Marine Aerosols

S. Gerard Jennings, Colin O' Dowd, Y.J. Yoon, Darius Ceburnis, and O. Jourdan

Atmospheric Research Group
Department of Experimental Physics
National University of Ireland, Galway
http: // macehead.nuigalway.ie

with collaborators: F. Cavelli, M.C. Facchini, S. Decesari and S. Fuzzi

from Instituto di Scienze dell' Atmosphera e del Clima, CNR, Bologna, Italy

and J.P. Putaud

from the Environment Institute, JRC, Ispra, Italy

Acknowledgments

This work was supported by (i) the Irish Research Council for Science, Engineering and Technology, (ii) the National Programme for Research in Third Level Institutions, Ireland, and (iii) the European Commission under Contract EVK2-CT2001-00127, (QUEST). Y.J. Yoon also acknowledges support from the Korean Polar Research Institute under Project PE05007.

Prof. R. Donovaro is acknowledged for the helpful contribution to the discussion of the results. SeaWiFS chlorophyll products were provided by the SeaWiFS project, NASA / Goddard Space Flight Center and ORBIMAGE.

Some Issues in Atmospheric Aerosol research work

- In order to determine anthropogenic influences of atmospheric aerosols on climate one needs to know the natural background and its variability

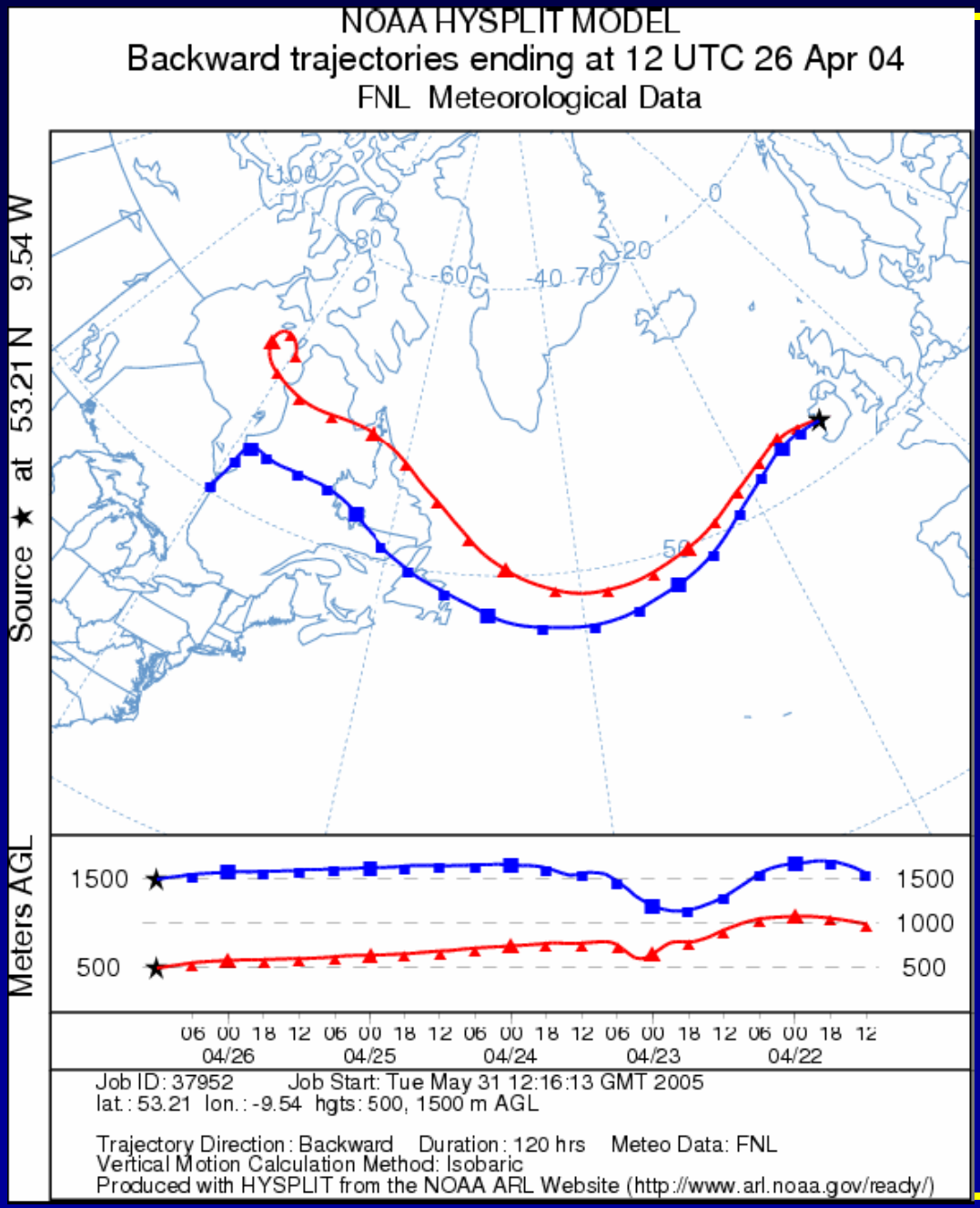
- Information on aerosol chemical organic composition of the atmospheric aerosol is generally lacking –work to date has mostly been on the inorganic fraction

