



Ministério da Ciência e Tecnologia - MCT

Instituto Nacional de Pesquisas Espaciais - INPE

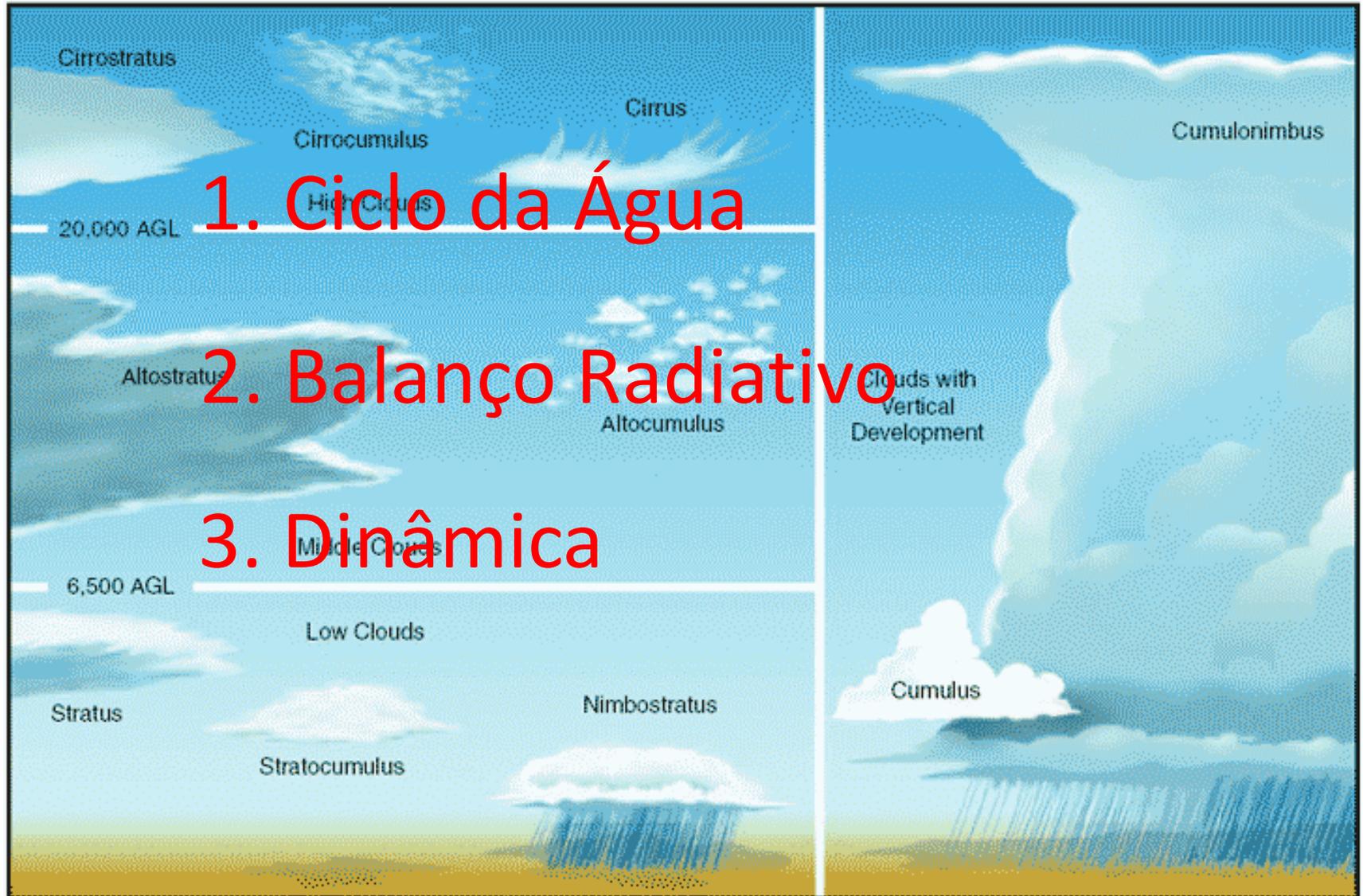
Centro de Previsão de Tempo e Estudos Climáticos - CPTEC

Microfísica de Nuvens

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A importância das nuvens



Microfísica de Nuvens

- Mudanças de fase da substância água
- As possíveis mudanças são:

Vapor \rightleftharpoons Líquido

Líquido \rightleftharpoons Sólido

Vapor \rightleftharpoons Sólido

Formação das Nuvens

- A parcela de ar sobe e resfria até a saturação no NCL,
- Núcleos de Condensação de Nuvens (NCN) são ativados,
- A pressão de saturação do vapor decresce com a continua ascensão e resfriamento - a parcela torna-se supersaturada,
- Maior número de NCN são ativados em regiões de umidade relativa mais altas.

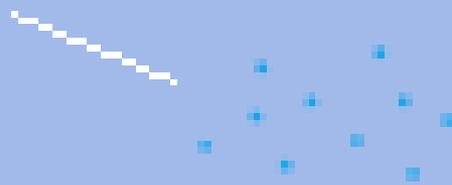
Núcleos de Condensação de Nuvens

Partículas suspensas no ar que dão suporte para o crescimento das gotas de nuvens ou gelo

areia, poeira, pólen, sal em suspensão devido ao spray das ondas do mar, poeira vulcânica, partículas emitidas a partir de fábricas, etc.

