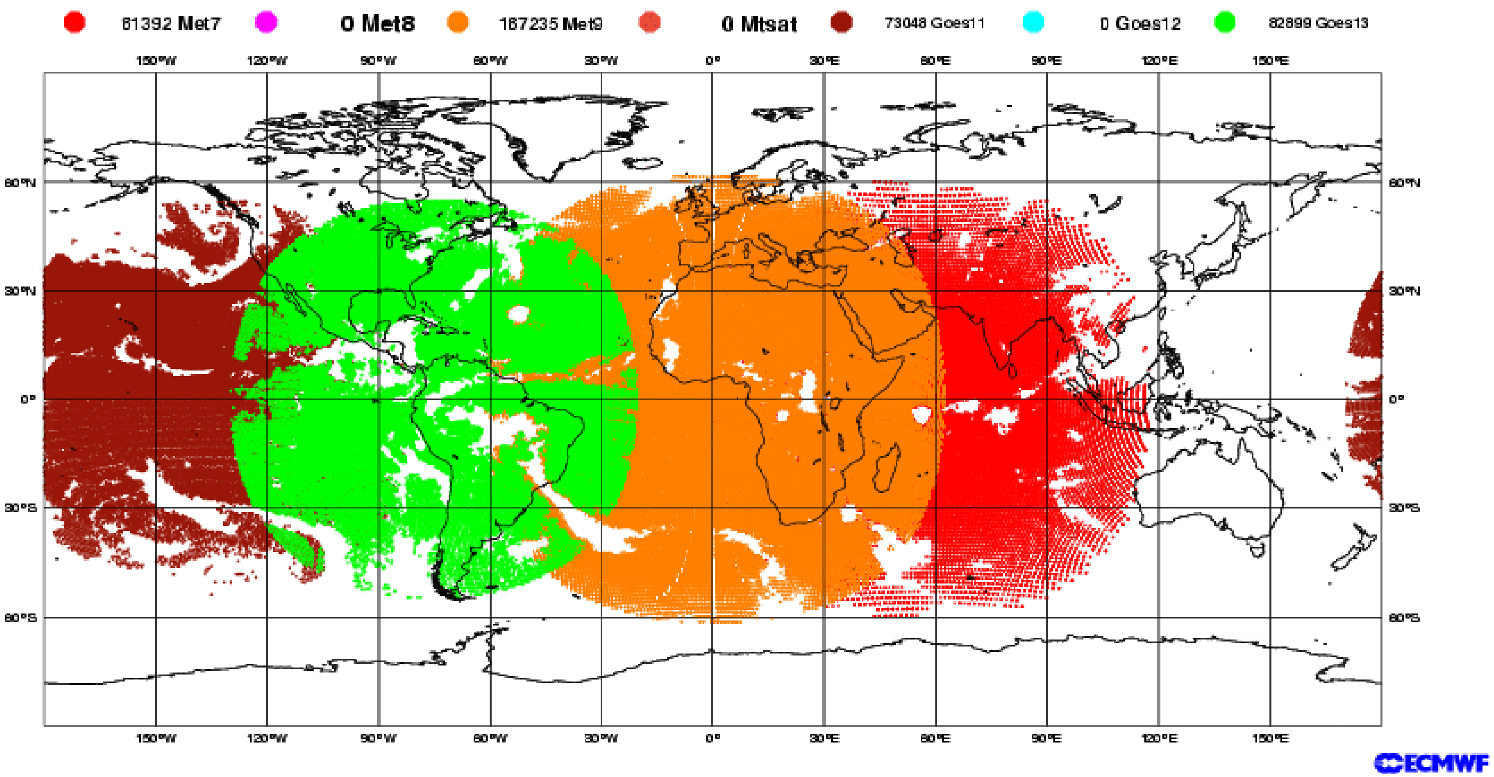


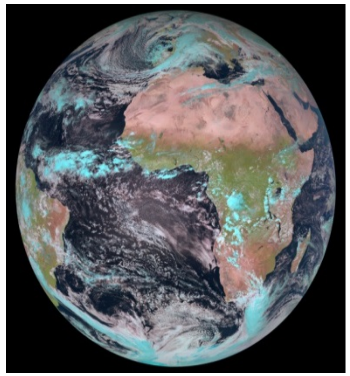
Global Observing System (GOS)

Geostationary satellites



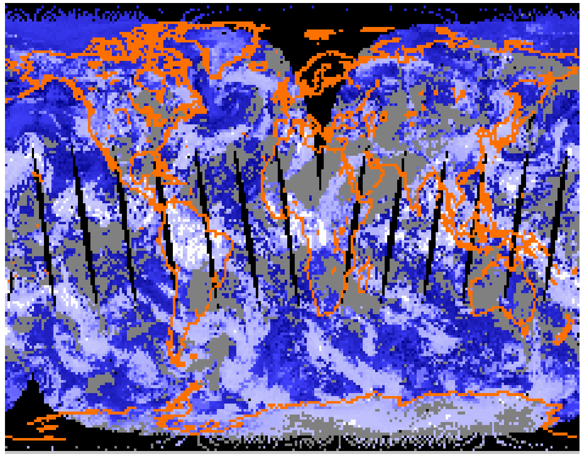
ECMWF Data Coverage (All obs DA) - GRAD
03/Oct/2011; 00 UTC
Total number of obs = 384574



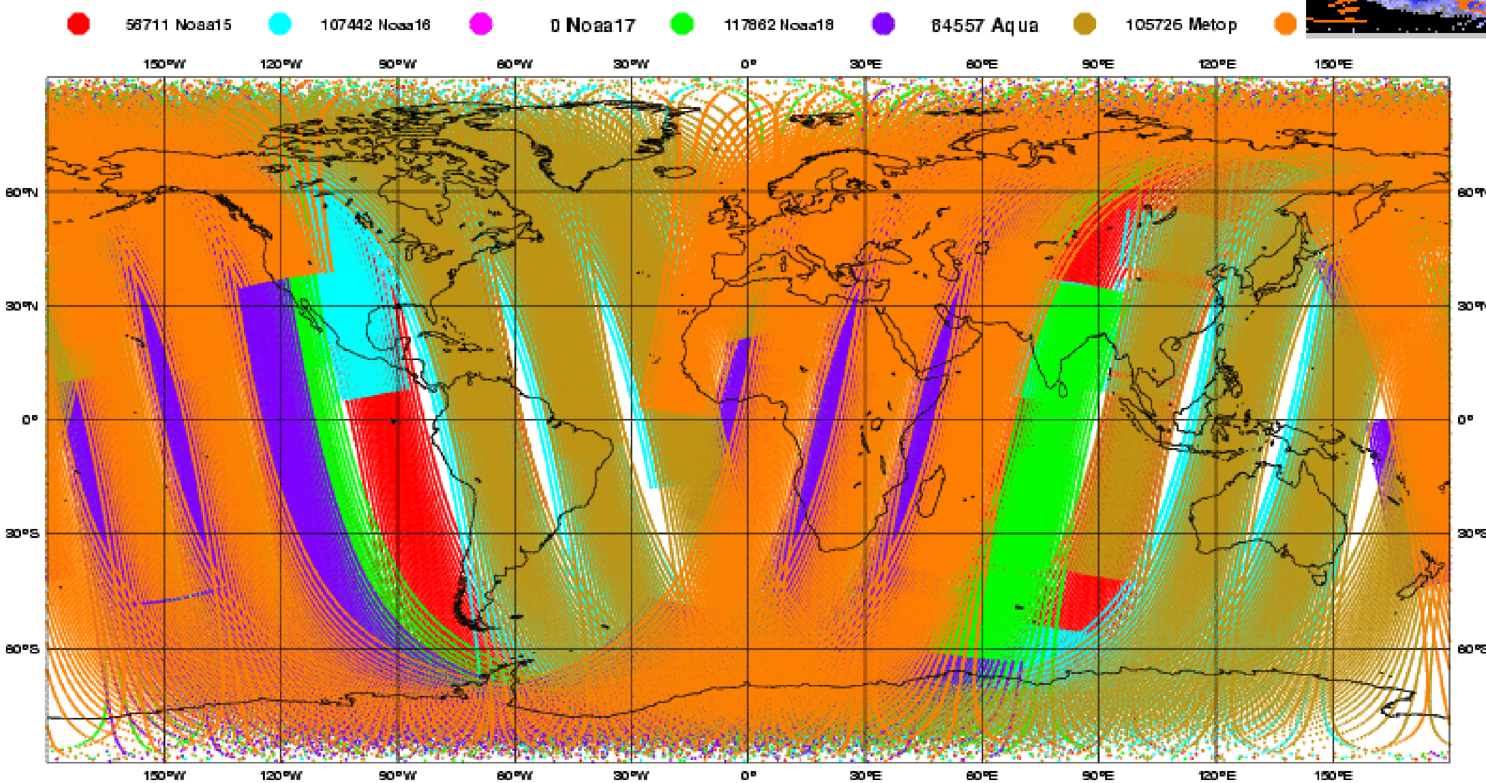


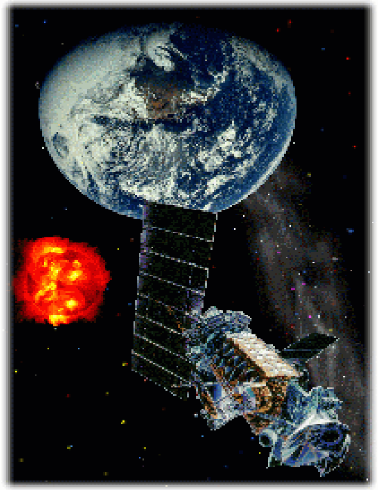
Global Observing System (GOS)

