Extreme precipitation in Kislovodsk on July 27, 2018: formation mechanisms and connection with large-scale atmospheric circulation

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Kislovodsk, IAP CAS

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Aims and Motivation

- The danger of extreme precipitation and the complexity of its forecasting is associated with the suddenness of their formation

- Such precipitation is associated with significant economic, social and environmental losses and risks

- Improving the accuracy of operational forecasts is possible through a better understanding of the formation mechanisms and moisture sources for this type of precipitation, followed by the appropriate use of regional models. These models are a good tool for analyzing localized extreme precipitation events, but they are time- and resource-intensive. Identifying the causes of such precipitation and its statistical categorization helps speed up and improve operational forecasting

- Using WRF simulation and data analysis we can encourage the

1. Observations

Data from the weather archive rp-5

Дата / Местное время		T	Po	P	Pa	U	DD	Ff	ff10	ff3	N	WW	W1	W2	Tn	Tx	Cl	Nh	H	Cm	Ch	VV	Td	RRR	tR	E	Tg	E'	sss
2018г. 27 июля, пятница	21	19.3	680.5	758.2		96	Ветер, дующий с юго-юго-востока	Легкий ветер (2 м/с)			90 или более, но не 100 %	Состояние неба в общем не изменилось.	Гроза (грозы) с осадками или без них.	Ливень (ливни).			Кучево-дождевые волокнистые (часто с наковальней), либо с кучево-дождевыми лысыми, кучевыми, слоистыми, разорванно-дождевыми, либо без них.	90 или более, но не 100 %	600-1000	Высококучевых, высокослоистых или слоисто-дождевых облаков нет.	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	18.7						
	18	23.9	679.3	755.6		76	Ветер, дующий с юго-юго-запада	Тихий ветер (1 м/с)			90 или более, но не 100 %	Состояние неба в общем не изменилось.	Гроза (грозы) с осадками или без них.	Ливень (ливни).		31.2	Слоисто-кучевые, образовавшиеся из кучевых.	40 %.	1000-1500	Высококучевые, образовавшиеся из кучевых (или кучево-дождевых).	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	19.4	45.0	12				
	15	18.7	679.9	757.7		96	Ветер, дующий с юго-юго-востока	Слабый ветер (4 м/с)		18 м/с	90 или более, но не 100 %	Гроза слабая или умеренная без града, но с дождем и/или снегом в срок наблюдения. Максимальный диаметр градин составляет 7 мм.	Гроза (грозы) с осадками или без них.	Ливень (ливни).			Кучево-дождевые волокнистые (часто с наковальней), либо с кучево-дождевыми лысыми, кучевыми, слоистыми, разорванно-дождевыми, либо без них.	90 или более, но не 100 %	600-1000	Высококучевых, высокослоистых или слоисто-дождевых облаков нет.	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	18.1						
	12	31.1	679.0	753.4		50	Ветер, дующий с северо-северо-востока	Тихий ветер (1 м/с)			60 %.						Кучево-дождевые лысые с кучевыми, слоисто-кучевыми или слоистыми, либо без них.	60 %.	1000-1500	Высококучевых, высокослоистых или слоисто-дождевых облаков нет.	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	19.4						
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Let's review the observation data. A sharp change in weather and the onset of heavy rainfall were recorded between 12:00 and 15:00 (9:00-12:00 UTC).

Data from the weather archive rp-5

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A sharp drop in temperature – more than 12°C in 3 hours (from 31.1°C to 18.7°C). Humidity increases from 50% to 96% in 3 hours.

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A sharp drop in temperature – more than 12°C for 3 hours (from 31.1°C to 18.7°C).

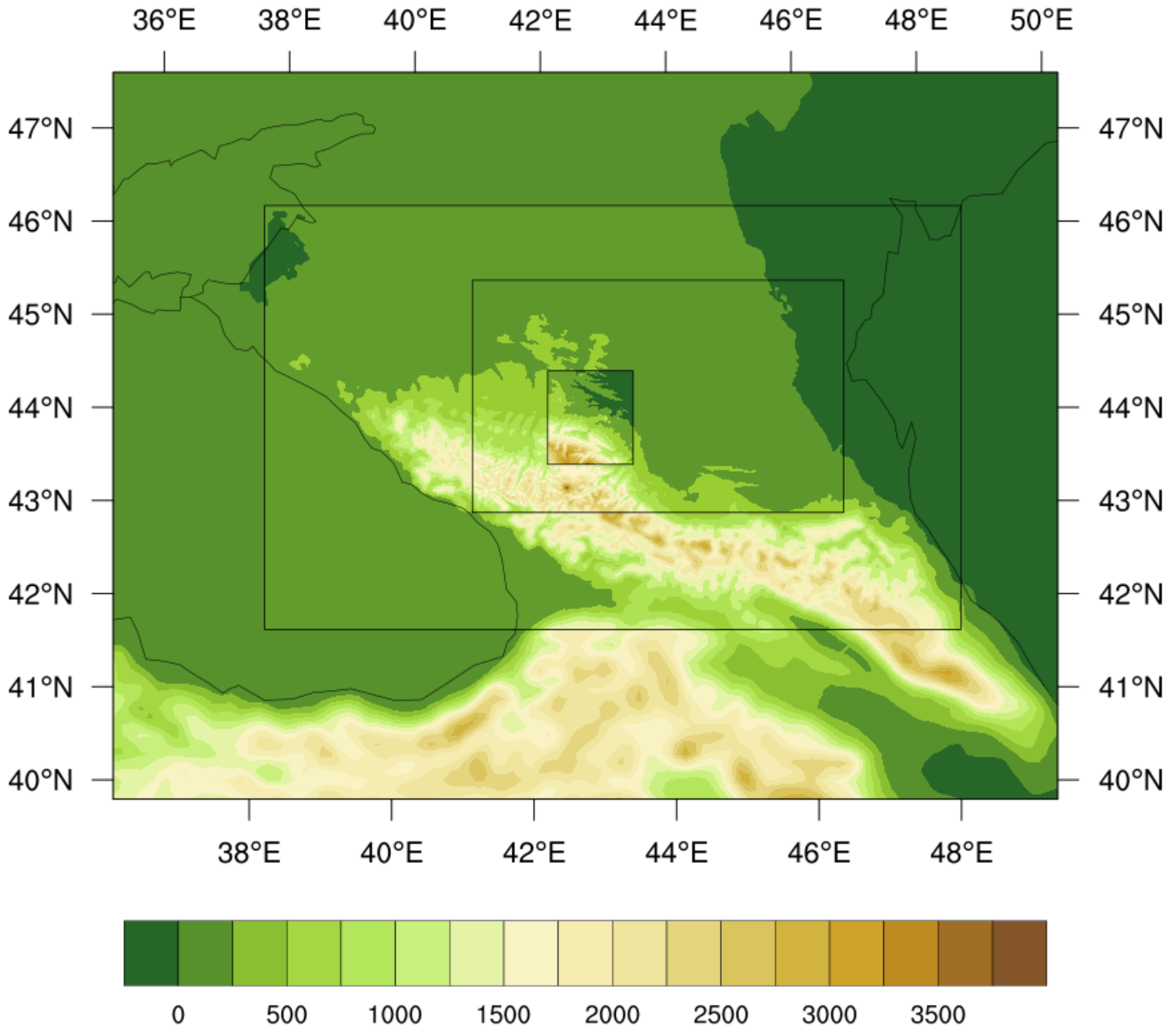
Humidity increases from 50% to 96% for 3 hours.

Wind gusts reached 18 m/s.

45 mm of precipitation fell (averaged over 12 hours).

2. Model

WRF-ARW model. Grid and parameterizations



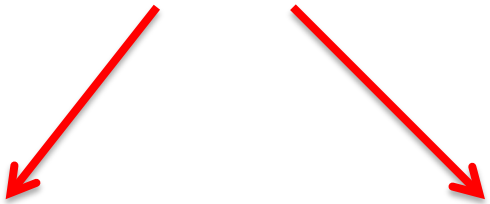
- Kislovodsk. July 27, 2018. 12:00 to 6:00 p.m. local time.
- Four days were simulated. Launch 8 hours before the expected event.
- Grid – 4 domains: 10800, 3600, 1200, 400

WRF-ARW model. Grid and parameterizations

Calculated time	27.07.2021 00 UTC-31.07.2021 00 UTC
Nested grids	3, учет влияния рельефа и озер, nudging ~ от 3,5 км
Map projections	Lambert
Grid space	10 800 м / 3600 м / 1200 м / 400м
Number of grid space, north-south	82/142/232/280
Number of grid space, east-west	106/232/370/256
Number of vertical levels	40
Time step	10 с
Microphysics	New Thompson et al. scheme
Planetary Boundary layer (PBL)	Monin-Obukhov (Zilitinkevitch)
Surface Layer	5-layer thermal diffusion
Land Surface	Mellor-Jamada-Janjic scheme (Janjic, 1994, MWR)

3. Analysis of extreme precipitations' causes

Possible mechanisms and humid sources:



Advection (dynamic)

Convection (thermodynamic)

+ Orography and frontal mechanisms

- In general, two main mechanisms can be identified for the generation of extreme precipitation in the region: advection and convection, or dynamic and thermodynamic. Orography and frontal mechanisms can be distinguished separately.

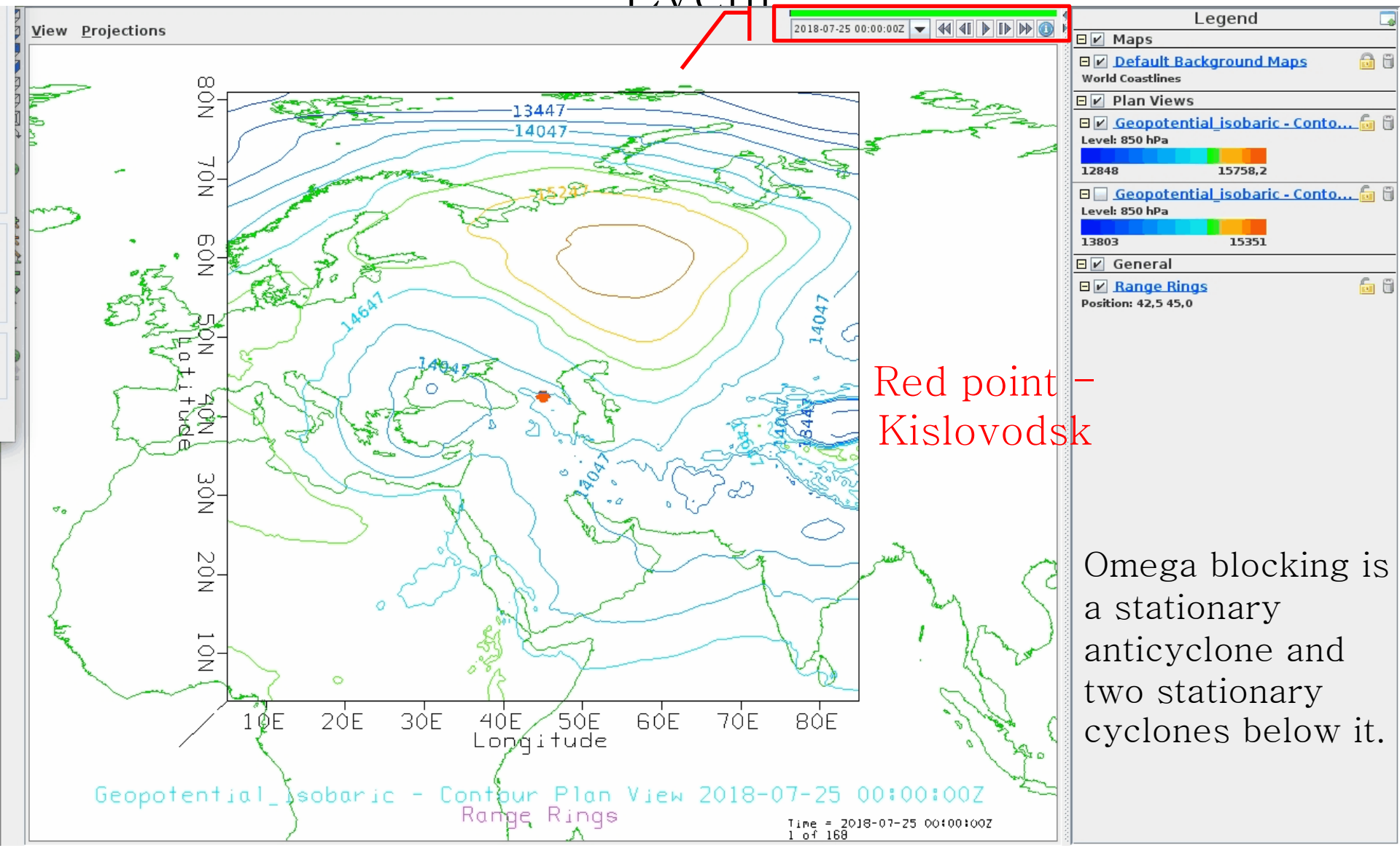
Simultaneous action of factors:

- Omega blocking – a stationary anticyclone and two stationary cyclones below it
- Frontal air mass transfer – cold air intrusion
- Convective

also checked:

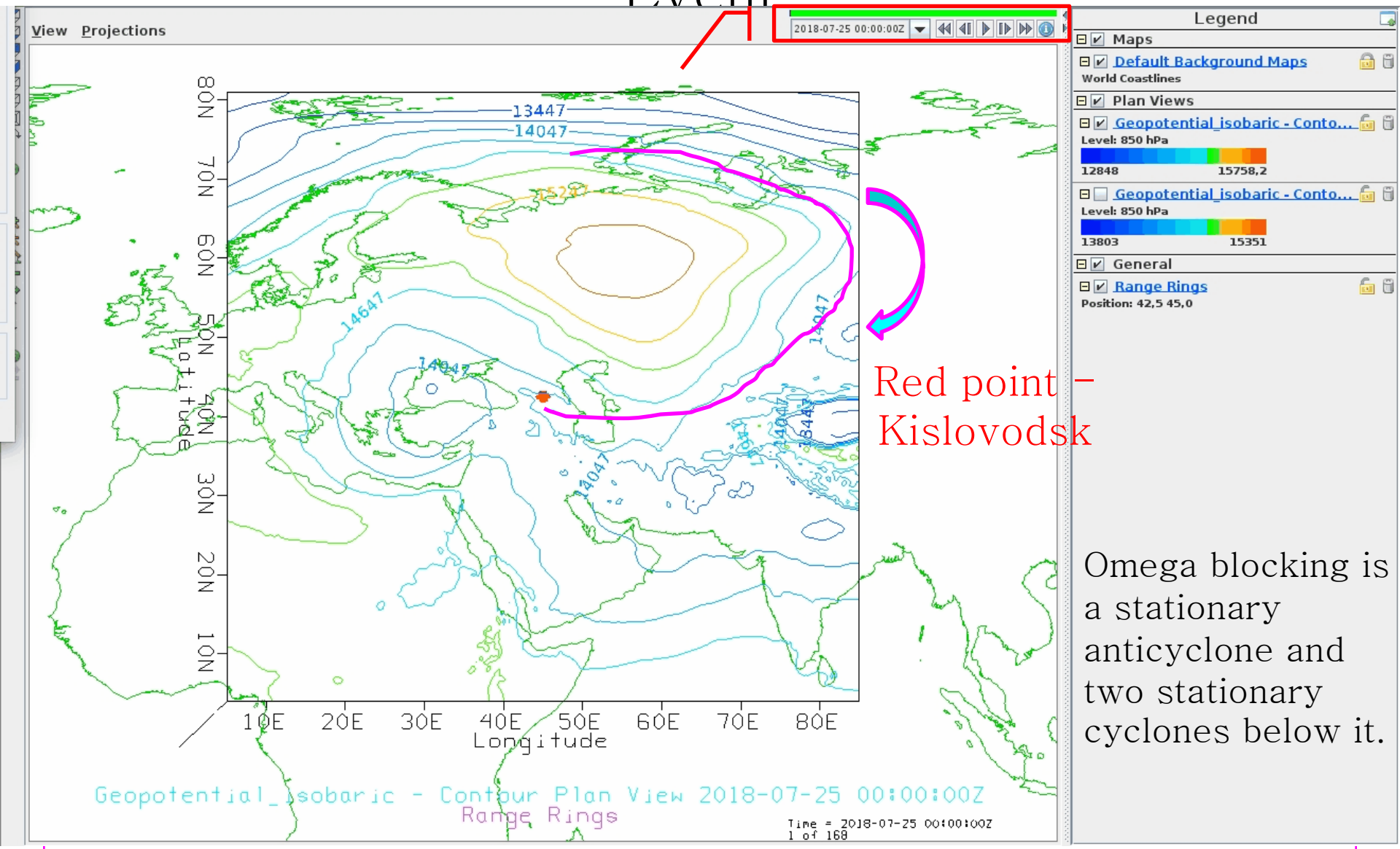
- Local orography
- Atmospheric rivers and LLJ for clarifying humid sources

Modeling and reanalysis. Causes of Extreme Event



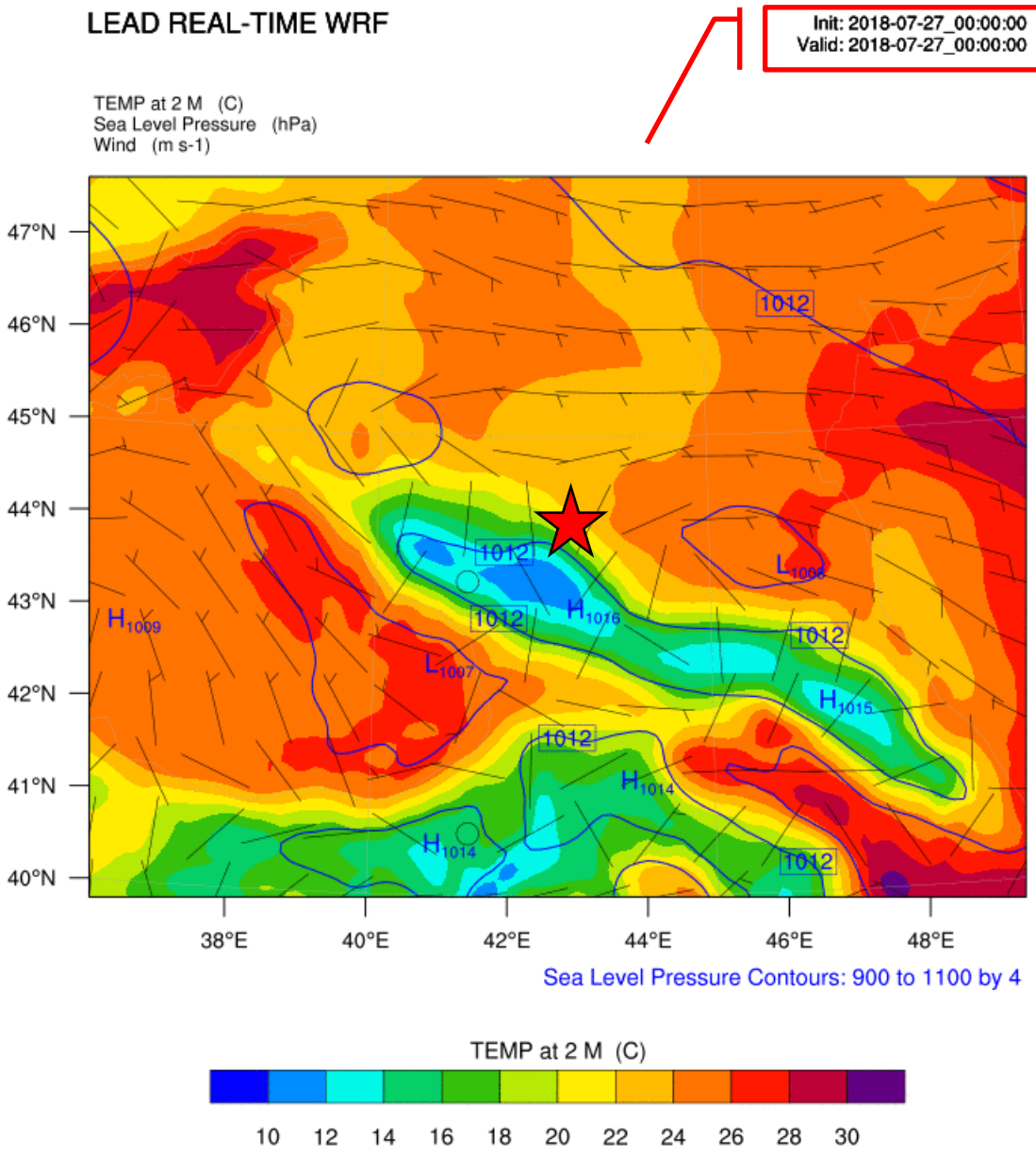
ERA-5 reanalysis data.

Modeling and reanalysis. Causes of Extreme Event



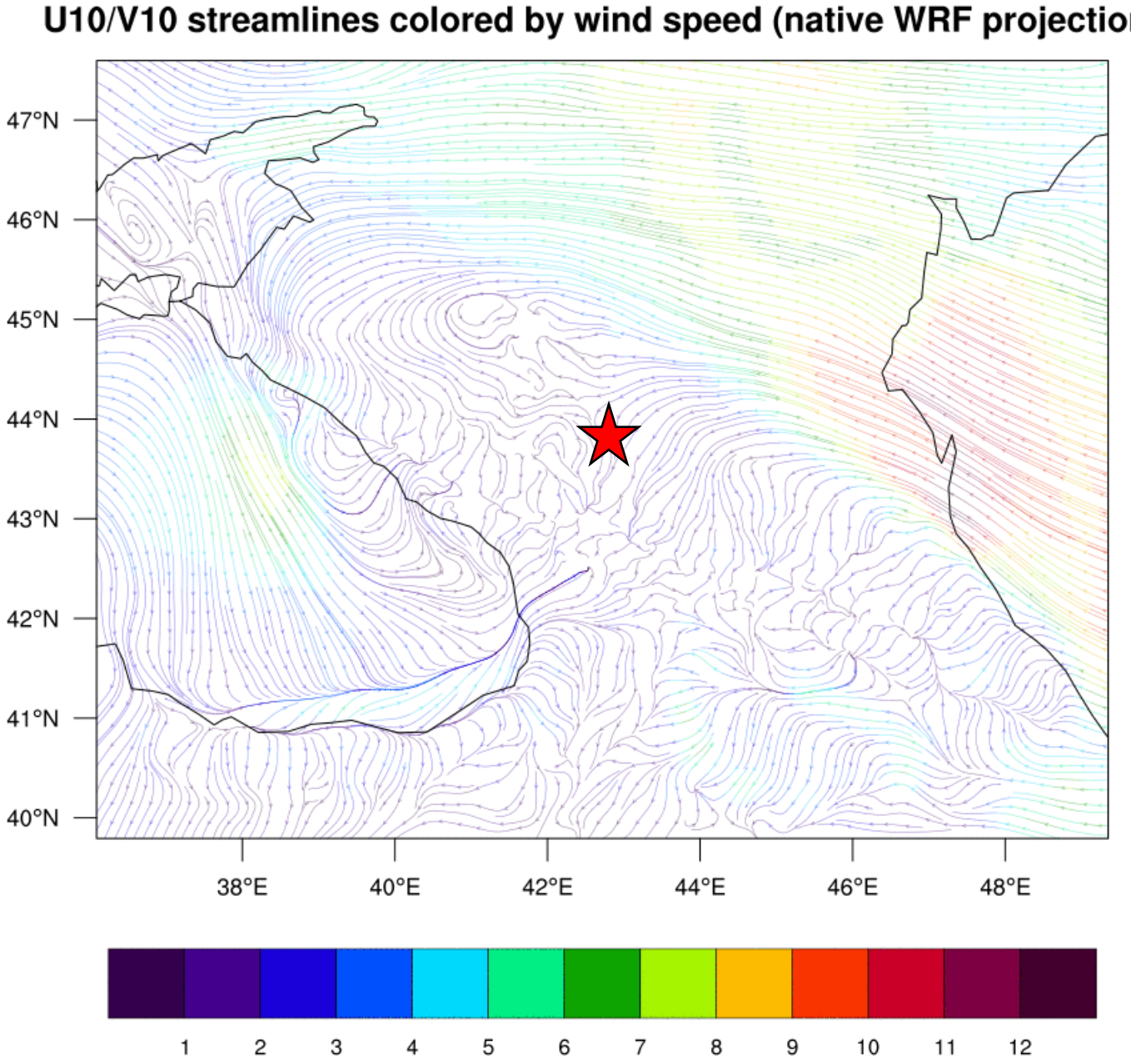
Omega blocking is a stationary anticyclone and two stationary cyclones below it.

ERA-5 reanalysis data. Frontal transport of cold Arctic air along the eastern boundary of the anticyclone.



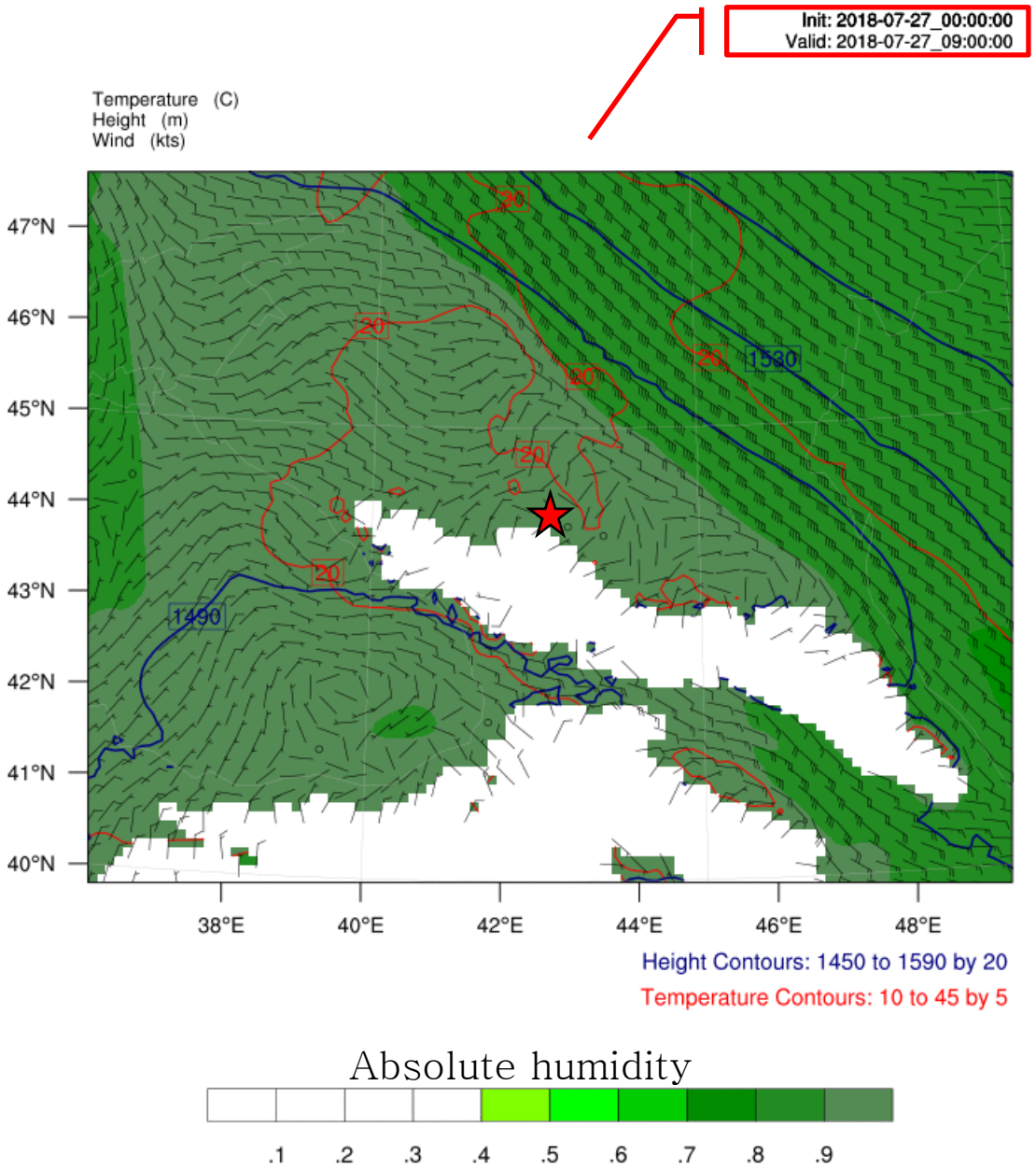
- The pressure over the measurement area varies within very small limits; movements of cyclonic air masses have not been recorded.

Red Star – Kislovodsk.
July 27, 2018
Time 00 UTC – 23 UTC



Red Star – Kislovodsk. July 27, 2018. Time: 06 UTC, 09 UTC, 12 UTC

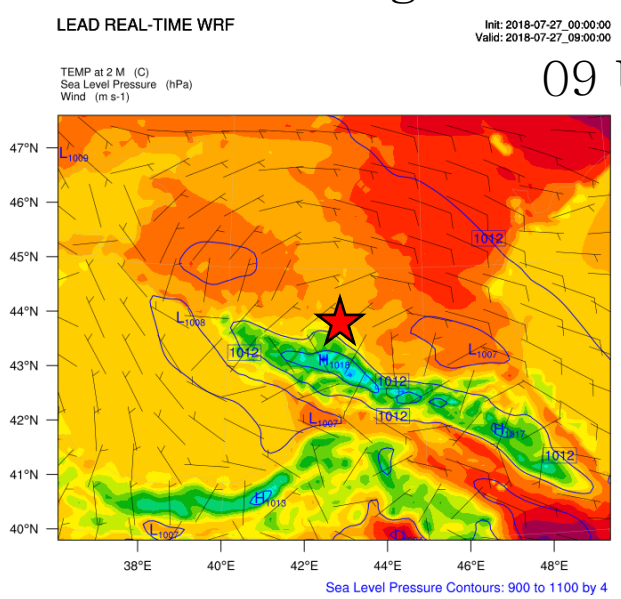
- According to observations, wind speeds at a height of 2 meters changed from S 1-2 m/s at 0 UTC to NNW 1 m/s at 6 UTC, then to NNE 1 m/s at 9 UTC, and by the start of the downpour, had become SSE 4 m/s with gusts of 18 m/s at 12 UTC.
- At a height of 10 meters, according to modeling, wind direction changes less

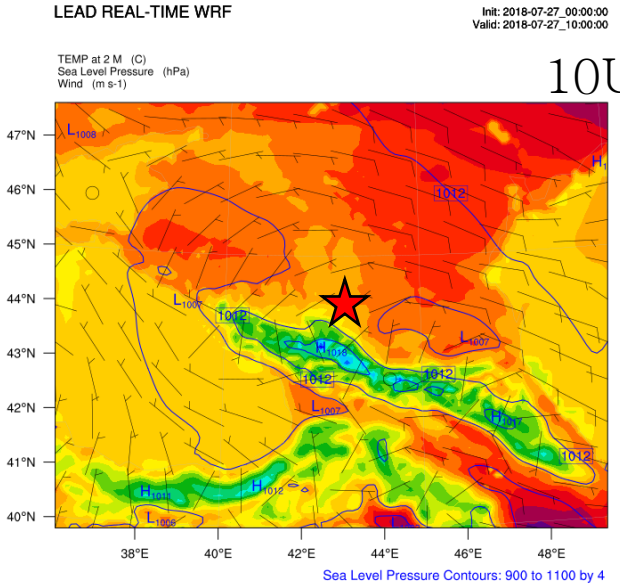


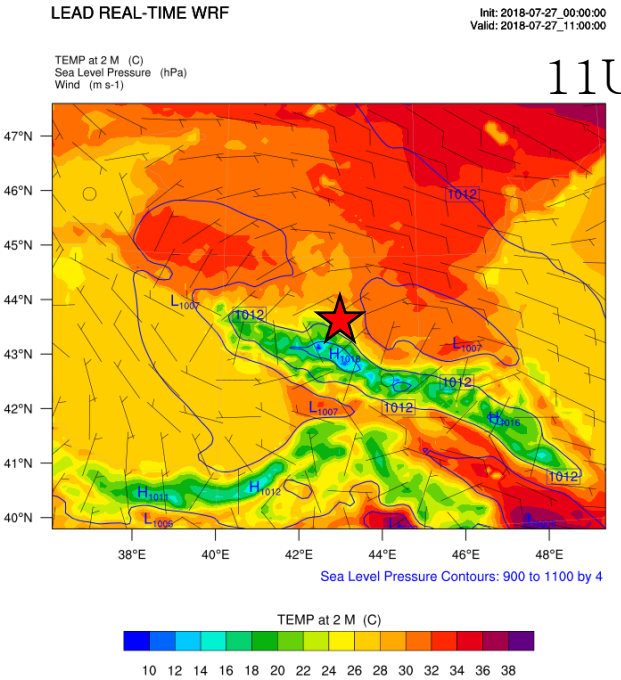
- At 850 hPa, the wind is predominantly NWW over the Kislovodsk area. The air is humid.

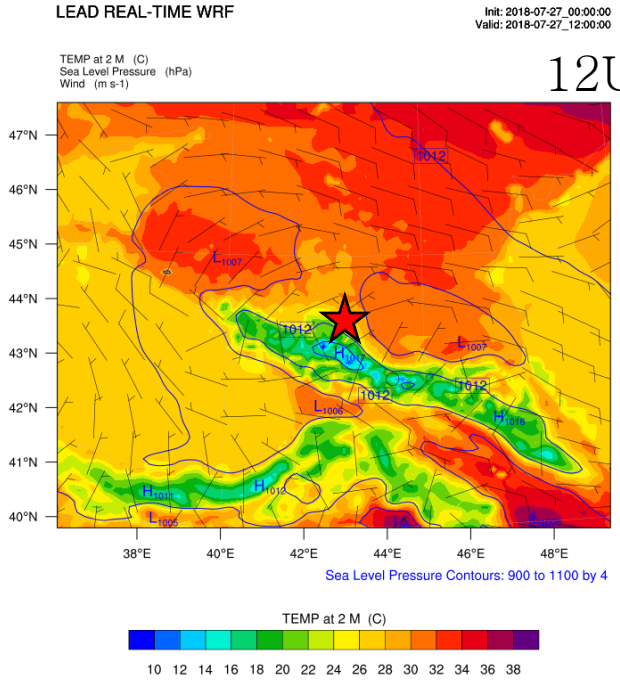
Red Star – Kislovodsk. July 27, 2018. Time: 09-15 UTC

- Judging by the temperature fields, the cold masses advection from the northeast began 3 hours before the extreme precipitation.









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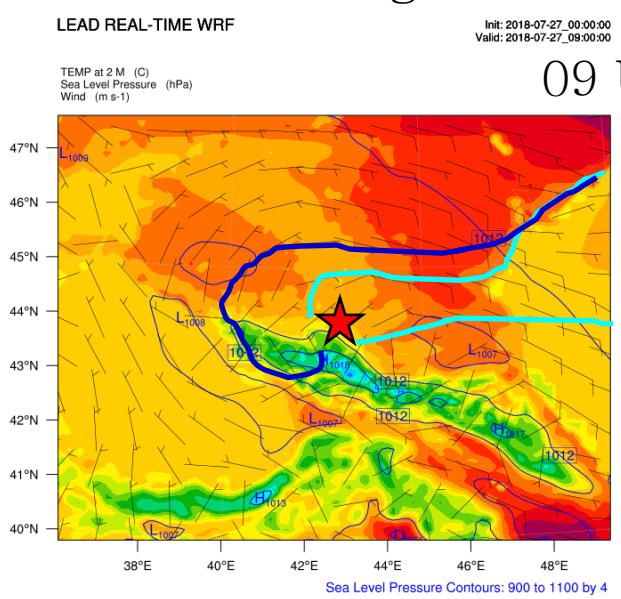
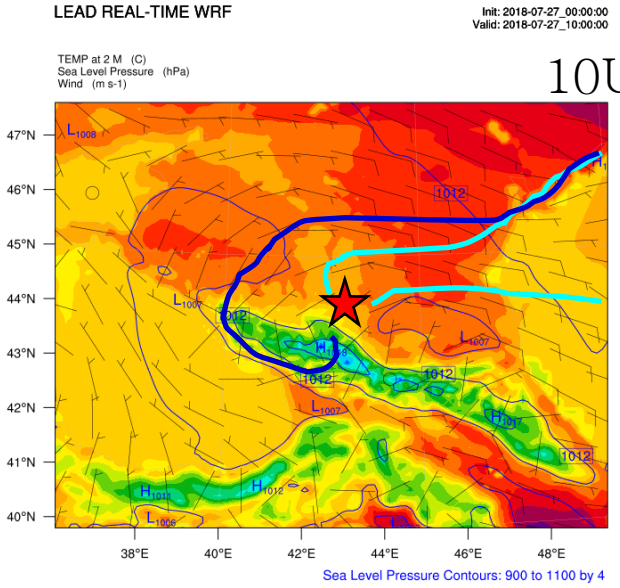
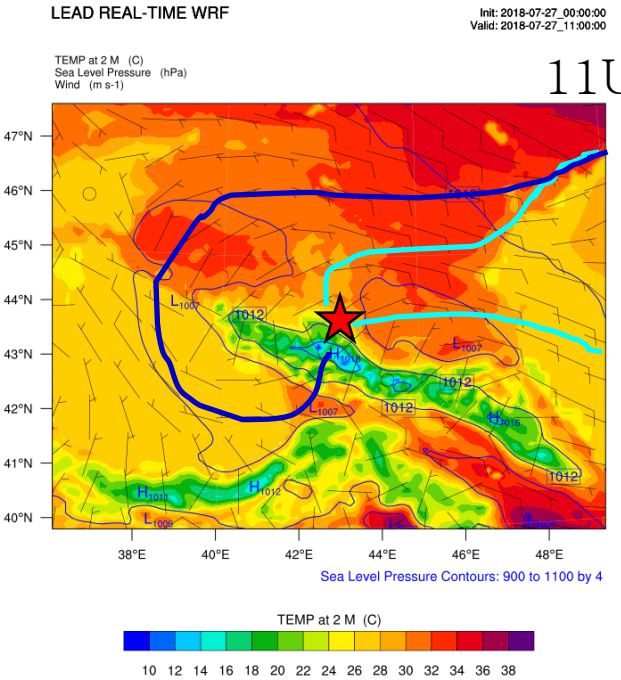
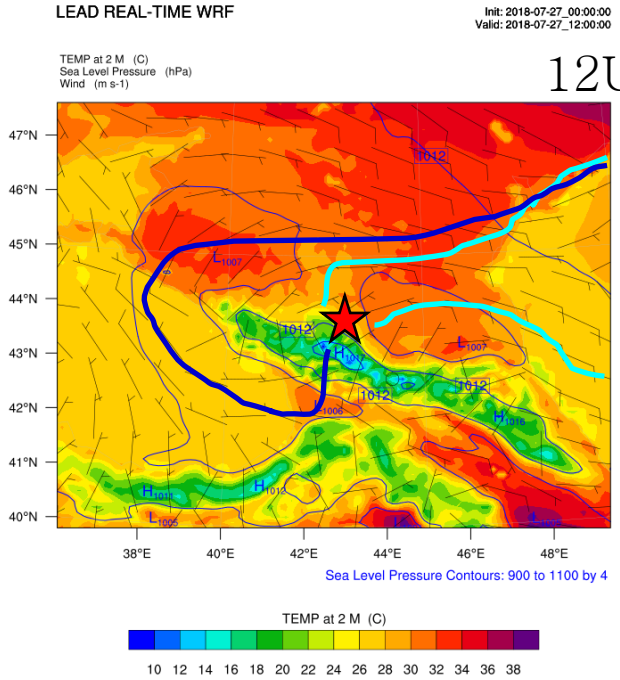




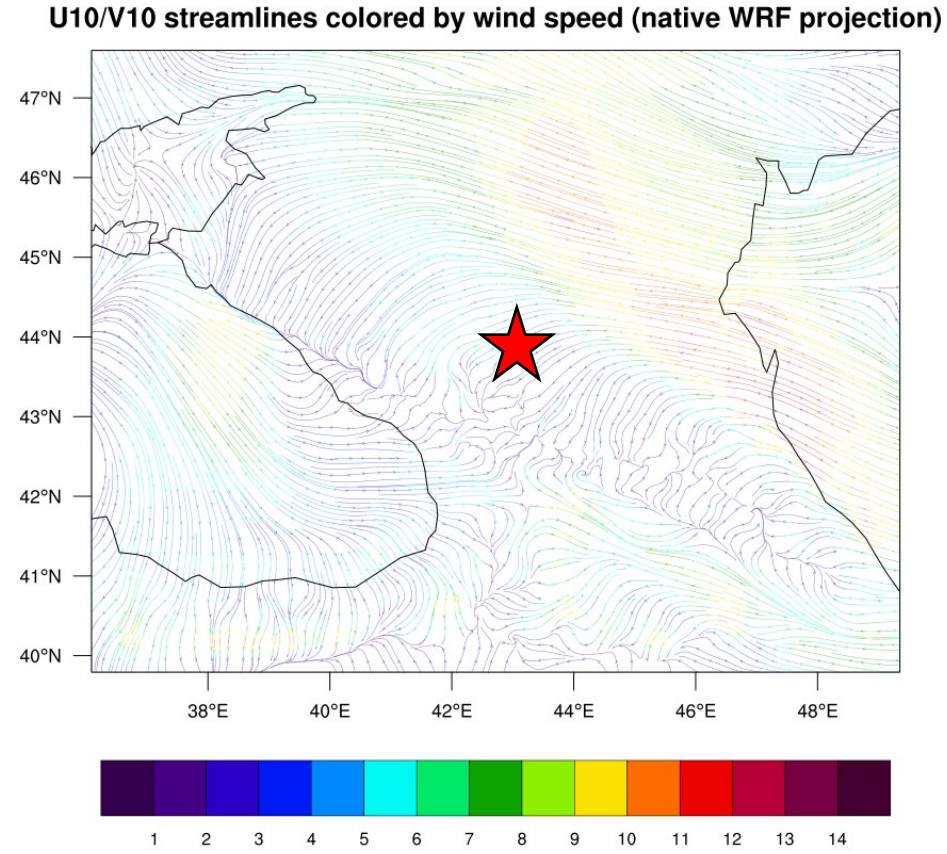




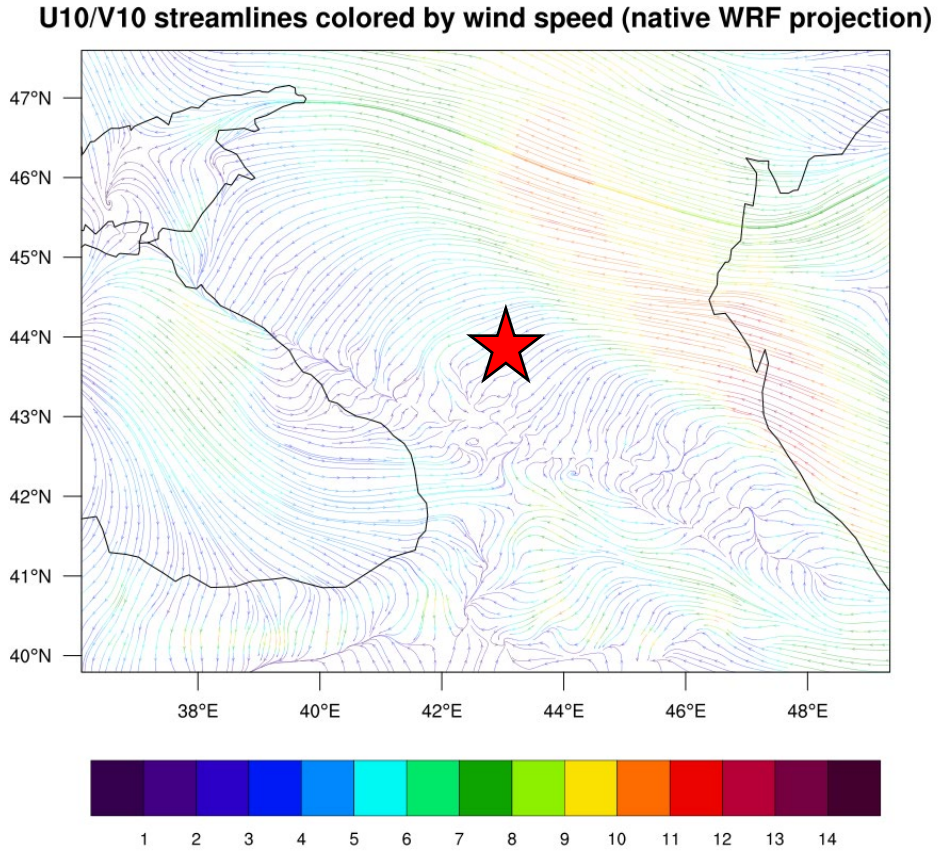
Red Star – Kislovodsk. July 27, 2018.

- The results of the calculation with spectral nudging (Nudging) showed more accurate results than the results of the calculation without spectral nudging (No Nudging). This is also clearly evident in comparison with the observational data.

Domain d01. Nudging. 12 UTC. 27.07.2018.

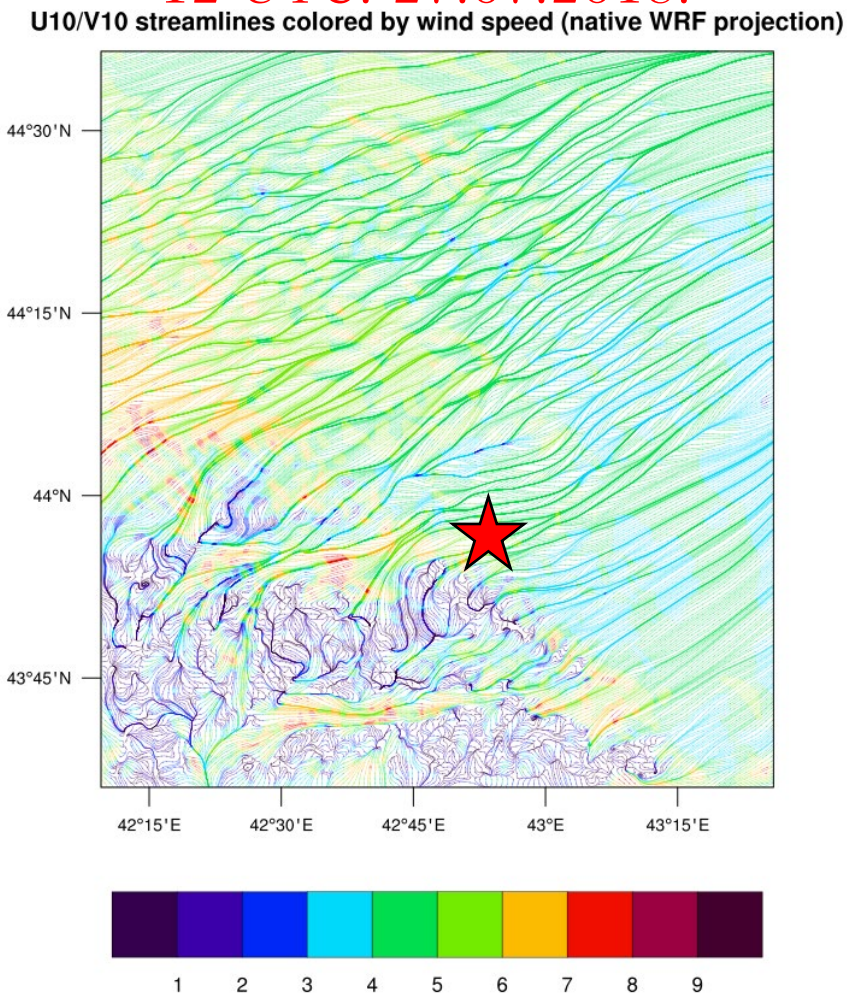


Domain d01. No nudging. 12 UTC. 27.07.2018.

