Signs of chaos in observed and simulated El Niño/Southern Oscillation

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Open questions in ENSO research

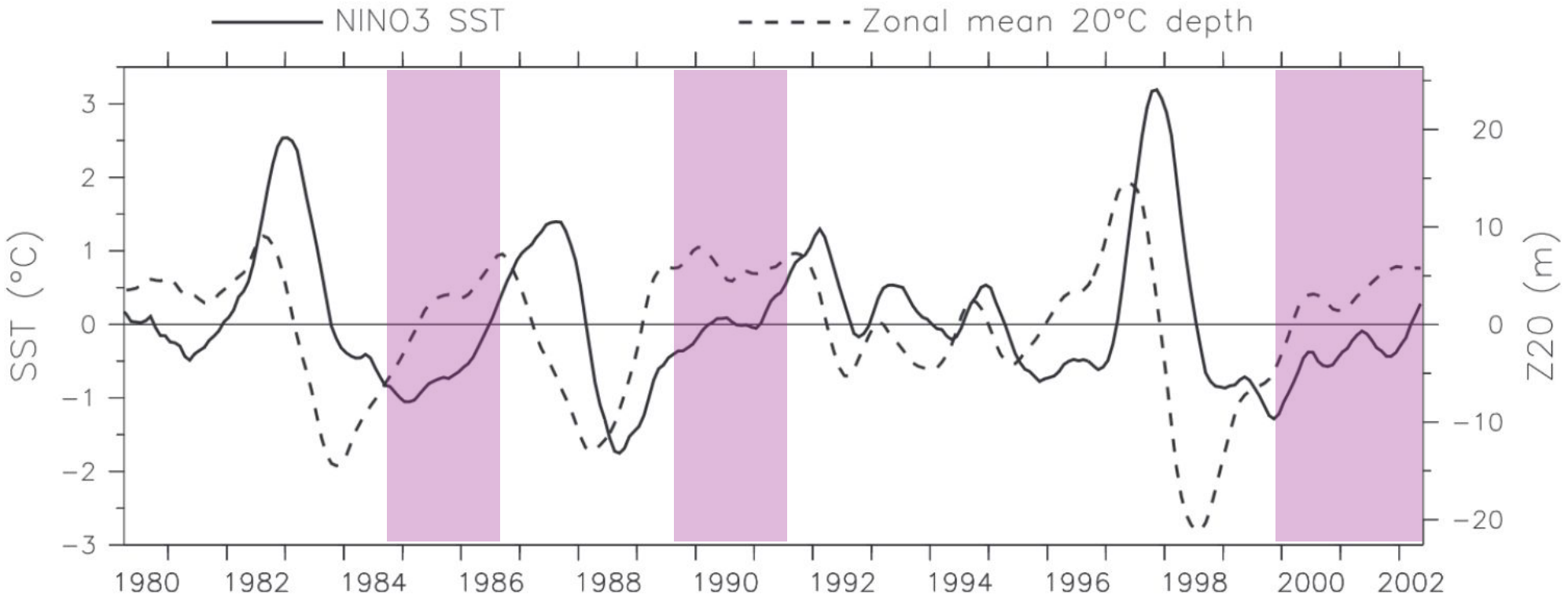
- **Is ENSO an oscillation?**

  No – looks like a series of events,
  Memory (predictability) is lost after La Nina,
  Noise reinitiates the cycle.

GEOPHYSICAL RESEARCH LETTERS, VOL. 29, NO. 23, 2125, doi:10.1029/2002GL015924, 2002

Is ENSO a cycle or a series of events?