Condensation

Nuclei



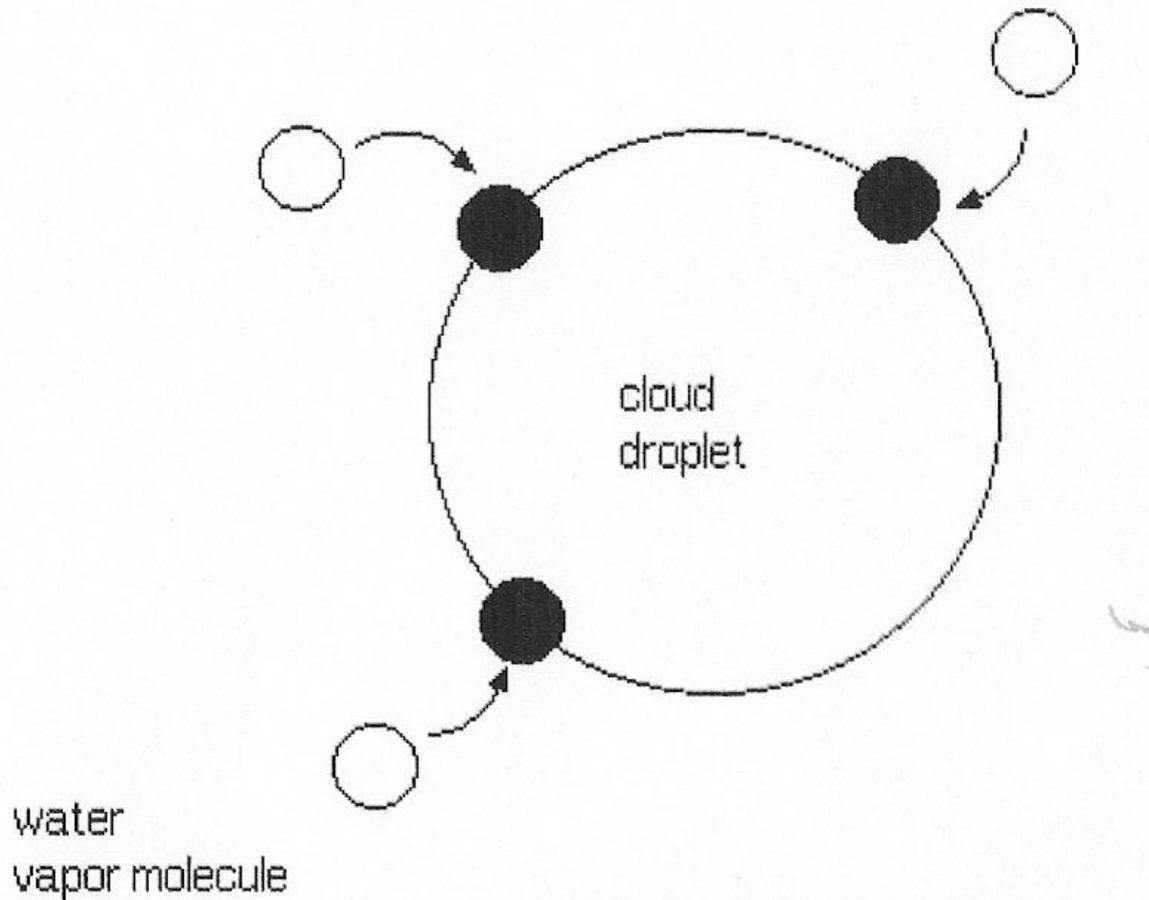
— Air Parcels
and
Water Vapor
COMET

Nuvens Quentes - Processos de Crescimento das Gotas de Nuvem

- Condensação - Difusão
- Colisão e coalescência
- Derretimento do gelo

Crescimento das Gotas

Cloud Droplet Growth by Condensation

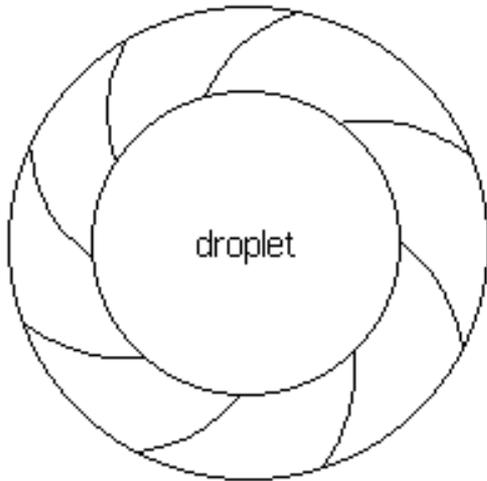


Crescimento das Gotas

Comparisons between e_s of a Droplet and its Environment

the environment and the air surrounding the droplet
are assumed to be saturated

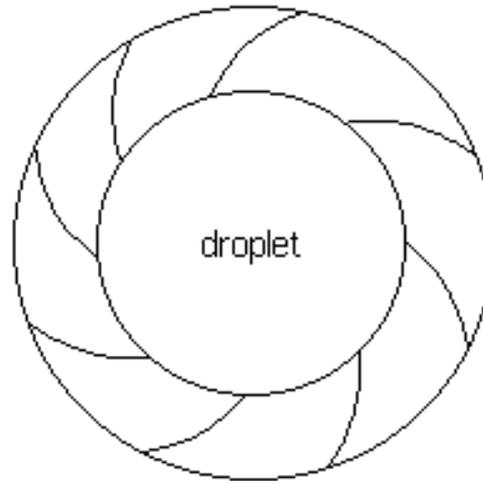
$e_{s_{environment}}$



$$e_{s_{env}} > e_{s_{droplet}}$$

The droplet grows by
condensation

$e_{s_{environment}}$



$$e_{s_{env}} < e_{s_{droplet}}$$

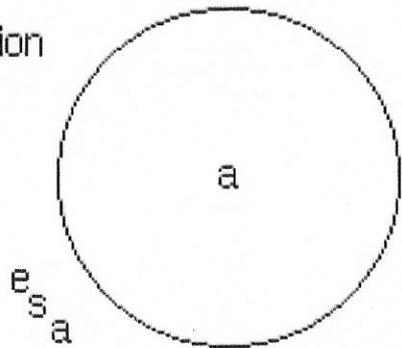
The droplet shrinks by
evaporation

Vapor é transportado
da região de maior
para a região de
menor pressão de
saturação

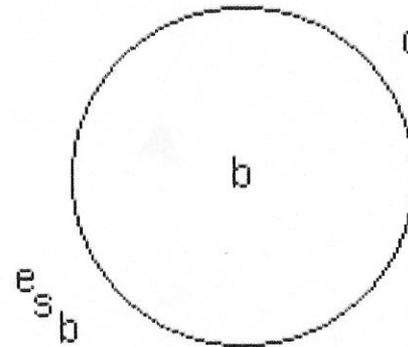
Crescimento das Gotas

Interaction of Droplets with different e_s

shrinks
by
evaporation



grows
by
condensation



$$e_{s a} > e_{s b}$$

vapor is transported from a to b

Classificação das Gotas

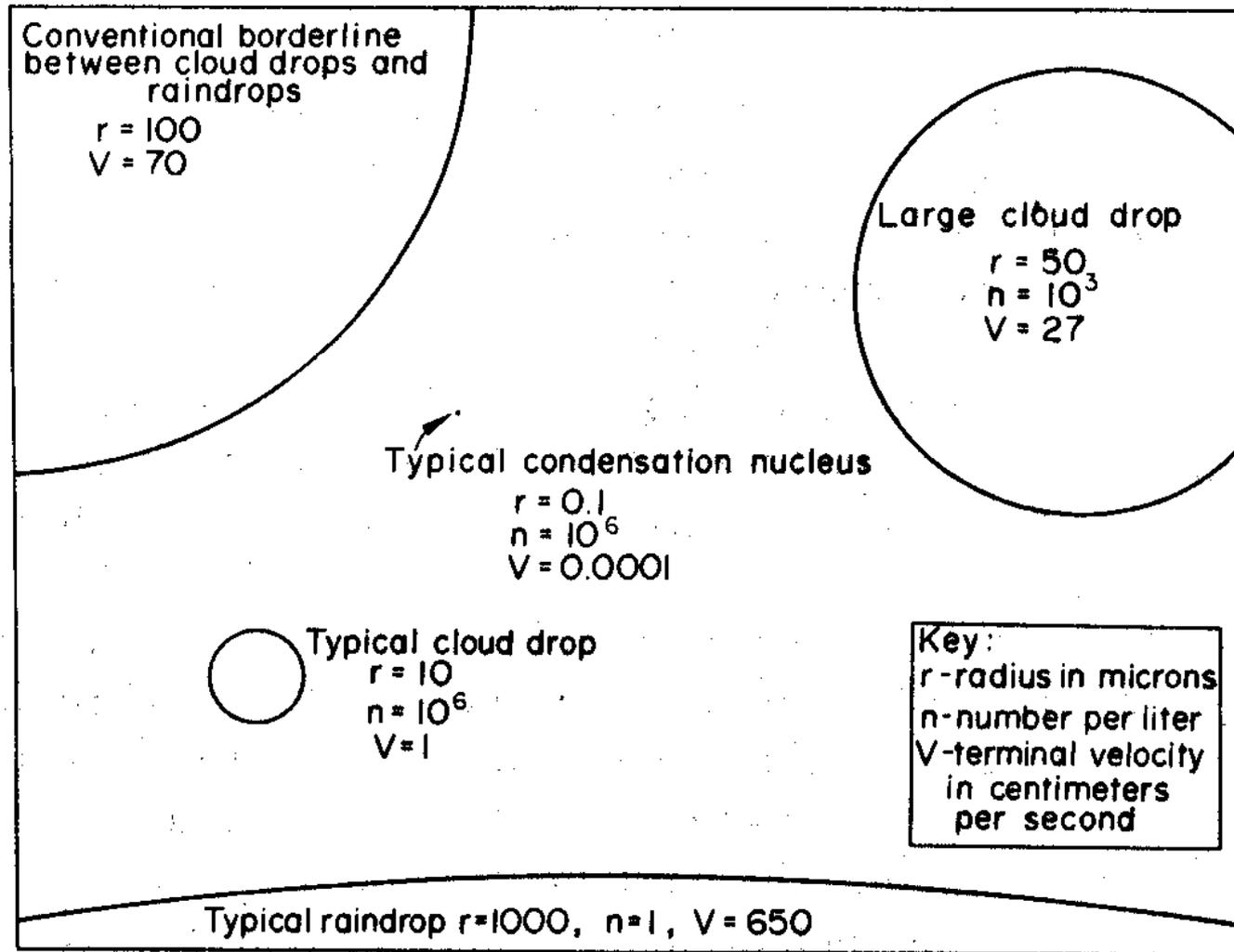
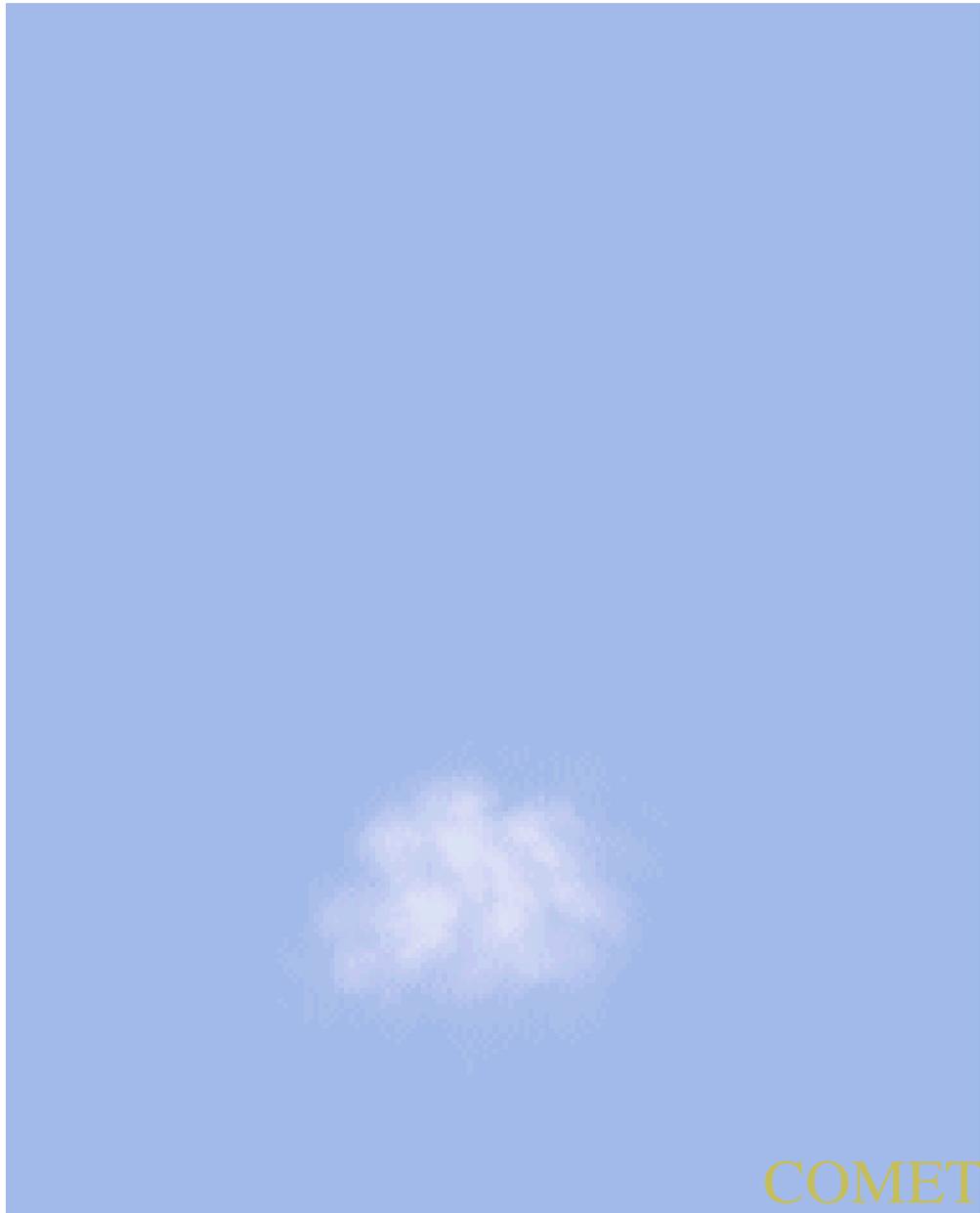


