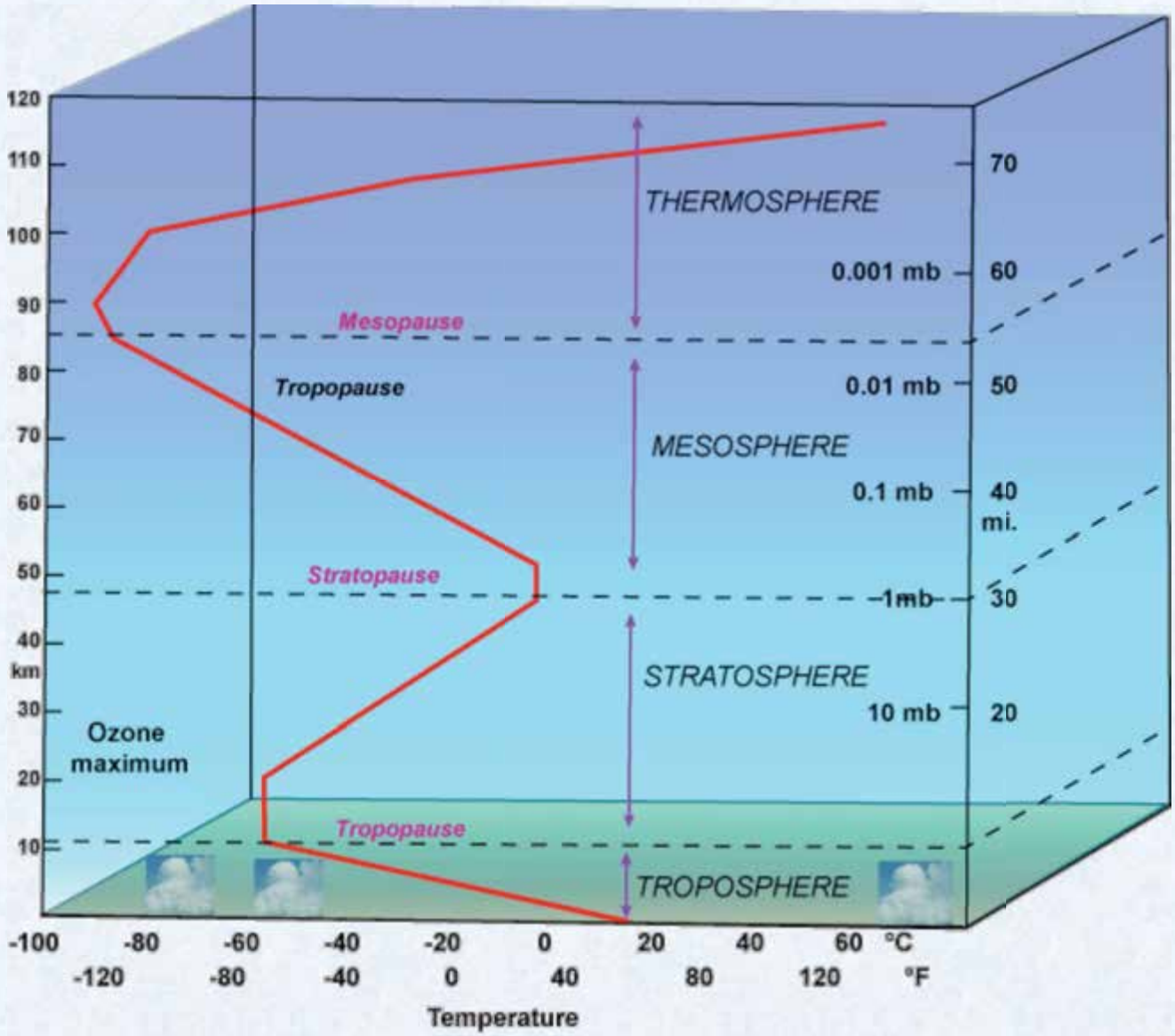
Emeritenstamm, 21. März 2016

Physik, Technologie, Informatik und menschliche Erfahrung - die Grundlagen der Wettervorhersage

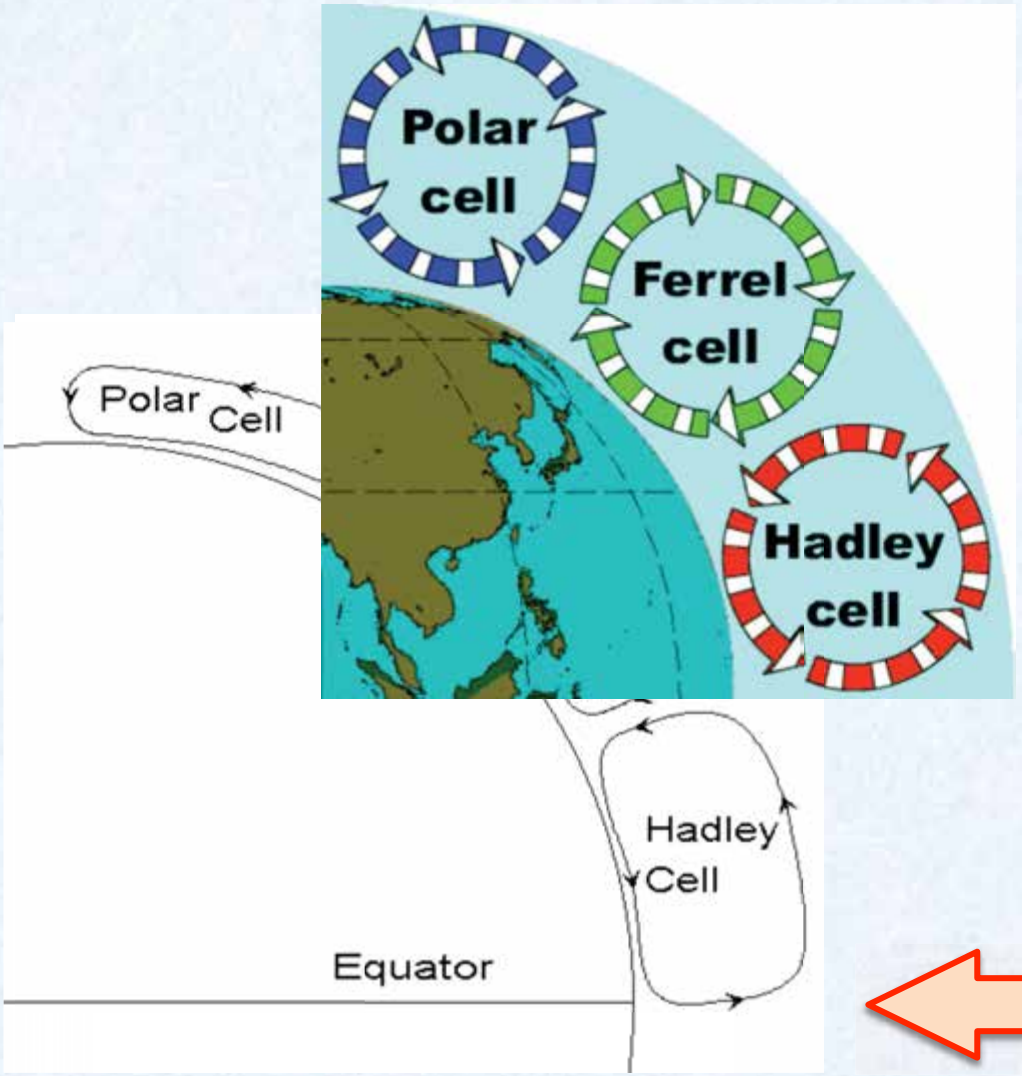
Hans Richner
Institut für Atmosphäre und Klima
ETH Zürich

The vertical structure of the atmosphere



Why is there weather?

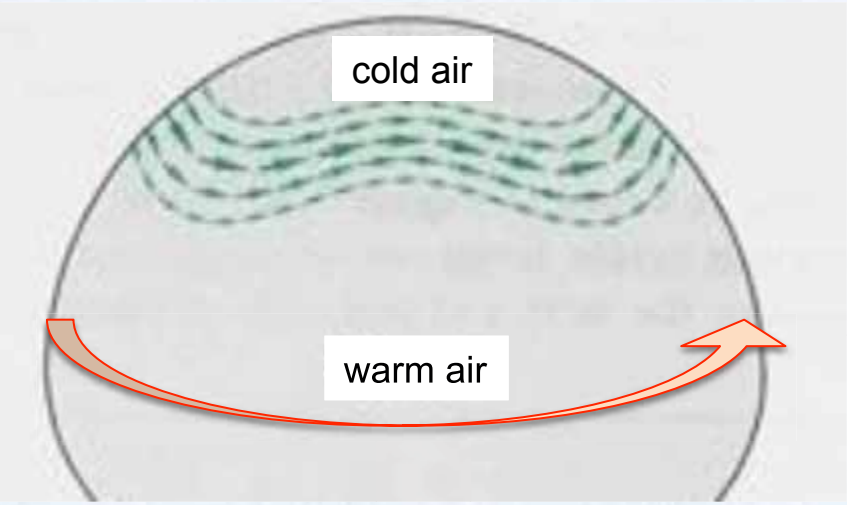
a) meridional circulation

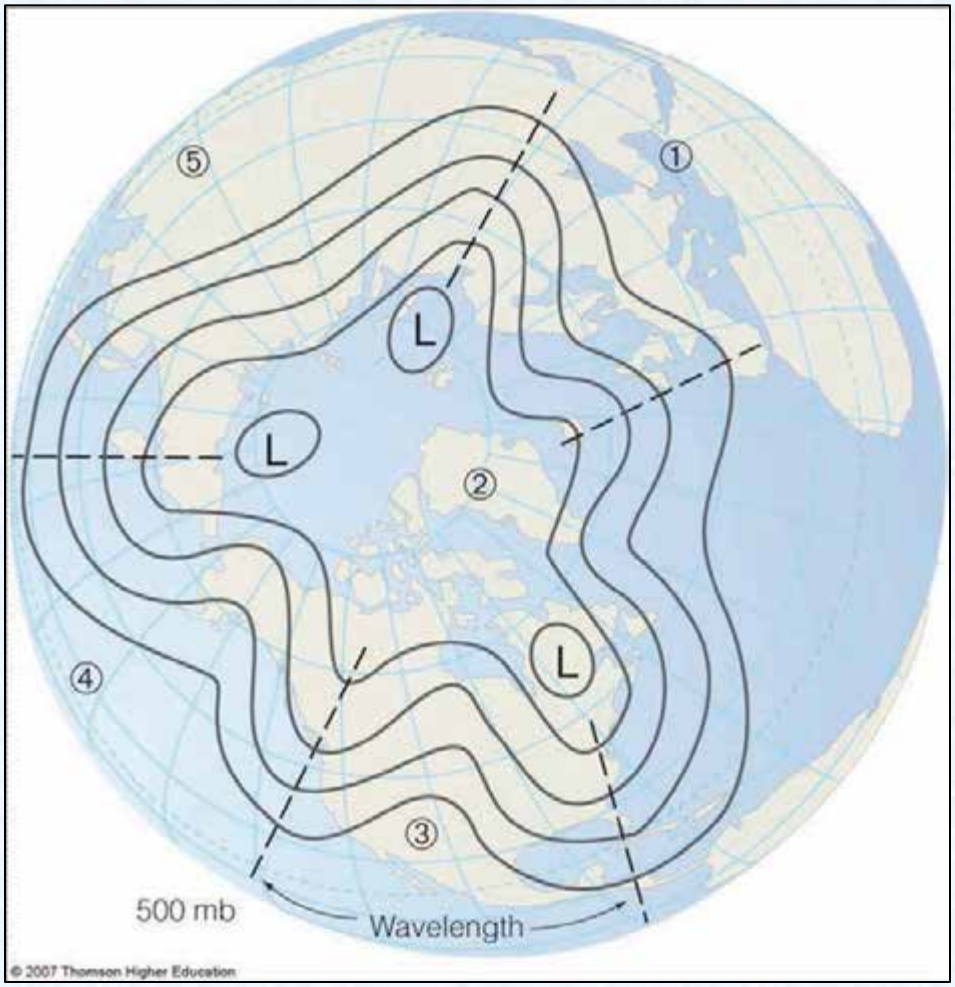


Insolation – ultimately the only source of energy for the earth!

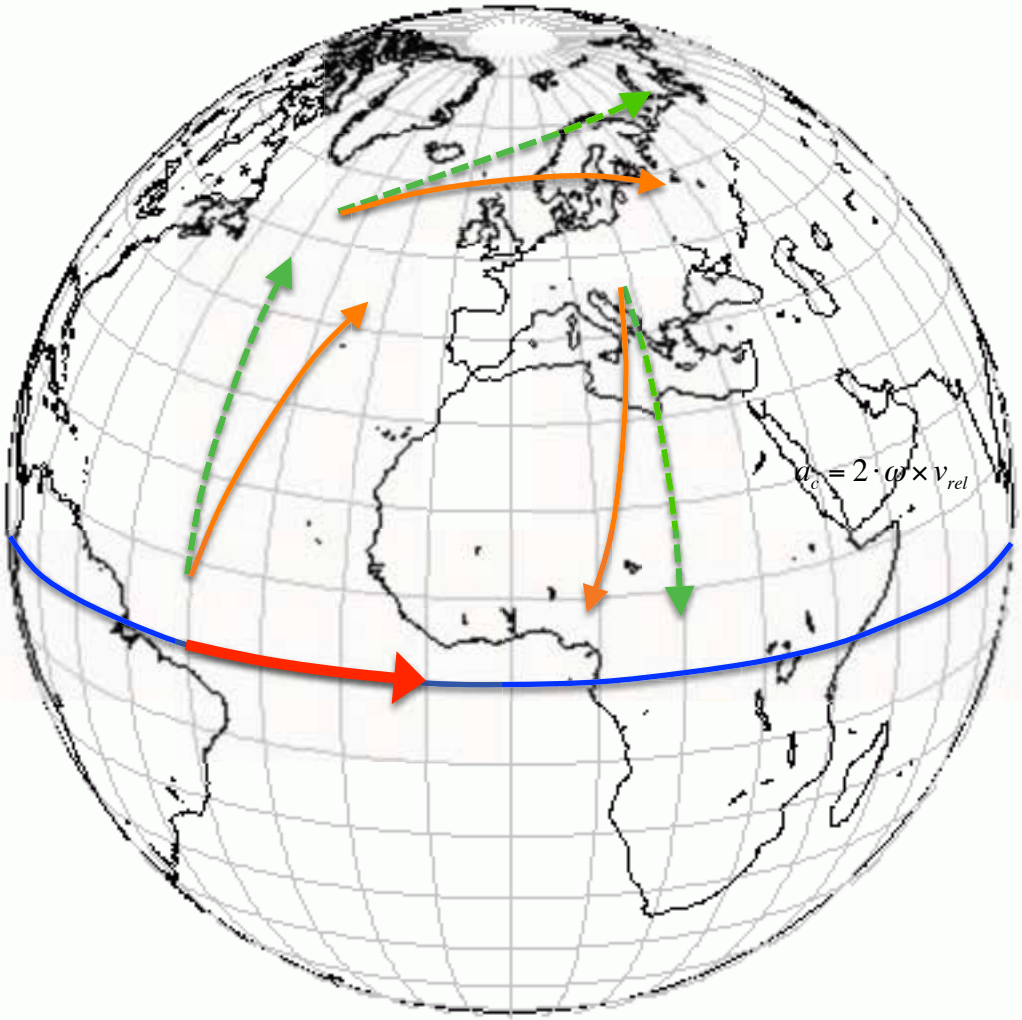
Why is there weather?

circumpolar circulation





Coriolis effect



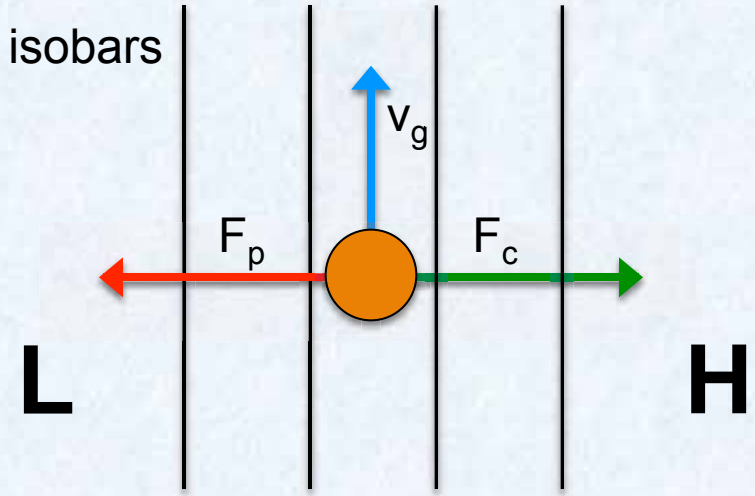
Coriolis acceleration:

$$a_c = 2 \cdot \left(\vec{\omega} \times \vec{v}_{rel} \right)$$

consequence:

on the **northern** hemisphere, a parcel of air is always deflected to the **right**;
on the **southern** hemisphere to the **left**

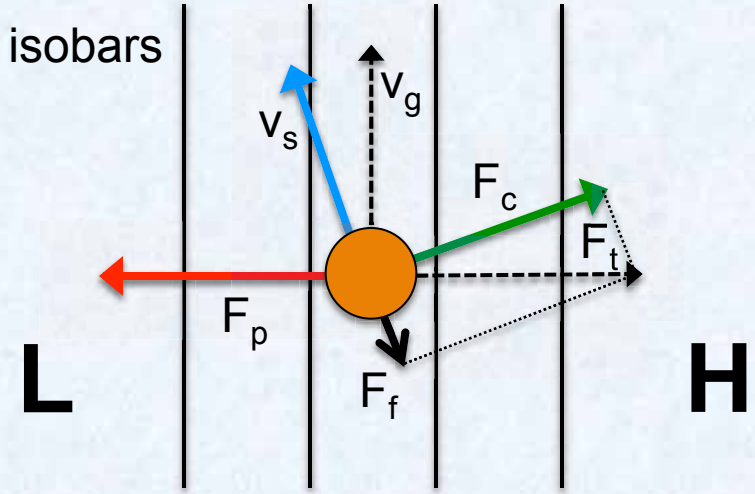
this is really important for the weather:
the geostrophic wind



the geostrophic wind
(northern hemisphere)

consequence:

- winds always blow **along** the isobars
- the higher the pressure gradient (i.e., the closer the isobars), the stronger the wind



