New Heat Flux Model for Antarctica with a Machine Learning Approach

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Motivation

- > 99% of Antarctica is covered by Ice
  - Largest potential source for **sea level rise**

- Geothermal Heat Flux (GHF) is an important boundary condition for **ice-sheet modelling**
  - Affects Ice temperature and rheology
  - Can lead to basal melting and decoupling of ice-bed interface

[Credit: ESA/Planetary Visions]


[From Whitehouse et al., 2019]
Motivation

Global existing GHF measurements

- Very sparse data in Antarctica
- Different approaches for estimation of continent wide GHF distribution


mW/m²
Method

• **Idea:** GHF is related to its geodynamic environment

  → Machine learning for prediction

**Gradient Boosting Regression Tree Algorithm [1]**

1) Loss function needs to be optimized (e.g. squared error)

2) Weak learners make predictions (e.g. decision trees)

3) Additive model adds weak learners to minimize the loss function

Method - Data

<table>
<thead>
<tr>
<th>Feature</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moho</td>
<td>Szwillus et al., 2019</td>
</tr>
<tr>
<td>LAB</td>
<td>Afonso et al., 2019</td>
</tr>
<tr>
<td>Topography</td>
<td>Hirt &amp; Rexer, 2015 (Earth 2014) &amp; Morlinghem et al., 2019 (BedMachine)</td>
</tr>
<tr>
<td>Susceptibility</td>
<td>Inferred from Hemant &amp; Maus, 2005</td>
</tr>
<tr>
<td>Tectonic units</td>
<td>Schaeffer &amp; Lebedev, 2015</td>
</tr>
<tr>
<td>Mean curvature from grav. gradients</td>
<td>Ebbing et al., 2018</td>
</tr>
<tr>
<td>Vertical magnetic component</td>
<td>Yixiati et al. (In prep.)</td>
</tr>
<tr>
<td>Distance to ridges</td>
<td>UTIG (Plates project)</td>
</tr>
<tr>
<td>Distance to trenches</td>
<td>UTIG (Plates project)</td>
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<tr>
<td>Distance to transform faults</td>
<td>UTIG (Plates project)</td>
</tr>
<tr>
<td>Distance to young rifts</td>
<td>UTIG (Plates project)</td>
</tr>
<tr>
<td>Distance to volcanos</td>
<td>Global Volcanism Program &amp; Van Wyk de Vries et al., 2018</td>
</tr>
</tbody>
</table>

- Available heat flow higher than 200 mW/m² is filtered out and subsequently binned with a resolution of 0.5°
- Only continental data is used (> -1 km)
- Data is split randomly into training (80 %) and test data (20 %)
Results – Heat Flow Map

- Preliminary predicted heat flow for Antarctica
- Overall higher in West Antarctica, especially on Peninsula and Viktoria Land
- Some measurements fit quiet well, others (e.g. near the south pole) are underestimated by the prediction
- Not enough measurements for meaningful evaluation

For Comparison:
Results - Statistics

- Plot of the actual and the predicted test data set
- A perfect prediction model would lie exactly on the diagonal line
- Lower GHF is closer to the line than higher values, which are mainly underestimated (due to rather rare occurrences)

- Moho depth, distance to volcanos and ridges are selected as most important features for heat flow prediction by the machine learning algorithm

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Results – Well Known Area

Predictions for USA

- Relatively high amount of measurements in USA
- Helpful for interpretation of reliability of prediction model
  - Overall trends are predicted well
  - Isolated high values could not be predicted
Conclusions & Outlook

• Still **room for improvement**: parameter testing, filtering of data, using more/other features, etc ...

• Overall **reasonable results** and **solid predictions** for highly sampled areas

Next:

• Review **reliability** of the few existing heat flow measurement estimates on the continent

• Train and test model only with Australian data

• Global data often not reliable in polar regions
  • Use **regional data** for Antarctica and neighbors during Gondwana

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References and Further Reading


Nice explanation of Gradient Boosting:
2 https://arogozhnikov.github.io/2016/06/24/gradient_boosting_explained.html

Heat Flux Models of Antarctica:


Nice Study with machine learning for heat flux prediction:

Graphic from 2nd Slide: