

# Aerosol/chemistry/cloud modelling across the scales: Overview & plans

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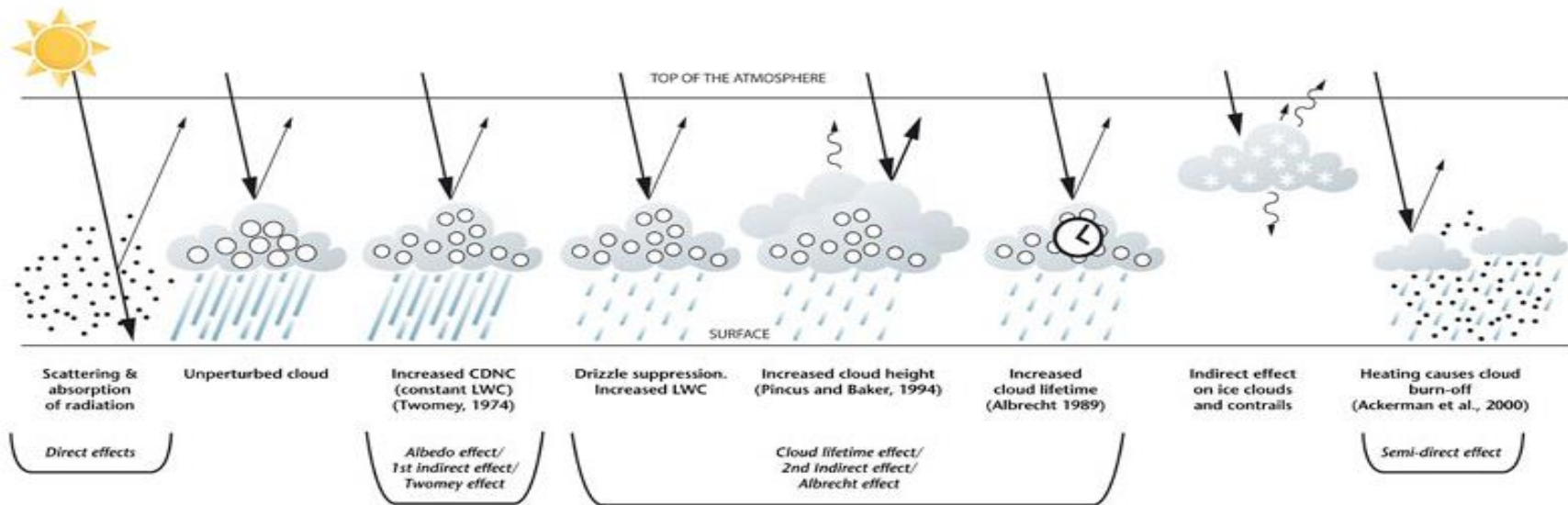
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Reading University: Nicolas Bellouin

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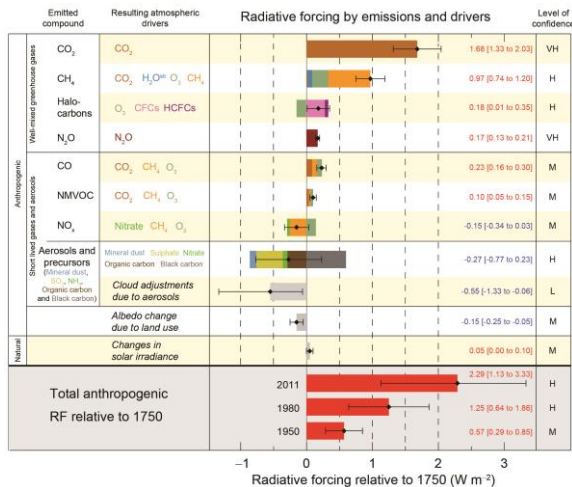
- Motivation
- Aerosol in the UM
  - MURK
  - CLASSIC
  - UKCA-MODE
- Aerosol-cloud interaction in the UM
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# Aerosol-cloud-radiation interactions



# Aerosol impact across scales

## Aerosol and climate



## Aerosol and air quality

Over 9,000 deaths due to air pollution exposure in London in 2010

Over 3 million premature deaths in 2012 according to WHO



## Aerosol and weather



Fig 2: Fog at Heathrow Airport. (Taken from BBC website, CO Jeffrey Phillips)

# Aerosol in the UM

## **MURK**

- Single mass prognostic tracer representing an aggregate of species
- Primary aerosol representation for visibility and aerosol-cloud interaction in high-res operational NWP (UKV)

## **CLASSIC**

- Prognostic mass-only multi-species, fixed size scheme. Only external mixing and some microphysics represented.
- Aerosol representation in Global NWP and climate

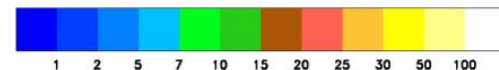
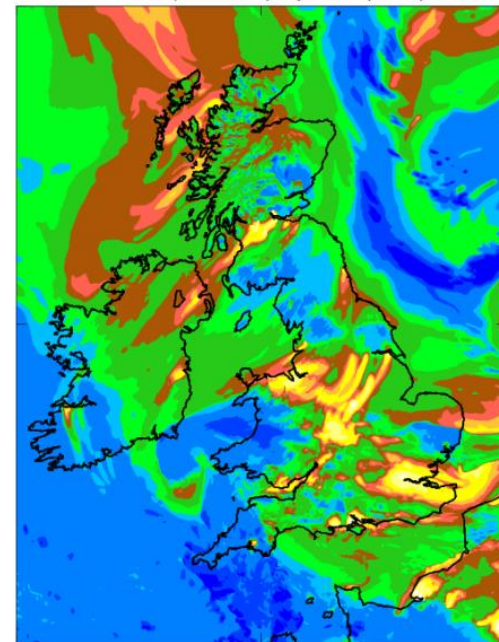
## **UKCA-MODE**

- A two moment (mass and number) multi-species scheme with detailed aerosol evolution that includes wet and dry deposition, nucleation of aerosol from gas phase and chemical processing, microphysics, internal and external mixing represented
- Aerosol representation in climate and ESM

# Aerosol in the UM - MURK

- 1 tracer “anthropogenic” aerosol, which represents emissions, transport and wet deposition of tracer
- Used operational UKV forecast model for visibility prediction and in data assimilation
- Visibility parameterised as a function of aerosol concentration and total water
- DA uses murk as a control variable
- Autoconversion also linked to murk
- Aerosol-fog interactions, using MURK, have led to false fog signal and flight cancellations, e.g...

