On the coupled interdecadal variations of the extra-tropical surface air temperature and the isentropic meridional airmass transport in Northern winter

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Motivations

On top of the long-term global warming, the winter surface air temperature (SAT) exhibits significant interdecadal changes. Decadal changes of the winter continental SAT show remarkable regional differences. The decadal warming or cooling across the Northern Hemisphere may not always be in-phase between the two continental regions but exhibit complex zonal features.

(1) What's the coherent interdecadal changes of the winter SAT between the two continents? **(2)** What's the coupled relationships between the winter SAT and the IMMT in the NH winter at decadal time scale? **(3)** Possible forcing of this coupled interdecadal variation?

Data and Methods

ERA5 (1950-2020): daily dataset at 1.5 × 1.5° grids and 37 pressure levels from 1000 to 1 hPa.

- Isentropic-level Meridional Mass Transport (IMMT): meridional mass transport below 280K.
- CB60N: the zonally integrated IMMT across the polar circle (60°N) within the CB layer.
- PDO index; AMO index.
- Maximum Covariance Analysis (MCA).

Interdecadal variation of the winter SAT dominated by changes of the IMMT

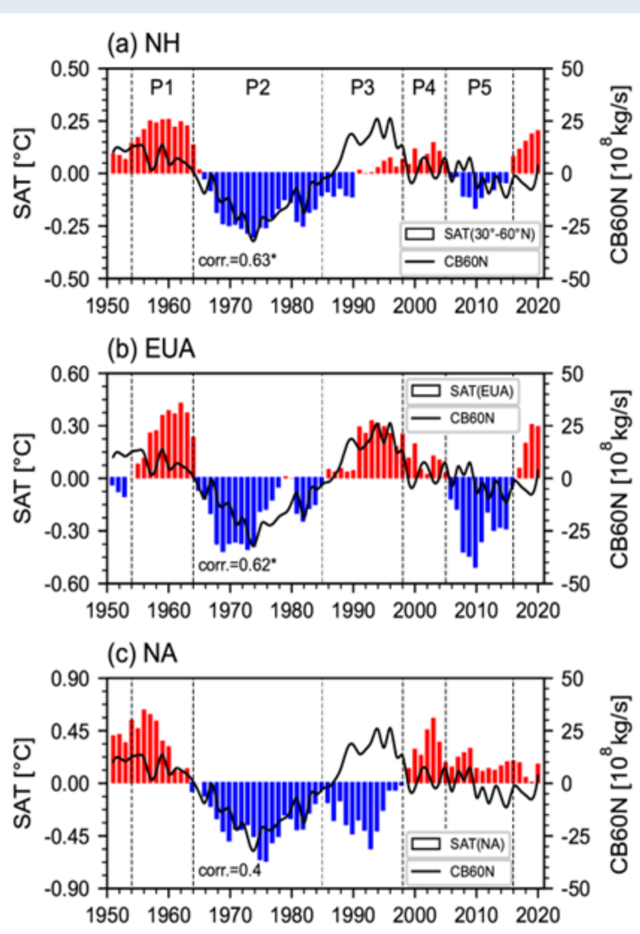

