Summary

The basic concept of the so called ‘greenhouse effect’ is that the ‘absorption and emission’ of the long wave IR (LWIR) flux in the atmosphere by so called ‘greenhouse gases’ increases and controls the surface temperature. The downward LWIR flux from the atmosphere does indeed establish an exchange energy with the blackbody emission from the surface that reduces the net LWIR cooling flux emitted by the surface. However, this does not control the surface temperature. The energy transfer processes that determine the surface temperature are complex and have to be analyzed within the framework of an open cycle tropospheric heat engine. This engine consists of a set of coupled thermal storage reservoirs that transport the surface heat from the absorbed solar flux to the middle troposphere by moist convection. From here it is radiated back to space, mainly by the water bands that act as the cold reservoir of this heat engine. The surface energy transfer processes include convection, evaporation and thermal conduction, not just the LWIR flux. When these energy transfer processes are examined in detail, including the time dependence, a description of the ‘greenhouse effect’ emerges that is very different from the conventional ‘equilibrium average climate state’ approach that has been used for the last 50 years. This approach is based on simplistic conservation of energy arguments. It creates global warming as a mathematical artifact of the simplifying equilibrium assumptions used in the climate simulation models. The root cause error is the failure to apply the Second Law of Thermodynamics. In order for the surface to dissipate the absorbed solar flux there must be a thermal gradient. The LWIR exchange energy limits the net LWIR cooling flux, so the surface must warm up until there is an adequate thermal gradient and/or humidity gradient to dissipate the solar heat by moist convection. The land-air and ocean-air interfaces have very different energy transfer properties and have to be analyzed separately. The various flux terms have to be interpreted as rates of heating and cooling of a thermal mass. The change in local temperature is the net change in heat content or enthalpy.
divided by the local heat capacity. Convection is a mass transport process that is coupled to both the gravitational potential and rotation of the earth. This coupling our basic weather patterns. It is impossible for the increase in LIWR flux produced by the observed increase in atmospheric CO$_2$ concentration to couple to this dynamic thermal reservoir system in way that produce an observable change in surface temperature. Instead, climate change can be explained in terms of ocean oscillations, small changes in solar flux and long term changes in ocean circulation produced by plate tectonics.

**Introduction**

The earth is an isolated planet that is heated and cooled by electromagnetic radiation. The heat source is the sun. The incident radiation is a nearly collimated beam ($\pm 0.26^\circ$) with an average energy flux near 1366 W m$^{-2}$. The spectral distribution of the solar flux at the top of the atmosphere is similar to that of a blackbody near 5800 K. The cooling radiation is emitted in the LWIR spectral region ($>5 \mu$m or $<2000$ cm$^{-1}$). The illumination geometry is that of a sphere illuminated by a disk. The geometric area ratio is 4, so conservation of energy gives an average emitted cooling LWIR flux of approximately 240 W m$^{-2}$. However, the spectral distribution of the LWIR flux is not that of a blackbody emitter. The idea that the LWIR flux emitted by the earth corresponds to an ‘effective emission temperature’ near 255 K derived from Stefan’s Law is incorrect. The flux terms have to be interpreted as rates of heating and cooling of a set of coupled thermal reservoirs at different levels within the atmosphere [Clark, 2013a, 2013b, 2011]. The change in local reservoir temperature is the change in heat content or enthalpy divided by the local heat capacity. The stratosphere is heated mainly by the absorption of the UV solar flux and cooled by emission from the CO$_2$ bands, and from ozone. The troposphere is cooled mainly by LWIR emission from the water bands that are part of the cold reservoir of the tropospheric heat engine at an altitude near 5 km. The hot reservoirs are the land and the oceans that are heated by the solar flux. The surface heat is dissipated and transported through the troposphere by moist convection [Gilbert, 2010; Jelbring, 2003]. Conservation of long term average energy does not imply a short term conservation of flux. There is no ‘average equilibrium climate state’ that can perturbed by changes in ‘greenhouse gas concentration’. The earth’s orbit is elliptical, the rotation axis is tilted at 23.5° to the orbital plane and the period of axial rotation is 24 hours. The peak solar flux at the surface with the sun overhead is near 1000 W m$^{-2}$. At night, the local solar flux is zero. The absorbed solar flux is stored as heat and released over a wide range of time scales.

The tropospheric heat engine is subject to a number of unique constraints imposed by the basic Laws of Physics. Like any heat engine, the energy transfer is limited by the First and Second Laws of Thermodynamics. In particular, the heat flow must follow the thermal gradient. In addition, the surface evaporation depends on the humidity gradient, which is related to the thermal gradient through the temperature dependence of the water vapor pressure. Convection is a mass transport process that is subject to the Law of Gravity and Conservation of Momentum. As the warm air rises from the surface, it must perform mechanical work to overcome the gravitational potential. This produces cooling as the internal energy of the air mass is reduced. If the air is moist, this convective cooling can produce condensation with the release of latent heat. Convective ascent
Determines the lapse rate or temperature profile of the troposphere. The earth also rotates. The convection is coupled to the rotation or angular momentum of the earth. This produces the characteristic Hadley, Ferrel and Polar cell convective structure and the trade winds that drive the ocean gyre circulation [UK Met Office, 2017]. The result is the weather patterns that we observe. Climate is the long term average of these patterns. It is an average of the thermodynamic and fluid dynamic properties of the tropospheric heat engine.

The final constraint is a more complex and subtle one. The tropospheric heat engine operates at low temperatures and pressures. This means that the radiative properties of the working fluid, moist air (dilute steam) cannot be described using simple blackbody theory. The radiative energy transfer has to be analyzed using high resolution molecular radiative transfer algorithms. The IR spectrum of the atmosphere consists of many thousands of overlapping spectral lines. Each line is the result of a transition between two specific molecular vibration-rotation states. The molecular collision frequency in the troposphere is $> 10^9$. This means that the lifetimes of the molecular excited states are reduced significantly by the collisions. This produces a pressure dependent line broadening. The underlying cause is the Heisenberg Uncertainty Principle applied to time and energy. An important result is that the molecular lines in the lower troposphere are broadened into a quasi-continuum. The upward and downward LWIR fluxes are not equivalent. The troposphere splits naturally into 2 independent thermal reservoirs. Almost all of the downward LWIR flux reaching the surface originates from within the first 2 km layer of the troposphere. This is the lower tropospheric reservoir. The emission to space occurs mainly from the upper tropospheric reservoir, between 2 km and the tropopause. This forms the cold reservoir of the tropospheric heat engine. The heat lost to space from the upper tropospheric reservoir is replaced by heat transported from the surface by convection. The mechanical work required to overcome the gravitational potential and transport the warm air to the middle troposphere produces a cooling of about 33 K. This is the source of the so called ‘greenhouse effect temperature’ [Taylor, 2006].

At the surface, the absorbed solar flux is dissipated through a combination of moist convection and net LWIR emission. In order for heat flow to occur, there must be a thermal gradient or temperature difference. This is of course a consequence of the Second Law of Thermodynamics. At night, when the surface and surface air temperatures are similar, the downward LWIR flux from the lower troposphere balances most of the upward LWIR flux from the surface. There is a net LWIR cooling flux emitted through the atmospheric LWIR transmission window. This depends on humidity and cloud cover. During the day, the surface is illuminated by the solar flux. The increase in temperature is insufficient to remove the solar heat by LWIR emission. The energy transfer properties of the land and ocean surfaces are different and need to be considered separately. Over land, the surface warms until the heat is dissipated by moist convection. The surface heating also establishes a thermal gradient that conducts heat below the surface. This stored surface heat is released later in the day as the surface cools and the thermal gradient reverses. Over the oceans, the surface is almost transparent to the solar flux. Approximately half of the solar flux is absorbed within the first meter layer of the ocean and 90% is absorbed within the first 10 m layer. The surface cools through a combination of net LWIR emission and wind driven evaporation. This cooling takes place within the first 100 µm layer of the ocean surface. The
cooler water sinks and is replaced by warmer water convected from below. The ocean surface continues to warm up until the water vapor pressure is sufficient to drive the wind driven evaporation.