Polar satellites



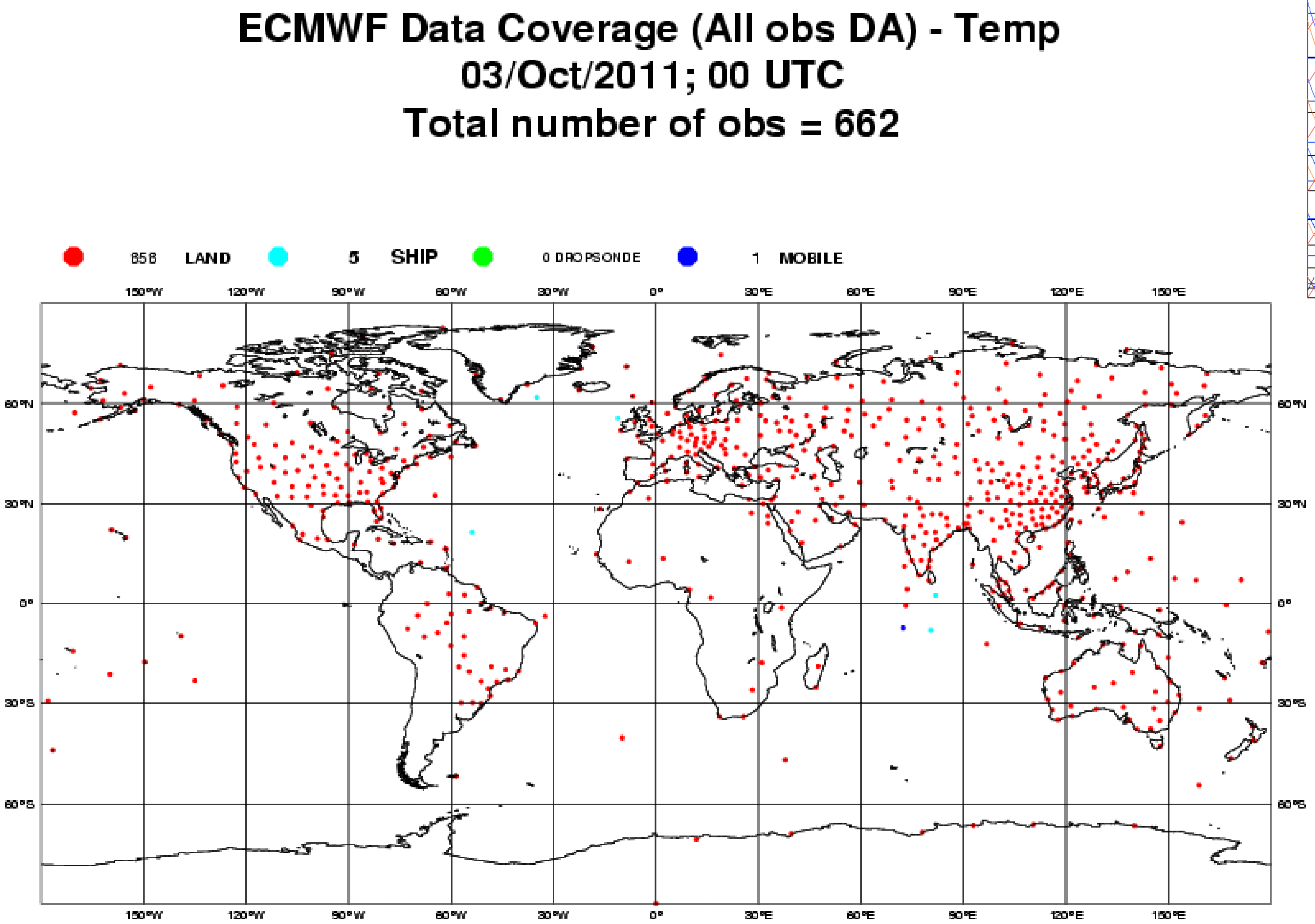
ECMWF Data Coverage (All obs DA) - AMSU-A
03/Oct/2011; 00 UTC
Total number of obs = 586141

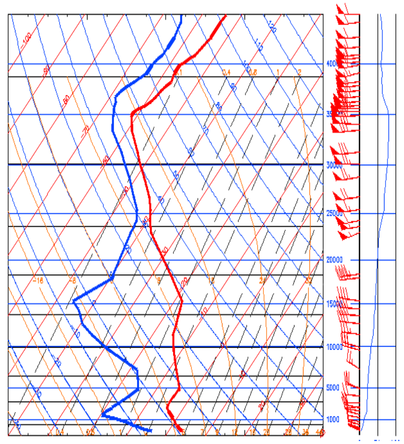


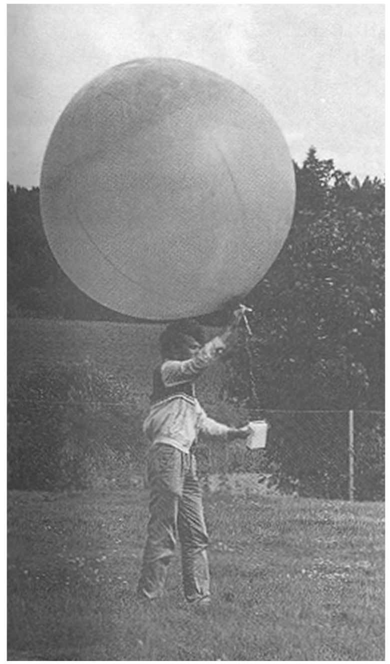


ECMWF

Global Observing System (GOS)

