Relations between heat flow, topography and Moho depth for Europe

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Abstract

The relation between heat flow, topography and Moho depth for recent maps of Europe is presented. New heat flow map of Europe (Majorowicz and Wybraniec, 2010) is based on updated database of uncorrected heat flow values to which paleoclimatic correction is applied across the continental Europe. Correction is depth dependent due to a diffusive thermal transfer of the surface temperature forcing of which glacial–interglacial history has the largest impact. This explains some very low uncorrected heat flow values 20–30 mW/m2 in the shields, shallow basin areas of the cratons, and in other areas including orogenic belts were heat flow was likely underestimated. New integrated map of the European Moho depth (Grad et al., 2009) is the first high resolution digital map for European plate understand as an area from Ural Mountains in the east to mid-Atlantic ridge in the west, and Mediterranean Sea in the south to Spitsbergen and Barents Sea in Arctic in the north. For correlation we used: onshore heat flow density data with palaeoclimatic correction (5318 locations), topography map (30 x 30 arc seconds; Danielson and Gesch, 2011) and Moho map (longitude, latitude and Moho depth, each 0.1 degree). Analysis was done in areas where data from all three datasets were available. Continental Europe area could be divided into two large domains related with Precambrian East European craton and Palaeozoic Platform. Next two smaller areas correspond to Scandinavian Caledonides and Anatolia. Presented results show different correlations between Moho depth, elevation and heat flow for all discussed regions. For each region more detailed analysis of these relation in different elevation ranges is presented. In general it is observed that Moho depth is more significant to HF then elevation. Depending on region and elevation range HF value in mW/m2 is up to two times larger than Moho depth in km, while HF relation to elevation varies much more.

I. Tectonic setting

The complex tectonic history of Europe reflects the break-up of a Neoproterozoic supercontinents Rodinia/Pannotia (Dalziel 1997) to form the fragment of Baltica and the subsequent growth of continental Europe beginning with the Caledonian orogeny. Caledonian and younger Variscan orogenesis involved accretion of Laurentian and Gondwanan terranes to the rifted margin of Baltica during the Palaeozoic (Pharaoh 1999). The suite of sutures and terranes that formed, so called Trans-European suture zone (TESZ) adjacent to the rifted margin of Baltica, extends from the British Isles to the Black Sea region. The TESZ is far more complex than a single suture, but in a broad sense, it is the boundary between the accreted Phanerozoic terranes and Proterozoic Baltica. Understanding its structure and evolution is one of the key tectonic challenges in Europe, and is certainly of global importance to studies in terrane tectonics and continental evolution. The younger Alps, Carpathian Mountains arc and Pannonian back-arc basin in the south form interrelated components of the Mediterranean arc-basin complex, and are the result of intricate Mesozoic/Cenozoic plate interactions in the Mediterranean region as the Tethys Ocean closed during convergence of Europe and Afro-Arabia. All tectonic processes and geological structures mentioned above have their image in Moho map. The oldest Archean and Proterozoic crust of thickness 40-60 km, continental Variscan and Alpine crust of thickness 25-35 km, and the youngest oceanic crust of Atlantic of thickness 10-20 km.

II. Input data sets

A. corrected heat flow map

The most recent high amplitude surface temperature change from recent Pleistocene glacial period to Holocene is the largest influence upon observed variations of heat flow with depth due to diffusive nature of the process. Earlier in time glacial interglacial periods of surface temperature, changes in the similar amplitude are of less influence (Majorowicz et al. 2008). The northern and central Europe area was covered by ice sheet during the last glacial maximum (LGM) 25–15 ka ago and cold climate be present there and in surrounding areas to the south. The synthetic heat flow transient profiles were calculated as a response to glacial cycles with glacial–interglacial surface temperature amplitude 7C-14C range for a homogeneous model with diffusivity 0.9 9 10-6 m2 s-1. The paleoclimatic correction for the above amplitude of change as proposed by Demezhko et al. (2006) has been calculated for the above forcing range as depth dependent heat flow correction (Majorowicz and Wybraniec 2010). This correction has been applied to thousands of reported uncorrected heat flow values in the IHFC (International Heat Flow Comm.) data base and additional new data reported in recent years for Poland and Germany. As correction is highest for shallow wells and low for deep wells (>2km). Therefore, it allows to bring the data to the same level. As an example, this correcting method resulted in increasing heat flow for Eastern European Craton in many cases based on measurements in few hundred meters deep well significantly (>10mW/m2). See figure 1.