Over the last 200 years, the atmospheric CO₂ concentration has increased by approximately 120 ppm from 280 to 400 ppm. This has produced an increase in the downward LWIR flux from the troposphere to the surface near 2 W m⁻², depending on humidity. When this increase in flux is added dynamically to the surface flux balance, the increase in surface temperature is too small to be observed. Instead, climate change can be explained in terms of ocean oscillations, small changes in solar flux and long term changes in ocean circulation produced by plate tectonics.

The current description of the ‘greenhouse effect’ is based on the invalid concept of an ‘infrared equilibrium average climate’. This produces global warming as a mathematical artifact created by the simplifying assumptions used in the climate simulations [Clark, 2017]. Concepts such as an average global temperature and its relationship to an average global flux are incorrect and have little useful physical meaning [Volokin, & ReLlez, 2014; Essex et al, 2006]. There is no exact ‘equilibrium flux balance’ at the top of the earth’s atmosphere. The upward and downward LWIR fluxes through the troposphere are not equivalent because of line broadening effects. The LWIR flux emitted to space is decoupled from the surface by the tropospheric heat engine. Instead, there are dynamic or time dependent rates of heating and cooling that change the temperature within the thermal reservoirs of the climate system. The local temperature change is the cumulative change in heat content or enthalpy of the local thermal reservoir divided by the local heat capacity. This is illustrated in Figure 1. The various flux terms shown in Figure 1 will now be considered in more detail.
Figure 1: Thermal reservoirs, surface energy transfer and thermal storage (schematic). The surface is heated by the sun and cooled by a combination of net LWIR emission, convection and evaporation. Heat is stored below the surface and released over a range of time scales. There is no ‘equilibrium average temperature’.

The Solar Flux

The illumination of the earth by the solar flux is illustrated in Figure 2a. The earth is an isolated planet that is heated by the sun and cooled by the emission of LWIR radiation back to space. The average (1 au) solar flux at the top of the atmosphere (TOA) is approximately 1366 W m^{-2} [VIRGO, 2017]. However, the earth’s orbit is elliptical, the rotation axis is tilted at 23.5° to the orbital plane and the period of axial rotation is 24 hours. The illumination geometry is that of a
disk of collimated light projected onto a sphere. When light is projected onto a tilted surface, the
effective illumination area increases and the intensity decreases with the cosine of the tilt angle.
As the solar flux propagates through the atmosphere it is attenuated by absorption and scattering
so that the peak ‘clear sky’ flux at the surface with the sun overhead is approximately 1000 W m⁻².

To compare the solar flux at different latitudes, it is convenient to use the total cumulative daily
flux rather than the average. This is the total ‘clear sky’ solar flux available each day to heat the
local surface. ‘Clear sky’ values vs. day of the year are plotted for selected latitudes in Figure 2b.
The peak values are near 25 MJ m⁻² day⁻¹, but the winter values decrease significantly with
increasing latitude.

Data were calculated using the ‘clean air’ algorithms from IEEE 738 [1993].

The normalized area weighted solar flux and cumulative solar flux at the surface are shown in
Figure 2c. More than half (~60%) of the flux is incident in the ±30° latitude bands and ~80% is
incident within the ±45° bands.

The Solar Spectrum and Absorption by Water

It is also important to understand the spectral distribution of the solar flux and the penetration
depth of the flux into water. This is illustrated in Figure 3. The overall spectral distribution is
similar to that of a black body at a temperature near 5800 K. Below 300 nm, the solar flux is
attenuated by stratospheric ozone and below 200 nm by molecular oxygen. The transmitted UV
and blue wavelengths undergo molecular (Rayleigh) scattering. This depends on the inverse fourth
power of the wavelength, which explains the blue color of the sky. In the near IR (NIR) spectral
region, the solar flux is attenuation by absorption from the water vapor overtones [ASTM, 2012].
The maximum penetration depth for pure water occurs near 500 nm [Hale & Querry, 1973]. This
is close to the 550 nm peak of the solar flux. Approximately half of the solar flux is absorbed in
the first meter layer of the ocean and 90% is absorbed within the first 10 m. This means that the
temperature rise from the solar heating of the ocean is much smaller than that for a dry land surface.
Large quantities of heat are stored and released by the oceans. This acts to stabilize the climate
temperatures. This ocean heat is also circulated to higher latitudes by the wind driven ocean gyre
circulation.
a) The earth is a sphere that intersects a circular disk of the solar flux. The TOA intensity on the sphere decreases with the cosine of the angle of incidence. Only half of the earth is illuminated. The LWIR radiation is emitted from the entire the sphere.

b) Daily total cumulative solar flux vs. day of year for selected latitudes. The intensities are ‘clear sky’ values incident at the surface. This includes atmospheric attenuation and the cosine geometric factor.

c) The normalized and cumulative area weighted solar flux vs. latitude. Approximately 60% of the flux is incident within the ±30° latitude bands and 80% is within the ±45° latitude bands.

Figure 2: The illumination of the earth by the solar flux
The Greenhouse Effect

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Figure 3: The solar spectrum and water absorption

The Net LWIR Flux at the Surface

Both the land and the ocean surfaces are close to blackbody emitters in the LWIR spectral region. The total intensity of the emitted flux follows Stefan’s Law and is proportional to the fourth power of the absolute temperature. The spectral distribution follows the Planck curve. The emission
peak shifts to shorter wavelength as the temperature increases. The downward LWIR emission from the atmosphere consists of a very large number of overlapping molecular lines [Rothman et al, 2005]. These are mainly transitions between the rotation/vibration states of H$_2$O and CO$_2$. There are also minor contributions from CH$_4$, O$_3$, N$_2$O and other IR active gases. Near the surface, the lines are pressure broadened and merge together to form a quasi-continuum with a blackbody envelope. There is however a transmission window in the 8 to 12 µm (850 to 1250 cm$^{-1}$) spectral region. Blackbody emission curves for 273, 288, 303 and 318 K (0, 15, 30 and 45 C) are shown in Figure 4a. The corresponding increase in the total emission from Stefan’s law is shown in Figure 4b. The surface LWIR flux balance or exchange energy is illustrated in Figure 4c. This shows the surface emission at 300 and 320 K and the downward LWIR flux from the atmosphere at 300 K surface air temperature. The atmospheric spectral data were calculated using MODTRAN at 2 cm$^{-1}$ resolution from 100 to 1500 cm$^{-1}$ [MODTRAN, 2017]. (Wavenumbers are the inverse of the wavelength in cm, 1000 cm$^{-1}$ = 10 µm. These are the units used in the HITRAN database). The surface relative humidity was 70% and the CO$_2$ concentration was 380 ppm. The tropical model option was used. The downward flux from the atmosphere balances most of the upward flux from the surface. In this example, the net LWIR cooling flux at the same 300 K surface and air temperature is 94 W m$^{-2}$. This is 22% of the total flux emitted by the surface. The net cooling originates from the shaded orange area between the two 300 K spectral curves. When the surface temperature is increased to 320 K (47 C) to simulate the increase in the land surface temperature, the net cooling flux increases to 203 W m$^{-2}$. The increase comes from the blue shaded area in Figure 4c. However, approximately 60% of this additional flux is emitted outside of the LWIR transmission window. It is absorbed by the atmospheric H$_2$O and CO$_2$ bands near the surface and the heat generated produces additional convection. The increase in LWIR flux from the increase in surface temperature is insufficient to dissipate the excess solar heat. Instead this heat must be removed from the land surface by moist convection. The surface temperature continues to heat up until the convection is sufficient to remove the excess heat. There is a time delay or phase shift between the peak solar flux and the peak surface temperature. The surface then cools later in the day until the air and surface temperatures equalize. Under these conditions, convection essentially stops and the surface continues to cool at night by net LWIR emission.

The magnitude of the net LWIR cooling flux increases as the humidity (water vapor concentration) decreases. It also decreases as the cloud cover increases. Clouds are water (or ice) particles that act as blackbody radiators. The downward LWIR emission from the cloud base ‘fills in’ the LWIR transmission window. This is illustrated in Figure 4d. This shows the downward flux at the surface for 300 K air temperature and 90 and 10% humidity. The effect of cloud cover, altocumulus, 2.4 km base, 70% RH is also shown. The 300 K surface emission is also plotted. The data are from MODTRAN calculations.

