
# OCEANIC HEAT BUDGET

**Mehmet Buğra BAYKUŞ**

**517111002**

## 1. INTRODUCTION

Our sun is the source of all energy and energy interactions on Earth. As the energy impinges upon the Earth’s surface, a portion of it is absorbed and stored by the solid Earth, its water surfaces, and the atmosphere, while the remaining energy is utilized by reactions within the atmosphere or reflected back into space.

Of the absorbed and retained portion of the solar energy reaching the Earth’s surface, much of it is distributed throughout the oceans and atmosphere by the circulatory patterns set up by the different density current created by the energy absorption.

The sea and atmosphere are in constant motion. Waves, tides, and convective processes carry energy to all levels of the ocean and throughout all latitudes. All these motions of the sea are the direct result of energy that reaches the surface of the Earth and is absorbed by the land and water.

While some of the energy is transferred by reflection from the surface, the absorption is important primarily because it makes energy available to the Earth and its atmosphere through coversion into other forms.

About half the solar energy reaching Earth is absorbed by the ocean and land, where it is temporarily stored near the surface. Only about a fifth of the available solar energy is directly absorbed by the atmosphere.

Of the energy absorbed by the ocean, most is released locally to the atmosphere, mostly evaporation and infrared radiation. The remainder is transported by currents to other areas especially middle latitudes.