B. MOHO map for European Plate

The European plate has a 4.5 Gy long and complex tectonic history. This is reflected in the present day large scale structures. The new digital Moho depth map is compiled from more than 250 data sets of individual seismic profiles, 3D models obtained by body and surface waves, receiver function results, and maps of seismic and/or gravity data compilations (Grad et al., 2009). The first digital, high resolution map of the Moho depth for the whole European plate covers the area from the Ural Mountains in the east to mid-Atlantic ridge in the west, and from the Mediterranean Sea in the south to the Barents Sea and Spitsbergen in Arctic in the north. In general three large domains within European plate crust are visible. The oldest Archean and Proterozoic crust has thickness 40-60 km, continental Variscan and Alpine crust has thickness 20-40 km, and the youngest oceanic Atlantic crust has thickness 10-20 km. See figure 2.

C. Digital Elevation Model

Elevation above sea level gives additional information - total thickness of continental crust. High resolution Digital Elevation Model was used to calculate elevation at points where Heat Flow was measured. See figure 3.

III. Analysis and results

For analysis Europe was divided into 4 areas: Area related with Precambrian East European craton (A), area related with Palaeozoic Platform (B), area related with Scandinavian Caledonides (C) and area related to Anatolia (D). For each of these areas heat flow measurements were analyzed in relation to Moho depth and elevation above sea level. Value of coefficients a and b in sum of a*M+b*H-HF were calculated to minimize it's value for all mesurements in given area (M – Moho depth in km, H – elevation in km, HF – heat flow in mw/m2). Values of calculated coefficients: for area A: a=1.35, b=-28.23, for area B: a=2.28, b=-3.00, for area C: a=1.64, b=--11.01 and for area D: a=1.18, b=21.02. Quality of correlation was checked for all analyzed areas. See figure 5 for correlation quality check for area A.

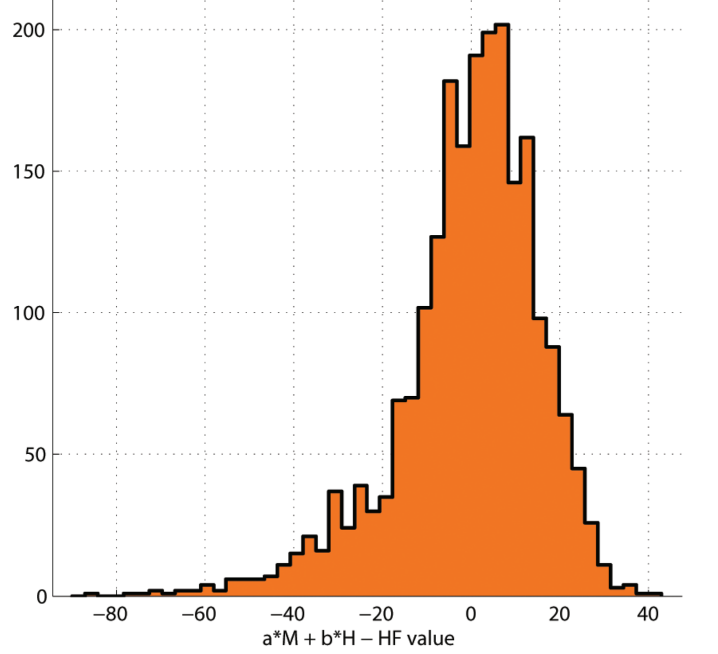

Figure 5. Histogram of calculated corelation values for area A. For perfect corelation all values shold be equal 0. Histogram is not simmetric due to high values of heat flow at some points.

IV. Conclusion

Correlation of heat flow wits total crust thickness: moho depth + elevation above sea level. Depending on region and elevation range HF value in mW/m2 is up to two times larger than Moho depth in km, while HF relation to elevation varies much more. Correlation to elevation above sea level is negative for most of europe (to higher we get the smaller the heat flow). Only for area of anatolia this correlation is positive.