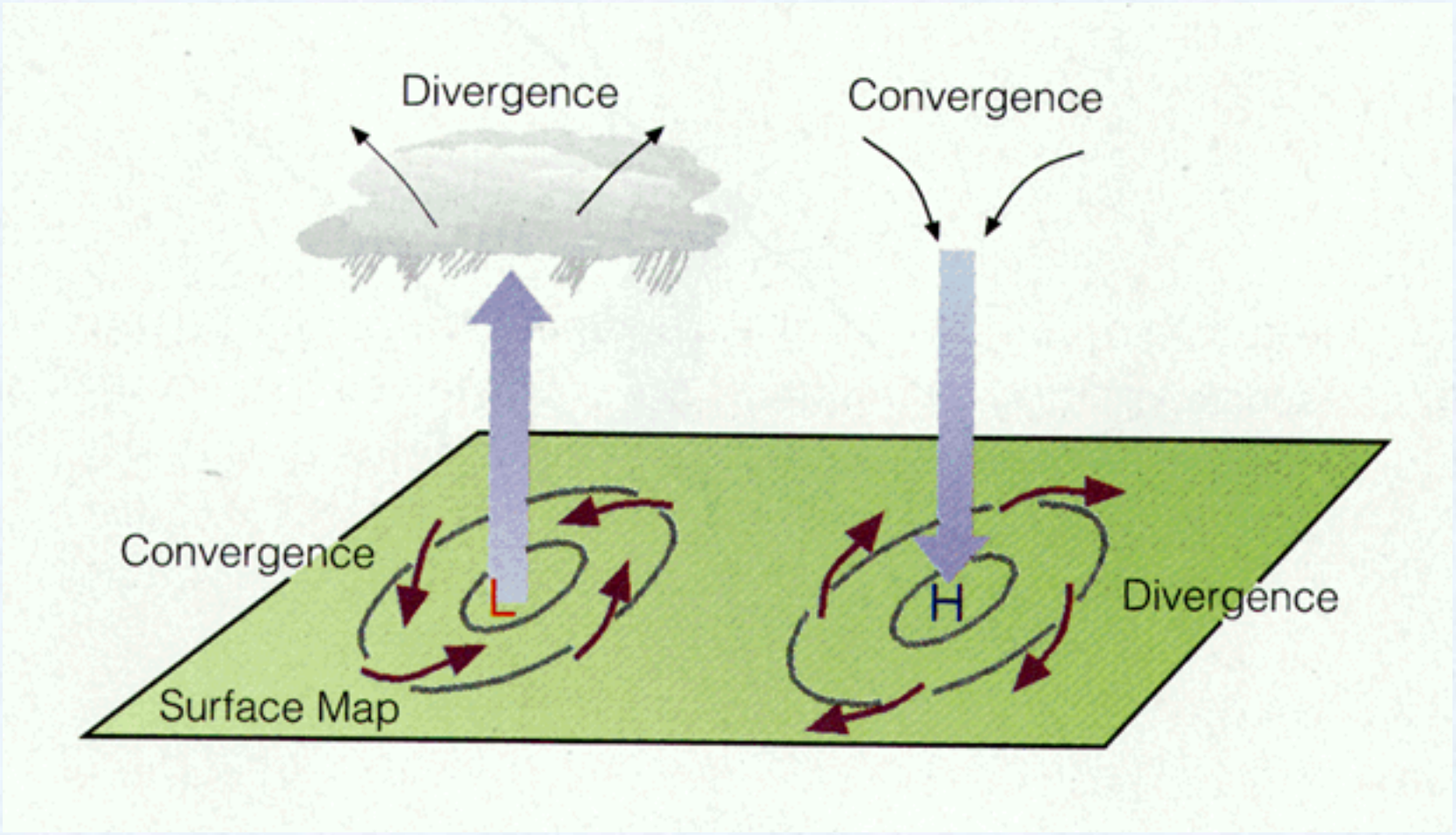
near-ground wind

near ground, the geostrophic wind experiences an additional force: **friction**

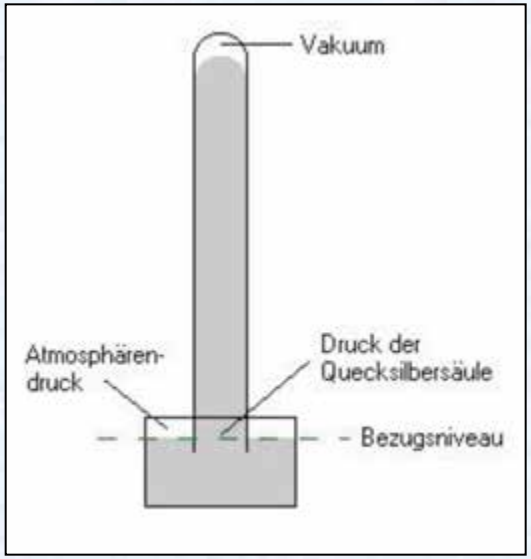
pressure centers

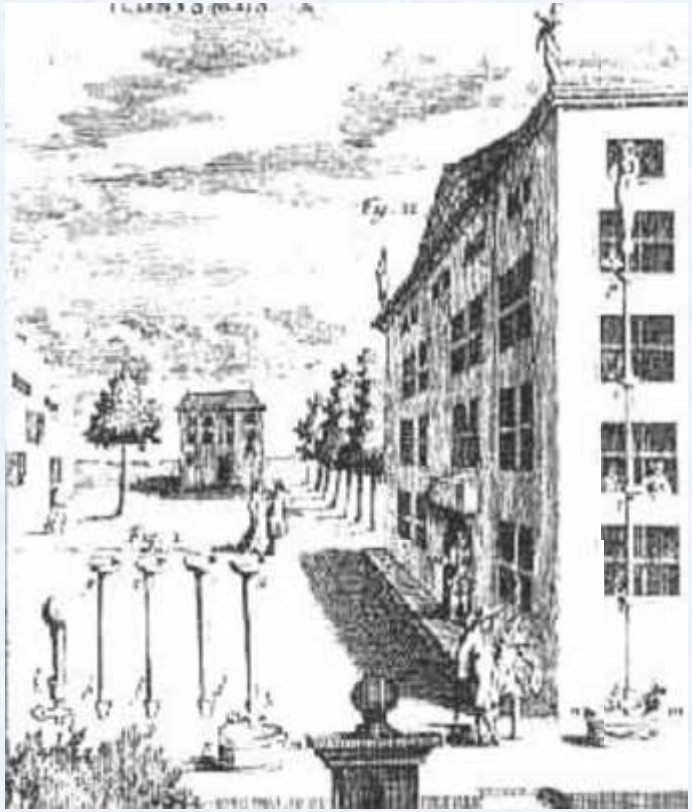
low pressure:
ccw rotation
cyclone

high pressure
cw rotation
anticyclone

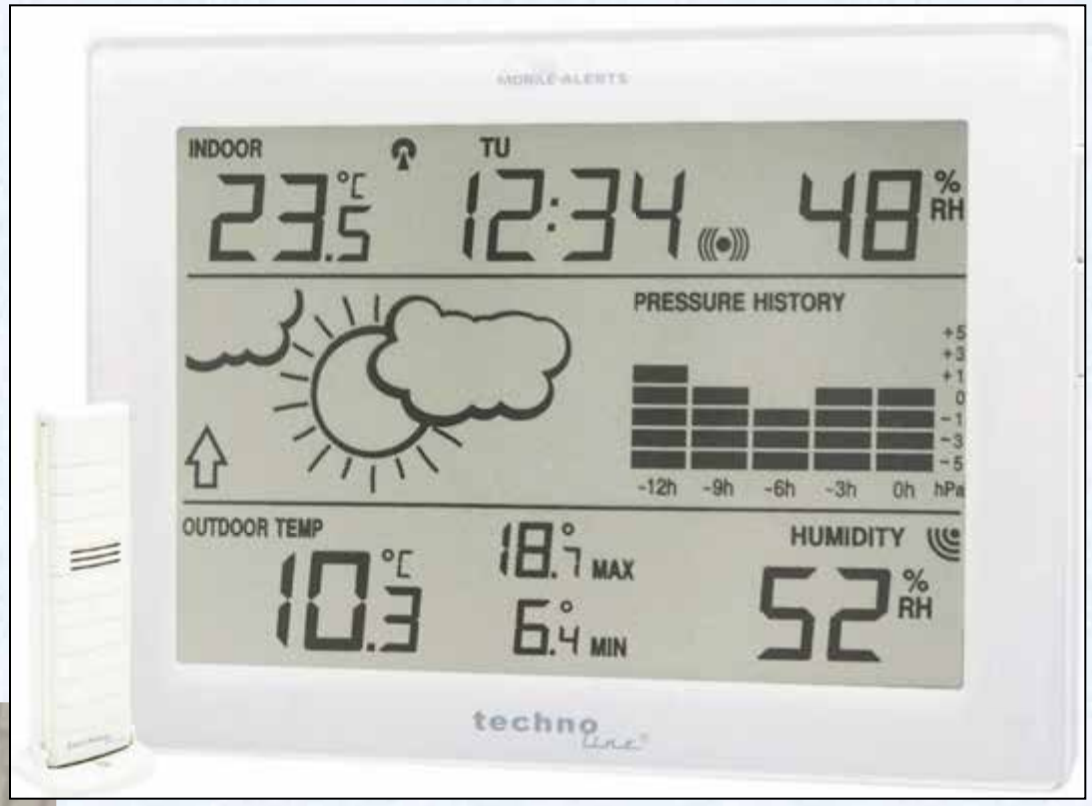


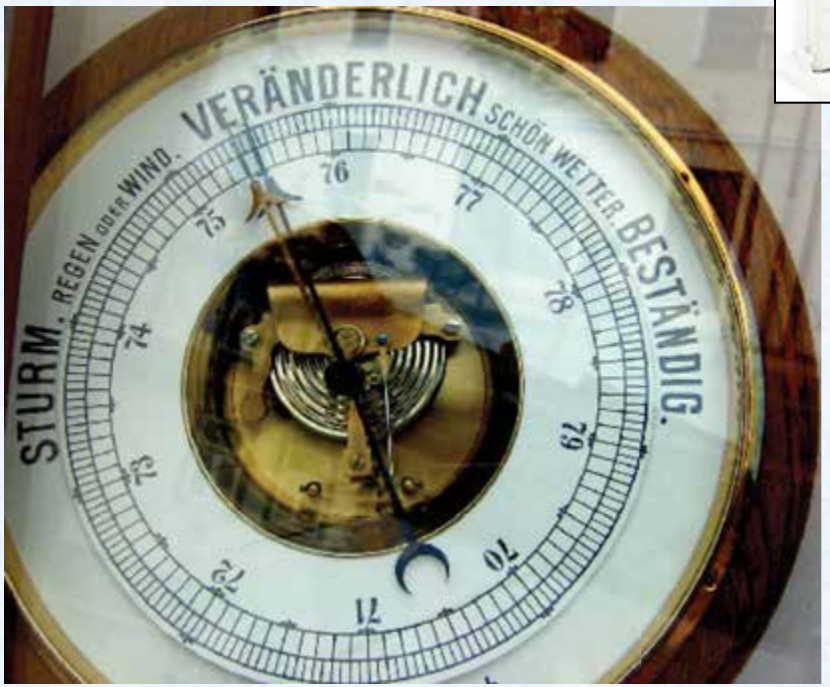
Evangelista Torricelli (1608 – 1647): Assistent of Galileo and inventor of the barometers; discovered that air pressure changes with the weather



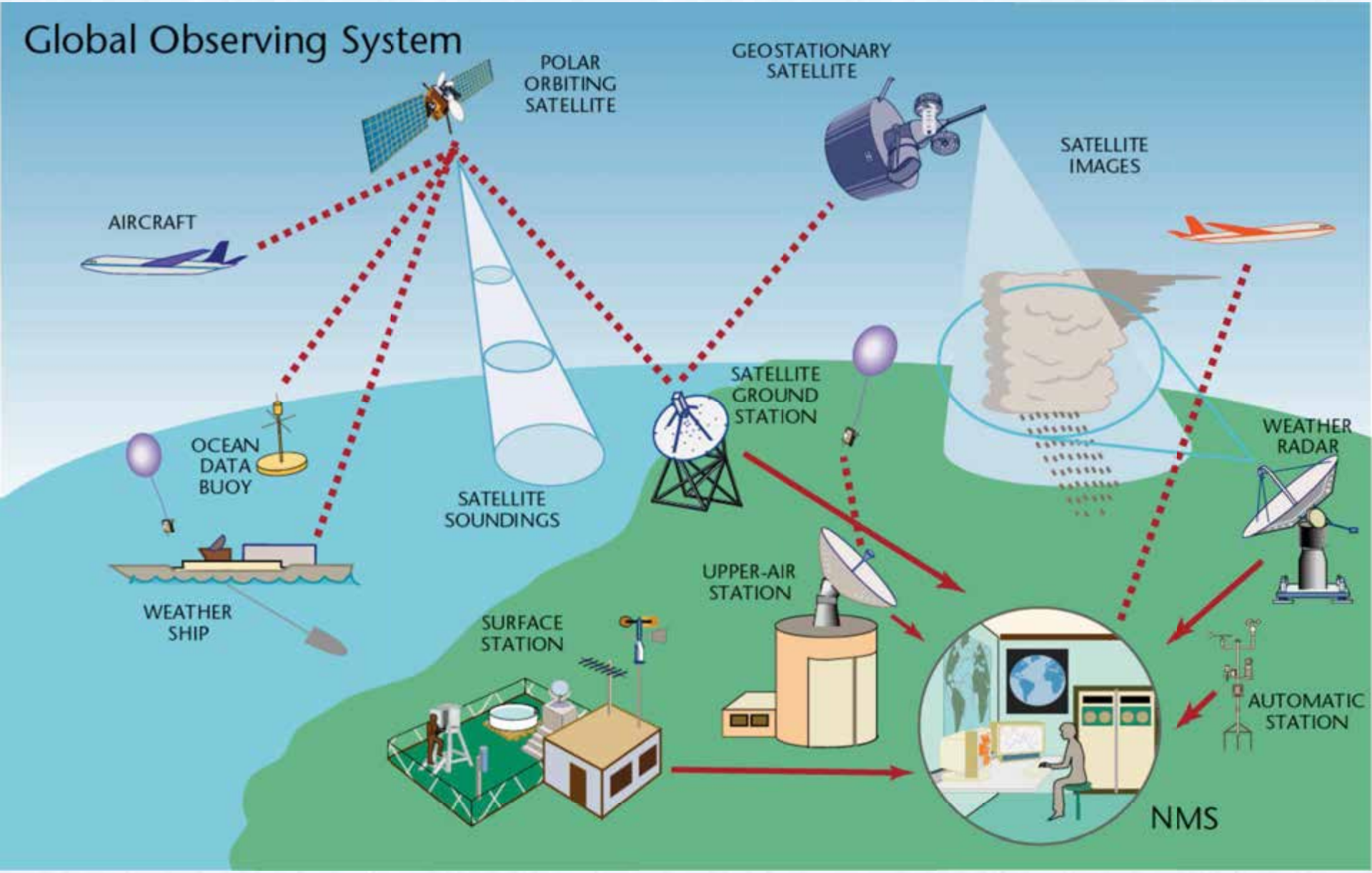


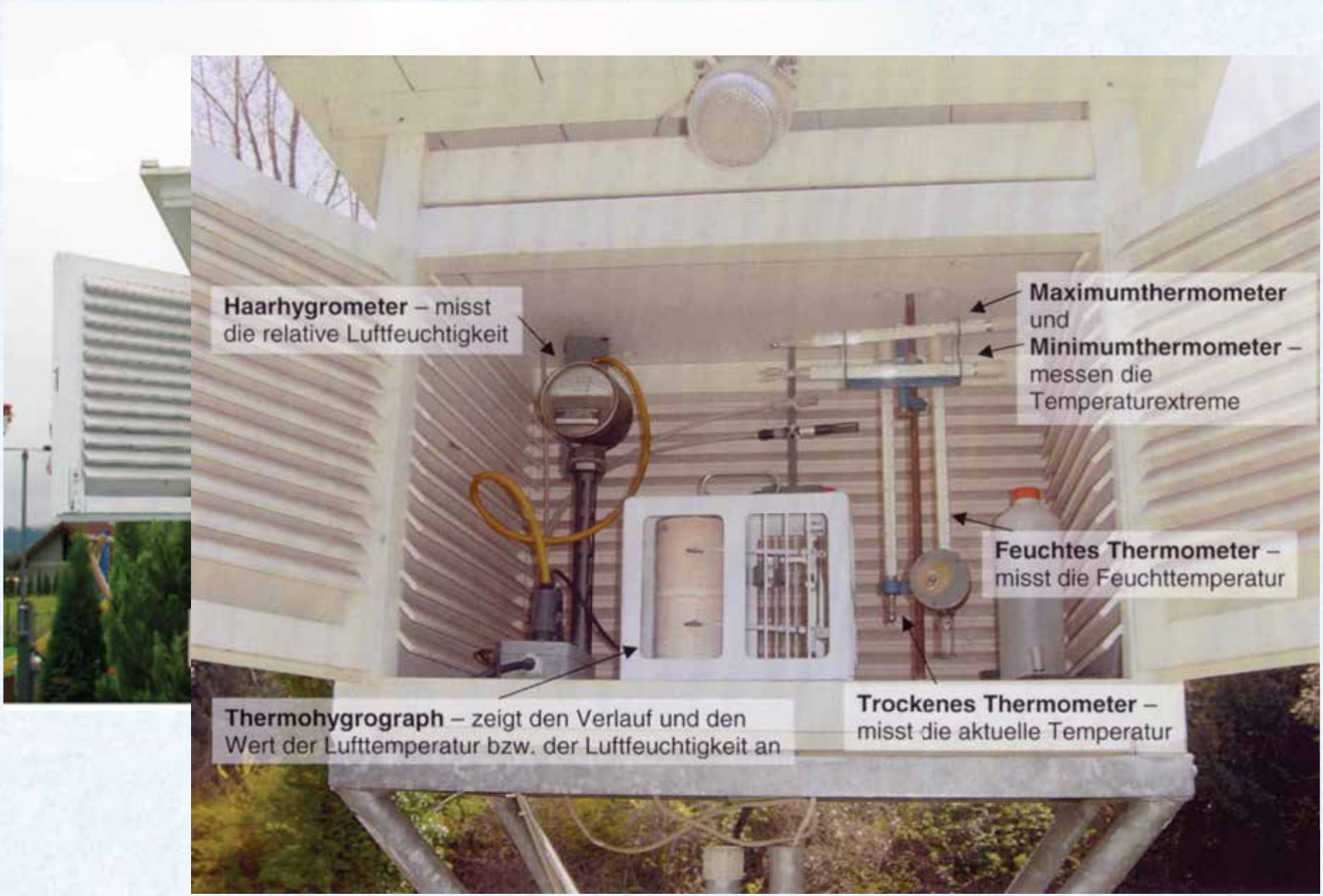
Emeritenstamm, March 21, 2016



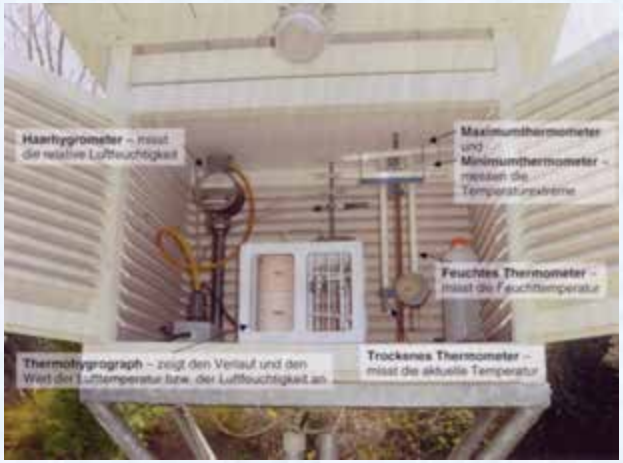


Hans Richner, IAC*ETH*: Weatherforecast

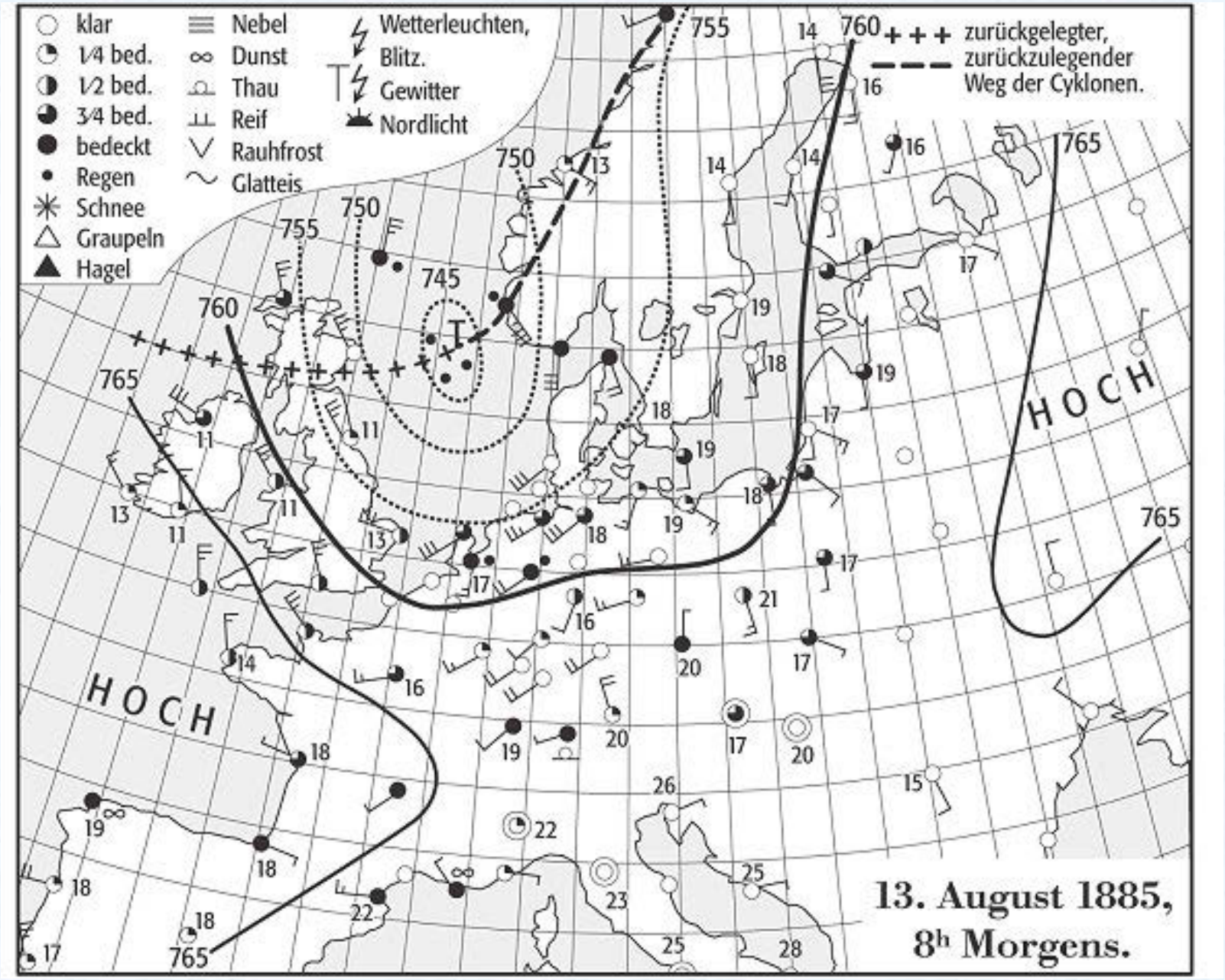

Global Observing System
POLAR ORBITING SATELLITE
GEOSTATIONARY SATELLITE
SATELLITE IMAGES
AIRCRAFT
SATELLITE GROUND STATION
OCEAN DATA BUOY
SATELLITE SOUNDINGS
WEATHER RADAR
UPPER-AIR STATION
WEATHER SHIP
SURFACE STATION
AUTOMATIC STATION
NMS

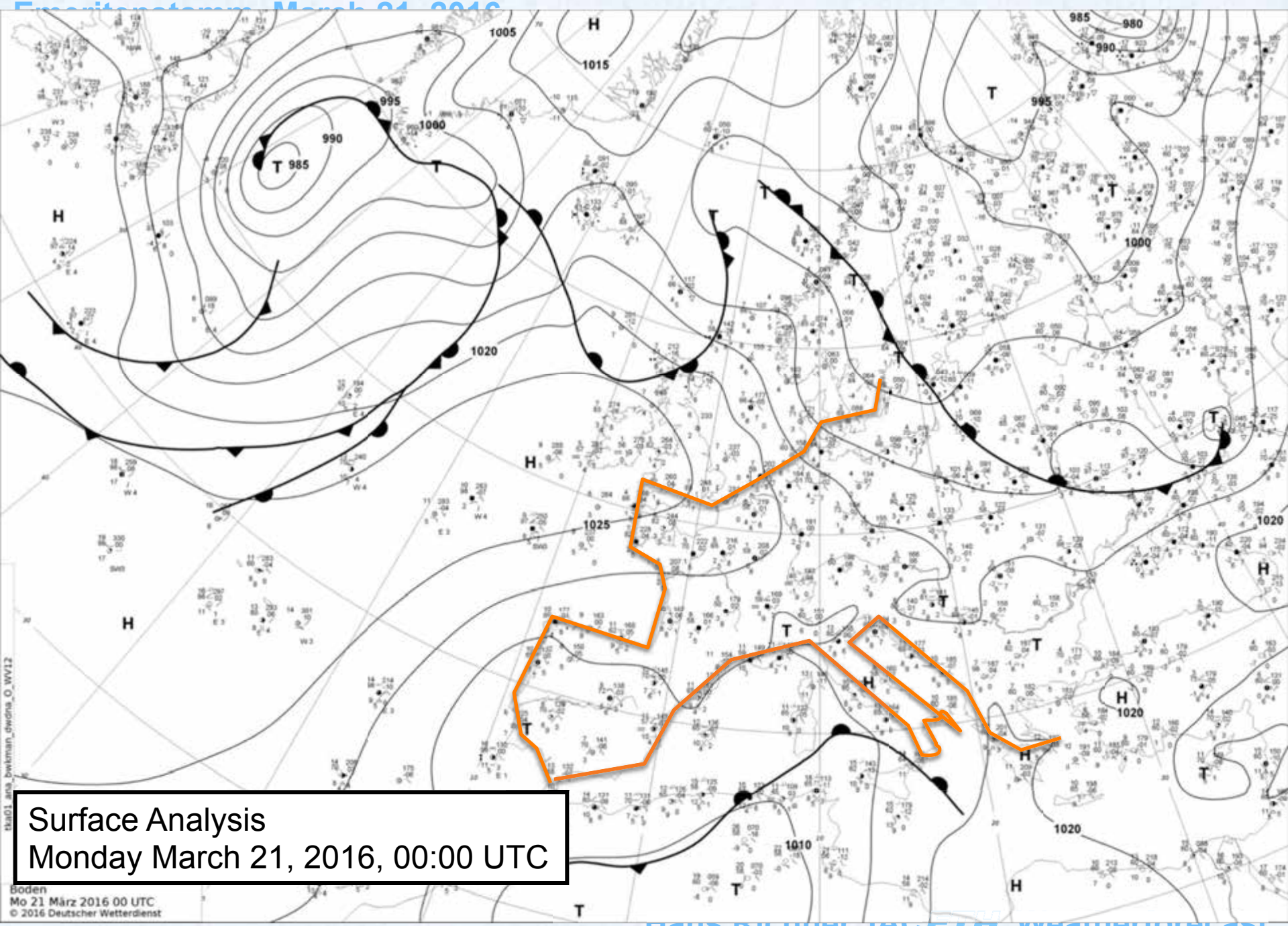

Haarhygrometer – misst die relative Luftfeuchtigkeit
Maximumthermometer und **Minimumthermometer** – messen die Temperaturextreme
Feuchtes Thermometer – misst die Feuchttemperatur
Thermohygrograph – zeigt den Verlauf und den Wert der Lufttemperatur bzw. der Luftfeuchtigkeit an
Trockenes Thermometer – misst die aktuelle Temperatur

