Using CERES Data to Improve Snowmelt Modeling

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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.

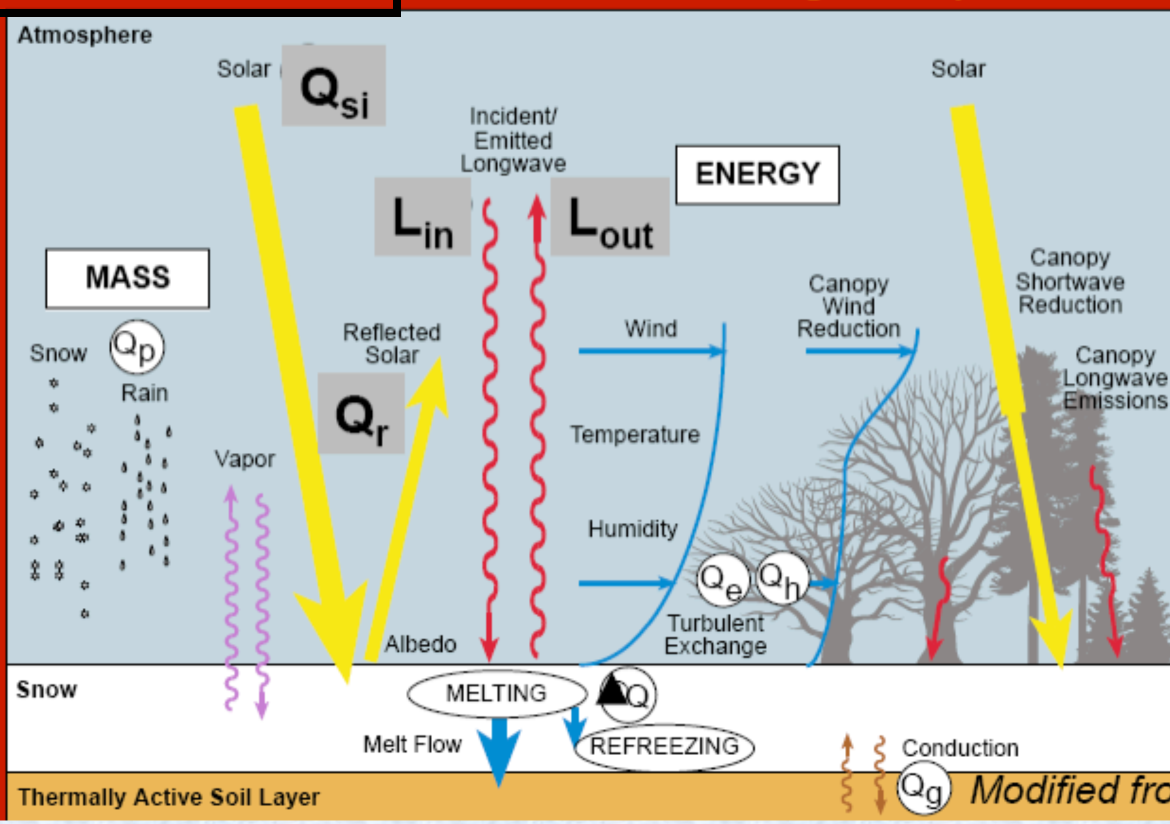
•accurately compute boundary layer feedbacks in climate models.

Energy balance modeling

Snow Energy Exchanges

Example: Utah Energy Balance Model

$$\boxed{\overbrace{(Q_{si}-Q_r)}^{Q_{sn}} + \overbrace{(L_{in} - L_{out})}^{Q_{le}}} + Q_h + Q_e + Q_g + Q_p - dU/dt = Q_m$$



Modified from D. Cline

- Q_{sn} = net solar flux
- Q_{le} = net long-wave flux
- Q_h = sensible heat flux
- Q_e = latent heat flux
- Q_g = ground heat flux
- Q_p = advected heat from rain
- dU/dt = change in internal Q
- Q_m = 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 Samami, 1985:

$$R_s = R_a(k_R)\sqrt{(T_{\max} - T_{\min})}$$

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 transmitivity (τ).

Conditions	Value of τ
No precipitation at $\Delta T > 10C$ (assumed clear sky conditions)	$\tau = 0.70$
No precipitation today, but precipitation fell the previous day	$\tau = 0.60$
Precipitation occurring on present day	$\tau = 0.40$
Precipitation today and also the previous day	$\tau = 0.30$

[a] ΔT is defined as ($Tair_{max} - Tair_{min}$).