Vienna
07-12 IV 2013

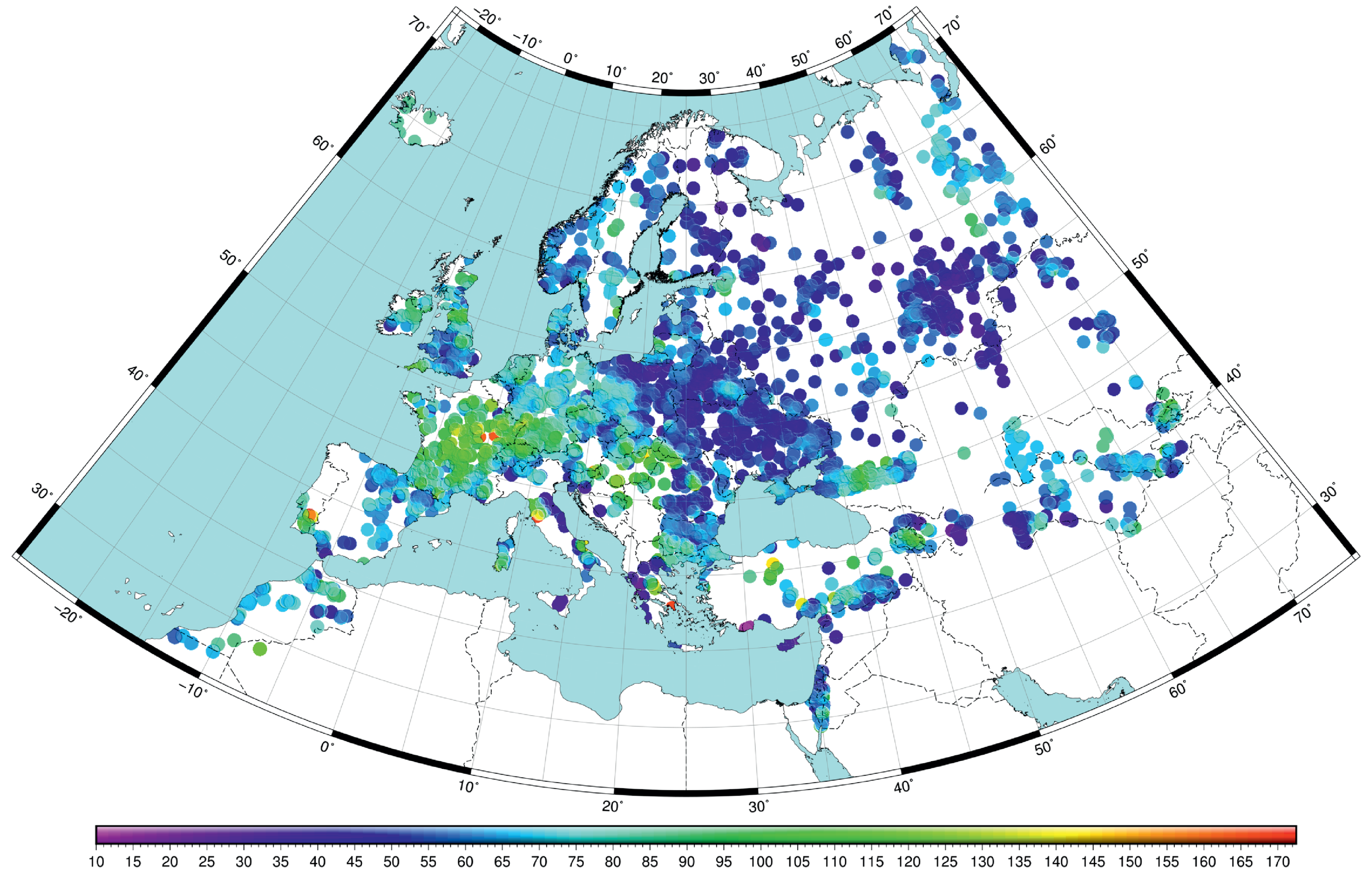

Figure 1. Heat flow map of the European plate corrected for the recent Pleistocene glacial period to Holocene high amplitude surface temperature change which influence heat flow in wells generally shallower than 2km (majority of reported heat flow values). Heat flow is in mW/m2. Circles on map are 50 km in diamiter. In case of cirles overlapping values are averaged.

