LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Probabilistic Weather Prediction

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Oberpfaffenhofen

Summary

(Hagedorn 2009)

- "Nothing is certain"

  …in this world there is nothing certain but death and taxes.
  (Benjamin Franklin)

- In many situations, decisions have to be based on probabilities

  …the theory of probabilities is at bottom only common sense reduced to calculus.
  (Pierre-Simon, Marquis de Laplace)

- Interpretation of probabilities is sometimes not straightforward

  …math is hard, let's go shopping.
  (Barbie)

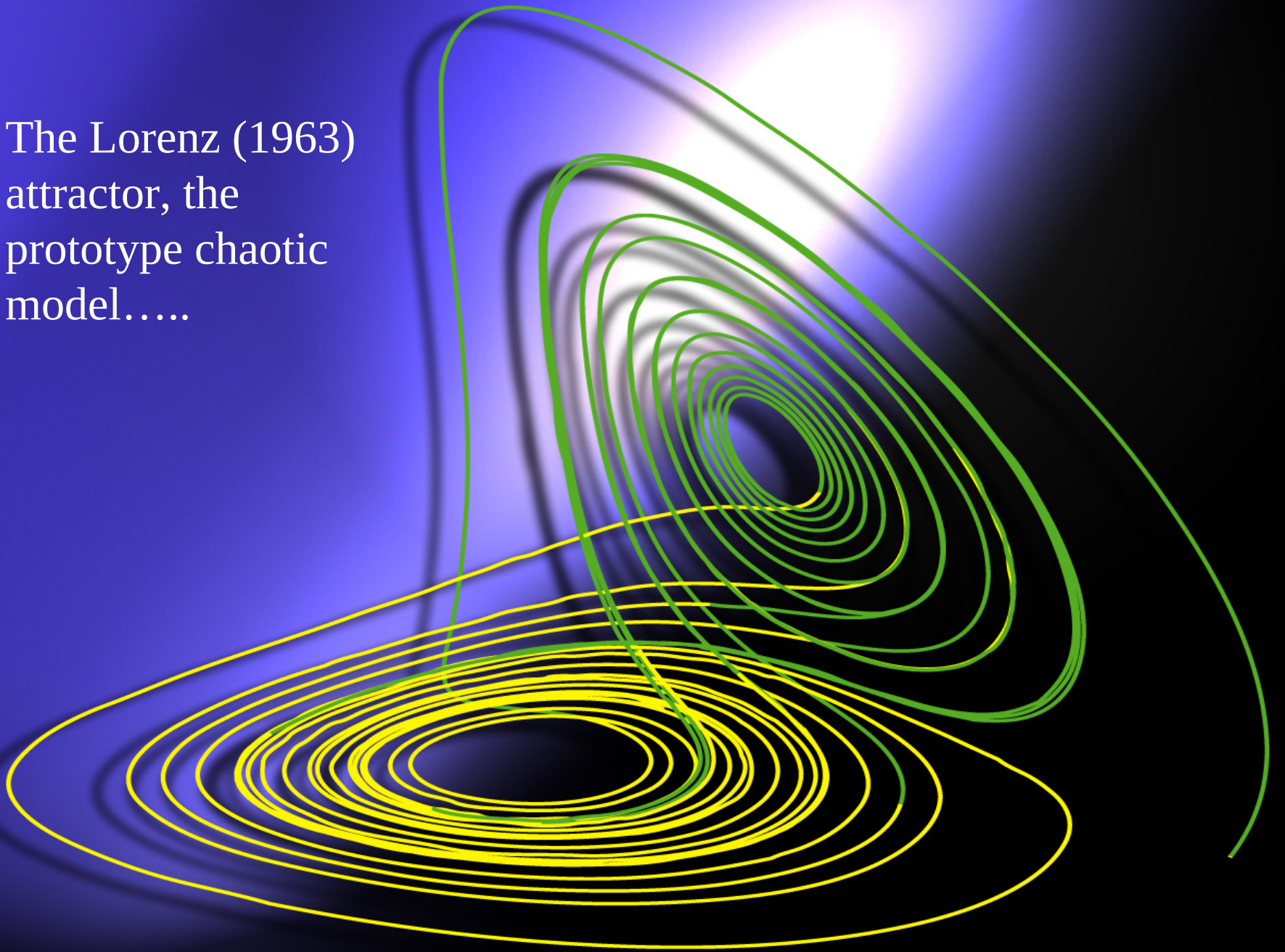
- Appropriate presentation can help to make the right decisions

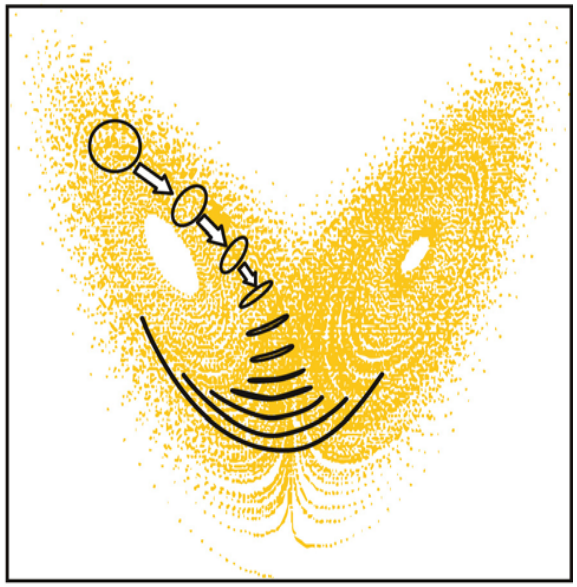
  …solving a problem simply means representing it so as to make the solution transparent.
  (Herbert A. Simon)

Outline

1. Predictability
2. Nowcasting and Forecasting
3. Probabilistic Predictions and Verification
4. Examples from Met Office

The Lorenz (1963) attractor, the prototype chaotic model…..





(Palmer 2009)