It is also important to note that almost all of the downward LWIR flux reaching the surface from the air originates from within the first 2 km layer of the troposphere. This is a consequence of the
pressure broadening of the molecular rotation-vibration lines in the lower troposphere. This is discussed in more detail below.

Figure 4: Blackbody emission and the net LWIR cooling flux
Moist Convection and the Lapse Rate

Moist convection is usually split into two flux terms, the sensible heat flux or dry air convection and the latent heat flux or surface evaporation. Convection is a complex fluid dynamic process. However, the sensible heat flux is often simplified to just the surface-air temperature difference ($T_s - T_a$) multiplied by a bulk convection coefficient $k_{\text{conv}}$.

$$\Delta Q_{\text{sens}} = k_{\text{conv}}(T_s - T_a)$$  \hfill (1)

Over the ocean, $k_{\text{conv}}$ values near 5 W m$^{-2}$ K$^{-1}$ may be used. Over land, higher values near 20 W m$^{-2}$ K$^{-1}$ may be used. Definitions vary, so care is needed when comparing published convection data. Direct convection at the surface involves the transfer of heat (molecular motion) from the surface to the adjacent air molecules. The warm air is buoyant and is replaced by cooler air from above. As the convective heat flux increases, so does the air mass circulated at the surface. In addition to direct convection, indirect heating also occurs. This includes the absorption of excess LWIR flux from the surface mainly by the atmospheric H$_2$O and CO$_2$ bands and the release of latent heat from water vapor condensation as clouds form during convective ascent and cooling. In addition, part of the near IR (NIR) radiation from the direct solar flux is absorbed by the water vapor overtone bands. This NIR absorption can be seen in Figure 3a above.

Over land, evaporation is a complex process that involves the transfer of moisture to the surface as well as evaporation. This includes loss of moisture from the soil and from vegetation [Mengelkamp et al, 2006]. Over the oceans, the mechanism is wind driven evaporation [Yu et al, 2008; Yu, 2007]. The primary heat source for evaporation is the absorbed solar flux. The thermal energy breaks the hydrogen bonds that hold liquid water molecules together. The water vapor that is removed from the surface carries this thermal energy from the surface as latent heat. This reduces the amount of heat available for the sensible heat flux or the net LWIR emission. The latent heat is released when the water vapor condenses to form clouds at higher altitudes.

The Lapse Rate

As the warm air ascends from the surface it expands and cools. The change in temperature with altitude is called the lapse rate. For a dry air parcel under ideal adiabatic expansion conditions (no heat exchange with the surrounding air), the lapse rate is -9.8 K km$^{-1}$. This is the magnitude of the acceleration due to gravity. However, under most conditions, particularly over the oceans, the air is moist and water condenses above the saturation level to form clouds. This releases latent heat that reduces the magnitude of the lapse rate below its dry air value [Tsonis, 2007]. Figure 5a shows the calculated lapse rate for surface air temperatures of 273 and 300 K at a surface relative humidity of 70%. Figure 5b shows the corresponding pressure changes and Figure 5c shows the changes in the H$_2$O and CO$_2$ concentration. The H$_2$O concentration decreases by approximately 3 orders of magnitude because of the decrease in vapor pressure with temperature. The corresponding change in CO$_2$ concentration is approximately a factor of 3.
Figure 5: Tropospheric lapse rate: temperature, pressure and \( \text{H}_2\text{O}, \text{CO}_2 \) concentration changes with altitude.
The Molecular Linewidth

The absorbed solar heat is returned to space as LWIR radiation. As the LWIR flux passes through the atmosphere it undergoes absorption and re-emission by the IR spectral bands. These consist of a large number of individual lines that are transitions between specific molecular rotation-vibration states. Figure 6 shows the locations and line strengths of the $^1\text{H}_2\text{O}$ and $^{12}\text{C}^{16}\text{O}_2$ molecular lines in the 200 to 2000 cm$^{-1}$ spectral region for line strengths $>10^{-23}$ at a temperature of 296 K. These data are from the HITRAN database [Rothman et al, 2005]. The absorption and emission properties of these lines depends on the pressure, temperature and species concentration as well as the line strength. The LWIR flux to space therefore has to be analyzed using high resolution radiative transfer techniques that include the linewidth effects.

![Molecular lines](image)

**Figure 6:** The locations of the $^1\text{H}_2\text{O}$ and $^{12}\text{C}^{16}\text{O}_2$ molecular lines in the 200 to 2000 cm$^{-1}$ spectral region for line strengths $>10^{-23}$.

For an air parcel in the atmosphere, within the plane parallel layer approximation, the parcel is absorbing LWIR flux from above and below and is also emitting LWIR flux upwards and
downwards. The horizontal flux is assumed to cancel out. The net heating or cooling depends on the difference between the absorption and emission terms as illustrated in Figure 7a. The molecular collision frequency in troposphere is larger than $10^9$. This means that as soon as an IR photon is absorbed, the excited molecular vibration-rotation state is quenched by collisions and the thermal energy is transferred to the local air mass. Conversely, the emission of IR photons removes heat from the local air mass. The absorbed and emitted LWIR flux is fully coupled to the bulk thermal mass of the air in the atmosphere. The change in temperature of an air parcel over a given time $t$ is the cumulative net flux absorbed or emitted divided by the heat capacity of the air volume. The absorption and the molecular linewidths decrease as the pressure, temperature and the species concentration decrease with altitude. In particular, the water vapor concentration decreases rapidly as the temperature decreases. The upward radiative transfer process of absorption and emission is gradually replaced by a transition to a free photon flux. This is illustrated in Figure 7b. The mechanism for line broadening is the decrease in excited state lifetime as the molecular collision frequency increases with pressure. This is a result of the Heisenberg uncertainty principle for time and energy.

The decrease in linewidth with altitude is illustrated in Figure 7c. This shows the H$_2$O and CO$_2$ absorption lines in the 590 to 600 cm$^{-1}$ spectral region at altitudes of 0, 5 and 10 km. The path length is 100 m. The arrows indicate the changes in linewidth for the H$_2$O line near 595 cm$^{-1}$ and the CO$_2$ line near 598.5 cm$^{-1}$ as the altitude increases from the surface to 10 km. The H$_2$O linewidth decreases from approximately 1 cm$^{-1}$ to 0.05 cm$^{-1}$ whereas the CO$_2$ linewidth decreases from 0.19 to 0.04 cm$^{-1}$. These are 5% and 21% of the initial values.

The transition from absorption-emission to a free photon flux for H$_2$O occurs in the middle troposphere at a temperature near 253 K (-20C). This is location of the cold reservoir of the tropospheric heat engine. As the surface temperature changes, the altitude of the cold reservoir changes. The tropospheric cooling rates vs altitude are shown in Figure 8a for H$_2$O and CO$_2$ at 3 surface air temperatures, 275, 285 and 295 K, 50% RH and 380 ppm CO$_2$. The surface temperatures are 2 K higher at 277, 287 and 297 K. The altitude of the peak cooling rate decreases from 6.4 to 4.8 then 3.4 km as the surface temperature decreases.

Near the surface, the molecular lines are sufficiently pressure broadened that they merge into a quasi-continuum. Almost all of the downward flux reaching the surface originates from within the first 2 km layer of the troposphere. The cumulative downward flux from H$_2$O and CO$_2$ vs. altitude is shown in Figure 8b. Four cases are plotted for surface temperatures of 272 and 300 K each with relative humidities of 20 and 70%. The downward flux near the surface increases with temperature and humidity. Even for the lowest flux case, 272 K and 20% RH, 95% of the surface flux originates from within the first 2 km layer. This means that the downward flux to the surface is decoupled from the LWIR emission to space. The concept of radiative forcing is invalid [IPCC, 2013]. There is no equilibrium flux that can be perturbed by an increase in ‘greenhouse gas’ concentration.
Figure 7: Molecular line broadening and the transition from absorption/emission to a free photon flux.

b) Transition from absorption-emission to free photon flux as the linewidth decreases with altitude. H$_2$O line near 231 cm$^{-1}$

c) H$_2$O and CO$_2$ absorption lines, 0, 5 and 10 km, 100 m path length, 590 to 600 cm$^{-1}$. The decrease in linewidth with altitude is much greater for H$_2$O than for CO$_2$. 

\[ F_{\text{net}} = AF_{\text{up}} + AF_{\text{dn}} - 2F_{\text{Em}} \]
Figure 8: Line broadening effects.  

a) Tropospheric cooling rates for H₂O and CO₂. The peak cooling rate for H₂O shifts to higher altitudes as the surface temperature increases. This is the main cooling reservoir of the tropospheric heat engine.

b) Cumulative fraction of the downward flux at the surface vs. altitude for surface temperatures of 272 and 300 K, each with 20 and 70% RH. Almost all of the downward flux reaching the surface originates from within the first 2 km layer. This is the lower tropospheric reservoir.

Figure 8: Line broadening effects. a) The water band emission to space from the upper tropospheric reservoir and b) the downward flux at the surface from the lower tropospheric reservoir.
The LWIR Emission to Space

As discussed above, the total LWIR flux emitted to space is in approximate long term energy balance with the absorbed solar flux. However, the NIR emission originates from different altitudes with different temperatures so the spectral distribution is not that of a blackbody. Figure 9a shows the LWIR emission to space from the Niger Valley, N. Africa recorded from the Nimbus 4 satellite, early afternoon May 5th 1970. This figure, or similar ones have been used for many years to justify ‘global warming’ by claiming that an increase in ‘CO\textsubscript{2}’ absorption’ in the upper troposphere somehow increases the surface temperature [ACS, 2012]. This is simply impossible. The LWIR flux that reaches the surface originates from within the first 2 km layer. The LWIR flux in the upper troposphere is decoupled from the surface because of molecular line narrowing [Clark 2013a]. Starting from the left of Figure 9a, in the 400 to 600 cm\textsuperscript{-1} region, the emission is from the H\textsubscript{2}O rotation band at an effective emission temperature of \(\sim\)250 K (\(-23\) C) and an altitude near 7 km. In the 600 to 800 cm\textsuperscript{-1} region, the emission is from the main CO\textsubscript{2} band at an effective emission temperature near 220 K (\(-53\) C) and an altitude near 12 km. Between 800 and 1300 cm\textsuperscript{-1}, the emission is from the hot desert surface at a temperature near 320 K (47 C). In the middle of this is the O\textsubscript{3} stratospheric band which is absorbing some of the surface flux. Between 1300 and 1600 cm\textsuperscript{-1}, most the emission is from the H\textsubscript{2}O \(\nu_2\) vibrational band, with some overlapping contribution from CH\textsubscript{4}. A simplified emission level diagram is shown in Figure 9b.

The atmospheric temperature profile is set by the lapse rate, not the LWIR emission. As the warm air rises from the surface it expands and cools. At night, in this geographic region, the surface cools to approximately 300 K, (27 C) and the surface emission profile shifts to the region indicated by the blue areas. The net LWIR emission from the surface decreases by over 100 W.m\textsuperscript{-2}. However, the atmospheric emission bands change little because LWIR emission is coupled to the bulk thermal air mass of the atmosphere. The diurnal temperature fluctuation in the middle troposphere is approximately 2 K or less. The atmosphere is always cooling by LWIR emission to space. It is heated during the day and early evening by convection from the surface. These complex energy transfer processes should not be reduced to a single ‘equilibrium average flux temperature’. Instead, the LWIR emission to space should be interpreted as a set of cooling fluxes that cool different levels in the atmosphere.
The Weather Station Temperature.

The various heating and cooling flux terms interact with the surface as illustrated above in Figure 1. However, the temperatures recorded by a weather station are not surface temperatures. Instead, the weather station temperature is the meteorological surface air temperature (MSAT). This is the temperature measured in a ventilated enclosure paced for convenience at eye level, 1.5 to 2 m above the ground [Oke, 2006]. Historically in the US, the maximum and minimum daily temperatures were recorded using Six’s thermometer [Benjamin, 2006]. The minimum MSAT generally occurs near dawn. At this time, the surface air layer and the ground are usually at similar temperatures and the minimum MSAT is approximately that of the bulk temperature of the air mass of the local weather system that is passing through. The maximum MSAT is generally recorded in the early afternoon after the peak solar flux. It is the air temperature produced by the
convective mixing of the warm air rising from the surface as it interacts with the cooler air at the MSAT thermometer level. Under full summer sun illumination, the bare, dry ground temperature may easily reach or exceed 50 °C (~120 °F). The maximum MSAT will generally be some 20 °C cooler near 30 °C (~85 °F) [Clark, 2013b; 2011].

The maximum and minimum MSATs measure temperatures that result from two very different processes. In many parts of the world, the weather systems are formed over the oceans and the ocean temperature of formation is ‘carried’ by the air mass over long distances. This information is found in the minimum MSAT data. The sun heats the surface during the day and the surface temperature that drives the convection depends on the solar flux and the surface evaporation. The increase in temperature from the minimum to the maximum is a combined measure of convective mixing, solar flux, cloud cover and surface moisture/precipitation.

It is also important to understand that the climate record is not simply the average of the weather station data archive. The data have been ‘homogenized’ to produce points on a regular coordinate grid, typically 5° x 5° latitude longitude grids for easier comparison to model output. (The climate models do not have the fidelity to simulate the temperature record that they are supposed to be predicting). Some adjustments are necessary to account for station changes and instrumental bias effects. However, the same groups of climate modelers have also been ‘homogenizing’ the weather station data and well documented extra warming has mysteriously appeared in the climate record. The climate temperature record has been ‘adjusted’ to better fit the modeling results [Cheetham, 2015a; D’Aleo, 2010; Johnson, 2015, Parker and Ollier, 2017, Worall, 2017]. In addition, in many locations, the thermometer and enclosure have been changed from mercury in glass in a white painted wooden louvered ‘Stevenson screen’ structure to a thermistor in a smaller, plastic ‘beehive’ structure. This has led to discontinuities in the climate record and concern over electronic averaging times [Quayle et al, 1991; Marohasy, 2017]. Considerable caution is therefore needed when published climate data is used.

An important concept in the interpretation of the weather station record is the night time transition temperature at which the land surface and air temperatures equalize and convection is significantly reduced [Clark 2013b]. During the night, the surface cooling is limited mainly to the net LWIR emission. This is nominally 50 ±50 W m$^{-2}$. During the day, as the sun heats the surface, convection increases and heat is conducted below the surface where it is stored and released later in the day. A major factor that influences the convection transition temperature is the ocean surface temperature in the region of formation of the prevailing weather systems. These ocean temperatures show characteristic regional quasi-periodic fluctuations or oscillations. Three well known ocean oscillations are the Pacific Decadal Oscillation (PDO), the Atlantic Multi-decadal Oscillation (AMO) and the El Nino Southern Oscillation (ENSO). All of these have major impacts on the earth’s climate and their effects can be seen in the climate record [Cheetham, 2015b].

The AMO and PDO have periods of oscillation near 60 years. The AMO is associated with changes in the surface temperature in the North Atlantic Ocean. The PDO is associated with changes in temperatures in the North Pacific Ocean. The ENSO is a short term oscillation with a
period between 3 and 7 years. It involves changes in the size and location of the Pacific warm pool and is caused by variations in wind speed over the equatorial Pacific Ocean. Figure 10 shows the PDO, AMO and ENSO oscillations over selected time periods: PDO one and five year averages from 1900; AMO one year averages from 1856 and ENSO monthly averages from 1950 [AMO, 2017; ENSO, 2017; PDO, 2017]. The long term 30 year fluctuations on the PDO and AMO are clearly visible. Figure 11 shows the associated changes in the temperature record related to the ocean oscillations [Clark, 2013b; HADCRUT4, 2017; UAH, 2017].

Figure 11a shows the five year average minimum MSAT record for the Los Angeles civic center from 1925 to 2005. The PDO is also plotted over the same period of record. The characteristic ‘fingerprint’ of the PDO can clearly be seen in the LA data. However, there is a slope to the LA data that does not show in the PDO record. This is an approximate indicator of the urban heat island (UHI) effect in Los Angeles as the surrounding urban area has increased. This ‘PDO’ signature can be seen in most of the minimum MSAT weather station records in California. It provides a reference that can be used as a probe of the UHI effect and other station anomalies. This analytical technique has also been extended to UK temperatures using the AMO [Clark, 2013b].

