FASST and SNTHERM in both Forested and Open Sites

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ABSTRACT

We carried out numerical experiments of snow accumulation, depletion and density as well as surface energy fluxes over 4 CLPX sites in Colorado using SNTHERM and FASST (Fast All-season Soil STrength). SNTHERM is a multilayer snow model developed to describe changes in snow properties as a function of depth and time using a one-dimensional mass and energy balance. The model is intended for seasonal snow covers and addresses conditions found throughout the winter, from initial ground freezing in the fall to snow ablation in the spring. It has been used by many researchers over a variety of terrains. FASST is a one-dimensional dynamic state of the ground model. It calculates the ground's moisture content, ice content, temperature, and freeze/thaw profiles, as well as soil strength and surface ice and snow accumulation and depletion. Both models predicted the observed melt-out dates between 0.2 – 2.8 days at all sites. Even though FASST is only a single-layer snow model, the RMSE snow depth compared very favorably against SNTHERM, often performing better during the accumulation phase. We found large difference in the modeled turbulent heat fluxes, especially during melting.

Keywords: SNTHERM, FASST, snow depth

MODELS

SNTHERM

SNTHERM is a multi-layered, one-dimensional energy and water balance point model designed to predict temperature profiles within strata of snow and frozen soil at non-forested sites (Jordan, 1991). SNTHERM uses time series meteorological data combined with initial snowpack depth, density and stratigraphy to predict snowpack energy and mass fluxes. Multiple studies have demonstrated that SNTHERM successfully simulates snowpack mass and energy exchanges at diverse locations and under varying conditions, both as a stand alone model and coupled with models that can account for the presence of vegetation (Davis et al., 1997; Hardy et al., 1997a; Hardy et al., 1997b; Hardy et al., 1998; Koivusalo and Heikinheimo, 1999; e.g. Colee, 2000).

FASST

FASST (Fast All-season Soil Strength), a year-round state-of-the-ground model, was initially developed to provide information to mobility and sensor performance algorithms for military purposes. It has since been used in non-military situations (Holcombe, 2004). FASST predicts the soil moisture, ice content, and temperature as a function of depth as well as snow and ice

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accretion/depletion as a function of meteorological forcing and site characteristics. Incorporated into the model are a three layer canopy and a one layer lower vegetation (crops, shrubs, grasses) algorithm. Ten low vegetation and five canopy types are currently accommodated based on the BATS (Biosphere-Atmosphere Transfer Scheme) developed by Dickenson et al. (1986). The model is applied over an Area composed of irregularly shaped polygons.

The fundamental operations of FASST are the calculation of an energy and water budget that quantify both the flow of heat and moisture within the soil and also the exchange of heat and moisture at all interfaces (ground-air; ground-snow; snow-air) using both meteorological and terrain data (Frankenstein and Koenig, 2004a and 2004b). FASST is designed to accommodate a range of users from those who have intricate knowledge of their site to those who only know the site location. It allows for 22 different terrain materials, including asphalt, concrete, bedrock, permanent snow and the USCS soil types. At a minimum, the only weather data required is the air temperature.

FIELD DATA

Field data to which the model output were compared were collected during the winter of 2002 – 2003 as part of the NASA Cold Land Processes Experiment (CLPX). Data collection included an observational and remote sensing dataset of snow and soil conditions. The observational data were confined to three 25-km x 25-km plots (Fraser Experimental Forest, Rabbit Ears Pass and North Park), also called Meso-cell Study Areas, or MSAs. Each MSA is broadly characterized by topography, vegetation and climate chosen to represent a significant portion of the major global snow cover environments (Cline et al., 2003).

Each MSA contains three Intensive Study Areas (ISAs). The ISAs are one kilometer square areas with a micrometeorological station located near the center. Snow depth and soil moisture and temperature profiles are also measured at each micrometeorological station. We used four of the nine CLPX ISA sites to explore SNTHERM's and FASST's predictive abilities. The sites chosen were Illinois River (NI) in the North Park MSA, Buffalo Pass (RB) and Walton Creek (RW) in the Rabbit Ears MSA and Fool Creek (FF) in the Fraser MSA.

Buffalo Pass has moderate relief, rolling hills and mixed vegetation of coniferous and deciduous forests. The snowpacks are moderate to deep. The vegetation type in this ISA is dominated by Englemann spruce (*Picea englemannii*) and alpine fir (*Abies lasiocarpa*). The soil type is a highly organic peat and the mean elevation is 3144 m. At the meteorological station, the terrain is broad, flat and treeless.