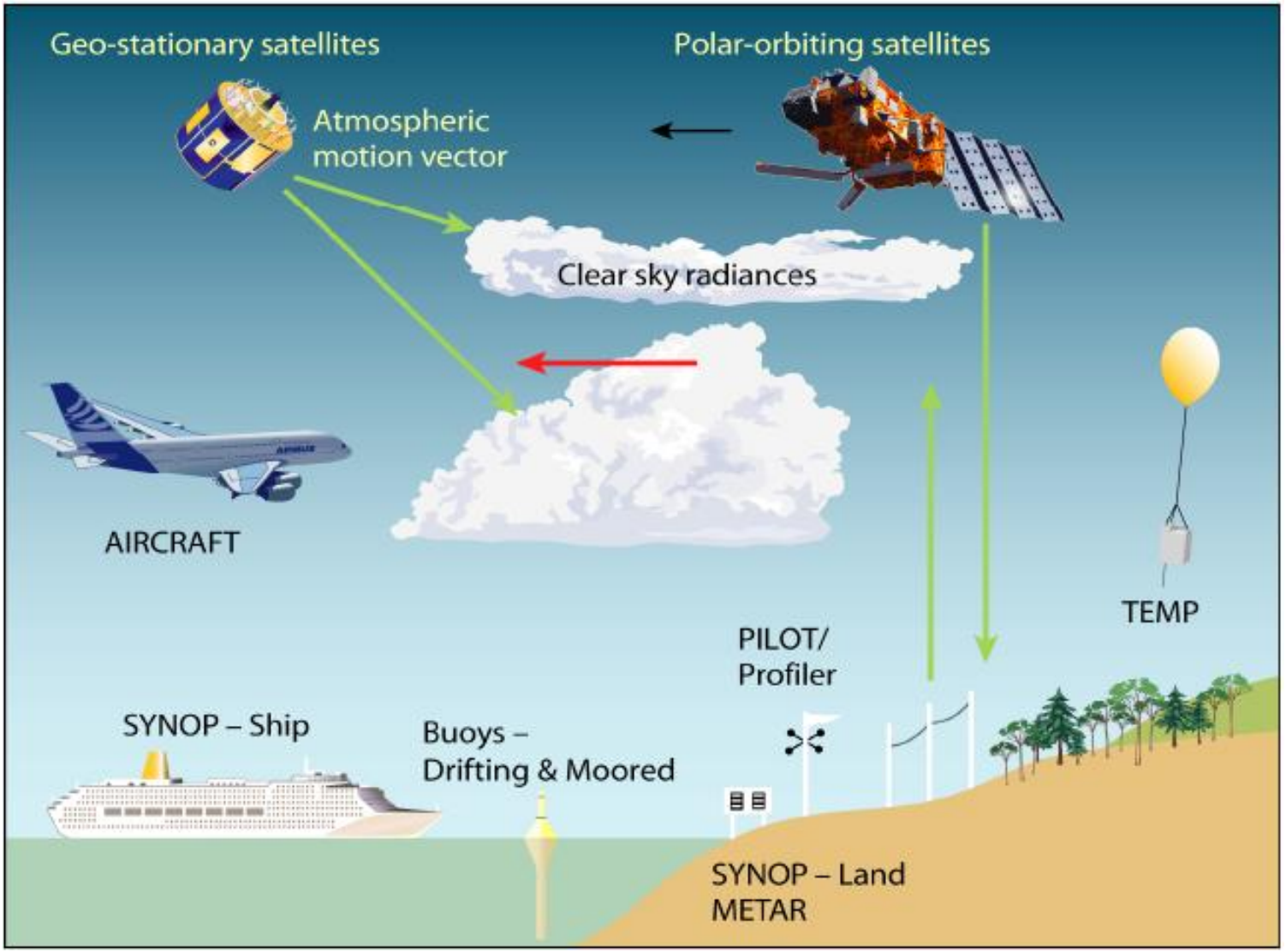
$$\frac{dX}{dt} = F[X] \quad \text{is a nonlinear system}$$

$$\Rightarrow \frac{d\delta X}{dt} = \frac{dF}{dX} \quad \delta X \equiv J \quad \delta X$$

Since F is a nonlinear function of X

$$\Rightarrow J = J(X)$$

Observations

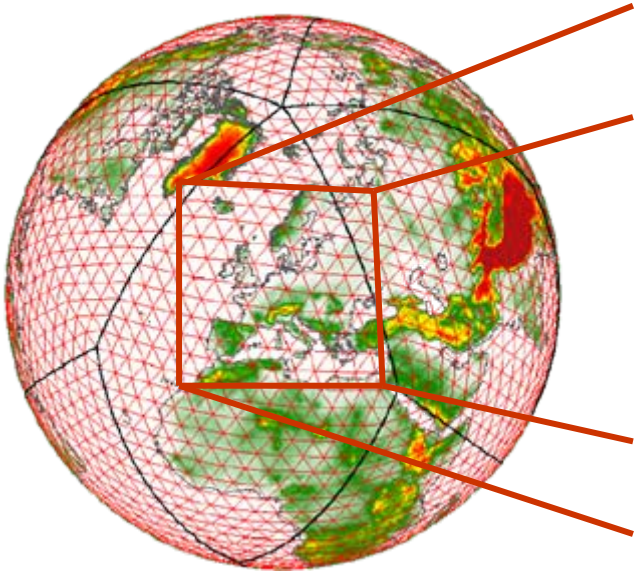


Nowcasting

- Extrapolation of observed values in space and time
- Persistence, lagrangian, simple physical model

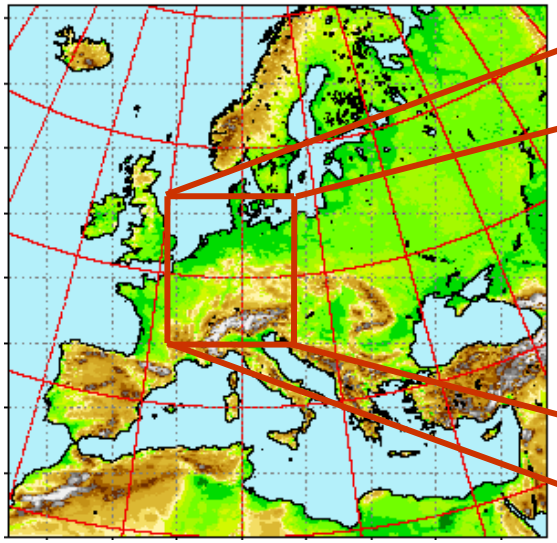
The operational NWP system at DWD

GME 30 km



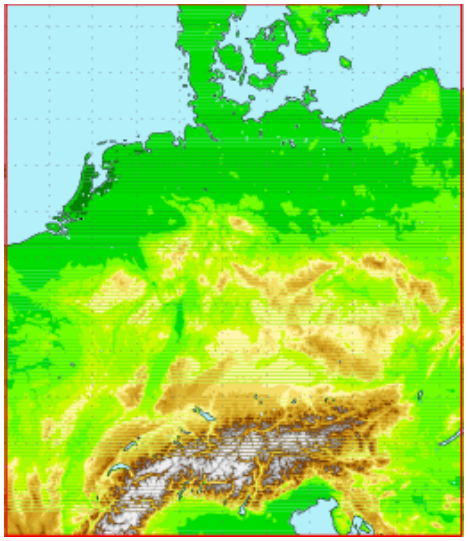
- hydrostatic equations
- parameterized convection

