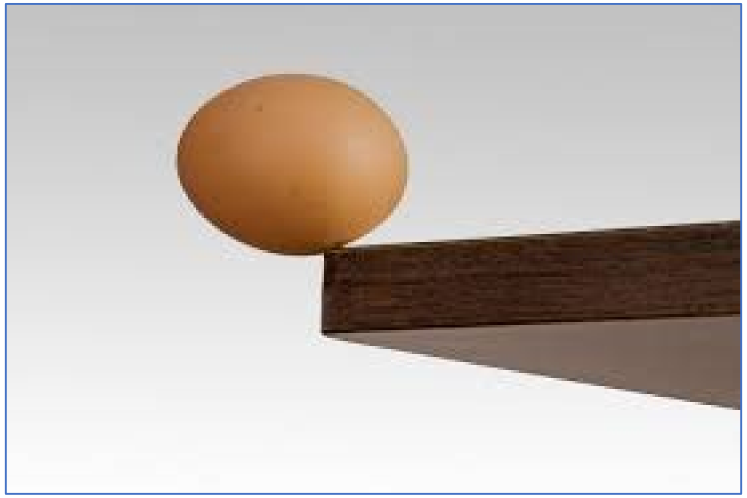
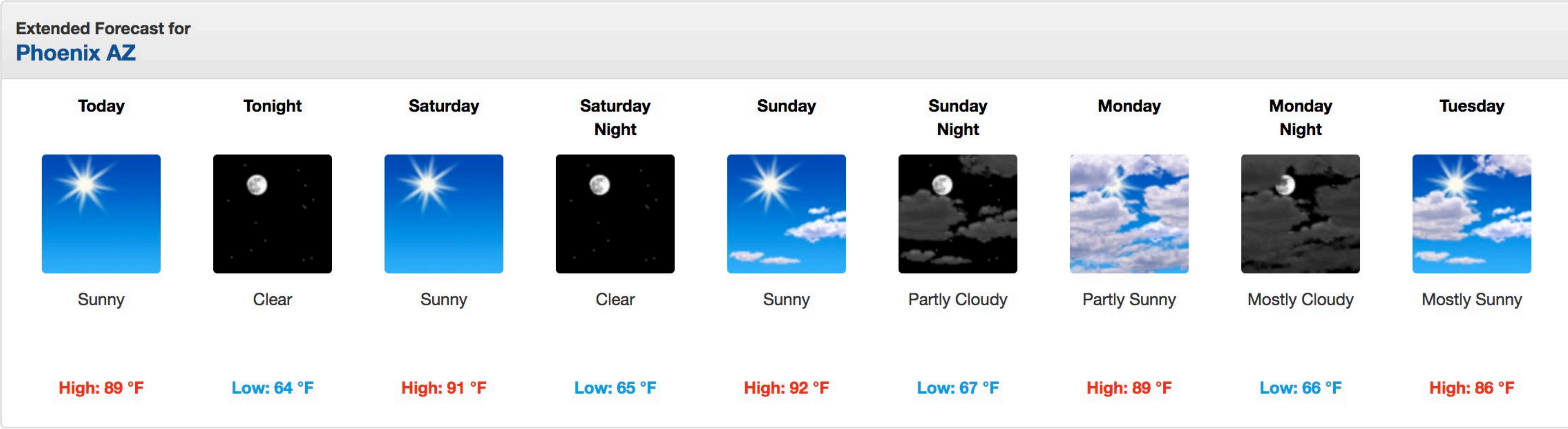
Tipping Points in Weather Prediction

Extreme sensitivity of forecasts to the atmospheric state and what to do about it



