ECMWF Forecasts:
A tale about signal, noise, error and value

- The quest for perfect forecasts: recent achievements and issues
- Imperfect forecasts: how to use them
  (backwards and forwards probabilities)
- Extending useful forecast range

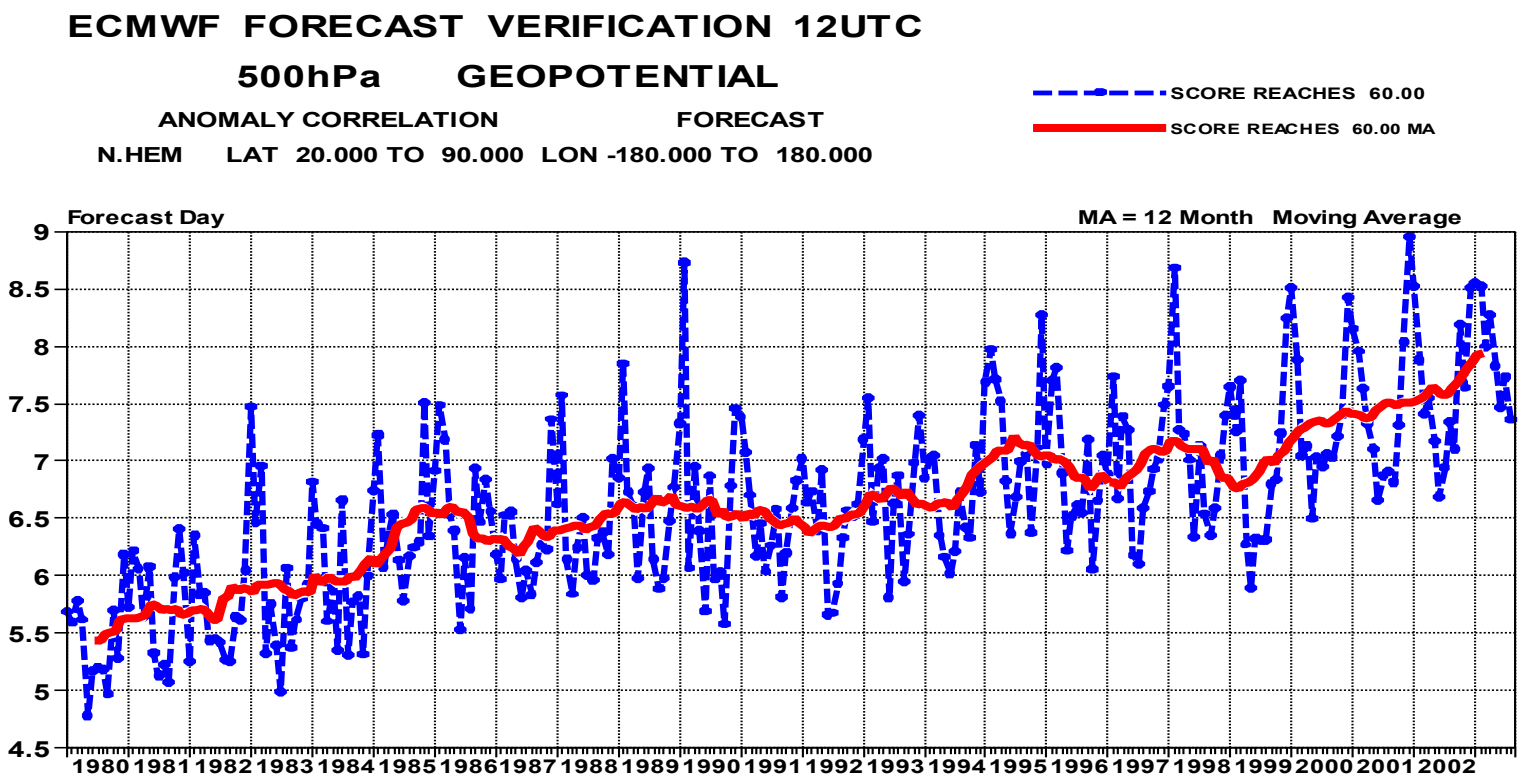
François Lalaurette, ECMWF

The quest for perfect forecasts

- Improving the forecasts through improved data assimilation, numerics, physics is what all NWP centres are aiming at - ECMWF is no exception!
- Impressive progress has been achieved in recent years
  - ➔ More and better use of satellite data
  - ➔ Revised convection
  - ➔ Improved 4D-var formulation
  - ➔ Etc…

Time series (N.Extratropics)

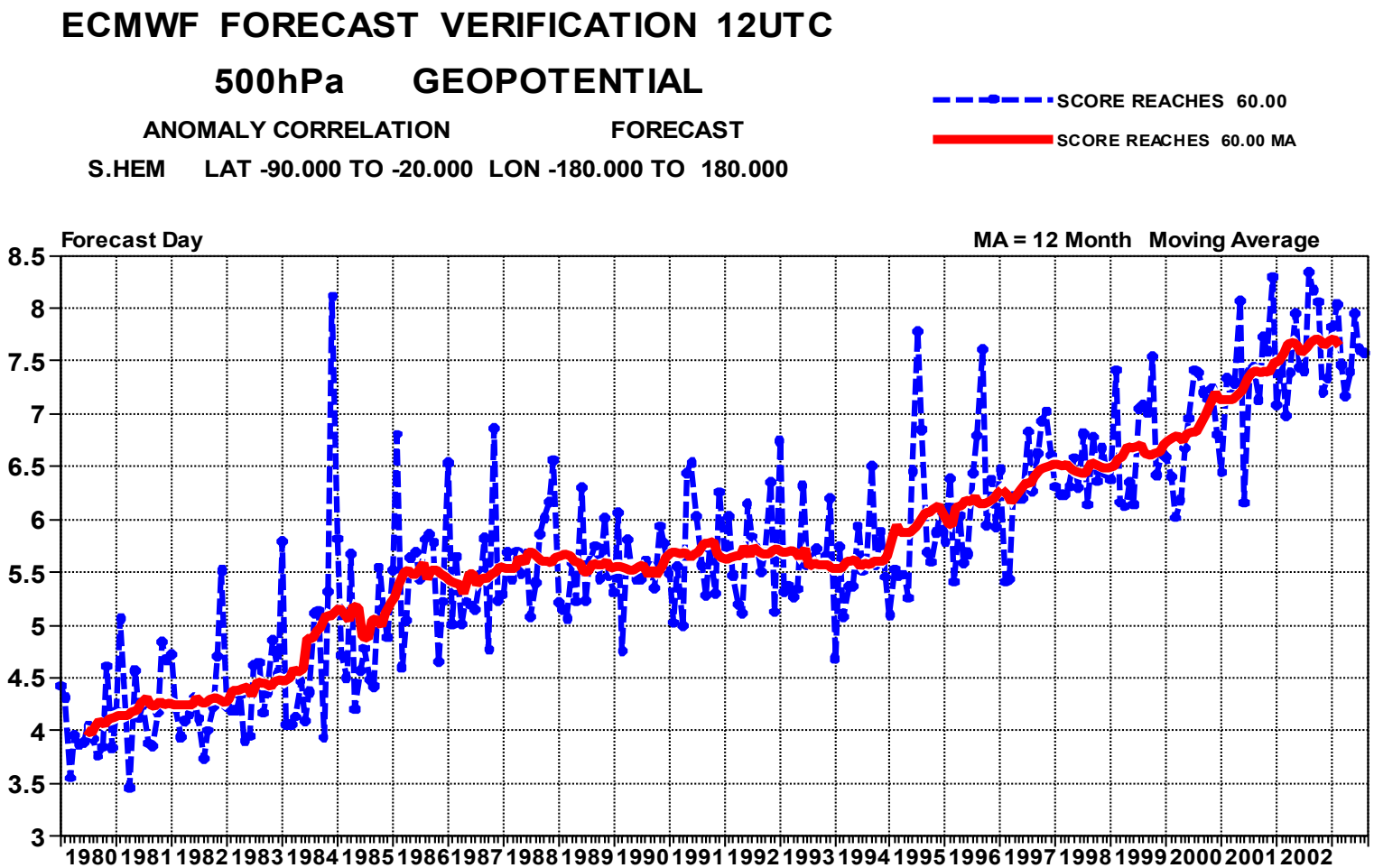
http://www.ecmwf.int/products/forecasts/d/charts/verification/timeseries/monthly_mean/



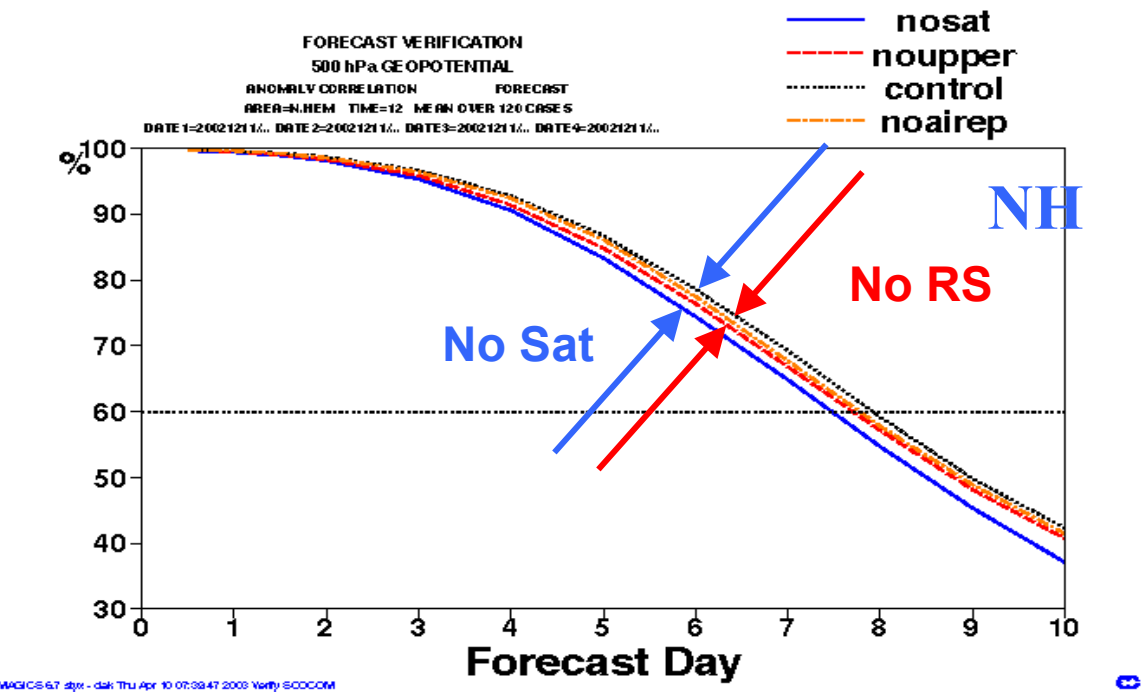
ECMWF

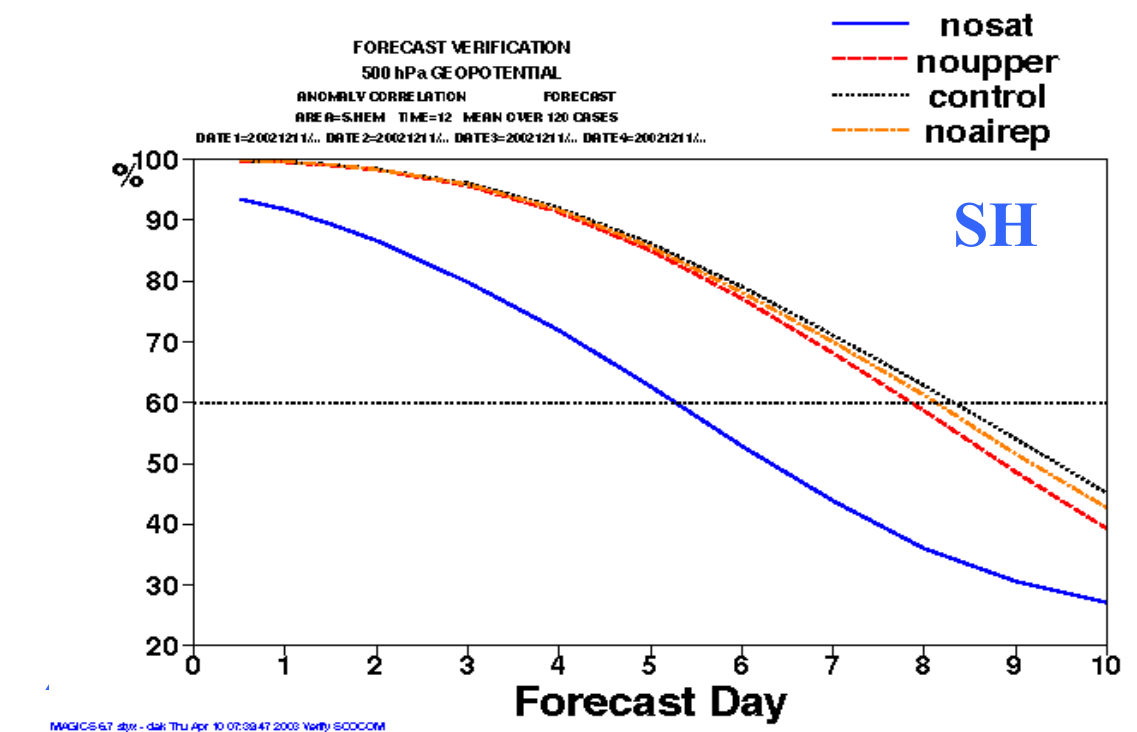
Time Series (S. Extratropics)

http://www.ecmwf.int/products/forecasts/d/charts/verification/timeseries/monthly_mean/



ECMWF



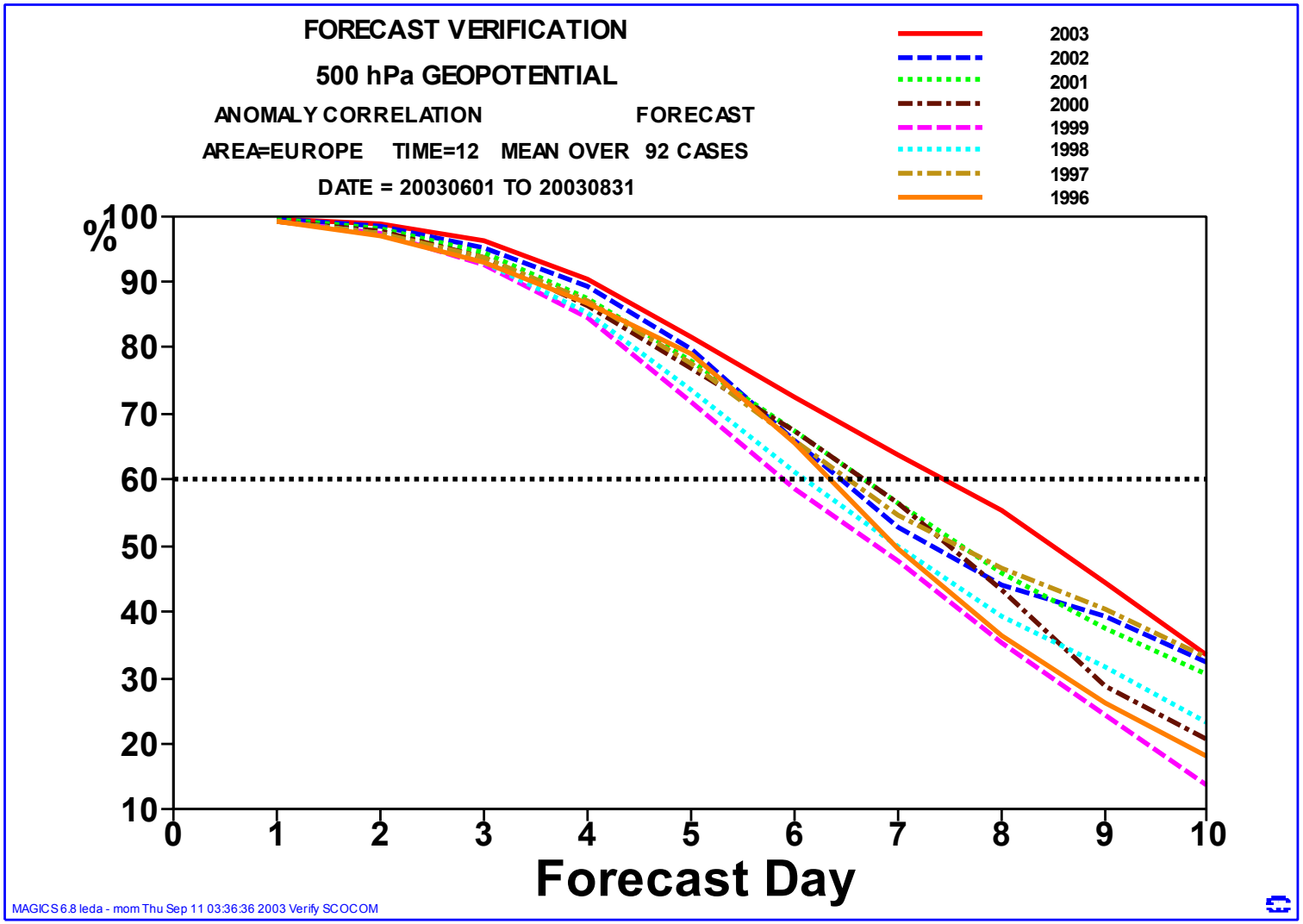


Observing System Experiment Scores (courtesy G. Kelly)

(2 summer months + 2 winter months)

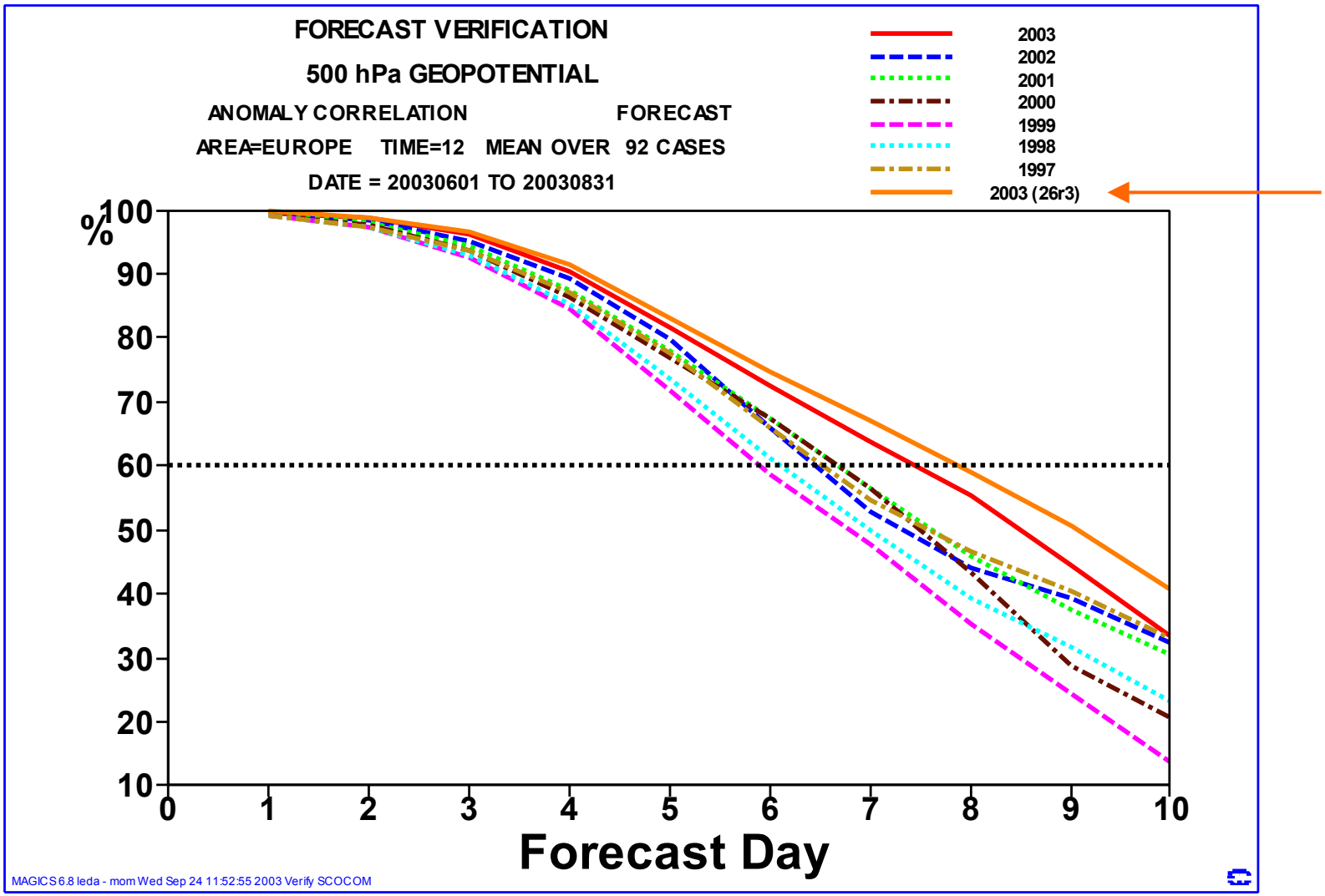
Satellite data are now the main source of information even in the NH

Summer 2003 vs previous summers



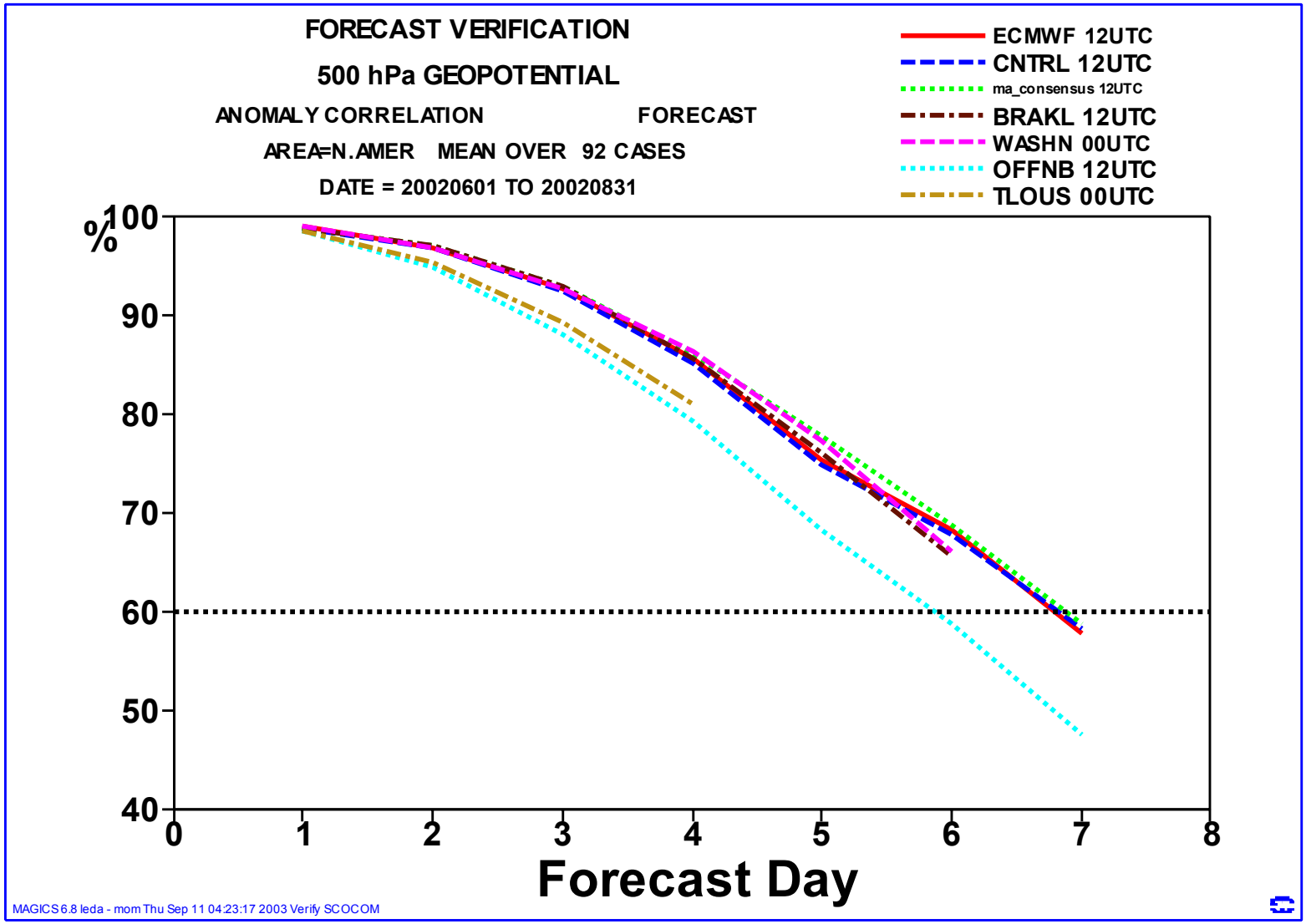
ECMWF

Summer 2003 vs previous summers



ECMWF

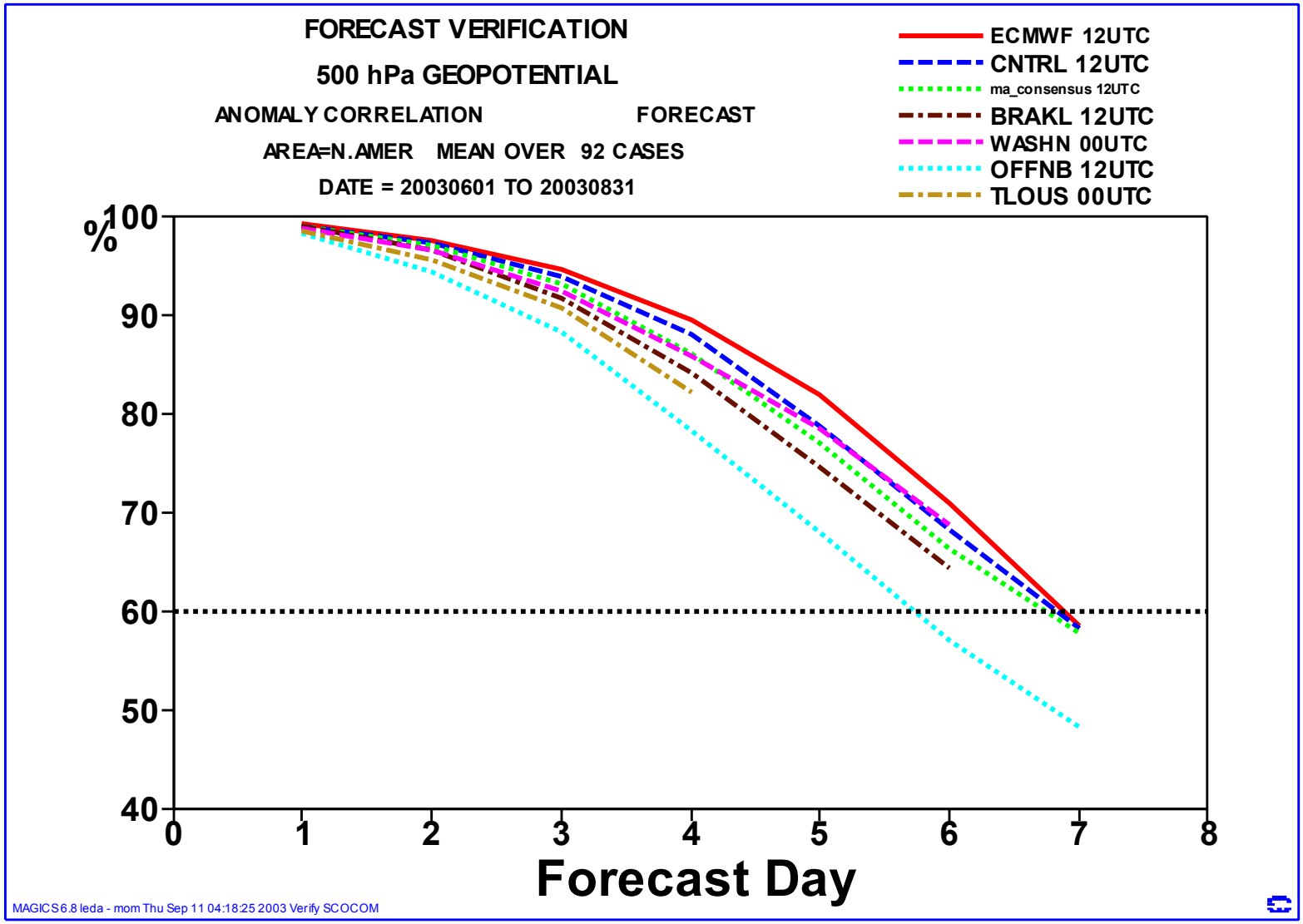
Summer scores – has the N. America problem gone away?



