Younger Dryas glaciation and climate in the Mourne Mountains, Northern Ireland

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Overview

• Here, we present evidence that small glaciers, with a total area of 11.67-17.13 km^2, formerly occupied the Mourne Mountains, NE Ireland (Fig. 1).
• Glacier mass-balance modelling is used to simulate the climate necessary to allow these glaciers to form, and we assess the likelihood that such conditions occurred during the Younger Dryas stadial (YD; c. 12.9–11.7 ka BP).

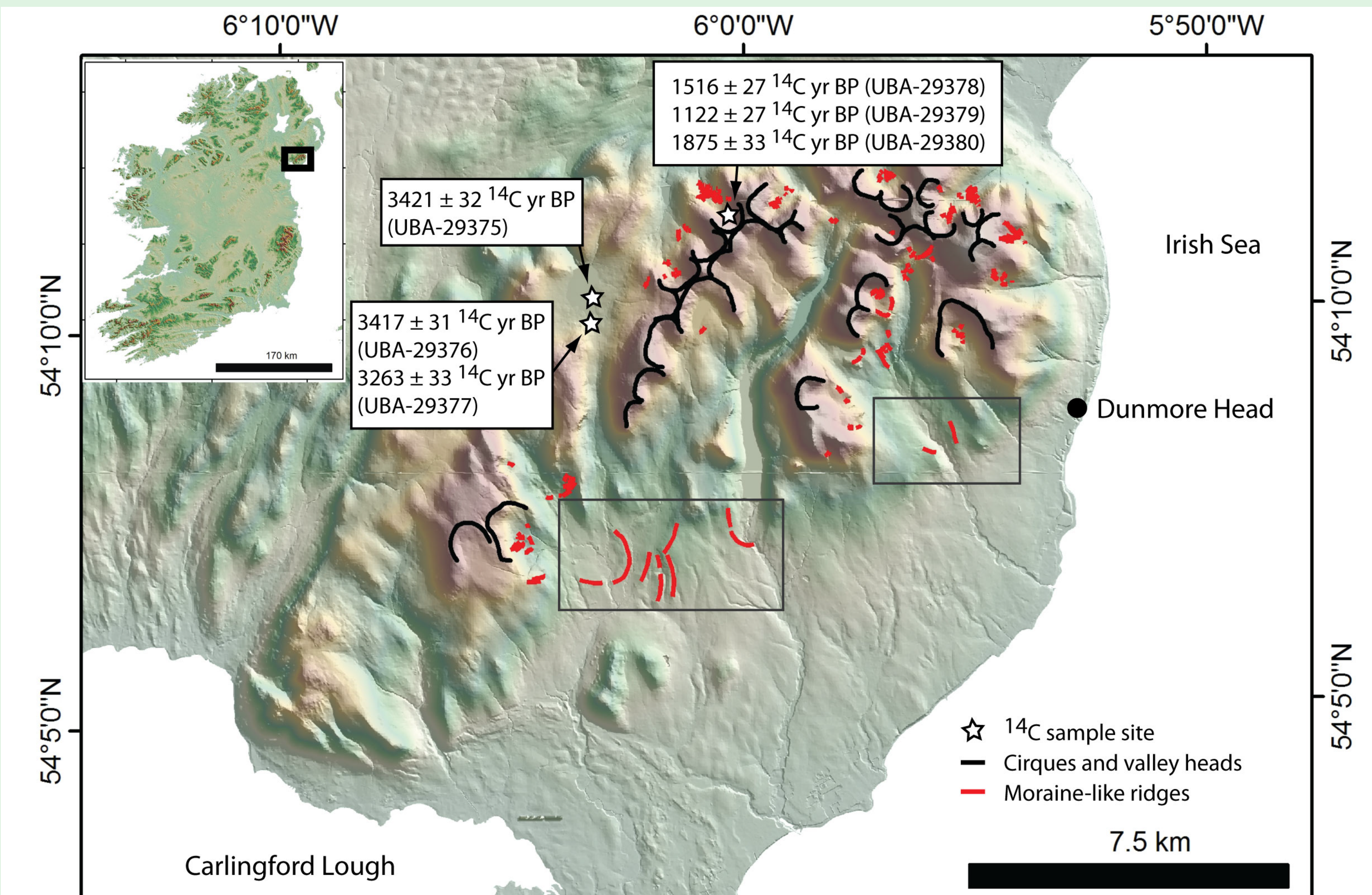

Fig. 1. Map of the Mourne Mountains. Moraine-like ridges in the boxed areas are presumed to have been deposited by ice flow through, and around, the mountains during the Killard Point Stadial (c. 17.2–16.6 ka). The radiocarbon ages reported here were obtained from basal peat deposits, but are of little use in constraining the chronology of former glaciations.

Former glaciers

