Weather Forecasting

Prediction in the natural world

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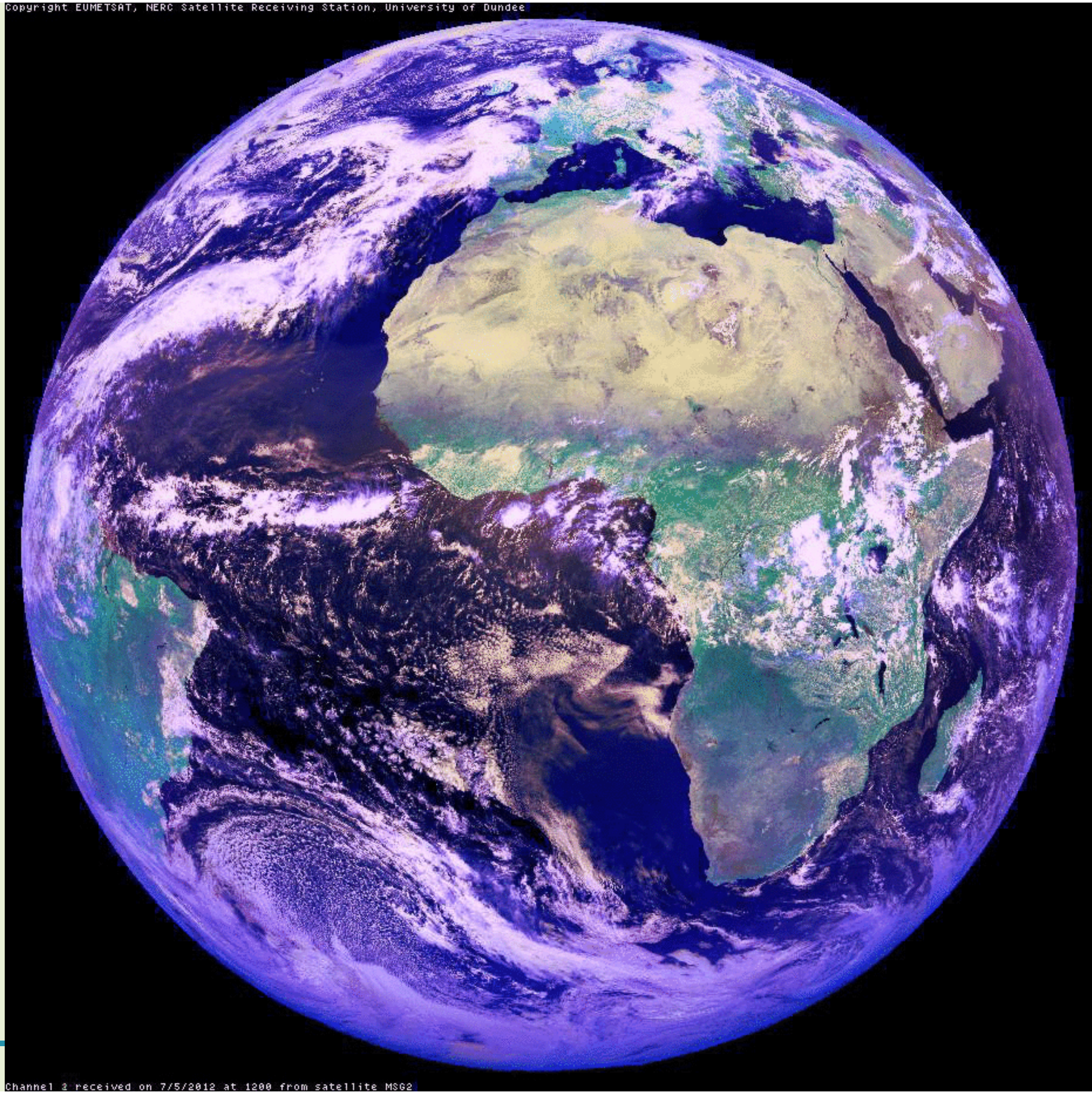
Many aspects of Weather Forecasting

- The science of meteorological prediction;
- The psychology of forecasting;
- The challenge of communication.


Copyright EUMETSAT, NERC Satellite Receiving Station, University of Dundee
Channel 2 received on 7/5/2012 at 1200 from satellite MSG2

Observing the Weather

- All science starts with data
- Meteorology proper started with instrumentation
    - Wind speed and direction (very ancient)
    - Temperature (Renaissance)
    - Air Pressure (Renaissance)
    - Sunshine Duration (Victorian)
    - Rainfall Amounts (Victorian)
    - Quantitative wind measurement (Victorian)

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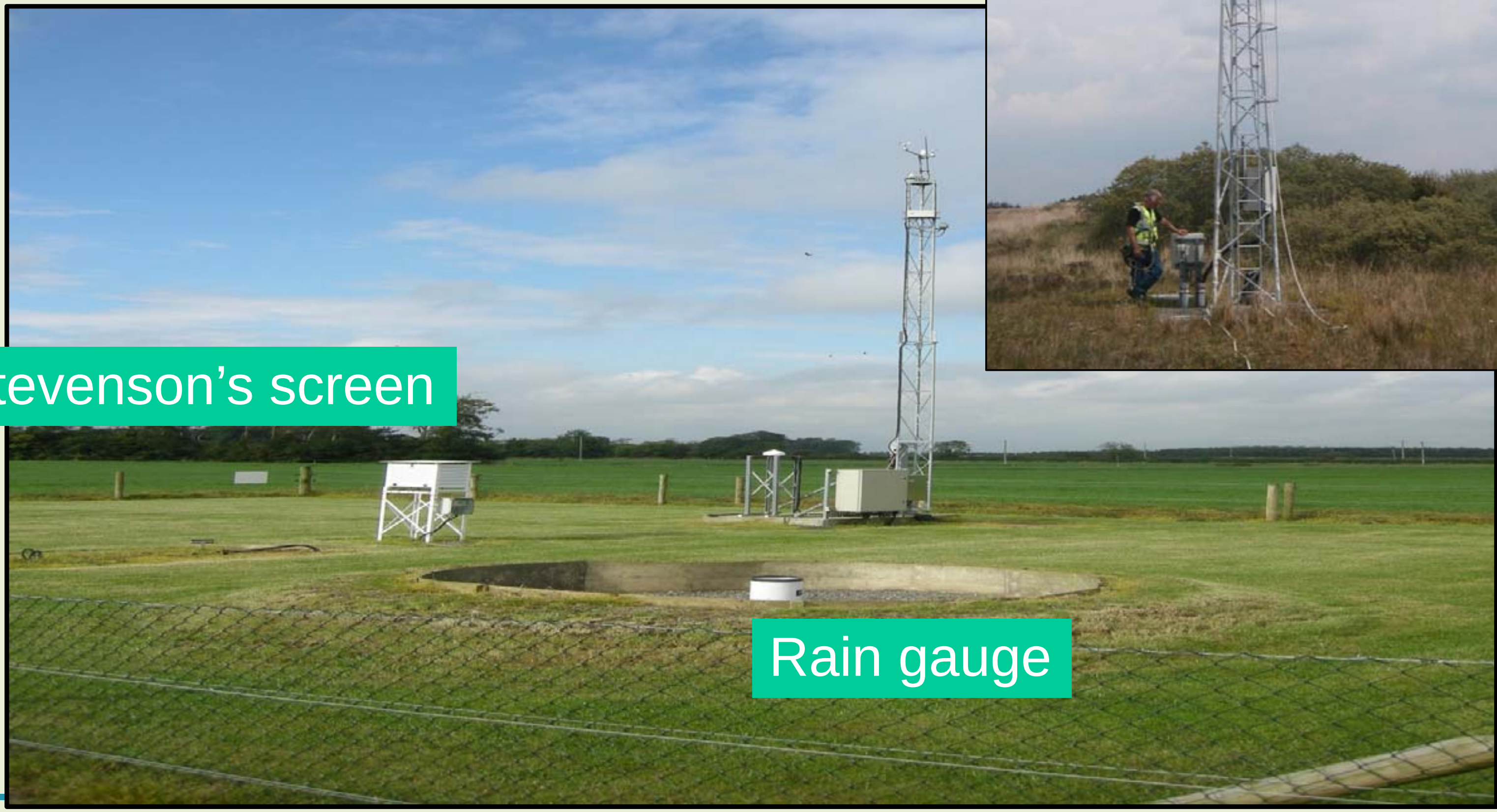
Met Éireann builds our own automatic stations



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The Equations of the Atmosphere

GAS LAW (Boyle's Law and Charles' Law.)
Relates the pressure, temperature and density
CONTINUITY EQUATION
Conservation of mass; air neither created nor distroyed
WATER CONTINUITY EQUATION
Conservation of water (liquid, solid and gas)
EQUATIONS OF MOTION: Navier-Stokes Equations
Describe how the change of velocity is determined by the pressure gradient, Coriolis force and friction
THERMODYNAMIC EQUATION
Determines changes of temperature due to heating or cooling, compression or rarifaction, etc.

