

We appreciated reviewer's comments and suggestions very much. Your comments and suggestions have improved our manuscript a lot. Both the scientific questions and technologic notes are very important to us, and we have answered and replied to them case by case as follow in blue color. The list of the all relevant changes made in the manuscript has been shown after the responses to the reviewer. 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.

After reviewing the first revision of the manuscript by Guan et al., I am making the following recommendations, summarized as major revisions due to the number and variety of revisions necessary in the text. The first revision is an improvement over the original manuscript, but remains below the standards ACP maintains. I appreciate the thoughtful and thorough response of the authors to the reviewers' comments, and hope that they are able to continue to revise the manuscript to resolve the remaining issues.

Major comments:

(1) It is not clear if the analysis uses monthly-mean data or cold season-mean data. Equation 2 implies that the analysis uses cold season-mean data, but the text sometimes suggests otherwise. The authors should clarify this point in Section 2 and alter their language throughout the remainder of the text. For example, when referring to temperature trends, the authors should use "cold season-mean temperature trends." If the authors did indeed use monthly-mean data, should alter Equation 2 accordingly, and be more specific about what sort of high-pass filter was applied to the data in the course of the dynamical adjustment methodology.

Response: The analysis used cold season-mean data, mean of monthly temperature from Nov.-March. We have been checked carefully, clarified it in Section 2 and revised the confused placed in the whole manuscript. And we have modified the places of "temperature trends" to "cold season-mean temperature trends" to avoid the misunderstanding. The data were filtered by removing the cold season mean from the mean for each month within a given cold season.

(2) What sort of high pass filter was applied? Were the data merely detrended? Was a running mean removed? Please be specific, otherwise the study will not be strictly reproducible.

Response: The data were filtered by removing the cold season mean from the mean for each month within a given cold season. We have added the specific of high pass filter in the revised manuscript.

(3) Which CMIP5 experiment was used? I presume it was the CMIP5 historical experiment. Although this detail may seem to some to be obvious, I think it would make the text more precise. Furthermore, what were the forcings included in the historical experiments. The authors should investigate model-by-model which forcings were included. Lastly, how many ensemble members were used for each model included in the analysis? 1? If so, which one? These details could be summarized in a sentence or two, and need not take up additional space in a table or text. As it stands these critical details are missing.

Response: Both CMIP5 historical experiment and RCP4.5 scenario have been used in the study, because the historical experiment is ended on the year of 2005, we selected the middle level scenario to fill the simulated temperature in the period after 2005. Table 1 in the manuscript listed the models we used in the study, we totally agreed with reviewer's comments on the models and we do not think we can get a robust conclusion on which ensemble member take the major role, your suggestion proposed a very meaningful and interesting work, we appreciated and work on in our next paper. In order to avoid readers having the similar confusion, we revised the description of this part and we hope our next manuscript will be lucky enough to be reviewed by the reviewer again. Thanks.

Minor comments:

(1) Title: I appreciate the authors revising the title to include cold season, but upon reviewing their new title, I think that the original one is better. See my next comment about adding cold season to the abstract.

Response: The title will be changed to the original one. The new title is “Role of radiatively forced temperature changes in enhanced semi-arid warming in cold season over East Asia”. Thanks for your caution.

(2) Line 39-40: Add "observed" prior to "warming" and strike "observed in previous decades"

Response: The revision has been done.

(3) Line 41: Add "during the boreal cold season" after "change".

Response: We have added in the revised manuscript.

(4) Line 44: Probably do not need to use tenths of a percent. It will suffice to round the contributions to 44 and 56%, respectively.

Response: The sentence has been reorganized in the manuscript.

(5) Line 46: Change "such as" to "represented by". These patterns of variability may not be purely internal, but are being used here to represent internal variability.

Response: The modification has been done, and we checked the whole manuscript and make sure there is no similar expression appeared any more.

(6) Line 55: Add "the so-called" prior to "global warming hiatus". There may be a few readers who are unfamiliar with the term.

Response: “the so-called” has been added prior to “global warming hiatus” in the revised manuscript.

(7) Line 75: What are these studies? This sentence implies that there are more than one. However, only one reference follows in the next sentence, Zhang et al. 2013. This statement needs more support from references.

Response: Sorry for our careless, the related references have been added in the right place.

(8) Line 79-80: Over what period did rapid industrialization occur? Can you add a reference here?

Response: The rapid industrialization occurred since the late 1980s. The period of rapid industrialization and its references have been added in the revised manuscript.

(9) Line 81-83: Quite to the contrary, Wallace et al. interpreted the dynamically induced warming as primarily due to internal variability not greenhouse gases. Here the authors make it sound like Wallace et al. claimed that the dynamical changes were caused by greenhouse gases. This is not the case. Needs rewriting.

Response: Sorry for our inappropriate description. The sentence has been changed to “dynamic effects induced by internal variability have been proposed to interpret the rapid warming over continents and non-uniformity of local warming distribution (Wallace et al., 2012).” in the revised manuscript.

(10) Line 88: Change "process of" to "warming".

Response: The revision has been done.

(11) Line 92: Change "changes of atmospheric circulations..." to "changes in atmospheric circulations..."

Response: The revision has been done.

(12) Line 94: "and so on" appears many times in the paper. This is terribly imprecise language. The reader does not know what "and so on" means. Remove it. Simply end the sentence with "interaction between land and atmosphere, and feedback from snow."

Response: We have modified the sentence, and will pay much attention to use the phrase of “and so on”.

(13) Line 126: Remove the sentence beginning "The wet regions are most distributed..." It adds little new information that cannot be deduced from the previous sentence.

Response: we appreciate reviewer's comment. The sentence has been removed, and we will avoid the similar problem in future.

(14) Line 135: Wallace et al. defined the cold season as November to April, not November to March.

Response: Thanks and we have corrected the careless.

(15) Line 141-142, I suggest this sentence be rewritten as follows, "The sea level pressure (SLP) data are standardize and the temperature time series are high pass filtered and standardize prior to carrying out the following dynamical adjustment steps." Next, add a sentence that describes the high pass filter. Then address the DA steps.

Response: Thanks for your suggestion. We have rewritten this part as below "The sea level pressure (SLP) data are standardized and the temperature time series are high pass filtered by removing the cold season mean from the mean for each month within a given cold season and then standardized prior to carrying out the following dynamical adjustment steps:"

(16) Line 144: this clause should read "correlate the grid-point temperature time series with the SLP field to generate a one-point cross correlation map;"

Response: The sentence has been corrected.

(17) Line 151, after mutually orthogonal, I suggest you add ", taking care to high pass filter each successive residual temperature time series prior to calculating correlation patterns (step 1)."

Response: The sentence has been inserted in the revised manuscript.

(18) Line 156, I suggest this sentence be rewritten as follows "The residual part is associated with radiatively forced factors, called the RFT."

Response: The sentence has been rewritten in the revised manuscript.

(19) Line 159: Remove "and so on."

Response: “and so on.” has been removed in the revised manuscript.

(20) Line 159: Replace "For" with "In the", then on Line 160, change "is" to "are".

Response: The corrections have been done in the revised manuscript.

(21) Line 172-174: Rewrite this sentence as "The difference evaluations of DIT and RFT indicate that the DIT and RFT played difference roles in determining the raw temperature variability."

Response: The sentence has been rewritten.

(22) Line 188: Change "is" to "was", also add "during the period 1902-2011"; you have not demonstrated that radiative forcing is always more important than dynamically induced changes.

Response: The correction has been done; the sentence has been revised as “The difference of DIT trend distribution from RFT indicates that the influence of radiative forcing on regional temperature changes was much different with dynamic factor during the period of 1902-2011.”

(23) Line 189: This sentence is confusing and should be rewritten or removed.

Response: We decided to remove it to avoid the confusion.

(24) Line 192: This sentence expresses a truism. It should be removed. The maps HAVE TO exhibit different locations of high contribution. $RAW = DIT + RFT$

Response: We agreed to remove this sentence.

(25) Line 193: I think you mean "variability" where you say "change" here. It is unclear if you are referring to interannual variability or trends. I believe you are referring to trends.

Response: Fig. 4a is the dynamic contribution to the raw temperature, not the temperature interannual variability or trends. We have deleted “change” in the revised manuscript. The contribution of RFT (DIT) to raw temperature is calculated as formula (2):

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

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

(26) Line 197-198: This sentence is confusing. It could be rewritten as "Figure 4 illustrates that regional temperature variability is mostly determined by RFT."

Response: The sentence has been modified as "Figure 4 illustrates that regional temperature is mostly determined by RFT." in the revised manuscript.

(27) Line 200: Add "variability" after "temperature" and "cold season" before "temperature". Remove "in the cold season" after "precipitation".

Response: The "cold season" has been added before the "temperature" and the "in cold season" after "precipitation" has been removed. Same as question (25), the contribution in Fig.4 and Fig. 5 in the manuscript is the contribution to the raw temperature, not the temperature interannual variability or trends. So the sentence has been modified as "This regional discrepancy is confirmed by the contributions of DIT (blue line) and RFT (red line) to the cold season temperature as a function of annual precipitation over East Asia (Fig. 5)."

(28) Line 206: Replace "provides" with "shows".

Response: The replacement has been done.

(29) Line 211: Replace "dominated" with "dominant"

Response: The replacement has been done.

(30) Line 212: Replace "However" with "Conversely"

Response: The replacement has been done.

(31) Line 213: Replace "over different areas" with "as a function of annual mean precipitation". This is more precise in terms of your subject. It gives some detail to how the "different areas" are organized.

Response: Great suggestion. And the revision has been done in the revised manuscript.

(32) Line 216: Replace "leaded by" with "associated with"

Response: The corrections have been done.

(33) Line 217: replace the sentence beginning "It improves" with "This extends understanding of the ESAW (Huang et al., 2012), and suggests that the role of radiative forcing was critical in the process of warming over East Asia."

Response: The modification has been done in the revised manuscript.

(34) Line 219: I suggest that part of this sentence be removed. The part about "expressed different variability of DIT and RFT" is confusing. Perhaps the authors could write "These results are not limited to monthly-mean temperatures. Figure 7 shows the distributions of raw..."

Response: We appreciated your suggestion and modified the sentence in the revised manuscript.

(35) Line 229: Replace "is" with "shows" and add "-induced" after "dynamically" and add "-forced" after "radiatively".

Response: The corrections have been done.

(36) Line 231: Replace "had a warming trend" with "was positive"

Response: The corrections have been done.

(37) Line 235: Remove "the area along of"

Response: It has been removed.