• In the Mournes there are many geomorphological indicators of former glaciation (Fig. 1)
• Some moraine-like ridges are considered to have been deposited by small (< 2 km long) mountain- or cirque-style glaciers.
• However, radiocarbon dating of basal peat (see Fig. 1), has been unable to conclusively verify moraine ages, and they are difficult to group morphostratigraphically, creating challenges when trying to delineate former glacier margins.
• Because of this difficulty, we generate 'minimum' and 'maximum' reconstructions of former glaciers (Fig. 2), in the hope that these bracket the 'true' glacier surface areas.

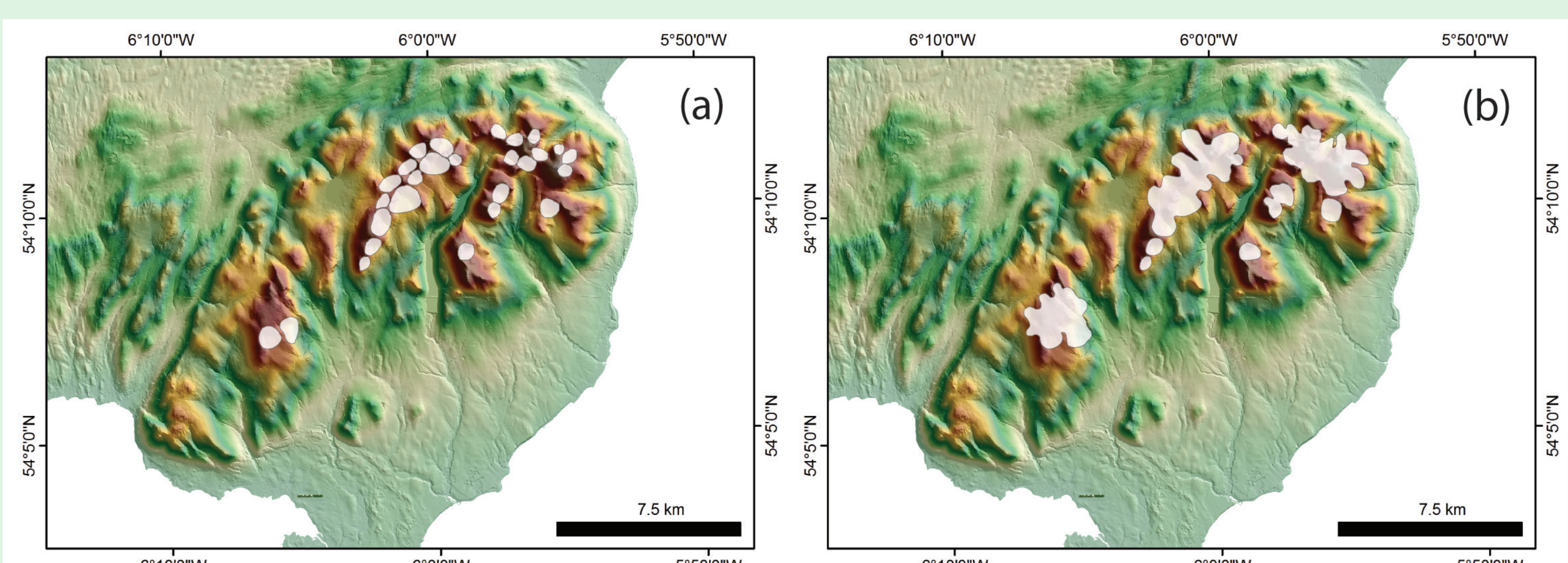

Fig. 2. Geomorphologically-based reconstructions of former glaciers in the Mourne Mountains (shown in white). (a) 'Minimum' reconstruction of cirque-type glaciers (total area = 11.67 km2). (B) 'Maximum' reconstruction of larger, partly-coalesced mountain glaciers (total area = 17.13 km^2).