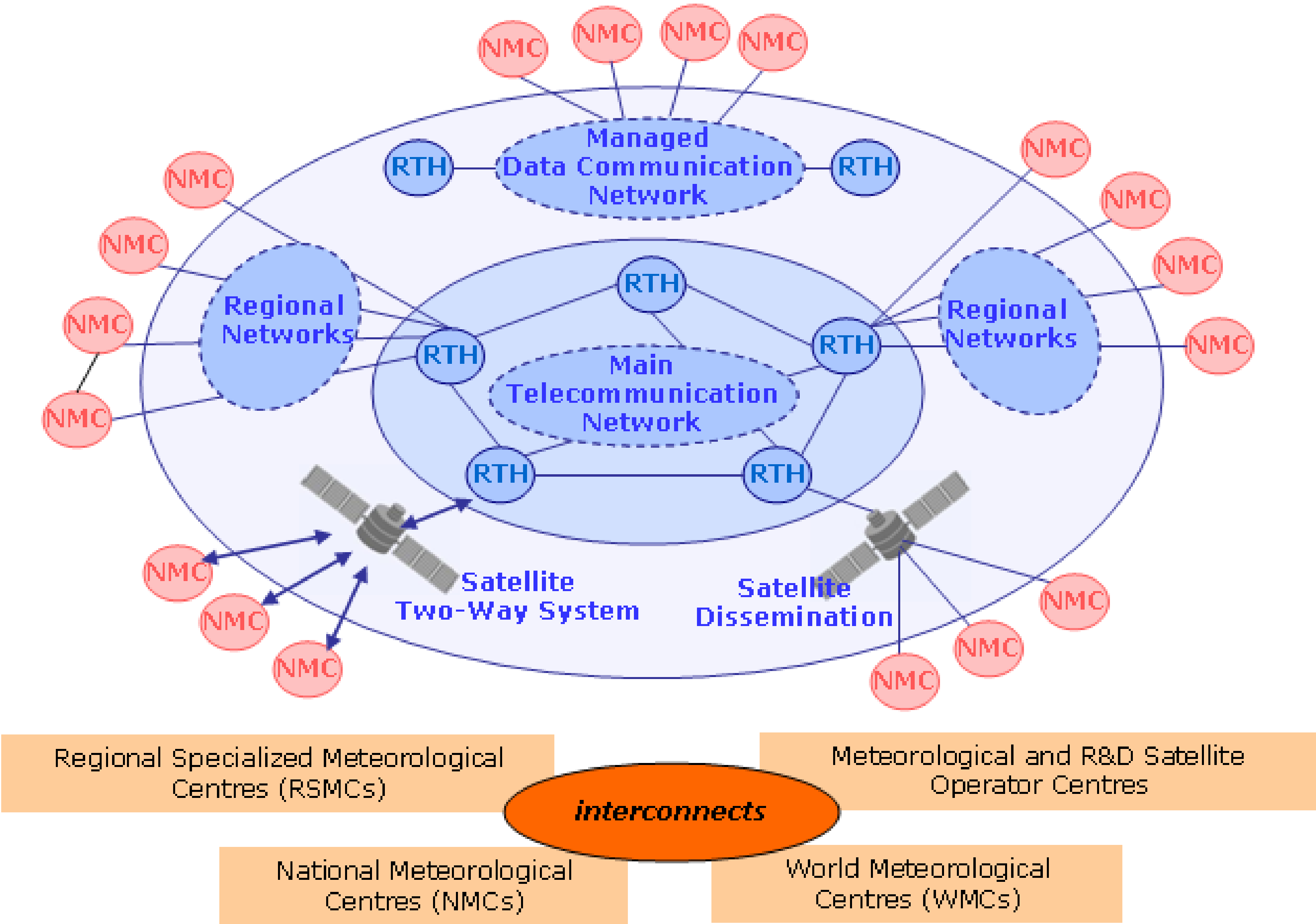






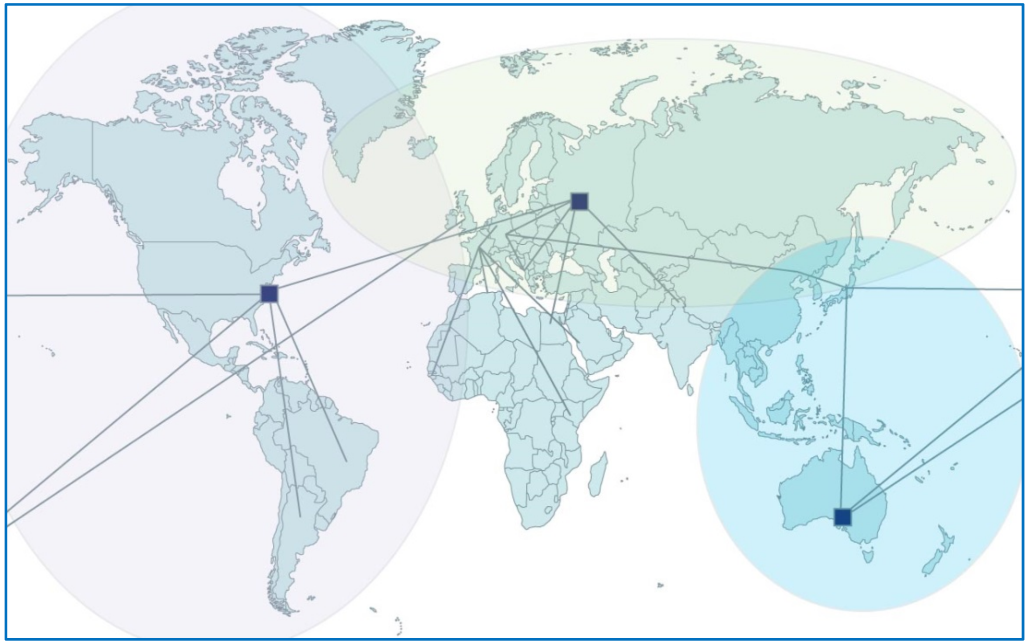
ECMWF

Global Telecommunication System (GTS)



Global Telecommunication System (GTS)

Main Telecommunication Network links 3 World Meteorological Centres: Melbourne, Moscow and Washington



Regional Telecommunication Networks establish 6 continental networks

National Telecommunication Networks transfer information to and from meteorological national services

Wind representation models

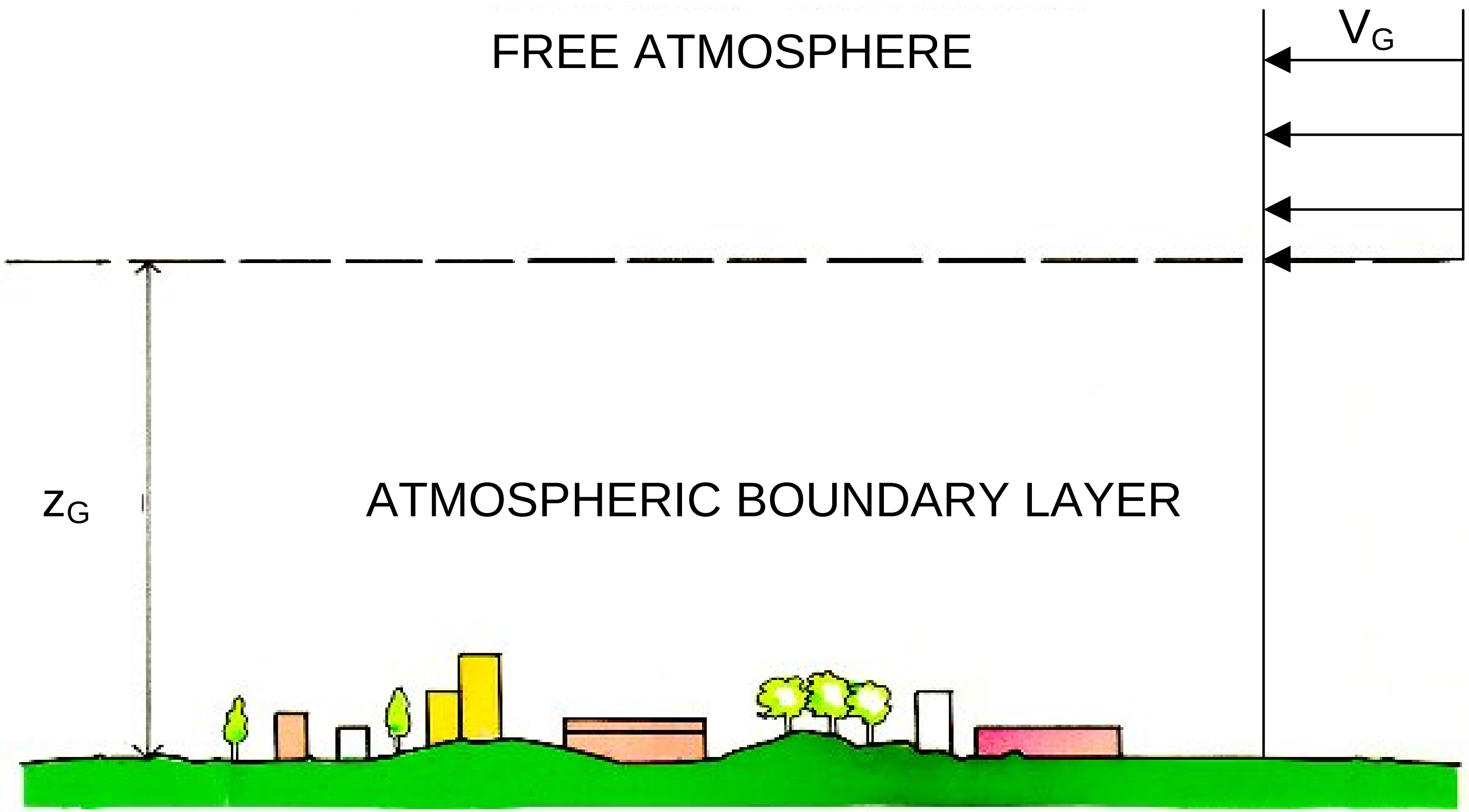
Prognostic and diagnostic models represent the actual frontier of research and high level applications to special problems.

On the other hand, several models have been formulated to represent the wind in a simplified but consistent way.

These models involve the decomposition of the global circulation problem into a set of partial problems, each schematized according to its intrinsic properties. In such framework, many suitable models are currently available for representing, separately and at local scales, the most important wind types, namely extra-tropical and tropical cyclones, monsoons, downbursts, tornadoes, …

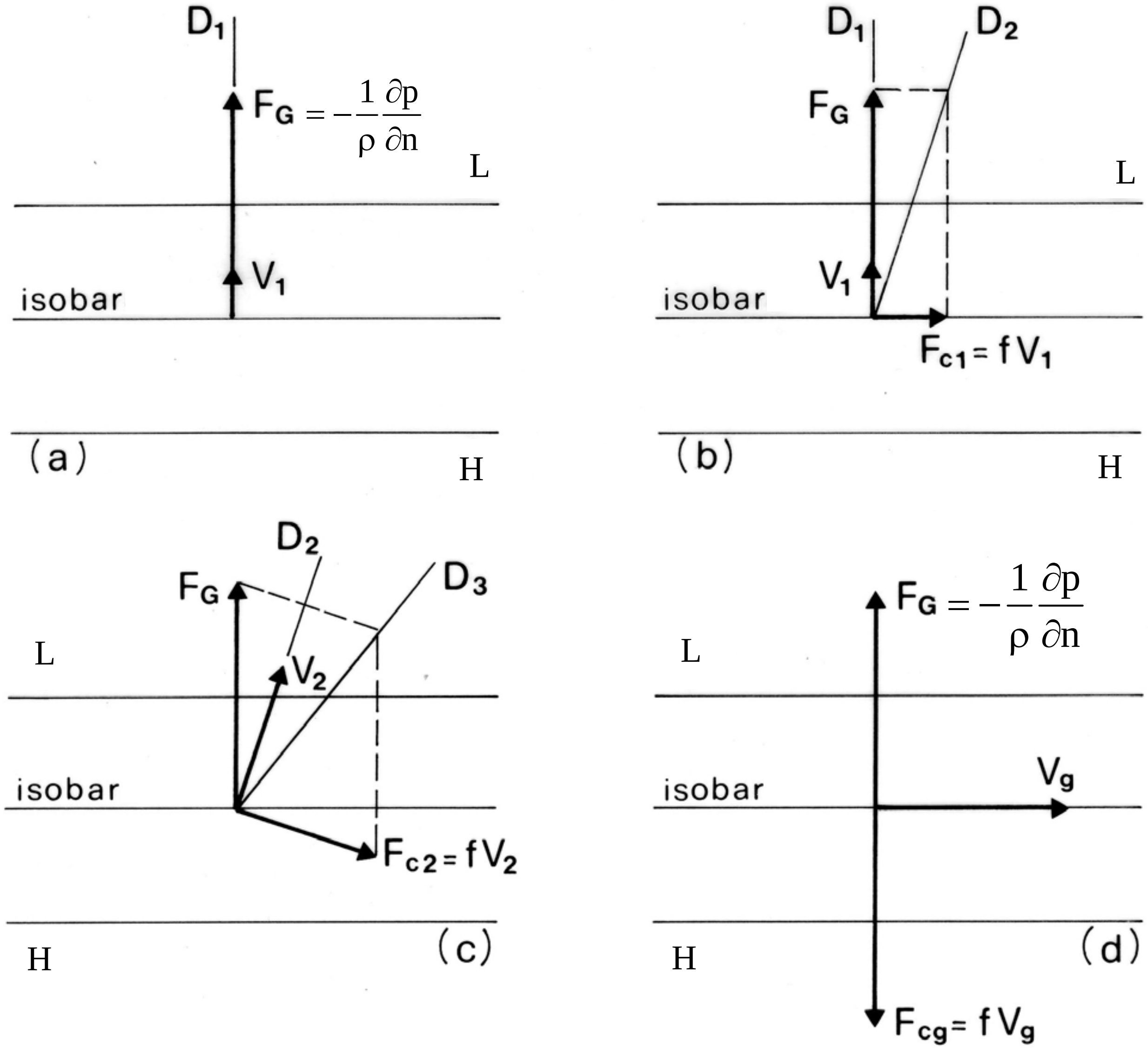
The models developed for schematizing the extra-tropical cyclone provide sound idealizations of the physical reality and are widely diffused in both the meteorological and engineering sectors.