Fig.1 Interdecadal evolutions of the CB60N index and the decadal SAT

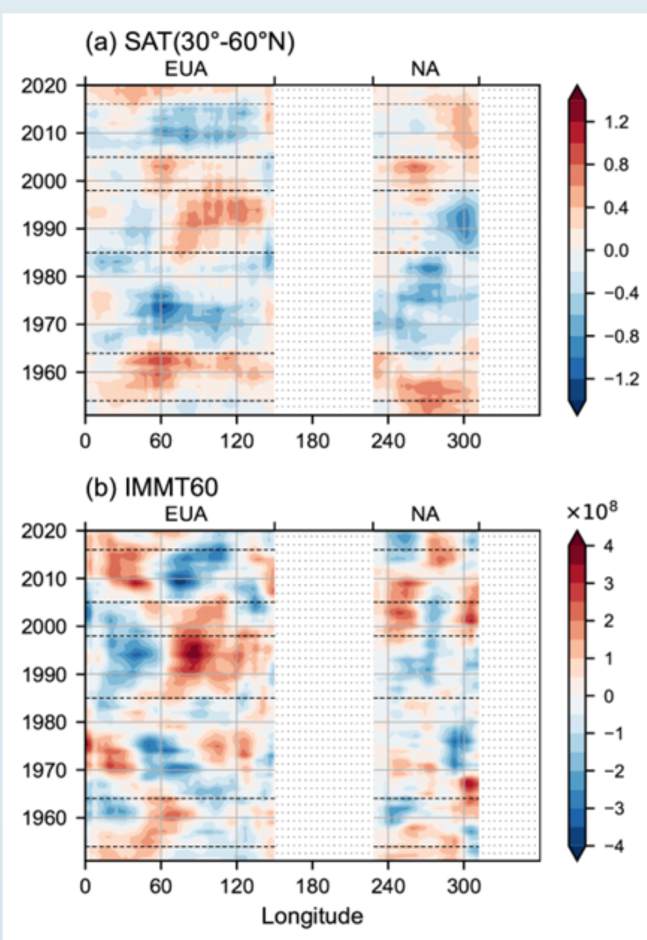

Fig.2 Longitude-time evolutions of the decadal SAT and the IMMT anomalies

- The decadal SAT variations between two continents are not always in-phase (out-of-phase at P3 and P5).
- The decadal variations between the SAT and the CB60N are highly coupled (corr.=0.63).
- This coupling basically indicates the dominant role of the dynamical transporting process in determining the overall SAT changes in midlatitudes.

	P1(1954–1963)	P2(1964–1984)	P3(1985–1997)	P4(1998–2004)	P5(2005–2016)
EUA	Warmer	Colder	Warmer	Warmer	Colder
NA	Warmer	Colder	Colder	Warmer	Warmer

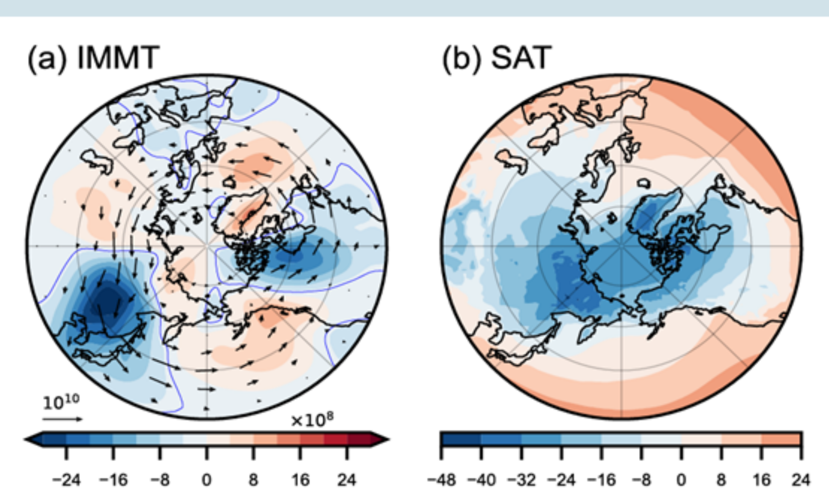

Fig.3 Winter climatology of (a) the isentropic mass flux (vectors) and the IMMT (shadings) (units: kg/s), and (b) the SAT (units: °C).

- The winter climatology of the airmass transport flow shows the two main cold air outbreak routes: the East Asian route and the North American route.
- Along the two main routes, there exist the two main cold SAT centres over the north-east part of the two continents, indicating the coupled climatology between the IMMT and SAT.
- The sub-route over the western Europe may explain the not-always consistent SAT anomalies between the Asian region and the European region.

