Environment Canada Environnement Canada

Canada

Centre report:
Recent changes in the NWP suites of Environment Canada

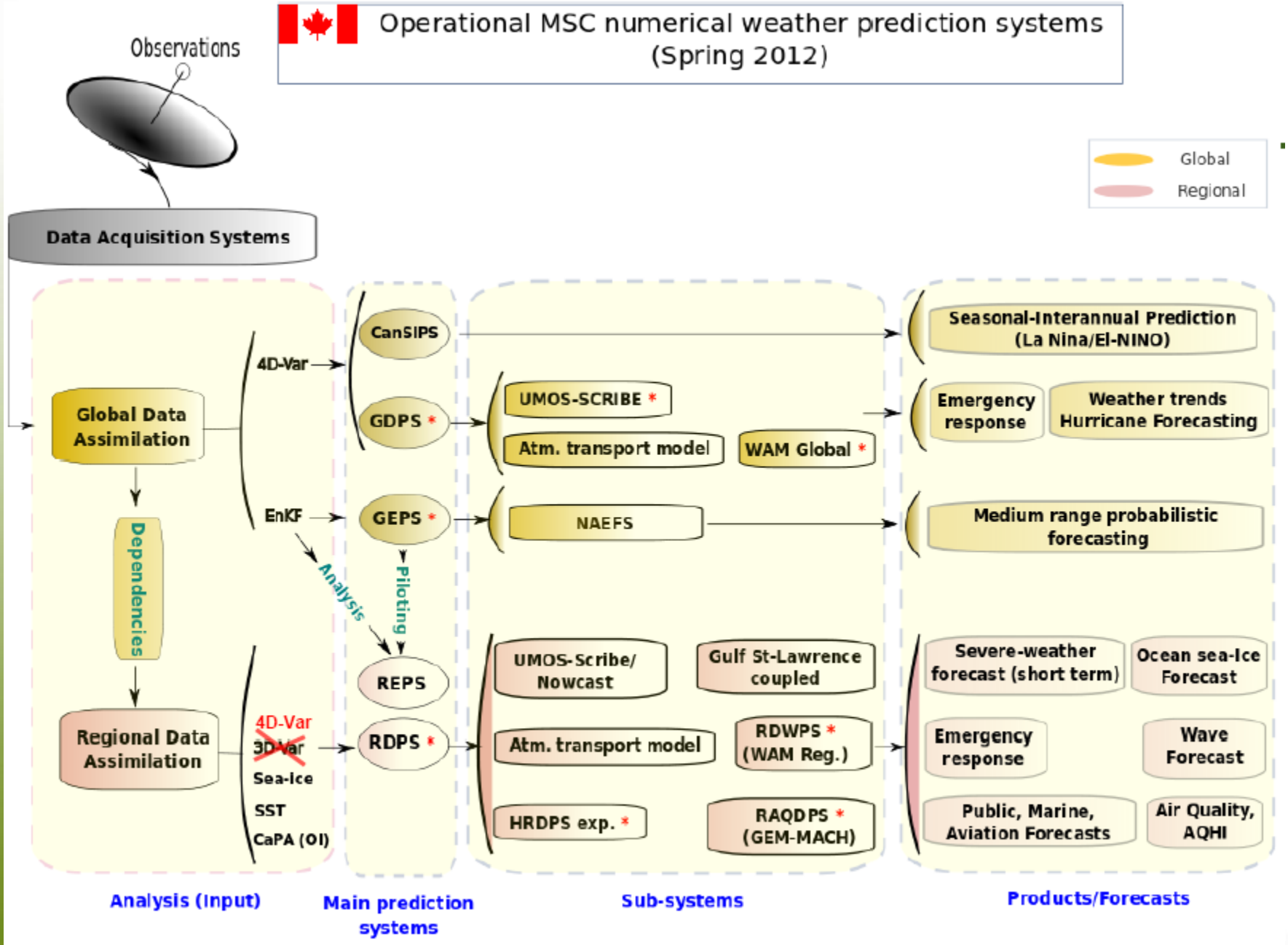
WGNE-28 – Toulouse, France

Ayrton Zadra

RPN – Environment Canada

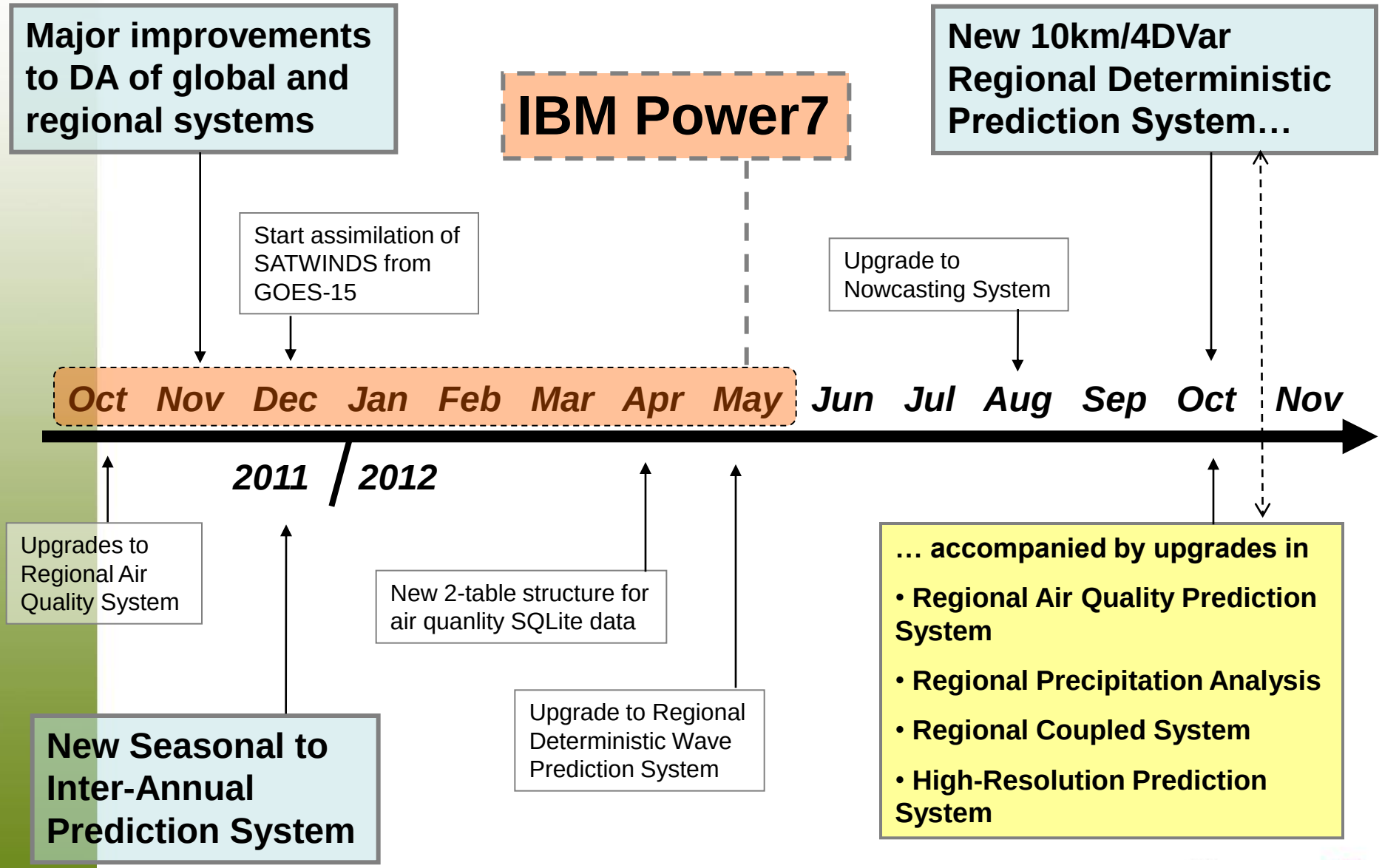
05-09 November 2012

Operational MSC numerical weather prediction systems (Spring 2012)



* : Systems subject to an operational verification

Summary of recent changes



Improvements to global & regional DA systems
(Nov 2011)

New Satellite Data

- 62 infrared channels from the **IASI** instrument on board the METOP satellite.
- 7 microwave channels from the **SSM/IS** instrument on board the DMSP F16 satellite.
- 1 water vapor channel from the **GOES-W**, **METSAT-1R** and both **METEOSAT** satellites.
- Restriction to the infrared channels of the **AIRS** instrument in the polar regions was removed.
- **Horizontal thinning** of all satellite radiance data, previously done at 250 km (except 200 km for SSM/I) was **reduced to 150 km**, therefore adding much more satellite data to the systems.

Amount of data assimilated in the global system

- increase **from ~1.9 million to ~4.2 million** pieces of information per day.

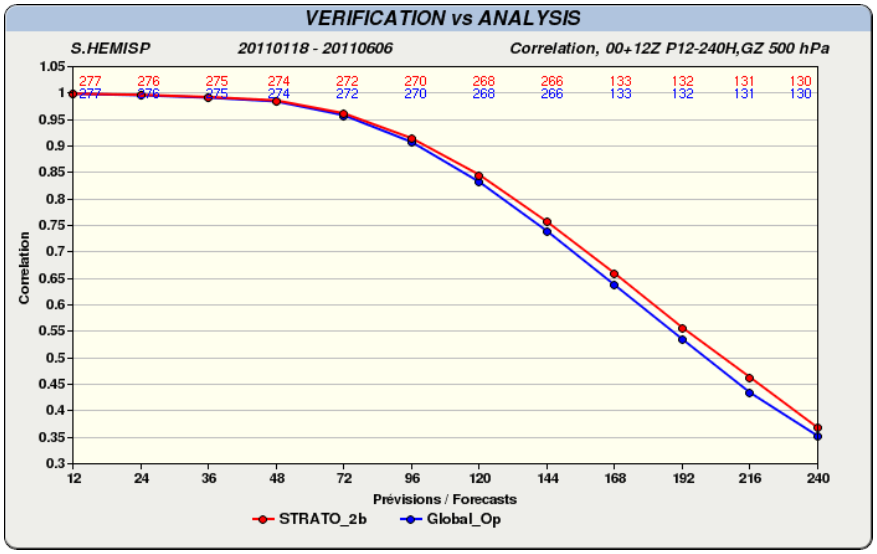


***Fig.1**: GZ-500hPa anomaly correlations over the S. Hemisphere during the parallel run (Jan-Jun 2011): **old** vs **new** global system.*

Other Assimilation Changes

- Moisture observations measured from properly equipped aircraft (AMDAR) are assimilated.
- New satellite data bias correction scheme. The main impact is the reduction of the time period to compute the bias corrections from 15 to 7 days. The same code is used for all radiance data.
- Modified version of the RTTOV radiative transfer code for satellite radiance data.
- **New sea surface temperature analysis** on a grid of 0.20 degrees resolution.

New Canadian Seasonal to Inter-annual Prediction System (CanSIPS)

(Dec 2011)

• Newly developed **global coupled seasonal prediction system** for forecasting **monthly to multi-seasonal (up to 1 year)** climate conditions.

• CanSIPS **can skillfully predict the ENSO** phenomenon and its influence on the climate up to a year in advance.

• CanSIPS is the result of a close **collaboration between CMC and the Canadian Centre for Climate Modeling and Analysis** (CCCma).

• Also **contributing to the multi-model ensemble** forecasts produced by **WMO** and the **APEC** Climate Centre.

• Products from CanSIPS available on: http://www.weatheroffice.gc.ca/saisons/

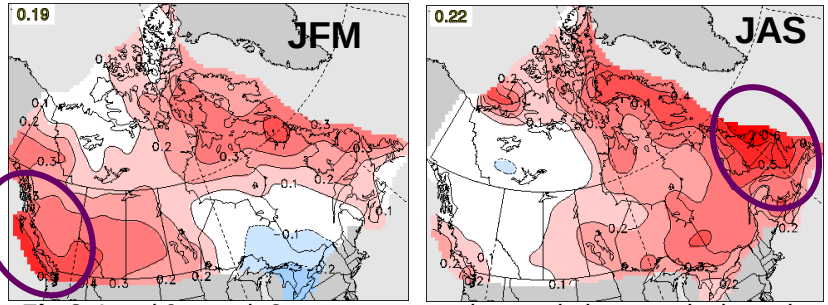


***Fig.2**: Lead 9-month 2m-temp. anomaly correlation: results based on CanSIPS hindcasts show long-lead skill for western (eastern) Canada in winter/spring (summer/fall).*

Characteristics

• 2 atmospheric models (CanAM3 & CanAM4) coupled to 1 ocean model (CanOM4)

• 10 members for each coupled model

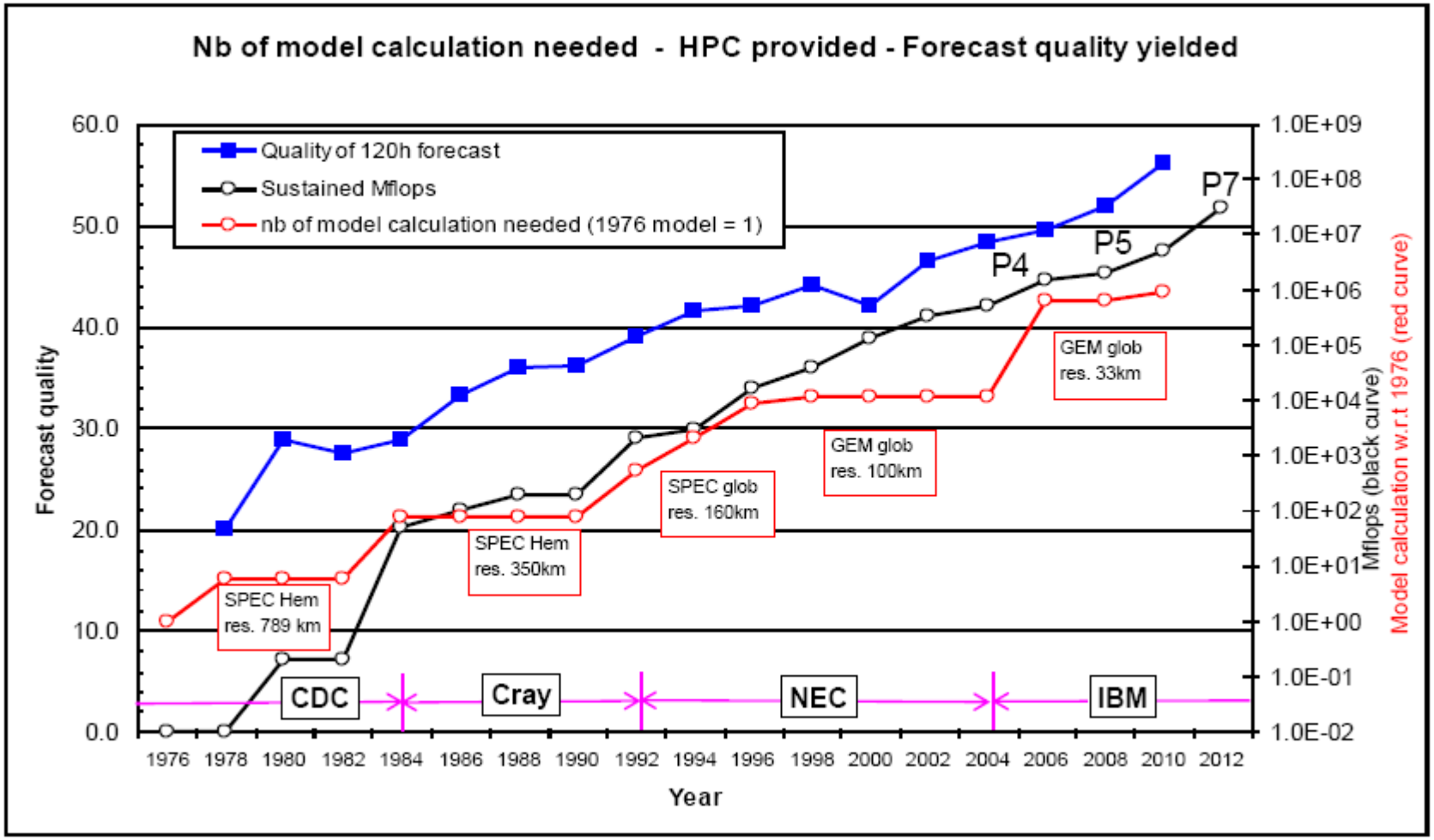
• Initialization/assimilation includes

- *atmospheric T, u, v, q assimilation*
- *SST and sea-ice nudging*
- *simple off-line ocean T assimilation*

New IBM Power7

- 2 clusters; 8192 cores each
- ~ 1/2 PFlops peak total
- *on average,* ***performance gain per CPU about 2.7x*** *compared to P5 CPU*

- System was installed off-site
- Migration of operational jobs took a year to complete
- Fully operational since early May 2012



Major upgrade of the Regional Deterministic Prediction System (RDPS)
(Oct 2012)

Upgrade included:

- **increase in resolution to 10 km** from the previous 15 km
- **4D-Var** data assimilation system replacing the previous 3D-Var
- important **changes in the physics**

Significant improvements in forecasts with most metrics throughout most of the atmosphere, especially:

- for the winter season
- for the lower portion of the atmosphere and at the surface

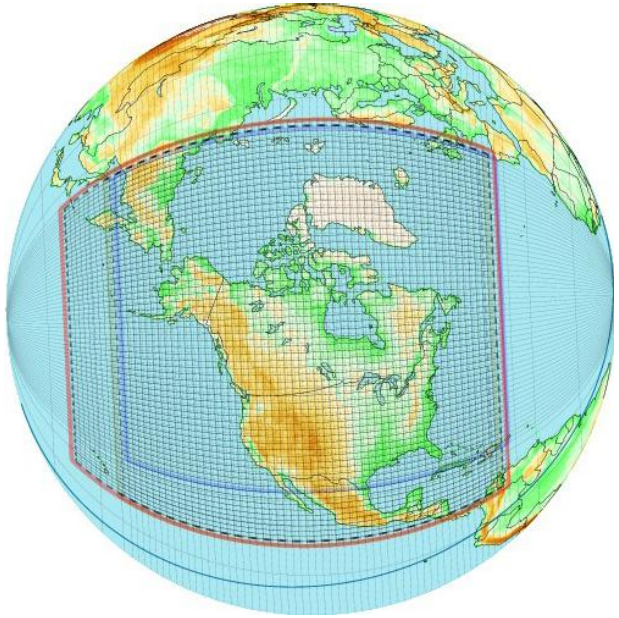


***Fig.4**: The red line indicates the domain covered by the RDPS.*

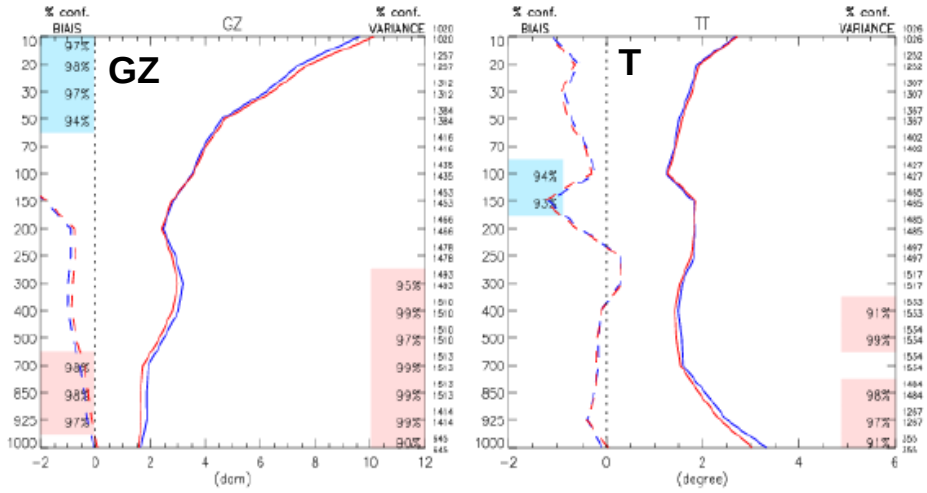
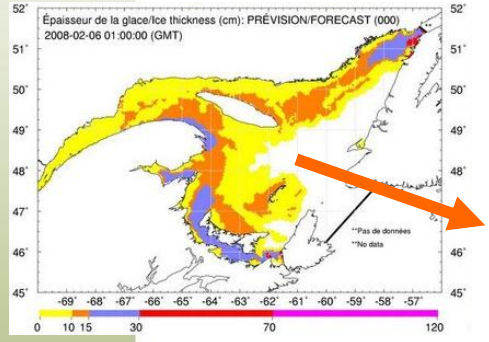


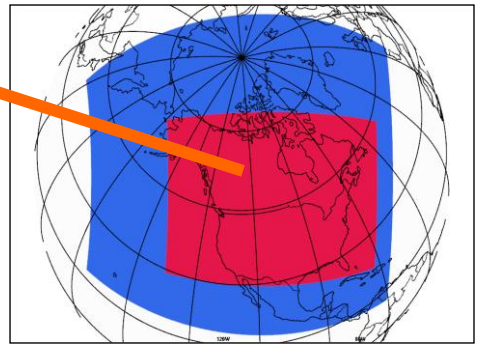
***Fig.5**: Vertical profiles of bias (dashed lines) and error standard deviation (solid lines) of 48-h forecasts against radiosonde data, over Canada during the winter 2011, from the **old (15km)** versus **new (10km)** RDPS.*

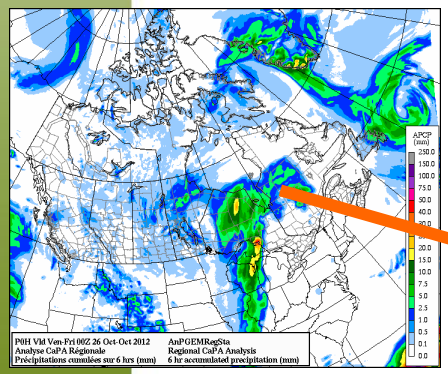
Upgrade of various sub-systems associated with the new RDPS

