

MICROFÍSICA DA PRECIPITAÇÃO

Capítulo 3 – O aerossol atmosférico e nucleação heterogênea

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Maio - Junho de 2006

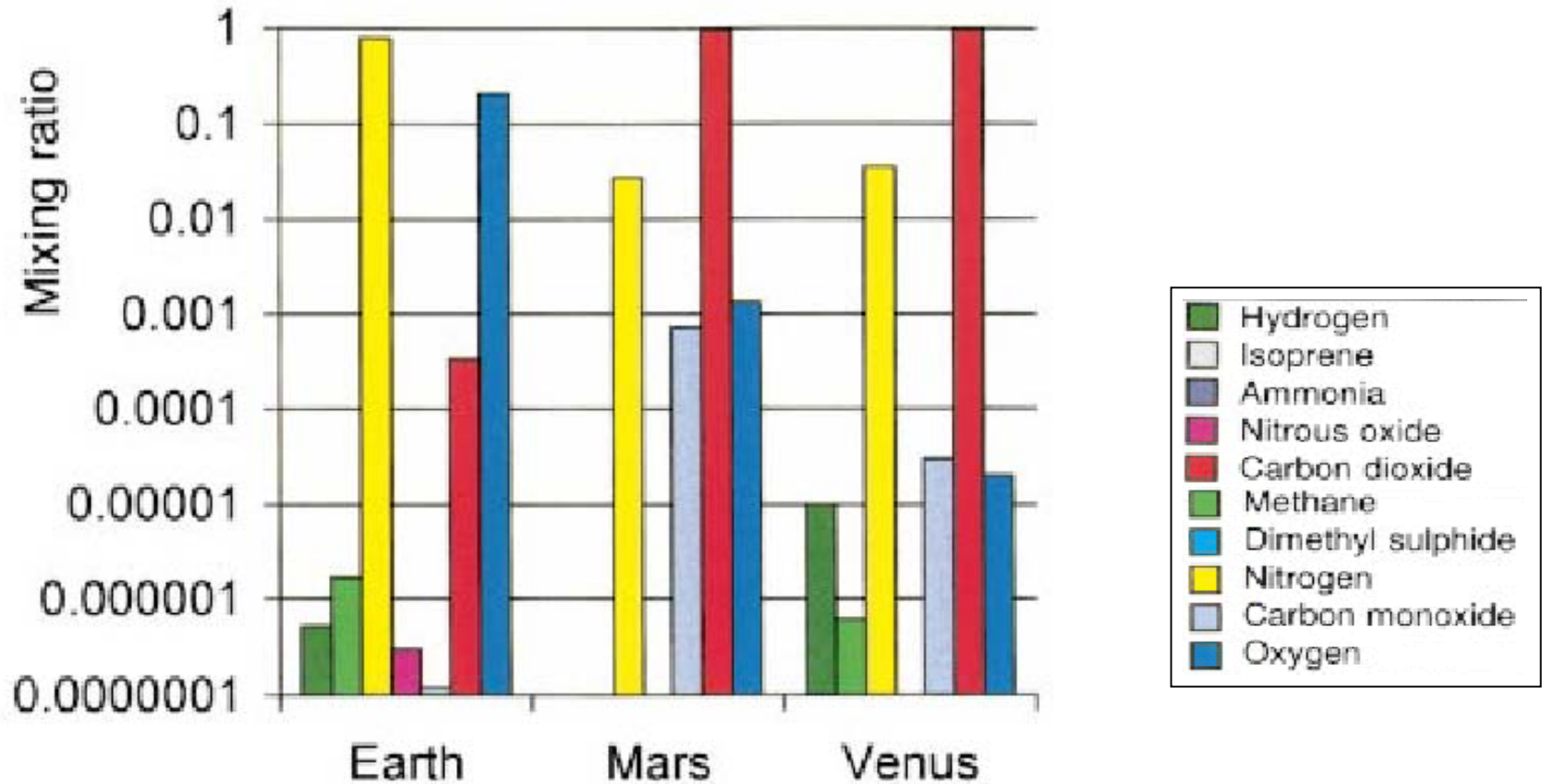
Conteúdo

- ❑ Objetivos
- ❑ Introdução à microestrutura de nuvens e da precipitação
- ❑ Equilíbrio de fases
 - Potencial químico do vapor de água no ar úmido
 - Calor latente da mudança de fase
 - A equação de Clausius-Clapeyron
 - A variação da energia livre de Gibbs no processo de nucleação homogênea
- ❑ **Aerossol atmosférico**
 - A variação da energia livre de Helmholtz no processo de nucleação heterogênea**
 - O equilíbrio entre gotas de solução aquosa e o ar úmido**
 - A nucleação por íons**
- ❑ O processo de difusão de vapor no crescimento e na evaporação de gotículas
 - O crescimento de uma população de gotículas em nuvens quentes
- ❑ A interação dinâmica entre as gotículas – O processo de colisão e coalescência
 - O crescimento de gotas na corrente ascendente
- ❑ A formação de gelo na atmosfera
 - O crescimento de cristais de gelo por difusão de vapor
 - O desenvolvimento da precipitação na fase gelo
- ❑ Composição química de hidrometeoros
- ❑ Microfísica da carga e da eletricidade atmosférica
- ❑ O sensoriamento remoto da precipitação
 - O espectro de tamanho de gotas
 - A taxa de precipitação e os parâmetros integrais e suas variabilidades

Cap. 3 - Aerossol atmosférico

A variação da energia livre de Helmholtz no processo de nucleação heterogênea

O equilíbrio entre gotas de solução aquosa e o ar úmido
A nucleação por íons



Composição da Atmosfera

Mistura de gases

Constituinte	Fórmula	Conc. por volume
Nitrogen	N_2	78.08%
Oxygen	O_2	20.95%
Argon	Ar	0.934%
Water vap.	H_2O	0 - 4% (variable)
Carbon dioxide	CO_2	0.0360% (360 ppmv)
Methane	CH_4	0.00017% (1700 ppbv)

+ **gases traço** (muito baixa concentração)

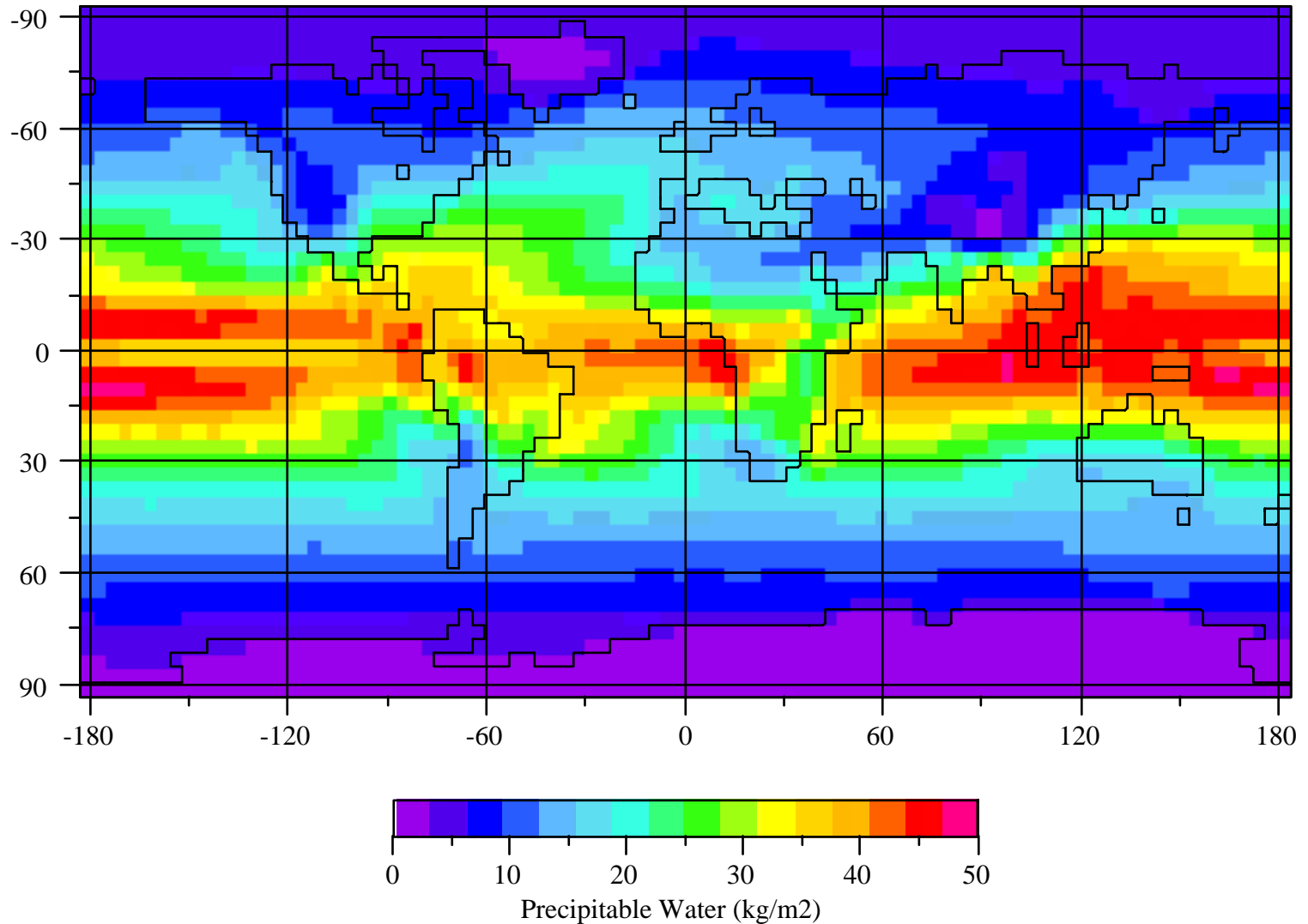
+ **aerossol**

Gases traço

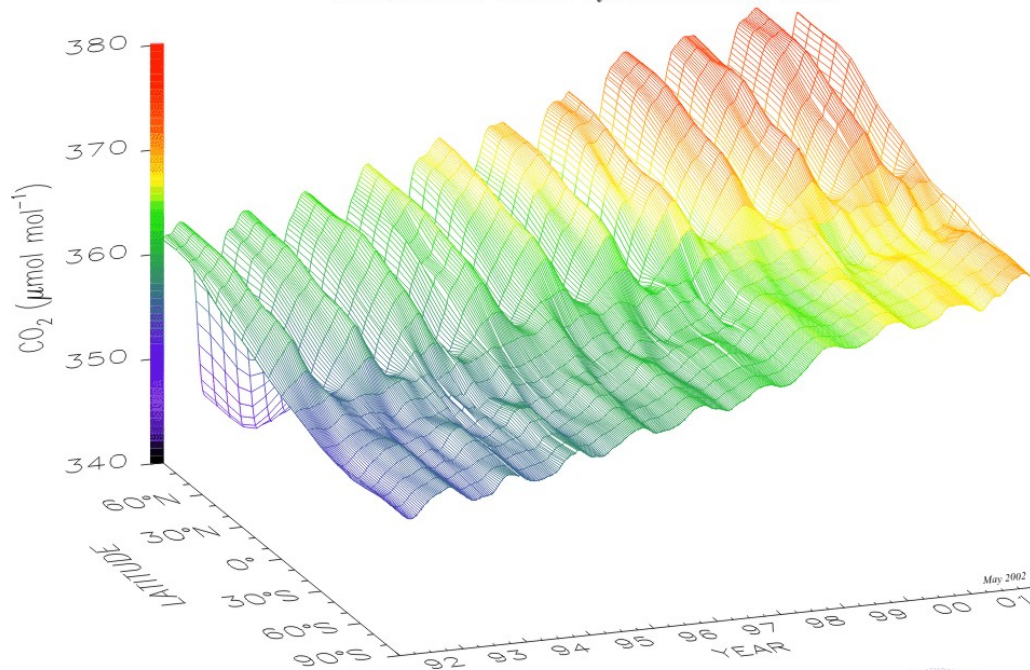
- A composição atmosférica é não estática
- Reflete o balanço das trocas de fluxos
- Está conectado com as substâncias dos ciclos biogeoquímicos

Gas		Lifetime (years)	Global Warming Potential (Time Horizon in years)		
			20 yrs	100 yrs	500 yrs
Carbon dioxide	CO ₂		1	1	1
Methane ^a	CH ₄	12.0 ^b	62	23	7
Nitrous oxide	N ₂ O	114 ^b	275	296	156
Hydrofluorocarbons					
HFC-23	CHF ₃	260	9400	12000	10000
HFC-32	CH ₂ F ₂	5.0	1800	550	170
HFC-41	CH ₃ F	2.6	330	97	30
HFC-125	CHF ₂ CF ₃	29	5900	3400	1100
HFC-134	CHF ₂ CHF ₂	9.6	3200	1100	330
HFC-134a	CH ₂ FCF ₃	13.8	3300	1300	400
HFC-143	CHF ₂ CH ₂ F	3.4	1100	330	100
HFC-143a	CF ₃ CH ₃	52	5500	4300	1600
HFC-152	CH ₂ FCH ₂ F	0.5	140	43	13
HFC-152a	CH ₃ CHF ₂	1.4	410	120	37
HFC-161	CH ₃ CH ₂ F	0.3	40	12	4
HFC-227ea	CF ₃ CHFCF ₃	33	5600	3500	1100
HFC-236cb	CH ₂ FCF ₂ CF ₃	13.2	3300	1300	390
HFC-236ea	CHF ₂ CHFCF ₃	10	3600	1200	390
HFC-236fa	CF ₂ CH ₂ CF ₃	220	7500	9400	7100
HFC-245ca	CH ₃ FCF ₂ CHF ₂	5.9	2100	640	200
HFC-245fa	CHF ₂ CH ₂ CF ₃	7.2	3000	950	300
HFC-365mfc	CF ₃ CH ₂ CF ₂ CH ₃	9.9	2600	890	280
HFC-43-10mee	CF ₃ CHFCF ₂ CF ₃	15	3700	1500	470
Fully fluorinated species					
SF ₆		3200	15100	22200	32400
CF ₄		50000	3900	5700	8900
C ₂ F ₆		10000	8000	11900	18000
C ₃ F ₈		2600	5900	8600	12400
C ₄ F ₁₀		2600	5900	8600	12400
c-C ₄ F ₈		3200	6800	10000	14500
C ₅ F ₁₂		4100	6000	8900	13200
C ₆ F ₁₄		3200	6100	9000	13200
Ethers and Halogenated Ethers					
CH ₃ OCH ₃		0.015	1	1	<<1
HFE-125	CF ₃ OCHF ₂	150	12900	14900	9200
HFE-134	CHF ₂ OCHF ₂	26.2	10500	6100	2000
HFE-143a	CH ₃ OCF ₃	4.4	2500	750	230
HCFE-235da2	CF ₃ CHClOCHF ₂	2.6	1100	340	110
HFE-245fa2	CF ₃ CH ₂ OCHF ₂	4.4	1900	570	180
HFE-254eb2	CHF ₂ CF ₂ OCH ₃	0.22	99	30	9
HFE-7100	C ₄ F ₉ OCH ₃	5.0	1300	390	120
HFE-7200	C ₄ F ₉ OC ₂ H ₅	0.77	190	55	17
H-Galden 1040x	CHF ₂ OCF ₂ OC ₂ F ₄ OCHF ₂	6.3	5900	1800	560
HG-10	CHF ₂ OCF ₂ OCHF ₂	12.1	7500	2700	850
HG-01	CHF ₂ OCF ₂ CF ₂ OCHF ₂	6.2	4700	1500	450

Variabilidade espacial: H₂O atmosférico



Global Distribution of Atmospheric Carbon Dioxide NOAA CMDL Carbon Cycle Greenhouse Gases



Three dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the NOAA CMDL cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Principal investigators: Pieter Tans and Thomas Conway, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678 (ptans@cmdl.noaa.gov, <http://www.cmdl.noaa.gov/ccgg>).



Resumo

Composição da atmosfera

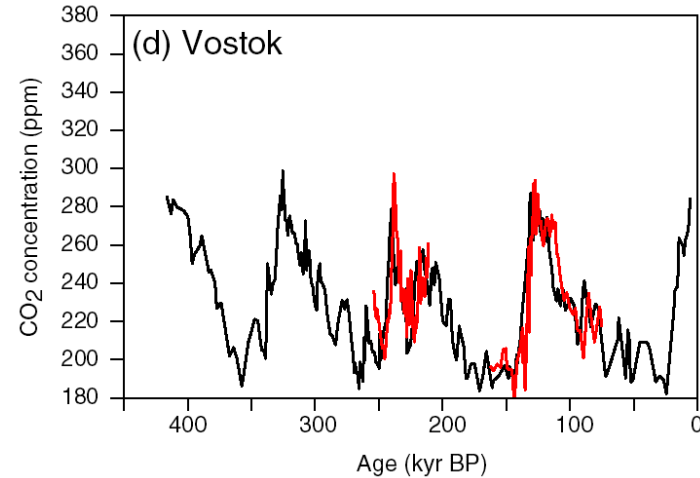
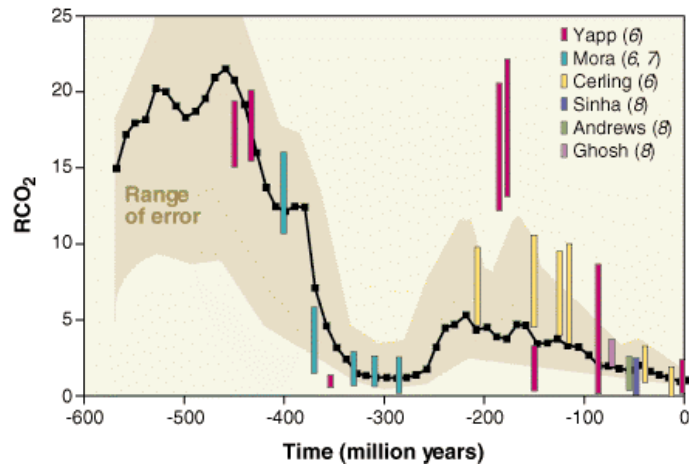
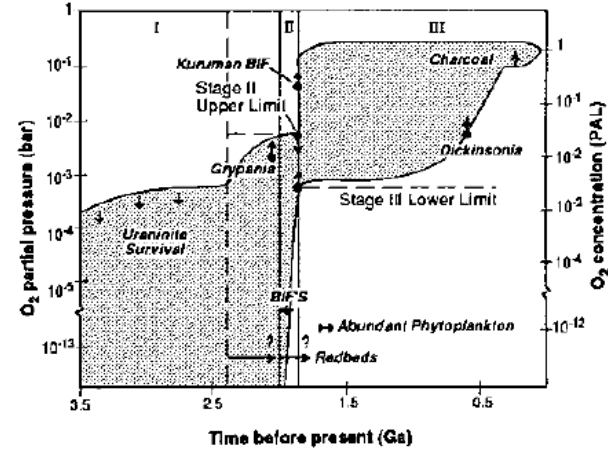
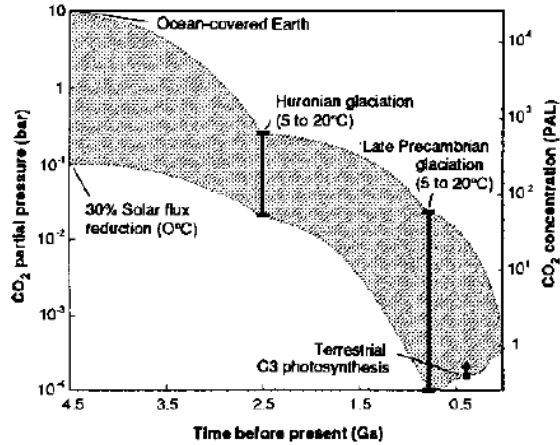
Composta de:

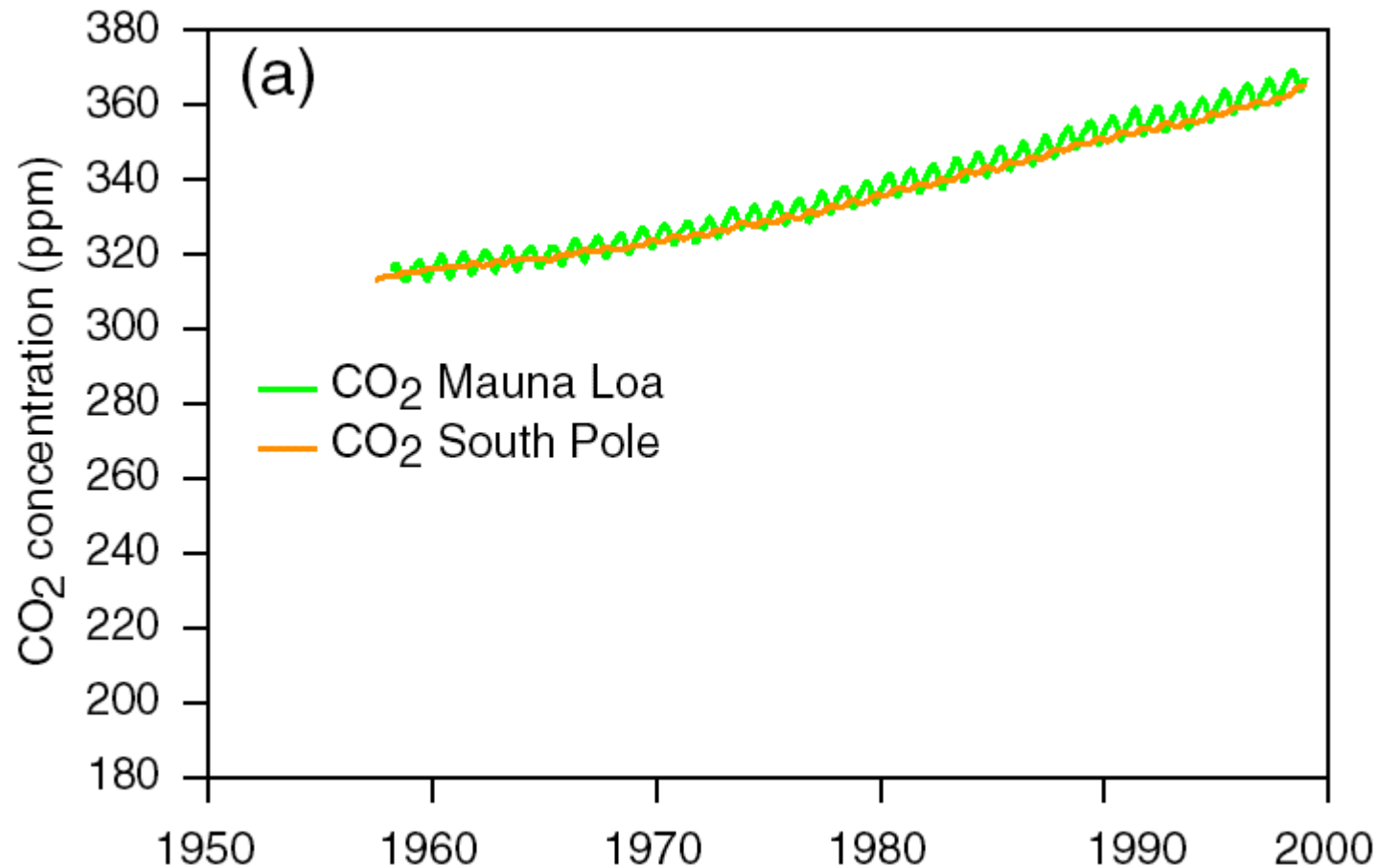
Nitrogenio e Oxigênio

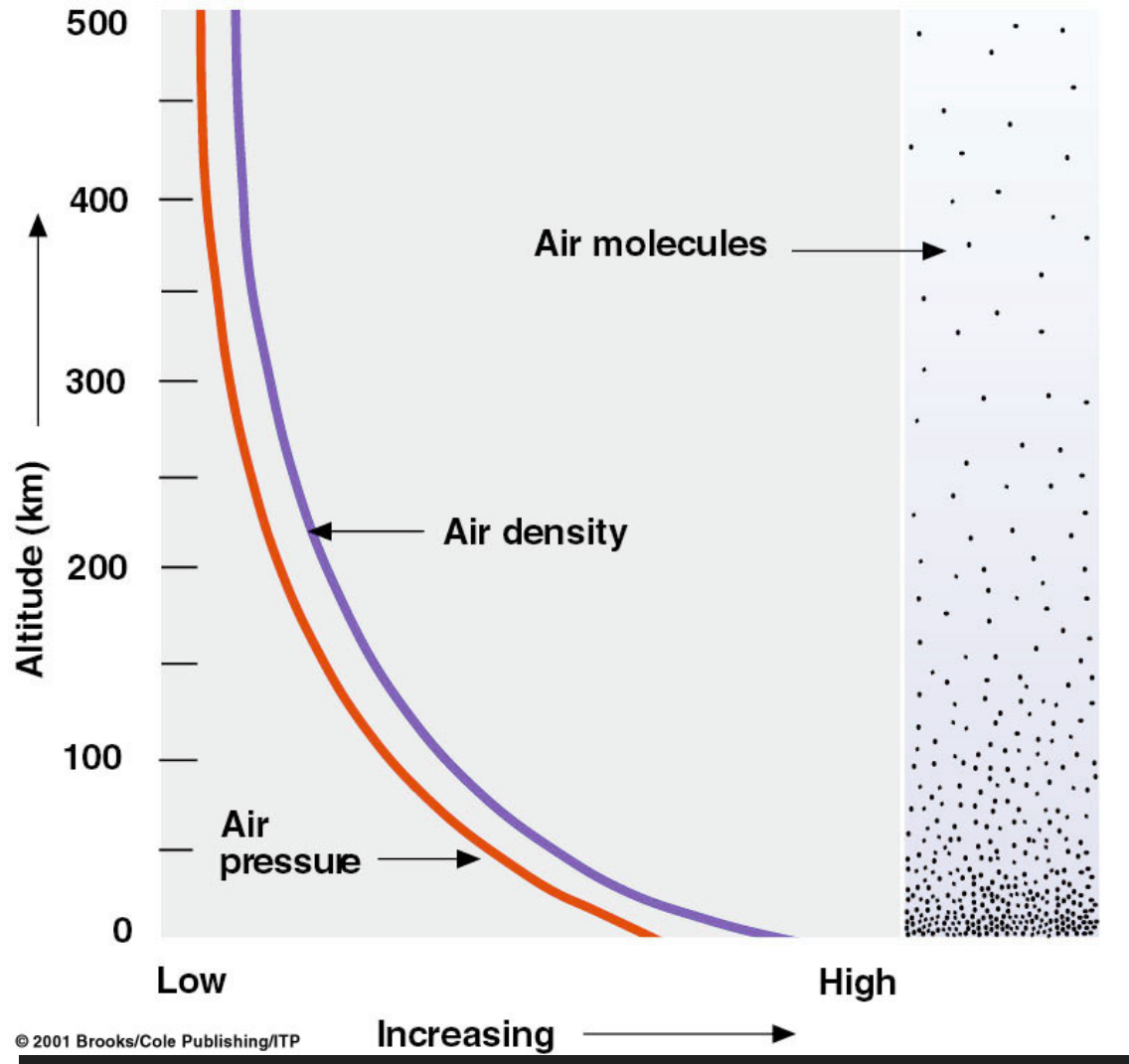
Alguns gases traço possuem importante papel como gases estufa:
vapor de água, dióxido de carbono, metano

