An analysis of Wintertime Cold-Air Pool in Armenia Using Climatological Observations and WRF Model Data

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ABSTRACT

The number of extreme weather events including strong frosts, cold waves, heat waves, droughts, hails, strong winds has increased in Armenia by 20% during the last 20 years. The paper studies the formation of cold-air pools in Ararat Valley, Armenia during the winter season. Observational data from 47 meteorological stations of Armenia were used, and daily minimum temperatures lower than -10 ^{0}C were assessed over the period 1966-2017. December, 2016 was considered as the 4-th coldest month, after the years 2013, 2002 and 1973. The focus area of this study is the low-elevated basin of Ararat Valley for which climatological analysis of winter temperature regime has been performed. Monthly average temperatures for December were significantly below normal values, particularly, for low-elevated part of Ararat Valley. 24-hour simulations derived from Weather Research and Forecasting model (WRF) were used to assess the WRF model's capabilities to reproduce strong cold-air pool (CAP) over the Ararat Valley observed on 20 December 2016 when minimum temperatures decreased up to -20 ^{0}C and lower. The WRF model was applied with spatial resolutions of 9 and 3 km and 65 vertical levels based on Global Forecast System model's (GFS) initial and boundary conditions at 0.25x0.25 deg. resolution.

Keywords

WRF model, cold-air pool, Ararat Valley, Armenia

1. INTRODUCTION

Climate change significantly impacts the territory of Armenia leading to increase in the number of extreme weather events including strong frosts, cold waves, heat waves, droughts, hails, strong winds. Thus, our estimates have shown that the number of extreme weather events has increased in Armenia by 20 % during the last 20 years. The WRF was applied to investigate the modeling aspects of severe weather events in Armenia. Previously topographically induced strong winds and CAPs have been studied based on WRF simulation results [1-3]. CAPs are considered as well known climatological feature of Ararat Valley (AV), particularly during the winter season. A strong temperature inversions and CAPs negatively impact agriculture and a number of socio-economic sectors. Formation of CAPs over AV is affected by both synoptic and local factors. Observational data indicate that the mean depth of CAPs in January consists of 680 meters. This situation contributes to tool high level of air pollution in Yerevan. Gevorgyan et al (2015) showed that the high-resolution WRF model has a clear advantage in modeling of CAPs in Armenia compared to relatively coarse general circulation models. However, WRF model fails to capture fine-scale processes associated with CAPs resulting in underestimation of intensity of observed CAPs over AV and significant positive biases in simulated near-surface temperatures. It should be noted that Gevorgyan et al (2015) used relatively coarse resolution GFS data for initialization of the WRF model. The spatial resolution in the GFS model was 0.5x0.5 deg. (50 km) and the WRF model was applied to directly downscale the data from 50 km to 3 km resolution. This study uses updated GFS model with two times higher spatial resolution (0.25x0.25 deg.) and two-step downscaling technique based on nesting capability of the WRF model. Those improvements are expected to increase the accuracy of simulation results derived from the WRF model over Armenia [2], [6].

2. DATA AND METHOD

This study uses observational data from 46 meteorological stations of Armenia. In order to study CAP over low-elevated parts of AV, 10 stations were considered (Table 1). Monthly, daily and sub-daily temperature observations were processed over a period of 1966-2017 estimating temporal variability of days with temperatures lower than -10 ^{0}C.

The WRF-ARW model version 3.8.1 [7] was applied. Initial and boundary conditions were derived from GFS analysis and forecasts with 0.25 deg. spatial resolution and three-hourly time-step. The updated GFS model version [9] was used (after January, 2015). Two-step nesting (one-way) was applied using two model domains centered over Yerevan at 9 and 3 km spatial resolutions, respectively (Fig. 1).

The 60 sigma levels have been employed with the 21 levels located within the lowest 1500 m layer, allowing for quite fine vertical resolution for CAP. The WRF Single-Moment 6-Class Microphysics scheme (WSM6), Dudhia shortwave radiation scheme, Rapid Radiative Transfer Model (RRTM) long wave radiation scheme, the Noah land-surface model and Grell-Freitas ensemble scheme cumulus parameterization option (only for the parent domain, while for 3-km nested domain the cumulus parameterization was turned off) have been selected.

