Ocean Surfaces Warm and Cool Diurnally and Seasonally Less than Land Surfaces Do: Why?

- Identify physical properties of matter that differ for water and rock/sand/soil
- Consider which of these properties might help explain the different magnitude of temperature variations over land and ocean surfaces

Some Properties of Matter (Rock/Sand/Soil vs. Water)

Physical Property	Land (Rock/Sand/Soil (dry))	Water (Ocean)
Albedo	Higher (~0.17-0.4)	Lower (~0.06)
Density	Higher (~2.5-3.5 gm/cm^3)	Lower (~1 gm/cm^3)
Transmissivity (transparency) for solar radiation	~0	Higher (but most visible light absorbed within ~< 200 m depth)
Thermal conductivity		
Specific heat	Lower (~0.2 cal/gm/ºC)	Higher (~1 cal/gm/ºC)
Viscosity [fluidity]	Viscosity very high [fluidity ~0]	Viscosity lower than land [fluidity higher than land]
Volatility ("evaporability")	~0	Higher than land

Changes in Temperature and Heat Content

The change in temperature than any object experiences (ΔT) is proportional to the change in it's heat content (ΔH):

$$\Delta T \propto \Delta H$$

The constant that converts this proportionality to an equation is the reciprocal of the ***heat capacity*** (C_H):

$$\Delta T = \Delta H / C_H$$

- C_H has *dimensions* of energy/temperature
- It has *units* of Joules/Kelvin or Joules/℃, calories/℃, etc.

Heat capacity is defined as the *amount of heat that the object must gain or lose to change it's temperature by one degree*.

Changes in Temperature and Heat Content

The heat capacity of an object depends on:

1. The kind of material that the object is made from
   (Some materials must gain or lose more heat than others to change their temperature by a given amount)

2. The amount (mass) of that object
   (The more material you have, the more heat you have to add or remove to change the temperature by a given amount.)

Changes in Temperature and Heat Content

The ***specific heat*** (c_H) of a material is the amount of heat that a *unit mass* of the material must gain or lose to change its temperature by one degree.

Specific heat depends only on:

1. The kind of material that the object is made from
   (Some materials must gain or lose more heat than others to change their temperature by a given amount.)

This makes specific heat an *intrinsic physical property* of the material, independent of the amount of material in an object.

- c_H has *dimensions* of energy/mass/temperature
- It has *units* of Joules/kg/°C, Joules/gm/°C, calories/gm/°C, etc.

Changes in Temperature and Heat Content

The heat capacity of an object and the specific heat of the material from which the object is made are related as follows:

$$c_H = C_H / m$$

where *m* is the mass of the object.

Hence, we can write the relation between the change in temperature of an object resulting from a change in its heat content as:

$$\Delta T = \left(\frac{1}{c_H\, m}\right) \Delta H$$

The *rate of change* in temperature and heat content of an object is just the change divided by the time over which the change occurs, Δt:

$$\frac{\Delta T}{\Delta t} = \left(\frac{1}{c_H\, m}\right) \frac{\Delta H}{\Delta t}$$

Ocean Surfaces Warm and Cool Slower Than Land Surfaces: the Role of Specific Heat

$$\frac{\Delta T}{\Delta t} = \left(\frac{1}{c_H\, m}\right)\frac{\Delta H}{\Delta t}$$

This relation gives us a tool for understanding why ocean surfaces warm and cool diurnally and seasonally less than land surfaces do.

Suppose that ocean and land surfaces gain or lose heat at the same rate (so the rate at which heat enters or leaves the surface, $\frac{\Delta H}{\Delta t}$, is the same for both). (For example, suppose that the solar absorption flux or the LWIR emission flux is the same for both.) Further suppose that the same mass of material (*m*) at the surface gains or loses that heat.

It follows that $\frac{\Delta T}{\Delta t}$ must be smaller for the ocean surface than for land surface (for both warming and cooling) because specific heat (c_H) is greater for water than for land.

Ocean Surfaces Warm and Cool Slower Than Land Surfaces: the Role of Viscosity/Fluidity

$$\frac{\Delta \mathrm{T}}{\Delta \mathrm{t}} = \left(\frac{1}{\mathrm{c_H}\, m}\right) \frac{\Delta \mathrm{H}}{\Delta \mathrm{t}}$$

Again suppose that ocean and land surfaces gain or lose heat at the same rate (so the rate at which heat enters or leaves the surface, $\Delta H / \Delta t$, is the same for both). Because water is fluid and often stirred by the wind, water at the surface mixes vertically with water below it. As a result, water at the surface gains or loses some heat, then mixes downward and is replace by unwarmed or uncooled water from below, which then gains or loses some heat, and so on. This in effect spreads the gain or loss of heat through the surface over a greater mass of material than would be true on land, where the same bit of material (and hence smaller total mass of material) gains or loses all of the heat.

It follows that $\frac{\Delta \mathrm{T}}{\Delta \mathrm{t}}$ must be smaller for the ocean surface than for land (for both warming and cooling) because the mass of material (m) affected by the gain or loss of heat is greater for water due to vertical mixing than it is for land.

Ocean Surfaces Warm Slower than Land Surfaces: the Role of Transparency

$$\frac{\Delta \mathrm{T}}{\Delta \mathrm{t}} = \left(\frac{1}{\mathrm{c_H}\, m}\right)\frac{\Delta \mathrm{H}}{\Delta \mathrm{t}}$$

Suppose that the sun shines equally on ocean and land surfaces, and ignore differences in albedo between the two, so that the rate at which the ocean and land absorb solar radiation, $\Delta H/\Delta t$, is the same for both.

Because water is partly transparent to visible light, solar radiation entering it is absorbed gradually over a depth perhaps as great as 100-200 meters. In contrast, solar radiation absorbed by land is absorbed almost immediately by a much smaller mass of opaque material right at the surface.

It follows that $\frac{\Delta \mathrm{T}}{\Delta \mathrm{t}}$ must be smaller for the ocean surface than for land (for warming) because the mass of material (*m*) affected by the gain or loss of heat is greater for water due to its partial transparency than it is for land.

(Note, though, that this would *not* apply to cooling because water and land are equally non-transparent to LWIR radiation.)

Ocean Surfaces Warm Slower Than Land Surfaces: the Role of Volatility

$$\frac{\Delta \mathrm{T}}{\Delta \mathrm{t}} = \left(\frac{1}{\mathrm{c_H}\, m}\right)\frac{\Delta \mathrm{H}}{\Delta \mathrm{t}}$$

Suppose that the sun shines equally on ocean and land surfaces, and ignore differences in albedo between the two, so that the rate at which the ocean and land absorb solar radiation is the same for both.

Because water is volatile, some of it evaporates, converting some of its heat into latent heat, thereby in effect reducing the rate at which heat is added, $\Delta H/\Delta t$, compared to land, because dry rock/sand/soil doesn’t evaporate.

It follows that $\frac{\Delta \mathrm{T}}{\Delta \mathrm{t}}$ must be smaller for the ocean surface than for land (for warming) because the evaporation of water effectively reduces any heat added to it, decreasing the net $\Delta H/\Delta t$.

(Note, though, that at night and during fall and winter, when the surface usually loses heat, the extra heat lost by water compared to land due to evaporation would, all else being equal, increase the magnitude of $\Delta H/\Delta t$ for water relative to land, which would tend to make $\Delta T/\Delta t$ larger over water, which is not what we actually observe, so water’s greater volatility helps explain only the smaller warming over the ocean relative to land during the day and in spring and summer, not the smaller cooling at night and in fall and winter.)