Heat budget of the Earth

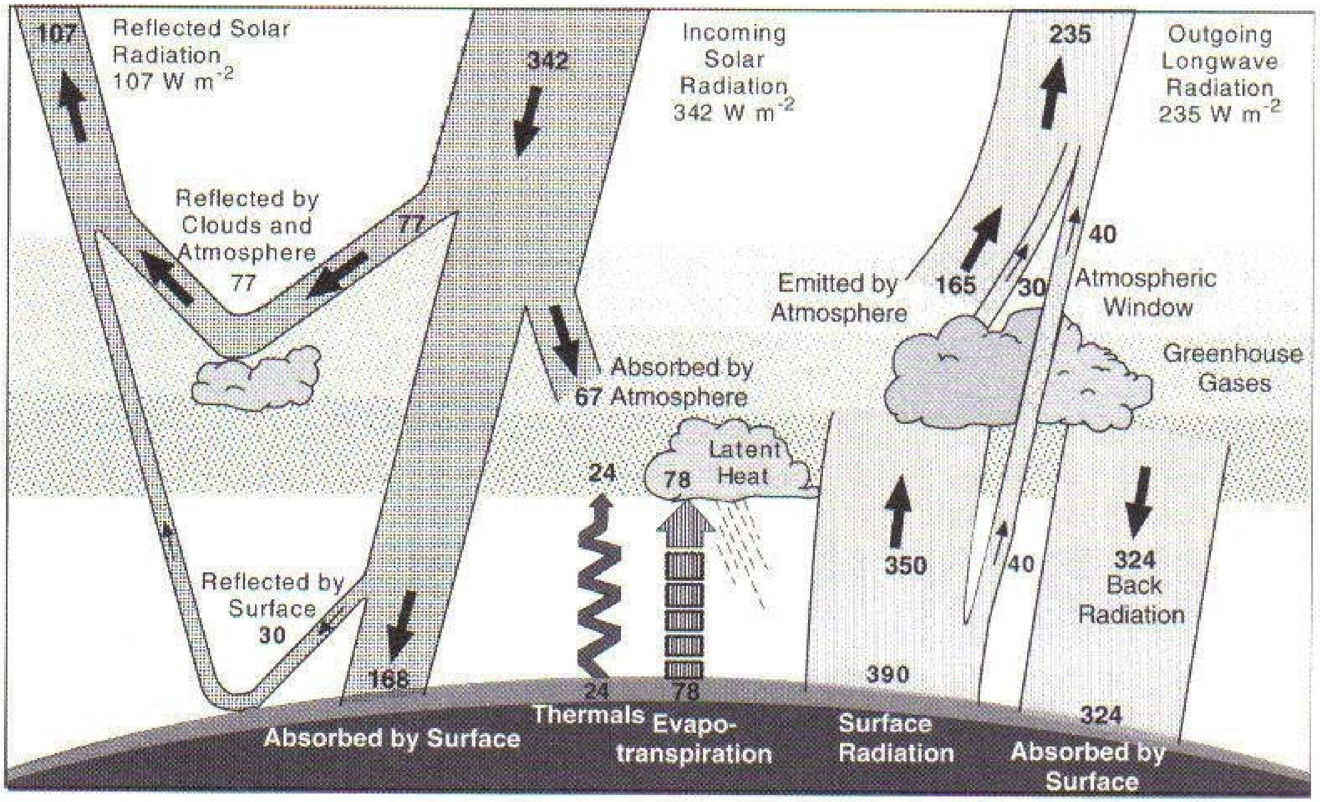


Figure 1. The earth's radiation balance. The net incoming solar radiation of 342 W m^{-2} is partially reflected by clouds and the atmosphere or at the surface, but 49% is absorbed by the surface. Some of that heat is returned to the atmosphere as sensible heating and most as evapotranspiration that is realized as latent heat in precipitation. The rest is radiated as thermal infrared radiation and most of that is absorbed by the atmosphere and re-emitted both upwards and downwards, producing a greenhouse effect, as the radiation lost to space comes from cloud tops and parts of the atmosphere much colder than the surface. From Kiehl and Trenberth (1997).

The Global Energy Budget

•Comments on previous overhead:

•31% of the incoming solar radiation is reflected or scattered back to space – the ALBEDO

•235 Wm^{-2} warms the Earth and atmosphere, 168 Wm^{-2} of which warms the surface.

•235 Wm^{-2} corresponds to a black body temperature of -19 C, thermal emission at 10 um.

•This is colder than Earth's surface and is reached at around 5 km.

•Thus the peak terrestrial emission is in the atmospheric window in the IR.

•This fraction is transmitted directly to space, but majority is intercepted and interacts.

•Clouds can absorb and emit thermal radiation but are also reflectors of solar radiation and so act to cool the surface.

•Strong cancellation between these effects the global net effect appears to be a slight cooling at the surface.

•235 Wm^{-2} equates to 120 PW (120×10^{15} W) globally. A 1 % in this value (around 2.5 Wm^{-2} will dominate over other present man-made energy inputs.