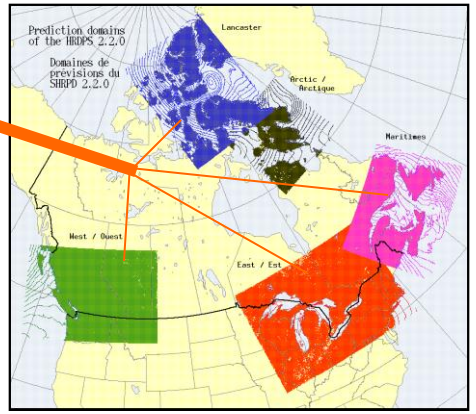
(Oct 2012)



- **Regional (North America) Air Quality Prediction System**
  - *from 15 to 10 km*
  - *improved set of emission files*
- **Regional Coupled Prediction System** (Gulf of ST. Lawrence)
  - *from 15 to 10 km*
- **High-Resolution (2.5 km) Deterministic Prediction System**
  - *adjustments to dynamics and physics*
  - *operational implementation of the West domain 2 x day*
- **Regional Deterministic Precipitation Analysis** (CaPa)
  - *from 15 to 10 km*
  - *improved quality control and station data treatment*







Upcoming NWP operational implementations

by Jan 2013

Global Deterministic	*- resolution: from 33 km to **25 km*** *- new vertical coordinates / grid + improved physics* *- 4D-Var analysis increments: from T108 to T180*
Global EPS	*- resolution: from 100 km to **66 km*** *- analysis (EnKF): multi-scale (3x more assimilated data)*
Regional EPS	*- resolution: from 33 km to **15 km***
Monthly Forecast System	*- from experimental to operational; with hindcast*

by the end of 2013

Global Deterministic	*- resolution: from 25 km to **15 km*** *- from lat-lon to **Yin-Yang grid*** *- from 4D-Var to **EnVar*** *- new sea-ice and land-surface analyses*
Global EPS	*- from 66 km to **50 km*** *- analysis (EnKF): multi-scale (3x more assimilated data)*
High-resolution System	*- Single grid (2.5-km resolution) covering most of Canada*
Regional Ice System	*- Arctic; 5-km resolution; experimental*
Global Ocean	*- ¼ degree resolution; experimental*

Major upgrade of the Global Deterministic Prediction System (GDPS)

(expected to become operational in Jan 2012)

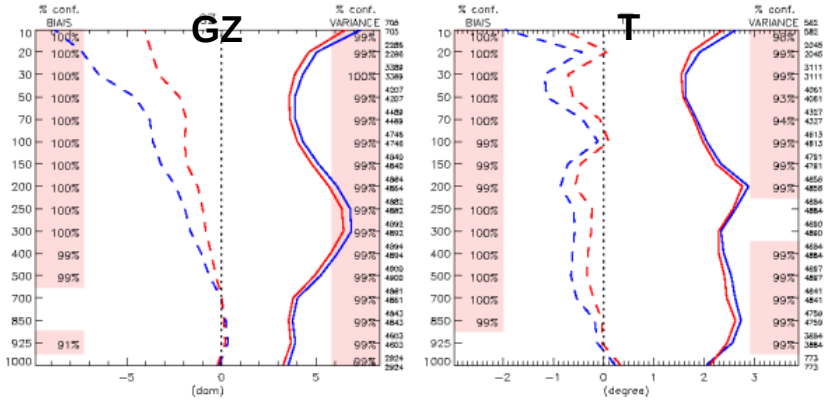


***Fig.6**: Vertical profiles of bias (dashed lines) and error standard deviation (solid lines) of 120-h forecasts against radiosonde data, over the S. Hemisphere, during the summer 2011, from the **old** versus GDPS.*

forecast model

horizontal resolution		- from **33km** to **25km**	- improvements seen in analysis cycle
dynamics		- new vertical coordinate - new vertical grid (from **regular** to **Charney-Phillips**)	- reduction of errors in stratosphere - noise reduction; improved numerical stability and conservation properties
physics	**orographic blocking**	- **amplification of bulk drag coefficient**, based on Wells et al. (2008) & Vosper et al. (2009)	- significant reduction of tropospheric errors in winter hemisphere
	boundary layer	- **turbulent hysteresis** effect	- reduction of errors associated with frontal inversions; improvement of upper-air scores

DA (4Dvar)

outer loop		- from **33km** to **25km**	- more data (AMSU-A and Aircraft) due to increase of # bins - all changes contributed to forecast improvements, roughly doubling the gain due to model changes
inner loop	**TL / AD**	- from **160km** to **100km** - Δt: from **45min** (9 bins) to **18min** (21 bins)	
	background error statistics	- from **T108** to **T180**	
minimization:# of iterations		- from **55** (30+25) to **65** (35+30)	

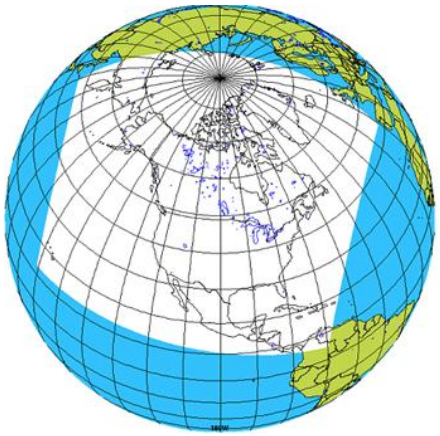
Upgrade of Global & Regional Ensemble Prediction Systems

(expected to become operational in Jan 2012)

Changes to the Regional EPS

- **Model component**
  - horiz. resolution: from 33 to 15km
  - vertical levels from 28 to 40
  - improved treatment of stochastic physical tendency perturbations to avoid unrealistic precipitation rates
  - improved boundary layer parameterization

- **Assimilation component**
  - no changes (i.e same initial conditions as the global EPS)



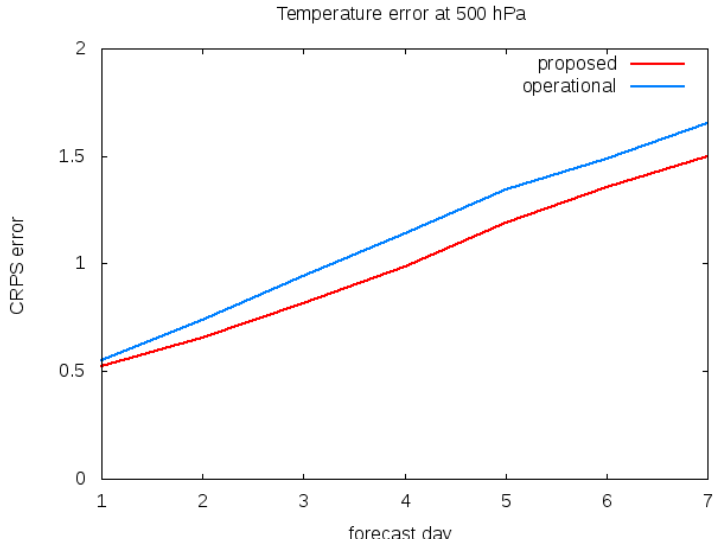


***Fig.6**: Global verification (CRPS error) of temperature at 500hPa against radiosondes, ov OLD versus NEW GEPS, showing a gain in predictability of 12h and plus.*

Changes to the Global EnKF and EPS

- multi-scale algorithm
- time-step: from 30 to 20min
- horiz. resolution: from 100 to 66km
- vertical levels: from 58 to 74
- topography filter
- reduced thinning of observations (2.7 X radiances)
- improved dynamics and physics

Upgrade of Monthly Forecast System

(expected to become operational in Jan 2013)

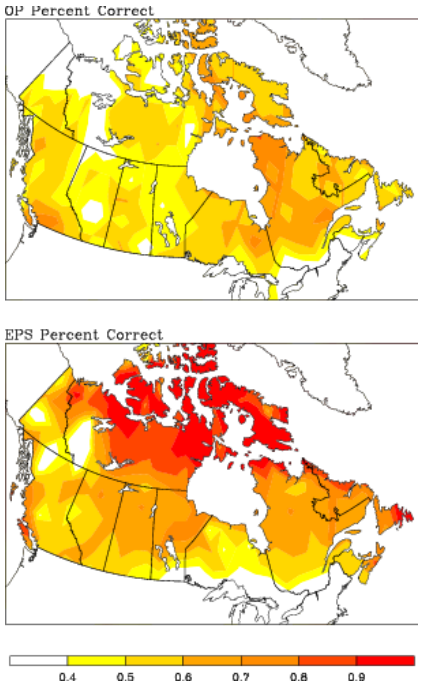


Fig.8: *Percentage correct for categorical forecasts: winter T2m 30-day average. Old system (top) versus new (bottom)*

Novelties

- Global-EPS based
- 2 components
  - *real-time forecasting system*
  - *hindcast (model climate & statistics)*

Real-time forecast

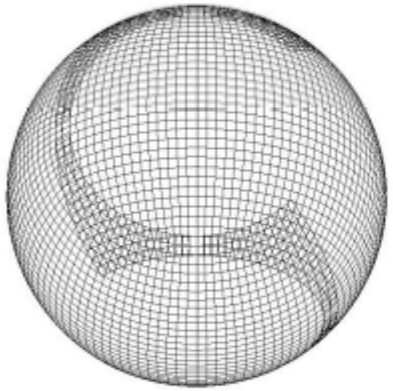
- Extend GEPS to 32 days once a week (00Z Thursday)
- Persistent SST anomaly added to time-evolving SST climatology
- Perturbed physics
- 21 members, ensemble Kalman Filter

Hindcast

- To generate GEPS model climatology
- For the same date, past 15 years 4 members each year, 60 members for each date
- Use 3 weeks centered at the date of the current Thursday, total of 180 members

Model Dynamics: new approaches for global grids

- Yin-Yang grid
  - Very good scaling; no pole problem
  - **Operational in 2013 at 15 km resolution** on 75 P7 nodes (2400 cores)
    => **Global 240-h forecast in about 1h**

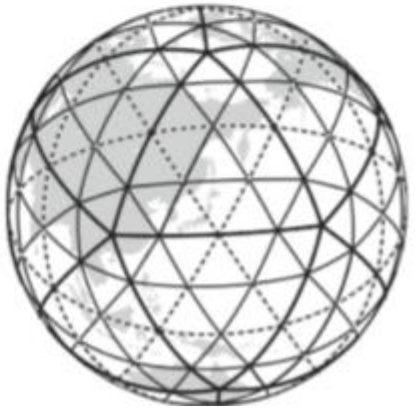


- Each piece is regular Lat/Lon grid

- Global forecast obtained by 2-way coupling of 2 LAM models

- Coupling done simultaneously at the solver level of both grids
=> no blending/relaxation of the two solutions needed

- Icosahedral grid
  - Scaling even better than Yin-Yang grid



Ensemble-Variational assimilation (En-Var)

- currently being tested in the context of replacing 4D-Var in the Global Deterministic Prediction System (GDPS)
- hybrid approach that uses a **variational assimilation approach** in combination with the already available **4D ensemble covariances** from the EnKF
- 4D analysis without the need of the TL/AD of forecast model
- more computationally efficient and easier to maintain/adapt than 4D-Var
- like 4D-Var, incremental approach:
  - *analysis increment at the horizontal/temporal resolution of EnKF ensembles*
  - *background state and analysis at the horizontal/temporal resolution of the high-resolution deterministic forecast model*

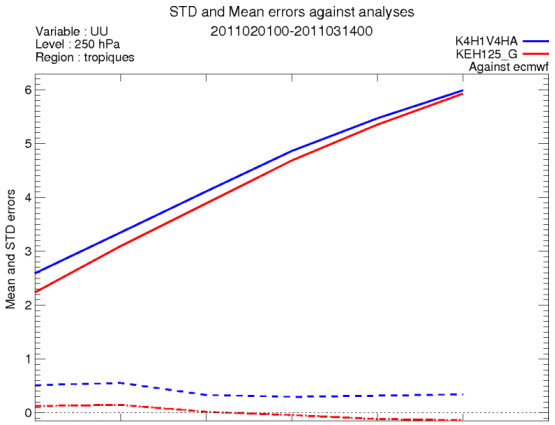


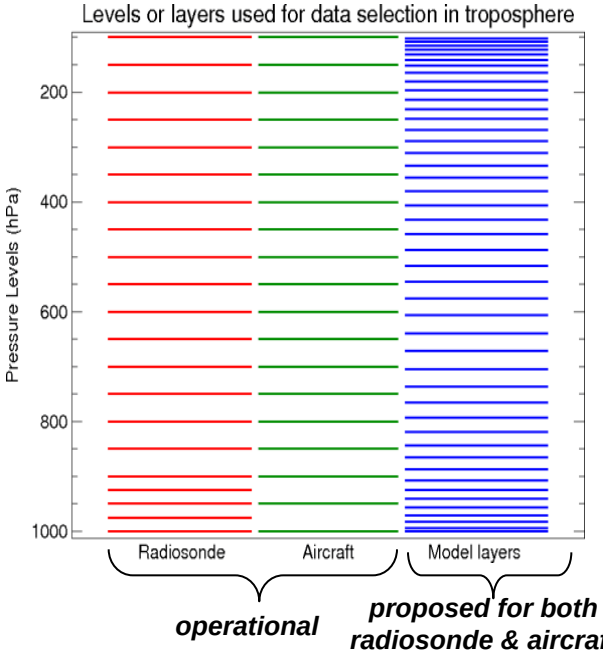
Fig.7**: Mean and STD errors of 250-hPa zonal wind, against ERA-Interim analysis, over the Tropics., 6 weeks Feb/Mar 2011, **4DVar** versus **EnVar

Tests with GDPS-25km:
- similar quality forecasts as 4D-Var below ~20hPa in extra-tropics, significantly improved in tropics
- above ~20hPa, scores similar to 3D-Var, worse than 4D-Var; potential benefit from raising EnKF model top to 0.1hPa

Ongoing tests combined with:
- 15km version of GDPS on Yin-Yang grid
- new surface analysis system
- modified satellite radiance bias correction scheme
- improved use of radiosonde and aircraft data
- additional AIRS/IASI channels and modified observation errors for all radiances
- explore possibility of raising EnKF model top to 0.1hPa???

Proposed Upgrades and Improvements to the MSC Data Processing for Radiosonde and Aircraft Data

- **Increased volume of data: selection of observations according to model levels**
- **Revised observation error statistics**
- **Revised rejection criteria for radiosonde data based on those used at ECMWF**
- **Horizontal drift of radiosonde balloon taken into account in both data assimilation and verification systems**
- **Bias correction scheme for aircraft temperature reports**



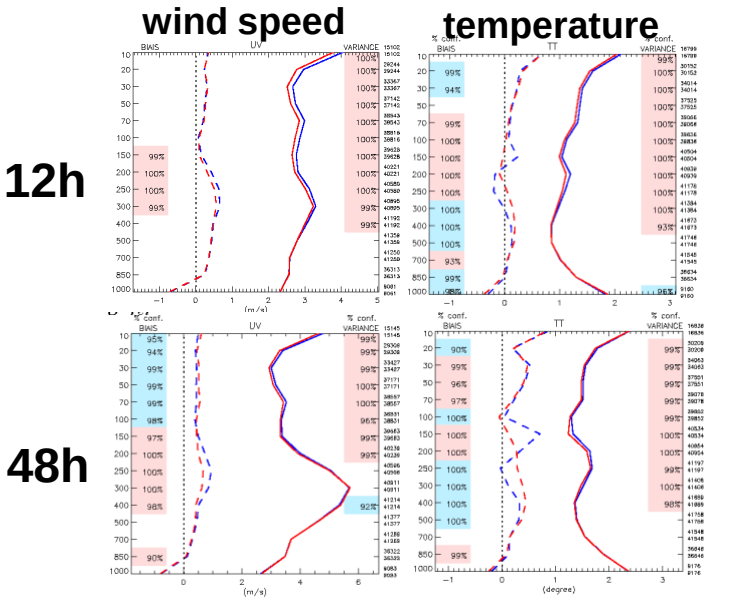


Fig.: Verification scores against radiosondes over the N. Hemisphere, Jan-Feb 2009 (dash = bias; solid = stde)

Impact of proposed changes

- **General short-range forecast improvements above 500 hPa in both wind and temperature fields**
- **The temperature forecast biases are significantly improved due to the bias correction scheme for aircraft below 200 hPa and to the new rejection criteria for radiosonde humidity data above**

The new Canadian Land Data Assimilation System (CaLDAS)

(in 2013)

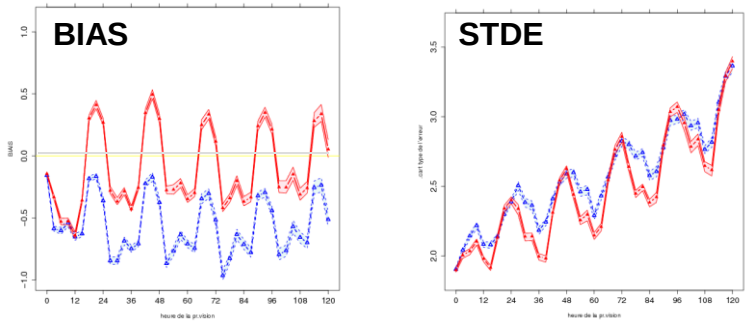
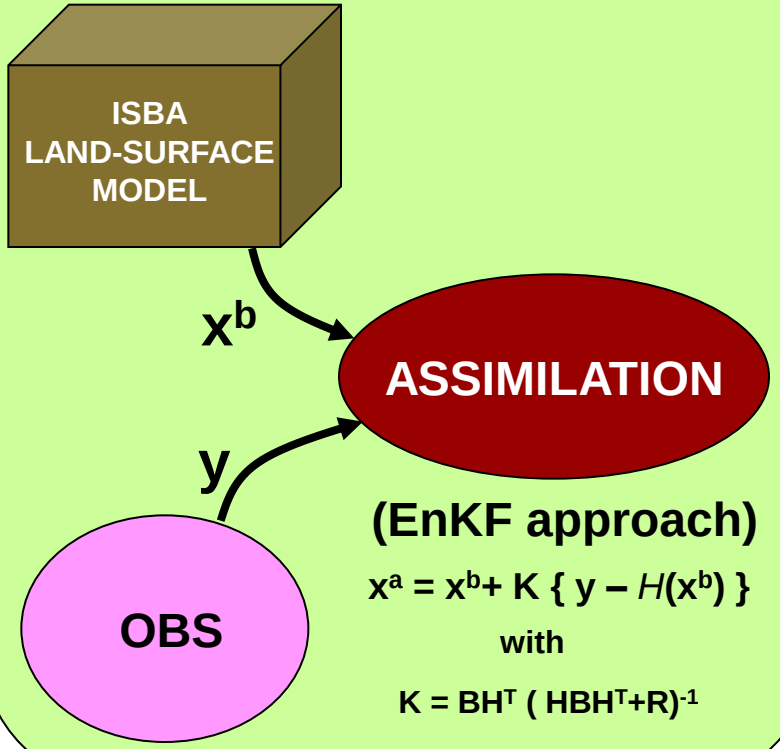


***Fig.**: Impact of CaLDAS on screen lecel air dew-point temperature forecasts over Canada, over the summer 2008: operational system versus CaLDAS.*

IN

- **Ancillary land surface data**
  Orography, vegetation, soils, water fraction, ...
- **Atmospheric forcing**
  T, q, U, V, Pr, SW, LW
- **Observations**
  Screen-level (T, Td)
  Stations snow depth
  L-band passive (SMOS,SMAP)
  MW passive (AMSR-E)
  Multispectral (MODIS)
  Combined products (GlobSnow)

CaLDAS



OUT

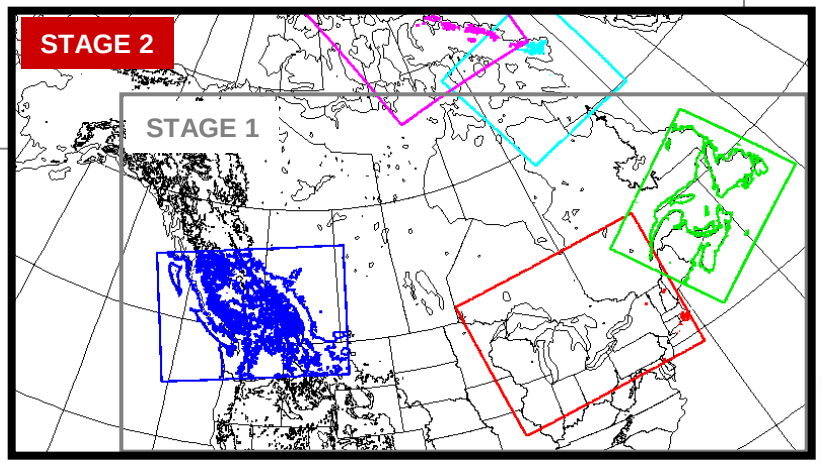
- **Land surface initial conditions for NWP and hydro systems**
- **Land surface conditions for atmospheric assimilation systems**
- **Current state of land surface conditions for other applications (agriculture, drought, ...)**

High Resolution Deterministic Prediction System (HRDPS)