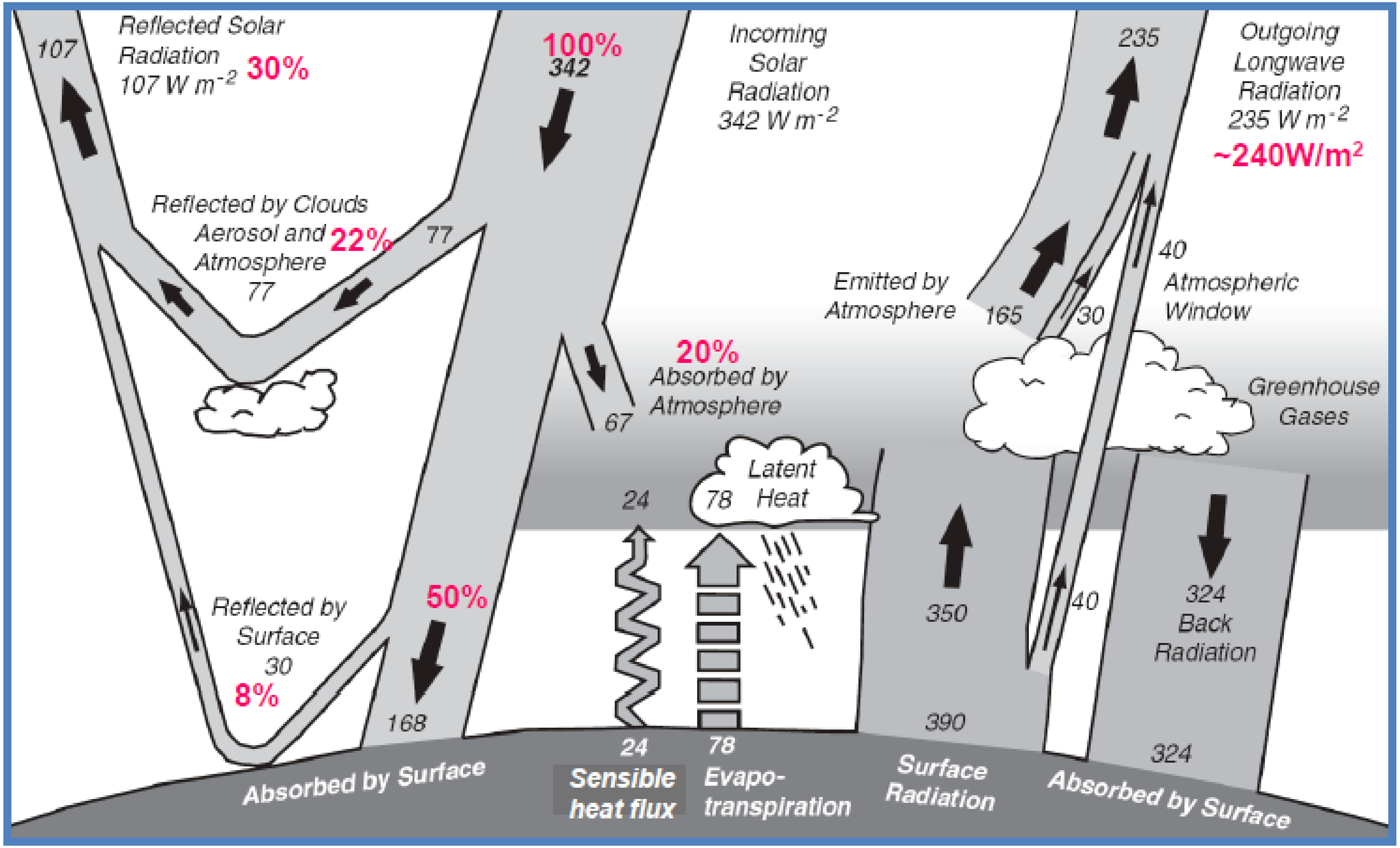


**Figure 1:** The mean annual radiation and heat balance of the Earth (Houghton et al 1996)

Heat lost by the tropical ocean is the major source of energy needed to drive the atmospheric circulation. And, solar energy stored in the ocean from summer to winter helps ameliorate Earth's climate.

The thermal energy transported by ocean currents is not significant changes in the transport, particularly in the Atlantic.

For these reasons, oceanic heat budgets and transports are important for understanding Earth's climate and its short and long term variability.

## 2. INPUTS and OUTPUTS of OCEANIC HEAT BUDGET

- **"Input"** identifies a process through which the ocean gains heat.
- **"Output"** represents a heat loss to the ocean.

A complete list of all inputs and outputs is as follows; **(+)** indicates input or heat gain, **(-)** signifies output or heat loss.

## 2.1. Primary Inputs and Outputs

- Radiation from the sun **(+)**
- Long-wave back radiation **(-)**
- Direct heat transfer air/water (Transfer of sensible heat) **(-)**; when from air to water **(+)**
- Evaporative heat transfer **(-)** ; when condensation **(+)** (This situation occurs very rarely, mainly during sea fog conditions.)
- Advective heat transfer (currents, vertical convection, turbulence) **(-** or **+)**; this effect cancels on the global scale or in closed basins.

## 2.2. Secondary Inputs and Outputs

- Heat gain from chemical/biological processes **(+)**
- Heat gain from the Earth's interior and hydrothermal activity **(+)**
- Heat gain from current friction **(+)**
- Heat gain from radioactivity **(+)**

# 3. HEAT BUDGET-THE RESULTANT HEAT

## The sum of the changes in heat fluxes into or out of a volume of water

$$Q_T = Q_{SW} + Q_{LW} + Q_S + Q_L + Q_V$$

- The Resultant Heat (gain or loss) $Q_T$ [w.m$^{-2}$]
- Insolation $Q_{SW}$, the flux of sunlight into the sea
- Net Infrared Radiation $Q_{LW}$, net flux of infrared radiation from the sea
- Sensible Heat Flux $Q_S$, the flux of heat out of the sea due to conduction
- Latent Heat Flux $Q_L$, the flux of heat carried by evaporated water
- Advection $Q_V$, heat carried away by currents

# 3.1. Heat Budget Terms

## 3.1.1. Insolation

**Solar constant**

- Rate at which energy reaches the outside of the atmosphere
- Measured by satellites

**Long term world averages:**

- 29% lost to space by atmosphere and cloud scattering
- 19% absorbed by atmosphere
- 4% reflected by ocean
- 48% absorbed

**Factors influencing $Q_{SW}$ :**

- Latitude, season, time of day
- Length of day
- The cross-sectional area
  - ❖ The surface absorbing sunlight
- Attenuation
  - ❖ Clouds, path length, gas molecules, aerosol, dust
- Reflectivity
  - ❖ Surface roughness
- Surface solar insolation
- Average annual range ($30 < Q_{SW} < 260$ W.m$^{-2}$)