The terrain within the Walton Creek ISA is similar to that of the Buffalo Pass ISA. It is also characterized by moderate to deep snowfall. Soil type is a gravelly loam to a gravelly sandy loam (USDA Forest Service, 1994). The meteorological tower (elev. 2950 m) is located on an open gentle slope with southeasterly aspect.

Illinois River is characterized by windy, flat aspect, low relief prairie terrain with vegetation characteristic of a wet grassland including widespread riparian areas. The snow is generally shallow and windswept, which allows the development of frozen soils. This ISA has a mean elevation of 2480 m and a soil type of inorganic sandy, silty, gravelly clay.

Fool Creek lies within the Fraser MSA. The Fraser MSA is an area of high relief with dense predominantly coniferous sub-alpine forests, alpine tundra above tree line and largely un-forested irrigated grazing lands in the lowest elevations. Moderate to deep snowpacks are typical, increasing with elevation (Cline et al., 2003). The Fool Creek meteorological tower (elev. 3100 m) is located in a forest clearing on a moderate (20°) slope with southerly aspect. Soil type is a well-drained gravelly to very gravelly sandy loam (Retzer, 1962).

RESULTS AND DISCUSSION

For the deeper snowpacks, we began the FASST and SNTHERM simulations near the end of March, corresponding to near peak accumulations and when snow pits were dug at the three sites.

For the ephemeral snow at Illinois River, we began the models on 21 February 2003, during the first field initiative. We used the same meteorological forcing data for both models. The main differences in model initialization centered on the level of detail concerning the snowpack properties with SNTHERM requiring detailed knowledge of the snowpack while FASST only needs the total snow depth.

We judged the performance of FASST against SNTHERM and the observed total acoustic measured snow depth at four of the nine CLPX ISAs using the maximum absolute difference and the Root Mean Square Error

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(M_i - O_i\right)^2}$$

where M and O are the model and observed values respectively. Except for the Illinois River ISA we investigated the model behavior over the total period of record, accumulation phase and melt season.

Snow Depth

Plots of the snow depths are shown in Figures 1 – 4. At the two Rabbit Ears Pass MSA sites, FASST tends to under-predict the snow depth during the accumulation phase while SNTHERM tends to over-predict. With the onset of melting, SNTHERM performs very well. Looking at the RMSE for these two sites (Table 1), the FASST RMSE and maximum differences are slightly larger than the SNTHERM (0.143 m versus 0.138 m RMSE for the entire period) values at Buffalo Pass (RB) while for Walton Creek (RW), FASST performs better, especially during the accumulation period (0.043 m versus 0.246 m RMSE). During the melt phase at Walton Creek, the differences are much smaller (0.045 m versus 0.071 m RMSE).

At Illinois River (NI) where the snowpack is more ephemeral, SNTHERM consistently performed better than FASST (0.027 m versus 0.037 m RMSE, 0.15 m versus 0.18 m maximum difference), especially during the period at the beginning of the run from days 52 – 73 where there is notable accumulation (0.034 m versus 0.060 m RMSE, 0.07 m versus 0.14 m maximum difference). Looking at Figure 2a, during this first accumulation period FASST over-predicts the snow depth, then melts faster than what was observed while SNTHERM oscillates between over and under predicting and also melts faster than what was observed. If we look at periods where the models correctly predict snow versus no snow, FASST is successful 1388 of 1935 and SNTHERM 1438 of 1935 hourly time steps. Illinois River is the only location where FASST modeled snow loss due to wind ablation. The maximum amount modeled is only 9×10^{-4} m and occurs near the beginning of the simulation on day 54. At this point, it is unclear whether the procedure outlined in Jordan et al. (1999) to simulate wind ablation over sea ice correctly captures the situation at Illinois River.

