

CURRENT AND FUTURE ENSEMBLE PREDICTION SYSTEM PRODUCTS

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Environnement Canada
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Why is the weather so difficult to forecast?

- Why is there so much uncertainty about the atmosphere?
- Don't we have large, sophisticated atmospheric computer models?
- Don't we use the fastest supercomputers?

2 reasons:

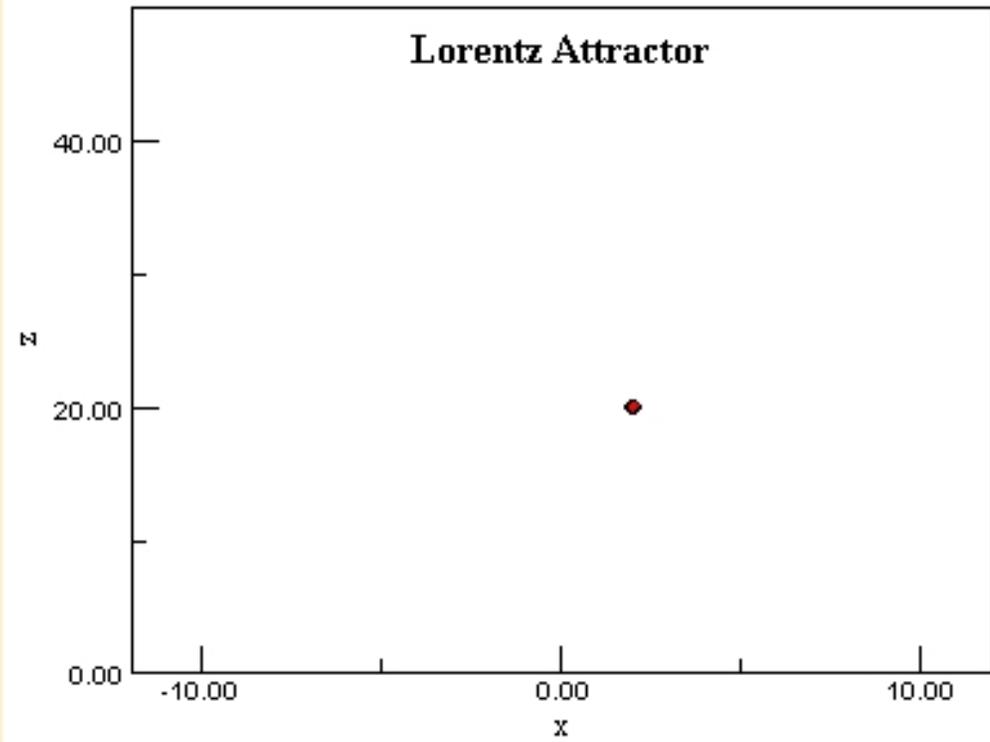
1. Models are not complete, true representations of all the physics governing atmospheric behaviour
 - spatial and temporal scales of the physical processes go from 1000s of km to μm
 - smallest scales are too small to be represented by the models
2. Even with perfect models (all scales represented) there is still uncertainty because of "*Dynamical Chaos*" (Lorentz, 1963)
 - because the evolution in time of the atmosphere is non-linear
 - non-linearity means description of the atmosphere is very sensitive to initial conditions
 - because the atmosphere is always incompletely observed, it is impossible to start the models in exactly the same state as the atmosphere itself
 - therefore without perfect knowledge of the initial state of the atmosphere it is impossible to perfectly forecast its evolution into the future (even if we had perfect models)

Deterministic forecasts will always be uncertain

But that does not mean that the atmosphere is random; just not precisely predictable

Therefore we need probabilistic methods to describe that uncertainty

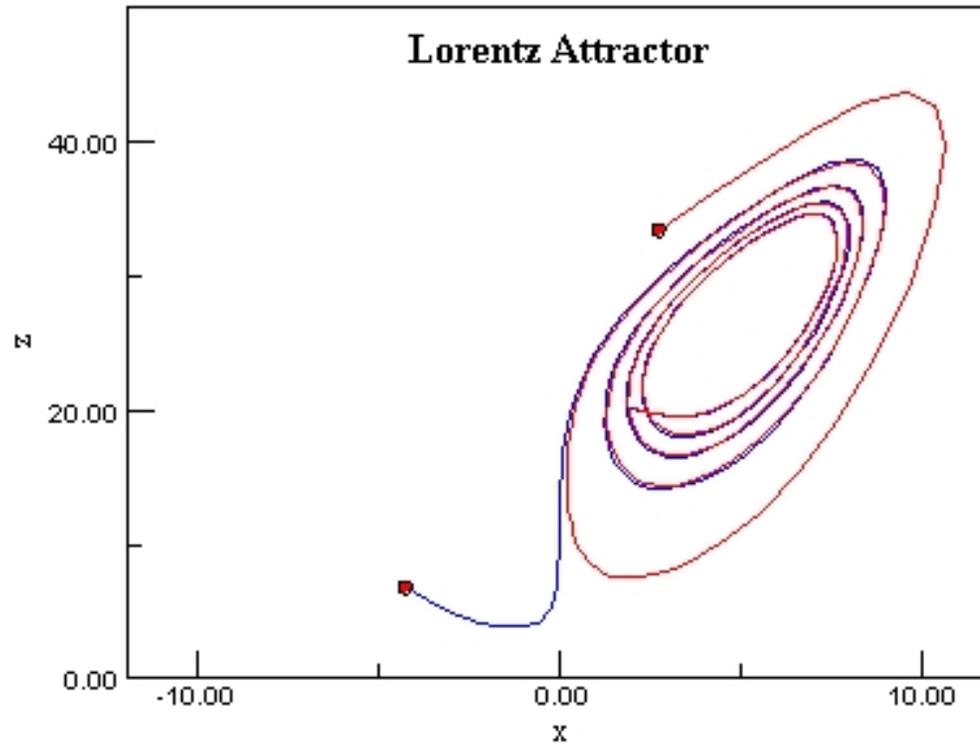




t	x1	y1	z1	x2	y2	z2
+0.00	+2.00	+5.00	+20.00	+2.10	+5.00	+20.00

$x2_0 =$
 $y2_0 =$
 $z2_0 =$

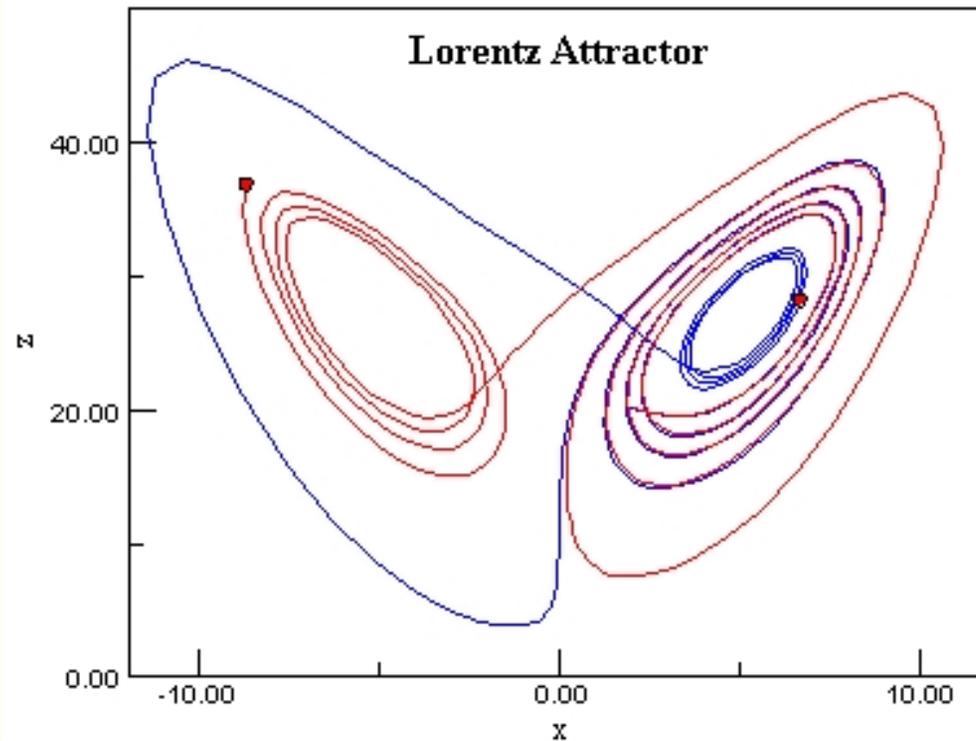




t	x1	y1	z1	x2	y2	z2
+3.48	-4.24	-8.59	+6.60	+2.78	-3.07	+33.26

$x2_0 =$
 $y2_0 =$
 $z2_0 =$

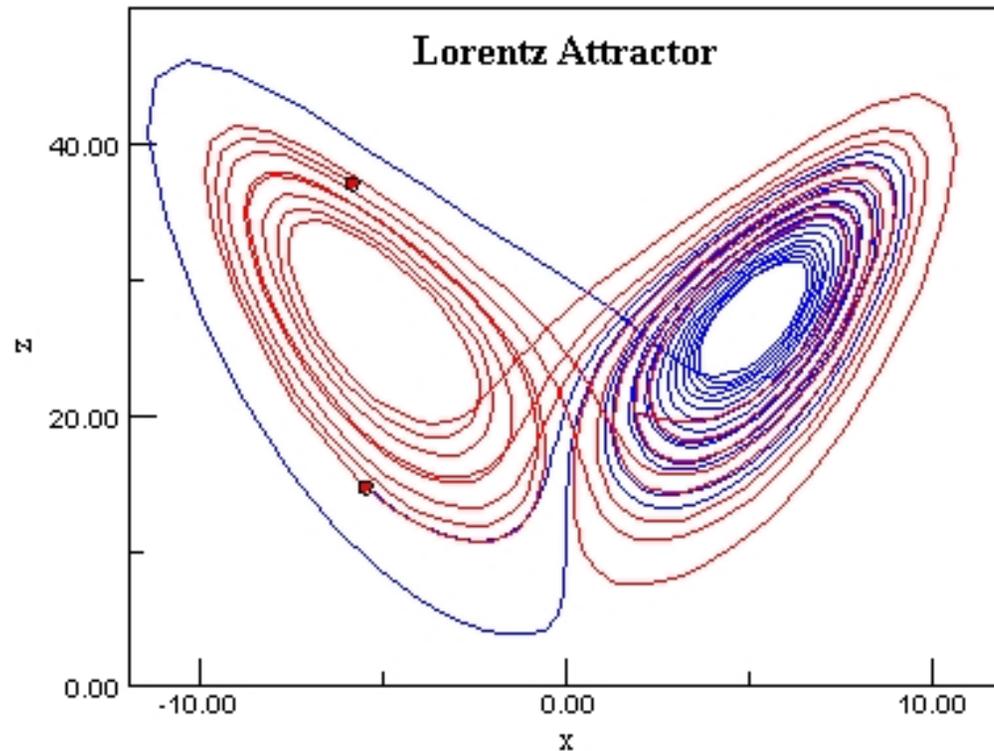




t	x1	y1	z1	x2	y2	z2
+6.08	+6.75	+7.79	+28.17	-8.68	-7.29	+36.79

$x2_o =$
 $y2_o =$
 $z2_o =$





t	x1	y1	z1	x2	y2	z2
+11.60	-5.47	-9.70	+14.64	-5.80	-0.04	+36.97

$x2_0 =$
 $y2_0 =$
 $z2_0 =$



Ensemble Prediction System

probabilistic forecasts

- Assessment of possible variations of weather forecasts.
- EPS outputs → downscaling → application models
- Construct forecast pdf from finite sample.
- Can be used to extend forecast period beyond day 5.

risk management

- Calculate probabilities of particular outcomes.
- Assign risks.

decision making

- Decision making based on probability ranges and cost/loss ratio.

forecast confidence

- Spread-skill relationship can be used to assess confidence in forecasts.
- Forecast is incomplete without information on its flow dependent expected skill.



The Canadian EPS

Multi-model, 16 member ensemble (8 SEF + 8 GEM)

- T149 for SEF, 1.2° (~150 km) for GEM
- Perturbed observations and different parameterization is used for each member

Since June 2001:

- 10 day runs once a day
- 8 perturbed runs from each model
- Surface scheme:
 - force-restore

Starting January 2006:

- As part of the NAEFS:
 - 15 day runs twice per day
 - 10 perturbed runs from each model
 - Surface scheme:
 - 10 members with F-R
 - 10 members with ISBA

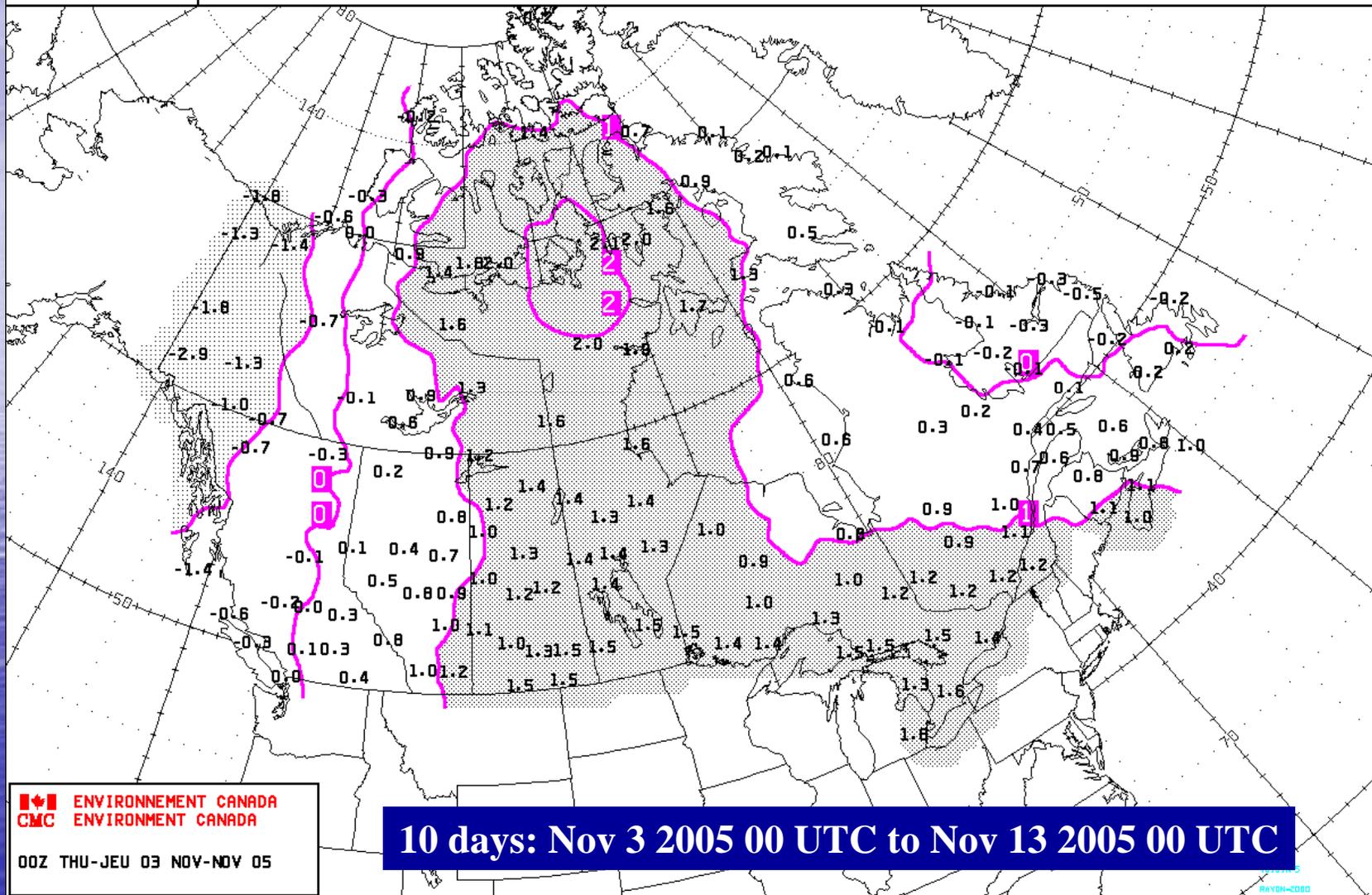
http://weatheroffice.ec.gc.ca/ensemble/index_e.html