COSMO-EU 7 km



- compressible equations
- parameterized convection

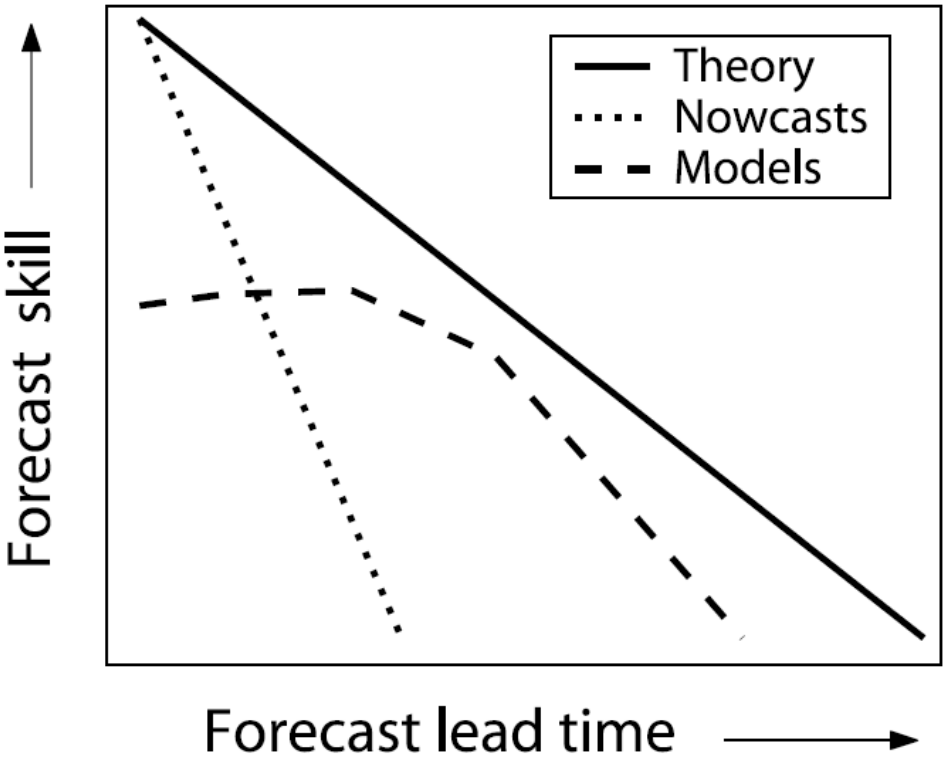
COSMO-DE 2.8 km



- compressible equations
- explicit convection

(Seifert 2010)

Forecast Skill of Nowcasting and NWP



- Theory:
  theoretical limit of predictability (chaos)

- Nowcasting Methods:
  very high initial skill followed by rapid decrease

- NWP Models:
  skill over a longer period since dynamical processes simulated

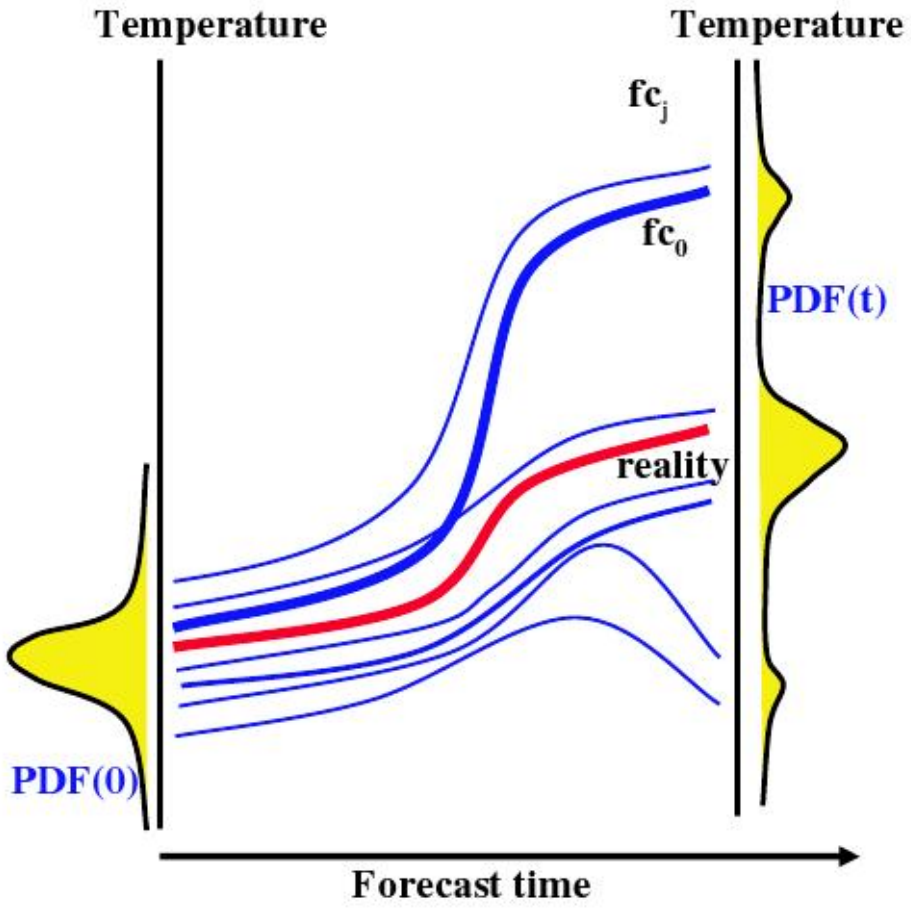
(after Kober 2009)

Lin et al, 2005; Golding, 1998

3. Ensemble prediction systems

A complete description of weather prediction can be stated in terms of an appropriate probability density function (PDF).

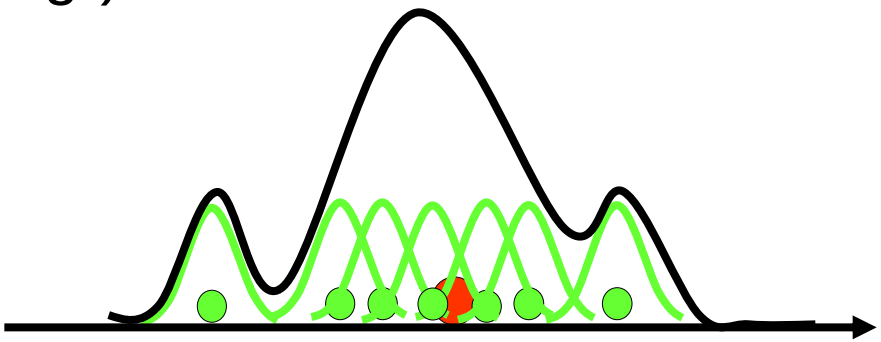
Ensemble prediction based on a finite number of deterministic integration appears to be the only feasible method to predict the PDF beyond the range of linear growth.



(Buizza 2009)

Constructing Probabilistic Forecasts

- Define a probability distribution around each ensemble member (“dressing”)