“Ordinary” Forecasts



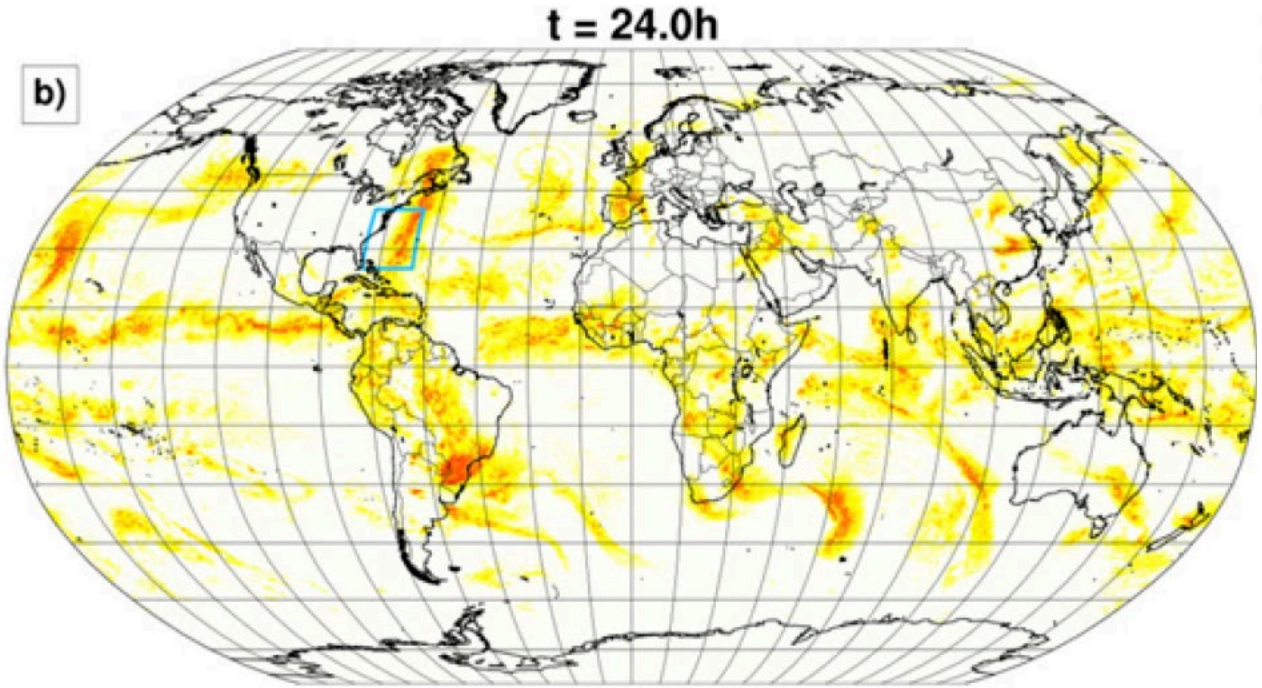
Extended Forecast for

Phoenix AZ

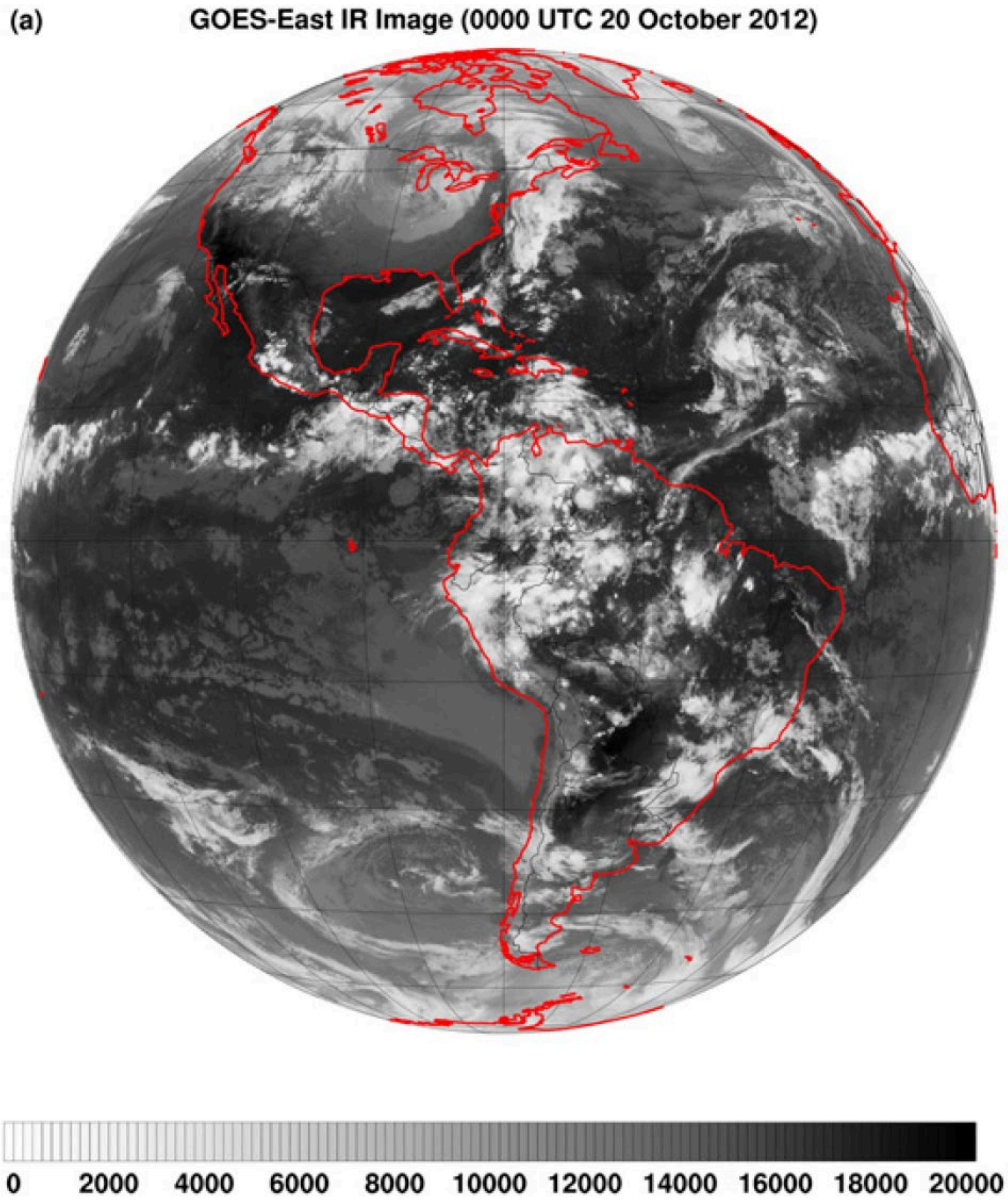
Today	Tonight	Saturday	Saturday Night	Sunday	Sunday Night	Monday	Monday Night	Tuesday
Sunny	Clear	Sunny	Clear	Sunny	Partly Cloudy	Partly Sunny	Mostly Cloudy	Mostly Sunny
High: 89 °F	Low: 64 °F	High: 91 °F	Low: 65 °F	High: 92 °F	Low: 67 °F	High: 89 °F	Low: 66 °F	High: 86 °F