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

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

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)

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

$$CF = 1\text{-}T_f/a$$

T_f = Bristow and Campbell (1984) transmission factor, which depends on diurnal T range

a = maximum value of T_f (i.e., clear sky)

Alternate method

Clear sky

$$L_{0,\ \text{clear}} = \varepsilon_{\text{clear}} \sigma T^4$$

$$\varepsilon_{\text{clear}} = C(e/T)^{1/m}$$

2 m air temperature

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

Brutsaert 1975, assumes mid-latitude standard atmosphere

Cloudy sky

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

F = empirical, depends on RH and τa

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.

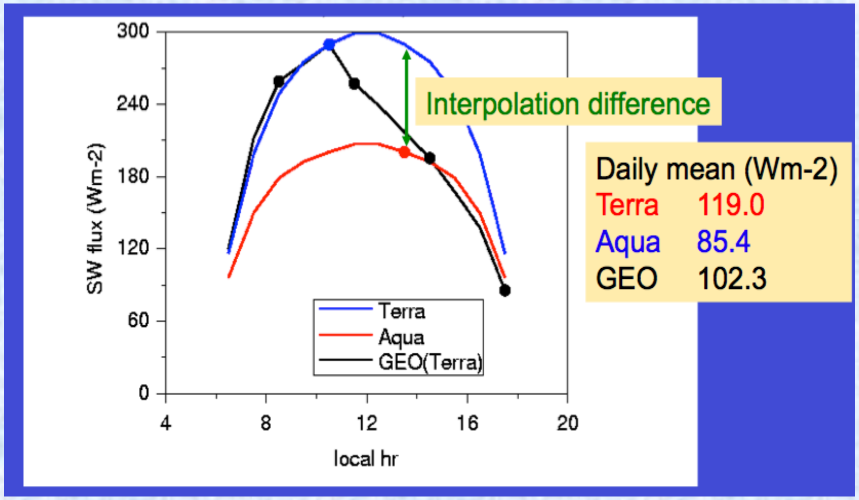
Potential problem: Model tuning

Satellite data

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

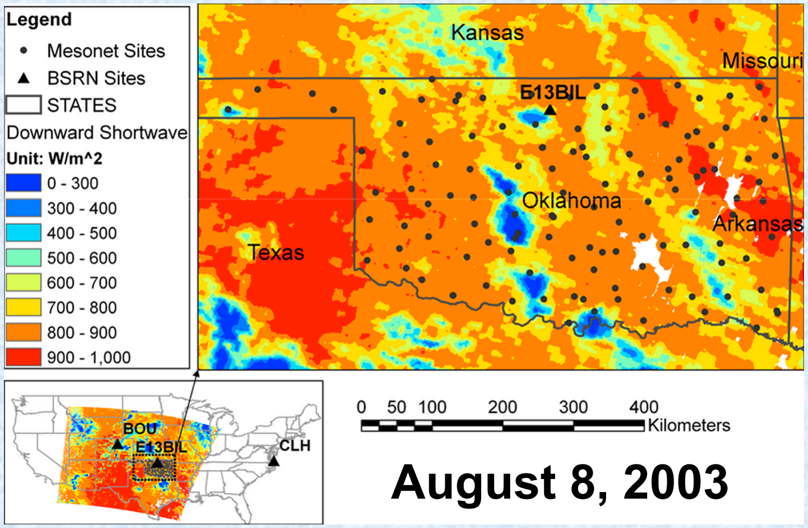
MODIS fluxes: Good spatial resolution (5 km), but only two values daily (four for LW).

