Soil Moisture Data Assimilation in the Canadian Land Data Assimilation System (CaLDAS)

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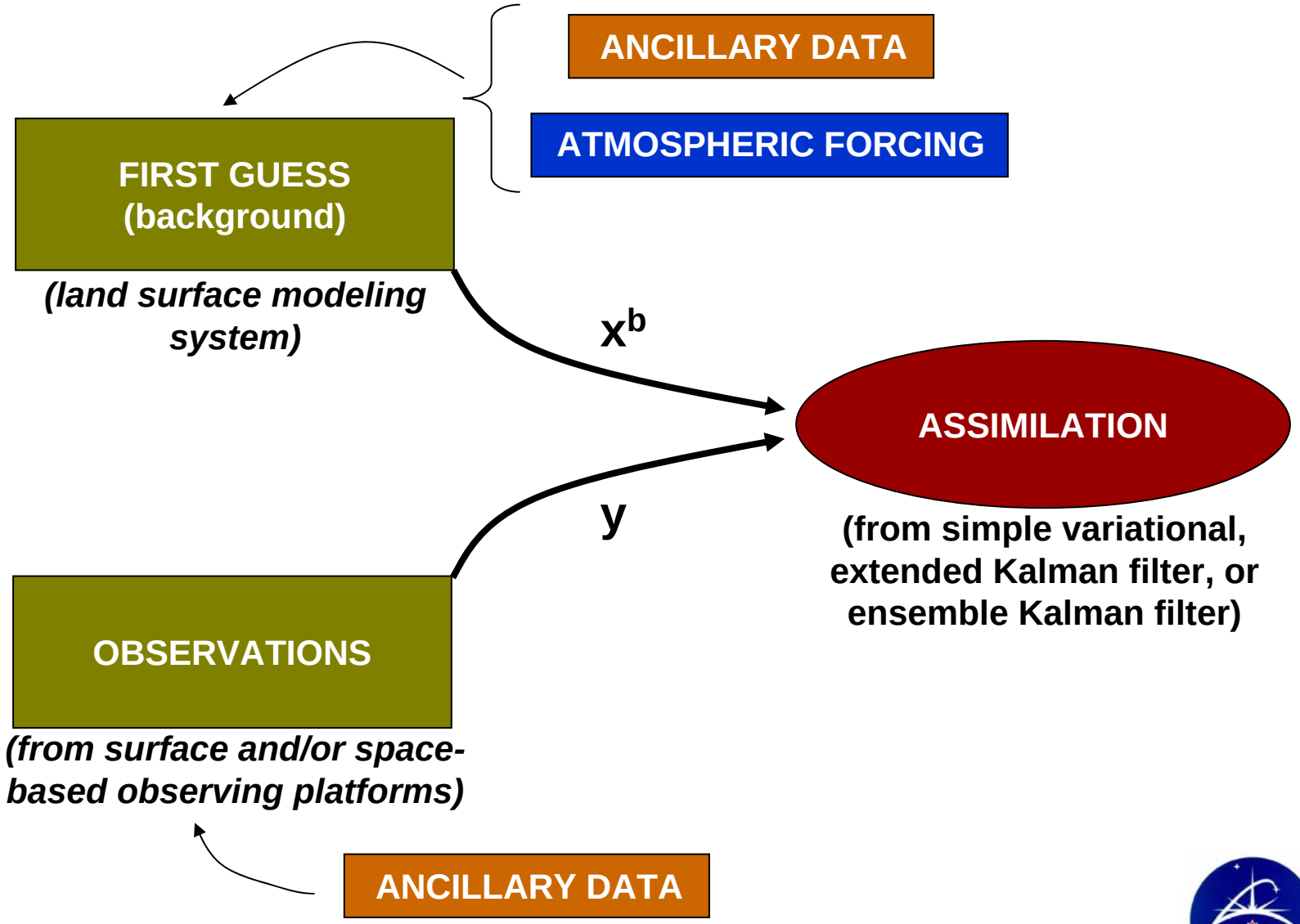
Objectives / Requirements for the new Land -Surface Modeling and Data Assimilation System

- ***Improve environmental predictions from Environment Canada's operational systems including :***
  - *deterministic NWP systems (regional, global, LAM), ensemble prediction systems (regional, global), seasonal, climate, hydrology …*

- ***Provide accurate analysis of the current state of the land surface, including the following variables :***
  - *soil moisture, snow conditions (coverage, water equivalent, density), temperatures, albedo, emissivity, vegetation characteristics (leaf area index and fractional coverage)*

- ***Provide operational products that could be useful to other government departments, like for example :***
  - *Agriculture and Agri-Food Canada (AAFC), Natural Resources Canada (NRCan).*

Canadian Land Data Assimilation System (CaLDAS)



Data Assimilation

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.

Modeling of First-Guess Uncertainty : B Matrix

Initial conditions

Soil moisture
Surface temperature
Snow conditions

Land surface characteristics (ancillary data)

Vegetation characteristics (fraction coverage, LAI)
Soil texture
Albedo
Emissivity
orography

Atmospheric forcing

U, V, T, q, SW↓, LW ↓, ***precipitation***

Land surface modeling

UNCERTAINTY ASSOCIATED with ATMOSPHERIC FORCING – INCLUDING PRECIPITATION

Ensemble of precipitation analyses

Perturbed Precipitation Gauge Observations

Optimum Interpolation Assimilation

REPS or perturbed outputs from GEM-15

First-guess

Ensemble of forcing for :

Radiation
Air temperature
humidity
Surface Pressure

DOWNSCALING
(TERRAIN ADJUSTING)

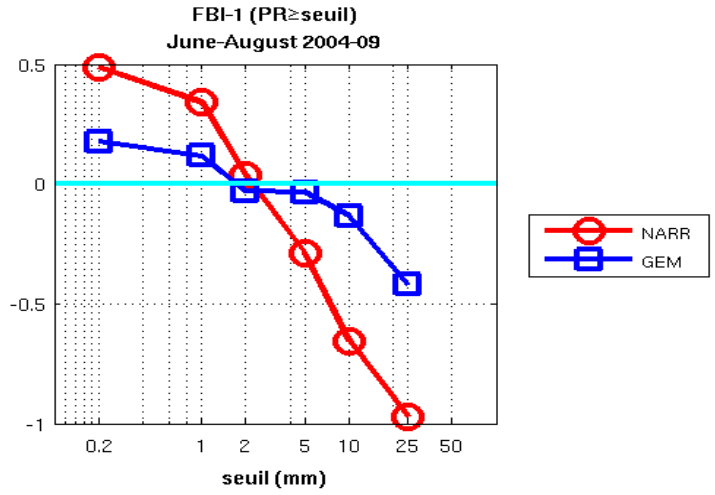
EXTERNAL LAND SURFACE MODEL (ensemble modeling)

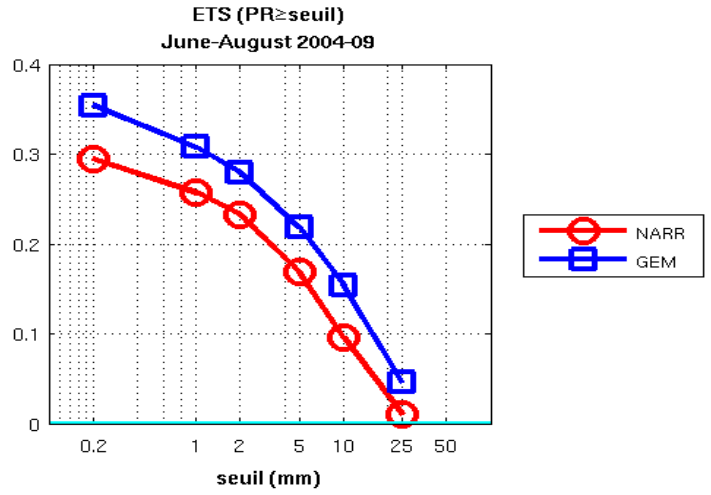
GEM-15 vs NARR (North American Regional Reanalysis) (6 –h Precipitation) Comparison with ~ 100 Manned Stations

Bias

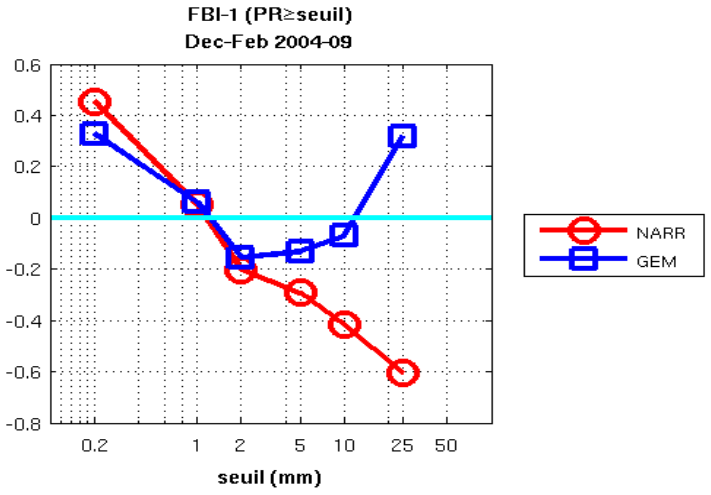
Equitable Threat Score

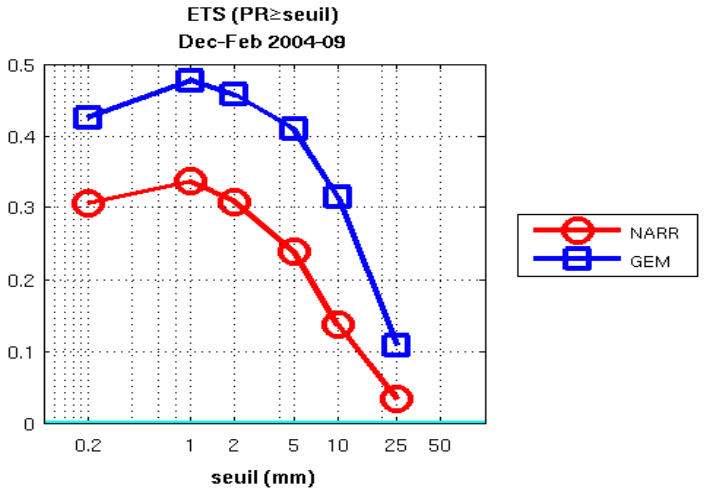
June - August 2004 -2009



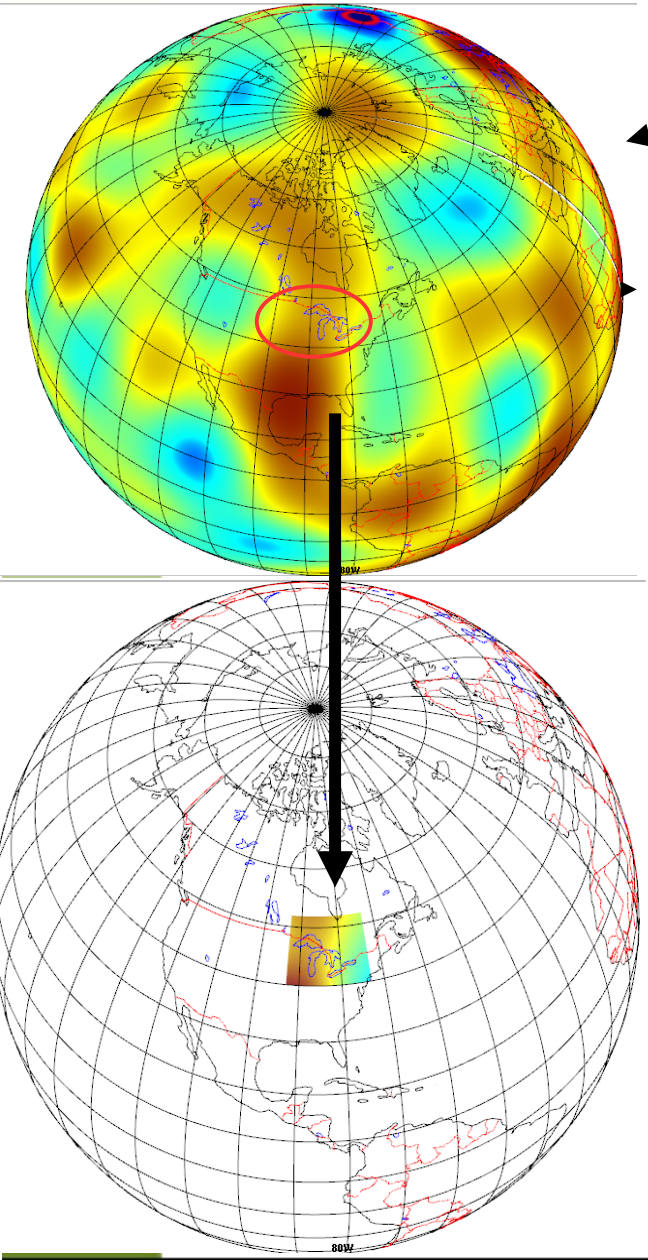


Dec - Feb 2004-2009





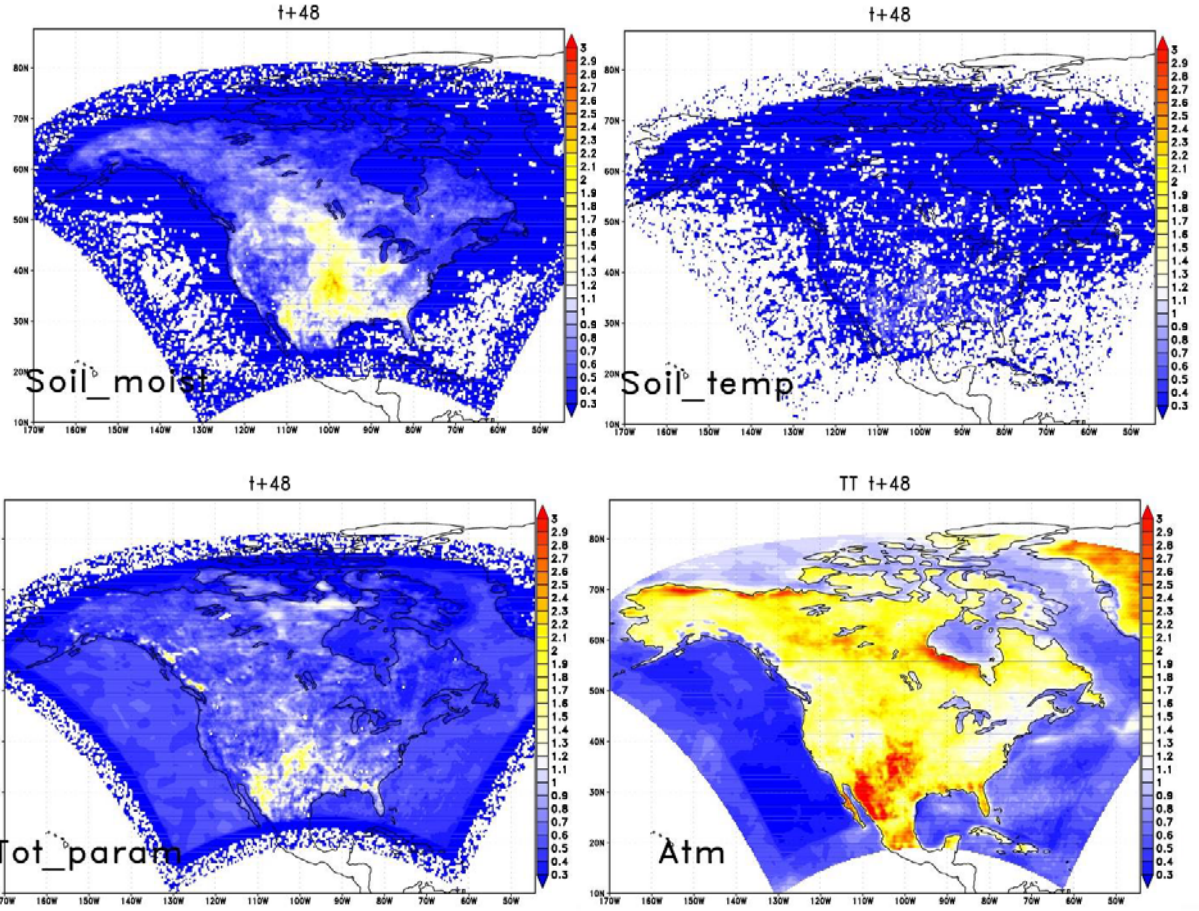
UNCERTAINTY ASSOCIATED with LAND SURFACE CHARACTERISTICS



First-order Markov Processes

APPLICATION in REGIONAL ENSEMBLE PREDICTION SYSTEM

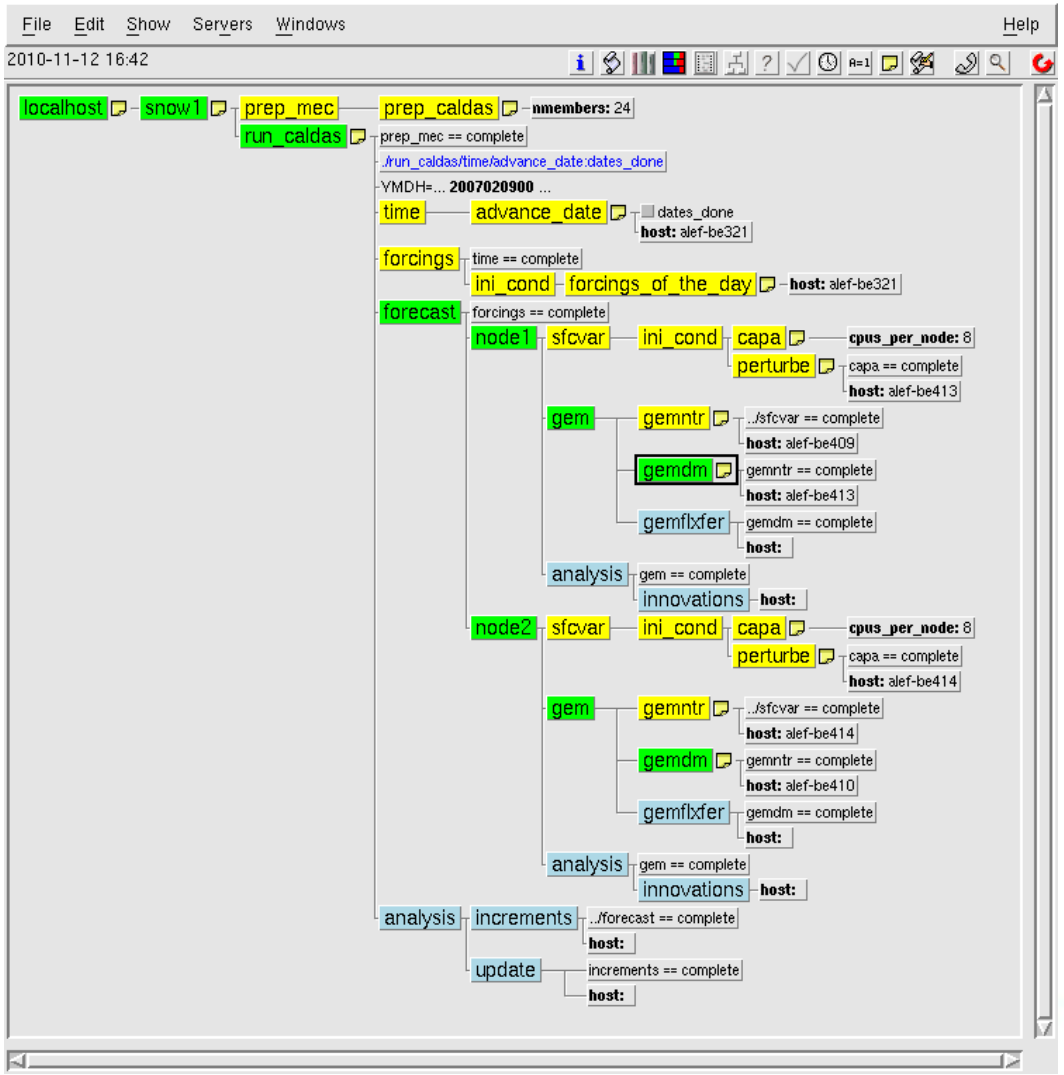
STD (K) for 48h (ensemble) predictions of T_{2m}



CaLDAS : Status

A first version of CaLDAS has been coded and developed. Both an Ensemble Kalman Filter (EnKF) version and a simplified 2D-Var version are available. Both of these versions have been tested within the context of synthetic experiments.

CaLDAS within the Supervisor Monitor Scheduler (SMS) Task Sequencer



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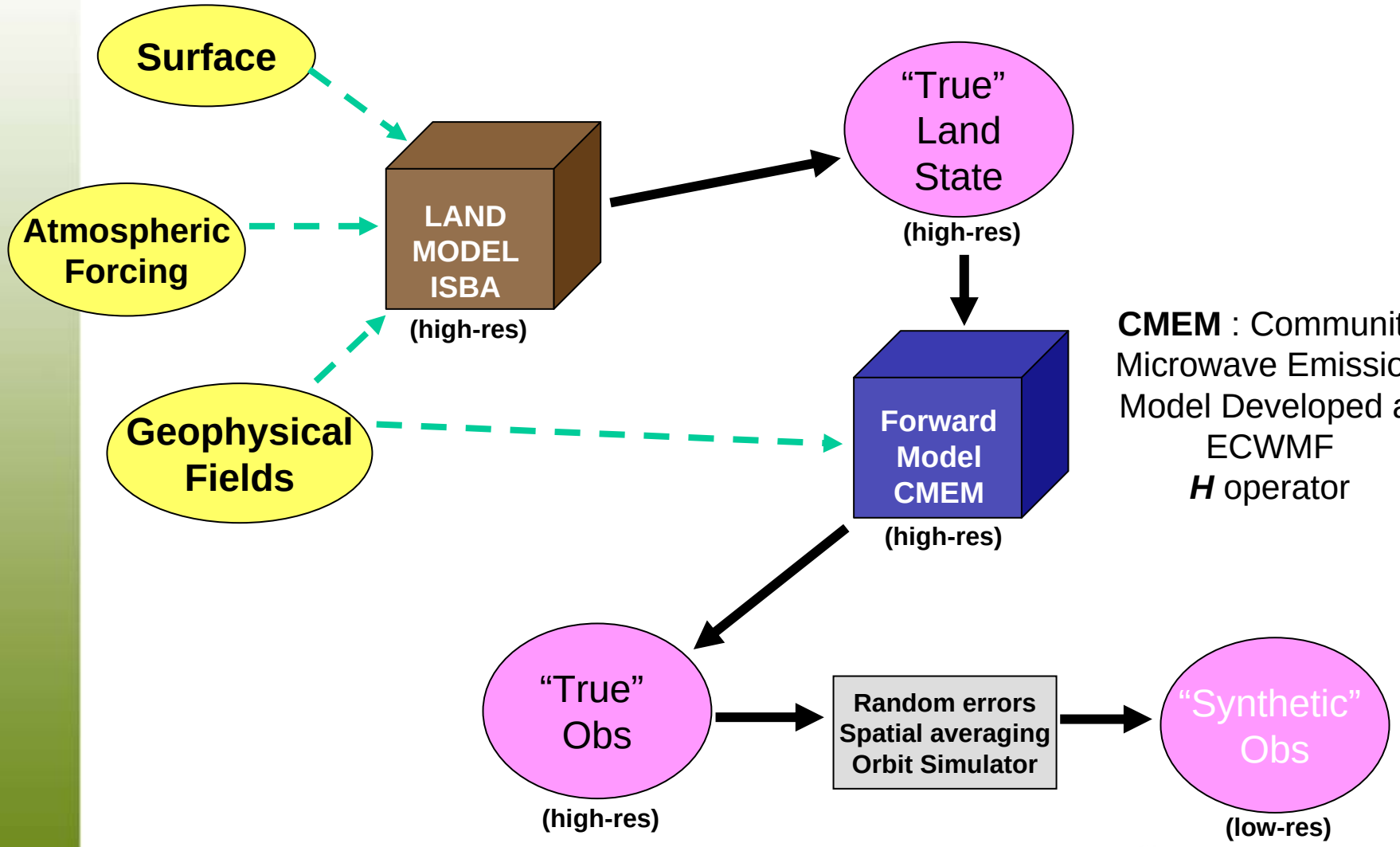
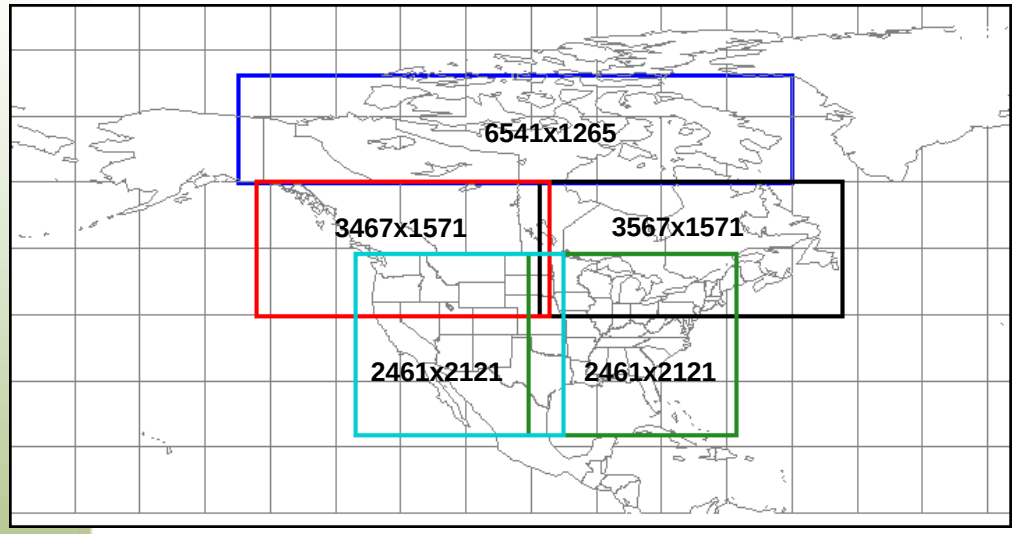
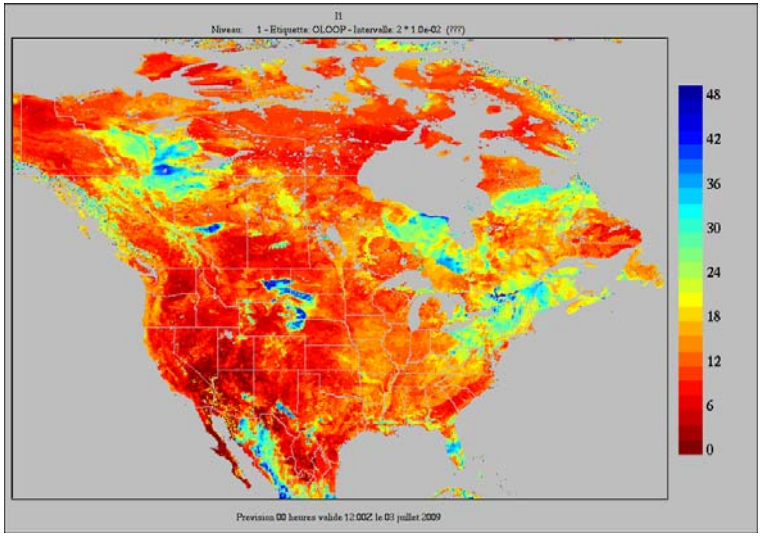
Synthetic Experiment Design (I)
Generation of Synthetic "Truth" Observations



