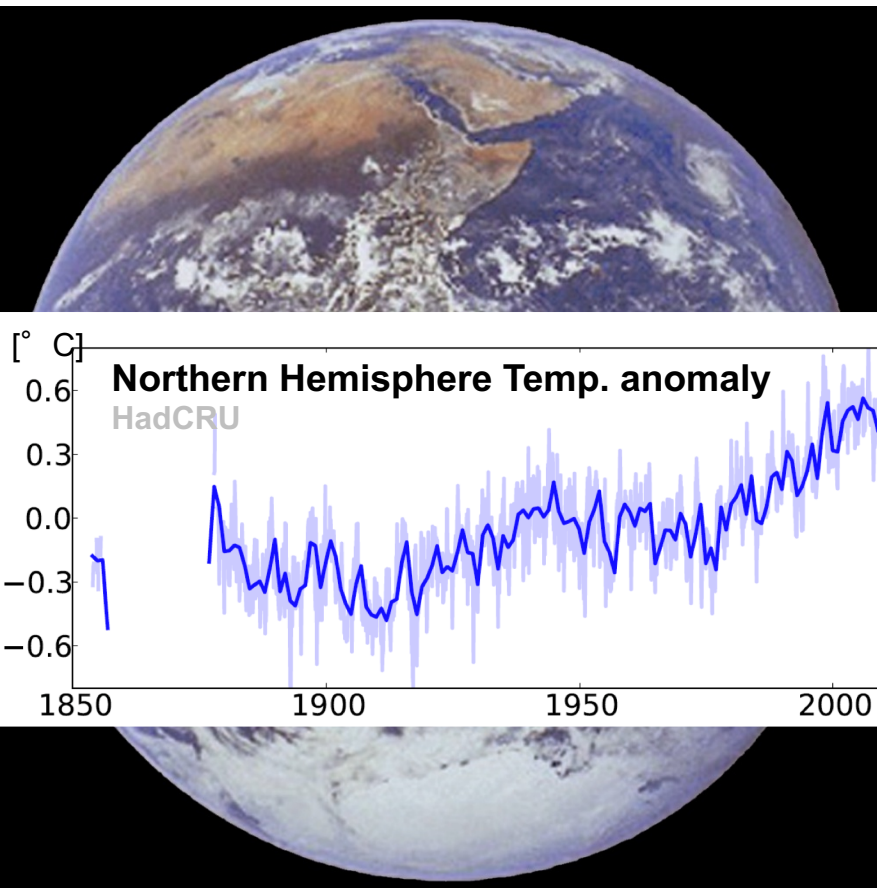


The climate problem

Gerrit Lohmann

**Alfred Wegener Institut
Helmholtz Zentrum für
Polar- und Meeresforschung**

Bremen, 17.06.2019

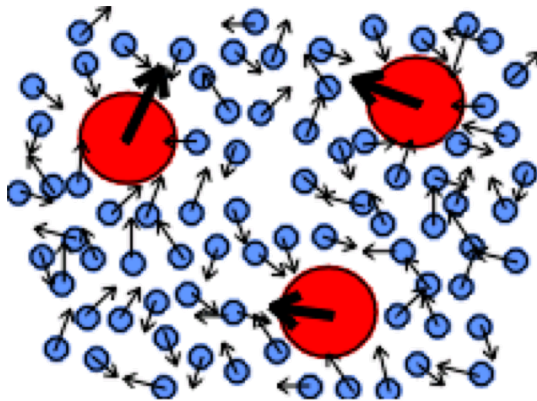


Physics in the 20. century

- Views: Elementary Particles, Quantum Mechanics, Theory of Relativity
- Limit of divisibility (Democritus, Aristotle: matter not a continuous whole: "From infinitely small particles, the world can not be assembled"

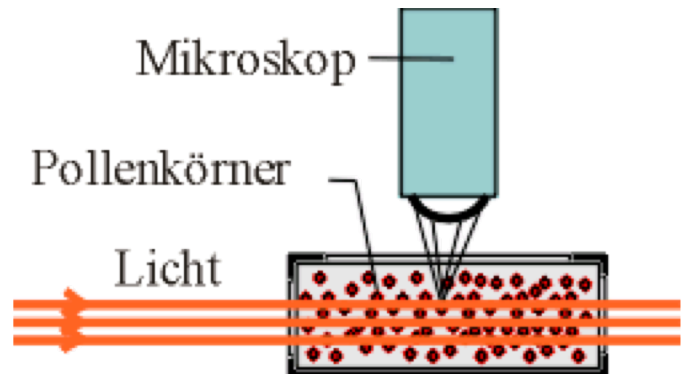
Grainy composition of nature

Brownian motion: shift of particles
(under the microscope)



Irregular

Brown: living material?



1. Molecules: disorderly motion collides with particles from all directions by chance
2. Molecules have a mass and are not infinitely small.

5. *Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen; •*
von A. Einstein.

In dieser Arbeit soll gezeigt werden, daß nach der molekularkinetischen Theorie der Wärme in Flüssigkeiten suspendierte Körper von mikroskopisch sichtbarer Größe infolge der Molekularbewegung der Wärme Bewegungen von solcher Größe ausführen müssen, daß diese Bewegungen leicht mit dem Mikroskop nachgewiesen werden können.

$$\lambda_x = \sqrt{x^2} = \sqrt{2 D t}$$

560

A. Einstein. Bewegung etc.

Umgekehrt läßt sich die gefundene Beziehung zur Bestimmung von N benutzen. Man erhält:

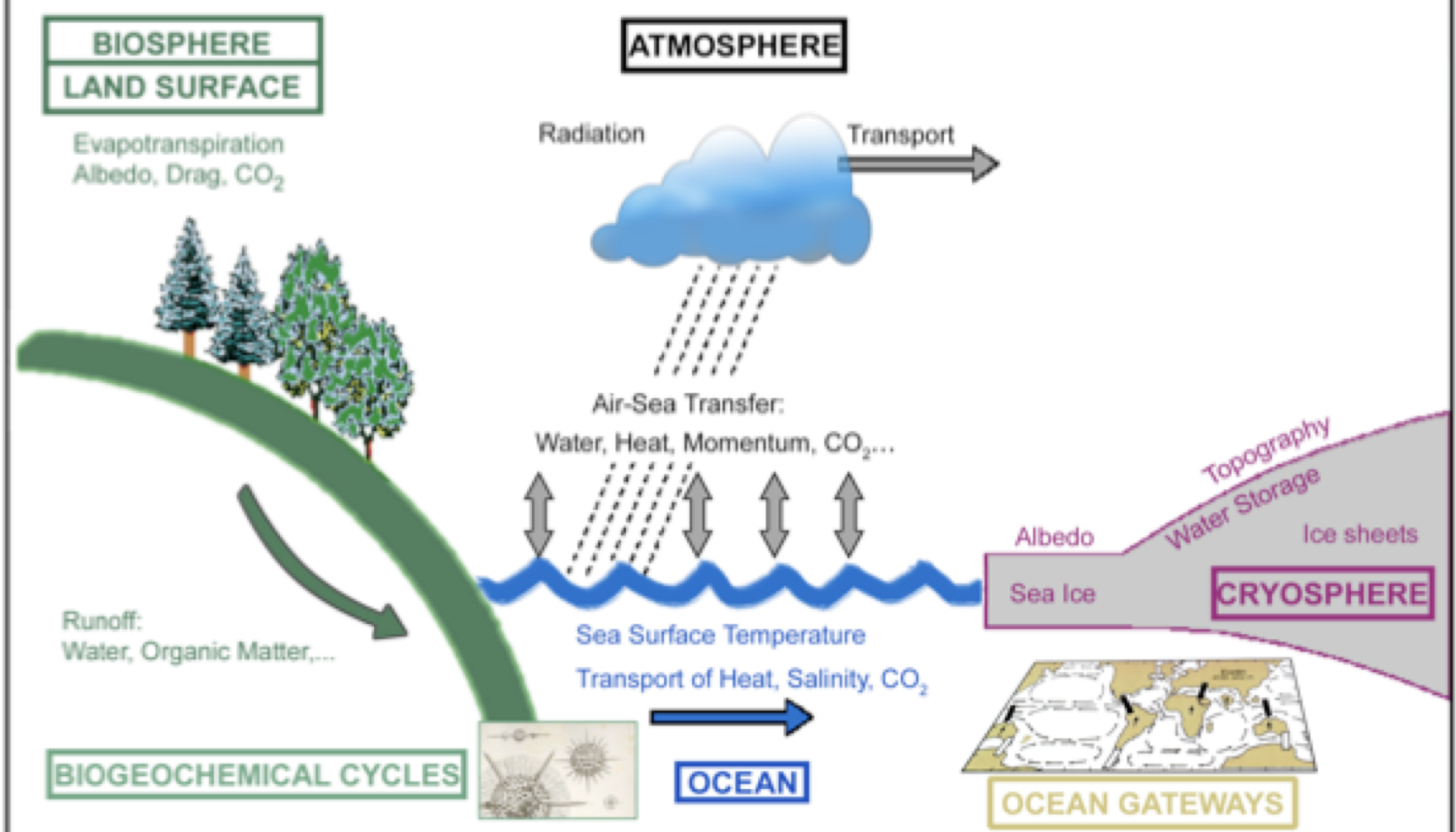
$$N = \frac{t}{\lambda_x^2} \cdot \frac{R T}{3 \pi k P}$$