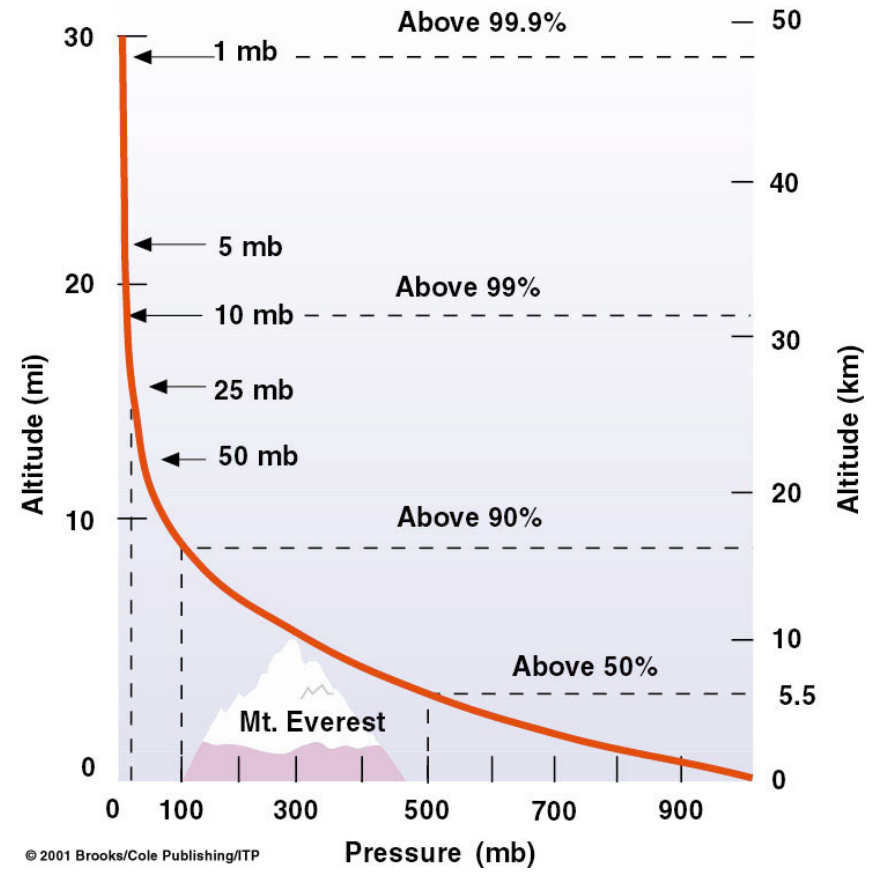
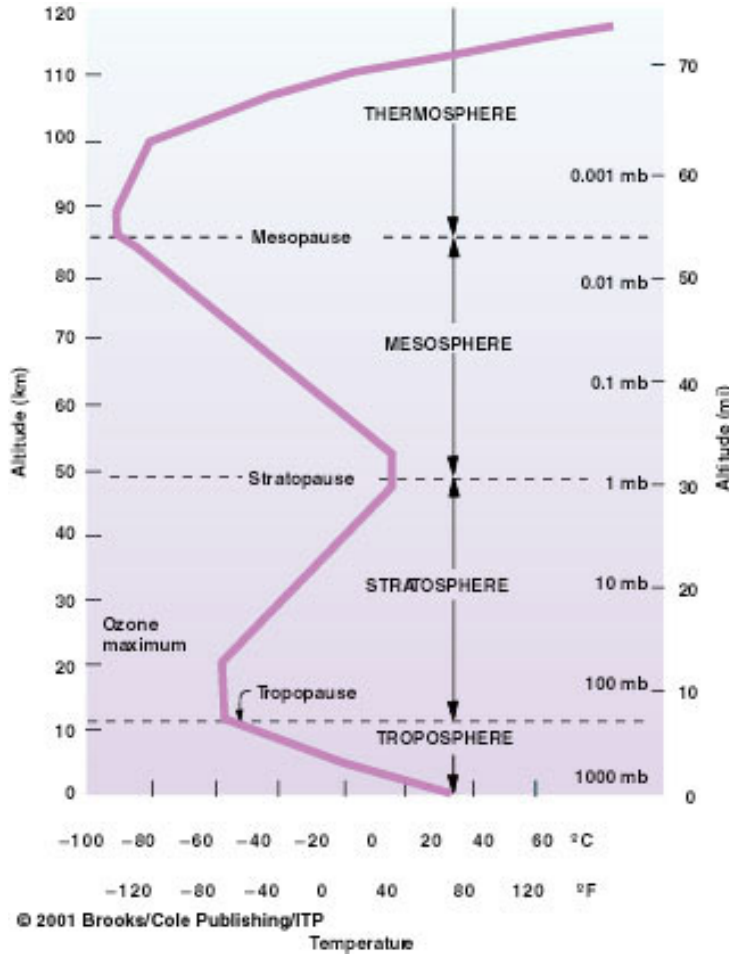
A concentração atmosférica reflete os ciclos biogeoquímicos

O tempo de residência é a característica resultante desse ciclo
Curtos tempos de residência estão associados à variações espaço-temporal da concentração

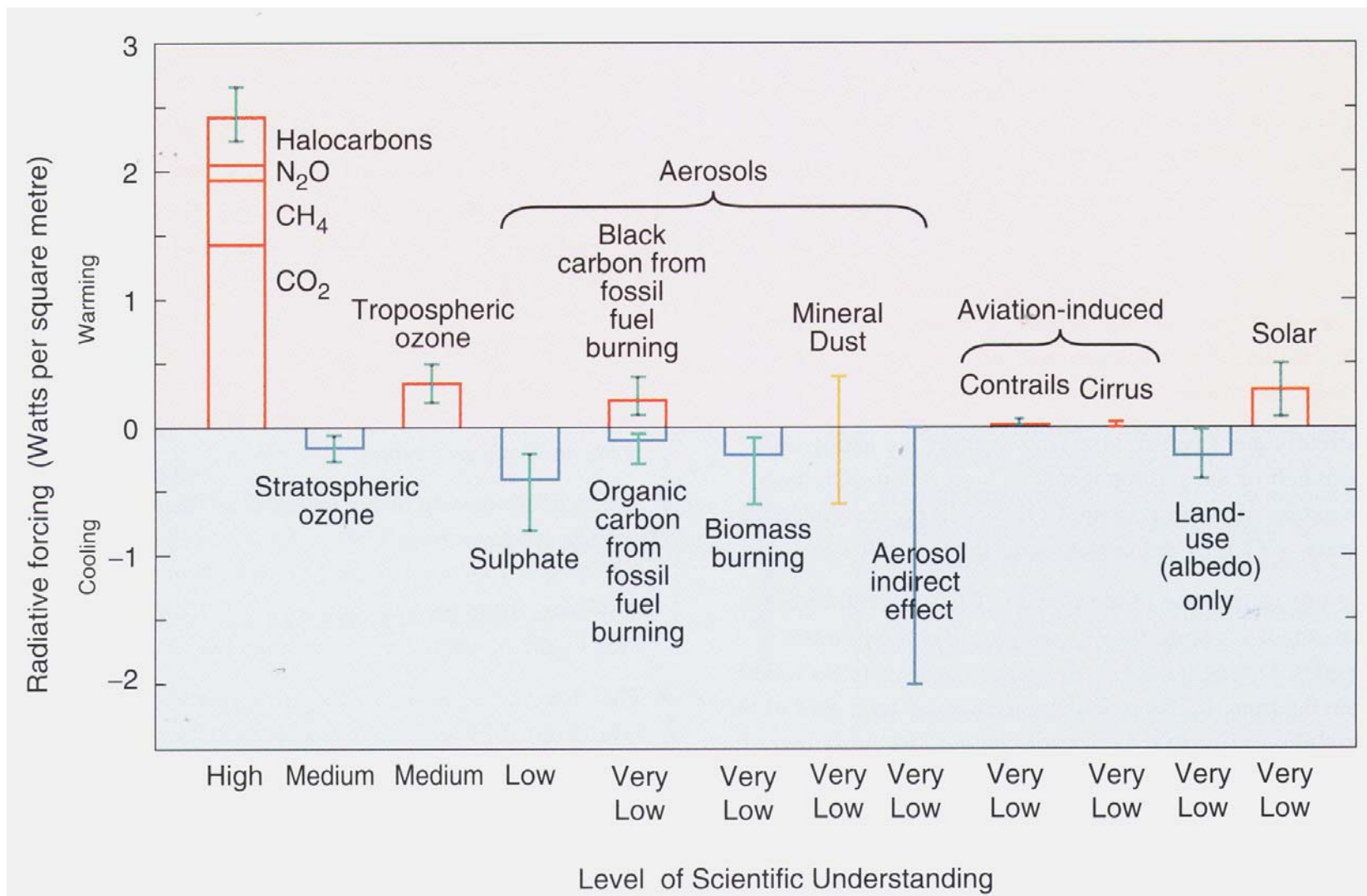








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Fontes de partículas primárias

Ocorrência Antropogênica

- Wind Blown Dust
Roads, Over Grazing, Farming practices, Mining
- Biomass Burning
Land Clearing Practices
- Emissions from fossil fuel combustion
Fly Ash
Condensation of Hot Vapors

Ocorrência Natural

- Wind Blown Dust
Deserts
- Volcanoes
- Fires
- Plant Particles
(pollen)
- Sea Salt Spray
(NaCl)

O sistema aerossol:

- A velocidade de sedimentação das partículas é pequena
- Efeitos inerciais durante os movimentos das partículas podem ser desprezados (a razão entre forças inerciais e forças viscosas é pequena)

$$\text{No de Reynolds} = (\rho v r) / \mu < 1$$

- O movimento browniano das partículas devido à agitação térmica das moléculas do gás é importante

Fontes primárias de gases importantes para a formação de partículas secundárias

Compound

Anthropogenic

Naturally Occurring

SO₂

Fossil-Fuel
Smelters
Oil Refining

Volcanoes

NO_x

Fossil-Fuel Combustion
Mobil Sources
Soil Release (Fertilizer)

Soil Release
Lightning

NH₃

Farm Animals

Wild Animals
Vegetation
Ocean

Volatile
Organics

Mobile Sources

Vegetation

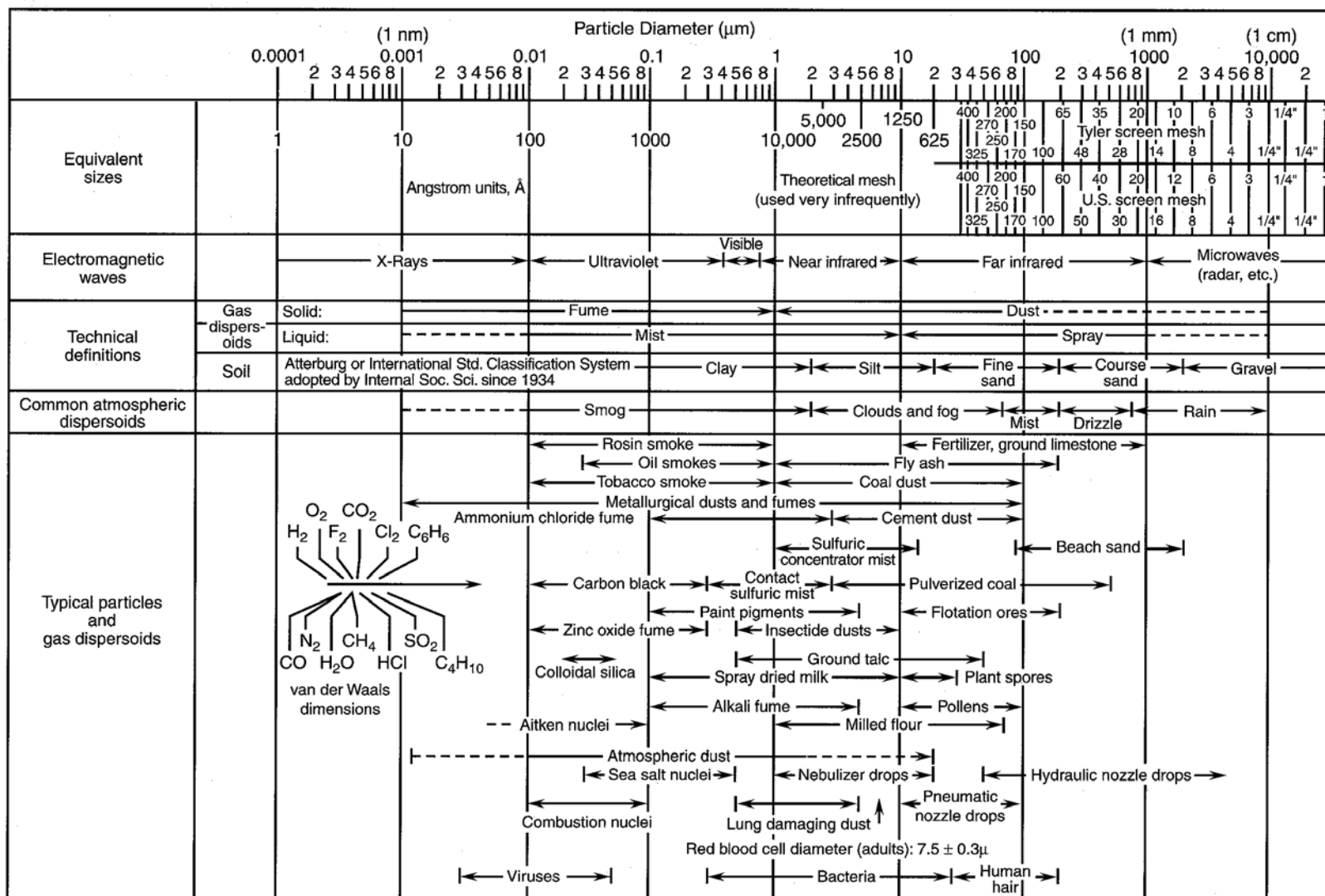


FIGURE 9.1 Some characteristics of particles and aerosols in ambient atmospheres and industrial settings (adapted from Lapple, 1961).

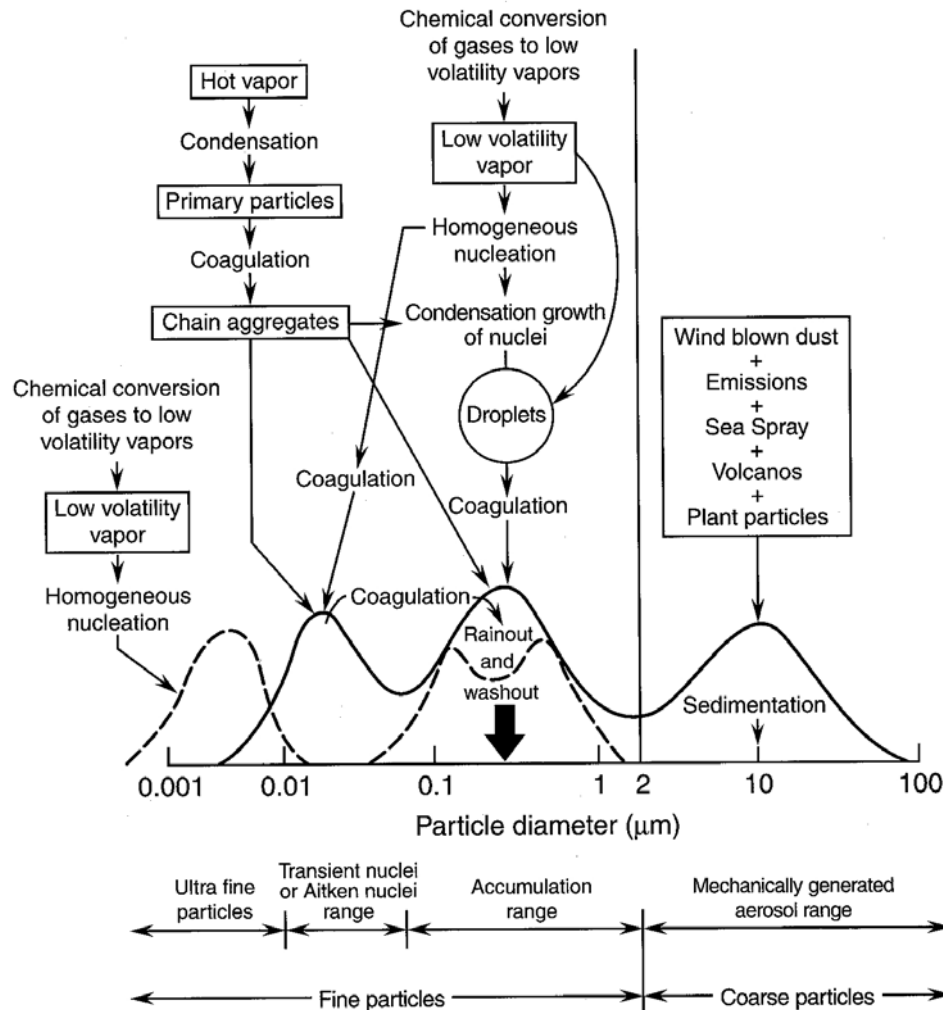
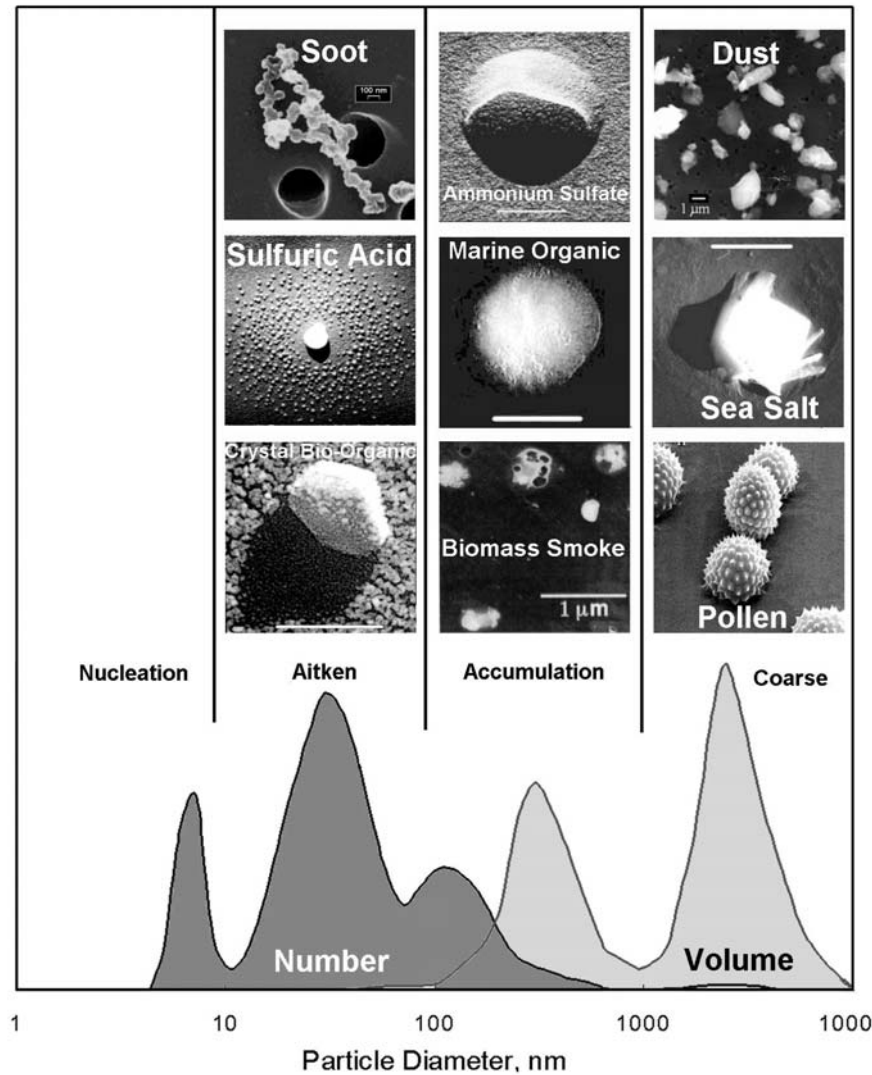
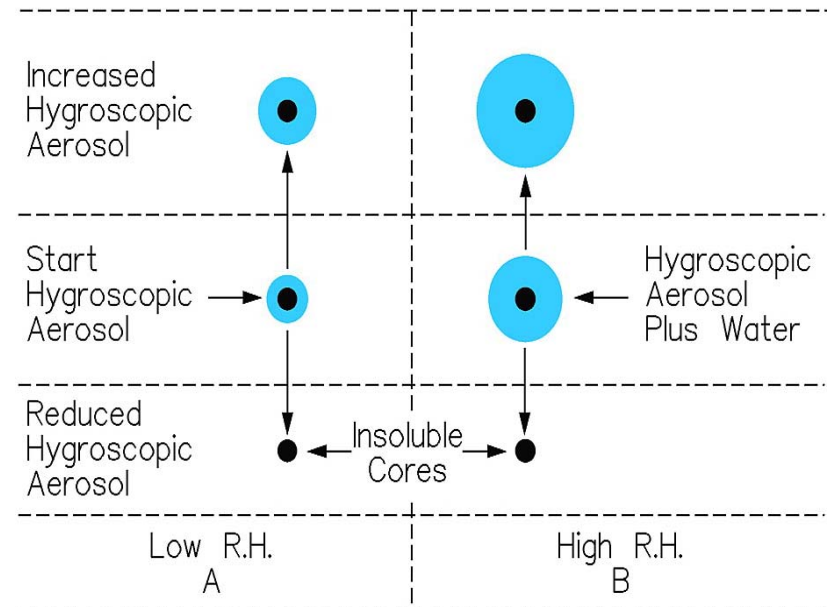


FIGURE 9.7 Schematic of an atmospheric aerosol size distribution showing four modes. The original hypothesis of Whitby and co-workers is shown by the solid, trimodal curves, and the fourth, ultrafine particle mode, as well as the two peaks sometimes observed in the accumulation mode are shown by the dashed lines (adapted from Whitby and Sverdrup, 1980).