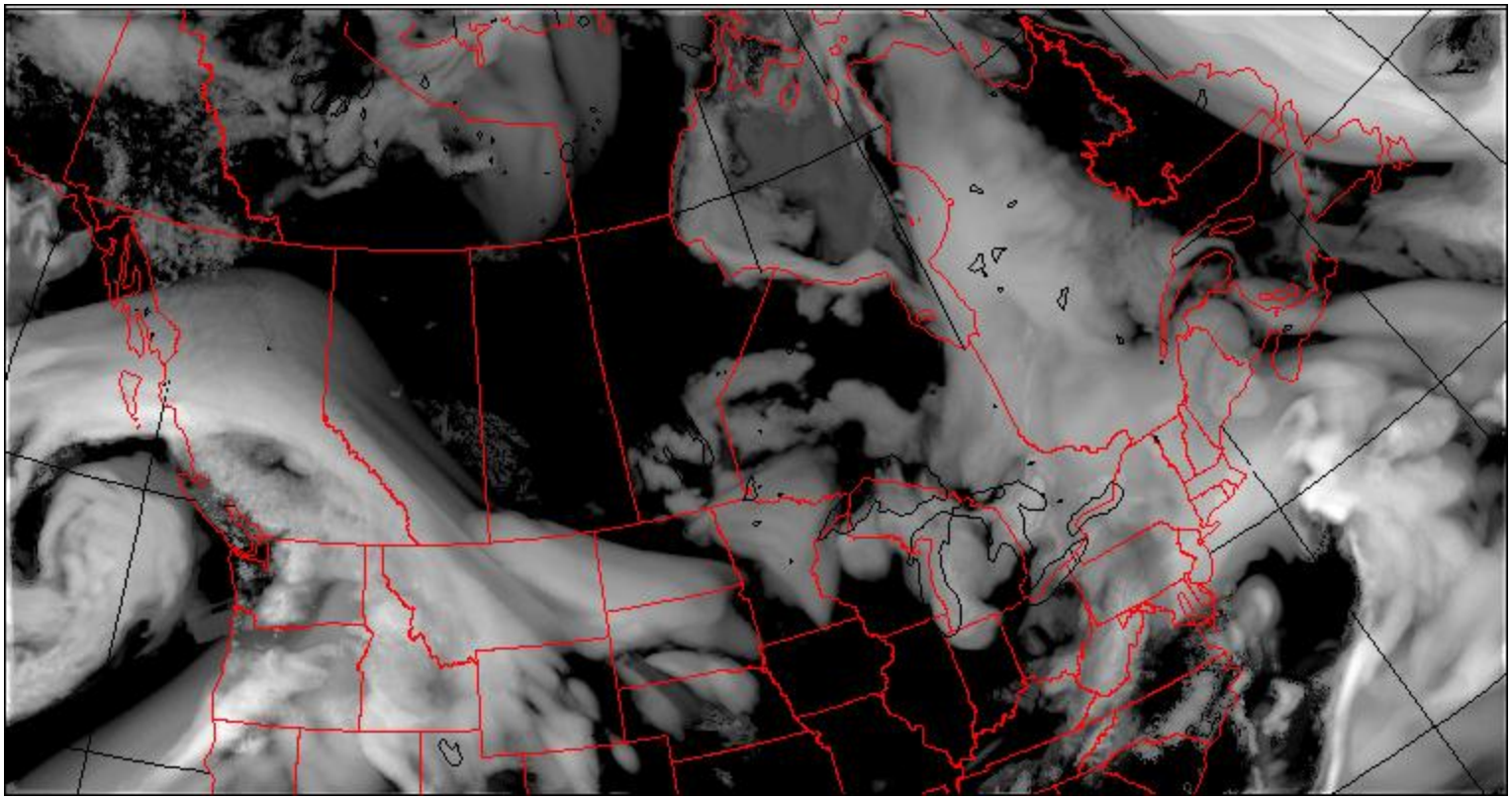
FUTURE SYSTEM (to become the next-generation "*Regional DPS*")

- **single 2.5-km grid, with national coverage (skip the "grey zone")**
- **4 x 48 h runs per day (operational)**
- **high-resolution En-VAR upper-air data assimilation system**
- **hydrometeor fields nested from 6-h forecast of 2.5-km cycled system**
- **improved, high-resolution initial conditions at surface**
  - **from high-resolution surface data assimilation system (CaLDAS)**
  - **coupling with GEM-SURF**
- **redistribution of vertical levels; upper-boundary nesting**
  - **50% more levels below 1.5 km AGL**
- **upgraded microphysics scheme**

Note: Stage-1 = single-grid version of multiple grid approach, with increased vertical resolution and improved physics. Expected to become operational in 2013.



Simulation using prototype of Stage-1 HRDPS over Stage-2 grid



Animation: Column-maximum REFLECTIVITY, computed from hydrometeor fields from 2-moment microphysics scheme

Sub-km External Surface Model (GEM-SURF)
(in 2013)

Main goal is to improve numerical prediction over
- ecosystems
- cities
- water surfaces

External surface model
- horizontal resolution as high as that of surface databases (e.g. 100m)
- computational cost of off-line system is much less than that of atmospheric model

Atmospheric forcing
- from low-res model, or observations, or analyses
- forcing:
  - at lowest atmosp. level: *T, q, U, V*
  - at surface: radiation and precip

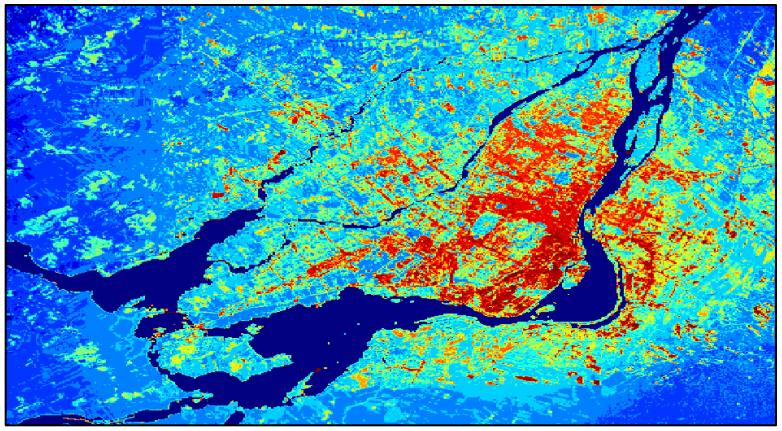


***Fig.**: High-resolution modeling of the urban environment: nocturnal 2m-temperature simulation of Montreal island, 120-m resolution (Leroyer et al., 2011).*

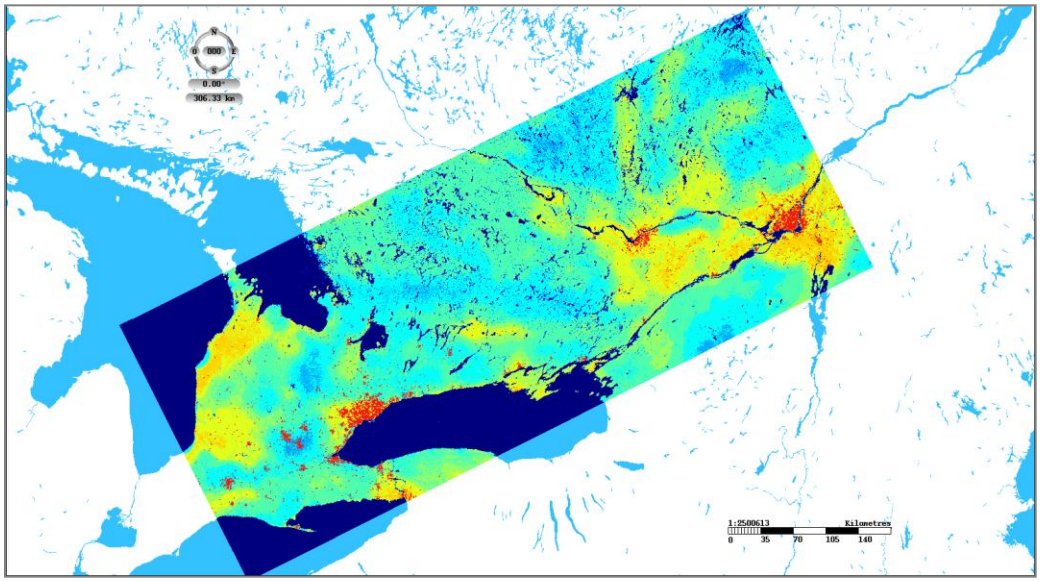
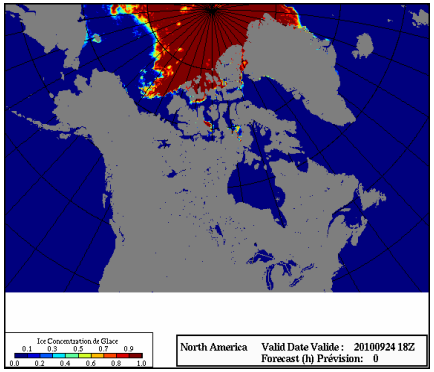
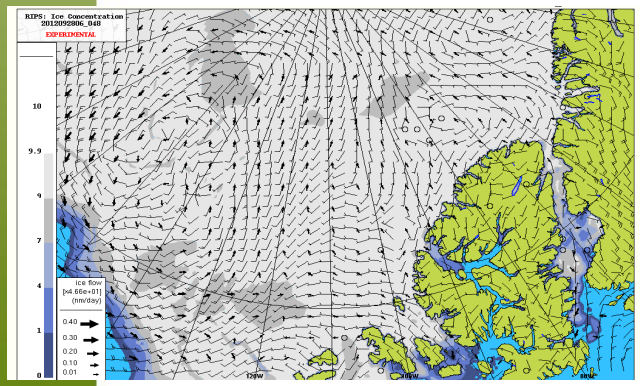


***Fig.**: Result from preliminary tests towards the implementation of high-resolution numerical prediction of land surface temperature over Canada.*

Regional Ice Prediction System (RIPS)

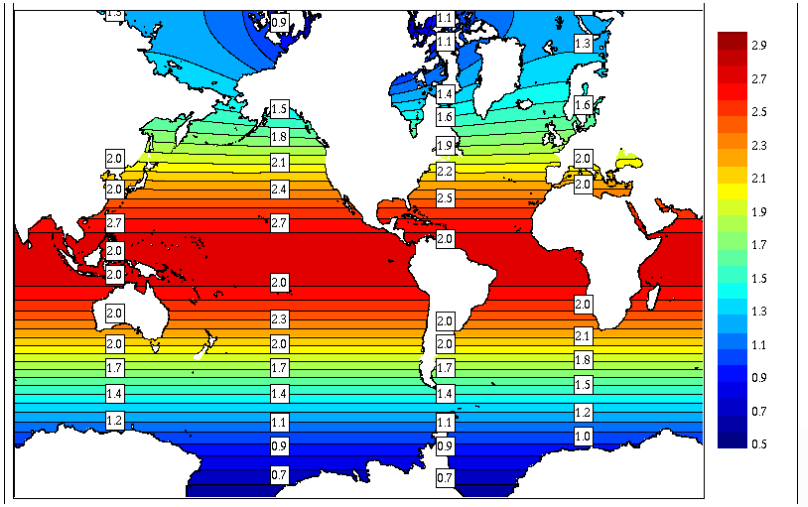
- **5km N.American grid**
- **3DVar Ice analysis**
  - SSMI, AMSR-E, CIS daily charts
- **CICE4.1 Ice model**
  - Forced by CMC RDPS
- **48hr forecasts at 0, 6, 18, 24Z**
- **To be run experimentally by March 2013**





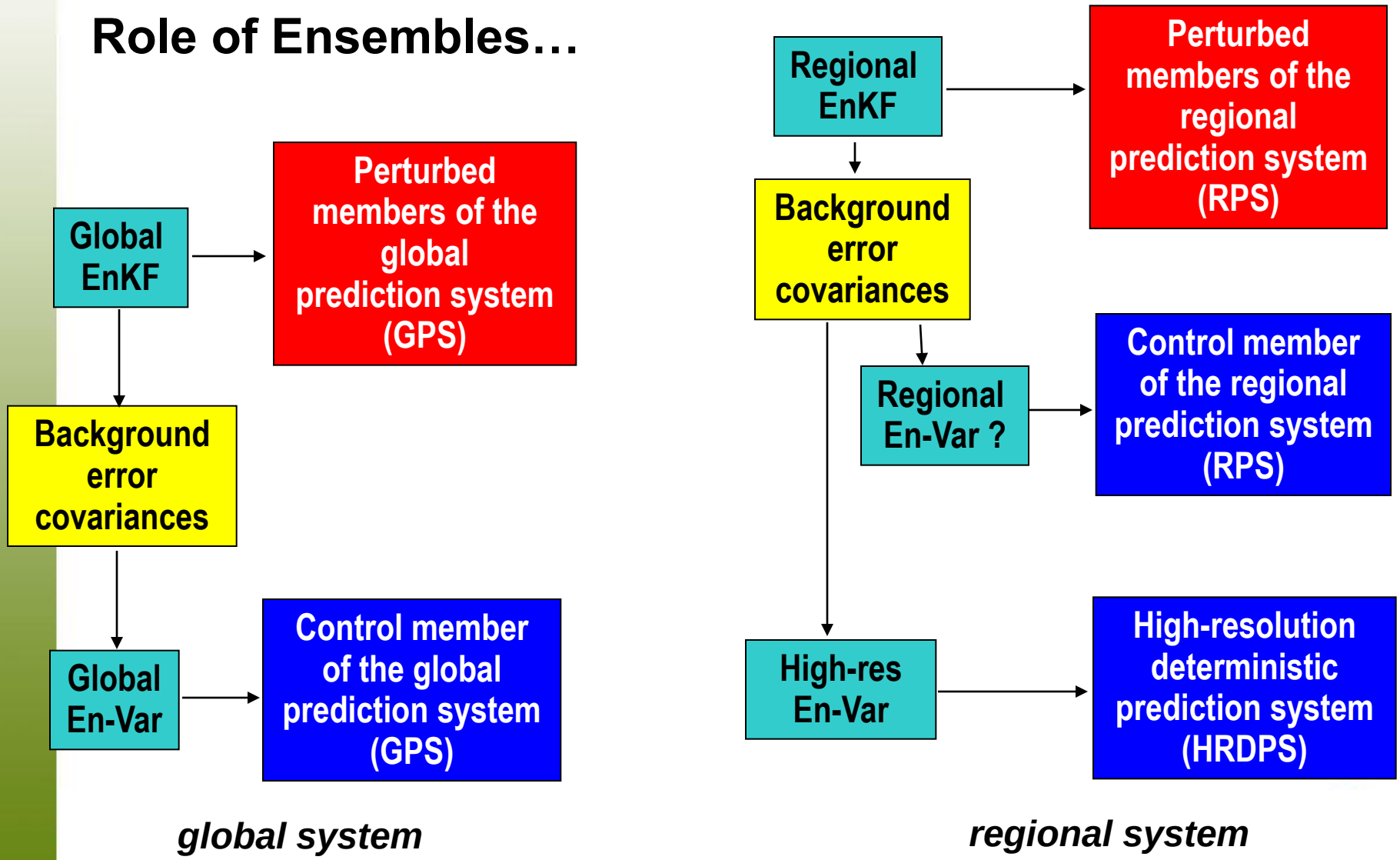
Global Ice-Ocean Prediction System

- **Mercator Ocean Assimilation System (SAM2-SEEK):**
  - Sea surface temperature
  - Temperature and salinity profiles
  - Sea level anomaly from satellite altimeters
- **3DVar Ice analysis**
- **Daily blended ice-ocean analysis and 10day forecast**
- **Model configuration:**
  - ORCA025 (~1/4°), <15km in Arctic
  - NEMOv3.1, LIM2-EVP
- **Expected operational implementation**:
  - June 2013



2013-2017: Toward a Reorganization of the NWP Suites at Environment Canada

Role of Ensembles…



2013-17 R&D Plans for Environmental Numerical Prediction Research Section

- Development of an integrated marine Arctic prediction system in support of METAREA monitoring and warnings
- Development of an Integrated Environmental Prediction System for the Great Lakes and St. Lawrence River Basins
- Development of the Land surface and near surface modeling and data assimilation system
- Ongoing research & development for an improved precipitation analysis for the country (to include radar data, satellite data). In collaboration with NOAA, development of a daily global precipitation analysis with a resolution of 1/2 degree
- Development of a global Atmosphere-Ocean-Waves-Ice modeling and data assimilation system

Acknowledgements

Weather Prediction: Martin Charron, Paul Vaillancourt, Jason Milbrandt, Abdessamad Qaddouri, Michel Roch, Ron McTaggart-Cowan, Claude Girard, Hai Lin

Environmental Prediction: Greg Smith, Pierre Pellerin, Vincent Fortin, Stephane Belair

Data Assimilation: Veronique Boucher, Mark Buehner, Luc Fillion, Stephane Laroche, Peter Houtekamer

Air Quality: Veronique Boucher, Sylvie Gravel, Jean de Grandpre

Seasonal Prediction: Greg Flato, Bill Merryfield

CMC-Development: Bertrand Denis, Normand Gagnon

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Appendix 1: Details on CanSIPS

CanSIPS models

CanCM3

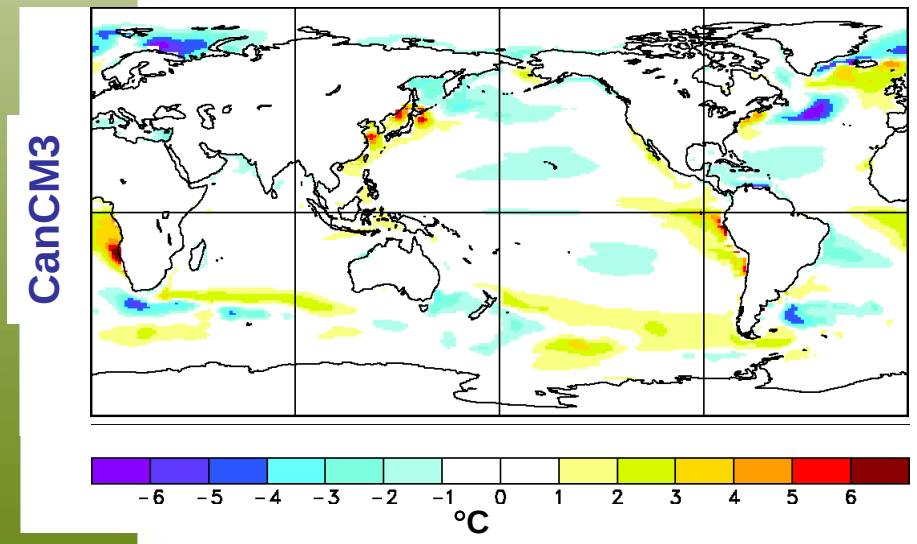
CanAM3 *Atmospheric model*
- T63/L31 (≈2.8° spectral grid)
- Deep convection scheme of Zhang & McFarlane (1995)
- No shallow conv scheme
- Simple radiative forcing

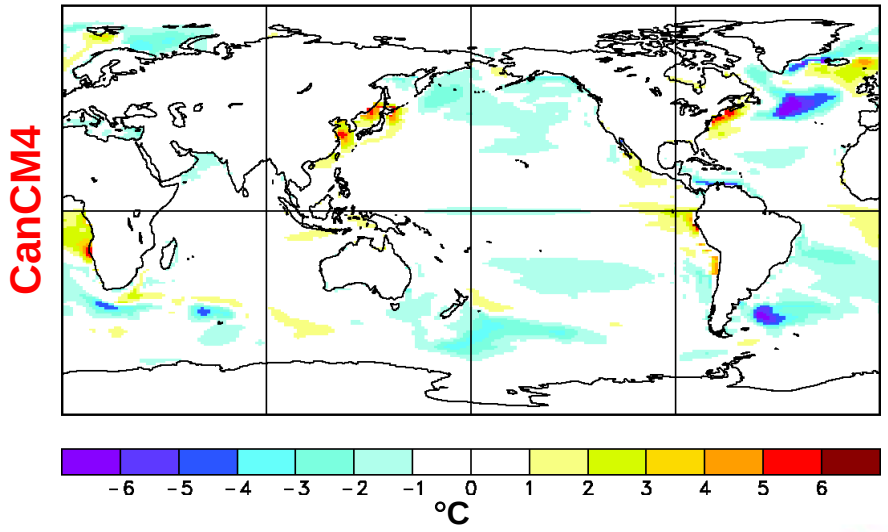
CanOM4 *Ocean model*
- 1.41°×0.94°×L40
- GM stirring, aniso visc
- KPP+tidal mixing
- Subsurface solar heating climatological chlorophyll

