Understanding and modeling the scaling spectrum of climate

Beatrice Ellerhoff, Kira Rehfeld
18 March 2020

01_Intro.mp3
A few instructions on the use of this document:

- The white triangles ▶️ mark clickable contents
- Play Sound and ▶️ indicate short audio explanations
- Play Sound is supported by the Okular pdf viewer
- Alternatively, the audio records can be listened to under this ▶️ link

A quick summary of central questions of our research:

- How can we model & understand the scaling background continuum of temperature variability?
- How is variability on short timescales linked to variability on long timescales?
- What is the contribution of forcing mechanisms to climate variability on different scales?
The climate - a highly interactive, continuously evolving & complex system

The very different physical characteristics of climate subsystems are coupled through the transfer of energy, momentum & mass. Perturbations affect the many subsystems differently.

This variety meets challenging questions of physics such as turbulence & non-linear interactions. The need for modeling future climate conditions and the effects of global heating makes it even more important to understand the highly complex climate system.

▶ 03_ClimateSystem.mp3 ➤ Play Sound

▷ femkemilene / CC BY-SA; Freepik from www.flaticon.com

▷ beatrice.ellerhoff@iup.uni-heidelberg.de
Climate forcings and responses act on all timescales

The climate is constantly changing as a result of the interplay between many characteristic timescales associated to external & internal forcings as well as to the subsystems' responses.

This interplay makes it hard to model climate variations in time. Climate variability still remains insufficiently explained. It is, however, expected to be at least as relevant to the society as changes in the mean temperature \[\Delta\text{Katz and Brown, 1992}\].

▶ 04_Timescales.mp3  ➤ Play Sound

Adapted from ▶ Peixto and Oort, 1984; Rohling et al., 2018, 2012

▶ beatrice.ellerhoff@iup.uni-heidelberg.de
Scaling continuum of temperature variability follows power laws $S(f) \propto f^{-\beta}$

Spectral analysis of climate signals makes it possible to assess the characteristic features of climate variability.

The background continuum of temperature variability follows different power-laws on monthly to decadal versus millennial to longer periods. Moreover, the scaling is spatially dependent [Huybers and Curry, 2006].

This finding has major implications on our understanding of climate variability. We aim to update and to extend this result using proxy and instrumental data in order to gain further insights into the scaling spectrum of climate.

▶ 05_ScalingBackground.mp3
Here, we present results for the Common Era:

$1/f$-noise is found for global spectra at monthly to centennial periods and $\beta \approx 0.3$ for the mid latitudes. At the weather regime, we find $1.49 \leq \beta \leq 2.18$, confirming previous results [Fredriksen and Rypdal, 2016; Fredriksen and Rypdal, 2017; Lovejoy, 2015].

The forcing spectrum is modeled as a composite of total solar irradiance, CO$_2$, volcanic & orbital forcing. The characteristic peaks at yearly and diurnal periods are reflected in the response spectra.

$\beta=0.26\pm 0.03$  $\beta=1.14\pm 0.03$  $\beta=1.01\pm 0.03$  $\beta=1.49\pm 0.03$  $\beta=2.18\pm 0.04$
Outlook

We would like to take the above results and the discussions from the EGU sessions as a starting point for further investigations of the scaling spectrum of climate.

This could be based on higher order spectral analysis, testing for correlations between forcings & responses. The modeled forcing could be further used for single-forced experiments with energy balance models. All in all, we seek to evaluate the potential of these methods to reveal dynamical processes governing the continuous spectrum of surface temperature.

We would be happy to receive your questions & to discuss related topics with you: ▶ live chat ▶ e-mail

🎵 07_Outro.mp3 ▶ Play Sound

▶ beatrice.ellerhoff@iup.uni-heidelberg.de
Thanks to:

▷ **STACY colleagues &** ▷ **Marie-France Loutre** for discussions
The ▷ **ICOS lab (B. Kromer, S. Kühr & S. Hammer)** for data support
## Data

<table>
<thead>
<tr>
<th>Name</th>
<th>Calibration</th>
<th>Ref. (Calibration)</th>
<th>Ref. (data)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volcanic Forcing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crowley</td>
<td>$1 \text{ AOD} = -25 \text{ W/m}^2$</td>
<td>IPCC, 2014</td>
<td>Crowley and Unterman, 2013</td>
</tr>
<tr>
<td><strong>Total Solar Irradiance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steinhilber</td>
<td></td>
<td></td>
<td>Steinhilber, Beer, and Fröhlich, 2009</td>
</tr>
<tr>
<td>CMIP5</td>
<td></td>
<td></td>
<td>Schmidt et al., 2011</td>
</tr>
<tr>
<td>**CO}_2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MaunaLoa</td>
<td>$5.35 \ln\left(\frac{\text{CO}_2}{278 \text{ppm}}\right) \text{ W/m}^2$</td>
<td>Köhler et al., 2017</td>
<td>Tans and Keeling, 2019</td>
</tr>
<tr>
<td>Köhler</td>
<td></td>
<td></td>
<td>Köhler et al., 2017</td>
</tr>
<tr>
<td>Meinshausen</td>
<td>$5.35 \ln\left(\frac{\text{CO}_2}{278 \text{ppm}}\right) \text{ W/m}^2$</td>
<td>&quot;&quot;</td>
<td>Meinshausen et al., 2017</td>
</tr>
<tr>
<td><strong>Insolation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orbital forcing</td>
<td></td>
<td></td>
<td>Berger, 1978; Crucifix, 2016; Laskar et al., 2004</td>
</tr>
<tr>
<td><strong>Local temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central England record</td>
<td></td>
<td></td>
<td>Parker, Legg, and Folland, 1992</td>
</tr>
<tr>
<td>Heidelberg record</td>
<td></td>
<td></td>
<td>IUP Heidelberg (ICOS Lab)</td>
</tr>
<tr>
<td><strong>Global temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pages2k multi-proxy reconstr</td>
<td></td>
<td></td>
<td>Neukom et al., 2019</td>
</tr>
<tr>
<td>hadCRUT4 record</td>
<td></td>
<td></td>
<td>Morice et al., 2012</td>
</tr>
</tbody>
</table>

✉️ beatrice.ellerhoff@iup.uni-heidelberg.de


IPCC. Climate Change 2013 - The Physical Science Basis. 2014. DOI: 10.1017/cbo9781107415324.

Peter Köhler et al. “Continuous record of the atmospheric greenhouse gas carbon dioxide (CO2), raw data”. In: PANGAEA, 2017. DOI: 10.1594/PANGAEA.871265.


S. Lovejoy. “A voyage through scales, a missing quadrillion and why the climate is not what you expect”. In: Climate Dynamics (2015). DOI: 10.1007/s00382-014-2324-0.


beatrice.ellerhoff@iup.uni-heidelberg.de
References