ENSEMBLE
8 SEP 8 GEM

10 DAY MEAN - MOYENNE SUR 10 JOURS

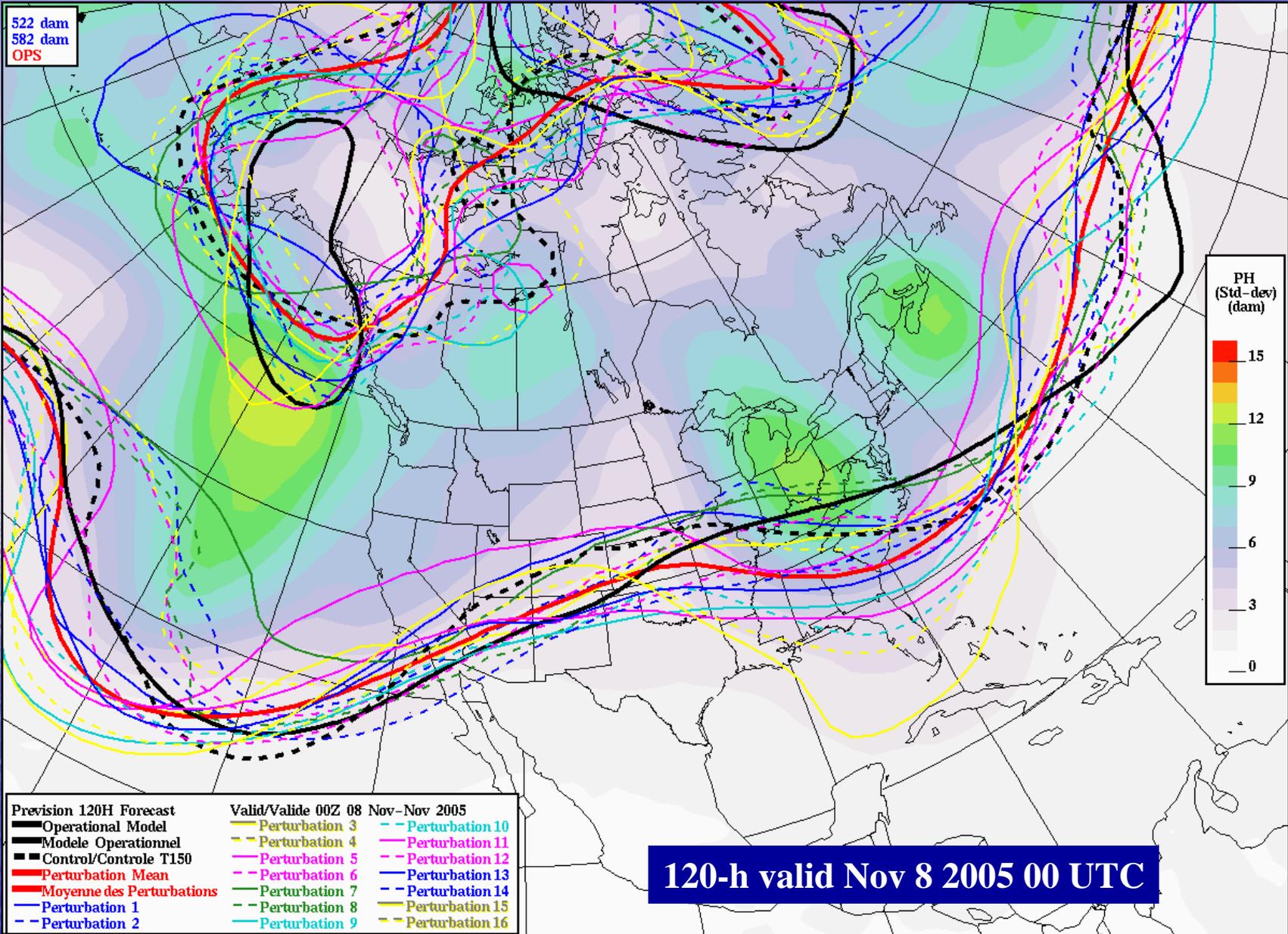
NORMALISED TEMPERATURE ANOMALY
ANOMALIE DE TEMPERATURE NORMALISEE



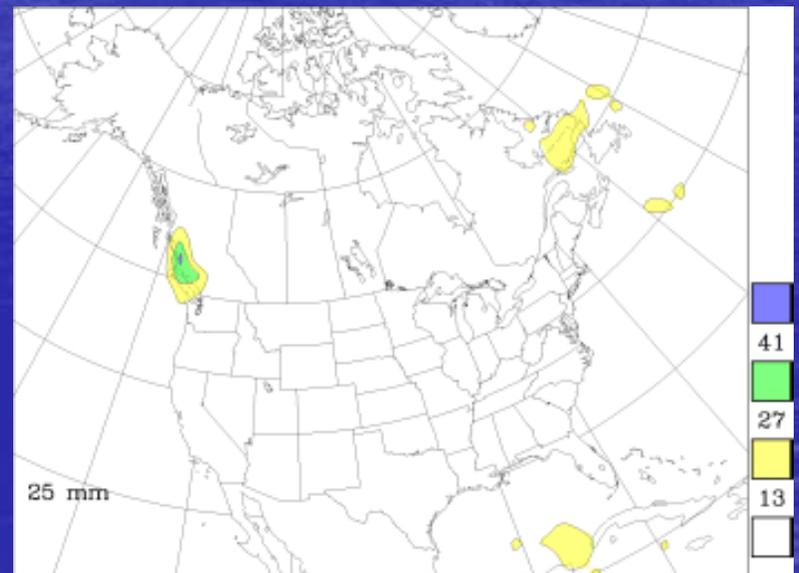
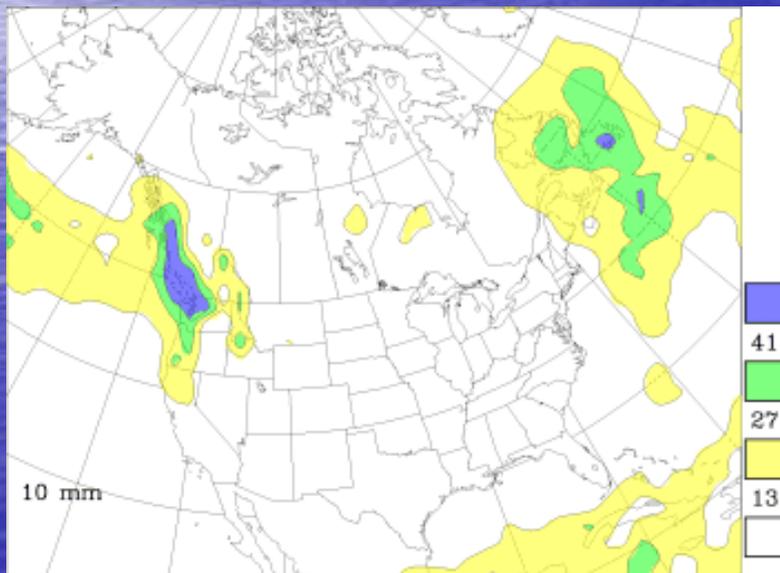
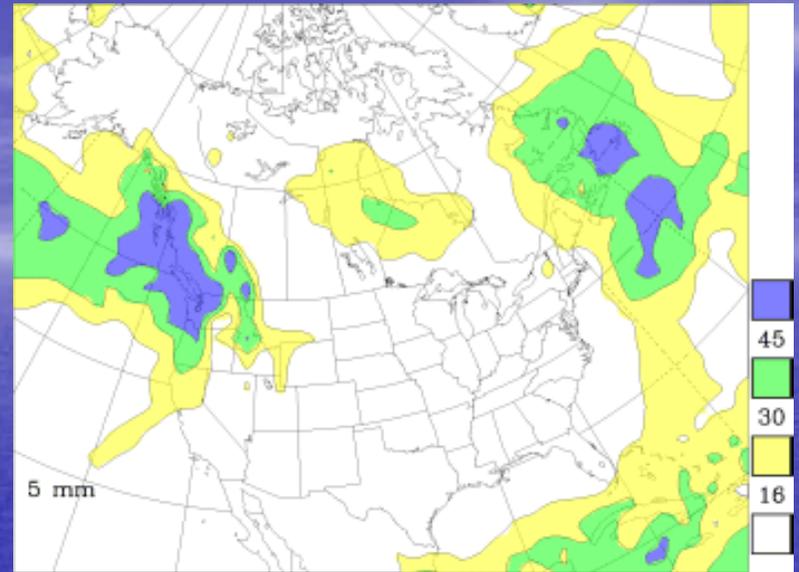
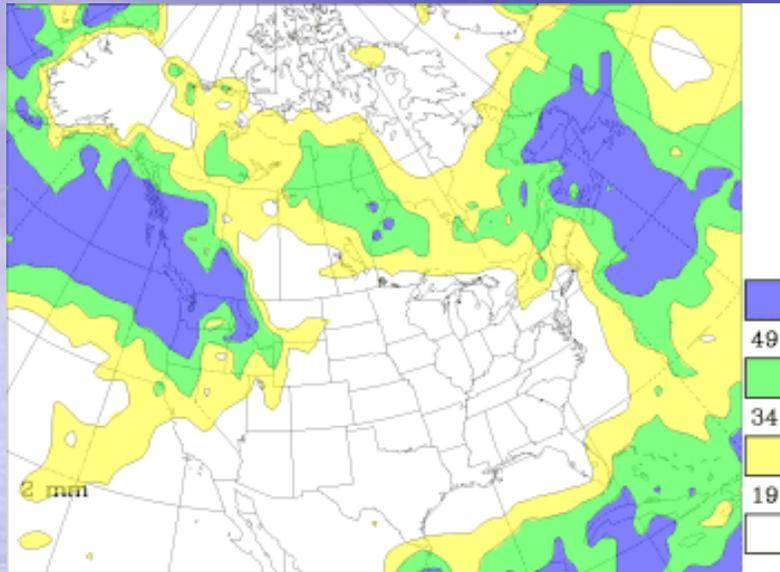
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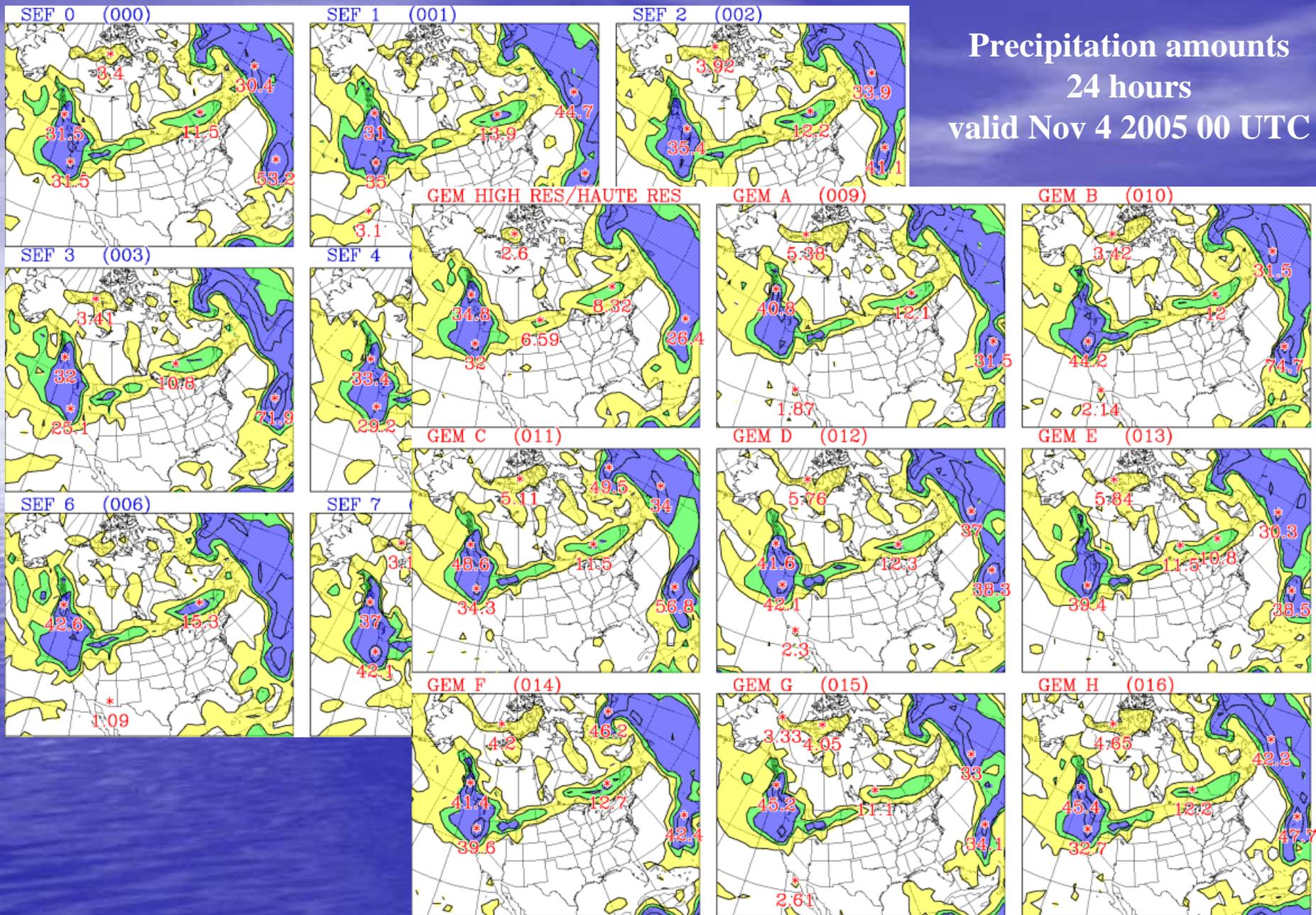




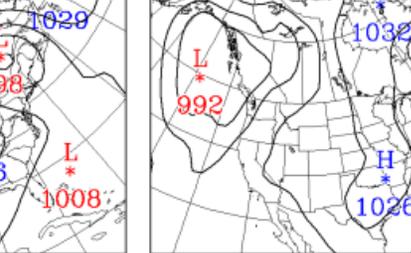
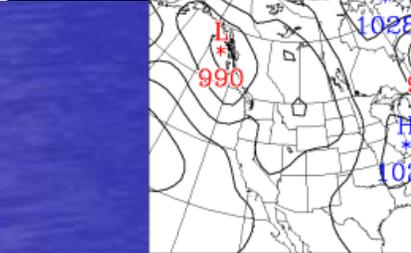
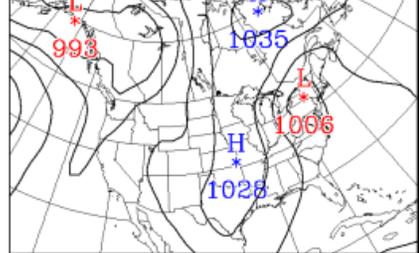
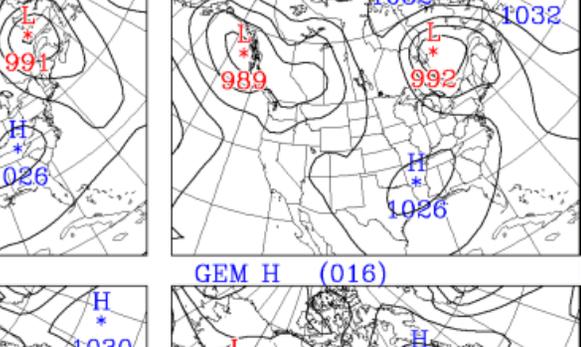
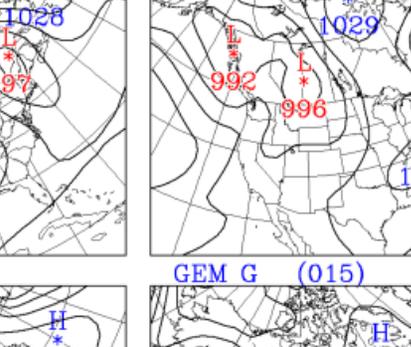
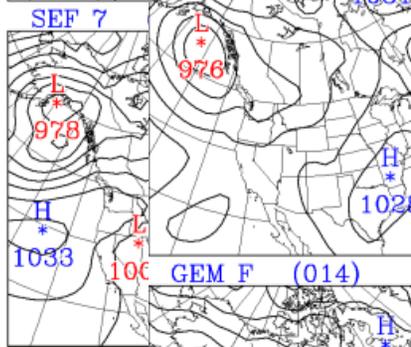
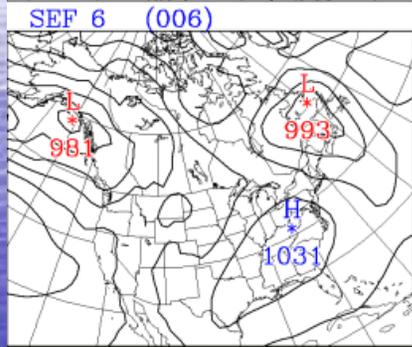
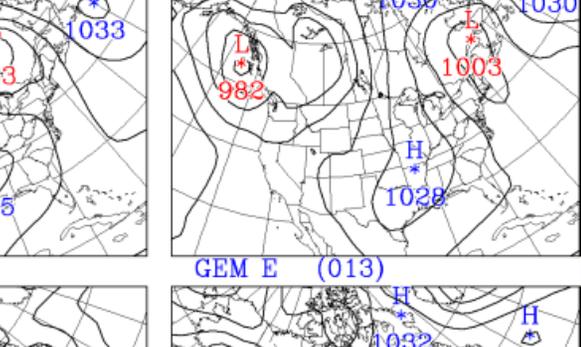
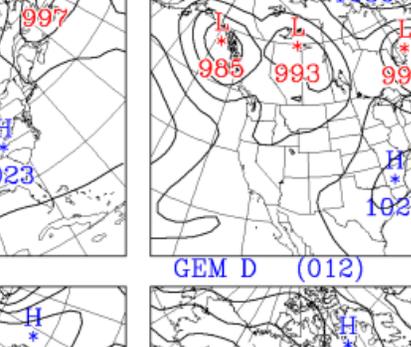
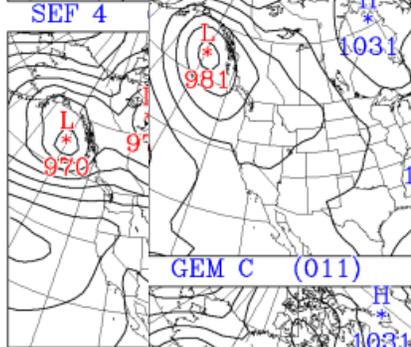
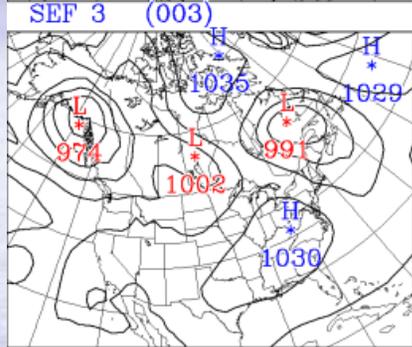
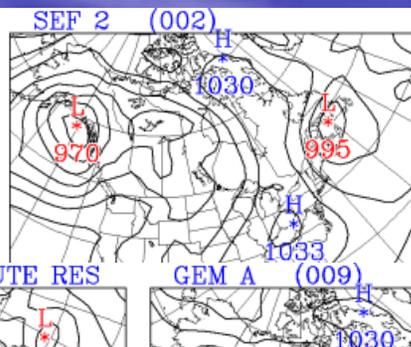
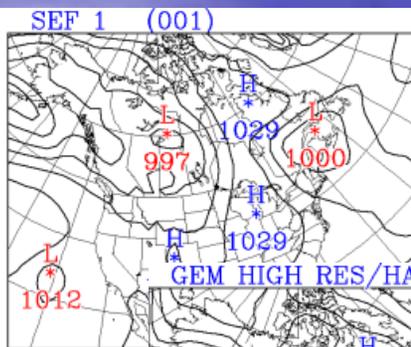
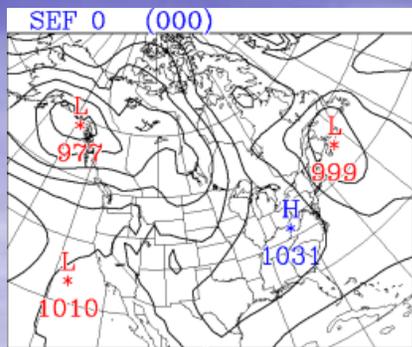
144-h valid Nov 9 2005 00 UTC



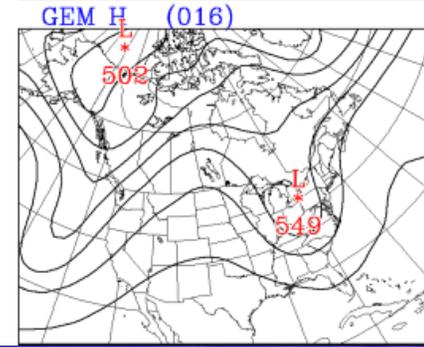
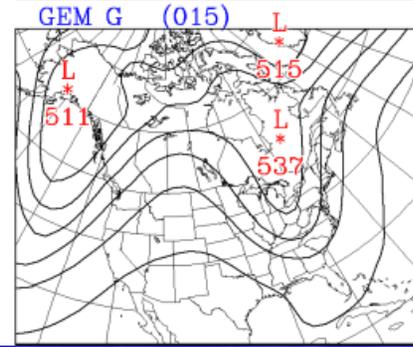
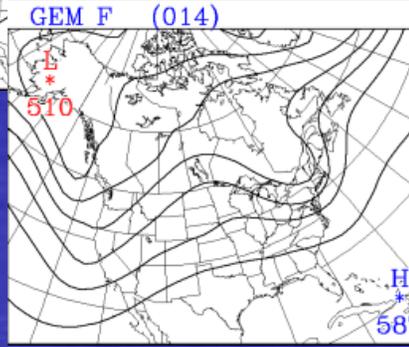
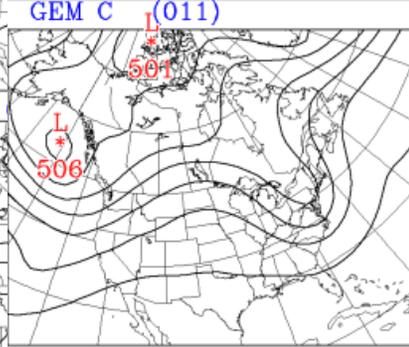
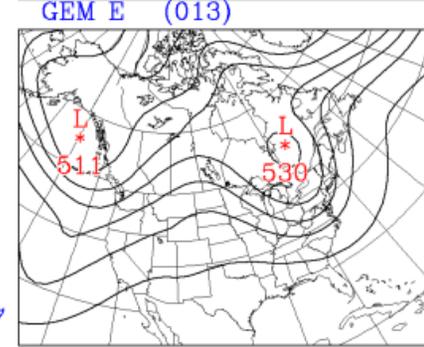
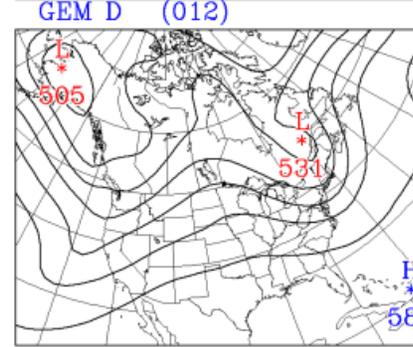
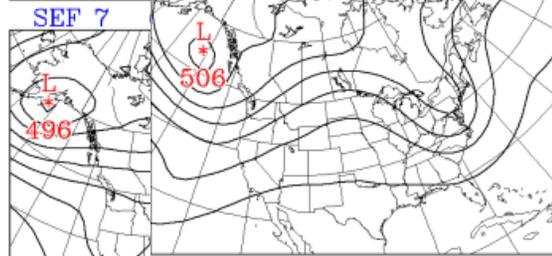
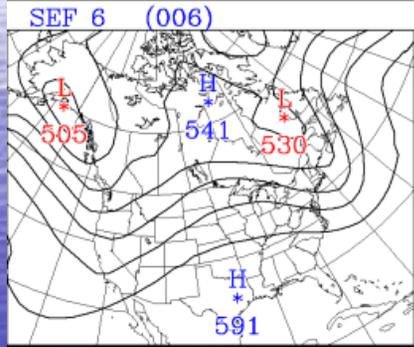
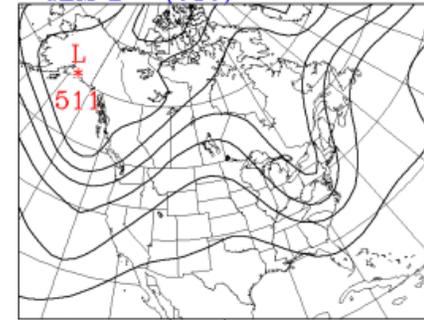
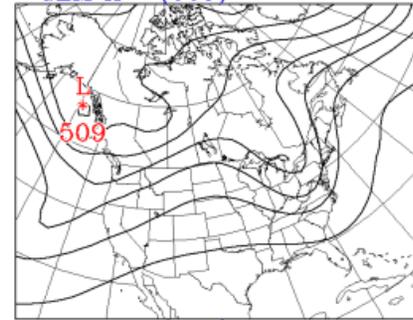
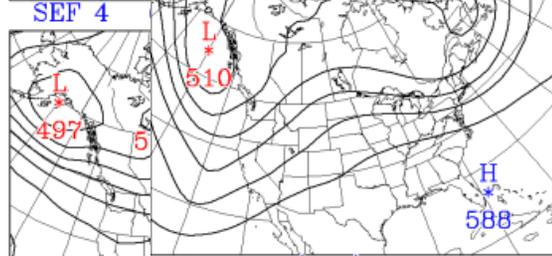
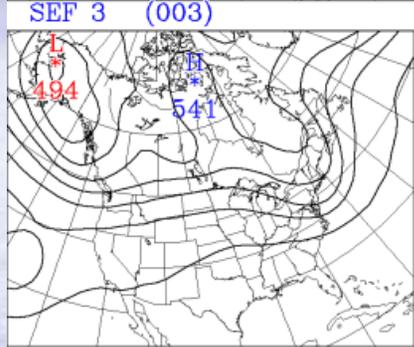
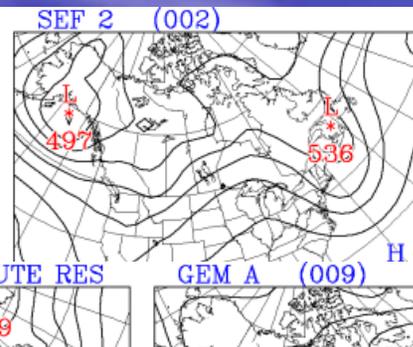
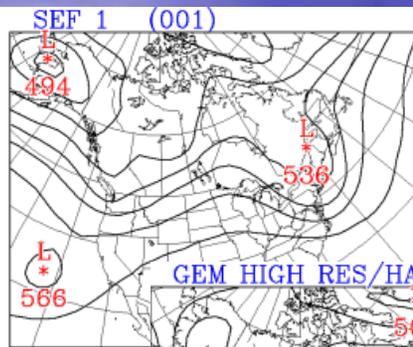
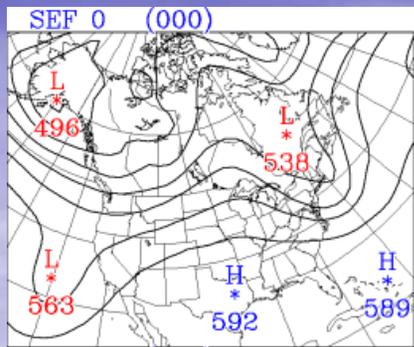
Precipitation amounts 24 hours valid Nov 4 2005 00 UTC



Mean Sea Level Pressure 120 hours valid Nov 8 2005 00 UTC



Geopotential Heights 500 hPa, 120 hours valid Nov 8 2005 00 UTC



North American Ensemble Forecasting System (NAEFS)

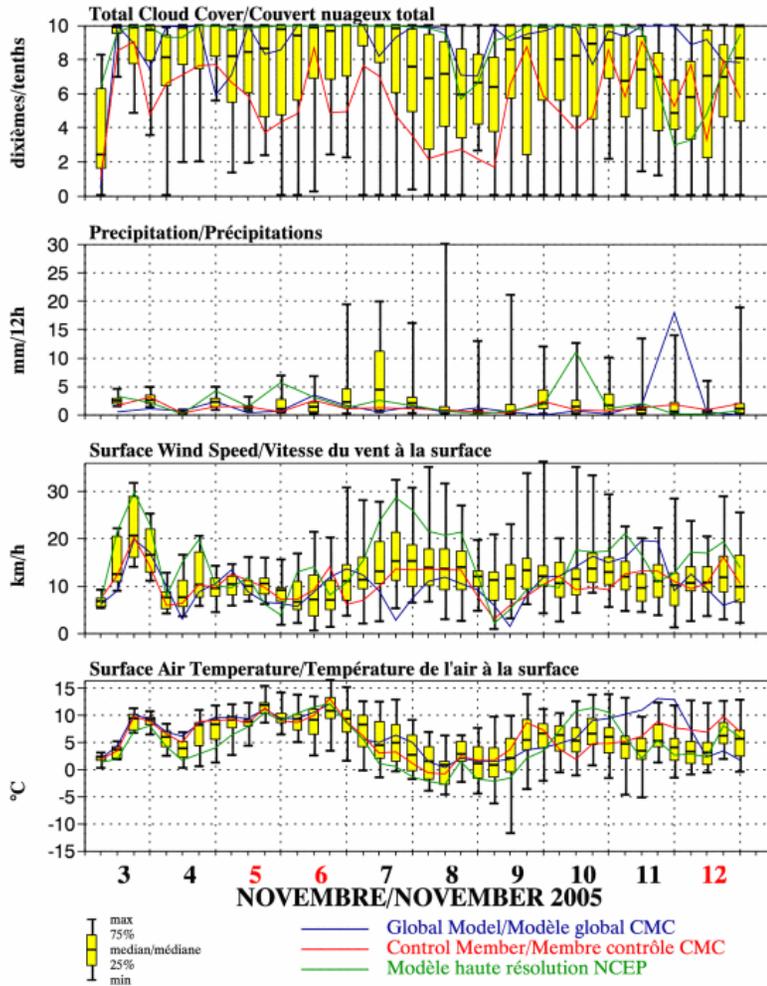
- November 2004: NAEFS created with SMC, NCEP and Mexican National Weather Service
- Exchange of ensemble members and techniques
- Experimental products generated from combined ensemble of NCEP and SMC members: gives more variability between members
- In 2006 Canadian EPS will be issued twice a day, for 15 day forecasts
- Products based on combined ensemble will be offered to public/clients in 2006





