Better Weather Forecasts Resulting from Improved Land Surface Processes in EC's Numerical Prediction Systems

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Greater Emphasis on Surface Meteorology

Upper-air evaluation to compare Centers' performance

Different approach (more global) needed to determine true value of NWP systems

Emphasis on near-surface forecasts, felt by most NWP clients
Many Clients / Systems to Interface with

Sub-Monthly NWP Systems At Environment Canada

- **RDPS North Amer. EnVar**
  - Forecast Length (days): 1
  - Grid Spacing (km): 10

- **REPS North Amer. Downscaling**
  - Forecast Length (days): 2
  - Grid Spacing (km): 15

- **GDPS Global EnVar**
  - Forecast Length (days): 10
  - Grid Spacing (km): 25

- **GEPS Global EnKF**
  - Forecast Length (days): 50
  - Grid Spacing (km): 50

- **HRDPS Canada Downscaling**
  - Forecast Length (days): 25
  - Grid Spacing (km): 25

- **Experimental Local / Urban Downscaling**
  - Forecast Length (days): 250
  - Grid Spacing (km): 250

- **HRDPS Canada Downscaling**
  - Forecast Length (days): 2.5
  - Grid Spacing (km): 2.5
EC's Effort to Improve Land Surface

Characteristics and properties

Modeling – representation of processes

Data assimilation

Coupling with atmosphere
The Surface Processor - Characteristics

DATABASES

- GTOPO30
- GMTED2010
- SRTM-DEM-v4
- ASTER-DEM
- CDED2012
- USGS-GLCC
- MODIS-MCD12Q1
- CCRS
- GlobCover2.3
- LCC2000-V
- CanVec-9.0
- OSM
- NLCD2006
- Census-StatCan2006
- FAO
- CANSIS
- BNU Soil Dataset
- JPL Soil Type
- USDA STATSGO
- HWSD
- 3D GlobVeg
- NHD, NHN

Vegetation fractions
Urban parameters
Water fraction
Soil texture
Drainage Density

Orographic parameters
Water fraction

OUT

LEAF AREA INDEX
VEG. FRACTIONS
VEG. PARAMETERS
ALBEDOs
ROOT-ZONE DEPTH
SAND
CLAY
URBAN PARAMETERS

IN

GEM or GEM-Surf

PreX

MODIS ALBEDO CLIM.
MODIS NDVI CLIM.
BIOME-BGC CLIM.
Example: Global, 15 km, surface roughness

(Yin)

(Yang)

(Bernard Bilodeau)
Example: Regional, 2.5 km, Veg. Height

Simard et al. (2011) – JPL
From GLAS aboard ICESat

$z_0 = \alpha h$

Used for $Z0$ (local only), no orographic component
Impact on Near-Surface Winds

Pan Canadian 2.5-km system
10-m wind speed STDEs

Reglam vs B3 (z0 from LUT)

20 summer cases (00 UTC)

Reglam vs B35 (z0 from JPL)

(Manon Faucher)
Example: Local, 250 m, land cover

GREATER TORONTO AREA

Light grey: pavement fraction
Dark brown: building fraction
Example: Local, 250 m, urban

(Vanh Souvanlasy)
Example: Local, 250 m, urban

Pavement fraction

(Vanh Souvanlasy)
Urban Areas in North America

(Vanh Souvanlasy, Sylvie Leroyer)
## Land Surface Models

<table>
<thead>
<tr>
<th>Component</th>
<th>Model Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Land</td>
<td>ISBA, SVS, CLASS</td>
</tr>
<tr>
<td>Water</td>
<td>Simple scheme with constant surface temperature (NEMO for 3D lakes + 1D lake model)</td>
</tr>
<tr>
<td>Urban</td>
<td>TEB</td>
</tr>
<tr>
<td>Glaciers</td>
<td>Force-restore scheme (with snow), module from CLASS</td>
</tr>
<tr>
<td>Sea ice</td>
<td>3-layer model with snow on top (LIM2 or CICE)</td>
</tr>
<tr>
<td>Snow</td>
<td>Simple schemes over glaciers and sea ice; one layer model in ISBA and SVS, slightly more complex in TEB and CLASS</td>
</tr>
</tbody>
</table>
The Soil, Vegetation, and Snow Scheme