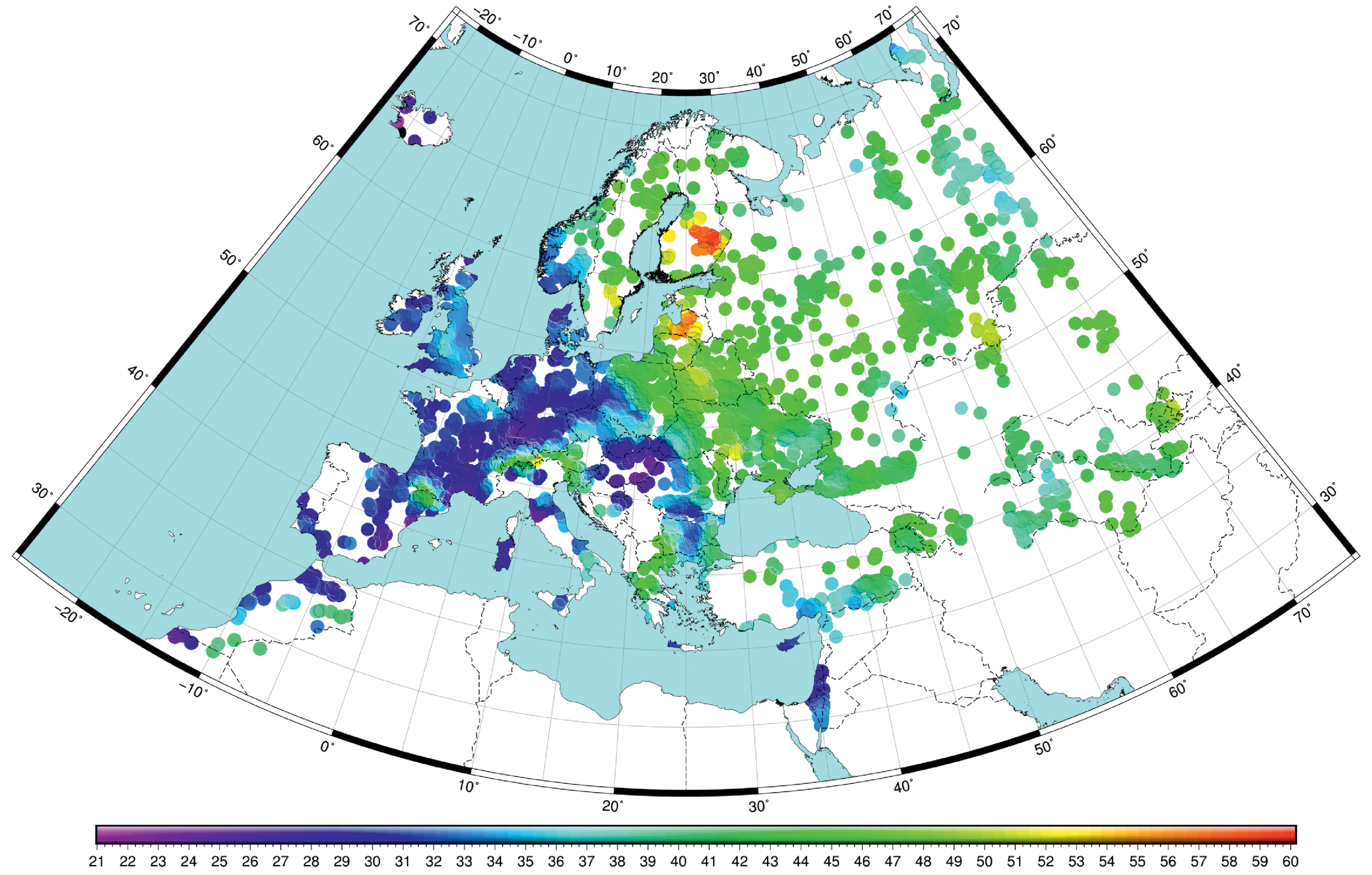

Figure 2. Moho depth map (in km) of the European plate at areas where all three datasets have data. The map highlights the three age groups of the European crust - thin and young oceanic crust of the Atlantic Ocean, the continental crust of Variscan and Alpine Europe, and thickest and oldest crust of Archean and Proterozoic Baltica. Circles on map are 50 km in diamiter. In case of cirles overlapping values are averaged.

