The “C” in Climate

Peter Colarco

Atmospheric Chemistry & Dynamics Branch

NASA Goddard Space Flight Center

The “C” in Climate

Peter **C**olarco

Atmospheric Chemistry & Dynamics Branch

NASA Goddard Space Flight Center

The little-“o” in Operations

Peter Colarco
Atmospheric Chemistry & Dynamics Branch
NASA Goddard Space Flight Center

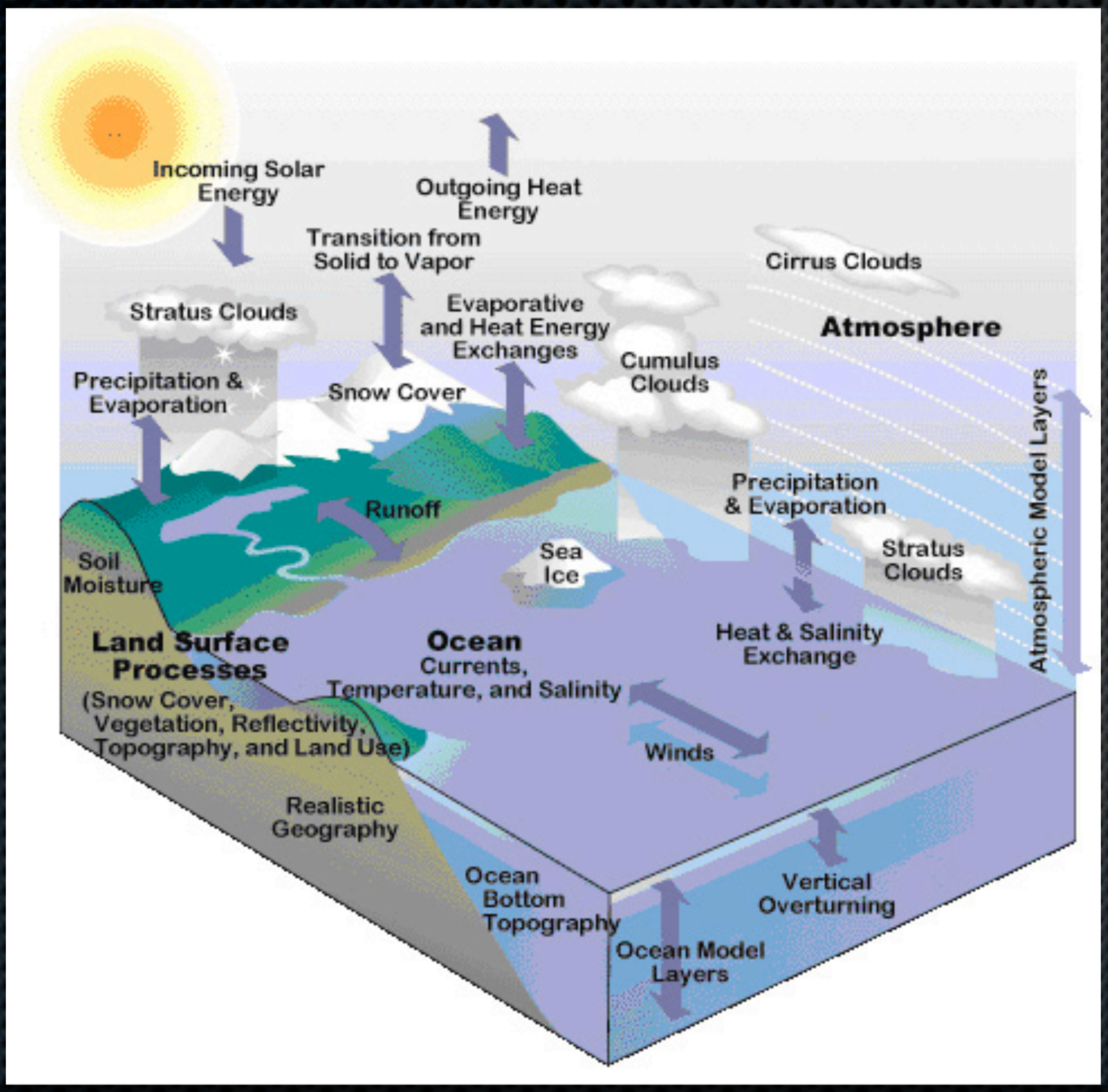
The little-“a” in Aerosol

Peter Colarco

Atmospheric Chemistry & Dynamics Branch

NASA Goddard Space Flight Center

What is a climate model?



- Coupled component representation of Earth system
- Probably a coarser resolution (and run for longer time integration) than operational forecast model

Image source: http://www.windows2universe.org/earth/climate/cli_models2.html

Aerosols

- Suspended particles or droplets (d < 10 μm)
- Cloud condensation nuclei/ice nuclei
- Redistribute radiation
- Chemistry
- Other feedbacks...