Multiple energy and water budgets (new subgrid-scale tiling)

Multi-layer model for soil moisture

New snow pack under the vegetation

Root density function depending on vegetation type

Changes to vegetation thermal coefficient, albedo, and emissivity

Stomatal resistance from photosynthesis scheme

Not changed: still a single canopy layer scheme
SVS: Impact on Soil Moisture

Near-surface soil moisture

SMAPVEX12
Southern Manitoba
June 2012

50-cm soil moisture

(Shunli Zhang)
SVS: Impact on L-Band Forward Modeling

Horizontal Polarization: 40° Incidence Angle
May – September 2012

ISBA
CORRELATION MEAN: 0.44
(Shunli Zhang, Marco Carrera)

SVS
CORRELATION MEAN: 0.46
EC's Land Data Assimilation Effort

**IN**
- Ancillary land surface data
  - Orography, vegetation, soils, water fraction, ...
- Atmospheric forcing
  - $T, q, U, V, Pr, SW, LW$
- Observations
  - Screen-level ($T, T_d$)
  - Surface stations snow depth
  - L-band passive (SMOS, SMAP)
  - MW passive (AMSR-E)
  - *Optical / IR (MODIS, VIIRS)
  - Combined products (GlobSnow)

**CaLDAS**

**LAND MODEL (SPS)**

**OUT**
- Analyses of...
  - Surface Temperature
  - Soil moisture
  - Snow depth or SWE
  - Vegetation*

**ASSIMILATION**
- EnKF + EnOI

**Observations (OBS)**

**ENKF**

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

$K = BH^T \left( HBH^T + R \right)^{-1}$

*) not done yet...
## First Implementations of CaLDAS

<table>
<thead>
<tr>
<th>OBS</th>
<th>Method</th>
<th>Control variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen-level air temperature and dew point temperature</td>
<td>EnKF</td>
<td>Soil moisture and surface temperature</td>
</tr>
<tr>
<td>Surface obs of snow depth</td>
<td>EnOI</td>
<td>Snow water equivalent</td>
</tr>
</tbody>
</table>

**Regional** (Canada + part of USA), 2.5 km  
**Global**, Yin-Yang grid, 25 km

Both systems implemented in Fall 2014 at MSC-Operations
CaLDAS: Impact on HRDPS (2.5 km)

RMSE, Td_2m
20 summer cases
Canada

Without CaLDAS

With CaLDAS

(Manon Faucher)
CaLDAS: Impact on RDPS (10 km)

ENF + CaLDAS OFFL 3

Without CaLDAS

With CaLDAS

RMSE, TT_2m
20 summer cases
USA

(Jean-Francois Caron)
CaLDAS: Impact on GDPS (25 km)

Upper-air evaluation Against radiosondes Southern Hemisphere June-July-August About 100 cases 5-day forecasts

(Bernard Bilodeau)
CaLDAS: Impact on GEPS (Ensemble)

Continuous Rank Probability Score (CRPS)

Over North America

2-m temperature

Reliability component of the CRPS

(Normand Gagnon)
Assimilation of L-Band Data in CaLDAS

SMOS NRT-light L-band Tbs (40 km, multi-angles)

QA/QC: exclusive alias-free zone, simple tests

Rescaling of Tbs based on CDF matching

Tb obs. error chosen as 5 K (homogeneous)

EnKF: 24 members, 10 km analyses, wg and w2

EnKF: 3h frequency, CMEM forward model

Tested in synthetic mode and over SMAPVEX12
Mean of sampled fields (6 cm).

AAFC SAGES mean (5, 20 and 50 cm).

Open loop

Marco Carrera
Towards a More Complete CaLDAS

Starting point: CaLDAS-screen 2.5km (OP)

Addition of the SMOS component (combination with screen-level obs, simultaneous or sequential)

Addition of the SVS surface scheme for the first guess

To be tested first in regional 10-km mode (NAM)

To be extended afterward to Canada 2.5-km (first) and to global 15 km (second)
Ready for SMAP... (Passive at Least...)