2002

ECMWF

Summer scores – has the N. America problem gone away?



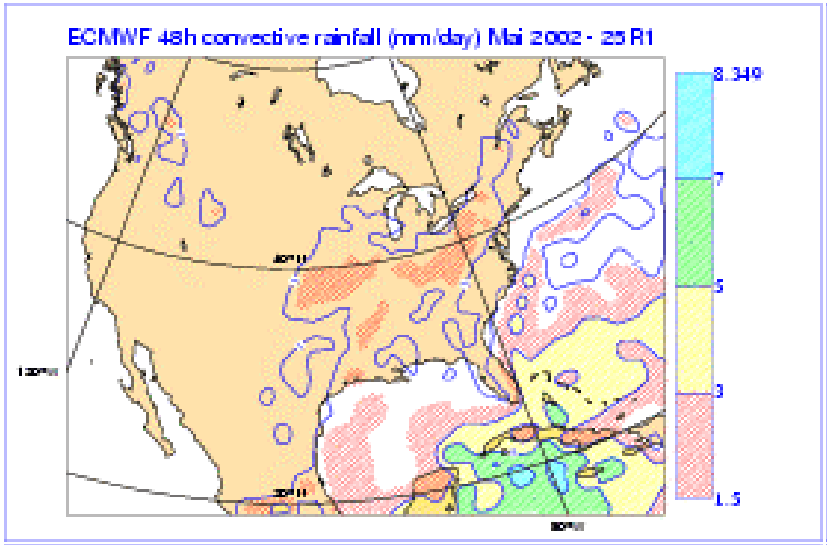
2003

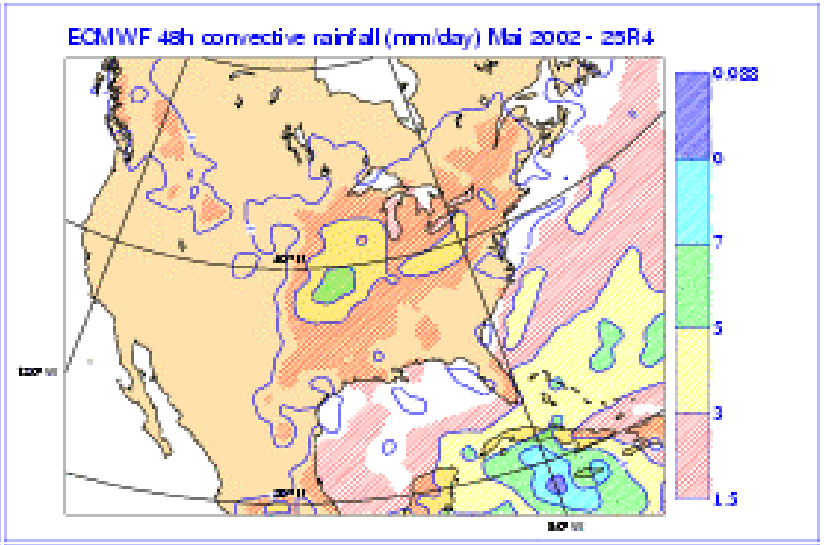
ECMWF

Has the N. America problem gone away? Impact of revising the triggering of convection (courtesy P. Bechtold)

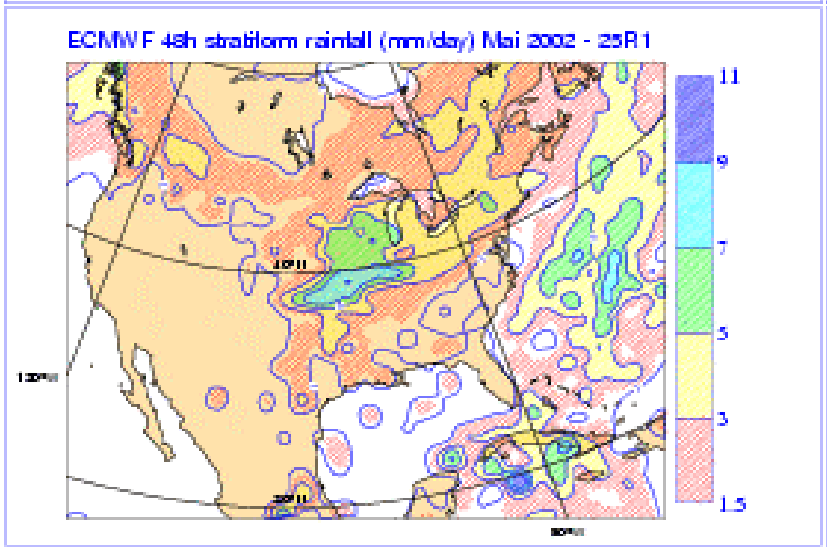
25R1 | 25R4

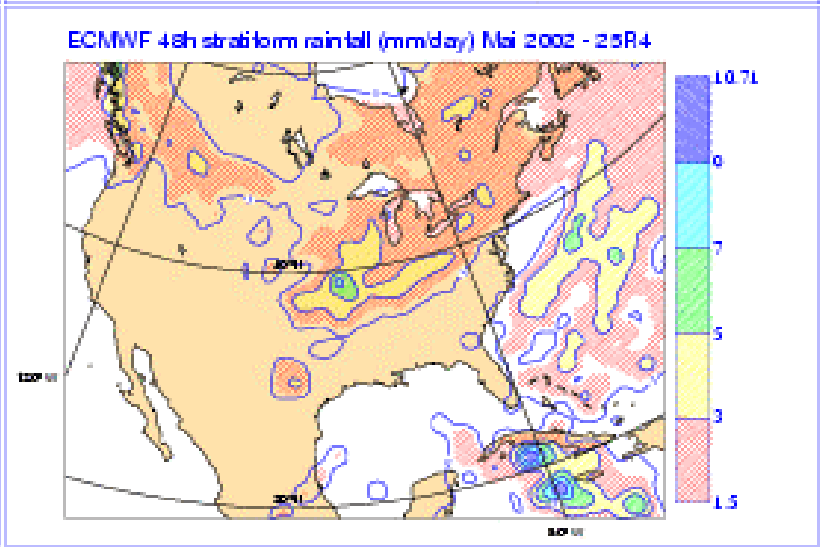
Conv Precip





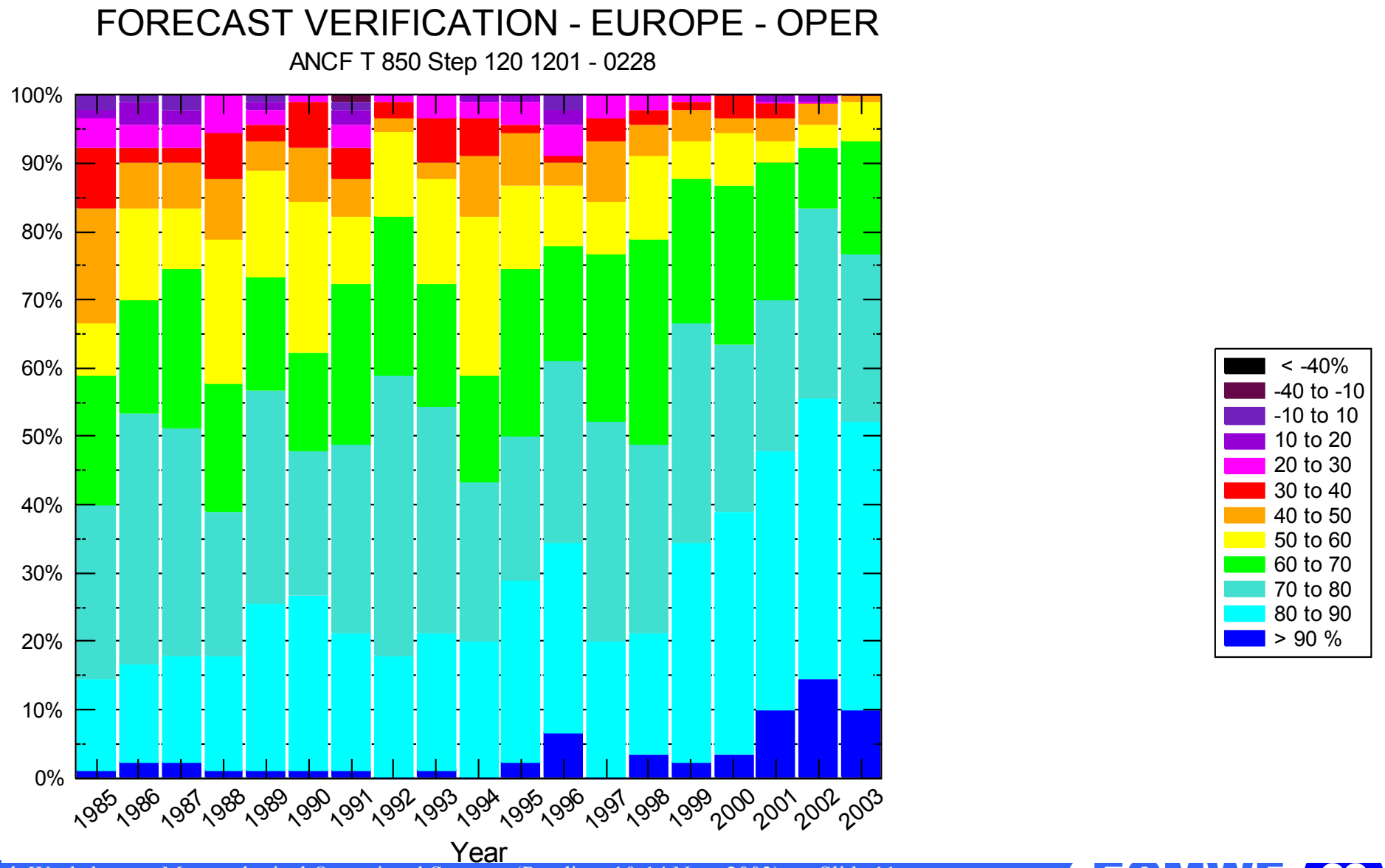
Strat Precip



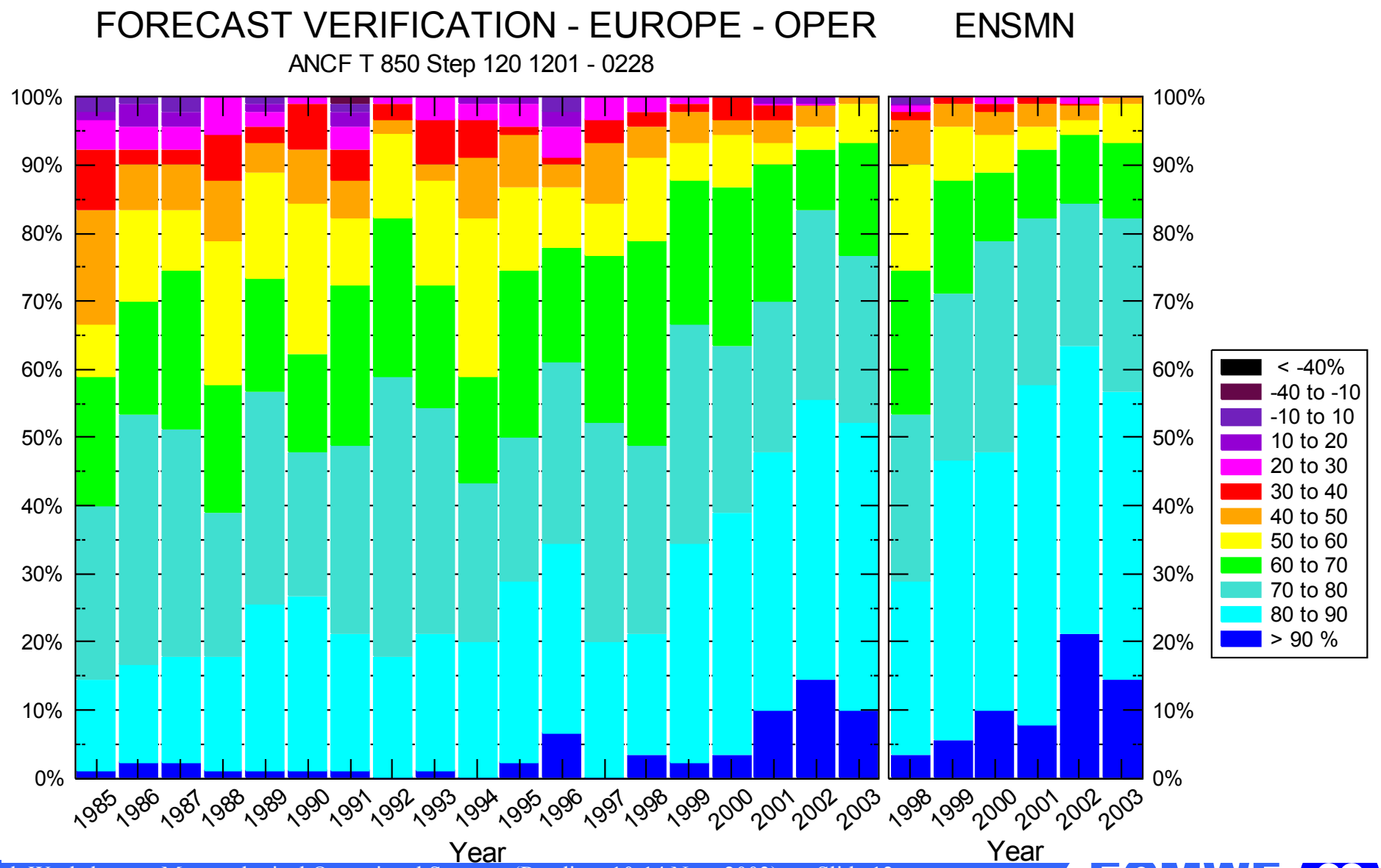


ECMWF

Recent progress (winter temperature anomalies)

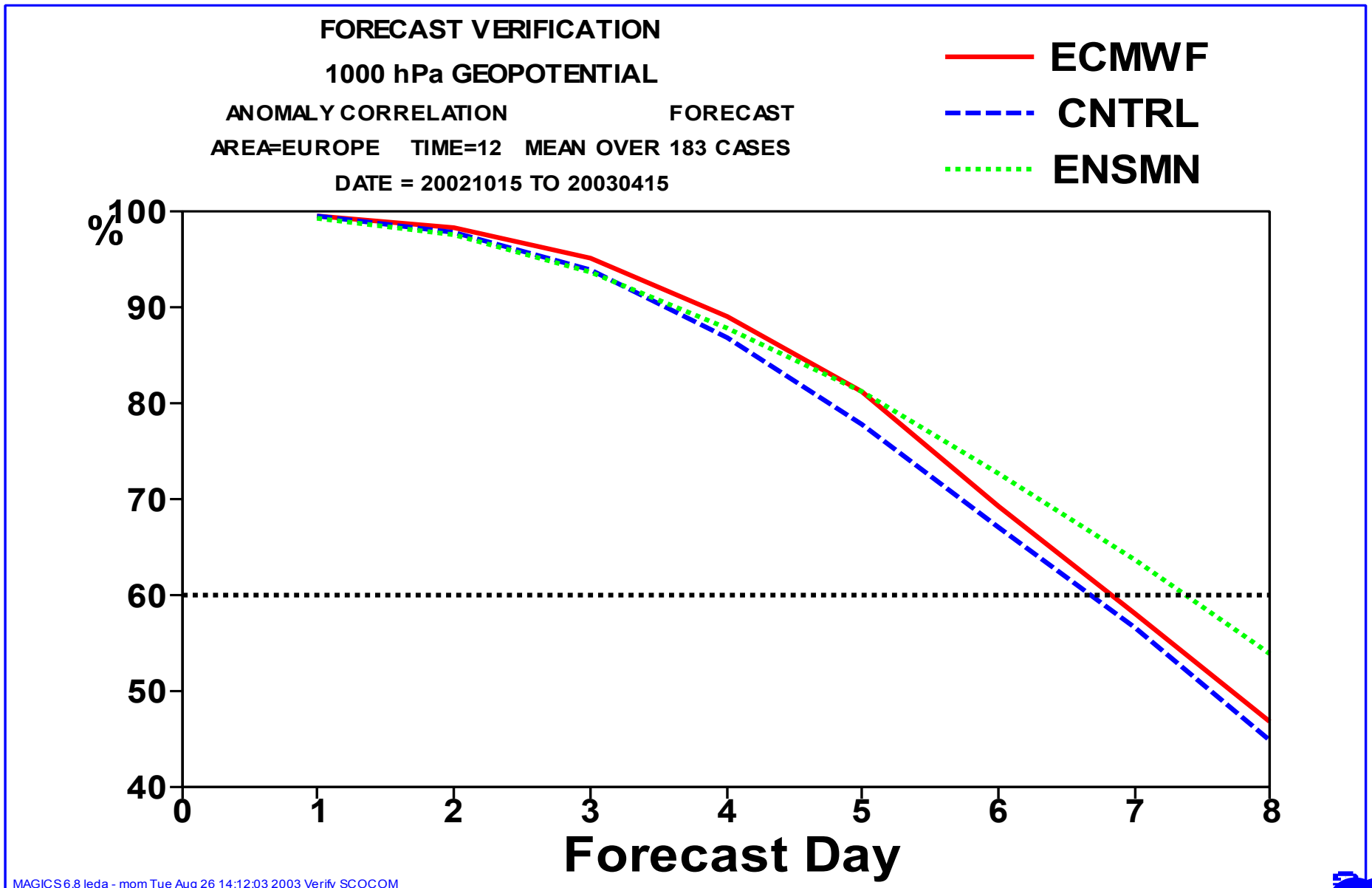


Recent progress (winter temperature anomalies)



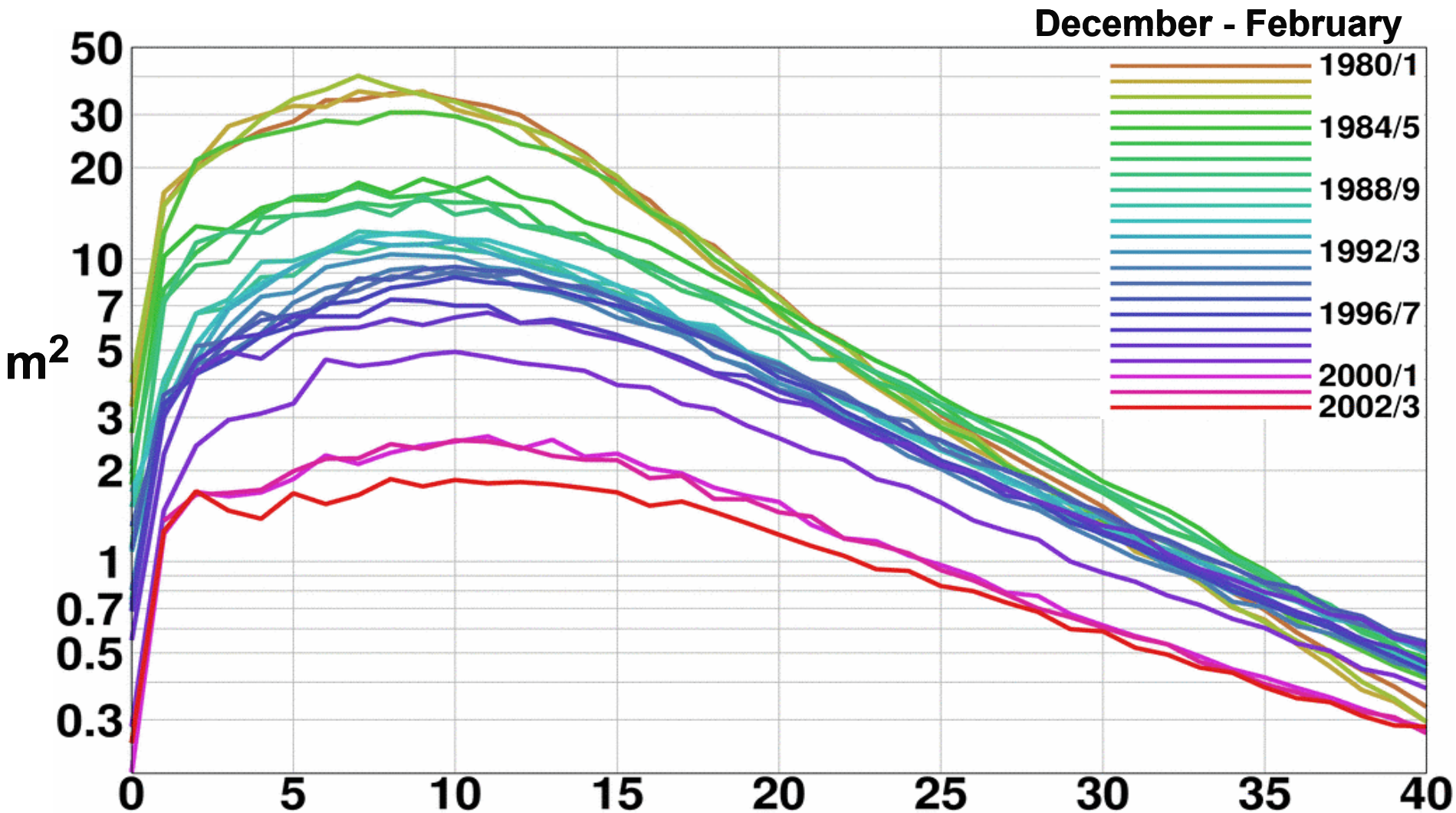
ECMWF

Winter 2002-2003: the T511/T255 gap



Recent progress – high resolution delivers...

(Courtesy A. Simmons)



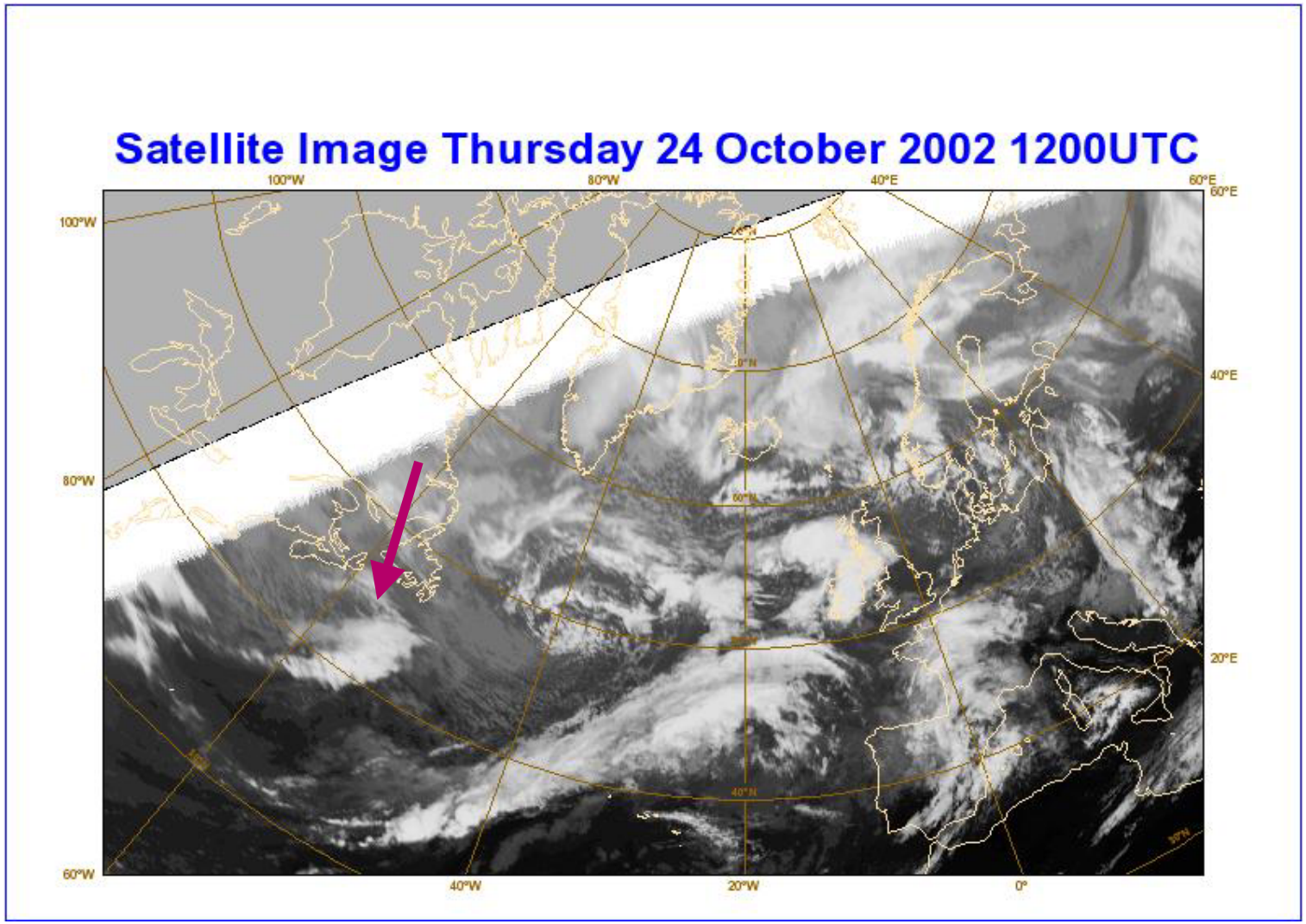
Spectra of mean-square day-1 500hPa height error variance

ECMWF

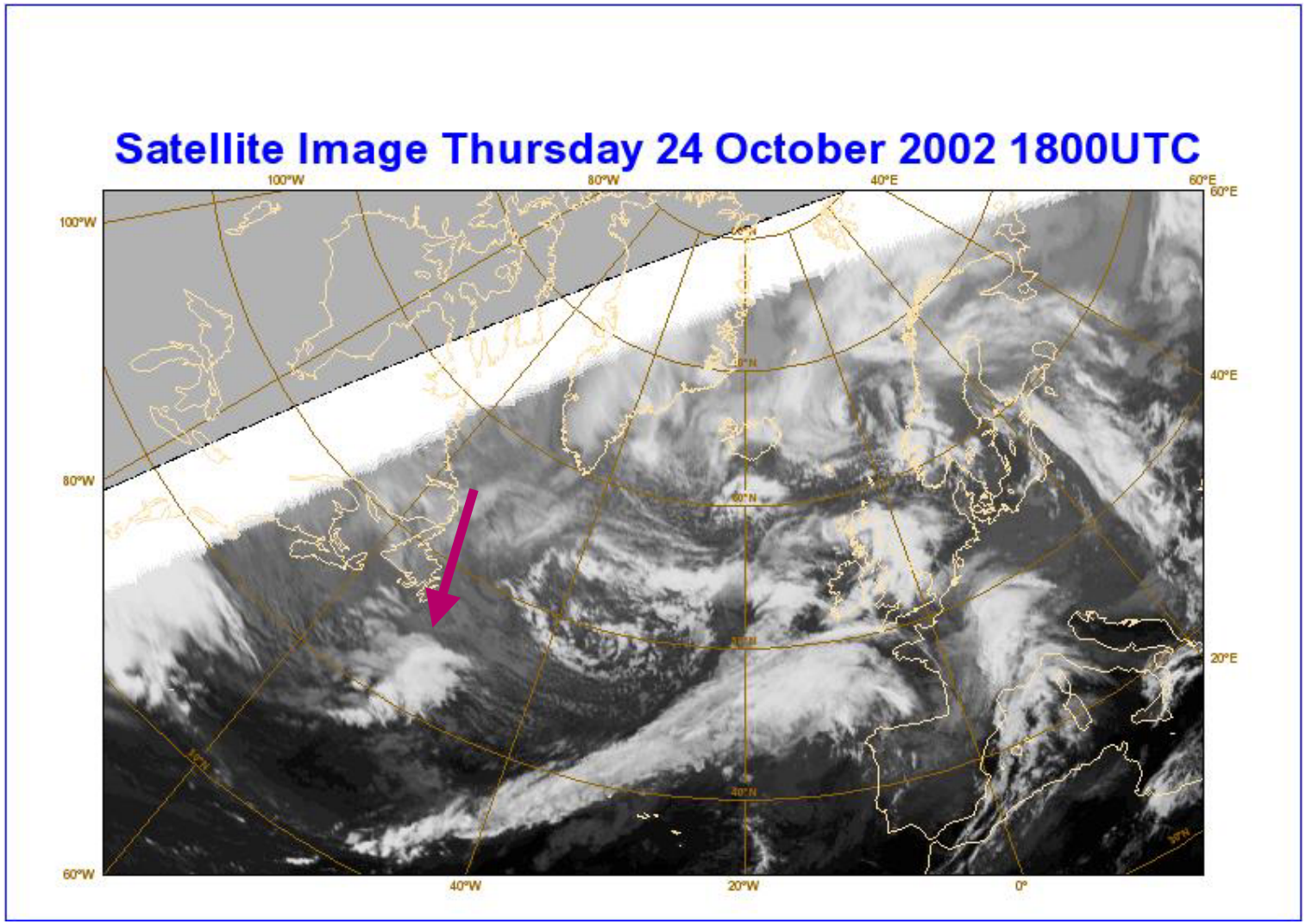
Impact of resolution: the 27/10/2002 storm

- A “classic” storm development over North-western Atlantic
- Impact of resolution meant a global shift in the ensemble distribution vs the T511 scenario

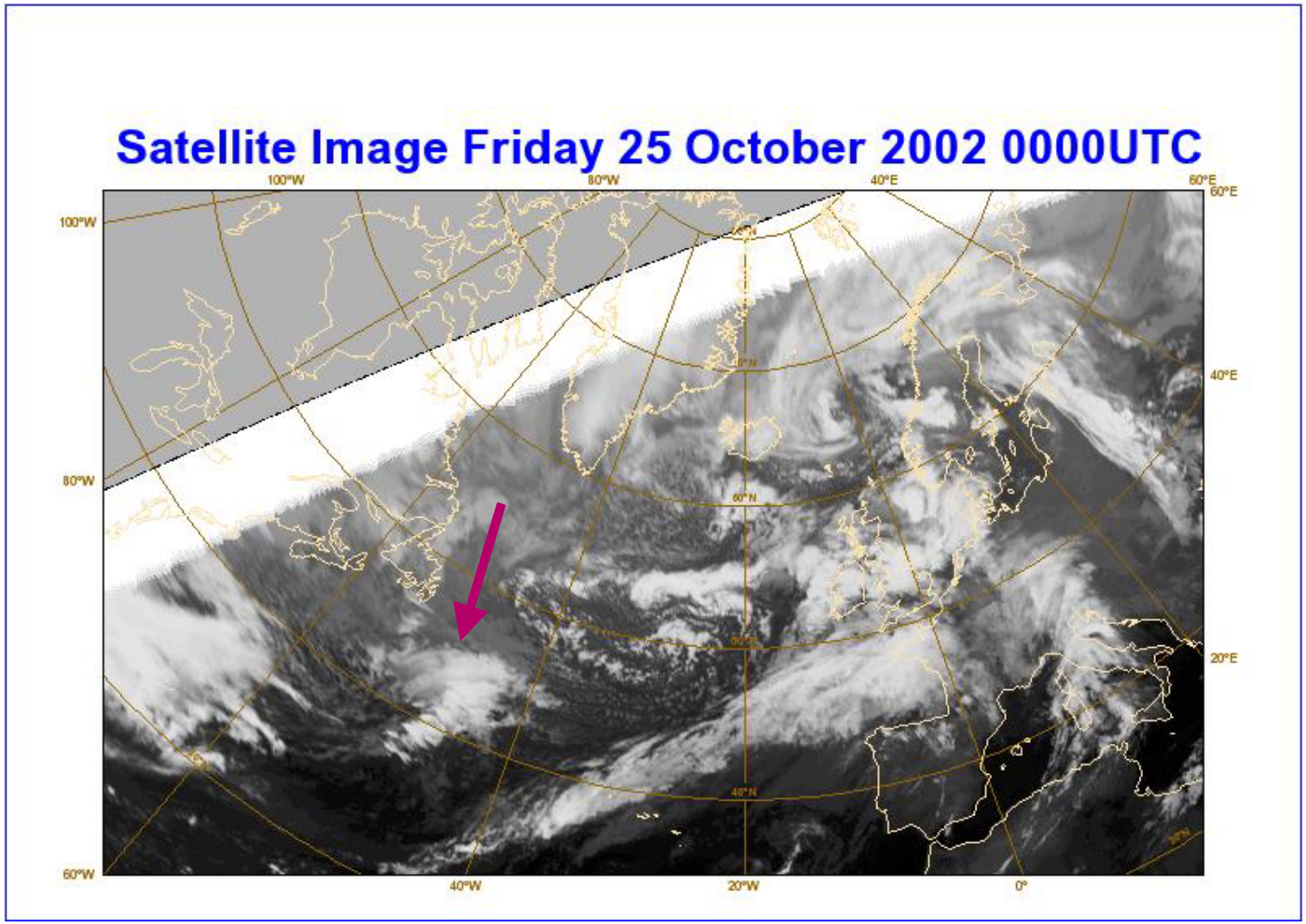
Meteosat 7 Infra-red imagery



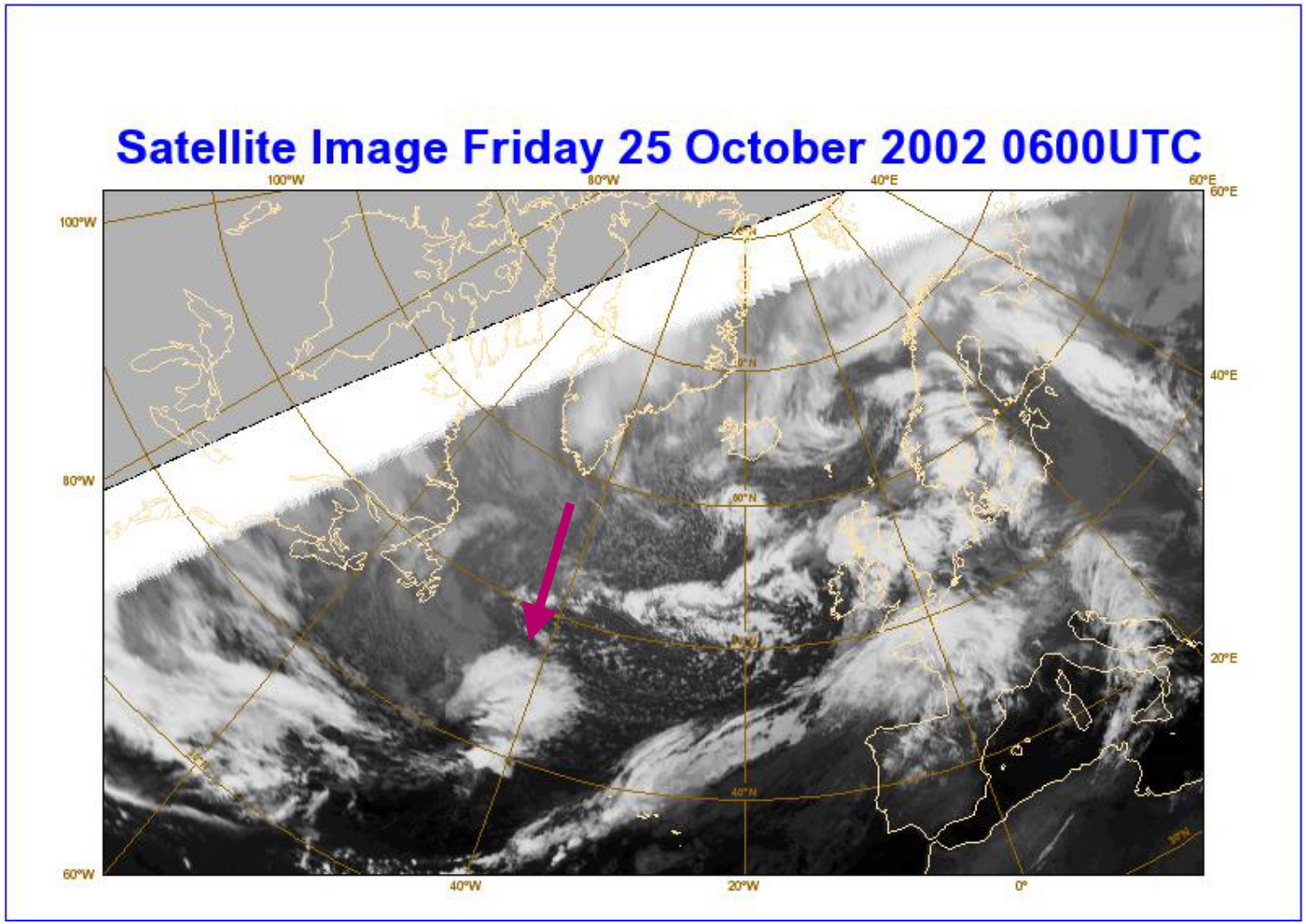
Meteosat 7 Infra-red imagery



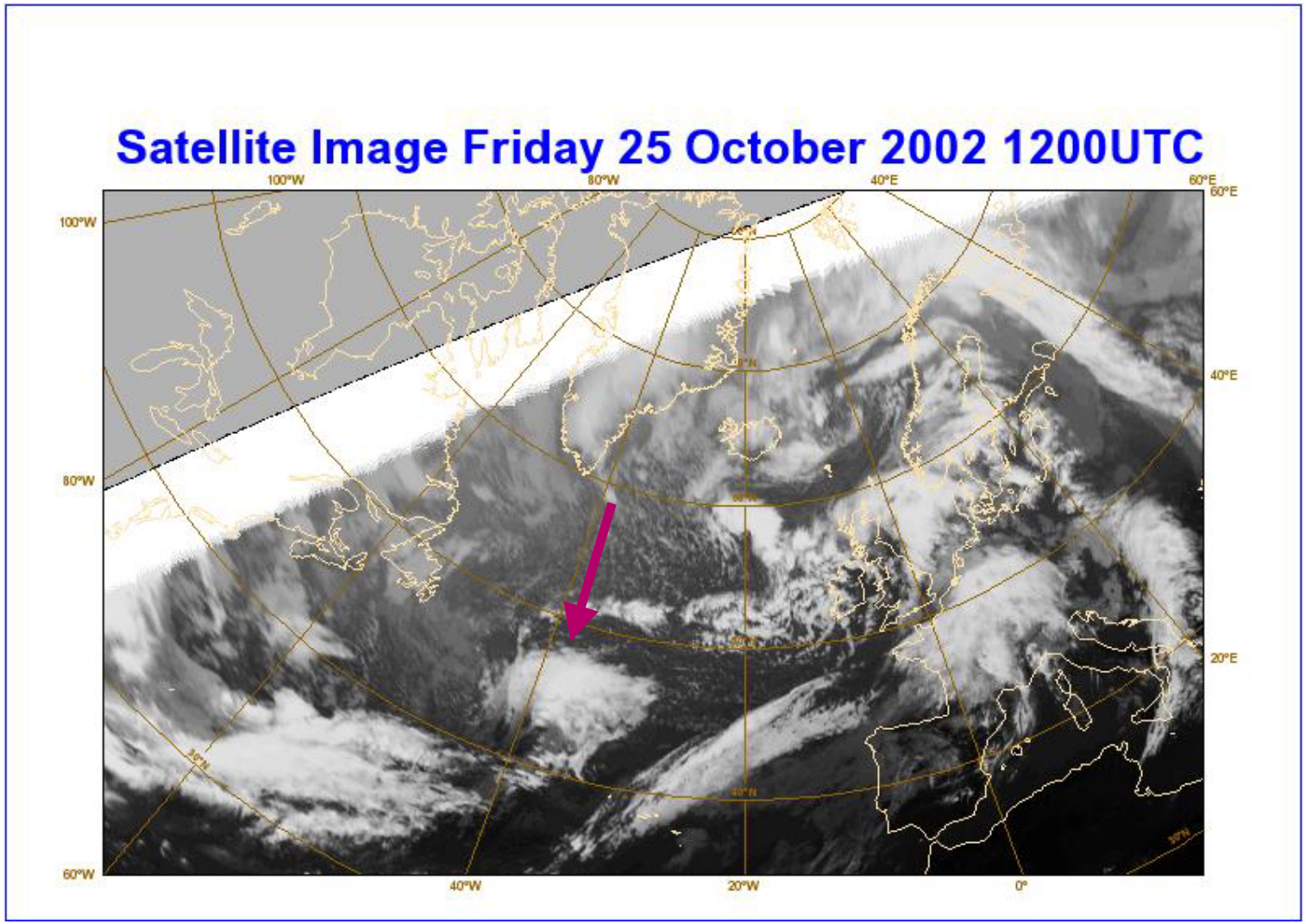
Meteosat 7 Infra-red imagery



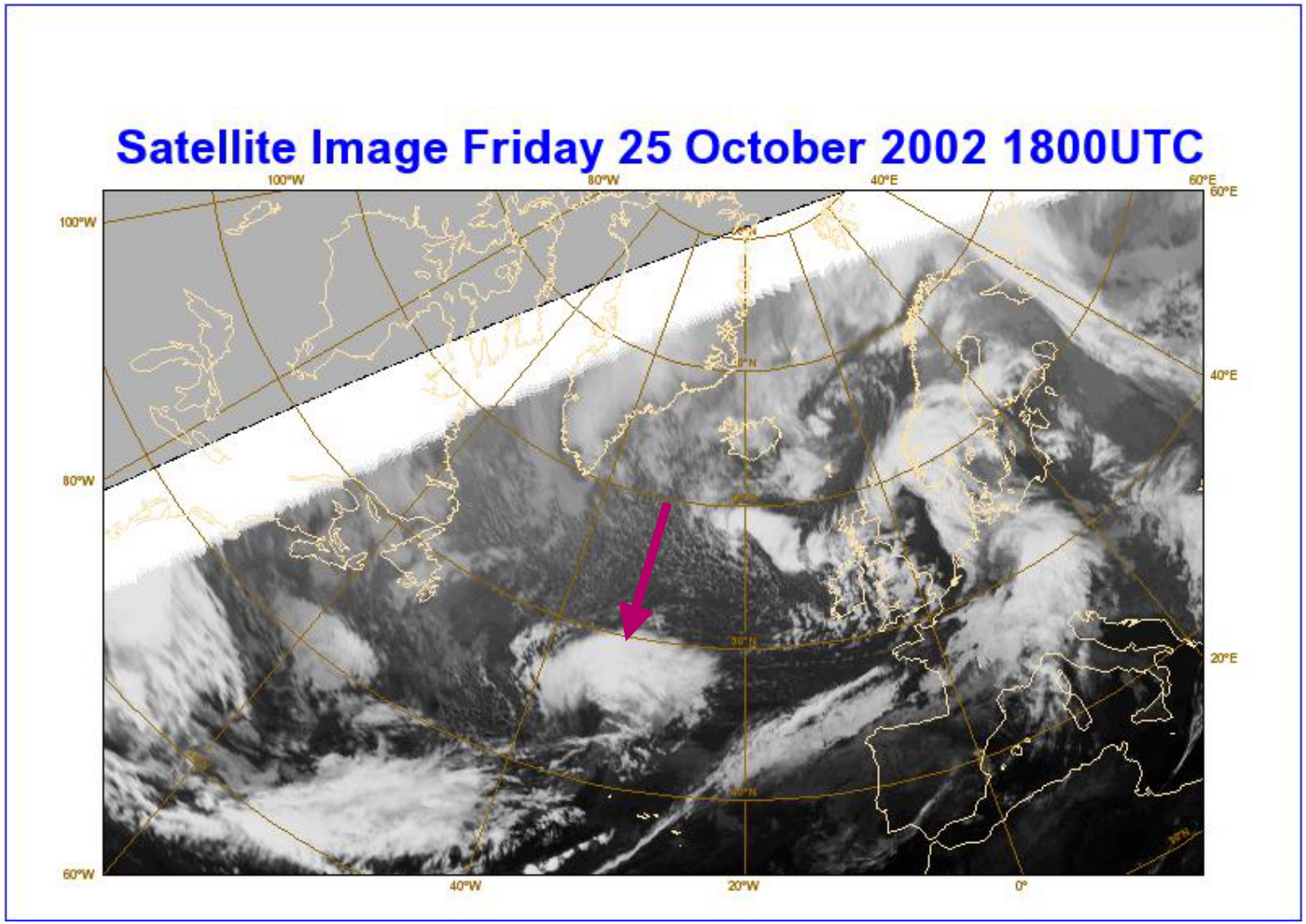
Meteosat 7 Infra-red imagery



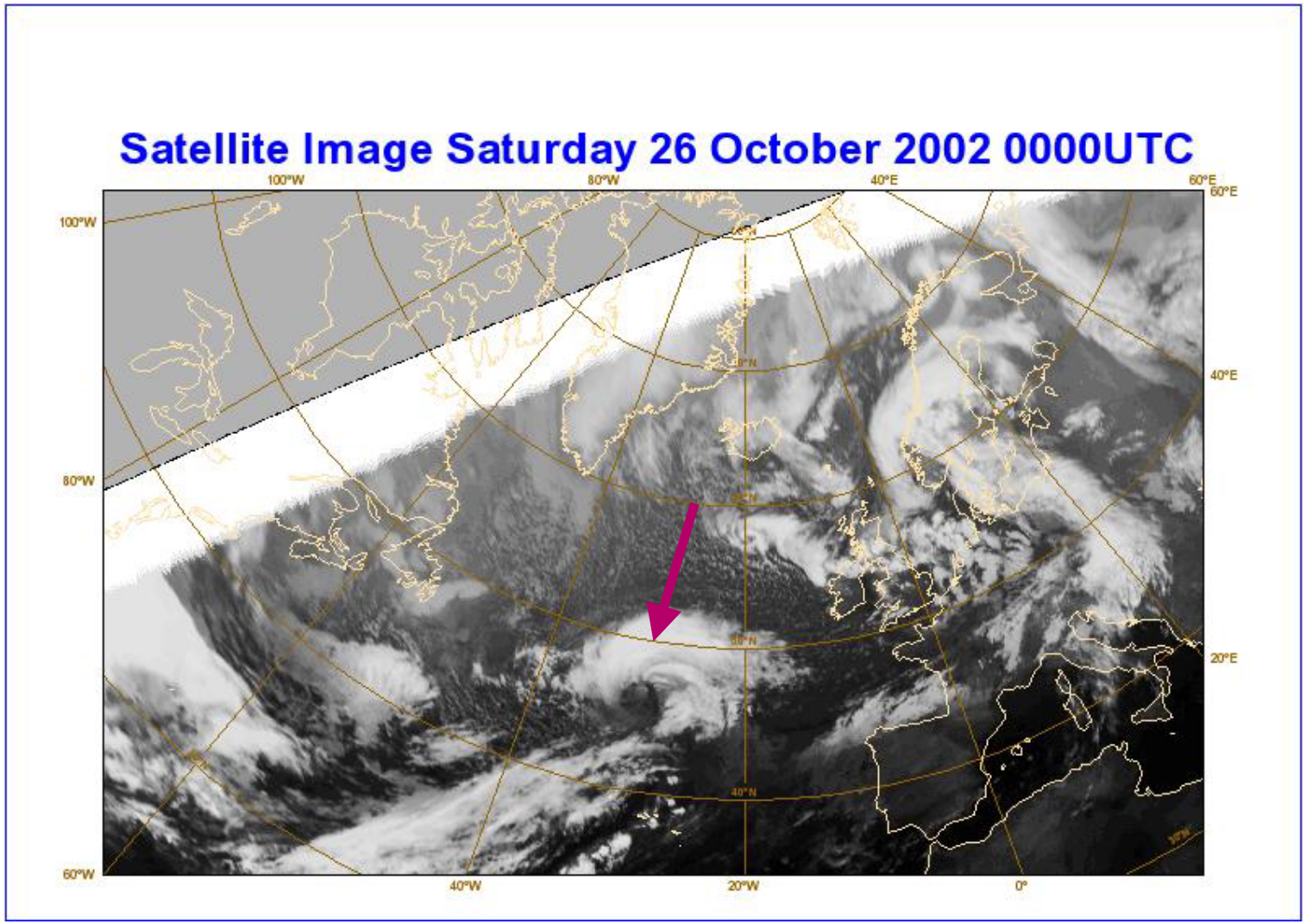
Meteosat 7 Infra-red imagery



Meteosat 7 Infra-red imagery

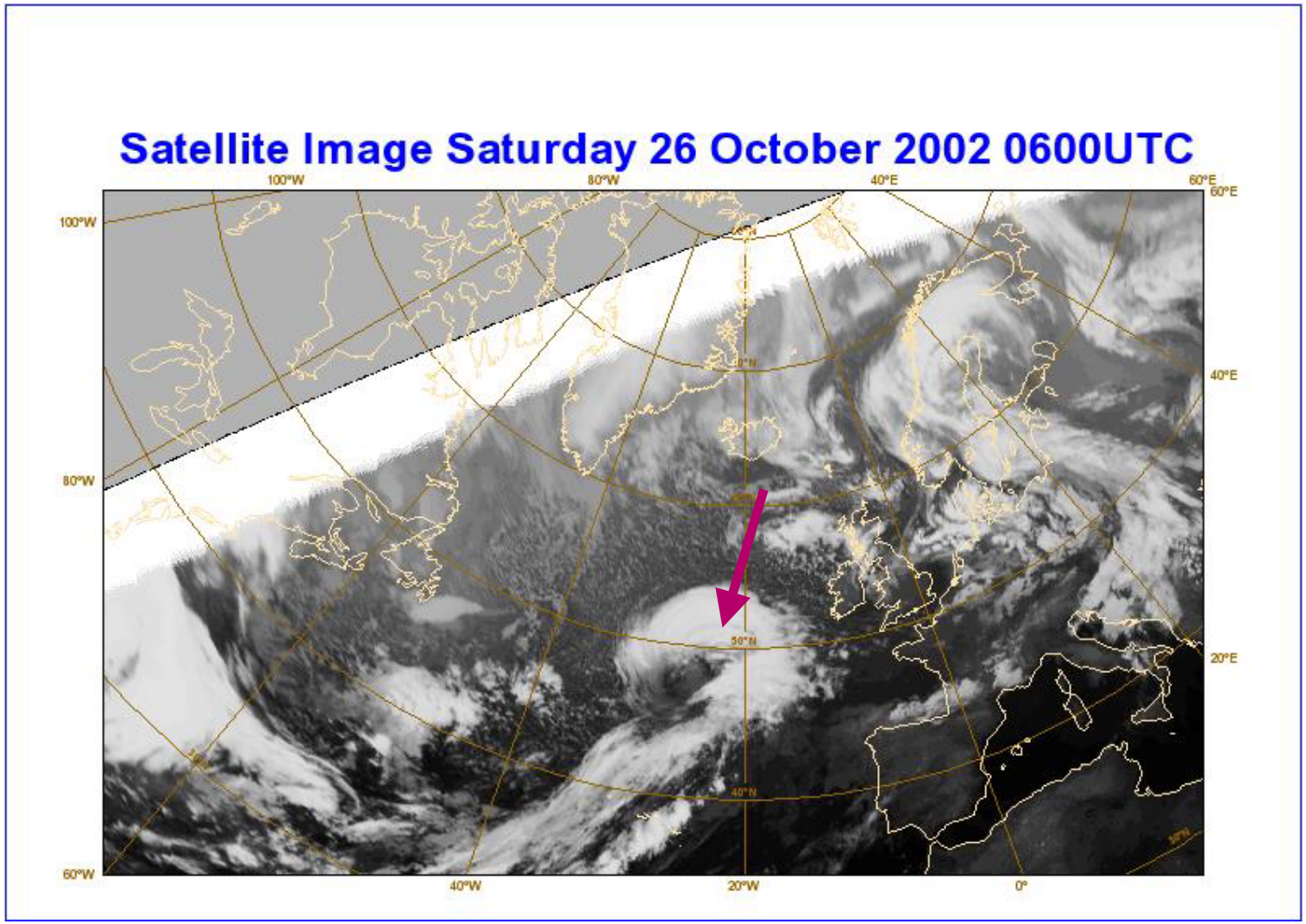


Meteosat 7 Infra-red imagery

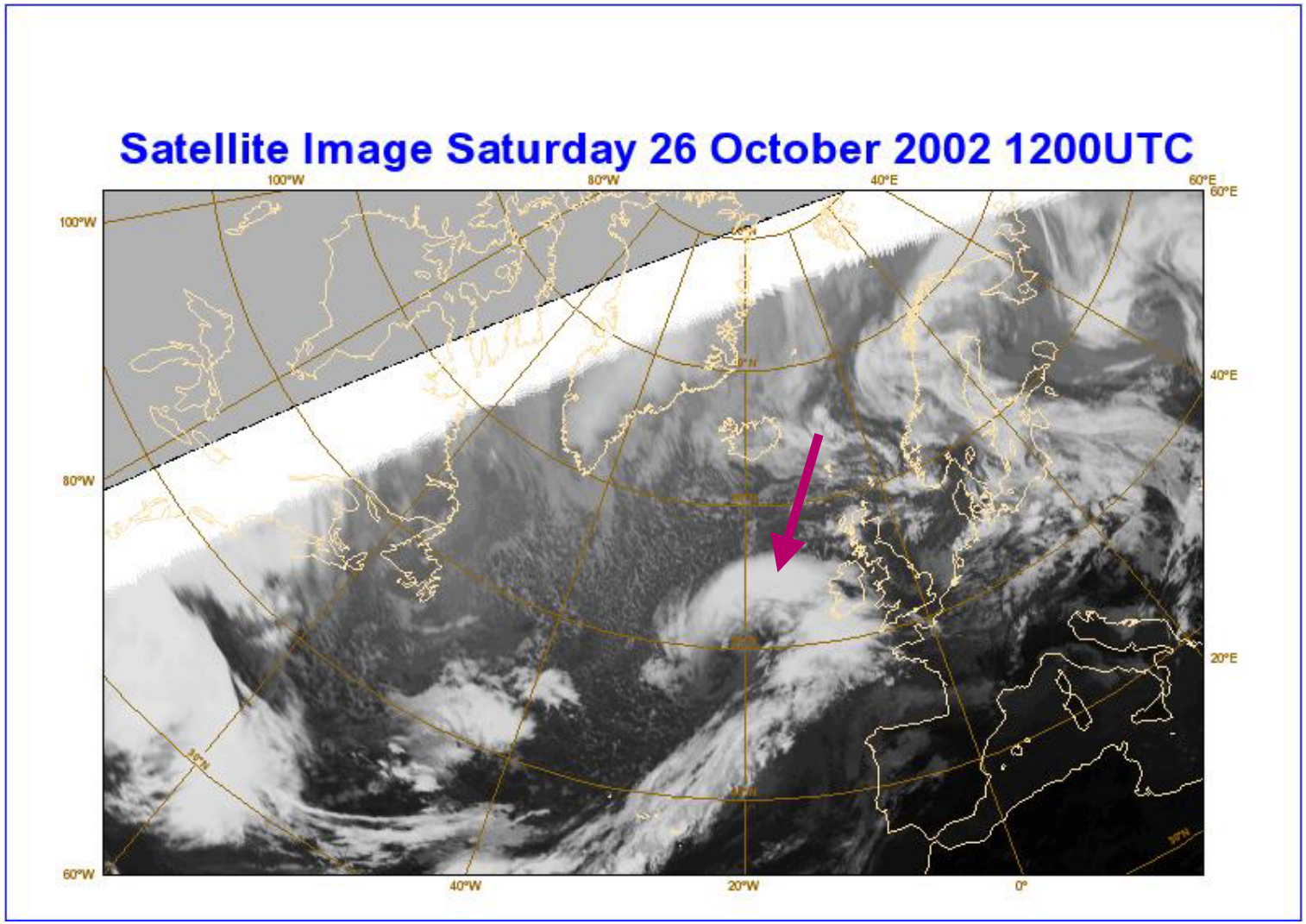


ECMWF

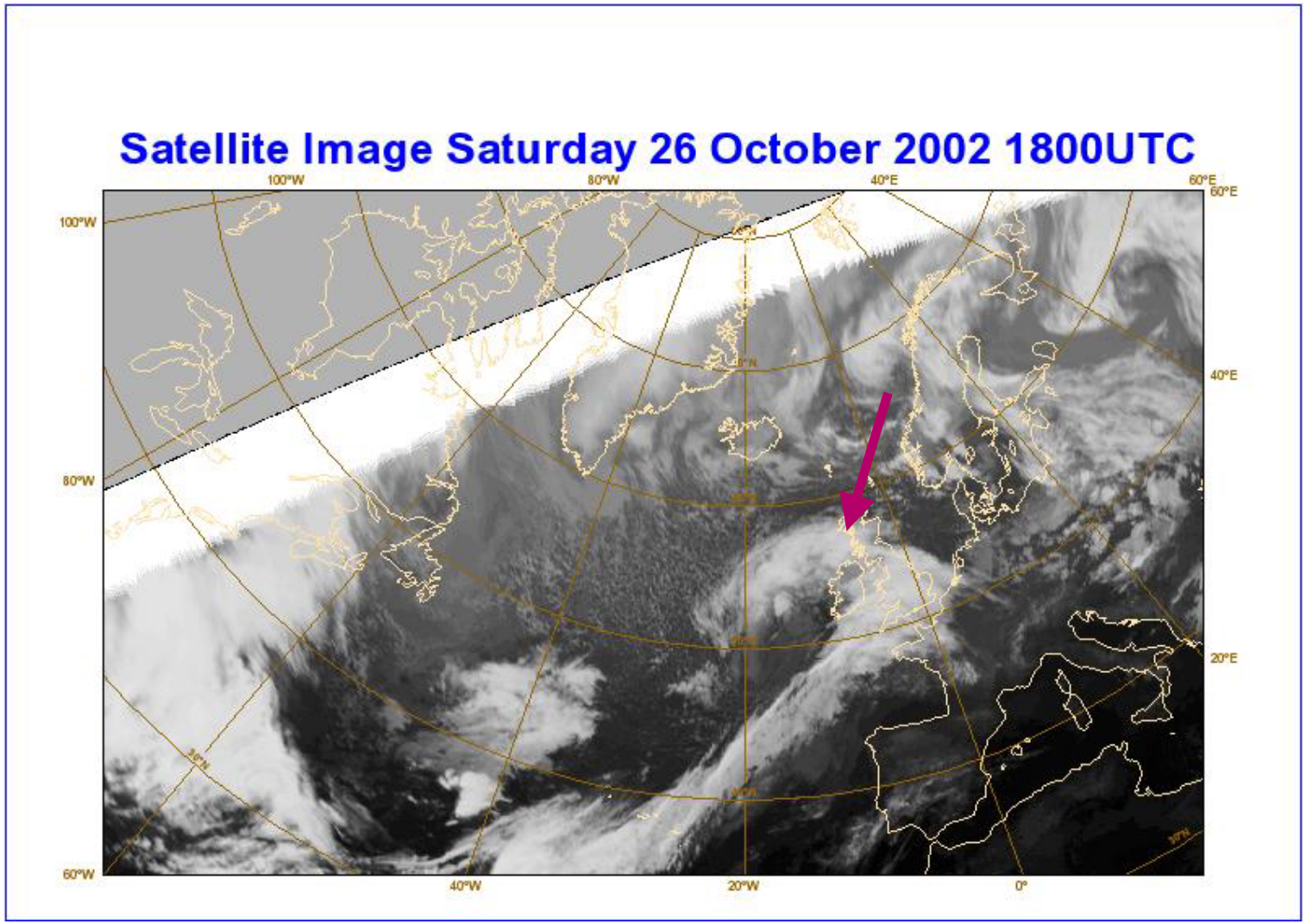
Meteosat 7 Infra-red imagery



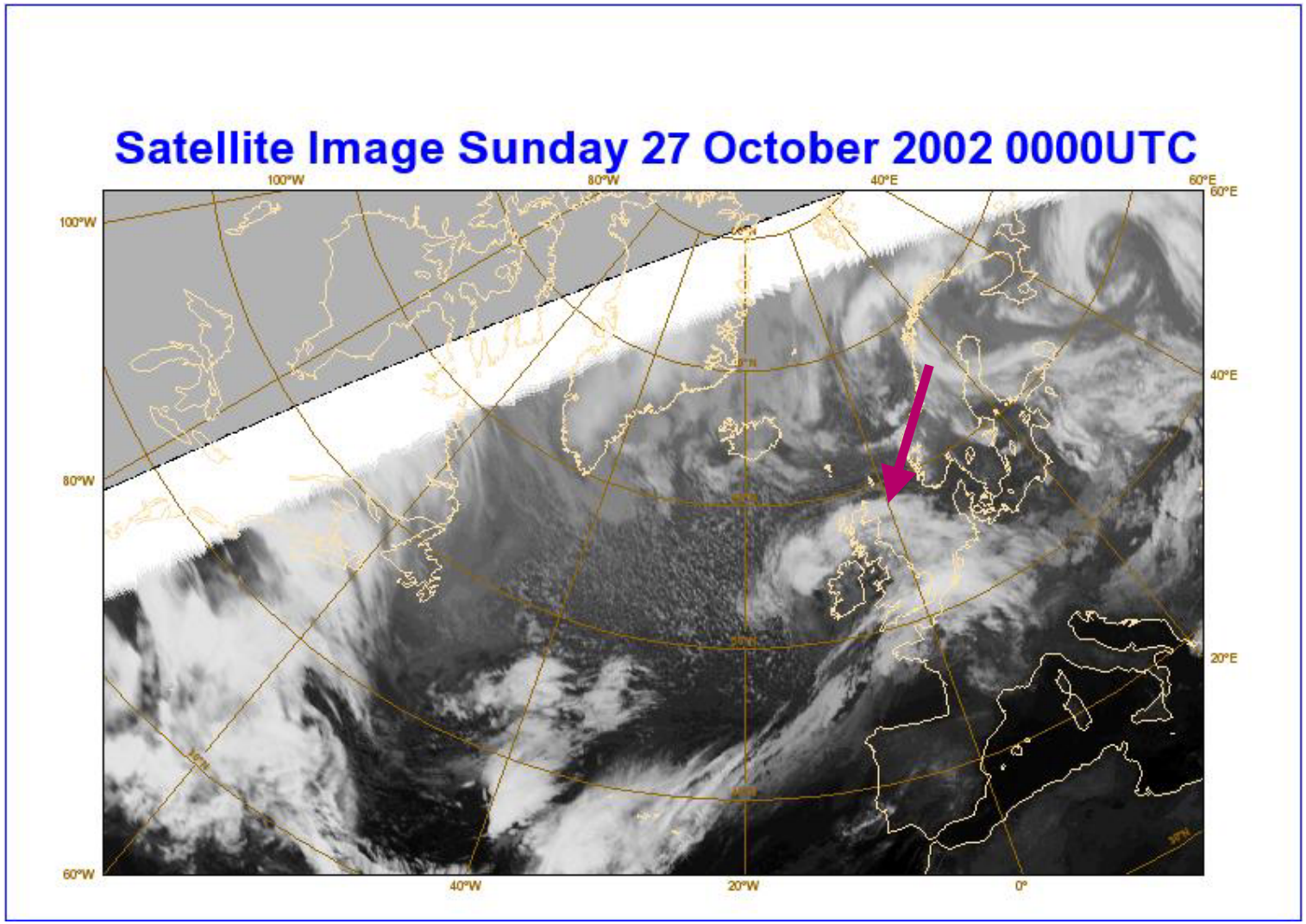
Meteosat 7 Infra-red imagery



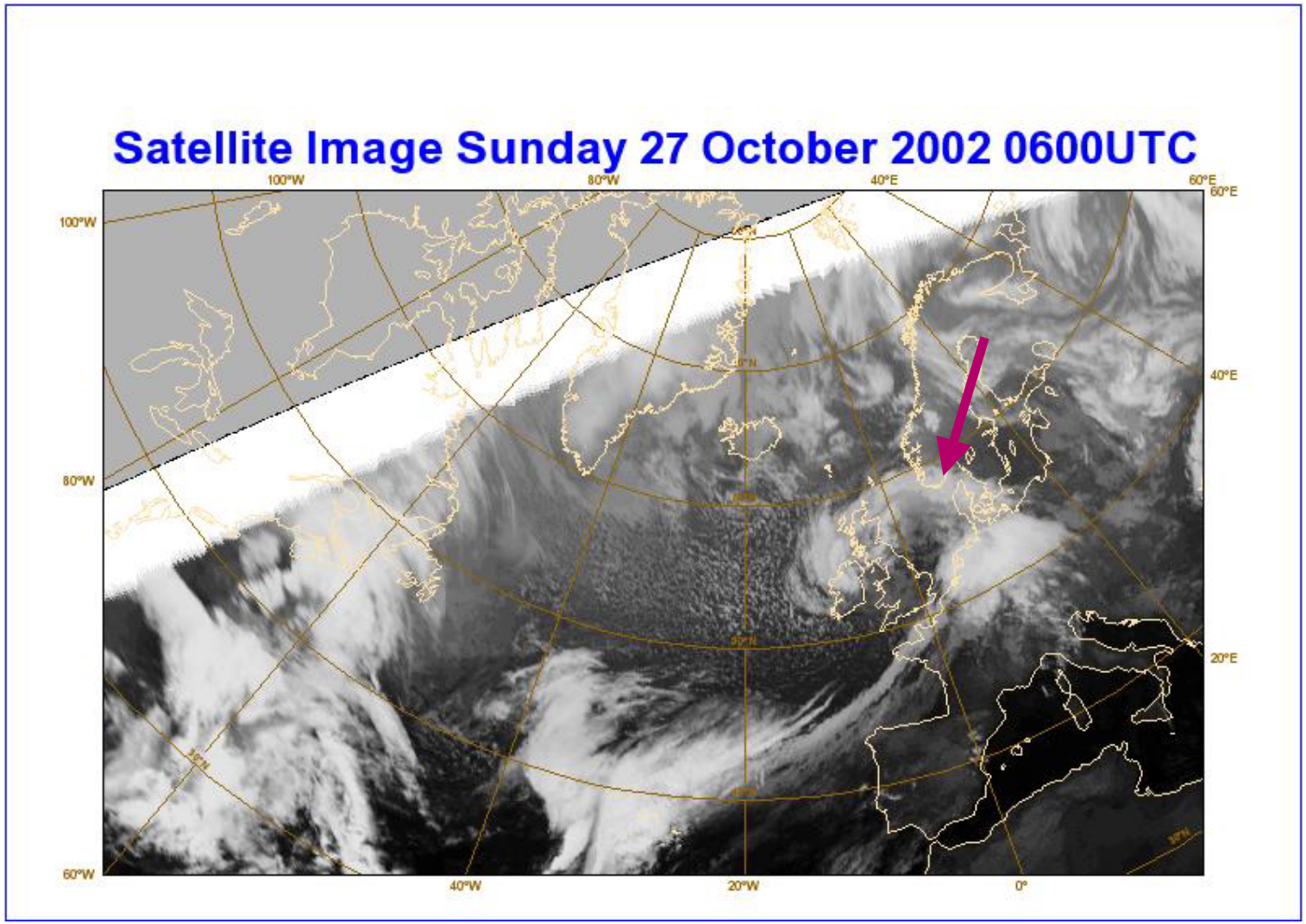
Meteosat 7 Infra-red imagery



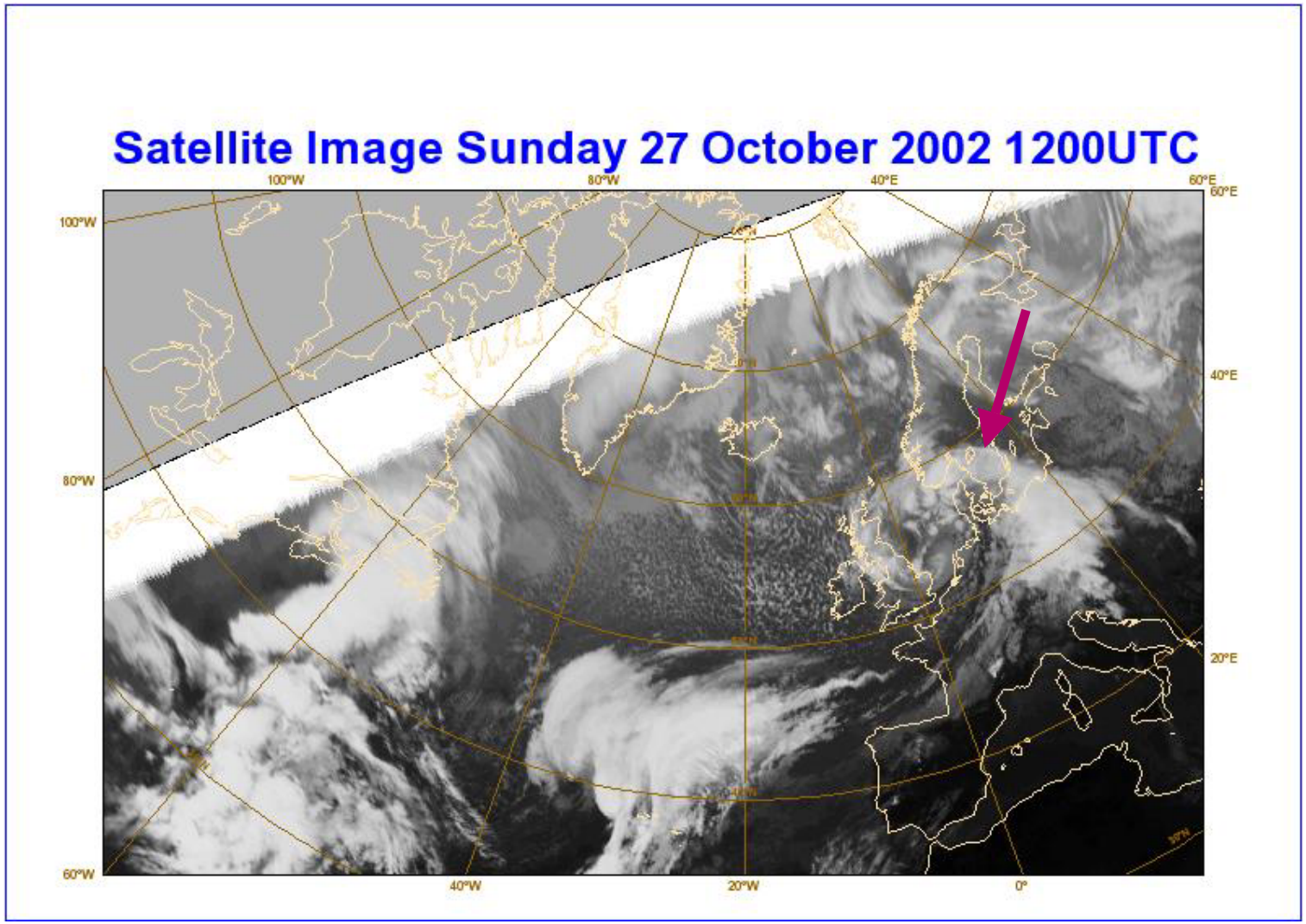
Meteosat 7 Infra-red imagery



Meteosat 7 Infra-red imagery

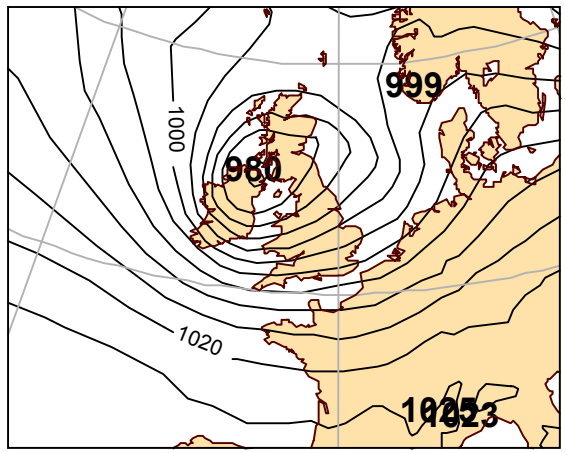


Meteosat 7 Infra-red imagery

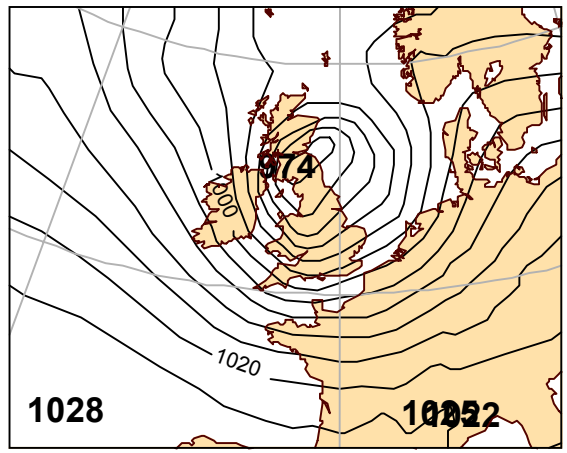


T511 forecasts valid for 27/11 12UTC

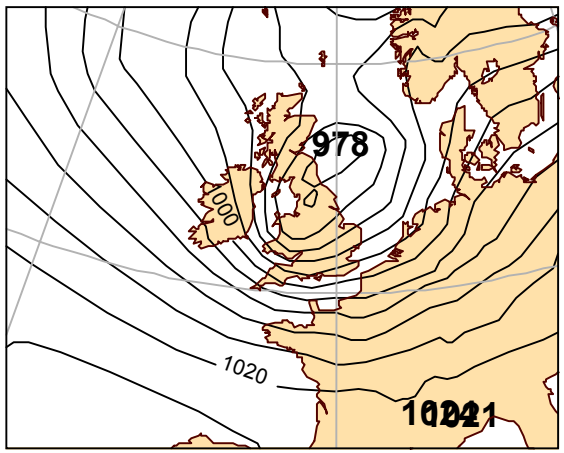
20021024 12UTC ECMWF FC t+ 72 VT: 20021027 12UTC
Surf: msl



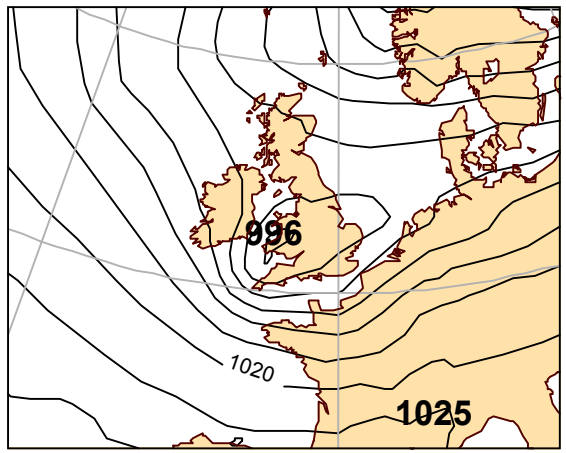
20021024 00UTC ECMWF FC t+ 84 VT: 20021027 12UTC
Surf: msl



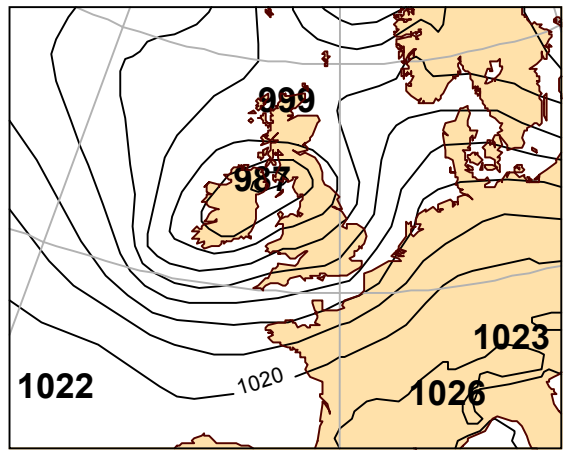
20021023 12UTC ECMWF FC t+ 96 VT: 20021027 12UTC
Surf: msl



20021023 00UTC ECMWF FC t+108 VT: 20021027 12UTC
Surf: msl



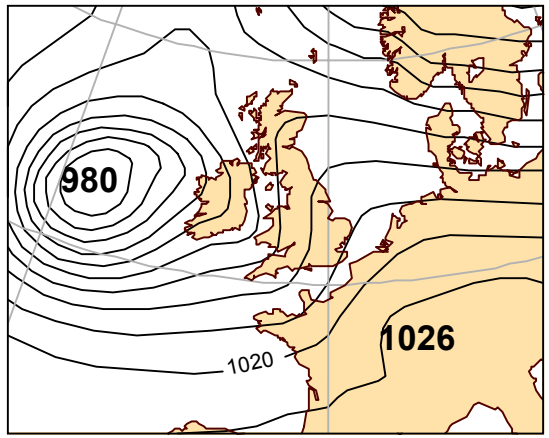
20021022 12UTC ECMWF FC t+120 VT: 20021027 12UTC
Surf: msl



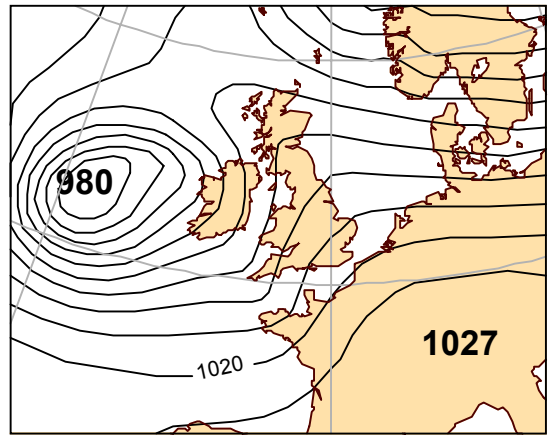
ECMWF

T255 (EPS Control) forecasts valid for 27/11 12UTC

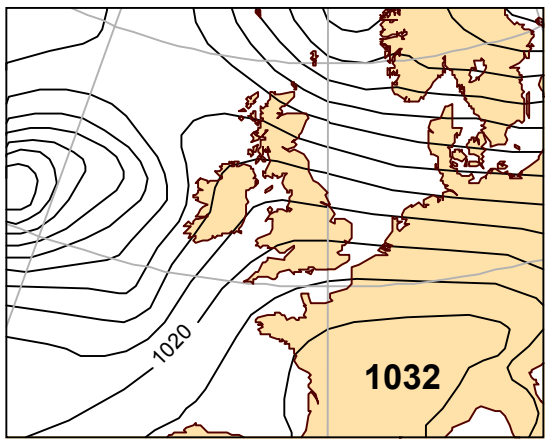
20021024 12UTC ECMWF EPS Cont FC t+ 72 VT: 20021027 12UTC
Surf: msl



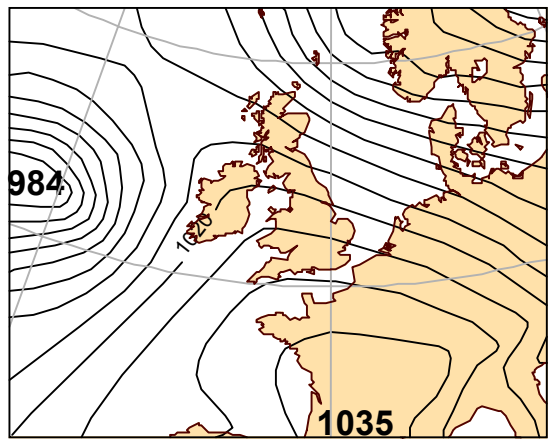
20021024 00UTC ECMWF EPS Cont FC t+ 84 VT: 20021027 12UTC
Surf: msl



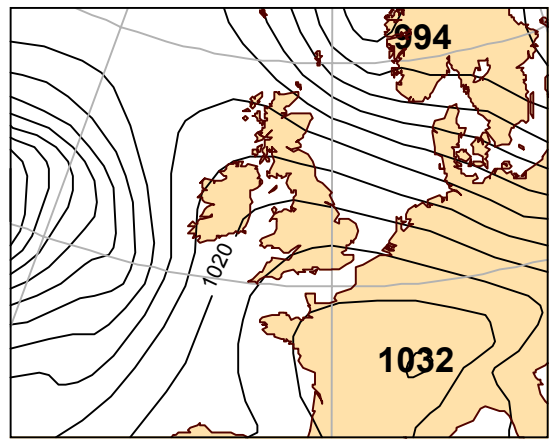
20021023 12UTC ECMWF EPS Cont FC t+ 96 VT: 20021027 12UTC
Surf: msl



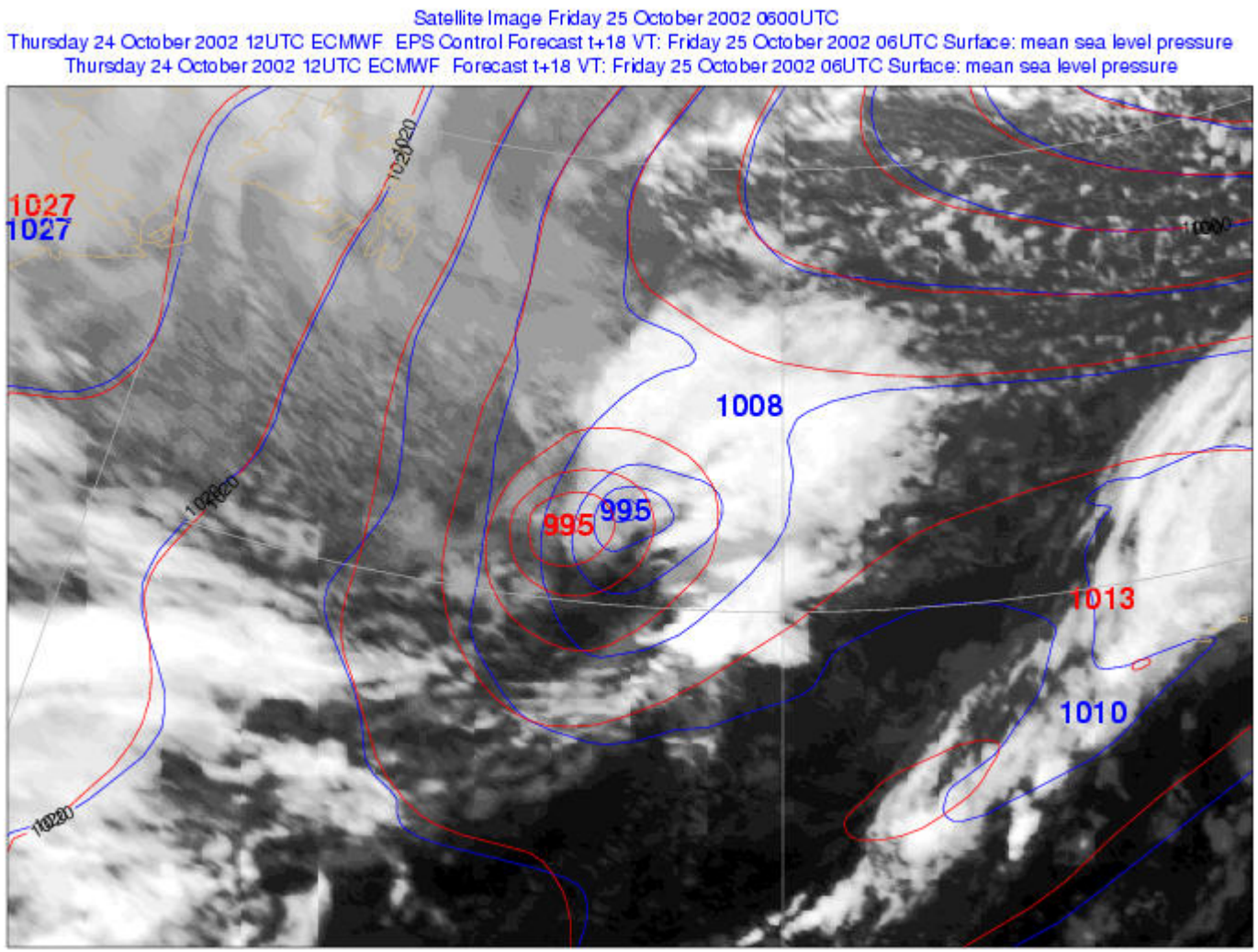
20021023 00UTC ECMWF EPS Cont FC t+108 VT: 20021027 12UTC
Surf: msl



20021022 12UTC ECMWF EPS Cont FC t+120 VT: 20021027 12UTC
Surf: msl

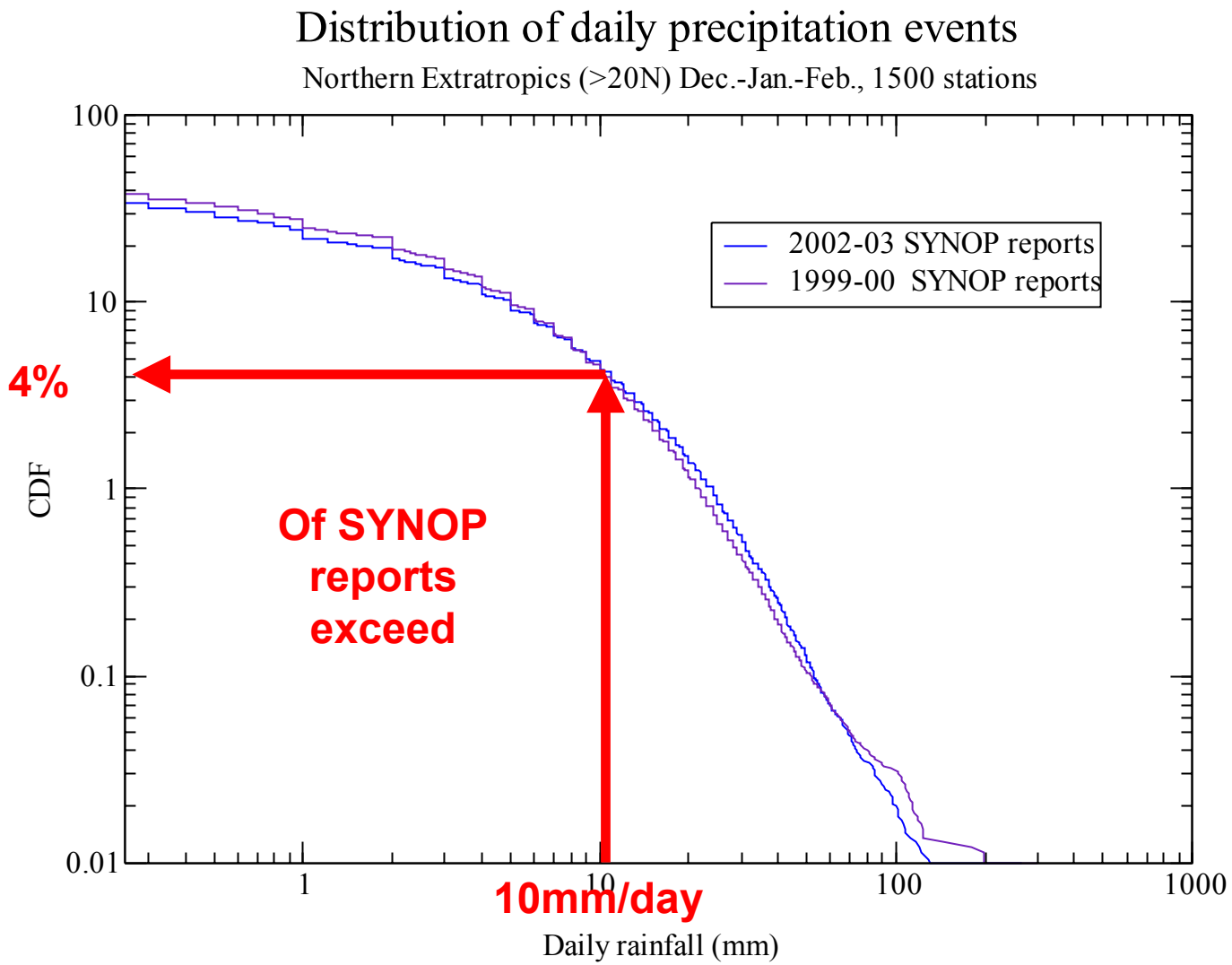


T255 and T511 18h forecasts + Meteosat7 IR

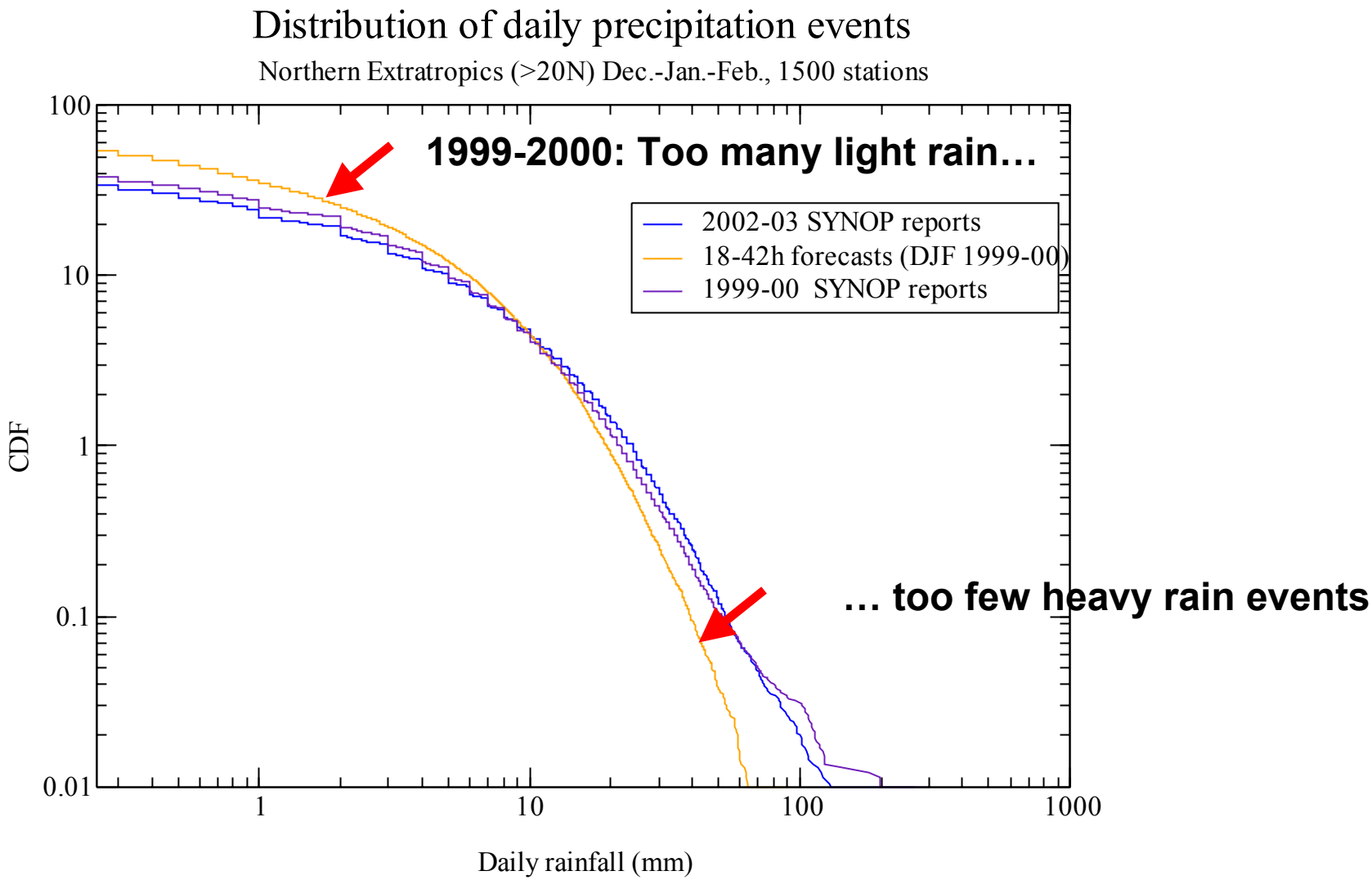


ECMWF

Recent progress: Rainfall events distribution

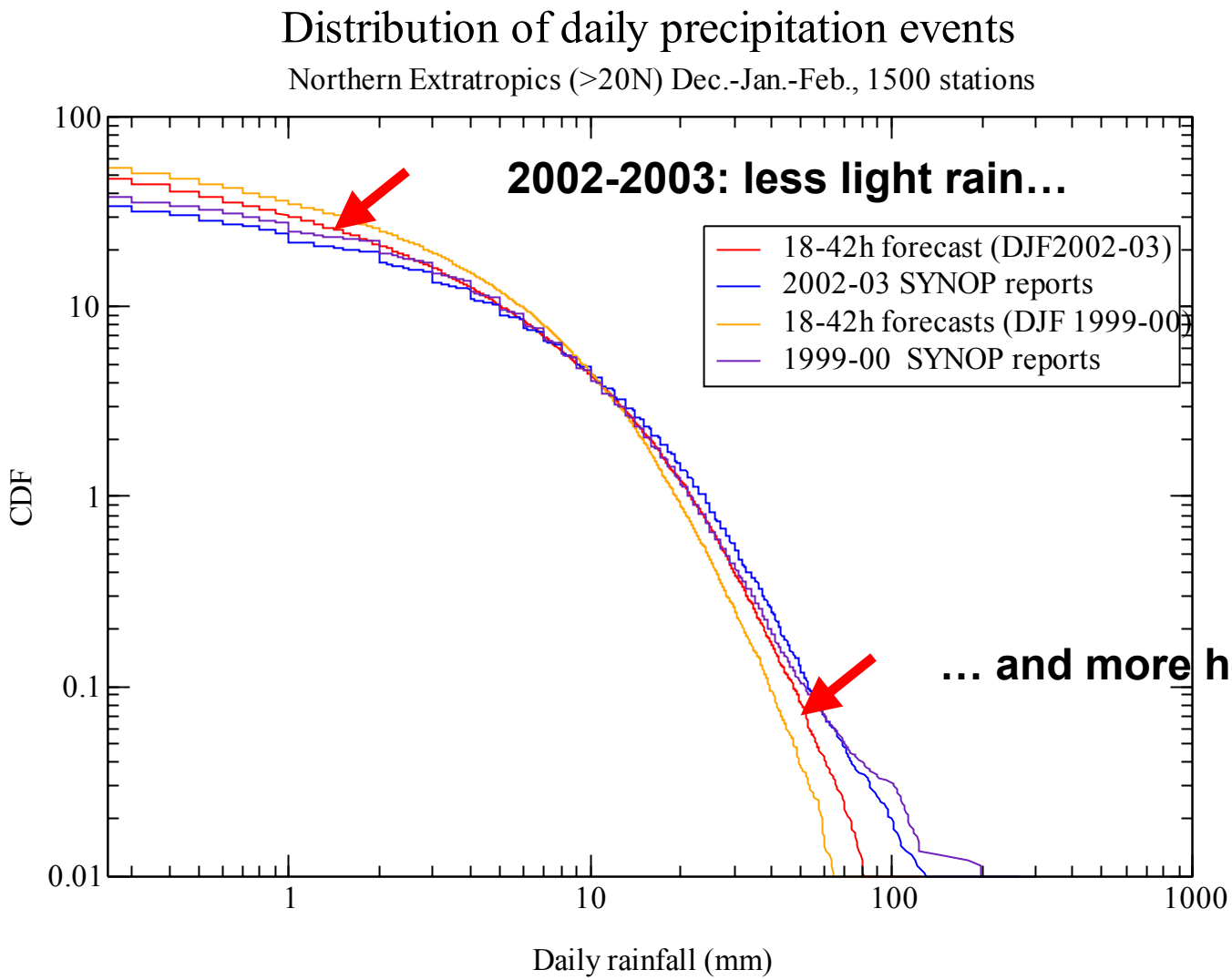


Recent progress: Rainfall events distribution



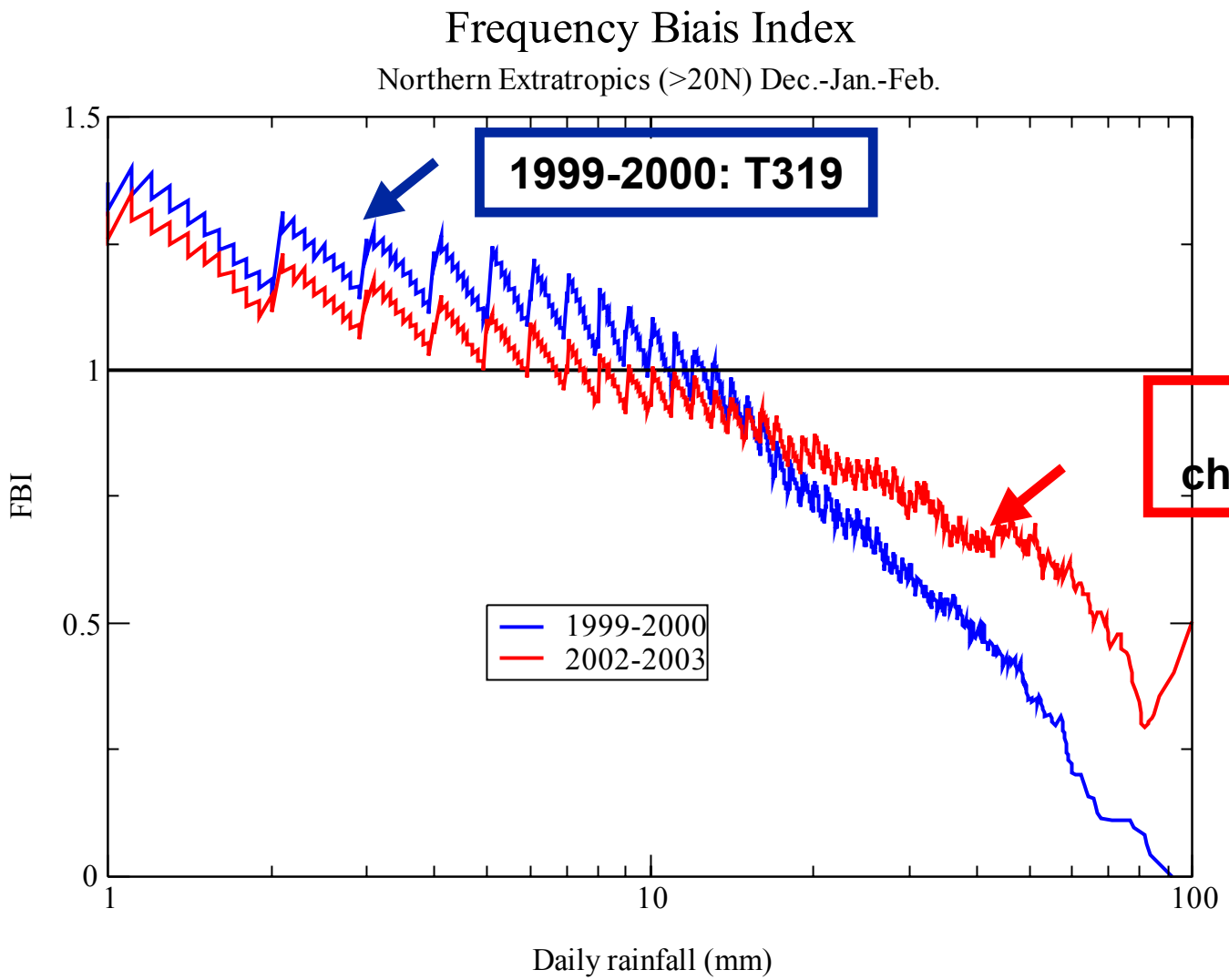
ECMWF

Recent progress: Rainfall events distribution



ECMWF

Recent progress: Rainfall events distribution



ECMWF

ECMWF Forecasts:
A tale about signal, noise, error and value

- The quest for perfect forecasts: recent achievements
- **Imperfect forecasts: how to use them**
  (backwards and forwards probabilities)
- Extending the forecast range

François Lalaurette, ECMWF

The quest for perfect forecasts

- Improving the forecasts through improved data assimilation, numerics, physics is what all NWP centres are aiming at
- Impressive progress has been achieved in recent years
  - ➔More and better use of satellite data
  - ➔Revised convection
  - ➔Revised 4D-var formulation
  - ➔Etc…
- **But what is the impact on our users?**

Do improved forecasts bring greater appraisals?

- 15 October 1987: the Great Storm
  - ➔Weather forecasters are heavily criticised, TV weatherman Michael Fish comes in for a large amount of criticism after he answered a viewers query, 'a lady has rung in to ask if there is going to be a hurricane tonight ..... there is not!“
- 26-27 December 1999: Lothar and Martin
  - ➔Warnings for both storms were issued, but several newspapers criticised both 1) the underestimation of the winds speed (the first warning at 0400UTC on 26/12 forecasted 110 to 130km/h over Ile de France, but gusts > 150km/h were observed in many places) and 2) the timing (too late warnings)

Error and value

- **NWP forecasts are wrong…**

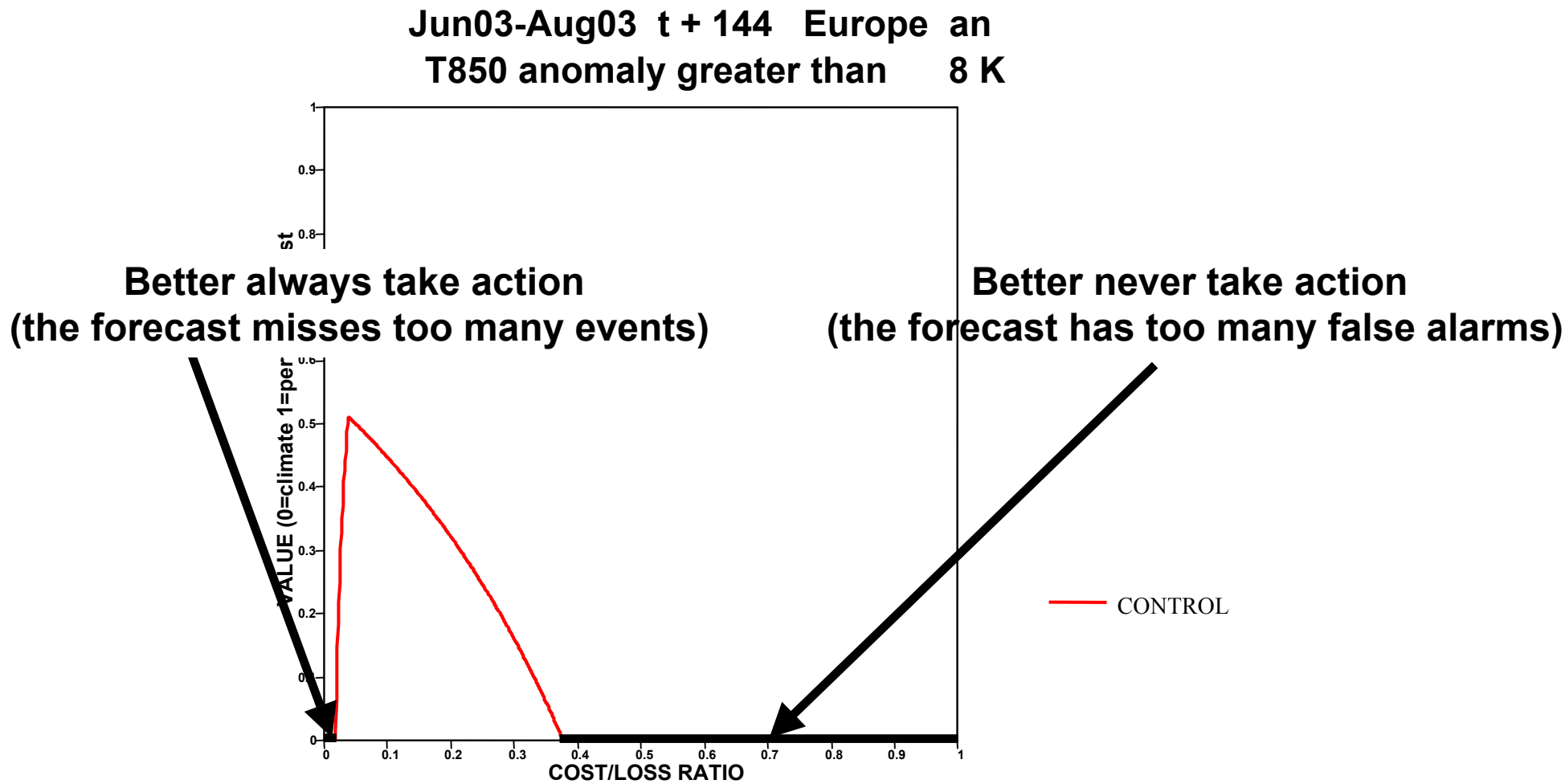
  ➔ **But by how much?**

  - Modellers have their own metrics (Root Mean Square Errors, Anomaly Correlation) from which they can assess their global improvements
  - Are these relevant for our users?

  ➔ **Decision making and value**

  - Is the knowledge of the meteorological forecast making a difference?
  - And if the answer is ”yes”, can we measure the economic benefit of making meteorologically informed decisions?
    - Yes, but only if the error characteristics are known
    - Not all applications will benefit from the forecast

Economic Value

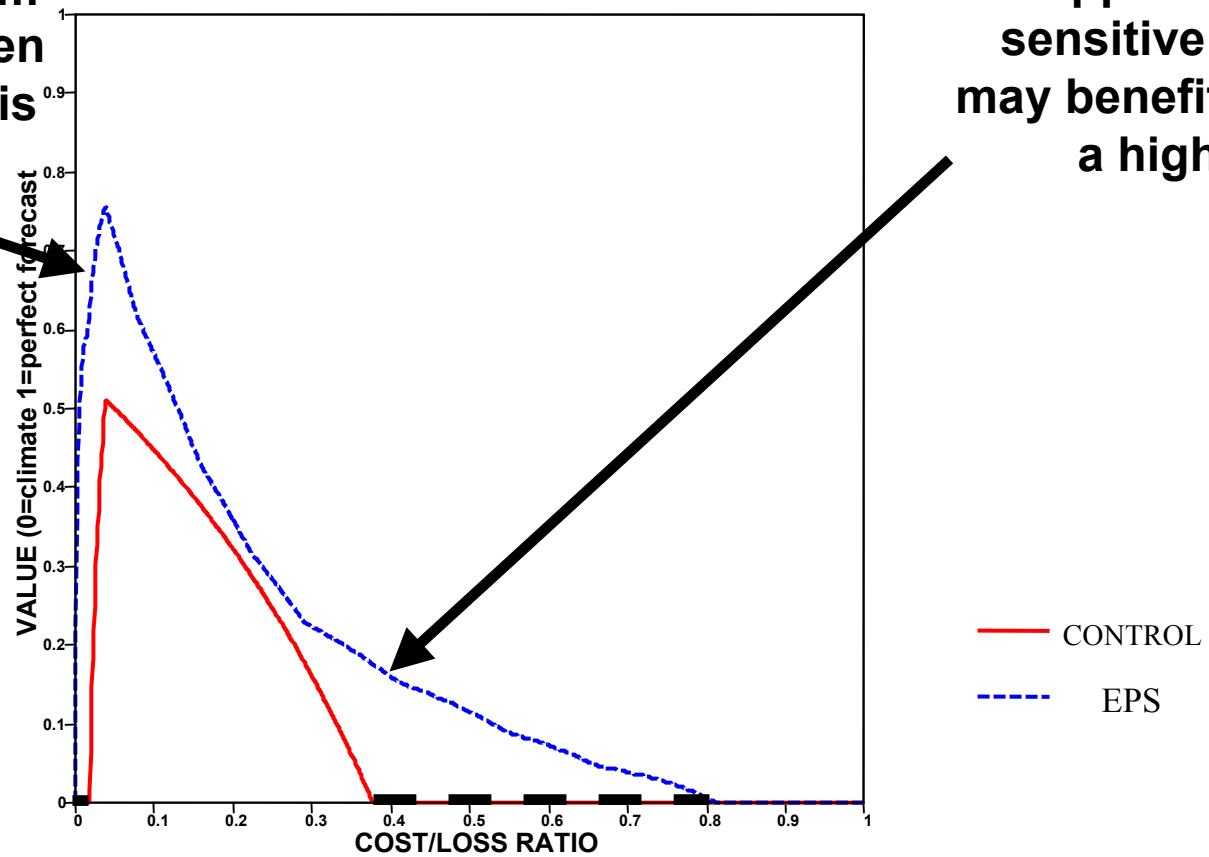


ECMWF

Economic Value: Adding Probabilities

Applications that are sensitive to missed events may benefit from acting even when the probability is low

Jun03-Aug03 t + 144 Europe an T850 anomaly greater than 8 K



If probabilities are available, applications that are sensitive to false alarms may benefit from waiting for a high probability

Extra value added by the probabilistic forecast

Probabilities are nothing new

- Traditionally, probabilities have been used (implicitly) to make decisions in uncertain environments

  - I cannot *forecast* the temperature in Rome a year ahead from today, but I know that it is *likely* to be warmer than in London

- Using probabilities adds value to dynamical forecasts

  - Backwards – if, when the model forecasts 10m/s, it still reached 20m/s or more in 10% of cases-> probability to get 20m/s or more will be set to 10% each time the model predicts 10m/s (the future will replicate the past)

  - Forwards – given initial uncertainties and model errors attached to today's analysis, the probability of reaching 20m/s is… (the future is governed by the laws of dynamics and uncertainties can be sampled by Monte-Carlo techniques: EPS)

Probabilities: Backwards and Forwards

- Forwards probabilities are prone to errors that must be known before value is extracted
- Probabilistic errors can be evaluated/corrected by statistical treatment
  - ➔Precipitation downscaling using subgrid scale error distributions
  - ➔EPSgram verification
- "Value extraction" is a very pragmatic approach
  - ➔Mix parameters, forecast ranges, locations, thresholds (e.g. MOS, or Atger, 2001)
  - ➔Maximum likelihood (Bayesian) or Maximum benefit/ protection?
  - ➔Should we care about probabilities?

Should we care about probabilities?

- **As scientists, the answer is "yes"**
  - ➔ **The EPS problem is posed as a PDF forecast**
  - ➔ **Therefore, the forecast PDFs should be verified (Brier Scores, reliability, rank histograms, …)**
  - ➔ **The probabilistic version of the quest for a perfect forecast…**
- **As users, the answer is "maybe"**
  - ➔ **EPS probabilities are imperfect**
  - ➔ **So the alternative is between:**
    - Calibrating probabilities (still you will have to use verification data to decide whether or not your application can benefit from the probabilistic forecast)
    - Or use the ensemble as raw input (together with verification data) for your decision-making strategy (maximum value extraction)

Statistics: can they solve all problems?