(38) Line 236: Rewrite as "The RFT trend (Fig. 8c) exhibits an obvious warming over the northern area, with a small cooling over South China. This is similar to the trends in daily minimum temperature, but the areal extent of cooling was much larger than the radiatively forced daily minimum temperature in 7c.

Response: The sentence has been rewritten as "The RFT trend (Fig. 8c) exhibits an obvious warming over the northern area, with a larger cooling scale over South China than daily minimum temperature in Fig. 7c."

(39) Line 240: Replace the sentence beginning "In order to distinguish the" with "In order to distinguish the contributions to regionally-averaged temperature trends, raw, DIT, and RFT minimum and maximum trends are shown as a function of annual-mean precipitation in Fig. 9 and Fig. 10, respectively."

Response: The revision has been finished.

(40) Line 243: "over different regions" is not only vague, it is not accurate. The daily minimum warming rate is higher than the daily maximum "over all regions".

Response: The sentence has been modified.

(41) Line 246: Replace this sentence with "Similar to monthly-mean temperatures, the DIT trend did not show much variation with increasing annual-mean precipitation in both daily minimum and maximum temperatures."

Response: The revision has been done.

(42) Line 255: Replace "patterns cover" with "correlations over"...replace "with a 95%" with "significant at the 95% "

Response: The revision has been done.

(43) Line 256: Replace "patterns" with "correlations" and "with a" with "also significant at the"

Response: The revision has been done.

(44) Line 257: Replace "It suggests the" with "This indicates a"

Response: The revision has been done.

(45) Line 262: replace "coefficient of AMO index and DIT" with "coefficients between the AMO index and DIT"

Response: The revision has been done.

(46) Line 264: Replace "opposite with" with "opposite to"

Response: The revision has been done.

(47) Line 266-277: This entire paragraph needs to be rewritten for clarity and grammar. Please refer to my major comment (3). Furthermore, the last 3 sentences are misleading. The multi-model mean should be smoother than the observed curve, you have averaged much of the internal variability out (even in a historical run). Is the notable consistency you refer to in terms of the smoothed curves or the raw time series?

Response: The paragraph has been reorganized in the revised manuscript, and the notable consistency in the manuscript is referred to the warming trend between RFT and simulated SAT from the 1970s to the late 1990. We have done the modification to make this concise.

(48) Line 278-279: Which time series are being correlated? The CMIP5 multi-model ensemble mean and the observed DIT and RFT time series?

Response: The sentence has been changed to "The distributions of correlation coefficients of DIT and RFT with simulated temperature of CMIP5 in the period of 1902-2010 are expressed in Fig. 13a and b". Figure 13a is the correlation coefficient between CMIP5 multi-model ensemble mean and DIT, and Figure 13b is the correlation coefficient between CMIP5 multi-model ensemble mean and RFT.

(49) Line 283-284: Rewrite the sentence starting "It indicates" as "It indicates the forced temperature changes in CMIP5 have a closer relationship with RFT than DIT." Remove the

part "namely, CMIP5 models reflect part of raw temperatures." It is confusing and difficult to understand what you mean.

Response: The corrections have been done in the revised manuscript.

(50) Line 287: Probably best to include "multi-model" when referring to the ensemble mean.

Response: The revision has been done.

(51) Line 287: This sentence would read better as "Multi-model ensemble mean temperature trends shown as a function of annual precipitation in Fig. 14 stand in contrast to the regional RFT trends over the drylands shown in Fig. 6.

Response: The modification has been done in the revised manuscript.

(52) Line 290: End the stance at "ensemble mean temperature." Then change "which demonstrates" to "In contrast to observations, the CMIP5 simulations exhibit a uniform temperature change over East Asia."

Response: Thanks. We have finished the revision.

(53) Line 295: Remove "and so on."

Response: It has been removed in the revised manuscript.

(54) Line 295: Revise as "It is more likely related to regional factors not well represented in the models."

Response: The revision has been done.

(55) Line 297: Change "suggest" to "provide evidence"

Response: The revision has been done.

(56) Line 300: Again, probably can round these figures to full percentages, 44 and 56%.

Response: They have been revised in the manuscript.

(57) Line 300: Add "variability" after "to the SAT"

Response: Same as question (25), the 44 and 56% are referred to the DIT and RFT contribution to the raw temperature, not the temperature interannual variability or trends. So we would like to keep the sentence. Thanks.

(58) Line 301: Replace "was on" with "varied on"

Response: The revision has been done.

(59) Line 303: This sentence is confusing and should be rewritten. What does "took a continuous warming effect over the globe" mean?

Response: The sentence has been changed to "Guan et al., (2015) found that the radiatively forced temperature has a warming trend in the past decades". It wants to claim that the performance of radiatively forced temperature is warming all the time.

(60) Line 310: Change "substantially declining" to "substantial decline"

Response: The revision has been done.

(61) Line 316: Remove "Besides,"

Response: The "Besides" has been removed in the revised manuscript.

(62) Line 321: Change "process" to "processes"

Response: The revision has been done.

(63) Line 322: remove "well" altogether, add "warming hiatus across the entire Northern Hemisphere" after "regional warming and".

Response: The revision has been done.

(64) Line 331: Replace "But" with "However,"

Response: The revision has been done.

(65) Line 518: In Figure 3 caption, Move "cold season" prior to "trend". Remove "in the cold season"

Response: The revision has been done.

(66) Line 521: In Figure 4 caption, rewrite "Spatial distribution of the contribution of dynamically induced (a) and radiatively forced (b) temperature to raw cold-season temperature variability from 1902 to 2011 over East Asia."

Response: The caption of Figure 4 has been rewritten as "Spatial distribution of contribution of dynamically induced (a) and radiatively forced (b) temperatures to raw cold-season temperature from 1902 to 2011 over East Asia." in the revised manuscript.

(67) Line 541: Add "variability" after "raw temperature"

Response: Same as response to question (25), we would like to keep the sentence. Thanks.

(68) Figure 13: What are the small purple diamond shapes in the Figure? Are these an artifact of the analysis or something that was not described. Either explain them or remove them.

Response: These diamonds are null value. Sorry for the color fill and they have been set as no color fill (Figure R1) in the revised manuscript.

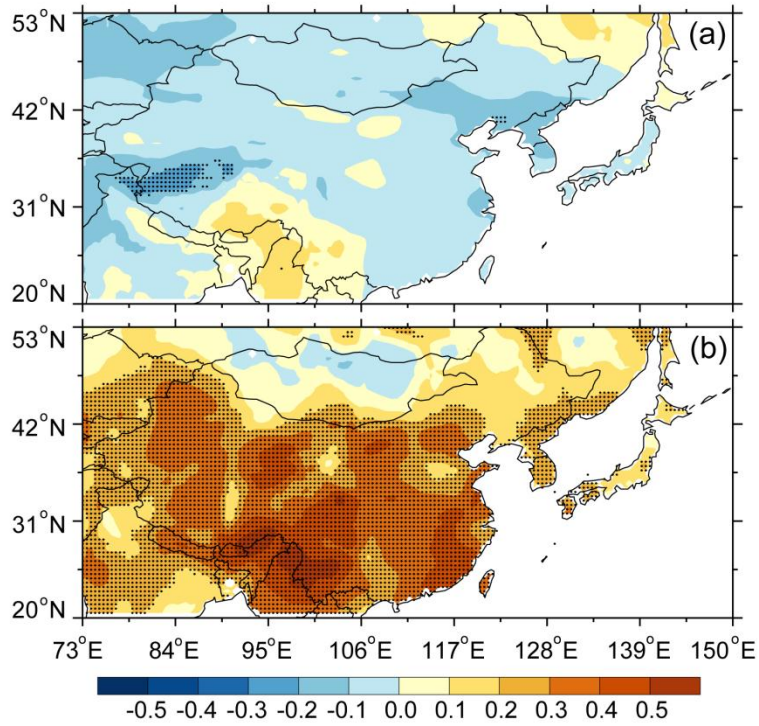


Figure R1. Spatial distribution of correlation coefficient between ensemble-mean CMIP5 simulations and dynamically induced temperature (a), and between ensemble-mean CMIP5 simulations and radiatively forced temperature (b) in the cold season from 1902 to 2011 over East Asia.

list of all relevant changes made in the manuscript:

1. Line 1-3: Change the title “Radiative forced enhanced semiarid warming in cold season over East Asia” to “Role of radiatively forced temperature changes in enhanced semi-arid warming in cold season over East Asia”.
2. Line 36-37: Change “the warming observed in previous decades” to “the observed warming in past decades”.
3. Line 38: Insert “during the boreal cold season” after “temperature change”.
4. Line 41: Change “43.7 and 56.3%” to “44 and 56%”.
5. Line 44: Change “such as” to “represented by”.
6. Line 52: Insert “the so-called” after “between”.
7. Line 67: Insert “; 2015” after the reference “Huang et al., 2012”.
8. Line 76: Insert “Huang et al., 1998; Higuchi et al., 1999; Shabbar et a., 2001;” before the reference “Zhang et al., 2013”.
9. Line 77: Insert “since the late 1980s” after “The rapid industrialization”.
10. Line 78-79: Insert “(Jiang et al., 1998; Dong et al., 2007; Ge, 2009; Maya and David, 2010)” after “East Asia”.
11. Line 80-81: Change “greenhouse gases (GHGs)” to “internal variability”.
12. Line 87: Change “process of” to “warming”.
13. Line 92: Change “of” to “in”.
14. Line 93: Delete “, and so on”.
15. Line 110: Insert “cold season-mean” before “temperature”.
16. Line 112: Insert “cold season-mean” before “temperature”.
17. Line 114: Insert “cold season-mean” before “temperature”.
18. Line 116: Insert “cold season-mean” before “RFT” and “temperature”, respectively.
19. Line 119: Insert “cold season-mean” after “the”.
20. Line 121: Insert “cold season-mean” before “temperature”.
21. Line 127: Delete “The wet regions are most distributed in the South area”.
22. Line 136: Change “November-March” to “November-April”.
23. Line 142-147: Change “The data of 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.” to “The sea level pressure (SLP) data

are standardized and the temperature time series are high pass filtered by removing the cold season mean from the mean for each month within a given cold season and then standardized prior to carrying out the following dynamical adjustment steps:”.