The most difficult snowpack for SNTHERM to model was that at Fool Creek (FF). Using the measured hourly meteorological data, SNTHERM grossly under estimates the snow depth. If the measured upwelling shortwave radiation (S_{up}) is multiplied by a factor of 2.5, then SNTHERM captures the observations well as can be seen in Figure 4 and Table 1. The same is not true for FASST. FASST does well capturing the snowpack dynamics with the original meteorological data and slightly worse with the $2.5S_{up}$ version. The discrepancy relates to how S_{up} is used by the two models. In the current version of FASST, S_{up} is only used in the albedo (α_s) calculation. FASST determines the snow albedo several ways. First, if S_{up} is available an albedo is calculated as S_{up}/S_{down} where S_{down} is the downwelling short wave radiation. Second, a snow albedo (α_{sD}) is obtained using the method of Douville et al. (1995). Third, an albedo (α_{sR}) is calculated using the surface temperature dependent method of Roesch (2000). The final albedo is $\alpha_s = \min(S_{up}/S_{down}, \max(\alpha_{sD}, \alpha_{sR}))$. The net short wave radiation in FASST is $(1 - \alpha_s)S_{down}$ instead of $S_{down} - S_{up}$ as in SNTHERM.

Table 1. RMSE and maximum difference in snow depth for all four ISAs for SNTHERM and FASST.

ISA and time span DDDHHMM	FASST RMSE (m)	FASST max difference (m)	SNTHERM RMSE (m)	SNTHERM max difference (m)
NI 0521100 - 1322300	0.037	0.15	0.027	0.18
NI 0521100 - 0731200	0.060	0.14	0.034	0.07
RB 0881000 - 1812300	0.143	0.36	0.138	0.37
RB 0881000 - 1400000	0.182	0.36	0.177	0.37
RB 1400000 - 1812300	0.070	0.16	0.064	0.17
RW 0872225 - 1612325	0.044	0.12	0.211	0.40
RW 0872225 - 1401825	0.043	0.12	0.246	0.40
RW 1401825 - 1612325	0.045	0.108	0.071	0.17
FF 0822125 - 1731025	0.077	0.20	0.971	1.71
FF 0822125 - 1301225	0.082	0.20	1.170	1.71
FF 1301225 - 1731025	0.072	0.16	0.687	1.47
FF2.5 0822125 - 1731025	0.115	0.21	0.077	0.20
FF2.5 0822125 - 1301225	0.131	0.17	0.101	0.20
FF2.5 1301225 - 1731025	0.094	0.21	0.038	0.13

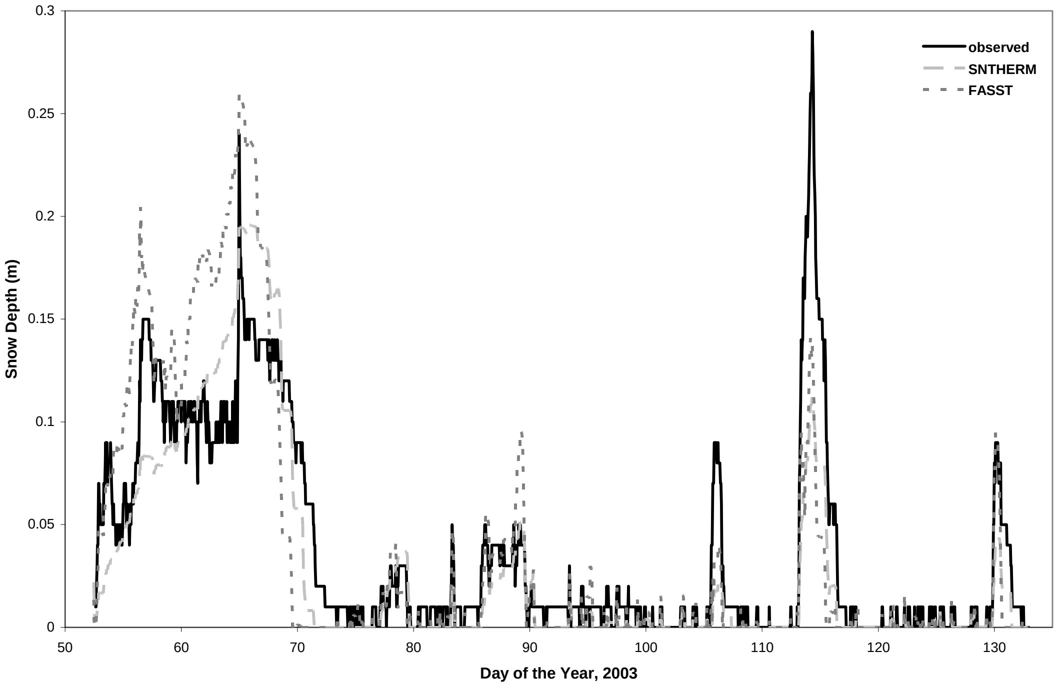

Figure 1. Snow depth comparisons between observed, FASST and SNTHERM for Illinois River ISA.