Seven equations; seven variables (u, v, w, ρ, p, T, q).

The Primitive Equations

$$\frac{du}{dt} - \left(f + \frac{u\tan\phi}{a}\right)v + \frac{1}{\rho}\frac{\partial p}{\partial x} + F_x = 0$$

$$\frac{dv}{dt} + \left(f + \frac{u\tan\phi}{a}\right)u + \frac{1}{\rho}\frac{\partial p}{\partial y} + F_y = 0$$

$$p = R\rho T$$

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

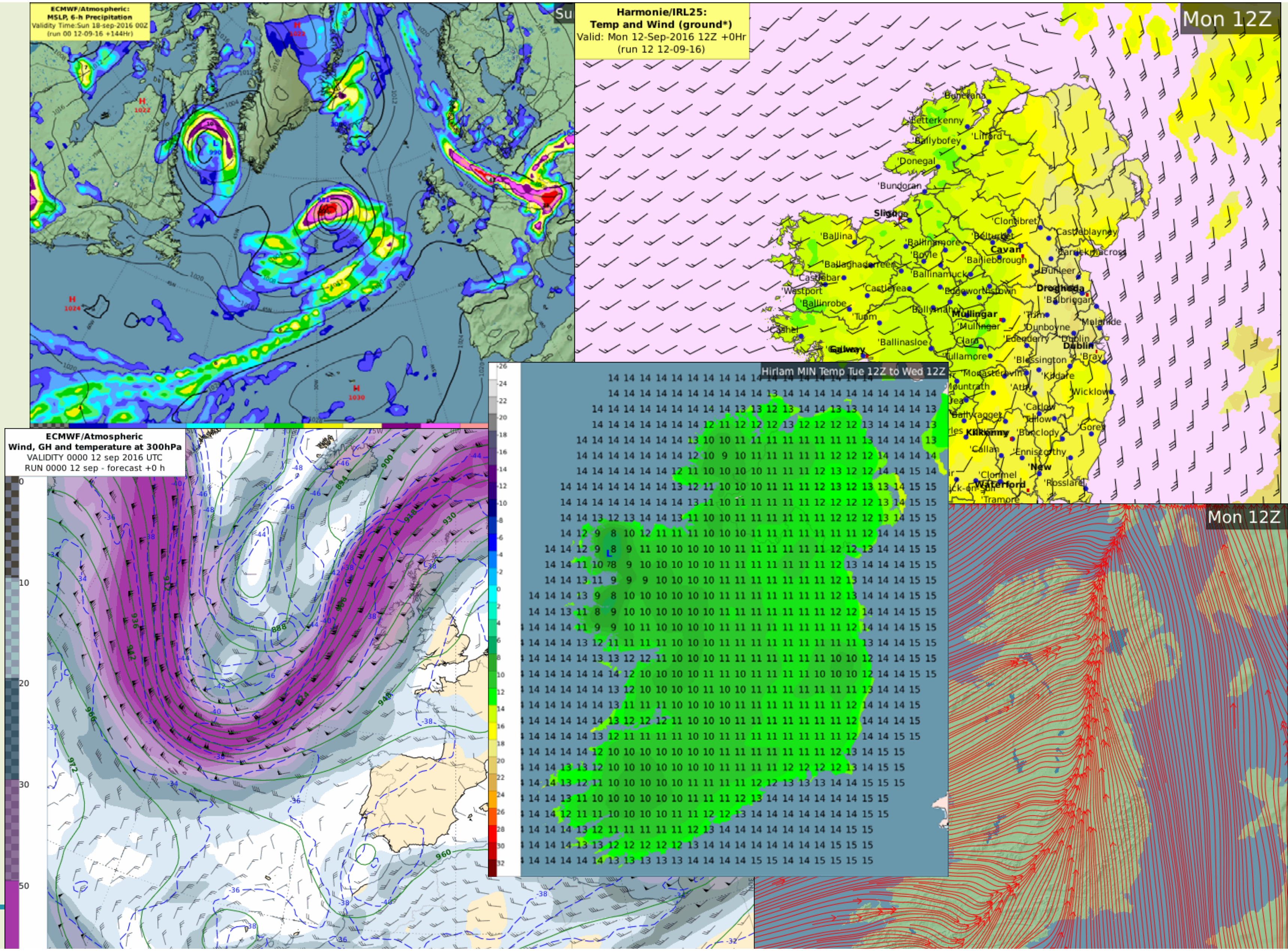
$$\frac{dT}{dt} + (\gamma - 1)T\nabla\cdot\mathbf{V} = \frac{Q}{c_p}$$

$$\frac{\partial \rho}{\partial t} + \nabla\cdot\rho\mathbf{V} = 0$$

$$\frac{\partial \rho_w}{\partial t} + \nabla\cdot\rho_w\mathbf{V} = [\textbf{Sources} - \textbf{Sinks}]$$

Seven equations; seven variables $(u, v, w, p, T, \rho, \rho_w)$.

The ECMWF’s Cray XC30 supercomputer can perform up to 2 quadrillion calculations a second.



ECMWF/Atmospheric:
MSLP, 6-h Precipitation
Validity Time:Sun 18-sep-2016 00Z
(run 00 12-09-16 +144Hr)
Harmonie/IRL25:
Temp and Wind (ground*)
Valid: Mon 12-Sep-2016 12Z +0Hr
(run 12 12-09-16)
Mon 12Z
ECMWF/Atmospheric
Wind, GH and temperature at 300hPa
VALIDITY 0000 12 sep 2016 UTC
RUN 0000 12 sep - forecast +0 h
Hirlam MIN Temp Tue 12Z to Wed 12Z
Mon 12Z

Deterministic Forecasting

- Starting from here (the “Synoptic Analysis”) develop a picture of how the Weather Systems will evolve over time.
- An underlying narrative which then dictates the “experience” of weather at any one location.
- This was the dominant approach to weather forecasting up until the last 20 years
- Computing approach (“Numerical Weather Prediction”) brought tremendous improvements in weather forecasting – could now issue reasonably accurate forecasts for 5 or 6 days ahead.
- BUT – still significant uncertainties.

Probabilistic Forecasting

- Try to acknowledge, and get some feel for, the uncertainties underlying the weather forecast.
- Why can’t we make perfect forecasts?
  - Limited Data
  - Inaccurate Data
  - Inability to rigorously “solve” the equations
  - Questions of scale..
- Ensemble Forecasting
  - Use this approach to get some idea of the envelope of possibilities
  - How likely are these possibilities to actually occur?

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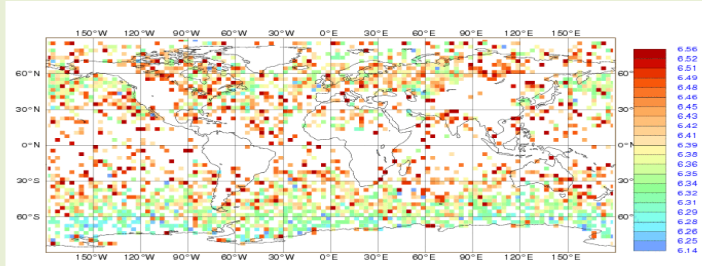
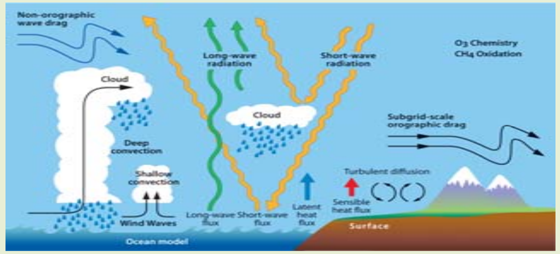
Why are forecasts sometimes wrong?



