We appreciated the insightful suggestions and comments provided by reviewers. The responses to the reviewers's comments and suggestions have been stated as below in blue color. The list of the all relevant changes made in the manuscript has been shown after the responses to the reviewers. And the revised manuscript has been shown after the list of the all relevant changes, the revised places in the revised manuscript are also marked in blue color.

Review of ' Role of radiatively forced temperature changes in enhanced semi-arid warming over East Asia'

Reviewer #1:

1. Scientific comments: Title: since the manuscript focuses exclusively on the cold season, the authors should consider adding "cold season" to the title, perhaps before "temperature changes".

Response: We appreciated reviewer's comments and agreed to do the change. The new topic of revised manuscript is 'Radiative forced enhanced semi-arid warming in cold season over East Asia."

2. P22976-L26: it is unclear what the authors mean by "The non uniform of population and economic distributed in this area led to an obvious change discrepancy to the environment." Needs clarification.

Response: " The non uniform of population and economic distributed in this area led to an obvious change discrepancy to the environment." has been changed to "The regional environment change has a close relationship with local population density and economic development level". This sentence aims to state that the environment change induced by the human activities has a spatial discrepancy, which will be illustrated in the results of revised manuscript. As the regional discrepancy, the radiatively forced temperature change extracted by the dynamical adjustment method needs investigating in further.

3. P22978-L1: probably best to refer to the method as "dynamical adjustment".

Response: we agree with reviewer’s suggestion and the "dynamic adjusted" has been changed into "dynamical adjustment" in the revised manuscript.

4. P22979-L10: (MAJOR) since there are large trends in the data, I suggest that the authors high pass filter or detrend the predictand time series prior to calculating the cross-correlation maps used in Step (1). This follows Smoliak et al. (2015) and ensures that you are not fitting trends in the PLS regression process. Bear in mind that this detrending or high pass filtering need only be applied to the predictand. If the authors analysis is fitting trends, this methodological change will influence the results. If not, the authors can be confident that their dynamically influenced temperature (DIT) reflects the influence of month to month and year to year changes in the atmospheric circulation.

Response: We thanks reviewer’s insightful question. Per the reviewer’s question, in our study, we have done the high pass filter to the predictand time series prior to calculating the cross correlation maps used in Step (1). The dynamical adjustment method we used totally follows the steps in Smoliak et al., (2015). In order to avoid the misunderstanding of the method and appearing the similar puzzle from readers, we rewrite the method introduction of section 3 to state the procedure of dynamical adjustment method.

5. P22980-L4: the authors should probably state that non-radiative factors resulting from thermodynamic processes will also be lumped into the RFT. They may be able to argue that thermodynamic effects are small over the semi-arid regions.

Response: We agreed with the reviewer's suggestions and revised the statement of RFT. The non-radiative factors resulting from thermodynamic process, which lumped into the RFT has been stated and more description has been added in the revised manuscript.

6. P22980-L9: define the cold season length (calendar months) here or in section 2 or 3.

Response: We have added the definition of cold season in section 3, which is as follow that in the previous results (Huang et al., 2012). Semi-arid region as a sensitive area to climate change appeared enhanced warming in boreal cold season (Nov.-Mar.), it is also satisfied with the suitable period of dynamical adjustment.

7. P22980-L10: why did the authors choose the period 1902-2011. This should be justified.

Response: The data was selected in the manuscript is from CRU, with a period of 1901 to 2012. As our study has been focused in the cold season, the cold season contains the Nov., Dec. in this year and Jan., Feb., Mar. in next year, which induced the period of data has been changed from 1901-2012 to 1902-2012. In addition, the sea level pressure data we used in the dynamical adjustment method have a time period of 1901-2011, so the period 1902-2011 was chosen.

8. P22981-L24: is it appropriate to use annual-mean precipitation as a basis for classifying climate regions for a cold season analysis? Why?

Response: The annual-mean precipitation of 1961-1990 is as climatology index has been widely used (Fu et al., 2002; Huang et al., 2012; Feng and Fu, 2013). The climate regions are determined by the climatological annual mean water budget, not by the cold season or warm season mean. So the annual-mean precipitation is appropriate as a basis for classifying climate regions for a cold season or a warm season analysis. However, annual-mean precipitation is not working well in the high latitude areas in classifying climate regions, which we have recognized that, and our study area is located in the middle latitude of East Asia. In order to illustrate the confirmation of our results, the function of raw, radiatively forced and dynamically induced temperature with aridity index (AI) (Feng and Fu, 2013; Huang et al., 2015a; Huang et al., 2015b) has been also plotted as follow (Fig. 1). It takes a similar curve with annual-mean precipitation. Besides, results in this manuscript is a part of series work on the regional enhanced warming, in order to consistent with previous results (Huang et al., 2012) and supply a better understanding to readers, we prefer the annual-mean precipitation of 30 years as the climatology index for classifying the climate regions.

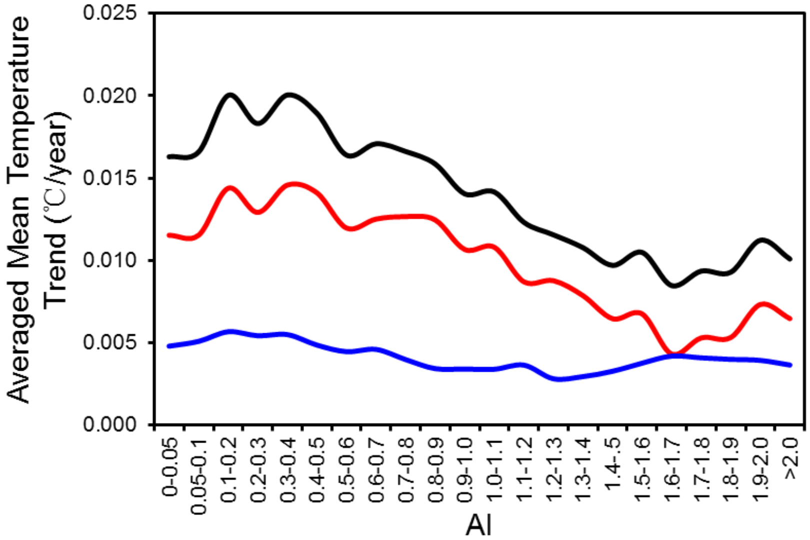

Figure 1. Regionally averaged temperature trend as a function of AI for raw (black), dynamically induced (blue) and radiatively forced (red) temperatures in the cold season from 1902 to 2011 over East Asia.

9. P22982-L7: how does this result improve on previous studies? "Confirm" may be a strong word here. I believe the results are more of a "suggestive" nature.

Response: Huang et al., (2012) found that warming trend was particularly enhanced, in the boreal cold season (Nov. to Mar.) over semi-arid regions (with precipitation of 200-600 mm yr^{-1}). In mid-latitude semi-arid areas of Europe, Asia, and North America, temperatures in the cold season increased by 1.41, 2.42, and 1.5 ^{o}C in the period of 1901-2009. The results revealed the semi-arid region of Asia is the most sensitive region to enhanced warming and needs further investigation. Our work aims to explore the reason that induced the enhanced warming in the semi-arid region of Asia. Therefore, it claims as an improved work on the Huang et al., (2012). In order to avoid misunderstanding, we have detected this sentence. And we accepted the suggestion and changed the “confirms” to “suggests”.

10. P22983-L13: what does this sentence mean? "A relative homogenization of temperature" is confusing and could be reworded.

Response: The sentence of “The DIT as the basic background provided a relative homogenization of temperature change on a large scale” wants to illustrate that temperature difference between low and high latitudes area for large scale are majorly decided by the dynamically induced temperature (DIT). It was proposed to relative to the RFT, which is greatly induced the local discrepancy warming. P22983-L13-14 has been reorganized as “The DIT was mainly dominated by major dynamic factors, such as the NAO (Li et al., 2013), PDO (Trenberth and Hurrell, 1994; Kosaka and Xie, 2013) and AMO (Wyatt et al., 2012; Wyatt and Curry, 2014).

11. P22983-L15: where are the teleconnection indices obtained? This should be stated explicitly in the text.

Response: The sources of these teleconnection indices have been provided in the text.

12. P22983-L17: why did the authors correlate an 11-year running mean with the teleconnection indices? Were the SAT data and teleconnection indices filtered like this? Why did the authors select 11-years as the averaging period? Are the results not significant otherwise? This should be clarified. I understand and accept that these patterns play a role in the DIT, but more could be done to establish their relationship.

Response: The 11-yr running is a filter for removing interannual signal. The filter applied to teleconnection indices can remove the inter-annual signal, and reflect the relationship between dynamically induced temperature and teleconnection indices over the decadal scale. Only NAO has been filtered by 11-yr running, because the NAO is a teleconnection index with interannual signal. As the 11-yr running is a simple and easy understanding method in extracting the decadal variability for long-term, it maybe a little stronger, but the signal left is favor in reflecting the variability for long-term. Meanwhile, we totally agree and thanks your suggestion, more could be done to establish the temperature change with dynamic factors. We have another paper which is under reviewing by JGR now, and discussing the influence of different dynamic factors on the variability of dynamic temperature change. Therefore, three major teleconnection indices (NAO, PDO and AMO) have been listed in the paper to illustrate the effective of the dynamical adjustment method in dividing the raw temperature into dynamically induced temperature and radiatively forced temperature.

13. P22984-L19: how were these correlations computed? The ensemble mean time series with the DIT and Arafat time series? Was any filtering employed? Were the time series detrended? The ensemble mean will tend to downplay randomly phased dynamical variability in each of the model runs, whereas the external forcing is highly similar between the models, so the ensemble mean will primarily reflect the RFT. I find this comparison somewhat disingenuous.

Response: Fig. 13 is a spatial distribution of correlation coefficient between ensemble-mean CMIP5 simulations and dynamically induced temperature (a), and between ensemble-mean CMIP5 simulations and radiatively forced temperature (b) in the cold season from 1902 to 2011 over East Asia. Ensemble-mean is the mean of 20 models data, which has been listed in table1. DIT and RFT are the dynamically induced temperature and radiatively forced temperature datasets. We did not do filtering to DIT, RIT and ensemble-mean of CMIP5 datasets, but we detrended the time series before calculating the correlations. We agreed with that the CMIP5 model runs have a similar external forcing. Figure 13 is used to prove the effectiveness of dynamical adjustment method in the selected region. As stated in Fig. 13b, it indicated the radiatively forced temperature has a close relationship with simulated temperature of CMIP5. It is mainly forced by external forcing. In order to avoid the disingenuous, we reorganized the description and discussion of Fig. 13.

Table 1. CMIP5 models examined in this study.

Model name	Modelling centre
BCC-CSM1.1	Beijing Climate Center, China
CanESM2	Canadian Centre for Climate, Canada
CCSM4	National Center for Atmospheric Research, USA
CNRM-CM5	Centre National de Recherches Meteorologiques, France
CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research, Australia
GFDL-CM3	Geophysical Fluid Dynamics Laboratory, USA
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory, USA
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory, USA
GISS-E2-R	NASA Goddard Institute for Space Studies, USA
HadGEM2-CC	Met Office Hadley Centre, UK

HadGEM2-ES	Met Office Hadley Centre, UK
INM-CM4	Institute for Numerical Mathematics, Russia
IPSL-CM5A-LR	Institute Pierre-Simon Laplace, France
IPSL-CM5A-MR	Institute Pierre-Simon Laplace, France
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Japan
MIROC-ESM-	Japan Agency for Marine-Earth Science and Technology, Japan
MIROC5	Atmosphere and Ocean Research Institute, Japan
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany
MRI-CGCM3	Meteorological Research Institute, Japan
NorESM1-M	Norwegian Climate Centre, Norway

14. P23000: how many degrees of freedom were used in this two-tailed students t test? Were the running mean time series used in the t-test? If so, the effects of autocorrelation should be considered. This could be done by computing the so called "effective degrees of freedom". This reduces the degrees of freedom based on the lag-1 auto-correlation of the time series being considered.

Response: The degree of freedom is 108 in this two-tailed student's *t* test, and we did not do the running mean time series to PDO and AMO. For Fig. 11b and Fig. 11c, the PDO, AMO and the dynamically induced temperature time series are all without 11-year-running mean. In Fig. 11a, we applied the 11-year running mean to NAO (remove the high frequency signal), not the dynamically induced temperature time series. We agree with reviewer's comment that the filter process will reduce the degrees of freedom. Fig. 2 as below is similar with Fig. 11 of the manuscript, but without 11-yr running mean to NAO. We can find that the area with 95% confidence in Fig. 2a as below is larger than it in Fig. 11a of the manuscript. In order to avoid the problem of freedom change after filter, we use the Fig. 2 as below to replace the Fig. 11 in the revised manuscript.

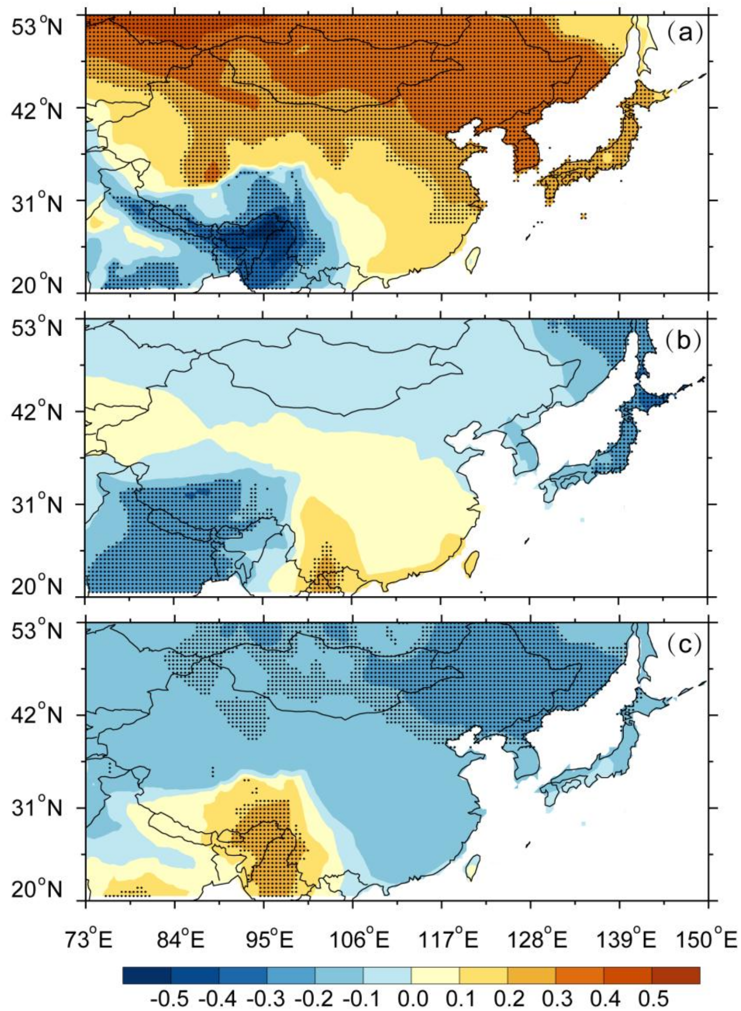

Figure 2. Spatial distribution of the correlation coefficient between detrended dynamically induced temperature and detrended NAO (**a**), PDO (**b**), and AMO (**c**) in the cold season from 1902 to 2011 over East Asia. The stippling indicates the 95 % confidence level according to a two-tailed Student's t test.

References:

Huang, J., Guan, X., and Ji, F.: Enhanced cold-season warming in semi-arid regions, Atmos. Chem. Phys., 12, 5391–5398, doi:10.5194/acp-12-5391-2012, 2012.

Huang, J., Ji, M., Xie, Y., Wang, S., and He, Y.: Global semi-arid climate change over last 60 years, Clim. Dyn., doi:10.1007/s00382-015-2636-8, 2015a.

Huang, J., Yu, H., Guan, X., Wang, G., and Guo, R.: Accelerated dryland expansion under climate change, Nature Clim. Change, doi:10.1038/nclimate2837, 2015b.

Feng, S., and Fu, Q.: Expansion of global drylands under a warming climate. Atmos. Chem. Phys. 13, 10081-10094, doi: 10.5194/acp-13-10081-2013, 2013.

Fu, C., and Z. S.: Study of aridification in Northern China— A global change issue forcing directly the demand of nation. Earth Science Frontiers, 9, 271-275, 2002. (in Chinese)

Editorial comments: In general the manuscript needs copy-editing to improve the English prior to publication. I will highlight a few particular areas for improvement here:

Thanks for editors' comments; we will revise them case-by-case in the manuscript.

P22976-L4: I suggest the authors insert "regional" between "investigate" and "surface temperature change"

Response: "regional" has been inserted between "investigate" and "surface temperature change"

P22976-L21: to say that Asia is the most sensitive area to climate change is an extremely strong statement. I would accept "Asia is arguably the most...", but additional references are necessary to back up this strong introductory claim.

Response: The sentence of “to say that Asia is the most sensitive area to climate change is an extremely strong statement” has been changed to “Asia is arguably the most sensitive area to climate change”.

P22978-L7: this sentence is awkward and should be rephrased. For example, "This study uses monthly precipitation, maximum daily temperature, and minimum daily temperature data from the land-only TS3.21 dataset obtained from the Climatic Research Unit at the University of East Anglia...".

Response: The sentence has been changed.

P22978-L17: I suggest rephrasing "which almost covers the most area of East Asia" to "which comprises much of East Asia."

Response: The revision has been done.

P22979-L11: I suggest rephrasing following past references, "...based on partial least squares (PLS) regression using sea level pressure (SLP) to predict SAT."

Response: this part has been rephrased.

P22981-L4: remove "ly" from "radiatively"

Response: It has been done.

P22982-L6: do the authors mean "previous knowledge"? "previous acknowledge" does not make much sense in this sentence.

Response: In order to avoid to misunderstanding, we have deleted this sentence.

P22982-L17: typo, "cover" should be "over"

Response: It has been revised.

P22984-L11: remove "obvious". Too casual of a word.

Response: removed the word

P22984-L19: typo, "modes" should be "models"

Response: It has been revised.

P22985-L8: I suggest that the authors rephrase "...the NAO, PDO, and AMO took a decadal variability" as "...the NAO, PDO, and AMO on decadal time scales."

Response: We took the suggestions and rephrased the sentence.

P22993: the figures all look nice in general; Figure 4 could be improved by scaling the color bar to the data better. There are no values below about 30%, so this could be the bottom of the color scale.

Response: Figure 4 has been updated.

Reviewer #2:

This is an interesting study. The authors investigated the surface temperature change over East Asia using a new technique that can identify and separate the dynamically induced temperature (DIT) and radiatively forced temperature (RFT) changes. They show evidences that the DIT and RFT make 43.7 and 56.3% contributions to the SAT over East Asia, respectively. The DIT changes connected to the North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), and Atlantic Multi-decadal Oscillation (AMO) are investigated. The radiatively forced SAT changes are responsible for the regional scale enhanced semi-arid warming (ESAW). Such enhanced warming is also found in radiatively forced daily maximum and minimum SAT. The results are helpful to our understanding of regional climate change. The manuscript is generally well written and I recommend accepting it for publication after a moderate revision. Specific comments (based on page sequence):

1. While the manuscript has provided an excellent statistical analysis of surface

temperature changes associated with internal atmospheric modes such as NAO, PDO, and AMO, the authors should acknowledge that the relationships are mainly based on statistical analysis, and the underlying dynamical and physical mechanisms deserve further studies.

Response: We totally agree and thanks your suggestion, more could be done to establish the temperature change with dynamic factors and explore the mechanism of internal atmospheric modes, we have another paper which is under reviewing by JGR now, and discussing the influence of different dynamic factors on the variability of dynamic temperature change, which concentrate on the dynamical and physical mechanisms. Three major teleconnection indices (NAO, PDO and AMO) have been listed in this paper aim to illustrate the effective of the dynamical adjustment method in dividing the raw temperature into dynamically induced temperature and radiatively forced temperature.

2. The authors said they focus on the area between 30 and 50N, but actually they talked about a larger domain from 20 to 53N.

Response: Sorry for the type mistake, it has been corrected.

3. The authors do not mention how the relative contributions (the percentage) for DIT and RFT are calculated. Please clarify this in the method description.

Response: The method of relative contributions (the percentage) for DIT and RFT has been added in the method section.

4. The authors do not provide the information of CMIP5 models used in the study. They claimed that the ensemble of CMIP5 model reflects the GHG forcing. Actually many models includes the anthropogenic aerosols, even land use. Taking this into consideration, authors should rethink their explanation for the peak of RFT. The authors should also list the models they used in the analysis by a table.

Response: A table of CMIP5 model list used in the study has been added in the manuscript as table 1. And the explanation for the peak of RFT has been reorganized, the revised one contains the discussion on the impact of GHG forcing, anthropogenic aerosols, and land use on the regional RFT.

Table 1. CMIP5 models examined in this study.

Model name	Modelling centre
BCC-CSM1.1	Beijing Climate Center, China
CanESM2	Canadian Centre for Climate, Canada
CCSM4	National Center for Atmospheric Research, USA
CNRM-CM5	Centre National de Recherches Meteorologiques, France
CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research, Australia
GFDL-CM3	Geophysical Fluid Dynamics Laboratory, USA
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory, USA
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory, USA
GISS-E2-R	NASA Goddard Institute for Space Studies, USA
HadGEM2-CC	Met Office Hadley Centre, UK
HadGEM2-ES	Met Office Hadley Centre, UK
INM-CM4	Institute for Numerical Mathematics, Russia
IPSL-CM5A-LR	Institute Pierre-Simon Laplace, France
IPSL-CM5A-MR	Institute Pierre-Simon Laplace, France
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Japan
MIROC-ESM-	Japan Agency for Marine-Earth Science and Technology, Japan
MIROC5	Atmosphere and Ocean Research Institute, Japan
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany
MRI-CGCM3	Meteorological Research Institute, Japan
NorESM1-M	Norwegian Climate Centre, Norway

5. The authors should provide the information of effective sample number for the significance test in Figure 11. Low- pass filtering (11-yr running mean) was used for the NAO index (may also for the AMO and PDO indices) in this study. This may substantially reduce the independent sample number. So the “significant” signal in Figure 11 may be questionable.

Response: The sample number for the significance test in Figure 11 is 110. In Fig. 11a, we applied the 11-year running mean to NAO (remove the high frequency signal), not the dynamically induced temperature time series. We did not do the Low-pass filtering to the PDO and AMO indices .We agree with reviewer’s comment that the filter process will reduce the degrees of freedom. Fig. 1 as below is similar with Fig. 11 of the manuscript, but without 11-yr running mean to NAO. In order to avoid the problem of freedom change after filter, we use the Fig. 1 as below to replace Fig. 11 in the revised manuscript.