Figure 11b shows the 1 year average of the AMO plotted with the HADCRUT4 climate record generated by the UK Hadley Center. Both the longer term maxima and minima and the shorter term ‘fingerprint’ detail can clearly be seen in both plots. The correlation coefficient between the two data sets is 0.8. The influence of the AMO extends over large areas of North America, Europe and parts of Africa through the propagation of the convection transition temperature. The climate trend for the continental US can be reconstructed using a linear combination of the AMO and PDO data D’Aleo, 2008].

Figure 11c shows the global lower troposphere temperature from 1979 generated by the University of Huntsville Ala. climate group using satellite microwave sounding data. This is plotted with the ENSO data over the same period of record and scaled to match the UAH data. The lower troposphere temperature tracks the ENSO with a delay of a few months. The increase in extent of the Pacific warm pool significantly increases the amount of water vapor released into the troposphere and this in turn heats the troposphere by condensation. The El Nino peaks of 1998 and 2016 can clearly be seen in the data.

The data in Figure 11 clearly demonstrate that changes in ocean surface temperature are a major factor in the changes observed in the weather station record both for single stations and for the global climate record. However, the weather station record only extends back to the latter part of the nineteenth century, although some sparse earlier data is available. Earlier climate changes have to be reconstructed using proxy data such as isotope ratios or historical and archaeological records. These longer term climate trends will now be considered.
Figure 10: Ocean oscillations, PDO 1 and 5 year averages from 1900, AMO 1 year averages from 1856 and ENSO monthly averages from 1950.
Figure 11: Temperature changes related to the ocean oscillations.

a) Los Angeles minimum MSAT and PDO from 1925-5 year temperature anomaly averages. The PDO ‘signature’ can clearly be seen in the MSAT data. The slope is an indication of urban heat island effects.

b) HADCRUT4 global temperature and the AMO, 1 year averages. The two temperature series are clearly related.

c) ENSO and UAH lower troposphere MSU global temperature anomalies. The UAH data follows the ENSO with a time lag of a few months. The ENSO data was scaled by ½ to match the UAH data.
Longer Term Climate Change

Figure 12 shows proxy climate temperature reconstructions for the last 2000 and 10000 years [Paleoclimate, 2017]. Figure 12a shows the medieval maximum, Maunder minimum and modern warming period. These climate changes are related to changes in the solar constant as determined by the sunspot count and other measures of solar activity. This is discussed in more detail below. Figure 12b also shows the earlier Minoan and Roman warming periods. The lower plot shows the change in atmospheric CO$_2$ concentration over the last 10,000 years. The earth has been cooling for about the last 6000 years and the modern warming period is just a continuation of the previous warming and cooling cycles with a smaller temperature rise. There is no discernable influence from changes in CO$_2$ concentration. Time zero here is 1950, so the recentizable influence of CO$_2$ concentration is not shown. Figure 13 shows the so called Milankovitch cycles or changes in the earth’s orbital and axial motion produced by planetary perturbations, mainly by Jupiter [Milankovitch, 1941; 1920; 2015, Varadi et al, 2003]. Figure 13a shows the type of motion: eccentricity, obliquity and precession. Figure 13b shows the Milankovitch cycles, high latitude solar insolation and stages of glaciation for the last 1000,000 years. The earth has cycled through a series of Ice Ages, with each one lasting approximately 100,000 years. During the change from cold to warm, the atmospheric CO$_2$ concentration has increased from approximately 200 to 280 ppm. However, the change in CO$_2$ concentration lags the change in temperature. This means that the increase in ocean temperature produces the increase in CO$_2$ concentration as the solubility of CO$_2$ in the oceans decreases with increasing temperature. These solubility changes however involve complex changes in the ocean buffer chemistry of carbonate and bicarbonate ions [Follows, 2006]. Figure 13c shows the Milankovitch cycles on an expanded scale from -200,000 to +100,000 years.

Figure 14 shows proxy reconstructions of the climate temperature and CO$_2$ concentration for the last 65 million years. Figure 14a shows the climate temperature reconstruction from Zachos et al [2001]. Major climate, tectonic and biological events are also included. Figure 14b shows the related changes in the location of the continents produced by plate tectonics and Figure 14c shows the changes in temperature and CO$_2$ from various reconstructions [Paleoclimate, 2017]. There is no discernable relationship between CO$_2$ concentration and temperature over this time period. However, plate tectonics has produced changes in ocean circulation that have had a major impact on the climate. The first of these was separation of S. America from Antarctica with the formation of the Drake Passage and the circumpolar circulation of the Southern Ocean. The second was the formation of the Isthmus of Panama and the closure of the Arctic Ocean to the Pacific Ocean. Both of these events have resulted in climate cooling.

From this discussion it is clear that changes in atmospheric CO$_2$ concentration have had no effect on climate for at least the last 65 million years. Climate change can be understood in terms of ocean oscillations with periods of 3 to 7 and 60 years, changes in solar activity with periods of the order of 100 to 1000 years, Milankovitch cycles (planetary perturbations) with periods of the order of 10,000 to 100,000 years and changes in ocean circulation related to plate tectonics over even
longer geological time scales. The climate energy transfer processes that underlie surface temperature and temperature change will now be considered in more detail.

**Figure 12**: Proxy temperature reconstructions for 2000 and 10,000 years.

a) A 2000 year global temperature reconstruction based on non-tree ring proxies. This shows the medieval maximum, the Maunder minimum and the modern warming period.

b) A 10,000 year temperature reconstruction based on GISP ice core data. This shows that the earth has been cooling for about 6000 years. The Minoan, Roman, Medieval and Modern warm periods are indicated. The lower plot shows the change in atmospheric CO₂ concentration, also from the ice core data.
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Figure 13: Milankovitch cycles: planetary perturbations of the earth’s orbit and axial rotation

a) Changes in the earth’s orbital eccentricity and axial obliquity (tilt) and precession (wobble) induced by planetary perturbations (schematic).

b) Milankovitch cycles: changes in eccentricity, obliquity and precession induced by planetary perturbations for the last million years. Changes in solar flux at 65° north and the glaciation cycles are also shown.

c) Milankovitch cycles for the last 200,000 years and for the next 100,000 years
a) $\delta^{18}O$ and $\delta^{13}C$ isotope ratios and temperature reconstruction for the last 65 million years. Major climatic, tectonic and biotic events are also noted.

b) Changes in the location of the continents induced by plate tectonics over the last 69 million years.
Figure 14: Isotope proxy reconstruction of climate temperature and CO$_2$ over the last 65 million years. The motion of the continents induced by plate tectonic is also included. There is no discernable connection between CO$_2$ concentration and temperature. However, the effects of plate tectonics including the opening of the Drake Passage, the closure of the Arctic Ocean and the formation of the Isthmus of Panama all have major impacts on the climate temperature.

Quantitative Analysis of the Surface Temperature

Based on the discussion above, there is no reason to expect that the observed increase in atmospheric CO$_2$ concentration from 280 to 400 ppm has had any effect on the earth’s climate [Keeling, 2017]. Over land, thermal conduction transports the solar heat below the surface. The diurnal variation is dissipated within the first meter layer below the surface and seasonal variation can be detected down to approximately 5 m. Any small changes in LWIR flux from CO$_2$ produce changes in the rate of cooling of this thermal mass that are simply too small to detect as variations in the surface temperature. Over the oceans, the LWIR flux is absorbed in the first 100 µm layer at the surface. Here it is coupled to the wind driven evaporation flux where again it cannot produce a measurable change in surface temperature. The surface energy transfer and the surface temperature will now be considered in more quantitative detail.
The Land-Air Interface

