지구의 원시바다 형성에 대한 열역학적 분석

3조
곽태예, 김기현
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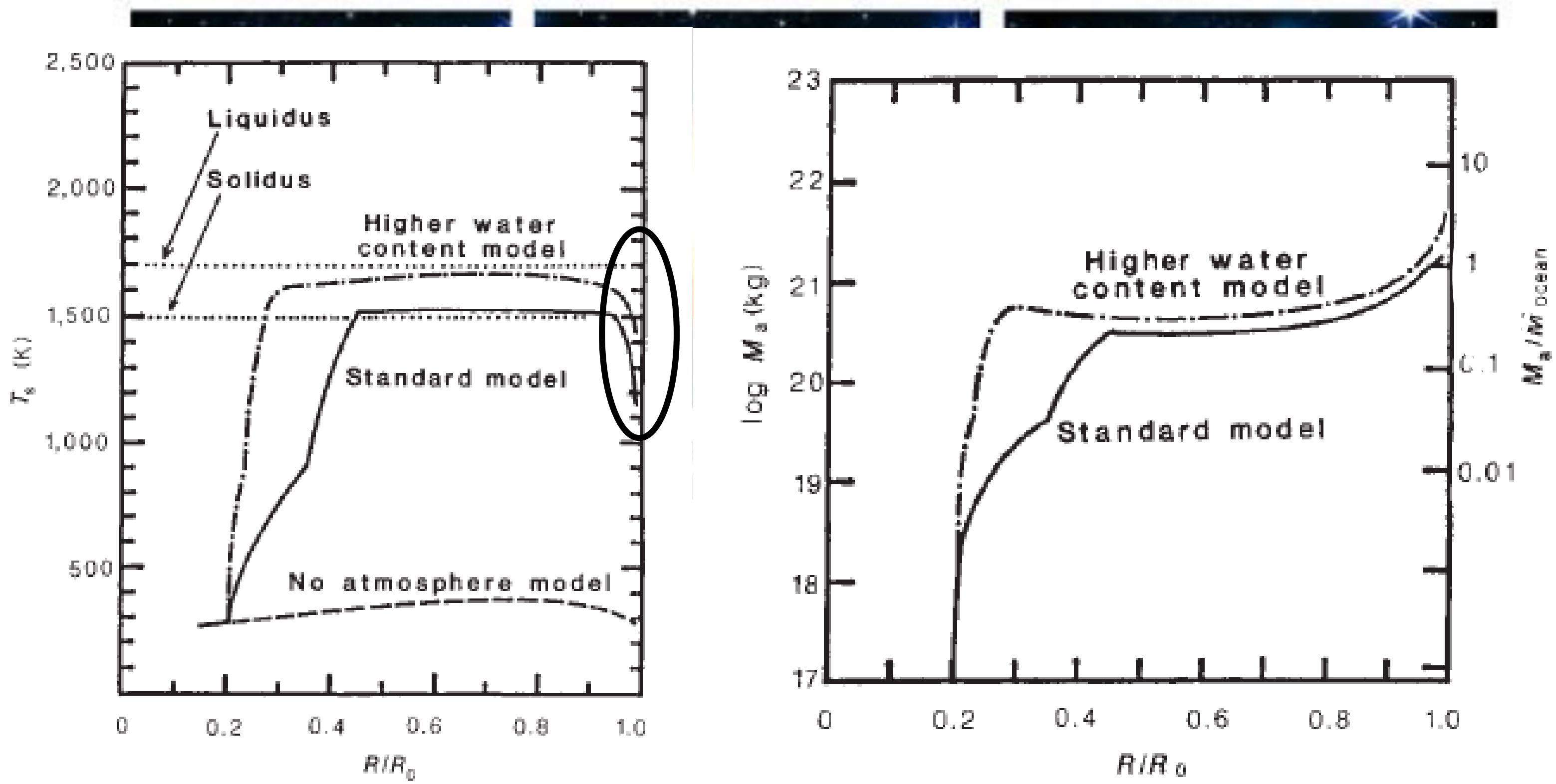
이론적 배경

지구와 바다의 탄생



(Abe Y. and Matsui T., 1986)

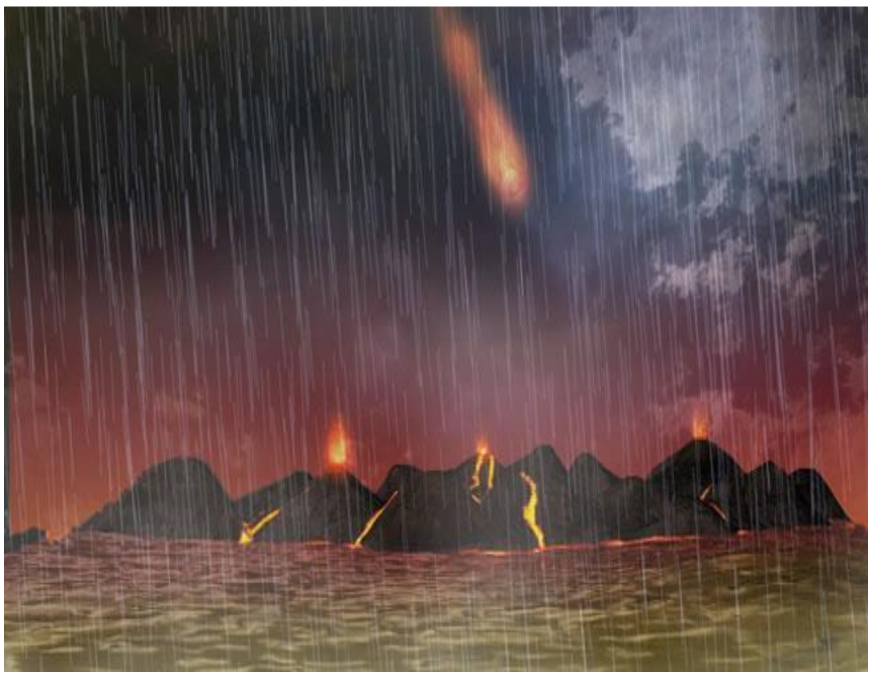
accretion 후반 대기 구조 변화 – 응결이 시작되는 온도

the interior after accretion. The variables P_s and X_{H_2O} at the base of the atmosphere are assumed to be 2×10^7 Pa (200 bars) and 0.9, respectively, as long as

(Abe Y. and Matsui T., 1988)

표면 기압 : 200000 mb
수증기 몰 비율 : 0.9
∴ 표면 수증기압 : 180000 mb

가정1
: 상층부터 표층까지 수증기 몰 비율이 일정하다



$$e_{sw} = 6.11\exp\left(19.83 - \frac{5417}{T}\right)$$

T = 567.9 K

가정2
: 상대습도가 100%일 때 응결이 일어난다.

accretion 후반 대기 구조 변화 - 상대 습도(1)

$$e_{sw} = 6.11\exp\left(19.83 - \frac{5417}{T}\right)$$

이 식을 이용해 온도에 따른 포화 수증기압 계산

T(K)	e_{sw}(mb)	T(K)	e_{sw}(mb)	T(K)	e_{sw}(mb)
570	186,543	1070	15,828,299	1570	79,368,197
670	770,544	1170	24,398,013	1670	97,583,033
770	2,201,968	1270	35,130,225	1770	117,209,653
870	4,943,035	1370	47,961,644	1870	138,051,219
970	9,392,205	1470	62,764,034	1970	159,919,413

accretion 후반 대기 구조 변화 - 상대 습도(2)

