Environnement Canada Environment Canada

Canada

Ensemble forecasting at the Canadian Meteorological Centre

Normand Gagnon and Bertrand Denis
Canadian Meteorological Centre, development division,
Meteorological Service of Canada, Environment Canada
Dorval, Québec

MSC Ensemble prediction team

- **Pieter Houtekamer, Martin Charron and Herschel Mitchell,**

  Meteorological Research Division, Dorval

- **Xing-Xiu Deng, Gérard Pellerin, Stéphane Beauregard, Jacques Hodgson and Lewis Poulin,**

  Canadian Meteorological Centre, Dorval

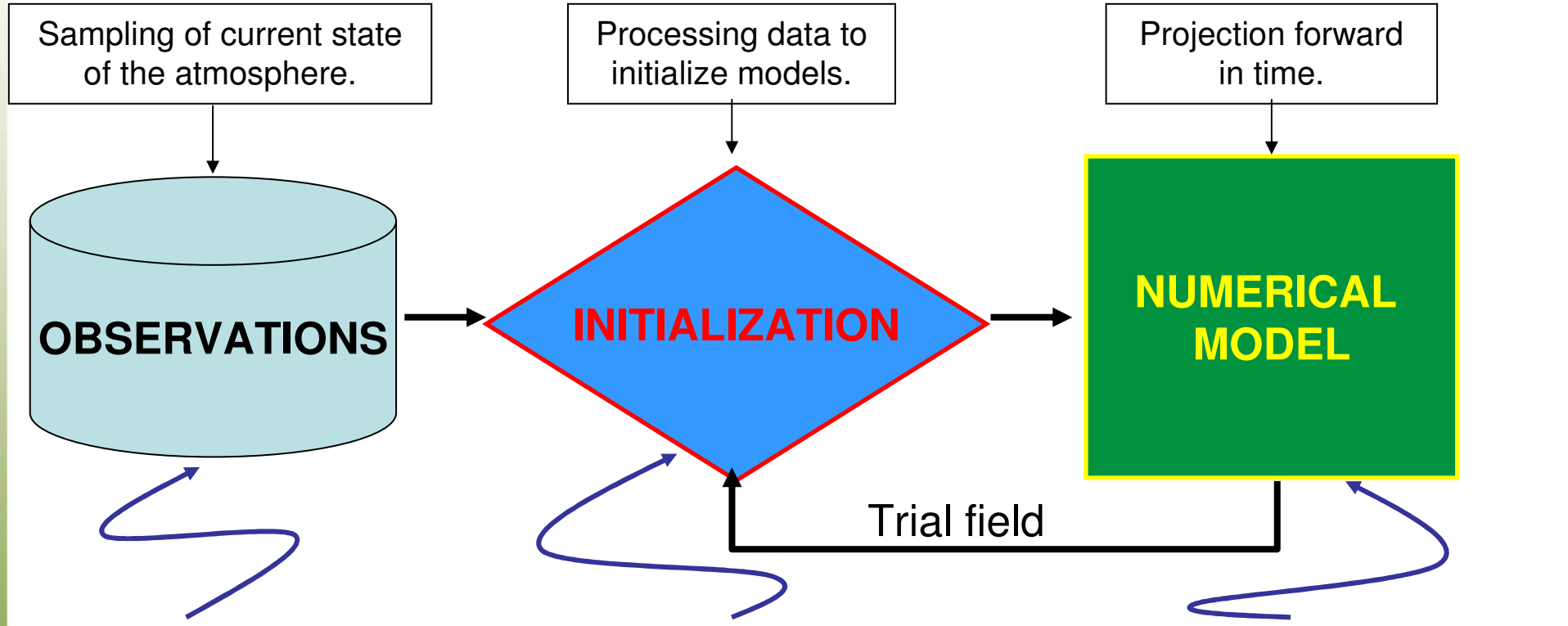
- **Ronald Frenette,**

  Laboratoire national des conditions menaçantes, Montréal

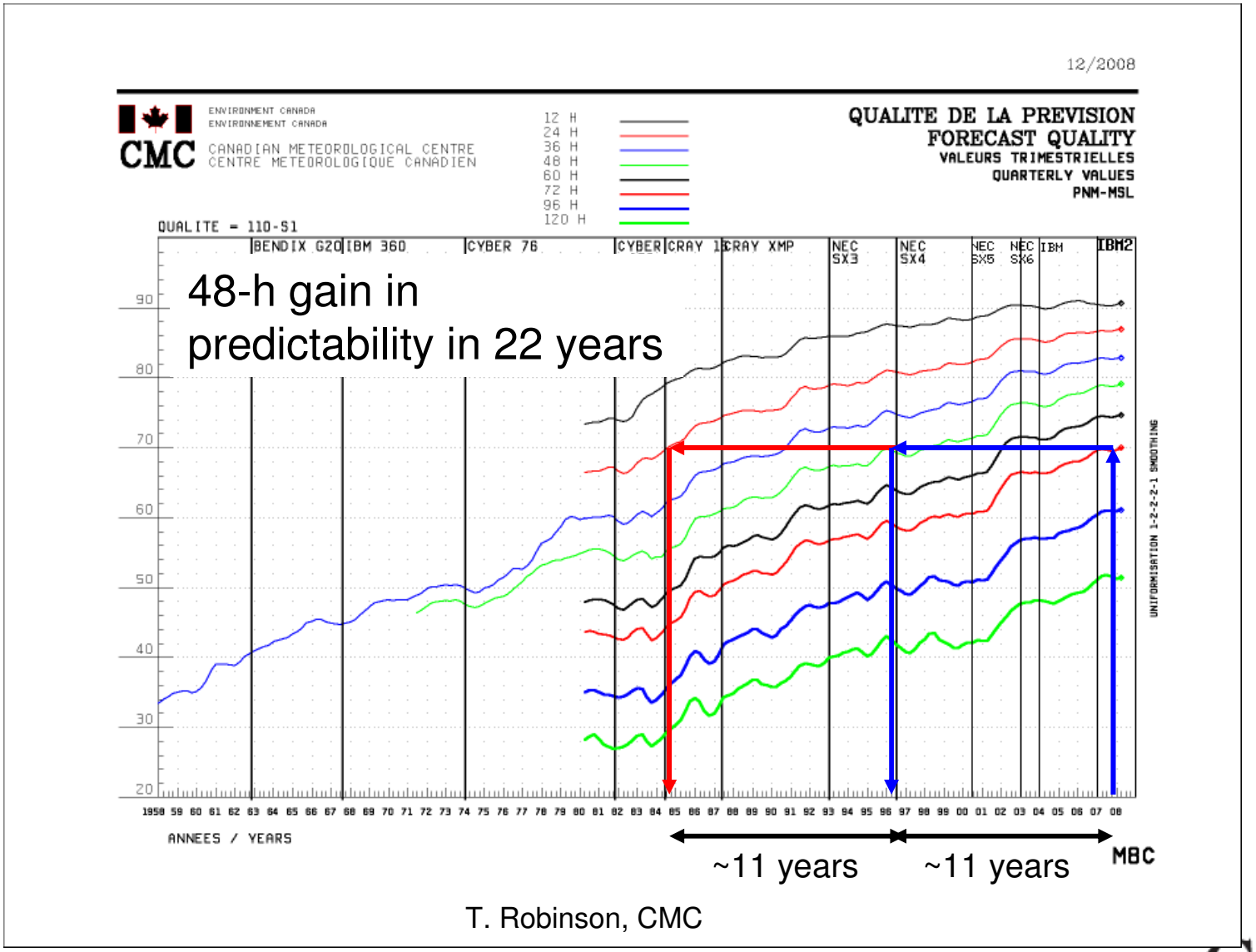
Outline

- *Why ?* Weather forecasting and uncertainty
- *What ?* MSC ensemble prediction system
  - Global (up to 16 days)
- *What else ?*
  - Regional (up to 3 days) *EXPERIMENTAL!*
  - Seasonal (up to 120 days) *NOT DISCUSSED TODAY*
  - NAEFS
- *What we offer?* Products and digital data
- *So ?* Summary

Principles of Numerical Weather Prediction

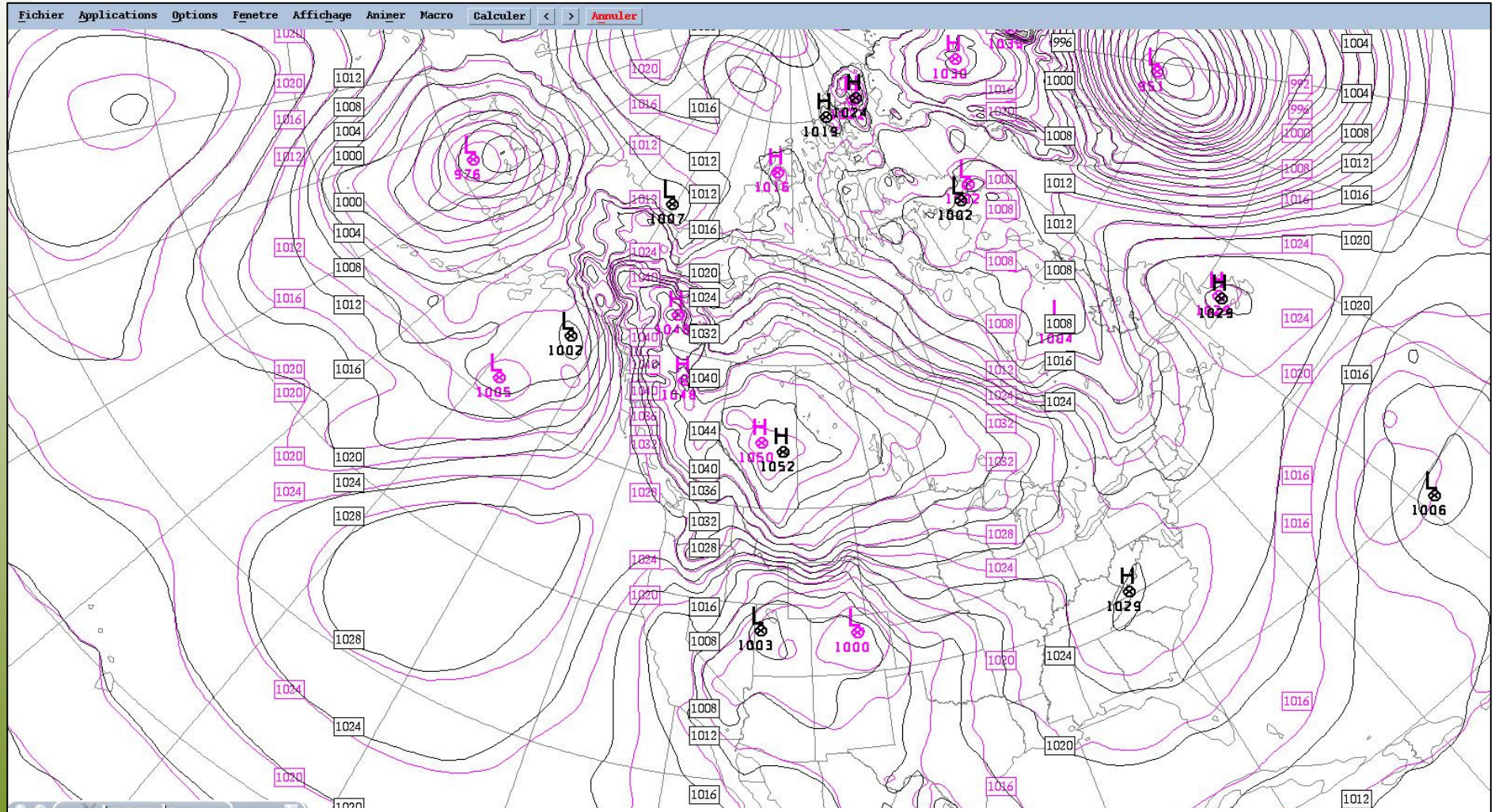


Models are improving!



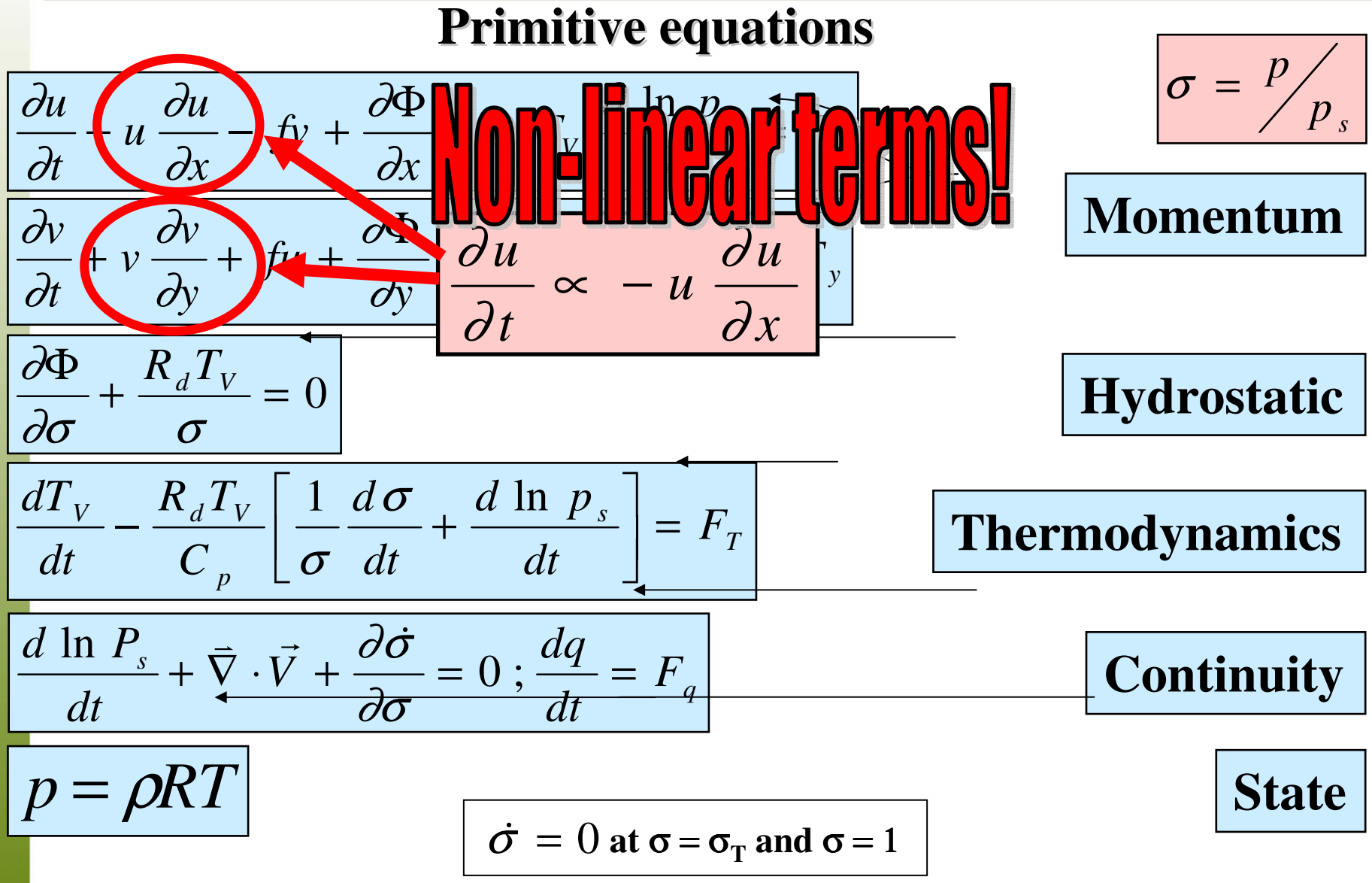
T. Robinson, CMC

But still one big problem: chaos

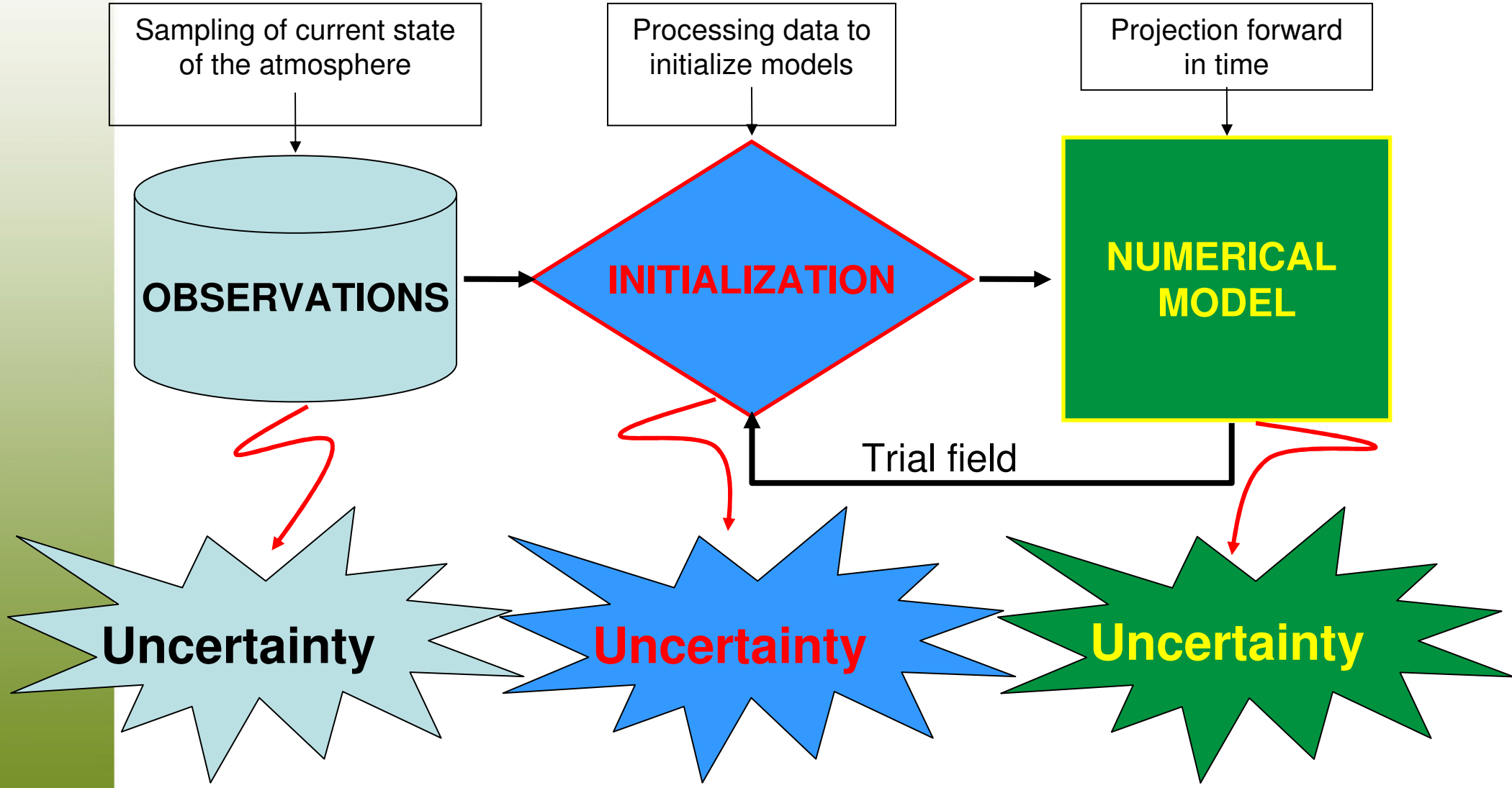


120-h integration – mean sea level pressure
Two integrations done with identical NWP models but on different computers

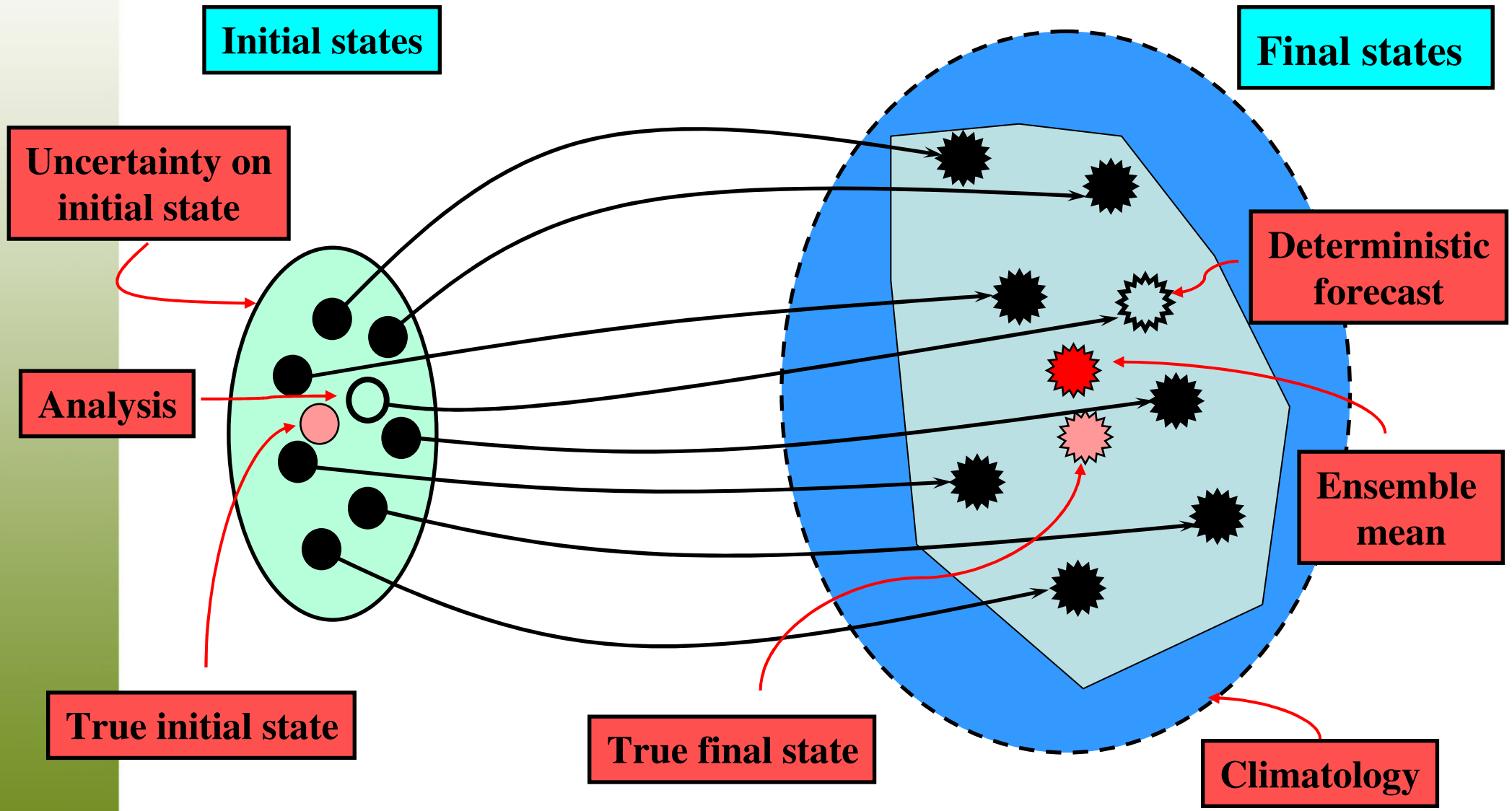
Principles of NWP – modeling



Sources of error create uncertainties in initial conditions and then in forecasts

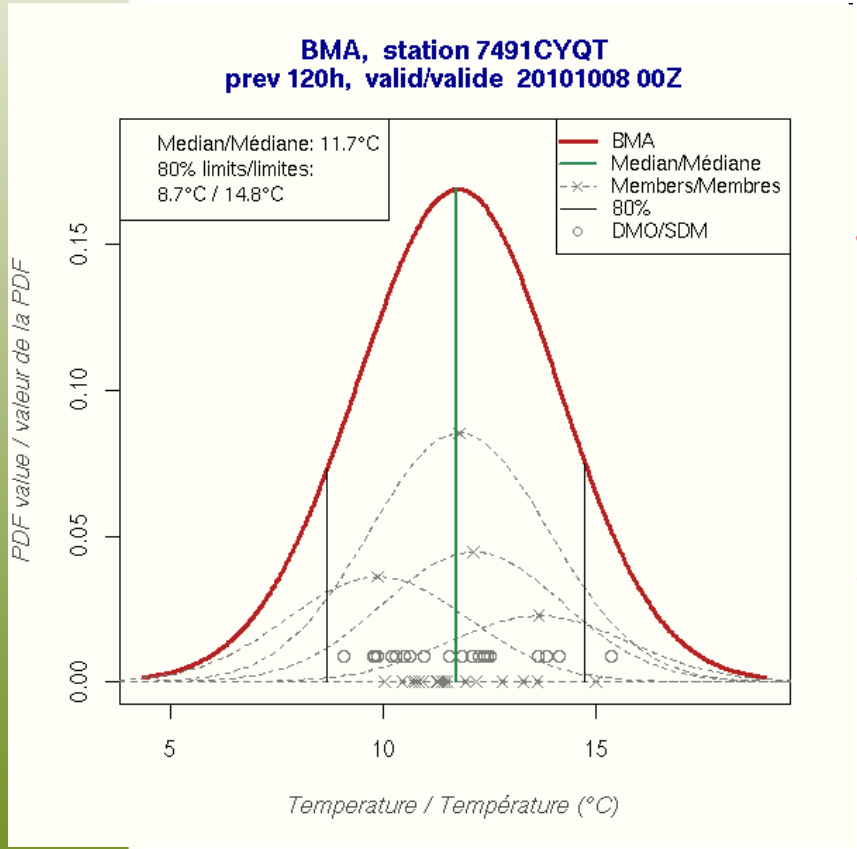


Then comes… Ensemble forecasting



R. Verret, N. Gagnon, CMC

Atmospheric Ensemble forecasting basics



- An Ensemble Prediction System is a set of integrations of one or several NWP models that differ in their initial states (and sometimes in their configurations and boundary conditions).
- Ensemble prediction is an attempt to estimate the non-linear time evolution of the forecast error probability distribution function.
- With Ensemble forecast, it is possible to evaluate, express and forecast uncertainty.

