OGGM v1.7a SfcTypeModel — GLAMBIE model submission

Fixed-geometry and dynamic-spinup (varying-geometry) glacier mass-change estimates, 1975–2025

Fabien Maussion

September 2026

1. What is submitted

Two regional glacier mass-change datasets, both produced with the Open Global Glacier Model (OGGM) using an identical model setup, calibration and climate forcing. They differ only in how glacier geometry is treated over time:

1. Fixed geometry — glacier geometry is held constant at its inventory-date state for the whole period:

```
glambie_submission_fixed_geometry_v17a_SfcTypeModel.csv
```

2. Dynamic spinup (varying geometry) — glacier geometry evolves in time, simulated with the ice-flow model after a dynamic spinup:

```
glambie_submission_spinup_geometry_v17a_SfcTypeModel.csv
```

Both cover all 19 GTN-G / RGI first-order regions, monthly, from January 1975 to December 2025, in units of m w.e. (specific mass balance, regional area-weighted).

Because the two datasets share their mass-balance model, parameters and forcing, the difference between them isolates the effect of the geometry assumption alone.

2. Model description

2.1 The OGGM framework

All computations use the Open Global Glacier Model (OGGM; Maussion et al., 2019), an open-source modelling framework for glaciers worldwide. Glacier outlines are taken from the Randolph Glacier Inventory version 6.0 (RGI Consortium, 2017). Each glacier is represented by **elevation-band flowlines**: the glacier is discretised into elevation bins, and each bin is characterised by its area, mean elevation and ice thickness.

Ice thickness is obtained by mass-conservation inversion, calibrated so that the total ice volume of each glacier matches the consensus estimate of Farinotti et al. (2019).

2.2 Mass balance: temperature-index model with surface-type distinction

The mass-balance model is `SfcTypeTIModel`, a monthly temperature-index model with surface-type distinction. The approach was first described in Schuster et al. (2023) and was reimplemented for OGGM v1.7 by Patrick Schmitt.

Basic principle

For each elevation band and each month, the specific mass balance is the difference between solid precipitation (accumulation) and melt:

$$B = P_{\text{solid}} - f_{\text{melt}} \cdot \max(T - T_{\text{melt}}, 0)$$

where P_{solid} is the solid fraction of precipitation, T the near-surface air temperature extrapolated to the band elevation, T_{melt} the melt threshold temperature and f_{melt} the melt factor. Precipitation is partitioned into solid and liquid using linear interpolation between a temperature below which all precipitation falls as snow ($T_{\text{all\_solid}}$) and above which all of it falls as rain ($T_{\text{all\_liq}}$).

Global parameters used here: $T_{\text{melt}} = -1.0\,^{\circ}\text{C}$, $T_{\text{all\_solid}} = 0.0\,^{\circ}\text{C}$, $T_{\text{all\_liq}} = 2.0\,^{\circ}\text{C}$, temperature lapse rate $-6.5\,^{\circ}\text{C km}^{-1}$.

Surface-type distinction

The difference from previous OGGM versions is that the melt factor depends on the surface type. Snow and firn have a higher albedo than bare ice and therefore melt more slowly for the same air temperature.

This is implemented with a bucket system. Snow accumulating on the glacier surface is placed in a bucket which ages month by month, progressively becoming firn and finally ice. In the configuration used here the buckets age monthly over a 6-year window, giving 73 buckets per elevation band. Each bucket carries its own melt factor, interpolated between the snow and ice values as a function of bucket age:

$$f_{\text{melt}} = f_{\text{melt,ice}} + \left(f_{\text{melt,snow}} - f_{\text{melt,ice}}\right) \cdot e^{-t/\tau}$$

with an e-folding timescale $\tau = 1$ year. The snow melt factor is set to $f_{\text{melt,snow}} = 0.5\, f_{\text{melt,ice}}$ (i.e. fresh snow melts at half the rate of bare ice for the same temperature forcing), matching the ratio used in GloGEM (Huss and Hock, 2015).

Fresh snow density is assumed to be 300 kg m^{-3}, evolving towards ice density with the same functional form.

2.3 Climate forcing

The model is forced with monthly ERA5 reanalysis (Hersbach et al., 2020) temperature and precipitation, downscaled to each glacier's elevation bands using a constant temperature lapse rate.