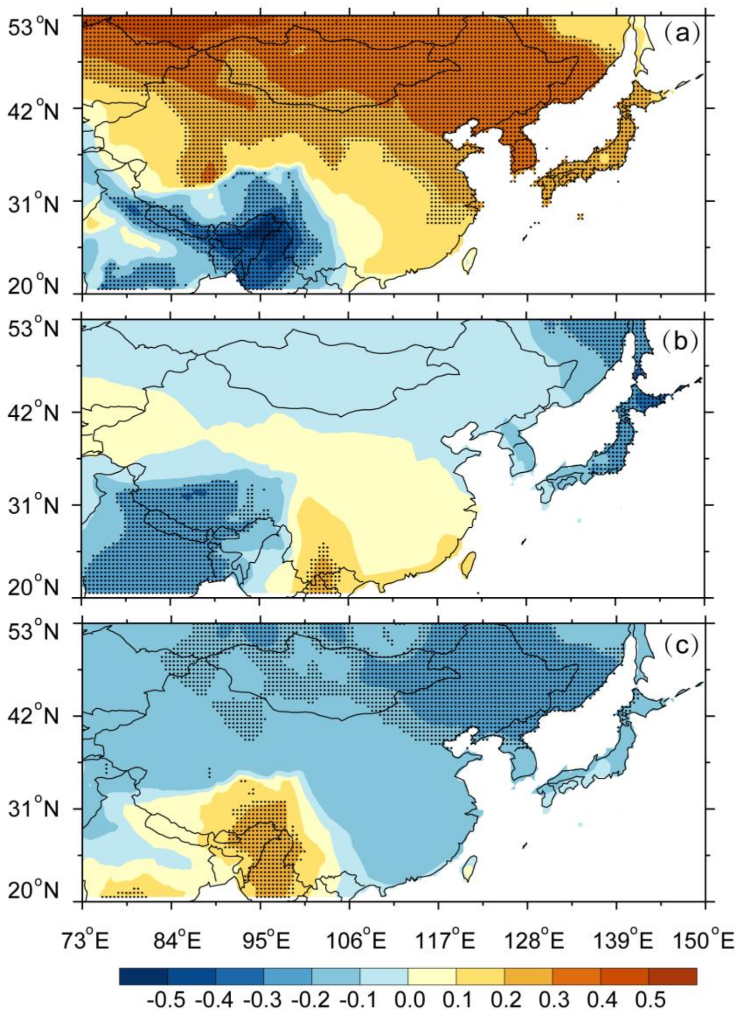

Figure 1. Spatial distribution of the correlation coefficient between detrended dynamically induced temperature and detrended NAO **(a)**, PDO **(b)**, and AMO **(c)** in the cold season from 1902 to 2011 over East Asia. The stippling indicates the 95 % confidence level according to a two-tailed Student's *t* test.

6. How do you explain the increasing/decreasing in the DIT/RFT in the heavy-rain regions (larger than 1000 mm/yr)?

Response: From the spatial distribution of contribution of DIT and RFT, it exhibits a larger contribution of DIT in the south of China (Fig. 4a), which is typical wet region with the annual precipitation larger than 1000 mm/yr (Fig. 1 of manuscript). And in the same area, the contribution of RFT (Fig. 4b) illustrated a relative smaller contribution of RFT. These regions are developed area, with plenty of factories and produced a great deal of industrial aerosol, which may perform a cooling effect. Therefore, the DIT takes an increasing contribution and RFT takes a decreasing contribution in these regions.

list of all relevant changes made in the manuscript:

1. Line1-2: Change the title "Role of radiatively forced temperature changes in enhanced semi-arid warming over East Asia" to "Radiative forced enhanced semi-arid warming in cold season over East Asia".
2. Line5: Insert "H. Yu[1]" as a co-author.
3. Line37: Insert "regional" between "investigate" and "surface temperature".
4. Line63: Insert "arguably" after "Asia is".
5. Line67-70: Change "The nonuniform of population and economic distributed in this area led to an obvious change discrepancy to the environment" to "The regional environment change has a close relationship with local population density and economic development level".
6. Line99-100: Change "dynamic adjusted" to "dynamical adjustment".
7. Line106-108: Change "The monthly precipitation data, land surface temperature data of version TS3.21, and monthly daily maximum and minimum temperature datasets are obtained from Climate Research Unit…" to "This study uses monthly precipitation, monthly mean temperature, monthly daily maximum and minimum temperature from the land-only TS3.21 dataset obtained from the Climate Research Unit…".
8. Line116-120: Insert the following part:

   The contribution of RFT (DIT) to raw temperature is calculated as formula (2)

   $$CR = \frac{1}{n}\sum_{i=1}^{n}(\tilde{T}_i^2 / T_i^2) \times 100\% \qquad (2)$$

   Where n is the number of years of temperature dataset, $\tilde{T}_i$ is the radiatively forced temperature or dynamically induced temperature in year *i*, Ti is the raw temperature in year *i*.
9. Line121: Change "30 °N and 50°N" to "20°N and 53°N".
10. Line122: Change "almost covers the most area" to "comprises much".
11. Line135: Insert "(November-March)" after "in the cold season".
12. Line137-139: "The dynamical adjustment methodology used in this study (Smoliak

et al., 2015) is based on the partial least square (PLS) regression of sea level pressure (SLP) to SAT." to "The dynamical adjustment methodology used in this study has been improved by Smoliak et al., (2015)."

13. Line142: Delete "temperature and".
14. Line142-143: Insert ", and the temperature time series are standardized and high pass filtered" after "sea level pressure (SLP) are standardized".
15. Line160-162: Insert "For semi-arid region of East Asia we are interested in, non-radiative factors resulting from thermodynamic processes is also a part of RFT. As their proportion are small over the semi-arid regions, its effects in RFT are ignored in this study. "
16. Line187: Change "radiatively" to "radiative"
17. Line217-219: Sentence of " It improves the previous acknowledge on the reason induce the ESAW (Huang et al., 2012), and confirms that role of radiative forced part in the process of warming East Asia. " has been changed to " It improves the understanding of the ESAW (Huang et al., 2012), and suggests that role of radiative forced part in the process of warming East Asia."
18. Line229: Change "cover" to "over".
19. Line252-253: The sentence of "The DIT as the basic background provided a relative homogenization of temperature change on a large scale. It was mainly dominated by major dynamic factors, such as the NAO (Li et al., 2013), PDO (Trenberth and Hurrell, 1994; Kosaka and Xie, 2013) and AMO (Wyatt et al., 2012; Wyatt and Curry, 2014)." has been changed to " The DIT was mainly dominated by major dynamic factors, such as the NAO (Li et al., 2013), PDO (Trenberth and Hurrell, 1994; Kosaka and Xie, 2013) and AMO (Wyatt et al., 2012; Wyatt and Curry, 2014)."
20. Line 257-258: Delete" low frequency".
21. Line273: Add "(Taylor et al., 2012)" after "(CMIP5)".
22. Line276: Change "(Taylor et al., 2012)" to "(Table 1)".
23. Line277: Change "Northern Hemisphere" to "East Asia".
24. Line279: Deleted "obvious".
25. Line289: Change "modes" to "models".

26. Line290-292: Change "The high positive correlation coefficient between RFT and ensemble mean of CMIP5 confirms the dominant contribution of GHGs to the warming over a large scale." to "The high positive correlation coefficient between RFT and ensemble mean of CMIP5 indicates the radiatively forced influence take a major proportion in simulated temperature change."
27. Line296-297: Add "prefer a uniform temperature change over all the regions." after "CMIP5 simulations" and deleted "reflect temperature variability as the change of GHGs."
28. Line298-303: Change the sentence of "The significant difference between RFT and simulated temperatures over the drylands indicates that the long-term global-mean SAT warming trend was mainly related to radiative forcing produced by the global, well mixed GHGs. And the peak of RFT indicated the regional anthropogenic radiative forcing caused the enhanced warming in the semi-arid regions." to "The significant difference between RFT and simulated temperatures over the drylands indicates that the enhanced warming over semi-arid region was not mainly related to radiative forcing produced in models, such as GHGS, land cover change, aerosol and so on. It is more related with regional factors not totally considered in the models."
29. Line305: Change "confirm" to "suggest".
30. Line309-310: Change "AMO took a decadal variability" to "AMO was on decadal time scales".
31. Line313: Change "radiative" to "radiatively".
32. Line332: Add "warming trend slowdown" before "(WTS) claimed that".
33. Line347: Add "41575006" after (41305009)
34. Line349-354: Add "The authors acknowledge the World Climate Research Programme's (WCRP) Working Group on Coupled Modelling (WGCM), the Global Organization for Earth System Science Portals (GO-ESSP) for producing the CMIP5 model simulations and making them available for analysis, and the Climate Explorer for making the NAO, PDO and AMO indices were available to downloaded (http://climexp.knmi.nl/)."
35. Line525: Updated Figure 4.
36. Line627: Updated Figure 11.

37. Line723: Add Table 1.
38. Line629-634: Change “between detrended dynamically induced temperature and NAO (detrended and 11 year running mean) (a), between detrended dynamically induced temperature and detrended PDO (b), and between detrended dynamically induced temperature and detrended AMO (c)” to “between detrended dynamically induced temperature and detrended NAO (a), PDO (b), and AMO (c)”

Radiative forced enhanced semi-arid warming in cold season over East Asia ~~Role of radiatively forced temperature changes in enhanced semi-arid warming over East Asia~~

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Abstract

As the climate change occurred over East Asia since 1950s, intense interest and debate have arisen concerning the contribution of human activities to the warming observed in previous decades. In this study, we investigate regional surface temperature change using a recently developed methodology that can successfully identify and separate the dynamically induced temperature (DIT) and radiatively forced temperature (RFT) changes in raw surface air temperature (SAT) data. For regional averages, DIT and RFT make 43.7 and 56.3% contributions to the SAT over East Asia, respectively. The DIT changes dominate the SAT decadal variability and are mainly determined by internal climate variability, such as the North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), and Atlantic Multi-decadal Oscillation (AMO). The radiatively forced SAT changes made major contribution to the global-scale warming trend and the regional-scale enhanced semi-arid warming (ESAW). Such enhanced warming is also found in radiatively forced daily maximum and minimum SAT. The long-term global-mean SAT warming trend is mainly related to radiative forcing produced by global well-mixed greenhouse gases. The regional anthropogenic radiative forcing, however, caused the enhanced warming in the semi-arid region, which may be closely associated with local human activities. Finally, the relationship between global warming hiatus and regional enhanced warming is discussed.

1 Introduction

Asia is arguably the most sensitive area to climate change, because it comprises almost 39% of the world's land area (White and Nackoney, 2003; Huang et al., 2013) and supports four billion people, which accounts for 66.67% of the world population. A great portion of its drylands showed a most significantly enhanced warming in the boreal cold season over mid-to high-latitude areas (Huang et al., 2012). The regional environment change has a close relationship with local population density and economic development level~~The nonuniform of population and economic distributed in this area led to an obvious change discrepancy to the environment~~. Jiang and Hardee (2011) found that economic growth technological changes and population growth are the main elements in anthropogenic effects on emission, which cannot be simulated easily by numerical models (Zhou et al., 2010). More recently, there are some studies on understanding the implications of population growth, worker structure and economic intensity for various scenarios of environmental change. The anthropogenic heating resulting from energy consumption has a significant continental-scale warming effect in mid-to high-latitudes in winter based on model simulations (Zhang et al., 2013). The rapid industrialization, urbanization, population growth, and other anthropogenic activities occurred in East Asia.

In the previous studies, dynamic effects induced by greenhouse gases (GHGs) have been proposed to interpret the rapid warming over continents and non-uniformity of local warming distribution (Wallace et al., 2012). The dynamic factors exhibit their influences on surface temperature changes in terms of circulation changes, such as the North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), Atlantic Multi-decadal Oscillation (AMO). Guan et al. (2015) found that the dynamically induced temperature and radiatively forced temperature had opposite contributions to the surface air temperature (SAT) during the process of hiatus over the Northern Hemisphere. Most of the obvious patterns occurred over mid-to high-latitudes where they are known as places having the earliest warming (Ji et al., 2014) and a phenomenon of enhanced warming over semi-arid region (enhanced semi-arid warming, ESAW) (Huang et al., 2012). The ESAW was proposed to be caused by various factors, including changes of atmospheric circulations, sea surface temperature, interaction between land and atmosphere, feedback from snow, and so on (Hu and Gao, 1994; Zhang et al., 2001; Huang et al., 2008; Guan et al., 2009; He et al., 2014). But the roles of different factors in the process of ESAW have not been confirmed.