FIG. 5.1. Comparative sizes, concentrations, and terminal fall velocities of some of the particles involved in cloud and precipitation processes. (From McDonald, 1958.)

Crescimento por colisão e Coalescência

- Consiste em dois passos:
- Colisão inicia quando a gota atinge o raio de **18** microns
- Eficiência da colisão aumenta com o aumento do tamanho da gota
- Nem todas as colisões resultam em coalescência
- A coalescência é afetada pela turbulência, presença de contaminantes na superfície, campo elétrico e cargas
- Spectro de tamanho de gotas favorece mais colisões



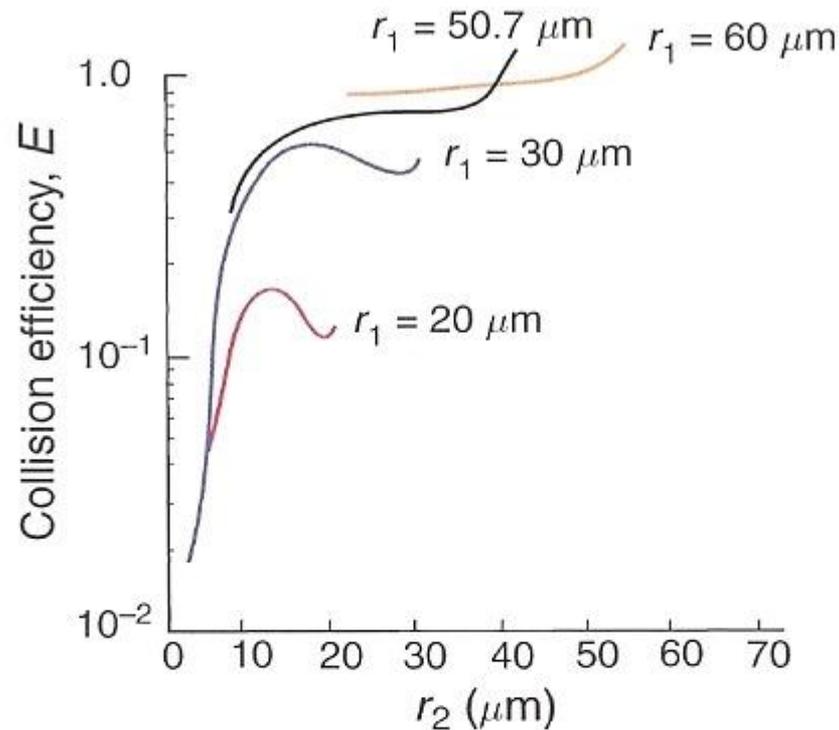
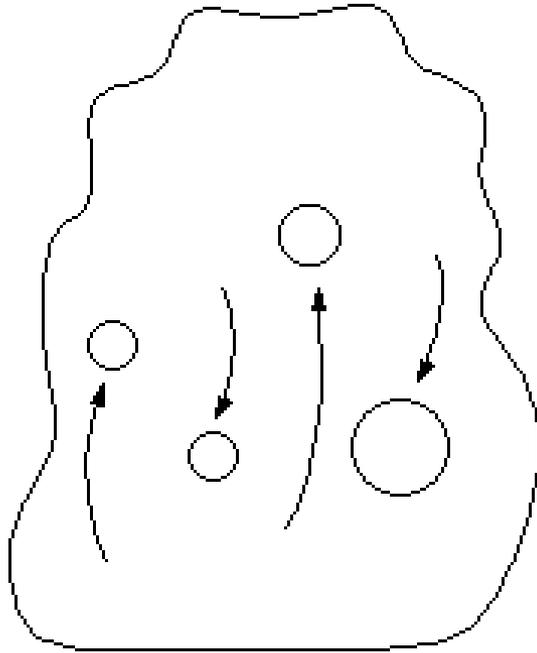
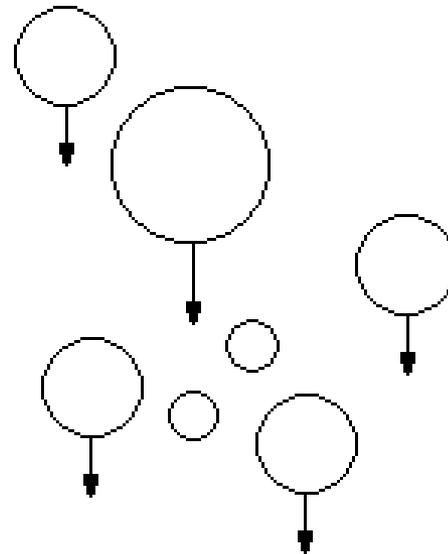


Fig. 6.20 Calculated values of the collision efficiency, E , for collector drops of radius r_1 with droplets of radius r_2 . [Adapted from H. R. Pruppacher and J. D. Klett, *Microphysics of Clouds and Precipitation*, Kluwer Academic Pub., 1997, Fig. 14-6, p. 584, Copyright 1997, with kind permission of Springer Science and Business Media. Based on *J. Atmos. Sci.* **30**, 112 (1973).]