CERES temporal interpolation



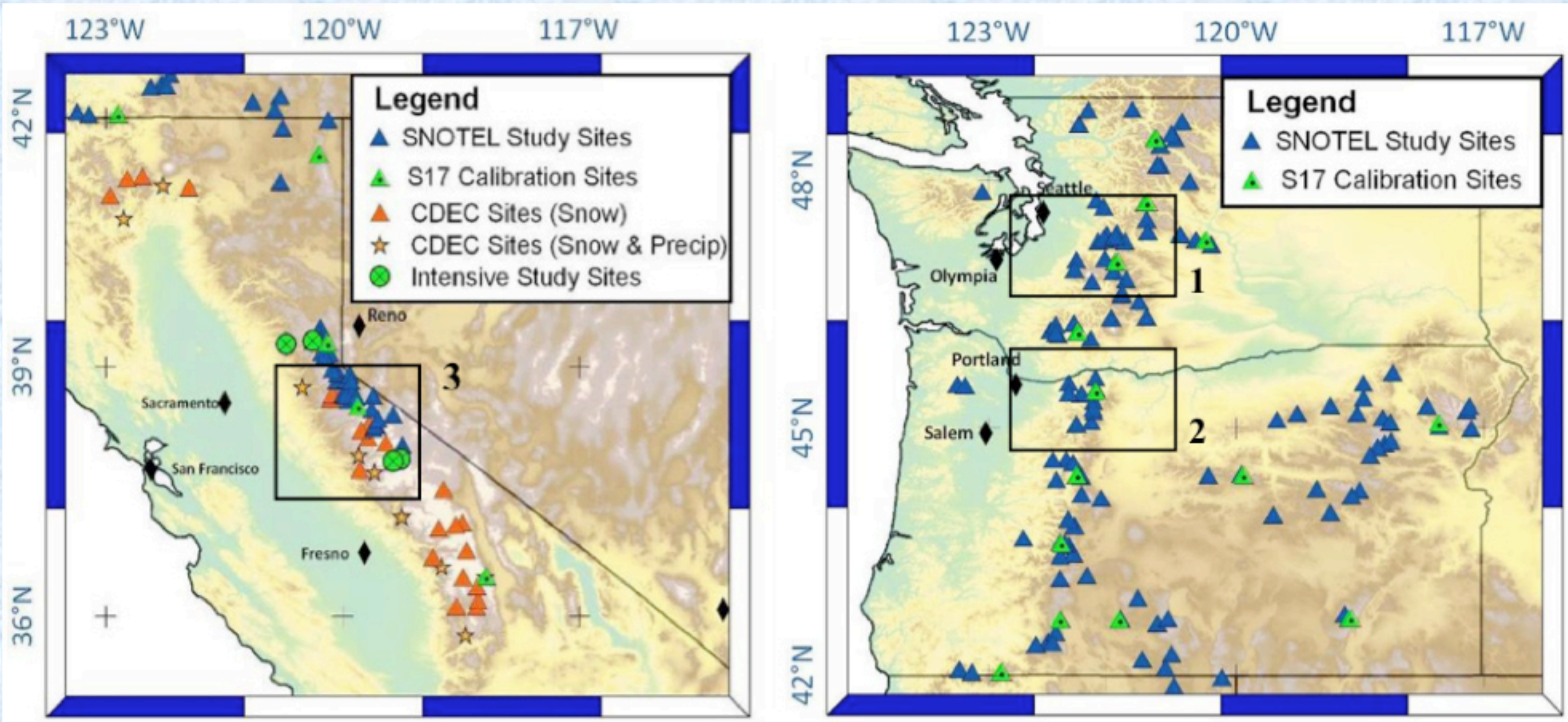
Courtesy of David Doelling

MODIS spatial field



Su, Wood, Wang, and Pinker, 2008

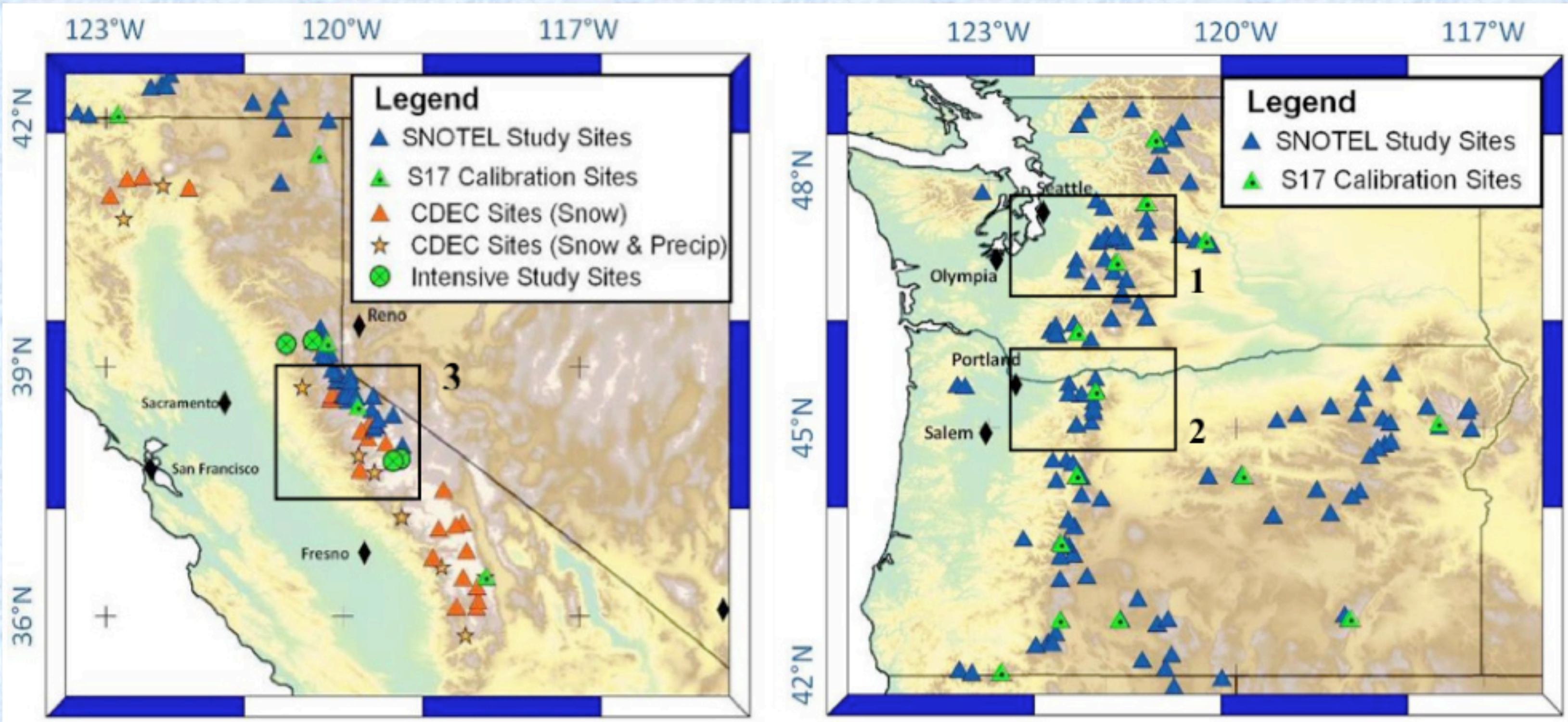
Field sites for model evaluation



Typical measurements