CanCM4

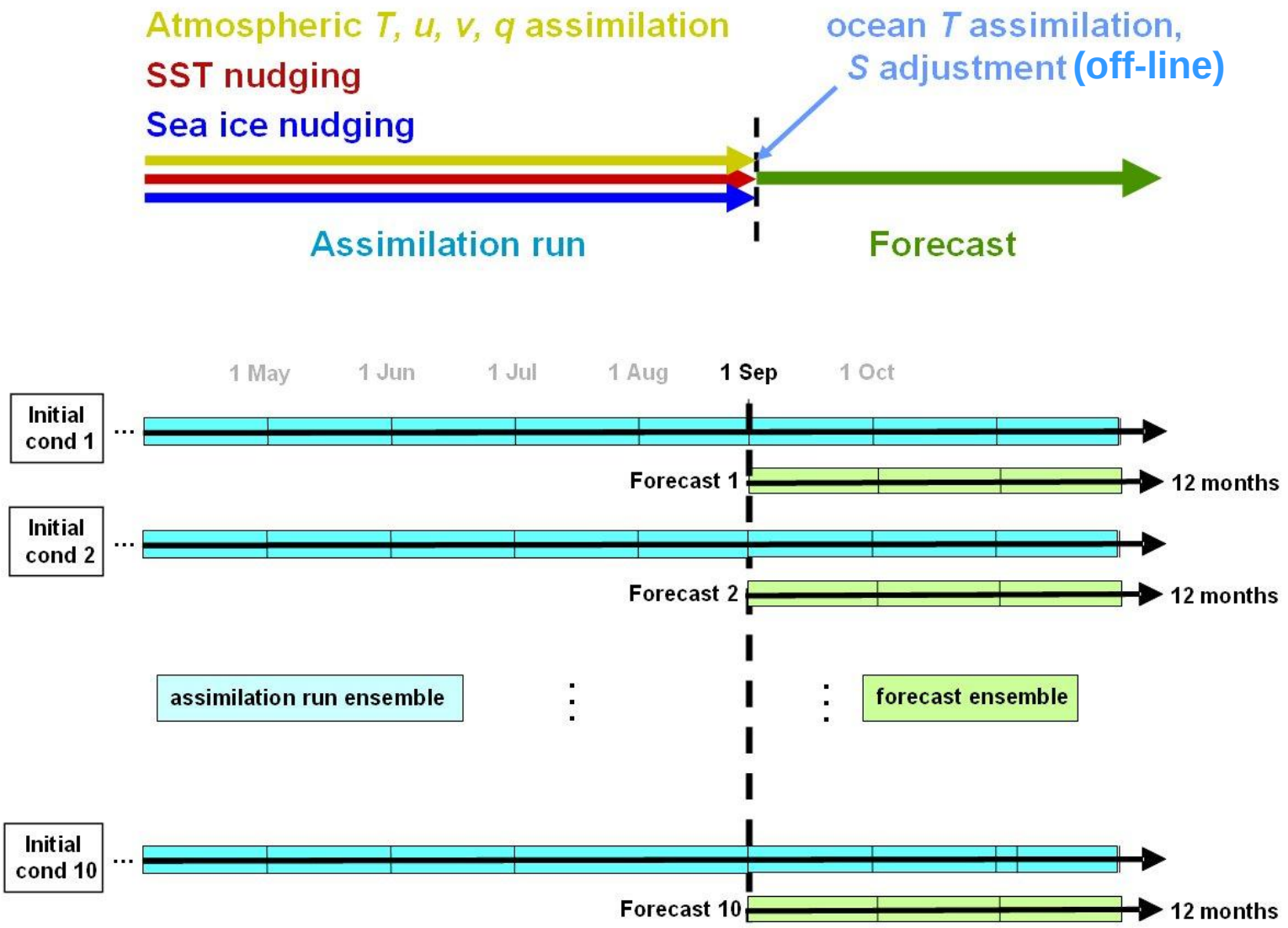
CanAM4 *Atmospheric model*
- T63/L35 (≈2.8° spectral grid)
- Deep conv as in CanCM3
- Shallow conv as per von Salzen & McFarlane (2002)
- Improved radiation, aerosols

SST bias vs OISST 1982-2009



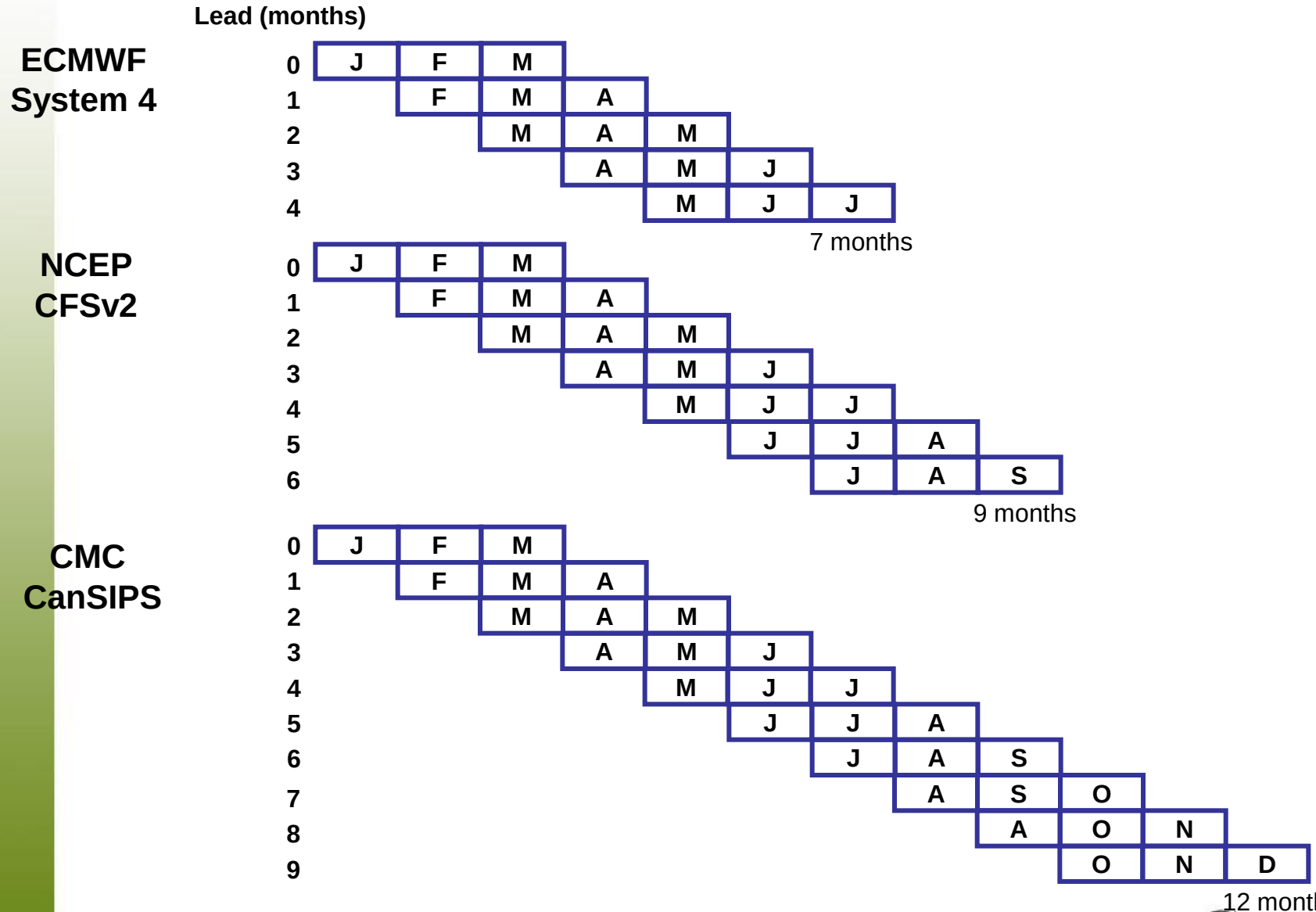


CanSIPS initialization



Operational Multi-Seasonal Forecast Ranges

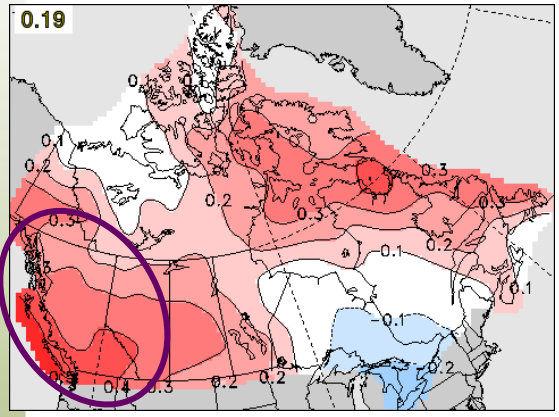
Example: 1 January start



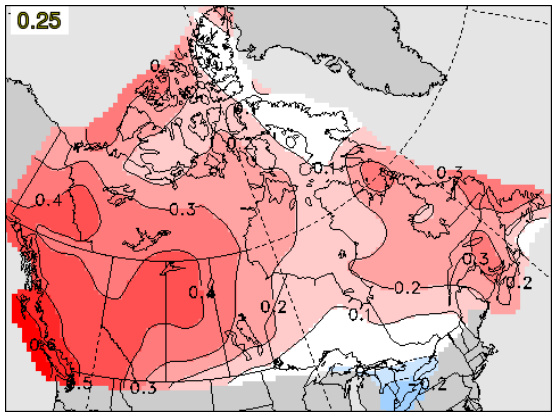
Is there value at longest lead times?

Long-lead skill for western Canada in winter/spring

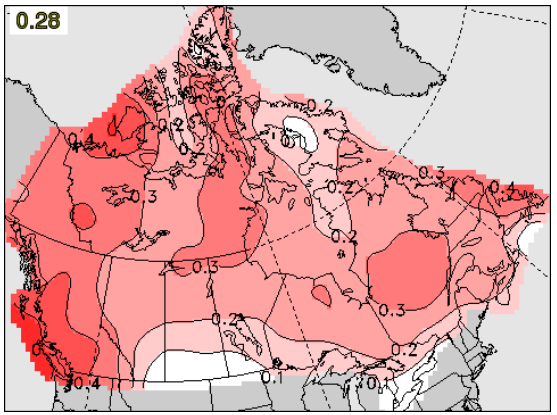
JFM



FMA

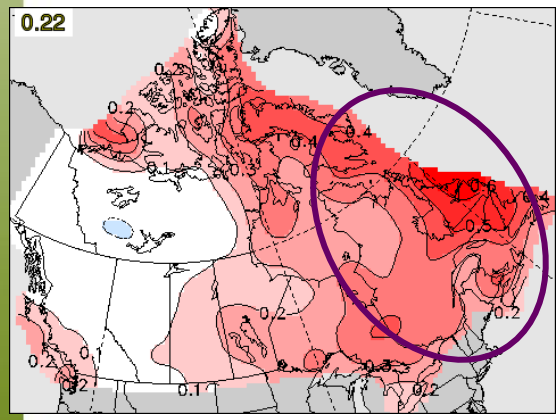


MAM

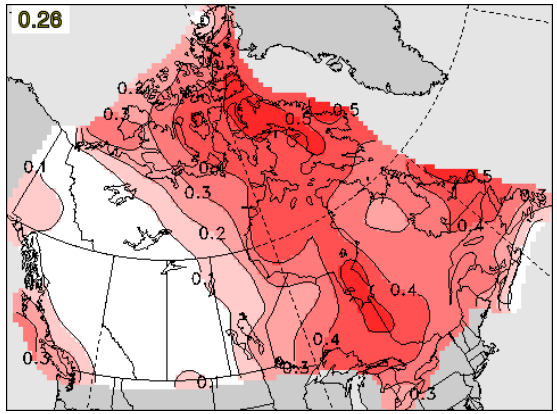


Long-lead skill for eastern Canada in summer/fall

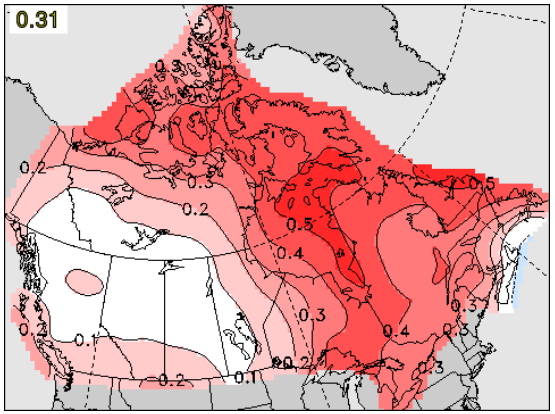
JAS



ASO



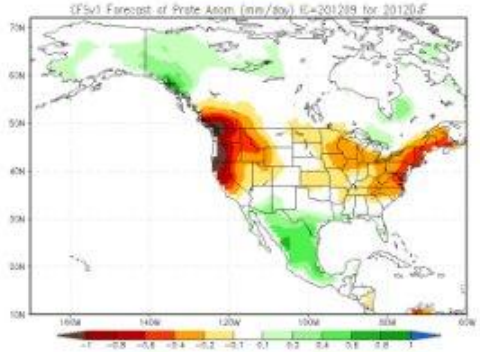
SON



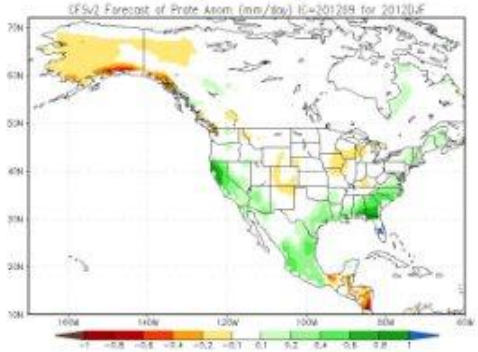
Lead 9 month 2m temperature anomaly correlation

US National Multi-Model Ensemble (NMME)

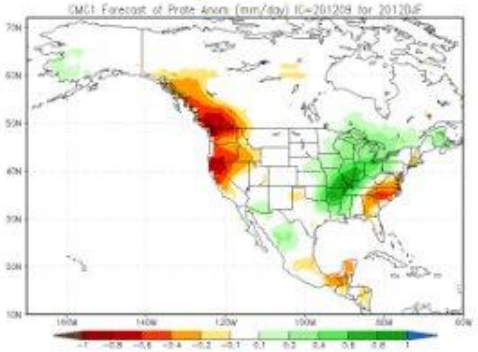
CFSv1



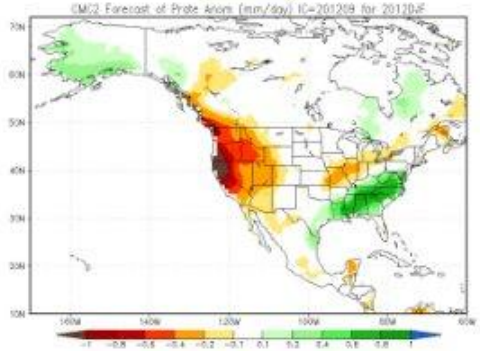
CFSv2



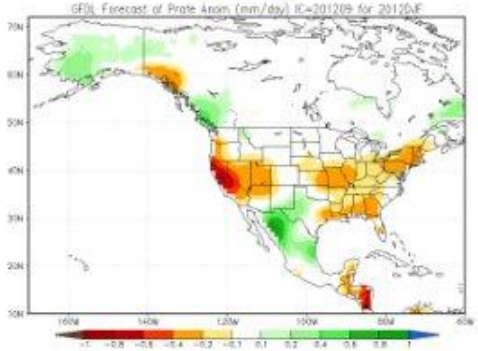
CMC1 = CanCM3



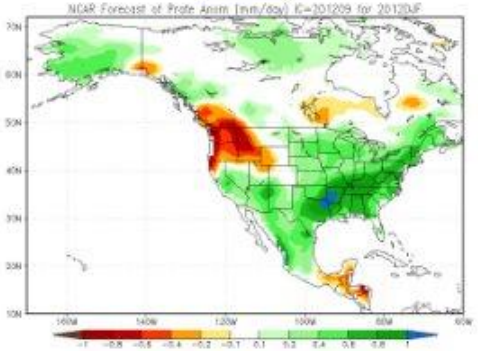
CMC2 = CanCM4



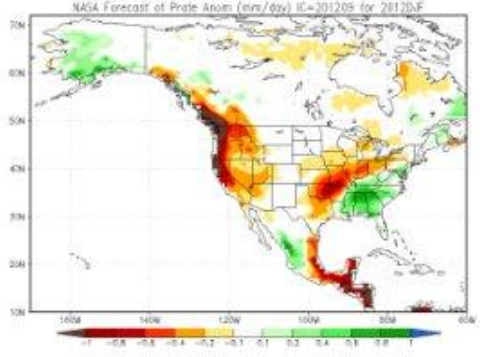
GFDL



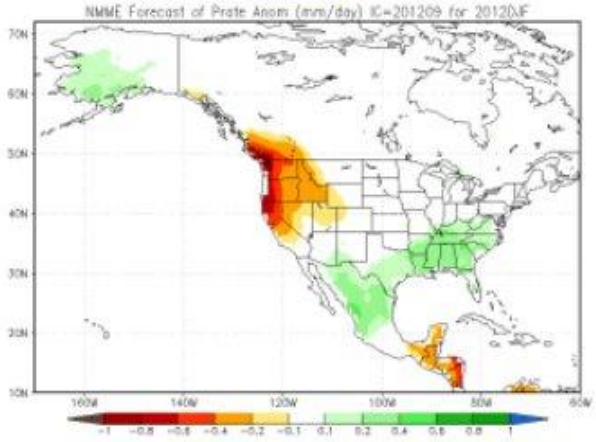
NCAR



NASA



NMME

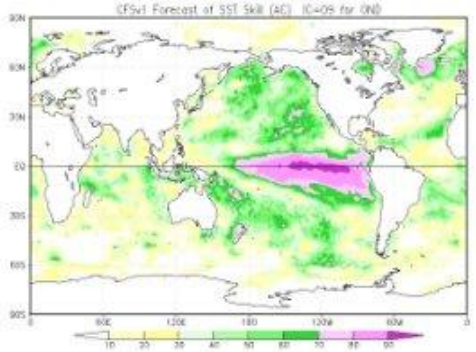


NMME models + ensemble mean

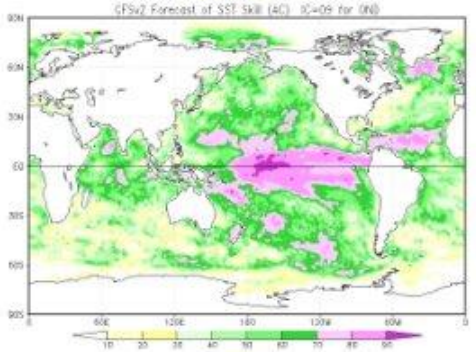
precip DJF 2012 (from Sep 2012)

US National Multi-Model Ensemble (NMME)

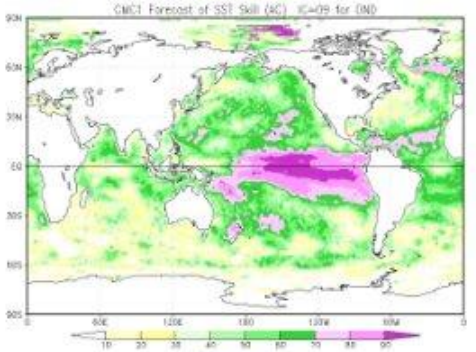
CFSv1



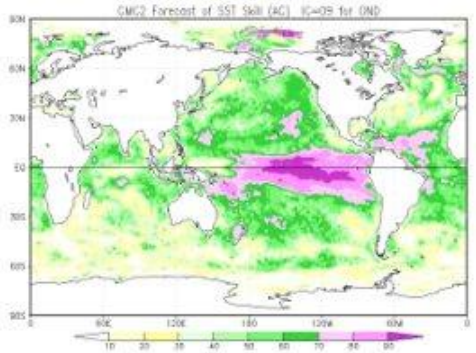
CFSv2



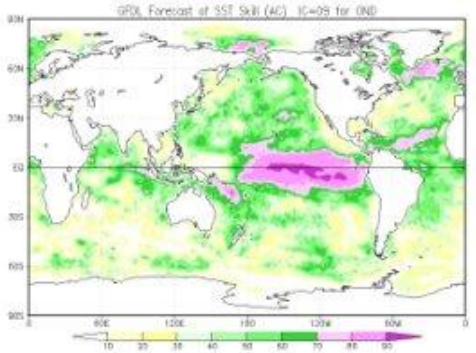
CMC1 = CanCM3



CMC2 = CanCM4



GFDL



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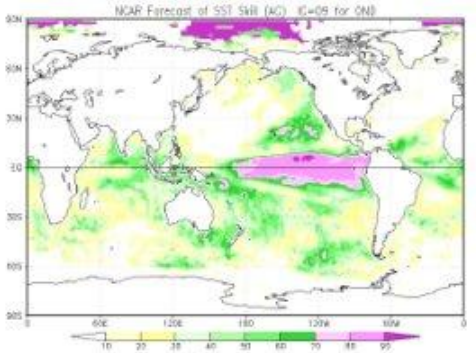
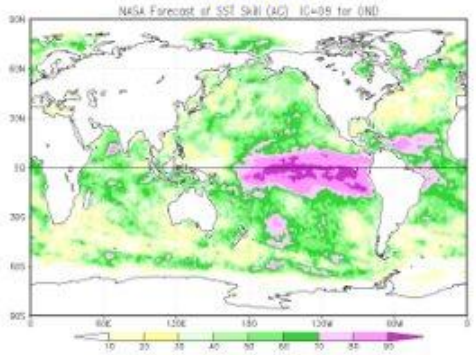
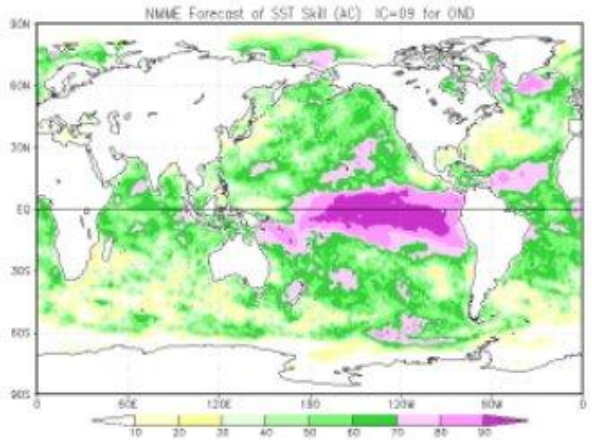


NASA



NMME



NMME models + ensemble mean anomaly correlation

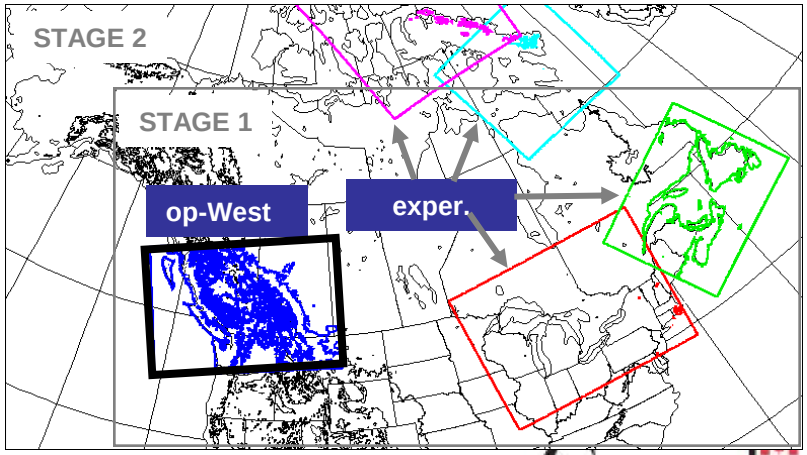
OND SST from Sep initialization

Appendix 2: Details on the HRDPS and future RDPS (2.5 km)