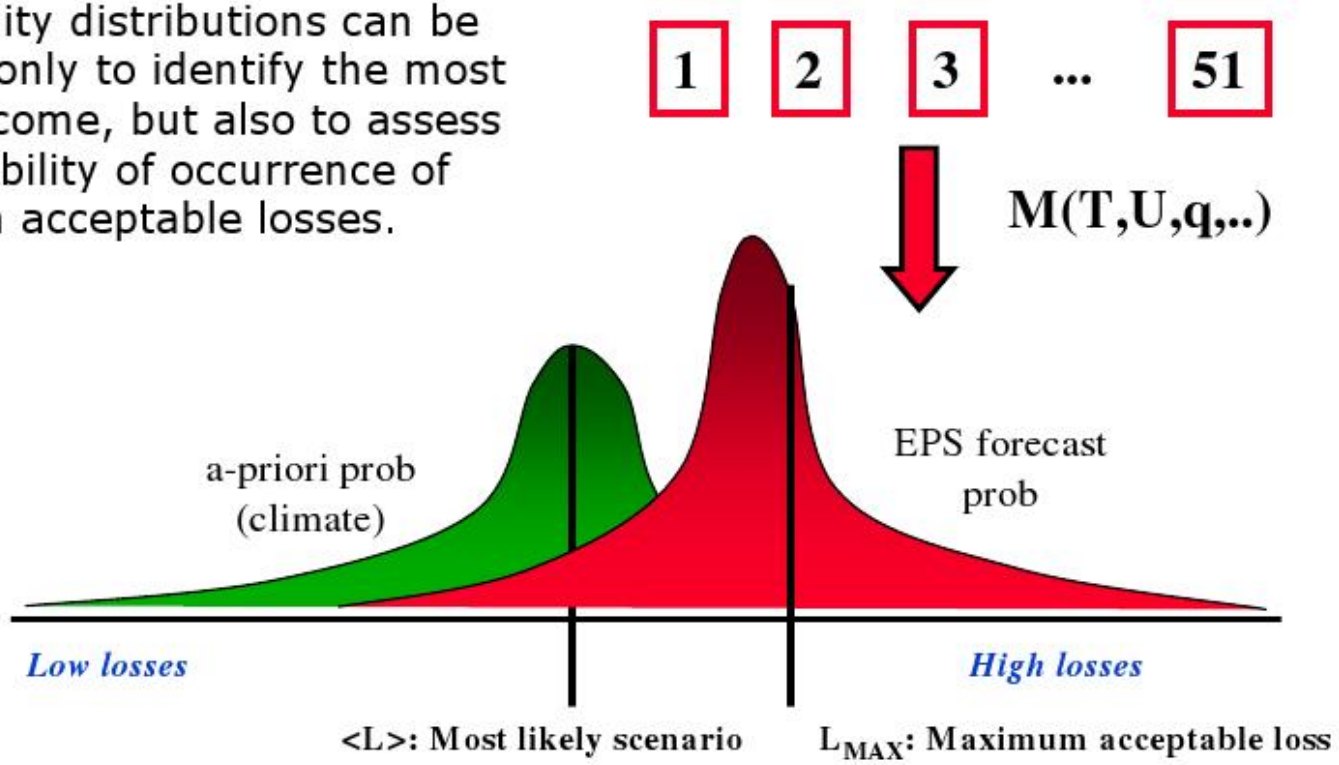


- A number of methods exist to find appropriate dressing kernel (“best-member” dressing, “error” dressing, “second moment constraint” dressing, etc.)
- Average the resulting n_{ens} distributions to obtain final pdf (Bayesian model averaging, logisitic regression, “analogs”, blending, etc.)

(after Hagedorn 2009)

3. The value of ensemble prediction: scenario analysis

- Ensemble forecasts can be *translated* into forecast probability distribution of gains/losses.
- Probability distributions can be used not only to identify the most likely outcome, but also to assess the probability of occurrence of maximum acceptable losses.



(Buizza 2009)

Assessing the quality of a forecast system (Hagedorn 2009)

- Characteristics of a probabilistic forecast:

Rank Histogram

- **Consistency**: Do the observations statistically belong to the distributions of the forecast ensembles? (consistent degree of ensemble dispersion)

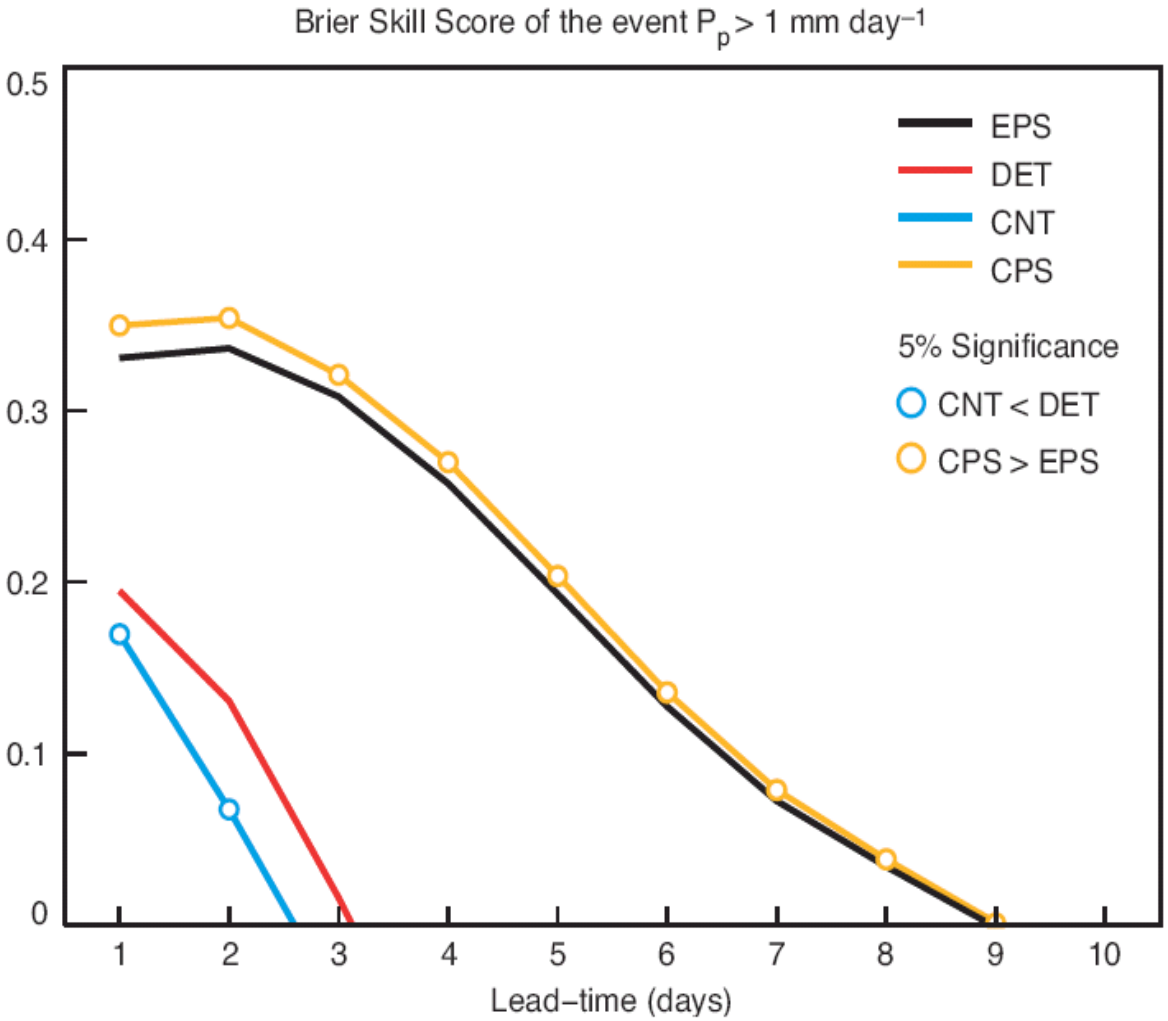
Reliability Diagram

- **Reliability**: Can I trust the probabilities to mean what they say?
- **Sharpness**: How much do the forecasts differ from the climatological mean probabilities of the event?
- **Resolution**: How much do the forecasts differ from the climatological mean probabilities of the event, and the systems gets it right?

