CAFE
Climate Advanced Forecasting of sub-seasonal Extremes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 813844

Sub-seasonal predictions and verification: part 1

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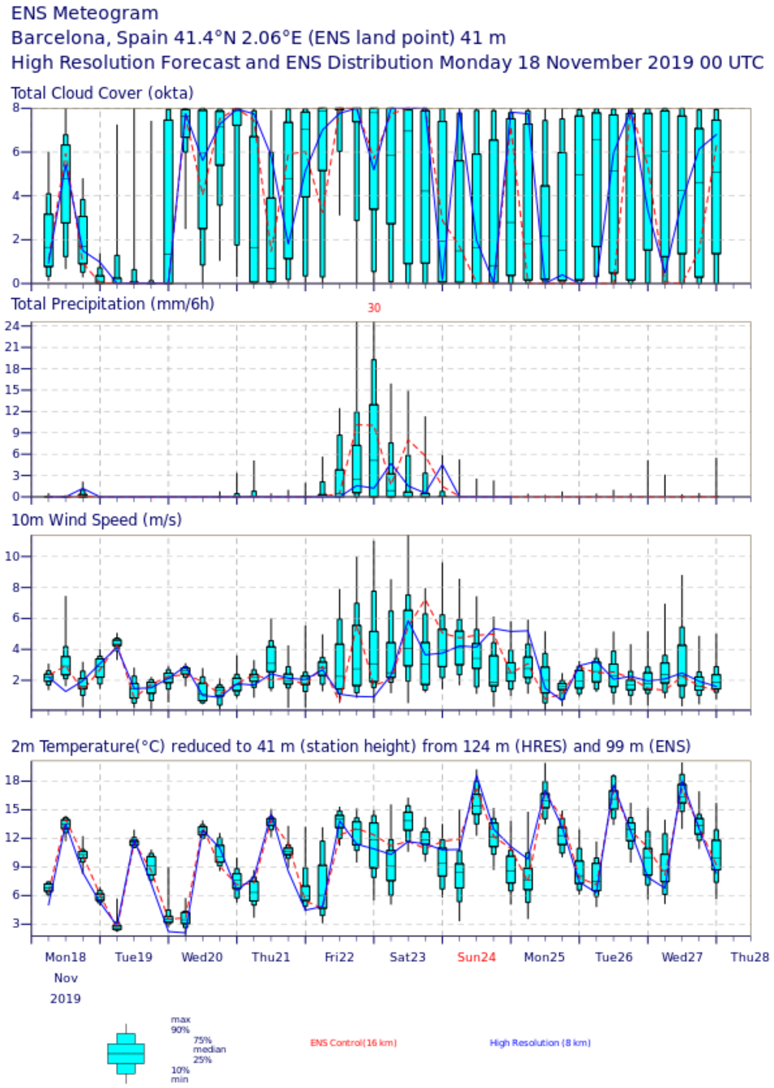
About ECMWF:

https://www.ecmwf.int/

ECMWF is a research institute and a 24/7 operational service providing:

- global numerical weather forecasts four times per day
- air quality analysis, atmospheric composition monitoring
- climate monitoring
- ocean circulation analysis
- hydrological and fire risk predictions

it has one of the largest supercomputer facilities and meteorological data archives in the world.



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Part I:

- Sub-seasonal predictions: bridging the gap between weather and climate
- Introduction to the chaotic nature of weather and climate systems
- Chaos and representation of uncertainties
- Ensemble predictions
- Predictability and skill

Part II:

- Standard verification methods
- What's a reliable probabilistic forecast
- Resolution and sharpness of a probabilistic forecast
- Current skill of sub-seasonal predictions
- Conditional skill

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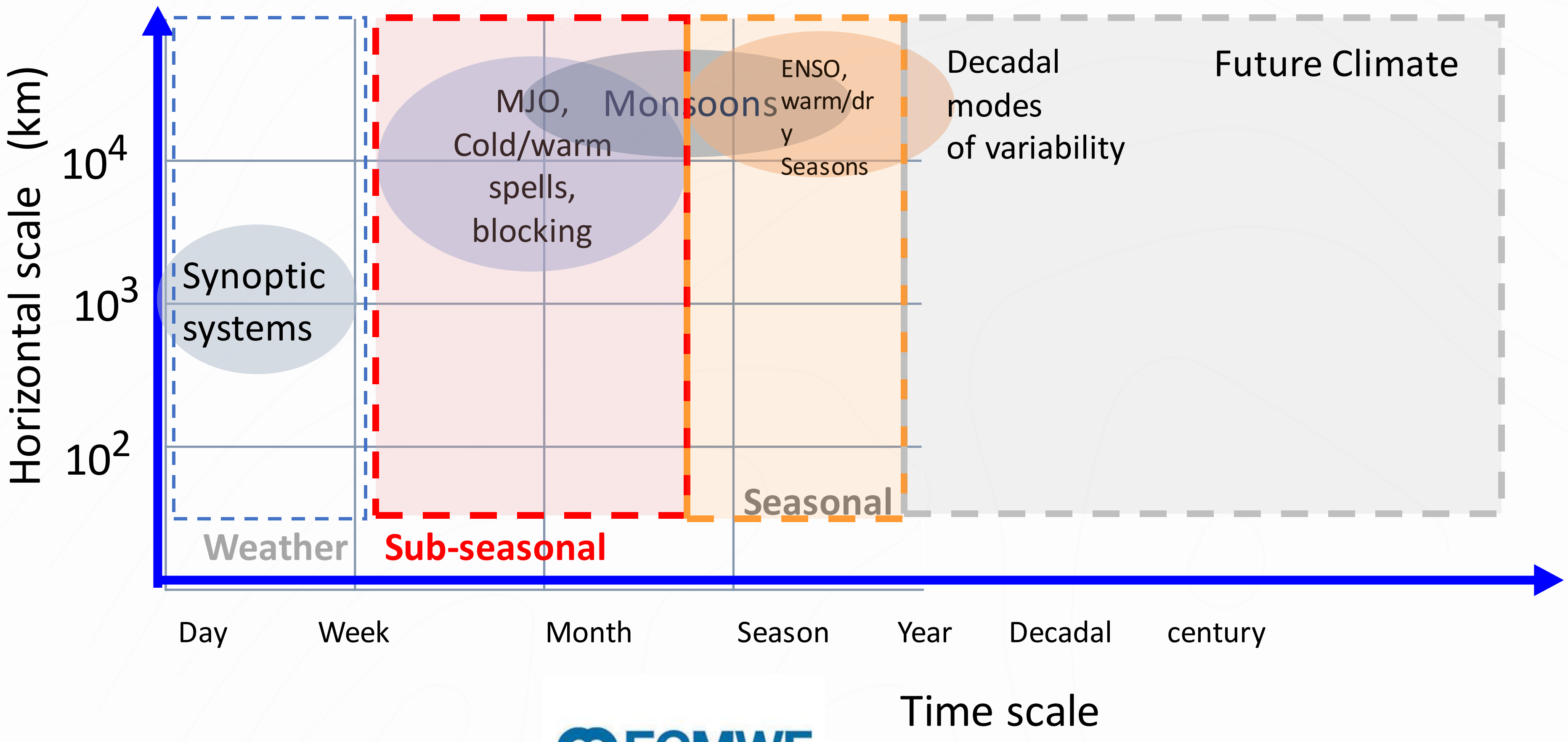
Sub-seasonal time scale: longer than 2 weeks but shorter than a season



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Sources of sub-seasonal predictability

- Madden-Julian Oscillation (MJO)
- Extra-tropical modes (RW, weather regimes: blockings, NAO, PNA, SAM..)
- Slowing varying processes: Soil moisture/vegetation, snow, sea ice,
- Ocean SSTs/heat content
- Quasi-Biennal Oscillation, ENSO, etc….
- Stratospheric Sudden Warming