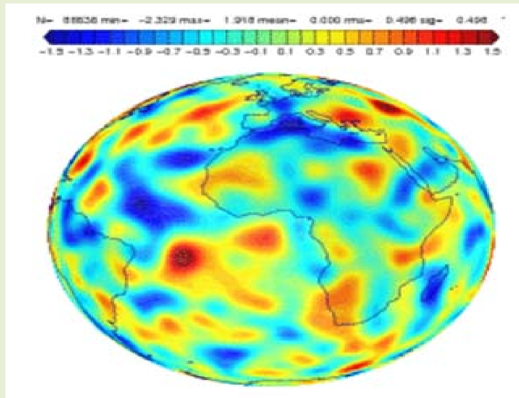
Initial condition uncertainties

- Lack of observations
- Observation error
- Limitations of the data assimilation



Model uncertainties

- Limited resolution
- Parameterisation of physical processes



The atmosphere is chaotic

- small uncertainties grow to large errors (unstable flow)
- small scale errors will affect the large scale (non-linear)
- error-growth is flow dependant

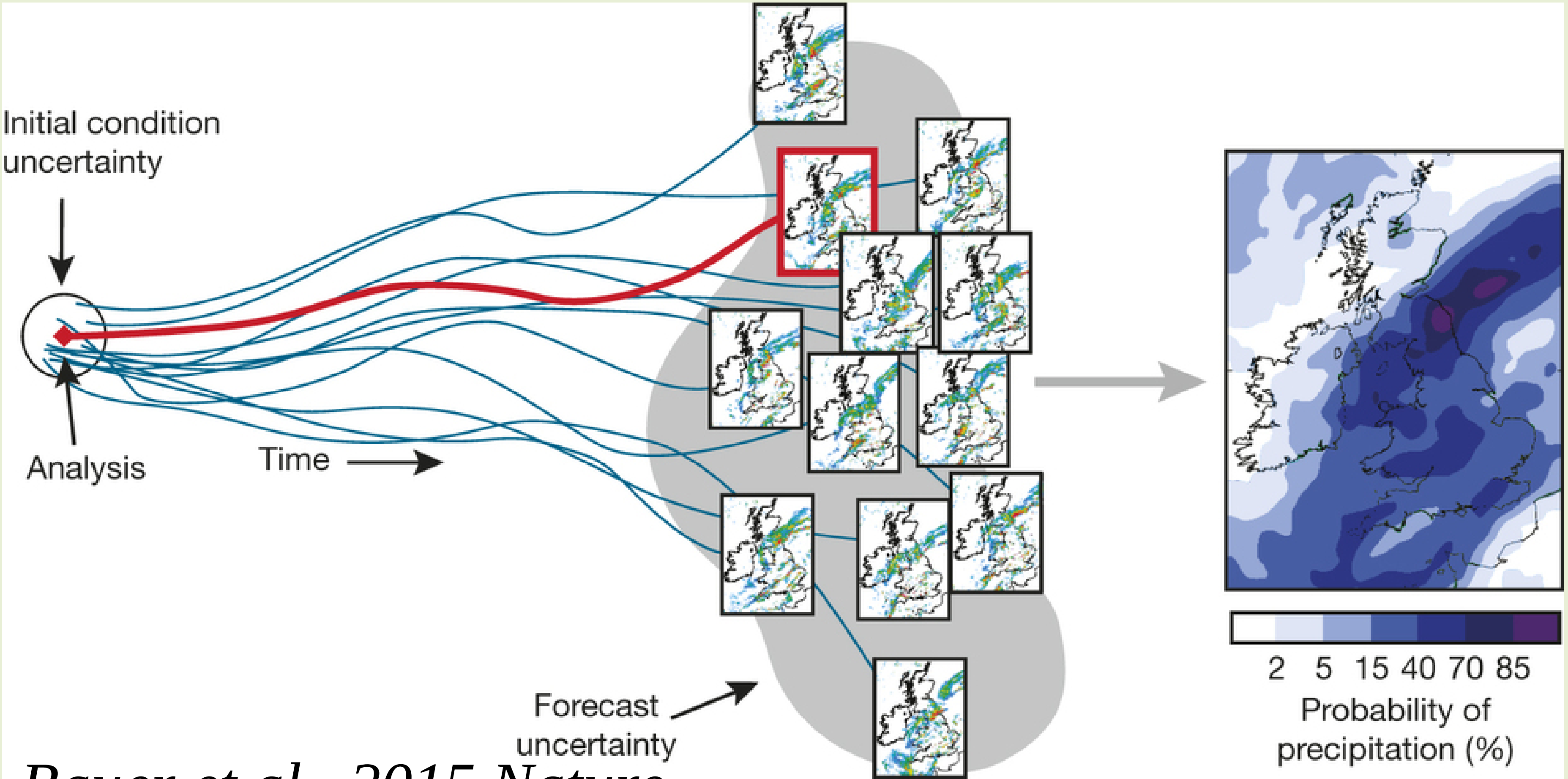
What is an ensemble?

A set of forecasts run from slightly **different initial conditions** to account for initial uncertainties

The forecast model also contains **approximations** that can affect the forecast evolution

The ensemble of forecasts provides a range of **future scenarios** consistent with our knowledge of the initial state and model capability

Ensemble forecasts



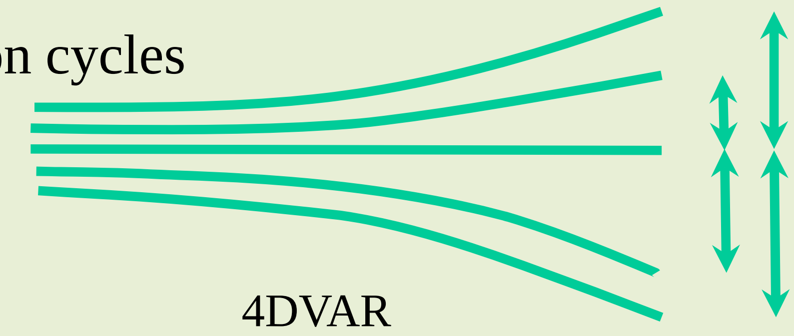
Bauer et al., 2015 Nature

Ensemble: how do we generate the initial uncertainties?

Combination of 2 types of perturbations

Ensemble of data assimilations (EDA)

- Randomly perturbed observations and SST fields
- Run 10 independent data assimilation cycles

