Advances in Land Data Assimilation at Environment Canada

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MRD = Meteorological Research Division
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CMC = Canadian Meteorological Centre
New approach for land data assimilation based on offline surface modeling ...

... and on more sophisticated methods for land surface data assimilation

with emphasis on assimilation of space-based remote sensing data (for soil moisture, terrestrial snow, and vegetation)

Single system for all NWP systems (deterministic and ensemble-based) + hydrology models

Better coupling with atmospheric assimilation and prediction systems (Global 4DVAR, Global and Regional EnKF, as well as Global and Regional EPS)

High-resolution land surface modeling (based on high-resolution information for orography, land use / land cover)
CURRENT RESEARCH THEMES (for the assimilation component)

• First guess: High-resolution land surface modeling

• Modeling of first guess uncertainty

• Optimizing the use of screen-level observations (analyses) in land data assimilation

• Simple variational (or EKF) vs EnKF (and vs Hybrid?)

• Assimilation of snow (fractional coverage and SWE) based on space-based remote sensing

• Vegetation characteristics from ecosystem modeling (first guess only at this time + previous work with MODIS)

• Impact of surface processes on NWP prediction (special emphasis on medium range)
HIGH-RESOLUTION (OFFLINE) LAND SURFACE MODELING
URBAN METEOROLOGY (Leroyer et al.)

Radiative Surface Temperature (°C)
July 6th 2008 (10:54 LST)

MODIS MOD11A1 product
Resolution: 1km
(exactly 928 m)
- Atmospheric effects corrected
- Satellite View Angle : 15

Urban off-line modeling system
Assimilation of soil water content every day
Resolution: 928 m → upscaling
HIGH-RESOLUTION (OFFLINE) LAND SURFACE MODELING
VANCOUVER 2010 OLYMPIC GAMES (Bernier et al.)

Snow depth analysis (based on 100-m high-res runs, no assimilation)
Screen-level air temperature – 1 January to 31 December 2008
MODELING of FIRST GUESS UNCERTAINTY (EnKF)

Analysis equation

\[ x^a = x^b + B H^T \left[ H B H^T + R \right]^{-1} \left[ y - H(x^b) \right] \]

CONTRIBUTORS for B

• 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\downarrow, LW\downarrow, precipitation

• Land surface modeling
UNCERTAINTY RELATED TO ATMOSPHERIC FORCING (EnKF)
(Carrera, Bilodeau)

Perturbed precipitation observations (surface + radar)

REPS or perturbed outputs from REG-15

Ensemble of forcing for radiation, air temperature and humidity, and surface pressure

CaPA

Ensemble of precipitation analyses

Downscaling

External land surface model
UNCERTAINTY RELATED TO LAND SURFACE CHARACTERISTICS
(Solomon, Charron)

Spatially and temporally coherent perturbations for albedo, LAI, Fveg, and roughness length, based on spherical harmonics with coefficients obtained from Markov chains.

\[ \psi(\lambda, \varphi, t) = \mu + \sum_{l=1}^{L_{\text{max}}} a_{lm}(t) Y_{lm}(\lambda, \varphi) \]
ANCILLARY SURFACE DATA

**Orography**
- USGS-GTOPO30 (~900m)
- SRTM-DEM (~90m)
- CDED1 (~20m)
- USGS-GLCC (~1km)
- NTDB (~20m)
- EOSD (~25m)
- CCRS-2005 (~300m)
- GlobCover-2005 (~300m)
- Circa-2000 (~30m)
- FAO (~8km)
- STATSGO (~1km)
- AAFC-SLC
- Harmonized World Soil Db

**Land use / land cover**
- CanVec (~20 m)
- USGS-GLCC (~1km)
- GlobCover (~ 300 m)

**Soil texture**
- CanVec (~20 m)
- USGS-GLCC (~1km)
- GlobCover (~ 300 m)

**Land / water fractions**
- CanVec (~20 m)
- USGS-GLCC (~1km)
- GlobCover (~ 300 m)

Other databases for **urban** environment
(Belair, Leroux, Chan)
From 1 July to 1 August 2007

Great Lakes region

10-km grid, 200 x 120 points

“Truth” based on open loop with soil moisture initialised at field capacity

Synthetic obs generated using CMEM ($T_{BH}$ and $T_{BV}$) and surface layer stability functions (screen-level temperature and relative humidity)

Soil moisture on 1 July set at wilting point (beginning of cycles)

Assimilation with EnKF (Supervisor Monitor Scheduler - SMS)

10 members, same forcing and same surface conditions as “truth”

Exp_1: L-Band Brightness temperatures ($T_{BH}$ and $T_{BV}$ every 6h)

Exp_2: Screen-level observations ($T_{2m}$ and $RH_{2m}$ every 6h)
CONVERGENCE of ROOT-ZONE SOIL MOISTURE (After 10 days)

\[
\frac{W_2 - W_2_{\text{Truth}}}{W_{fc} - W_{\text{wilt}}}
\]

Assimilation of synthetic L-Band brightness temperatures

Assimilation of synthetic screen-level air temperature and relative humidity

Valid 10 July 2007
CONVERGENCE of ROOT-ZONE SOIL MOISTURE (After 30 days)

\[ \frac{W_2 - W_{2\text{Truth}}}{W_{fc} - W_{wilt}} \]

Assimilation of synthetic brightness temperatures

Assimilation of synthetic screen-level air temperature and relative humidity

Valid 30 July 2007
DOMAIN-AVERAGED CONVERGENCE of SOIL MOISTURE

Domain-averaged convergence index

Soil Moisture Convergence Index

1 JUL 2007
6 JUL
11 JUL
16 JUL
21 JUL
26 JUL

Time

Screen-level

L-Band brightness temperatures

Canada
OTHER EXPERIMENTS (Simple VAR and JOINT ASSIMILATION)