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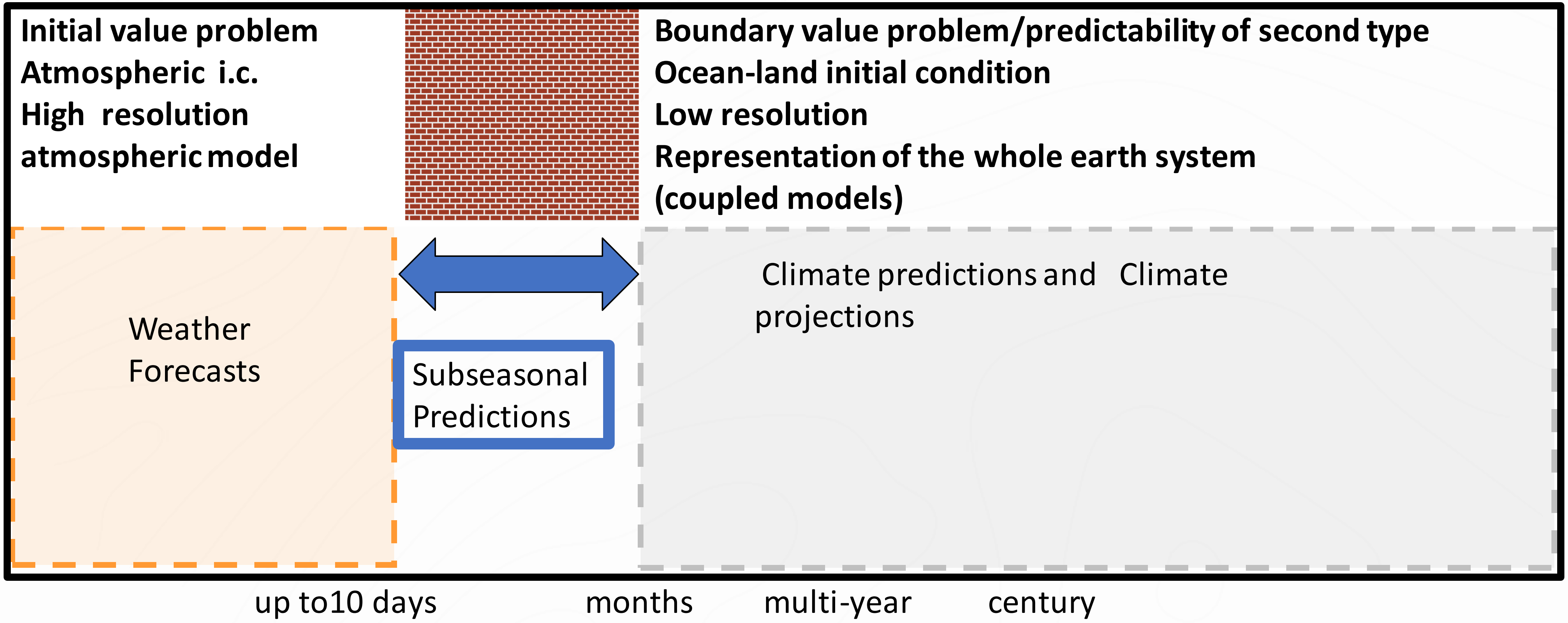
Historical separation between weather and climate research



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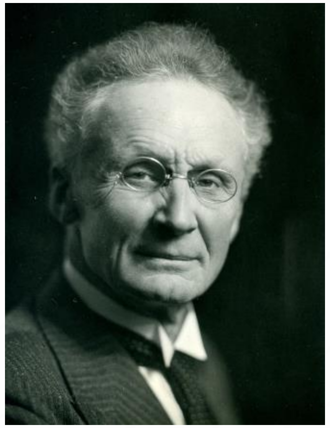


V. Bjerknes (1862-1951)

" father of modern weather forecasting"

Norwegian physicist who proposed weather forecasting as a deterministic initial value problem based on the laws of physics

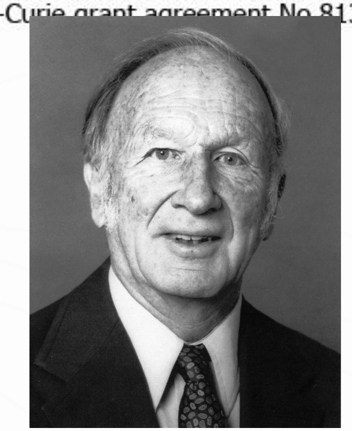
L. F. Richardson (1881-1953)

"produced the first numerical weather forecast"

He devised a method of solving the mathematical equations that describe atmospheric flow by dividing the globe into cells and specifying the dynamical variables at the centre of each cell.

H. Poincaré (1854-1912)

"small differences in the initial conditions produce very great ones in the final phenomena" *Poincare 1903*

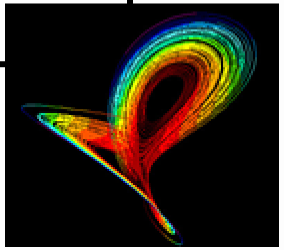


E. Lorenz (1917 –2008)

"... one flap of a sea-gull's wing may forever change the future course of the weather" (Lorenz, 1963)

He discovered a chaotic deterministic system and laid foundations for modern chaos theory

$$\dot{X} = -\sigma X + \sigma Y$$
$$\dot{Y} = -XZ + rX - Y$$
$$\dot{Z} = XY - bZ$$



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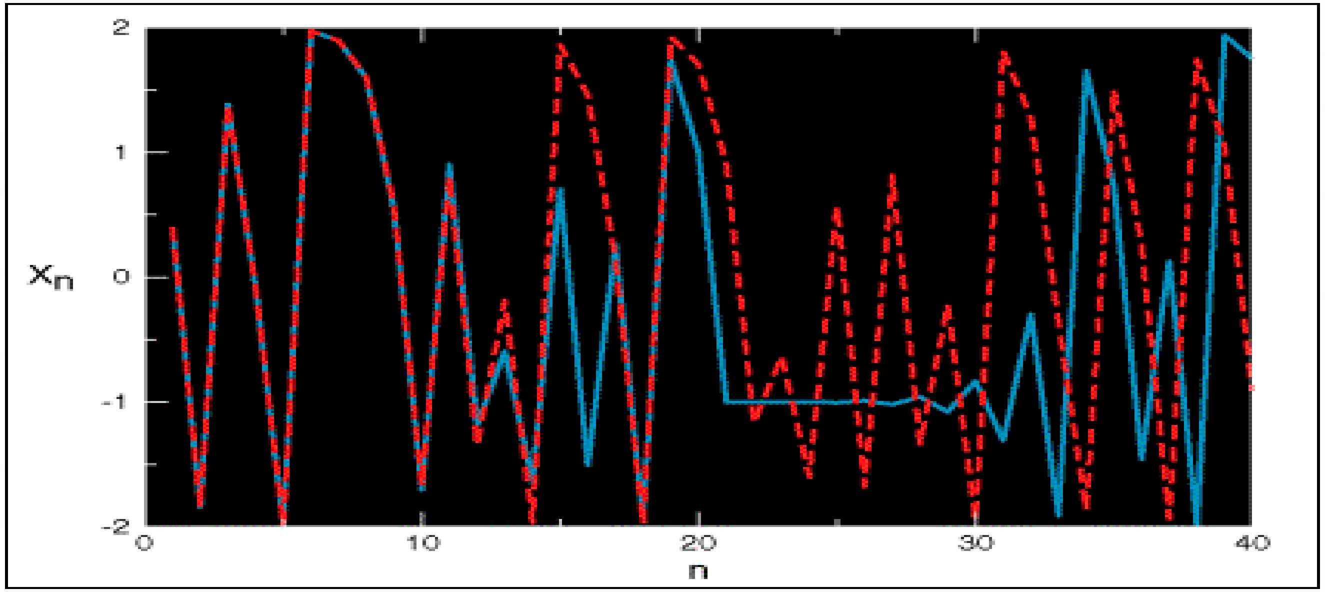
Chaos in simple systems:

Please have a go to play with this!

Chaos can be found even in very simple systems:

$$x_{n+1} = x_n^2 - 2 \qquad -2. < x < 2.$$



This system is deterministic – if you start from exactly the same initial condition you will always get exactly the same answer. But because we calculate X-squared it is also non-linear. **This is one of the necessary conditions for chaos.**

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What is deterministic chaos?