Context

- Ensemble forecasts have evolved significantly over the past years:
  - Systematic approach to model uncertainty.
  - Perturbations as simulation of uncertainty.
  - Better simulation of uncertainties in forecast processes.
  - Increasing number of members.
  - Increasing resolution of members.

Context

- Common usages of Ensemble forecasts:
  - Ensemble mean as a substitute for a single deterministic forecast.
  - Clustering to produce a small set of forecast states characterized with the cluster mean.
  - ***A priori*** **prediction of forecast skill.**
  - **Ensemble probability distribution function.**
  - **Measure of uncertainty.**
  - **Extension of forecast range.**

Sources of error – uncertainties

- Initial conditions related uncertainty:
  - Measurement errors inherent to the instruments.
  - Improperly calibrated instruments.
    - Systematic errors – bias.
    - Random errors.
  - Incorrect registration of observations.
  - Data coding errors.
  - Data transmission errors.
  - Lack of coverage – incomplete information.
  - Representativeness error:
    - Ideally an observing system should provide information on all model variables, at each initial time, representative at the model scale and on the model grid.
    - Model unresolved scales are sampled by observations.

Sources of error – uncertainties

- Initial conditions related uncertainty:
  - Data assimilation errors:
    - Imperfect data quality control.
    - Deficiencies in trial fields – the trial fields are usually 6-h model forecasts.
    - Unrepresentative observations and model error statistics.
    - Deficiencies in the data assimilation scheme.

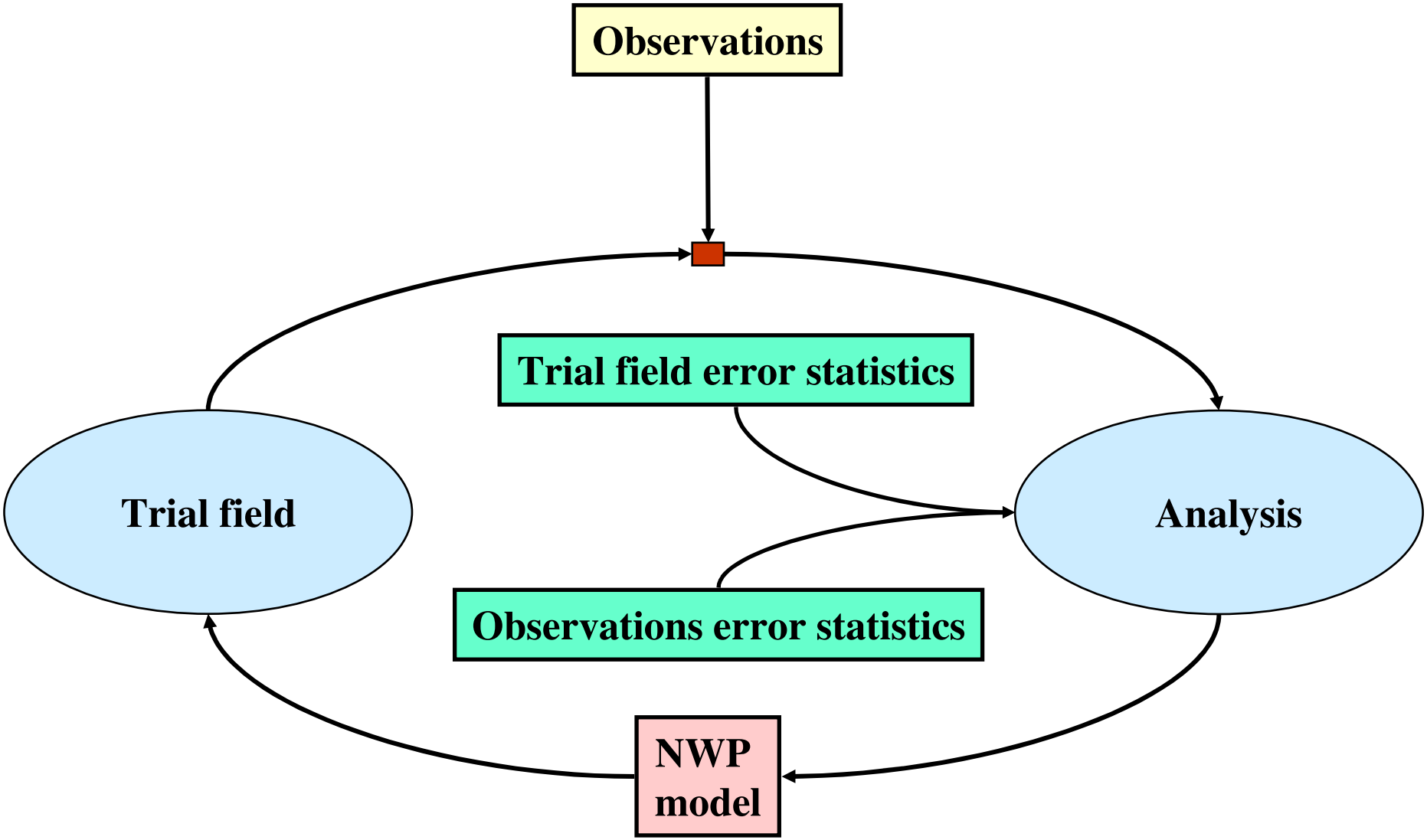
Sources of error – uncertainties

- Model related uncertainty:
  - Space and time truncation – lack of resolution.
  - Effects of unresolved processes.
  - Dynamics formulation.
  - Physics parameterization.
  - Closure assumptions.
  - Approximations due to numerics.
  - Lack of full understanding of Physics of the atmosphere.
  - Coding errors.
  - Model jumpiness – higher resolution may increase model jumpiness.
- Imperfect boundary conditions:
  - Prescribed fields (ex. Vegetation, type of soil etc.).
  - Analysed fields (ex. Soil moisture, sea surface temperature etc.).

MSC Ensemble Prediction System

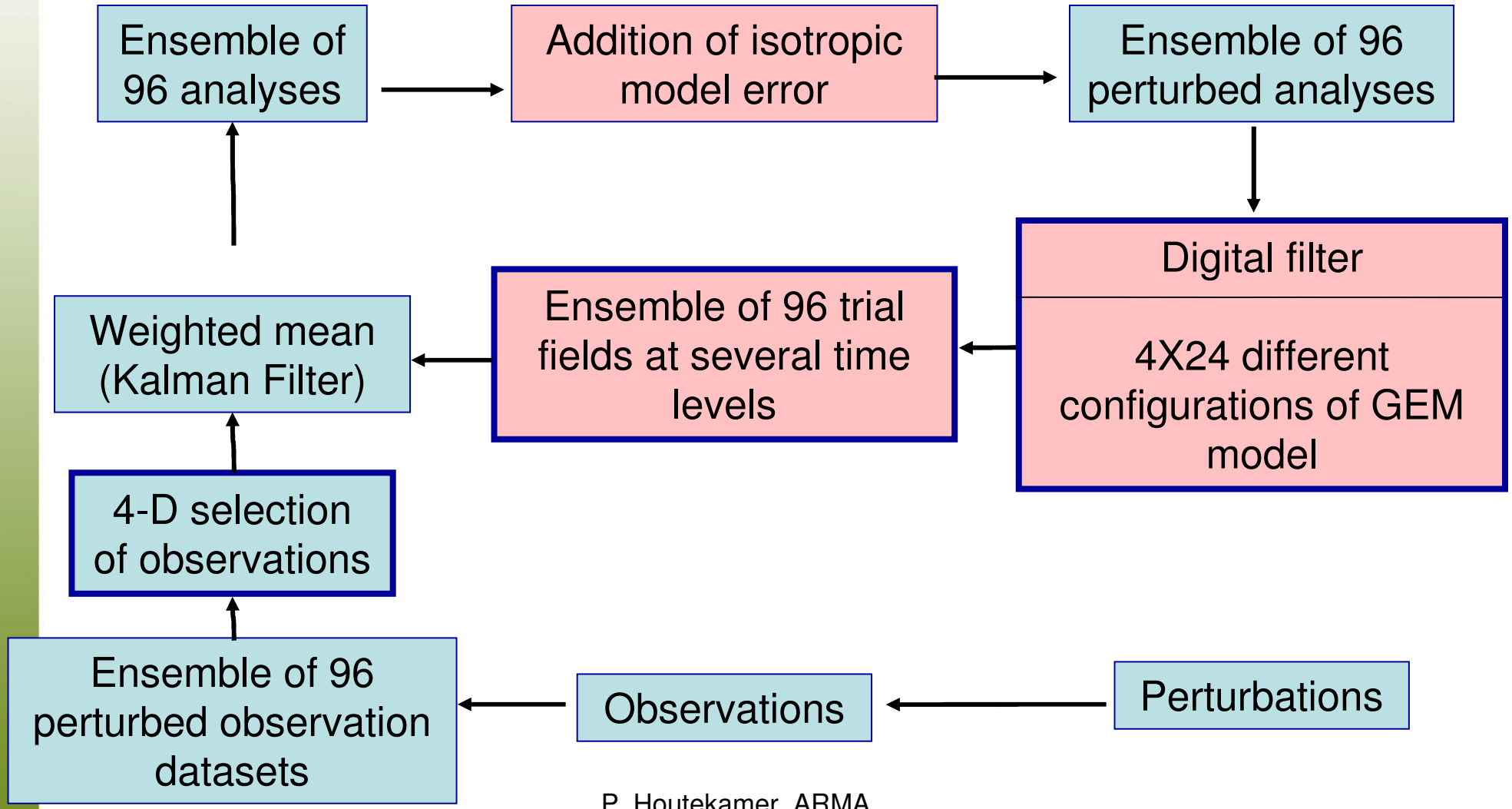
- Members: current – As of May 2010
  - 20+1 members:
  - GEM 0.9° (~100 km resolution) L28 (forecast), L58(analyses).
  - 16-day integration.
  - Twice a day (00 and 12 UTC).
- Simulation of initial condition uncertainties:
  - ensemble Kalman filter data assimilation with perturbed observations.
- Simulation of model uncertainties:
  - A multi-model approach, each member having its own physics parameterization.
  - Stochastic perturbations added to tendencies in the parameterized physical processes.
  - Stochastic kinetic energy back-scattering scheme to re-introduce dissipated energy.

