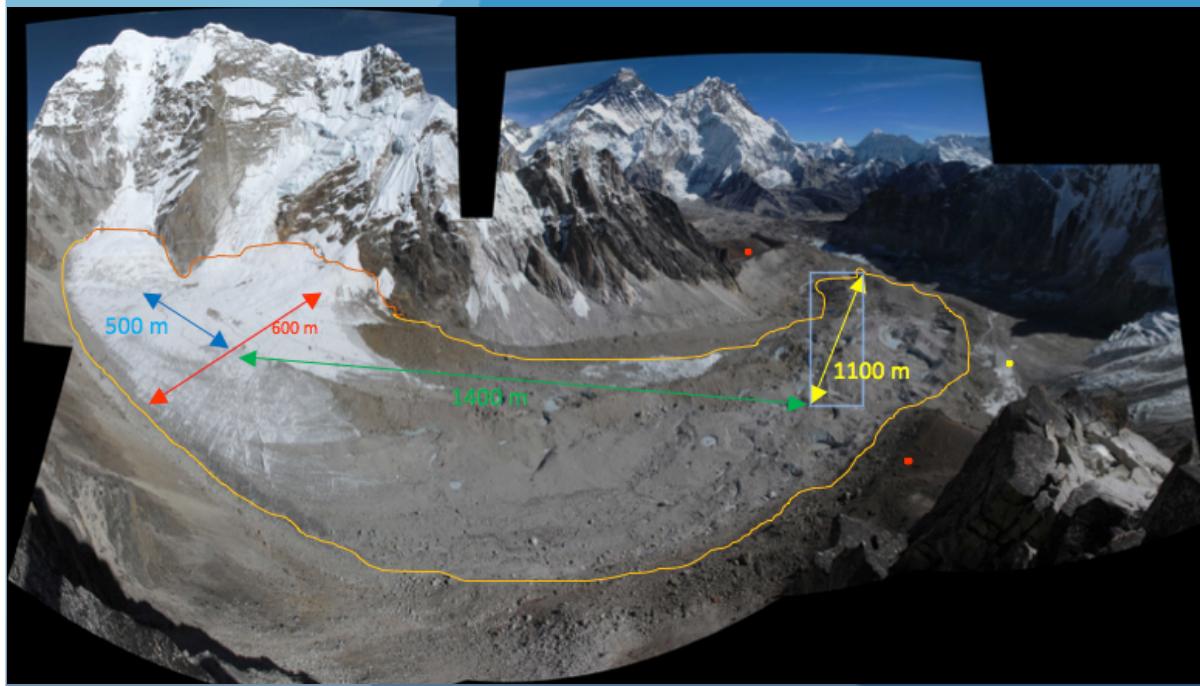


# Incorporating moisture content in modeling the surface energy balance of debris-covered Changri Nup Glacier

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Patrick Wagnon<sup>4,5</sup>, Marie Dumont<sup>3</sup>, and Robert Hawley<sup>1</sup>



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(2) CNRS-MétéoFrance, Toulouse, France

(3) CNRS-MétéoFrance, CEN, Grenoble, France

(4) IRD/LTHE/LGGE Grenoble, France

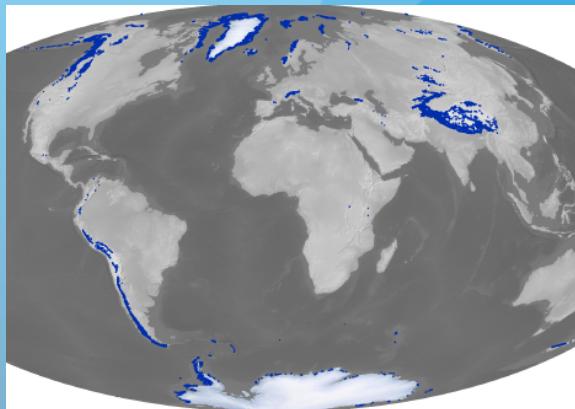
(5) ICIMOD, Kathmandu, Nepal



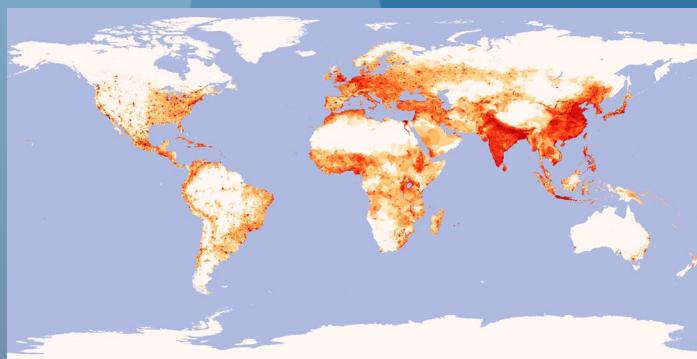
NSF GRF DGE-1313911

# High Mountain Asia

- + Third Pole



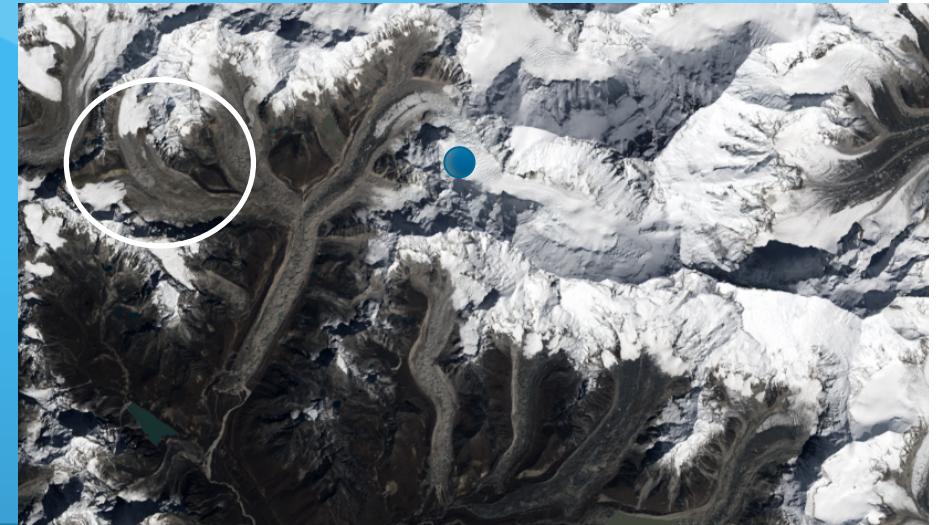
- + 10 major rivers → 20% global population



# Debris-Covered Glaciers

- + Common in Third Pole region, particularly South Central Himalaya (67% glaciers have at least 20% debris cover) (Scherler & al, 2011)
- + Debris affects the way glaciers respond to climate: reduced albedo vs. increased thermal shielding (Østrem, 1959; Nakawo & Young, 1981)

# Research Questions



- + *How much is Changri Nup glacier (Nepal) melting?*
- + *How can we calculate surface melt on a glacier covered in debris?*

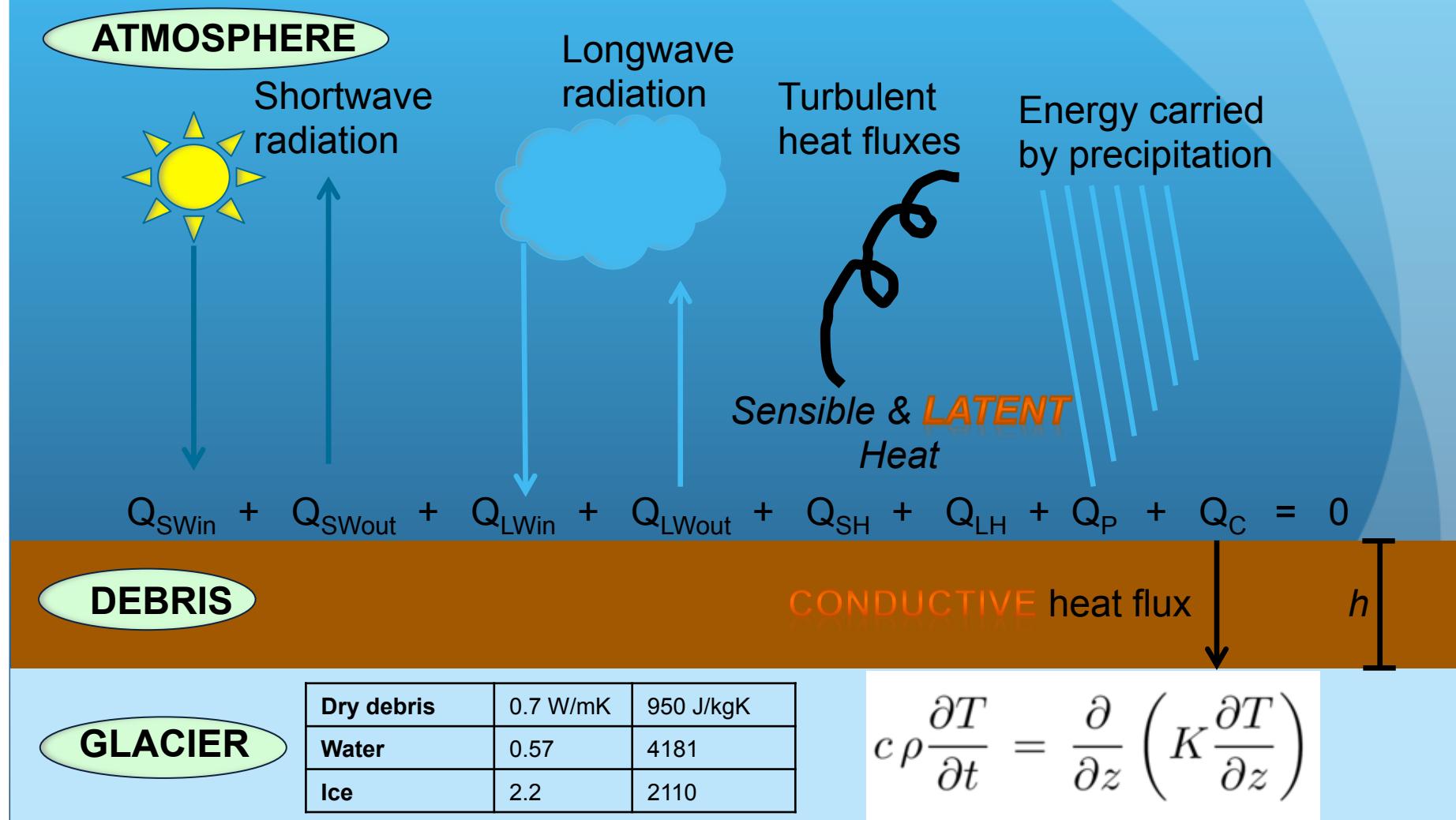


# Prior Work

- Basic model corroborated with experiments (Nakawo & Young, 1982)
- Accounting for diurnal changes in temperature gradient (Nicholson & Benn, 2006)
- Explicit, full representation of heat conduction (Reid & Brock, 2010)
- Year-round flux calculations (using Crocus) (Lejeune & al, 2013)
- Simulation of Østrem curve (enhancement to shielding transition) (Evatt & al, 2015)



# Debris Energy Balance Model



# Moisture

*Measurements & models → neglecting moisture in energy balance computations leads to overestimating sub-debris melt*

*(Sakai & al, 2004; Collier & al, 2014; Rounce et al, 2015)*

*Indications of moisture's impact on energy fluxes & balance*



- *End member cases (Nicholson & Benn, 2006)*
- *Relative humidity as proxy (Reid & Brock, 2010; Reid & al., 2012; Rounce & al, 2015)*
- *Wetness factor (Fujita & Sakai, 2014)*
- *Reservoir-approach to partially saturated debris (Collier & al, 2014, 2015)*

# A New Model (ISBA-DEB)

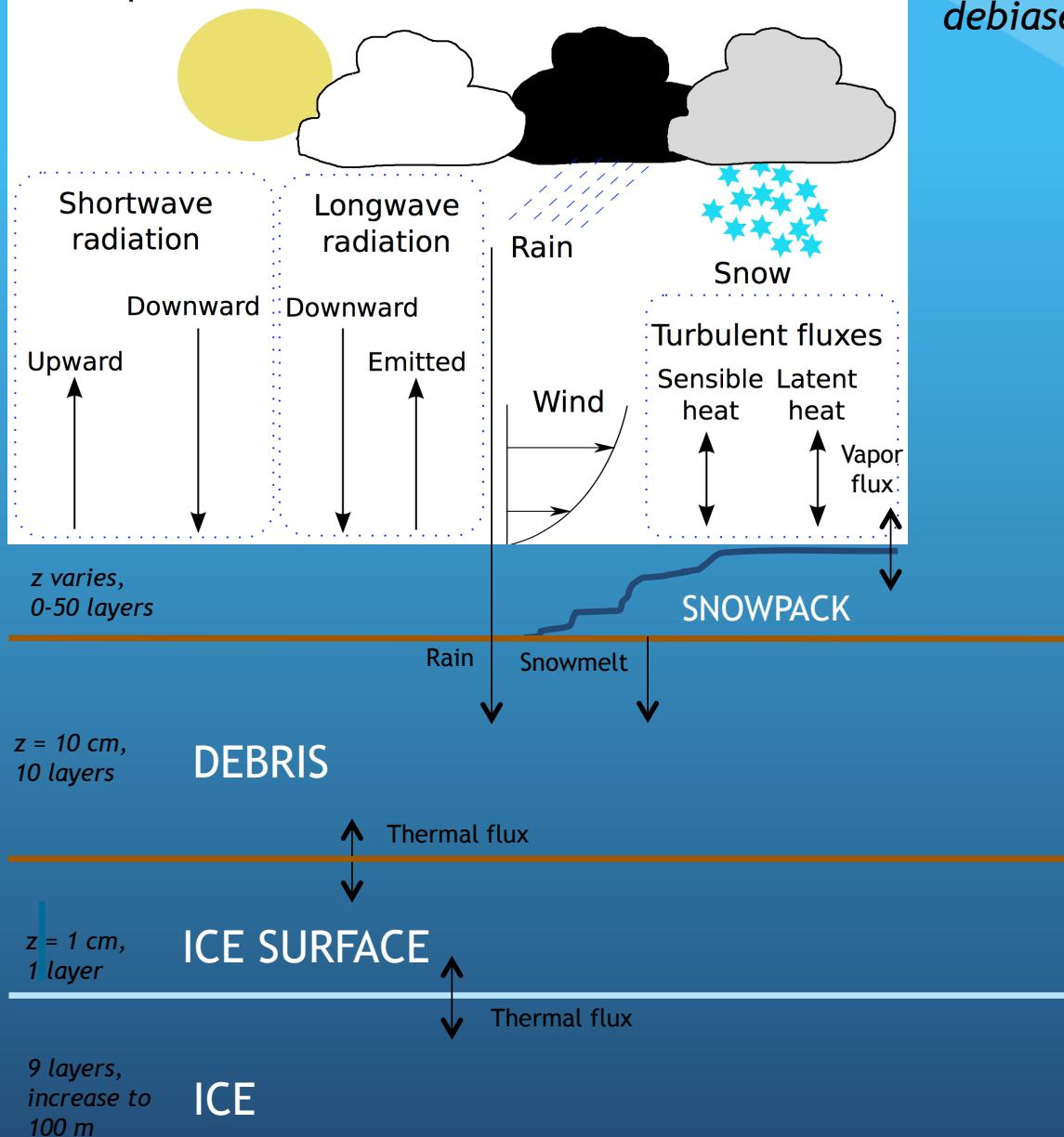
- + Land surface scheme inside Météo-France's SURFEX platform:  
Interactions between Soil, Biosphere, and Atmosphere (ISBA)  
(Noilhan & Planton, 1989):

*A physically-based scheme that solves both heat and moisture diffusion in soil ... already coupled with the Crocus snow model*

- + This is not soil!
- + Needs modifications

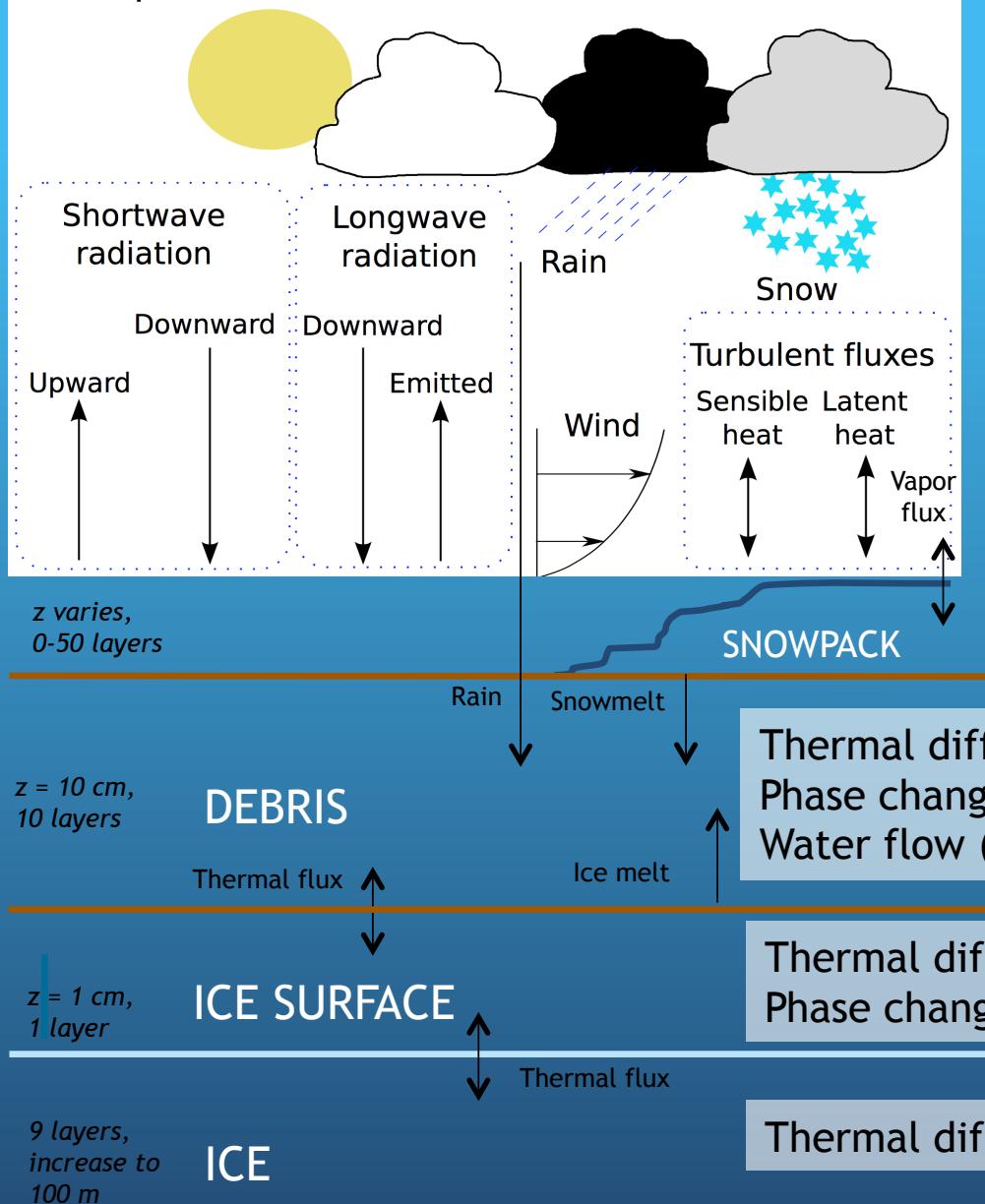


## Atmosphere



*In-situ measurements; gaps filled with debiased ERA-Interim Reanalysis*

## Atmosphere

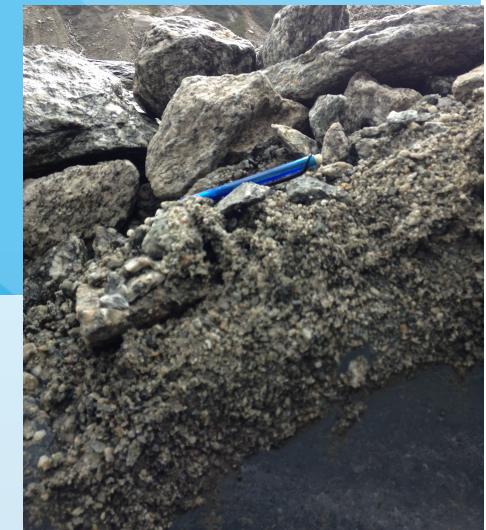
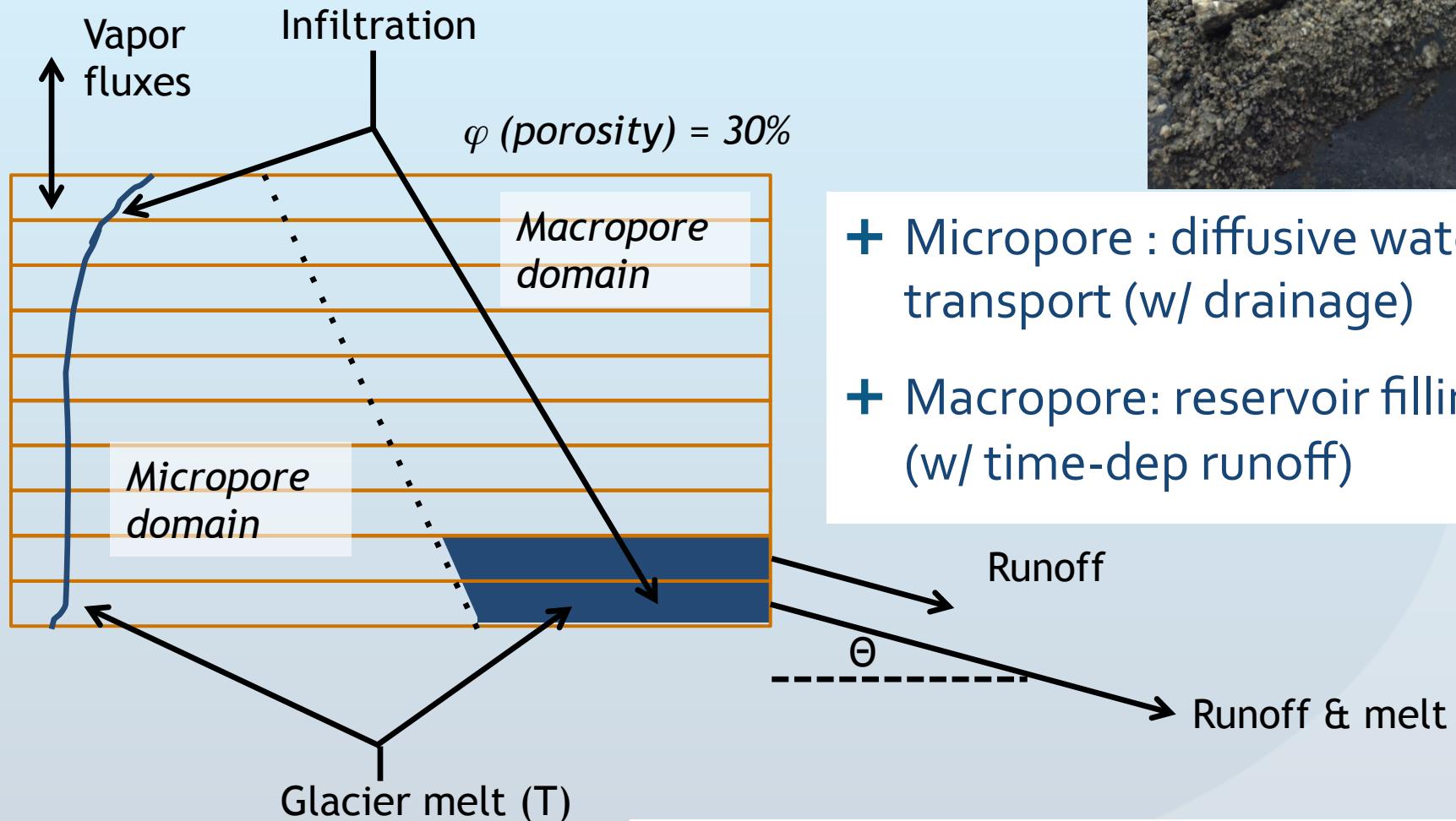


*In-situ measurements; gaps filled with debiased ERA-Interim Reanalysis*

**Model prognoses:**

- Temperature (whole profile)