24. Line 148: Change “with its corresponding SLP” to “with the SLP field”.
25. Line 155-156: Insert “, taking care to high pass filter each successive residual temperature time series prior to calculating correction patterns (step1)”.
26. Line 162-163: Change “The rest is the residual part associated with radiatively forced factors” to “The residual part is associated with radiatively forced factors”.
27. Line 165: Delete “, and so on”.
28. Line 166: Change “For” to “In the”.
29. Line 167: Change “is” to “are”.
30. Line 180-181: Change “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” to “The different evolutions of DIT and RFT indicate that the DIT and RFT played different roles in determining the raw temperature variability”.
31. Line 195: Change “is” to “was”, “higher than” to “different with”, respectively.
32. Line 196: Insert “during the period of 1902-2011”.
33. Line 197-198: Delete “The discrepancy of distributions between DIT and RFT trends demonstrates the roles of DIT and RFT were different”.
34. Line 200: Delete “It exhibits quite different locations of high contribution for DIT and RFT”.
35. Line 201: Delete “change”.
36. Line 205-207: Change “The difference between Fig. 4a and Fig. 4b illustrated the regional temperature is mainly contributed by RFT” to “Figure 4 illustrates that regional temperature is mostly determined by RFT”.
37. Line 208: Insert “cold season” before “raw temperature”.
38. Line 209: Delete “in the cold season”.
39. Line 215: Change “provides” to “shows”.
40. Line 219: Insert “cold season-mean” before “temperature”.
41. Line 220: Change “dominated” to “dominant”.
42. Line 222: Change “However” to “Conversely”.

43. Line 222-223: Change “over different areas to “as a function of annual mean precipitation”.
44. Line 226: Change “leaded by” to “associated with”.
45. Line 227-230: Change “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” to “This extends understanding of the ESAW (Huang et al., 2012), and suggests that the role of radiative forcing was critical in the process of warming over East Asia”.
46. Line 231-232: Delete “, the daily minimum and maximum temperatures expressed different variability of DIT and RFT as well”.
47. Line 234: Insert “cold season-mean” before “temperature”.
48. Line 242: Change “Figure 8 is the distributions of raw, dynamically and radiatively of daily maximum temperature trends” to “Figure 8 shows the distributions of raw, dynamically induced and radiatively forced of daily maximum cold season-mean temperature trends”.
49. Line 244: Insert “cold season-mean” before “temperature”.
50. Line 245: Change “had a warming trend” to “was positive”.
51. Line 249: Delete “the area along of”.
52. Line 250-254: Change “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.” to “The RFT trend (Fig. 8c) exhibits an obvious warming over the northern area, with a larger cooling scale over South China than daily minimum temperature in Fig. 7c”.
53. Line 255-258: Change “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.” to “In order to distinguish the contributions to regionally-averaged cold season-mean temperature trends, raw, DIT and RFT minimum and maximum trends are shown as a function of annual-mean precipitation in Fig. 9 and Fig. 10, respectively”.
54. Line 259: Change “over different regions” to “over all regions”.

55. Line 262-265: Change “But, the DIT trend did not show a similar variability over different area in both daily minimum and maximum temperatures.” to “Similar to monthly-mean temperature, the DIT trend did not show much variation with increasing annual-mean precipitation in both daily minimum and maximum temperatures”.
56. Line 273-276: Change “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” to “It exhibits positive correlations over most East Asia area, significant at the 95% confidence level over Mongolia, Inner Mongolia and Northeast China; and negative correlations over India and Southwest China, also significant at the 95% confidence level”.
57. Line 276: Change “It suggests the” to “This indicates a”.
58. Line 281-282: Change “correlative coefficient of AMO index and DIT” to “correlative coefficients between the AMO index and DIT”.
59. Line 284: Change “with” to “to”.
60. Line 285-287: Change “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)” to “The RFT variability is always considered as a result of GHGs, land cover change, human activities, clouds (Huang et al., 2005; 2006) and aerosols (Huang et al., 2011; Li et al., 2011)”.
61. Line 289-291: Delete “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”.
62. Line 292-298: Change “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) over the 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 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” to “In order to manifest the

effects of radiative in RFT, a comparison between RFT and a 20-model ensemble mean of CMIP5 simulations (Table 1) (Taylor et al., 2012) over the East Asia is plotted (Fig. 12), which shows a notable consistent warming trend between RFT and simulated SAT from the 1970s to the late 1990”.

63. Line 300: Insert “in the period of 1902-2011” after “CMIP5”, “a and b” after “Fig. 13”, respectively.
64. Line 305-307: Change “It indicates the temperature of CMIP5 has a closer relationship with RFT than DIT, namely, CMIP5 models reflect part of raw temperatures” to “It indicates the forced temperature changes in CMIP5 have a closer relationship with RFT and DIT”.
65. Line 308: Insert “multi-model” before “ensemble mean”.
66. Line 310-312: Change “The ensemble mean temperature trend as a function of annual precipitation (Fig. 14) highlights the regional RFT over the drylands (Fig. 6)” to “Multi-model ensemble mean cold season-mean temperature trends shown as a function of annual precipitation in Fig. 14 stand in contrast to the regional RFT trends over the drylands shown in Fig. 6”.
67. Line 313: Insert “multi-model” after “the”.
68. Line 314-316: Change “, which demonstrates the CMIP5 simulations prefer a uniform temperature change over all the regions” to “In contrast to observations, the CMIP5 simulations exhibit a uniform temperature change over East Asia”.
69. Line 319: Delete “and so on” and insert “likely” after “more”.
70. Line 320: Change “with” to “to”, and change “totally considered” to “well represented”.
71. Line 322: Change “suggest” to “provide evidence”.
72. Line 325: Change “43.7 and 56.3%” to “44 and 56%”.
73. Line 326: Change “was” to “varied”.
74. Line 328-331: Change “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” to “Guan et al. (2015) found that the radiatively forced temperature has a warming trend in the past decades”.
75. Line 336: Change “substantially declining” to “substantial decline”.

76. Line 342: Delete “Besides”.
77. Line 343-344: Change “Huang et al, 2015” to “Chen et al., 2010”.
78. Line 347: Change “process” to “processes”.
79. Line 348-349: Change “Our results also well explained the co-existence of regional warming and hiatus of the Northern Hemisphere” to “Our results also explained the co-existence of regional warming and warming hiatus across the entire Northern Hemisphere”.
80. Line 357: Change “But” to “However”.
81. Line 363: Insert “The authors thank two anonymous reviewers for their constructive comments”.
82. Line 382-385: Insert reference “Chen, B., Huang, J., P. Minnis, Hu, Y., Yi, Y., Liu, Z., Zhang, D., and Wang, X.: Detection of dust aerosol by combining CALIPSO active lidar and passive IIR measurements, *Atmos. Chem. Phys.*, 10, 4241-4251, doi:10.5194/acp-10-4241-2010, 2010”.
83. Line 386-388: Insert reference “Dong, W., Chou, J., Feng, G.: A New Economic Assessment Index for the Impact of Climate Change on Grain Yield, *Adv. Atmos. Sci.*, 24, 336-342, doi:10.1007/s00376-007-0336-y, 2007.”.
84. Line 391-392: Insert reference “Ge, Y.: Globalization and Industry Agglomeration in China, *World Development*, 37, 550-559, doi:10.1016/j.worlddev.2008.07.005, 2009.”
85. Line 401-404: Insert reference “Higuchi, K., Huang, J., and Shabbar, A.: A wavelet characterization of the North Atlantic Oscillation variation and its relationship to the North Atlantic sea surface temperature, *Int. J. Climatol.*, 19, 1119-1129, doi:10.1002/(SICI)1097-0088(199908)19:10<1119::AIDJOC414>3.0.CO;2-7, 1999.”
86. Line 405-407: Insert reference “Huang, J., Fu, Q., Zhang, W., Wang, X., Zhang, R., Ye, H., and Warren, S.: Dust and black carbon in seasonal snow across northern China, *B. Am. Meteorol. Soc.*, 92, 175-181, doi:10.1175/2010BAMS3064.1, 2011.”
87. Line 410-411: Insert reference “Huang, J., Higuchi, K., and Shabbar, A.: The relationship between the North Atlantic Oscillation and El Niño-Southern Oscillation, *Geophys. Res. Lett.*, 25, 2707-2710, 1998.”

88. Line 412-414: Insert reference “Huang, J., Minnis, P., Lin, B., Yi, Y., Khaiyer, M., Arduini, R., Fan, A., and Mace, G.: Advanced retrievals of multilayered cloud properties using multispectral measurements, *J. Geophys. Res.*, 110, D15S18, doi:10.1029/2004JD005101, 2005.”
89. Line 415-418: Insert reference “Huang, J., Minnis, P., Lin, B., Yi, Y., Sun-Mack, S., Fan, T., and Ayers, J.: Determination of ice water path in ice-over-water cloud systems using combined MODIS and AMSR-E measurements, *Geophys. Res. Lett.*, 33, L21801, doi:10.1029/2006GL027038, 2006.”
90. Line 419-420: Insert reference “Huang, J., Yu, H., Guan, X., Wang, G., and Guo, R.: Accelerated dryland expansion under climate change, *Nature Clim. Change*, doi:10.1038/nclimate2837, 2015.”
91. Line 429-431: Delete “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.”
92. Line 436-438: Insert reference “Jiang, K., Hu, X., Matsuoka, Y., Morita, T.: Energy Technology Changes and CO₂ Emission Scenarios in China. *Environment Economics and Policy Studies* 1, 141-160, doi: 10.1007/BF03353898, 1998.”
93. Line 453-454: Insert reference “Maya, F., and David, I. L.: Industrialization, pollution, and infant mortality, *Environment and Development Economics*, 15, 557-584, doi: 10.1017/S1355770X10000185, 2010.”
94. Line 468-470: Insert reference “Shabbar, A., Huang, J., and Higuchi, K.: The relationship between the wintertime North Atlantic Oscillation and blocking episodes in the North Atlantic, *Int. J. Climatol.*, 21, 355-369, doi:10.1002/joc.612, 2001.”
95. Line 575: Insert “cold season” before “trend”.
96. Line 576: Delete “in the cold season”.
97. Line 580: Change “raw temperature in the cold season” to “raw cold-season temperature”.
98. Line 615: Insert “cold season-mean” before “temperature”.
99. Line 704: Updated Figure 13.
100. Line 714: Insert “cold season-mean” before “temperature”.