Snow water equivalent
2m temperature (T_{max}, T_{min})
Precipitation

Field sites for model evaluation



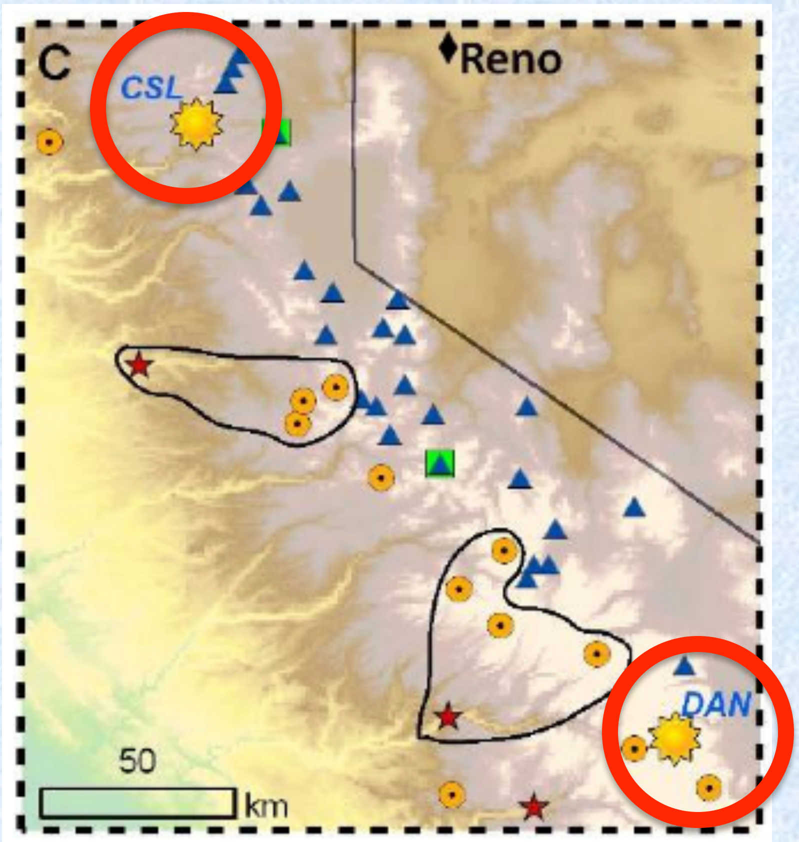
Typical measurements

Snow water equivalent
2m temperature (T_{max}, T_{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

