Towards a prediction of meteorological uncertainties

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METEO FRANCE

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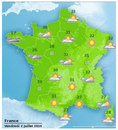
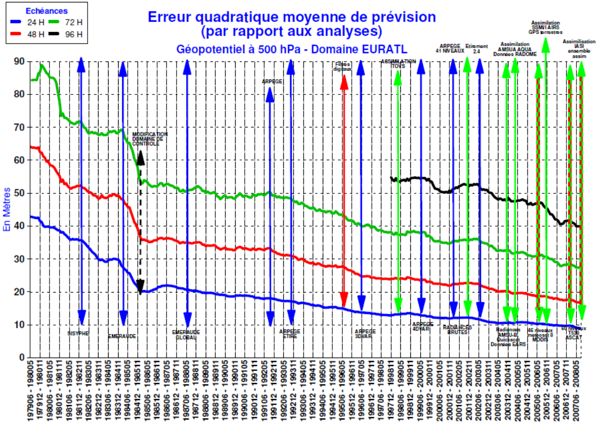
Equations $\Rightarrow$
numerical model

Initial state $\Rightarrow$

$\Rightarrow$ **Forecasts at** $t_0 + \delta t$



▷ Operational NWP began in the 50s.
▷ Since then, NWP forecast performance has advanced significantly : model improvements, increase of observations *etc.*



▷ But errors remain ...

▷ Different sources of uncertainty :

- Initial state
- Models, e.g., representation of subgrid-scale processes (convection, clouds, turbulence, radiation *etc.*)
- Numerical schemes
- Coupling to other models (e.g., surface, ocean, atmospheric chemistry)

⇒ **From initial state to long-range forecasts, meteorological information is affected by uncertainty.**

Uncertainty is a key information that gives the users an indication of how confident they can be in a forecast

▷ What is the impact of the different sources of uncertainty on the forecasts ?

▷ How to account for the uncertainties ?

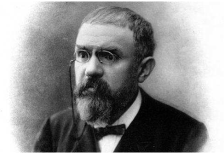
▷ How to measure or quantify the uncertainties ?

▷ How to communicate this uncertainty to users ?

Outline

2 - Poincaré's intuition

Science et Méthode (1908)

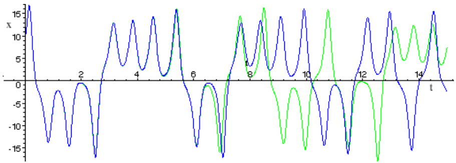


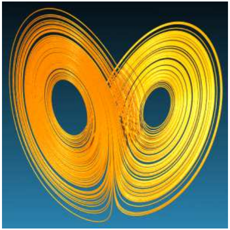
"Why have meteorologists such difficulty in predicting the weather with any certainty ? Why is it that showers and even storms seem to come by chance ... a tenth of a degree more or less at any given point, and the cyclone will burst here and not there, and extend its ravages over districts that it would otherwise have spared. If they had been aware of this tenth of a degree, they could have known beforehand, but the observations were neither sufficiently comprehensive nor sufficiently precise, and that is the reason why it all seems due to the intervention of chance. Here, again, we find the same constract between a very triffling cause that is inappreciable to the observer, and considerable effects, that are sometimes terrible disasters."

2 - Lorenz' experiment

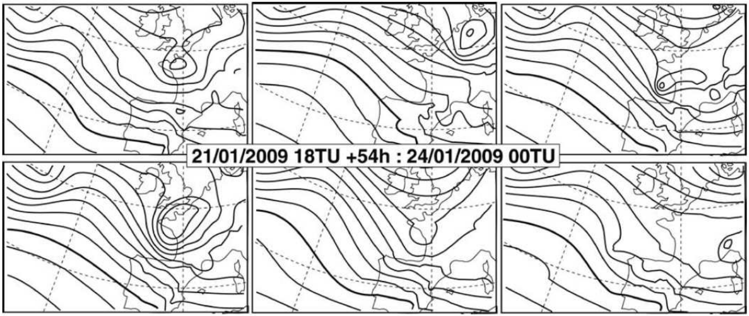
▷ Popularized by Lorenz works (1963) :

- two very close initial conditions diverge after a certain time
- all solutions converge to a strange attractor





2 - Daily experiment in NWP



▷ 6 forecasts from 6 similar initial conditions : small differences became large !