Not what we are talking about

Error growth is localized and “feature” based



Judt, 2018: JAS

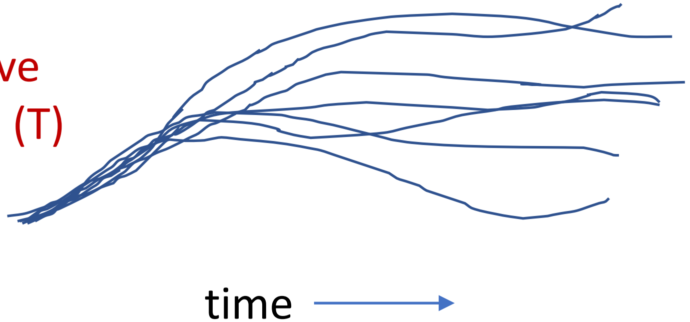


Extreme Sensitivity

- 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

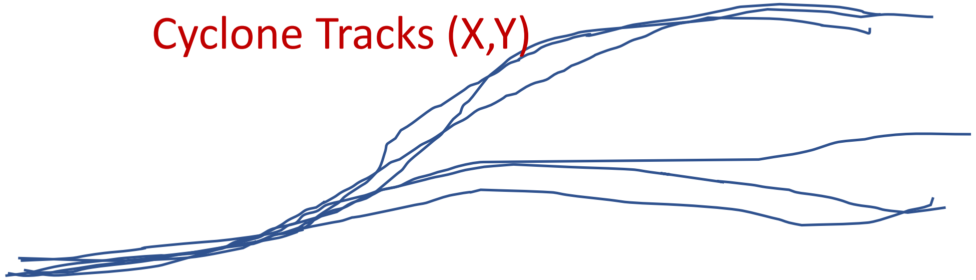
Palmer 1999, ECMWF

Types of Thresholds



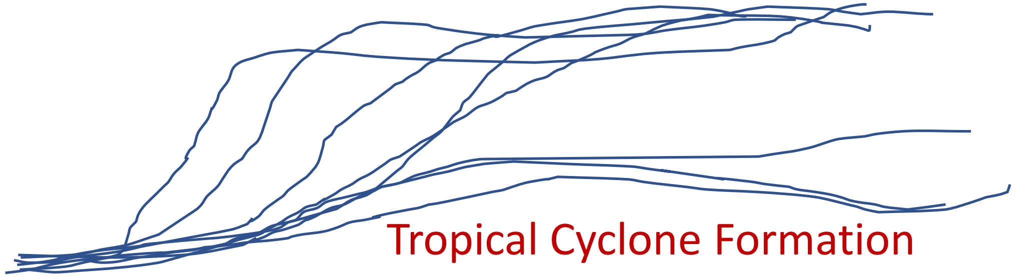
Convective initiation (T)

Transition to very uncertain state



Cyclone Tracks (X,Y)