Surface Radiation Budget

•Surface rock or soil partly reflects and partly absorbs incoming radiation

•Absorption leads to an increase in surface temperature

•Heat is lost to balance the SW input by LW radiation from the surface and conduction into the ground and convection in the atmosphere.

•If the surface is damp then evaporation will lead to the removal of heat by evaporation

•Vegetation uses some of the incoming radiation for photosynthesis

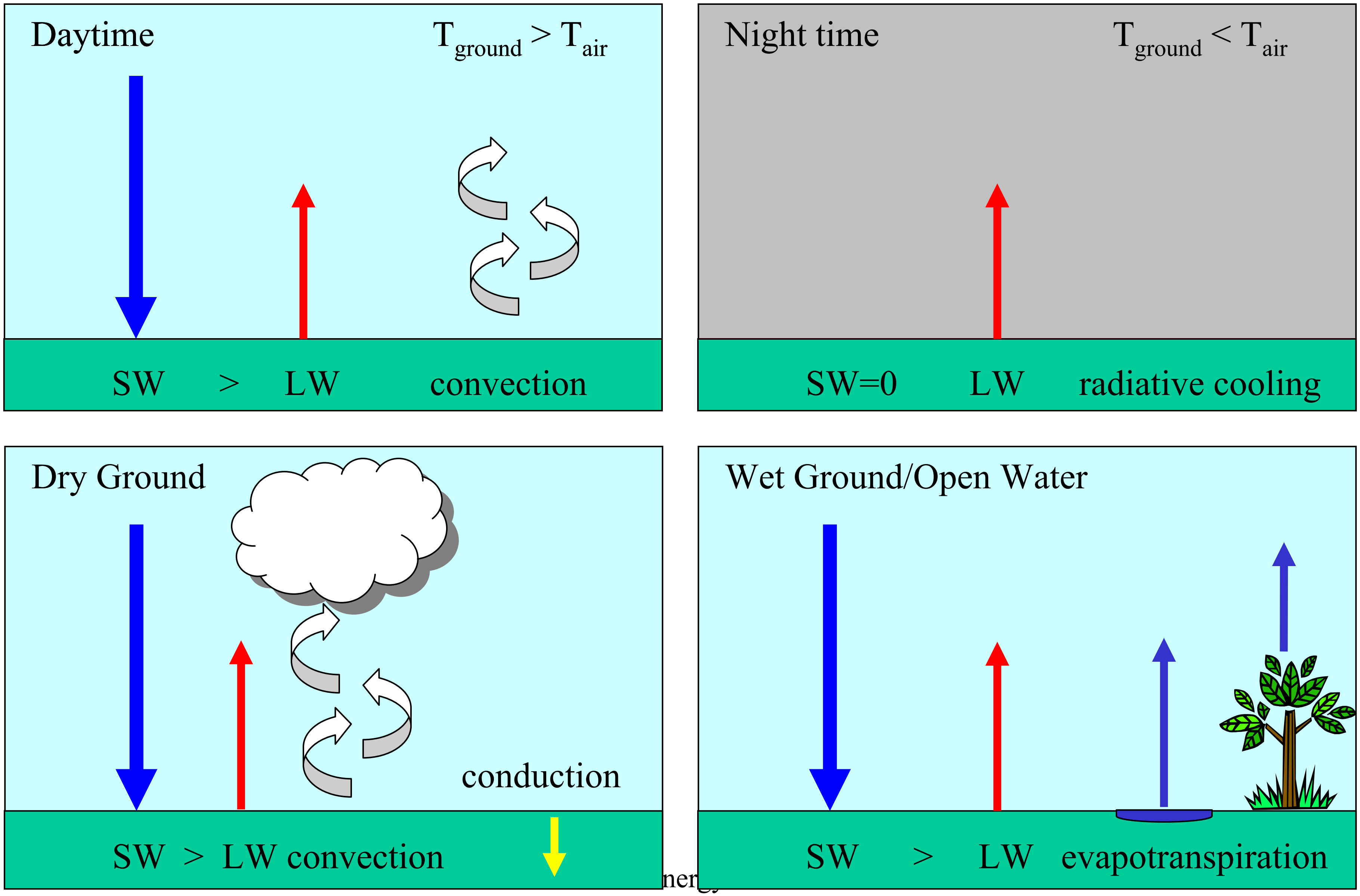
•It has been estimated that around 5% of the incident solar radiation (12% of the visible radiation) is used in producing biomass.