- Lack of knowledge of aerosol chemical organic composition results in mass closure [total gravimetric mass = sum of the masses of individual aerosol chemical species] not generally being achieved

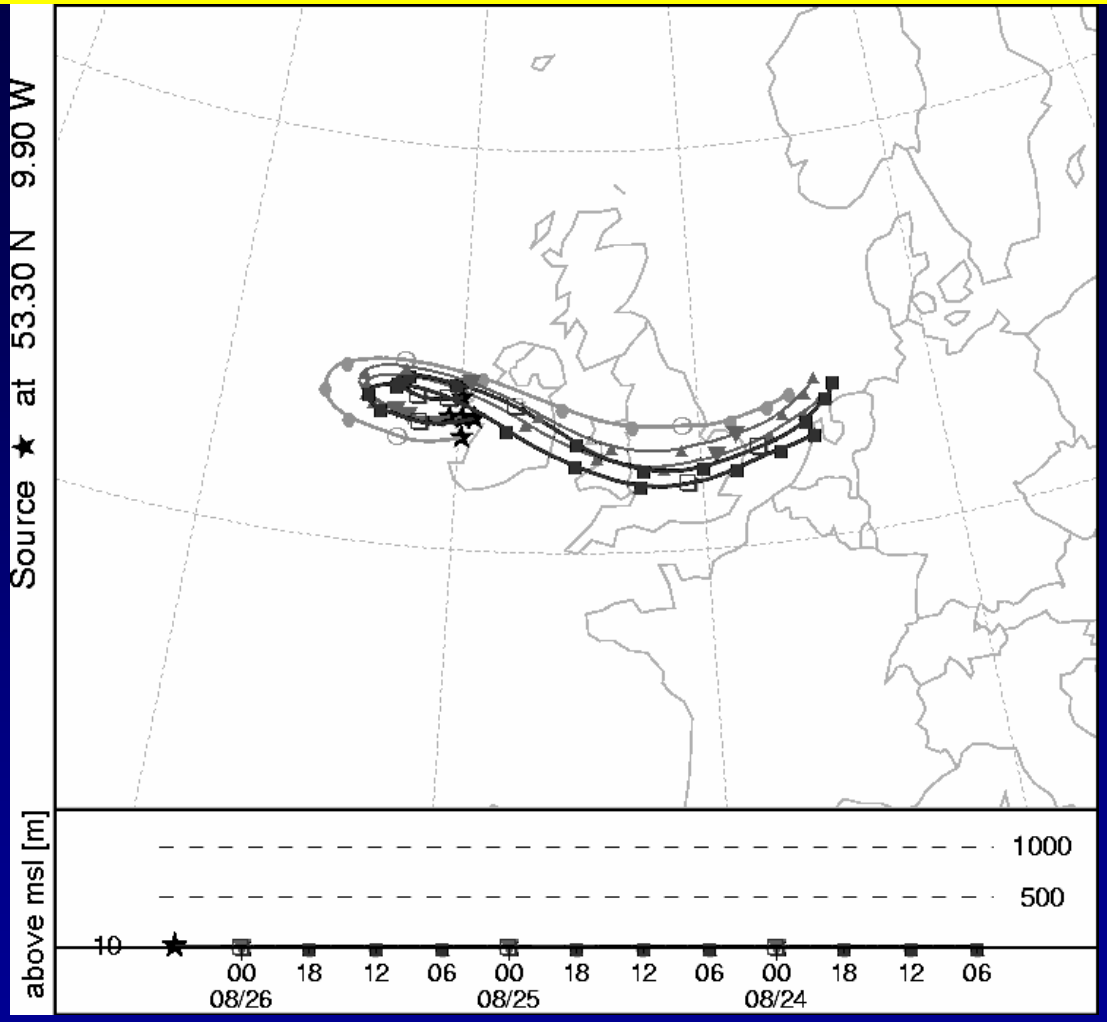
Mace Head Atmospheric Research Station – is a WMO Global Atmosphere Watch [GAW] global site

Breaking waves with Mace Head in the background

Picture, courtesy of K. Hämeri



Typical clean marine air mass backward (5 day) trajectories (for April 2004) arriving at Mace Head