In this study, the roles of different factors in the process of ESAW will be investigated using a recently developed methodology that can successfully identify and separate the dynamically induced temperature (DIT) and radiatively forced temperature (RFT) changes in the raw temperature data. Section 2 introduces the datasets used in this study. Section 3 provides detailed description of the dynamical adjustment~~dynamic-adjusted~~ method. Section 4 shows enhanced warming in semi-arid regions and the behaviors of DIT and RFT over different regions of East Asia. It analyzes the variability of DIT and the effects of major natural factors that dominate the dynamic temperature change, and shows the change of RFT. Section 5 lists all the main findings, followed by some discussion.

2 Datasets and study area

This study uses~~The~~ monthly precipitation~~ data, land surface temperature data of version TS3.21~~, ~~and~~ monthly mean temperature, monthly daily maximum and minimum temperature from the land-only TS3.21 dataset obtained f~~ datasets are obtained f~~rom the Climate Research Unit at the University of East Anglia (Mitchell and Jones, 2005). The data cover the period of 1901-2012 with a high spatial resolution of 0.5°×0.5°. The regionally-average temperature trend of region *k* is calculated using

$$\overline{T}_k = \frac{\sum_{i=1}^{N_k} w_{ki} \times T_{ki}}{\sum_{i=1}^{N_k} w_{ki}} \qquad (1)$$

where N_k is the number of grids in region *k*, T_{ki} is the temperature of grid *i* in region *k*, and $W_{ki} = \cos(\theta_i \times \pi / 180)$, with θ_i is the latitude of the grid *i*. The temperature trend of region k is calculated by least square method based on the time series of $\overline{T}_k$.

The contribution of RFT (DIT) to raw temperature is calculated as formula (2)

$$CR = \frac{1}{n}\sum_{i=1}^{n}(\tilde{T}_i^2 / T_i^2) \times 100\% \qquad (2)$$

Where n is the number of years of temperature dataset, $\tilde{T}_i$ is the radiatively forced temperature or dynamically induced temperature in year *i*, T_i is the raw temperature in year *i*.

The study area is between 2~~3~~0 °N and 53~~0~~ °N, and between 73°E and 150°E, which comprises much~~almost covers the most area~~ of East Asia. The distribution of 30-yr averaged annual precipitation from 1961-1990 (Fig. 1) illustrates most of semi-arid region (annual precipitation between 200-600 mmyr^{-1}) located in the northeast, and most of arid region is in the northwest area. It exhibits a generally increase pattern of annual precipitation from Northwest to Southeast. The wet regions are most distributed in the South area. Although precipitation is related to surface temperature, the long-term mean precipitation is the simplest index for classifying climate regions (Huang et al., 2012).

3 Dynamical adjustment methodology

The dynamical adjustment method was first proposed by Wallace et al. (2012) and used to analyze non-uniformity of spatial warming over the Northern Hemisphere. The SAT, or the raw temperature data is divided into two parts by the dynamical adjustment method: DIT and RFT. Wallace et al. (2012) claimed the dynamical adjustment method can remove the dynamic component of the SAT induced by atmospheric circulation pattern from the raw SAT in the cold season (November-March) over land areas poleward of 20°N.

The dynamical adjustment methodology used in this study has been improved by ~~(~~Smoliak et al., (2015)~~ is based on the partial least square (PLS) regression of sea level pressure (SLP) to SAT~~. The exact process of partial least square (PLS) is to derive monthly dynamical adjustment of Northern Hemisphere land surface temperature field in a pointwise manner, namely, temperature time series of each grid point is a predictand. The data of ~~temperature and~~ sea level pressure (SLP) are standardized, and the temperature time series are standardized and high pass filtered prior to carrying out the following dynamical adjustment steps: (1) correlate the grid-point temperature time series with its corresponding SLP to generate a one-point cross-correlation map; (2) project the monthly SLP field onto the correlation pattern, weight each grid point by the cosine of its latitude to obtain the first PLS predictor time series Z1; (3) regress this PLS predictor Z1 out of both the each grid-point temperature time series and its SLP predictor field using conventional least square fitting procedures, which can obtain a residual temperature time series and residual SLP field. Repeat these steps on the residual temperature time series and residual SLP field to obtain the respective PLS predictor Z2 and Z3, ..., Zn, which are mutually orthogonal. In our study, the improved dynamical adjustment methodology (Smoliak et al., 2015) has been applied to the temperature dataset and three predictors are retained, which are determined by cross-validation.

Following the process stated above, the components associated with changes of atmospheric circulation patterns that are expressed in terms of SLP are partitioned, and referred to as DIT variability. The rest is the residual part associated with radiatively forced factors, called the RFT. The RFT is considered as a result of build-up of GHGs, stratospheric ozone depletion, volcanic eruption, aerosol emission, local anthropogenic forcing, and so on. For semi-arid region of East Asia we are interested in, non-radiative factors resulting from thermodynamic processes is also a part of RFT. As their proportion are small over the semi-arid regions, its effects in RFT are ignored in this study. Therefore, we can use the dynamical adjustment method to identify the roles of DIT and RFT in the process of enhanced warming.

4 Results analysis

Figure 2 compares the variation of cold season-mean SAT of raw, dynamically and radiatively forced temperatures over East Asia in the period of 1902-2011. The curves exhibit a warming trend in the past century as a whole and an obvious warming from the 1970s to the 1990s. Then, the raw temperature change (black line) appeared a stoppage since about 2000 until now. The DIT (blue line) exhibits obvious decadal variability, with a relatively warming period from the 1970s to the 1990s and an obvious cooling period from 2000 to 2011 in the cold season. The RFT (red line) shows a rapid increasing rate since the late 1970s, which is consistent with the raw temperature data. The different evolutions of DIT and RFT indicate that the time series of DIT and RFT had different roles in the process of raw temperature variability.

Figure 3 shows the spatial distribution of raw, DIT and RFT trends over East Asia in the period of 1902-2011. Figure 3a exhibits a gradually increasing warming pattern from south to north and a strong warming trend located over northern East Asia, especially in Mongolia and Northeast China. The rate of warming was less than 0.005^{o}C/year in the south of 40^{o}N, with a small scale of cooling region over the southwest. The distribution of DIT trend (Fig. 3b) shows a basic warming background of East Asia. The warming rate over most areas was less than 0.01^{o}C/year, with a higher value in the northern part than in the southern part as a whole, and a cooling scale was located in the Northeast of East Asia. The distribution of RFT trend (Fig. 3c) exhibits a similar distribution as that of the raw temperature. It shows an obvious warming over the northern area, which reached 0.025^{o}C/year in some regions. A larger scale of cooling located in the southern region demonstrates that the cooling in the raw temperature was due to the radiative~~ly~~ factors. The difference of DIT trend distribution from RFT indicates that the influence of radiative forcing on regional temperature changes is much higher than dynamic factor.

The discrepancy of distributions between DIT and RFT trends demonstrates the roles of DIT and RFT were different. Figure 4 gives the distributions of contributions of DIT and RFT to the raw temperature in the cold season over East Asia in the period of 1902-2011. It exhibits quite different locations of high contribution for DIT and RFT. The dynamic contribution to the raw temperature change (Fig. 4a) has high values over the northwest and along the coastal area of Southeast China, but the peak value is much less than its radiative value. In the spatial distribution of RFT contribution (Fig. 4b), the positive centres were located over the northeast and southwest areas, and the values were much higher than those in Fig. 4a. The difference between Fig. 4a and Fig. 4b illustrated the regional temperature is mainly contributed by RFT. This regional discrepancy is confirmed by the contributions of DIT (blue line) and RFT (red line) to the raw temperature as a function of annual precipitation in the cold season over East Asia (Fig. 5). Figure 5 shows that the RFT made a greater contribution than the DIT over the whole region. The contribution of RFT increased as the annual precipitation increased. Opposite to the radiative contribution, the dynamical contribution decreased with the increase of annual precipitation.

According to Huang et al. (2012), the enhanced warming occurred over the semi-arid regions. Figure 6 provides the long-term trends of DIT and RFT as a function of annual-mean precipitation. It illustrates that the RFT had a major contribution to the regional variation and showed a similar curve as the raw temperature over different regions. Both the raw data and RFT reached the peak in the area of 300-400 mmyr^{-1}. The fact that the peaks of temperature trend of both raw data and RFT occurred over semi-arid regions indicates that the radiative factors had dominated roles in the process of enhanced warming over the semi-arid regions. However, the DIT trend did not show obvious difference over different areas. It kept a mean rate of 0.005^{o}C/year, which is far away from the 0.017^{o}C/year of the highest value in the drylands of the RFT trend. The greater warming rate in semi-arid region appeared in both raw temperature and RFT indicated that enhanced warming occurred in drylands is mainly leaded by RFT. It improves ~~the previous acknowledge on~~ the ~~reason induced~~understanding of the ESAW (Huang et al., 2012), and suggests~~confirms~~ that role of radiative forced part in the process of warming East Asia.

These results are not limited to the monthly-mean temperatures, the daily minimum and maximum temperatures expressed different variability of DIT and RFT as well. Figure 7 shows the distributions of raw, dynamically induced and radiatively forced daily minimum temperature trends over East Asia in the period of 1902-2011. The raw daily minimum temperature illustrates a similar distribution as the raw monthly-mean temperature, with a stronger warming trend over northern East Asia, especially over Mongolia and Northeast China. The dynamically induced daily minimum temperature (Fig. 7b) shows a warming pattern over most areas, with a small cooling in the area along the Northeast China. The RFT trend (Fig. 7c) had an obvious warming ~~e~~over the northern area, with a smaller cooling over South China than in the monthly-mean temperature.

Figure 8 is the distributions of raw, dynamically and radiatively of daily maximum temperature trends over East Asia in the period of 1902-2011. The raw daily maximum temperature trend (Fig. 8a) had a warming trend over Northern East Asia, especially over

Mongolia. But the warming extent was apparently less than that in the daily minimum temperature. The cooling in the southern part was larger than that in the daily minimum temperature. The dynamically induced daily maximum temperature (Fig. 8b) shows a slight warming over most areas, with a cooling located in the area along of Northeast China. The RFT trend (Fig. 8c) had an obvious warming over the northern area, with a small cooling scale over South China, which is similar with the raw daily minimum temperature. But the scale of cooling area was much larger than the radiatively forced daily minimum temperature in Fig. 7c.

In order to distinguish the regionally-averaged temperature changes, the daily minimum and maximum of raw, DIT and RFT as a function of annual-mean precipitation are shown in Fig. 9 and Fig. 10, respectively. The daily minimum (Fig. 9) had a higher warming rate than the daily maximum (Fig. 10) over different regions, especially in the drylands. The peaks of RFT over the drylands in both daily minimum and maximum temperatures indicate the dominated roles of radiative effects in the regional warming. But, the DIT trend did not show a similar variability over different area in both daily minimum and maximum temperatures. The higher values of RFT of both daily minimum and maximum temperatures in the drylands emphasize the major roles of RFT in the local enhanced warming process.

The DIT ~~as the basic background provided a relative homogenization of temperature change on a large scale. It~~ was mainly dominated by major dynamic factors, such as the NAO (Li et al., 2013), PDO (Trenberth and Hurrell, 1994; Kosaka and Xie, 2013) and AMO (Wyatt et al., 2012; Wyatt and Curry, 2014). The correlation coefficients between DIT and NAO/PDO/AMO (Fig. 11) illustrate the influences of these dynamic factors. Figure 11a shows the distribution of the correlation coefficient between the ~~low-frequency~~ NAO and the DIT. It exhibits positive patterns cover most of the East Asia area, with a 95% confidence level over Mongolia, Inner Mongolia and Northeast China; and negative patterns over India and Southwest China, with a 95% confidence level. It suggests the strong positive influence of the NAO on the DIT over the northern area and the negative effect over the southwest of East Asia. Figure 11b is the correlation coefficient between PDO and DIT. Only the negative correlation coefficients over boundary of China and India pass the confidence level of 95%. In South China and North China, there were positive and negative patterns, respectively. Meanwhile, the negative correlative coefficient of AMO index and DIT (Fig. 11c) covered the most area of East Asia, except for a small positive region in the southwest of East Asia. The general spatial distribution is opposite with the distribution of the NAO.