William S. Kessler



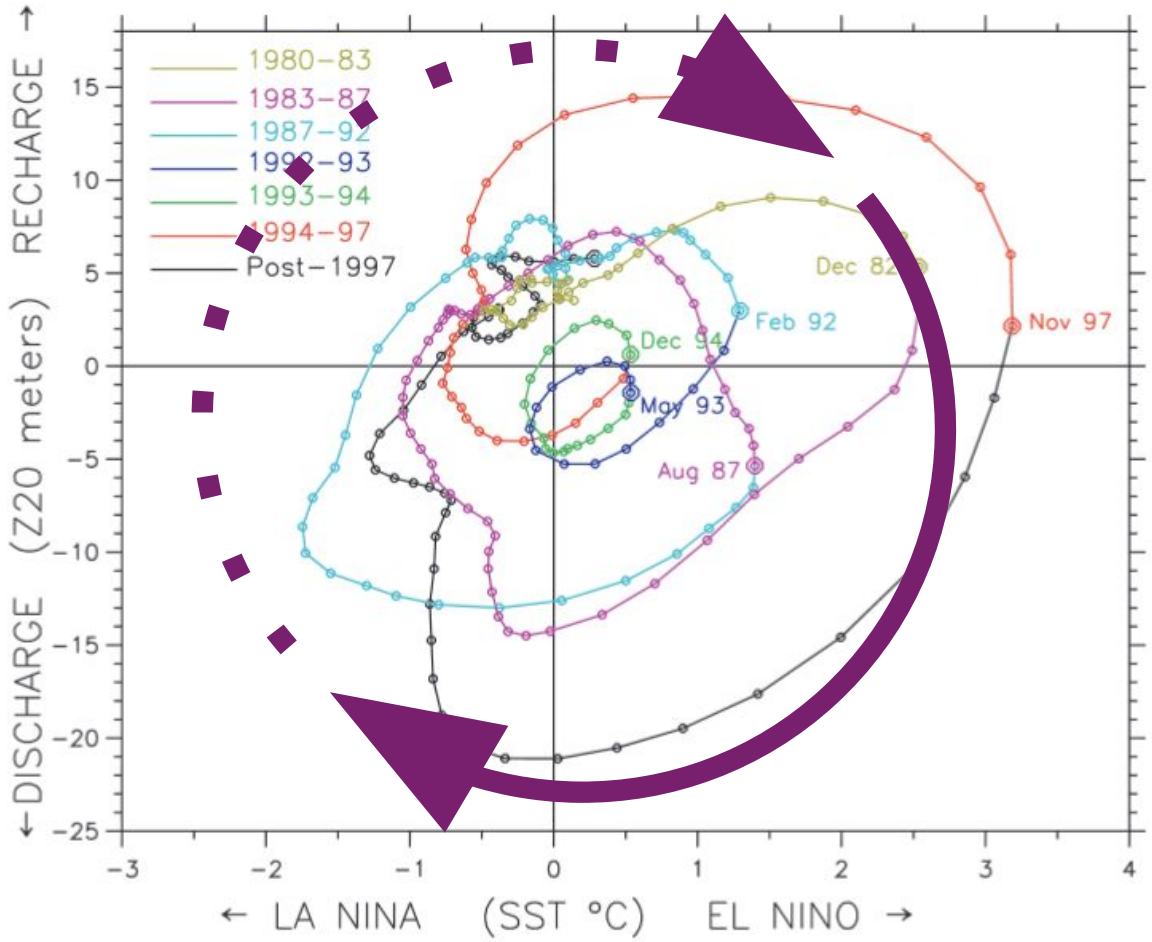
Kessler et al. 2002

GEOPHYSICAL RESEARCH LETTERS, VOL. 29, NO. 23, 2125, doi:10.1029/2002GL015924, 2002

Is ENSO a cycle or a series of events?

William S. Kessler

slow oscillation



fast oscillation

Kessler et al. 2002

Is ENSO irregularity produced by chaos – or by noise?

El Niño on the Devil's Staircase: Annual Subharmonic Steps to Chaos

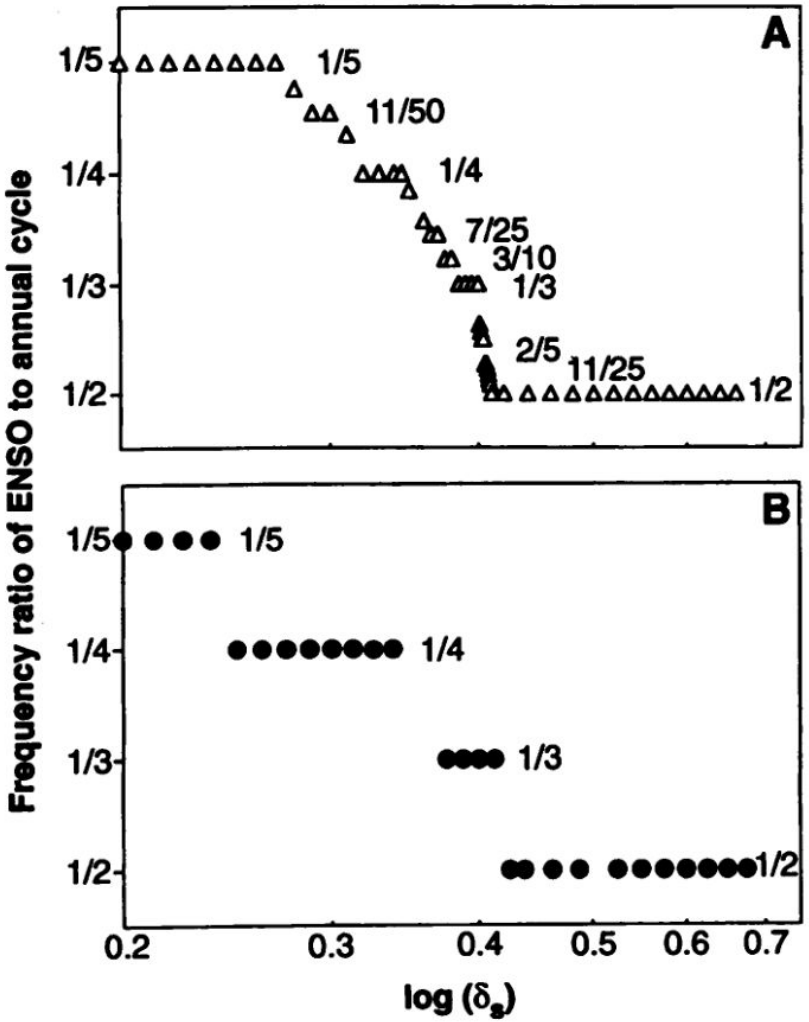
Fei-Fei Jin, J. David Neelin,* Michael Ghil

The source of irregularity in El Niño, the large interannual climate variation of the Pacific ocean-atmosphere system, has remained elusive. Results from an El Niño model exhibit transition to chaos through a series of frequency-locked steps created by nonlinear resonance with the Earth's annual cycle. The overlapping of these resonances leads to the chaotic behavior. This transition scenario explains a number of climate model results and produces spectral characteristics consistent with currently available data.