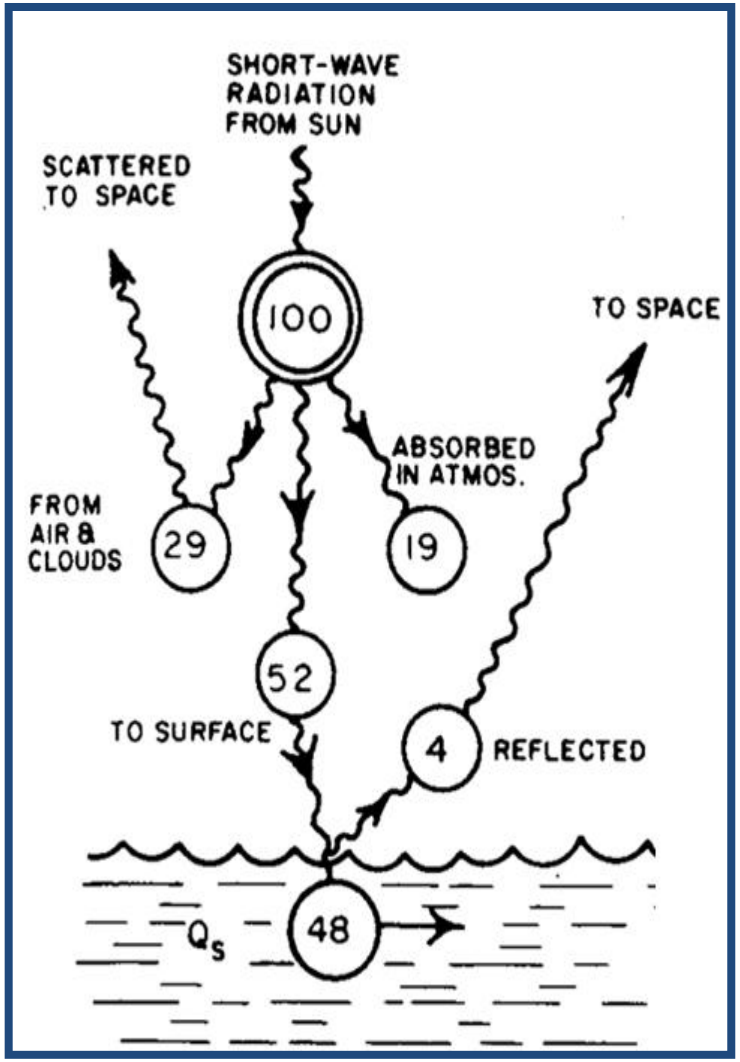


**Figure 2:** Insolation (Long term world averages)

## 3.1.2. Net Infrared Radiation

**Factors influencing $Q_{LW}$ :**

- Atmospheric transmittance
    - Greenhouse gasses (Carbon dioxide, methane, nitrous oxide, ozone, CFCs...)
- The clarity of the atmospheric window
    - Clouds thickness, cloud height, atmospheric water vapor content
    - Changes in water vapor and clouds are more important than changes in $T_{surface}$
- Water Temperature
- Ice and snow cover
- Average annual range ($-60 < Q_{LW} < -30$ W.m$^{-2}$)

### 3.1.3. Latent Heat Flux

- Heat of evaporation/condensation
- Difficult to estimate value

**Factors influencing $Q_L$ :**

- Wind velocity
- Atmospheric humidity
- Others: Sea state, salinity, temperature, cloud cover
- Average annual range ($-130 < Q_L < -10$ W.m$^{-2}$)

### 3.1.4. Sensible Heat Flux

- Temperature decreases upward from sea surface → heat conducted away → $Q_S < 0$
- Temperature increases upward from sea surface → heat conducted into sea → $Q_S > 0$

**Factors influencing $Q_S$ :**

- Wind velocity
- Air-sea temperature difference

**Average annual range**

- $-42 < Q_S < -2$ W.m$^{-2}$

## 3.1.5. Advection

- Globally *Qv*= 0
- Sun's direct radiation dominant to about $50^o$ latitude
  - ➢Low latitudes ($<30^o$): ocean gains heat
  - ➢High latitudes ($>30^o$): ocean loses heat to atmosphere
- Thermal equilibrium → Ocean must advect heat ($Qv \neq 0$)
- *Qv* proportional to velocity & water temperature
- The oceans transport about one-half of the heat needed to warm higher latitudes, the atmosphere transports the other half.