Extra-tropical cyclone



V_G = gradient velocity
z_G = gradient height

Free atmosphere – Straight isobars

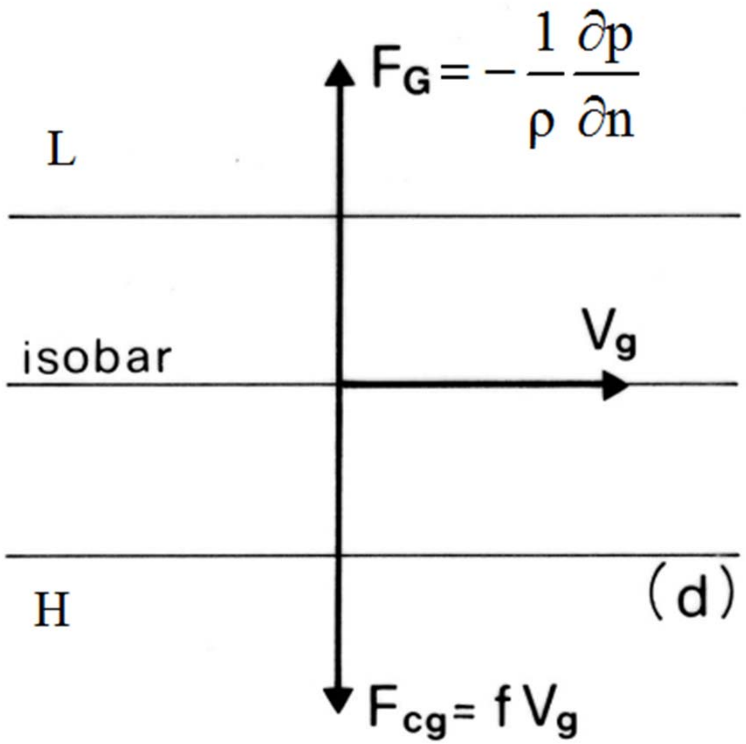


F_G = gradient force
F_c = Coriolis force

$V_G = V_g$ =
geostrophic velocity

Free atmosphere – Straight isobars

Stationary motion



F_G = gradient force

F_c = Coriolis force

$V_G = V_g$ = geostrophic velocity

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

$$\boxed{V_g = -\frac{1}{\rho f}\frac{\partial p}{\partial n}}$$

f = $2\Omega\sin\varphi$ = Coriolis parameter

$\Omega = 0.729\times10^{-4}$ rad/s

φ = latitude

Free atmosphere – Curved isobars

Stationary motion

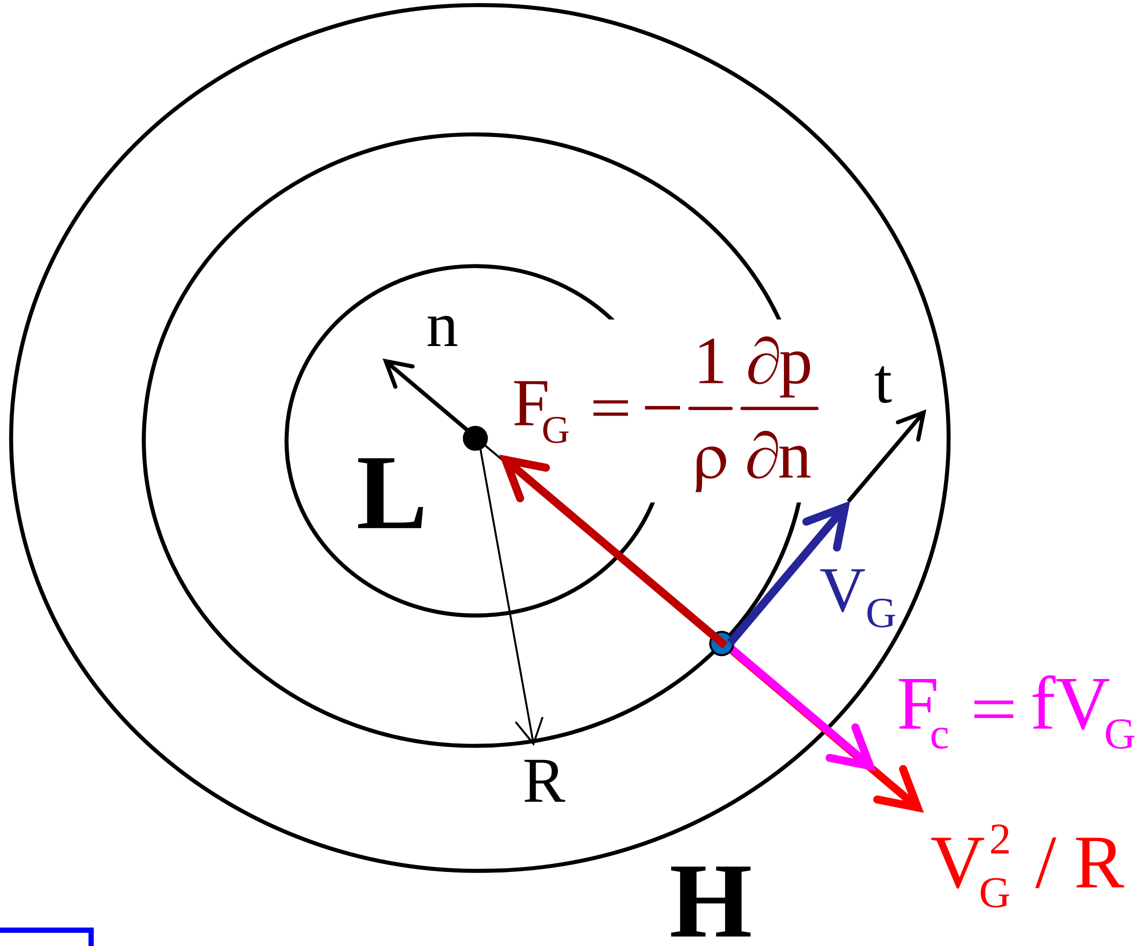
F_G = gradient force
F_c = Coriolis force
F_R = centrifugal force
V_G = gradient velocity

$$F_G - F_c - F_R = 0 \Rightarrow$$

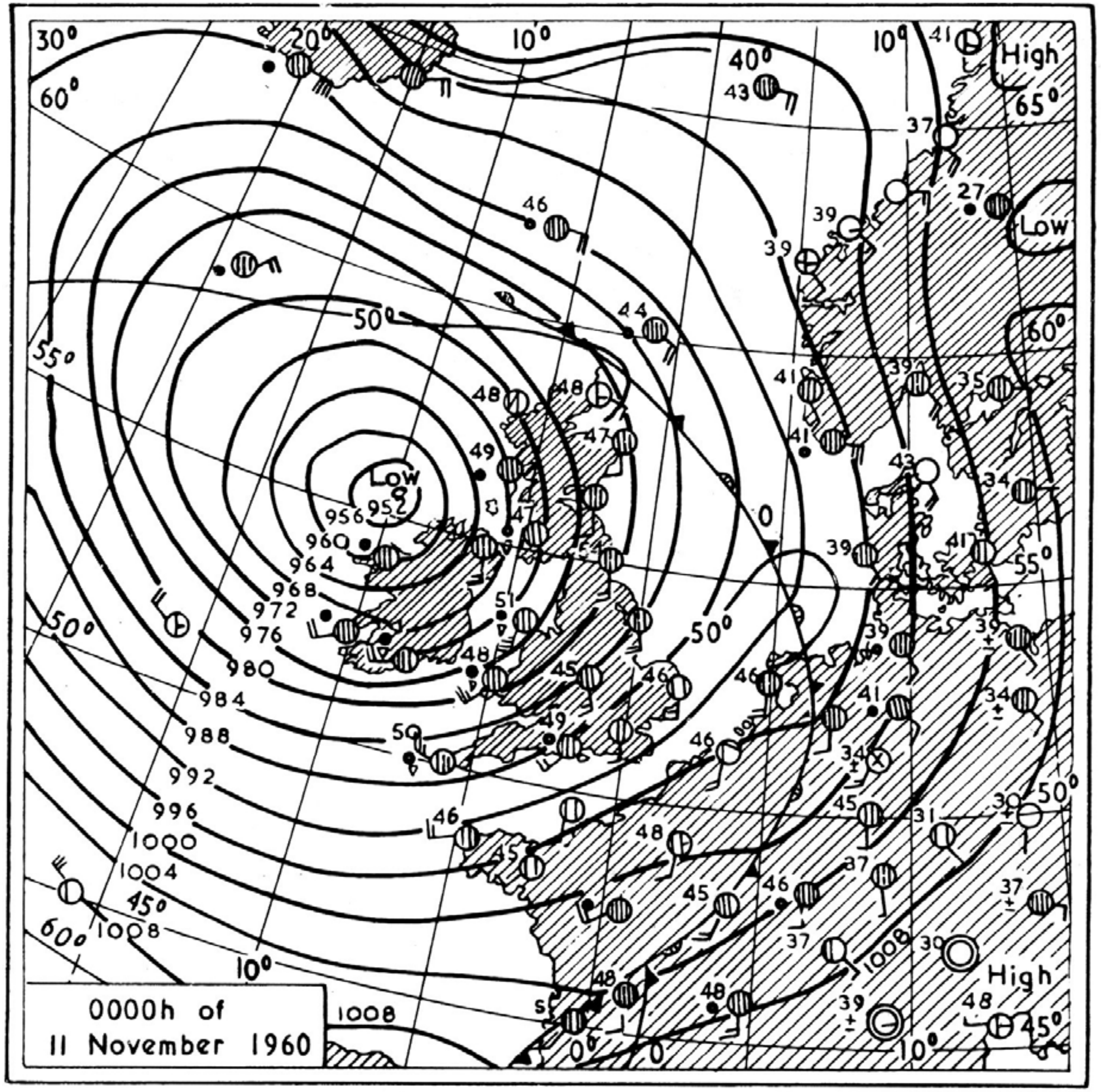
$$-\frac{1}{\rho}\frac{\partial p}{\partial n} = fV_G + \frac{V_G^2}{R} \Rightarrow$$

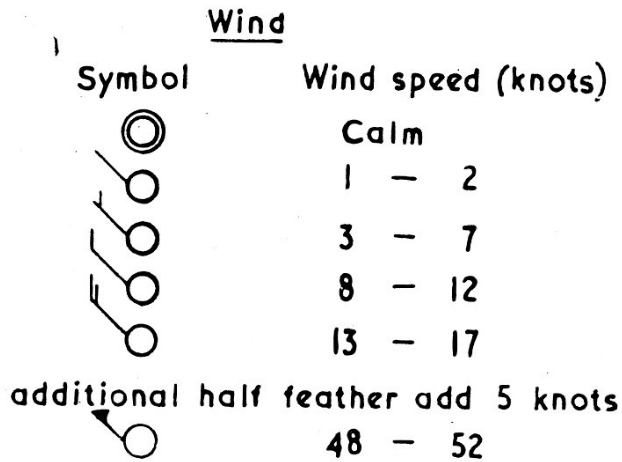
$$V_G^2 + f\,RV_G + \frac{R}{\rho}\frac{\partial p}{\partial n} = 0 \Rightarrow$$

$$\boxed{V_G = -\frac{fR}{2} + \sqrt{\frac{f^2R^2}{4} - \frac{R}{\rho}\frac{\partial p}{\partial n}}}$$