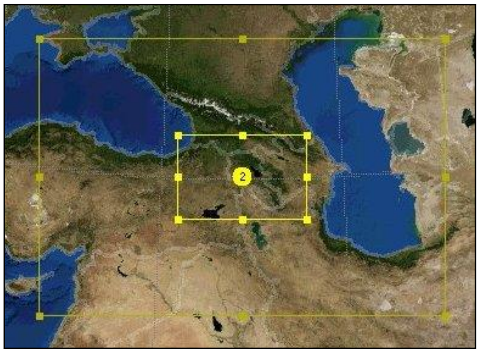
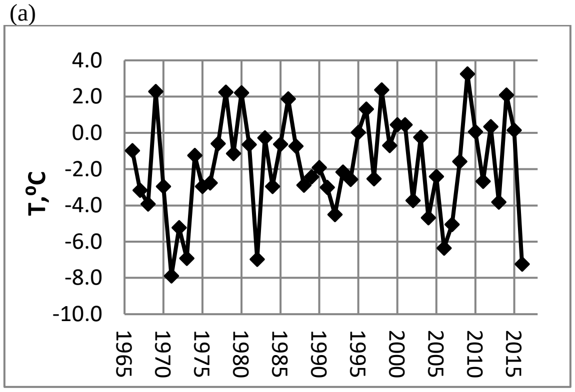


Fig. 1. The WRF model domains with 9 and 3 km spatial resolutions.

In order to simulate the typical boundary-layer process under consideration, two different PBL schemes, namely the turbulent kinetic energy (TKE) closure Mellor-Yamada-Janjic (MYJ) [5] and the non-local first order Yonsei University (YSU) [4] schemes, were tested. The selected PBL schemes have been extensively studied previously [6], [8]. The 36-hour WRF simulations started at 0000 UTC 19 December, 2016 were performed to simulate the observed CAP. The first 12 h were given as a spin-up time, and, thus, the simulation period from 1200 UTC 19 December to 1200 UTC 20 December is analyzed in Fig. 4a-b.

3. RESULTS OF CLIMATOLOGICAL ANALYSIS

Fig. 2a shows the interannual variability of mean winter temperatures at Yerevan Zvartnots station located in the lower parts of AV. It can be seen from Fig. 2a, that the second coldest winter season was observed in 2016-2017 after 1972-1973. On the other hand, 24 days with temperatures lower than -10 ^{0}C were observed during the winter 2016-2017 (Fig. 2b).



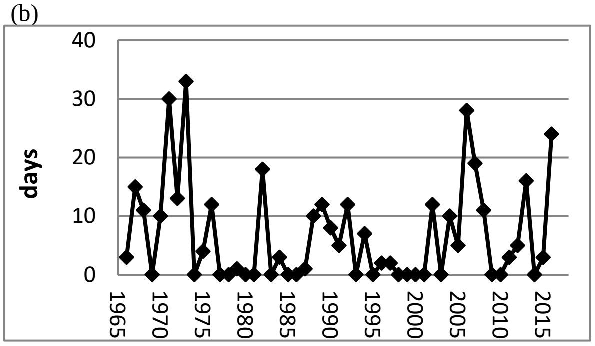


Fig. 2. Mean winter (December-February) temperatures (a) and the number of days with temperatures lower than -10 ^{0}C at Yerevan-Zvartnots station over 1966-2017

It can be seen from Table 1 that the highest number of cold days (lower than -10 ^{0}C) was observed over the low-elevated parts (lower than 1000 m above sea-level). The number of cold days varied from 19 to 27. Winter 2016-2017 was included in 10 coldest winters. Monthly mean temperatures for December (-4.5 ^{0}C), January (-8.7 ^{0}C), and February (-11.1 ^{0}C), were ranged as the 5-th, 5-th and 2-nd coldest months, respectively. It should be noted that lower than normal temperatures were observed for other stations of Armenia. Number of cold days at Yerevan-Zvartnots station consisted of 8, 7 and 9 for December, January and February, respectively. It should be noted that the cold weather led to significant damages for agriculture.

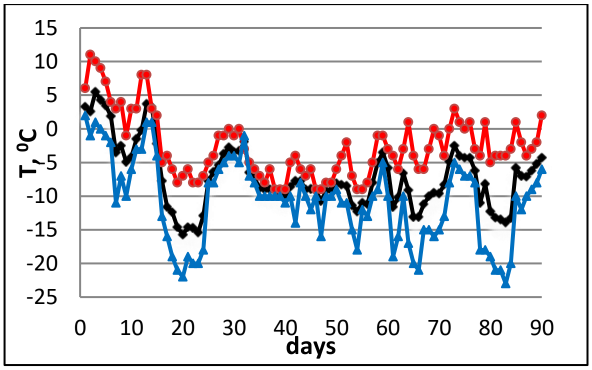


Fig. 3. Mean (black), minimum (blue) and maximum (red) daily temperatures observed during the 2016-2017 winter season at Yerevan-Zvartnots station.