- Oceanic heat transport exceeds atmospheric transport in some regions.

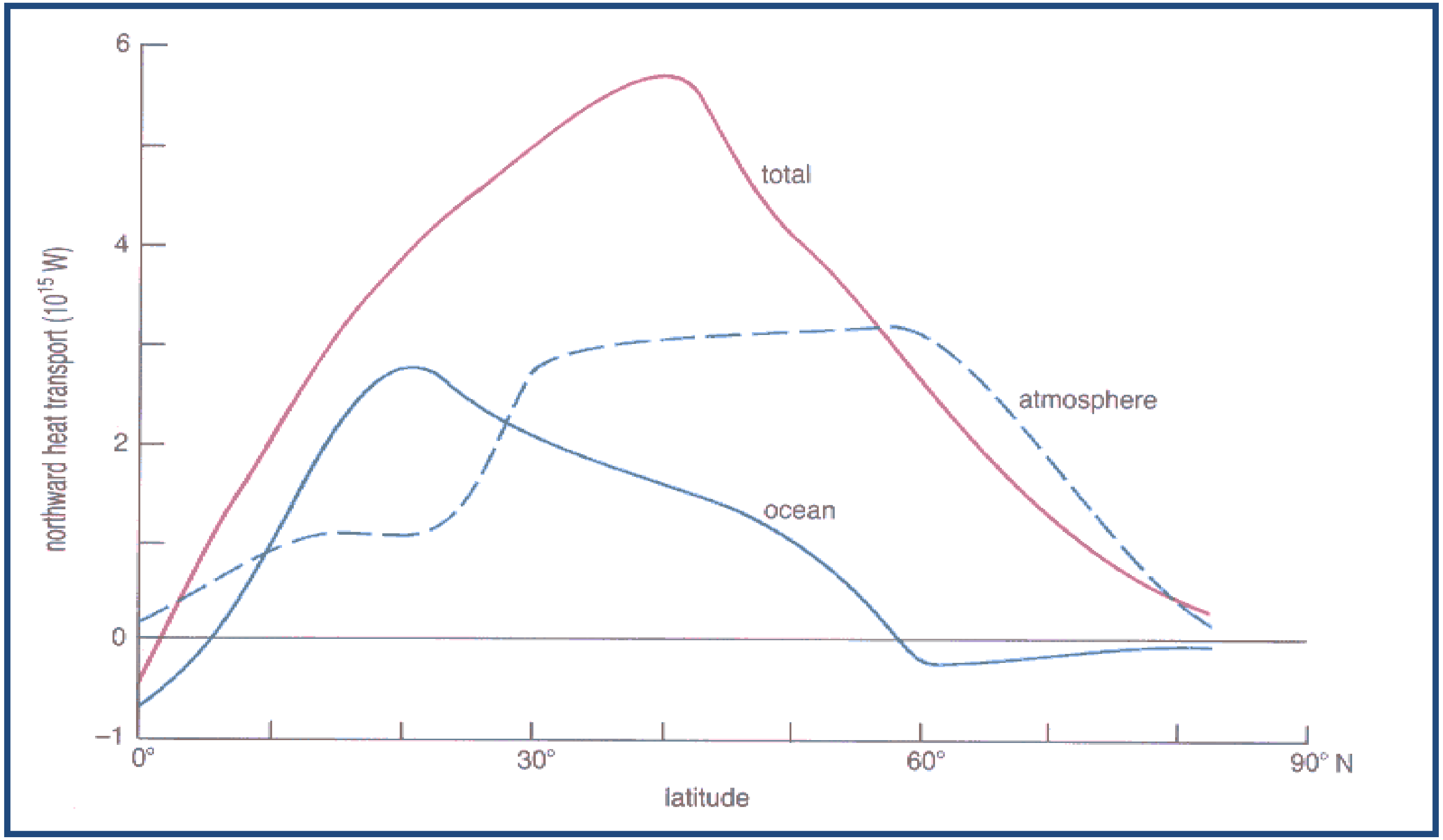


**Figure 3:** Heat Transport

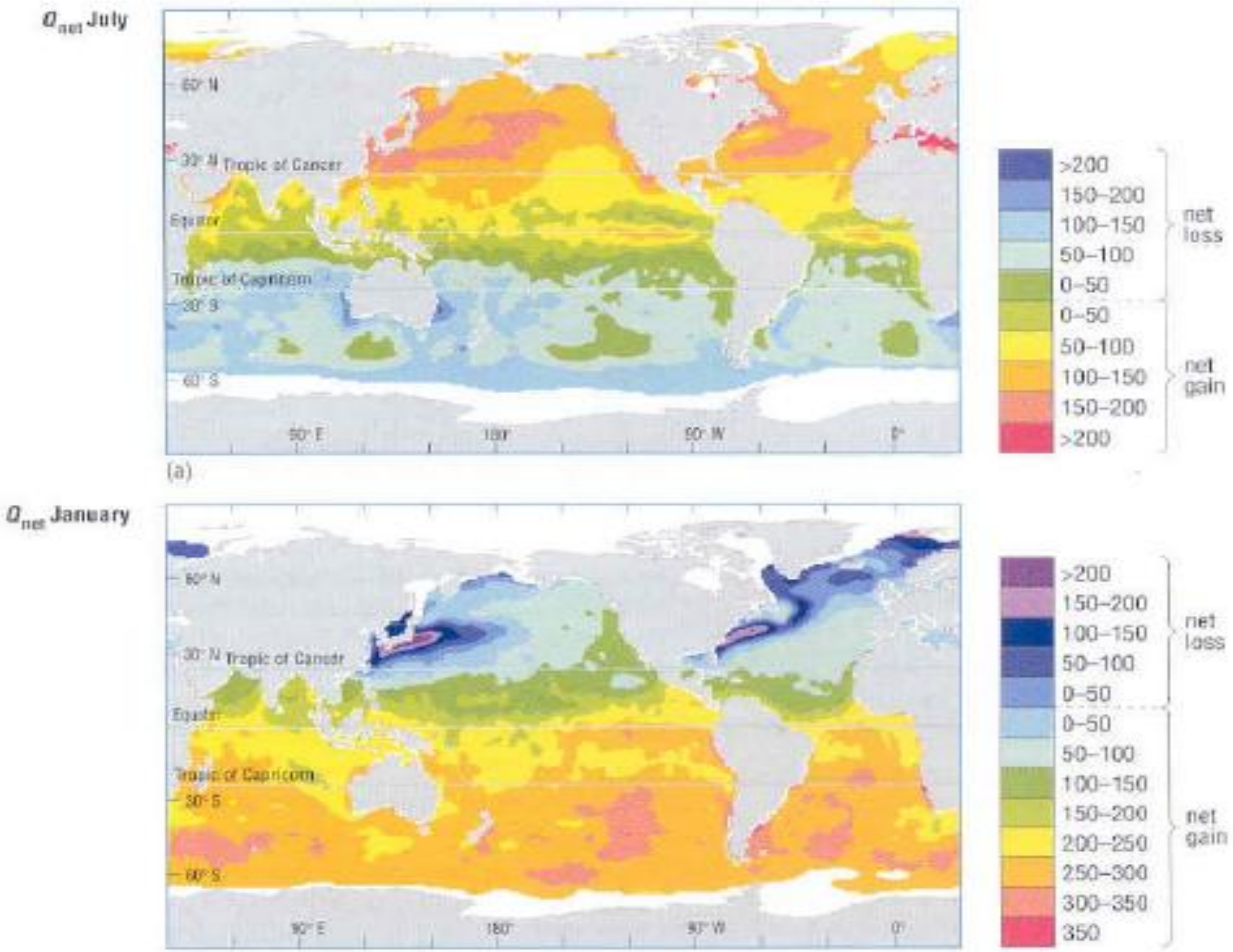


**Figure 4:** Total Heat Flux by Season

## 3.2. Calculating Surface Fluxes

Bulk formulas could be use for calculating the surface fluxes. (including wind stres)