Domain-average convergence index

Screen-level data

- Simple VAR
- EnKF

EnKF

\[(TT, HR)_{2m}\]

\[T_{Bv,h} + (TT, HR)_{2m}\]

* TB data every 3 days
REMOTE-SENSING PRODUCTS for SNOW ASSIMILATION
FRACTIONAL SNOW COVERAGE AREA (Wang, Derksen)

a) MODIS Cloud Gap Filled fractional snow coverage area (5 km)

b) MODIS Cloud Gap Filled persistence map (days since clear view of ground)

c) Fractional snow coverage area estimated using EC’s implementation of the EUMETSAT algorithm (yellow=clouds) (1 km)

d) NOAA IMS binary snow/no-snow map (4 km)

(Valid on 26 April 2007)
REMOTE-SENSING PRODUCTS for SNOW ASSIMILATION
SNOW WATER EQUIVALENT (Derksen, Wang)

Example statistical uncertainty results for passive microwave SWE retrievals based on the variance explained in brightness temperatures due to grid cell (a) lake and (b) forest fractions.
UPCOMING RESEARCH THEMES (for the assimilation component)

• Modeling of innovations uncertainty (R)

• Incremental assimilation

• Coupling with REPS and GEPS

• Impact on hydrology

• Evolution of land surface model (Canadian multi-budget version of ISBA, or CLASS)

FIRST VERSION of CaLDAS to be SYSTEMATICALLY TESTED for OPERATIONAL IMPLEMENTATION at CMC will be READY in 2010 – EXPECTED IMPLEMENTATION in 2011
Thank you all for your attention
LAND DATA ASSIMILATION at ENVIRONMENT CANADA

CURRENT SITUATION

ANALYSES

SEQ. ASSIMILATION
Global 800x600

SNOW
Gaussian 1080x540

SEQ. ASSIMILATION
Regional 576x641

ASSIMILATION

Ensembles
GEM and SEF (ISBA, FR, glaciers, water)

Global
GEM 800x600 uniform (ISBA, glaciers, water)

Regional
GEM 576x641 variable (ISBA, glaciers, water)

Local
GEM-LAM East and West (ISBA, glaciers, water)

MODELS

GENESIS
Soil texture, orography, vegetation, lakes, and glaciers

DATABASES

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

Canada

Environment
Canada

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LAND DATA ASSIMILATION at ENVIRONMENT CANADA
In DEVELOPMENT

Canadian Land surface Data Assimilation System (CaLDAS)
- Simple Var or EnKF for soil moisture and surface temperature (screen-level + sat)
- Snow mass and coverage (surface data + sat)
- High-res global grids (same as external system)

External Land Surface Modeling System (GEM-Surface)
- High-resolution grid over Canada (1 km or less) – Lower resolution grid over world (5 km or less)
- (CLASS or ISBA, TEB, WATER, SNOW, GLACIERS, EOLE, blowing snow)

GenPhysX
- Soil texture, orography, vegetation, water bodies, glaciers, and cities

Land Surface Models
- CaPA
  - Model, surface and satellite data

ANALYSES
- TS, ES, TP
  - External system’s Grid (high-res)

ASSIMILATION
- TS, ES

LAND SURFACE MODELS
- TM-Lakes
  - High-res grid Satellite
- GL-Lakes
  - High-res grid Satellite
- Vegetation

OTHER MODELS
- ENSEMBLES
  - (FR, ISBA, CLASS, WATER, GLACIERS)

DATABASES
- HYDROLOGY

Forcings

MESH

Canada
HIGH-RESOLUTION OFFLINE LAND SURFACE MODELING

INITIAL SURFACE CONDITIONS
- Surface Temperatures
- Soil water content
- Soil ice content
- Snow characteristics

LAND SURFACE CHARACTERISTICS (GenPhysX)
- Topography
- Roughness
- Land/water fractions
- Soil texture
- Natural cover types
- Urban cover types
- Glaciers

ATMOSPHERIC FORCING (forecasts / observations / analyses)
- Near-surface air characteristics (temperature, humidity, winds)
- Surface pressure
- Incident radiation (solar and infrared)
- Precipitation (rain and snow)

DOWNSCALING MODELS
- GEM-Surface (ISBA, CLASS, TEB)
  - Low res forcing
  - High res forcing

OUTPUTS / PRODUCTS
- Surface (snow) temperature
- Snow characteristics (depth, albedo, density)
- Low-level air temperature and humidity
- Low-level winds (from adaptation + roughness)
VEGETATION CHARACTERISTICS from ECOSYSTEMS MODELING
(Chan, ..., Belair)

Biome-BGC

ATMOSPHERIC FORCING from MSC NWP PRODUCTS

Biome-BGC integration

“Analyses” of Leaf Area Index

Land use / Land cover databases

Photosynthesis (GPP)

Maintenance Respiration

Growth Respiration

Heterotrophic Respiration

C flux

N flux

GPP

MR

GR

HR

plant

litter

Soil

allocation to new growth

atmospheric CO2

allocation to new growth

atmospheric N

soil mineral N

N uptake

Biome-BGC Carbon and Nitrogen Dynamics
SYSTEMS to be TESTED for OPERATIONAL IMPLEMENTATION at CMC

*Improved surface modeling in GEM (inline)*

READY for PRE-IMPLEMENTATION TESTS in 2010
POSSIBLE IMPLEMENTATION in 2011

*First version of CaLDAS*

FIRST CONFIGURATION in 2010
POSSIBLE IMPLEMENTATION in 2011

*First version of high-resolution offline land surface system*

PRE-IMPLEMENTATION SHOULD START in 2010
POSSIBLE IMPLEMENTATION in 2012