The New Canadian Surface Modeling and Assimilation System

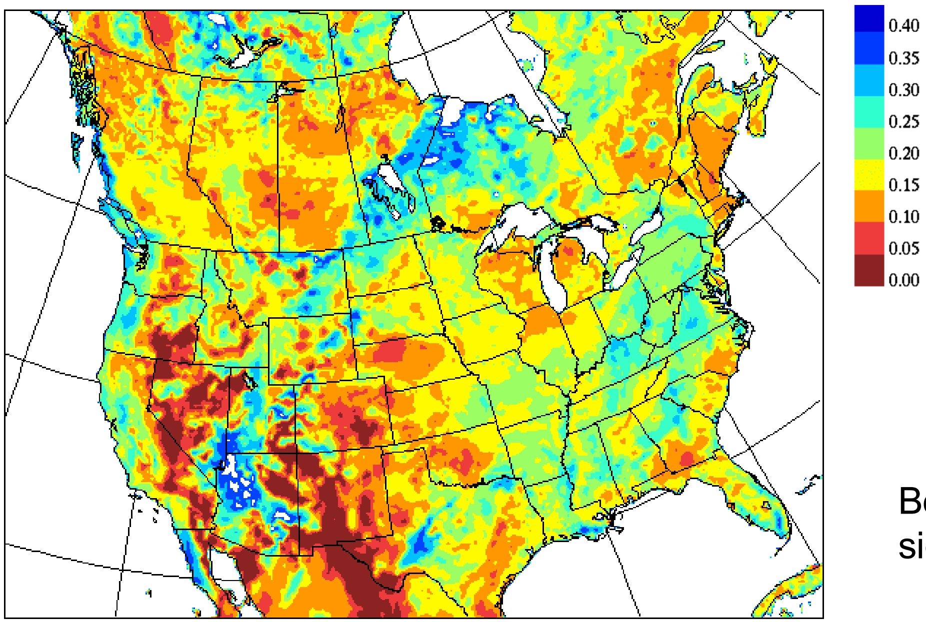
Stéphane Bélair, Bernard Bilodeau, Vincent Fortin, Pierre Pellerin

Recherche en prévision numérique (RPN)
Meteorological Research Division (MRD)
Environment Canada

Thanks to many others, including G. Balsamo and J.-F. Mahfouf

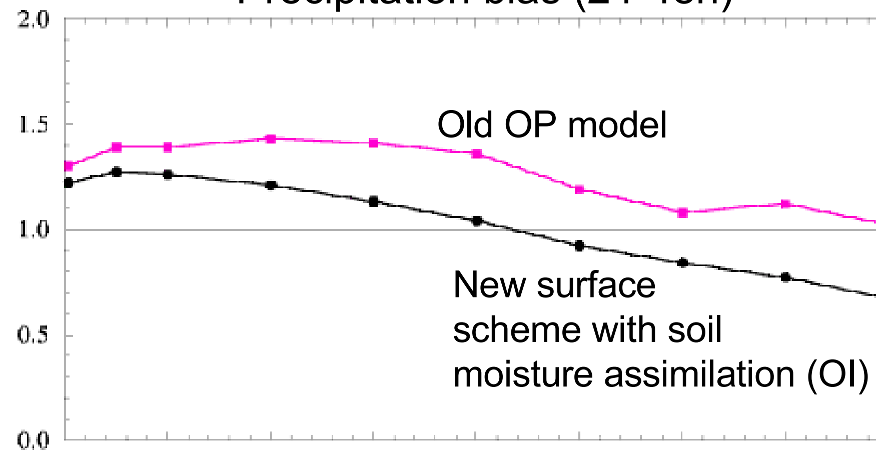
Impact of Surface Processes on NWP: Short-Range Regional Model

Near surface soil moisture

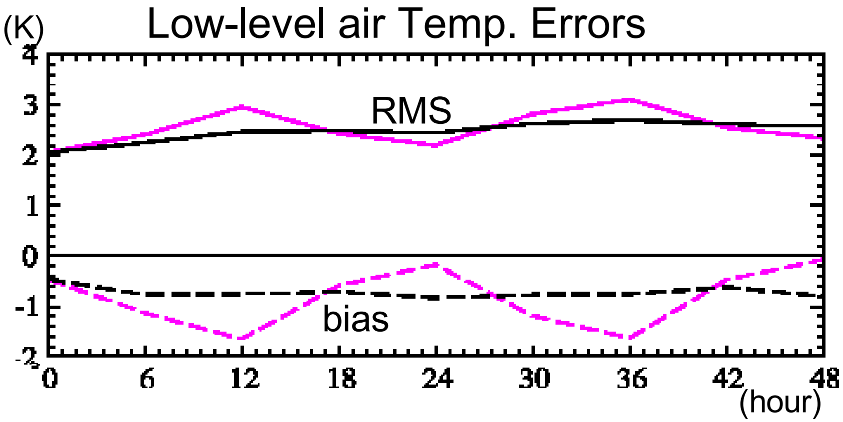


(valid at 1200 UTC 22 October 2004)

Precipitation bias (24-48h)



Low-level air Temp. Errors



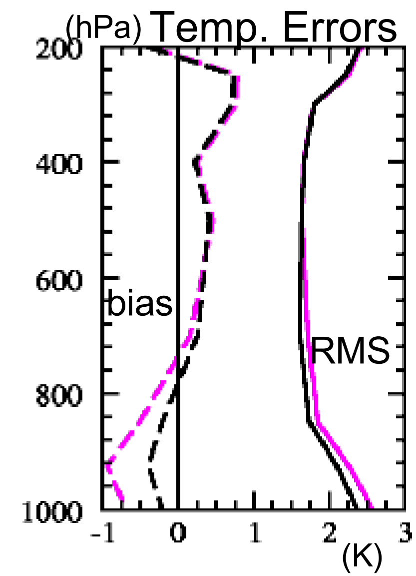
Better soil moisture resulted in significant improvements for:

- Low-level air temp. and humidity
- Diurnal cycle of the PBL
- Precipitation biases

NOTE: mostly in summer

<u>To investigate</u>: impact on the statistical characteristics of precipitation and on the generation of convective activity

