COMMENT ON THE PAPER "ON THE INFLUX OF SMALL COMETS INTO THE EARTH'S UPPER
ATMOSPHERE II. INTERPRETATION" BY L. A. FRANK, J. B. SIGWARTH AND J. D. CRAVEN

Thomas M. Donahue

Department of Atmospheric and Oceanic Science, Space Physics Research
Laboratory, The University of Michigan, Ann Arbor, Michigan 48109-2143

Abstract. The suggestion that the Earth is being bombarded by cometoids that subject it to an influx of $3x10^{11}$ water molecules/cm^2-sec encounters severe aeronomical problems. There is a serious disposal problem for water molecules deposited near 100 km. The implications for Venus and Mars also present serious problems. It is argued that the proposable is untenable.

In an effort to explain transitory decreases in ultraviolet dayglow emission rates that they observed from the DE-1 spacecraft (Frank, et al., 1986a) L. A. Frank, J. B. Sigwarth and J. D. Craven (1986b) have made a startling suggestion. They propose that water is injected into the thermosphere by a stream of comets and absorbs the radiation. They require a flux of water of $3x10^{11}$ molecules/cm^2-sec averaged over the entire earth. The authors argue that the water and its dissociation products will penetrate to the lower thermosphere before they come to rest. There are a large number of problems with the proposed mechanism.

The authors recognize that the flux of water — $1.34x10^{15}$ gm/yr — is so large that it would supply all of the water in the oceans, cryosphere, and crust — $2x10^{24}$ gm — in 1.5 billion years if the inflow rate is steady. Since disposing of the oxygen associated with two extra oceans would require that the interior of the earth become oxidized to a depth of several hundred kilometers to a much greater degree than it is (0.5% Fe_2O_3 to 10% FeO), a steady influx of comets over geological time is ruled out. Consequently, Frank, et al. (1986b) propose that the comet showers are episodic. They suggest that a periodic perturbation of the Oort cloud once every 250 million years sends clouds of small comets into the inner solar system. Thus the Earth's ocean would have been acquired in about 15 steps over 4.5 billion years.

Although current wisdom favors outgassing of most of the ocean soon after the Earth was accreted, almost all of the supporting evidence for this view bears on outgassing of volatiles in general. It is presumed that water was one of the volatiles (in fact the quintessential volatile) that was originally accreted and then outgassed. Data concerning ocean volume and sea level are too imprecise and limited in time to rule out accession of the ocean in 6.6% increments once every 250 million years. Although there is strong evidence that enough liquid water to create sedimentary rocks was present on the Earth's surface 3.8 billion years ago (Holland, 1984), it is difficult to say how

much liquid water was needed to produce them. That the material from which the Earth accreted was rich in water is attested to by the great abundance of hydrated minerals in the interior. The notion that enough water to provide the planet with an ocean was not released during accretion is a strange one, but possibly not one that can be rigorously excluded. It should be noted, for example, that it may be difficult to explain why the D/H ratios in sea water is elevated so much above the general solar system value if the comets in question were accreted beyond the orbit of Saturn. But until the isotope ratio is measured for comets this argument, while strong, is not decisive.

It is difficult to see how Venus and Mars could avoid this cometary bombardment and thus be accreting at about the same rate per unit area as Earth. The escape flux of hydrogen from the three planets is about 10^7/cm^2-sec from Venus (Kumar, et al., 1983), $3x10^8$/cm^2-sec from Earth (Donahue, 1977), $1.8x10^8$/cm^2-sec from Mars (McElroy and Donahue, 1972; Anderson and Hord, 1973; Liu and Donahue, 1976). In the case of Venus there are numerous measurements of the mole fraction of water vapor in the lower atmosphere (vonZahn, et al., 1983). Taking 200 ppm by volume to be a generously large value for this quantity would put the water content of the atmosphere at about $5 x 10^{22}$ molecules/cm^2. The presumed cometary supply would double this quantity in 5500 years. So there is a severe disposal problem on Venus. If the surface of Venus is assumed to be somehow a sink for $3x10^{11}$ water molecules/cm^2-sec the oxidation rate would have to be about 0.1 mm/year over the entire planet if the FeO concentration in material freshly exposed on the crust of Venus is the same as the terrestrial value. More troublesome is the consequence that the surface would be highly oxidized. This condition appears to be incompatible with the presence of sulfur gases in the atmosphere (Lewis and Prinn, 1984).

