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Physical mechanisms of extreme precipitations on the southern coast of the Caspian Sea

Goals

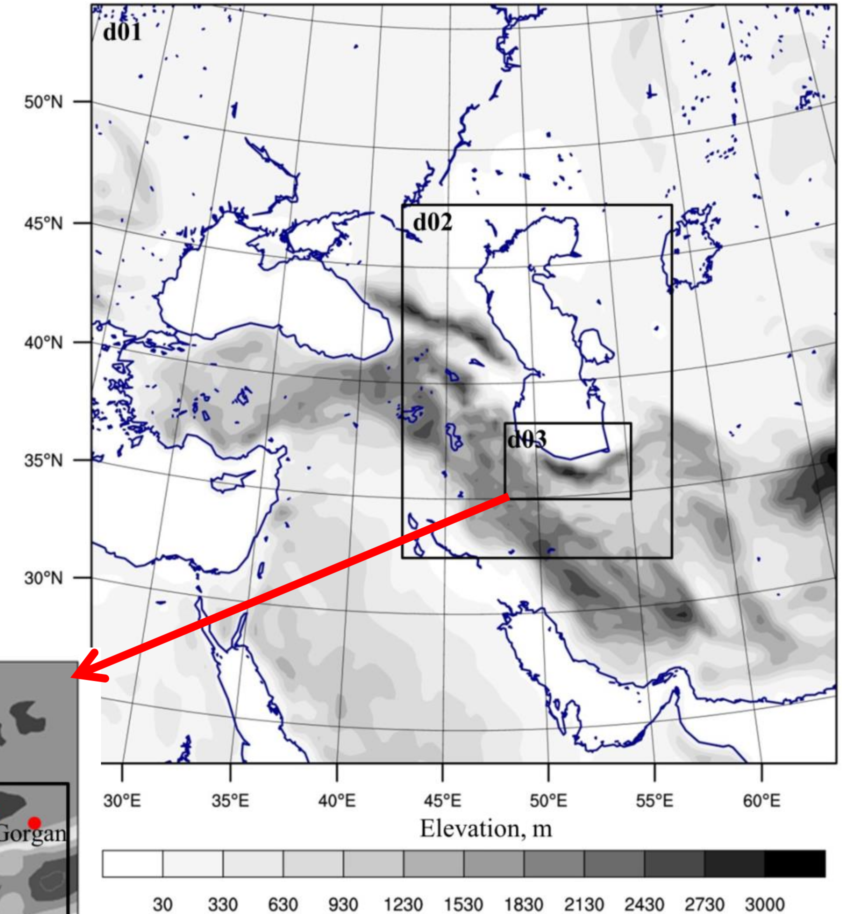
- Genesis of extreme precipitation on the southern coast of the Caspian Sea (synoptic or mesoscale effects?)

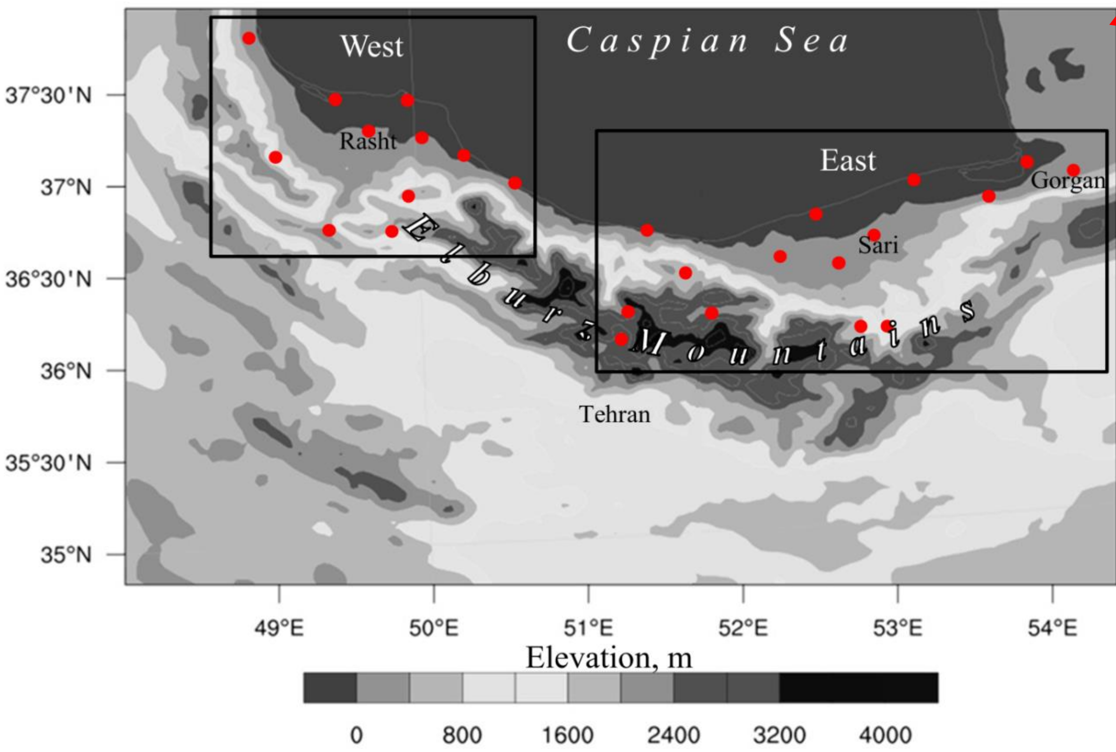
- Quantitative estimations of the mesoscale effects on the extreme precipitation (in the light of possible enhancement of the “lake effect” in the future climate)

- Ability of mesoscale numerical model to simulate extreme precipitation on the southern coast of the Caspian Sea

Study area

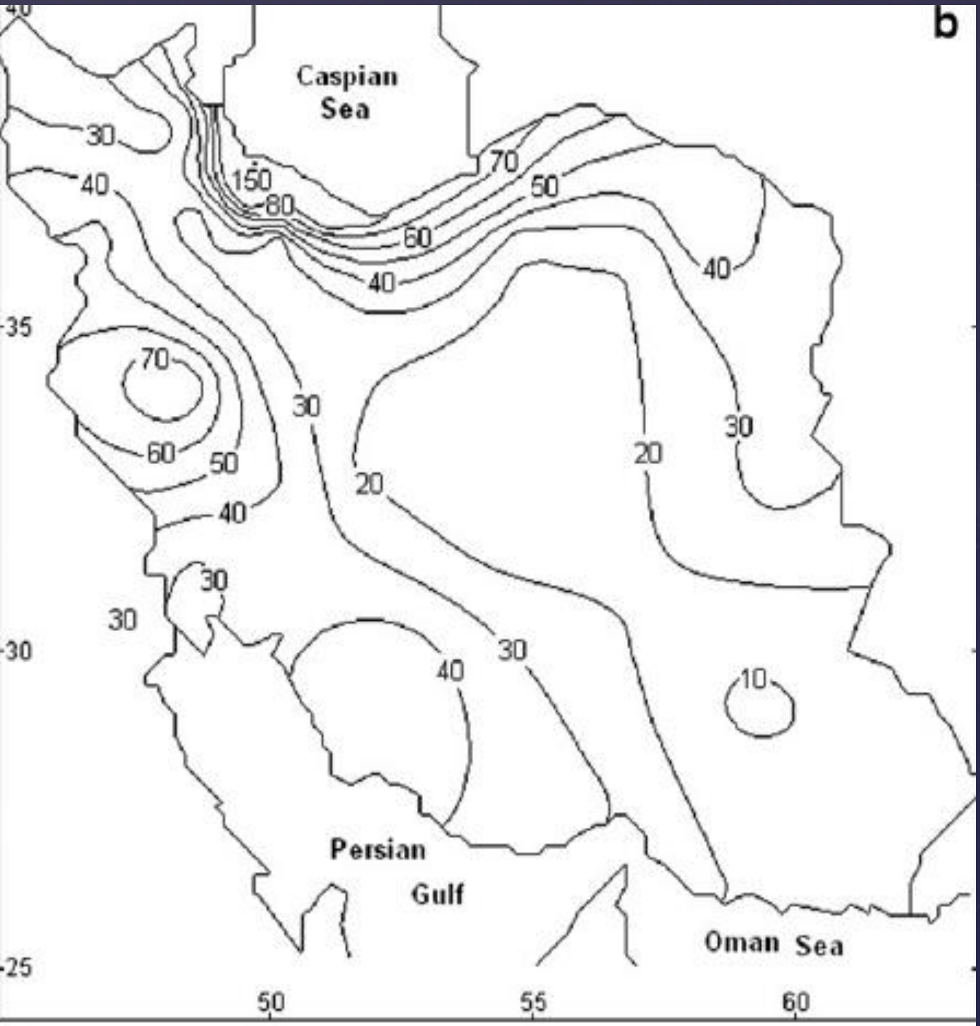
We studied 8 episodes with extreme precipitation (daily sums exceeds 50 mm at least on one station, and precipitation is observed in more than one half of the stations considered)





