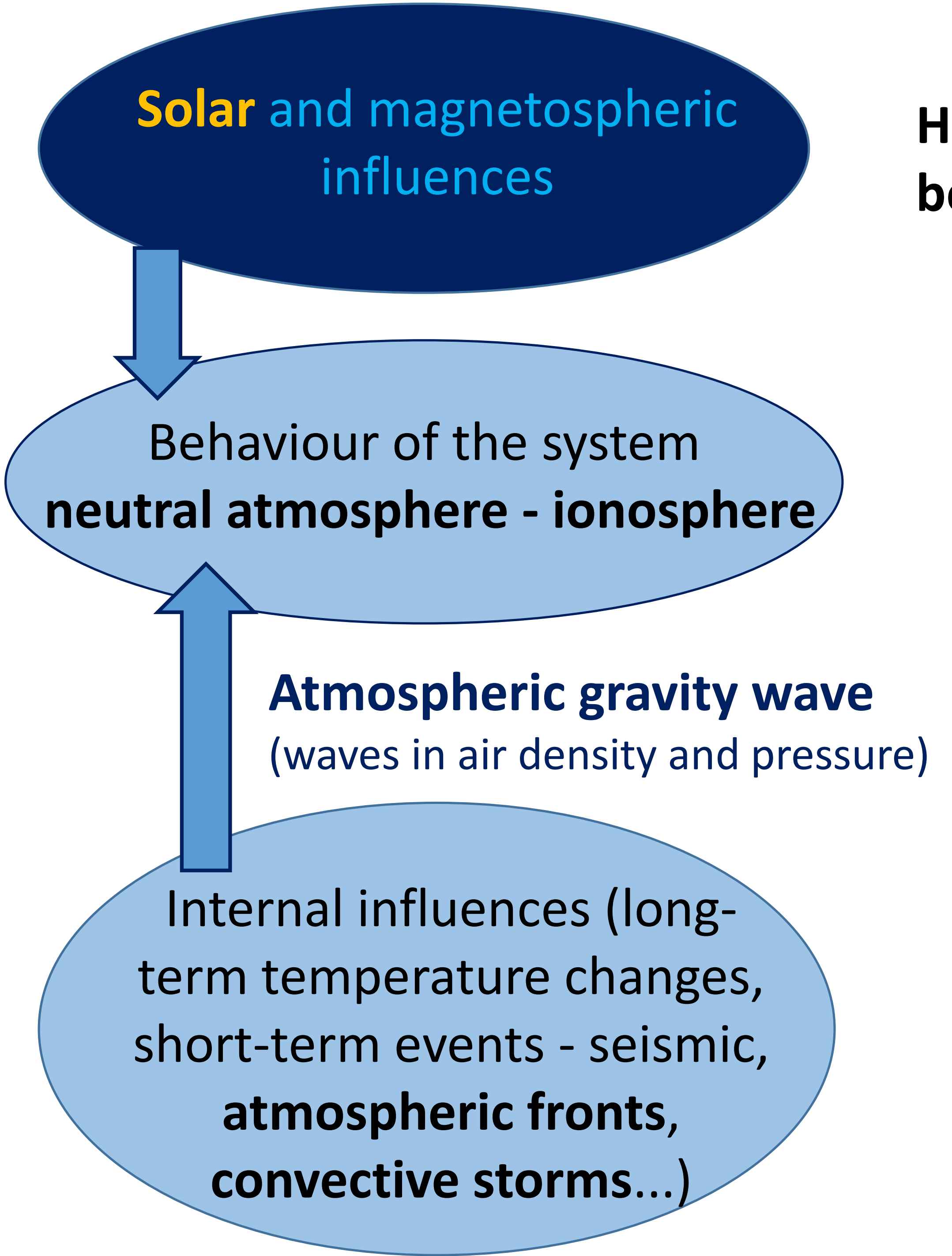
Impact of tropospheric severe weather events on ionospheric disturbances during different phases of Solar Cycle

Kateřina Potužníková, Petra Koucká Knížová, Daniel Kouba, Katya Georgieva, Boian Kirov, Čeněk Potužník, Petr Zacharov

ÚSTAV FYZIKY ATMOSFÉRY
AV ČR, v. v. i.



How does the solar cycle affect the vertical coupling between the troposphere and the ionosphere?

Reporting periods:

- **solar maximum: June to September 2013 to 2015**
- **solar minimum: June to September 2018 to 2020**

troposphere-ionosphere coupling is still not well understood

- complicated structure of the summer ionosphere
- Offen insufficion wave transition condition at stratosphere and mesosphere

First results:

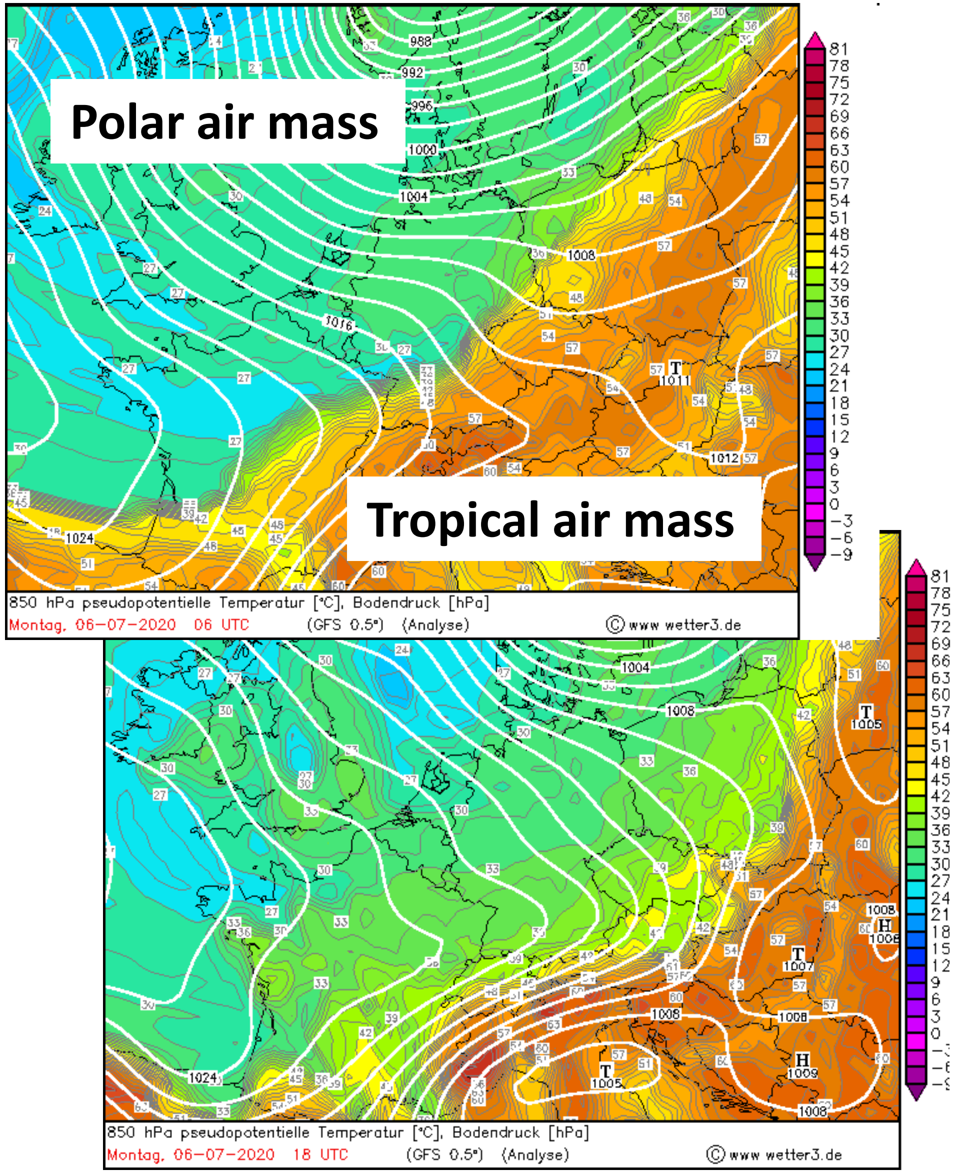
- **Is there a difference in the frequency and character of severe weather events?**

Convective thunderstorm 28. 7. 2014:

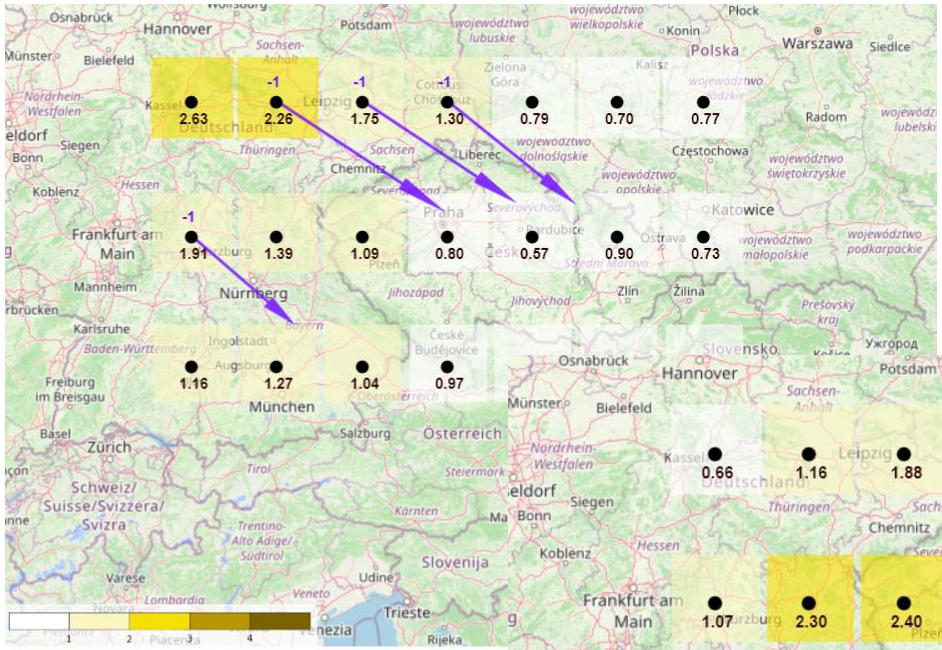
- **Gravity waves - response in the ionosphere**

Fast **cold front** passage - **850 hPa pseudoequivalent temperature**

For comparison:
reanalysis based on US model **GFS,** wetter3.de

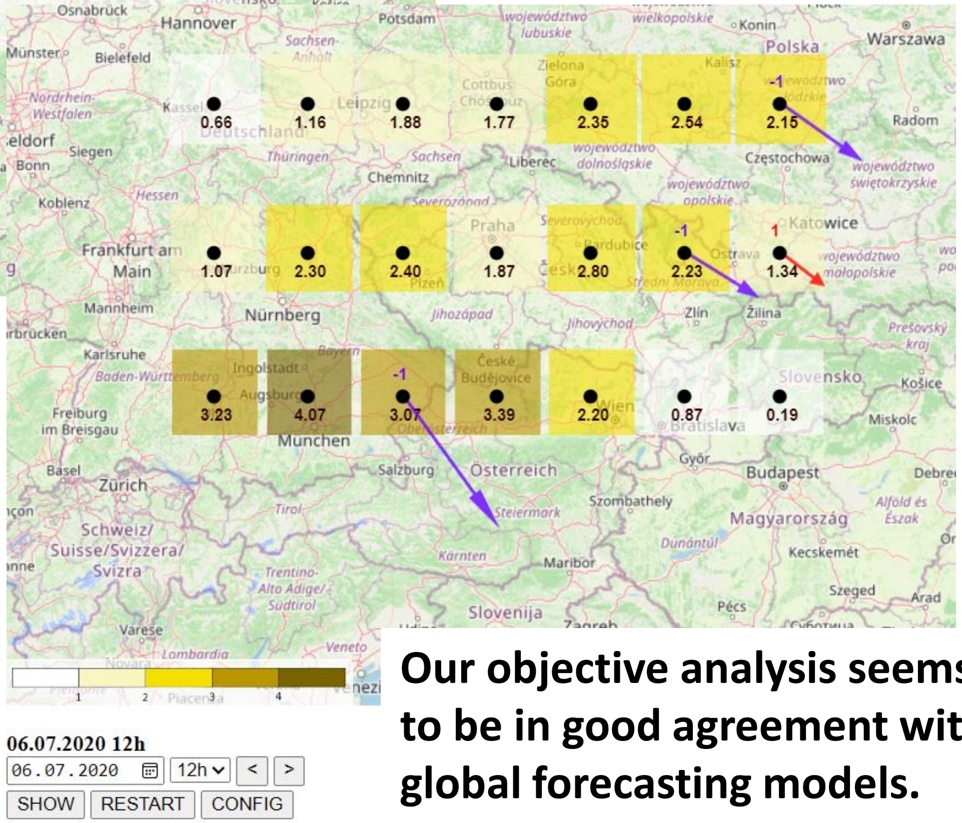


Our objective analysis (OA) of atmosfpheric fronts



OA projects 850 hPa wind velocity vector in the direction perpendicular to the isotherms at the 850 hPa level (direction of the temperature gradient).