If a significant variation with heliocentric distance of cometary lifetime in the inner solar system is invoked to reduce the influx at Venus so that it becomes compatible with the low hydrogen escape rate, the problem with Mars would become even more serious. The question is how to reconcile an influx of water greater (probably much greater) than $3x10^{11}$ molecules per cm^2-sec at Mars, an escape flux of only $1.8x10^8$ per cm^2-sec with the absence of a reservoir of water on Mars that contains more than the Martian equivalent of a terrestrial ocean. The proposed cometary source would have supplied a large fraction of an ocean during the past few hundred million years. If that water is sequestered, where is it? If not, how can an escape scenario be developed in which the present escape flux is three or four orders of magnitude below the value

required to get rid of the hydrogen associated
with the cometary supply of water. Obviously,
the problem of the oxygen sink also needs to be
addressed.

There are even deeper problems associated
with producing an escape flow of hydrogen at Mars
that is of the order of 5×10^{11} atoms/cm^2-sec (or
much larger if there is a sizeable heliocentric
variation). One of these is a fundamental energy
limit on the rate at which hydrogen powered by
extreme ultraviolet heating can escape from a
planet (Watson, et al., 1981). This limit is
9×10^{11} atoms/cm^2-sec for Mars and applies to a
"blowoff" form of escape in which the atmosphere
is dominated by water vapor and its dissociation
products. The limit is set by the rate at which
heat can be supplied to offset the adiabatic
cooling of the rapidly expanding gas. In
practice the actual flux would fall below this
limit for a number of reasons. Hence, if the
rate of water influx at Earth averaged over the
lifetime of the planet is 10^{11} molecules/cm^2 sec,
the influx at Mars could not exceed five times
that at Earth at the extreme, and in practice
probably could not even exceed the terrestrial
influx rate itself without causing this
fundamental constraint to imply the presence
of something like the equivalent of a
terrestrial ocean of water somewhere on Mars.

One reason that the escape flux of hydrogen
would not attain the theoretical energy limit is
that there are not enough solar photons available
at Mars to dissociate the incoming water. The
diurnally averaged solar flux of photons whose
energy is above the dissociation limit of water
is only 1.5×10^{11} photons/cm^2 sec. Hence no more
than about 3×10^{11} hydrogen atoms/cm^2 sec can be
generated and escape, and the water must
accumulate if it arrives at a rate greater than
1.5×10^{11} molecules/cm^2-sec.

Frank et al. (1986b) also recognize that
there is a difficulty disposing of the water
molecules and their dissociation products when
they arrive in the lower thermosphere of the
Earth. If they are to be transported away by
vertical molecular and eddy diffusion the flux
required (Hunten and Donahue, 1976; Donahue,
1977) is

$$\phi_i = \frac{b_i f_i}{H} - (K + D_i)\, n\, \frac{df_i}{dz} \qquad (1)$$

where D_i is the molecular diffusion coefficient,
n is the total atmospheric number density, b_i is
the molecular diffusion parameter $D_i n$, f_i the
mixing ratio for total hydrogen, H the
atmospheric scale height, and K the eddy
diffusion coefficient. If it is assumed that
most of the hydrogen is transported downward and
very little upward, and K is taken to be 10^6
cm^2/sec at 100 km, a flux of 6×10^{11}/cm^2-sec
requires a mixing ratio gradient of about 2000
ppm/km at 100 km, decreasing to 150 ppm/ km at 50
km. The mixing ratio for hydrogen in all forms
near 100 km would need to be of the order of 5%.
The assumption of diffusive equilibrium at higher
altitudes then calls for atomic hydrogen
densities between 10^{11} and 10^{12}/cm^3 at the
exobase, more than a factor of a million higher
than those that are observed. This would result
in an escape flux due to Jeans escape alone of
about 10^{14}/cm^2-sec, which violates the basic

