Climate of the Past

Statistical precursor signals for Dansgaard–Oeschger cooling transitions

Michael Kleinen and Peter Ditlevsen

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Abstract | Introduction | Data and methods | Results | Discussion | Conclusions | Appendix | References

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Abstract

Dansgaard–Oeschger events dominate abrupt climate tipping across and their tails. It is important to investigate the possibility of identifying early warning signals for the associated transitions. In general, the science and data long-extension of the Bolzmann-Ornstein-Uhlenbeck process is a bistatically forced stochastic process with a cubic drift. We show that the cooling transitions are preceded by a statistical precursor signal in the Greenland ice core data. We show that the cooling transitions are preceded by a statistical precursor signal in the Greenland ice core data. The Dansgaard–Oeschger (DO)

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Appendix B: Details of conceptual models used in Fig. 5

We describe specific settings for four conceptual models representing different conditions for the Dansgaard-Johnsen (DJ) model. Unless stated otherwise, the parameters of the DJ model with different boundary conditions are tuned and the scale factors are fixed to unity.

The "Greenhouse" (GH) case is the DJ model with $\Delta T_{GH} = 10$ K, $\Delta\beta_{GH} = 0.5$ ‰ and $\Delta\alpha_{GH} = 0.5$ ‰. The "Glacial" (GL) case is the DJ model with $\Delta T_{GL} = -10$ K, $\Delta\beta_{GL} = -0.5$ ‰ and $\Delta\alpha_{GL} = -0.5$ ‰. The "Glacial Greenhouse" (GLGH) case is the DJ model with $\Delta T_{GLGH} = -10$ K, $\Delta\beta_{GLGH} = 0.5$ ‰ and $\Delta\alpha_{GLGH} = 0.5$ ‰. The "Glacial Greenhouse" (GLGH) case is the DJ model with $\Delta T_{GLGH} = -10$ K, $\Delta\beta_{GLGH} = 0.5$ ‰ and $\Delta\alpha_{GLGH} = 0.5$ ‰.

The model boundary condition for the GH case is the ice-free condition (Greenhouse) with the surface temperature increased by 10 K, the surface water isotopic composition increased by 0.5 ‰ and the surface salinity increased by 1 psu. The GL case is the glacial condition with the surface temperature decreased by 10 K, the surface water isotopic composition decreased by 0.5 ‰ and the surface salinity decreased by 1 psu. The GLGH case is the glacial Greenhouse condition with the surface temperature decreased by 10 K, the surface water isotopic composition increased by 0.5 ‰ and the surface salinity increased by 1 psu.

Mixed-mode conditions (Mixed-mode, Mixed-mode-no-isotopes (MM0) and Mixed-mode-no-isotopes-no-mixing) are set to the intermediate conditions between the GH and GL cases (Jones et al., 2012; Bergsland and Jackson, 2016). They differ only in terms of salinity with the mixed-mode salinity being the average of the GH and GL salinities. The mixing parameter γ is set to 0.5 in the mixed-mode and MM0 simulations. In the mixing-free (MF) case, γ is set to unity. The mixed-mode and MM0 simulations differ in terms of isotopic composition with the mixed-mode isotopic composition being the average of the GH and GL isotopic compositions. The MM0 case is the mixed-mode case with the isotopic composition set to the GH case. The mixed-mode condition represents a situation in which the surface water properties are influenced by the connection region that reflects the surface salinity in the connection region. The MM0 case represents a situation in which the surface water properties are influenced by the connection region that reflects the surface salinity in the connection region and the surface water isotopic composition is influenced by the GH condition. The MF case represents a situation in which the surface water properties are not influenced by the connection region and the surface water properties are determined by the local forcing. The parameters, the DJ reduced-mixing, $\Delta\alpha$, $\Delta\beta$ and ΔT of the system given deeply into the connection region are the same as those used for the Greenhouse, Glacial and Glacial-Greenhouse cases.

Appendix A: Probability of observing robust precursor signals

The statistical significance of precursor signals of critical transitions, in terms of positive trends or increasing variance, is often assessed using Kendall's rank correlation coefficient, τ (Dakos et al., 2012; Boettner and Lenton, 2013; Lenton, 2013). We consider a stationary null hypothesis for the observed variance and autocorrelation at the end-point. The τ-surrogate data are prepared from the original observations by adding a small amplitude random perturbation (white noise) to the end-point and recalculating the autocorrelation function of the perturbed time series (Dakos et al., 2012; Boettner and Lenton, 2013; Lenton, 2013). The linear trend-preserving (LT) DJ indicator for the original indicator time series and the τ-surrogate data are then calculated. The probability of false positive (FP) is then estimated as the fraction of the τ-surrogate data that exceeds the original τ value. For the LT DJ indicator, τ-surrogate data are prepared by adding white noise to the original time series, y_t, prior to detrend by the LT DJ. The τ-surrogate data are then calculated as the difference between the τ-surrogate data and the LT DJ trend. The FP probability is then estimated as the fraction of the τ-surrogate data that exceeds the original τ value. For the LT DJ indicator, the τ-surrogate data are prepared by adding white noise to the original time series, y_t, prior to detrend by the LT DJ. The τ-surrogate data are then calculated as the difference between the τ-surrogate data and the LT DJ trend.

The model-mode conditions (Mixed-mode, Mixed-mode-no-isotopes (MM0) and Mixed-mode-no-isotopes-no-mixing) are set to the intermediate conditions between the GH and GL cases (Jones et al., 2012; Bergsland and Jackson, 2016). They differ only in terms of salinity with the mixed-mode salinity being the average of the GH and GL salinities. The mixing parameter γ is set to 0.5 in the mixed-mode and MM0 simulations. In the mixing-free (MF) case, γ is set to unity. The mixed-mode and MM0 simulations differ in terms of isotopic composition with the mixed-mode isotopic composition being the average of the GH and GL isotopic compositions. The MM0 case is the mixed-mode case with the isotopic composition set to the GH case. The mixed-mode condition represents a situation in which the surface water properties are influenced by the connection region that reflects the surface salinity in the connection region. The MM0 case represents a situation in which the surface water properties are influenced by the connection region that reflects the surface salinity in the connection region and the surface water isotopic composition is influenced by the GH condition. The MF case represents a situation in which the surface water properties are not influenced by the connection region and the surface water properties are determined by the local forcing. The parameters, the DJ reduced-mixing, $\Delta\alpha$, $\Delta\beta$ and ΔT of the system given deeply into the connection region are the same as those used for the Greenhouse, Glacial and Glacial-Greenhouse cases.

Code and data availability

The Greenland ice core data used in this study are available at https://doi.org/10.1594/PANGAEA.879482. The model output data used in this study are available at https://doi.org/10.5281/zenodo.2584149 (Willeit, 2019).

Supplement

The supplement related to this article is available online at https://doi.org/10.5194/cp-2019-00-supplement.

Author contributions

The conceptual study was developed by the author with contributions from Will. Both authors wrote the manuscript and discussed the results and implications.

Competing interests

The contact author has declared that neither of the authors has any competing interests.

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Review statement

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