Fig. 3 shows the temporal variability of mean, minimum and maximum daily temperatures observed at Yerevan-Zvartnots station. It can be seen from Fig. 3 that significant temperature drop was observed in the mid-December and mid-February when minimum daily temperatures were lower than -20 ^{0}C.

Table 1. The number of days with temperature lower than -10 ^{0}C in AV over 1966-2017

Meteo-rological stations	1966-2017					2016-2017 Number of days/rank			
	Hei-ght, m	XII	I	II	XII-II	XII	I	II	XII-II
Ararat	818	44	165	51	260	6/4	5/13	8/2	19/4
Artashat	829	46	150	70	343	7/4	7/10	8/3	22/4
Yerevan-Zvartnots	854	55	212	81	348	8/4	7/14	9/4	24/4
Armavir	870	51	188	83	322	7/4	8/12	8/5	23/4
Yerevan-Agro	942	72	317	98	415	8/5	9/13	10/3	27/4
Yerevan-Arabkir	1113	30	106	41	177	5/3	11/5	0/10	16/5
Eghvard	1321	50	121	79	250	7/3	19/1	6/3	32/2
Talin	1637	105	248	168	521	7/5	12/8	10/3	29/3

Table 2. Weather observations for 0300 UTC and 1200 UTC of 20 December at 10 meteorological stations in Armenia

Meteo-rological stations	Height, m	Temperature, ^{0}C		Wind, m s^{-1}		Relative humidity, %	
		03	12	03	12	03	12
Aragats h/m	3227	-24.8	-18.6	10	7	90	85
Amberd	2071	-20.4	-7.2	1	1	85	82
Talin	1637	-17	-10.4	0	2	85	74
Eghvard	1321	-18.3	-9.5	0	1	75	63
Yerevan-Arabkir	1113	-14.5	-7.7	0	1	90	62
Ashtarak	1090	-15.4	-8.6	1	2	85	71
Yerevan-Agro	942	-21.4	-8.6	0	1	80	54
Armavir	870	-20.4	-7.8	0	0	75	50
Yerevan-Zvartnots	854	-20.7	-9.7	0	0	84	57
Artashat	829	-18.6	-9	0	0	90	67
Ararat	818	-20	-7.6	0	0	90	68

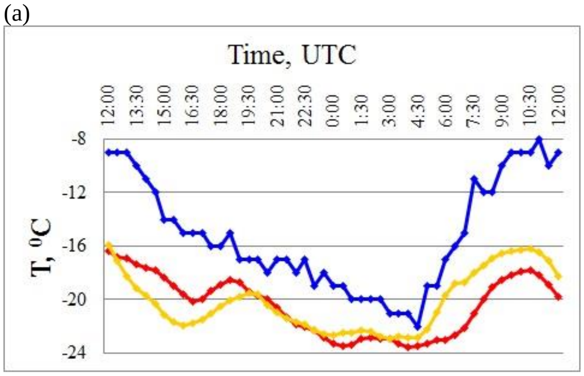
Table 2 shows that temperature increases with elevation by 3.5-4 ^{0}C in the morning (0300) from low elevated parts of the Ararat Valley (Yerevan-Zvartnots, Yerevan-Agro, Armavir) where temperatures were below -20 ^{0}C to highly elevated parts (Talin -17 ^{0}C). The depth of the inversion layer consisted of approximately 800 m. Despite low temperatures (-8 - -10 ^{0}C) maintained over low elevated stations during daytime, Table 2 shows that temperature inversion disappeared and temperature decreases with height.

Furthermore, calm wind conditions (0-1 m s^{-1}) prevailed within the inversion layer and high relative humidity was observed (75-90 %, Table 2). Such weather conditions lead to high air pollution.

4. SIMULATION OF COLD-AIR POOL IN ARMENIA

The results of WRF model simulations are presented in this section. The simulated and observed 2-meter temperatures at Yerevan-Zvartnots station from 1200 UTC 19 to 1200 UTC 20 December 2016 are shown in Fig. 4a. Although diurnal variation of temperature is generally captured by both MYJ and YSU PBL schemes, near-surface temperatures are significantly underestimated in the WRF model. It should be noted the YSU scheme outperforms the MYJ scheme showing lower negative biases in temperatures during the morning and daytime of 20 December. The observed and modeled minimum temperatures are in close agreement varying from -22 to -24 ^{0}C. It is worth noting that there are strong relationships between the observed and simulated 30-min temperatures with correlation coefficients consisting of 0.85 and 0.88 for MYJ and YSU, respectively. On the other hand, mean biases in modeled temperatures are significant consisting of -5.3 and -5.0 ^{0}C for MYJ and YSU.