Mass-balance Modelling

• Glacier reconstructions (Fig. 2) were used as targets for mass-balance modelling. In this model, glacier mass-balance was estimated using a positive degree-day (PDD) approach (Laumann and Reeh, 1993; Braithwaite, 2008; Heyman et al., 2013), based on equation 1:

$$MB = \Sigma P_{snow} - T^{+} * DDF \qquad \text{[eq.1]}$$

• Where, P_{snow} is the mean monthly precipitation (in mm) for months with a mean monthly temperature below a snowfall threshold of +1°C, T^{+} is the monthly PDD sum (°C), and DDF is the degree-day factor (mm/°C/day) for melting.

• The PDD model was validated by applying it to modern glaciers of the Mont Blanc Massif; the Austrian-Italian Alps; the SW French Alps; and SW Norway (Fig. 3).
• In each case, the model was run to match mapped modern glacier extents from the Randolph Glacier Inventory (RGI: version 5) (Pfeffer et al., 2014).

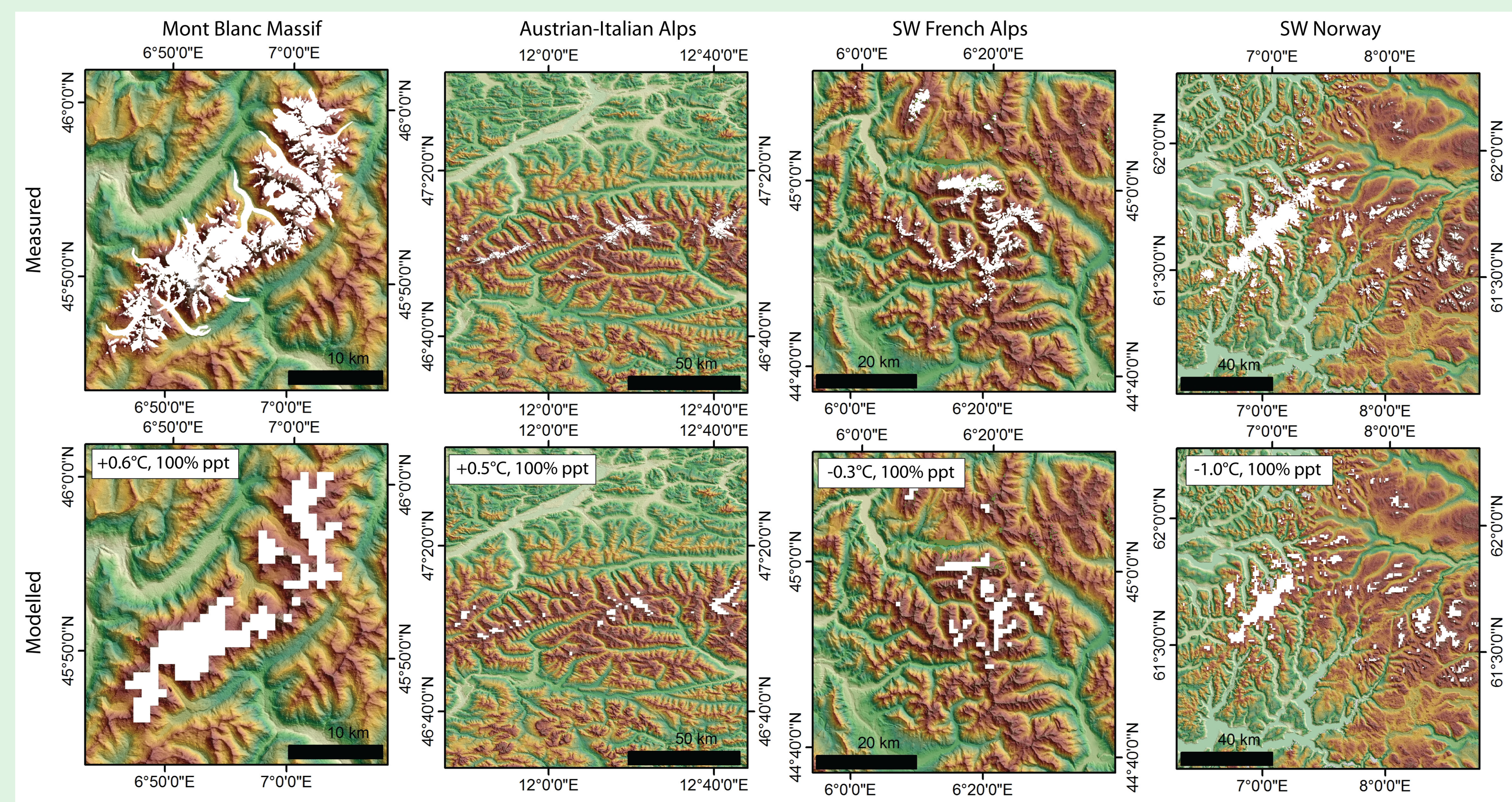

Fig. 3. Comparison between the measured extent of current glaciers from the RGI database version 5 (upper images) and the modelled accumulation areas (65% of the total area) of glaciers (lower images) in numerous regions of Europe. For the model runs, a DDF of 4.1 mm/°C/day was used, and the temperature perturbation (applied equally to all months) required to match the extent of modern glaciers is shown in the upper left of each image.

Results

• Model runs indicate that the cooling required to produce glaciers with an area of 11.67–17.13 km^2 in the Mournes ranges from -6.8 to -11.0 °C, depending on the glacier reconstruction, the DDF, the AAR, and precipitation perturbation (see Fig. 4).
• Differences in glacier reconstruction alone result in a variation of up to ~ 0.3 °C; differences in precipitation perturbation alone (from -50% to +30%) result in a variation of up to ~ 1.5°C; while differences in DDF alone result in a variation of up to ~ 2.7°C.