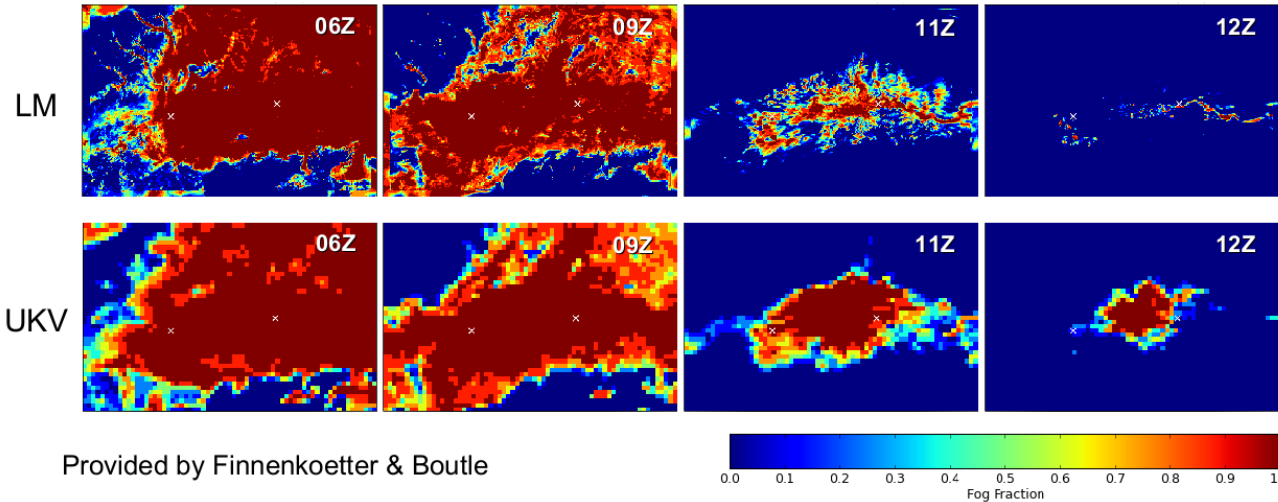
UKV op Total aerosol (for visibility) in micrograms per cubic metre  
Wednesday 0700Z 29/05/2013 (+28h)



# Aerosol in the UM - MURK

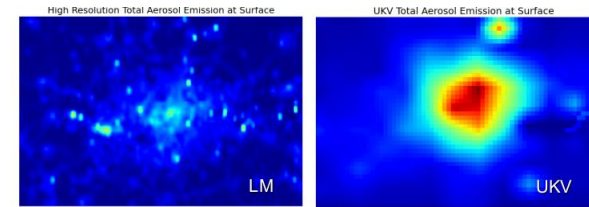
Comparison of London model (300m) and UKV (1.5km) 03Z run

- Very similar initial fields (→ London model also giving false alarm) but fog dissolves earlier in the London Model.



Provided by Finnenkoetter & Boutle

Aerosol emission ancillaries

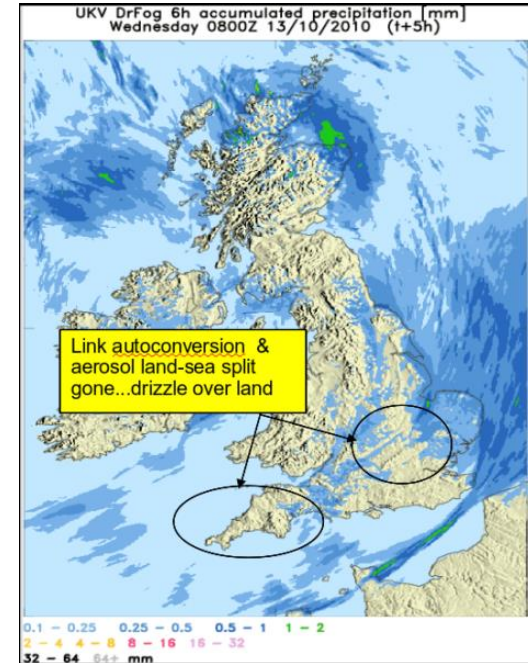
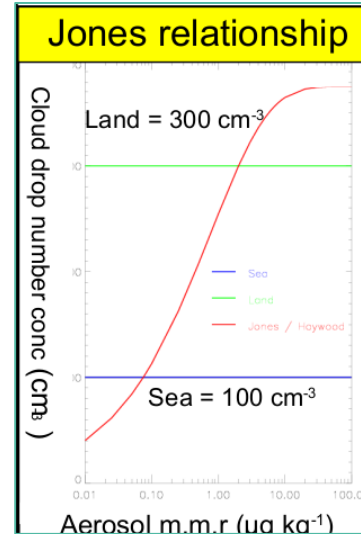
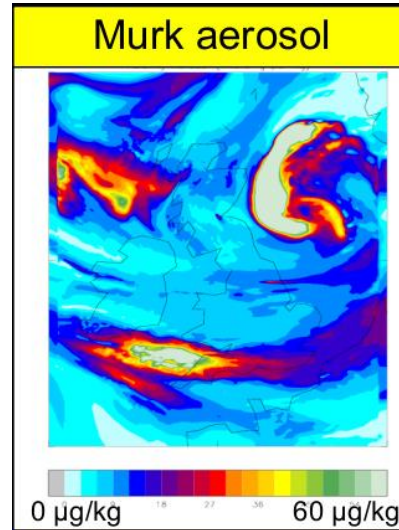
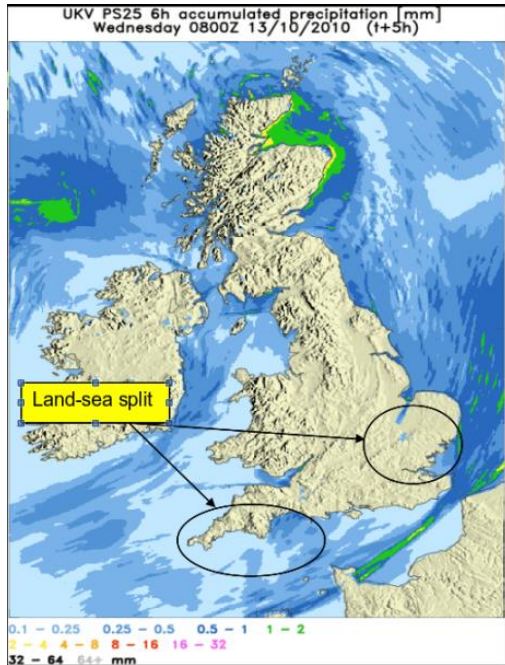


