Non-gradient Models of Snowpack Energy Budget and Temperature Distribution

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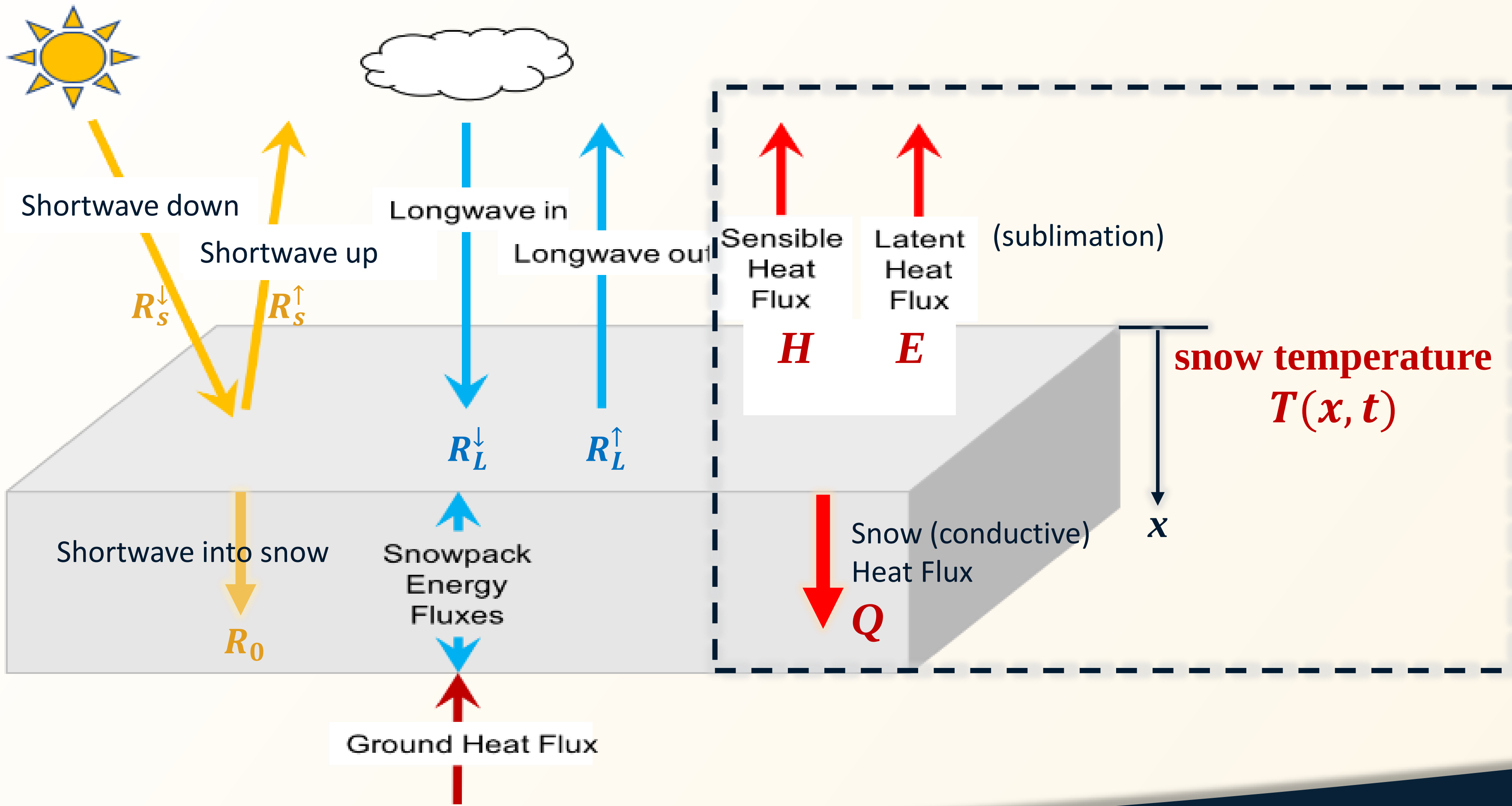