현재 수증기압 : 180000 mb
포화 수증기압 : 앞에서 구한 자료 ⇨ **이를 이용해 상대 습도 r을 구한다.**

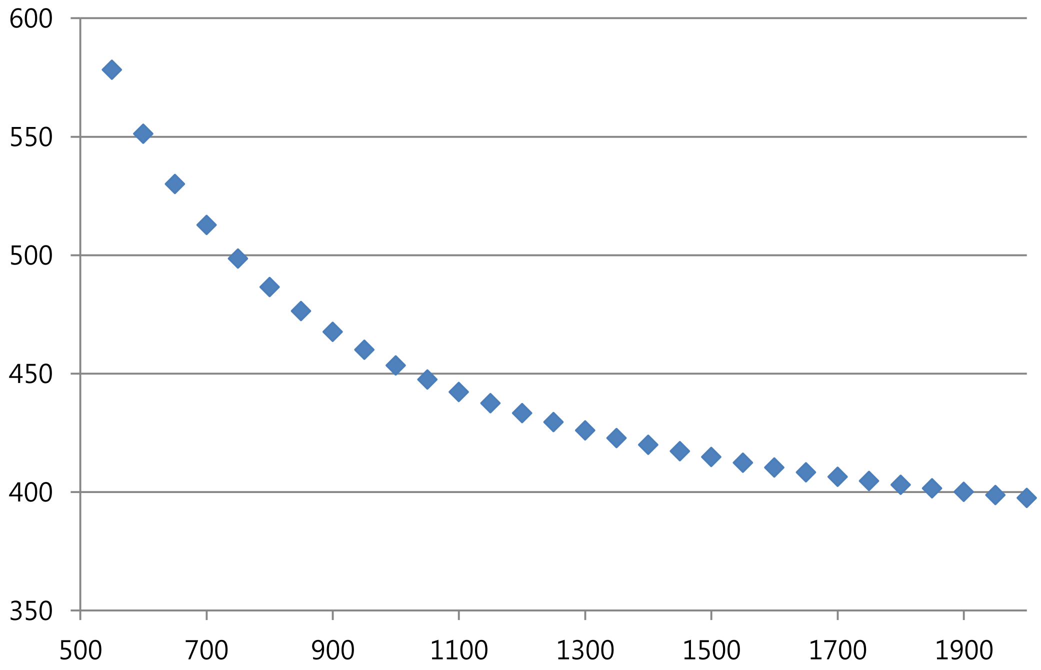
T(K)	r(%)	T(K)	r(%)	T(K)	r(%)
570	≈100	1070	1.1	1570	0.23
670	23.4	1170	0.74	1670	0.18
770	8.2	1270	0.51	1770	0.15
870	3.6	1370	0.38	1870	0.13
970	1.9	1470	0.29	1970	0.11

accretion 후반 대기 구조 변화 - T(LCL)

$$T_{LCL} = \frac{1}{\frac{1}{T-55} - \frac{\ln r}{2840}} + 55$$

Bolton(1980)의 식을 이용해 T(LCL) 계산

가정3 : 과거 γ값이 현재와 같다.



accretion 후반 대기 구조 변화 - Lapse Rate 계산(1)

$$\Gamma = \frac{g}{c_p}$$

Lapse rate는 등압 비열과 중력 가속도의 비라는 관계식을 이용한다.

가정4 : 원시 지구 대기는 이상 기체이다.
가정5 : accretion 후반의 g는 현재와 비슷하다.

$$\boxed{C_{pg}(P, T) = \sum_{i}^{\mathrm{all}} x_i C^{I}_{pi0}(T)} - T \int_0^P \left(\frac{\partial^2 v}{\partial T^2} \right)_{P'} dP'$$

and C^{I}_{p0} is given by

$$C^{I}_{p0}(T) = C_1 + C_2 T + C_3 T^2 + C_4 T^3$$

(Abe Y. and Matsui T., 1988)

TABLE 1. Thermodynamical parameters used in this study. (Saito 1982; Hougen et al. 1959)

Species	P_c (10^5 Pa)	T_c (K)	Accentric factor	Constants for heat capacity calculation (J/mol·K)			
				C_1	C_2	C_3	C_4
H_2O	220.4	647.3	0.344	32.24	1.923×10^{-3}	1.055×10^{-5}	-3.511×10^{-9}
CO_2	73.76	304.2	0.225	22.26	5.981×10^{-2}	-3.501×10^{-5}	7.469×10^{-9}

accretion 후반 대기 구조 변화 - Lapse Rate 계산(2)
T=600K일 때

$C_p(H_2O)$ =36.43(J/mol·K)

$C_p(CO_2)$ = 47.16 (J/mol·K)

1mol당 비열이므로 1kg당 비열로 바꾸기 위해서 M으로 나눔

$C_p(H_2O)$ = 2024.1 (J/kg·K)

$C_p(CO_2)$ = 1071.7 (J/kg·K)

Cp가 질량비에 따라 선형적인 합으로 결정됨

$$C_p = 2024.1 \times 0.8 + 1071.7 \times 0.2$$

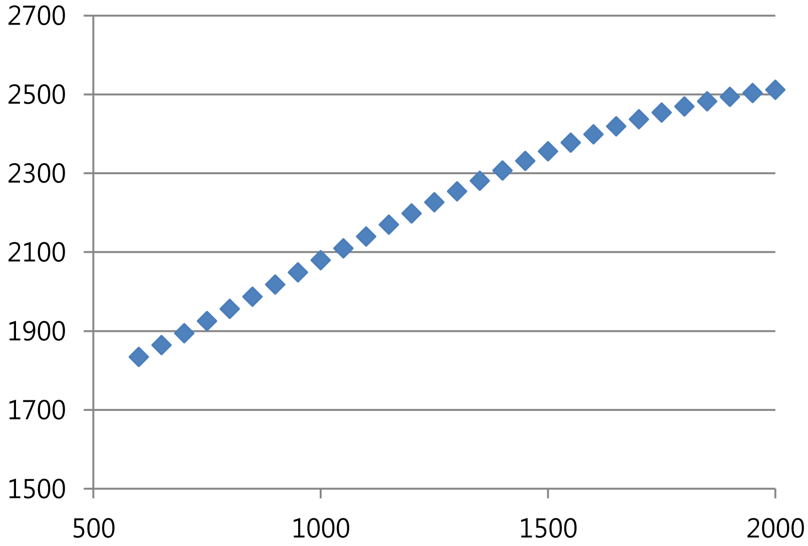
$$= 1833.6\ (\mathrm{J/kg\cdot K}) \qquad (H_20\ 80\%,\ CO_2\ 20\%)$$

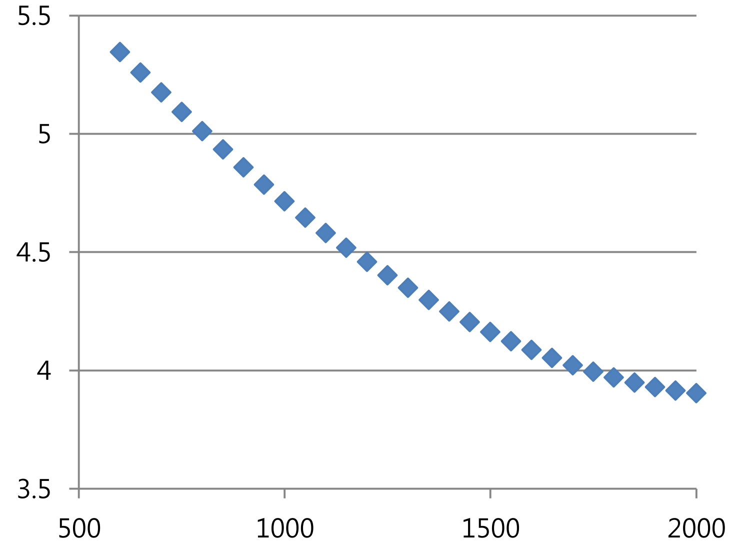
$$\therefore \text{Lapse Rate} = 9.8/1833.6 \approx 5.34\ (\mathrm{K/km})$$