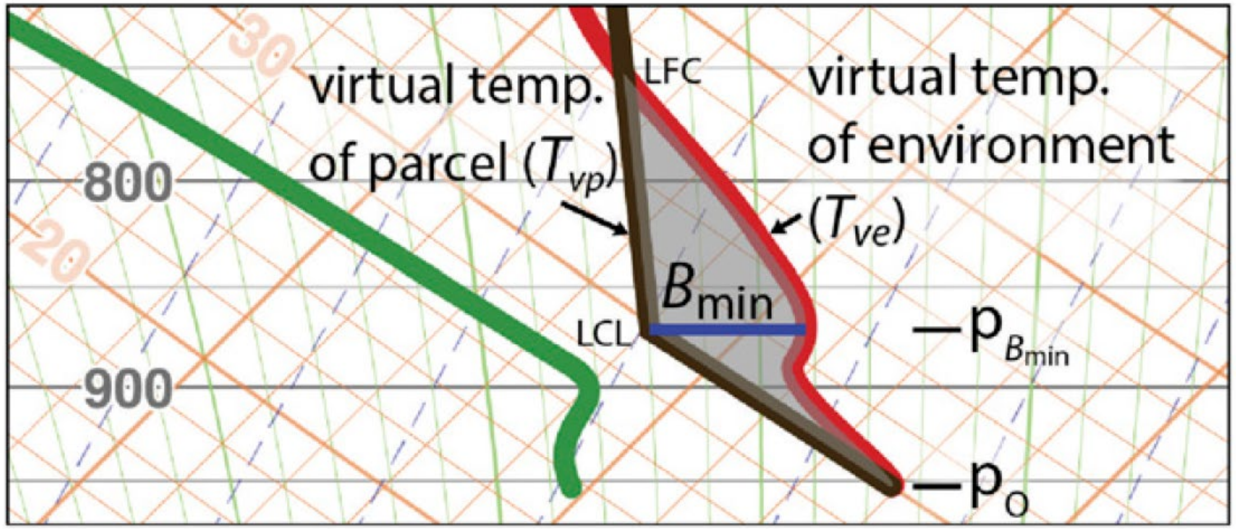
Transition to separated states (e.g. clusters)



Tropical Cyclone Formation and Intensification (V); Warm-front passage (T)

Uncertain transition

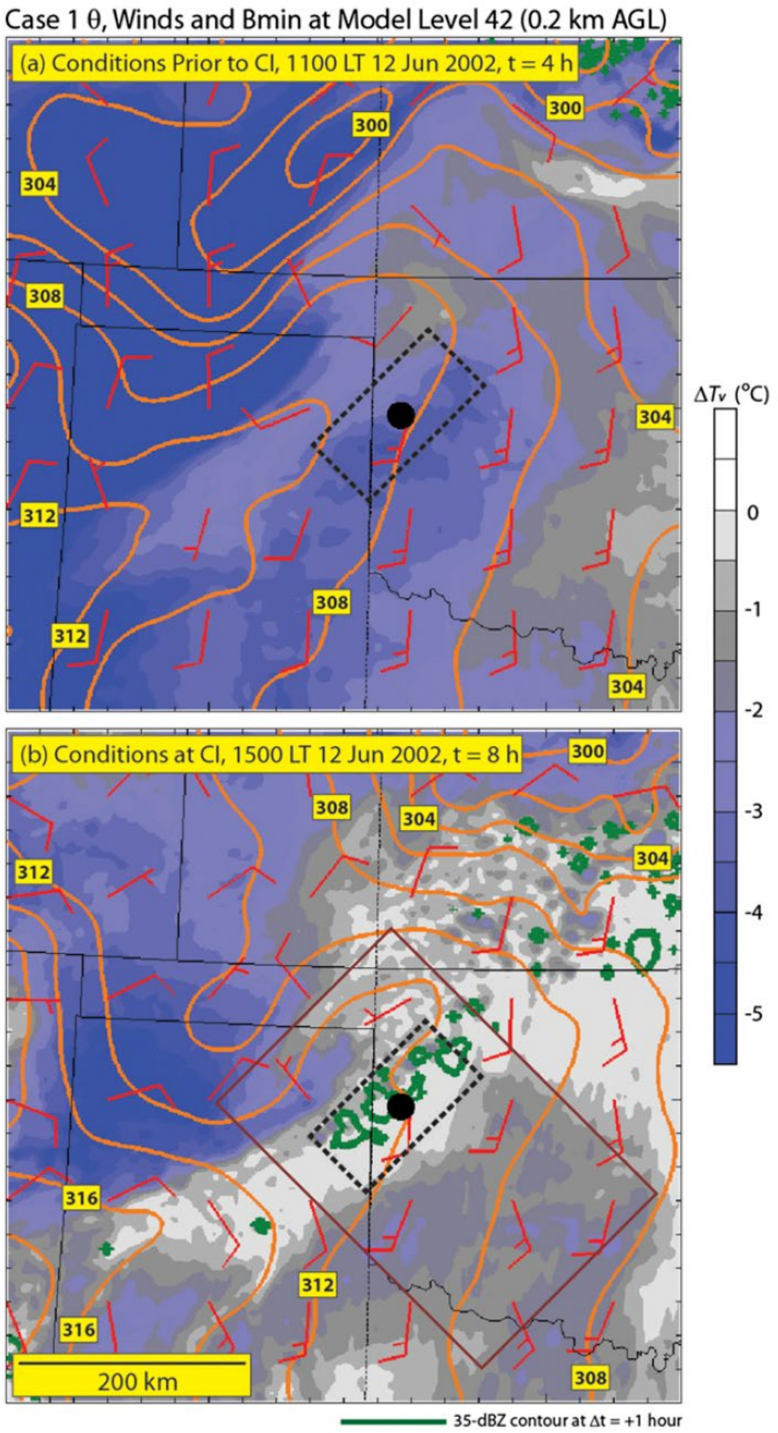
Convection Initiation



Bmin ~ 0 is "tipping point"

