GLOMAP-Mode Aerosol in UKCA.

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The Global Aerosol Distribution

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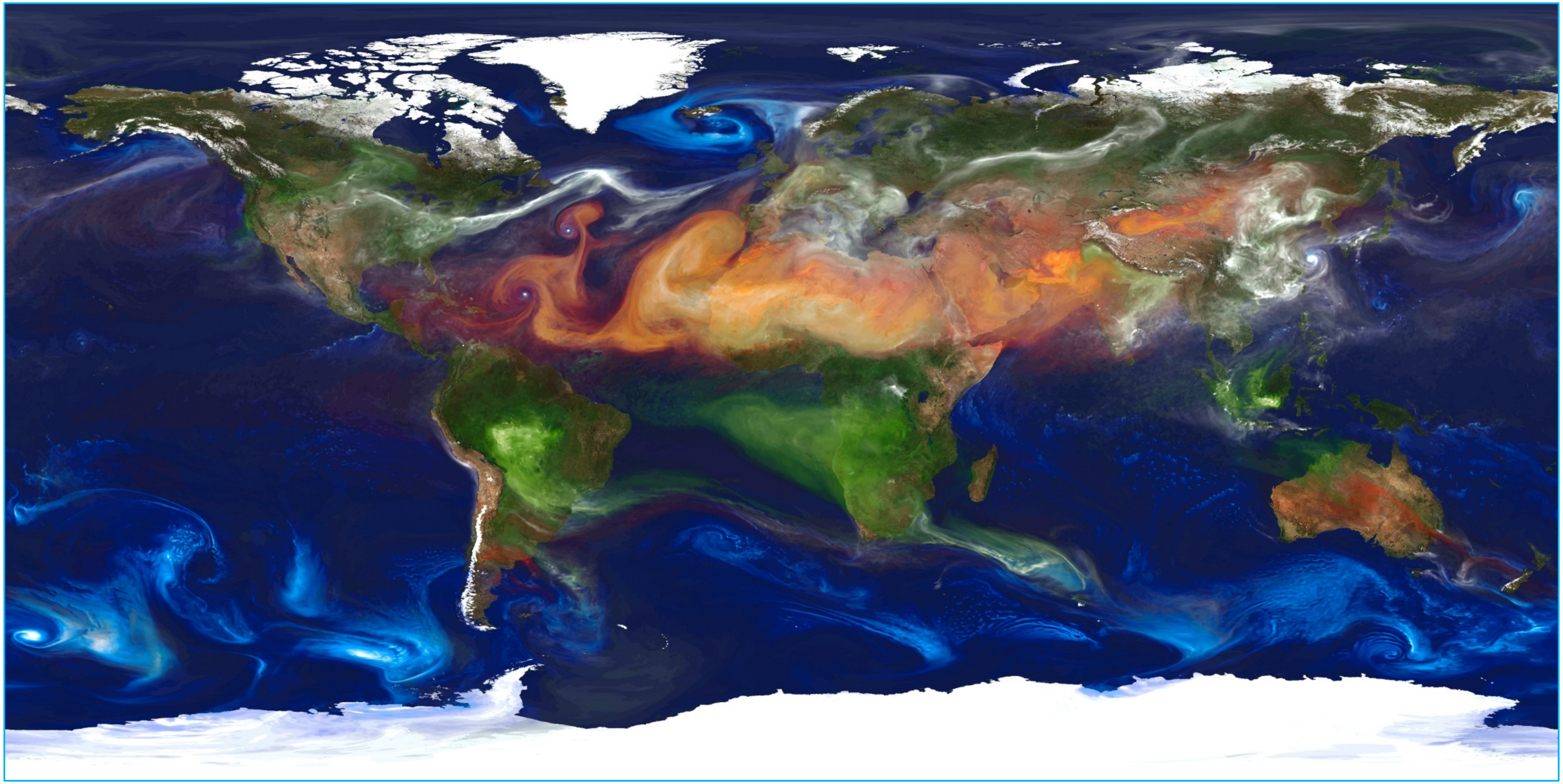

NASA: A portrait of global aerosol.
Composite of satellite and model data.

Green: Smoke, Orange: Dust
Blue: Sea spray, White: Sulfates

Why model aerosol?

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Direct forcing

- Aerosol can absorb and scatter solar radiation.

Indirect forcing

- Aerosol can act as cloud condensation nuclei and change cloud brightness and lifetime.

Atmospheric chemistry

- Aerosol provide a surface area for chemical reactions.

Biogeochemical cycles

- Aerosols interact with living species in many ways, e.g. some aerosol provide nutrients to nutrient poor regions.

Health Effects

- Increases in aerosol concentration linked to increased likelihood of cancer and heart disease.

Build Your Own Global Aerosol Model

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Model design needs to consider the degree of representation necessary to represent this complexity with **sufficient** accuracy.

Challenge 1: Large range in aerosol sizes, particles range from a few nanometers (1E-9 m) to tens of micrometers (1 μm is 1E-6 m).

Example measured size distribution.