Current monitoring of SMOS observation
Same apparatus will be used for SMAP
Test with data as soon as possible
Traditional Land-Atmosphere Coupling

- Vertical resolution near the surface
- Height of lowest atmospheric level
- Exchange coefficients
Lower atmospheric levels near the surface (as close as 1.5m for thermodynamic level)

Changes to the nature of the land-atmosphere interactions with atmospheric levels intersecting with vegetation and urban canopies.

Two-way coupling: low-res atmospheric model with high-res surface system
Increased Vertical Resolution near Surface

Figure 1 in Bernier and Belair, 2012, J. Appl. Meteorol.
Impact on Screen-Level Variables

15 winter cases, and 15 summer cases

Figure 3 in Bernier and Belair, 2012, J. Appl. Meteorol.
Impact on Near-Surface Profiles

15 winter cases, and 15 summer cases

Figure 4 in Bernier and Belair, 2012, J. Appl. Meteorol.
**Vertical Aspect of Coupling**

- **SINGLE GEM (ATMOSPHERE) GRID AREA (LOW RES)**

- **INCREASED VERTICAL RESOLUTION**

  **SPATIAL AVERAGE** of **IMPLICIT LOWER BC** for **VERT. DIFFUSION** (to be applied over atmospheric level just above canopy / soil water / ice)

- **SPATIAL AVG of TENDENCIES** for EACH INTERSECTING LEVEL

- **WATER**
  - **LAND / VEG (ISBA / SVS)**
  - **URBAN (TEB)**

- **MULTIPLE SURFACE GRID AREAS (HIGH RES)**
• **CaM-TEB (Canadian Multilayer version of TEB)**
• Several model levels intersect the buildings.
• Variable building heights exist within a grid cell.

*(Husain et al. 2013)*
Horizontal Aspect of Coupling

\[
\frac{\partial \theta}{\partial t} = \frac{1}{\rho} \frac{\partial}{\partial z} \left( \rho K_T \frac{\partial \theta}{\partial z} \right) = -\frac{1}{\rho} \frac{\partial}{\partial z} \rho w' \theta' \\
- \left( w' \theta' \right)_S = \alpha_\theta + \beta_\theta \theta_{NK_{\text{atm}}}^+ \\
\left( w' \theta' \right)_S = C_T u_c \left[ \theta_S^+ - f_S \theta_{NK_{\text{atm}}}^+ \right]
\]

\[
\alpha_\theta = -C_T u_c \theta_S^+ \\
\beta_\theta = -C_T u_c f_S
\]

Spatially averaged

**Spatial average of implicit lower BC for vert. diffusion**

- SINGLE GEM (ATMOSPHERE) GRID AREA (LOW RES)
  - WATER
  - LAND / VEG (ISBA / SVS)
  - URBAN (TEB)

- MULTIPLE SURFACE GRID AREAS (HIGH RES)
Towards 2-Way Coupling

(Rochoux et al, 2015, submitted)
Subgrid-scale variability of turbulent fluxes for 25-km grid spacing model based on external 2.5-km land surface model

Provided by M. Rochoux, EC

Potential Benefit of Two-Way Coupling
Final Words

An effort much greater than originally expected when this new phase started a decade ago...

All aspects important

Comments and recommendations are welcome!
The end... backup slides (urban stuff)
The Town and Energy Balance Scheme
(Masson, 2000)

Street canyon concept:
Drag, radiation budgets

Multiple reflections, trapping absorption

**Input:**
Urban fabric (material layers, depths)
Morphology (aspect ratio, roughness)

**Output:**
Surface temperatures, Energy budgets,
T, q, wind at pedestrian level
TEB: Urban Heat Islands

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

Urban offline model
(100-m grid spacing)

(Leroyer et al., 2011)
TEB: Urban Heat Islands

- Radiative Surface Temperature (°C)
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Urban offline model (100-m grid spacing)

(Leroyer et al., 2011)
Tokyo Case: Urban Areas

Radar / Raingauge Analysis (JMA)

GEM - 250m

19-h Forecast (with TEB)

(Courtesy of N. Seino, JMA/MRI)

(Lubos Spacek)
Tokyo Case: Impact of TEB

CONTROL RUN – with URBAN

19-h Forecast
Valid at 1600 JST
26 Aug. 2011

Without URBAN (no TEB)