$$T = \rho_a \, C_D \, U_{10}^2$$

$$Q_S = \rho_a \, C_p \, C_S \, U_{10} \, (t_s - t_a)$$

$$Q_L = \rho_a \, L_E \, C_L \, U_{10} \, (q_s - q_a)$$

- $\boldsymbol{U_{10}}$ **:** Wind speed at 10 m above the sea level
- $\boldsymbol{\rho_a}$ **:** Density of air

| | | |
|---|---|---|
| $C_p$ | Specific heat capacity of air | $1030\ \mathrm{J \cdot kg^{-1} \cdot K^{-1}}$ |
| $C_D$ | Drag coefficient (see 4.3) | $(0.50 + 0.071\, U_{10}) \times 10^{-3}$ |
| $C_L$ | Latent heat transfer coefficient | $1.2 \times 10^{-3}$ |
| $C_S$ | Sensible heat transfer coefficient | $1.0 \times 10^{-3}$ |
| $L_E$ | Latent heat of evaporation | $2.5 \times 10^6$ J/kg |
| $q$ | Specific humidity of air | kg (water vapor)/kg (air) |
| $q_a$ | Specific humidity of air 10 m above the sea | kg (water vapor)/kg (air) |
| $q_s$ | Specific humidity of air at the sea surface | kg (water vapor)/kg (air) |
| $Q_S$ | Sensible heat flux | $\mathrm{W/m^2}$ |
| $Q_L$ | Latent heat flux | $\mathrm{W/m^2}$ |
| $T$ | Wind stress | Pascals |
| $t_a$ | Temperature of the air 10 m above the sea | K or °C |
| $t_s$ | Sea-surface temperature | K or °C |

**Figure 5:** Parameters for Bulk Formulas

On the other hand, direct measurement could be use for obtaining surface fluxes.

- Characteristics
  - On low-flying aircraft or offshore platforms
    - ➢ Usually at 30m height
    - ➢ Need fast-response instruments
    - ➢ Expensive
    - ➢ Measurements ≠ large space or longer time

Only for calibration

## 4. OCEAN CURRENTS HEAT TRANSPORT

Ocean currents can flow for great distances, and together they create the great flow of the global conveyor belt which plays a dominant part in determining the climate of many of the Earth's regions. Perhaps the most striking example is the Gulf Stream, which makes northwest Europe much more temperate than any other region at the same latitude. Another example is Lima, Peru where the climate is cooler (sub-tropical) than the tropical latitudes in which the area is located, due to the effect of the Humboldt Current.

