Atmospheric Research 227 (2019) 140–146

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Agriculture intensification increases summer precipitation in Tianshan Mountains, China

Peng Cai[a,b,c,d,g], Rafiq Hamdi[a,e,f], Geping Luo[a,c,*], Huili He[a,b,c,d,g], Miao Zhang[a], Piet Termonia[e,f], Philippe De Maeyer[b,d,g]

[a] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Xinjiang, China
[b] Department of Geography, Ghent University, Gent, Belgium
[c] University of Chinese Academy of Science, Beijing, China
[d] Sino-Belgian Joint Laboratory of Geo-information, Urumqi, China
[e] Royal Meteorological Institute, Brussels, Belgium
[f] Department of Physics and Astronomy, Ghent University, Ghent, Belgium
[g] Sino-Belgian Joint Laboratory of Geo-information, Gent, Belgium

ARTICLE INFO

Keywords:
LULCC
Convective precipitation
Tianshan Mountains
Mountain-plain wind
ALARO-SURFEX

ABSTRACT

The land-use and land-cover change has a significant impact on the climate at different spatio-temporal scales. In this study, we explored the long term oasis expansion effects on regional summer precipitation in the north slope of Tianshan Mountains, China using high-resolution regional climate model. The results indicate that the oasis expansion increases the summer precipitation in the middle Tianshan Mountains while it has only a small effect over the oasis regions itself. The results indicate further that the oasis expansion affects mainly the late afternoon summer convective precipitation. The advection of air with additional moisture from the oasis areas to the mountains due to the mountain/plain circulation system during the day triggers the orographic precipitation in the middle mountain regions. These new results indicate that the oasis expansion could attribute significantly to the recent finding from observational studies about the increasing trend of precipitation in the middle Tianshan Mountains.

1. Introduction

The land-use and land-cover change (LULCC) alters surface energy and moisture budgets and has significant impacts on the climate on local, regional, sub-continental and global scale (Chase et al., 1999; Davin et al., 2007; de Vrese et al., 2016; Lawrence and Chase, 2010; Lawrence et al., 2012; Lee et al., 2009; Pielke and Avissar, 1990; Pongratz et al., 2010; Quesada and Arneth, 2017; Stohlgren et al., 1998). Recently, both the local and remote effects on precipitation from the conversion of natural land cover to irrigated agriculture lands have got wide attention. For example, Cook et al. (2014) explored the irrigation effects using a global climate model. They found that irrigation enhanced cloud cover and precipitation in Western North America, the Mediterranean and the Middle East while it caused a reduction in summer Monsoon precipitation over Asia. On intercontinental and transcontinental scale, de Vrese et al. (2016) found that the precipitation in some of the arid regions in Eastern Africa is related to irrigation-based agriculture in Asia. Moreover, on regional scale, both observational and model simulation studies indicate that irrigated agriculture expansion in the central United States has resulted in an increase of summer precipitation in the Midwestern United States, situated hundred miles downwind (Alter et al., 2015; DeAngelis et al., 2010; Harding et al., 2013; Lo and Famiglietti, 2013; Moore and Rojstaczer, 2002; Yun et al., 2013). The irrigated agriculture effects on local, regional and sub-continental precipitation have been shown in other regions, including India (Roy et al., 2011), Australia (Hirsch et al., 2015; Nair et al., 2011) and Southeast Asia (Quesada et al., 2017; Shukla et al., 2014; Xu et al., 2015). Mahmood et al. (2014) suggested that the crop phenology, ambient atmospheric moisture content and background synoptic-scale atmospheric circulation are critical for triggering convective cloud and precipitation development in agriculture areas. For example, Chase et al. (1999) showed that the land use changes in the adjacent Great Plains affected the cloud cover and precipitation in the mountain regions through altering the local mountain-plains

---

[*] Corresponding author at: State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Xinjiang, China.

E-mail address: luogp@ms.xjb.ac.cn (G. Luo).

https://doi.org/10.1016/j.atmosres.2019.05.005
Received 22 April 2019; Accepted 3 May 2019

circulation.

The Mountain-Oasis-Desert System (MODS) is characterized by the presence of Mountains which act as a water tower for the oases that are spread between the Mountains and the surrounding background desert. MODS are widely spread in the arid area of Central Asia (CA, including Kyrgyzstan, Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan and the Xinjiang province of China). The oasis, an intrazonal landscape, consists mainly of irrigated agricultural lands (> 90%) (Zhang et al., 2017), and is the essence of arid areas and the main human settlements and socioeconomic activity area. Since the 1950s, the oasis has expanded significantly, from the conversion of natural grass and bare land, accompanied by a series of environmental problems such as the desiccation of the Aral Sea, the scarcity of water resources, soil erosion and salinization, dust storms and desertification (Micklin, 1988). However, with the implication of the Belt and Road initiative in this region, the oasis expansion might be enhanced in the future. Moreover, the ecosystems in this region are very fragile and sensitive to climate change and human activities. Thus, it's very urgent to explore how the historical human activities, especially the oasis expansion, impact the local climate.