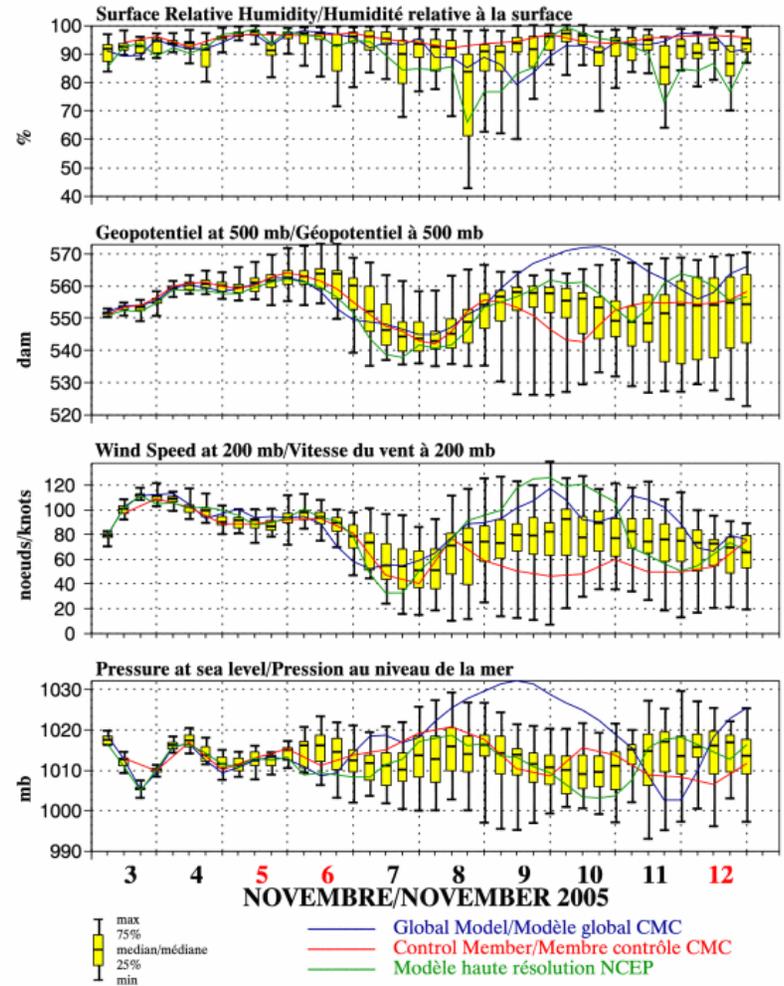
Ensemble and Deterministic Forecasts issued 3 NOVEMBER 2005 0 UTC
Prévisions d'ensembles et déterministe émises le 3 NOVEMBRE 2005 0 UTC
pour / for (Ensemble CMC & NCEP)

MONTREAL (DORVAL) (YUL) 45.47 N 73.75 W/O



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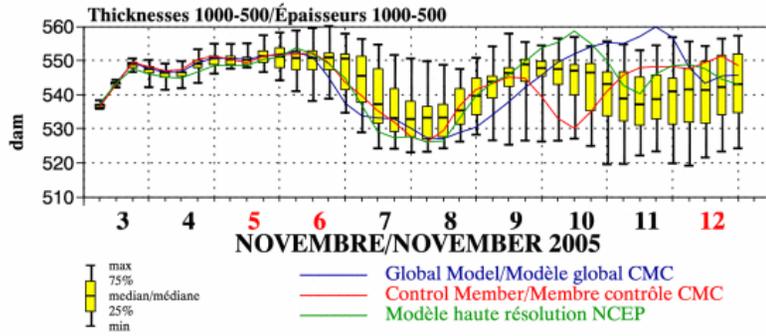
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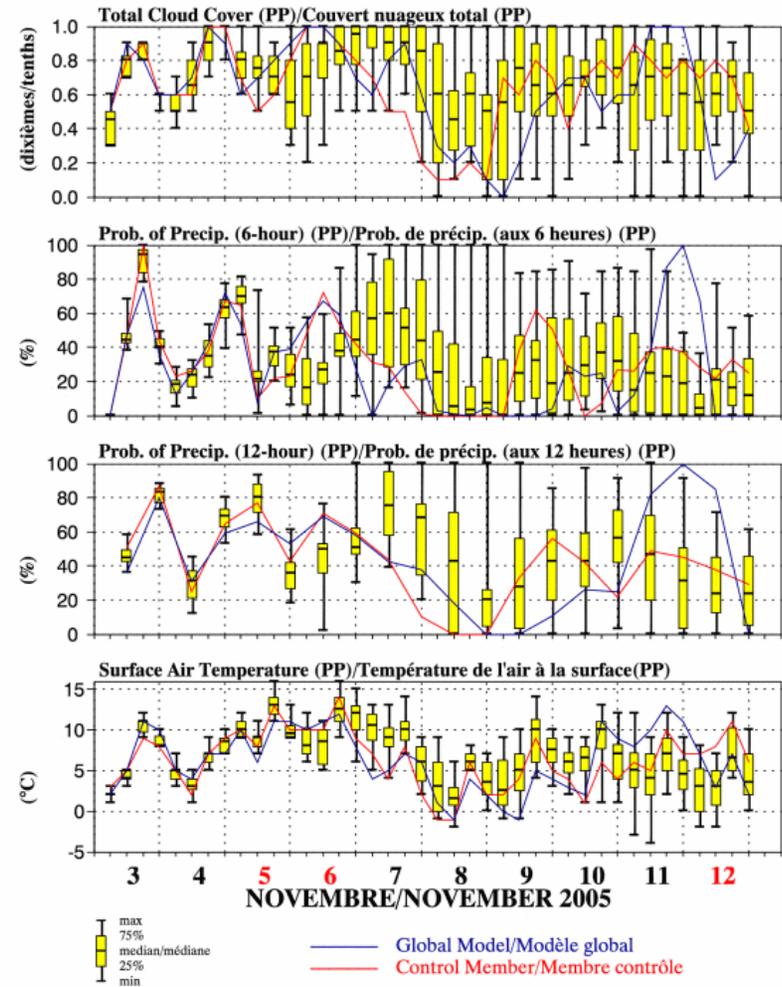
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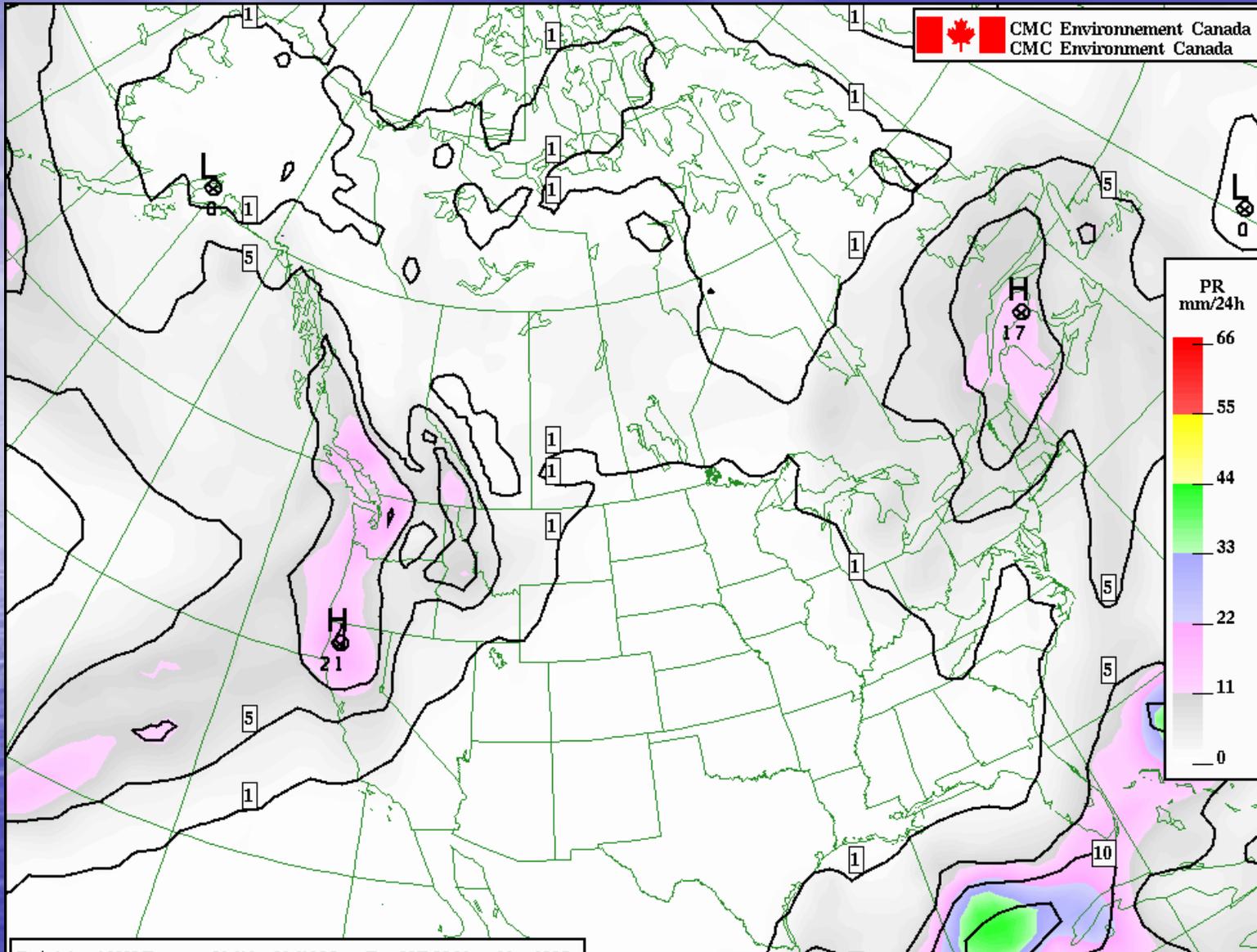
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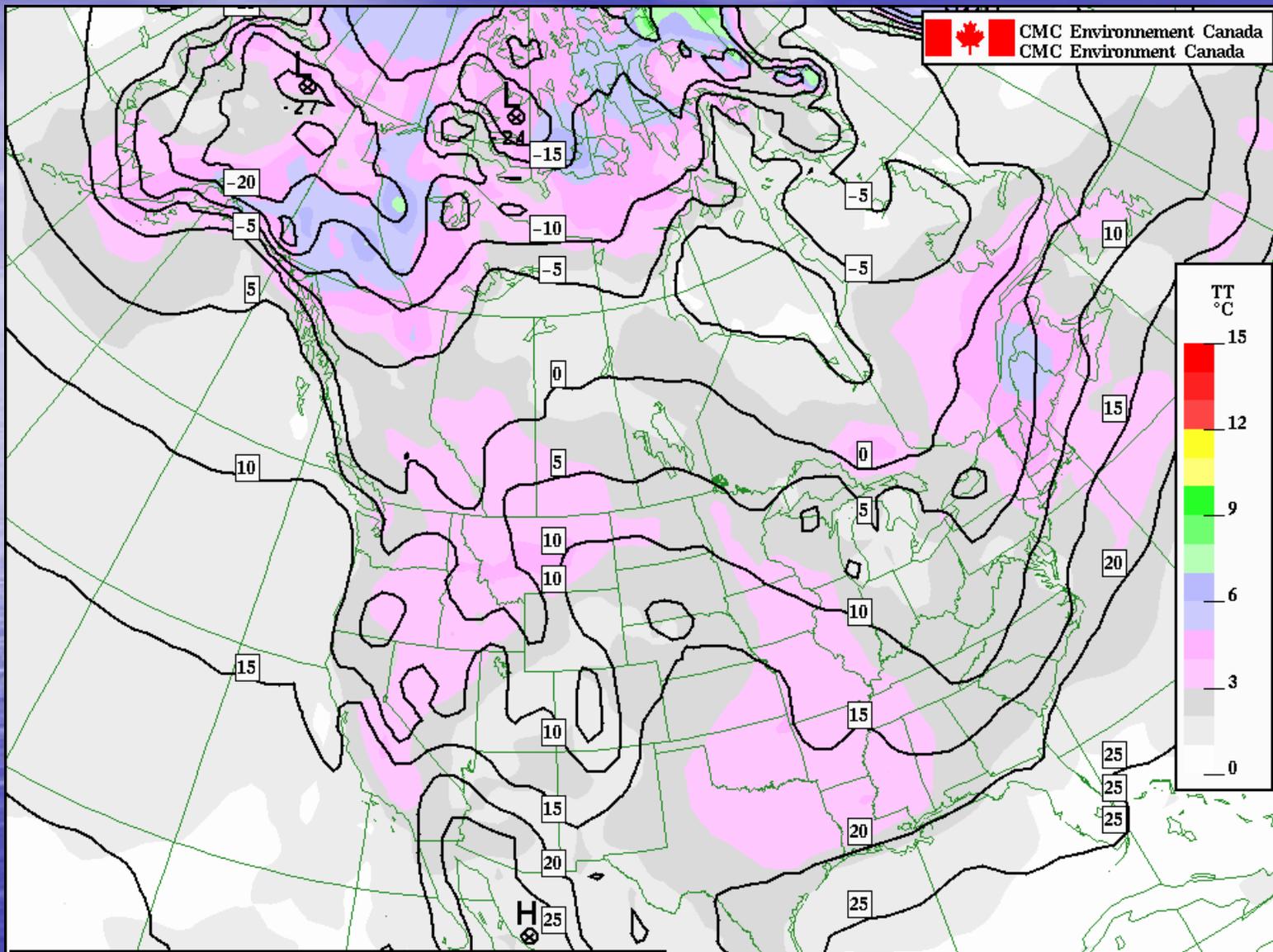




Prévision 120H Forecast Valide- Valid Mar- Tue 00Z 08 Nov- Nov 2005
 Mean & Standard Deviation Chart for --- Precipitation ---
 Carte de moyenne et écart type pour --- Précipitations ---
 issued on 20051103 at 00Z émisses le 20051103 à 00Z

Membres du CMC et de NCEP CMC & NCEP members
 Écart type en arrière plan Standard Deviation as background
 contours à 1, 5, 10, 20 et 50 mm/24h contours at 1, 5, 10, 20 and 50 mm/24h





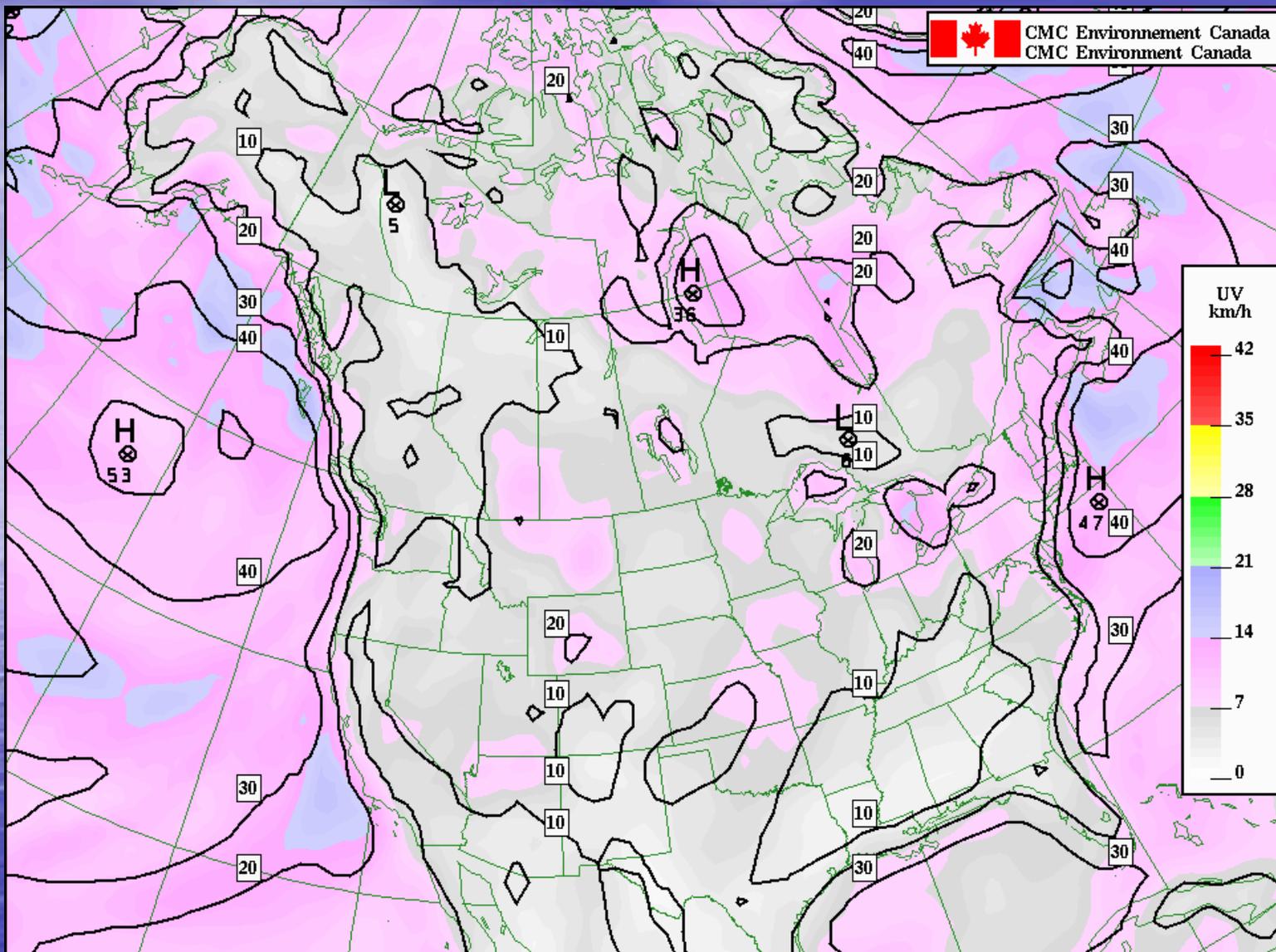
Préviation 120H Forecast Valide- Valid Mar- Tue 00Z 08 Nov- Nov 2005
 Mean & Standard Deviation Chart for --- Surface Air Temperature ---
 Carte de moyenne et écart type pour --- Température de l'air à la surface ---
 issued on 20051103 at 00Z émises le 20051103 à 00Z

Membres du CMC et de NCEP CMC & NCEP members
 Écart type en arrière plan Standard Deviation as background
 5 °C entre les contours 5 °C between contours





CMC Environnement Canada
CMC Environment Canada



Prévision 120H Forecast Valide- Valid Mar- Tue 00Z 08 Nov- Nov 2005
 Mean & Standard Deviation Chart for --- Surface Wind Speed ---
 Carte de moyenne et écart type pour --- Vitesse du vent à la surface ---
 issued on 20051103 at 00Z émise le 20051103 à 00Z

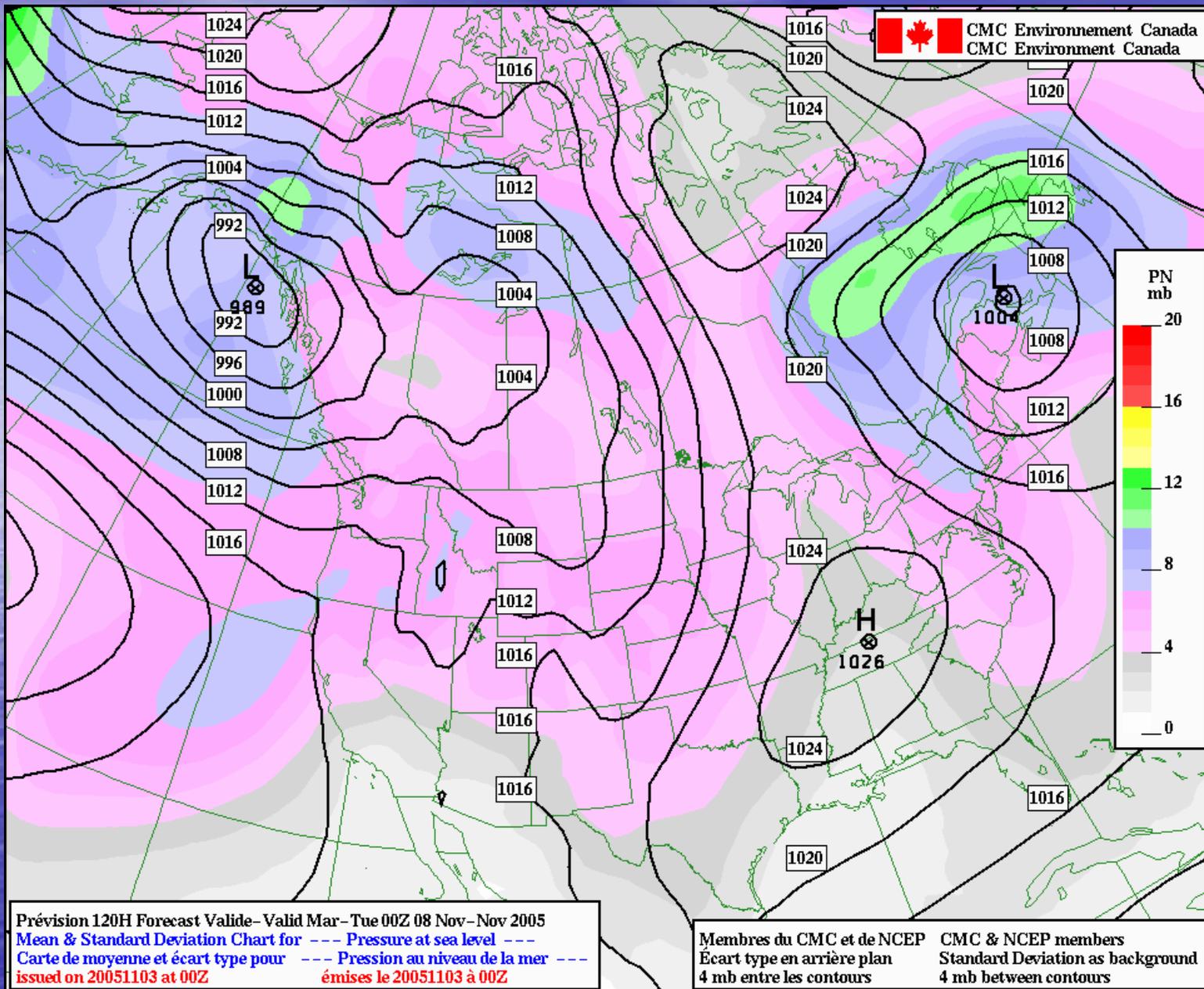
Membres du CMC et de NCEP CMC & NCEP members
 Écart type en arrière plan Standard Deviation as background
 10 km/h entre les contours 10 km/h between contours