2.4 Calibration

Mass-balance parameters are calibrated per glacier against the geodetic mass-balance observations of Hugonnet et al. (2021) over the reference period 2000–2020, using OGGM's `informed_threestep` strategy. Three parameters are involved:

- the **precipitation factor** p_f, a multiplicative correction on ERA5 precipitation, informed by WGMS observations (a function of total winter precip at the glacier location);
- the **temperature bias** ΔT, an additive correction on ERA5 temperature, informed by a precomputed regional temperature-bias field;
- the **melt factor** $f_{\text{melt,ice}}$, with a first-guess value of 6 kg m^{-2} day^{-1} $^{\circ}\text{C}^{-1}$.

The strategy adjusts these in a prescribed order until the modelled 2000–2020 mean specific mass balance matches the geodetic observation for that glacier (more info here). The model therefore reproduces the observed geodetic mass balance over the calibration period essentially exactly by construction (for fixed geometry - see below); the informative content of the submission lies in the temporal variability and in the periods outside the calibration window.

3. The two submissions

3.1 Fixed geometry

In the fixed-geometry dataset the glacier geometry — area and surface elevation of every elevation band — is held constant at its inventory-date state for the whole 1975–2025 period. The mass balance is evaluated month by month on that unchanging geometry, and no ice-flow model is run.

This is the conventional "climatic" mass-balance product: it isolates the direct climate signal, answering the question *"what mass balance would today's glacier geometry have experienced under the climate of each year?"*. It contains no glacier-geometry feedback of any kind — no retreat, no thinning and no change in the accumulation-area ratio.

Its principal limitation is that it attributes the modern, already-reduced glacier extent to the whole period, including the 1970s and 1980s. Where glaciers have lost a large fraction of their low-elevation ablation area since 1975, the fixed-geometry calculation therefore systematically underestimates early-period melt and overestimates late-period melt. Another caveat is that it doesn't take the glacier thickness into account and isn't mass conservative: it will happily melt dozens of meters of ice at the terminus even if there isn't any available, for example.

3.2 Dynamic spinup (varying geometry)

In the dynamic-spinup dataset the glacier geometry evolves in time. OGGM's flowline ice-flow model is run forward from a reconstructed past state, so that glacier area and surface elevation respond to the cumulative mass balance, and the mass balance in turn responds to the changing geometry.

Because the glacier state in 1970 is not observed, it is reconstructed with OGGM's dynamic spinup & calibration procedure: candidate past glacier states are integrated forward and iteratively adjusted until the model simultaneously matches, at the inventory date, (i) the observed RGI glacier area and (ii) the observed geodetic mass-change rate. The spinup is started in 1970, five years before the first reported year, so that any residual relaxation of the ice-flow model after initialisation has time to settle before 1975.

Monthly mass balance is then extracted from the dynamical run using OGGM's hydrological output, which is mass-conserving: the on-glacier melt is capped by the snow, firn and ice actually available in each month and rescaled so that the sum of accumulation and melt reproduces the mass change of the ice-flow model exactly. The specific mass balance is normalised by the glacier area with an ice thickness of at least 2 m, which excludes numerically negligible, near-zero-thickness cells at the glacier margins.

For glaciers where the dynamic spinup does not converge, OGGM falls back to a fixed-geometry extension from the inventory date back to 1970, and switches to the full dynamical evolution from the inventory date onward. This affects a substantial fraction of glaciers by count but a small fraction by area, since it is concentrated in small glaciers.

The limitations are that the match to geodetic isn't perfect as it is for fixed geometry (it's harder to match a moving target), but fixed geometry is "artificially" accurate as discussed above. The key limitation however is that the glacier states in 1975 are highly uncertain, and cannot really be considered a "reconstruction" for reasons discussed at length in Eis et al. (2019). It's possible that in some regions, this leads to strong differences in interpretation in the pre-2000 period.

4. Regional aggregation

Regional series are area-weighted aggregates of the individual glacier runs. Regional mass change is computed as the sum of glacier-wide mass change divided by the summed glacier area, rather than as an average of per-glacier specific mass balances, so that the regional series remains mass-conserving.

The `observational_coverage_percentage` column reports, for each region, the fraction of the total RGI catalogue area that is actually represented by successfully modelled glaciers. Coverage is 88–100% per region for the fixed-geometry dataset and 87–100% for the dynamic-spinup dataset; the shortfall consists of glaciers that fail at some stage of the preprocessing or model chain, and is dominated by small glaciers. For the dynamic-spinup dataset the reported reference area varies in time, reflecting the modelled glacier area.

5. Evaluation

Over the geodetic calibration period (2000–2019) the global area-weighted specific mass-balance rate is **−0.378 m w.e. yr^{-1}** for the fixed-geometry dataset and **−0.379 m w.e. yr^{-1}** for the dynamic-spinup dataset, against **−0.389 ± 0.012 m w.e. yr^{-1}** from Hugonnet et al. (2021). All 19 regions agree with the corresponding regional geodetic estimates within their stated uncertainties. This is largely by construction — the model is calibrated against these observations — and should be read as a consistency check rather than as independent validation.