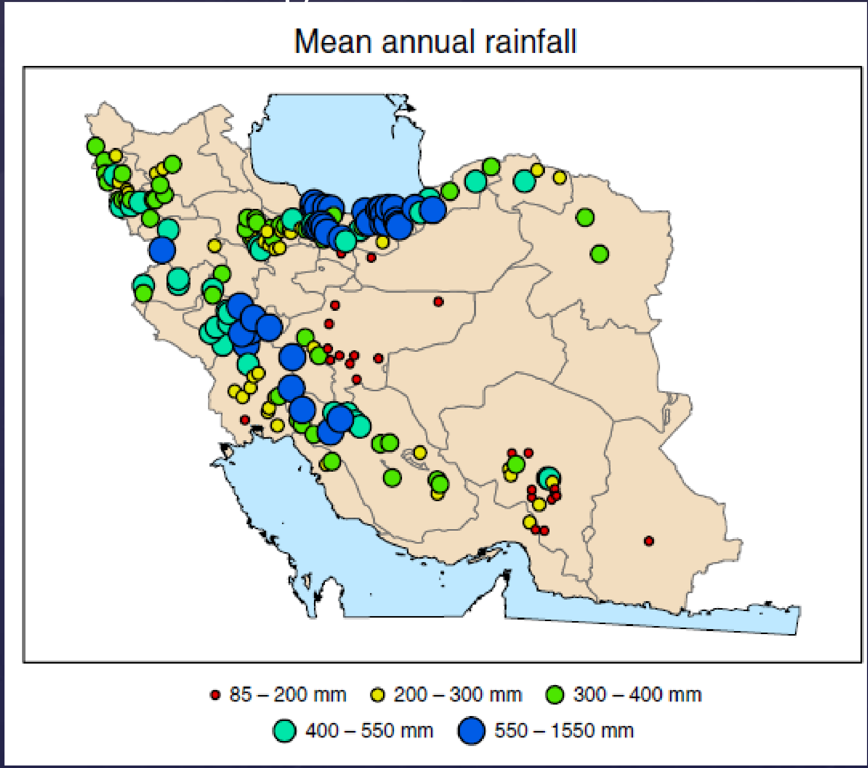
Precipitation climatology

Mean winter precipitation



(Ghasemi and Khalili 2008)

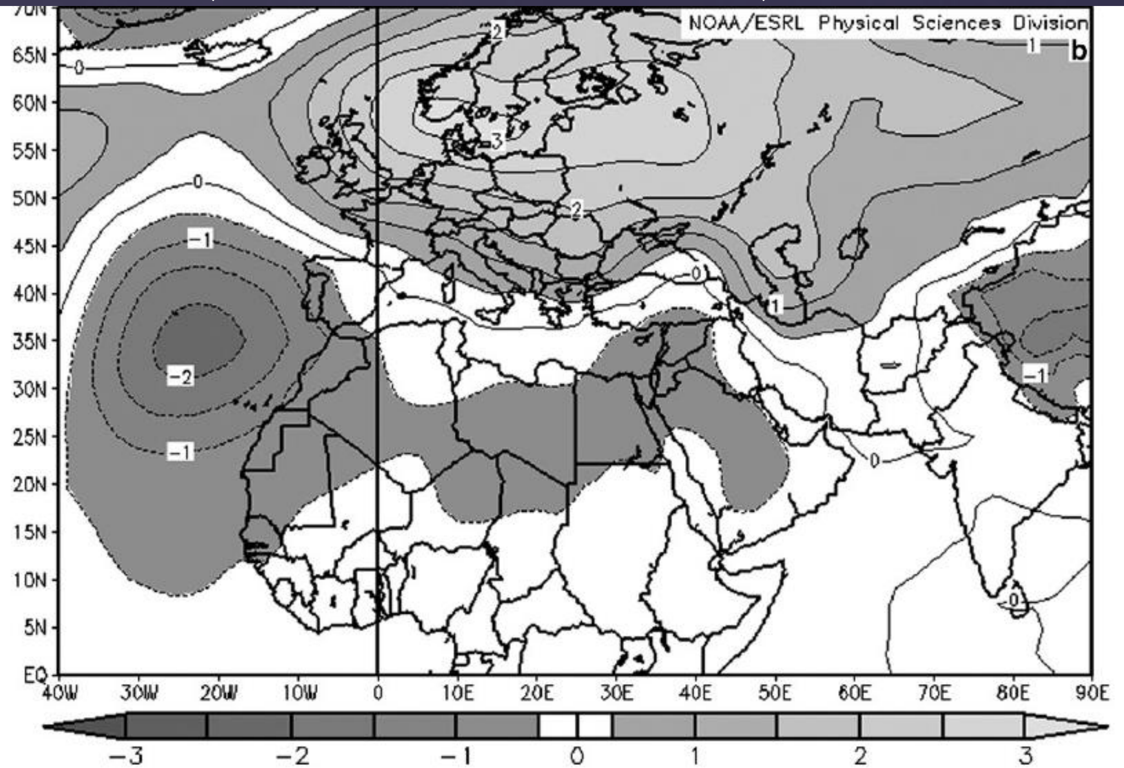
On the Iranian coast of the Caspian Sea heavy and extreme precipitation occurs rather frequently (Ghasemi and Khalili 2008). Active cyclogenesis on the Mediterranean and Iranian branches of the polar front is realized against the background of possible anomalies of the surface temperature of the Caspian Sea, as well as in the presence of high Elborz mountain ranges.



(Najafi and Moazami 2015)

Synoptic conditions

(Ghasemi and Khalili 2008)



Correlation coefficient between precipitation and circulation indices

	PC4
AO	0.22 (0.25)
NAO	0.09 (0.11)
NCP	0.38 (0.41)
PWP	−0.01 (−0.01)
WeMOI	−0.42 (−0.42)
NHSC	0.03 (0.11)
SCAND	0.13 (0.06)

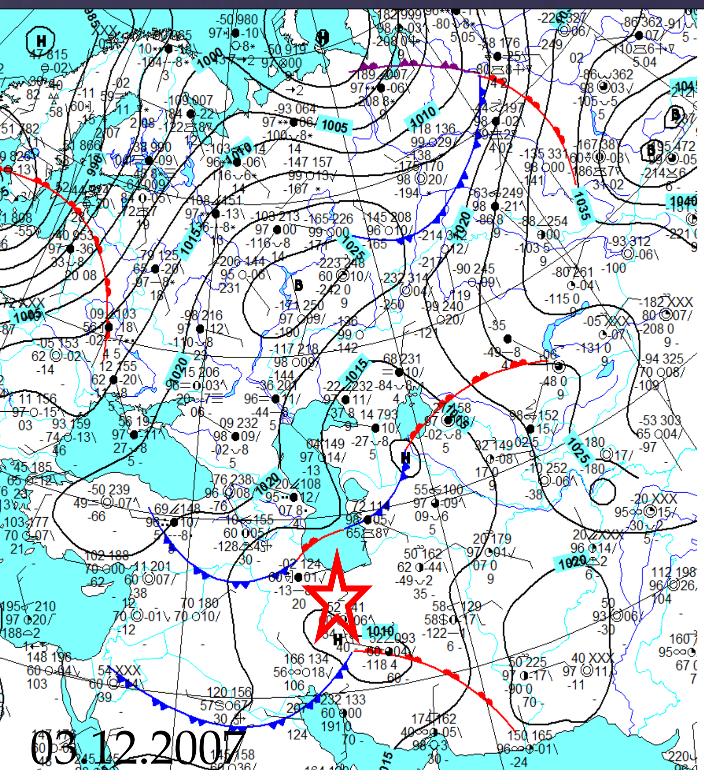
(Molanejad et al. 2015)

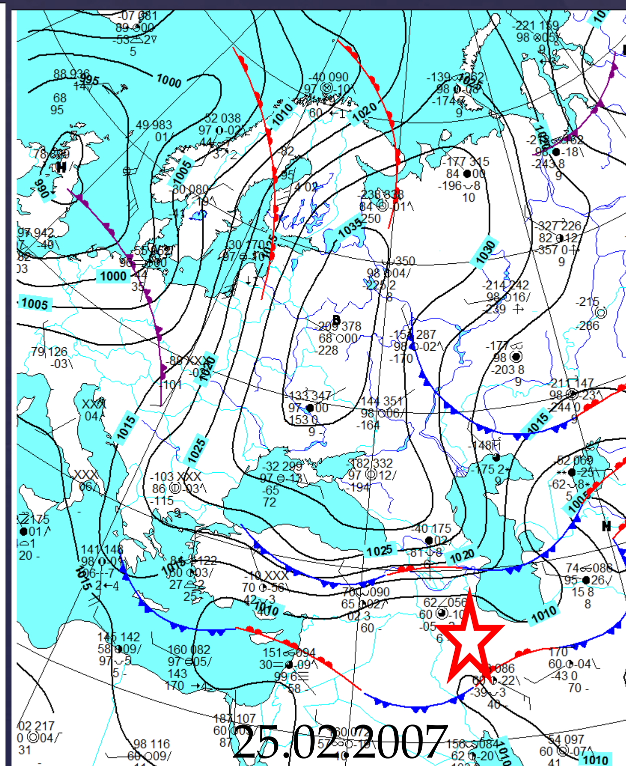
Table 2 Climatology of cyclones formed in the southern coasts of Caspian Sea that resulted in heavy rainfall (more than 50 mm) during 1996-2005 in different months covering the area north of 36° N, south of 38° N, west of 55° E and east of 48° E, in five weather stations.