- Liquid & solid water content & location (debris)
- Glacier melt (ice surface)

# Moisture Transport: Dual Flow



- + Micropore : diffusive water transport (w/ drainage)
- + Macropore: reservoir filling (w/ time-dep runoff)

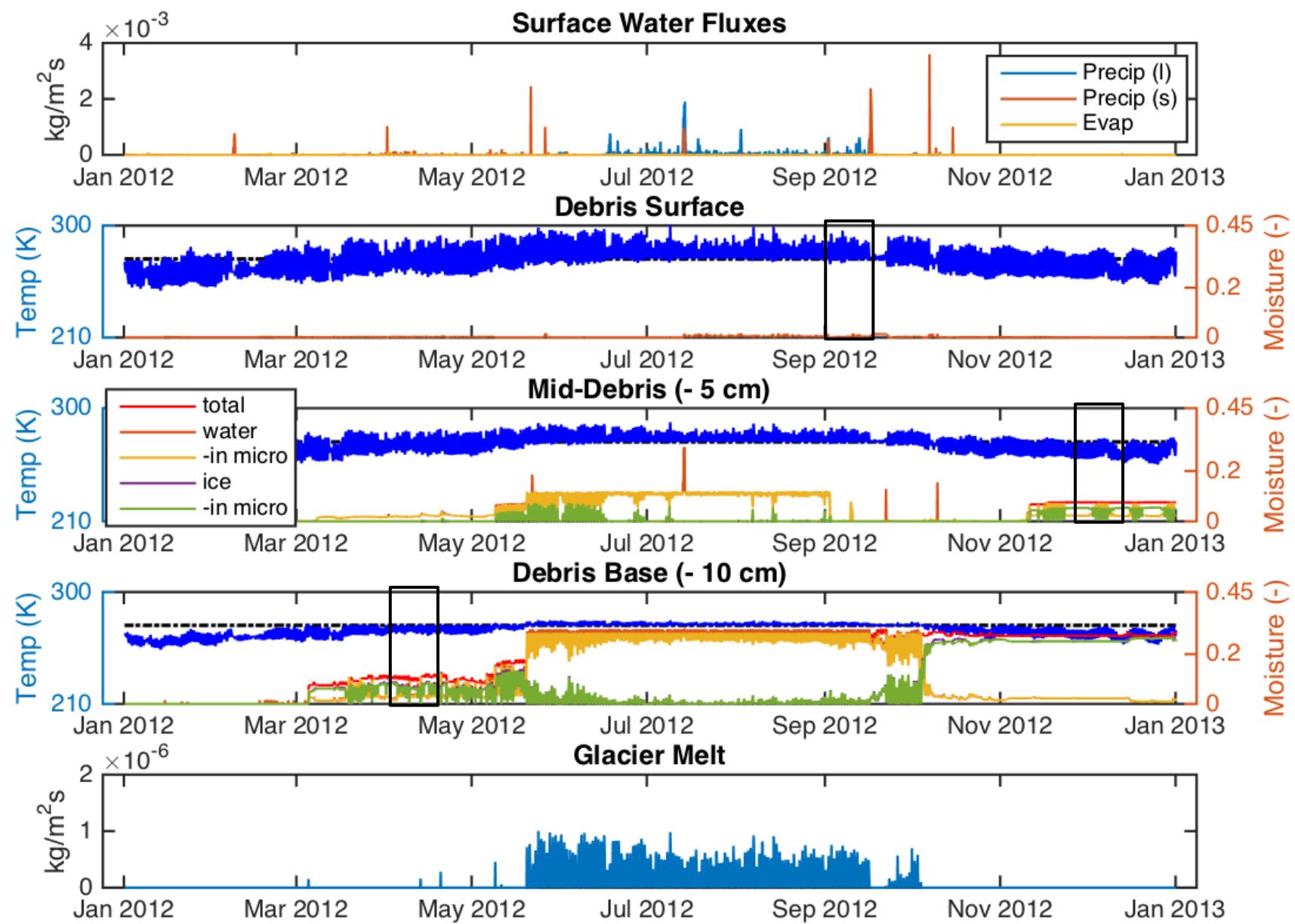
Inspired by preferential flow in soils  
(reviews in van Dam & al, 2008; Bevan & Germann, 2013)

