Using CERES Data to Improve Snowmelt Modeling

Laura M. Hinkelman
Jessica Lundquist
University of Washington

Rachel Pinker
University of Maryland
Need for snow models

• Snow accumulation and melt critical to water supply, energy production, and flooding in western US.

• Historical records no longer accurate predictors.

→ Models needed to
  • improve seasonal forecasting.
  • improve representation of the hydrological cycle in large-scale models.
  • determine response of snow processes to global warming.
  • accurately compute boundary layer feedbacks in climate models.
Energy balance modeling

Snow Energy Exchanges

\[ Q_{sn} = \text{net solar flux} \]
\[ Q_{le} = \text{net long-wave flux} \]
\[ Q_h = \text{sensible heat flux} \]
\[ Q_e = \text{latent heat flux} \]
\[ Q_g = \text{ground heat flux} \]
\[ Q_p = \text{advected heat from rain} \]
\[ \frac{dU}{dt} = \text{change in internal } Q \]
\[ Q_m = \text{melt heat flux} \]
Incoming solar flux estimation

1) Use latitude, longitude, solar geometry to calculate potential insolation.

2) Modify potential insolation for slope, aspect, shading by surrounding topography.

3) Determine transmittance factor to decrease potential insolation.

4) Further reduce solar irradiance for areas under forest cover.
Transmissivity from diurnal temperature range

Bristow and Campbell, 1984:

\[ R_s = R_a[A[1 - \exp(-B(\Delta T)^C)]] \]

Hargreaves and Samani, 1985:

\[ R_s = R_a(k_R)\sqrt{(T_{\text{max}} - T_{\text{min}})} \]

\( R_a \) is potential irradiance (from geometry), \( R_s \) the actual received irradiance. A, B, C, and \( k_R \) are empirical coefficients.
Transmissivity from precipitation records

Table 1. Decision matrix used to assign value for atmospheric transmittivity ($\tau$).

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Value of $\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No precipitation at $\Delta T &gt; 10^\circ$C (assumed clear sky conditions)</td>
<td>$\tau = 0.70$</td>
</tr>
<tr>
<td>No precipitation today, but precipitation fell the previous day</td>
<td>$\tau = 0.60$</td>
</tr>
<tr>
<td>Precipitation occurring on present day</td>
<td>$\tau = 0.40$</td>
</tr>
<tr>
<td>Precipitation today and also the previous day</td>
<td>$\tau = 0.30$</td>
</tr>
</tbody>
</table>

* $\Delta T$ is defined as $(T_{\text{air, max}} - T_{\text{air, min}})$.

Spokas and Forcella, 2006
Downwelling longwave flux estimation

1) Estimate the emissivity of the atmosphere (including clouds).
2) Estimate effective atmospheric temperature.
3) Apply Stefan-Boltzman equation.
4) Add longwave flux emitted by surrounding terrain (some models).
5) Further modify flux for areas under forest cover.
UEB parameterization of emissivity

Clear sky

\[ \varepsilon_{\text{acls}} = 1.08 \left[ 1 - \exp \left( - \left( \frac{e_a}{100} \right)^{T_a/2016} \right) \right] \]

Satturlund (1979) for clear sky emissivity, using 2 m air temperature and atmospheric water vapor.

Cloudy sky

Adjust clear sky emissivity for cloud fraction (CF)

\[ \varepsilon_a = CF + (1-CF)\varepsilon_{\text{acls}} \]

\[ CF = 1 - \frac{T_f}{a} \]

\[ T_f = \text{Bristow and Campbell (1984) transmission factor, which depends on diurnal } T \text{ range} \]

\[ a = \text{maximum value of } T_f \text{ (i.e., clear sky)} \]
Alternate method

Clear sky

\[ L_0, \text{clear} = \varepsilon_{\text{clear}} \sigma T^4 \]
\[ \varepsilon_{\text{clear}} = C \left( \frac{e}{T} \right)^{1/m} \]

2 m air temperature

Empirical, where e = surface vapor pressure (mb), C and m are constants

Cloudy sky

\[ L_0 = \varepsilon_{\text{clear}} F \sigma T^4 \]

Brutsaert 1975, assumes mid-latitude standard atmosphere

F = empirical, depends on RH and \( \tau_a \)

Sicart et al., 2006
Complicating factors

Snowmelt depends on NET radiation:
• Must estimate albedo of the snowpack for reflected shortwave.
• Must estimate surface temperature of the snowpack for outgoing longwave.
Both have considerable uncertainty and are seldom measured.
Project description

Assumption: Using measured surface fluxes instead of simple parameterizations should improve snowmelt modeling results.

- Inherently better accuracy
- Better capture spatial and temporal variability

Replace parameterized fluxes with CERES SYN and MODIS-based values.

Run both versions of models at selected locations and compare to observations.

Potential problem: Model tuning
Satellite data

CERES SYN: Captures temporal variability, poor resolution (1°).

MODIS fluxes: Good spatial resolution (5 km), but only two values daily (four for LW).

CERES temporal interpolation


MODIS spatial field

August 8, 2003

Courtesy of David Doelling

Field sites for model evaluation

Typical measurements

Snow water equivalent

2m temperature ($T_{\text{max}}, T_{\text{min}}$)

Precipitation
Field sites for model evaluation

Typical measurements
- Snow water equivalent
- 2m temperature ($T_{\text{max}}, T_{\text{min}}$)
- Precipitation

Additional variables
- Wind speed
- Relative humidity
- Radiative fluxes
Intensive observation sites

**CSL: Central Sierra Snow Lab**
- 2 m temperature
- Relative humidity
- Precipitation
- Wind speed
- Insolation
- Snow water equiv

**DAN: Dana Meadows**
- 2 m temperature
- Relative humidity
- Wind speed
- Incoming and net SW
- Snow water equiv

- (No precipitation)

- **10 min**
- **daily**
- **hourly**
- **daily**
Central Sierra Snow Lab
Dana Meadows
Downwelling SW flux comparisons

3-Hourly Insolation at CSL, YR2004

Simulated Incoming SW (W m$^{-2}$)

Using Temp. Range

Observed Incoming SW (W m$^{-2}$)

R$^2$=0.85378
RMSE=123.3065
n=1456
MAE=63.8841
bias=48.908

CERES SYN (3-hly)
Central Sierra Snow Lab, CA
January 2004

2004
Downwelling SW flux comparisons

Hourly Insolation at DAN, YR2004

(a) Observed by MODIS

(b) MODIS (sine fit)

Observed Satellite T-based

Dana Meadows, CA

November 2004
Early modeling results

2004 melt season
Point Snow Model (version of DHSVM)

Performance variable
MODIS fluxes appear greater than SYN values
Project plan

• Test sensitivity of models to radiative inputs and perform base runs with standard inputs.
• Obtain SW and LW fluxes from SYN and MODIS for 2003-2004 and 2004-2005 winters.
• Compare SYN and MODIS fluxes to obs.
• Analyze spatial variability in MODIS data.
• Run snow models with satellite fluxes at ground sites with extensive observations and evaluate.
• Run snow models for entire river basins, evaluate.
• Investigate methods of combining satellite data sets for optimum model performance.