Using long-term meteorological and hydrological stations, Deng et al. (2015) found that summer (JJA) precipitation account for approximately 66% of the annual precipitation in the Tianshan Mountains, including the oasis (< 1500 m), the middle (1500–2200 m) and high mountain regions (> 2200 m). They found that in summer, the precipitation presented a decreasing trend for the past 50 years, while the middle mountains precipitation experienced an increasing trend. Similar results are found by Yao et al. (2016). They found that when grouping the stations' altitude using 500 m interval, the precipitation trend increases significantly with elevation with the highest correlation being from 1500 to 2000 m. Based on observations data, other studies have investigated the precipitations trend in the Tianshan Mountains. Zhang et al. (2009) found that increasing trend in annual precipitation are found for middle to high elevation stations. Guo and Li (2015) found that precipitation has experienced an increasing trend with an acceleration of the trend since the middle of 1980s. They found that the precipitation increased coherently in the north slope of the middle Tianshan mountains with elevation in the range between 1500 and 2500 m. Based on meteorological stations records during 1960–2016, Xu et al. (2018) found that Tianshan mountains experienced a wetting trend with an average wet rate of 5.82 mm/decade. The increased magnitude of annual precipitation were highest in the elevation range between 1500 and 2000 m (9.22 mm/decade) and the lowest for elevation below 500 m (3.45 mm/decade). During the summer, the elevation dependency of the increasing trend was the highest.

Most of the above mentioned studies have tried to link the precipitation trend to large scale circulations. However, how the oasis expansion might alter the local and regional precipitation trend, has never been explored. The aim of this study is, therefore, to explore to what extent the historical oasis expansion during the period 1986–2016 has affected the local summer precipitation trend using regional climate model simulations at high spatial resolution.

2. Methods

2.1. Study area

The Tianshan Mountains, located in the hinterland of CA, is the largest mountain range in the world arid area. It lies in the central part of Xinjiang province and is surrounded by two deserts, Gurbantunggut desert in the north and Taklimakan desert in the south, forming several typical MODSs, including the MODS in the north slope of the Tianshan Mountains (see Fig. 1a) which is the focus of our study area. With the rapid development of the economy and the increase of the population, the oasis area in the north slope of Tianshan Mountains has increased by > 4 times since the 1950s, resulting in a significant LULCC (Zhang et al., 2017). The study area is situated between 84°50′E and 89°08′E and 46°15′N and 43°18′N, with a total area of 99,792 km^2 (Fig. 1a). This region is a typical continental arid and semi-arid climate, with a mean annual temperature around 6 °C and an annual precipitation amount around 220 mm. In the past 50 years, the climate in this region has experienced a warmer and wetter trend (Hu et al., 2013; Li et al., 2011; Xu et al., 2010), which will continue in the future according to future climate projections (Luo et al., 2018). Our study area contains 2 oases covering an area of 220 km × 75 km and 40 km × 25 km (Fig. 1a).

2.2. Model and experiments

The climate model ALARO, is a new version of the Aire Limitée Adaptation Dynamique Développement International (ALADIN) model with updated physical parameterizations to enable simulations at 3–10 km mesh-size (Termonia et al., 2018), has been used at the Royal Meteorological Institute of Belgium for the operational numerical weather prediction applications since 2010, and for regional climate modeling as well (Berckmans et al., 2017; De Troch et al., 2013; Giot et al., 2016; Hamdi et al., 2012; Termonia et al., 2018). The land surface model SURFEX, which consists of the ISBA (Interactions between Soil, Biosphere and Atmosphere) (Noilhan and Planton, 1989) scheme for natural surfaces and the TEB (Town Energy Balance) (Masson, 2000) scheme for urban surfaces, has been implemented in the ALARO-0 model (Hamdi et al., 2014b). The combined ALARO-SURFEX model has shown its potential for representing the regional climate and land surface processes (Berckmans et al., 2017; Hamdi et al., 2014a, 2016; Hamdi et al., 2015).

The model is driven by the global reanalysis dataset ERA-Interim and run at a horizontal resolution of 50 km with 169 × 117 grid points within a domain that encompasses most of Asia (D1 in Fig. 1c). Then, the outputs were used to drive the ALARO-SURFEX model on a smaller domain nested within the outer domain (D1) at a horizontal resolution of 4 km with 500 × 500 grid points (D2 in Fig. 1b and c). This inner domain (D2) covers the three Mountains that are Altai Mountains in the north, Tianshan Mountains in the central and Kunlun Mountains in the south of Xinjiang province, and the north part of the Tibetan Plateau in order to capture the synoptic-scale features. Our main region of interest is located in the central area of the inner domain (Fig. 1a and b).

During the 31 summers (1986–2016), two simulations have been performed: (i) CTL where the land use/cover presents the current situation of the oasis areas in the study region and (ii) NO_OASIS where the oasis areas have been replaced by the surrounding desert. The difference CTL-NO_OASIS is used to detect the potential effect of oasis expansion on the summer precipitation. In order to make the simulated oasis expansion effects more confident, we use the student-test to calculate the significance of oasis expansion effects on each grid point and only present the grid points with $p < 0.001$.

2.3. Data

The initial and lateral boundary conditions for the meteorological fields are derived from the global atmospheric reanalysis product ERA-Interim at 6-h interval (Dee et al., 2011). The land cover data and corresponding land surface parameters for the SURFEX model is provided by the ECOCLIMAP dataset (Masson et al., 2003), in which the global 1 km resolution land cover data is divided into 573 types (243 types for version I) based on satellite observations (Faroux et al., 2013). We updated the land cover data of ECOCLIMAP using the land cover data generated by the Xinjiang Institute of Ecology and Geography (XIEG), Chinese Academy of Sciences (Fig. 2) (Wang et al., 2014).