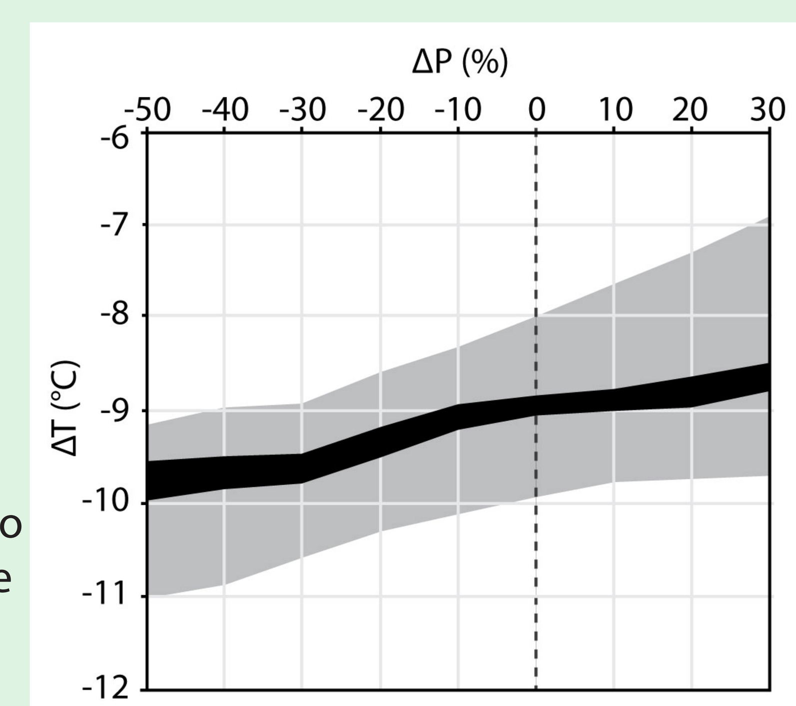

Fig. 4. Climate perturbations required to reproduce the reconstructed ice masses (Fig. 2) in the Mourne Mountains. Outputs are based on glacier accumulation area ratios (AARs) of 0.65 and 0.50. The black line represents model runs with a DDF of 4.1 mm/°C/day, and the thickness of this line reflects the difference between the minimum and maximum reconstruction. The grey area reflects model runs with DDF ranging from 2.5 to 8.0 mm/°C/day

Results cont.

• Under a highly seasonal climate (i.e., with a winter cooling of -30°C and a summer cooling of -8°C) (see Golledge, 2010), an annual precipitation reduction of between ~ 16 and ~ 75% (depending on the DDF used) would need to be applied in order to restrict ice masses to 11.67-17.13 km^2 (see Fig. 5).

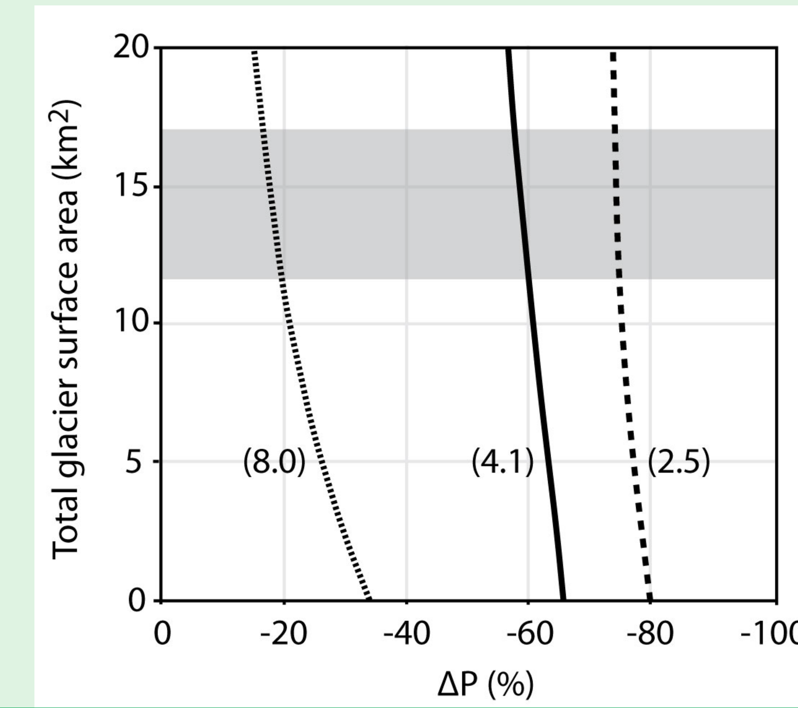

Fig. 5. Annual precipitation perturbations required to reproduce the reconstructed ice masses in the Mourne Mountains assuming a highly seasonal climate, with winter cooling of -30°C and summer cooling of -8°C (see Golledge, 2010). For each line, the adjacent bracketed number refers to the DDF used. The grey shading represents the 'target' surface area of the reconstructed ice masses (i.e., 11.67–17.13 km^2).

Conclusions