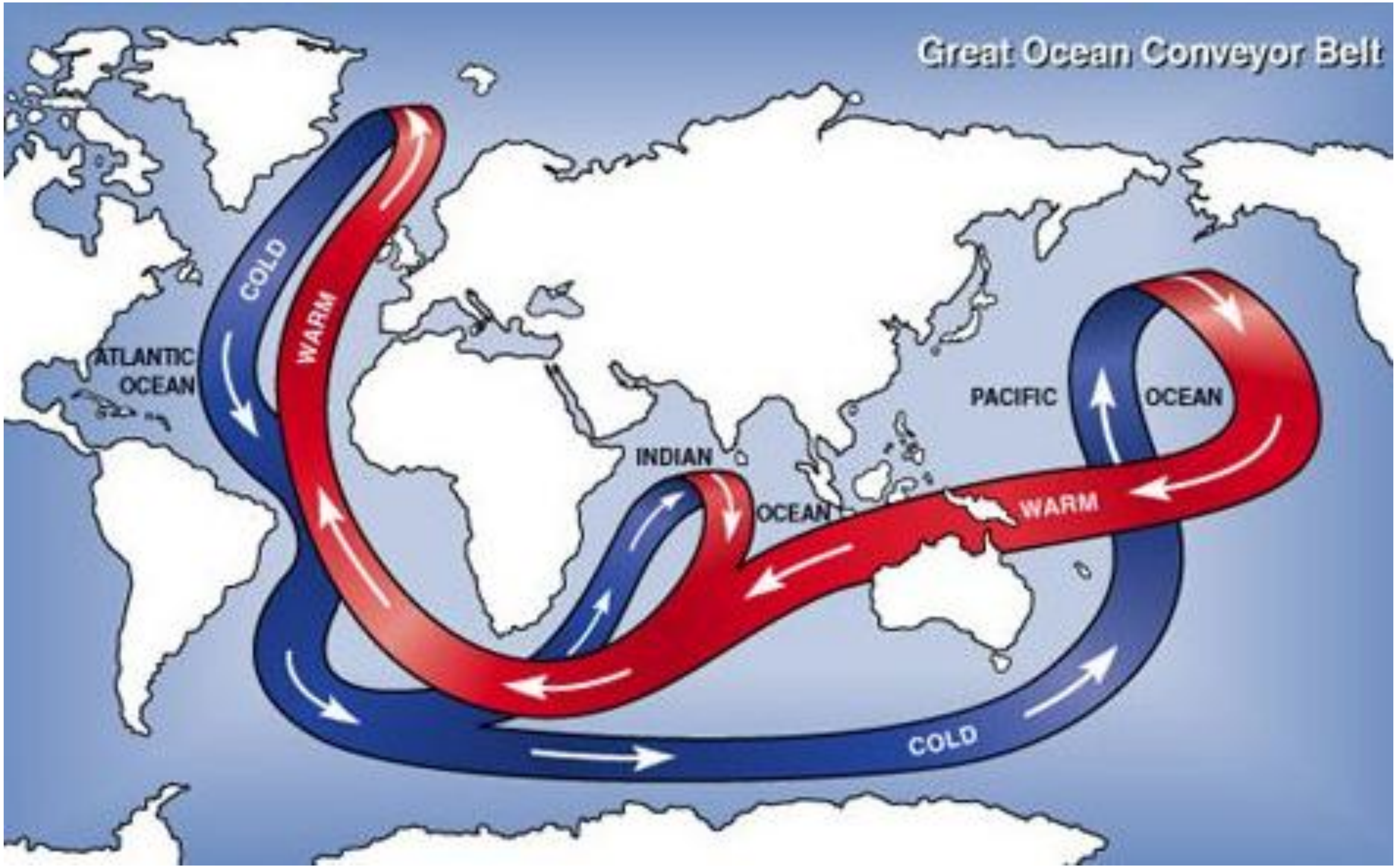


**Figure 6:** Great Ocean Conveyor Belt

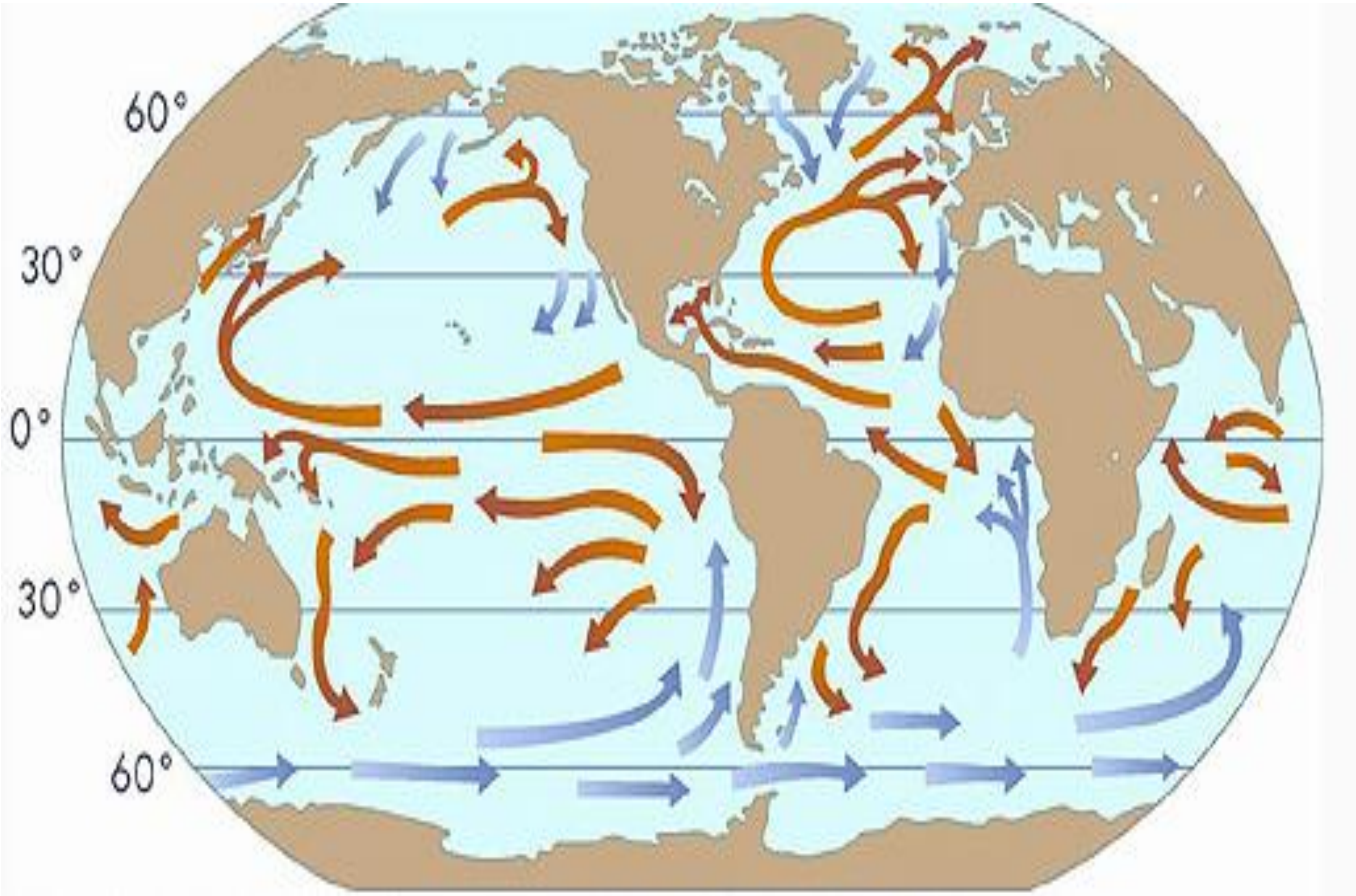


**Figure 7:** Major Ocean Surface Currents

Horizontal and vertical currents also exist below the pycnocline in the ocean's deeper waters. The movement of water due to differences in density as a function of water temperature and salinity is called thermohaline circulation. The whole ocean is involved in slow thermohaline circulation. Ripple marks in sediments, scour lines, and the erosion of rocky outcrops on deep-ocean floors are evidence that relatively strong, localized bottom currents exist. Some of these currents may move as rapidly as 60 centimeters (24 inches) per second.

These currents are strongly influenced by bottom topography, since dense, bottom water must forcefully flow around seafloor projections. Thus, they are sometimes called contour currents. Bottom currents generally move equator-ward at or near the western boundaries of ocean basins (below the western boundary surface currents). The deep-water masses are not capable of moving water at speeds comparable to that of wind-driven surface currents. Water in some of these currents may move only 1 to 2 meters per day. Even at that slow speed, the Coriolis effect modifies their pattern of flow.

## 5. RESULTS

- Sunlight is absorbed primarily in the tropical ocean. The amount of sun-light changes with season, latitude, time of day, and cloud cover.
- Most of the heat absorbed by the oceans in the tropics is released as water vapor which heats the atmosphere when water is condenses as rain. Most of the rain falls in the tropical convergence zones, lesser amounts fall in mid-latitudes near the polar front.
- Heat released by rain and absorbed infrared radiation from the ocean are the primary drivers for the atmospheric circulation.

- The net heat flux from the oceans is largest in mid-latitudes and offshore of Japan and New England.
- Heat fluxes can be measured directly using fast response instruments on low-flying aircraft, but this is not useful for measuring heat fluxes over oceanic areas.
- Heat fluxes through large regions of the sea surface can be calculated from bulk formula. Seasonal, regional, and global maps of fluxes are available based on ship and satellite observations.

- The most widely used data sets for studying heat fluxes are the Comprehensive Ocean-Atmosphere Data Set and the reanalysis of meteorological data by numerical weather prediction models.
- The oceans transport about one-half of the heat needed to warm higher latitudes, the atmosphere transports the other half.
- Solar output is not constant, and the observed small variations in output of heat and light from the sun seem to produce the changes in global temperature observed over the past 400 years