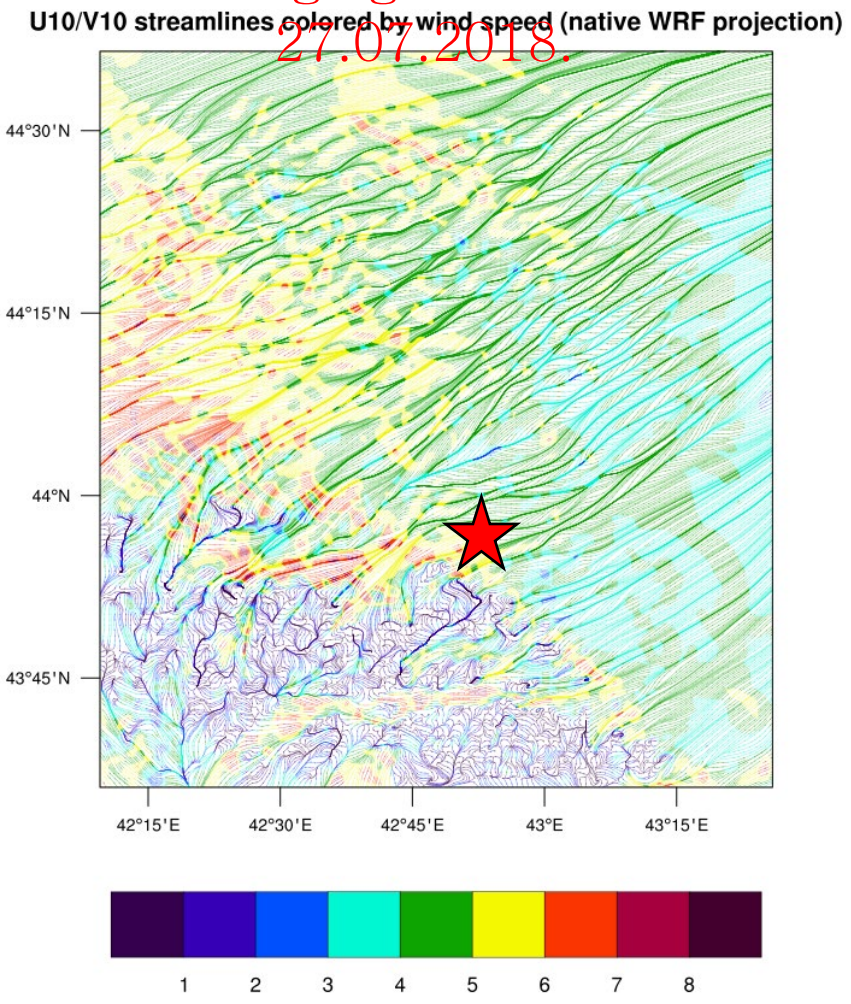


- The results of the calculation with spectral nudging (Nudging) showed more accurate results than the results of the calculation without spectral nudging (No Nudging). This is also clearly evident in comparison with the observational data.

Domain d04. Nudging. 12 UTC. 27.07.2018.

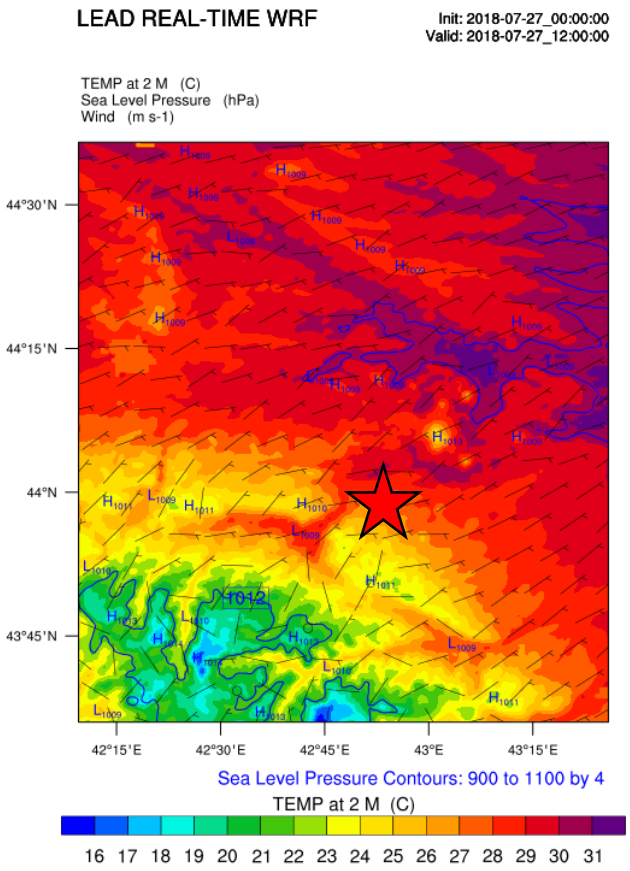


Domain d04. No nudging. 12 UTC. 27.07.2018.

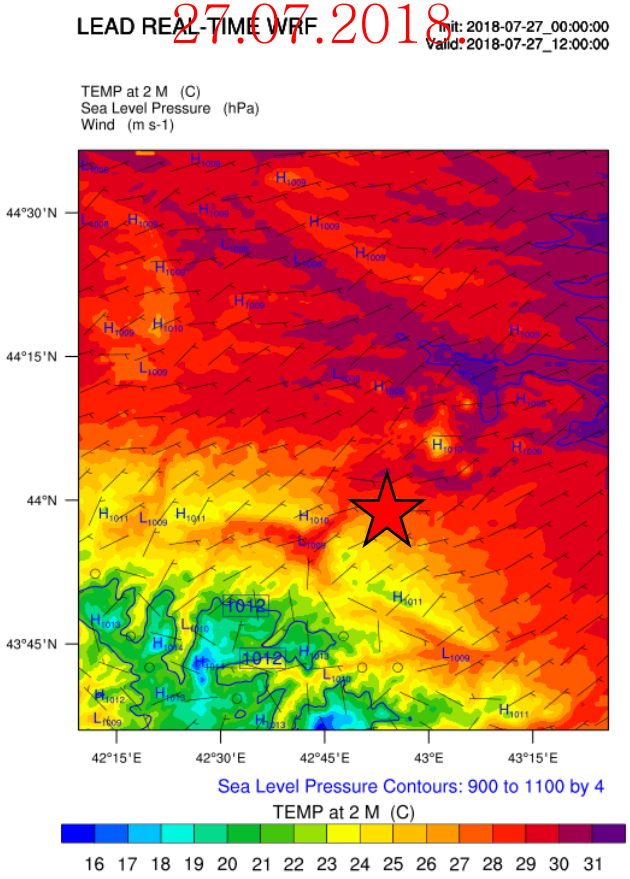


- The results of the calculation with spectral nudging (Nudging) showed more accurate results than the results of the calculation without spectral nudging (No Nudging). This is also clearly evident in comparison with the observational data.

Domain d04. Nudging. 12 UTC. 27.07.2018.

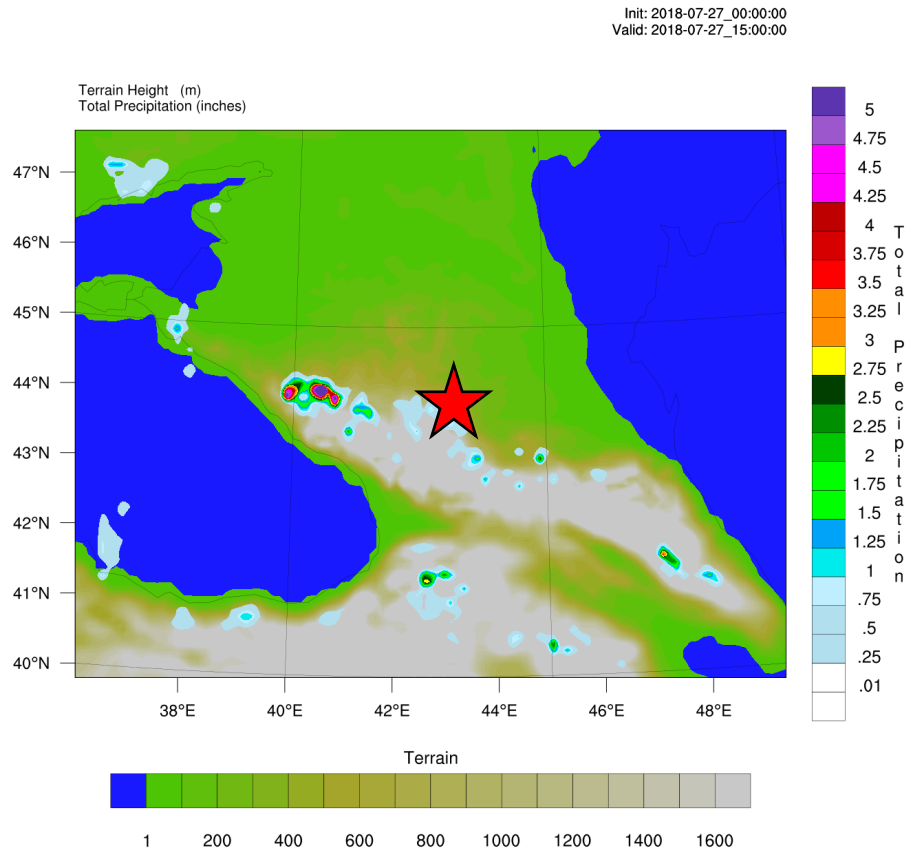


Domain d04. No nudging. 12 UTC. 27.07.2018.

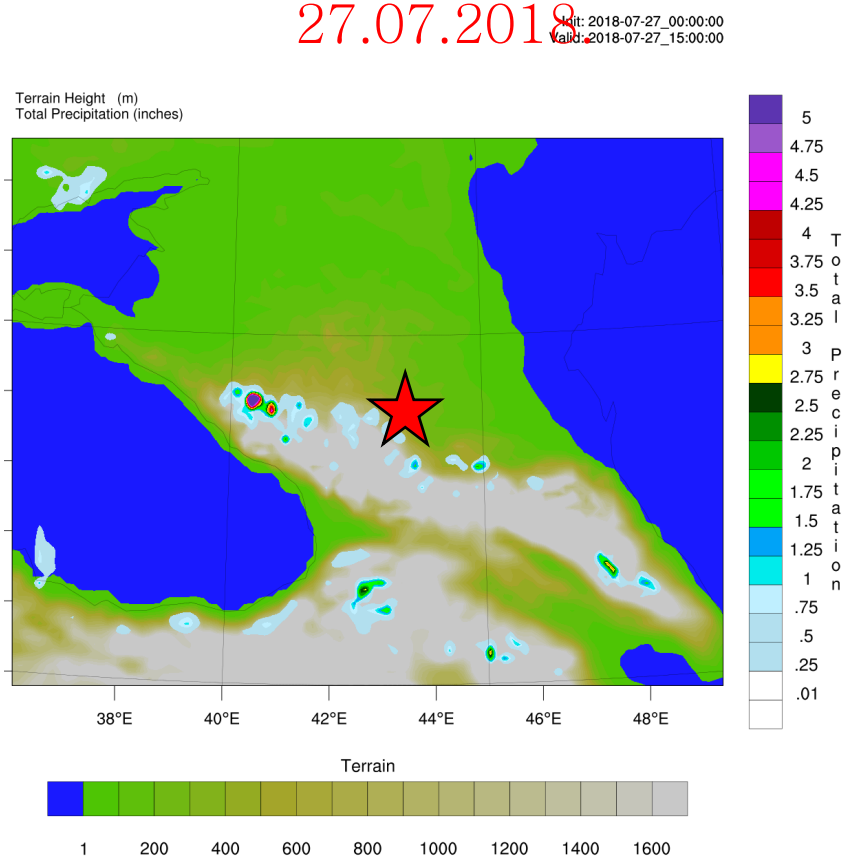


- The results of the calculation with spectral nudging (Nudging) showed more accurate results than the results of the calculation without spectral nudging (No Nudging). This is also clearly evident in comparison with the observational data.

Domain d01. Nudging. 15 UTC. 27.07.2018.



Domain d01. No nudging. 15 UTC. 27.07.2018.



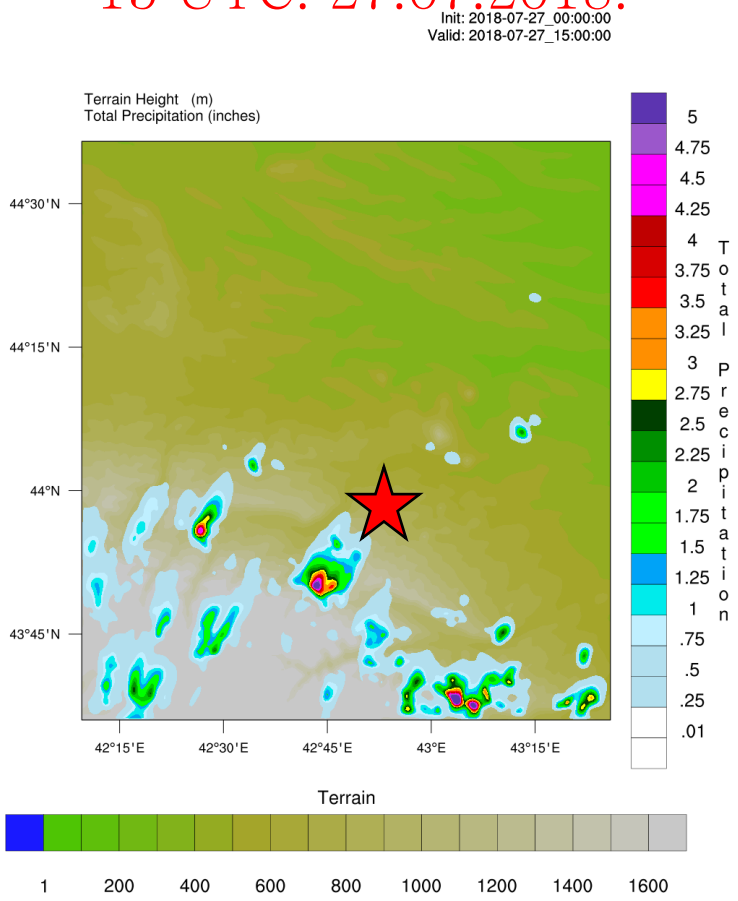
Осадки за первые 3 часа (с 12 по 15 UTC).

OUTPUT FROM WRF V4.1.3 MODEL
WE = 106 ; SN = 82 ; Levels = 40 ; Dis = 10.8km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 3

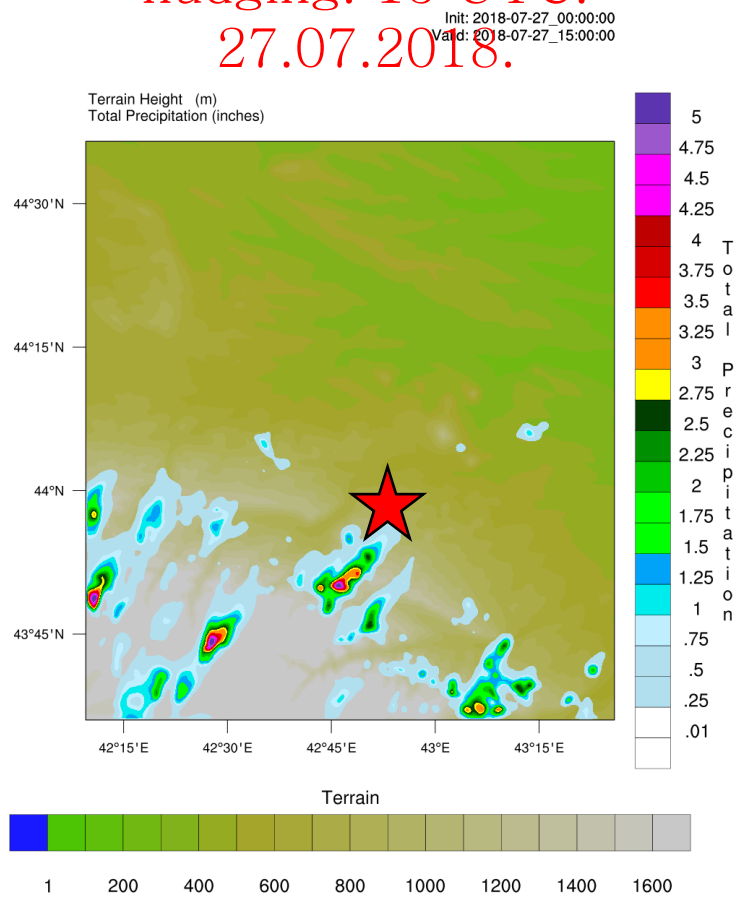
OUTPUT FROM WRF V4.1.2 MODEL
WE = 106 ; SN = 82 ; Levels = 40 ; Dis = 10.8km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 3

- The results of the calculation with spectral nudging (Nudging) showed more accurate results than the results of the calculation without spectral nudging (No Nudging). This is also clearly evident in comparison with the observational data.

Domain d04. Nudging. 15 UTC. 27.07.2018.



Domain d04. No nudging. 15 UTC. 27.07.2018.



Осадки за первые 3 часа (с 12 по 15 UTC).

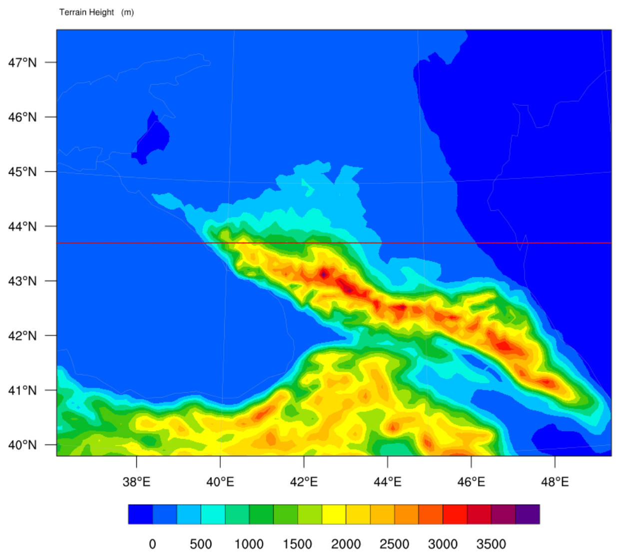
OUTPUT FROM WRF V4.1.3 MODEL

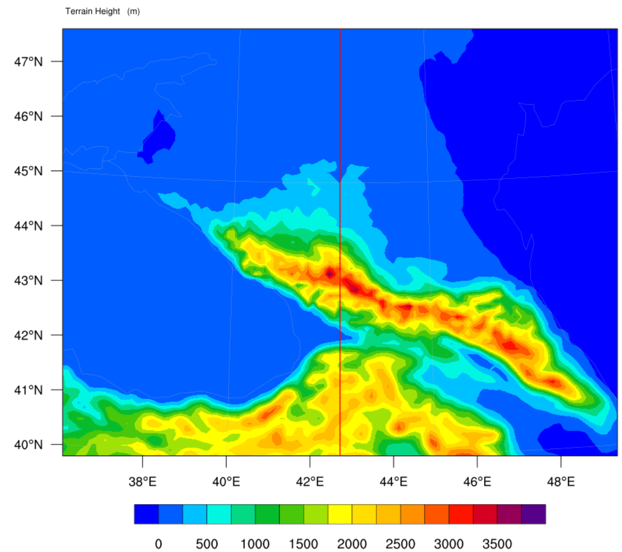
OUTPUT FROM WRF V4.1.2 MODEL

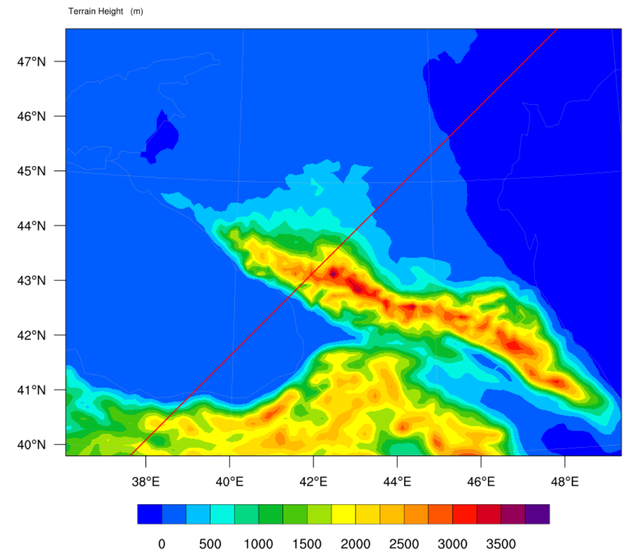
- The frontal transport of cold Arctic air along the eastern boundary of the anticyclone is evident in the velocity, temperature, and humidity fields constructed using modeling results. A comparison with observational data is shown below. In addition to the slides presented, the vertical humidity distribution for the two domains d01 and d02 is shown in the next two slides. The distributions of humidity, temperature, and wind at 850 and 700 hPa are shown afterward.

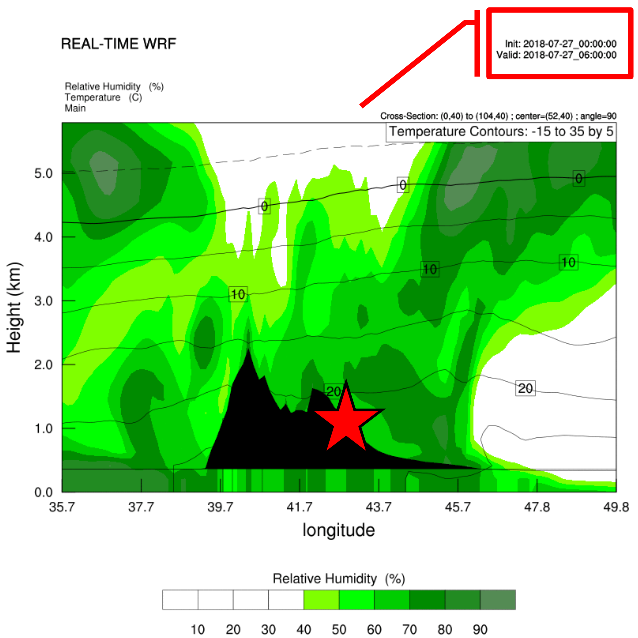
- The calculation results with "spectral nudging" showed more accurate results

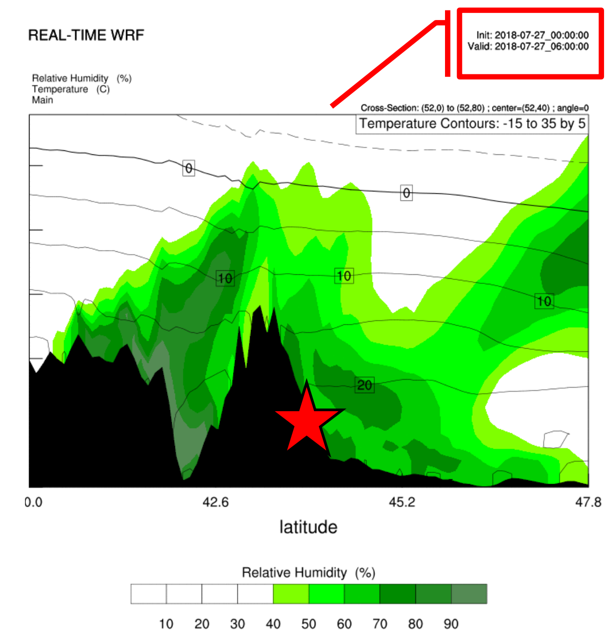
- Distribution of humidity and temperature by height, d01. 27.07.2018. 06-18 UTC

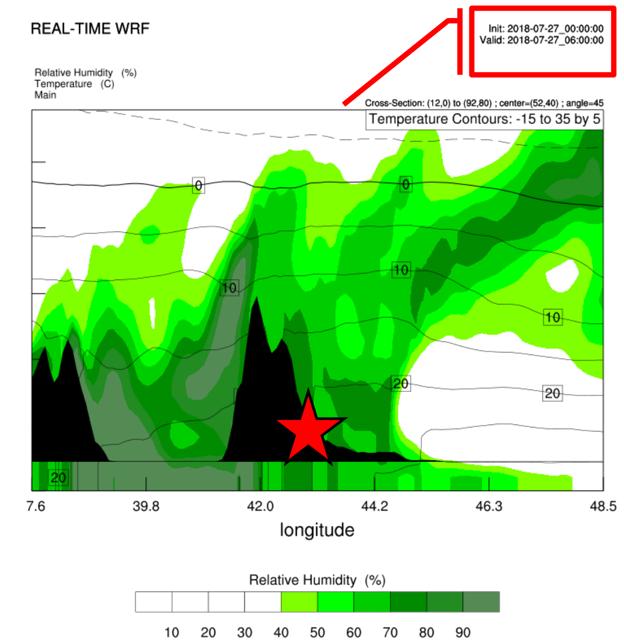




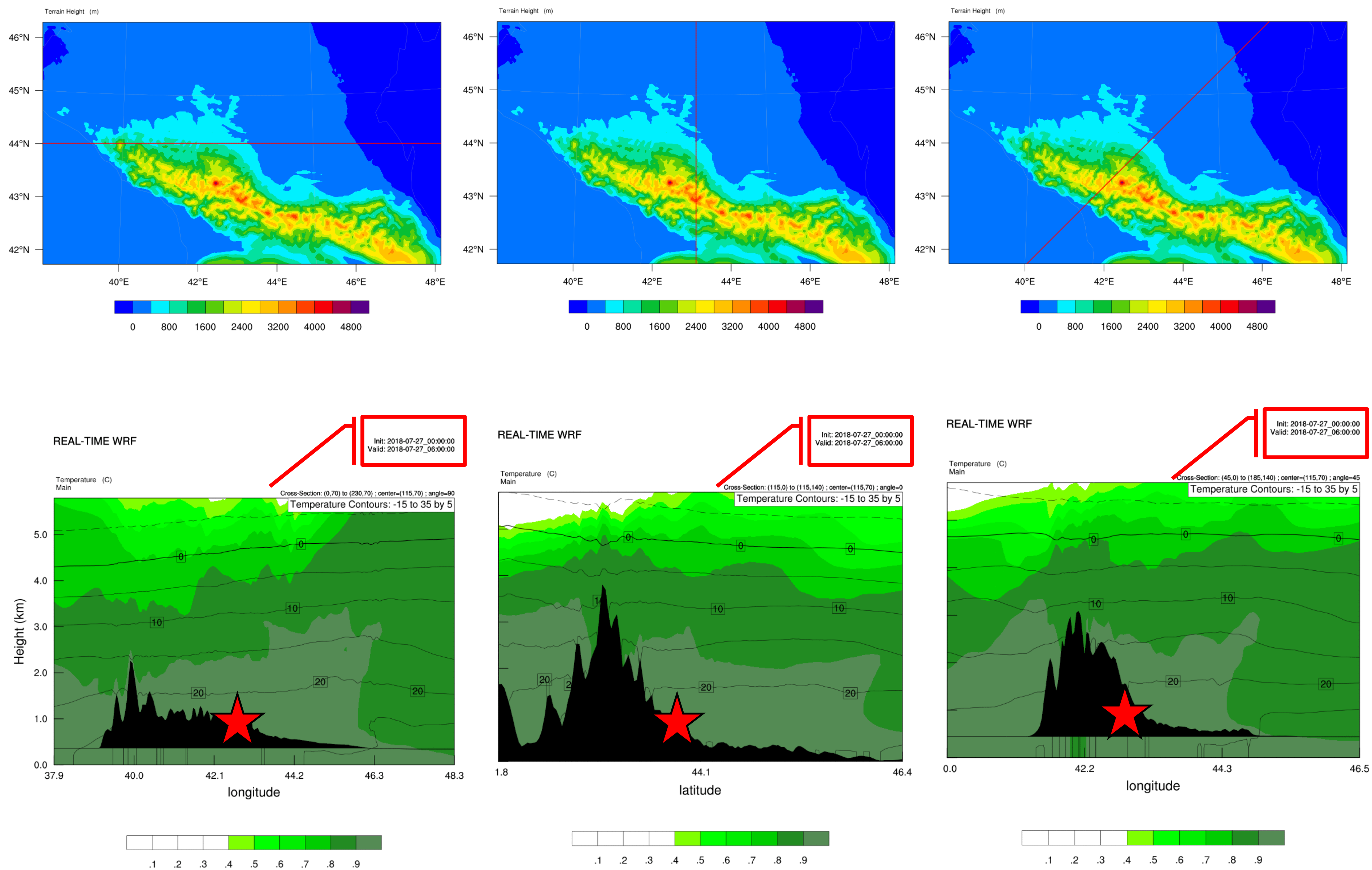




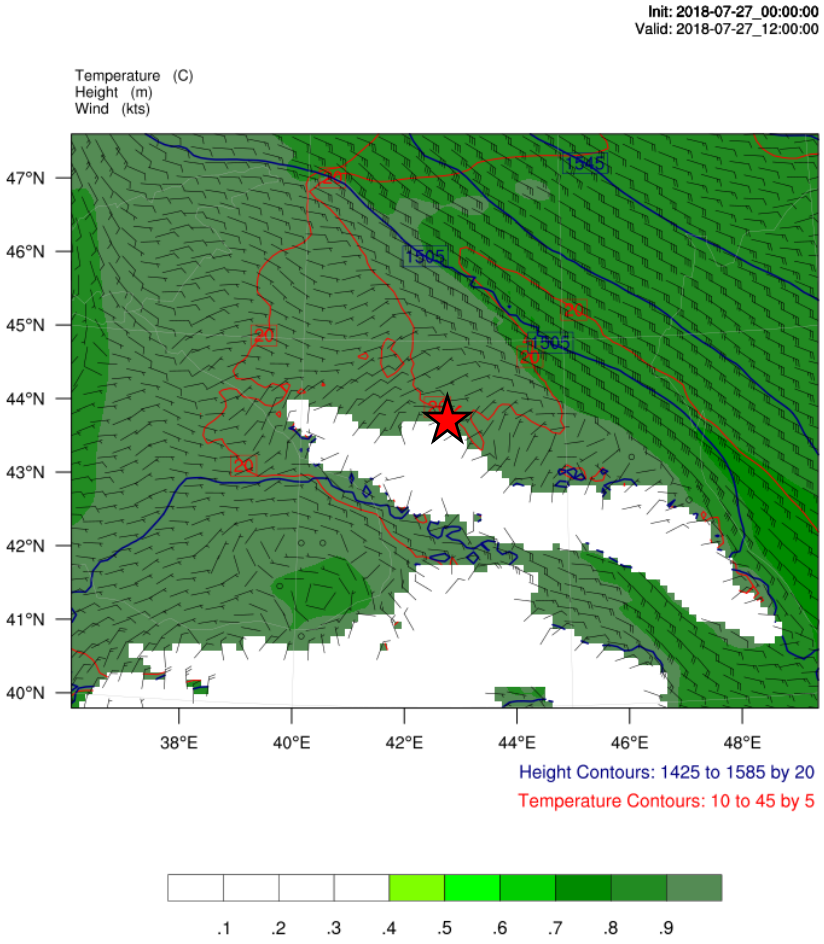




- Distribution of humidity and temperature by height, d02. 27.07.2018. 06-18

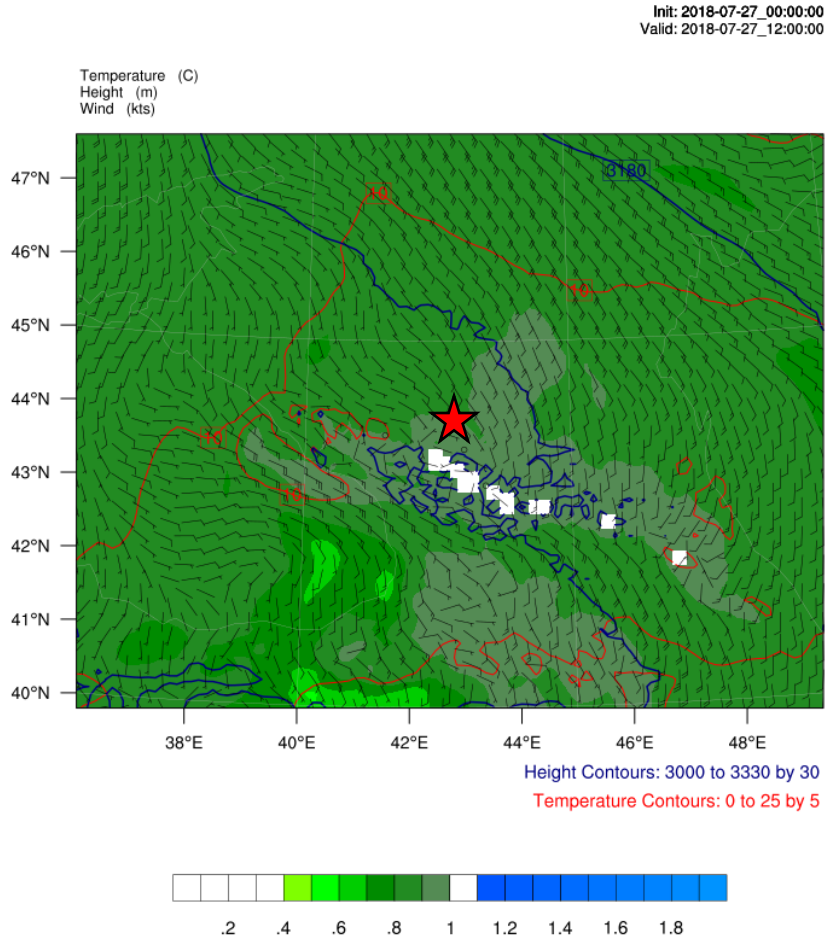


- Distribution of humidity, temperature and wind at the level 850, 700 hPa. 12 UTC



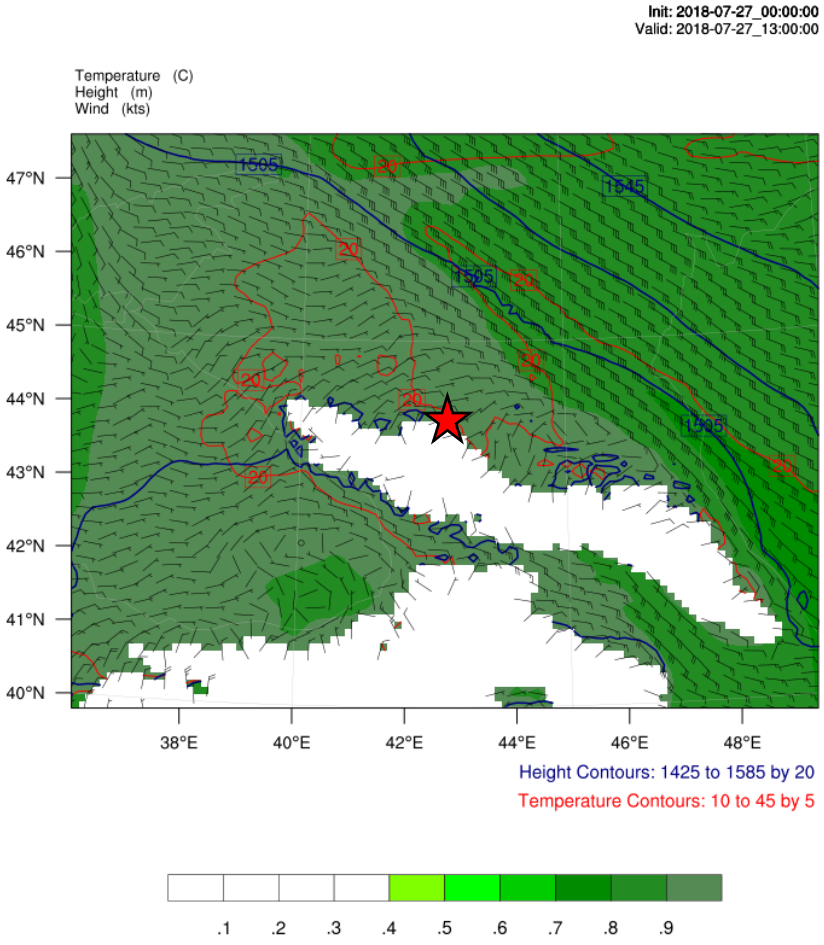
850 hPa.

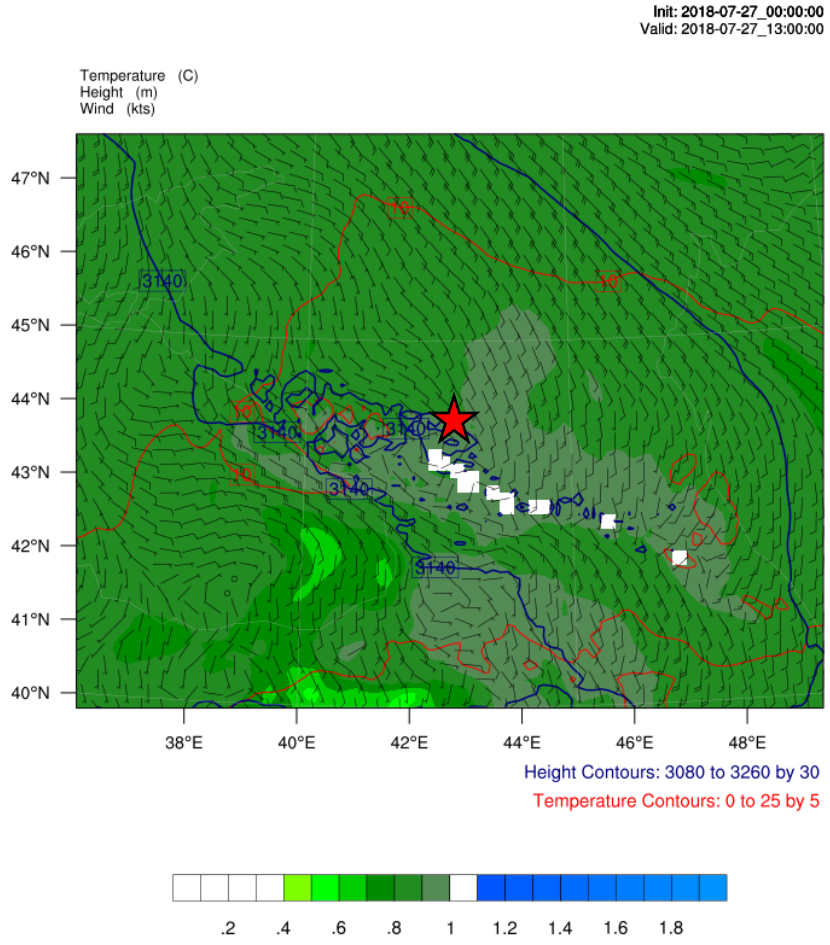
Red Star – Kislovodsk. July 27, 2018.



700 hPa.

- Distribution of humidity, temperature and wind at the level 850, 700 hPa. 13 UTC





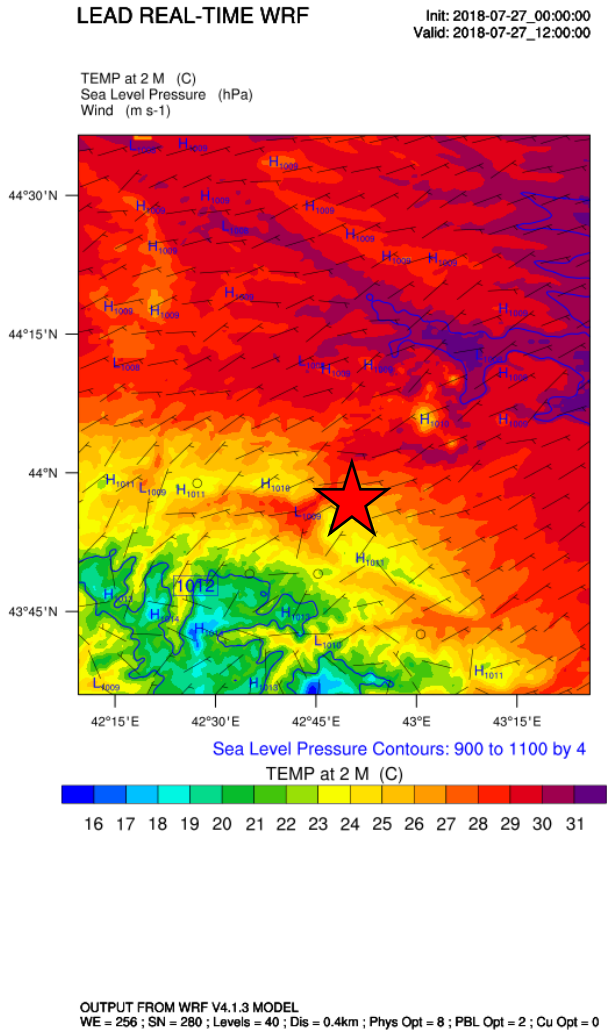
850 hPa.

Red Star – Kislovodsk. July 27, 2018.

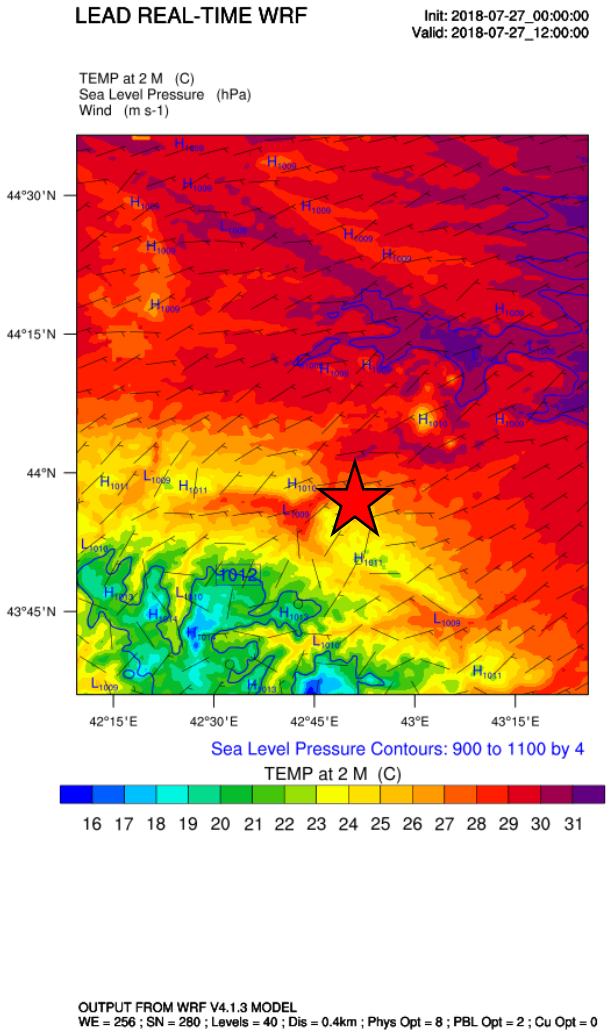
700 hPa.

- To analyze the model's sensitivity to a purely convective mechanism ("convective precipitation"), simulations were conducted with sea surface temperatures 2 degrees higher and 2 degrees lower than the actual surface temperature: SST+ 2 and SST-2.
- The results showed minor changes in the velocity, precipitation, and temperature fields in all three cases. Moreover, the changes are non-monotonic: with a consistent increase in SST, precipitation changes unevenly; in most cases, precipitation on the map increases slightly with increasing SST, but there are areas with minimal SST-2, over which precipitation occurs that is not observed for the actual SST, and for SST+ 2.
- The same non-uniformity is also visible in the velocity, humidity, and temperature fields; in the fields, only the distribution of parameters by coordinates changes randomly, without a clear correlation.