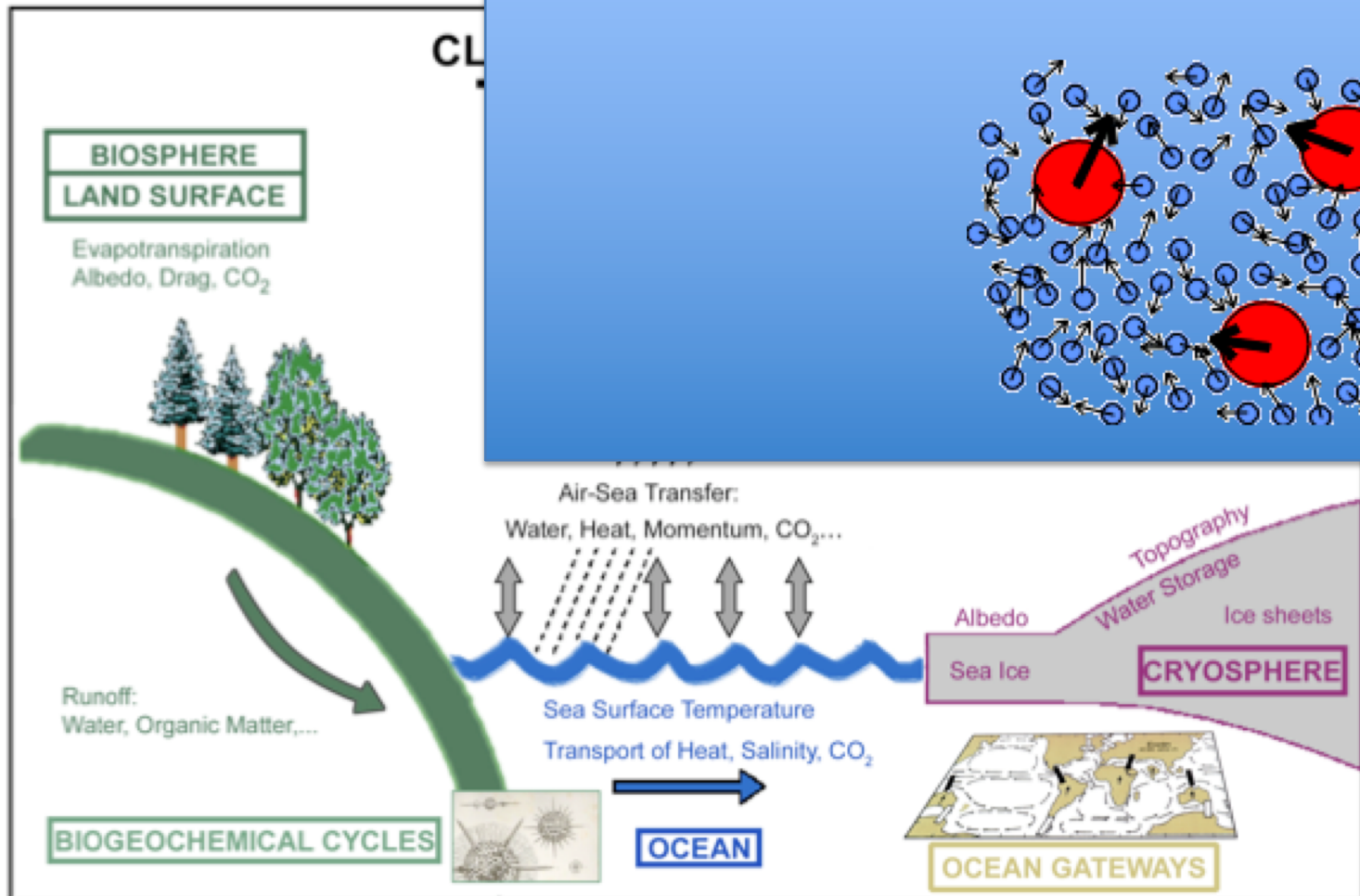
Möge es bald einem Forscher gelingen, die hier aufgeworfene, für die Theorie der Wärme wichtige Frage zu entscheiden!

Bern, Mai 1905.

CLIMATE SUB-SYSTEMS

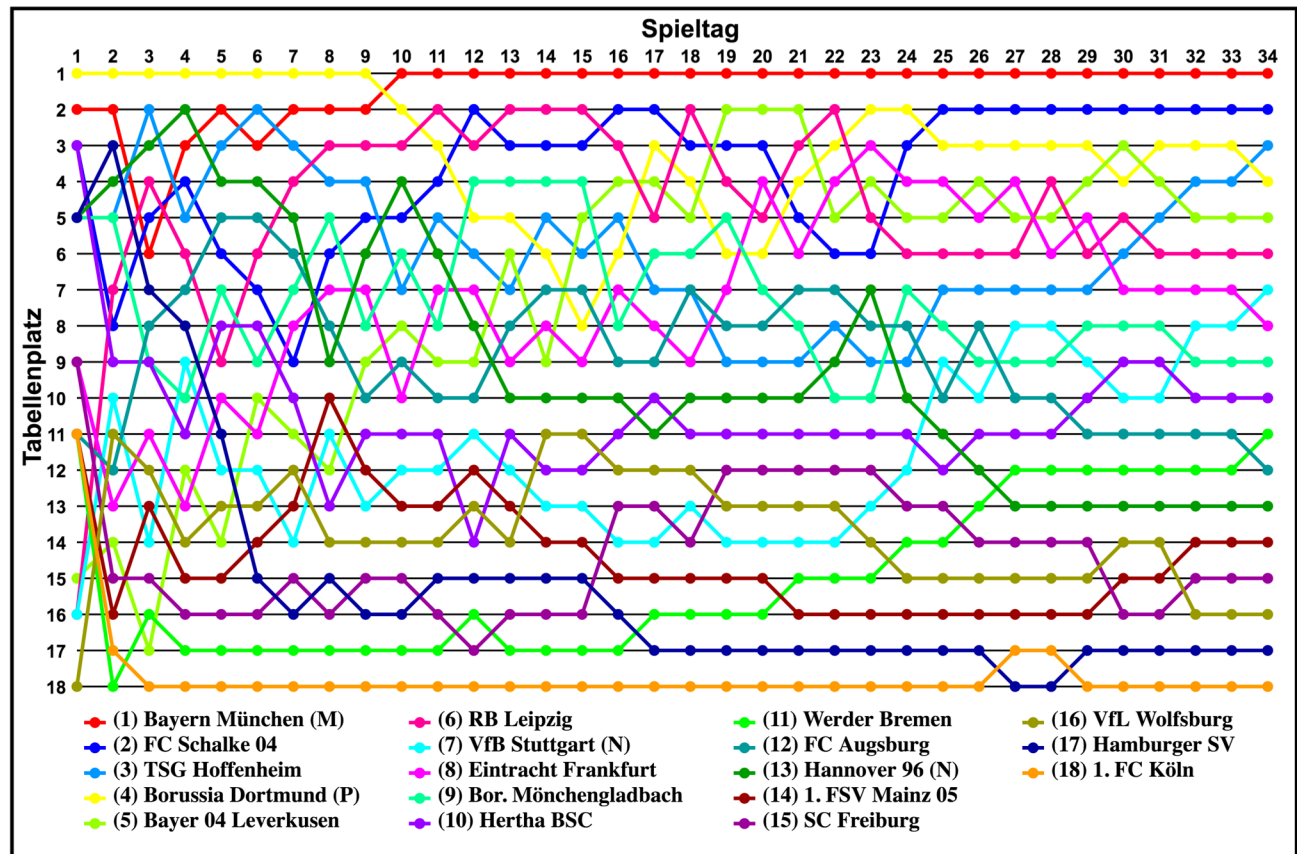


- Brown' Particle: climate
- Molecules: Weather

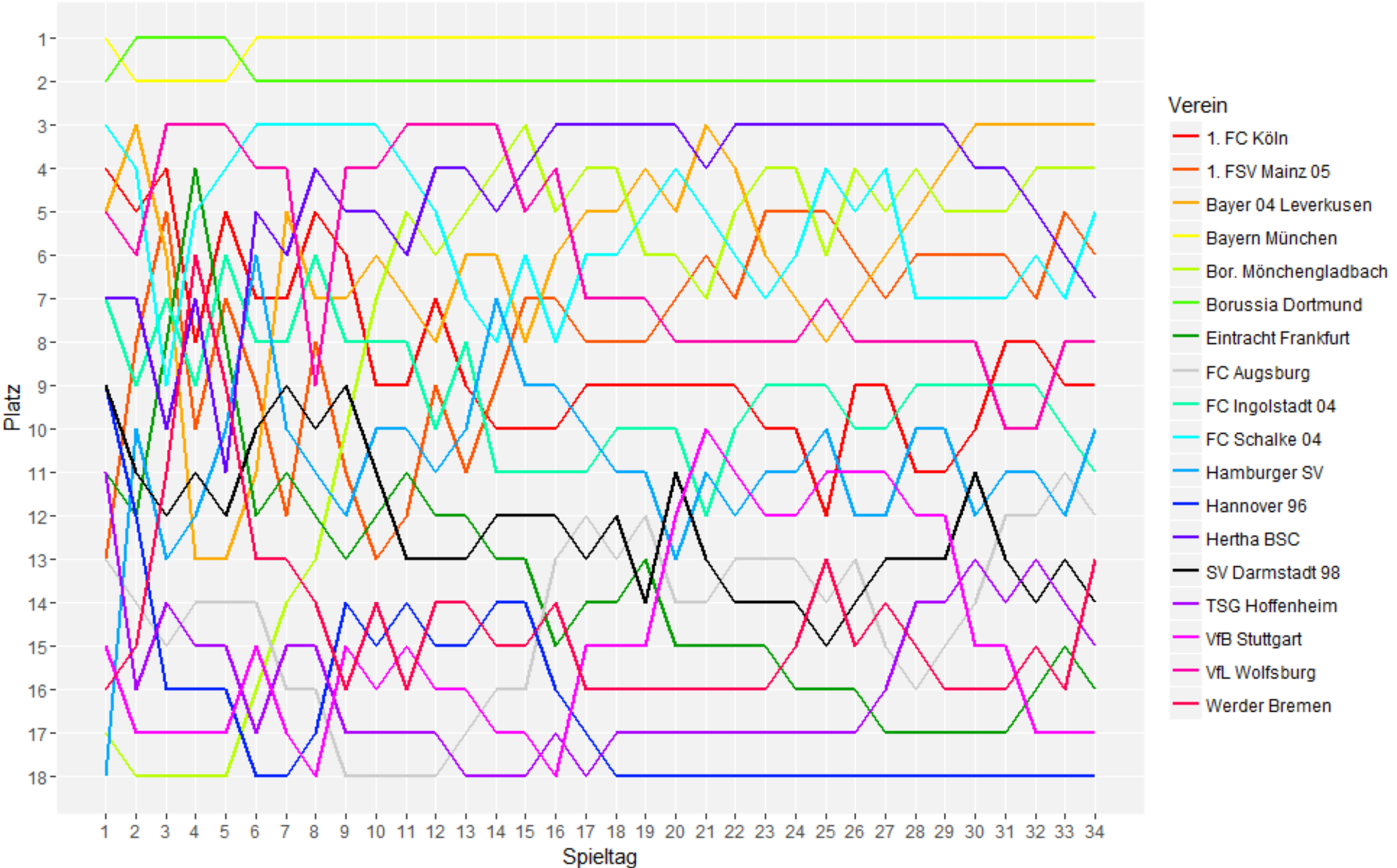


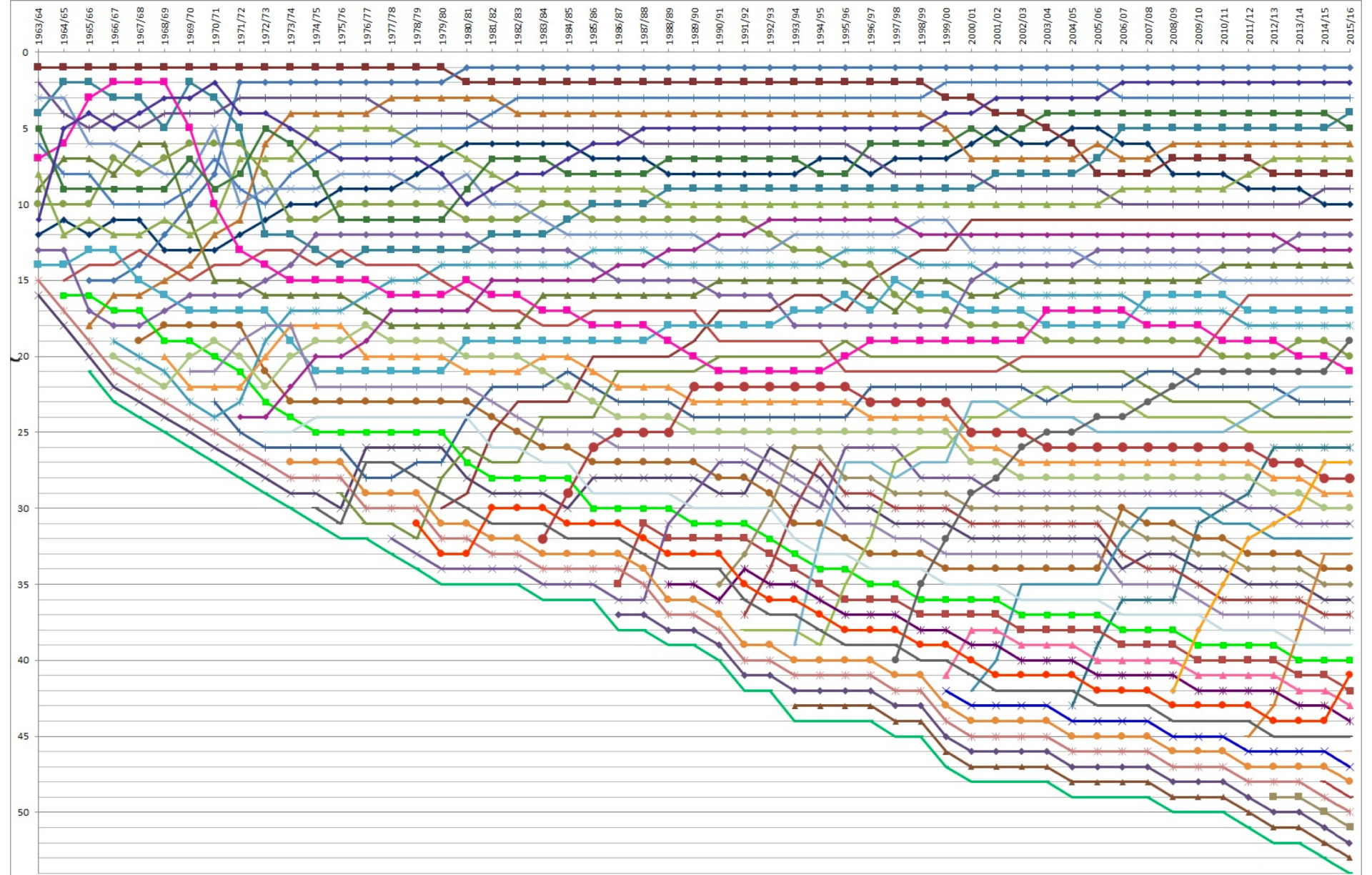
Predictability: Weather and Climate