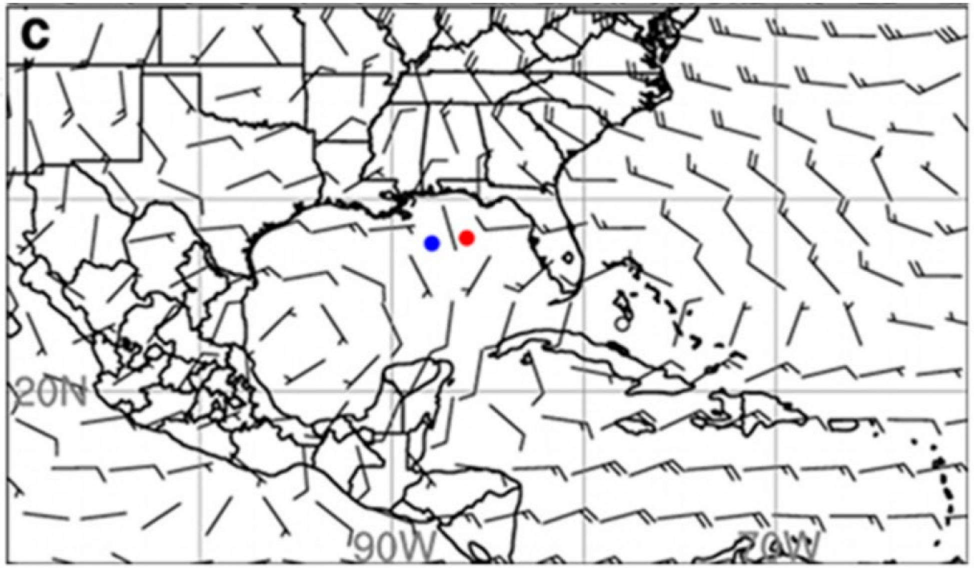
$$\left.\frac{\partial B}{\partial t}\right)_{p_B} = \frac{\partial T_{\mathrm{vp}}(p_B)}{\partial t} - \frac{\partial T_{\mathrm{ve}}(p_B)}{\partial t}.$$

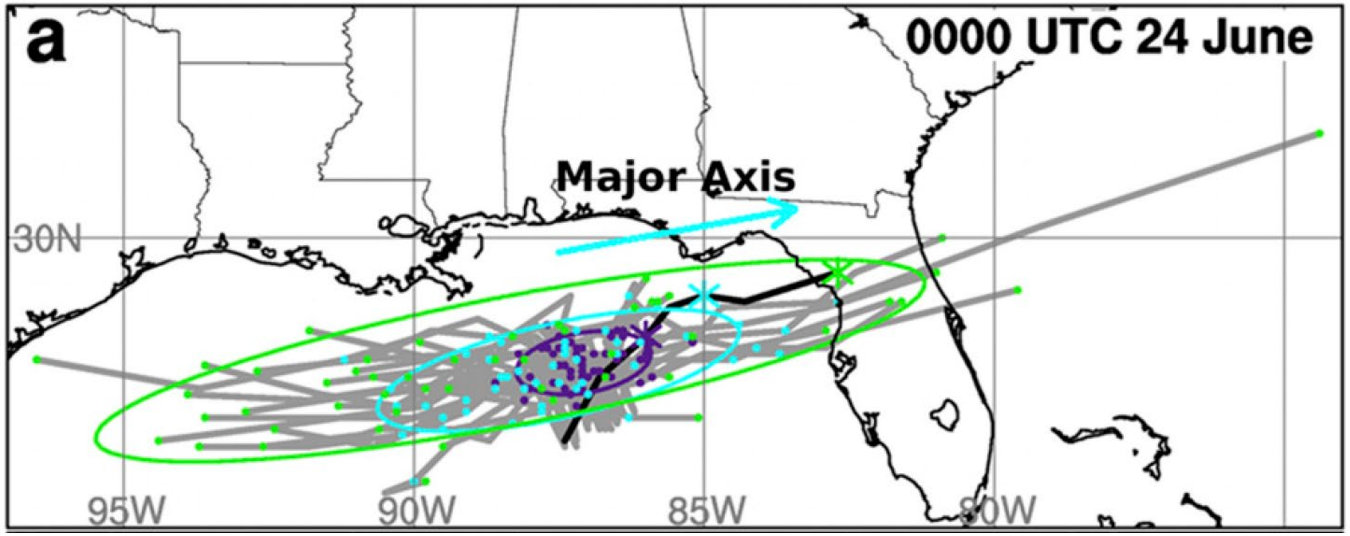
Large trend means even if Bmin ~ 0, system may have some predictability



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.

