3rd HEPEX Meeting
Stresa - 27th -29th 2007

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Adaptation by Analogs of PQPFs for use in a Hydro-meteorological Forecasting Chain

Flood warning: *Informations* required

3 (commonly accepted) facts:

1- to forecast the discharges of a catchment beyond its concentration time Tc:
Quantitative Precipitation Forecasts are **required**

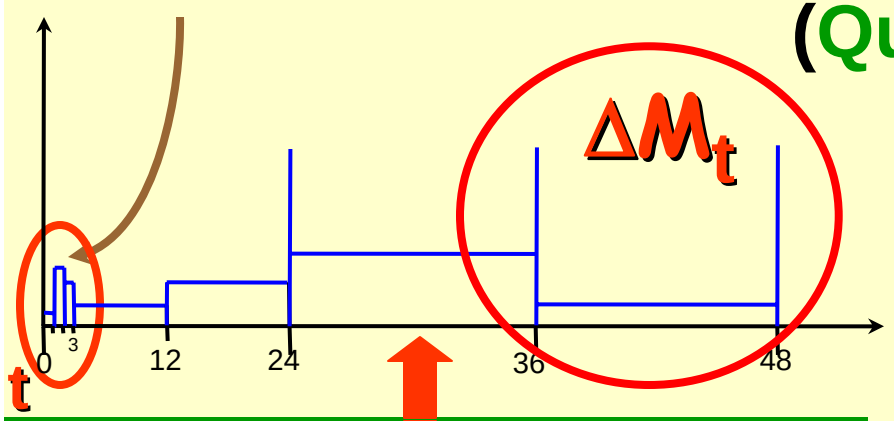
2 – given the uncertainties of precip. forecasts, these must be Probabilistic , ⇨ PQPFs

3 – Raw precip. outputs of NWP models are inadequate for direct use in hydrology:
⇨ they must be **adapted**

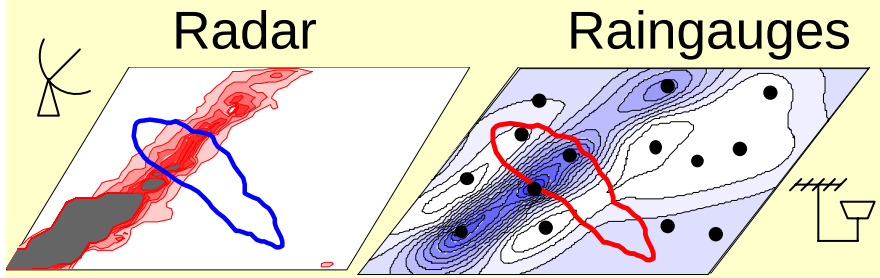
A simple hydrometeorological forecasting chain:

Quant. Precip Forecast

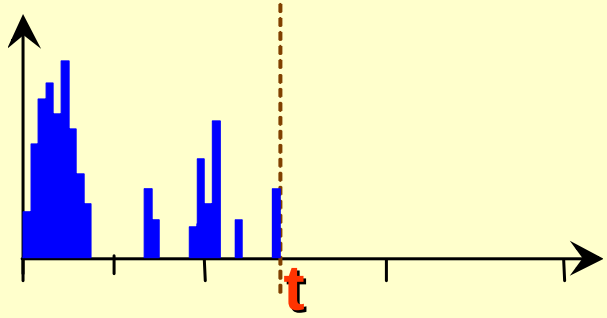
Nowcast / Short term forecasts



Observed Rainfall :



Time series of basin average rainfall



Hourly Scenarios :

- Nowcast QPFs:

Fri 11 / 12 / 24 / 36 / 48

from radar imagery

3 hours max ahead ?

Conditional by observed

- Short term QPFs:

available forecasts for QPF's

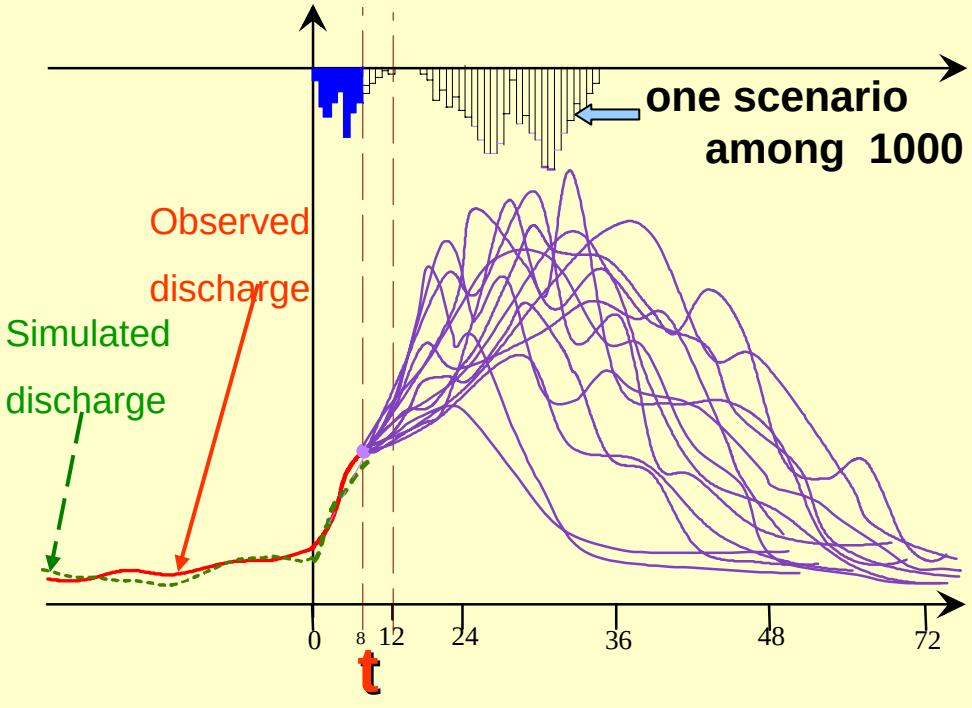
4 main modules

2-3 days max ahead

totals over 6, 12, 24 h ?

different providers?

Rainfall-Runoff Model:

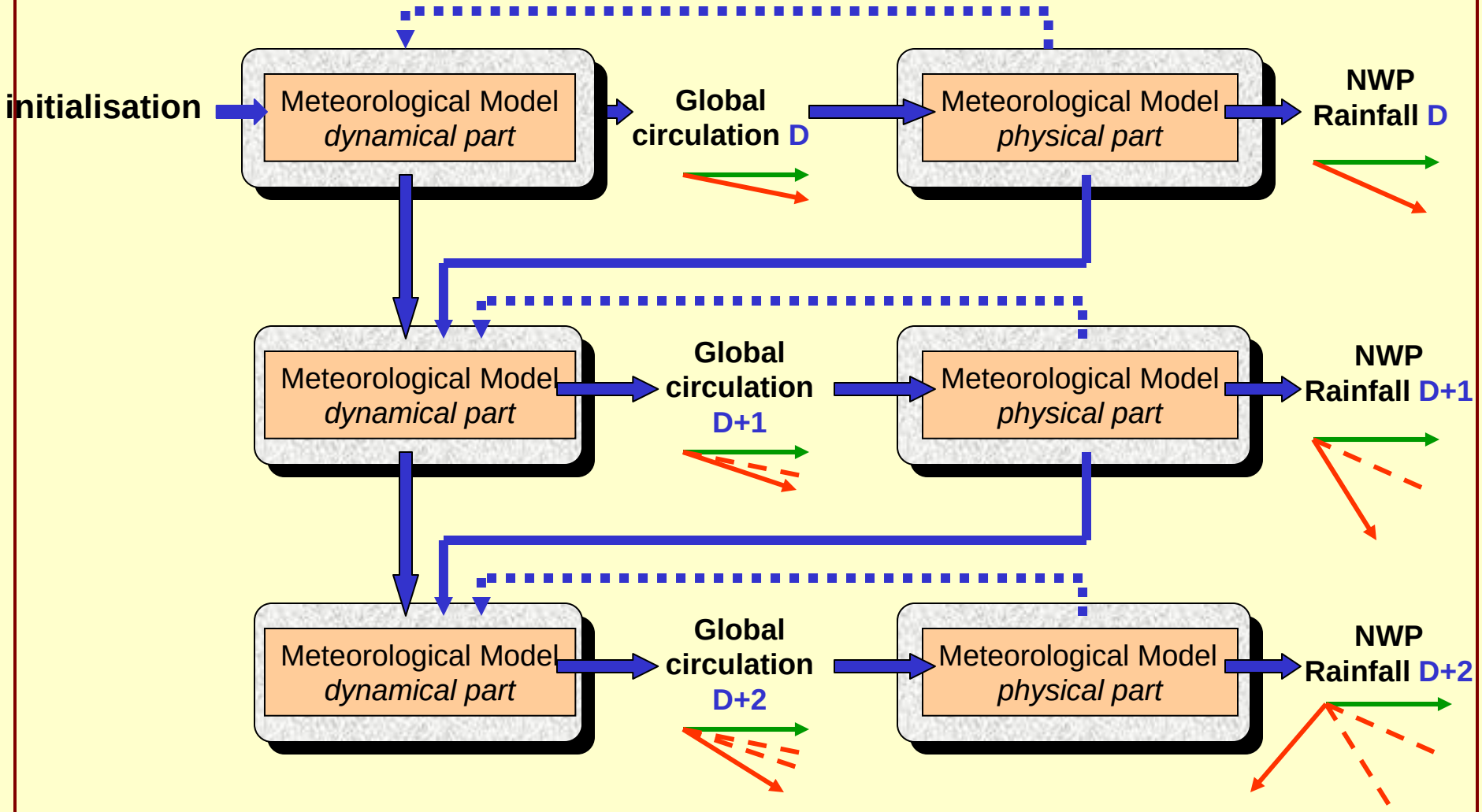


Contents

Adaptation of NWP models outputs for PQPFs: An ANALOG-based statistico-dynamical approach

General principles

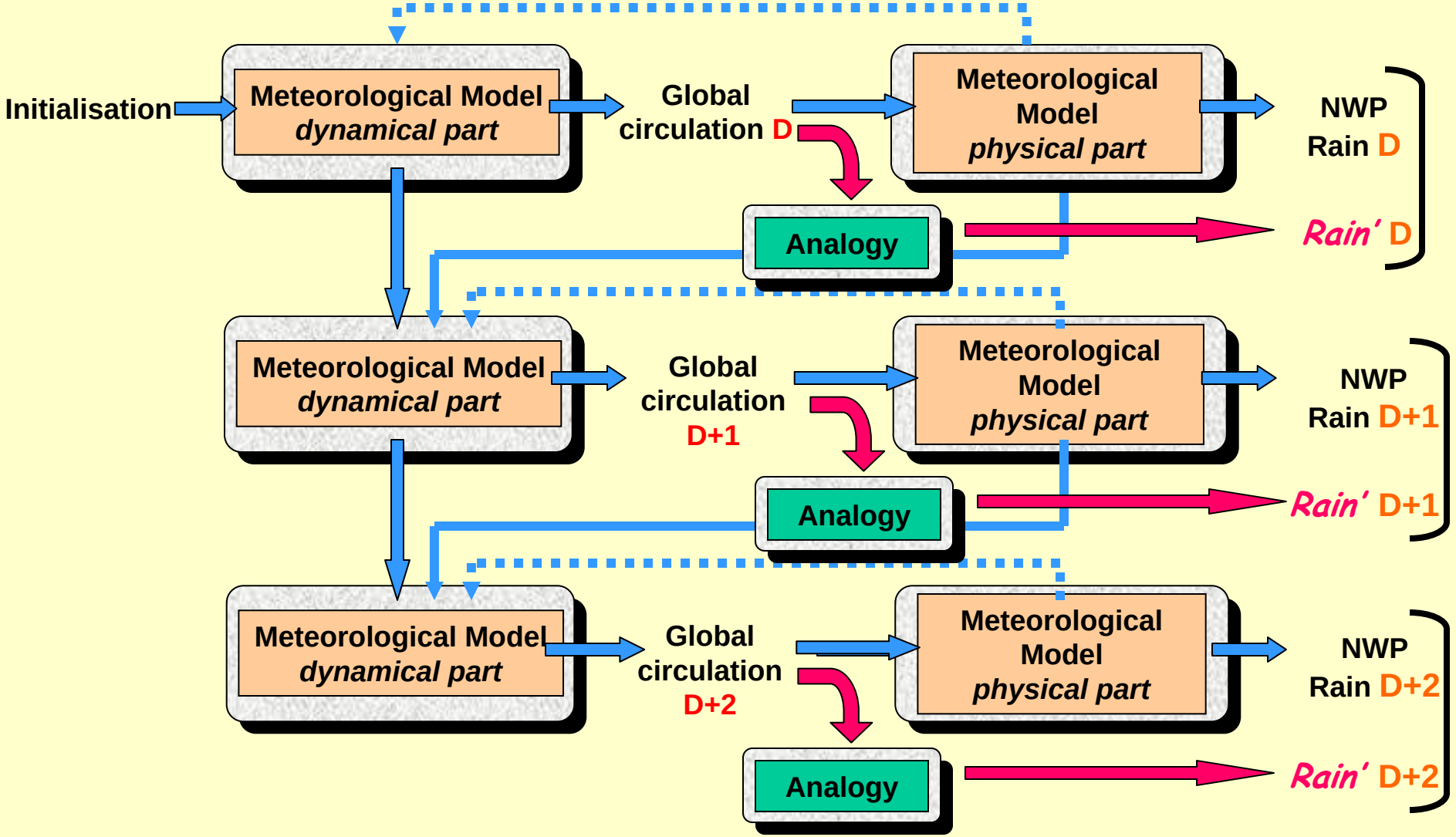
The NWP models (short overview …) :



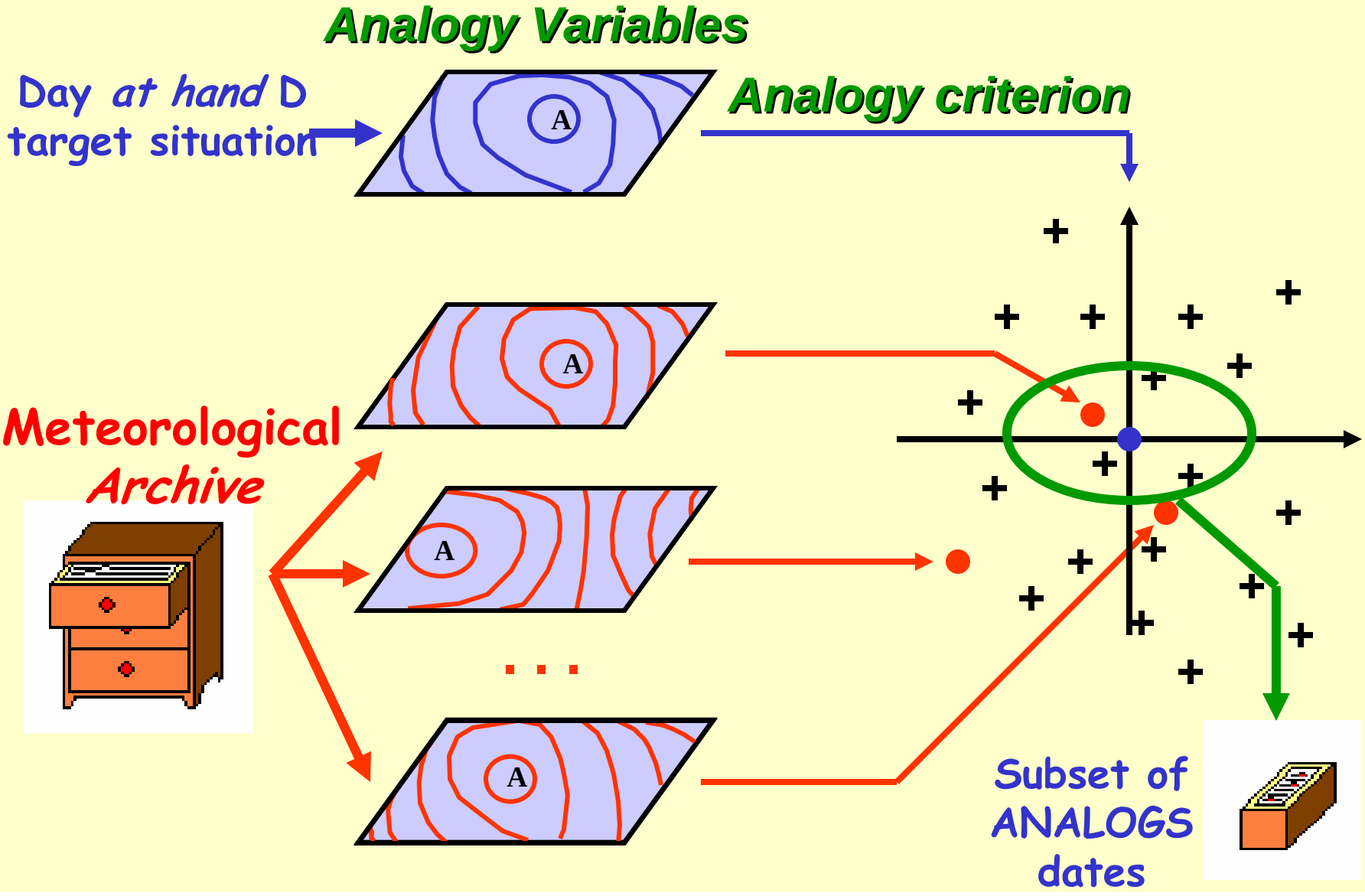
Numerical Model + ANALOG adaptation

The NWP models ... :

... and adaptation by Analogy :



Analog sorting



Conditional distributions

Subset of ANALOGOUS dates

Basin A

Basin B

1953

2001

1953

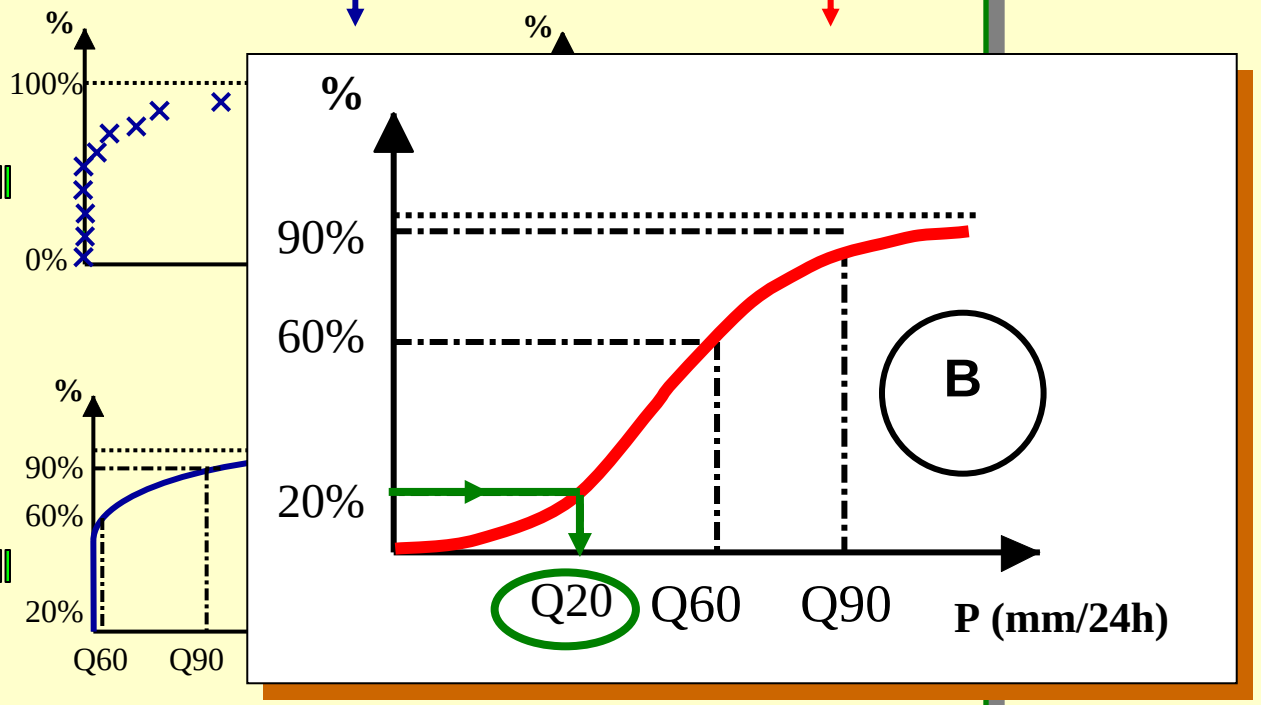
2001

Precipitation Archive

of basin-averaged daily rainfalls

Empirical distributions

Fitted cumulative distribution fonction



Calibration : performed in a Perfect Prog. context

Data used

- *climatological* **Archive** → **Reanalyses** NCEP/NCAR

  Large choice of variables :
  - géopotentiels,
  - temperature,
  - Précipitable water,
  - Relative humidity

  Homogenous Archive

  Temporal resolution : **12h**

  Spatial resolution: **2.5 x 2.5°**

  Period : **1953 - 2003**

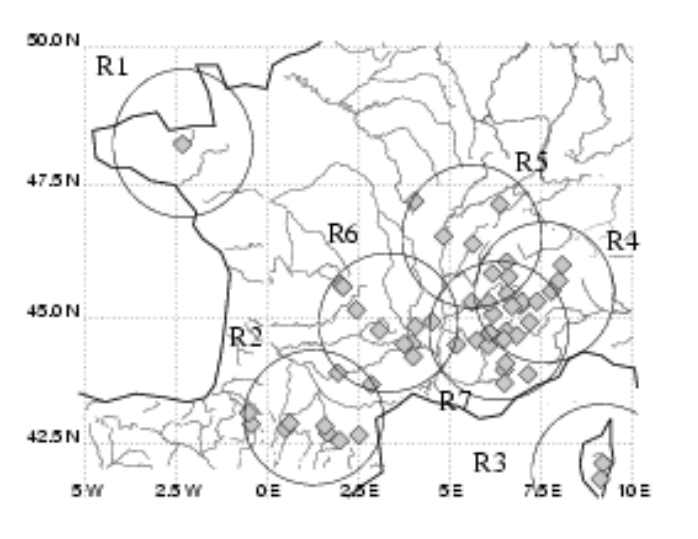
- *Basin-rainfall* **Archive**

  Daily Totals

  6 hTU - 6 hTU

  ~**75** basins (rainfall groups)

  $$R^* = \sqrt{\frac{R}{R_{10}}}$$

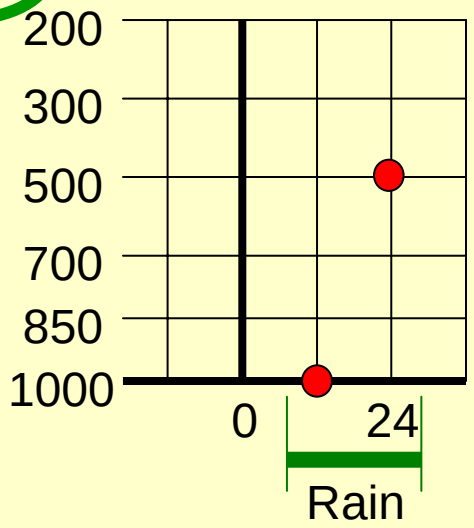


Optimisation Strategy : One / two step analogy

Candidate Analogy Variables

Candidate Analogy Criteria

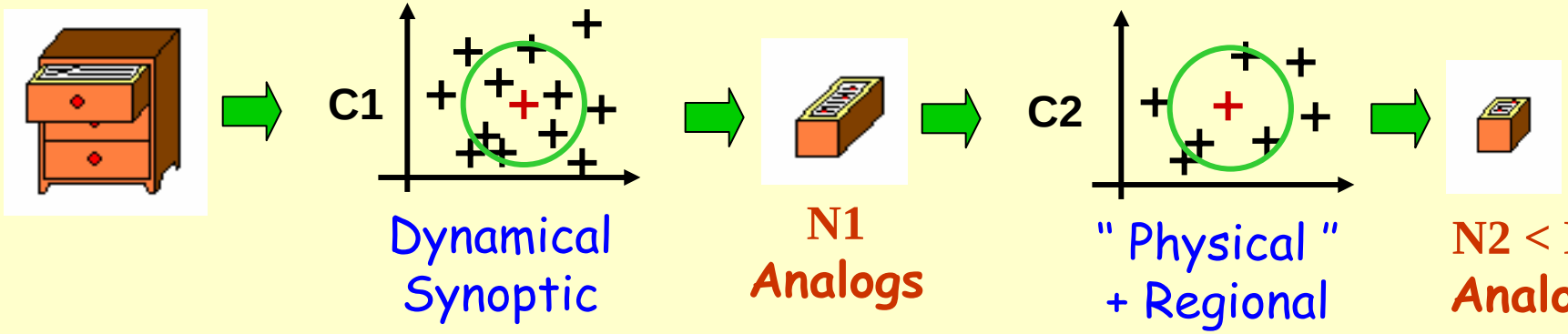
Geopotentials ⟷ S1 *Teweless Wobus*



➢ One step Analogy

Global Circulation Analogy :
1000 hPa at 12h00
500 hPa at 24h00

➢ Two step Analogy



Dynamical Synoptic

N1 Analogs

" Physical " + Regional

N2 < N1 Analogs

Preliminary Conclusions

Summary of results in *perfect prog.* conditions *(G. Bontron 2004)*

Two Levels of Analogy :

→ 1st level : Géopotentials HGT 500 et 1000 hPa
Specific " window 1 " for each *(group of)* basin

→ 2nd level : Humidity RHU *or better* PWA x RHU at 850 hPa
Specific "window 2 " for each *(group of)* basin
Number of analogs : **N1 = 70** and then **N2 = 30**

Two pending questions...