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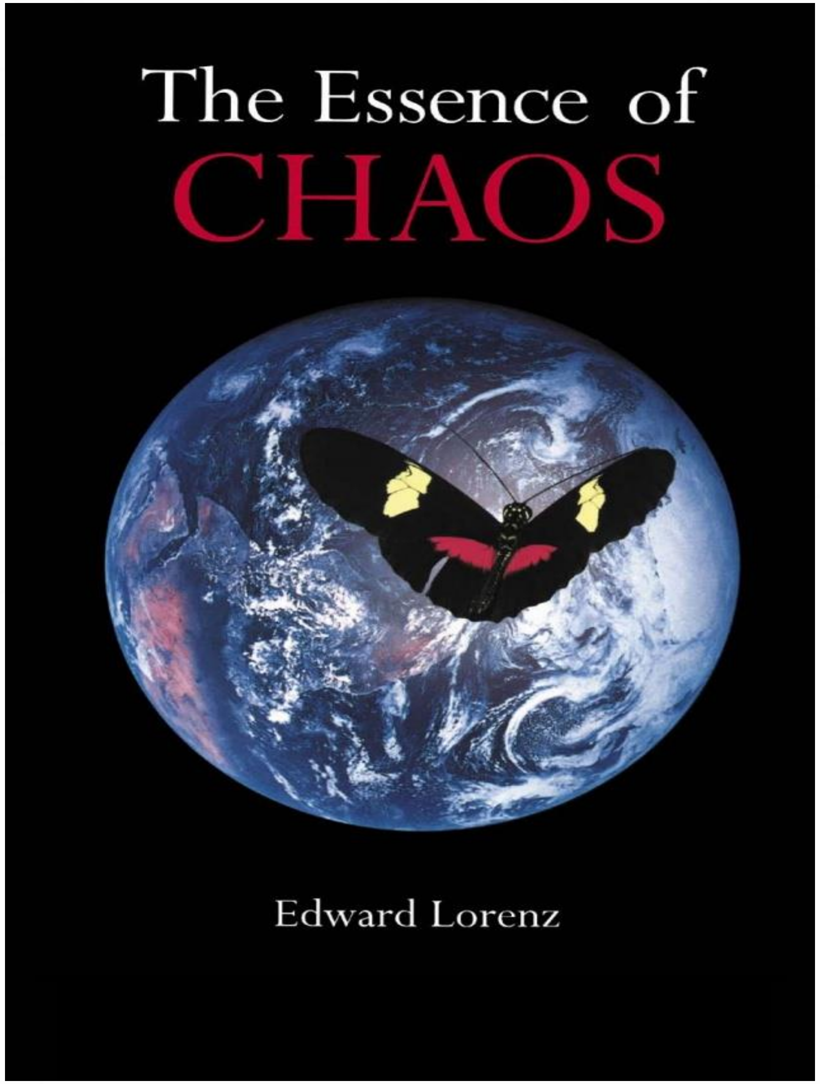
A physical system that

- follows deterministic rules (absence of randomness)
- *but appears* to behave randomly; it *looks* random
- is sensitive dependent on the initial conditions
- needs to be nonlinear
- growth of perturbations is flow dependent



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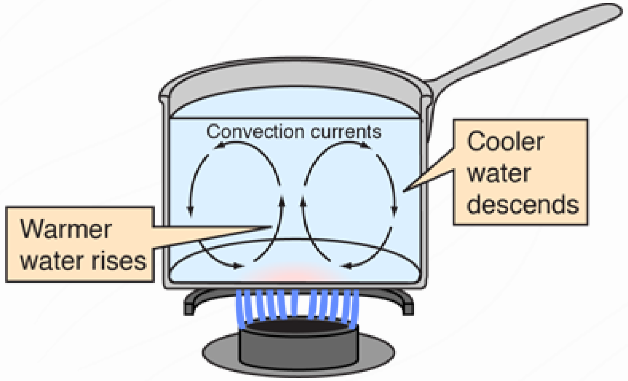
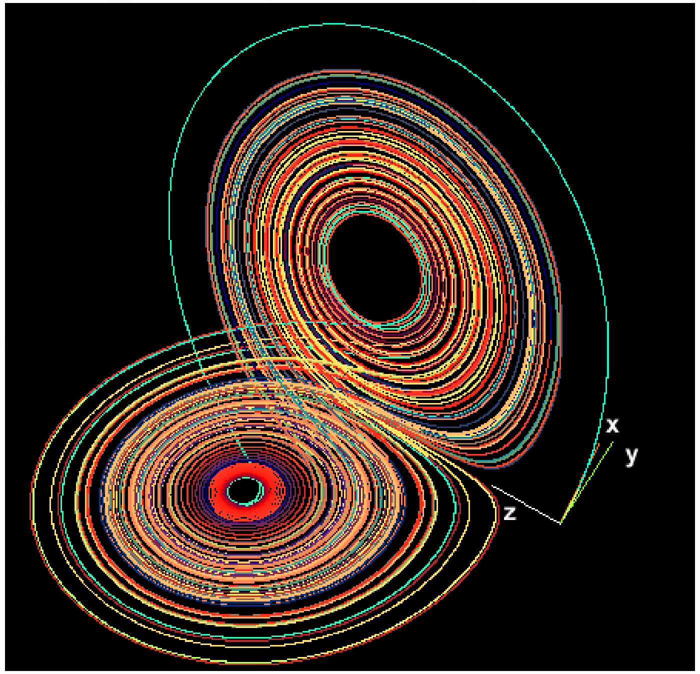
In 1963, Edward Lorenz developed a simplified mathematical model for atmospheric convection. The model is a system of three ordinary differential equations now known as the Lorenz equations.



$$\boxed{\begin{aligned}\dot{X} &= -\sigma X + \sigma Y\\ \dot{Y} &= -XZ + rX - Y\\ \dot{Z} &= XY - bZ\end{aligned}}$$



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σ = 10 b = 8 / 3 and r = 28

Lorenz (1963)

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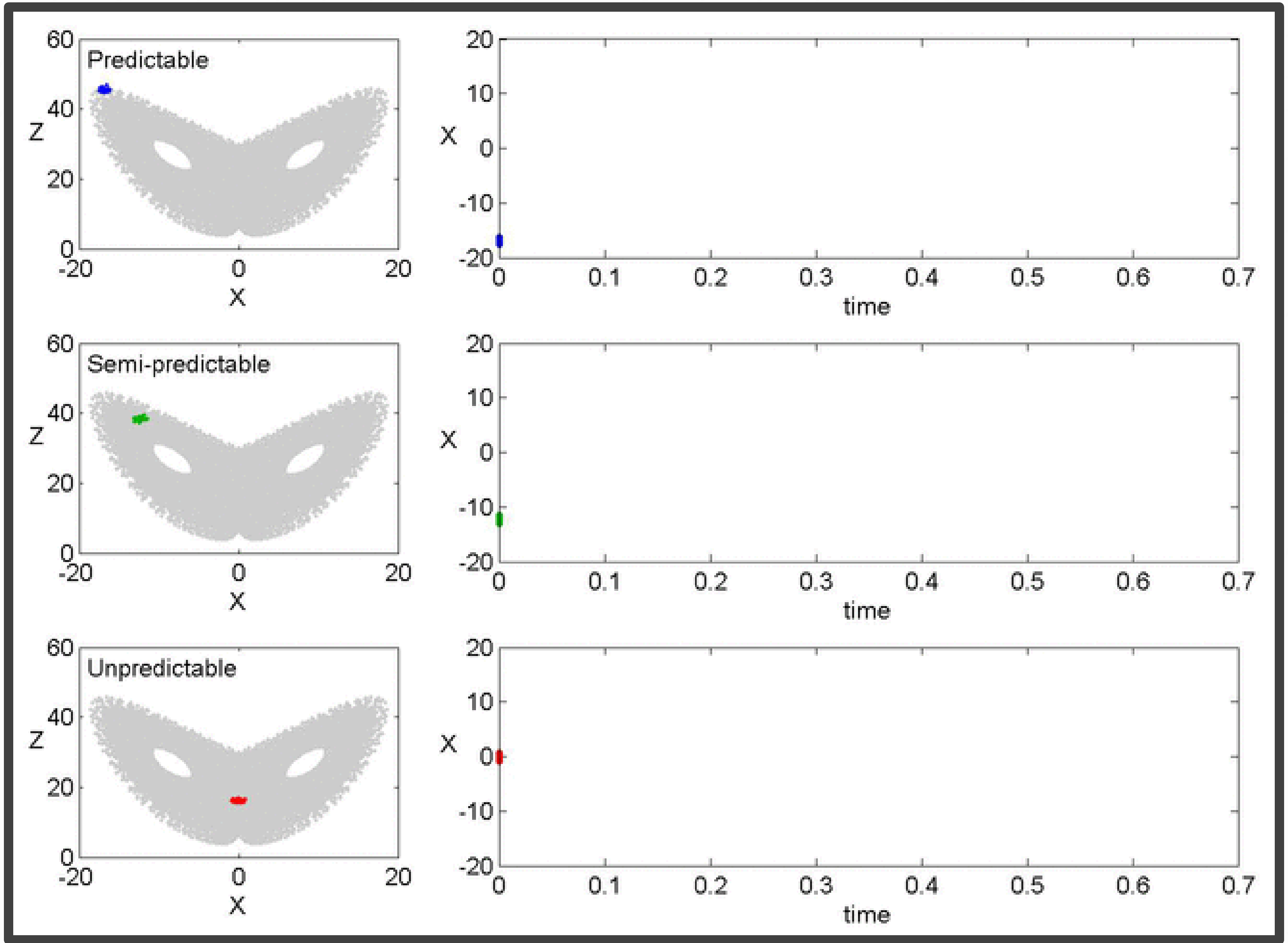