- Brown's Particle: Climate
- Molecules: Weather



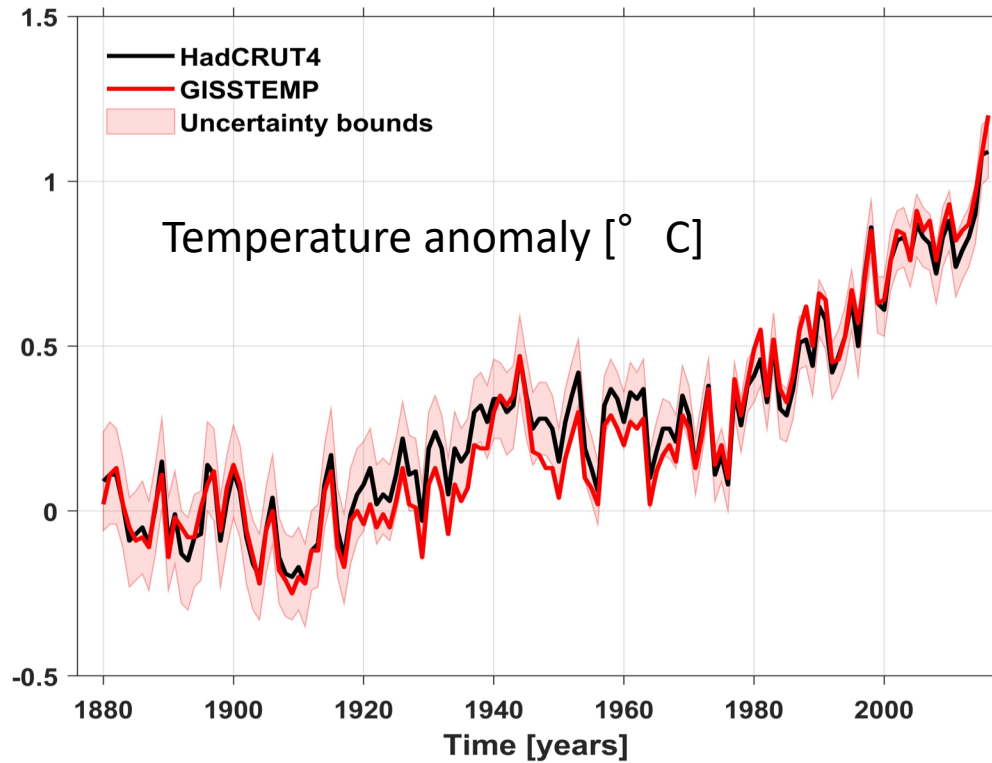
Bundesliga 2015/2016



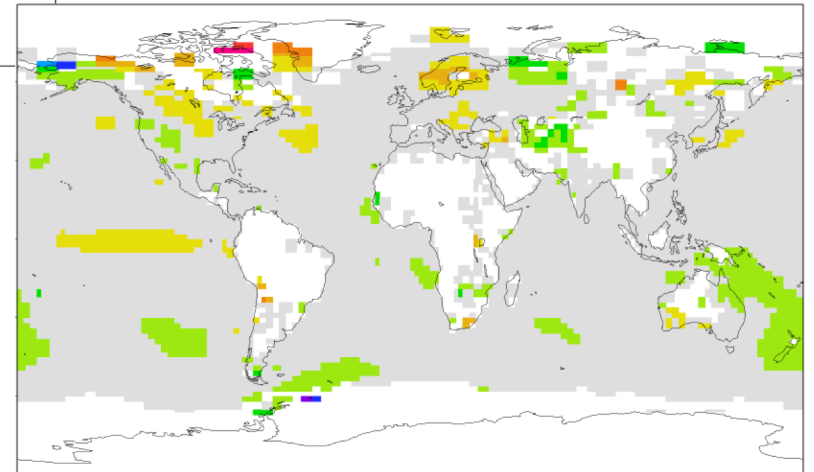
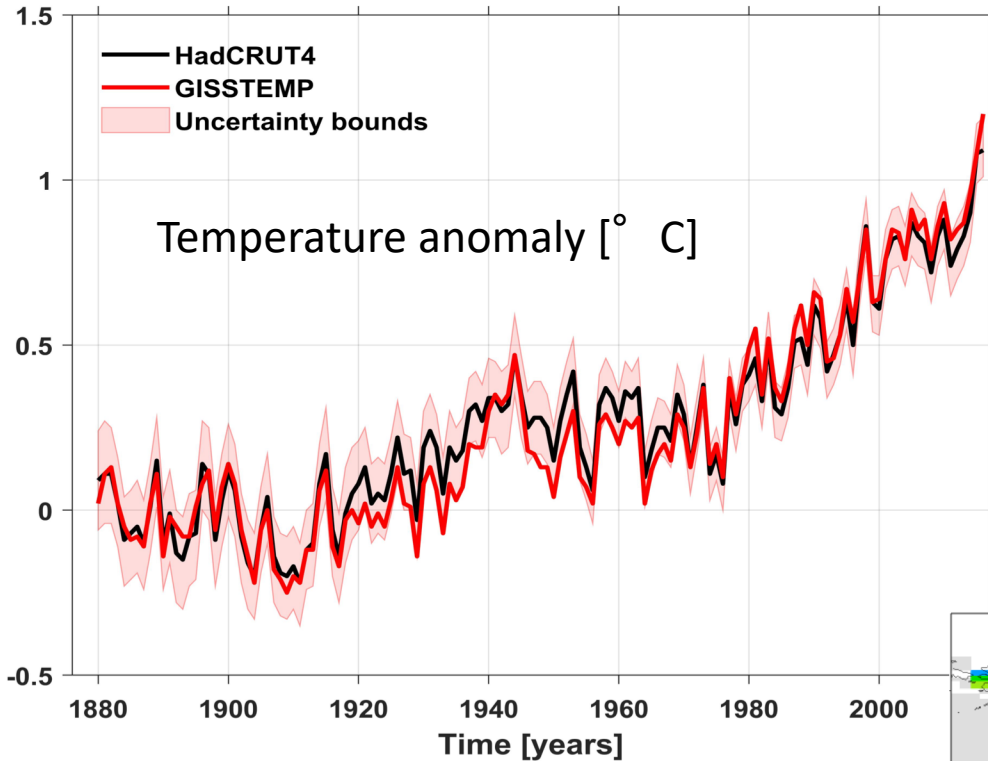