1) True operational validation? over a long serie of ***«true» NWP forecasts…?***
≠ perfect prog !

2) Implementation as such ?
…***or***…
Is there something to gain in operational practice ?

Contents

A forecast archive: *the EPS at ECMWF*

Extraction of our forecast archive :

Variables : ***HGT 500** and 1000 hPA*

***RHU** at 850hPA*

Period: from 1997 to 2001

1 Ensemble Forecast (50 traces + Control) issued per day

At leadtimes : 0, 12, 24, 36, … up to 240h (by steps of 12h)

BUT: How to use these real forecasts

Our proposal (from a particular model) :

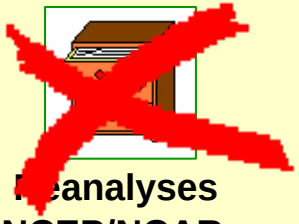
Re-Optimising the ***number of analogs*** selected as a function of the ***leadtime***

in an optimal way?

Re- optimisation for operational use : Principle

① Select a leadtime

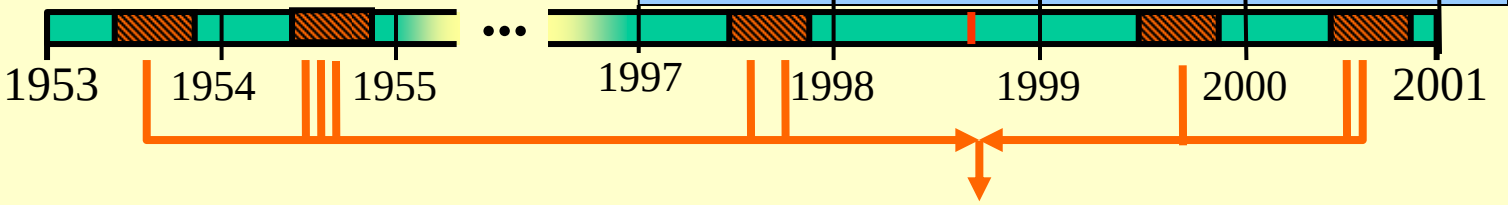
② Select a target situation



1997 - 2001

Forecasts Archive EPS

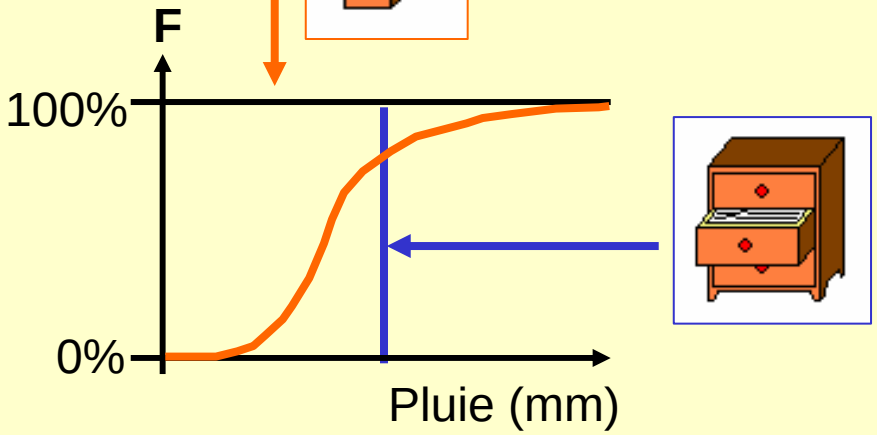
Réanalyses NCEP/NCAR



③ Elaboration of a « *forecast* »

④ Comparison with observation

⑤ Performance Score for ***this*** target situation



⑥ Performance Score for **this leadtime** over the ***whole*** ***forecast archive***

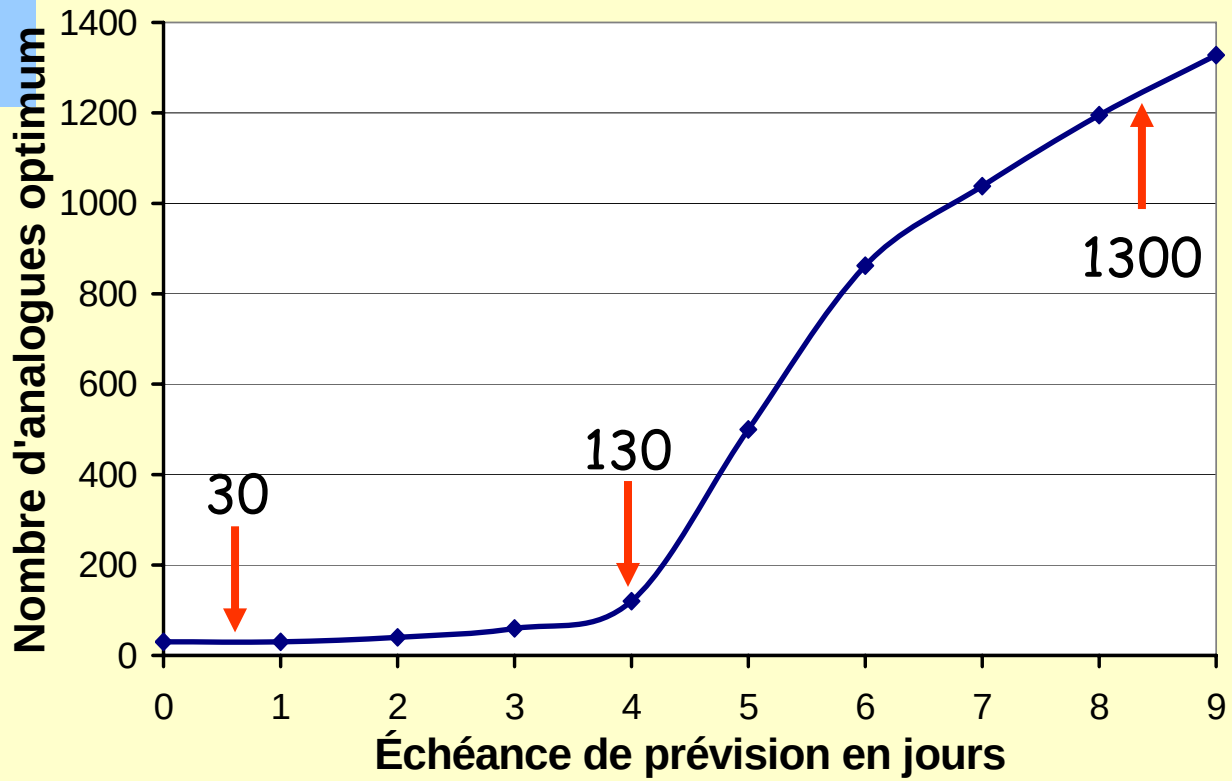
Re-optimisation result : Nb of analogs to consider

1 level of analogy

M1

Forecasts used : **control** *(deterministic)*.

Question : Optimal nb of analogs to select?



The optimal number of analogs must increase with the leadtime

→ Come closer to climatology for most remote leadtimes …?

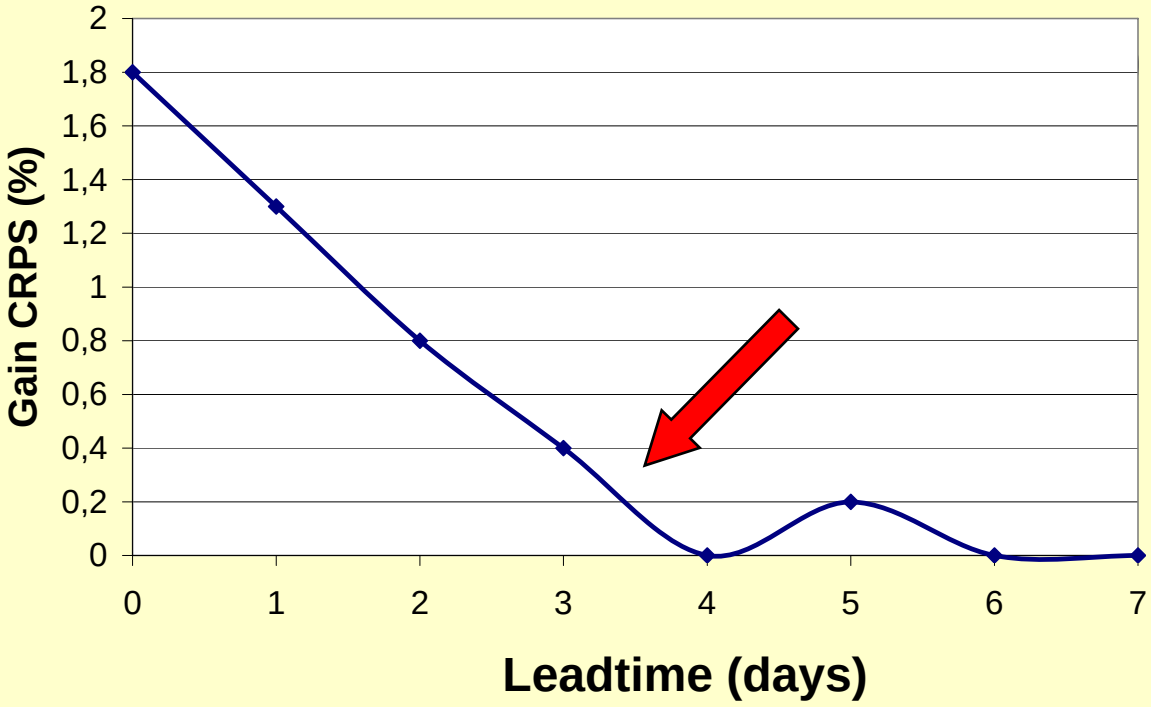
Re-optimisation results : limited gain with step 2

1st + 2nd level of analogy

M2

Forecasts used: control *(deterministic)*

Performances ***after re-optimisation***



Gain Increase due to 2nd order Analogy (*i.e. humidity*)

Gain provided by **2nd level** : decreases with growing leadtime

→

Capacity of ECMWF Model to forecast the *RHU* variable beyond **3** days … ?

Contents

Case study :

Event of

6 to 8 Sept 2005

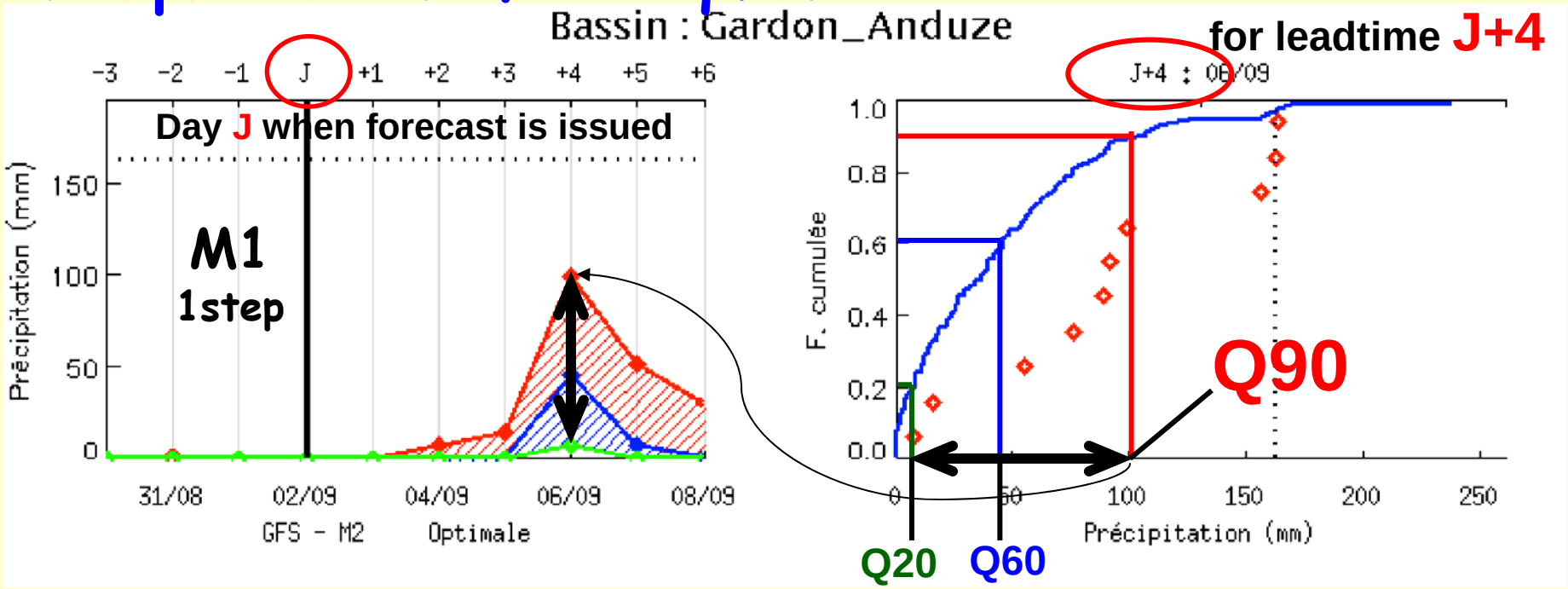
Forecasts based on
NOAA-GFS model outputs
and adapted by Analogs

Presentation of the documents displayed:

Evolution with time and risk (quantile) maps

Interpretation of the quantiles

Probabilistic Forecast for leadtime J+4



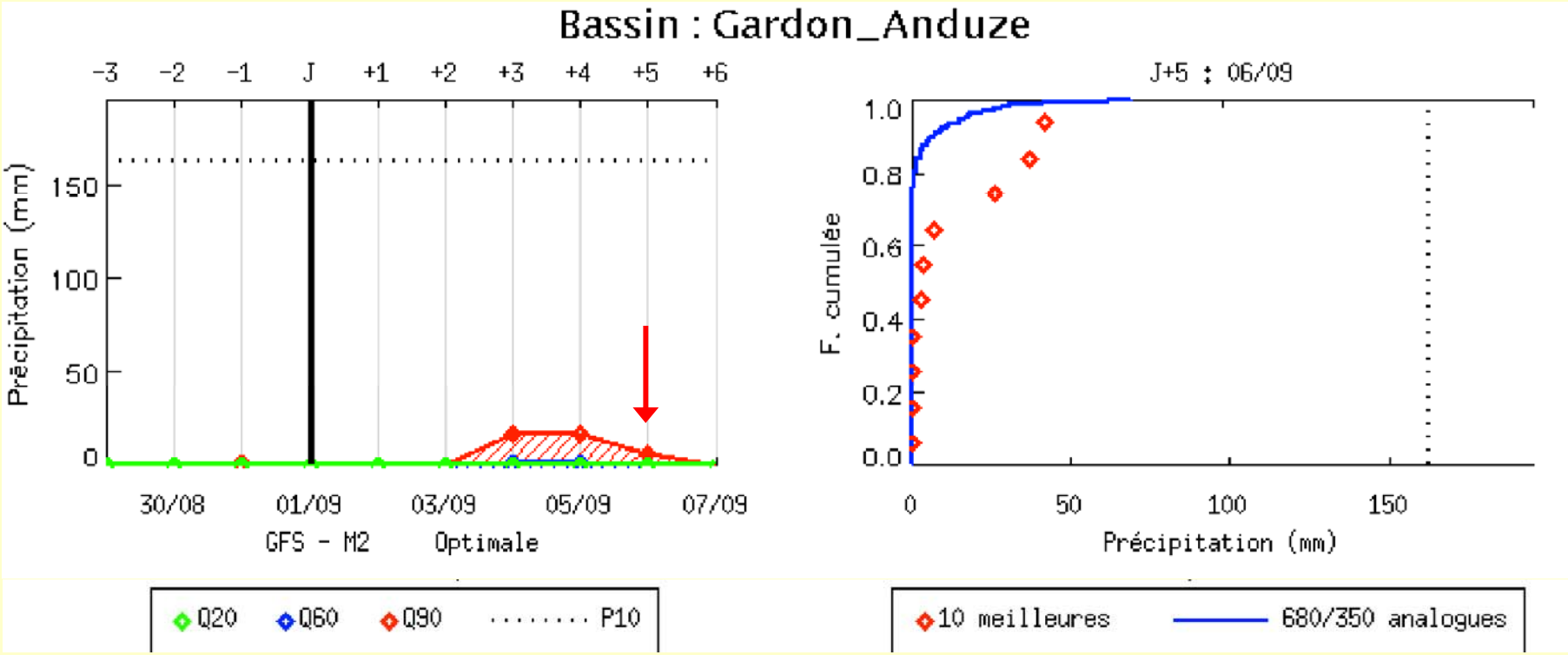
Beginning of the sequence on:

Thurs. 1st Sept 2005

Forecast issued Thursday September 1st

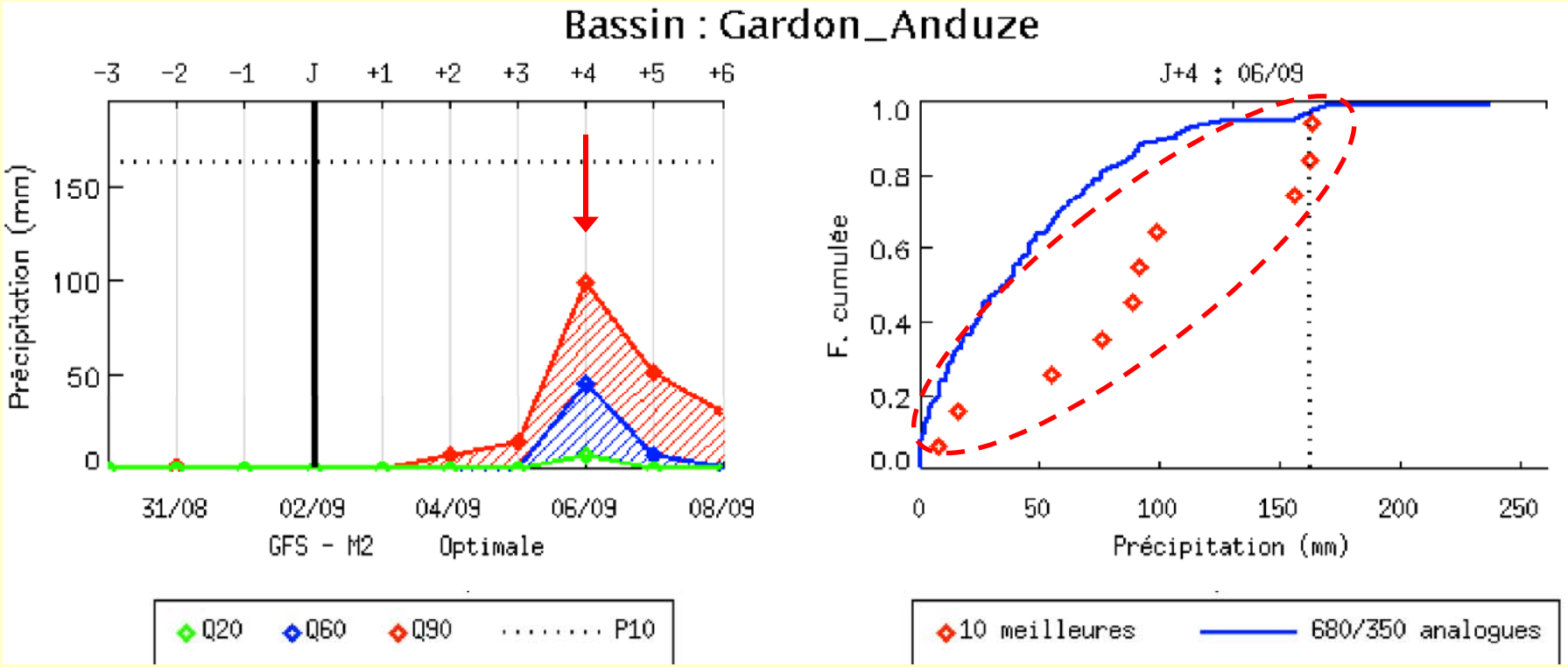
N.B. Intense event on Sept.6th

M1



Forecast issued Friday September 2nd

M1

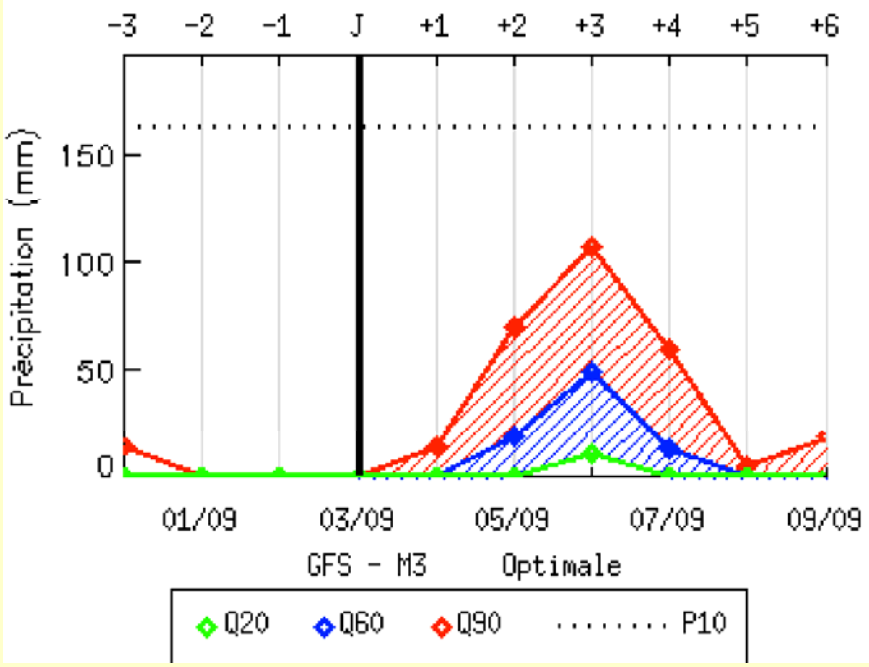


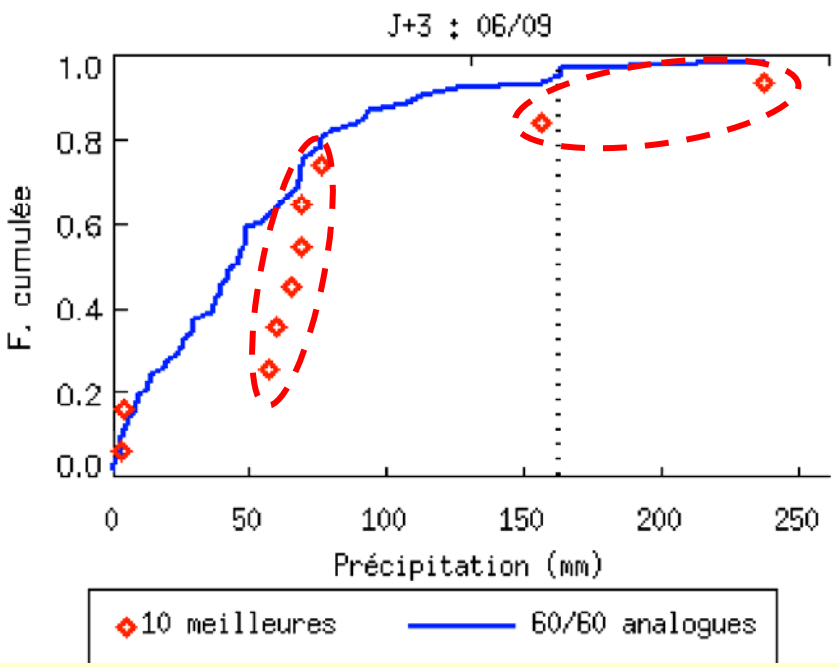
Distribution of rainfalls on the Gardon d'Anduze for Tuesday 6 Sept. *(J+4)* (at 8h up to Wednesday 8h)

