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Snow models based on heat balance

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Today's contents

- Introduction
  - My research theme (background)
  - <u>Our snow models</u>
- Problems applying to glacier

My research theme

- Energy and Water Exchange between the Atmosphere and Ground Surfaces
- Target
  - Snow cover
  - Vegetation
- Method
  - Modeling
  - Observation
- Area
  - Siberia, Mongolia, Japan

Introduction of our snow models (Point scale)

Kondo and Yamazaki (1990) TSM1

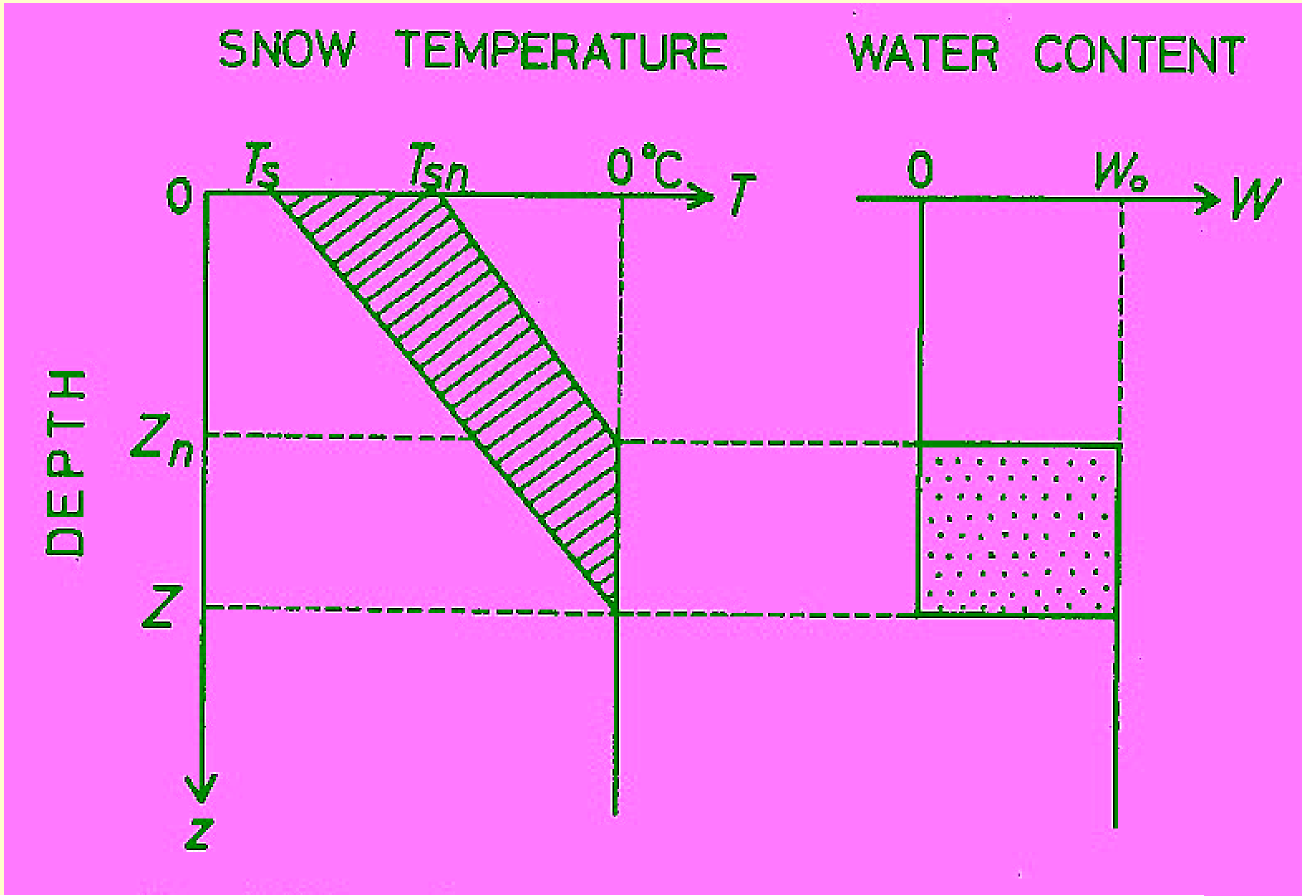
- Yamazaki (2001) TSMM

Kondo and Yamazaki (1990) TSM1

- To estimate Snowmelt and fluxes
- Solving heat balances of whole snow cover and surface (two equations)
- Inputs:

  Solar radiation, downward longwave radiation, wind speed, air temperature, humidity and precipitation