Brier Skill Score

- **Skill**: Are the forecasts better than my reference system (chance, climatology, persistence,...)?

Brier-Score based combination



Mark Rodwell et. al.

Numerical forecast systems in Europe

global high resolution models

TIGGE (10 global EPS)

Thorpex Interactive Grand Global Ensemble

Limited area short range ensembles (1-3 days)

AEMET SREPS
Spain

PEACE
France

GLAMEPS
LAMEPS (Hungary)
ALADIN-LAEF (Austria)
NORLAMEPS (Norway)

MOGREPS - NAE
UK

SRNWP-PEPS
"Poor mans" ensemble
Eumetnet, Germany

COSMO SREPS
Italy

Limited area medium range ensemble

(2-5 days)

COSMO LEPS

TIGGE-LAM: archive at ECMWF (-24 hours)

Some examples of current developments at the Met Office

1. High-resolution (1.5 km) ensemble
2. Probabilistic precipitation forecasts
3. Scale-dependent blending of nowcast and forecast

(courtesy of Nigel Roberts)

Development of a 1.5 km ‘downscaling’ ensemble system at the Met Office

Embed UK 1.5 km model forecasts (UKV model) in selected MOGREPS-R (18 km) members

Based on evidence that mesoscale uncertainty has the greatest impact on the accuracy of local weather forecasts and high resolution is necessary to represent local weather

Selection required because it will only be possible to run a few members at 1.5 km

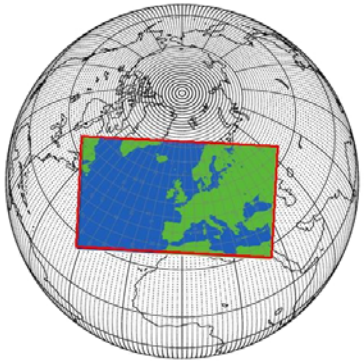
Target high-impact weather ~6 to 36 hours ahead

Demonstration system by 2012

(courtesy of Nigel Roberts)

Regional MOGREPS (MOGREPS-R)

(Met Office Global and Regional Ensemble Prediction System)



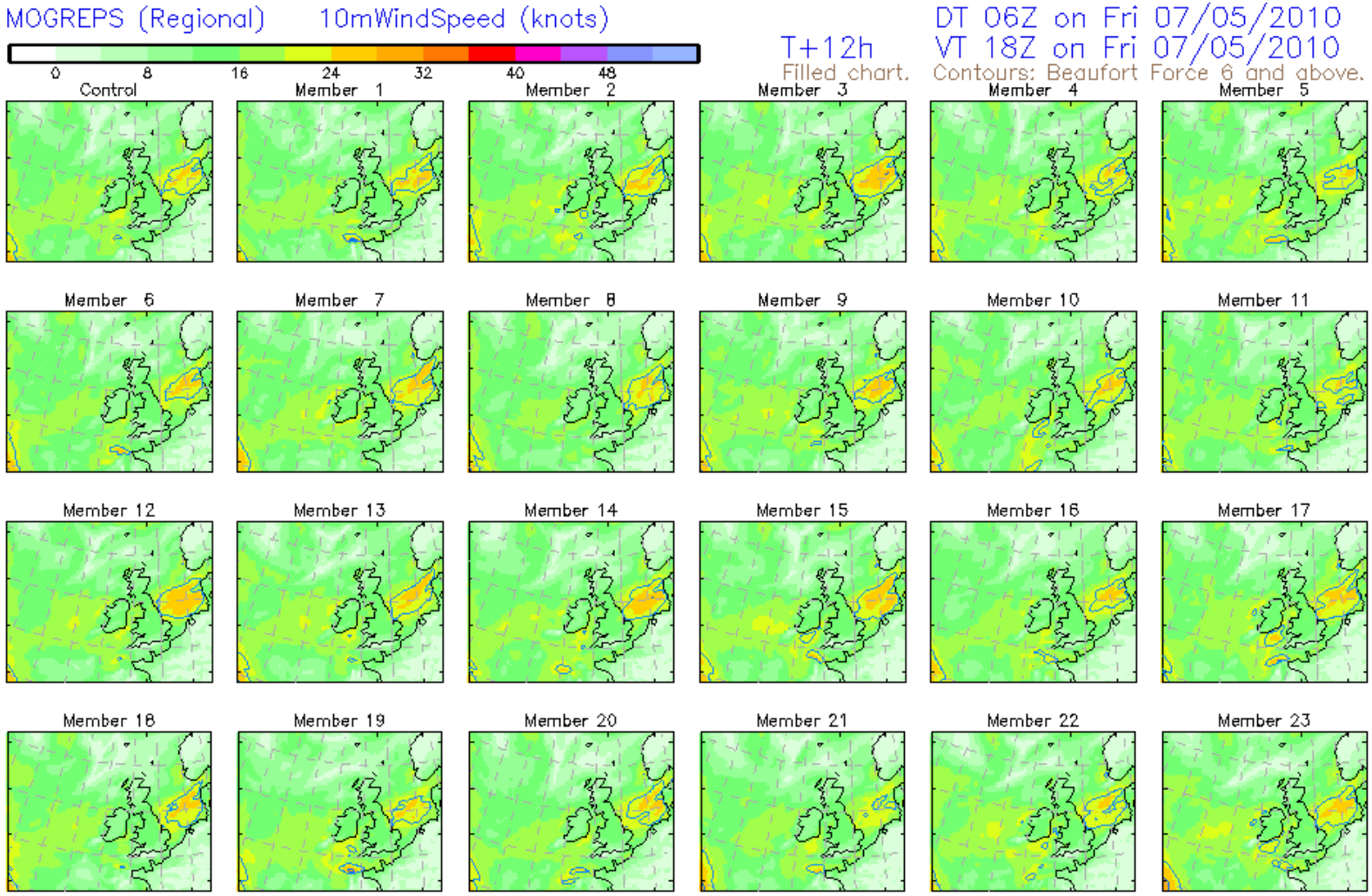
- Regional Ensemble (18 km,L38 – T+54), currently run at 06Z and18Z
- 23 perturbed members + control
- ETKF Initial Conditions
- Fully operational
- Currently being upgraded to 70 levels

(courtesy of Nigel Roberts)