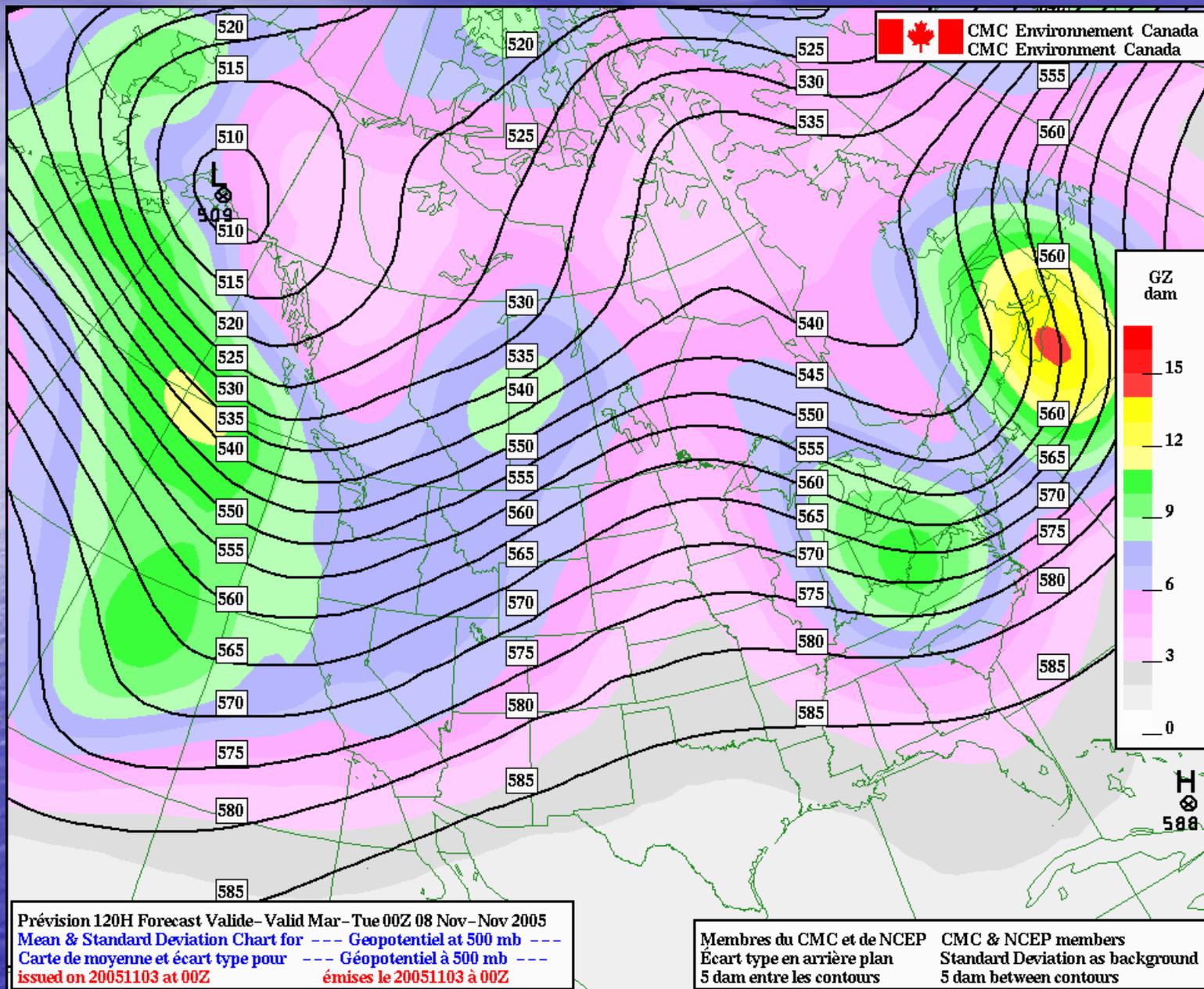


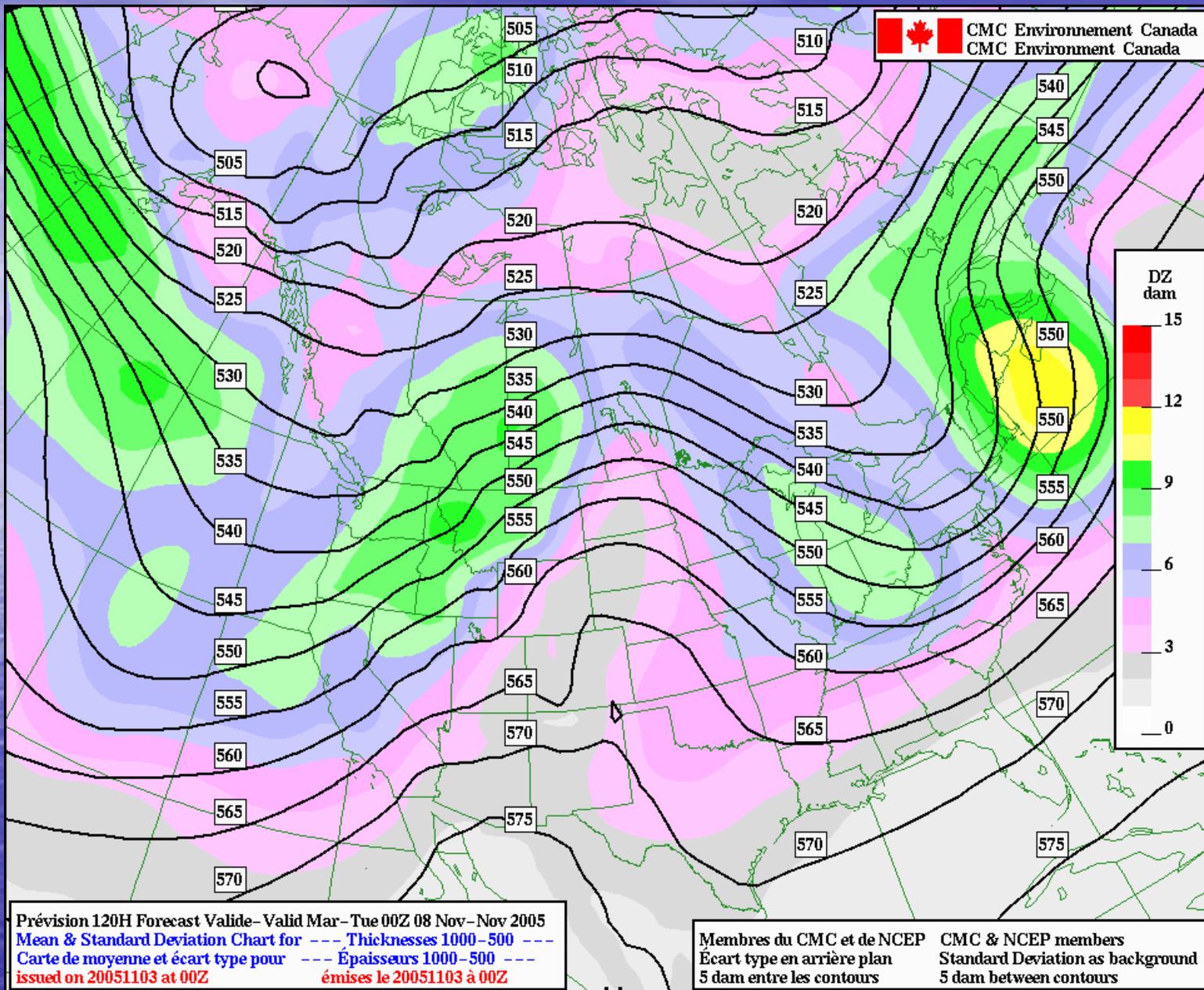
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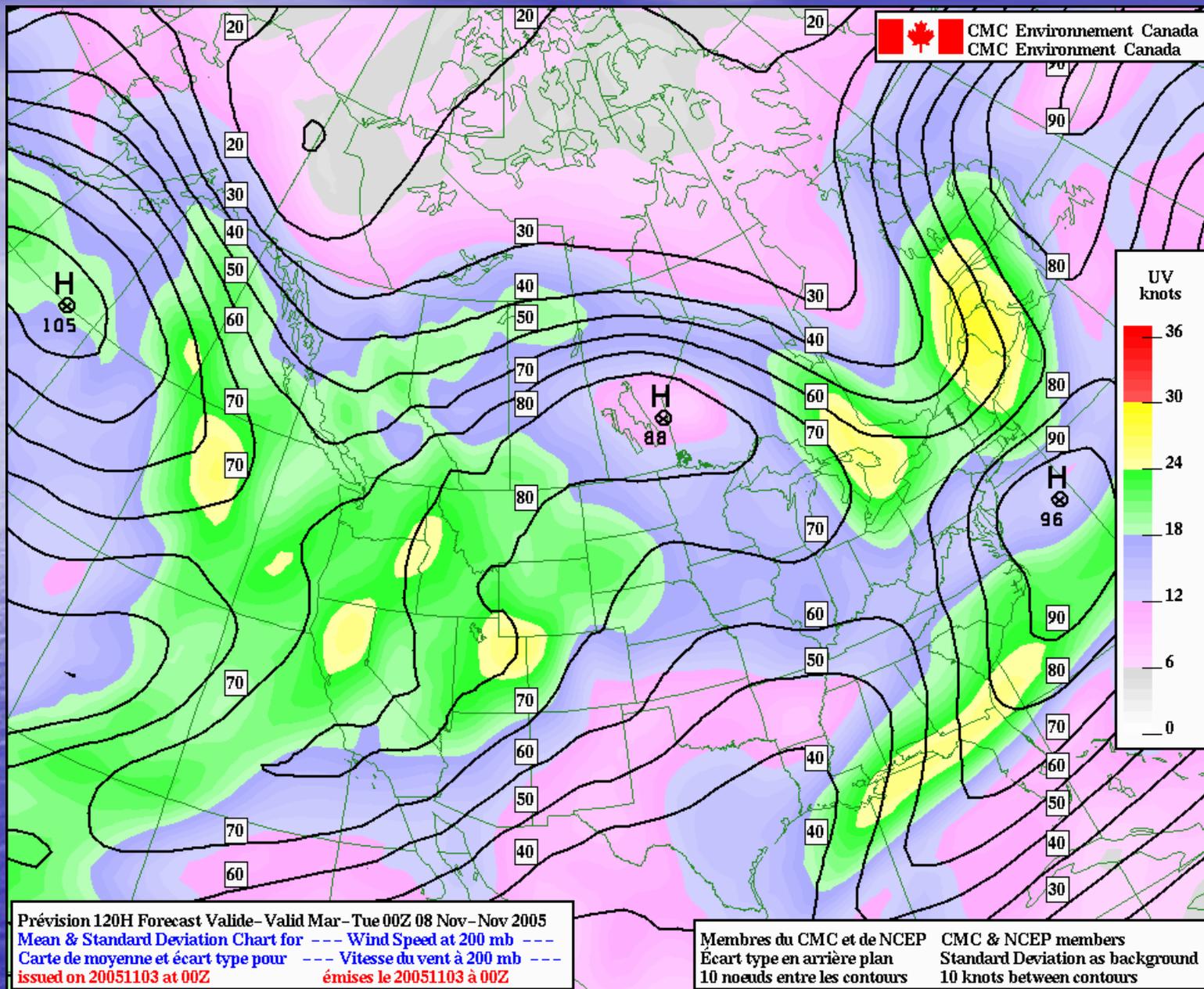
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 Centre météorologique canadien













EXPÉRIMENTAL --- EXPERIMENTAL!

Probabilité d'accumulation de précipitations supérieures à 5 mm pour la période pour les membres du CMC
Probability of precipitation accumulation over 5 mm for the whole period for CMC members

Ensemble type / Type d'ensemble :

CMC and NCEP combined / combinés

Type de produit / Product type :

- Moins de 0.2 mm - Less than 0.2 mm
- Plus de 2 mm - More than 2 mm
- Plus de 5 mm - More than 5 mm
- Plus de 10 mm - More than 10 mm
- Plus de 25 mm - More than 25 mm
- Plus de 50 mm - More than 50 mm

Issued date / Date d'émission :

Year/Année : Month/Mois : Day/Jour :

2005 Novembre/November 1

Day before	Issued Day	Day after
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2005-11-01

Jour précédent	Jour d'émission	Jour suivant
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Day before	Beginning Forecast Day at 00Z	Day after
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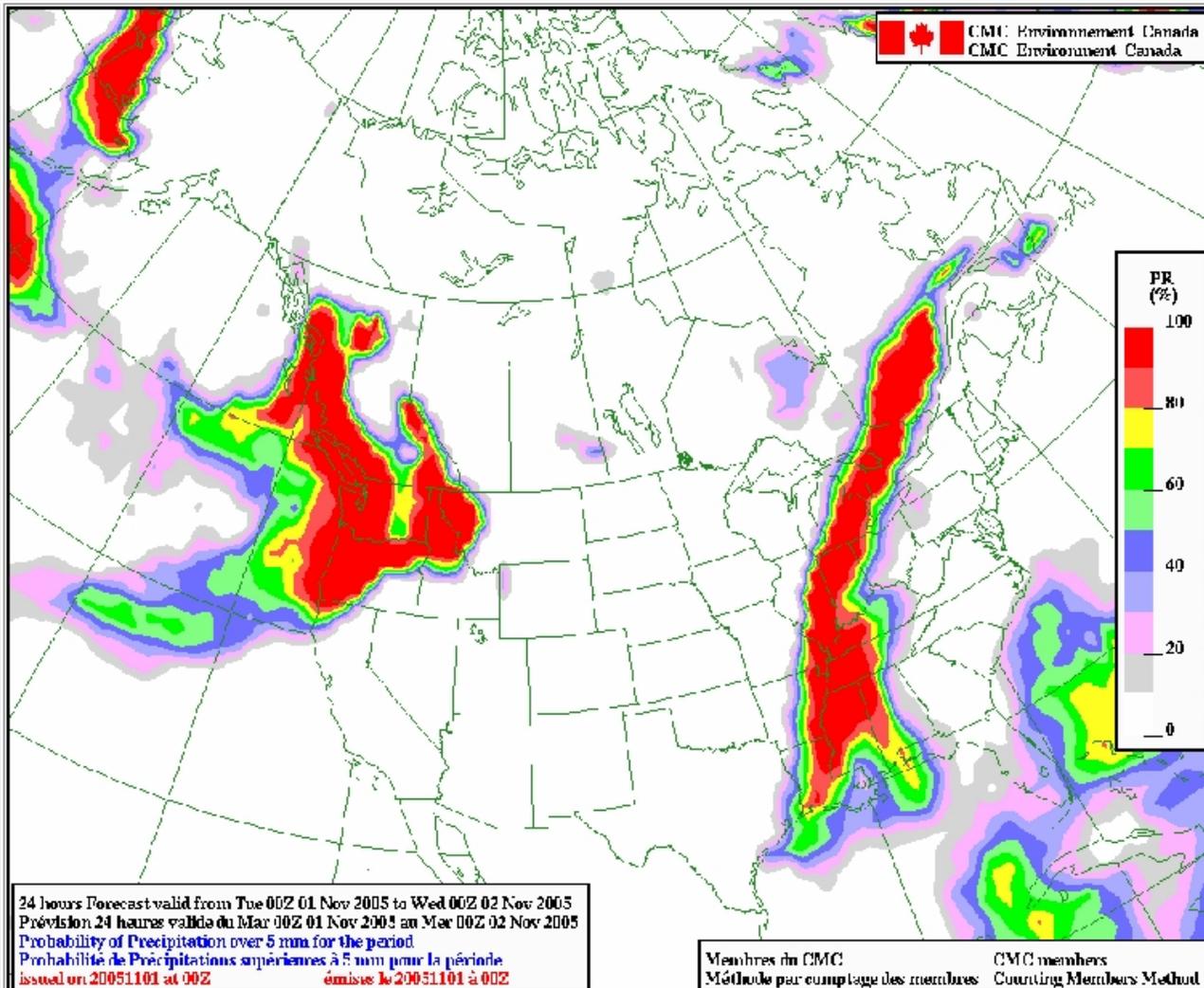
2005-11-01

Jour précédent	Jour de début de la prévision à 00Z	Jour suivant
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Day before	Ending Forecast Day at 00Z	Day after
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2005-11-02

Jour précédent	Jour de fin de la prévision à 00Z	Jour suivant
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Information : [English](#) [Français](#)

[Comments --- Commentaires](#)





EXPÉRIMENTAL --- EXPERIMENTAL!

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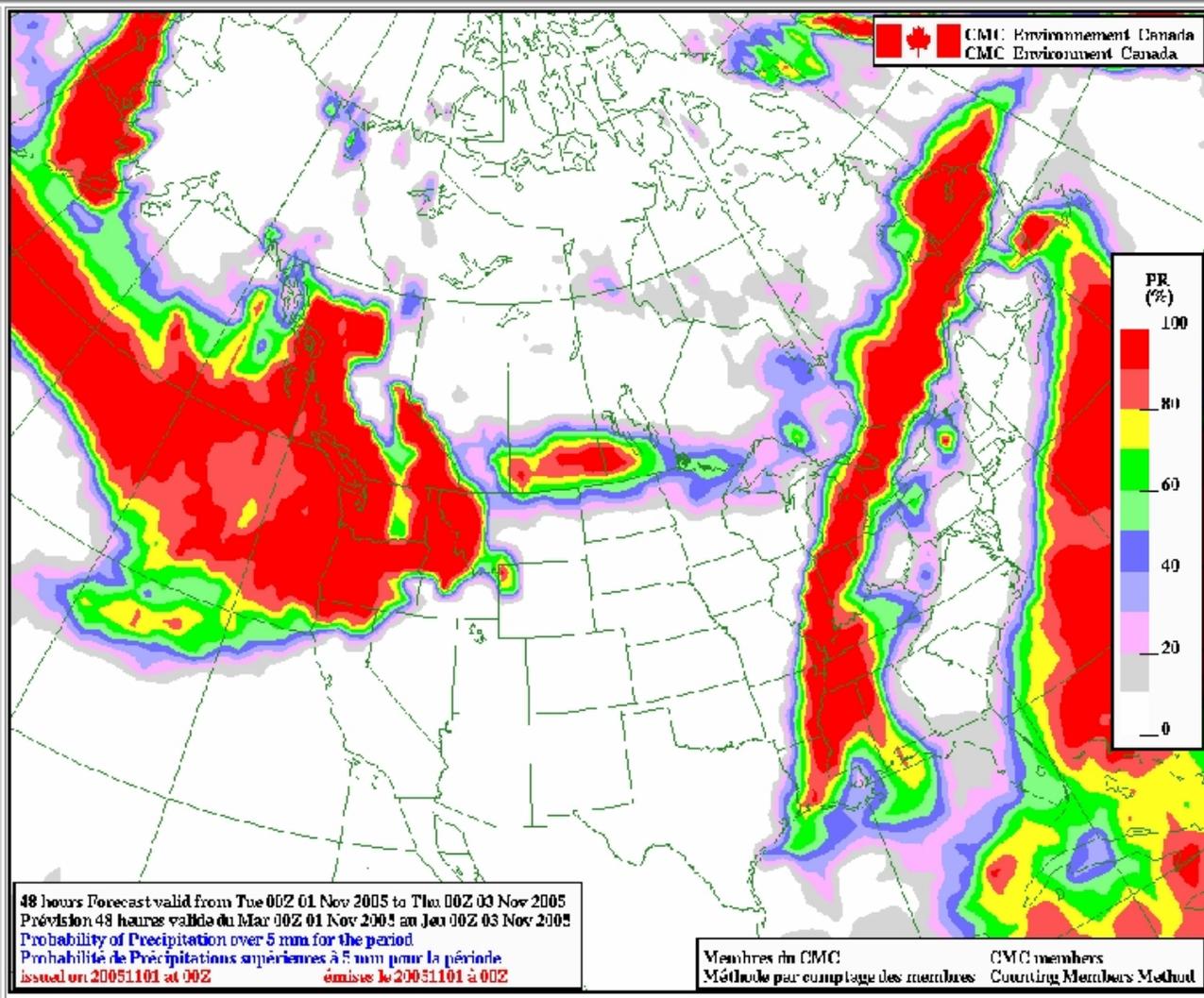
Issued date / Date d'émission :

Year/Année : 2005
Month/Mois : Novembre/November
Day/Jour : 1

Day before	Issued Day	Day after
←	2005-11-01	
Jour précédent	Jour d'émission	Jour suivant

Day before	Beginning Forecast Day at 00Z	Day after
	2005-11-01	→
Jour précédent	Jour de début de la prévision à 00Z	Jour suivant

Day before	Ending Forecast Day at 00Z	Day after
←	2005-11-03	→
Jour précédent	Jour de fin de la prévision à 00Z	Jour suivant



Information : [English](#) [Français](#)

[Comments --- Commentaires](#)



Montreal – Wednesday 2004-03-31

Probability thresholds	30%	60%	80%
Minimum temperatures	8-10°C	5-12 °C	2-15 °C
Maximum temperatures	18-21°C	16-24°C	15-26°C
Winds	> 40 km/h	> 25 km/h	> 15 km/h
Precipitation amounts	> 15 mm	> 8 mm	> 2 mm



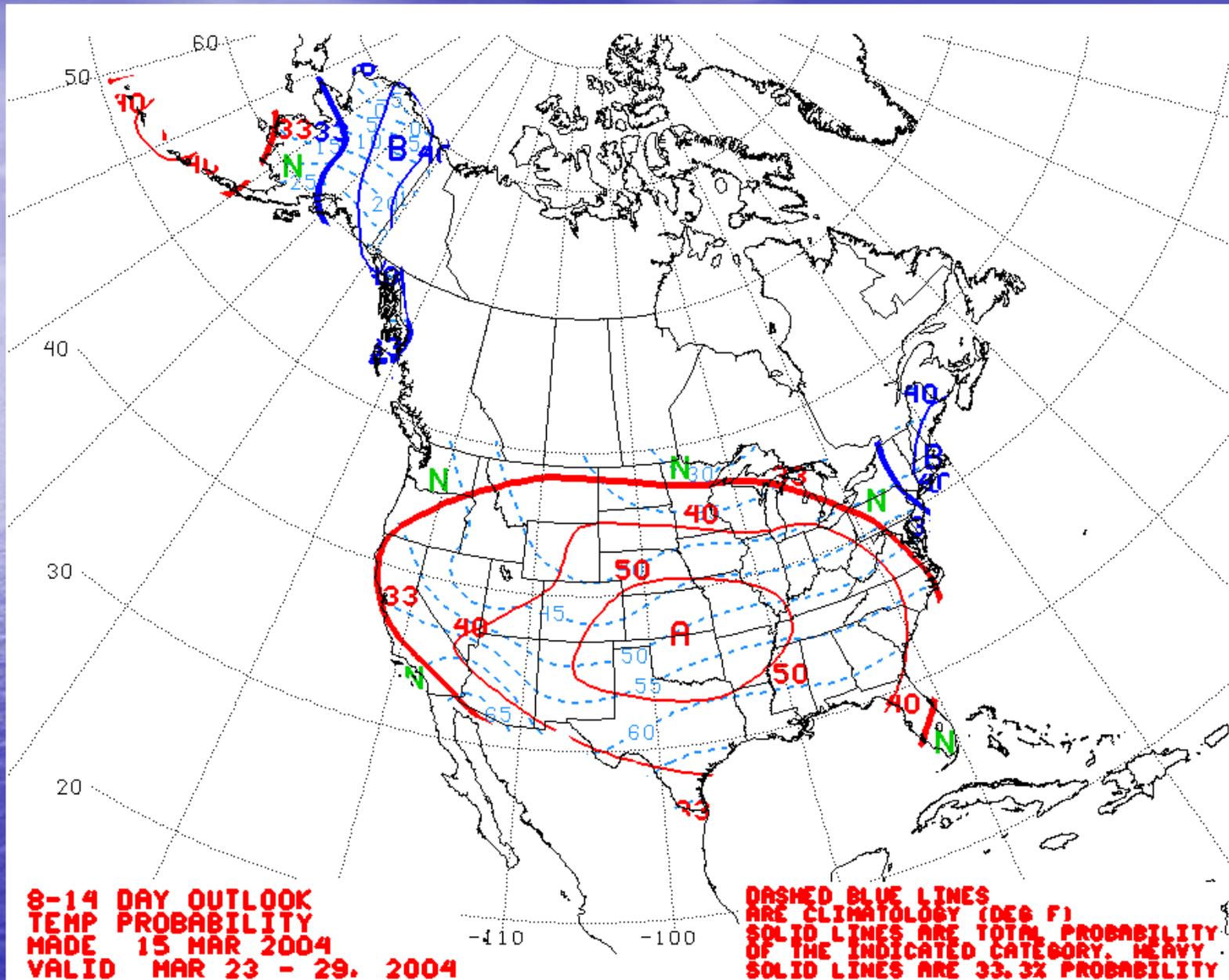
Outlook for Montreal for the period from Monday
2005-04-05 to Sunday 2005-04-11.