accretion 후반 대기 구조 변화 – Cp, Lapse rate

$$C_{pg}(P,T) = \sum_{i}^{\text{all}} x_i C^{l}_{pi0}(T)$$

$$\Gamma = \frac{g}{c_p}$$

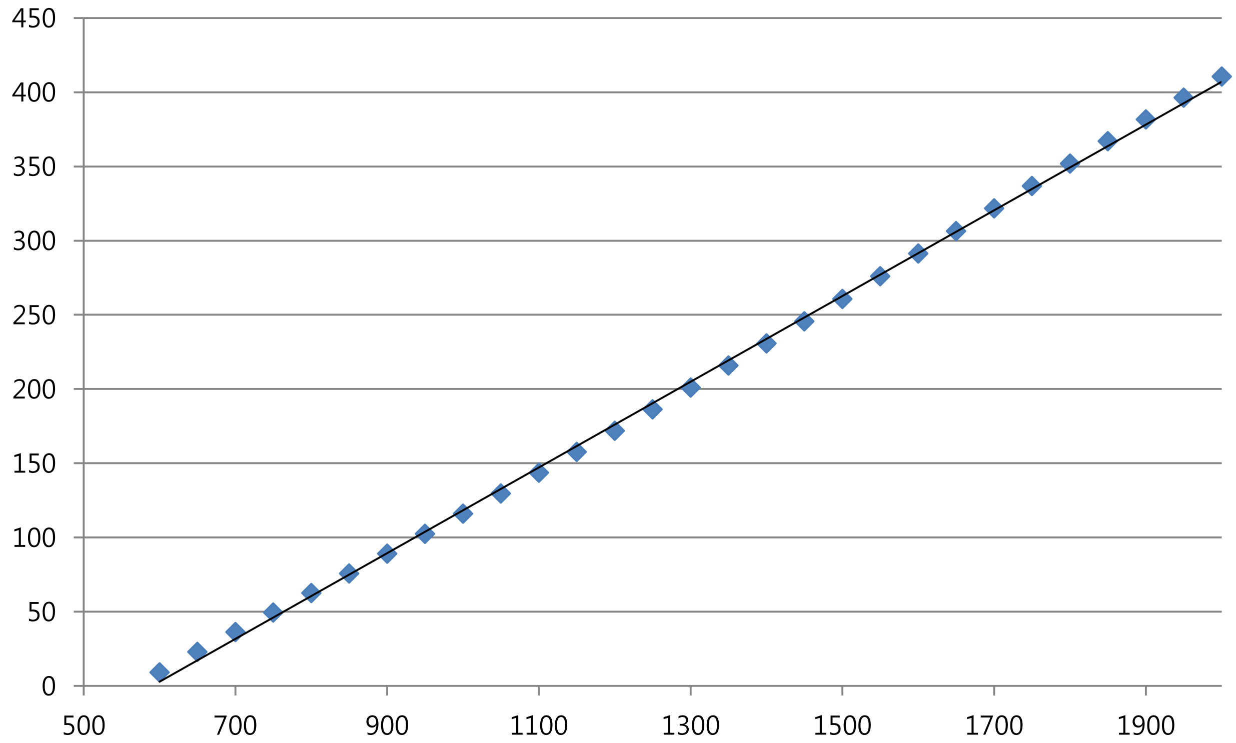




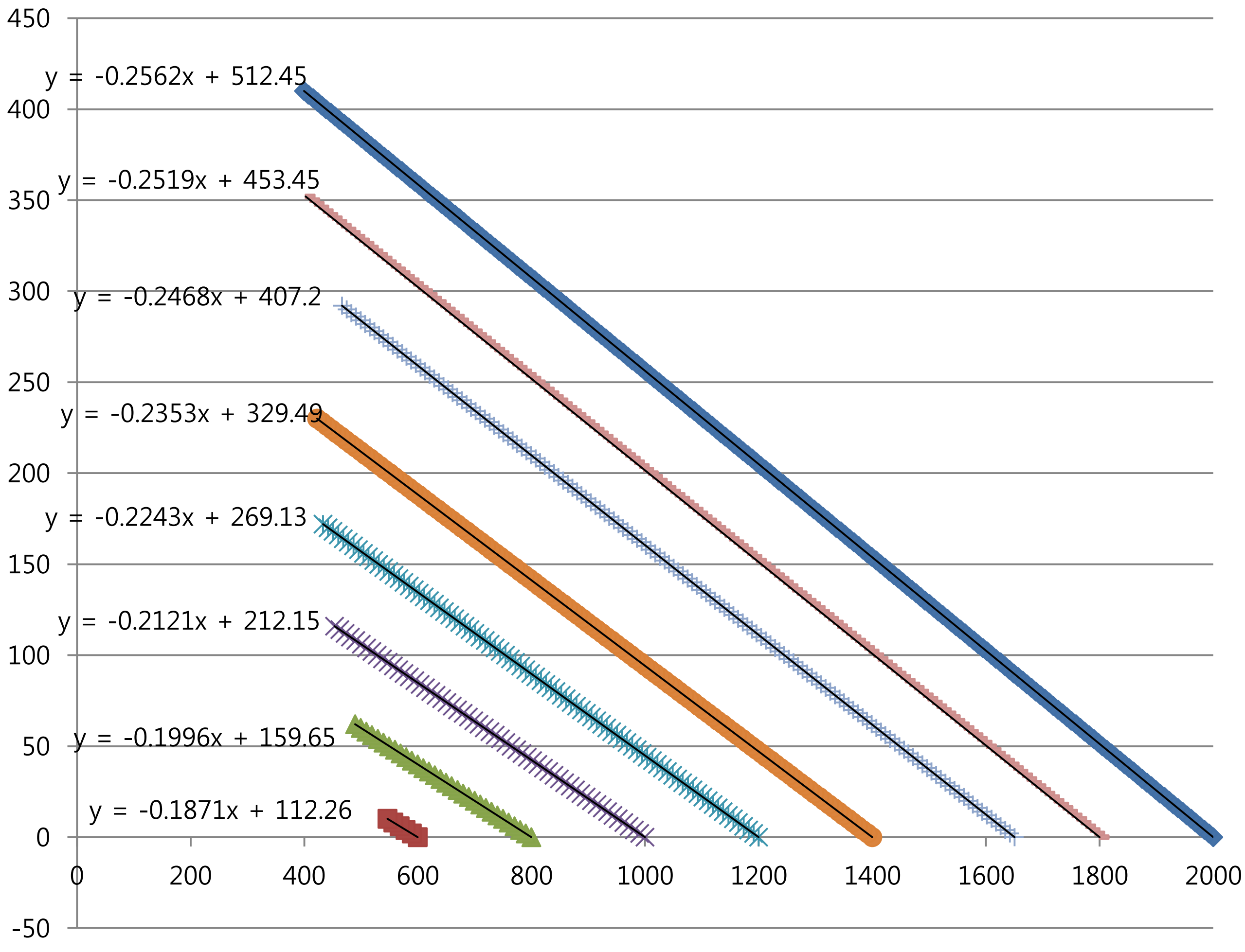
accretion 후반 대기 구조 변화 - z(LCL)

