THE HYDROLOGIC HEAT PUMP

Unlike carbon dioxide, water vapor's role in heating the atmosphere is not limited to radiative forcing. The total amount of water in the atmosphere in all of its phases has been estimated to be sufficient to cover the earth's surface to a depth of approximately 2.5 centimeters. The total global precipitation is often estimated at one meter. That gives us an annual recycling rate of forty times per year—or about once every nine days. In each of these cycles, water is evaporated from the surface of the planet at one temperature and falls to earth at some later time at another and much lower temperature.

This hydrologic heat pump contributes some three watts per square meter of the atmosphere's total heat budget. This is not a lot, relatively speaking, but it is something. Any increase in the amount of water vapor added to the atmosphere over time is more likely to be represented as an increase in the cyclic rate rather than an increase in the vapor concentration. This is because water vapor condenses out so easily and readily at the normal range of atmospheric temperatures. This increase in the cyclic rate, in turn, will be made manifest in an increase in total annual global precipitation amounts. This increase has, in fact, taken place.

Globally, the total annual precipitation increased over two percent in the period 1900 to 1980, with the precipitation over land slightly higher [Dai, et al, 1997]. Given the greater role played by water vapor in the atmosphere's heat budget, this might well be more significant in terms of global warming than the increase in carbon dioxide over the same time span. It is certainly a contributing factor.

Over the last two centuries, the amount of land irrigated over the face of the earth has increased dramatically. Not only has the desert been brought to bloom, but irrigation has grown increasingly common in areas that are comparatively well-watered by rain. This is done to produce both increased yields and more consistent yields from year to year. In addition, the use of irrigation for domestic lawns and gardens has increased tremendously. All of this increases the rate of evaporation from the Earth's surface, and has the potential for increasing both the concentration of water vapor in the atmosphere, and the increase in the cycling rate. Both of these, in turn, lead to increased global warming.

Evaluating the Heat Transfer

Table HHP01 shows the specific enthalpies of water vapor at selected temperatures. If we assume a mean surface temperature of 25°C, an annual evaporation and precipitation of one meter of rainfall, and a mass of one thousand kilograms per cubic meter of liquid water, then some 418,000 kilojoules of enthalpy will be added to the atmosphere per square meter of surface in one year.

If we assume that that water vapor subsequently condenses out at 0°C and falls to earth, then some 382,000 kilojoules will be removed from the atmosphere.

The remaining 36,000 kilojoules is added to the atmosphere's heat budget each year. The vernal equinox year has $3.1557 \text{ X } 10^7$ seconds. This gives us an annual enthalpy transfer of 1.14 Watts per square meter. This is not a lot compared to other sources of atmospheric heating, but it is not insignificant either.

Given the strong transfer of water vapor from the equatorial regions to the mid-latitudes and polar regions, a mean difference in temperature of some 25°C between evaporation and condensation does not seem too unreasonable. This is the value used in ***Water and the Earth's Heat Budgets***.

TABLE

Data in the following table is taken from various tables in the essay ***Gross Vaporization***. The derivations of the table values are given very briefly following the table. Readers wishing a more thorough examination of how the values were obtained are referred to the above paper from which the data were obtained.