2 - Limits to deterministic forecasts

Forecast skill horizon

▷ Lead time at which two initially close forecasts diverge is called the forecast skill horizon

▷ It depends on :

- the scale of the phenomena
- the characteristics of the flow and its instabilities

▷ Examples : mid-latitude storm 2-3 days, thunderstorms a few hours

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Probabilistic prediction

▷ For lead times longer that the forecast skill horizon, meteorological prediction has sense only if we consider the associated uncertainty

▷ Uncertainty is a key information that must be quantified

▷ For that purpose a probabilistic approach becomes necessary.

Outline

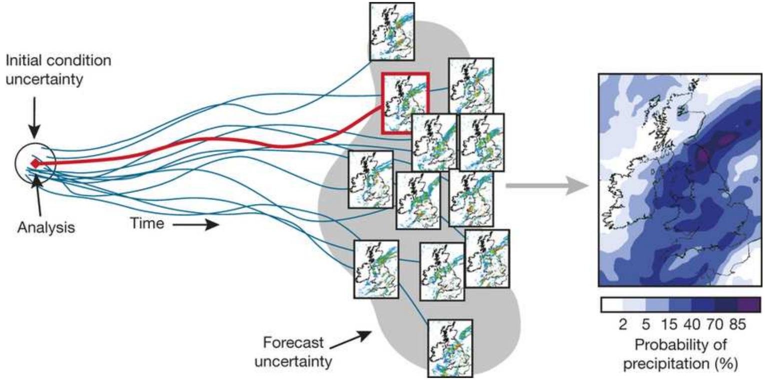
3 - Probabilistic approaches

▷ **Estimate the forecast probability distribution function (pdf) :**

- Explicit computation with the Liouville equation
  $\Rightarrow$ unaffordable for high-dimensional systems
- Add statistics of past errors to the deterministic forecast
  $\Rightarrow$ good starting point but does not allow for a representation of the uncertainty “of the day”
- Sample the pdf with an ensemble of perturbed forecasts
  $\Rightarrow$ this method, known as ensemble prediction, has been developed since the 90s.

3 - Ensemble prediction

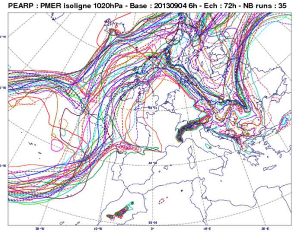
▷ The model is run several times, started from slightly different initial conditions and, possibly, with different configurations of the model
⇒ we now run an ensemble of forecasts

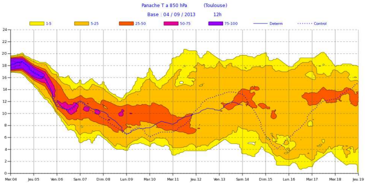


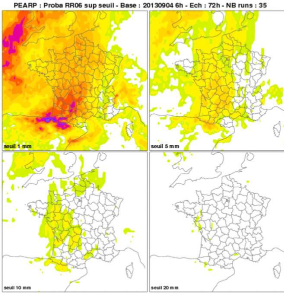
3 - Ensemble prediction

▷ Using an ensemble prediction system :

- provides true alternative scenarii
- provides an estimate of forecast uncertainty
- helps to better anticipate the prediction of severe weather







3 - Design of ensemble prediction

▷ An ensemble prediction system is based on the representation of the different sources of uncertainty :

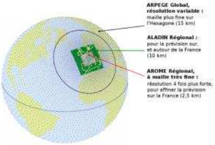
- initial errors
- model errors
- coupling errors

▷ The quality of perturbation methods directly impacts the quality of ensemble forecasts.