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

5 X. Guan¹, J. Huang^{1,*}, R. Guo¹, H. Yu¹, P. Lin² and Y. Zhang¹

6
7
8 ¹Key Laboratory for Semi-Arid Climate Change of the Ministry of Education, College of
9 Atmospheric Sciences, Lanzhou University, 730000 Lanzhou, China

10 ² Program in Atmospheric and Oceanic Sciences, Princeton University, 08544 Princeton,
11 New Jersey, USA

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27 Corresponding author address:
28 Dr. Jianping Huang
29 College of Atmospheric Sciences
30 Lanzhou University,
31 Lanzhou, China, 730000
32 Phone +86 (931) 891-4282
33 E-mail: hjp@lzu.edu.cn

34 **Abstract**

35 As the climate change occurred over East Asia since 1950s, intense interest and
36 debate have arisen concerning the contribution of human activities to the observed
37 warming-~~observed~~ in past-previous decades. In this study, we investigate regional surface
38 temperature change during the boreal cold season using a recently developed
39 methodology that can successfully identify and separate the dynamically induced
40 temperature (DIT) and radiatively forced temperature (RFT) changes in raw surface air
41 temperature (SAT) data. For regional averages, DIT and RFT make 44.7 and 56.3%
42 contributions to the SAT over East Asia, respectively. The DIT changes dominate the
43 SAT decadal variability and are mainly determined by internal climate variability,
44 represented by such as the North Atlantic Oscillation (NAO), Pacific Decadal Oscillation
45 (PDO), and Atlantic Multi-decadal Oscillation (AMO). The radiatively forced SAT
46 changes made major contribution to the global-scale warming trend and the
47 regional-scale enhanced semi-arid warming (ESAW). Such enhanced warming is also
48 found in radiatively forced daily maximum and minimum SAT. The long-term
49 global-mean SAT warming trend is mainly related to radiative forcing produced by
50 global well-mixed greenhouse gases. The regional anthropogenic radiative forcing,
51 however, caused the enhanced warming in the semi-arid region, which may be closely
52 associated with local human activities. Finally, the relationship between the so-called
53 global warming hiatus and regional enhanced warming is discussed.

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62 1 Introduction

63 Asia is arguably the most sensitive area to climate change, because it comprises
64 almost 39% of the world's land area (White and Nackoney, 2003; Huang et al., 2013) and
65 supports four billion people, which accounts for 66.67% of the world population. A great
66 portion of its drylands showed a most significantly enhanced warming in the boreal cold
67 season over mid-to high-latitude areas (Huang et al., 2012; [2015](#)). The regional
68 environment change has a close relationship with local population density and economic
69 development level. Jiang and Hardee (2011) found that economic growth technological
70 changes and population growth are the main elements in anthropogenic effects on
71 emission, which cannot be simulated easily by numerical models (Zhou et al., 2010).
72 More recently, there are some studies on understanding the implications of population
73 growth, worker structure and economic intensity for various scenarios of environmental
74 change. The anthropogenic heating resulting from energy consumption has a significant
75 continental-scale warming effect in mid-to high-latitudes in winter based on model
76 simulations ([Huang et al., 1998](#); [Higuchi et al., 1999](#); [Shabbar et a., 2001](#); Zhang et al.,
77 2013). The rapid industrialization [since the late 1980s](#), urbanization, population growth,
78 and other anthropogenic activities occurred in East Asia ([Jiang et al., 1998](#); [Dong et al.,](#)
79 [2007](#); [Ge, 2009](#); [Maya and David, 2010](#)).

80 In the previous studies, dynamic effects induced by ~~greenhouse gases~~
81 ~~(GHGs)~~ [internal variability](#) have been proposed to interpret the rapid warming over
82 continents and non-uniformity of local warming distribution (Wallace et al., 2012). The
83 dynamic factors exhibit their influences on surface temperature changes in terms of
84 circulation changes, such as the North Atlantic Oscillation (NAO), Pacific Decadal
85 Oscillation (PDO), Atlantic Multi-decadal Oscillation (AMO). Guan et al. (2015) found
86 that the dynamically induced temperature and radiatively forced temperature had opposite
87 contributions to the surface air temperature (SAT) during the ~~warming process of~~ hiatus
88 over the Northern Hemisphere. Most of the obvious patterns occurred over mid-to
89 high-latitudes where they are known as places having the earliest warming (Ji et al., 2014)
90 and a phenomenon of enhanced warming over semi-arid region (enhanced semi-arid
91 warming, ESAW) (Huang et al., 2012). The ESAW was proposed to be caused by various

92 factors, including changes [inof](#) atmospheric circulations, sea surface temperature,
93 interaction between land and atmosphere, feedback from snow, ~~and so on~~ (Hu and Gao,
94 1994; Zhang et al., 2001; Huang et al., 2008; Guan et al., 2009; He et al., 2014). But the
95 roles of different factors in the process of ESAW have not been confirmed.

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

105 **2 Datasets and study area**

106 This study uses monthly precipitation, monthly mean temperature, monthly daily
107 maximum and minimum temperature from the land-only TS3.21 dataset obtained from
108 the Climate Research Unit at the University of East Anglia (Mitchell and Jones, 2005).
109 The data cover the period of 1901-2012 with a high spatial resolution of $0.5^\circ \times 0.5^\circ$. The
110 regionally-average [cold season-mean](#) temperature trend of region k is calculated using

$$\bar{T}_k = \frac{\sum_{i=1}^{N_k} W_{ki} \times T_{ki}}{\sum_{i=1}^{N_k} W_{ki}} \quad (1)$$

111 where N_k is the number of grids in region k , T_{ki} is the [cold season-mean](#) temperature
112 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 .
113 The [cold season-mean](#) temperature trend of region k is calculated by least square method
114 based on the time series of \bar{T}_k .
115

116 The contribution of [cold season-mean](#) RFT (DIT) to raw [cold season-mean](#) temperature is
117 calculated as formula (2)

118
$$CR = \frac{1}{n} \sum_{i=1}^n (\tilde{T}_i^2 / T_i^2) \times 100\% \quad (2)$$

119 Where n is the number of years of temperature dataset, \tilde{T}_i is the [cold season-mean](#)
120 radiatively forced temperature or dynamically induced temperature of year i , T_i is the raw
121 [cold season-mean](#) temperature of year i .

122 The study area is between 20°N and 53°N, and between 73°E and 150°E, which
123 comprises much of East Asia. The distribution of 30-yr averaged annual precipitation
124 from 1961-1990 (Fig. 1) illustrates most of semi-arid region (annual precipitation
125 between 200-600 mm yr^{-1}) located in the northeast, and most of arid region is in the
126 northwest area. It exhibits a generally increase pattern of annual precipitation from
127 Northwest to Southeast. ~~The wet regions are most distributed in the South area.~~ Although
128 precipitation is related to surface temperature, the long-term mean precipitation is the
129 simplest index for classifying climate regions (Huang et al., 2012).

130 **3 Dynamical adjustment methodology**

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

138 The dynamical adjustment methodology used in this study has been improved by
139 Smoliak et al., (2015). The exact process of partial least square (PLS) is to derive
140 monthly dynamical adjustment of Northern Hemisphere land surface temperature field in
141 a pointwise manner, namely, temperature time series of each grid point is a predictand.
142 [The sea level pressure \(SLP\) data are standardized and the temperature time series are](#)
143 [high pass filtered by removing the cold season mean from the mean for each month](#)
144 [within a given cold season and then standardized prior to carrying out the following](#)
145 [dynamical adjustment steps:](#) ~~The data of sea level pressure (SLP) are standardized, and~~

146 ~~the temperature time series are standardized and high pass filtered prior to carrying out~~
147 ~~the following dynamical adjustment steps:~~ (1) correlate the grid-point temperature time
148 series with ~~theits corresponding~~ SLP field to generate a one-point cross-correlation map;
149 (2) project the monthly SLP field onto the correlation pattern, weight each grid point by
150 the cosine of its latitude to obtain the first PLS predictor time series Z1; (3) regress this
151 PLS predictor Z1 out of both the each grid-point temperature time series and its SLP
152 predictor field using conventional least square fitting procedures, which can obtain a
153 residual temperature time series and residual SLP field. Repeat these steps on the residual
154 temperature time series and residual SLP field to obtain the respective PLS predictor Z2
155 and Z3, ..., Zn, which are mutually orthogonal, taking care to high pass filter each
156 successive residual temperature time series prior to calculating correction patterns (step1).
157 In our study, the improved dynamical adjustment methodology (Smoliak et al., 2015) has
158 been applied to the temperature dataset and three predictors are retained, which are
159 determined by cross-validation.

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

171 **4 Results analysis**

172 Figure 2 compares the variation of cold season-mean SAT of raw, dynamically and
173 radiatively forced temperatures over East Asia in the period of 1902-2011. The curves
174 exhibit a warming trend in the past century as a whole and an obvious warming from the
175 1970s to the 1990s. Then, the raw temperature change (black line) appeared a stoppage

176 since about 2000 until now. The DIT (blue line) exhibits obvious decadal variability, with
177 a relatively warming period from the 1970s to the 1990s and an obvious cooling period
178 from 2000 to 2011 in the cold season. The RFT (red line) shows a rapid increasing rate
179 since the late 1970s, which is consistent with the raw temperature data. The different
180 evolutions of DIT and RFT indicate that the ~~time series of~~ DIT and RFT played had
181 different roles in ~~the process of determining the~~ raw temperature variability.

182 Figure 3 shows the spatial distribution of raw, DIT and RFT trends over East Asia in
183 the period of 1902-2011. Figure 3a exhibits a gradually increasing warming pattern from
184 south to north and a strong warming trend located over northern East Asia, especially in
185 Mongolia and Northeast China. The rate of warming was less than $0.005^{\circ}\text{C}/\text{year}$ in the
186 south of 40°N , with a small scale of cooling region over the southwest. The distribution
187 of DIT trend (Fig. 3b) shows a basic warming background of East Asia. The warming
188 rate over most areas was less than $0.01^{\circ}\text{C}/\text{year}$, with a higher value in the northern part
189 than in the southern part as a whole, and a cooling scale was located in the Northeast of
190 East Asia. The distribution of RFT trend (Fig. 3c) exhibits a similar distribution as that of
191 the raw temperature. It shows an obvious warming over the northern area, which reached
192 $0.025^{\circ}\text{C}/\text{year}$ in some regions. A larger scale of cooling located in the southern region
193 demonstrates that the cooling in the raw temperature was due to the radiative factors. The
194 difference of DIT trend distribution from RFT indicates that the influence of radiative
195 forcing on regional temperature changes ~~was much different with higher than~~ dynamic
196 factor during the period of 1902-2011.

197 ~~The discrepancy of distributions between DIT and RFT trends demonstrates the roles~~
198 ~~of DIT and RFT were different.~~ Figure 4 gives the distributions of contributions of DIT
199 and RFT to the raw temperature in the cold season over East Asia in the period of
200 1902-2011. ~~It exhibits quite different locations of high contribution for DIT and RFT.~~
201 The dynamic contribution to the raw temperature ~~change~~ (Fig. 4a) has high values over
202 the northwest and along the coastal area of Southeast China, but the peak value is much
203 less than its radiative value. In the spatial distribution of RFT contribution (Fig. 4b), the
204 positive centres were located over the northeast and southwest areas, and the values were
205 much higher than those in Fig. 4a. Figure 4 illustrates that regional temperature is mostly

206 ~~determined by RFT. The difference between Fig. 4a and Fig. 4b illustrated the regional~~
207 ~~temperature is mainly contributed by RFT.~~ This regional discrepancy is confirmed by the
208 contributions of DIT (blue line) and RFT (red line) to the cold season raw temperature as
209 a function of annual precipitation ~~in the cold season~~ over East Asia (Fig. 5). Figure 5
210 shows that the RFT made a greater contribution than the DIT over the whole region. The
211 contribution of RFT increased as the annual precipitation increased. Opposite to the
212 radiative contribution, the dynamical contribution decreased with the increase of annual
213 precipitation.