72 hour back trajectories ending at 0600 UTC, 26 August 1999 at Mace Head. The hourly averaged local wind direction was 243 ° [from the marine sector]

5 days air mass back trajectories from a model (Draxler, R.R. and Rolph G. D.,

http://www.arl.noaa.gov/ready/hysplit4.html)

Criteria for marine air classification are :

(i) Wind direction should be within 190^0 – 300^0 clean air sector

(ii) Black carbon mass concentration - measured by an Aethalometer (MaGee Scientific) - is lower than 40 ng m^{-3} or aerosol absorption < 0.75 Mm^{-1}

(iii) Total aerosol particle number concentration above 14nm is less than about 700 cm^{-3}

(iv) 5 days air mass back trajectories from a model (Draxler, R.R. and Rolph G. D., http://www.arl.noaa.gov/ready/hysplit4.html) should show that the air mass has stayed only over the North Atlantic Ocean before arriving at the station

(v) Only periods ranging from about 12-36 hours with stable aerosol size spectra were chosen to ensure constant marine air mass characteristics

Marine Aerosol Formation Mechanisms:

Primary Marine Aerosol: (mechanical production)

Air entrained by ocean waves produce air bubbles. Rising air bubbles to the ocean surface can collect organic material in the sub-layer and ocean surface. Bursting bubbles will disperse the organic material into the atmosphere.

Secondary Marine Aerosol: (gas to particle conversion)

Starting size for new particles about 0.5-1 nm (typically 10-20 molecules)

1st stage :	Nucleation
2nd stage:	Condensation Growth
	Coagulation growth (also a loss mechanism)

When are marine aerosol particles important?

At sizes larger than 100 nm they can directly scatter incoming radiation (direct effect)

Also, at these sizes, they can act as cloud condensation nuclei (CCN) – (indirect effect - influencing cloud droplet size and cloud albedo)

Bubble-mediated Aerosol Production

Film Droplets:

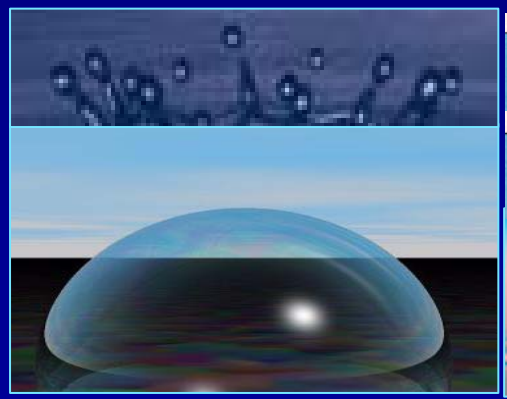
The bubble thin liquid cap bursts and shatters into many small droplets

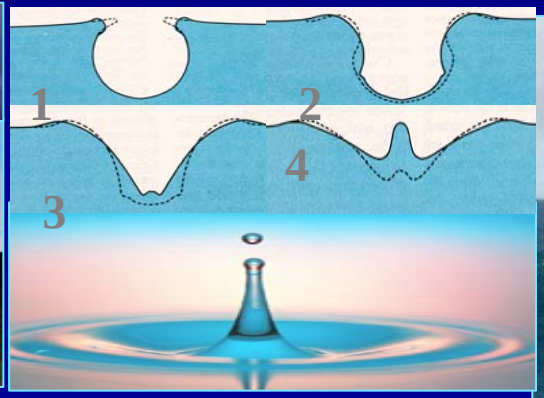
Jet Drops:

Produced by the collapse of the spherical cavity after bursting

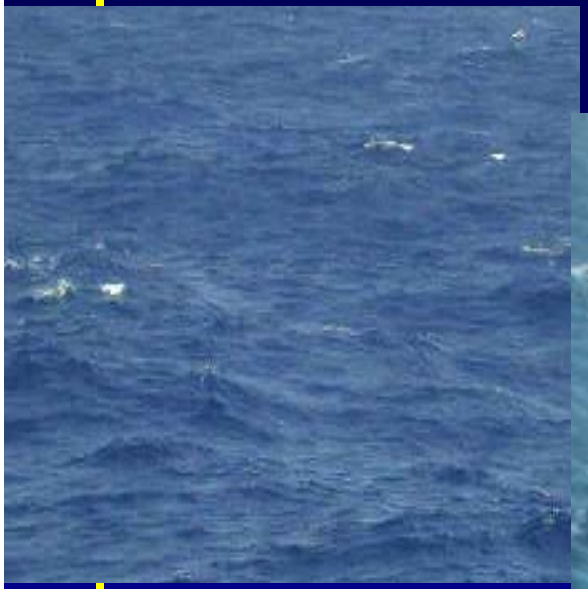
Spume Drops:

Wind speed > 8-10 m/s tear wave crests and inject large spume drops





Wind Stress, Whitecaps, Bubbles and Sea-spray aerosol

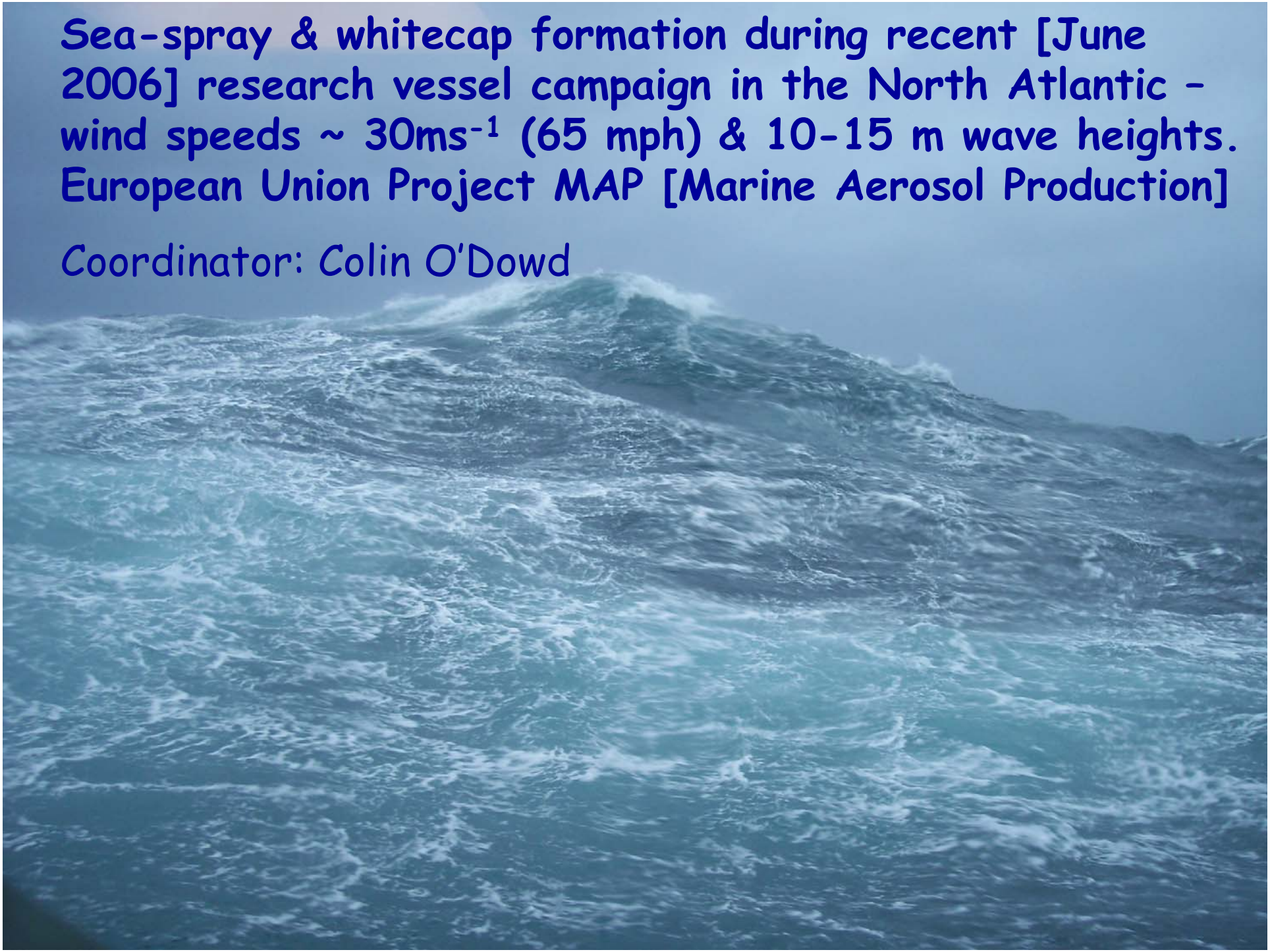


Whitecaps are initiated at wind speeds > 4 ms^{-1}

Whitecap coverage increases with increasing wind speed

Sea-spray & whitecap formation during recent [June 2006] research vessel campaign in the North Atlantic – wind speeds ~ 30ms^{-1} (65 mph) & 10-15 m wave heights. European Union Project MAP [Marine Aerosol Production]