Shortwave down
Shortwave up
$R_s^{\downarrow}$
$R_s^{\uparrow}$
Longwave in
Longwave out
$R_L^{\downarrow}$
$R_L^{\uparrow}$
Sensible Heat Flux
H
Latent Heat Flux
E
(sublimation)
snow temperature
$T(x,t)$
x
Shortwave into snow
R_0
Snowpack Energy Fluxes
Snow (conductive) Heat Flux
Q
Ground Heat Flux

Dynamic Model of Snow Surface Temperature

(https://doi.org/10.1029/2022GL101222)

$T_s(t) = T(0,t)$

snow surface heat flux

diurnal frequency

initial surface temperature

$$\frac{dT_s}{dt} = \frac{\sqrt{2\omega_0}}{I_s}\left(Q\left(T_s, R_0, R_n^L\right) + c_1 R_0 + c_2 \frac{dR_0}{\omega_0 dt} \right) - \omega_0 \left(T_s - T_0\right)$$

$$c_1 = \frac{1+(u-1)\sqrt{u/2}}{1+u^2}, \quad c_2 = \frac{u-(u+1)\sqrt{u/2}}{1+u^2}, \qquad u \equiv \frac{\omega_0 d^2}{\alpha}$$

e-fold penetration depth of solar radiation in snow

thermal inertia of snow

thermal diffusivity of snow

MEP Model of Snow Surface Heat Fluxes

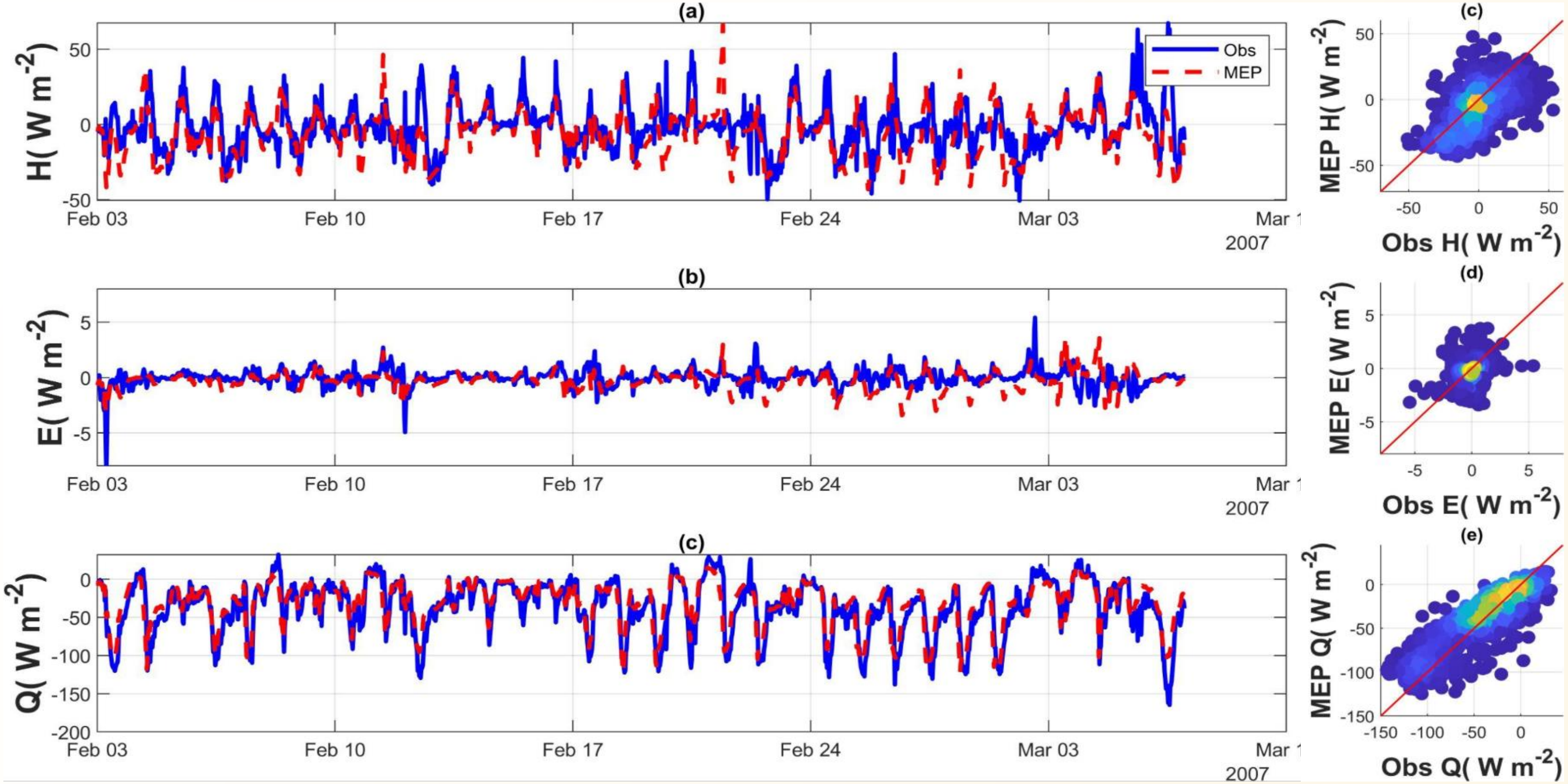
(https://doi.org/10.1002/2013JD021150)