3. Results

3.1. Spatial patterns of oasis expansion effects on precipitation

Fig. 3a presents the oasis expansion effect on the averaged summer

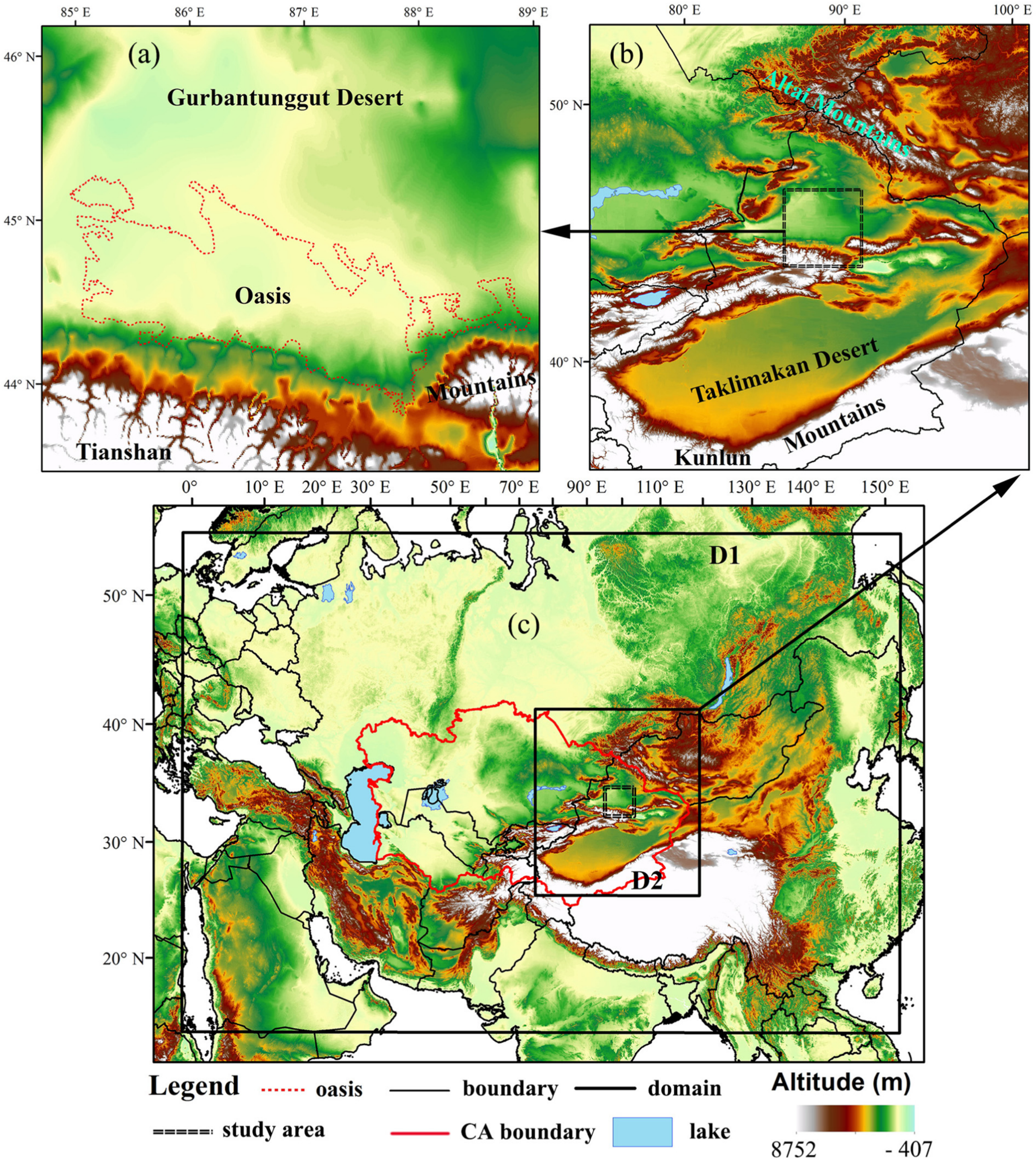

Fig. 1. The location of our study area (a), the topography of Xinjiang province (b) and the two-nested ALARO modeling domains and Central Asia (CA) regions (c). The shaded contour represents altitude.

precipitation during the period 1981–2016 computed from the difference CTL-NO_OASIS. Only grid point with a statistically significant change are shown in the plot. As seen from Fig. 3, the oasis expansion enhances significantly the summer precipitation in the mountain areas for the grid points with elevation mostly above 1300 m and below 2800 m. The results show a slight decrease of the summer precipitations for grid points with elevation higher than 3000 m, and almost a neutral effect in the desert area. Within the oasis area, the results show a significant increase in precipitation in some areas but a neutral effect for most parts. The average positive effects of oasis expansion in the oasis and the middle mountain areas are 3.20 mm and 8.00 mm, respectively, while the average negative effect in the high mountain areas is −1.45 mm.

We further explored the oasis expansion effects on both convective and large scale precipitation as shown in Fig. 3b and Fig. 3c. It is clearly seen that the oasis expansion has a greater effect on the summer convective precipitation which accounts for 76.5% of the total precipitation. The pattern of the impact on large scale precipitation is similar to the convective precipitation but with much smaller values with an average value of 1.69 mm. There is also more large scale precipitation impact over the oasis areas and on some part of the desert.