Figure 15 illustrates the diurnal flux balance for dry convection over land under full summer sun conditions. This is based on measured flux data from the University of Irvine ‘Grasslands’ monitoring site [Clark, 2013a; 2013b; 2011; Goulden, 2012]. The solar heating flux, the convection and net IR cooling fluxes and the subsurface thermal transfer are plotted for a 24 hour cycle in Figure 15a. The corresponding surface and air temperatures are shown in Figure 15b. In this illustrative example, the total thermal flux dissipated by the surface during the 24 hour period from both net LWIR emission and convection in Figure 15a is 25.4 MJ m\(^{-2}\) representing full summer sun ‘clear sky’ conditions. Of this, approximately 23 MJ m\(^{-2}\), or 90% is dissipated during the day and early evening. The convective flux is 14.5 MJ m\(^{-2}\) or 57% of the total flux and the associated LWIR flux is 8.5 MJ m\(^{-2}\) or 33% of the total flux. Only 2.4 MJ m\(^{-2}\) is dissipated at night through the LWIR transmission window. The time delay or phase shift between the maximum solar flux and surface cooling flux in this case is almost 2 hours. The convection continues after sunset until the ground and air temperatures equalize. After that the surface cooling is limited to the net IR flux through the LWIR window. Under these conditions, the lower tropospheric reservoir acts as a ‘thermal blanket’ that slows the night time cooling. This is how the surface temperature is maintained at night. The night time surface cooling flux typically varies between 0 and 100 W m\(^{-2}\), depending on humidity and cloud cover. The solar flux will usually vary, depending on cloud cover. The increase in the downward LWIR flux from a 120 ppm increase in atmospheric CO\(_2\) concentration is approximately 2.0 W m\(^{-2}\). This corresponds to 0.16 MJ m\(^{-2}\) per day or 0.7% of the total clear sky solar flux. This is too small to have any measurable effect on surface temperatures when it is added to the net LWIR flux term and used to calculate the total flux balance [Clark, 2013a, 2013b; 2011]. In signal processing terms it is ‘buried in the noise’.

If the solar flux is reduced because of partial cloud cover, the diurnal flux behavior will be similar, but with a reduced magnitude. If water is present, surface evaporation will add a latent heat flux. This will reduce the surface heating and therefore the LWIR emission and the sensible heat flux. Energy is still conserved and the latent heat will be released through condensation of the water vapor in the troposphere as the warm air rises from the surface and cools above the saturation level. The surface evaporation will also vary with the wind speed and the humidity gradient. Vegetation will also increase the surface area and reduce the temperature rise. The details of vegetation related photosynthesis and evapotranspiration are complex, but the net result can still be considered in terms of a time dependent net surface flux balance [Mengelkamp et al, 2006]. The important point is that the net LWIR flux is insufficient to dissipate the absorbed solar flux and the excess solar heat must be dissipated by (moist) convection. The observed increase in atmospheric concentration of CO\(_2\), or any other so called ‘greenhouse gas’ cannot produce any ‘global warming’.
The Ocean-Air Interface

The energy transfer processes at the ocean-air interface are very different from those at the land-air interface. The surface temperature gradients are much smaller, most of the solar flux penetrates below the surface and the dominant cooling process is wind driven evaporation. The cooler water produced at the surface then sinks and cools the bulk ocean layers below. It is replaced by upwelling warm water. This is a Rayleigh-Benard type of convection with columns of water moving in opposite directions. It is not a simple diffusion process. This convection cycle
continues to provide heat to the surface at night, so the wind driven evaporation continues at night. Over 50% of the solar flux is absorbed within the first 1 m layer of the ocean and 90% is absorbed within the first 10 m. The thermal storage is not localized and heat is transported and recirculated over very long distances. However, the penetration depth of LWIR radiation from the CO$_2$ bands into water is less than 100 micron. This means that the LWIR flux from CO$_2$ is coupled to the surface evaporation and small changes in this LWIR flux cannot heat the ocean below.

During the summer at most latitudes, the solar heating exceeds the wind driven cooling. The lower subsurface layers are not coupled to the surface by convective mixing and a stable thermal gradient is established. During the winter, the wind driven evaporation exceeds the solar heating and the surface temperatures cool and establish a uniform temperature layer down to 100 m or lower. Figure 16 shows the seasonal variation in ocean temperature at nominal depths of 5, 25, 50, 75 and 100 m derived from Argo float data [Clark, 2013a, 2013b; 2011]. Figure 16a shows the temperature data from a float drifting in the S. Pacific Ocean at latitudes and longitudes near 21° S and 105° W. Higher latitudes show a similar behavior with lower temperatures because of reduced solar heating. It is also important to note that at high latitudes, the surface area of a spherical zone decreases significantly. This geometric factor increases the depth of ocean currents as they flow to higher latitudes, further limiting their interaction with the surface [Alexander et al, 2001]. Small changes in subsurface ocean temperatures can therefore result in large changes in polar ice formation.

At low latitudes near the equator, the diurnal and seasonal temperature variations may not be sufficient to mix the subsurface layers below the 25 to 50 m levels and heat can accumulate at these depths for extended periods. Figure 16b shows the temperature data from an Argo float drifting in the S. Pacific Ocean at latitudes and longitudes near 1.5° S and 126° W. The diurnal mixing layer is shallow and only extends down to the 50 m level about half of the time. The floats are not tethered and the decrease in near-surface temperature with time is caused by an eastward drift.

Heat continues to accumulate as the ocean water travels westwards with the Pacific equatorial current. This leads to the formation of the equatorial ocean warm pool in the western Pacific Ocean. The ocean surface temperature increases until the wind driven evaporation balances the tropical solar heating at a surface temperature near 30 C and an average wind speed near 5 m s$^{-1}$. Variations in the wind speed across the Pacific Ocean then produce the characteristic ENSO oscillations. As the wind speed slows, the evaporation decreases and the ocean current velocity decreases. Both of these factors increase the rate of surface heating and the warm pool extent increases.

The energy transfer processes for the Pacific warm pool are illustrated schematically in Figure 17. Here, a change in wind speed of 1 m s$^{-1}$ produces a change in latent heat flux of approximately 40 W m$^{-2}$. The observed increase in atmospheric CO$_2$ concentration of 120 ppm has only produced an increase of 2 W m$^{-2}$ in the downward LWIR flux at the surface. This corresponds to a decrease
in average wind speed of 5 cm s$^{-1}$. This small change in LWIR flux is simply overwhelmed by the magnitude and variability in the wind driven latent heat flux [Clark, 2013b].

Figure 16: Argo float data for average latitudes of 21° and 1.5° S. At 21° S and higher latitudes, the solar heating and wind driven evaporation interact to produce a stable subsurface thermal gradient in the summer that is removed by excess cooling during the winter. Near the equator, the solar heating exceeds the evaporation in the eastern Pacific Ocean leading to the formation of the equatorial warm pool.
Figure 17: Energy transfer in the Pacific warm pool (schematic).

a) Ocean surface layer detail. Evaporation occurs from a thin surface layer <1 μm thick and NIR absorption/emission is limited to the first 100 μm layer. Approximately 5% of the solar flux is also absorbed in first 1 mm layer.

b) Ocean energy transfer in the Pacific warm pool. The approximate magnitudes of the various flux terms are indicated. The cooler water sinks from the surface and is replaced by warmer water from the bulk ocean below. This is a Rayleigh-Bénard convective flow process.
Figure 18a shows the air temperature and the ocean temperature at 1.5 and 25 m depths for 40 days starting at the beginning of July 2010. These data were recorded at the TAO/TRITON buoy located on the equator in the Pacific warm pool at a longitude of 156 E. Figure 18b shows the corresponding wind speed and solar flux. There is a clear inverse relationship between the diurnal peak in the ocean temperature at 1.5 m depth and the wind speed. The diurnal temperature peaks increased when the wind speed was less than \( \sim 4 \text{ m s}^{-1} \). This can be seen in areas indicated by the dotted lines.

![Graph showing temperature, wind speed, and solar flux](image)

**Figure 18**: Air and 1.5, 25 m ocean temperatures, wind speed and solar flux, 40 days of data from July 1, 2010, TAO/TRITON buoy data, 0°, 156° E. The two periods with low wind speeds and higher 1.5 m SST are indicated with the dotted lines.