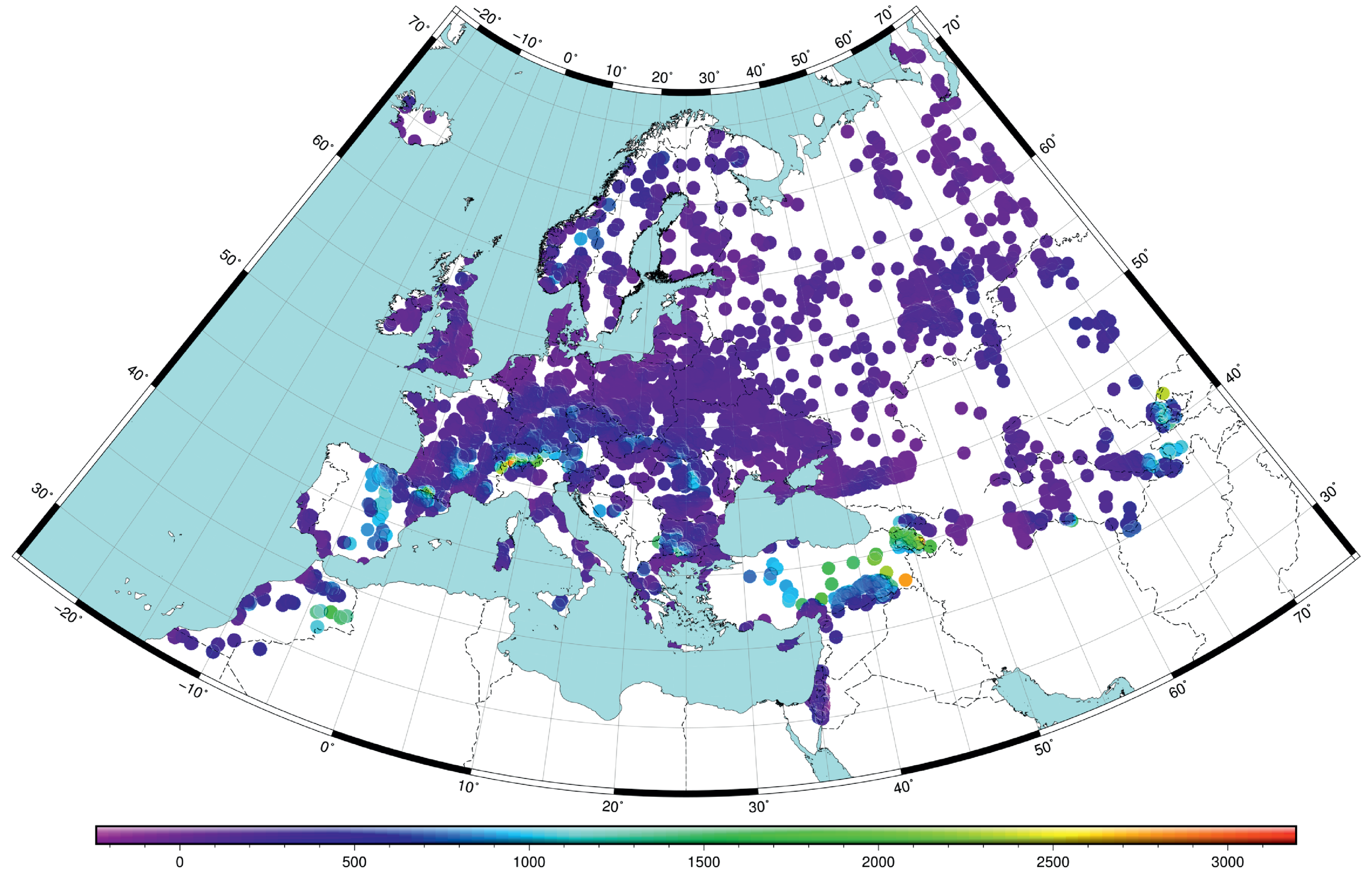

Figure 3. Map shows values of elevation above (or below) sea level at areas where all three datasets have data. Data were obtained by SRTM setelitte. Circles on map are 50 km in diamiter. In case of cirles overlapping values are averaged.