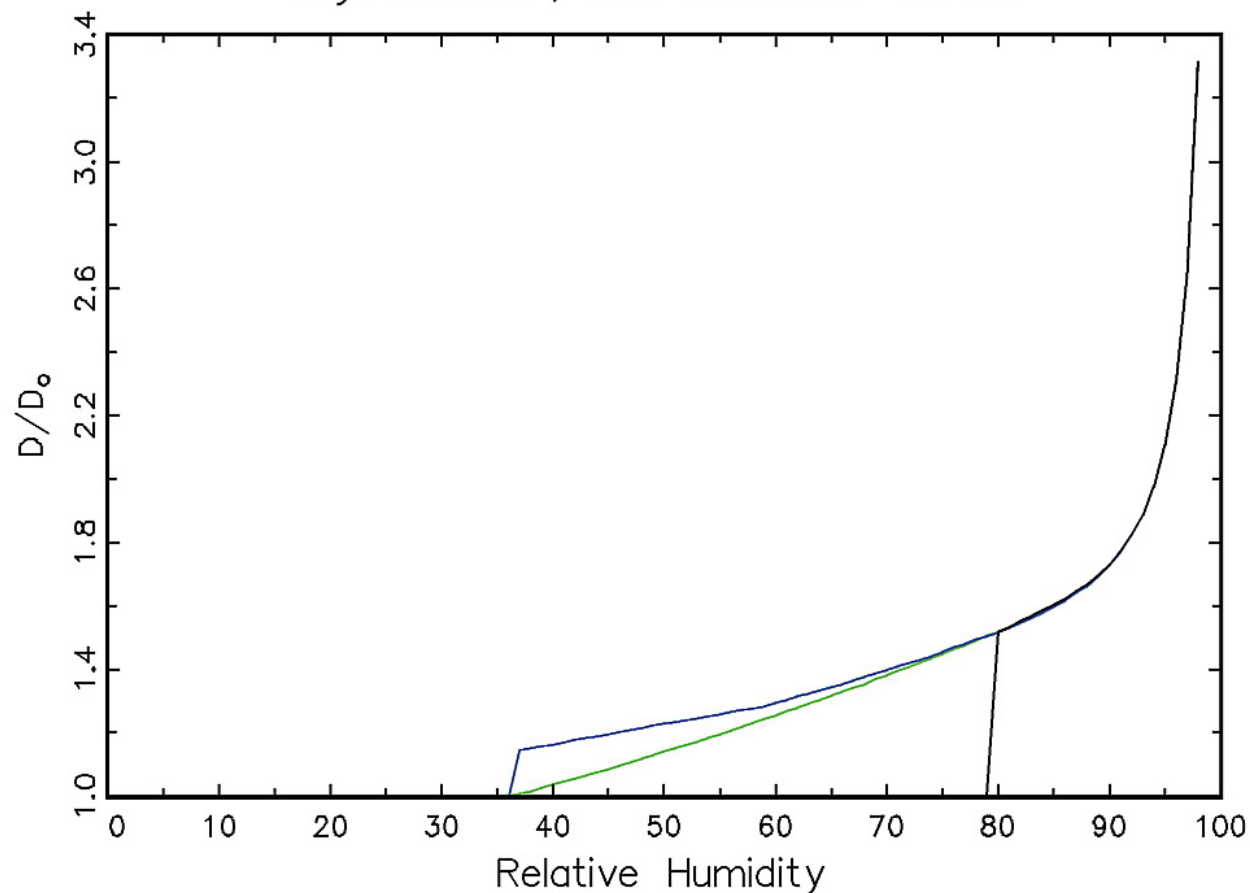
Aerossol higroscópico

- Água coletada por partículas na atmosfera
- Partículas de aerossol crescem e espalham mais luz
- *Deliquescence* – o valor da UR para o qual o cristal começa a absorver água e tornar uma gotícula de solução
- *Hysteresis* – água é retida sobre a partícula para valores de UR inferiores ao previsto pelo equilíbrio

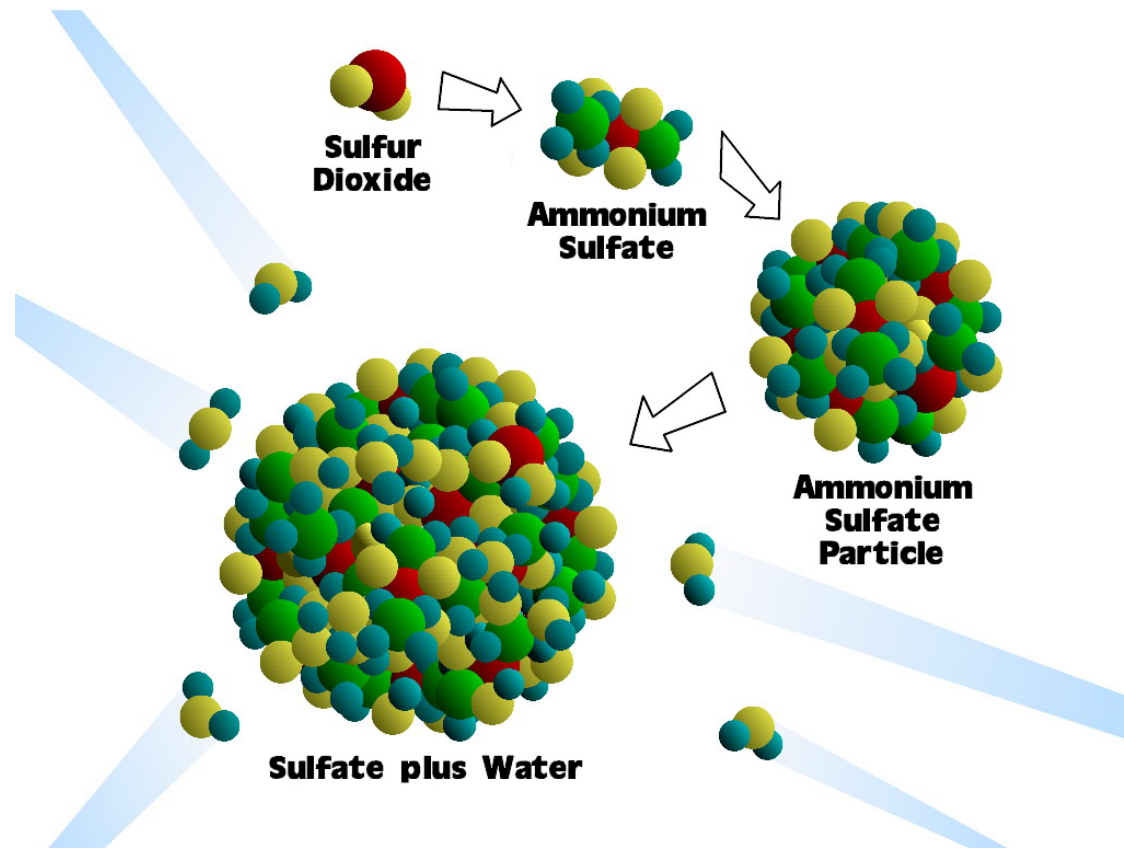


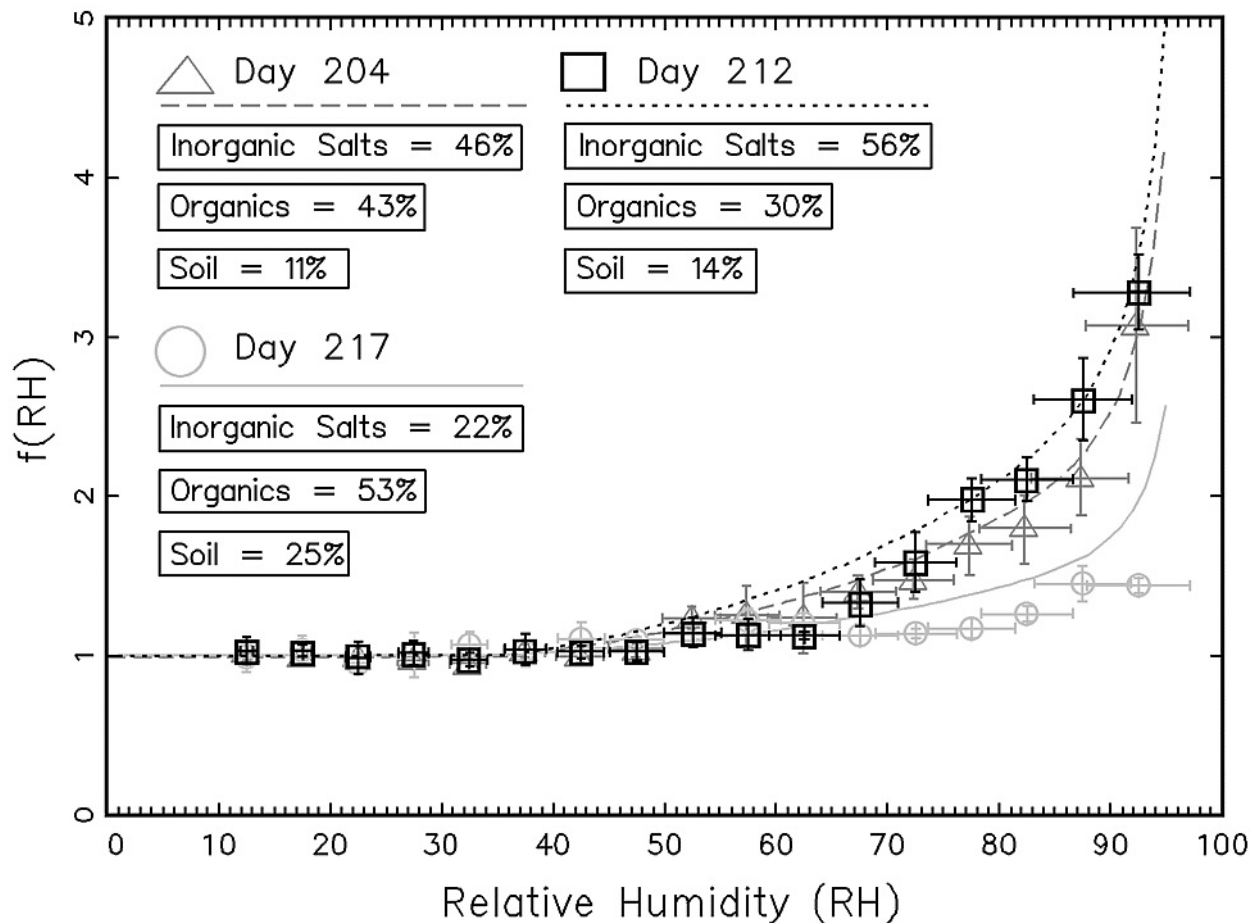
Curvas Sulfato de Amônia $(\text{NH}_4)_2\text{SO}_4$ D/D₀

Ammonium Sulfate Deliquescent,
Crystallization, and Smoothed Curves



Crescimento do sulfato





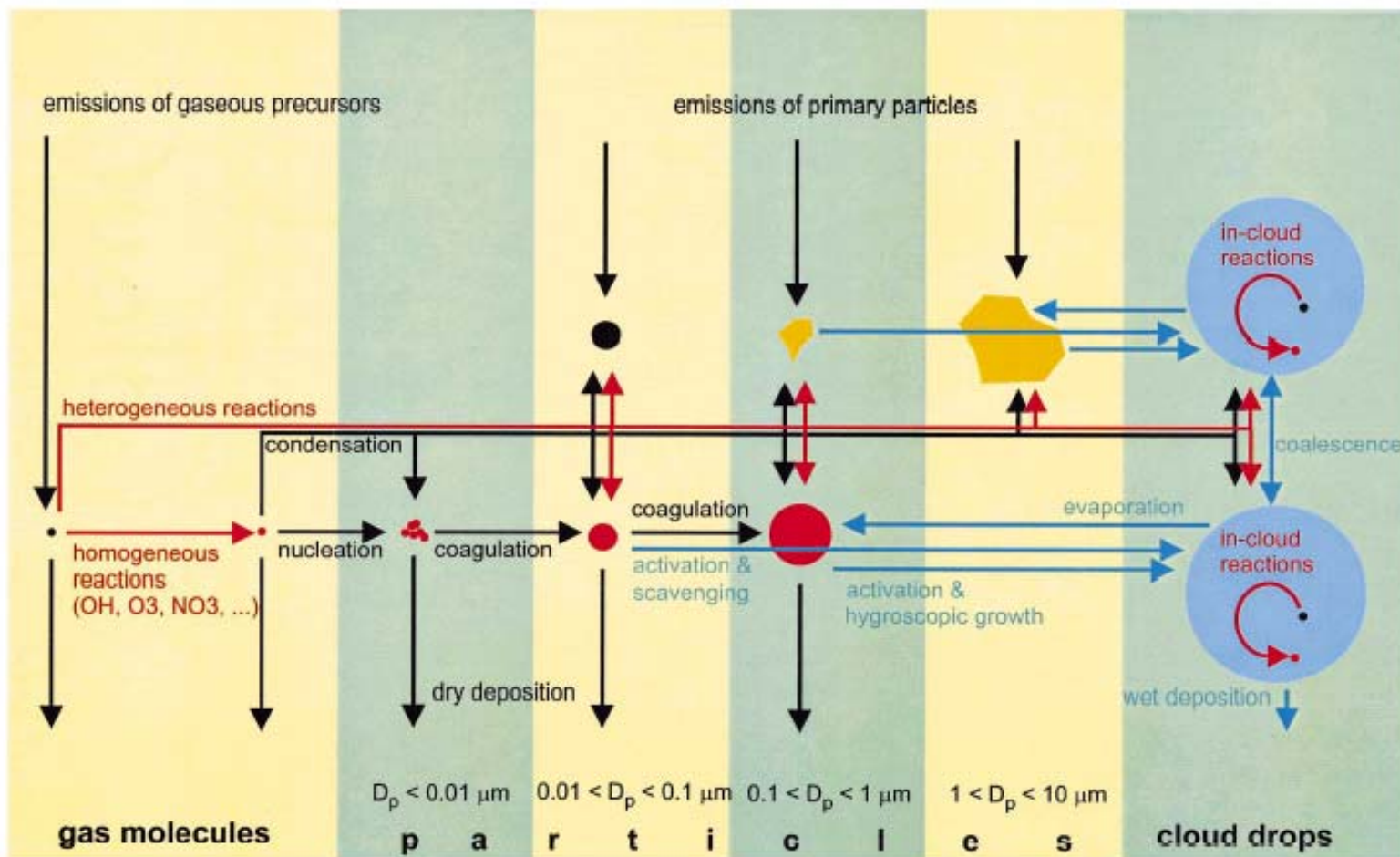


Fig. 1. Scheme of the microphysical processes that influence the size distribution and chemical composition of the atmospheric aerosol. The scheme highlights the large range of sizes that are involved in the formation and evolution of aerosol particles, and how aerosols participate in atmospheric chemical processes through homogeneous, heterogeneous and in-cloud reactions.

Características do Aerossol Atmosférico

	Partículas Finas	Partículas Grossas
Formação	Reações químicas Nucleação Condensação Coagulação Processos nuvem/fog	Quebra mecânica Suspensão de poeiras
Composição	Sulfato Nitrato Amônio Íon Hidrogênio Carbono Elementar Compostos Orgânicos Água Metais	Poeira ressuspensa Cinza de óleo e carvão Elementos do solo CaCO ₃ , NaCl Pólen, esporos, fungos Pneus
Solubilidade	Higroscópico, solúvel	Insolúvel e não higroscópico
Fontes	Combustão Conversão gás-partícula	Ressuspensão de poeira industrial e solo Construção/demolição Aerossol marinho
Tempo de vida	Dias a semanas	minutos
Alcance	100s 1000s de km	< 10s de km

Estimated global emission rates of particles into the atmosphere (Tg yr^{-1})

	Source strength (Tg yr^{-1})	Reference
<i>Sea salt</i>		
Total	5900	Tegen et al. (1997)
0–2 μm	82.1 } 2460 }	Gong et al. (1997)
2–20 μm		
<i>Soil dust</i>		
< 1 μm	250 } 1000 }	Tegen and Fung (1995)
1–10 μm		
0.2–2 μm	250 } 4875 }	Penner, personal comm.
2–20 μm		
<i>Organic carbon</i>		
Total	69	Lioussé et al. (1996)
Biomass burning	54.3 } 28.8 }	Penner, personal comm.
Fossil fuel		
Terpene oxidation	18.5	Griffin et al. (1999)
<i>Black carbon</i>		
Total	12 } 5.6 }	Lioussé et al. (1996)
Biomass burning		
Fossil fuel	6.6	
<i>Sulfate (as H_2SO_4)</i>		
Total	150	Chin and Jacob (1996)
Natural	32 } 111 }	Koch et al. (1999)
Anthropogenic		
<i>Nitrate</i>	11.3 ^a	Adams et al. (1999)
<i>Ammonium</i>	33.6	Adams et al. (1999)

^aNitrate source strength is based on a computed burden of 0.13 Tg and an assumed lifetime of 4.2 d (same as ammonium).

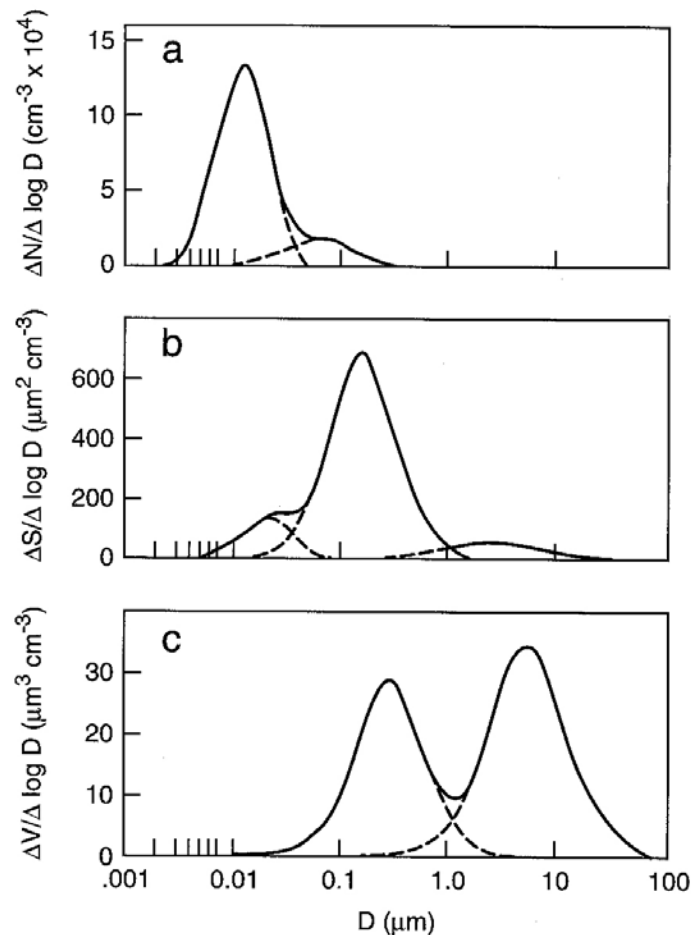
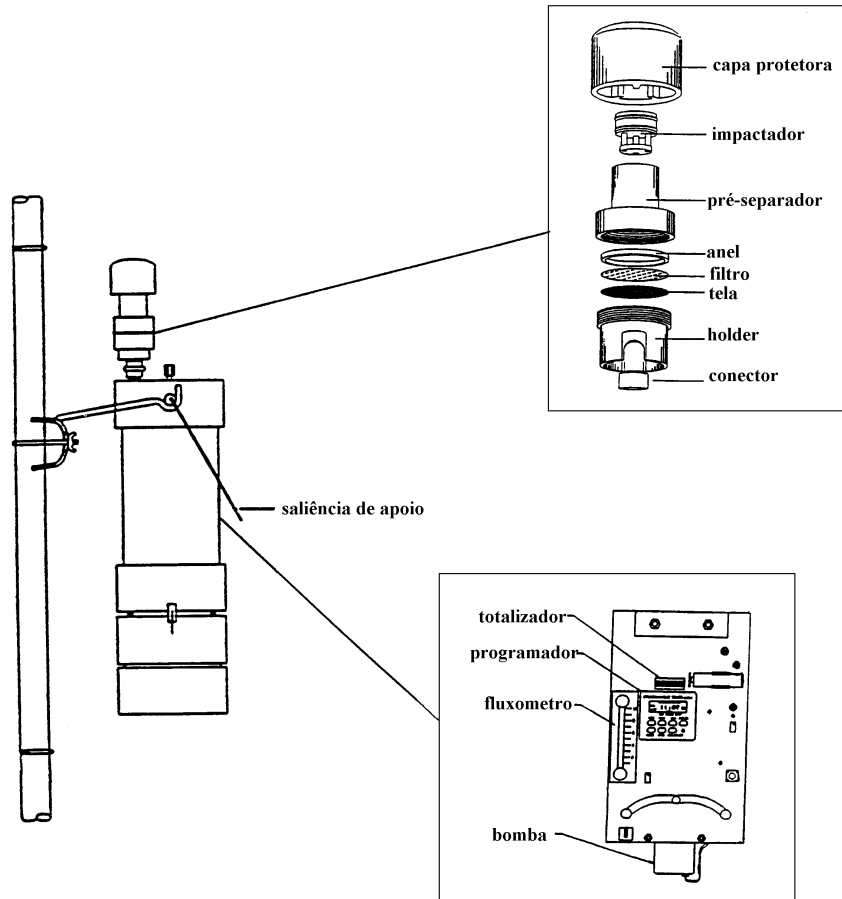


FIGURE 9.6 Number, surface, and volume distributions for a typical urban model aerosol (adapted from Whitby and Sverdrup, 1980).



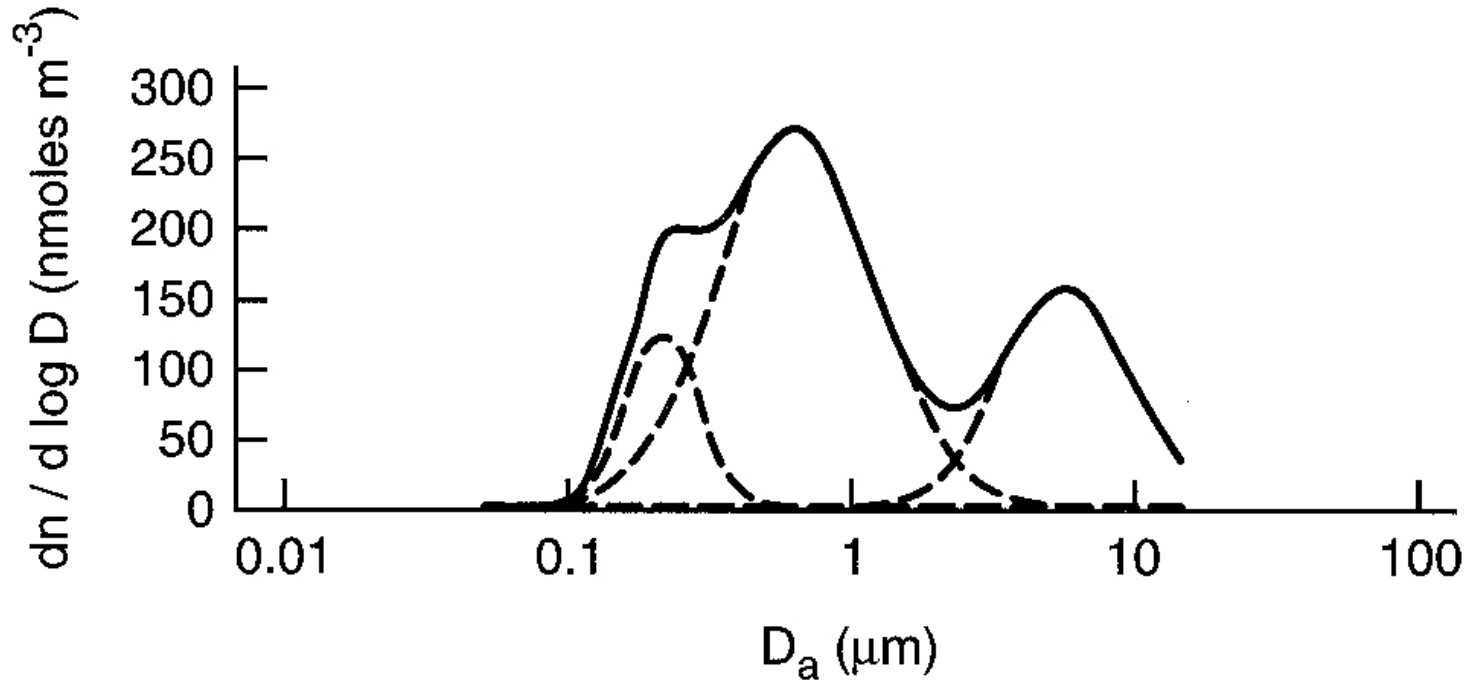
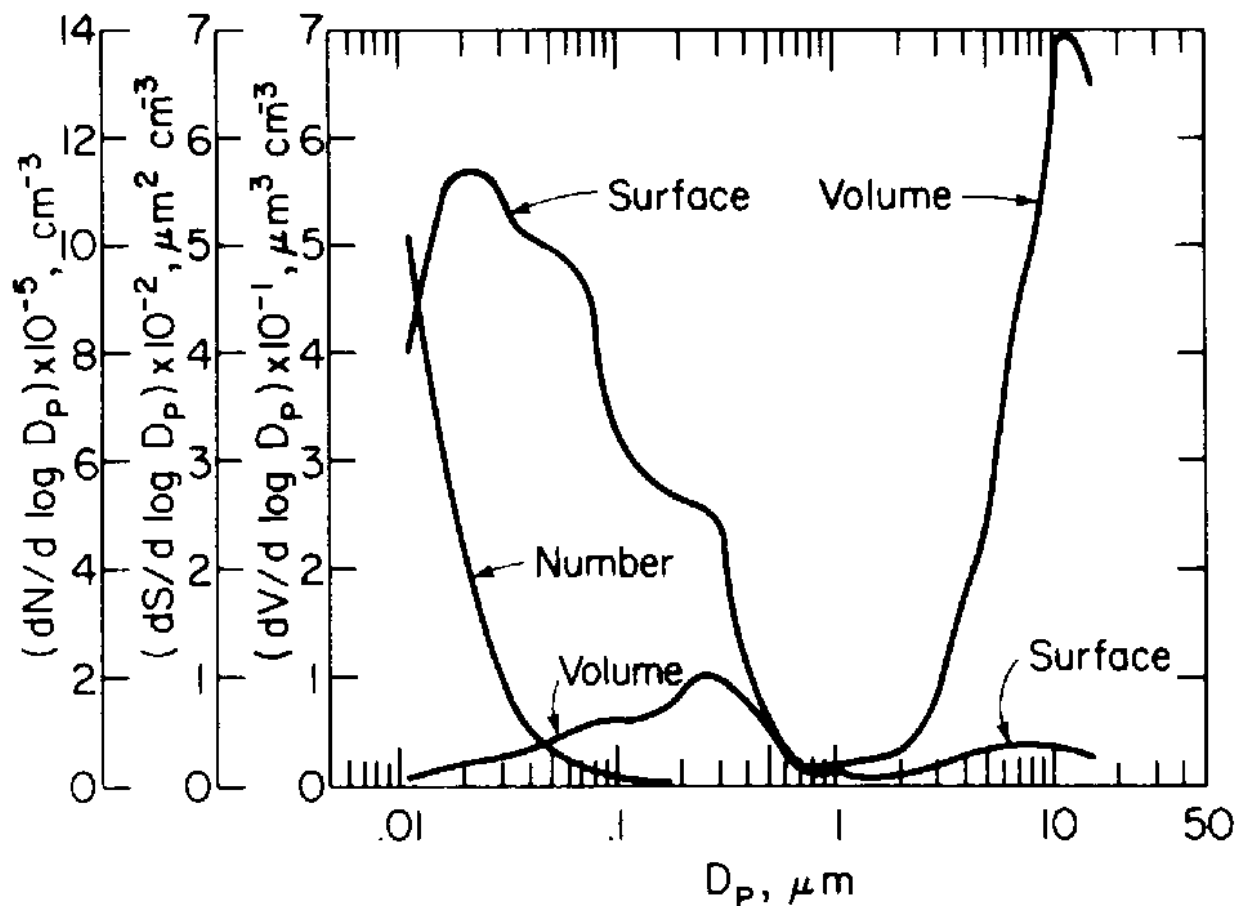


FIGURE 9.8 Typical size distribution of nitrate in southern California in 1987 fitted by the sum of three log-normal distributions with peaks at 0.2, 0.7, and 4.4 μm (adapted from John *et al.*, 1990).

Properties of Aerosols



Distribuições de número, superfície e volume de partículas pelo diâmetro (Willeke and Whitby, 1975).

