Santa Anna Winds

Santa Ana winds are warm and dry winds. In the desert region of the United States, high pressure pushes air off the plateaus forcing the air into narrow mountain valleys. As the air is forced through the valley it is compressed and warms. As the air warms the saturation point rises and its relative humidity drops.

Santa Ana winds are responsible for wildfires in southern California. The dry wind desiccates the surface and whips wildfires into raging fire storms.
1. Upper layer: 342 W/m² in; 107 + 235 = 342 W/m² out
2. Atmosphere: 67 + 350 + 24 + 78 = 519 W/m² in; 165 + 30 + 324 = 519 W/m² out
3. Surface: 168 + 324 = 492 W/m² in; 390 + 24 + 78 = 492 W/m² out

Evapo-transpiration (1m/yr) = 78 W/m²; Surface LW radiation = $\sigma T^4 = 390$ W/m² ($T = 288$ K).
Surface albedo = $30/168 = 18\%$. Planetary albedo = $107/342 = 31\%$.
Output of LW radiation to space = $235/390 = 60\%$.
Uncertainty = 10-20%. Ocean vs land. GHG do not produce energy.
40 W/m² re-emitted back to space as long-wave radiations through an atmospheric window. The rest is re-absorbed as IR radiation.
The sun emits radiation like a black body at a temperature of 5800°C.

In physics, a black body is an object that absorbs all radiation that falls onto it.

• No radiation is reflected.

• The object appears black when cold.

• Black-body radiation depends on its temperature.

The Earth emits radiation like a black body at a temperature of +15°C.
What Makes the Earth Warm

• Almost all the energy comes from the sun.
• Sunlight comes over a wide range of electromagnetic radiations.
  – Long to short wavelengths
  – Most of the radiation that reaches the Earth is in the infrared and visible wavelengths.
• In return, the Earth surface emits its own radiation.
• For the sunlight, we talk about short-wavelength radiation.
• For the Earth surface, we talk about long-wavelength radiation.
Atmospheric Transparency Affects Climate and Weather

- How transparent the atmosphere is to incoming radiation affects the temperature of the Earth
  - Energy comes from the sun and the Earth’s surface
- Dust and aerosols absorb light
  - Volcanoes, forest fires and farming put dust into the atmosphere
  - Chemical and physical composition of the atmosphere makes it warmer or cooler
The Greenhouse Effect

• Each gas in the atmosphere has its own absorption spectrum
  – Certain gases are strong absorbers in the infrared
  – They absorb radiation emitted by the warmed surfaces of the Earth
  – They then re-emit this radiation
  – Making the Earth’s surface warmer
  – This trapped heat makes the greenhouse effect.
The diagram illustrates the relative intensity of radiation emitted from Earth's surface and the absorption by atmospheric gases.

- Radiation emitted from Earth's surface is shown at the top of the graph.
- The largest atmospheric window, where CFCs and ozone absorb radiation, is indicated between 8 and 12 micrometers (µm).
- Radiation absorbed in the atmosphere by water vapor (H₂O) and carbon dioxide (CO₂) is shown below the curve.

The x-axis represents wavelength (µm), while the y-axis represents relative intensity.
Ozone absorbs here
Arrhenius in 1896 ..

• Interested in the ice ages, he ran a computation suggesting that cutting CO\textsubscript{2} by half would lower temperature in Europe by 4-5\textdegree C.
• He asked Hogborn is that was possible.
• Hogborn calculated natural emissions of CO\textsubscript{2}, as well as factories and industries. He found an emission from humans roughly comparable to that from natural geochemical processes. Not a big deal for the short term, but could be in the long term.
• Arrhenius estimated that a doubling of CO\textsubscript{2} would increase the Earth temperature by 5-6\textdegree C.
• They did not see that as a problem for Sweden, nor for the long term (Hogborn estimated the ocean would take 5/6\textsuperscript{th} of it), and thought it would take 3,000 years to affect the climate.
• People objected that the modelisation was too simplistic (e.g. no change in cloud) and water vapor was a more important GHG.
• Idea did not catch on until an engineer named Callendar in 1938 attributed recent warming to a 10% increase in CO\textsubscript{2}.
Arrhenius in 1896 ..

• Topic surged again in cold war days, where it was realized that the absorption bands of CO$_2$ and water vapor differed. This eliminated the earlier spectroscopic argument that water vapor dominated CO$_2$.

• Carbon 14 was used to trace carbon in ocean and atmosphere; Revelle studied the absorption of CO$_2$ by the oceans and concluded that CO$_2$ emissions could be a problem as the oceans would not take all of it, but only 60%.

• Bolin and Eriksson showed that one reason is that most of the CO$_2$ would evaporate back instead of being swept into the abyss.

• In the late 1950s, the concept that CO$_2$ emissions could be serious for climate finally caught on.

• That’s when C. Keeling, hired by Revelle, started measuring CO$_2$ in Hawaii and Antarctica. He got results after two years.