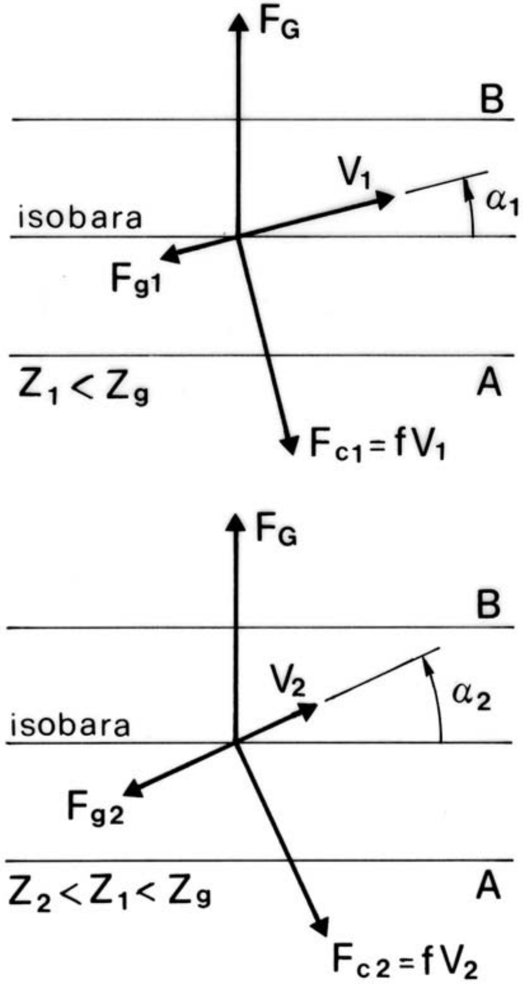


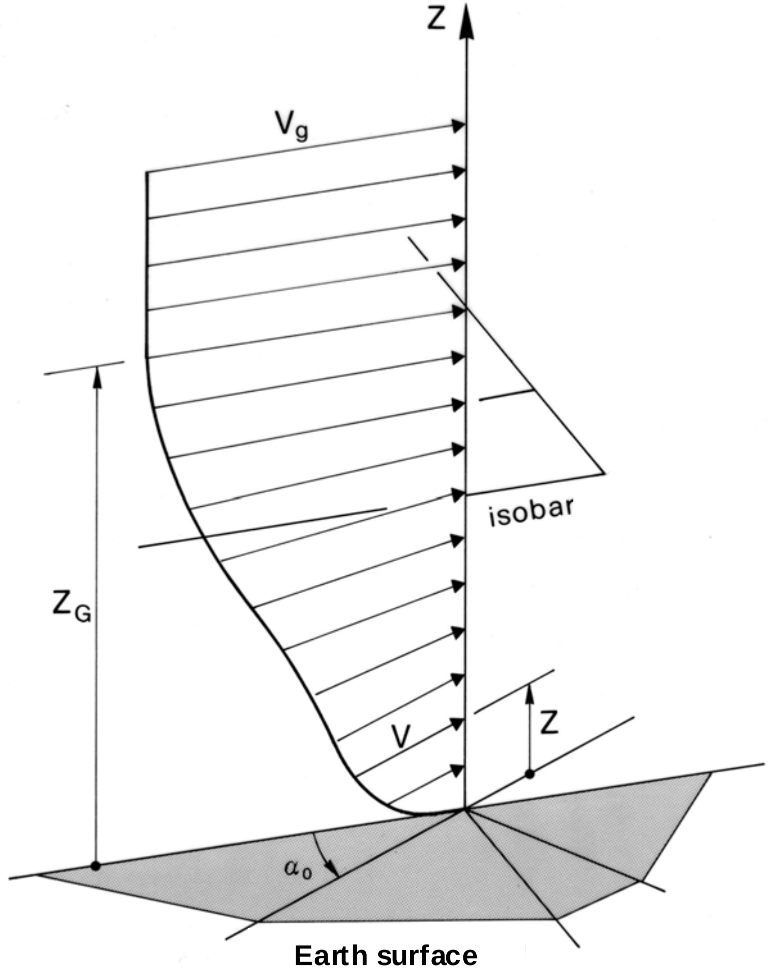
Free atmosphere – Curved isobars





Atmospheric Boundary Layer – Ekman spiral



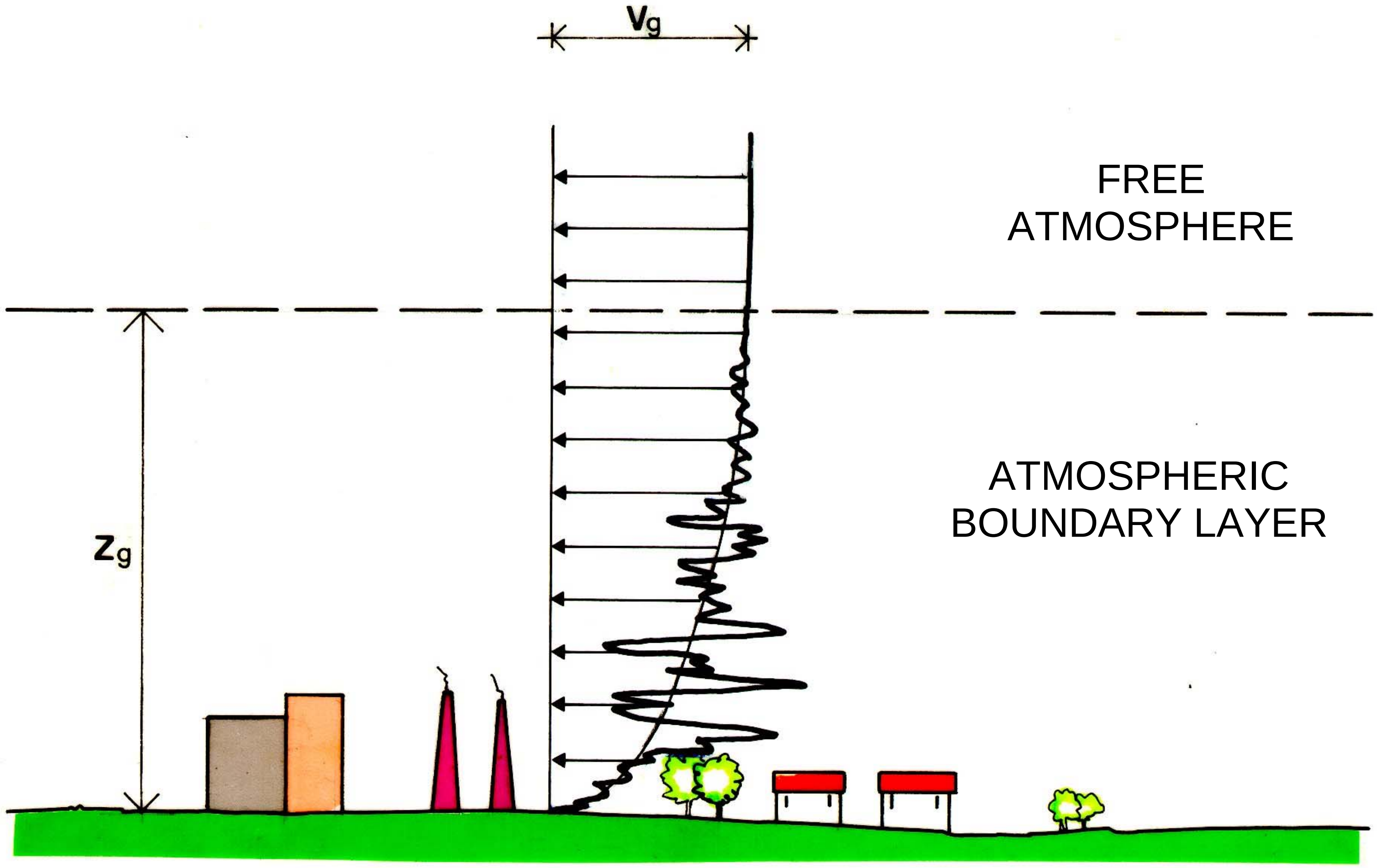


$F_g \propto -V$ = friction force

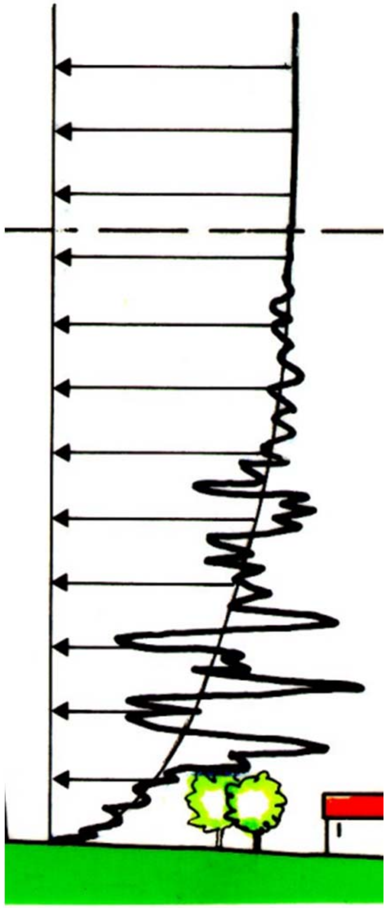
$\alpha_o \sim$ 5° in smooth terrains

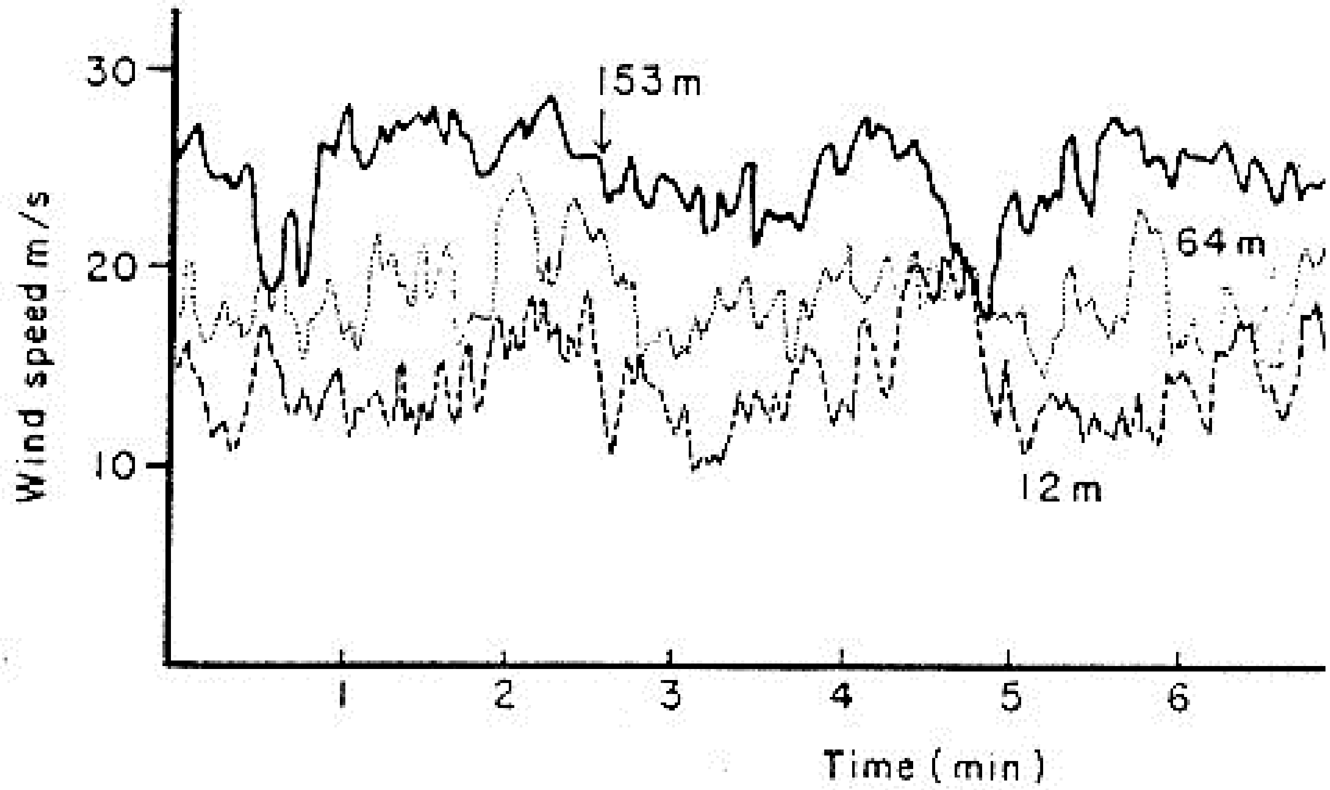
$\alpha_o \sim$ 35° in rough terrains

Atmospheric Boundary Layer

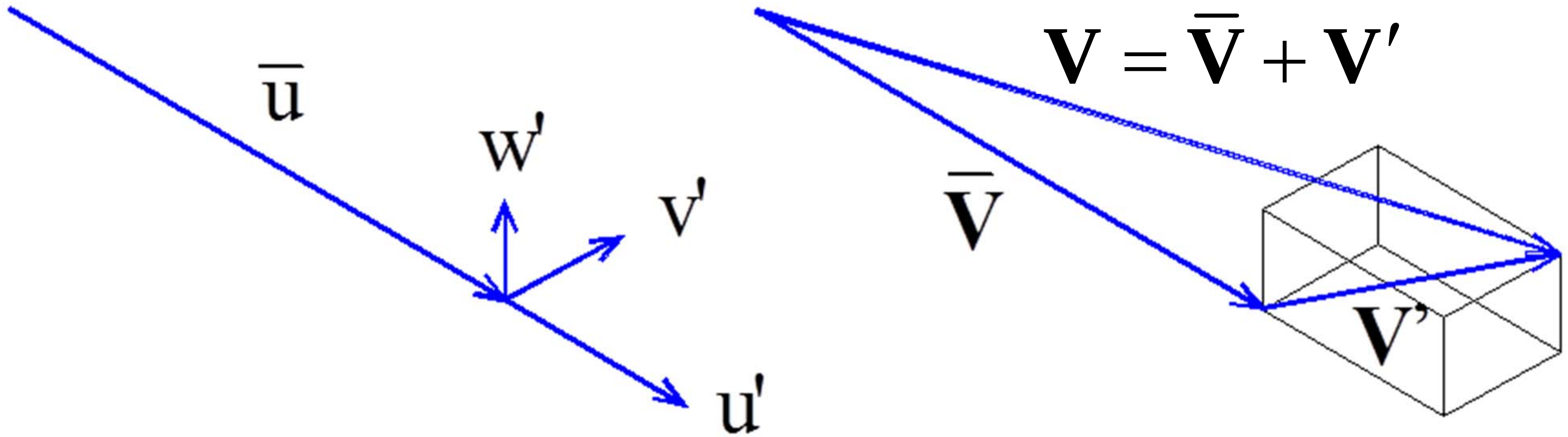


Atmospheric Boundary Layer



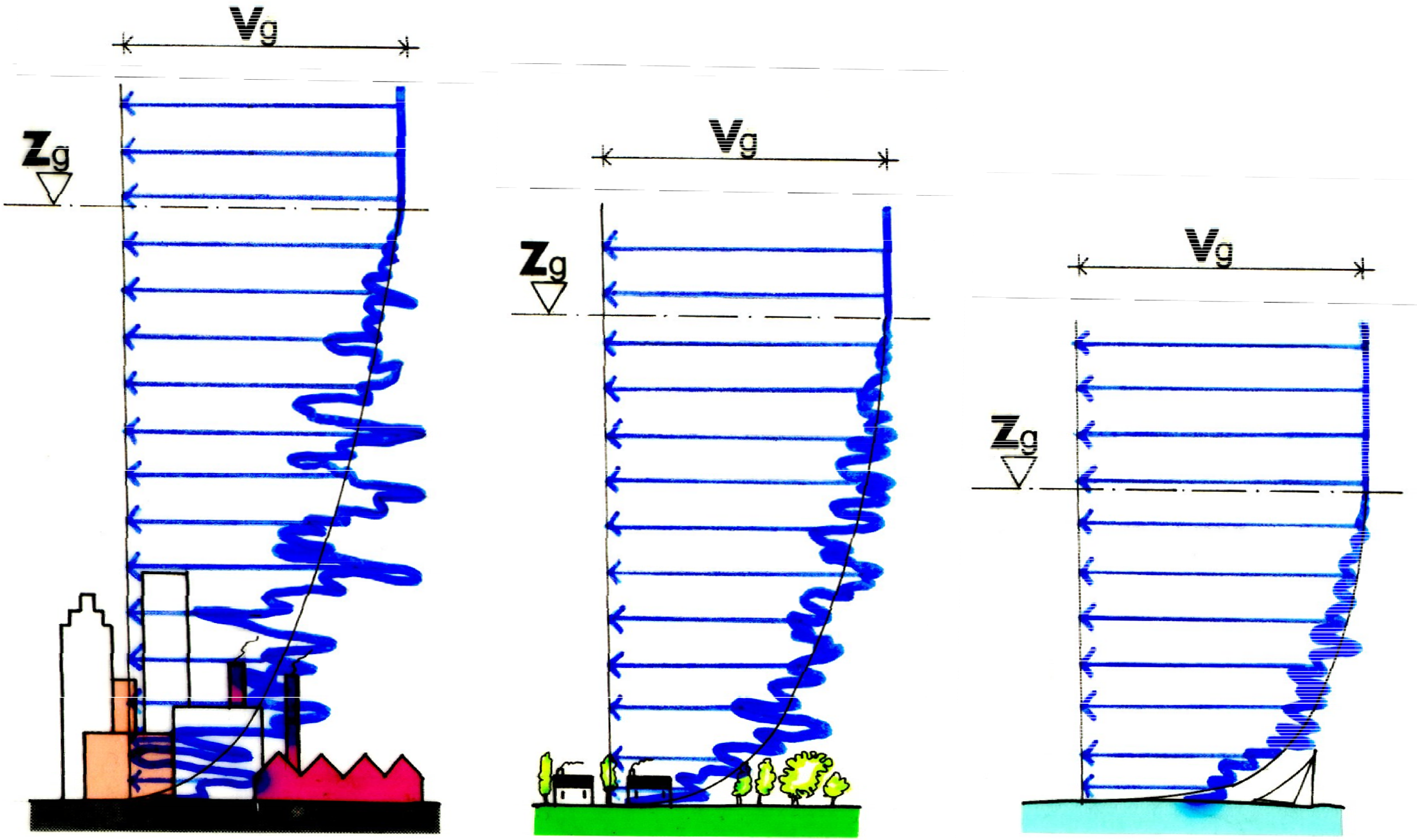


Atmospheric turbulence



$\bar{u}$	= mean wind velocity	$\mathbf{V}$	= instantaneous velocity
u'	= longitudinal turbulence	$\bar{\mathbf{V}}$	= mean wind velocity
v'	= lateral turbulence	$\mathbf{V}'$	= turbulent fluctuation
w'	= vertical turbulence		

Atmospheric Boundary Layer



Roughness length

Category	z_0 (m)	Landscape description
1	**0.0002**	Sea: Open sea or lake (irrespective of the wave size), tidal flat, snow-covered flat plain featureless desert, tarmac and concrete, with a free fetch of several kilometers.
2	**0.005**	Smooth: Featureless land surface without any noticeable obstacles and with negligible vegetation; e.g. beaches, pack ice without large ridges, morass, and snow-covered or fallow open country.
3	**0.03**	Open: Level country with low vegetation (e.g. grass) and isolated obstacles with separations of at least 50 obstacle heights; e.g. grazing land without windbreaks, heather, moor and tundra, runway area of airports.
4	**0.10**	Roughly open: Cultivated area with regular cover of low crops, or moderately open country with occasional obstacles (e.g. low hedges, single rows of trees, Isolated farms) at relative horizontal distances of at least 20 obstacle heights.