- | | | | | | | | |
|----------------------|---------------------|---------------------|--------------------------|----------------------|------------------------|------------------------|---------------------|
| 1. FC Kaiserslautern | 1. FC Köln | 1. FC Nürnberg | 1. FC Saarbrücken | 1. FSV Mainz 05 | Alemannia Aachen | Arminia Bielefeld | Bayer 04 Leverkusen |
| Bayer Uerdingen | Blau-Weiß 90 Berlin | Borussia Dortmund | Borussia Mönchengladbach | Borussia Neunkirchen | Dynamo Dresden | Eintracht Braunschweig | Eintracht Frankfurt |
| Energie Cottbus | FC Augsburg | FC Bayern München | FC Homburg | FC Ingolstadt 04 | FC Schalke 04 | FC St. Pauli | Fortuna Düsseldorf |
| Fortuna Köln | Hamburger SV | Hannover 96 | Hansa Rostock | Hertha BSC | Karlsruher SC | Kickers Offenbach | MSV Duisburg |
| Preußen Münster | Rot-Weiss Essen | Rot-Weiß Oberhausen | SC Freiburg | SC Paderborn 07 | SG Wattenscheid 09 | SpVgg Greuther Fürth | SpVgg Unterhaching |
| SSV Ulm 1846 | Stuttgarter Kickers | SV Darmstadt 98 | SV Waldhof Mannheim | Tasmania Berlin | Tennis Borussia Berlin | TSG 1899 Hoffenheim | TSV 1860 München |
| VfB Leipzig | VfB Stuttgart | VfL Bochum | VfL Wolfsburg | Werder Bremen | Wuppertaler SV | | |

Motivation: Observational Record



Motivation: Observational Record



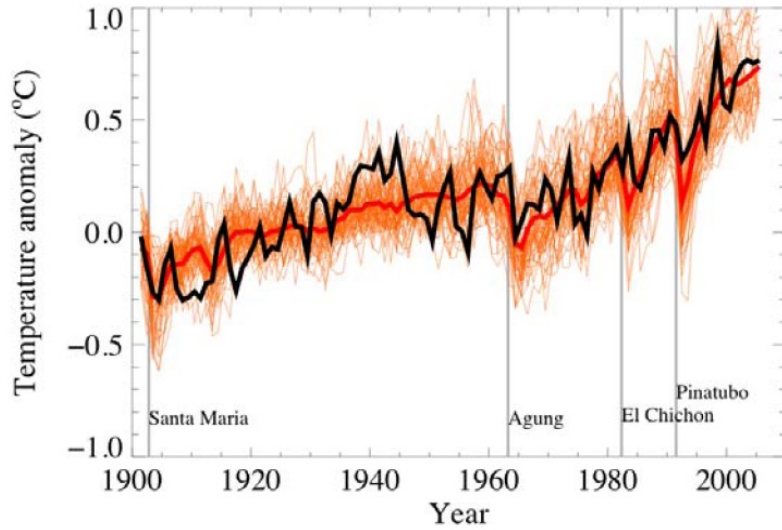
Uncertainty largely due to missing information at high latitudes

Temperature Anomaly 1930
White areas: not enough data



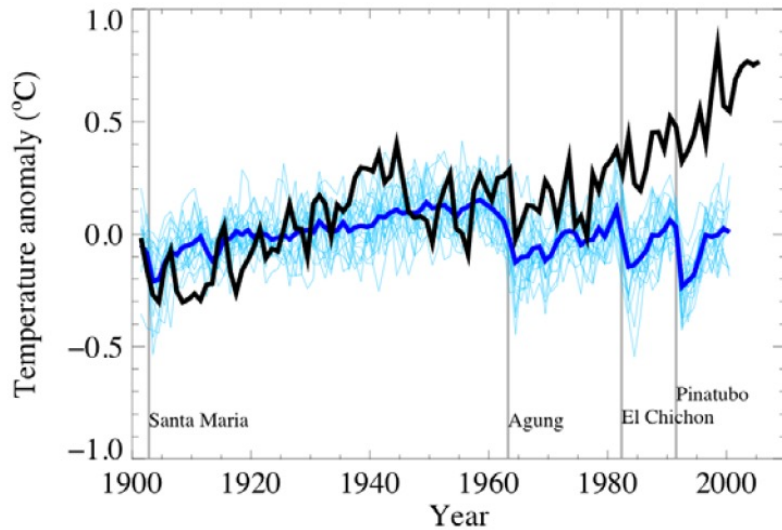
Attribution

a **greenhouse gas emissions**



consistent

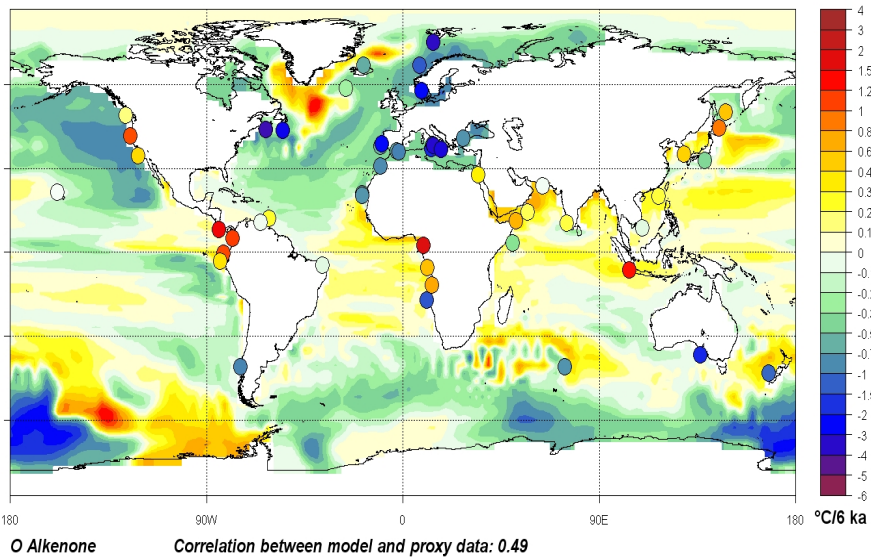
b



inconsistent

no greenhouse gas emissions

Annual mean global SST trends (model) and local alkenone-based temperature trends