Coordinator: Colin O'Dowd



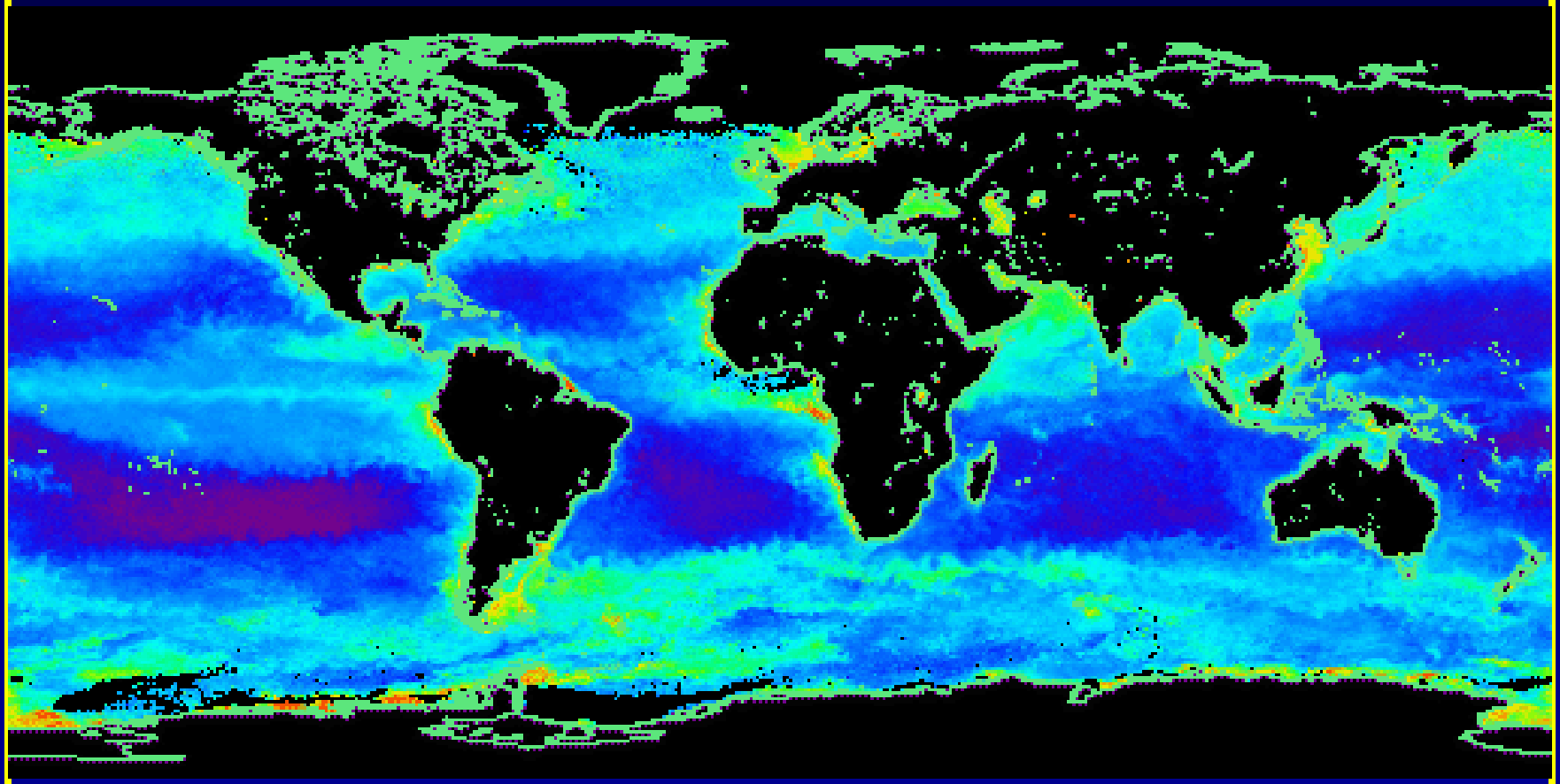
Chlorophyll-a measurements

- The colour in most of the worlds' oceans at visible wavelengths varies with concentration of chlorophyll and other plant pigments present – the more marine phytoplankton (microscopic marine plants) that is present, the greater is the concentration of plant pigments and the greener is the ocean water

- The Sea-viewing Wide field – of – view Sensor (SeaWiFS) satellite is used to provide quantitative data on ocean bio-optical properties