$$E = B(\sigma) H$$

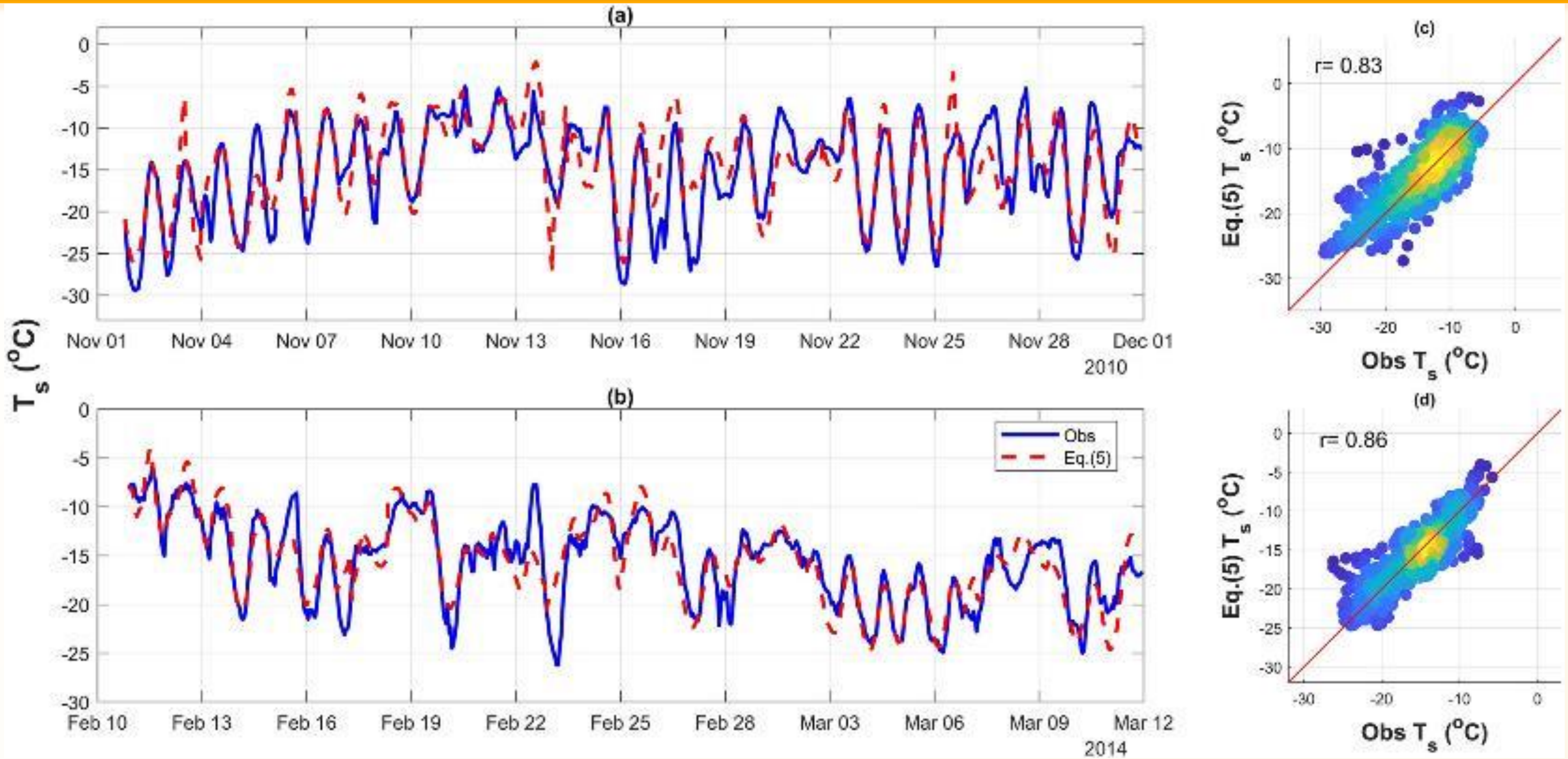
$$Q = \frac{B(\sigma)}{\sigma} \frac{I_s}{I_0} H |H|^{-\frac{1}{6}} - \boxed{R_0}$$