Temp. Errors

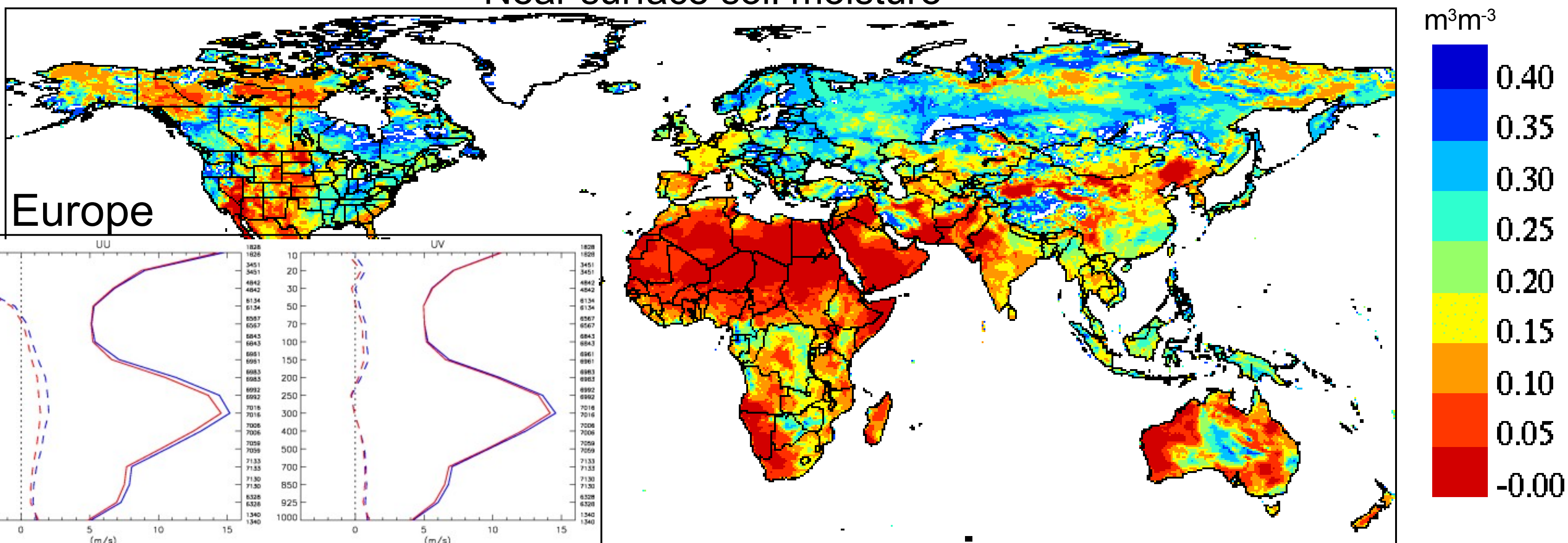


48-h integrations

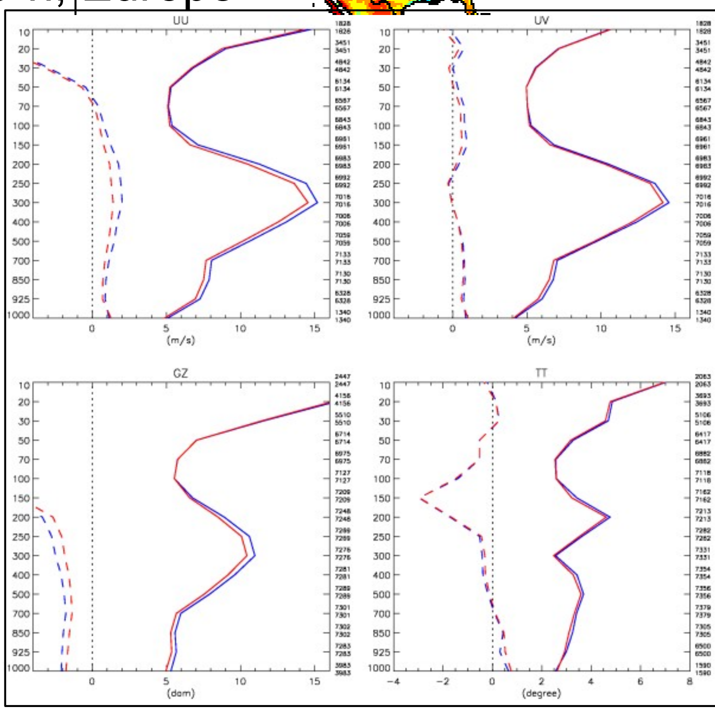
(*Bélair et al.*)

Impact of Surface Processes on NWP: Medium-Range Global Model

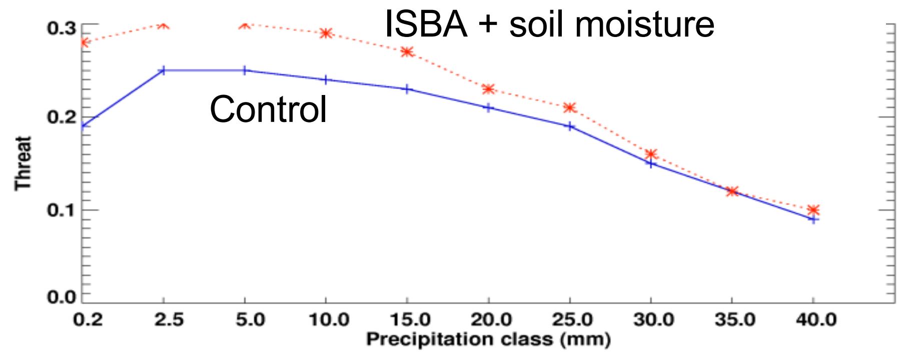
Near surface soil moisture



120-h, Europe



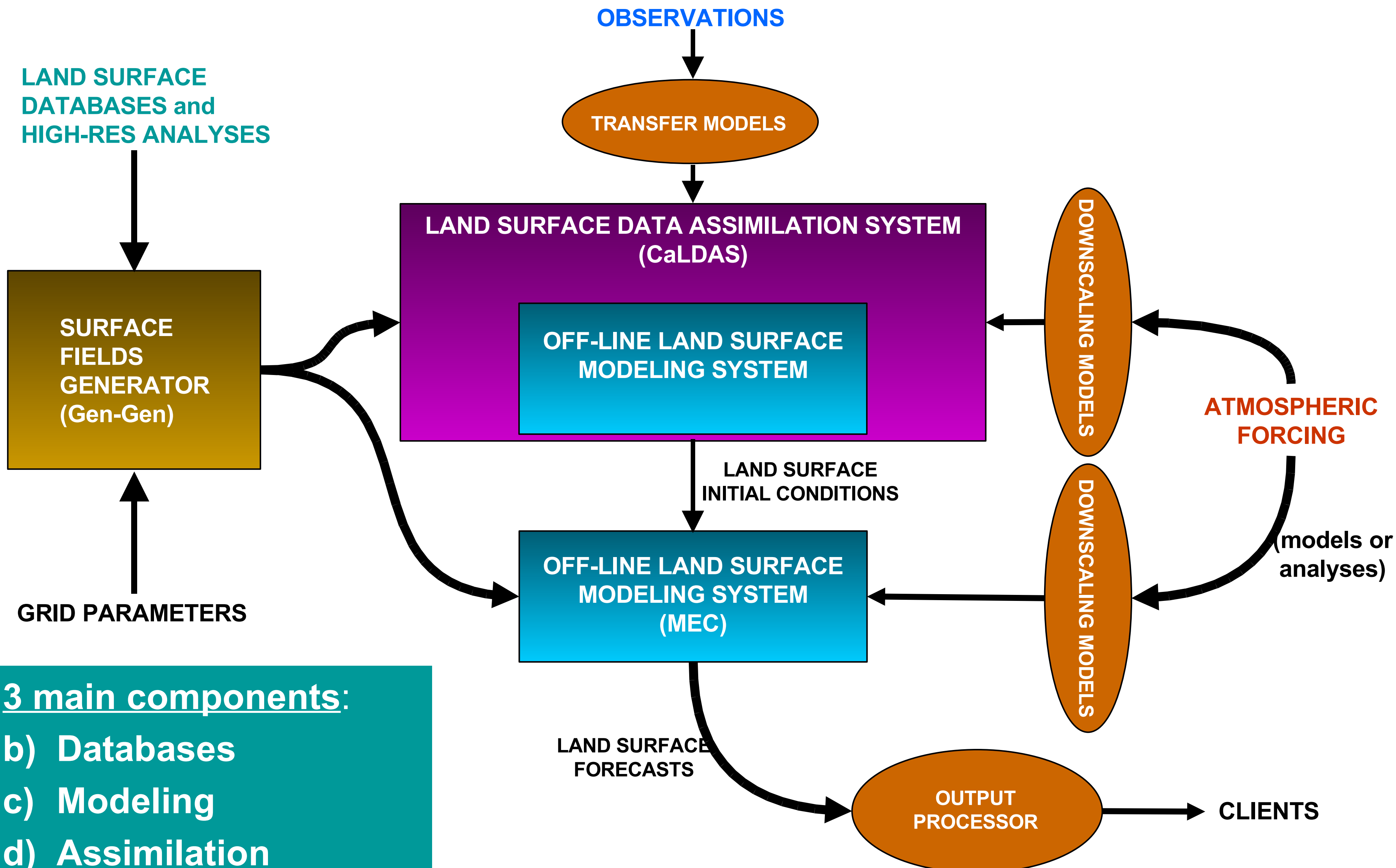
Precipitation Threat Score (Day 4)- SHEF



Has been implemented in the global forecasting system (31 October 2006).

