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The Canadian Land Data Assimilation System (CaLDAS)

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Outline

- Current operational system for land surface data assimilation.
- Focused improvements associated with CaLDAS.
- High-resolution modeling work with external modeling system.
- Development activities with the ensemble Kalman filter.
- CaLDAS within the Global Data Assimilation Cycle.

Land Surface Modeling and Assimilation System Objectives and Requirements

I. **Improve environmental predictions from Environment Canada's operational systems, including ;**

- *deterministic NWP systems (regional, global, LAM), ensemble prediction systems (regional and global), hydrologic models*

II. **Provide accurate analysis of the current state of the land surface, including the following variables ;**

- *albedo, emissivity, vegetation characteristics (leaf area index and fractional coverage), soil moisture, snow conditions (coverage, water equivalent and density), surface temperatures*

III. **Provide operational products that could be useful to other government departments, for e.g.,**

- *Agriculture and Agri-Food Canada, Natural Resources Canada*

LAND DATA ASSIMILATION SYSTEM CURRENTLY OPERATIONAL
Meteorological Service of Canada

Soil moisture *analyses are produced from screen-level observations using the optimum interpolation technique.*

Terrestrial ***snow*** *analyses are obtained from an external assimilation of in-situ surface measurements, also using the optimum interpolation technique.*

Vegetation *characteristics are specified using look-up tables based on land use / land cover databases.*

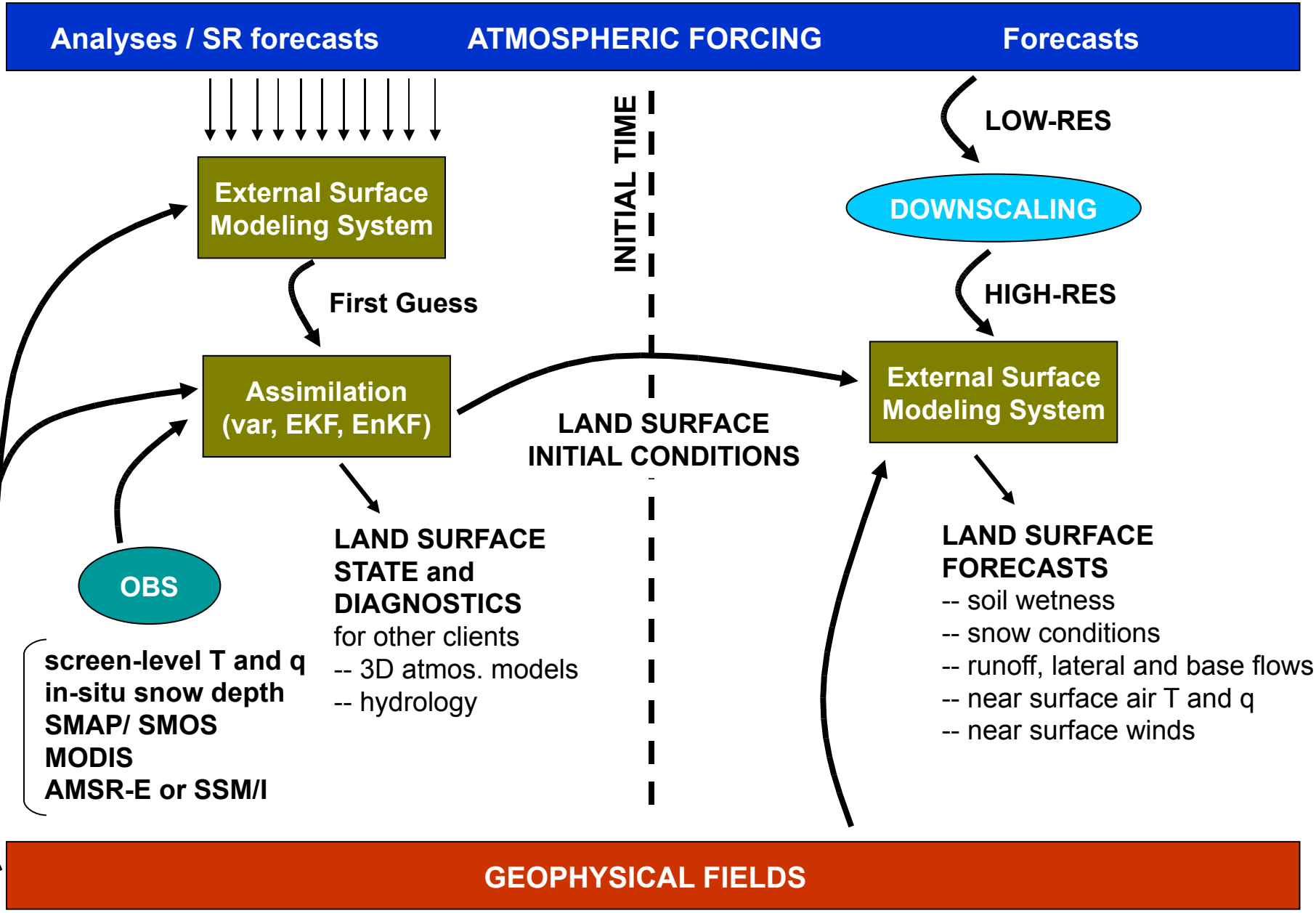
FOCUS with NEW SYSTEM (CaLDAS)