The RFT variability is always considered as a result of GHGs, but more climate effects of aerosols were revealed in the recent decades (Li et al., 2011). The fast industrialization process over East Asia produced more anthropogenic GHGs and aerosols, and impacted the local climate change (Qian et al., 2009, 2011). The temperature of Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012) is always marked with its correspondence to the concentration of the GHGs. In order to manifest the effects of GHGs in RFT, a comparison between RFT and a 20-model ensemble mean of CMIP5 simulations (Table 1~~Taylor et al., 2012~~) over the ~~Northern Hemisphere~~East Asia is plotted (Fig. 12), which shows that the time series of the CMIP5 simulations are smoother than the observed SAT curve. But, the notable consistent exists between RFT and simulated SAT in the~~ obvious~~ warming period from the 1970s to the late 1990. The consistent curve of RFT and CMIP5 indicated the simulation reflect radiative part of raw temperature.

The distributions of correlation coefficients of DIT and RFT with simulated temperature of CMIP5 are expressed in Fig. 13. Figure 13a exhibits a negative pattern over most of the area except for the boundary between Northwest China and Russia and southwest. But in Fig. 13b, the correlation coefficient of RFT with CMIP5 ensemble mean temperature has a positive pattern over most of China, which passes the 95% confidence level, excluding the northeast of China and Mongolia. It indicates the temperature of CMIP5 has a closer relationship with RFT than DIT, namely, CMIP5 models reflect part of raw temperatures. The high positive correlation coefficient between RFT and ensemble mean of CMIP5 indicates ~~confirms~~ the radiatively forced influence take a major proportion in simulated temperature change~~ dominant contribution of GHGs to the warming over a large scale~~. The ensemble mean temperature trend as a function of annual precipitation (Fig. 14) highlights the regional RFT over the drylands (Fig. 6). It illustrates that the enhanced warming over the semi-arid regions led by the RFT does not appear in the ensemble mean temperature, which demonstrates the CMIP5 simulations prefer a uniform temperature change over all the regions. ~~reflect temperature variability as the change of GHGs.~~ The significant difference between RFT and simulated temperatures over the drylands indicates that the enhanced warming over semi-arid region~~long-term global-mean SAT warming trend~~ was not mainly related to radiative forcing produced ~~by the global, well mixed GHGs.~~ in models, such as GHGS, land cover change, aerosol and so on. It is more related with regional factors not totally considered in the models. ~~And the peak of RFT indicated the regional anthropogenic radiative forcing caused the enhanced warming in the semi-arid regions.~~

5 Summary and discussion

Our results ~~confirm~~ suggest that the enhanced warming in the drylands was induced by the RFT. The DIT and RFT extracted from the raw temperature had different contributions in the process of temperature change. For the regionally averaged values, the DIT and RFT contributed 43.7 and 56.3% to the SAT over East Asia, respectively. The DIT that was dominated by the NAO, PDO and AMO was on~~took~~ ~~a~~ decadal time scales~~variability~~. The RFT changes were the major contributions to the global-scale warming trend and the regional-scale enhanced warming in the semi-arid regions. Previous studies (Guan et al., 2015) pointed out the well mixed GHGs took a continuous warming effect over globe in the radiatively forced temperature change. The local processes dominated the enhanced warming in the semi-arid regions. These possible local processes have been listed in Fig. 15.

The regional RFT was mainly induced by the interaction among atmosphere, land surface, snow/ice and frozen ground cover change, and regional human activities. For example, the drying of sandy or rocky soil by higher temperatures would increase surface albedo, reflecting more solar radiation back to the space. And the substantially declining of snow/ice and frozen ground change in the past 30 years, particularly from early spring through summer (Zhai and Zhou, 1997) may cause the surface temperature to increase in the cold season via the influence on albedo. The thickness of seasonally frozen ground has decreased in response to winter warming (Lemke et al., 2007), which will emit more

CO_2 into the atmosphere. The net radiation in the semiarid regions will become a radiation sink of heat relative to the surrounding regions. Besides, Multiza et al. (2010) found that local anthropogenic dust aerosols associated with human activities (Huang et al., 2015) such as agriculture and industrial activity accounted for 43 % of the total dust burden in the atmosphere. The radiatively forced effect of aerosol maybe another key process in enhanced warming of semi-arid area. More investigations are needed to quantify the contribution of different local process.

Our results also well explained the co-existence of regional warming and hiatus of the Northern Hemisphere. The major interpretation of the warming trend slowdown (WTS) claimed that natural variability played an important role in global temperature variability (Easterling and Wehner, 2009; Wyatt et al., 2012, Wyatt and Curry, 2014; Kosaka and Xie, 2013). The RFT had a warming contribution offset the cooling effect of DIT, and result in hiatus over the Northern Hemisphere (Guan et al., 2015). According to the results of our study, the RFT had made a major contribution to global warming, where the most obvious warming appeared in the drylands. And we conclude that the long-term global-mean SAT warming trend was mainly related to the radiative forcing produced by the global, well mixed GHGs. But, the regional anthropogenic radiative forcing caused the enhanced warming in the semi-arid regions. Therefore, the hiatus as a phenomenon of global scale was not in conflict with the regionally enhanced warming in the semi-arid regions.

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Climate Explorer for making the NAO, PDO and AMO indices were available to downloaded (http://climexp.knmi.nl/).

References:

Easterling, D. R. and Wehner, M. F.: Is the climate warming or cooling?, Geophys. Res. Lett., 36, L08706, doi:10.1029/2009GL037810, 2009.

Guan, X., Huang, J., Guo, N., Bi, J., and Wang, G.: Variability of soil moisture and its relationship with surface albedo and soil thermal parameters over the Loess Plateau, Adv. Atmos. Sci., 26, 692-700, 2009.

Guan, X., Huang, J., Guo, R., and Lin, P.: The role of dynamically induced variability in the recent warming trend slowdown over the Northern Hemisphere, Sci. Rep., 5, 12669, doi:10.1038/srep12669, 2015.

He, Y., Huang, J., and Ji, M.: Impact of land–sea thermal contrast on interdecadal variation in circulation and blocking, Clim. Dynam., 43, 3267-3279, 2014.

Hu, Y. and Gao, Y.: Some new understandings of processes at the land surface in arid area from the HEIFE, Acta. Meteorol. Sin., 52, 285-296, 1994.

Huang, J., Zhang, W., Zuo, J., Bi, J., Shi, J., Wang, X., Chang, Z., Huang, Z., Yang, S., and Zhang, B.: An overview of the semi-arid climate and environment research observatory over the Loess Plateau, Adv. Atmos. Sci., 25, 906–921, 2008..

Huang, J., Guan, X., and Ji, F.: Enhanced cold-season warming in semi-arid regions, Atmos. Chem. Phys., 12, 5391-5398, doi:10.5194/acp-12-5391-2012, 2012.

Huang, J., Ji, M., Liu, Y., Zhang, L., and Gong, D.: Review of climate change research in arid and semi-arid regions, Advances in Climate Change Research, 9, 9-14, 2013 (in Chinese).

Huang, J., Liu, J., Chen, B., and Nasiri, S.: Detection of anthropogenic dust using CALIPSO lidar measurements, Atmos. Chem. Phys. Discuss., 15, 10163–10198, doi:10.5194/acpd-15-10163-2015, 2015.

Ji, F., Wu, Z., Huang, J., and Chassignet, E. P.: Evolution of land surface air temperature trend, Nature Clim. Change, 4, 462-466, 2014.

Jiang, L. and Hardee, K.: How do recent population trends matter to climate change?, Popul. Res. Policy. Rev., 30, 287-312, 2011.

Kosaka, Y. and Xie, S. P.: Recent global-warming hiatus tied to equatorial Pacific surface cooling, Nature, 501, 403-407, 2013.

Lemke, P., Ren, J., Alley, R. B., Allison, I., Carrasco, J., Flato, G., Fujii, Y., Kaser, G., Mote, P., Thomas, R. H., and Zhang, T.:Observations: changes in snow, ice and frozen ground, in: Climate change : the physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change, edited by: Solomon, S., Qin, D., Manning, M., Chen,Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 372–374, 2007.

Li, J. P., Sun, C., and Jin, F. F.: NAO implicated as a predictor of Northern Hemisphere mean temperature multidecadal variability, Geophys. Res. Lett., 40, 5497-5502, 2013.

Li, Z., Niu, F., Fan, J., Liu, Y., Rosenfeld, D., and Ding, Y.: Long-term impacts of aerosols on the vertical development of clouds and precipitation, Nat. Geosci., 4, 888-894, doi: 10.1038/NGEO1313, 2011.

Mitchell, T. D. and Jones, P. D.: An improved method of constructing a database of monthly climate observations and associated high-resolution grids, Int. J. Climatol., 25, 693-712, 2005.

Mulitza, S., Heslop, D., Pittauerova, D., Fischer, H. W., Meyer, I., Stuut, J. B., Zabel, M., Mollenhauer, G., Collins, J. A., and Kuhnert, H.: Increase in African dust flux at the onset of commercial agriculture in the Sahel region, Nature, 466, 226-228, 2010.

Qian, Y., Gustafson Jr, W. I., Leung, L. R., and Ghan, S. J.: Effects of soot-induced snow albedo change on snowpack and hydrological cycle in western United States based on Weather Research and Forecasting chemistry and regional climate simulations, J. Geophys. Res., 114, D03108, doi:10.1029/2008JD011039, 2009.

Qian, Y., Flanner, M., Leung, L., and Wang, W.: Sensitivity studies on the impacts of Tibetan Plateau snowpack pollution on the Asian hydrological cycle and monsoon climate, Atmos. Chem. Phys., 11, 1929-1948, doi:10.5194/acp-11-1929-2011, 2011.

Smoliak, B. V., Wallace, J. M., Lin, P., and Fu, Q.: Dynamical adjustment of the Northern Hemisphere surface air temperature field: methodology and application to observations, J. Climate, 28, 1613–1629, 2015.

Taylor, K. E., Stouffer, R. J., and Meehl, G. A.: An overview of CMIP5 and the experiment design, Bull. Am. Meteorol. Soc., 4, 485-498, 2012.

Trenberth, K. E., and Hurrell, J. W.: Decadal atmosphere-ocean variations in the Pacific, Clim. Dynam., 9, 303-319, 1994.

Wallace, J. M., Fu, Q., Smoliak, B. V., Lin, P., and Johanson, C. M.: Simulated versus observed patterns of warming over the extratropical Northern Hemisphere continents during the cold season, Proc. Natl. Acad. Sci., 109, 14337-14342, 2012.

White, R. P. and Nackoney, J.: Drylands, people, and ecosystem goods and services: a web-based geospatial analysis (PDF version), World Resources Institute (available at: http://pdf. wri. org/drylands pdf accessed on 30 January 2012), 2003.

Wyatt, M. G. and Curry, J. A.: Role for Eurasian Arctic shelf sea ice in a secularly varying hemispheric climate signal during the 20th century, Clim. Dynam., 42, 2763-2782, 2014.

Wyatt, M. G., Kravtsov, S., and Tsonis, A. A.: Atlantic multidecadal Oscillation and Northern Hemisphere's climate variability, Clim. Dynam., 38, 929-949, 2012.

