Weather forecasting

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Outline

Areas of interest

Environmental Effects

Hydrostatic Balance

Mathematical model of the atmosphere

Numerical model and data assimilation

Chaotic behaviour

Ensemble weather forecast

SMHI Forecast Accuracy

Areas of interest

- Wind
  - Wind power
  - Storms
- Moisture
  - Rain
  - Agriculture
- Temperature
- Pressure

Environmental Effects

- Moisture and ice
- Air pollution
- Coriolis effect
  - Different directions depending on hemisphere
  - Depends on velocity and the earth's rotation
- Other effects
  - Friction occurs close to the ground

Hydrostatic balance

A common assumption

Vertical pressure changes are only dependent on gravity

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g$$

Only applicable when vertical scale is relatively small

Cannot measure local effects

Example: Rain showers

Isn't assumed in mesoscale models,

high resolution models

Mathematical model of the atmosphere

$$\frac{du}{dt} = fv - \frac{1}{\rho}\frac{\partial p}{\partial x} + F_r$$

$$\frac{dv}{dt} = -fu - \frac{1}{\rho}\frac{\partial p}{\partial y} + F_r$$

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g$$

$$\frac{C_p}{T}\frac{dT}{dt} - \frac{R}{p}\frac{dp}{dt} = Q$$

$$p = \rho R T$$

$$\frac{1}{\rho}\frac{d\rho}{dt} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

Newton's 2 law (3 first)

