WATER IN THE ATMOSPHERE

Ubiquity of Water in the Free Atmosphere: Water (H_2O) is a universal constituent of the free atmosphere; and every significant portion of that atmosphere contains some water. Water is found in the free atmosphere in all three of its physical phases; that is, as a gas, as a liquid, and as a solid. It is the only common substance to bear that distinction.

Abundance of Water in the Free Atmosphere: After nitrogen and oxygen, water is the third most abundant constituent in the free atmosphere. This assumes that we count all three of its phases. Water vapor alone is the fourth most common gas, after argon. Its abundance is extremely variable, ranging from the merest trace in the high stratosphere to as much as ten percent in humid tropical swamps on the hottest days. On the average, it makes up a bit more than one percent of the total number of molecules in the atmosphere.

Water in the Atmospheric Heat Budget: Water, in all of its three phases, is far and away the most important factor in the atmospheric heat budget. As water vapor, it accounts for 49% of the energy absorbed by the atmosphere from its various radiative sources. As clouds of liquid water droplets and ice crystals, it accounts for an additional 20% of absorbed radiant energy. Finally, through conduction and the hydrologic heat pump, it adds a last 4%. These figures have water playing a role in 73% of the heat budget. This compares with 14% for carbon dioxide, the second-place holder.

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

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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. The difference in the enthalpic content of the evaporating and precipitating water remains in the atmosphere as a significant source of heat.

The Primal Opposition—Attraction versus Repulsion: Since water can and does occur in any and all of its three phases within the free atmosphere, the phase that dominates any particular portion of that atmosphere at any particular time depends upon the relative strengths of two separate and conflicting sets of forces.

Intermolecular Repulsion: On the one hand, we have the kinetic forces of thermal agitation. Kinetic energy makes molecules move from place to place, rotate and spin, and vibrate. These movements make molecules move away from one another due to impulse transfer during molecule-to-molecule "contact". In essence, thermal agitation acts pretty much as a force of intermolecular repulsion.

In addition, there is also a force of intermolecular repulsion that is one of the van der Waals forces. However, it comes into play only at very short intermolecular distances—less than one molecular diameter.

The sum of these forces of repulsion, if unchecked, would lead ice to melt into water and would lead both ice and water to vaporize.

Intermolecular Attraction: On the other hand we have the forces of intermolecular attraction, which make molecules move toward one another. For pure water, these include the hydrogen bond and the various other van der Waals forces of attraction.

In addition, there are also many hygroscopic forces that attract water to various particulates in the atmosphere. These particulates are often described as cloud condensation nuclei (CCN). They play an extremely important role in atmospheric condensation. Indeed, it is not too much of a stretch to say that weather, as we know it, is not possible without them.

Finally, ionized molecules are strongly attracted to other ionized molecules and to ionized substrates having opposite charges. Anyone who has seen a Wilson cloud chamber in action can testify to the potency of ionization as an attractive force in condensation.

It is the sum of all of these attractive forces that lead molecules of vapor to condense into water and ice in the atmosphere.

Perpetual Nature of Both Forces: Both of these sets of forces are essentially continuous and perpetual. Their relative strengths determine how much of the water present will be in the ice phase, how much will be in the liquid phase, and how much will be in the vapor phase. Take note that these phases are by no means exclusive of one another. It is fairly common for water to be present in all three phases simultaneously in even small portions of the free atmosphere. Water vapor, of course, is always present.

Absence of Balance: The conflict between molecular attraction and repulsion does not represent a balance, but an imbalance. The ideas of equilibrium, stasis, and balance are immensely attractive to all logical thinkers. However, it is a mistake (and a costly one) to apply these concepts to any process in the free atmosphere. The mathematical laws of probability applied to statistical mechanics ensure that the free atmosphere is never in a state of equilibrium.

Gross evaporation never equals gross condensation. The number of vapor molecules in a mass of humid air that are moving toward a surface never equals the number that are moving away from it. The number of vapor molecules "captured" by a surface is never the same as the number "escaping" from that surface. Even on the macroscopic scale, equivalence is more a matter of instrumental insensitivity than reality.

The canny scientist will accept the essential imbalance of natural processes as a fact of nature; and will not look for a balance that does not exist.

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