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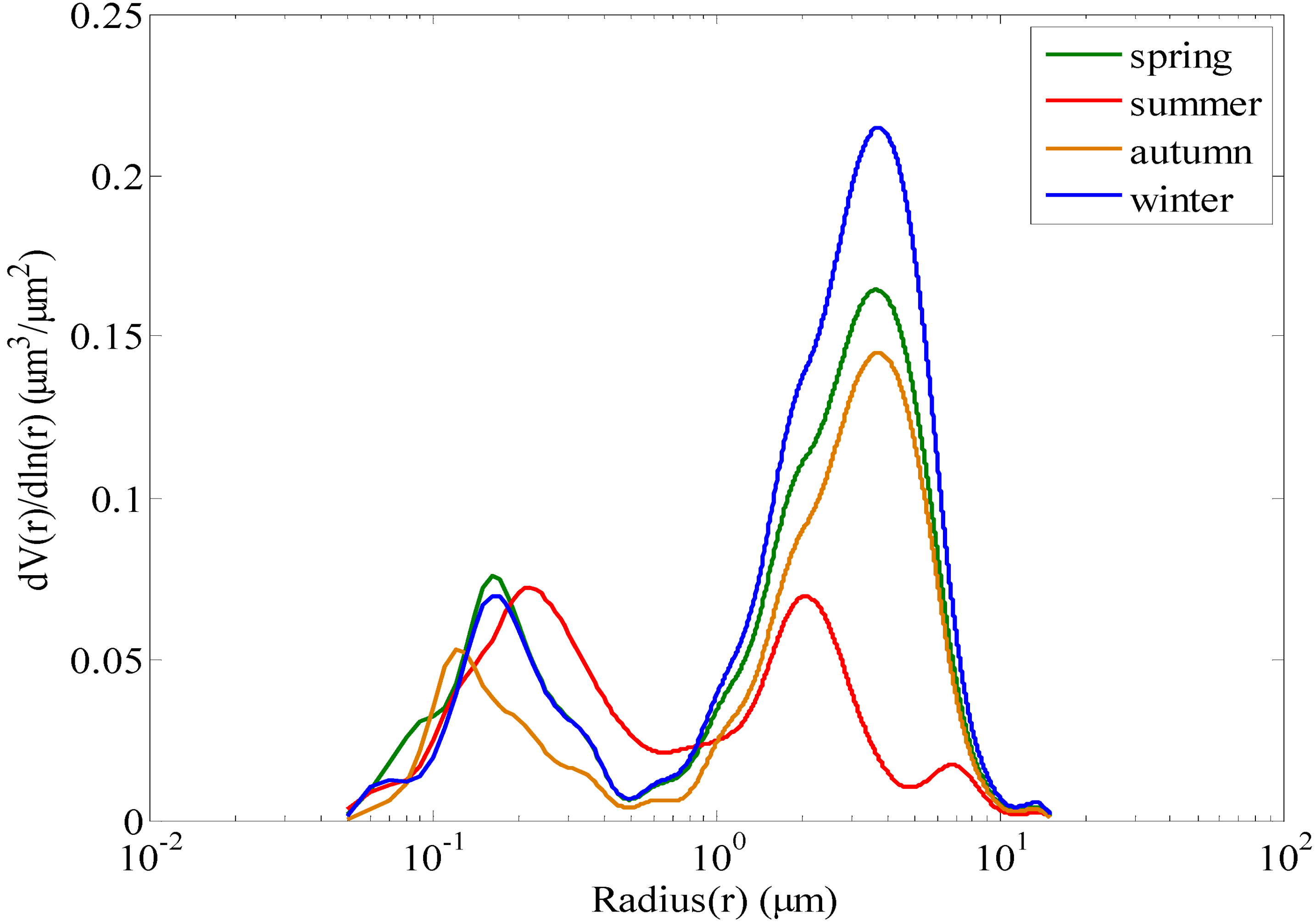
Measured aerosol size distribution in Wuhan, China



Seasonal variations of aerosol size distributions in Wuhan (China)

Wei Gong, Shanshan Zhang and Yingying Ma, *Atmosphere* 2014, *5*(1), 81-91

Representing the aerosol size distribution

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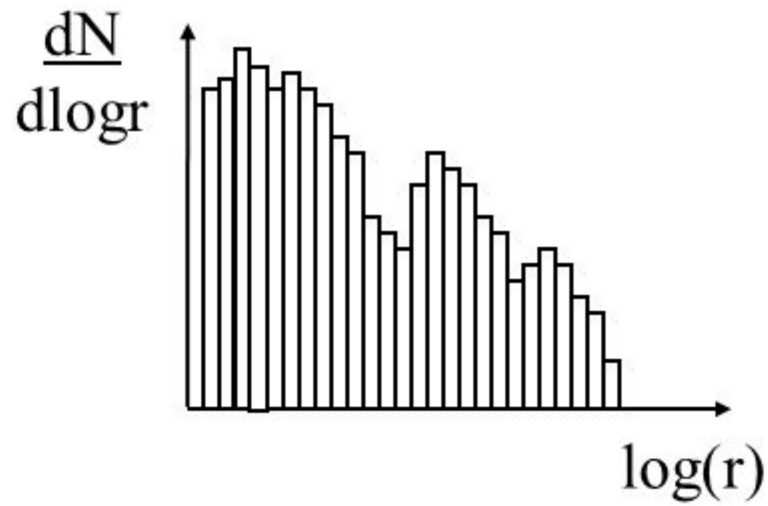
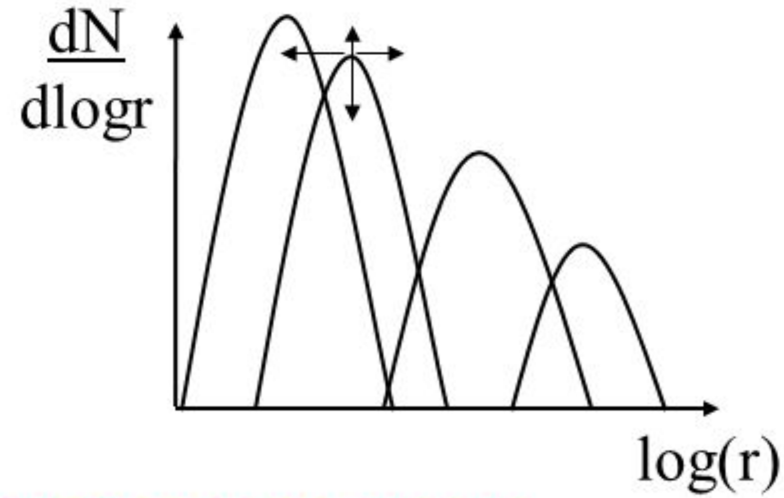
Sectional or Bin Schemes

- Divide the range of aerosol sizes into a number of **interacting** sections (or bins)
- No assumptions are made about the shape of the distribution
- Bins can have one or two prognostic variables
- Too computationally expensive for ESMs.



Modal Schemes

- Represent the size distribution using a number of interacting log normal distributions.
- Cannot capture some potential detail in the distribution.
- Each mode have two prognostic variables (mass and number)
- Computationally cheaper



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Challenge 2: Particles vary in composition – different species mix together.