Zhai, P. and Zhou, Q.: The change of northern hemisphere snow cover and its impact on summer rainfalls in China, Quarterly Journal of Applied Meteorology, 8, 231-235, 1997 (in Chinese).

Zhang, G., Cai, M., and Hu, A.: Energy consumption and the unexplained winter warming over northern Asia and North America, Nature Clim. Change, 3, 466-470, 2013.

Zhang, Q., Wei, G., and Huang, R.: Observation and study of atmospheric drag coefficients in Dunhuang, Sci. China Ser. D., 31, 783-792, 2001 (in Chinese).

Zhou, L., Dickinson, R. E., Dai, A., and Dirmeyer, P.: Detection and attribution of anthropogenic forcing to diurnal temperature range changes from 1950 to 1999: comparing multi-model simulations with observations, Clim. Dynam., 35, 1289-1307, 2010.

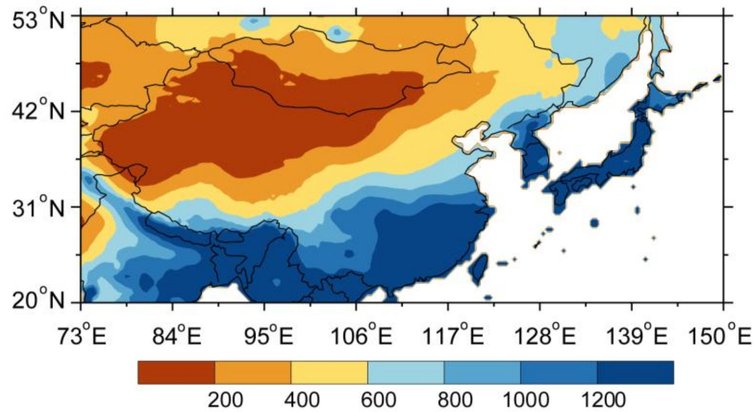


Figure 1. Spatial distribution of annual mean precipitation from 1961-1990 ($mmyr^{-1}$)

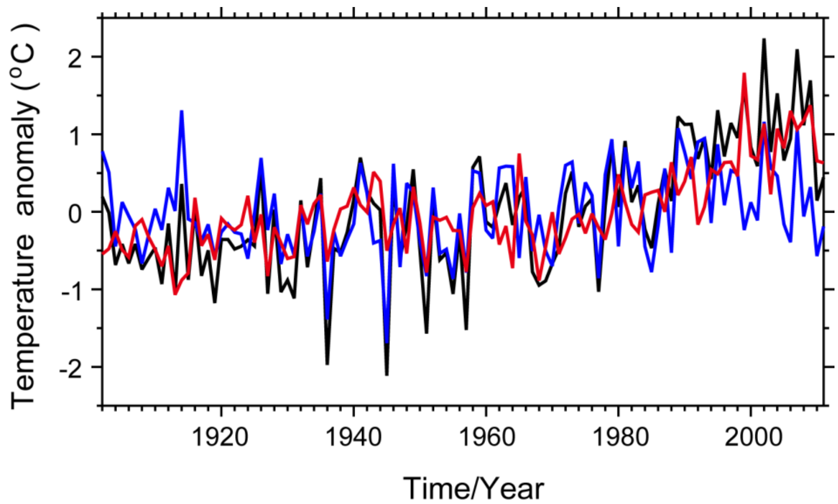


Figure 2. Time series of regionally averaged temperature anomalies of raw (black), dynamically induced (blue) and radiatively forced (red) temperatures in the cold season (November to March) from 1902 to 2011 over East Asia.

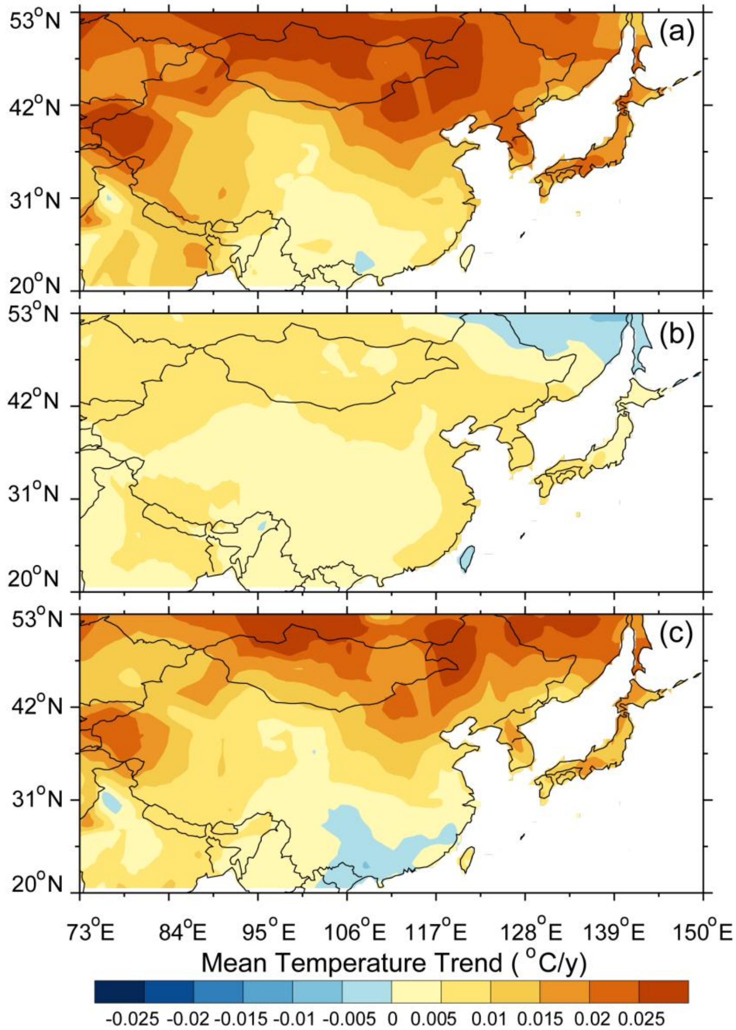
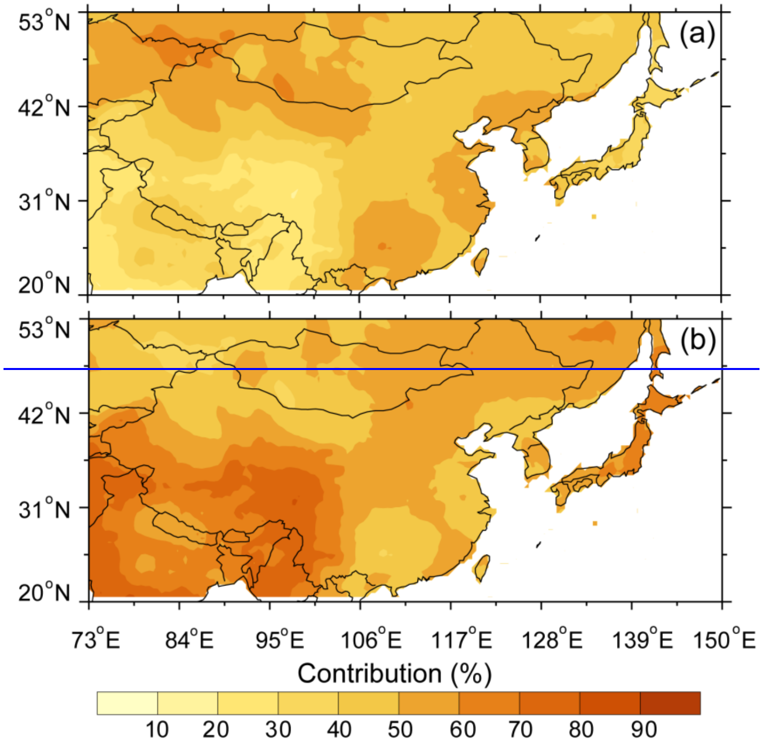


Figure 3. Spatial distribution of trend of raw (a), dynamically induced (b) and radiatively forced (c) temperatures in the cold season from 1902 to 2011 over East Asia.


(a)
(b)
53°N
42°N
31°N
20°N
73°E
84°E
95°E
106°E
117°E
128°E
139°E
150°E
Contribution (%)
10
20
30
40
50
60
70
80
90

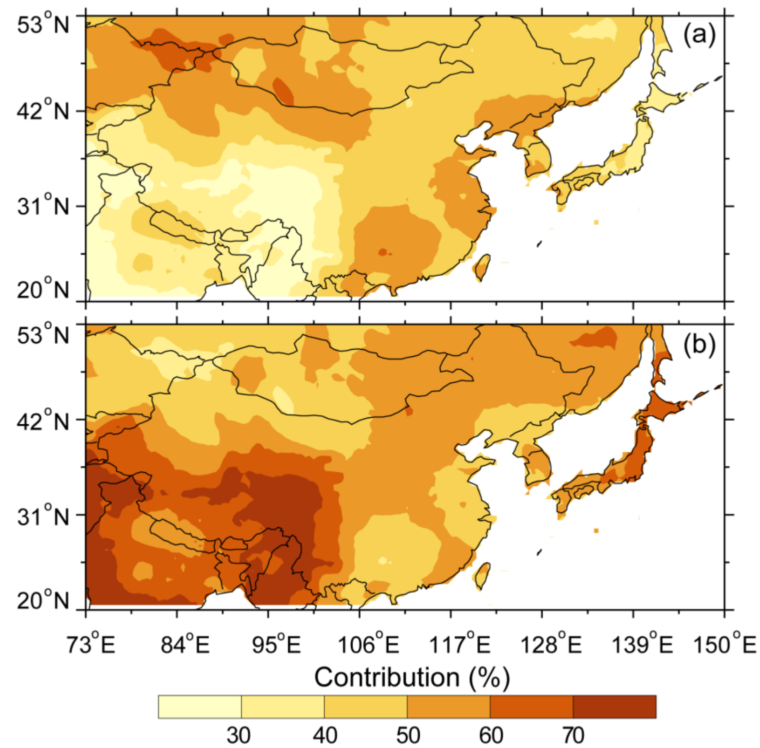

(a)
(b)
53°N
42°N
31°N
20°N
73°E
84°E
95°E
106°E
117°E
128°E
139°E
150°E
Contribution (%)
30
40
50
60
70

Figure 4. Spatial distribution of contribution of dynamically induced (a) and radiatively forced (b) temperatures to raw temperature in the cold season from 1902 to 2011 over East Asia.

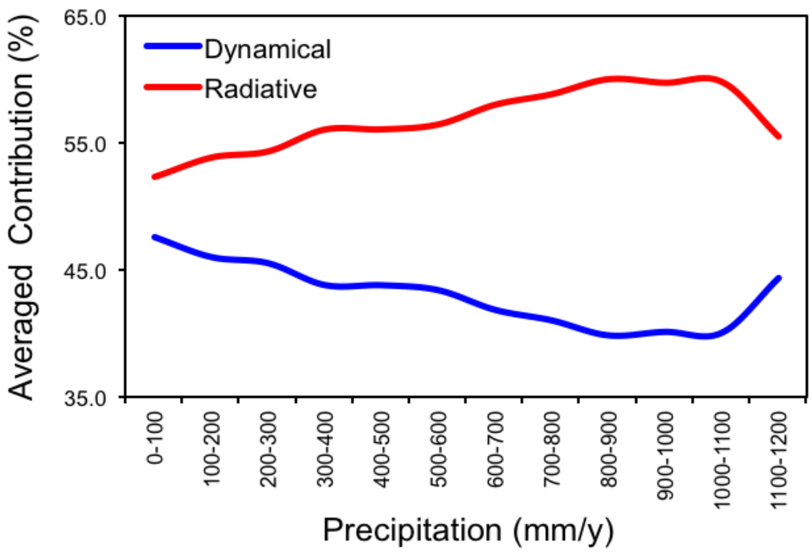


Figure 5. Contributions of dynamically induced (blue) and radiatively forced (red) temperatures to the raw temperature as a function of annual precipitation in the cold season from 1902 to 2011 over East Asia.