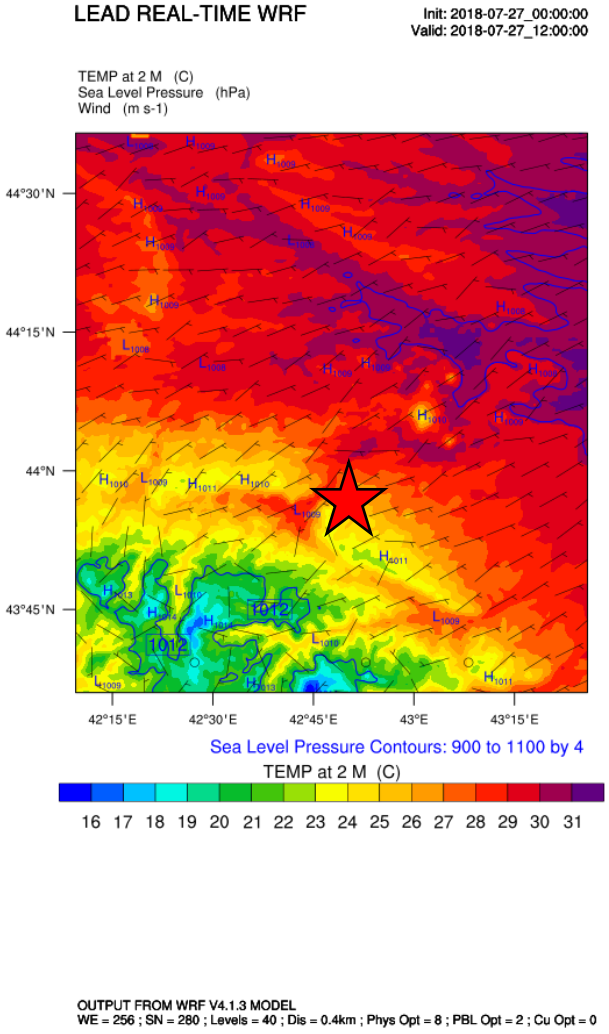
domain d04. 12 UTC



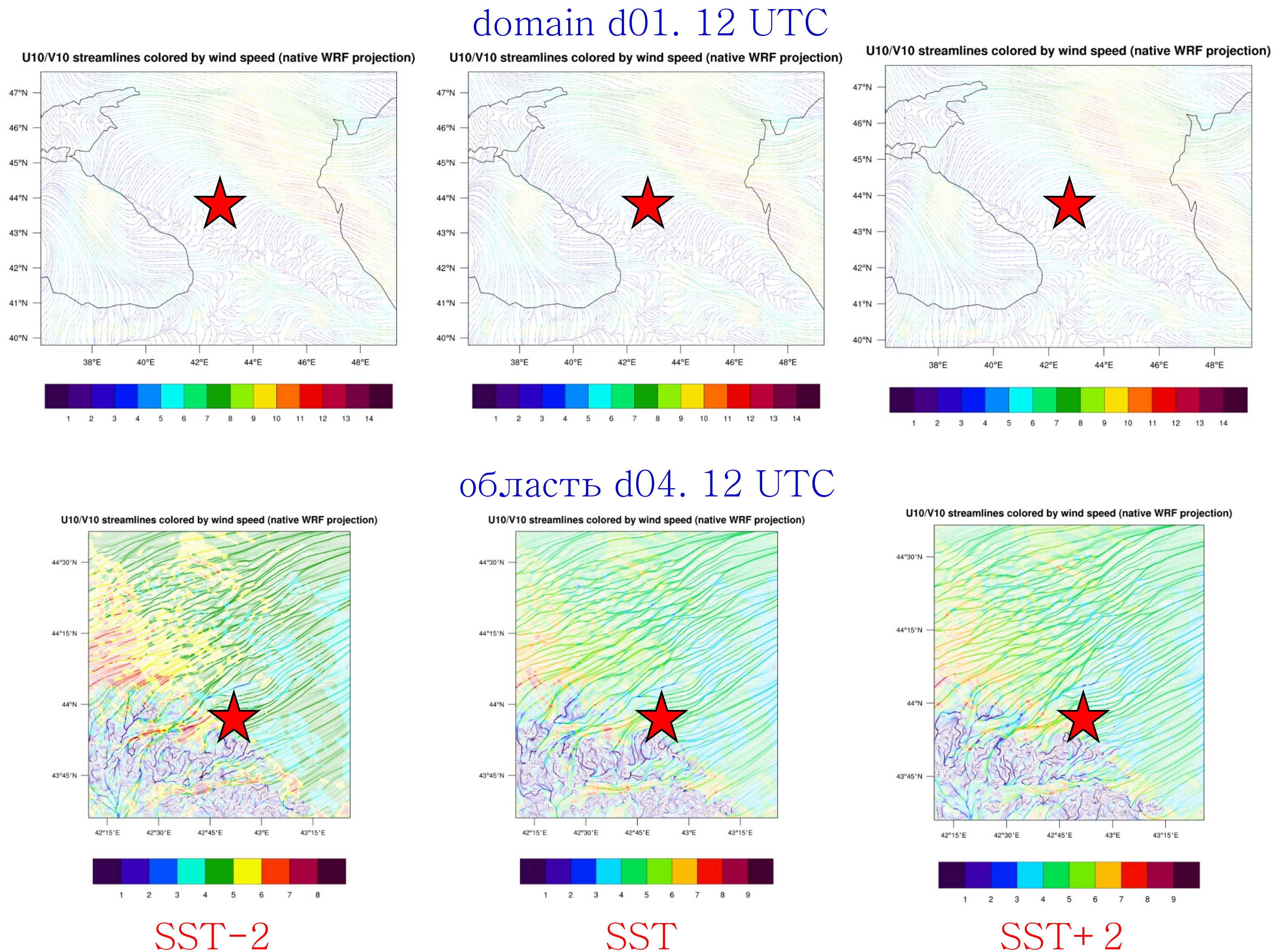
SST-2



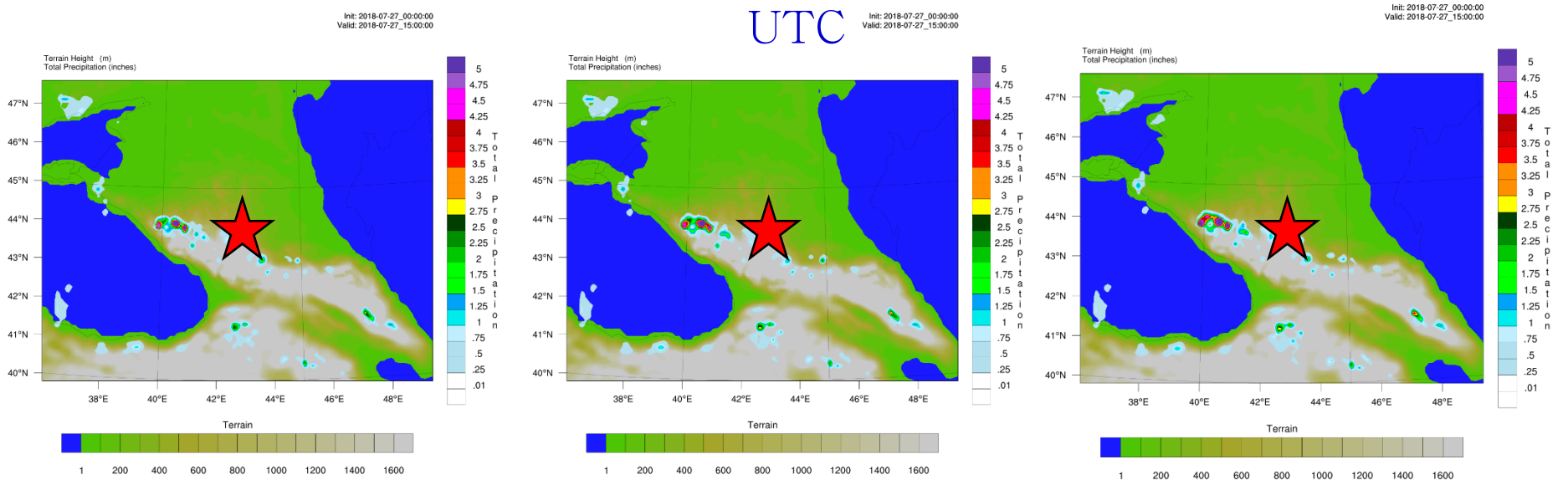
SST



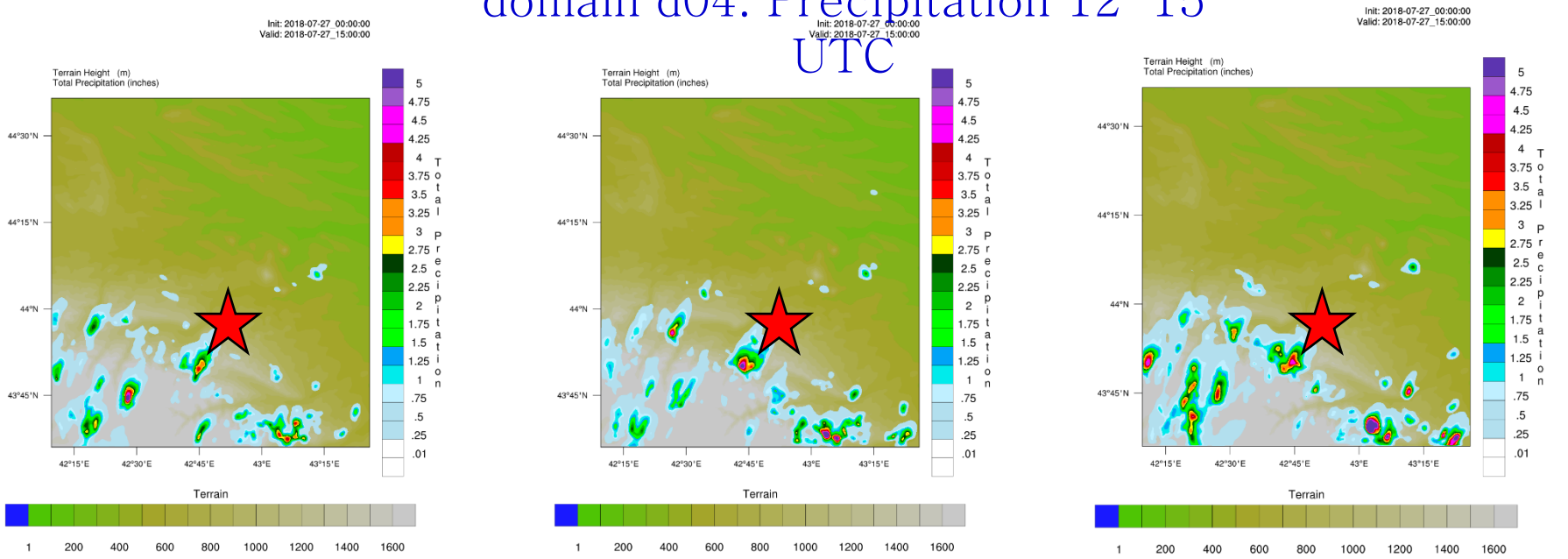
SST+ 2


domain d01. 12 UTC
U10/V10 streamlines colored by wind speed (native WRF projection)
47°N
46°N
45°N
44°N
43°N
42°N
41°N
40°N
38°E
40°E
42°E
44°E
46°E
48°E
1 2 3 4 5 6 7 8 9 10 11 12 13 14
область d04. 12 UTC
U10/V10 streamlines colored by wind speed (native WRF projection)
44°30'N
44°15'N
44°N
43°45'N
42°15'E
42°30'E
42°45'E
43°E
43°15'E
1 2 3 4 5 6 7 8
1 2 3 4 5 6 7 8 9
SST-2
SST
SST+2

domain d01. Precipitation 12-15 UTC

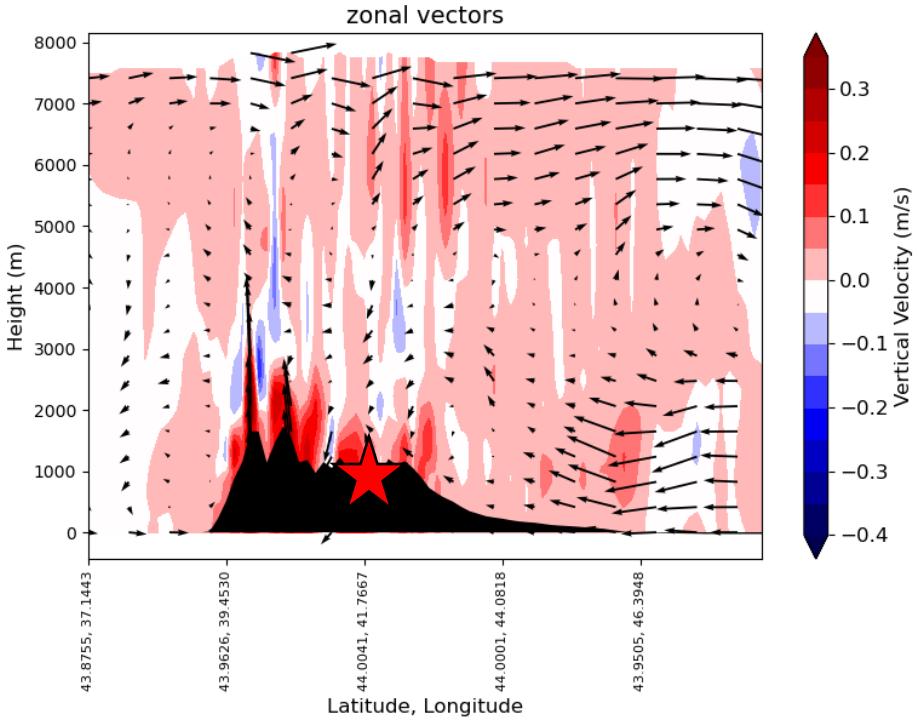


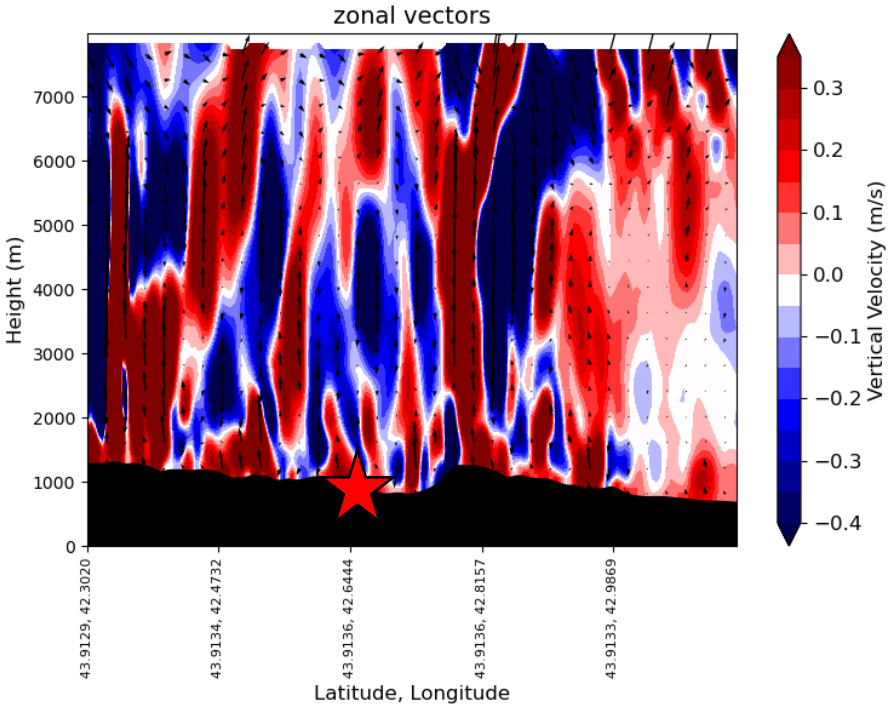
domain d04. Precipitation 12-15 UTC



SST-2 SST SST+2

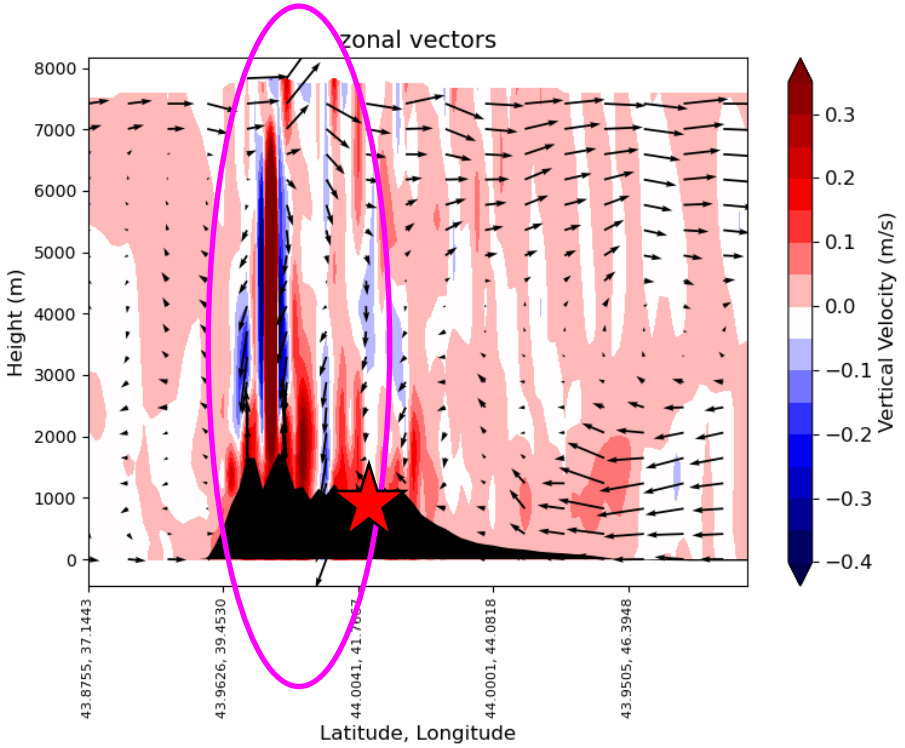
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

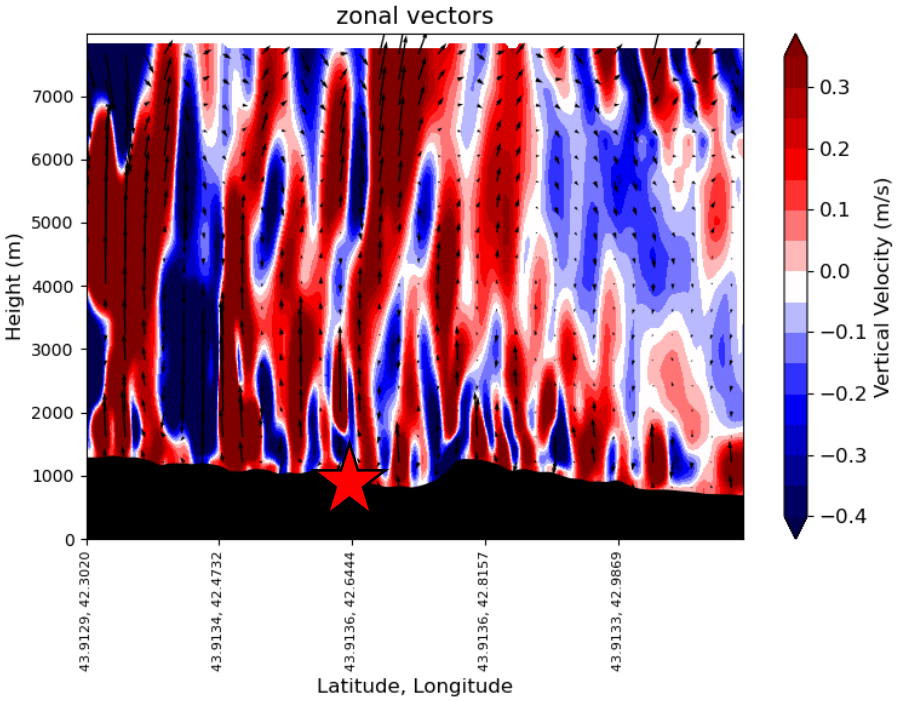




d01 11 UTC d04

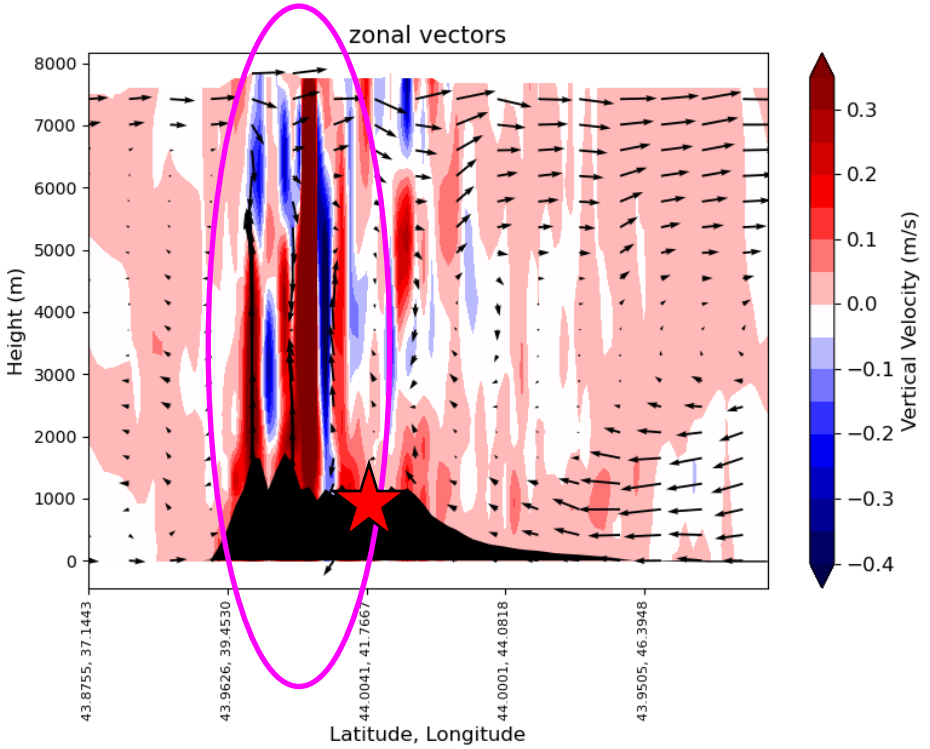
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

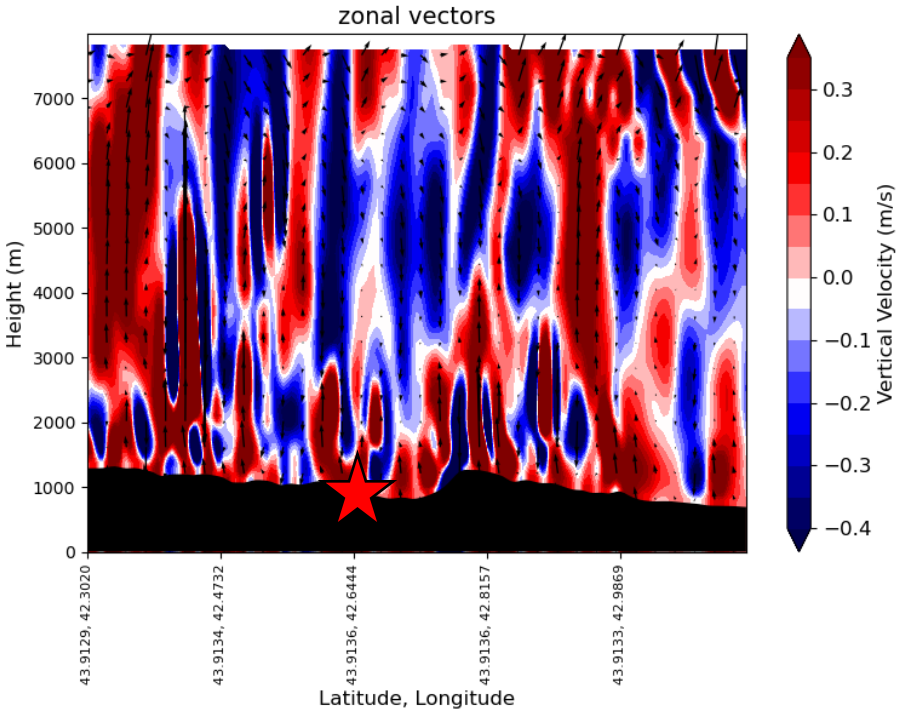




d01 12 UTC d04

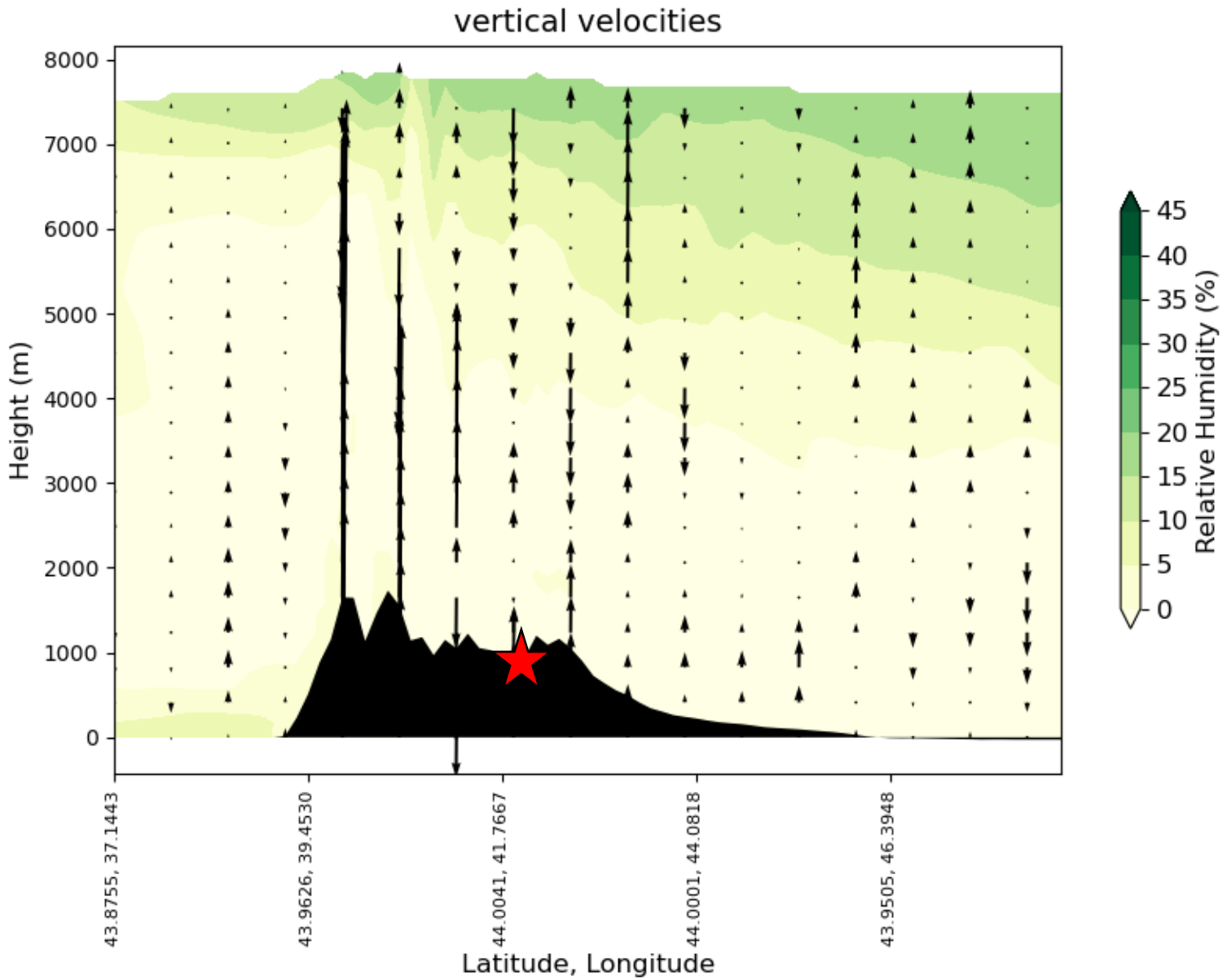
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).



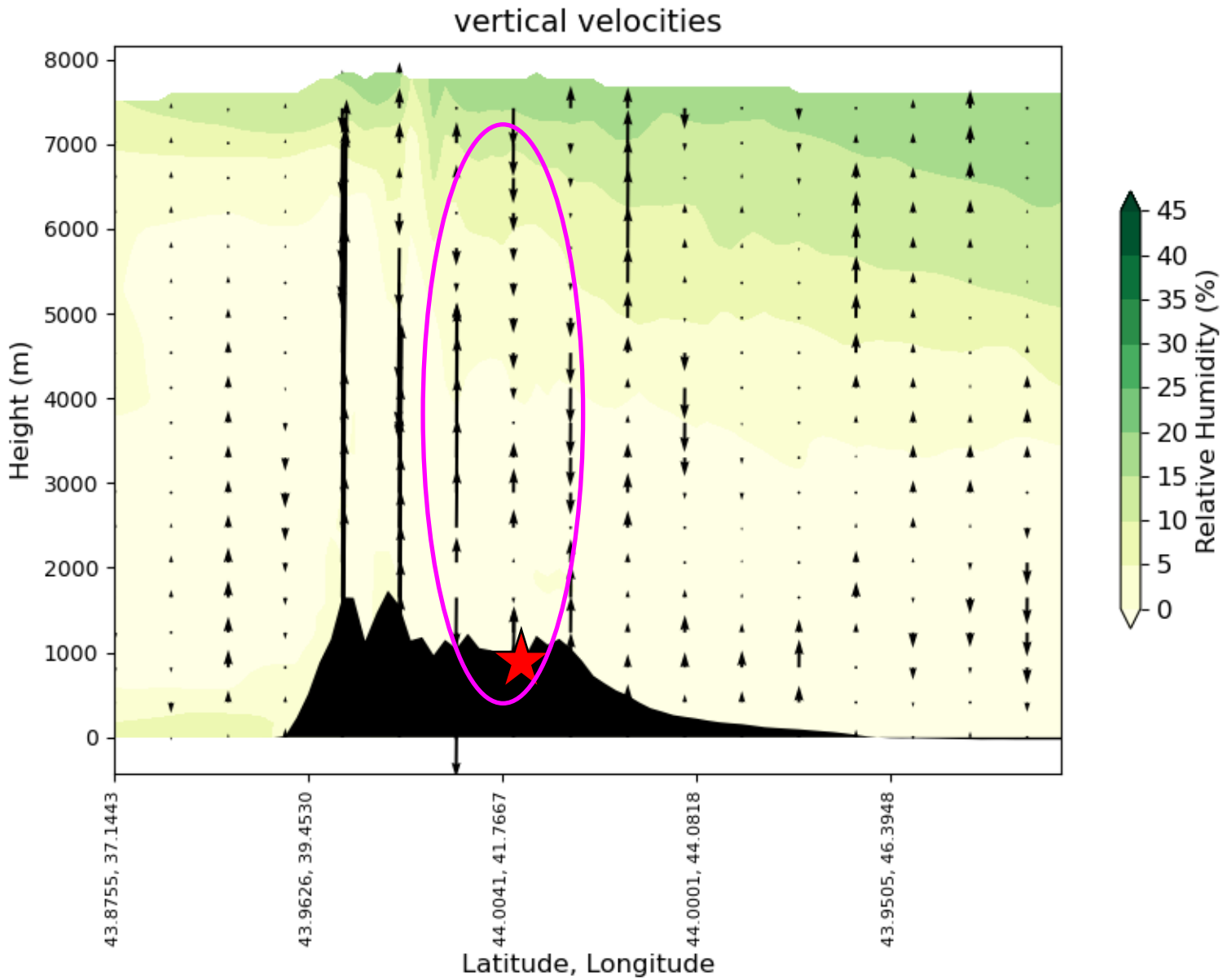


d01 13 UTC d04

13 UTC


vertical velocities
Height (m)
8000
7000
6000
5000
4000
3000
2000
1000
0
43.8755, 37.1443
43.9626, 39.4530
44.0041, 41.7667
44.0001, 44.0818
43.9505, 46.3948
Latitude, Longitude
Relative Humidity (%)
45
40
35
30
25
20
15
10
5
0

13 UTC


vertical velocities
Height (m)
8000
7000
6000
5000
4000
3000
2000
1000
0
43.8755, 37.1443
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44.0001, 44.0818
43.9505, 46.3948
Latitude, Longitude
Relative Humidity (%)
45
40
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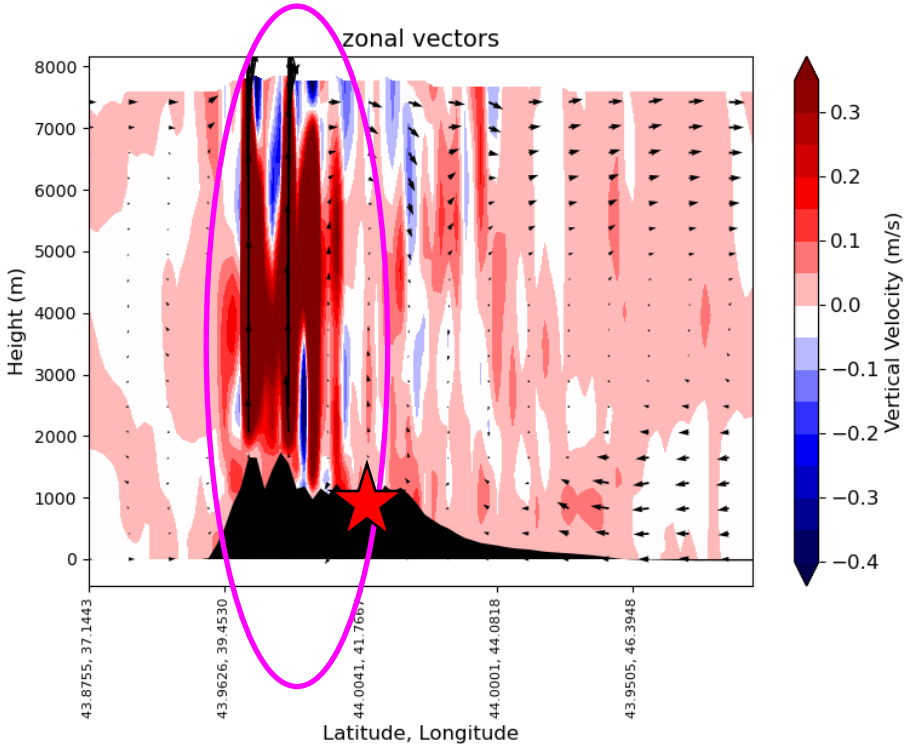
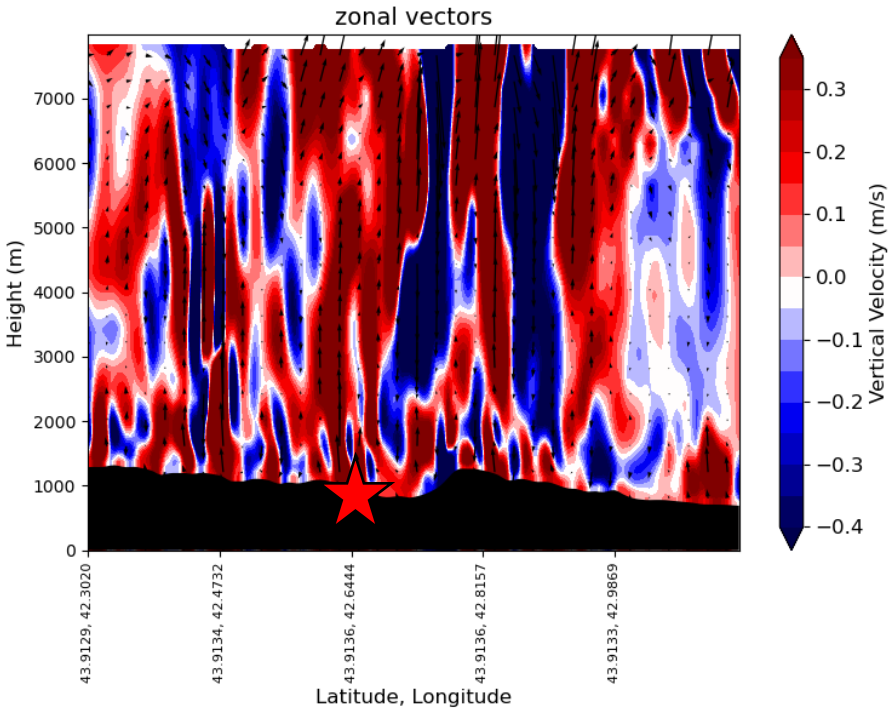
30
25
20
15
10
5
0

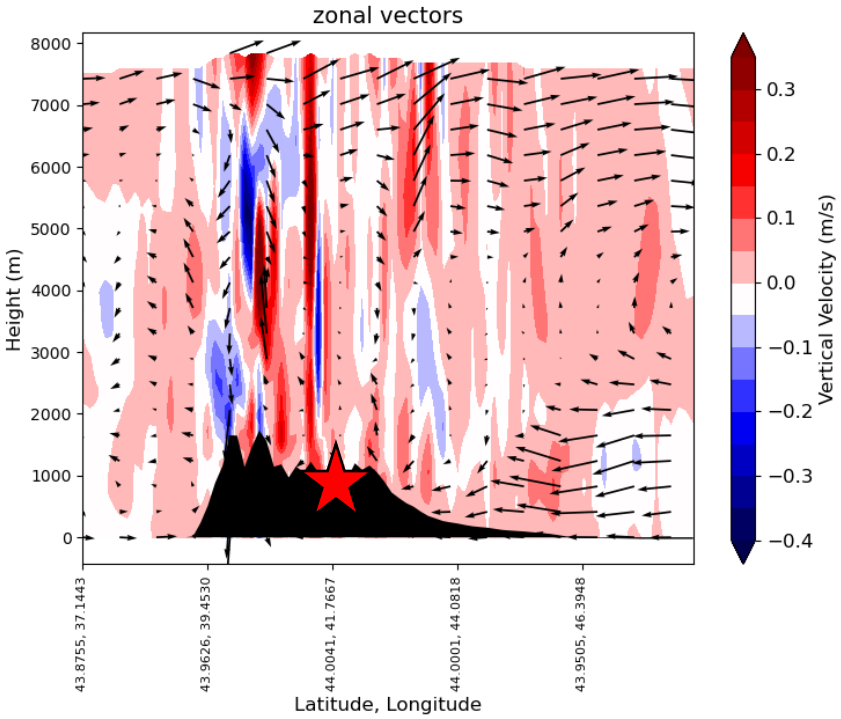
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

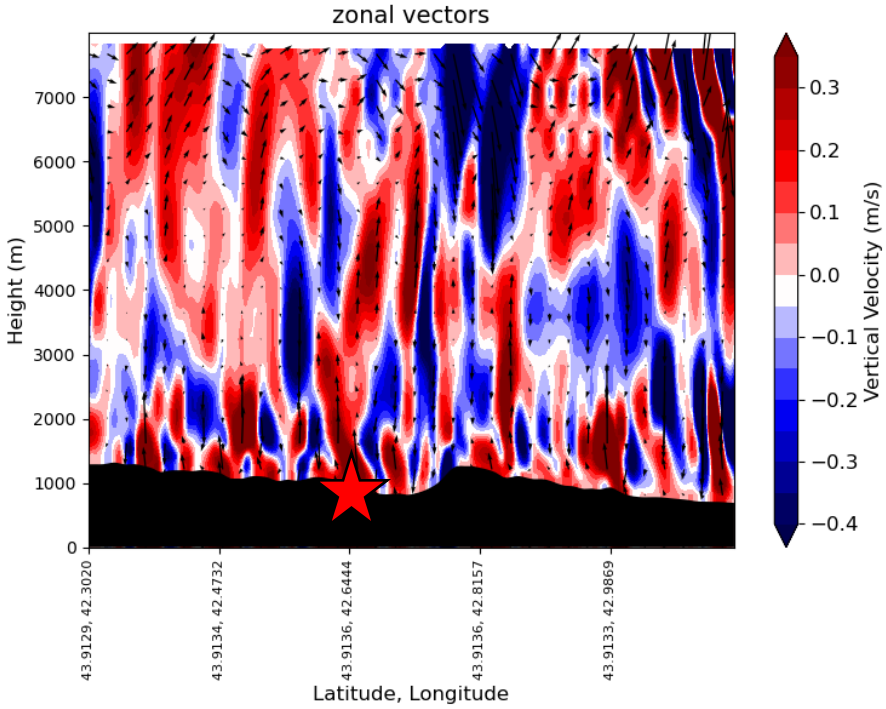




d01 14 UTC d04

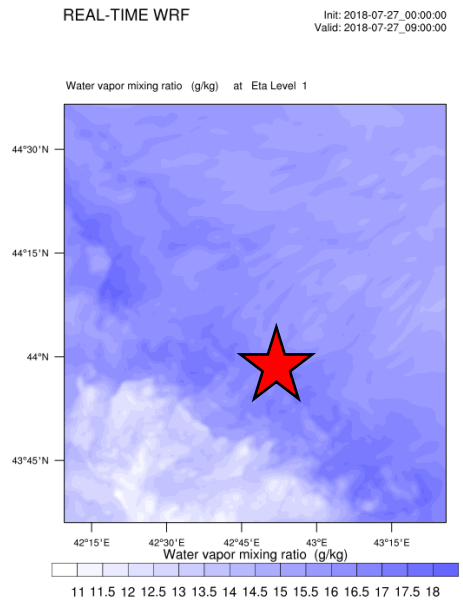
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

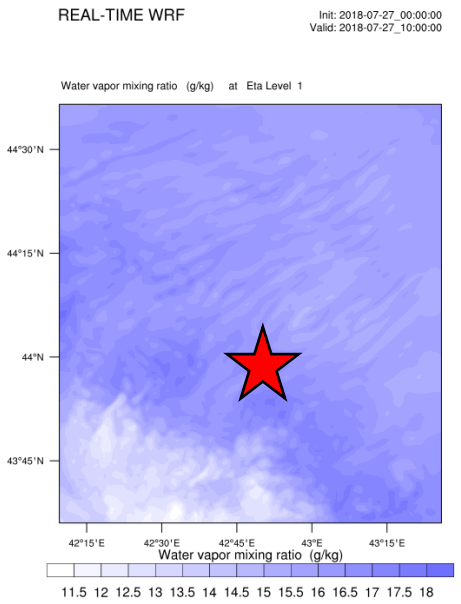


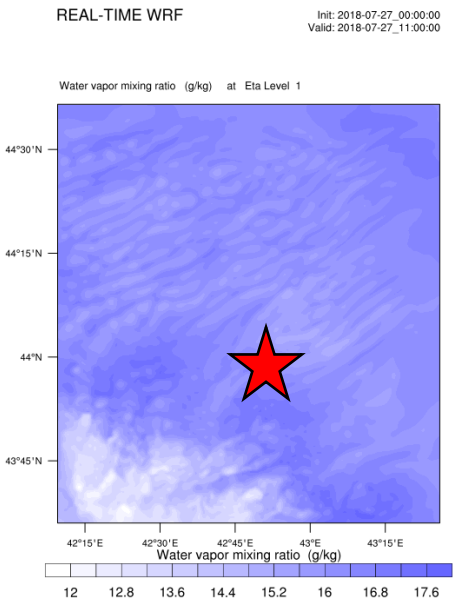


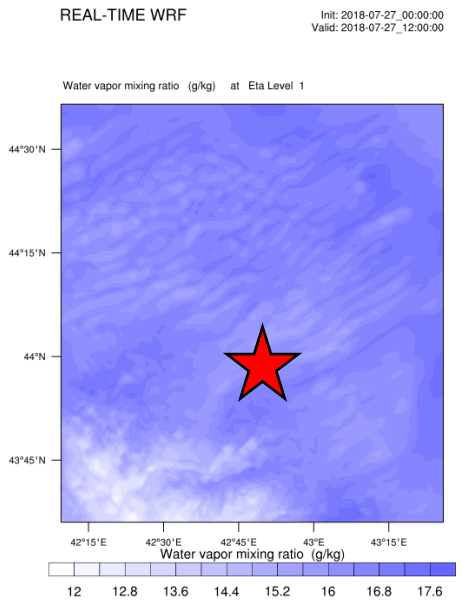
d01 15 UTC d04

- The transport of cold Arctic air along the eastern boundary of the anticyclone (a cold air advection) leads to the formation of elongated horizontal cloud structures, visualized by water vapor content, observed before the intense precipitation on July 27. Such structures, leading to the formation of "cloud streets," are characteristic of cold air advections.









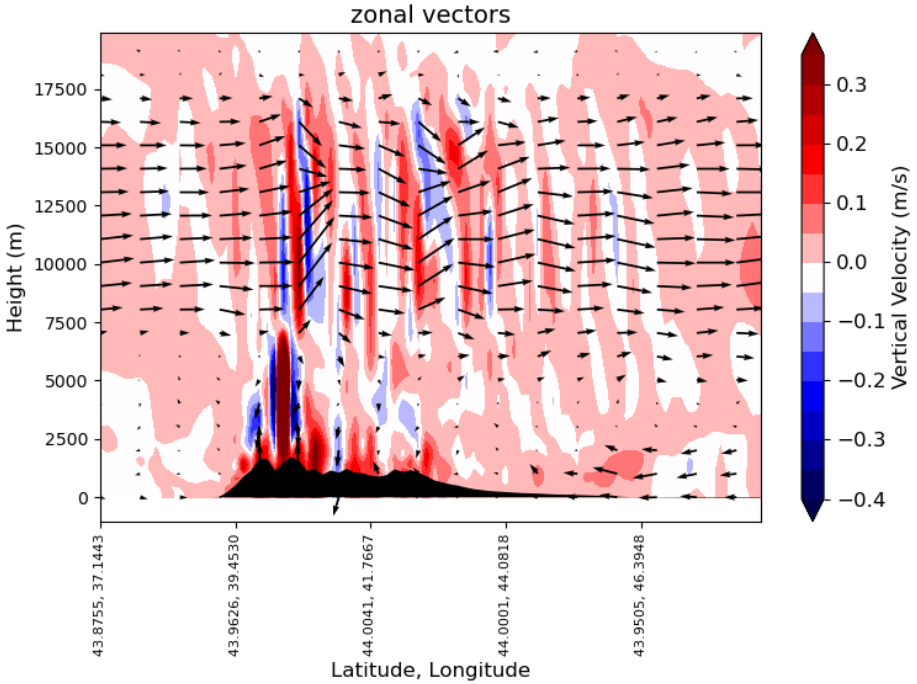
09 UTC 10 UTC 11 UTC 12 UTC

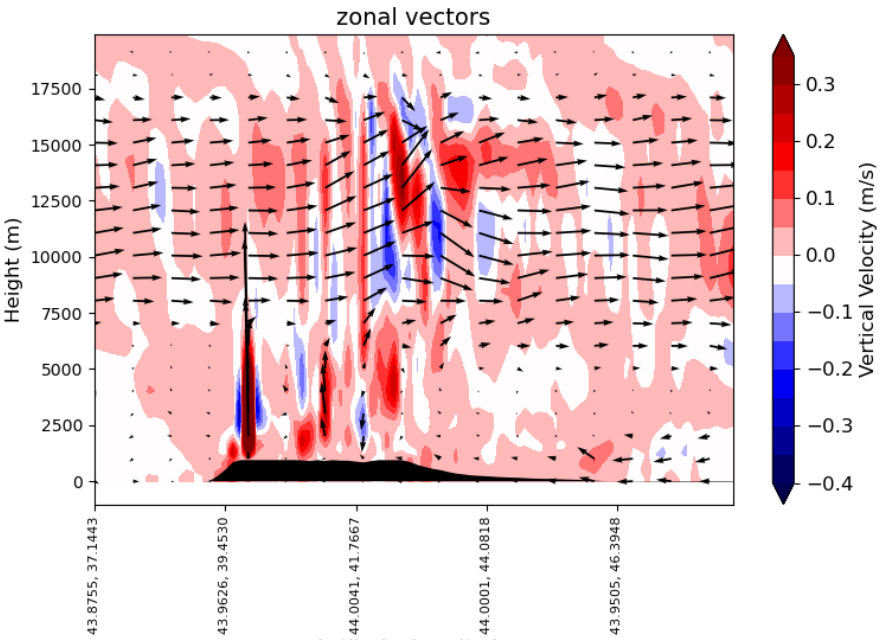
- As shown above in the moisture fields (in cross-sections, with temperature, etc.), the advection occurred into warm, moist air, leading to precipitation. Recent findings, however, indicate that a small amount of the moisture owes its origin to Arctic air masses where the humidity increased partly via atmospheric rivers and the low-level jet stream (not shown in the slides).