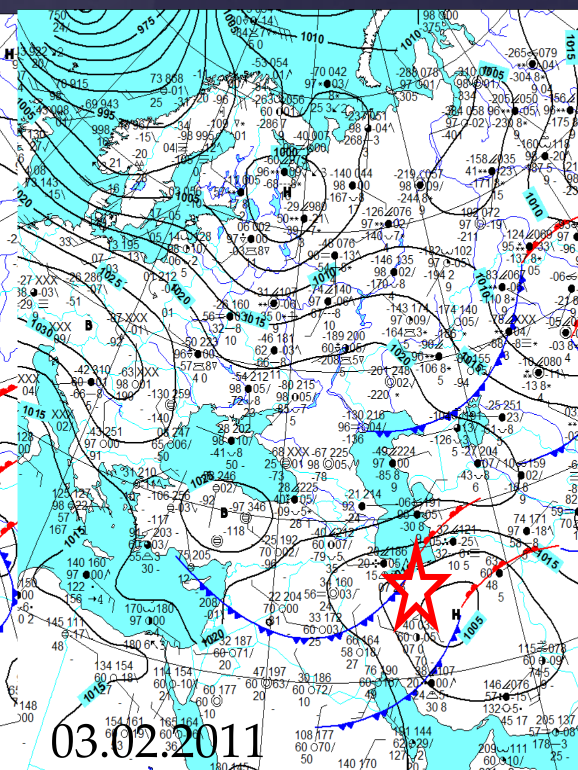
Weather Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Bandar-e-Anzali	1	1						1	9	5	3	4
Rasht		2			1				2	3	4	2
Babolsar			1						1	3	4	1
Sari		1	1	1					1		1	
Gorgan	1	2										1

Synoptic conditions

All cases develop against a background of high atmospheric pressure north and / or west of the Caspian Sea. Northern outbreaks along the periphery of the anticyclone provoke intensification of the Mediterranean part of the polar front due to the convergence of tropical and continental polar (or transformed arctic) air. Anticyclone usually moves along the north of the Caspian region from west to east.