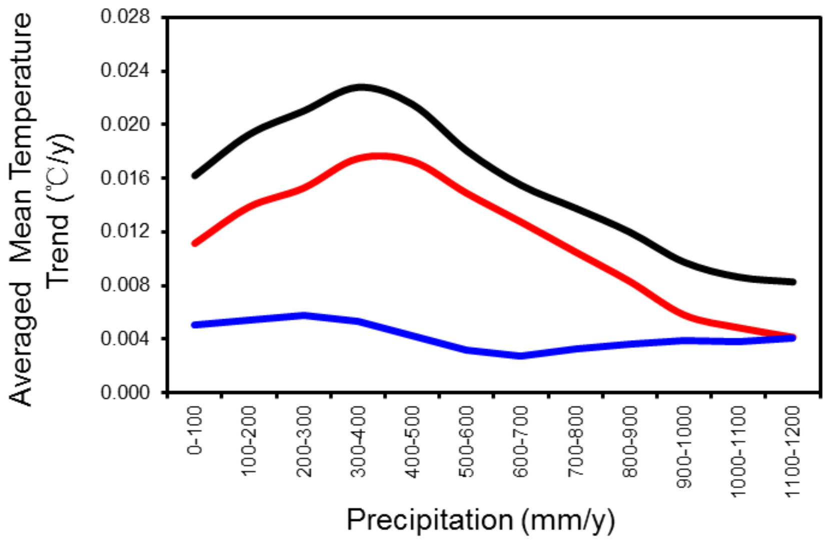


Figure 6. Regionally averaged temperature trend as a function of annual precipitation for raw (black), dynamically induced (blue) and radiatively forced (red) temperatures in the cold season from 1902 to 2011 over East Asia.

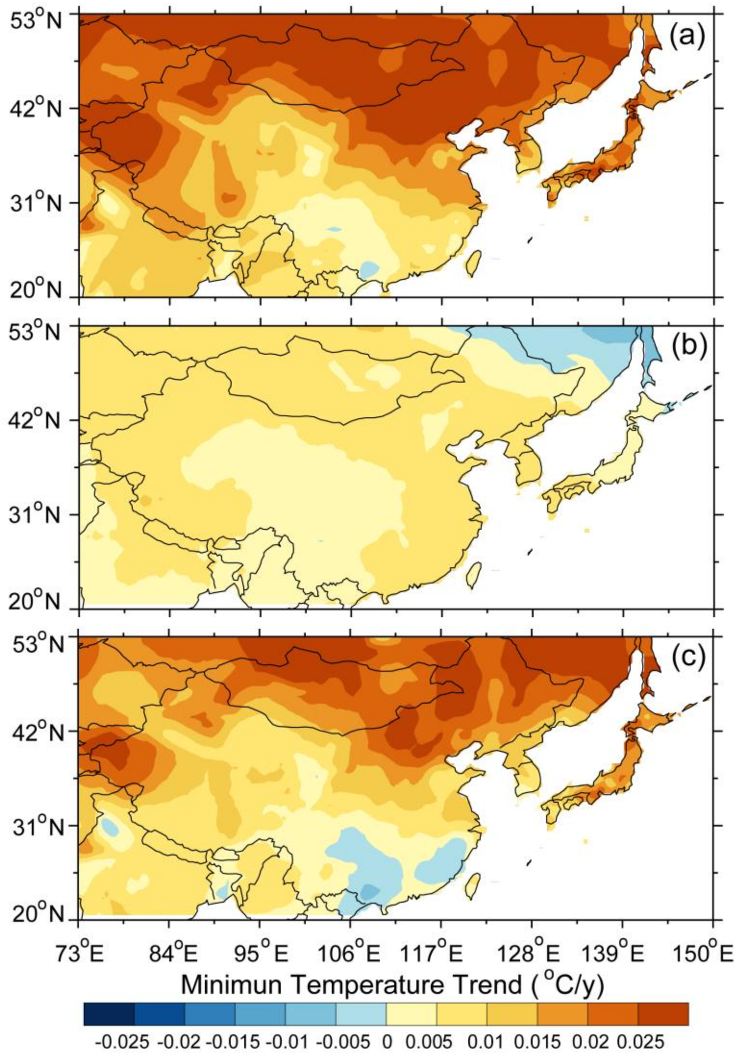


Figure 7. Same as Fig. 3, except for daily minimum temperatures.

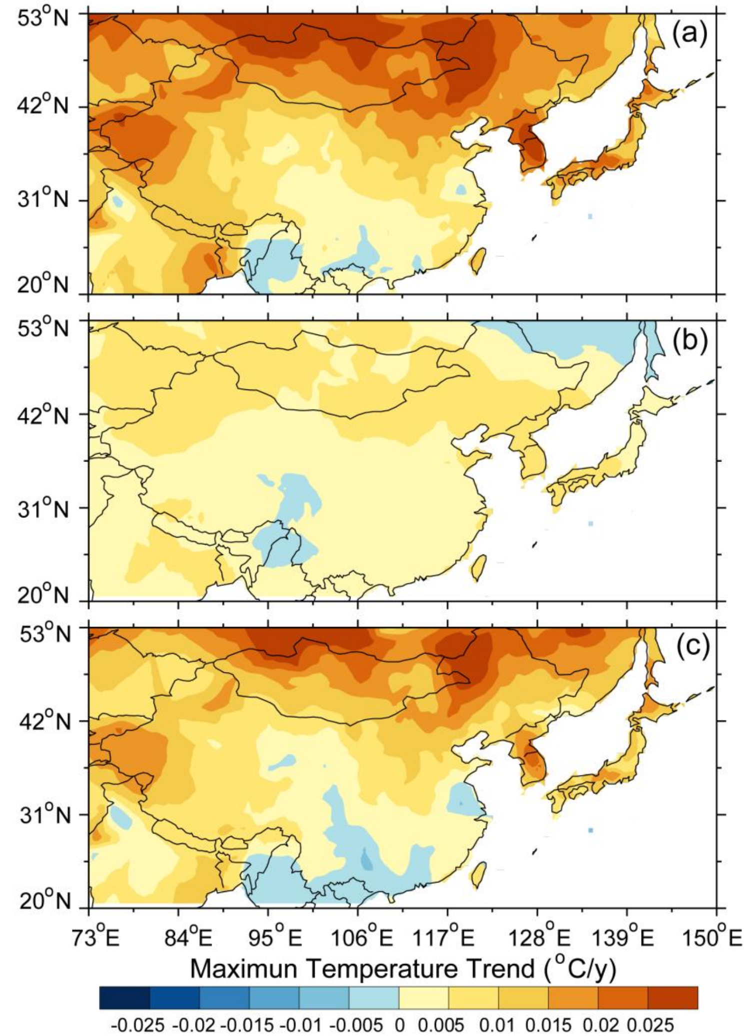


Figure 8. Same as Fig. 3, except for daily maximum temperatures.

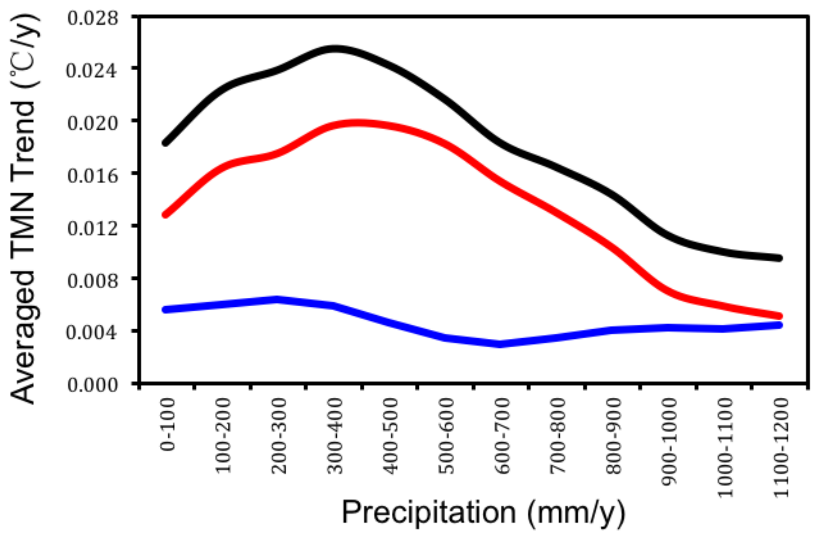


Figure 9. Same as Fig. 6, except for daily minimum temperature.

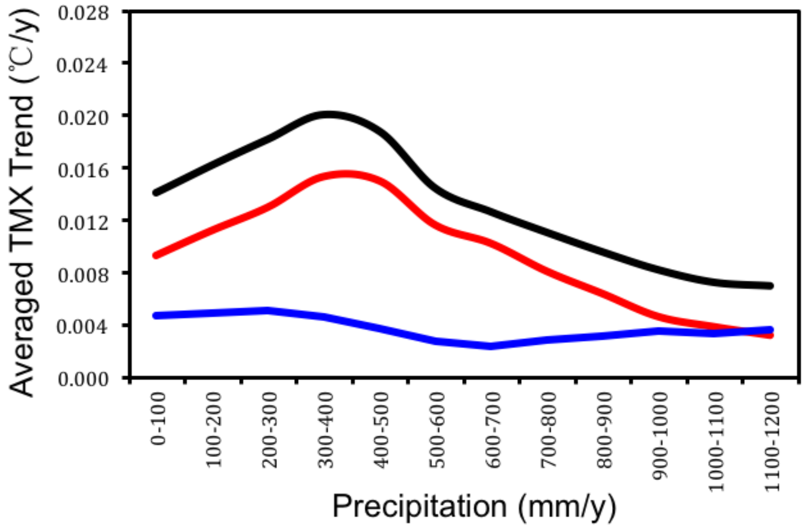
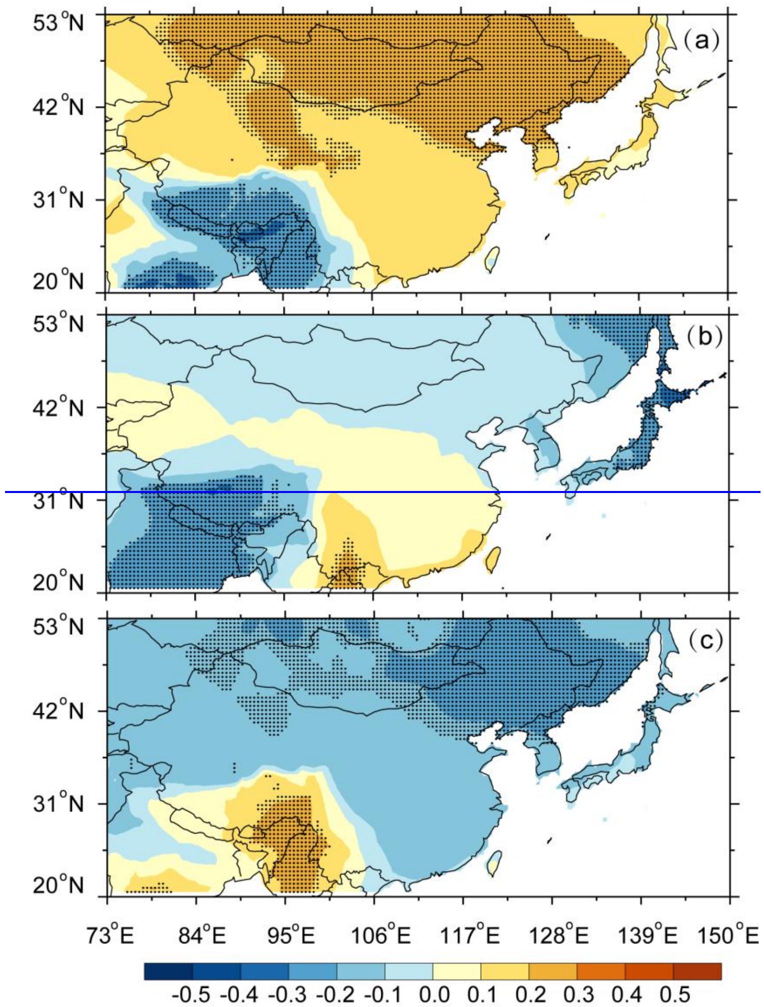


Figure 10. Same as Fig. 6, except for daily maximum temperature.