$$\Delta z = \frac{\Delta T}{\Gamma}$$

원시 대기 온도가 고도에 따라 선형적으로 감소한다고 가정

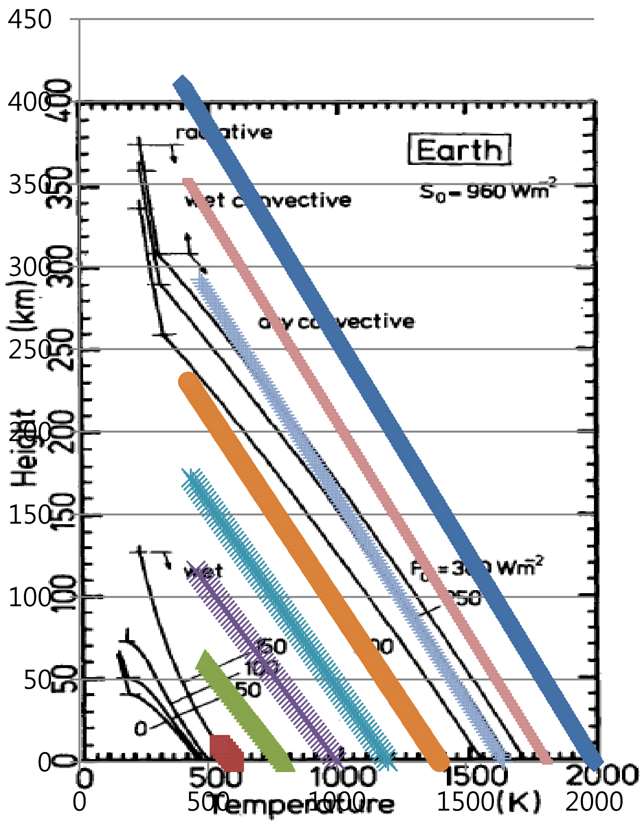


고도와 온도 분포

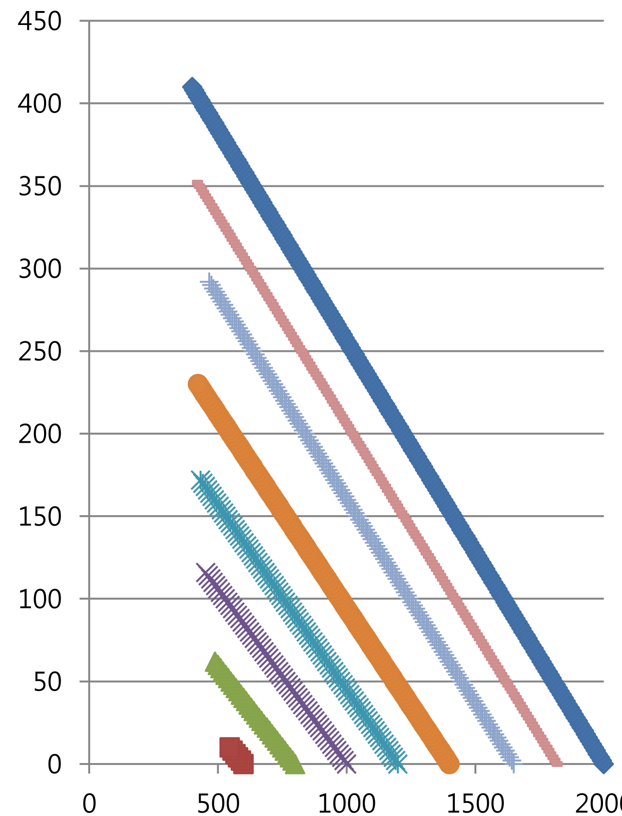


y = -0.2562x + 512.45
y = -0.2519x + 453.45
y = -0.2468x + 407.2
y = -0.2353x + 329.49
y = -0.2243x + 269.13
y = -0.2121x + 212.15
y = -0.1996x + 159.65
y = -0.1871x + 112.26
450
400
350
300
250
200
150
100
50
0
-50
0
200
400
600
800
1000
1200
1400
1600
1800
2000

고도와 온도 분포-논문과의 비교



(Abe Y. and Matsui T., 1988)



Evolution of an Impact-Generated H_2O–CO_2 Atmosphere and Formation of a Hot Proto-Ocean on Earth

YUTAKA ABE AND TAKAFUMI MATSUI

Geophysical Institute, Faculty of Science, University of Tokyo, Bunkyo-ku, Tokyo, Japan

(Manuscript received 26 February 1987, in final form 25 April 1988)

Accretion에 따른 지구 표면에서의 impact energy flux F_0 의 값에 따른 지구 원시바다의 형성을 다룸

지구의 대기를 두 개의 층(대류권, 성층권)으로 나누고 F_0값에 따라 대류권에서 온도와 수증기의 분포를 모델을 이용하여 나타냄

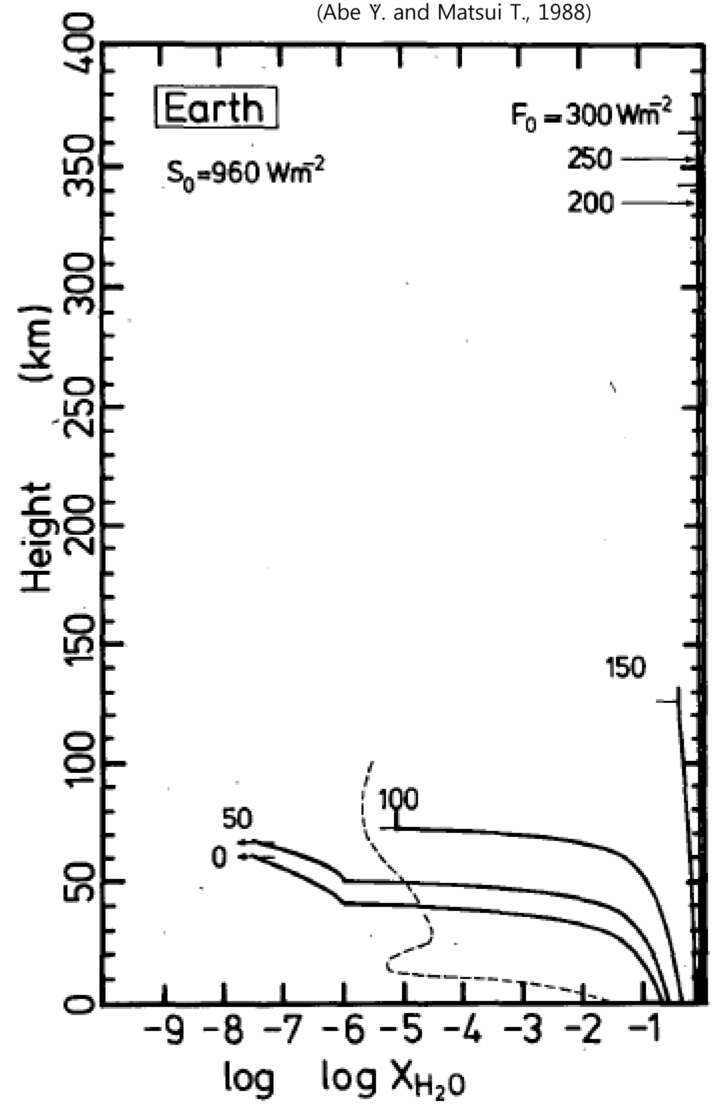
타당성 검증

가정1 : 상층부터 표층까지 수증기 몰 비율이 일정하다.

TABLE 3. Model parameters and major results.

Model	S_0 ($W\ m^{-2}$)	F_0 ($W\ m^{-2}$)	P_s (10^5 Pa)	X_{H_2O} At the cold trap	X_{H_2O} At the surface	T_s (K)
E0	960	0	50	2.8×10^{-8}	0.20	455.2
E50	960	50	50	2.8×10^{-8}	0.25	466.6
E100	960	100	50	6.8×10^{-6}	0.37	484.5
E150	960	150	90	0.38	0.73	570.0
E200	960	200	200	0.86	0.90	1545.0
E250	960	250	200	0.85	0.90	1652.0
E300	960	300	200	0.86	0.90	1712.0
V0[b]	1830	0	80	0.09	0.53	535.0

(Abe Y. and Matsui T., 1988)



타당성 검증

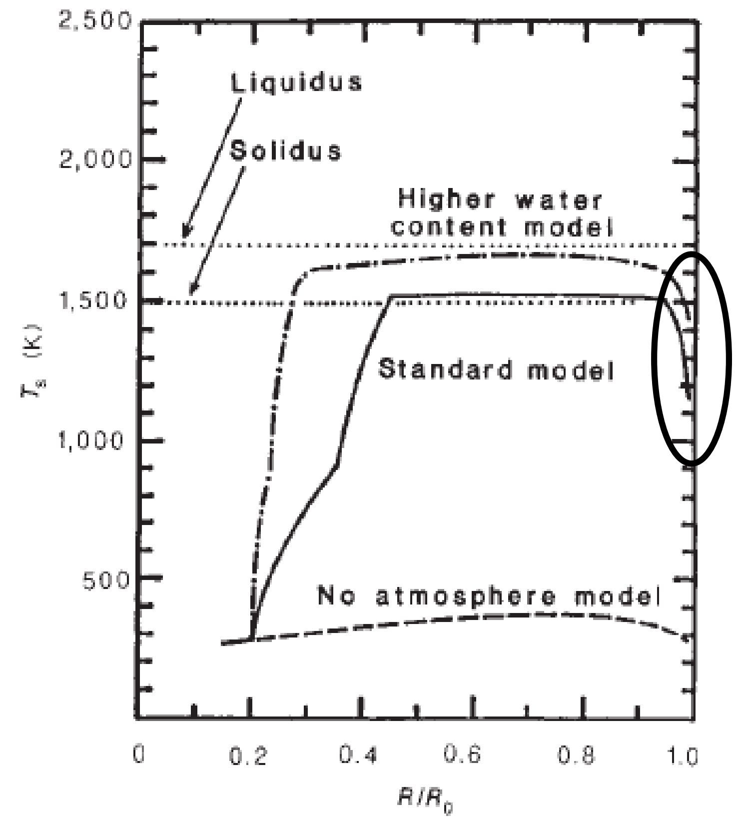
가정2 : 상대습도가 100%일 때 응결이 일어난다.

We assumed that the relative humidity in the atmosphere is 100%. It results in a slight overestimation

가정3 : γ값이 현재와 같다.

논문에서 그 당시 Cv 값을 구할 수 있는 방법이 소개되어 있지 않아 확인해볼 수 없다.