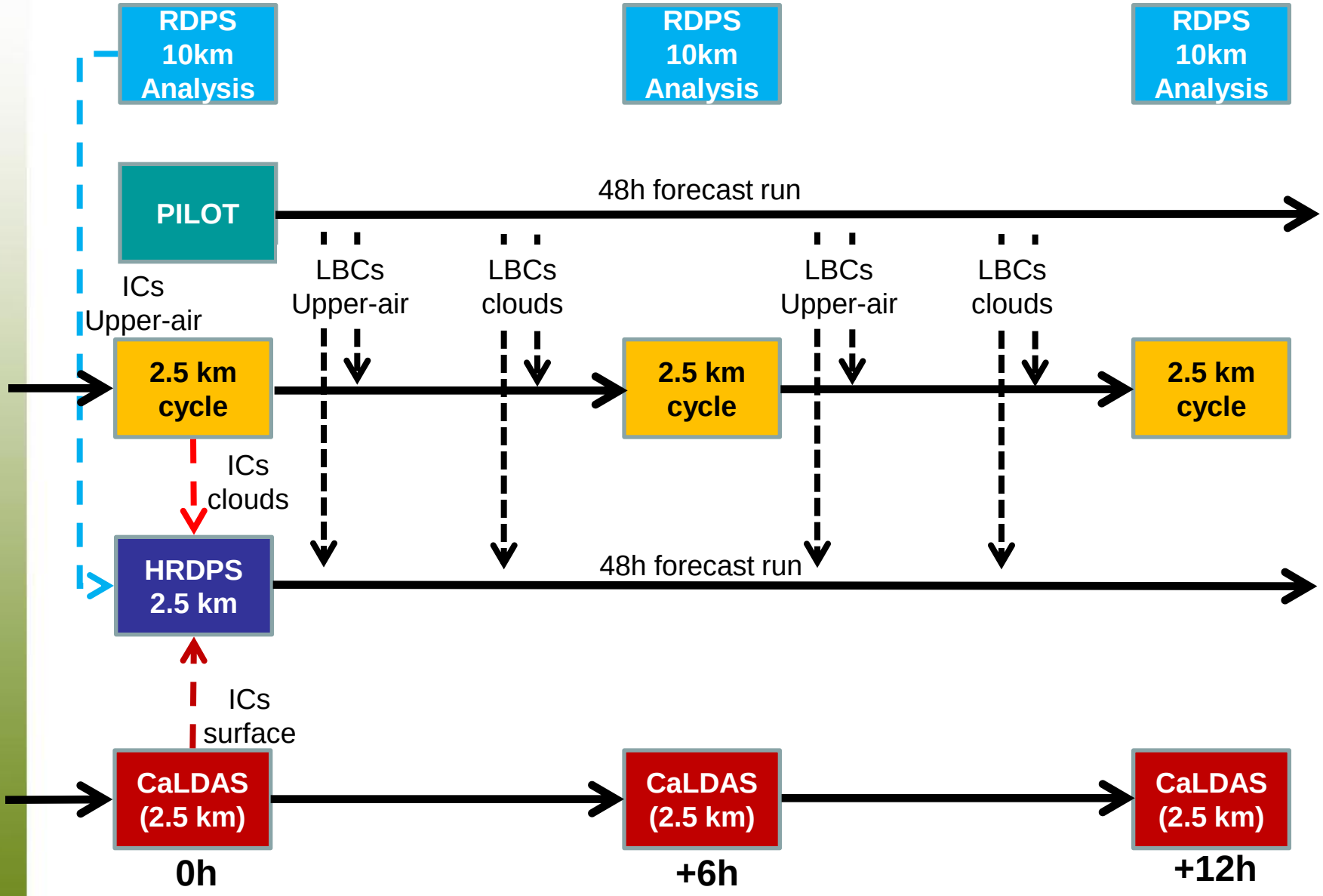
CURRENT SYSTEM

- GEM (Global Environmental Multiscale) model, Δx = 2.5 km LAM grids
  - 1 operational; 2 x 42 h per day (eastern Canada domain)
  - 4 experimental; 1 x 24 h per day
- nested from regional forecast run
  - Δx = 10 km
  - 3D-Var regional data assimilation system)
- 58 vertical levels (Charney-Phillips)
- correlated-k distribution radiation scheme
- detailed two-moment microphysics
  - 6 hydrometeor categories (mass, number)
  - 12 prognostic hydrometeor variables

  (this is possible due to GEM numerics)
  - several explicit precipitation types

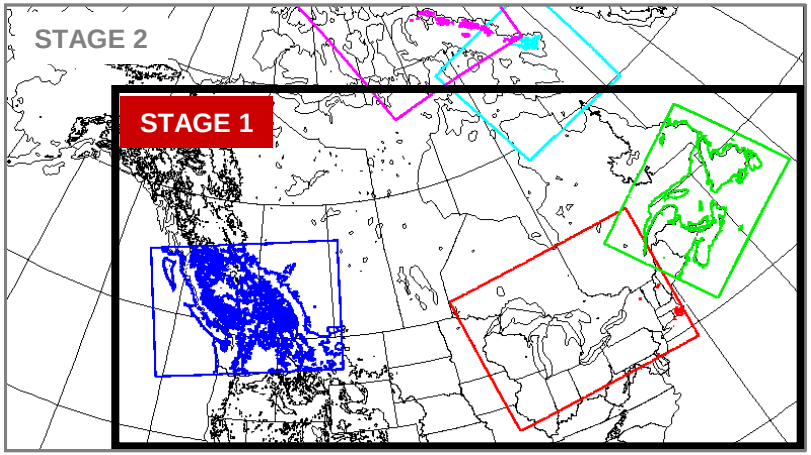


Future sequence for ICs and BCs (National-2.5 system):



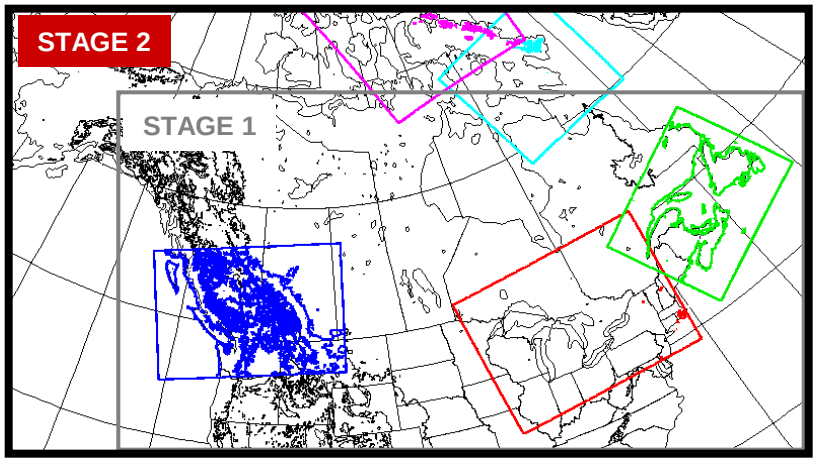
FUTURE SYSTEM (Stage 1 of National-2.5 km system; end of 2013)

- single 2.5-km grid, with national coverage
- 2-4 x 48 h runs per day (operational)
- upper-air fields nested from regional forecast run
- hydrometeor fields nested from 6-h forecast of 2.5-km cycled system
- improved, high-resolution initial conditions at surface
  - from high-resolution surface data assimilation system (CaLDAS)
- redistribution of vertical levels; upper-boundary nesting
  - 50% more levels below 1.5 km AGL
- upgraded microphysics scheme
  - prognostic graupel density

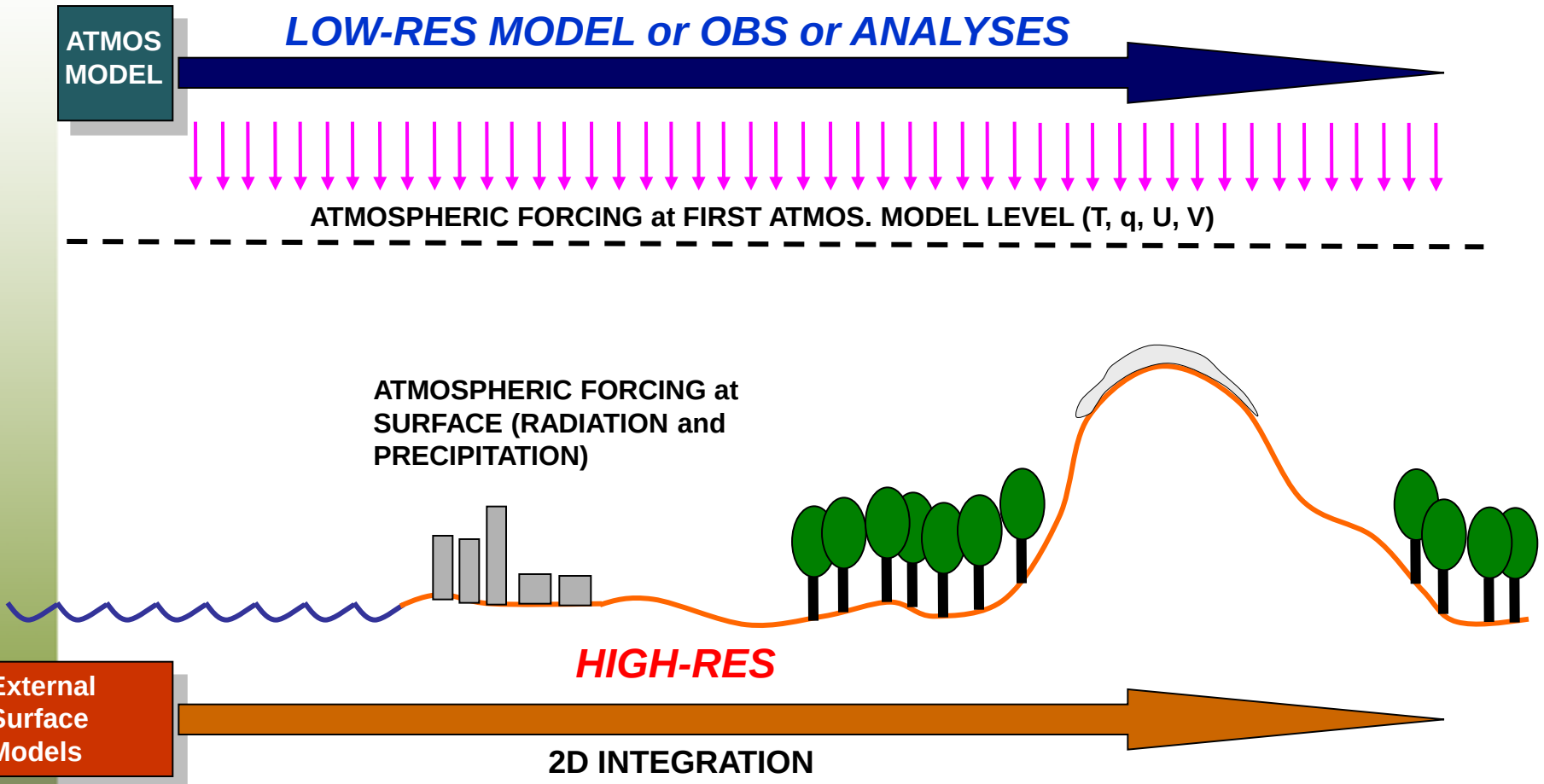


FUTURE SYSTEM (Stage 2 of National-2.5 km system; 2015)

- single 2.5-km grid, extended coverage
- 4 x 48 h runs per day (operational)
- high-resolution En-VAR upper-air data assimilation system



Appendix 3: Environment Canada's External Surface Modeling System



With horizontal resolution as high as that of surface databases (e.g., 100 m)

Computational cost of off-line surface modeling system is *much less* than an integration of the atmospheric model

PLANS for OPERATIONAL IMPLEMENTATION at MSC (2013)

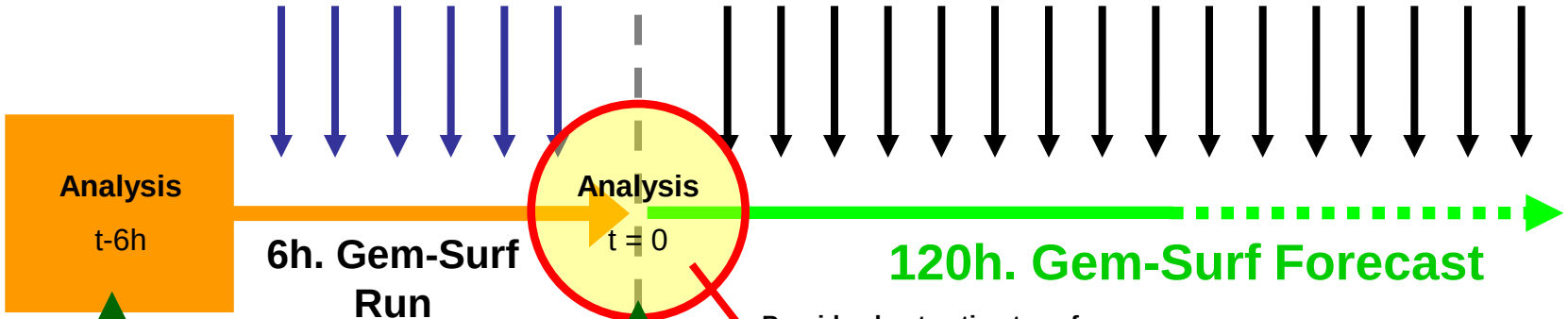
- **120 hr forecast run (every 6hr)**

Best estimates of Hourly Forcing
SW, LW – RDPS, 6-12 hr. – at surface
UU,VV – RDPS, 0-6 hr. – at screen lev. (10m)
P0 – RDPS, 0-6 hr. – at surface

PR –Canadian Precipitation Analysis (CaPA) – at surface
TT, HU – Optimal Interpolation (OI) – at screen lev. (2m)

t=0

Hourly Forcing at 1st atmospheric level
From RDPS and GDPS forecasts
(TT, HU, SW, LW,UU,VV,P0,PR)
Forcing is **downscaled and adapted** to Gem-Surf Resolution

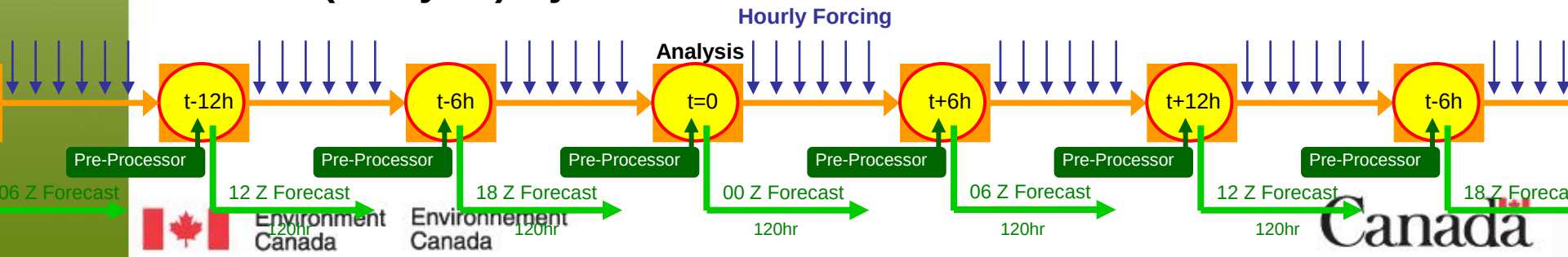


Pre-Processor of Geophysical Fields
- Coherence & Consistency tests for GenPhysx and UrbanX variables
- Calculation of time-dependent variables (e.g,LAI,α)

Pre-Processor

Provides best estimates of :
- **Soil Moisture**
- **Surface Temp.**
- **Snow charac.** (density, depth,albedo)
- **Urban charac.** (roof, wall, road temp. etc.)

- **Continuous (Analysis) Cycle**



Appendix 4: Urban Modeling in Support to Numerical Weather Prediction and Emergency Response at Environment Canada

Major Projects related with Urban Modeling at Environment Canada:

CBRN Research and Technological Initiative projects (CRTI) (2004/08)

Environmental Prediction of Canadian Cities (EPiCC) (2007/09)

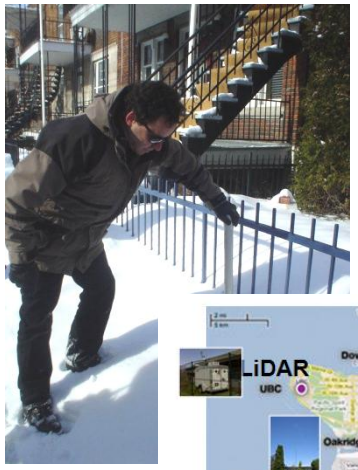
Montreal Urban Snow Experiment (MUSE, in 2005 and 2006)

EPiCC field campaigns (Montreal and Vancouver, in 2008 and 2009)

IRTC-CRTI

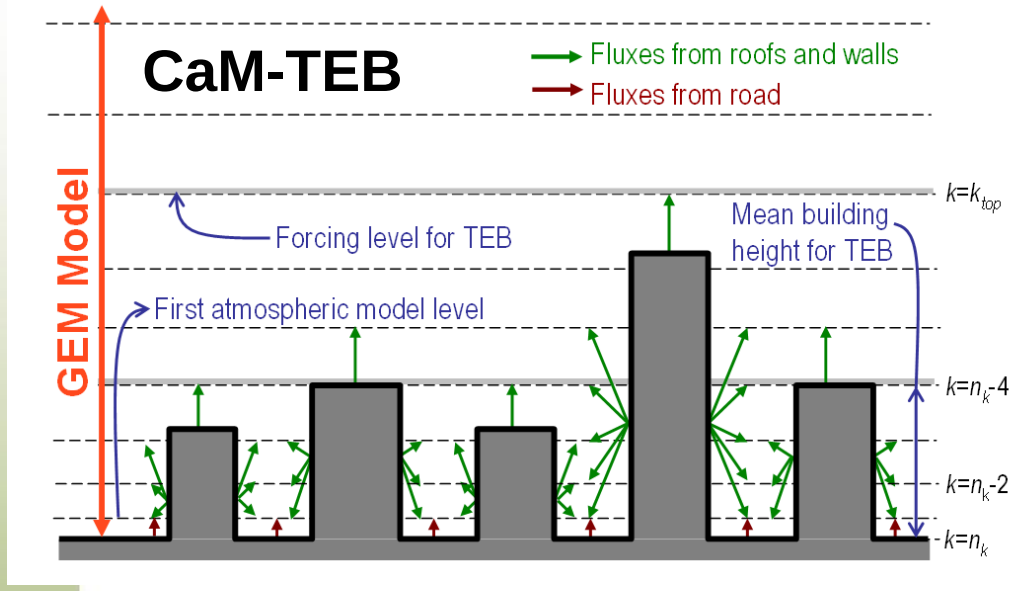
EPiCC

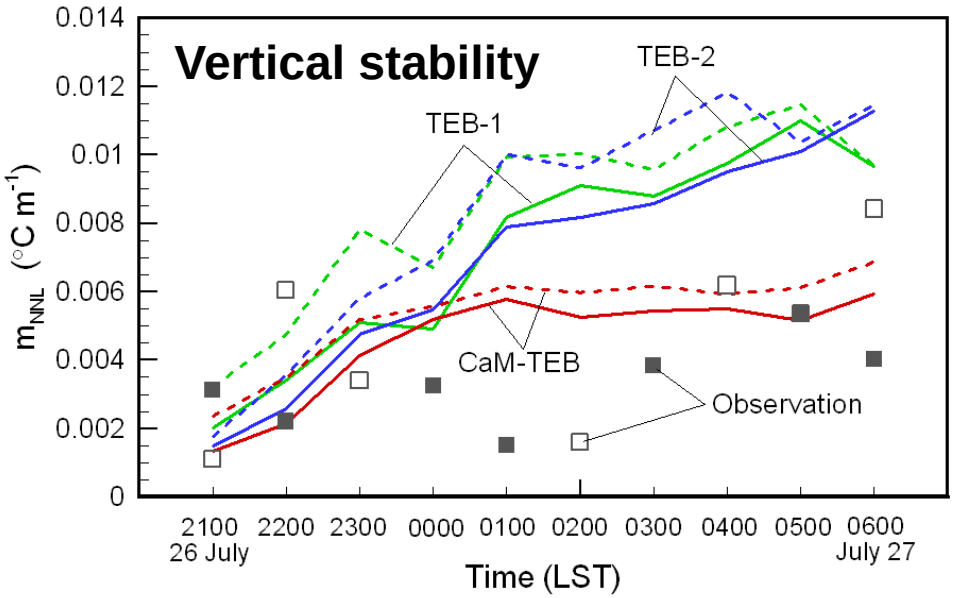
Environmental Prediction in Canadian Cities



Environment Canada Environnement Canada

Oklahoma City, OK, USA (Joint Urban 2003)



