# Debris-Covered Glacier Working Group:
# **Melt model intercomparison experiment**

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1) **Overall goal:**

Compare the sub-debris ice melt rate calculated by a suite of sub-debris glacier ice melt models forced by identical input data

2) **Specific Objectives:**

1. Assess how well the various existing models perform under **different climate forcing**
2. Identify **strengths** and **limitations** of the models against validation data from the same sites
3. Advance our understanding of how the choice of a particular melt model will impact sub-debris melt

3) **Work plan:**

1. Call for participants to identify models to be compared. All participants will be added to the "Melt Model Family Tree"
2. Identify target glacier locations
3. Upload forcing data to zenodo community hub
4. Agree on the experimental setup
5. Perform model comparison and submit model results
6. Synthesize results for publication(s)

4) **Approach:**

The model intercomparison will be carried out at the point scale of the sites of on-glacier Automatic Weather Stations (AWSs) that provide high quality meteorological input data and where debris properties (conductivity, surface roughness, etc) are measured or estimated by the data providers. We aim to run the models at select sites with high quality data, representative as much as possible of distinct climatic settings. **All participating models will have to be run at each site.**

We seek to compare both energy-balance models, empirical models (such as the degree-day model) and approaches of intermediate complexity.

**Three steps to participate and start modelling:**

1. Go to https://zenodo.org/communities/iacswgondcgs/, click on "Melt Model Intercomparison Documents", download and read the documents.
2. Request access and download the 9 datasets and the "Melt Model Intercomparison parameter sets (MC Simulations)". Make sure to **download the newest version available**!
3. Start modelling according to the guidelines in the following pages:

5) **Experiment setup:**

Models will be run at ***hourly*** (*daily* if not possible) time step and **ONLY for the snow free period** of the recorded data at each site (one season to one year). The beginning and end of the snow free period for each site can be found in the file "**MMIC_model_run_dates.xlsx**" on https://zenodo.org/record/3134764 . For **occasional snowfalls** (during the snow free period) and the associated period of snow cover on the ground, modellers will run their routines for snow accumulation and melt (if they have one) and will indicate in the model description how snowfall/snowmelt were calculated/simulated. They will clearly indicate the periods of snowfall and snow on the ground they have used. Models that do not have snow routines will deal with snowfalls as they think best (e.g. set melt to zero, set surface temperature to zero, etc) and provide this information also in the model description. We will only compare models when there are no snowfalls.

### 5.1_Energy balance models

Energy-balance models will **not** be calibrated. Each model will be run with prescribed input data (from the AWS) and prescribed debris-properties (measured at the same location or estimated as best as they can by data providers). Clear documentation of the input and site data is provided.

**There are four experiments to perform. Each model will be *run*:**

1. forced with the debris thickness and conditions measured at the site.
2. as in #1, but employing a Monte Carlo approach to force the model with a standardized set of perturbed debris properties, in accordance to the debris properties uncertainty estimates provided by the data providers. 100 sets of perturbed debris properties per site are provided for this.
3. with the debris and meteorological conditions determined for the AWS but with varying debris thickness of 1, 2, 4, 6, 8, 10, 12, 15, 20, 30, 50, 100 centimeters.
4. as in #3, but employing for every debris thickness a Monte Carlo approach to force the model with a standardized set of perturbed debris properties, in accordance to the debris properties uncertainty estimates provided by the data providers. The same 100 sets of perturbed debris properties per site are provided for this as in #2.

**Each model will produce the following *outputs (color codes in accordance to Table 1)*:**

1. A time series of hourly melt rate (m w eq.) and surface temperature (°C) for the AWS site over the period of simulations, and the corresponding 100 time series from the Monte Carlo simulations accounting for uncertainty.
2. A time series of hourly melt rate and surface temperature for the debris thicknesses specified to recreate a debris thickness-melt curve, and the corresponding 100 time series (per debris thickness) from the Monte Carlo simulations accounting for uncertainty.
3. Time series of hourly energy fluxes for the AWS site over the period of simulations, and the corresponding 100 time series from the Monte Carlo simulations (optional) accounting for uncertainty.
4. (where model structure allows) A time series of debris temperature profiles, and the corresponding 100 time series from the Monte Carlo simulations accounting for uncertainty.

5. (where model contains a snow module) A time series of snow depth or snow cover flag, for each time step of the model run. This should agree (as much as possible) with the snow depth data provided for the site.