Forecast issued Saturday September 3rd

M2

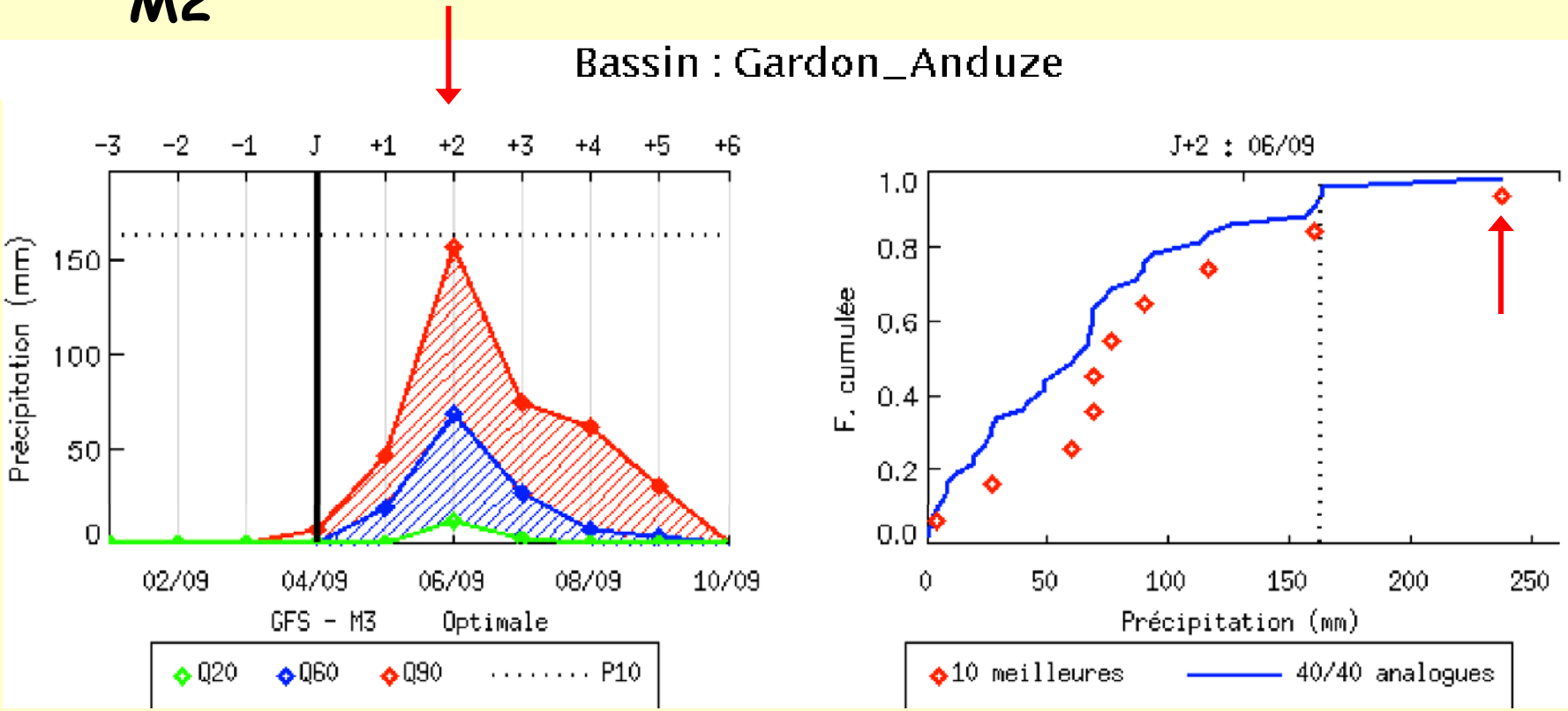
Bassin : Gardon_Anduze





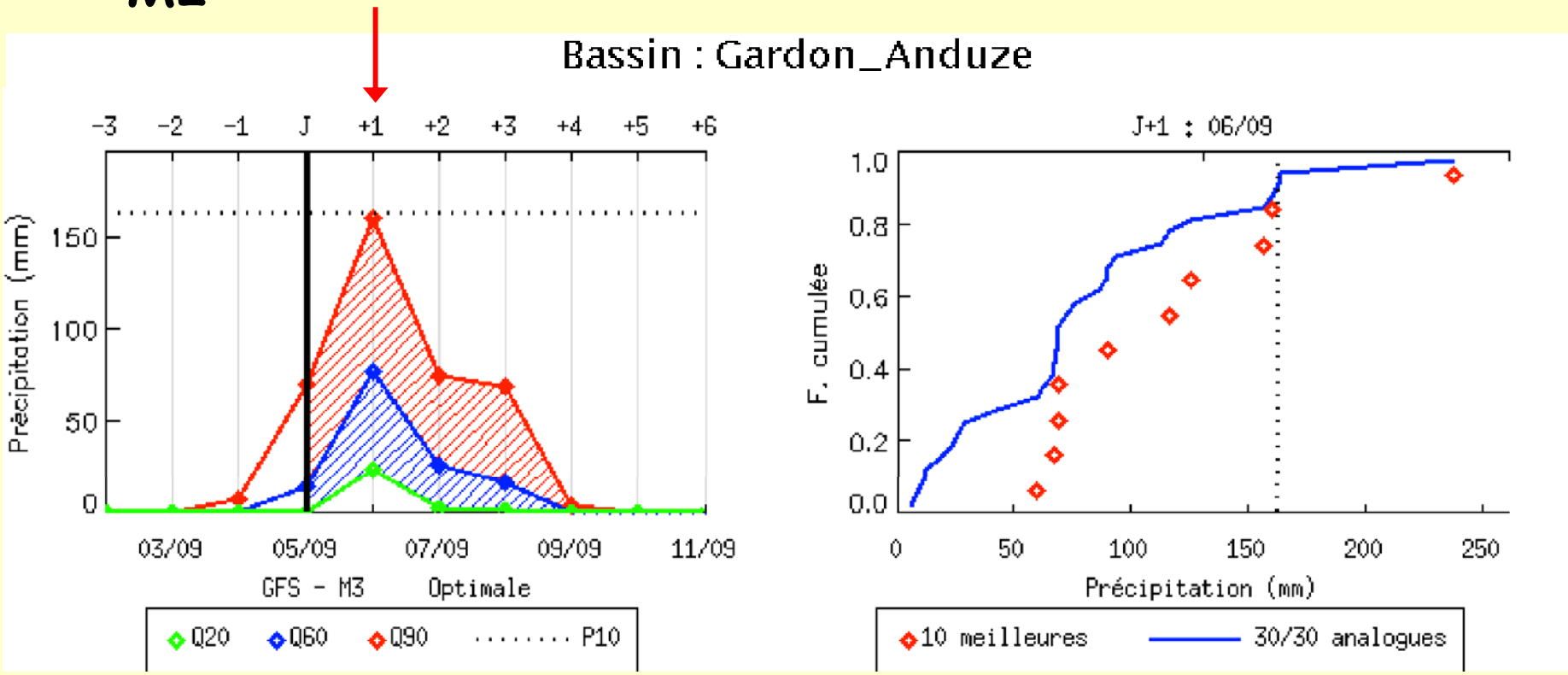
Forecast issued Sunday September 4th

M2



Forecast issued Monday September 5th

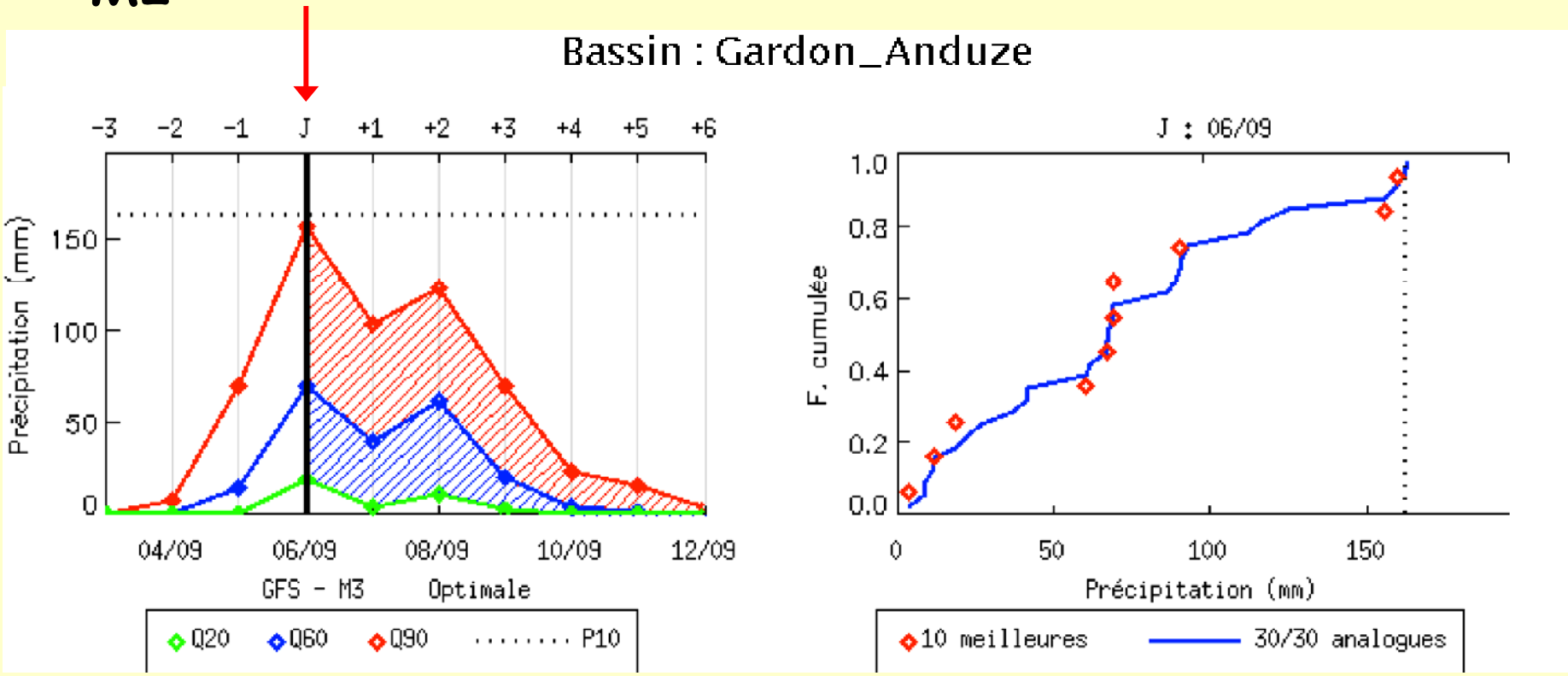
M2



Forecast issued Tuesday September 6th

For the 6 of Sept.

M2

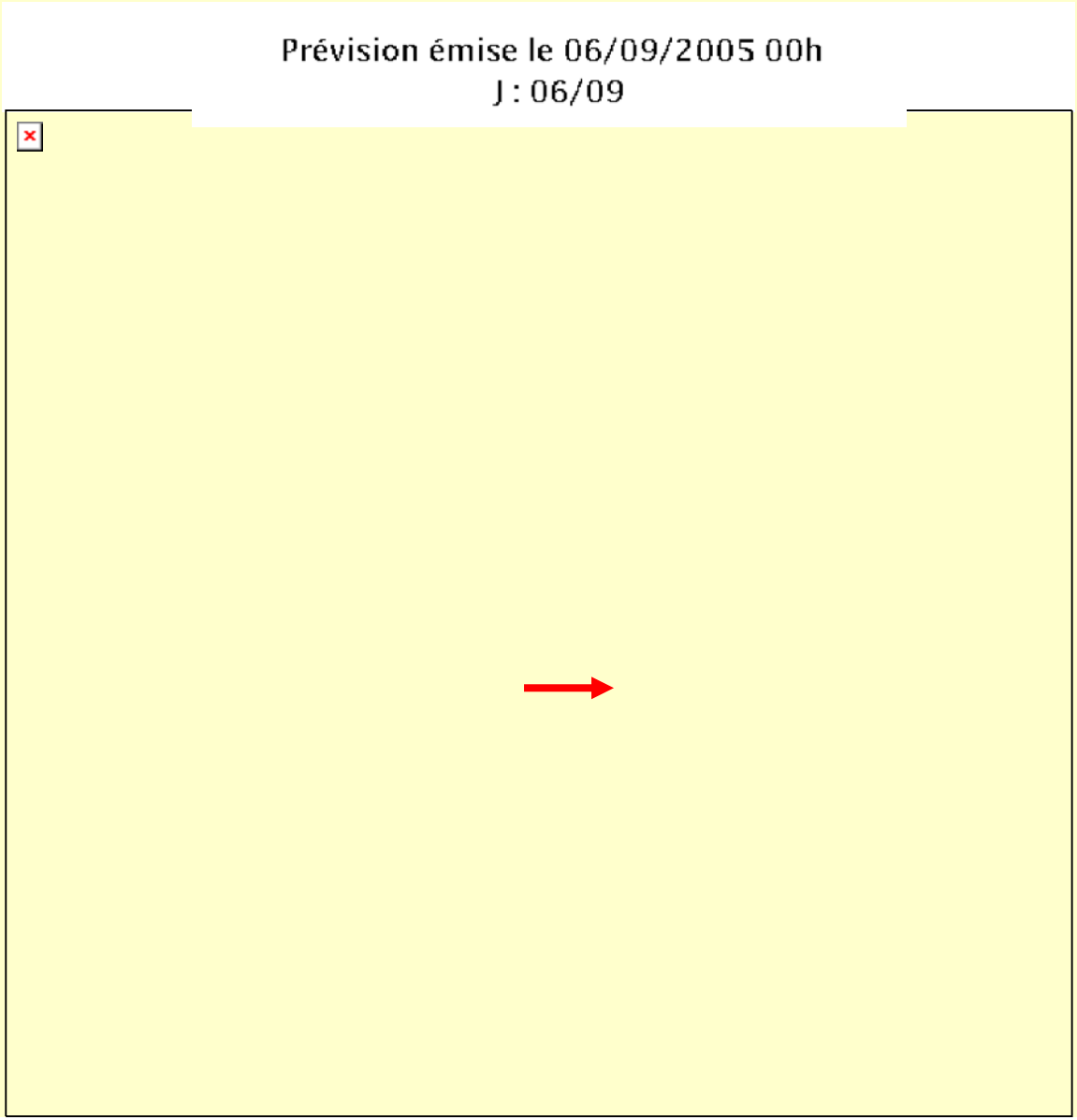


Tuesday 6 Sept.

+ Good localization of the basins at risk ?

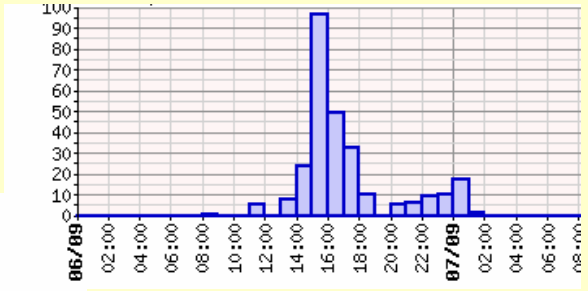
M2

Map of the 90% quantile per basins

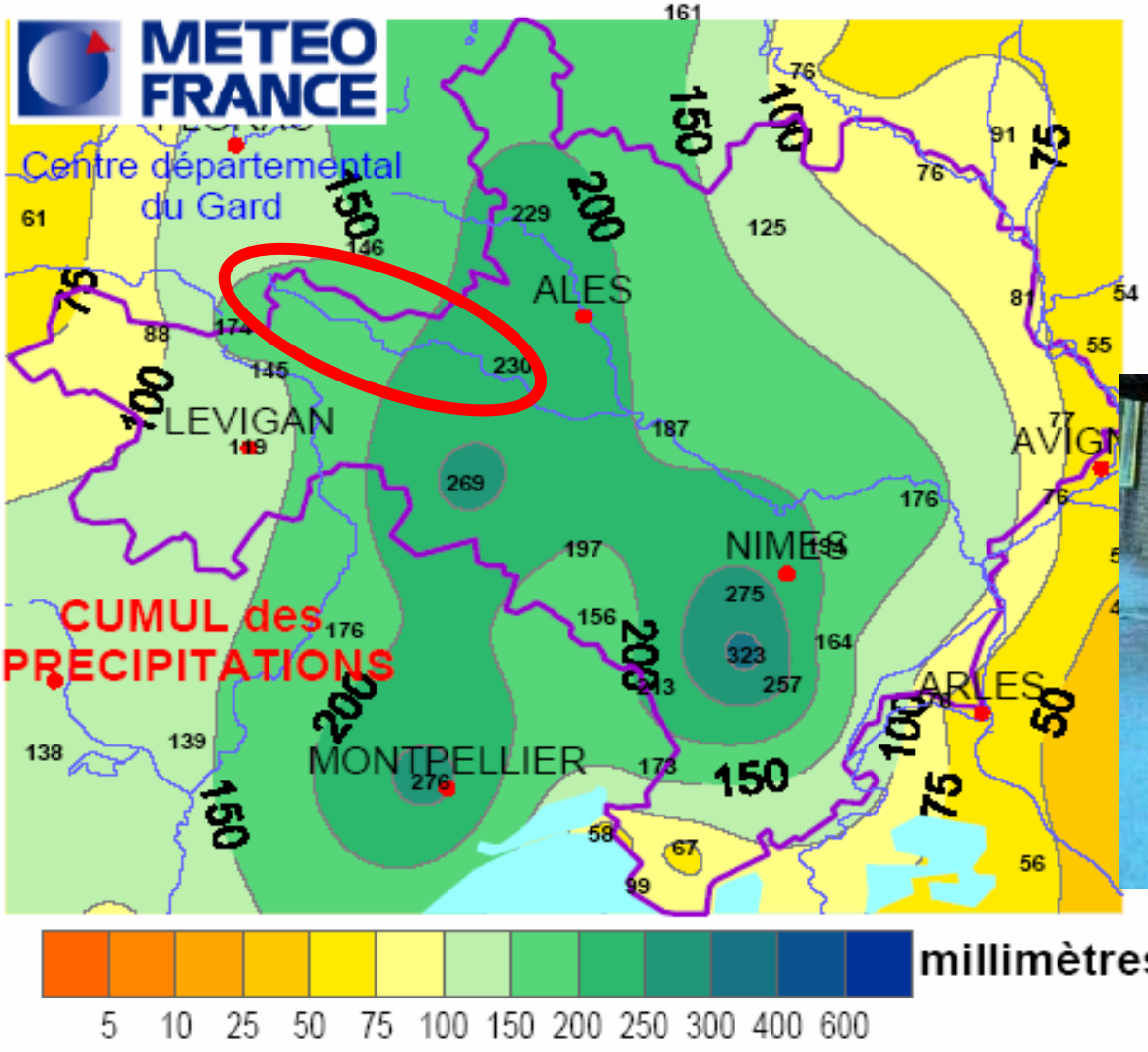


CASE STUDY

What happenned in the end ?



Tuesday Sept. 6th, around 15h, 100 mm fell in one hour over Nîmes …



Contents

Conclusions 1/3

Current status of the ANALOG approach:

- Improvement of the one-step analogy based on geopotential only
- Interest of a second step (with local variables like humidity ...)

Conclusions 2/3

***Real-time** implementation: tests on a forecast archive*

New optimisation for operational forecast : necessary
(to fit NWP output characteristics)

→ here: Re-optimisation of number of analogs
as a function of the leadtime

Validation of the ANALOG method: very encouraging

Conditional Rainfall Distribution based on ANALOGS:

→ will be used as daily PQPFs for days J & J+1

in our hydrometeorological forecasting chain

Perspectives

*Thanks to an **archive** of NWP **Forecasts** :*

New optimisation also on others parameters

(windows, variables,… not only the number of analogs)

*Thanks to **several** archives of forecasts:*

Development of a multi-models approach?

(Cf. NOAA-GFS v.s. CEP)

*Thanks to a new **precipitation** archive (to be elaborated…):*

New optimisation for rainfalls over ***6 or 12h***

*Thanks to a new **reanalyses** archive :* ERA 40's at 1°

Complete Reoptimisation of the method ?!

Thank you for your attention

Grazie per l'attentione

Conclusions

- **An analogy based only on general circulation fields is insufficient to explain an event like the one of the september 8th, 2002.**

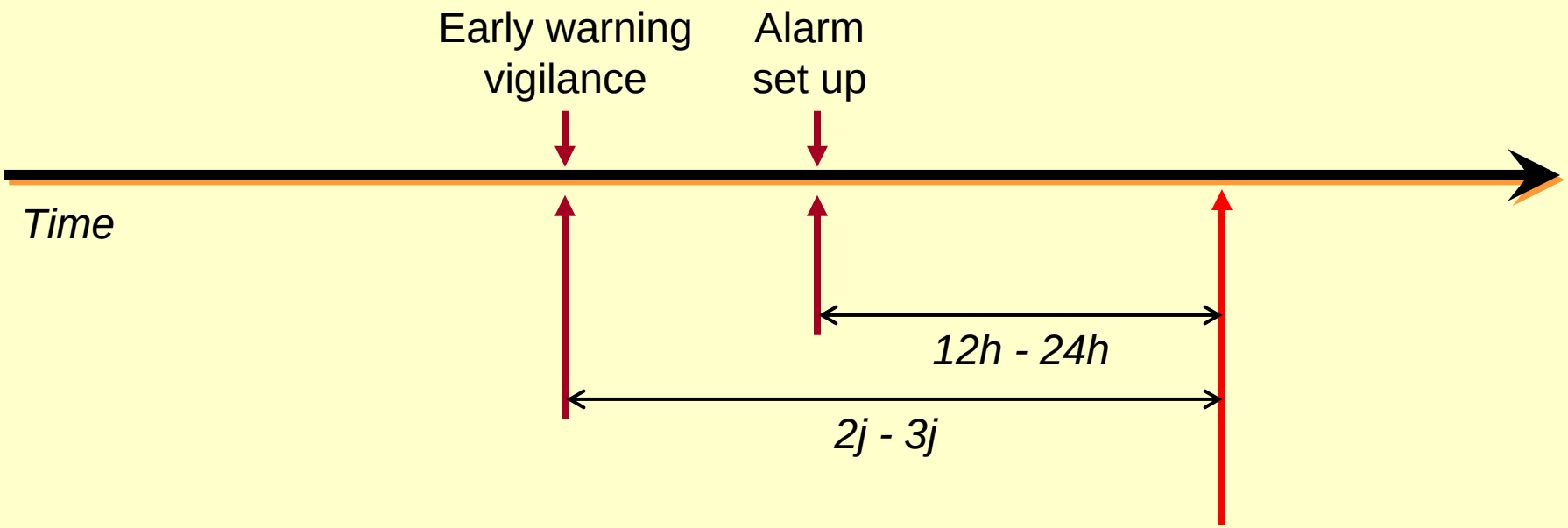
- **Locals variables (like humidity ...) can play an important role in the detection of these events, *but* are they well foreseen by NWP models ?**

➔ We hope we could take advantage of future improvements of the NWP models

- **Temporal limitation of the archive : How to forecast exceptional events ?**
  Spatial limitation of the archive : Resolution for local variables ?

For such events (T>10yr), Analogue based forecasting : not able to provide accurate quantitative forecasts **BUT** able to help setting up alerts / early warnings.

Flood warning: *Leadtimes* required



- **Beyond**

Flood

Flood warning: *A simple hydrometeorological chain*

Our choices:

- keep the forecasting chain as basic and parsimonious as possible

- keep its differents blocks well identified and their inputs well traceable

- be able to welcome different forecast providers

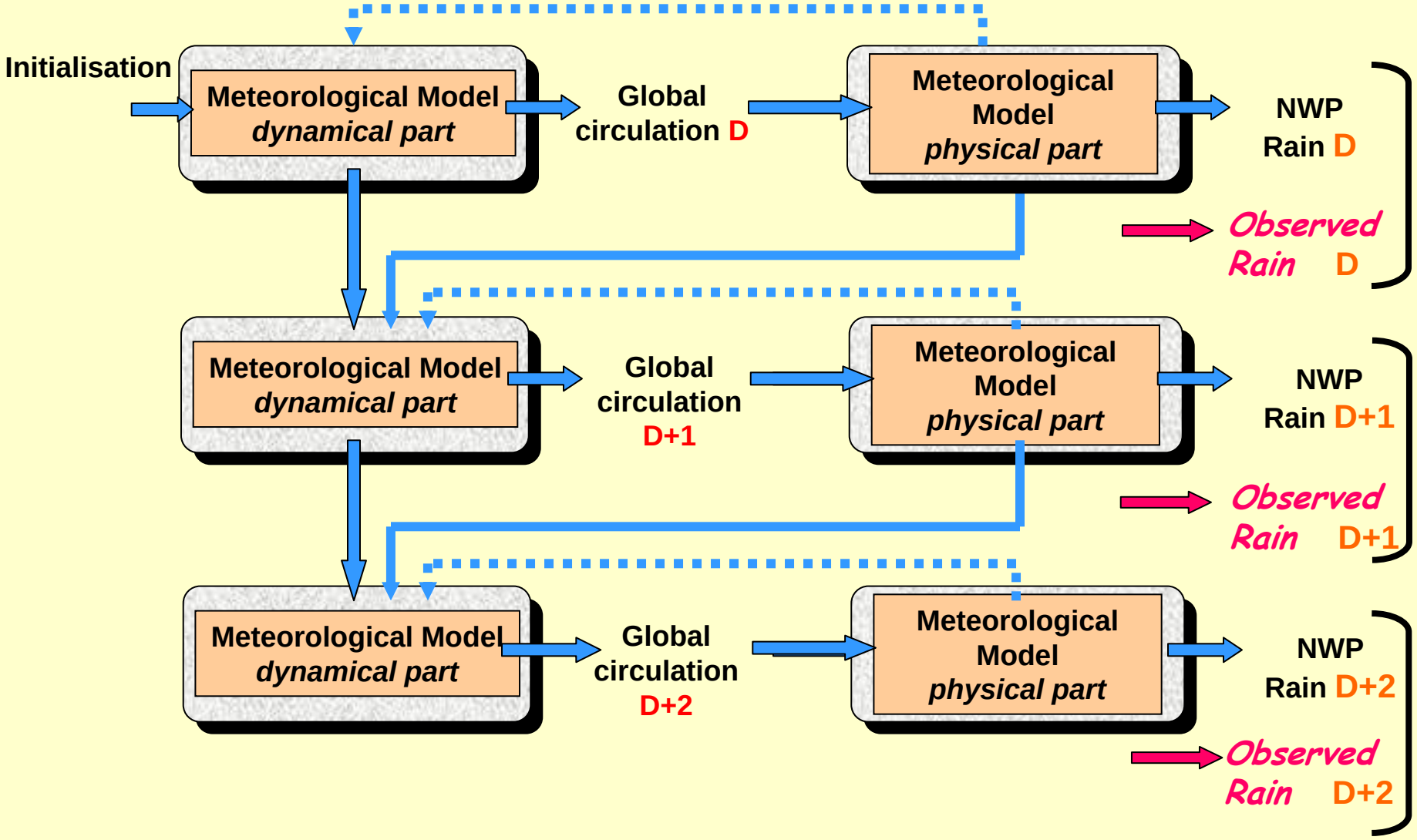
⇨ Quick look at the chain

(see also poster)