5	**0.25**	Rough: Recently-developed "young" landscape with high crops or crops of varying height, and scattered obstacles (e.g. dense shelterbelts, vineyards) at relative distances of about 15 obstacle heights.
6	**0.5**	Very rough: "Old" cultivated landscape with many rather large obstacle groups(large farms, clumps of forest) separated by open spaces of about10 obstacle heights. Also low large vegetation with small inter-spaces, such as bushland, orchards, young densely-planted forest.
7	**1.0**	Closed: Landscape totally and quote regularly covered with similar-size large obstacles, with open spaces comparable to the obstacle heights; e.g. mature regular forests, homogeneous cities or villages.
8	**≥ 2**	Chaotic: Centres of large towns with mixture of low-rise and high-rise buildings. Also irregular large forests with many clearings.

$z_0 = 0{,}001$ m

$z_0 = 0{,}003$ m

$z_0 = 0{,}03$ m

$z_0 = 0{,}1$ m

$z_0 = 0{,}3$ m

$z_0 = 1$ m

Atmospheric stability

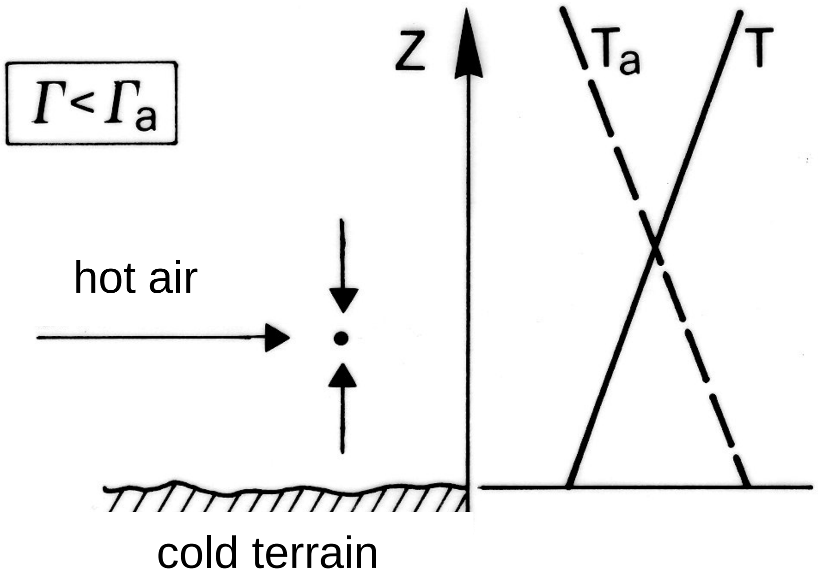
$\Gamma = -\partial T / \partial z$ = lapse rate
$\Gamma_a = g / C_p$ = adiabatic lapse rate
g = gravity acceleration
C_p = specific heat of the air at constant pressure

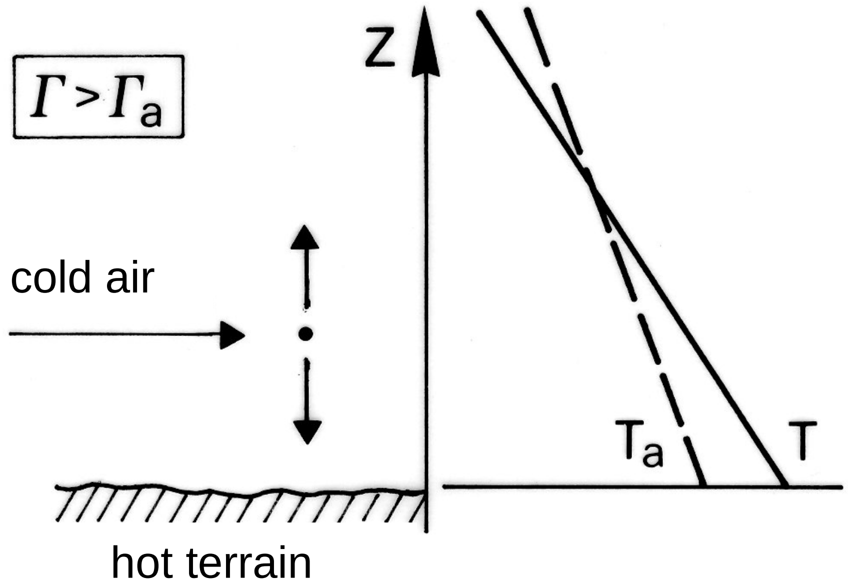
$\boxed{\Gamma < \Gamma_a}$ $\Rightarrow$ **Stably stratified atmosphere**
any particle tends to return to its initial position

$\boxed{\Gamma > \Gamma_a}$ $\Rightarrow$ **Unstably stratified atmosphere**
any particle tends to move farther away from its initial position

$\boxed{\Gamma = \Gamma_a}$ $\Rightarrow$ **Neutrally stratified atmosphere**
any particle tends to retain its new position