El Niño Chaos: Overlapping of Resonances Between the Seasonal Cycle and the Pacific Ocean-Atmosphere Oscillator

Eli Tziperman,* Lewi Stone, Mark A. Cane, Hans Jarosh

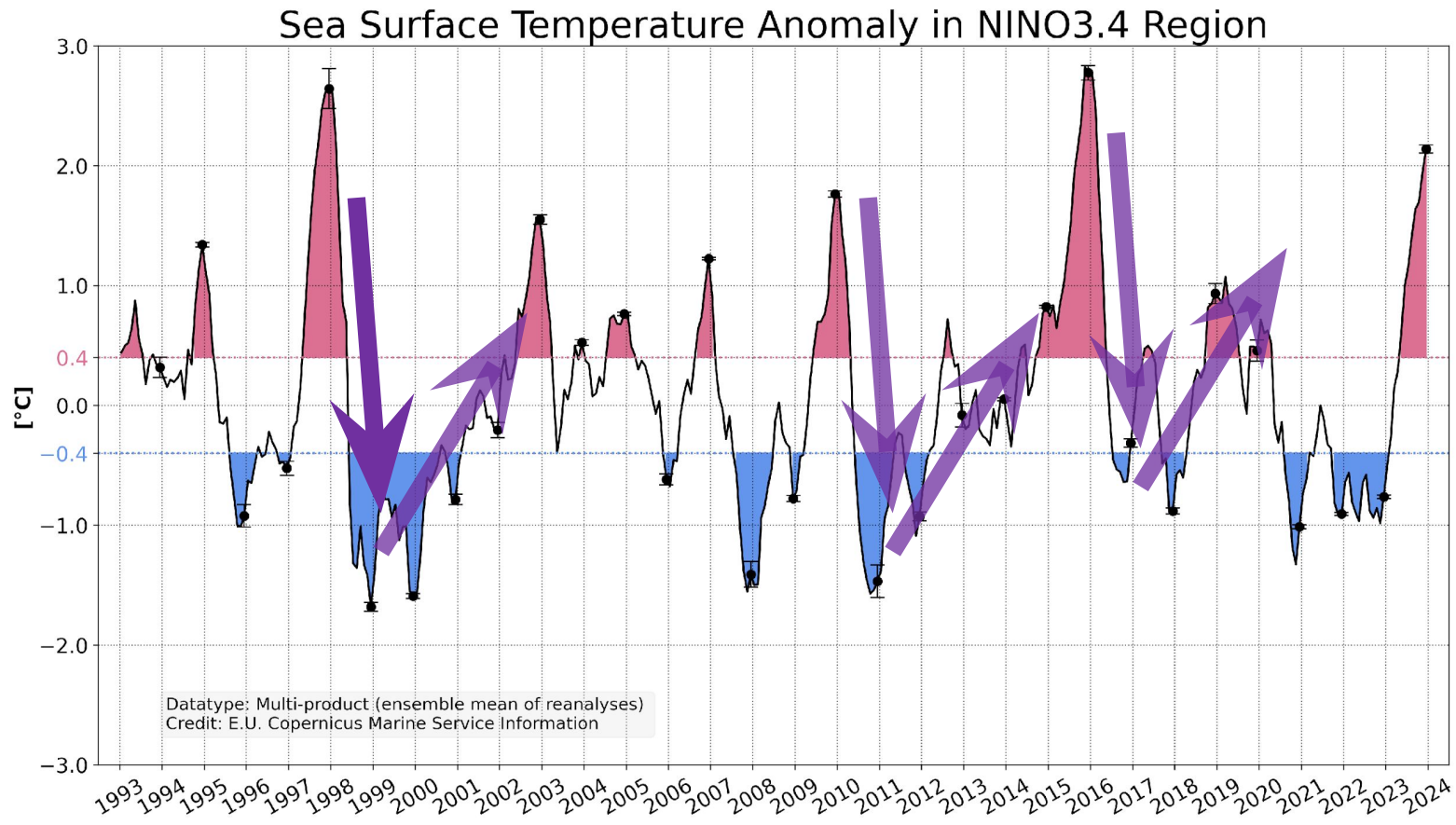
The El Niño–Southern Oscillation (ENSO) cycle is modeled as a low-order chaotic process driven by the seasonal cycle. A simple model suggests that the equatorial Pacific ocean-atmosphere oscillator can go into nonlinear resonance with the seasonal cycle and that with strong enough coupling between the ocean and the atmosphere, the system may become chaotic as a result of irregular jumping of the ocean-atmosphere system among different nonlinear resonances. An analysis of a time series from an ENSO prediction model is consistent with the low-order chaos mechanism.



coupling strength

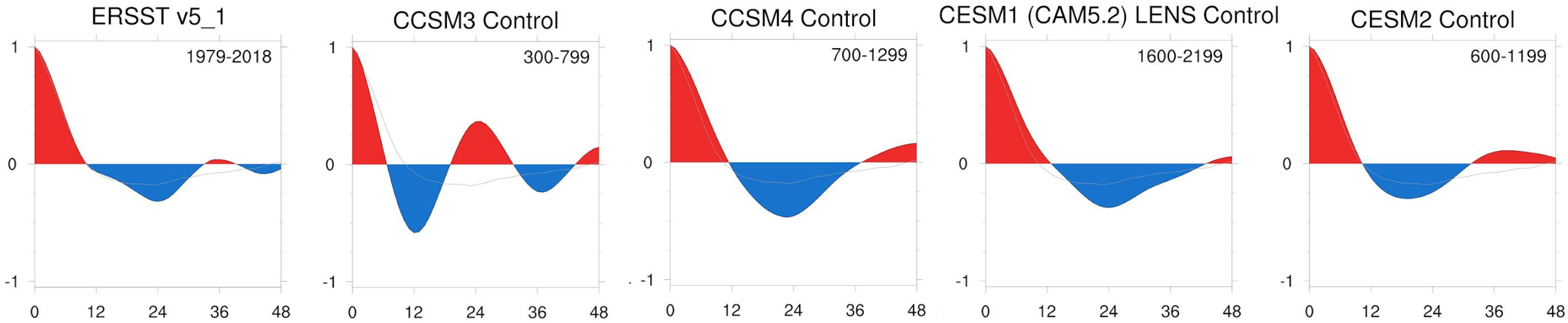
Jin et al. 1994

Longer instrumental record helps revisit ideas



An asymmetric oscillation underpining ENSO?