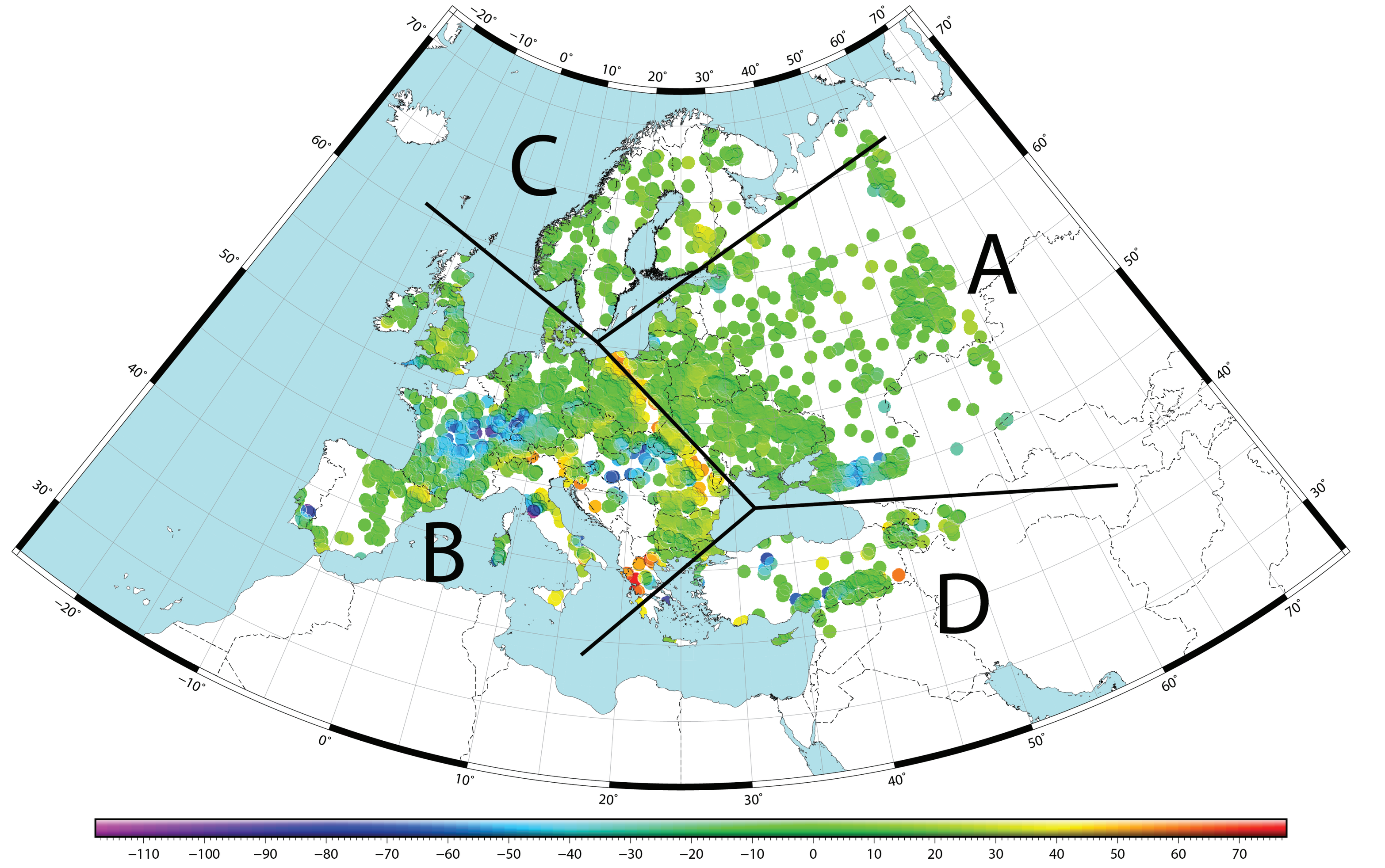

Figure 4. Map shows values of calculated correlations a*M+b*H-HF. For each area (A, B, C, D) set of parameters a and b was different. Expected value of correlation was 0 - perfect correlation. Circles on map are 50 km in diamiter. In case of cirles overlapping values are averaged.