Stably stratified atmosphere **Unstably stratified atmosphere**

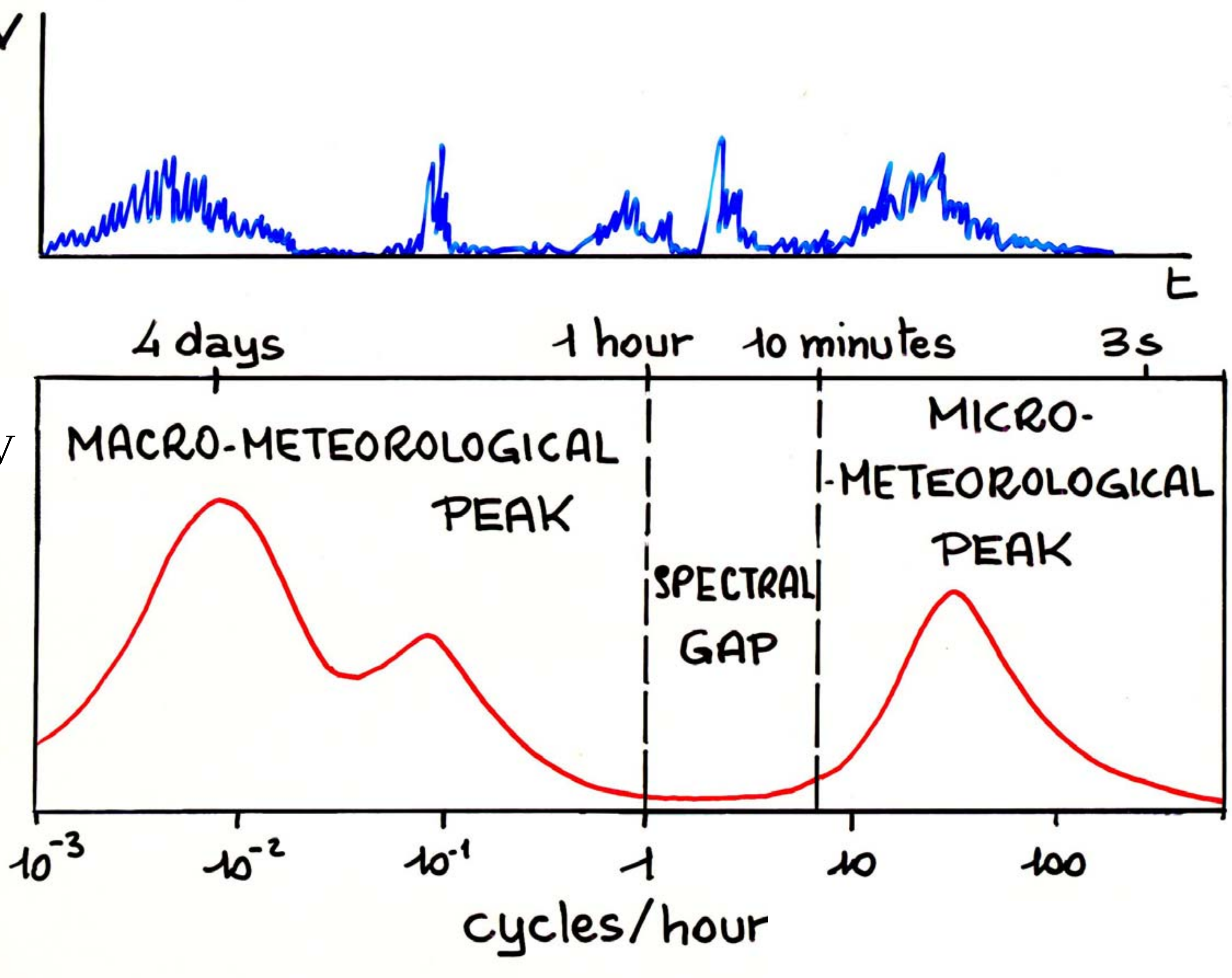




High wind velocity $\Rightarrow$ Large friction forces $\Rightarrow$
Large turbulent fluctuations $\Rightarrow$ Rapid atmospheric mixing $\Rightarrow$
Adiabatic atmospheric condition $\Rightarrow$ **Neutrally stratified atmosphere**

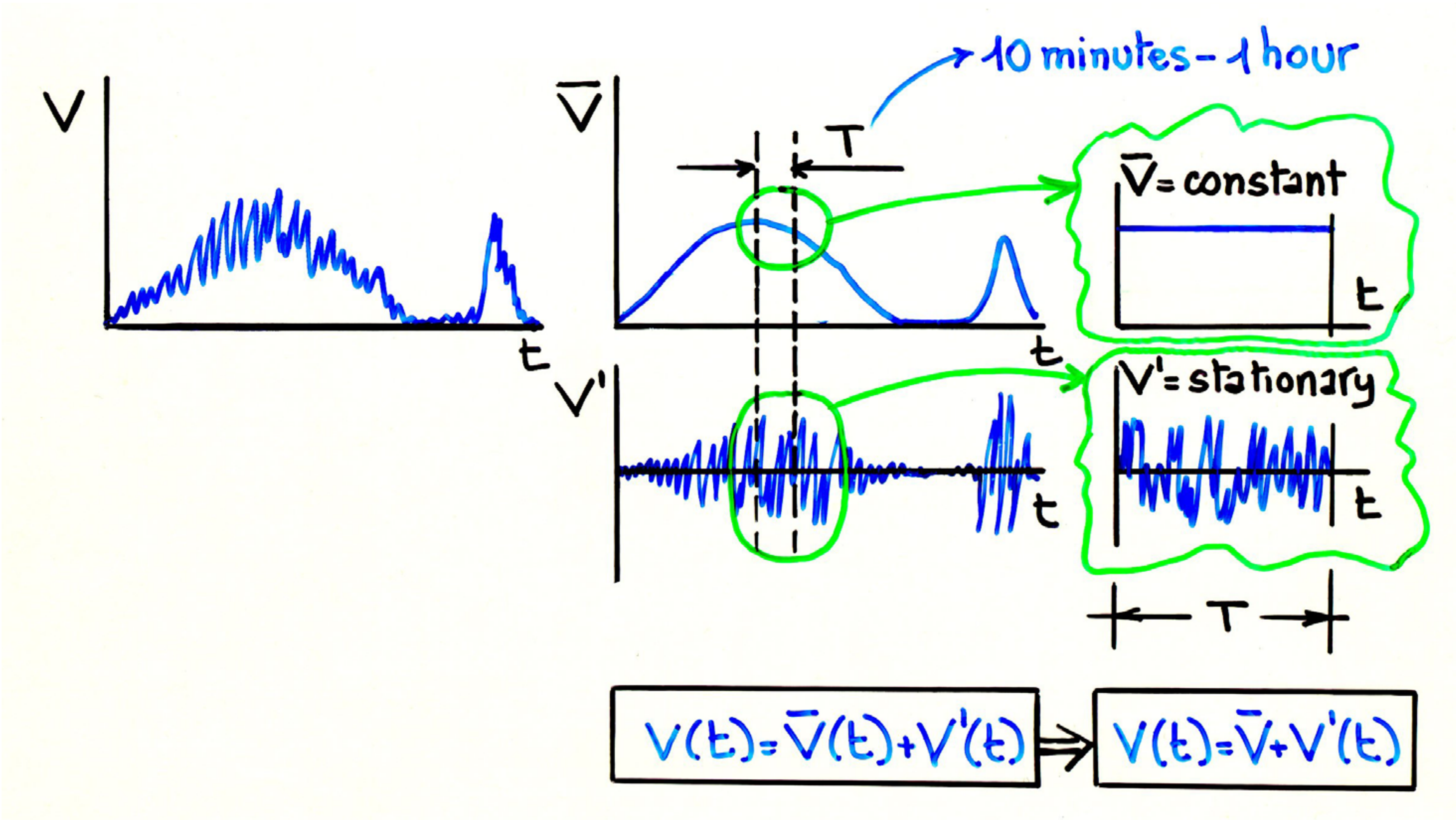
$\Rightarrow$ $\boxed{\Gamma = \Gamma_a}$ $\Rightarrow$ **Velocity V independent of temperature T**

Wind velocity and spectral density function

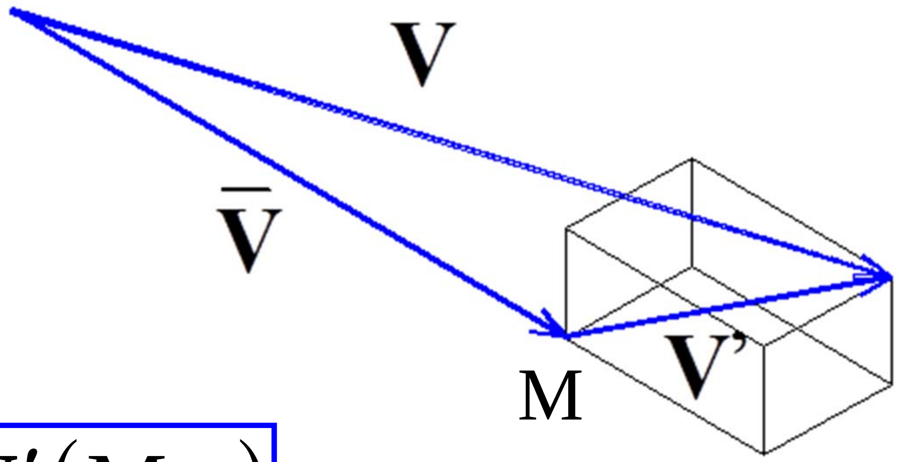


nS_V

Wind velocity and spectral density function



Wind velocity



$$\boxed{\mathbf{V}(\mathrm{M};\mathrm{t}) = \bar{\mathbf{V}}(\mathrm{M};\mathrm{t}) + \mathbf{V}'(\mathrm{M};\mathrm{t})}$$

$\bar{\mathbf{V}}(\mathrm{M};\mathrm{t})$ = **Mean wind velocity** (slowly varying)

- deterministic function of space M
- random function of time t

$\mathbf{V}'(\mathrm{M};\mathrm{t})$ = **Atmospheric turbulence** (rapidly varying)

- random function of space M and time t