214 According to Huang et al. (2012), the enhanced warming occurred over the semi-arid
215 regions. Figure 6 ~~show provide~~ the long-term trends of DIT and RFT as a function of
216 annual-mean precipitation. It illustrates that the RFT had a major contribution to the
217 regional variation and showed a similar curve as the raw temperature over different
218 regions. Both the raw data and RFT reached the peak in the area of 300-400 mm yr^{-1} . The
219 fact that the peaks of cold season-mean temperature trend of both raw data and RFT
220 occurred over semi-arid regions indicates that the radiative factors had domin~~ant~~ated
221 roles in the process of enhanced warming over the semi-arid regions.
222 ~~Conversely~~However, the DIT trend did not show obvious difference as a function of
223 annual mean precipitation over different areas. It kept a mean rate of $0.005^{\circ}\text{C}/\text{year}$, which
224 is far away from the $0.017^{\circ}\text{C}/\text{year}$ of the highest value in the drylands of the RFT trend.
225 The greater warming rate in semi-arid region appeared in both raw temperature and RFT
226 indicated that enhanced warming occurred in drylands is mainly ~~leaded by~~ associated
227 with RFT. This extends understanding of the ESAW (Huang et al., 2012), and suggests
228 that the role of radiative forcing was critical in the process of warming over East Asia.
229 ~~It improves the understanding of the ESAW (Huang et al., 2012), and suggests that role~~
230 ~~of radiative forced part in the process of warming East Asia.~~

231 These results are not limited to the monthly-mean temperatures. ~~, the daily minimum~~
232 ~~and maximum temperatures expressed different variability of DIT and RFT as well.~~
233 Figure 7 shows the distributions of raw, dynamically induced and radiatively forced daily
234 minimum cold season-mean temperature trends over East Asia in the period of
235 1902-2011. The raw daily minimum temperature illustrates a similar distribution as the

236 raw monthly-mean temperature, with a stronger warming trend over northern East Asia,
237 especially over Mongolia and Northeast China. The dynamically induced daily minimum
238 temperature (Fig. 7b) shows a warming pattern over most areas, with a small cooling in
239 the area along the Northeast China. The RFT trend (Fig. 7c) had an obvious warming
240 over the northern area, with a smaller cooling over South China than in the monthly-mean
241 temperature.

242 Figure 8 ~~show~~is the distributions of raw, dynamically induced and radiatively forced
243 of daily maximum cold season-mean temperature trends over East Asia in the period of
244 1902-2011. The raw daily maximum cold season-mean temperature trend (Fig. 8a) was
245 positivehad a warming trend over Northern East Asia, especially over Mongolia. But the
246 warming extent was apparently less than that in the daily minimum temperature. The
247 cooling in the southern part was larger than that in the daily minimum temperature. The
248 dynamically induced daily maximum temperature (Fig. 8b) shows a slight warming over
249 most areas, with a cooling located in ~~the area along of~~ Northeast China. The RFT trend
250 (Fig. 8c) exhibits an obvious warming over the northern area, with a larger cooling scale
251 over South China than daily minimum temperature in Fig. 7c.had an obvious warming
252 over the northern area, with a small cooling scale over South China, which is similar with
253 the raw daily minimum temperature. But the scale of cooling area was much larger than
254 the radiatively forced daily minimum temperature in Fig. 7c.

255 In order to distinguish the contributions to regionally-averaged cold season-mean
256 temperature trends, changes, the daily minimum and maximum of raw, DIT and RFT
257 minimum and maximum trends are shown as a function of annual-mean precipitation ~~are~~
258 ~~shown~~ in Fig. 9 and Fig. 10, respectively. The daily minimum (Fig. 9) had a higher
259 warming rate than the daily maximum (Fig. 10) over all regionsover different regions,
260 especially in the drylands. The peaks of RFT over the drylands in both daily minimum
261 and maximum temperatures indicate the dominated roles of radiative effects in the
262 regional warming. Similar to monthly-mean temperature, the DIT trend did not show
263 much variation with increasing annual-mean precipitation in both daily minimum and
264 maximum temperatures. But, the DIT trend did not show a similar variability over
265 different area in both daily minimum and maximum temperatures.The higher values of

266 RFT of both daily minimum and maximum temperatures in the drylands emphasize the
267 major roles of RFT in the local enhanced warming process.

268 The DIT was mainly dominated by major dynamic factors, such as the NAO (Li et
269 al., 2013), PDO (Trenberth and Hurrell, 1994; Kosaka and Xie, 2013) and AMO (Wyatt
270 et al., 2012; Wyatt and Curry, 2014). The correlation coefficients between DIT and
271 NAO/PDO/AMO (Fig. 11) illustrate the influences of these dynamic factors. Figure 11a
272 shows the distribution of the correlation coefficient between the NAO and the DIT. It
273 exhibits positive ~~correlations over patterns cover~~ most ~~of the~~ East Asia area, ~~with~~
274 ~~asignificant at the~~ 95% confidence level over Mongolia, Inner Mongolia and Northeast
275 China; and negative ~~patternscorrelations~~ over India and Southwest China, ~~also significant~~
276 ~~at the with a~~ 95% confidence level. ~~This indicates at suggests the~~ strong positive
277 influence of the NAO on the DIT over the northern area and the negative effect over the
278 southwest of East Asia. Figure 11b is the correlation coefficient between PDO and DIT.
279 Only the negative correlation coefficients over boundary of China and India pass the
280 confidence level of 95%. In South China and North China, there were positive and
281 negative patterns, respectively. Meanwhile, the negative correlative coefficients ~~between~~
282 ~~the AMO index and DIT of AMO index and DIT~~ (Fig. 11c) covered the most area of East
283 Asia, except for a small positive region in the southwest of East Asia. The general spatial
284 distribution is opposite ~~to~~with the distribution of the NAO.

285 The RFT variability is always considered as a result of GHGs, ~~land cover change, but~~
286 ~~more climate effects of human activities, clouds (Huang et al., 2005; 2006) and~~ aerosols
287 ~~were revealed in the recent decades (Huang et al., 2011; Li et al., 2011).~~ The fast
288 industrialization process over East Asia produced more anthropogenic GHGs and
289 aerosols, and impacted the local climate change (Qian et al., 2009, 2011). ~~The~~
290 ~~temperature of Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al.,~~
291 ~~2012) is always marked with its correspondence to the concentration of the GHGs.~~ In
292 order to manifest the effects of ~~radiative~~GHGs in RFT, a comparison between RFT and a
293 20-model ensemble mean of CMIP5 simulations (Table 1) (Taylor et al., 2012) over the
294 East Asia is plotted (Fig. 12), which shows ~~that the time series of the CMIP5 simulations~~
295 ~~are smoother than the observed SAT curve. But, the a~~ notable consistent ~~exists~~ warming

296 trend between RFT and simulated SAT ~~in the warming period~~ from the 1970s to the late
297 1990. ~~The consistent curve of RFT and CMIP5 indicated the is simulation reflect~~
298 ~~radiative part of raw temperature.~~

299 The distributions of correlation coefficients of DIT and RFT with simulated
300 temperature of CMIP5 in the period of 1902-2011 are expressed in Fig. 13a and b. Figure
301 13a exhibits a negative pattern over most of the area except for the boundary between
302 Northwest China and Russia and southwest. But in Fig. 13b, the correlation coefficient of
303 RFT with CMIP5 ensemble mean temperature has a positive pattern over most of China,
304 which passes the 95% confidence level, excluding the northeast of China and Mongolia.
305 It indicates the forced temperature changes in CMIP5 have a closer relationship with RFT
306 and DIT. the temperature of CMIP5 has a closer relationship with RFT than DIT, namely,
307 ~~CMIP5 models reflect part of raw temperatures.~~ The high positive correlation
308 coefficient between RFT and multi-model ensemble mean of CMIP5 indicates the
309 radiatively forced influence take a major proportion in simulated temperature change.
310 ~~The Multi-model~~ ensemble mean cold season-mean temperature trends shown as a
311 function of annual precipitation in (Fig. 14) stand in contrast to the ~~highlights the~~
312 regional RFT trends over the drylands shown in (Fig. 6). It illustrates that the enhanced
313 warming over the semi-arid regions led by the RFT does not appear in the multi-model
314 ensemble mean temperature. In contrast to observations, the CMIP5 simulations exhibit a
315 uniform temperature change over East Asia, which demonstrates the CMIP5 simulations
316 ~~prefer a uniform temperature change over all the regions.~~ The significant difference
317 between RFT and simulated temperatures over the drylands indicates that the enhanced
318 warming over semi-arid region was not mainly related to radiative forcing produced in
319 models, such as GHGS, land cover change, aerosol ~~and so on~~. It is more likely related
320 to regional factors not well represented ~~totally considered~~ in the models.

321 **5 Summary and discussion**

322 Our results provide evidences ~~suggest~~ that the enhanced warming in the drylands was
323 induced by the RFT. The DIT and RFT extracted from the raw temperature had different
324 contributions in the process of temperature change. For the regionally averaged values,
325 the DIT and RFT contributed 443.7 and 566.3% to the SAT over East Asia, respectively.

326 The DIT that was dominated by the NAO, PDO and AMO ~~varied~~was on decadal time
327 scales. The RFT changes were the major contributions to the global-scale warming trend
328 and the regional-scale enhanced warming in the semi-arid regions. ~~Previous studies~~
329 ~~(Guan et al. (2015) found that pointed out the the well-mixed GHGs took a continuous~~
330 ~~warming effect over globe in the~~ radiatively forced temperature has a warming trend in
331 the past decadeschange. The local processes dominated the enhanced warming in the
332 semi-arid regions. These possible local processes have been listed in Fig. 15.