가정5 : accretion 후반의 g는 현재와 비슷하다.



타당성 검증

가정4 : 원시 지구 대기는 이상 기체이다.

accretion by using a one-dimensional radiative-convective atm
high (~200 bar) and close to the critical point of water vapor (
the nonideal behavior of gases in the calculation. It is shown th

$$\left(\frac{\partial T}{\partial P}\right)_s = -\frac{S'_P}{S'_T} \quad (dry) \qquad (6)$$

with

$$S'_T = \frac{C_{pg}(P, T)}{T} \qquad (7a)$$

$$S'_P = -\left(\frac{\partial v}{\partial T}\right)_p . \qquad (7b)$$

$$C_{pg}(P, T) = \sum_i^{\text{all}} x_i C^I_{pi0}(T) - T\int_0^P \left(\frac{\partial^2 v}{\partial T^2}\right)_{p'} dP' \qquad (10a)$$

$$C_{pv}(P, T) = C^I_{pv0}(T) - T\int_0^P \left(\frac{\partial^2 v_v^*}{\partial T^2}\right)_{p'} dP' \qquad (10b)$$

and C^I_{p0} is given by

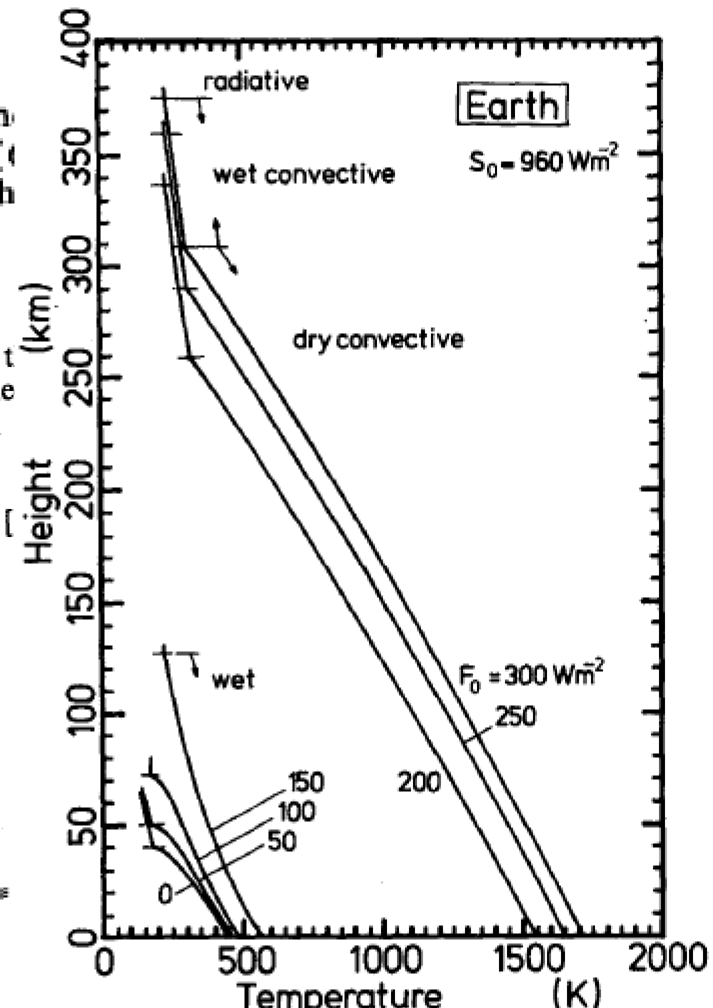
$$C^I_{p0}(T) = C_1 + C_2T + C_3T^2 + C_4T^3 \qquad (11)$$

where v is t
b are define

$a(T) \equiv \sum_i$

$\times$ [

$c_i \equiv$



타당성 검증- 포화수증기압

saturation vapor pressure of H_2O over liquid water

$$\ln P^*(T) = \alpha - \frac{\beta}{t} + \frac{\gamma x}{t}\left[\exp(\delta x^2) - 1\right] - \epsilon \exp(-\eta y)$$

$t = T\,(\mathrm{K}) + 0.01$

$x = t^2 - 293\,700$

$y = [647.26 - T\,(\mathrm{K})]^{5/4}$

$\alpha = 24.021415$

$\beta = 4616.9134$

$\gamma = 3.1934553 \times 10^{-4}$

$\delta = 2.7550431 \times 10^{-11}$

$\epsilon = 1.0246503 \times 10^{-2}$

$\eta = 1.3158813 \times 10^{-2}.$

$$e_{sw} = 6.11\exp\left(19.83 - \frac{5417}{T}\right)$$

타당성 검증

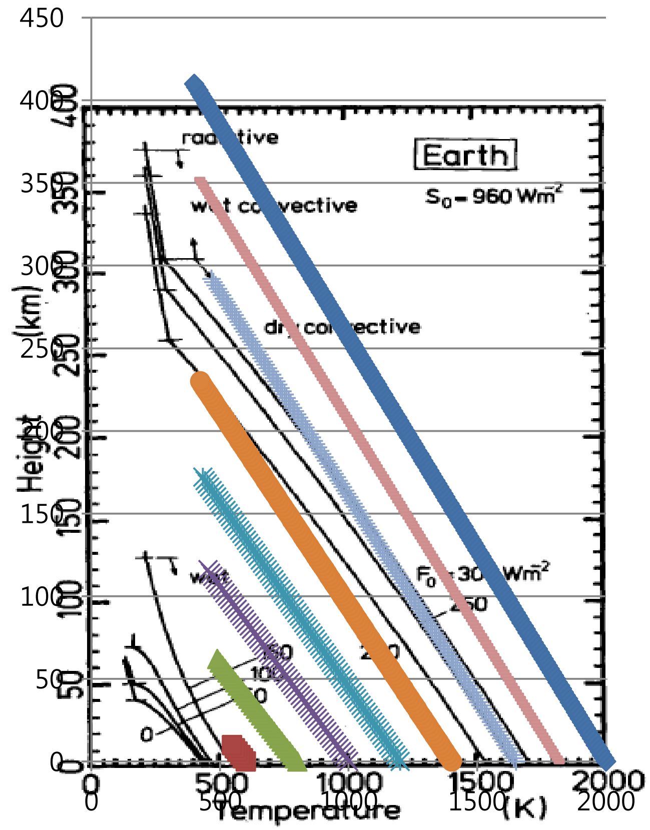
가정6 : Cp를 구하는 과정에서 두 번째 항은 생략한다.

$$C_{pg}(P,T) = \sum_{i}^{\mathrm{all}} x_i C^{I}_{pi0}(T) - T\int_0^P \left(\frac{\partial^2 v}{\partial T^2}\right)_{p'} dP' \quad (10a)$$

$$C_{pv}(P,T) = C^{I}_{pv0}(T) - T\int_0^P \left(\frac{\partial^2 v_v^*}{\partial T^2}\right)_{p'} dP' \quad (10b)$$

and C^{I}_{p0} is given by

$$C^{I}_{p0}(T) = C_1 + C_2T + C_3T^2 + C_4T^3 \quad (11)$$



결과 : Cp값이 논문보다 조금 크게, 단열감률은 조금 작게 나왔다.