•The reflected radiation depends strongly on wavelength

•In the near IR leaves may reflect ~40% and absorb 60% of the available sunlight

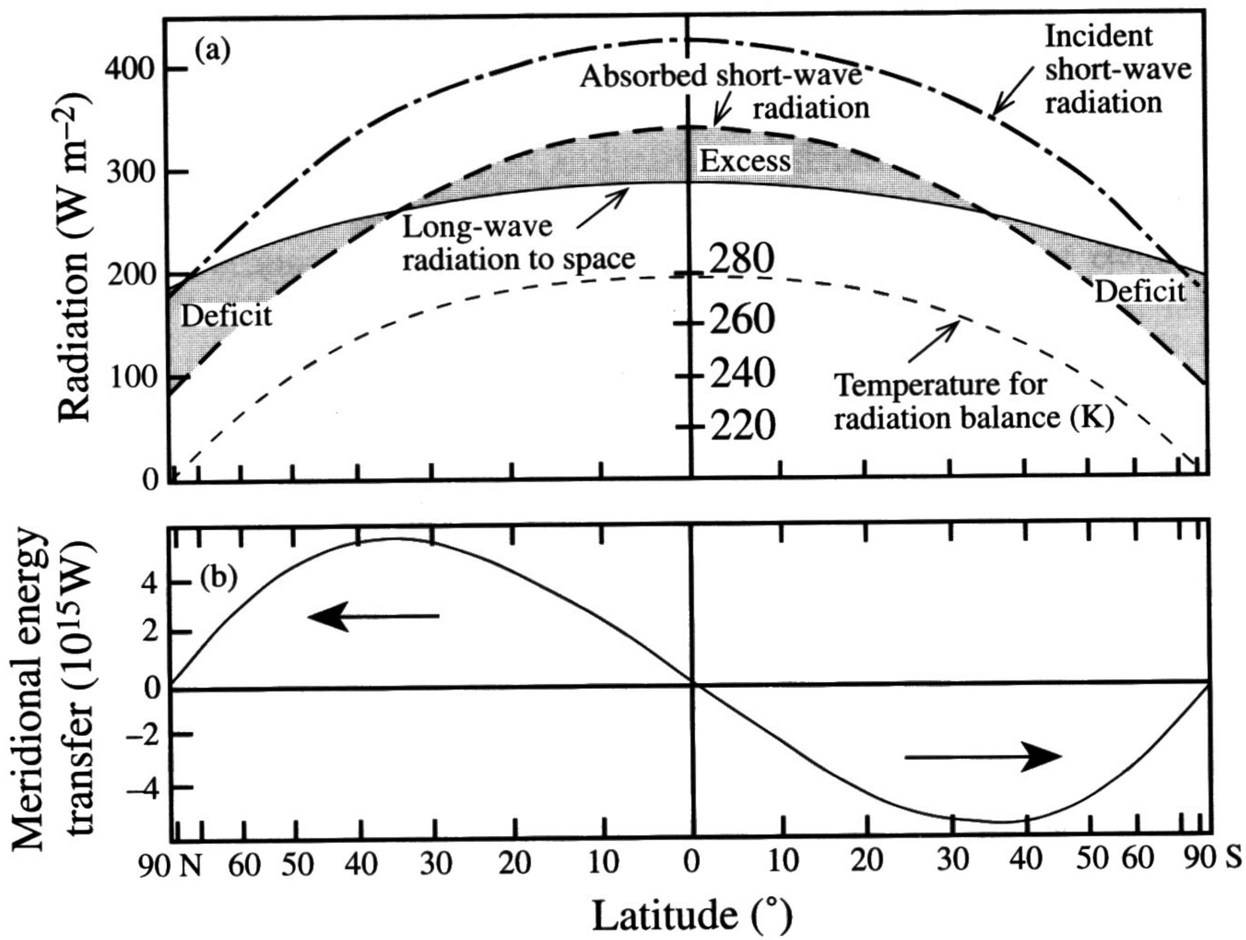
•However, dense forests absorb 70%, reflect 17% and transmit to the soil 13% of the available sunlight

Surface Radiation Budget 2



Variations in the Heat Budget Across the Globe

The calculated short and longwave energy budgets of the Earth-atmosphere system averaged over time as a function of latitude.



Variations in the Heat Budget Across the Globe 2

There is an excess of incoming shortwave radiation between 35 °S and 40 °N and a deficit at higher latitudes compared with the outgoing longwave radiation budget.

If equilibrium were to be maintained at every latitude the short and longwave radiation should balance locally and the two curves in the previous figure would be identical.

The fact that they are not, and as local mean temperatures close to the equator are not increasing with time and those close to the poles are not decreasing, heat energy must be transported from low latitudes poleward.

This is achieved by circulation within both the ocean and the atmosphere, transporting heat away from the equator towards the pole and maintaining a higher temperature at latitudes greater than 50° than would be possible from a system in radiative equilibrium, illustrated by the thin broken curve in the previous figure

Distribution of Radiation

The annual cycles of absorbed solar radiation (ASR); outgoing longwave radiation (OLR) and the net radiation at the top of the atmosphere (TOA) are shown in following figures)

•At the surface deserts, snow and ice have high albedo and so do not absorb much solar radiation

•Main departure from latitudinal symmetry due to regions of persistent clouds (e.g. Amazon, Indonesia, Pacific Ocean around 10 N, E Pacific, Gulf of Guinea).

• ASR differences between JJA and DJF show in excess of 200 Wm^{-2} highlighting the dominance of the solar input

•The OLR is more uniform with latitude and season (note scale)

•The OLR varies primarily with deep convection as cloud tops are very cold

•Conversely the dry cloud free regions are where most radiation escapes to space

•The Inter Tropical Convergence Zone (ITCZ) is clearly seen as a negative OLR as semi-permanent convection in the region reduces OLR lost to space,

•In tropics the differences between DJF and JJA are related to changing convection patterns in mid latitudes this is more a function of temperature.