In order to further illustrate the different impact of the oasis expansion on both convective and large scale precipitation, we present in Fig. 3d the summer precipitation computed from the difference CTL-NO_OASIS as a function of the elevation in each grid point where a statistically significant difference is found. In agreement with the

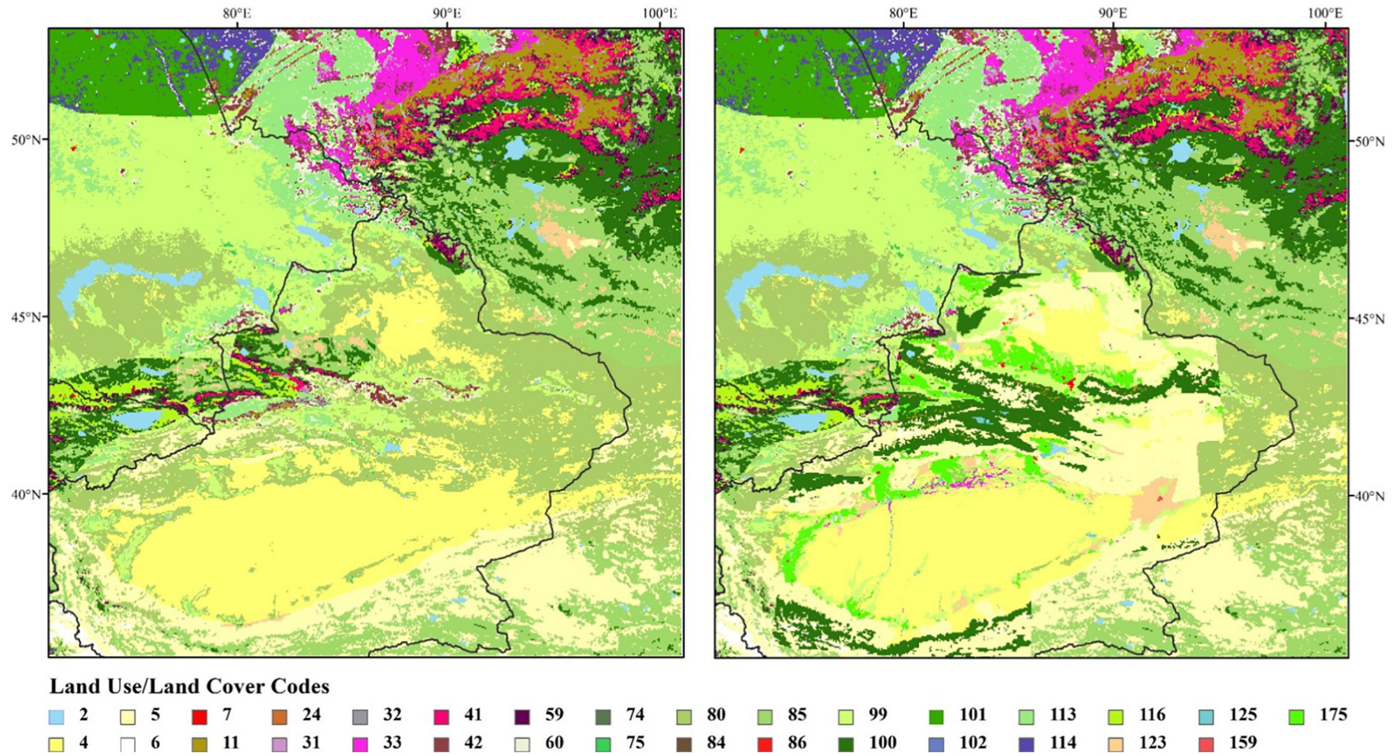

Fig. 2. The default land cover data from ECOCLIMAP (a) and the updated land cover data using the XIEG land cover database (b). 2: Inland waters; 4: Bare land; 5: Rocks; 6: Permanent snow and ice; 7: Urban and built-up; 11: Boreal Evergreen Needle leaf Forest; 24: Asian boreal Deciduous Needleleaf Forest; 31: North Hemisphere (NH) Subpolar Mixed Forest; 32: NH Humid subtropical Mixed Forest; 33: NH Continental Mixed Forest; 41: NH Subpolar Wood Land; 42: NH Continental Wood Land; 59: NH Subpolar Wooded Grassland; 60: NH Continental Wooded Grassland; 74: Asia polar Closed Shrubland; 75: Asia continental Closed Shrubland; 80: NH arid Open Shrubland; 84: Asia dry tropical Open Shrubland; 85: NH Polar Open Shrubland; 86: N-America Subpolar Open Shrubland; 99: NH semiarid Continental Grassland; 100: Asia Subpolar Grassland; 101: Asia humid Continental Grassland; 102: Asia semiarid tropical Grassland; 113: N-Amer., Asia semiarid continental Crops; 114: Asia humid continental Crops; 116: Asia subpolar Crops; 123: Bare soil with sparse polar vegetation; 125: Subpolar wetlands; 159: Mineral extraction, construction sites; 175: Irrigated crops.

previous results, the oasis expansion produces mainly an increase of summer convective and large scale precipitation for grid points with elevation below 2800 m. For grid point with elevation between 2800 m and 4000 m, there is both a slight increase and decrease of the convective and large scale precipitation. For grid point above 4000 m, there is a slight decrease in both precipitation types. As expected, the oasis expansion effect on large scale precipitation did not increase with the elevation and stays below 5 mm for almost all grid points. However, the convective precipitation increases with elevation with a difference up to 32 mm for a grid point with 2000 m elevation. The summer mean convective precipitation induced by the oasis expansion impact is mostly between 5 mm and 15 mm for grid points located below 1800 m of altitude.

3.2. *Temporal patterns of oasis expansion effects on precipitation*

Fig. 4 shows the hourly summer convective and large scale precipitation during the period 1981–2016 computed from the difference CTL-NO_OASIS. During nighttime, the oasis expansion effect on both convective and large scale precipitation is similar and stay below 0.2 mm. From 1200 (local time, LT) and up to 1600 LT, the convective precipitation is increasing reaching a maximum of 0.42 mm at 1600 LT while the impact on large scale precipitation is very small and stay below 0.1 mm up to 2300 LT. From 1700 LT until 2300 LT, the impact of the oasis expansion on convective precipitation decreases with time.