automatic weatherstation

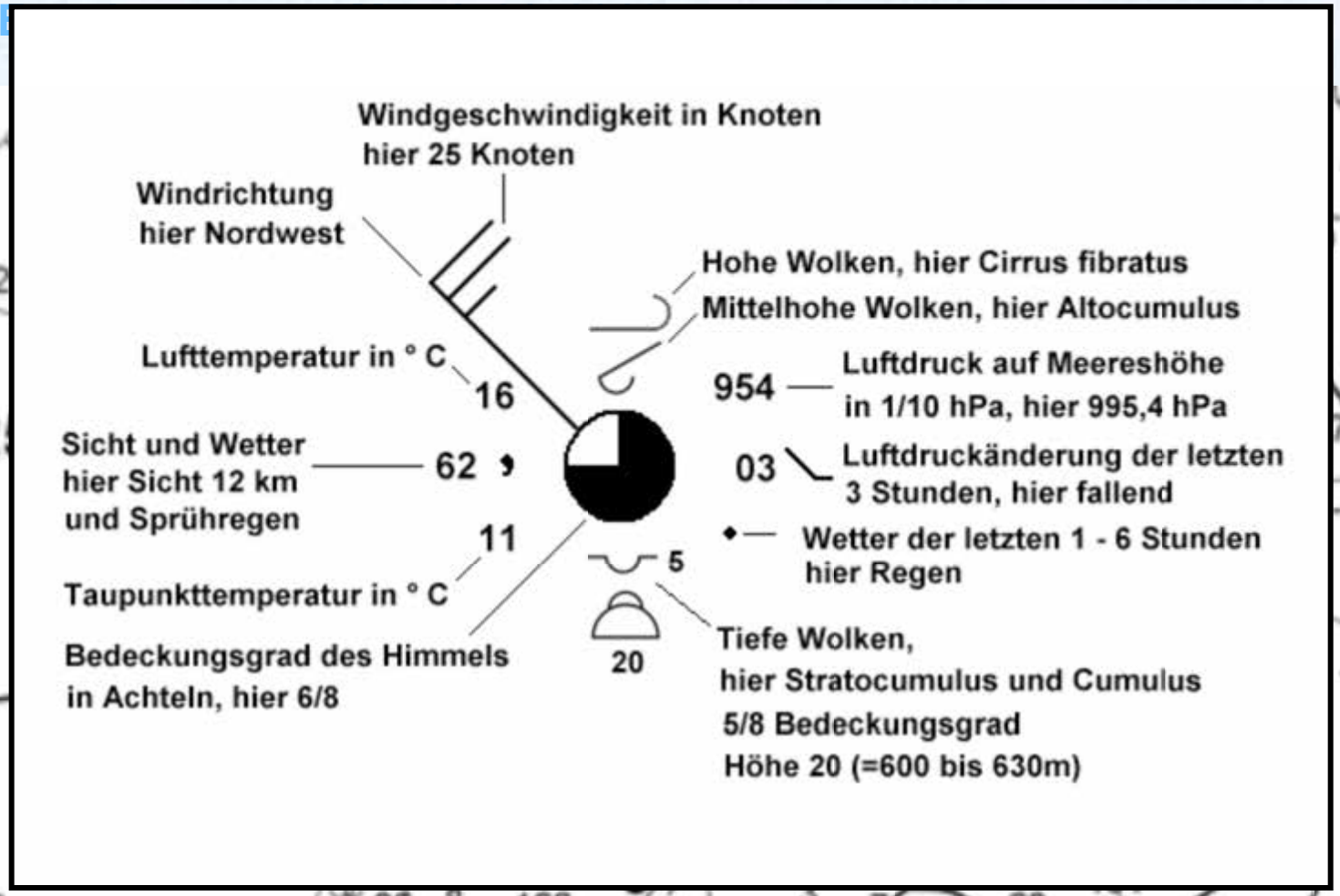


heated and ventilated thermometer

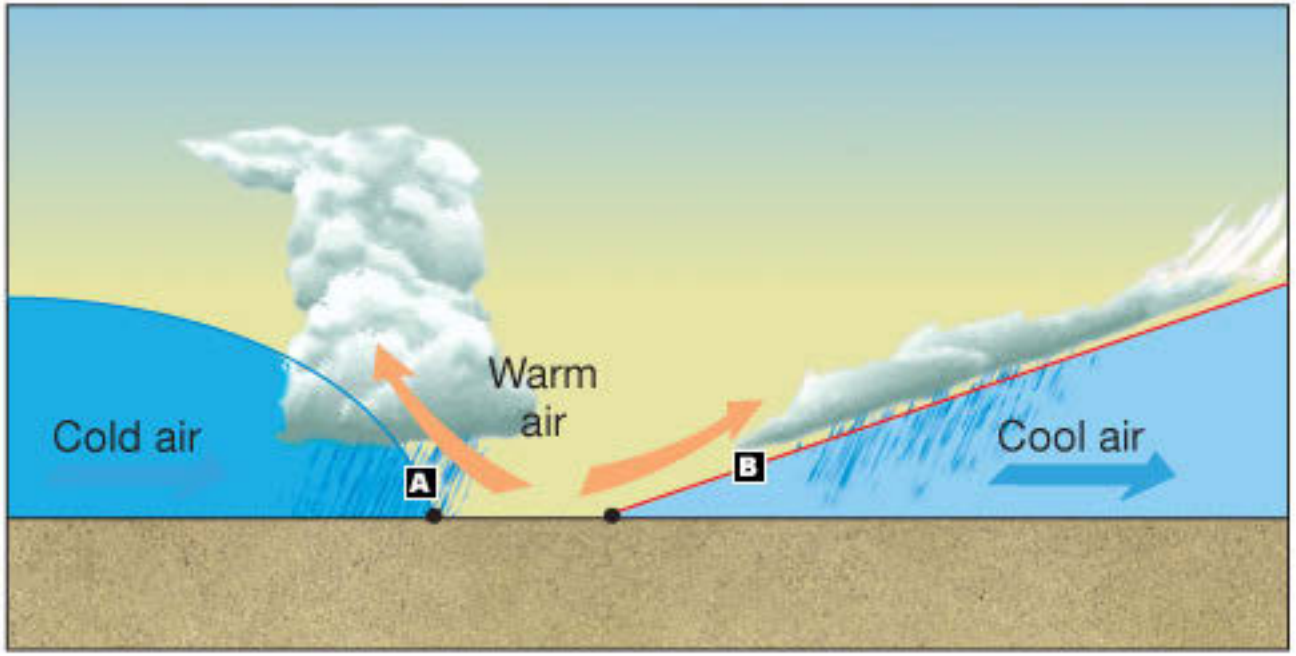

klar
1/4 bed.
1/2 bed.
3/4 bed.
bedeckt
Regen
Schnee
Graupeln
Hagel
Nebel
Dunst
Thau
Reif
Rauhfrost
Glatteis
Wetterleuchten,
Blitz.
Gewitter
Nordlicht
zurückgelegter,
zurückzulegender
Weg der Cyklonen.
HOCH
HOCH
13. August 1885,
8h Morgens.



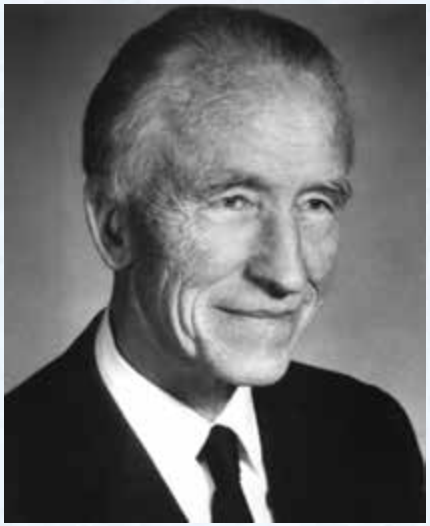
Surface Analysis
Monday March 21, 2016, 00:00 UTC


Windgeschwindigkeit in Knoten
hier 25 Knoten
Windrichtung
hier Nordwest
Hohe Wolken, hier Cirrus fibratus
Mittelhohe Wolken, hier Altocumulus
Lufttemperatur in ° C
16
954
Luftdruck auf Meereshöhe
in 1/10 hPa, hier 995,4 hPa
Sicht und Wetter
hier Sicht 12 km
und Sprühregen
62
03
Luftdruckänderung der letzten
3 Stunden, hier fallend
Wetter der letzten 1 - 6 Stunden
hier Regen
11
5
Taupunkttemperatur in ° C
Tiefe Wolken,
hier Stratocumulus und Cumulus
5/8 Bedeckungsgrad
Höhe 20 (=600 bis 630m)
Bedeckungsgrad des Himmels
in Achteln, hier 6/8
20

fronts



A.



cold air is heavier than warm air!

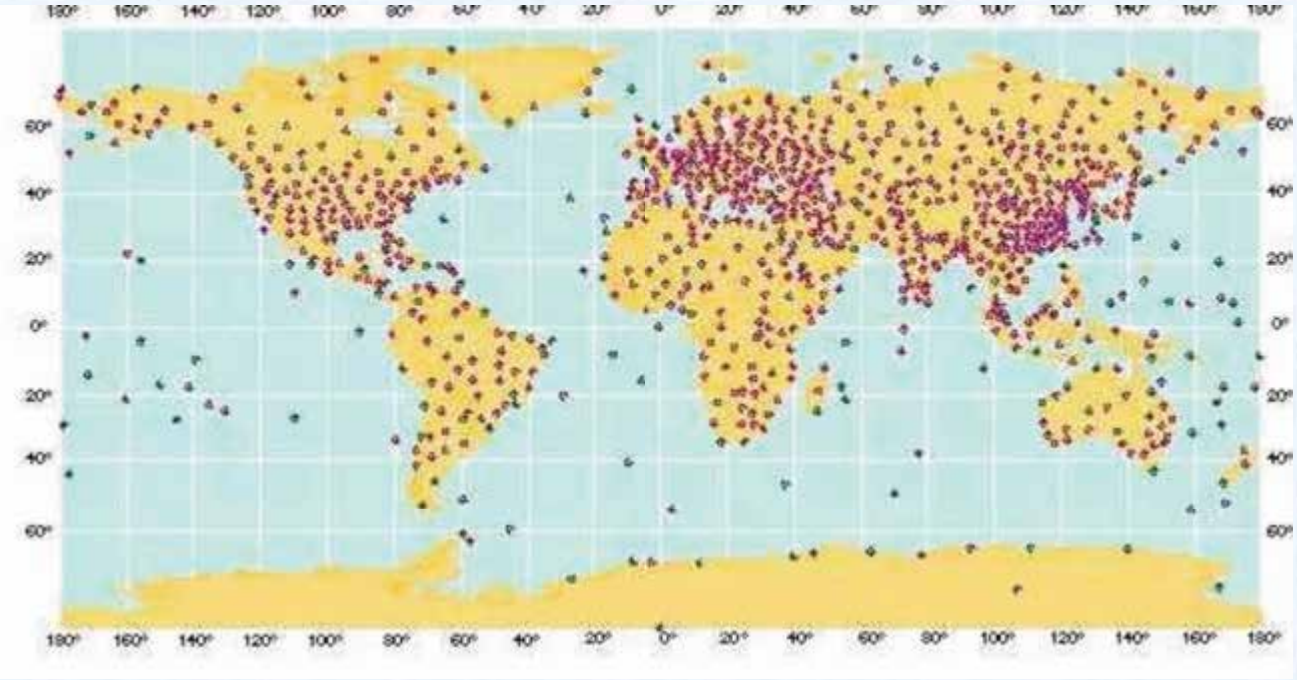
coldfront: moves with the speed of the cold air mass, displaces the warm air upwards

warmfront: warm air glides over cold air mass, front moves considerably slower than the warm air mass itself

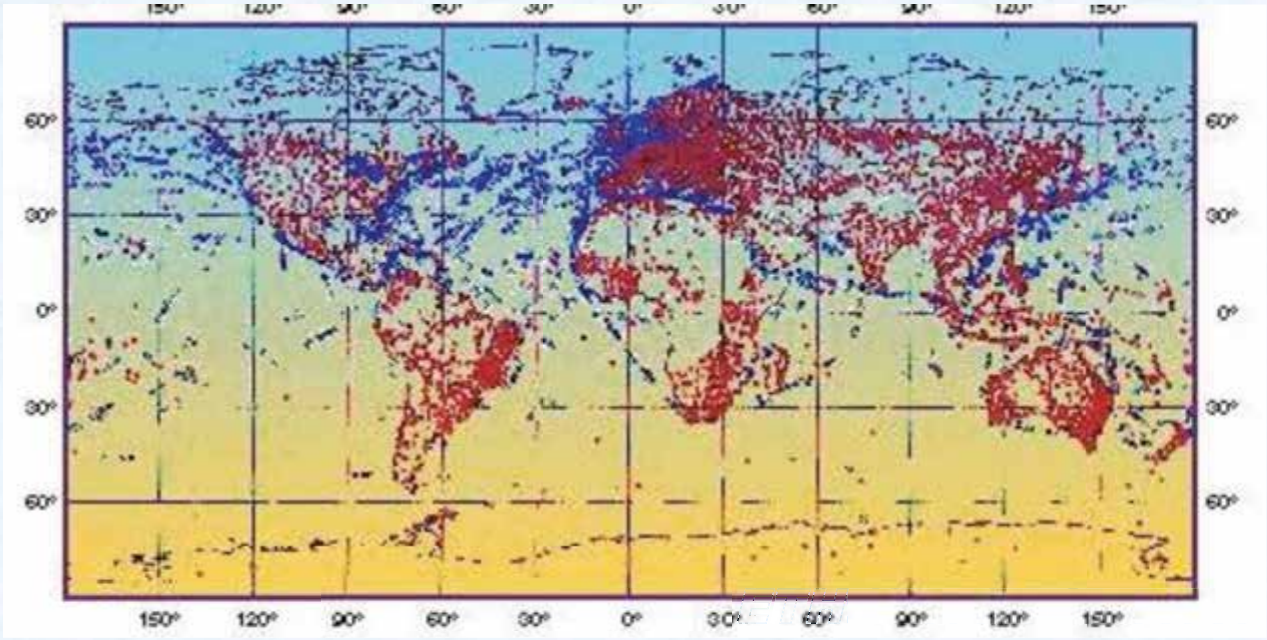
Jacob Bjerknes 1897- 1975


MétéoSuisse

Emeritenstamm, March 21, 2016



radiosonde stations
("weather balloons")
about1300

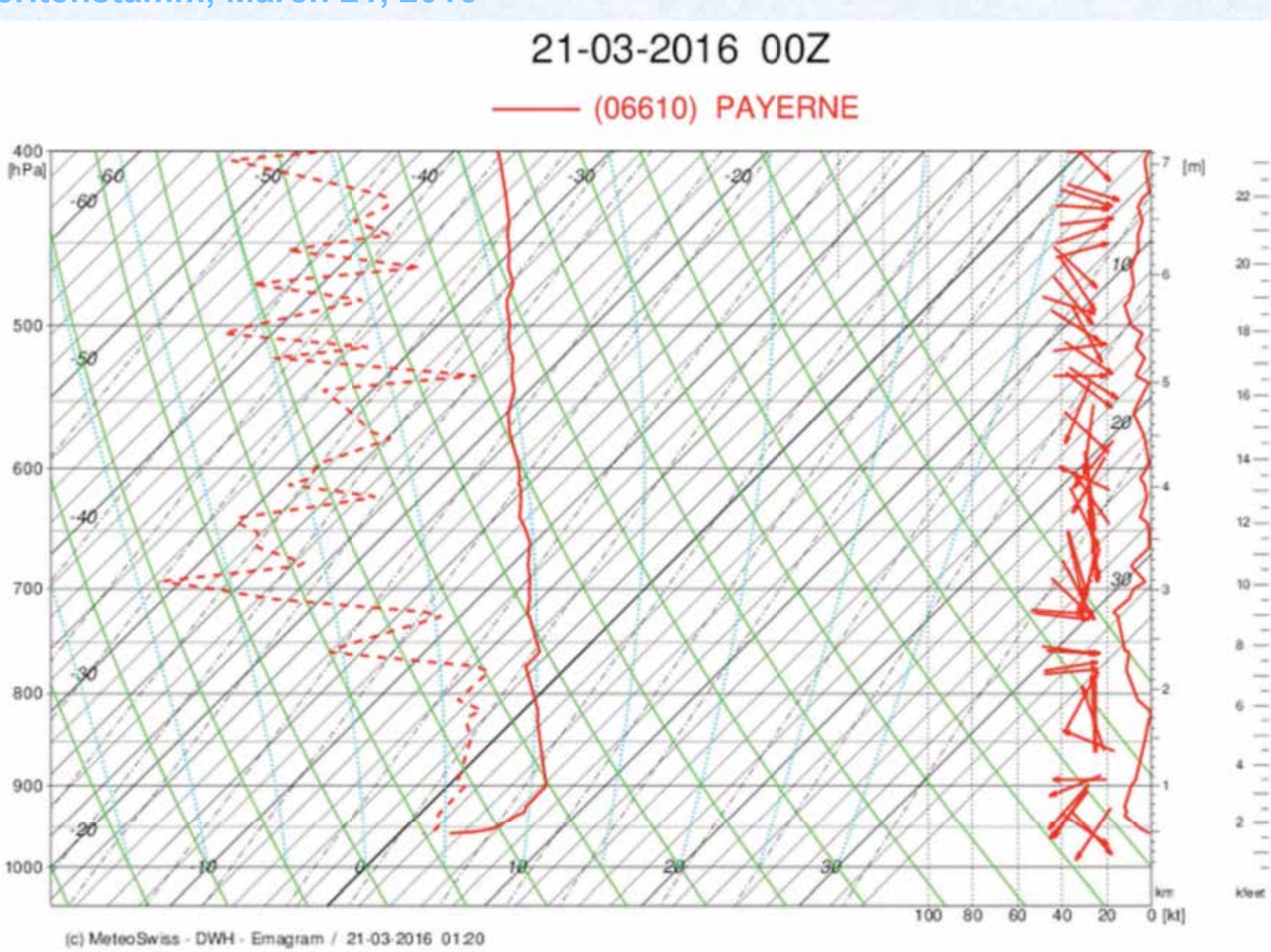


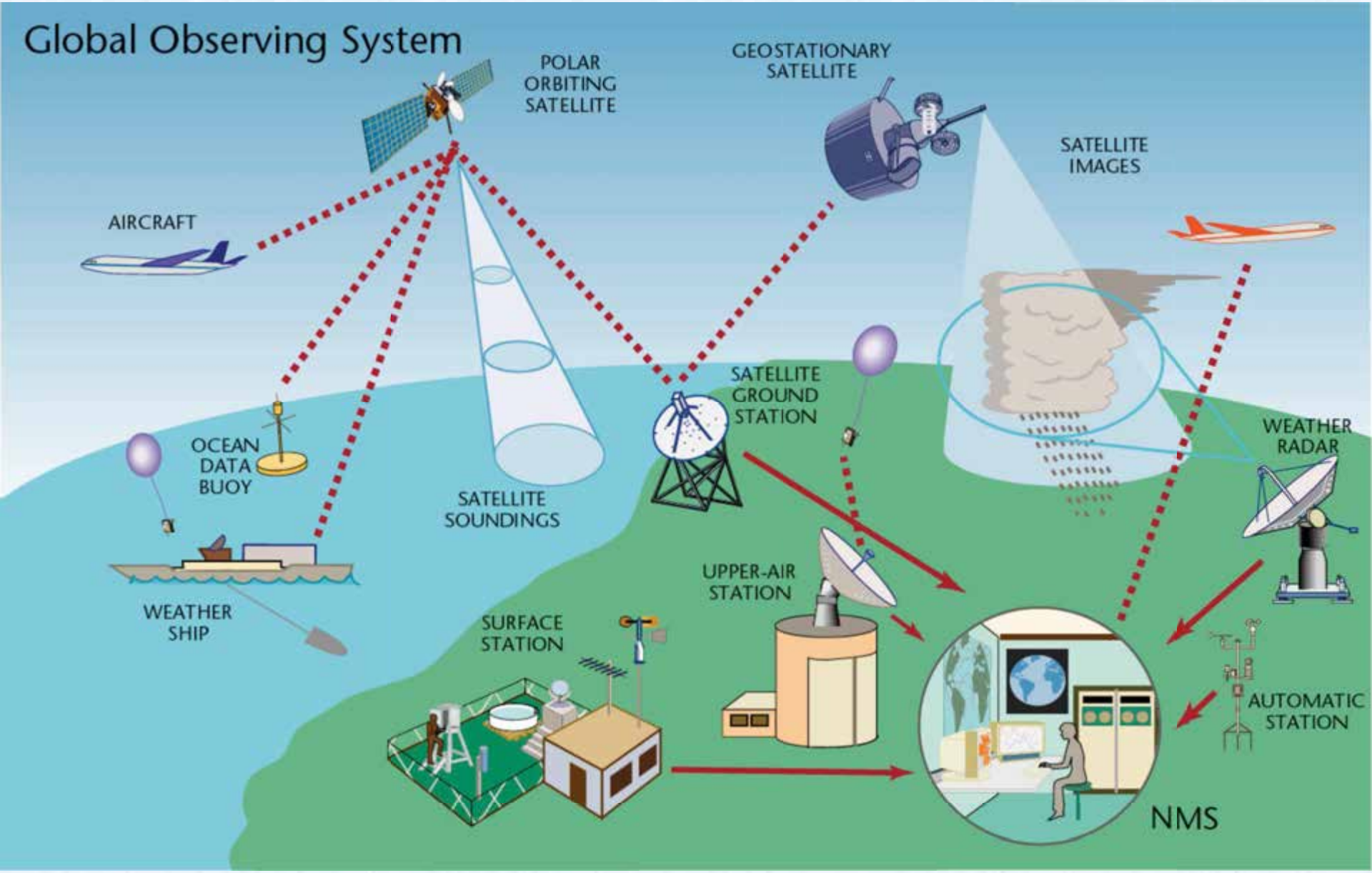
surface stations
about 11'000
RBSN: 4000
RBCN: 3000

TEMP message
(2 parts of 4, Mumbai, 15 m asl)

```
TTAA 70001 43003 99009 26856 00000 00091 26457 34002 92781
27268 35520 85522 22867 34008 70177 11263 32519 50588 03984
30027 40761 15779 28023 30972 29780 26541 25099 40375 26539
20247 51571 27036 15428 65167 27035 10666 80364 23530 88999
77999 31313 41708 82333 =

TTBB 70008 43003 00009 26856 11979 25858 22963 27463 33947
28068 44940 28270 55902 25465 66865 23064 77837 22471 88830
21870 99797 19266 11751 15263 22600 00461 33597 00061 44574
02164 55542 03970 66536 04371 77526 03774 88516 04376 99506
03781 11478 05987 22170 59567 33100 80364 21212 00009 00000
11977 34510 22944 35021 33913 35520 44875 33011 55841 34508
66795 34020 77733 31013 88704 32519 99618 29018 11600 29520
22532 29531 33509 30528 44487 28528 55442 26522 66422 28519
77383 27033 88298 26541 99236 26038 11158 26541 22137 28032
33103 23527 44100 23530 31313 41708 82333 41414 00900 51515
11911 35520 22800 34019 33600 29520 =
```