(*Bélair et al.*)

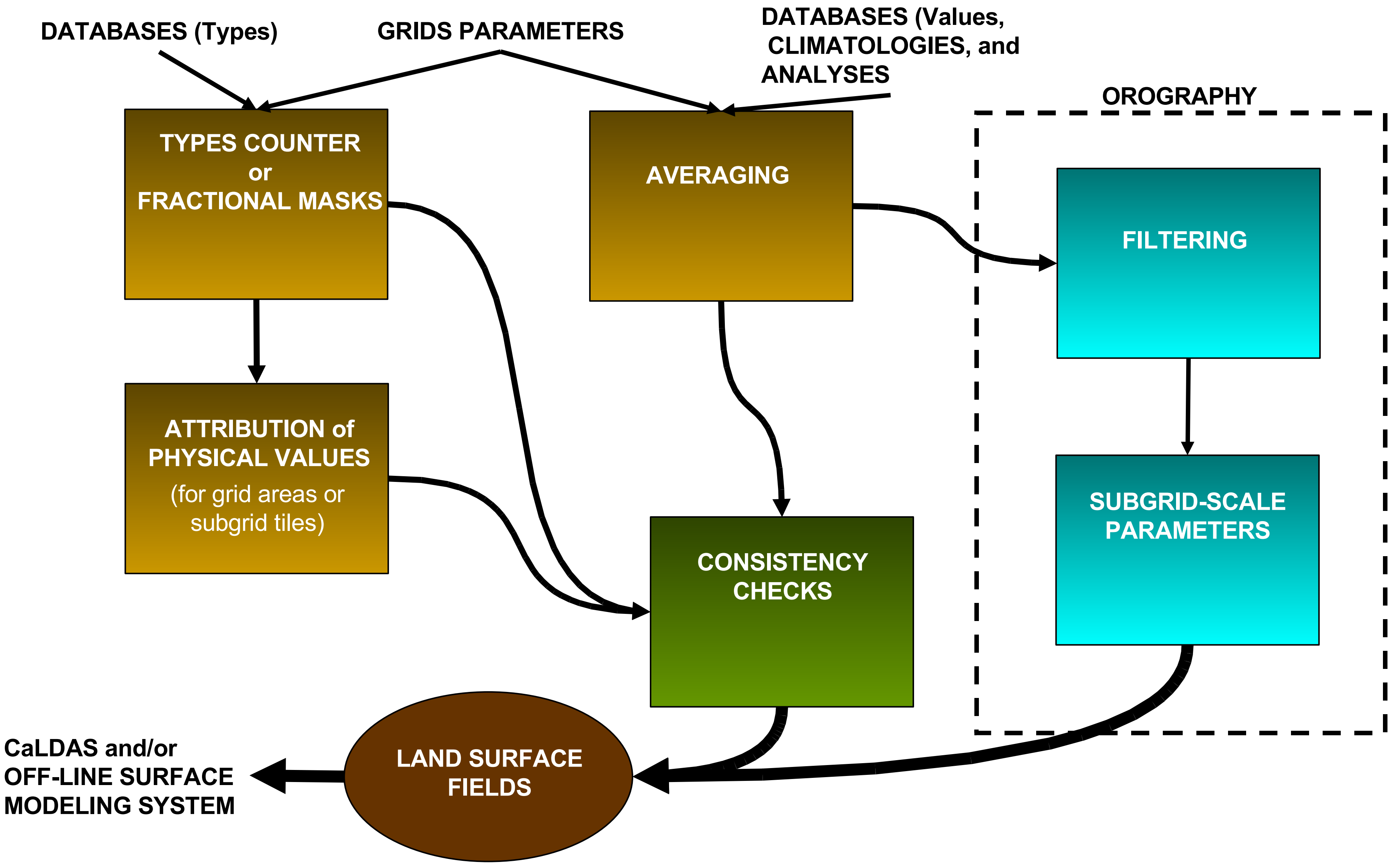
End-to-End (External) Surface System (currently under development)



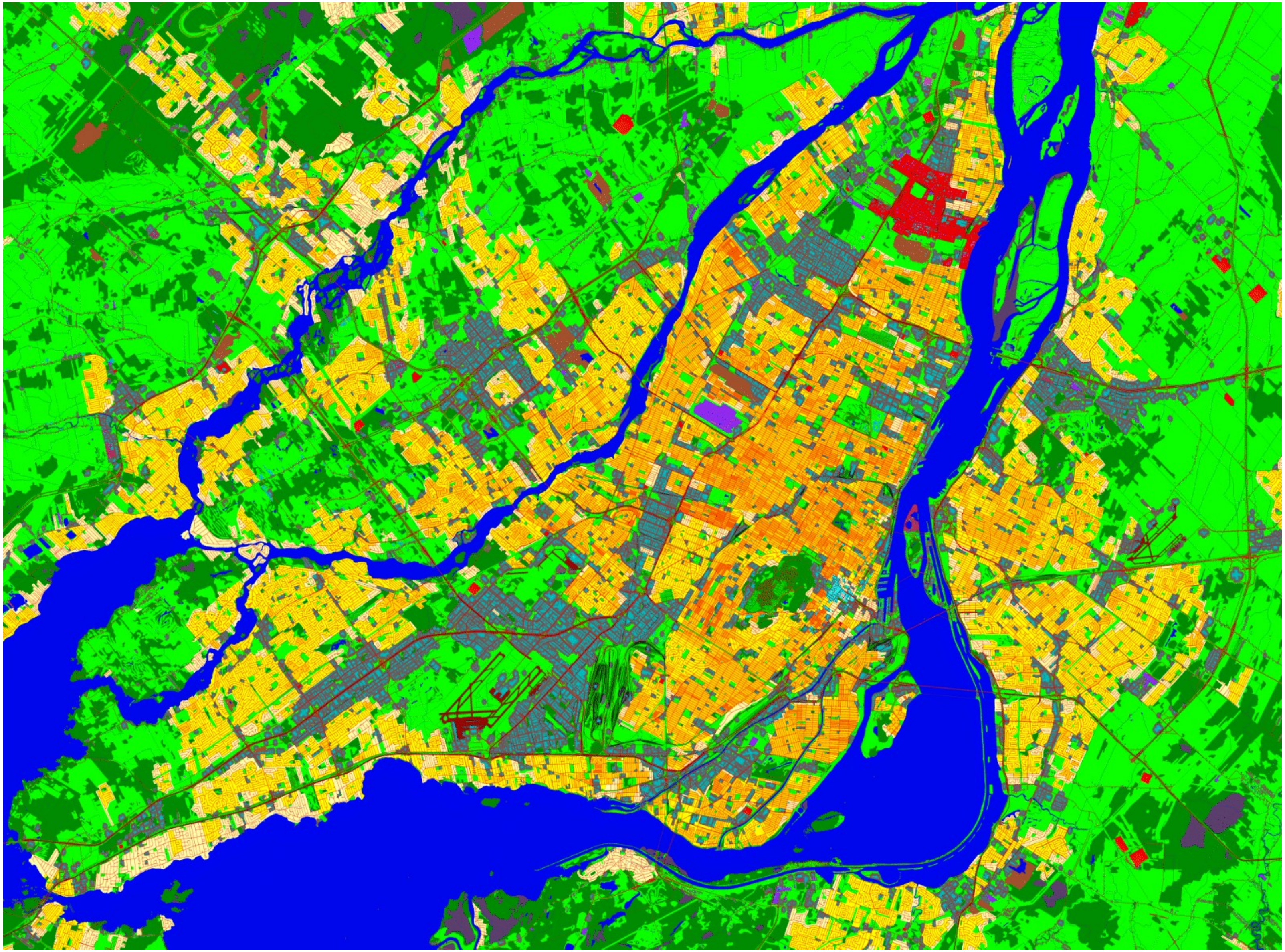
3 main components:

b) Databases
c) Modeling
d) Assimilation

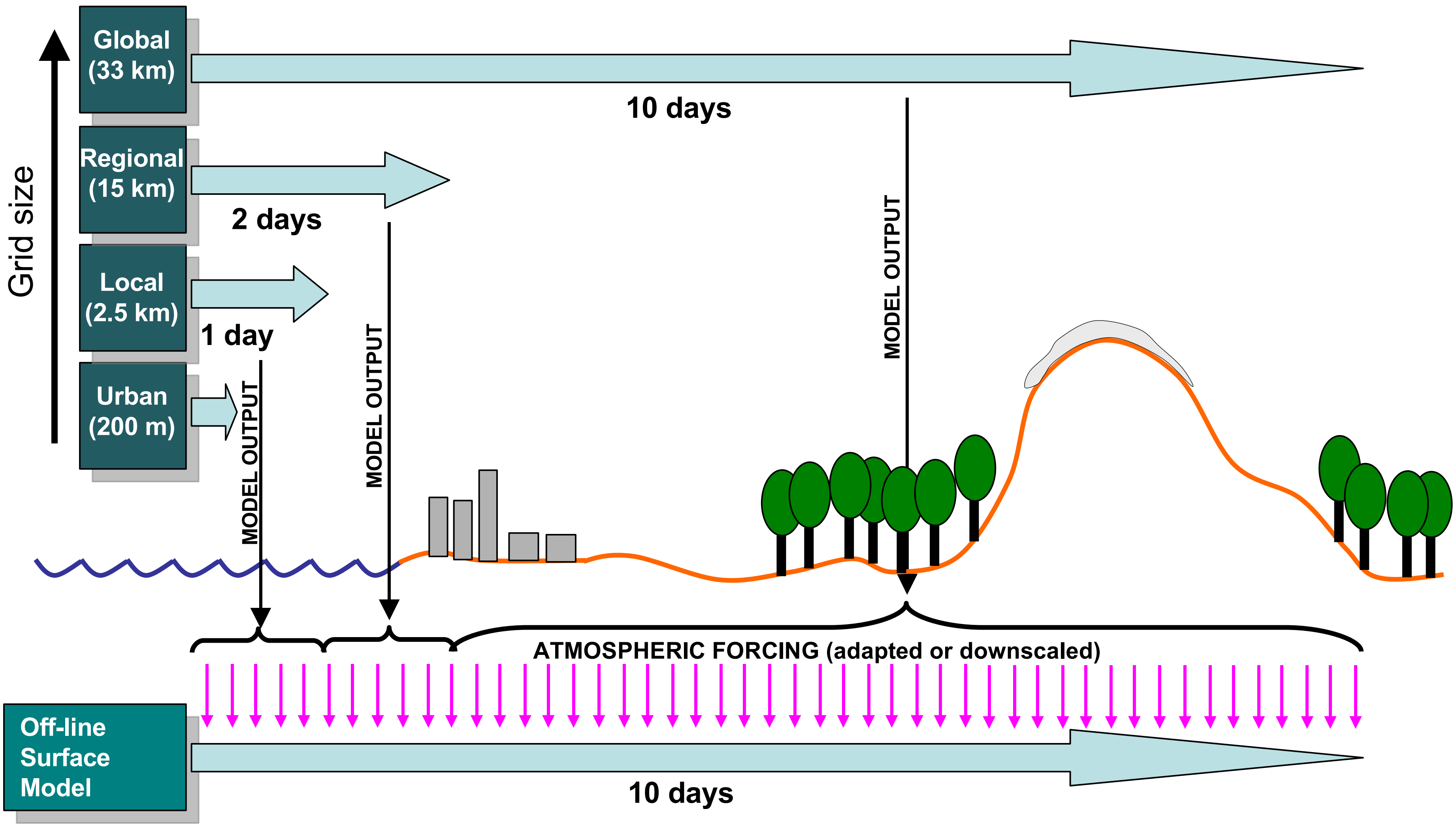
Surface Fields Generator



Example of Urban Covers: Montreal (Scaled-down, 44 classes)



Refining CMC's Forecasts at the Surface



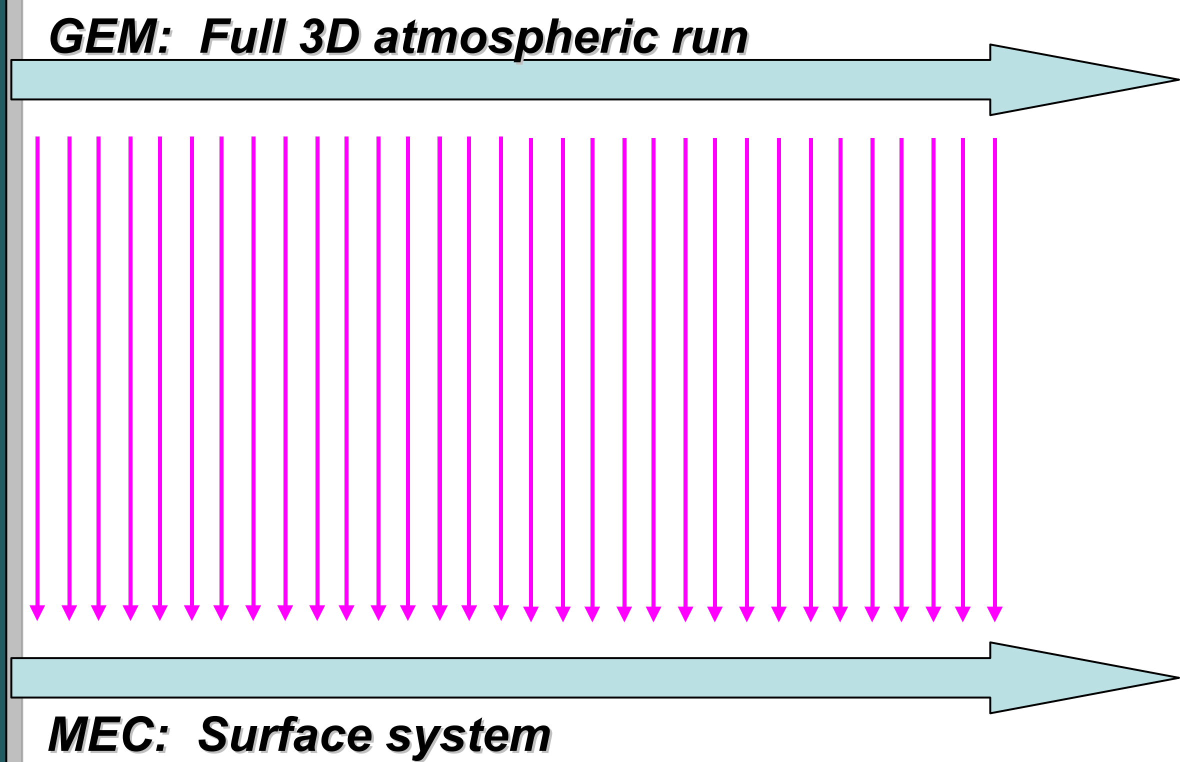
With horizontal resolution as high as that of surface databases (e.g., 200 m)

Cost of the off-line surface modeling system is *<u>much less</u>* than an integration of the atmospheric model

Environmental Community Model (MEC) and the Global Environmental Multiscale (GEM) Models – Same Code

GEM	MEC
Entry	Entry
Dynamics	Dynamics
Physics	Physics
Radiation	Radiation
Surface	Surface
Turbulence	Turbulence
Clouds and precip	Clouds and precip

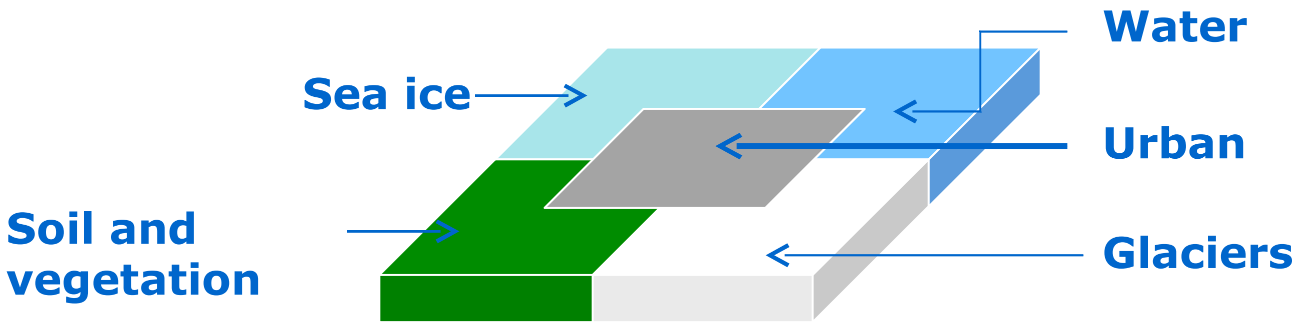
(only do what is necessary to run the surface in an external manner)



Can run in 1-way or 2-way modes

(tests up to now in 1-way mode)

RPN's Surface Modeling System



Soils and vegetation	ISBA, CLASS
Water	Simple scheme with constant surface temperature (Lake model?)
Urban covers	TEB
Glaciers	Force-restore scheme (with snow), CLASS
Sea ice	3-layer model with snow on top
Snow	Very simple scheme over glaciers and sea ice; better in ISBA, CLASS and TEB.