From H. Christensen University of Oxford

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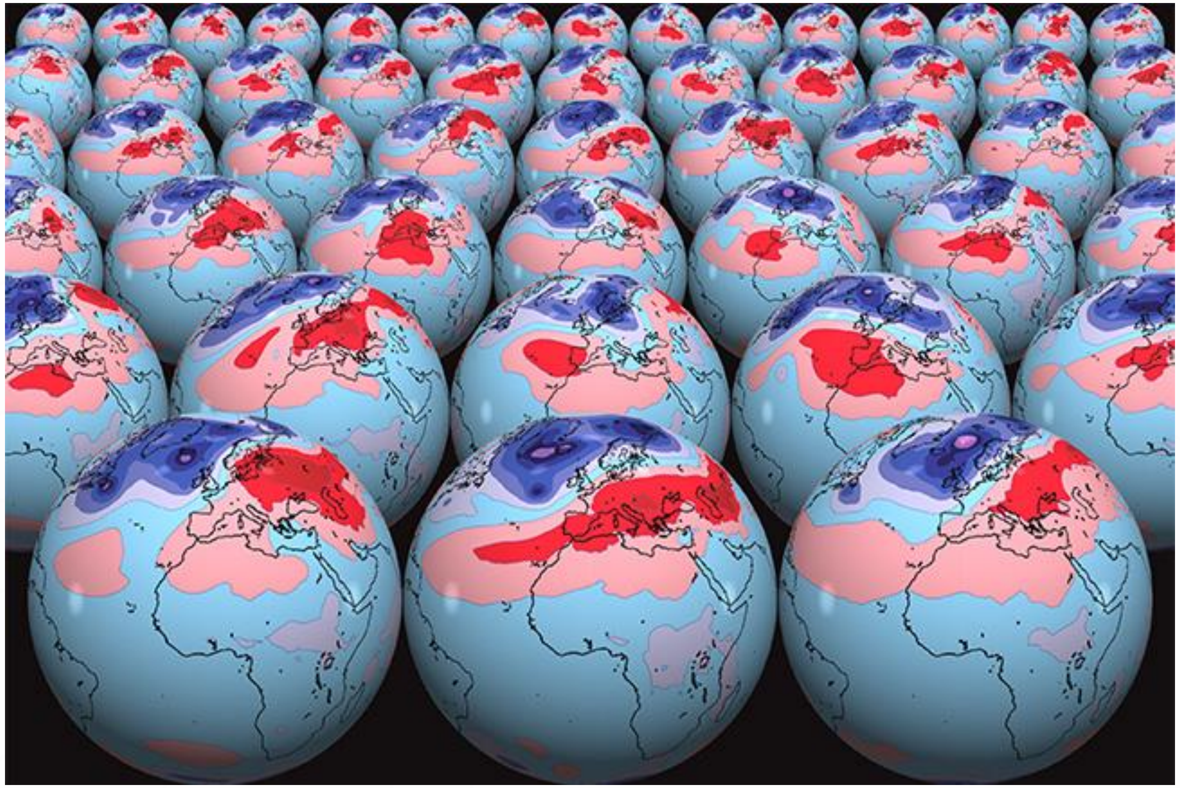
Ensemble predictions:

An ensemble prediction is a set of forecasts that present the range of future weather/climate possibilities.

Multiple simulations are run, each with a slight variation of its initial conditions and with slightly perturbed weather models.

These variations represent the inevitable uncertainty in the initial conditions and approximations in the models.

They produce a range of possible weather conditions.



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Representing forecast uncertainties:

Uncertainties in the initial conditions → Perturbations in the initial conditions of atmosphere and ocean

Necessary approximations in the construction of a numerical model → Perturbations during model integration of the real atmospheric system

Perturbations are constructed in a way that all perturbed members are equally likely.

Perturbations are flow-dependent → they are different from day-to-day.

Larger is the number of member in the ensemble and better is the representation of the uncertainties. The ensemble size is limited by computer resources.

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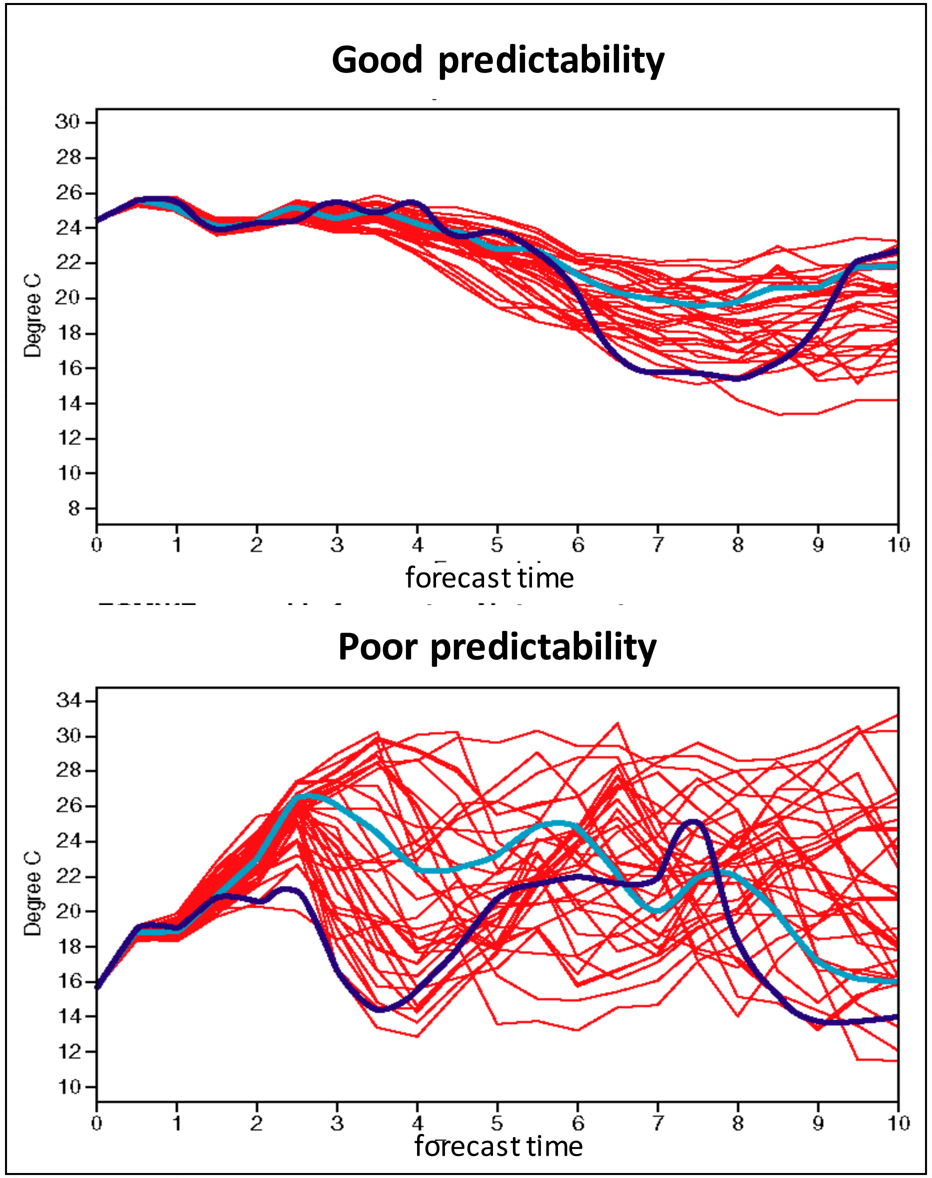
Chaos and ensemble forecasting

The climate is a chaotic system where the future state of the system can be very sensitive to small differences in the current (initial) state of the system.

In practice, the initial state of the system is always uncertain.

Our forecast models are not perfect in all aspects (e.g. small-scale features such as clouds).