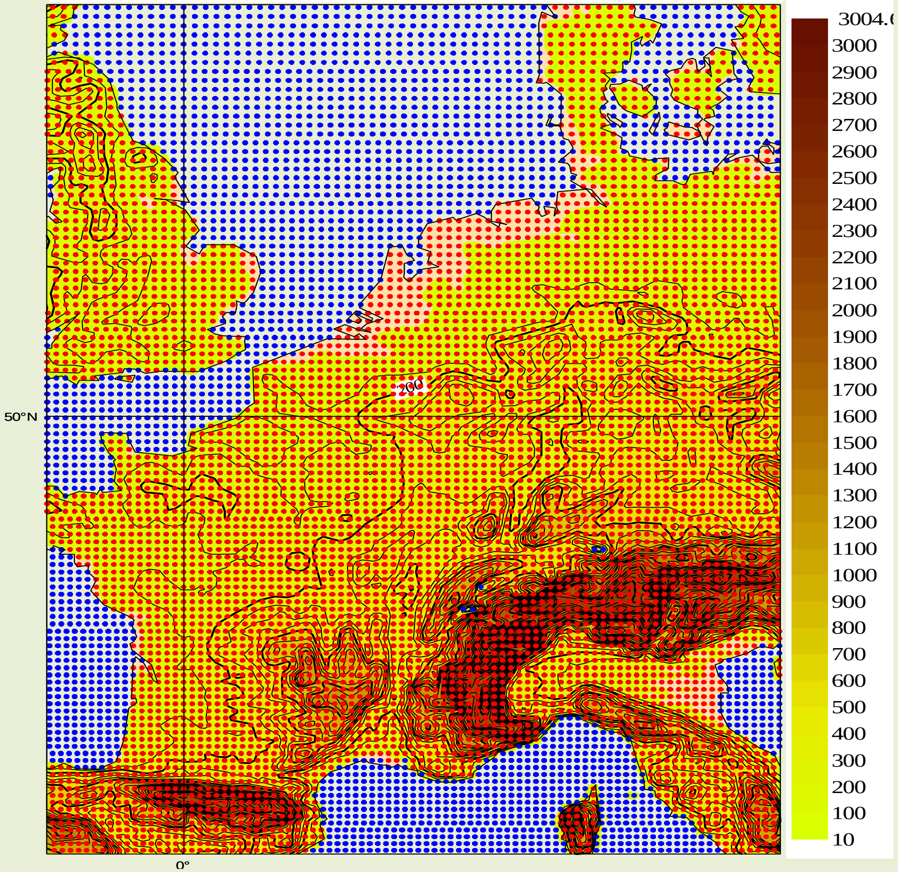


Singular vectors: perturbations that grow quickly over the first 48 hours of the forecast

Best approach given limited available computer resources

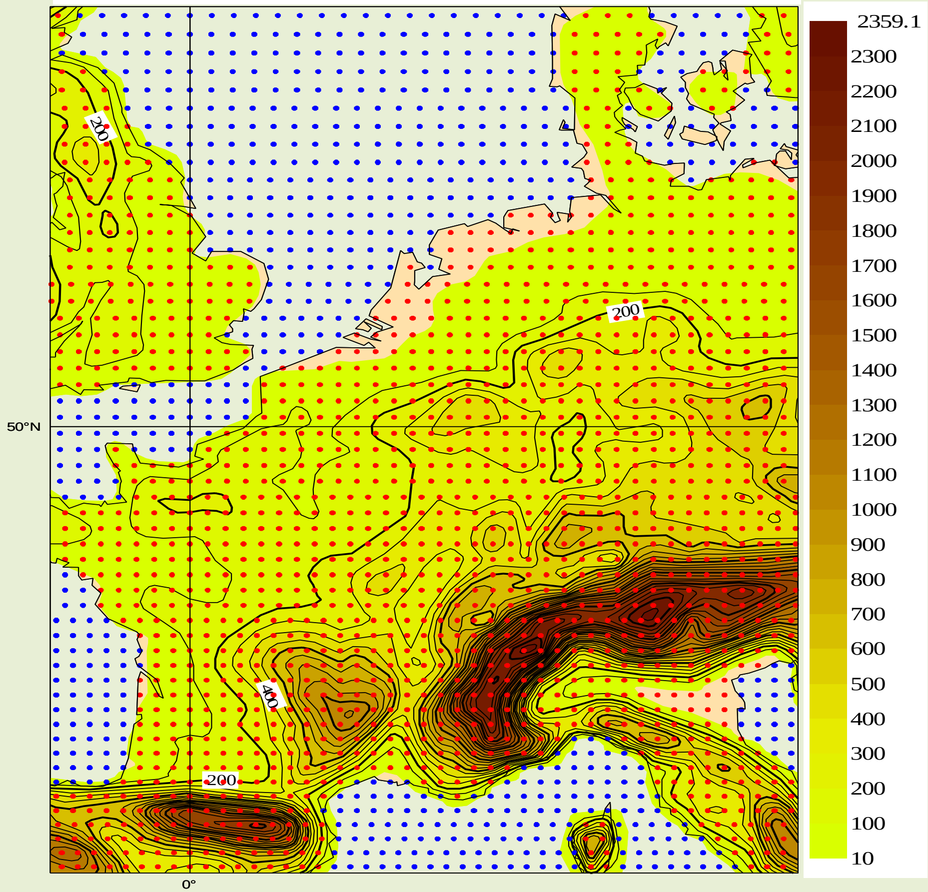
Model grids

OROGRAPHY, GRID POINTS AND LAND SEA MASK IN TL 1279 (OP 2010) ECMWF MODEL
orography shaded (height in m), land grid points (red), sea grid points (blue)



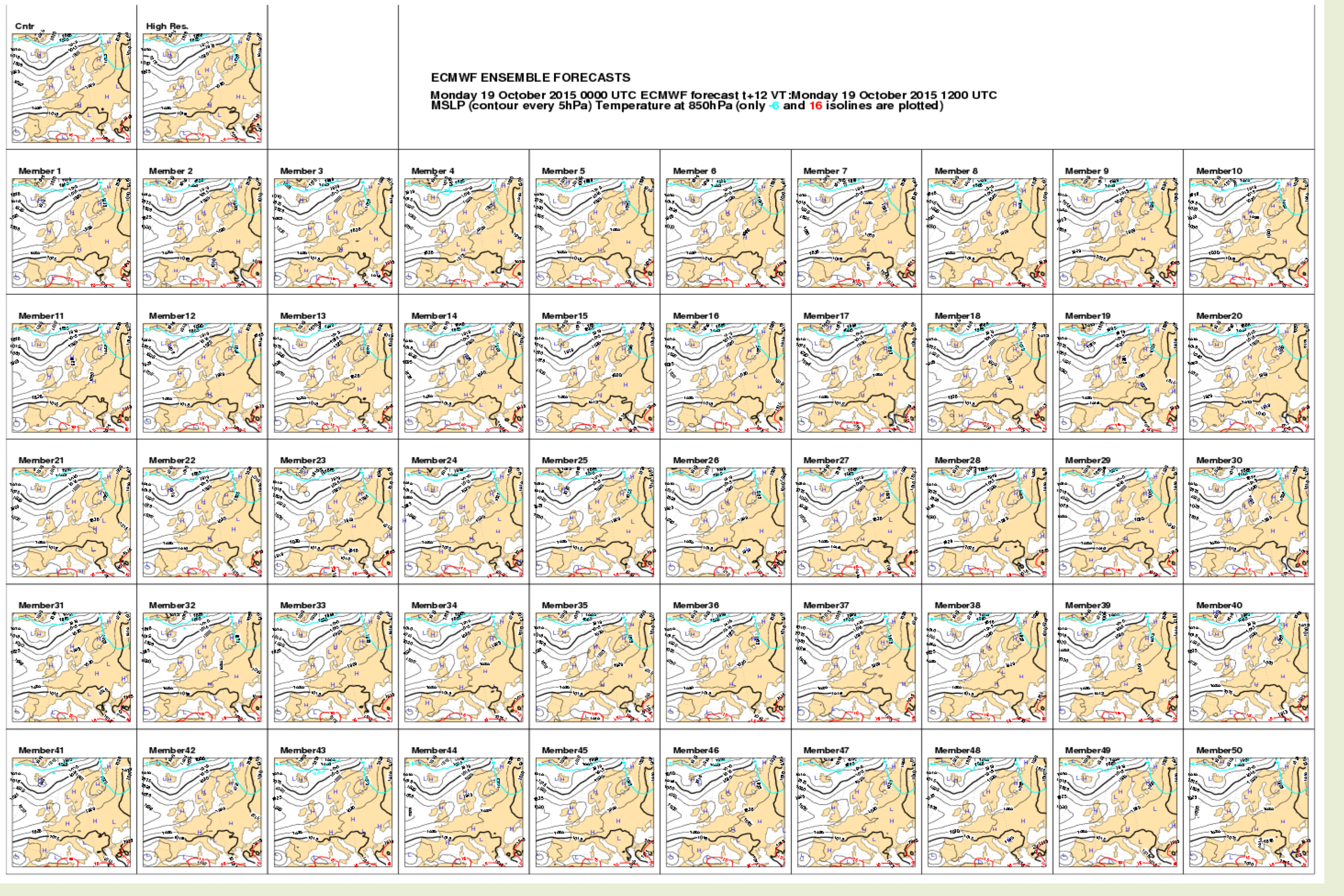
HIGH RES (9km)