21-03-2016 00Z
(06610) PAYERNE
400
[hPa]
500
600
700
800
900
1000
[m]
km
[kt]
100 80 60 40 20 0
(c) MeteoSwiss - DWH - Emagram / 21-03-2016 01:20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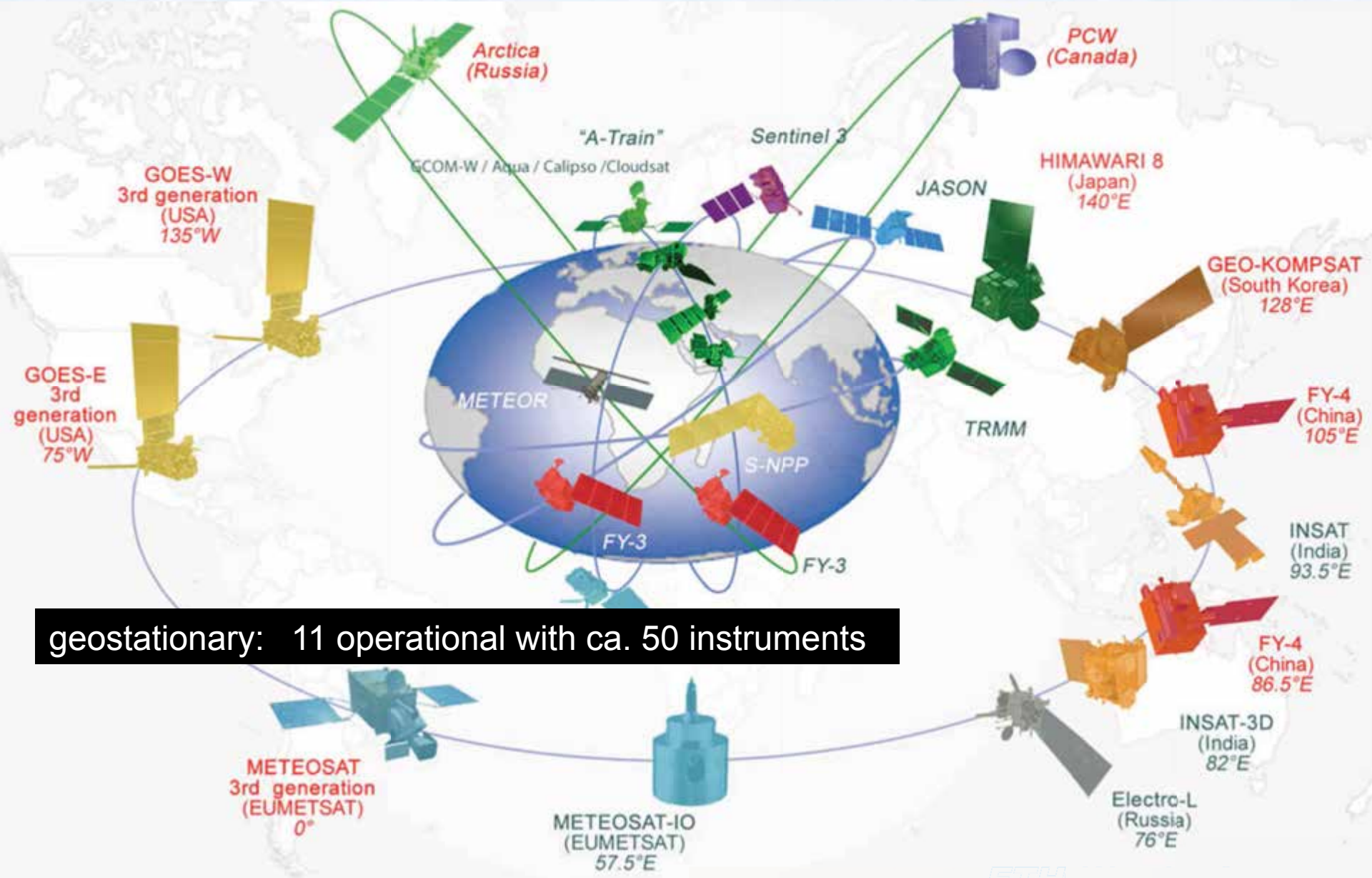
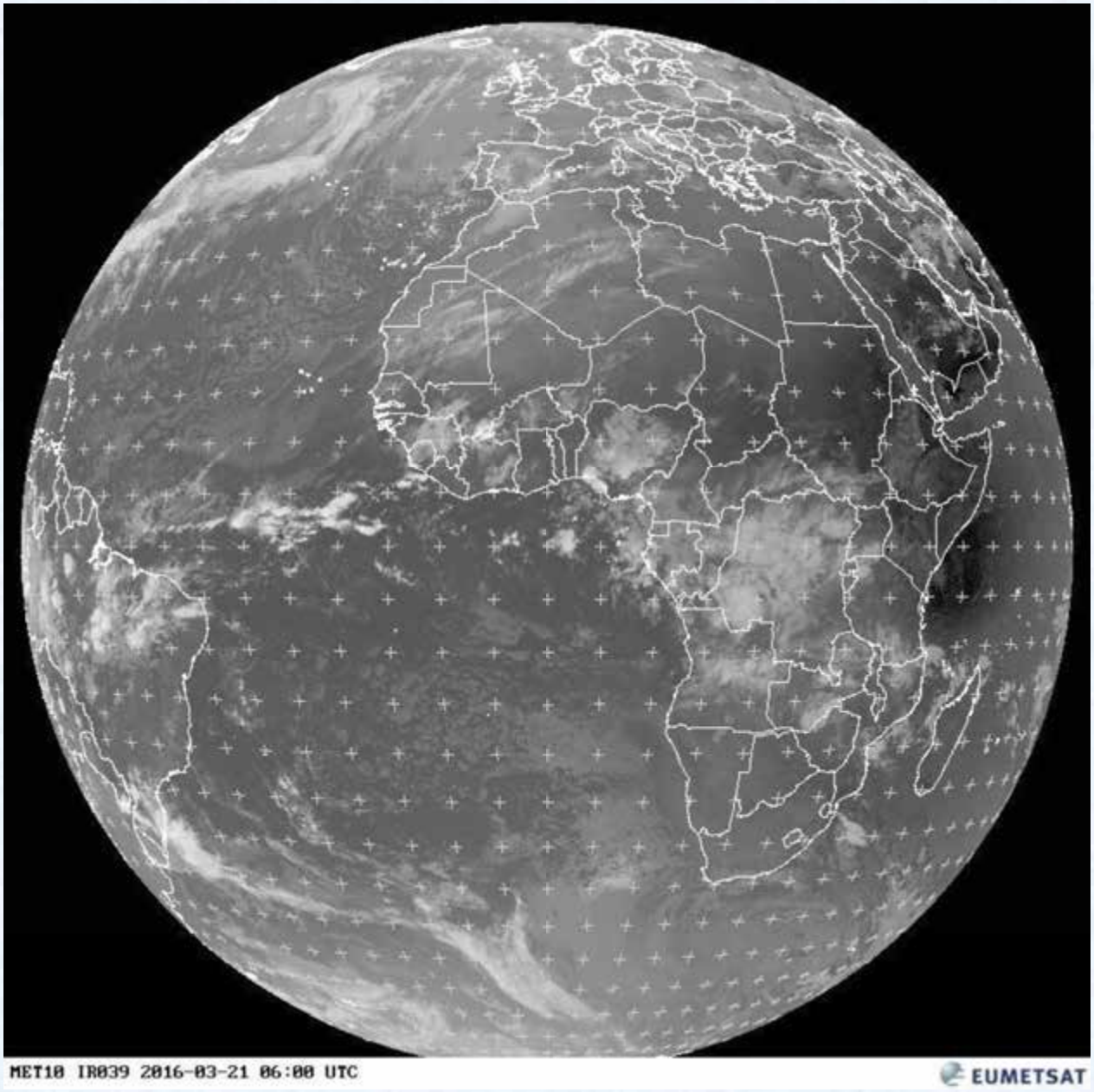
NMS

meteorological satellites



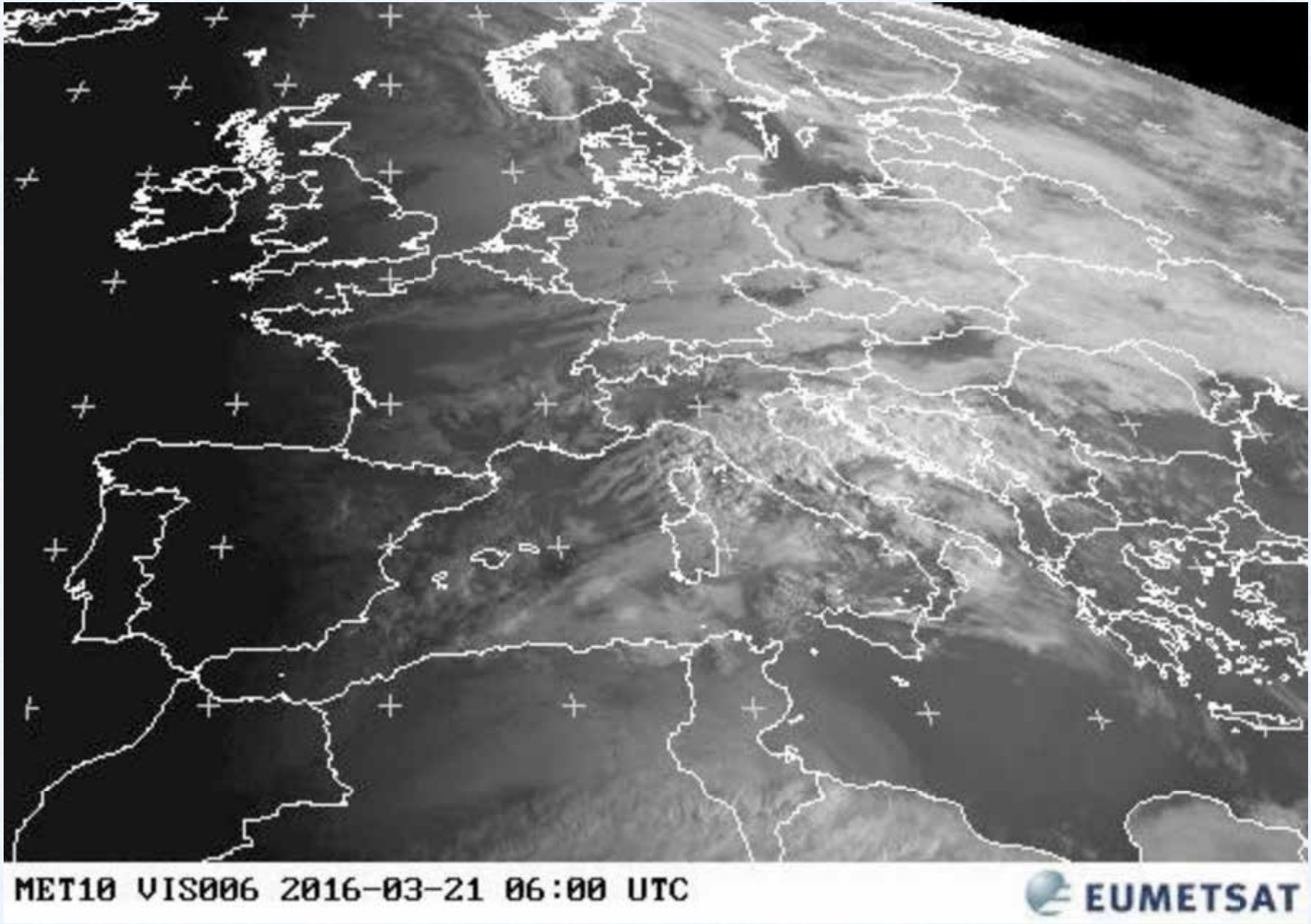
geostationary: 11 operational with ca. 50 instruments

Emeritenstamm, March 21, 2016



Meteosat10
Infrarot
2016-03-21 06:00

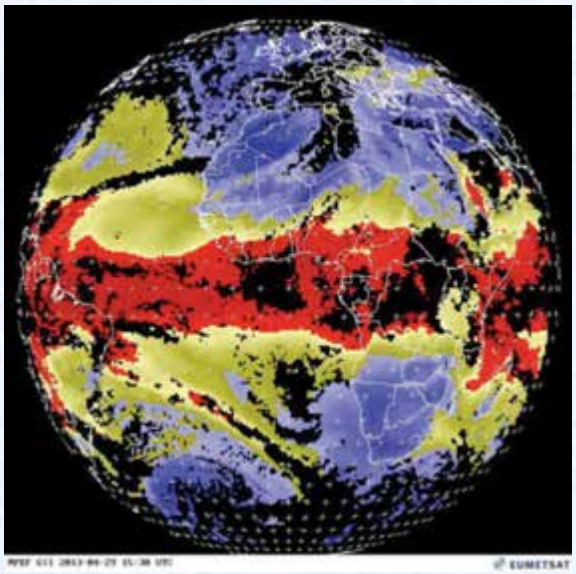
Emeritenstamm, March 21, 2016



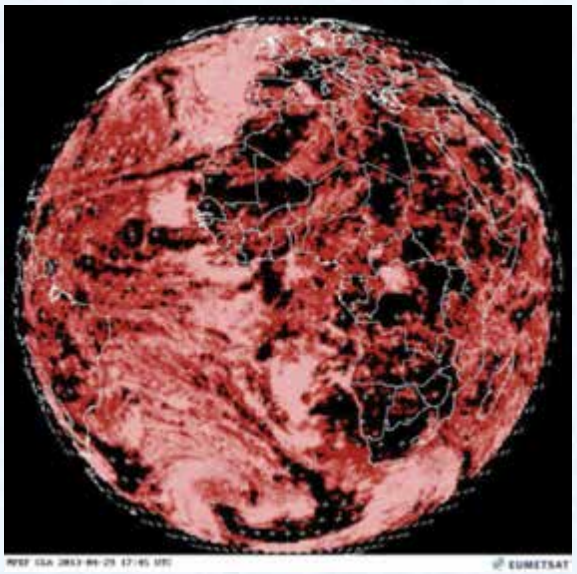
Hans Richner, IAC*ETH*: Weatherforecast

Emeritenstamm, March 21, 2016

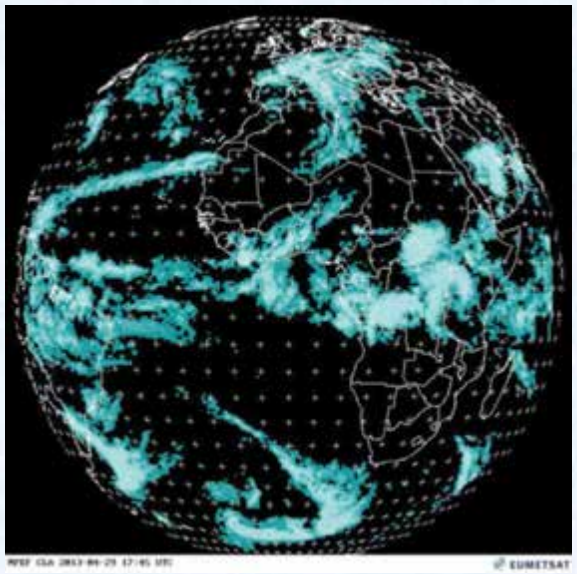
stability

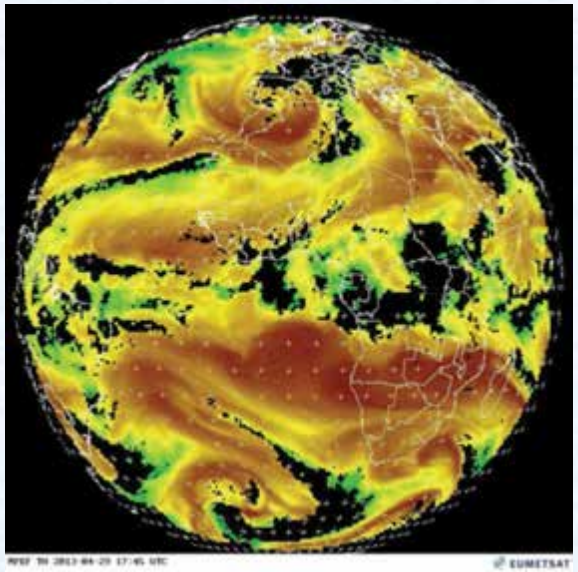


low clouds

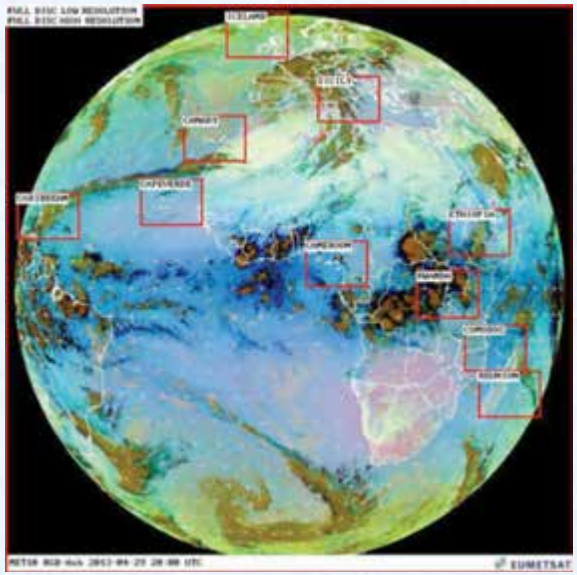


medium clouds



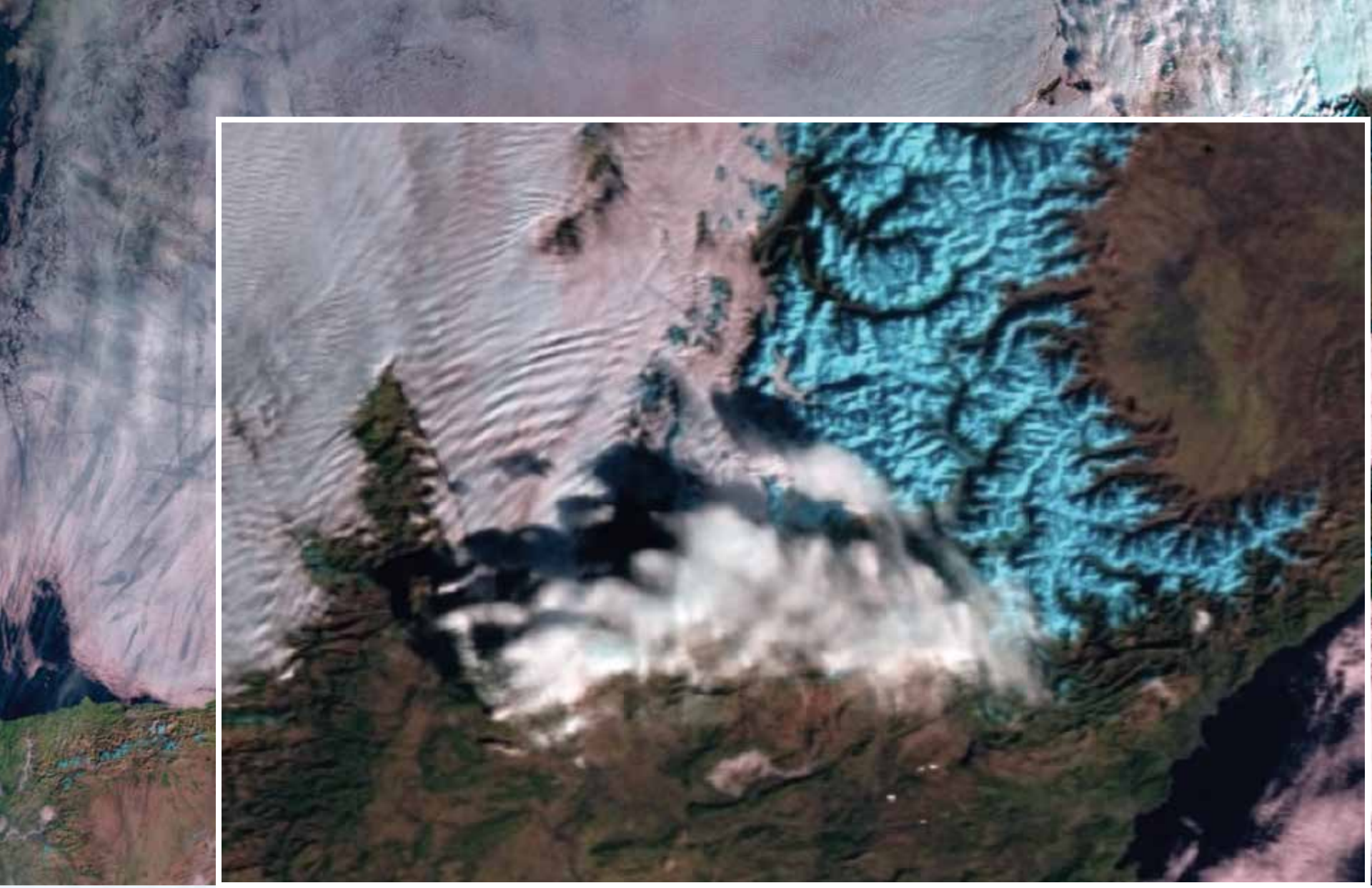


rel. humidity (troposphere)