- **Value is highly dependant on the availability of sound verification statistics…**
- **… but statistics only build up slowly – and the more so the more the events definition is refined**

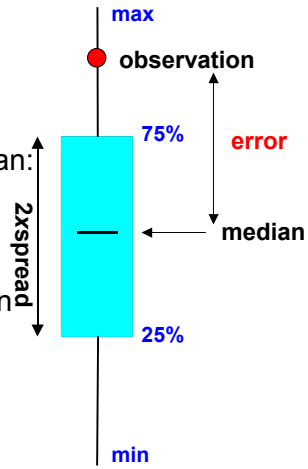
EPSgrams: Verification (with G. van der Grijn)

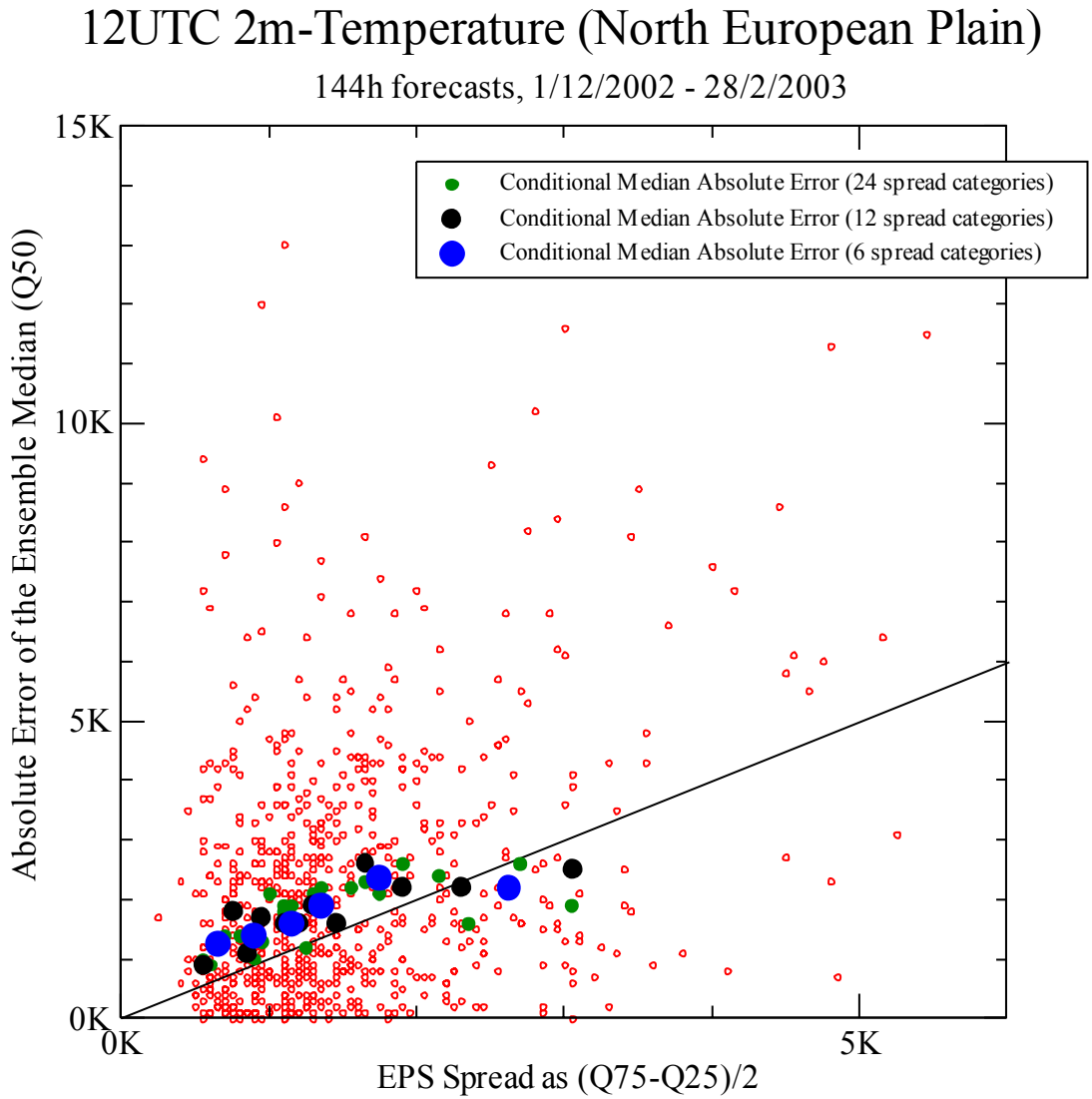
EPS spread and error - definitions

- Spread is defined as (Q75 –Q25)/2
- Predictor: ensemble MEDIAN
- P=50% that observation is in/out blue box
- If spread is evenly distributed around median:

  P=50% that forecast error > spread

  Hence, the median of the error distribution should exactly match the spread





ECMWF

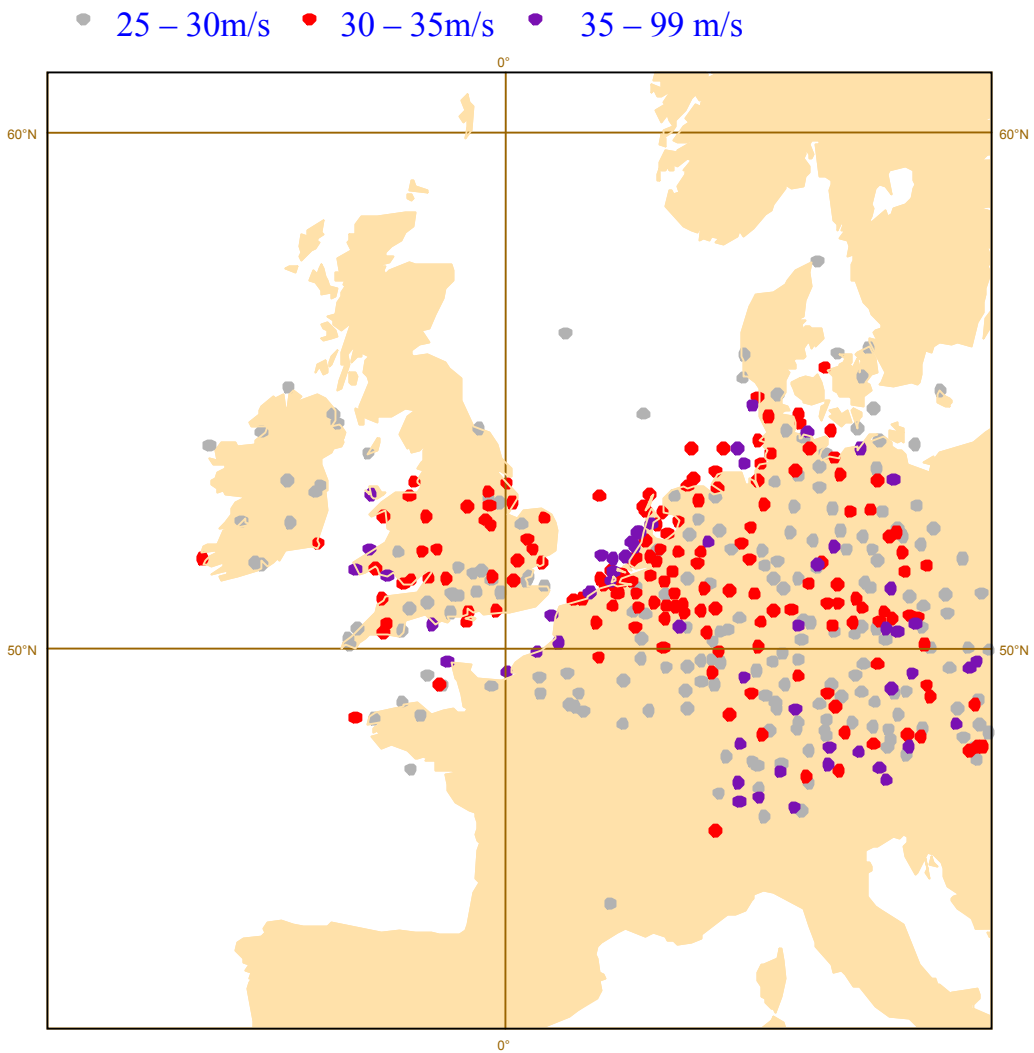
Statistics: can they solve all problems?

- Value is highly dependant on the availability of sound verification statistics…
- … but statistics only build up slowly – and the more so the more the events definition is refined
- **Extreme events are therefore likely to stay at the edge of statistical calibration: there is still therefore a need for… perfect models!**
- **Two attempts to build severe weather products from imperfect models:**
  - ➔ **The Extreme Forecast Index (EFI, see also H. Gmoser's presentation on Friday)**
  - ➔ **Tropical Cyclone Strike Probability maps**

Severe weather products: EFI and TC tracks

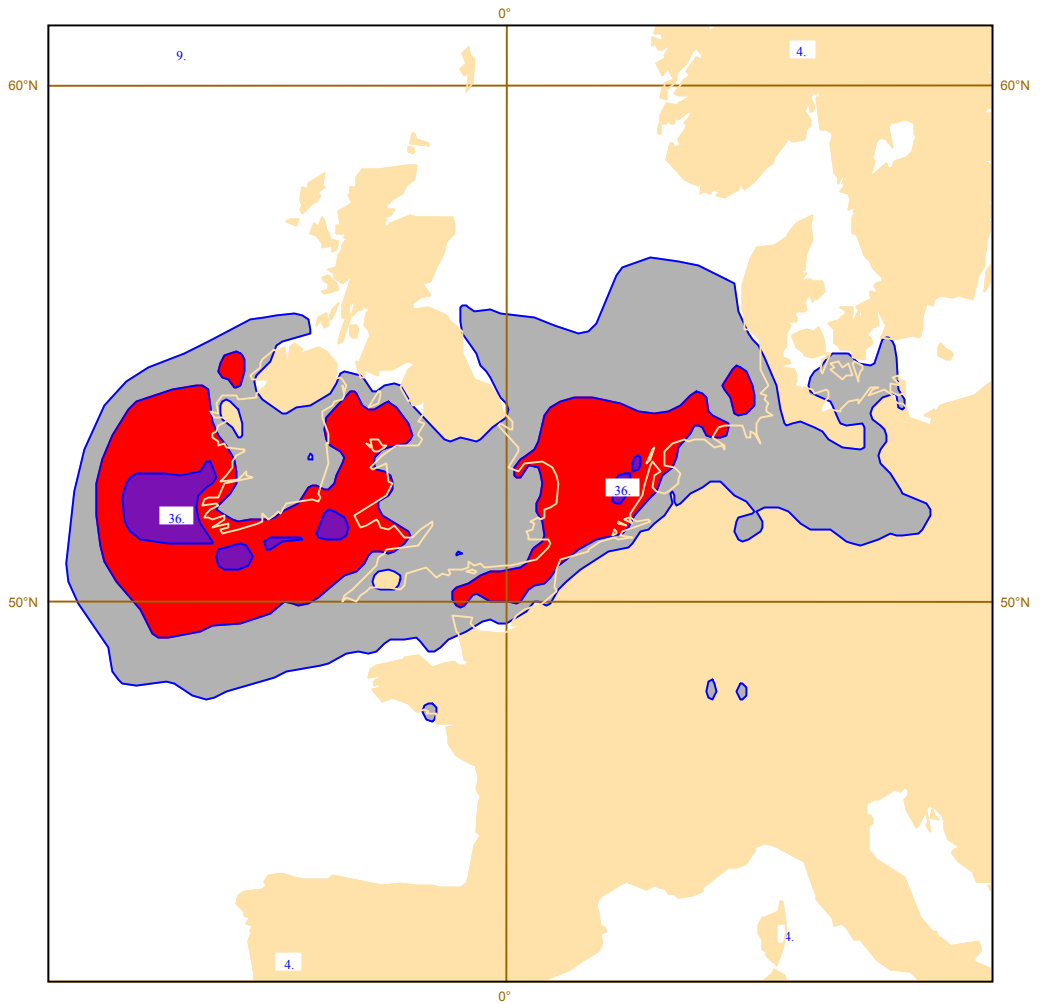
- **Both products are based on an attempt:**
  - **➔Not to calibrate extreme events forecasts**
  - **➔But to "project" the forecast onto the model climate**
    - The EFI measures the distance between the EPS probability distribution and the model climate one
    - Strike probability maps identify Tropical Cyclones within parameter ranges that are adapted to the model resolution/ physics representation

Maximum wind gust reported on 27 Oct. 2002



Did T511 forecast such strong winds?

Saturday 26 October 2002 12UTC ECMWF Forecast t+(12-36) VT: Sunday 27 October 2002 Surface: wind gust at 10m

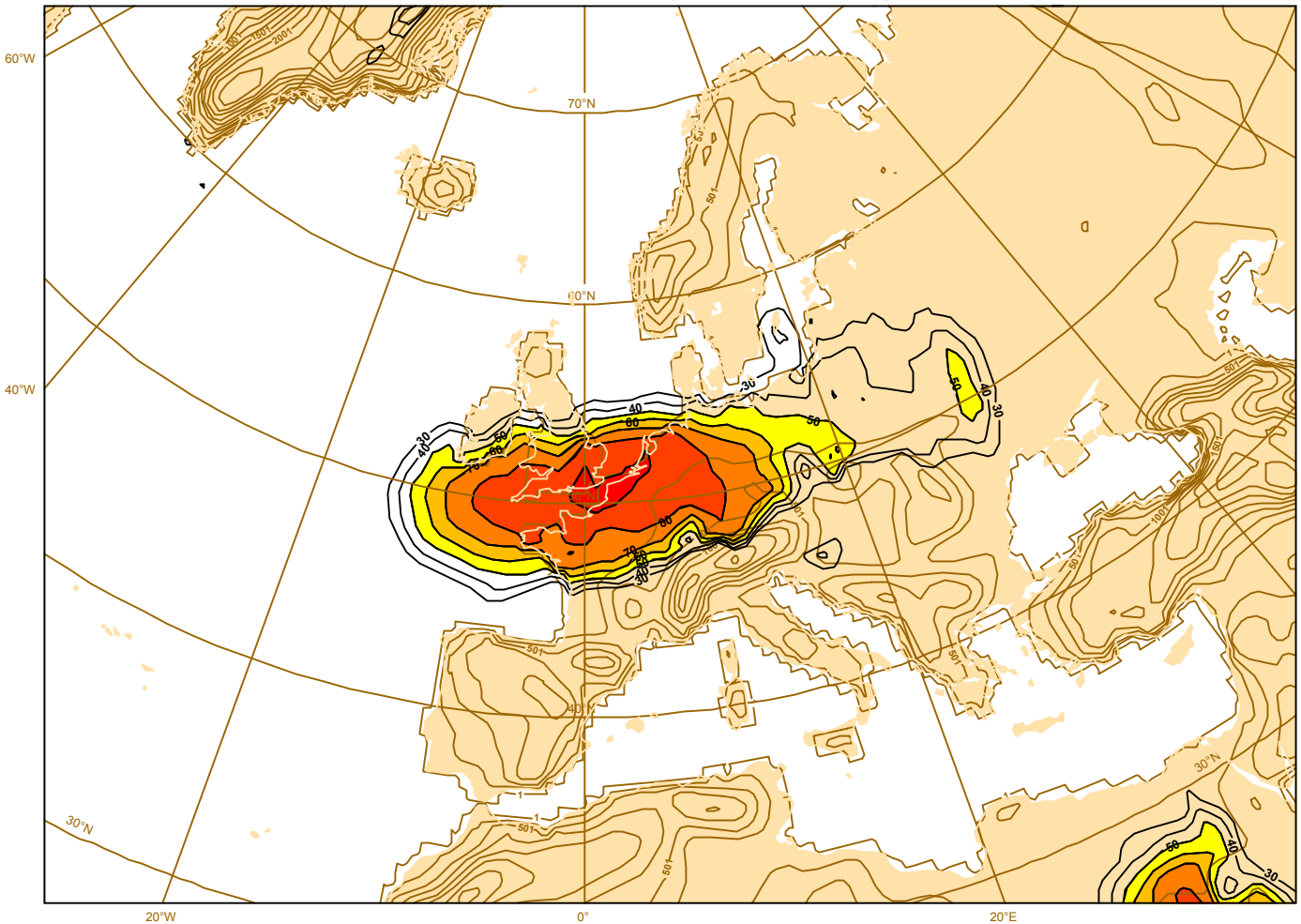


- In the very short range, the wind gust estimates were spot-on for the Dutch, Welsh and East Anglia/ Kent coast lines
- The wind gust over land were underestimated significantly, most notably over South Germany, Switzerland, Austria and the Czech Republic on Sunday eve.

ECMWF

EFI signatures

Maximum 0-24UTC 10m Wind Gust EPS Extreme Forecast Index 3
Base **25 October 2002 12UTC**, VT: Sunday 27 October 2002

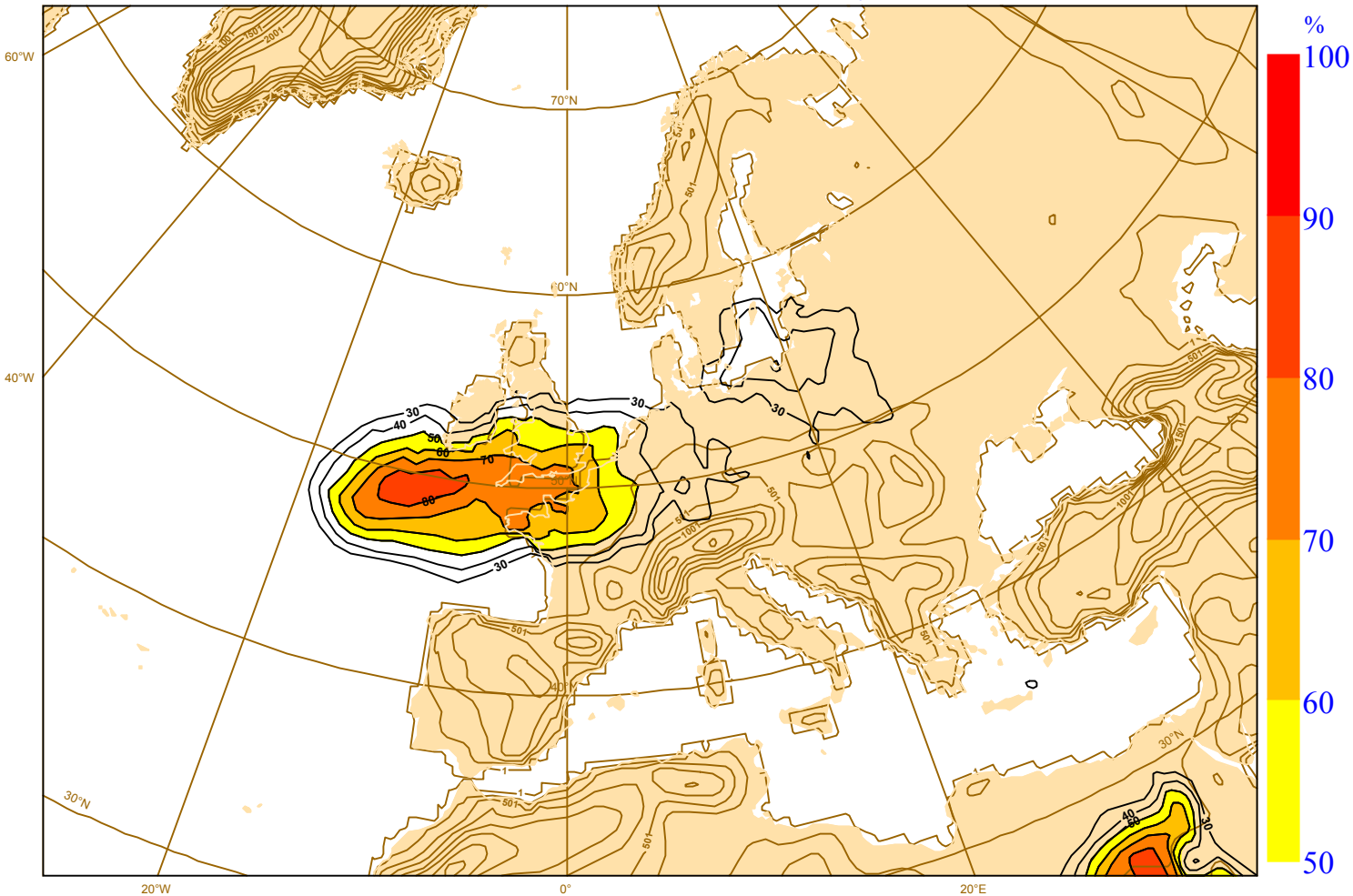


- **Friday 25 12UTC map had a good cover of both the English and Continental extent of the strong winds**

ECMWF

EFI signatures

Maximum 0-24UTC 10m Wind Gust EPS Extreme Forecast Index 3 _12
Base **25 October 2002 00UTC**, VT: Sunday 27 October 2002

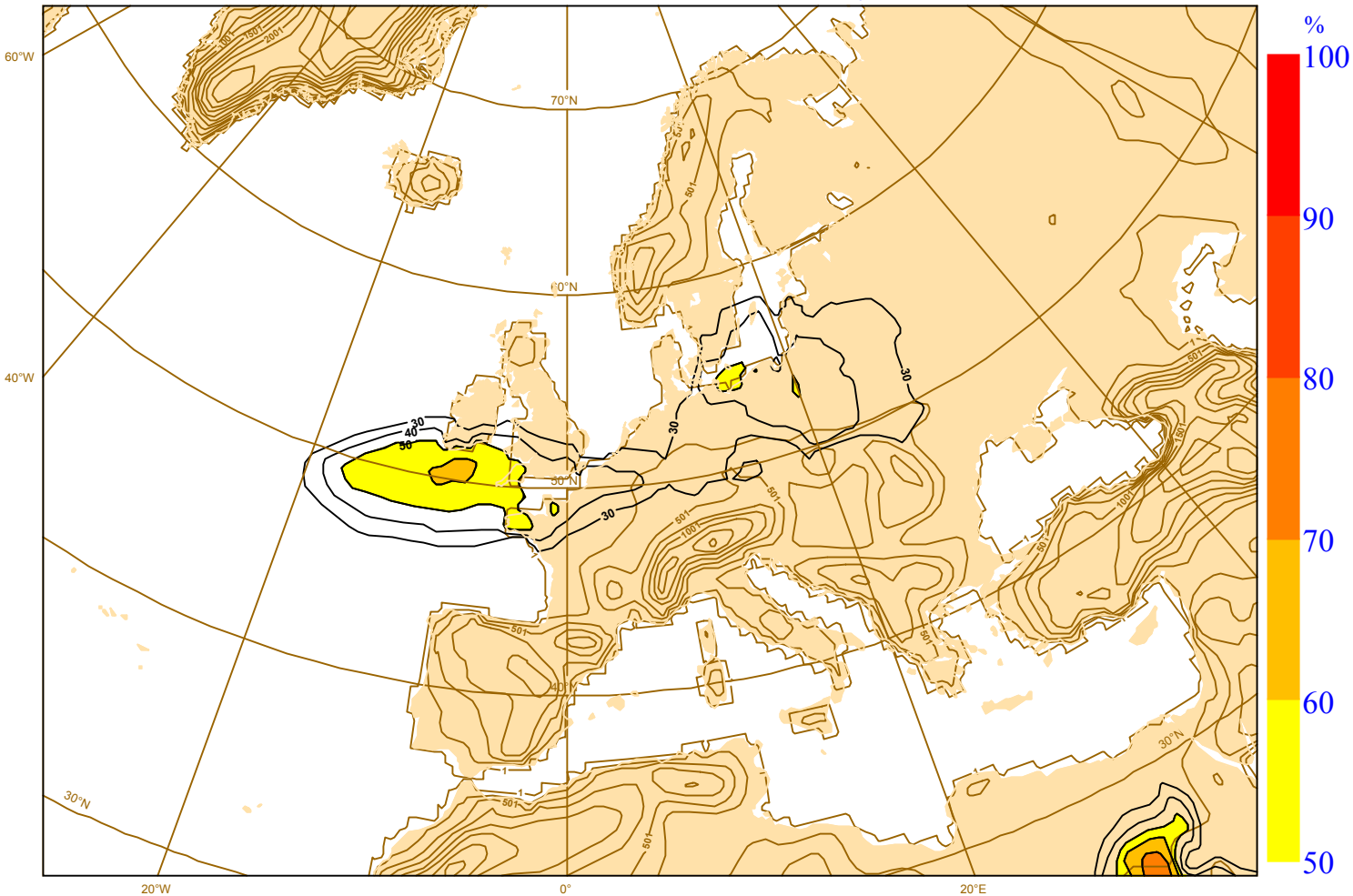


- **Earlier forecasts increasingly suffered from the “slow moving” syndrome of the T255 runs - as discussed previously**

ECMWF

EFI signatures

Maximum 0-24UTC 10m Wind Gust EPS Extreme Forecast Index 3
Base **24 October 2002 12UTC**, VT: Sunday 27 October 2002

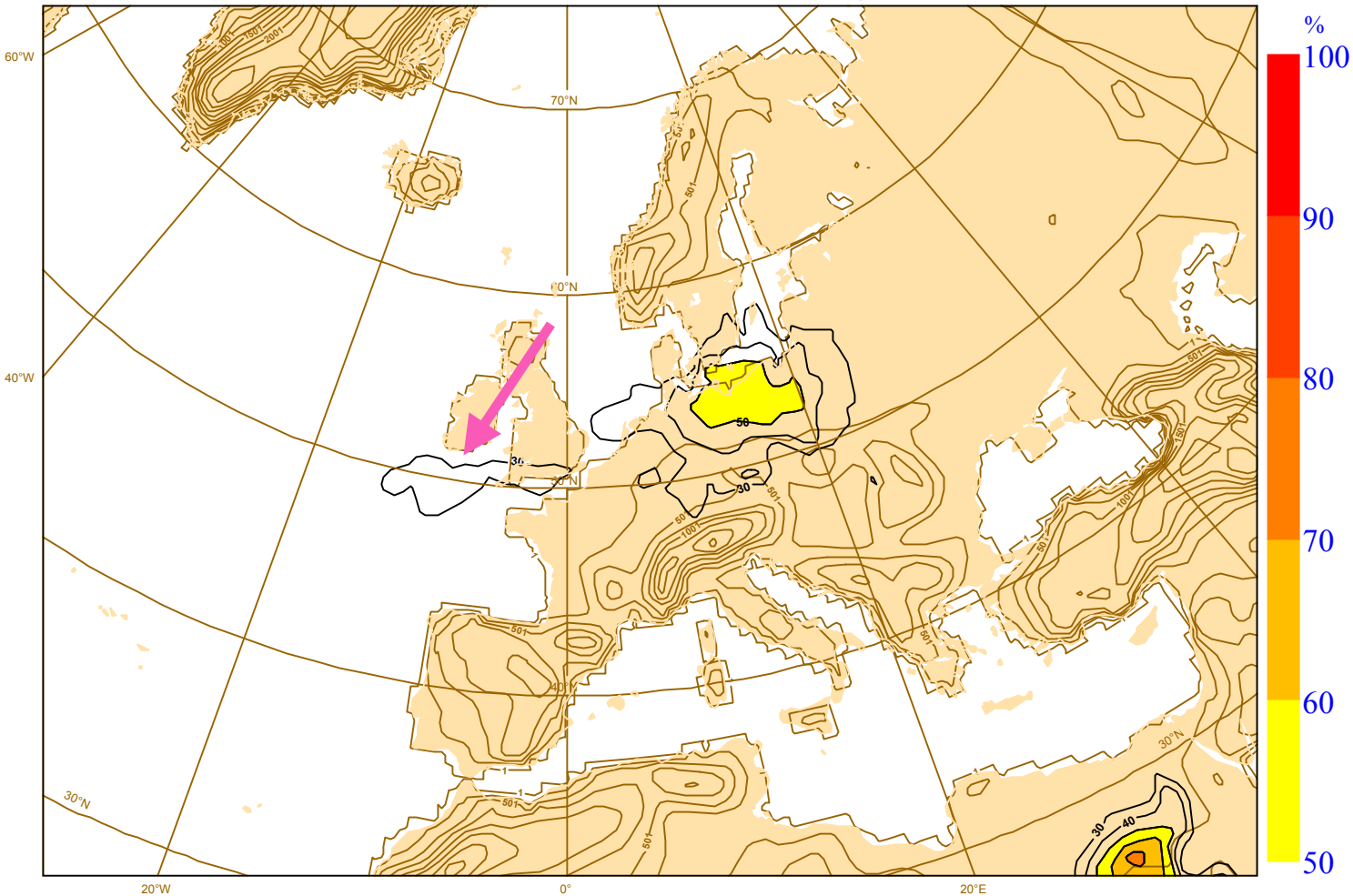


- **Earlier forecasts increasingly suffered from the “slow moving” syndrome of the T255 runs - as discussed previously**

ECMWF

EFI signatures

Maximum 0-24UTC 10m Wind Gust EPS Extreme Forecast Index 3 _12
Base **24 October 2002 00UTC**, VT: Sunday 27 October 2002

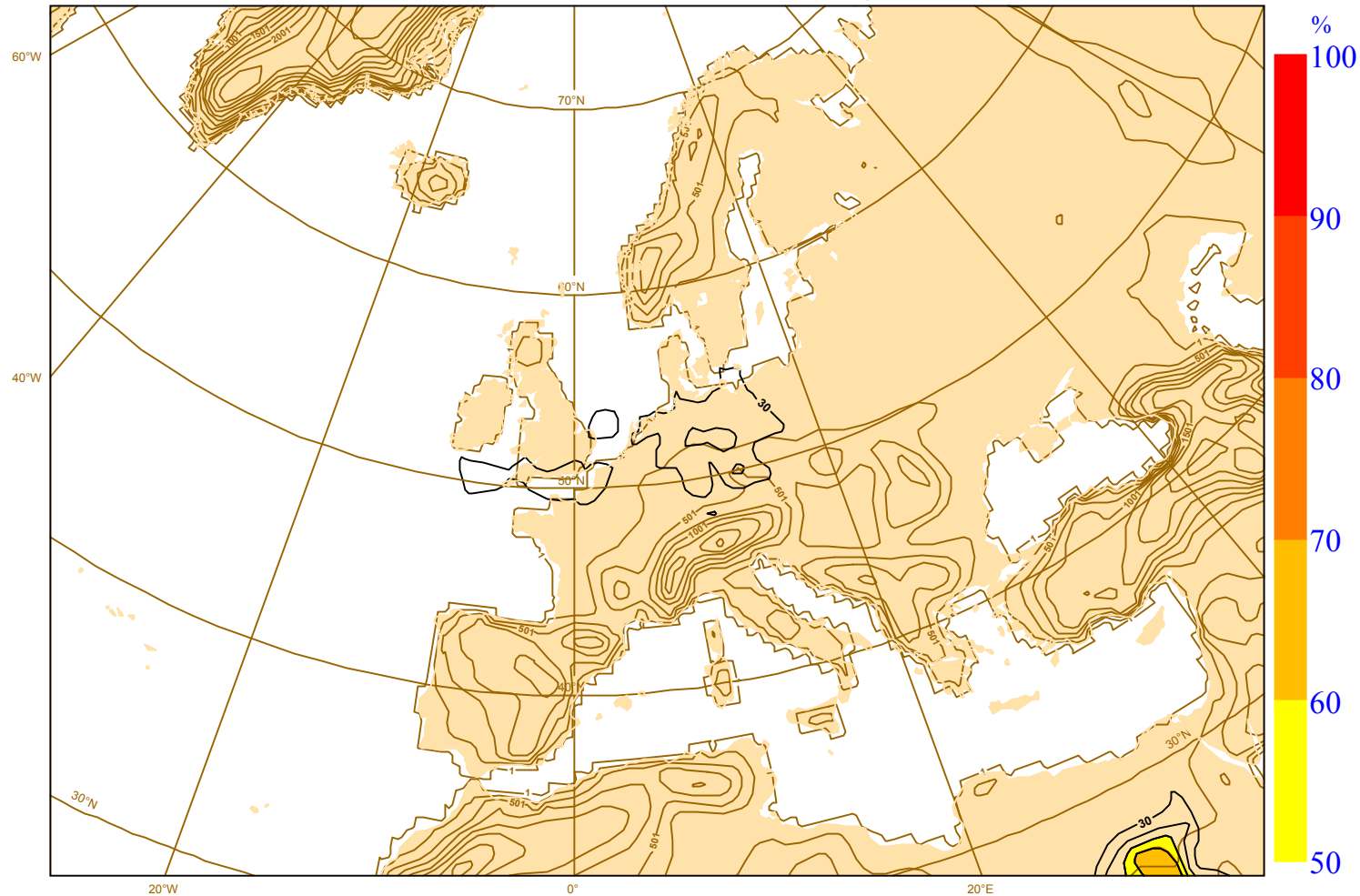


- **Earlier forecasts increasingly suffered from the “slow moving” syndrome of the T255 runs - as discussed previously**

ECMWF

EFI signatures (add heat wave?)