OROGRAPHY, GRID POINTS AND LAND SEA MASK IN TL 639 (EPS 2010) ECMWF MODEL
orography shaded (height in m), land grid points (red), sea grid points (blue)

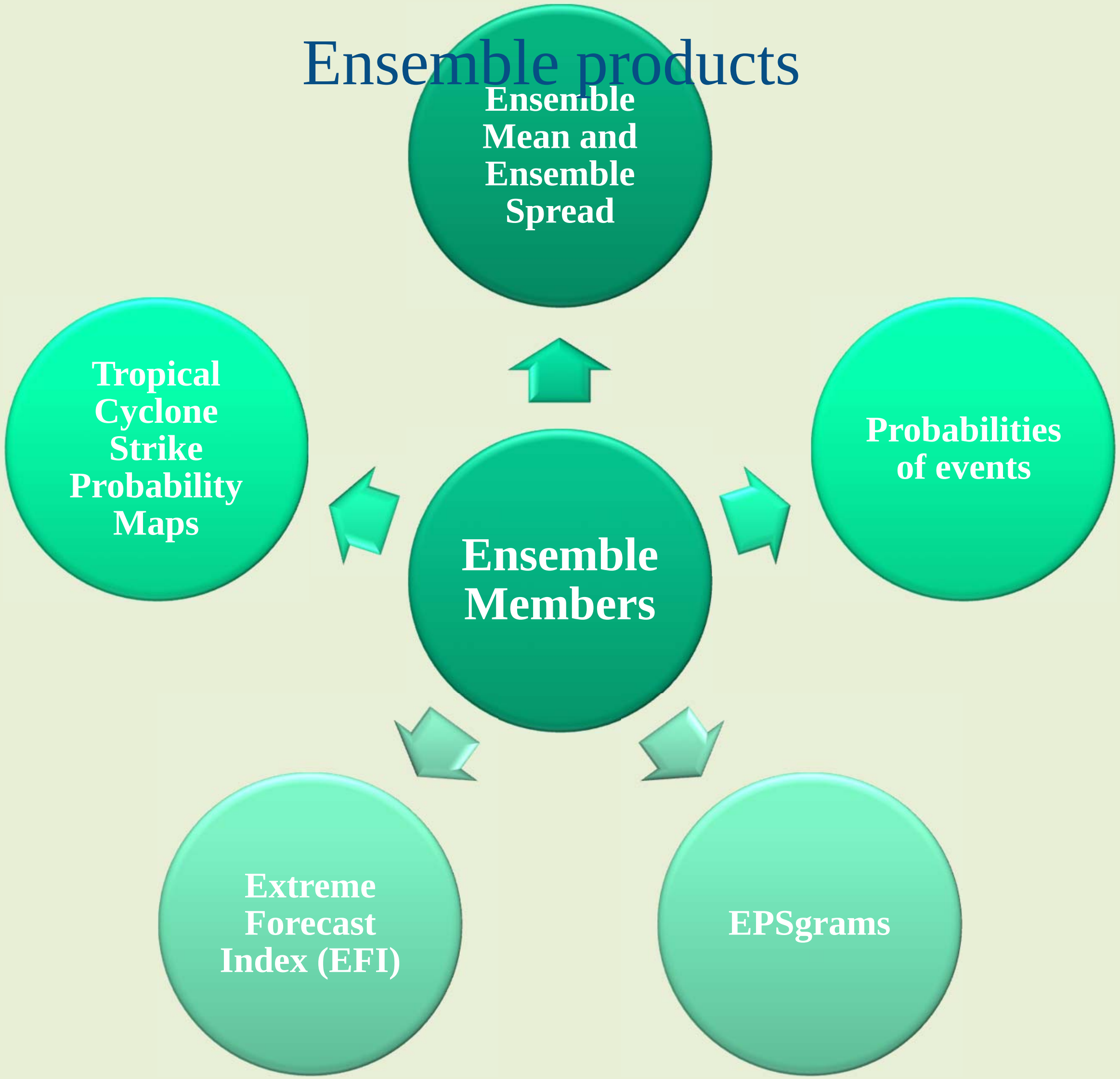


ENSEMBLE (32 km)