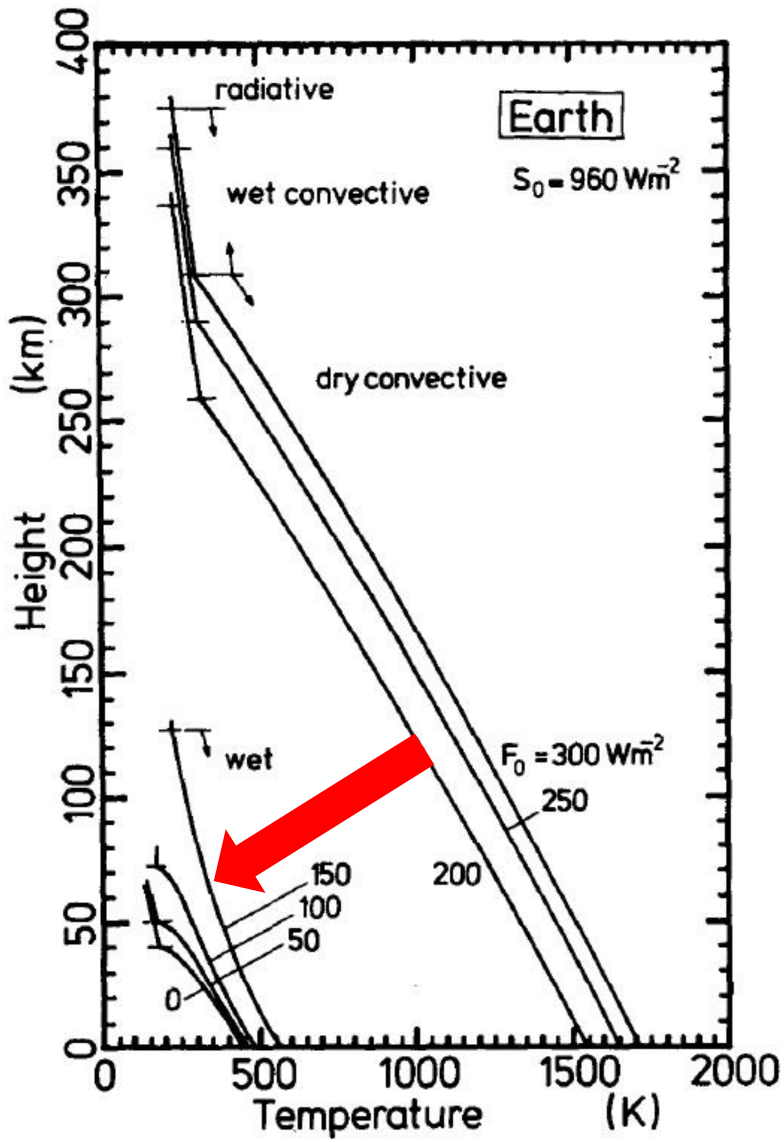
참고문헌

- YUTAKA ABE AND TAKAFUMI MATSUI, **“Evolution of an Impact-Generated H20-COZ Atmosphere and Formation of a Hot Proto-Ocean on Earth”, 1988**
- YUTAKA ABE AND TAKAFUMI MATSUI, **“Evolution of an Impact-induced atmosphere and magma ocean on the accreting Earth”, 1988**
- Anastasios A.Tsonis**, “An introduction to Atmospheric Thermodynamics 2th”, 2007**

감사합니다~!

Evolution of the atmosphere during the accretion (F_0=200 to F_0=150)

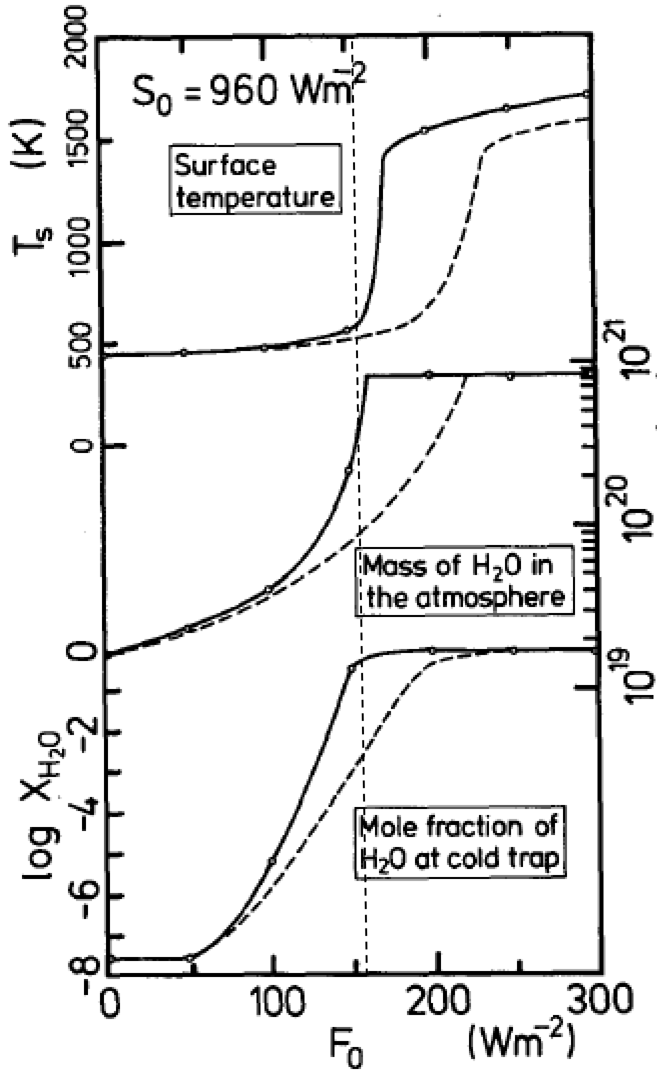
Evolution of the atmosphere during the accretion



- Considerable difference in atmospheric structure between F_0=200 to F_0=150
- When F_0 > 150 W m-2, the lower atmosphere is dry (no condensation of H20 occurs).
- dry convective layer disappears at F_0 ~ 150 W m-2

(Abe Y. and Matsui T., 1988)

Evolution of the atmosphere during the accretion

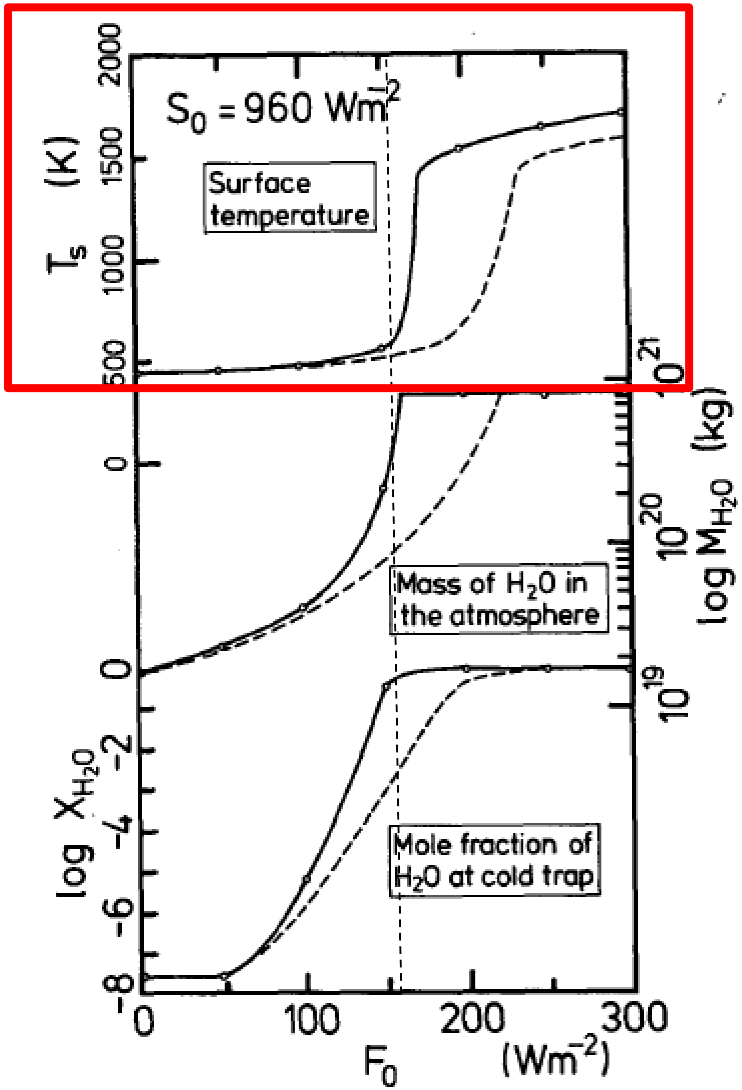


- F_0 < ~150 W m-2,
- liquid and gas phases are in equilibrium at the lower atmosphere.
- In such a two components system with two phases, degree of freedom is 2.
- F_0 and the mass of C02 in the atmosphere, the mass of H20 in the atmosphere is automatically determined

- F_0 > ~150 W m-2,
- the lower atmosphere is composed of gas phase only and the degree of freedom is 3.
- Therefore, the mass of H20 in the atmosphere is also an independent variable.
- results at F_0 > ~150 W m-2 are dependent to an assumed H20 inventory (~ 10^{21} kg) in this study.