CMEM : Community Microwave Emission Model Developed at ECWMF
H operator

High-Resolution : Nature Run “Truth Run”





- *1–km resolution integrations of the ISBA land-surface model;*
- *Atmospheric forcing provided by short-range forecasts from the GEM-15 model;*
- *Geophysical fields generated from high-resolution land-surface databases;*
- *Time period : 30 March 2009 – 31 March 2010.*
- *North America : 5 separate integration grids*

1200 UTC 3 July 2009
Superficial Soil Moisture
[10-cm depth]

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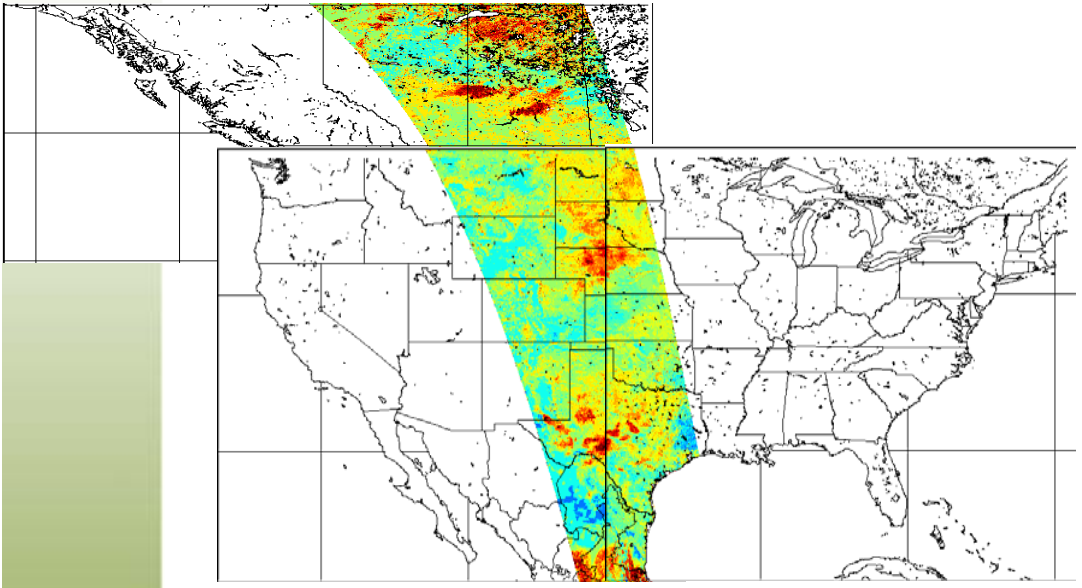
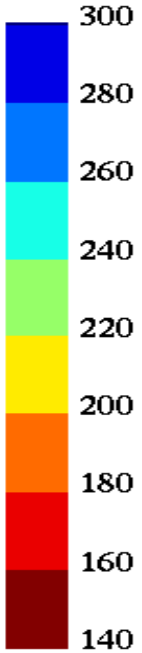
Brightness Temperatures (K) : Horizontal Polarization (40°)