Modelling the aerosol size distribution

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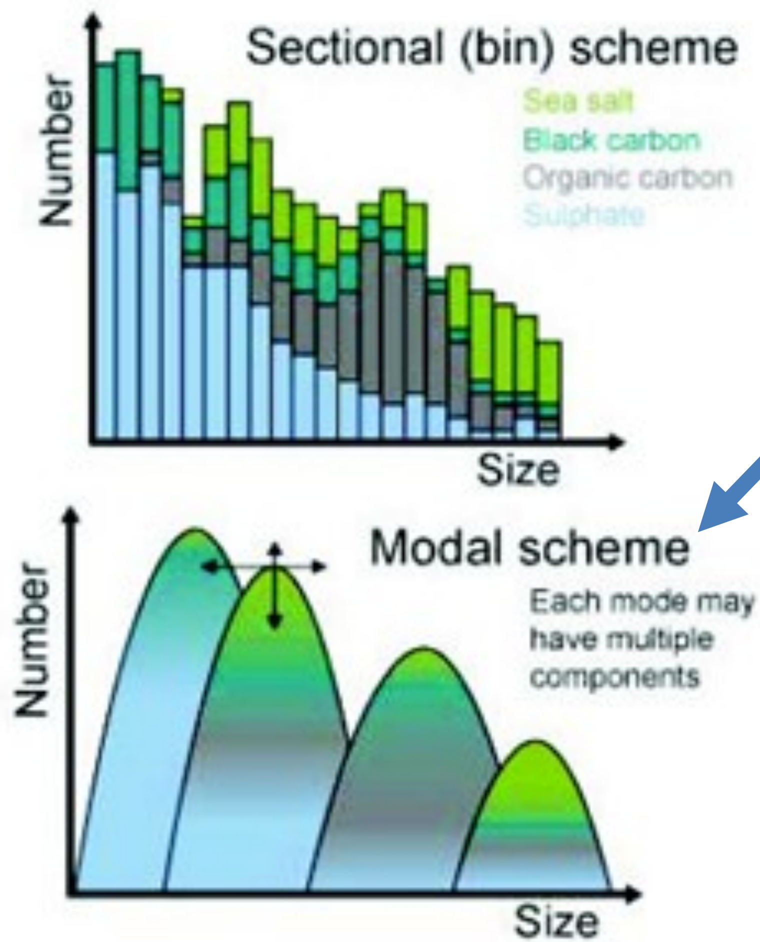

UKCA: Uses GLOMAP-Mode aerosol.

- 7 interacting lognormal modes
- 2 distributions (hydrophilic and hydrophobic)
- Composition can vary between modes.
- Composition is uniform within a mode.
- Some rules about species permitted in each mode.

Limitations:

- Cannot account for different composition within a species.
- Assumes a degree of instantaneous mixing.
- Mode width is fixed.

Schematic GLOMAP-Mode size distribution.

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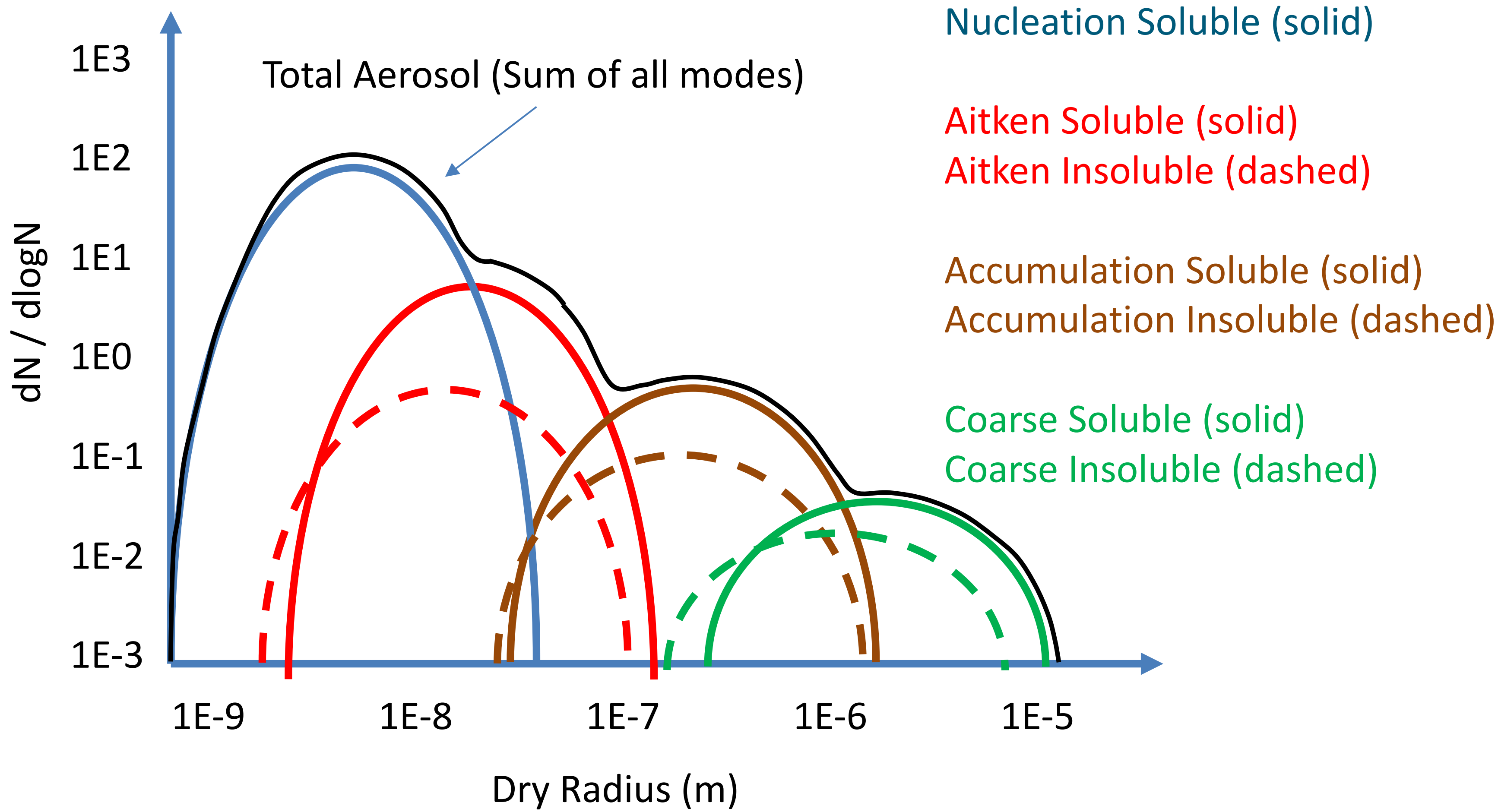

Each gridbox contains information on the mass, radius and composition of each of the 7 modes; can recreate an simulated aerosol size distribution.