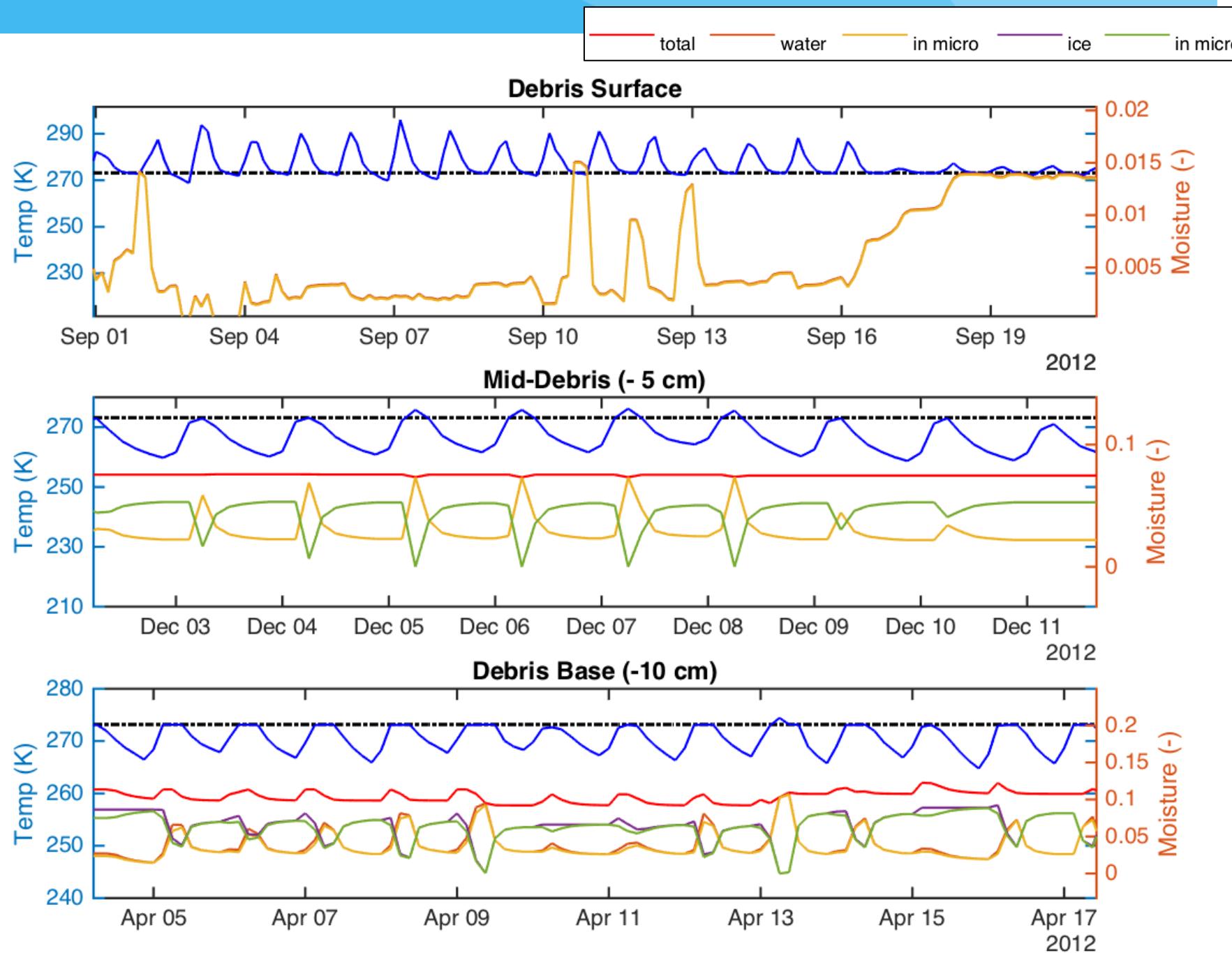
Background

ISBA-DEB Model

Model Output

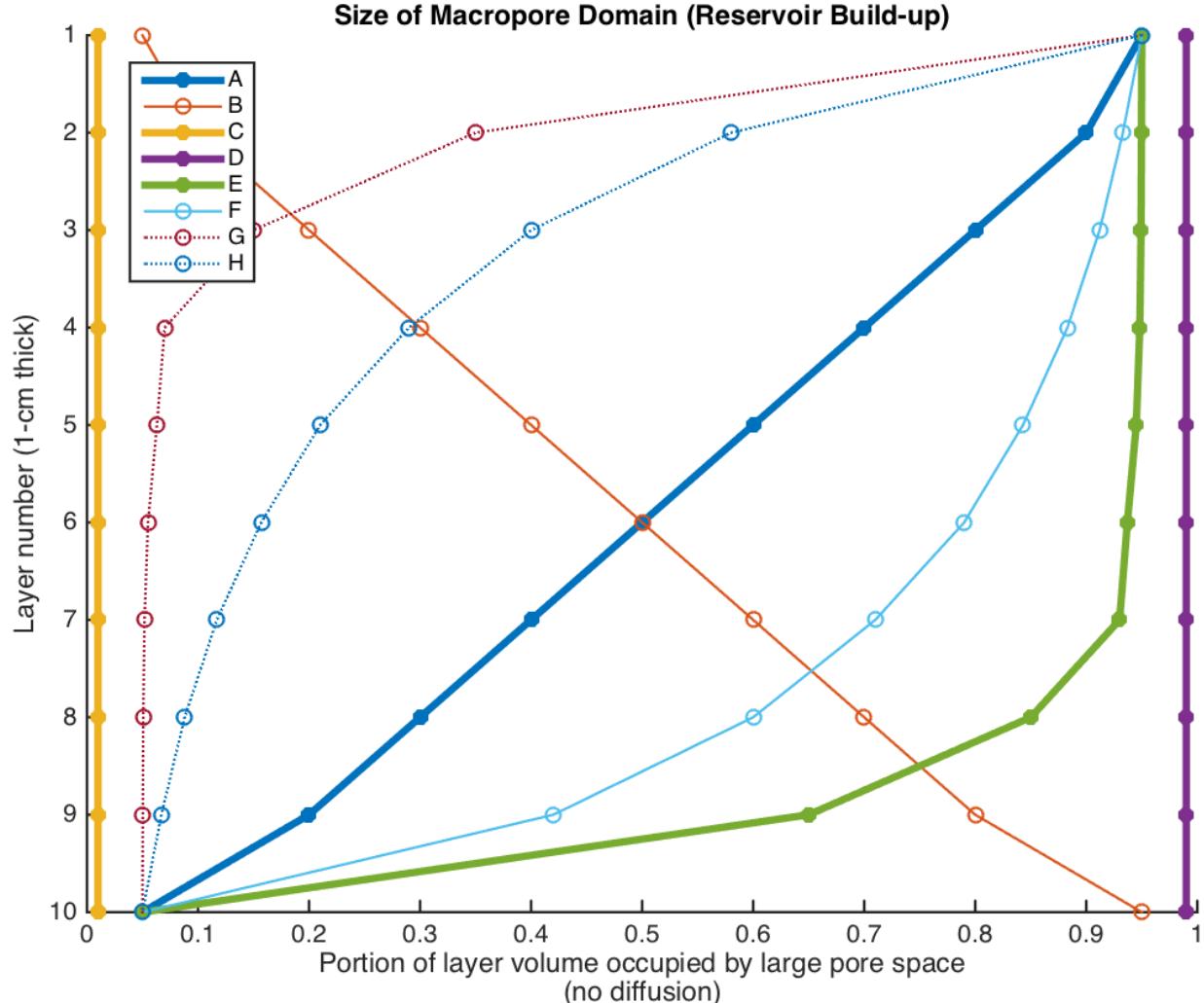
Future Work & Conclusions



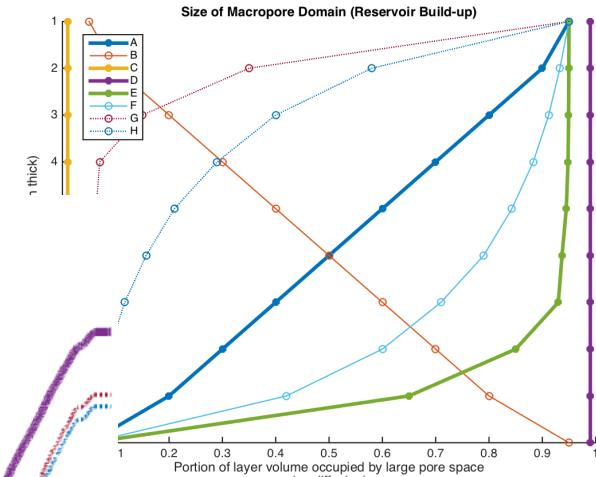
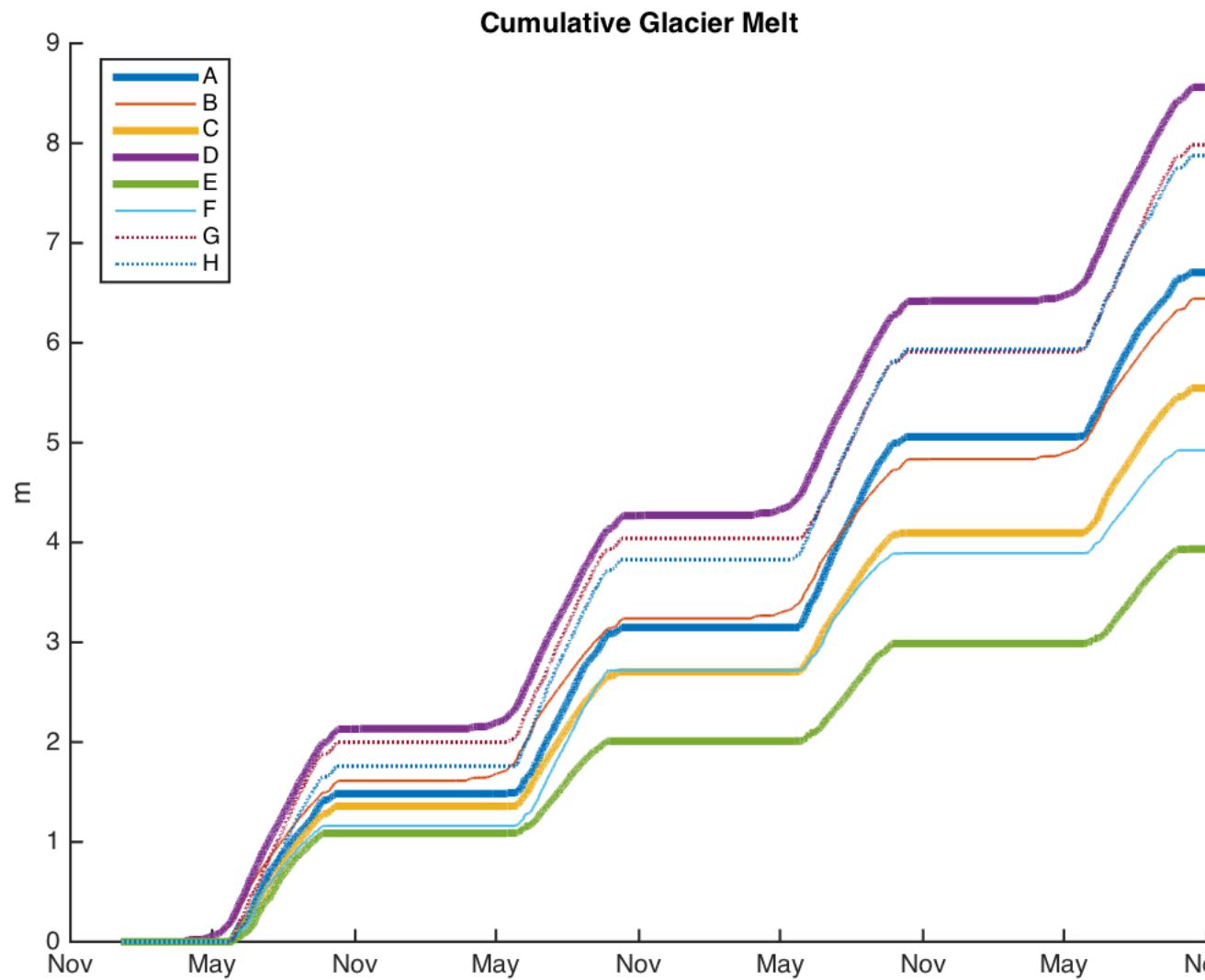


# Macro vs. Micropore Space

Given distribution of macro/micropores has large effect on prognosed location of moisture



# Macro vs. Micropore



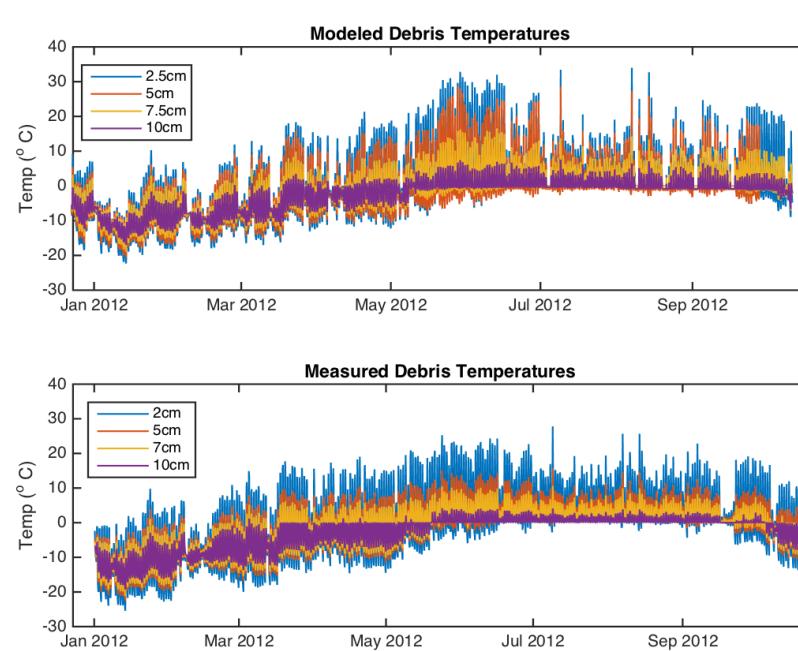
**CHANGRI NUP:**

- Micro: 1.4 m
- Macro: 2.2 m
- Exponential: 0.9 m
- Linear gradient: 1.7 m
- Wet: 1.2 m
- Dry: 2.1 m

Measured: 90.6 cm  
*summer mass balance*

# Future work

- Ongoing work to evaluate ISBA-DEB in the context of Changri Nup's debris temperature, surface temperature, and surface mass balance



- Quantify sensitivities of model to given parameters (macro/micro partitioning, roughness length, slope, etc.)

# Conclusions

- ISBA-DEB can represent a partially saturated debris layer with a dual flow model that includes both moisture diffusion and reservoir build-up
- Moisture certainly affects calculations of sub-debris melt
- Grain size profile matters: sub-debris melt (and surface evaporative flux) are highly sensitive to the macropore / micropore partitioning
- Promising agreement with melt measurements on Changri Nup

# Acknowledgements

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- LGGE: Christian Vincent, Fanny Brun



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