• Then more models, more controversy, and ice cores ...
The Greenhouse Effect

• A natural phenomenon
• Major greenhouse gases are:
  - Water: 36-72%
  - Water and clouds: 66-85%.
  - CO₂: 9-26%
  - CH₄: 4-9%
  - O₃: 3-7%
  - N₂O, CFC-12, etc.
• How about CO? N₂? Ar? O₂? Aerosols?
Residence time of GHG

- $\text{CO}_2 = 3,000$ years.
- $\text{CH}_4 = 12$ years.
- $\text{N}_2\text{O} = 120$ years.
- Halocarbons = several weeks to 50,000 years.

- Aerosols vs GHG who wins?
- Aerosols only stay a few weeks (dust falls back; we do not build up clouds of dust over our heads).
Residence time $\text{CO}_2$: Atmosphere (Hmw): $750 \text{ Gt} / 210 \text{ Gt/yr} = 3-4 \text{ yr}$
Surface ocean: $1,020 / 2 = 510 \text{ yr}$ ; Deep ocean: $38,100 / 8.4 = 4,535 \text{ yr}$
Carbon fluxes

Total flux: needed to explain the CO$_2$ concentration. Fossil fuel: what is emitted. The difference is absorbed by the ocean and possibly land.
Carbon fluxes

Temperature variation (ΔT)

Carbon Dioxide

Dust concentration
Carbon Dioxide Variations

The Industrial Revolution Has Caused A Dramatic Rise in CO₂

Year (AD)

CO₂ Concentration (ppmv)

Thousands of Years Ago

Ice Age Cycles
Planetary Energy Balance
(at the top of the atmosphere)

• Input : Solar Energy absorbed (SW)

• Output : Terrestrial Energy emitted (LW)

• When In = Out, energy balances.

• If the Earth was not emitting radiation, it would continuously warm up.

• Over one particular season, energy in may not equal energy out, but over a whole year, it should.

• What happen if In > Out or In < Out?
IN N’ OUT

• Energy in = solar flux is $\Omega = 1,372 \text{ W/m}^2$

• Flux above the atmosphere is less: night vs day, variable inclination of the solar illumination, the flux onto the earth is equivalent to the flux across a disk of diameter equal to the diameter of the earth. The ratio sphere area to disk area is 4. Disk area = $\pi r^2$ vs sphere area = $4 \pi r^2$.

• Energy incoming is therefore $E_{\text{in}} = \Omega/4 = 343 \text{ W/m}^2$

• Energy out: Earth reflects 30% of the energy back to space. 70% is absorbed by the atmosphere or materials at the earth’s surface.

• Albedo, $a = 30\%$

• That’s 103 W/m$^2$
IN-N-OUT

- $E_{in} = \frac{\Omega}{4} = 343 \text{ W/m}^2$

- $E_{out} = a\frac{\Omega}{4}$ is reflected back to space = 103 W/m$^2$

  \[+ \sigma T^4 \text{ radiated at surface from back body radiation.}\]

- A black body at temperature $T$ radiate energy as: $E = \sigma T^4$
  \[\sigma \text{ is the Stefan-Boltzmann constant } = 5.67 \times 10^{-8} \text{ J/m}^2 \text{ s K}^4.\]

- $E_{in} = E_{out} \rightarrow \frac{\Omega}{4} = a\frac{\Omega}{4} + \sigma T^4 \rightarrow aT = (1-a) \frac{\Omega}{4\sigma}^{1/4}$

- $\rightarrow T = 255 \text{ K (-18°C).}$

- Actual temperature is 288K.

- Why the difference?
Upper layer: 342 W/m² in; 107+235 = 342 W/m² out
Surface: 168 + 30 + 324 = 522 W/m²; Output = 390 + 24 + 78 + 30 = 522 W/m²

Evapo-transpiration (1m/yr) = 78 W/m²; Surface LW radiation = \( \sigma T^4 \) = 390 W/m² (T = 288 K).
Surface albedo = 30/168 = 18%. Planetary albedo = 107/342 = 31%.
Output of LW radiation to space = 235/390 = 60%.
In-N-out double double

- Outer surface:
  \[(1-a) \frac{\Omega}{4} = \sigma T_o^4\]

- At surface:
  \[(1-a) \frac{\Omega}{4} + \sigma T_o^4 = \sigma T_s^4\]
  \[\rightarrow \sigma T_o^4 = 240.1 \text{ W/m}^2\]
  \[\rightarrow \sigma T_s^4 = 480.2 \text{ W/m}^2\]
  \[\rightarrow T_s = 303\text{K (}+30^{\circ}\text{C).}\]

Too hot. Why?
In-N-Out double double animal style

- Outer surface: \( \Omega / 4 = a\Omega / 4 + \sigma T_o^4 + F_w \)

\( F_w \) = IR radiated directly into space (40W/m²).

- At layer \( T_o \):
  \( 2\sigma T_o^4 = \sigma T_1^4 + 0.5 F_e + 0.7 F_s \)

\( F_e \) = latent heat flux leaving earth (78W/m²)

\( F_s \) = portion of solar flux absorbed in atmosphere (67W/m²)

- At layer \( T_1 \):
  \( 2 \sigma T_1^4 = \sigma T_0^4 + \sigma T_s^4 - F_w + F_c + 0.5 F_e + 0.3 F_s \)

\( F_c \) = Flux of convective heat leaving the surface (17 W/m²).