- Furthermore, (as can be seen from the wind velocity cross-section by latitude, as well as from the moisture cross-sections by latitude, longitude, and at a 45-degree angle, and at 850, 700, 500, and 300 hPa), moist air enters from the Black Sea, "rolling" over the mountain range, and is brought by wind from the Caspian Sea at an altitude of 3-5 km as well. Cold pool triggered convection is not clearly observed - over the Caspian Sea, the temperature decreases with altitude, and unstable stratification of the atmosphere is observed before the extreme event.

Vertical velocity. Cross-section along the latitude of Kislovodsk to an altitude of 18,000 m. Domain d01. Orography smoothing effect – surprisingly insignificant!

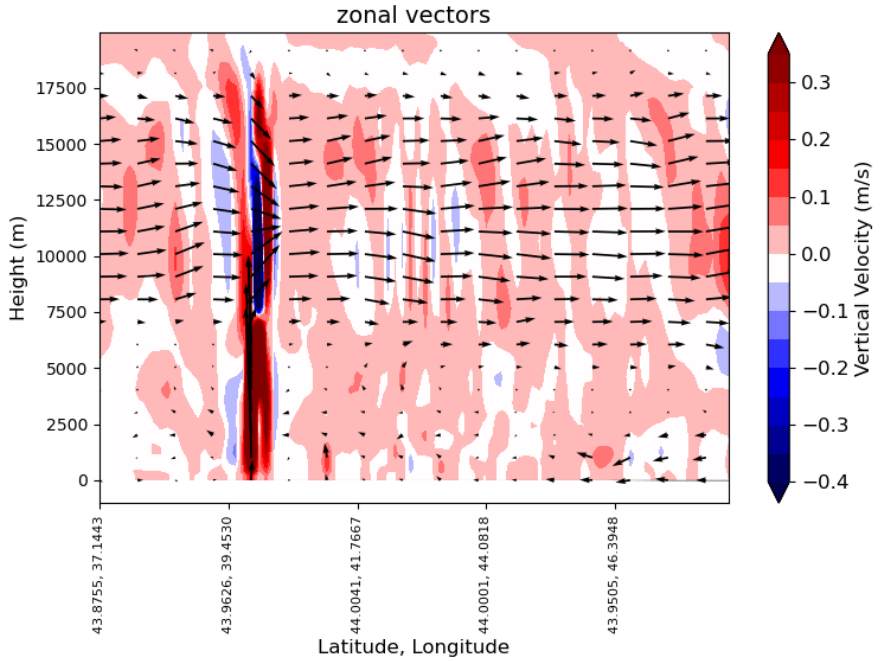
for 12,13,14,15,16,17 UTC

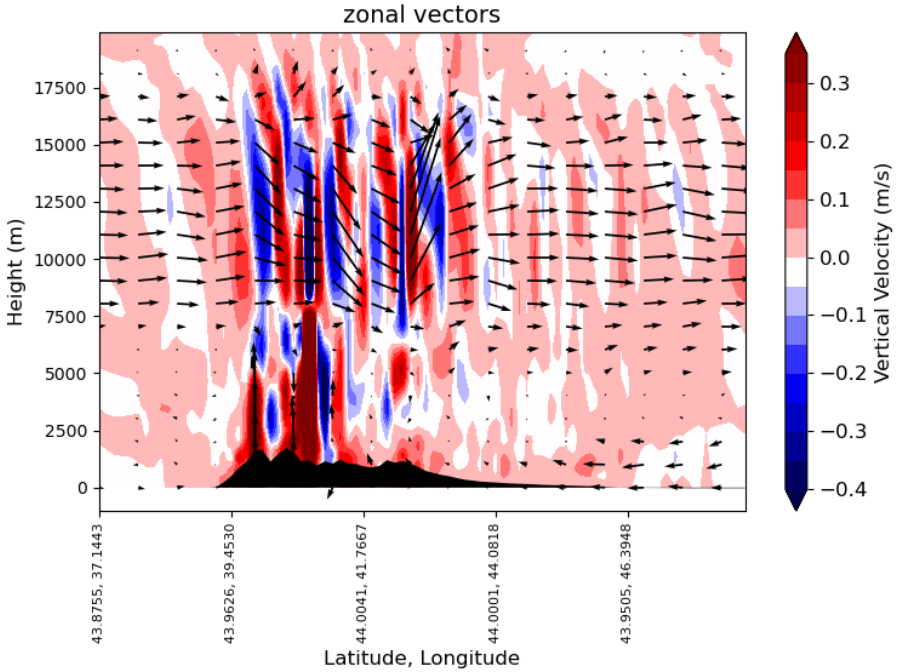


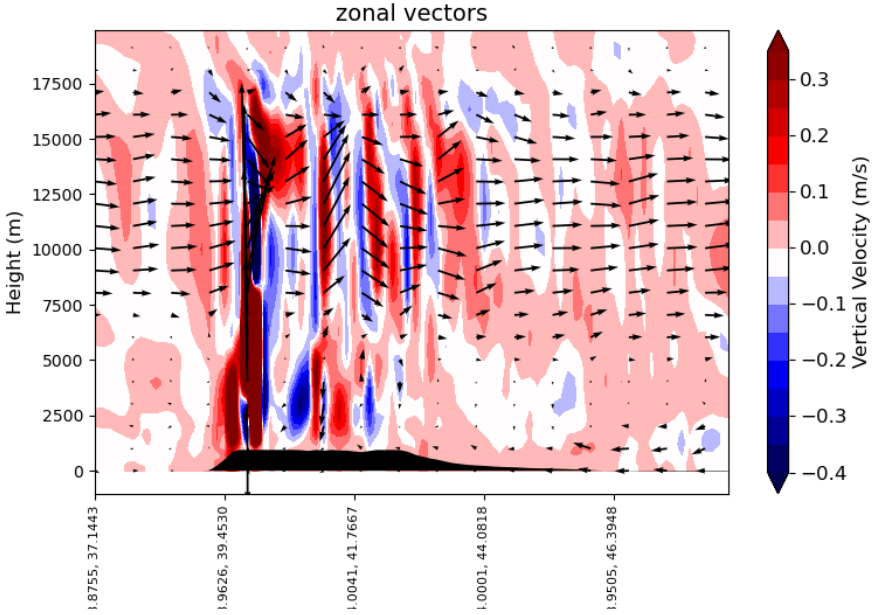


Heights are shown in black

12 UTC
d01

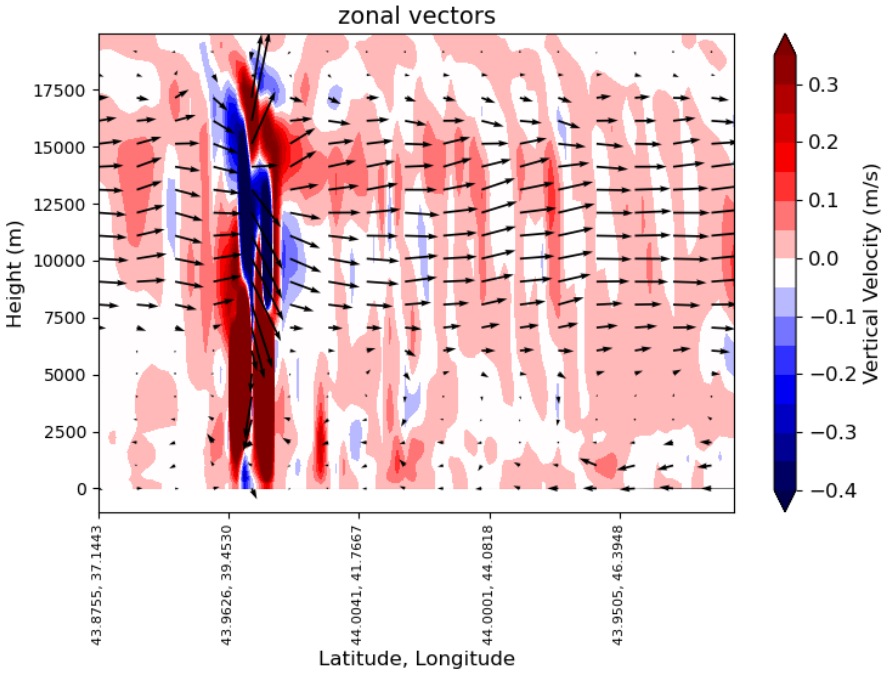


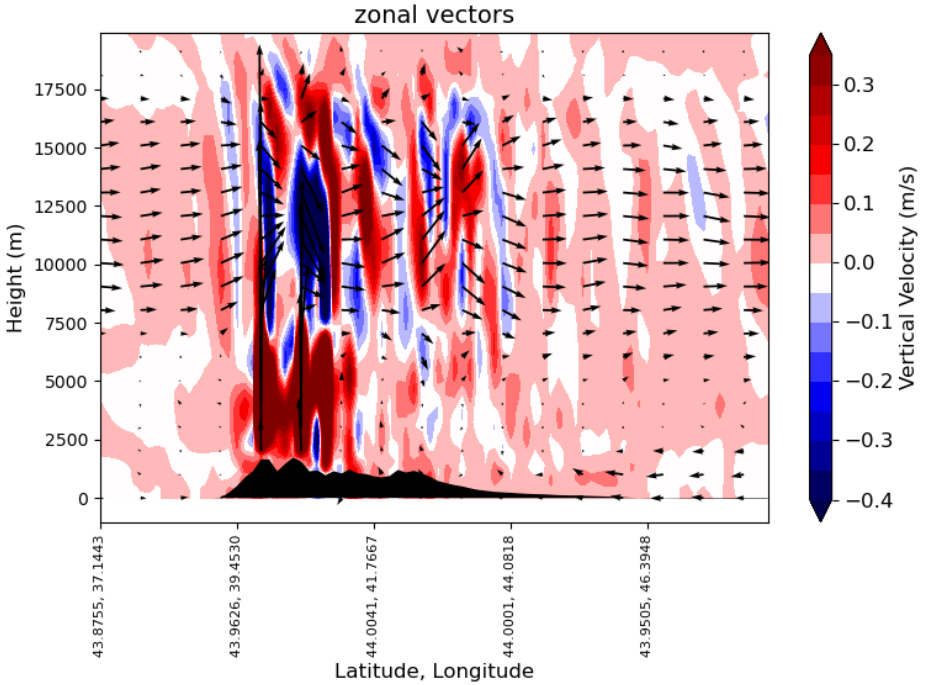


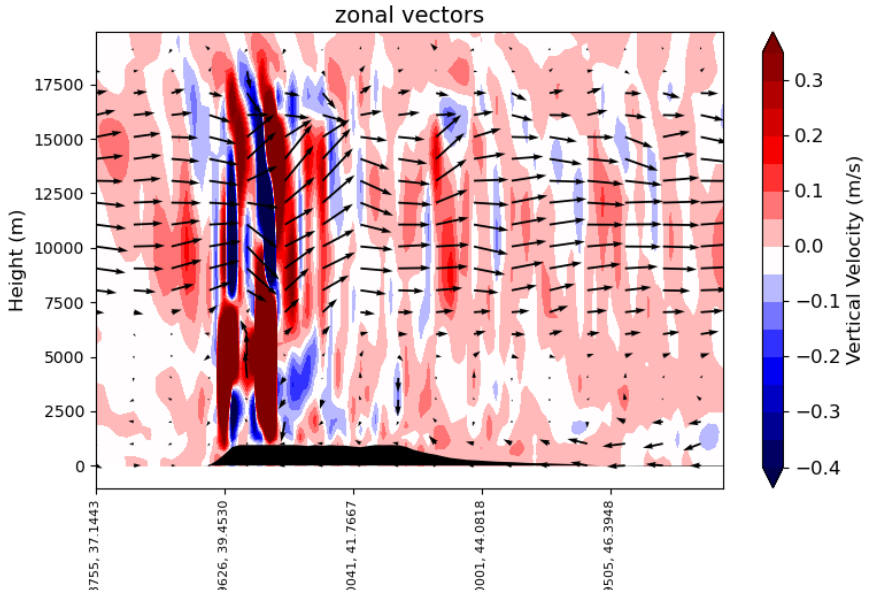


Heights are shown in black

13 UTC
d01

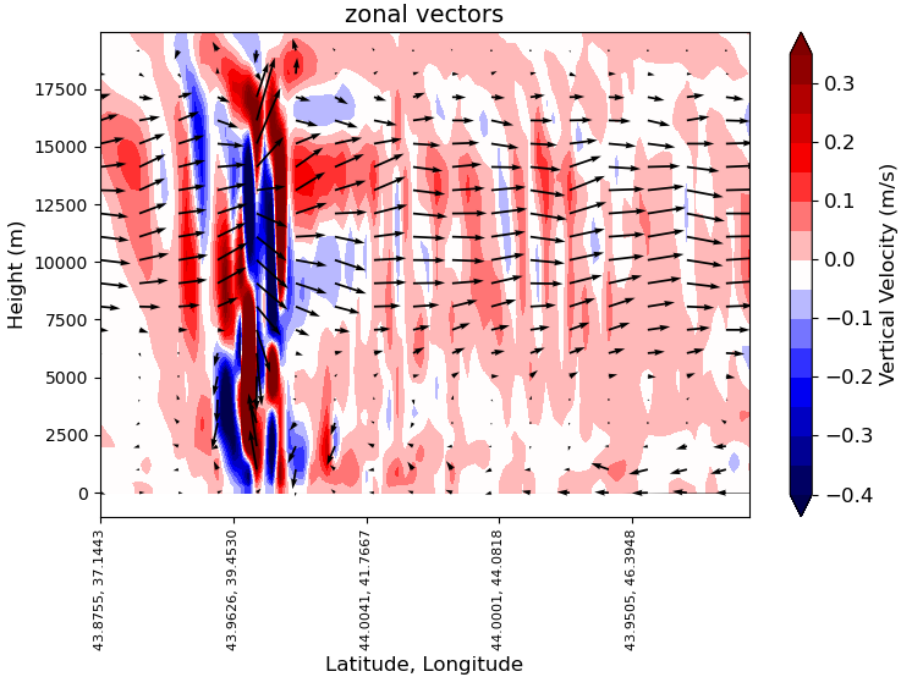


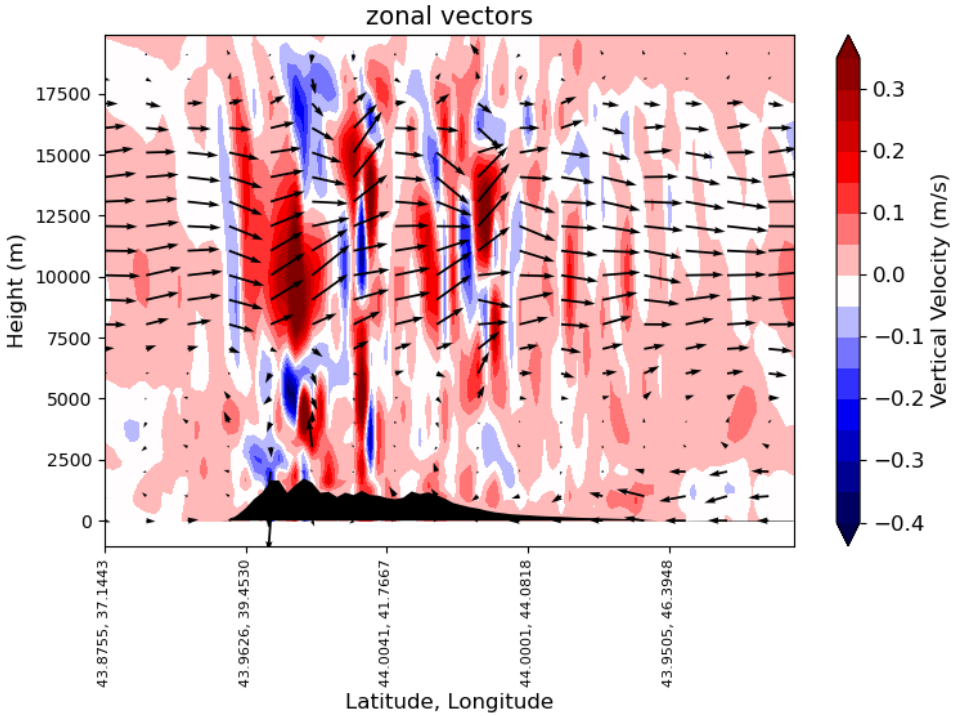


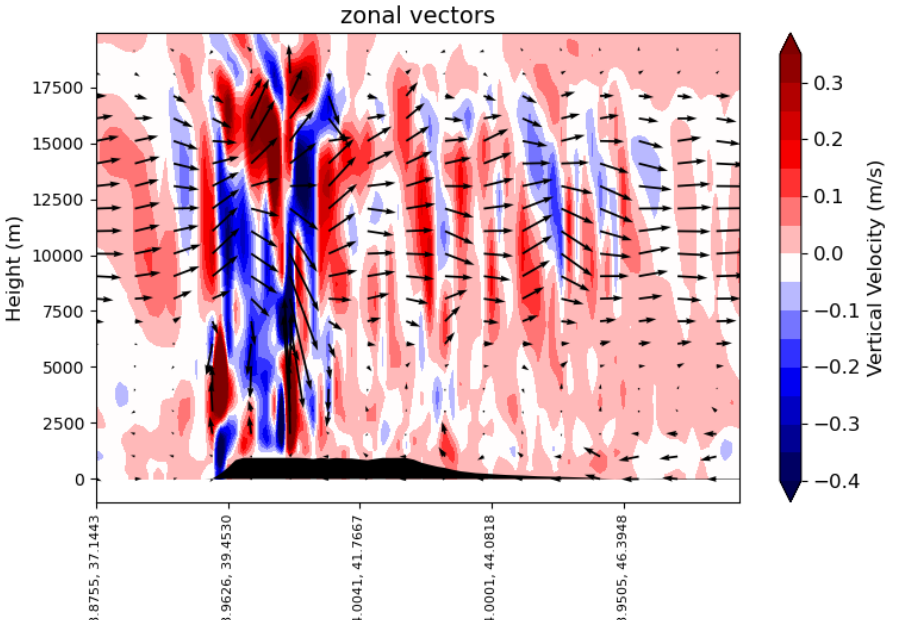


Heights are shown in black

14 UTC
d01

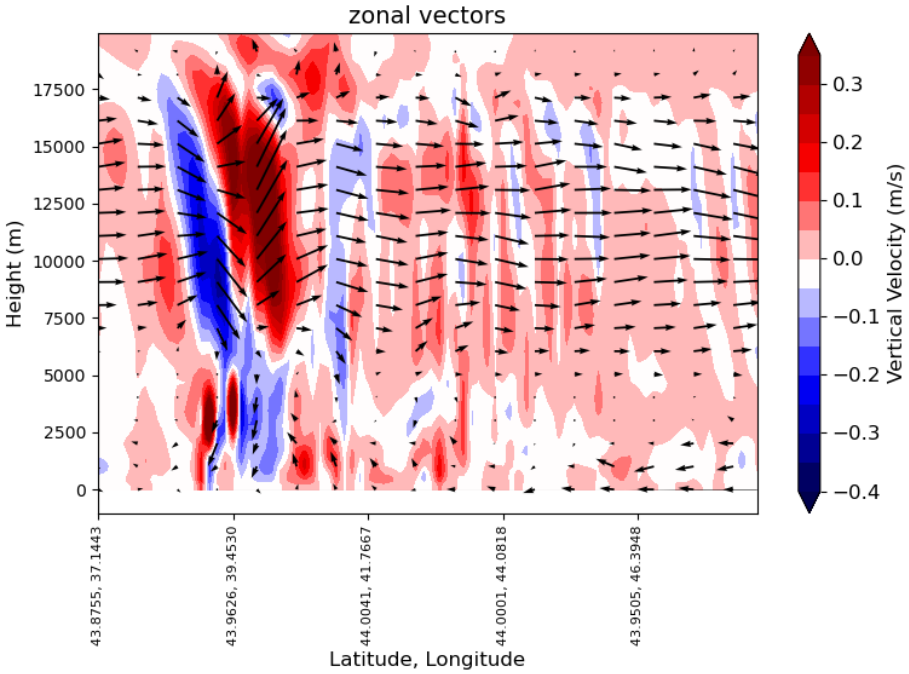


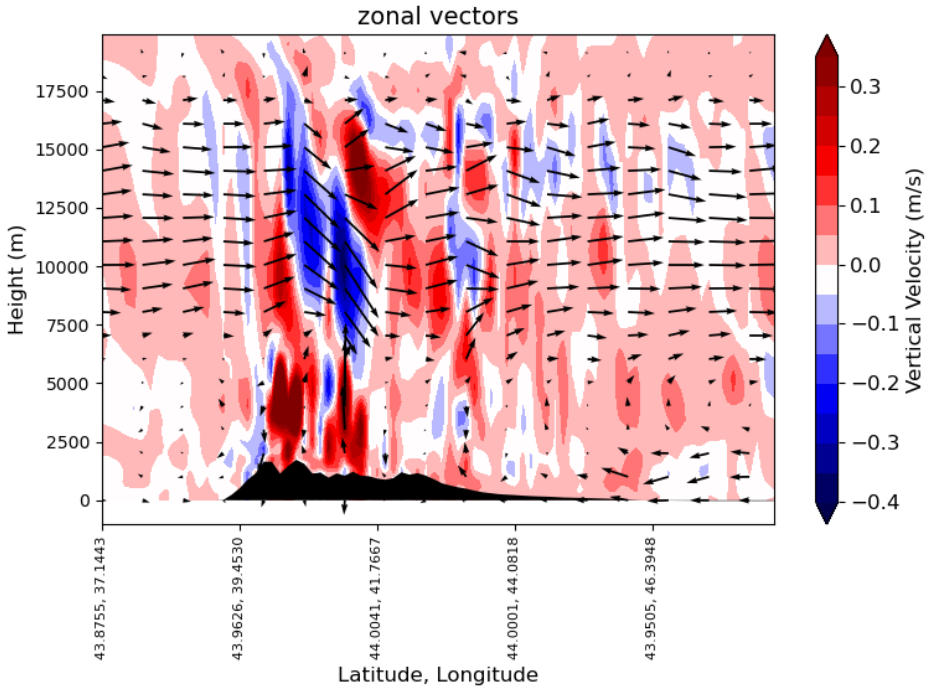


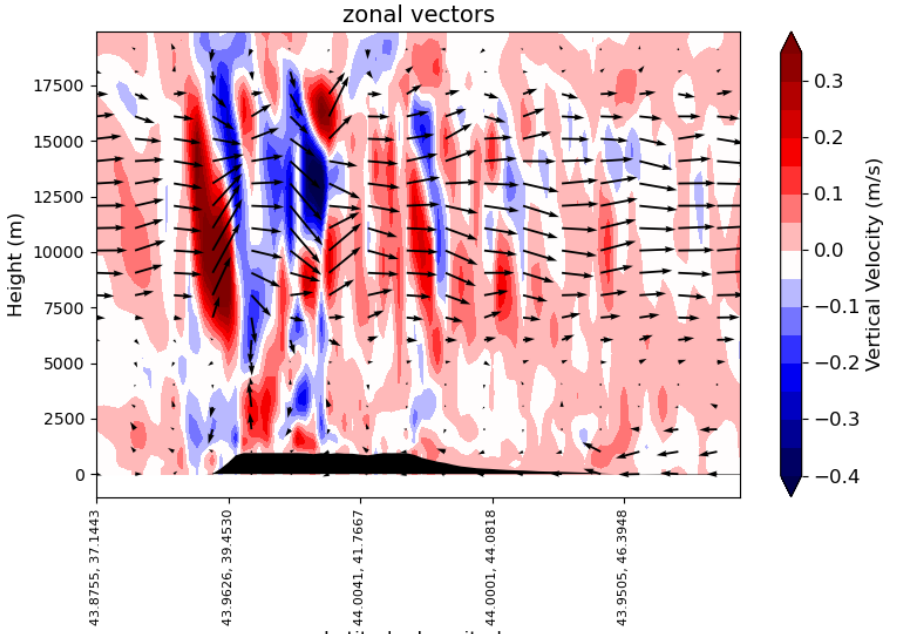


Heights are shown in black

15 UTC
d01

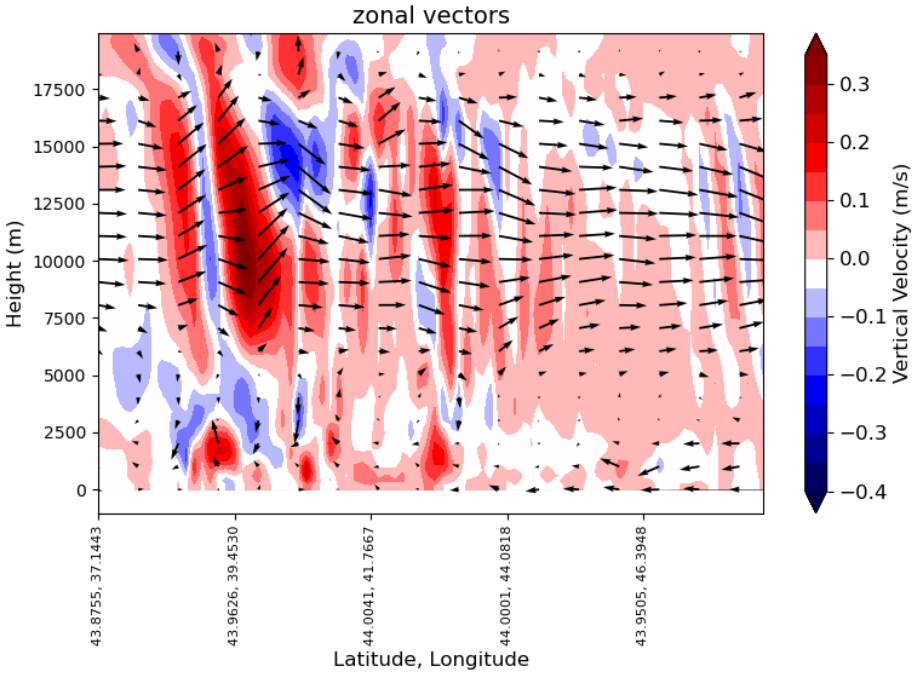


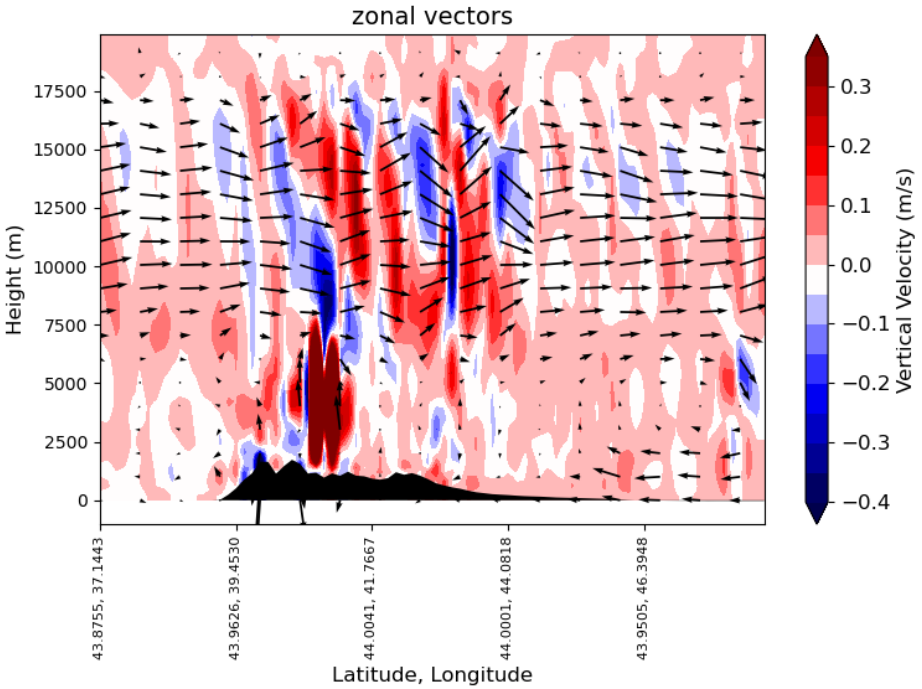


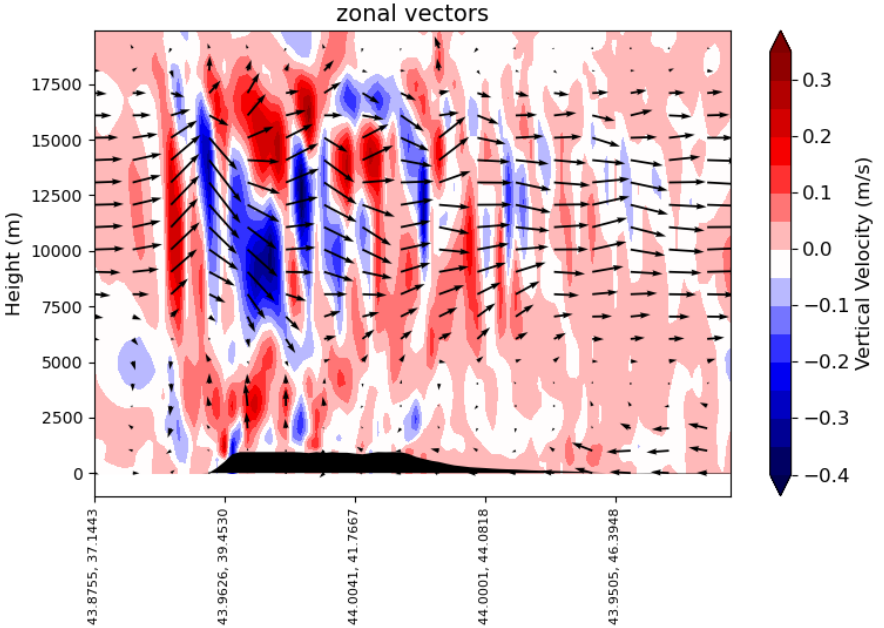


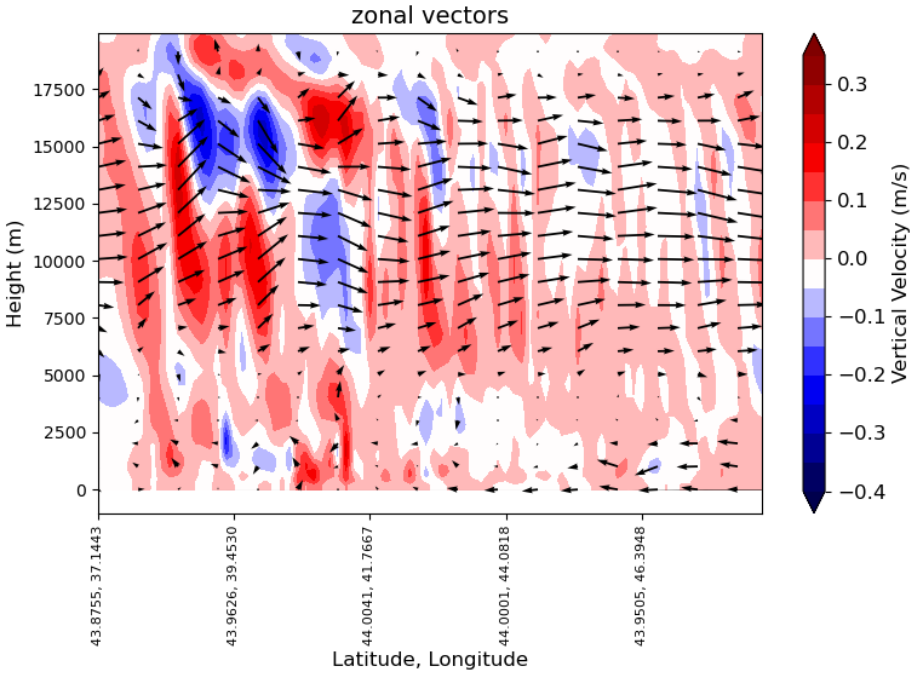
Heights are shown in black

16 UTC
d01









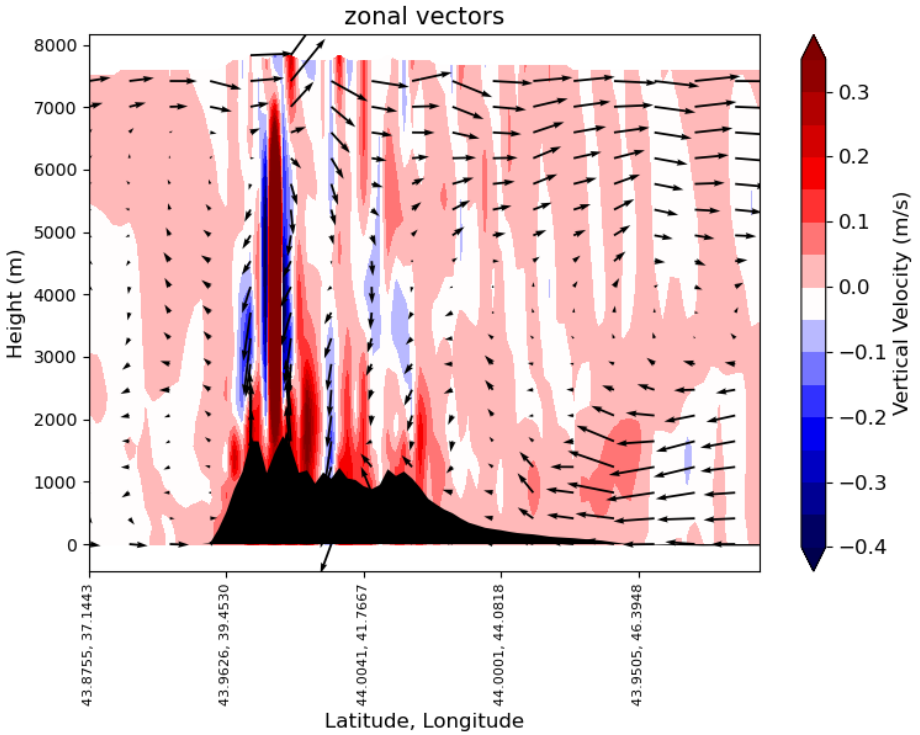
Heights are shown in black

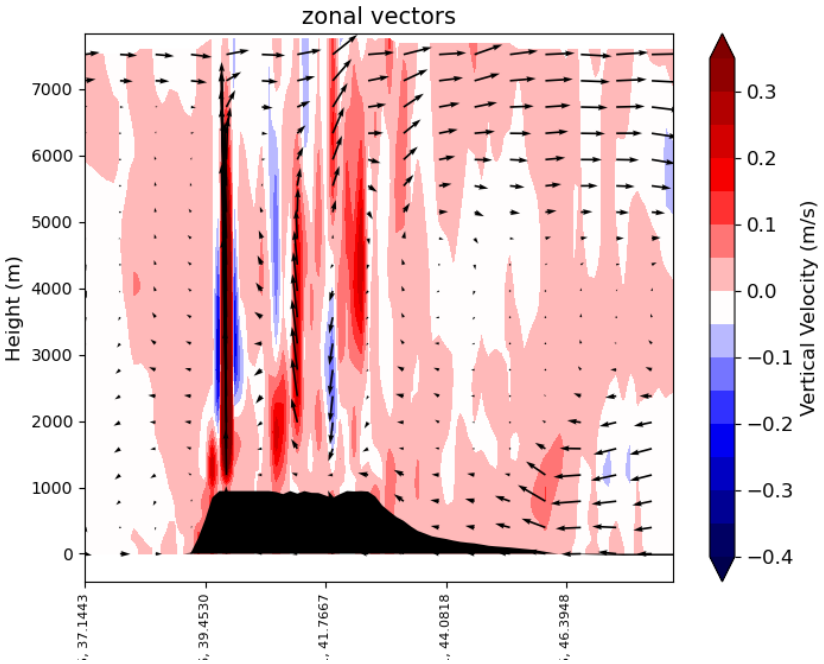
17 UTC

d01

Vertical velocity. Cross-section along the latitude of Kislovodsk to an altitude of 8,000 m. Domain d01. Orography smoothing effect – surprisingly insignificant!