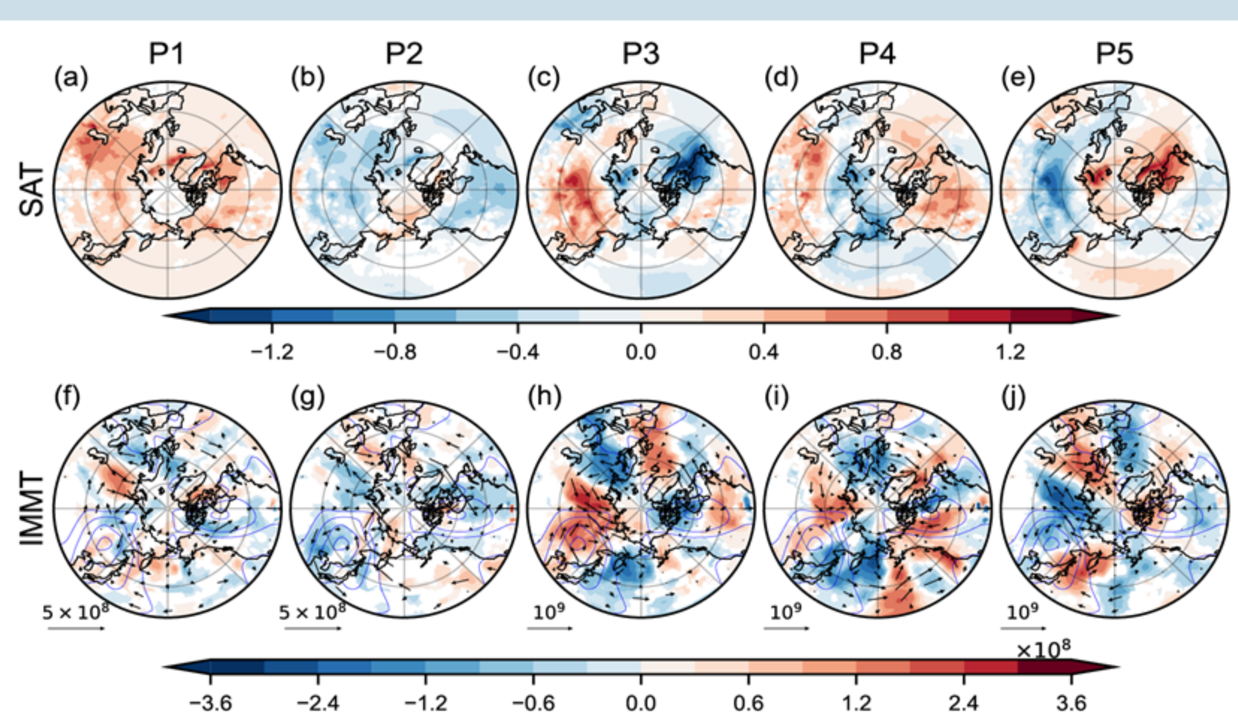

Fig.4 Composite anomaly fields of (a–e) the decadal SAT and (f–j) the isentropic mass flux and the IMMT in selected five periods.

- Most of the warm/cold SAT anomaly centres are accompanied by local positive/negative IMMT (or poleward/equatorward mass transport) anomaly centres to the slightly north of the SAT centres.
- SAT and IMMT are always partially out-of-phased in the meridional direction.
- P5 reflects the recent 'Warm Arctic - Cold Eurasia' pattern indicated in previous studies.