TABLE HHP01

SPECIFIC ENTHALPIES OF WATER VAPOR AT SELECTED TEMPERATURES

SYSTEM TEMP	SYSTEM TEMP	MEAN DEGREES OF FREEDOM	THERMAL TERM	MEAN MOLECULAR KINETIC ENERGY	SPECIFIC ENTHALPY
	$\bar{T}$	$\underset{\sim}{\bar{f}}_{\circ}$	$k_B\bar{T}$	$\underset{\sim}{\bar{u}}^{\Sigma}$	$\underset{\sim}{U}$
°C	**K**	**degrees per molecule**	**x 10^{-20} Joules molecule^{-1}**	**x 10^{-20} Joules molecule^{-1}**	**kJ kg^{-1}**
40	**313.15**	**6.0936**	**0.4324**	**1.3173**	**440**
35	**308.15**	**6.0876**	**0.4254**	**1.2950**	**433**
30	**303.15**	**6.0815**	**0.4185**	**1.2727**	**425**
25	**298.15**	**6.0759**	**0.4116**	**1.2505**	**418**
20	**293.15**	**6.0715**	**0.4047**	**1.2287**	**411**
15	**288.15**	**6.0672**	**0.3978**	**1.2069**	**403**
10	**283.15**	**6.0629**	**0.3909**	**1.1851**	**396**
05	**278.15**	**6.0585**	**0.3840**	**1.1633**	**389**
00	**273.15**	**6.0546**	**0.3771**	**1.1417**	**382**
-05	**268.15**	**6.0512**	**0.3702**	**1.1201**	**374**
-10	**263.15**	**6.0477**	**0.3633**	**1.0986**	**367**
-15	**258.15**	**6.0442**	**0.3564**	**1.0771**	**360**
-20	**253.15**	**6.0408**	**0.3495**	**1.0557**	**353**
-25	**248.15**	**6.0377**	**0.3426**	**1.0343**	**346**
-30	**243.15**	**6.0351**	**0.3357**	**1.0130**	**339**
-35	**238.15**	**6.0325**	**0.3288**	**0.9918**	**332**

All table values are for a system consisting of clean humid air at a pressure of 10^5 Pascals in contact with a pure natural water surface. Note that these values are dependent only on the mass vaporized and not upon the rate of vaporization.

SPECIFIC ENTHALPIES OF WATER VAPOR

$$\underset{\sim}{\bar{\boldsymbol{f}}}_{\circ} = \frac{\boldsymbol{2C_v}}{\boldsymbol{k_{ukg}}}$$

This is the mean number of degrees of freedom per vapor molecule at the indicated temperature.

$$\mathrm{k_B}\bar{\boldsymbol{T}} = \bar{\boldsymbol{u}}_{-i}$$

This is the thermal term in Joules per molecule found in so many of these equations. It is equal to the mean impulse kinetic energy of translation measured normal to and away from any surface at the instant of departure of a molecule from that surface. With a change in subscript sign, it becomes the mean impulse kinetic energy of translation measure normal to and toward any surface at the instant of impact.

$$\underset{\sim}{\bar{\boldsymbol{u}}}^{\Sigma} = \underset{\sim}{\bar{\boldsymbol{f}}}_{\circ}\,\tfrac{1}{2}\,\mathrm{k_B}\bar{\boldsymbol{T}}$$

This is the mean total molecular kinetic energy in Joules per molecule. It is the sum of the kinetic energies of translation, rotation, and vibration.

$$\underset{\sim}{\boldsymbol{U}} = \underset{\sim}{\bar{\boldsymbol{N}}}_{kg}\underset{\sim}{\bar{\boldsymbol{u}}}^{\Sigma}$$

This is the total vapor kinetic energy in Joules per kilogram, although the table shows it in kilojoules. It is the product of the number of vapor molecules in one kilogram times the mean total kinetic energy per molecule. This total includes both internal and external kinetic energies.

REFERENCES

INTERNAL REFERENCES: These are other papers in this collection that are either cited or linked during the course of the discussion or whose content is especially relevant to the current discussion.

Gross Vaporization – This paper explains why selected liquid water molecules leave the surface of the water and become water vapor molecules using the concepts of kinetic gas theory and statistical mechanics. The rate of gross vaporization is seen as a dynamic balance between thermal forces (especially intermolecular impulses) that tend to drive molecules apart and binding forces that tend to draw them together. The rate of gross vaporization is then based on a statistical distribution of impulses normal to the surface and the number of those impulses that are greater than the sum of the binding forces.

Water and the Earth's Heat Budgets – This paper develops six heat budgets for the earth-atmosphere system, and shows tables of values for each budget. The six budgets are: 1) Disposition of Insolation, 2) Energy Budget of the Atmosphere – Inflow, 3) Energy Budget of the Atmosphere – Outflow, 4) Energy Budget of the Earth's Surface – Inflow, 5) Energy Budget of the Earth's Surface – Outflow, and 6) Sources of Earthshine.

GENERAL REFERENCES: These are works by other authors that contain general treatments of kinetic gas theory, statistical mechanics and thermodynamics, atmospheric physics, and other scientific fields that are used in the current discussion.

Charles Kittel; **Thermal Physics**; John Wiley & Sons, New York, 1969.

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