6. Known limitations

- **No uncertainty estimate is provided.** The `glacier_change_uncertainty` columns are left blank. The submitted values are a single deterministic realisation and carry no formal error bars.
- **Above/below water-level partitioning is not provided in this version, although it would be possible (with limitations).** The full mass change is reported in the `above_water_level` column and the `below_water_level` column is left blank. The dynamic-spinup model output does track the glacier volume below sea level, so a sea-level-relevant / non-sea-level-relevant split *could* be derived for the dynamic-spinup submission — but only at annual resolution, not at the monthly resolution required by the submission format. Rather than mix resolutions or interpolate, the split is omitted here. It could be provided in a later version if a coarser resolution for that variable is acceptable.
- **Frontal ablation is not represented.** Calving is switched off in this model setup, and the modelled calving flux is exactly zero for every glacier in both datasets. Mass loss from marine- and lake-terminating glaciers is therefore captured only through surface mass balance and, in the dynamic-spinup dataset, through the geometric evolution of the glacier — not through frontal processes. This is a limitation for the heavily tidewater-influenced regions in particular (RGI01, RGI03, RGI05, RGI19).
- **Calibration-period dependence.** Both datasets are calibrated to 2000–2020 geodetic observations. Agreement with observations in that window is by construction; the pre-2000 portion of the record is an extrapolation driven by the climate forcing and, for the dynamic-spinup dataset, by the reconstructed glacier state.
- **Limitations before 2000.** As described in Section 3.1 and 3.2, both submissions have limitations prior to 2000. It's unclear which is most accurate or realistic.

7. Model and data versions

Item	Value
Model	OGGM, commit `e849270678a2dccc0ec413ba62146e90044923d3` (v1.6.4.dev79)
Mass-balance model	`SfcTypeTIModel` (monthly, surface-type distinction)
Calibration strategy	`informed_threestep`, geodetic reference period 2000–2020
Climate forcing	ERA5, monthly
Glacier inventory	RGI 6.0
Ice thickness	Consensus estimate (Farinotti et al., 2019)
Flowlines	Elevation bands, map border 160 grid points
Dynamic spinup	`area/dmdtda` matching, start year 1970

References

Eis, J., Maussion, F., and Marzeion, B.: Initialization of a global glacier model based on present-day glacier geometry and past climate information: an ensemble approach, The Cryosphere, https://doi.org/10.5194/tc-13-3317-2019, 2019.

Farinotti, D., Huss, M., Fürst, J. J., Landmann, J., Machguth, H., Maussion, F., and Pandit, A.: A consensus estimate for the ice thickness distribution of all glaciers on Earth, *Nature Geoscience*, 12, 168–173, https://doi.org/10.1038/s41561-019-0300-3, 2019.

Hersbach, H., Bell, B., Berrisford, P., et al.: The ERA5 global reanalysis, *Quarterly Journal of the Royal Meteorological Society*, 146, 1999–2049, https://doi.org/10.1002/qj.3803, 2020.

Hugonnet, R., McNabb, R., Berthier, E., Menounos, B., Nuth, C., Girod, L., Farinotti, D., Huss, M., Dussaillant, I., Brun, F., and Kääb, A.: Accelerated global glacier mass loss in the early twenty-first century, *Nature*, 592, 726–731, https://doi.org/10.1038/s41586-021-03436-6, 2021.

Huss, M. and Hock, R.: A new model for global glacier change and sea-level rise, *Frontiers in Earth Science*, 3, 54, https://doi.org/10.3389/feart.2015.00054, 2015.

Maussion, F., Butenko, A., Champollion, N., Dusch, M., Eis, J., Fourteau, K., Gregor, P., Jarosch, A. H., Landmann, J., Oesterle, F., Recinos, B., Rothenpieler, T., Vlug, A., Wild, C. T., and Marzeion, B.: The Open Global Glacier Model (OGGM) v1.1, *Geoscientific Model Development*, 12, 909–931, https://doi.org/10.5194/gmd-12-909-2019, 2019.

RGI Consortium: Randolph Glacier Inventory — A Dataset of Global Glacier Outlines, Version 6.0, NSIDC, https://doi.org/10.7265/4m1f-gd79, 2017.

Schuster, L., Rounce, D. R., and Maussion, F.: Glacier projections sensitivity to temperature-index model choices and calibration strategies, *Annals of Glaciology*, 64(92), 293–308, https://doi.org/10.1017/aog.2023.57, 2023.