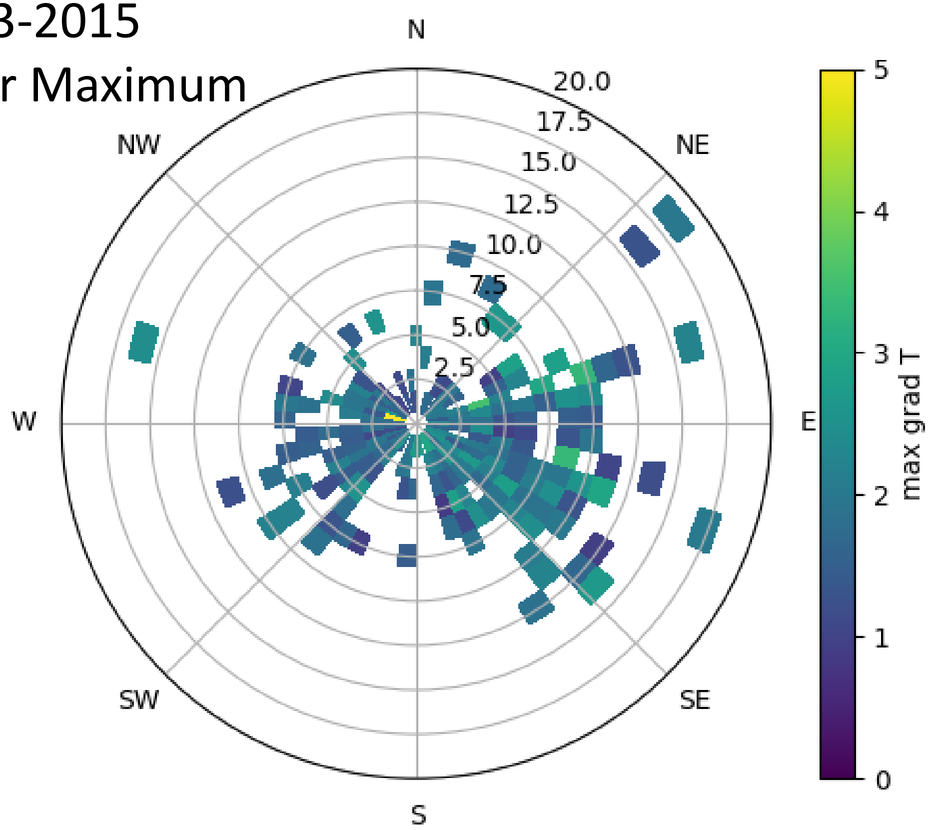
- **Direction and speed of frontal boundary**
- **temperature gradient** at the frontal boundary



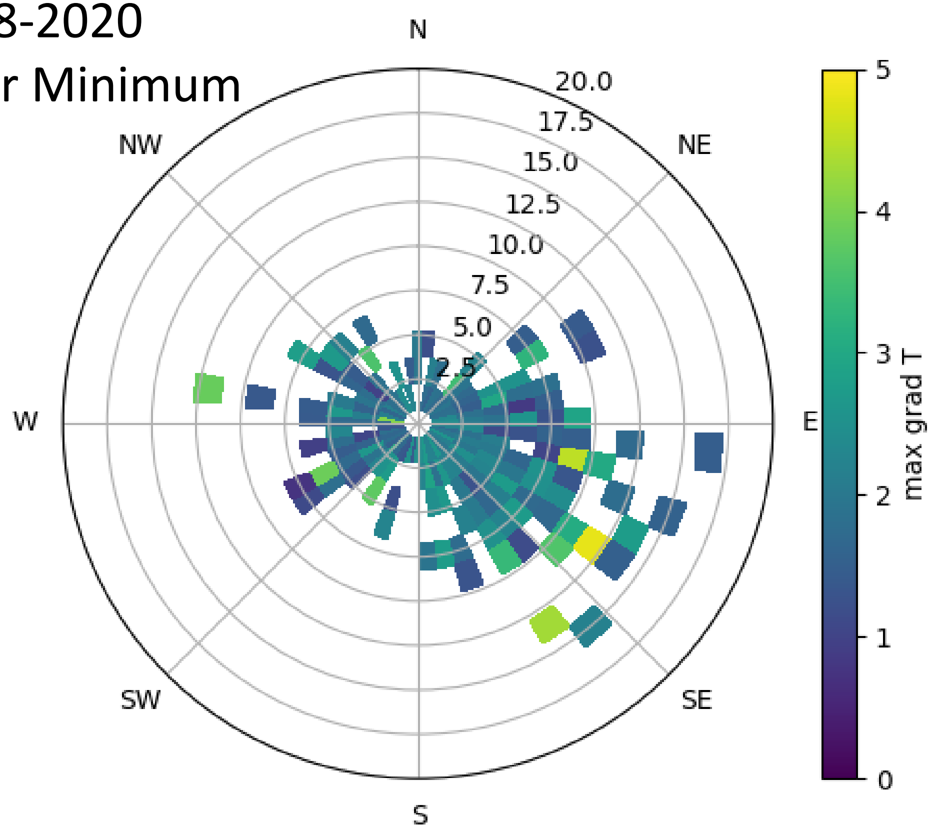
Our objective analysis seems to be in good agreement with global forecasting models.

Speed and direction of **Cold fronts** - Only fronts faster than 5 m/s are considered.
Temperature gradient at the frontal boundary (colour scale)

2013-2015
Solar Maximum



2018-2020
Solar Minimum

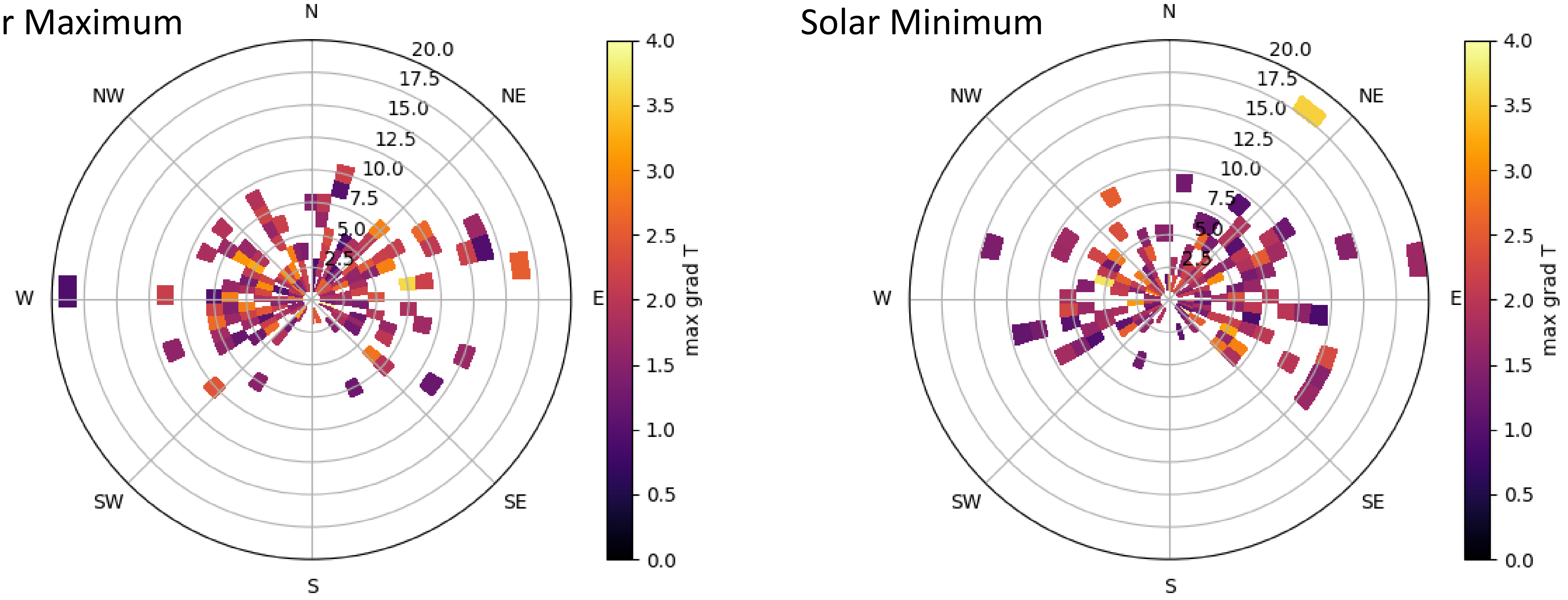


- Prevailing southeast direction of cold frontal boundary passage
- The Stronger temperature gradients on the fast-moving frontal boundaries at the time of solar minimum.

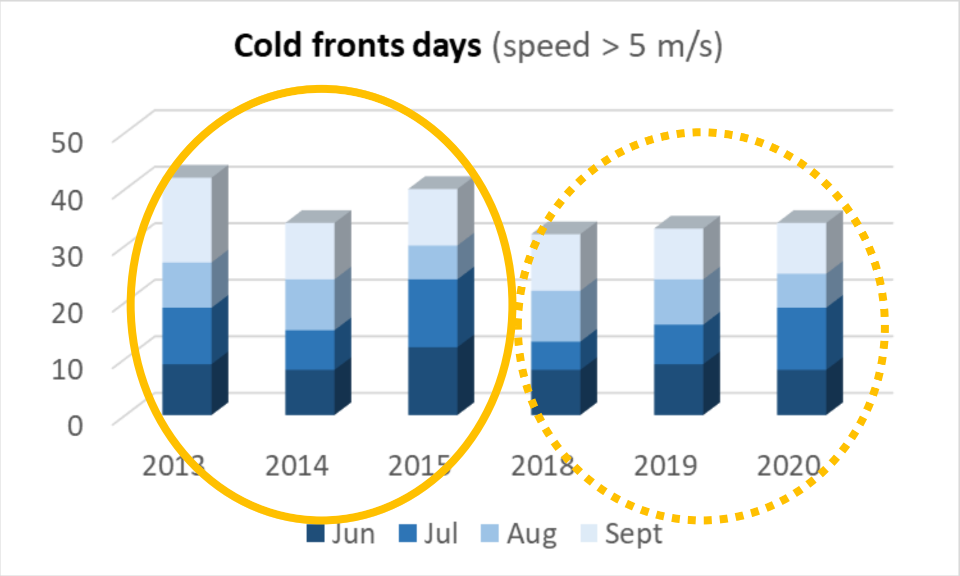
Speed and direction of **Warm fronts** - Only fronts faster than 5 m/s are considered.
Temperature gradient at the frontal boundary (colour scale)

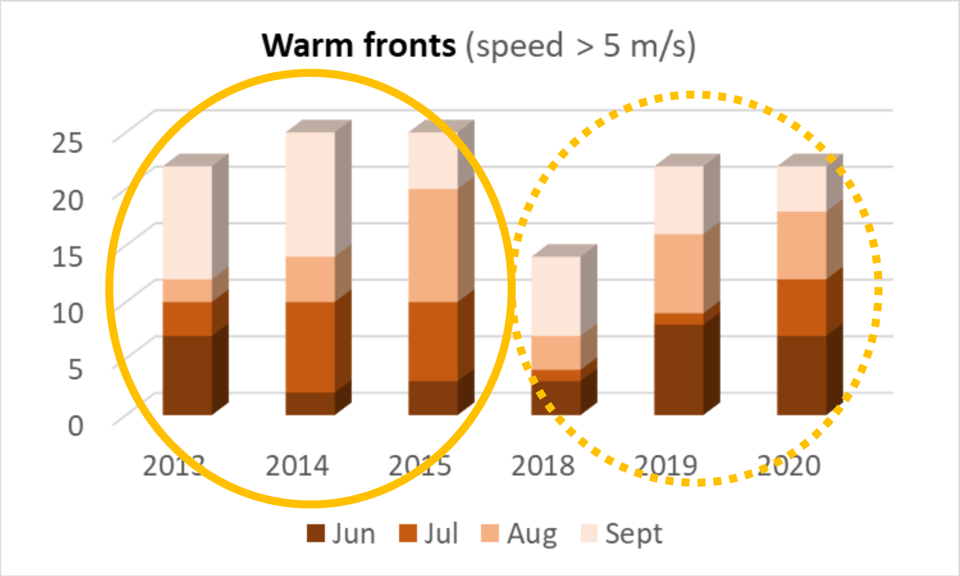
2013-2015
Solar Maximum

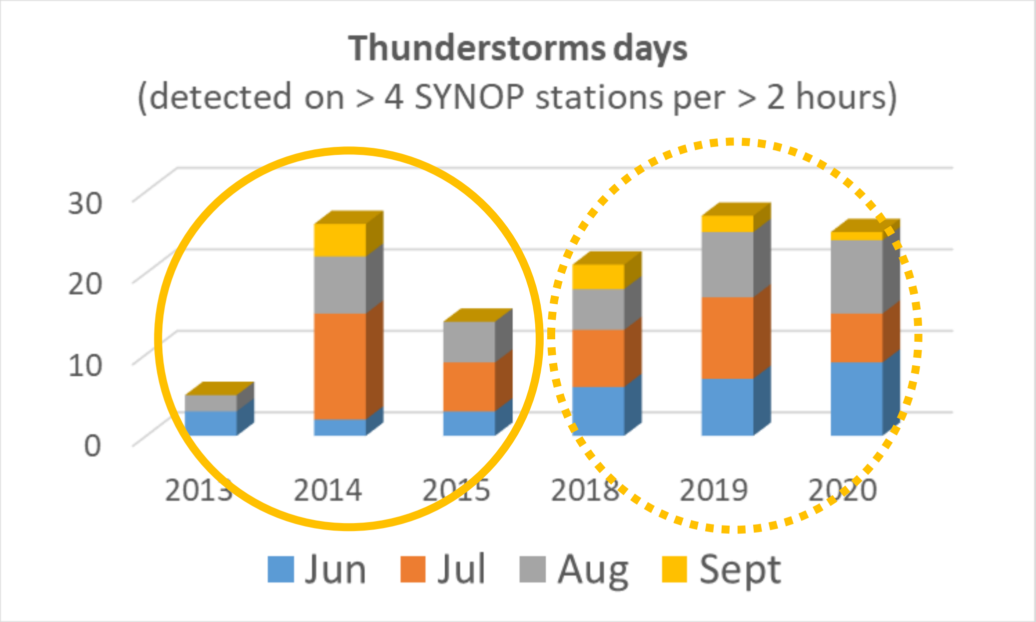
2018-2020
Solar Minimum



- For the warm fronts, the westward and eastward front progressions dominate in both periods.
- No significant difference in the speed of progression or temperature gradients.