1. With no perturbation in precipitation, 8.1–9.9°C of cooling (applied to all months) is required to reproduce glaciers in the Mournes. This suggests a greater temp depression than necessary to reconstruct glaciers in other areas bordering the Irish Sea (Fig. 6).
2. If precipitation is reduced by 10–50%, modelling suggest a cooling of 8.2–11.0°C is required to reproduce glaciers in the Mournes.
3. Glaciers may have existed in the Mournes during the YD if conditions were notably seasonal, with dry, arid winters and comparatively mild summers. If strong seasonality is assumed, with summer cooling of -8°C and winter cooling of -30°C (as suggested for Western Scotland by Golledge, 2010), a precipitation reduction of between ~ 74% and ~ 75% would be required to only generate small ice-masses in the Mourne Mountains (assuming a DDF of 2.5). An alternative, and perhaps more plausible, scenario is that glaciers occupied the mountains during the early stages of the Younger Dryas, when temperature depression and sea-ice induced aridity were less severe.
4. The ice mass reconstructions presented here may relate to some pre-YD phase of glaciation (perhaps during the Clogher Head, Killard Point and/or East Antrim phases of ice sheet readvance). It is therefore possible that the Mournes were ice-free at the Younger Dryas or glaciers may have occupied the mountains continuously from the LGM to the onset of the Holocene.