Improved high-resolution first guess for soil moisture, snow, and vegetation.

Assimilation of space-based remote sensing data.

Better specification of land surface geophysical characteristics (orography, vegetation, albedo, ...).

The LAND SURFACE SYSTEM (in development)



High-Resolution Modeling
Land Surface

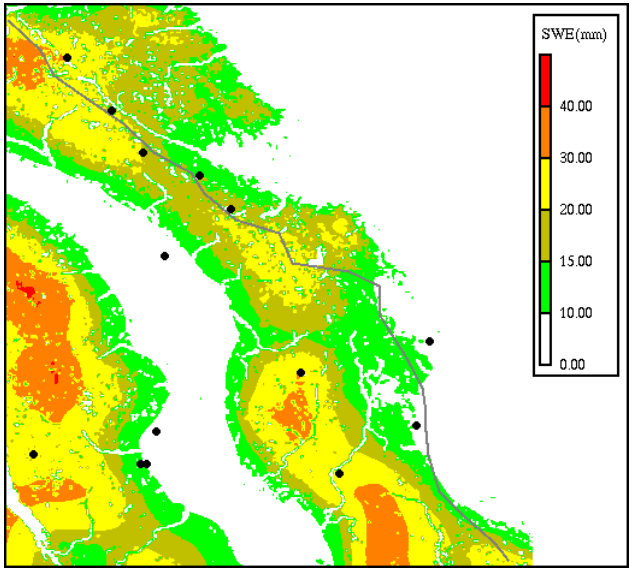
Focus : Improve the first-guess component of CaLDAS

Prototype version of an external 2-D land surface system was tested in the context of several projects.

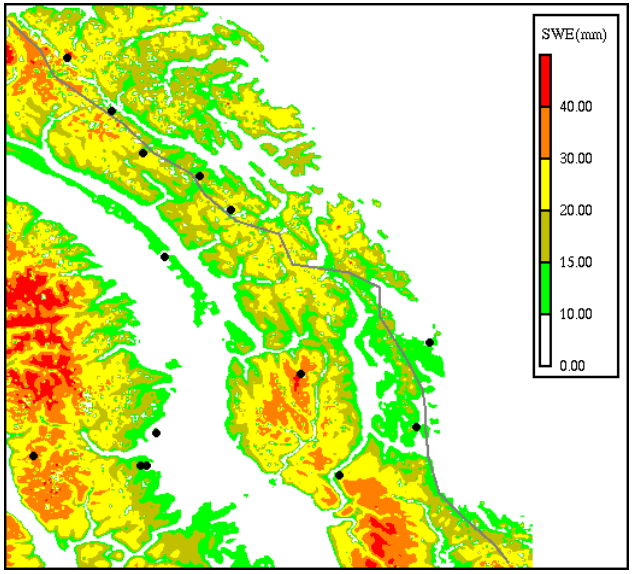
- NAESI (National Agri-Environmental Standards Initiative)
- Urban Meteorology (CRTI, EPICC)
- Vancouver 2010 Olympics Project