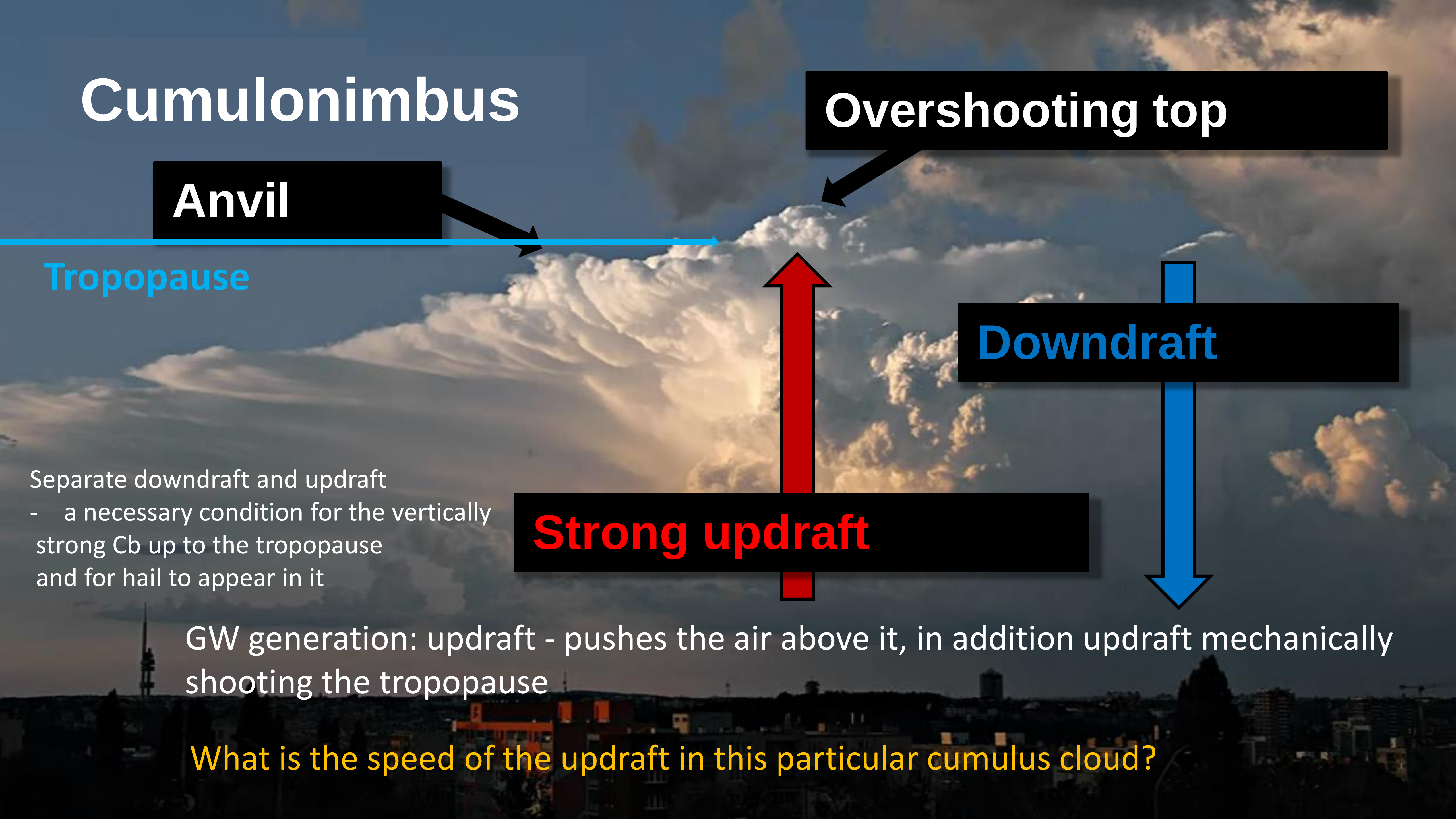






- During the **MaxSolar**, there was a **greater number of both cold fronts and warm fronts** than during MinSolar.
- **The number of thunderstorms was generally greather during the three-year period of the solar minimum,**
  - with the exception of July 2014 with a record-long period of warm and humid tropical days in central Europe.
  - possible explanation - **Frequency of severe thunderstorms across Europe increased and accoding climatic scenarious it expected to increase in the 21st century.**

Cumulonimbus



Separate downdraft and updraft

- a necessary condition for the vertically strong Cb up to the tropopause and for hail to appear in it

GW generation: updraft - pushes the air above it, in addition updraft mechanically shooting the tropopause

What is the speed of the updraft in this particular cumulus cloud?

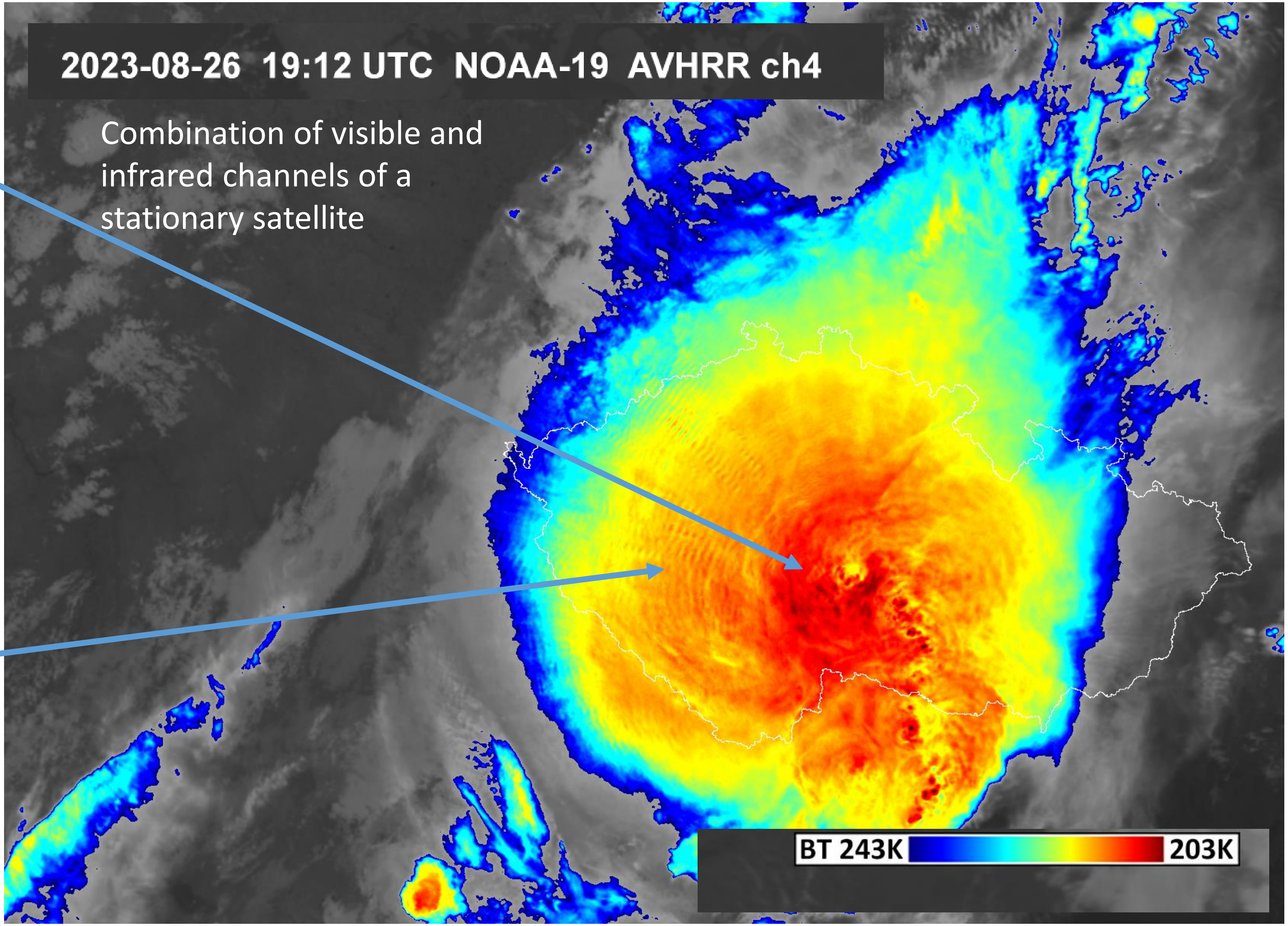

2010-08-15 17:49-18:15 UTC
0h 26m 25x (ΔT = 0.8 s) Ricoh GX100
© 2010 Martin Setvák


$24\ [m/s] = \mathbf{87}\ [\boldsymbol{km/h}]$ = 57 mph

Example of MCS - mesoscale convective system (Several storm cells joined together)

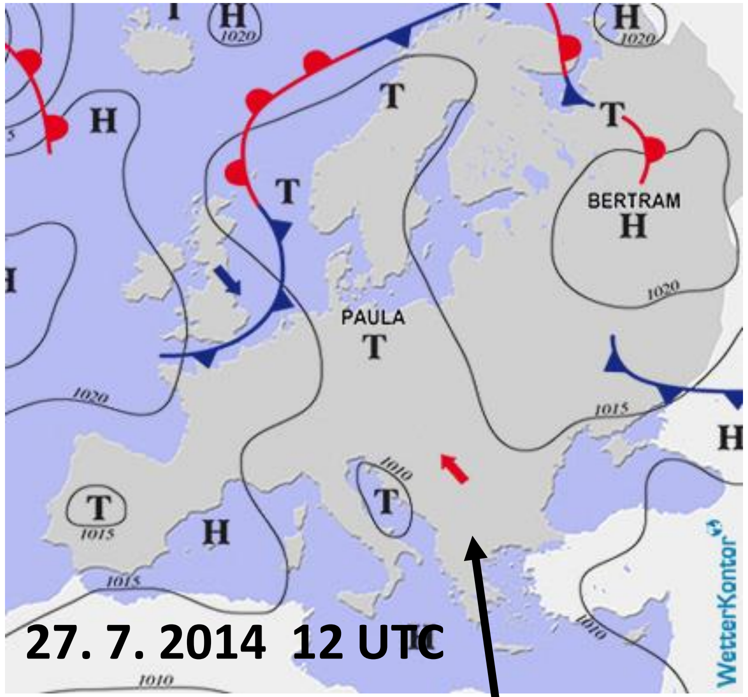
overshooting tops composed of fine ice crystals with a temperature of about - 70°C

GW - gravity waves at the upper cloud boundary just below the tropopause



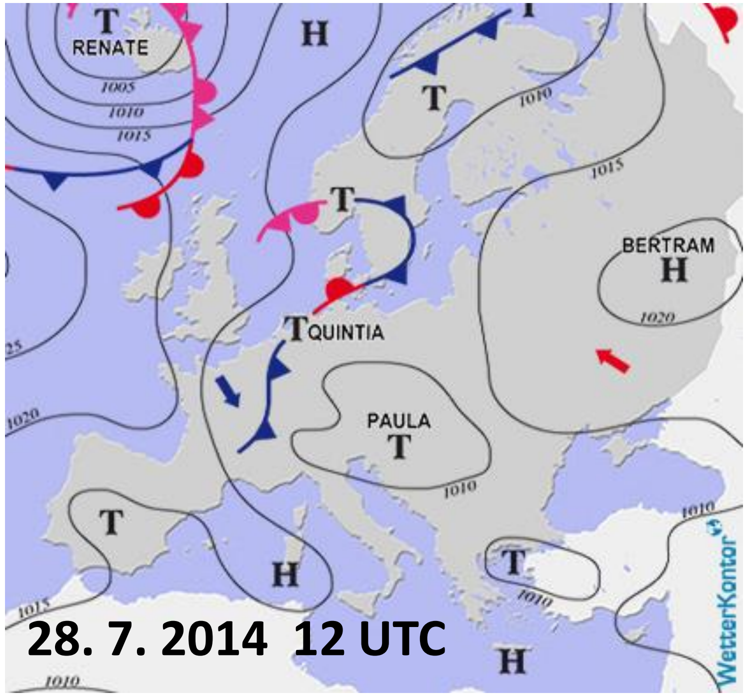
Thunderstorm event during period of **solar Maximum**

Synoptic pressure chart indication areas of hight and low pressure and atmosperic front



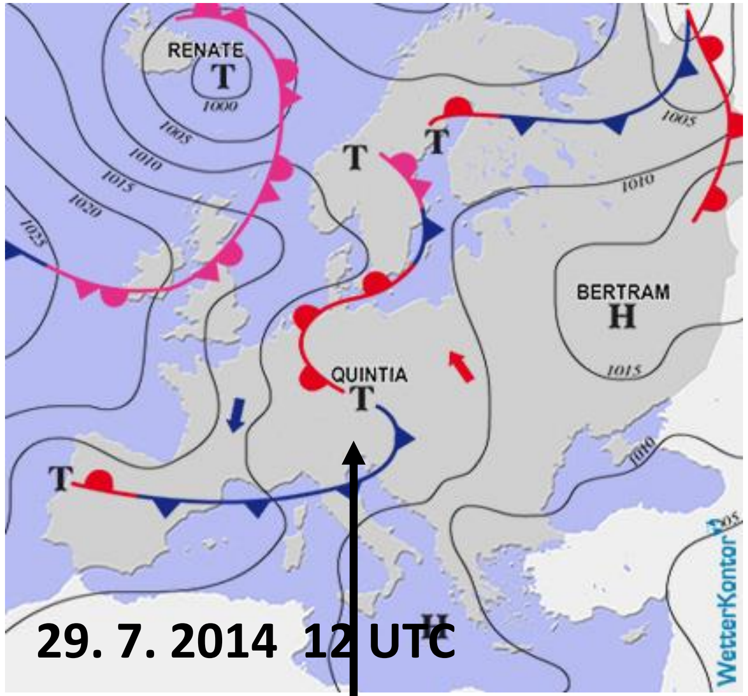
27. 7. 2014 12 UTC

inflow of hot and wet fllow



28. 7. 2014 12 UTC

A slight low pressure extends from northern Scandinavia into central Europe and the Balkans, supporting vertical convection and thunderstorms formation

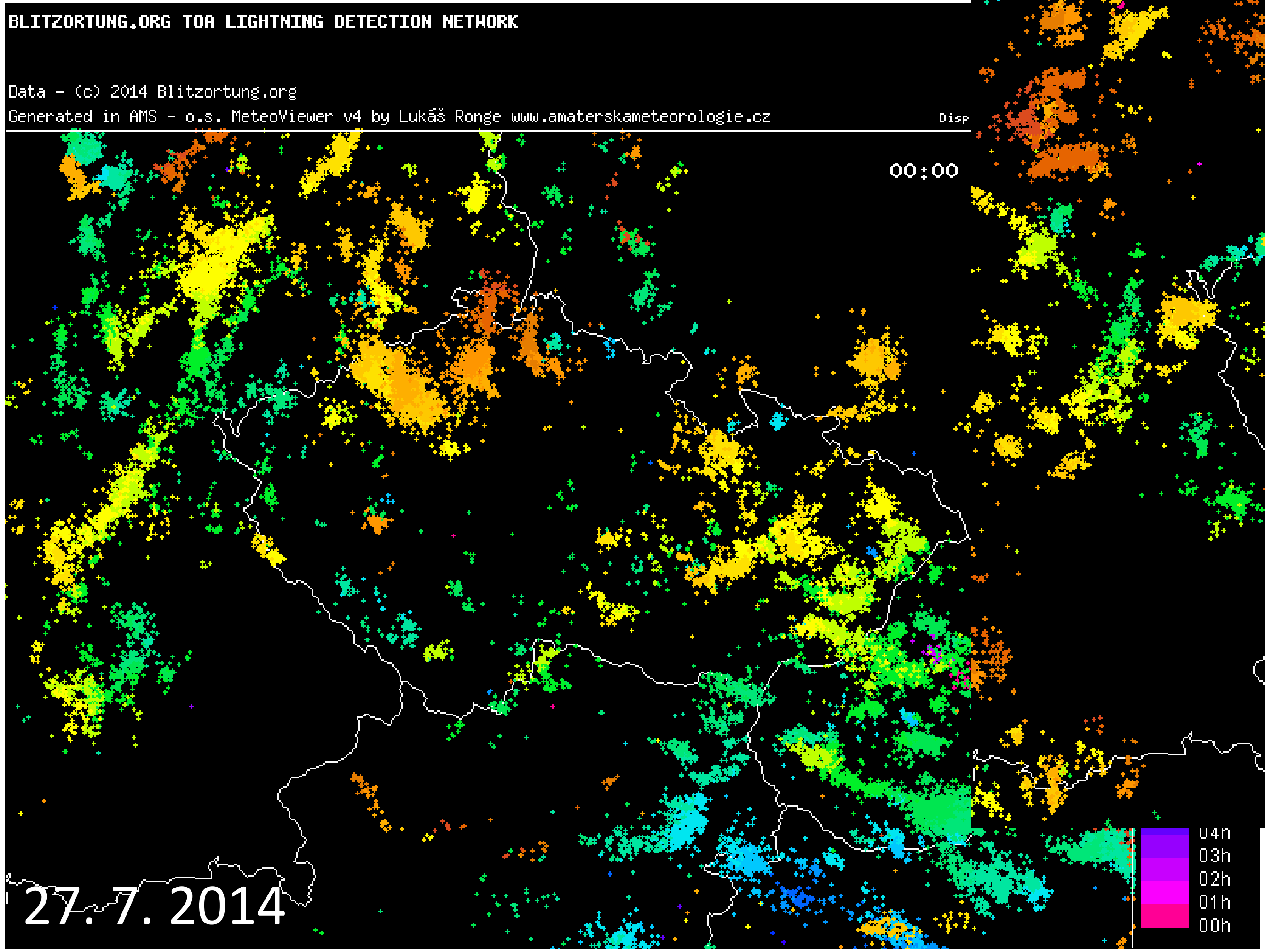


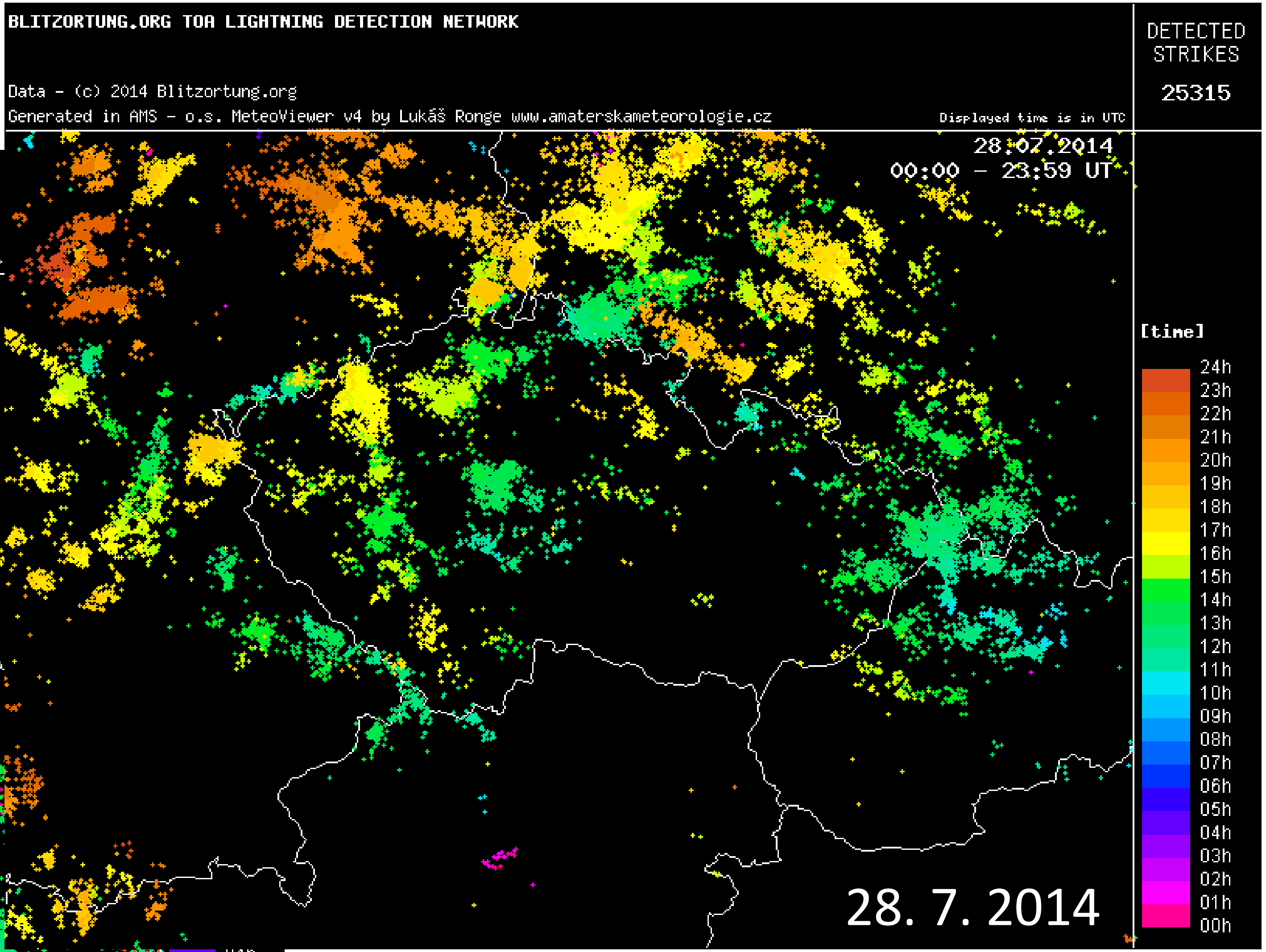
29. 7. 2014 12 UTC

A frontal cyclone (surface low) has formed with its center over northwestern Poland**, cold front** supported **updrafts** and morning **thunderstorms**

Time evolution of lightning activity - colours indicate locations of lightning - one colour for each hour

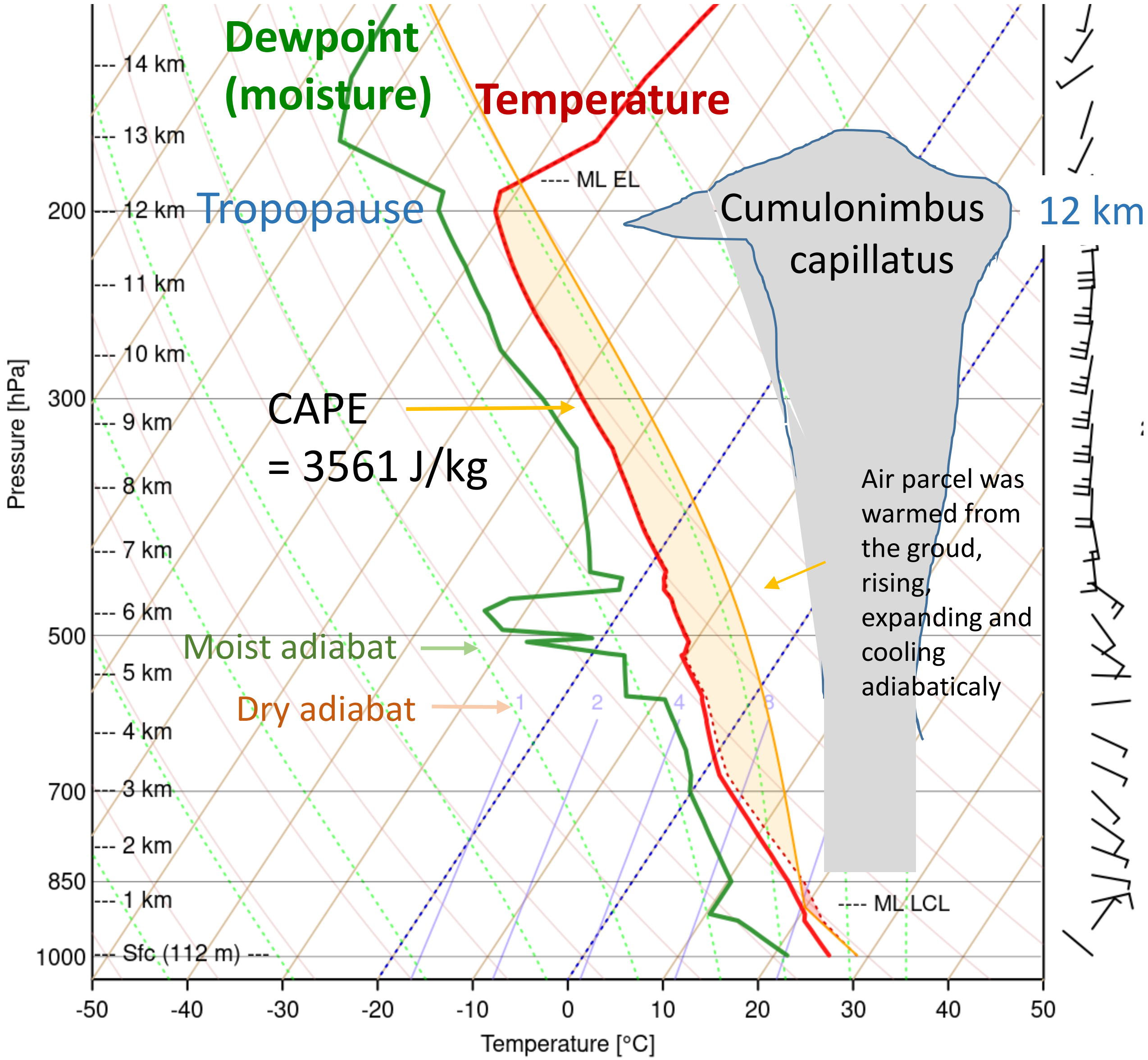
Single-cell thunderstorms formed throughout the two days.





source: Blitzortung.org

Aerological diagram from the thunderstorm day of 28 Jul 2014 at 18 UTC, Prague



Record from Radiosounding measuremen

Prague (14.45 E, 50.00 N)

CAPE (convective available potencial energy) – the area between the parcels temperature vertical profil curve and surrounding air temperature curve

You can also use CAPE to estimate the speed of the updraft in a storm cloud.