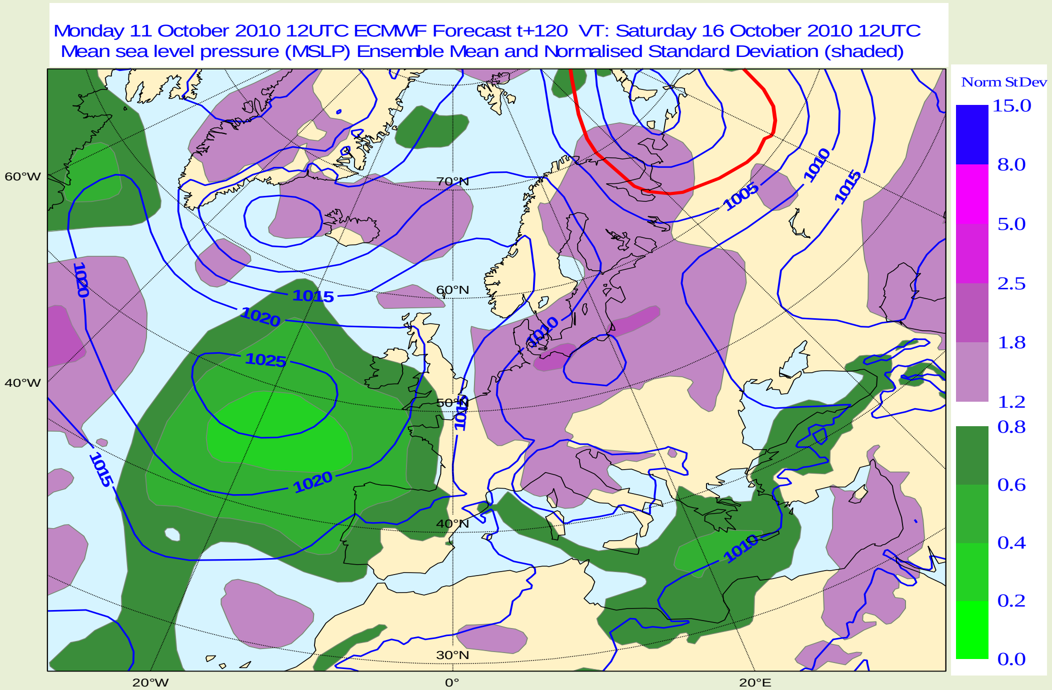
Ensemble forecasts

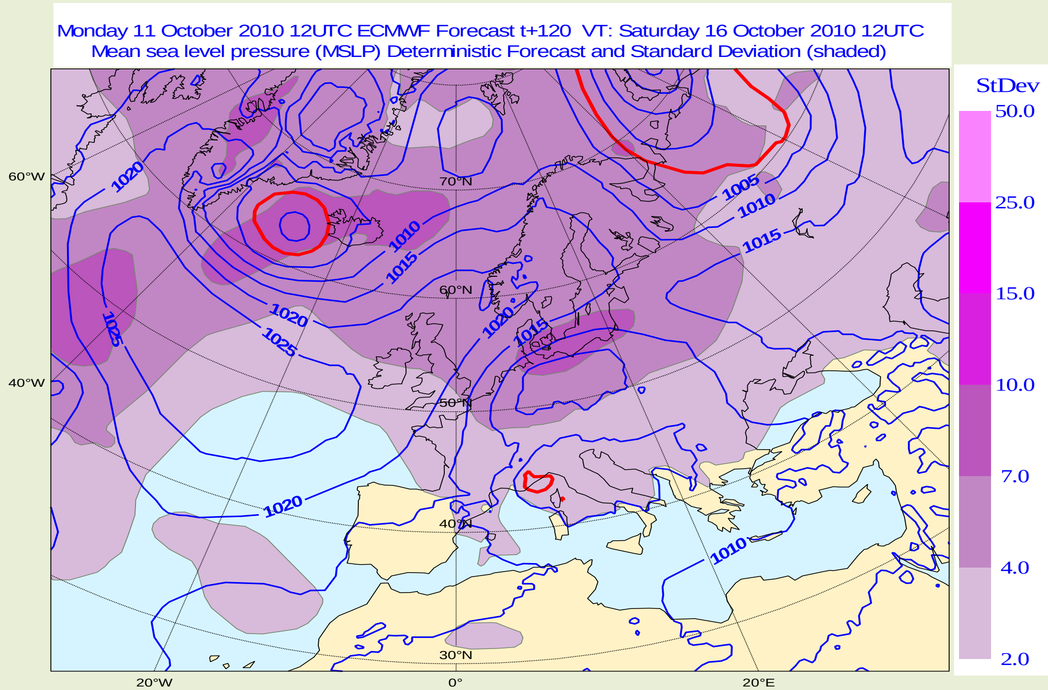


Ensemble products

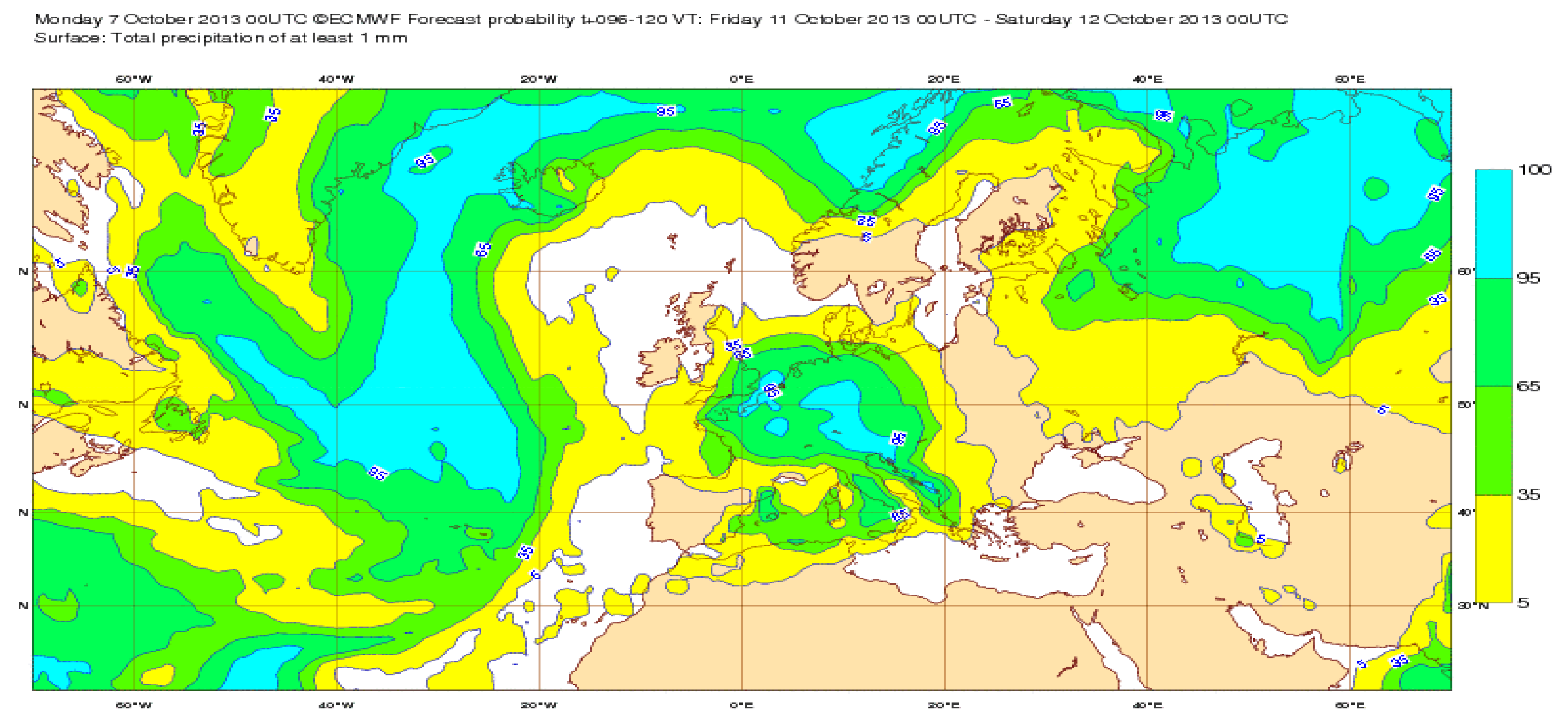


ECMWF Ensemble mean and spread

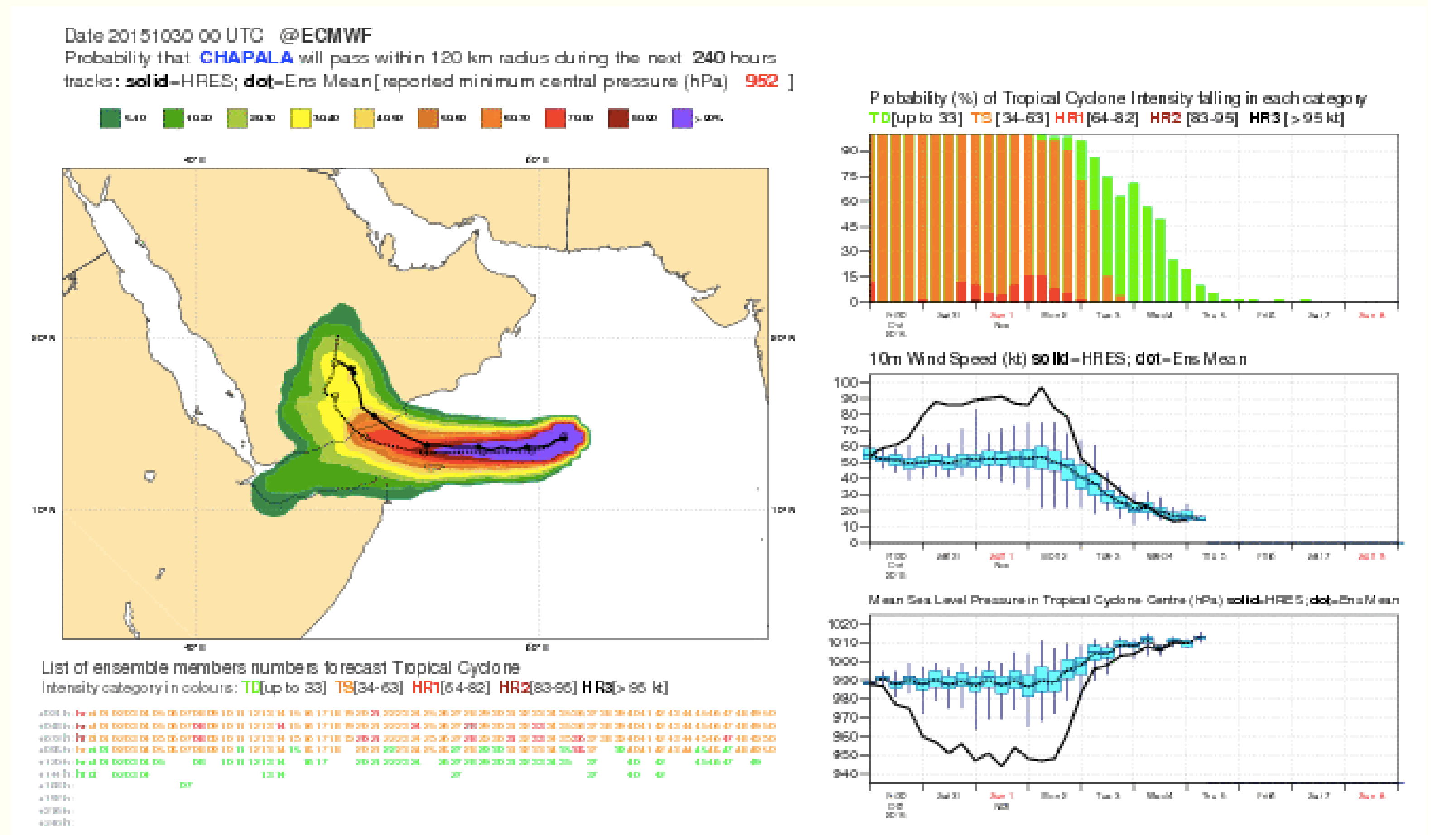




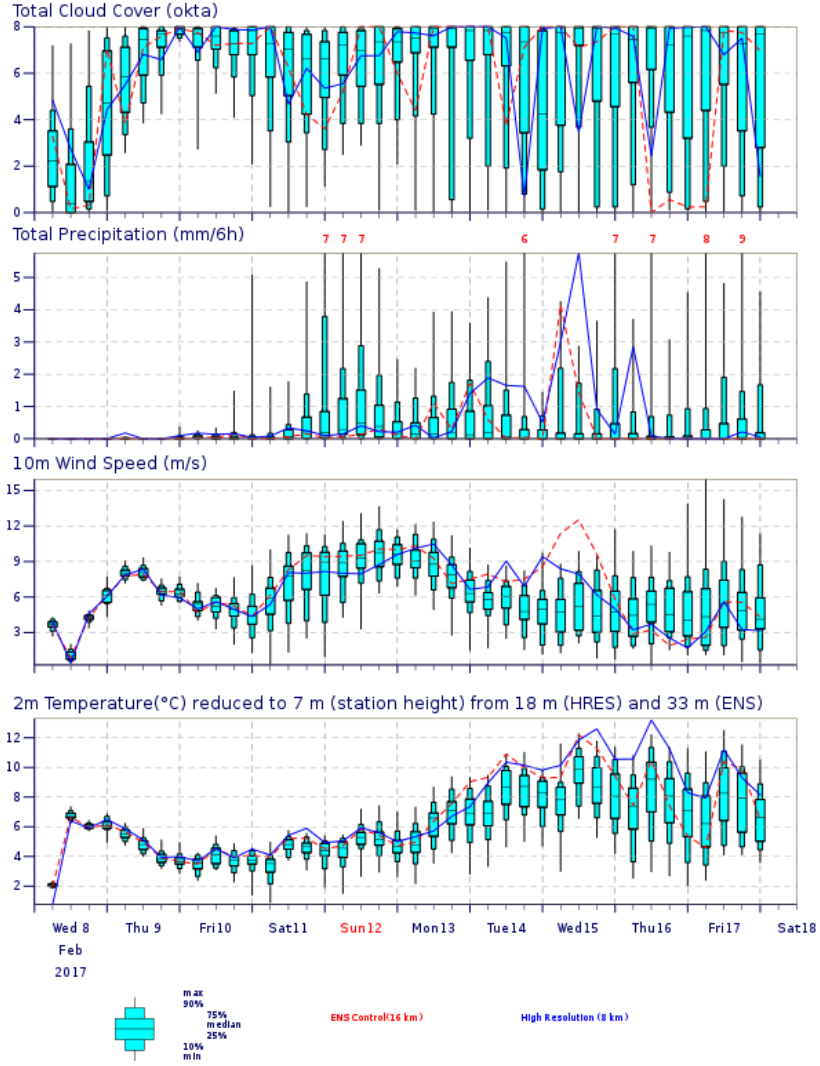
ECMWF Probabilities for 24h precipitation > 1 mm



ECMWF Tropical cyclone tracks

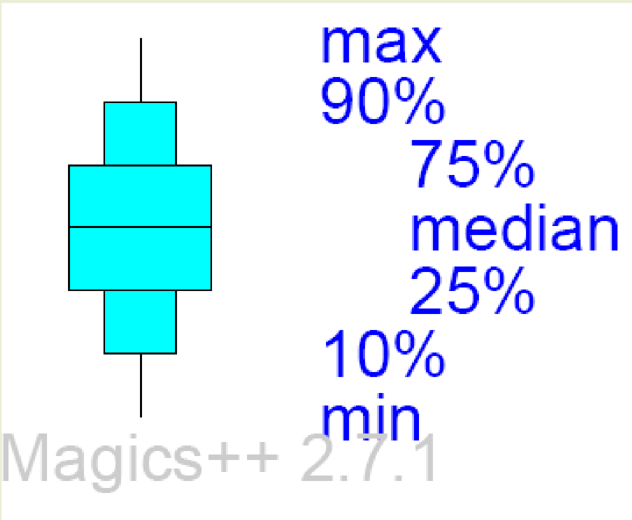


ENS Meteogram
Dublin 53.49°N 6.14°W (ENS land point) 7 m
High Resolution Forecast and ENS Distribution Wednesday 8 February 2017 00 UTC