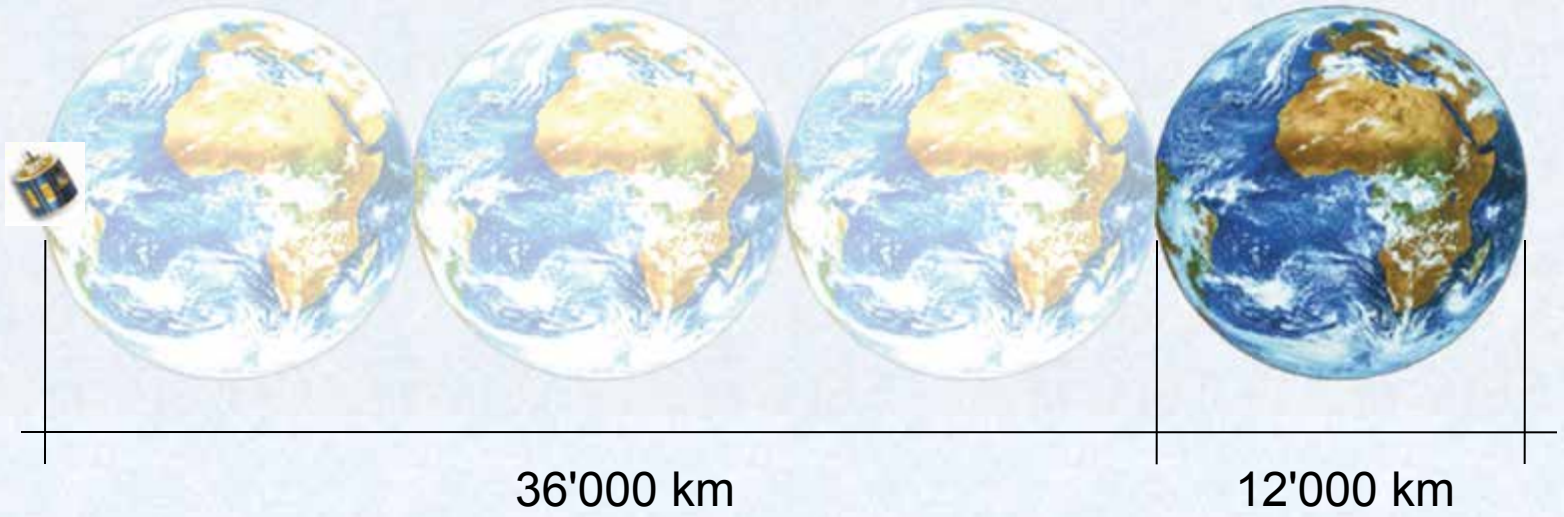


ash

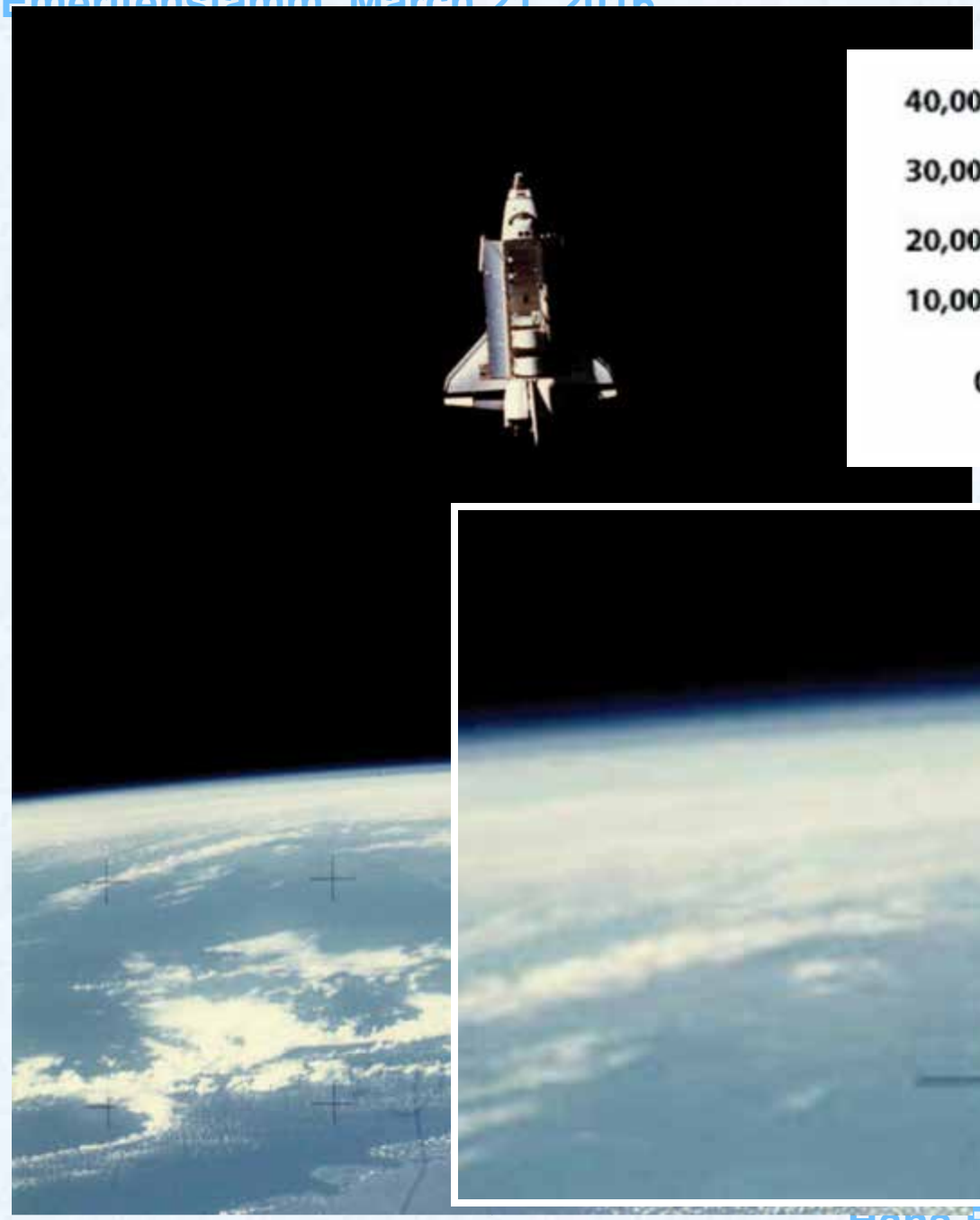
the manifold information drawn from observations by met-satellites

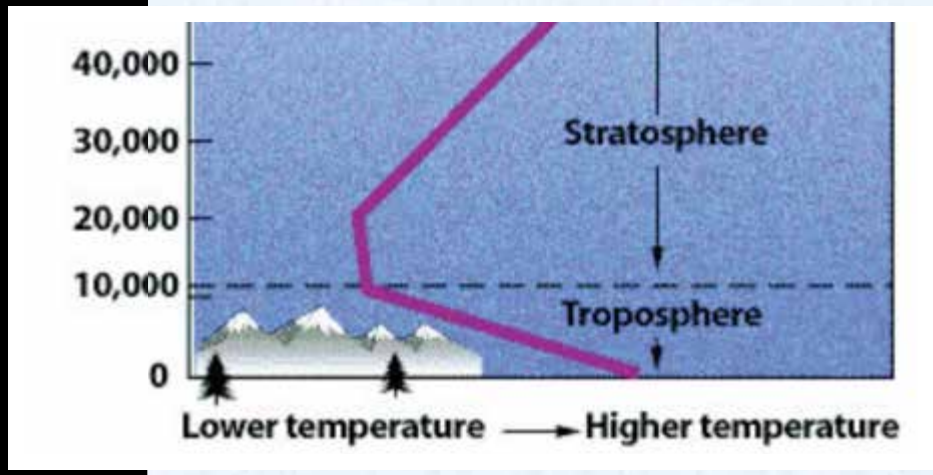


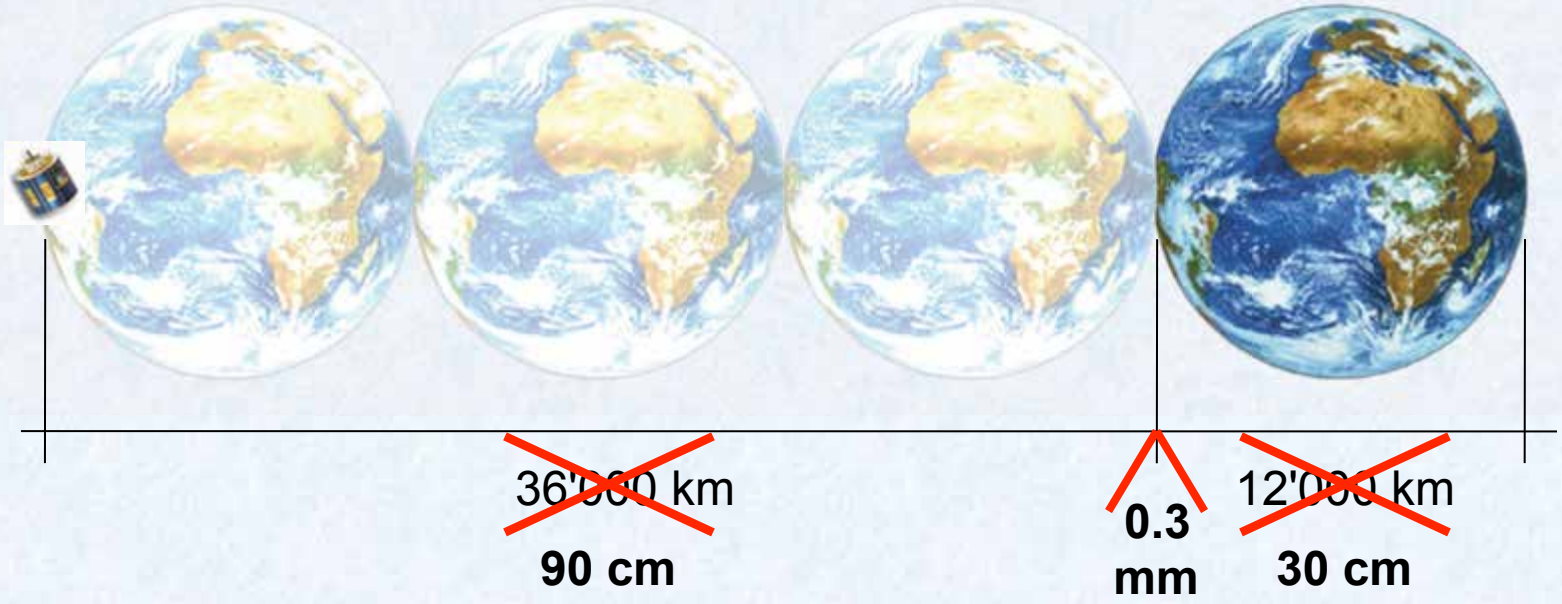
January 5, 2013: Pyrenees and westerly Alps, snow and clouds



conditions for a satellite to be geostationary
(i.e., to have an orbital period of 24 hours)




40,000
30,000
20,000
10,000
0
Stratosphere
Troposphere
Lower temperature
Higher temperature

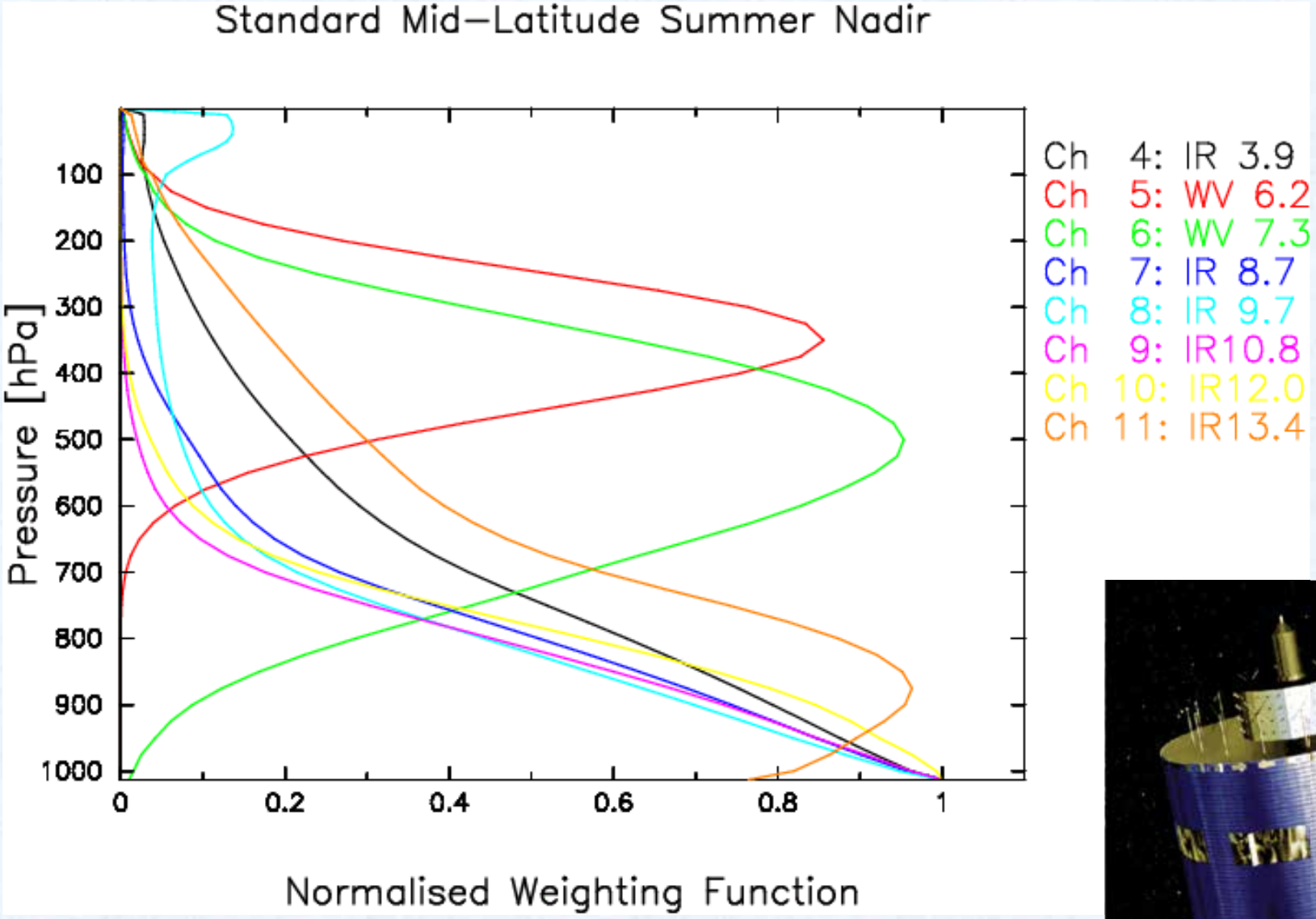


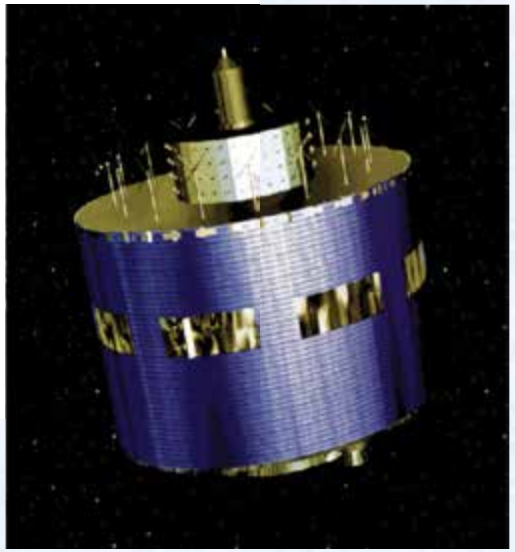
a mental experiment:

let us shrink the earth to the size of a globe (i.e., to about 30 cm diameter)

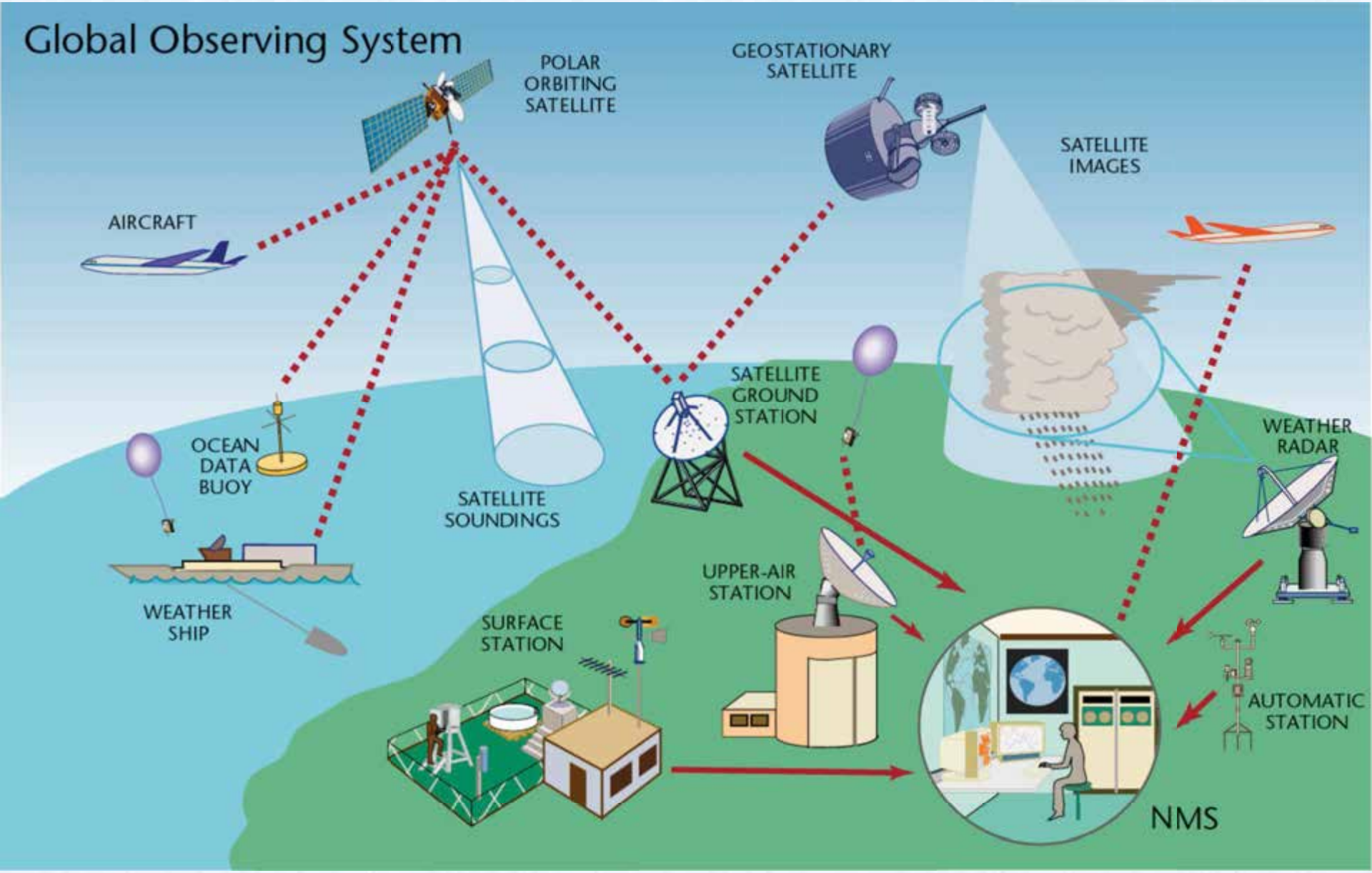
the troposphere, a layer of about 10 km – contains 90 % of the mass of the atmosphere and 99 % of the water vapor – becomes a film of less than 0.3 on the surface of our globe

a geostationary satellite observes a film of less than 0.5 mm from a distance of 90 cm – within this film it measures cloud heights, rough temperature profiles, humidity distribution, etc.





weighting functions for the "Spinning Enhanced Visible and Infrared Imager (SEVIRI)" **on Meteosat Second Generation (MSG)**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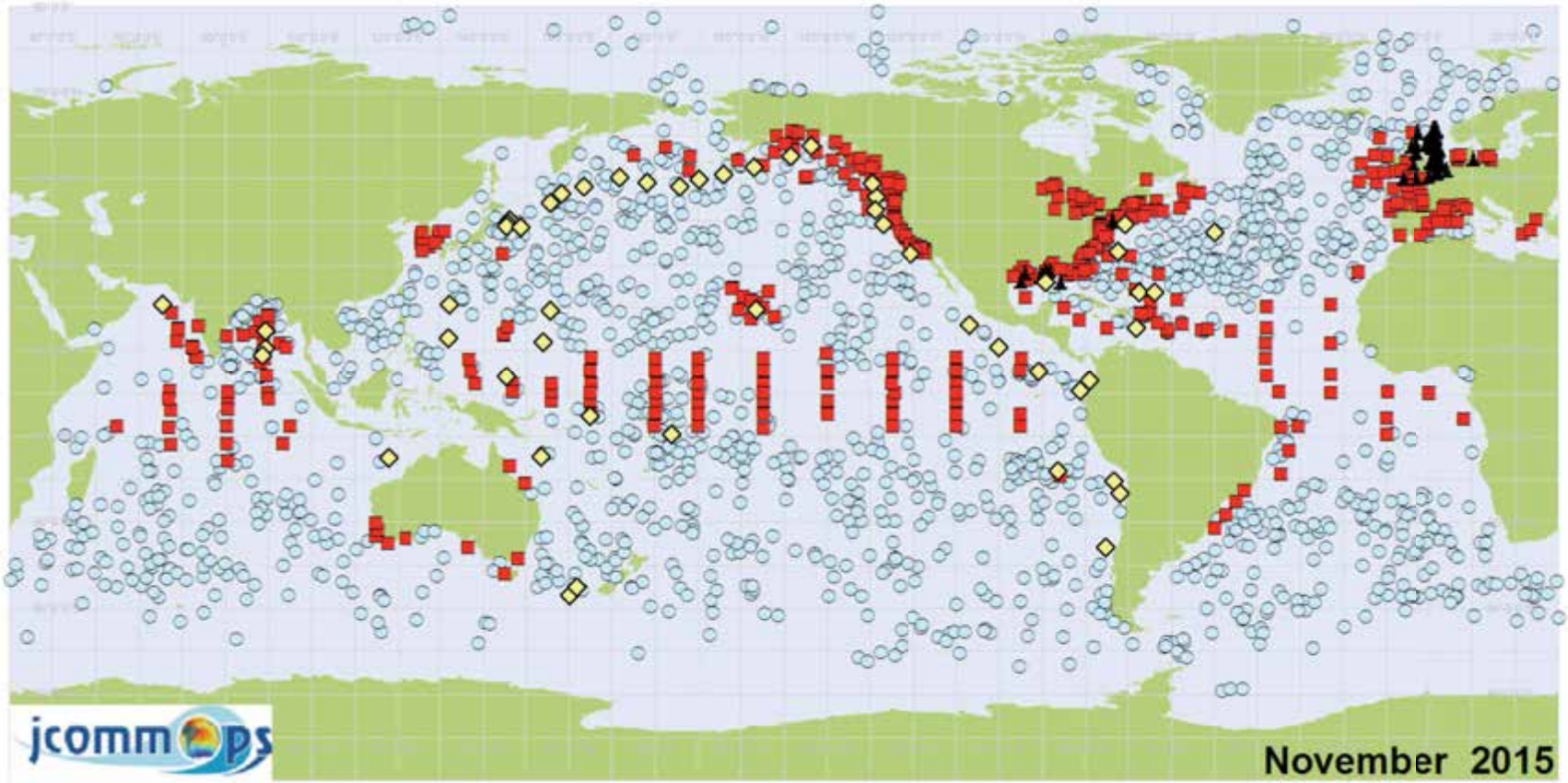
drifting buoy (drifter)

Servicing an ATLAS mooring of the TOGA-TAO Array. ATLAS moorings measure surface winds, air temperature, relative humidity, sea surface temperature, and subsurface temperature to depths of 500 m.