$$E + H + Q = \boxed{R_n^L}$$

$$\sigma \boxed{(T_s)} = \frac{\lambda^2}{c_p R_v} \frac{q^{sat}(T_s)}{T_s^2}, \quad B(\sigma) = 6\left(\sqrt{1 + \frac{11}{36}\sigma} - 1\right)$$



Seasonal snowpack at Quebec site
(https://doi.org/10.1029/2022GL101222)



AWS11 site in Antarctica. Simulations restart every 4 days at the sunset time.

Analytical Model of Snow Temperature Profile

(Publication in preparation)

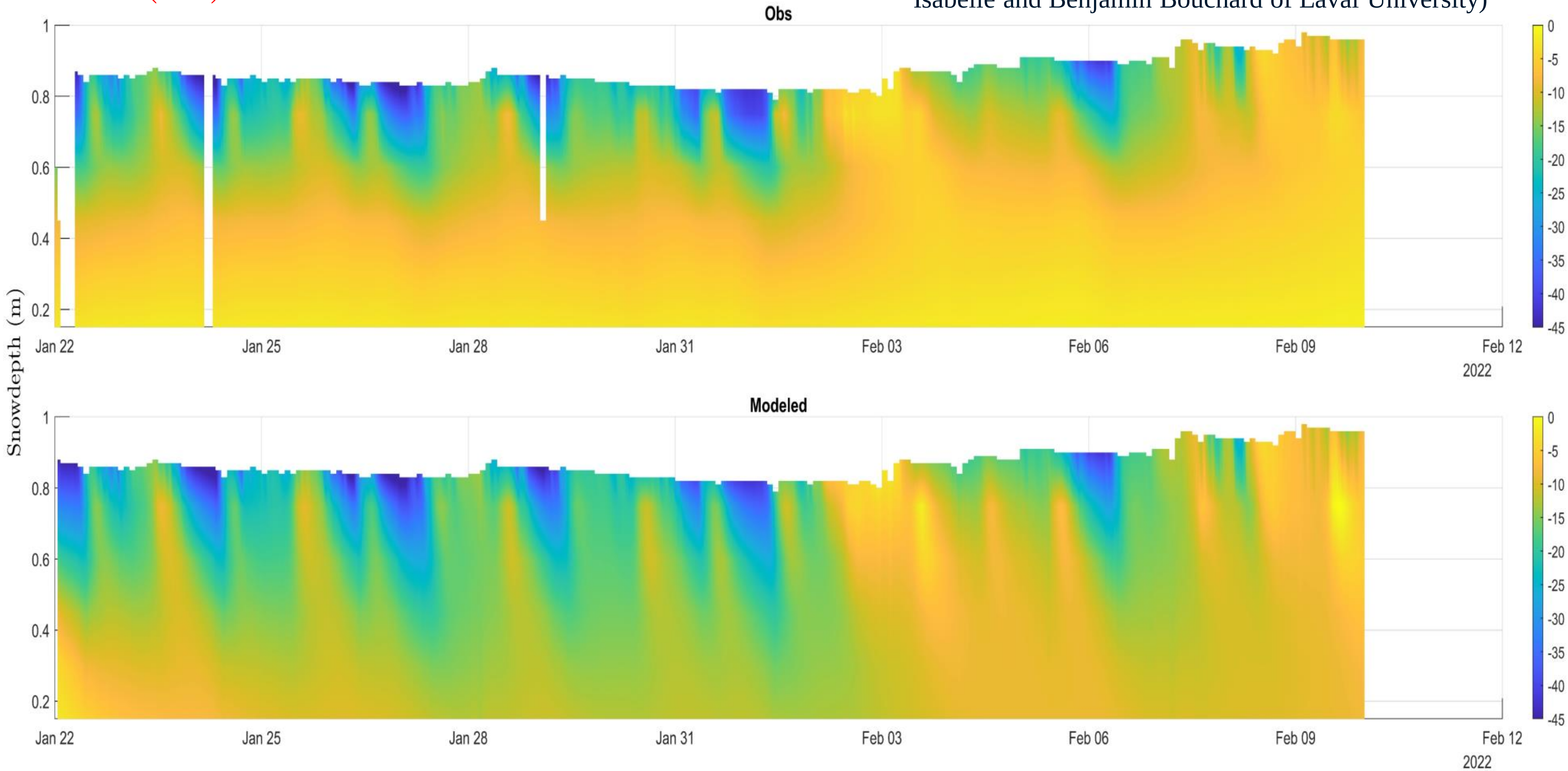
$$T(x,t) = T_0 + \int_0^t \left[T_s(\tau) - T_0\right] d\left\{\operatorname{erf}\left[\frac{x}{2\sqrt{\alpha(t-\tau)}}\right]\right\} +$$