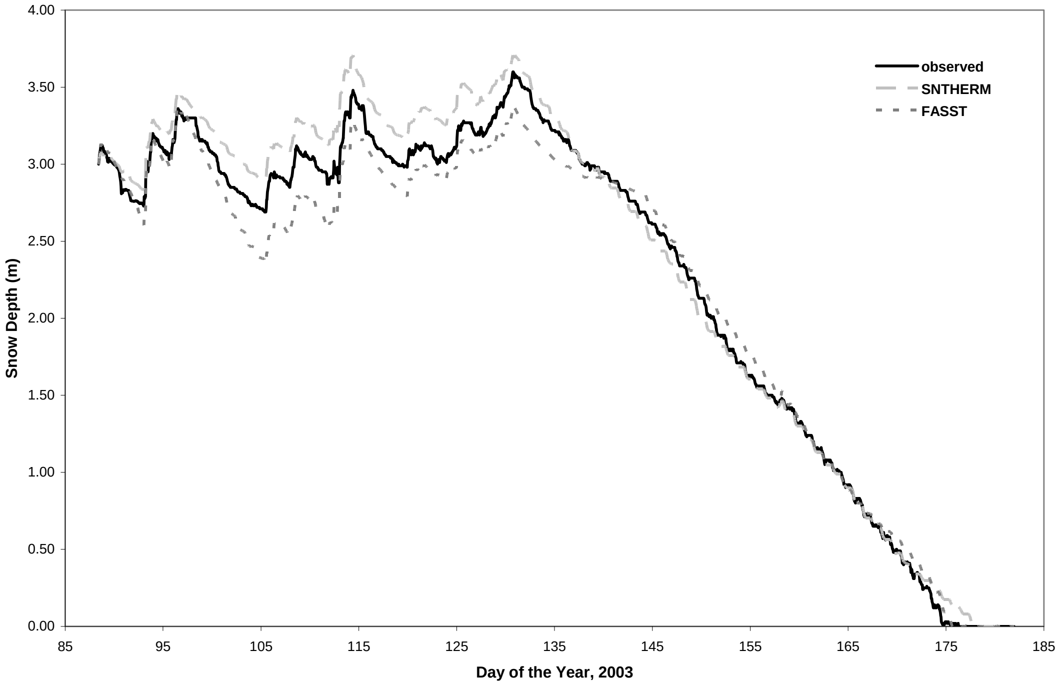

Figure 2. Snow depth comparisons between observed, FASST and SNTHERM for Buffalo Pass ISA.