Very Uncertain Forecasts: Predicting Predictability

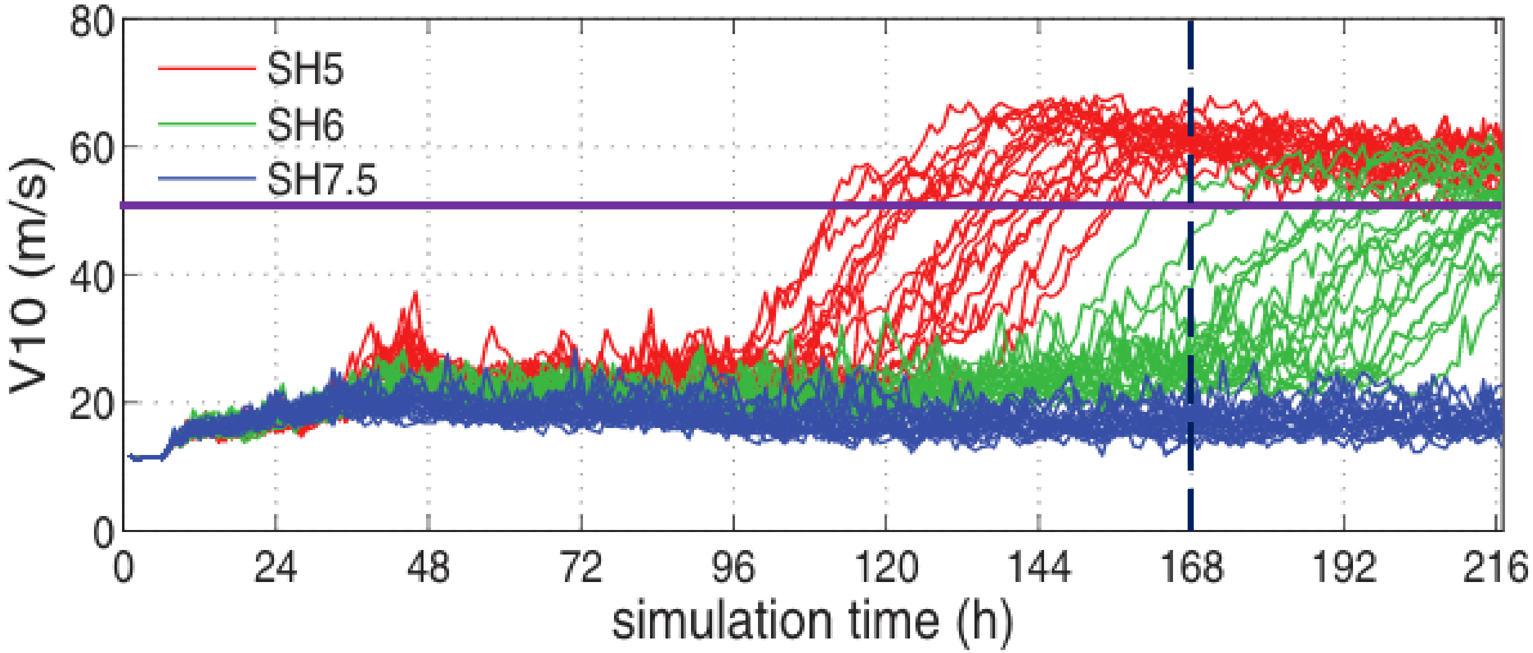
Emergency Manager (EM) wants forecast at day 7: Will there be a major hurricane (MH)?