Maximum 0-24UTC 10m Wind Gust EPS Extreme Forecast Index 3
Base **22 October 2002 12UTC**, VT: Sunday 27 October 2002



- **Earlier forecasts increasingly suffered from the "slow moving" syndrome of the T255 runs - as discussed previously**

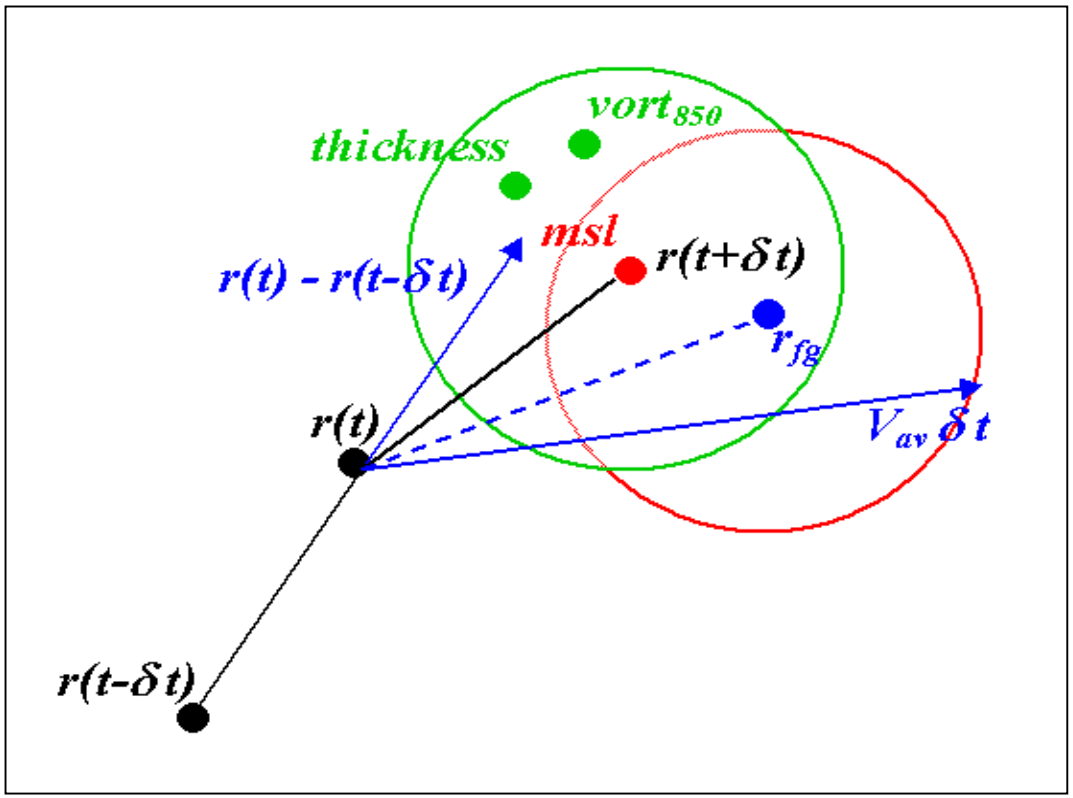
ECMWF

Tropical Cyclones forecast tracks: Basic description (G. van der Grijn)

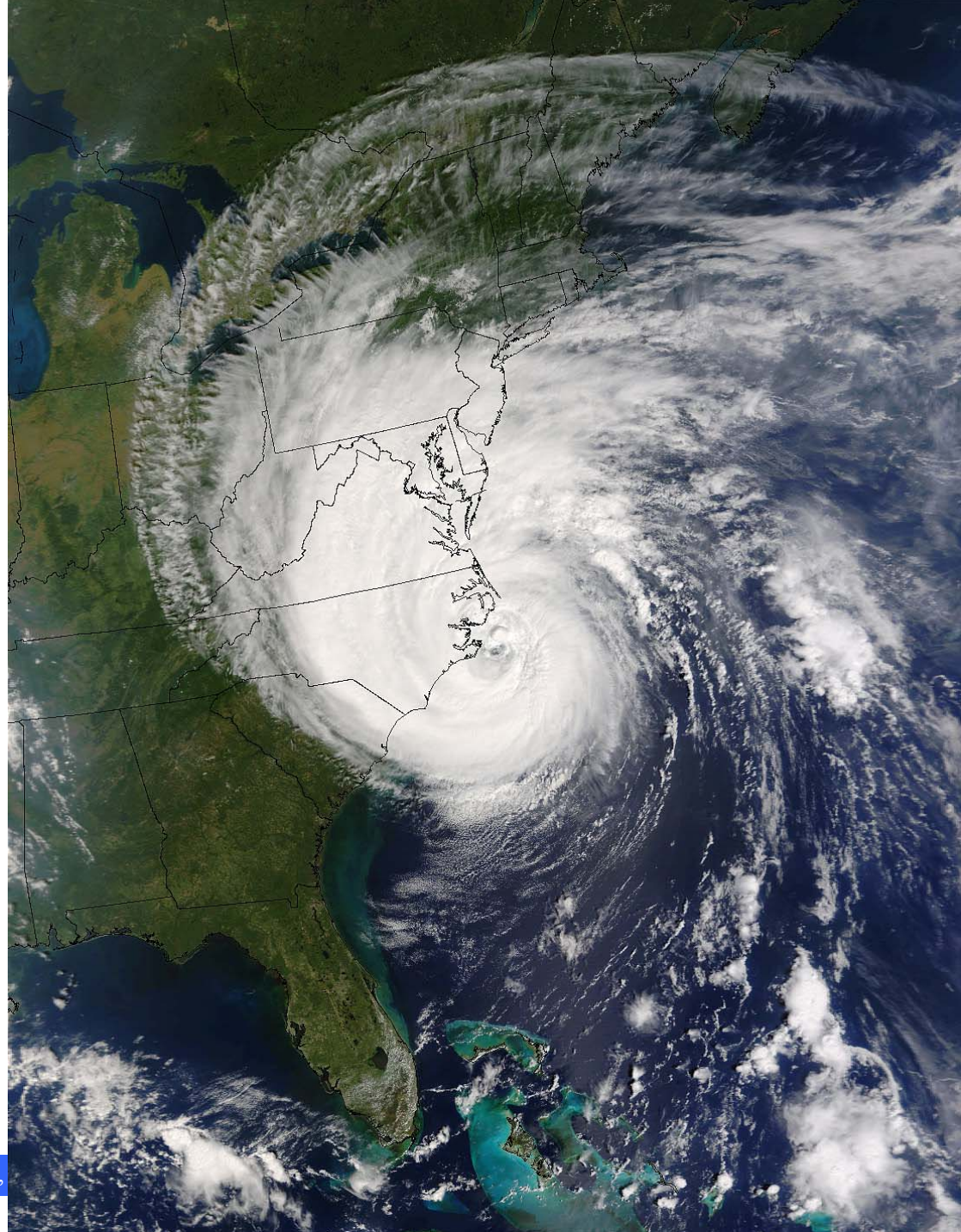
At forecast time *t*, a TC is present at *r(t)*. The first guess position vector for the next-track position r_{fg} at time $t+\Delta t$ is based on a weighted combination of the previous displacement and the steering flow.

When the first guess (r_{fg}) of the next track position is found, the tracker looks for a local minimum in mean sea level pressure (msl) within a certain radius around the first guess.

This msl minimum is considered to be a genuine TC if a local maximum of 850hPa vorticity and a local maximum of 850hPa-200hPa thickness is found in the vicinity.



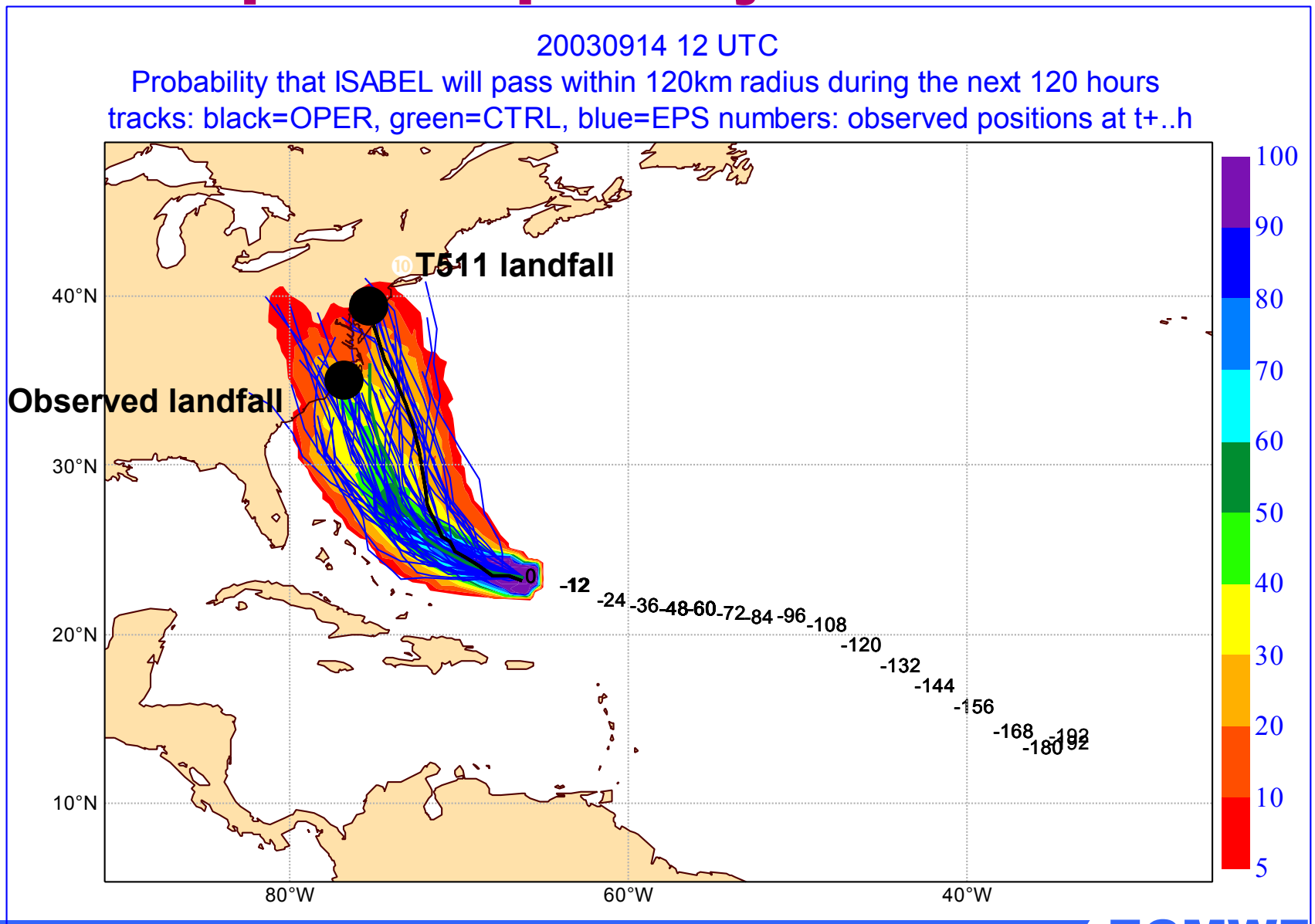
Special Topics: Tropical Cyclones



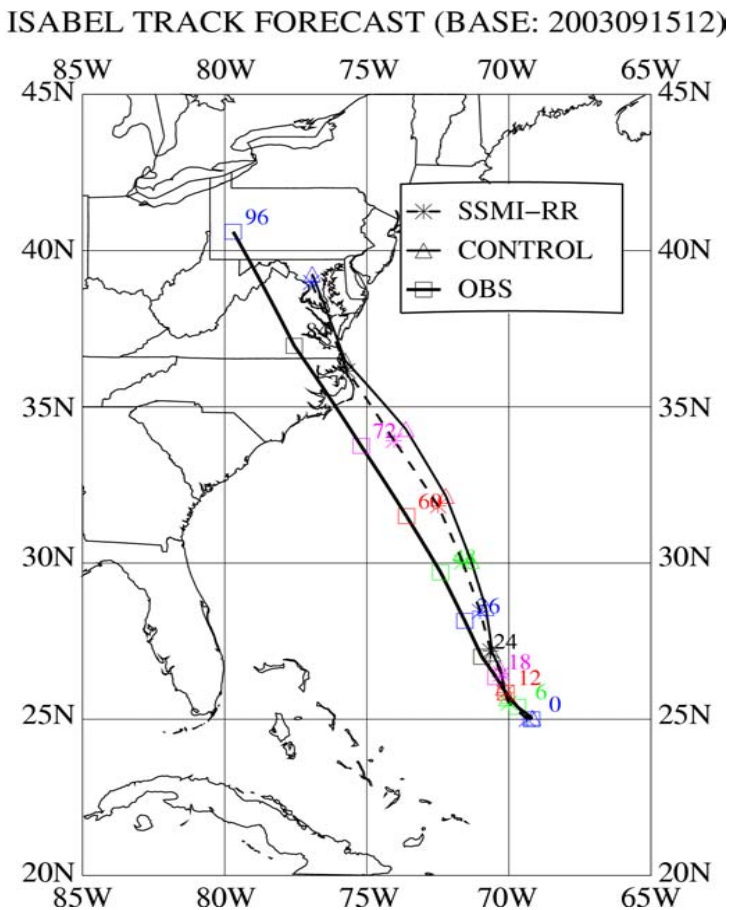
Hurricane Isabel, 18 Sept. 2003 1555UTC

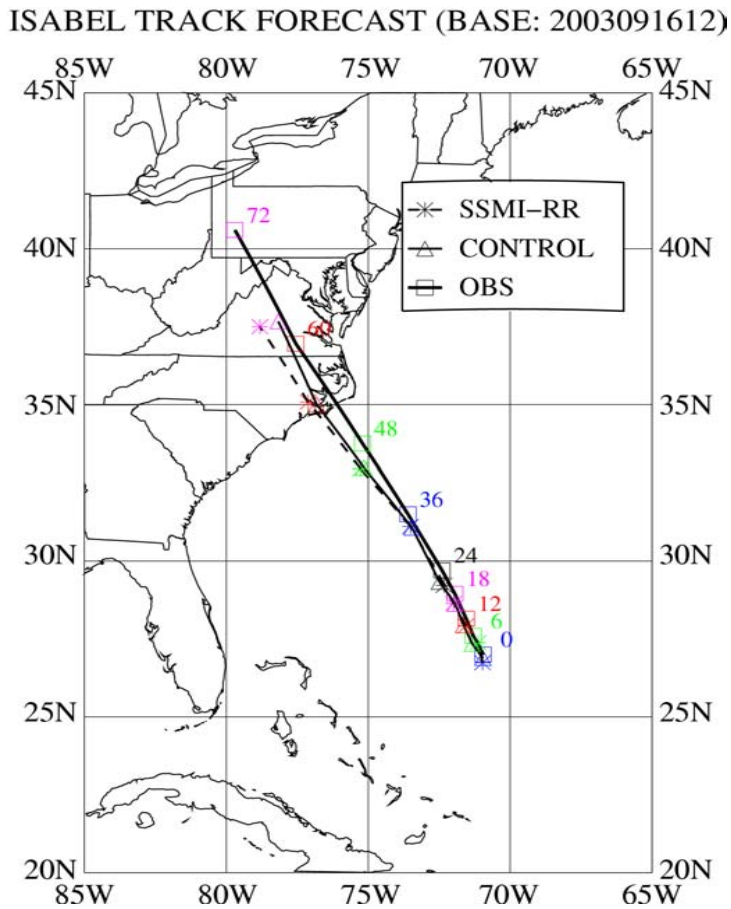
MODIS on Terra, http://terra.ssec.wisc.edu

Special Topics: Tropical Cyclones

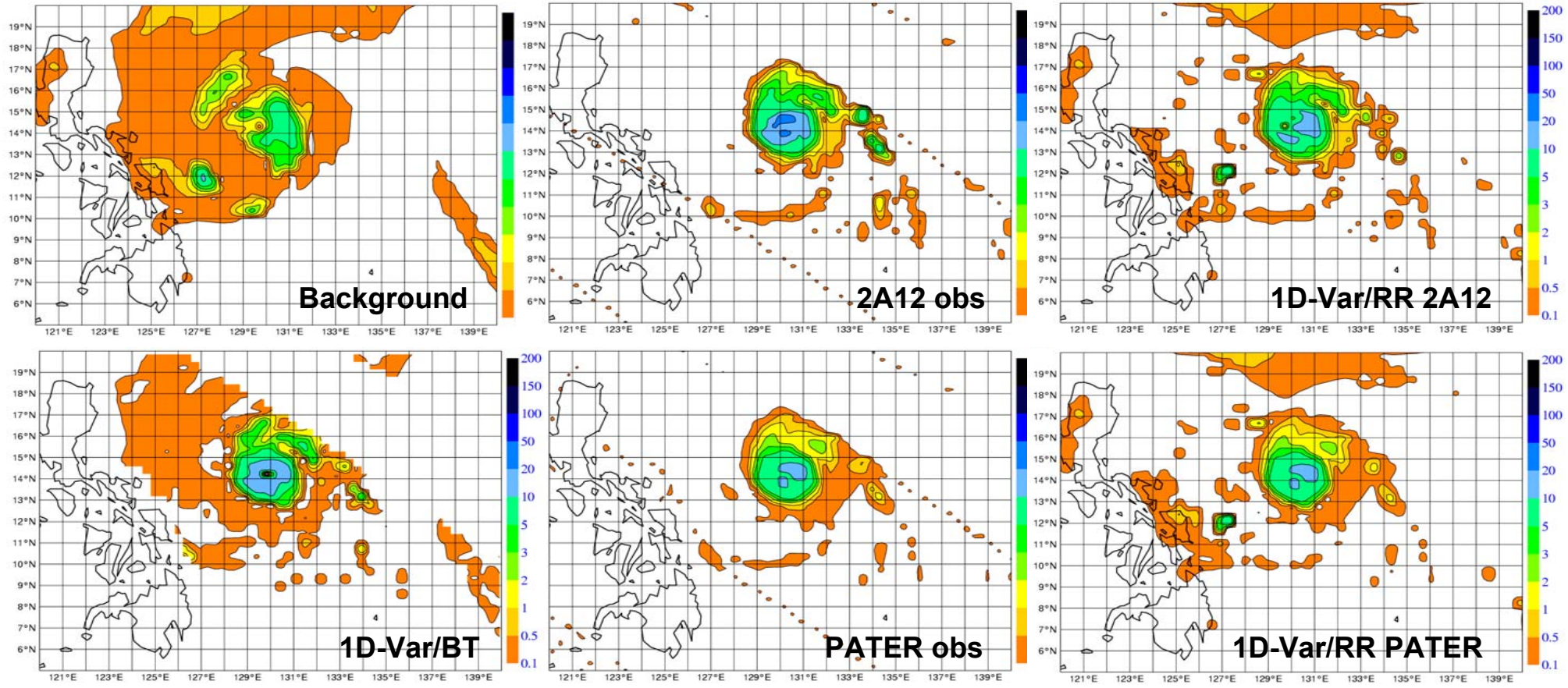


Hurricane ISABEL: impact of SSM/I-Rain Rate Assimilation on the T511 forecast (courtesy from P. Bauer, E. Moreau, P. Lopez, A. Benedetti, A. Tompkins, M. Janiskova et F. Chevallier)





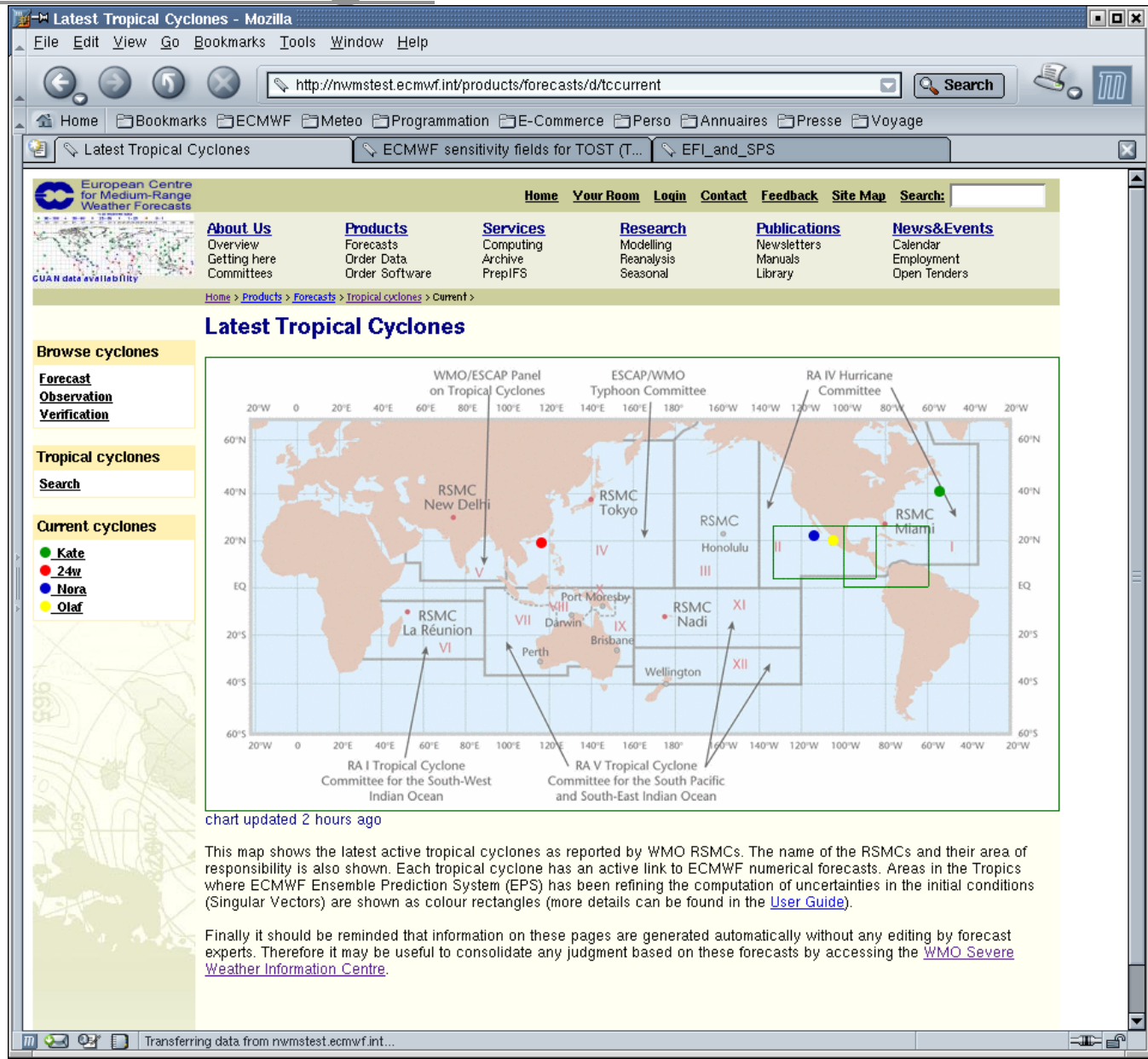
1D-Var results



Case of super-typhoon MITAG (5 March 2002 @1200 UTC)
TMI data
Surface rainfall rates (mm hr^{-1})

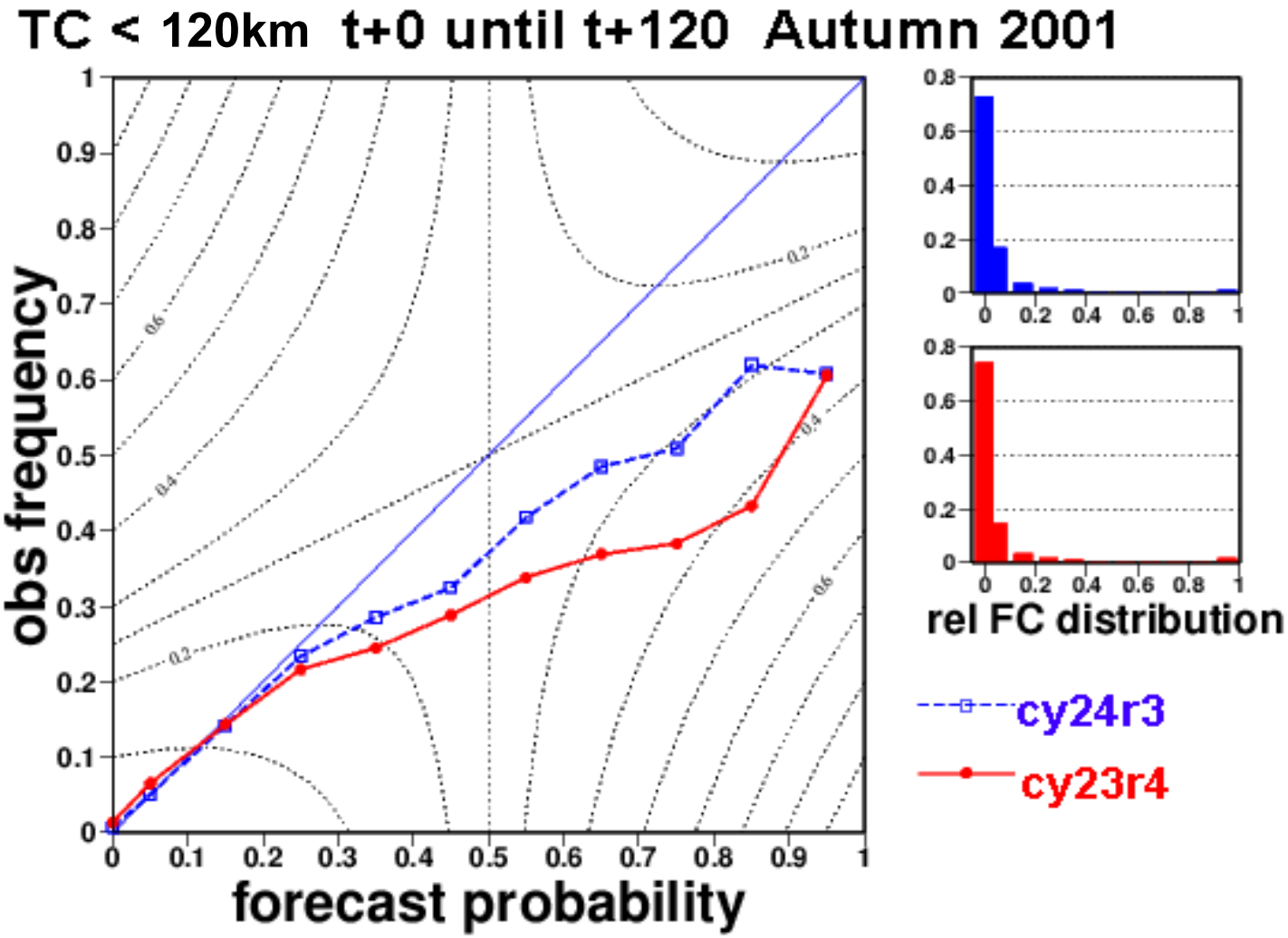
New Tropical Cyclone Web Pages

(G. van der Grijn, C. Sahin and C. Gibert)