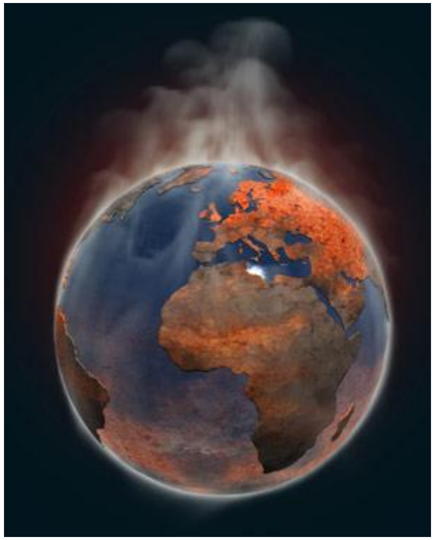
(Abe Y. and Matsui T., 1988)

Evolution of the atmosphere during the accretion



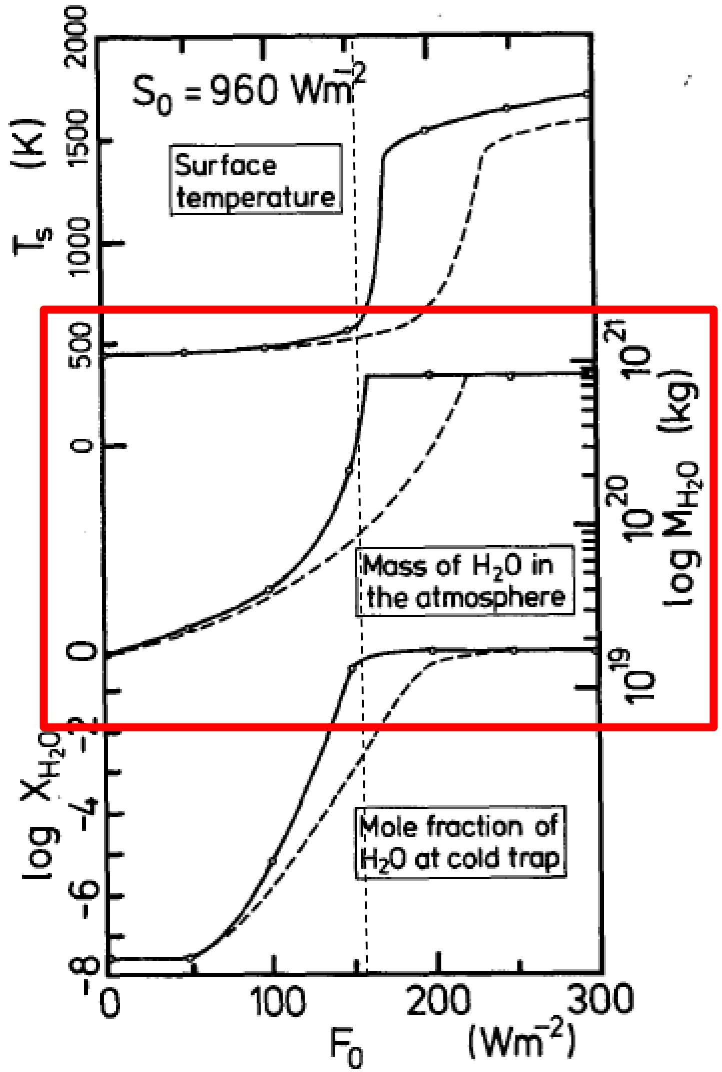
- About F_0 ~150 W m-2, temperature is rapidly decrease.
- This is similar to the change in atmospheric structure at the critical condition for the runaway greenhouse

- Runaway greenhouse effect



(Abe Y. and Matsui T., 1988)

Evolution of the atmosphere during the accretion

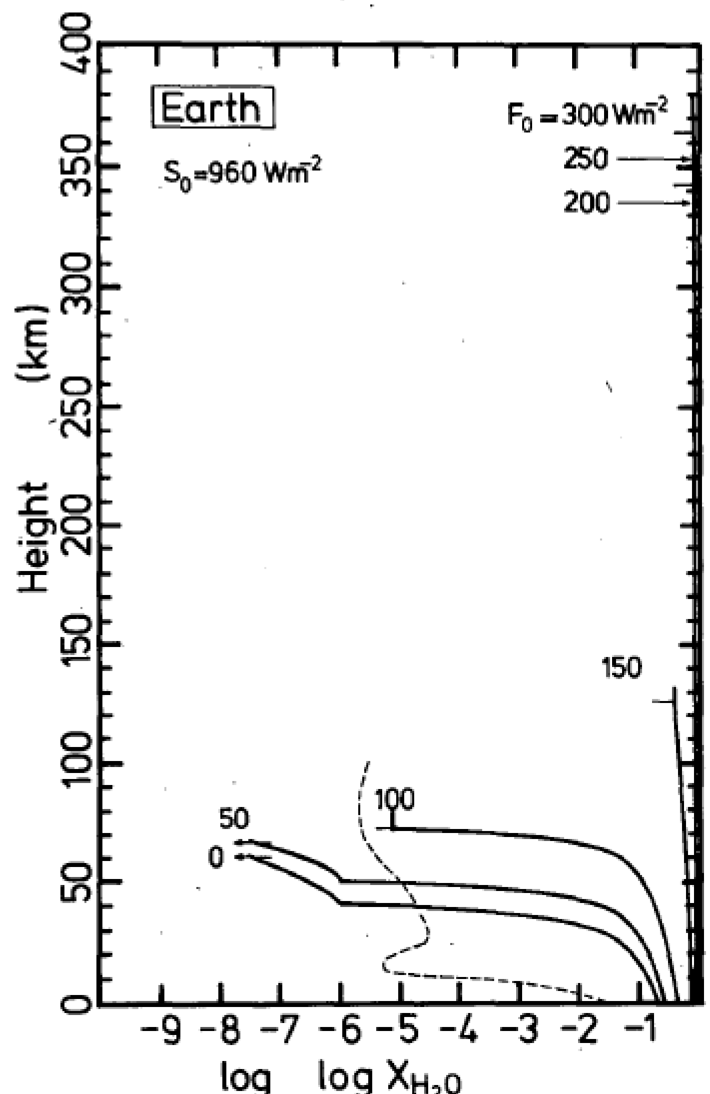


- F_0 >~150 W m-2, mass of H20 in the atmosphere is almost constant.
- F_0 <~150 W m-2, rapid decrease of H20 in the atmosphere because of condensation at surface and forming a proto-ocean.

(Abe Y. and Matsui T., 1988)

Evolution of the atmosphere after the end of accretion

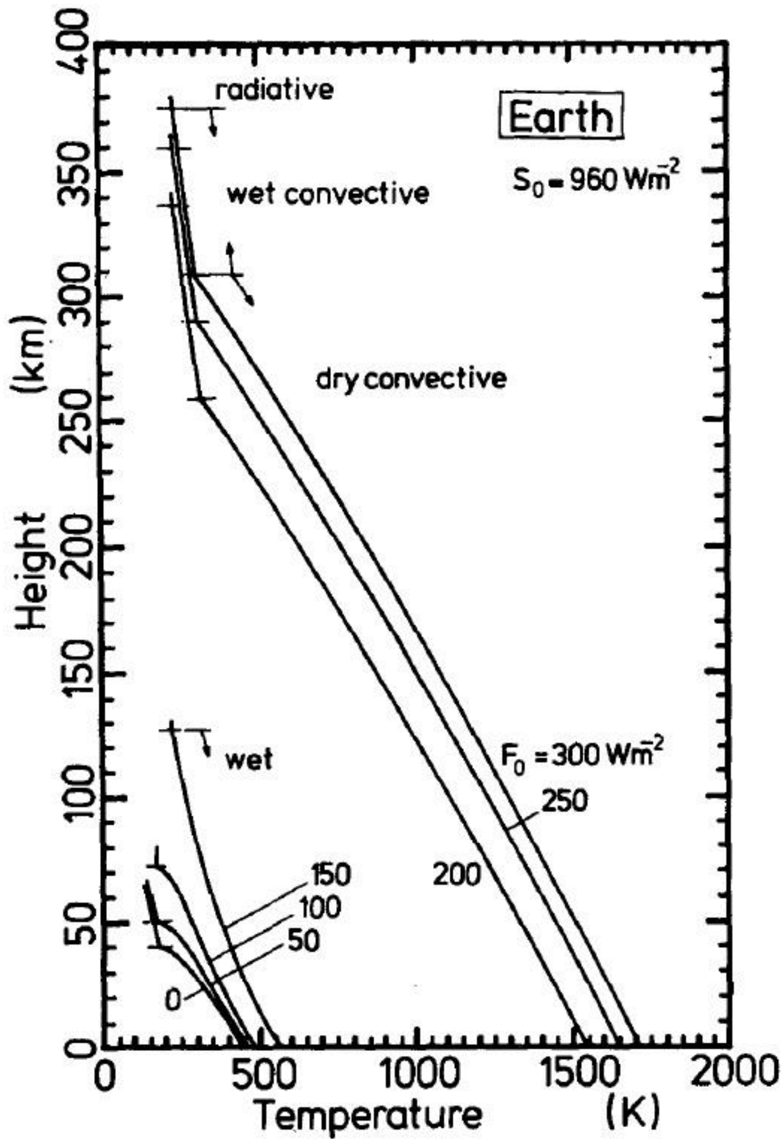
- Change of H20 concentration in atmosphere
- F_0 > 150 W m-2, the atmosphere is almost composed of H2O.
- Even when F_0 = 0 W m-2, H2O concentration at surface is much higher than present, because of high temperature.