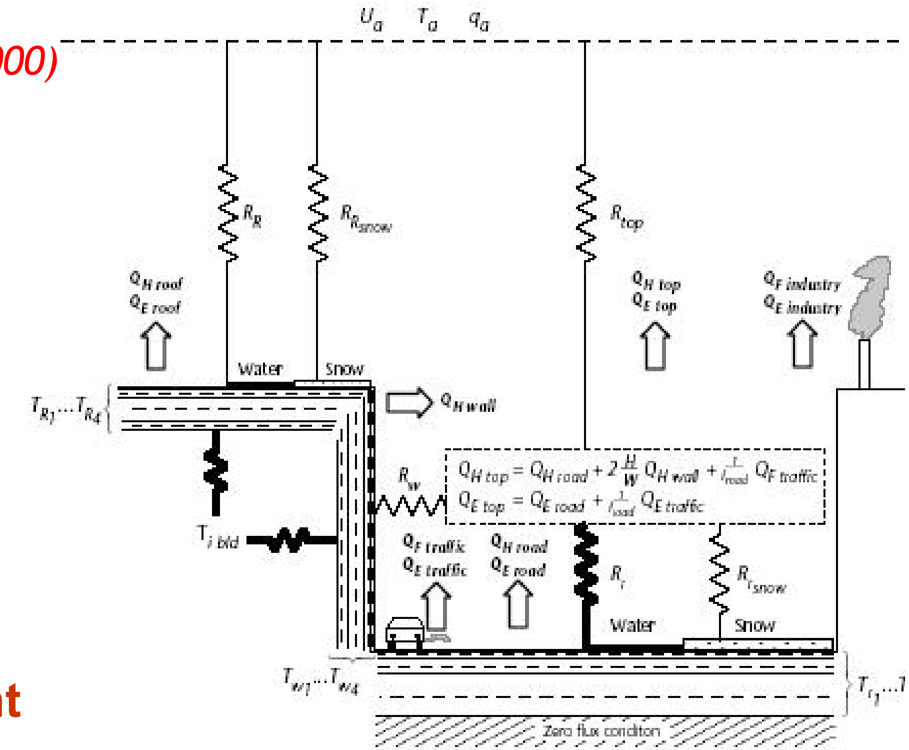
ISBA versus CLASS

- ISBA: Interactions between Surface Biosphere and Atmosphere (from Météo-France) - currently used operationally in CMC’s local, regional, and global forecasting systems
- CLASS: Canadian Land Surface Scheme (from Environment Canada’s climate branch)
- Work is underway to test the possibility of replacing ISBA with CLASS
- A few important things still needs to be done:
  - Modular-mosaic approach consistent with RPN’s
  - Remove duplicate treatments between CLASS and the rest of the physics
  - Assimilation of CLASS variables (more complex than for Canada’s version of ISBA)
  - NWP-style evaluation (has not been done yet with this scheme)
- CLASS is at least 5 times more computationally expensive than ISBA
- Before the transfer, demonstration that CLASS improves the results has to be done

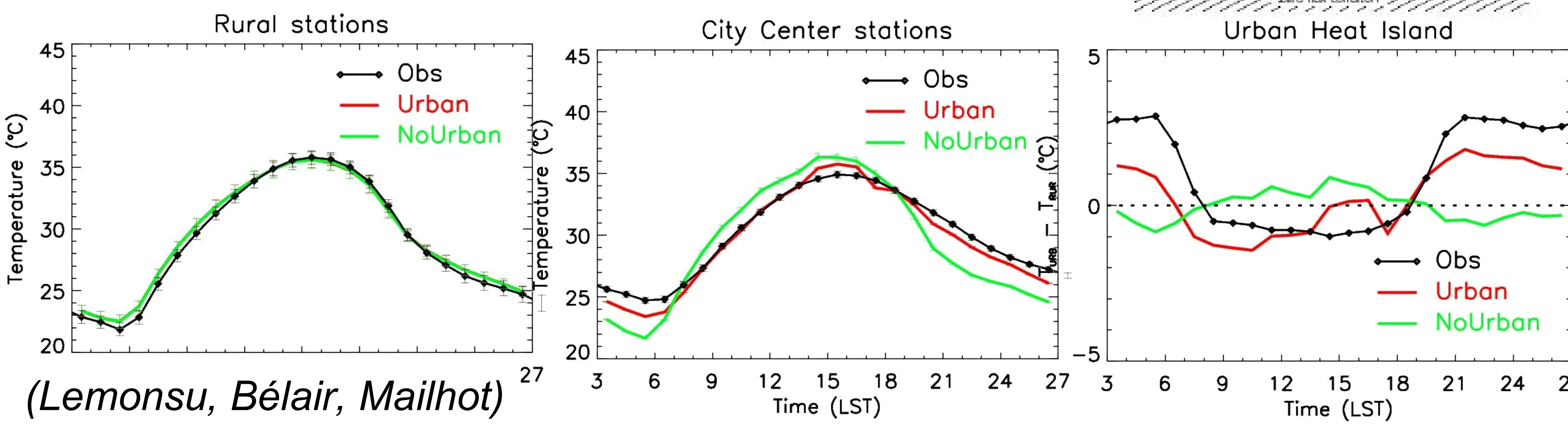
TEB: Town Energy Balance scheme

Town Energy Balance, TEB *(Masson, BLM, 2000)*

- Simplified 3D geometry of urban canopy
  (idealized canyon according to Oke, 1987)
- Radiation trapping inside the street
- Heat storage
- Mean urban microclimate inside the street
- Water and snow on roads and roofs
- Anthropogenic forcing of heat and humidity



Example for IOP6 of OKC JU experiment



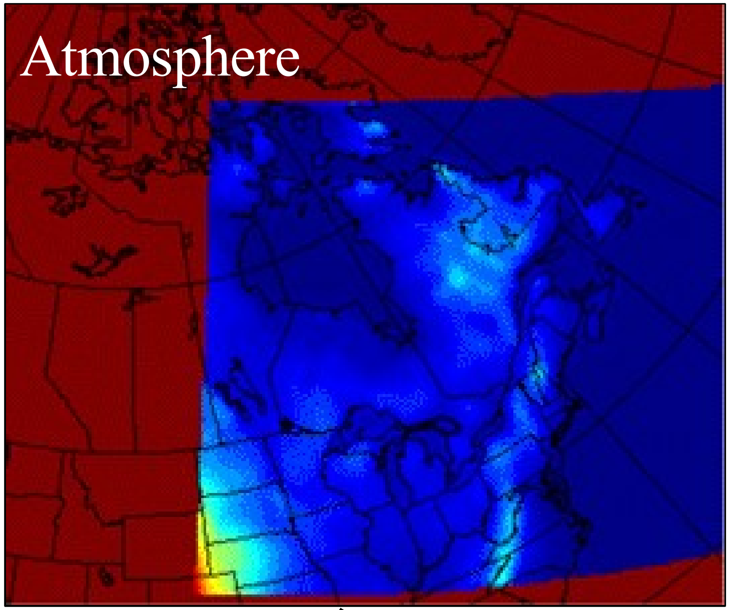
(Lemonsu, Bélair, Mailhot)

2-Way Coupling: Soon to come
See Example for Ocean-Atmosphere Coupling

Coupler (OASIS3-Gossip)

