Analysis and Assimilation of Land Surface Skin Temperature in NCEP Operational NWP Models

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Outline of Presentation

- LST and brightness temperature (Tb) in NWP models
- Comparison of GDAS, GFS, GLDAS and GOES-derived LST and Verification at SURFRAD site
  - Summer: July and August, 2007
  - Winter: January, 2008
  - Data: 0.3125 x 0.3125 deg; GOES (0.5 deg => 0.3125 deg)
- Brightness temperature (Tb) assimilation in GSI
  - Satellite Sensor: NOAA-18 AMSU_A; CH 15 (89 GHz)
- Analysis of Tb simulation with the CRTM driver
  - Multi-Case: July 1 to 6, 2007 (Sum); Jan 1 to 6, 2008 (Win)
  - Probability of Density Function (PDF) of Tb difference
  - Tb Bias and RMSE
LST in NCEP NWP models

**Upward longwave radiation:** \( \text{LW}^\uparrow = \varepsilon \sigma (T_{\text{skin}})^4 \)

**Sensible heat flux:** \( \text{SH} = \rho C_p C_h (T_{\text{skin}} - T_{\text{air}}) \)

\( C_h \) (m/sec) = \((C_h^*) \times lVl = \) aerodynamic conductance
\( C_h^* \) is non-dimensional surface exchange coefficient
\( lVl \) is the wind speed at same level as \( T_{\text{air}} \)
\( T_{\text{skin}} \) is land surface skin temperature (LST)

- Errors in \( C_h \) and \( T_{\text{skin}} \) can offset each other to still yield reasonable sensible heat flux
- But CRTM surface emission module cannot tolerate large error in LST.

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Satellite Brightness Temperatures (Tb)

- GSI analysis assimilates satellite obs Tb in various IR and MW channels
  - Analysis increment: derived from difference of observed and simulated Tb
  - Simulated Tb is product of CRTM radiative transfer applied to GFS forecast of atmospheric states and earth surface states (land, ice, sea)

Example expression for simulated Tb for a microwave channel:

\[
Tb = T_{surf} \varepsilon \, e^{-\tau(0,H)/\mu} + T_{atm} \left(1 - \varepsilon \right) e^{-\tau(0,H)/\mu} + T_{atm}^{\uparrow},
\]

\[
T_{atm}^{\downarrow} = \int_{0}^{H} T(z) \left[ \alpha(z)/\mu \right] e^{-\tau(z,0)/\mu} \, dz + T_{cosm} \, e^{-\tau(0,H)/\mu}
\]

\[
T_{atm}^{\uparrow} = \int_{0}^{H} T(z) \left[ \alpha(z)/\mu \right] e^{-\tau(z,H)/\mu} \, dz.
\]

\[
\tau(z_{0}, z_{1}) = \int_{z_{0}}^{z_{1}} \alpha(z) \, dz
\]

\[\alpha = \text{atmospheric absorption}\]

For surface sensitive channels (aka “window channels”):
- atmospheric absorption (\(\alpha\)) is weak, so Tsurf & sfc emissivity (\(\xi\)) are key factors
- Surface emissivity (\(\xi\)) is strong function of land surface states:
  - snow cover/density, vegetation cover/density, soil moisture amount,
  - soil moisture phase (frozen vs. liquid)
- If LST has a large error, Tb would have a large error too.

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GDAS/GFS/GLDAS have a large cold bias over western CONUS (Arid area).
Summer


Cold bias reaches -12°C over western CONUS; and somewhat warm bias over eastern CONUS.
Still cold bias over western CONUS in August, but not as large as that in July.
LST [K] Verification at SURFRAD Sites, July 2007

Large cold bias during daytime

SURFRAD Network
LST [K] Verification at SURFRAD Sites, July 2007

Summer
GDAS/GFS are a little warmer over Northern CONUS, and cooler over Southern CONUS and Mexico, compared to GOES.
GDAS/GFS are much cooler in Texas, New Mexico and Eastern Mexico (over -6C), warm bias over snow areas in N. GDAS and GFS are similar. Warm bias appears in central CONUS and cold bias appears in eastern CONUS.
LST [K] Verification at SURFRAD Sites, Jan. 2008

FPK
Warmer during night

GDAS: Cooler during daytime
GFS is close to GOES.