TERRESTRIAL SNOW in CaLDAS: HIGH-RESOLUTION MODELING for the FIRST GUESS

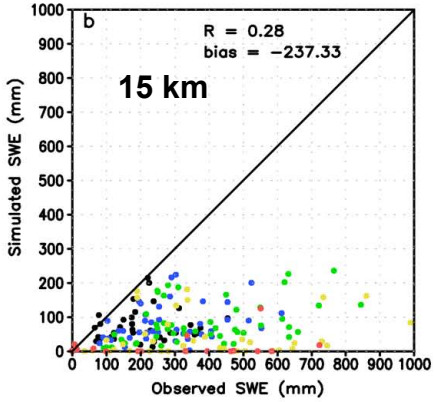
No adaptation of atmospheric forcing

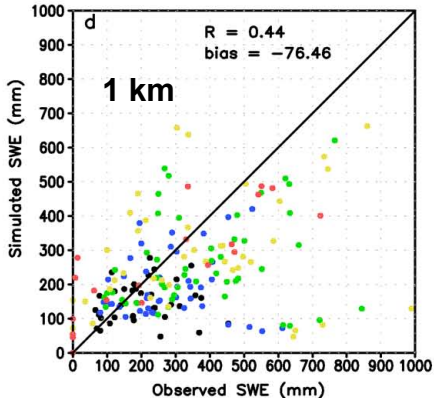


Adaptation of atmospheric forcing



Mean Snow Water Equivalent (mm)





- 15 December – 31 January
- February
- March
- April
- 1 May – 15 June

Objective evaluation for Winter and Spring between 2004 and 2007 using manual monthly snow surveys in the mountain region

Prototype versions of an external land surface system were tested in the context of the NAESI and the Vancouver 2010 Olympics Project. Integrations for 2004-2007 with an external 1-km land surface system, with and without surface assimilation, were performed. Even without assimilation, results are positive.

Design of Assimilation Algorithm

Analysis equation

$$\mathbf{x}^a = \mathbf{x}^b + \underbrace{\mathbf{B}\mathbf{H}^T \left[\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R}\right]^{-1}}_{Gain\ Matrix} \underbrace{\left[\mathbf{y} - H\left(\mathbf{x}^b\right)\right]}_{Innovation\ Vector}$$

Keys to the success of data assimilation methods rests largely upon the accurate specification of the input error parameters.

- Variational and Kalman filtering techniques are associated with respective advantages and disadvantages.

- Both variational and ensemble Kalman filtering techniques are currently being evaluated for inclusion within CaLDAS.

2D-Variational Scheme

• A 2D-variational assimilation scheme, following the work of Dr. Balsamo, has been coded within the SMS (Supervisor Monitor Scheduler) task sequencer.

• At present the scheme only assimilates screen-level parameters, namely 2-meter temperatures and humidity values. Future work will include L-band brightness temperatures.

• Initial tests indicate that the 2D-variational scheme provides robust and realistic results.

Ensemble Kalman Filter (EnKF)

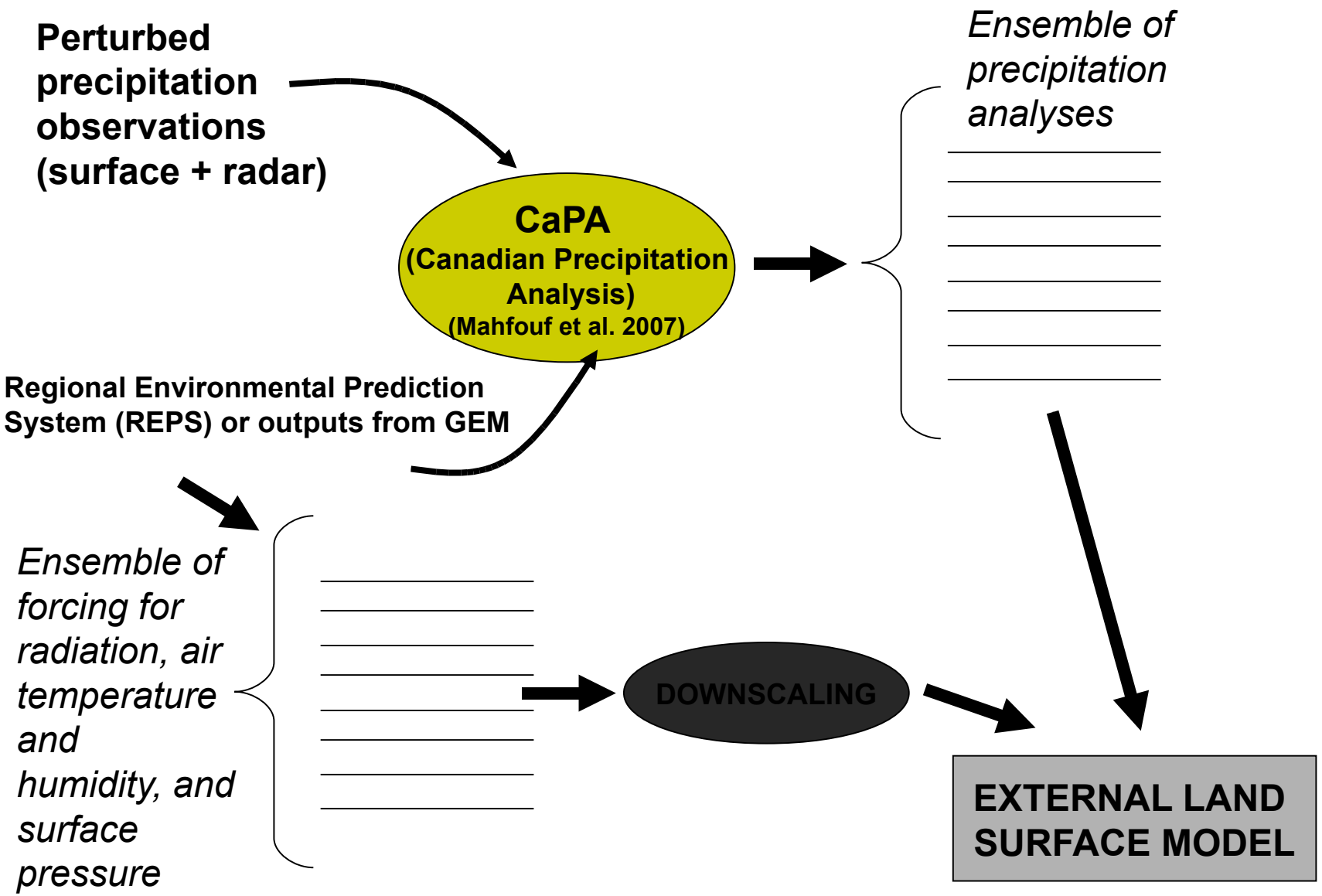
- Matrices $\mathbf{BH}^T$ and $\mathbf{HBH}^T$, used in the calculation of the Kalman gain, are derived from the spread of an ensemble of predictions from N members :

$$\mathbf{BH}^T \approx \overline{\left(\mathbf{x}^b - \overline{\mathbf{x}^b}\right)\left(H\left(\mathbf{x}^b\right) - \overline{H\left(\mathbf{x}^b\right)}\right)^T}$$