Distribution of Radiation 2 ASR

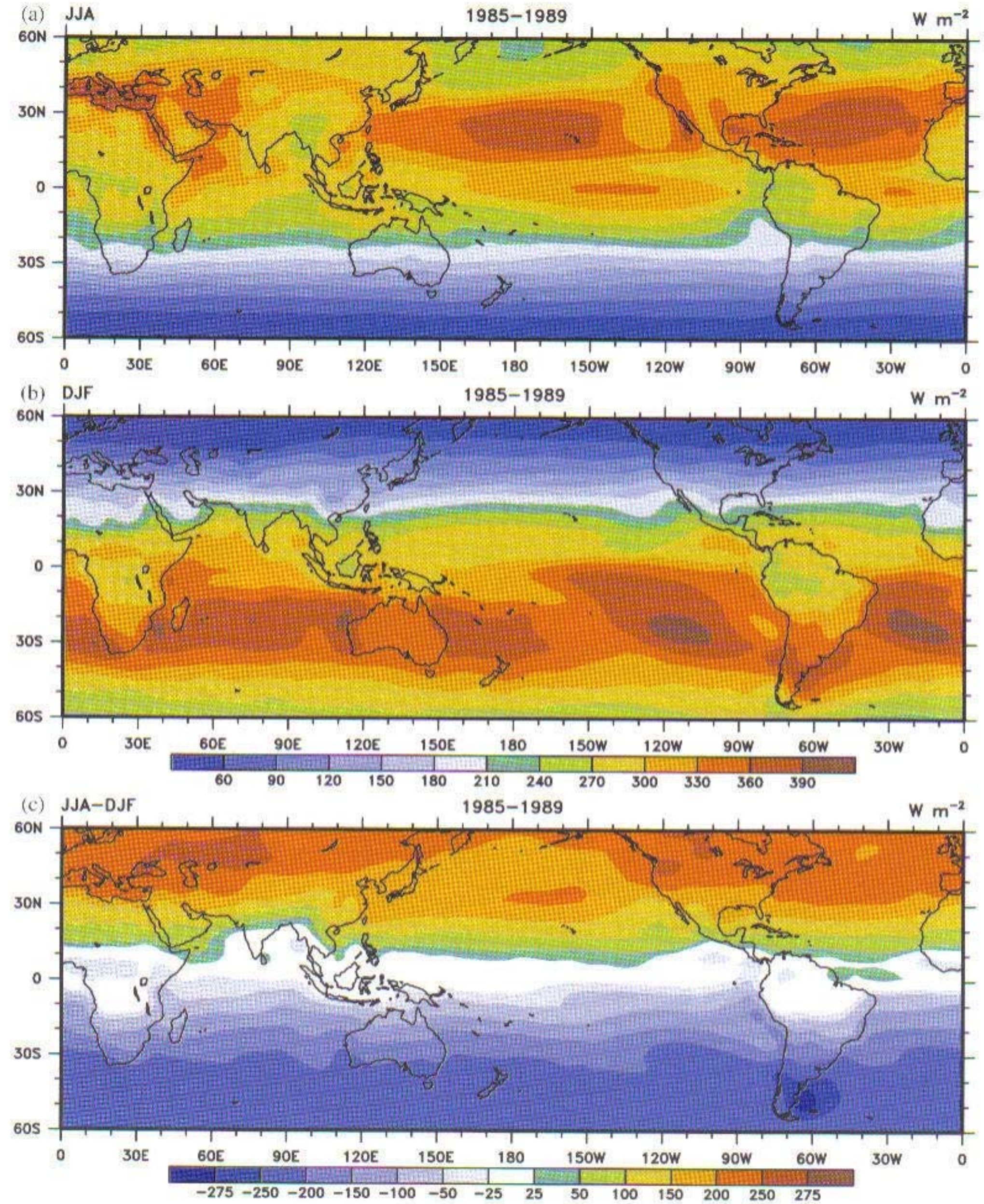


Figure 2. Top of atmosphere (TOA) absorbed solar radiation for the period of the Earth Radiation Budget Experiment, 1985–89 averaged for: (a) June, July and August (JJA), (b) December, January and February (DJF), and (c) their difference JJA–DJF. The contour interval in (a) and (b) is 30 W m^{-2} and in (c) is 25 or 50 W m^{-2}.