2nd law of thermodynamics

Gas Law

Conservation of mass

u - east west winds

v - north south winds

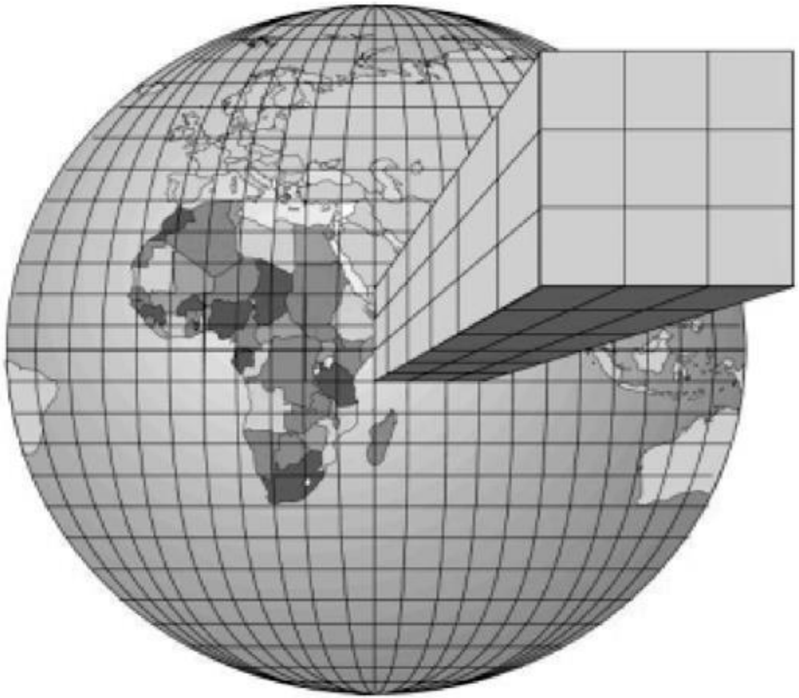
w - vertical winds

f - coriolis parameter

Numerical model and data assimilation

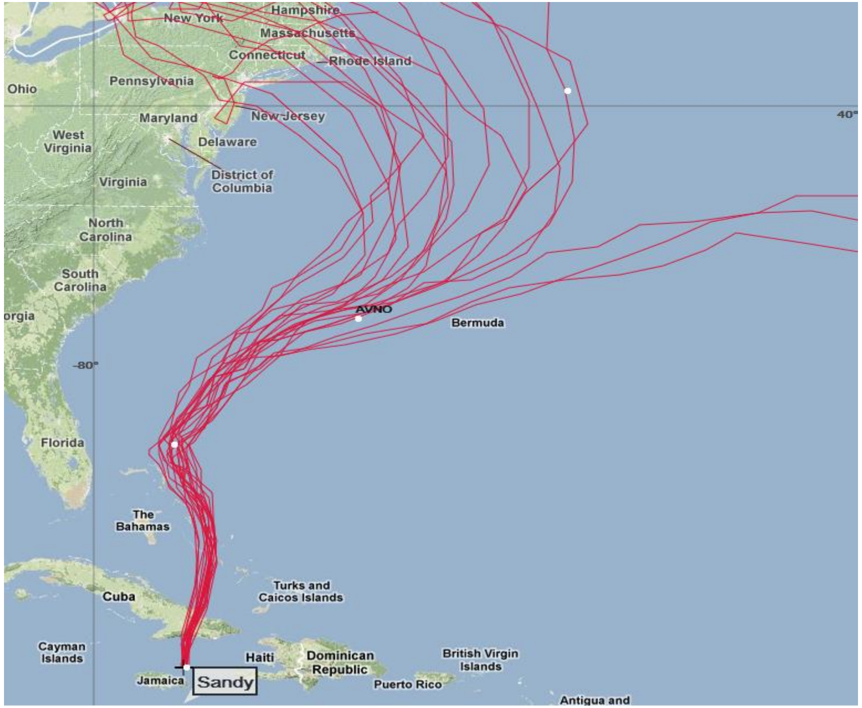
Procedure

1. Division of weather forecast area in a grid
2. Initialization using assimilated data
3. Time evolution is governed by the mathematical equations
4. Iteration in time
5. Input data assimilation

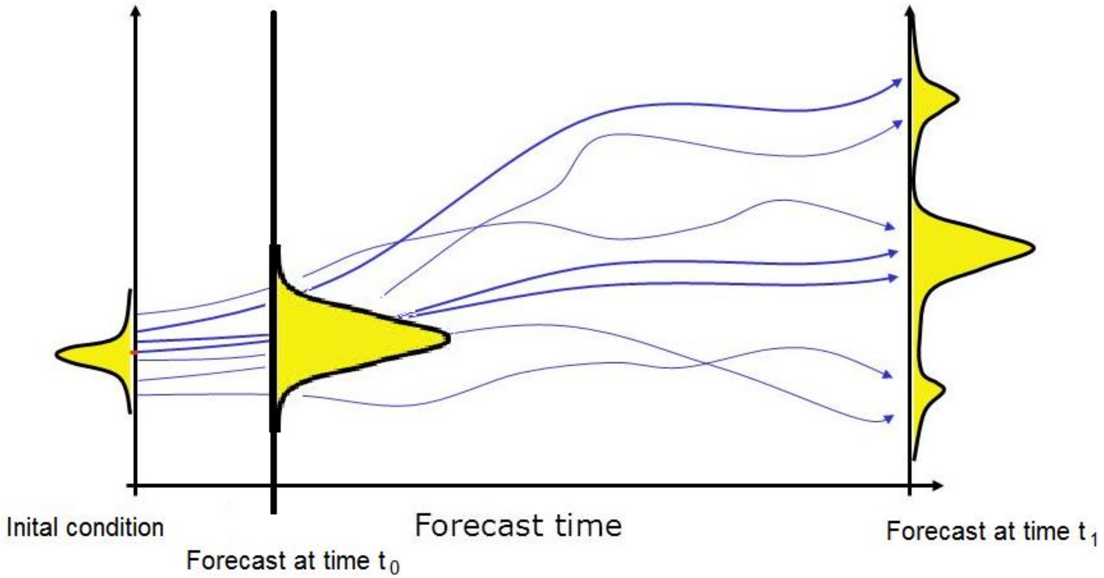


Weather is chaotic

- Computationally heavy
- Forecast limited to 6 days
- Hurricane Sandy



Ensemble weather forecast



- Probability density functions (**PDF**) for different time instants.