Fog and visibility strongly tied to the emission ancillary



# Aerosol in the UM - MURK

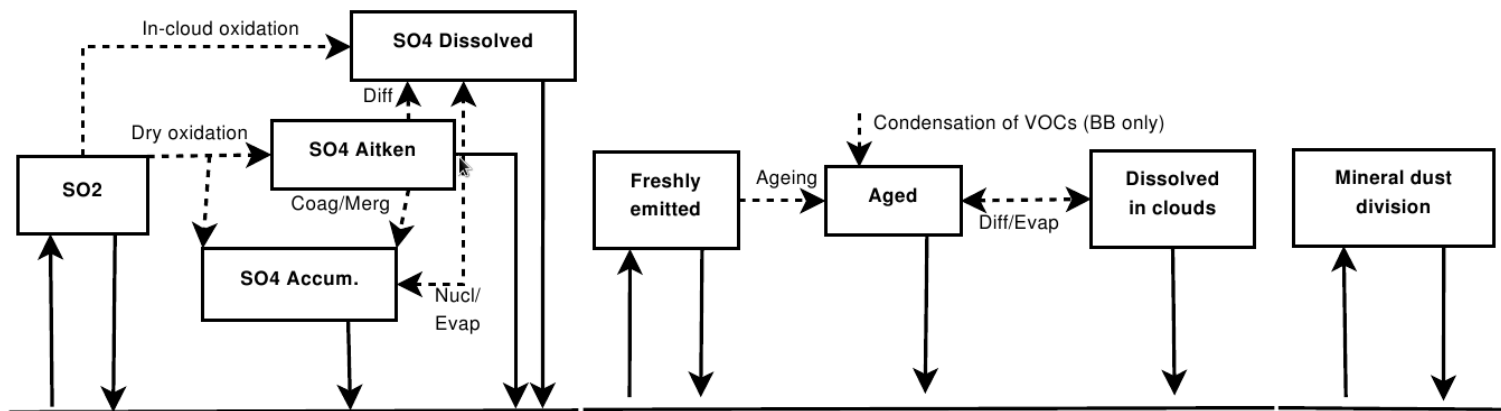
## MURK coupling to cloud microphysics





# Aerosol in the UM - Classic

CLASSIC



Sulphur cycle

BB, soot, OCFF

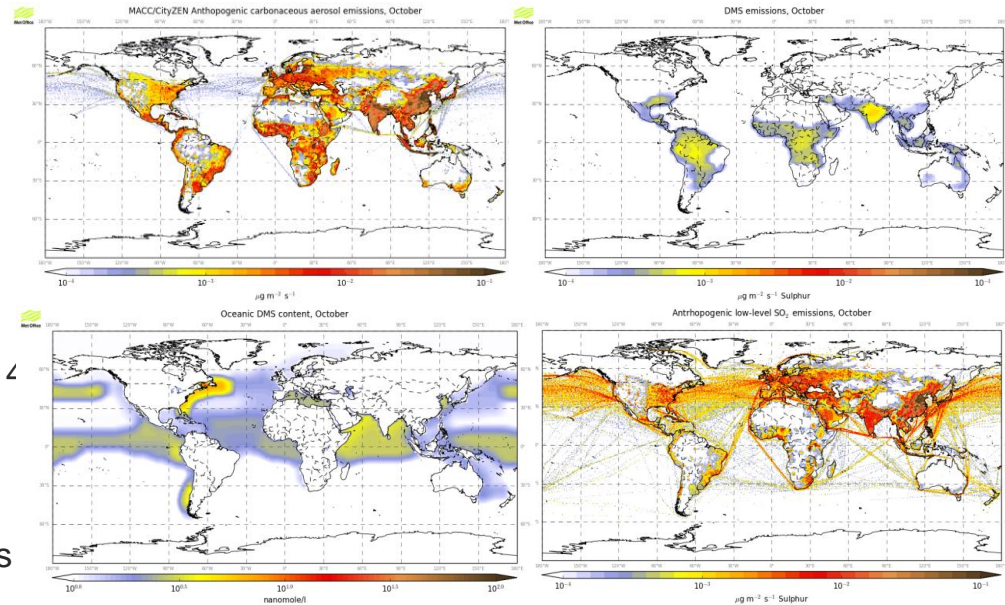
Dust

- Single moment scheme, mass-based
- Diagnostic Sea Salt, climatological SOA
- Externally mixed aerosol particles
- CDNC diagnosed using Jones et al. (2001)

# Aerosol in the UM – Classic

## Classic

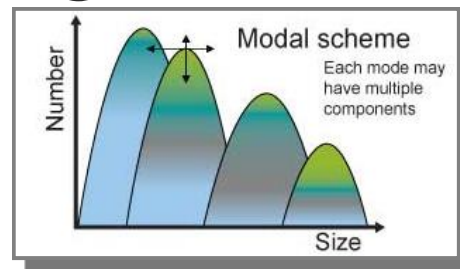
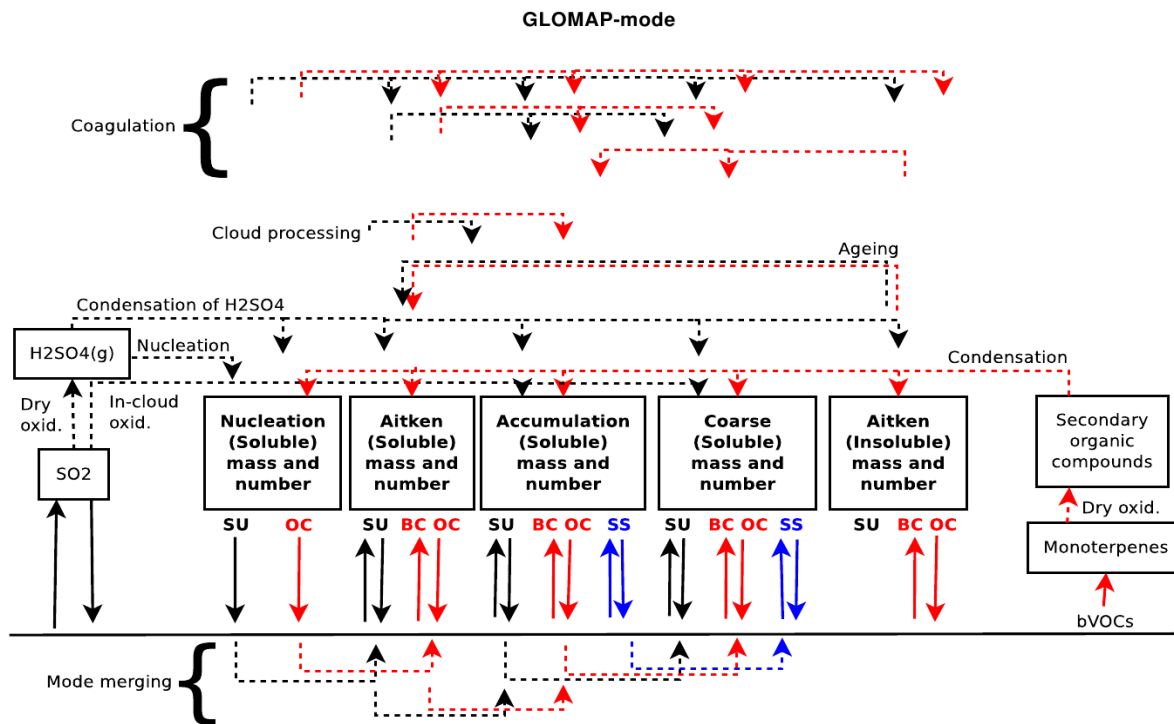
- prognostic, single moment aerosol representation, used to support research campaigns
  - INCOMPASS, SWAMMI, MONSOON - over India, pre/during monsoon 2016
  - CLARIFY – Aerosol-cloud interaction over the tropical south Atlantic
- Carbonaceous aerosol
  - Fossil fuel, biomass burning, bio-fuel
  - Anthropogenic emissions - MACC/CityZEN, 2014 monthly mean
- Sulphate aerosol forecasts
  - Anthropogenic SO<sub>2</sub> (MACC/CityZen), Volcanic SO<sub>2</sub>, Land based DMS Ocean DMS conc (fluxes wind based)