assumption. Therefore, much of the flux of
hydrogen would have to go upward. Limiting flux
($b_i f_i/H$) then requires that f_i be 3×10^{-2}. If the
downward flux is to be vanishingly small this
mixing ratio must be maintained throughout the
mesosphere and stratosphere. Such large
amounts of hydrogen compounds would remove all of
the ozone from the middle atmosphere. The frost
point would be exceeded globally near the
mesopause and a global cloud layer blanket the
Earth. Furthermore, the observed mixing ratios
for "total hydrogen" are close to 15 ppm, a
factor of 5×10^{-4} smaller than those that would be
called for. At higher altitudes hydrogen
densities would be needed that are larger than
those observed by a factor of 2000. Finally the
upward flux of hydrogen has been inferred by
Brieg, et al., (1976) from H^+, O^+ and O
densities. The value obtained was about
3×10^8/cm^2-sec, a factor of 2000 smaller than the
flux required by the cometary source. These
difficulties would be overcome if K were several
orders of magnitude larger. Not only is this
difficult to justify physically, it would shift
the homopause upward by about 50 km and so is
precluded.

To solve these problems Frank, et al.
(1986b) suggest that advection in the middle
atmosphere with a vertical velocity of about 2
m/sec at 90 km may transport the hydrogen
compounds downward. It is not at all clear what
kind of global circulation pattern is being
proposed. In any event the vertical velocity
needed is more like 5 m/sec than 2 m/sec because
the total hydrogen mixing ratio is about 15 ppm
rather than 30 ppm. These speeds are
extraordinarily large. They would lead to
transport lifetimes —z/w — where z is a
vertical scale, for which 5 km is an appropriate
value, of 1000 sec at 90 km, 4500 sec at 80 km,
rising to 2.3×10^5 sec at 50 km. Such short
transport times would change the entire
photochemical structure of the region. In
particular they would move the atomic oxygen
maximum down toward 85 km. The associated
heating would also change the thermal structure
of the mesosphere drastically. But the most
serious problem with the proposal is that
measured vertical winds at these altitudes
measure at most 25 cm/sec and usually are far
smaller (Balsley and Riddle, 1984). These
measurements have been made over a period of
several years at Poker Flats, Alaska. Other,
less sensitive, techniques employed at lower
latitudes, nevertheless set upper limits to the
vertical mesospheric wind well below the values
needed here.

I conclude that water influxes of the
magnitude invoked by Frank, et al. (1986b) are
aeronomically unacceptable if the water is
deposited, as they assert, in the lower
thermosphere. There is no way to dispose of the
water without seriously violating observational
constraints. Transport by eddy and molecular
diffusion would require mixing ratios for water
and its products orders of magnitude too high.
Transport by vertical advection, keeping the
mixing ratio acceptably low, calls for vertical
winds two orders of magnitude too large. If the
water vapor were to somehow travel coherently
downward as far as 55 km the mixing ratio of

water produced by the dispersion of the jets
would be some tens of ppm, still too high but
perhaps not outrageously so. Bevilacqua, et al.
(1983) and Olivero et al (1986) measure 6 ppm by
volume at 55 km. (It should be kept in mind that
the source of water in the stratosphere is mainly
oxidation of CH_4 and not surface water.) It
seems possible that these impulses occurring at
any one place with a frequency of about once per
week should produce observable signatures for
Doppler radars such as the Mesosphere,
Stratosphere, Troposphere (MST) radar at Poker
Flats.

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