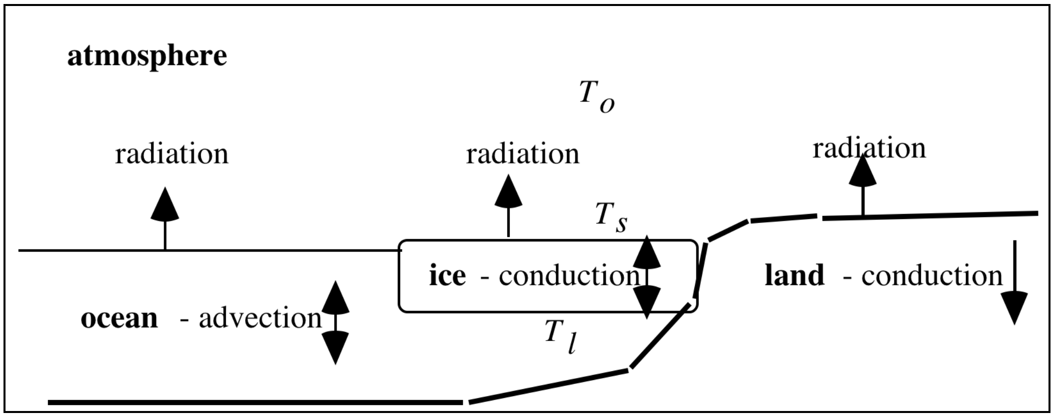
HEAT TRANSPORT SUMMARY

(Rees Chapter 6)

Modes of Heat Transport



ocean - Heat transport is primarily by advection. A hot parcel of water flows to the surface where it radiates heat.

ice - Heat is advected to the base of the ice which is at a constant temperature T_l (i.e., the melting point of the ice). The upper surface of the ice radiates heat to achieve a temperature T_s. The heat conducts through the ice so the interior has a temperature between T_l and T_s.

land - Heat transport within the rock or soil is primarily conductive. The land surface radiates heat.

Fourier's Law of Heat Conduction Heat flows from areas of high temperature to areas of low temperature in the direction of the temperature gradient.

$$\mathbf{q} = -K \nabla T$$

q	-	heat flux vector	W m^{-2}	
T	-	temperature	°K	
K	-	thermal conductivity	W m^{-1} °K^{-1}	(2.3 for ice)

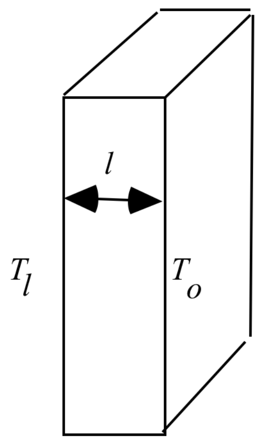
For most solids, the thermal conductivity is nearly isotropic and relatively insensitive to temperature so the linear equation is a good approximation. This linear relationship also keeps the differential equations tractable. The law of energy conservation provides a way to derive the equation for diffusion of heat. Consider the factors that control the temperature of a volume of material.

$$\Gamma \nabla \cdot \nabla\, T(\mathbf{x},t) \quad - \quad \frac{\partial T}{\partial t} \quad = \quad \frac{Q(\mathbf{x},t)}{\rho c}$$

divergence of heat flux	change in temperature with time	internal heat generation

$Q()$	-	heat generation	W m^{-3}	
c	-	heat capacity	J kg^{-1} °K^{-1}	(energy needed to heat 1 kg by 1°K)
ρ	-	density	kg m^{-3}	
$\Gamma = K/\rho c$		thermal diffusivity	m^2 s^{-1}	

The thermal diffusivity is a measure of the length of time it takes a heat pulse to travel a distance *l*.



1) Start with an isothermal block at a temperature of T_O.
2) Increase the temperature on the left side to T_1.
3) After approximately τ seconds, the heat pulse will reach the right side of the block

$$\tau = \frac{l^2}{\Gamma}$$

Later we'll introduce another material property called the thermal inertia *P* which is a measure of how well a material retains heat.

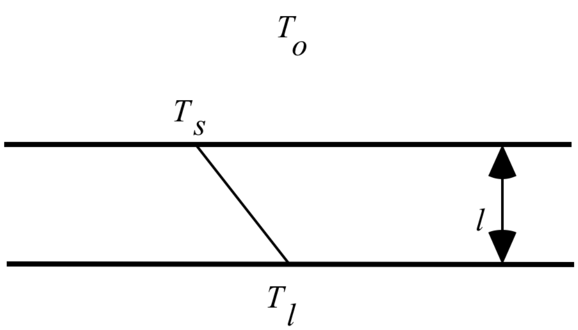
$$P = (K\ \rho\ c)^{1/2} = \Gamma^{1/2} \rho c$$

copper	-	high thermal inertia
dry sand	-	low thermal inertia

Boundary Conditions Most remote sensing applications can be approximated by some combination of three boundary conditions. We'll usually simplify matters by assuming one of the boundary conditions dominates.

T	-	prescribed temperature
$q_c = K\dfrac{\partial T}{\partial z}$	-	heat flux limited by conduction
$q_r = \varepsilon\,\sigma\left(T_1^4 - T_o^4\right)$	-	heat flux limited by radiation

Liquid Ocean vs. Ice Covered Ocean Lets investigate the insulating effect of a layer of ice on the ocean. How efficiently does it prevent the escape of heat and how does this depend on ice thickness?



T_o	-	local air temperature
T_s	-	unknown surface temperature of the ice
T_l		freezing point of seawater (273˚K)
l	-	ice thickness.

Case 1. Zero ice thickness, air temperature of 250˚K. - Radiation controls the heat loss.

$q_r = 0.99\ x\ 5.67\ x 10^{-8}\ (273^4 - 250^4) = 93\ W\ m^{-2}$

Case 2. Ice-covered ocean

The radiative heat flux at the surface of the ice is $q_r = \varepsilon\,\sigma\left(T_s^4 - T_o^4\right).$

The conductive heat flux through the ice is $q_c = K\,\dfrac{T_1 - T_s}{l}.$

Of course at the surface these fluxes must be equal $\varepsilon\,\sigma\left(T_s^4 - T_o^4\right) = K\,\dfrac{T_1 - T_s}{l}.$

One can arrive at a transcendental equation for the surface temperature. $T_s^4 = T_o^4 + K\,\dfrac{T_1 - T_s}{l\varepsilon\sigma}.$

As an example consider a 1 m-thick ice layer. After iterating the transcendental equation we find a surface temperature of 259˚K. This can be inserted into either of the two above equations to yield a heat flux out of the ocean of only 32 W m^{-2}, which is less than 1/2 of the radiative flux.

Notes from: Thomas, R. H., *Polar Research from Satellites*, Joint Oceanographic Institutions, Inc, 1755 Mass Ave. NW Washington, DC 30036-2102

"Contrasts between conditions at the equator and at the poles is the main driver of large-scale atmospheric and oceanic circulation systems that redistribute heat, water gases and nutrients around the world and determine climate, habitability, and biological productivity. Unique aspects of the polar regions that influence the climate machine include:

- the dramatic albedo change associated with the annual cycle of snow cover on land and sea ice on the ocean;
- the insulation between atmosphere and the ocean provided by the sea-ice cover;
- the effects of the melting and freezing of sea ice on the ocean-density structure that controls the formation of the deep and bottom waters which cool and ventilate the deep oceans."