Example MOGREPS-R ensemble forecasts

T+12

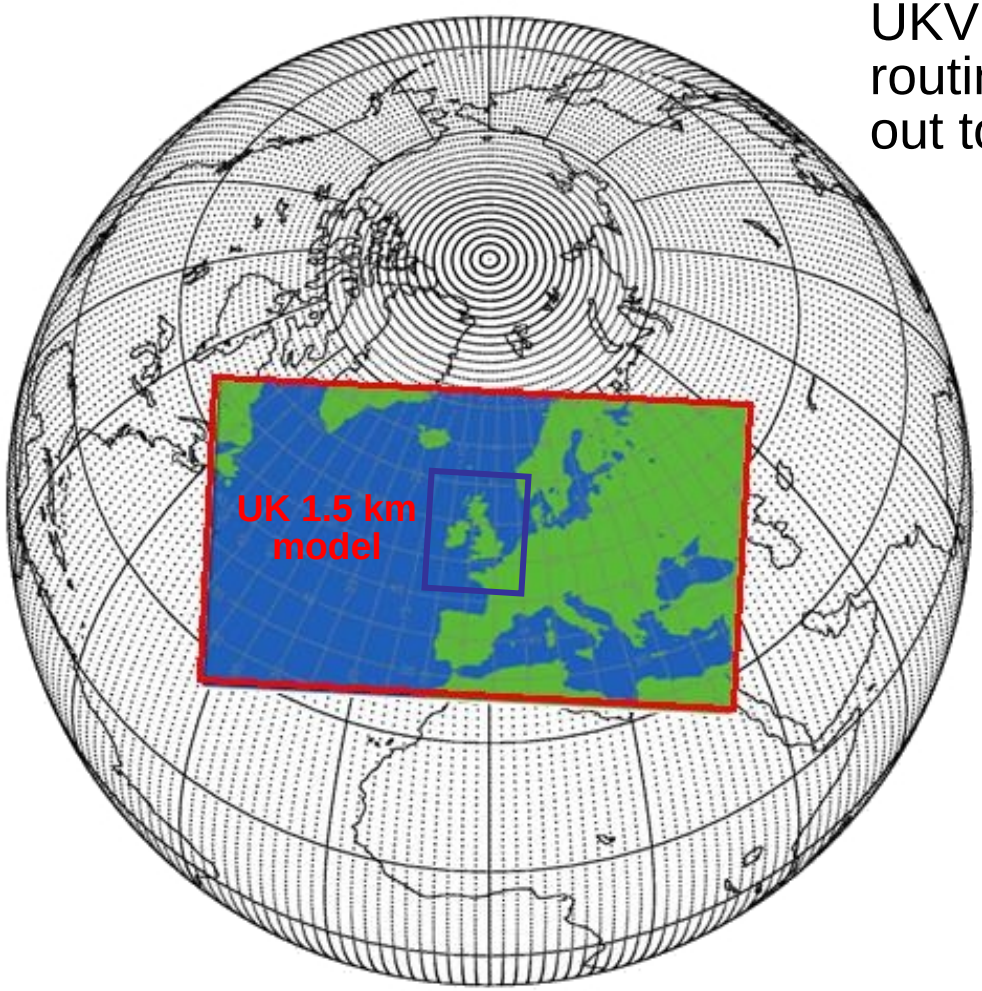
Variability – but can't represent many local effects



(courtesy of Nigel Roberts)

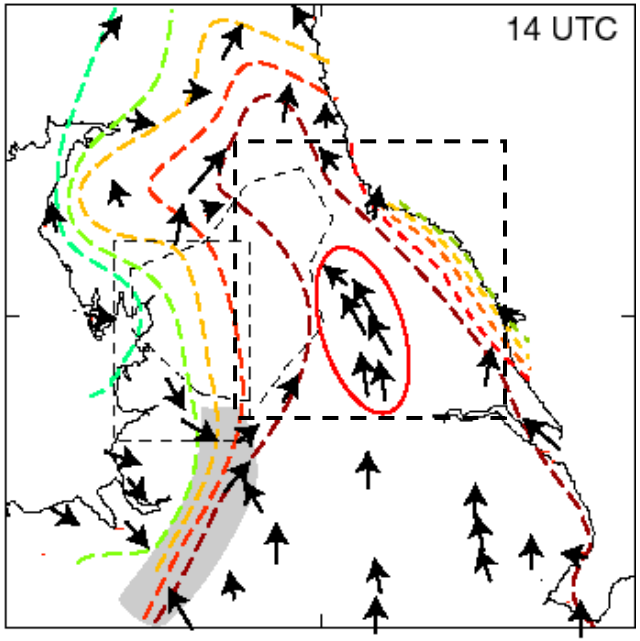
Regional MOGREPS and UKV

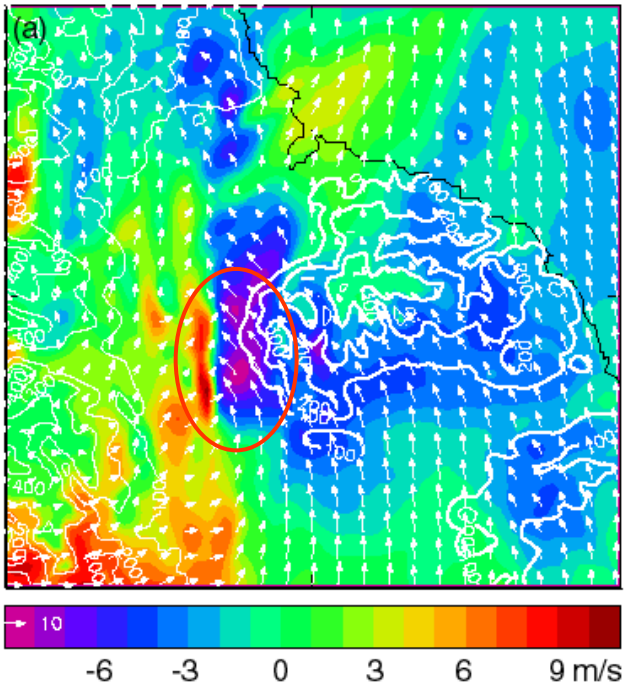
UKV (1.5km) now running routinely every 6 hours out to T+36



(courtesy of Nigel Roberts)