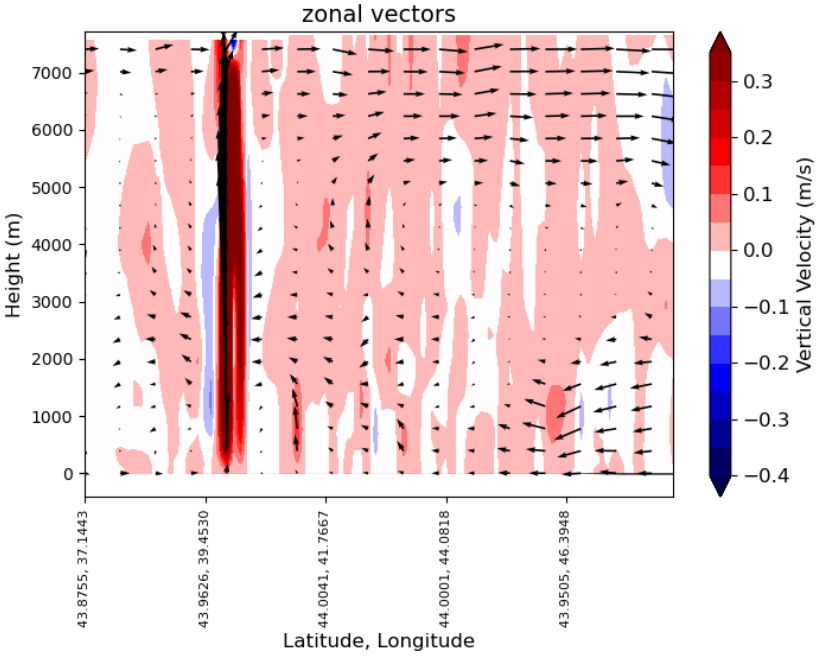
for 12,13,14,15,16,17 UTC

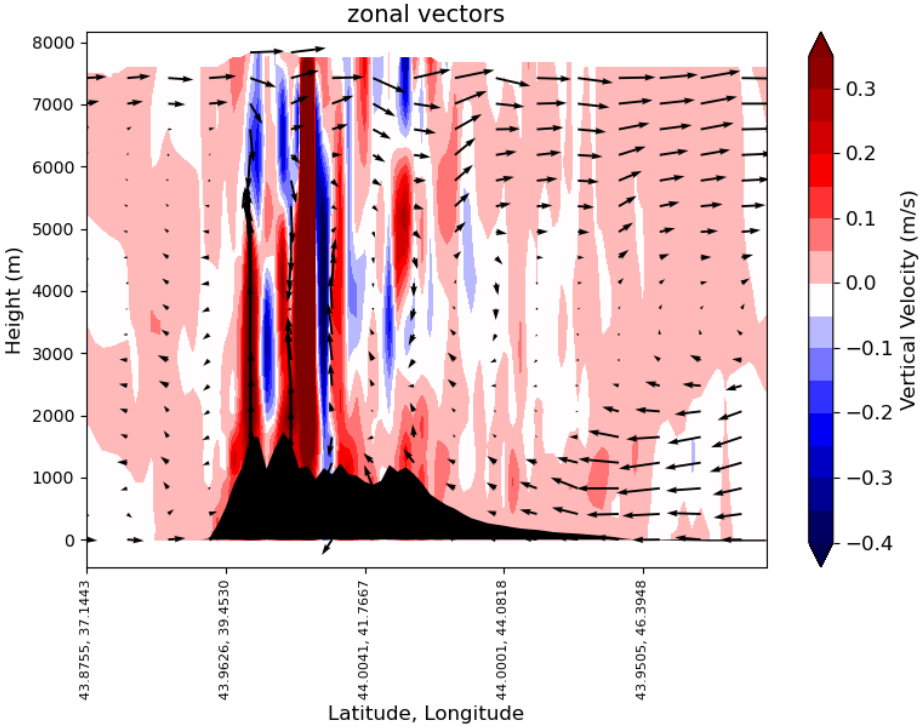


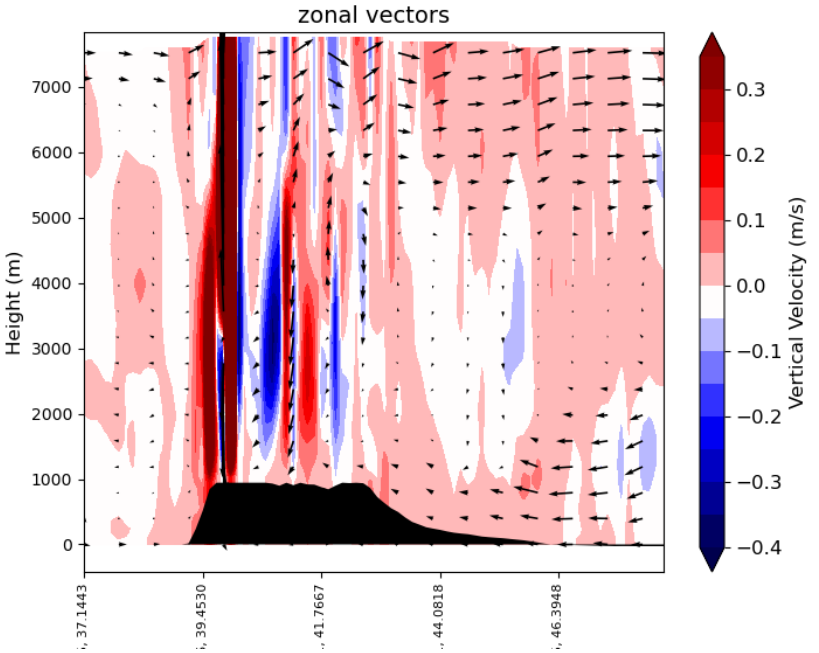


Heights are shown in black

12 UTC
d01

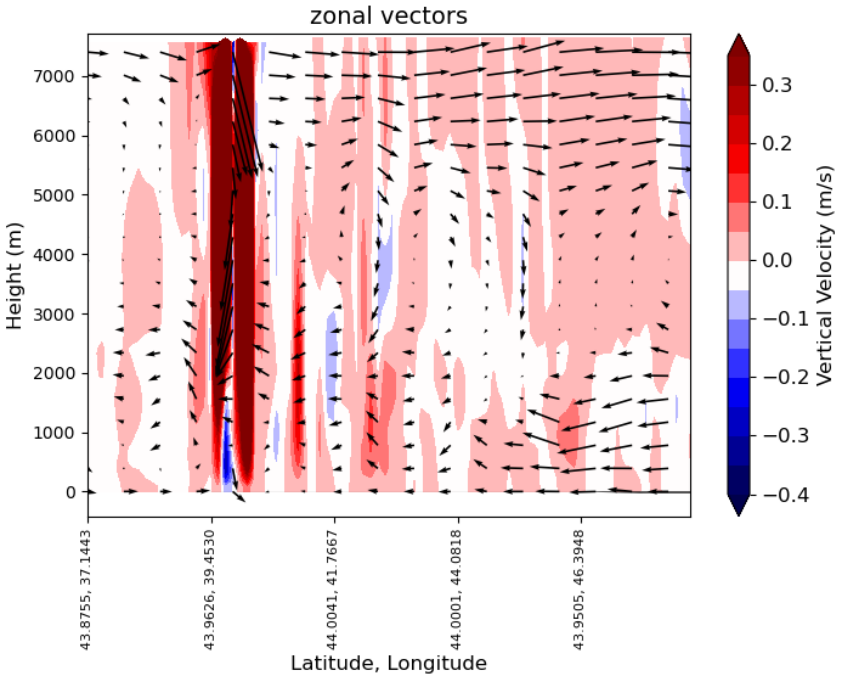


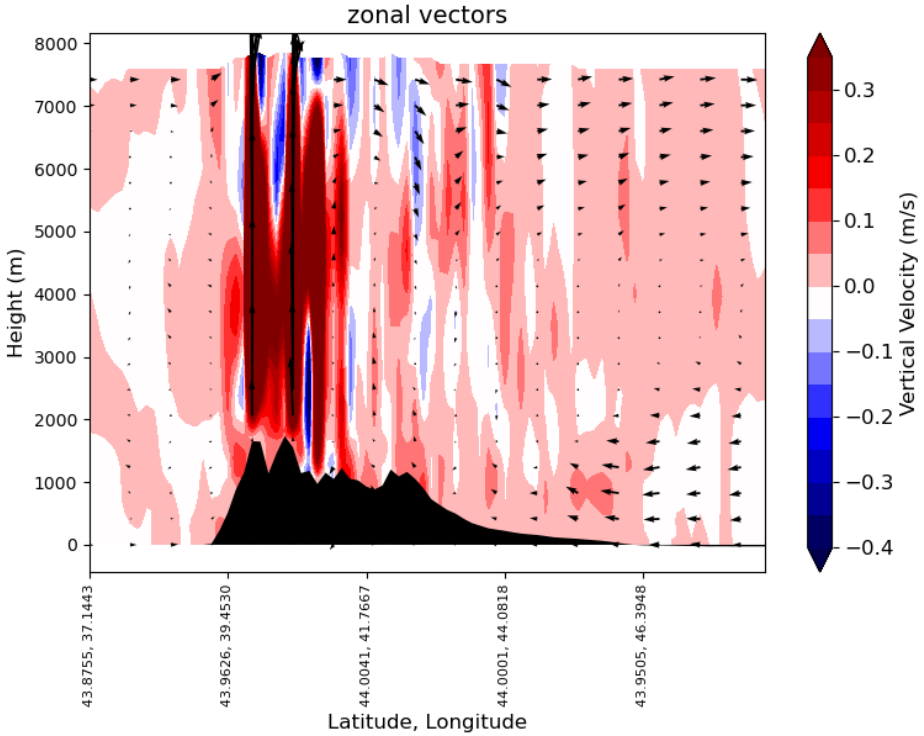


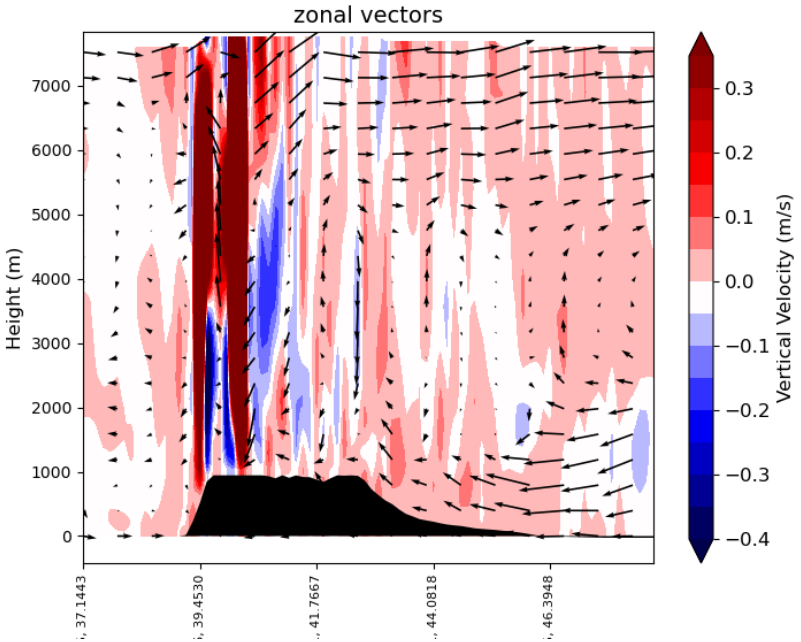


Heights are shown in black

13 UTC
d01

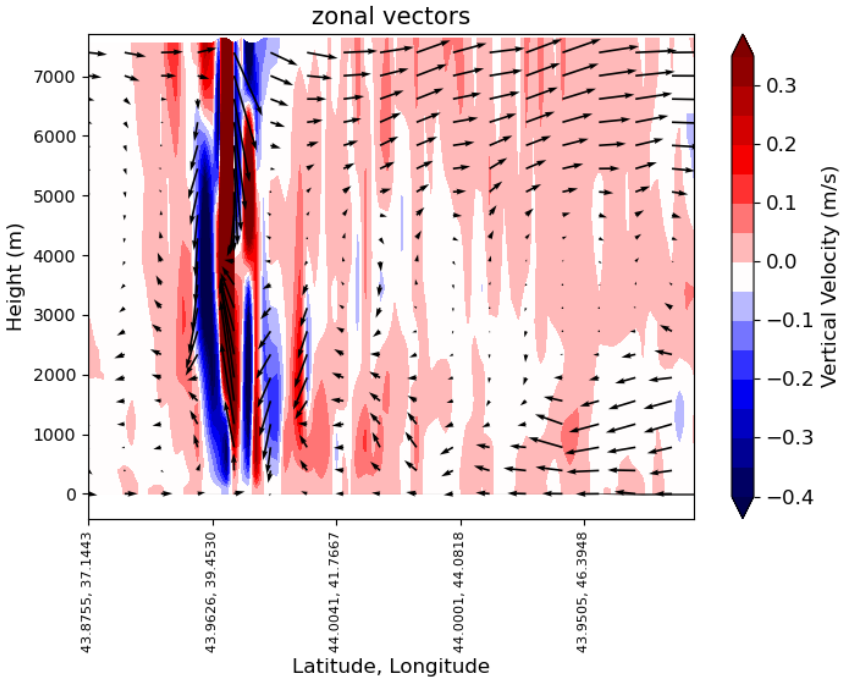


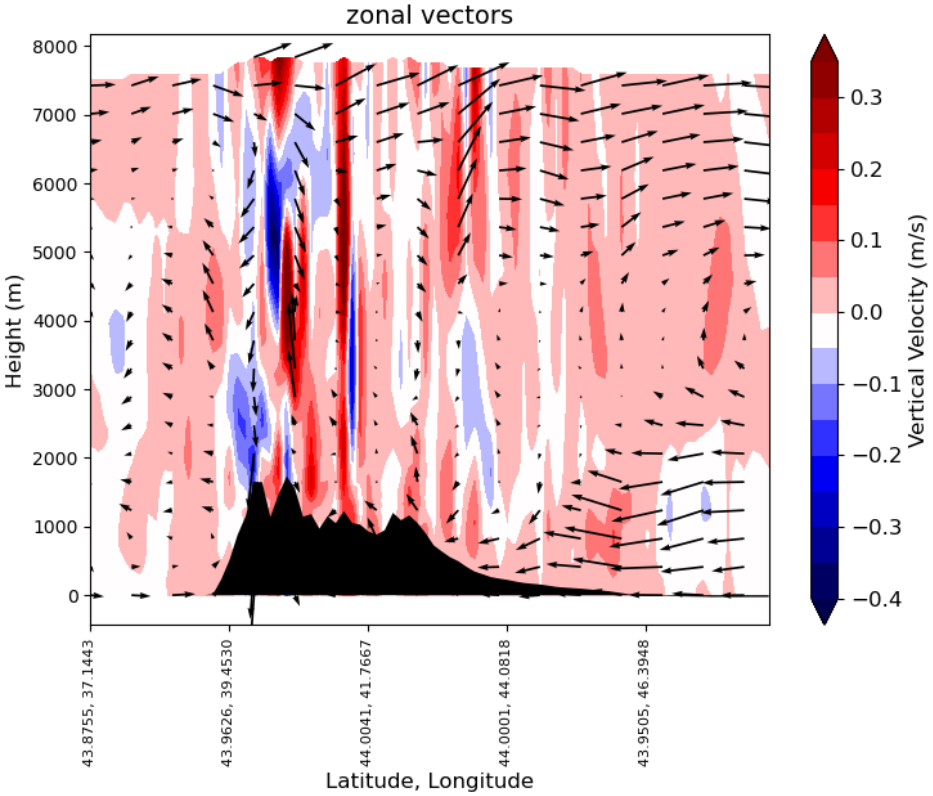


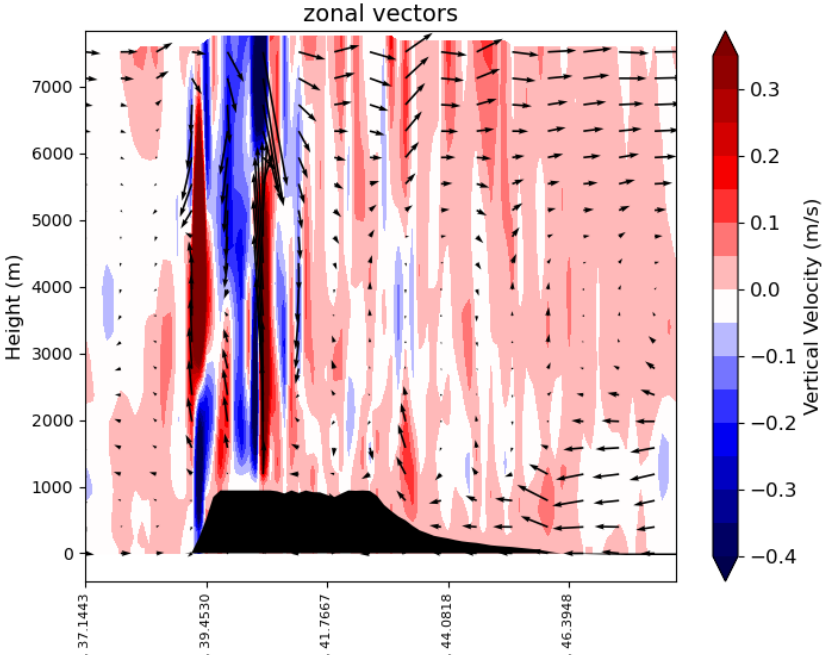


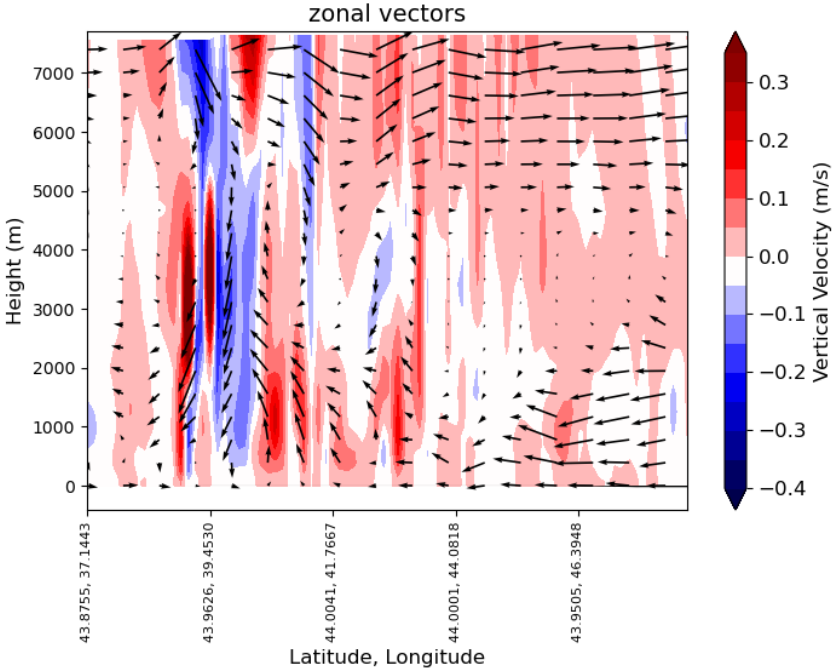
Heights are shown in black

14 UTC
d01



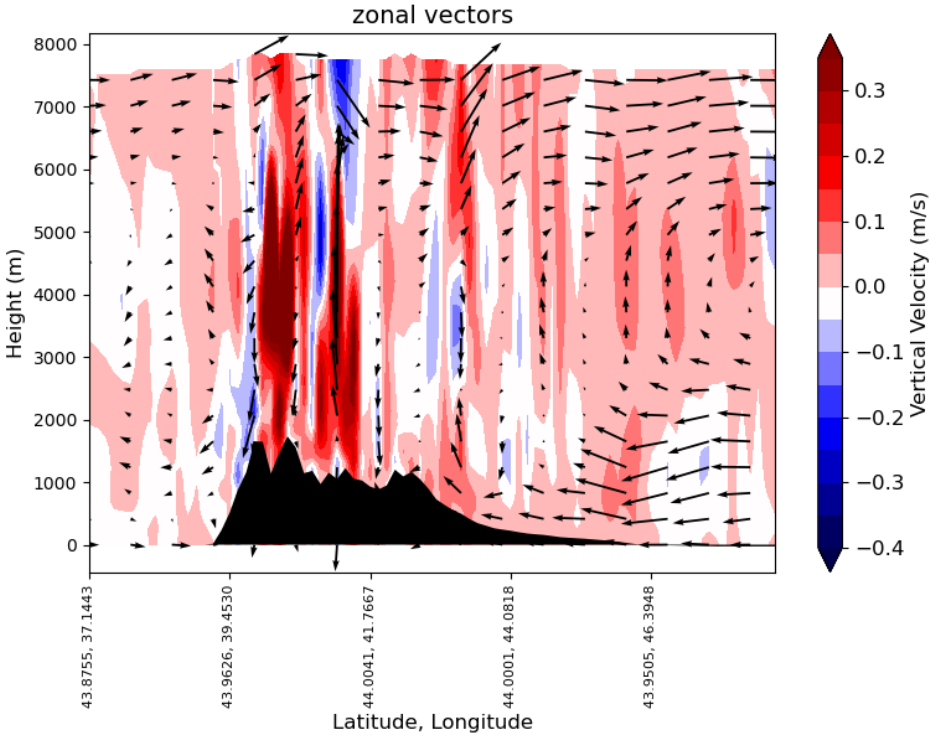


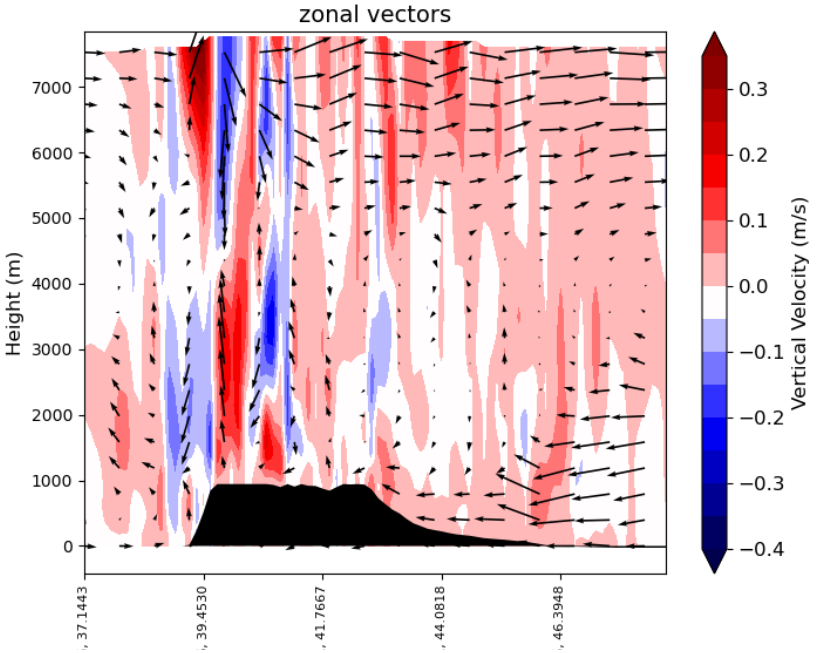




Heights are shown in black

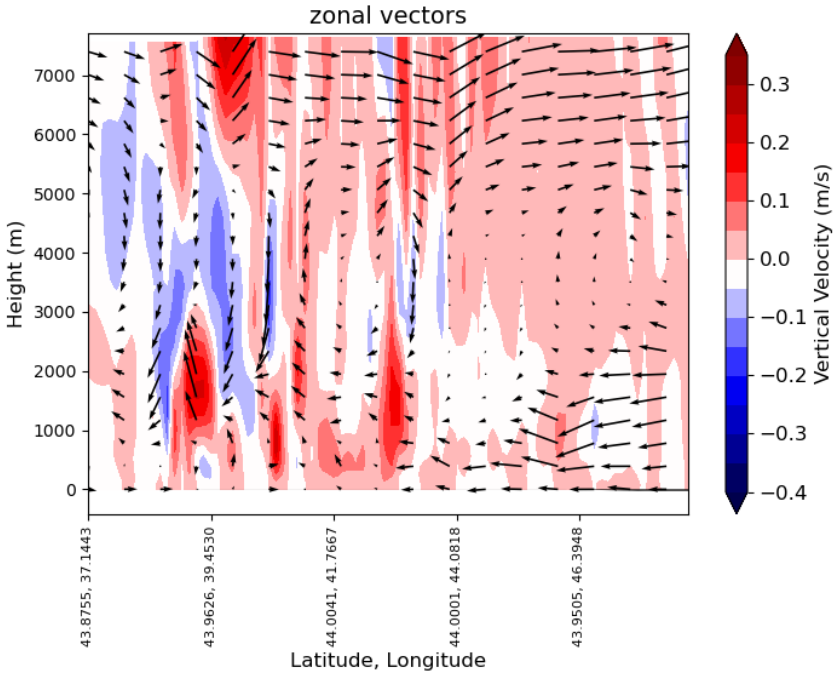
15 UTC
d01





Heights are shown in black

16 UTC
d01

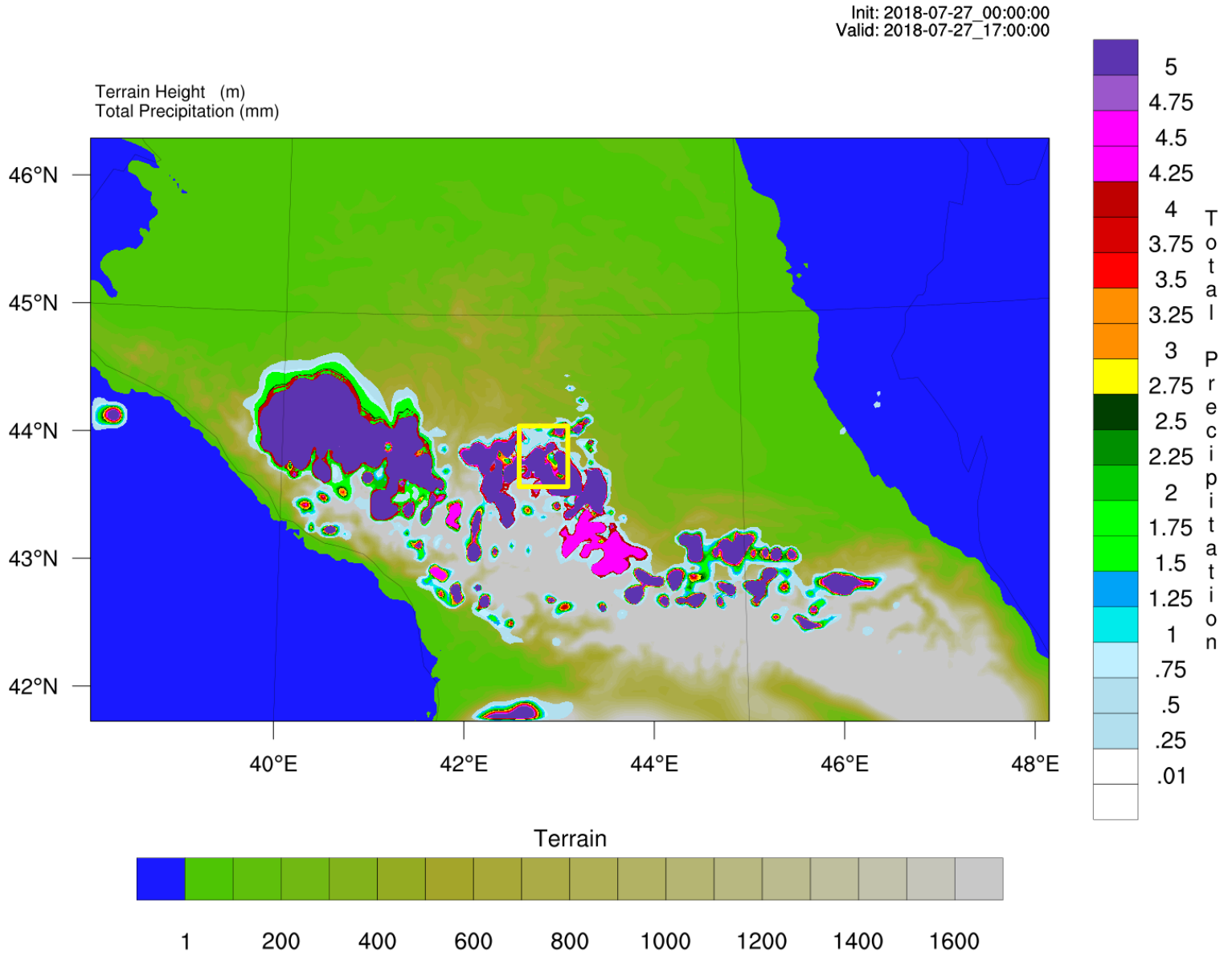


Precipitation. Domain d02. Orography smoothing effect – is mostly expressed in where the rain occurs and in the amount of precipitation

for 12-17 UTC

The total amount of precipitation, averaged over the d02 domain, was calculated during drawing the figures and the figure was given on the slide

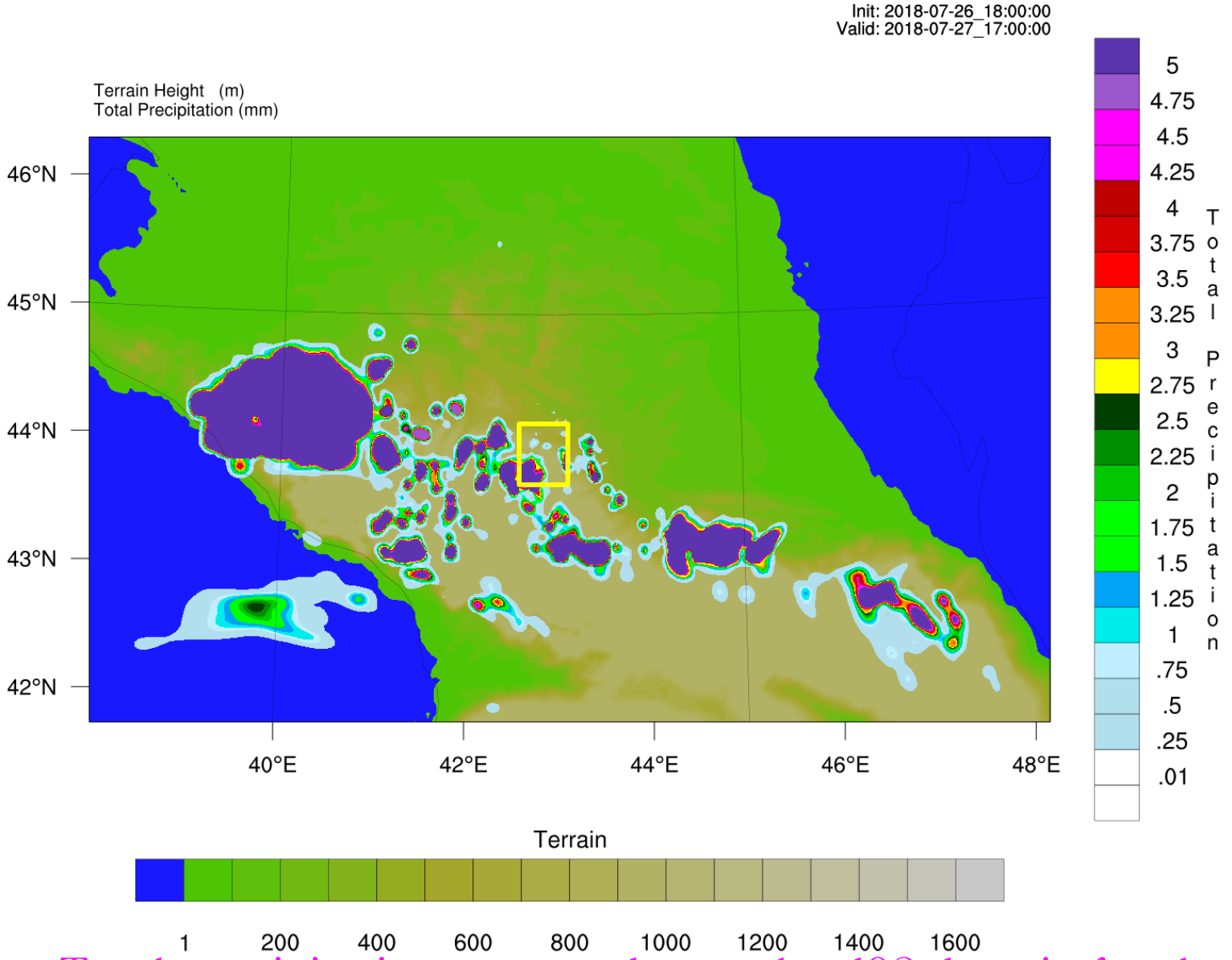
Original orography



Total precipitation averaged over the d02 domain for the period 07/27/2023 00 UTC -07/27/2023 17 UTC: 1,74678 inches

d02

orography is smoothed out to the height of Kislovodsk

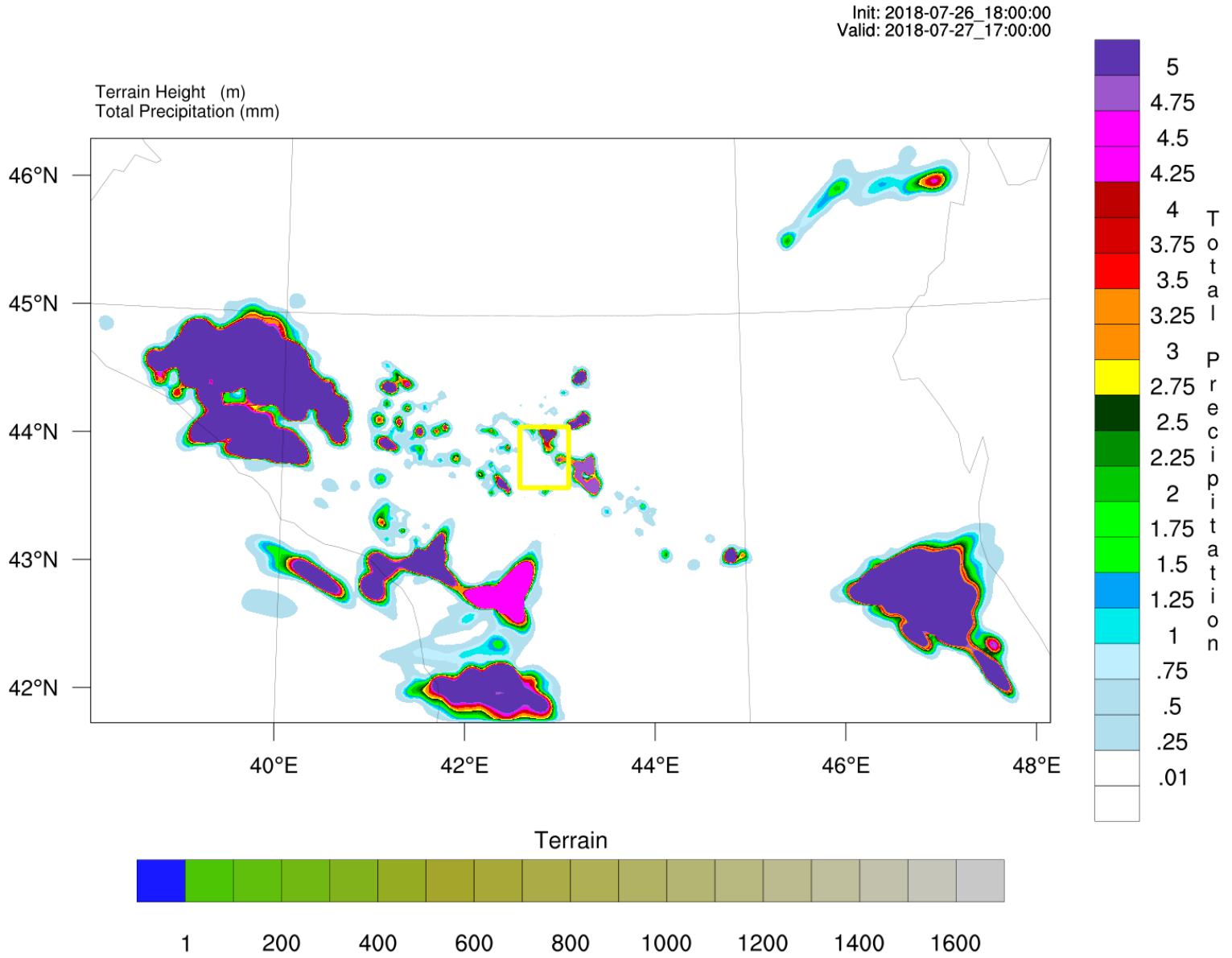


Total precipitation averaged over the d02 domain for the period 07/26/2023 18 UTC -07/27/2023 17 UTC: 3,14281 inches

d02

OUTPUT FROM WRF V4.1.3 MODEL
WE = 232 ; SN = 142 ; Levels = 40 ; Dis = 3.6km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 0

orography is smoothed out to 1 m



Total precipitation averaged over the d02 domain for the period 07/26/2023 UTC - 07/27/2023 17 UTC: 3,41976 inches

d02

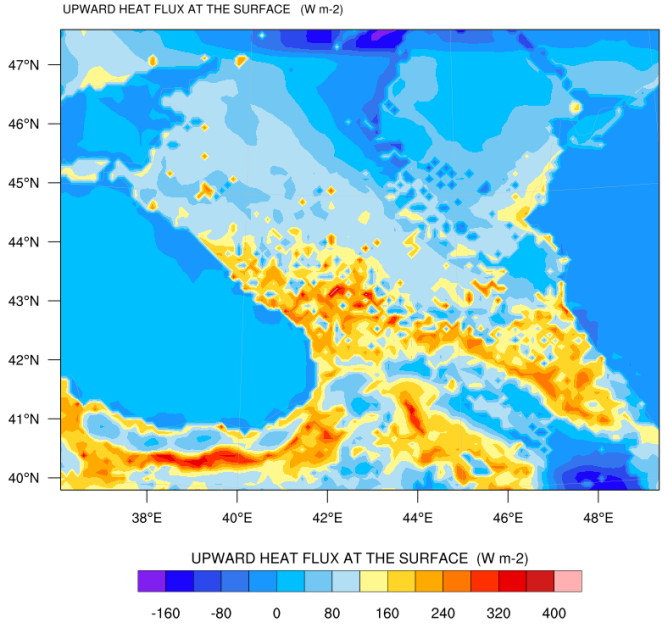
Heat fluxes from the surface. Domain d01. Orography smoothing effect.

for 12,13,14,15,16,17 UTC

Scale below each figure
(heat flow values do not differ significantly)

LEAD REAL-TIME WRF

Init: 2018-07-27_00:00:00
Valid: 2018-07-27_12:00:00



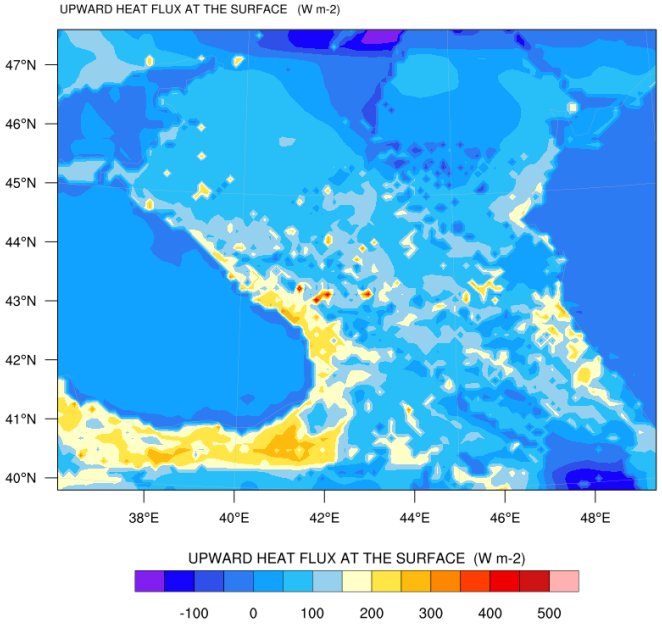
OUTPUT FROM WRF V4.1.3 MODEL
WE = 106 ; SN = 82 ; Levels = 40 ; Dis = 10.8km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 3

12 UTC

d01

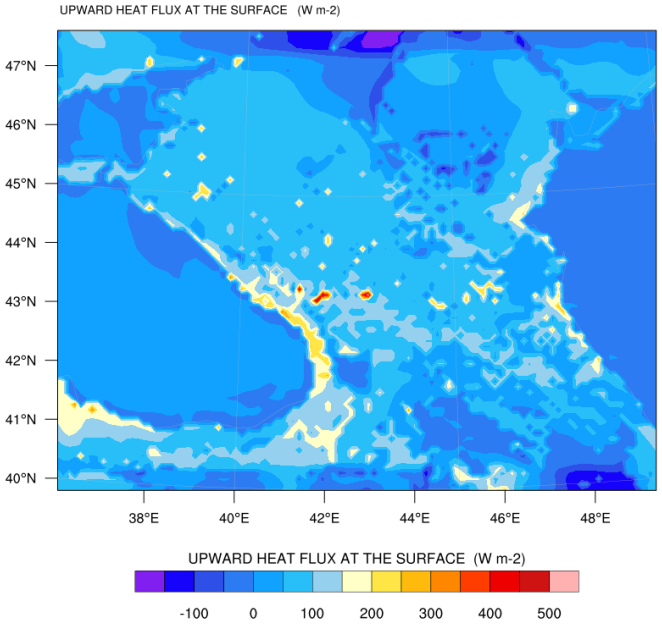
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_12:00:00



LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_12:00:00



LEAD REAL-TIME WRF

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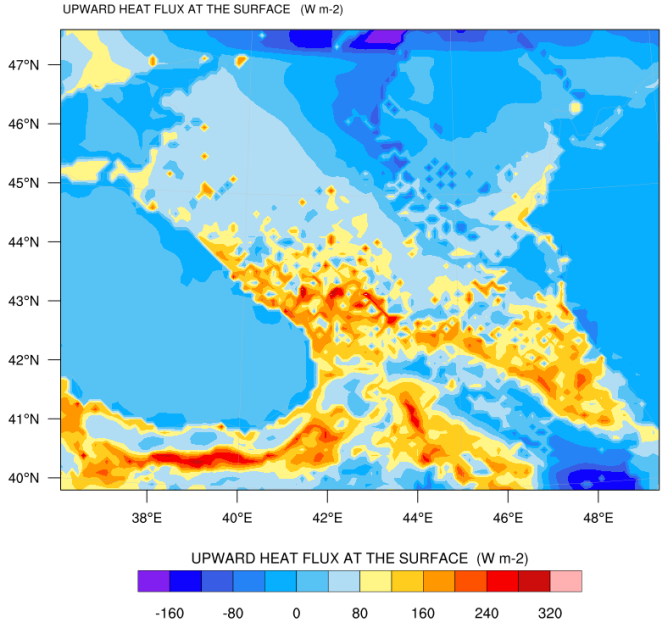
Valid: 2018-07-27_13:00:00



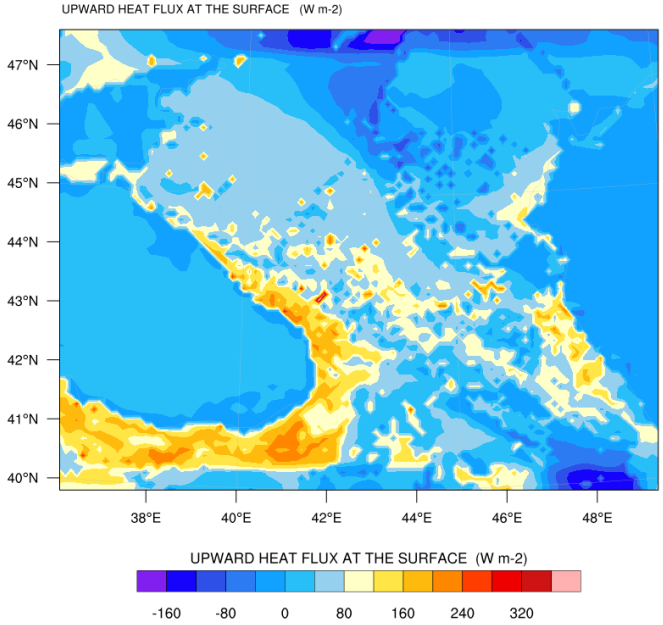
OUTPUT FROM WRF V4.1.3 MODEL
WE = 106 ; SN = 82 ; Levels = 40 ; Dis = 10.8km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 3

13 UTC

d01

LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_13:00:00



LEAD REAL-TIME WRF

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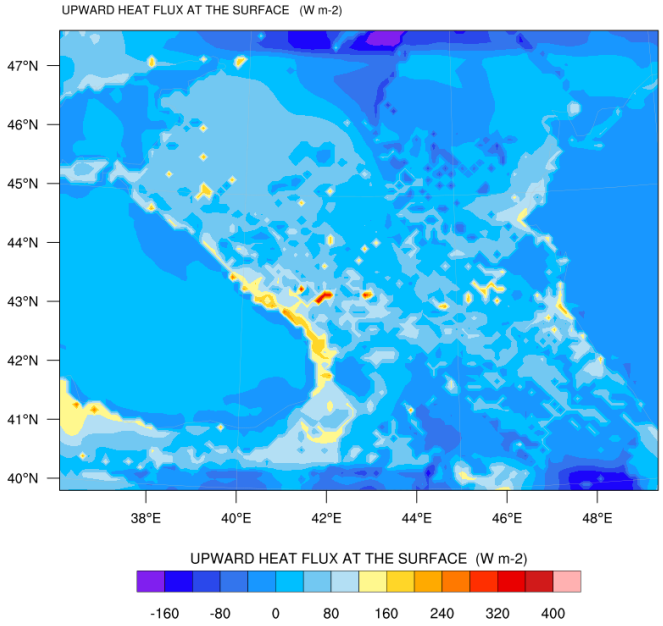
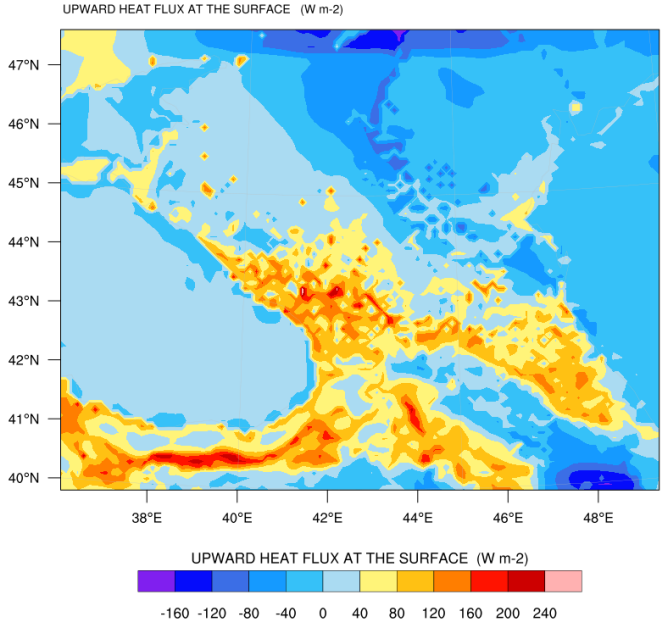
Valid: 2018-07-27_13:00:00



LEAD REAL-TIME WRF

Init: 2018-07-27_00:00:00
Valid: 2018-07-27_14:00:00



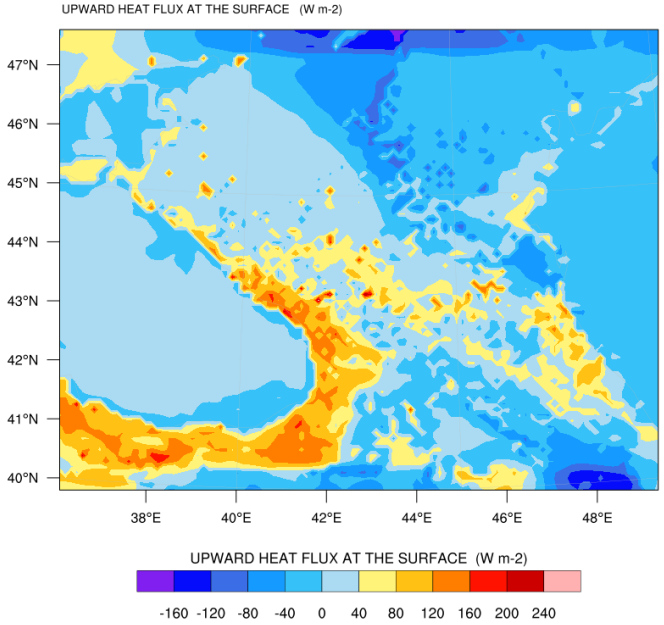
OUTPUT FROM WRF V4.1.3 MODEL
WE = 106 ; SN = 82 ; Levels = 40 ; Dis = 10.8km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 3

14 UTC

d01

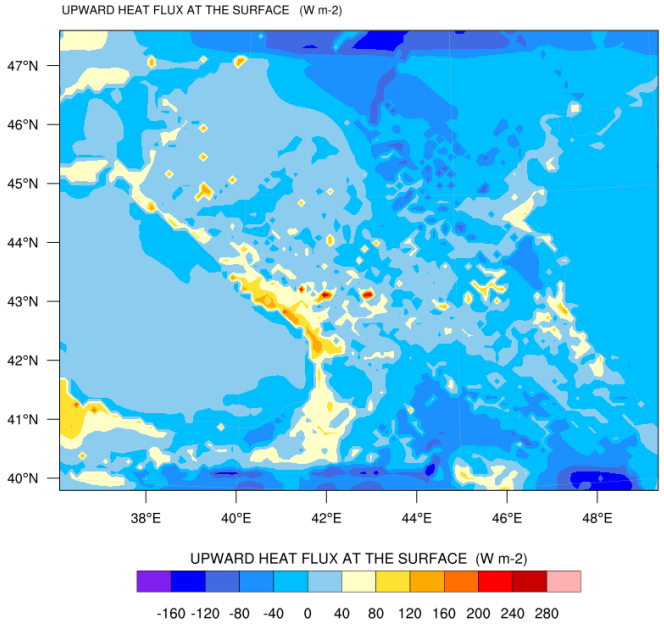
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_14:00:00



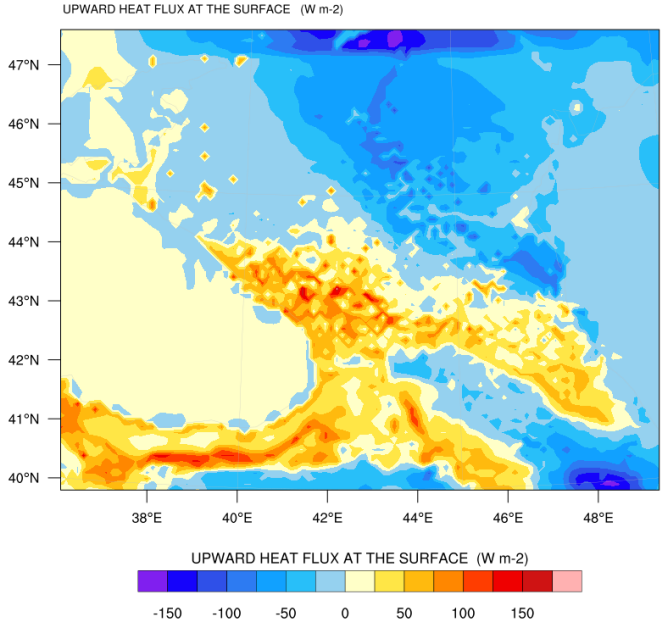
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_14:00:00



LEAD REAL-TIME WRF

Init: 2018-07-27_00:00:00
Valid: 2018-07-27_15:00:00



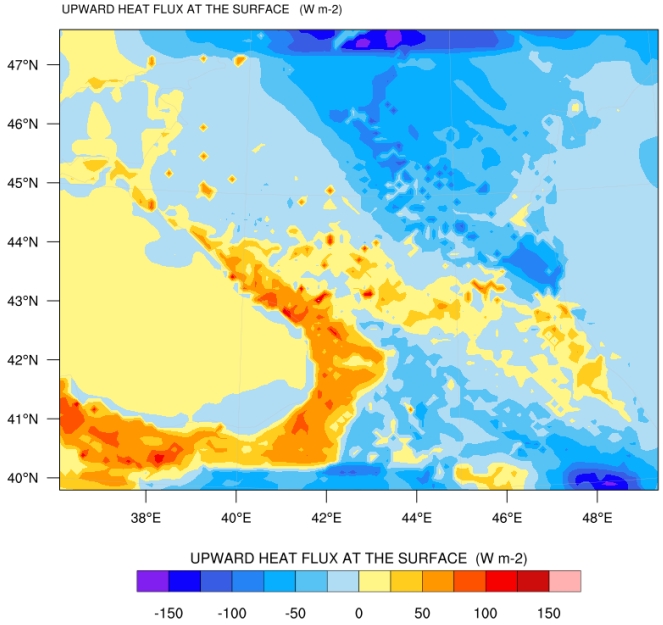
OUTPUT FROM WRF V4.1.3 MODEL
WE = 106 ; SN = 82 ; Levels = 40 ; Dis = 10.8km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 3

15 UTC

d01

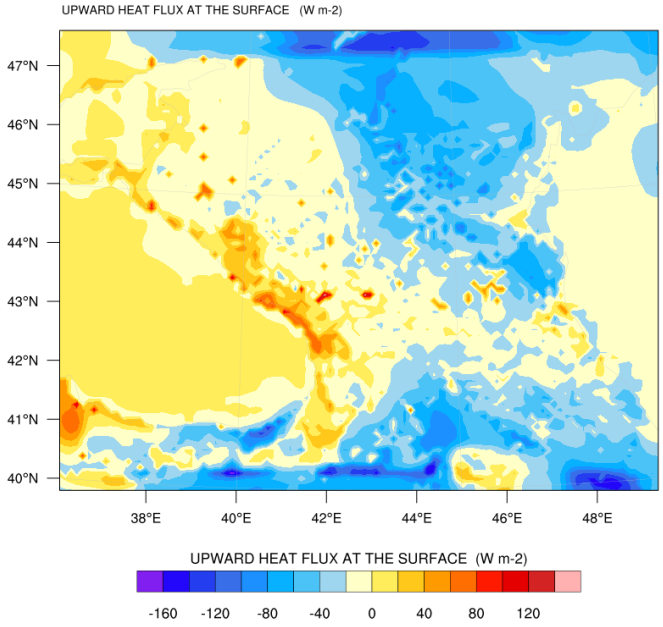
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_15:00:00



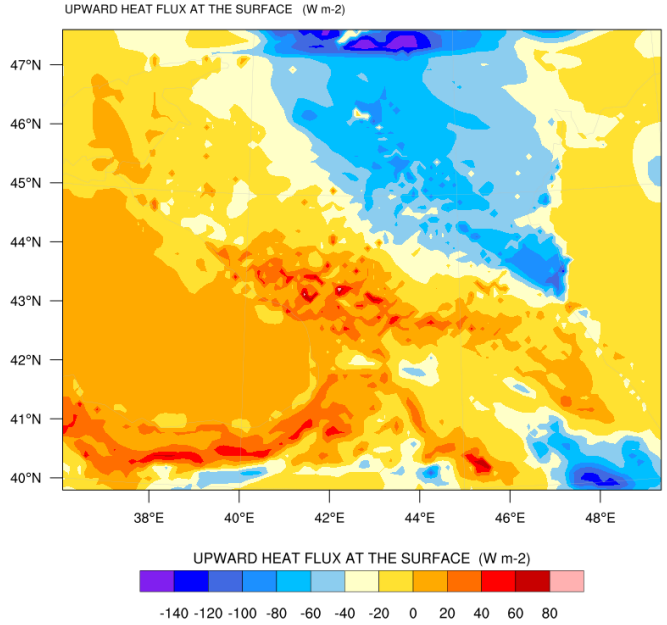
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_15:00:00



LEAD REAL-TIME WRF

Init: 2018-07-27_00:00:00
Valid: 2018-07-27_16:00:00



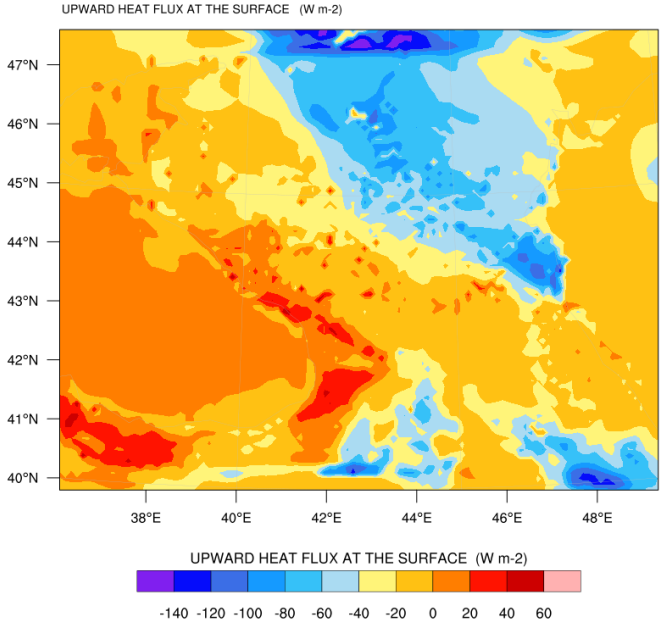
OUTPUT FROM WRF V4.1.3 MODEL
WE = 106 ; SN = 82 ; Levels = 40 ; Dis = 10.8km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 3