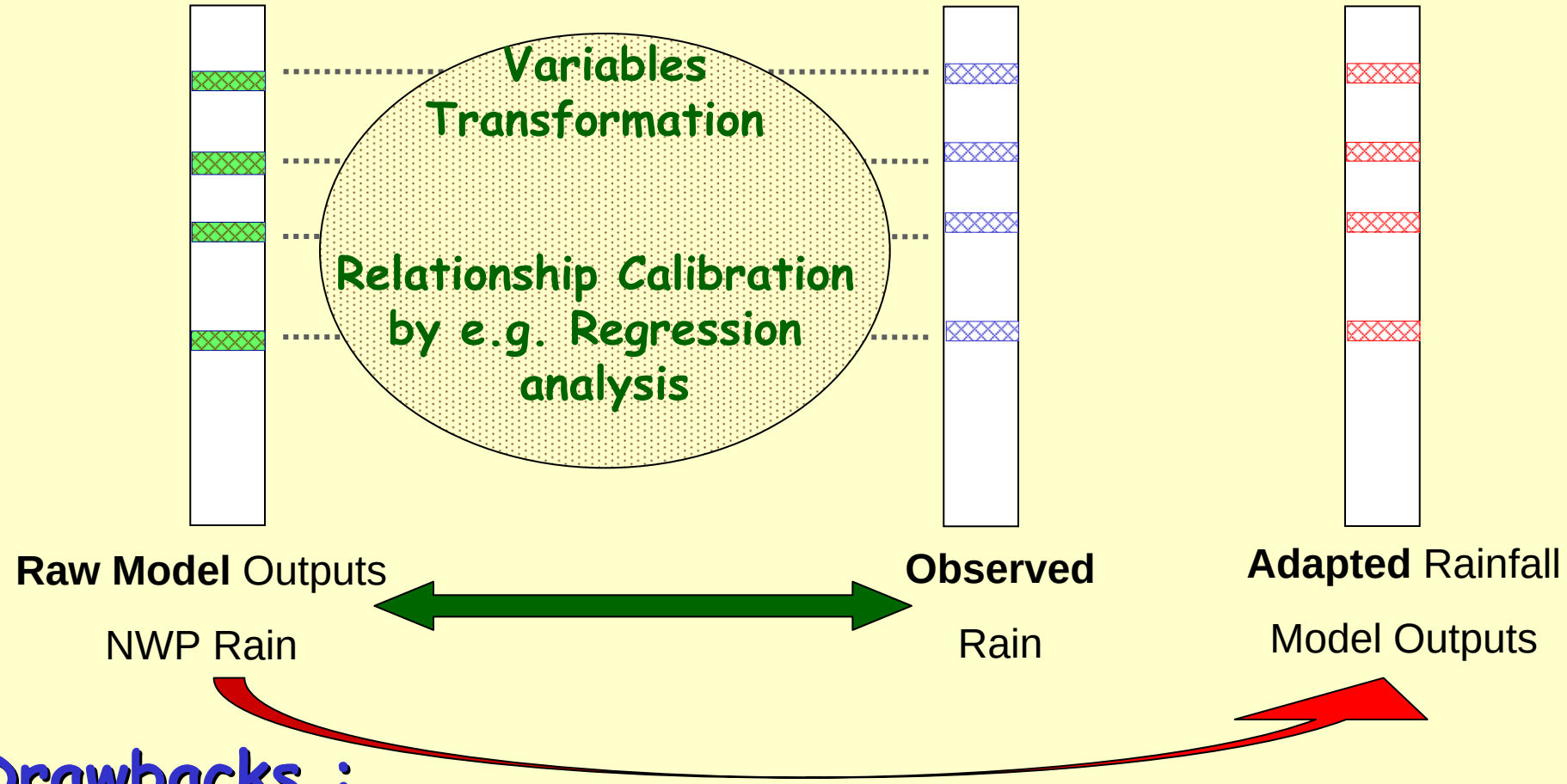
Numerical Model + Rainfall adaptation

The NWP models ... :

... and classical (MOS) adaptation :



Numerical Model + MOS rainfall adaptation

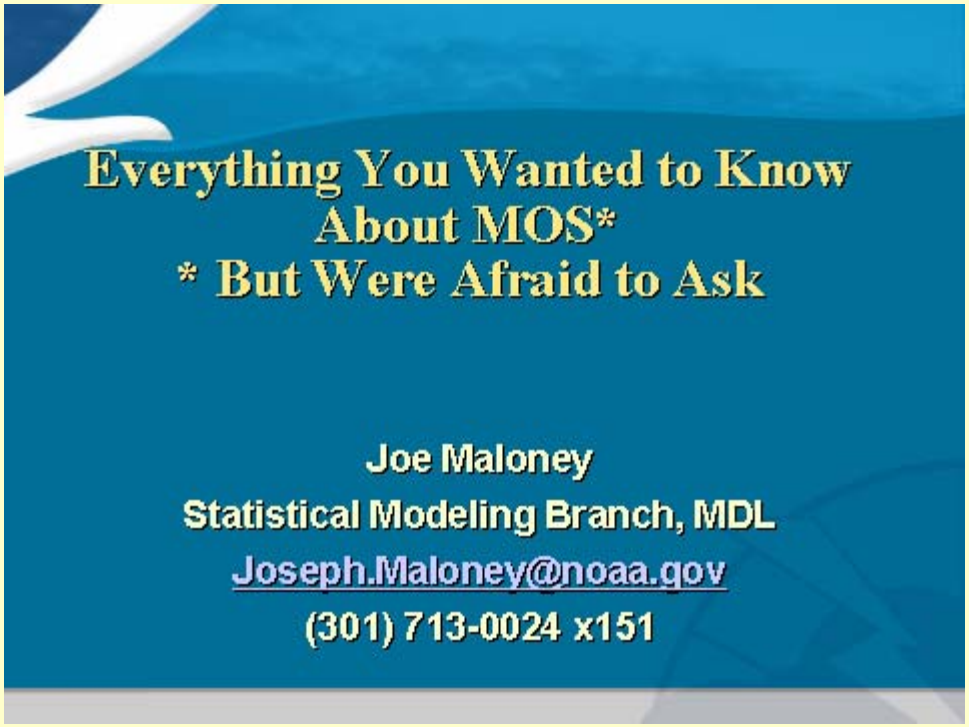


Drawbacks :

- *robust relationship ...?* ⇨ long series of model outputs (> ~ 5 years)

but also this adaptation must be reprocessed

for any change in the NWP model … *(~ every 6 months..?!)*


Everything You Wanted to Know
About MOS*
* But Were Afraid to Ask
Joe Maloney
Statistical Modeling Branch, MDL
Joseph.Maloney@noaa.gov
(301) 713-0024 x151

Meteorological archive

REANALYSES NCEP / NCAR

- homogeneous archive **1953-2001**
- various available lead-times **12h**
- spatial resolution **2.5 ° x 2.5 °**
- many available levels
- many available variables

Geopotentials	⇨	1000	850	700	500	300	200	*(hPa)*
Temperature	⇨		850		500		200	*(hPa)*
Wind velocity	⇨		850		500		200	*(hPa)*
Relative humidity	⇨		850		500		200	*(hPa)*
Wind divergence	⇨				500			*(hPa)*
Precipitable Water								
Potential vorticity	⇨	315	330	450				*(°K)*

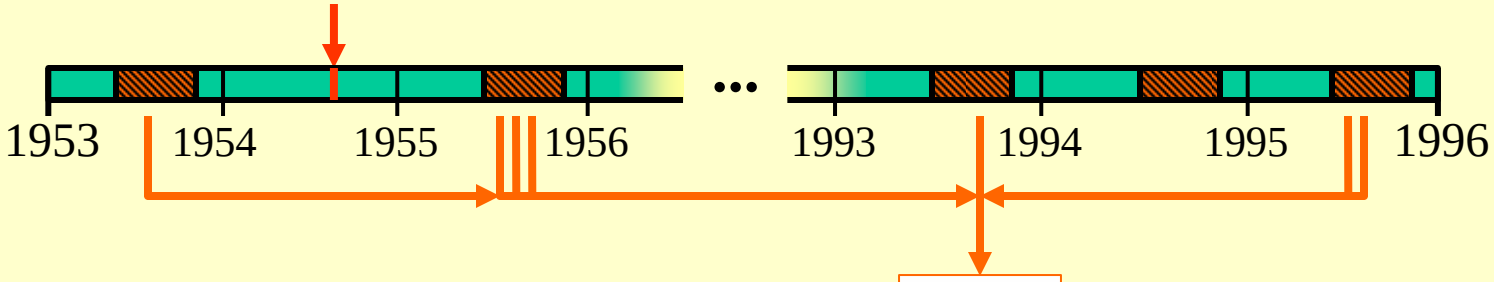
Optimisation Strategy (in Perfect Prog.)

Objective : **to get the most efficient algorithm**

① Selecting parameters *(analogy variables, or domain, or etc…)*

② Selecting a target situation

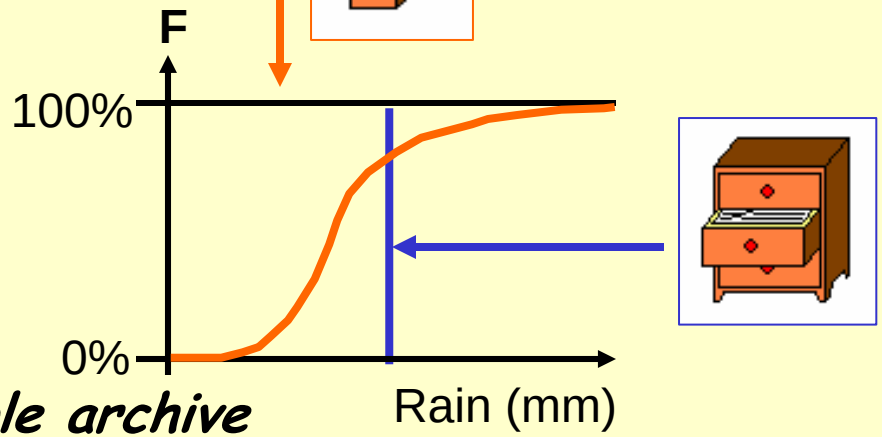
Calibration	: 1953-1996
Validation	: 1997-2001



③ Elaboration of a « *forecast* »

④ Comparison with observation

⑤ Performance Score for ***this*** target situation



⑥ Performance Score over the ***whole archive*** for a given set ***of parameters***

Precipitation archive

Target variable : Daily basin-averaged precipitation 6 h UTC - 6 h UTC
over the period : 1953 - 2001

- **~ 75 test basins :**

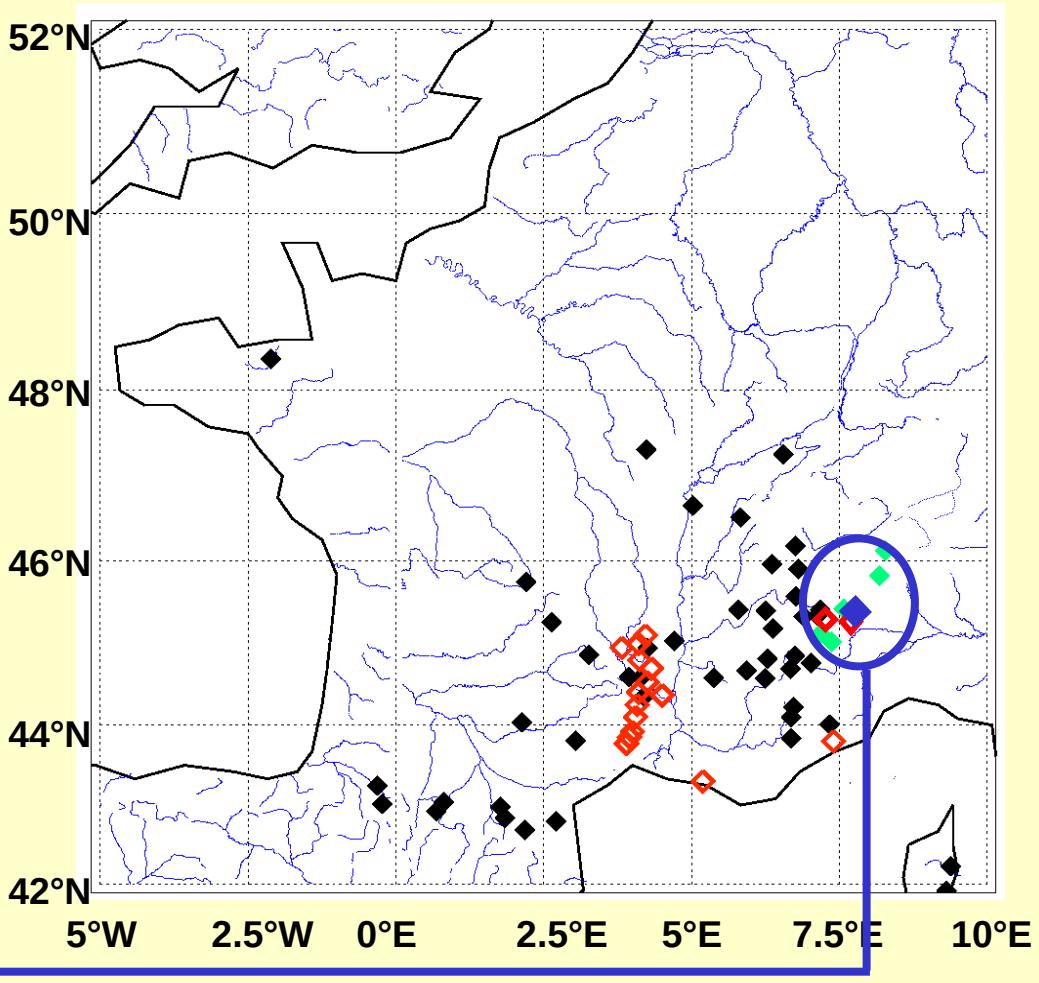
managed by different institutions

♦**EdF** ♦ **SPC** ♦ARPA Piemonte

- **Transformed Rainfall :**

$$\sqrt{\frac{R}{R_{10}}}$$

10 yr Rain



5 italian basins

One / two step analogy ?

Candidate Analogy Variables

Candidate Analogy Criteria

Geopotentials

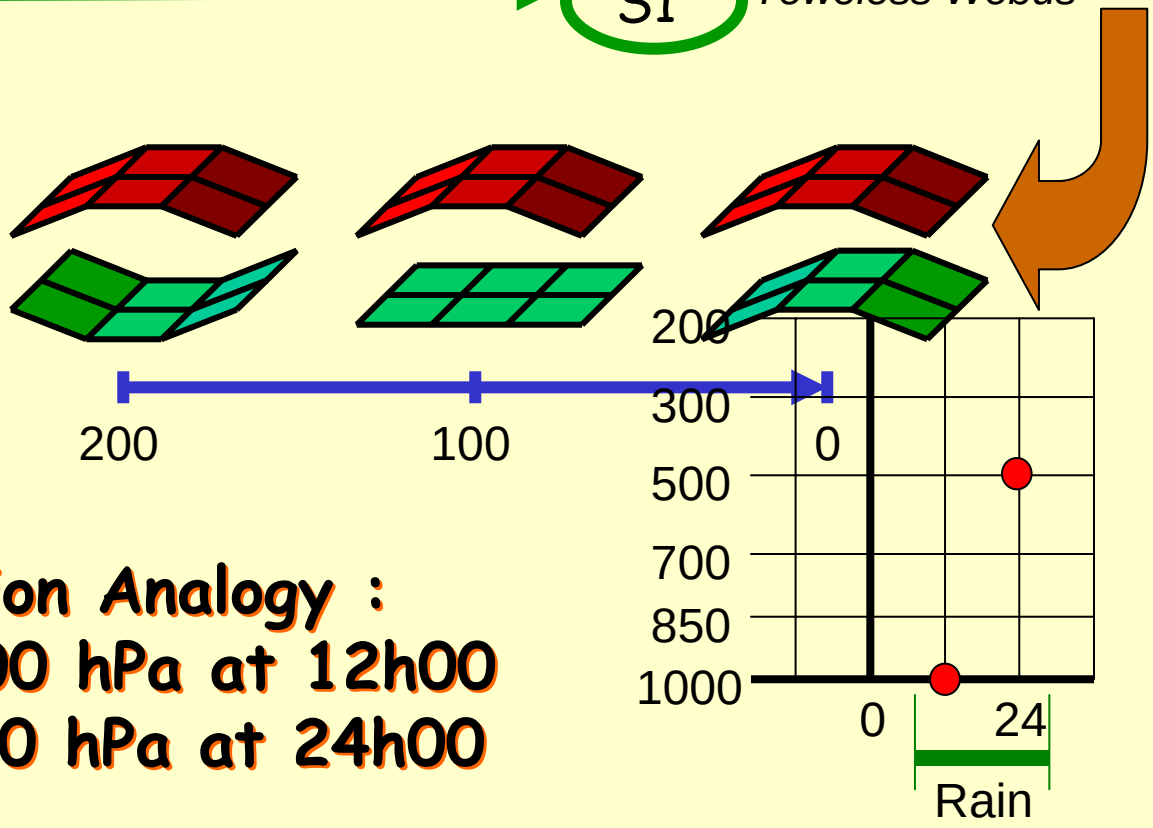
Temperature

Wind Speeds (u, v, w)

Humidity

Potential Vorticity, …

S1 *Teweless Wobus*



Global Circulation Analogy :

1000 hPa at 12h00

500 hPa at 24h00

Geopotential only provide limited skill *(for rain forecast)*

⇨ **what about using more local / physical variables ?**

⇨ **and eventually how ?**

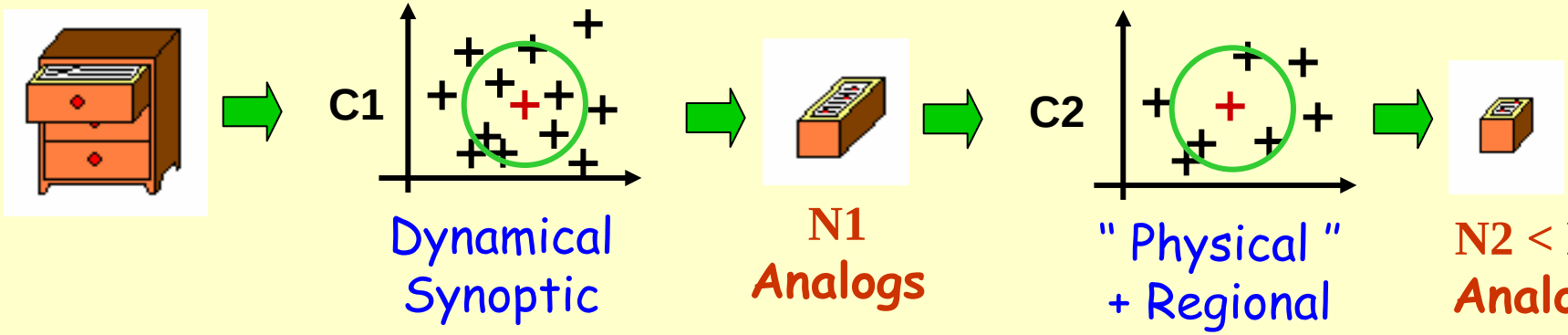
TOWARDS A TWO-STEP ANALOGY

Geopotential only provide limited skill *(for rain forecast)*

⇨ **what about using more local / physical variables ?**

⇨ **and eventually how ?**

➢ Two step Analogies



2nd level : variable /domain selection +optimisation

Candidate Variables:

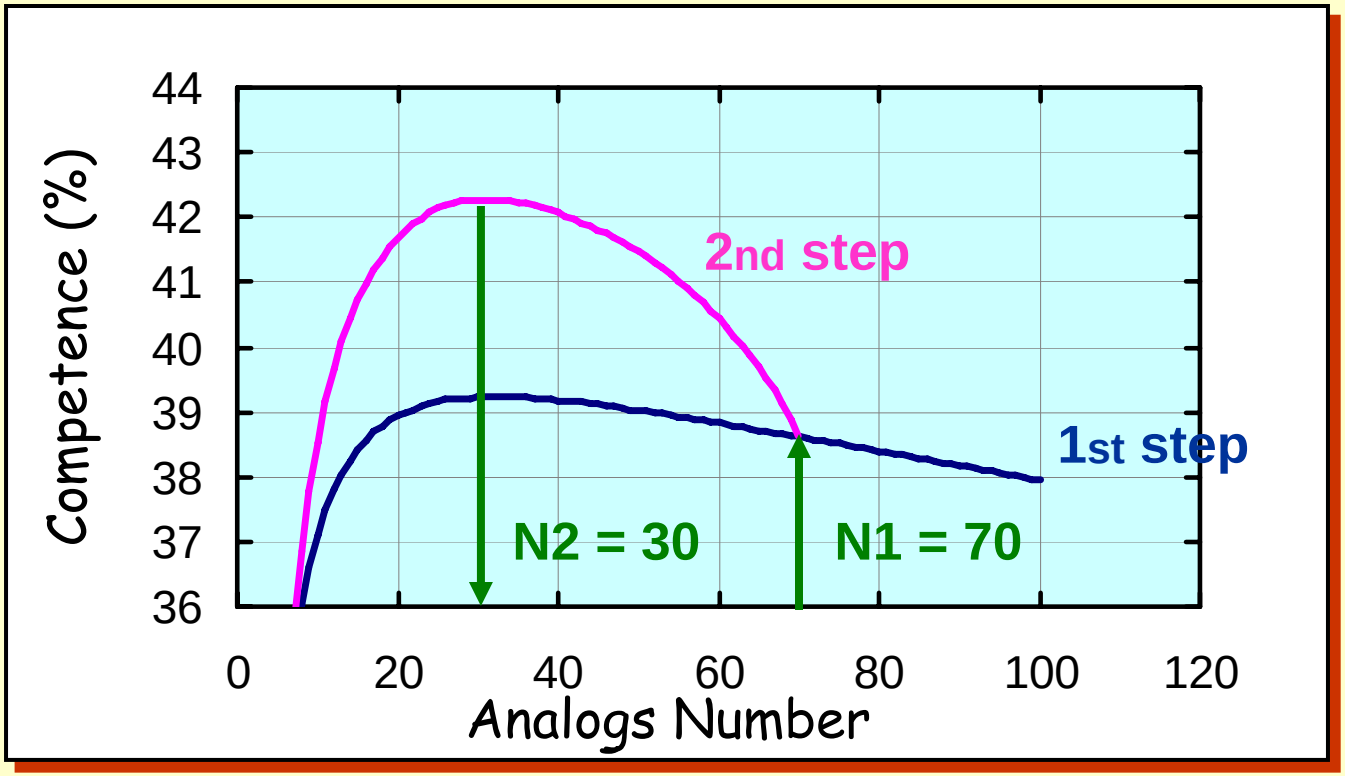
PWA Precipitable Water

RHU Relative Humidity

VWC Vertical Wind Component

PW% **+** **criterium used : RMSE**

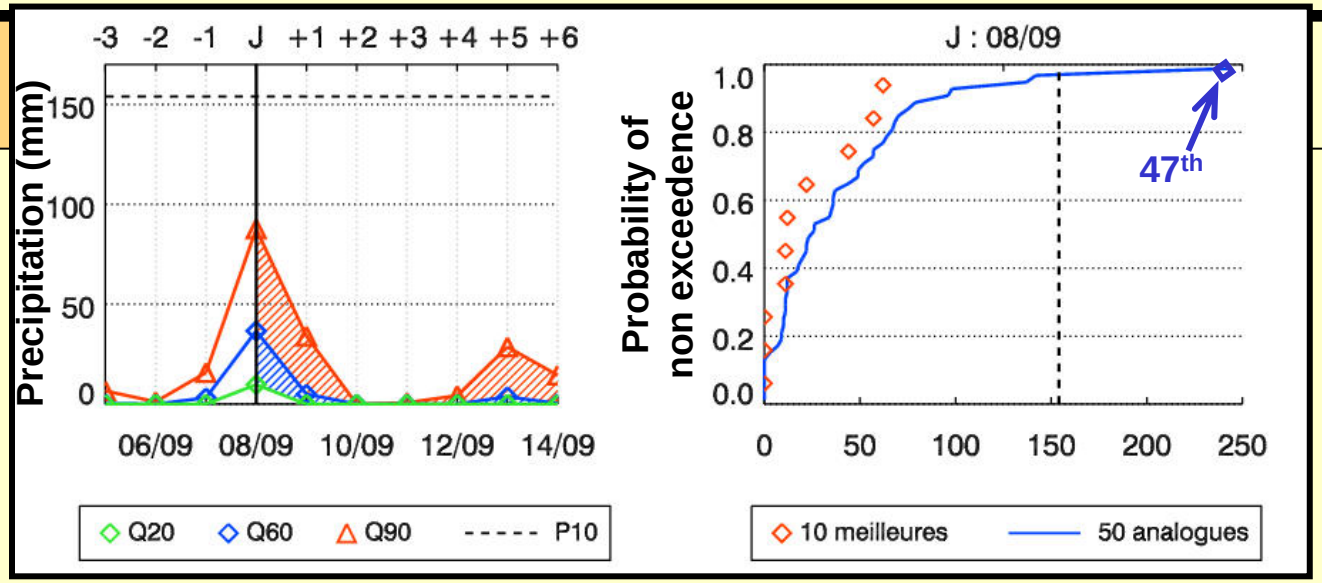
PWA x RHU



Zoom on the 8th september 2002 forecasts

One step analogy

Geopotentials
$N = 50$



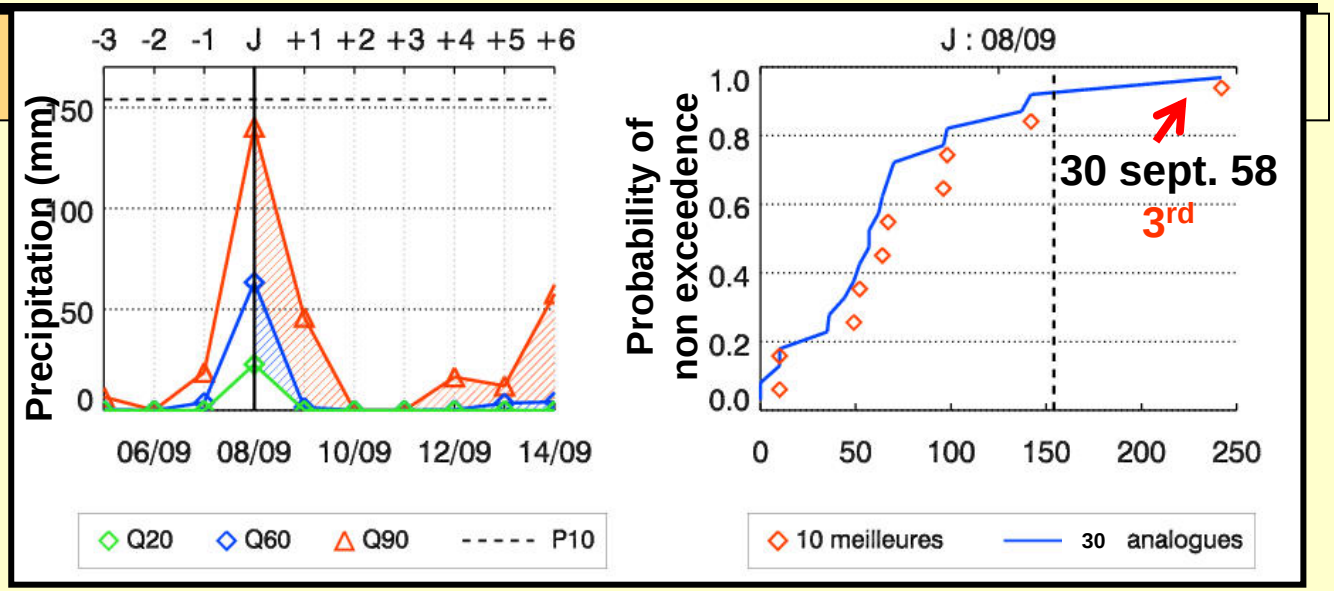
2 step Analogy

1st step :