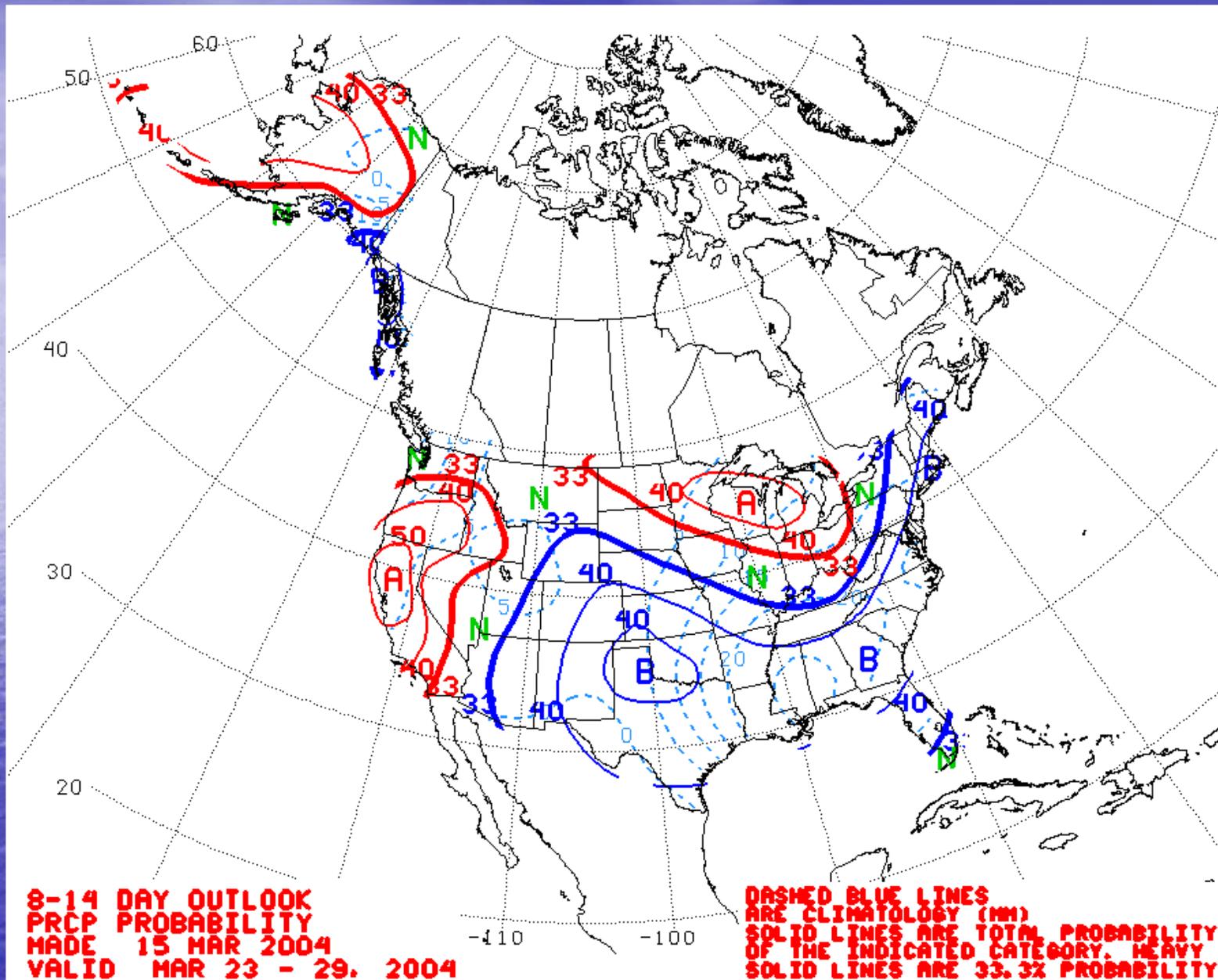
Temperatures: Low ranging from minus 2 to 8. High
ranging from 5 to 15. Temperatures warming during
the week.

Precipitation: 60% chance that the total
precipitation amounts will exceed 10 mm during
the week. Dryer at the beginning of the week.

Normals for the period: Low 2 High 9.







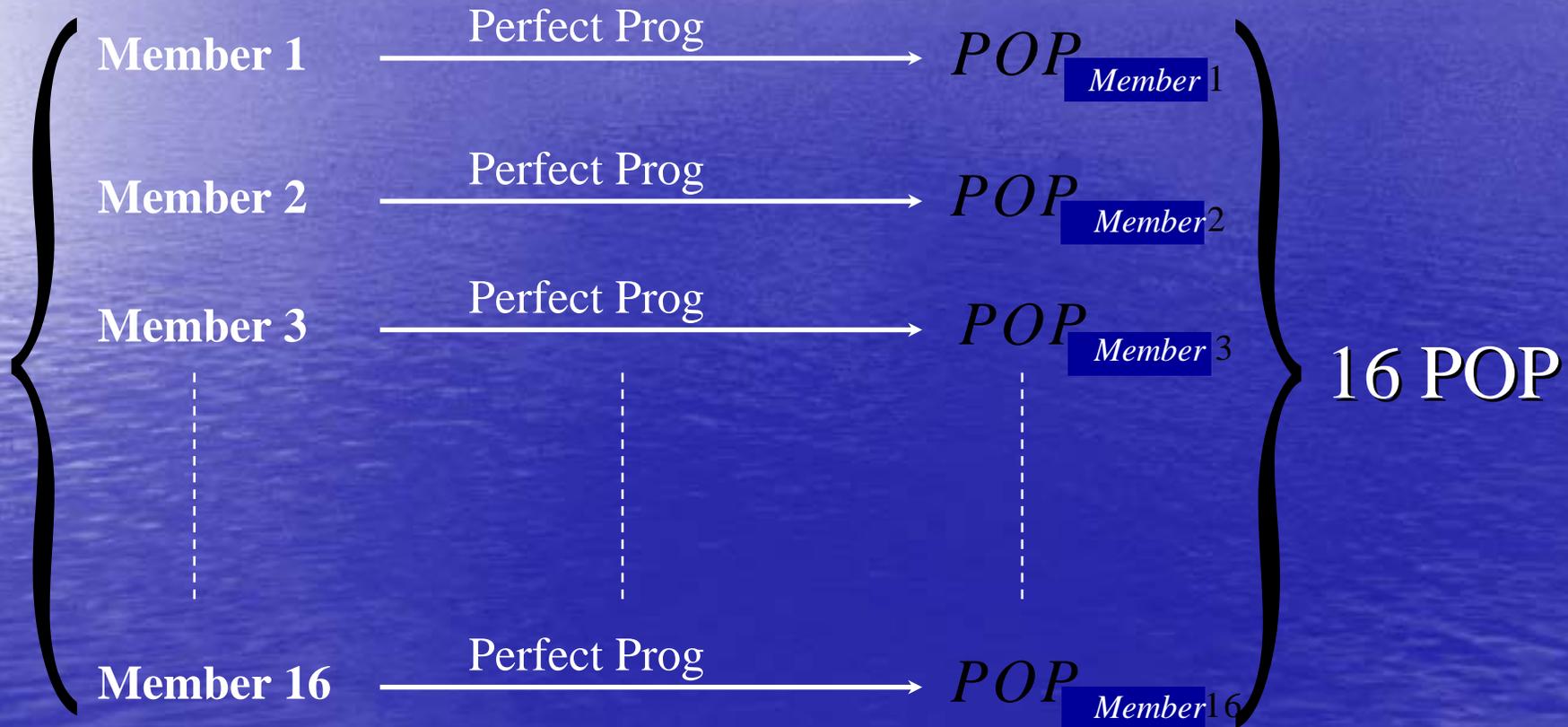
Confidence index

- Goal of the study:
 - Provide a confidence index for the medium range public forecast
- Means of reaching the goal:
 - Spread of the ensemble
 - Use the probability of precipitation as an integrated variable (proxi) that can provide the confidence index



Probabilities of Precipitation (POP)

Perfect prog approach
(uses geopotential heights as predictors)



Verification tools

Brier Score

$$PS = \frac{1}{N} \sum_{i=1}^{264} \sum_{j=1}^{273} (p_{i,j} - o_{i,j})^2$$

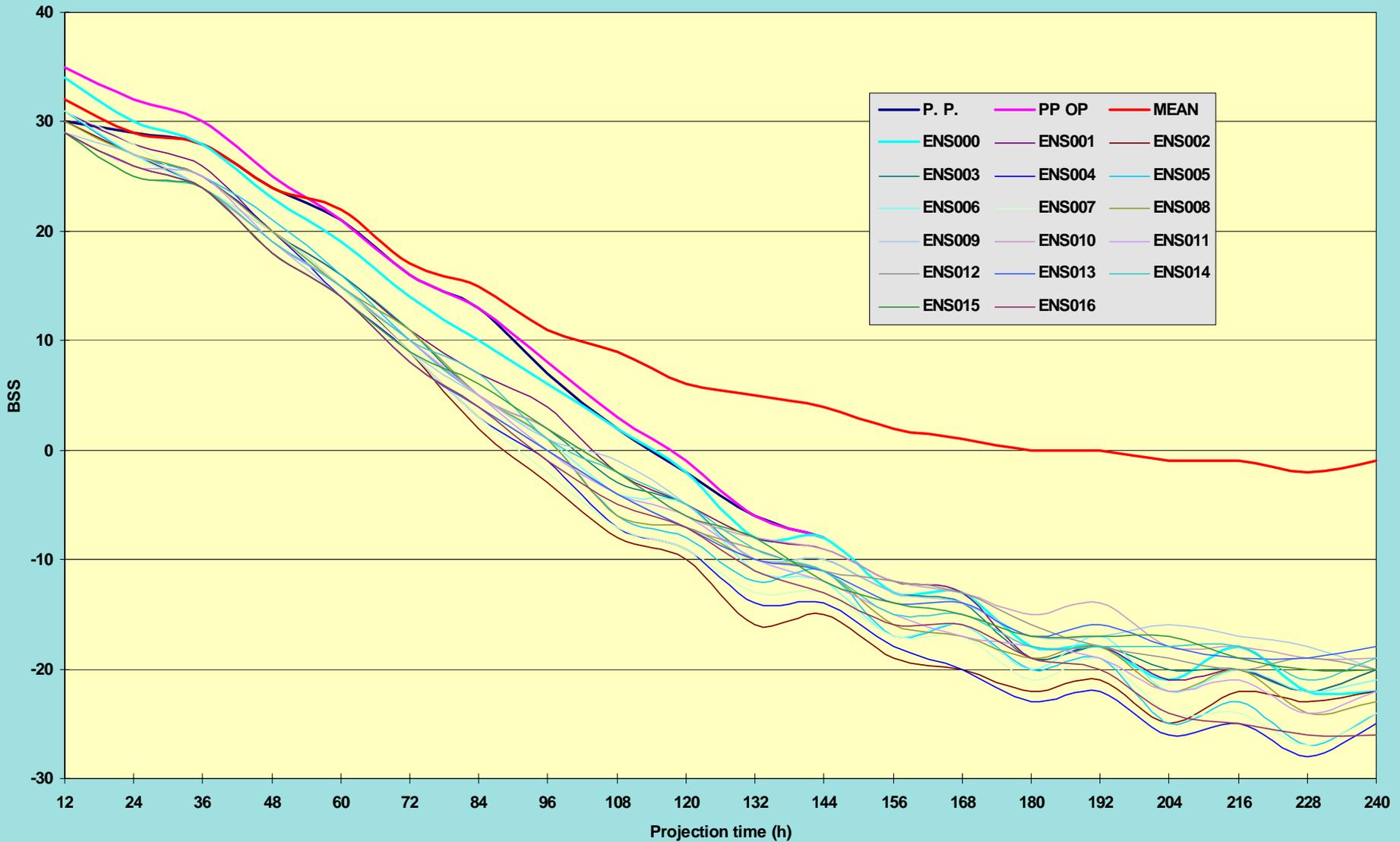
$$BS = (1 - PS) \times 100$$

Brier Skill Score

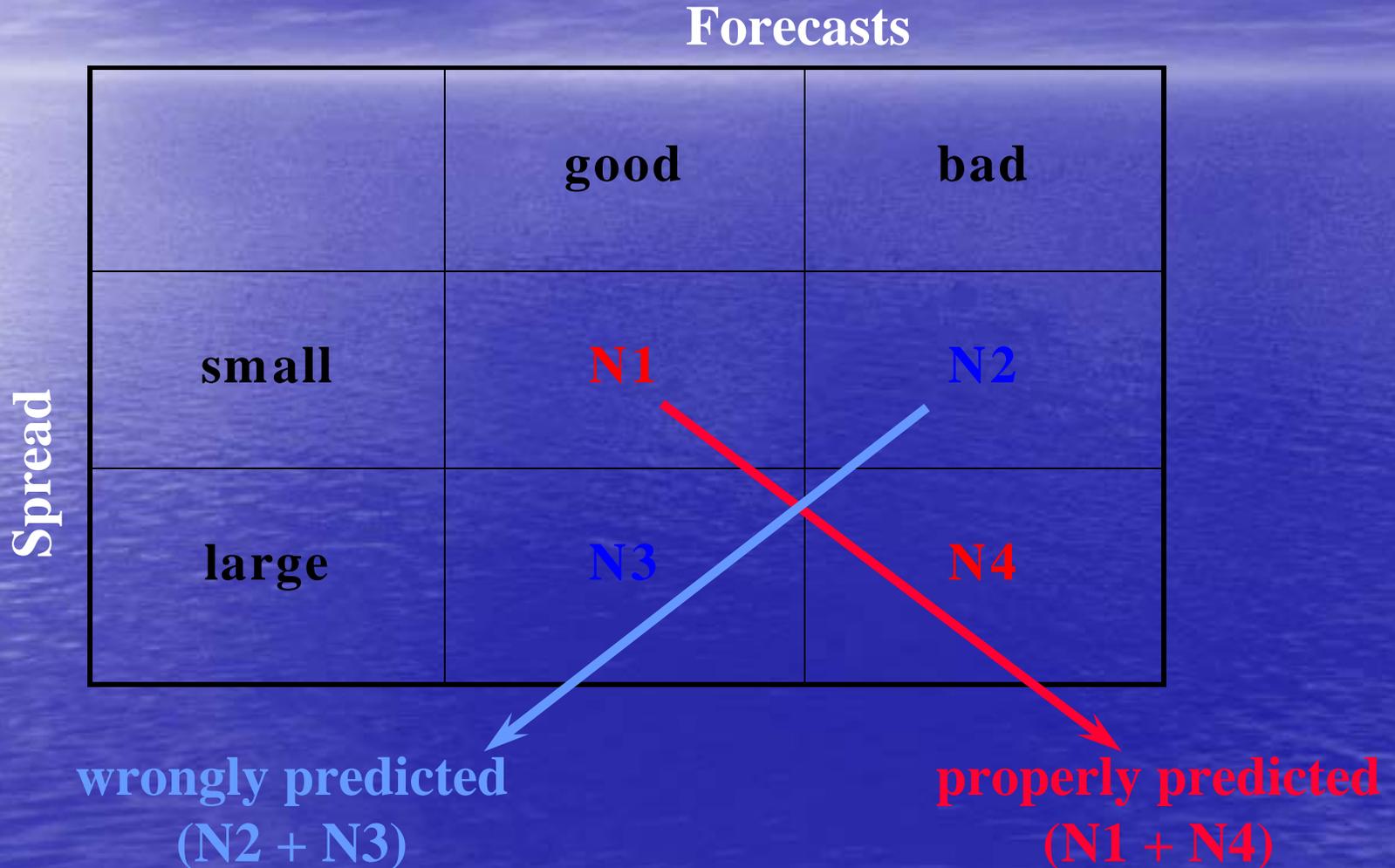
$$BSS = 100 - 100 \frac{PS}{PS_C}$$



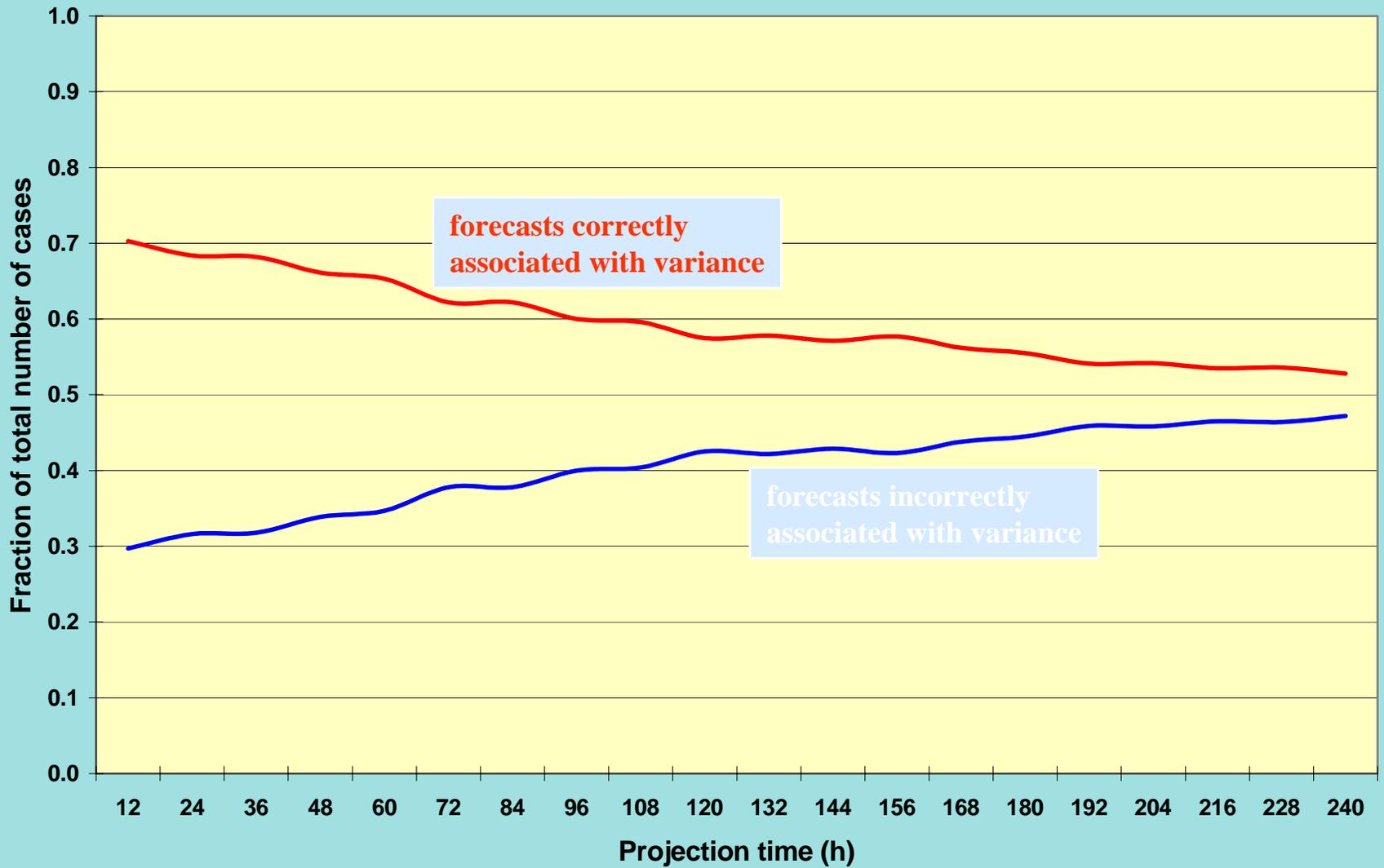
BSS all members and mean 12-h PoP (0.2 mm)
June 1 2000 - December 31 2000