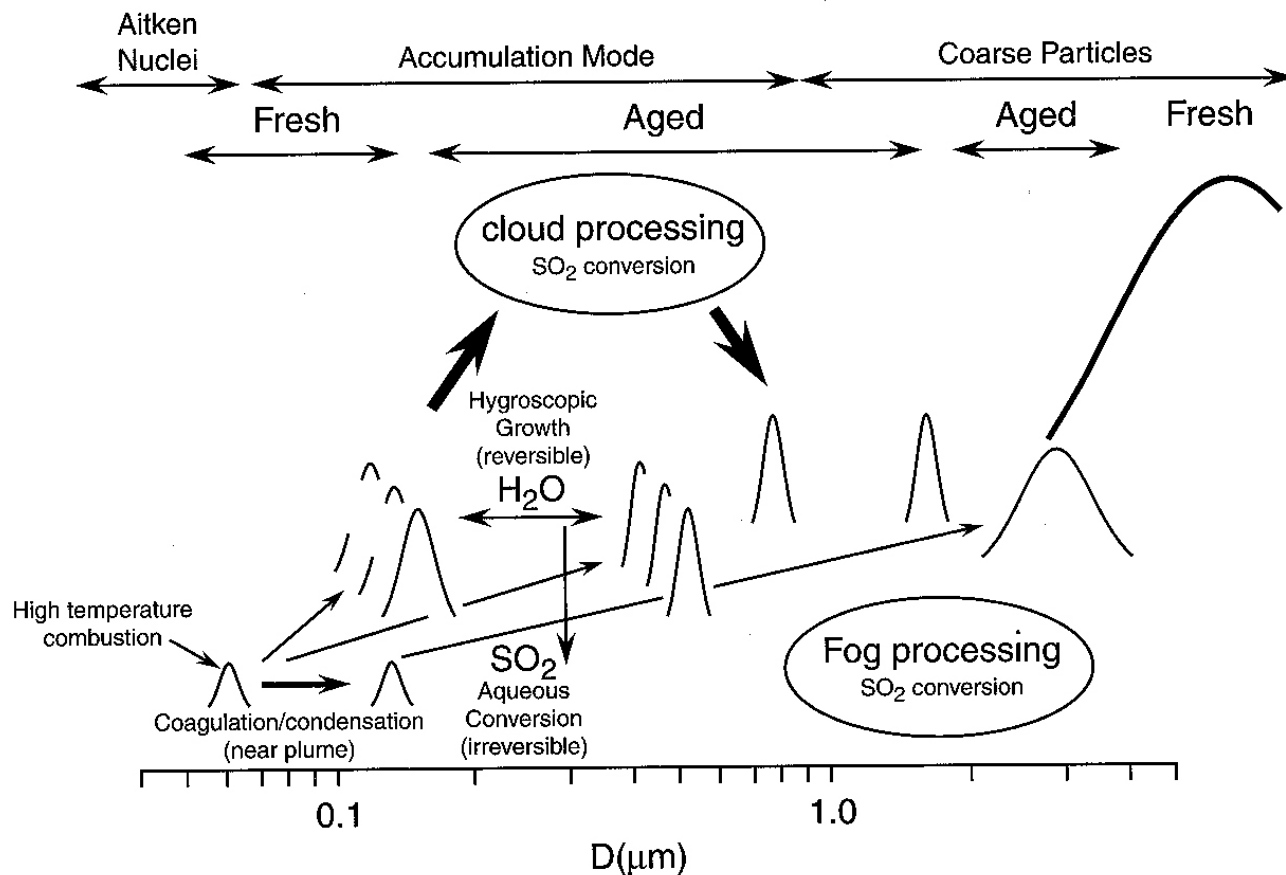


FIGURE 9.10 Modified particle modes and growth processes for sulfate particles involving aqueous-phase reactions in low altitude fogs and in higher altitude clouds upon advection of boundary-layer air upwards. (Adapted with permission from Ondov and Wexler, 1998. Copyright 1998 American Chemical Society.)

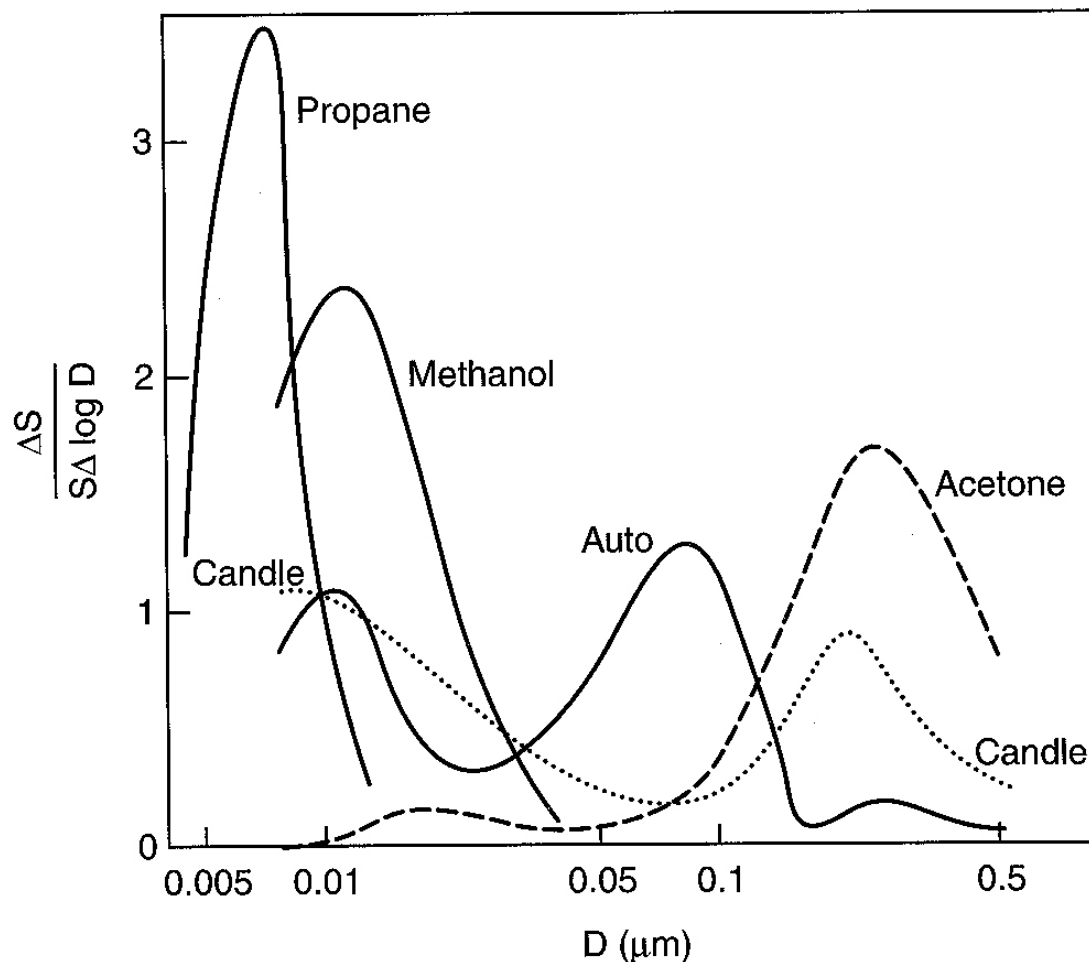
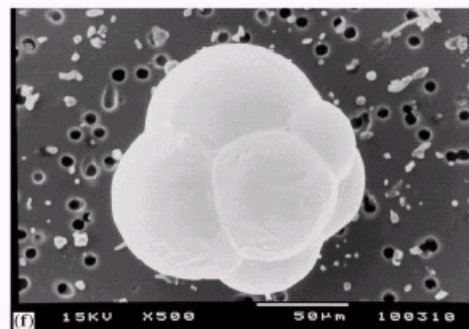
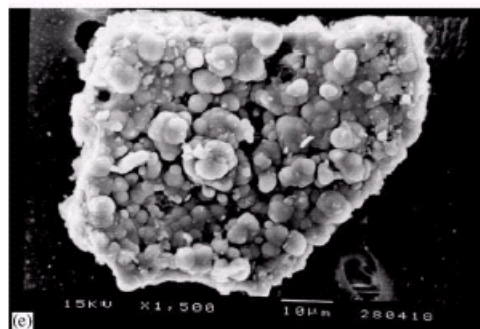
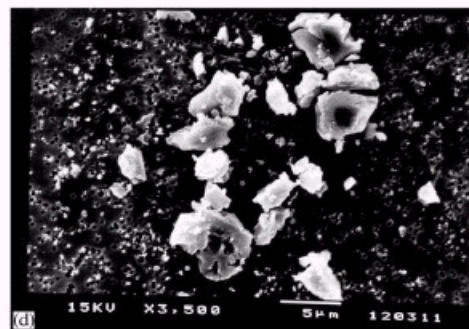
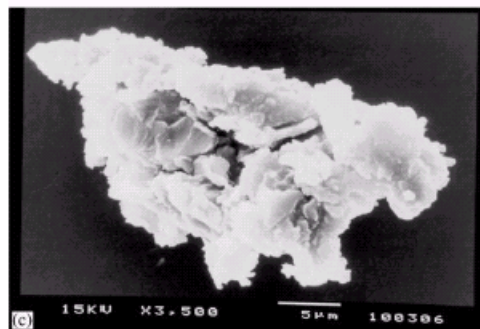
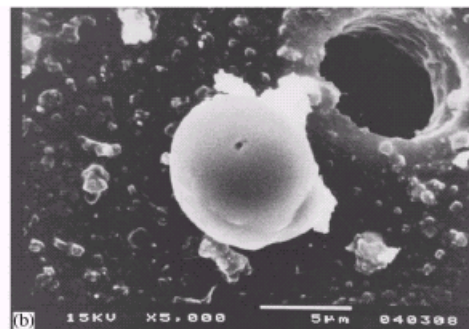
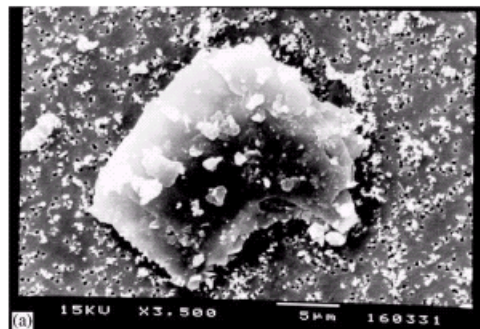
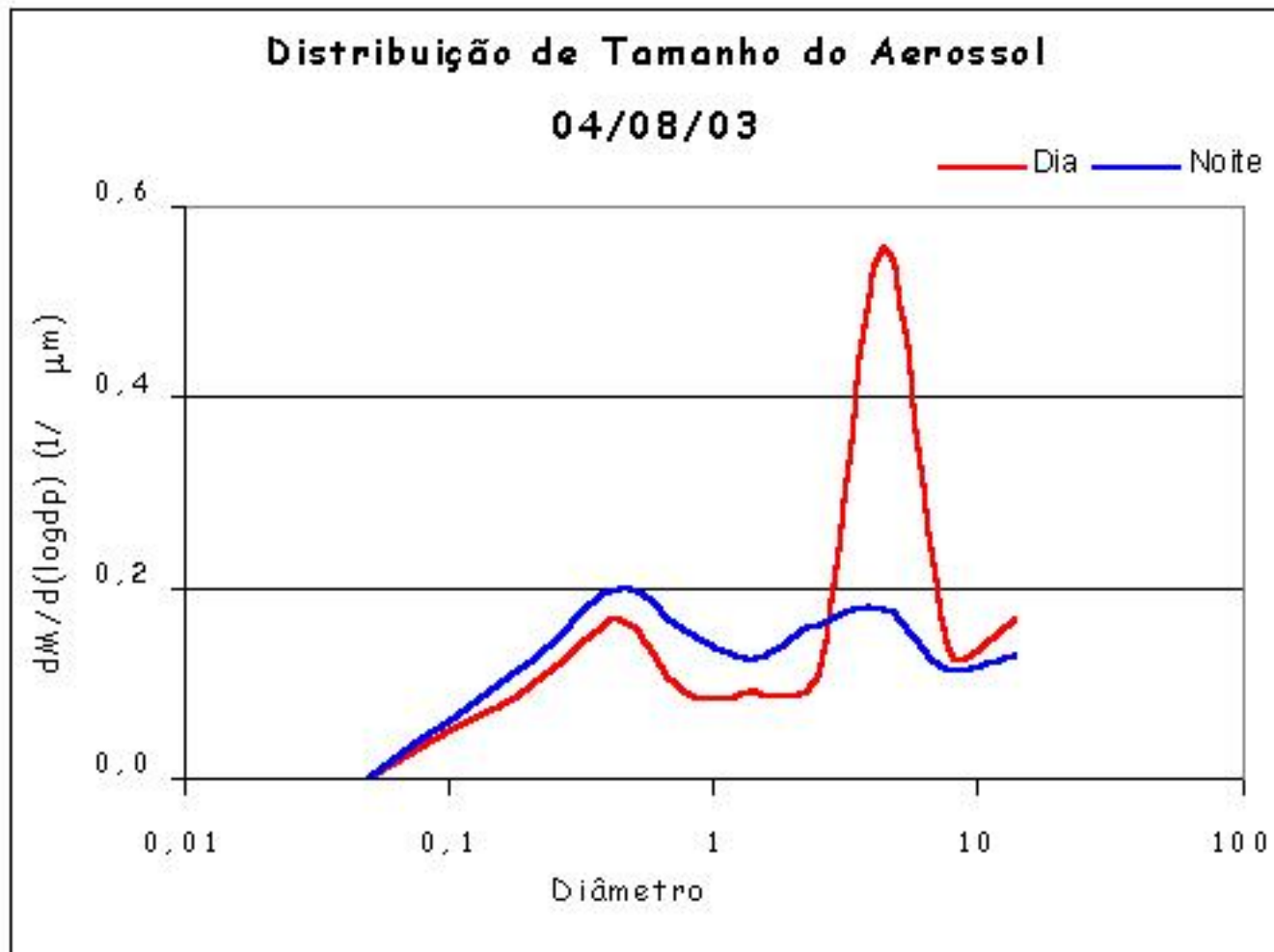


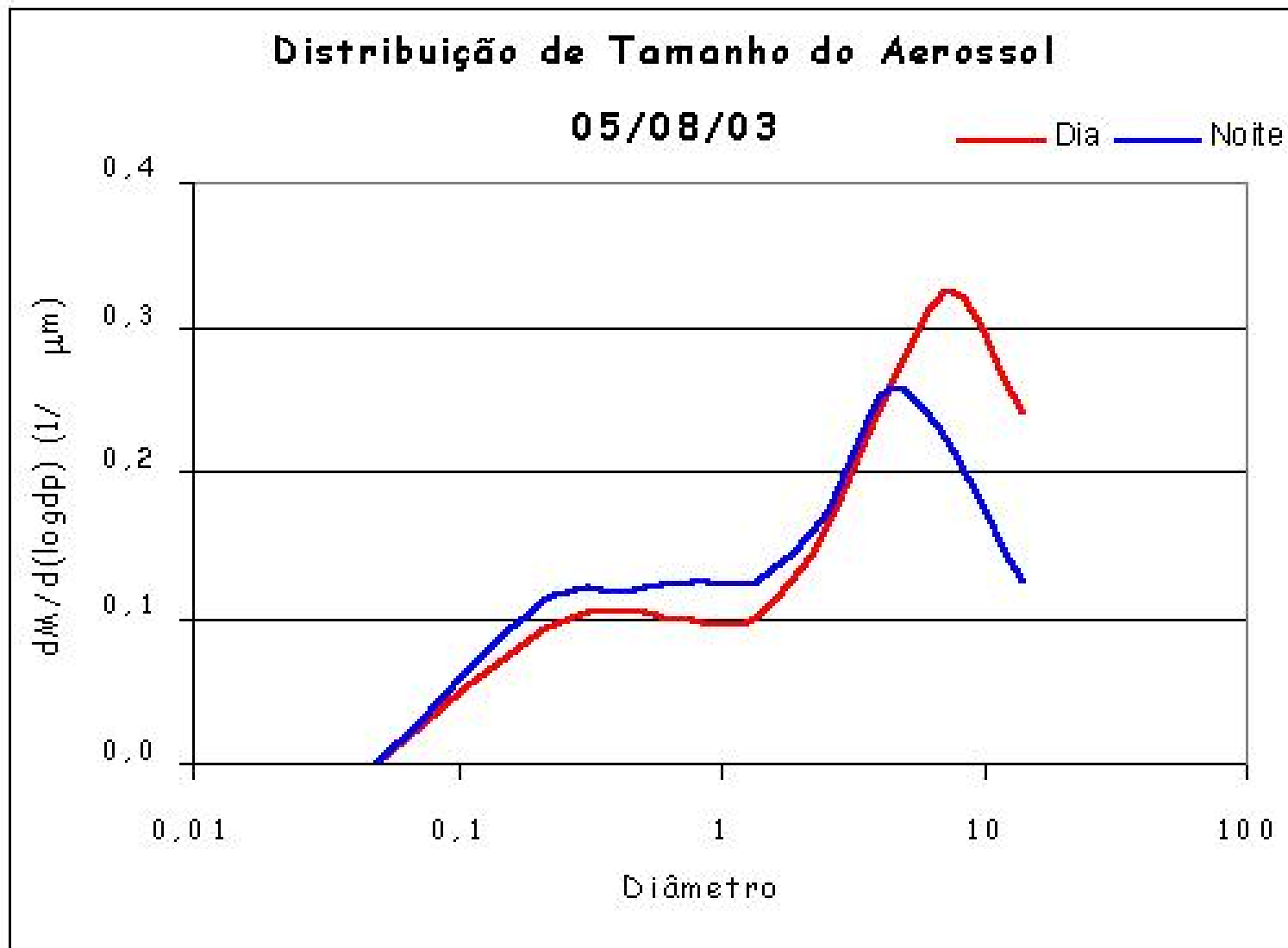
FIGURE 9.11 Surface distribution of particles from the combustion of several organics and from automobiles and a candle (adapted from National Research Council, 1979).

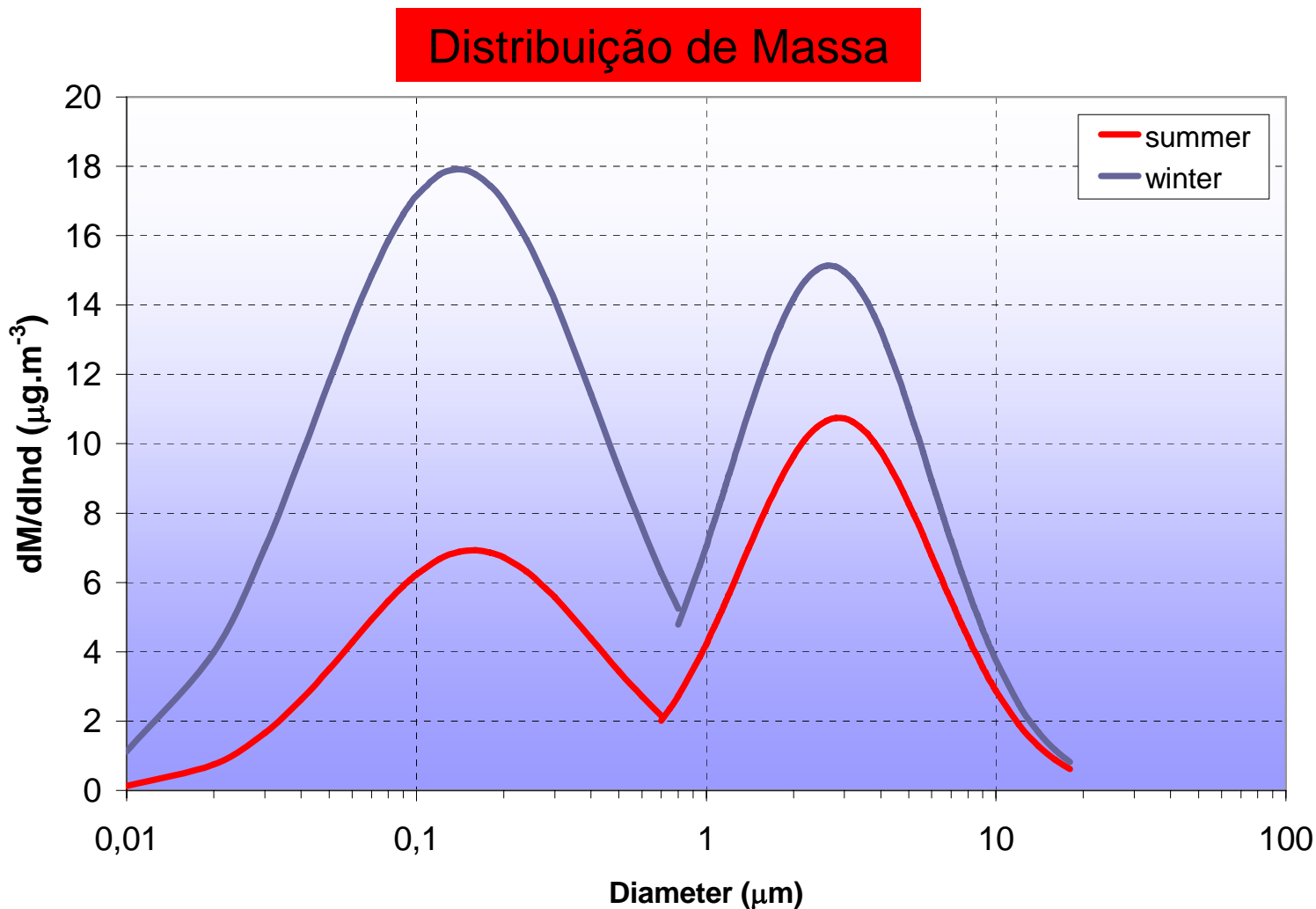
Exemplos micrográficos de Partículas de Aerossol

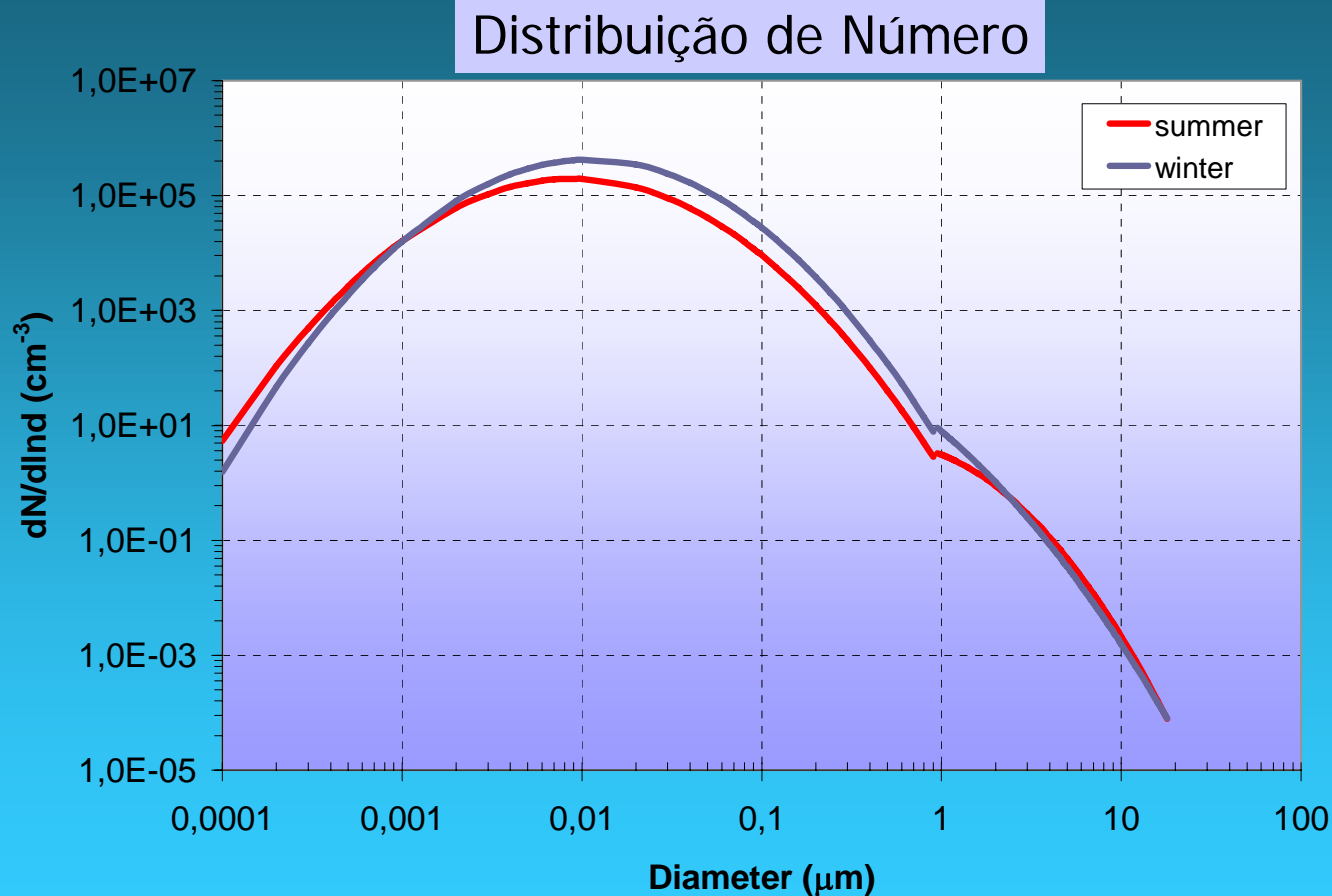


Distribuição do Tamanho de Massa









Tese de Regina M. Miranda, 2001

Table 1 – Summary of physical and chemical properties of dry and wet season aerosols in Rondônia. The averages were calculated with the highest time resolution provided by the measurements. Typically the averages were calculated for 5 to 30 minutes integration time.

Specie or property	Unit	Dry season average	Dry Season Std. Dev.	Dry season peak	Wet season average	Wet Season Std. Dev.
PM ₁₀ TEOM	µg m ⁻³	55.2	52.2	250	10.1	5.5
PM ₁₀ SFU	µg m ⁻³	83.0	63.7	300	8.6	3.9
Fine mass (FPM)	µg m ⁻³	66.9	55.1	250	2.9	1.71
Coarse mass (CPM)	µg m ⁻³	17.8	11.7	50	5.7	3.1
Particle number (CPC)	#/cc	8045	5668	40000	890	920
Organic carbon (OC)	µg m ⁻³	10.1	9.4	55	2.04	0.89
Elemental carbon (EC)	µg m ⁻³	3.8	4.2	25	0.47	0.37
Total carbon (TC)	µg m ⁻³	13.9	13.2	80	2.31	0.95
Black carbon (BCE)	µg m ⁻³	3.60	2.99	18.0	0.19	0.22
Sulfur fine mode	ng m ⁻³	1104	870	2500	83.9	78.8
Potassium fine mode	ng m ⁻³	1109	865	3000	33.5	28.5
NO ₂	ppb	2.73	1.59	16.0	0.67	0.61
CO	ppm	0.89	0.74	8.0	0.15	0.18
AOT 500 nm ⁽¹⁾	-	0.91	0.56	3.3	0.13	0.11
Angstrom Exponent		1.70	0.49	2.5	0.72	0.53

⁽¹⁾ AOT is the aerosol optical thickness at 500 nm measured with the AERONET sun-photometer network. The Angstrom Exponent is derived from the sun photometer aerosol optical thickness and is an indication of the aerosol size distribution.