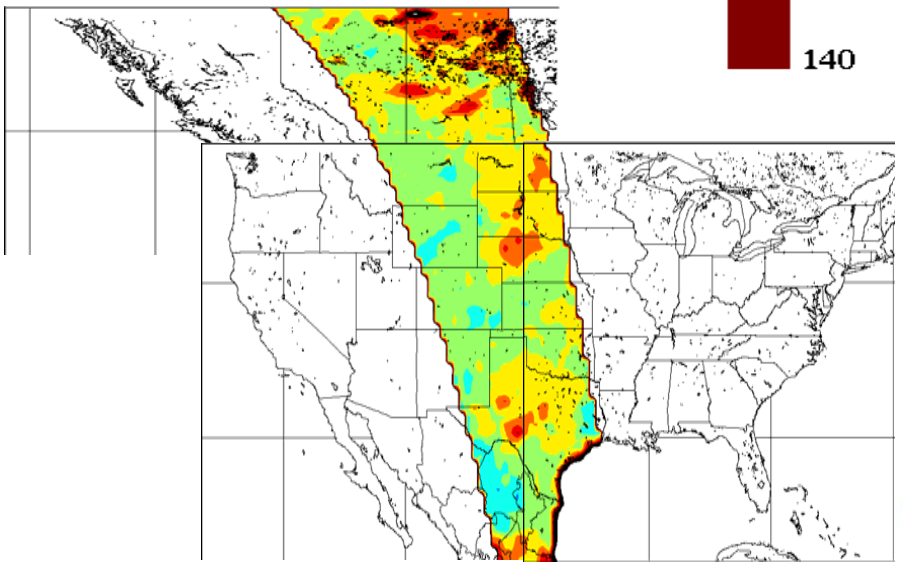
1200 UTC 2 July 2009



Nature Run 1-km



SMOS/SMAP -Scale : 40-km



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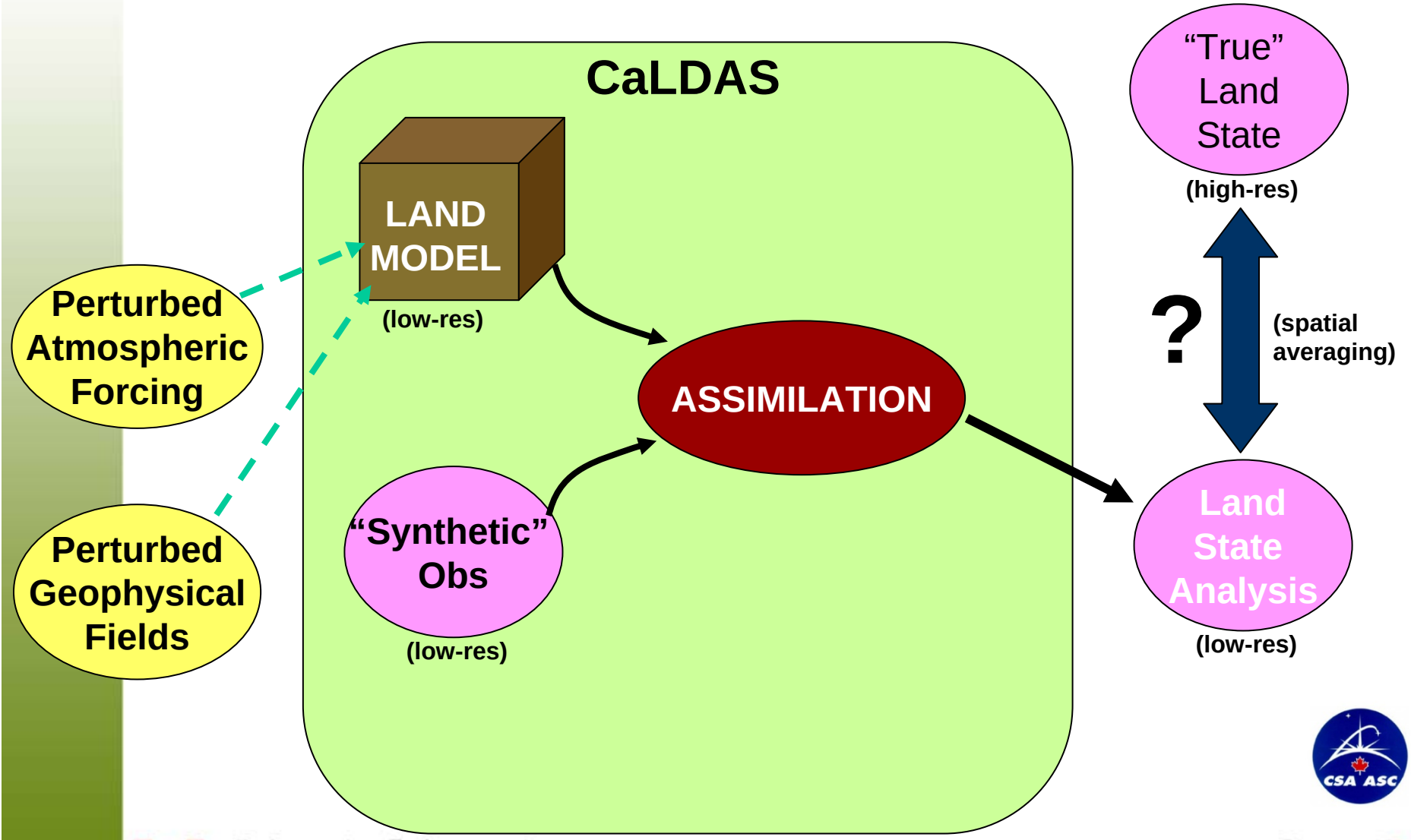
Synthetic Experiment Design (II)
EnKF Data Assimilation Run



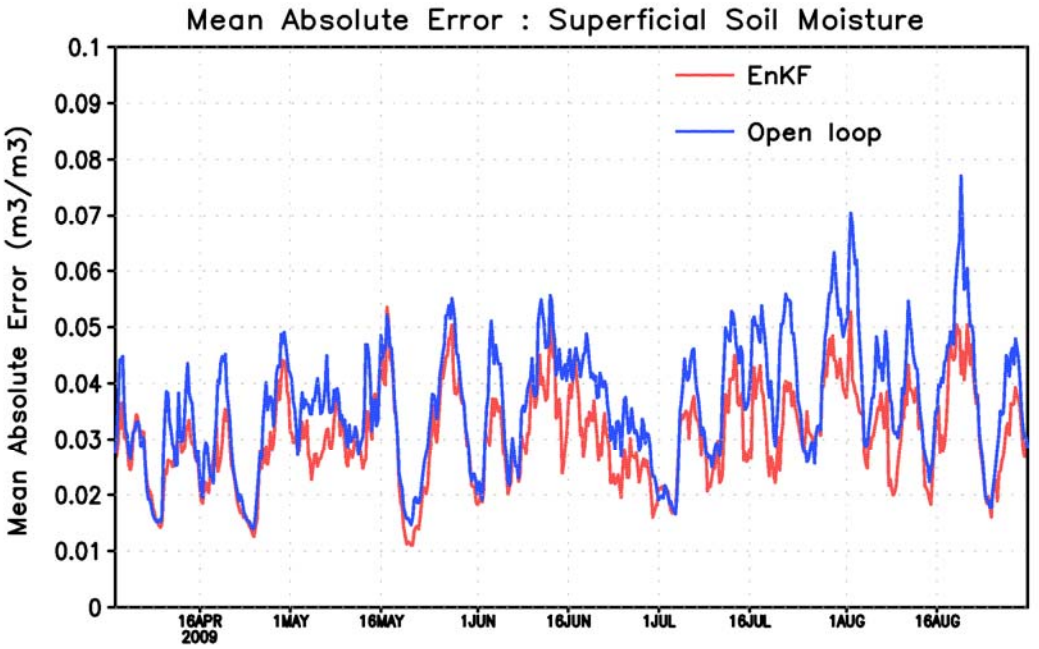
Synthetic Experiment-Specifications

- **Assimilation grid** : 40-km resolution covering the eastern portion of North America.
- **Control variable** : Superficial soil moisture (10-cm depth).
- **Observations assimilated** : HH, VV polarization L-brightness temperatures at 40^{o} incidence angle, spatially and temporally located using a SMOS-orbit simulator. Roughly a 2-3 day repeat cycle.

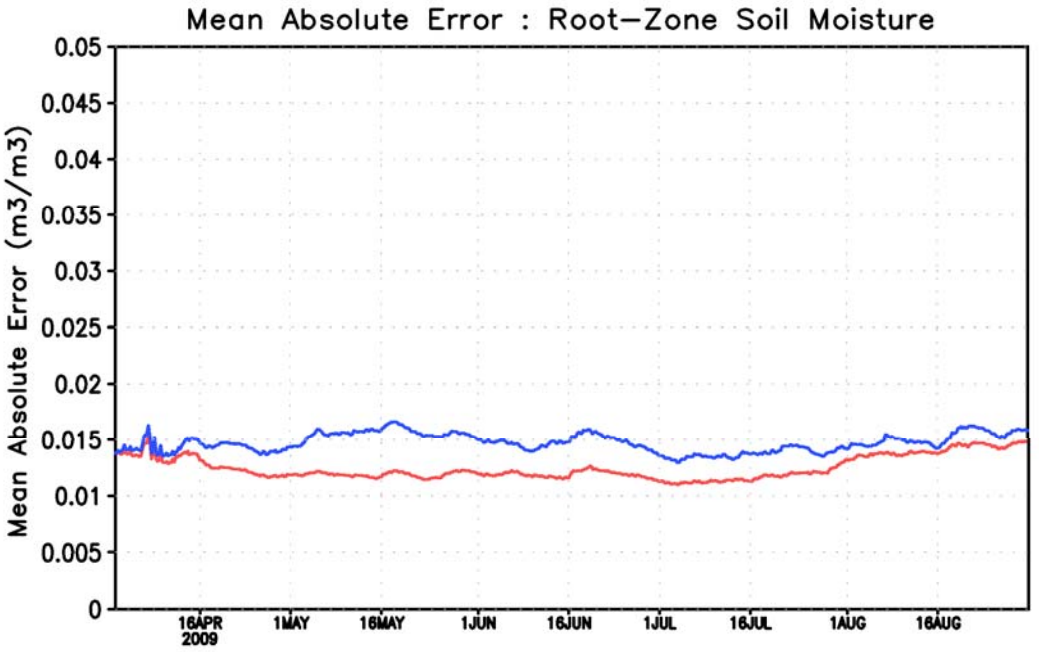
- **EnKF assimilation** run with 48 members.

- Each ensemble members is integrated with perturbed precipitation, radiation, air temperature derived from 30-42 hr GEM-15 forecasts.
- Surface albedo, vegetation fraction and leaf area index values were also perturbed as described.
- **Open loop integration** consists of one integration of the land-surface model .