3 - Data assimilation

Observations

Background



$\Longrightarrow$

$\Downarrow$

Data assimilation

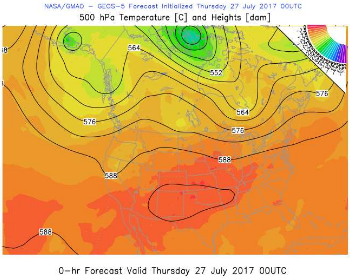
$\Longrightarrow$ **Initial state**

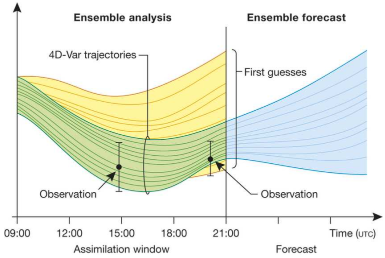
3 - Initial uncertainty

▷ Observations and backgrounds are affected by errors
⇒ errors on the initial state

▷ These errors can be estimated with Monte-Carlo methods, with a generalization of the ensemble methods to the assimilation step
⇒ Ensemble data assimilation techniques

- Several initial states can be calculated based on different sets of perturbed observations (in agreement with observation errors)
- The ensemble of initial states provides an estimate of the initial uncertainty and can be used to initialize ensemble forecasts.





3 - Model uncertainty

▷ Several techniques to represent model uncertainty exist :

- Multi-physics approach : each member uses a different set of physical parametrizations
- Multi-parameters approach : each member uses a different set of parameters
- Multi-models approach : each member uses a different model
- Stochastic approaches : stochastic perturbations are added to some fields at each time step

3 - Ensemble prediction at Météo-France

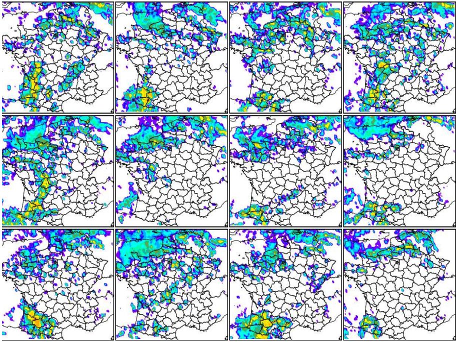
▷ **Arpège ensemble prediction (PEARP)**

- 35 forecasts over the globe
- 2 runs/day, up to 4-5 days
- Horizontal resolution (variable) : $\approx$ 10km over France
- Initial uncertainty : ensemble data assimilation + singular vectors
- Multi-physics approaches

3 - Ensemble prediction at Météo-France

▷ **Arome ensemble prediction**
⇒ for the very short range and fine-scale phenomena over western Europe

- 12 forecasts
- 2 runs/day, 45h lead time
- Horizontal resolution 2.5km
- Initial uncertainty : downscaled perturbations from PEARP
- Lateral boundary conditions : downscaled PEARP forecasts



- Stochastic approaches for model error
- Random perturbations of some surface variables

Outline

4 - Downstream models

Knowledge of meteorological uncertainties is important :

▷ for weather forecasters

▷ for users and “meteo-sensitive” applications :

- energy
- hydrology
- transport of pollutants
- air quality
- marine production
- aeronautic production
- agronomy
- *etc.*

4 - Using the ensembles

"A 30% chance of rain tomorrow" : how does the public understand probabilistic weather forecasts ?

▷ Probability information can be more complex as it requires an event definition, which may be unique to each individual user

▷ One needs to develop strategies to improve risk communication, for instance based on the user's cost/loss ratio

⇒ determine a decision threshold : if the probability is larger than the decision threshold then the user acts as is the event was forecast

▷ The major challenge for ensemble prediction may be the development of automatic post-processing tools, in order to present the probabilistic information under an understandable and useful form for decision making.

4 - DigitAg Ph-D Thesis (start November 2017)

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- Produce a probabilistic information for users

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Participants

- Ivana Aleksovska (PhD student)
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