16 UTC

d01

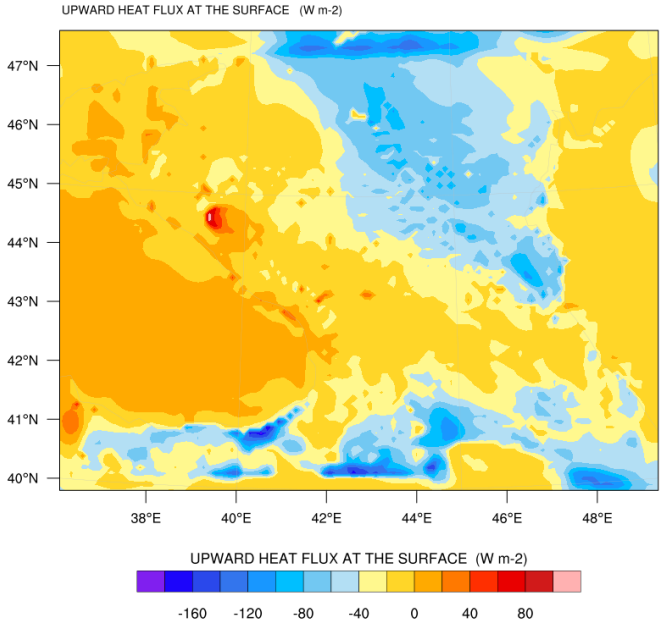
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_16:00:00



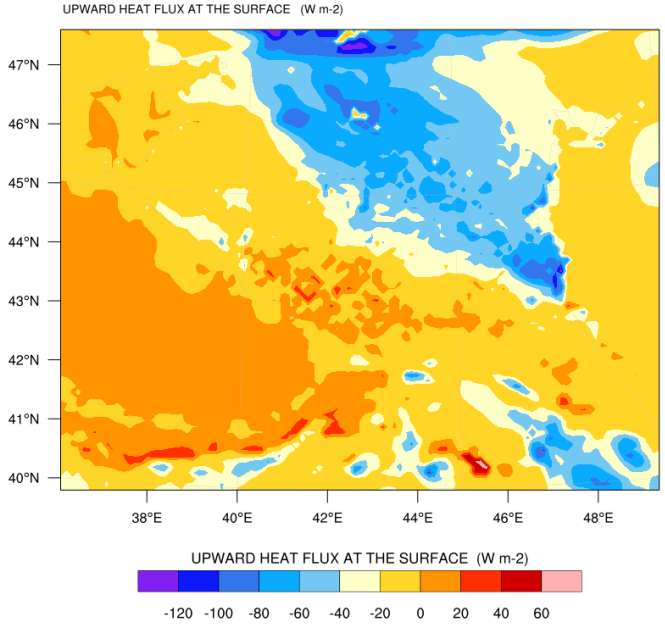
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_16:00:00



LEAD REAL-TIME WRF

Init: 2018-07-27_00:00:00
Valid: 2018-07-27_17:00:00



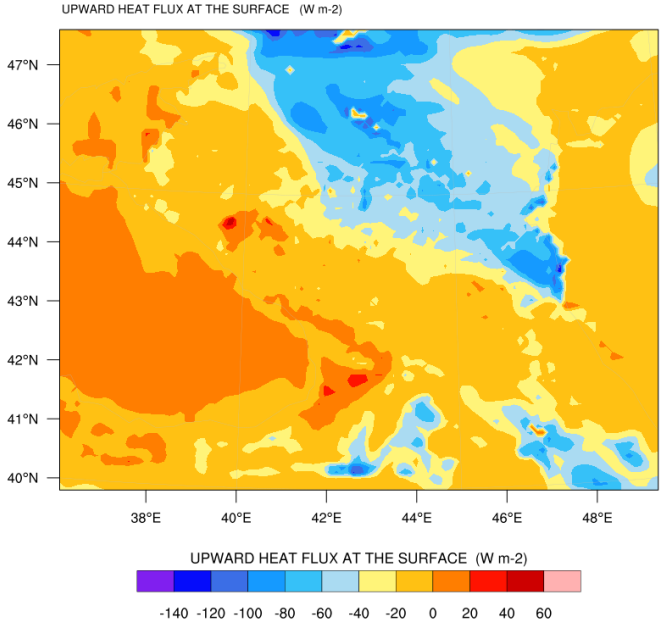
OUTPUT FROM WRF V4.1.3 MODEL
WE = 106 ; SN = 82 ; Levels = 40 ; Dis = 10.8km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 3

17 UTC

d01

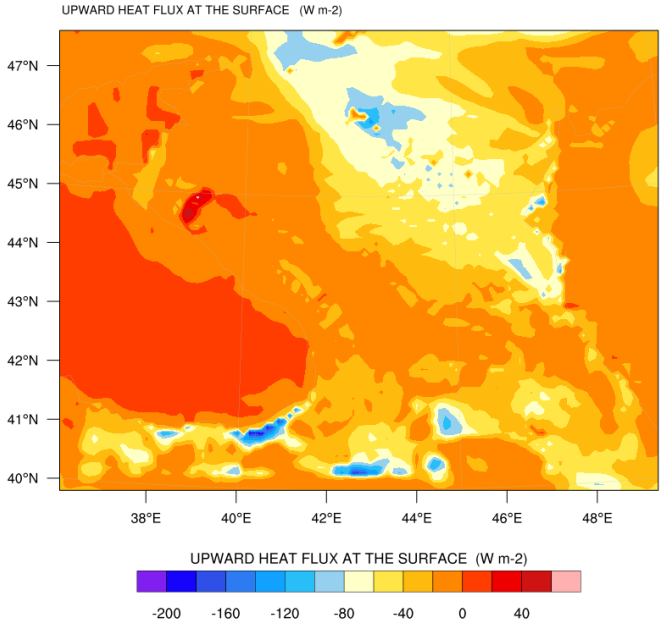
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_17:00:00



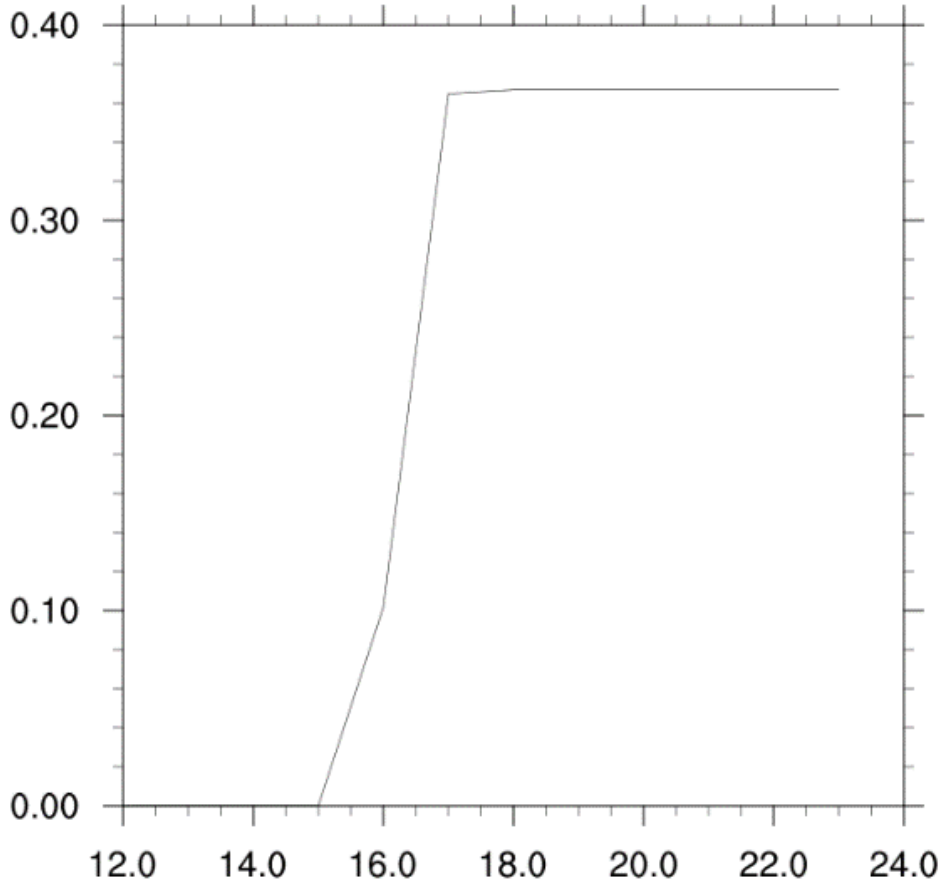
LEAD REAL-TIME WRF

Init: 2018-07-26_18:00:00
Valid: 2018-07-27_17:00:00

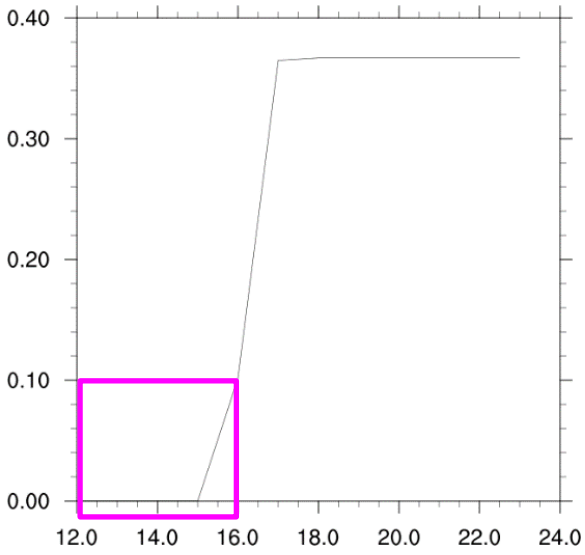


4. Modeling findings and verification with observational data. Additional analysis of the causes of formation

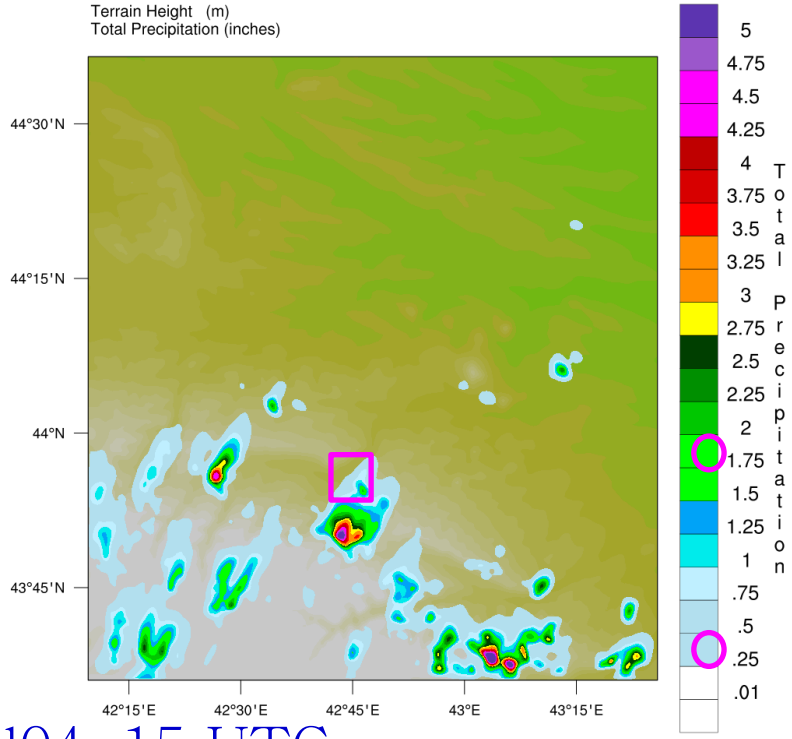
Modeling. Verification. Precipitation



Precipitation is given in inches. (1,8 inch for 12 hours)
The time of the sharp increase in precipitation coincides with weather archive data (15 UTC - 45 mm),
the value according to the modeling results (the main modification of Nudging, the closest

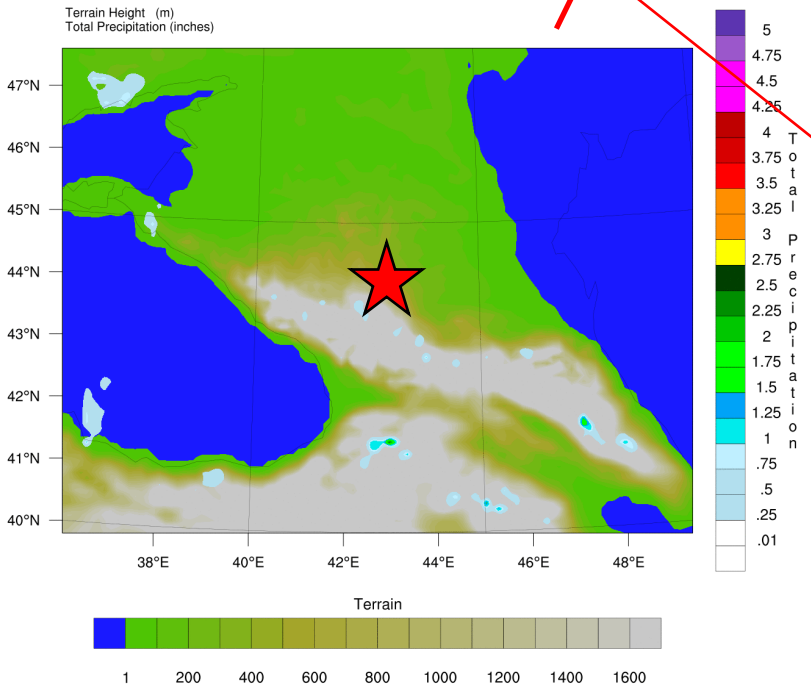


Init: 2018-07-27_00:00:00
Valid: 2018-07-27_15:00:00

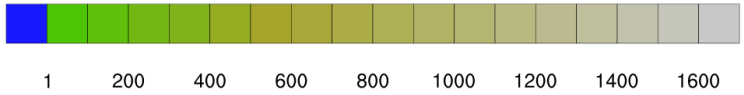


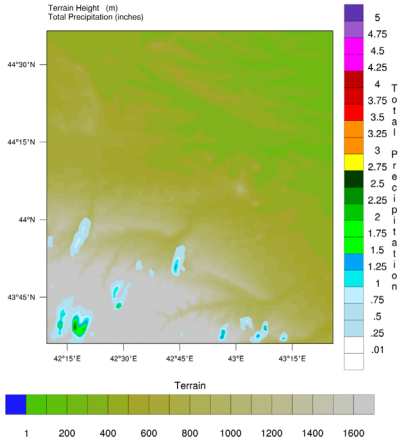
d01. 12-21 UTC

Init: 2018-07-27_00:00:00
Valid: 2018-07-27_12:00:00

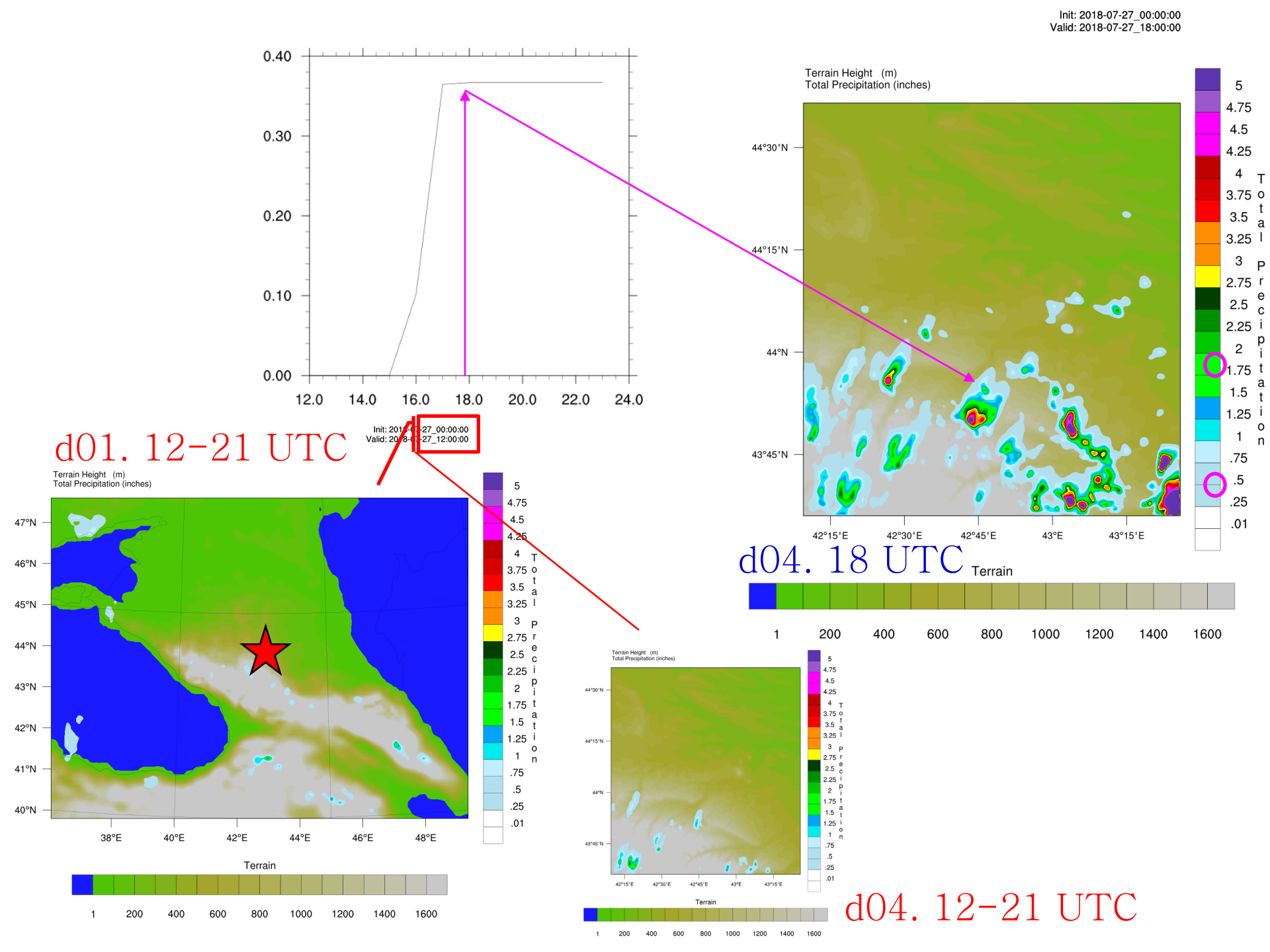


d04. 15 UTC

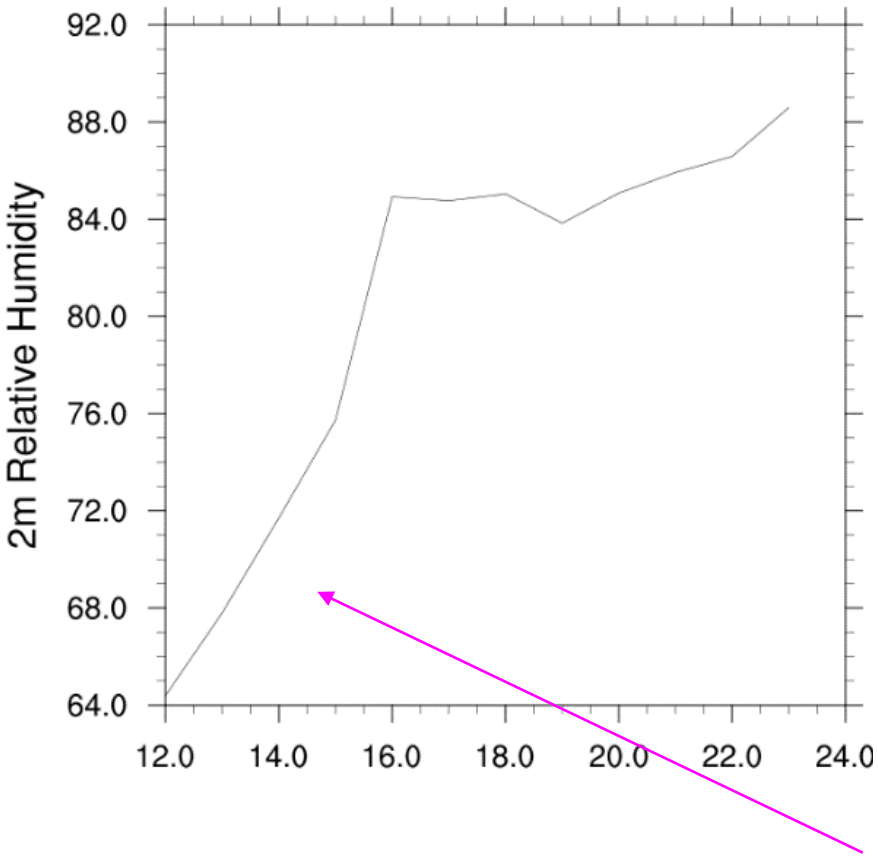


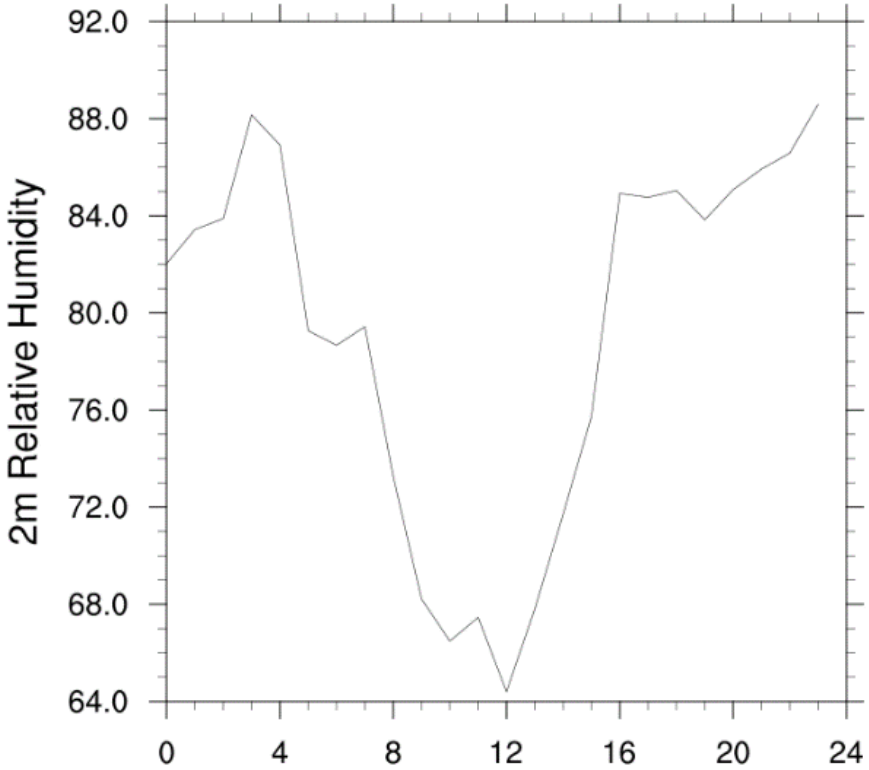


d04. 12-21 UTC


Init: 2018-07-27_00:00:00
Valid: 2018-07-27_18:00:00
0.40
0.30
0.20
0.10
0.00
12.0
14.0
16.0
18.0
20.0
22.0
24.0
d01. 12-21 UTC
Init: 2018-07-27_00:00:00
Valid: 2018-07-27_12:00:00
Terrain Height (m)
Total Precipitation (inches)
47°N
46°N
45°N
44°N
43°N
42°N
41°N
40°N
38°E
40°E
42°E
44°E
46°E
48°E
5
4.75
4.5
4.25
4
3.75
3.5
3.25
3
2.75
2.5
2.25
2
1.75
1.5
1.25
1
.75
.5
.25
.01
Total Precipitation
Terrain
1
200
400
600
800
1000
1200
1400
1600
Terrain Height (m)
Total Precipitation (inches)
44°30'N
44°15'N
44°N
43°45'N
42°15'E
42°30'E
42°45'E
43°E
43°15'E
d04. 18 UTC
Terrain
1
200
400
600
800
1000
1200
1400
1600
Terrain Height (m)
Total Precipitation (inches)
d04. 12-21 UTC
Terrain
1
200
400
600
800
1000
1200
1400
1600

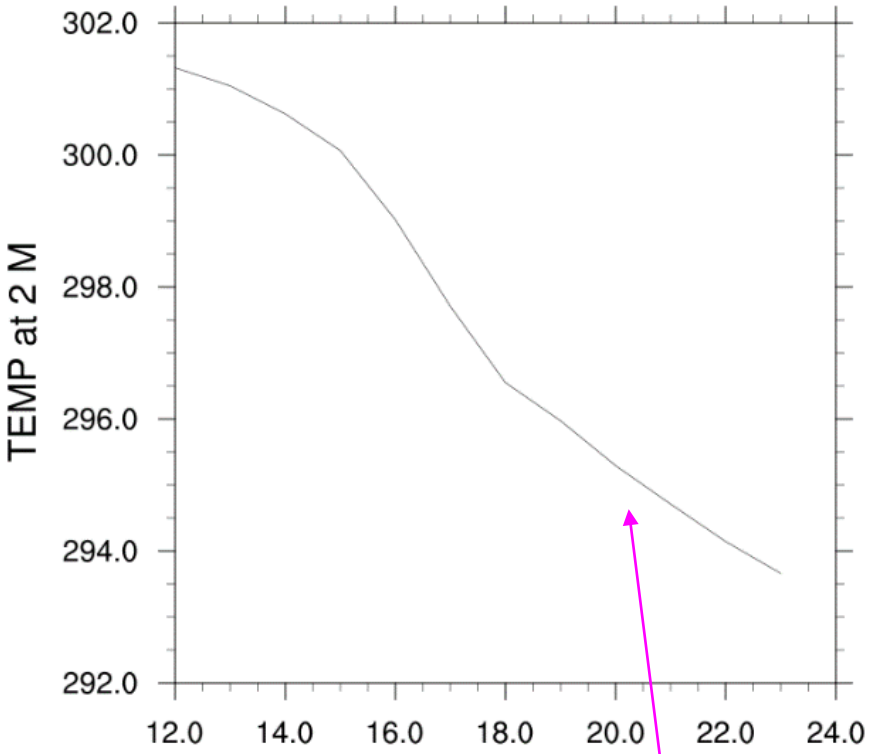
Modeling. Verification. Humidity

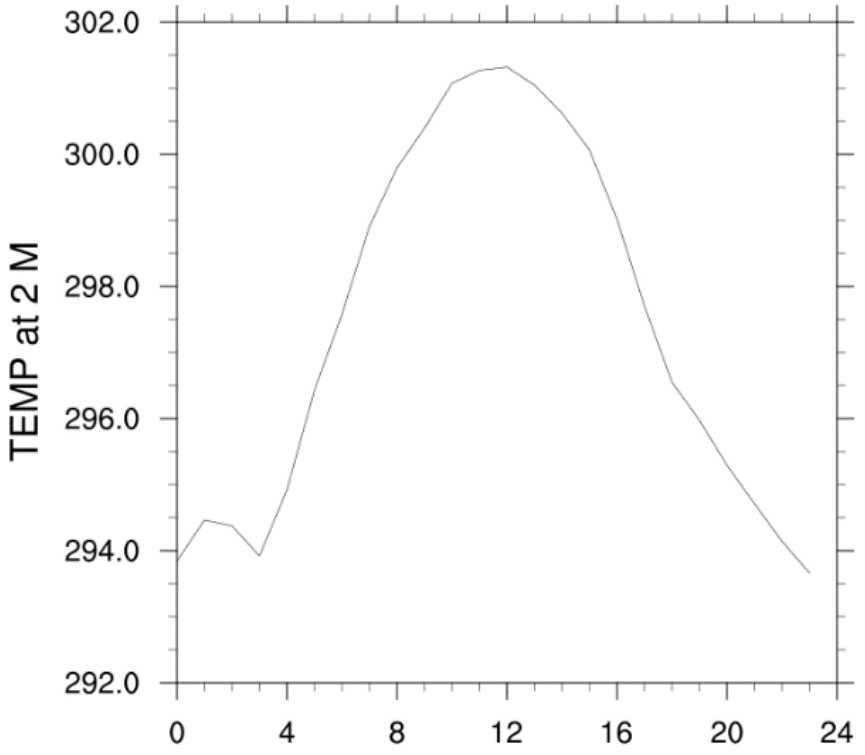




Relative humidity is given in %. The time of the sharp increase in humidity coincides with the weather archive data, the magnitude of the change according to the modeling results (the main modification of Nudging, the closest in results to the observation data) from 64 to 80%, according to observations from 50 to 96% for 3 hours, - about 2 times less.

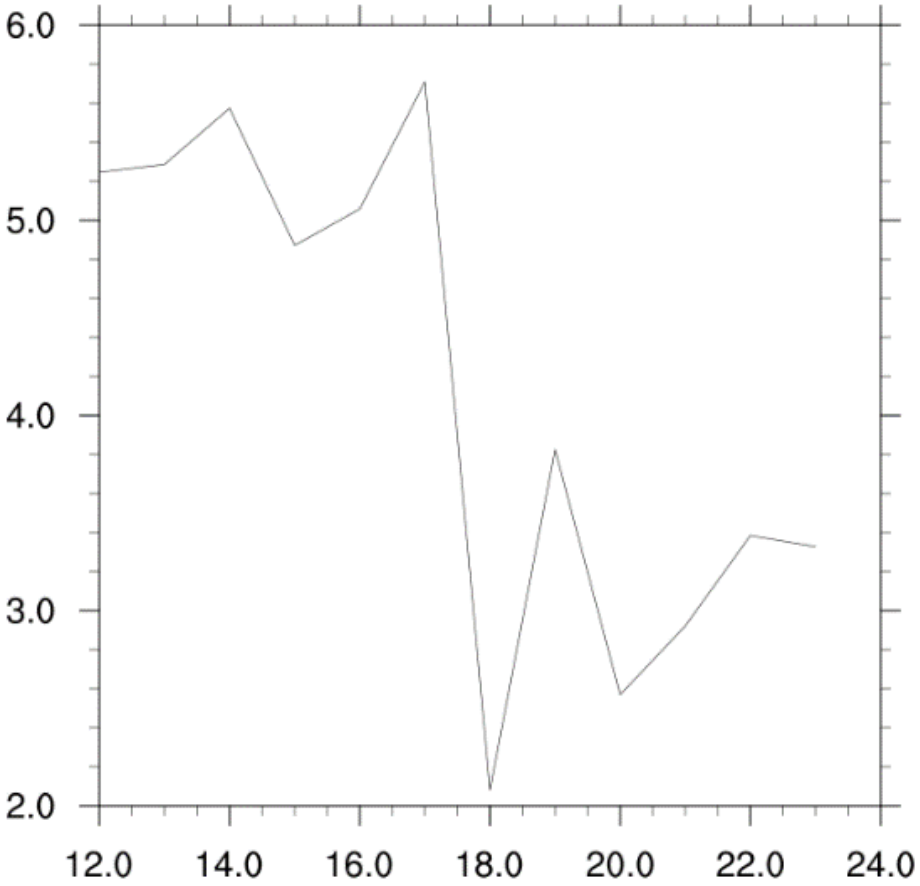
Modeling. Verification. Temperature





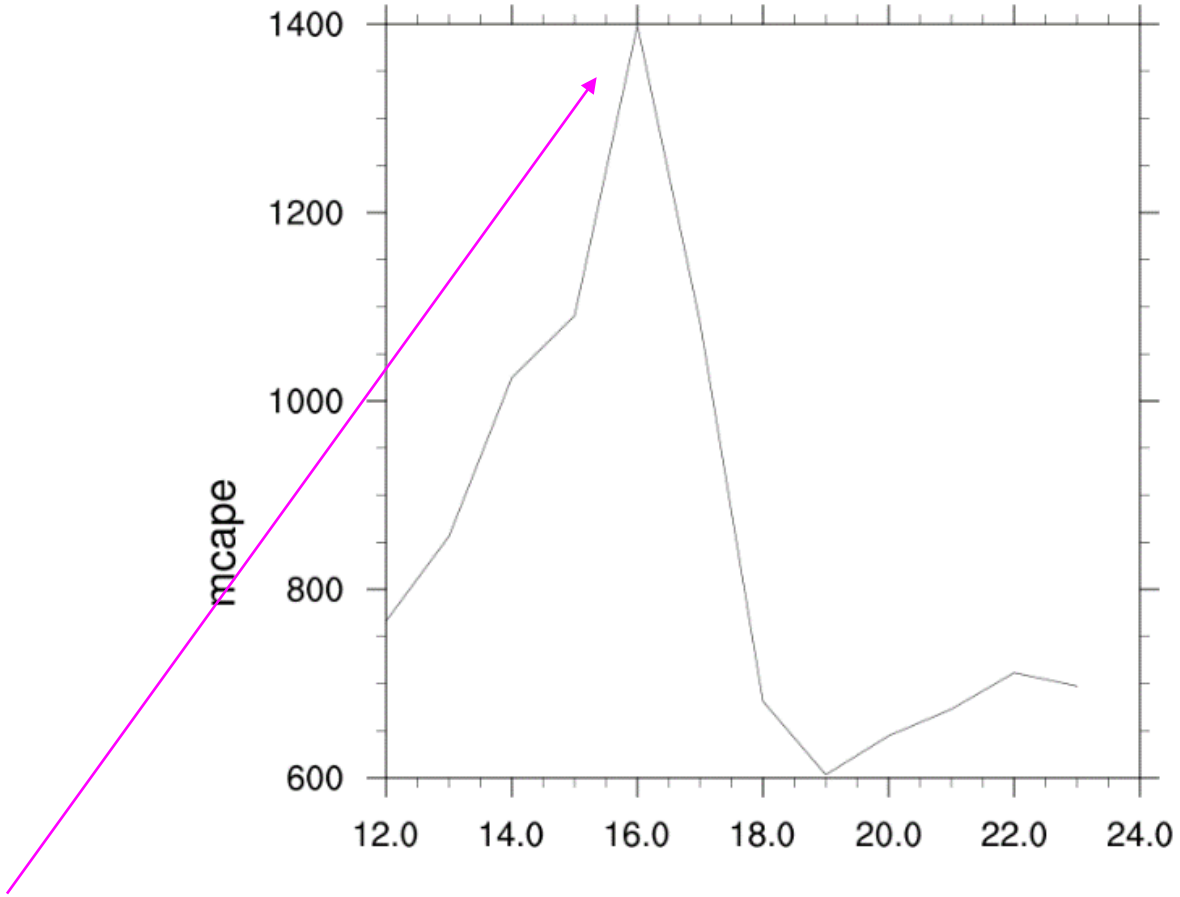
The temperature is given in K. The time of the sharp decrease in temperature coincides with the weather archive data, the magnitude of the drop according to the modeling results (the main modification of Nudging, the closest in results to the observational data) is approximately 4 K in 3 hours – less than the observed one by about 3 times (more than 12°

Modeling. Verification. Wind velocity



Wind velocity at a height of 10 m expressed in m/s. During heavy precipitation, wind velocity increases, which is consistent with weather archive data. The modeling results (the main Nudging modification, which is closest in results to observational data) generally match the averaged observational data. However, squalls up to 18 m/s were not detected in the modeling fondings—only an increase to approximately 6 m/s, which is three times

Modeling. Verification. CAPE



The peaks in the CAPE (an amount of buoyancy energy available to produce vertical acceleration of air particle) index at the observation point correspond to heavy precipitation events. CIN – a numerical measure that indicates the amount of energy preventing an air parcel from rising from the surface to the level of free convection, – do not show large influence of cold pool.

- A possible reason for the inaccuracy of modeling the amplitudes of humidity, temperature, and precipitation is the lack of an underlying surface with sufficient resolution, leading to an inaccuracy (shift) in the coordinate. This is clearly visible in the humidity, temperature, and precipitation fields, where the indicated possible shift in coordinate is visible.

- The precipitation graph at the observation point shows that the case with the actual sea surface temperature (Nudging) is closest to the observed data. This indirectly confirms the accepted hypothesis of extreme precipitation formation due to the frontal transport of cold Arctic air along the eastern boundary of the anticyclone (where omega-blocking preserved) and the insignificance of the convective mechanism ("triggering deep convection"), although not completely, as the possible inaccuracy of modeling due to insufficient underlying surface resolution must be taken into account.

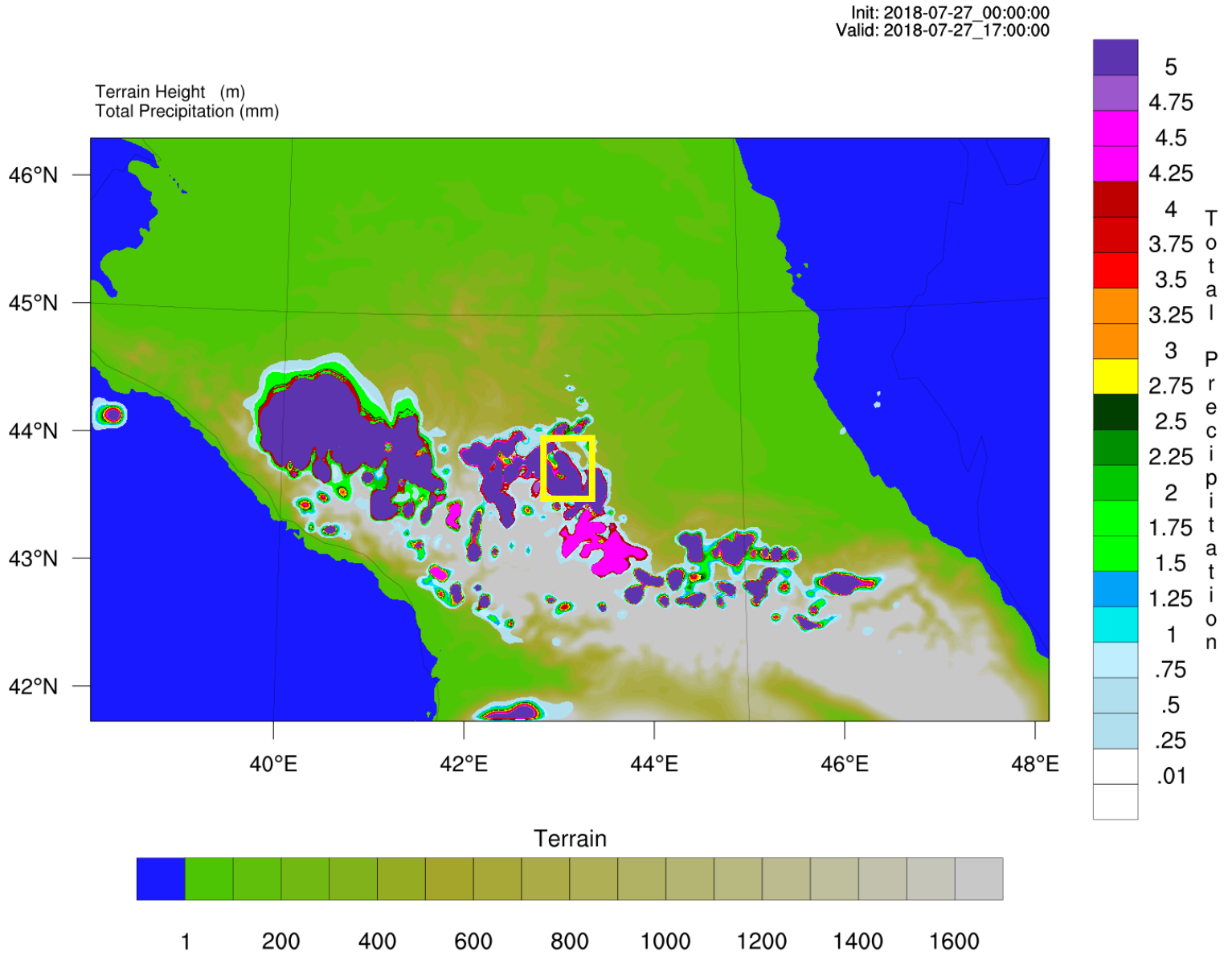
- The time moment is clearly captured – the humidity peak at 12 UTC, the temperature peak from 10 to 13 UTC.

5. Conclusion

- WRF model can be used with sufficient reliability for subsequent operational precipitation forecasting in Kislovodsk.
- Sensitivity experiments were conducted to assess a sensitivity to the SST of the Black and Caspian Seas, local topography, parameterization selection, and spectral “nudging."
- Based on the analysis of the modeling results, a conclusion was made about the cause of the extreme phenomenon: the transfer of cold Arctic air along the anticyclone boundary and its advection into warm, moist air over the observation area from the NNE,
- as well as from the SW, an additional small transfer of moist air (partly due to the rise along the mountain slope) through the mountain ridge from the Black Sea, which led to increased convection at the time of the cold advection (from 12 UTC),
- Orography smoothing effect – surprisingly insignificant.
- It is noteworthy that our recent findings additionally indicate that a small portion of the moisture is transported by Arctic air due to water transport from the Arctic region via atmospheric rivers and the low-level jet stream (not shown in the slides).

Thank You for Your attention!