Heat and Vapour Flux, surface temp., ice fraction

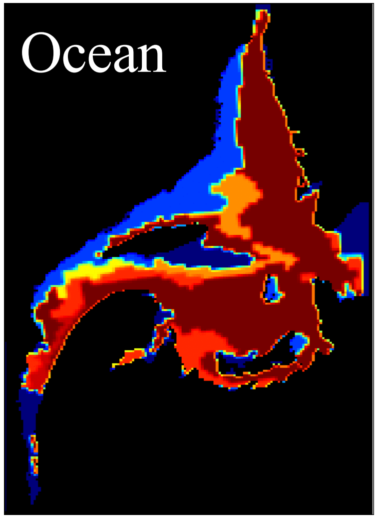
GEM



~**15 km**
timestep=**450s**

Coupling timestep = 450s

GOM



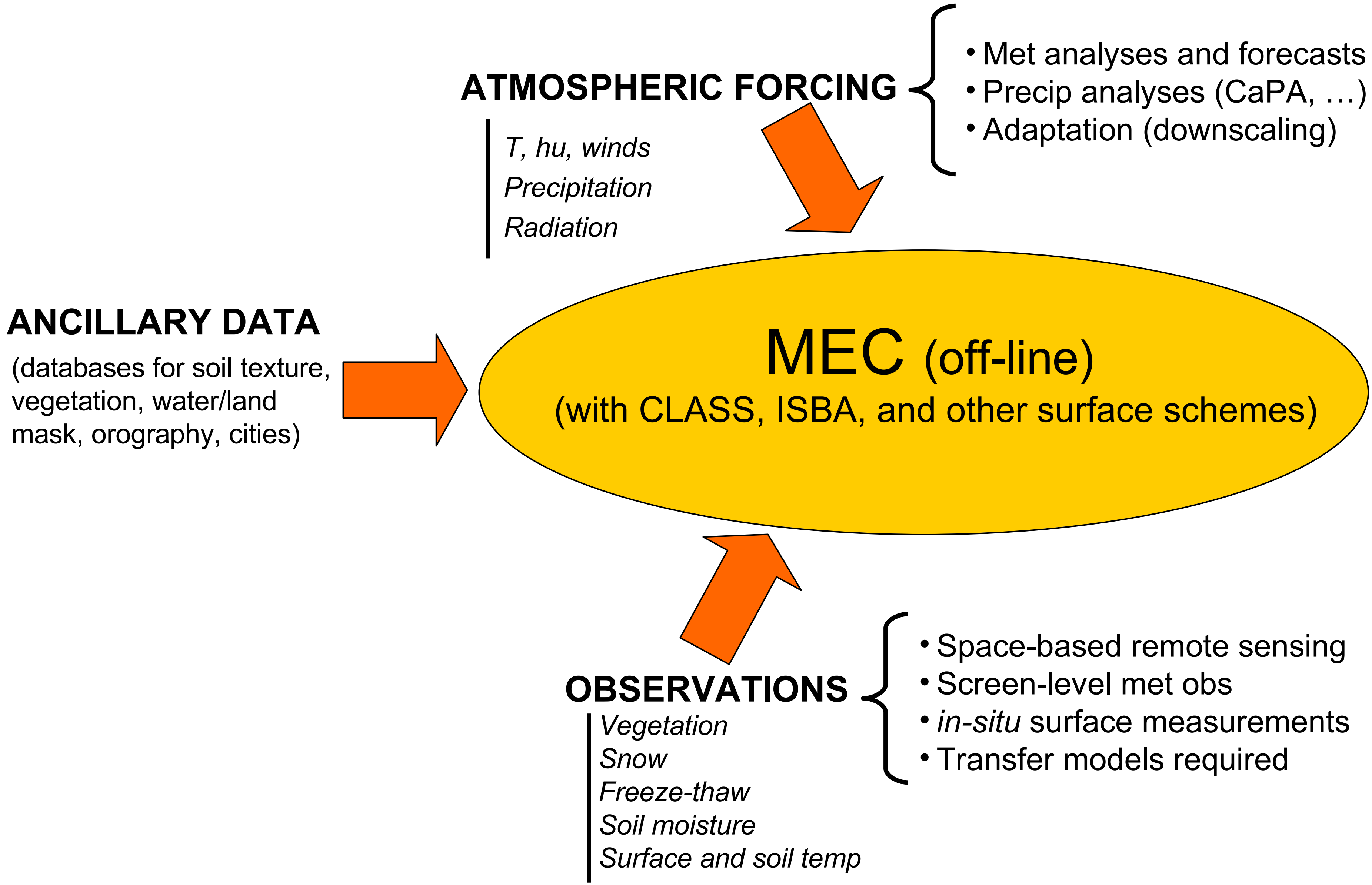
5 km
timestep=**225s**

Coupler (OASIS3-Gossip)

IR and Vis flux, Winds, Precipitation, Temperature Dew point temp.

(Pellerin, Faucher)

Canadian Land Surface Data Assimilation System (CaLDAS)



Variational Assimilation of Soil Moisture (Simplified 2D-Var)

<u>Cost function</u>

$$J(\mathbf{x}) = \frac{1}{2}\left(\mathbf{x}-\mathbf{x}^b\right)^T \mathbf{B}^{-1}\left(\mathbf{x}-\mathbf{x}^b\right) + \frac{1}{2}\left(\mathbf{y}-H(\mathbf{x})\right)^T \mathbf{R}^{-1}\left(\mathbf{y}-H(\mathbf{x})\right)$$

<u>Linear hypothesis</u>

$$H\left(\mathbf{x}+\delta\mathbf{x}\right) = H\left(\mathbf{x}\right) + \mathbf{H}\,\delta\mathbf{x}$$

In this technique, the linear observation operator **H** is evaluated using a finite difference approach, from two perturbed model integrations.

Also, the minimum of $J(\mathbf{x})$ is directly obtained from

$$\nabla J(\mathbf{x}) = 0$$

The analyzed state $\mathbf{x}^a$ is thus given by:

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{K}\left(\mathbf{y} - H(\mathbf{x}^b)\right)$$

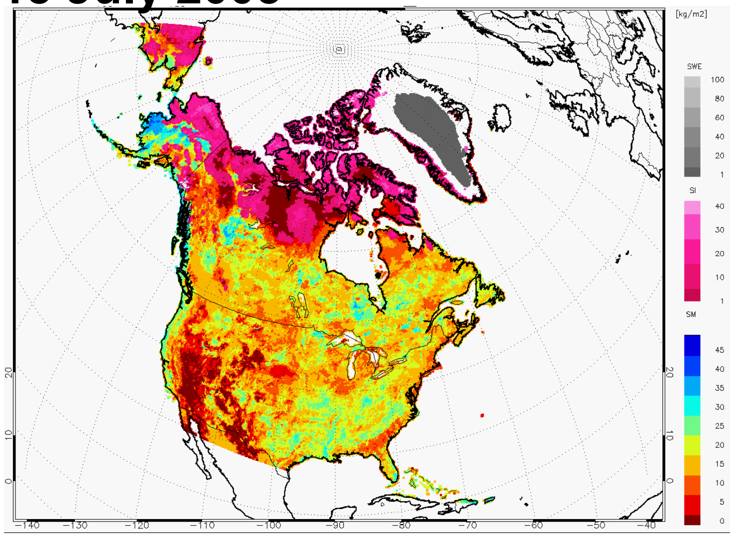
where **K** is the gain matrix:

$$\mathbf{K} = \left(\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}\right)^{-1}\mathbf{H}^T\mathbf{R}^{-1}$$

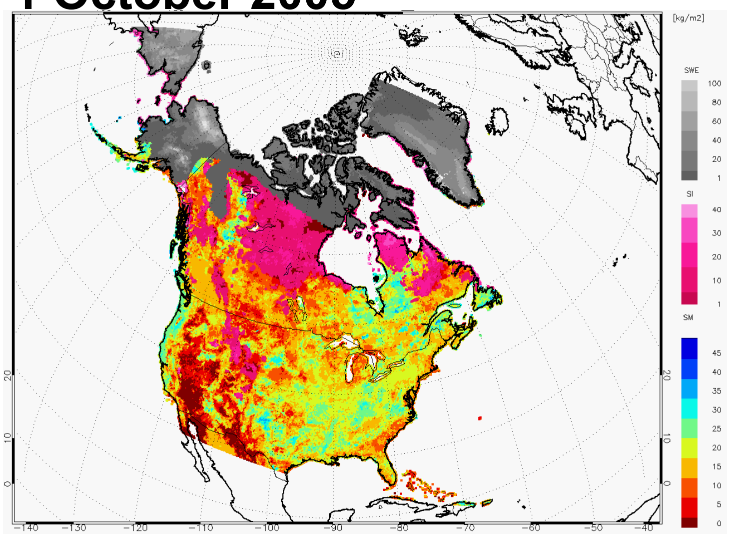
This formulation of the variational problem could be easily converted to an <u>**Extended Kalman Filter**</u>

(Balsamo, Mahfouf, Bélair, Deblonde, 2006a, b)

15 July 2005



1 October 2005



Canadian Precipitation Analysis (CaPA)