Ensemble forecasting takes into account these inherent uncertainties by running a large number of similar but not identical versions of the model in parallel. The resulting forecasts are expressed in probabilities.



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Lothar: 08Z, 26 Dec. 1999

Storms Lothar +Martin

- 100 fatalities
- 400 million trees blown down
- 3.5 million electricity users affected for 20 days
- 3 million people without water

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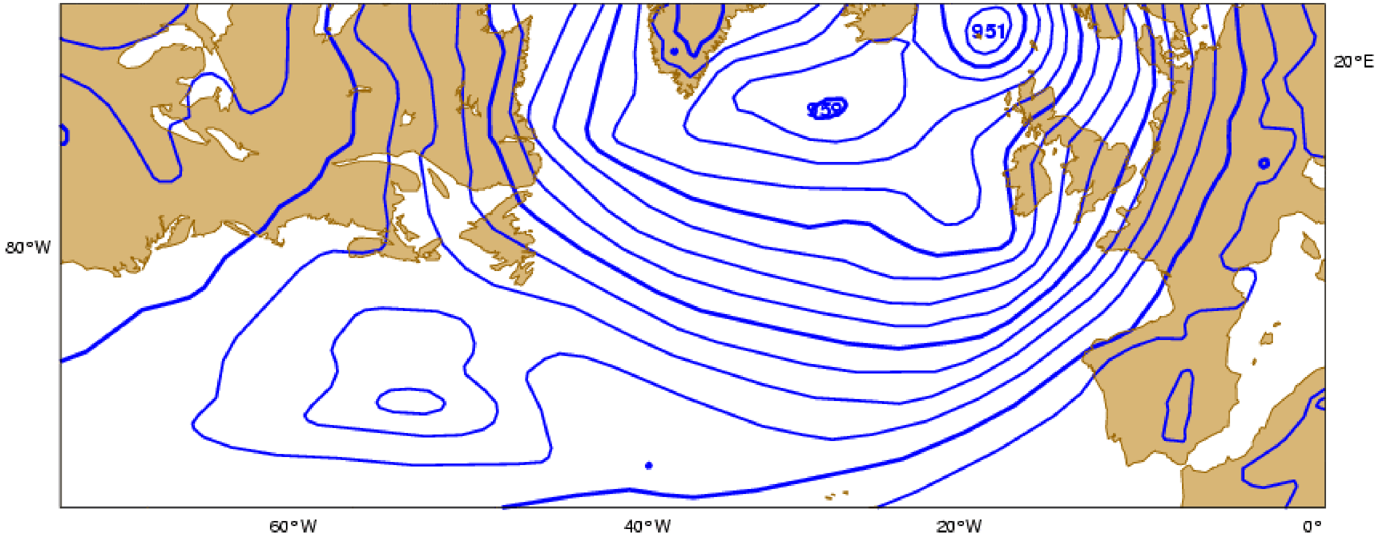
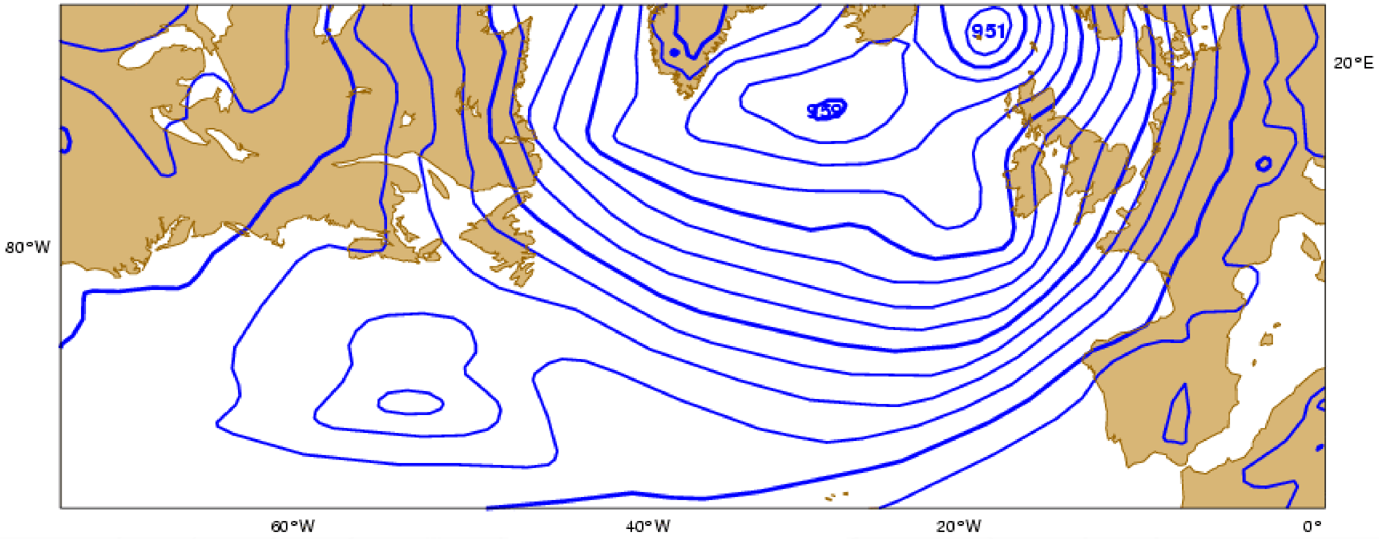
forecast 24 December 1999, 12UTC +0 h - mem no. 13 of 17



forecast 24 December 1999, 12UTC +0 h - mem no. 14 of 17



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Ensemble Initial Conditions 24 December 1999

the European Union's
programme under the
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Lothar (T+42 hours)

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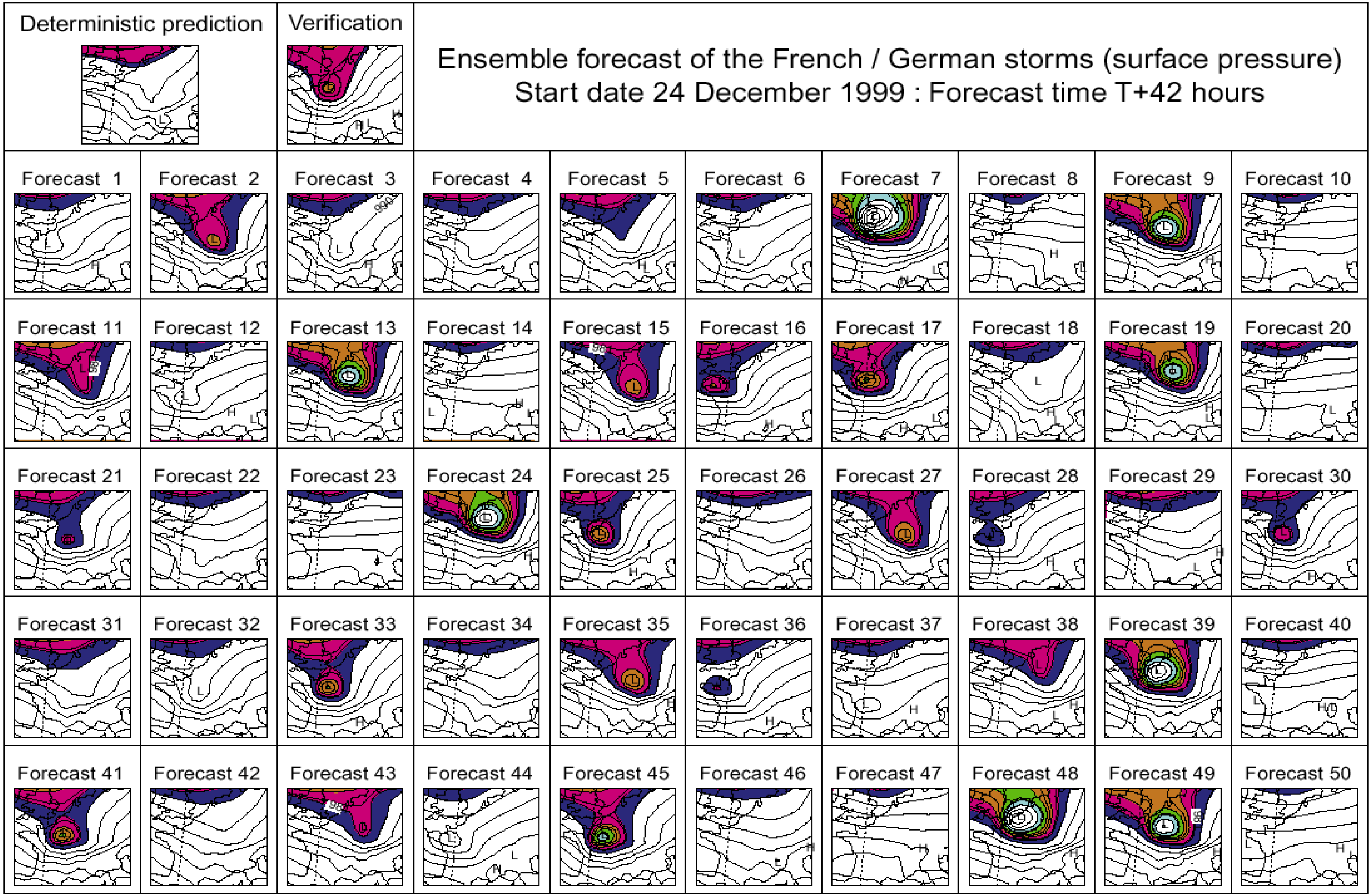

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Why ensemble forecasting?