333 The regional RFT was mainly induced by the interaction among atmosphere, land
334 surface, snow/ice and frozen ground cover change, and regional human activities. For
335 example, the drying of sandy or rocky soil by higher temperatures would increase surface
336 albedo, reflecting more solar radiation back to the space. And the substantially ~~declining~~
337 of snow/ice and frozen ground change in the past 30 years, particularly from early spring
338 through summer (Zhai and Zhou, 1997) may cause the surface temperature to increase in
339 the cold season via the influence on albedo. The thickness of seasonally frozen ground
340 has decreased in response to winter warming (Lemke et al., 2007), which will emit more
341 CO₂ into the atmosphere. The net radiation in the semiarid regions will become a
342 radiation sink of heat relative to the surrounding regions. ~~Besides,~~ Multiza et al. (2010)
343 found that local anthropogenic dust aerosols associated with human activities (Chen et al.,
344 2010~~Huang et al., 2015~~) such as agriculture and industrial activity accounted for 43 % of
345 the total dust burden in the atmosphere. The radiatively forced effect of aerosol maybe
346 another key process in enhanced warming of semi-arid area. More investigations are
347 needed to quantify the contribution of different local processes.

348 Our results also ~~well~~explained the co-existence of regional warming and warming
349 hiatus across the entire of the Northern Hemisphere. The major interpretation of the
350 warming trend slowdown (WTS) claimed that natural variability played an important role
351 in global temperature variability (Easterling and Wehner, 2009; Wyatt et al., 2012, Wyatt
352 and Curry, 2014; Kosaka and Xie, 2013). The RFT had a warming contribution offset the
353 cooling effect of DIT, and result in hiatus over the Northern Hemisphere (Guan et al.,
354 2015). According to the results of our study, the RFT had made a major contribution to
355 global warming, where the most obvious warming appeared in the drylands. And we

356 conclude that the long-term global-mean SAT warming trend was mainly related to the
357 radiative forcing produced by the global, well mixed GHGs. ~~However-But~~, the regional
358 anthropogenic radiative forcing caused the enhanced warming in the semi-arid regions.
359 Therefore, the hiatus as a phenomenon of global scale was not in conflict with the
360 regionally enhanced warming in the semi-arid regions.

361

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369 Global Organization for Earth System Science Portals (GO-ESSP) for producing the
370 CMIP5 model simulations and making them available for analysis, and the Climate
371 Explorer for making the NAO, PDO and AMO indices were available to downloaded
372 (<http://climexp.knmi.nl/>).

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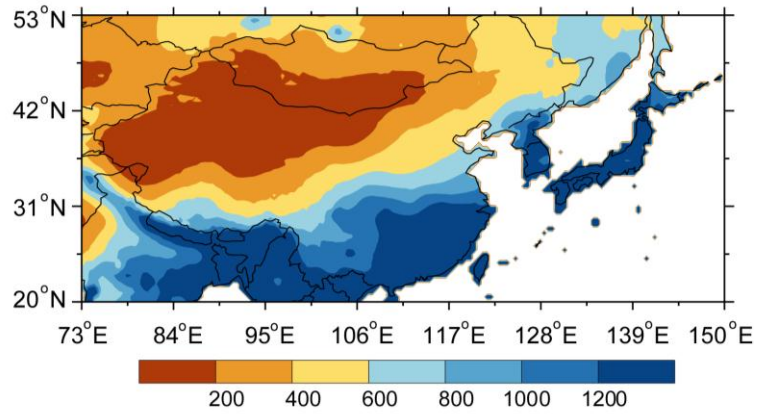
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520 **Figure 1.** Spatial distribution of annual mean precipitation from 1961-1990 (mm yr^{-1})

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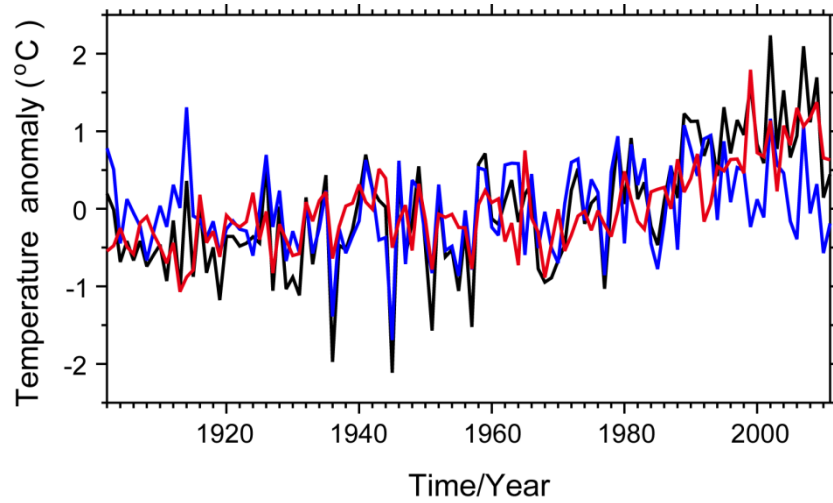
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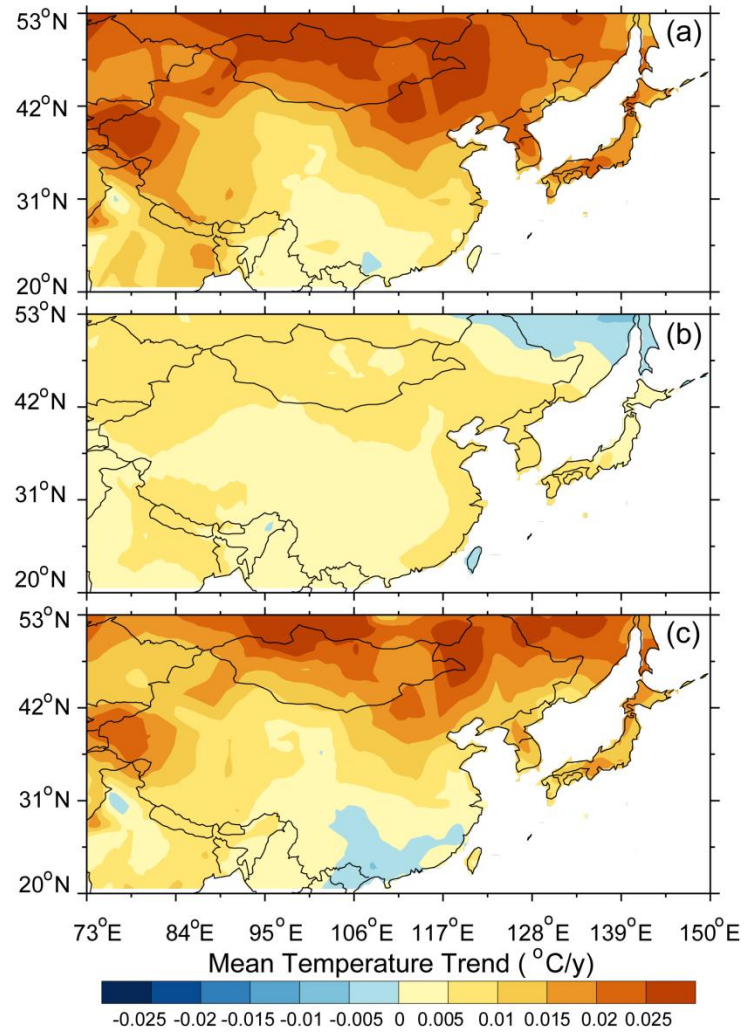
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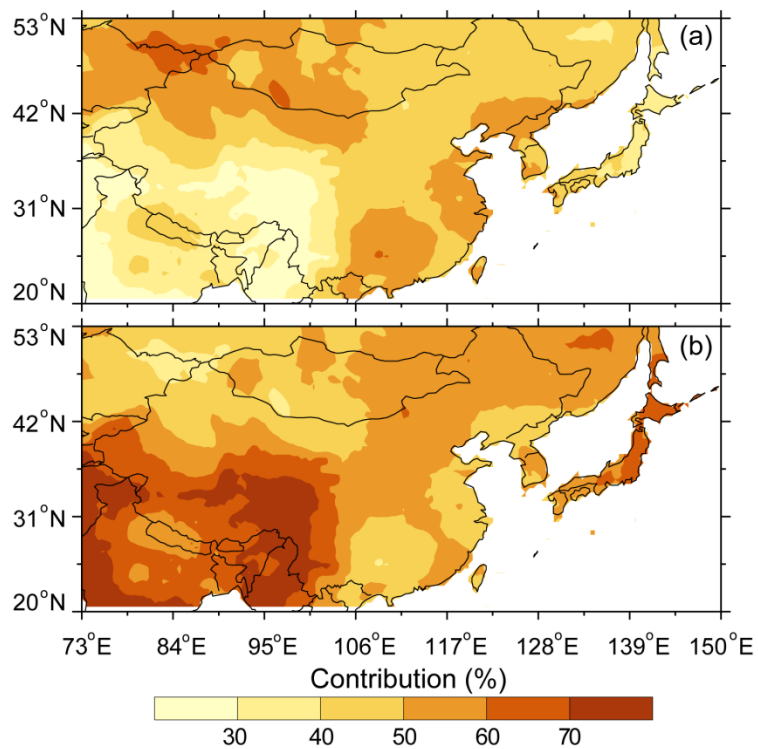
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Figure 2. Time series of regionally averaged temperature anomalies of raw (black), dynamically induced (blue) and radiatively forced (red) temperatures in the cold season (November to March) from 1902 to 2011 over East Asia.



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



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579 **Figure 4.** Spatial distribution of contribution of dynamically induced (a) and radiatively
 580 forced (b) temperatures to raw cold-season temperature ~~in the cold season~~ from 1902 to
 581 2011 over East Asia.