Journal of Geophysical Research –
Atmospheres - LBA Special Issue

Table 1

Descriptive statistics of the fine and coarse mode particulate matter during the wintertime sampling period, from 10 July to 10 September in 1997 in the São Paulo metropolitan area

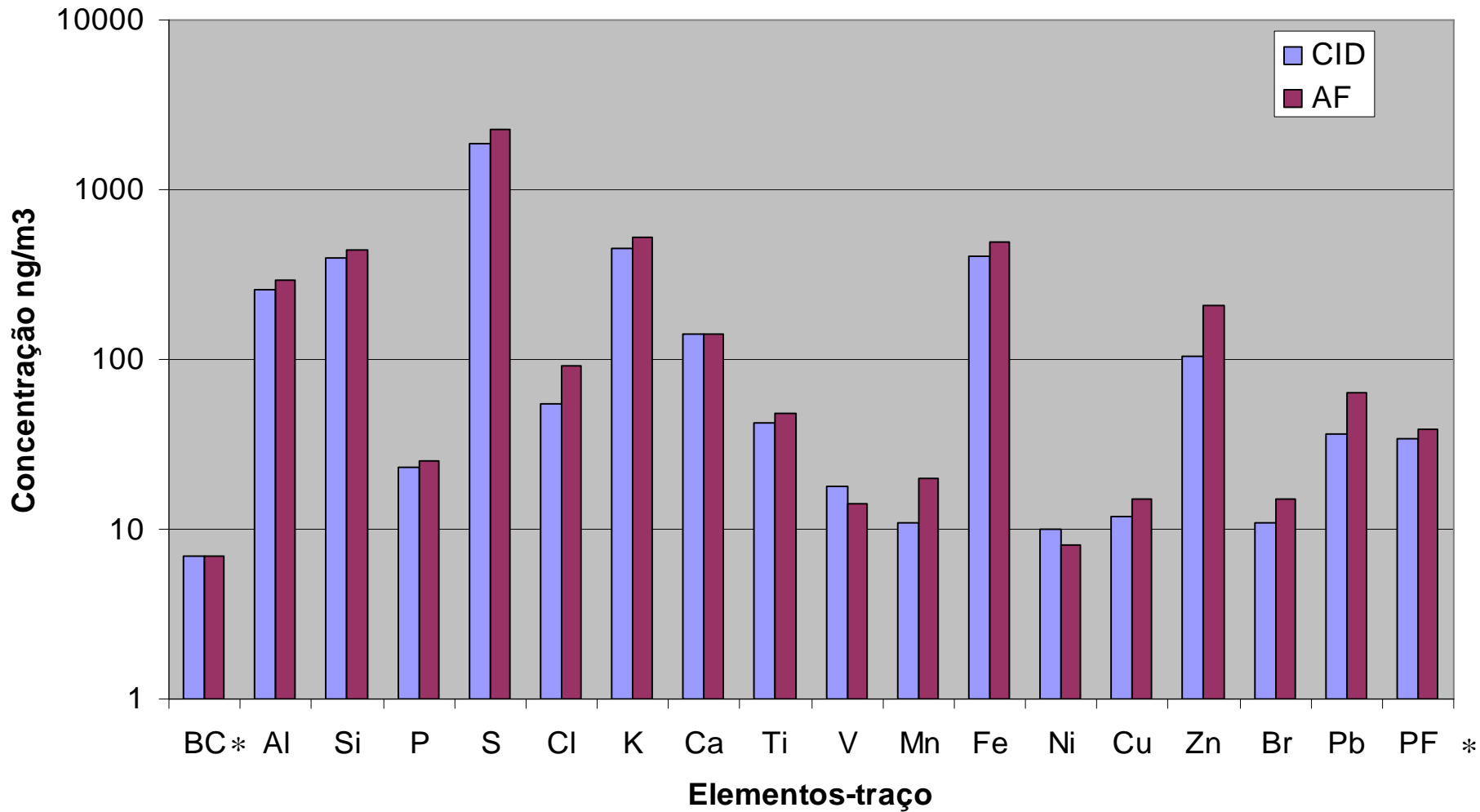
PM _{2.5} aerosol ($d_p < 2.5 \mu\text{m}$)				Coarse mode aerosol ($2.5 < d_p < 10 \mu\text{m}$)			
Specie	Mean (ng m^{-3})	σ^a (ng m^{-3})	Number of samples	Specie	Mean (ng m^{-3})	σ (ng m^{-3})	Number of samples
PM _{2.5} ^b	30.2 ^b	16.1 ^b	181	CPM ^b	46.1 ^b	38.1 ^b	177
Black carbon ^b	7.6 ^b	3.7 ^b	181	—	—	—	—
Organic carbon ^b	15.8 ^b	8.3 ^b	57	—	—	—	—
Al	437	282	179	Al	1521	1212	177
Si	511	288	179	Si	2269	1726	177
P	14.3	4.9	25	P	25	14	114
S	1510	1166	179	S	733	580	177
Cl	52	35	78	Cl	250	279	177
K	407	252	179	K	486	433	177
Ca	146	93	179	Ca	1196	864	177
Ti	31	24	179	Ti	217	165	177
V	11.7	6.5	179	V	12	12	177
Cr	9.6	3.7	9	Cr	24	15	51
Mn	12.6	8.1	179	Mn	32	23	177
Fe	532	273	179	Fe	1981	1426	177
Ni	3.9	2.8	179	Ni	5.8	6.2	177
Cu	19	11	179	Cu	44	44	177
Zn	126	107	179	Zn	189	234	177
Se	3.0	2.6	123	Se	3.0	3.4	86
Br	14.3	6.2	65	Br	24	14	27
Rb	4.6	2.5	84	Rb	7.6	4.9	106
Sr	2.4	1.0	72	Sr	8.5	6.2	177
Zr	4.1	2.1	28	Zr	12	15	101
Pb	42	34	179	Pb	38	45	177

^a σ is the standard deviation of the concentration distribution.

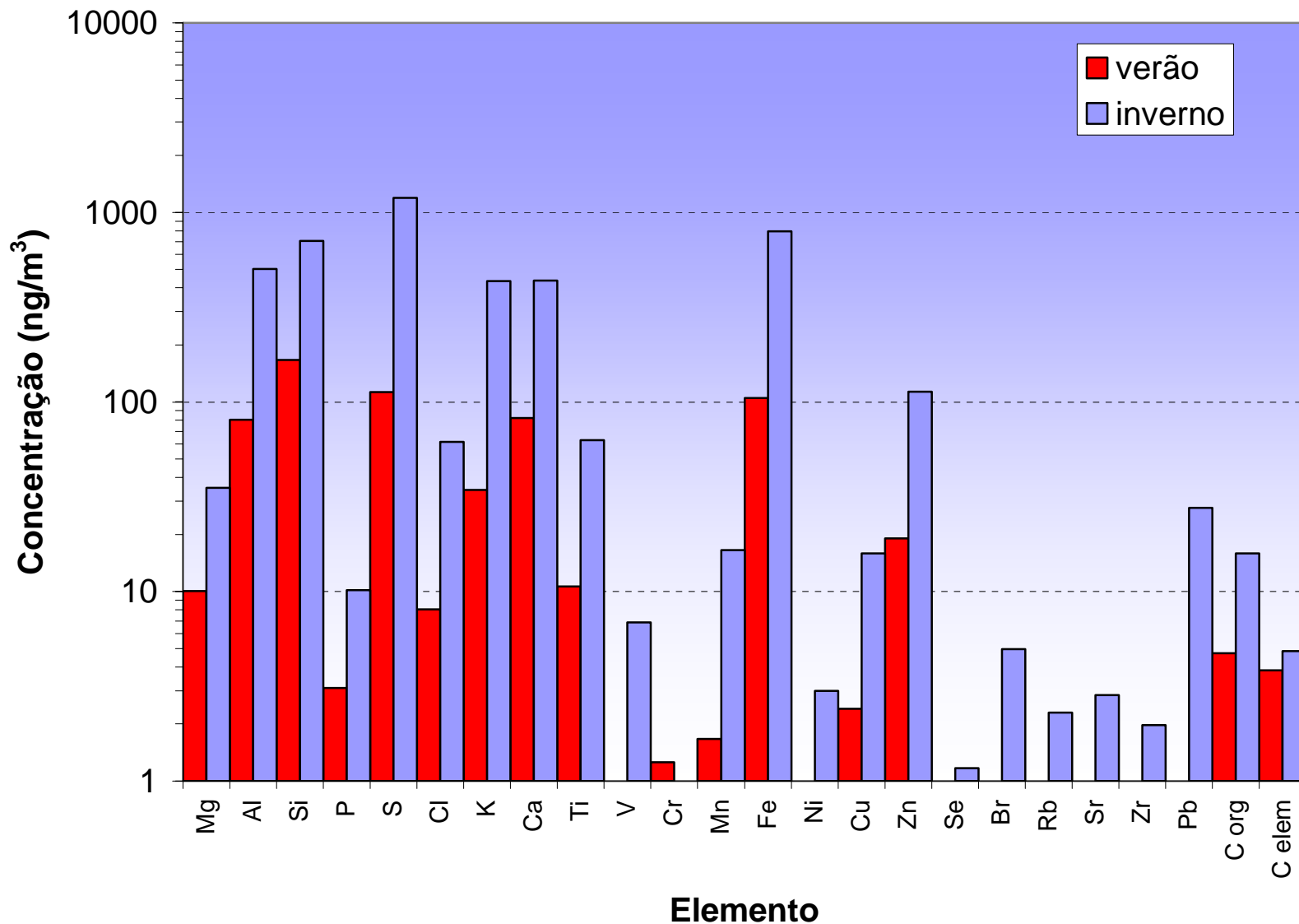
^b Concentrations in ($\mu\text{g m}^{-3}$).

A.D.A. Castanho, P. Artaxo / *Atmospheric Environment* 35 (2001) 4889–4902

Elementos-traços Particulado Fino Agosto de 1999



BC e PF em $\mu\text{g}/\text{m}^3$



Efeitos do Aerossol

Direto: por suas propriedades óticas o aerossol retroespalha a radiação solar incidente (efeito de esfriamento). - Aerossol com um alto conteúdo de carbono preto absorve a radiação solar incidente aquecendo a atmosfera (efeito de aquecimento)

Indireto: por sua habilidade de atuar como CCN – para a formação de gotículas de nuvem.

indireto – tipo I, aumentando o albedo das nuvens (efeito de esfriamento)

Indireto - tipo II, suprimindo a formação da precipitação (efeito de esfriamento + mudança no ciclo hidrológico)

Variação da Energia Livre de Helmholtz na nucleação heterogênea

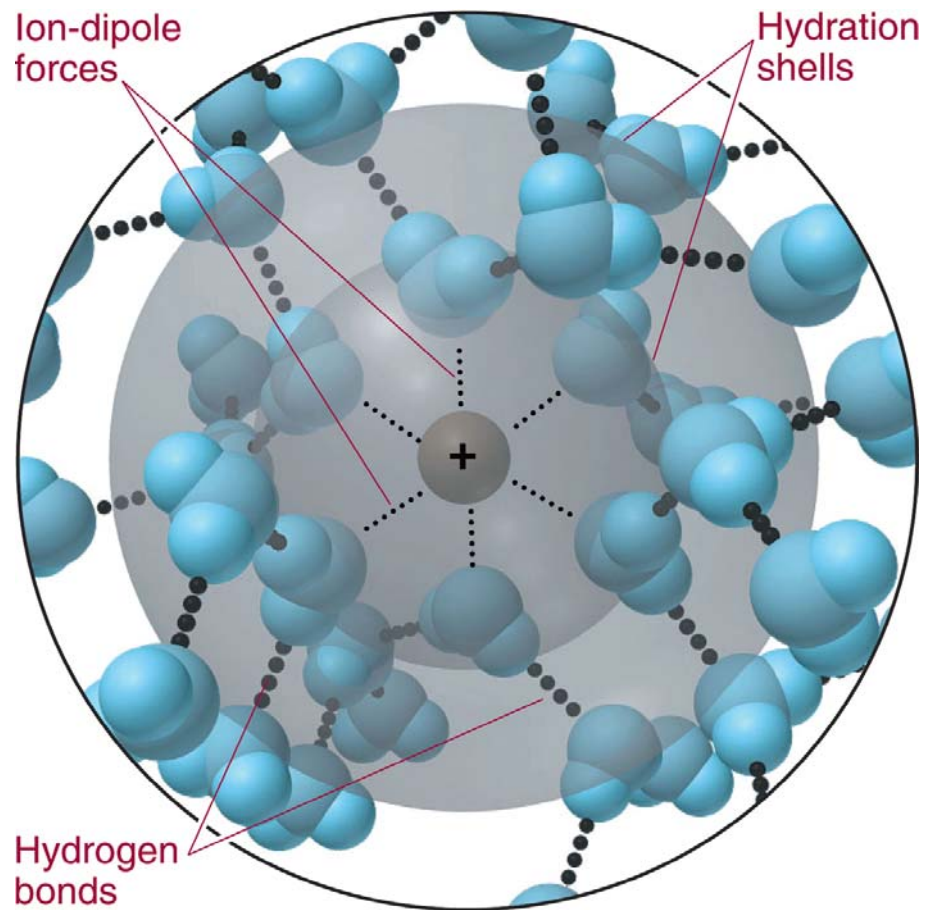
Nucleação Heterogênea – sobre CCN insolúvel parcialmente molhável

-
-
-

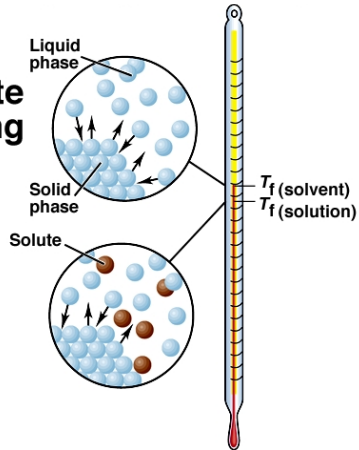
...Notas de aula...

O equilíbrio entre gotas de solução aquosa e o ar úmido

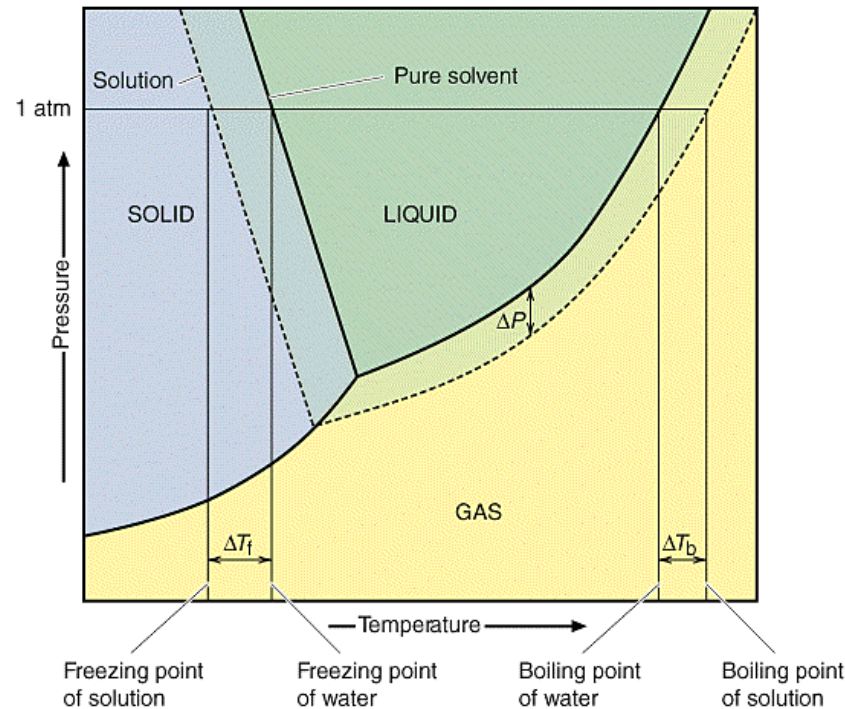
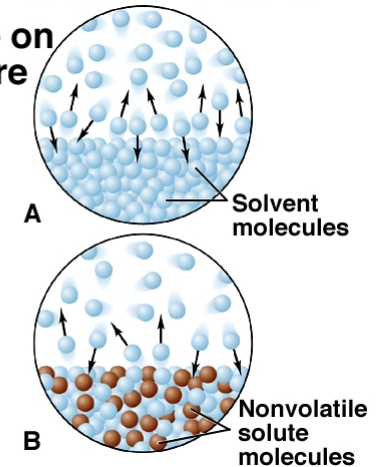
Camadas de “hidração” ao redor de um íon aquoso



Effect of Solute on the Freezing Point of a Solution



Effect of Solute on Vapor Pressure of Solution



O solvente em solução é mais desordenado que o solvente puro.

Isto significa que a solução possui menor tendência a vaporizar de modo que o equilíbrio é alcançado à menor pressão de vapor.

Equação de Köhler modificada

$$s \cong 1 + \frac{2\sigma_s M_w}{RT\rho_w r} - \frac{3M_w \Phi_s}{4\pi\rho_s (r^3 - r_N^3)} \left[\sum_{i \text{ inorg}} \frac{\nu_i m_i}{M_i} + \sum_{j \text{ org}} \frac{\nu_j m_j}{M_j} \right]$$

Termo de Kelvin

Termo de Raoult

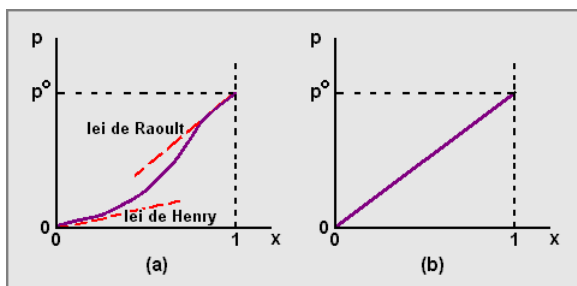


Figura 31: $p = f(x)$. a) Solução real. b) Solução ideal.

LEI DE HENRY : a solubilidade de um gás em um líquido é proporcional a pressão do gás sobre a solução.

LEI DE RAOULT : a pressão de vapor é proporcional à sua fração molar em solução – ou a pressão parcial do solvente sobre uma solução é dada pelo produto da pressão de vapor do solvente puro pela fração molar do solvente na solução.

- Solução ideal: É aquela que obedece a lei de Raoult para qualquer concentração
- A maior parte das soluções desviam do comportamento ideal
- Na prática, A lei de Raoult é uma boa aproximação para o comportamento das soluções diluídas.

A combinação das equações de Kelvin e de Raoult avaliada para $e_s^*(r)/e_s(\infty)$ resulta na equação de Köhler:

$$e_s^*(r)/e_s(\infty) = (1 - b/r^3) * \exp(a/r) \sim 1 + a/r - b/r^3$$

1. termo: as moléculas superficiais possuem energia extra
2. term: as moléculas do soluto deslocam as moléculas de água da superfície

$$a = 2 \sigma / \rho_w R_v T$$

$$b = (3 v m_s M_w)/(4 \pi M_s \rho_w)$$

m_s = massa do soluto, M_s , M_w = Peso molecular do soluto e da água

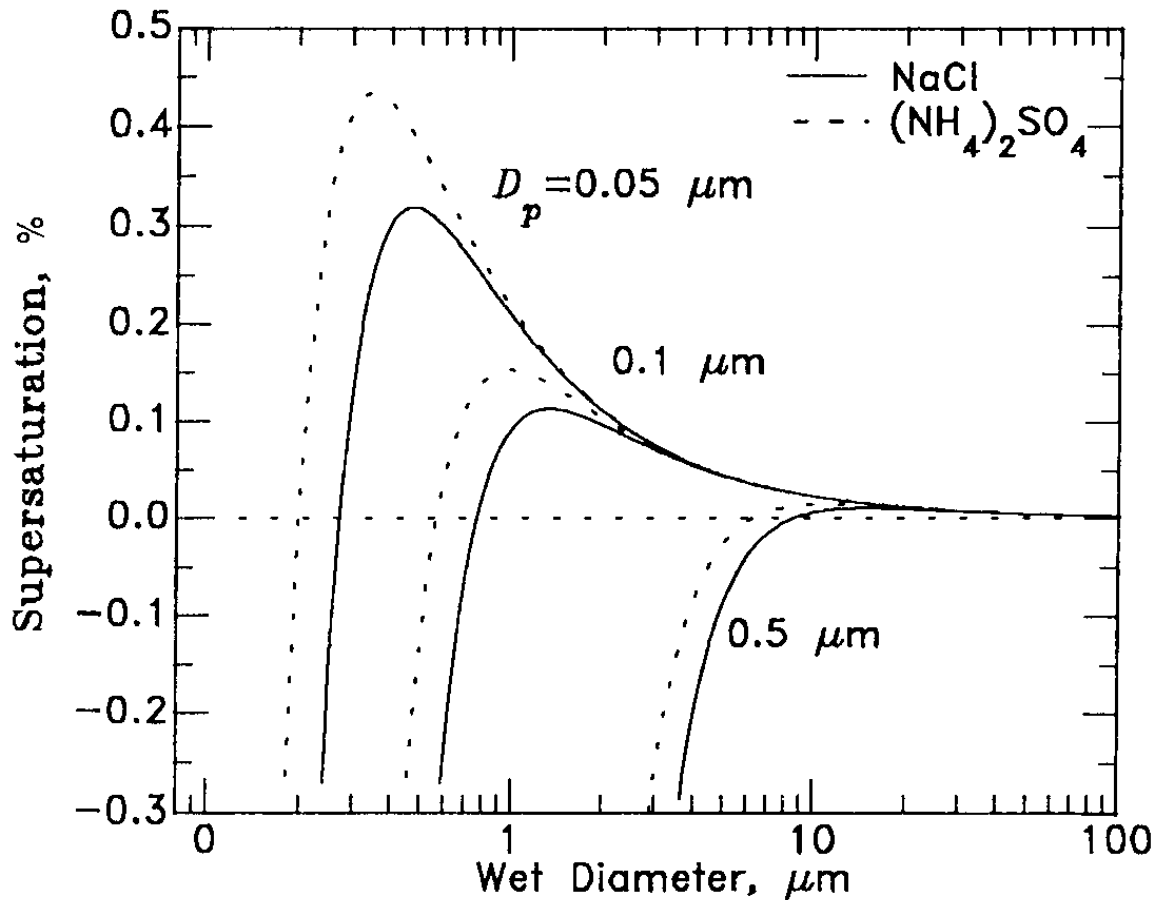
O raio crítico r_c e a supersaturação crítica S_c são dadas por:

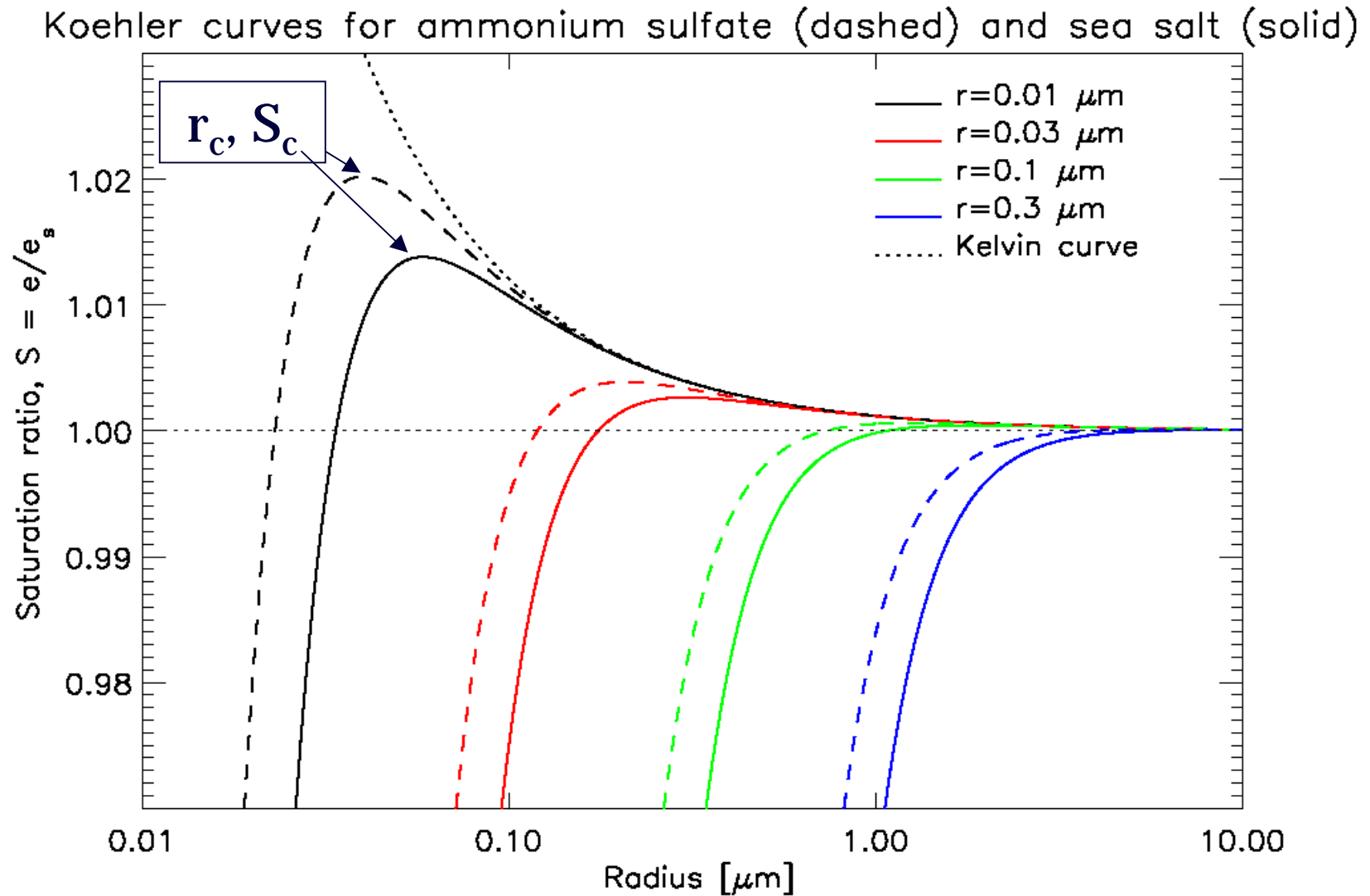
$$r_c = (3b/a)^{1/2} ,$$

$$S_c = (4 a^3/[27 b])^{1/2}$$

Ex. 3.1 Estude a Equação de Köhler

Curvas de Köhler



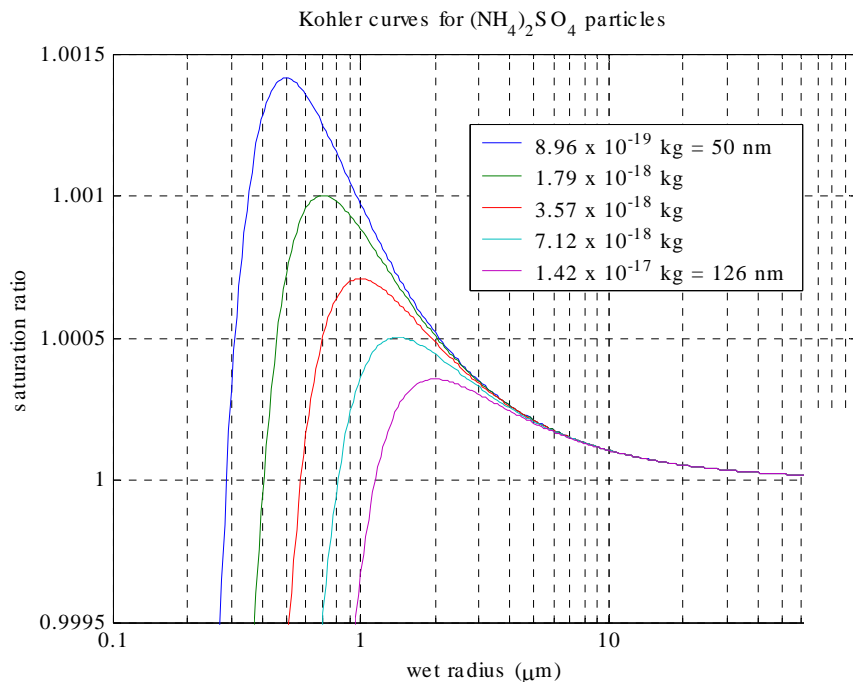


Aerossol-modelo

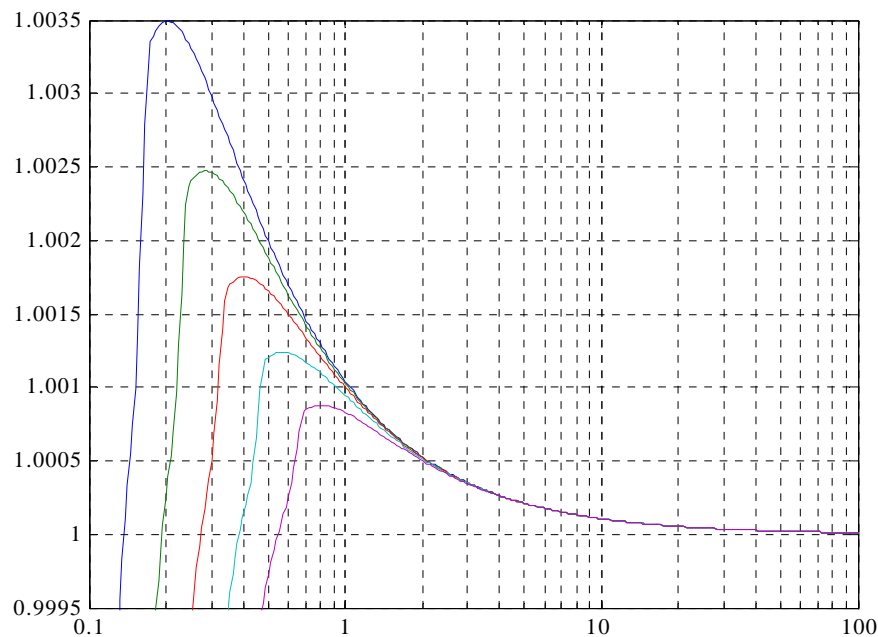
70% da massa solúvel :