Time series of domain-averaged soil moisture errors, considering only land points with very small water fractional coverage.)



Root-zone soil moisture is improved by roughly 0.002-0.003 m^3 m^{-3}.



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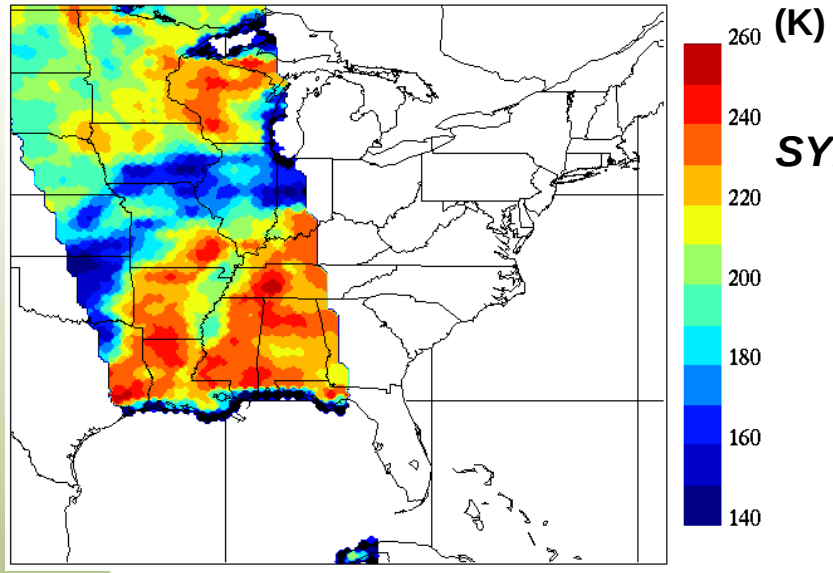
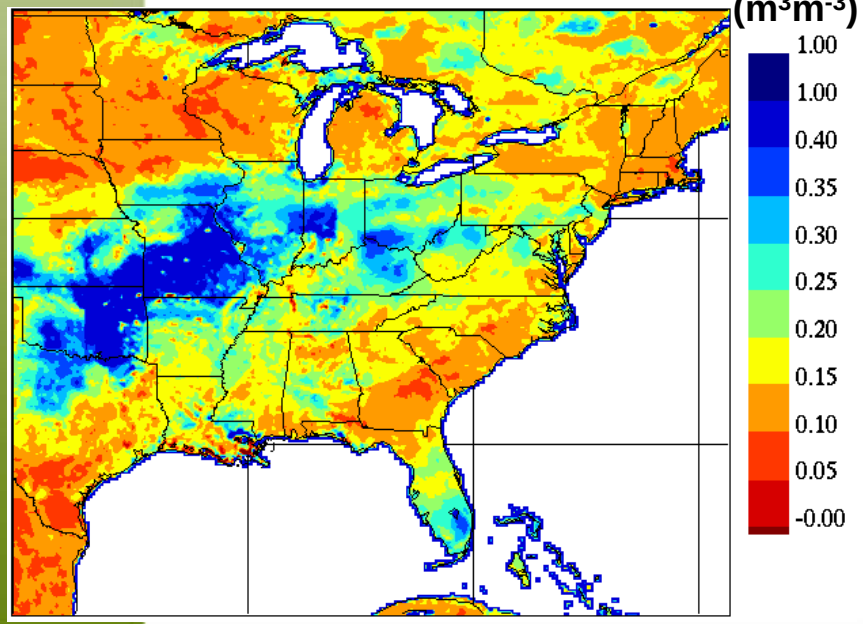
SOIL MOISTURE ANALYSIS from SYNTHETIC EXPERIMENTS with CaLDAS

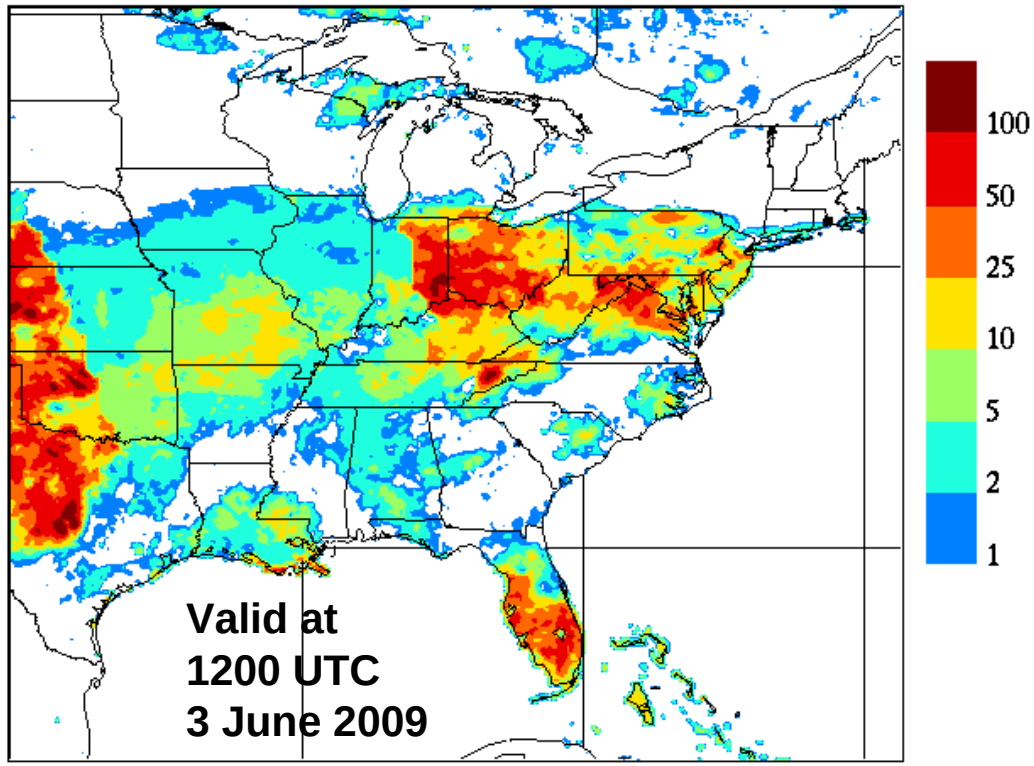


SYNTHETIC Tb L-band (H-pol) at 40º (K)