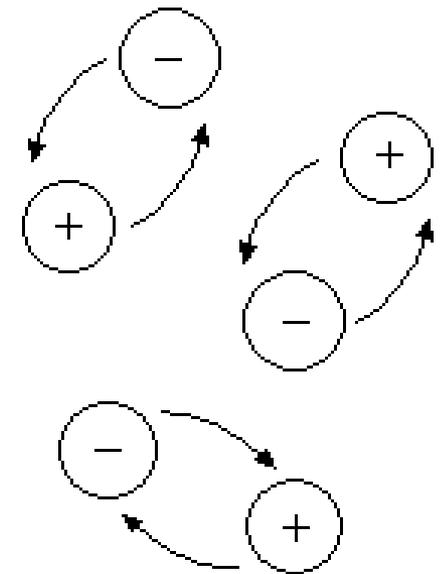
Fatores que afetam a Eficiência



Residence Time
in Cloud



Variable Fall
Velocities



Electric Fields

Nearly Homogeneous Droplet Distribution

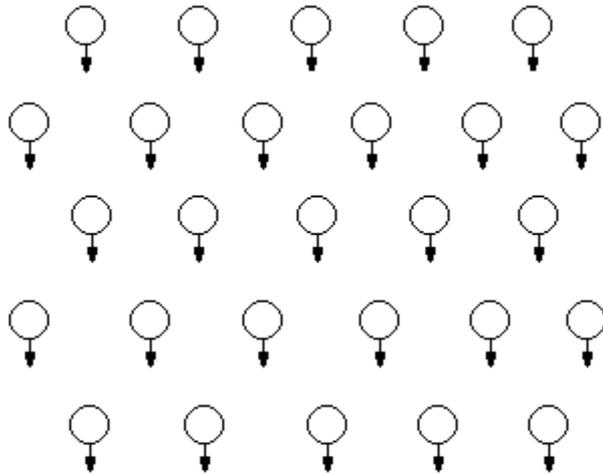


Fig. 12 Few collisions - slow development of rain

Wide Spectrum of Cloud Droplets

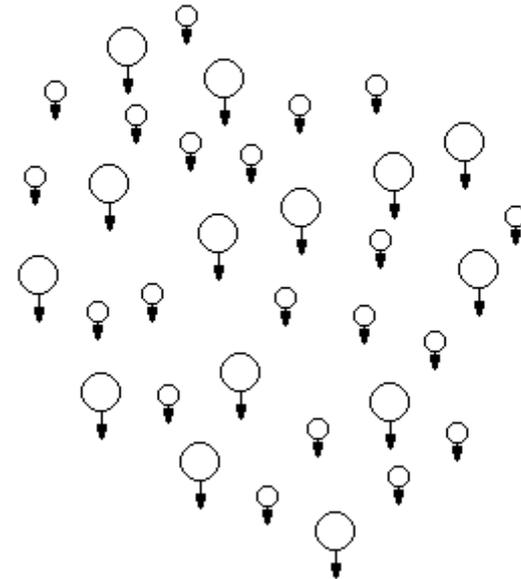
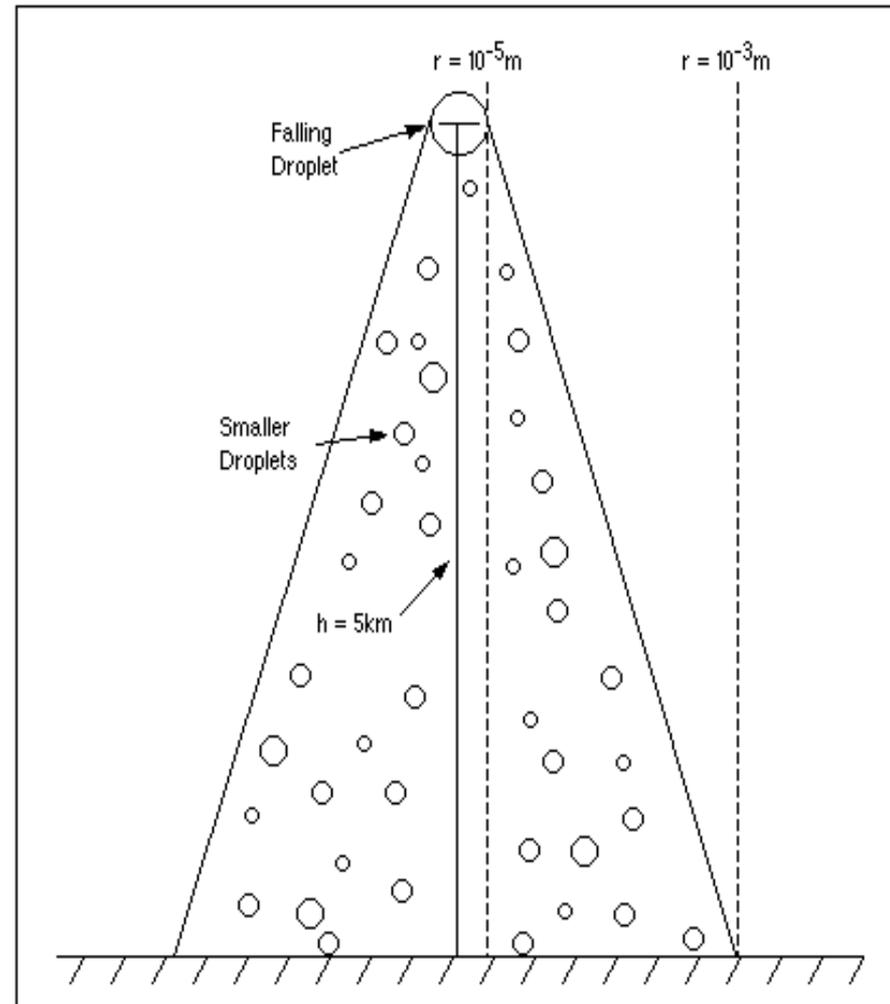


Fig. 13 Many collisions - rapid development of rain

Quebra das Gotas e Multiplicação

- Gotas em queda cobrem um volume cônico
- Gotas são instáveis logo após a coalescência
- Experimentos em túneis de vento: > 4.5 mm não são observadas
- Quebra das gotas resulta em um espectro de tamanho de gotas



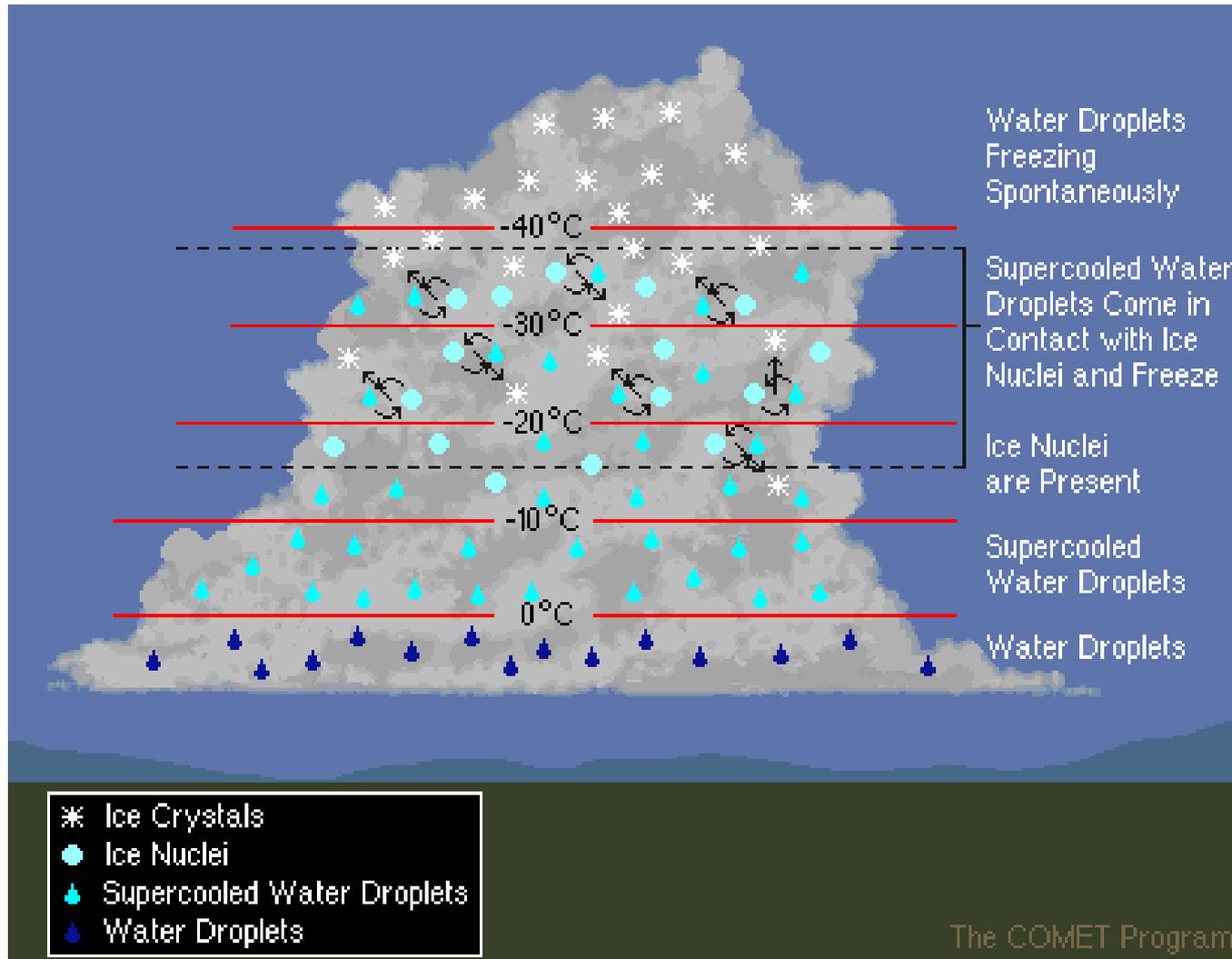
Nuvens Frias - Nucleação do Gelo

- Gelo se forma sobre os núcleos de condensação do gelo "Ice Nuclei (IN)"
- IN possuem a habilidade de atuar como uma superfície onde os cristais de gelo iniciam o crescimento.
- IN são ativados em função da temperatura

IN e temperatura de ativação

- Iodeto de Prata: -4°C
- Poeira: -9°C
- Cinza Vulcânica: -13°C

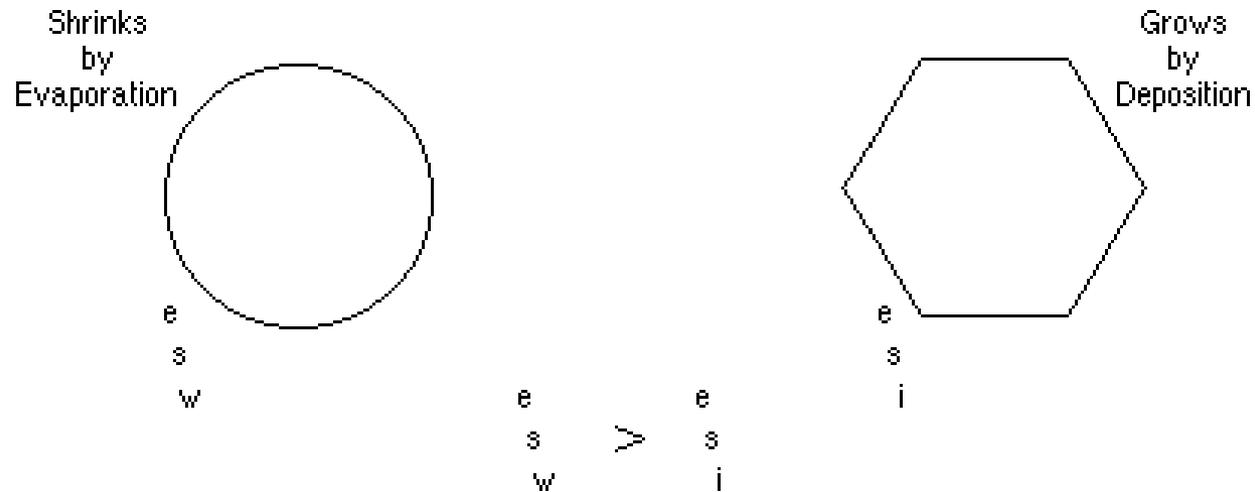
- Nucleação por contato
- Nucleação Homogênia
- Nuvens Quentes (temperatura do topo maior que -10°C) raramente possuem gelo