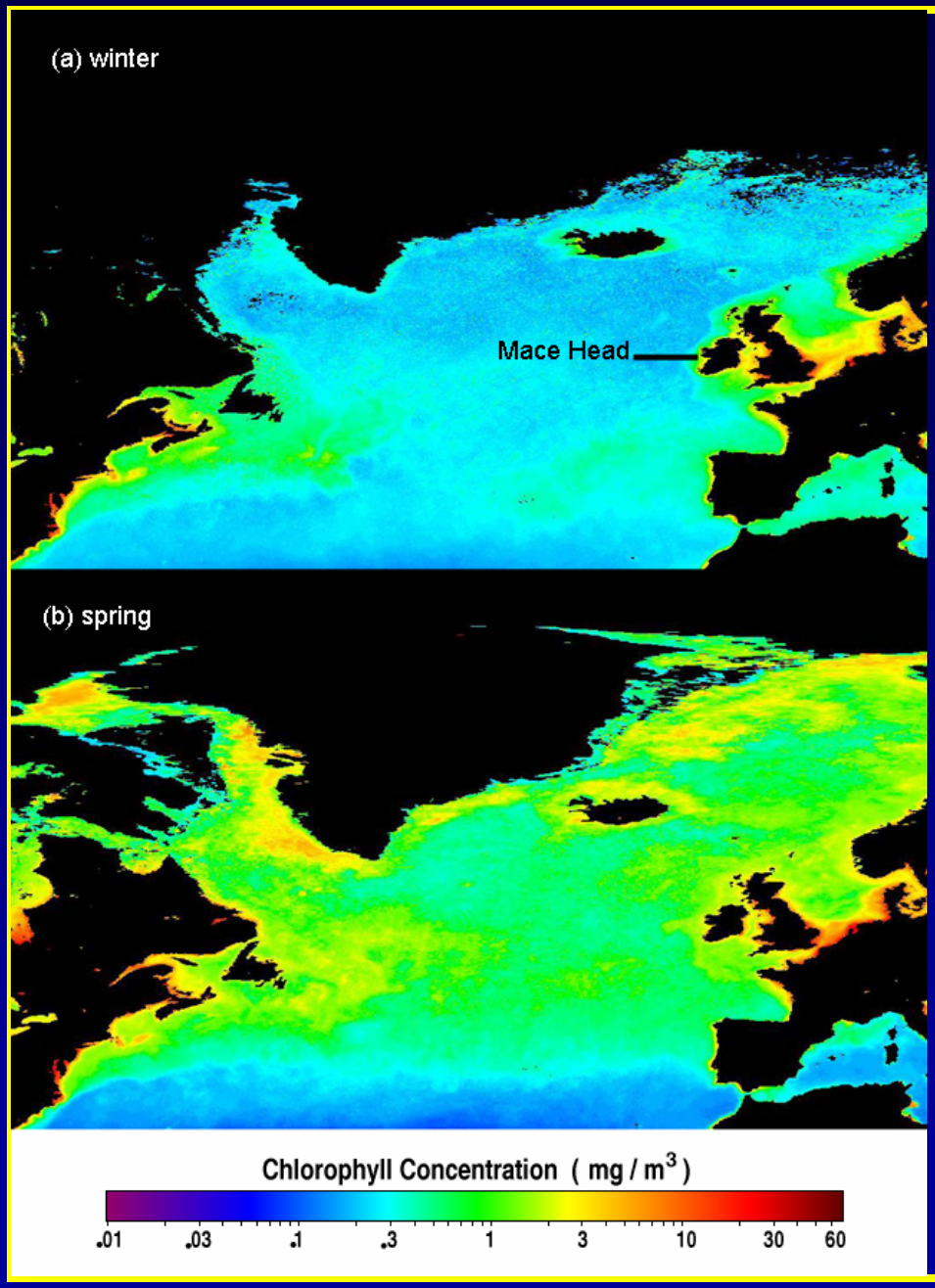
- The concentration of chlorophyll-a - which represents a proxy of phytoplankton biomass (i.e. primary organic matter) - is sensed by the SeaWiFS satellite and is produced as a SeaWiFS product – obtainable from the SeaWiFS home page

http://oceancolor.gsfc.nasa.gov/SeaWiFS/



Monthly variation in chlorophyll surface concentration

SeaWiFS Data : http://seawifs.gsfc.nasa.gov

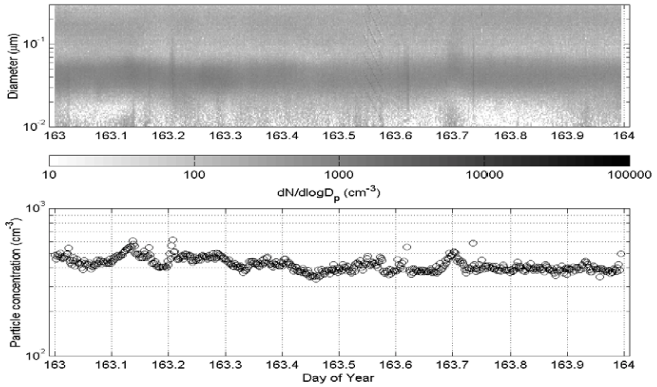


Winter Months

Spring Months

Chlorophyll Surface Water Organic Matter Concentration (mg m^{-3}) in the North Atlantic averaged over a 5 year period