SOIL MOISTURE ANALYSIS



SOIL MOISTURE ERROR DIAGNOSTIC

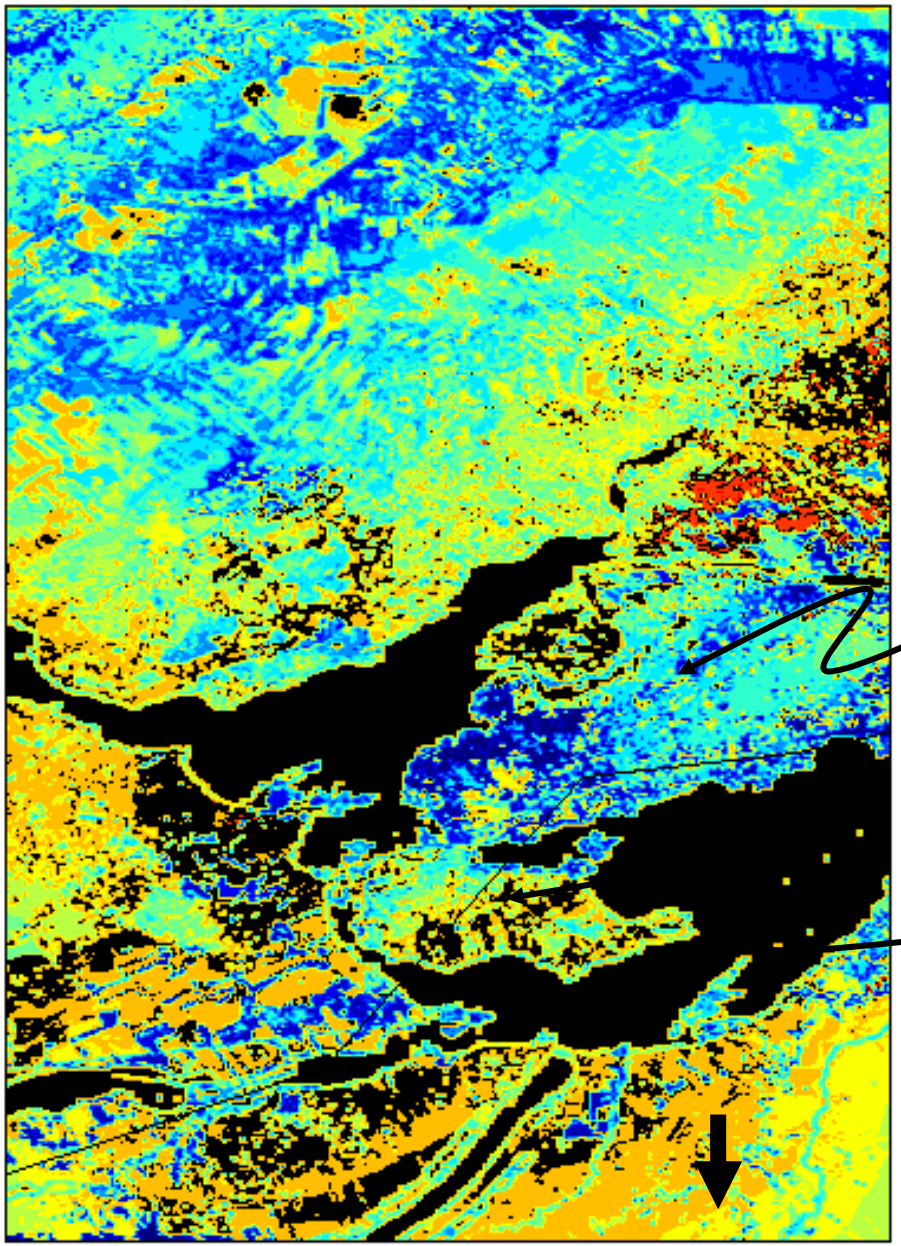


Research Themes and Applications

- **Different sources of information and observations related to soil moisture at varying temporal scales and spatial resolutions.**
  - SMOS/SMAP lower-resolution radiometer data (~ 40 km);
  - Screen-level observations of temperature and humidity at higher temporal frequency ;
  - Radarsat-2 C-band SAR data ;
  - Higher-resolution active radar measurements from SMAP;
- **Challenge is to develop methods and algorithms to optimally combine these different types of information.**
- **<u>Incremental CaLDAS</u> : Development of an incremental version of CaLDAS. Combination of a high-resolution land-surface model first-guess with the application of lower resolution analysis increments.**
- **Joint assimilation of passive and active L-band soil moisture measurements.**

HIGH-RESOLUTION MODELING of SOIL MOISTURE (120m)

(Valid on
1 August 2008)



Soil Water Index

1.8
1.4
1.0
0.6
0.2
-0.2
-0.6
-1.0

Montreal Island

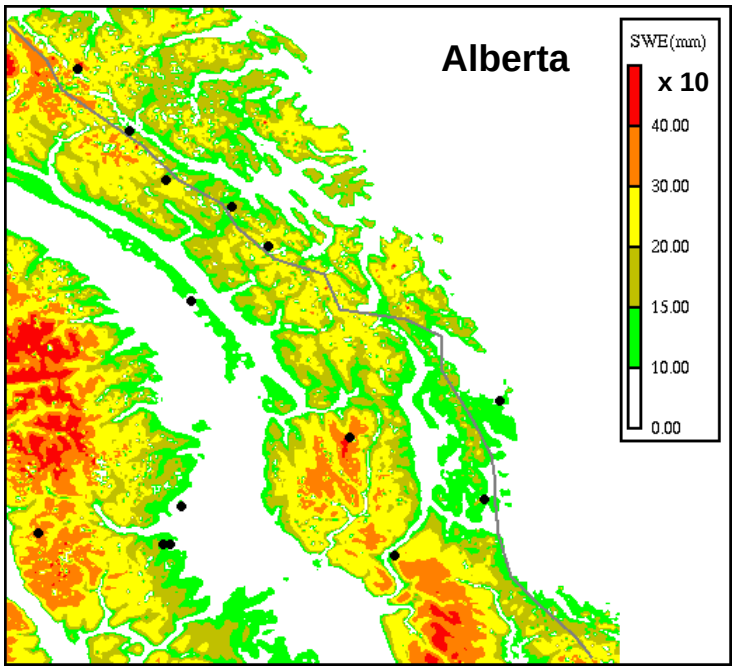
Ile Perrot

Ontario

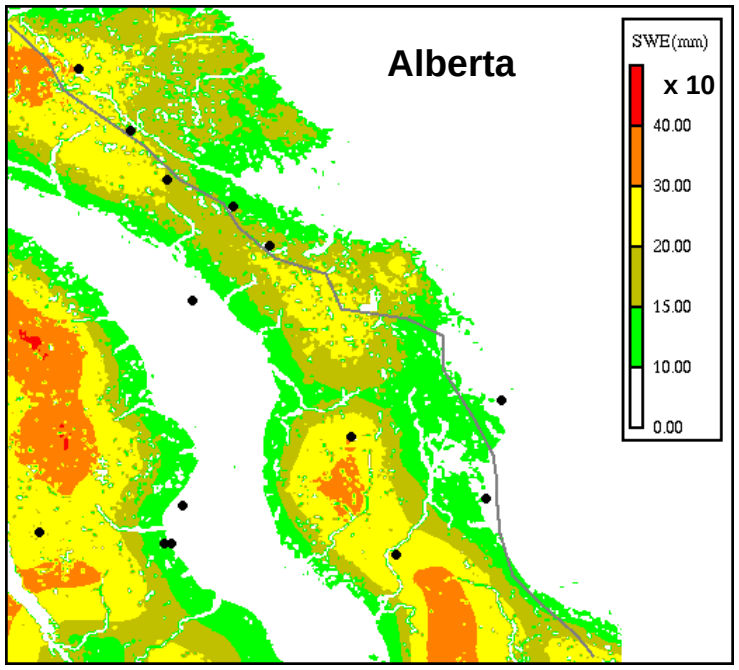
USA

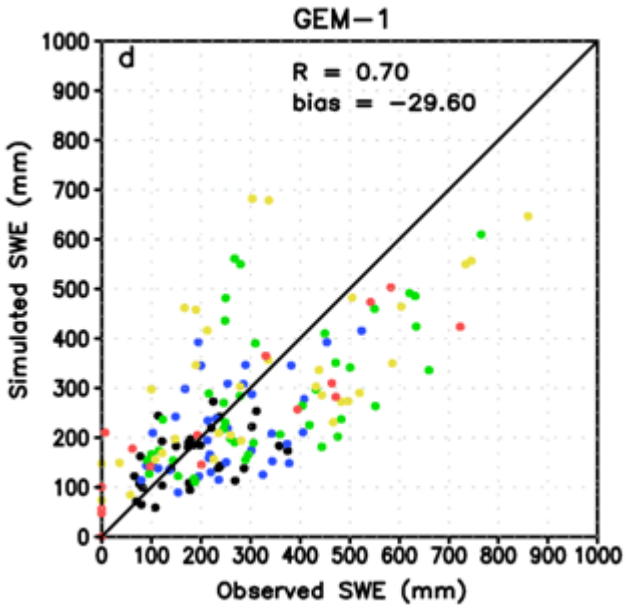
HIGH-RESOLUTION MODELING of TERRESTRIAL SNOW (1km)