Crescimento dos Cristais de Gelo

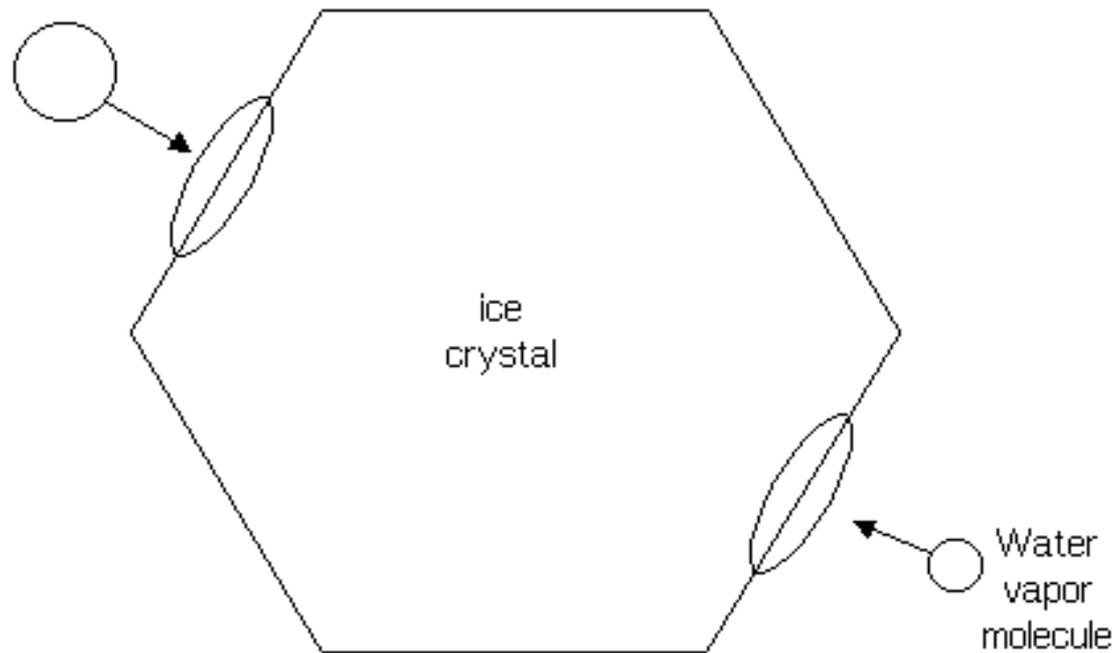
- Crescimento por **deposição**: Vapor de água condensa sobre as partículas de IN e congelam
- Crescimento por **contato**: IN inicia um cristal de gelo assim que entra em contato com uma gota de água supergelada.
- Crescimento por **congelamento**: congelamento das gotas de água supergelada
- **Acréscimo** de gotas de nuvens : partícula na fase de gelo atinge um tamanho suficiente para iniciar a queda e coleta gotas supergeladas,
- **Agregação**: partículas de gelo de unem para formar um floco de neve

Interaction of Cloud Droplets and Ice Crystals



Vapor is transported from the droplet
to the ice crystal

Growth by Deposition



A pressão de saturação sobre a superfície do gelo é menor que a da água líquida, portanto, em um mesmo ambiente, o vapor "prefere" se mover em direção da superfície do gelo ao invés da gota líquida

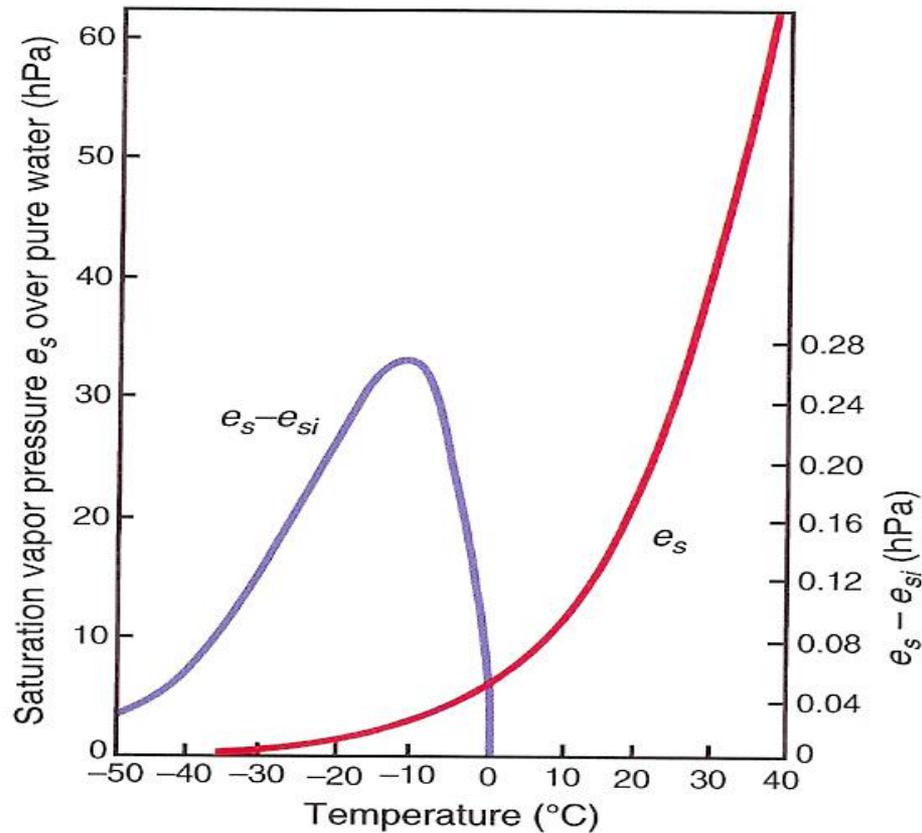
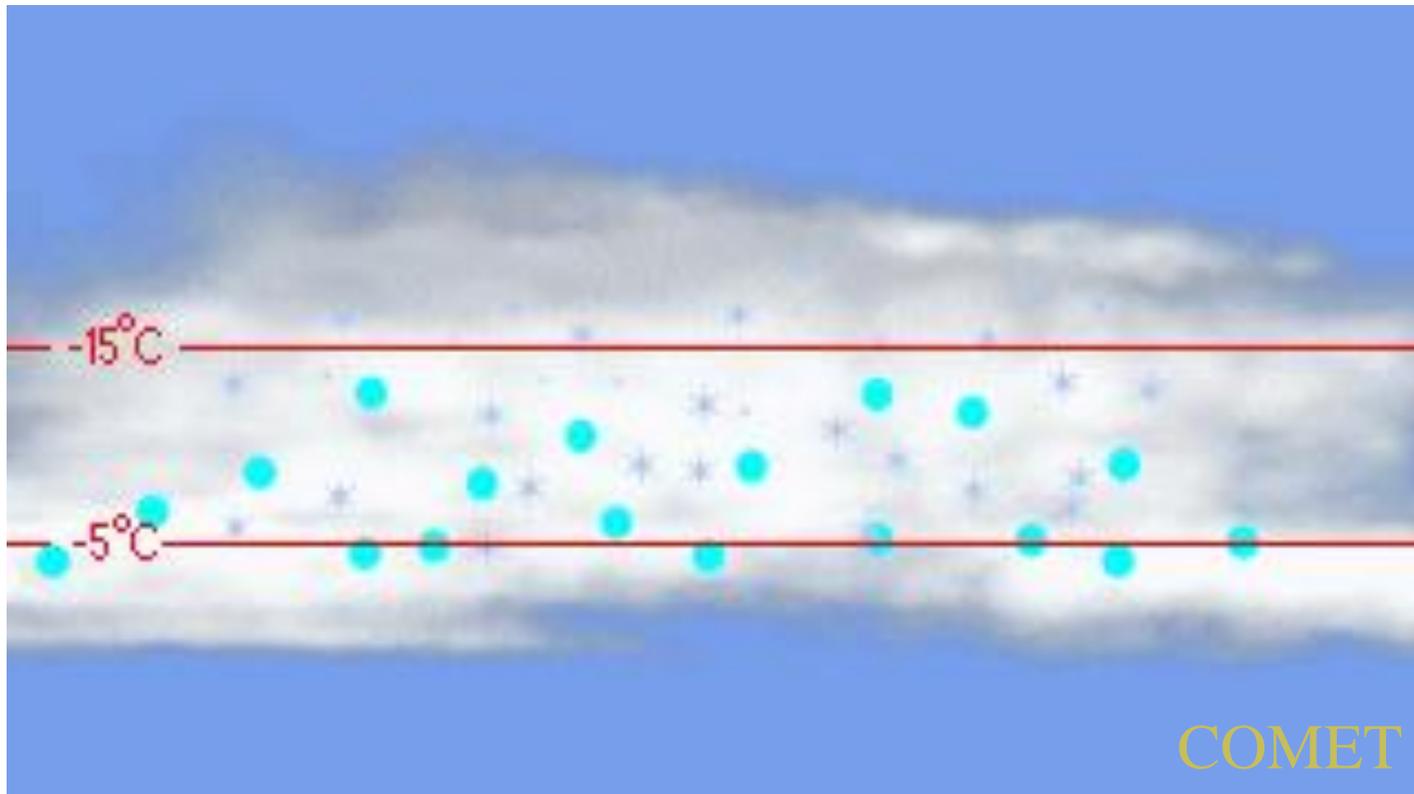
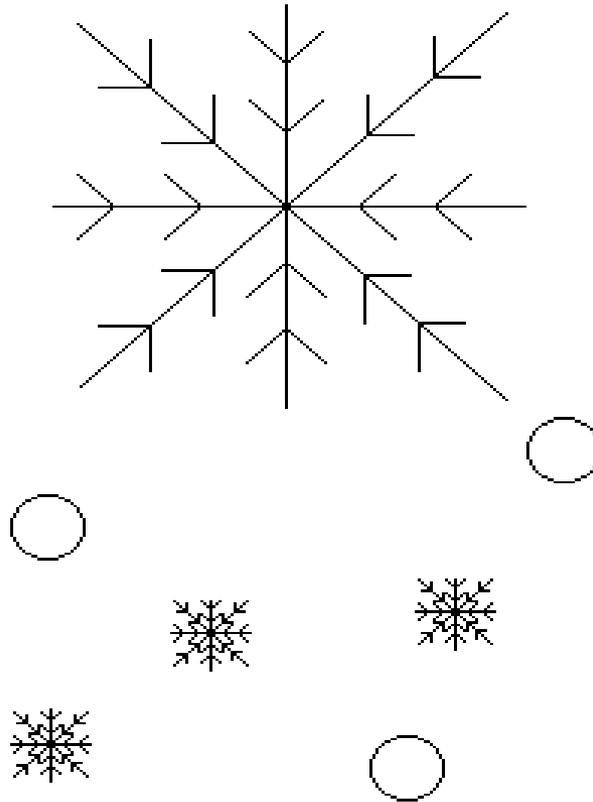