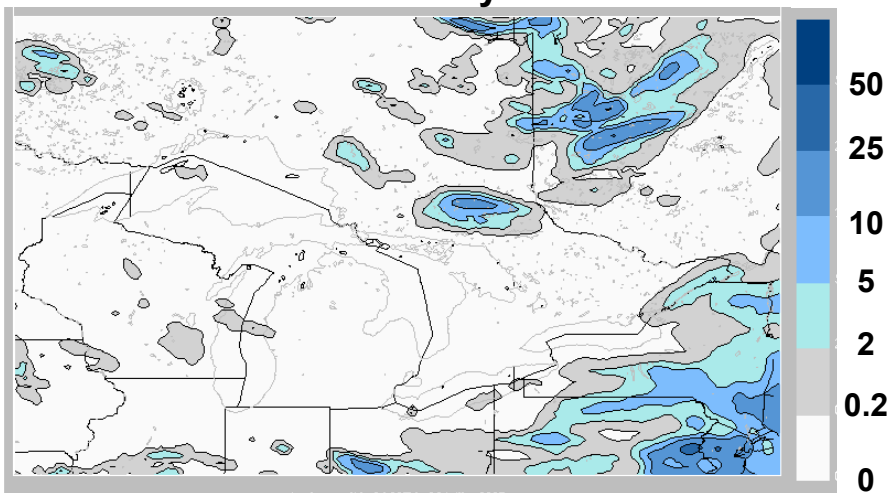
$$\mathbf{HBH}^T \approx \overline{\left(H\left(\mathbf{x}^b\right) - \overline{H\left(\mathbf{x}^b\right)}\right)\left(H\left(\mathbf{x}^b\right) - \overline{H\left(\mathbf{x}^b\right)}\right)^T}$$

- All of the error information is contained within the ensemble and thus the method used to generate the ensemble members is important to the success of the EnKF filter.

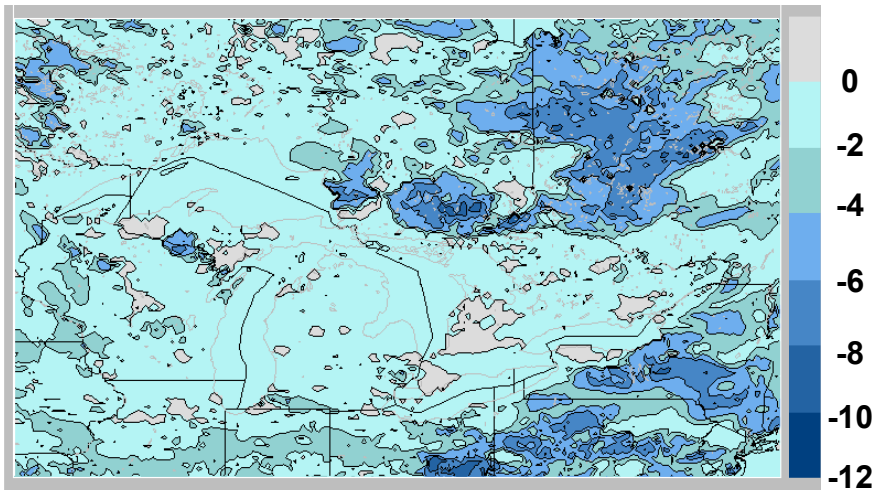
UNCERTAINTY RELATED WITH ATMOSPHERIC FORCING