TBL

DRA
Cooler during daytime

Winter

SURFRAD Network
LST [K] Verification at SURFRAD Sites, Jan. 2008

Warmer during night

Cooler during daytime

SXF

BON

Warmer during night

Cooler during daytime

GWN

PSU

Winter
Comparison of Tb observed and simulated by GSI/CRTM

“Thin” method

18Z, 20070701

Obs. Tb

Summer

Guess Tb

Cloud contamination

cold bias
Comparison of Tb observed and simulated by GSI/CRTM

**Winter**

Obs. Tb

**18Z, 20080106**

Guess Tb

"Thin" method

\[ \Delta \text{Tb (w/b)} \]

\[ \Delta \text{Tb (w/b) (Used)} \]
PDF distribution: Water & Land; Vegetation Type

**Domain: CONUS**

- **Clear Sky Only (Land)**
  - Bias near zero
  - veg_7: Ground Cover Only; veg_8: Broad leaf Shrubs w/ Ground Cover

- **Improved for clear sky!**

**CRTM_Driver**

15Z-21Z, July 1-6, 2007

- Not use “thin”
- Summer
- Cultivations
- Needleleaf-Evergreen
- CONUS
- Domain: CONUS
- Not use "thin"
- veg_7: Ground Cover Only; veg_8: Broad leaf Shrubs w/ Ground Cover
Bias and RMSE for Various Vegetation Types 15Z-21Z, July 1-6, 2007

**Summer**

**Bias**

NOAA-18 AMSU-A, CHANNEL 15
Domain: (132.5W-67.5W) & (25N-60N)
15Z-21Z July 1-6, 2007

**RMSE**

NOAA-18 AMSU-A, CHANNEL 15
Domain: (132.5W-67.5W) & (25N-60N)
15Z-21Z July 1-6, 2007

**Clear Sky Only (Land)**

**Improved for clear sky!**

**Tundra**

**Western Arid Area**

**All**
Winter

PDF distribution: Water & Land; Vegetation Type

Not use "thin"  

Domain: CONUS

Warm bias over snow

Land: with snow-free
Snow: over land & sea ice

Improved for clear sky for snow!

Cold bias: -3 to -4C

Clear Sky Only (Land)
Bias and RMSE for Various Vegetation Types  

Winter 15Z-21Z, Jan 1-6, 2008

Bias

NOAA-18 AMSU-A, CHANNEL 15
Domain: (132.5W-67.5W) & (25N-60N)
15Z-21Z Jan 1-6, 2008

RMSE

NOAA-18 AMSU-A, CHANNEL 15
Domain: (132.5W-67.5W) & (25N-60N)
15Z-21Z Jan 1-6, 2008

Clear Sky Only (Land)

Cloud contamination; Improved (clear sky)
Summary

- LST is important to remote sensing and data assimilation, and a critical factor to determine Tb for satellite surface sensitive channels.

- GDAS, GFS or GLDAS has a large and cold bias of LST over arid western CONUS in warm season during daytime, compared to the GOES-derived or the surface observation from SURFRAD stations.

- Due to large cold bias, most of satellite data related surface sensitive channels are rejected in GSI data assimilation.

- Alternative formulations of thermal roughness length are being tested in EMC land team to reduce large error of GDAS/GFS LST.
Backup
Vegetation Type

Veg_1: Broadleaf-Evergreen (Tropical Forest)
Veg_2: Broad-Deciduous Trees
Veg_3: Broadleaf and Needleleaf Trees
Veg_4: Needleleaf-Evergreen Trees
Veg_5: Needleleaf-Deciduous Trees
Veg_6: Broadleaf Trees with Ground Cover
Veg_7: Ground Cover Only (Perennial)
Veg_8: Broad leaf Shrubs w/ Ground Cover
Veg_9: Broadleaf Shrubs with Bare Soil
Veg_10: Dwarf Trees & Shrubs w/Ground Cover
Veg_11: Bare Soil
Veg_12: Cultivations
Veg_13: Glacial