Fig. 3.9 Variations with temperature of the saturation (i.e., equilibrium) vapor pressure e_s over a plane surface of pure water (red line, scale at left) and the difference between e_s and the saturation vapor pressure over a plane surface of ice e_{si} (blue line, scale at right).

Crescimento por deposição



Growth Collision with Cloud Droplets and other Ice Crystals



graupel, needles of snow, and finely dendritic or powder snows

Multiplicação das Partículas de gelo

- **Mecanismo Seeder-Feeder:**

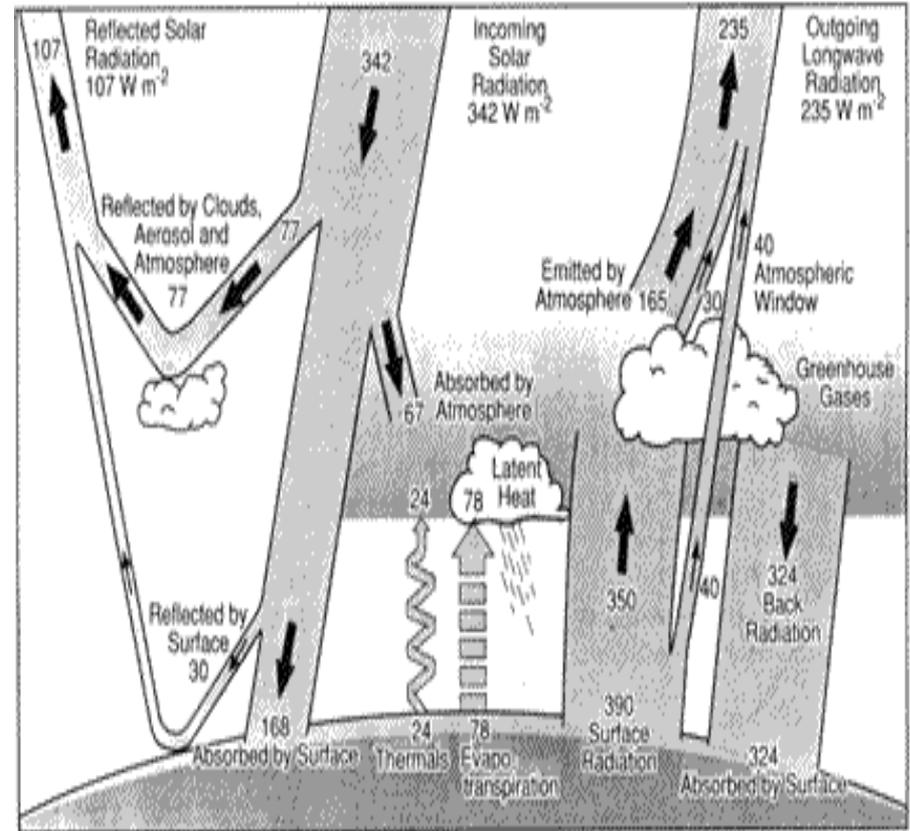
- Uma nuvem com cristais de gelo (seeder) em uma dada temperatura (ex. -14C) move sobre o topo de uma nuvem mais baixa com gotas supergeladas (ex. -6C) e precipita gelo nesta nuvem (feeder)

- **Divisão durante o processo de "riming":**

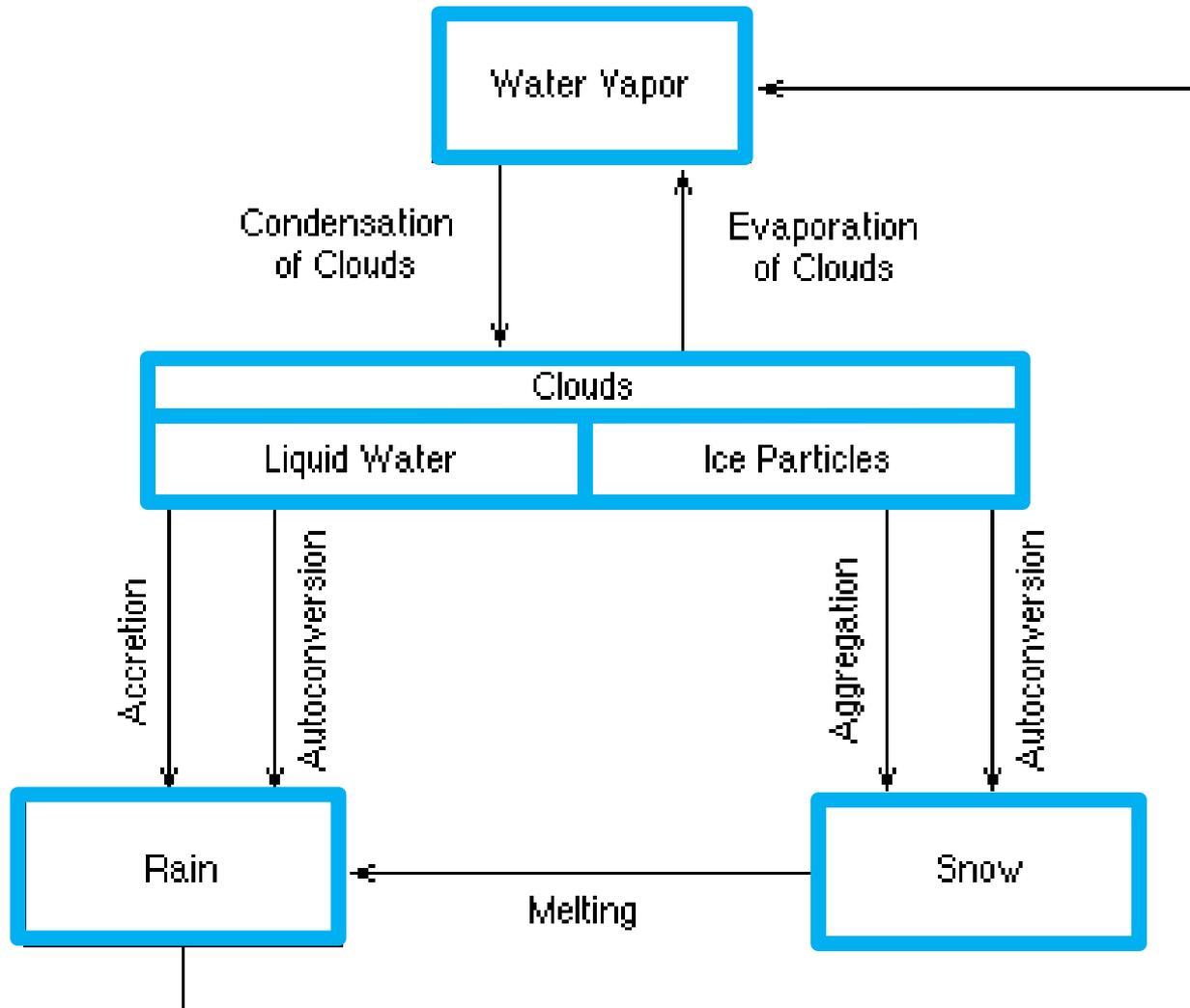
- As partículas de gelo coletam gotas supergeladas (via accretion), e o líquido inicia o congelamento. Em temperaturas próximas a -5C as gotas supergeladas iniciam o congelamento a partir da superfície para o centro da gota. A expansão devido ao congelamento do líquido interno quebra a casca formada na superfície da gota. Essa divisão produz mais IN para coletar gotas supergeladas