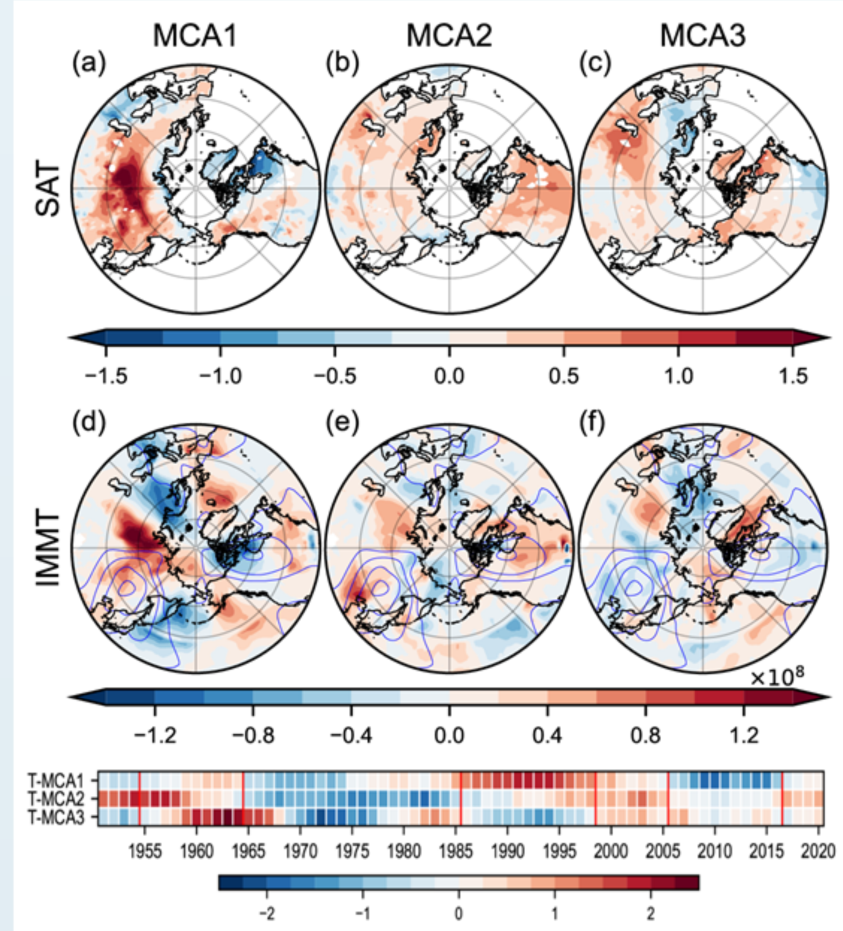

Fig.5 The first three leading MCA patterns between the decadal continental SAT and the IMMT. And the timeseries of three MCA modes.

- The first three leading MCA modes explain 90.5% (respectively, 57.7%, 18.9% and 13.8%) of the cumulative squared covariance fraction, and the correlations between the twin timeseries (T-MCAs) are respectively 0.97, 0.94 and 0.95 for the MCA1, MCA2 and MCA3.
- MCA1 represents a 'out-of-phase' pattern between two continents, while MCA2 represents a coherent 'both-warmer/colder' pattern.
- MCA1 and MCA2 share nearly the same spectrum peak at the period of 33.1 years and exist significant lead-lag correlation (at -14 year and maximum at +12 year).

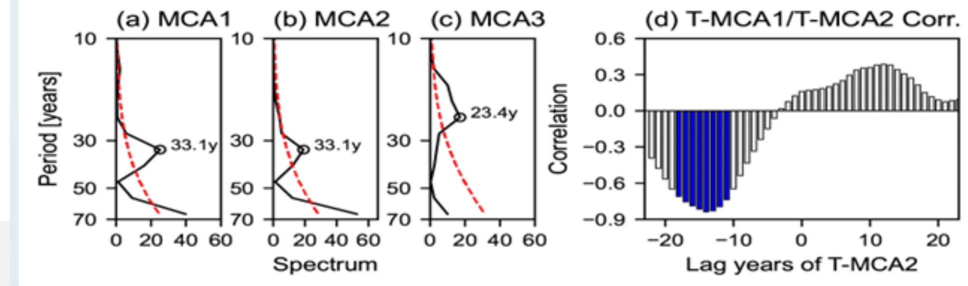

Fig.6 Power spectra of the T-MCAs and the Lead/lag correlations between the T-MCA1 and T-MCA2..

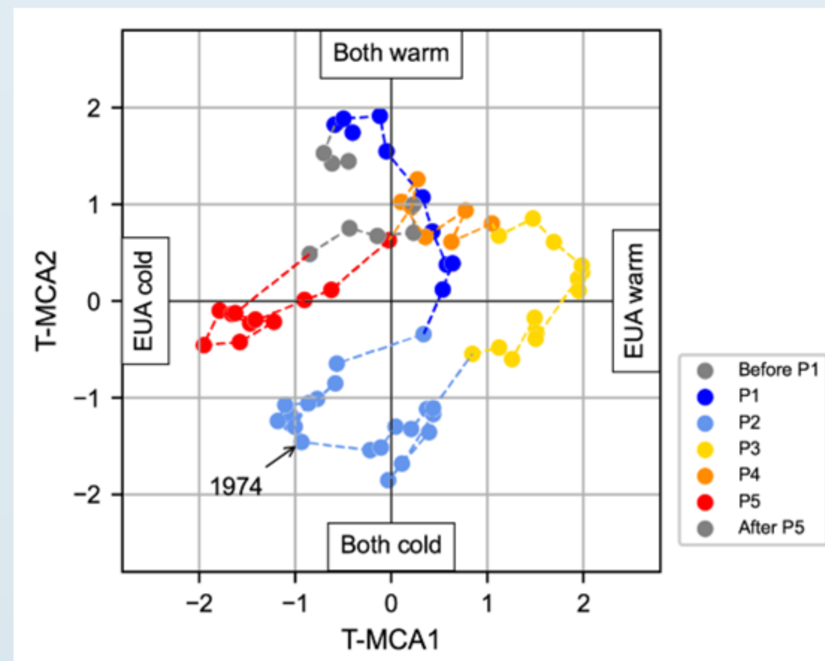

Fig.7 Orbit of the state vector representing the phase variation of the coupled T-MCA1 and T-MCA2.