- **15% NH_4HSO_4**
- **15% $(\text{NH}_4)_2\text{SO}_4$**
- **20% NH_4NO_3**
- **20% WSOC:**
 - **14% ácidos dicarboxylicos: MW 100 n=3**
 - **6% ácidos polycarboxylicos: MW 500 n= 9**

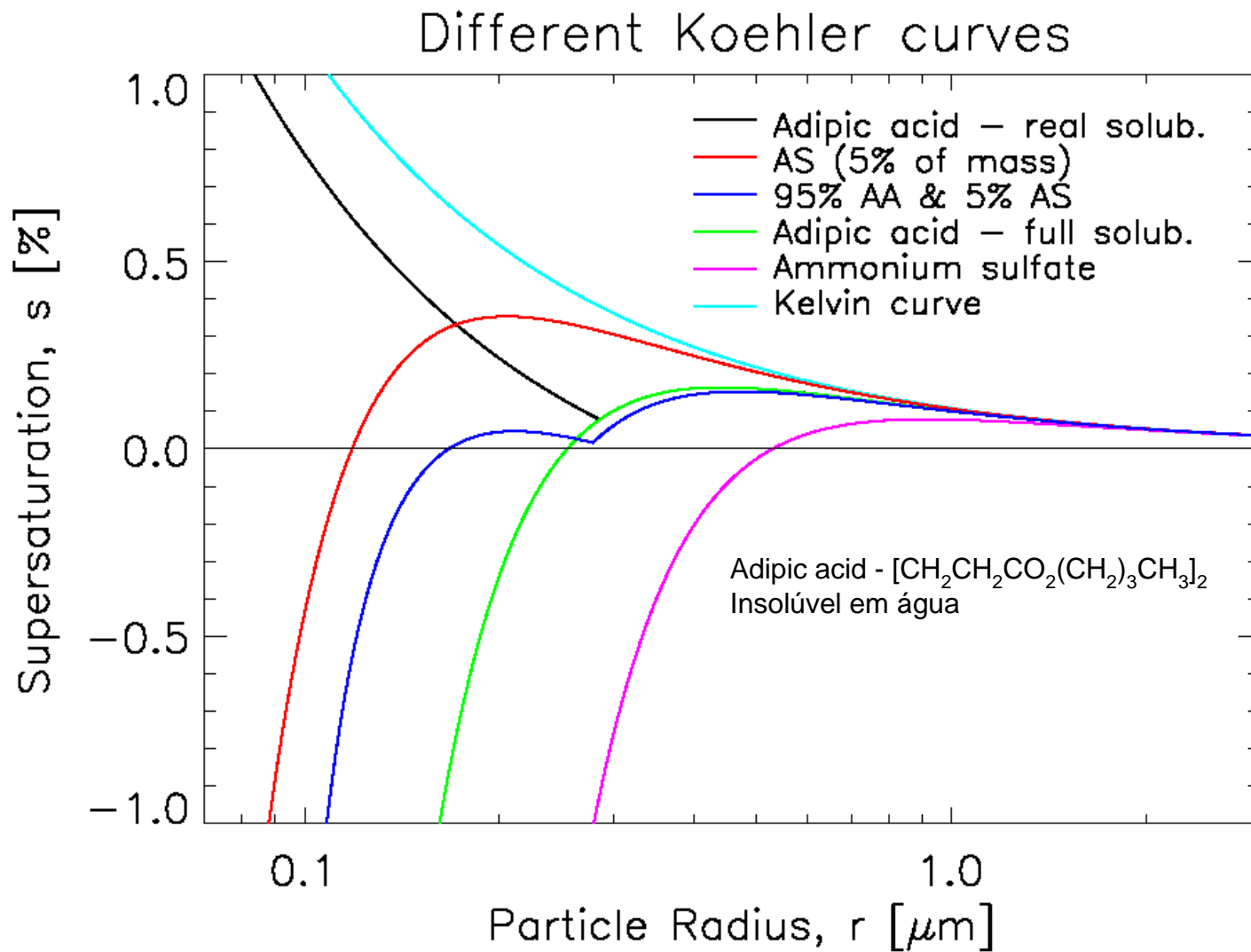
30% insolúvel, $d = 2.5 \text{ g cm}^{-3}$

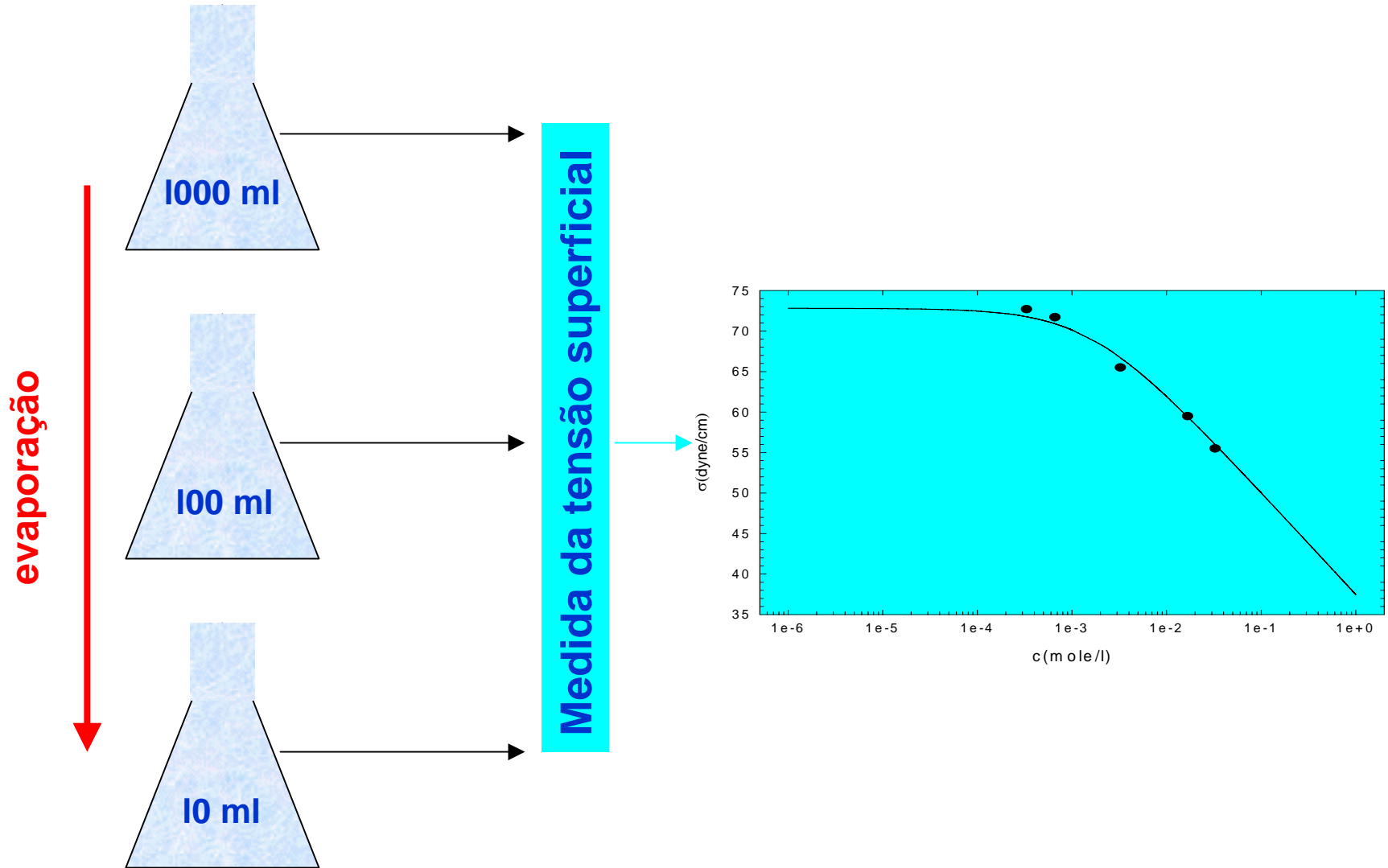


Gotículas ativadas a partir de aerossol de $(\text{NH}_4)_2\text{SO}_4$

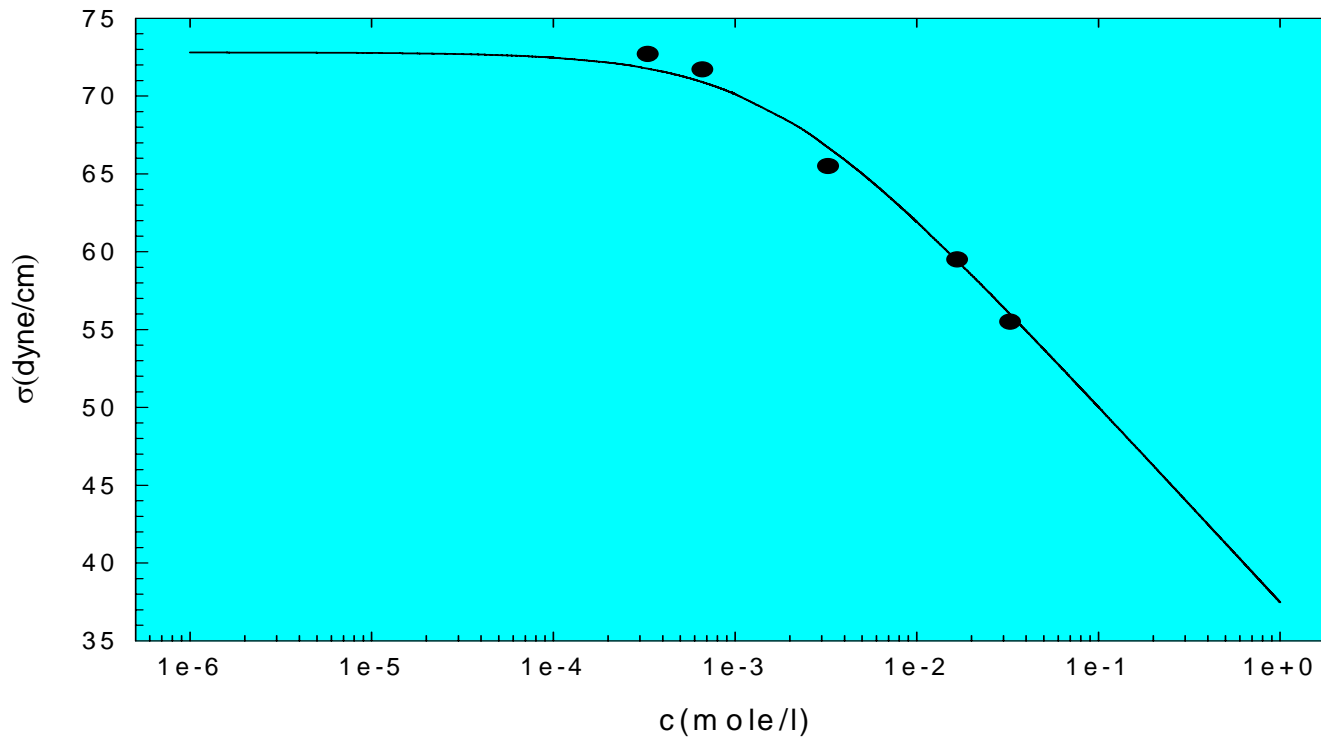


Gotículas ativadas a partir de um aerossol com massa composta com 75 % de surfactantes misturados – (aerossol-modelo)

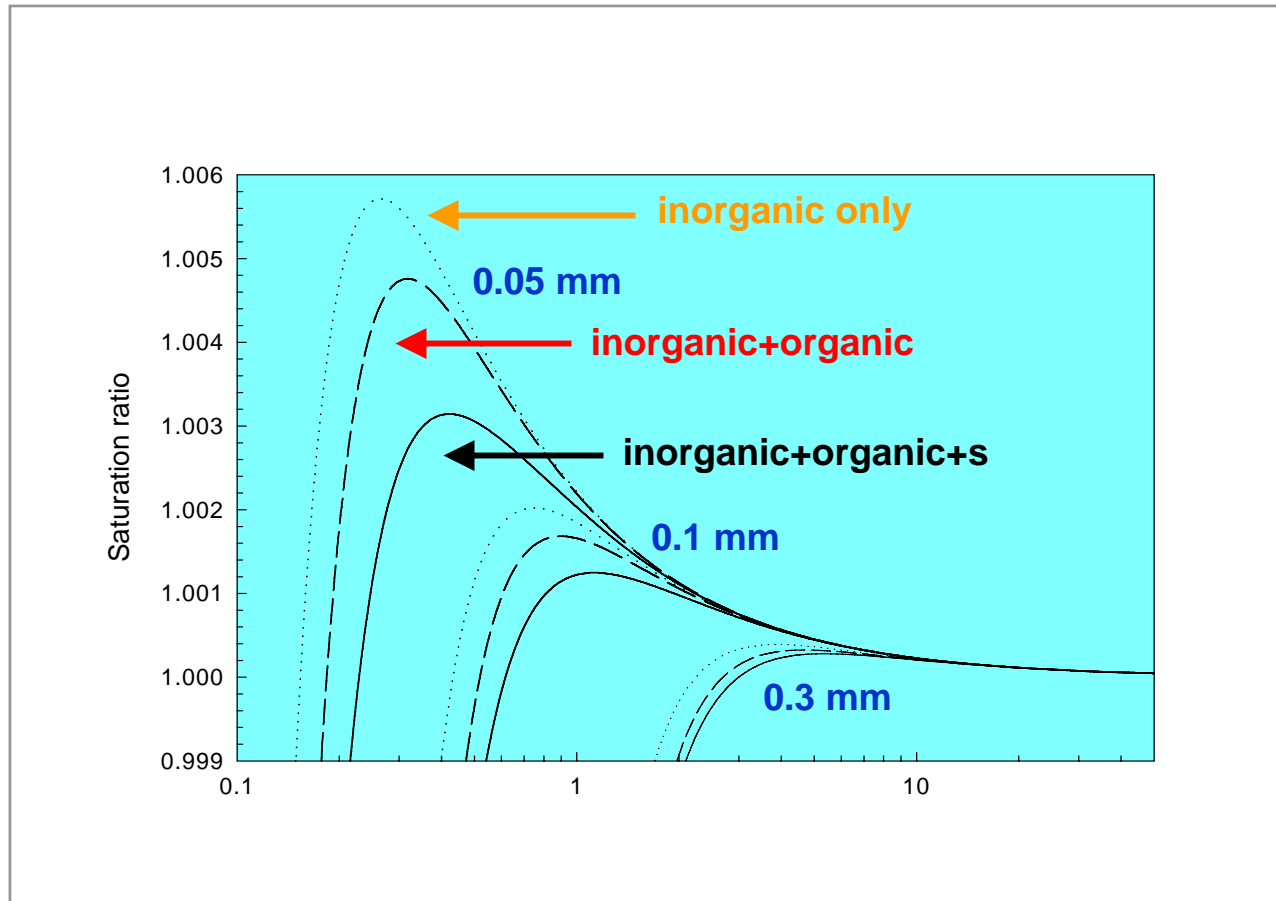




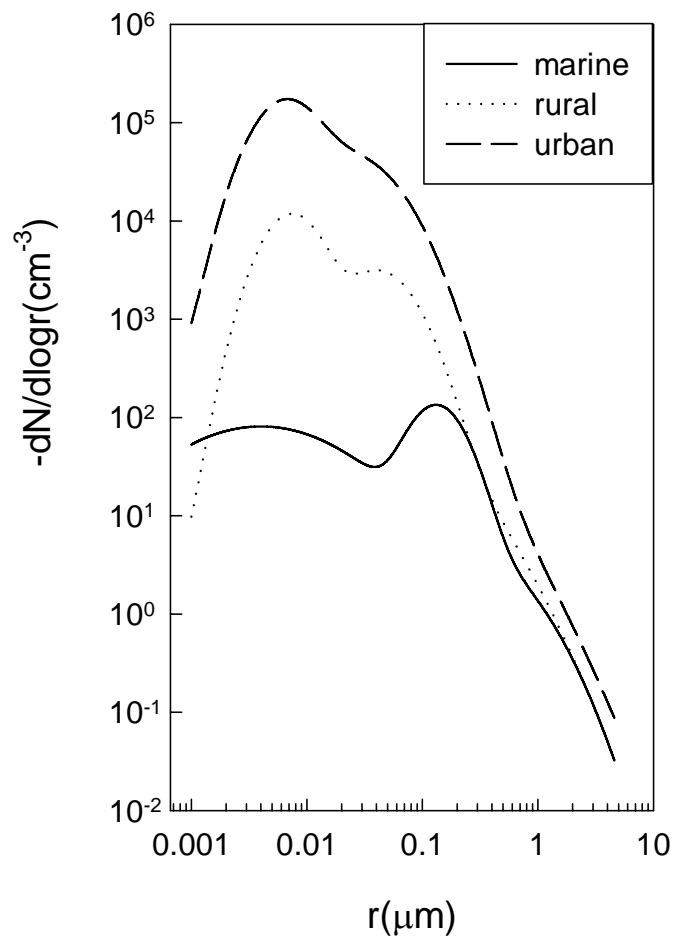
$$\sigma = 72.8 - 0.0187 T \ln(1 + 628.14 C)$$