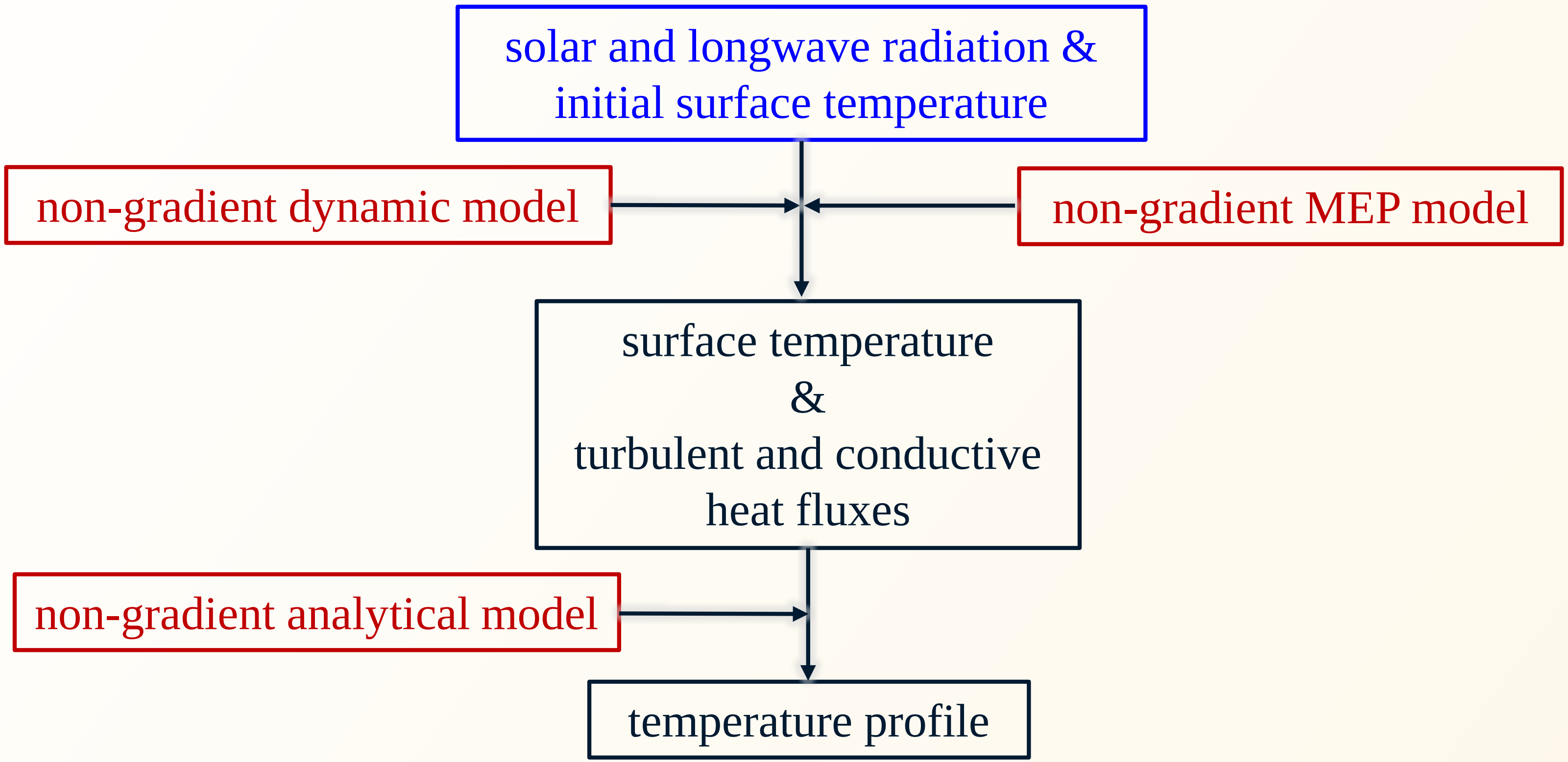
$$\frac{1}{2\rho c\omega_0 d}\int_0^t \exp\left(\frac{\alpha(t-\tau)}{d^2}\right)\left[\begin{array}{l}\exp\left(-\frac{x}{d}\right)\operatorname{erfc}\left(\sqrt{\frac{\alpha(t-\tau)}{d^2}} - \frac{x}{2\sqrt{\alpha(t-\tau)}}\right) - \\ \exp\left(\frac{x}{d}\right)\operatorname{erfc}\left(\sqrt{\frac{\alpha(t-\tau)}{d^2}} + \frac{x}{2\sqrt{\alpha(t-\tau)}}\right)\end{array}\right] R_0(\tau)\, d\tau$$

heat capacity of snow

$T(x,t)$

Neige site, Canada (Courtesy of Daniel Nadeau, Pierre-Erik Isabelle and Benjamin Bouchard of Laval University)




solar and longwave radiation &
initial surface temperature
non-gradient dynamic model
non-gradient MEP model
surface temperature
&
turbulent and conductive
heat fluxes
non-gradient analytical model
temperature profile

Model validation using S^3 field observations

https://www.arm.gov/news/blog/post/

Photos are courtesy of SAIL technician Travis Guy.

References:

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- Wang, J., R. L. Bras, V. Nieves, and Y. Deng (2014), A model of energy budgets over water, snow and ice surfaces, *Journal of Geophysical Research - Atmosphere*, 119, 6034–6051. https://doi.org/10.1002/2013JD021150
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