(a)



(b)

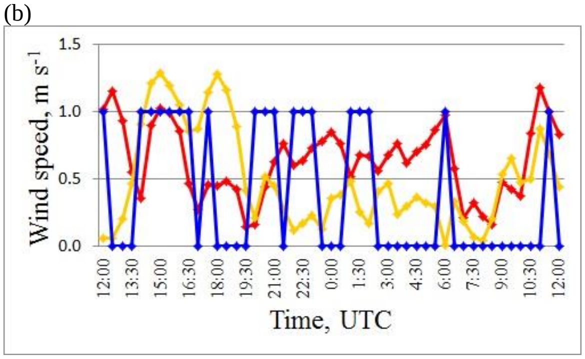


Fig. 4. 30-min temperature (a) and wind (b) observations (blue) and WRF simulations derived from MYJ (red) and YSU (orange) at Yerevan-Zvartnots station from 1200 UTC 19 December to 1200 UTC 20 December 2016.

Fig. 4b shows that calm wind conditions prevailed during the considered strong temperatures event. Both the observed and the modeled winds vary between 0 and 1 m s^{-1}. MYJ simulates slightly higher winds compared to the YSU scheme.

In order to further examine the performance of WRF model spatial distributions of near-surface temperatures simulated by WRF model are presented in Fig. 5a-b. The early morning time simulations are considered when the minimum temperatures are observed in Armenia. The YSU and MYJ simulate significantly different spatial temperature patterns over Armenia with MYJ-derived temperatures being substantially colder than the YSU ones. It can be seen from Fig. 5a that the MYJ scheme is able to capture cold-air pool formed over low-elevated parts of the Ararat Valley (south western to Yerevan) and over Shirak plain (western part of

Armenia) characterized by colder morning temperatures (lower than -25 ^{0}C). On the other hand, YSU fails to simulate the topographically induced CAP (Fig. 5b).

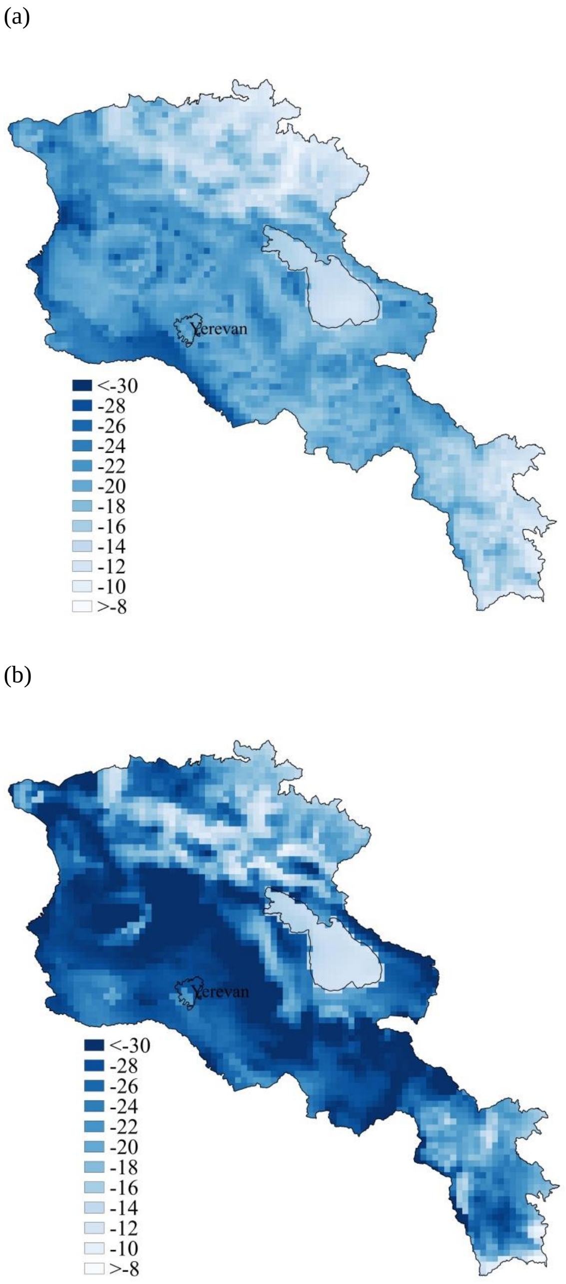


Fig. 5. Spatial maps of 2-meter temperatures over Armenia simulated by MYJ (a) and YSU (b). The results of 27-hour (at 0300 UTC 20 December 2017) simulations are presented