10 min

Snow water equiv daily

DAN: Dana Meadows

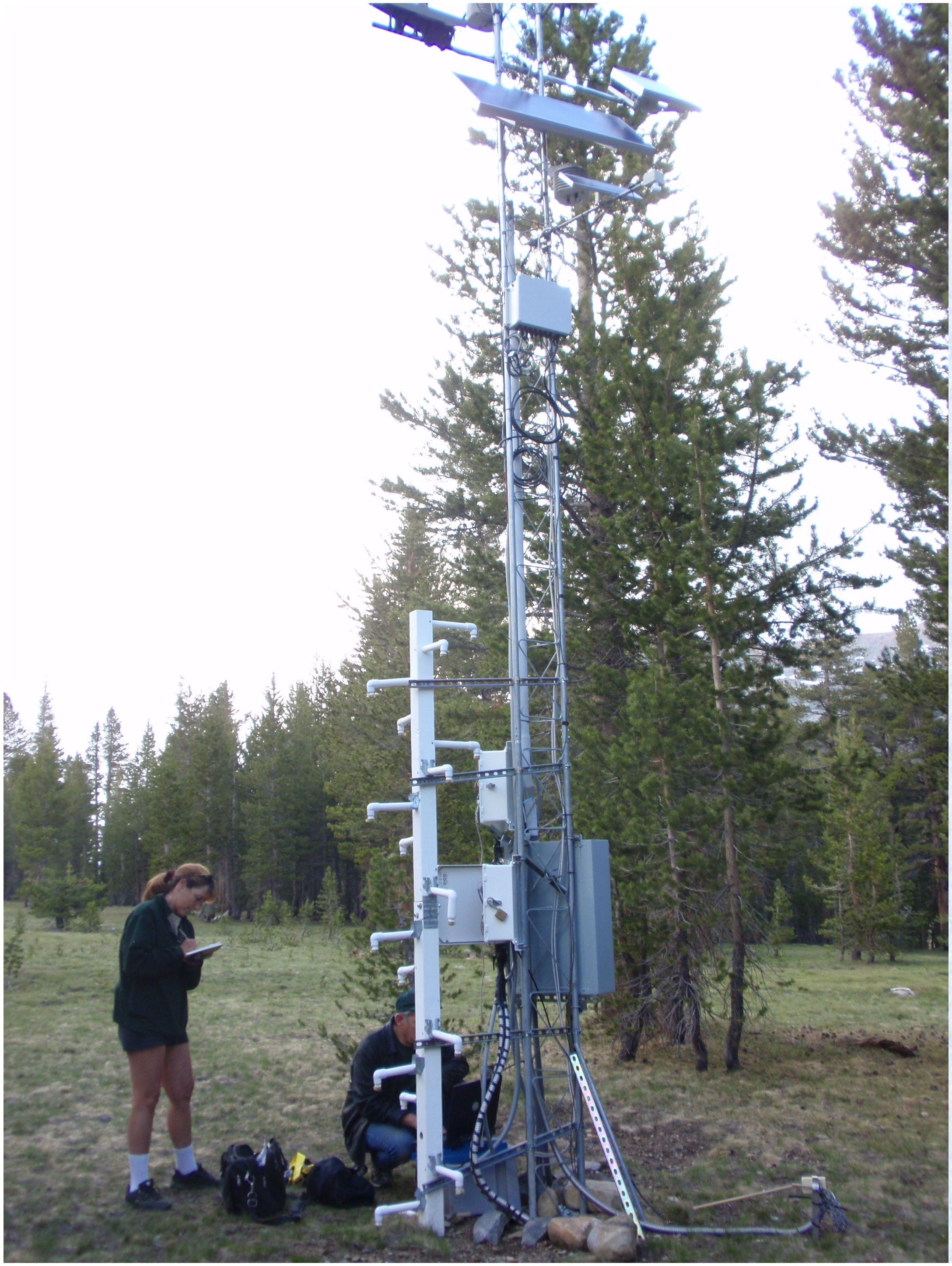
2 m temperature
Relative humidity
Wind speed
Incoming and net SW