Chemical Species Simulated

Standard setup of UKCA treats 5 chemical species:

1. Sulfate aerosol (SU)

2. Organic carbon (OC)

3. Black carbon (BC)

4. Sea salt (SS)

5. Dust (DU)

“Standard” UKCA Aerosol Scheme

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Mode name	Mean rad range nm	Species Permitted in Mode	Production / Emission
Nucleation Soluble	< 5	SO4	SO4: Nucleation
Aitken Soluble	5 -50	SO4, BC, OC	BC, OC: Primary Emission
Accumulation Soluble	50 – 500	SO4, BC, OC, SS, DU	SS: Primary Emission
Coarse Soluble	> 500	SO4, BC, OC, SS, DU	SS: Primary Emission
Aitken Insoluble	5 – 50	BC, OC	BC, OC: Primary Emission
Accumulation Insoluble	50 – 500	BC, OC, DU	DU: Primary Emission
Coarse Insoluble	> 500	BC, OC, DU	DU: Primary Emission

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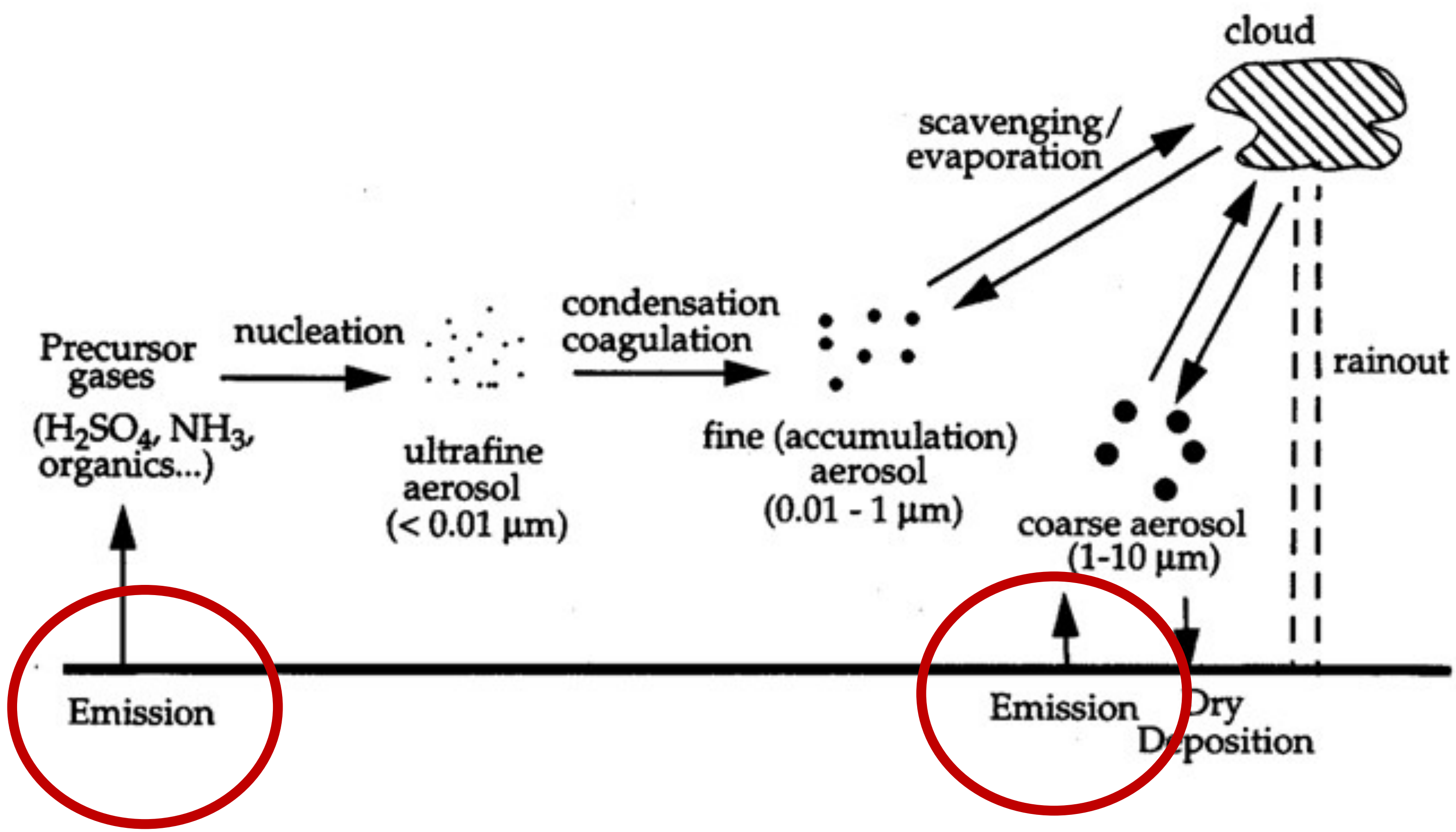
Challenge 2: Particles vary in composition – different species mix together.

Challenge 3: Microphysical processes change the aerosol size distribution.

Processes controlling and shaping the size distribution.



Jacob, Introduction to Atmospheric Chemistry, 2000.

Primary Emission

Off line emissions read in from ancillary files

- Gas phase sulfur species: DMS, SO_2 (natural and anthropogenic) are read in from ancillary files.
- A fraction of the SO_2 is assumed to be particulate (Aitken / accumulation size).
- Black and Organic Carbon: biofuel, fossil fuel and wildfires into Aitken model
- BC / OC emitted into Aitken mode. Sensitivity of results to assumed size.

Online emissions, calculated in the model

Sea spray:

- Calculated as a function of wind speed.
- Emitted into the accumulation and coarse soluble modes
- Future work will include submicron (Aitken mode) sea spray.

Mineral Dust

- Calculated depending on wind speed and soil moisture, land type (Woodward).
- Often dust is carried in 6 bins, that do not interact with the other species. Can also be treated in UKCA-Mode.

Processes controlling and shaping the size distribution.