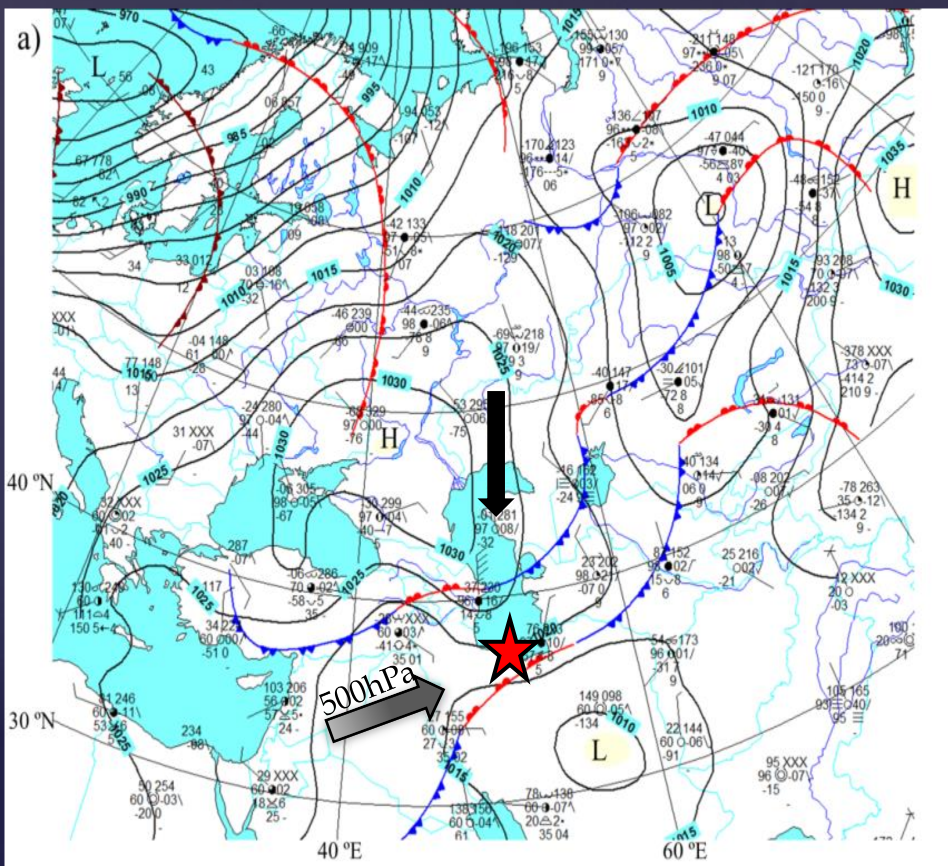




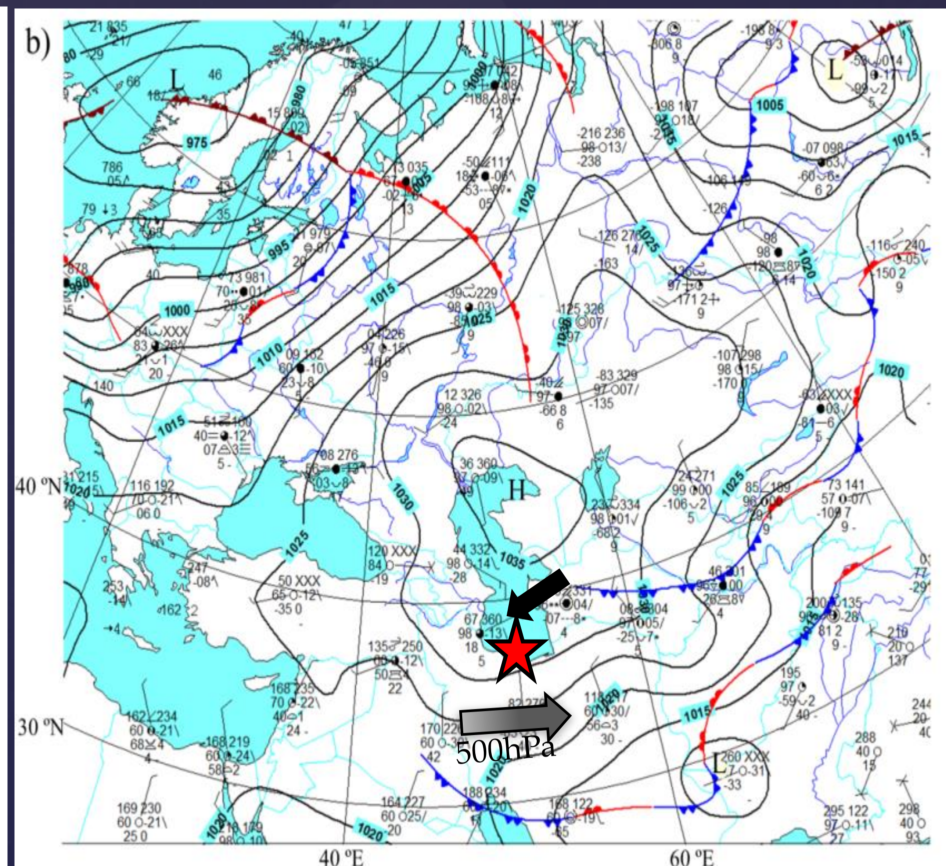


Synoptic conditions on 8-9 February 2016

8 February

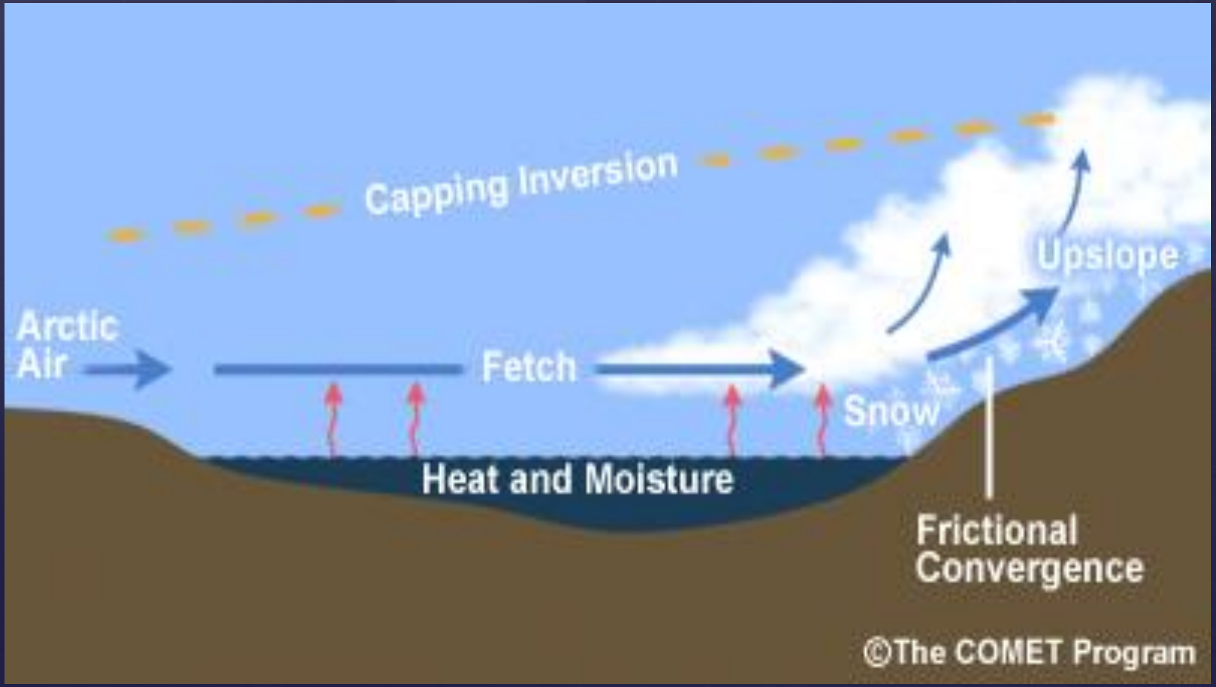


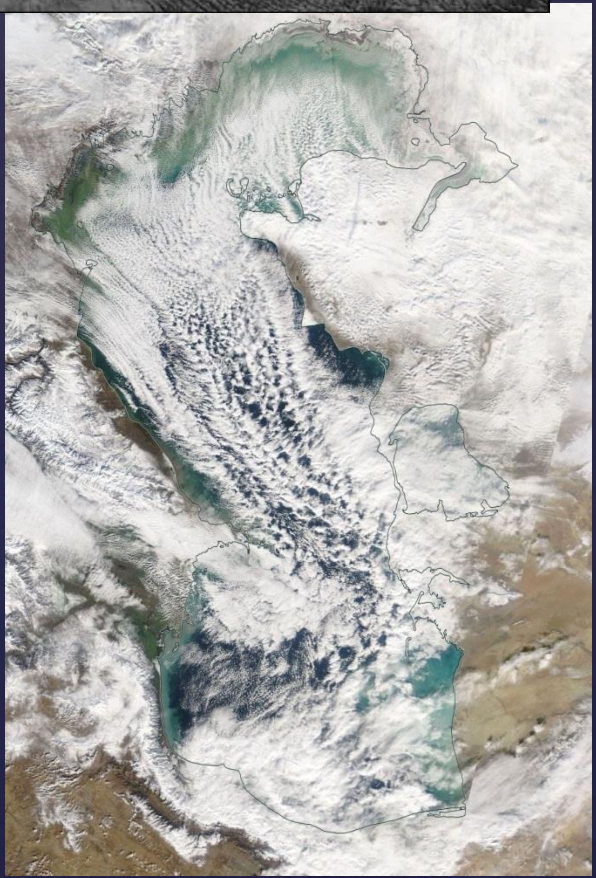
9 February



Lake effect


Satelitte image showing clouds forming and causing lake effect snow over the Great Lakes: NOAA





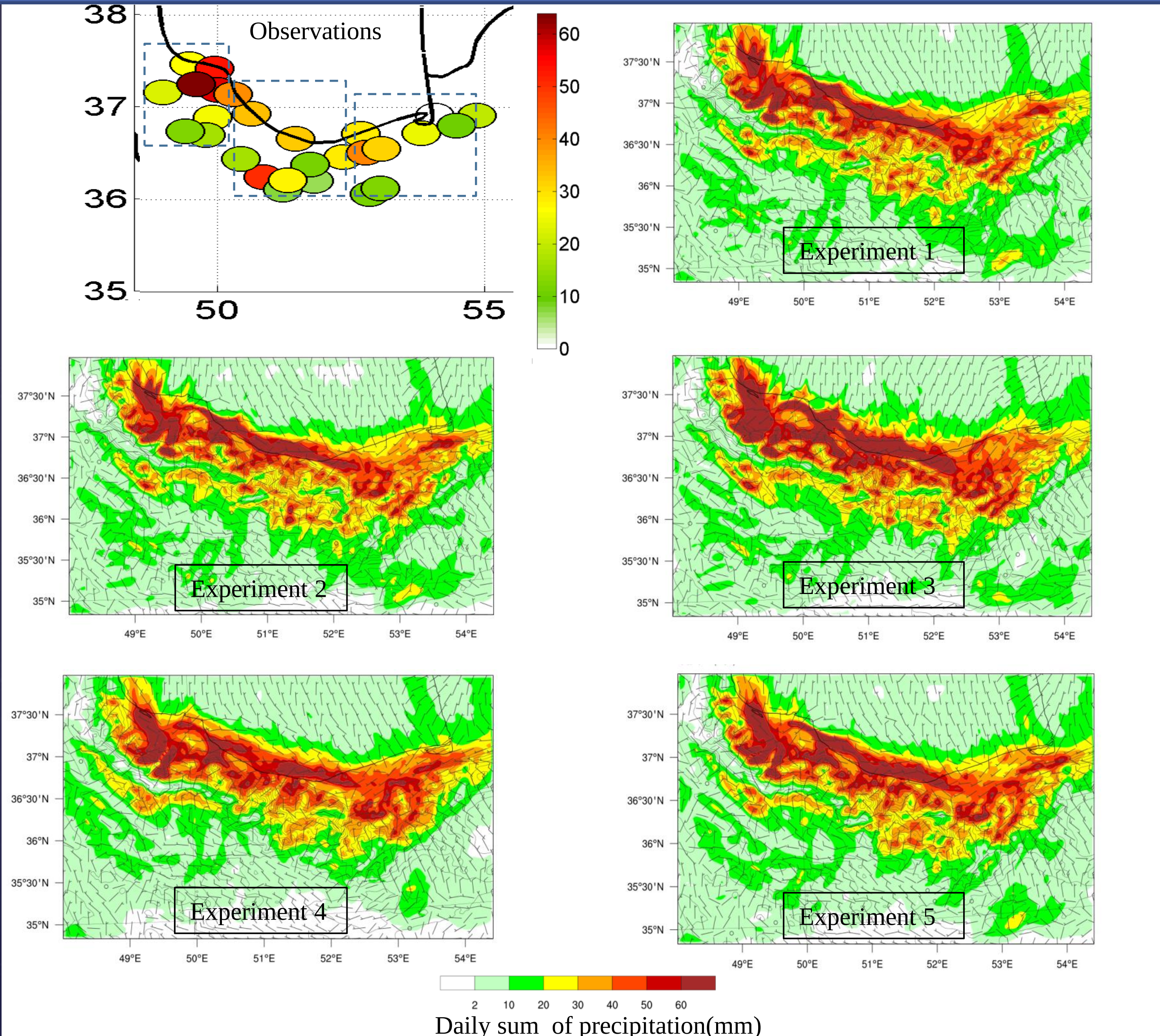
Numerical experiments with WRF-ARW model

I Realistic experiments (assessment of the quality of precipitation simulation by the model, selection of the optimal set of physics parametrizations)

Simulation of 8 episodes; episode 8-9 February 2016 was chosen for experiments on the sensitivity of simulation results to parametrizations

№	Convection (in the inner domain)	Boundary layer	Cloud microphysics
1	Kain-Fritsch	MYNN	Lin
2	Explicit	MYNN	Lin
3	Explicit	YSU	Lin
4	Explicit	MYNN	Thompson
5	Explicit	MYNN	WSM6