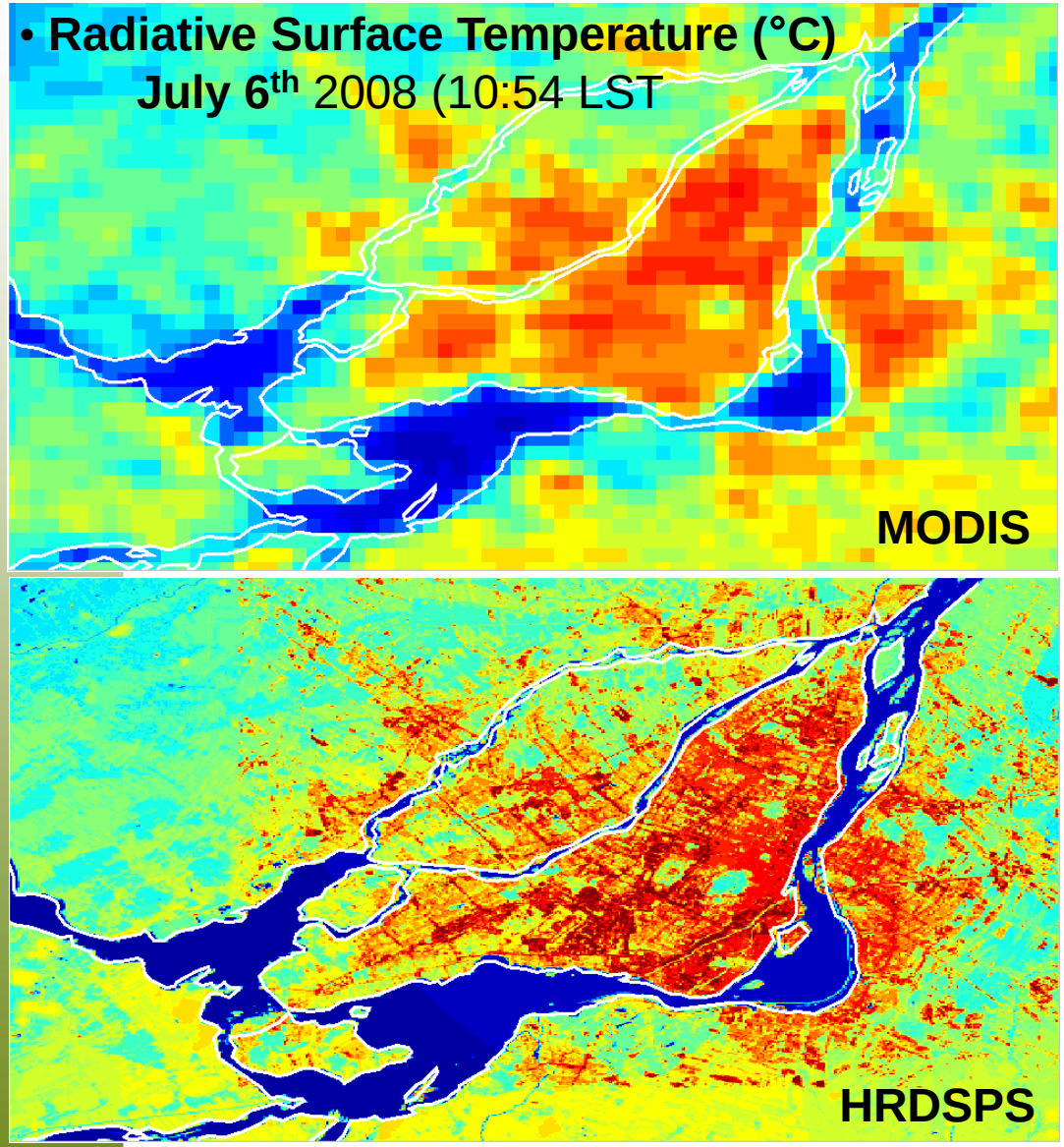


Lemonsu et al. (2009):
Evaluation of Canadian version of TEB

***Husain et al. (2012):**
Introduction of multi-layer version of TEB (Canada) Impact on the vertical stability of nocturnal boundary layer

Husain et al. (2013):
Impact of soil moisture on urban-induced circulations (to be submitted)

Montreal, Quebec, Canada



Lemonsu et al. (2008):
Montreal Urban Snow Experiment (MUSE)

Leroyer et al. (2009):
Impact of soil thawing on surface energy budget (urban)

Lemonsu et al. (2010):
Evaluation of TEB in winter conditions.

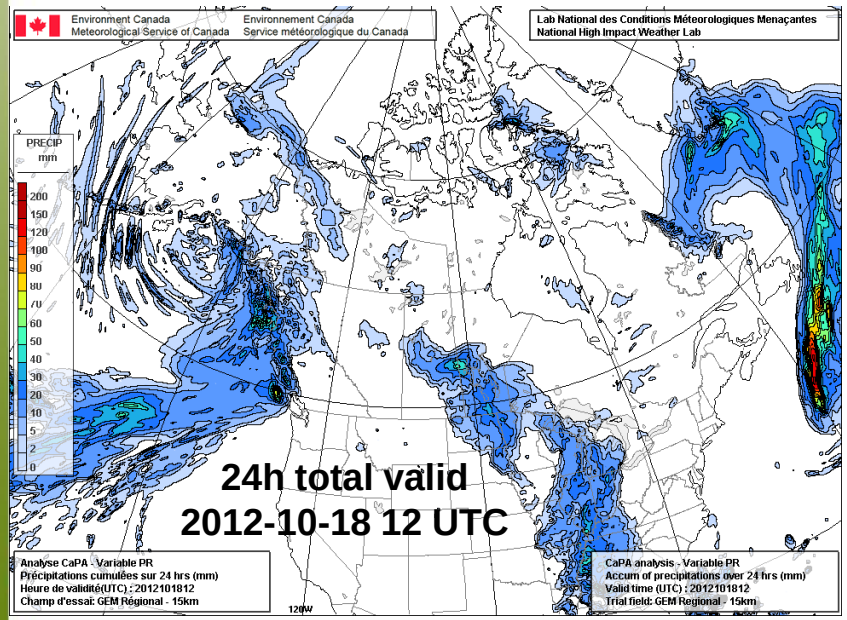
***Leroyer et al. (2011):**
Evaluation of high-resolution deterministic surface prediction system

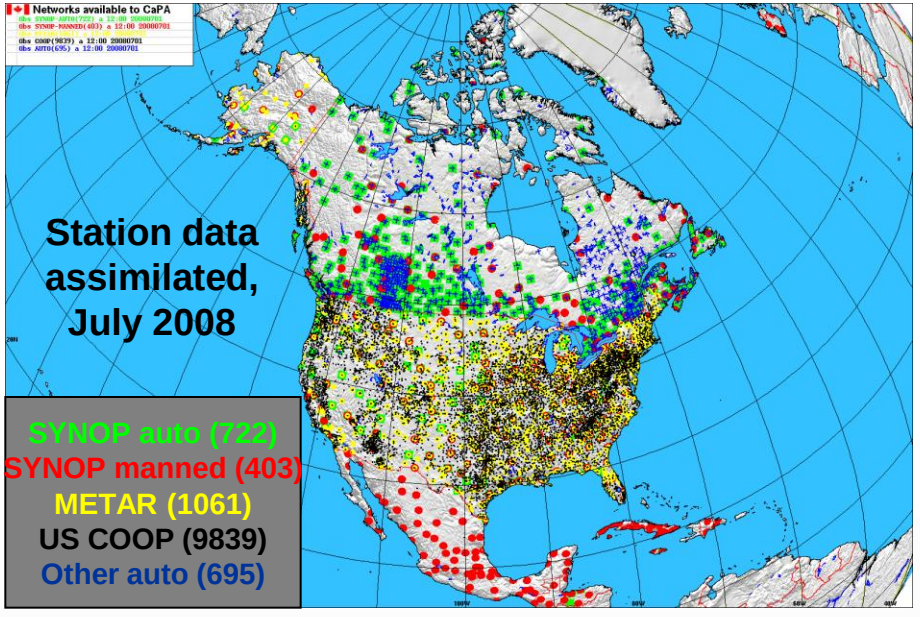
Outlook…

- ***For dispersion: coupling between mesoscale atmospheric model and microscale dispersion flow model (emphasis on multi-layer version of TEB, with greater resolution near the surface)***
- ***Impact of urban surfaces on significant weather (severe convective events, precipitation phase in winter events, freezing rain suppression / enhancement)***
- ***Emphasis on km-scale and sub-km-scale modeling***
- ***Projects: TOMACS (Tokyo) and Pan American Games (Toronto)***

Appendix 5:
Canadian Precipitation Analysis (CaPA):
6h and 24h QPE for North America at T+1

- OI methodology, first guess: RDPS 10 km 6-12h (GEM)
  - OP config.: RDPS + station data only
  - Strict quality-control procedure for solid precip. measurements
- Experimental product assimilates Doppler radar QPE
  - parallel run planned for summer 2013
- Products available here http://loki.qc.ec.gc.ca/DAI/CaPA

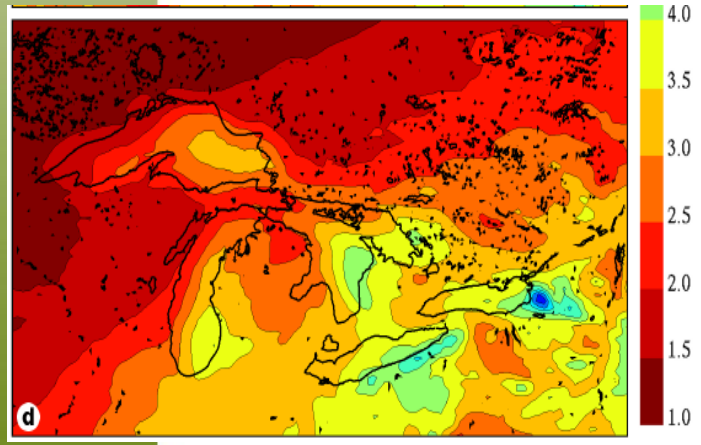




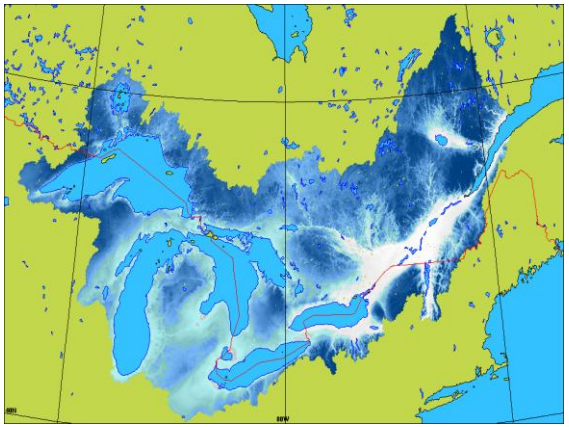
Water cycle prediction system based on coupled numerical models

- Focus on Great Lakes and St. Lawrence watershed:
  - Great Lakes: 2-way coupled atmos.-ocean model (GEM+NEMO)
  - Watershed: 1D model of land-surface + routing (MESH)
  - St. Lawrence: 2D hydrodynamic model (H2D2)
    - Includes pollutant transport model and habitat models

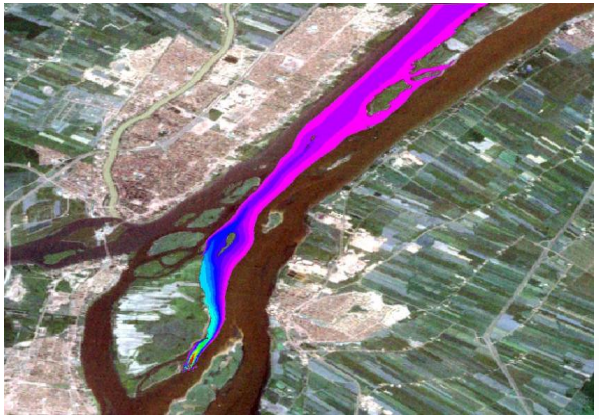
Impact of lakes on weather needs to be captured correctly: DJF 05-09 daily precip. shown



Tributary flow predicted, (with data assimilation of streamflow obs.) @ 500m



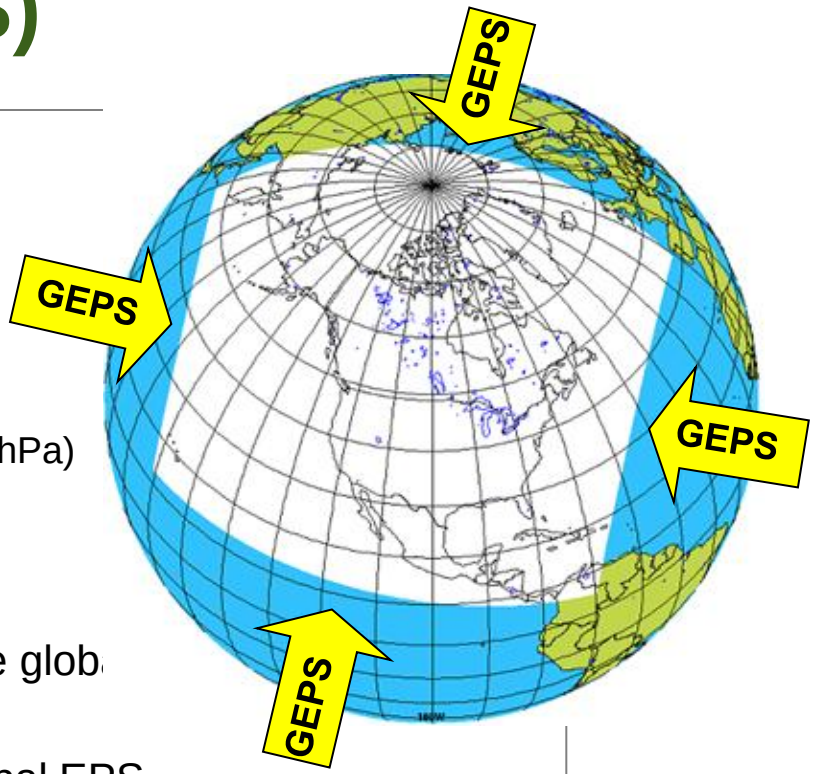
Connected to water quality and ecosystem models: e.g. predicted wastewater plume for Montreal



Environment Canada Environnement Canada

Appendix 6: Regional Ensemble Prediction System (REPS)

System's description



- REPS model lid near 10 hPa
- Use lid nesting technique
  - piloting from the top by the operational GEPS (top 2 hPa)
  - piloting between 10 and 35 hPa (3 levels)
  - blending between 35 and 100 hPa (3 levels)
- Initial conditions from the global EnKF (same as the glob
- Horizontal boundary conditions provided by the global EPS
- at 3 hours intervals
- Produces 72 hours forecasts
- The ensemble is made of 20 members stochastic perturbations of physical tendencies. One control member is not perturbed.

The Canadian Regional EPS in Fall 2012...

- **The Canadian REPS will consist of**
  - Maintaining the same assimilation component
    - Same initial condition as the global EPS
  - Model components:
    - An increase in horizontal resolution from 33 to 15 km
    - An increase in the number of vertical levels from 28 to 40
    - An improved treatment of stochastic physical tendency perturbations to avoid unrealistic precipitation rates
    - An improved boundary layer parameterization

The Regional EPS in 2014-2015...

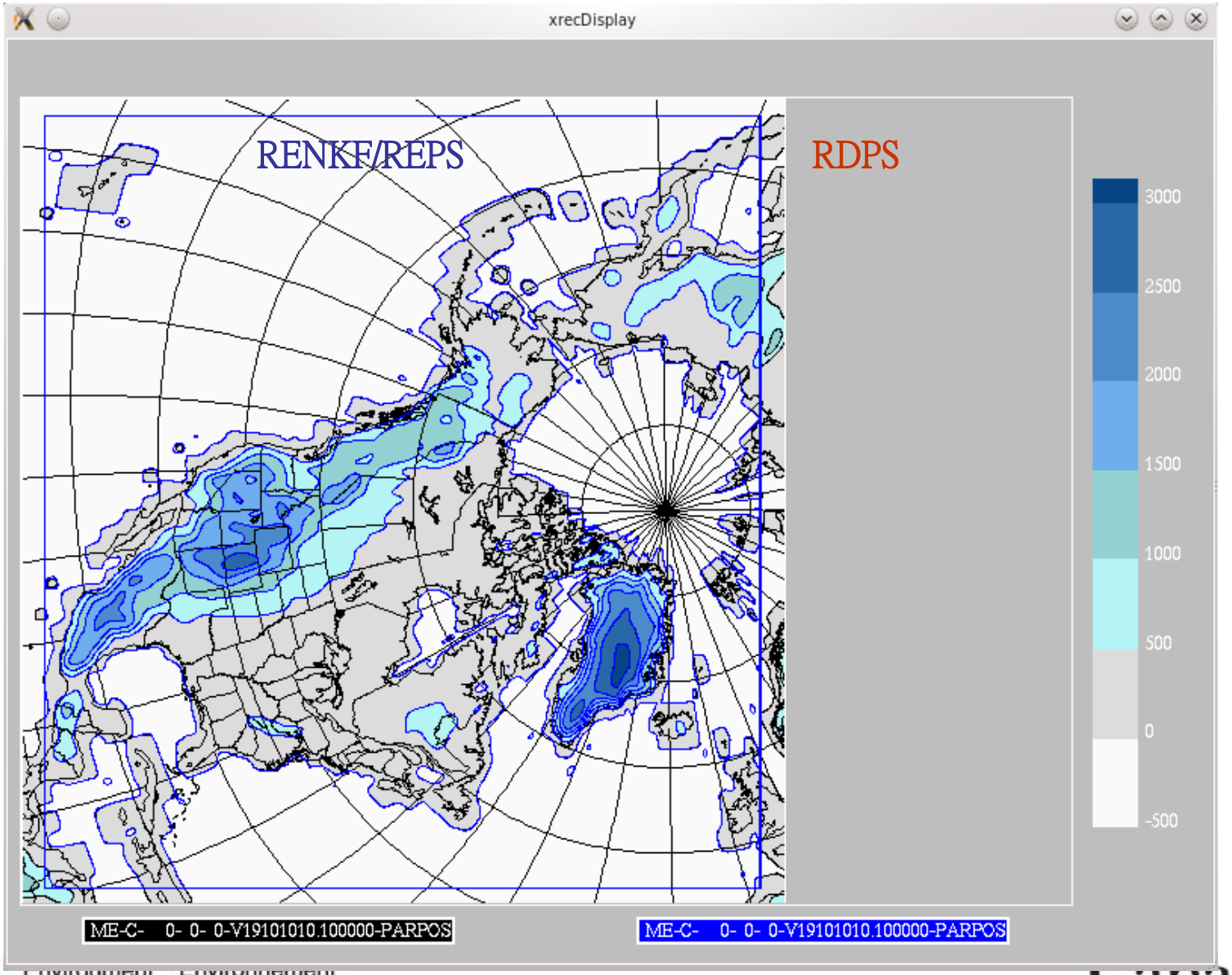
- **The Canadian REPS will consist of**
  - Assimilation component
    - Regional Ensemble Kalman Filter
      - A major milestone for the regional EPS
      - Background at 10-15 km grid spacing
  - Forecast component
    - Lead time of 4-5 days?
    - 4x per day? That is 00Z, 06Z, 12Z and 18Z.
    - Stochastic convection?
    - Increasing the horizontal resolution to 10 km.
    - Better surface and near-surface model error representation by perturbing uncertain parameters and fields related to the surface scheme.

Appendix 7: Environment Canada's Regional Ensemble Kalman Filter

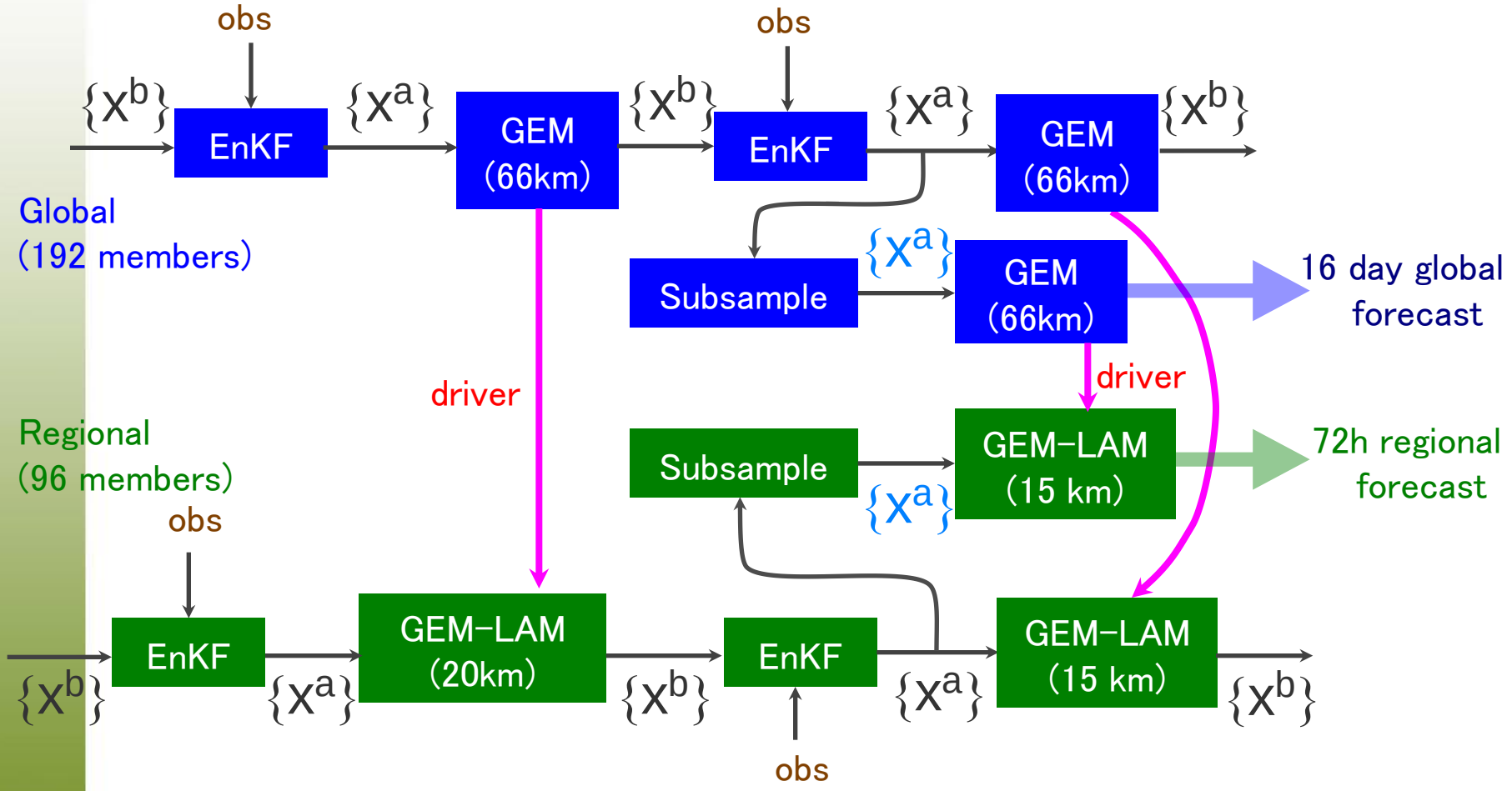
RENKF/REPS Configuration

- RENKF uses 96 Members
- Both RENKF and REPS have same model configuration; i.e.
  - 15 km, 41 Levels, top at 14.5 hPa
  - Timestep = 450s (7.5 min)
  - Digital Filter Initialization with a 3h limiting period
- Global Driver provides B.C. every 2h.
- No model error added yet (plan to use stochastic physics in the near future).