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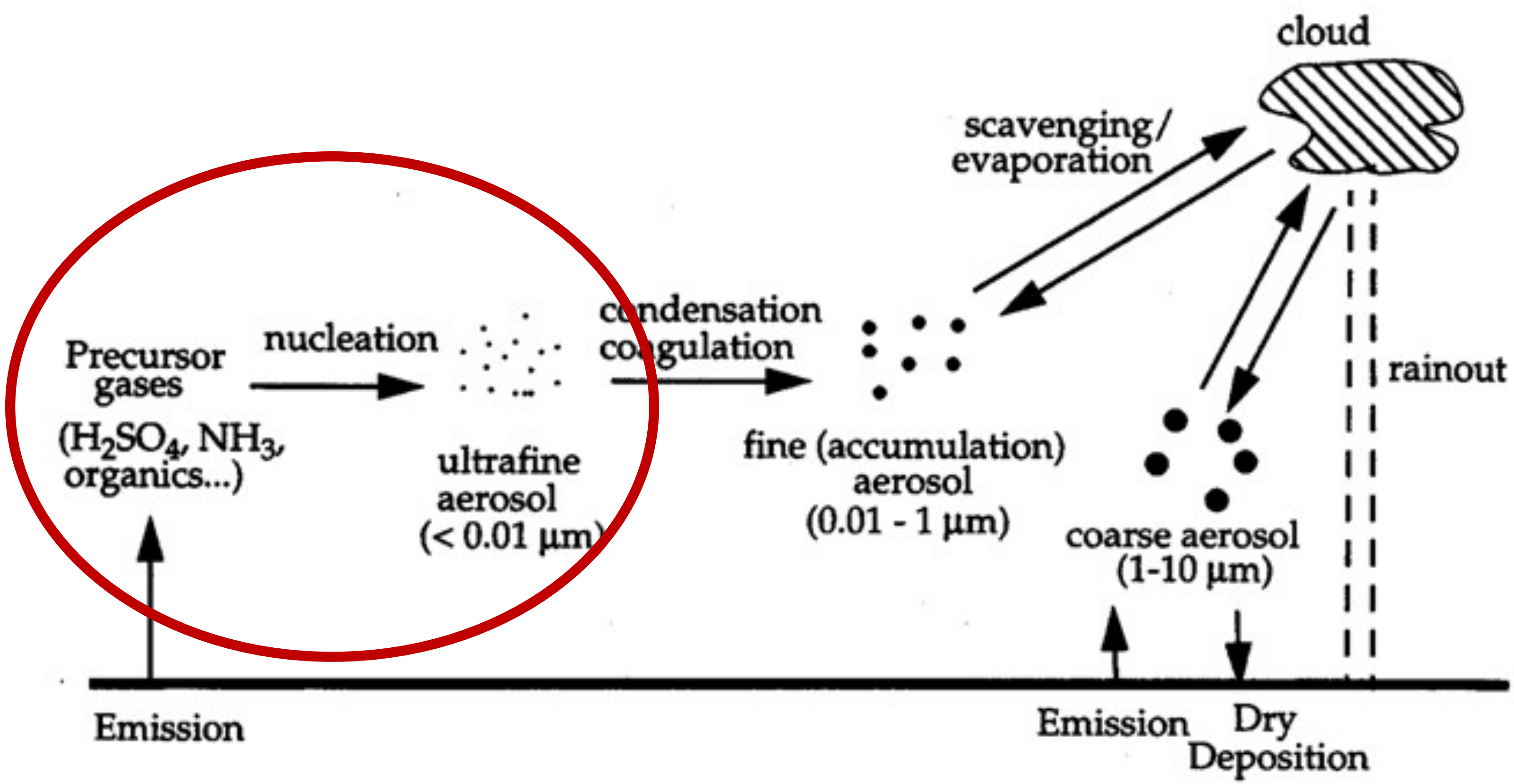

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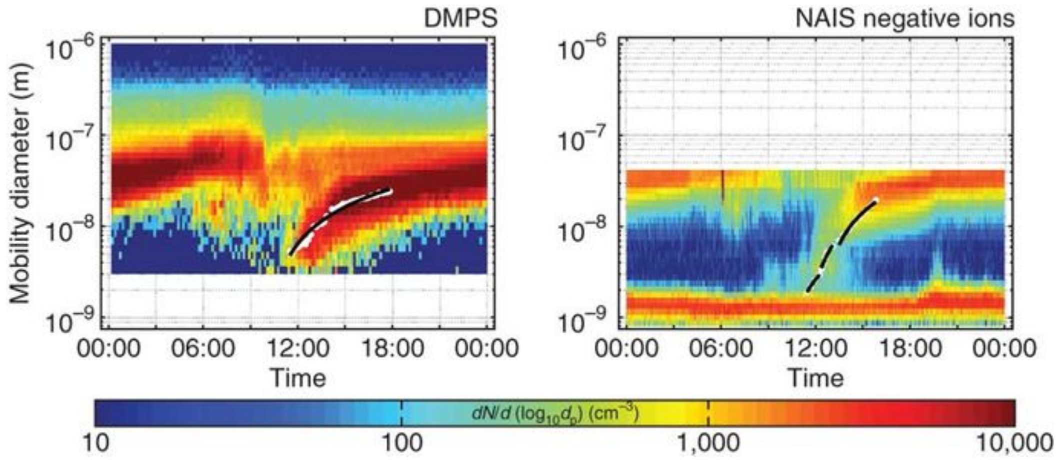
Nucleation

Upper Tropospheric Nucleation

- In the cold, clean, air of the upper troposphere semi-volatile gases can nucleate new aerosol particulates.
- Vehkamaki et al (2002), Kulmala et al (1998)