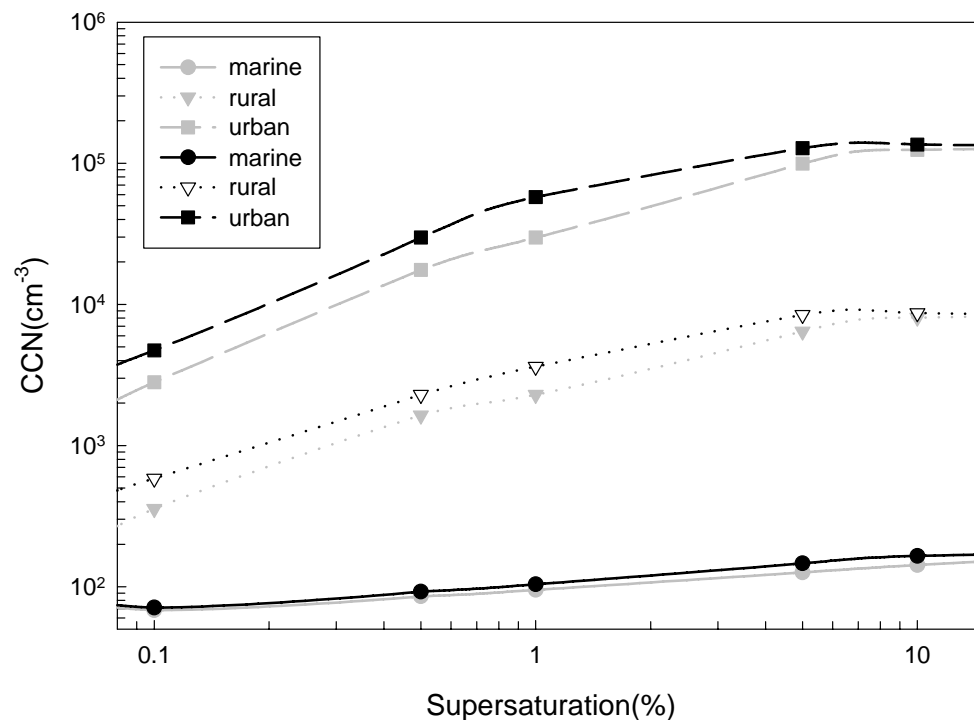
Efeito de componentes orgânicos na Sc



Influência dos orgânicos na ativação do espectro de CCN



Aumento do CCN devido aos orgânicos

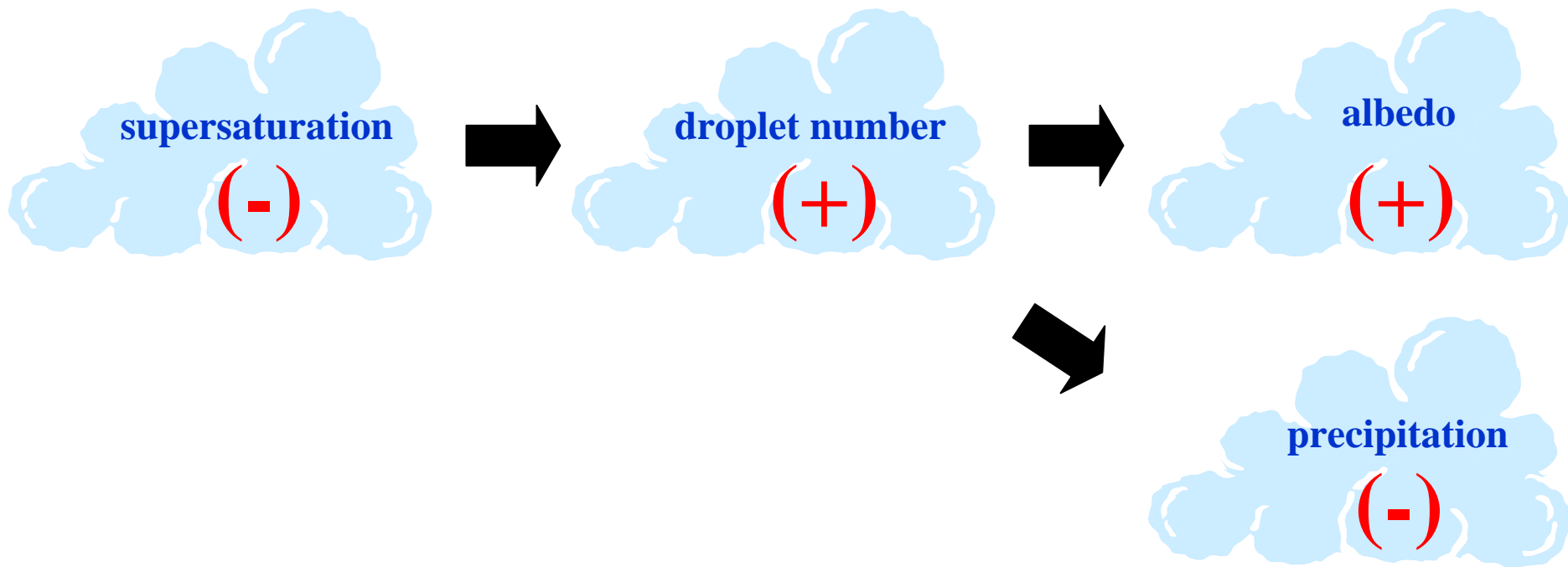


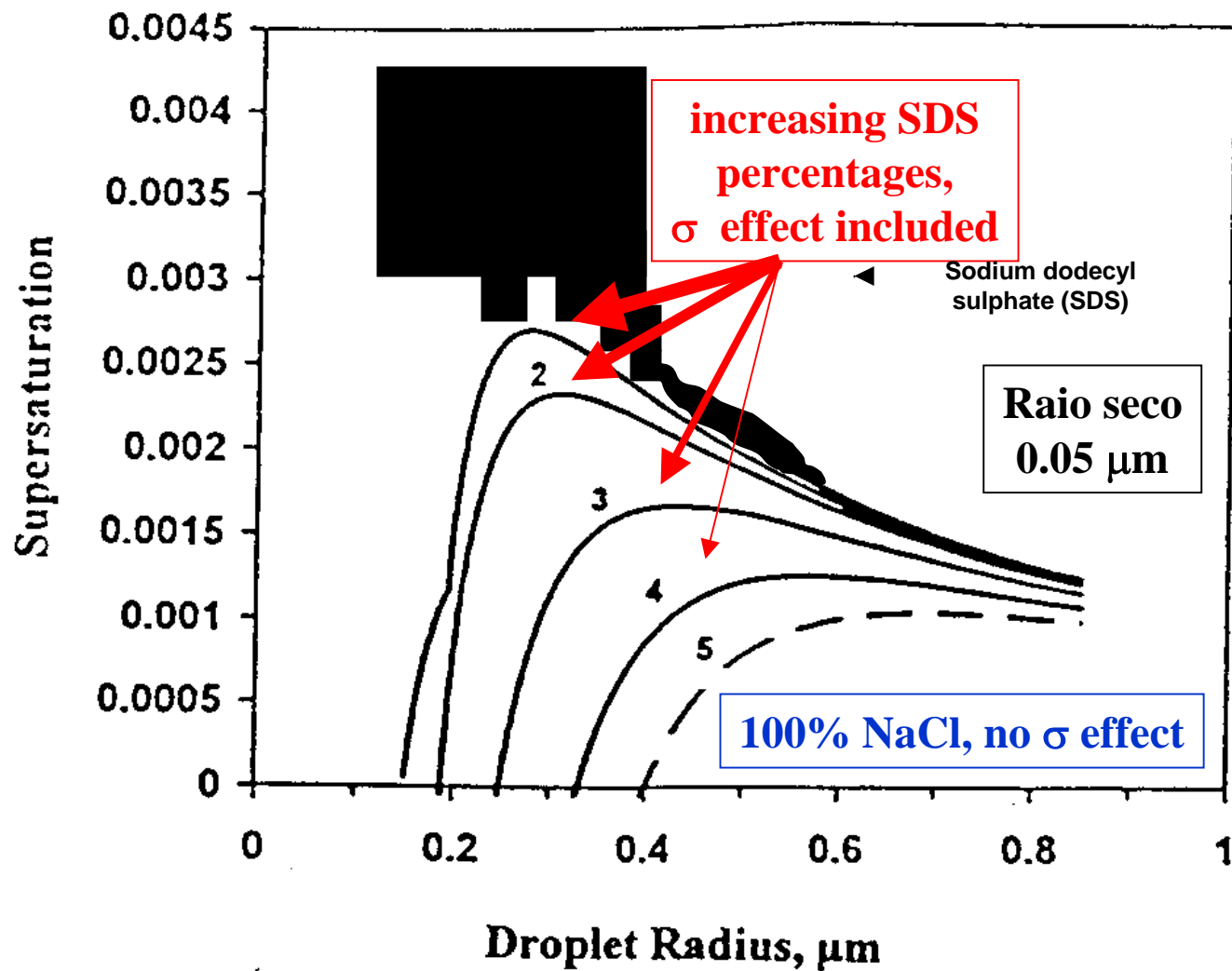
marinho:
Até 13%

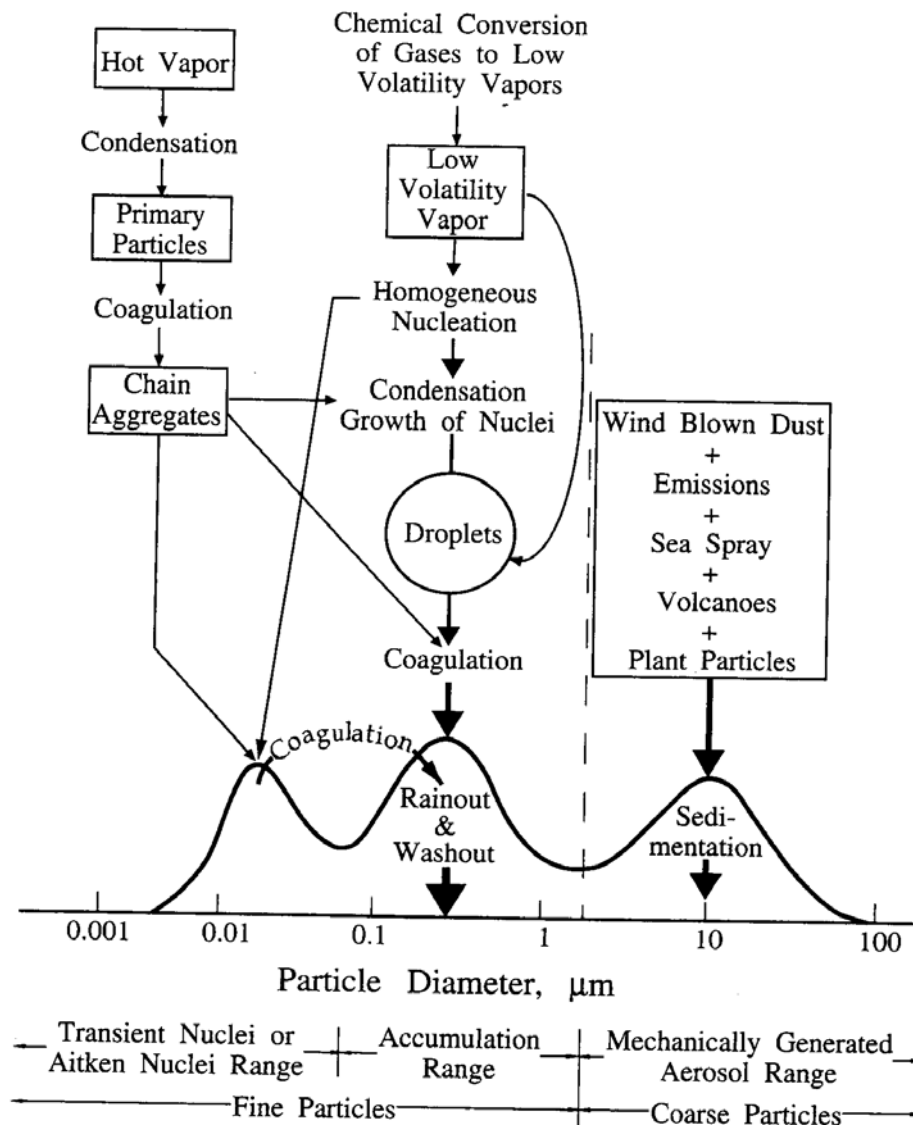
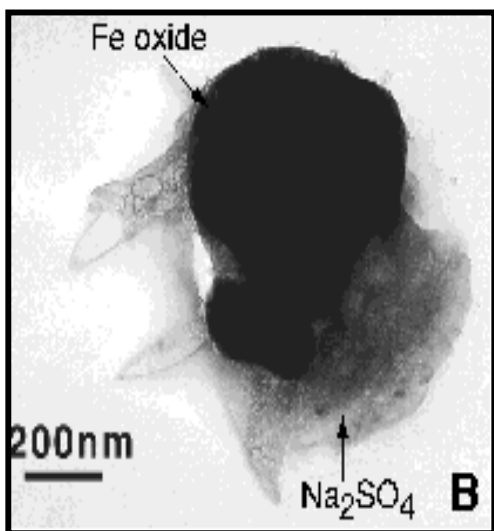
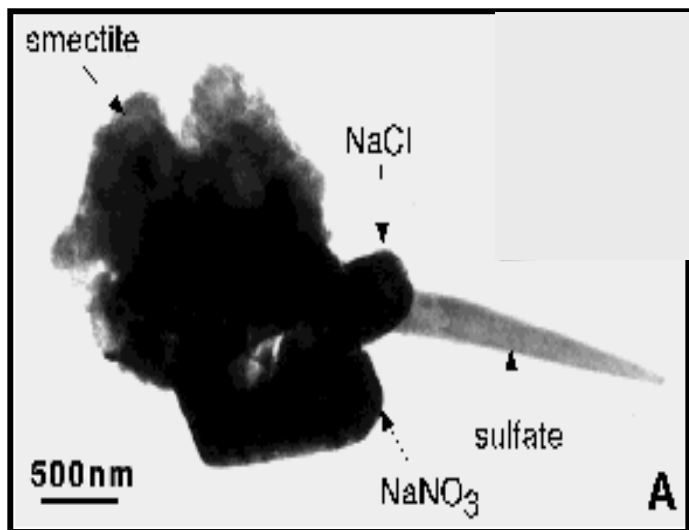
Rural :
Até 97%

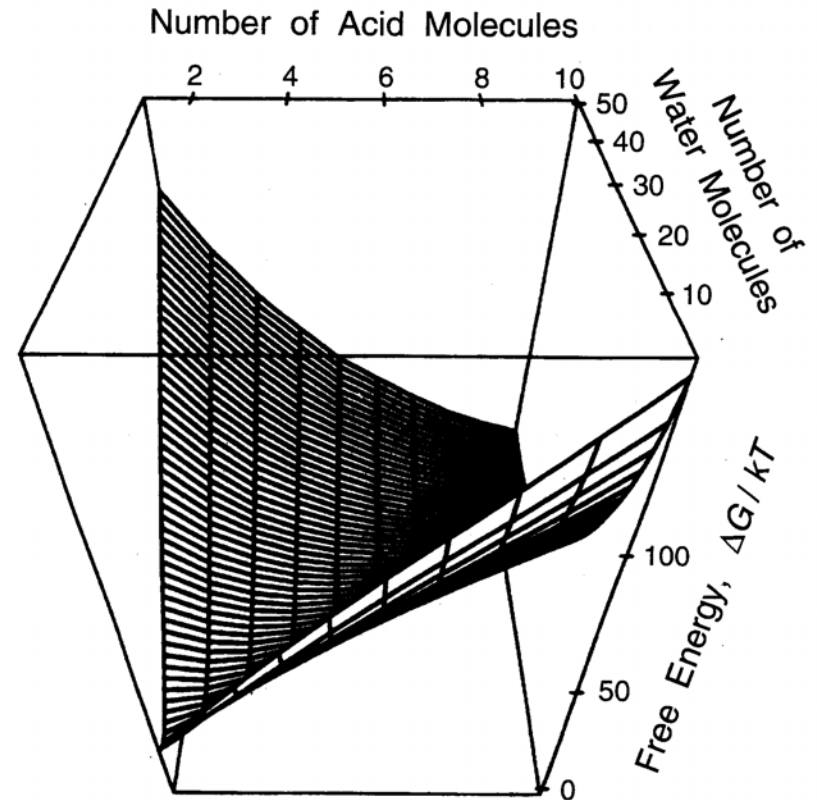
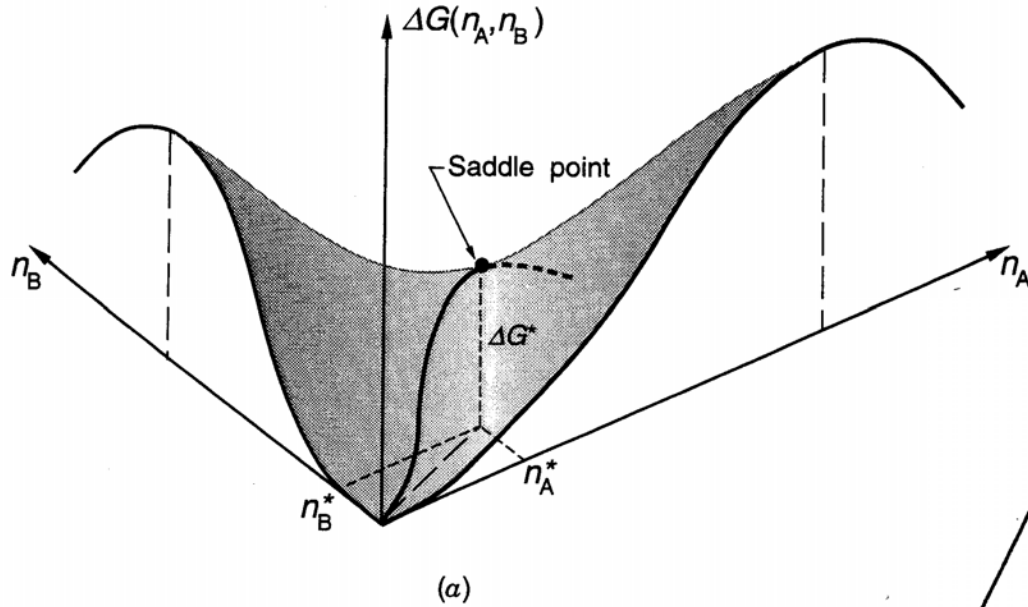
Urbano:
Até 110%

CCN orgânico e a forçante radiativa da nuvem









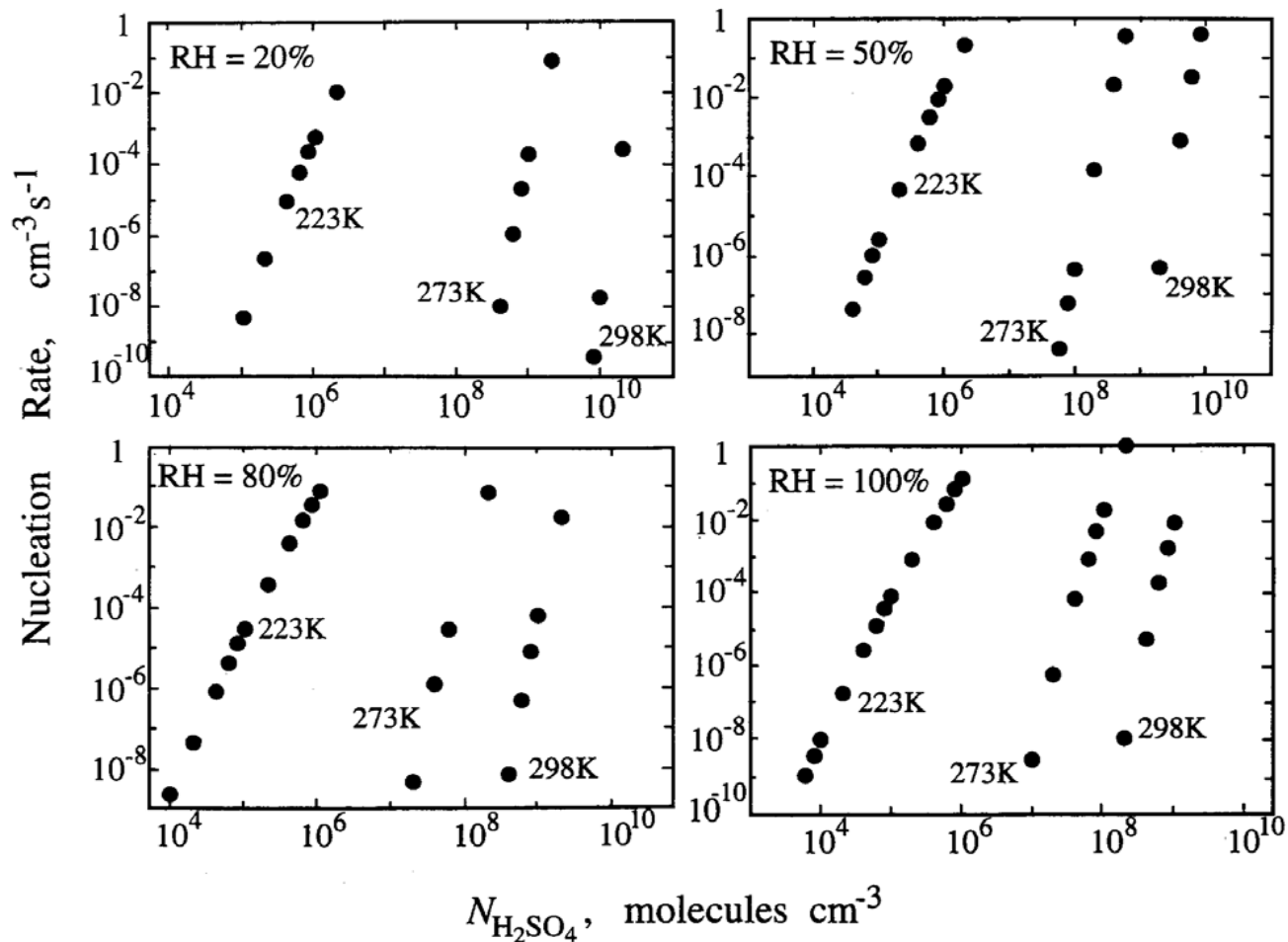


FIGURE 10.11 $\text{H}_2\text{SO}_4\text{-H}_2\text{O}$ binary nucleation rate ($\text{cm}^{-3} \text{s}^{-1}$) as a function of $N_{\text{H}_2\text{SO}_4}$, calculated from classical binary nucleation theory (Kulmala and Laaksonen, 1990). (a) Relative humidity = 20%; (b) RH = 50%; (c) RH = 80%; (d) RH = 100%.

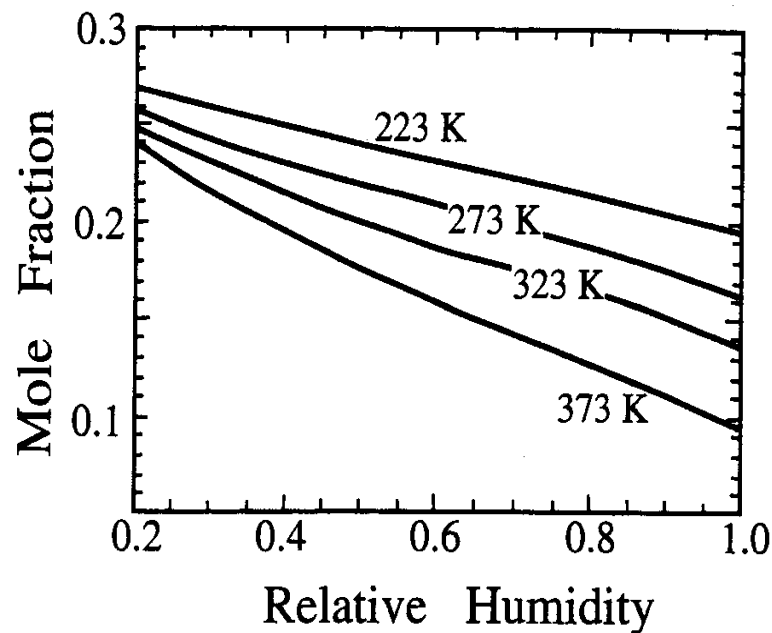
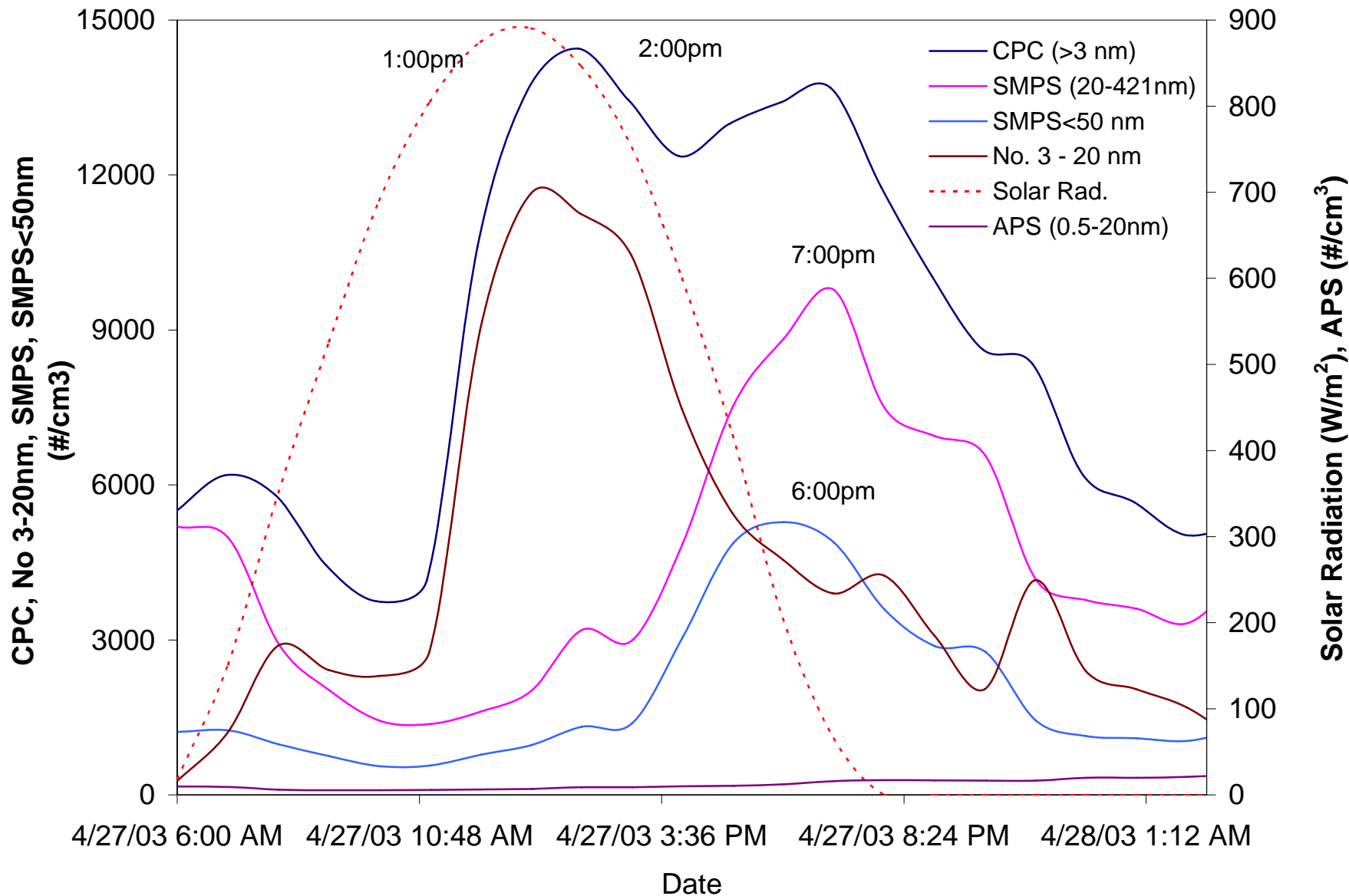
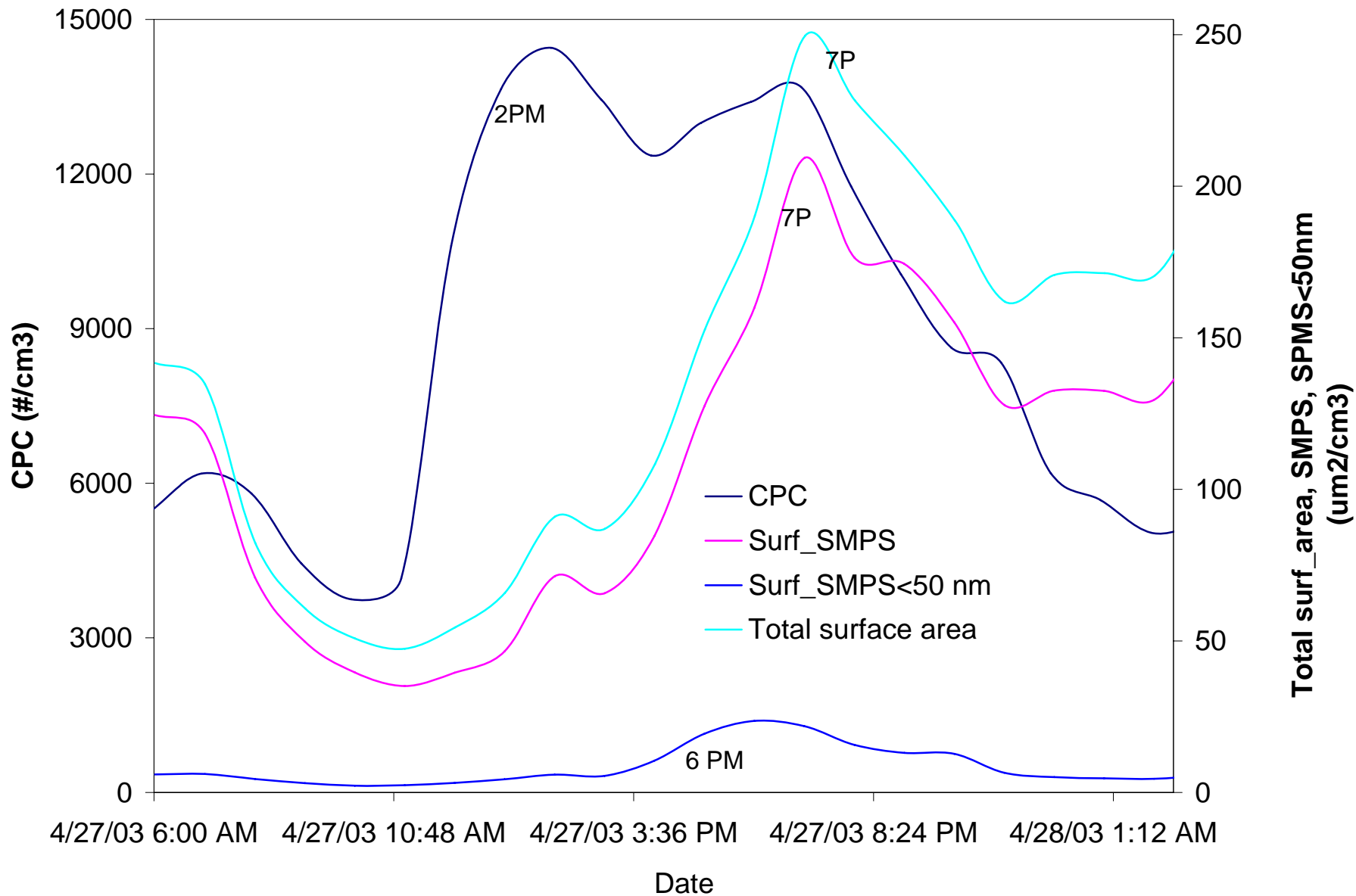
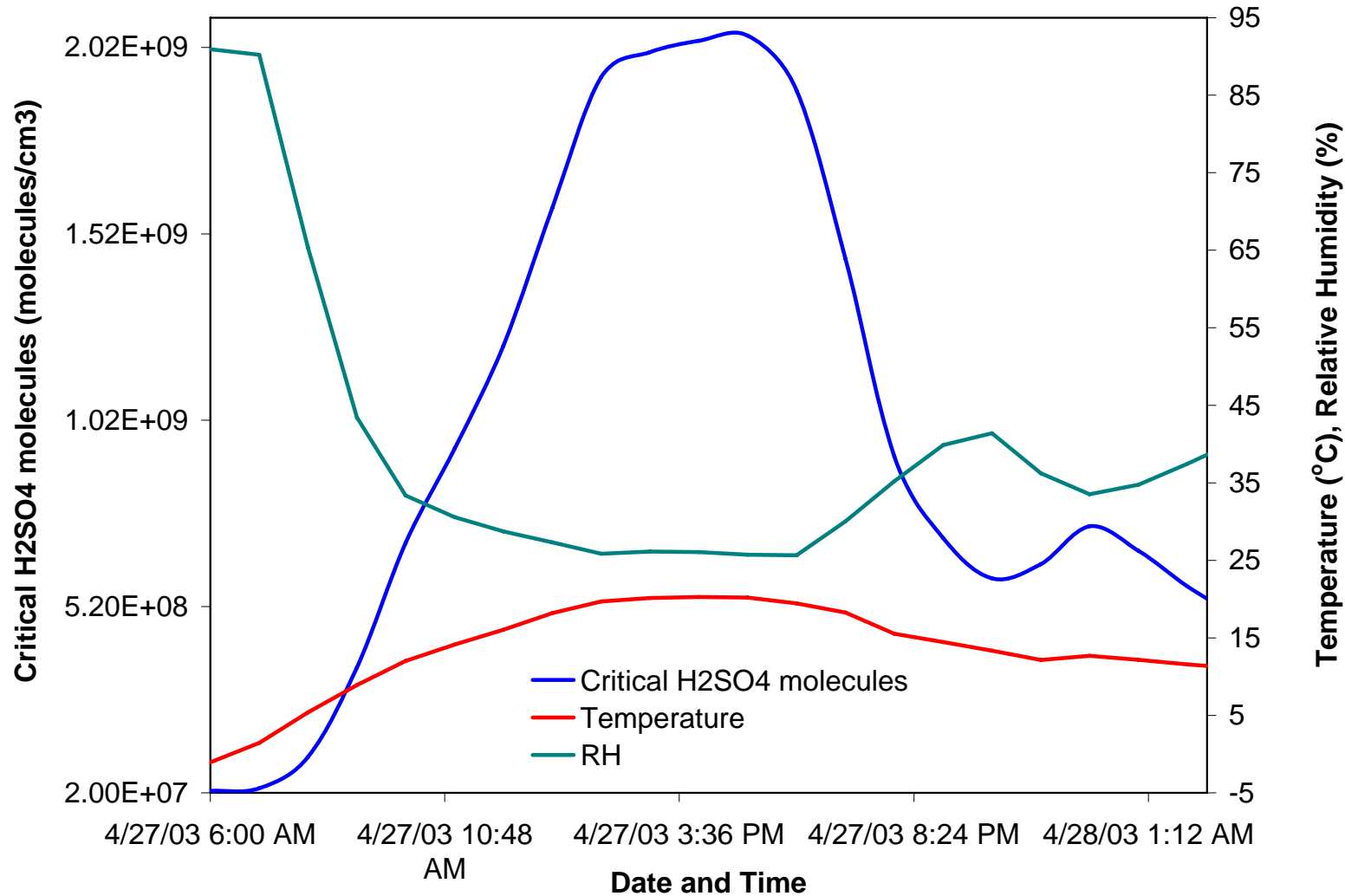