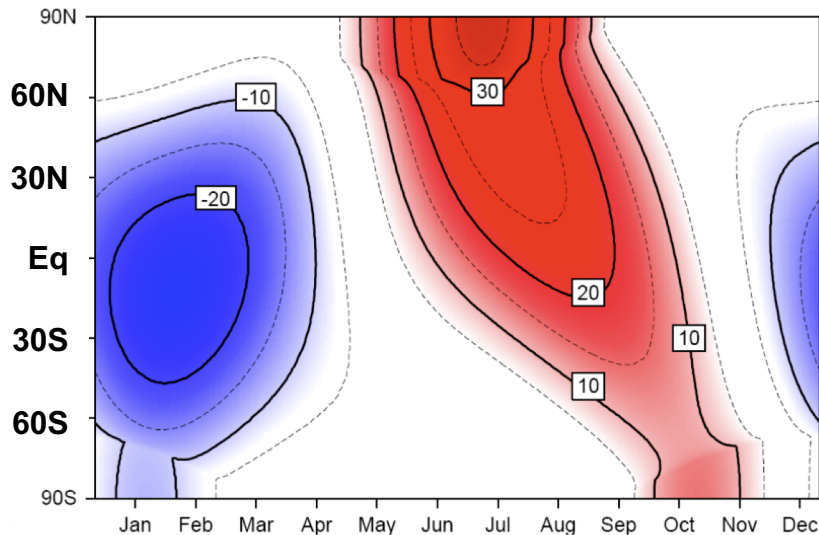


Simulationen des Holozäns: Einfluss von Erdorbitalparametern und Treibhausgasen



5300 Jahre alte Mumie
[Ötztaler Alpen](#) 3210m H

Erwärmung in den Tropen
Abkühlung in hohen Breiten

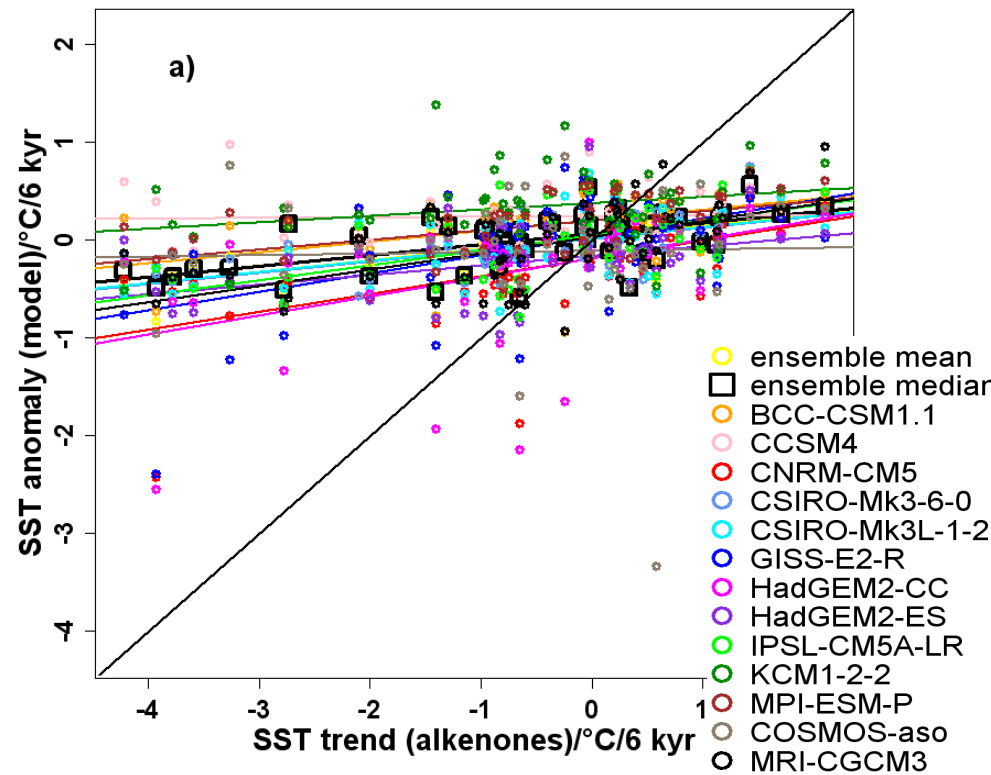
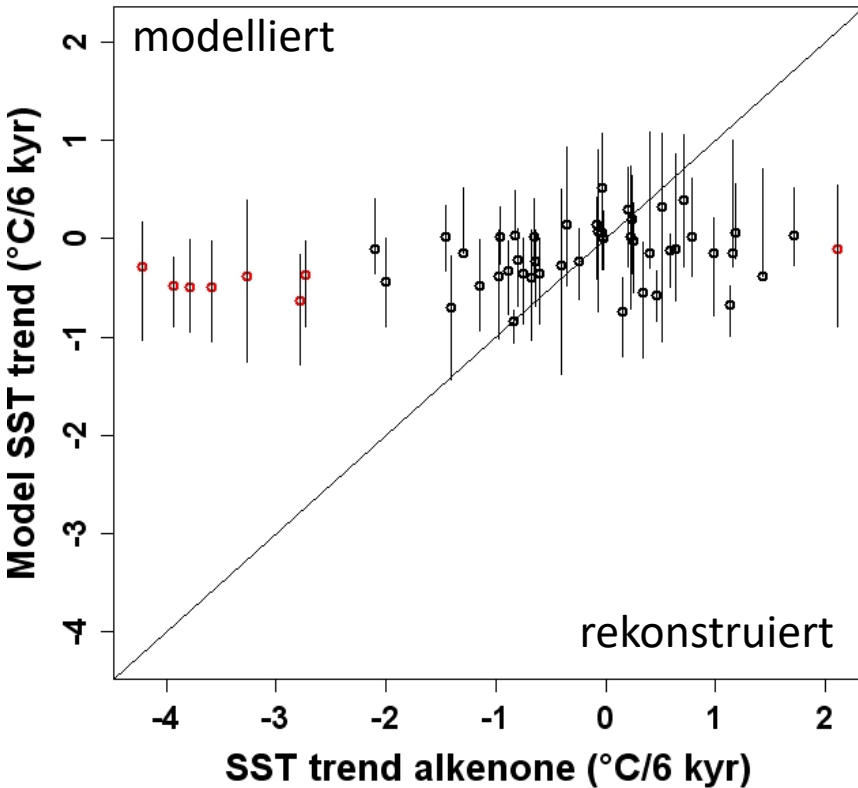
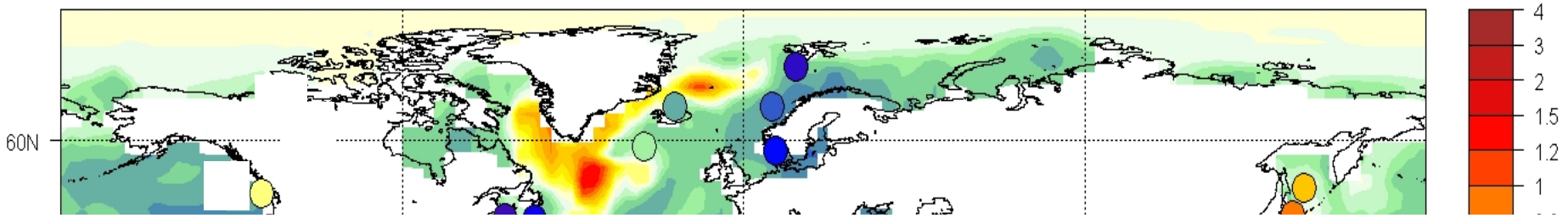