A forecast explicitly cast in probability terms is better not only because it provides the user with an estimate of the error 'of the day', but because it is more 'truthful' in representing the chaotic nature of the atmosphere.

A probability forecast conveys a message which explicitly reminds the user that there is always a forecast uncertainty which should be considered, computed and taken into account when making any practical use of the forecast.

In fact even 'deterministic' forecasts are in reality probability forecasts in disguise, since an error bar should always be associated with it. That error bar implies a probability distribution of predicted future states around a central value.

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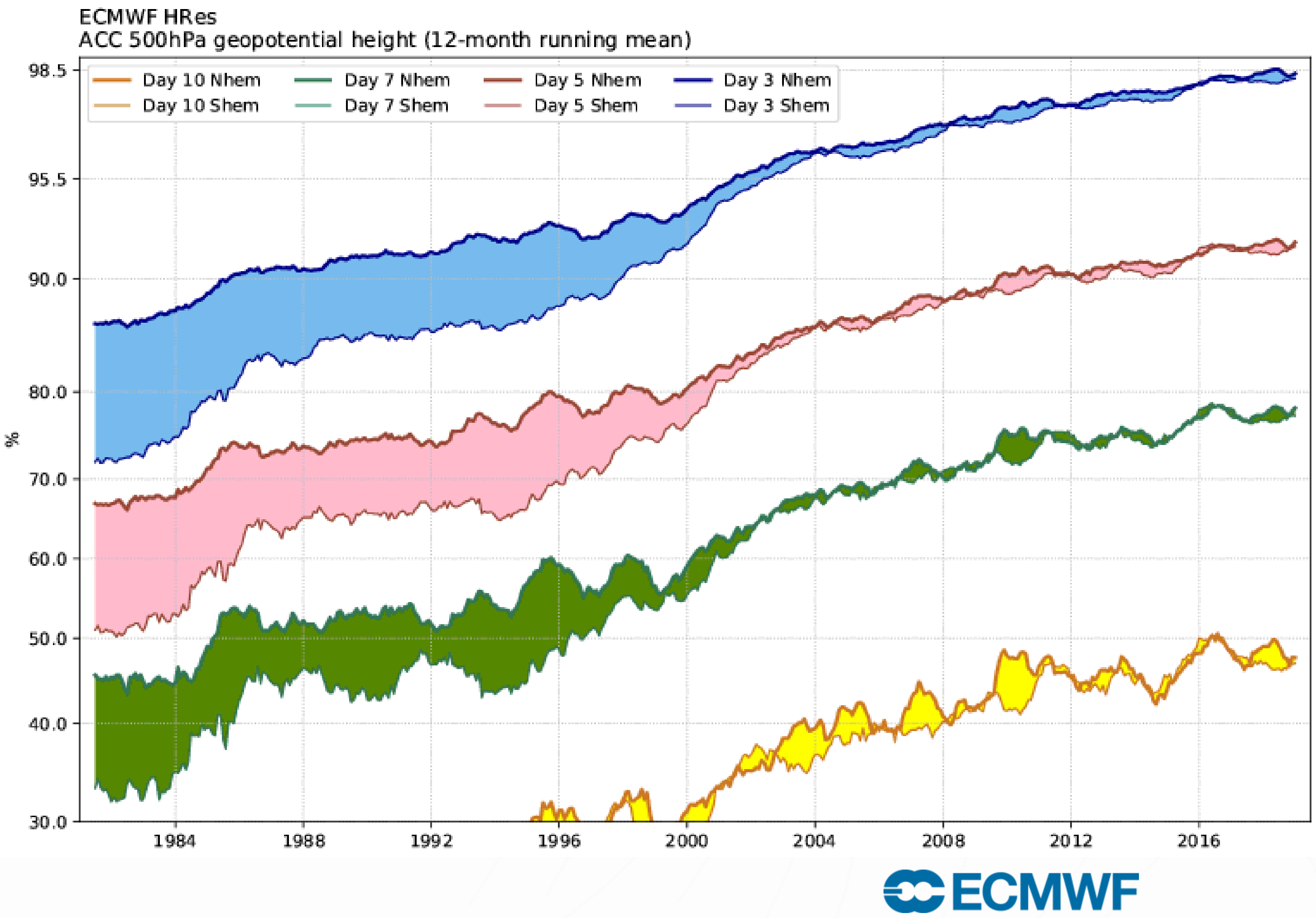
Evolution of the forecast skill between 1981 to 2016



Improvements in weather forecasts: due to the use of better models, advancement in computer technology, increase of observation data over the globe (satellite), development of advanced techniques of data assimilation and ensemble forecast.

Lorenz in 1982 concluded that the predictability limit for forecasts **of instantaneous weather patterns** is about two weeks.

Are we reaching the predictability limit?

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Predictability and potential skill

How we measure the atmospheric predictability ?
When do we know that we have reached the predictability limit ?

In a simple system (like the Lorenz 1963 model) by looking at the shape of the attractor it is possible to establish which are the zones with higher or lower predictability.

In a higher dimensional system like NWP/climate models the computation is not possible, so we use the concept of upper bound skill or potential skill to estimate the atmospheric predictability.

Potential skill or upper bound skill is the skill of a perfect system.

A predictability upper bound is the skill that is theoretically achievable with a perfect model for a given set of equations whereas forecast skill is what is actually achievable in a given numerical weather prediction (NWP) system that contains model errors, following Lorenz (1982) we call this predictability lower bound.

The potential forecast skill is the skill when the forecast error of such a system is nil. ---- > upper bound skill or potential skill

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The meteorological atmosphere is a chaotic system on time scales of a few days and weeks, depending on the spatial scales of interest. The climatic system is also chaotic, but on much longer timescales.

At extended ranges, atmospheric predictability arises from slow variations in lower-boundary forcing (e.g. ocean variations)

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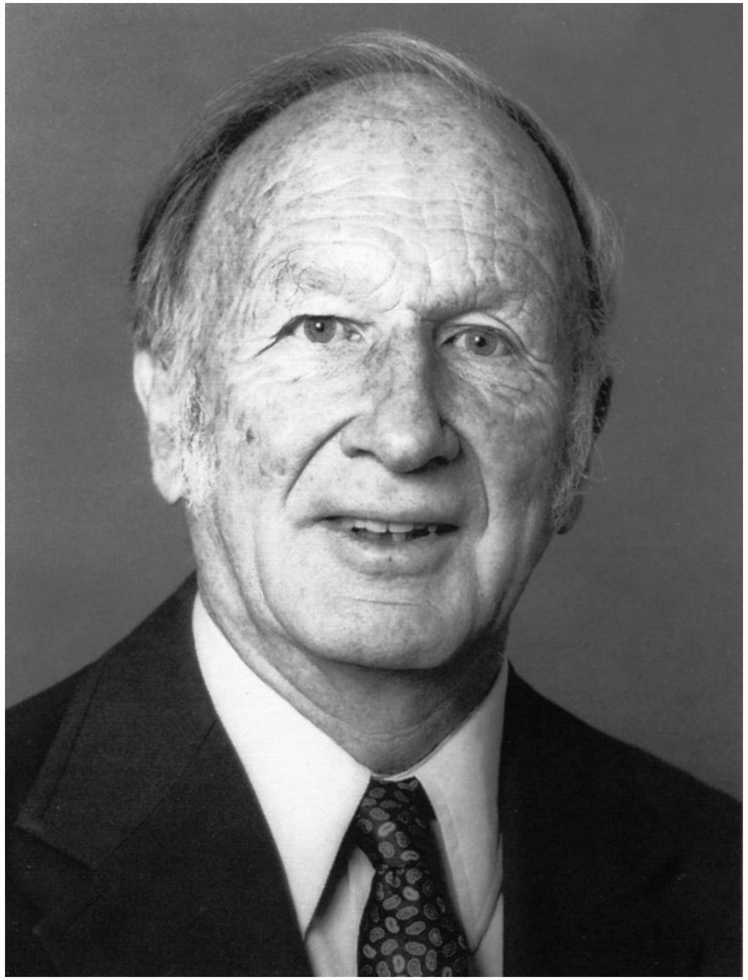
Edward Lorenz (1917 – 2008)



$$\dot{X} = -\sigma X + \sigma Y + f$$
$$\dot{Y} = -XZ + rX - Y + f$$
$$\dot{Z} = XY - bZ$$

What is the impact of f on the attractor?