Geopotentials
$N1 = 70$

2nd step :

PWA x RHU
$N2 = 30$

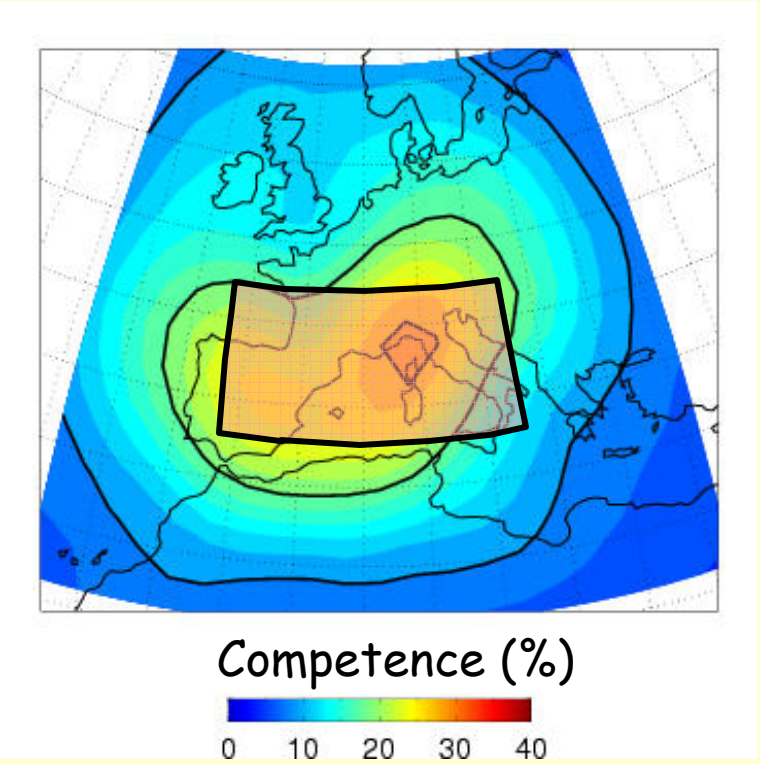


2nd level : spatial domain extension

1st selection

Circulation – Geostrophic wind

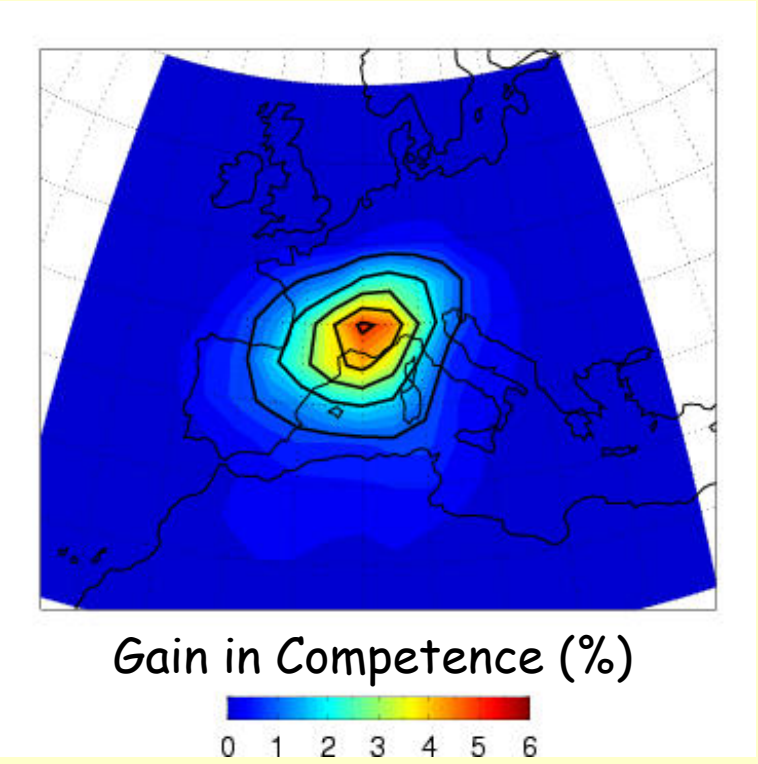
Synoptic scale



2nd selection

Humidity variables

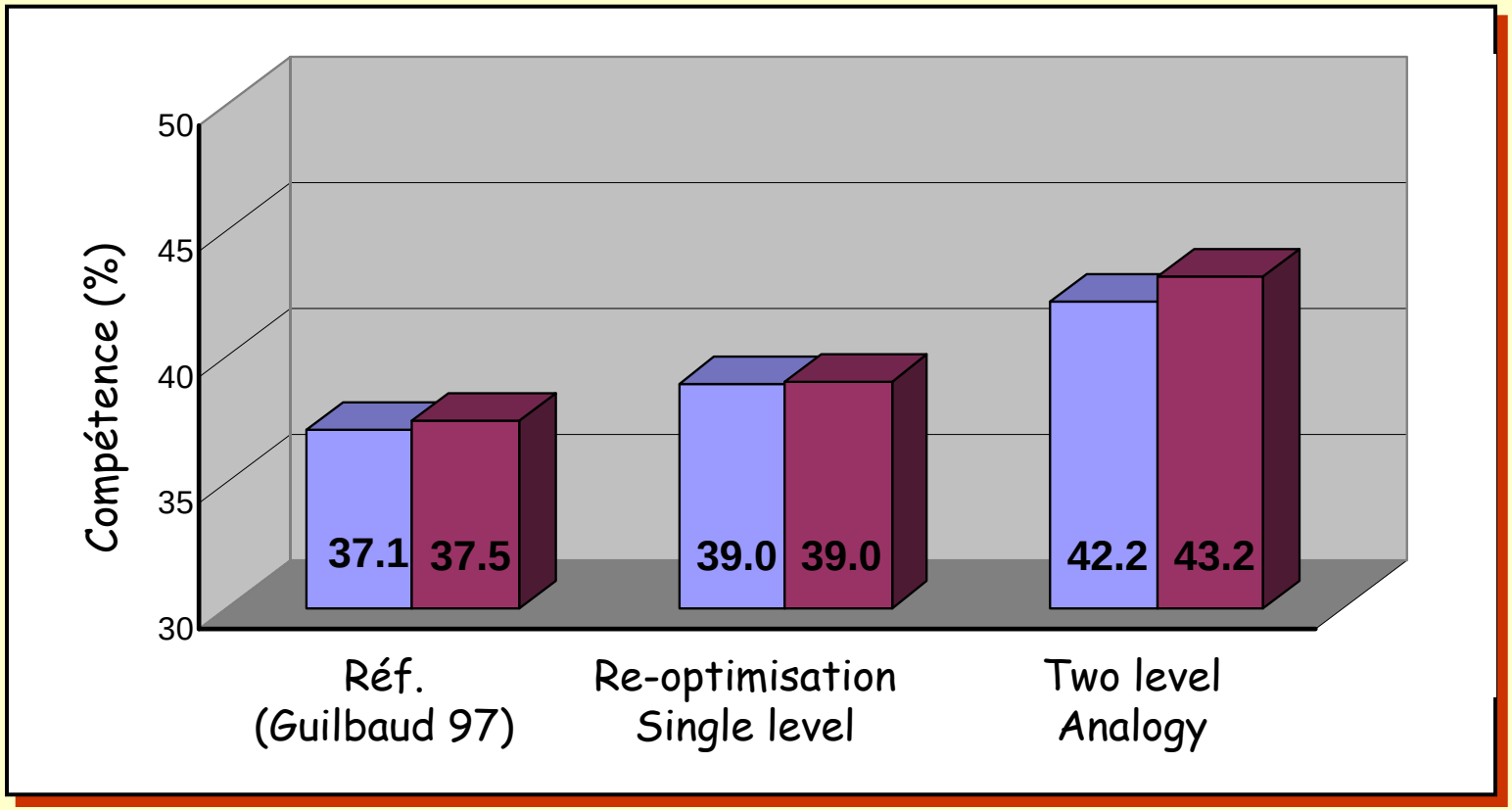
More local scale



Performances in validation *(which one? Perfect prog)*

Calibration : 1953 - 1996 *(44 yrs)*

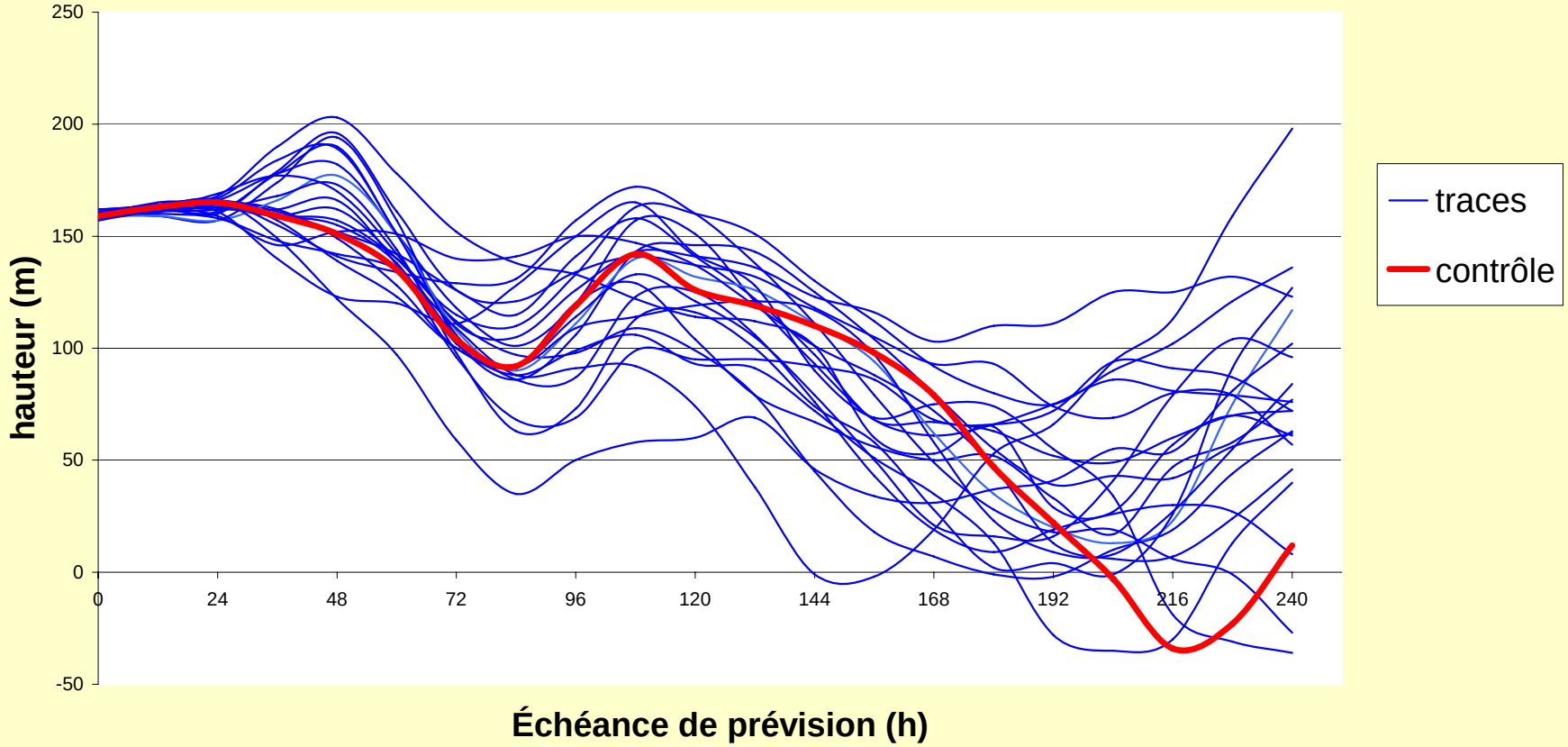
Validation : 1997 - 2001 *(Perfect Prog.)* *(5 yrs)*



A forecast archive: *the EPS at ECMWF*

An Example :

evolution of the geopotential height at 1000 hPa

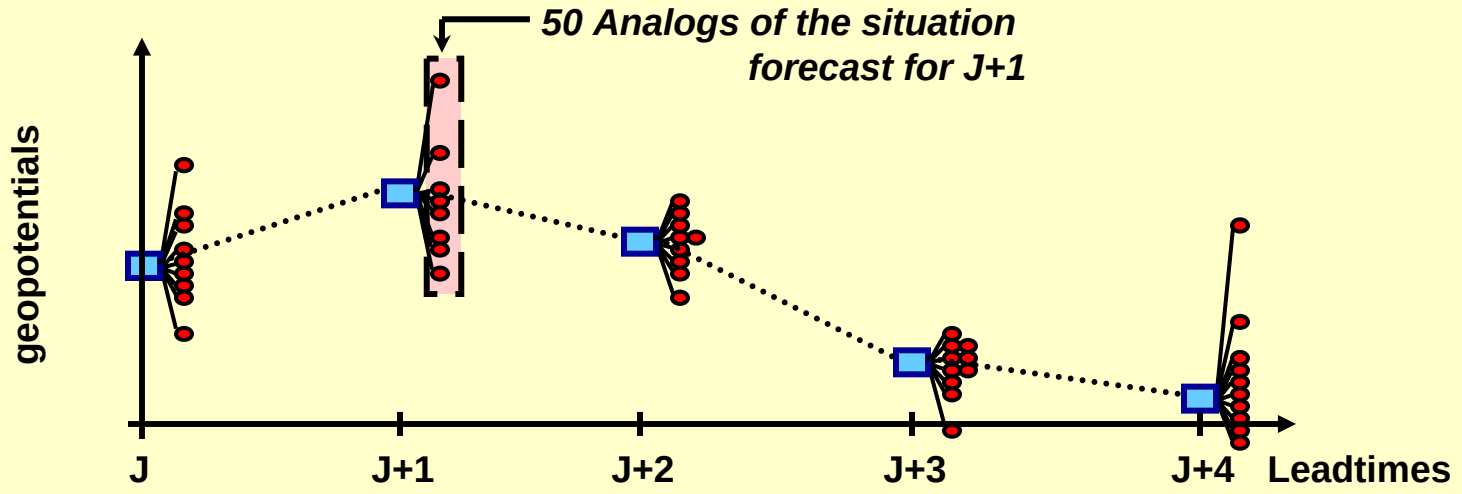


Current developments

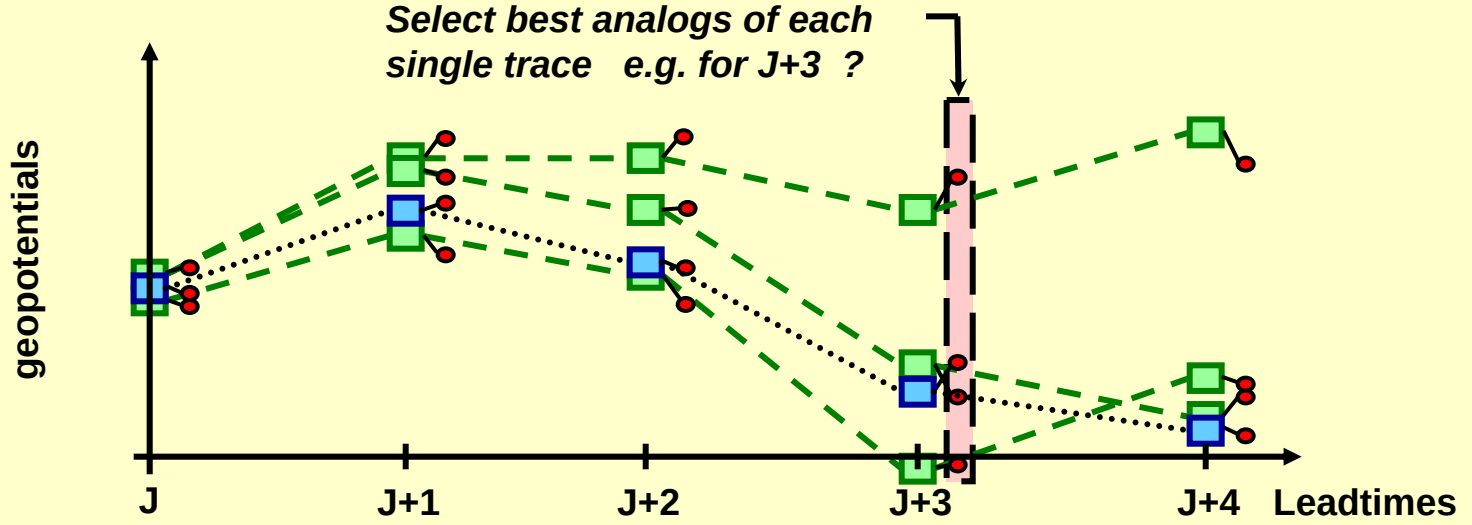
Using a new Meteorological archive ERA-40 (resol. 1°x1° v.s. 2°5 x 2°5)

Using the Ensemble Prediction System

Determistic
(single trace)
Synoptic
Forecasts



Ensemble
(multi traces)
Synoptic
Forecasts



EPS Meteorological Forecasts Archive

Retrieval of EPS data from ECMWF

- **MARS** system (Meteorological Archive Retrieval System)
- ⇨ ***EPS Forecasts*** available from (1992) ***1997 until 2003***

- **Variables :**

  Géopotential levels at 1000 and 500 hPa
  Relative humidity at 850 hPa

- **Forecasts used :**

  50 perturbed forecasts (***traces***) + *control* (1997 to 2001)
  Lead-times: 0 hour to 240 hours , at 12h interval
  Based on 12 UTC analyses

- **Domain :**

  Longitude : 30°E-> 45 °W

  Latitude : 30°N-> 75.5°N

spatial resolution used : 2.5° × 2.5°

Contents

Question : usefulness of a *new optimisation* ?

Calibration :
optimisation in perfect prog.

⇩

Target situations = days as *observed*

Operational

implementation

⇩

Target situation = days as *forecast* by *a model*

⇒ Uncertainty on the forecasts from this model

\+ Consistency variables archive/variables forecasts

⇒ Performing a **New optimisation…** ?

If yes : which parameters to re-optimise ?

Our proposal

:

Re-Optimising

the ***number of analogs*** selected as a function of the ***leadtime***

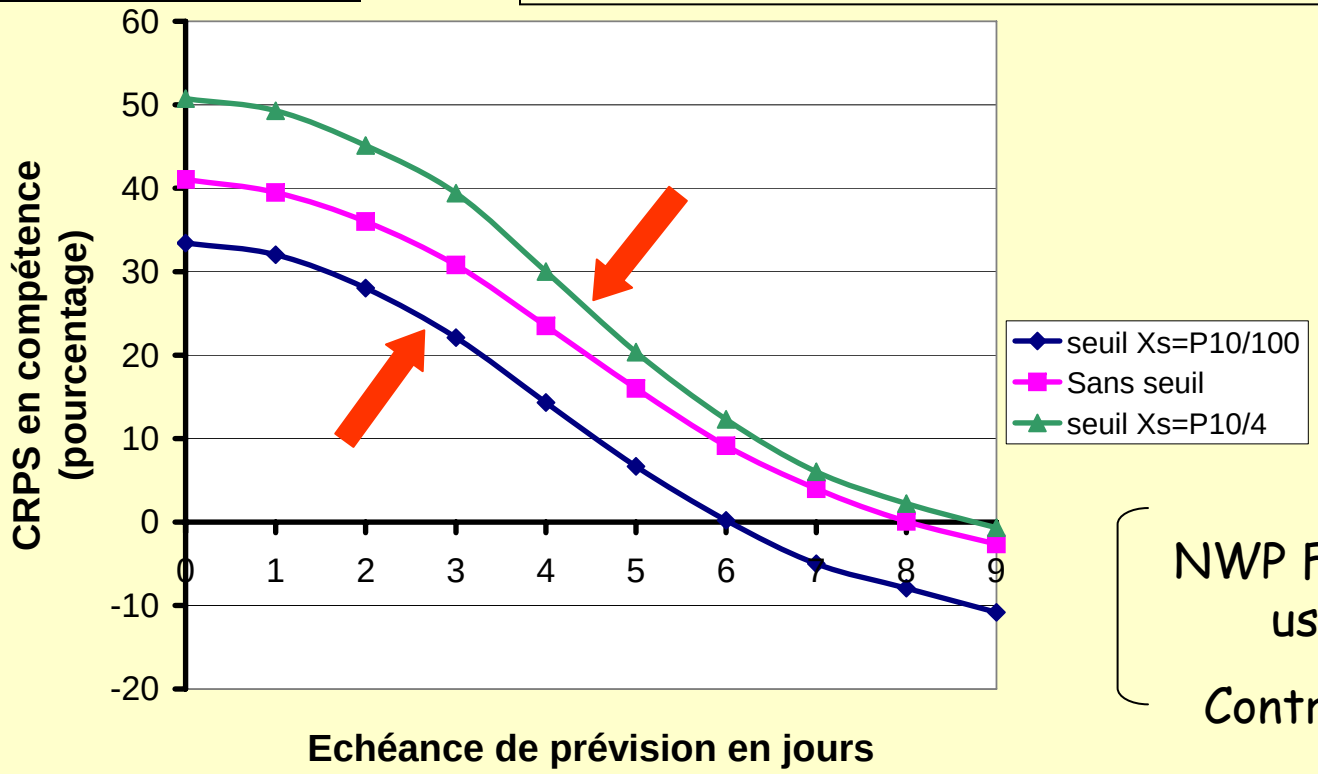
Contents

Evaluation of the ANALOG method : focused on rainy days

A day is evaluated only if: $R_{Obs} > Thrsh.$ **and/or** $R_{For.}(Qxx) > Thrsh$

Rain / No-Rain
Threshold: $P_{10}/100$
on Quantile : 60%

Day with substantial rain
Threshold : $P_{10}/4$
on Quantile : 90%



NWP Forecast used :

Control det.

Method performing better for days « substantially » rainy !