Temperaturverlauf für 30° -90° N

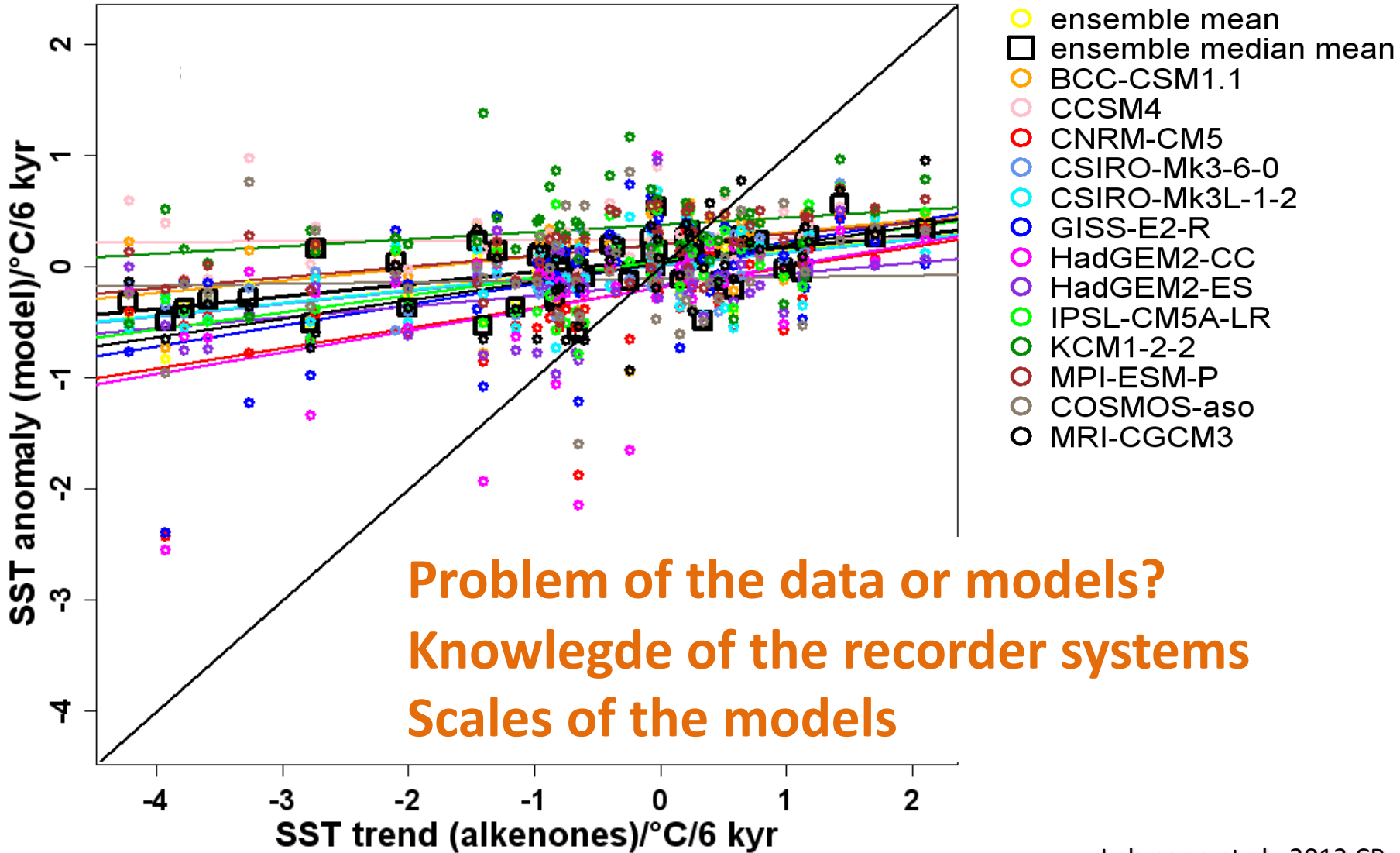


Holozäne Temperaturtrends 6000 Jahre

Annual mean global SST trends (model) and local alkenone-based temperature trends

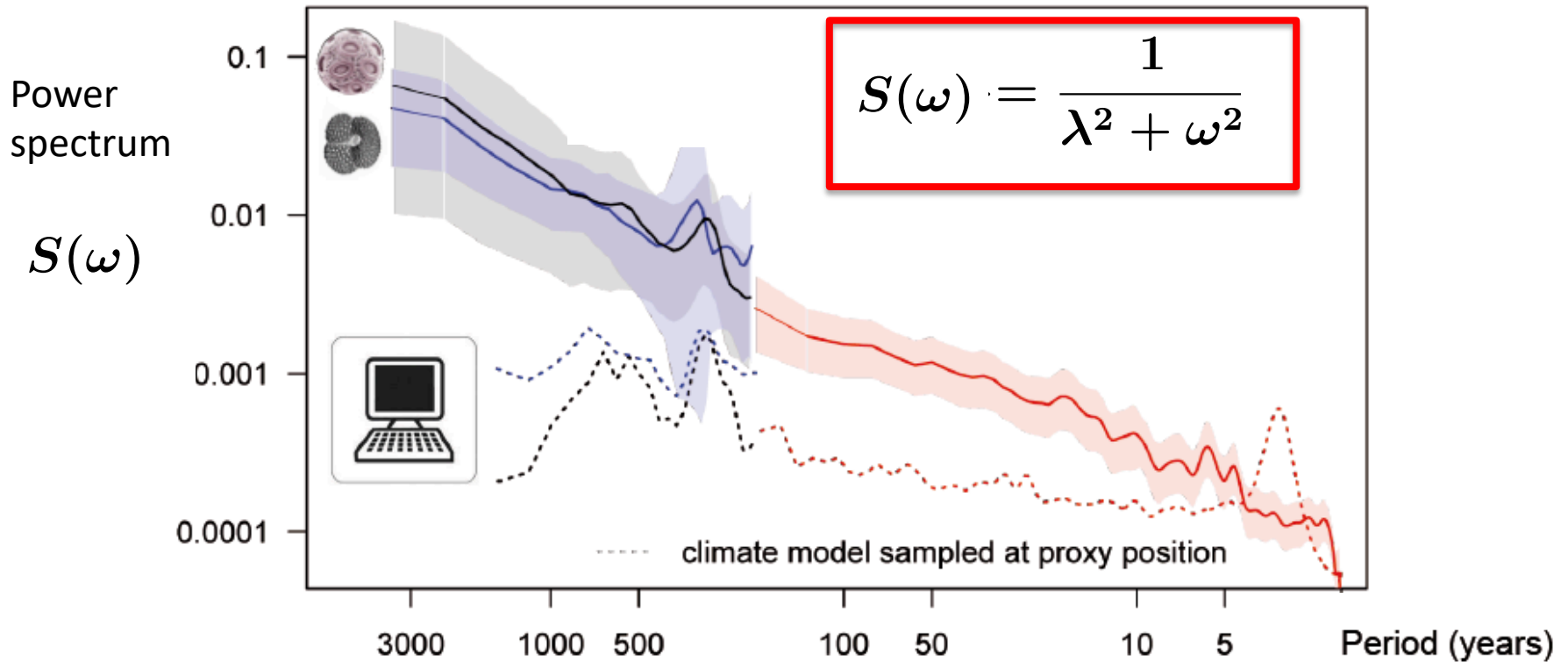


Models in PMIP3



Marine temperature variability

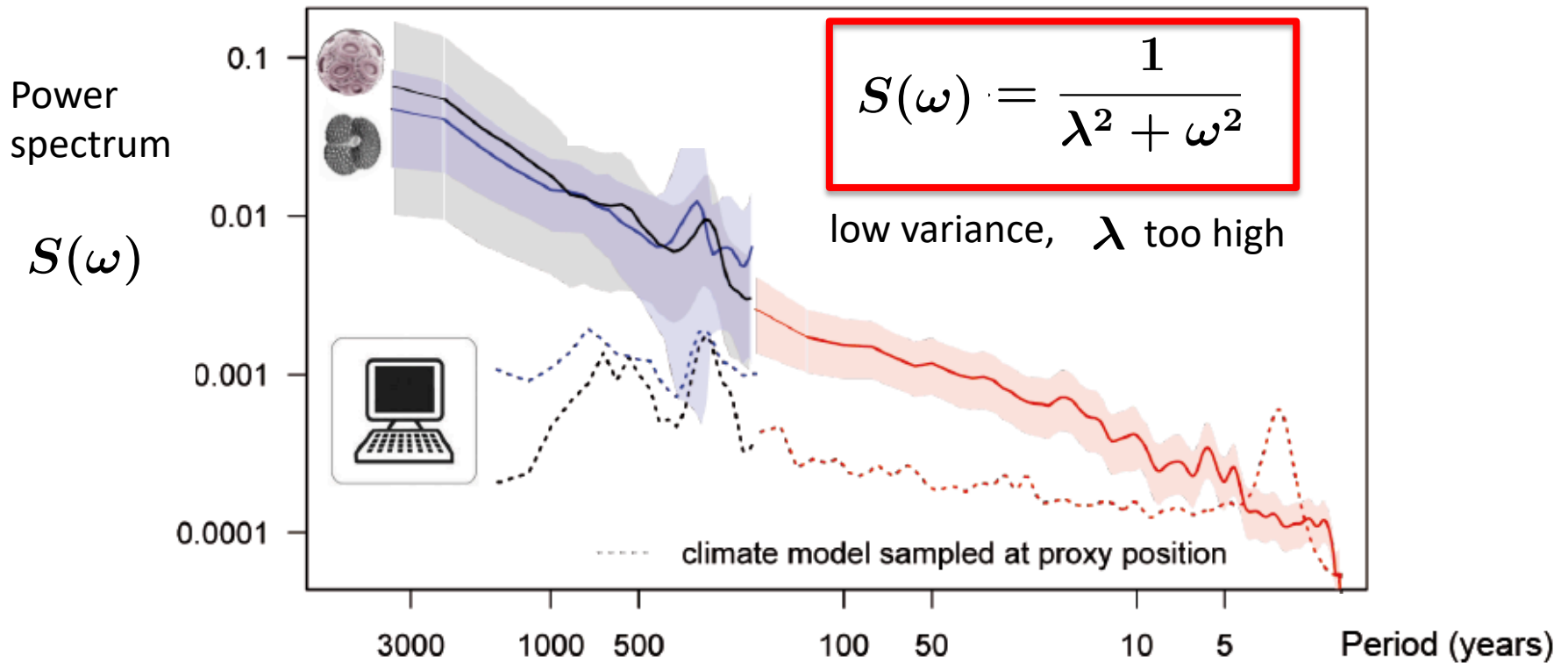
(annual to millennial time scales)