**Climate Change and the Solar Flux**

Based on the discussion above, changes in atmospheric CO\(_2\) concentration have had no effect on the earth’s climate for at least the last 65 million years. Short term climate changes with periods
up to 70 years may be explained in terms of ocean oscillations. Longer term changes in a nominal 100 to 1000 year time frame are related to variations in the sunspot cycle [Abdussamatov, 2013; Zharkova et al. 2015]. Recent Ice Age cycles have a 100,000 year period related to the change in eccentricity of the earth’s orbit. Over geological time scales of millions of years, climate changes are caused by changes in ocean circulation produced as the plate tectonic motion of the continents alters ocean boundaries. The climate related changes in the TOA solar flux are nominally ±1 W m². There is an increase of 1 W m² related to sunspot number fluctuations and a decrease of 1 W m² related to the change in orbital eccentricity. Figure 19 shows the variations in solar flux produced by changes in sunspot activity. Figure 19a shows the variation in the total solar insolation (TSI) for sunspot cycles 23 and 24 from 1996 to 2017 [VIRGO, 2017]. The average TSI is near 1366 W m². A change in sunspot index of 100 produces a change of approximately 1 W m² in the TSI. This may be used to quantify the change in TSI over the sunspot record. Figure 19b shows the sunspot index over the last 400 years and Figure 19c shows a reconstruction of the sunspot record from 800 to 2000 AD using ¹⁴C isotope data [Sunspots, 2017].

A simple estimate of the change in solar flux needed to induce climate change may be obtained from changes in sea level during the Ice Age cycle. At the last glacial maximum, sea level was 120 m lower than it is today. This water was stored as freshwater ice at higher latitudes. The solar flux over 10,000 years needed to melt an ice column 1 m² in area and 120 m deep and heat the water to 15°C is approximately 4.4 MJ m² yr⁻¹ coupled into the ice. This corresponds to an increase in 24 hour average solar flux of 0.14 W m². The increase in ‘clear sky’ surface flux vs. latitude for an increase in the TSI of 1 W m² is shown in Figure 20. The units used here are MJ m² yr⁻¹. Near the equator, the increase is 6.6 MJ m² yr⁻¹. The 4.4 MJ m² yr⁻¹ level is shown as the dotted line on the plot. This means that a change in TSI of the order of 1 W m² is capable of cycling the earth through an Ice Age based on straightforward conservation of energy arguments.

The change in solar flux produced by a change in eccentricity is simply a change in the TSI without any change in the spectral distribution of the solar flux. However, the change in TSI produced by the sunspot cycle occurs mainly in the UV part of the solar spectrum. This is shown in Figure 21. The scales are logarithmic. Figure 21a gives the spectral distribution of the solar irradiance both for TOA and at the earth’s surface. The variation in the irradiance ratio (max-min)/min over the sunspot cycle is also plotted [Harvey, 1997]. Figure 21b shows the UV variation on an enlarged scale along with the water absorption spectrum in the 300 to 600 nm region. The penetration depth into water at 400 nm is still significant, more than 20 m. This means that the increase in near UV solar flux can be absorbed and stored as heat below the ocean surface.

The observed climate warming since the end of the Maunder minimum is approximately 0.5°C per century. The effect of solar heating may be evaluated by scaling the cumulative change in the sunspot index. Figure 22 shows the HADCRUT4 temperature anomaly plotted with the scaled cumulative sunspot index from 1850 [NASA, Sunspot Cycle, 2015]. The scale factor and offset of the sunspot data were adjusted until the straight line fit aligned with the straight line fit to the HADCRUT4 data. The offset was -0.46°C. The scale factor was set as follows. A value of 0.01 was used to convert the sunspot index into a change in TOA flux in W m² based on VIRGO data.
This was the multiplied by 5.2, the area weighted average of the cumulative annual solar flux in MJ m\(^{-2}\) yr\(^{-1}\) at the surface from Figure 20 and divided by 420 MJ, the heat capacity of a 1 m\(^2\) x 100 m column of water. This gave the annual temperature increase for 100% coupling of the heat into the ocean to 100 m depth. This in turn was multiplied by a 0.71 coupling factor to align the data sets. This simple result shows that the change in solar flux coupled into the ocean is consistent with the observed warming since 1850. Other factors such as changes in cosmic ray intensities may also be involved [Svensmark, 2012; Svensmark et al, 2017; 2009].

Figure 19: Sunspot activity
Figure 20: Change in solar flux vs. latitude for a 1 W m$^{-2}$ increase in TSI. The dotted line shows the nominal calculated flux level needed to warm the earth out of an Ice Age over 10,000 years. Units are cumulative flux in MJ m$^{-2}$ yr$^{-1}$. The melt flux level corresponds to a 24 hour solar flux increase of 0.14 W m$^{-2}$.

The Faint Sun Paradox

During earlier geological times, approximately 2.5 billion years ago, the solar flux was only 80% of its current value. When conventional greenhouse effect equilibrium arguments are used, this leads to the so called ‘faint young sun paradox’. How did the downward LWIR flux maintain the surface temperature? Some kind of ‘enhanced greenhouse effect’ appears to be required [Goldblatt & Zahnle, 2011]. However, this problem disappears once the ocean evaporation temperature is considered. The effect of wind speed and solar flux on ocean surface temperature may be understood by using a scaling argument based on Yu’s formulation of the ocean evaporation [Yu 2007; Yu et al., 2008]. This is shown in Figure 23. The relative evaporation rate of 1.0 at 30 C indicated by the black circle is ocean warm pool surface temperature for which the cooling flux balances the current tropical solar flux at a wind speed of 5 m s$^{-1}$ and a surface–air temperature difference $\Delta T$ of 1 C. The relative humidity is set to 70%. The evaporative cooling flux is much more sensitive to the wind speed than the surface–air thermal gradient or the ocean surface temperature. A doubling of the wind speed from 5 to 10 m s$^{-1}$ doubles the evaporation rate. Similarly, halving the wind speed from 5 to 2.5 m s$^{-1}$ halves the evaporation rate. An increase from 1 to 2 and then to 3 C in the surface–air temperature difference only increases the evaporation rate by 10 and then 20%. Similarly, a reduction in solar flux to 80% of the current value only decreases the ocean surface temperature warm pool balance by 4 C to 26 C. This means that the ‘faint young sun paradox’ goes away. The tropical ocean warm pool was only 4 C cooler than it is now. This of course assumes similar ocean and wind circulation patterns to those of today.
Figure 21: Variation in the solar spectrum with the sunspot cycle and overlap with the water absorption in the 300 to 600 nm region.
The Greenhouse Effect Temperature and Radiative Forcing

In order to try and quantify the so called ‘greenhouse effect’ it is claimed that the surface temperature is 33 K warmer than it would be if the IR active gases were removed from the atmosphere. This is based on the difference between an ‘average surface temperature’ of 288 K
and an effective LWIR emission temperature to space of 255 K (-18 C) [Taylor, 2006]. First of all the whole concept of a single average temperature for the earth has little useful meaning [Essex et al, 2006]. Secondly, as discussed above in relation to Figure 9 above, the LWIR emission to space comes from a range of atmospheric levels with different temperatures and spectral distributions. In reality, this ‘greenhouse effect’ temperature difference is just the convective cooling produced as an air parcel ascends from the surface to the cold reservoir of the tropospheric heat engine near 5 km with a lapse rate of -6.5 K km\(^{-1}\). In addition, it is claimed that the temperature of the earth without any ‘greenhouse effect’ would be 255 K based on equilibrium average flux arguments. However, this argument ignores the cosine dependence of the solar flux illumination and uses incorrect flux/temperature averaging techniques. The average temperature of an airless earth has been estimated to be near -75 C (198 K) giving a ‘greenhouse effect temperature’ near 90 K [Volokin & ReLlez, 2014].

The assumption of an ‘average equilibrium infra-red atmosphere’ is also incorrect. This is based on conservation of energy arguments that set aside the Second Law of Thermodynamics and ignore the dynamic nature of the tropospheric heat engine. In the original climate model formulation developed by Manabe and Wetherald (M&W) in 1967, an exact flux TOA flux balance between the absorbed solar flux and the emitted LWIR flux was used. The surface was assumed to be a blackbody surface with zero heat capacity and a fixed atmospheric distribution of relative humidity was also used [M&W, 1967]. Unfortunately, these simplifying assumptions created CO\(_2\) induced global warming as a mathematical artifact of the model calculations [Clark, 2017]. The ‘average equilibrium infra-red atmosphere’ is just a mathematical construct that leads to a simple set of meaningless flux equations [Held & Soden, 2000; Ramanathan, 1998; Ramanathan and Coakley, 1978].