P(MH) ~ 0.35

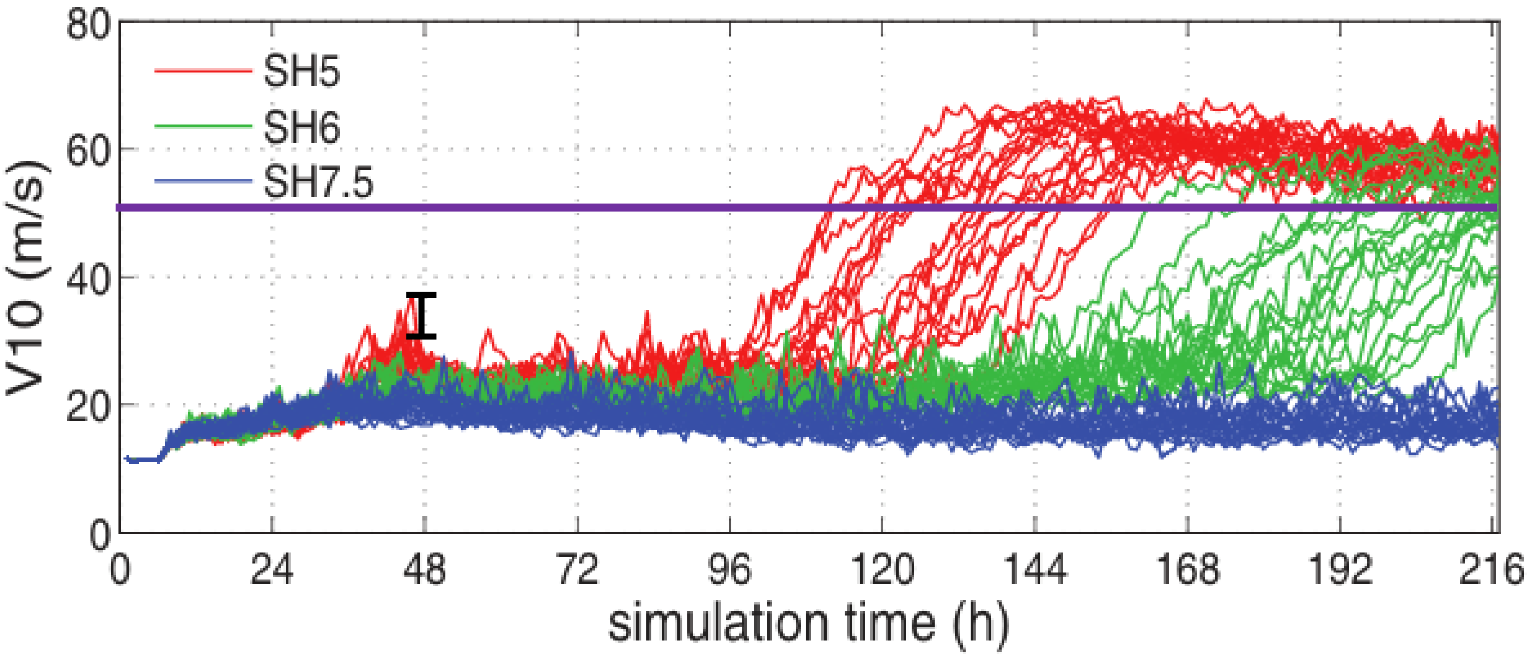
EM says that is not good enough to make a decision.

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

If you say 'Day 6', you are fired.



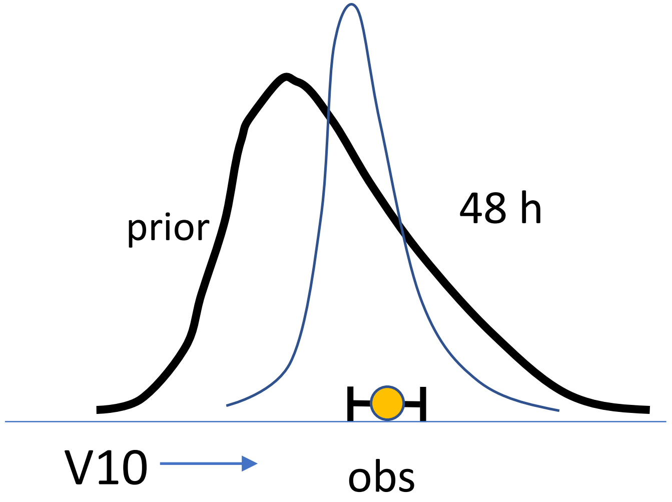
Tao and Zhang, 2015: JAMES

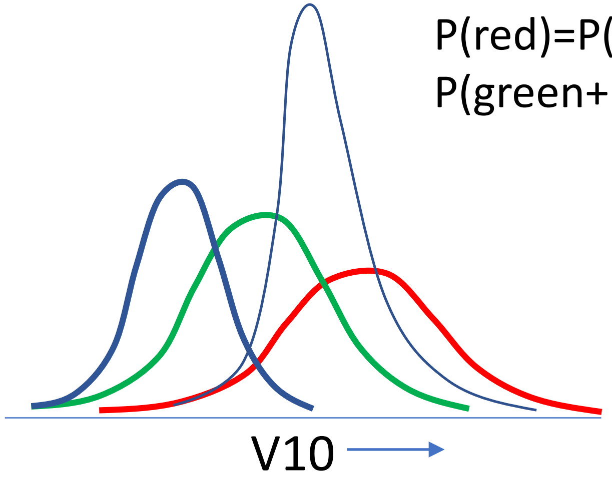


Two issues:

1. Uncertainty for a given environment
2. Uncertainty about the environment

P(MH, t=0) ~ 0.35 (at 168 h)