hourly

Snow water equiv daily

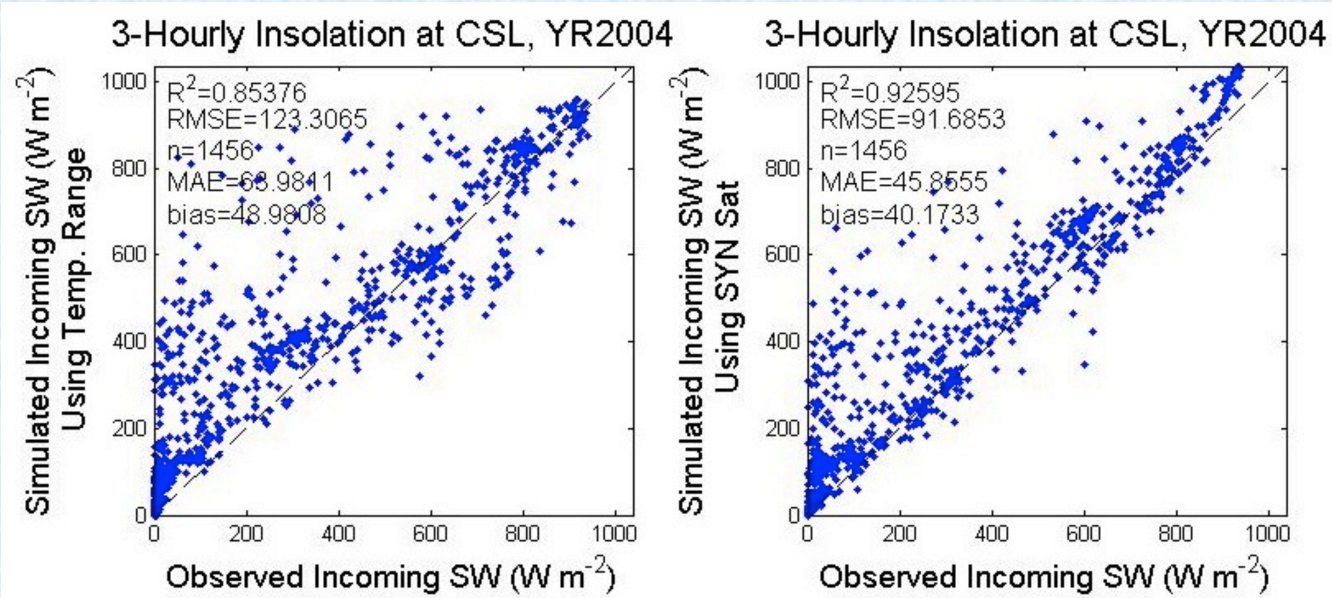
(No precipitation)