Principles of NWP – data assimilation



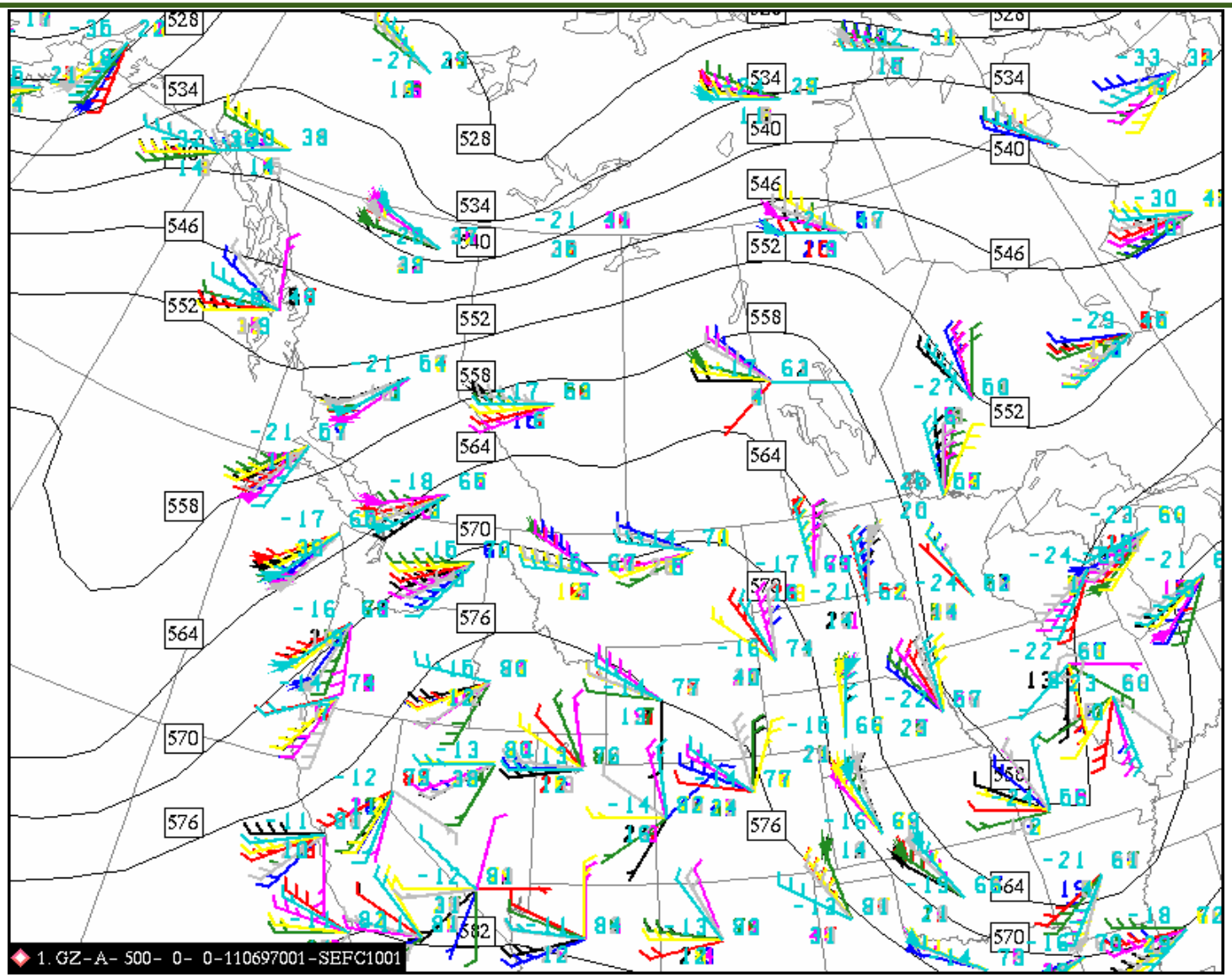
R. Verret, CMC

MSC EPS: Data assimilation component



P. Houtekamer, ARMA

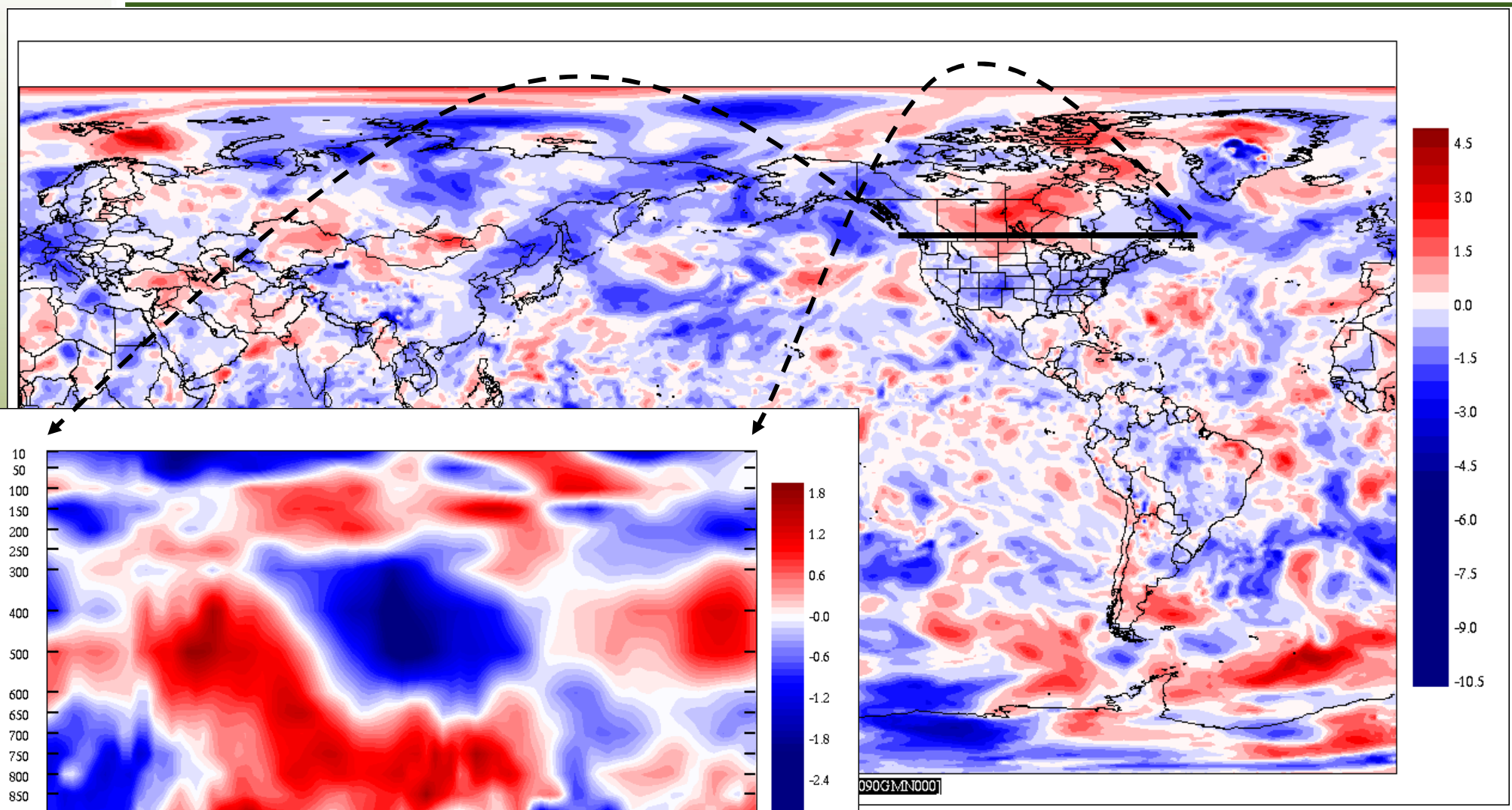
Canadian EPS



L. Lefaivre, CMC

Canadian EPS

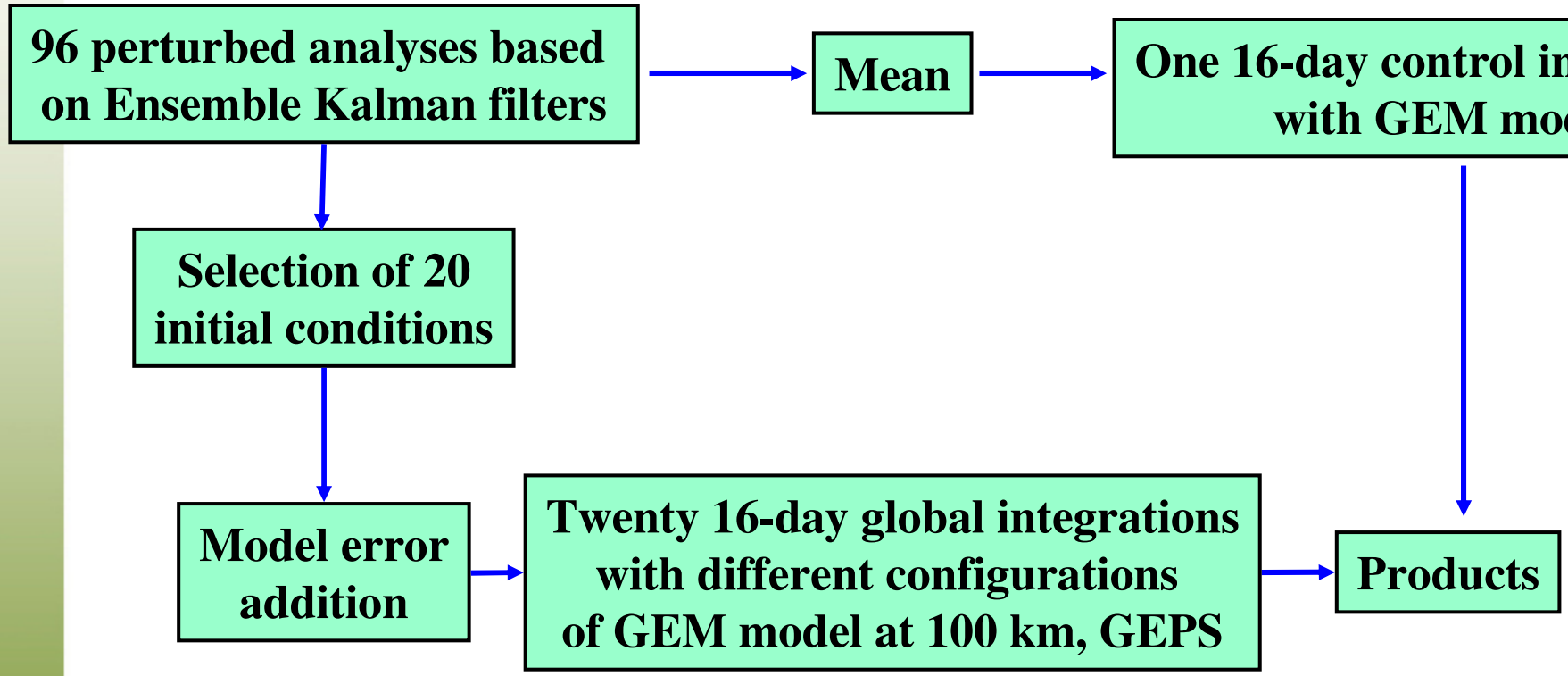
Initial perturbations – member 9 (GEM)
700 hPa temperatures
00 UTC 23-11-2009



N. Gagnon, CMC

Base-line: mean 96 analyses

MSC EPS: forecast component



Integration done twice a day (00 and 12 UTC)

Current parameterizations used in global MSC EPS

#	Deep convection	Land surface scheme	Mixing length	Vertical mixing parameter	GWD	Back-scattering	Stochastic Physics
0	Kain & Fritsch	ISBA	*Bougeault*	1.0	std	No	No
1	Kain & Fritsch	ISBA	*Bougeault*	1.0	Weak	Yes	Yes
2	Oldkuo	ISBA	Blackadar	0.85	Strong	Yes	Yes
3	Relaxed Arakawa Schubert	Force-restore	*Bougeault*	0.85	Weak	Yes	Yes
4	Kuo Symmetric	Force-restore	Blackadar	1.0	Strong	Yes	Yes
5	Oldkuo	Force-restore	*Bougeault*	1.0	Weak	Yes	Yes
6	Kain & Fritsch	Force-restore	Blackadar	0.85	Strong	Yes	Yes
7	Kuo Symmetric	ISBA	*Bougeault*	0.85	Weak	Yes	Yes
8	Relaxed Arakawa Schubert	ISBA	Blackadar	1.0	Strong	Yes	Yes
9	Kain & Fritsch	ISBA	Blackadar	0.85	Weak	Yes	Yes
10	Oldkuo	ISBA	*Bougeault*	1.0	Strong	Yes	Yes
11	Relaxed Arakawa Schubert	Force-restore	Blackadar	1.0	Weak	Yes	Yes
12	Kuo Symmetric	Force-restore	*Bougeault*	0.85	Strong	Yes	Yes
13	Oldkuo	Force-restore	Blackadar	0.85	Weak	Yes	Yes
14	Kain & Fritsch	Force-restore	*Bougeault*	1.0	Strong	Yes	Yes
15	Kuo Symmetric	ISBA	Blackadar	1.0	Weak	Yes	Yes
16	Relaxed Arakawa Schubert	ISBA	*Bougeault*	0.85	Strong	Yes	Yes
17	Kuo Symmetric	Force-restore	*Bougeault*	1.0	Weak	Yes	Yes
18	Kain & Fritsch	ISBA	Blackadar	0.85	Strong	Yes	Yes
19	Oldkuo	ISBA	*Bougeault*	0.85	Weak	Yes	Yes
20	Relaxed Arakawa Schubert	Force-restore	Blackadar	1.0	Strong	Yes	Yes