ECMWF

Tropical cyclone EPS probabilities: impact of diabatic, targeted perturbations



ECMWF

ECMWF Forecasts:
A tale about signal, noise, error and value

- The quest for perfect forecasts: recent achievements and issues
- Imperfect forecasts: how to use them
  backwards and forwards probabilities
- **Extending the forecast range**

François Lalaurette, ECMWF

Extending the forecast range

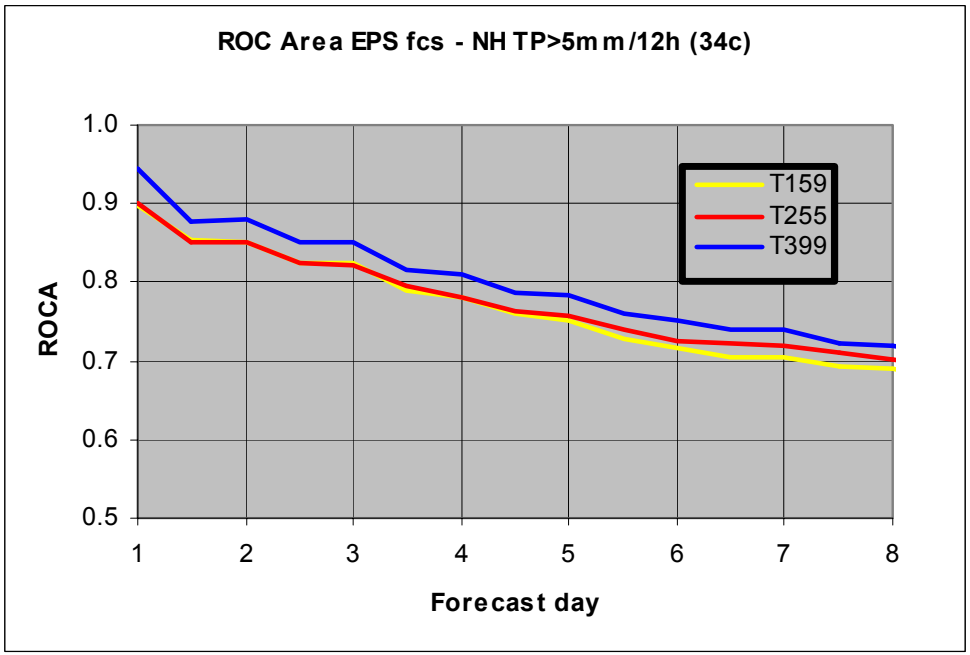
- ECMWF has been created in 1979 with the main objective of extending the range of numerical forecasts into the medium range
- Was it successful?
  - ➔Yes, looking at how good the Day 5 forecasts are today compared to what they were at the time
  - ➔But the vast majority of applications in Member States remain focused on the short range (1-2 days), medium range being merely an “outlook”
- So can we extend the “useful” forecast range?
  - ➔For this we have both to improve the forecasts AND tell the users that decision making in the early medium range is a risky, but potentially rewarding business…

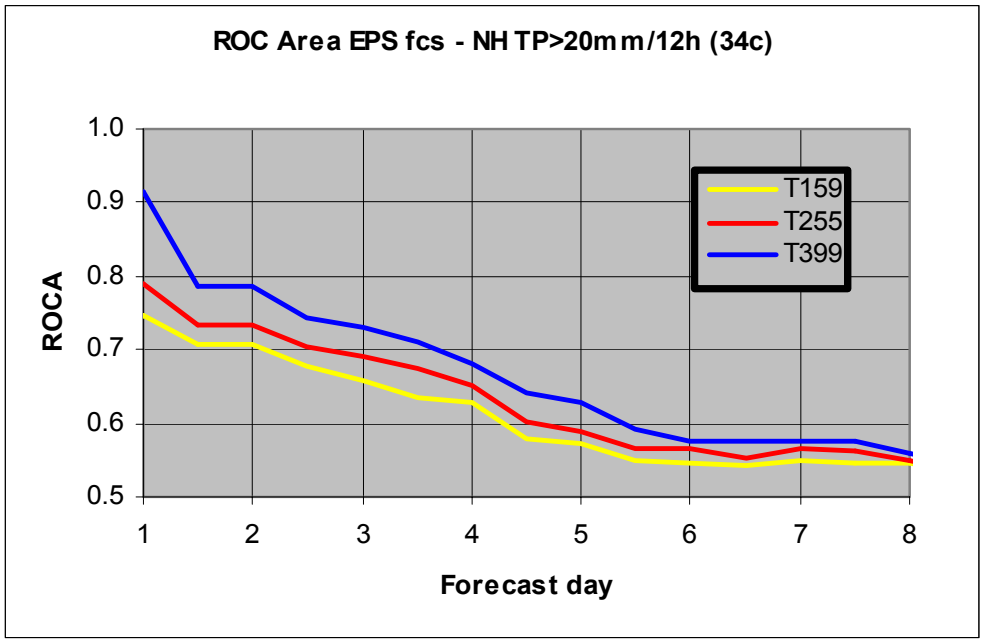
Extending the forecast range

- Early Medium Range: severe weather
- Medium-Range: beyond the 10-days limit…
- Extended medium range: Monthly forecasts
- Long-range: beyond 6 months
- Towards a “seamless” ensemble forecast system? E.g.
  - T399(50 km) to D+7 twice daily
  - continue once a day at T255(80 km) to D+15
  - continue twice a week at T159(123 km) to D+30, in coupled mode

Impact of a resolution increase on precipitation (courtesy R. Buizza)

A resolution increase from T_L255 to T_L399 would have a large impact on the quality of 12h-accumulated precipitation: ~12h predictability gain for 5 and 20 mm thresholds on average over NH (results based on 34 cases, cy23r4 and 25r5).

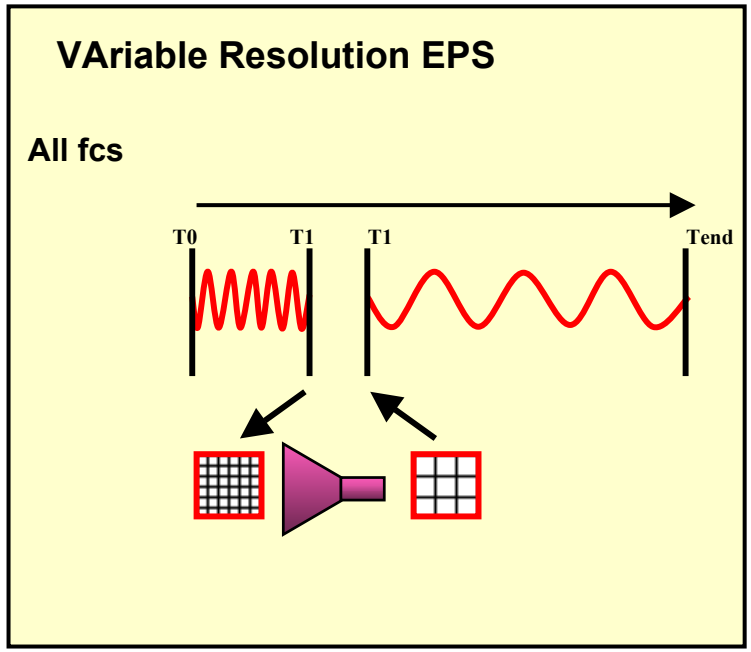




VAREPS (R. Buizza/ N. Wedi): an approach to reduce the EPS production costs

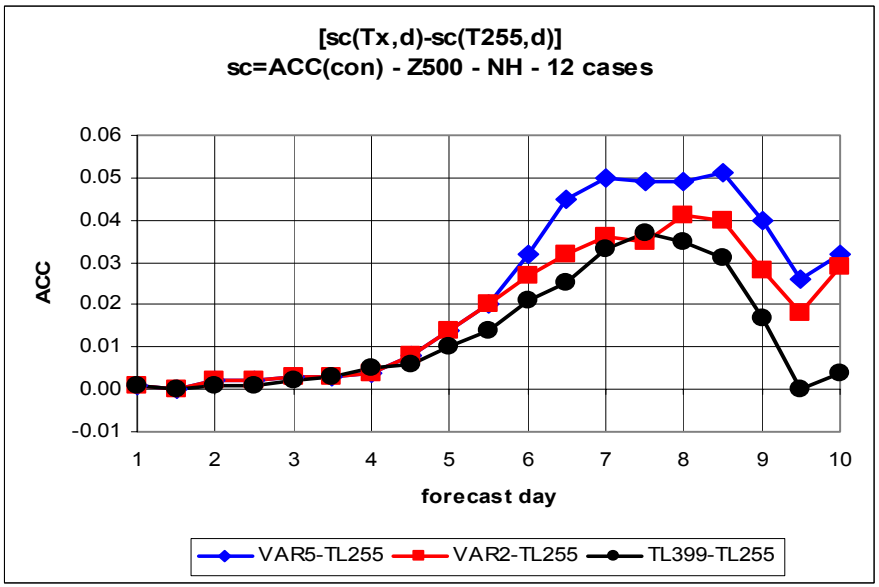
VAREPS project:

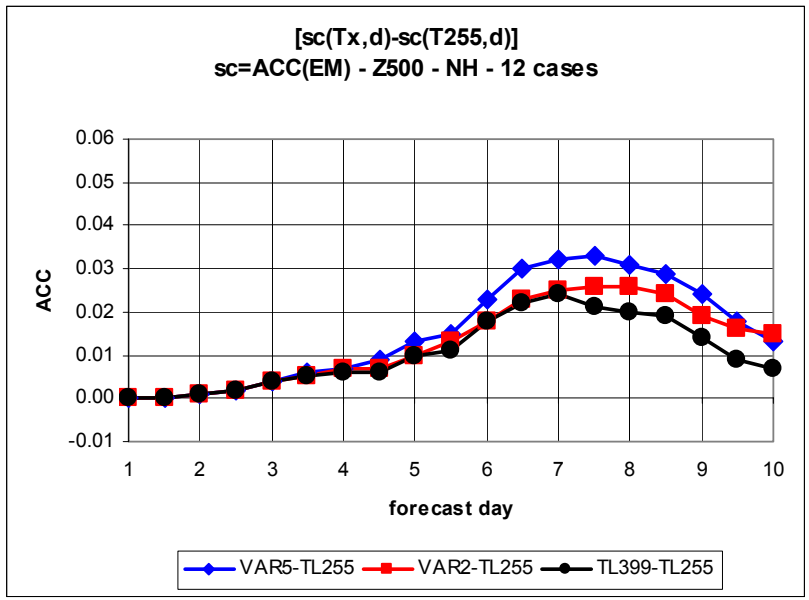
- phase 1: deterministic forecasts only (cy23r4)
- phase 2: test of T511>T255 VAREPS systems (cy23r4, 24r3, 25r1)
- phase 3: investigation of precipitation issue (cy26r3)
- phase 4: complete technical developments (MARS modifications to support VAREPS type; modifications to the wave part of the code)
- phase 5: test of full system



VAREPS Ph2: VAR5 ($T_L511>T_L255$) gives best Z500 fcst (R. Buizza/ N. Wedi)

Average control (left) and ensemble-mean ACC skill (12 cases, Z500, NH). Best is VAR5.

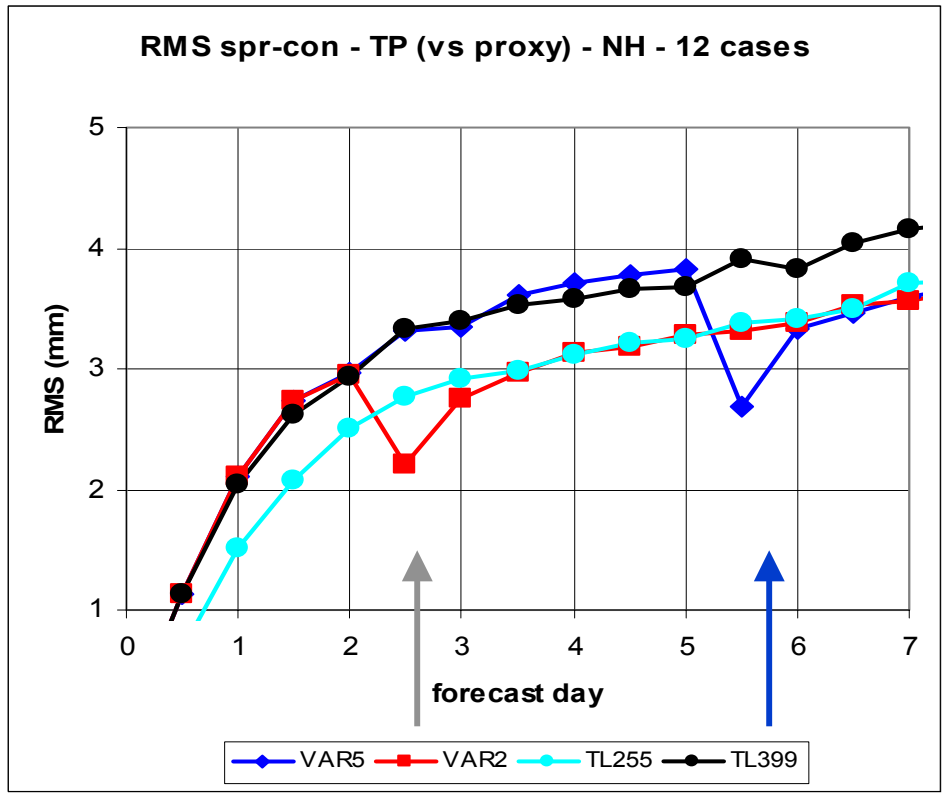




VAREPS Ph2: TP-spread problem

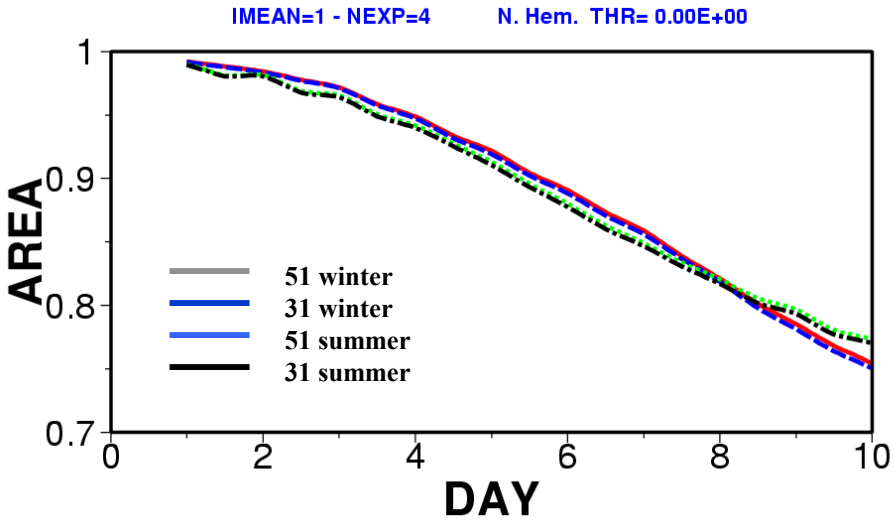
The truncation step of the VAREPS system affect the ensemble spread.

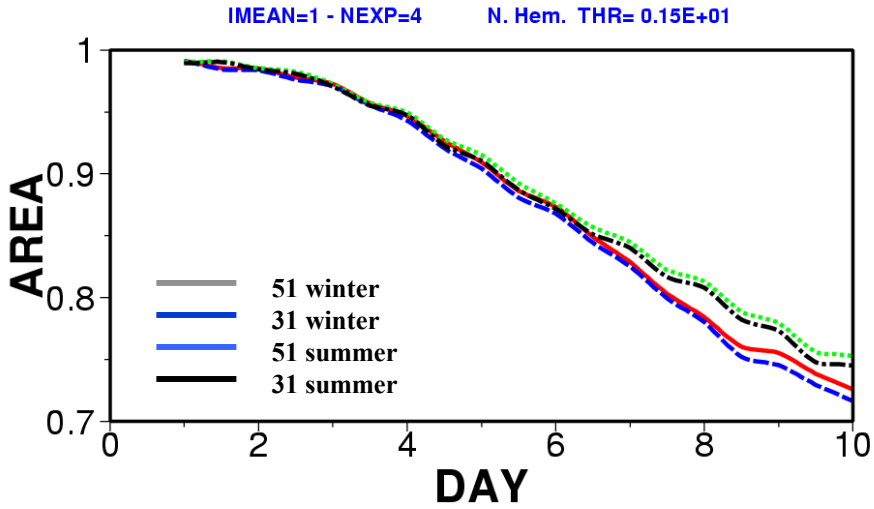
The ensemble-spread decreases during the 12 hours after the interpolation step from T_L511 to T_L255, and then recovers to T_L255 levels.

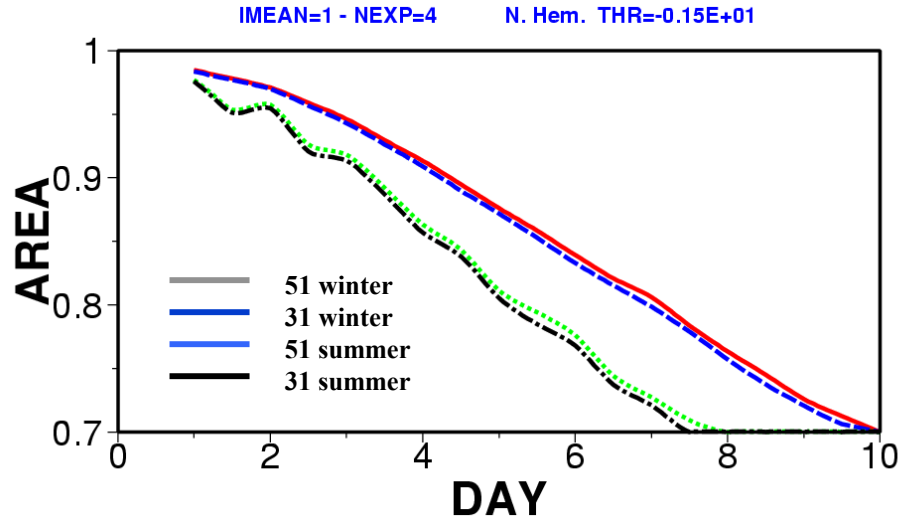


ROCA confirms the small impact of a size reduction

ROCA for the prediction of Z500 anomalies (with respect to climatology): the impact is very small for positive anomalies (top-right), but detectable for +/- anomalies of 1.5σ (bottom).

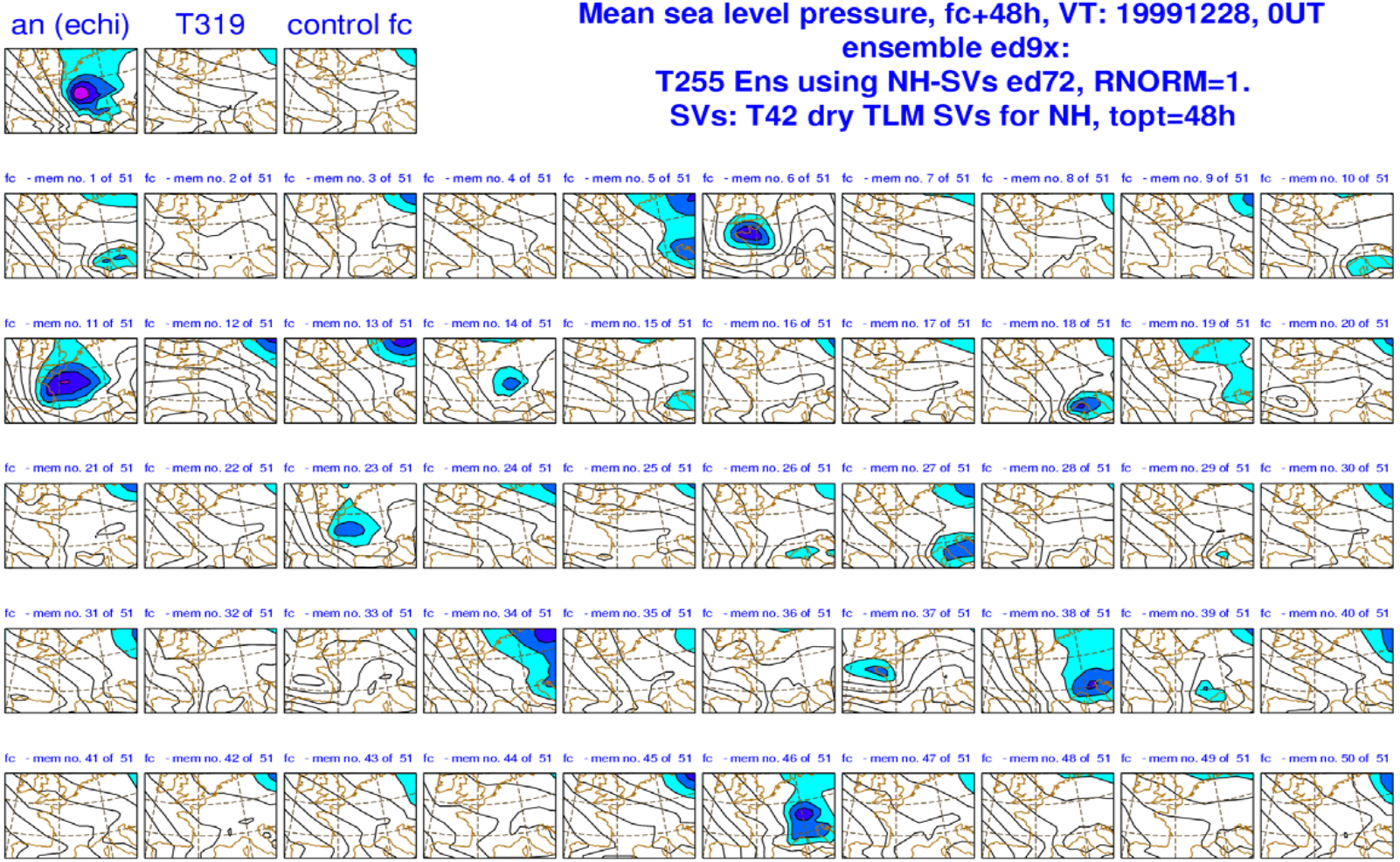






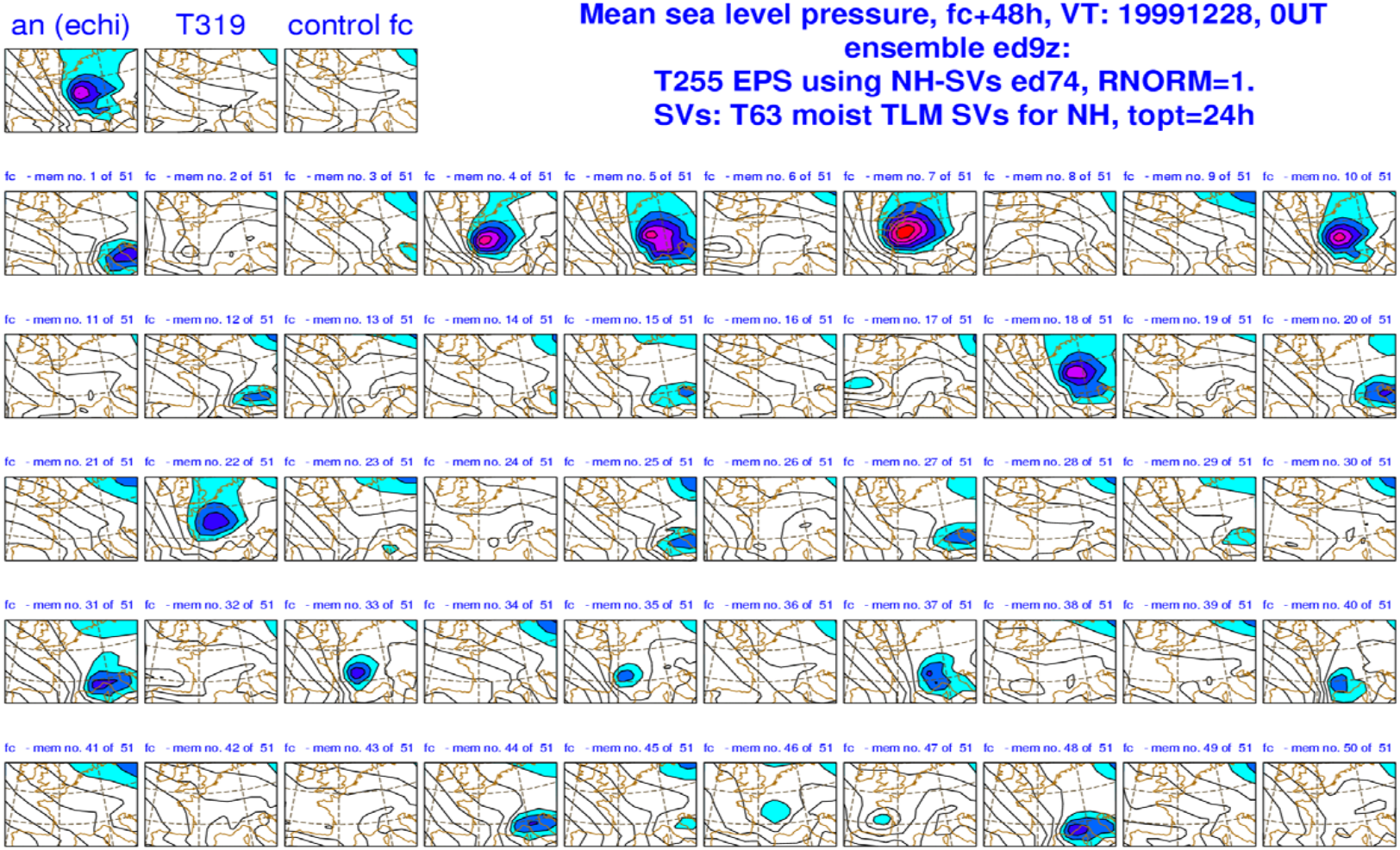
ECMWF

Martin, December 1999: operational SV configuration



(Shading: 960 – 990 hPa)

Martin, December 1999: Testing Moist Singular Vectors



(Shading: 960 – 990 hPa)

Tests of moist 1-day SVs in the EPS (T255) – courtesy M. Leutbecher

Storm name	verification date	observed p_c (hPa)	range (h)	Δp_c (hPa)	Δs (km)	# of forecasts old	# of forecasts new	# of forecasts 1+2	Improvement
Oct87	1987101612	957	96	5	600	9	9	14	0/+
Oct87	1987101612	957	72	5	600	4	13	13	+/+
Oct87	1987101612	957	48	5	600	3	7	12	+/+
Lothar	1999122606	961	78	10	600	8	13	3	+/–
Lothar	1999122606	961	54	10	600	8	11	17	+/+
Lothar	1999122606	961	30	5	200	6	7	4	+/–
Martin	1999122800	970	120	10	600	8	1	2	–/–
Martin	1999122800	970	96	10	600	5	12	10	+/+
Martin	1999122800	970	72	10	600	2	5	10	+/+
Martin	1999122800	970	48	5	300	1	4	3	+/+

old=operational SV config.

new=moist T63, 1-day SVs

Config "1+2": moist 1-day TL95 SVs and dry 2-day TL95 subspace SVs, Gaussian sampling of initial and evolved SVs.

Summary / discussion

- The quest for perfect forecasts has been a powerful and successful driver for model improvements at ECMWF
- Meteorologists however only reduce the value of their forecasts by being shy about their errors
  - ➔Not all “meteo-sensitive” applications can benefit from meteorological forecasts
  - ➔Users should not be trusted to define their requirements in terms of accuracy of the forecasts (only hits/misses ratio, or even better – through economic/ social value estimates)

Summary / discussion (2)

- The calibration of probability forecasts is a new issue
  - ➔Can it be done in a “one size fits all” type of application?
  - ➔Or should users be provided with Ensemble Direct Model Output AND (tailored) verifying statistics/ climatology?
- Future developments aim at extending the forecast range of useful (but imperfect) forecasts
  - ➔By getting even closer to “perfect”
  - ➔By improving on the reliability of “forwards” probability/ a-priori estimates of errors (more in Tim Palmer’s presentation later today)
  - ➔… and by running the models over extended ranges (more in Laura Ferranti’s presentation on Friday)