Central Sierra Snow Lab

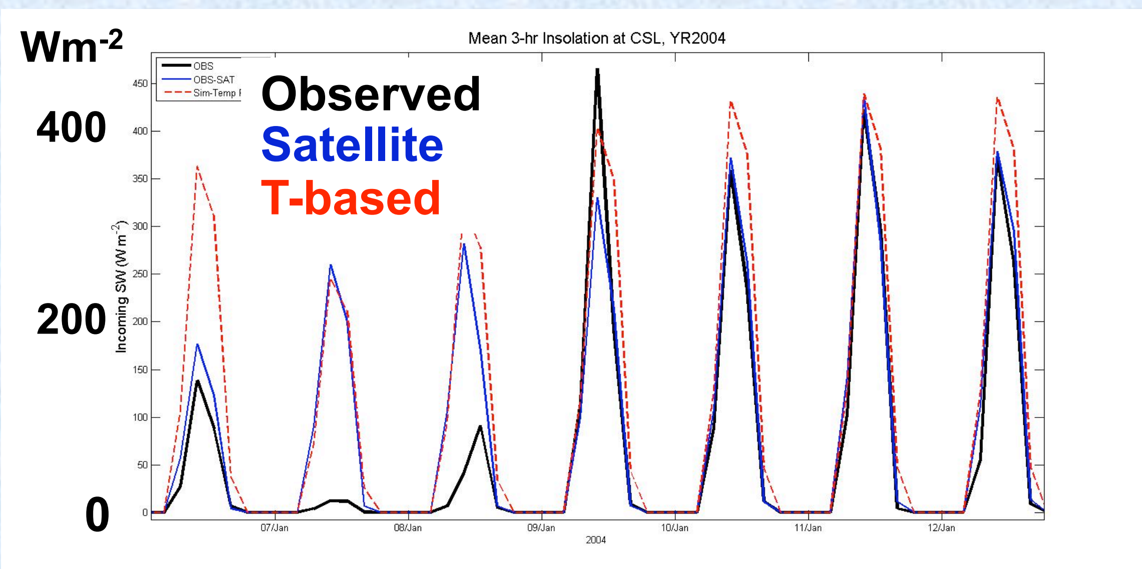


Dana Meadows

Downwelling SW flux comparisons



2004

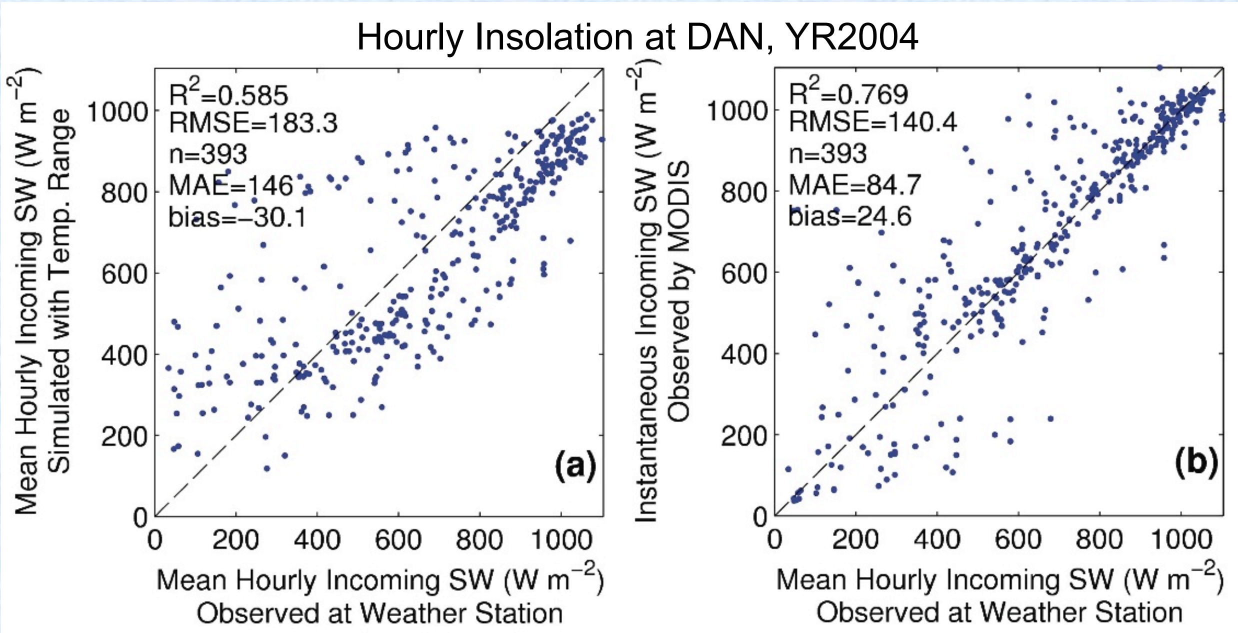


CERES SYN (3-hly)