Provided by M. Brooks and B. Johnson

**Cost increase ~30% to ~40%**

# Aerosol in the UM – UKCA-MODE



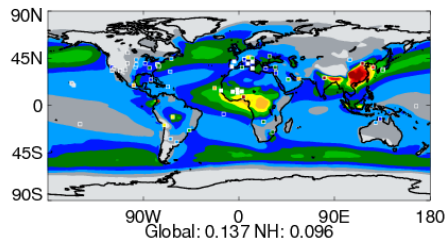
## GLOMAP-mode (Mann et al. 2011)

- Online calculation of aerosol optical properties (RADAER)
- Online aerosol activation to cloud droplets (UKCA-Activate, West et al. 2014)
- GLOMAP climatologies currently being developed for NWP

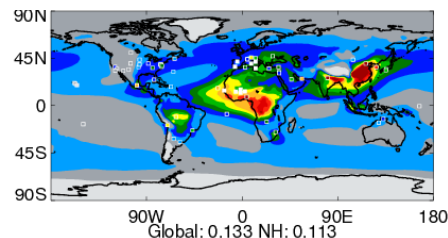
# Aerosol in the UM – UKCA-MODE

**CLASSIC vs. GLOMAP-mode:**  
**Annual mean AOD(550nm)**

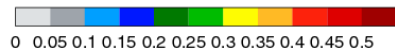
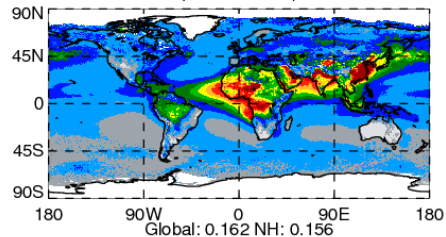
**HadGEM3 GA6  
CLASSIC**



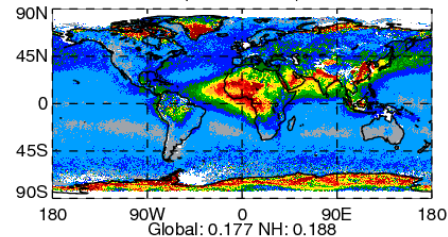
**HadGEM3 GA7  
GLOMAP-Mode**



**MODIS C6 Annual AOD (550nm)  
(2003-2012)**



**MISR C6 Annual AOD (550nm)  
(2002-2006)**



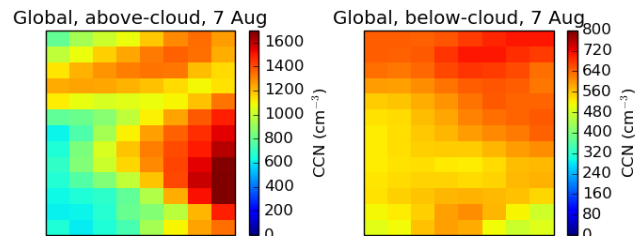
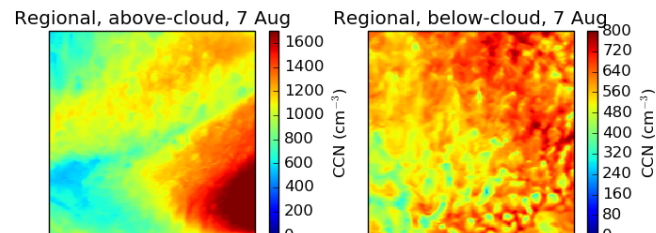
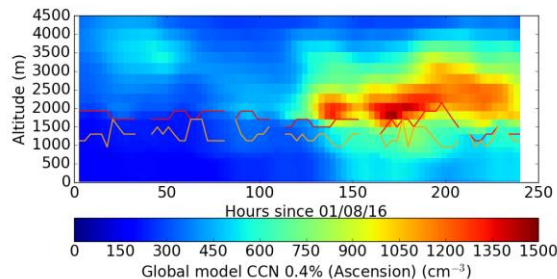
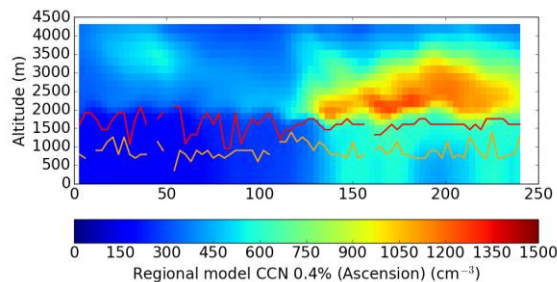
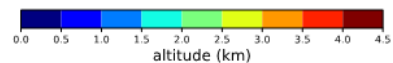
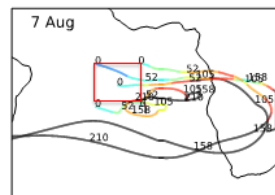
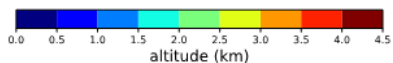
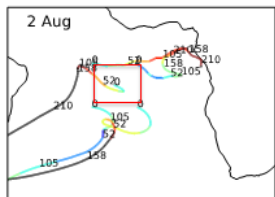
Provided by J.Mulcahy

# Aerosol in the UM – UKCA-MODE

- UKCA-MODE is the aerosol scheme implemented in UKESM/HadGEM3 climate model from GA7
- UKCA-MODE uses a double moment representation of aerosol to predict aerosol number, size distribution, composition and optical properties from detailed, physically-based treatment of aerosol microphysics and chemistry
- UKCA-MODE includes an aerosol activation scheme
- The aerosol is coupled to tropospheric and stratospheric chemistry in UKCA
- Should lead to improved representation of aerosol radiative effects and aerosol-cloud interactions
- But inconsistent with the Aerosol methods used in Global and regional NWP
- UKCA-MODE has recently developed and tested to run with high resolution NWP (in research mode)...