- MCA1 and MCA2 are coupled modes.
- The phase variation against the coupled T-MCA1 and T-MCA2 evolves in a clockwise direction before 1974, but in a counterclockwise direction thereafter.
- Changes of the MCA2 tend to lead that of the MCA1 before 1974, but to lag that of the MCA1 thereafter.
- An interdecadal change can be found around 1974 between the MCA1-MCA2 coupling.
- MCA1-reconstructed SAT timeseries can explain up to 45.5% of EUA-SAT, while MCA2-reconstructed SAT timeseries can explain up to 43.7% of NA-SAT (not shown).

Linking the coupled interdecadal variations to PDO and AMO

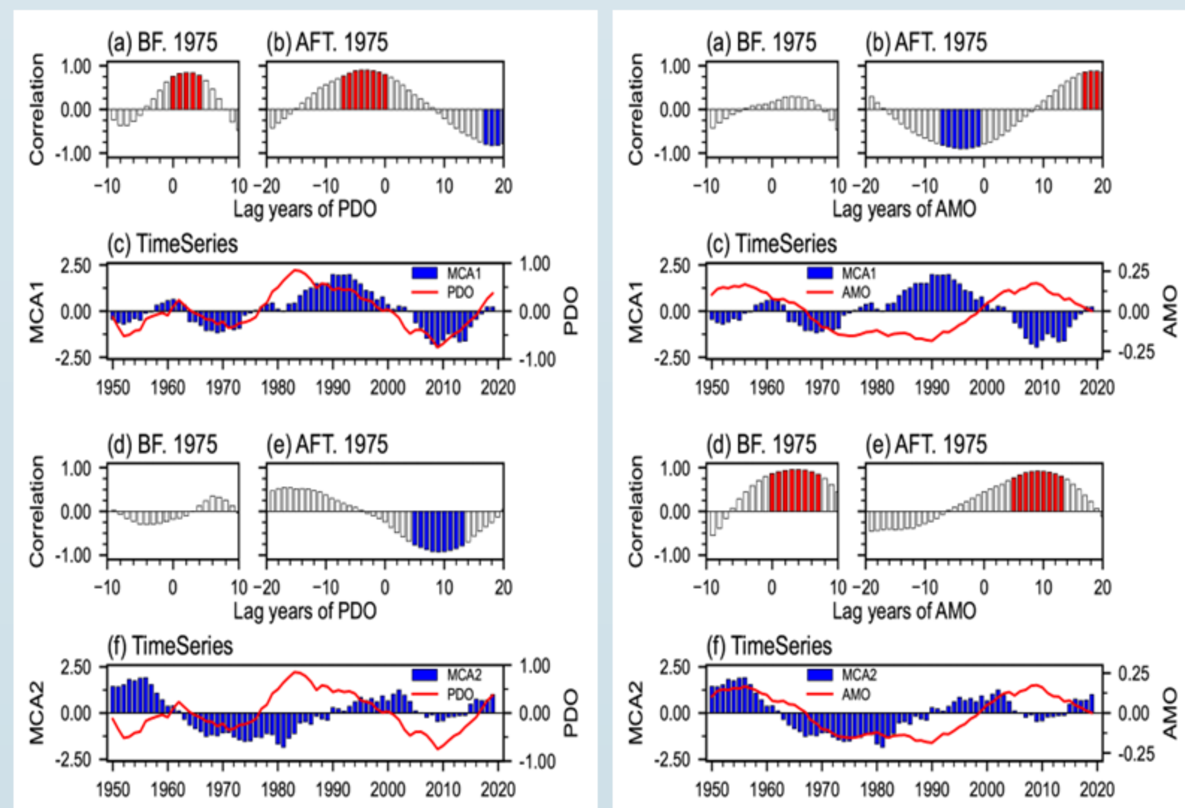

Fig.8 Lead–lag correlation between the PDO/AMO and T-MCA1 for the period of (a) 1950–1974 and (b) 1975–2021 and (c) the timeseries of the PDO/AMO and MCA1 in 1950–2021. (d–f) Are the same to (a–c) but for the T-MCA2.