Model improvements help explore questions



Lagged autocorrelation function of Nino-3.4 SST index:
Improvements across generations of NCAR models

- Persistent La Nina – as observed,
- ENSO less oscillatory/predictable – closer to obs.

CVDP - Philips et al. (2014)

Our approach

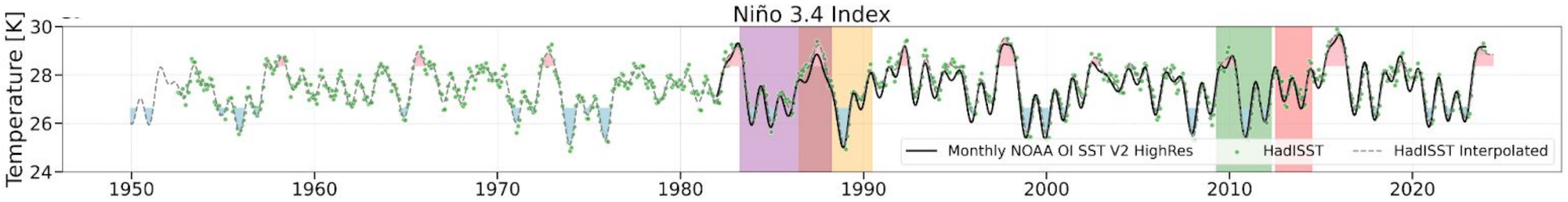
- **Analysis of orbits in observed and simulated Nino-3.4 SST index,**
  - Close return maps,
  - Time-delay embedding*

  * We use full Nino-3.4 SST to look at the annual cycle together with ENSO – i.e. we don't remove the seasonal cycle,

  ** We use submonthly data to reconstruct smoother orbits.
- **Mathematical model of ENSO,**
- **Analysis of CMIP6 models using metric of complexity.**

ENSO observations show unstable orbits

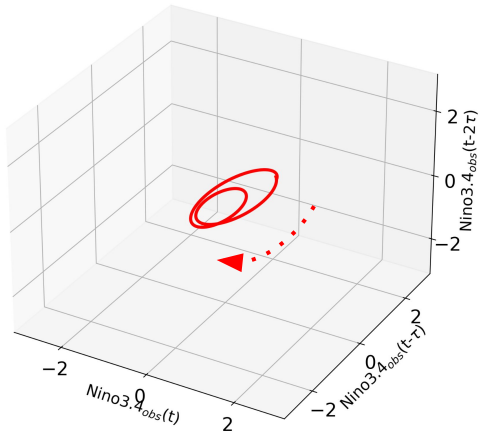
with periods that are a multiple of the anual cycle



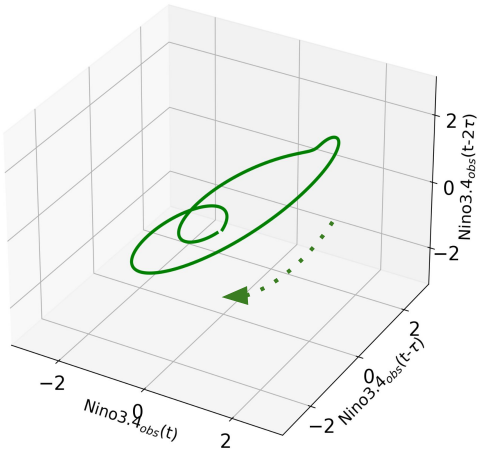
Reconstructed orbits with time-delayed embedding