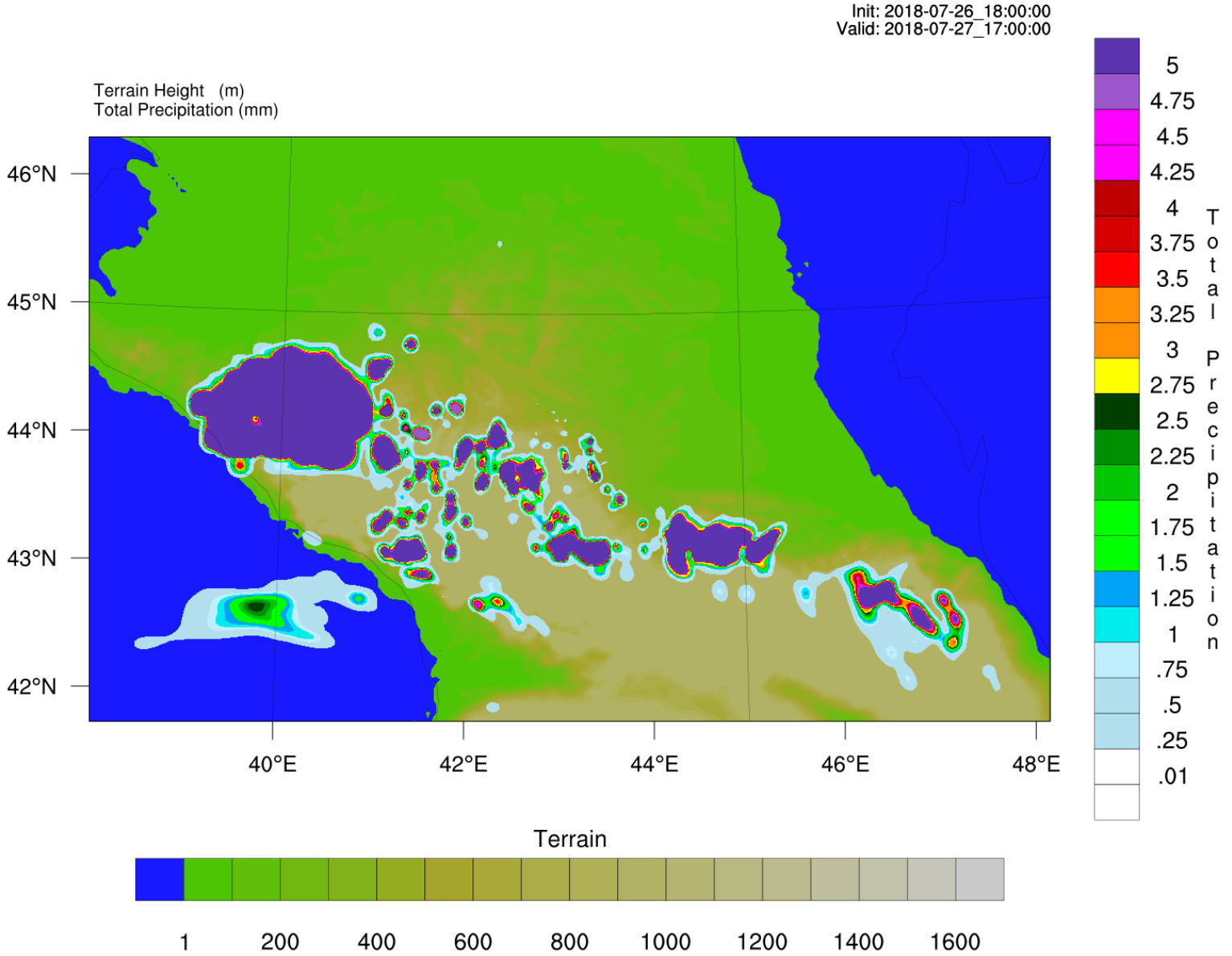
Original orography



Total precipitation averaged over the d02 domain for the period 07/27/2023 00 UTC -07/27/2023 17 UTC: 1,74678 inches

d02

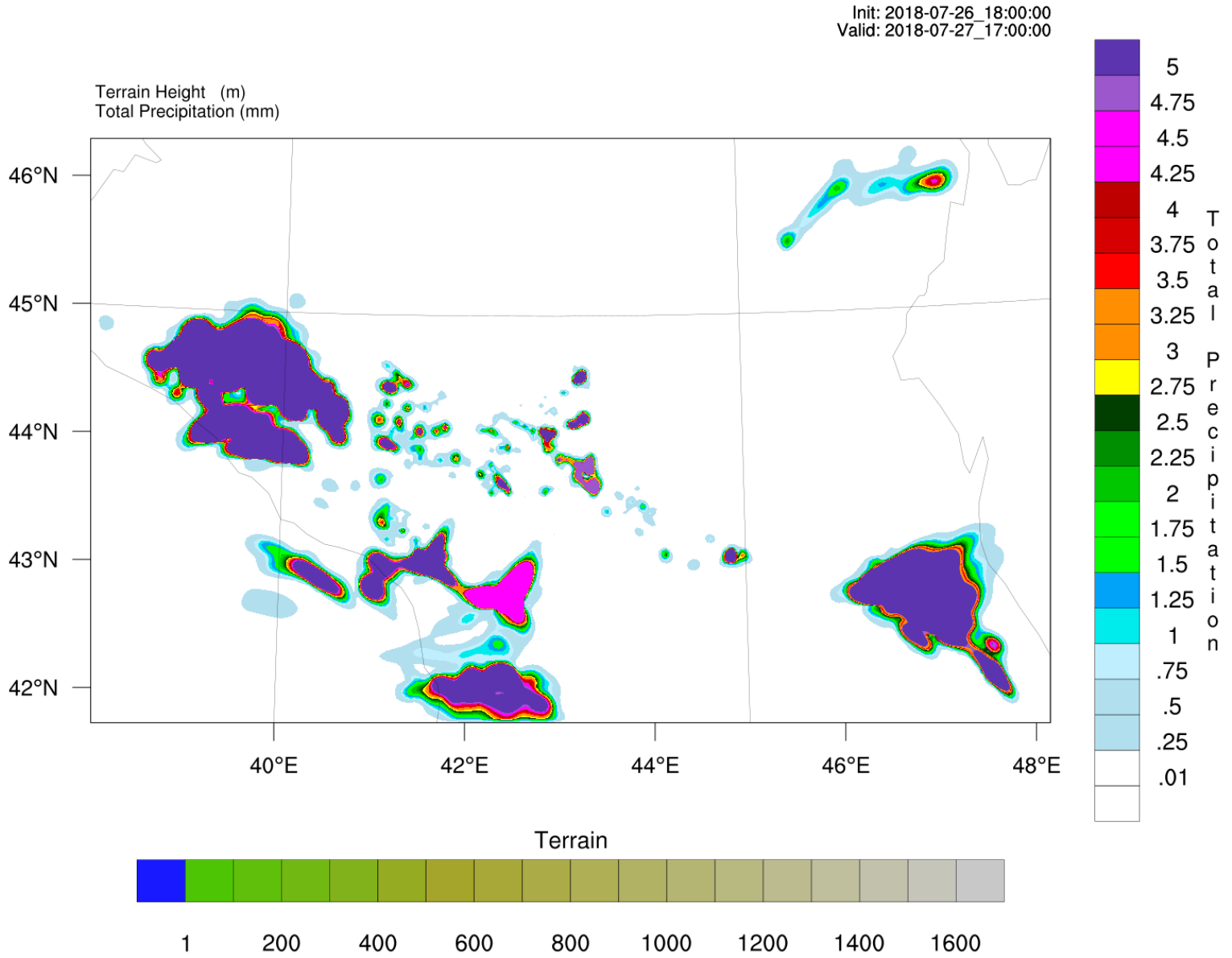
orography is smoothed out to the height of Kislovodsk



Total precipitation averaged over the d02 domain for the period 07/26/2023 18 UTC -07/27/2023 17 UTC: 3,14281 inches

d02

orography is smoothed out to 1 m

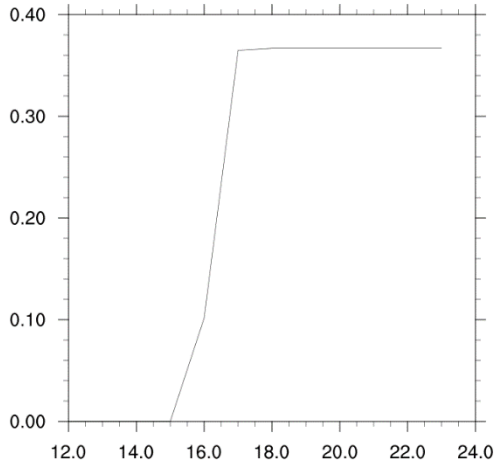


Total precipitation averaged over the d02 domain for the period 07/26/2023 UTC - 07/27/2023 17 UTC: 3,41976 mm

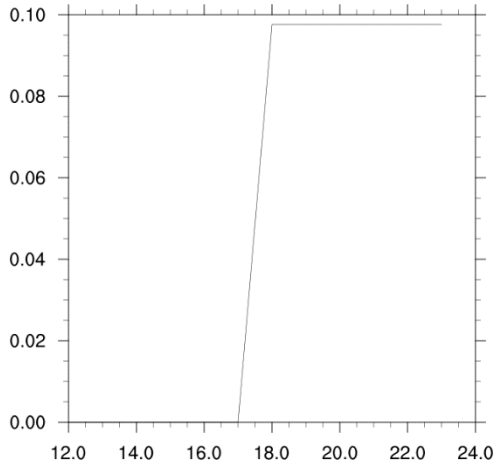
d02

Modeling. Verification. Precipitation

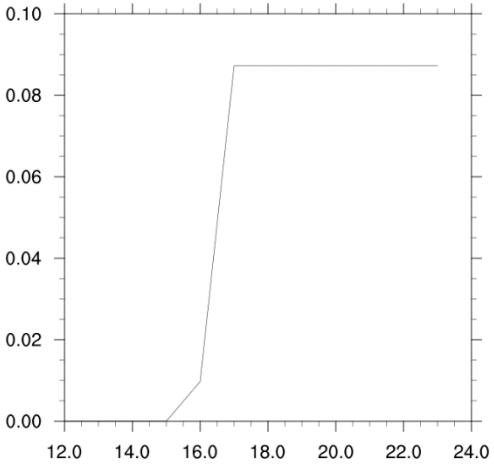
Nudging



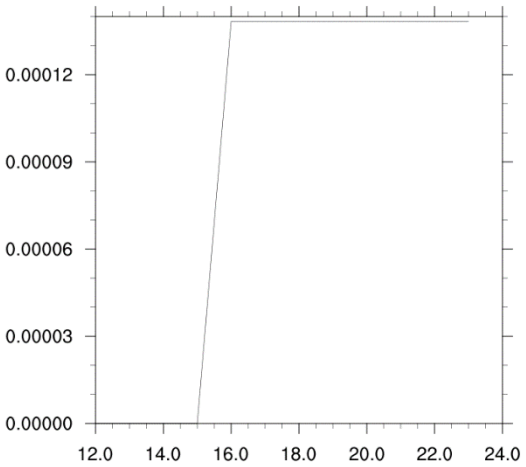
No nudging



Nudging SST+ 2



Nudging SST-2

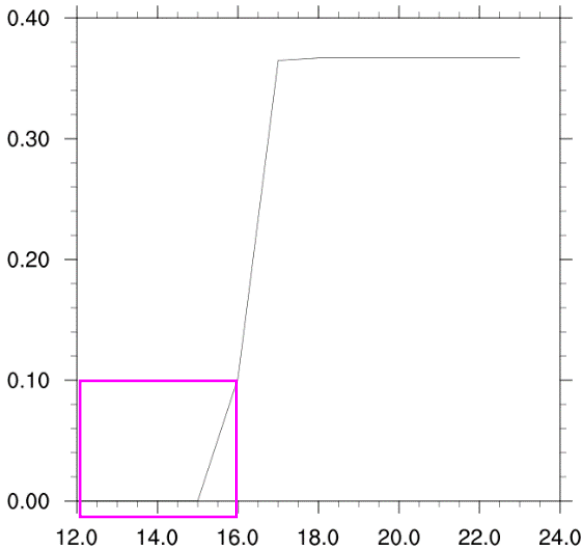


Precipitation is given in inches. (1,8 inch for 12 hours)

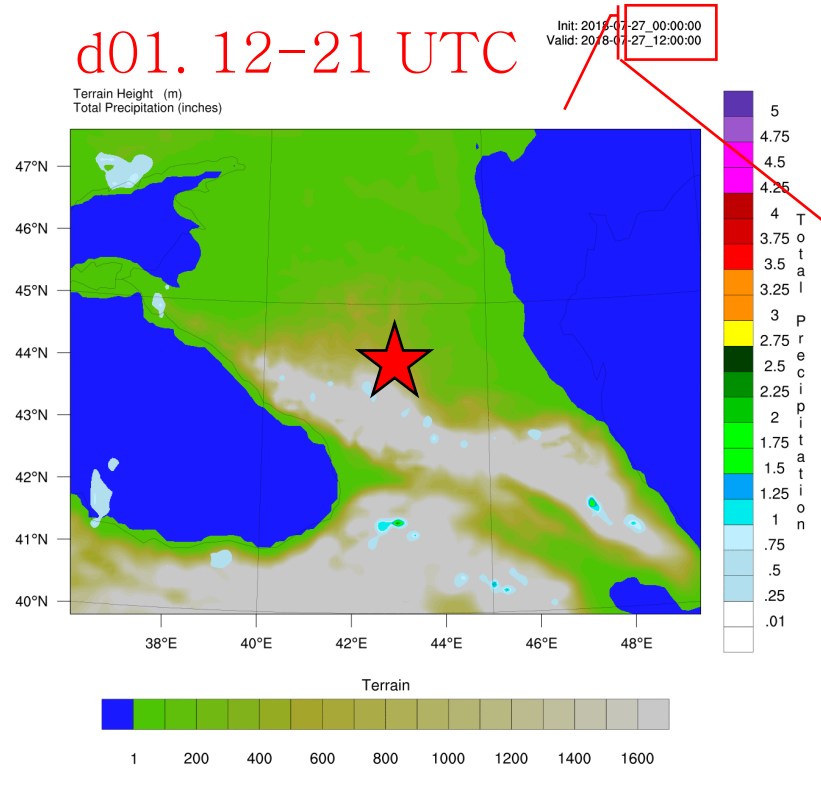
The time of the sharp increase in precipitation coincides with weather archive data (15 UTC - 45 mm),

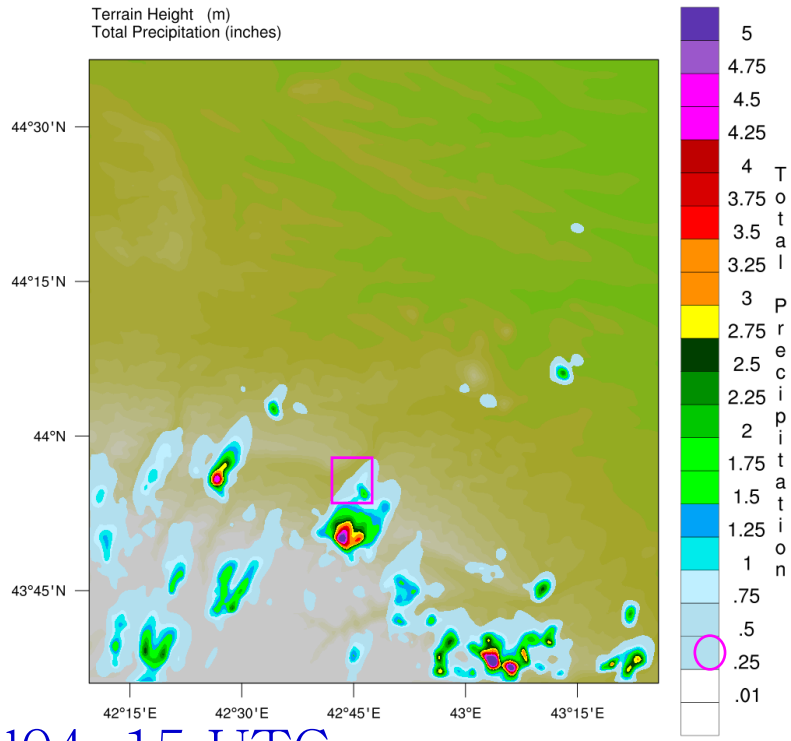
the value according to the modeling results (the main modification of Nudging, the closest

Nudging

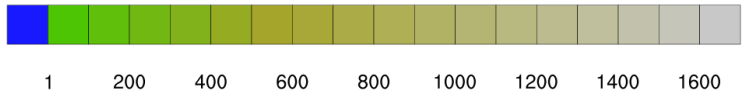


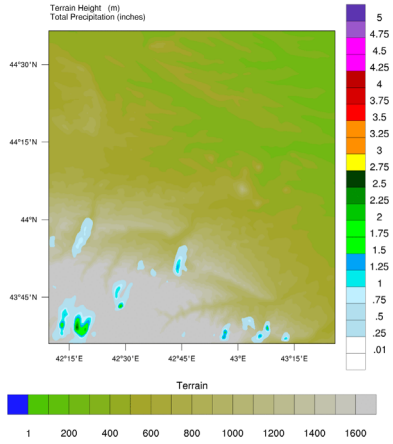
d01. 12-21 UTC





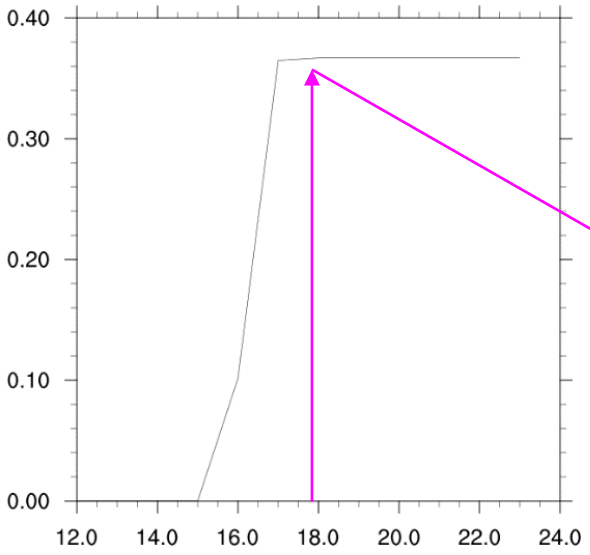
d04. 15 UTC





d04. 12-21 UTC

Nudging



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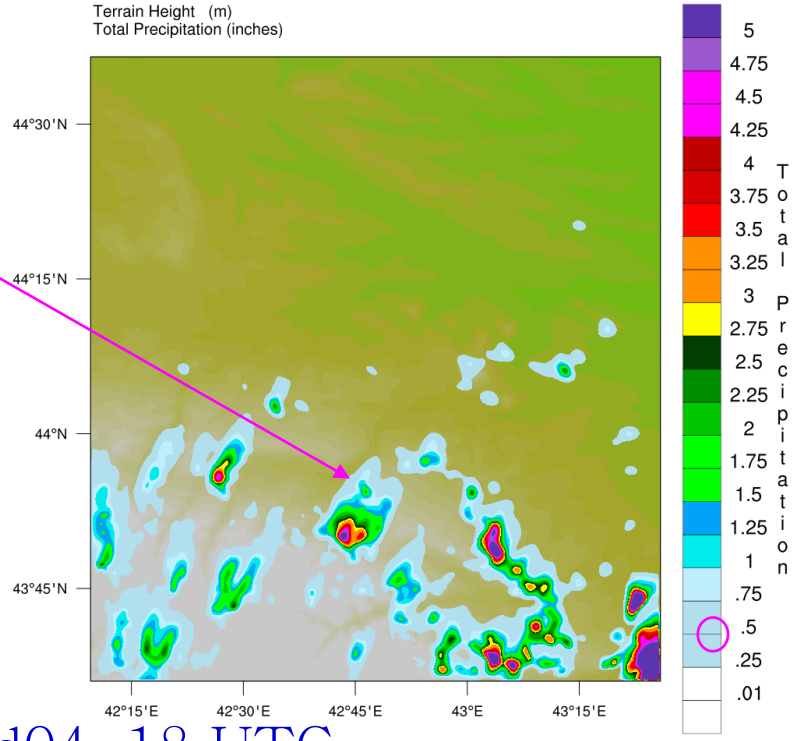
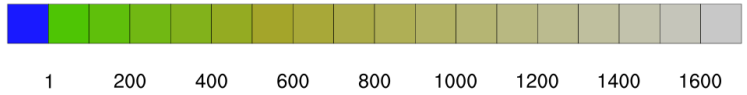
Valid: 2018-07-27_18:00:00

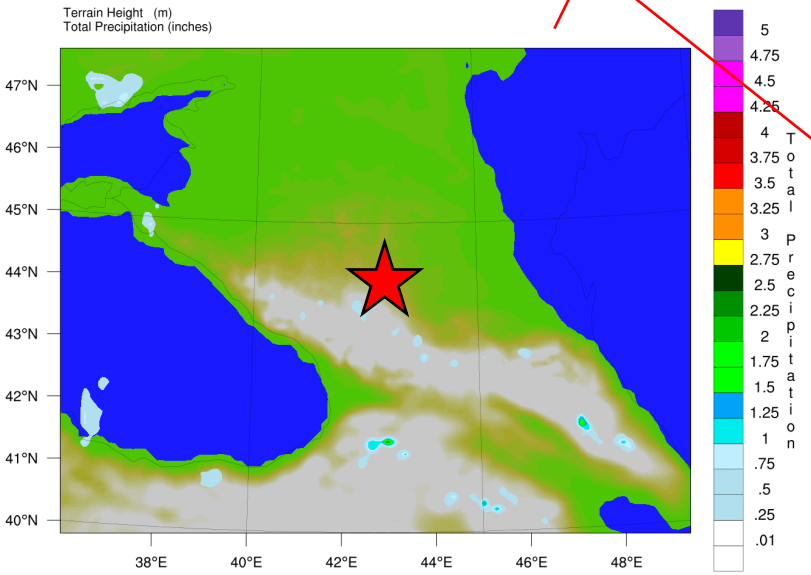


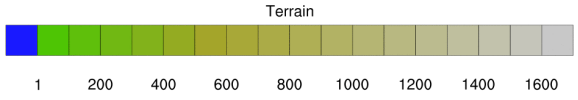
d04. 18 UTC

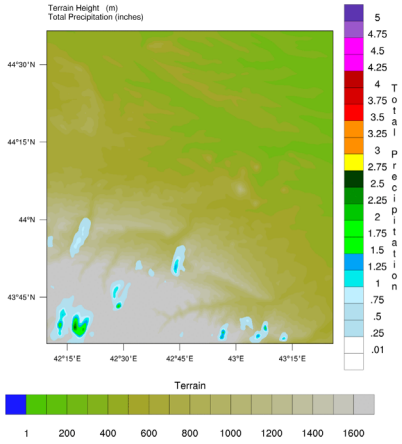


d01. 12-21 UTC

Init: 2018-07-27_00:00:00
Valid: 2018-07-27_12:00:00



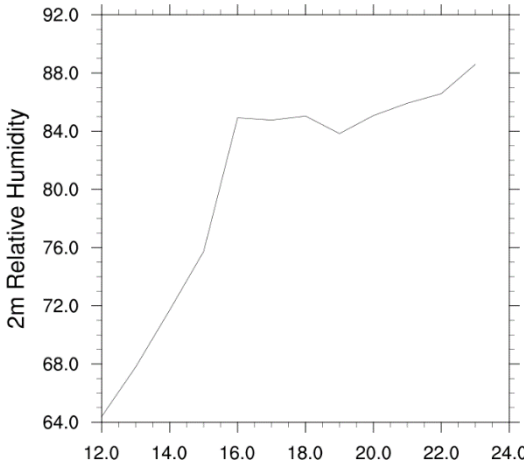


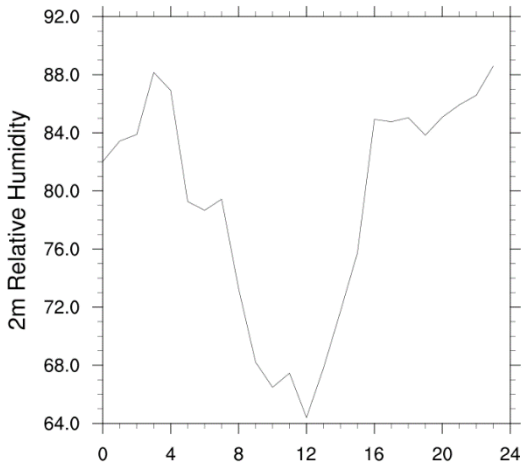


d04. 12-21 UTC

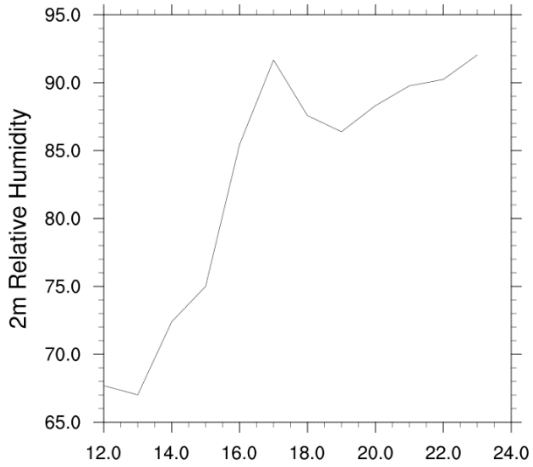
Modeling. Verification. Humidity

Nudging

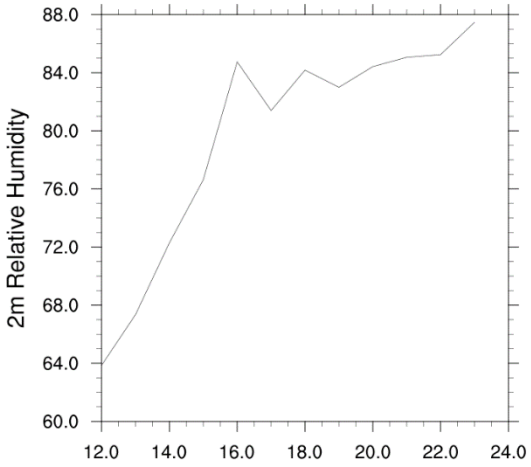




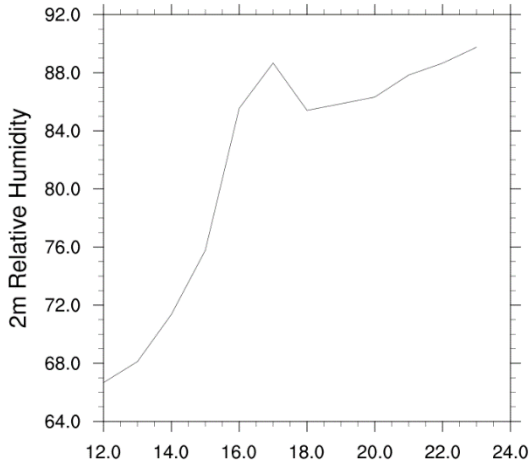
No nudging



Nudging SST+ 2



Nudging SST-2



Relative humidity is given in %. The time of the sharp increase in humidity coincides with the weather archive data, the magnitude of the change according to the modeling results (the main modification of Nudging, the closest in results to the observation data) from 64 to 80%, according to observations from 50 to 96% for 3 hours, - about 2 times less.

Data from the weather archive rp-5

Дата / Местное время		T	Po	P	Pa	U	DD	Ff	ff10	ff3	N	WW	W1	W2	Tn	Tx	Cl	Nh	H	Cm	Ch	VV	Td	RRR	tR	E	Tg	E'	sss
2018г. 27 июля, пятница	21	19.3	680.5	758.2		96	Ветер, дующий с юго-юго-востока	Легкий ветер (2 м/с)			90 или более, но не 100 %	Состояние неба в общем не изменилось.	Гроза (грозы) с осадками или без них.	Ливень (ливни).			Кучево-дождевые волокнистые (часто с наковальней), либо с кучево-дождевыми лысыми, кучевыми, слоистыми, разорванно-дождевыми, либо без них.	90 или более, но не 100 %	600-1000	Высококучевых, высокослоистых или слоисто-дождевых облаков нет.	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	18.7						
	18	23.9	679.3	755.6		76	Ветер, дующий с юго-юго-запада	Тихий ветер (1 м/с)			90 или более, но не 100 %	Состояние неба в общем не изменилось.	Гроза (грозы) с осадками или без них.	Ливень (ливни).		31.2	Слоисто-кучевые, образовавшиеся из кучевых.	40 %.	1000-1500	Высококучевые, образовавшиеся из кучевых (или кучево-дождевых).	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	19.4	45.0	12				
	15	18.7	679.9	757.7		96	Ветер, дующий с юго-юго-востока	Слабый ветер (4 м/с)		18 м/с	90 или более, но не 100 %	Гроза слабая или умеренная без града, но с дождем и/или снегом в срок наблюдения. Максимальный диаметр градин составляет 7 мм.	Гроза (грозы) с осадками или без них.	Ливень (ливни).			Кучево-дождевые волокнистые (часто с наковальней), либо с кучево-дождевыми лысыми, кучевыми, слоистыми, разорванно-дождевыми, либо без них.	90 или более, но не 100 %	600-1000	Высококучевых, высокослоистых или слоисто-дождевых облаков нет.	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	18.1						
	12	31.1	679.0	753.4		50	Ветер, дующий с северо-северо-востока	Тихий ветер (1 м/с)			60 %.						Кучево-дождевые лысые с кучевыми, слоисто-кучевыми или слоистыми, либо без них.	60 %.	1000-1500	Высококучевых, высокослоистых или слоисто-дождевых облаков нет.	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	19.4						
	09	26.4	679.2	754.9		56	Ветер, дующий с северо-северо-запада	Тихий ветер (1 м/с)			Облаков нет.											10.0	16.9						
	06	18.5	679.6	757.5		85	Ветер, дующий с юга	Легкий ветер (2 м/с)			Облаков нет.				16.9							10.0	15.9	Осадков нет	12	Сухая (без трещин, заметного количества пыли или сыпучего песка)	18.0		
	03	18.6	679.7	757.6		86	Ветер, дующий с юга	Тихий ветер (1 м/с)			Облаков нет.											10.0	16.2						
	00	19.3	679.9	757.7		86	Ветер, дующий с юго-юго-запада	Тихий ветер (1 м/с)			Облаков нет.											10.0	16.8						
26 июля, четверг	21	23.4	679.8	756.4		64	Ветер, дующий с юга	Тихий ветер (1 м/с)			70 – 80 %.						Слоисто-кучевые, образовавшиеся не из кучевых.	70 – 80 %.	1000-1500	Высококучевых, высокослоистых или слоисто-дождевых облаков нет.	Перистых, перисто-кучевых или перисто-слоистых нет.	10.0	16.1						

A sharp drop in temperature – more than 12°C for 3 hours (from 31.1°C to 18.7°C).

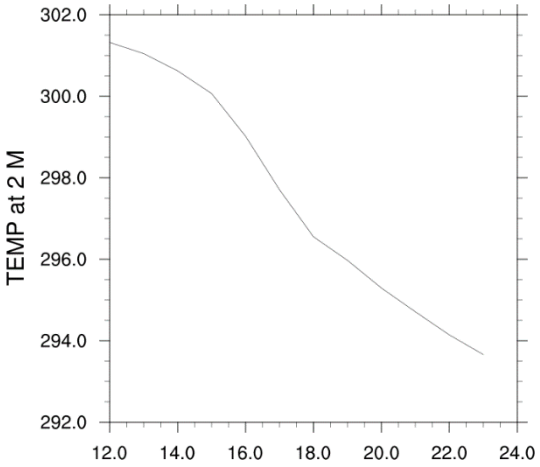
Humidity increases from 50% to 96% for 3 hours.

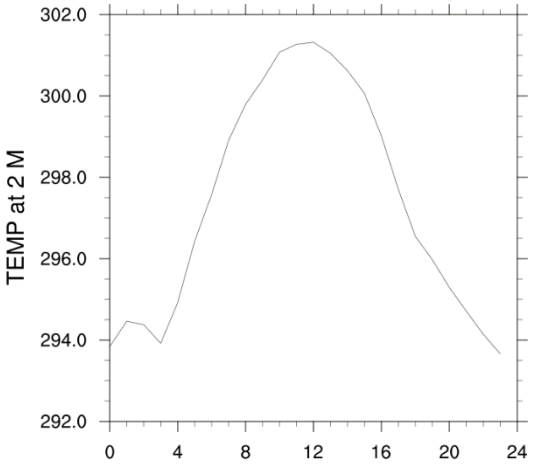
Wind gusts reached 18 m/s.

45 mm of precipitation fell (averaged over 12 hours).

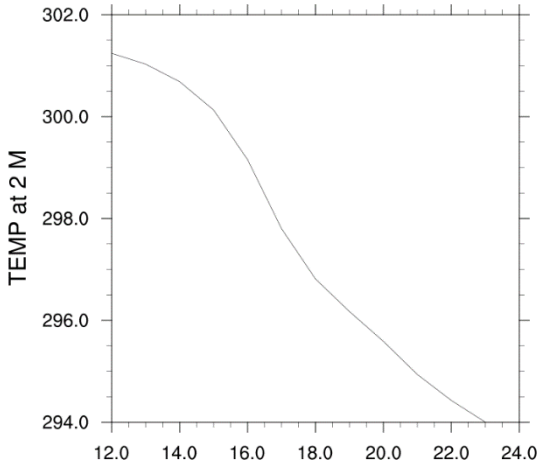
Modeling. Verification. Temperature

Nudging

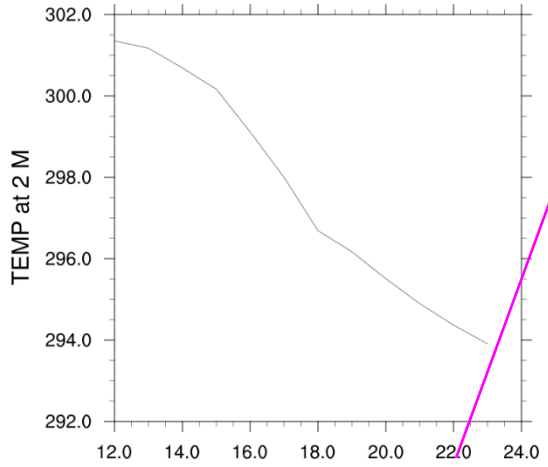




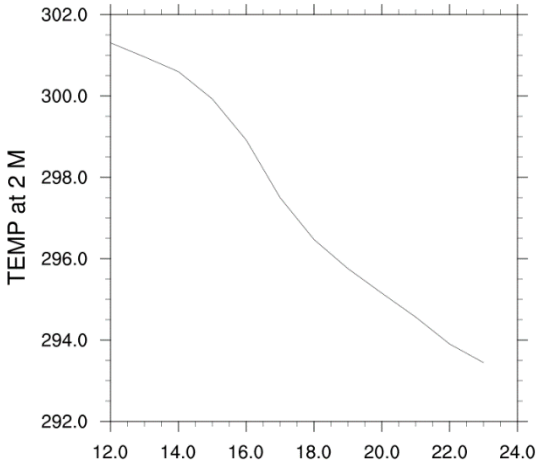
No nudging



Nudging SST+ 2



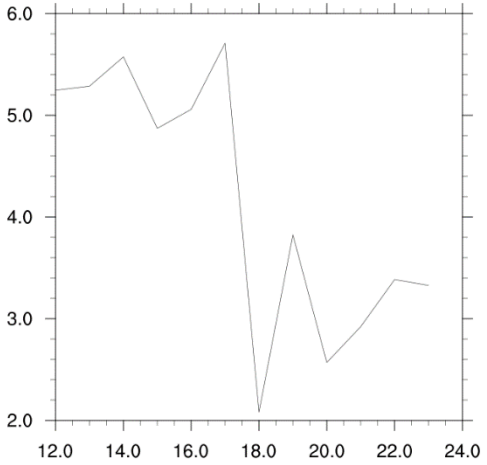
Nudging SST-2



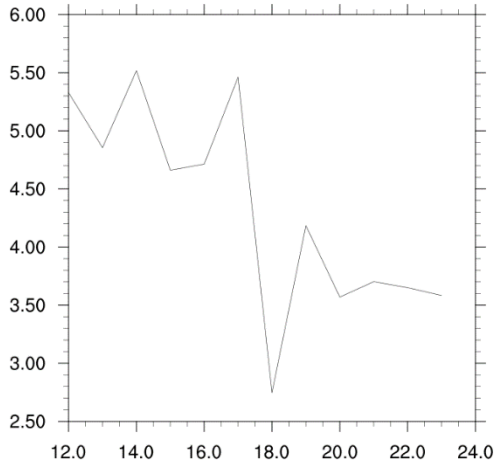
The temperature is given in K. The time of the sharp decrease in temperature coincides with the weather archive data, the magnitude of the drop according to the modeling results (the main modification of Nudging, the closest in results to the observational data) is approximately 4 K in 3 hours – less than the observed one by about 3 times (more than 12°

Modeling. Verification. Wind velocity

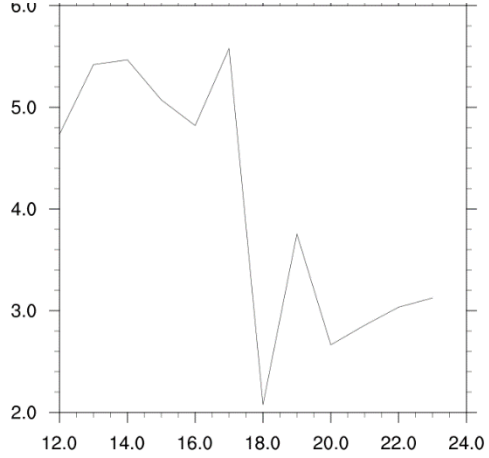
Nudging



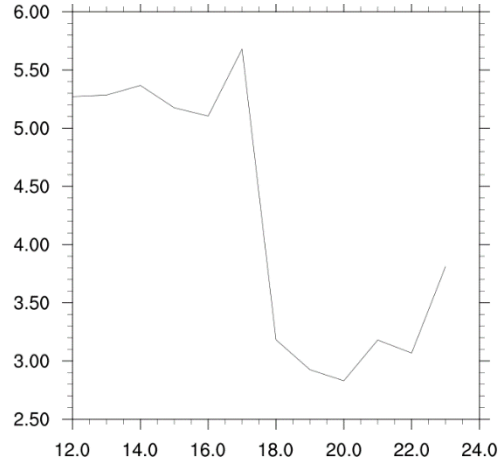
No nudging



Nudging SST+ 2



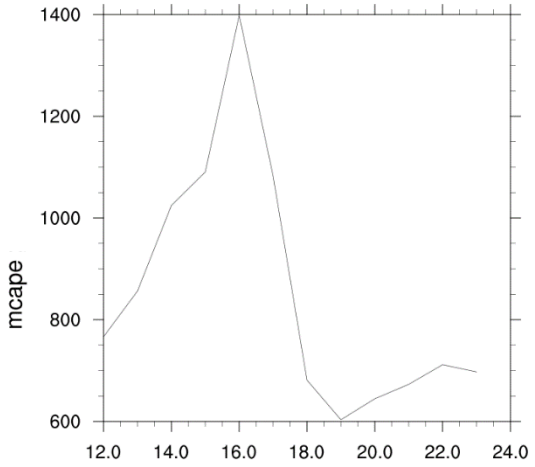
Nudging SST-2



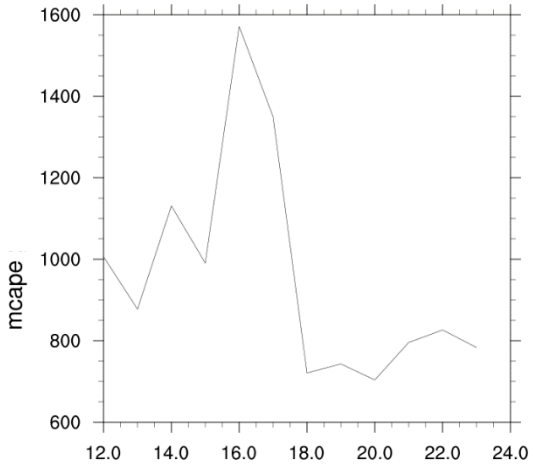
Wind velocity at a height of 10 m expressed in m/s. During heavy precipitation, wind velocity increases, which is consistent with weather archive data. The modeling results (the main Nudging modification, which is closest in results to observational data) generally match the averaged observational data. However, squalls up to 18 m/s were not detected in the modeling fondings—only an increase to approximately 6 m/s, which is three times

Modeling. Verification. CAPE

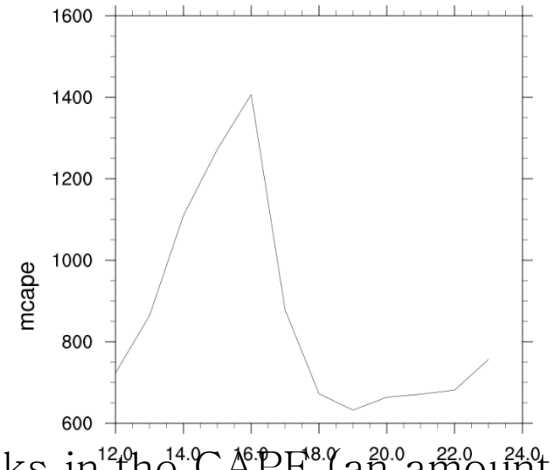
Nudging



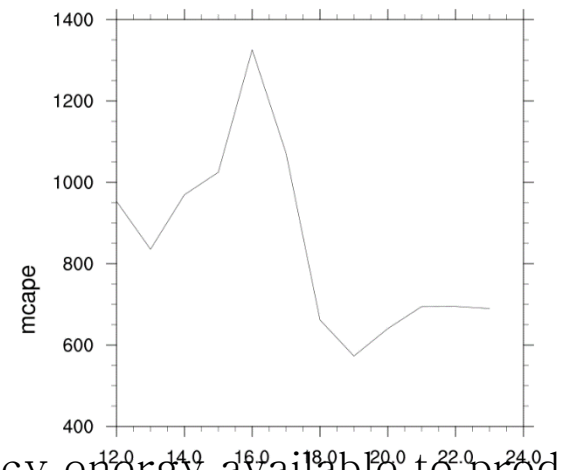
No nudging



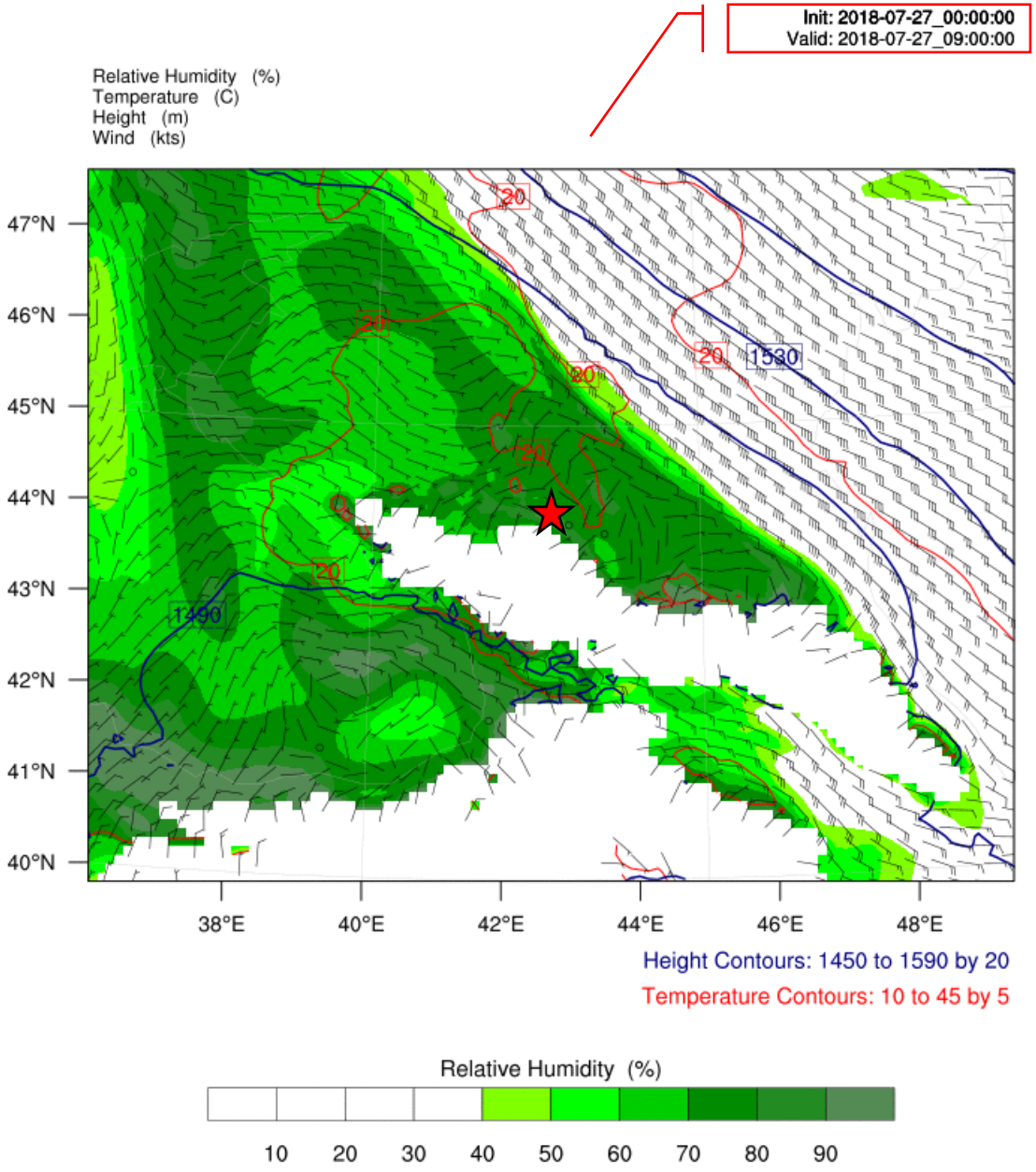
Nudging SST+ 2



Nudging SST-2



The peaks in the CAPE (an amount of buoyancy energy available to produce vertical acceleration of air particle) index at the observation point correspond to heavy precipitation events. CIN – a numerical measure that indicates the amount of energy preventing an air parcel from rising from the surface to the level of free convection, – do not show large influence of cold pool.



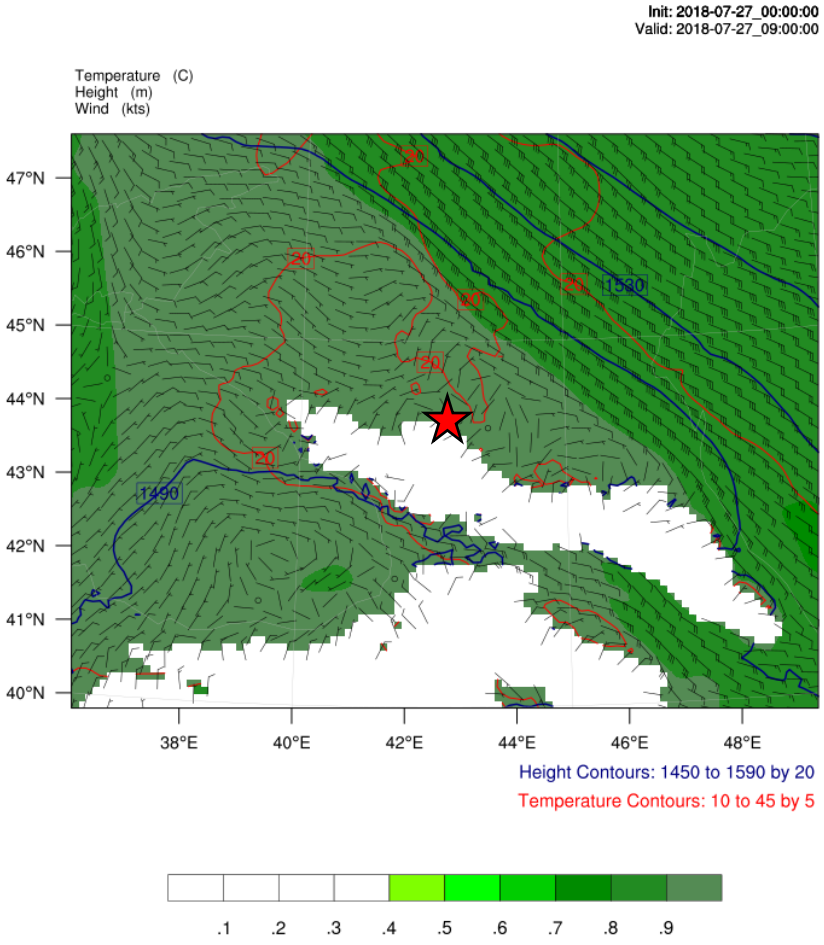
- At 850 hPa, the wind is predominantly NWW over the Kislovodsk area.

Red Star – Kislovodsk. July 27, 2018. Time: 09-15 UTC

Aims and Motivation

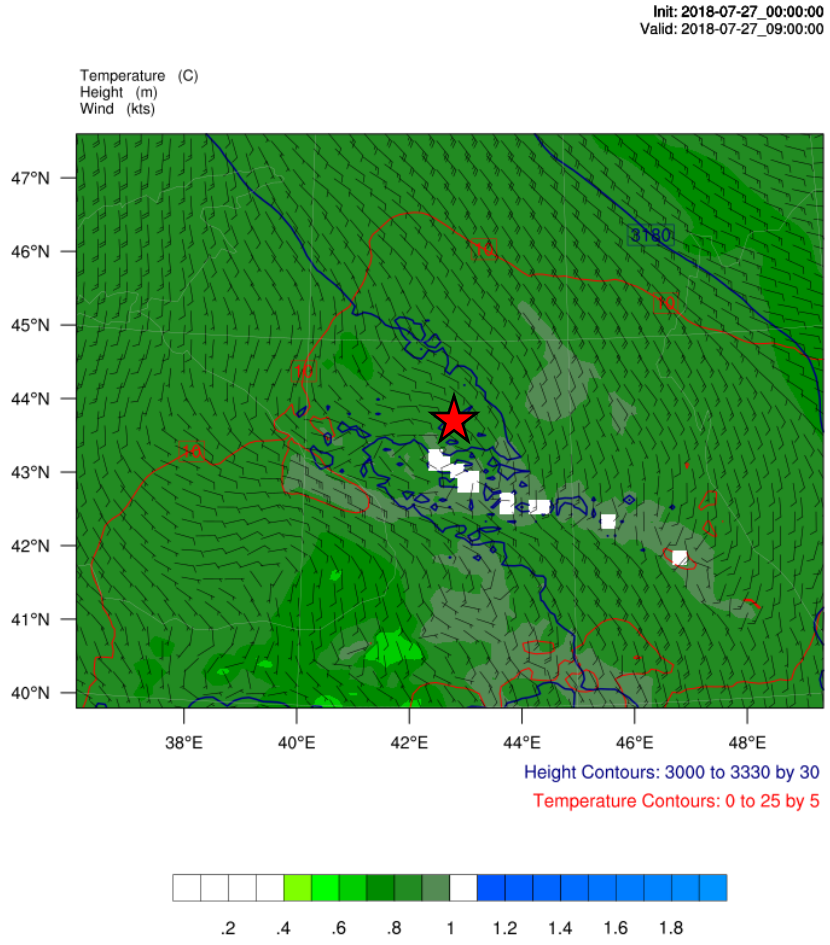
- The danger of extreme precipitation and the complexity of its forecasting is associated with the suddenness of their formation.
- An approximate assessment of the damage caused by and rainfalls is still insufficiently studied. This is particularly important in the context of improving the accuracy of operational forecasting and identifying the causes of their formation and development.
- Using WRF simulation and data analysis we can encourage the understanding of the mechanisms of extreme events and facilitate their forecast

- Distribution of humidity, temperature and wind at the level 850, 700 hPa. 9 UTC



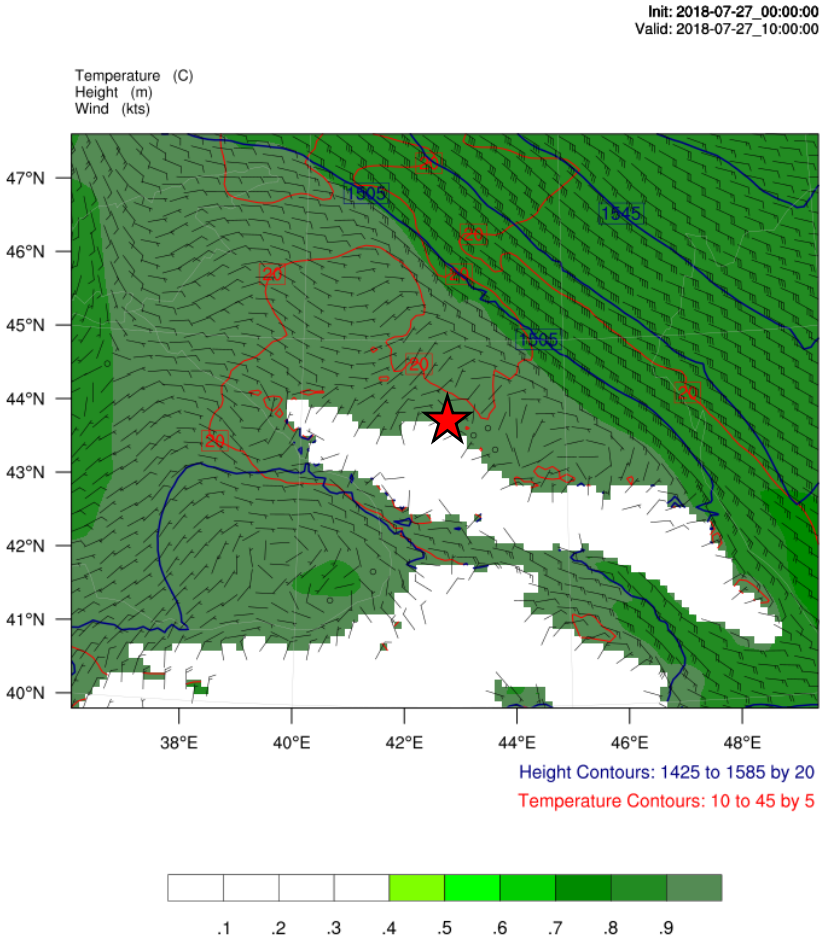
850 hPa.