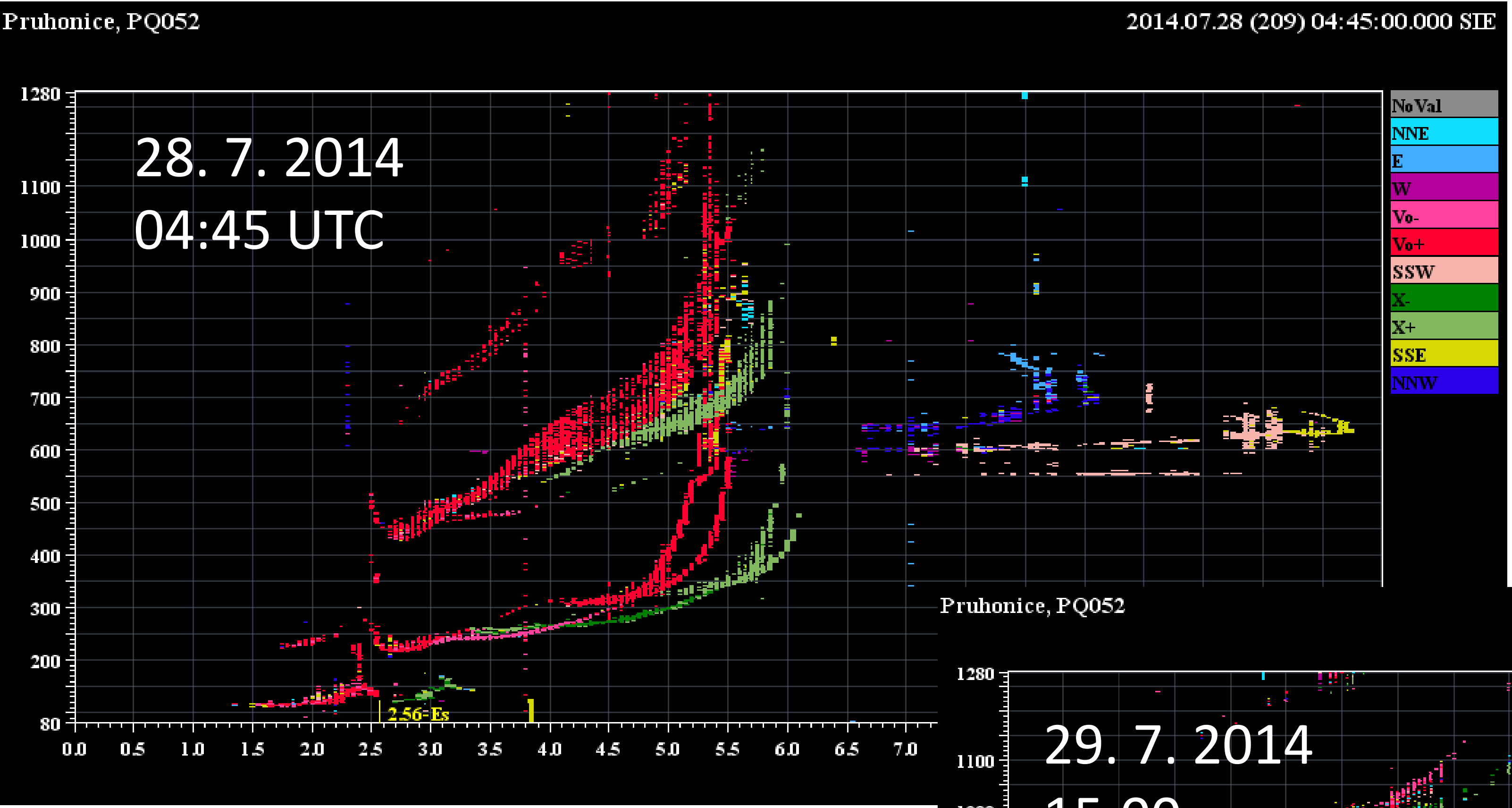
$w=(2.CAPE)^{-2}/2$

CAPE = 3561 J/kg

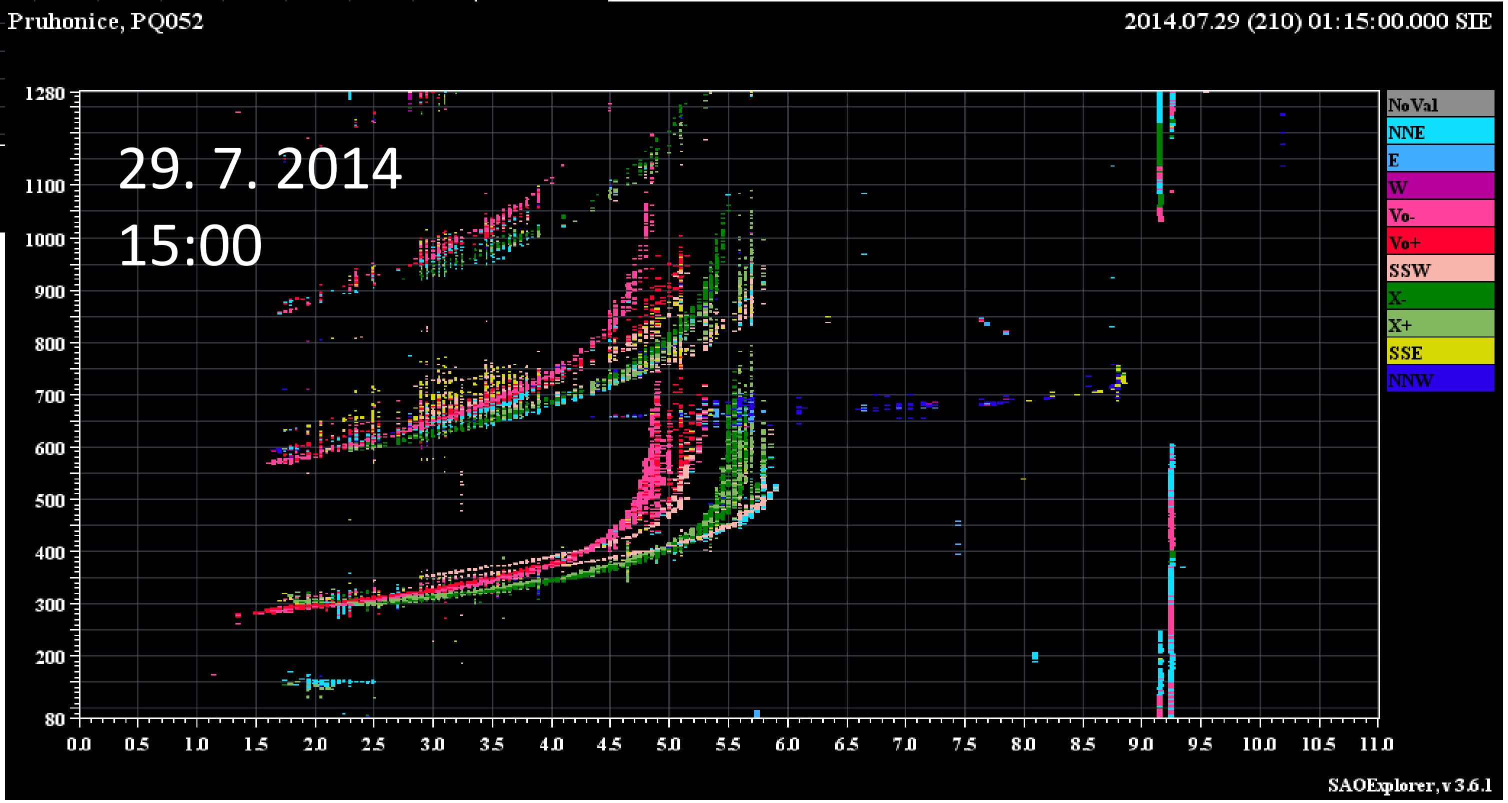
w = 42 m/s = **152 km/h** = 94,4 mph

correspons to fall velocity of a **10 cm hailstone**

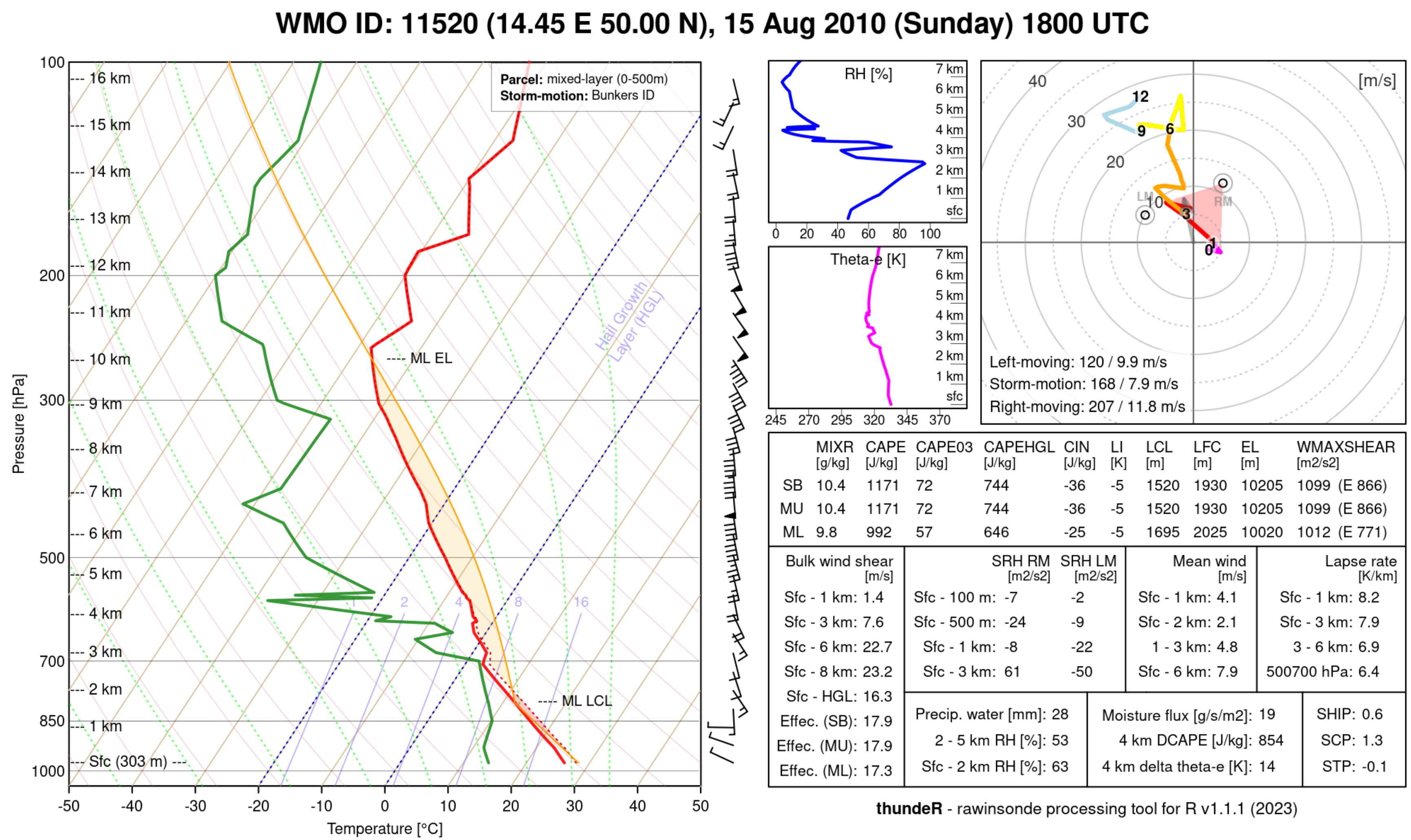
http://rawinsonde.com/



both days we see iregular stratifications (split echo and spread echo) of the sounding reflection of both ordinary and extraordinary signal in the ionospheric F layer



The iregularity on the profile are caused by propagation of waves – could be likely atributted to the evening thunderstorms in the troposphere