- The PDO and T-MCA1 are positively correlated with each other in general. PDO slightly lags the T-MCA1 in the period before 1975 and leads the T-MCA1 thereafter.
- The nearly out-of-phase relationship between the AMO and PDO after 1975 probably further contributes to the stronger variability of the T-MCA1.
- the PDO-regressed patterns of the SAT and IMMT at a 0-lag resemble that of the MCA1 ('EUA-warmer'), while PDO-regressed patterns at a 14y-lag (12y-lead) resemble that of the MCA2 ('both-colder/warmer').

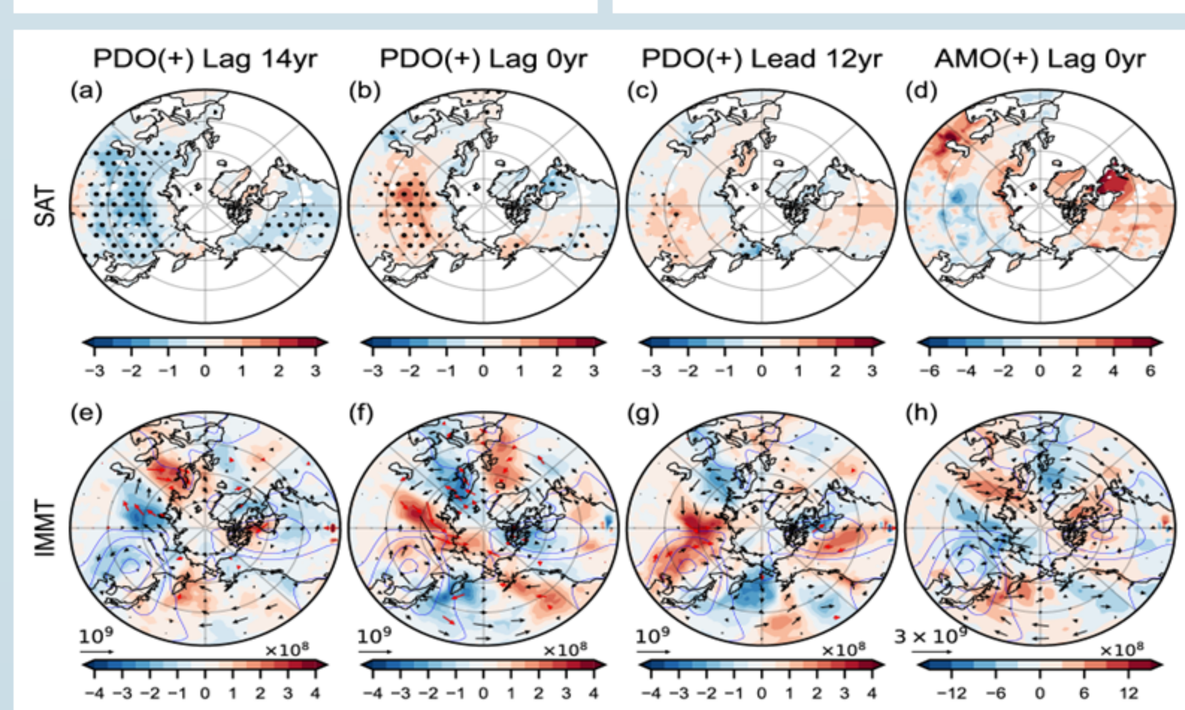

Fig.9 The SAT and IMMT anomalies regressed against PDO and AMO.

Summary

- The interdecadal variation of winter SAT over the two continents can be characterized with five typical periods (successively from a 'both-warmer', to a 'both-colder', and then a 'EUA-warmer' followed by another 'both-warmer' and a 'EUA-colder' period).
- The interdecadal variation of winter SAT is closely coupled with changes of the IMMT, which can be well reconstructed by the first two coupled MCA modes between SAT and IMMT.
- The MCA1 and MCA2 are significantly associated with the PDO which dominates the much-intensified MCA1 and the related 'EUA-warmer/colder' SAT pattern since 1975.

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