Schematic snow temperature and water content profiles



Two simultaneous eqs. of heat balance for

1) entire snow cover

2) snow surface with an infinitesimal thickness

Outputs

Snowmelt amount, surface temperature, freezing depth

Test basin

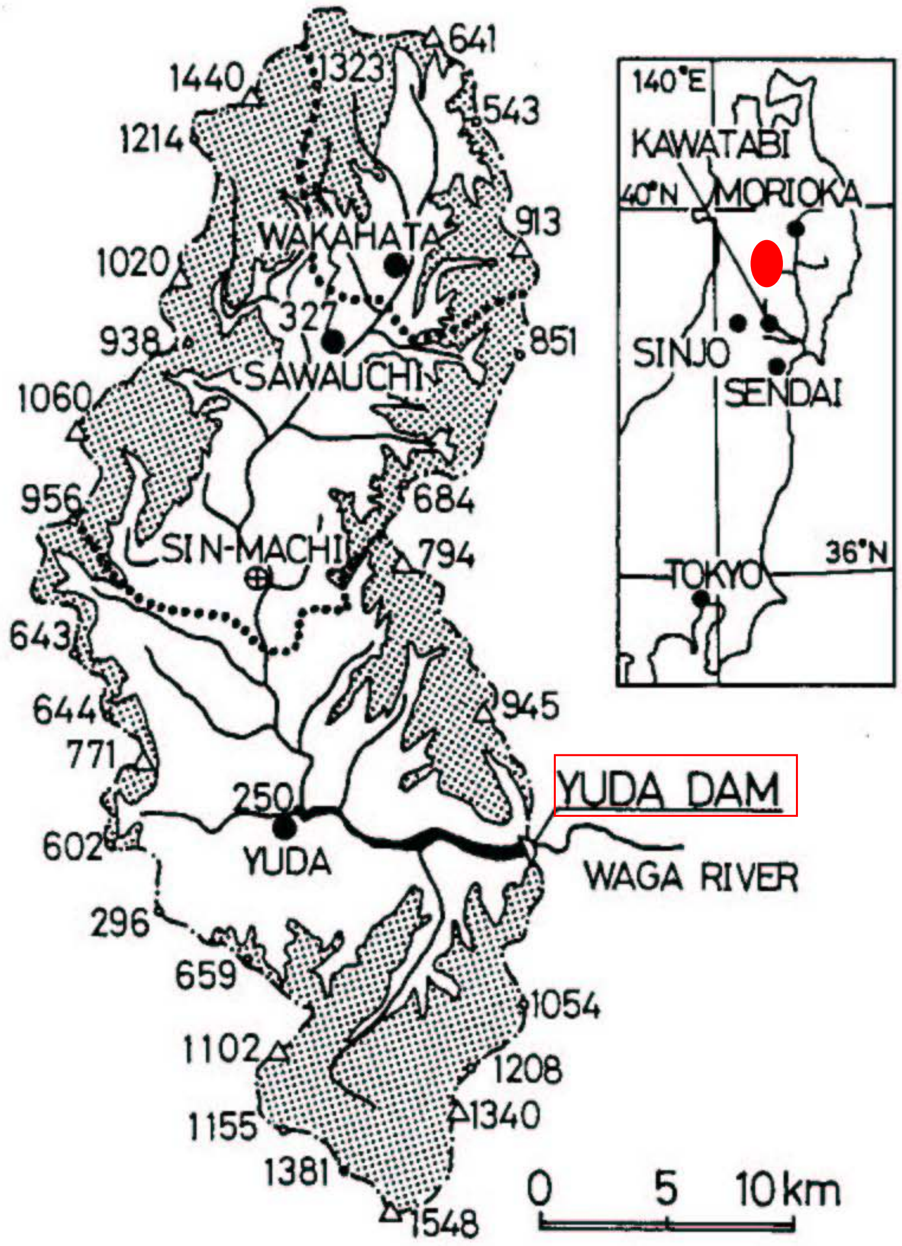


FIG. 9. Location of the test basin, Tohoku district, Japan. Stippled area denotes greater than 500 m above sea level, the dash-dotted line defines the watershed, the dotted lines separate the boundaries of regions.