	MIXR [g/kg]	CAPE [J/kg]	CAPE03 [J/kg]	CAPEHGL [J/kg]	CIN [J/kg]	LI [K]	LCL [m]	LFC [m]	EL [m]	WMAXSHEAR [m2/s2]
SB	10.4	1171	72	744	-36	-5	1520	1930	10205	1099 (E 866)
MU	10.4	1171	72	744	-36	-5	1520	1930	10205	1099 (E 866)
ML	9.8	992	57	646	-25	-5	1695	2025	10020	1012 (E 771)

Bulk wind shear [m/s]	SRH RM [m2/s2]	SRH LM [m2/s2]	Mean wind [m/s]	Lapse rate [K/km]
Sfc - 1 km: 1.4	Sfc - 100 m: -7	-2	Sfc - 1 km: 4.1	Sfc - 1 km: 8.2
Sfc - 3 km: 7.6	Sfc - 500 m: -24	-9	Sfc - 2 km: 2.1	Sfc - 3 km: 7.9
Sfc - 6 km: 22.7	Sfc - 1 km: -8	-22	1 - 3 km: 4.8	3 - 6 km: 6.9
Sfc - 8 km: 23.2	Sfc - 3 km: 61	-50	Sfc - 6 km: 7.9	500700 hPa: 6.4
Sfc - HGL: 16.3				
Effec. (SB): 17.9	Precip. water [mm]: 28		Moisture flux [g/s/m2]: 19	SHIP: 0.6
Effec. (MU): 17.9	2 - 5 km RH [%]: 53		4 km DCAPE [J/kg]: 854	SCP: 1.3
Effec. (ML): 17.3	Sfc - 2 km RH [%]: 63		4 km delta theta-e [K]: 14	STP: -0.1

$$\frac{E_k}{kg} = \frac{\frac{1}{2}\cancel{m}\, v^2}{\cancel{kg}}$$

$$= CAPE \left[\frac{J}{\cancel{kg}}\right]$$

$$\frac{1}{2} v^2 = J$$

$$v = \sqrt{2\ CAPE}$$

$$w = \sqrt{2\ CAPE}\ /\ 2$$

Answer to the question: What is the updraft speed in cumulonimbus on the timlapsed image?

80 km/h corresponds to a fall velocity of a 3 cm hailstone

$$CAPE = 1171 \ \Rightarrow w = 24\ [m/s] = \mathbf{87}\ [\boldsymbol{km/h}]$$

Thank you for your attention.

ÚSTAV FYZIKY ATMOSFÉRY
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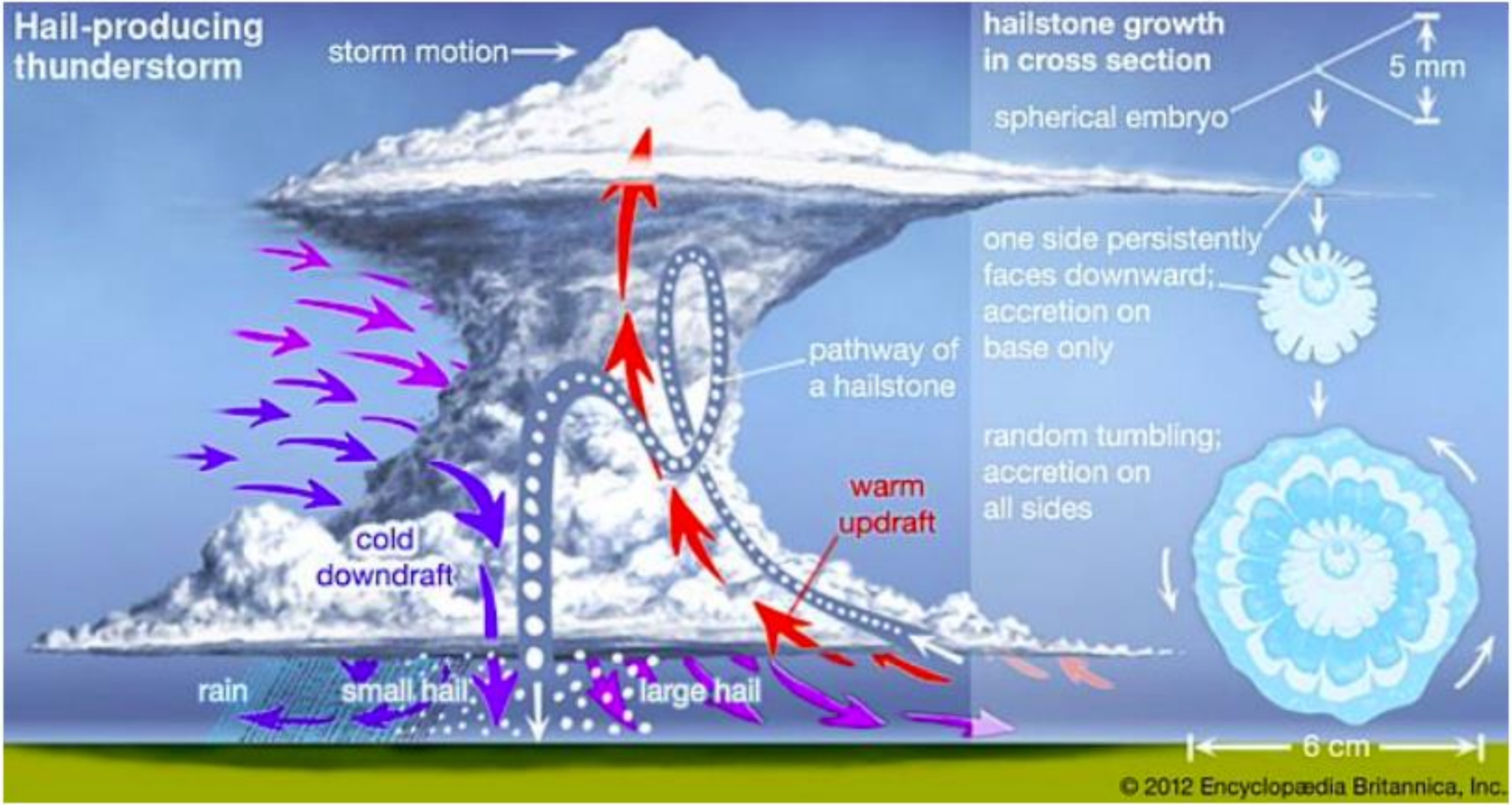


I'm sure you've heard of hailstones growing by repeatedly rising and falling in a storm cloud, trapping supercooled droplets and increasing their size. However, mathematical model studies of the hail cloud have not shown this repeated vertical

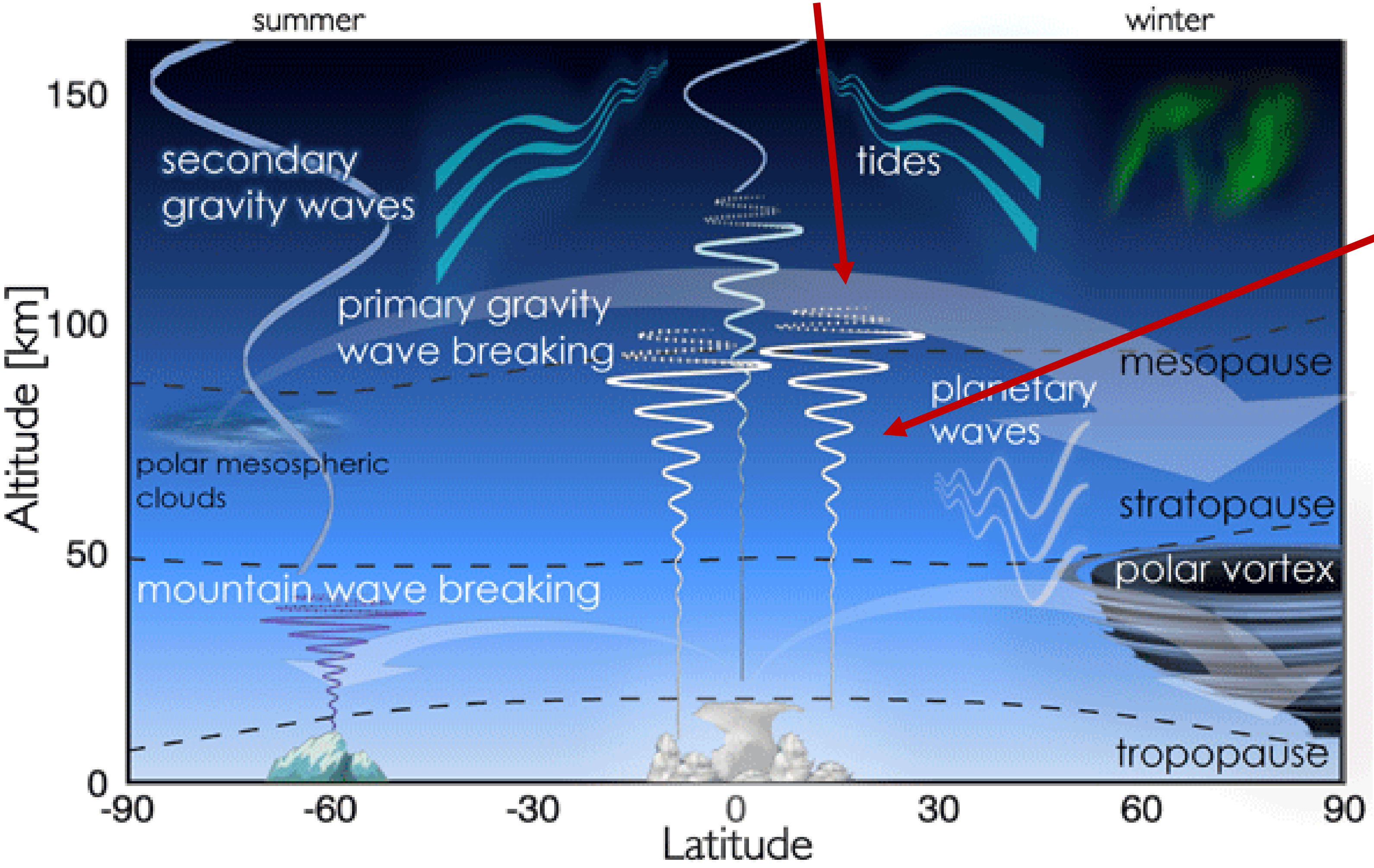
The lower and middle atmosphere is a constant source of waves in pressure and density with a wide range of temporal and spatial scales with vertical velocity component:

Planetary wave:
T(period) ~ day

Tides:
T ~ 6h ÷ 1 den

Gravity wave
T ~ buoyance period (Brunt-Väisälä) ÷ 6h

Infrasound
T ~ s ÷ period of accoustic cut off



wave <u>amplitude ↑</u> altitude ↑

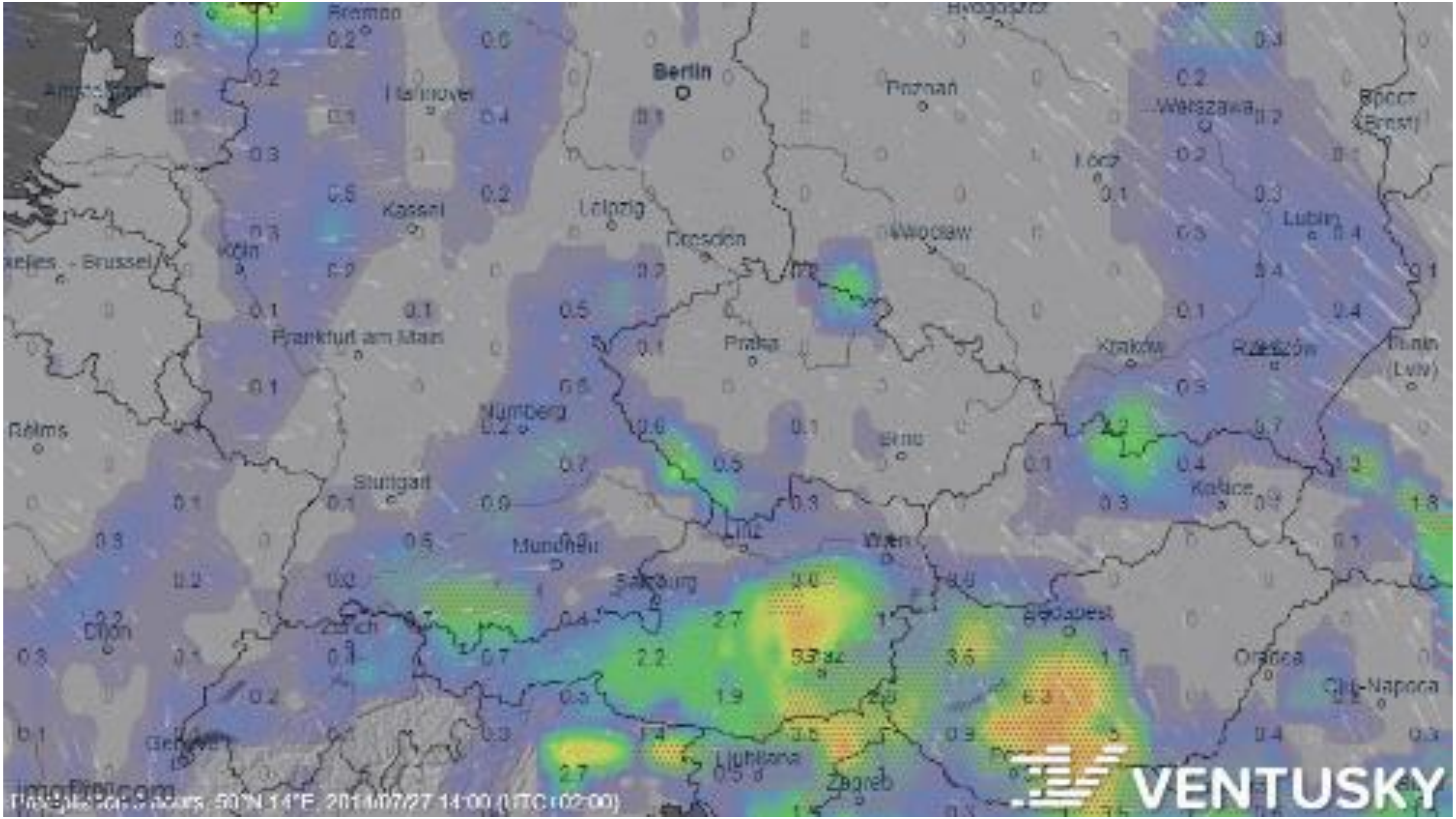
⇓

Local effect on lower atmosphere ⇒ significant effects in the ionosphere

(meteorological variability (**atmospheric front, thunderstorms…**) can **impact the performance of GPS/GNSS** particularly **during times of reduced solar activity)**

The atmospheric weather radar

• isolated storms across central Europe from 27 Aug to 29 Aug 2014



A small climatological excursion...