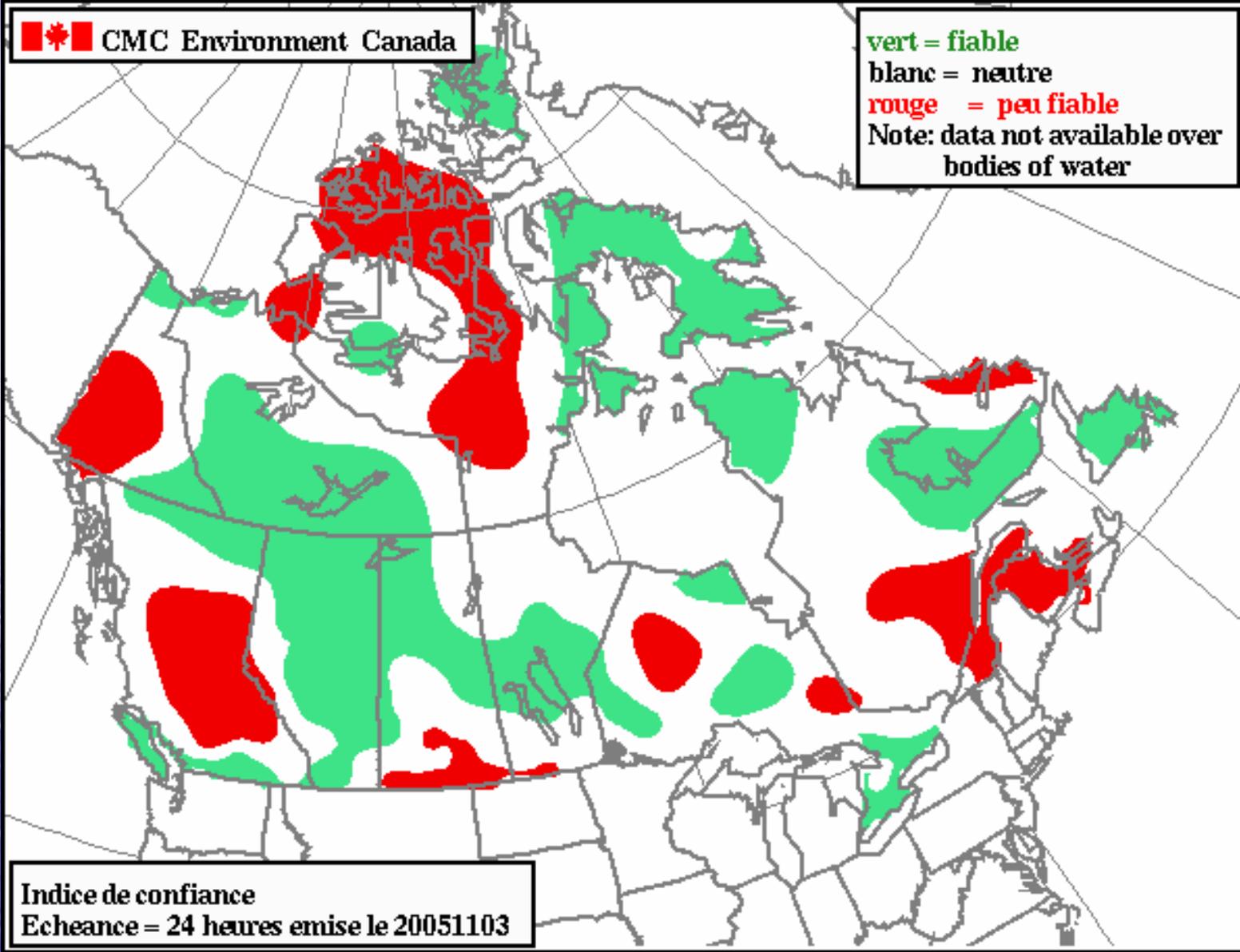


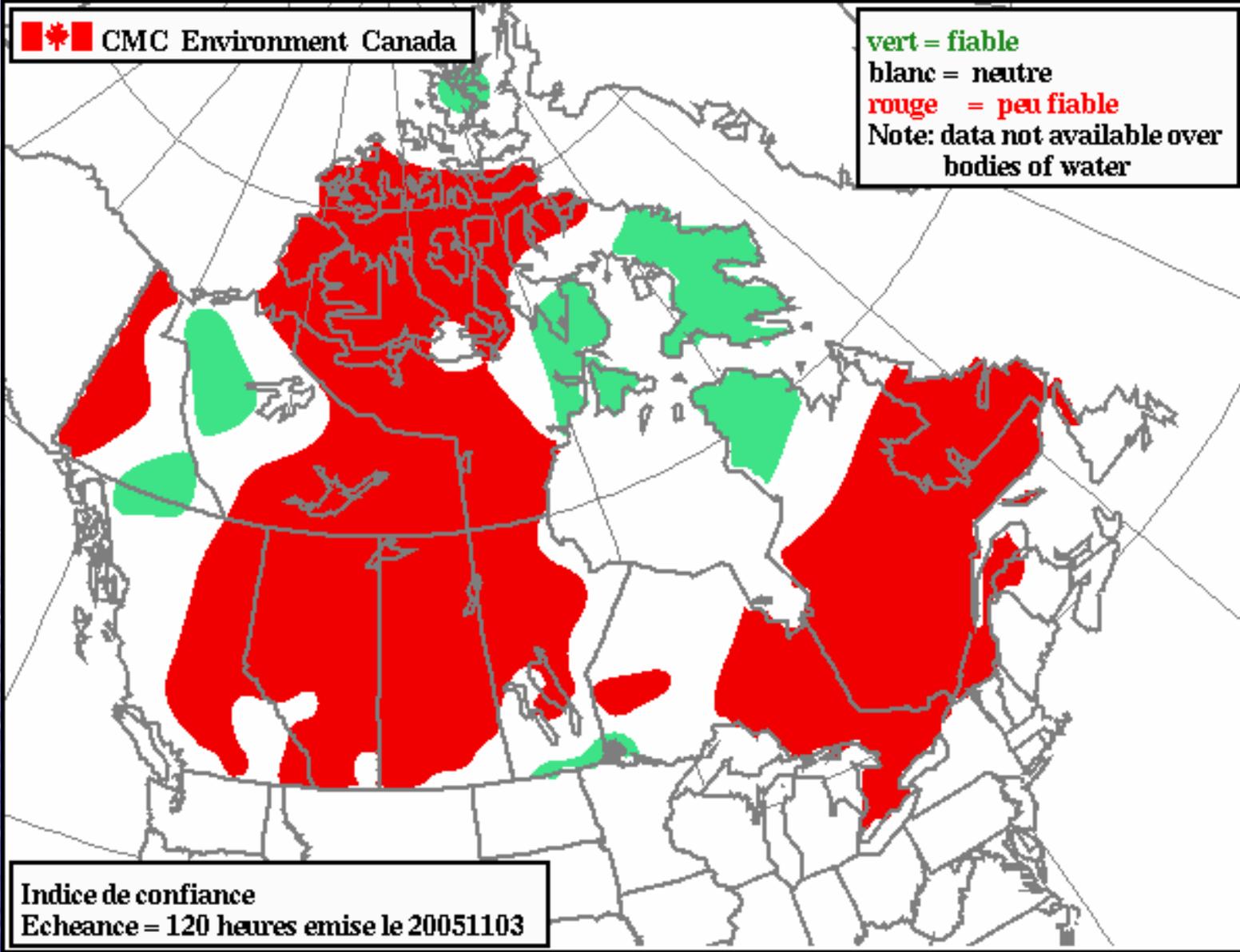
Spread-skill relationship evaluation

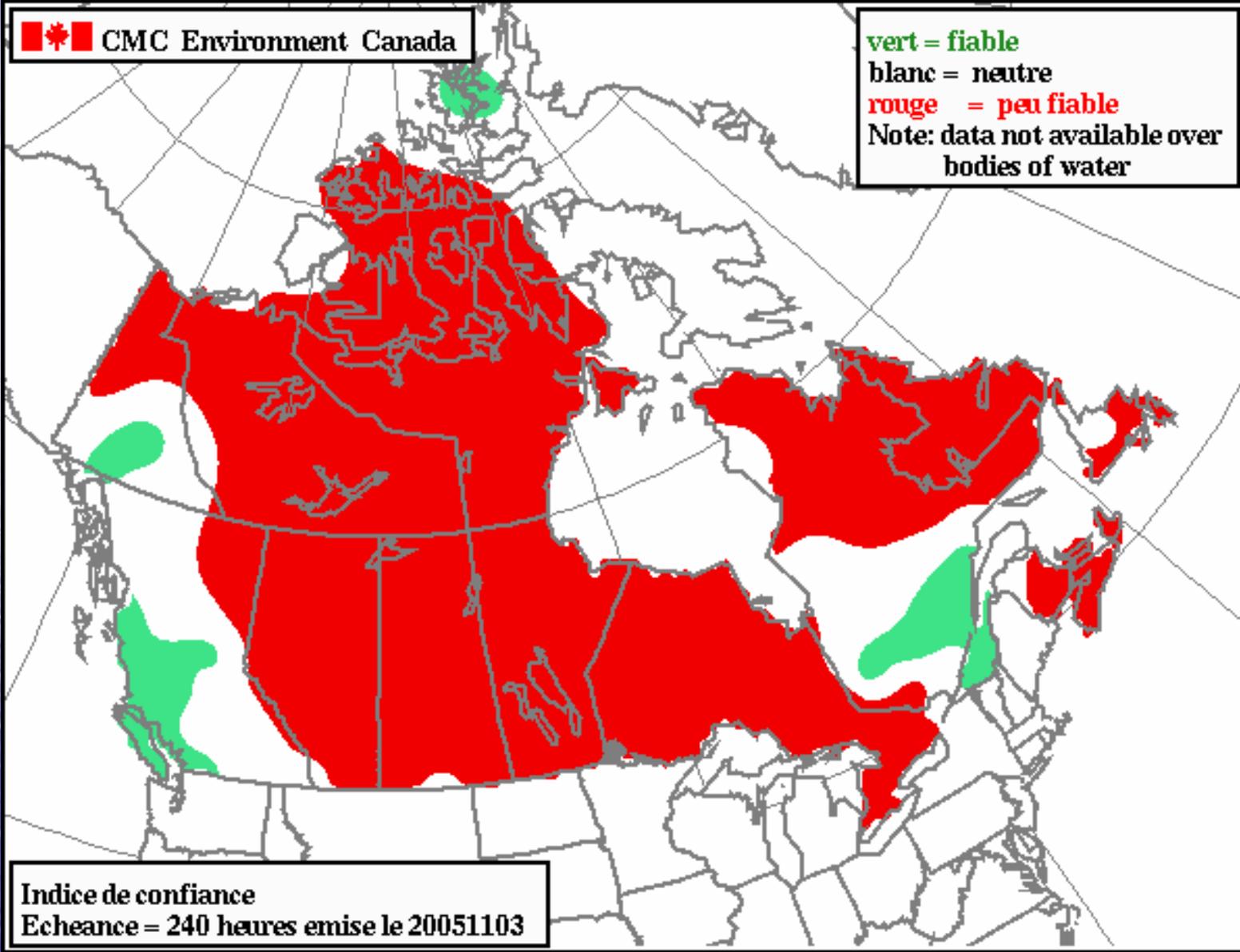


Separation









XCAN11 CMC 262000

**Forecasts for eastern Canada issued by Environment Canada at
4.00 PM EDT Friday 26 October 2001 for tonight Saturday and Sunday.
The next scheduled forecast will be issued at 5.00 AM Saturday.**

Region(s)

Montreal.

Tonight.. Periods of light rain. Low near 3. Southwest winds
30 km/h diminishing to 20 late in the evening.

Confidence index: 2

Saturday.. Cloudy with 40 percent chance of showers near midday.
Clearing in the evening. High near 8. Northwest winds 20 km/h
increasing to 30 near midday.

Confidence index: 2

Sunday.. Sunny. Low near minus 2. High near 7.

Confidence index: 1

Monday.. Mostly cloudy with chance of showers. Low near 4. High
near 9. Probability of precipitation 40 percent.

Confidence index: 2

Tuesday.. Sunny with cloudy periods. Low near 3. High near 5.

Confidence index: 3

Wednesday.. Sunny. Low near minus 3. High near 5.

Confidence index: 3

Thursday.. Cloudy with sunny periods. Low near 5. High near 14.

Confidence index: 3

Friday.. Mostly cloudy with a few showers. Low near 11. High
near 14. Probability of precipitation 60 percent.

Confidence index: 2

Saturday.. Rain. Low near 10. High near 16. Probability of
precipitation 80 percent.

Confidence index: 1

Sunday.. Variable cloudiness. Low near 6. High near 10.

Confidence index: 1

Normals for the period.. Low 1. High 10.

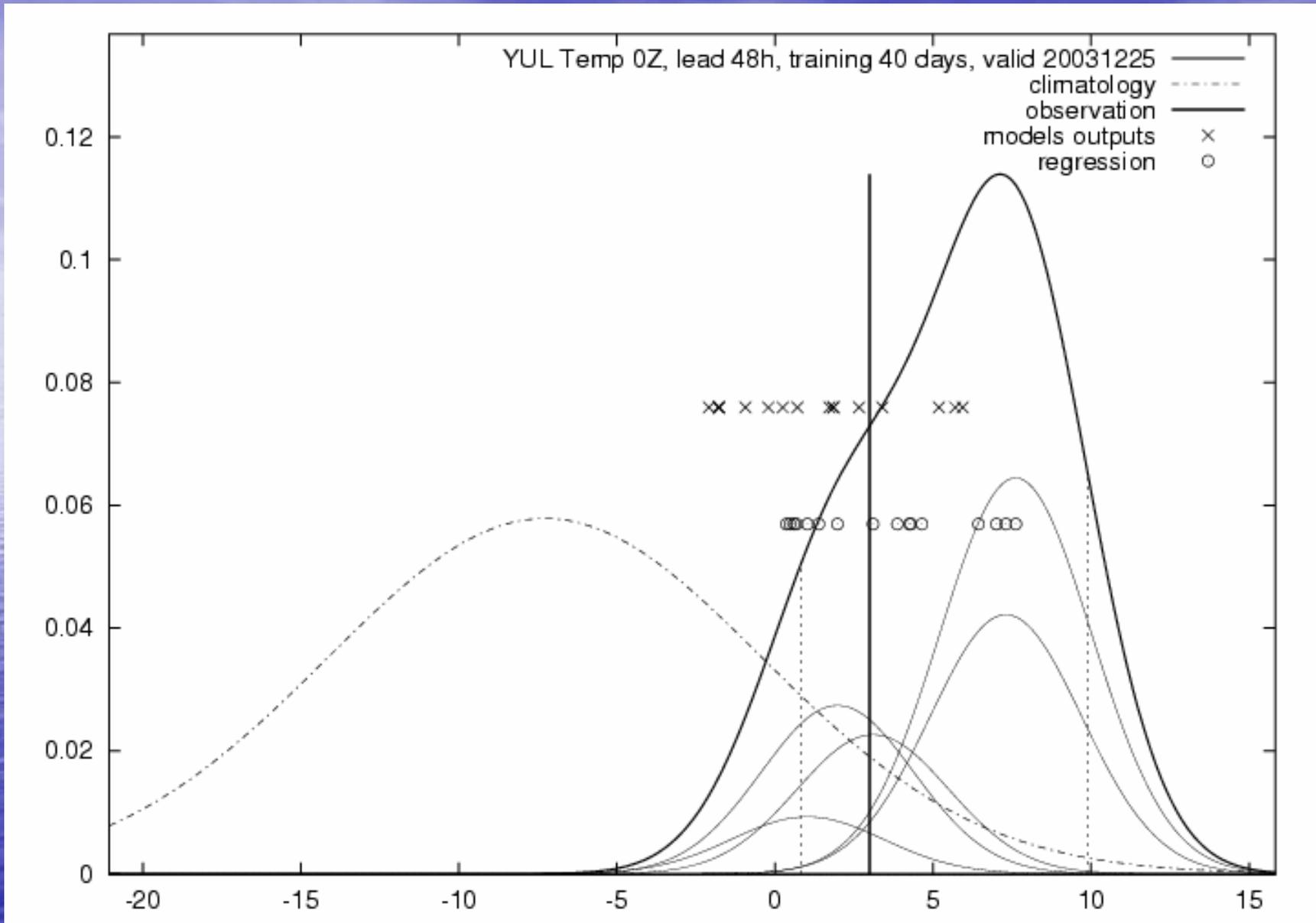
Confidence index can take the values 1, 2 or 3 and gives
an indication of the expected variability of the atmosphere.
The higher the value, the higher is the variability of the
atmosphere and forecasting is more difficult. Lower index
values indicate a more reliable forecast than higher values.



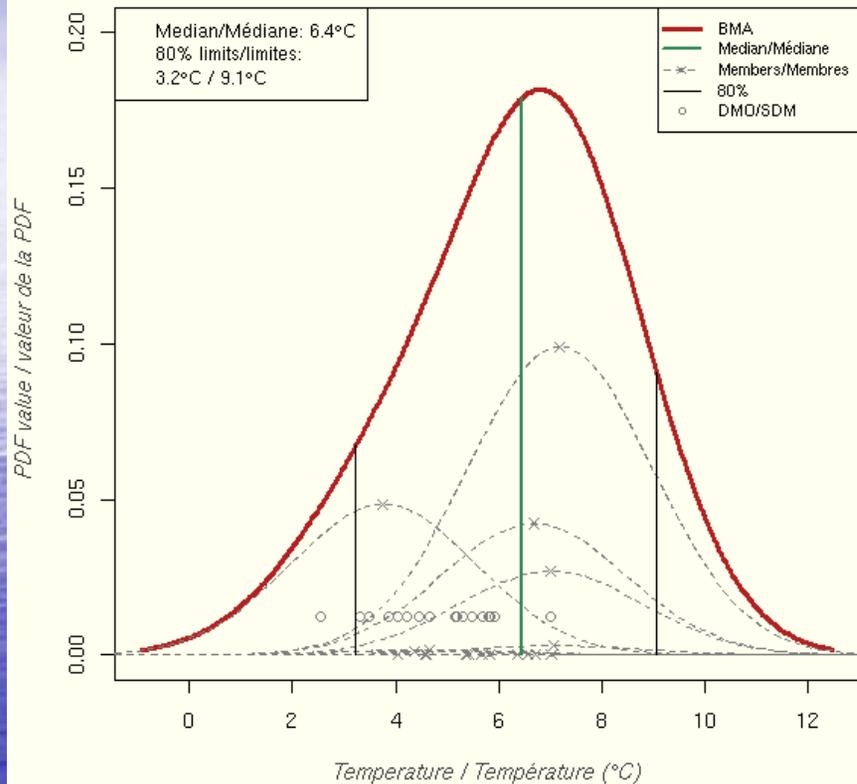
Bayesian Model Averaging (BMA)

- Designed for combining predictive distribution from different models.
- Particularly well suited to EPS with distinct models or to blend members from different EPS (super-ensemble).
- BMA PDF is a weighted average of PDF's centered on individual bias-corrected forecasts from EPS members.
- BMA works well at correcting bias and under-dispersion.
- There seems to be little dependency on the length of the training period although 40 days appear to work best.
- BMA weights appear to be useful diagnostic tool.
- Control and high resolution models often have larger weights.
- Future:
 - Include NCEP members.
 - Statistical weather elements (PP).
 - Challenges:
 - Precipitation.
 - Wind speed.

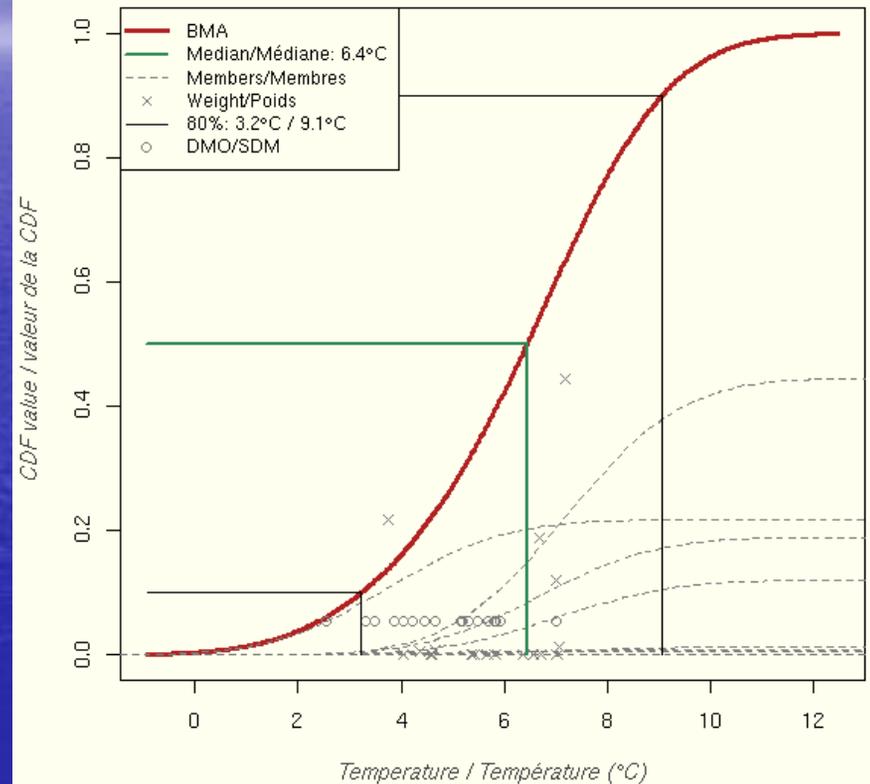




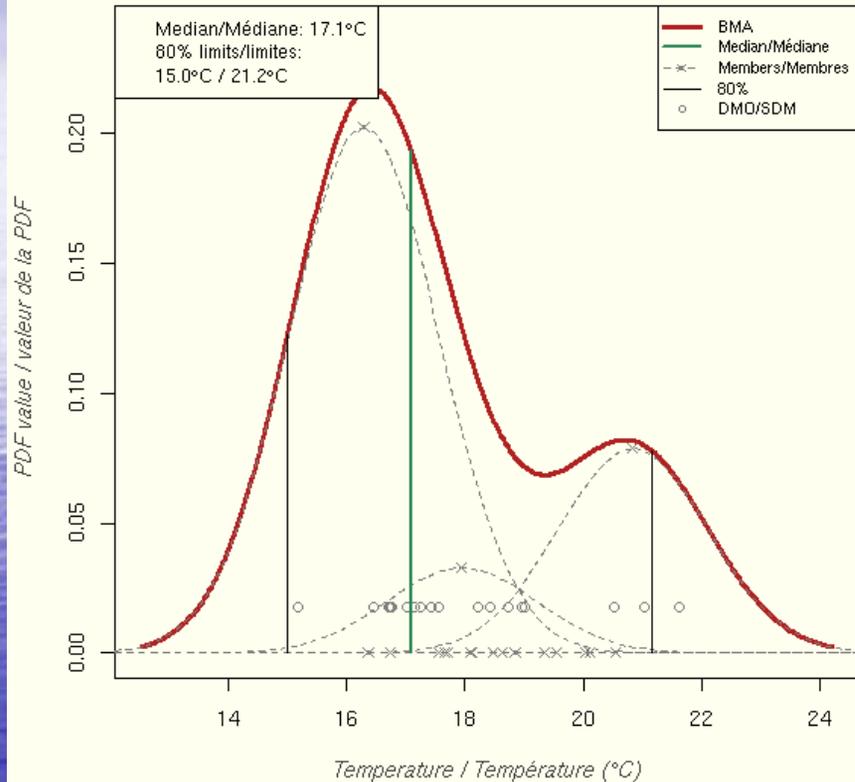
BMA, station 6271CYUL
prev 60h, valid/valide 20051103 12Z