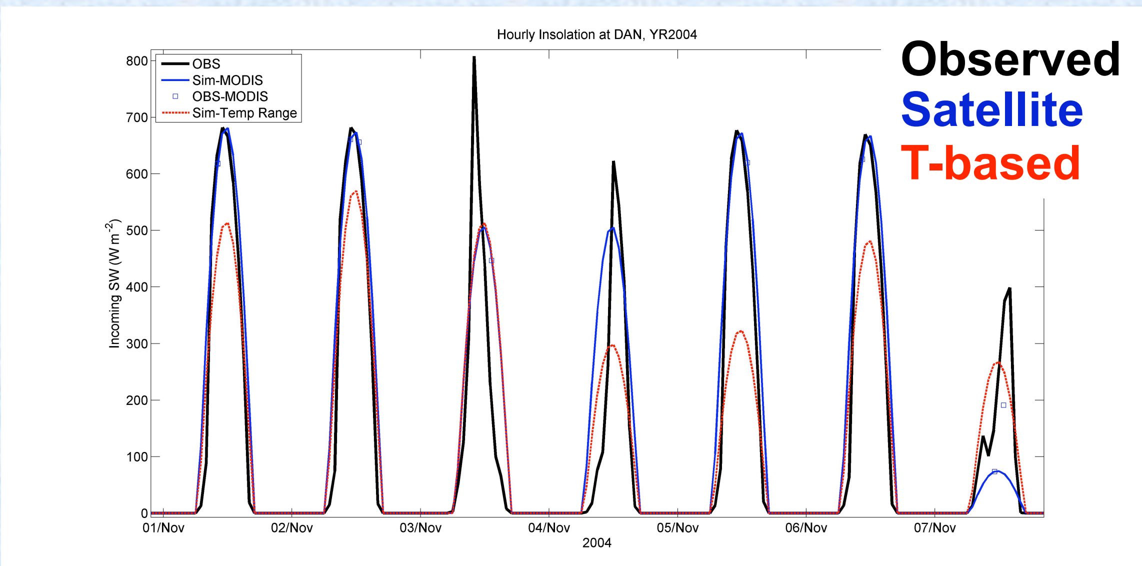
Central Sierra Snow Lab, CA

January 2004

Downwelling SW flux comparisons



2004

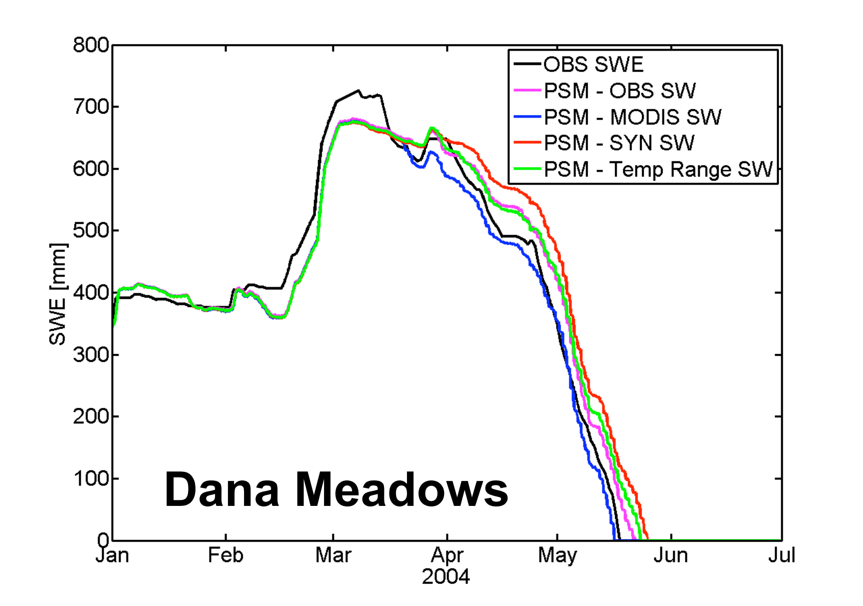


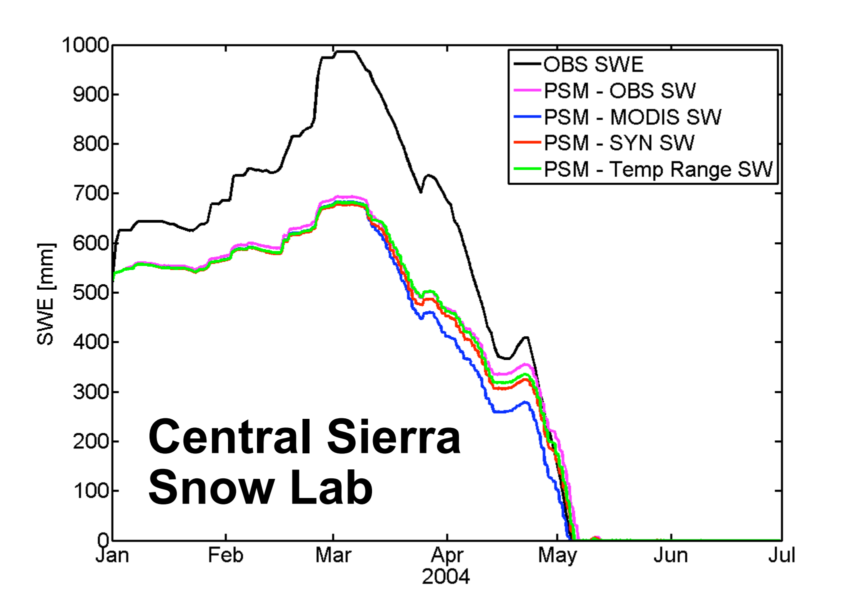
MODIS (sine fit)

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.

Central Sierra Snow Lab

Dana Meadows

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