Persisting and strong warming hiatus over eastern China during the past two decades

Yang Chen¹ and Panmao Zhai¹

¹ State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, China Meteorological Administration

No. 46, South Ave., Zhong-Guan-Cun, Haidian, Beijing, China

*Corresponding author: Yang Chen (E-mail: chenyang@camscma.cn, postal code: 100081)

Supplementary materials submitted to Environmental Research Letters
Figure S1. Accumulated occurrences of significant cooling trends for periods beginning in 1997 (a) and 1999 (b), and ending in differing years among 2012-2016. For instance, the accumulated frequency of 5 (green stars) in (a) indicates significant cooling was detected over all intervals of 1997-2012, 1997-2013, 1997-2014, 1997-2015, and 1997-2016, i.e., a persisting hiatus.
Supplement #2

Figure S2. Starting (a) and ending (b) year of the interval that registered strongest significant cooling trends.
Figure S3. Stations (open blue circles) hit by a record-breaking (with respect to all daily Tmin in January over 1961-2015) low Tmin in January 2016. Three dashed rectangles are the same as those shown in figure 2(f), highlighting the regions most susceptible to warming hiatus.
Supplement #4

“Circulation-analogue” method

Most existing studies explained warming hiatus from the perspective of thermodynamic effects, e.g., changes in radiative forcing (solar insolation, volcanic eruptions and anthropogenic releases of aerosols), and changes in ocean heat uptake (Maher et al 2007). However, the dynamic role in producing hiatus remains under-studied.

To disentangle dynamic and thermodynamic contributions in inducing the regional hiatus, a “circulation analogue” method, developed by Yiou et al (2007), is utilized. Specifically, for each calendar day-\(d\) (target date), the best 20 circulation analogues \(Z_{d1}, Z_{d2}, \ldots, Z_{d20}\) are collected among daily circulation patterns that occurred within 15 days (7 days on either side) centered on this specific day, but in other 55 years (15×55=825 candidate dates). The extent of analogy are measured by the criteria of minimizing the root mean square distance (formula details see Yiou 2014) of circulation patterns between the target date and candidate dates, over the domain of [80–140°E; 20–60°N]. Then, for each station, its dynamically-induced temperature anomaly is represented by the mean of temperature anomalies of the top 20 circulation-analogue days. The residual anomaly is interpreted as the thermodynamically-induced anomaly. Using alternative criteria, such as maximizing Spearman’s correlation or linear correlation between circulations of the target date and candidate dates, extending/shortening the window length for candidate dates (e.g., 31
days/7 days), expanding/narrowing the spatial domain for analogue calculation, adopting five or ten best circulation analogues or using the median of all temperature analogs, do not change results in a measurable manner.

This method simultaneously incorporates influences of both remote and local circulation elements (such as upstream blockings, downstream East Asian trough, recurrent disturbances embedded in westerly jet), rather than depends heavily on a single element index and simple assumption of linear relationship. Moreover, as widely adopted in previous linear regression, monthly reanalysis data of circulation variables substantially smoothed the atmospheric dynamic variability (changes in daily circulation patterns), and respond sensitively to forcings like sea surface temperature anomalies and anthropogenic warming. Thus on the basis of monthly circulation data, regressed temperature anomalies are more prone to represent a general response to thermodynamic forcing (Molteni et al 2017). Instead, based on daily circulations of large random variability, the circulation analogue method could impartially distinguish contributions of atmospheric dynamics and forced thermodynamics to temperature changes (Horton et al 2014). Considering complicated topography over eastern Asia, 500hPa geopotential height (Z500) from NCEP/NCAR reanalysis is used for circulation analogue method.

Before interpreting relevant results, we firstly evaluate the performance of this method in eastern China. Spatially, correlation coefficients between temperature analogues and real observations in most stations (over 99%) range from 0.57 to 0.92 (with a median of 0.69), far exceeding the 0.01 significance level. For the
domain-averaged series, the correlation coefficient between the analogue and original
series reaches 0.78, significant at the 0.001 level. So the circulation analogue-based
reconstruction captures the interannual variability of Tmin reasonably well, with their
peaks and valleys in two series matching excellently (figure S4).

References

Horton D E et al 2015 Contribution of changes in atmospheric circulation patterns to extreme
temperature trends Nature 522 465-469

Molteni F et al 2017 Modulation of air-sea fluxes by extratropical planetary waves and its impact
during the recent surface warming slowdown Geophys. Res. Lett. 44 1494-1502

Yiou P, Vautard R, Naveau P and Cassou C 2007 Inconsistency between atmospheric dynamics
and temperatures during the exceptional 2006/2007 fall/winter and recent warming in Europe
Geophys. Res. Lett. 34 L21808

Yiou P 2014 Anawege: a weather generator based on analogues of atmospheric circulation Geosci.
Model Dev. 7 531-543
Supplement #5

Figure S4. Dynamically-induced (blue) and thermodynamically-induced (green) Tmin anomalies.

The red curve represents observed Tmin anomaly as shown in figure 1(c). Gray shadings enclose the top and lowest boundaries of the top 20 temperature analogs (method details see supplement #4).