Selection of the optimal set of physics parametrizations



Selection of the optimal set of physics parametrizations

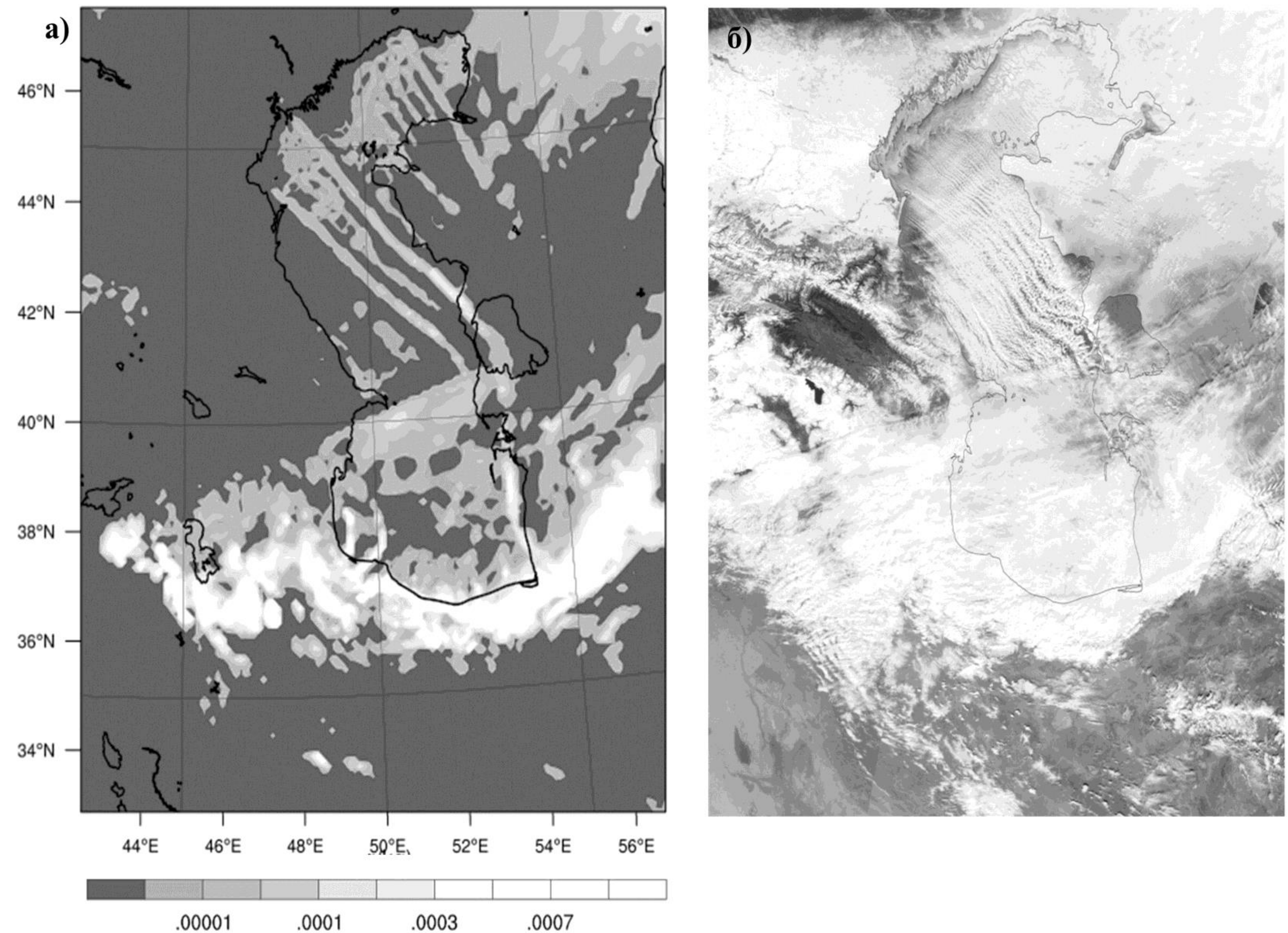
№	At stations within 8-km radius			Bias, мм (RE, %) in subregions	
	bias (mm)	MAE (mm)	Relative error RE, %	West	East
1	4.6	9.7	17	1.7 (5)	9.6 (41)
2	2.6	8.9	9	0.8 (2)	9.4 (40)
3	7.0	11.1	26	10.6 (32)	13.4 (57)
4	5.1	8.4	19	1.1 (3)	11.3 (48)
5	3.1	8.0	11	2.4 (7)	10.8 (46)

Verification of modeling results

	Mean daily sum (mm)	Max daily sum (mm)	Model bias (mm)	MAE (mm)	Relative error RE, %
25.02.2007	21.3	53	-0.1	6.4	-1
03.12.2007	23.9	89	0.5	8.4	2
15.12.2008	18.6	98	2.1	11.4	11
16.12.2008	14.1	75	-3.6	5.4	-26
26.01.2010	25.1	67	3.5	9.2	14
27.01.2010	14.8	28	-6.2	7	-42
10.01.2011	34.1	108	-9.3	12.1	-27
11.01.2011	18.6	57	-6.5	10.1	-35
12.01.2011	13.7	79	-2.3	6.4	-17
03.02.2011	32.6	92	-6.2	8.7	-19
08.01.2015	21	84	1.9	9.2	9
09.01.2015	18.2	71	-3.9	9.9	-22