Boundary Layer Nucleation

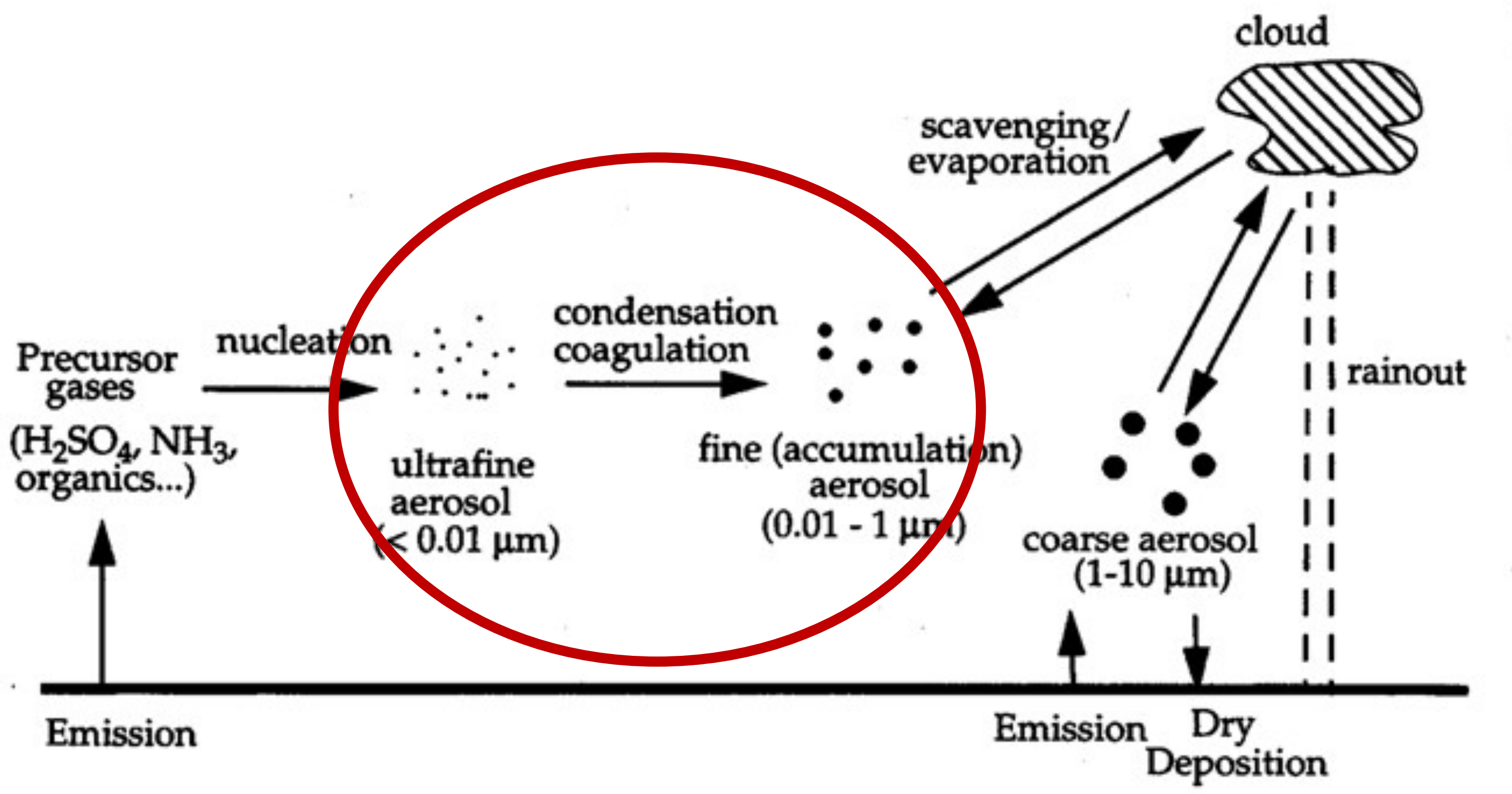
- Thought to involve additional vapours, e.g. organics and or ammonia.
- Metzger (2010), Paasonen (2010), Spracklen (2008)



Kulmala 2012

UKCA: logical switches are used to choose / combine nucleation parameterisations.

Processes controlling and shaping the size distribution.

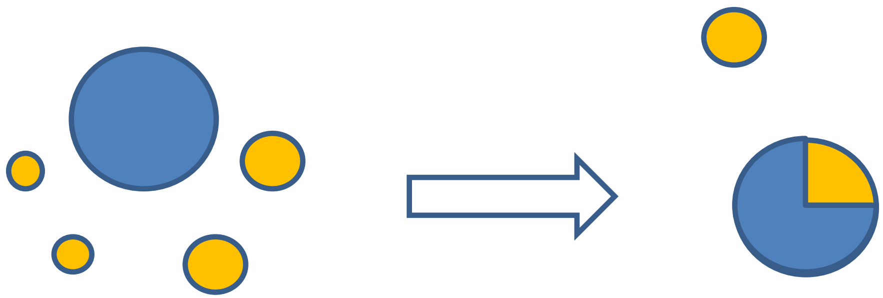


Jacob, Introduction to Atmospheric Chemistry, 2000.

Growth: Condensation & Coagulation

Coagulation:

- Reduces the number of aerosol; forms fewer larger particles.
- Can be represented numerically, modal scheme makes assumptions about mixing state.



Condensation

- Semi-volatile compounds preferentially condense onto the surface of pre-existing aerosol particles.
- Doesn't increase particle number, but does increase particle size.

Coagulation and condensational growth also change the aerosol composition; can move aerosol from the insoluble to the soluble distribution.

Processes controlling and shaping the size distribution.

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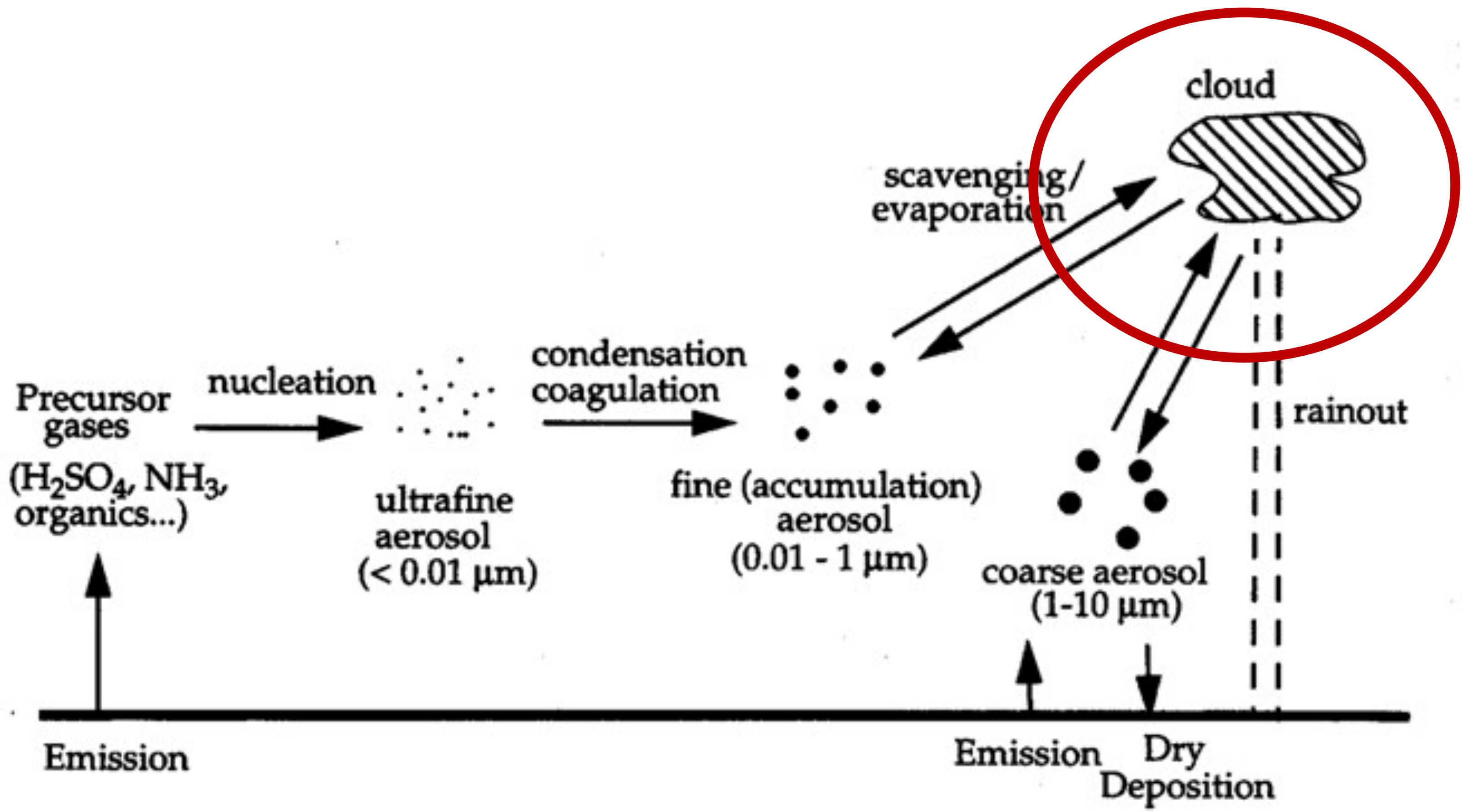