RENKF/REPS grid embedded within RDPS grid



Synchronous coupled EnKF: Global & Regional



- Bias correction from global 4D-Var.
- Background check from global and regional 4D-Var.

Future work prior to first operational implementation

- Localization distance adjustment.
  - Flow dependent covariance localization.
- Observation density: reduced data thinning. (< 150 km)
- Homogeneous-isotropic part of model error perturbations taken from the RDPS background error covariance matrix.
- Demonstrate added value of RENKF over Global ENKF to feed the REPS system directly and the Regional En_Var analysis with regional ensembles.

Appendix 8: Canadian AQ Forecasting System

- Primary messaging tool is the Air Quality Health Index (AQHI)
- Main target is urban areas > 100,000 population
- On-line forecast model GEM-MACH provides guidance on AQHI component values (NO_2, O_3, $PM_{2.5}$) and meteorological fields out to 48 hours

Canada's National Air Quality Health Index (AQHI)

- Follows example of Canadian national UV index
- Year-round, health-based, additive, no-threshold, hourly AQ index
- Developed from daily time-series analysis of air pollutant concentrations and mortality data (Stieb et al., 2008)
- Weighted sum of NO_2, O_3, & $PM_{2.5}$ concentrations
- 0 to 10+ range

Elements of Canada's AQ Forecasting System

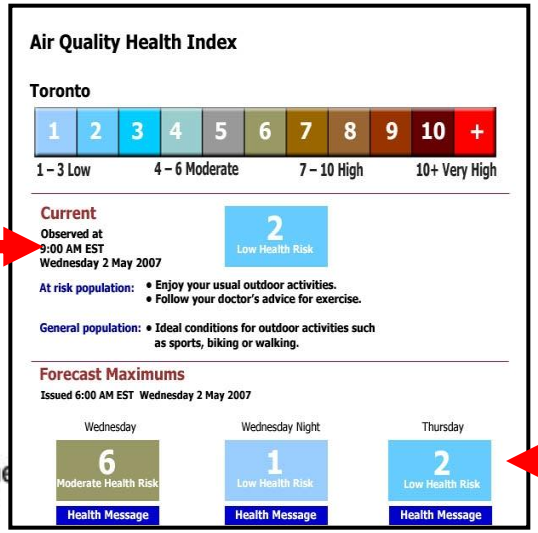
Schematic diagram of an AQHI forecast

Past and present situation
- Last 48 hr -
Real-time observations
of O_3, $PM_{2.5}$, NO_2

Numerical forecast
- Next 48 hr -
GEM-MACH
UMOS-AQ

Forecaster
(1 desk/forecast region)

AQHI = 10/10.4*100*[(exp(0.000871*$\mathbf{NO_2}$)-1)
+(exp(0.000537*$\mathbf{O_3}$) -1)+(exp(0.000487*$\mathbf{PM_{2.5}}$) -1)]



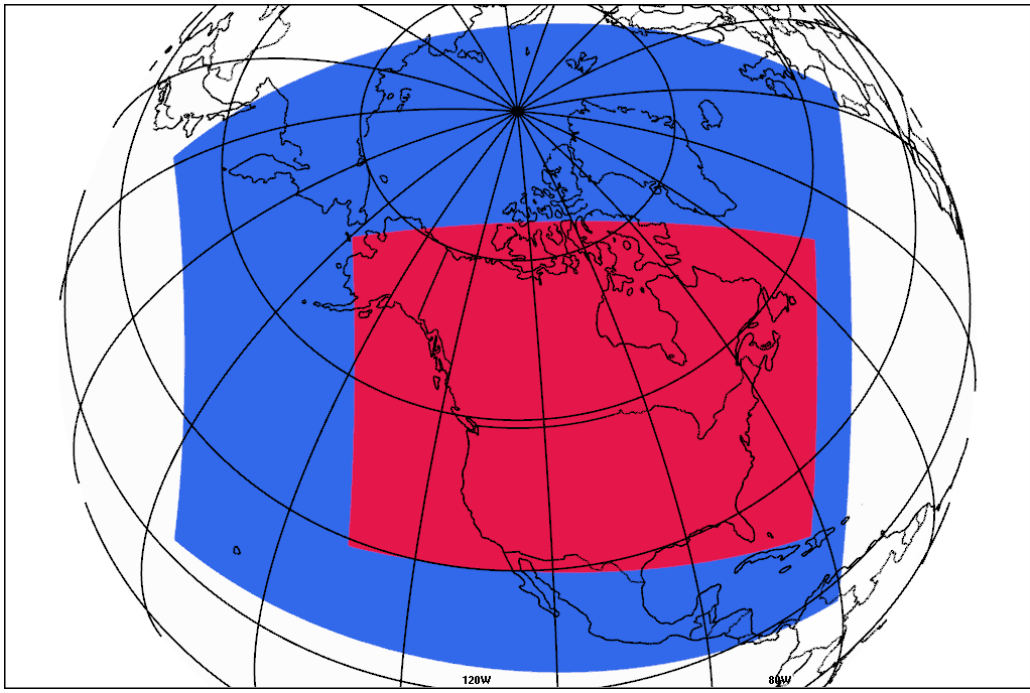
AQHI = 10/10.4*100*[(exp(0.000871*$\mathbf{NO_2}$)-1)
+(exp(0.000537*$\mathbf{O_3}$) -1)+(exp(0.000487*$\mathbf{PM_{2.5}}$) -1)]

GEM-MACH

- GEM-MACH is a multi-scale chemical weather forecast model composed of dynamics and physics (GEM) and *on-line* chemistry modules
- Operational configuration of GEM-MACH includes
  - limited-area-model (LAM) grid configuration for North America
  - **10**-km horizontal grid spacing, **80** vertical levels to 0.1 hPa
  - 2-bin sectional representation of PM size distribution (i.e., 0-2.5 and 2.5-10 μm) with 9 chemical components
  - forecast species include O_3, NO_2, and $PM_{2.5}$ needed for AQHI

RDPS and Operational GEM-MACH Grids

- EC's limited-area regional deterministic prediction system (**RDPS**) provides required initial and boundary conditions for **GEM-MACH**
- **GEM-MACH**'s grid points are co-located with RDPS grid points



RDPS grid (blue); GEM-MACH grid (red)

Emissions

- Emissions inventories used:
  - Canada: 2006 base year
  - USA: Projection to 2012 from 2005 base year
  - Mexico: 1999 base year
  - Biogenics: Estimated on-line using BEIS v3.09 algorithms

Future Developments

- Operational configuration:
  - Lengthen forecast from 48 to 72 hours
  - Include wildfire emissions
- Global configuration for assimilation/piloting purposes
  - 12-bin version for AOD assimilation
  - Simplified stratospheric chemistry for the assimilation of ozone and GHGs.

Appendix 9: Monthly Prediction System

- **GEPS based**
- **Two components**

  1) Real time forecasting system

  2) Hindcast (model climate and statistics)

Real time forecasting system

- Extend GEPS to 32 days once a week
- (00Z Thursday)
- Persistent SST anomaly added to time-evolving SST climatology
- GEM 4.4, 0.6x0.6L40
- Perturbed physics
- 21 members, ensemble Kalman Filter

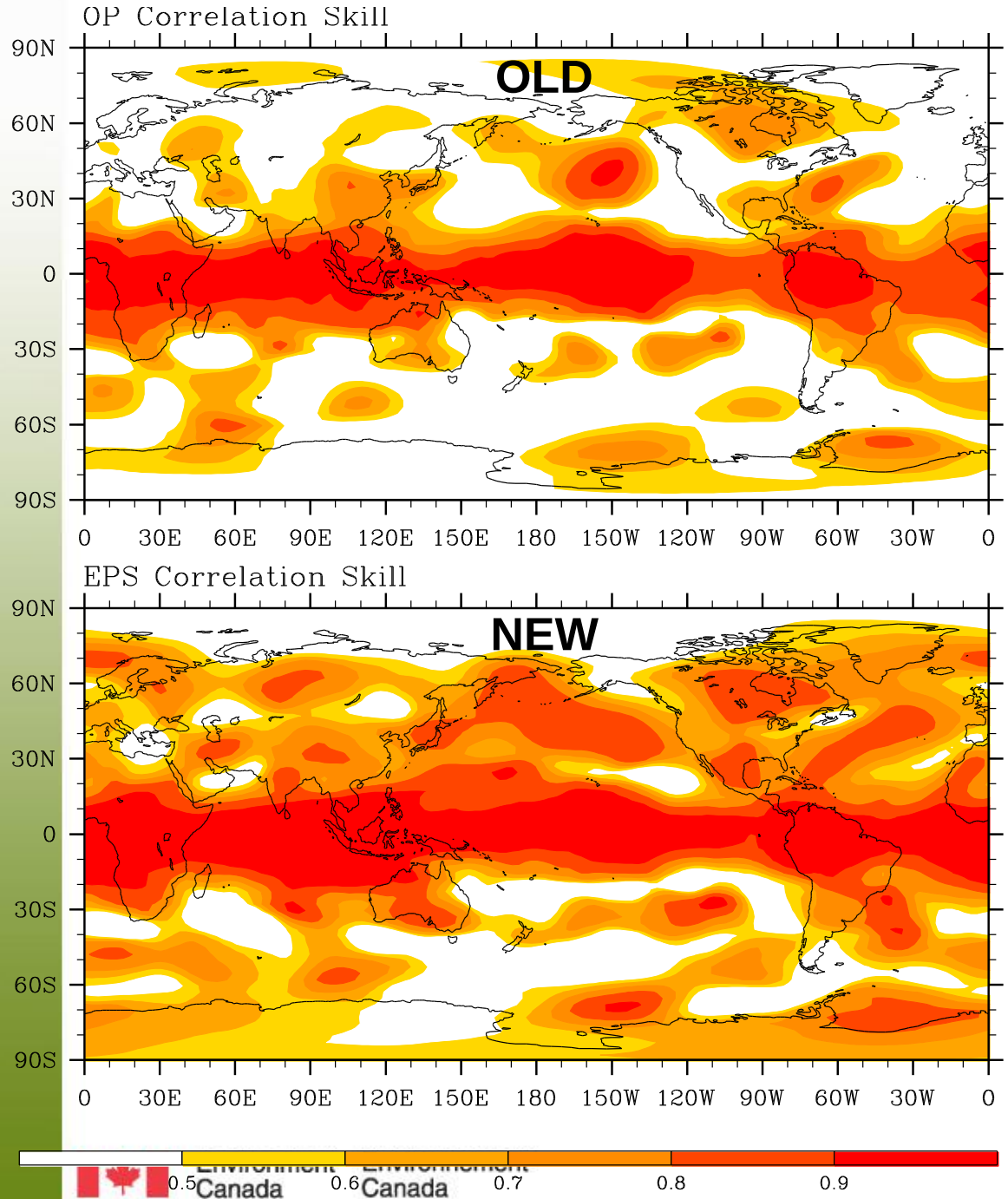
Hindcasts

- To generate GEPS model climatology
- For the same date, past 15 years
- 4 members each year, 60 members for each date
- Use 3 weeks centered at the date of the current Thursday, total of 180 members

Proposed products:

Forecast products of weekly average T2m and PR over Canada

- Ensemble mean anomaly maps
- Probability maps for above, below and near normal



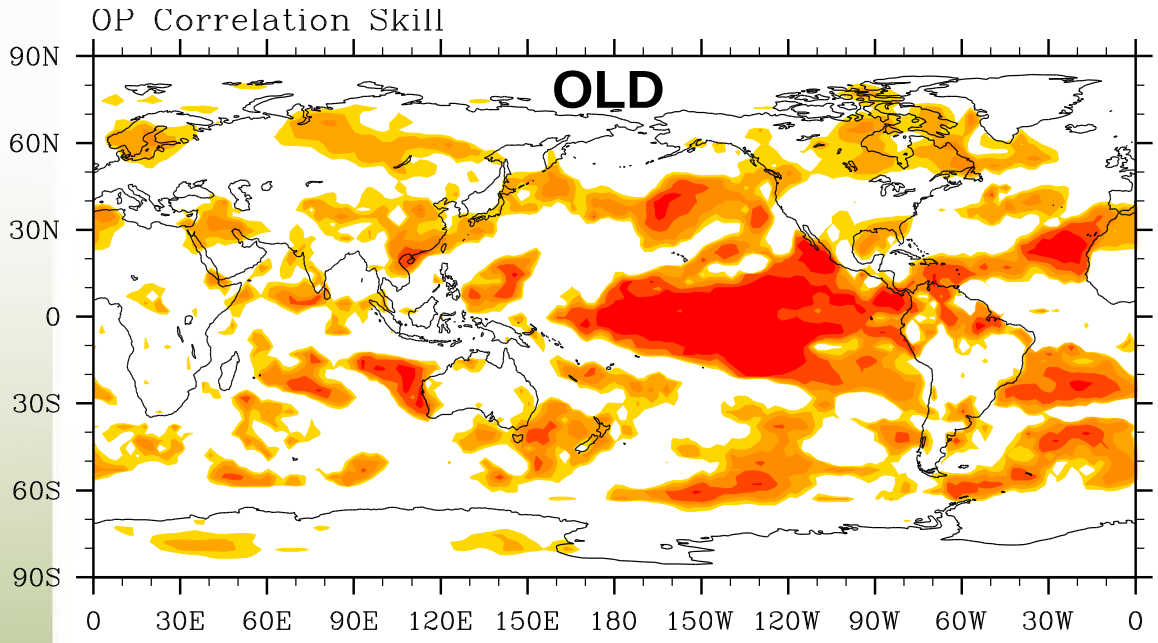
Correlation skill

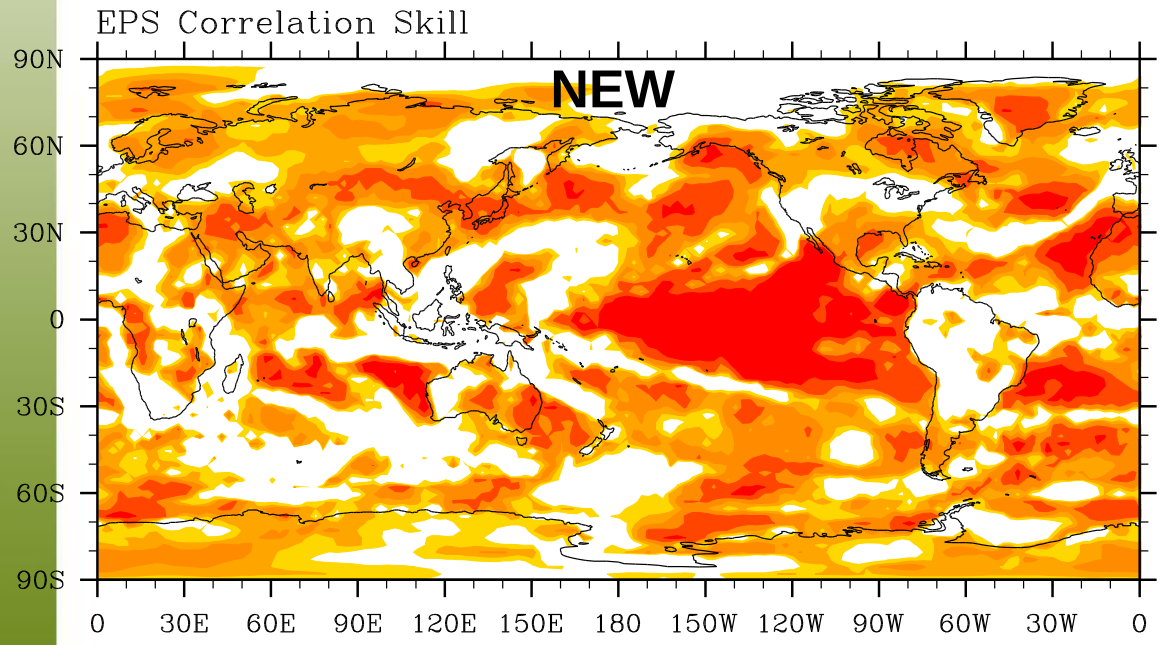
Winter Z500

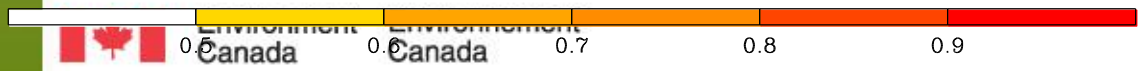
30-day average

Evaluation

- Winter (January and February)
- Summer (July and August)
- Past three years (24 forecasts for each season)







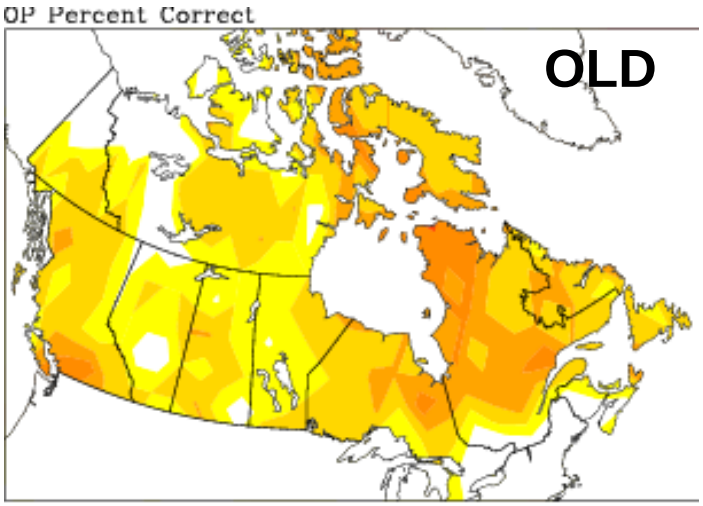
Correlation skill

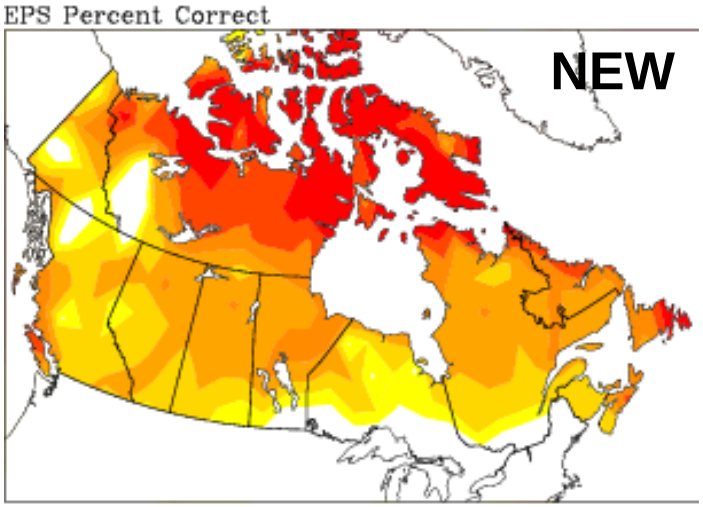
Winter T2m

30-day average

Evaluation

- Winter (January and February)
- Summer (July and August)
- Past three years (24 forecasts for each season)