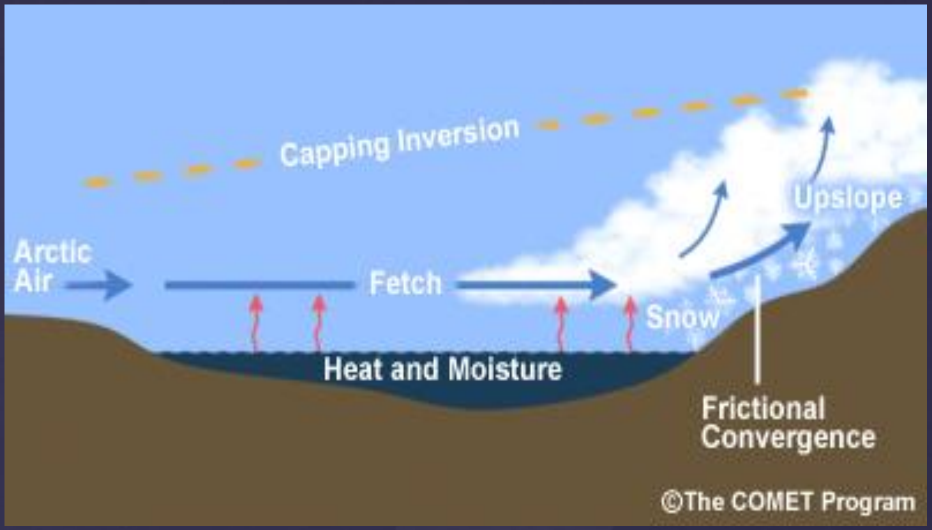
Verification of modeling results

WRF Terra/Modis



Mixing ratio of water vapor and ice in the cloud air, kg/kg

Lake effect



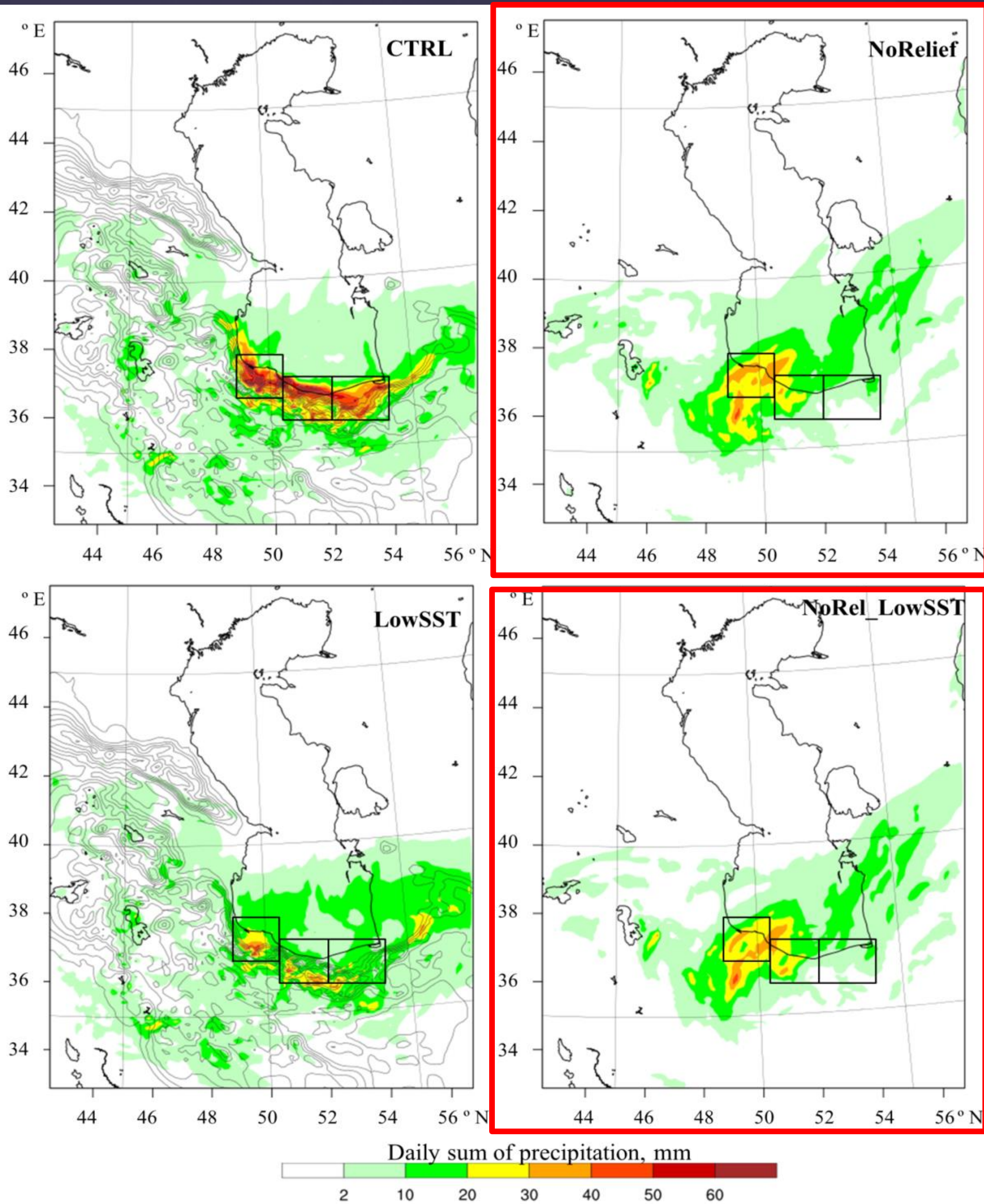
	Necessary conditions:	Conditions in the studied episodes:
SST	High	13-18 ºC
ΔT between lake and air at 850 hPa	> 13 K	18-28 ºC
Wind speed	High	15-20 m/s, up to 25 m/s
Wind share	Weak	Weak in the lowest 2-km
Flow direction	coincides with the main axis of the lake	coincides with the main axis of the lake
Path length over the lake	> 100 km	400-1000 km

Numerical experiments with WRF-ARW model

II Idealised experiments (to estimate the lake and relief effects) on the example of 8-9 February 2016

1. **CTRL** – realistic experiment
2. **NoRelief** – flat surface inside domains
3. **LowSST** – SST of Capsian Sea is set to 4°C
4. **NoRel_LowSST** – flat surface + SST= 4°C
5. **SST2.6** – SST of the Caspian Sea=SST CTRL + 1°C (according to RCP2.6 scenario)
6. **SST8.5** – SST of the Caspian Sea=SST CTRL + 4°C (according to RCP8.5 scenario)

Results of idealised experiments



Averaged daily precipitation (mm) in the different regions of the coast according to control and idealised experiments

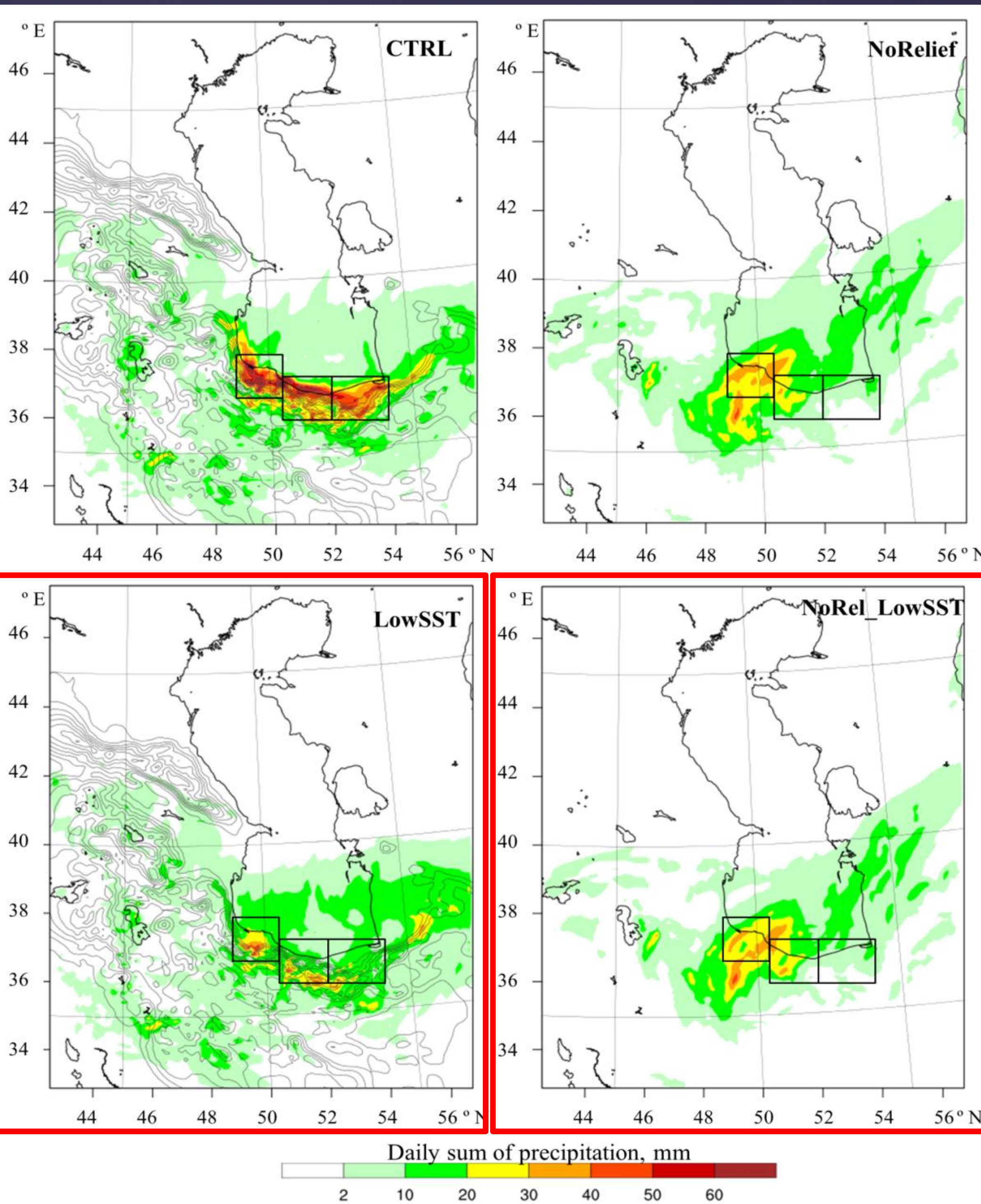
	Averaged daily precipitation, mm			Averaged over all regions
	West	Centre	East	
CTRL	33,1	31,7	25,5	30,1
NoRelief	25	16,3	5,5	15,6
LowSST	18,4	15	12,7	15,4
NoRel_ LowSST	23,3	16,5	5,7	15,2

NoRelief and NoRel_LowSST experiments are almost the same

Lake effect is small in the absence of relief (<7% of total precipitation)

In the presence of mountains, the contribution of the lake effect increases to 50%