\( \rightarrow \sigma T_o^4 = 220.1 \text{ W/m}^2 \)
\( \rightarrow \sigma T_o^4 = 340 \text{ W/m}^2 \)
\( \rightarrow \sigma T_o^4 = 397.1 \quad \rightarrow T_s = 289.3 \text{K.} \)
Positive and Negative Feedbacks

• The atmosphere and its interactions with the ocean and land surfaces experience positive and negative feedbacks.
• Positive feedback
  - Warm temperature create more evaporation, increases water vapor and greenhouse effect.
• Negative feedback
  – Evaporation also leads to more cloud formation which reflects more sunlight which cools the surface.
Is water vapor increasing?

Since 2000, water vapor in the stratosphere decreased by about 10 % (i.e. 25% less warming). In the 1990s, water vapor increased, leading to 30% more warming. The reason for the recent decline in water vapor is unknown. (Science Daily, Feb. 1, 2010).
Factors determining planet temperature

- Distance to the sun
- Albedo
- Greenhouse gases.
Venus, Mars, Earth

- Nearly all at the same distance from the sun (0.72AU, 1.0AU, 1.5AU).
- Probably all 4.5 billion years old but: Venus = 730K; Mars = 218K; Earth = 288K
- Albedo: Venus = 0.80, Earth = 0.30, Mars = 0.22
- Greenhouse effect:

  Venus: 510K, CO₂ makes 96% of atmosphere. Air pressure = 1,000 m water. Runaway greenhouse effect: cooler earlier on, closer to the sun, so water vapor never liquefied, yielding greenhouse heating, CO₂ baked out of the rocks, greenhouse warming increases, no O₂, no O₃, water gone by dissociation from UV rays.

  Mars: CO₂ 95% of atmosphere but atmosphere is thin, so planet is cold, water and CO₂ all ice in soil. Day-night temperature vary 100 K to generate strong winds. Runaway refrigerator: Mars was colder, low internal heat, no tectonics, water vapor condensed in ice, CO₂ dissolved with water and combined with rocks, yielding to cooling, more water vapor to condense, more CO₂ removal, etc.

Earth: Just right.
Why clouds form?

• Cloud forms when air rises and becomes saturated in response to (moist) adiabatic cooling.
Role of clouds in climate

- Important but not well captured by global climate models.
- Clouds contribute to the GH: they trap heat to make us warm and reduce day-night temperature differences.
- Clouds reflects solar energy: more water vapor may not warm the earth, it can cool it. It depends on cloud type (thickness, altitude)!
- Cold clouds are brighter; changes in low (keep us warm) and high-level (reflects more energy back) clouds cancel each other.
- Conclusions: Clouds will not save us from global warming.
- Scattering from aerosols in clouds cools the climate (higher reflectivity from the top of the clouds). Example Pinatubo eruption in 1992 cooled the ENTIRE planet by +1°C for one full year.
- Unusual sources of cloud formation: DMS (dimethyl sulfide), produced naturally by algae in the ocean, as a byproduct of photosynthetic activity, contribute to cloud formation.
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<th>Skeptical of global warming fears:</th>
<th>In favor of a global effort to reverse climate change:</th>
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<td>&quot;I believe that it is fair to say that the people once labeled as 'a small band of skeptics' — those who championed the position that warming would be modest and primarily in the coldest air-masses have won the day. Many of these same scientists are now forming a new environmental paradigm. It is that the concept of 'fragile earth' must be abandoned. And it asks the impertinent question: since when is everything that man does to the planet necessarily bad?&quot;</td>
<td>&quot;What would Winston Churchill have done about climate change? Imagine that Britain's visionary wartime leader had been presented with a potential time bomb capable of wreaking global havoc, although not certain to do so. Warding it off would require concerted global action and economic sacrifice on the home front. Would he have done nothing?... The uncertainty surrounding a threat such as climate change is no excuse for inaction. New scientific evidence shows that the threat from ozone depletion had been much deadlier than was thought at the time when the world decided to act. Churchill would surely have approved.</td>
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"Scientists who want to attract attention to themselves, who want to attract great funding to themselves, have to (find a) way to scare the public...and this you can achieve only by making things bigger and more dangerous than they really are."

- Petr Chylek, Professor of Physics and Atmospheric Science, Dalhousie University, Halifax, Nova Scotia

"Addressing climate change is no simple task. To protect ourselves, our economy, and our land from the adverse effects of climate change, we must ultimately dramatically reduce emissions of carbon dioxide and other greenhouse gases. To achieve this goal we must fundamentally transform the way we power our global economy, shifting away from a century’s legacy of unrestrained fossil fuel use and its associated emissions in pursuit of more efficient and renewable sources of energy. Such a transformation will require society to engage in a concerted effort, over the near and long-term, to seek out opportunities and design actions to reduce greenhouse gas emissions."

- Pew Center on Global Climate Change