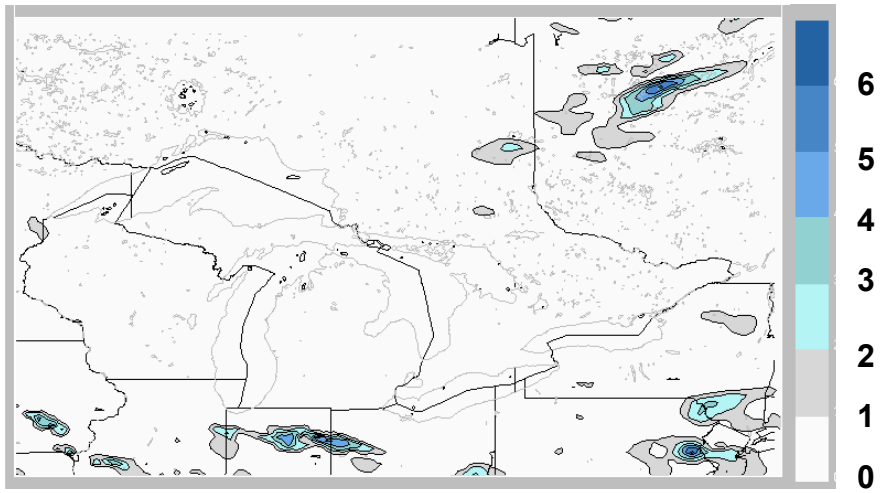
CaPA : 6-hr Precipitation (mm)
0600 UTC 5 July 2007



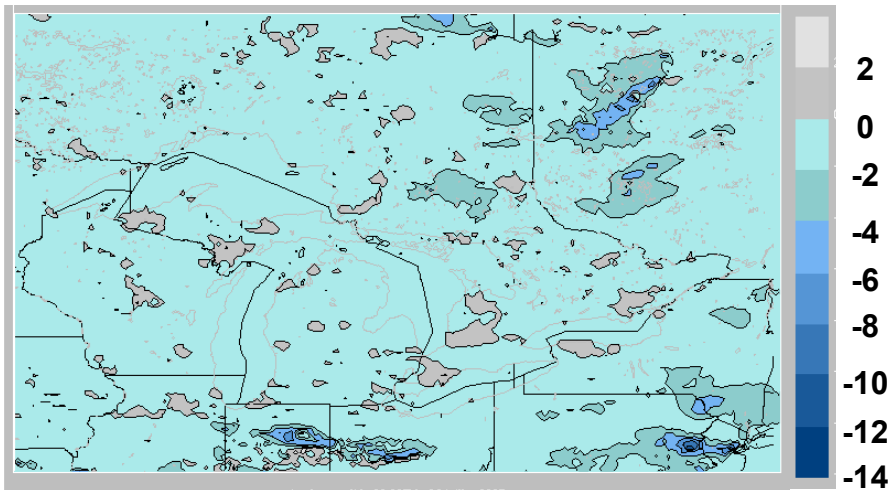
Gain Matrix element : Superficial soil moisture increments w.r.t Tb_h(L) innovations (10^{-3} K^{-1})



6-hr Precipitation Standard Deviation (mm)
(N=20) 0600 UTC 5 July 2007



Gain Matrix element : Root zone soil moisture increments w.r.t Tb_h(L) innovations (10^{-4} K^{-1})