(a)



(b)

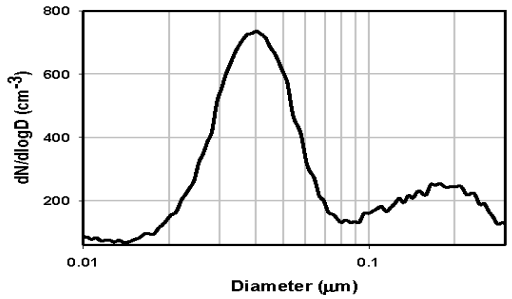


Figure 2. A typical aerosol size distribution measured by the SMPS system at the Mace Head Atmospheric Research station for a very clean marine air case: (11th June 2004, Day of year, DOY 163). (a) Surface plot of the size distribution (upper plate) and the total particle number concentration derived from the SMPS, and (b) daily averaged aerosol size distribution.

Example of clean and stable marine aerosol conditions showing size and number concentration over 24 hours

(Yoon et al, JGR, in press, 2006)

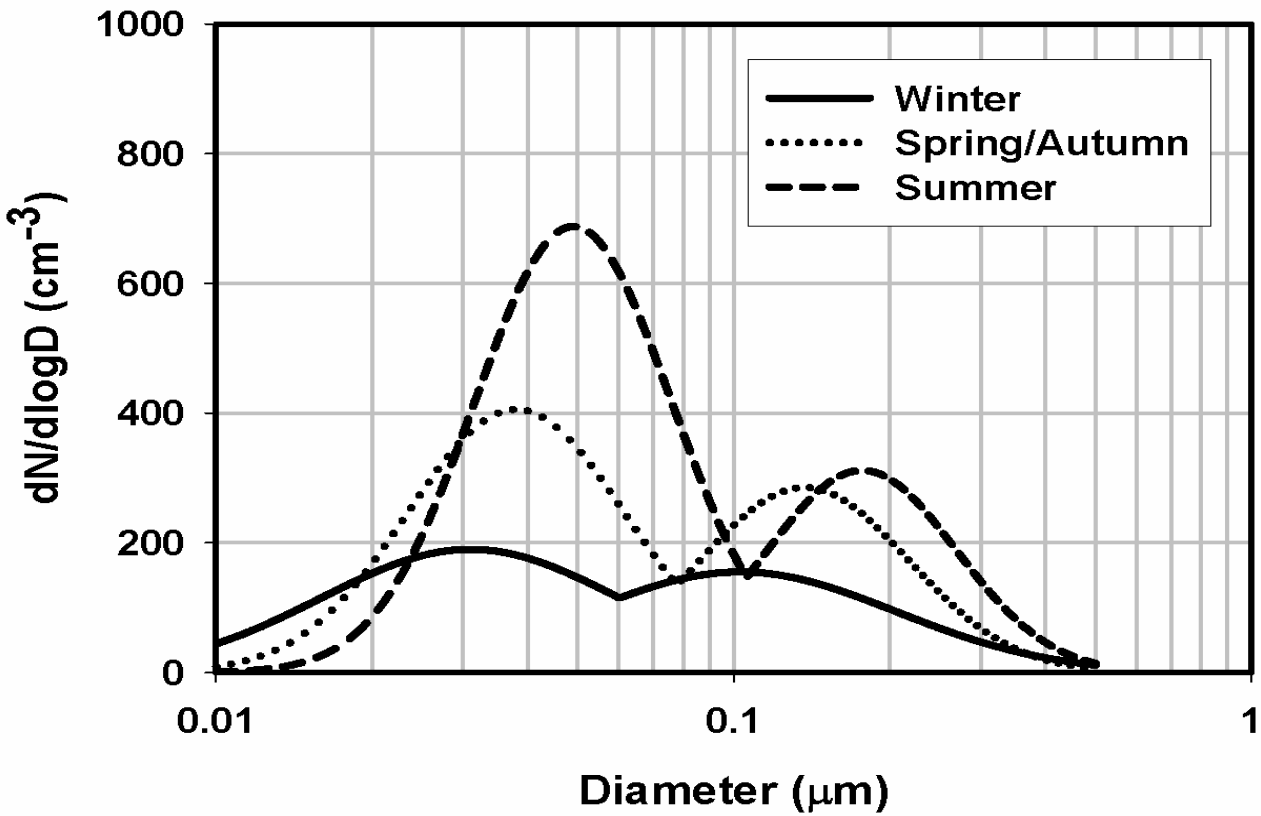
Seasonal marine aerosol size distribution log-normal fitting parameters for the Aitken mode and the accumulation mode based on 61 cases of very clean marine North Atlantic air