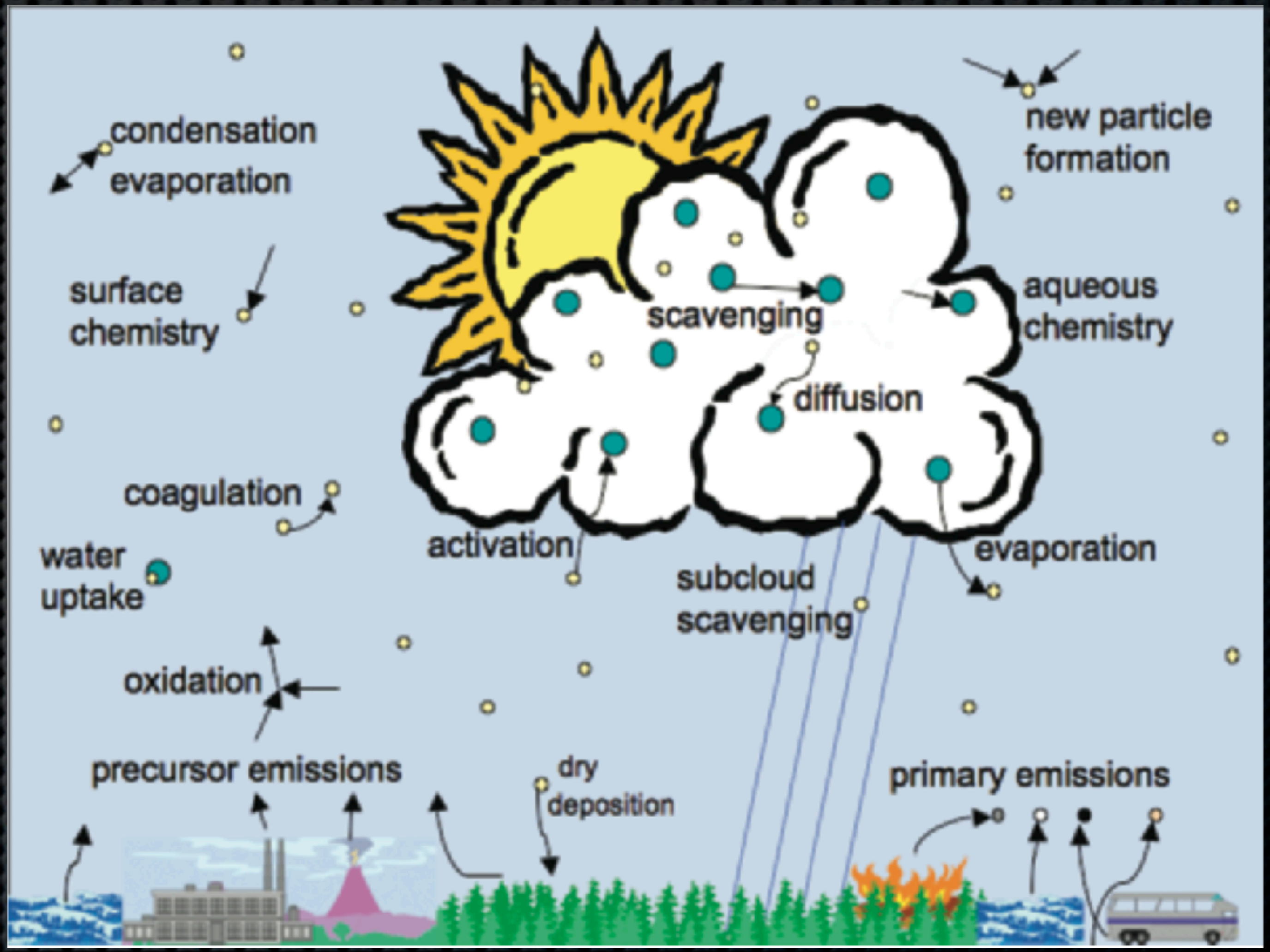


Image source: Ghan and Schwartz, “Aerosol Properties and Processes,” BAMS, July 2007

Aerosol Properties

Table 2. Treatment of aerosol properties in fourth-, fifth-, and sixth-generation climate models.

	Treatment		
Property	Fourth generation	Fifth generation	Sixth generation
Mass concentration and composition	Sulfate interactive (online) with climate model dust, sea salt, hydrophilic and hydrophobic OC and BC prescribed from offline aerosol model simulations	Interactive sulfate, dust, sea salt, hydrophilic and hydrophobic OC, BC, nitrate, ammonia	As for fifth generation
Size distribution	Prescribed for each aerosol type except dust; multiple sizes for dust and perhaps sea salt	Variable for each aerosol type (modal)	Variable (sectional, QMOM, or piecewise log-normal)
Mixing state	External	Internal and external mixtures	As for fifth generation
Refractive index	Prescribed	Volume average	Volume average treatment of inclusions
Optical properties	Prescribed, for each aerosol type; function of RH	Parameterized in terms of bulk refractive index and wet effective radius	As for fifth generation
Hygroscopicity	Prescribed	Volume average	Thermodynamic equilibrium
CCN spectrum	Empirical	Köhler theory for external mixtures of internally mixed inorganic and soluble organic salts	As for fifth generation, plus weakly soluble organics and surfactants

Image source: Ghan and Schwartz, “Aerosol Properties and Processes,” BAMS, July 2007

Processes

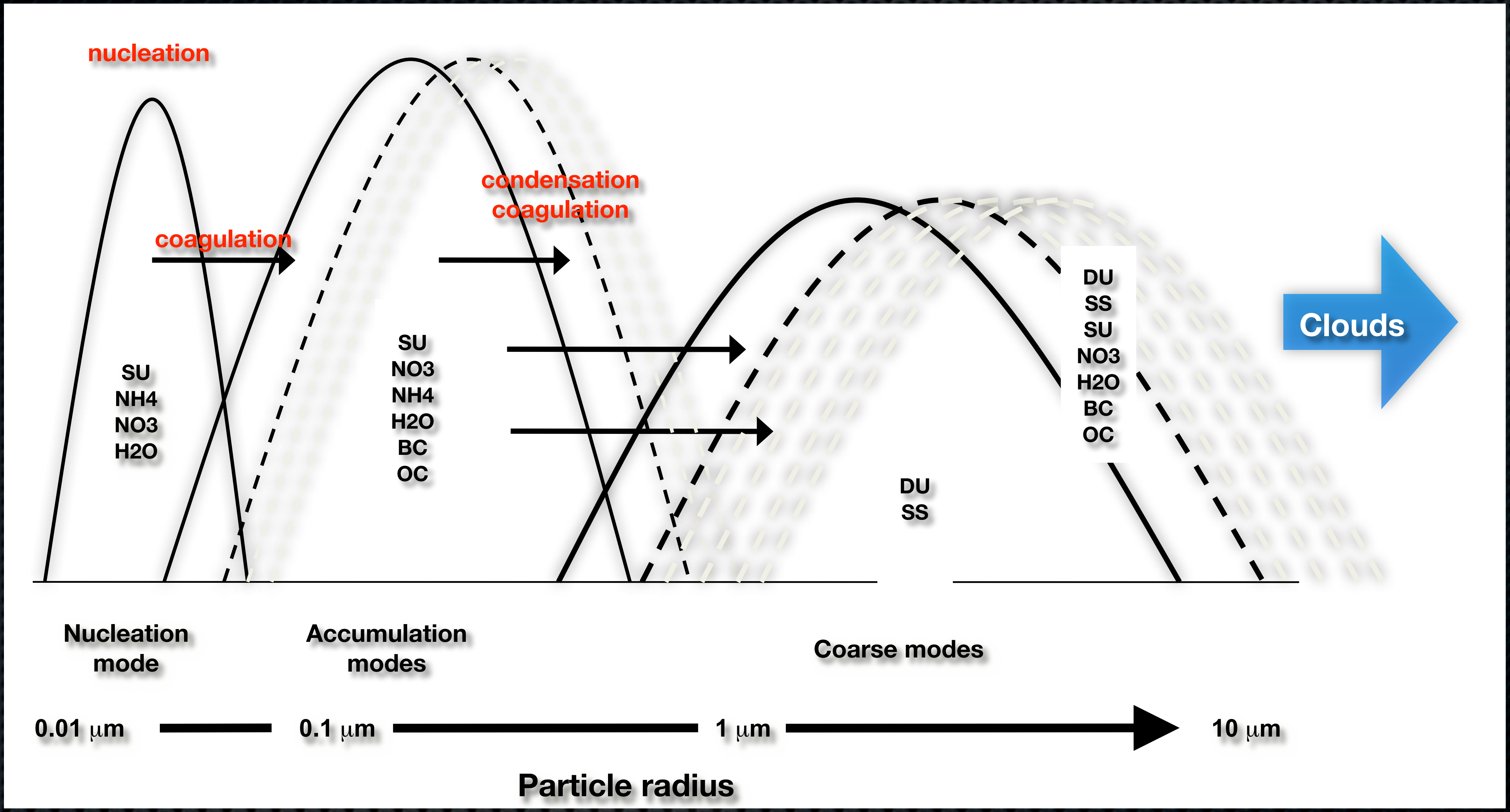
- Emissions
- Chemistry
- Nucleation
- Condensation
- Coagulation
- Clouds
- Loss mechanisms

Table 3. Treatment of aerosol processes in fourth-, fifth-, and sixth-generation climate models.

	Treatment		
Process	Fourth generation	Fifth generation	Sixth generation
Primary emissions	Prescribed for all species	Sea salt, dust emissions depend on wind speed in host model; also on soil moisture for dust	Sea salt, dust emissions depend on wind speed in host model; also on soil moisture for dust; emission from fires depends on area burned, fuel load, burning efficiency, and emissions factors for each species.
Precursor emissions	Prescribed for all precursor gases	DMS emissions depend on wind speed in host model	DMS emissions depend on wind speed and ocean chemistry in host model
Oxidation of precursors	Reaction of SO_2, DMS with prescribed oxidant concentrations Instantaneous oxidation of VOC with prescribed yield	Reaction of all precursors with oxidants whose concentrations are calculated in the model Multiple hydrocarbon groups Dependence of yield on total organic aerosol	New hydrocarbon treatment
New particle formation	Neglected	Binary homogeneous nucleation	Ternary nucleation ammonia, organics
Condensation of oxidized precursor gases	Instantaneous condensation	Size-dependent mass transfer treatment	As for fifth generation
Coagulation	Neglected	Brownian coagulation within and between modes	As for fifth generation
Evolution of hygroscopicity of BC, OC and dust ("aging")	Prescribed hydrophobic-to-hydrophilic conversion time for BC and OC, neglected for dust	Separate treatment of coagulation and condensation effects for BC and OC, condensation effects for dust	Separate treatment of coagulation, condensation, surface chemistry effects
Water uptake	For external mixtures only; no hysteresis in most models; equilibrium	Internal and external; hysteresis treated	Kinetic effects
Aerosol activation	Prescribed number activated	Maximum supersaturation and number activated parameterized in terms of updraft velocity and external mixtures of internally mixed inorganic and soluble organic salts.	Kinetic effects; activation to ice crystal
Aqueous phase reactions in clouds	Bulk treatment (same for all cloud droplets) pH dependence for prescribed ratio of ammonia/sulfate; poorly constrained cumulus cloud fraction	Bulk treatment (same for all cloud droplets); pH dependence for variable ratio of ammonia/sulfate; physically based stratiform and cumulus cloud fraction	Size-dependent cloud drop composition; reactions in hydrated aerosol
Convective transport and removal	Cumulus parameterization Poorly constrained precipitating area	Cumulus parameterization with physically based precipitating area	Statistics from embedded cloud models
In-cloud scavenging	Autoconversion and precipitation rate independent of aerosol Cloud-borne aerosol equals activated aerosol	Autoconversion and precipitation rates depend on aerosol Influence of collision/coalescence on cloud drop number concentration and cloud-borne aerosol; subgrid variability in autoconversion	Statistics from embedded cloud models with microphysics dependent on aerosol scavenging by ice crystals
Subcloud scavenging	Prescribed scavenging efficiency	Size-dependent collection efficiency	Aerosol from evaporated raindrops; precipitation statistics from embedded cloud models

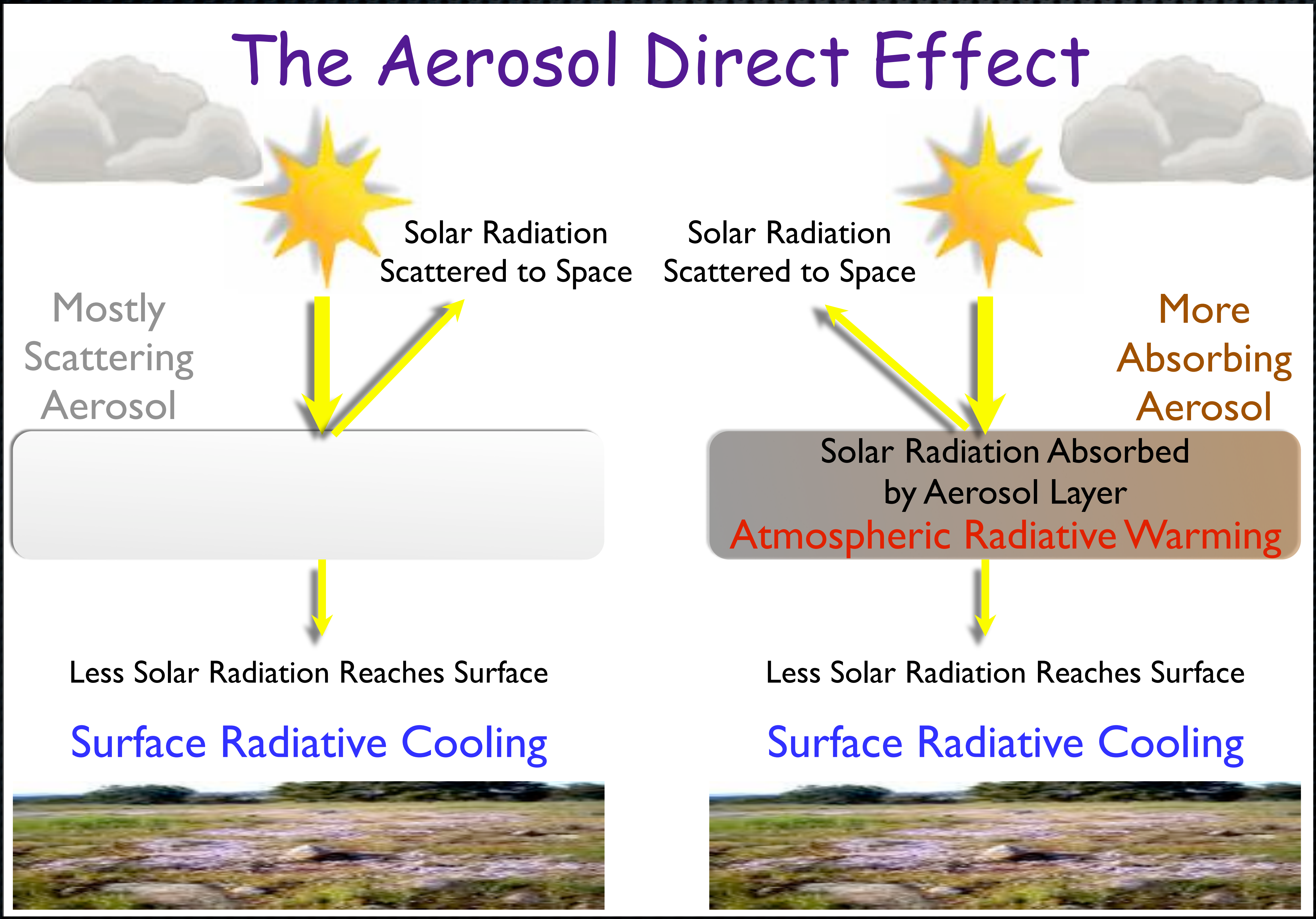
Image source: Ghan and Schwartz, "Aerosol Properties and Processes," BAMS, July 2007

Aerosol Microphysical Models

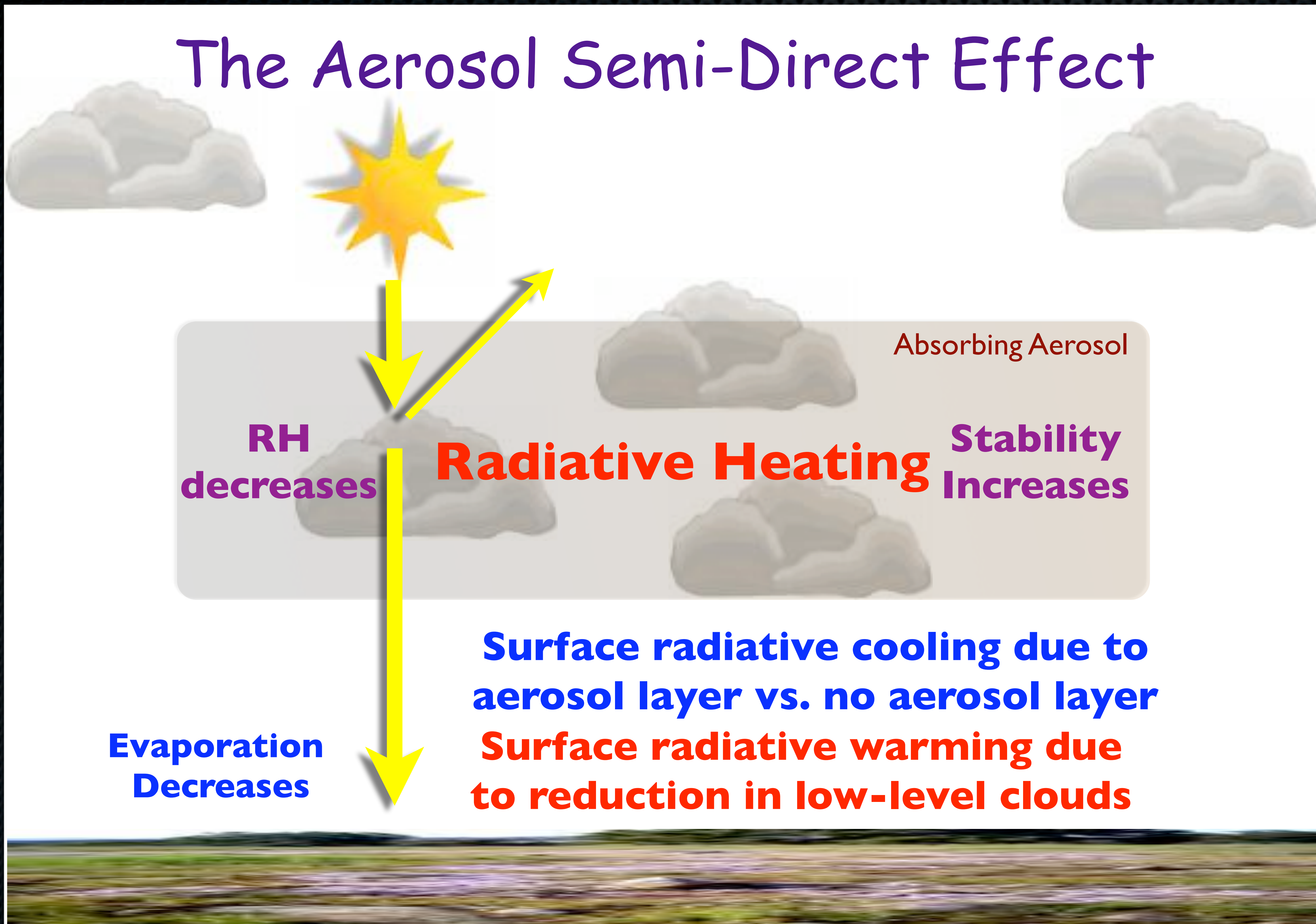


Bauer et al, "The Multiconfiguration Aerosol TRacker of mIXing state MATRIX, an aerosol microphysical module for global atmospheric models," ACP, 2008.

"Classical" Aerosol Climate Interactions

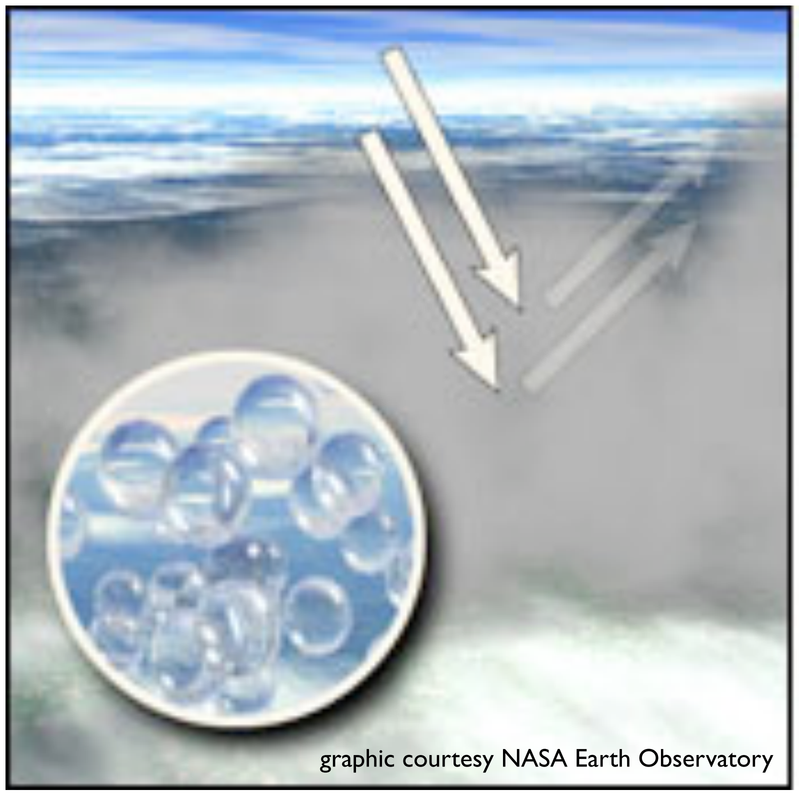


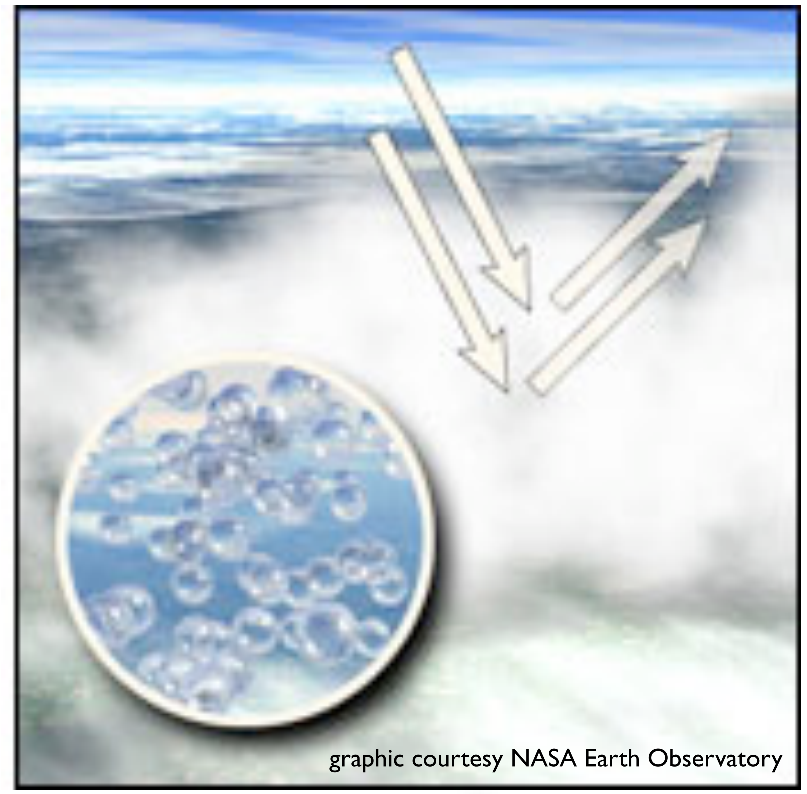
“Classical” Aerosol Climate Interactions



“Classical” Aerosol Climate Interactions

The Aerosol Indirect Effect





Larger cloud droplets, less reflective cloud. → **Twomey Effect** → Smaller cloud droplets, more reflective cloud.

Less Aerosols → **More Aerosols**

Larger cloud droplets, droplets rain out easier, clouds dissipate quicker. → **Albrecht Effect** → Smaller cloud droplets, droplets rain out less, longer-lived clouds.

Anthropogenic Direct Forcing

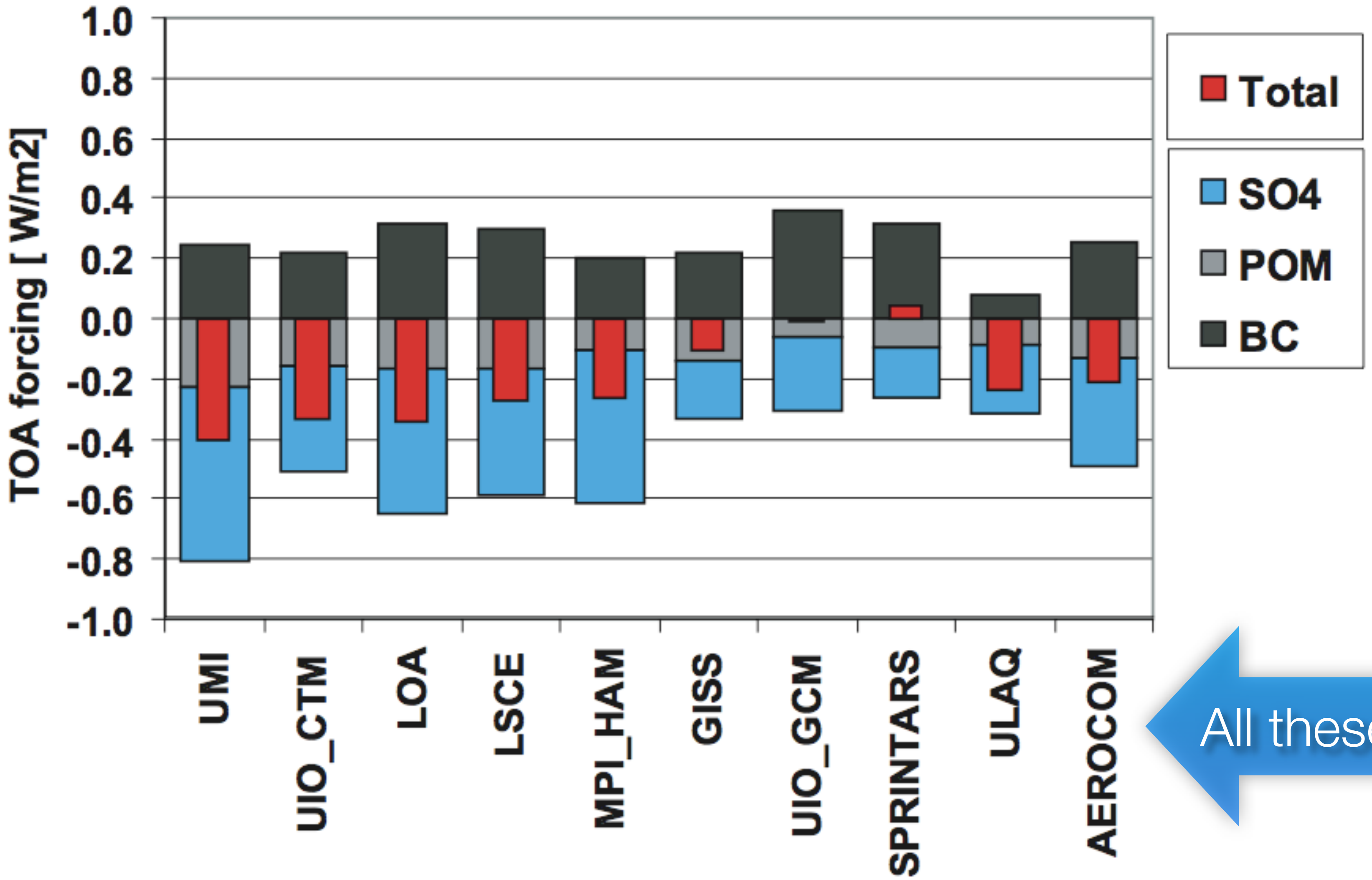


Fig. 2. Direct aerosol forcing for the three major anthropogenic aerosol components sulphate, black carbon and particulate organic matter in the AeroCom models. Shown on top in red is also the total direct aerosol forcing as diagnosed from a full aerosol run.