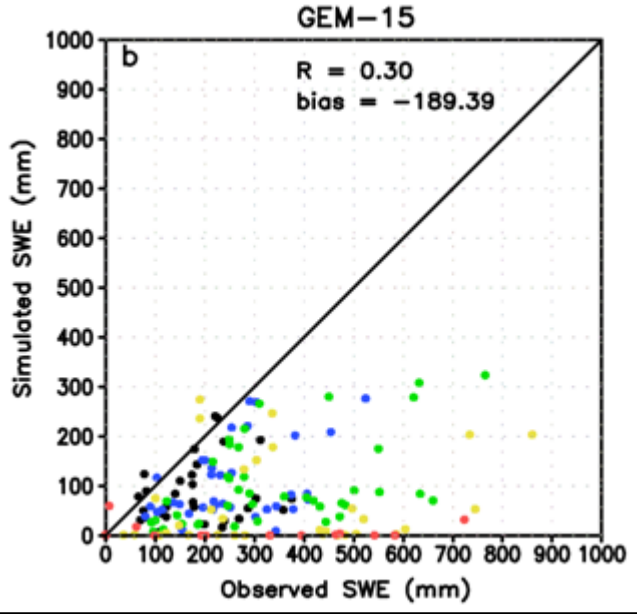
Mean Snow Water Equivalent



Winter
2005/2006



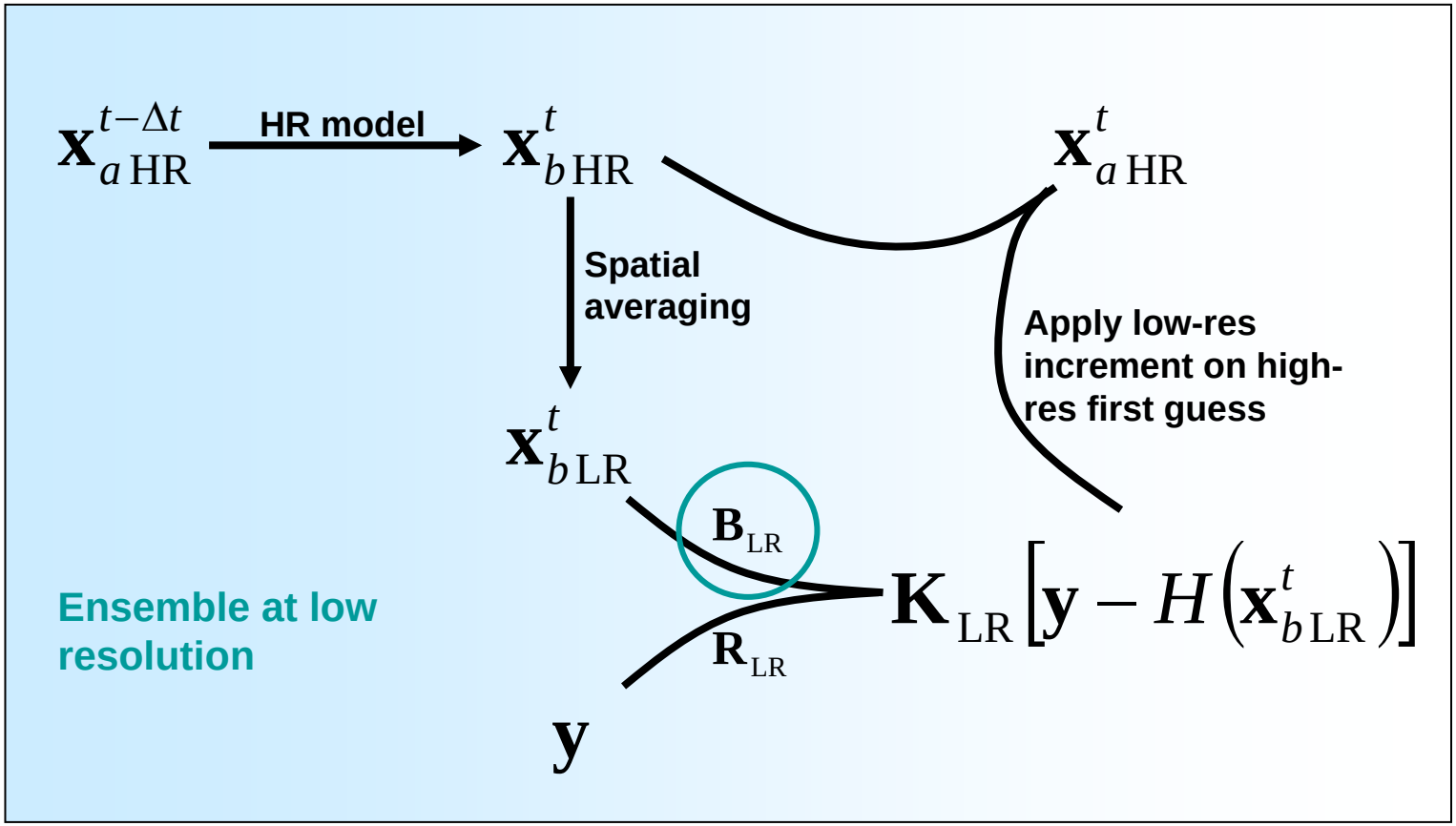




INCREMENTAL VERSION of CaLDAS

HIGH-RESOLUTION (100m-2km)

LOW-RESOLUTION (10km-40km)

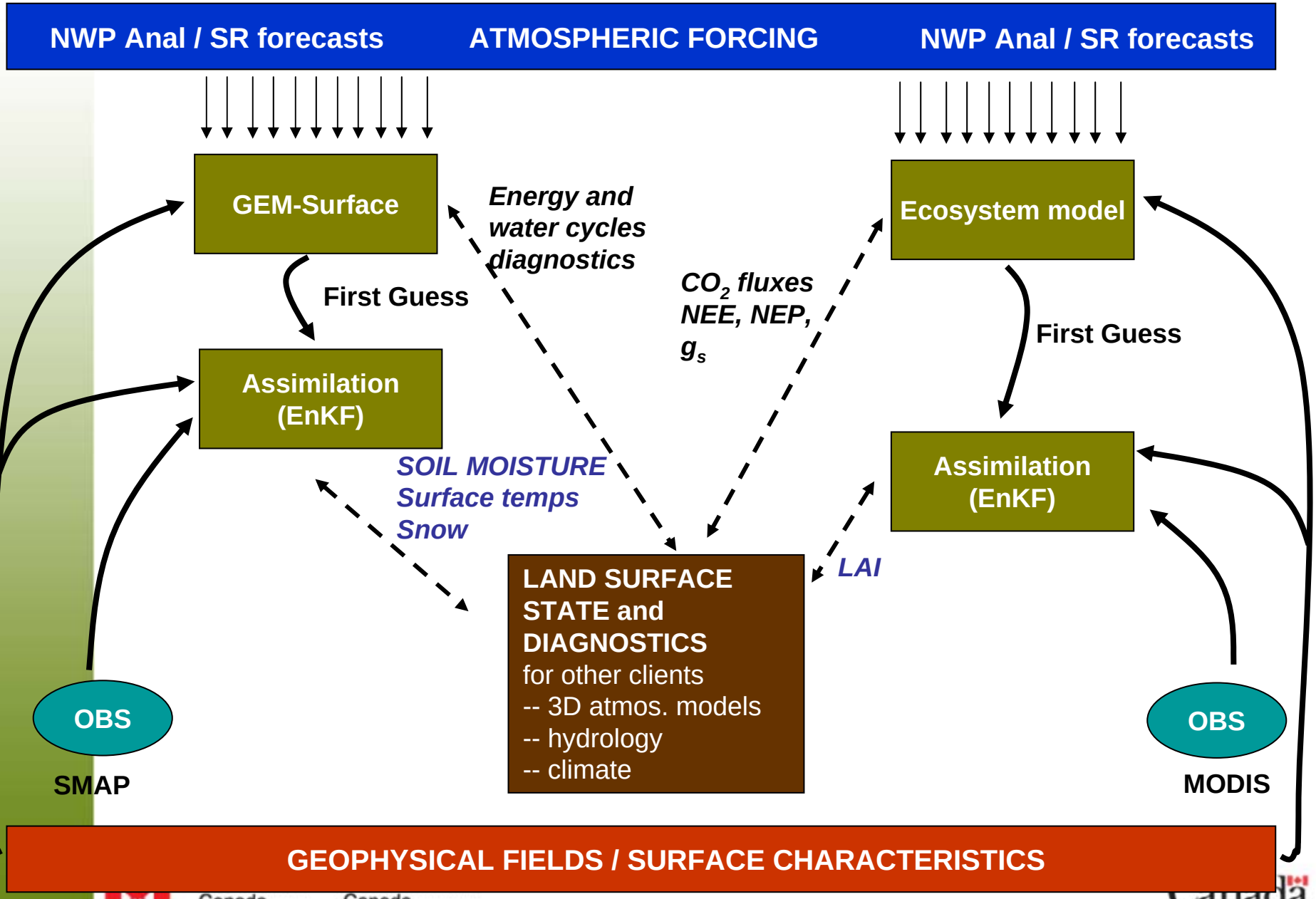


PREVIOUS ANALYSIS

BACKGROUND and OBSERVATIONS

NEW ANALYSIS

Future Land-Surface Modeling and Data Assimilation System



SMOS TB 40º H-pol
1015 UTC 11 June 2010

Environment Canada has been receiving the SMOS near real-time BUFR data since March 2010. These data will be assimilated within CaLDAS.