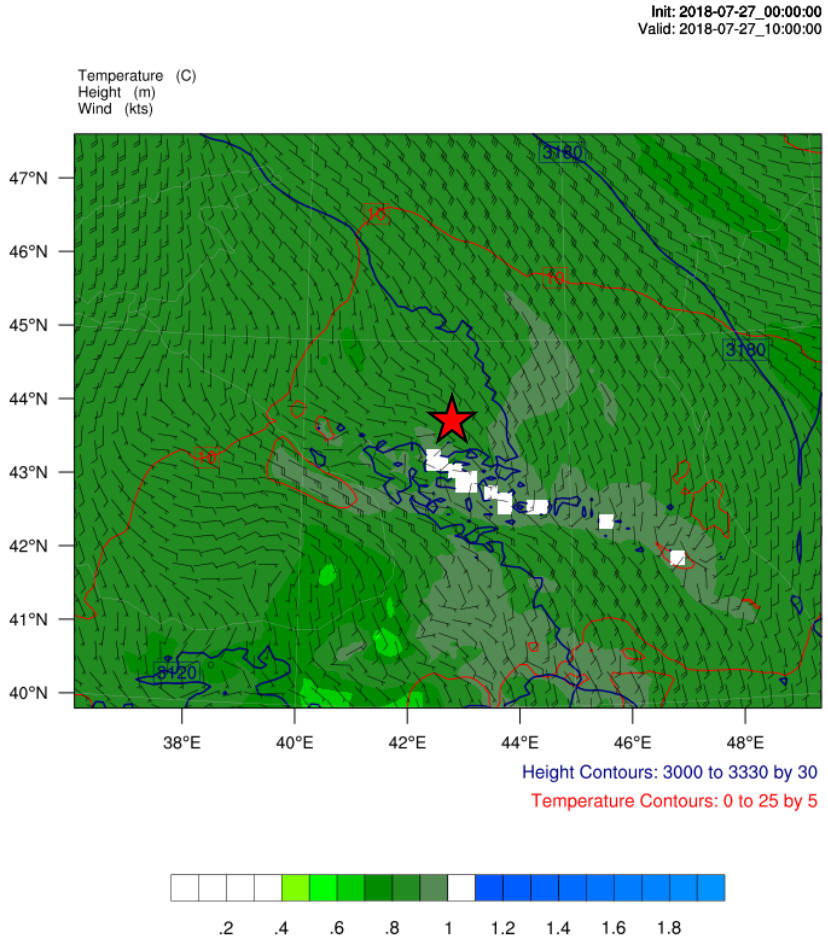
Red Star – Kislovodsk. July 27, 2018.



700 hPa.

- Distribution of humidity, temperature and wind at the level 850, 700 hPa. 10 UTC



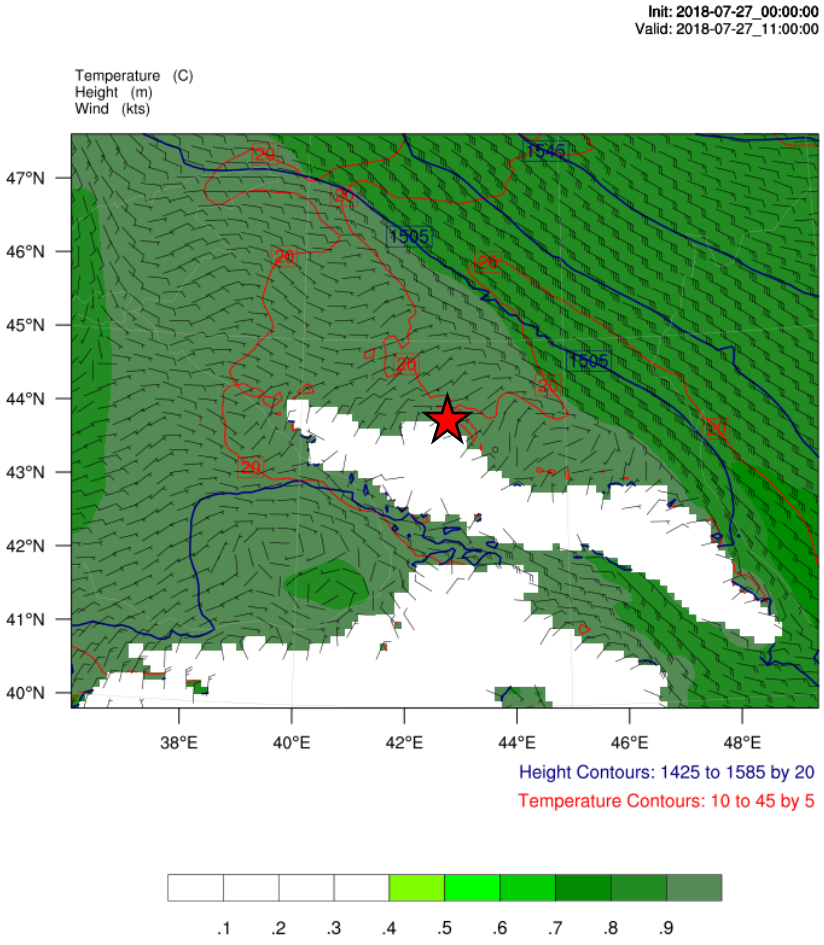


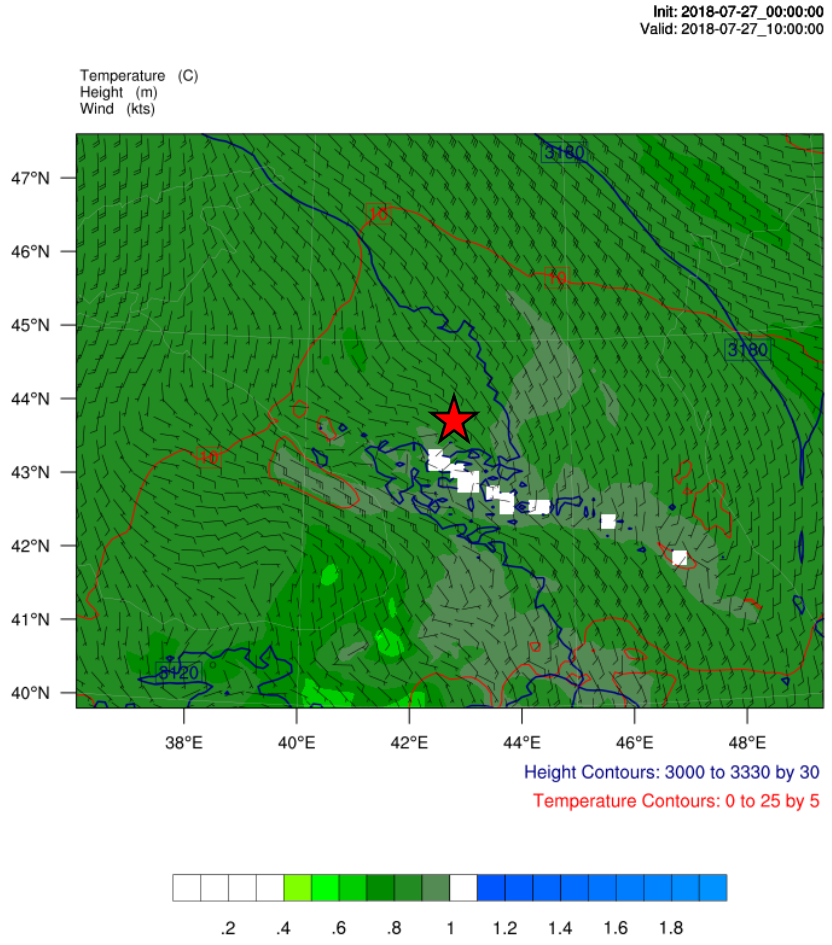
850 hPa.

Red Star – Kislovodsk. July 27, 2018.

700 hPa.

- Distribution of humidity, temperature and wind at the level 850, 700 hPa. 11 UTC



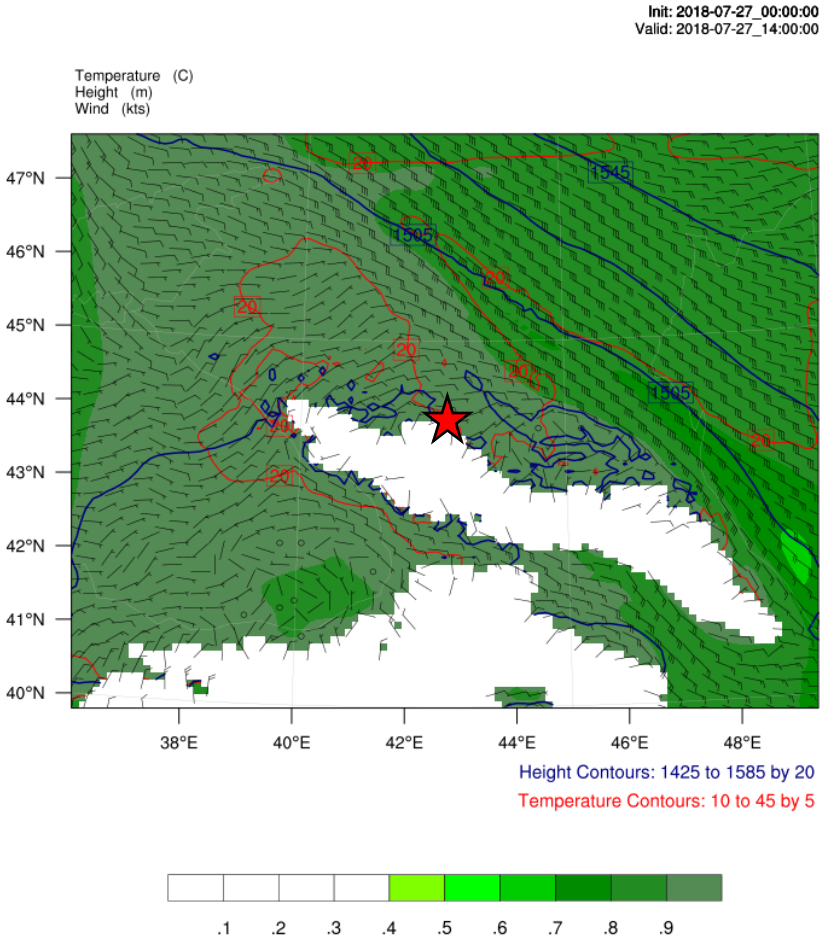


850 hPa.

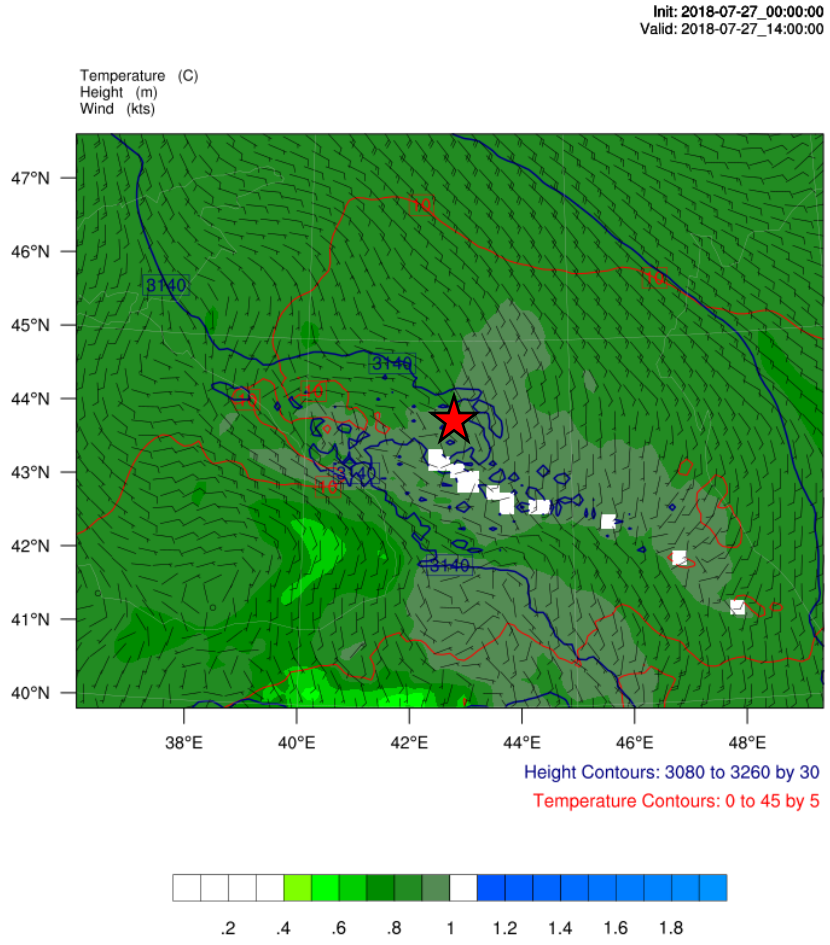
Red Star – Kislovodsk. July 27, 2018.

700 hPa.

- Distribution of humidity, temperature and wind at the level 850, 700 hPa. 14 UTC



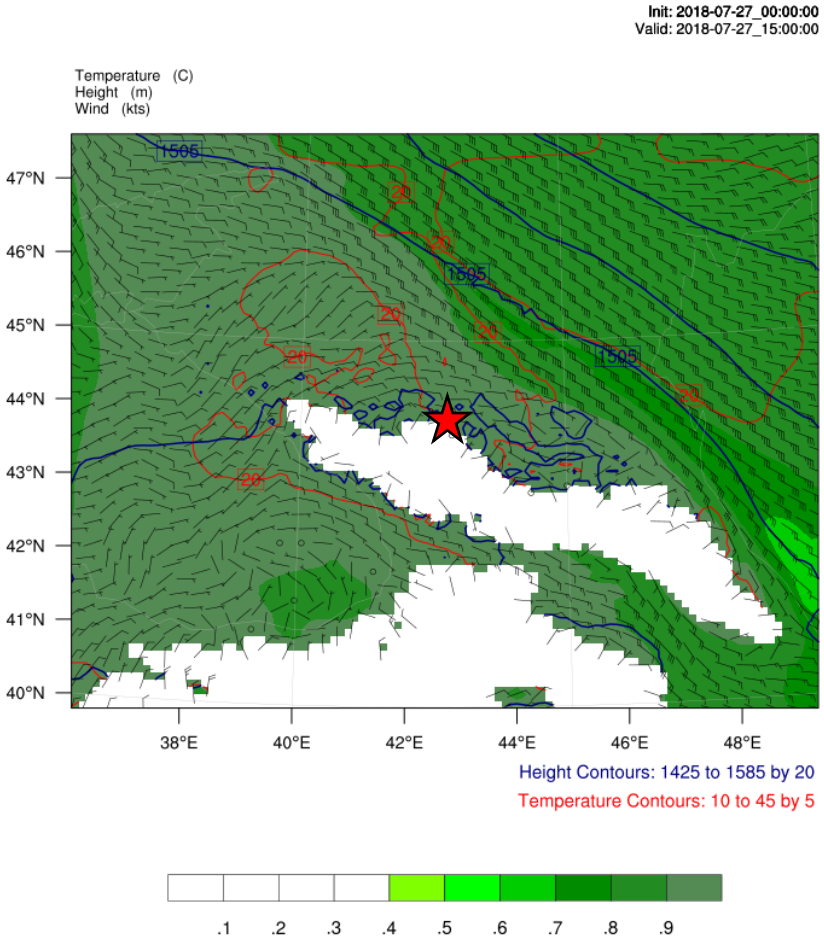
850 hPa.



700 hPa.

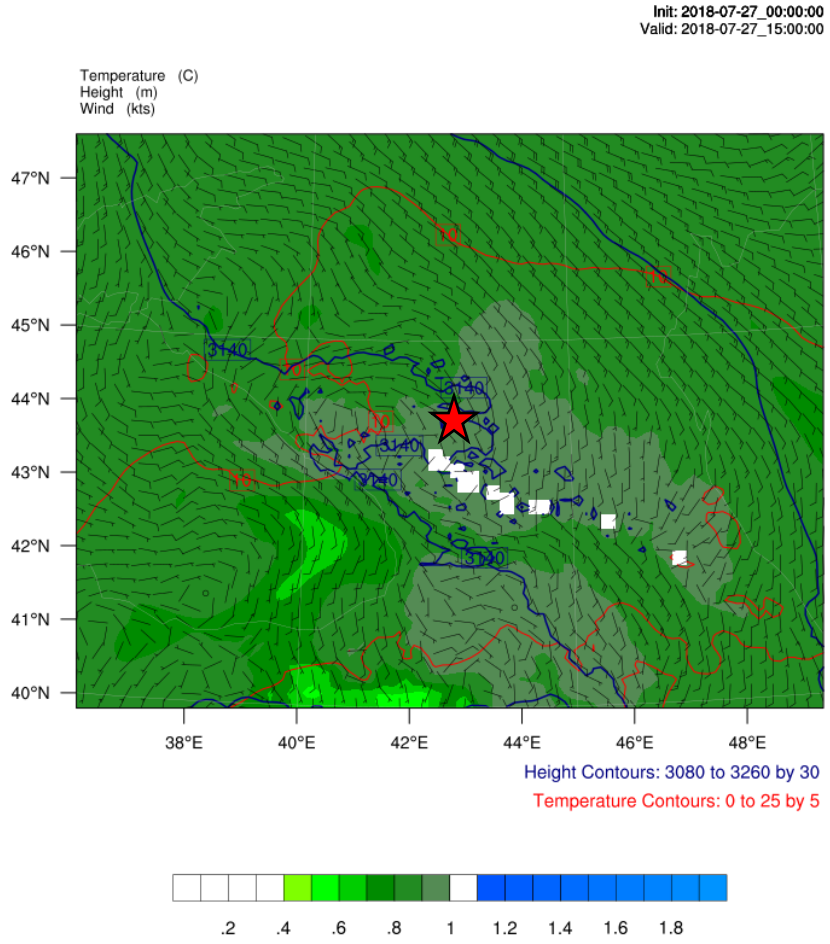
Red Star – Kislovodsk. July 27, 2018.

- Distribution of humidity, temperature and wind at the level 850, 700 hPa. 15 UTC



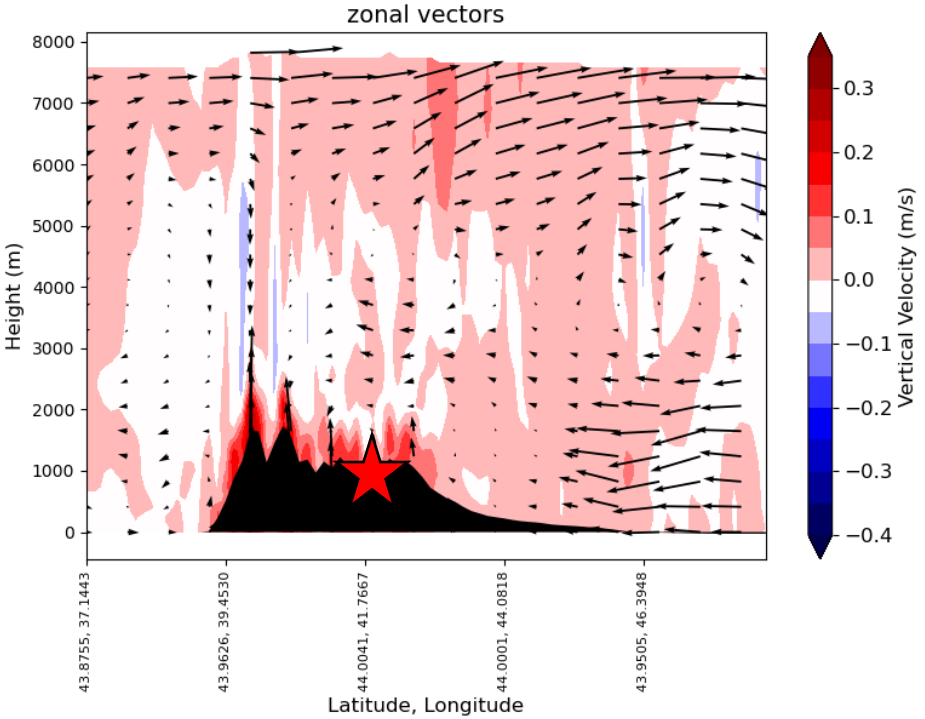
850 hPa.

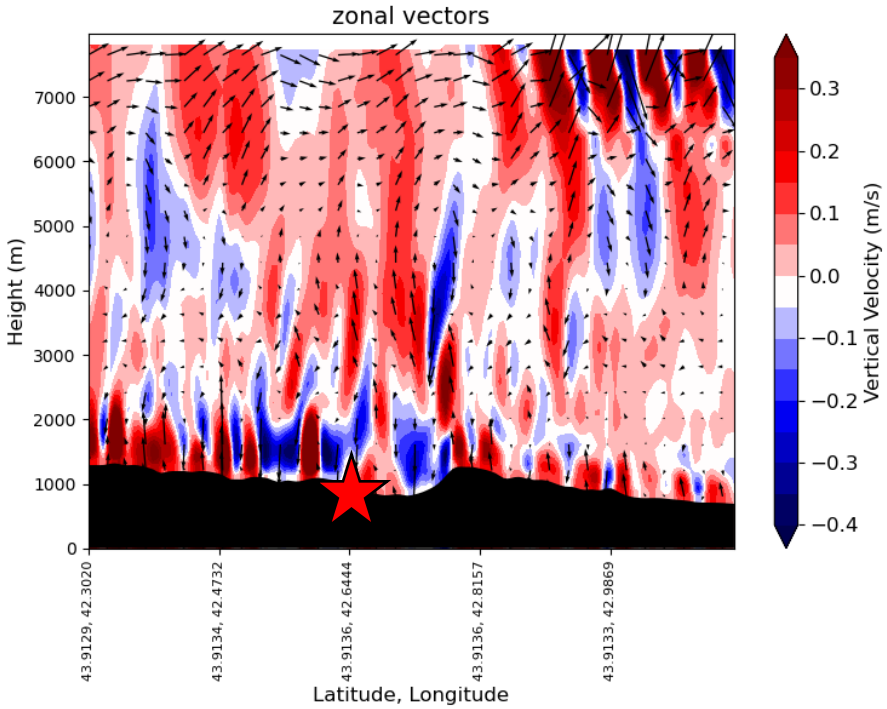
Red Star – Kislovodsk. July 27, 2018.



700 hPa.

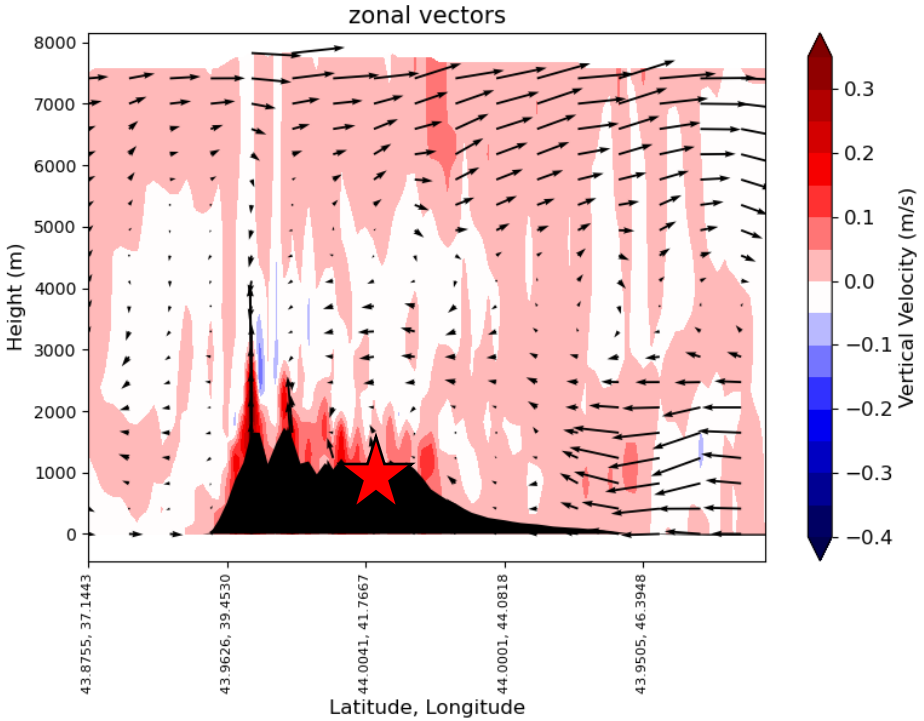
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

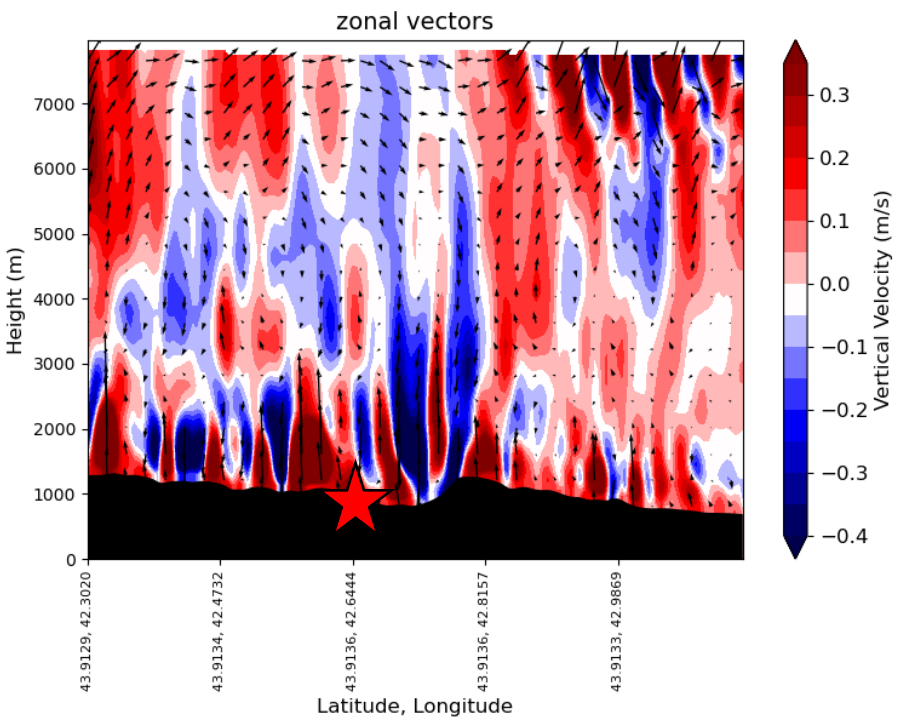




d01 08 UTC d04

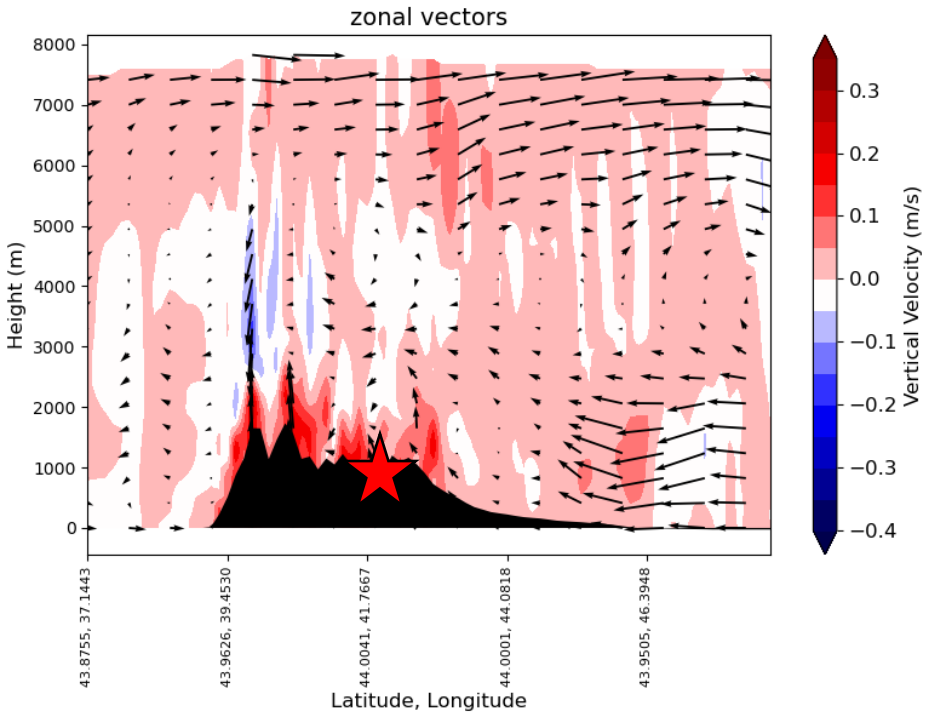
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

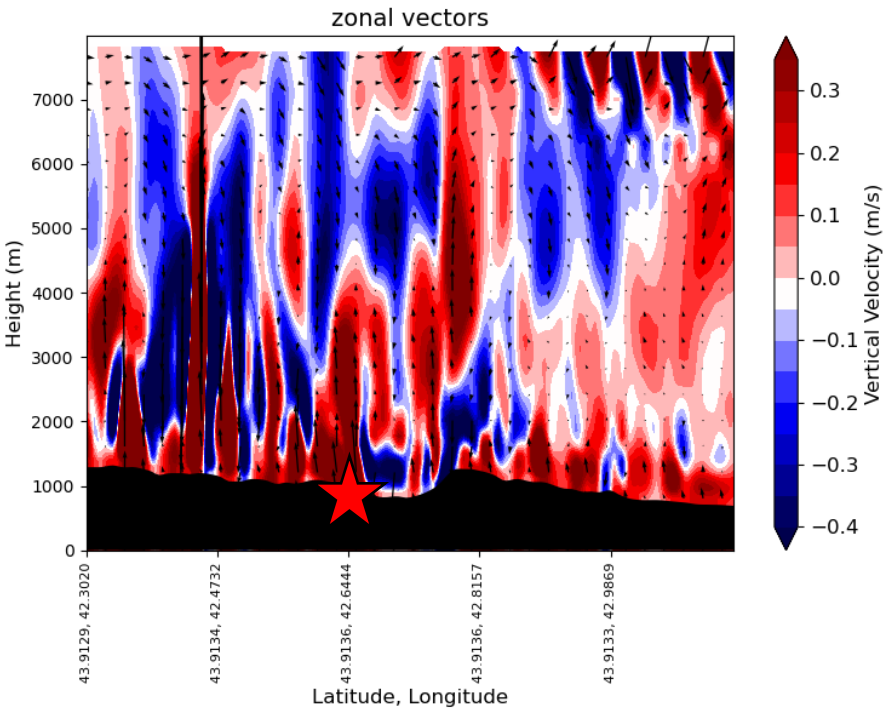




d01 09 UTC d04

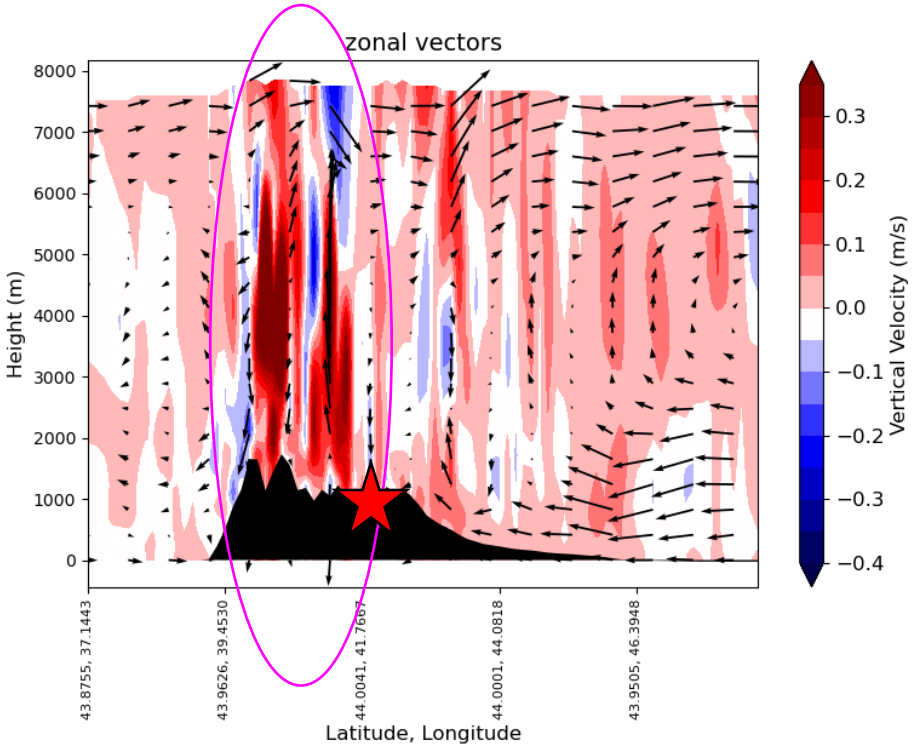
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

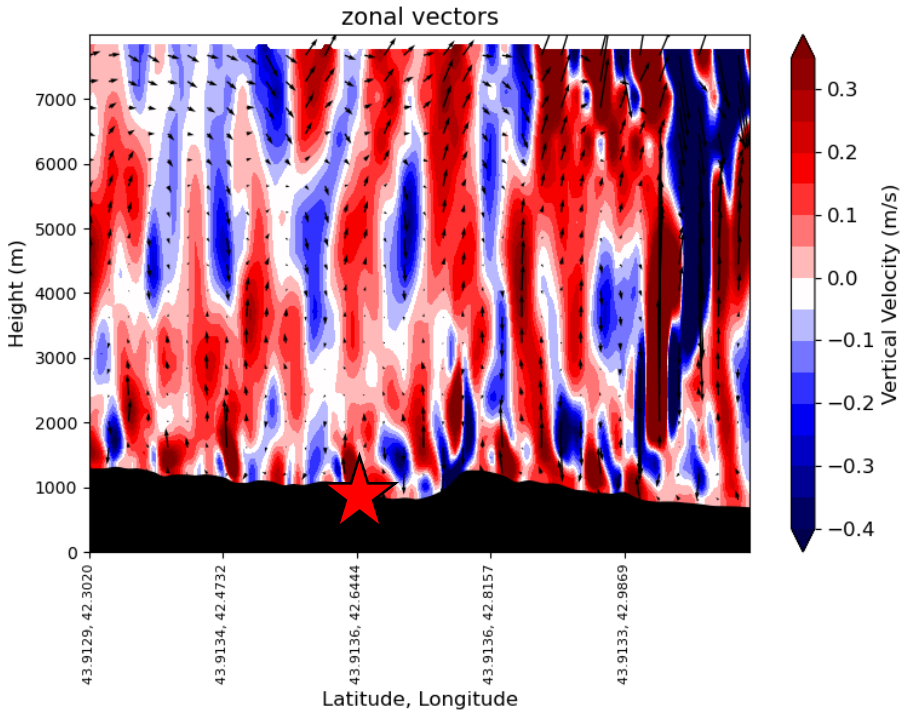




d01 10 UTC d04

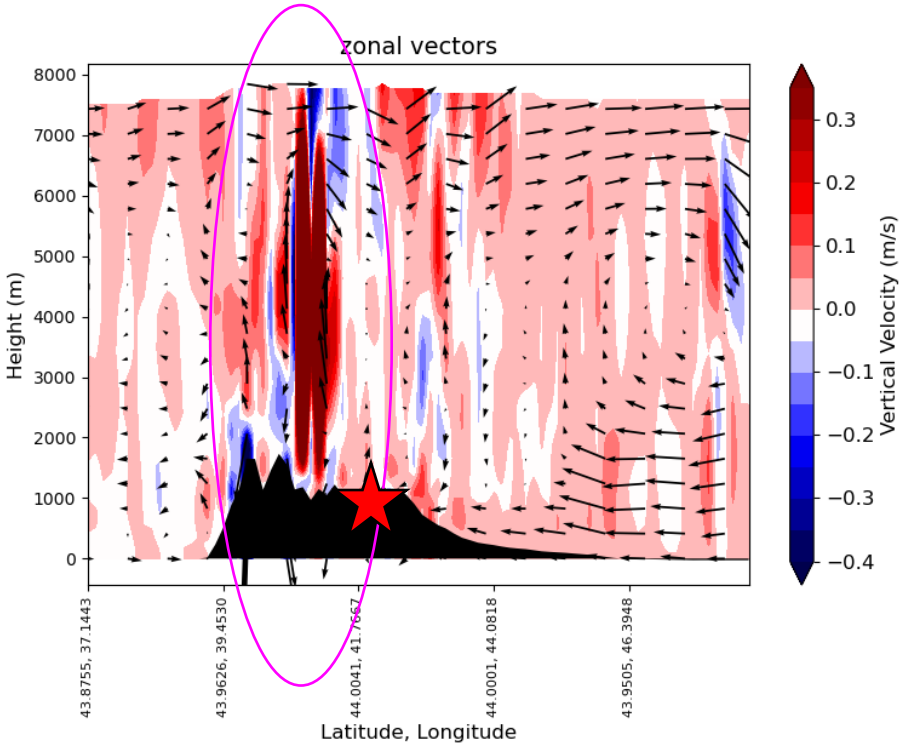
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

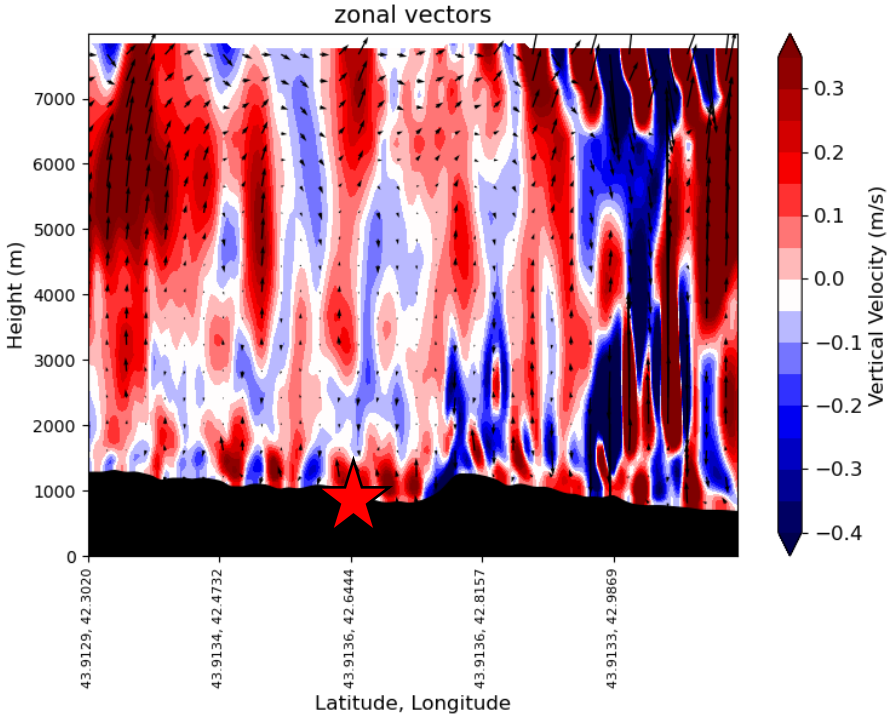




d01 16 UTC d04

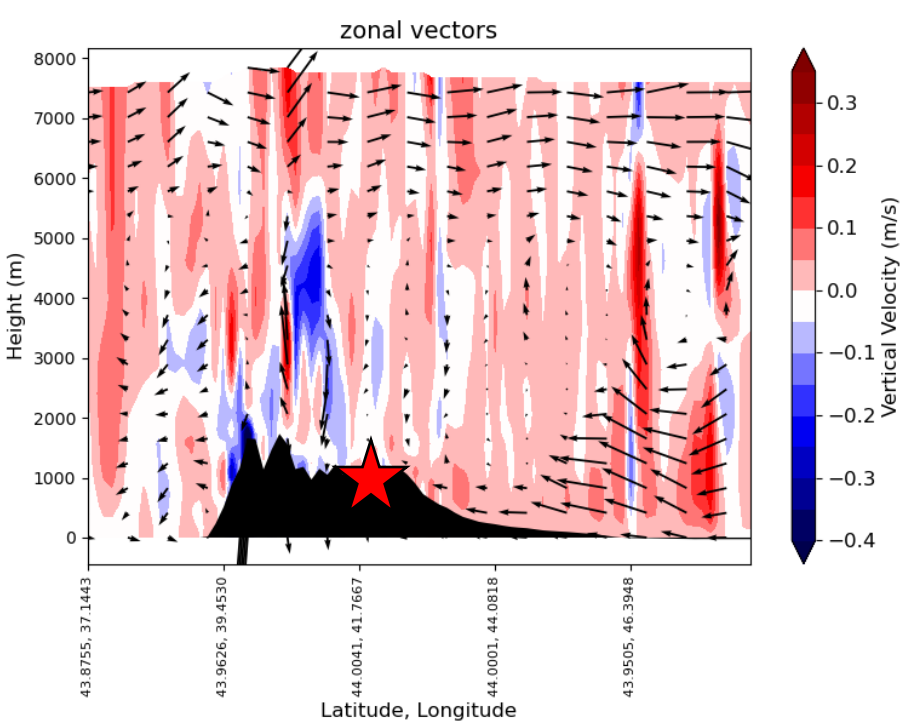
- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).

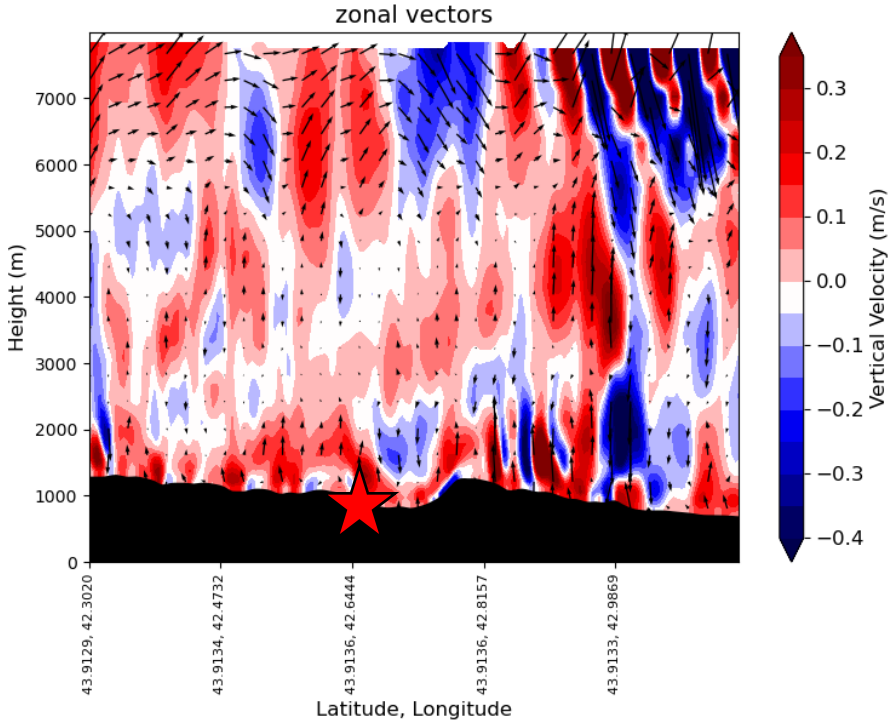




d01 17 UTC d04

- Since the cold air mass at an altitude of about 2-3 km passes over the surface of the mountains, convection at the time of the cold advection intensifies (from 12 UTC).





d01 18 UTC d04

Motivation. According to open sources

- More than 28 large trees were irretrievably lost in Kislovodsk due to a powerful hurricane. According to the Emerg ncy Situations and Civil Defense Center, there ities or missing persons. Four people suffered injuries of varying severity and were taken to the emergency room. One man was taken to the city hospital after be by a tree in his witnesses capturing s people being swept aw y by the muddy torrent.

Motivation. According to open sources

- Cars were floating on the city streets. A truck sank due to a puncture. Low-lying areas were flooded, including many of the resort's streets, pedestrian crossings, private homes, and the first floor of the Kristall Shopping Center. Power lines were down in 50 places, and nearly 100 homes were left without hot water. Among the resort facilities, the most severely damaged were the Ministry of Emergency Situations health center and the Raduga sanatorium, where the kitchen areas and basements were severely flooded. At the Piket sanatorium, many cars were damaged by fallen trees. Educational institutions were also damaged, with the kitchen areas and basements of kindergartens Nos. 1, 5, 16, and 22 suffering particular damage. A main power line support on the Berezovskaya River was washed away by the torrential downpour.