In Fig. 5, we present the impact of oasis expansion on a rainfall event on July 17th, 2007. Fig. 5a shows the spatial pattern of wind speed and specific humidity at the lowest model level at 2000 LT computed by the CTR simulation and Fig. 5b presents the specific humidity cross section computed from the difference CTL-NO_OASIS along AB at the same time. Latent fluxes were larger over the oasis areas with the CTR simulation with a maximum value of 400 w m^{-2} at 1500 LT (not shown). While sensible fluxes were lower with a maximum decrease of 120 w m^{-2}. The oasis expansion increases the evapotranspiration that enhances the moisture supply to the lower boundary layer (see Fig. 5a). Within the MODS, the mountain-plain wind circulation between the oasis and the mountain areas induces the advection of air with additional moisture (see Fig. 5b) and moist static energy (not shown) from the oasis areas to the mountain regions which is more convectively favorable and triggers, therefore, more orographic precipitation in the middle mountain regions.

4. Conclusion and discussions

We investigated the oasis expansion effects on local summer precipitation in the north slope of Tianshan Mountains, China by performing a sensitivity experiment for 31 summers during the period 1986–2016. In order to detect the maximum effect of oasis expansion on the summer precipitation, two simulations are performed: (i) CTL where the land use/cover presents the current situation of the oasis areas in the study region and (ii) NO_OASIS where the oasis areas have been replaced by the surrounding desert. The results show that the oasis expansion increases the summer precipitation mainly in the middle mountain regions and has only a small effect over the oasis regions itself. These results indicate that the oasis expansion could attribute significantly to the recent finding from observational studies about the increasing trend of precipitation in the middle Tianshan Mountains.

We further explored the oasis expansion effects on convective and

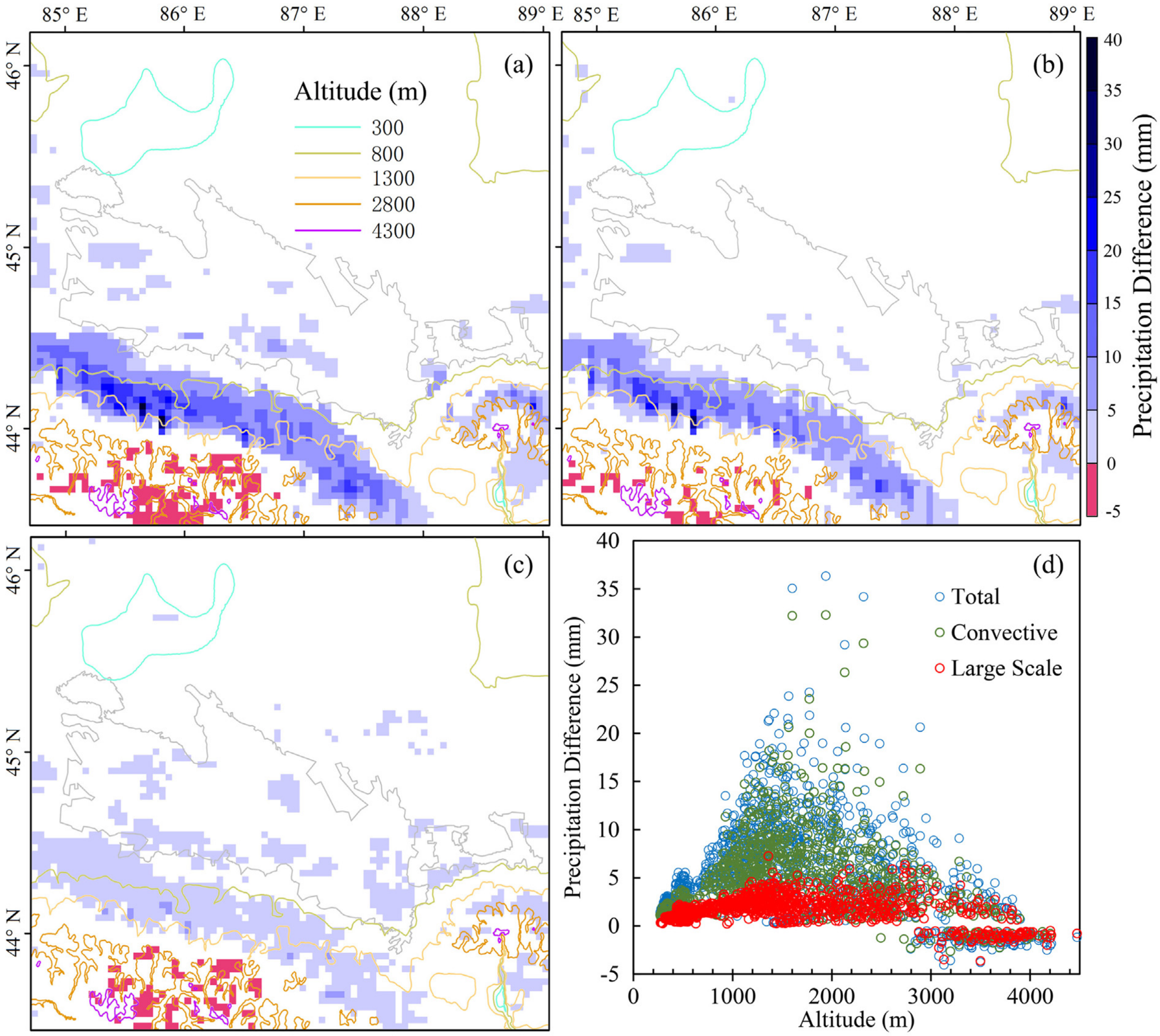

Fig. 3. The averaged summer precipitation during the period 1981–2016 computed from the difference CTL-NO_OASIS (a) total, (b) convective, (c) large scale. (d) The precipitation difference CTL-NO_OASIS as a function of the elevation in each grid point where a statistically significant difference is found. Only grid point with a statistically significant change ($p < 0.001$) are shown in the (a), (b) and (c) plots.