Distribution of Radiation 3 OLR

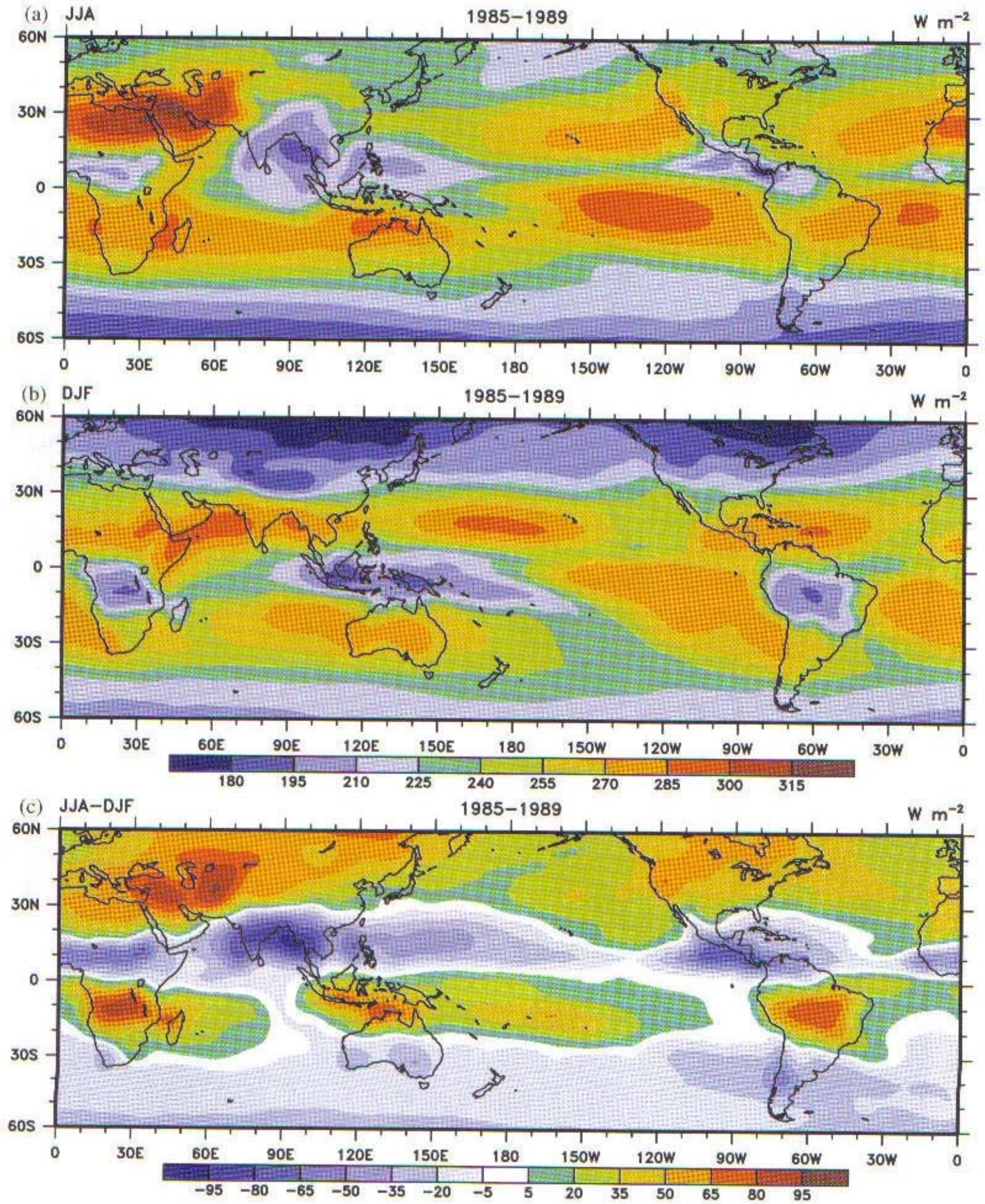
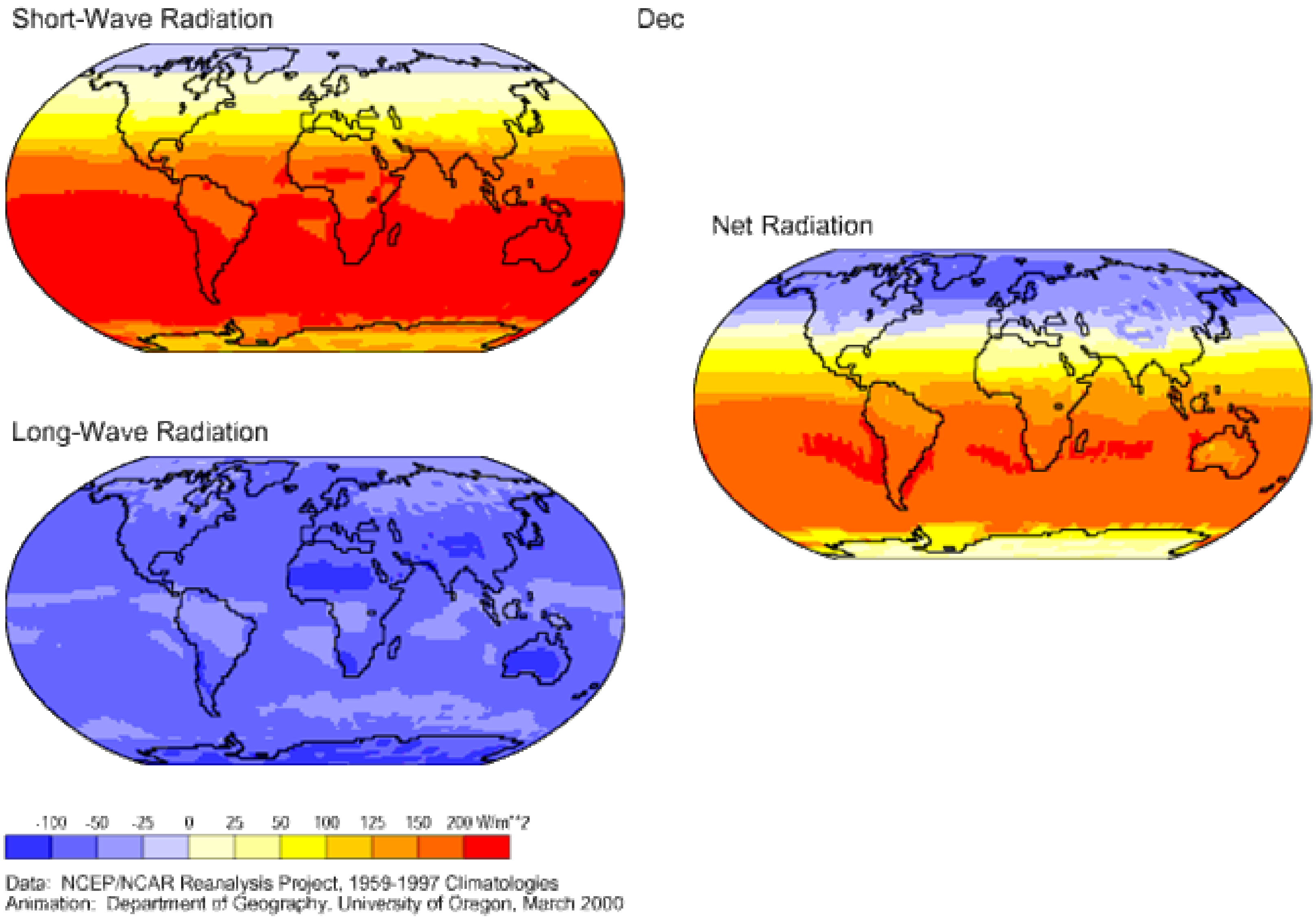