Table 1. Summary of experiments and outputs to provide for EB models.

| Experiment \ Output | Number of time series to provide per site * | | | | |
|---|---|---|---|---|---|
| | Melt rate (m w eq.)** | Surface T (°C) | Energy Fluxes | Internal debris T | Snow cover flag |
| #1 Standard runs | 1 | 1 | 1 x F | 1 x L opt. | 1 opt |
| #2 MC runs for #1 | 100 | 100 | 100 x F opt. | 100 x L opt. | - |
| #3 Standard runs for 12 thicknesses | 12 | 12 | 12 x F opt. | 12 x L opt. | - |
| #4 MC runs for #3 | 1200 | 1200 | - | - | - |

F=number of output fluxes; L=debris layers in model; opt=Optional/If available

* Provide outputs for each experiment in an understandable format, preferably as .csv or .mat files, with rows as time steps and columns as output variables.

** Conversion to water equivalent by assuming an ice density of 900 kg $m^{-3}$.

## 5.2_More empirical approaches

Models will be run (color codes in accordance to Table 2):

1. As in experiment #1 and #3 (for models that take into account debris thickness) of the Energy Balance experiments,
    a. with parameters from the literature if they are available for the specific site, or with original parameters.
    b. with calibrated parameters against the surface lowering/melt data measured at the sites, or measured surface temperature, using the entire available record. Partial re-calibration (using a part of the record for calibration and another part for validation) will not be performed due to the short length of the melt season for most sites.
2. As in #1 but employing a Monte Carlo approach by forcing the model with 100 sets of perturbed model parameters, varying each parameter by 10% of its expected/calibrated range, and randomly distributing them. For example, if a parameter is recalibrated at all nine sites, a 10% will be applied to the range of those nine parameter values.

Table 2. Summary of experiments and outputs to provide for empirical models.

| Experiment \ Output | Number of time series to provide per site* | |
|---|---|---|
| | Original/Literature parameters | Re-calibrated parameters |
| | Melt rate (m w eq.)** | Melt rate (m w eq.)** |
| #1 Standard runs | 1 | 1 |
| #2 MC runs for #1 | 100 | 100 |
| #3 Standard runs for 12 thicknesses | 12 | 12 |
| #4 MC runs for #3 | 1200 | 1200 |

* Provide outputs for each experiment in an understandable format, preferably as .csv or .mat files, with rows as time steps and columns as output variables.

** Conversion to water equivalent by assuming an ice density of 900 kg $m^{-3}$.

6) **These experiments have different goals:**

a) allows a comparison of model performance against field validation data

b) allows a quantification of modeled melt uncertainty in response to uncertainties in debris properties (and in the case of more empirical approaches, uncertainties in empirical parameters).

c) allows reconstruction of an Østrem curve (debris thickness versus melt, non-normalized) and comparison of model performances across a range of debris thicknesses

d) allows assessment of model sensitivity to poorly constrained debris properties, and of which parameters each model is most sensitive to.

7) **Each model will be *evaluated* against:**

- (essential, EB and TI models) Stake or ultrasonic depth gauge readings of surface lowering measured in close vicinity of the AWS, appropriately converted into melt rates
- (essential, only EB models) Measured surface temperature (from LWOUT or thermistor measurements) at or close to the AWS
- (if available and appropriate for model structure) Temperature profiles in the debris

These validation data are inevitably affected by (high) uncertainties, and we will estimate/provide uncertainties for them. The result will be a model evaluation rather than a rigorous validation. Modellers do not have to validate their outputs, as this will be done for all models together.

8) **Other modelling notes:**

- Use debris properties indicated for each site in the ID_YEAR_debris.csv file.
- Modellers should set albedo to 1 whenever this is exceeded (or set SWOUT = SWIN whenever SWOUT > SWIN, since this was not checked for all datasets).
- For Experiment #3: a) the Østrem curve will not be normalized with a bare ice melt rate; b) The same albedo is assumed for all debris thicknesses.
- Arolla: Pressure is provided at daily resolution in a separate file from a nearby station (not lapsed to elevation of AWS).
- Djankuat glacier: a) Only run 2007. b) If model requires precipitation as input, divide daily sum of precipitation by 24 hours.
- Miage: Should be run with a debris thickness of 0.22 m, the mean of the two values provided in the debris file.