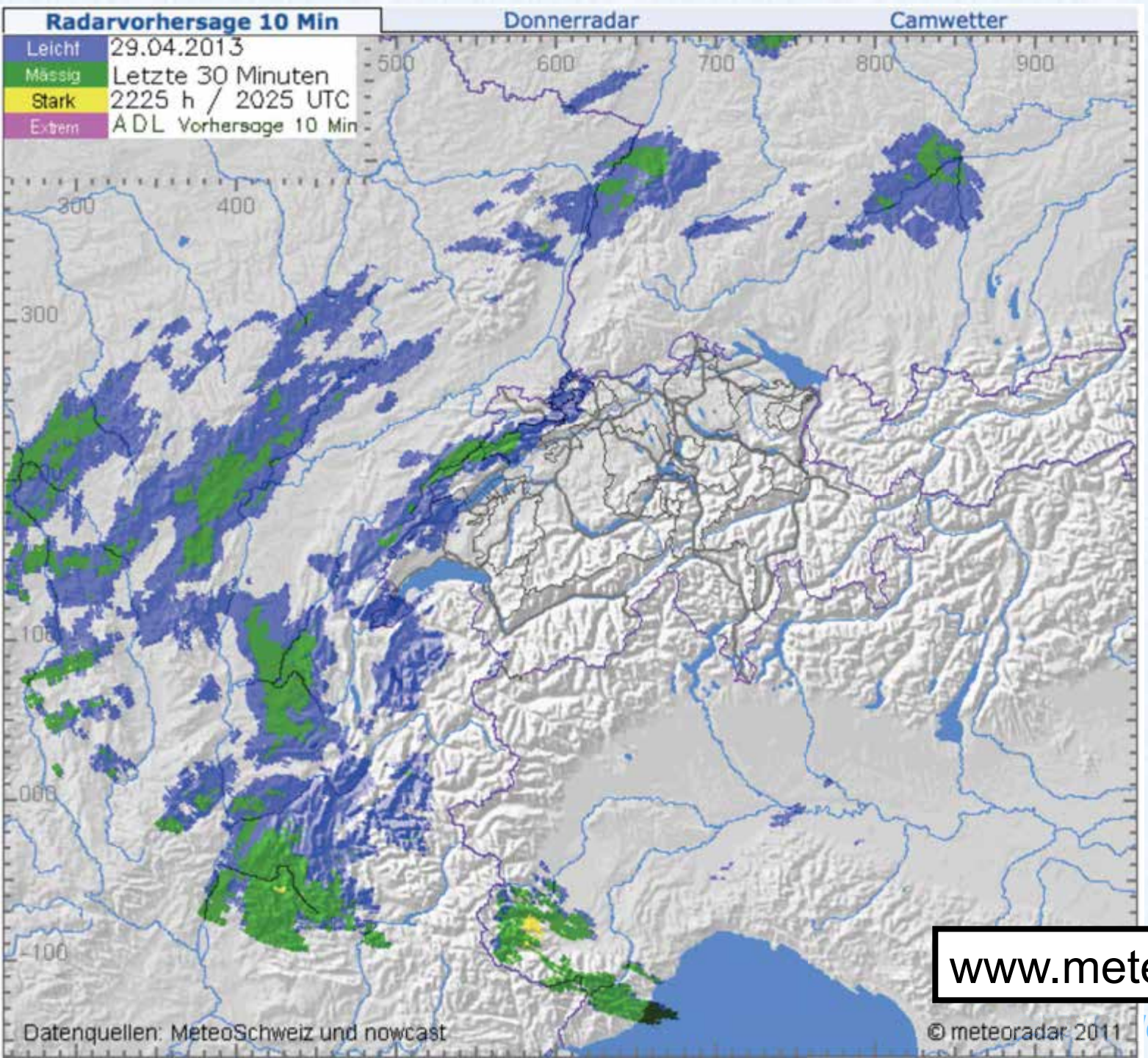
fixed buoy

DBCP Buoys by Platform Type monthly status 11/2015
(Data Buoy Cooperation Panel)



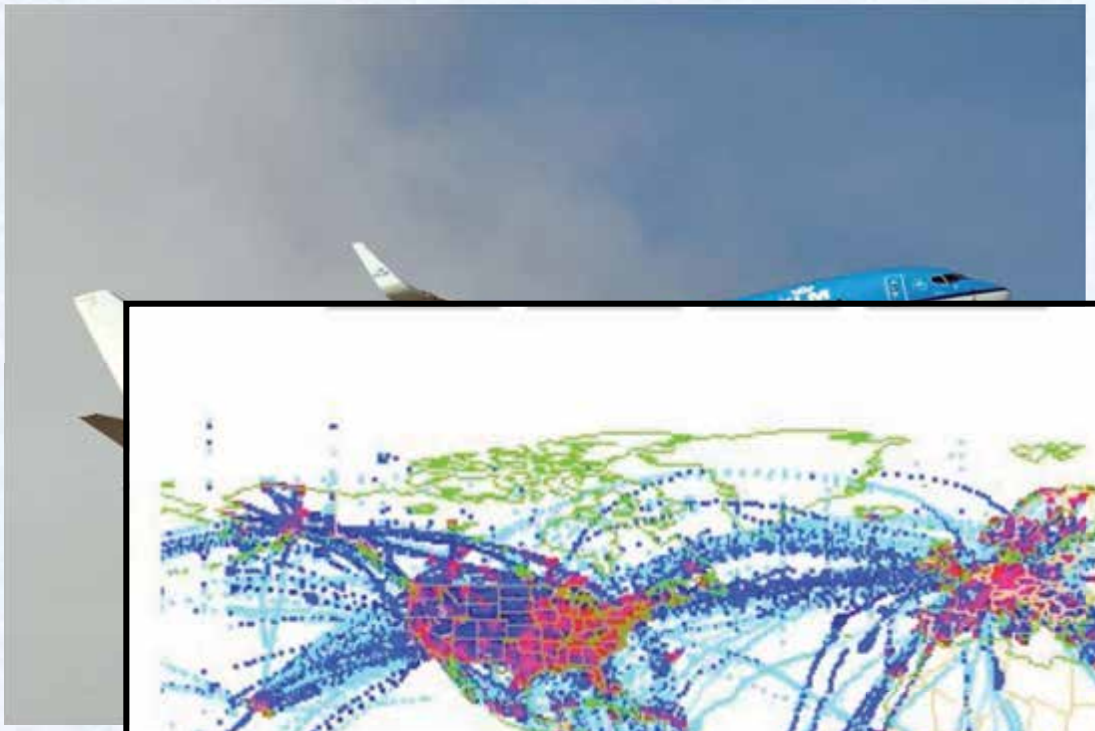
ETH Hönggerberg (Science City)

IAC***ETH***, 1974 - 2006



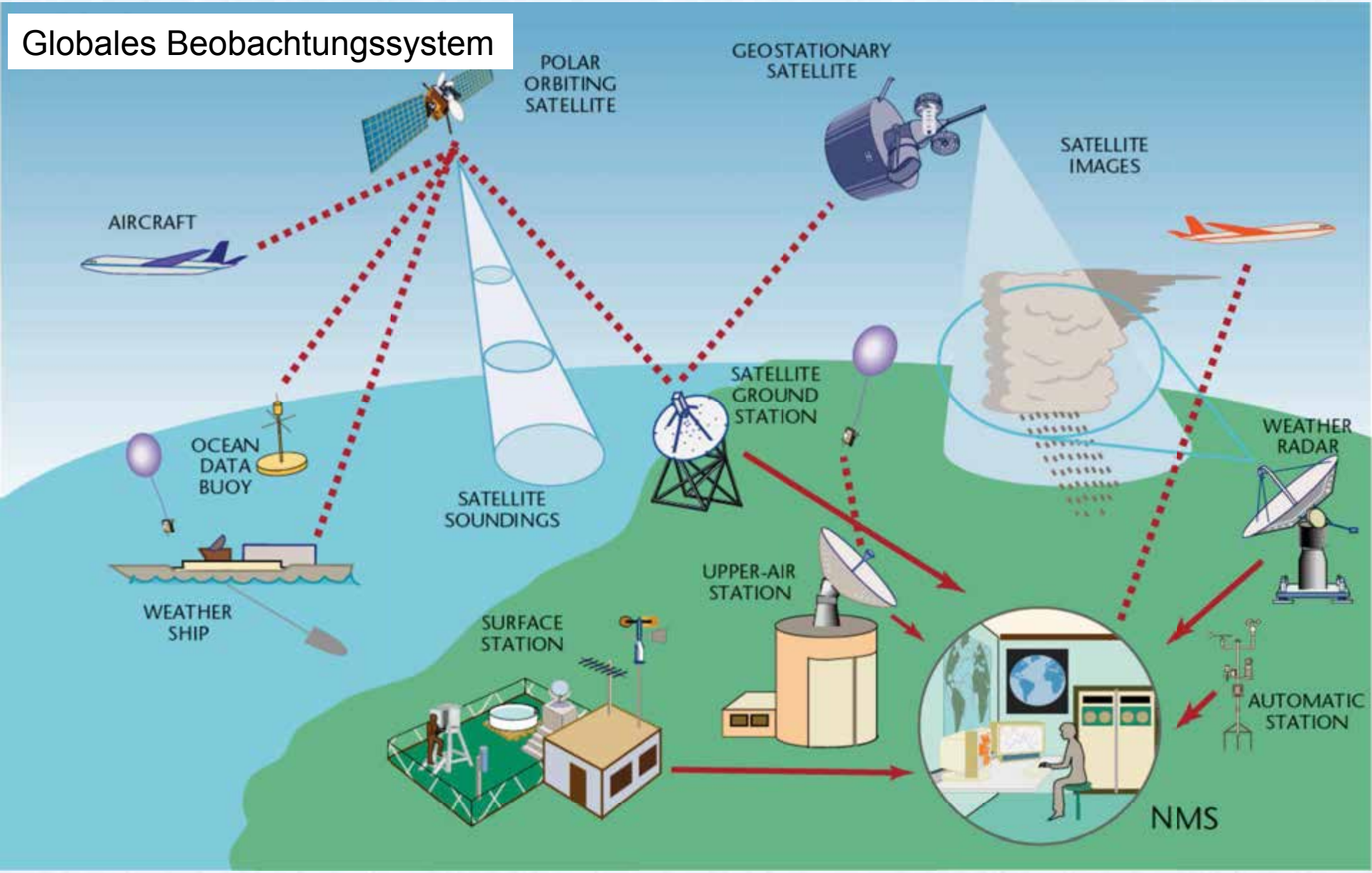
www.meteoradar.ch

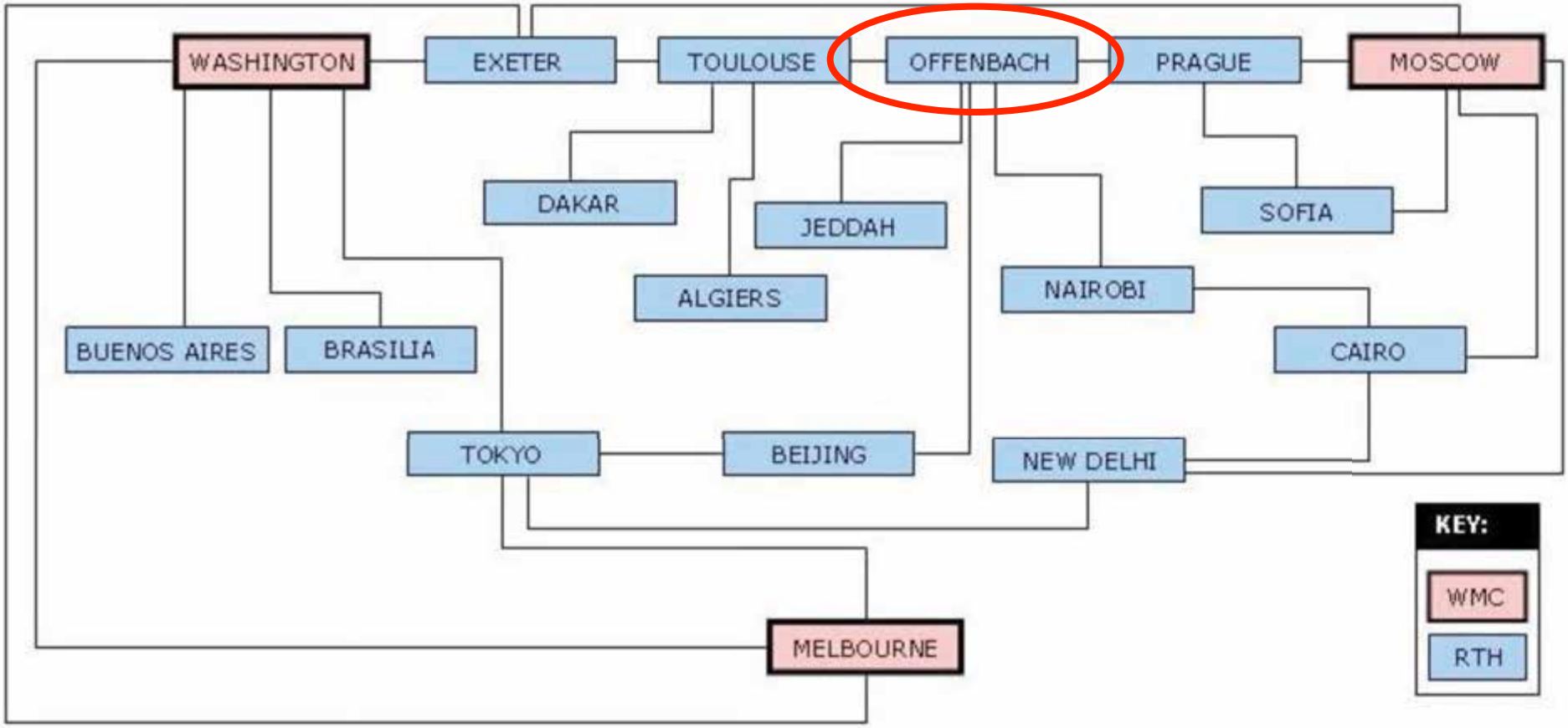
'eatherforecast



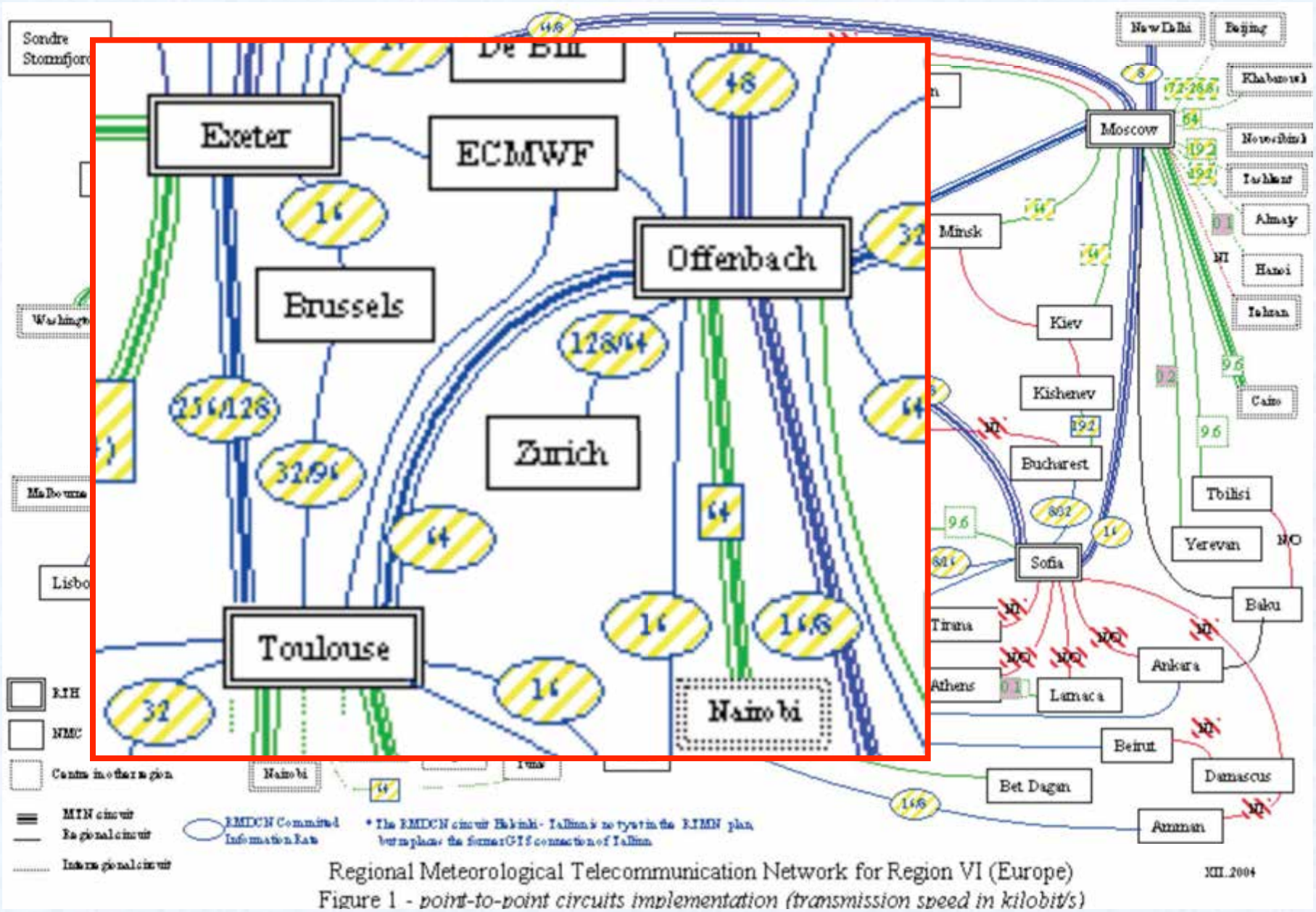
automatic transmission of meteo data by civil aircraft (AMDAR, ACARS)

Globales Beobachtungssystem





Backbone of GTS (Global Telecommunication System)


Exeter
ECMWF
Offenbach
Brussels
Zurich
Toulouse
Nairobi
Moscow
Minsk
Kiev
Kishenev
Bucharest
Sofia
Tirana
Athens
Lamaca
Ankara
Beirut
Damascus
Amman
Bet Dagan
Baku
Yerevan
Tbilisi
Cairo
Tehran
Almaty
Hanoi
Khabarovsk
Novosibirsk
Yakutsk
New Delhi
Beijing
Melbourne
Lisbon
RTH
NMC
MTN circuit
Regional circuit
RMDCN Committed Information Rate
Regional Meteorological Telecommunication Network for Region VI (Europe)
Figure 1 - point-to-point circuits implementation (transmission speed in kilobit/s)
XII.2004

World Meteorological Organization

WMO
World Meteorological Organisation
a UN organization analog to WHO, WTO, UNESCO, etc.

- coordination of global instrumentation, observation and data transmission
- founded 1950, 191 member countries
- successor of IMO founded in 1873

The "primitive equations" of the atmosphere

- the geostrophic momentum equations

$$\frac{Du}{Dt} - fv = -\frac{\partial \phi}{\partial x}$$
$$\frac{Dv}{Dt} + fu = -\frac{\partial \phi}{\partial y}$$

- the hydrostatic equation, a special case of the vertical momentum equation in which there is no background vertical acceleration.

$$0 = -\frac{\partial \phi}{\partial p} - \frac{RT}{p}$$

- the continuity equation, connecting horizontal divergence/convergence to vertical motion under the hydrostatic approximation ($dp = -\rho\, d\phi$):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0$$

- and the thermodynamic energy equation, a consequence of the first law of thermodynamics

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + \omega\left(\frac{\partial T}{\partial p} - \frac{RT}{pc_p}\right) = \frac{J}{c_p}$$

When a statement of the conservation of water vapor substance is included, these six equations form the basis for any numerical weather prediction scheme.

Vilhelm Bjerknes, (1862) – (1951)
early 1900s

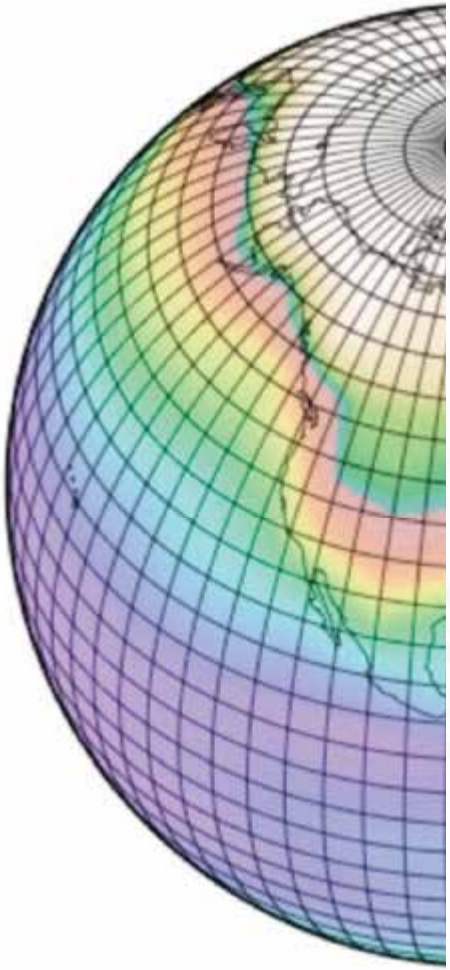
equations of motion (wind, pressure)

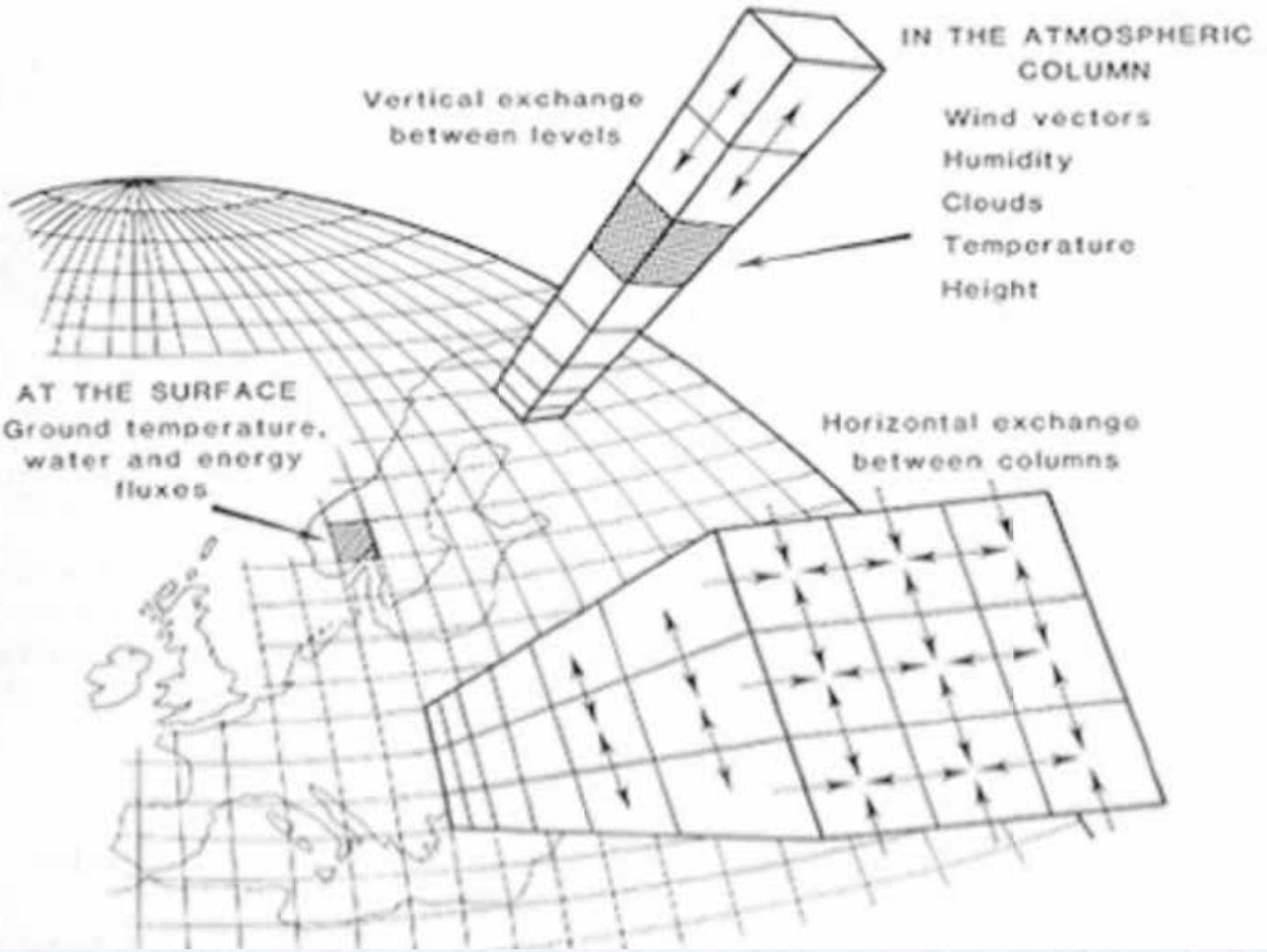
hydrostatic equation (temperatur, pressure, height)

conservation of mass (air cannot disappear)