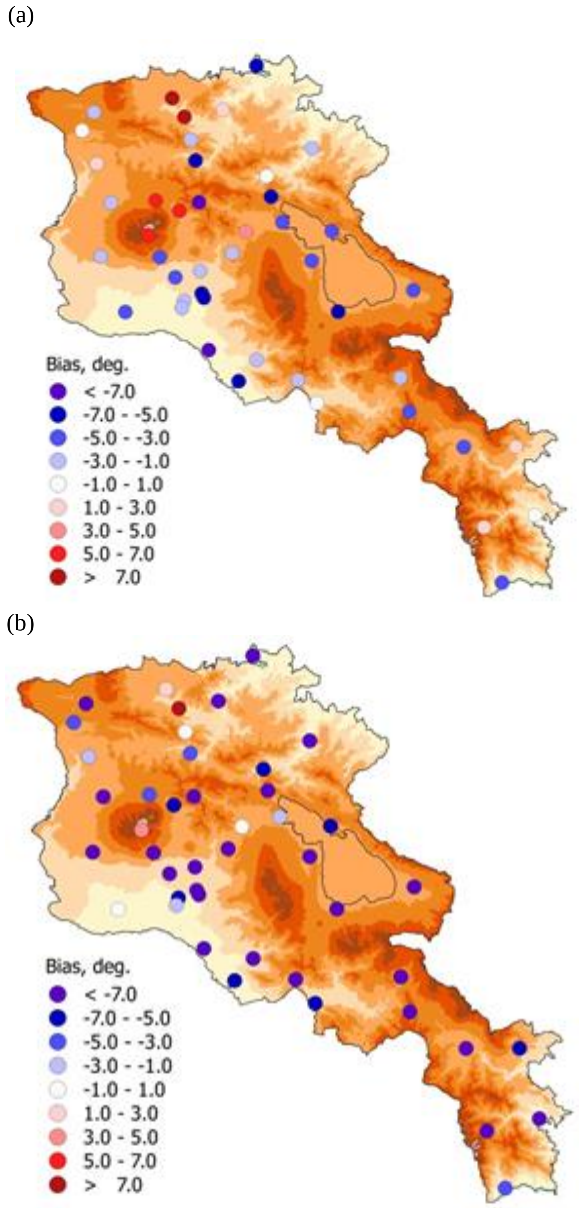


Fig. 6. Biases in 2-meter temperatures simulated by the MYJ (a) and YSU (b) schemes relative to stations observations at 0300 UTC 20 December, 2016

Fig. 6a and b show that negative biases in 2-meter temperature are present in WRF simulations. However, the negative temperature biases are significantly reduced in MYJ scheme at most of the stations in Armenia. The negative temperature biases at a significant number of stations consist of -7 ^{0}C and lower for the YSU scheme (Fig. 6b) including stations within the observed CAP. It should be noted that the MYJ scheme mostly underestimates the observed temperatures in Armenia as well (Fig. 6a).

5. CONCLUSIONS AND DISCUSSIONS

Climatological analysis of wintertime temperature regime over the Ararat Valley showed that low-level and near-surface temperature inversions play an important role in this area. Overall, both this and the previous studies [1-2] underscores the importance of observational and modeling studies of mesoscale processes in Armenia and South Caucasus region. During the December, January and February months cold temperatures most often are associated with local CAPs. During such situations near-surface temperatures in Ararat Valley increase in height from 800 to 1400 meters about sea-level within CAPs affecting Yerevan.

Simulation of strong CAP observed from 19 to 20 December 2016 showed that significant negative temperature biases are present in WRF model results. However, it has been shown that MYJ PBL scheme outperforms the MYJ scheme in simulating the spatial pattern of CAP over the Ararat Valley, while the YSU scheme simulates significantly colder temperatures over entire Armenia with negative temperature biases lower than -7 ^{0}C at most of the stations. However, on the positive side, both YSU and MYJ successfully reproduce diurnal variations of temperatures at Yerevan-Zvartnots station strongly affected by CAP with correlation coefficients between the observed and the simulated 30-min temperatures exceeding 0.8. Further work is needed to improve topographically induced mesoscale circulations and processes in Armenia. To this end increasing spatial resolution (up to 1 km), improving initial and boundary conditions in WRF model as well as considering further sensitivity experiments should be performed.

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