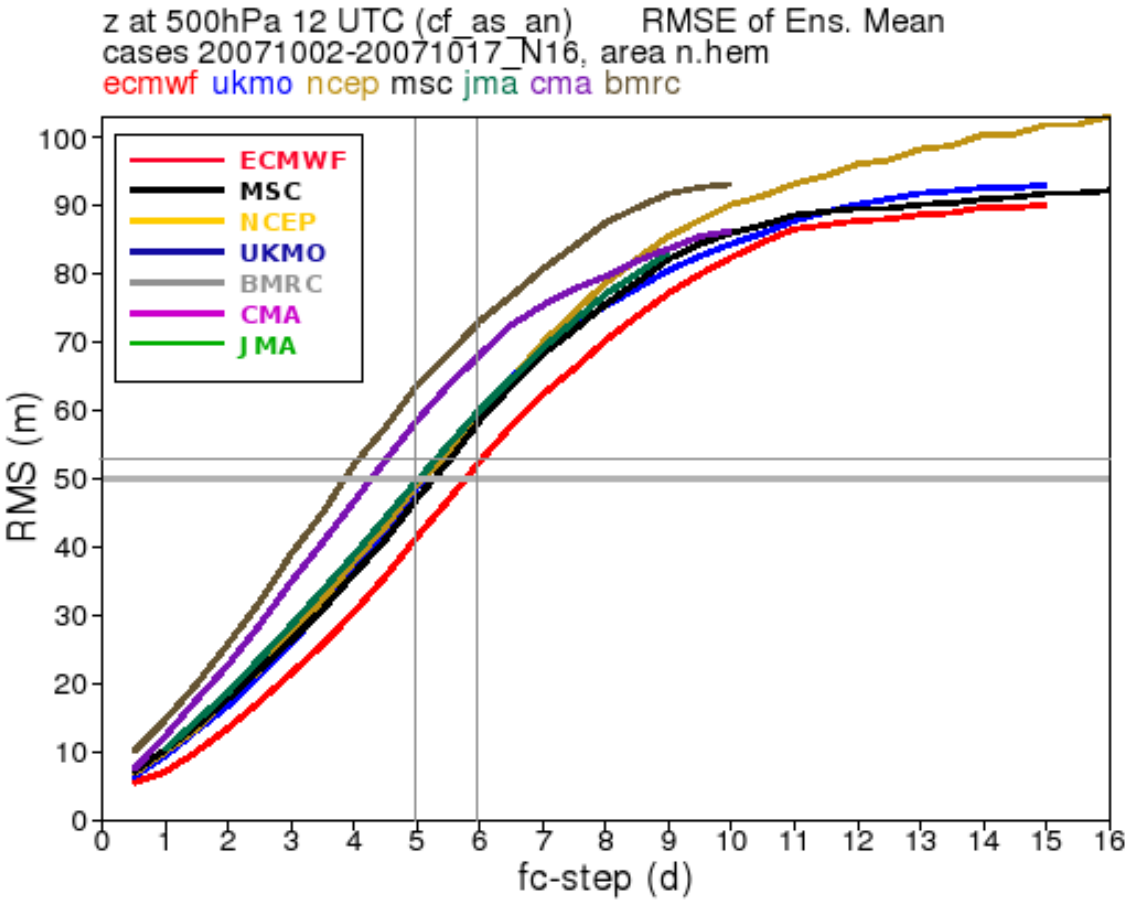
From P. Houtekamer, ARMA

500 hPa (5 km) heights intercomparison

1.3 O07 (16c): EC/MSC/NCEP/UK/BMRC/CMA/JMA EM

Most recent TIGGE results: this figure shows the O07 average RMSE of the ensemble-mean fc for Z500 over NH. The EC ensemble-mean outperforms the group of 2nd best ensembles (MSC, UKMO and JMA for this period) for the whole fc range, with ~0.6d gain in predictability at t+5d.

This indicates that the differences in skill of the ensemble probabilistic forecasts is not only due to model/analysis, but also to the ensemble design (e.g. use of SVs).



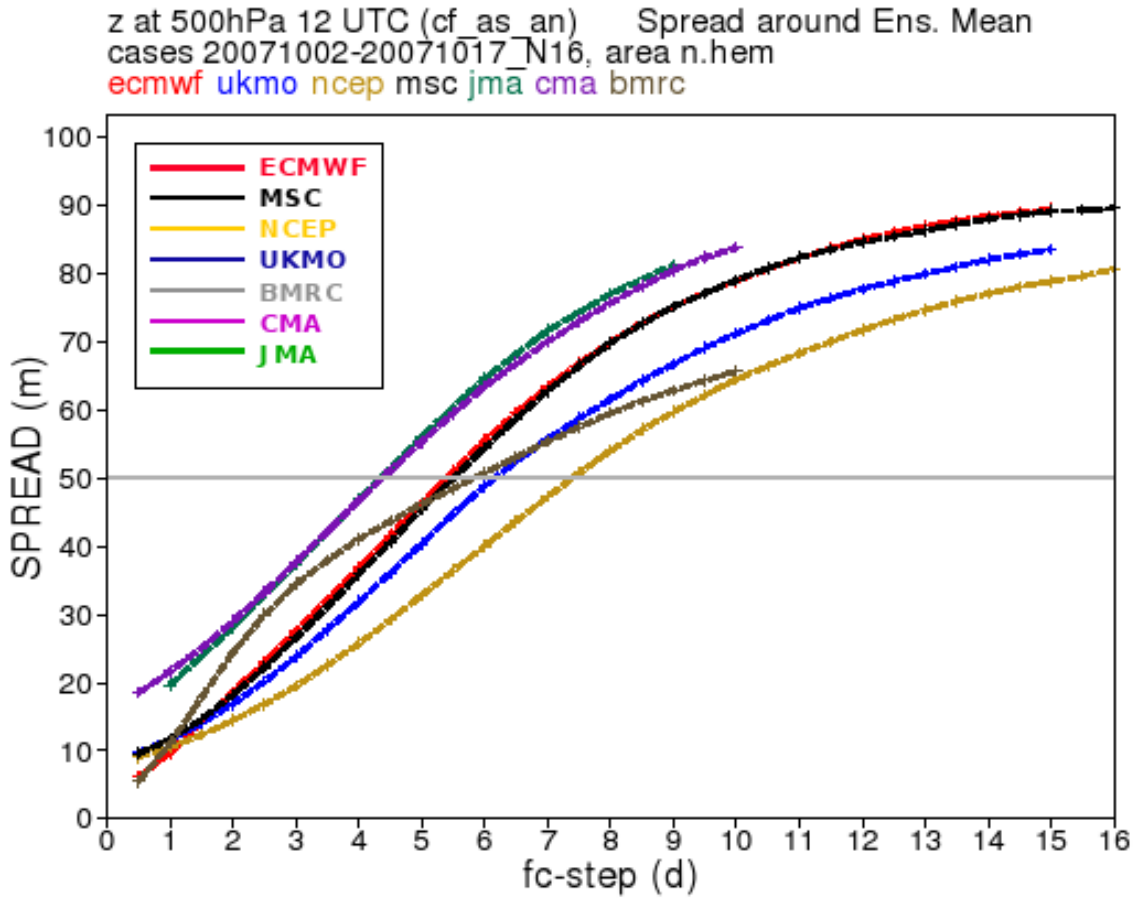
From Roberto Buizza (2007)

500 hPa (5 km) heights intercomparison

1.3 O07 (16c): EC/MSC/NCEP/UK/BMRC/CMA/JMA STD

Most recent TIGGE results: this figure shows the O07 average STD for Z500 over NH.

The EC and MSC ensembles have very similar STD. UKMO and NCEP has a smaller STD, while CMA and JMA have a larger STD.



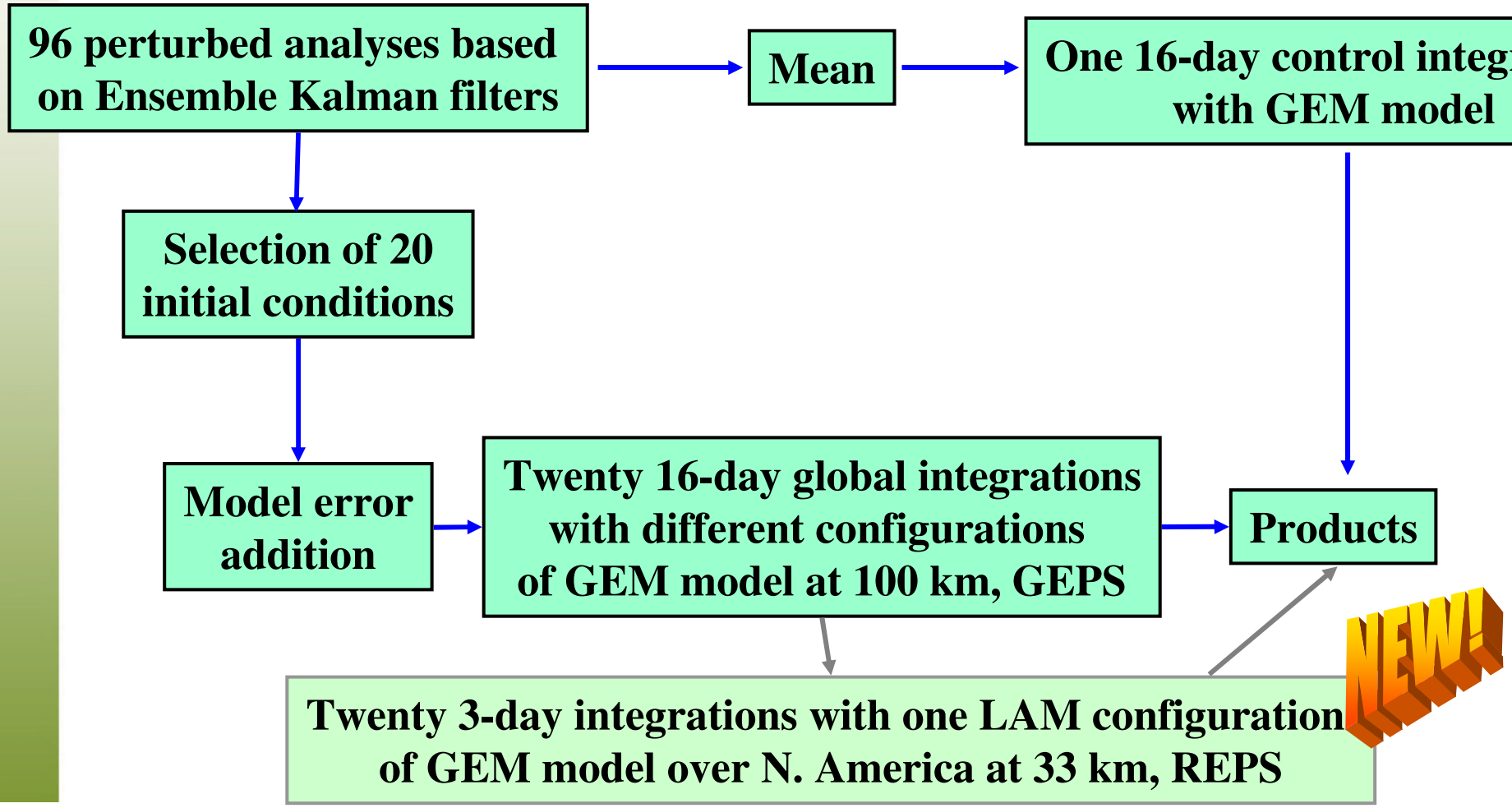
From Roberto Buizza (2007)

What else?