Jacob, Introduction to Atmospheric Chemistry, 2000.

In-cloud processing

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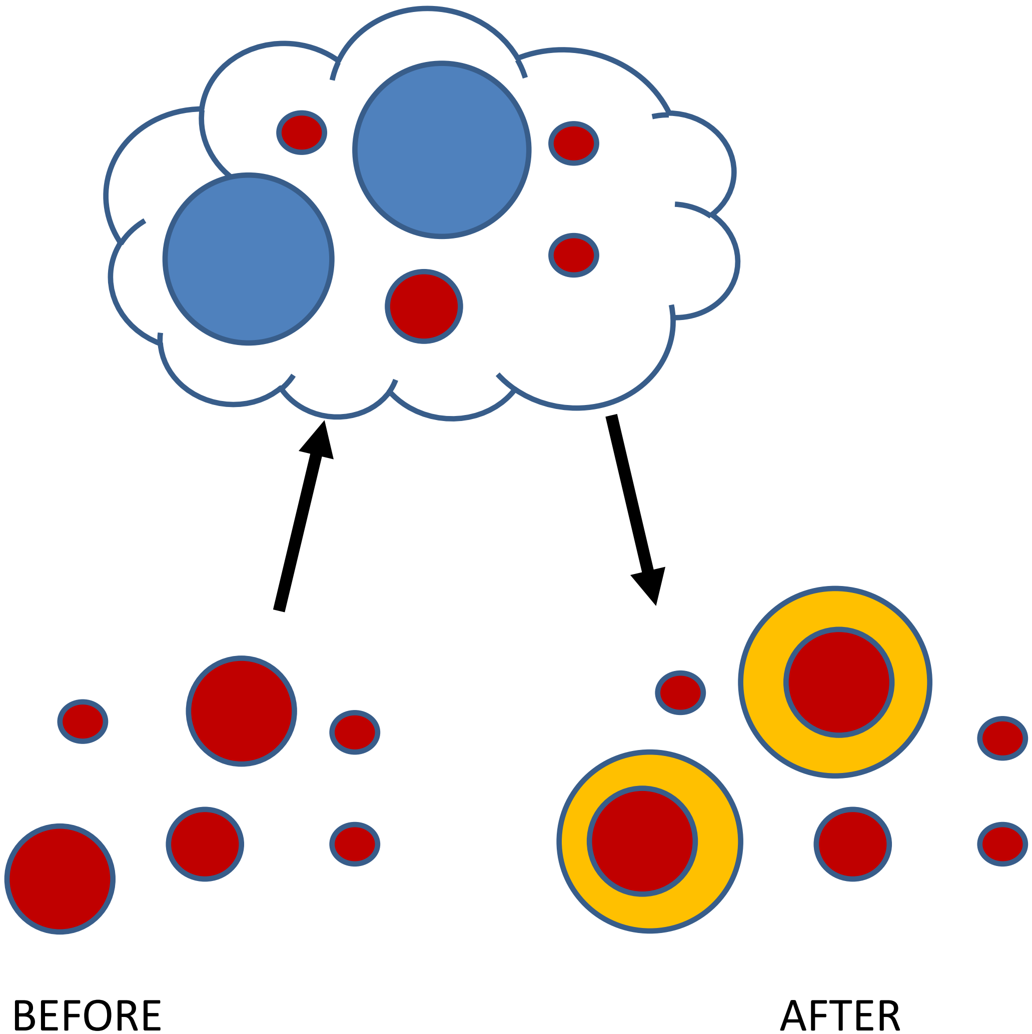
Only large hydrophilic aerosol can activate (form cloud droplets).



Aerosol particles can grow in size as a result of chemical processing in non-precipitating clouds.

Soluble species can dissolve in liquid cloud water, undergo chemical reactions and, when the cloud evaporates, be released into the particulate phase.

Can see the effect of this process in the bimodal size distribution in marine areas.

Deposition

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NAME	LOCATION	DEPENDS ON	NOTES
Dry Deposition	Model layer closest to Earth's surface.	Particle size Surface type (e.g. forest / ocean).	
Sedimentation / gravitational settling	*All model levels*	*Particle size (gravity)*	*Only removes aerosol in the lowest level.*
In cloud / nucleation scavenging	Within a raining cloud	Particle size Particle composition	
Below cloud / impaction scavenging	In model levels below a raining cloud	Particle size (smallest and largest most affected)	

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Challenge 2: Particles vary in composition – different species mix together.

Challenge 3: Microphysical processes change the aerosol size distribution.

Challenge 4: Link it to the other parts of the model.