Estimated and actual inflow to Yuda dam

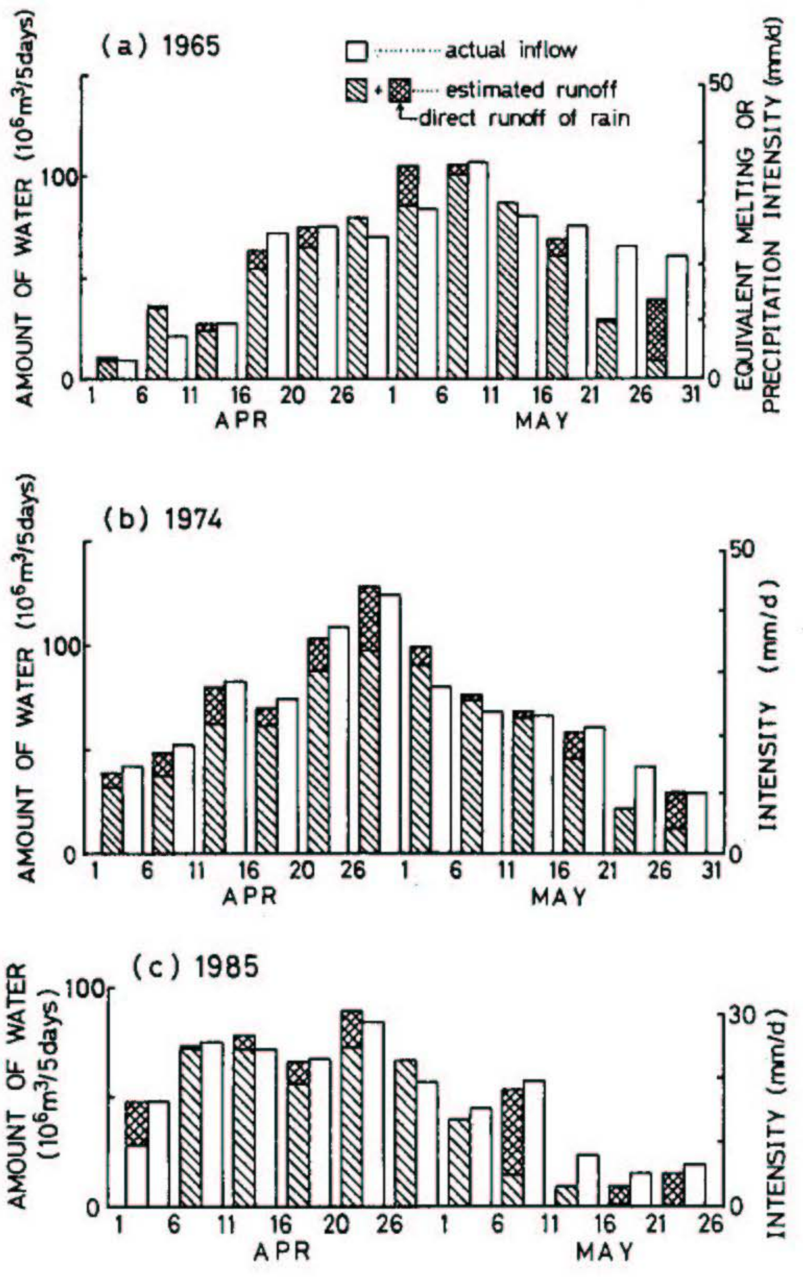
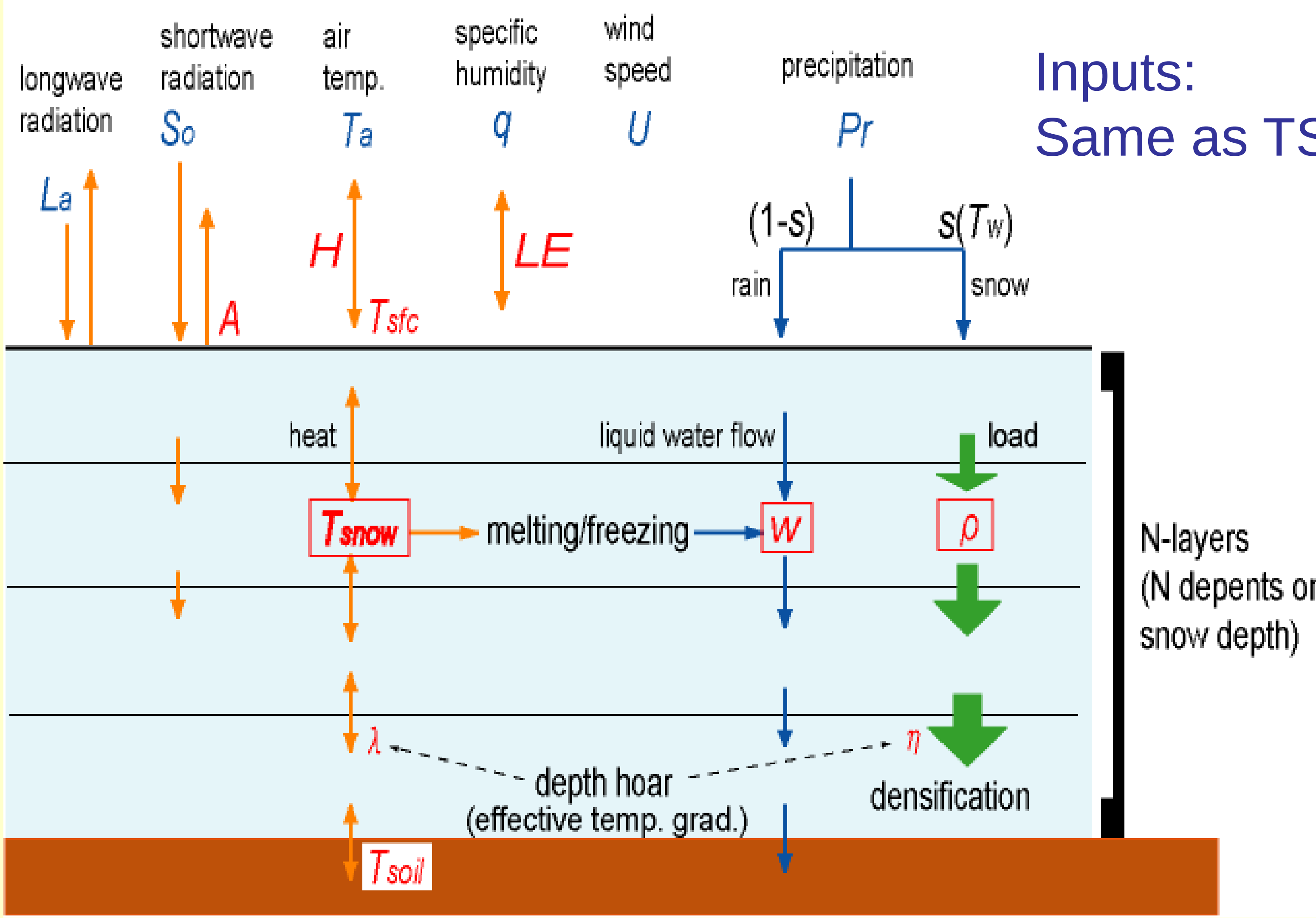


FIG. 10. Estimated and actual inflow to the dam. Increasing rates of water equivalent with elevation are (a) for 1965, $\gamma = 3.4 \times 10^{-4}$ m m^{-1}, (b) for 1974, $\gamma = 6.9 \times 10^{-4}$ m m^{-1}, (c) for 1985, $\gamma = 6.2 \times 10^{-4}$ m m^{-1}.

Multi-layer Snow model Yamazaki (2001) TSMM

Inputs:
Same as TSM1



Profiles of temperature, density & water content, ‘Depth hoar’

Basic equation

$$c\rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z} \right) - \frac{\partial I_n}{\partial z} - l_f F$$

T : snow temperature

c, ρ, λ : heat capacity, density and thermal conductivity

F : amount of snowmelt per unit time and volume

$$I_n = (1-r)(1-A)S^{\downarrow} \exp(-\mu z)$$

$S^{\downarrow}$: solar radiation

Surface boundary condition

Heat balance equation with an infinitesimal thickness

$$r(1-A)S^{\downarrow} + \varepsilon(L^{\downarrow} - \sigma T_S^4) - H - lE + G_0 = M$$

A : albedo

$r = \dfrac{A_{\max} - A}{A_{\max} - A_{\min}}$: absorptivity of solar radiation at the snow surface

$L^{\downarrow}$: downward longwave radiation

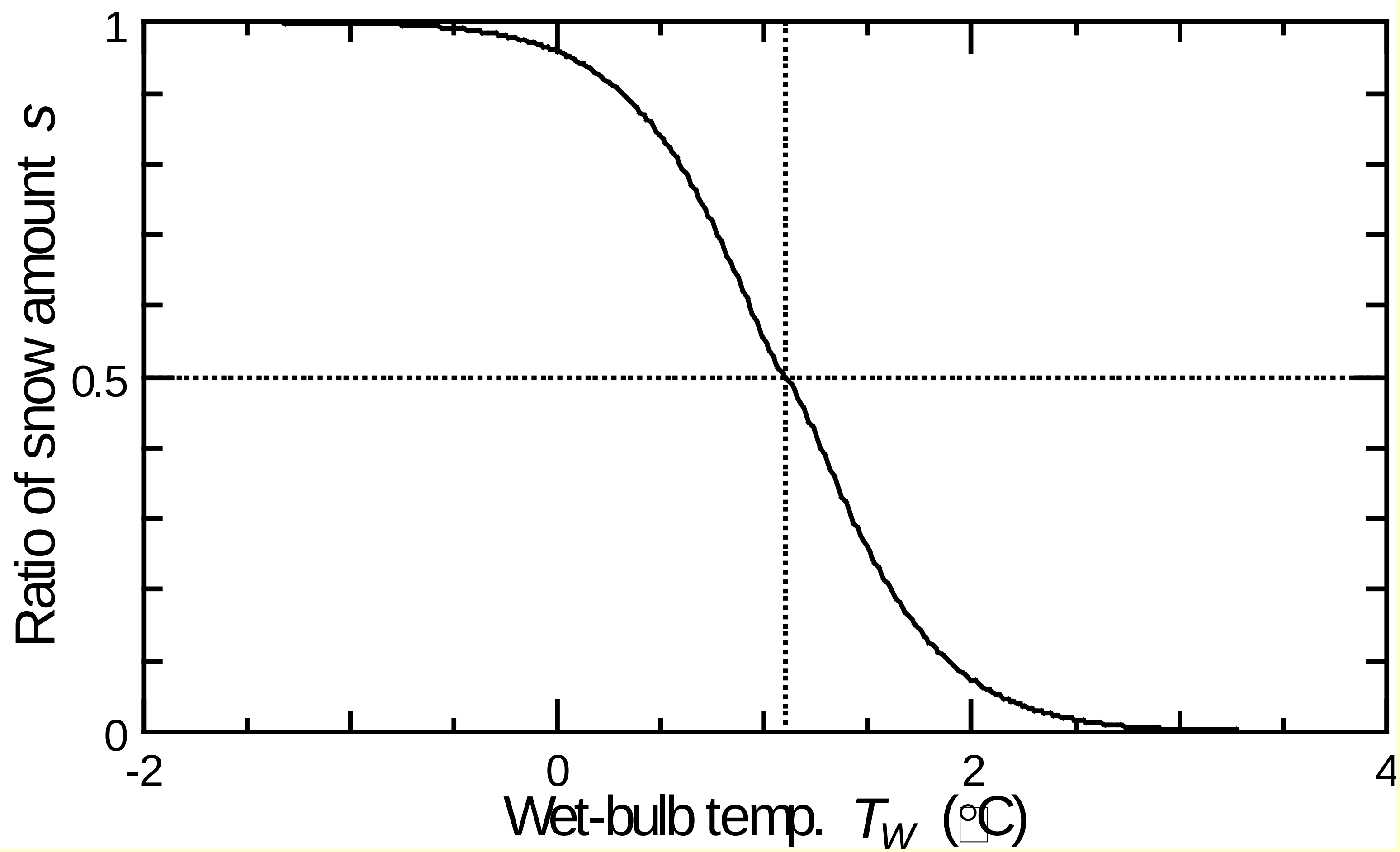
T_S : snow surface temperature

H, lE : sensible and latent heat flux

G_0 : conductive heat flux just beneath the snow surface

M : heat of snowmelt at the snow surface

The ratio of snowfall and rainfall



$$s(T_W) = 1 - 0.5\exp(-2.2(1.1 - T_W)^{1.3}) \quad (T_W < 1.1℃)$$

$$s(T_W) = 0.5\exp(-2.2(T_W - 1.1)^{1.3}) \quad (T_W \geq 1.1℃)$$

Snow type

Water content > 0.01 —Yes→ Wet grains

↓ No

$G_t > 4 \times 10^7 \,^\circ\mathrm{C\,m^{-1}s}$ —Yes→ Depth hoar

↓ No

$G_t > 1 \times 10^7 \,^\circ\mathrm{C\,m^{-1}s}$ —Yes→ Faceted crystals

↓ No

$\rho < 150\ \mathrm{kg\,m^{-3}}$ —Yes→ Precipitation particles

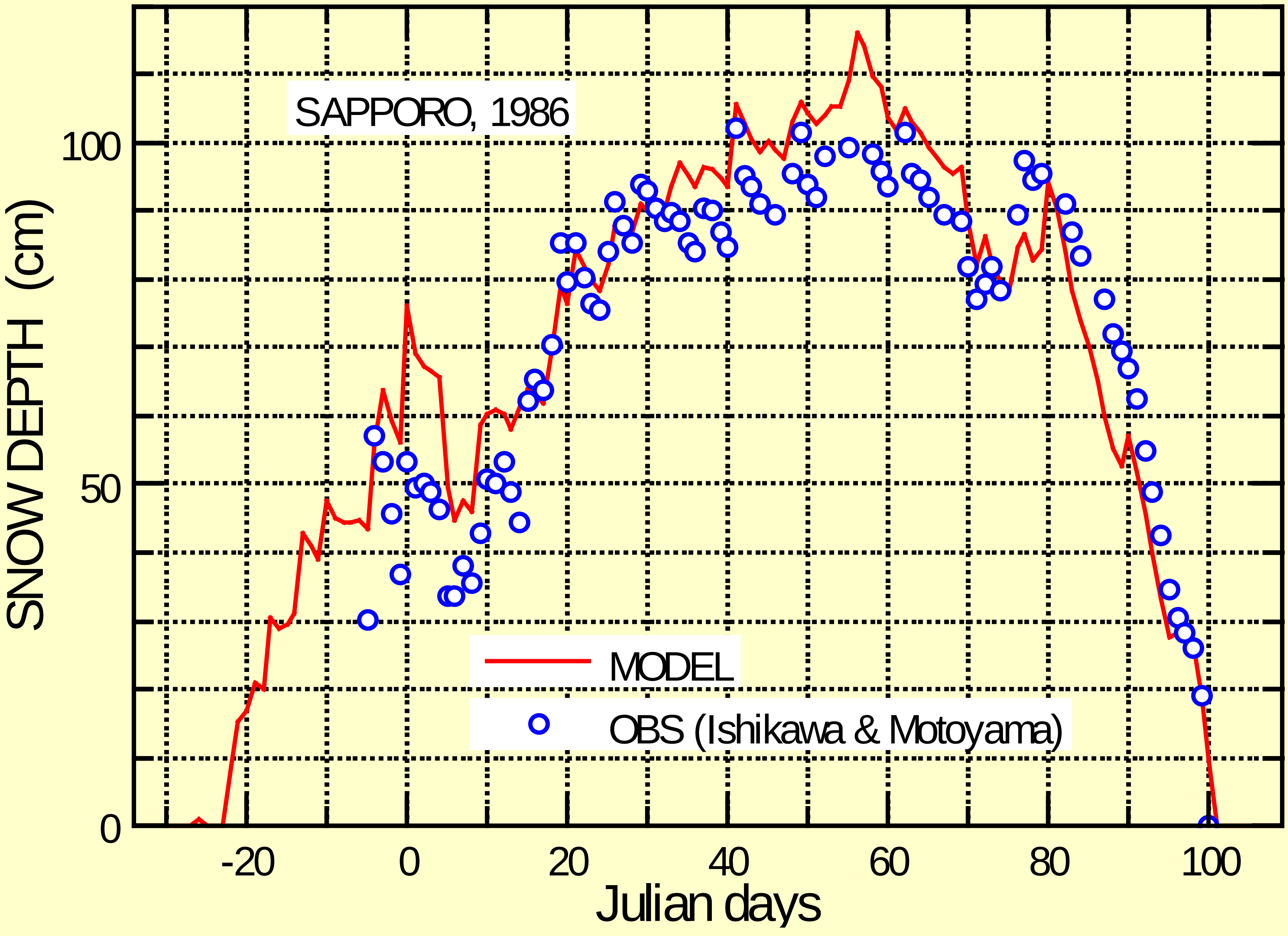
↓ No

$\rho < 250\ \mathrm{kg\,m^{-3}}$ —Yes→ Decomposing and fragmented precipitation particles