Re-optimisation : Nb of analogs to consider

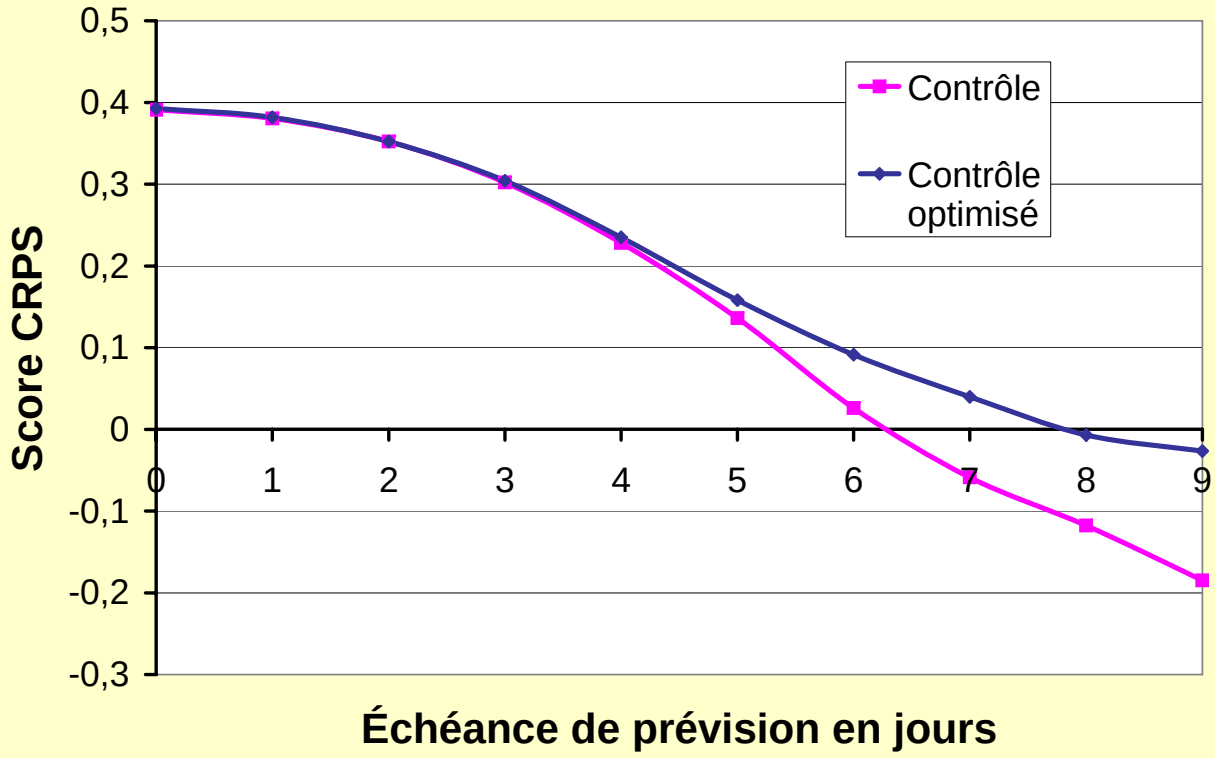
1 level of analogy

M1

Forecasts used: control *(deterministic)*

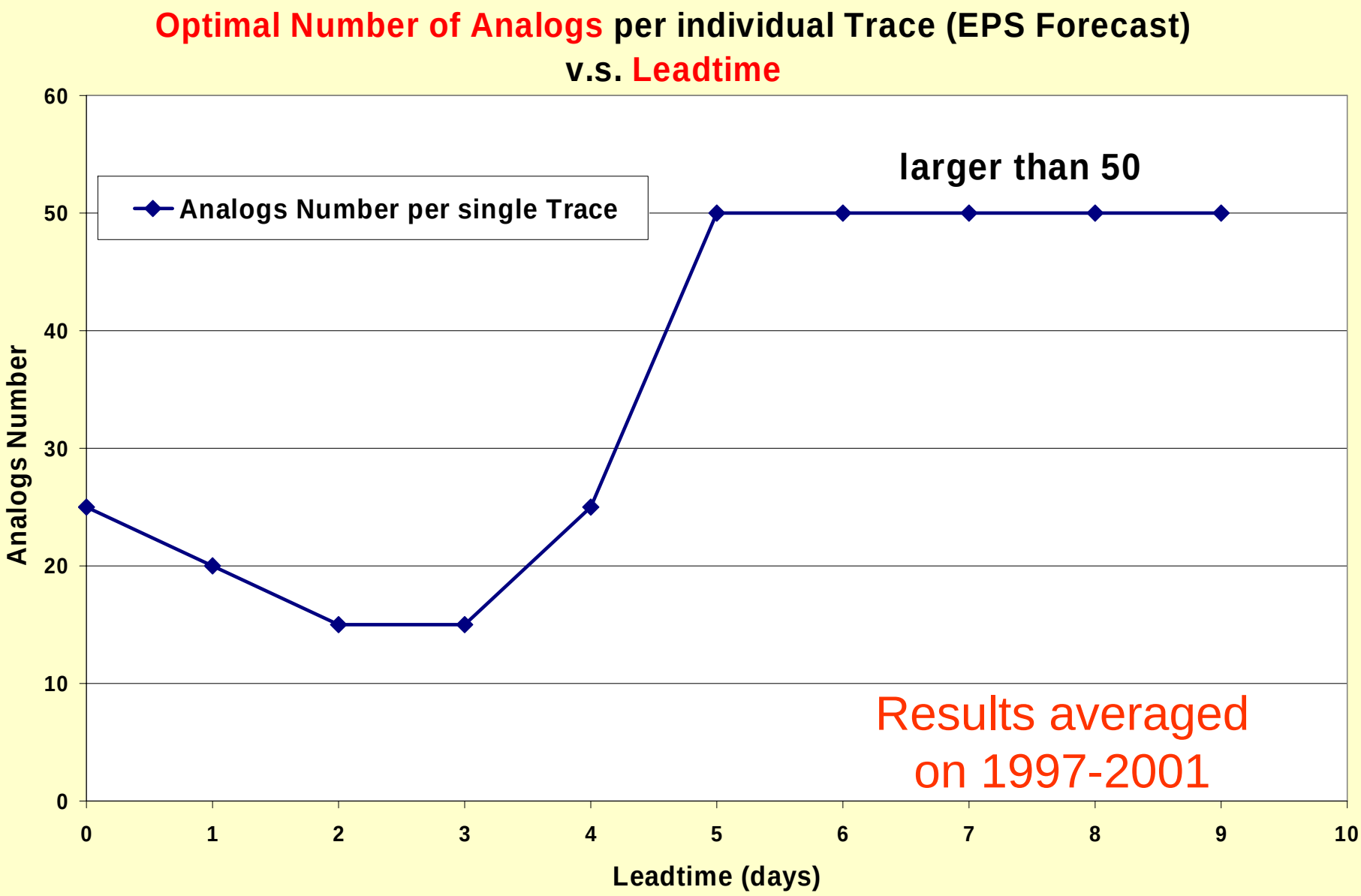
Performances

Gain in competence



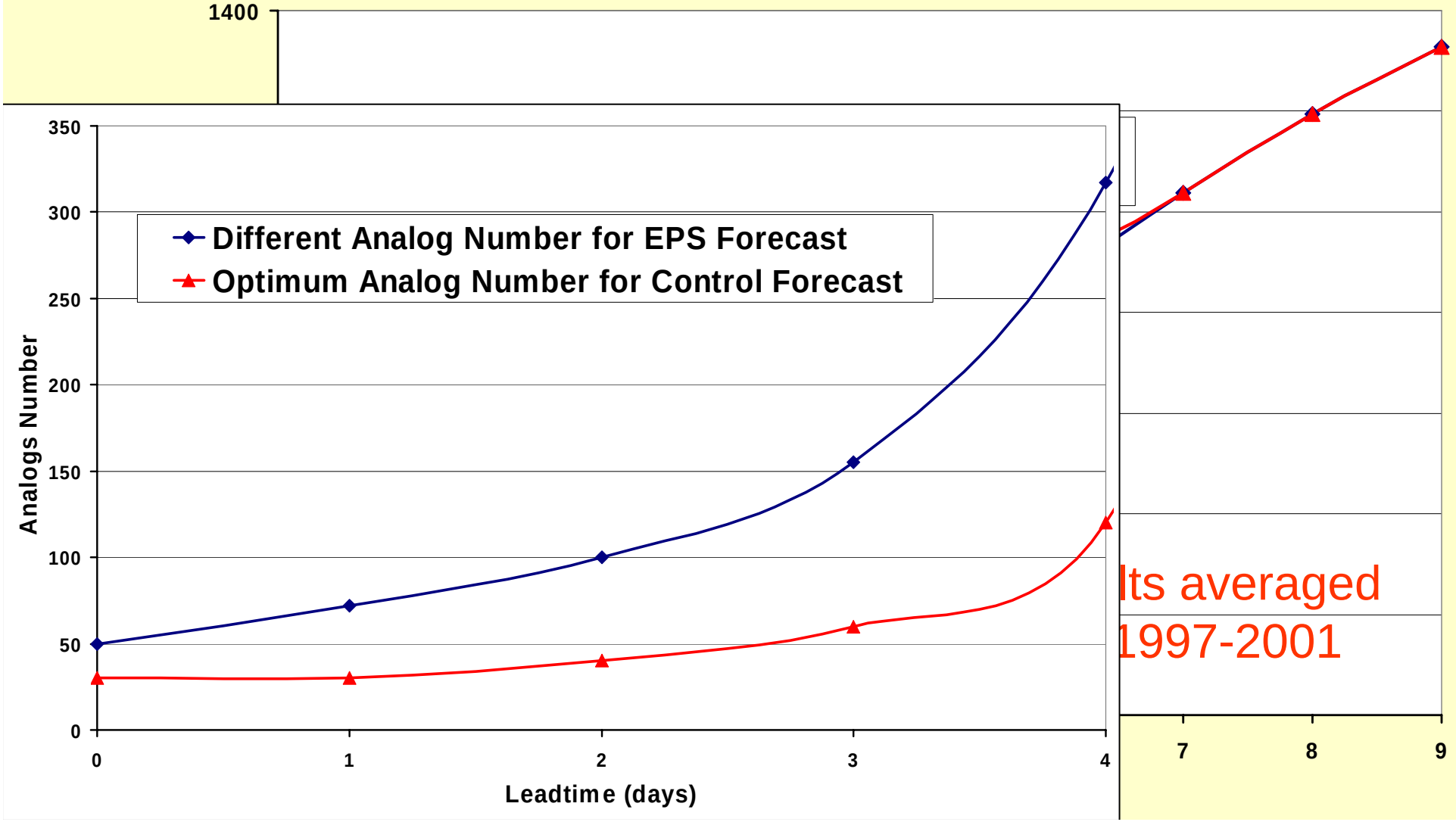
Significant gain in performance for the most remote leadtimes **although** competence low, close to 0 ...

Analog adaptation of EPS Forecasts

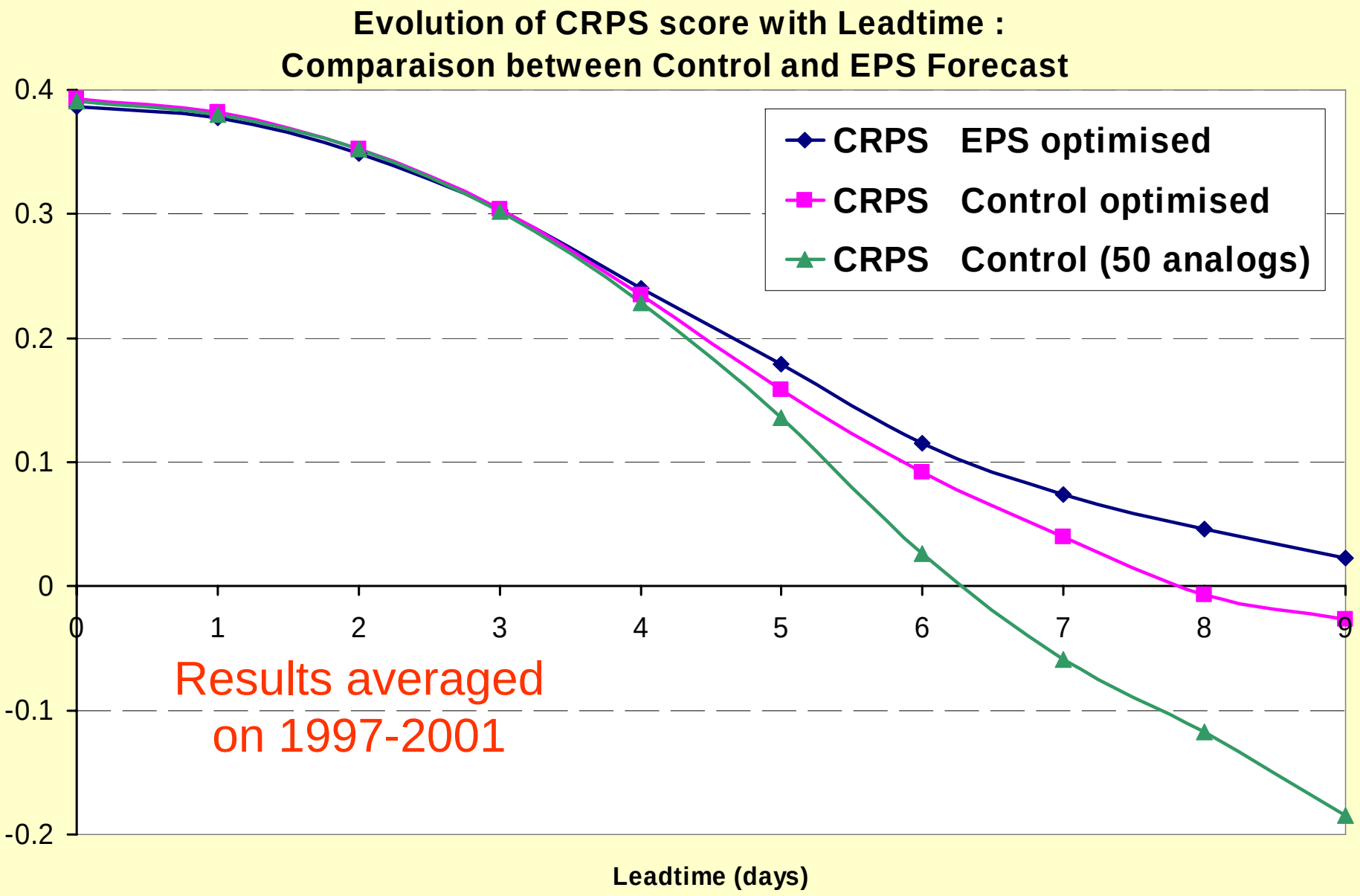


Analog adaptation of EPS Forecasts

Total number of Different (-non overlapping-) Analogs for the Optimum number of analogs (per trace) : Evolution with Leadtime for EPS & Control Forecast



Analog adaptation of EPS Forecasts



Day **J** when forecast is issued

Probabilistic Forecast for leadtime J+5

M1

Inputs :

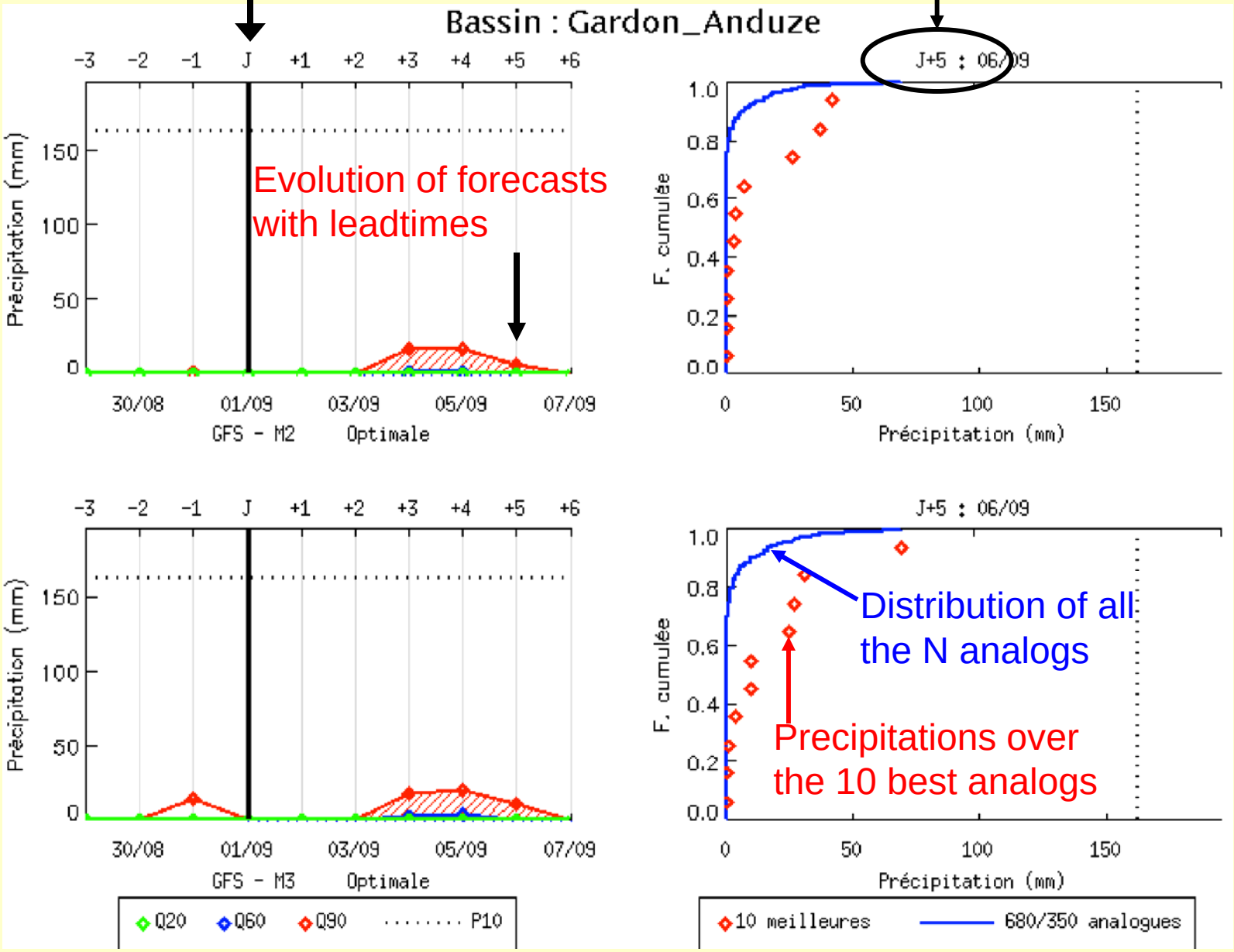
Géopt only

Z_{1000} + Z_{500}

M2

Inputs :

Géopotentiel + $PWA \times RHU_{850}$

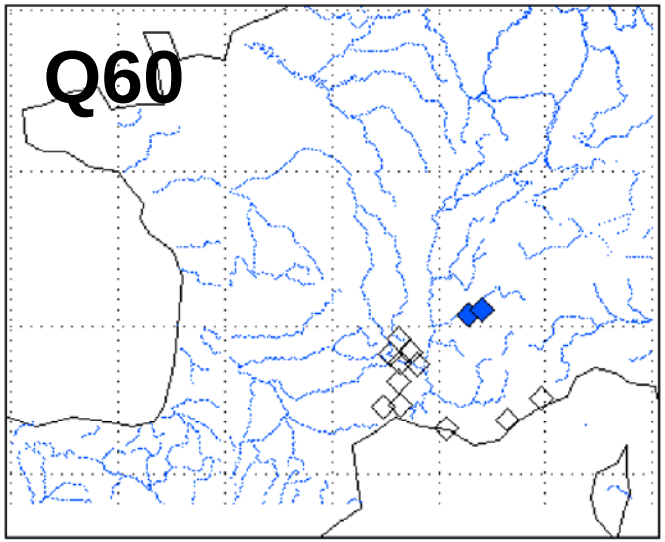


Risk maps : quantiles Q60 et Q90

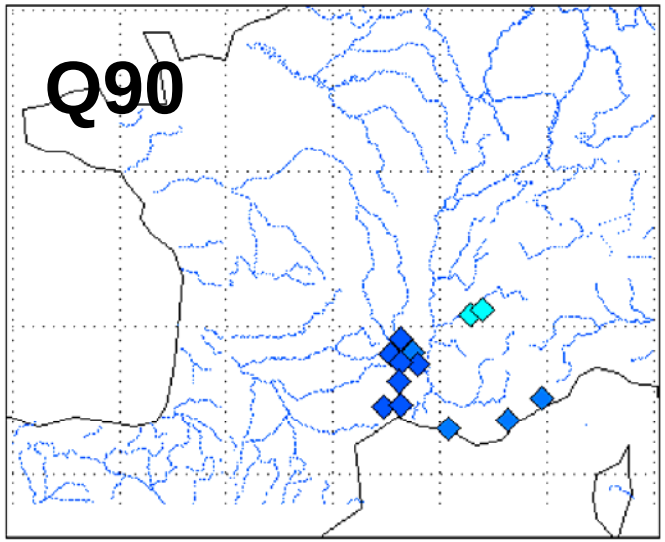
M1
Inputs :
Géopt seul
Z_{1000} + Z_{500}

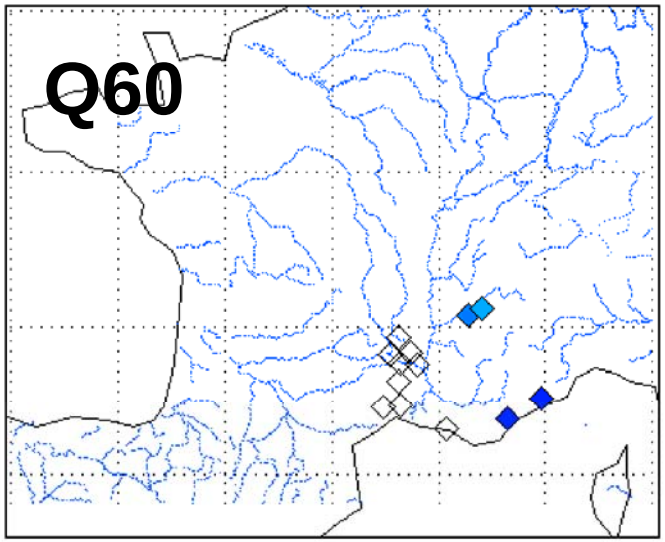
M2
Inputs :
Géopotentiel
+
PWA×RHU_{850}

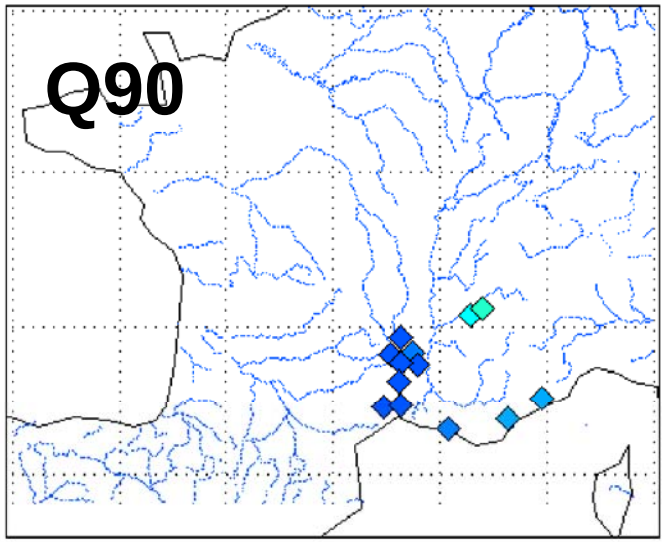
Prévision émise le 01/09/2005
J+5 : 06/09

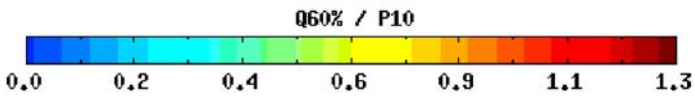


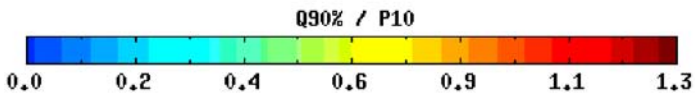
Prévision émise le 01/09/2005
J+5 : 06/09