Why should we be interested in the effects of tropospheric storms in the 21st century?

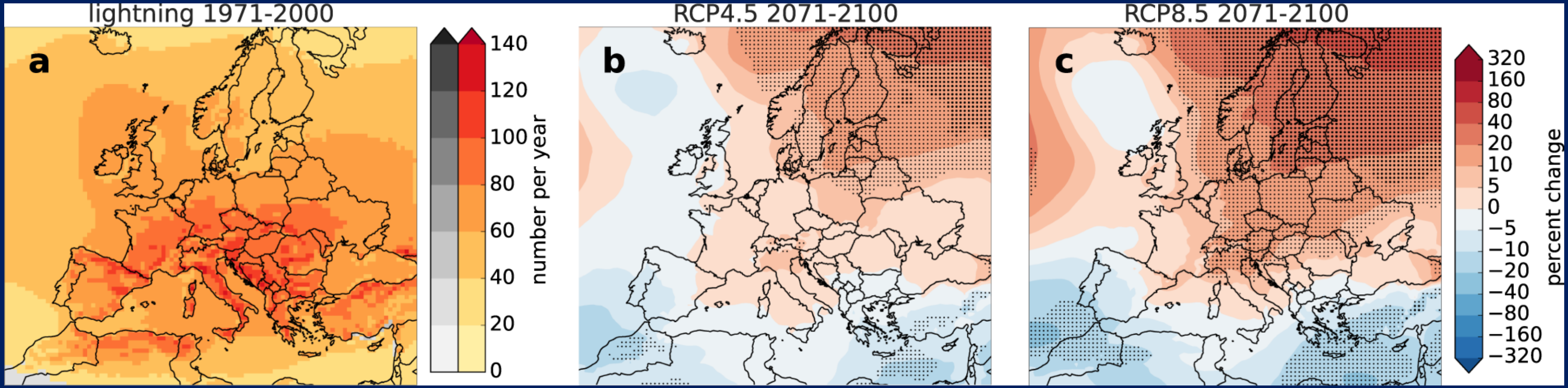
The increase in global mean surface temperature averaged over 2081-2100 compared to the pre-industrial period (average between 1850-1900) for the RCP (Representative Concentration Pathways of greenhouse gases) scenarios of climatological EURO-CORDEX model.

RCP	Change in temperature (°C) by 2081-2100
RCP2.6	1.6 (0.9-2.3)
RCP4.5	2.4 (1.7-3.2)
RCP6.0	2.8 (2.0-3.7)
RCP8.5	4.3 (3.2-5.4)

increase evaporation of the soil water → warmer atmosphre can absorb more moisture → moist and warm air is more thermally unstable → **Thunderstorms occures more frequently and are the more severe**

Places where there is now relatively little precipitation will become even drier under climate scenarios.
Places with currently relatively adequate rainfall and soil moisture will experience more dangerous, intense and short-lived precipitation events under the climate scenarios.

Rädler, A. T., P. Groenemeijer, E. Faust, R. Sausen, and T. Púčik, 2019: Frequency of severe thunderstorms across Europe expected to increase in the 21st century due to rising instability. *npj Climate Atmos. Sci.*, **2**, 30, https://doi.org/10.1038/s41612-019-0083-7.



Mean number of thunderstorm per year (1971 – 2000)

b RCP4.5 scenario

b RCP8.5 scenario

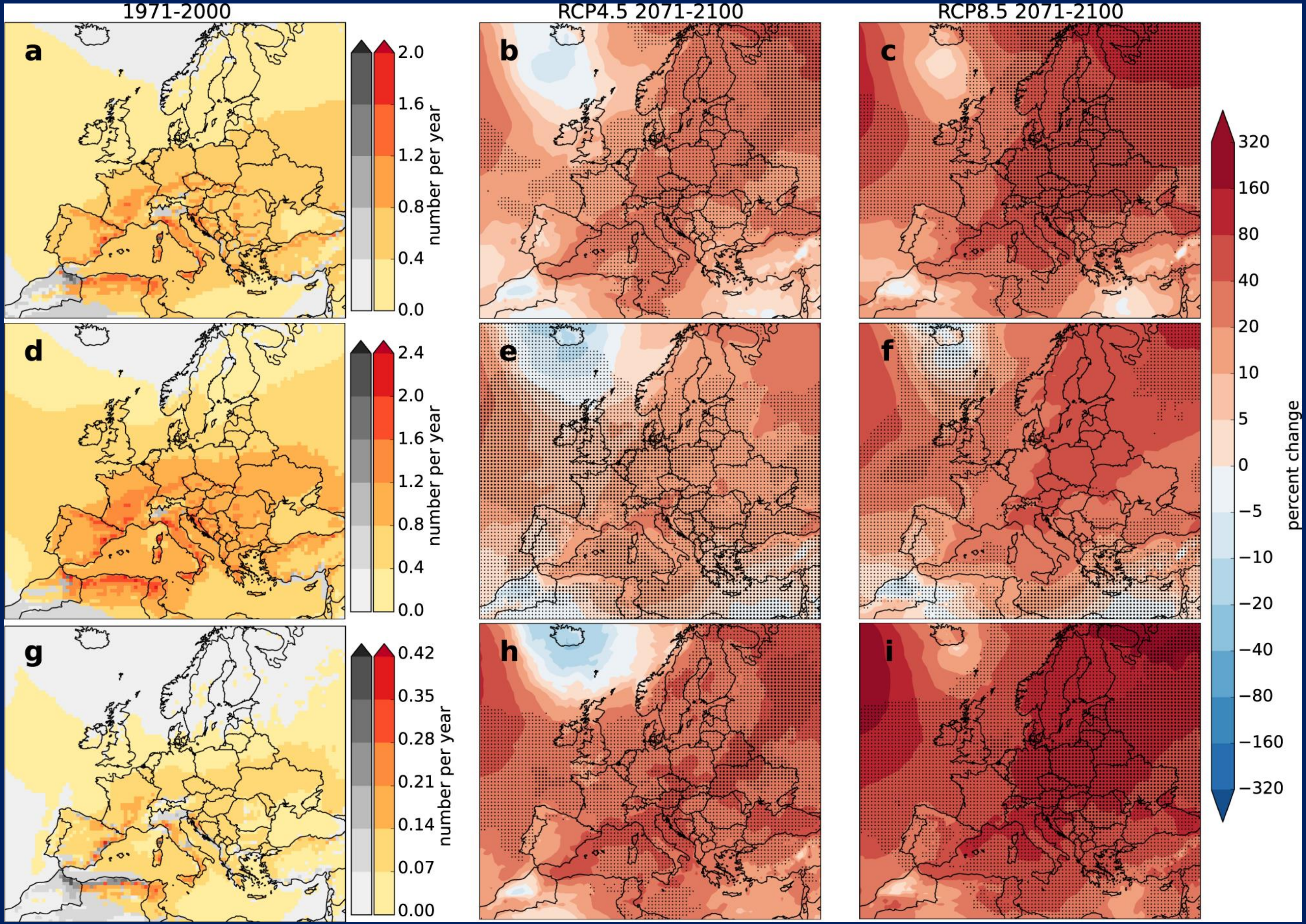
Percentage of change number of thunderstorm (1971 – **2100**)

EURO-CORDEX model

hail ≥ 2 cm

wind gusts ≥ 25 m/s

hail ≥ 5 cm



number per year (1971 – 2000)

percentage change (1971 – 2100)

RCP4.5 scenario

RCP8.5 scenario

average of days/year (for the period of 1979–2017)

- with thunderstorm **TDs**
- with severe thunderstorm **sevTDs**

Central and south EUROPE

Stuttgard (Germany)	**Warsaw** (Poland)	**Zadar** (Croatia)
TDs 31.3	**TDs** 26.8	**TDs** 34.6
SevTD 12.9	**SevTD** 7.9	**SevTD** 14.1

Southeastern EUROPE

Bucharest (Romania)	**Athens** (Greece)	**Sofia** (Bulgaria)
TDs 31.3	**TDs** 26.8	**TDs** 30.1
SevTD 12.9	**SevTD** 7.9	**SevTD** 8.2

From: Taszarek et al (2019)
A climatology of thunderstorms across Europe from a synthesis of multiple data sources.
J Clim 32:1813-1837.
https://doi.org/10.1175/JCLI-D-18-0372.1

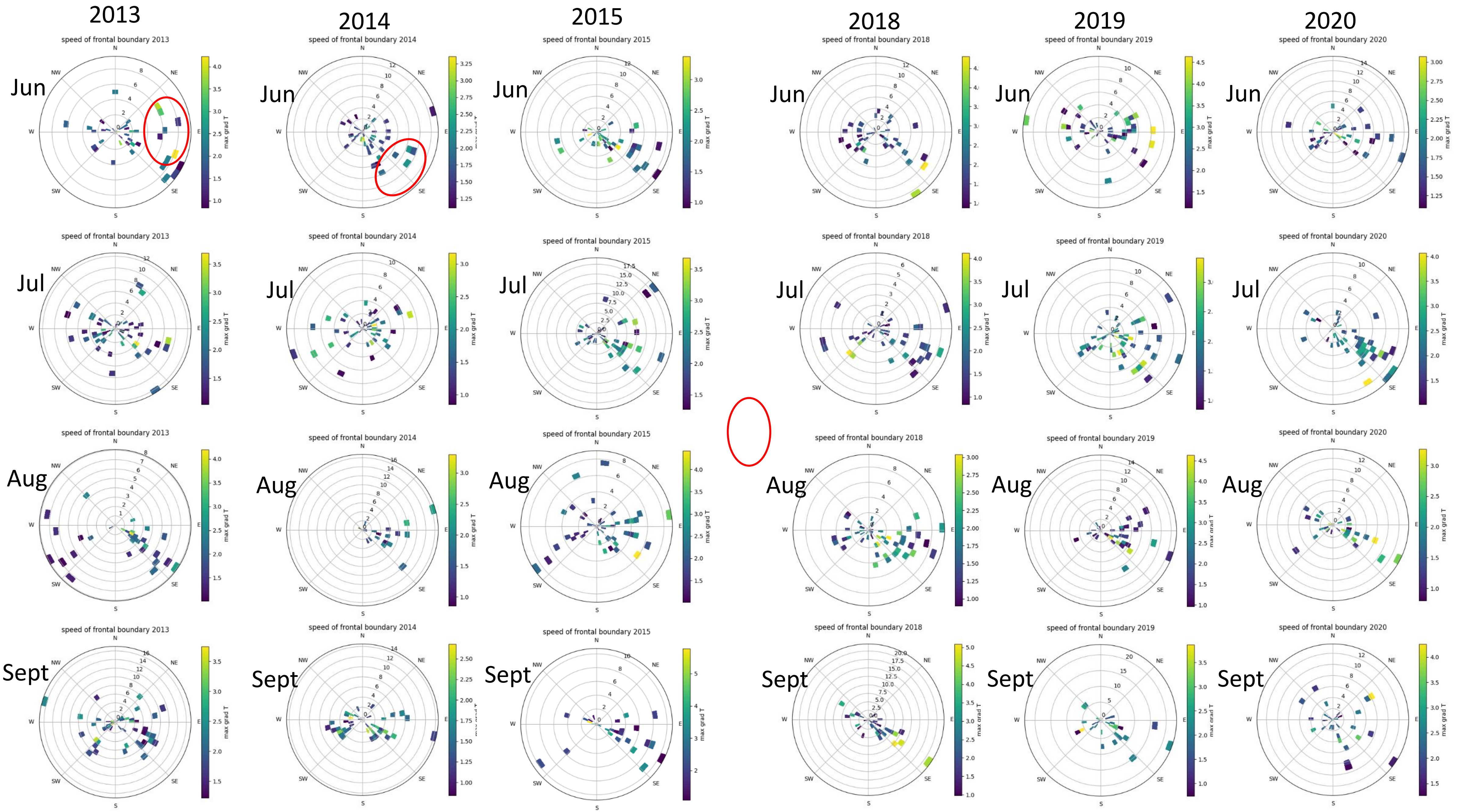
CONCLUSION

Described two types of mesoscale situations in the troposphere may possibly influence ionosphere and induce observed plasma disturbances:

- Atmospheric front (boundary between two air masses) associated with thunderstorm
- and thunderstorm inside one air mass

The observed ionospheric response is variable.
Extensive statistical study is needed, which we are currently working on.