Results of idealised experiments



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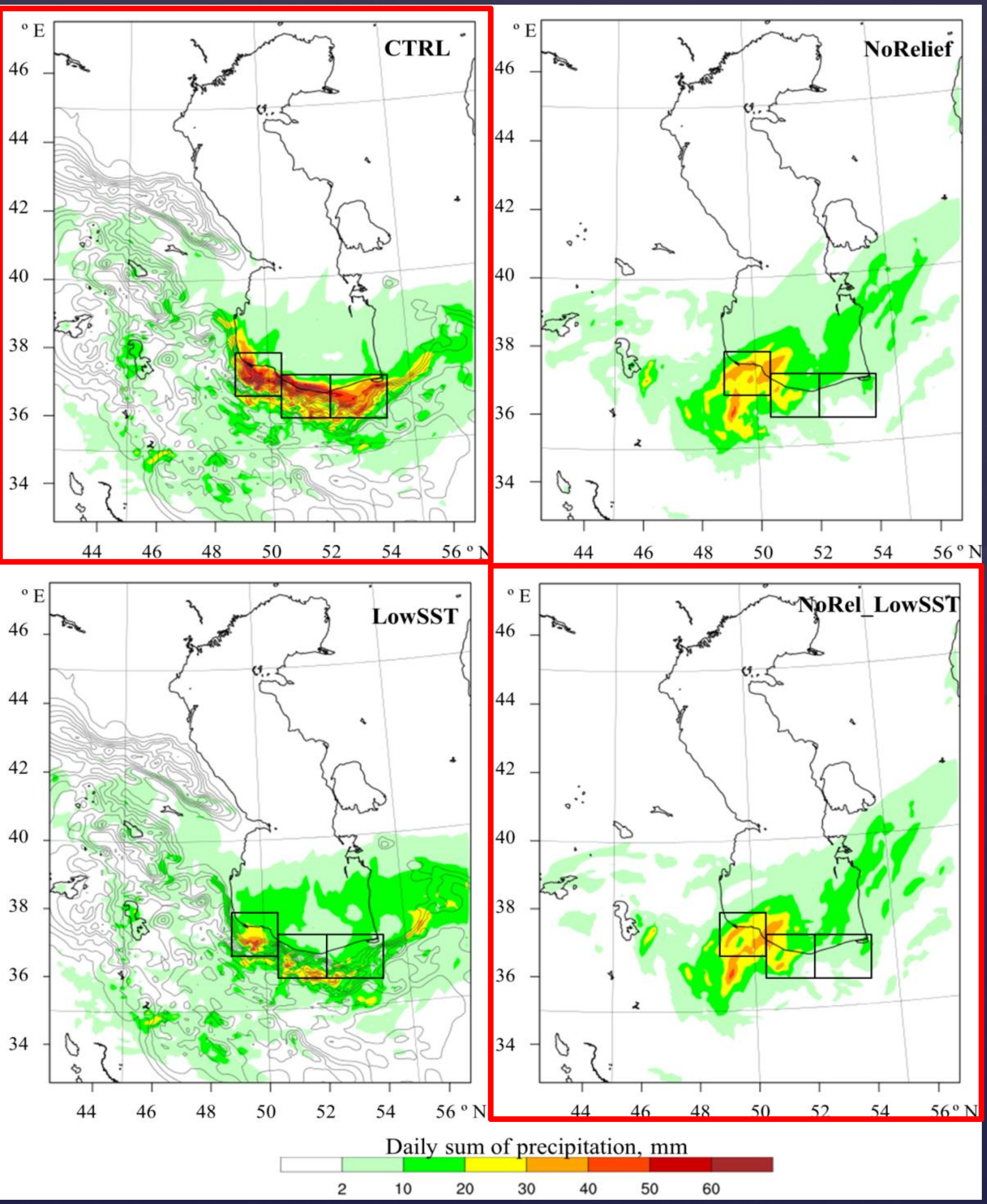
LowSST	18,4	15	12,7	15,4
NoRel_ LowSST	23,3	16,5	5,7	15,2

In the same way the contribution of the relief depends on the lake temperature: for a cold lake, the influence of the relief is expressed in a strong increase in precipitation in the east of the region, but also in decreasing precipitation in the west (on average in all regions, the relief effect is 1%).

In the presence of the warm Caspian Sea, the relief leads to an increase in the amount of precipitation everywhere, on average by 48%.

Results of idealised experiments



Averaged daily precipitation (mm) in the different regions of the coast according to control and idealised experiments

	Averaged daily precipitation, mm			Averaged over all regions
	West	Centre	East	
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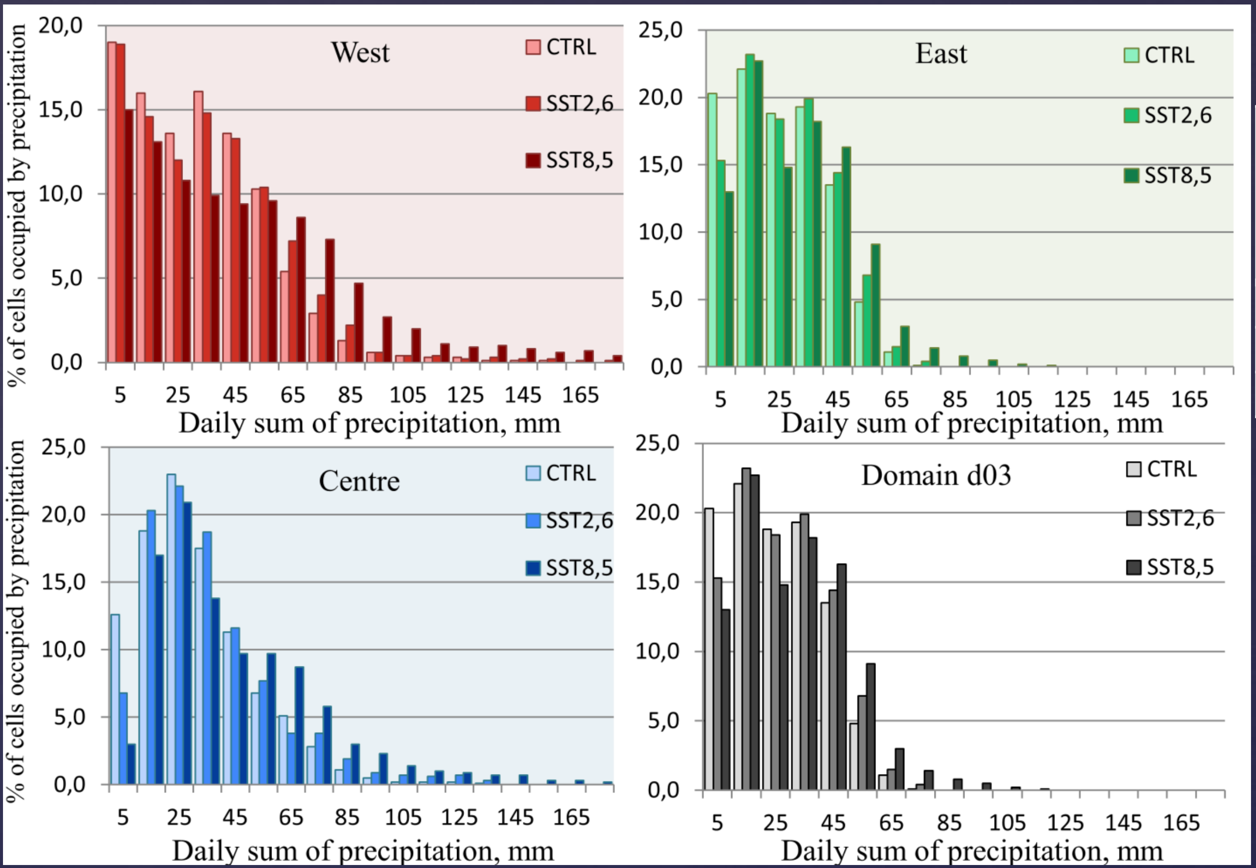
NoRel_ LowSST	23,3	16,5	5,7	15,2

48% of the precipitation is caused by synoptic scale processes, and the remaining **52%** is affected by the relief and warm Caspian Sea

Results of idealised experiments



Averaged daily precipitation (mm) in the different regions of the coast according to control and idealised experiments

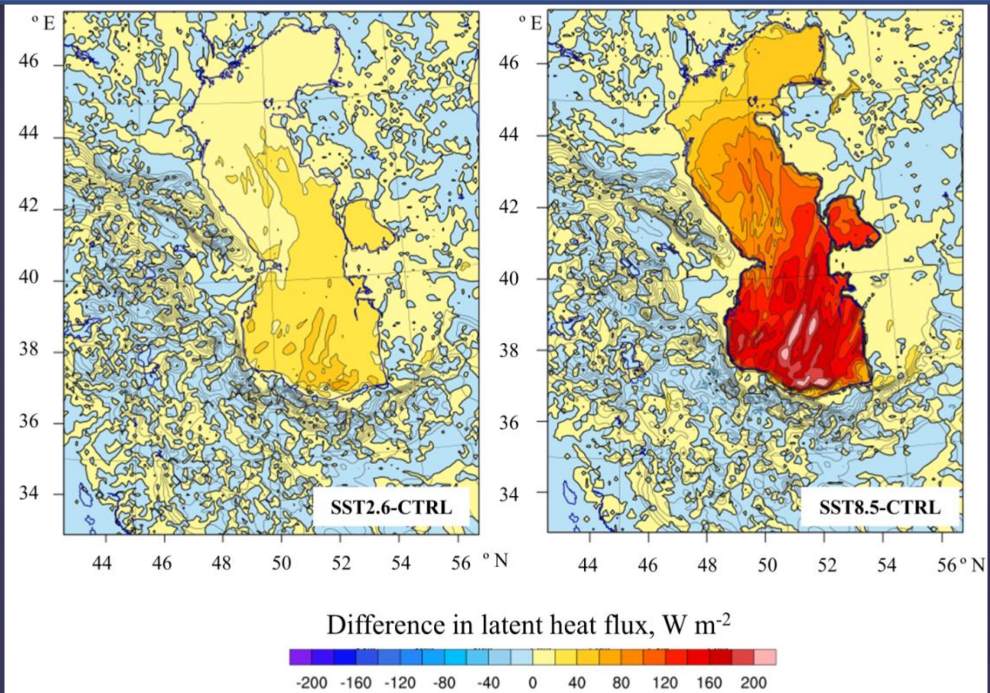
	Averaged daily precipitation, mm			Averaged over all regions
	West	Centre	East	
CTRL	33.1	31.7	25.5	30.1
SST2.6	36.1	35.5	27.4	33.0
SST8.5	48.6	45.4	30.7	41.6