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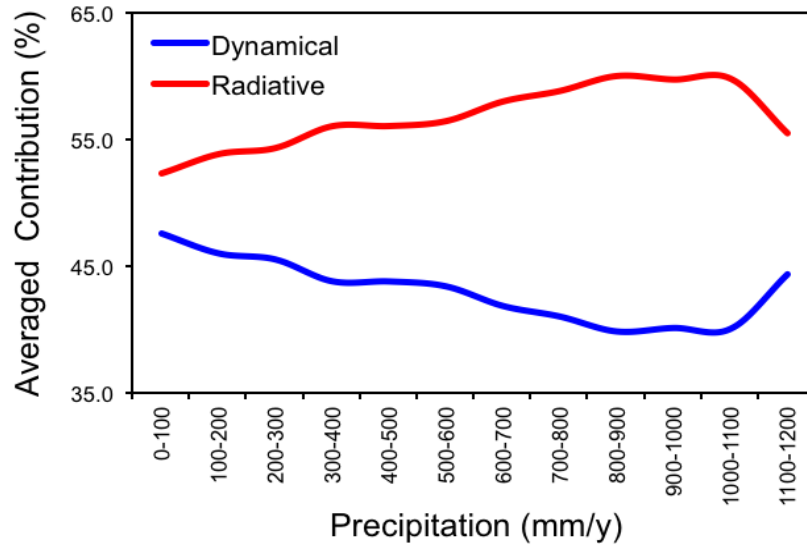
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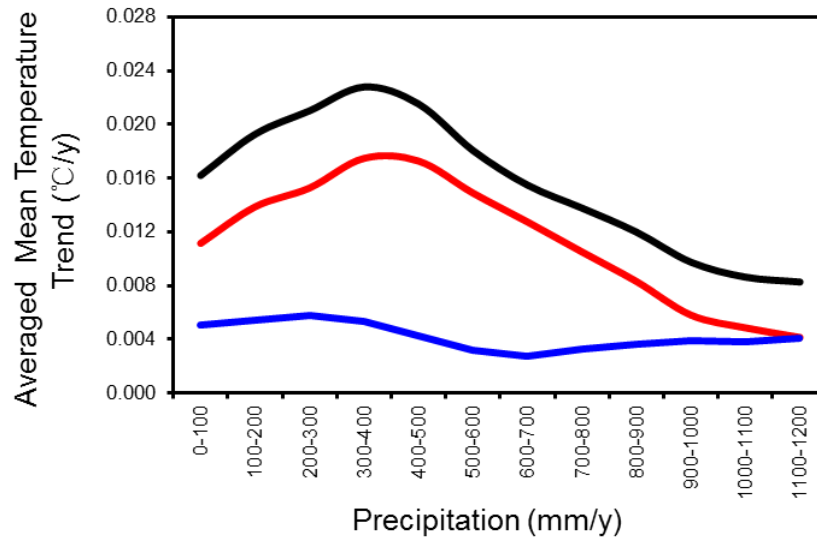
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Figure 5. Contributions of dynamically induced (blue) and radiatively forced (red) temperatures to the raw temperature as a function of annual precipitation in the cold season from 1902 to 2011 over East Asia.



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

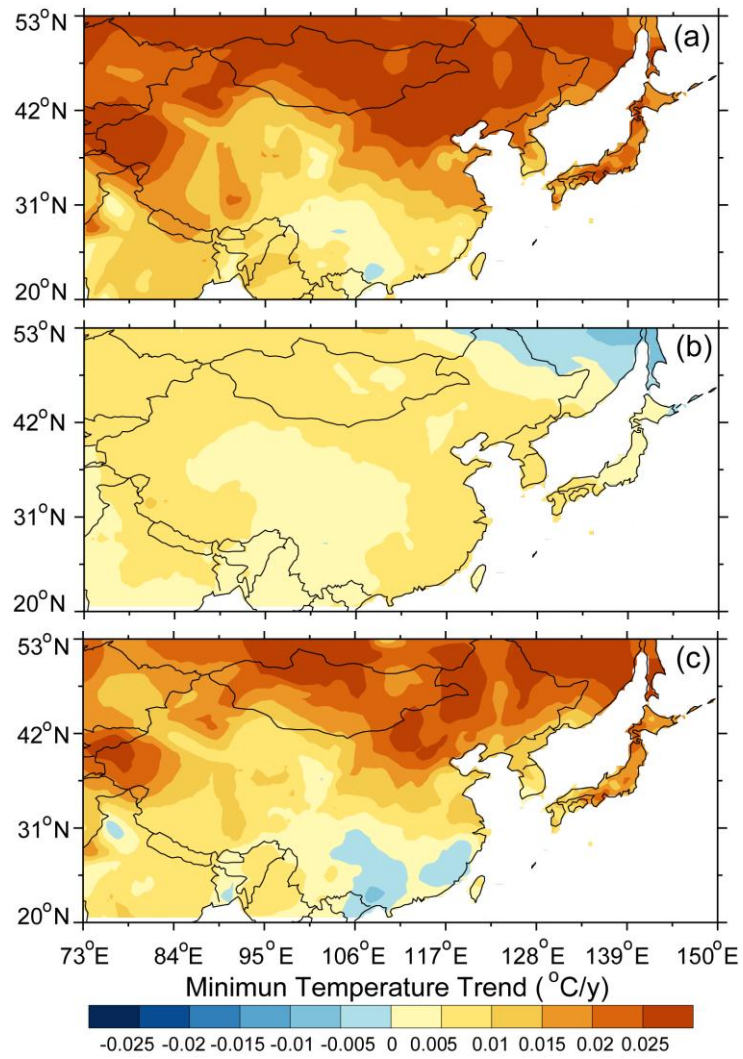
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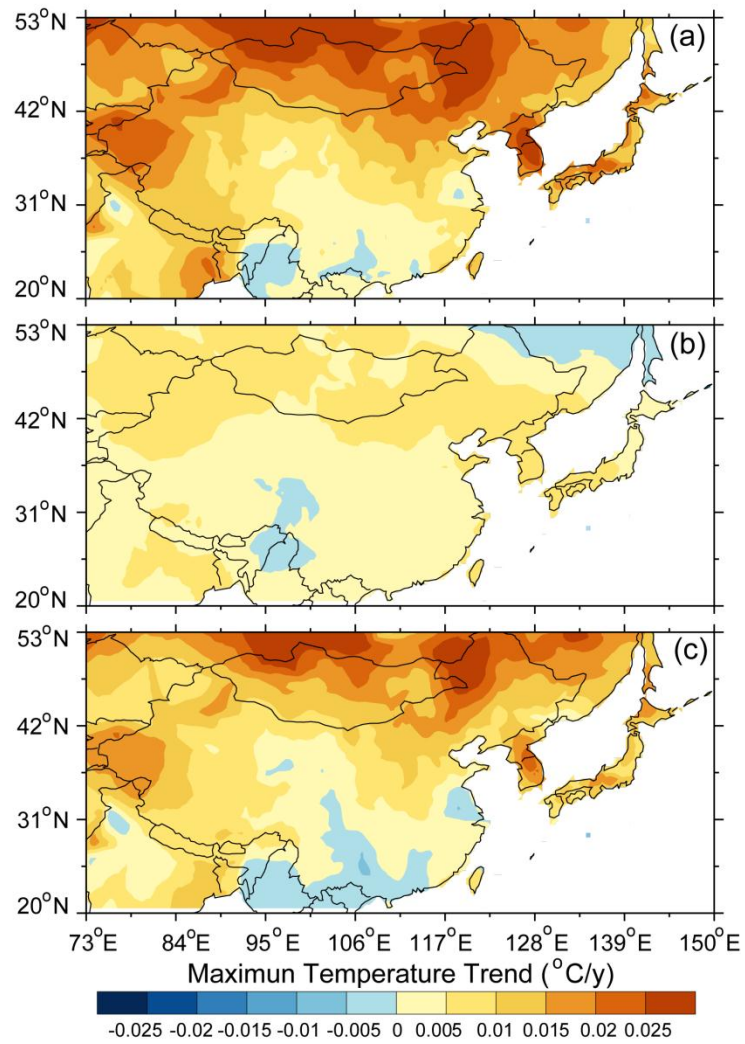
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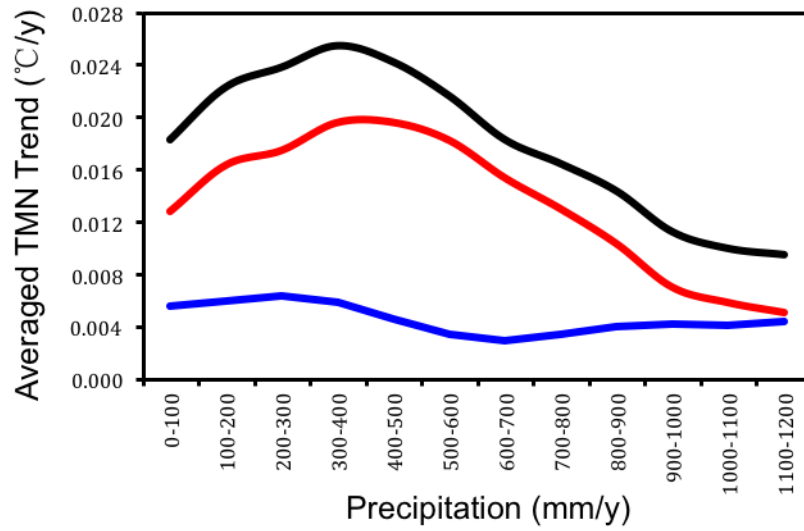
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Figure 7. Same as Fig. 3, except for daily minimum temperatures.



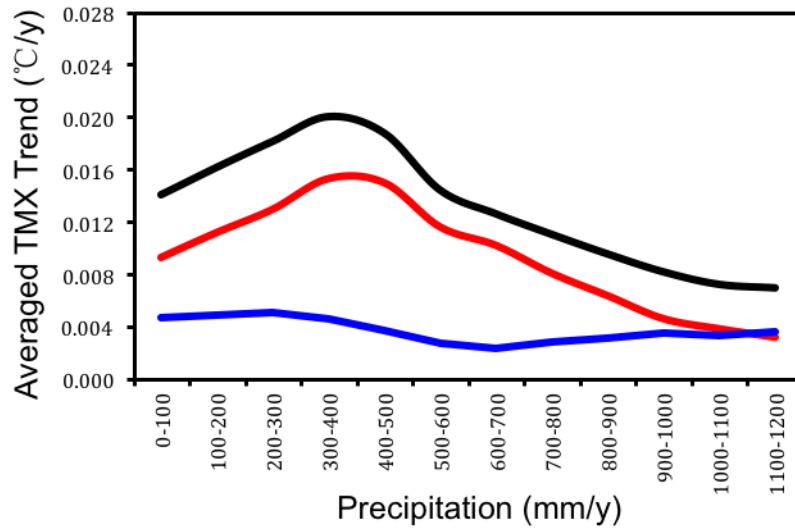
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Figure 8. Same as Fig. 3, except for daily maximum temperatures.