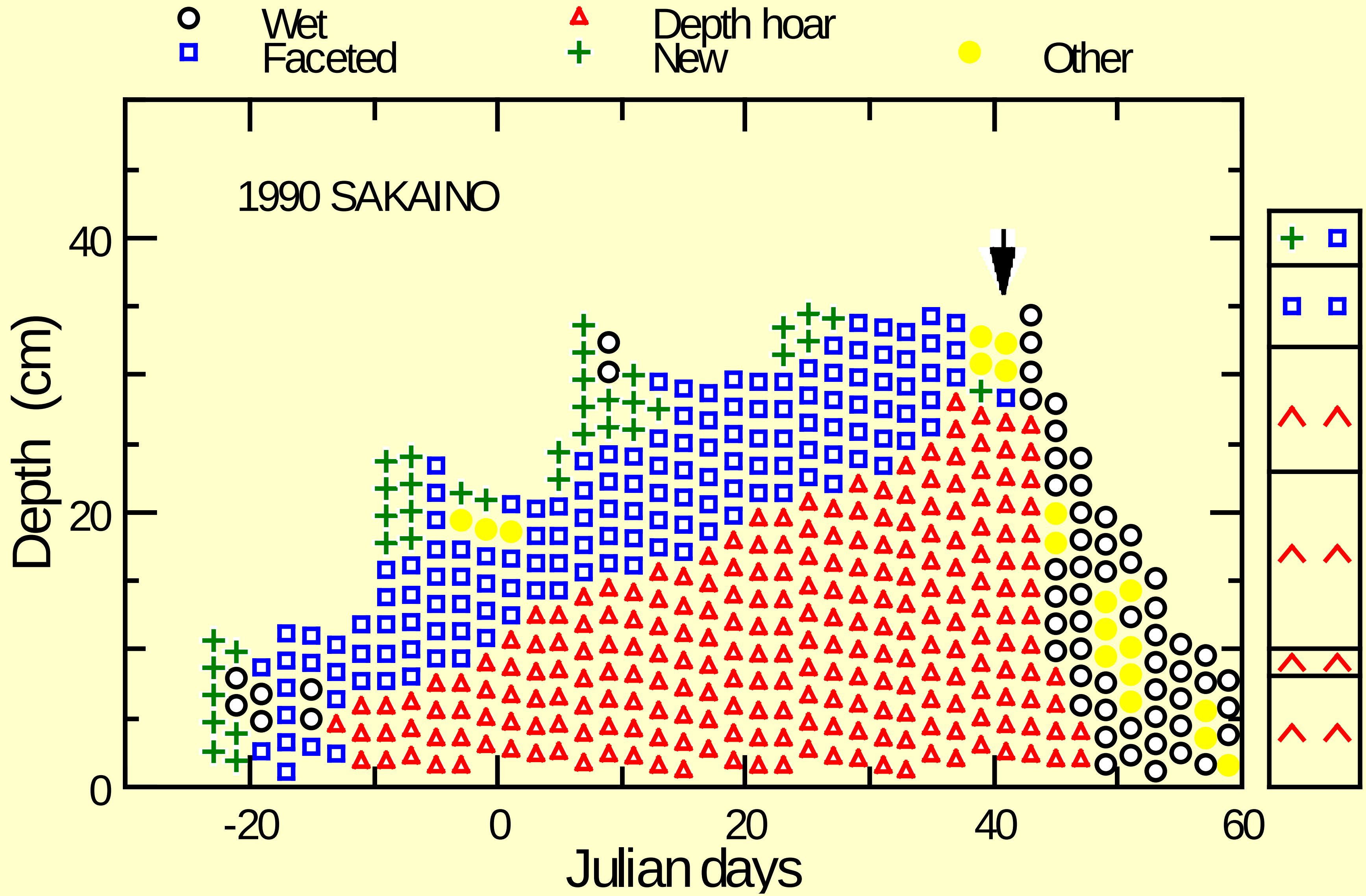
↓ No

Rounded grains

Simulated snow depth

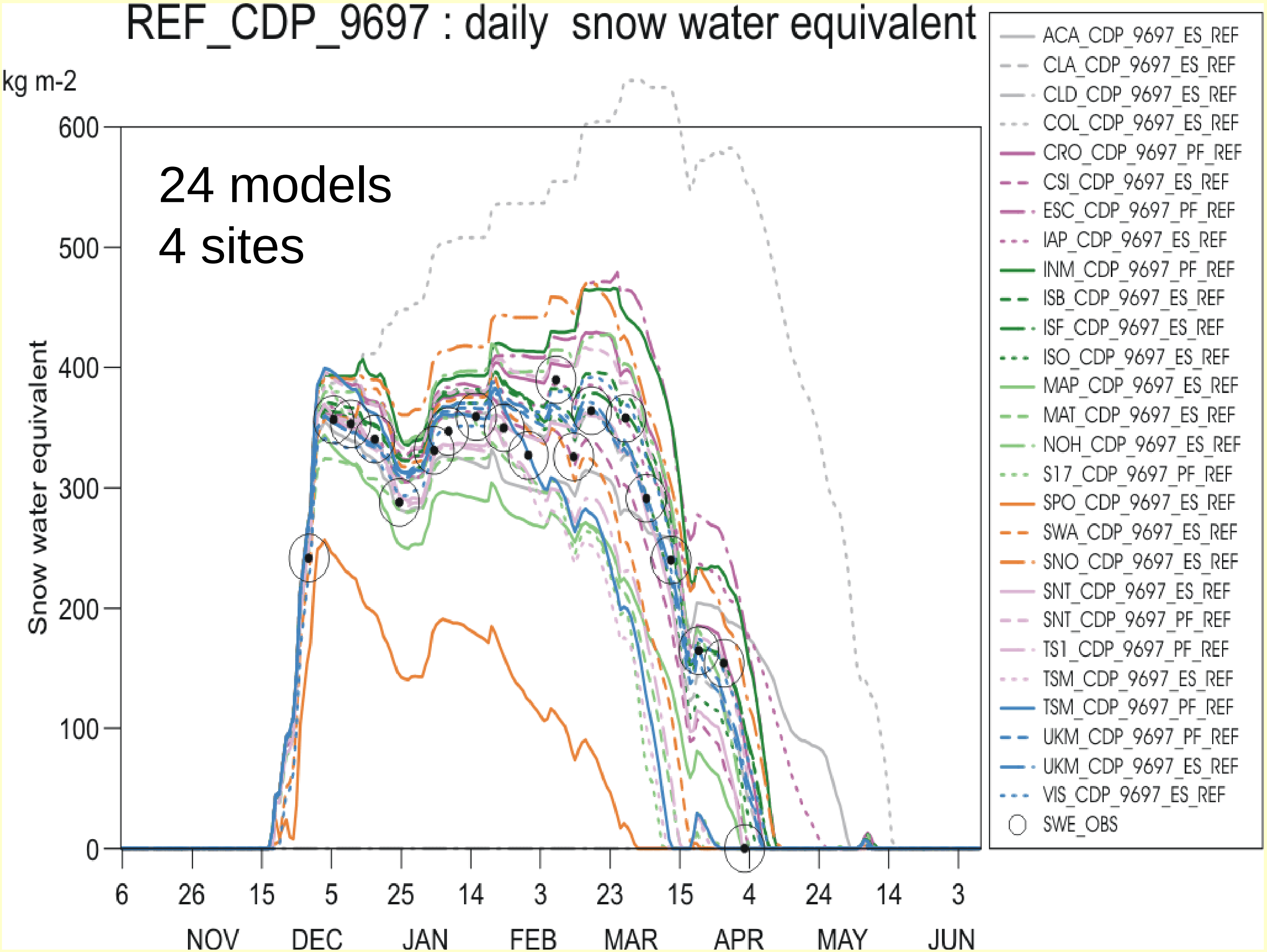


Simulated snow type

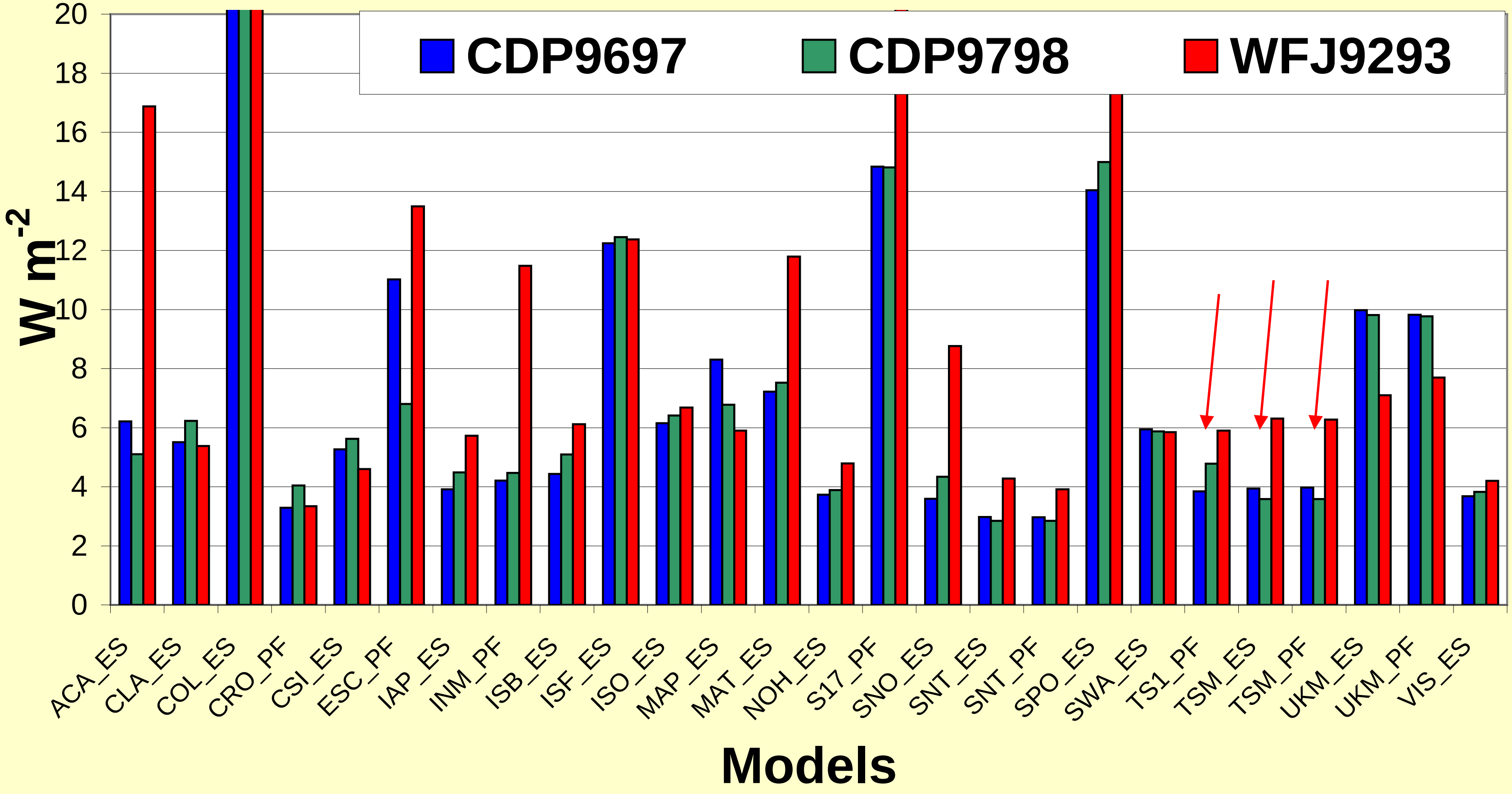


SnowMIP results

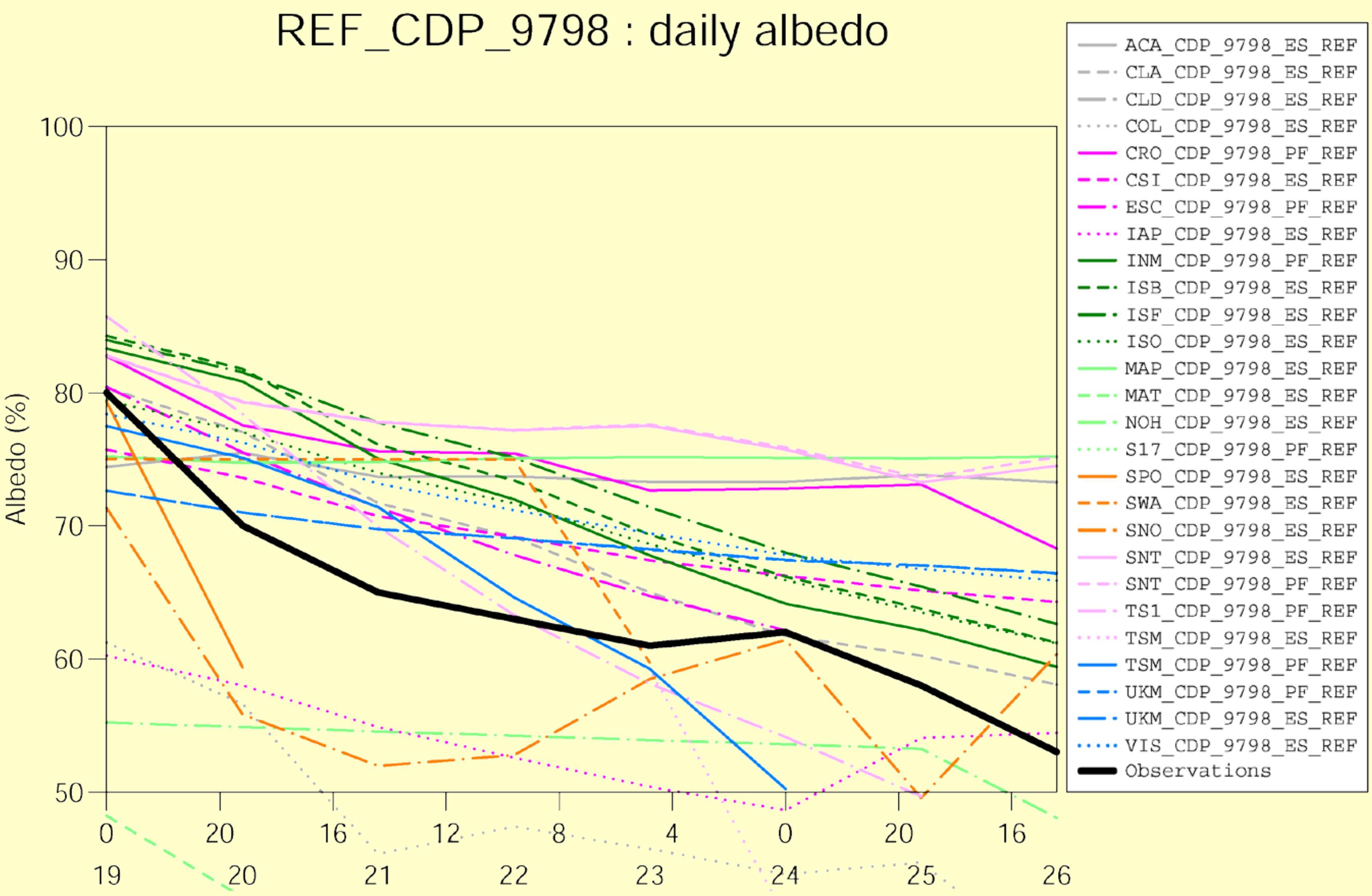
Snow models Intercomparison Project



Daily snow-emitted LW radiation rms error



Etchevers et al. (2003)



Etchevers et al. (2003)

Albedo parameterization

Our models

$$A_0 = A_{\max}$$