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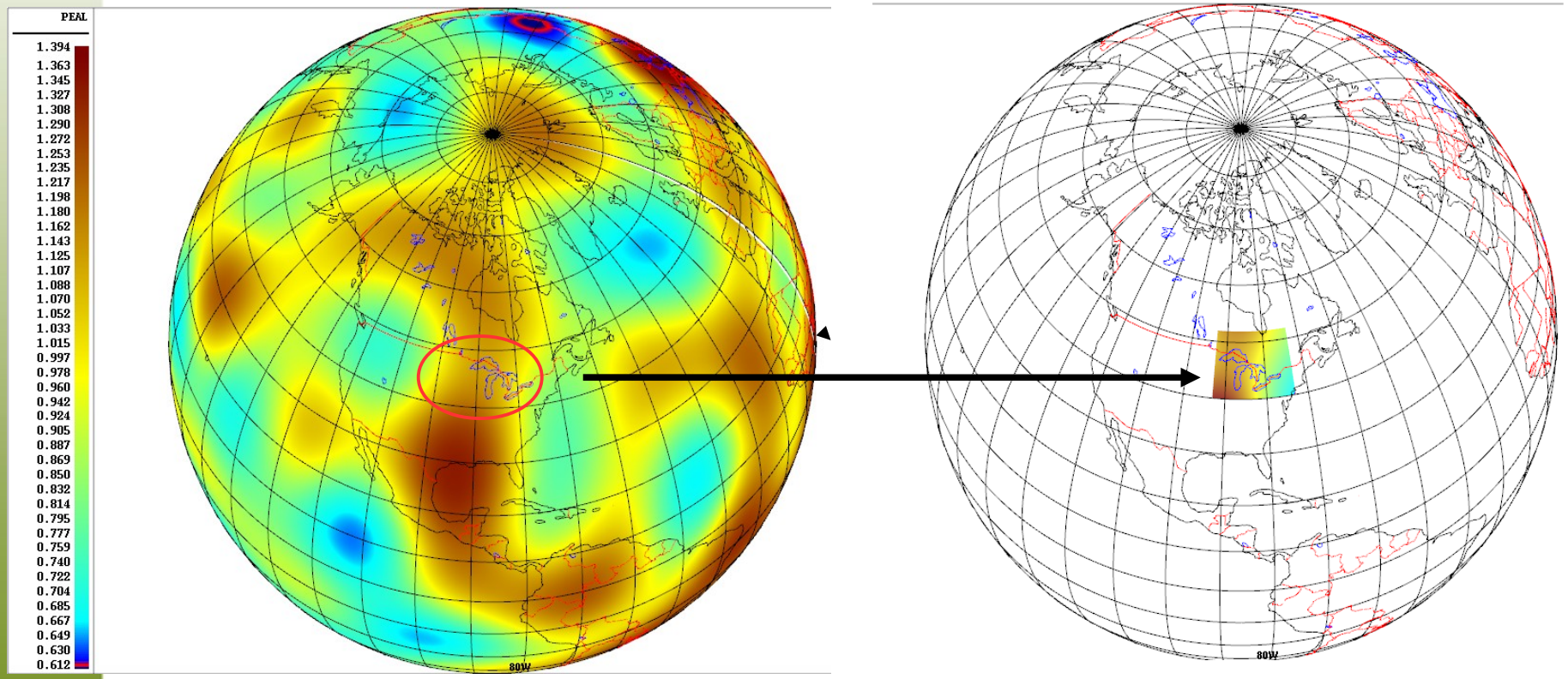
L-band (1.4 GHz) Brightness Temperatures

UNCERTAINTY RELATED WITH SURFACE CHARACTERISTICS

Spatially coherent perturbations : albedo, LAI, veg. fraction and roughness length