Regional EPS

NAEFS

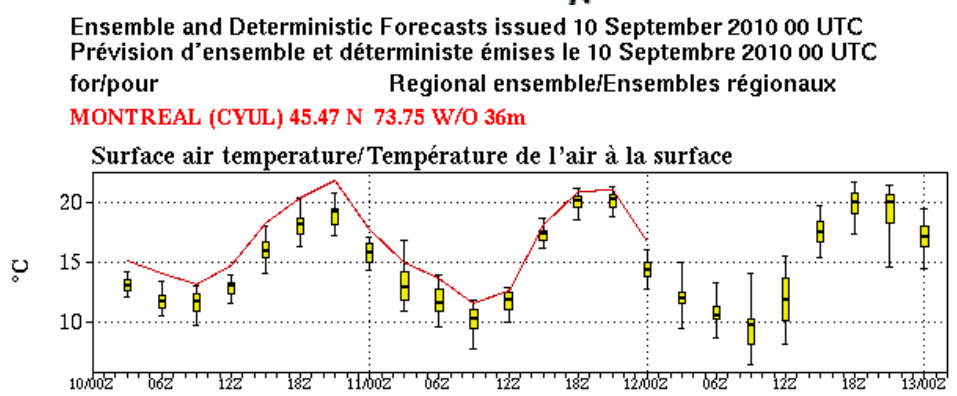
MSC EPS: forecast component

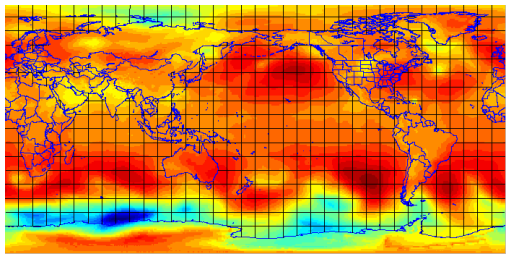


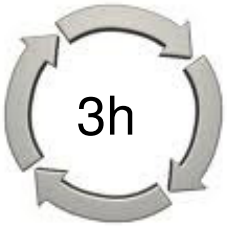
Integration done twice a day (00 and 12 UTC)

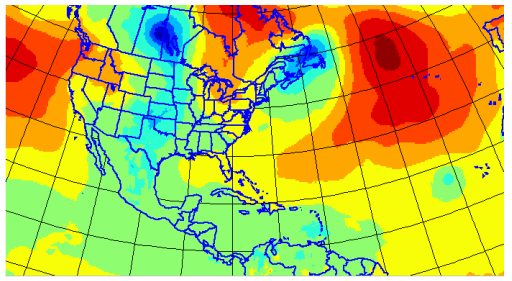
Higher resolution: the Regional EPS

- LAM with resolution of 33 km
- 20 members + 1 control
- Forecast period 72h
- 21 perturbed analysis and 3 h pilots from Global EPS









NAEFS

- Global ensembles:
  - NOAA, MSC, NMS of Mexico: official agreement signed in November 2004.
  - FNMOC (US NAVY) may join NAEFS in 2010.
- Advantages:
  - Larger ensemble allowing better PDF definitions (super-ensemble).
  - Improved probabilistic forecast performance.
  - Seamless suite of forecast products across international boundaries and across different time ranges (1-14 days).
  - Minimal additional costs – levering computational resources.
  - Synergy with NCEP on R&D work.
- Problems:
  - Combination of multi-model ensembles into a super-ensemble.
  - Real time exchange (operational considerations).

NAEFS

- Raw data exchange (00 and 12 UTC runs).
  - ~ 50 selected variables.
  - 6-hourly output frequency over 16 days.
  - GRIB format.
- Basic products:
  - Using same algorithms/codes.
  - Bias correction algorithm.
  - Forecast products in terms of climatological anomalies.
  - Week 2 (days 8 to 14) forecasts based on the combined MSC/NCEP ensembles.

MSC official Forecasts for days 6 and 7

Kitchener-Waterloo

Current Conditions — More info +

Observed at:	**Region of Waterloo Int'l Airport**
Date:	**7:00 AM EDT Wednesday 6 October 2010**
Condition:	**Mostly Cloudy**
Temperature:	**10.0°C**
Pressure:	**101.7 kPa**
Visibility:	**16 km**

10 °C

More for my mother ☺…

Forecast — More info +

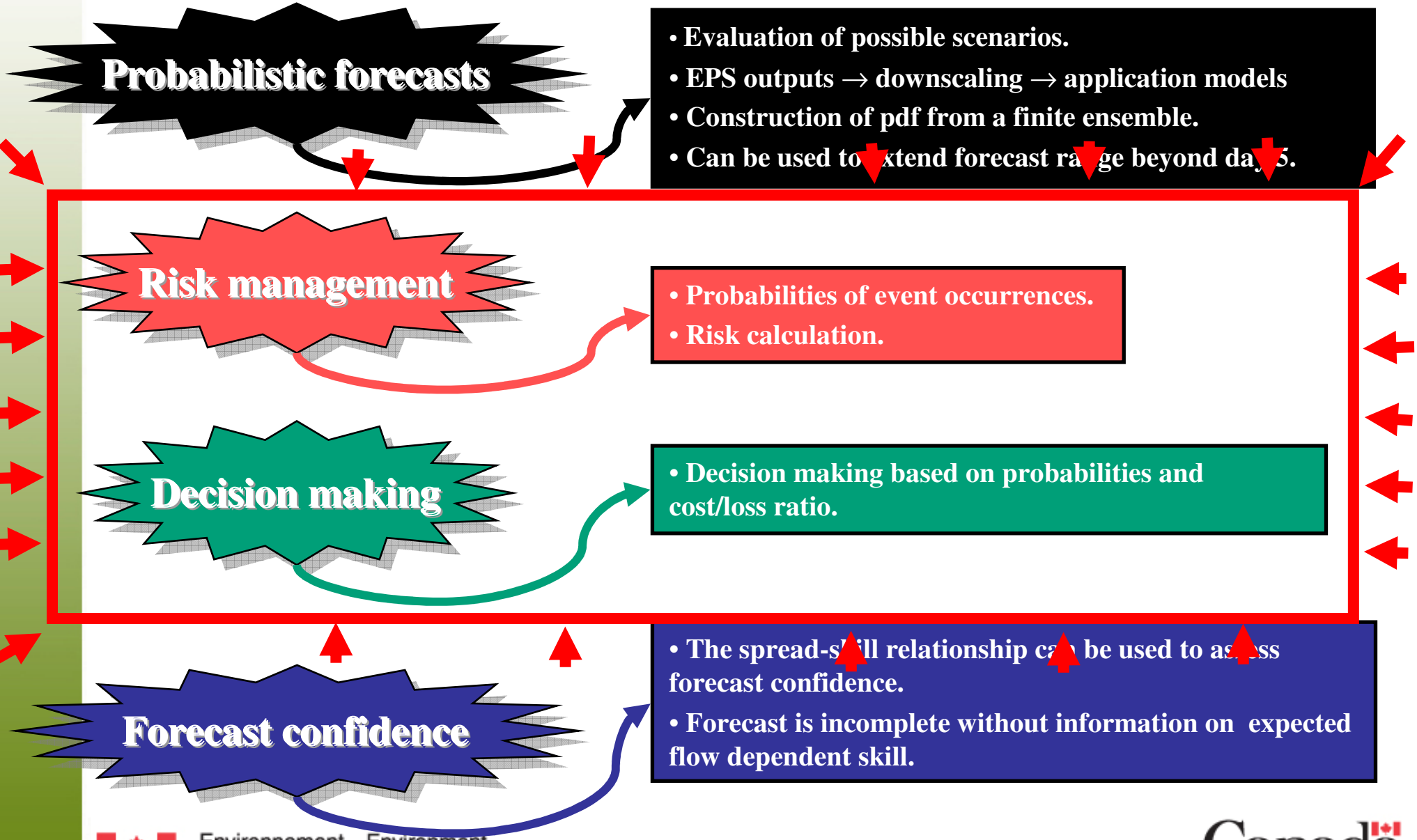
Today	Thu	Fri	Sat	Sun	Mon	Tue
12°C	17°C	18°C	21°C	21°C	17°C	18°C
	4°C	3°C	7°C	9°C	11°C	11°C
40%					30%	

Issued : 5:00 AM EDT Wednesday 6 October 2010

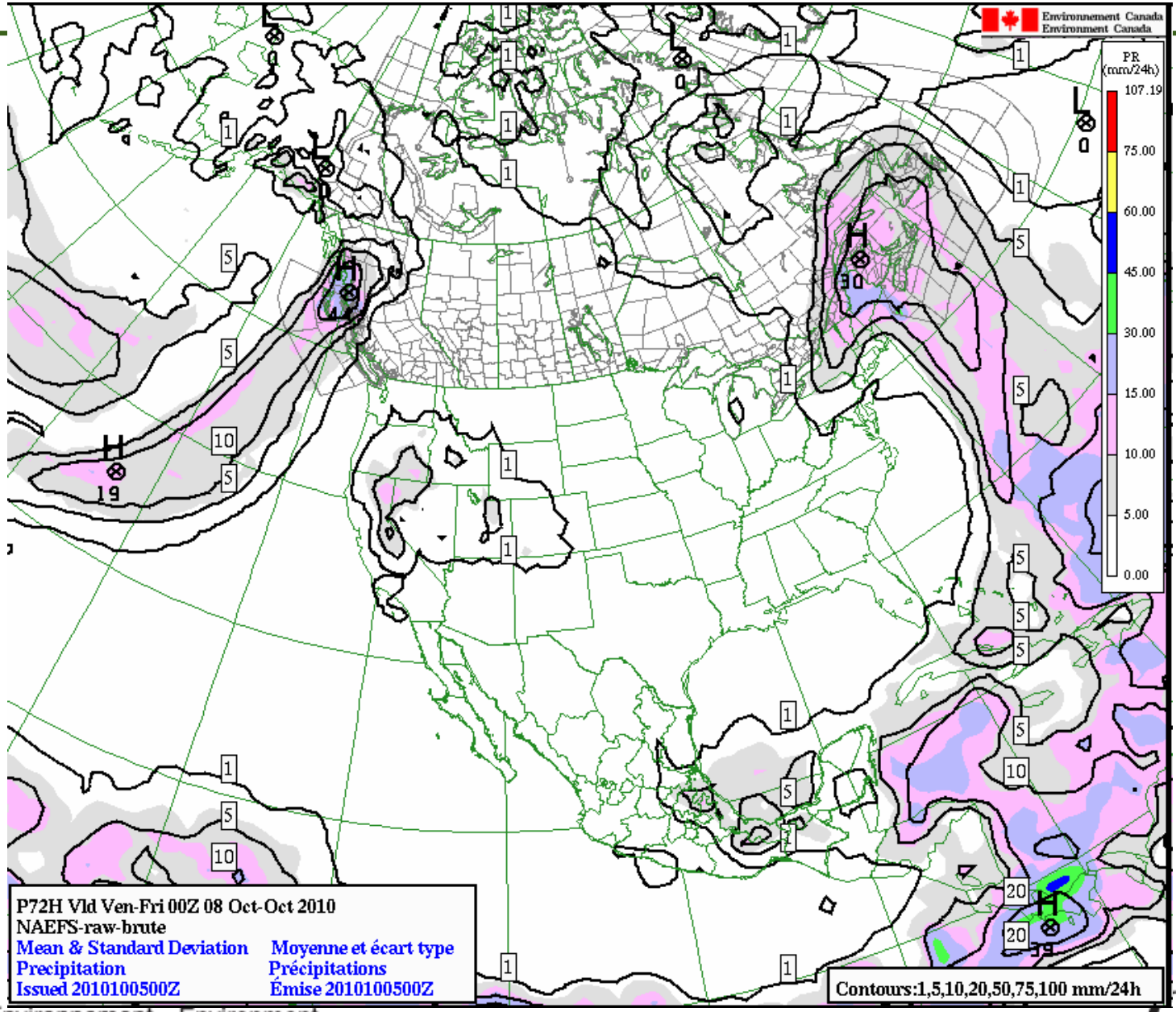
Today	Periods of rain ending early this morning then cloudy with 40 percent chance of showers. High 12.
Tonight	Cloudy with 40 percent chance of showers early this evening. Clearing late this evening. Low plus 4.
Thursday	Sunny. Wind becoming northwest 20 km/h late in the morning. High 17.
Friday	Sunny. Low plus 3. High 18.
Saturday	Sunny. Low 7. High 21.
Sunday	
Monday	A mix of sun and cloud with 30 percent chance of showers. Low 11. High 17.
Tuesday	A mix of sun and cloud. Low 11. High 18.

Produced with EPS forecasts!