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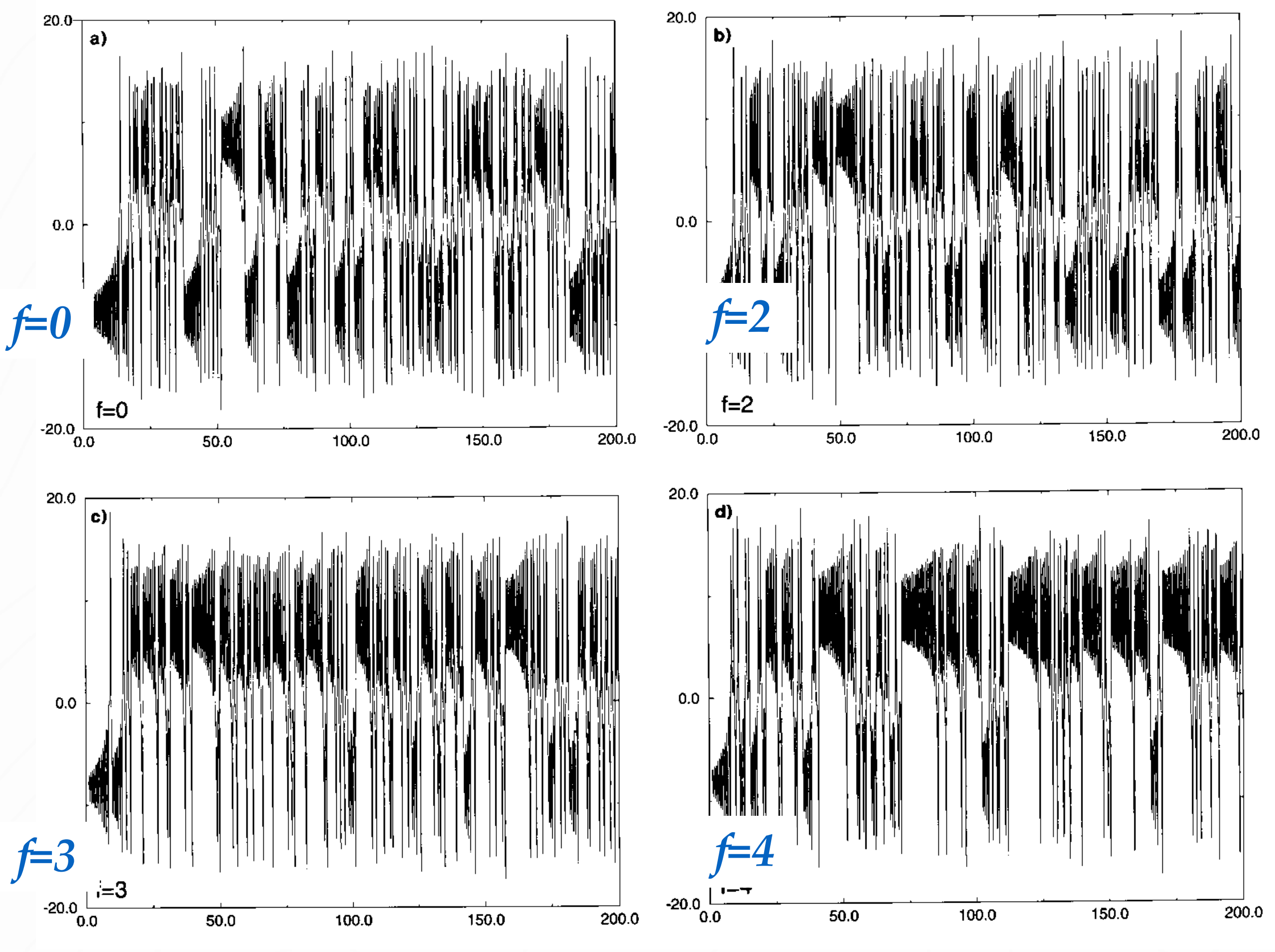
Add external steady forcing f to the Lorenz (1963) equations



The influence of f on the state vector probability function is itself predictable.

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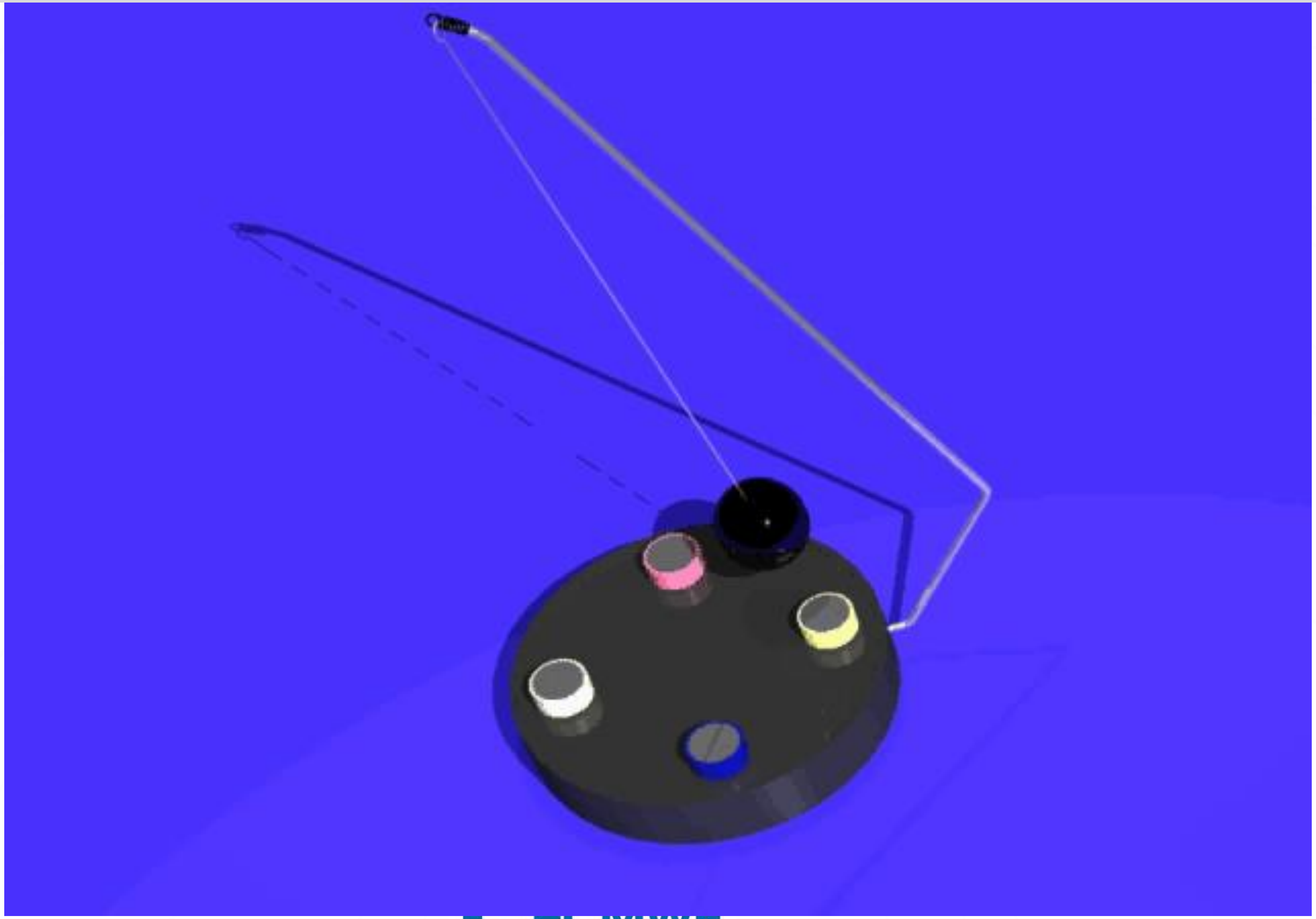
Mechanical analogue of preferred atmospheric circulation states