A Importância da Parametrização das Nuvens

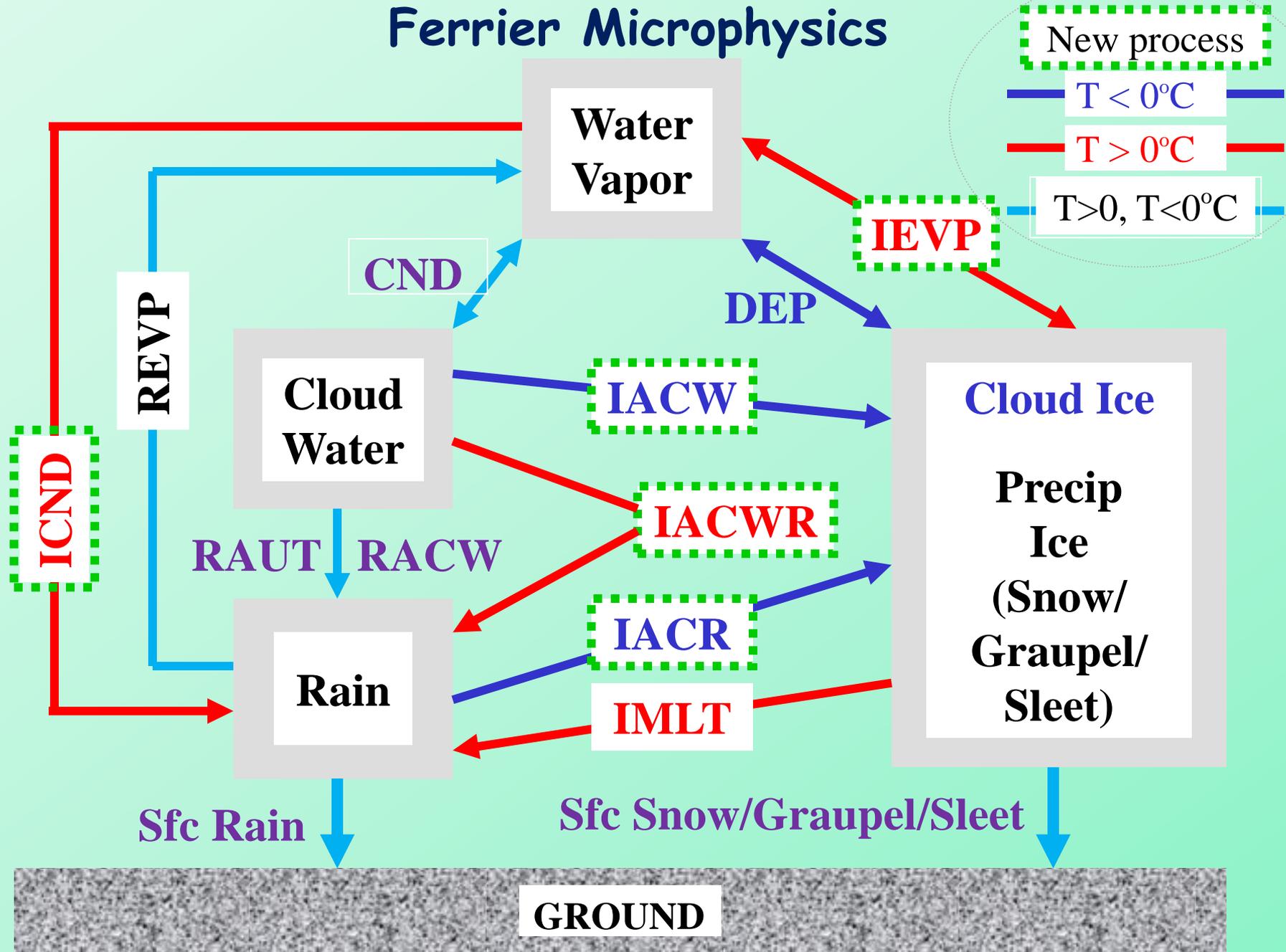
- * Presença das nuvens altera o balanço radiativo
- * Ajuste da umidade e da temperatura em pontos convectivamente estáveis.
- * Produção de precipitação para o modelo hidrológico
- * Identificação dos tipos de precipitação.



Zhao cloud microphysics



Ferrier Microphysics



Principais processos microfísicos

- RAUT: Cloud water autoconversion to rain ($T > 0$)
- RACW: Cloud water collection (accretion) by rain ($T > 0$)
- REVP: Rain evaporation ($T < 0$)
- CND: Condensation (> 0) or evaporation (< 0) of cloud water
- IDEP: Deposition (> 0) or sublimation (< 0) of ice crystals
- IACW: Cloud water collection (riming) by precipitation ice ($T > 0$)
- IACWR: Shedding of accreted cloud water to form rain ($T > 0$)
- IACR: Freezing of rain onto large ice at supercooled temp ($T > 0$)
- ICND: Condensation (> 0) onto wet, melting ice
- IEVP: Evaporation (< 0) from wet, melting ice
- IMLT: Melting ice ($T > 0$)

Conversões

Water Vapor (Qv)	Snow (Qs)	Rain (Qr)	Cloud (Qc)	Ice (Qi)
condensation	sublimation	accretion	accretion	initiation
evaporation	accretion	autoconversion	autoconversion (into rain)	sublimation
ice initiation	autoconversion (from ice)	evaporation	condensation	deposition
deposition (onto ice crystals)	freezing (from rain)	freezing (to snow)	freezing (to ice)	melting (to cloud)
	melting (to rain)	melting (from snow)	melting (from ice)	freezing cloud

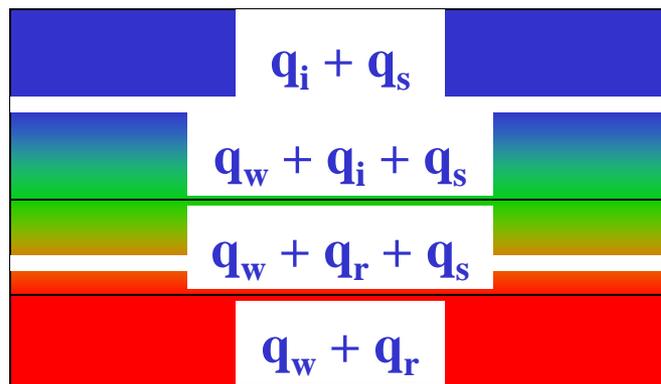
Comparação dos Esquemas de microfísica Zhao e Ferrier

FEATURE	Zhao & Carr (1997) [Modified version in GFS]	Ferrier et al. (2002) [In Eta]
Prognostic variables	Water vapor, cloud condensate (water or ice)	Water vapor, total condensate (cloud water, rain, cloud ice, snow/graupel/sleet)
Condensation algorithm	Sundqvist et al. (1989)	Asai (1965) [used in high res models]
Precip fluxes and storage	Top-down integration of precip, no storage, & instantaneous fallout.	Precip partitioned between storage in grid box & fall out through bottom of box
Precip type	Rain, freezing rain, snow	Rain, freezing rain, snow/graupel/sleet (variable rime density for precip ice)
Mixed-phase conditions	No coexistence of supercooled cloud water & ice, simple melting eqn.	Mixed-phase at $>-10^{\circ}\text{C}$, includes riming, more sophisticated melting/freezing

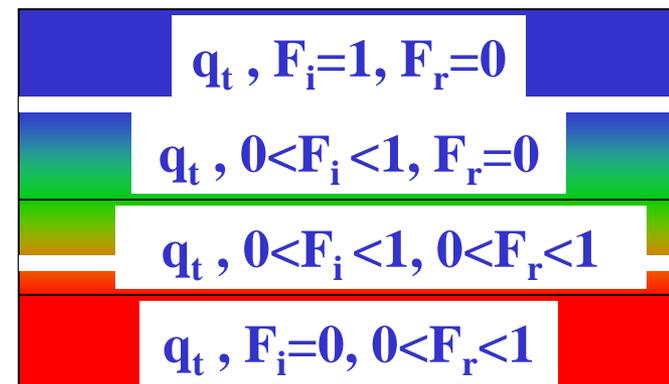
Deriving hydrometeors species from total condensate

- Water vapor (q_v), total condensate (q_t) advected in model
- Cloud water (q_w), rain (q_r), cloud ice (q_i), precip ice (“snow”, q_s) calculated in microphysics
- Local, saved arrays store fraction of condensate in form of ice (F_i), fraction of liquid in form of rain (F_r). Assumed fixed with time in column between microphysics calls. Note that $0 \leq F_i, F_r \leq 1$.
- $q_t = q_w + q_r + q_i + q_s$, $q_{ice} = q_i + q_s \Rightarrow F_i = q_{ice}/q_t$, $F_r = q_r/(q_w + q_r)$