Forecast Accuracy - SMHI

Prognoses index ("prognosindex")

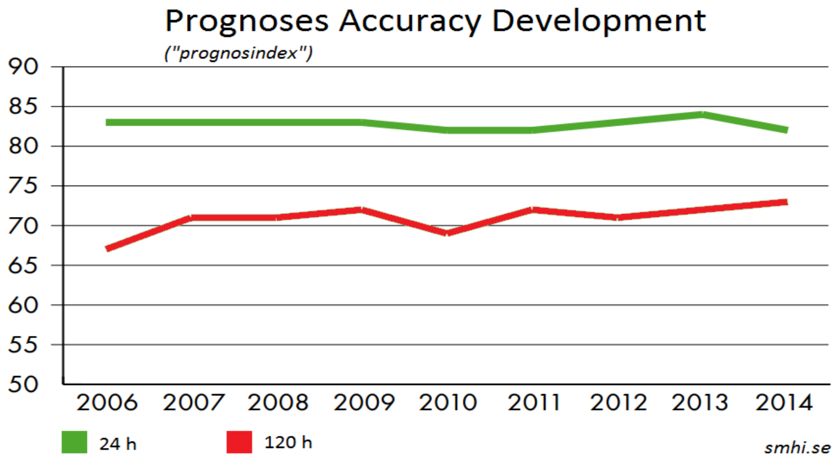
Temperature, wind speed, precipitation, clouds

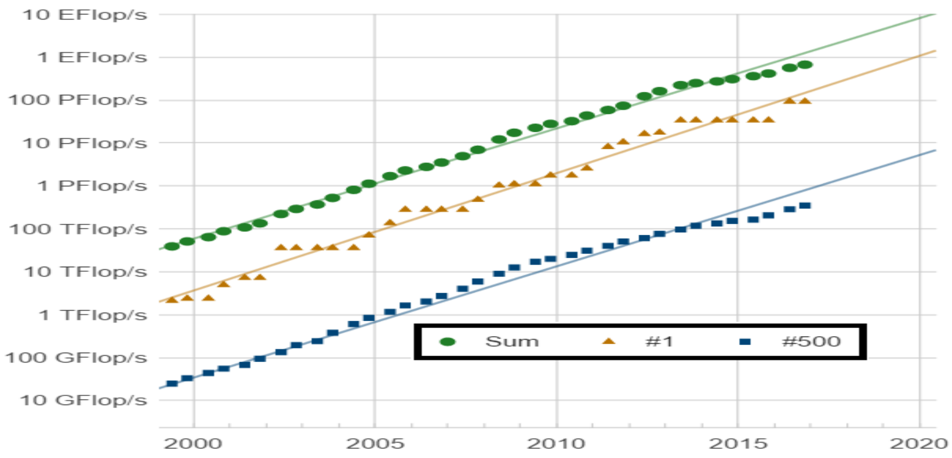
Goal: 85% accuracy for 24h forecasts

Accuracy in 2015 (not in graph):

83% for 24h forecasts (2014: 82%)

73% for 120h forecasts (2014: 73%)





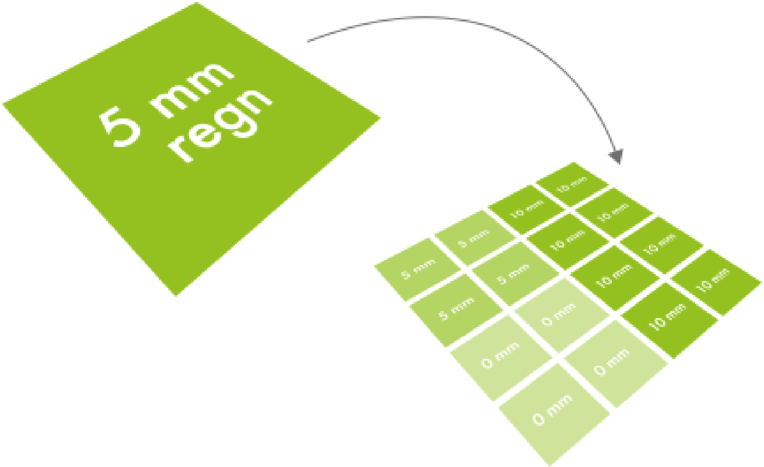
Forecast Accuracy Challenges

Computer generated prognoses done for areas of at least 2.5x2.5 km

- Smaller area => shorter prediction time

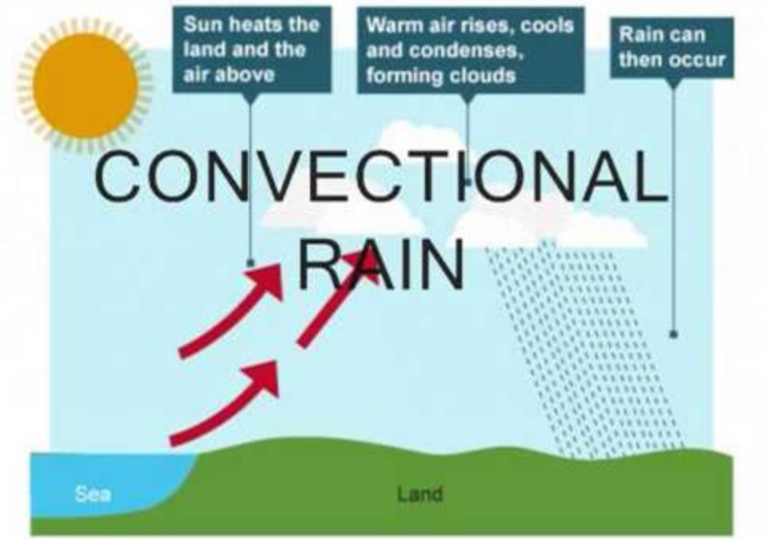
Weather generally “travels” east

- Accurate 5-day forecasts require accurate prognoses of all westward systems.
- Inaccurate 5-day forecast in Sweden may be caused by an error as far west as the pacific ocean



Forecast Accuracy Challenges - continued

- Increased convection in summer => more precipitation inland than near the coast.
  - Convectional rain difficult to predict (local weather phenomena)
- Conditions near weather station may not be indicative of the general area
- Public prefers deterministic forecasts
- Exact description (Navier-Stokes) chaotic
  - Any measuring error will will grow exponentially



Case study: Forecasting with an Artificial Neural Network

24h weather forecasts in Mumbai

Data: 8 years, 90 daily readings

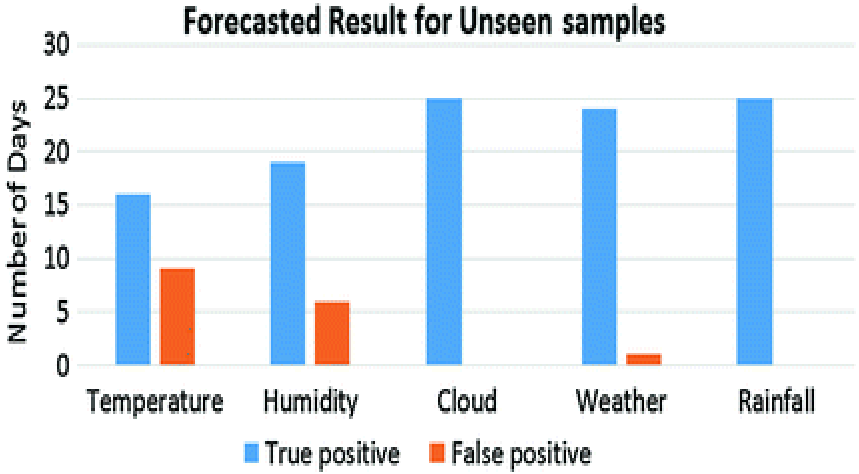
Trained with backpropagation

Good accuracy: Up to 92%

Sensitive to ANN topology

- 28-10-10-5 (Input-Hidden-Hidden-Output) outperforms 28-15-15-5

- Choice of activation functions (*Tansig, Logsig, Purelin)* very important: Accuracy drop from 92% to 36% possible when



Future of weather forecasting

- Focus primarily on development of existing systems
  - Faster computers, new observation stations, launching new satellites, etc.
- "Black box" nature of many complex systems-approaches such as Artificial Neural Networks an issue
  - Retraining a network (e.g. when moving or decommissioning) a weather station is expensive

Discussion Points

Since chaos is a fundamental property of the atmosphere, small deviations in data causes large impacts. This demands high precision in data and regular updating. Many weather phenomena such as hurricanes originates at inaccessible locations such as far out in the sea.

What practical solutions can be utilized to gather data with high precision and with continuous updating?

How can we gather data from all around the globe?

Weather is impacted by human influences. Examples include global warming and lowering of pH-values in natural water systems. What type of factors caused by humans can alter the weather and what consequences follow?

Can we use this effects to engineer the weather for our own benefits?
What are the difficulties with replacing the chaotic theoretical models with other solutions such as agent based modelling?
To summarize the previous questions, what can SMHI do in order to reach their goal of 85% accuracy?