Correction of a first guess field using a weighted average following:

$$x_a^j = x_b^j + \Sigma_{i=1..N}\, w^{ij}\,(y_o^i - y_b^i)$$

Which can be also written this way:

$$\delta x^j = \Sigma_{i=1..N}\, w^{ij}\, \delta y^i$$

The background is given by our best model products

The weight matrix is given by

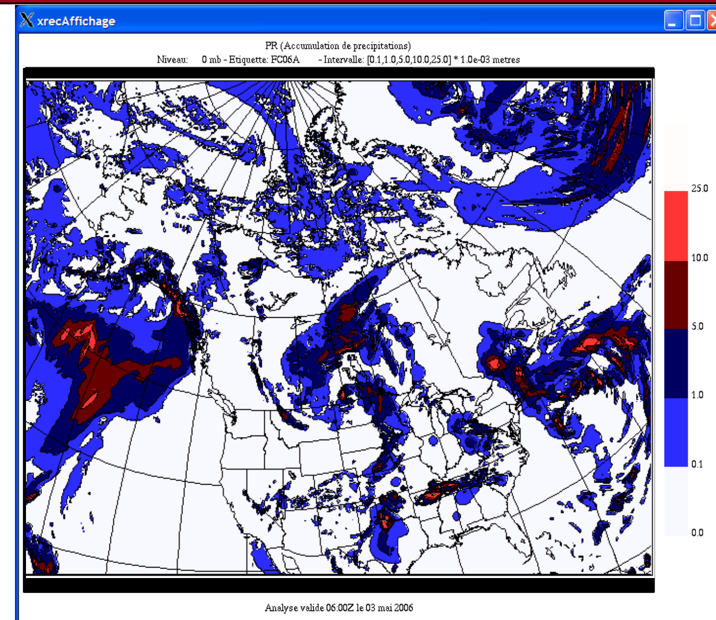
$$W=(B+O)^{-1}\, b$$

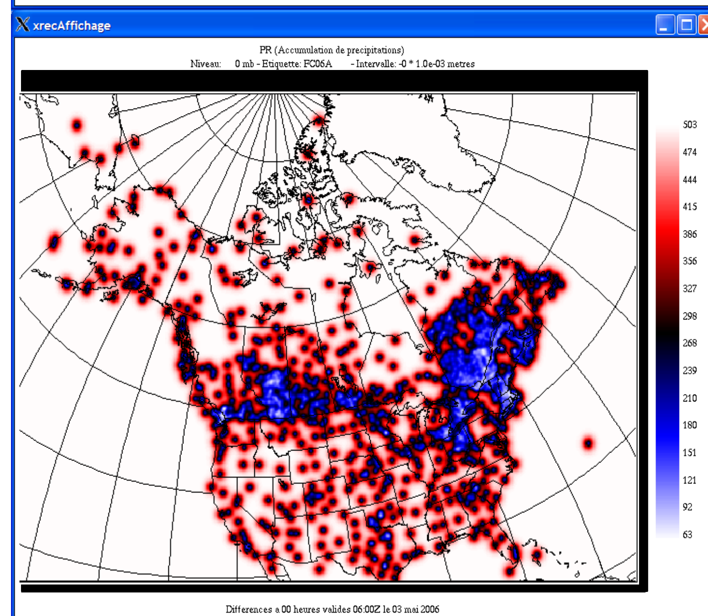
where B and O are the background and observations error covariance matrices, given by

$$B^{ij} = \sigma_b^2 \times \left(1 + \frac{r_{ij}}{L}\right) \times \exp\left(-\frac{r_{ij}}{L}\right)$$

$$O^{ij} = \sigma_o^2 \times \delta_{ij}$$

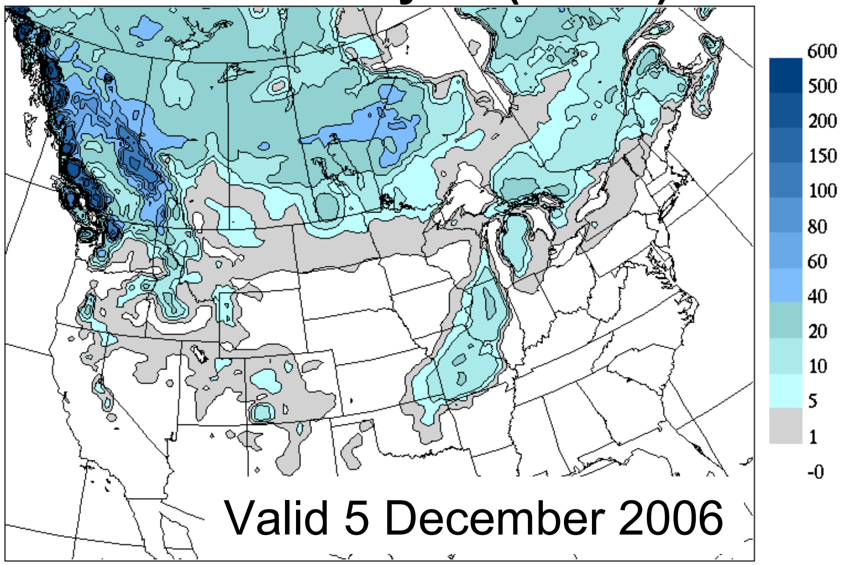
(*Mahfouf, Brasnett, Gagnon, Fortin*)





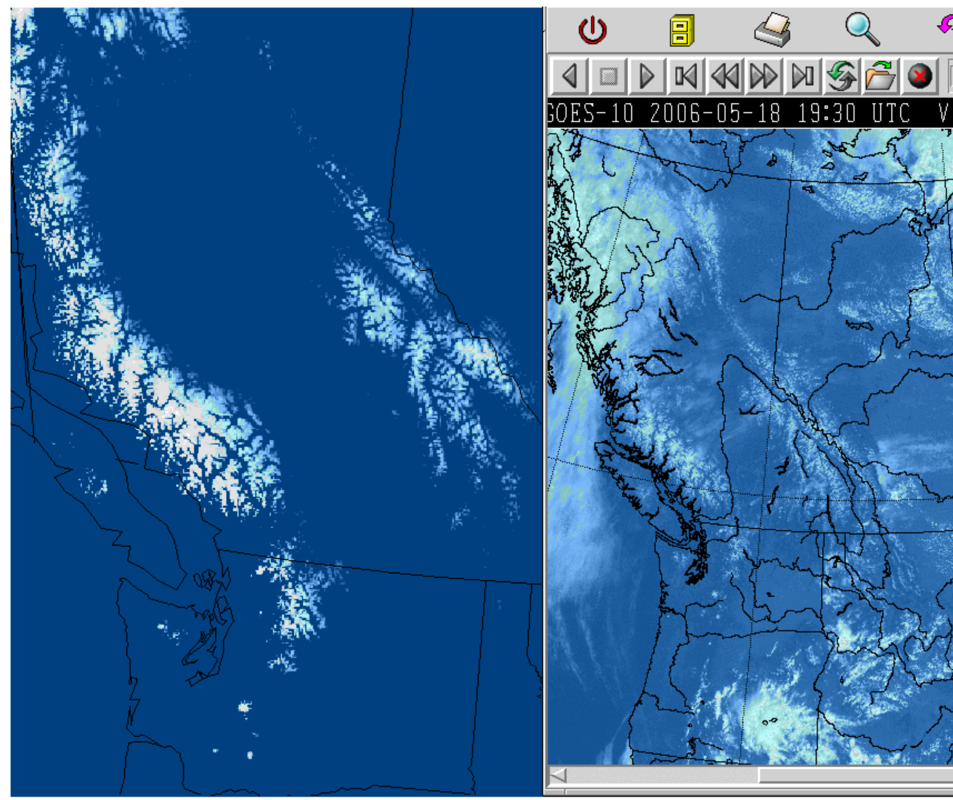
CMC's Snow Analysis

Global Analysis (33 km)



Prevision 00 heures valide 00:00Z le 05 decembre 2006

When done on a **<u>2.5-km grid</u>**, with adaptation of temperature forcing for the high-resolution orography, the analysis seems more realistic in mountainous regions



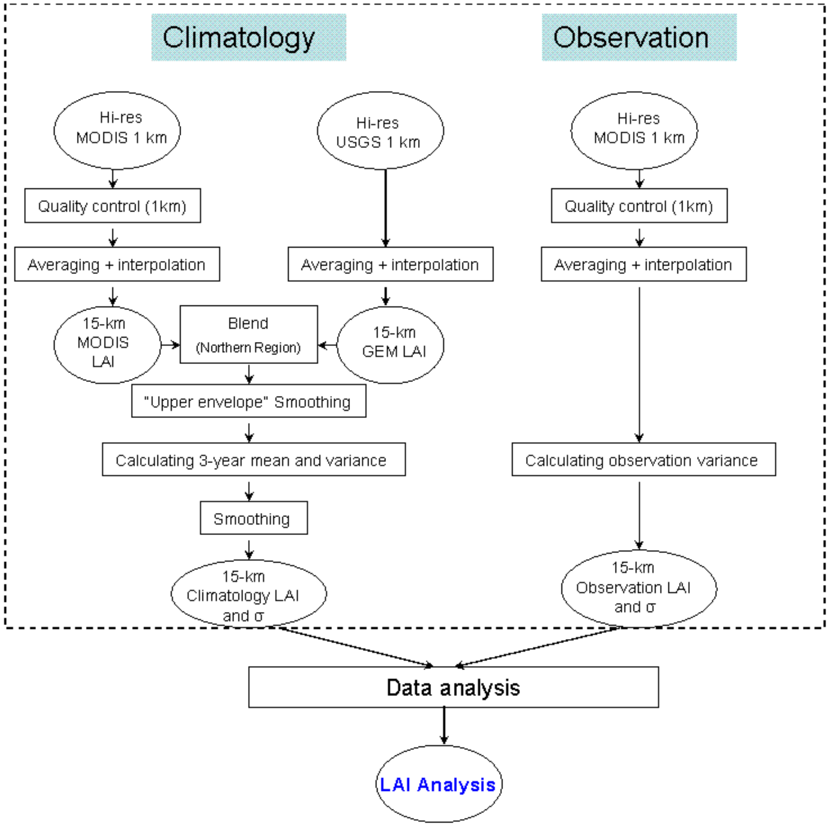
Strategy similar to CaPA (statistical interpolation)