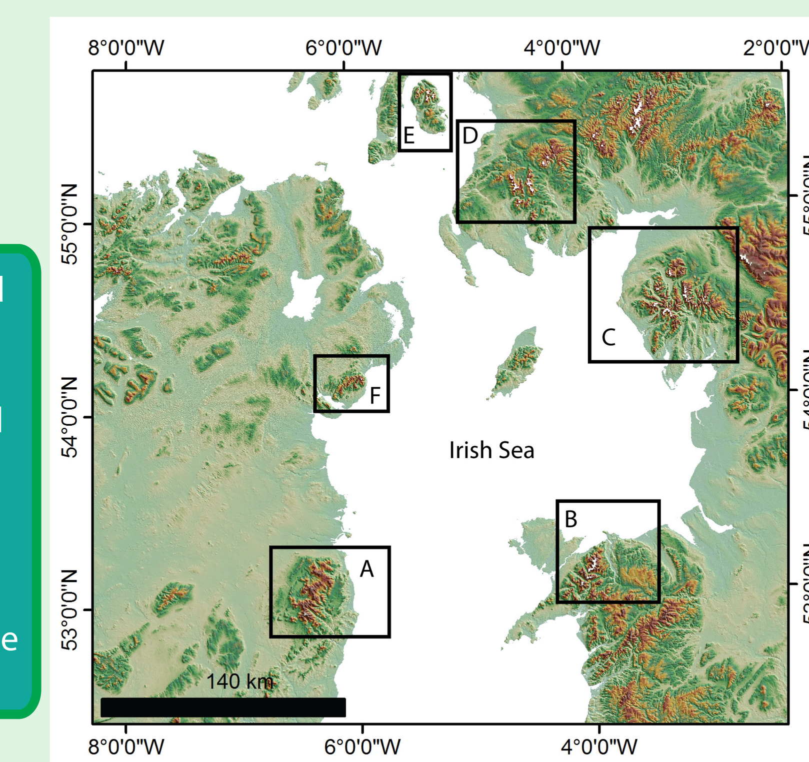

Fig. 6. Regions bordering the Irish Sea that are considered to have been occupied by glaciers during the Younger Dryas. The modelled accumulation areas are shown, based on an 8.0°C reduction in temperature (applied to all months), and no perturbation in precipitation, relative to present (with a DDF of 4.1). Note that this model run produces glaciers in (A) the Wicklow Mountains, (B) NW Wales, (C) the English Lake District, (D) in the Southern Uplands, (E) on the Isle of Arran, but not in (F) the Mourne Mountains.

References

Braithwaite, R.J., 2008. Temperature and precipitation climate at the equilibrium-line altitude of glaciers expressed by the degree-day factor for melting snow. Journal of Glaciology 54, 437–444. Golledge, N.R., 2010. Glaciation of Scotland during the Younger Dryas: a review. Journal of Quaternary Science 25, 550–566. Heyman, B.M., et al., 2013. Paleo-climate of the central European uplands during the last glacial maximum based on glacier mass-balance modeling. Quaternary Research 7(1), 49–54. Laumann, T., Reeh, N., 1993. Sensitivity to climate change of the mass balance of glaciers in southern Norway. Journal of Glaciology 39, 656–665. Pfeffer, W.T., et al., 2014. The Randolph Glacier Inventory: a globally complete inventory of glaciers. Journal of Glaciology 60 (221), 537–552.