In our experience and according to climatic scenarios strong summer thunderstorms are becoming more frequent in central Europe.

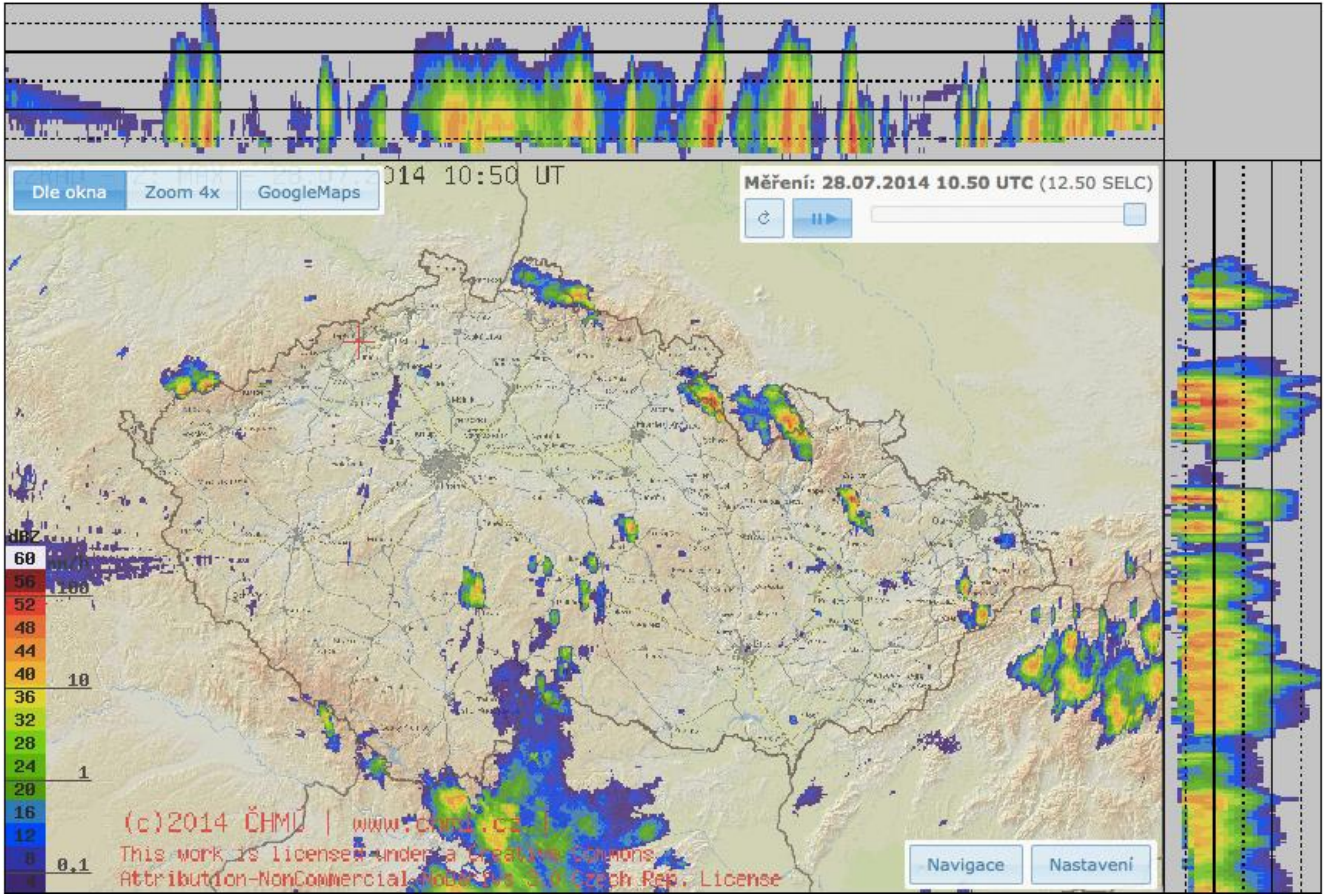

2013
2014
2015
2018
2019
2020
Jun
Jul
Aug
Sept
speed of frontal boundary 2013
speed of frontal boundary 2014
speed of frontal boundary 2015
speed of frontal boundary 2018
speed of frontal boundary 2019
speed of frontal boundary 2020
max grad T
N
NE
E
SE
S
SW
W
NW

[28.7.2014]

[Český hydrometeorologický ústav]

·

12:50 hod.: Jak už to v podobných situacích s instabilním teplotním zvrstvením bývá, první bouřky vznikají tam, kde vzestupným pohybům pomáhá i konfigurace terénnu. Proto na detekci blesků i na rozložení radarových odrazů najdeme cíle právě v horských oblastech. V průběhu odpoledne se dá očekávat vývoj dalších přeháněk a bouřek, postupně i mimo naše hory. I nadále se ale bude jednat o bouřky izolované, tedy s projevy značně lokálně rozdílně intenzivními.
V platnosti je výstraha pro celé území republiky, která informuje o předpovídaném výskytu OJEDINĚLÝCH silných bouřek, tedy zdaleka ne všude.



014 10:50 UT
Dle okna
Zoom 4x
GoogleMaps
Měření: 28.07.2014 10.50 UTC (12.50 SELC)
dBZ
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
100
10
1
0.1
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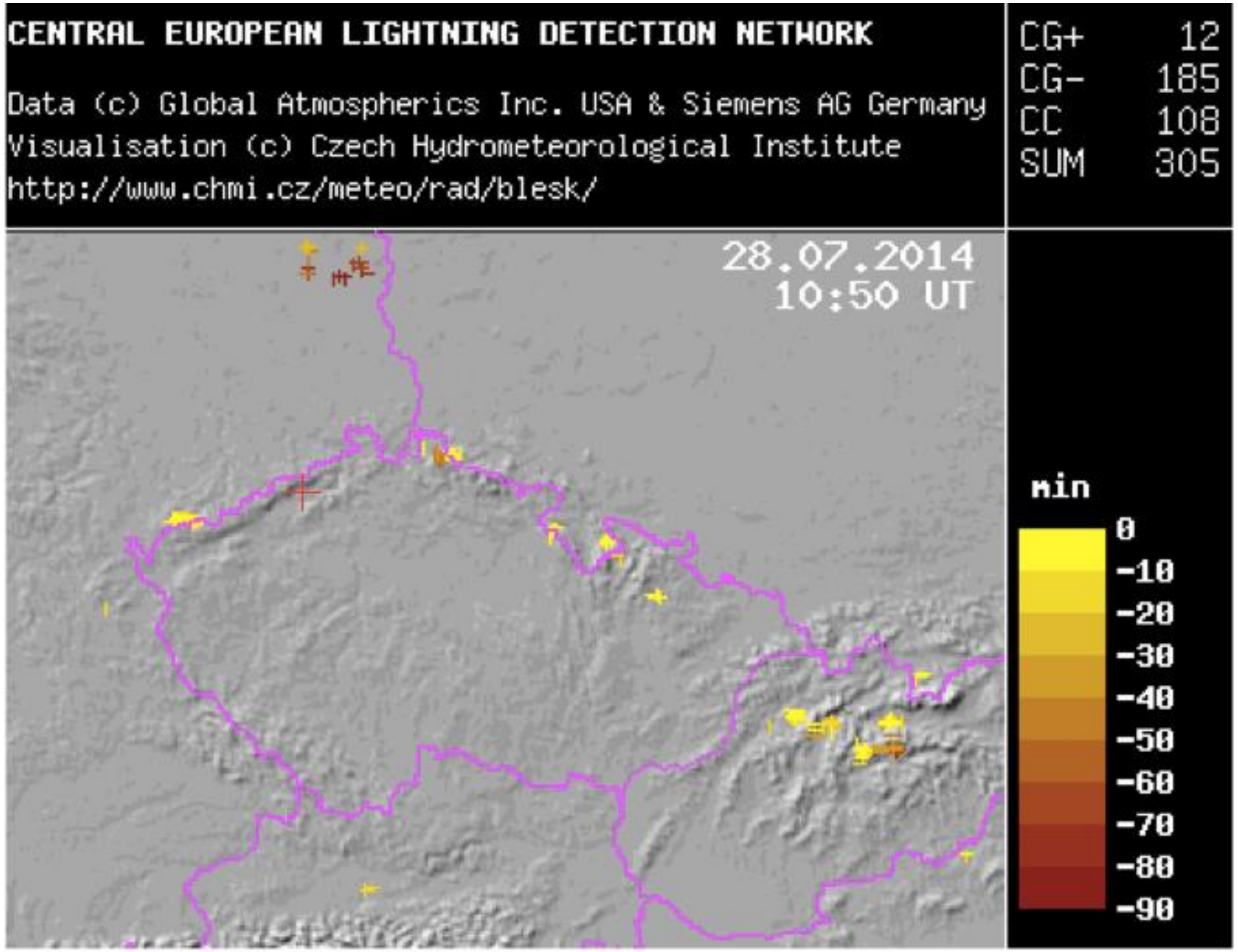
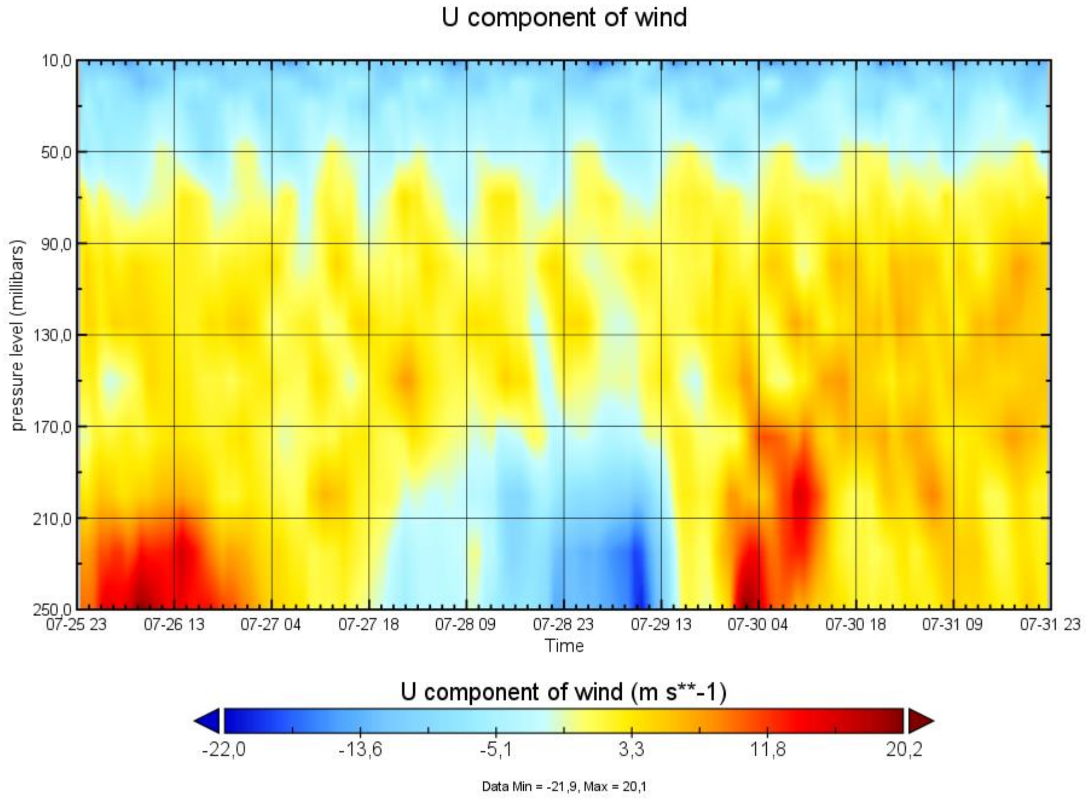
Navigace
Nastavení


CENTRAL EUROPEAN LIGHTNING DETECTION NETWORK
Data (c) Global Atmospherics Inc. USA & Siemens AG Germany
Visualisation (c) Czech Hydrometeorological Institute
http://www.chmi.cz/meteo/rad/blesk/
CG+ 12
CG- 185
CC 108
SUM 305
28.07.2014
10:50 UT
min
0
-10
-20
-30
-40
-50
-60
-70
-80
-90


U component of wind
pressure level (millibars)
10,0
50,0
90,0
130,0
170,0
210,0
250,0
07-25 23
07-26 13
07-27 04
07-27 18
07-28 09
07-28 23
07-29 13
07-30 04
07-30 18
07-31 09
07-31 23
Time
U component of wind (m s**-1)
-22,0
-13,6
-5,1
3,3
11,8
20,2
Data Min = -21,9, Max = 20,1