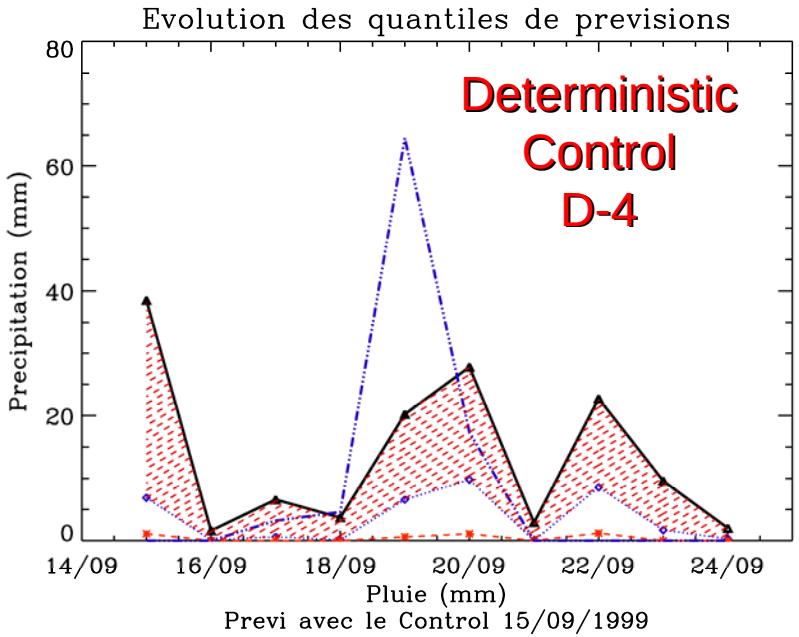


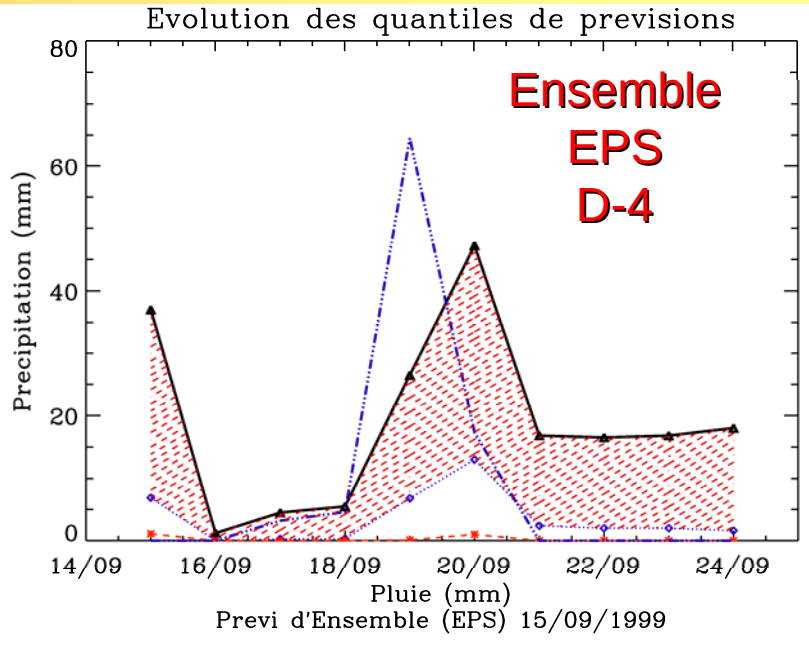


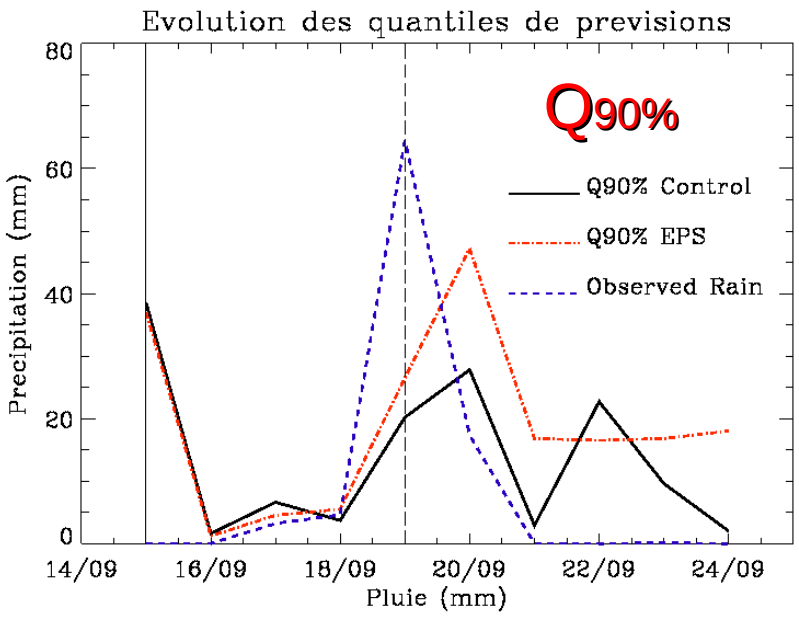




Analog adaptation : EPS v.s. Deterministic





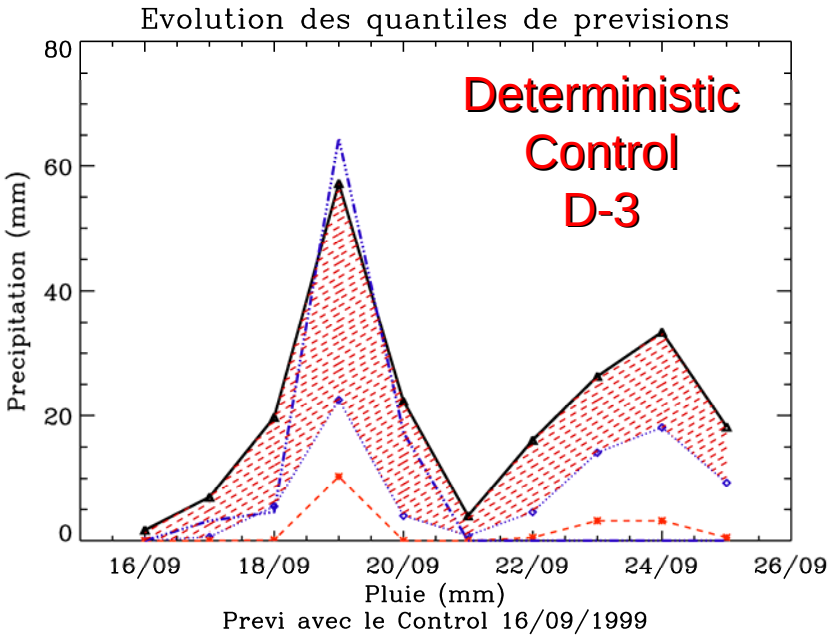


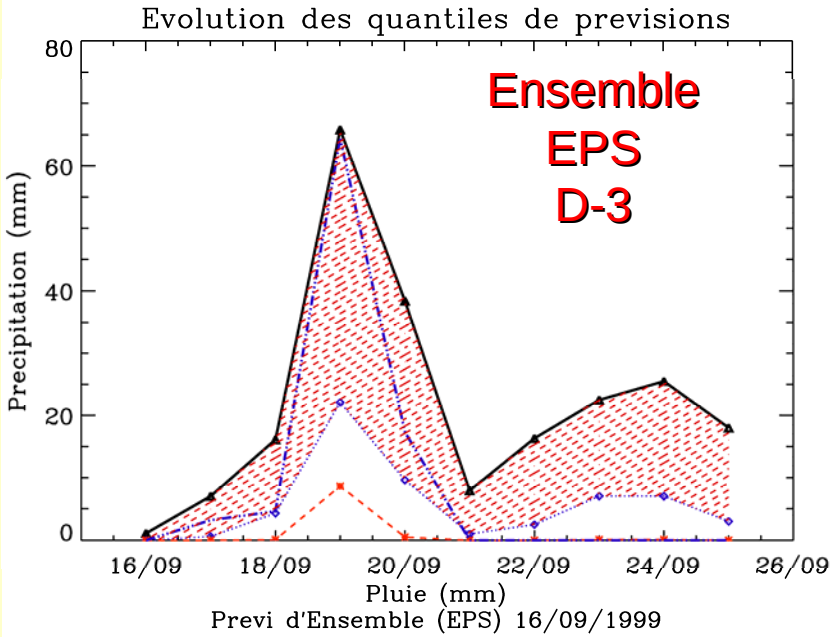
Comparison of the

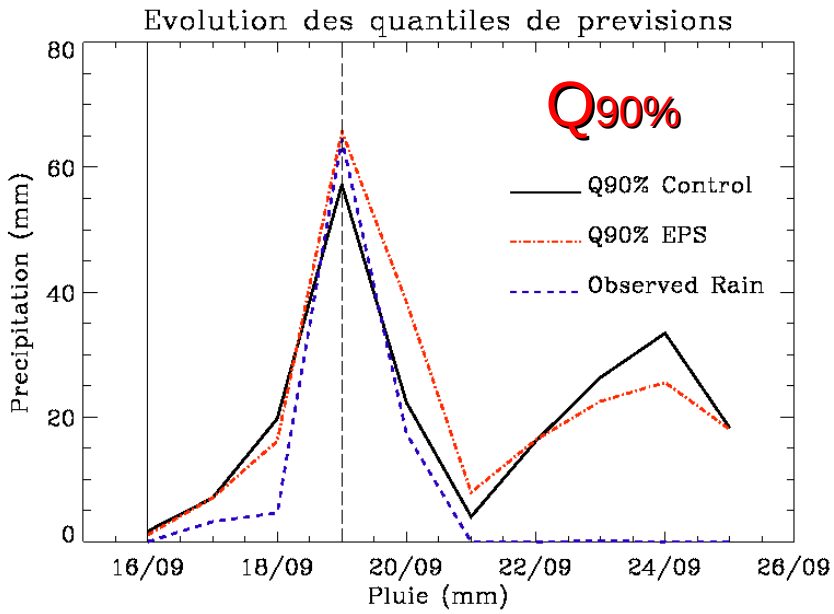
QPF's issued on D-4
(15/09/1999)
on the Stura basin

by EPS v.s. Control

Analog adaptation : EPS v.s. Deterministic







Comparison of the

QPF's issued on D-3
(16/09/1999)
on the Stura basin

by EPS v.s. Control

Analog adaptation of EPS Forecasts

Conclusion : on the use of EPS + test on a long (5yr) archive of forecasts

- **Number of analogs must increase with the leadtime**

  for both control *(single trace)*

  or EPS *(multi trace)* Forecast

- If analog number optimised (as above)

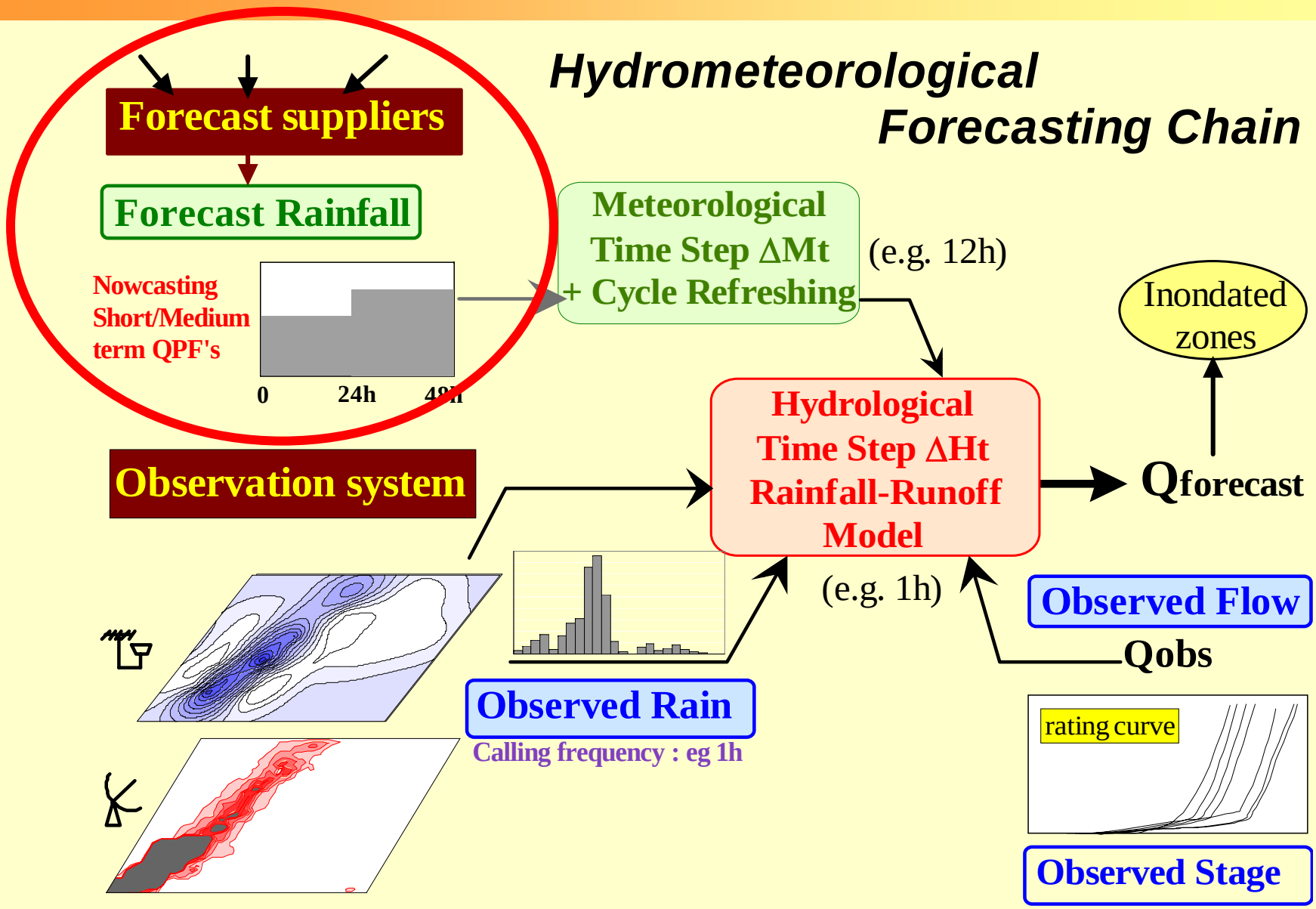
  light advantage for EPS *(on average)*

  and only for day 4th and beyond

  but **more significant** for large events

Contents

Sketch of the forecasting chain



Case study

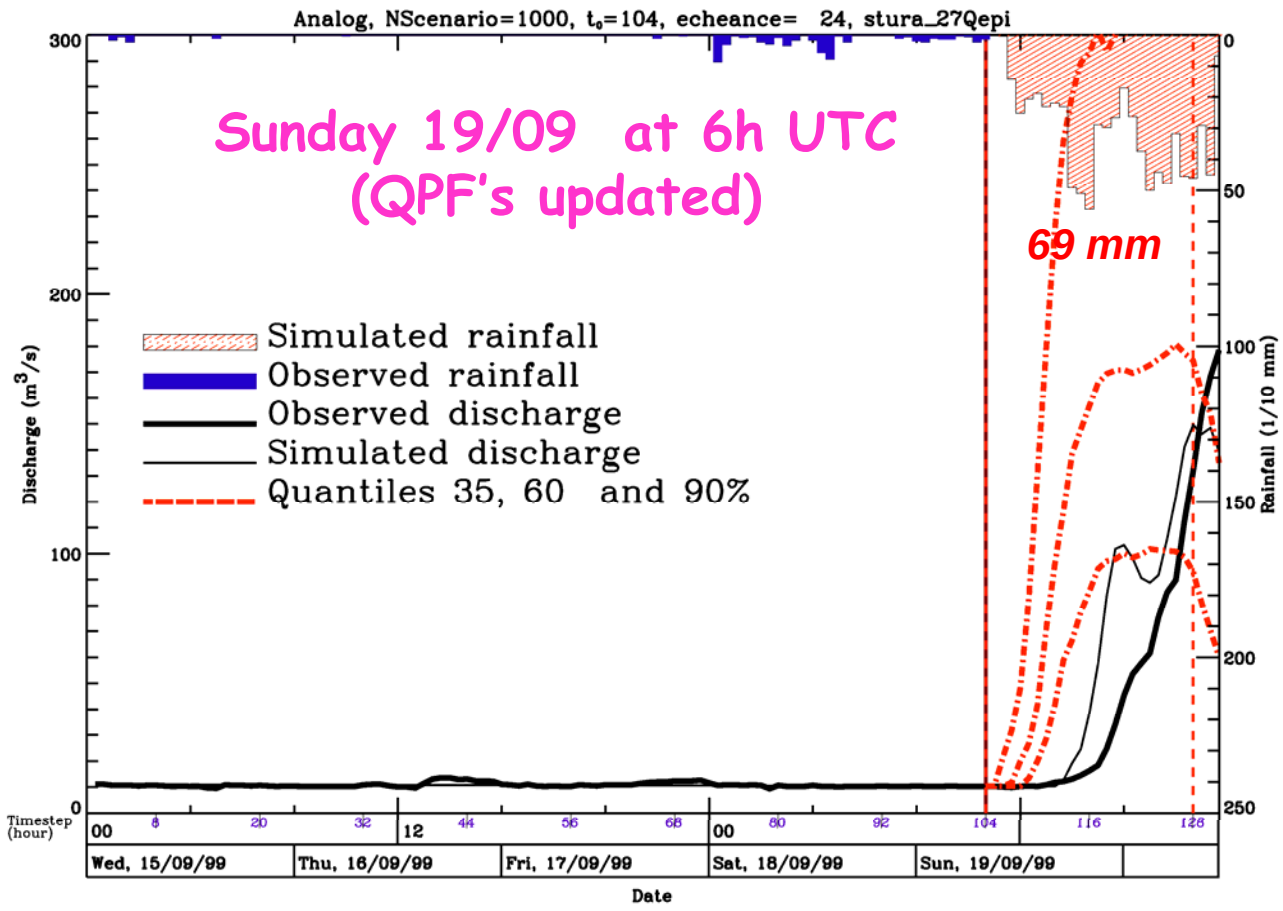
MAP-SOP 19/09/1999

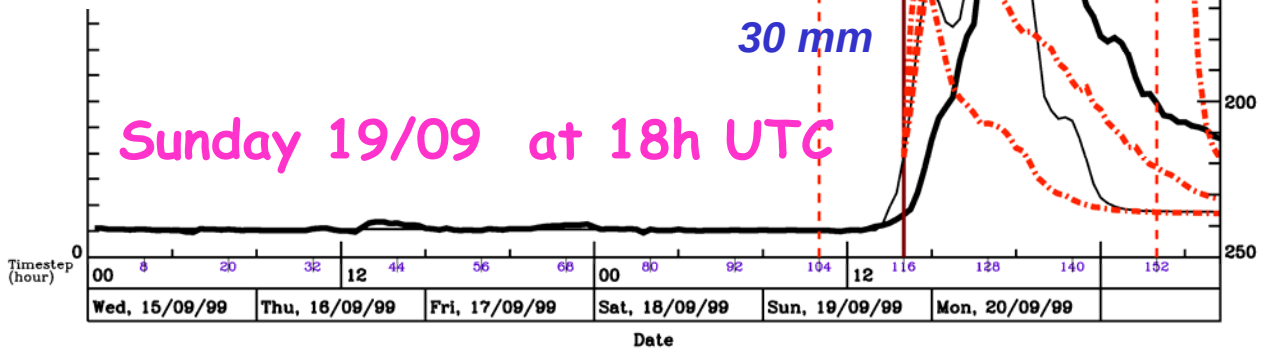
PQPF Forecasts Used

Control (single trace, ECMWF)

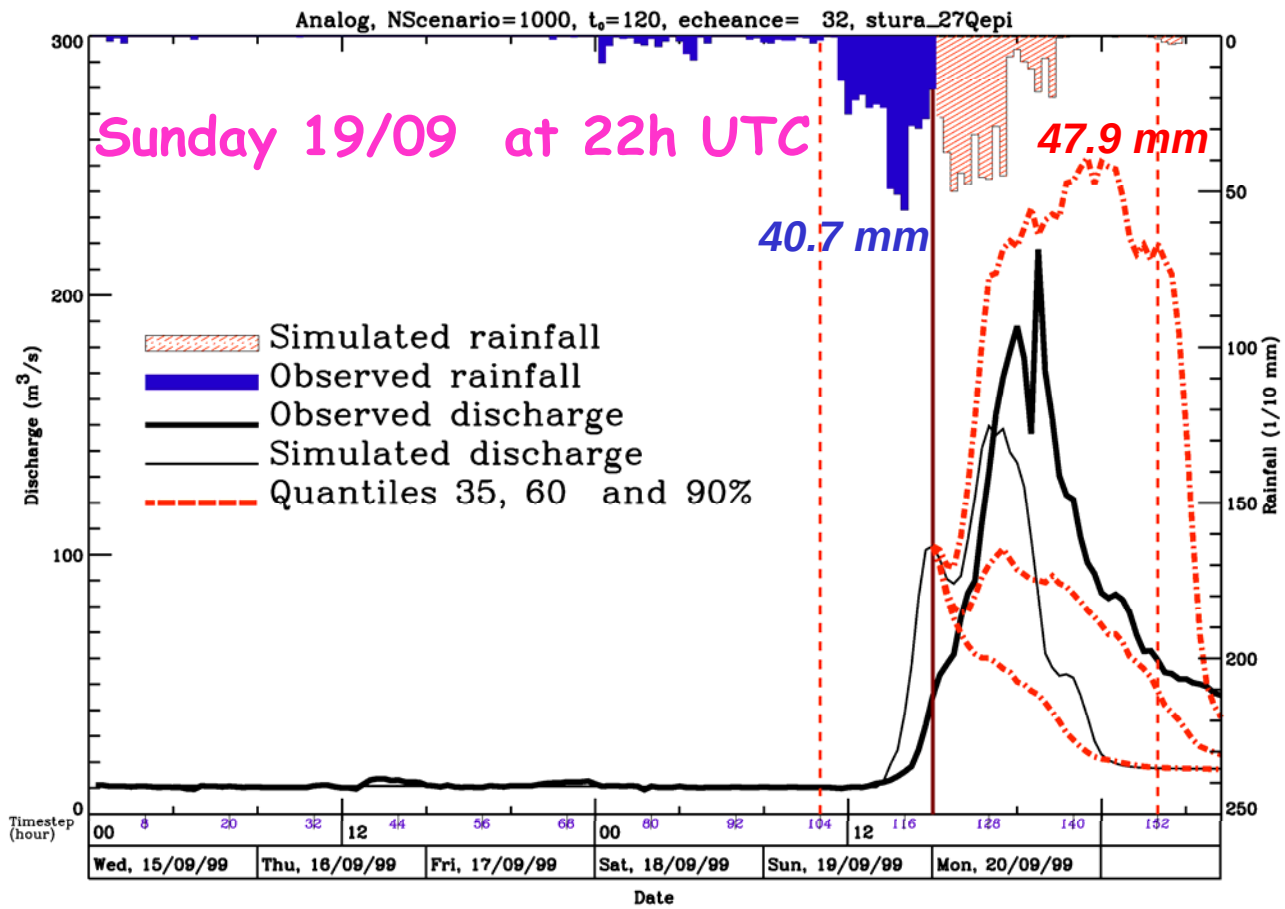
Stura basin at Lanzo

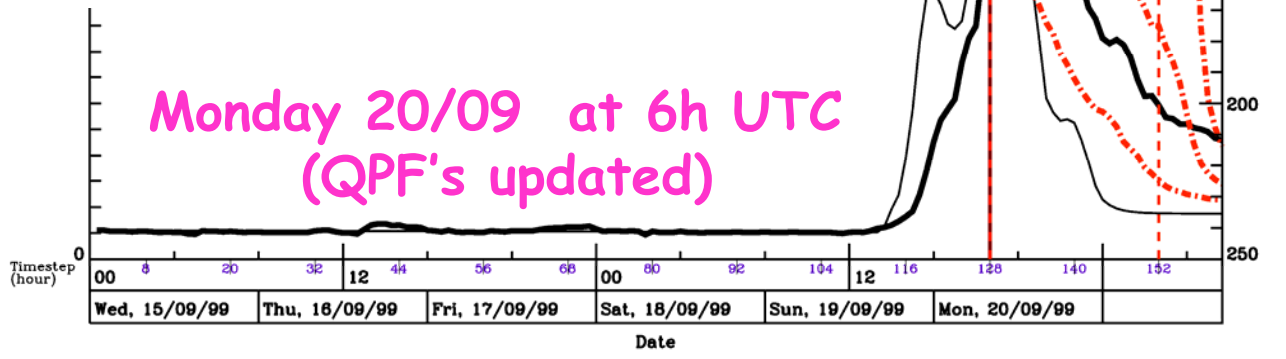
Case study : Sept 1999 (Stura basin)