Current climate models seem to underestimate variability

Marine temperature variability

(annual to millennial time scales)



Current climate models seem to underestimate variability

$$\frac{dT}{dt} = -\lambda T + \text{Noise} + \text{Forcing}$$

Equilibrium
response:

$$\Delta T = \frac{\text{Forcing}}{\lambda}$$

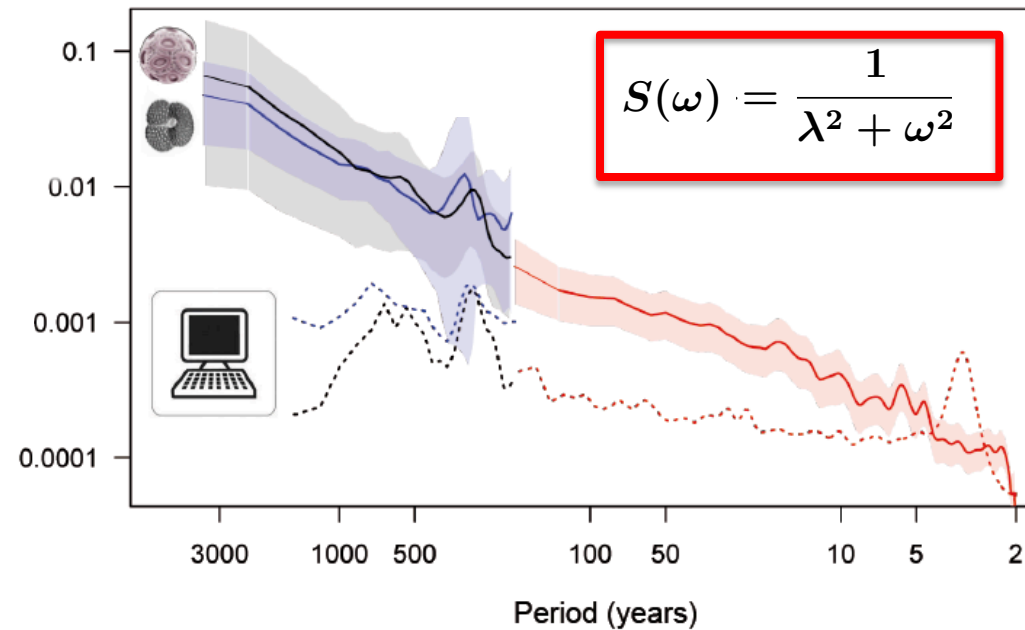
Stochastic climate model

$$\frac{dT}{dt} = -\lambda T + \text{Noise} + \text{Forcing}$$



Damping λ too high

Power spectrum

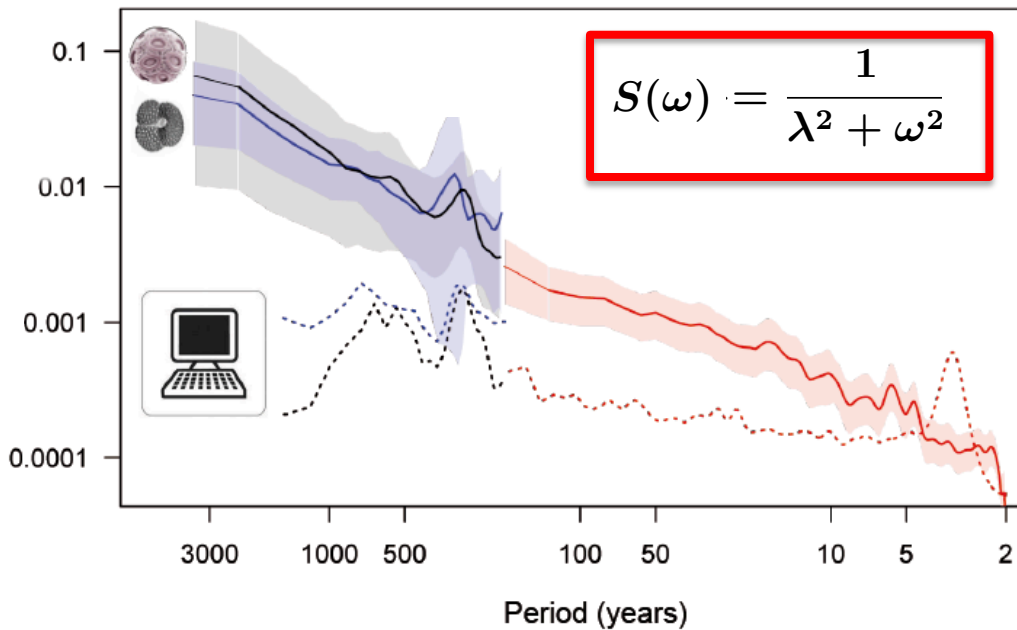


Variance too low

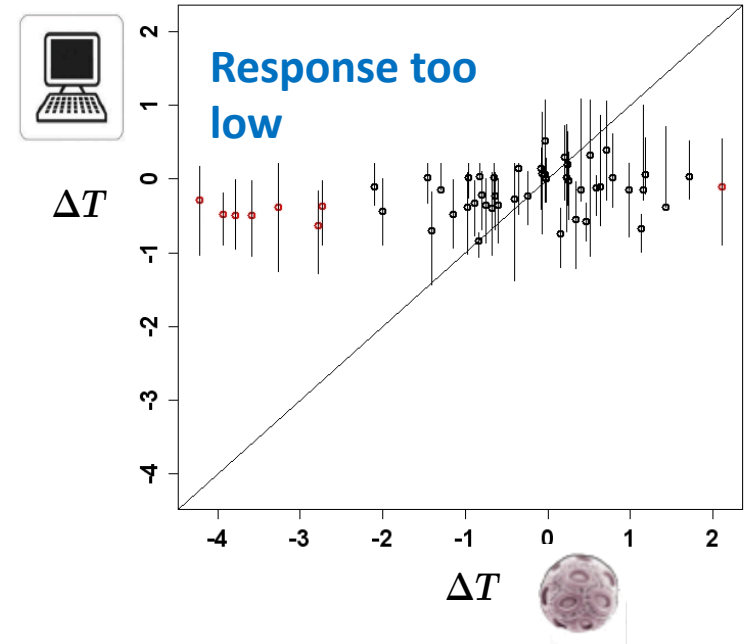
Stochastic climate model

$$\frac{dT}{dt} = -\lambda T + \text{Noise} + \text{Forcing}$$

Power spectrum



Equilibrium response



$$\Delta T = \frac{\text{Forcing}}{\lambda}$$