consistent with observed asymmetry

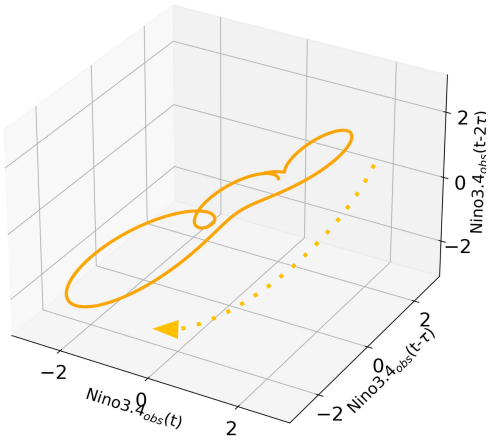
2 year orbit



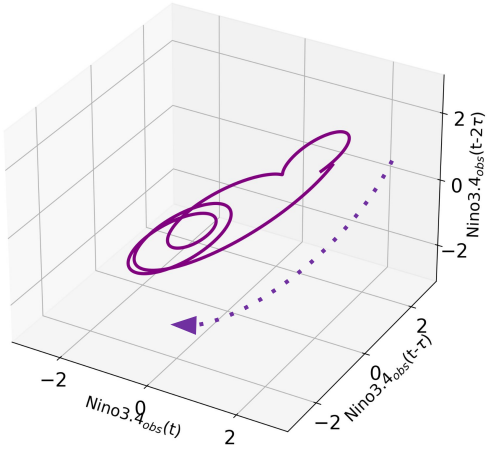
3 year orbit



4 year orbit



5 year orbit



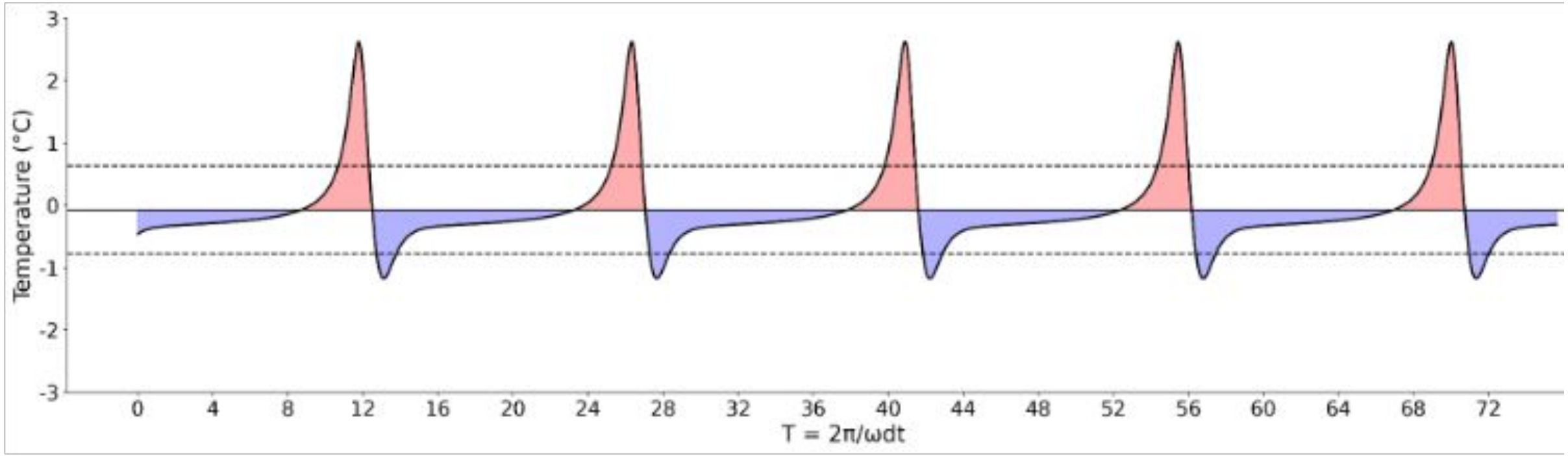
Smaller “loops” are the annual cycle

Conceptual model:

- Asymmetric oscillation,

$$x' = y$$

$$y' = x - y - x^3 + xy + \epsilon_1 + \epsilon_2 x^2$$

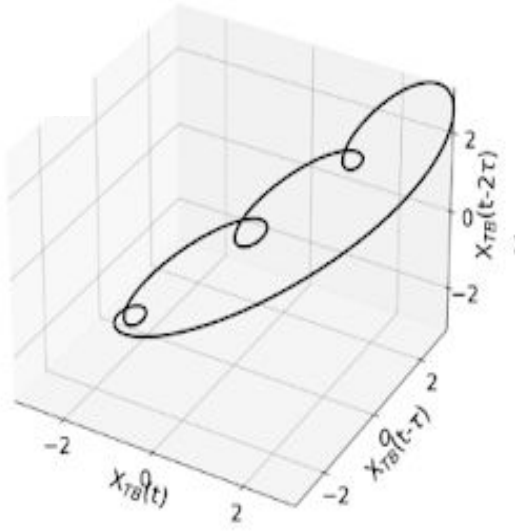


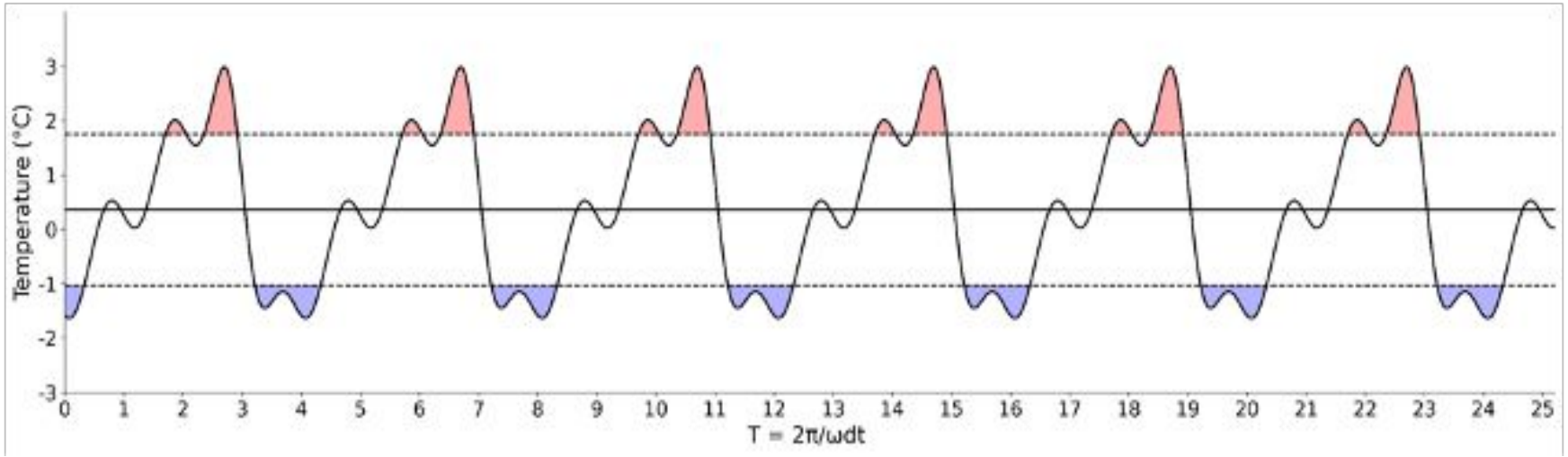
Conceptual model:

- Asymmetric oscillation,
- Periodic forcing

$$x' = y$$

$$y' = x - y - x^3 + xy + \epsilon_1 + \epsilon_2 x^2 + A\cos(\omega t)$$





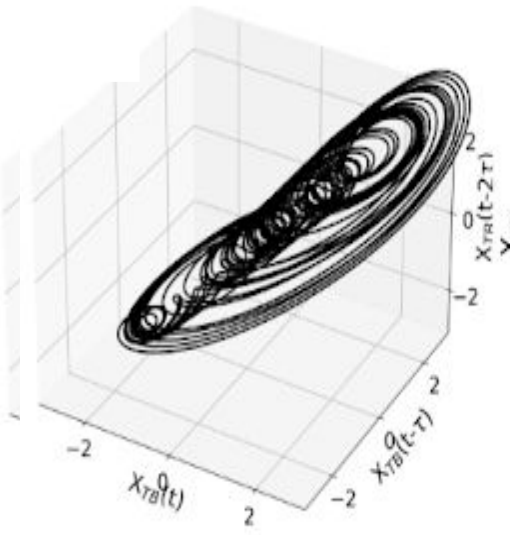
weak periodic forcing → regular period 4 oscillation

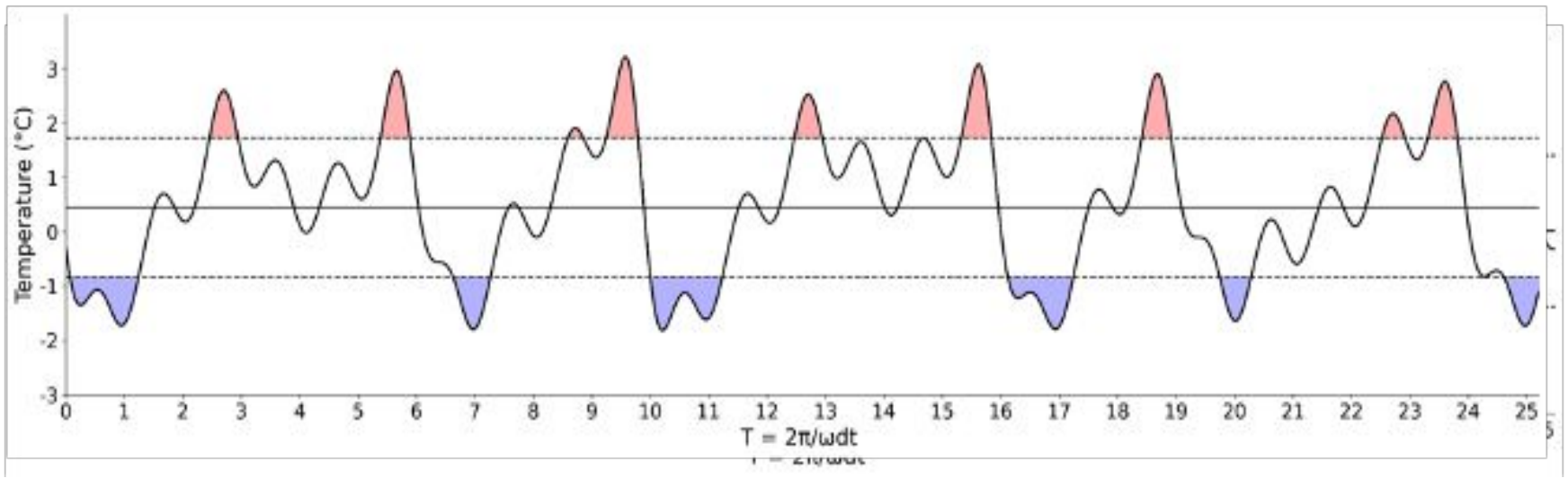
Conceptual model:

- Asymmetric oscillation,
- Periodic forcing

$$x' = y$$

$$y' = x - y - x^3 + xy + \epsilon_1 + \epsilon_2 x^2 + A\cos(\omega t)$$



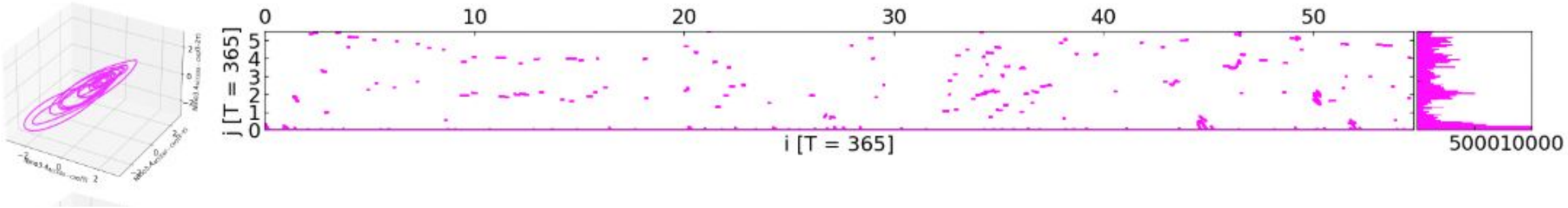


strong periodic forcing → chaotic orbits

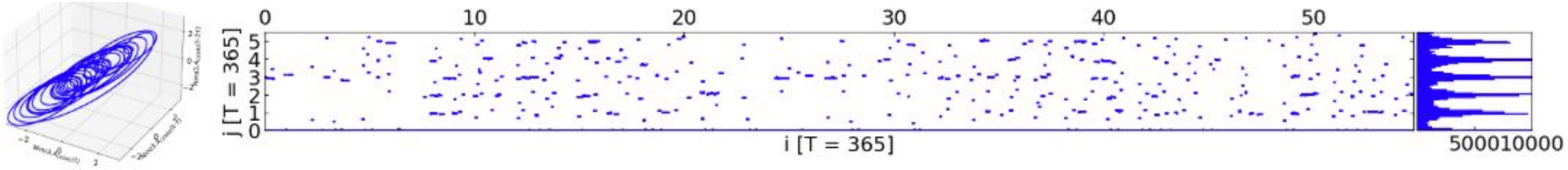
Two types of CMIP6 models

Only one type simulates chaotic orbits as observed

ACCESS-CM2



CESM2

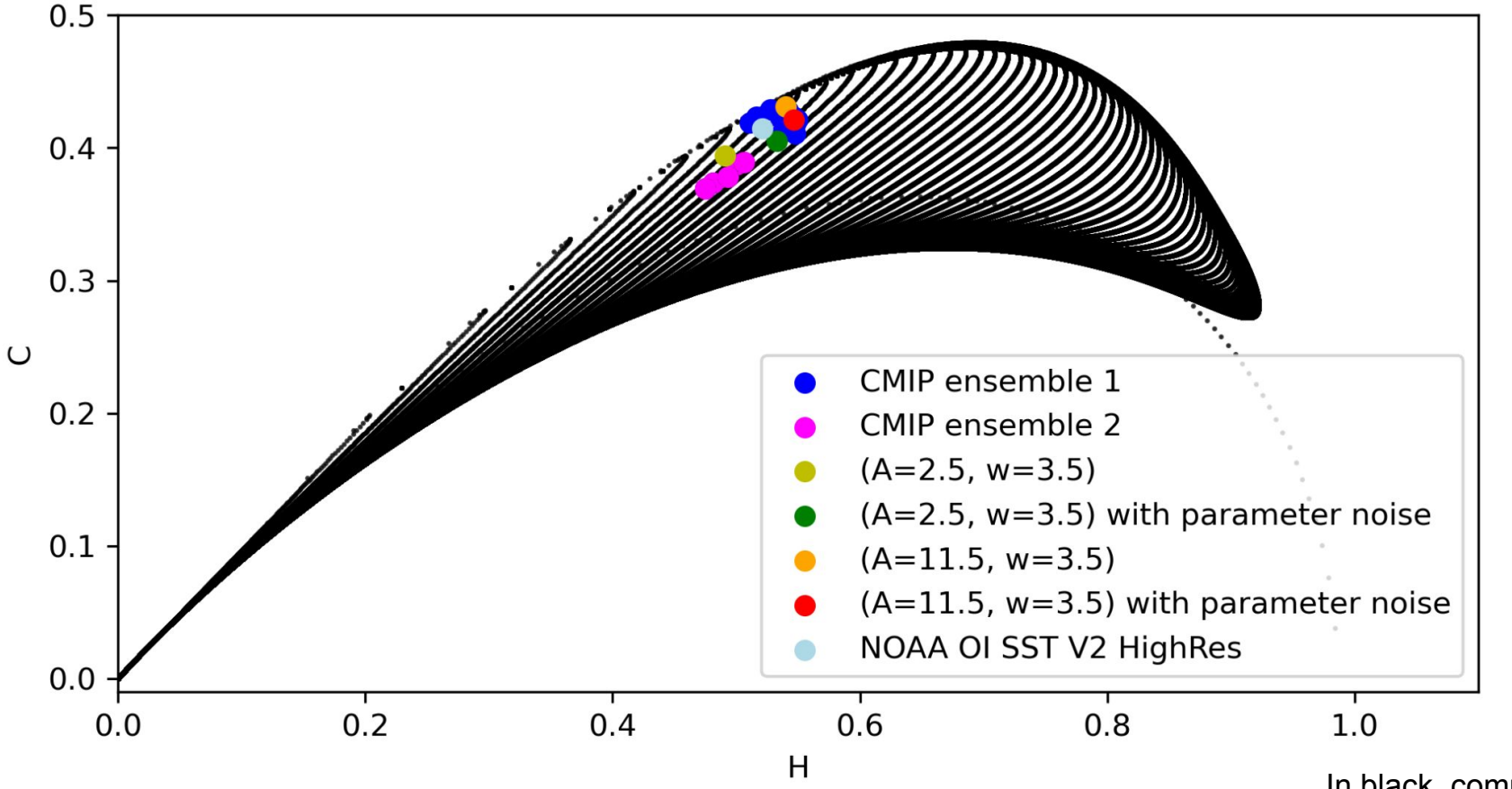


Orbits with periods multiple of the anual cycle

Subset of CMIP6 models with chaotic ENSO

According to complexity metric