# Aerosol in the UM – UKCA-MODE

- Global model = HADGEM with UKCA (UM vn10.3)
- Regional model = 1200 km domain at 10 S 12 W, resolution is 4 km



Provided by H. Gordon



# Aerosol-cloud interactions in the UM

- High resolution NWP (operational) – cloud number coupled to MURK, which controls autoconversion to rain
- Global NWP and Climate – cloud number derived from Classic climatologies, control autoconversion
- Global and Regional UKCA-MODE – Aerosol activation controlled by activate and this feeds to autoconversion and radiation.
- **NEW – CASIM and CASIM coupled to UKCA-MODE**

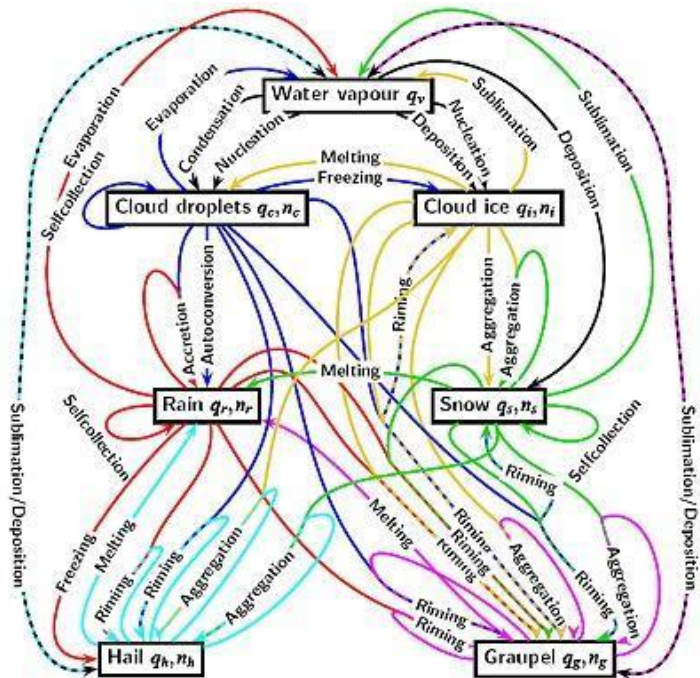
# Cloud AeroSol Interacting Microphysics - **CASIM**

- CASIM developed to incorporate aerosol effects incl. in-cloud processing of aerosol
- Longterm replacement for UM microphysics and the default microphysics scheme for the Met Office/NERC cloud model (MONC)
- User definable
  - number of cloud species (e.g. cloud, rain, ice, snow, graupel)
  - number of moments to describe each species (1,2 or 3)
- Coupled to aerosol
  - User defined aerosol
  - UKCA-MODE

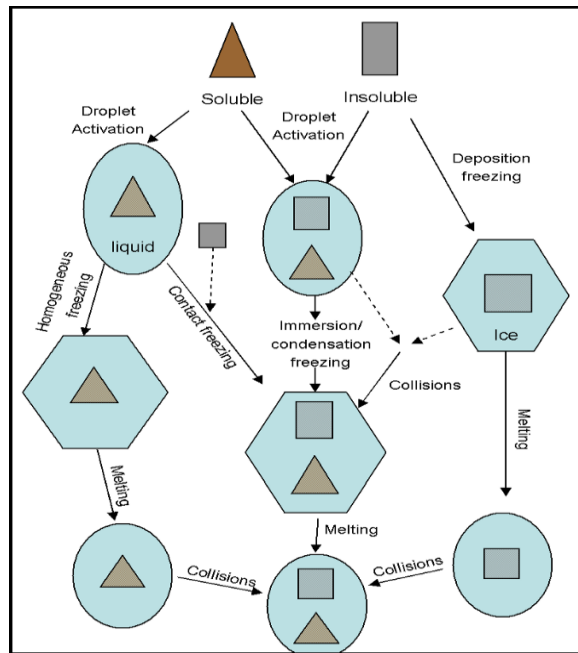
# Why bother?