Edited Call Sequence

UKCA_EMISSION_CTL – Emit gases

UKCA_CHEMISTY_CTL – Chemistry routines

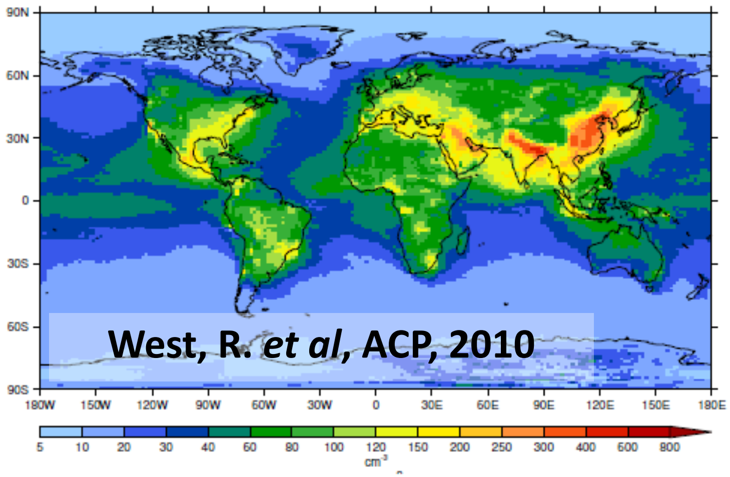
UKCA_AERO_CTL – Aerosol routines

- UKCA_AERO_STEP
  - UKCA_CALCDRYDIAM & UKCA_CALC_DRYDIAM
  - UKCA_PRIM_SU (and CAR,SS and DU)
  - UKCA_IMPC_SCAV & UKCA_RAINOUT
  - UKCA_WETOX
  - UKCA_CLOUDPROC
  - UKAC_DDEPAER_INCL_SEDI
  - UKCA_REMODE
  - UKCA_CALC_COAG_KERNAL
    - UKCA_CONDEN
    - UKCA_CALCNUCRATE
    - UKCA_COAGWITHNUCL
    - UKCA_AGEING
  - UKCA_CALCDRYDIAM & UKCA_VOLUME_MODE
  - UKCA_REMODE

UKCA_ACTIVATE – Cloud droplet number

Links to other parts of the model

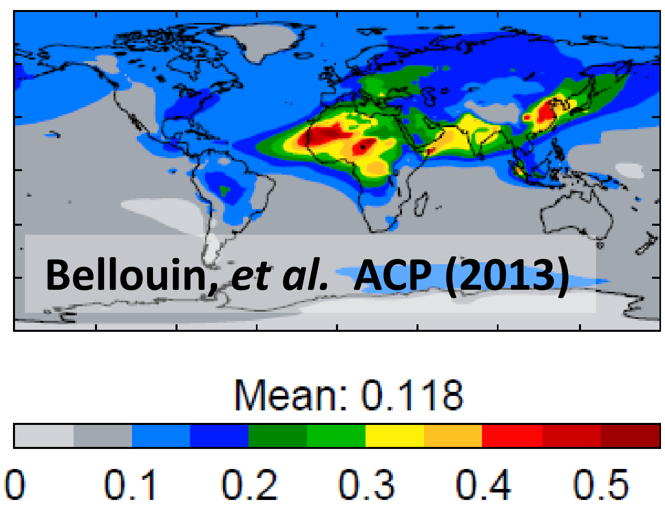
Cloud droplet number



UKCA_ACTIVATE (R. West, P. Stier)

Calculates the number of cloud droplets formed at cloud base. Depended on the number, size and composition of the aerosol.

GLOMAP-mode AOD



UKCA_RADAER (N. Bellouin)

Calculates the aerosol optical properties (e.g. scattering and absorbtion of radiative fluxes)

Finally, some science…

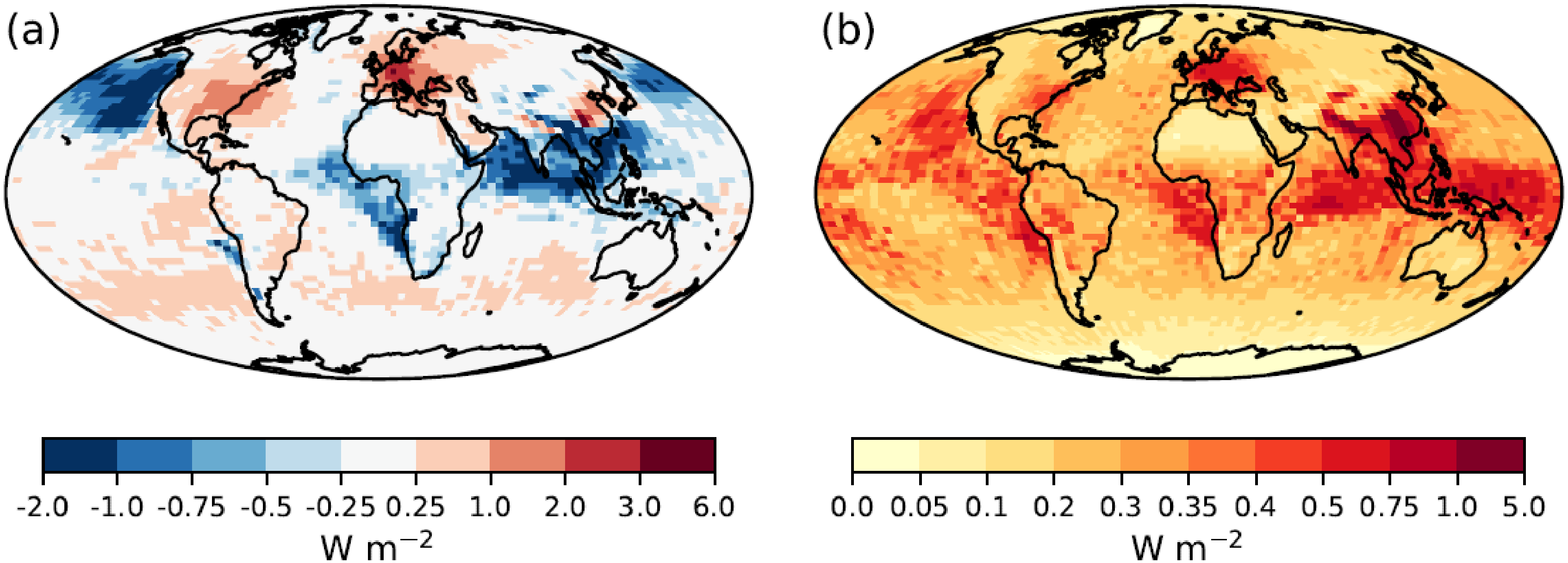


Figure 7. a) Mean and b) standard deviation of 1978-2008 aerosol ERF. Values were calculated using output from 270000 emulator-derived model variants at the individual pixel level. These samples of model variants are informed by the expert-elicited parameter pdfs.

Regarye et al, in prep.

Conclusions

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1. UKCA-Mode is a global aerosol model in which the aerosol size distribution is represented using (normally 7) interacting lognormal modes.

2. The model treats 5 species: sulfate, black carbon, organic carbon, sea spray and dust.

3. The model setup can be altered to use more / fewer modes and species.

4. Treats the main microphysical processes that control the size distribution – emission, nucleation, coagulation, condensation, in-cloud processing and dry and wet deposition.

5. Is coupled to (some) other parts of the model. More work to be done on this.

6. UKCA-Mode is a working model that compares well with observations.