Figure 3. As Fig. 2, but for TOA outgoing long-wave radiation. The contour interval is 15 W m^{-2}.

Distribution of Radiation



Distribution of Radiation 4

•The cloud signature in the ASR is well matched by that in the OLR signal.

•When net radiation is considered there is a cancellation

•In particular the high convective clouds are bright and reflect solar radiation but are also cold and reduce OLR.

•The main remaining cloud signature in the net radiation is the low stratocumulus cloud decks that are semi permanent over cold ocean waters. These clouds reflect solar radiation appreciably but their radiative temperature is similar to the surface and there is little effect on the OLR. Seen notably off California and Peru.

•The Sahara desert has a high OLR, consistent with dry, cloud free and warm conditions but it is also bright and reflects solar radiation. And hence is a region of net radiation deficit.

Distribution of Radiation 5 Net

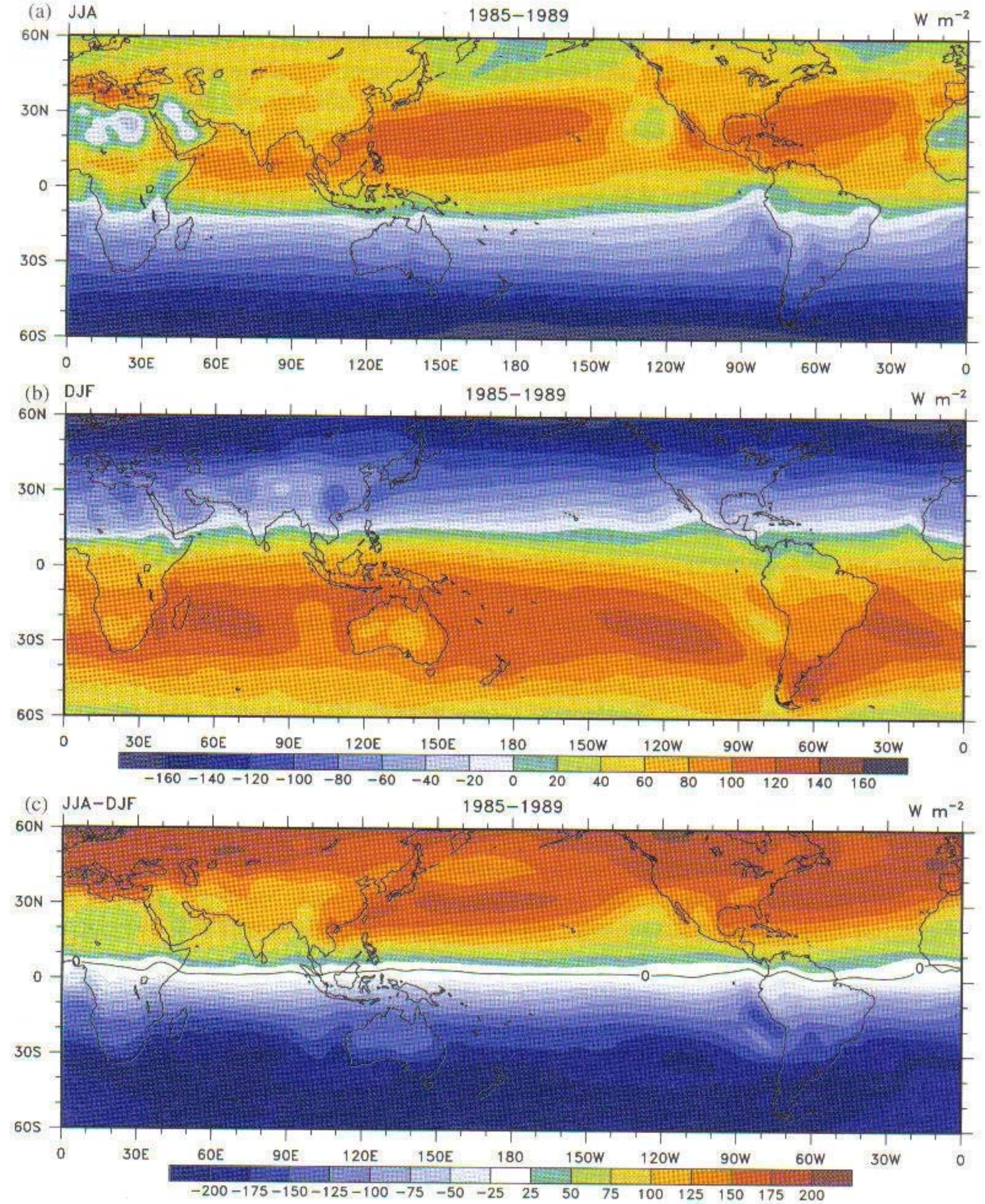


Figure 4. As Fig. 2, but for TOA net radiation. The contour interval in (a) and (b) is 20 W m^{-2} and in (c) is 25 W m^{-2}.

Heat Storage

•Absorbed radiative energy in the atmosphere is transformed into sensible and latent energy.

•Over land this manifests as increases in temperature and/or evaporation, the partitioning depends on available moisture and the ground vegetation cover.

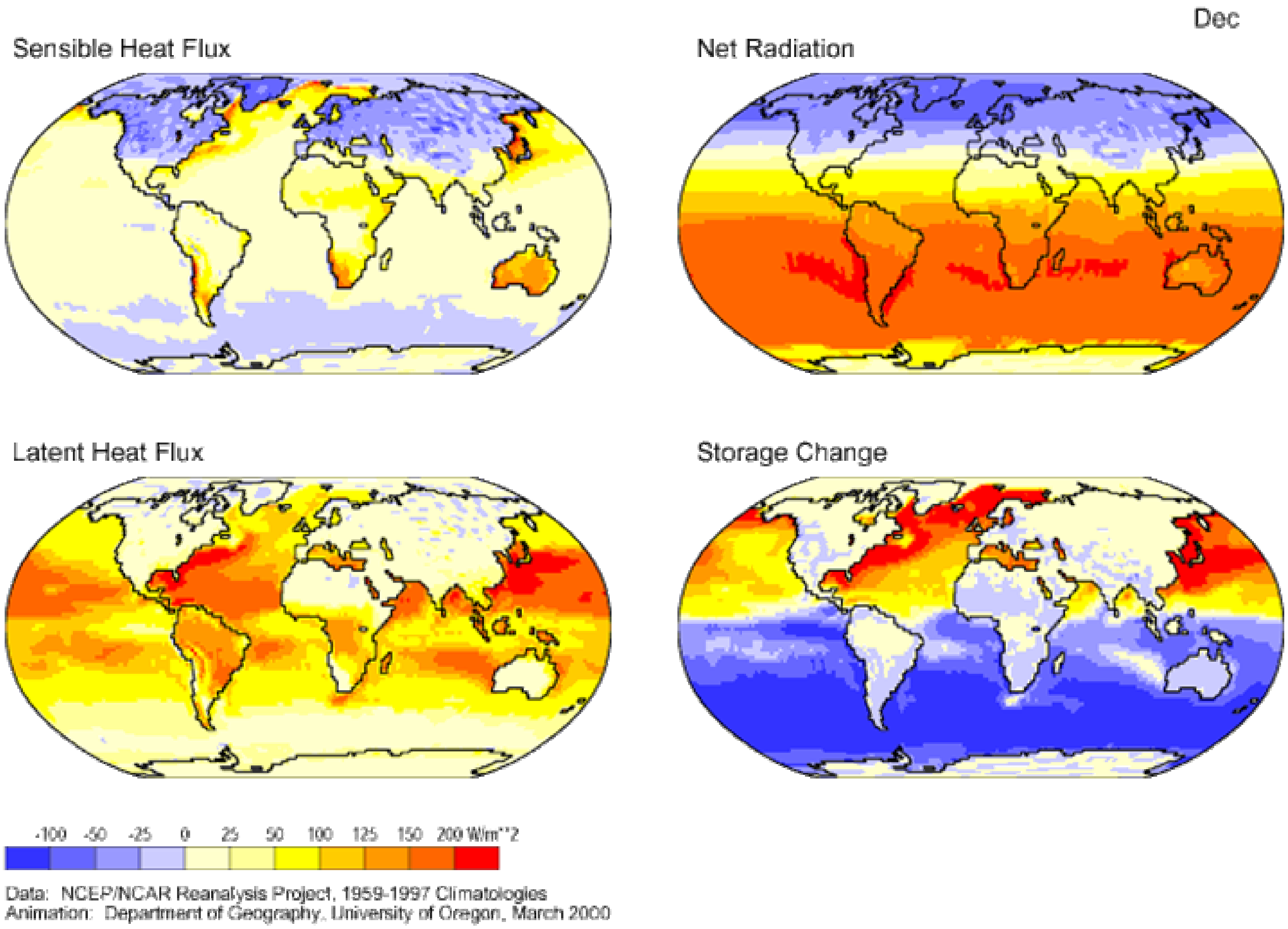
•In the tropics in summer the land warms relative to the ocean and hence develops monsoon systems.