Internal to microphysics



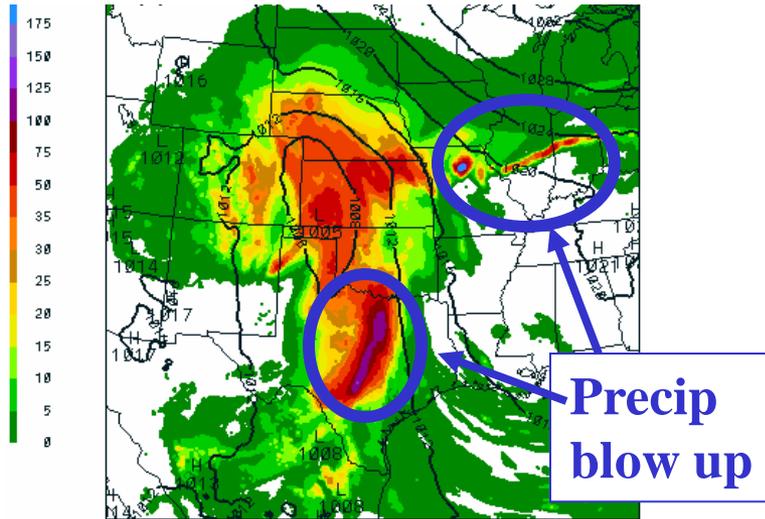
Rest of model



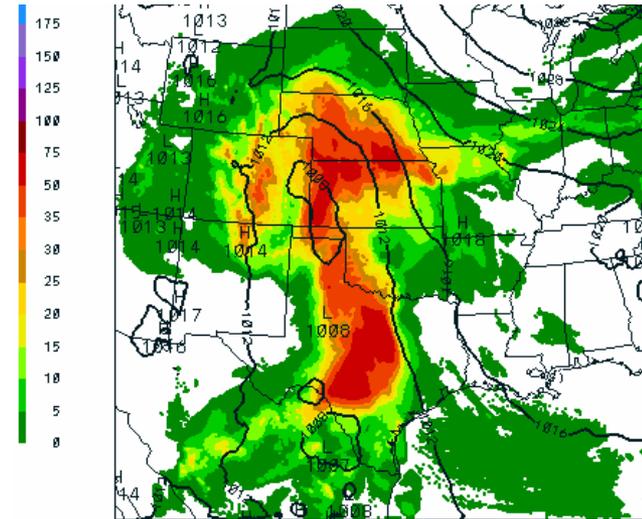
Reduced High Bias in Upper-Level Cloudiness

12Z 3 May '01 10-km Eta Central High Res Window Runs

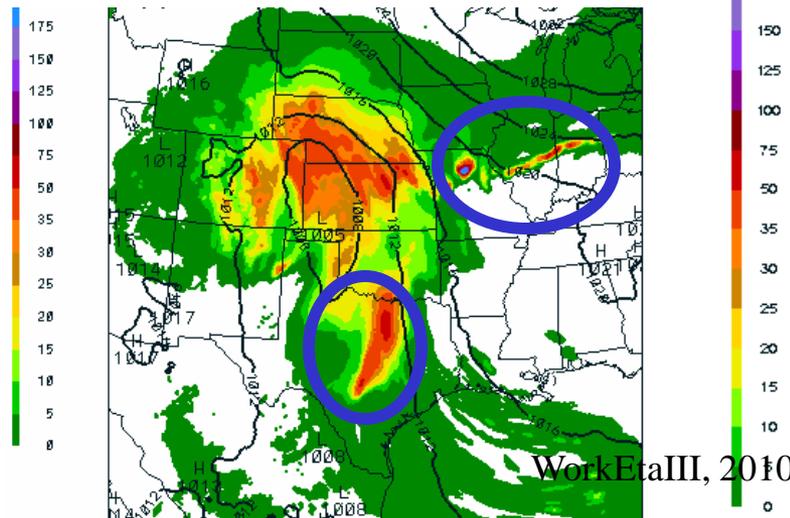
24-48h Total Precip 12Z 5/5/01 (Zhao)



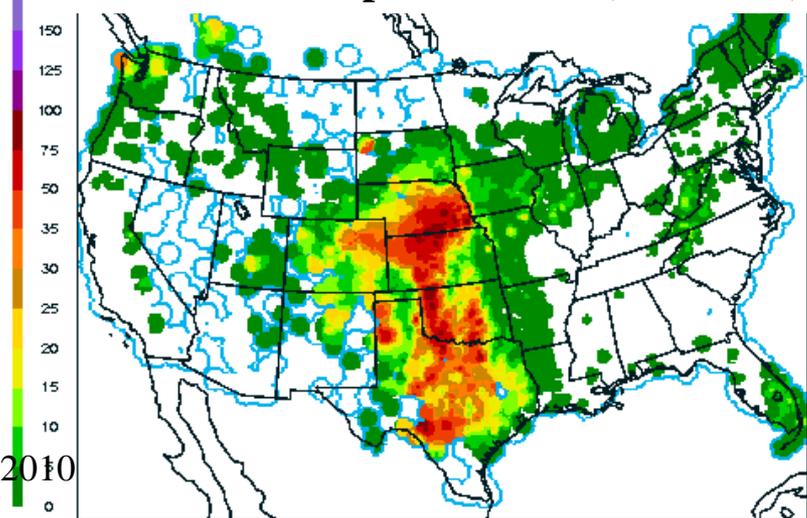
24-48h Total Precip 12Z 5/5/01 ("Ferrier")



24-48h Grid-scale Precip 12Z 5/5/01 (Zhao)



24h RFC Precip 12Z 5/5/01 (Observed)

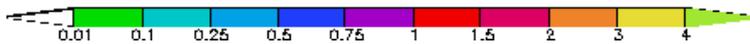
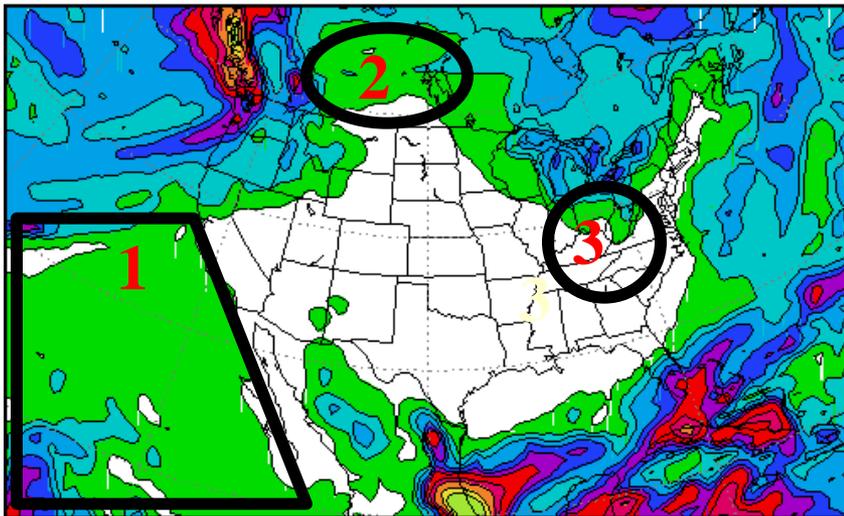


(color fill – 24h precip in mm,
contours of sfc pressure in mb)

Reduced high bias in light precipitation (areas 1, 2) & improved orographic precipitation (area 3)

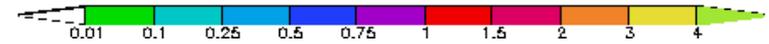
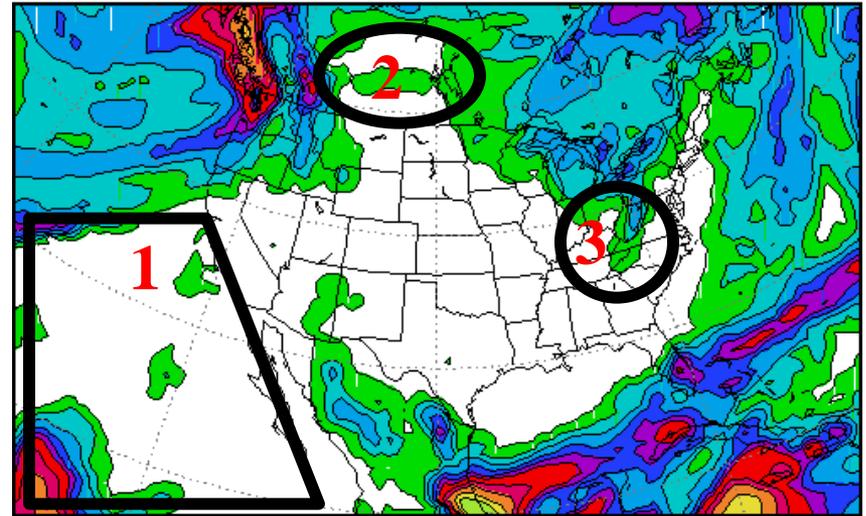
(0-60 h forecasts of accumulated precipitation in inches valid 12Z 28 Oct 2001)

60-H APCP ETA 60H FCST VALID 12Z 28 OCT 2001



22-km Eta Zhao
microphysics

60-H APCP ETA12 60H FCST VALID 12Z 28 OCT 2001



12-km Eta Ferrier
microphysics

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