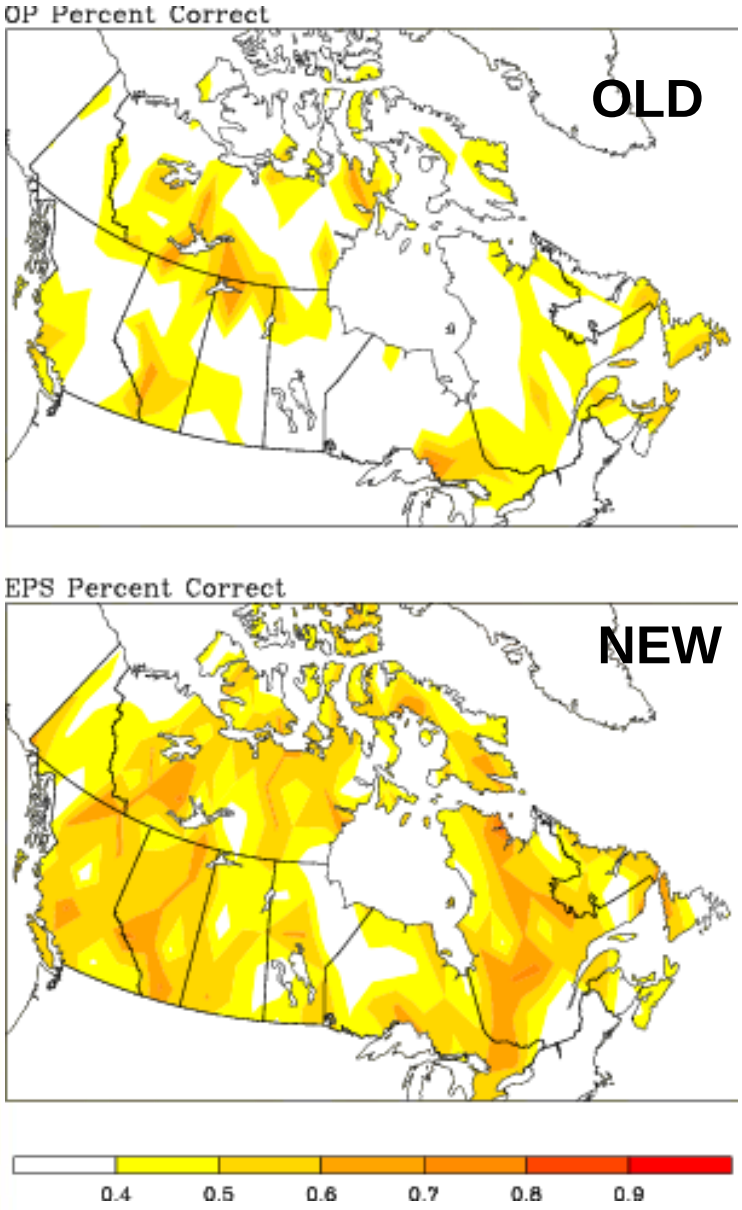
Percent Correct for categorical forecasts

Winter T2m

30-day average

Evaluation

- Winter (January and February)
- Summer (July and August)
- Past three years (24 forecasts for each season)



Percent Correct for categorical forecasts

Winter PR

30-day average

Evaluation

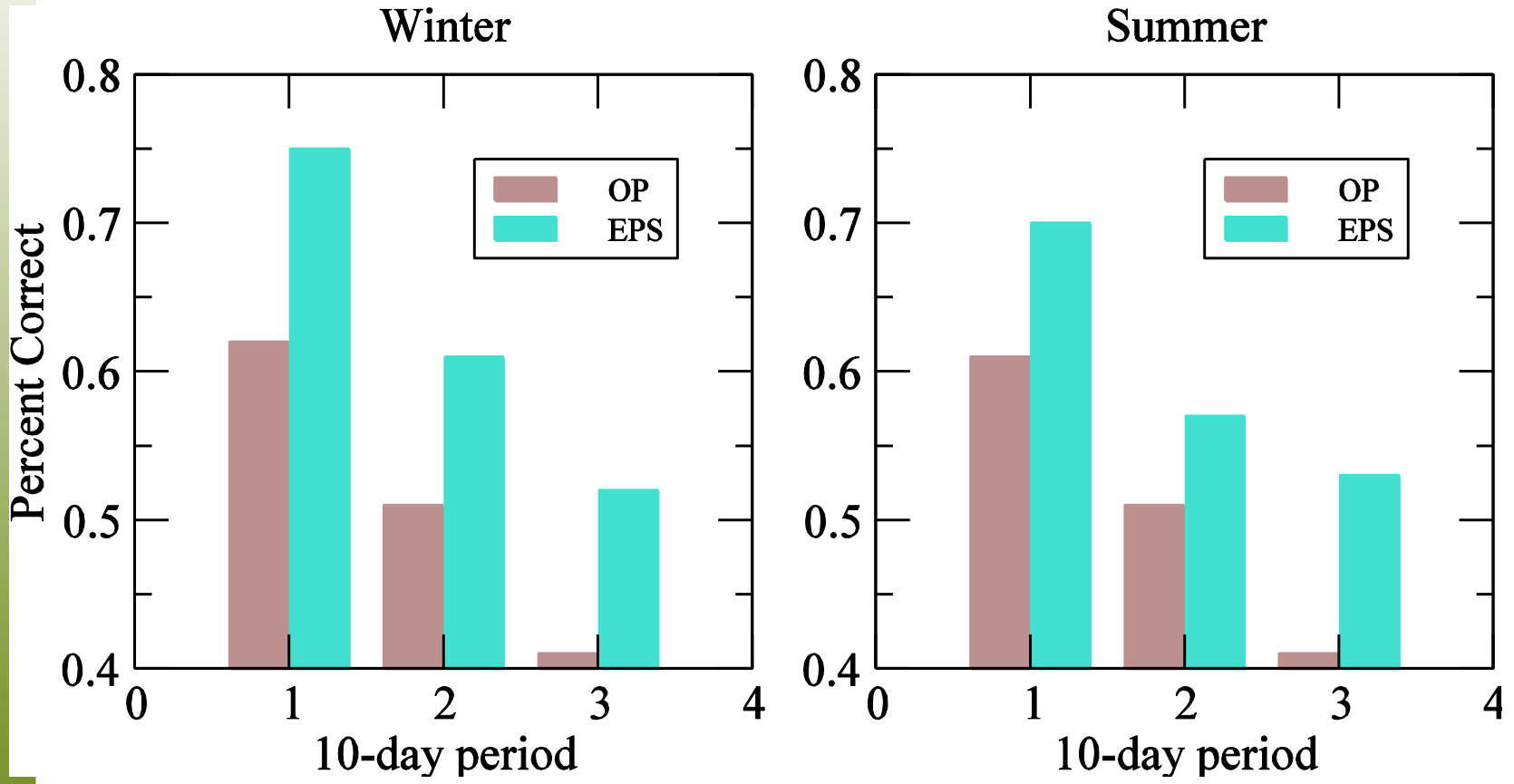
- Winter (January and February)
- Summer (July and August)
- Past three years (24 forecasts for each season)

Environment Canada Environnement Canada

10-day average T2m

Over Canada

Percent Correct for categorical forecasts



OP = old system

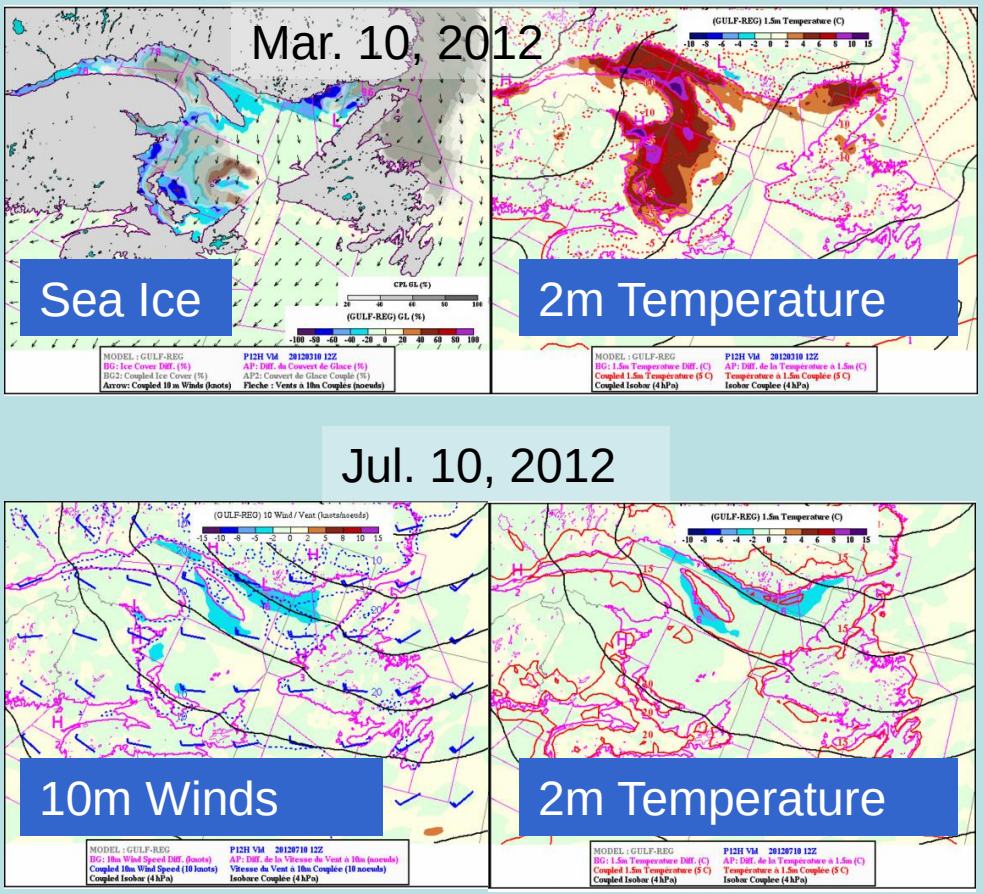
EPS = new system

Appendix 10: Plans for CONCEPTS Environmental Prediction Systems at EC

Gulf of St. Lawrence Coupled Atm-Ice-Ocean Forecasting System

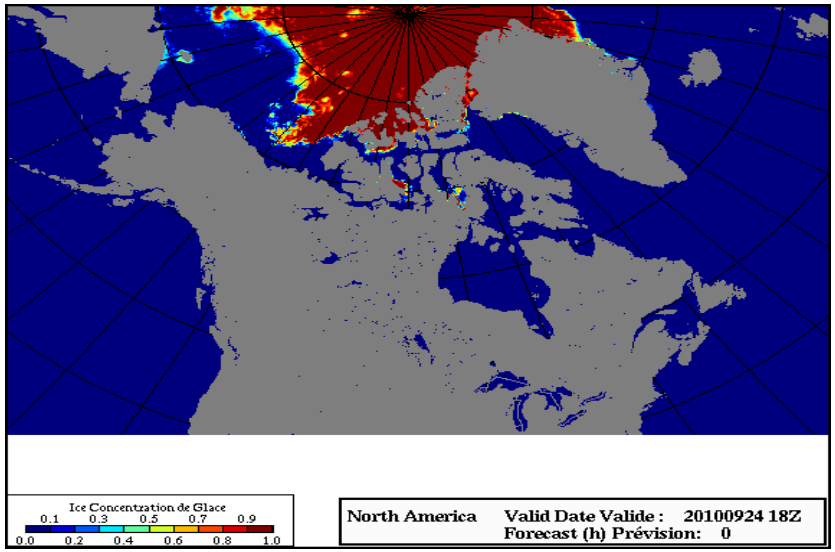
- Operational since June 2011
  - 48 forecast daily at 00Z
- Coupled system:
  - Atm: GEM (10km)
  - Ice: CICE (5km)
  - Ocean: MoGSL (5km)

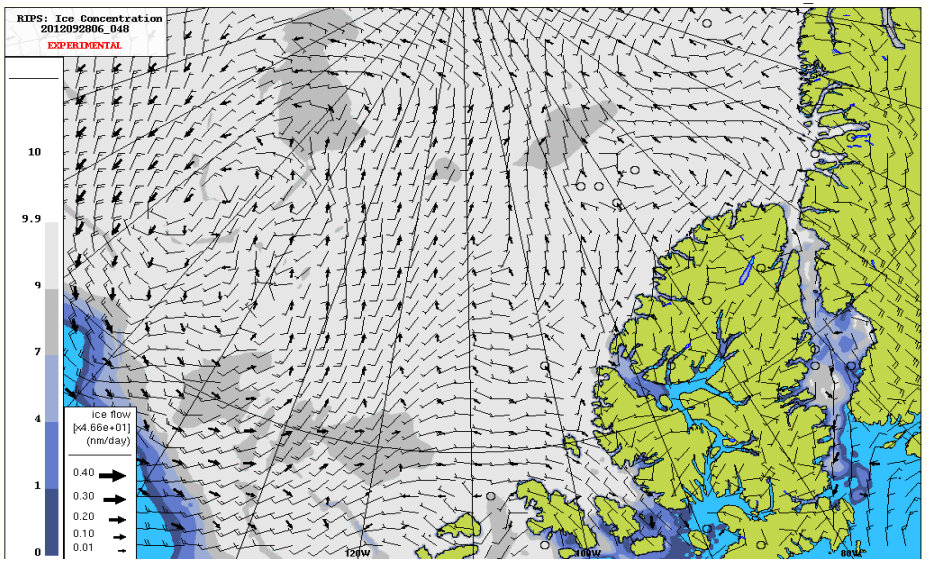
Coupled – Uncoupled differences



Regional Ice Prediction System (RIPS)

- 5km North American grid
- 3DVar Ice analysis
  - SSMI, AMSR-E, CIS daily charts
- CICE4.1 Ice model
  - Forced by CMC RDPS
- 48hr forecasts at:
  - 0Z, 6Z, 18Z, 24Z
- To be run experimentally at CMC by March 2013





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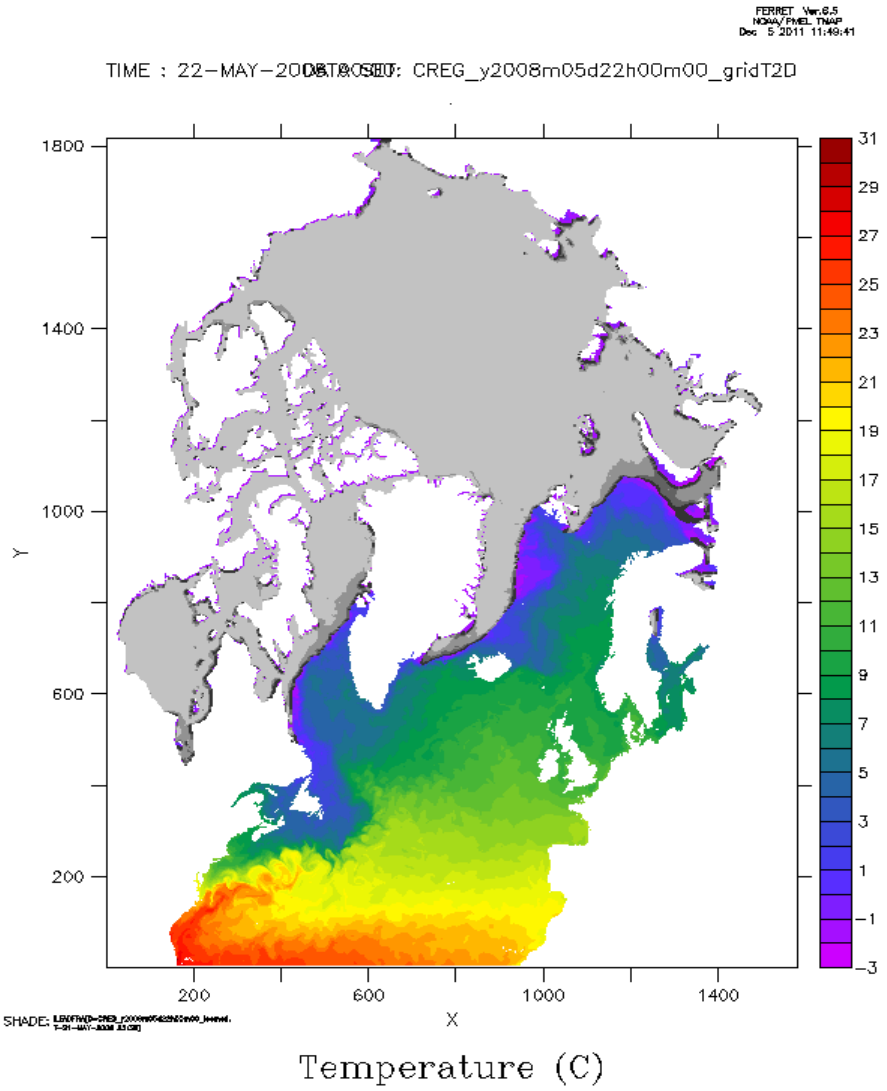
Regional Ice-Ocean Prediction System

- Couple RIPS to NEMO
  - 3-8km Arctic/N.Atl configuration (CREG12)
- SAM2 ocean assimilation (SEEK) with 3DVar ice assimilation
- Expected operational implementation for Mar. 2014



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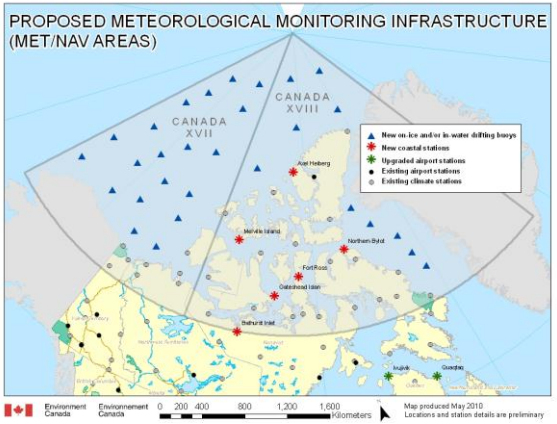
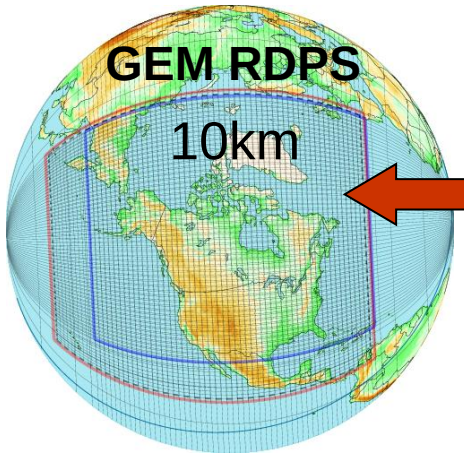
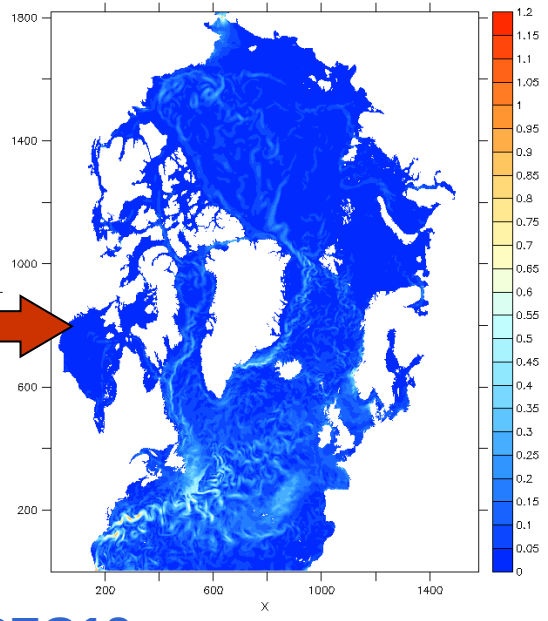
METAREA Integrated Marine Prediction System

- Coupled atmosphere-ice-ocean-wave-snow model
  - GEM (10km), NEMO-CICE(3-8km), WW3
  - 2-3 day forecasts
- Expected implementation:
  - March 2015



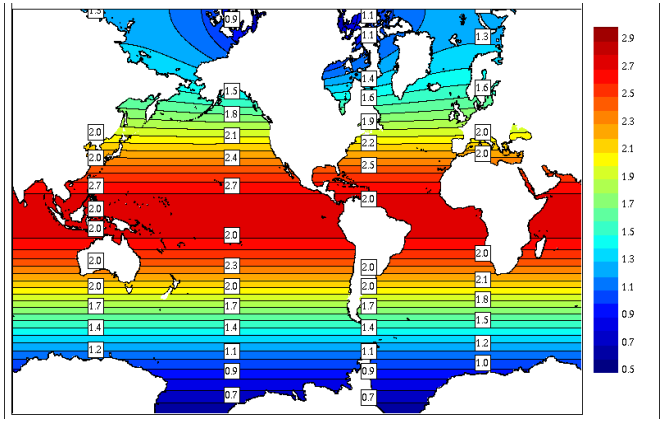


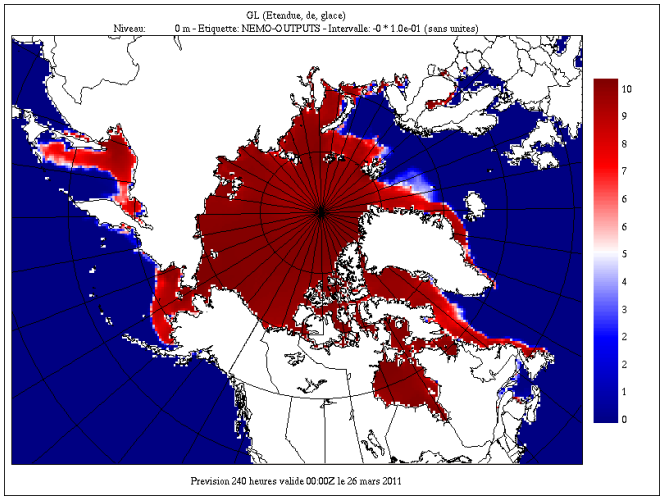


CREG12 velocity mag. (m/s)

CONCEPTS Global Ice-Ocean Prediction System

- Mercator Ocean Assimilation System (SAM2-SEEK):
  - Sea surface temperature
  - Temperature and salinity profiles
  - Sea level anomaly from satellite altimeters
- 3DVar Ice analysis:
  - SSM/I, AMSR-E, CIS charts, Radarsat
- Daily blended ice-ocean analysis and 10day forecast
- Model configuration:
  - ORCA025 (~1/4°), <15km in Arctic
  - NEMOv3.1, LIM2-EVP
- Expected operational implementation:
  - June 2013





Global Coupled Environmental Prediction System

- Medium-monthly forecasting
- Based on coupling of GDPS and GIOPS systems and integration into GEPS
- Expected implementation in 2015