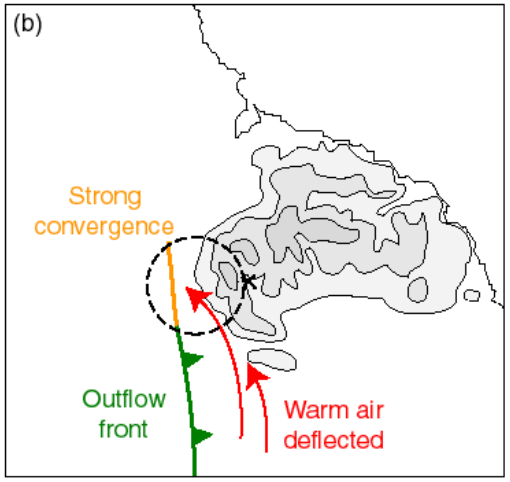
Example 1km forecast of low-level winds





Deflection of flow and local convergence lines were predicted by 1km model

- But still local uncertainties



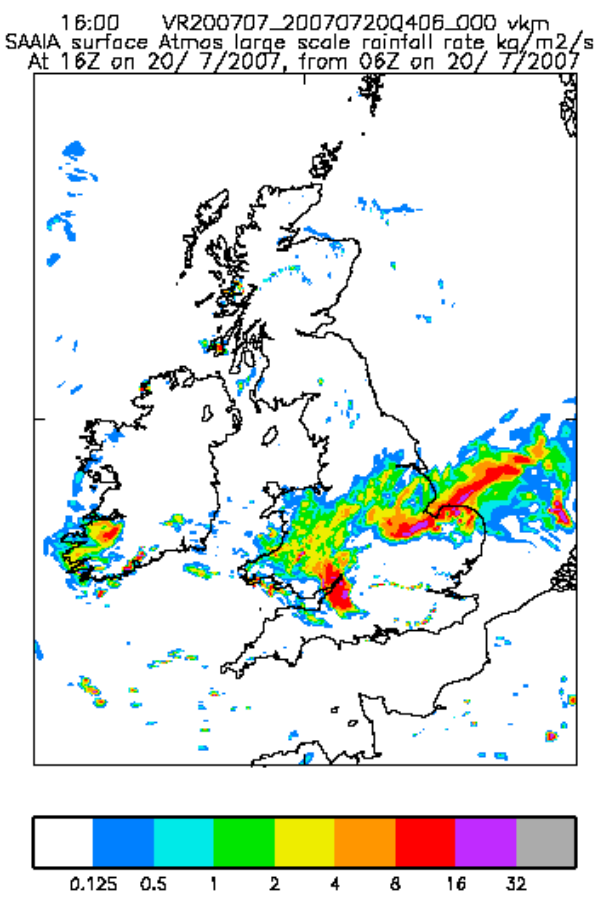
(courtesy of Nigel Roberts)

Example of a UKV (1.5km) precipitation forecast

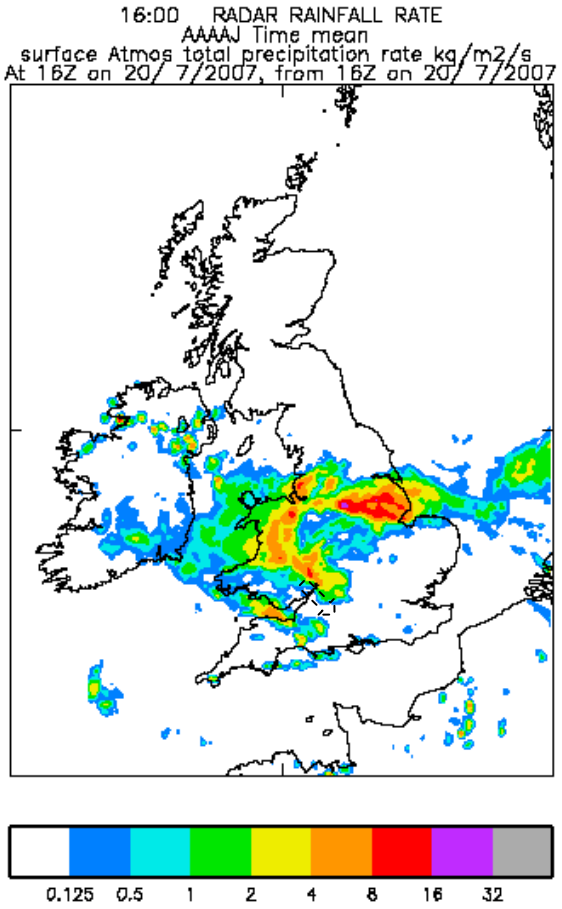
20th July 2007

Forecast good but with errors in rainfall distribution (and winds)

T+10 forecast



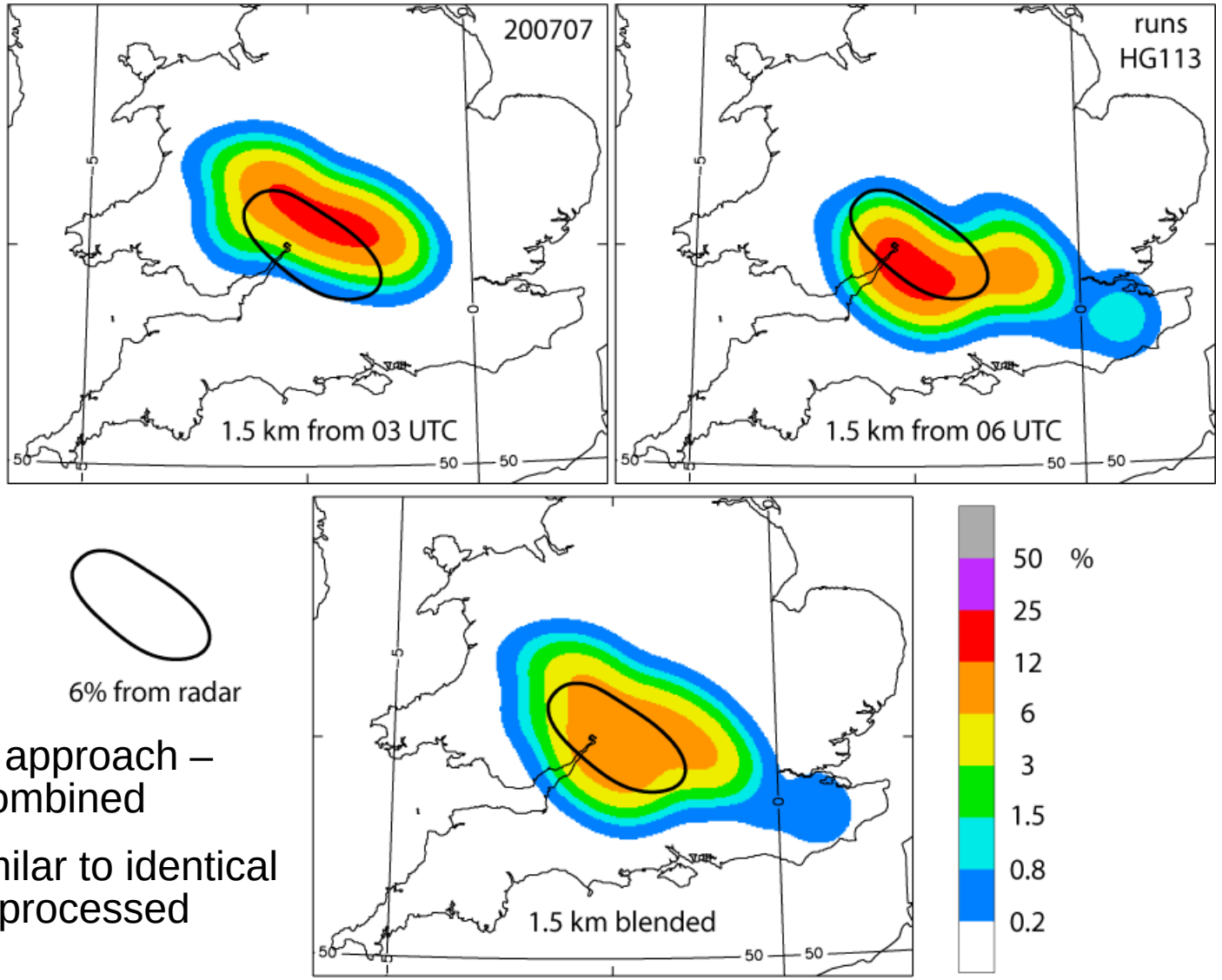
radar



(courtesy of Nigel Roberts)

Probabilities from UKV forecasts

Rainfall exceeding a threshold (could be wind information)



Neighbourhood approach – two forecasts combined

Probabilities similar to identical neighbourhood processed radar

(courtesy of Nigel Roberts)