## Aerosol-cloud interactions

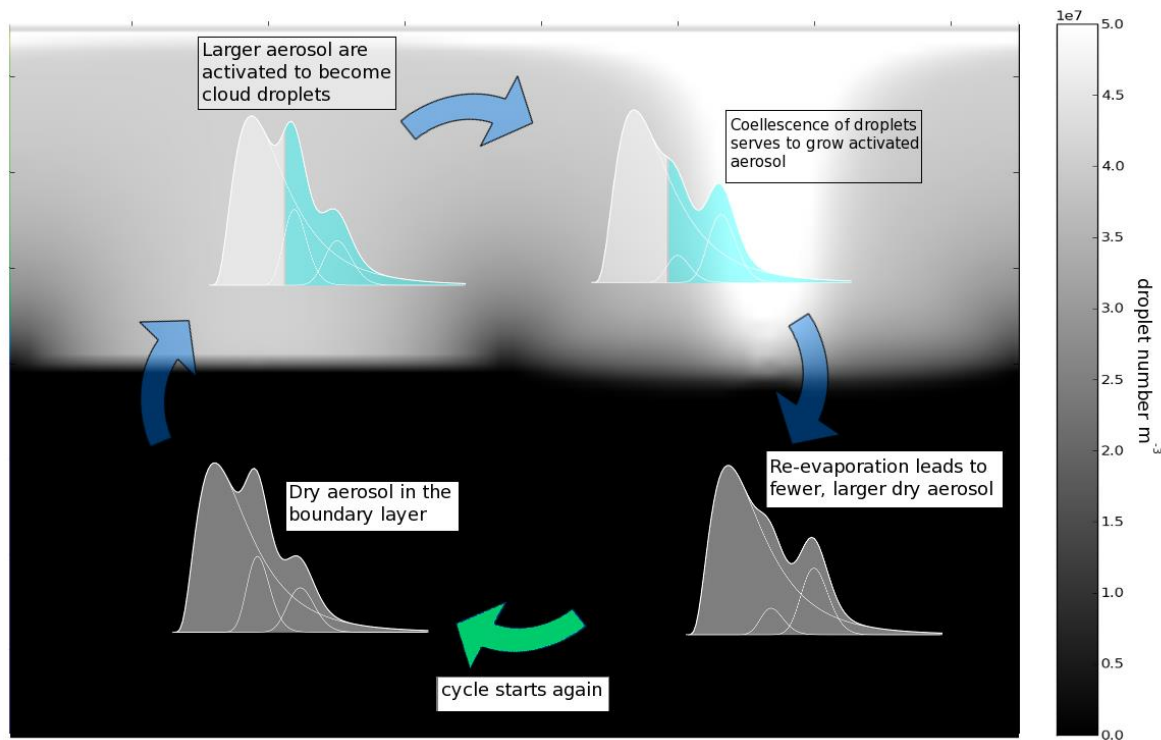
### Cloud Microphysics



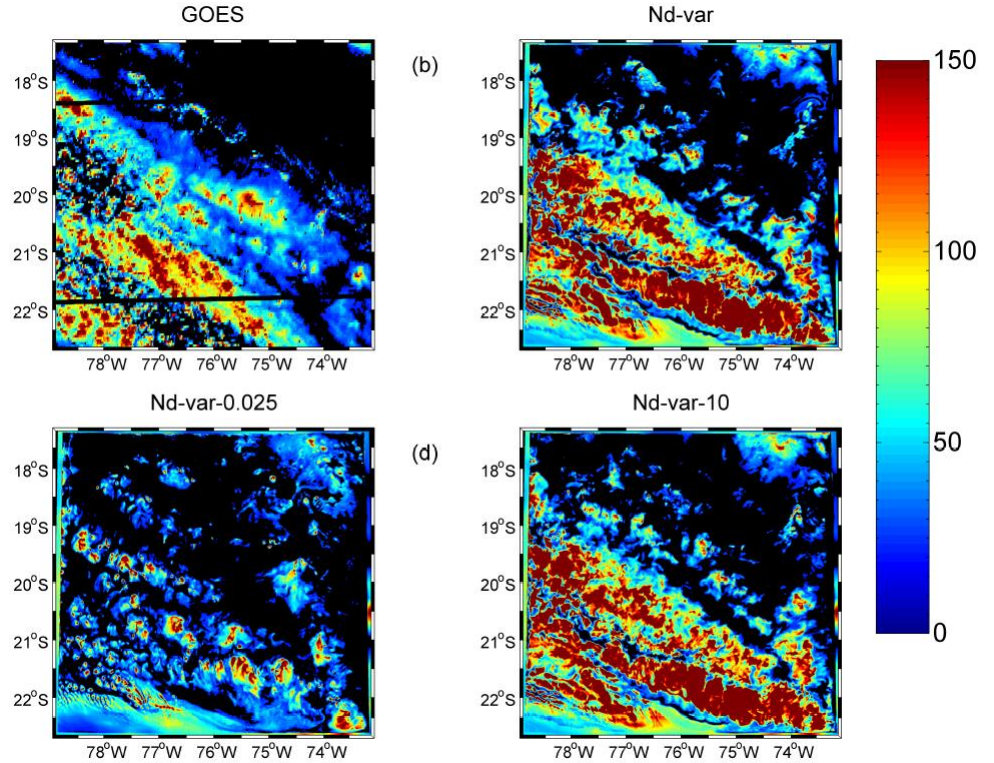
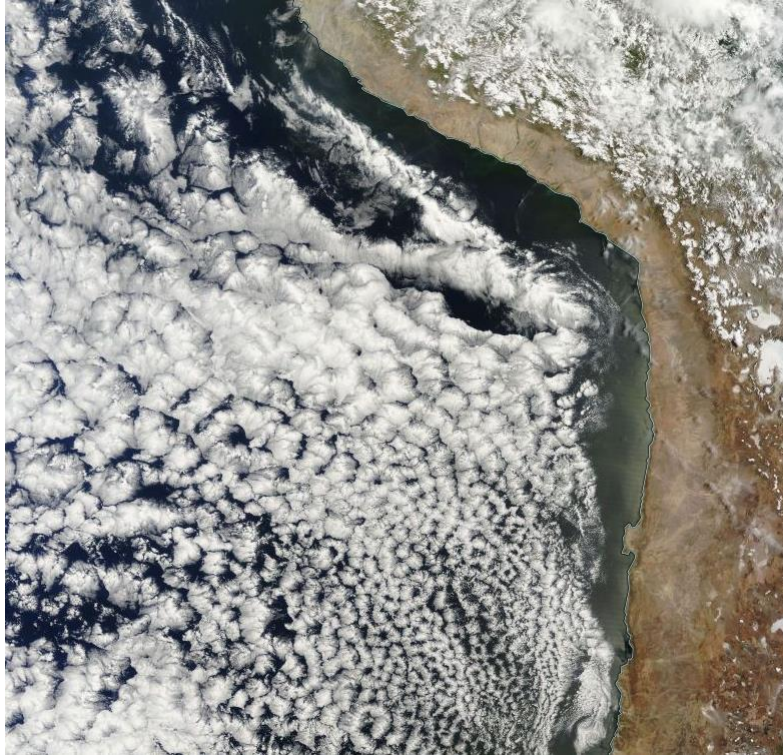
### In-cloud aerosol processes