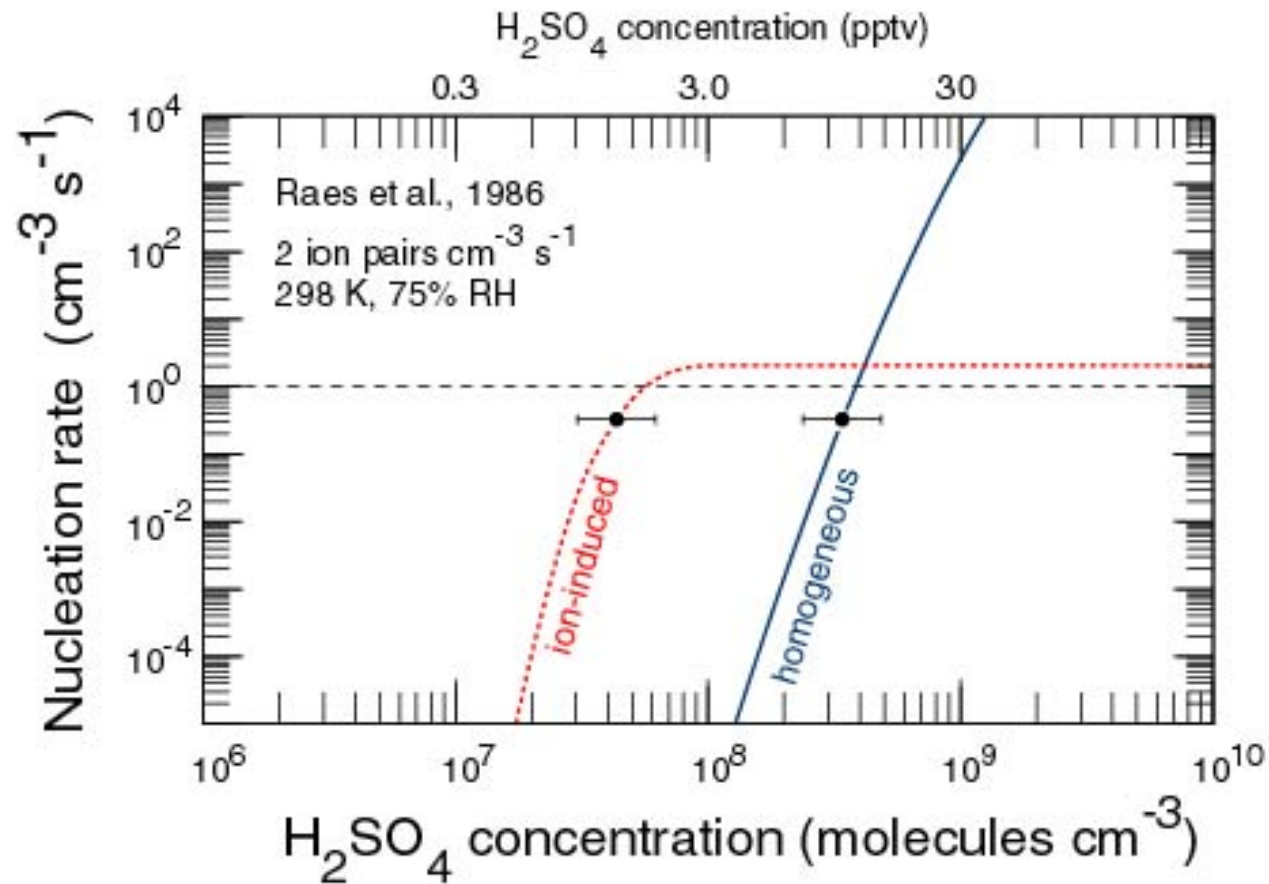
FIGURE 10.12 Composition of the critical $\text{H}_2\text{SO}_4\text{-H}_2\text{O}$ nucleus, calculated for $J = 1 \text{ cm}^{-3} \text{ s}^{-1}$, as a function of RH. The different curves correspond to the temperatures shown. (Reprinted from *Atmos. Environ.*, **23**, Jaeger-Voirol, A. and Mirabel, P., Heteromolecular nucleation in the sulfuric acid-water system, p. 2053, 1989, with kind permission from Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington OX5 1GB, UK.)





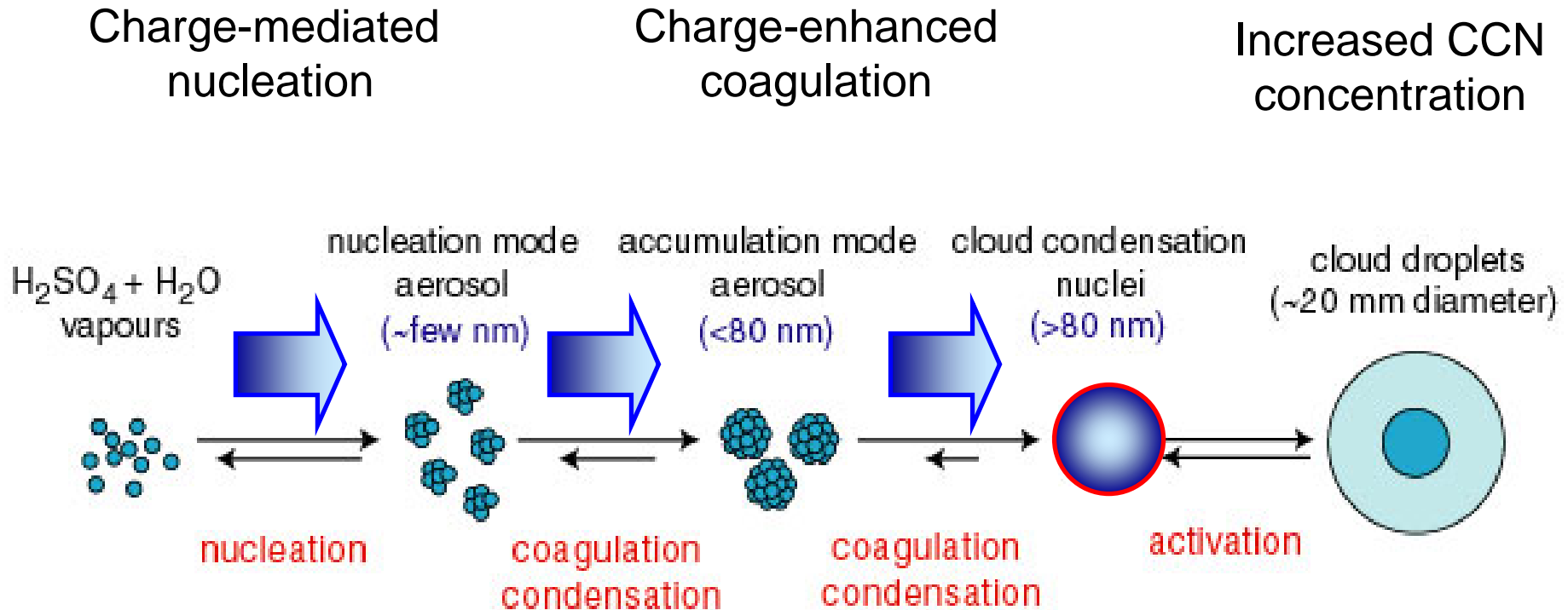


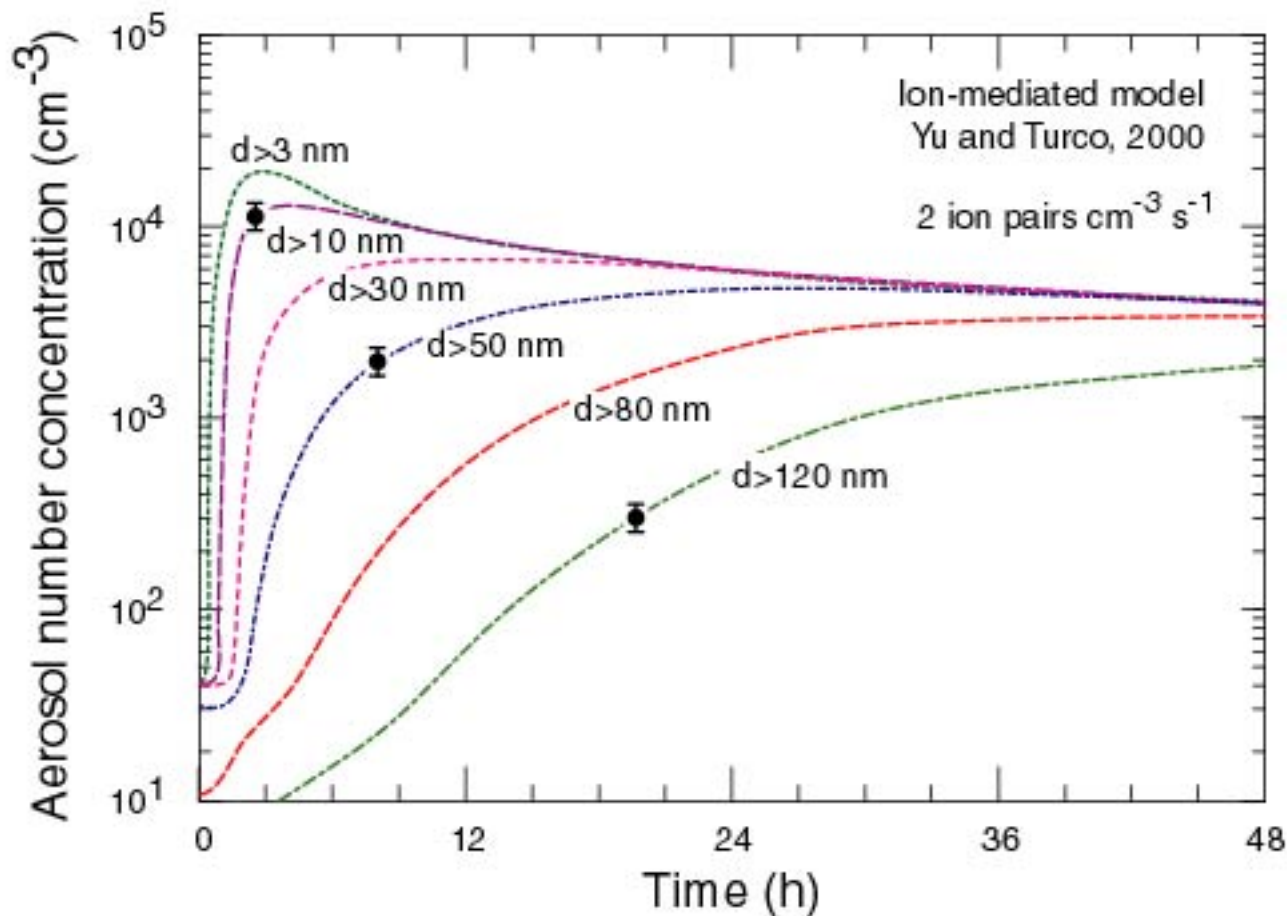
Nucleação por íons



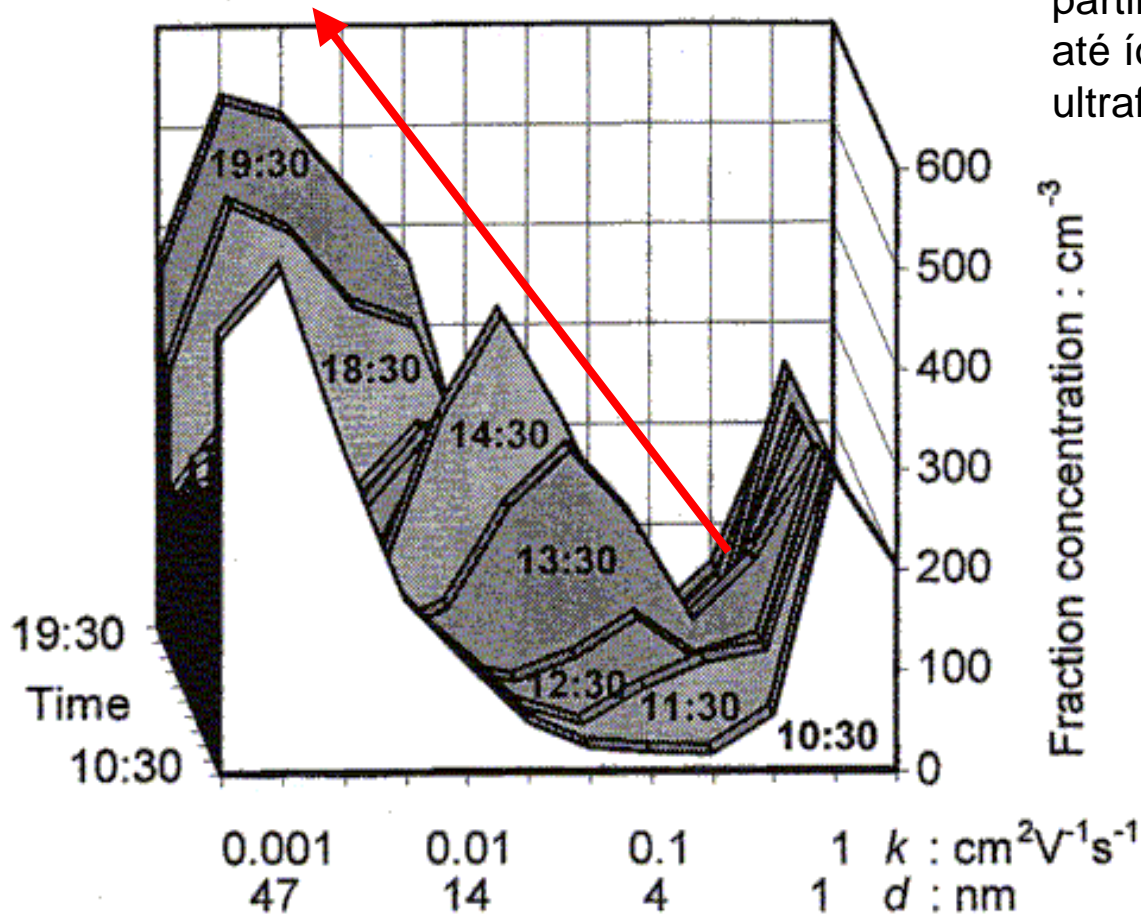
(Harrison and Karslaw, 2003)

Efeito da carga sobre os processos do aerossol





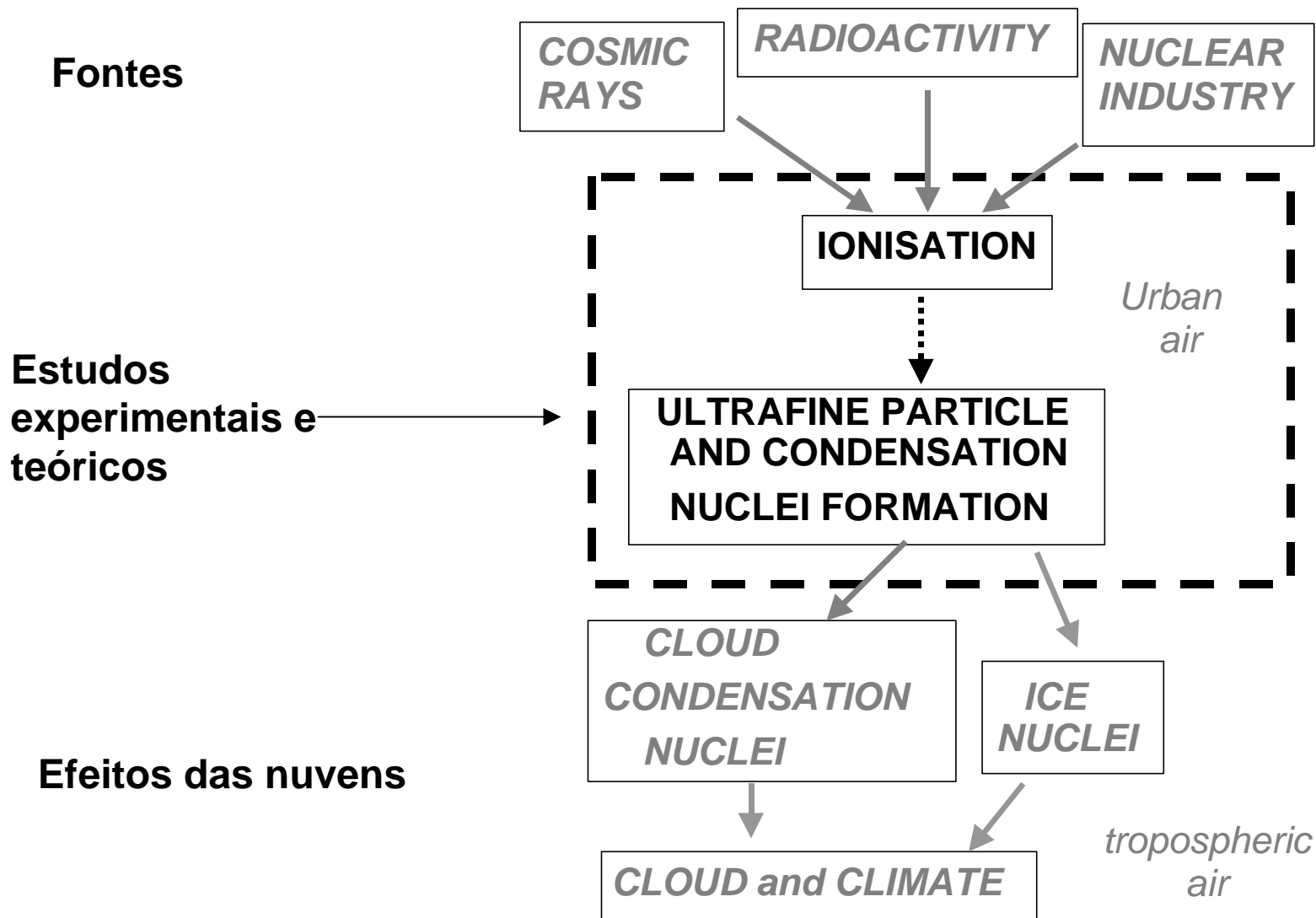
Observações do crescimento de íons



Partículas carregadas crescem a partir de aglomerados moleculares até íons intermediários (partículas ultrafinas)

Horrak *et al* (1998) Bursts of intermediate ions in atmospheric air
J. Geophys. Res. 103(D12), 13909-13915

Produção de aerossol por ionização



Equação da interação Ion-aerossol

(concentração de íons n_+ e n_- -
positivos e negativos)

Termo fonte q ,
principalmente a taxa
de produção cósmica
volumétrica de íons

$$\frac{dn_{\pm}}{dt} = q - \alpha n_{\pm} n_{\mp} - n_{\pm} \beta_{\pm} Z$$

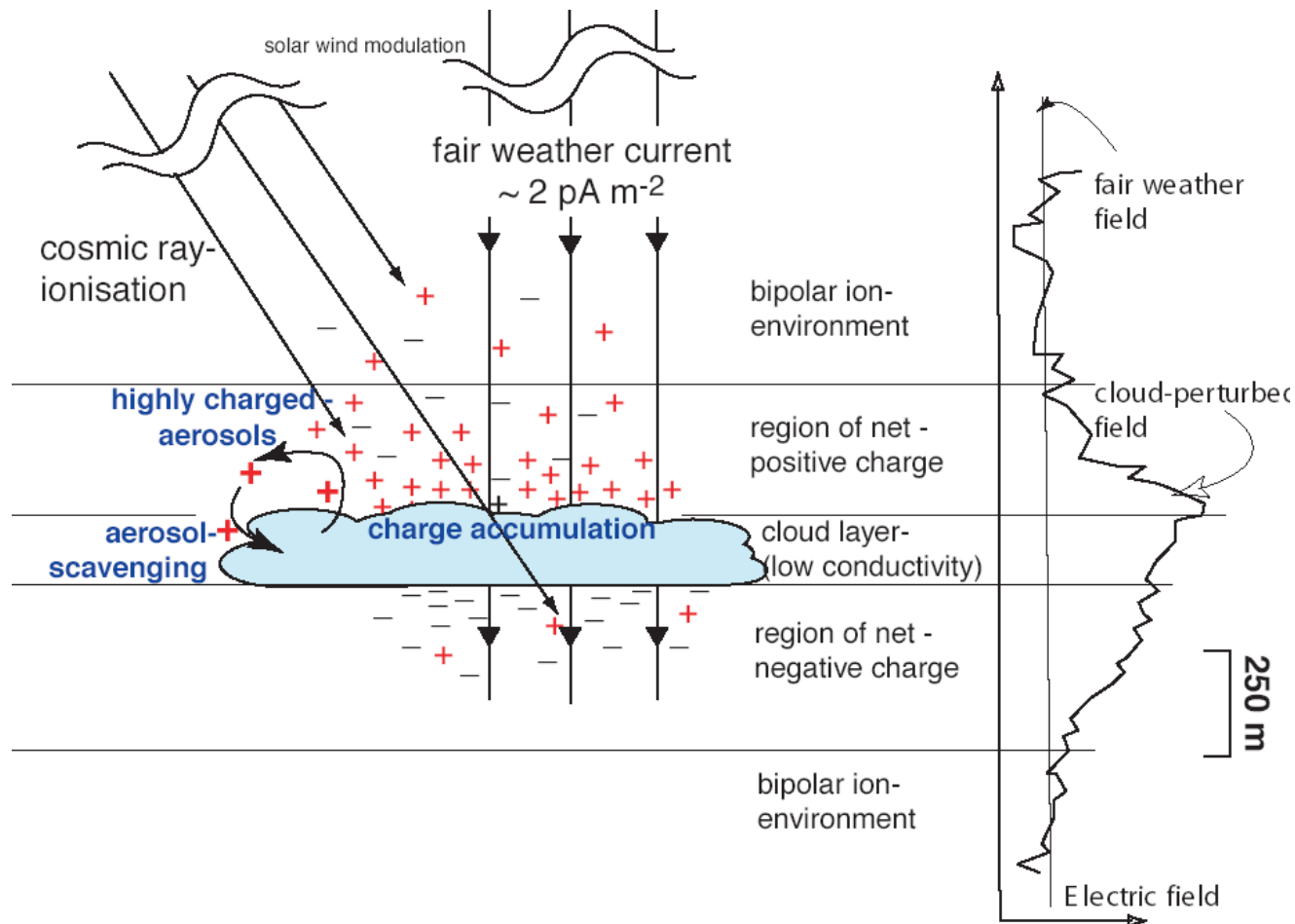
-?

Perda por recombinação
ion-ion

Perda por agregação ion-aerossol (Z
concentração monodispersa do
aerossol

Termo de nucleação

Mecanismo Ion-aerossol-nuvem



“Mecanismo próximo da nuvem” nucleação de gelo (carga imagem) e distribuição de tamanhos de partículas carregadas

Carlsaw, Harrison and Kirkby *Science* **298**, 5599, 1732-1737 (2002) ...and forthcoming (2003) : Harrison and Carlsaw, *Rev. Geophys*

A **M**odel of **A**tmospheric **C**hemistry and **C**oupled **A**erosol **M**icrophysics II

use in UMIST (University of Manchester) warm cloud model

MONSTER (Sander et al., 1992)

currently includes HNO_3 , NaCl , HCl , $(\text{NH}_4)_2\text{SO}_4$ equilibration,

aqueous S(IV) oxidation (O_3 , H_2O_2 and transition metal catalysed)

explicit cloud microphysics, condensation, coagulation and evaporation

consideration of every input category individually (e.g. 1280 bins)

incorporate organic parameterisation into MONSTER

effect on osmotic coefficient

effect on total solute molecule concentration

effect on surface tension

initialised by ground-based aerosol composition distribution

predict droplet number and diameter

i.e. study the effect of aerosol organics on cloud microphysics

Componentes do Modelo