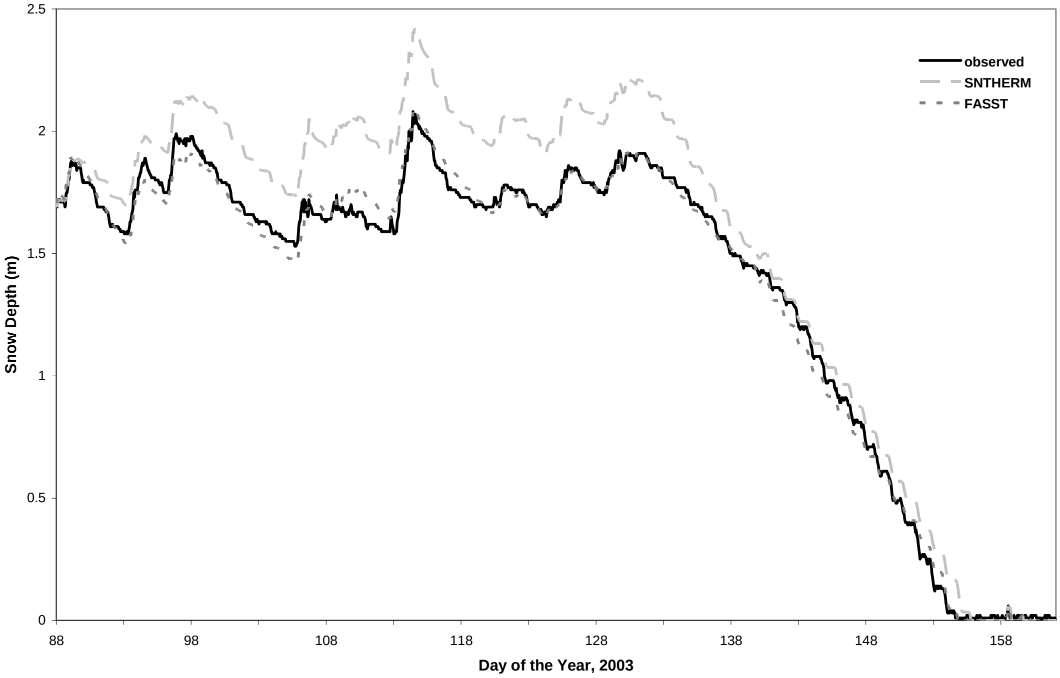

Figure 3. Snow depth comparisons between observed, FASST and SNTHERM for Walton Creek ISA.

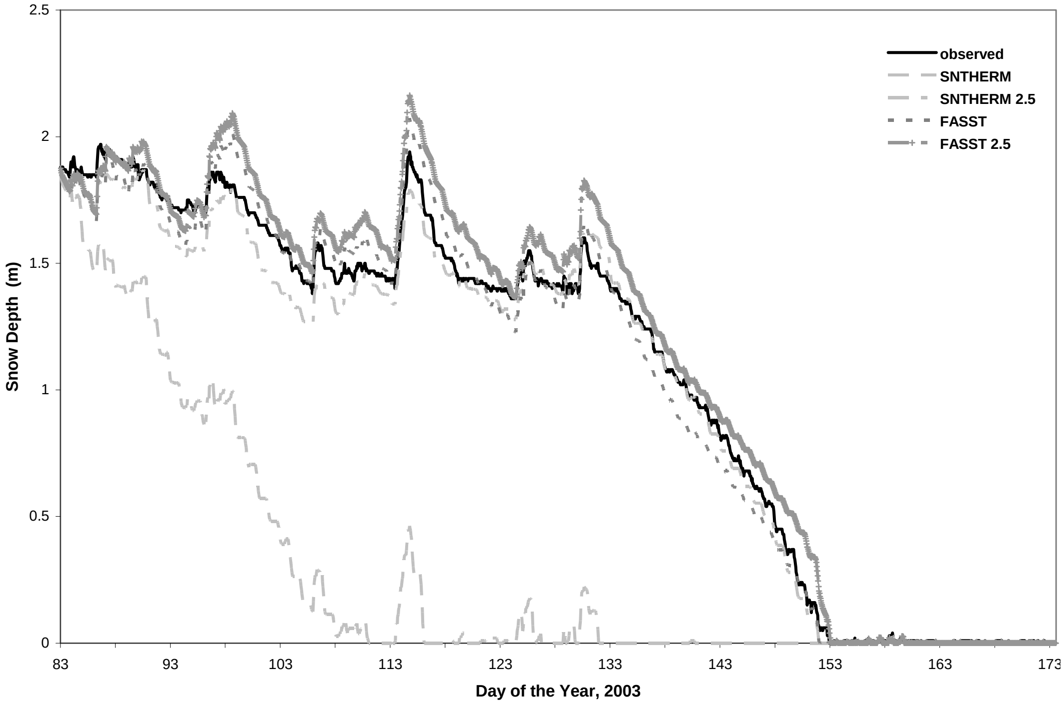

Figure 4. Snow depth comparisons between observed, FASST and SNTHERM for Fool Creek ISA.

RESULTS

It is evident from the previous discussions, that both models do a very good job at predicting the melt-out date and snow depth as demonstrated in the results shown in Table1 1. SNTHERM did better at predicting snow depth at Illinois River while FASST did better at Walton Creek. At the other two sites the models were within statistical agreement. At the Fool Creek and Illinois River FASST tended to under-predict the snow depth during the accumulation phase while SNTHERM over-predicted. The opposite is true at the Rabbit Ears MSA sites. In all cases, FASST lead the observed melt-out day while SNTHERM lagged at Buffalo Pass and Walton Creek and lead at Illinois River and Fool Creek. The maximum difference between the field and model predictions occurred at Illinois River with FASST (-2.8 days) while the minimum was at Walton Creek (FASST, -0.2 days).

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