# CASIM – Aerosol processing

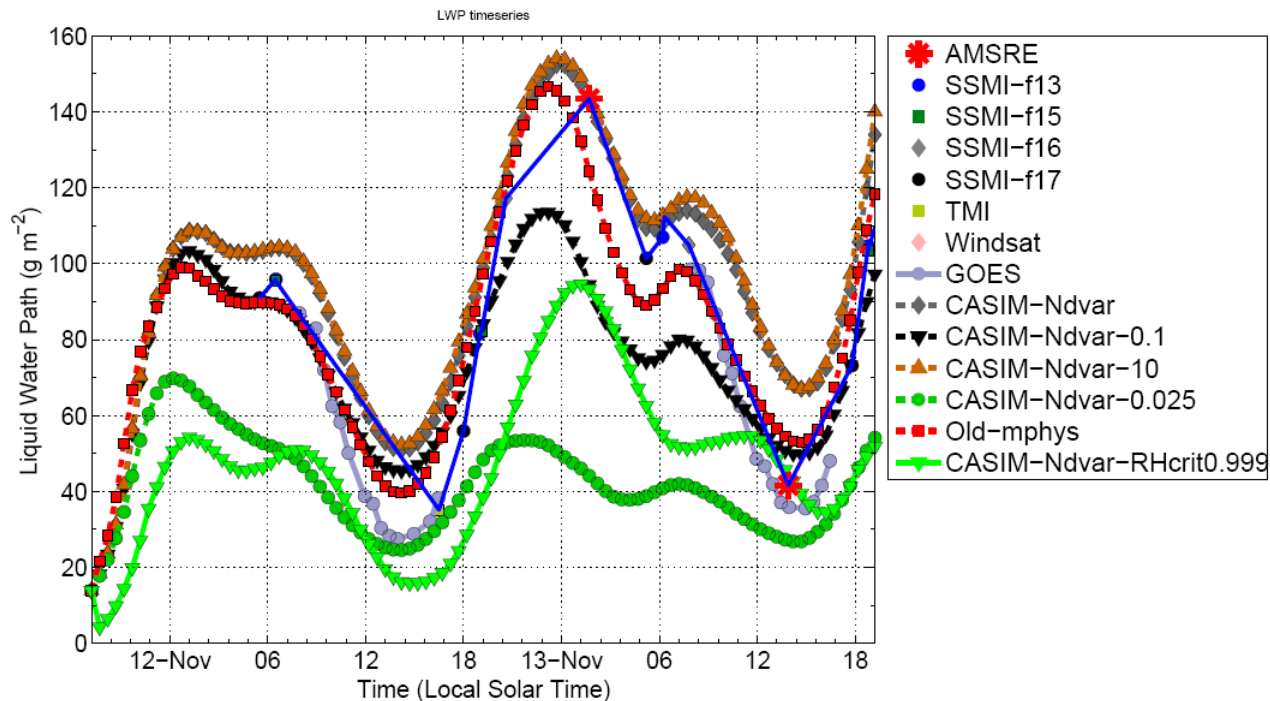


# Aerosol-cloud interactions in Marine Sc – CASIM



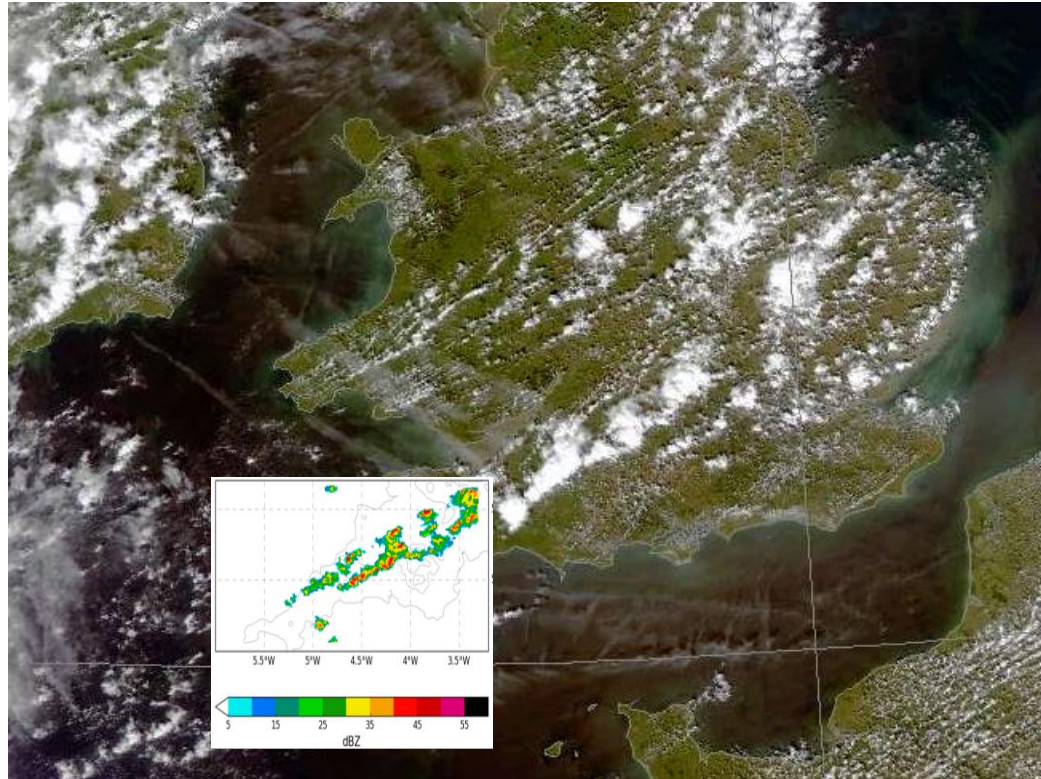


# Aerosol-cloud interactions in Marine Sc - CASIM

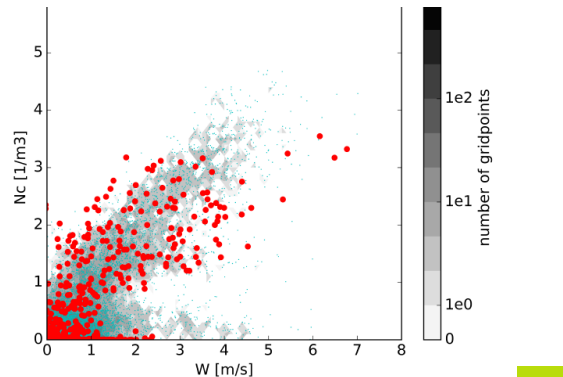
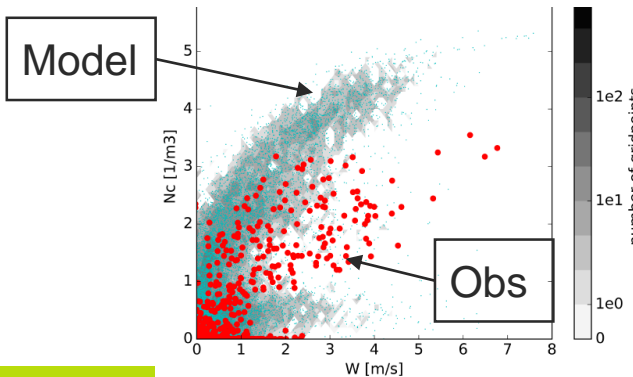
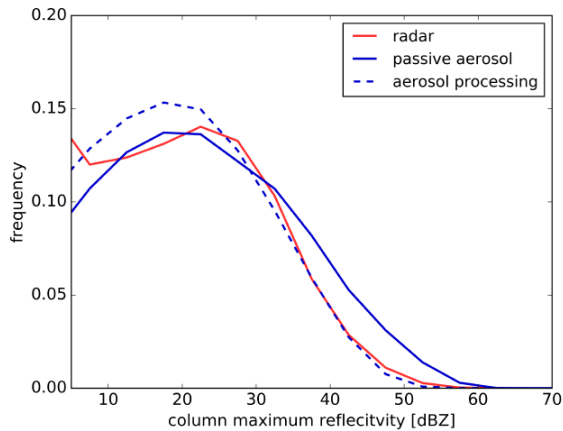
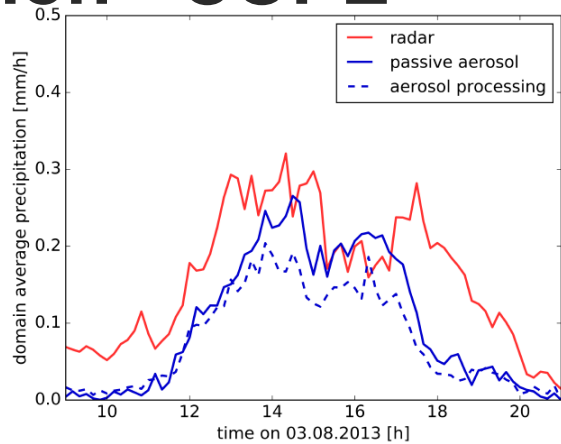