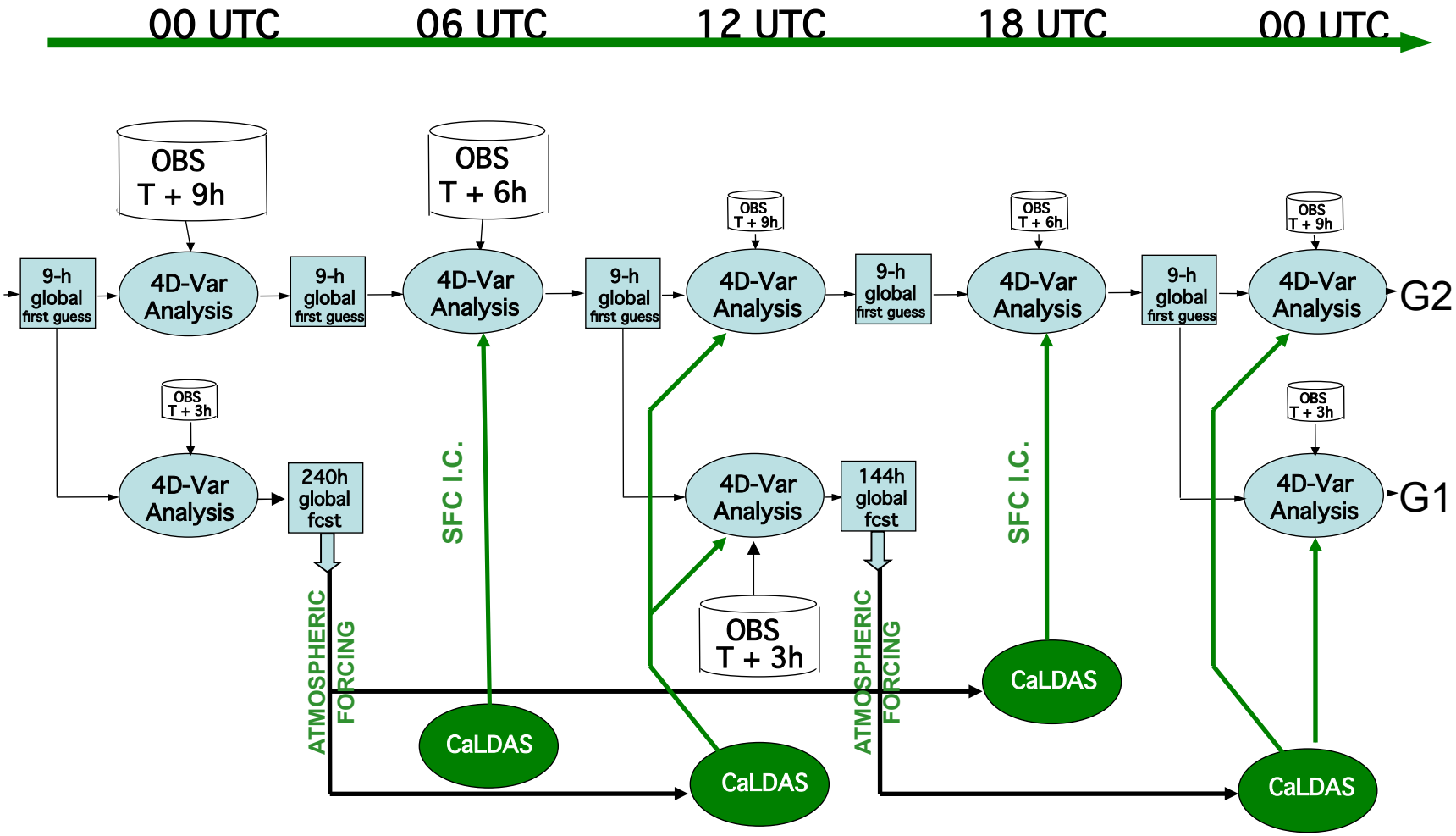
First-order Markov process (Li et al. 2008)

$$f(\lambda,\phi,\eta,t)=\mu+\sum_{l=1}^{L}\sum_{m=-l}^{l}\sum_{k=-K}^{K}a_{lmk}(t)\,Y_{lm}(\lambda,\phi)\,e^{ikn}$$



Perturbation of albedo generated on the sphere and interpolated over the Great Lakes region

CaLDAS within the Global model data assimilation cycle



G2 = Global Assimilation Cycle
G1 = Global Forecast Run

ONGOING AND UPCOMING RESEARCH / DEVELOPMENT ACTIVITIES

- ***Evaluation of assimilation system based on its impact on numerical predictions (numerical weather prediction and hydrology).***

- ***Specification / modeling of* B *and* R.**

- ***Complementarity between remote-sensing and screen-level observations.***

- ***Observation operators (for both passive and active data).***

- ***Incremental assimilation (low-resolution increments on high-resolution first guess).***

- ***Vegetation characteristics from ecosystem modeling : Biome BGC***

FIRST TRANSFER EXPECTED in ENVIRONMENT CANADA'S OPERATIONAL SYSTEMS in 2011