Model Δ

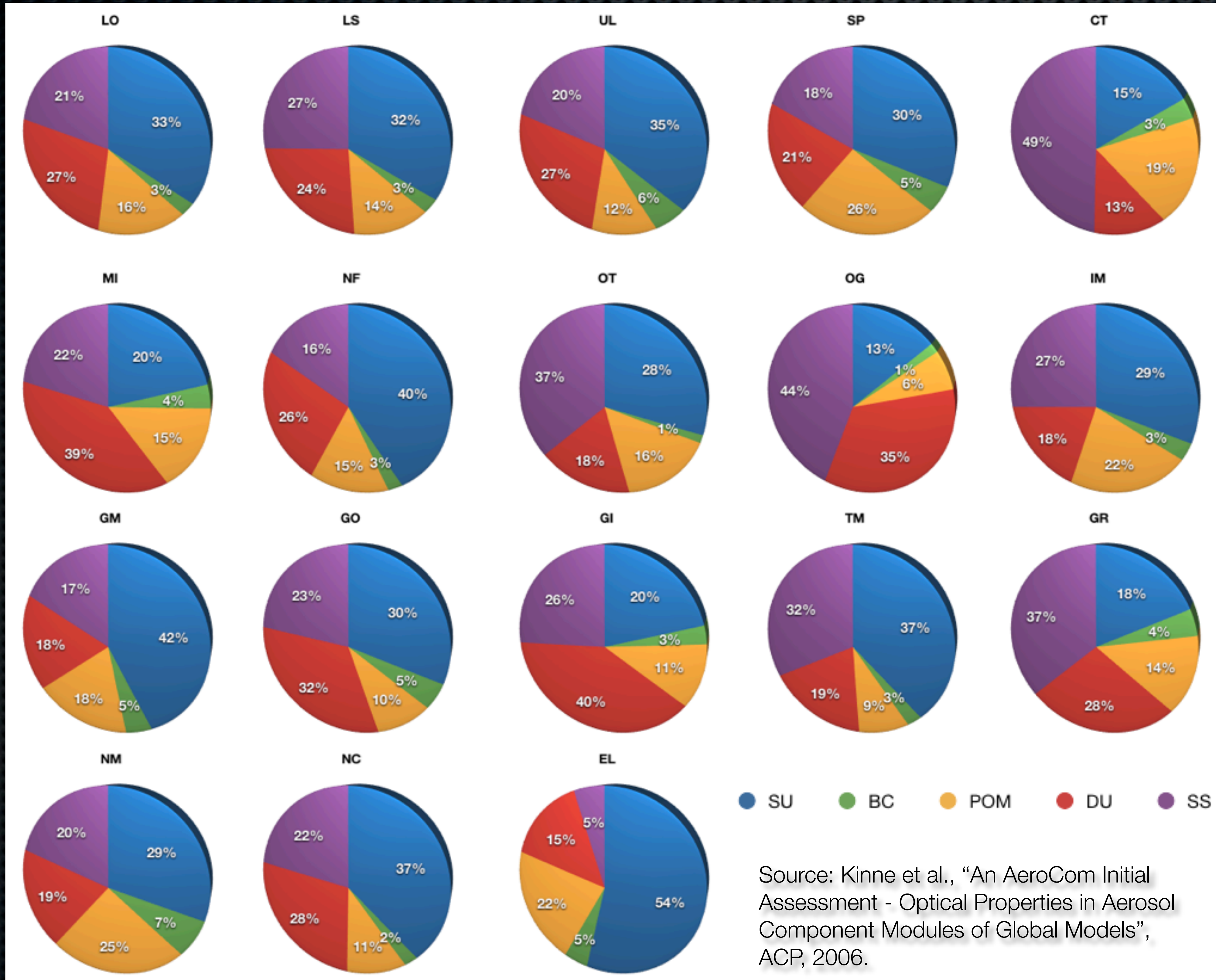
burdens (M_{SO4} = 0.6 - 1.8 Tg)
lifetimes (τ_{SO4} = 2.3 - 5.1 days)
optics (β_{ext} = 4.5 - 12.3 m^2 g^{-1})

Also: surface reflectance, asymmetry parameter

All these models have same emissions!

Schulz et al. 2006, Radiative forcing by aerosols as derived from the AeroCom present-day and pre-industrial simulations, Atmos. Chem. & Phys., 6, 5,225 - 5,246.

Component AOT



Source: Kinne et al., “An AeroCom Initial Assessment - Optical Properties in Aerosol Component Modules of Global Models”, ACP, 2006.

Summary

- Aerosols = complicated
- State of modeling: total AOT pretty well constrained
- Even a relatively straightforward climate problem (direct effect) is poorly constrained
- Requirement of additional measurements to constrain, e.g., size/composition distribution, absorption, vertical structure, etc.
- And there's clouds, chemistry, etc...