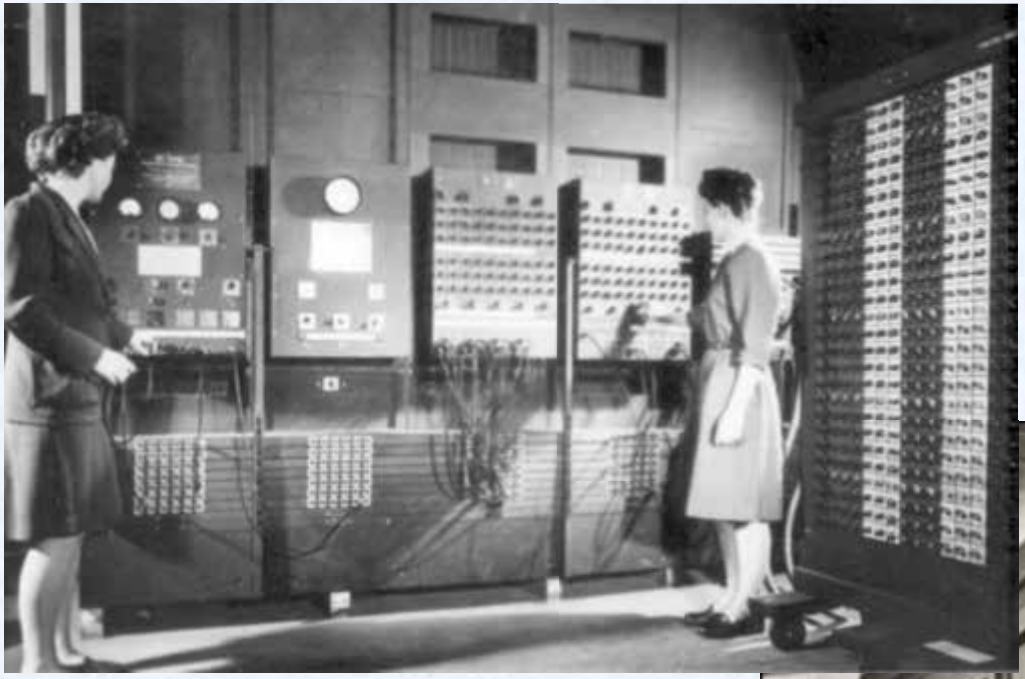
thermodynamic equation
(energy cannot disappear)

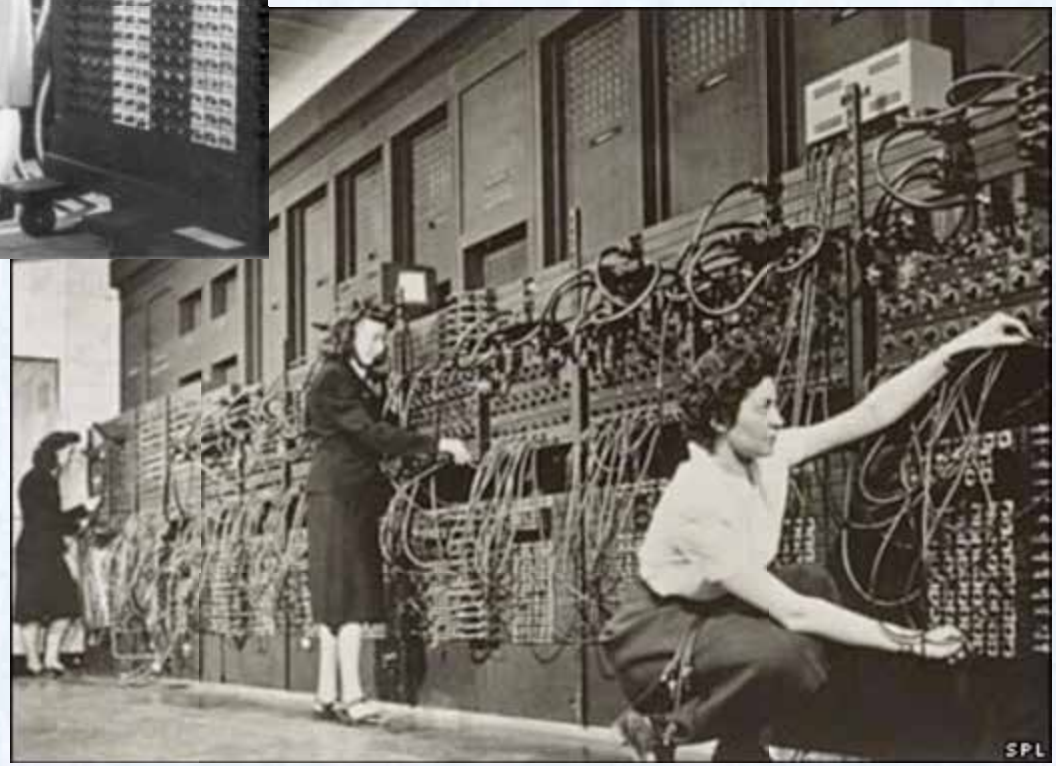
global model grid for GCMs and NWPs





Richardson 1904:
64'000 mathematicians need
2 months for the prediction of
1 day

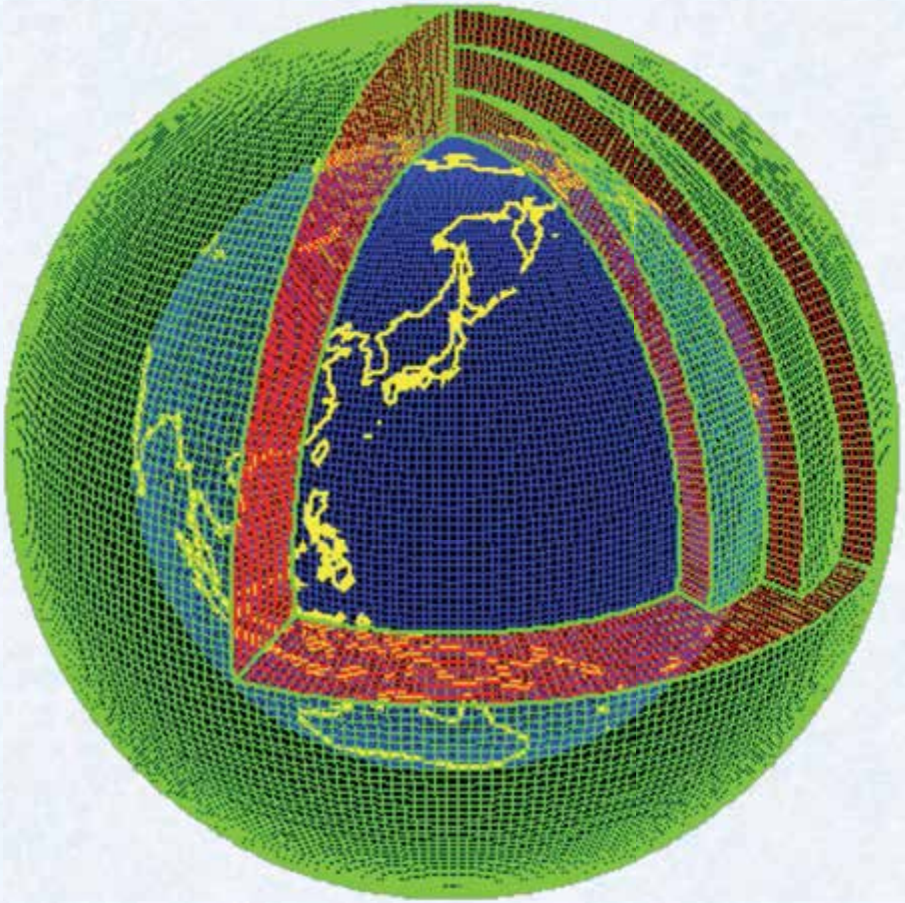




ENIAC (electronic numerical integrator and computer) 1946:

17,468	tubes
150 kW	power consumption
24 h	computation time
1 day	forecast

(programmed by 6 ladies!)



resolution: ca. 1 ° (ca. 100 km)

numerical weather prediction (NWP)

pressure and temperature fields quite good!

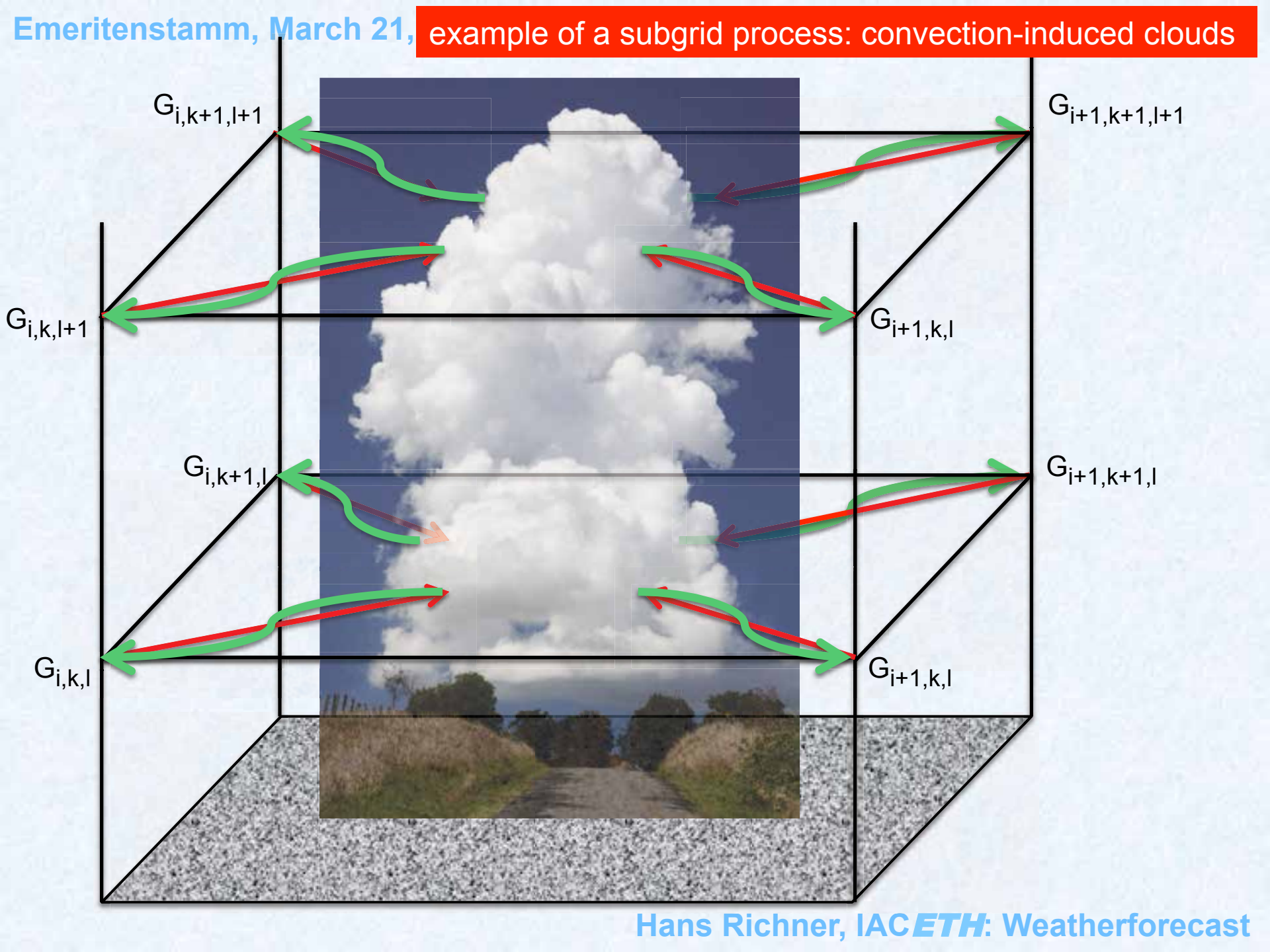
BUT

- resulting maps must be interpreted
- spatial resolution unsatisfactory for local forecasts
- many processes are too smal scaled, they literall fall through the grid

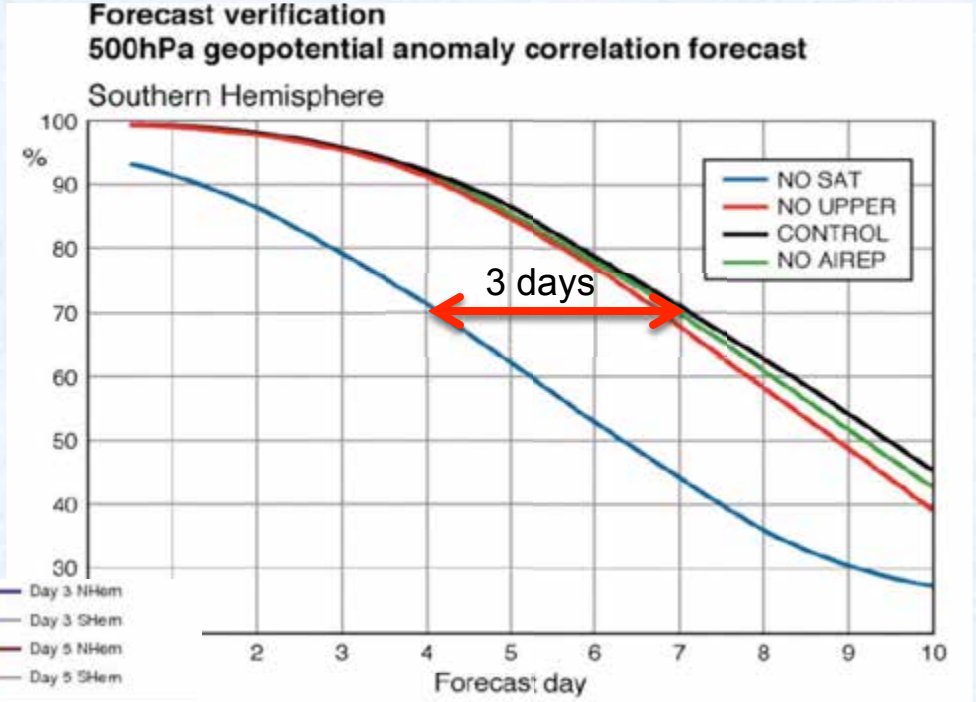
solution:
decrease grid size (increase resolution)

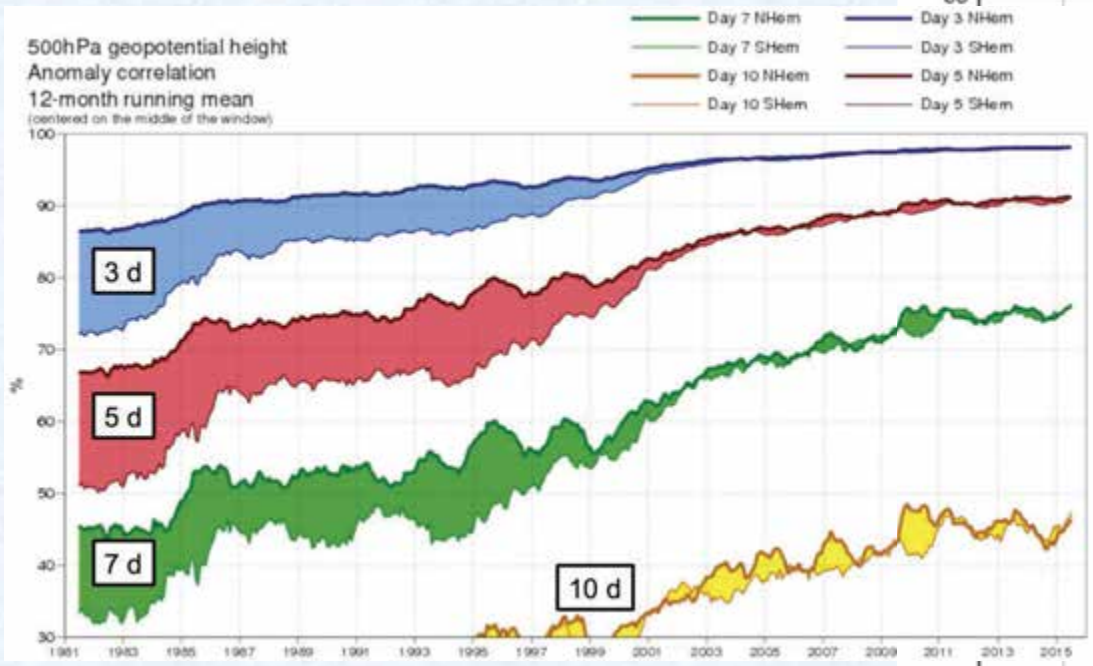
globally not possible, computing power not (yet?) available

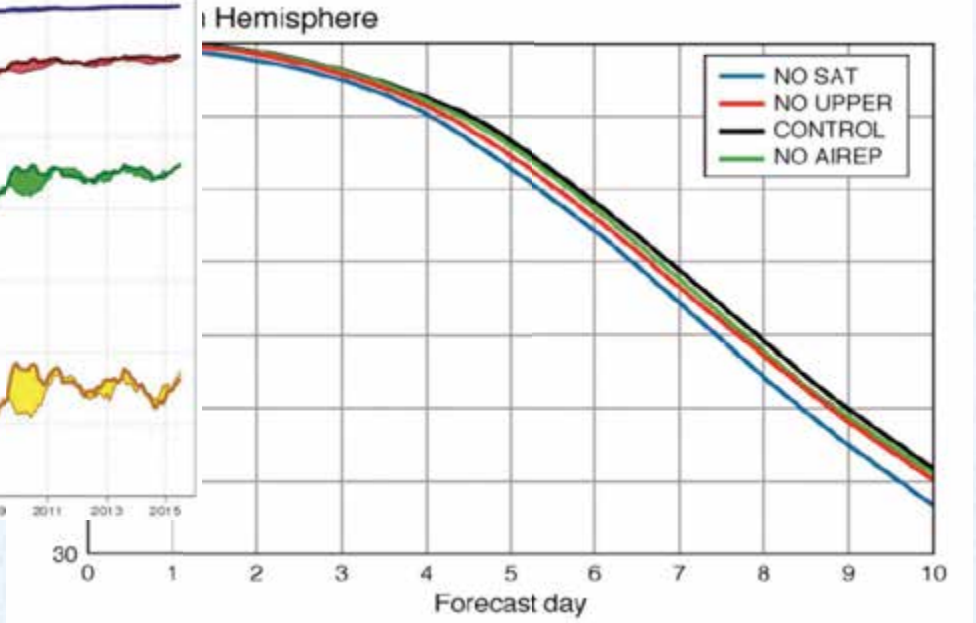
example of a subgrid process: convection-induced clouds