$$A_n = (A_{n-1} - A_{\min})\exp(-1/k) + A_{\min}$$

A_n: albedo in *n* days after the last snow

k, A_{max}: functions of daily mean air temperature

SnowMIP suggestion

parameterizations on snow type are efficient

Problems applying to glacier

- Our task is estimating “melt”
- Flow of glacier ???
  - It is essential for mass balance of glacier but …
- Distribution of
  - Albedo
  - Precipitation
- Long-wave radiation

Thank you !

Effective temperature gradient

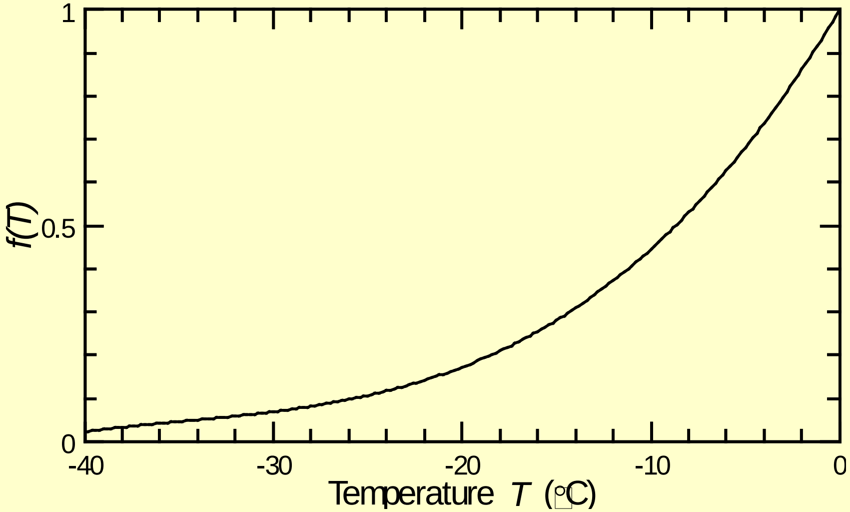
Index of depth hoar

$$g_t(z,t) = \Gamma f(T) \quad (\Gamma \geq 10\ ℃\ \mathrm{m}^{-1})$$

$$g_t(z,t) = 0 \quad (\Gamma < 10\ ℃\ \mathrm{m}^{-1})$$

$$\Gamma = |\partial T / \partial z|$$

$$f(T) = \frac{D_v(T)}{D_v(T_0)} \frac{\delta(T)}{\delta(T_0)}$$



D_v : diffusion coefficient of water vapor

δ : differential coefficient of saturated vapor density with respect to temperature