•Water is evaporated from the ocean surface, cooling the ocean.

•As water vapour and thus latent energy it can be transported considerable distance before removal by precipitation, provided an efficient heat transport mechanism.

• Increases in temperature cause an increase in the internal energy of the atmosphere, casuing it to expand, changing its altitude and hence potential energy. The combination of internal and potential energy can be expressed as enthalpy or sensible heat.

Heat Storage 2



Heat Transfer in the Ocean and Atmosphere

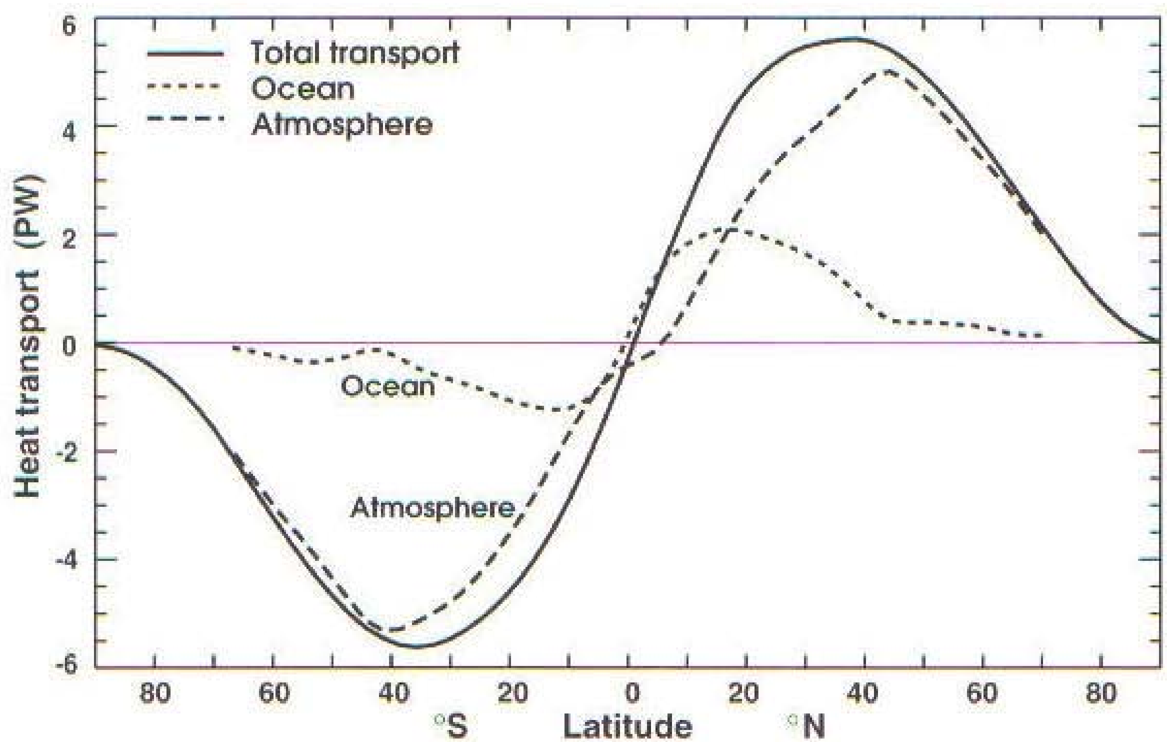


Figure 6. Poleward heat transports by the atmosphere (large-dashed line), ocean (small-dashed line) and the two combined (solid line) in petawatts (from Trenberth and Caron 2001).

Heat Transfer in the Ocean and Atmosphere

•Much of the heat transport polewards takes place by atmospheric circulation (see next lecture).

•However, a significant fraction, especially near the equator, where as we shall see the Hadley Cell only weakly transfers heat polewards, takes place through the surface waters of the ocean.

•The ocean surface heat transport is largely by wind blowing across the sea surface driving surface water currents

•The oceans are capable of storing heat for a wide range of time scales and subsequently transporting it to other locations.

•The thermohaline circulation (see next lecture but one) can store heat for 1000s of years.

•The strongest thermohaline circulation is in the Atlantic Ocean, whereas the Pacific Ocean is much fresher and features shallower circulations.

•This is largely due to differences in salinity. The atmosphere transports water vapour across the isthmus in central America from the Atlantic to the Pacific, leaving the former saltier than the latter.