ENSgram
…..or what are all those boxes?

- On the ENSgram you can see: ENS members, Control forecast (red) and HRES forecast (black)
- Values of the parameters are ordered increasingly



Max value of the distribution

90th percentile

75th percentile

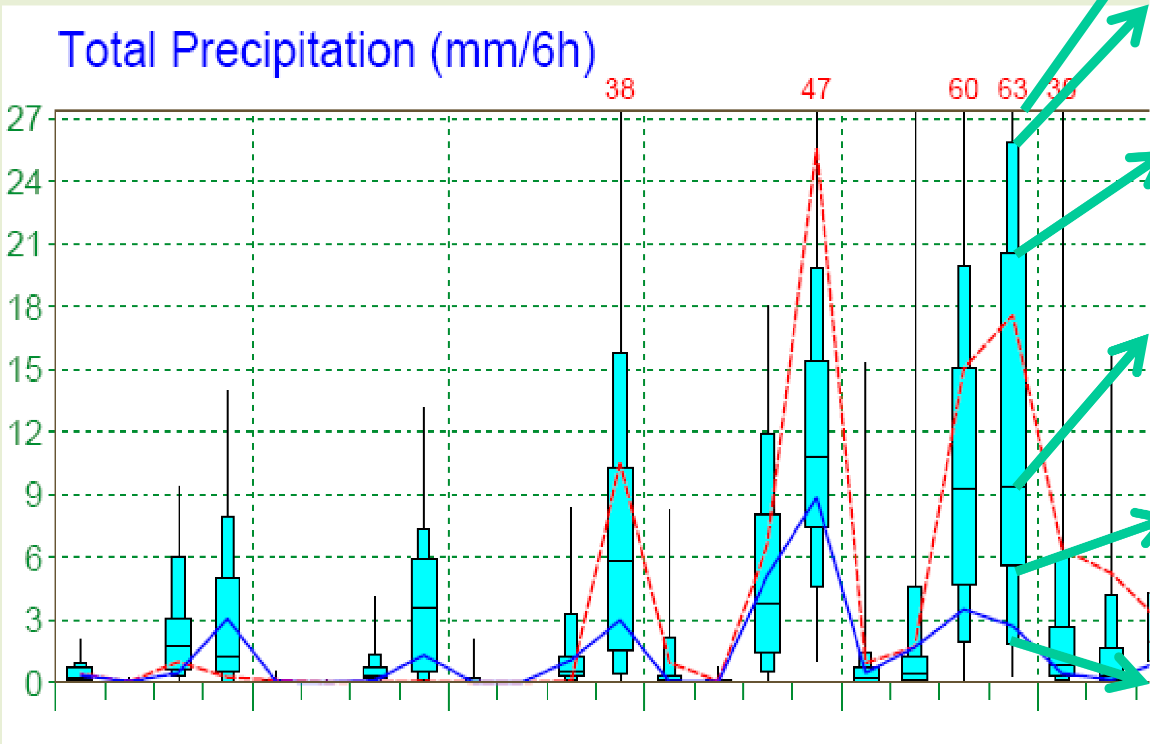
Numerical value separating to higher half of a sample to the lower half

25th percentile

10th percentile

Min value of the distribution

ENSgram
…..or what are all those boxes?