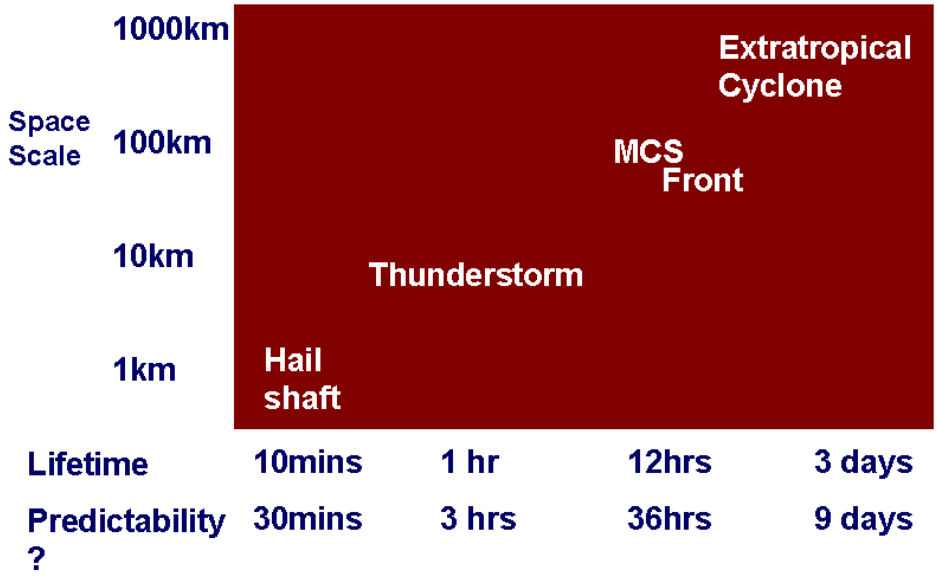
Blending ensembles
STEPS nowcasting ensemble with UKV and NAE ensembles

- **Generate 2 km resolution, seamless ensembles with a range of at least 48h**
- **Produce ensembles much larger than that available from MOGREPS-R (18km) and UKV (1.5km) ensembles**
  - **Use of noise with space-time statistical properties inferred from radar and UKV to perturb scales lacking skill and downscale MOGREPS-R**
  - **Use multiple realisations of the noise to generate large ensembles from small (~6) MOGREPS-R / UKV ensembles (generated from representative members of clustered, 24 member MOGREPS-R ensembles)**

Courtesy of Clive Pierce

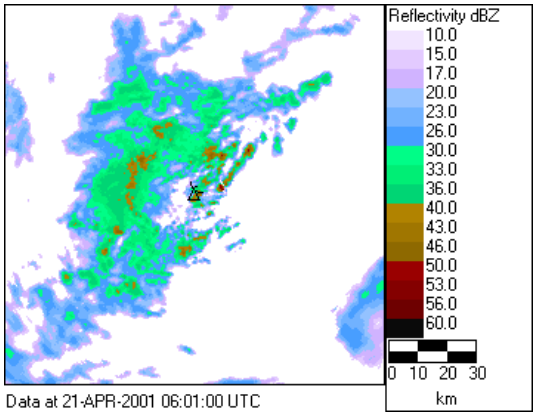
Blending ensembles

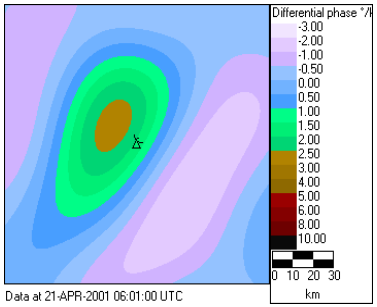
- **Use cascade framework (Bowler *et al*., 2006)**
- **Important sources of variability exist over wide range of scales**
- **Life times and predictability of features typically increase with their size**

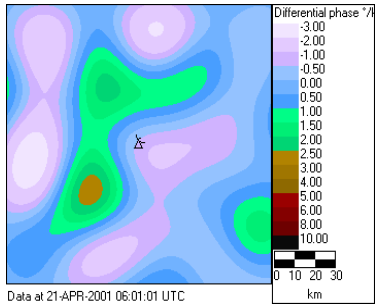


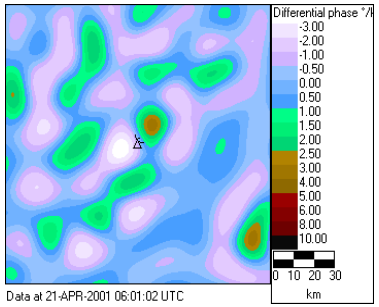
Courtesy of Clive Pierce

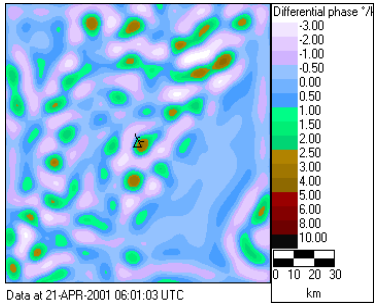
Blending ensembles
Scale cascade

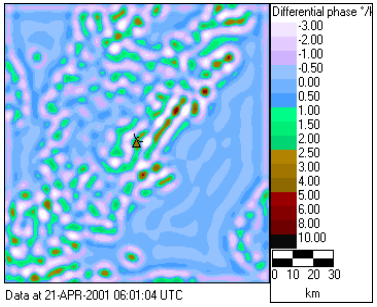


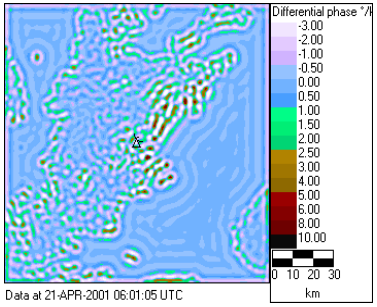


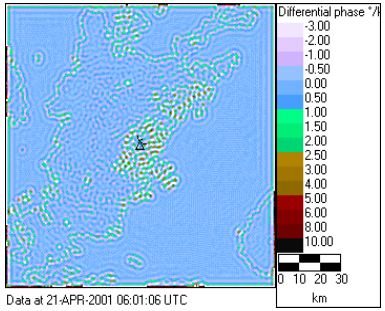












Courtesy of Clive Pierce

Blending ensembles

- **Cascade model framework**
- **Scale selective blend of extrapolated radar + satellite, UKV and MOGREPS ensemble forecasts with noise**
- **Noise serves to:**
  - **Replace and perturb features which lack skill in the extrapolation nowcast and UKV and MOGREPS-R forecasts**
  - **downscale the MOGREPS-R forecasts**
- **Noise progressively replaces extrapolated features from the smallest scales upwards but is arrested by the predictive skill of the UKV and MOGREPS-R forecasts**
- **Multiple realisations of the noise allow the generation of an ensemble of multiple forecast solutions from the same extrapolation and NWP forecasts**

Courtesy of Clive Pierce

Summary

- Chaos requires probabilistic forecasting
  - Error statistics and ensembles
  - Major focus of work at NMS‘s
  - But tending towards precipitation on larger scales and lead times
- Key problems
  - Design of ensemble to represent uncertainty
  - Dressing/calibrating nowcasts and NWP
  - Averaging/merging in space/time