Climate Models and the Irrelevance of Chaos

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Intro

Prediction

Prediction, roughly:

- Start with **initial conditions**.
- Apply **dynamics**.
- Get (expected) **outcomes.**

Prediction

Prediction, roughly:

- Start with **initial conditions**. $\Leftarrow$ small difference
- Apply **dynamics**.
- Get (expected) **outcomes.** $\Leftarrow$ large difference

If the system is **chaotic**, then an arbitrarily small difference in initial conditions leads to arbitrarily large difference in outcomes.

Prediction

Prediction, roughly:

- Start with **initial conditions**.
- Apply **dynamics**. $\Leftarrow$ small difference
- Get (expected) **outcomes.** $\Leftarrow$ large difference

Analogous property: an arbitrarily small difference in the dynamics leads to arbitrarily large difference in outcomes.

The controversy

The "LSE group" (allegedly): there is an analogy to chaos; it spells trouble for climate modeling (see Frigg, Bradley, et al. 2014).

The "USF group": there is no analogy, and (thus) the claimed problems for climate science don't exist (e.g. Winsberg 2018).

Enter this talk

Me: any analogy to chaos is largely irrelevant for the epistemology of climate science.

Because: chaos-like sensitivity is neither necessary nor sufficient for predictive error.

Plan

1. The debate.
2. The analogy & why it doesn't matter.
3. What does matter: safety.
4. Some takeaways.

The debate

Error

"Trying to predict the true climate with structurally wrong models is like trying to predict the trajectory of Mercury with Newtonian models. These models will invariably make misleading (and likely maladaptive) projections beyond some lead time." (Frigg, L. A. Smith, and Stainforth 2015, 3997)

"Only strong [read: *dis*analogous] versions [of chaos] are usually taken to have strong epistemological consequences, since they are likely to produce error." (Nabergall, Navas, and Winsberg 2019, 7)

The (alleged) argument

(1) Climate models systematically misrepresent actual laws.

(2) Dynamically unstable systems are *like* chaotic systems in that small differences in laws lead to large differences in outcomes.

(3) The climate is a dynamically unstable system.

(4) If there's a large difference between the outcomes generated by the model and the truth, then the prediction is erroneous.

(C) Predictions made using climate models are liable to be erroneous.

Error

Chaos (what is it?)

Roughly: start with small differences, get big differences.

Less roughly (SDIC): $d(x_t, y_t) > e^{\lambda t} d(x_0, y_0)$.

A gloss: "a system exhibits sensitivity to initial conditions [SDIC] if no matter the true initial state *x*, there is an **arbitrarily close** state *y* such that, if *y* had been the initial state, the future would have been **radically different**" (Mayo-Wilson 2015, 1238).

The problem (with the debate)

Chaos is neither necessary nor sufficient for erroneous predictions.

Not necessary is obvious: there are lots of reasons why a prediction could be erroneous.

E.g., $d(x_0, y_0) = d(x_t, y_t)$, but both are really large.

Insufficiency

The solar system is chaotic: $d(x_t, y_t) > e^{\lambda t} d(x_0, y_0)$.

The Lyapunov exponent (λ) is approx. $.2 \times 10^{-7}$.

Upshot: not really relevant for (say) landing a rover on the moon in a week.

What's gone wrong?

Chaos is only relevant to error insofar as the scales on which the system is chaotic line up with the scales on which our predictions actually operate.

What really matters: safety

A different view of prediction

A different view of prediction:

- Start with empirical evidence.
- Synthesize using various background assumptions.
- Use the resulting theory / model to generate a prediction.

Safety

Say that the support for a conclusion / prediction is "safe" when we have just as good reason to endorse the conclusion given "nearby" ways of systematizing the evidence.

Compare Reed (2000), G. E. Smith (2002, 2014), and Staley (2004).

An unsafe example

If the sun is at the focus of the ellipse:

$$
\begin{aligned}
d &= A\frac{(1-\epsilon^2)}{1-\epsilon\cos\theta} \\
a &\propto r^{-2}
\end{aligned}
$$

If the sun is at the center of the ellipse:

$$
\begin{aligned}
d &= A\sqrt{1-\epsilon^2\sin^2\theta} \\
a &\propto r
\end{aligned}
$$

An analogy to chaos?

Start with a “small” difference (from our point of view).

End up with a “big” difference (also from our point of view).

What really matters

When we're worried about error, what really matters is how safe our predictions / conclusions are in this sense.

Takeaways

Robustness is good

If a hypothesis is robust across multiple models, that's evidence that it's safe.

(How *good* this evidence is in actual cases is another question.)

Dynamical instability is important

The dynamical features highlighted by the LSE group explain *why* certain conclusions are unsafe.

Importantly, they also indicate that we cannot expect safe conclusions at the relevant level of scale at any point in the near future.

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