- 63 mm/6hr: max value
- 10% (90%) probability of precipitation greater (less) than 25 mm/6hr
- 25% (75%) probability of precipitation greater (less) than 20 mm/6hr
- 50% probability of precipitation greater (less) than 9 mm/6hr
- 75% (25%) probability of precipitation greater than 6 mm/6hr
- 90% (10%) probability of precipitation greater (less) than 2 mm/6hr

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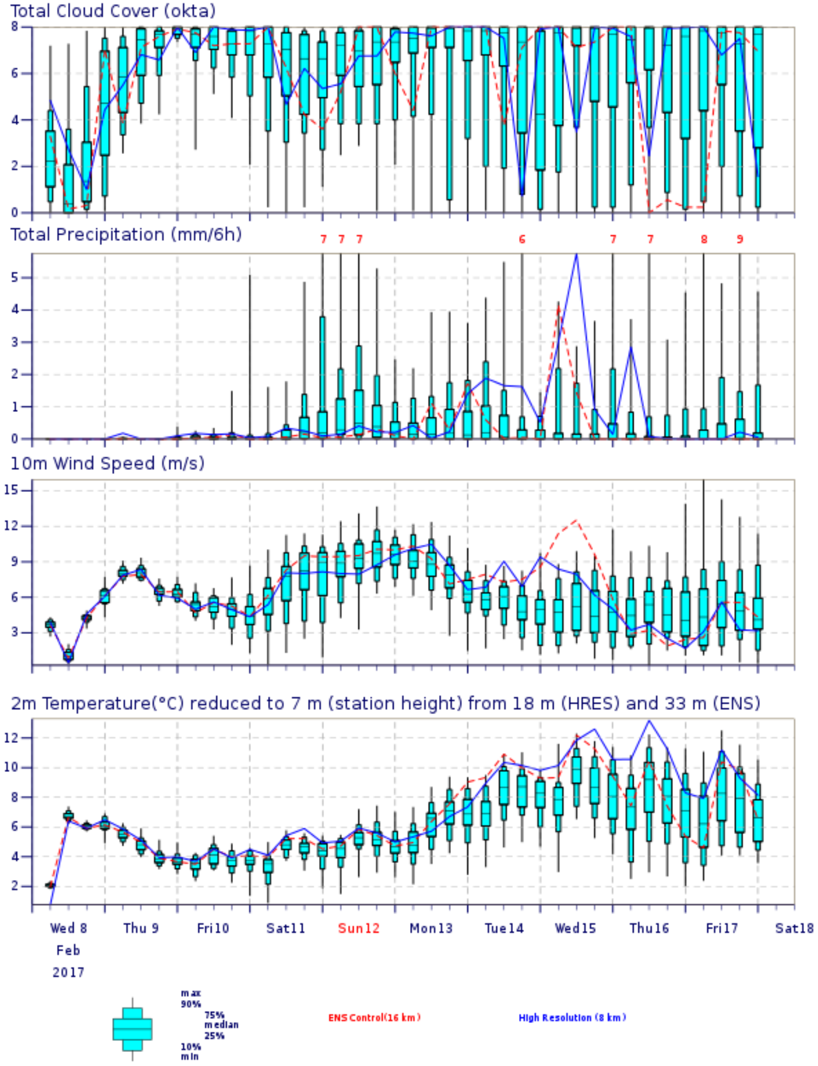


Communicating uncertainty

All forecasts have errors

It can be important to know the uncertainty in a forecast

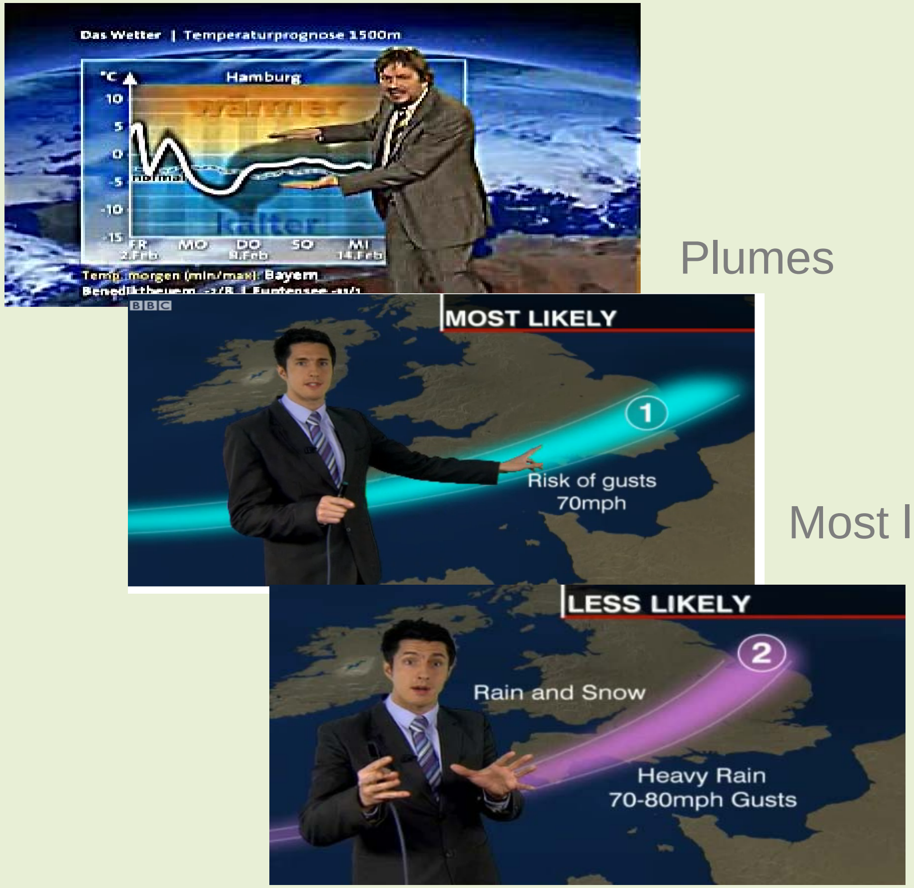
(what else could happen? what is the worst possibility?)

This is not a new idea

- Forecasters are used to adjusting their forecast with their experience of model errors (flow dependence, forecast range dependency)
- Inconsistency of the forecasts (in time, from one model to the other) were used as indication of the (un-)predictability of scenarios

Ensembles provide an explicit, detailed representation of model uncertainties, and potential of unusual events

Uncertainty information to public

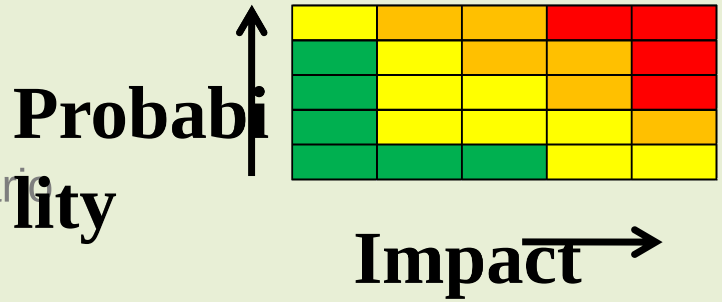


Plumes

Most likely scenario

Least likely scenario

Warnings



Societal impact

Communicating Uncertainty / Probability

- It is difficult to think in a probabilistic manner
- People (meaning us!) like a narrative, a story
  - Nightly weather broadcast usually follows this pattern
  - Has to be understandable and "memorable" to be of any value
  - Helps to put context around each person's experience of the weather
- We are programmed to look for cause and effect
- Random effects are something we don't easily assimilate

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Probabilistic elements in the weather

- Showers are probabilistic in nature
  - Can predict most likely places and times
  - Cannot predict exact places and times with any precision
  - Hail/Sleet showers are a real hazard on the roads
- Clouds… and therefore sunshine
- Fog
- Wind Gusts
- Small, intense, low pressure systems
- Tropical Cyclones / Hurricanes
- Tornados

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More deterministic elements in the weather

- The path of large weather systems
- Wind speed and direction (unless wind is extreme)
- Temperatures
- High Pressure Systems
- Seasonal patterns (e.g. the monsoon)

Human elements in forecasting

- Optimist or pessimist?
  - Can be coloured by recent experience
- Case study in Switzerland:
  - Threatening situation – thunderstorm warning issued – no thunderstorms – criticism…
  - One week late – similar threatening situation – no warning issued – thunderstorms occurred, leading to deluge and bridges washed away…
- Forecasters must try to avoid ingrained biases, experiental biases.
- Probabilistic forecasts help to give a "reality check"