Global Oceanic Heat Flow

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Objectives

1. Derive an equation for the local heat loss of the thermal boundary layer as a function of depth and age of the seafloor.
2. Identify the assumptions used for the equation.
3. Calculate an approximate total oceanic heat loss.
Assumptions

1. Steady-state spreading
2. No internal heat generation
3. No lateral heat flow
Theory

Conservation of energy:

\[ \rho_m C_p \vec{v} \cdot \nabla T = \nabla \cdot \vec{q} \]  \hspace{1cm} (1)

Thermal contraction:

\[ \rho(T) = \rho_m [1 - \alpha (T - T_m)] \]  \hspace{1cm} (2)

Isostasy:

\[ d(t) = \frac{-\alpha \rho_m}{\rho_m - \rho_w} \int_t^L (T - T_m) \, dz \]  \hspace{1cm} (3)
Theory cont.

Taking the gradient of both sides of Eq.(3) and then the dot product with the plate velocity,

\[ \mathbf{v} \cdot \nabla d(t) = \frac{-\alpha \rho_m}{\rho_m - \rho_w} \int_d^L \mathbf{v} \cdot \nabla Tdz \]  \hspace{1cm} (4)

Combining with Eq.(1)

\[ \mathbf{v} \cdot \nabla d = \frac{-\alpha}{(\rho_m - \rho_w)c_p} \int_d^L \nabla \cdot \mathbf{q}dz \]  \hspace{1cm} (5)

By neglecting lateral heat transport on the right side of Eq.(5) and integrating,

\[ \int_d^L \frac{\partial}{\partial z} q(z)dz = q(L) - q(d) = q_b - q_s \]  \hspace{1cm} (6)
Theory cont.

Substituting Eq.(6) into Eq.(5),

\[ \mathbf{\hat{v}} \cdot \nabla d = \frac{-\alpha}{(\rho_m - \rho_w) c_p} (q_b - q_s) \]  

(7)

The local fossil spreading velocity,

\[ \mathbf{\hat{v}} = \frac{\nabla A}{\nabla A \cdot \nabla A} \]  

(8)

The final expression becomes:

\[ \frac{\nabla A \cdot \nabla d}{\nabla A \cdot \nabla A} = \frac{-\alpha}{c_p(\rho_m - \rho_w)} (q_b - q_s) \]  

(9)

Equation from Parsons & McKenzie (1978):

\[ \frac{-(\rho_0 - \rho_w)c_p}{\alpha} \frac{\partial d}{\partial t} + q_u = q_b \int_0^a H(z)dz \]  

(10)
Approach

• Collect depth and age data sets.
• Estimate basal heat flow ($q_b$).
• Compute temperature-average values of heat capacity ($C_p$) and thermal expansion coefficient ($\alpha$).
• Assume that the sediment correction is not necessary, because it is thin for young seafloor and independent from depth gradients.
• Calculate the scalar substance rate ($\frac{\nabla A \cdot \nabla d}{\nabla A \cdot \nabla A}$).
Use the following values:

1. Basal heat flow $q_b = 38 \text{ mWm}^{-2}$
2. Heat capacity $C_p$ and thermal expansion coefficient $\alpha$ based on Doin and Fleitout (1996):
   \[ C_p = 1124 \text{ J kg}^{-1} \text{ °C}^{-1} \text{ and } \alpha = 3.85 \times 10^{-5} \text{ °C}^{-1} \]
3. Densities: $\rho_m = 3330 \text{ kg m}^{-1}$ and $\rho_w = 1025 \text{ kg m}^{-1}$
Limitations – Near Ridge Axis

This approach fails to predict the heat flow at the ridges for two reasons:

1. The assumption of local isostasy is not valid, because ridge-axis topography is partly supported by dynamics and flexure.

2. The seafloor subsidence rate near the ridge axis (< 2 Ma) is anomalously low due to the rapid quenching of the crust by hydrothermal circulation.

Therefore we use the HSC model to estimate the heat loss for oceanic crust < 3 Ma.
Surface heat flow Wei and Sandwell (2006)
Mid-Atlantic Ridge

(Top) Comparison of a half-space cooling model and average seafloor depth. 
(Bottom) Heat flow using equation (9) (Wei and Sandwell, 2006).
Global Ocean Seafloor

Surface heat flow (Wei and Sandwell, 2006)
(Top) Comparison of a half-space cooling model and average seafloor depth. (Bottom) Heat flow using equation (9) (Wei and Sandwell, 2006).
Use half-space cooling (HSC) model to estimate the contribution of spreading ridge (0 ~ 3 Ma) on heat flow (5.1 TW) (Wei and Sandwell, 2006).
The temperature-averaged heat capacity has a rather narrow range between 1094 and 1124 Jkg$^{-1}$°C$^{-1}$, whereas the temperature-averaged thermal expansion coefficient has a much larger range between 2.9 and 4.2 $\times$ 10$^{-5}$°C$^{-1}$ (Wei and Sandwell, 2006).
Conclusions

### Table 1
Cenozoic and global heat flow totals

<table>
<thead>
<tr>
<th>Model</th>
<th>(\alpha) (\left(10^{-5} {^\circ}C^{-1}\right))</th>
<th>(q_b) (\text{(W m}^{-2}))</th>
<th>0–66</th>
<th>3–66</th>
<th>0–3 Ma HSC (not included)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9</td>
<td>28.9</td>
<td></td>
<td>15.4</td>
<td>44.1</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>35.2</td>
<td></td>
<td>14.4</td>
<td>43.1</td>
<td></td>
</tr>
<tr>
<td>3.85</td>
<td>38.0</td>
<td></td>
<td>14.0</td>
<td>42.7</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>40.0</td>
<td></td>
<td>13.5</td>
<td>42.2</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>50.2</td>
<td></td>
<td>12.0</td>
<td>35.6</td>
<td></td>
</tr>
</tbody>
</table>

HSC, \(q_t = 960 \frac{\sqrt{t_2} - \sqrt{t_1}}{t_2 - t_1}\)

Lat. \(-70^\circ\) to \(90^\circ\)

<table>
<thead>
<tr>
<th>Lat.</th>
<th>(q_t)</th>
<th>0–66</th>
<th>3–66</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-70^\circ) to (90^\circ)</td>
<td>20.4</td>
<td>15.5</td>
<td>44.0</td>
<td></td>
</tr>
<tr>
<td>(-70^\circ) to (70^\circ)</td>
<td>20.14</td>
<td>15.3</td>
<td>43.7</td>
<td></td>
</tr>
</tbody>
</table>

Wei and Sandwell (2006)
Conclusion cont.

Wei and Sandwell (2006)
References


THANK YOU

QUESTIONS?