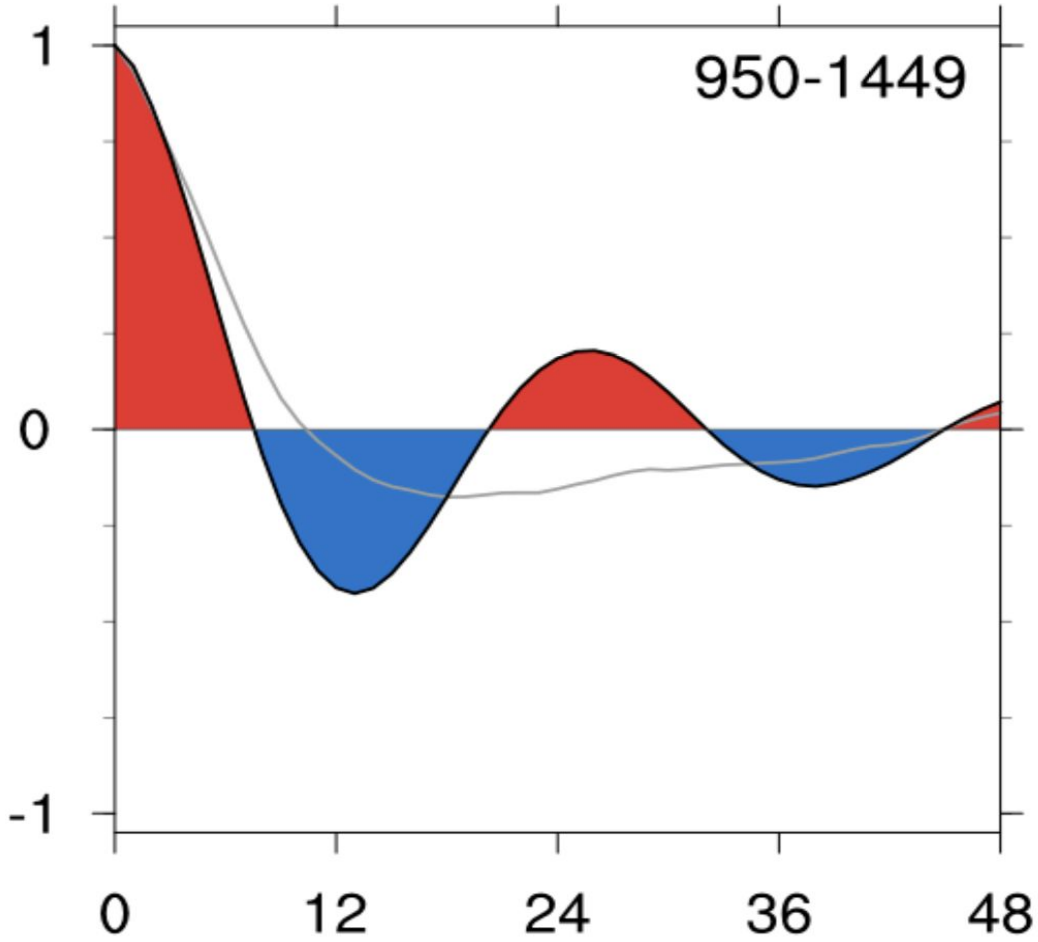
Complexity



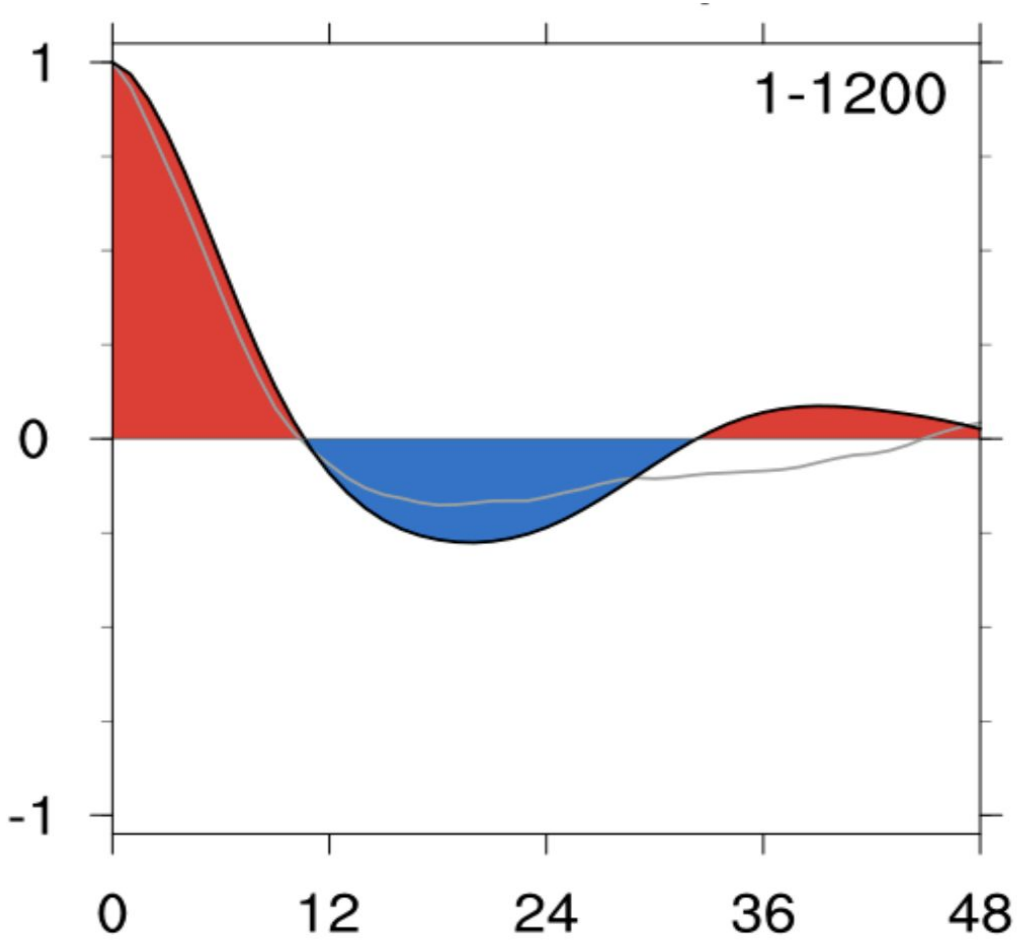
Information

In black, complexity (C) as a function of the information (H) for a system with five accessible states (N = 5).

ACCESS-CM2



CESM2



CVDP - Philips et al. (2014)

Conclusions

Open questions in ENSO research

- **Is ENSO an oscillation?**

  Yes, evolution of events becomes decorrelated due to chaos.

Most of the "action" occurs here

REVIEW 2018

El Niño–Southern Oscillation complexity

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