Soil moisture biases and their correction in CanSIPS operational forecasts

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The Canadian Seasonal to Interannual Prediction System (CanSIPS)

- Developed at CCCma
- Operational at CMC since Dec 2011
- 2 models CanCM3/4, 10 ensemble members each
- Forecasts initialized at the start of every month
- Hindcast verification period = 1981-2010
- Forecasts contribute to NMME and WMO/APCC/IRI ensembles
- Forecast range = 12 months

Reference: Merryfield et al., MWR, 2013
CanSIPS contribution to NMME
CanSIPS initialization

Atmospheric $T$, $u$, $v$, $q$ assimilation
SST nudging
Sea ice nudging

Assimilation run

Forecast

Initial cond 1

1 May

1 Jun

1 Jul

1 Aug

1 Sep

1 Oct

Initial cond 2

Initial cond 10

Forecast 1

12 months

Forecast 2

12 months

Forecast 10

12 months

assimilation run ensemble

forecast ensemble
CanSIPS initialization

Atmospheric $T$, $u$, $v$, $q$ assimilation
SST nudging
Sea ice nudging

Assimilation run

ocean $T$ assimilation, $S$ adjustment

Forecast

“Burst initialization”
CanSIPS Land initialization

Direct atmospheric initialization through 4D assimilation of 6-hourly $T$, $q$, $u$, $v$ using incremental analysis update ($\sim$ nudging)

Indirect land initialization through response to model atmosphere

Land model = CLASS2.7 (Verseghy, Atm.-Ocn 2000)

www.eoearth.org/view/article/152990

Land surface variables, e.g. soil moisture and snow, are not directly constrained; their states are determined by model response to previously assimilated “weather systems” from 3D atmospheric global analyses.
# Data Sources: Hindcasts vs Operational

<table>
<thead>
<tr>
<th>Field</th>
<th>Data Source during hindcast</th>
<th>Data Source during operations</th>
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</thead>
<tbody>
<tr>
<td>3D atmospheric variables</td>
<td>ERA40; ERA interim</td>
<td>CMC</td>
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<tr>
<td>SST</td>
<td>monthly NCEP ERSST (1979-1981) weekly NCEP OISST (1981-present)</td>
<td>daily CMC</td>
</tr>
<tr>
<td>Sea ice concentration</td>
<td>monthly HadISST (1979-present)</td>
<td>daily CMC</td>
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<tr>
<td>3D ocean temperature</td>
<td>monthly NCEP GODAS ocean analysis</td>
<td>daily NCEP GODAS ocean analysis*</td>
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<td>*pending availability of CMC NEMOVAR analysis</td>
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</tbody>
</table>
Change in atmospheric data source: Effect on soil moisture

- Plots below compare soil moisture in first forecast month for ERA vs CMC-based initialization
- VFSM = volume fraction of soil moisture (%)
- Anomalies are relative to 1981-2010 hindcast climatology

Global mean VFSM anomaly

Canada mean VFSM anomaly

CMC assimilation began 1 Jan 2010
Canada mean soil moisture anomalies in July initialized forecasts

- CanCM3
- CanCM4
- Grand ensemble mean
- ERA interim verification

2010 (ERA)
Initial year=2010 month=July

2011 (CMC)
Initial year=2011 month=July

2012 (CMC)
Initial year=2012 month=July

July lead 0 soil moisture anomalies

2010 (ERA)

2011 (CMC)

2012 (CMC)

DRY  WET
Solution: Modify CMC-based assimilation runs using bias correction method of Kharin & Scinocca (*GRL* 2012)

1. Extend ERA-based assimilation runs to mid-2012

2. From these runs make 6-hourly soil moisture time series from 1 Jan 2010

3. Repeat CMC-based assimilation runs, assimilating soil moisture from ERA-based runs from step 2 using:

   \[
   \frac{\partial X}{\partial t} = F(X) - \frac{1}{\tau} (X - X_R)
   \]

   The bias correcting term “G” is not a relaxation term. For a given grid point, it only depends on the day of the year.

   - usual model equations
   - \( \frac{\partial X}{\partial t} = F(X) \)
   - \( \frac{1}{\tau} (X - X_R) \)
   - assimilation terms

4. Construct cyclostationary bias correcting forcing ("G") from soil moisture assimilation term:

   \[
   G = -\frac{1}{\tau} (X - X_R)^{AC}
   \]

   - mean annual cycle
Solution: Modify CMC-based assimilation runs using bias correction method of Kharin & Scinocca (GRL 2012)

5. Repeat CMC-based runs again w/o soil moisture assimilation but with this bias correction

\[
\frac{\partial X}{\partial t} = F(X) + G
\]

6. Anticipated result: soil moisture drift corrected

![Graph showing VFSM anomaly, glb_avg from 2009 to 2013 with CanCM3 and CanCM4 lines. The graph shows a trend with vertical arrows indicating a drift correction issue.]
Result: Soil moisture restored to hindcast climatology in operational forecasts

Canada mean soil moisture anomalies in July initialized forecasts

- CanCM3
- CanCM4
- Grand ensemble mean
- + ERA interim verification

2012 (CMC)

2012 (ERA)

2012 (corrected CMC)

Correction implemented operationally beginning with June 2013-initialized forecast
Effects of soil moisture biases on precipitation forecasts

Mean differences in JJA forecasts for 2010-12 (lead 0)

Dots indicate statistical significance according to t test

CMC – ERA initialization

corrected CMC – ERA initialization
July 2012 temperature anomaly forecast

ERA Interim verification

CMC initialization

ERA initialization

corrected CMC initialization
Summary

• Change from ERA reanalysis for atmospheric assimilation in hindcasts to CMC analysis in operational forecasts led to *accumulating soil moisture deficit*

• This has been fixed using the bias correction procedure of Kharin & Scinocca (*GRL* 2012)

• Soil moisture in hindcasts is OK

• Soil moisture in operational forecasts produced after June 2013 inclusive is OK

• Soil moisture in operational forecasts produced from Nov 2011 to May 2013 inclusive suffers from this bias
Thanks!