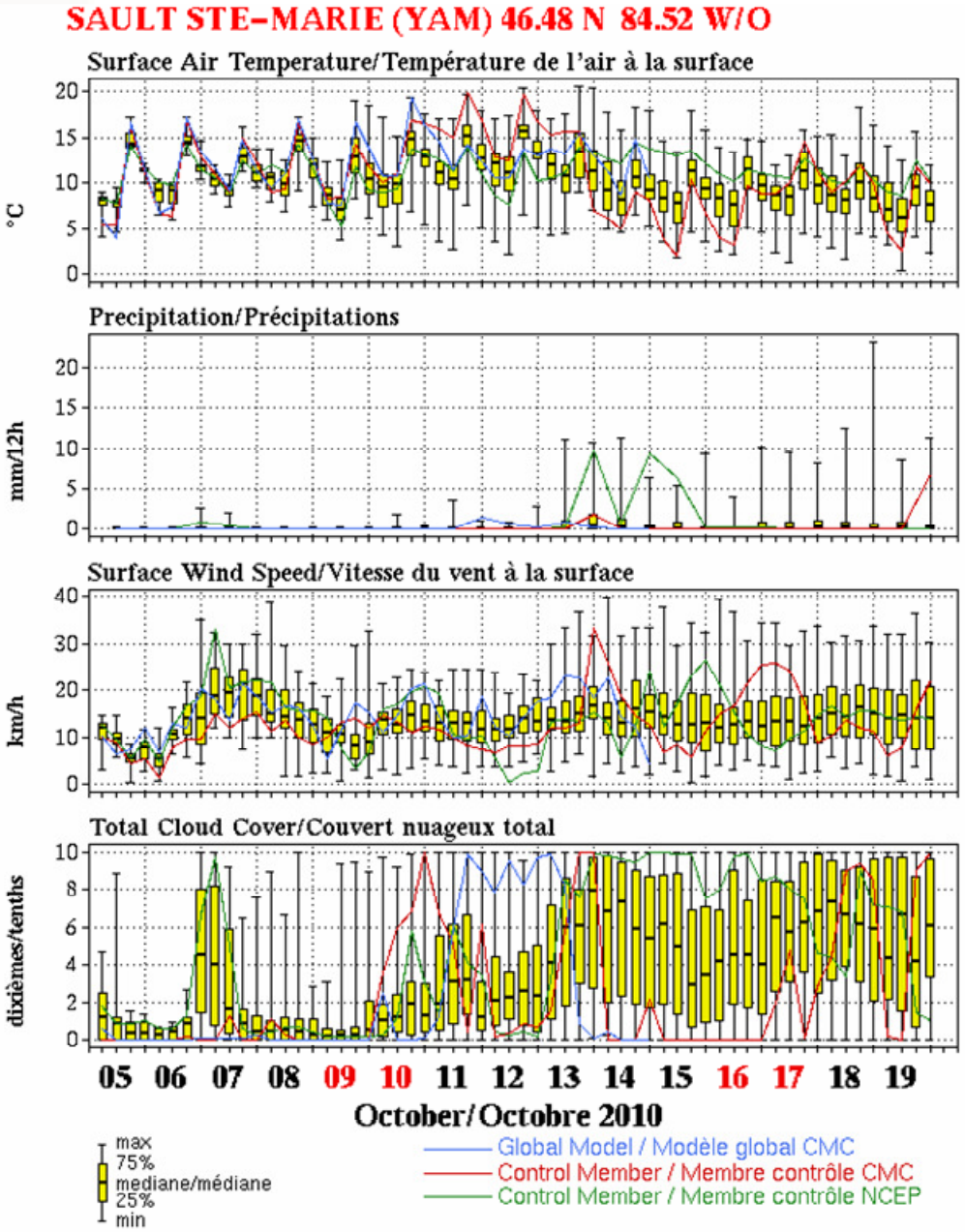
For you, decision makers…

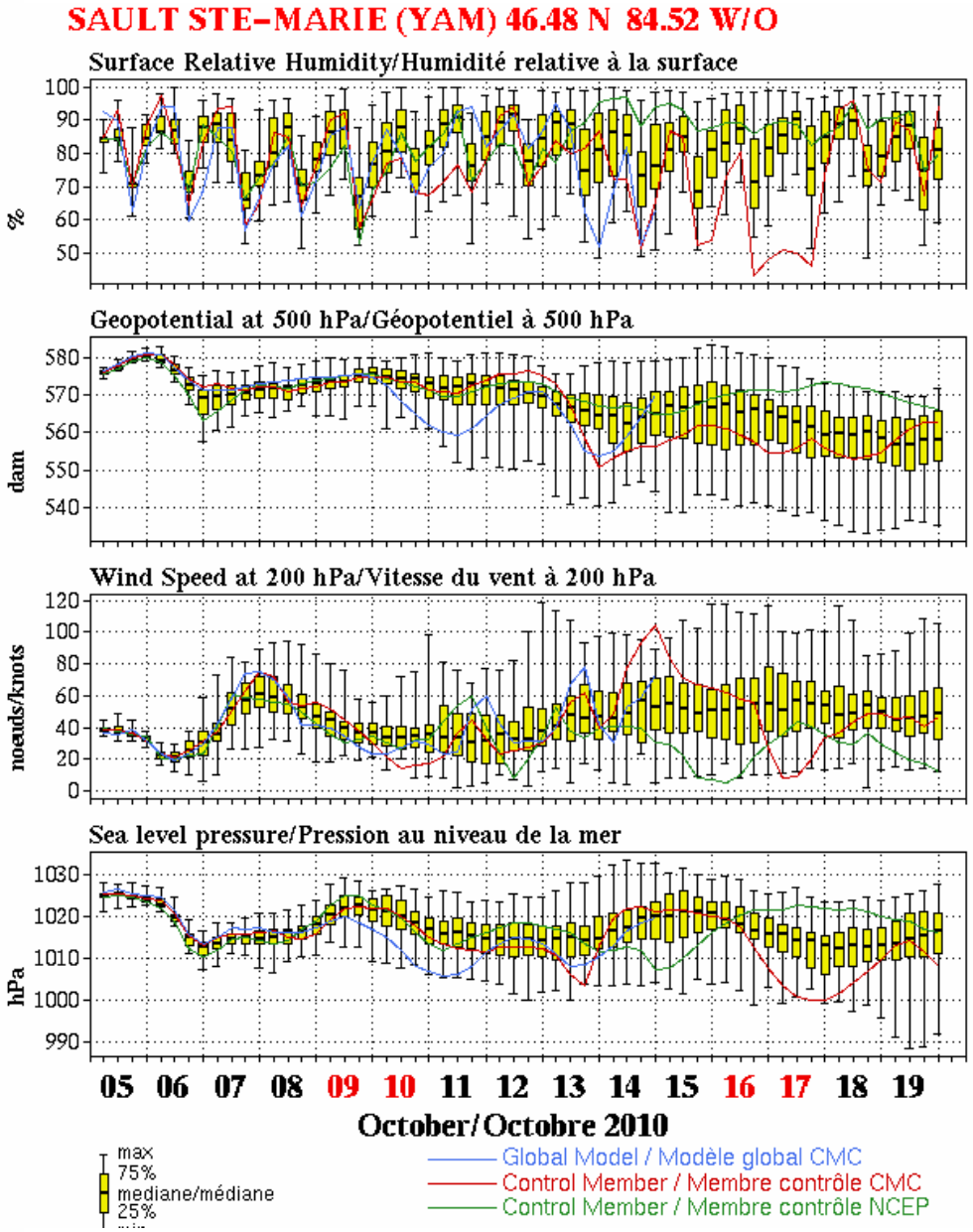


Mean and standard deviation maps



Meteograms

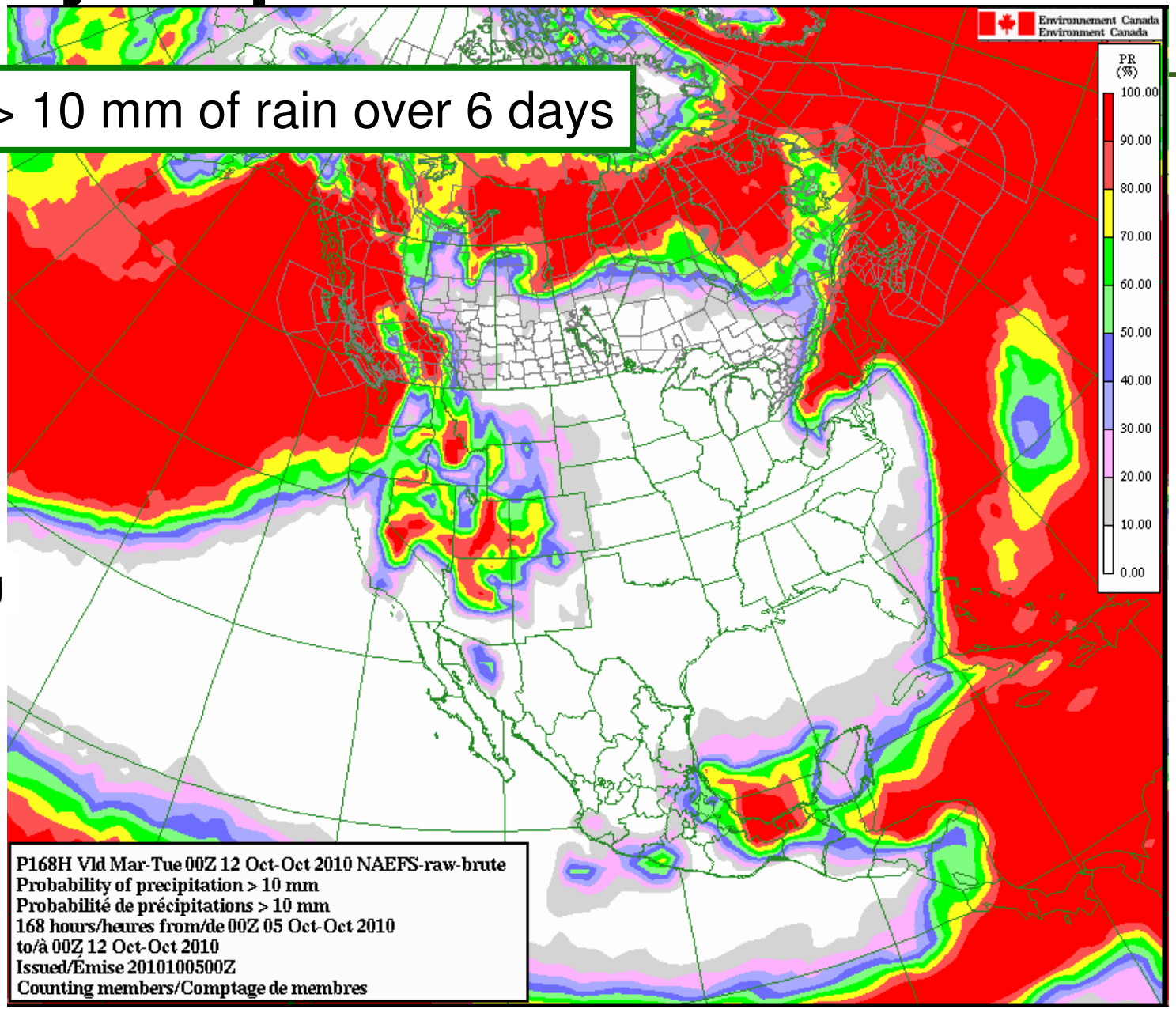

SAULT STE-MARIE (YAM) 46.48 N 84.52 W/O
Surface Air Temperature/Température de l'air à la surface
°C
Precipitation/Précipitations
mm/12h
Surface Wind Speed/Vitesse du vent à la surface
km/h
Total Cloud Cover/Couvert nuageux total
dixièmes/tenths
05 06 07 08 09 10 11 12 13 14 15 16 17 18 19
October/Octobre 2010
max
75%
mediane/médiane
25%
min
Global Model / Modèle global CMC
Control Member / Membre contrôle CMC
Control Member / Membre contrôle NCEP


SAULT STE-MARIE (YAM) 46.48 N 84.52 W/O
Surface Relative Humidity/Humidité relative à la surface
%
Geopotential at 500 hPa/Géopotentiel à 500 hPa
dam
Wind Speed at 200 hPa/Vitesse du vent à 200 hPa
noeuds/knots
Sea level pressure/Pression au niveau de la mer
hPa
05 06 07 08 09 10 11 12 13 14 15 16 17 18 19
October/Octobre 2010
max
75%
mediane/médiane
25%
Global Model / Modèle global CMC
Control Member / Membre contrôle CMC
Control Member / Membre contrôle NCEP

Probability maps

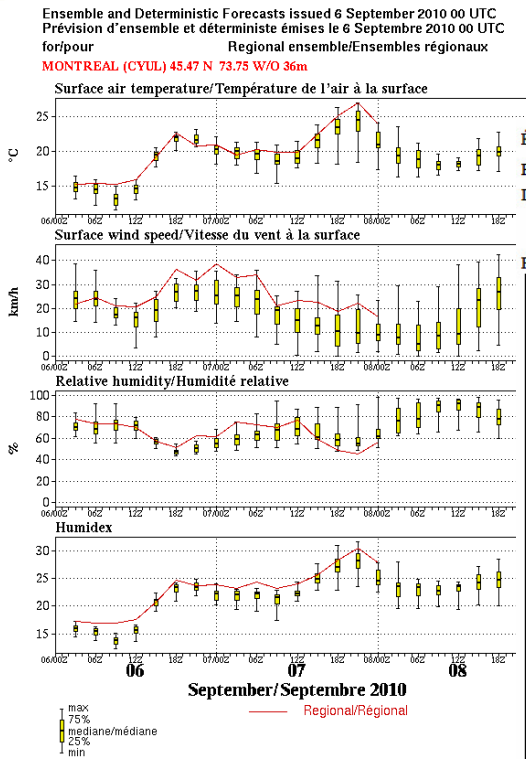
% of getting > 10 mm of rain over 6 days