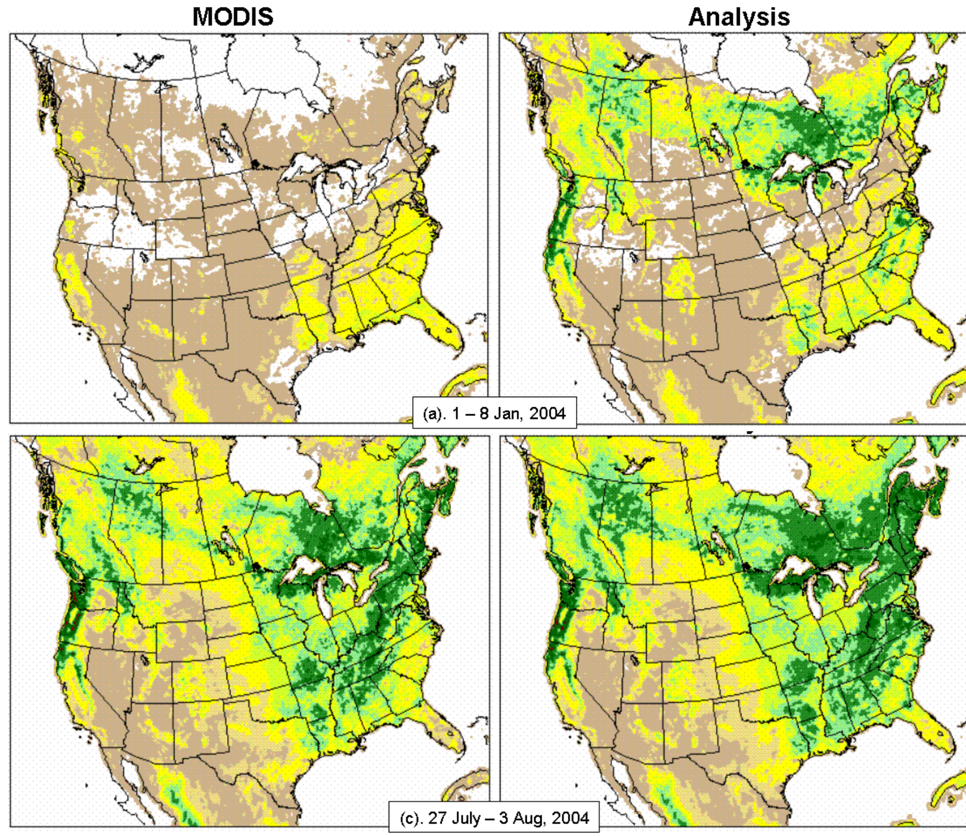
Background snow depth is given by a simple off-line snow model

Reports from SYNOP and METAR are used

(*Brasnett*)

Optimal Interpolation Analysis of LAI Using MODIS (Gu, Bélair, Mahfouf, Deblonde, 2006)





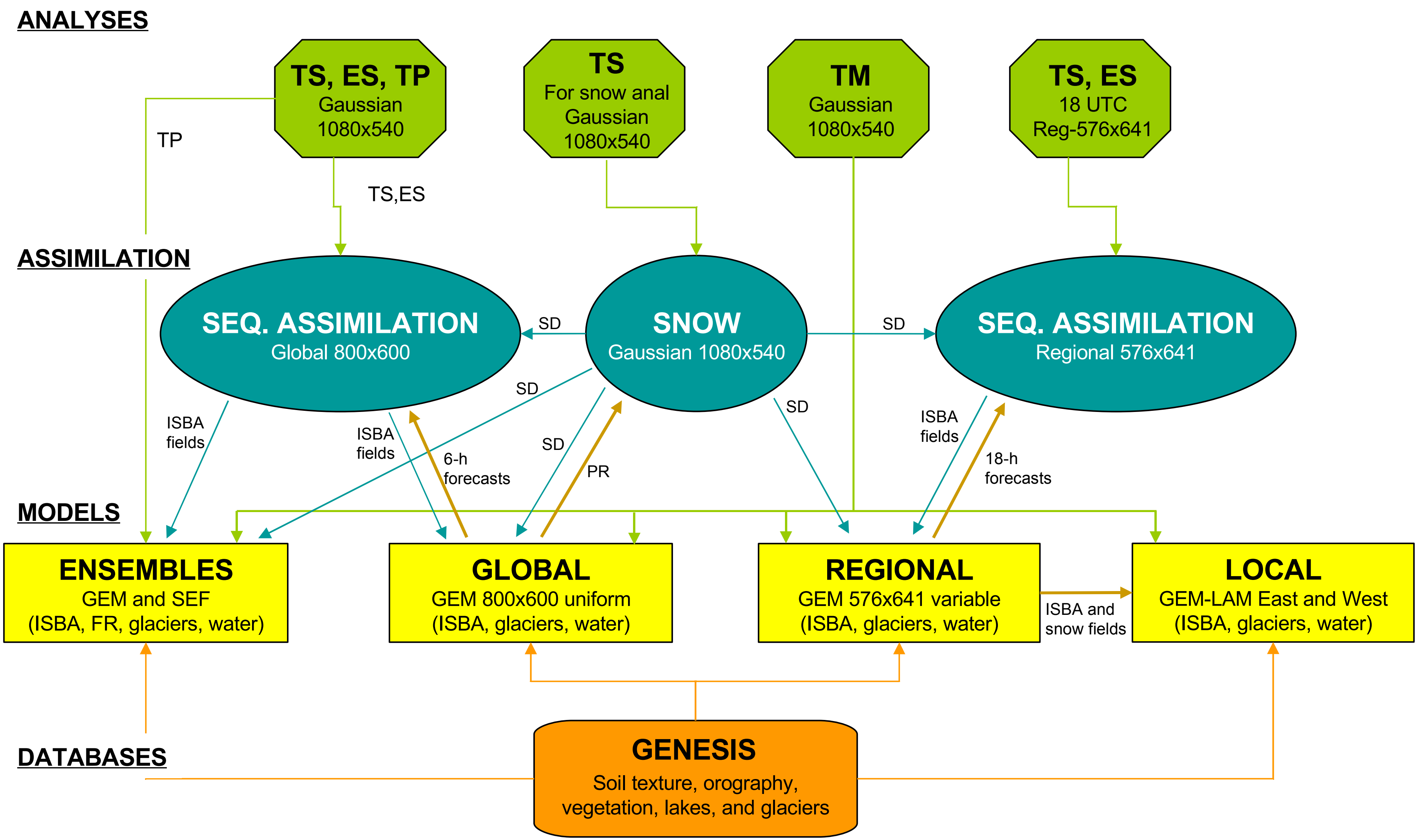
$$J(LAI_a) = \left[\frac{LAI_a - LAI_o}{\sigma_o}\right]^2 + \left[\frac{LAI_a - LAI_b}{\sigma_b}\right]^2 + \left[\frac{LAI_a - LAI_c}{\sigma_c}\right]^2$$

$$LAI_a = \alpha_o LAI_o + \alpha_c LAI_c$$

$$\alpha_o = \frac{\sigma_c^2}{\sigma_o^2 + \sigma_c^2}, \text{ and } \alpha_c = \frac{\sigma_o^2}{\sigma_o^2 + \sigma_c^2}$$

Land cover databases do not provide information on LAI (usually specified using a look-up table). LAI is important for evapotranspiration. Using the LAI analysis from MODIS (or other instruments) could reduce an important source of errors.

Land Surface Models, Analyses, and Assimilation in CMC's Operational System



ISBA fields: Tsurf(1,2), Wsoil(1,2), wice, snow albedo, snow density, wsliq, wlveg

Future CMC's Land Surface Models, Analyses, and Assimilation