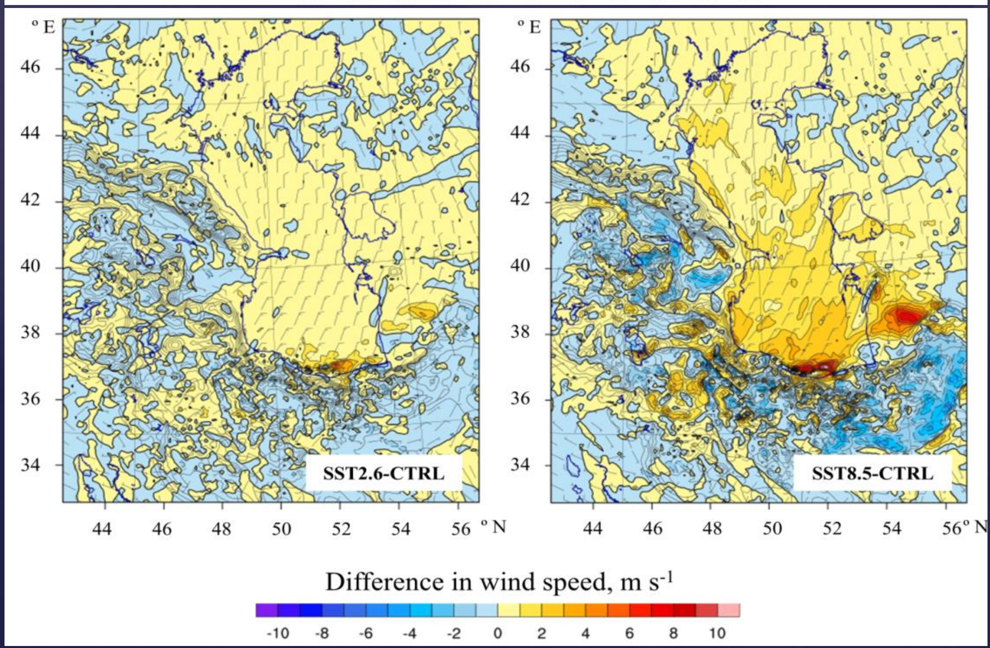
The spatial standard deviation of precipitation in all areas (especially in the central one) also increased.

The area of extreme precipitation extends further from the shore (toward the sea) than in the CTRL.

In the SST8.5 experiment, the number of model cells with heavy precipitation increased by more than 2 times in comparison with the CTRL.

Results of idealised experiments





Increase in the latent heat flux (by 150-200 W m^{-2} in the SST8.5 experiment)

Increase in the wind speed (due to the weakening of stratification and therefore weakening of flow blocking by the mountains)

Enhance of the lake effect

Conclusions

❖ The mechanism of precipitation is essentially mixed. Presence of the warm Caspian Sea, combined with the convergence of moisture on the northern slopes of the Elburz Mountains, led to a sharp intensification of the atmospheric front. The total contribution of the lake and relief is on average 50%, and in the east of the coast - up to 80%.

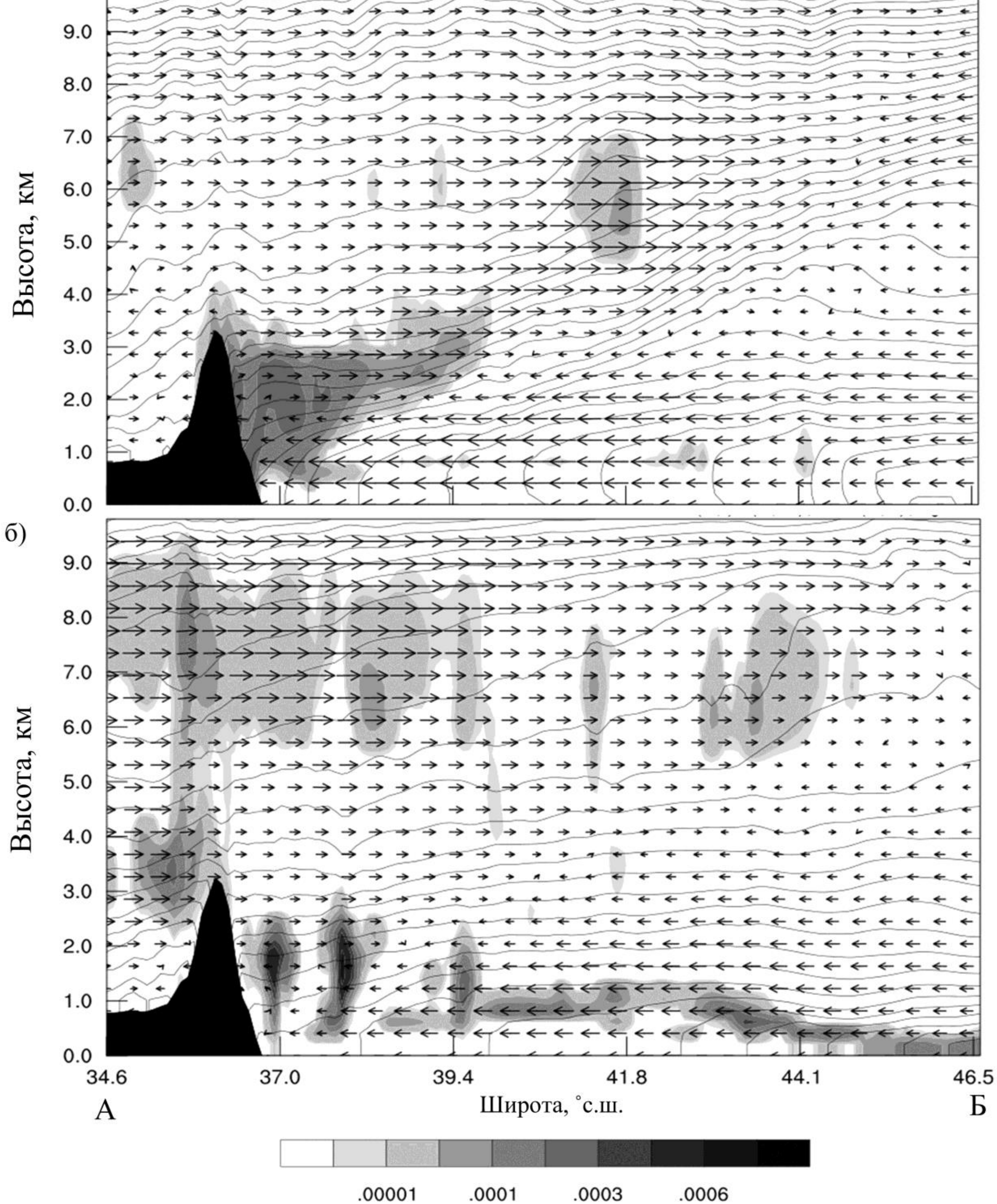
❖ The cold outbreak over the Caspian Sea itself makes a relatively small contribution to the increase in precipitation, while in the presence of mountain ranges, the moisture evaporated from the Caspian Sea surface converges, which leads to a sharp intensification of the lake effect (an increase in SST in the presence of a relief leads to a twofold increase in precipitation). Similar result was obtained, for example, for Lake Constance (Umek and Gohm 2016) and Great Salt Lake (Alcott and Steenburgh 2013).

❖ SST increase in the future climate, projected by the climate models, should lead to intensification of the lake effect. First of all, fraction of heavy and extreme precipitation will increase.

Thank you for attention!

Lake-effect conditions

SST: 13-18 ºC
ΔT: 18-28 ºC
Wind speed: 15-20 m/s, up to 25 m/s
Path length: 400-1000 km
LE: 300-450 W m^{-2}



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Высота, км
Высота, км
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
34.6
37.0
39.4
41.8
44.1
46.5
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