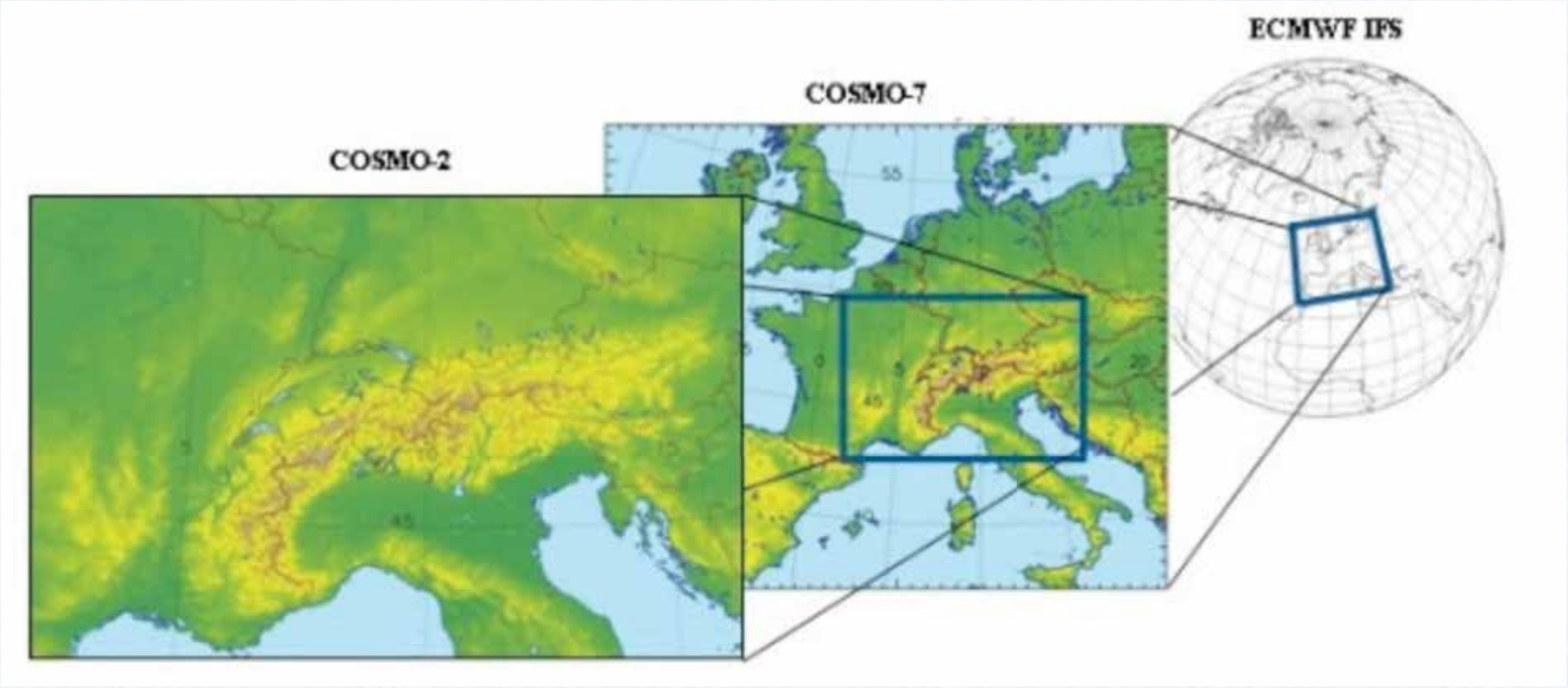
Emeritenstamm, March 21, 2016





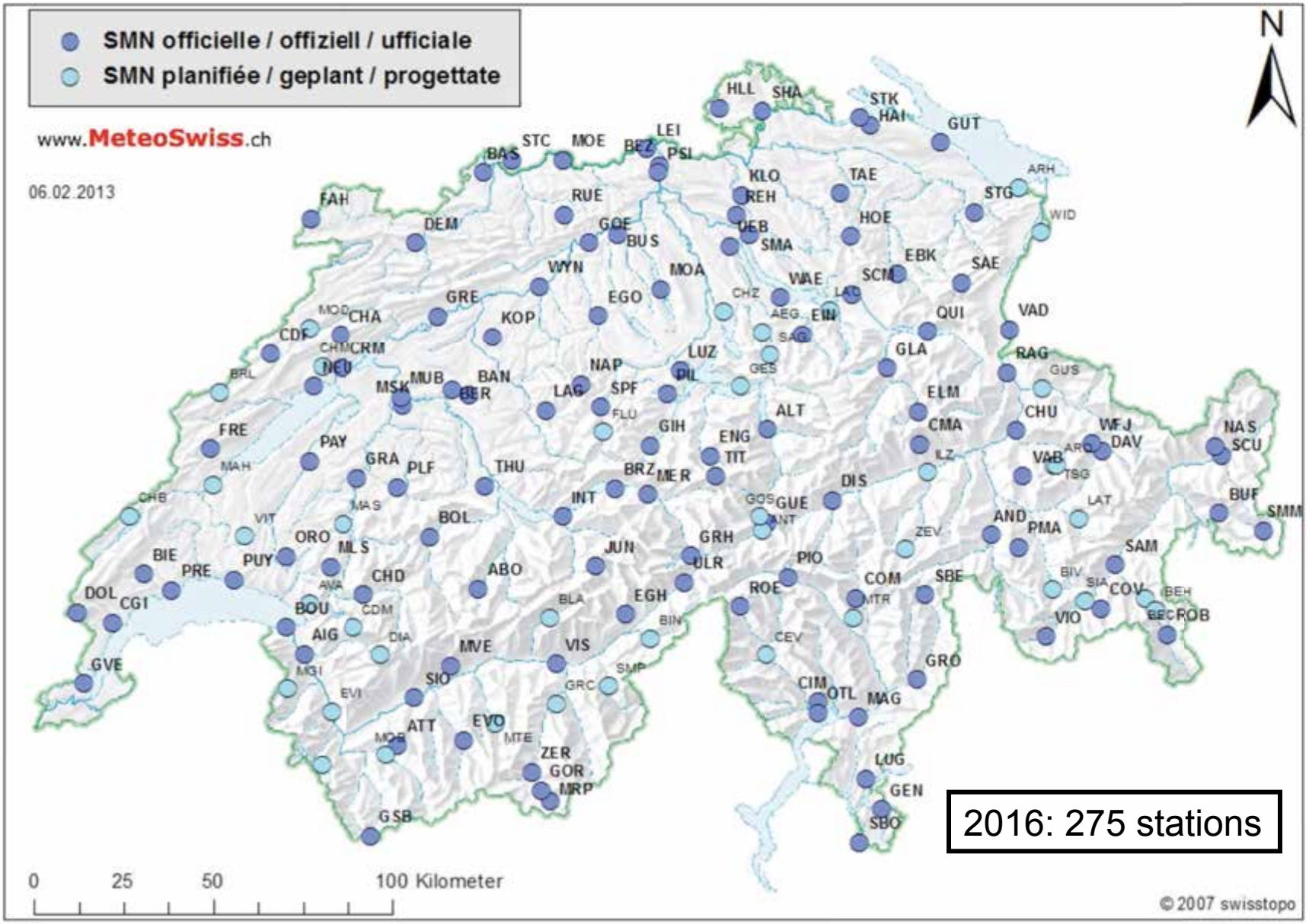


Hans Richner, IAC*ETH*: Weatherforecast



from global model to regional model:
➔ **nesting** of models

COSMO: Consortium for Small-Scale Modelling
(Germany, Greece, Italy, Poland, Rumania, Russia, Switzerland)


SMN officielle / offiziell / ufficiale
SMN planifiée / geplant / progettate
www.MeteoSwiss.ch
06.02.2013
N
2016: 275 stations
0
25
50
100 Kilometer
© 2007 swisstopo

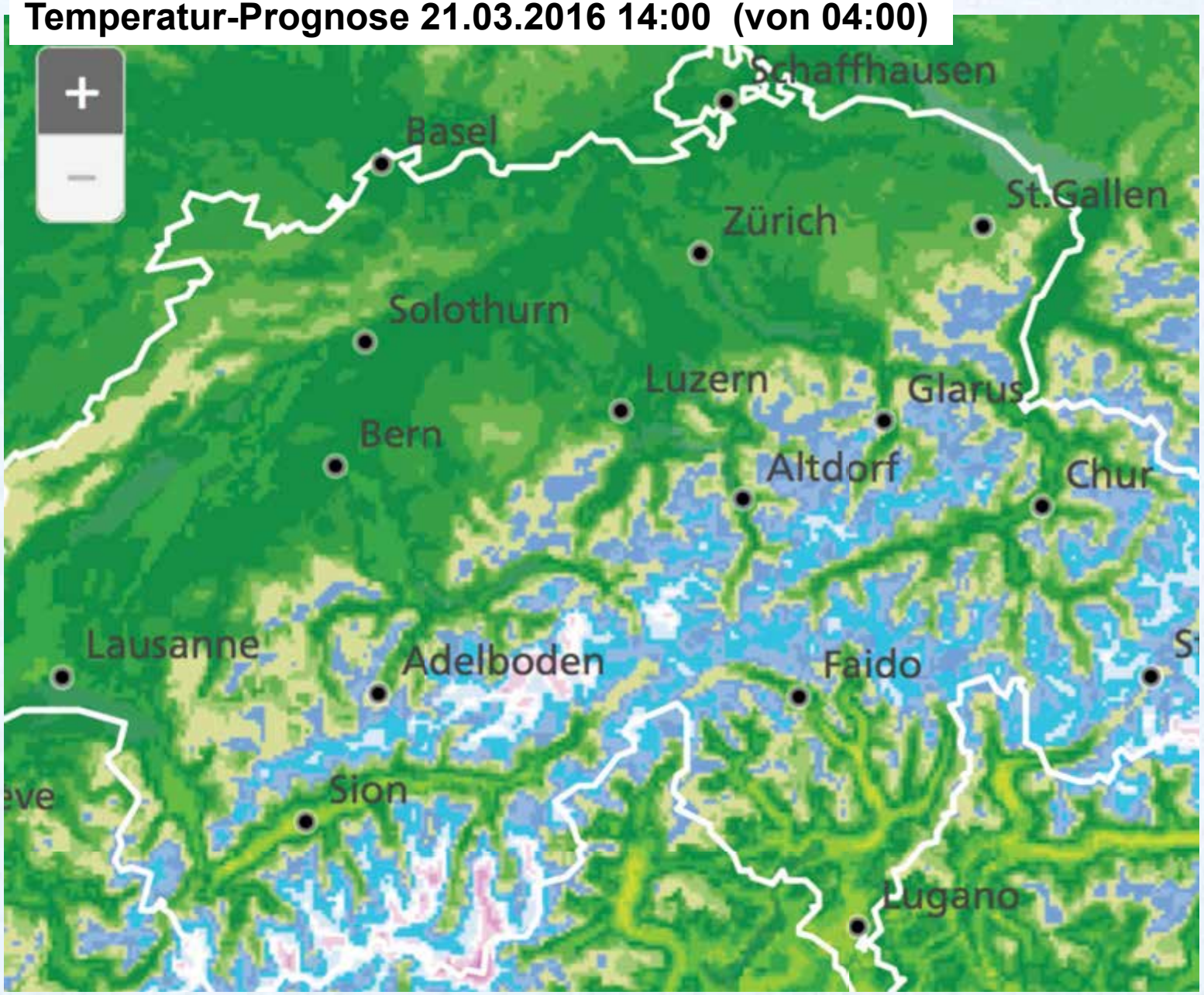
700 kW energy consumption,
cooling with 700 l/s
water from Lake Lugano

Swiss Nationale Supercomputing Center (CSCS)
"Kesch" and "Es-Cha" (Cray Storm)
96 GPUs, 24 CPUs
installed September 2015
23. international, 3. in Europa =>
$n \cdot 100$ Teraflops ($= n \cdot 10^{14}$)
(10^{14} s = 3.17 million years)

Hans Richner, IAC*ETH*: Weatherforecast

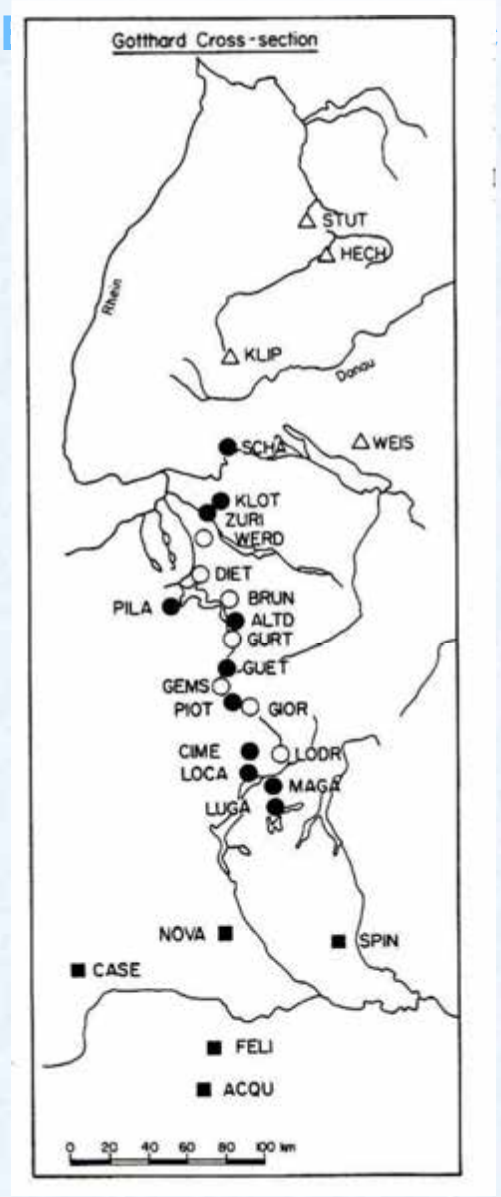
Emeritenstamm, March 21, 2016

Temperatur-Prognose 21.03.2016 14:00 (von 04:00)



18 bis 20
16 bis 18
14 bis 16
12 bis 14
10 bis 12
8 bis 10
6 bis 8
4 bis 6
2 bis 4
0 bis 2
-2 bis 0
-4 bis -2
-6 bis -4
-8 bis -6
-10 bis -8
-12 bis -10
-14 bis -12
-16 bis -14
-18 bis -16
-20 bis -18

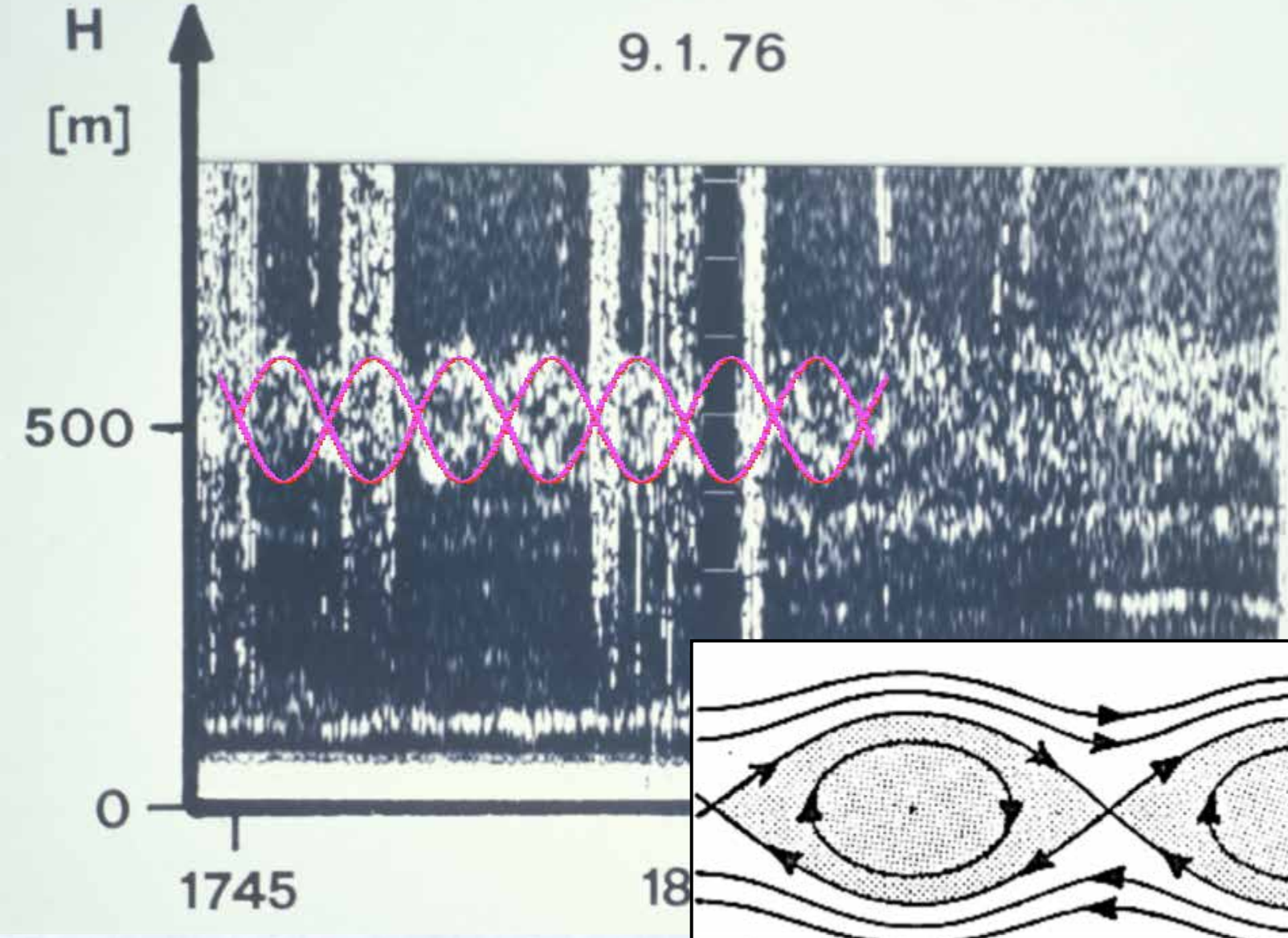
Hans Richner, IAC*ETH*: We



"the largest scientific undertaking ever conducted by the nations of the world" (WMO June 1982)

ALPEX: March/April 1982

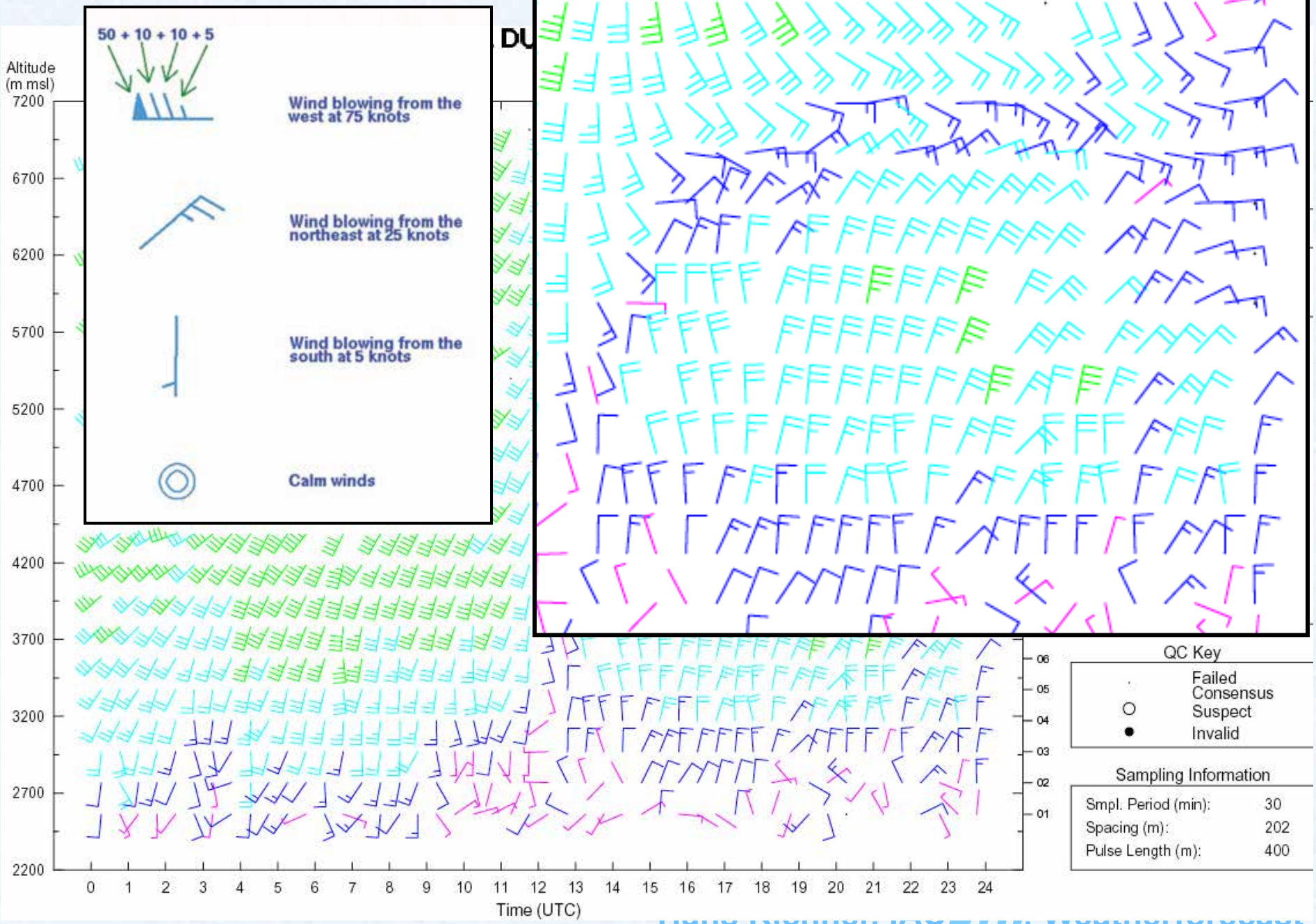
- 12 years of preparation
- 19 countries
- 17 research airplanes from 7 countries
- 11 research vessels
- 23 additional radiosonde stations
- 60 microbarographs
- 1 operation center at Geneva airport
- ca 200 active scientists



Lord Kelvin 1880


10m-mast
Anenometer
Surface station
Wind profiler
SODAR
Sonic
Trailer

Emeritenstamm, March 21, 2016



methods for warnings of foehn onsets

basis:
special local instrumentation

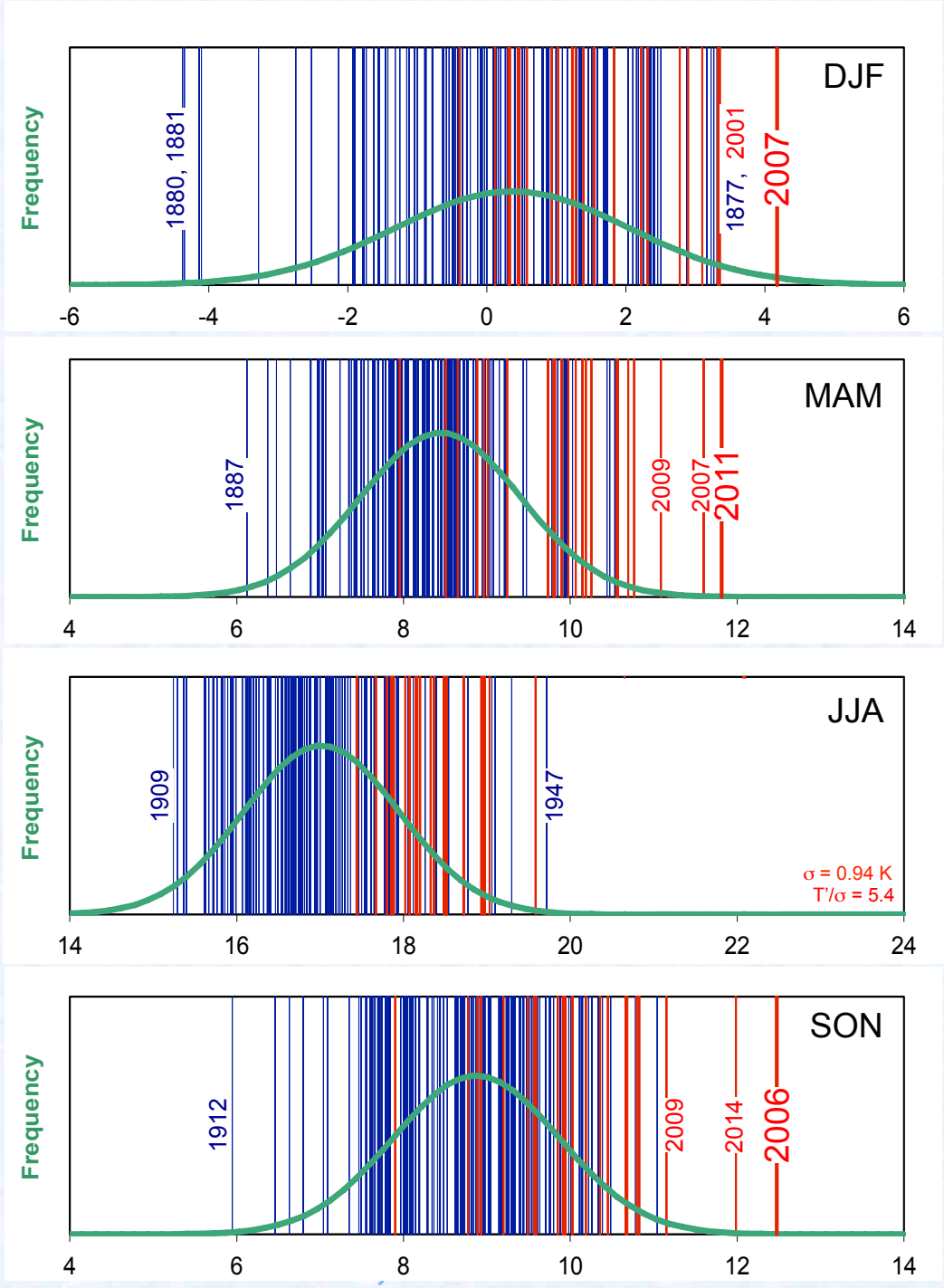
Climate change ???

mean seasonal temperatures
Basel, Bern, Geneva, Zurich
1864-1990 and **1991-2015**
(graphs courtesy Christoph Schär, IAC)

All seasonal records were exceeded in the last 15 years, often repeatedly.

Low temperatures hardly occur ("the climate plays only on the right part of the keyboard").

Records are partly extreme, particularly during summer.




thank you for your interest!