(Abe Y. and Matsui T., 1988)

Evolution of the atmosphere after the end of accretion

Evolution of the atmosphere after the end of accretion



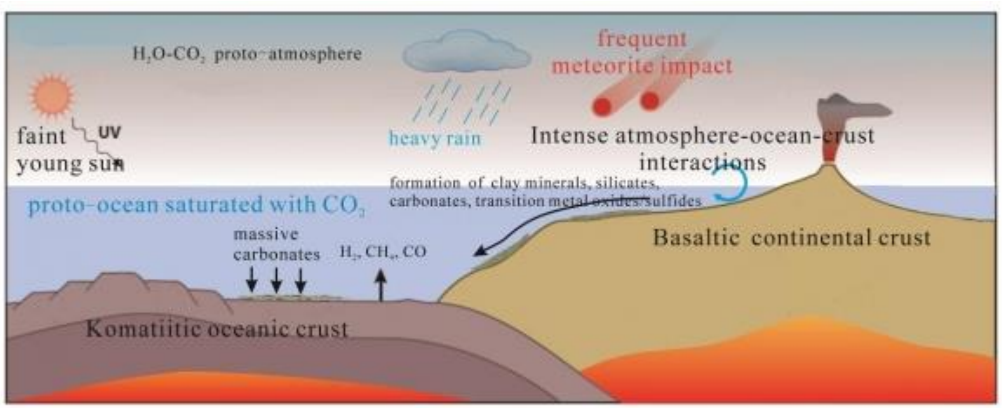
- The surface temperature after the end of accretion (F_0 = $0Wm^{-2}$) is 455 K.

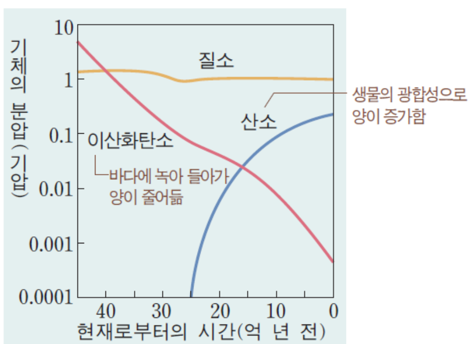
출처 : http://biotech.deu.ac.kr/jen/intro.htm

(Abe Y. and Matsui T., 1988)

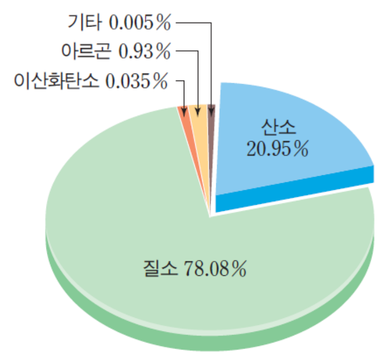
Evolution of the atmosphere after the end of accretion

- The surface temperature decreases with decreasing the mass of $C0_2$ in the atmosphere.
- CO_2 gradually dissolves into a proto-ocean and precipitates as carbonates.
- The lower atmosphere is saturated by water vapor and the surface temperature varies along an adiabat with changing the mass of $C0_2$ in the atmosphere.
- The removal rate of $C0_2$ from the proto-atmosphere determines the decreasing rate of the surface temperature.





▲ 기권의 진화

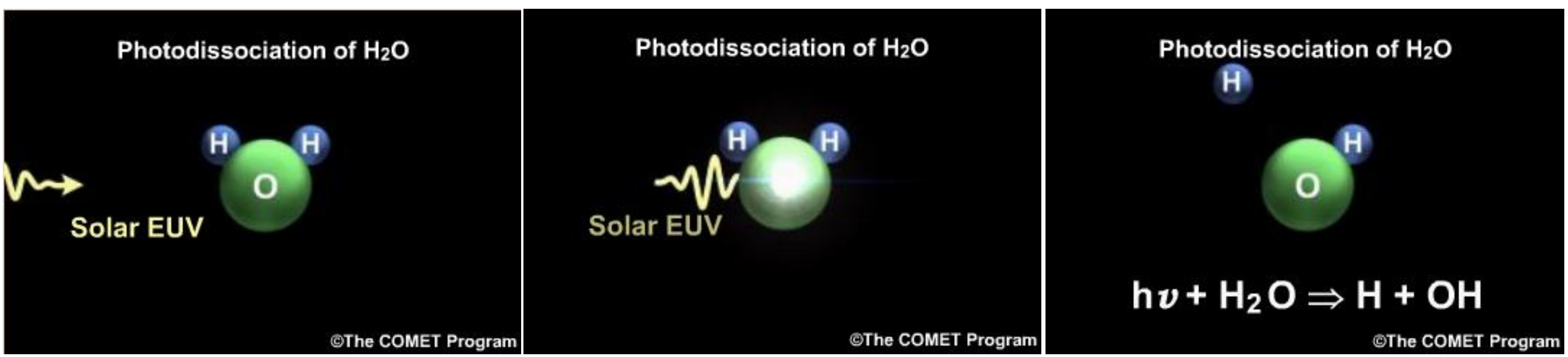


▲ 현재 대기 조성

출처 : http://www.earthsciences.hku.hk/news-and-events/seminars/experimental-approach-to-the-direct-interaction-between-the-proto-atmosphere-and-rocky-crust-of-the-early-earth-implications-to-the-early-evolution-of-earth-like-planets , http://study.zum.com/book/13456

Evolution of the atmosphere after the end of accretion

- The H_20 might be removed by the photo-dissociation and subsequent escape of hydrogen during the cooling stage of a proto-ocean.



출처 : http://www.windows2universe.org/physical_science/chemistry/photodissoc_h2o.html

Evolution of the atmosphere after the end of accretion

- Oskvarek and Perry (1976) estimated the temperature of a proto-ocean based on the oxygen isotope composition of the old (3.8 X 10^9 yr) chert in Isua metasediments, West Greenland.
- Their result shows that the upper bound of temperatures of the archaean ocean is between 360 and 420 K. This estimate is dependent on the initial value of isotopic ratio of oceanic water; $\delta^{18}O_{SMOW} = -6ppt$ is appropriate when water is initially equilibrated with igneous material at high temperature. When we adopt this initial value, the estimated temperature is 420 K.
- $$\Delta_{CW} = \frac{3.09 \times 10^6}{T^2} - 3.29$$

출처 : https://gerdapeacheysviews.wordpress.com/mistaken-microfossils/

Summary

1. 뜨거운 원시 해양은 부착의 마지막 단계의 충돌 에너지의 감소와 함께 지구에 형성되었다.
2. 원시 해양의 형성과 함께 대기의 위쪽의 H_20 농도가 감소하고, 이것은 대기에서의 H_20의 광해리와 수소의 탈출을 막는다.
3. 부착의 끝 단계에서 원시 지구의 표면 온도는 약 420K이고, 이것은 시생대 쳐트(3.8 X 10^9 yr)로부터 추정한 것이다.
4. 표면의 온도는 대기에서의 이산화탄소가 점차적으로 줄어들 때 함께 줄어들고, 이것은 물과 이산화탄소간의 지구화학적인 것에 의해서이다.