626



53°N
42°N
31°N
20°N
(a)
(b)
(c)
73°E
84°E
95°E
106°E
117°E
128°E
139°E
150°E
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5

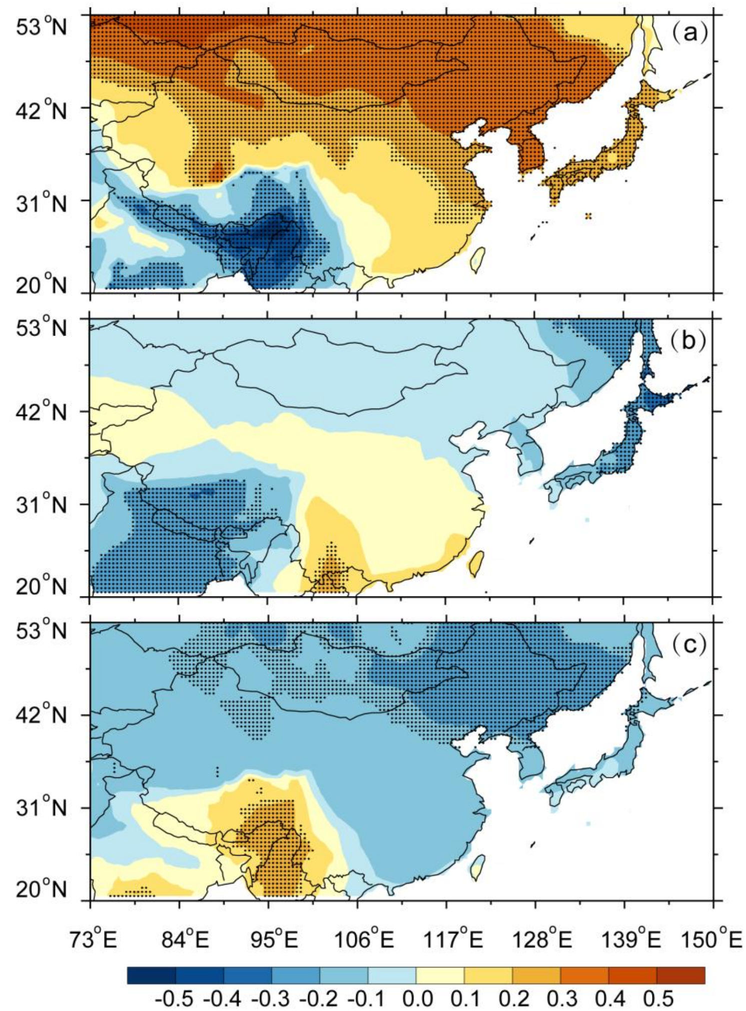


Figure 11. Spatial distribution of the correlation coefficient between detrended dynamically induced temperature and detrended NAO~~ (detrended and 11 year running mean)~~ (a), ~~between detrended dynamically induced temperature and detrended~~ PDO (b), and~~ between detrended dynamically induced temperature and detrended~~ AMO (c) in the cold season from 1902 to 2011 over East Asia. The stippling indicates the 95 % confidence level according to a two-tailed Student's t test.

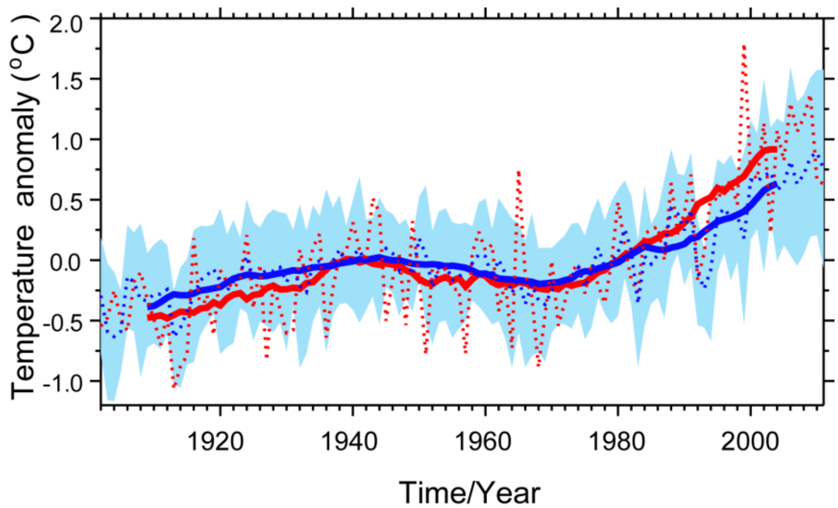


Figure 12. Time series of radiatively forced temperature (red) and ensemble-mean CMIP5 simulations (blue) based on 15-yr running mean in the cold season from 1902 to 2011 over East Asia. The blue shading indicates the standard deviation of the CMIP5-simulated field.

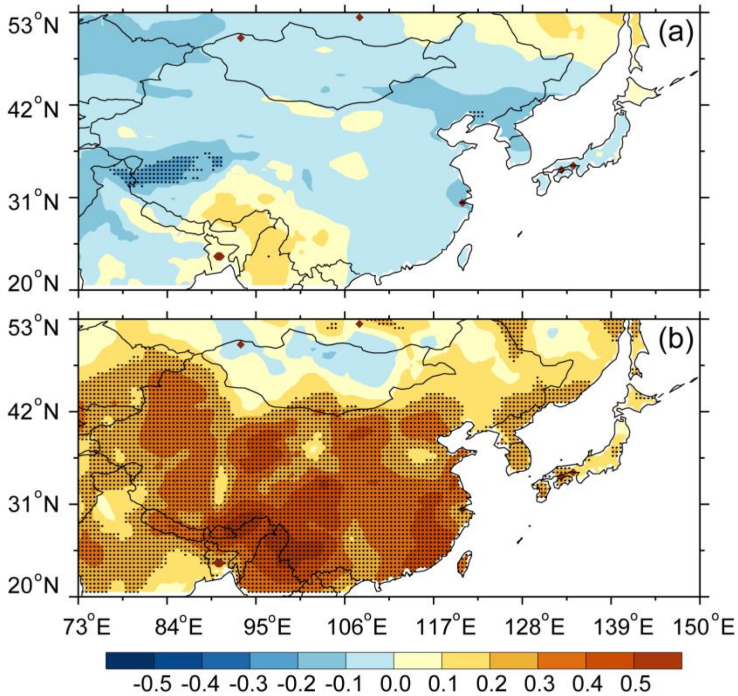


Figure 13. Spatial distribution of correlation coefficient between ensemble-mean CMIP5 simulations and dynamically induced temperature (a), and between ensemble-mean CMIP5 simulations and radiatively forced temperature (b) in the cold season from 1902 to 2011 over East Asia.

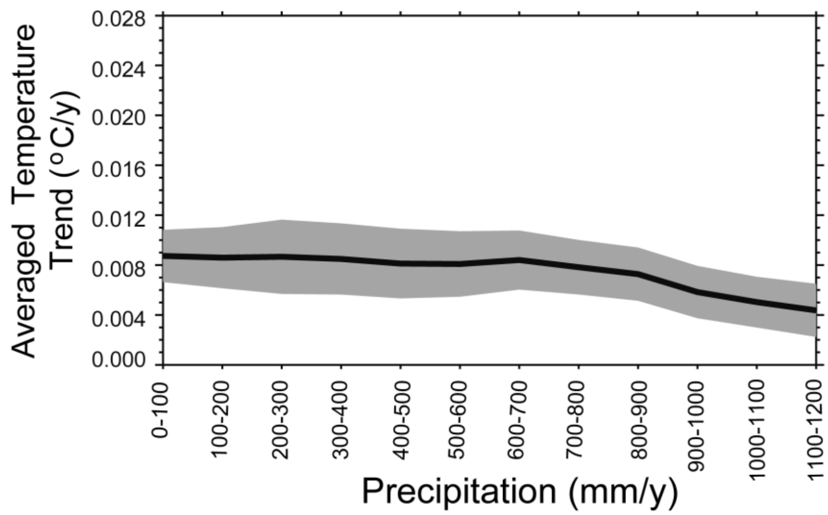


Figure 14. Regional averaged temperature trend as a function of climatological annual mean precipitation over East Asia for ensemble-mean CMIP5 simulations in cold season from 1902 to 2011, shading denotes 95% confidence intervals.

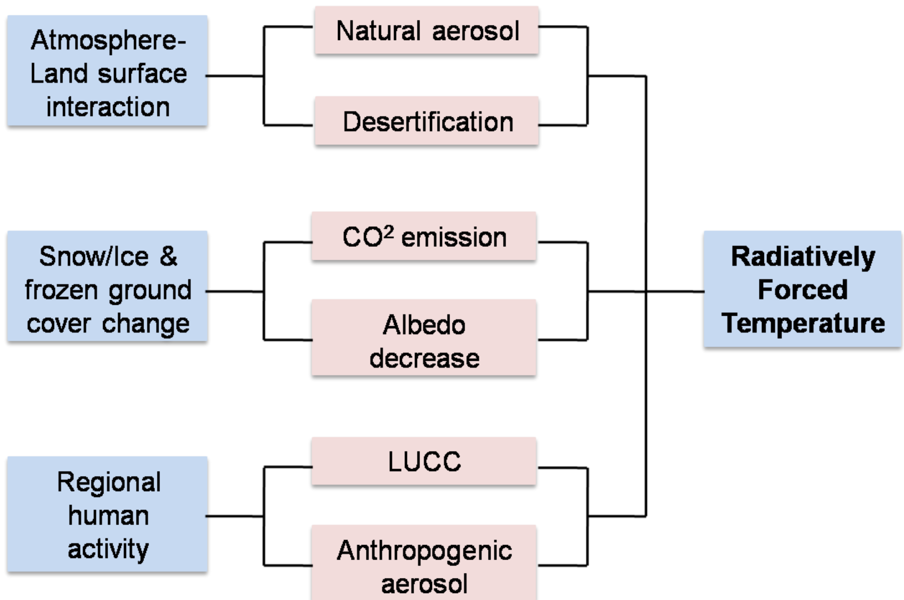


Figure 15. Schematic diagram of radiatively forced temperature.

Table 1. CMIP5 models examined in this study.

Model name	Modelling centre
BCC-CSM1.1	Beijing Climate Center, China
CanESM2	Canadian Centre for Climate, Canada
CCSM4	National Center for Atmospheric Research, USA
CNRM-CM5	Centre National de Recherches Meteorologiques, France
CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research, Australia
GFDL-CM3	Geophysical Fluid Dynamics Laboratory, USA
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory, USA
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory, USA
GISS-E2-R	NASA Goddard Institute for Space Studies, USA
HadGEM2-CC	Met Office Hadley Centre, UK
HadGEM2-ES	Met Office Hadley Centre, UK
INM-CM4	Institute for Numerical Mathematics, Russia
IPSL-CM5A-LR	Institute Pierre-Simon Laplace, France
IPSL-CM5A-MR	Institute Pierre-Simon Laplace, France
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Japan
MIROC-ESM-	Japan Agency for Marine-Earth Science and Technology, Japan
MIROC5	Atmosphere and Ocean Research Institute, Japan
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany
MRI-CGCM3	Meteorological Research Institute, Japan
NorESM1-M	Norwegian Climate Centre, Norway