Tipping Points in Weather Prediction

Extreme sensitivity of forecasts to the atmospheric state and what to do about it
“Ordinary” Forecasts

Extended Forecast for Phoenix AZ

Today  | Tonight  | Saturday | Saturday Night | Sunday  | Sunday Night | Monday  | Monday Night | Tuesday
--- | --- | --- | --- | --- | --- | --- | --- | ---
Sunny | Clear | Sunny | Clear | Sunny | Partly Cloudy | Partly Sunny | Mostly Cloudy | Mostly Sunny

Not what we are talking about
Error growth is localized and “feature” based

Judt, 2018: JAS
Extreme Sensitivity

- Indicative of strong non-linearity and extreme error growth
- Often applied to the climate system, but is more general
- Deterministic prediction is difficult (impossible?) when system is in a state of extreme sensitivity

Palmer 1999, ECMWF
Types of Thresholds

- Convective initiation (T)
- Transition to very uncertain state
- Tropical Cyclone Formation and Intensification (V);
  Warm-front passage (T)
- Uncertain transition
- Cyclone Tracks (X,Y)
- Transition to separated states (e.g. clusters)
Convection Initiation

$B_{\text{min}} \approx 0$ is “tipping point”

$$\left(\frac{\partial B}{\partial t}\right)_{p_B} = \frac{\partial T_{vp}(p_B)}{\partial t} - \frac{\partial T_{ve}(p_B)}{\partial t}.$$  

Large trend means even if $B_{\text{min}} \approx 0$, system may have some predictability
Deformation and Blocking

• tropical convection – mid-latitude interaction
• hurricane motion
• Split flows and blocking

Torn et al., 2018: MWR
What can be done about extreme sensitivity?

• Relate ensemble spread to features to simplify interpretation
  • Already done informally in forecasting
  • Machine learning (e.g. Gagne et al. 2017, W&F)

• Focused observations for specific sensitivities
  • example: TC position relative to axis of contraction (in deformation)

• Predict the predictability: quantify forecast confidence $C(t)$

Hypothesis: Even with extreme sensitivity, the time of a marked change in confidence may be predicted, even if the outcome itself cannot be.
Emergency Manager (EM) wants forecast at day 7: Will there be a major hurricane (MH)?

$P(MH) \sim 0.35$

EM says that is not good enough to make a decision.

When will EM know with 80% confidence about a MH at day 7?

If you say ‘Day 6’, you are fired.
Two issues:
1. Uncertainty for a given environment
2. Uncertainty about the environment

\[ P(MH, t=0) \sim 0.35 \text{ (at 168 h)} \]

\[ P(\text{red}) = P(MH) \sim 0.7 \]
\[ P(\text{green+blue}) = P(\text{no MH}) \sim 0.3 \]

- Now, consider the full distribution of possible observations
- Then consider observations preceding this time
Mesoscale Predictability Experiment

One could ask: Given the actual observing system, and its errors, when will I know more certainly the rainfall in the box?

Drops here will have the largest influence on rainfall 12 h later in box

Trapp et al., 2015: BAMS
Summary

- Extreme sensitivity => extreme uncertainty
- Predicting “confidence” in a scenario
- Advances: Ensemble techniques, ensemble sensitivity (or adjoint sensitivity)
- Issues: Does this make any sense? More formalism
- Challenges
  - Relate ensemble variation to “features”
  - Requires clustering in ensemble outcomes
  - Challenges: coupling machine learning and data assimilation
- Requires reduced model error; focused observations may help