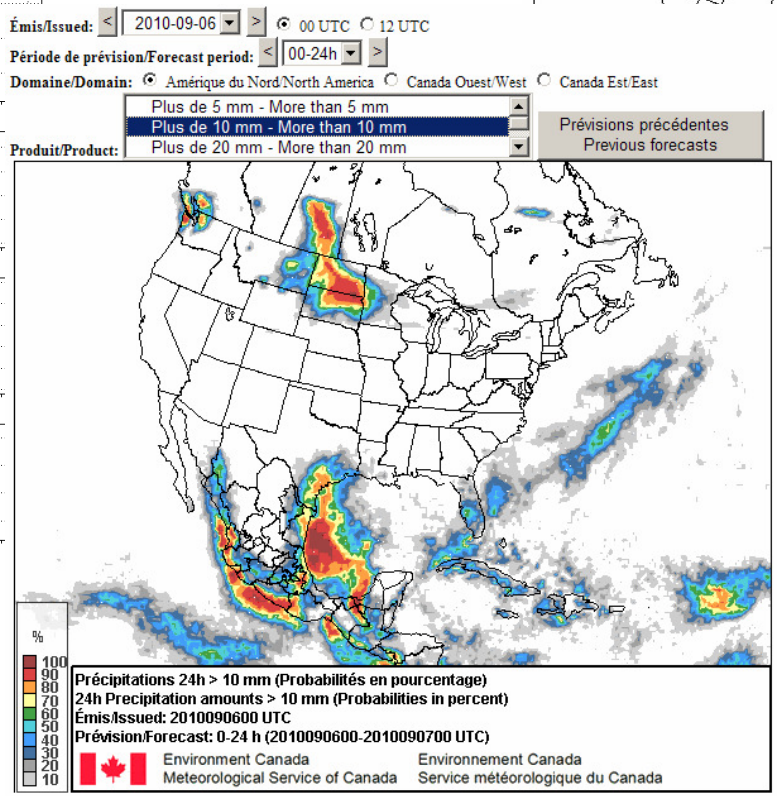
Done by member counting

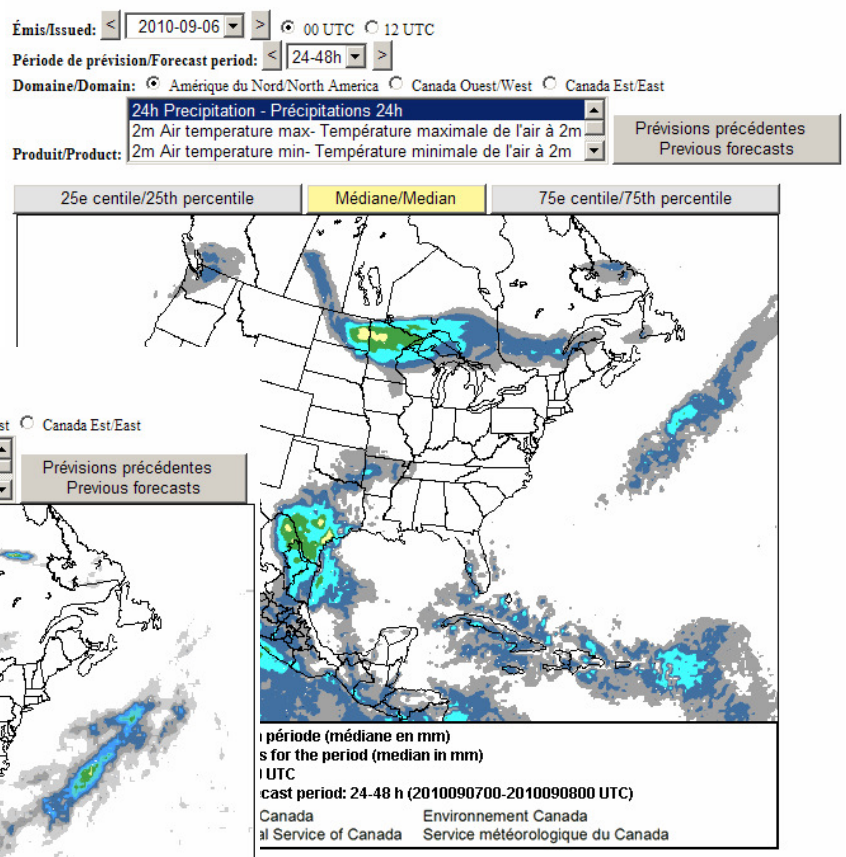


Running system in real time

- Forecasting tools for
- meteorologists

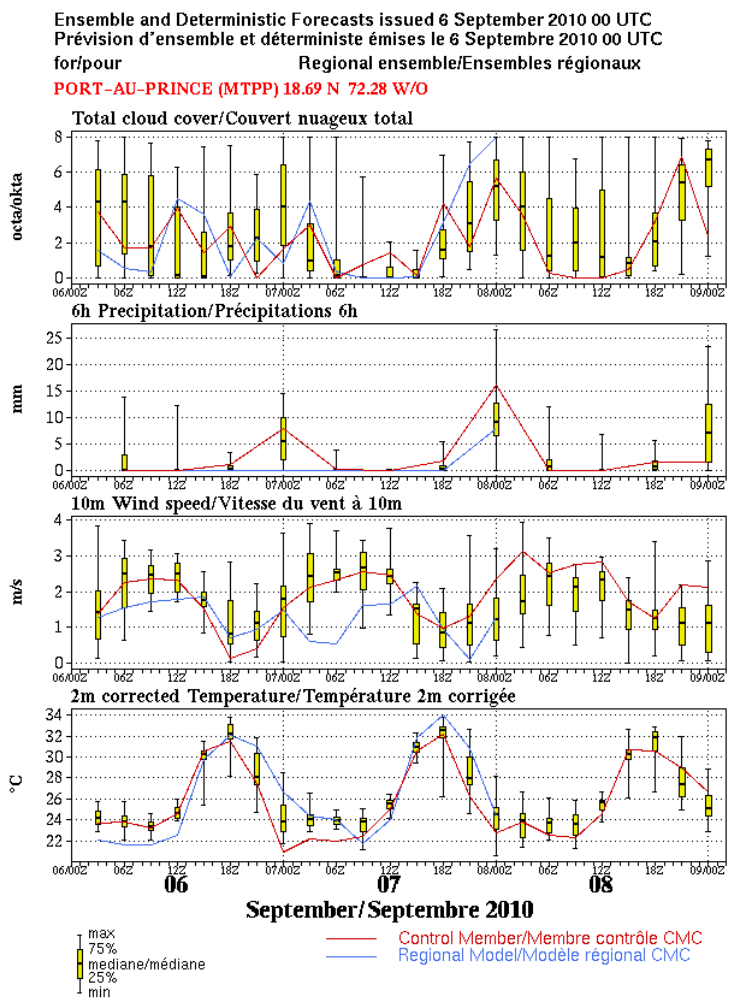


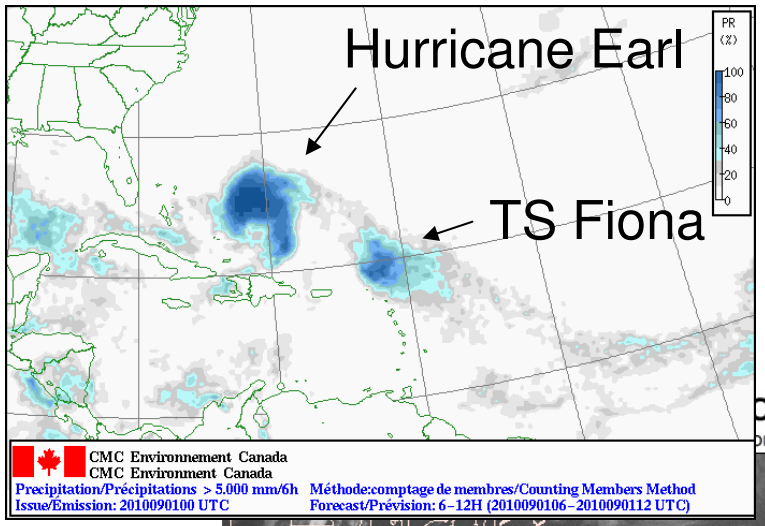


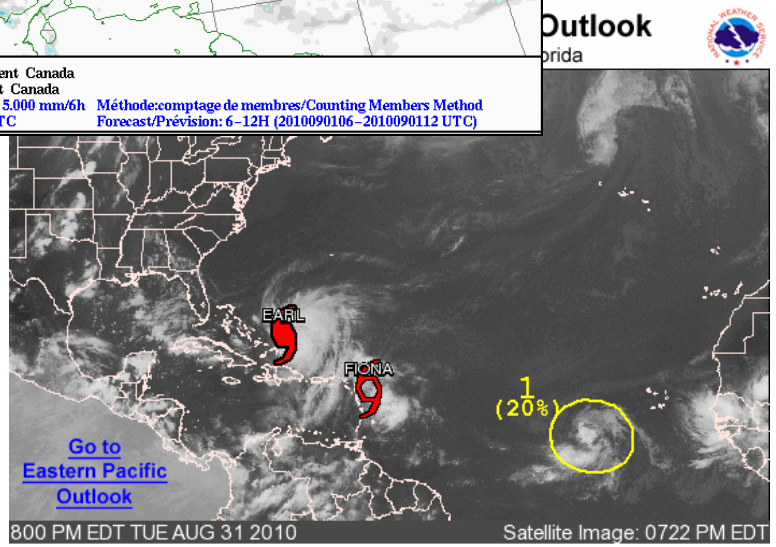


Experimental mode but run in real time

- Environment support to Haïti 2010
- Products sent to forecasters in Guadaloupe via Meteo France external web







NAEFS

CMC:

- 20 members + 1 control
- Multi-model:
  - 20 GEM – 0.9° L28 (~100 km)
  - Stochastic physics and back-scattering
- Perturbed Kalman filter data assimilation cycles.
- Integration done two times a day (00 and 12 UTC) out to 16 days.

NCEP:

- 20 members + 1 control
- Single model:
  - GFS – T190 L28 (~70 km)
- Ensemble Transform breeding vectors.
- Integration done four times a day (00, 06, 12, 18 UTC) out to 16 days.

Access to images

MSC EPS alone:
http://www.meteo.gc.ca/ensemble/index_e.html

NAEFS grand ensemble:
http://www.meteo.gc.ca/ensemble/index_naefs_e.html

Access to digital data

- Currently available global data on grid :

http://www.weatheroffice.gc.ca/grib/Low-resolution_GRIB_e.html

- Soon on on our datamart:
  - Raw model outputs on a higher resolution grids in GRIB2 format,
  - Values at points (cities) in XML format: meteograms

MSC Training on SPE

800 slides divided in 7 modules!

English http://collaboration.cmc.ec.gc.ca/cmc/ensemble/Formation-Training/Read-me.html

Français http://collaboration.cmc.ec.gc.ca/cmc/ensemble/Formation-Training/Lisez-moi.html

It was given to almost every MSC meteorologist during 2007-2010.

Summary

- Atmospheric numerical models have improved a lot in the recent decades.
- Because of sensitivity to initial conditions, deterministic forecast should be used with great cautiousness.
- Ensemble forecast provides information on forecast uncertainty.
- The global MSC system is among the best in the world currently.
- Images and digital products are made available to users twice per day up to day 16. These should be relevant to your mandate.
- A operational 33 km regional EPS system is coming in 2011.

NEW! Coming in Spring 2011:

- Staggered vertical levels
- Higher model top (2 hPa ~40 km, was 10 hPa ~30 km)
- New radiation scheme and ozone climatology
- 2 convection schemes dropped
- Forecasting part:
  - Higher horizontal resolution : ~ 66 km instead of ~ 100 km
  - Higher vertical resolution 40 levels instead of 28
  - Vertical envelope for physical tendency perturbations
- Assimilation part:
  - More satellite data
  - 192 members instead of 96
  - Reduced isotropic model error component
  - Same resolution as before

Plan in 2012:

- Improved surface properties:
  - Retirement of the old Force-restore scheme
  - Perturbations added to some sensitive surface fields
  - Ensemble assimilation cycles (20, 192 members?) at the surface for a better balance between atmosphere and soil properties

Thank you! Merci!
Danke!