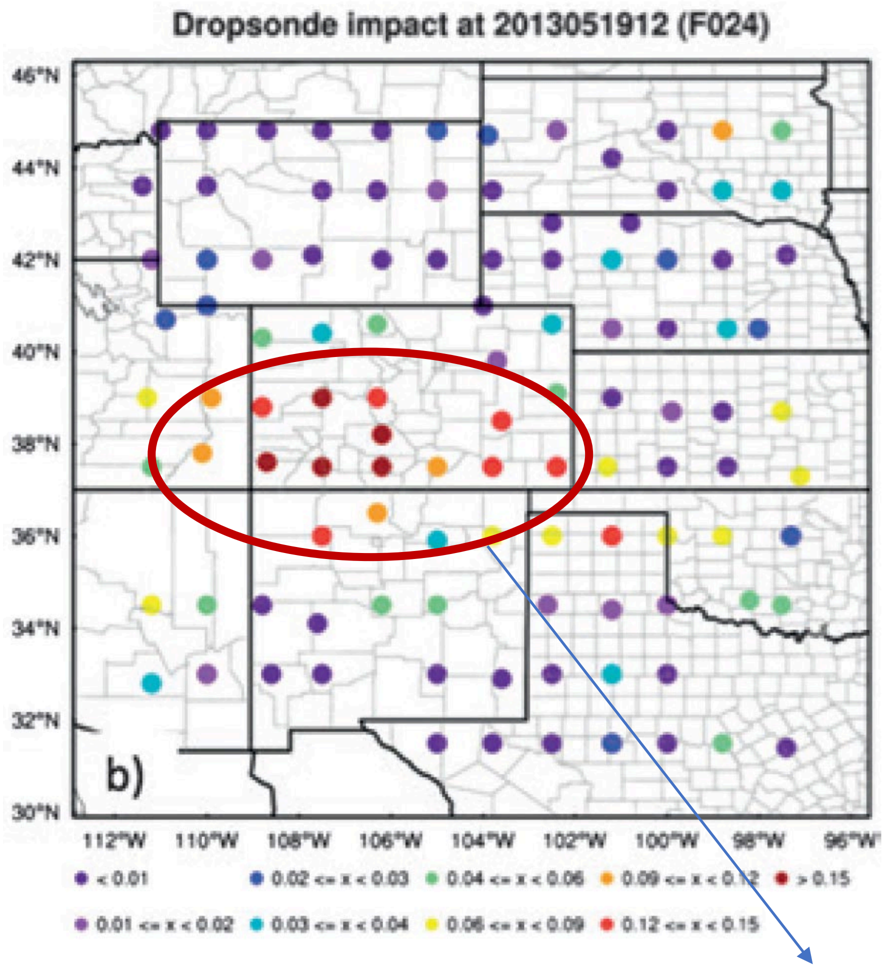


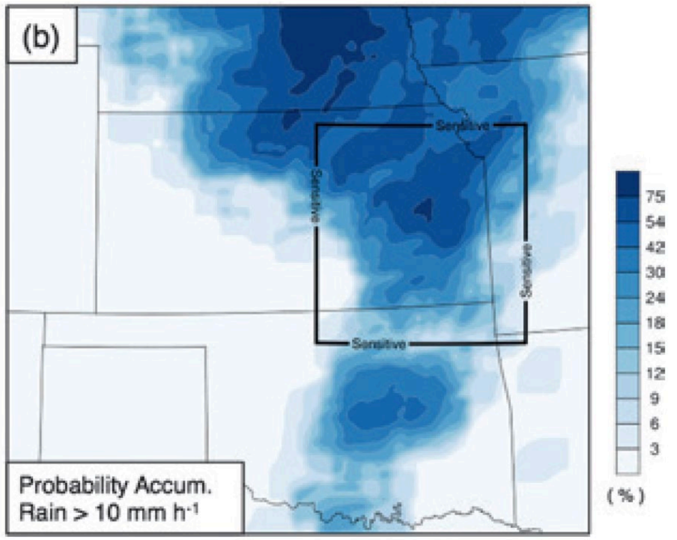
P(red)=P(MH)~0.7

P(green+blue)=P(no MH)~0.3

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

Mesoscale Predictability Experiment



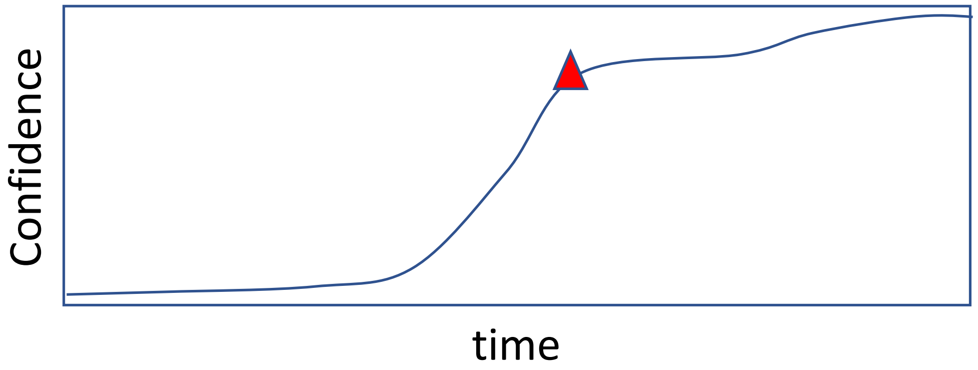


One could ask: Given the actual observing system, and its errors, when will I know more certainly the rainfall in the box?

Trapp et al., 2015: BAMS

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

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