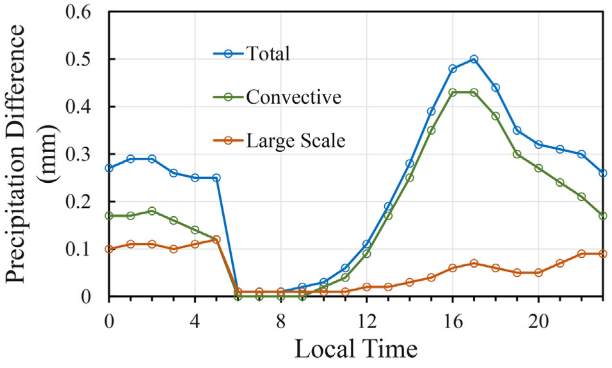

Fig. 4. The hourly summer total, convective and large scale precipitation averaged during the period 1981–2016 computed from the difference CTL-NO_OASIS.

large scale precipitation. The results indicate that the oasis expansion affects mainly the convective precipitation. The advection of air with additional moisture and moist static energy from the oasis areas to the mountains due to the mountain/plain circulation system during the day triggers the orographic precipitation in the middle mountain regions (Chase et al., 1999).

In the arid CA, water is valuable and essential for the local ecosystems and society. Within the mountains-oasis-desert system, the mountains area has a significant importance for the surviving of the oasis and determines the scale of the oasis since it acts as the water source for the oasis (Chen and Luo, 2008). The oasis expansion increases the summer precipitation in the middle mountains area, which will increase the runoff from the mountains. So, there is a positive feedback between the oasis expansion and the mountainous precipitation. Although, to a certain extent, this positive feedback could alleviate the water shortage in the oasis, the melt water from snow and glaciers in the high mountains is much more important for the water security for the long time (Duethmann et al., 2015).

The oasis expansion is expected to continue in the future with the development of economy and technology under the promotion of the Belt and Road initiative. Thus, the oasis expansion will affect the local climate. Moreover, the ecosystems in arid CA are very fragile and sensitive to the climate change and human activities (Han et al., 2016; Jiang et al., 2019; Li et al., 2018; Li et al., 2015). How to keep the stability of the ecosystems and develop the oasis in a sustainable way are very crucial under the limitation of the water resource.

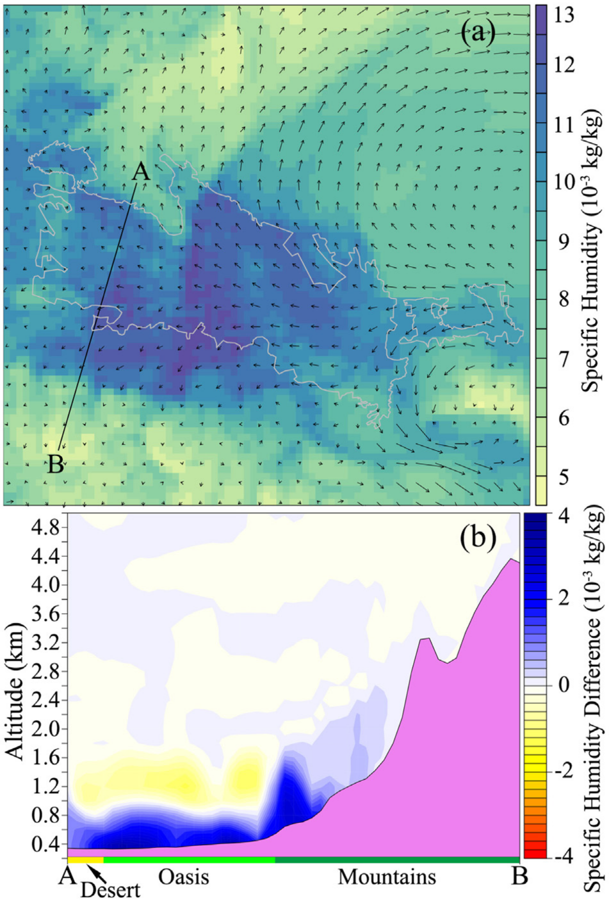

Fig. 5. (a) The spatial pattern of wind speed and specific humidity at the lowest model level at 2000 LT computed by the CTR simulation and (b) presents the specific humidity cross section computed from the difference CTL-NO_OASIS along AB at the same time.

Acknowledgments

This work was supported financially by the National Natural Science Foundation of China (Grant No. 41671108) and the International Partnership Program of the Chinese Academy of Sciences (Grant No. 131965KYSB20160004). Rafiq Hamdi is supported by the China Academy of Sciences President's International Fellowship Initiative (PIFI) (Grant No. 2018VMB0006). We are very grateful to the reviewers for their careful review and valuable comments. All land-use cover data, simulation data, inputs data will be offered promptly upon request.