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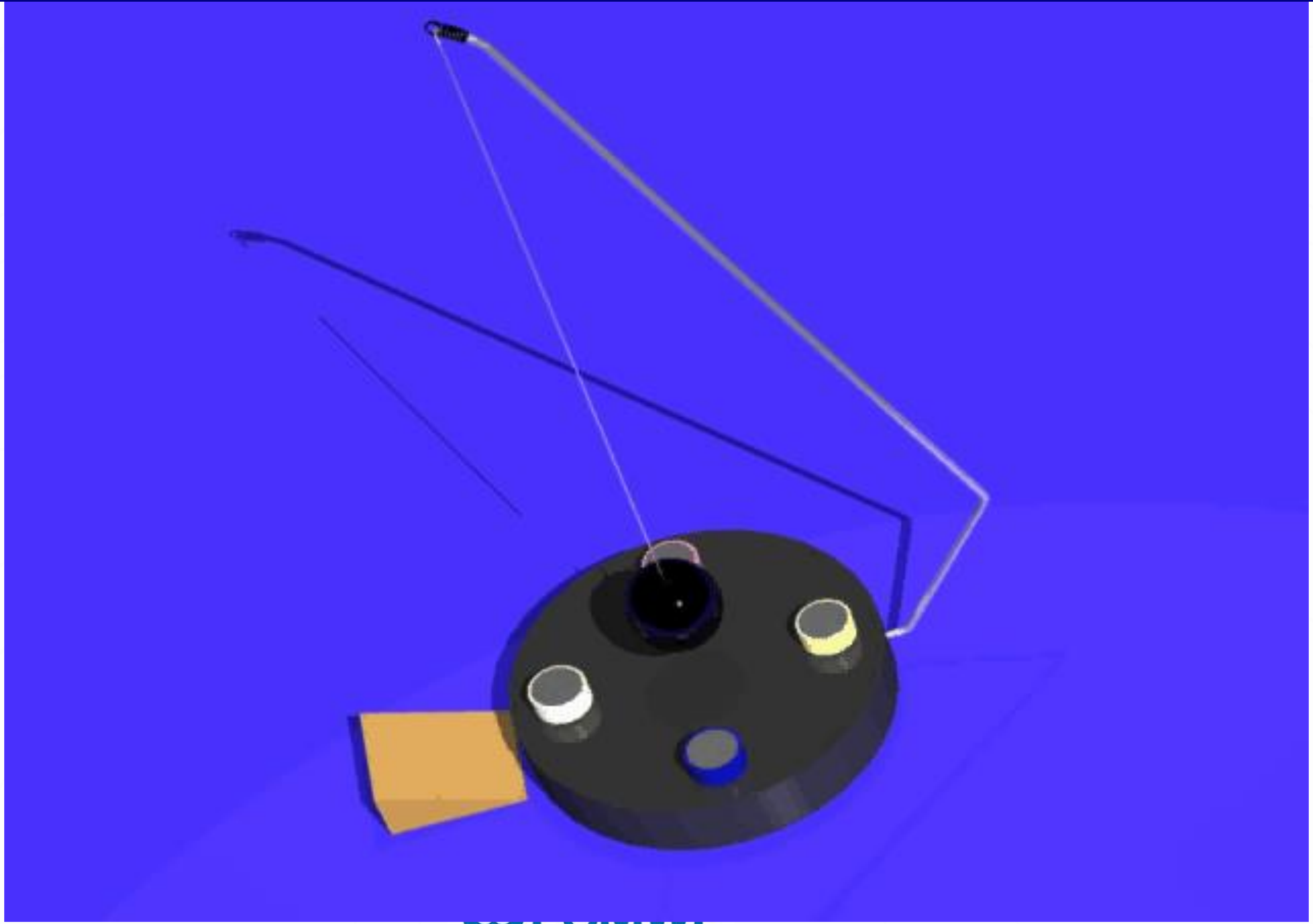
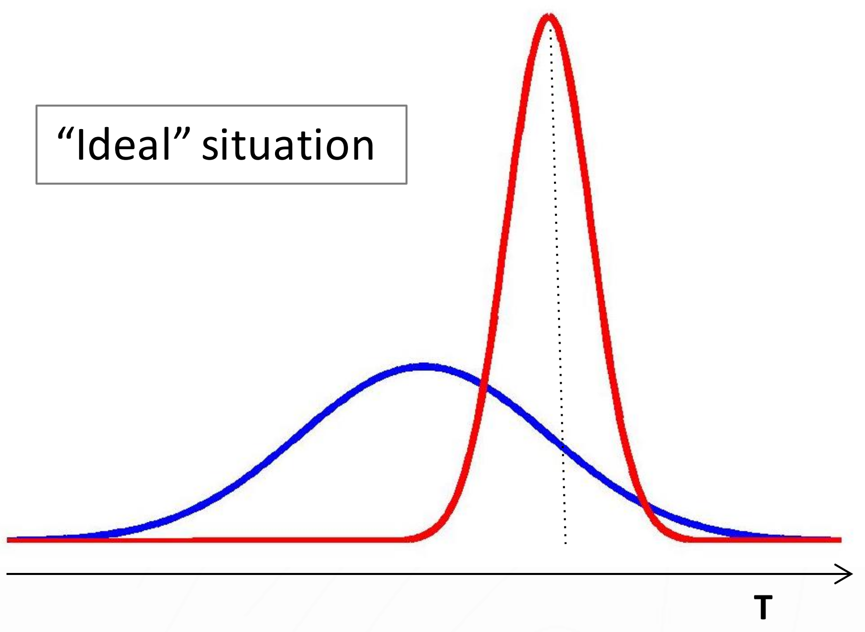
Preferred atmospheric circulation states: role of the forcing

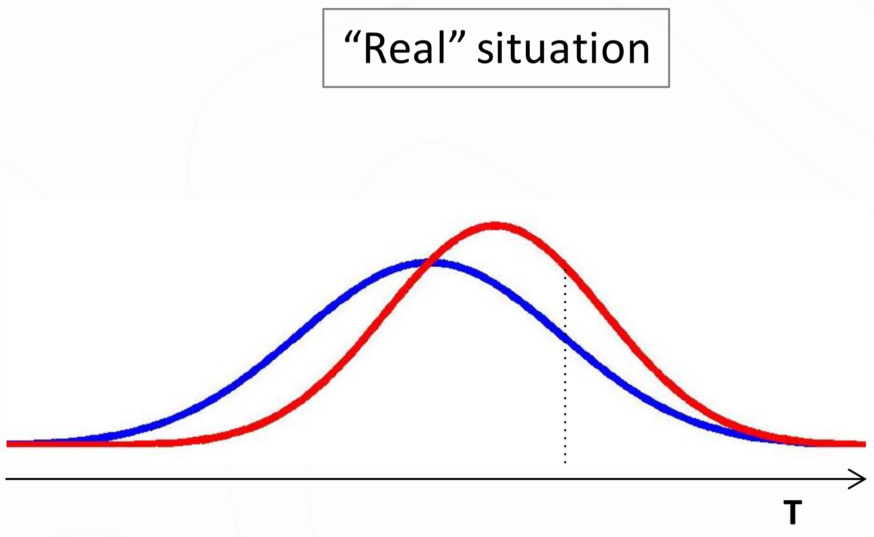


Forecasting probability distributions

Seasonal forecasts aim to predict an anomaly from the default climatological probability.

Probability density distributions of a hypothetical climatology and forecast given an observation.





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Questions:

- What is a chaotic system?
- What is ensemble weather/climate predictions?
- Is uncertainty in a forecast due to a lack of knowledge?
- What are the advantages of ensemble predictions?
- For subseasonal predictions is more important the representation of initial conditions or the representation of earth system processes?

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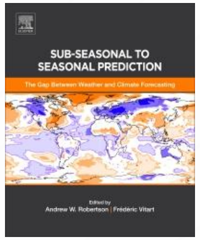
References :



Subseasonal to seasonal predictions: the gap between weather and climate forecasting

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