Joseph Fourier discussed the temperature of the Earth in 1827 using his recently developed theories of heat transfer [Fourier, 1827]. He clearly recognized that there was a daily and an annual variation in subsurface ground temperatures produced by solar heating of the surface and that there was a depth dependent time difference (phase shift) between the intensity of the solar flux and the change in subsurface temperature. He also understood the role of convection in both atmospheric and ocean thermal transport. The idea that changes in atmospheric CO\(_2\) concentration could cause climate change originated with Tyndall [1863] in the middle of the nineteenth century. He accepted the Ice Age theory introduced by Agassiz [1840] and at the time, changes in IR flux were a reasonable explanation. By the 1960s it was generally accepted that climate change could be caused by a ‘greenhouse effect’ involving changes in the atmospheric CO\(_2\) concentration [Imbrie and Imbrie, 1979; Weart, 1979; 2015]. This was reinforced by Carl Sagan’s incorrect 1960 interpretation of the high surface temperature on Venus as a ‘greenhouse effect’ [AIP 2015]. In spite of all of this speculation about the ‘greenhouse effect’ no-one bothered to do any basic thermal engineering calculations of the surface temperature changes that could be attributed to CO\(_2\). It was simply assumed that the increase in IR flux would be the cause. Fourier’s non-equilibrium description of the surface heat transfer was conveniently overlooked.
The modeling errors created by the M&W approach were ignored and this type of model was used to ‘predict’ global warming in the Charney Report and was adopted by NASA [Charney, 1979]. This provided a ‘benchmark’ for future global warming simulation studies. Climate model output was compared using the hypothetical warming produced by a doubling of the CO$_2$ concentration. Models results were compared to other model results. Physical reality was not allowed to intrude. The M&W model was then ‘improved’ without any attempt to correct the underlying mathematical assumptions. In fact, more invalid mathematical constructs were added. The LWIR flux was coupled into ocean layer 100 m thick even though the penetration depth of the LWIR flux was less than 100 micron [Hansen et al, 1981]. This paper also introduced the concept of ‘radiative forcing’ as a potential increase in surface temperature from ‘global radiative perturbations’. Addition claims that this ‘warming’ would lead to more ‘extreme weather’ were also made. All of this is based on nothing more than meaningless mathematical ritual: the application of perturbation theory to a fictional equilibrium infra-red climate. An empirical ‘climate sensitivity constant’ was then introduced. It was simply decreed, without any physical justification that a 1 W m$^{-2}$ increase in atmospheric LWIR flux from CO$_2$ produced a 2/3 C increase in ‘surface temperature’ [Hansen et al, 2005]. This was based on nothing more than a contrived correlation between the calculated increase in downward LWIR flux from CO$_2$ and the observed increase in the average weather station record [Jones et al, 1989; 1999]. Mid twentieth century cooling was ignored. This ‘climate sensitivity constant’ has been used to create ‘global warming’ using ‘radiative forcing constants’ for every imaginable ‘greenhouse gas’ that can be found in the atmosphere and is featured prominently in the IPPC reports [IPCC 2013]. This is nothing more than empirical pseudoscience. The climate model results are based on a linear extrapolation of the last ocean warming cycle. The Earth is now starting to cool again and this has clearly revealed the climate modeling fraud. The models continue to predict warming based on the increase in atmospheric CO$_2$ concentration, while there is clearly a ‘pause’ in the measured climate record. The creation of both cooling and warming by ‘cherry picking’ the climate record is illustrated in Figure 23, derived from Akasofu [2010]. The so called ‘pause’ is shown in Figure 24 [Spencer, 2013]. Climate model results have diverged significantly from the measured temperature record, even with ‘homogenization’.
Figure 24: The creation of both global cooling and global warming by ‘cherry picking’ time periods from the climate record [After Akasofu, 2010]. a) Warming period with Keeling curve superimposed and upward extrapolation. b) The recovery of the earth’s climate from the Little Ice Age with long term ocean oscillations superimposed. c) 1970s cooling scare. The sun has now passed through a sunspot maximum and the underlying trend may be expected to change from warming to cooling.
Figure 25: Comparison between tropical mid troposphere temperatures from satellites and balloons with 90 CIMP-5 rdp8.5 model simulations, from Spencer [2013]. The ‘pause’ or divergence of model ‘prediction’ from measurement is indicated.

Conclusions

The greenhouse effect has been explained in terms of the influence of the surface IR exchange energy on the surface cooling. This exchange energy reduces the net long wave IR (LWIR) emission from the surface. The surface must therefore heat up until the absorbed solar flux is dissipated by moist convection over land or by wind driven evaporation over the oceans. These energy transfer processes are dynamic or time dependent and vary on both a diurnal and seasonal time scale. The troposphere functions as an open cycle heat engine that is intermittently heated by the local solar flux and transports the surface heat by convection to the cold reservoir in the middle
troposphere. From here the heat is radiated to space. The land and especially the oceans act as the hot reservoirs of this heat engine. The troposphere splits naturally into two independent thermal reservoirs. Almost all of the downward flux reaching the surface originates from the lower tropospheric reservoir within the first 2 km layer. The upper tropospheric reservoir, from 2 km to the tropopause contains the cold reservoir with the LWIR water band emission to space. The various flux terms that determine the surface temperature and the subsurface thermal storage have been described in detail and their role in the quantitative determination of the surface temperature at the land-air and ocean-air interfaces explained. The radiative transfer of the LWIR flux through the atmosphere has to be analyzed using a high enough spectral resolution to resolve the pressure broadened molecular line structure. The change in linewidth plays a key role in both the downward LWIR emission to the surface and the emission to space.

The various flux terms that heat and cool the surface interact with the air-land and air-ocean interfaces. The weather station temperature however is the meteorological surface air temperature (MSAT). This is the temperature measured in a ventilated enclosure paced for convenience at eye level, 1.5 to 2 m above the ground. The minimum MSAT is approximately that of the bulk temperature of the air mass of the local weather system that is passing through. The maximum MSAT is the air temperature produced by the convective mixing of the warm air rising from the surface as it interacts with the cooler air at the MSAT thermometer level. In many parts of the world, the weather systems are formed over the oceans and the ocean surface temperature of formation is ‘carried’ by the air mass over long distances. This is the real source of the ‘global warming signal’ found in the climate record. The oceans have now stopped warming. This is source of the so called ‘pause’ in the climate record. The climate temperature record has also been ‘adjusted’ to better fit the climate modeling ‘predictions’. Considerable caution is therefore needed when published climate data is used. There can be no ‘CO₂ signature’ in the weather station records, regardless of the data processing used to create the climate record.

Over the last 200 years, the atmospheric concentration of CO₂ has increased by 120 ppm from 280 to 400 ppm. This has produced an increase in downward LWIR flux at the surface of approximately 2 W m⁻². This increase in LWIR flux has to be added to the time dependent surface flux terms used to calculate the change in surface temperature of the land and ocean thermal reservoirs. The resulting temperature changes from the increase in CO₂ flux are too small to measure when realistic values of the flux terms and their short term fluctuations are used.

Climate change can be explained in terms of ocean oscillations, changes in the solar flux and plate tectonics. The ocean oscillations, the ENSO, AMO and PDO produce time dependent changes in the climate record with periods of 3 to 7 years for ENSO and 60 to 70 years for the AMO and PDO. Change in solar activity related to the sunspot cycle have produced climate changes such as the medieval maximum, Maunder minimum and modern warming period with periods in the 100 to 1000 year time frame. Longer term variations in the solar flux are produced by planetary perturbations of the earth’s orbital and axial motion. These are known as Milakovich cycles. Over recent geological time these have cycled the earth through an Ice Age with a period near 100,000 years. Over longer geological time periods, the motion of the continents produced by
plate tectonics has produced climate change by changing ocean circulation patterns. For example, significant cooling was produced by the opening of the Drake Passage and the formation of the Southern Ocean.

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Normally, the references given in a review of this nature would be limited almost exclusively to the peer reviewed literature, with limited references to websites that provide access to climate data. Unfortunately, climate science has been thoroughly corrupted by the global warming fraud. The peer review process has collapsed and been replaced by blatant cronyism. Many of the articles published in ‘prestigious’ journals such as Nature, Science, PNAS and others that relate to climate modeling predictions of global warming are fraudulent and should never have been published. Consequently many of the important references given here are to website publications. This should not detract from the integrity of the information provided. Many of these website publications have received a more thorough review that they might have received through the traditional peer review process.

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