References

Alter, R.E., Fan, Y., Lintner, B.R., Weaver, C.P., 2015. Observational evidence that Great Plains irrigation has enhanced summer precipitation intensity and totals in the Midwestern US. J. Hydrometeorol. 16 (4), 150127131517005.

Berckmans, J., et al., 2017. Reinitialised versus continuous regional climate simulations using ALARO-0 coupled to the land surface model SURFEXv5. Geosci. Model Dev. 10 (1), 223–238.

Chase, T.N., Pielke Sr., R.A., Kittel, T.G.F., Baron, J.S., Stohlgren, T.J., 1999. Potential impacts on Colorado rocky mountain weather due to land use changes on the adjacent Great Plains. J. Geophys. Res. 104 (D14), 16673–16690.

Chen, X., Luo, G., 2008. Researches and progress of oasis ecology in arid areas [J]. Arid Land. Geography 4, 007.

Cook, B.I., Shukla, S.P., Puma, M.J., Nazarenko, L.S., 2014. Irrigation as an historical climate forcing. Clim. Dyn. 44 (5), 1715–1730.

Davin, E.L., de Noblet-Ducoudré, N., Friedlingstein, P., 2007. Impact of land cover change on surface climate: Relevance of the radiative forcing concept. Geophys. Res. Lett. 34 (13).

De Troch, R., Hamdi, R., Van de Vyver, H., Geleyn, J.-F., Termonia, P., 2013. Multiscale performance of the ALARO-0 model for simulating extreme summer precipitation climatology in Belgium. J. Clim. 26 (22), 8895–8915.

de Vrese, P., Hagemann, S., Claussen, M., 2016. Asian irrigation, African rain: Remote impacts of irrigation. Geophys. Res. Lett. 43 (8), 3737–3745.

DeAngelis, A., et al., 2010. Evidence of enhanced precipitation due to irrigation over the Great Plains of the United States. J. Geophys. Res. 115 (D15).

Dee, D.P., et al., 2011. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. Q. J. R. Meteorol. Soc. 137 (656), 553–597.

Deng, H., Chen, Y., Wang, H., Zhang, S., 2015. Climate change with elevation and its potential impact on water resources in the Tianshan Mountains, Central Asia. Glob. Planet. Chang. 135, 28–37.

Duethmann, D., et al., 2015. Attribution of streamflow trends in snow and glacier melt-dominated catchments of the Tarim River, Central Asia. Water Resour. Res. 51 (6), 4727–4750.

Faroux, S., et al., 2013. ECOCLIMAP-II/Europe: a twofold database of ecosystems and surface parameters at 1 km resolution based on satellite information for use in land surface, meteorological and climate models. Geosci. Model Dev. 6 (2), 563–582.

Giot, O., et al., 2016. Validation of the ALARO-0 model within the EURO-CORDEX framework. Geosci. Model Dev. 9 (3), 1143–1152.

Guo, L., Li, L., Variation of the proportion of precipitation occurring as snow in the Tian Shan Mountains, China, (2015) 1379–1393.

Hamdi, R., Van de Vyver, H., Termonia, P., 2012. New cloud and microphysics parameterisation for use in high-resolution dynamical downscaling: application for summer extreme temperature over Belgium. Int. J. Climatol. 32 (13), 2051–2065.

Hamdi, R., et al., 2014a. Evaluating the performance of SURFEXv5 as a new land surface scheme for the ALADINcy36 and ALARO-0 models. Geosci. Model Dev. 7 (1), 23–39.

Hamdi, R., Van de Vyver, H., De Troch, R., Termonia, P., 2014b. Assessment of three dynamical urban climate downscaling methods: Brussels's future urban heat island under an A1B emission scenario. Int. J. Climatol. 34 (4), 978–999.

Hamdi, R., Giot, O., De Troch, R., Deckmyn, A., Termonia, P., 2015. Future climate of Brussels and Paris for the 2050s under the A1B scenario. Urban Clim 12, 160–182.

Hamdi, R., et al., 2016. Evolution of urban heat wave intensity for the Brussels Capital Region in the ARPEGE-Climat A1B scenario. Urban Clim. 17, 176–195.

Han, Q., et al., 2016. Simulated grazing effects on carbon emission in Central Asia. Agric. For. Meteorol. 216, 203–214.

Harding, K.J., Snyder, P.K., Liess, S., 2013. Use of dynamical downscaling to improve the simulation of Central U.S. warm season precipitation in CMIP5 models. J. Geophys. Res. 118 (22), 12,522–512,536.

Hirsch, A.L., Pitman, A.J., Kala, J., 2015. The role of land cover change in modulating the soil moisture-temperature land-atmosphere coupling strength over Australia. Geophys. Res. Lett. 41 (16), 5883–5890.

Hu, Z., Zhang, C., Hu, Q., Tian, H., 2013. Temperature changes in Central Asia from 1979 to 2011 based on Multiple Datasets*. J. Clim. 27 (3), 1143–1167.

Jiang, L.L., et al., 2019. Monitoring land sensitivity to desertification in Central Asia: convergence or divergence? Sci. Total Environ. 658, 669–683.

Lawrence, P.J., Chase, T.N., 2010. Investigating the climate impacts of global land cover change in the community climate system model. Int. J. Climatol. 30 (13), 2066–2087.

Lawrence, P.J., et al., 2012. Simulating the biogeochemical and biogeophysical Impacts of transient land cover change and wood harvest in the Community Climate System Model (CCSM4) from 1850 to 2100. J. Clim. 25 (9), 3071–3095.

Lee, E., et al., 2009. Effects of irrigation and vegetation activity on early Indian summer monsoon variability. Int. J. Climatol. 29 (4), 573–581.

Li, Q., Chen, Y., Shen, Y., Li, X., Xu, J., 2011. Spatial and temporal trends of climate change in Xinjiang, China. J. Geogr. Sci. 21 (6), 1007.

Li, C., et al., 2015. Carbon stock and its responses to climate change in Central Asia. Glob. Chang. Biol. 21 (5), 1951–1967.

Li, C., et al., 2018. Effects of cropland conversion and climate change on agrosystem carbon balance of China's dryland: a typical watershed study. Sustainability 10 (12).

Lo, M.-H., Famiglietti, J.S., 2013. Irrigation in California's central valley strengthens the southwestern U.S. water cycle. Geophys. Res. Lett. 40 (2), 301–306.

Luo, M., et al., 2018. Defining spatiotemporal characteristics of climate change trends from downscaled GCMs ensembles: how climate change reacts in Xinjiang, China. Int. J. Climatol. 38 (5), 2538–2553.

Mahmood, R., et al., 2014. Land cover changes and their biogeophysical effects on climate. Int. J. Climatol. 34 (4), 929–953.

Masson, V., 2000. A physically-based scheme for the urban energy budget in atmospheric models. Bound.-Layer Meteorol. 94 (3), 357–397.

Masson, V., Champeaux, J.-L., Chauvin, F., Meriguet, C., Lacaze, R., 2003. A global database of land surface parameters at 1-km resolution in meteorological and climate models. J. Clim. 16 (9), 1261–1282.

Micklin, P.P., 1988. Desiccation of the Aral Sea: a water management disaster in the soviet union. Science 241 (4870), 1170–1176.

Moore, N., Rojstaczer, S., 2002. Irrigation's influence on precipitation: Texas High Plains, U.S.a. Geophys. Res. Lett. 29 (16), 2-1-2-4.

Nair, U.S., Wu, Y., Kala, J., Lyons, T.J., Hacker, J.M., 2011. The role of land use change on the development and evolution of the west coast trough, convective clouds, and precipitation in Southwest Australia. J. Geophys. Res. Atmos. 116 (D7).

Noilhan, J., Planton, S., 1989. A simple parameterization of land surface processes for meteorological models. Mon. Weather Rev. 117 (3), 536–549.

Pielke, R.A., Avissar, R., 1990. Influence of landscape structure on local and regional climate. Landsc. Ecol. 4 (2), 133–155.

Pongratz, J., Reick, C.H., Raddatz, T., Claussen, M., 2010. Biogeophysical versus biogeochemical climate response to historical anthropogenic land cover change. Geophys. Res. Lett. 37 (8).

Quesada, B., Arneth, A., 2017. Atmospheric, radiative, and hydrologic effects of future land use and land cover changes: a global and multimodel climate picture. J. Geophys. Res. Atmos. 122 (10), 5113–5131.

Quesada, B., Devaraju, N., Noblet-Ducoudré, N.D., Arneth, A., 2017. Reduction of monsoon rainfall in response to past and future land-use and land-cover changes: Reduced monsoon rainfall due to LULCC. Geophys. Res. Lett. 44.

Roy, S.S., Quintanar, A.I., Gonzalez, A., 2011. Impacts of irrigation on dry season precipitation in India. Theor. Appl. Climatol. 104 (1–2), 193–207.

Shukla, S.P., Puma, M.J., Cook, B.I., 2014. The response of the South Asian Summer Monsoon circulation to intensified irrigation in global climate model simulations. Clim. Dyn. 42 (1), 21–36.

Stohlgren, T.J., et al., 1998. Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. Glob. Chang. Biol. 4 (5), 495–504.

Termonia, P., et al., 2018. The ALADIN System and its canonical model configurations AROME CY41T1 and ALARO CY40T1. Geosci. Model Dev. 11, 257.

Wang, Y., et al., 2014. Effects of arable land change on regional carbon balance in Xinjiang. Acta Geograph. Sin. 69 (1), 110–120.

Xu, C., Chen, Y., Yang, Y., Hao, X., Shen, Y., 2010. Hydrology and water resources variation and its response to regional climate change in Xinjiang. J. Geogr. Sci. 20 (4), 599–612.

Xu, Z., Mahmood, R., Yang, Z.L., Fu, C., Hua, S., 2015. Investigating diurnal and seasonal climatic response to land use and land cover change over monsoon Asia with the community earth system model. J. Geophys. Res. Atmos. 120 (3), 1137–1152.

Xu, M., Kang, S., Wu, H., Yuan, X., 2018. Detection of spatio-temporal variability of air temperature and precipitation based on long-term meteorological station observations over Tianshan Mountains, Central Asia. Atmos. Res. 203, 141–163.

Yao, J., Yang, Q., Mao, W., Zhao, Y., Xu, X., 2016. Precipitation trend–elevation relationship in arid regions of the China. Glob. Planet. Chang. 143, 1–9.

Yun, Q., Huang, M., Yang, B., Berg, L.K., 2013. A modeling study of irrigation effects on surface fluxes and land-air-cloud interactions in the Southern Great Plains. J. Hydrometeorol. 14 (3), 700–721.

Zhang, H., Ouyang, Z., Zheng, H., Wang, X., 2009. Recent climate trends on the northern slopes of the Tianshan Mountains, Xinjiang, China. J. Mt. Sci. 6 (3), 255–265.

Zhang, Q., et al., 2017. An analysis of oasis evolution based on land use and land cover change: a case study in the Sangong River Basin on the northern slope of the Tianshan Mountains. J. Geogr. Sci. 27 (2), 223–239.