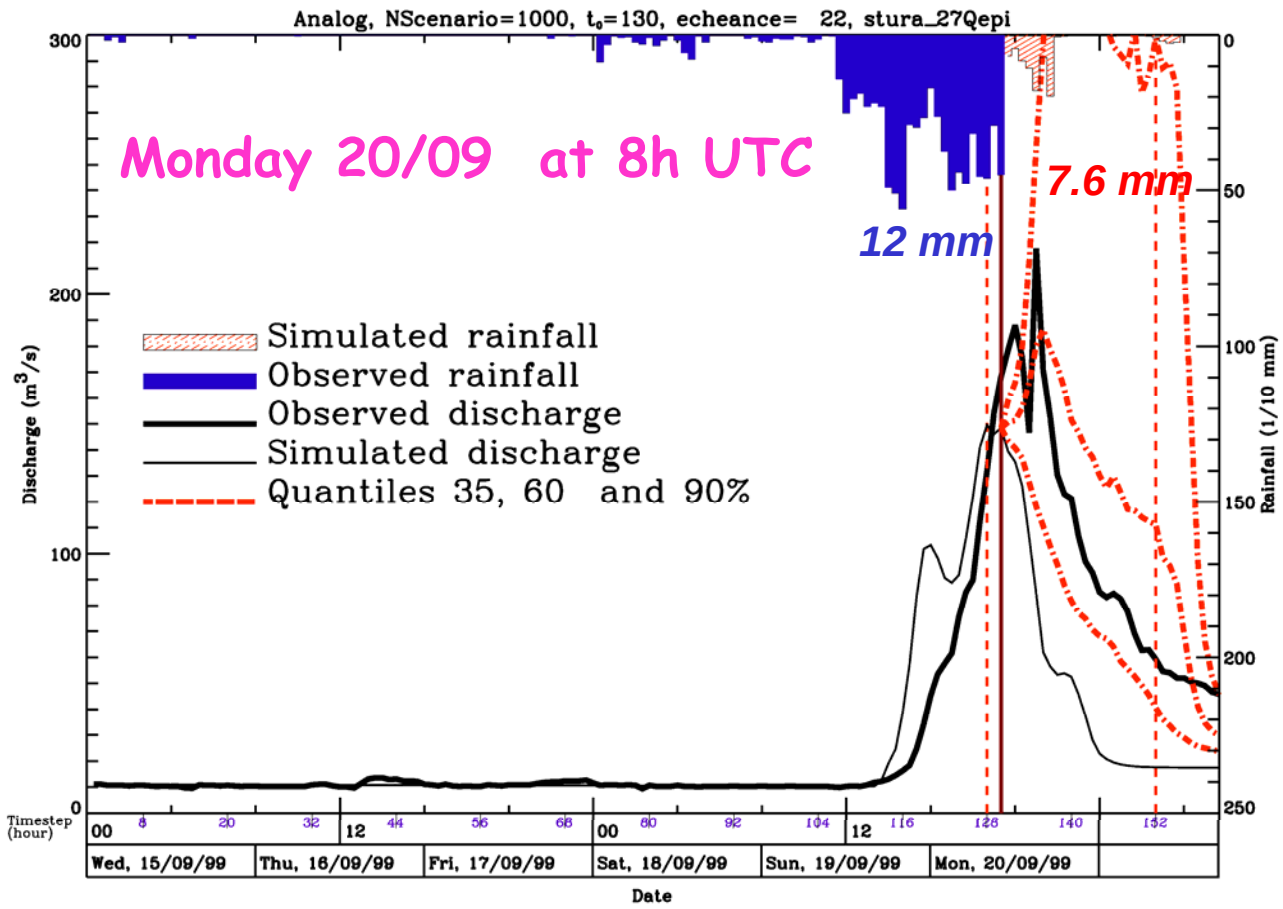


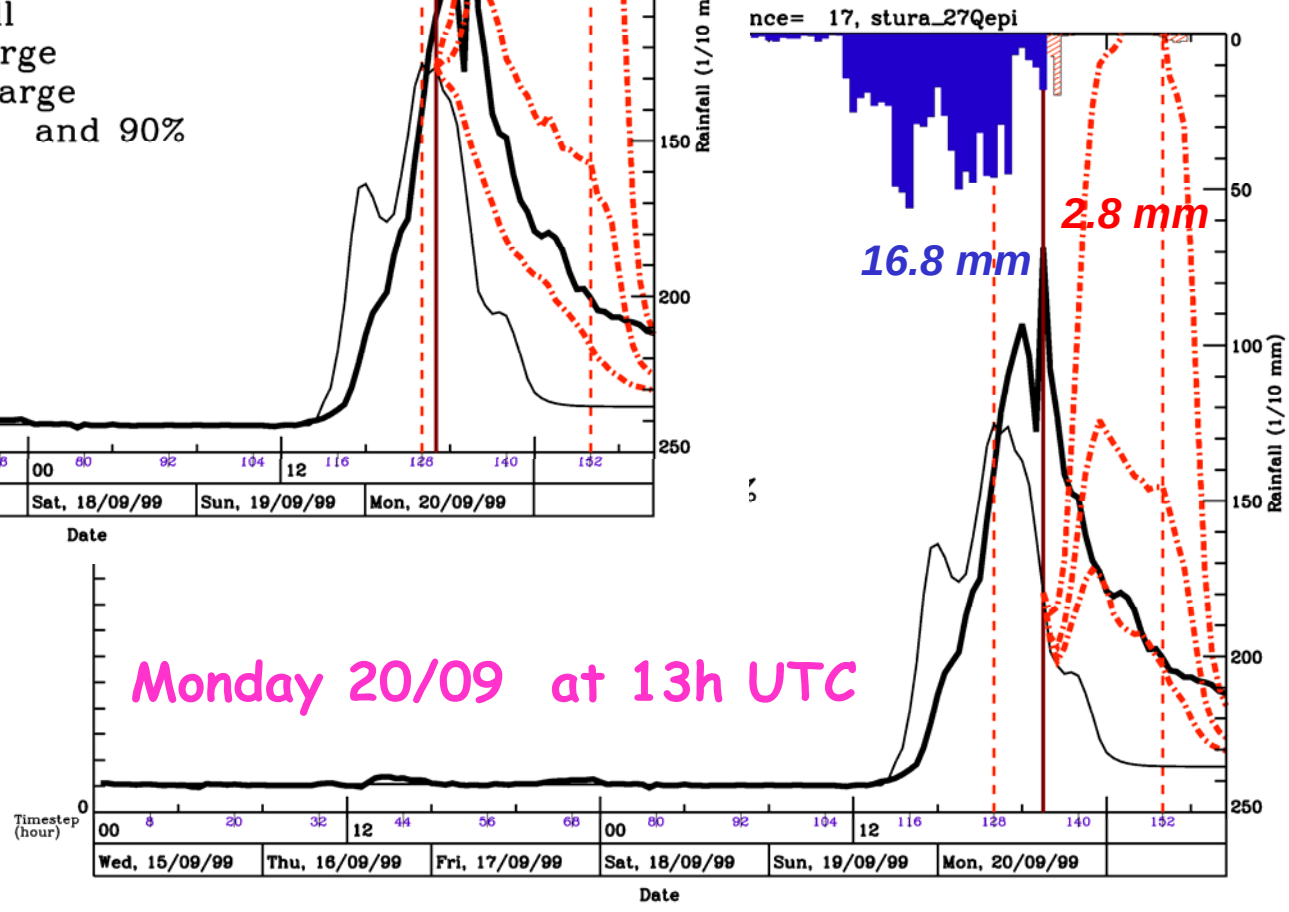
Case study : Sept 1999 (Stura basin)





Case study : Sept 1999 (Stura basin)





Case study

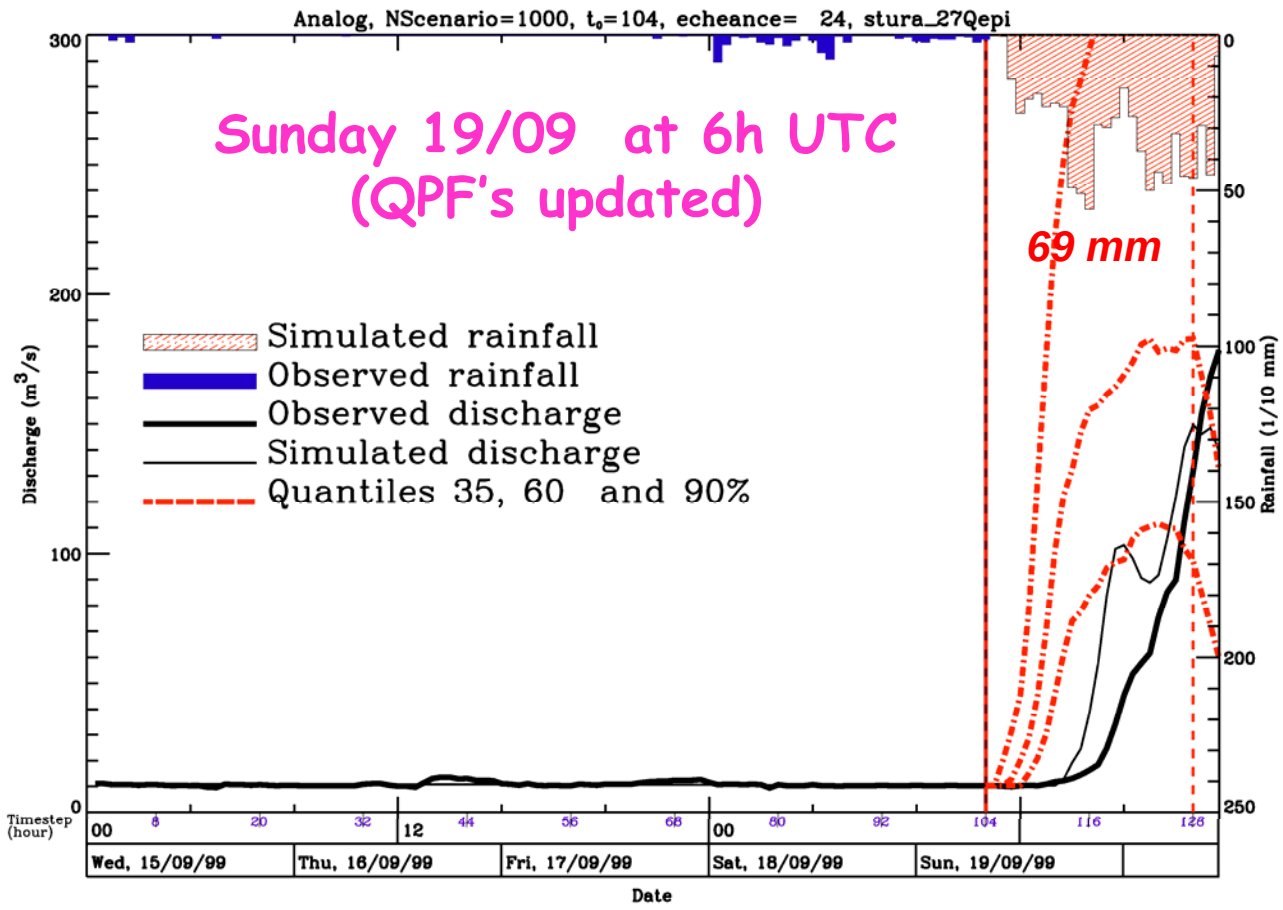
MAP-SOP 19/09/1999

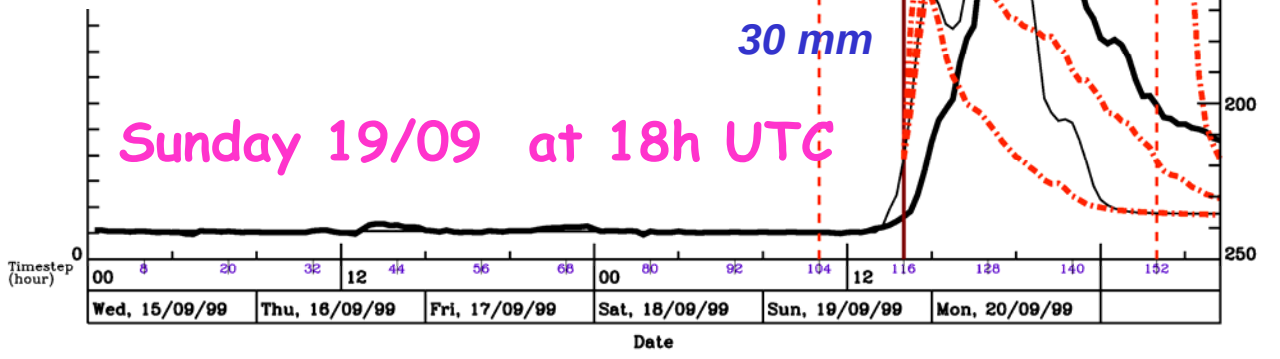
PQPF Forecasts Used

EPS (multi trace, ECMWF)

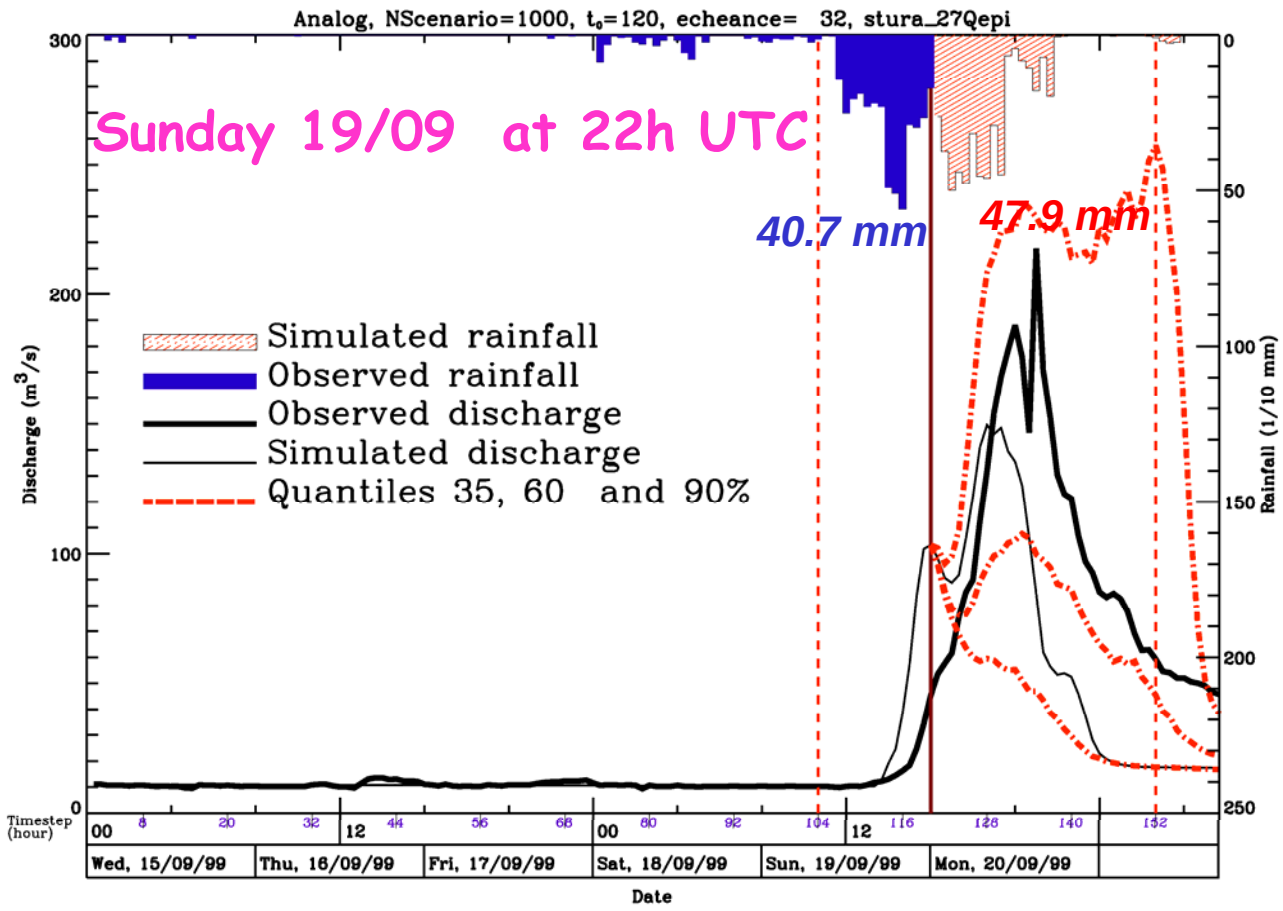
Stura basin at Lanzo

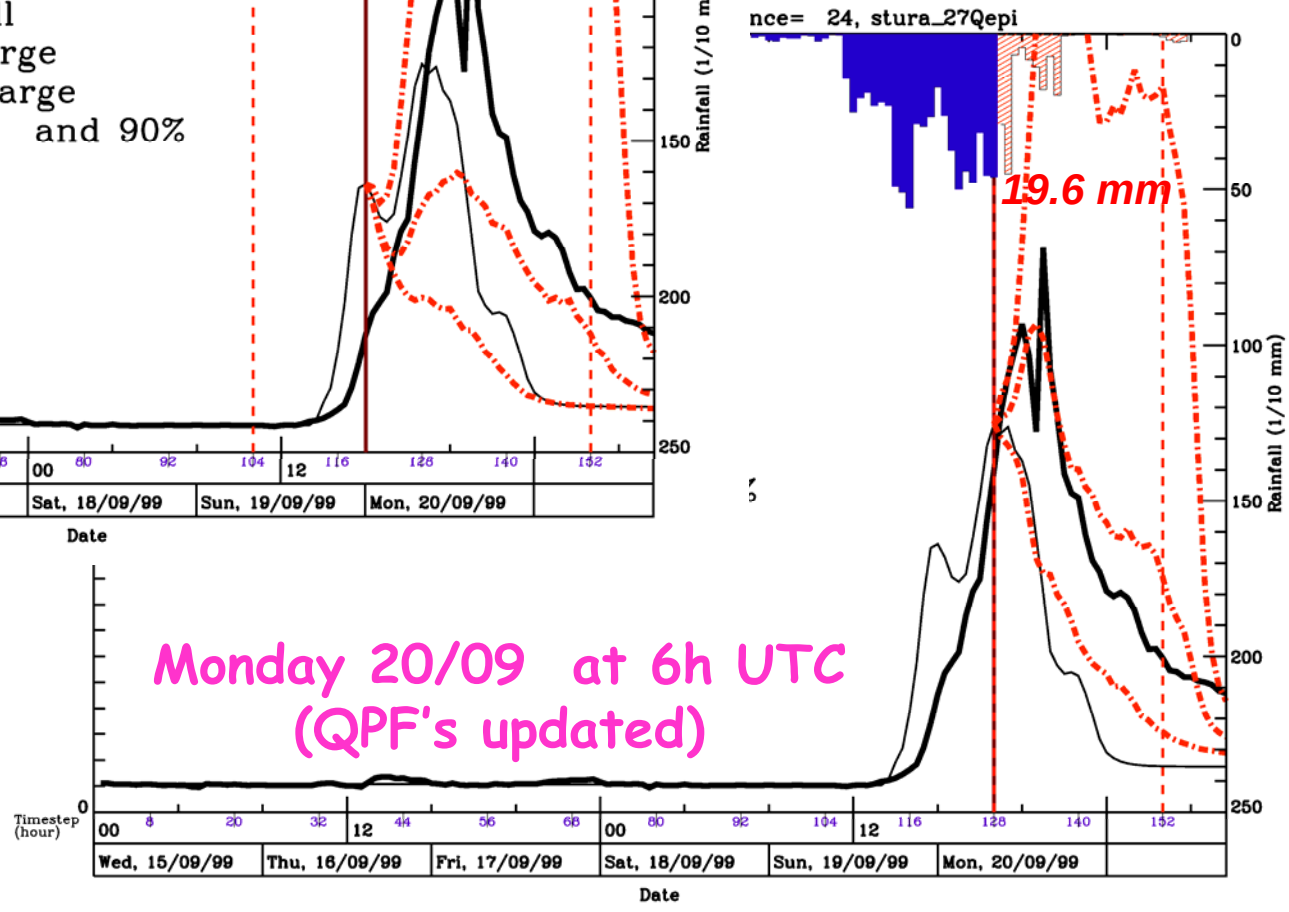
Case study : Sept 1999 (Stura basin)



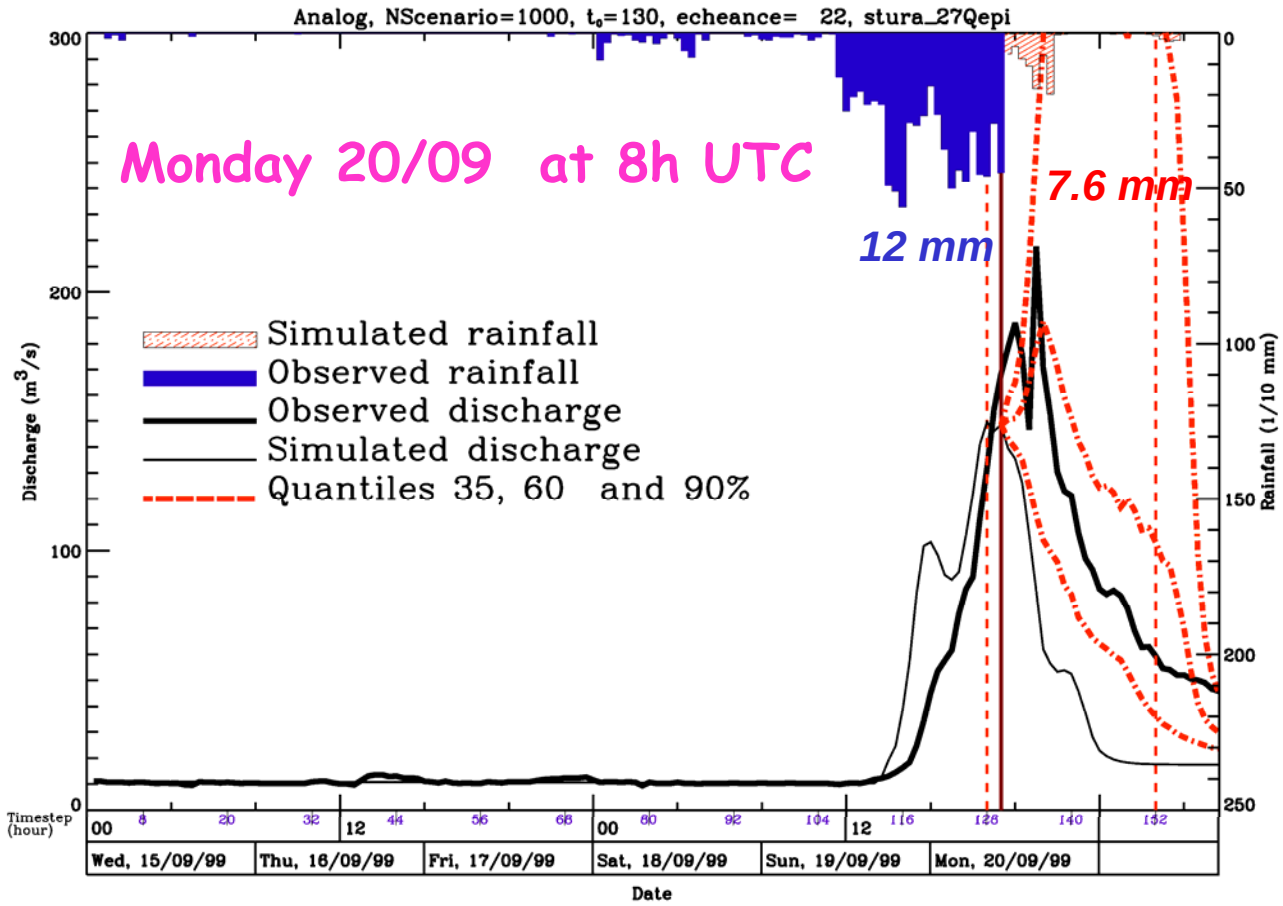


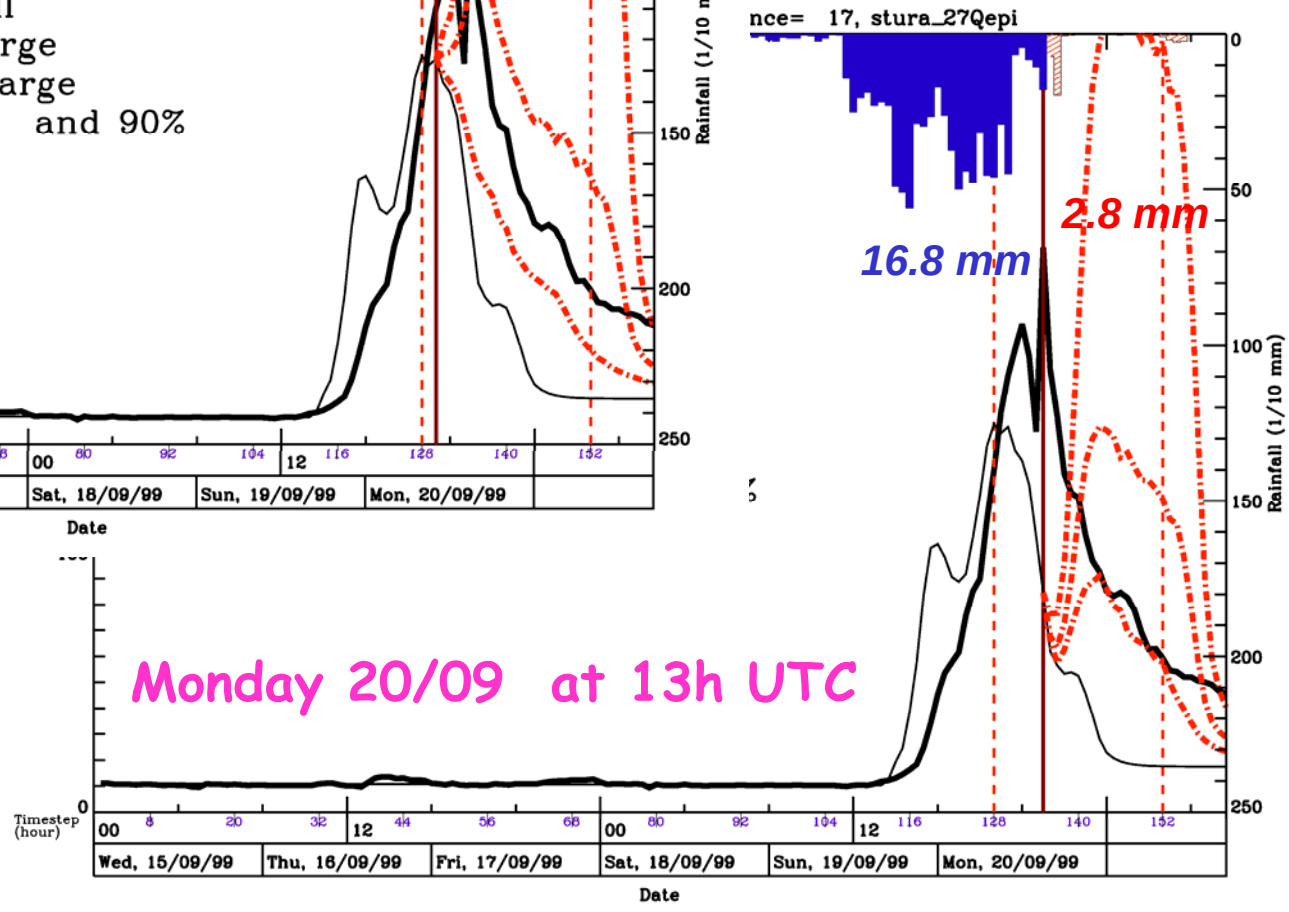
Case study : Sept 1999 (Stura basin)





Case study : Sept 1999 (Stura basin)





Contents

Conclusions 1 / 3

❶ ANALOG approach :

- great potential (non fully exploited yet)
  to adapt NWP model outputs into PQPF's
  at basin scale (~ 500 km²)

- humidity variables : not fully explored
  limitations in resolution with NCEP/NCAR

- move to ERA 40 reanalyses
- attempts to get to 12 h forecasts
  (see if possible to disaggregate the daily precipitation archive at 12 h time steps from the ERA- 40 ?)

Conclusions 2 / 3

❷ Use of a long archive (5yr) of deterministic and EPS forecast :

Real time aspects :

increase the number of analogs with the leadtime

humidity variables : only useful 2 or 3 days ahead

Use of EPS forecasts :

essentially worth at long leadtimes (> 3 or 4 days)

+ minor improvements to be expected

(larger for strong events)

Conclusions 3 / 3

❸ Integrated forecasting chain :

(capable of assimilating meteorological forecasts at time-steps ΔMt)

disaggregation of these PQPF's at time-steps ΔMt

into rainfall scenarios at hydrological at time-steps ΔHt

+ management of the meteorological forecast updating

Case study simulating the real-time operation

(running on the Stura catchment)

Thank you for your attention