# Convection - COPE

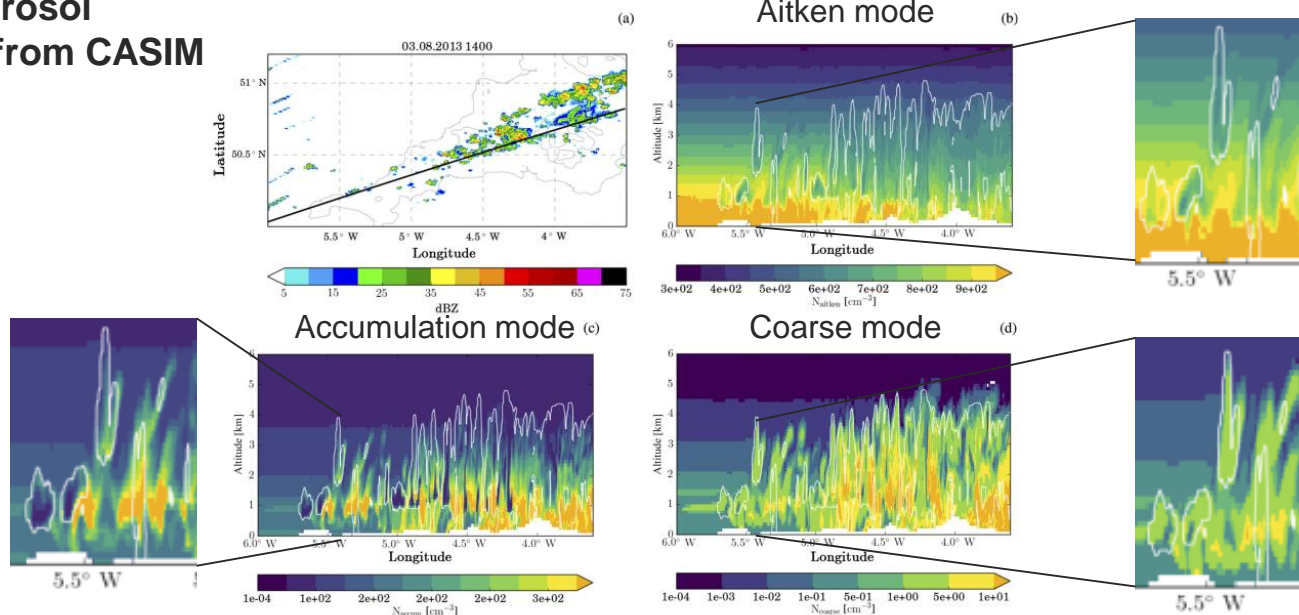


# Convection - COPE



# Convection - COPE

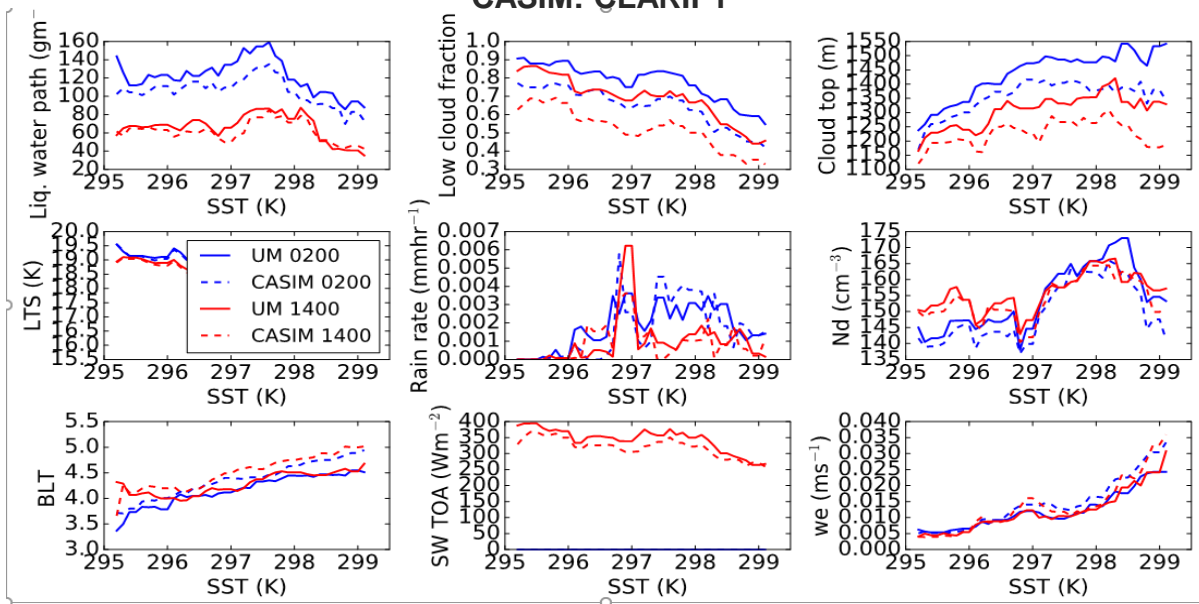
## Impact of aerosol processing from CASIM



**Figure 4.** Aerosol fields from the simulation with aerosol processing at 14:00 UTC. (a) The colour shading shows the column maximum reflectivity and the black line indicates the location of the cross sections plotted in the other panels: (b) number density of Aitken-mode aerosol, (c) accumulation-mode aerosol, and (d) coarse-mode aerosol. The white contour lines in panels (b, c, d) indicate areas with hydrometeor mixing ratios larger than  $1 \text{ mg kg}^{-1}$ .

# CASIM UKCA-MODE coupling

Initial comparison of UKCA and standard UM mphys versus UKCA and CASIM: CLARIFY



Provided by H. Gordon

**CASIM and UKCA-MODE one-way coupling**

# Summary

- UM contains
  - 3 prognostic aerosol schemes - MURK, Classic, UKCA-MODE
  - 2 methods for climatologies - 1 based on Classic and 1 based on MODE
  - 2 microphysics schemes – Standard (Wilson-Ballard) and CASIM
- All schemes are used at different scales and have various advantages and disadvantages
  - Not ideal since there is inconsistency across the scales
  - Can impact traceability

## **Overall plan – consolidate aerosol schemes**

- **UKCA-MODE basis for prognostic aerosol for all scales**
- **MODE climatologies basis for any aerosol climatology**

# Plan for UKCA-MODE development

- UKCA-MODE needs to be able to run with various complexity, depending on the application
- Provides traceability from most complex to most simple
- Research and develop UKCA mode as configurable aerosol modelling framework
  - Investigate the impact to removing modes for all scales
    - First step towards reducing the number of tracers
    - plan to start work on this in July – reduce to 3 soluble and 2 insoluble
  - Investigate methods for reducing the speciation required
    - Further reduce the number of tracers
    - make UKCA-MODE more like MURK → MURK2
- Optimise the code



# Plan for CASIM development

- Dec 2018 - CASIM UKV (high resolution LAM) configuration available.
  - This will provide a new functionality for the UM.
  - Adoption as the operational microphysics will depend upon computational cost as well as model skill improvements.
  - Potential improvements in the representation of drizzle and fog
- September 2019 – CASIM one-way coupling with UKCA for global, including smith cloud scheme and appropriate boundary layer treatment

# Plan for UKCA-MODE CASIM development

- October 2020 – GC/UKESM configuration
  - Main driver for a multi-moment aerosol interacting microphysics is to include a better representation of the indirect effect in our climate and earth system models (CCN and INP).
  - Implementation in the global model for climate will need development to interface with PC2 and 2-way coupling to the UKCA-GLOMAP.
  - Dependent on improving the computational efficiency of both UKCA-MODE and CASIM!

Thanks for listening  
Any Questions ?