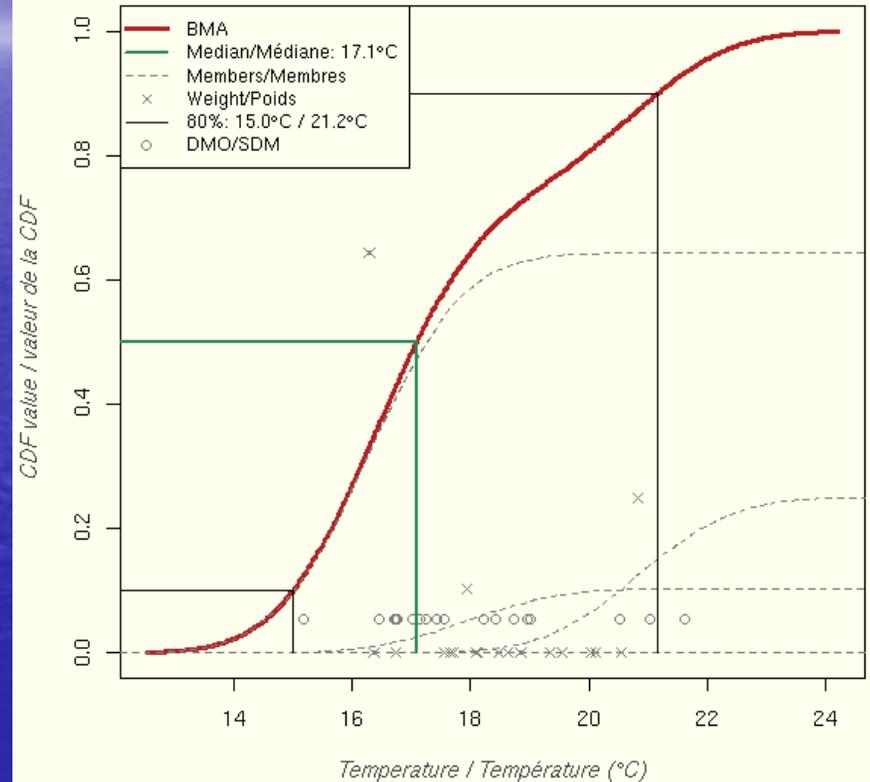
BMA, station 6271CYUL
prev 60h, valid/valide 20051103 12Z



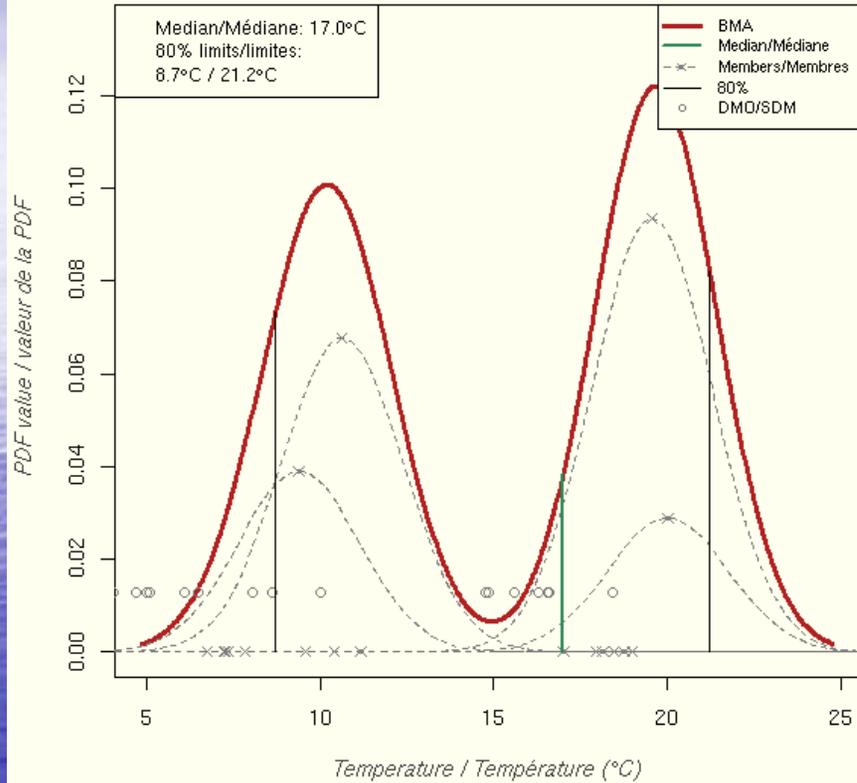
BMA, station 6271CYUL
prev 63h, valid/valide 20050920 15Z



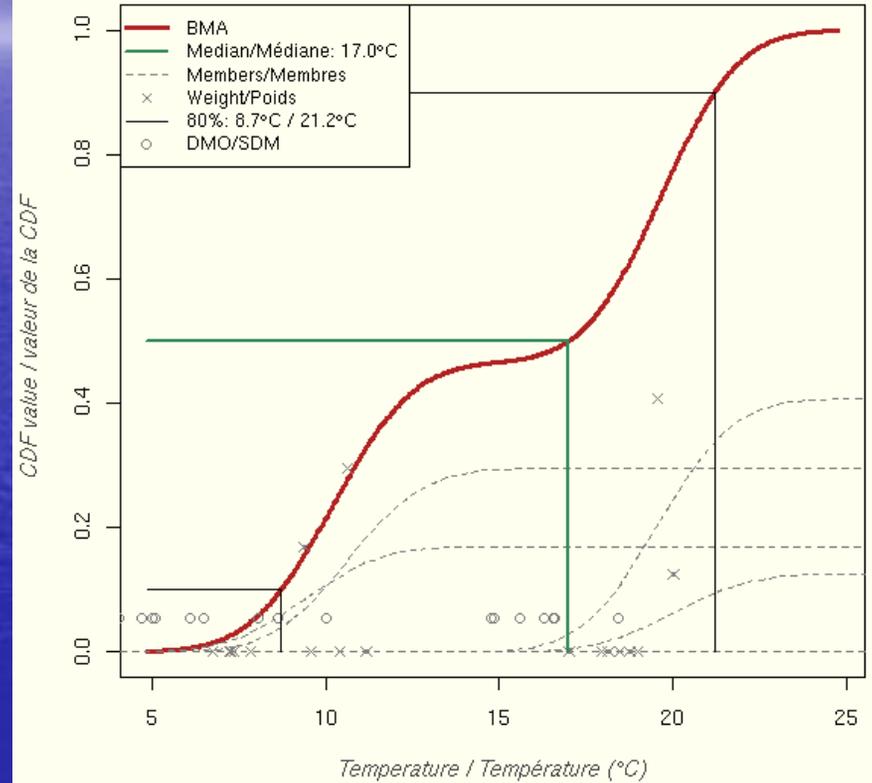
BMA, station 6271CYUL
prev 63h, valid/valide 20050920 15Z



BMA, station 6271CYUL
prev 120h, valid/valide 20051007 00Z



BMA, station 6271CYUL
prev 120h, valid/valide 20051007 00Z



Coming by the end of 2006

(for Canadian EPS)

- Land Surface Modeling: ISBA (Intéraction Sol-Biosphère-Atmosphère) instead of Force-Restore for all members
- GEM model for all members
- stochastic physics
- higher resolution (400X200 grid)
- New Ensemble Kalman Filter (EnKF) for perturbed analyses
- Regional ensemble forecast system
 - 20 members @ 28 km resolution for North America (LAM configuration)
 - 15 members @ 15 km resolution for Eastern Canada (LAM also)



MESH*: A Canadian Community Hydrologic Prediction System

** Modélisation Environnementale:
Surface et Hydrologie*

V. Fortin¹, A. Pietroniro², P. Pellerin¹, B. Davison³

- ¹ RPN: Numerical prediction research, Meteorological Service of Canada (MSC)
- ² NWRI: National Water Research Institute
- ³ HAL: Hydrometeorology and Arctic Lab, MSC



Environment Canada
Meteorological Service of Canada
Canadian Meteorological Centre

Environnement Canada
Service météorologique du Canada
Centre météorologique canadien



MEC and MESH

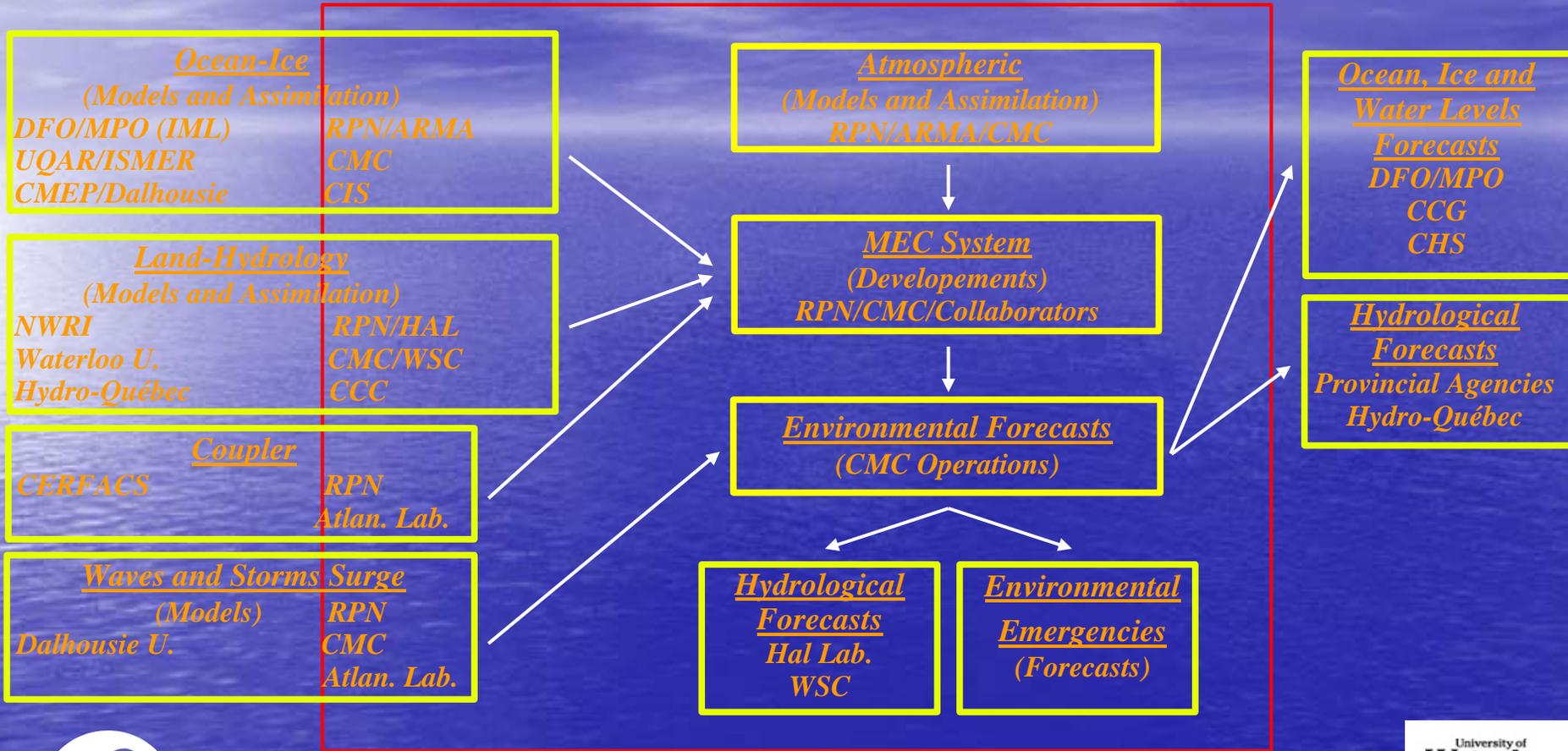
- MEC: A community environmental modelling system:
 - Stands for *Modélisation Environnementale Communautaire*
 - Multi-model / Multi-grid model driver and coupler
 - Should become the model driver for operational NWP in LAM mode at MSC
- MESH: A community hydrologic prediction system within MEC:
 - Stands for MEC – Surface and Hydrology



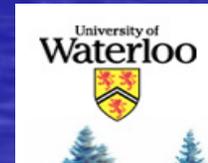
MEC

Modelling Environmental Community System
Système de Modélisation Environnementale Communautaire
Systeme MEC System
 Collaborations based on joint investment for mutual benefits

Meteorological Service of Canada

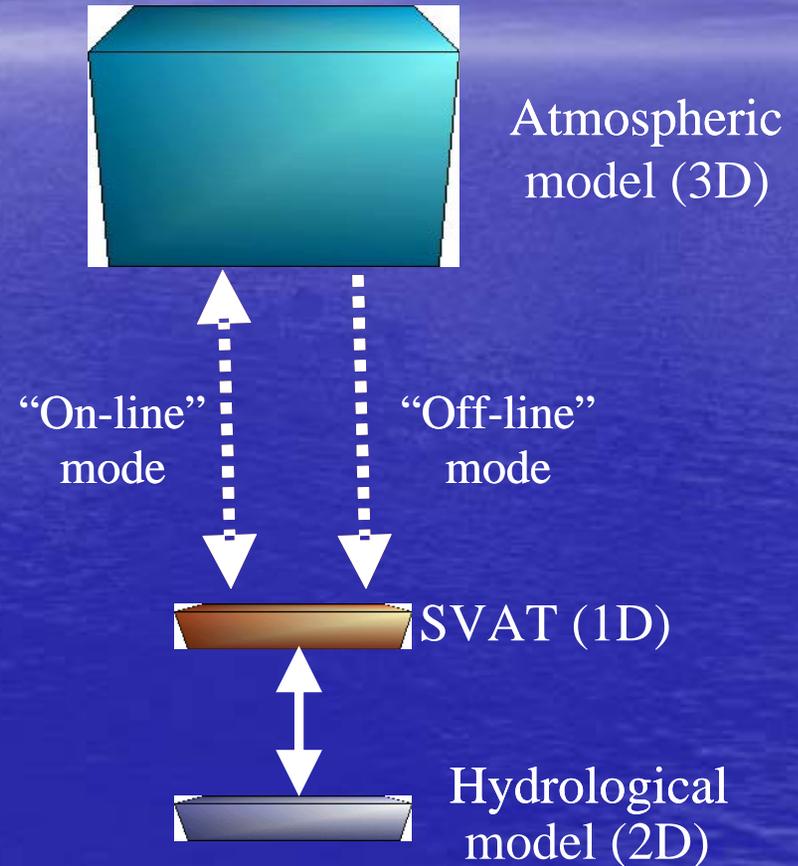


NWRI • INRE



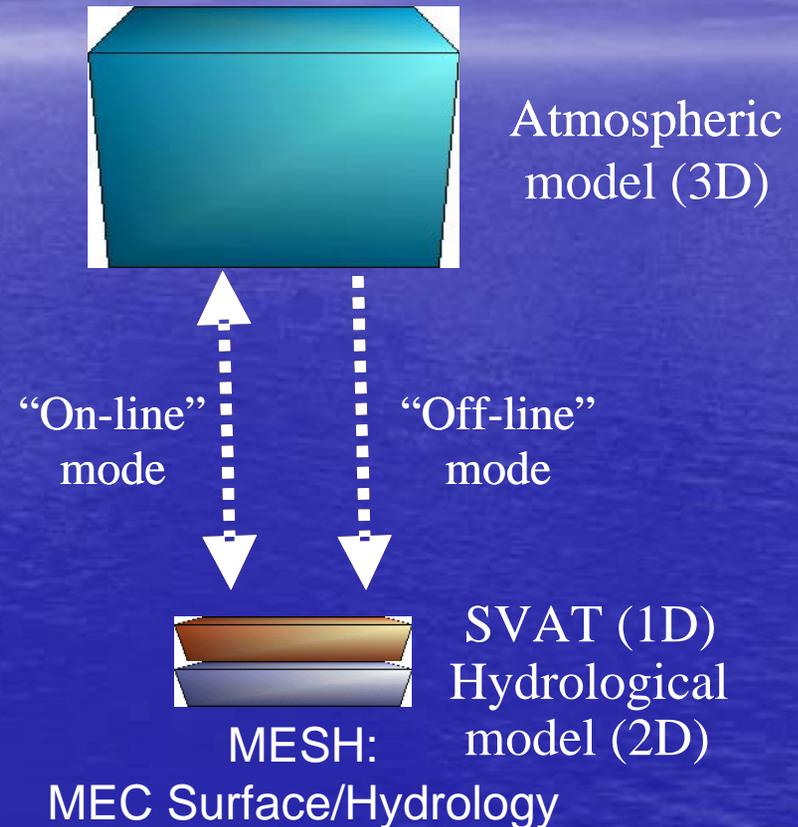
MEC: a hydrometeorologic model driver

- Models available within MEC:
 - Atmosphere: GEM
 - Surface: force-restore, ISBA, CLASS, WATFLOOD
 - Hydrology: GRU approach based on WATFLOOD
- Uses MPI for parallel processing
- It is quite simple to make surface/hydrological simulations offline at high resolution and over a large domain
 - e.g. with reanalyses or archived forecasts



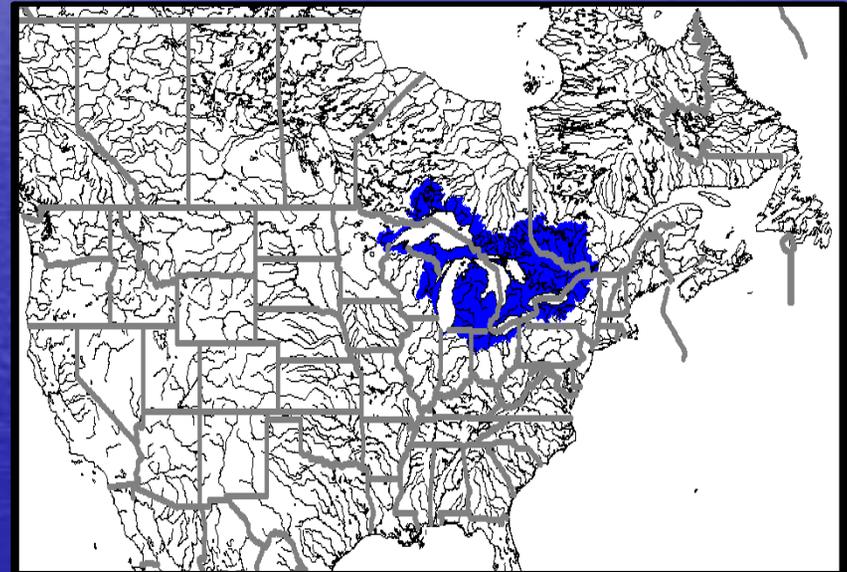
MEC/MESH mode

- The surface model is less costly to run than the atmospheric model, and can benefit from a higher resolution
 - It can be run at the resolution of the hydrologic model
 - The SVAT and the hydrologic model can then be closely linked to better parameterize subgrid-scale processes
 - The atmospheric and hydrological models still share the same SVAT



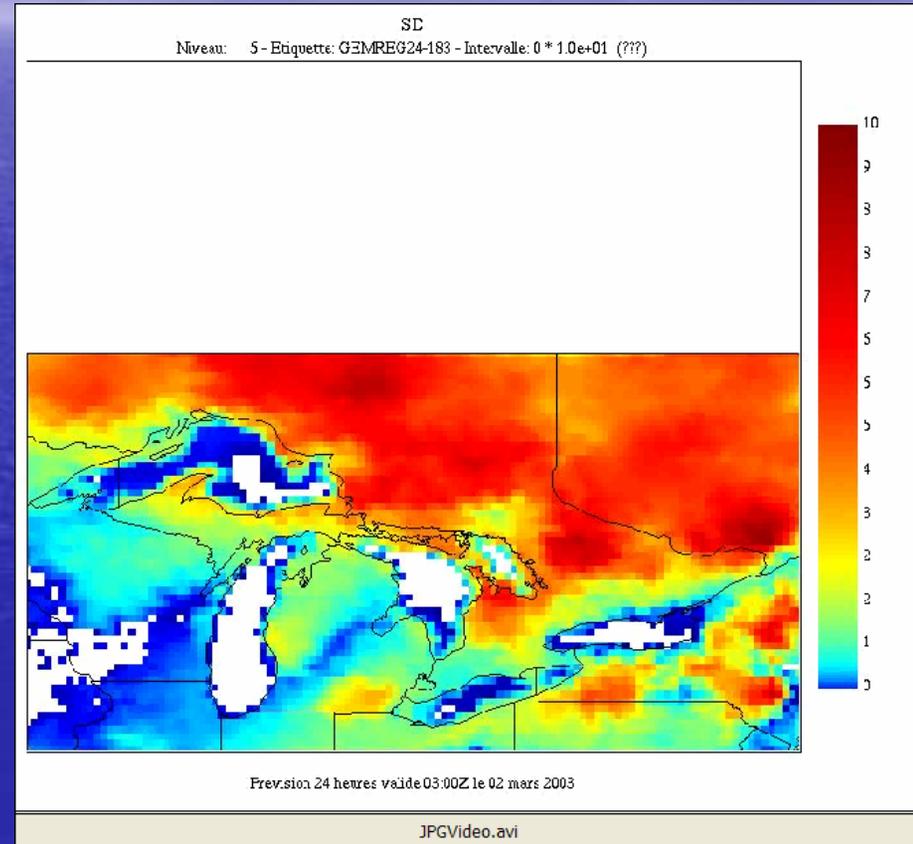
Ensemble Environmental Predictions using MEC/MESH

- Test case for MEC/MESH
 - St-Lawrence basin,
north of Montréal, QC
 - Including all of the
Great Lakes (~1M
km²)
 - March-August 2003



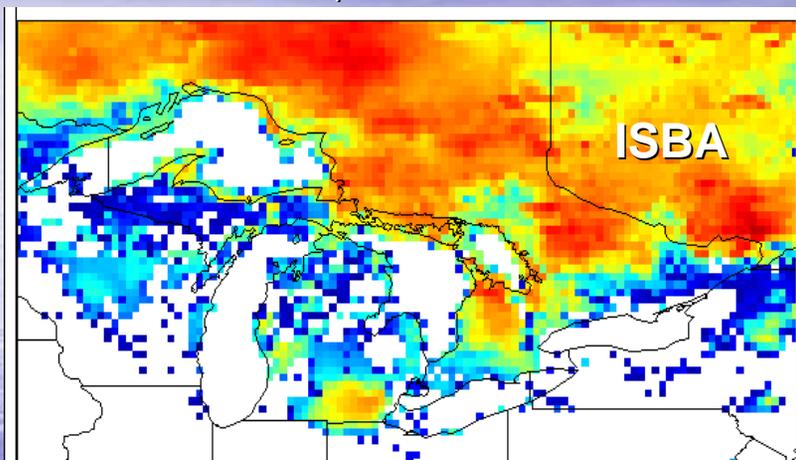
Snowmelt simulation with MEC

- Snow depth simulation
 - March-April, 2003
 - ISBA @ 15km
 - forced by GEM @ 24km
 - Continuous sequence of 18h-30h forecasts

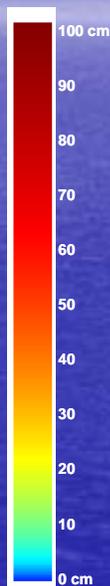
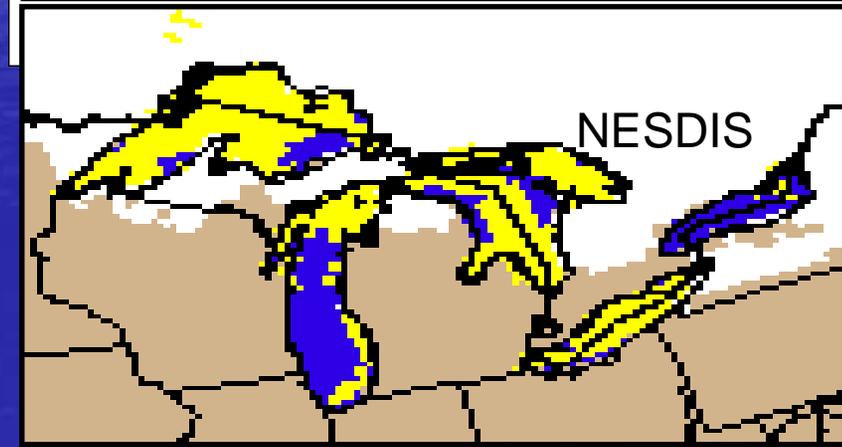
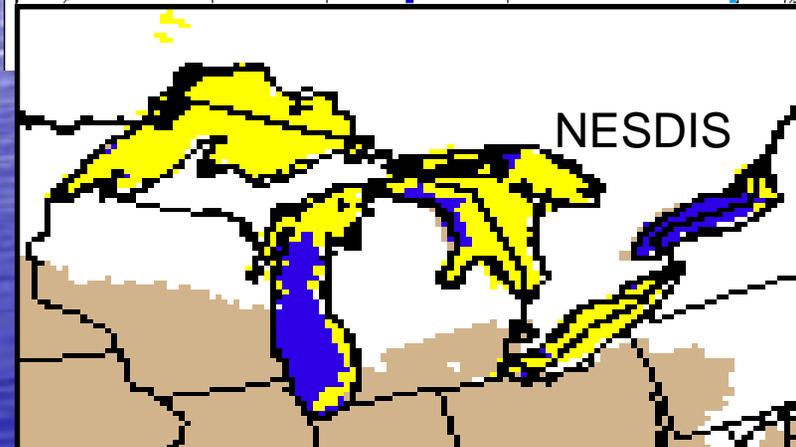
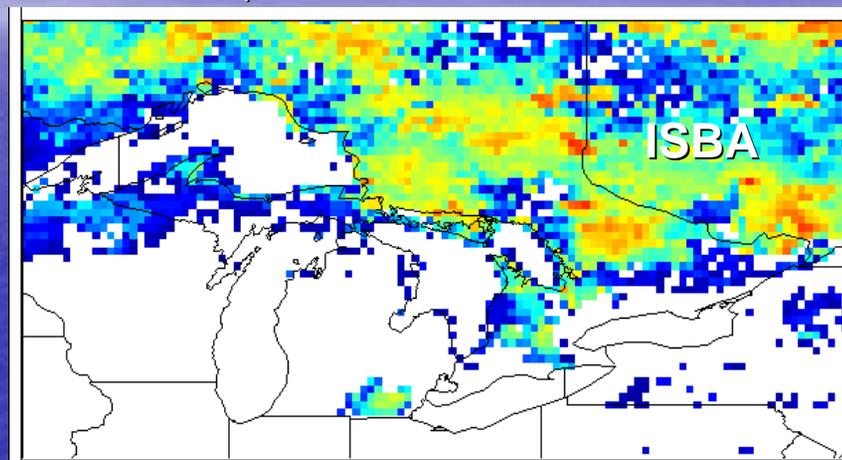


A comparison with NOAA/NESDIS snow cover analyses

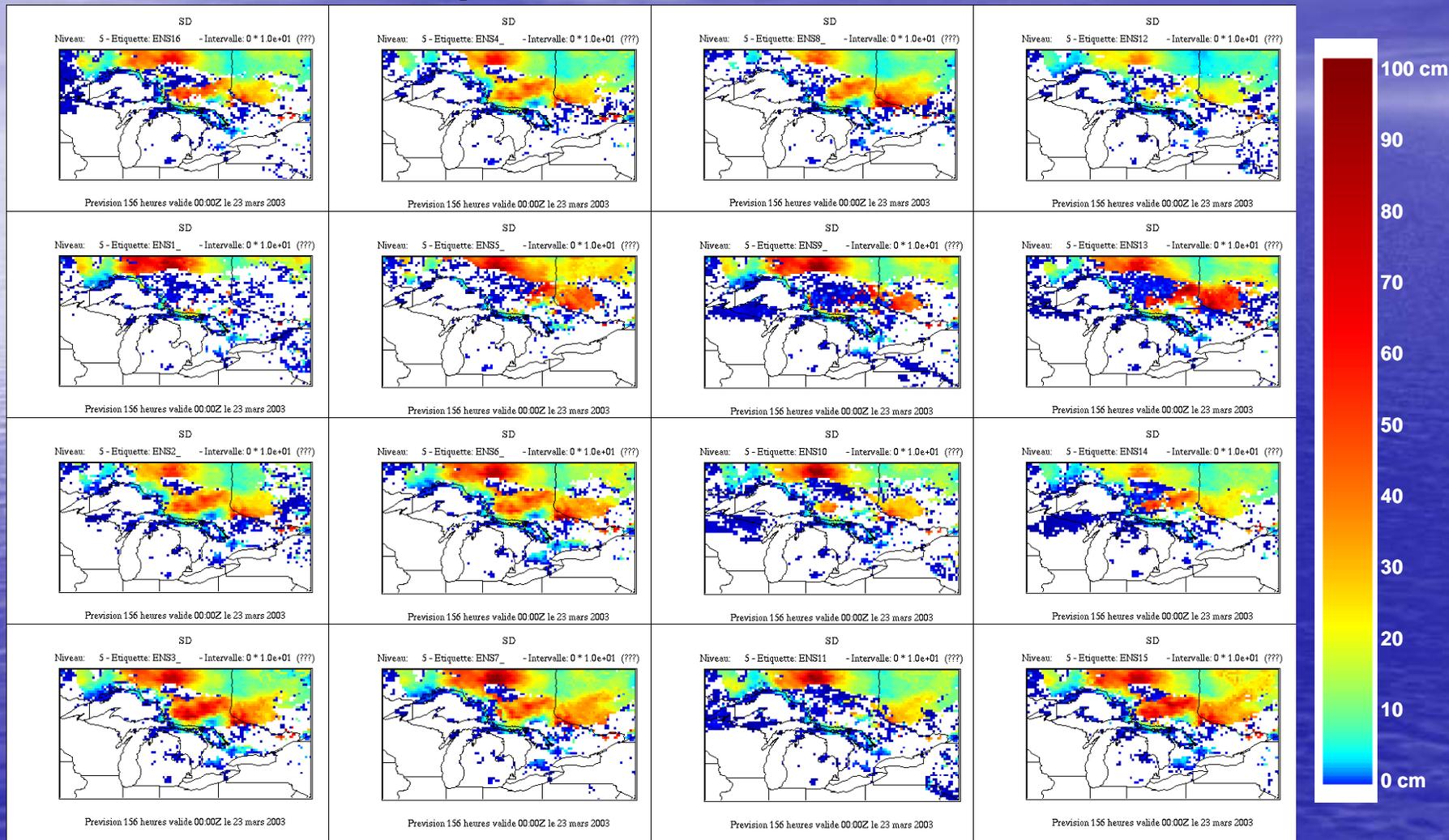
- March 16, 2003



- March 23, 2003



1-week ahead Ensemble forecasts of snow depth for March 23, 2003



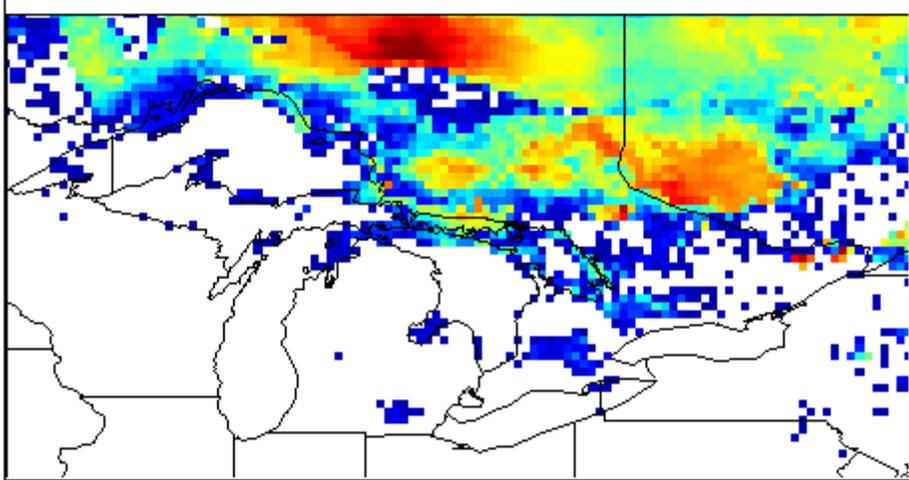
1-week ahead Ensemble forecasts of snow depth for March 23, 2003

7 day-ahead forecast

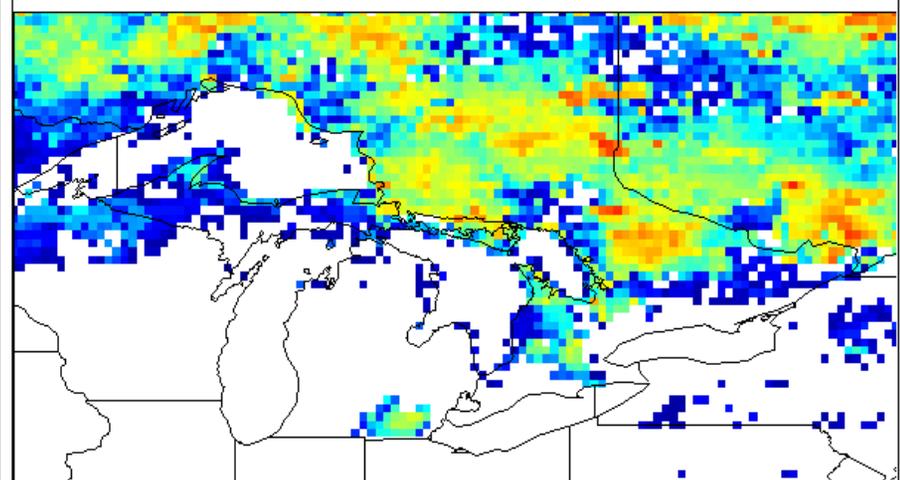
- Mean of the ensemble

Simulated snow depth

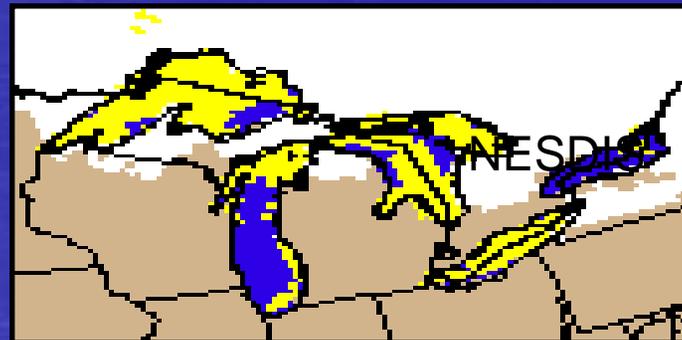
- From March 1st



Prevision 156 heures valide 00:00Z le 23 mars 2003

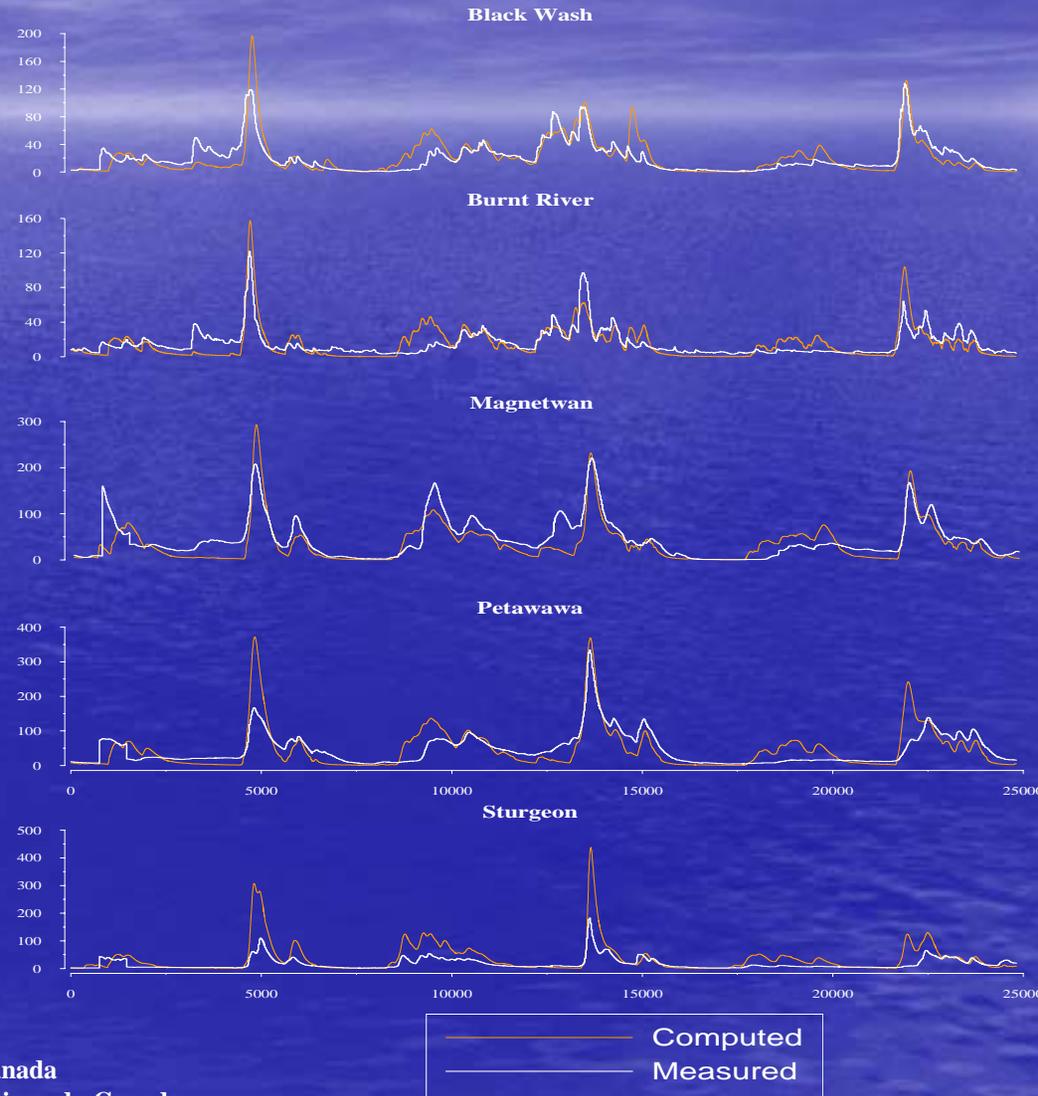


Prevision 528 heures valide 03:00Z le 23 mars 2003

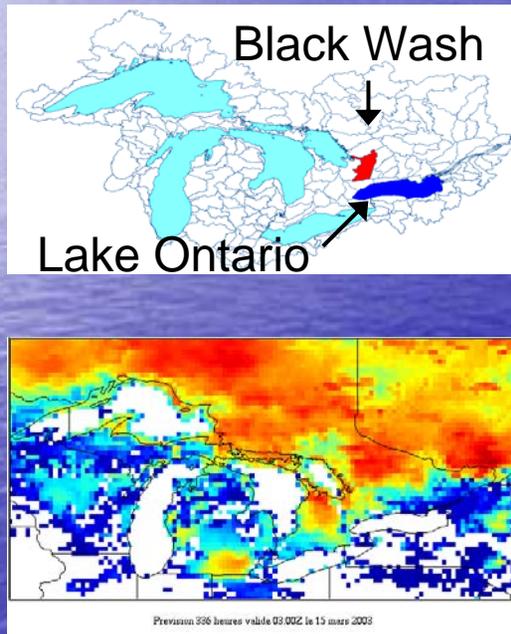


Streamflow simulations results for selected subwatersheds

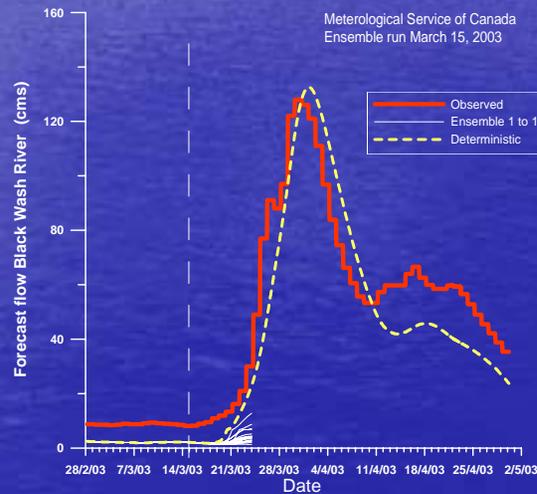
- Forced with synoptic observations of precipitation and temperature
- WATFLOOD land surface scheme



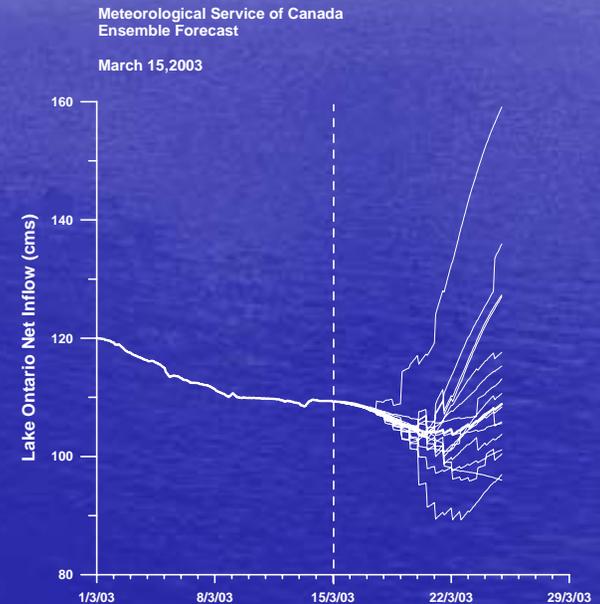
Ensemble streamflow and lake inflow forecasts – March 15, 2003



Snow depth
(as simulated by ISBA)



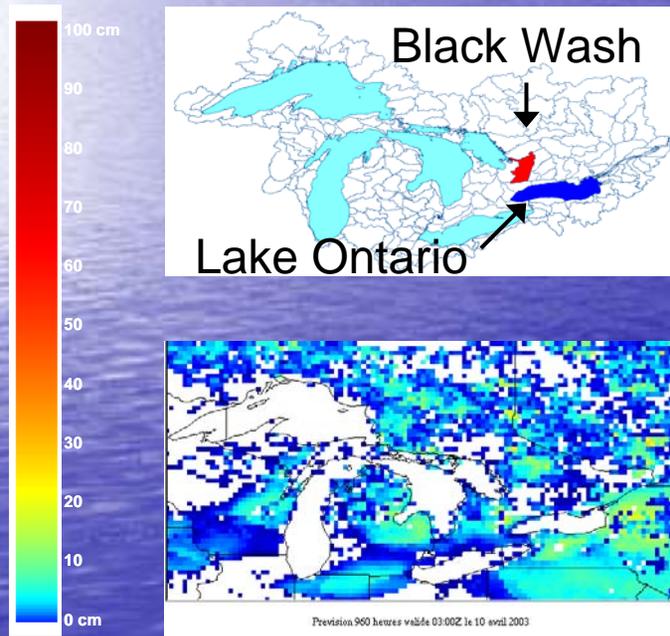
Black Wash



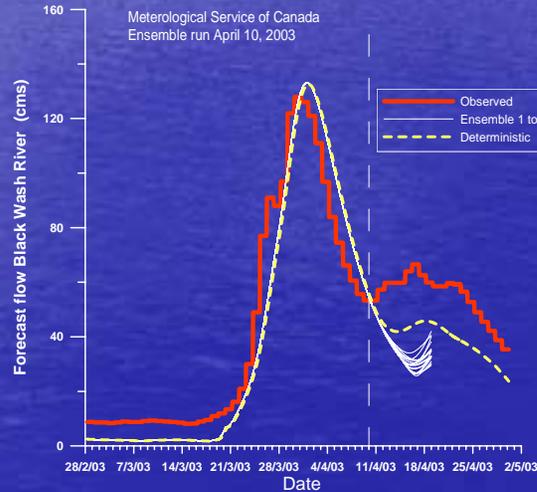
Lake Ontario



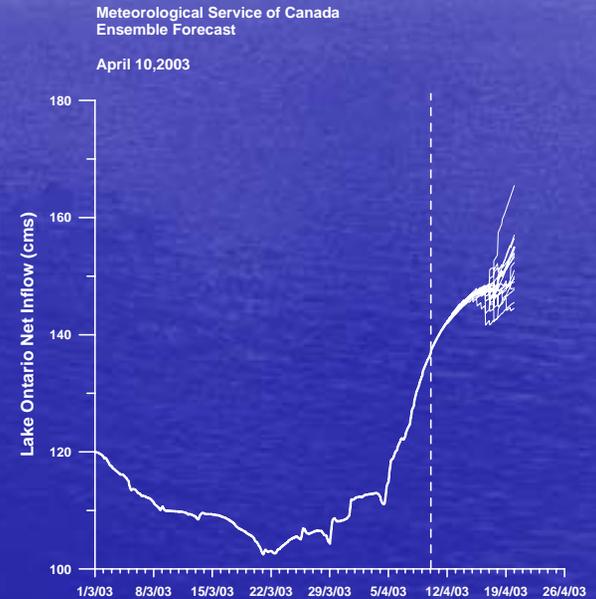
Ensemble streamflow and lake inflow forecasts – April 10, 2003



Snow depth
(as simulated by ISBA)



Black Wash



Lake Ontario



Hydrologic Ensemble Prediction Experiment (HEPEX)

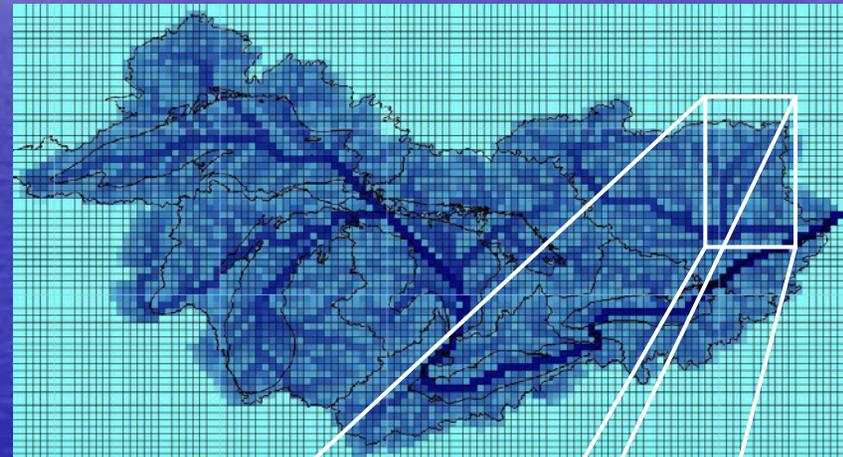
- Improve water resources management through streamflow forecasting based on meteorological ensemble forecasts
- Develop a community hydrologic prediction system (CHPS)
- For nowcasting as well as short- and medium-term forecasting (15 days)
- Based on MEC



The Great Lakes: A canadian test bed

- Forcing:
 - CaPA: 24 km
 - GEM: 24 km for 48h
 - GEM: 45 km for 240h
 - GEM ensemble: 1deg for 240h
- Models:
 - WATFLOOD: 15 km
 - HYDROTEL: \approx 5 km (Gatineau, Châteauguay)
- Test periods:
 - snowmelt: 03-04/2003
 - runoff: 08/2003

WATFLOOD



HYDROTEL