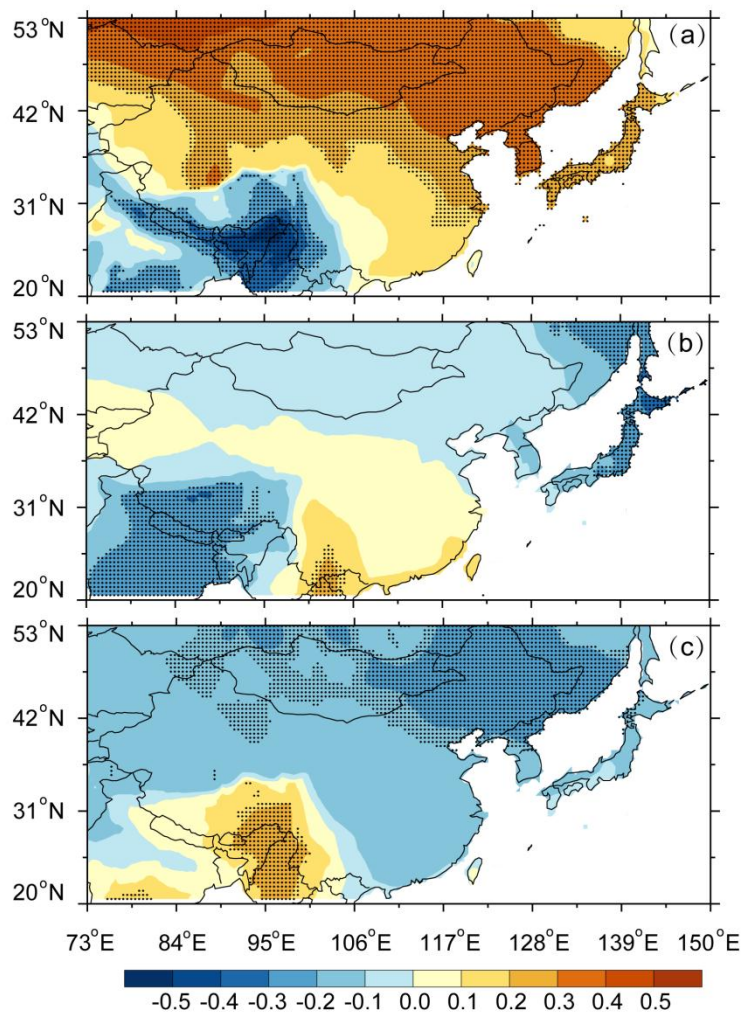
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Figure 9. Same as Fig. 6, except for daily minimum temperature.



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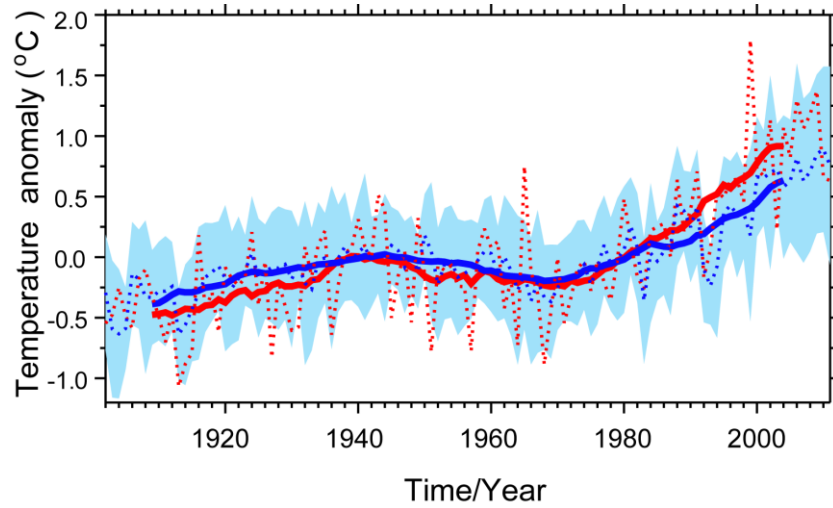
Figure 10. Same as Fig. 6, except for daily maximum temperature.



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

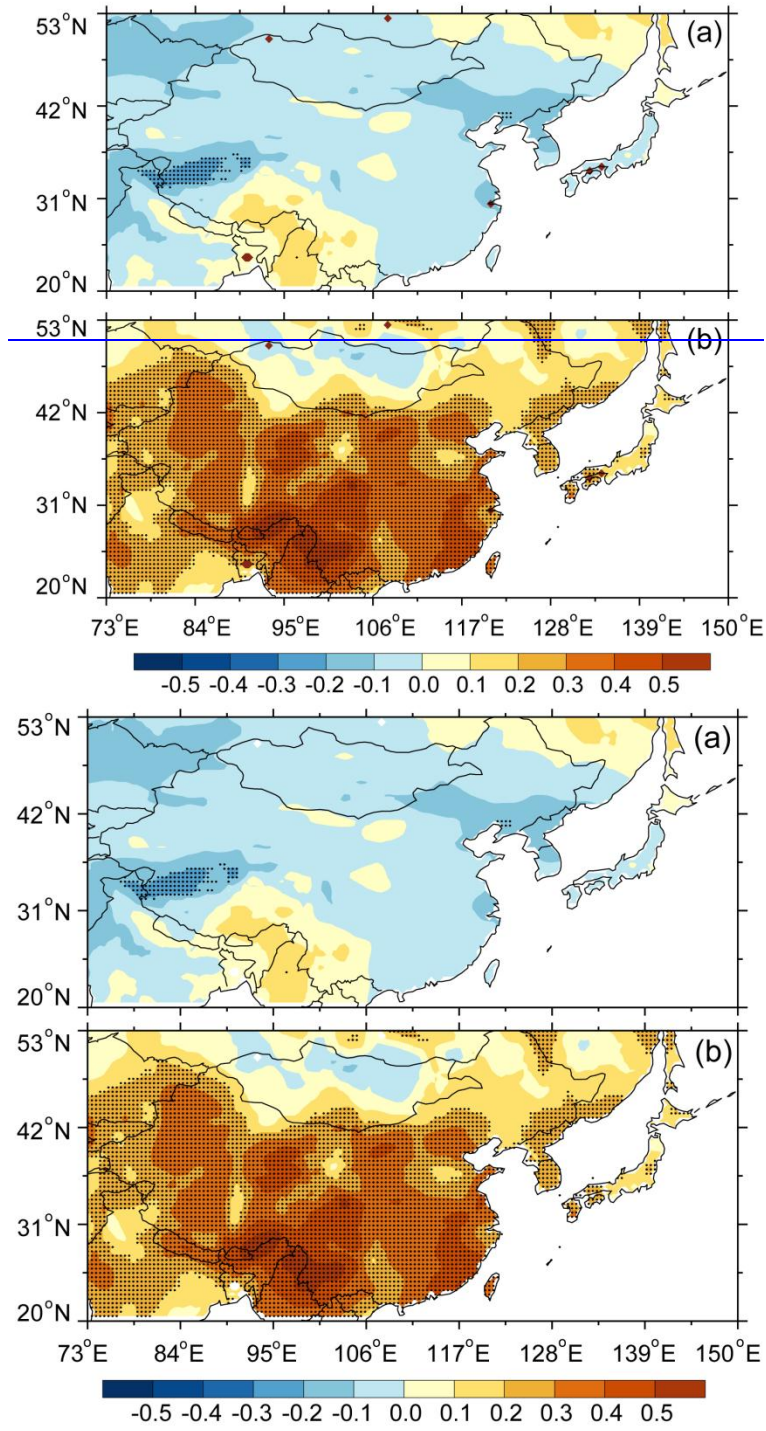
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688 **Figure 12.** Time series of radiatively forced temperature (red) and ensemble-mean
689 CMIP5 simulations (blue) based on 15-yr running mean in the cold season from 1902 to
690 2011 over East Asia. The blue shading indicates the standard deviation of the
691 CMIP5-simulated field.

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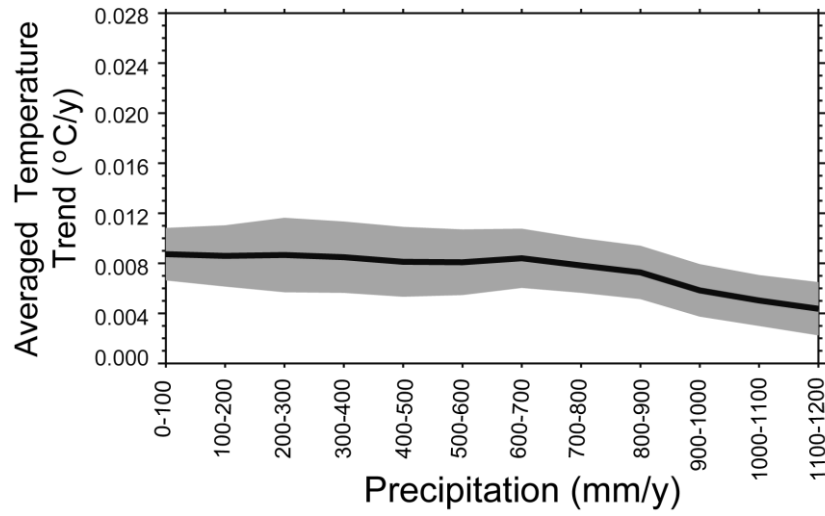
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Figure 13. Spatial distribution of correlation coefficient between ensemble-mean CMIP5 simulations and dynamically induced temperature (a), and between ensemble-mean CMIP5 simulations and radiatively forced temperature (b) in the cold season from 1902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

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

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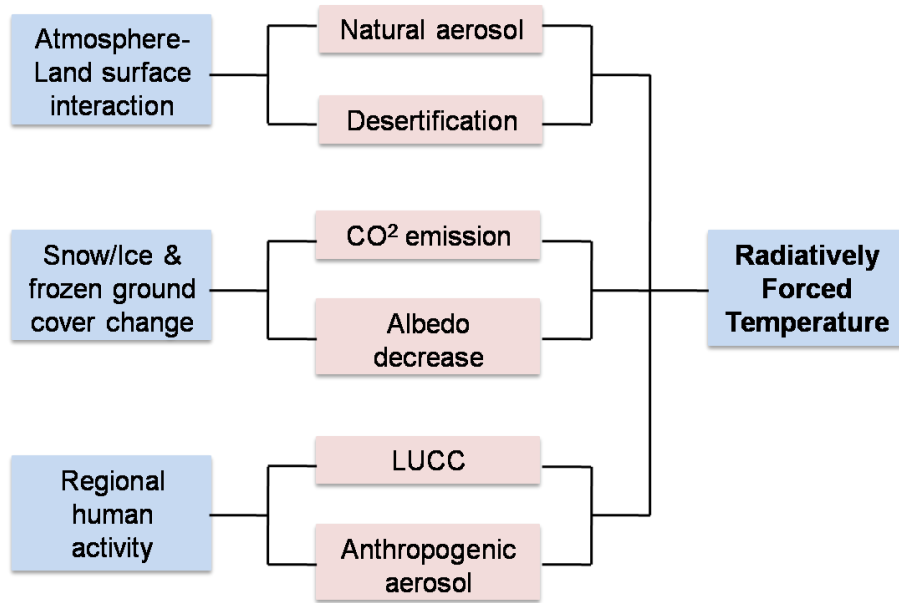
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Figure 15. Schematic diagram of radiatively forced temperature.

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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
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-CH	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

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