	Aitken mode			Accumulation mode		
	D_g	σ	N	D_g	σ	N
winter	0.031	1.94	137.2	0.103	2.00	116.7
spring/autumn	0.038	1.62	213.4	0.137	1.59	144.8
summer	0.049	1.55	327.5	0.177	1.52	142.4

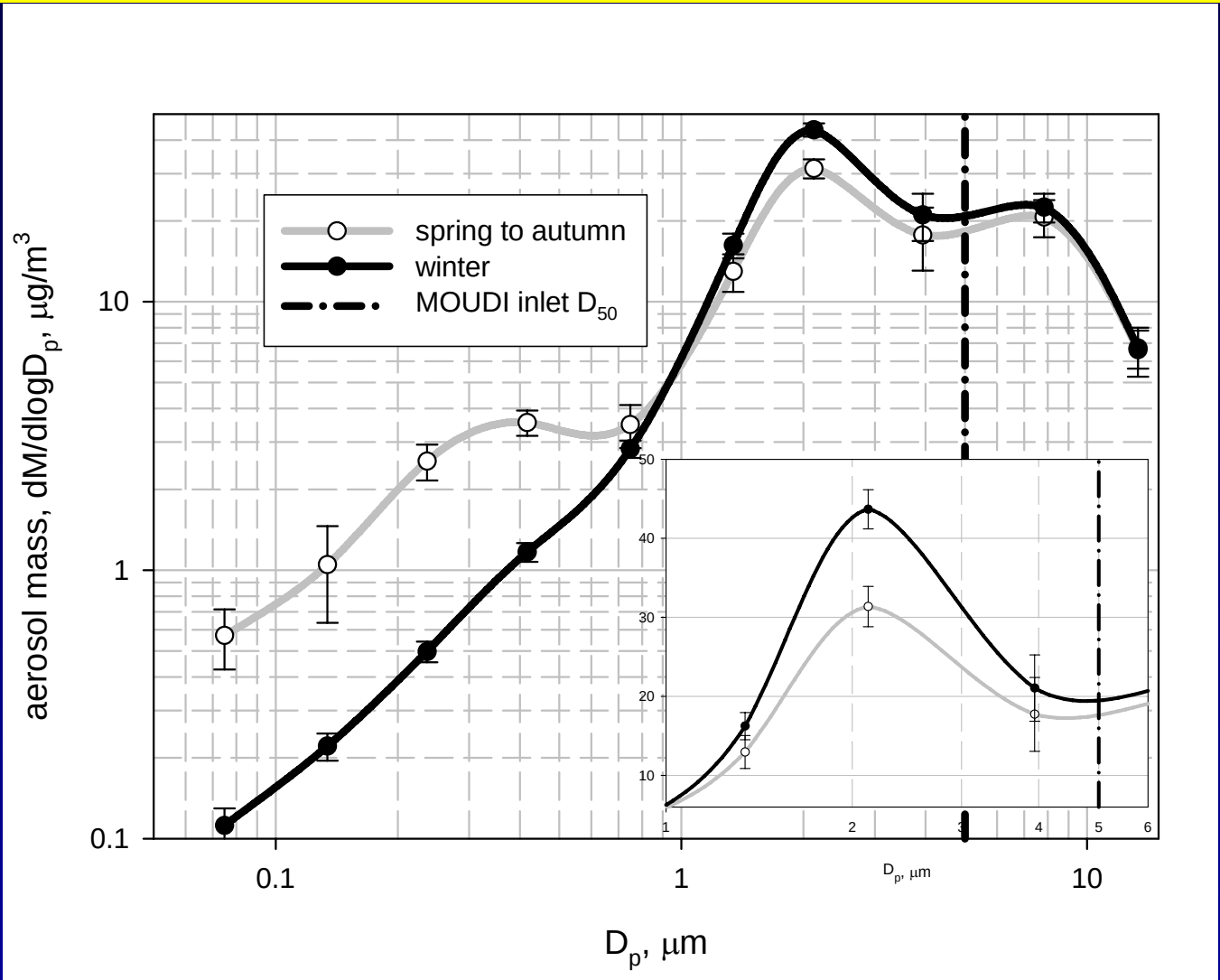
D_g: geometric mean diameter in μm,
σ: standard deviation, and
N: number concentration in cm^{-3}.

<u>Summary</u>: Modal diameters are ~ 60% - 70% larger in Summer

~ 22% – 33% larger in Spring / Fall



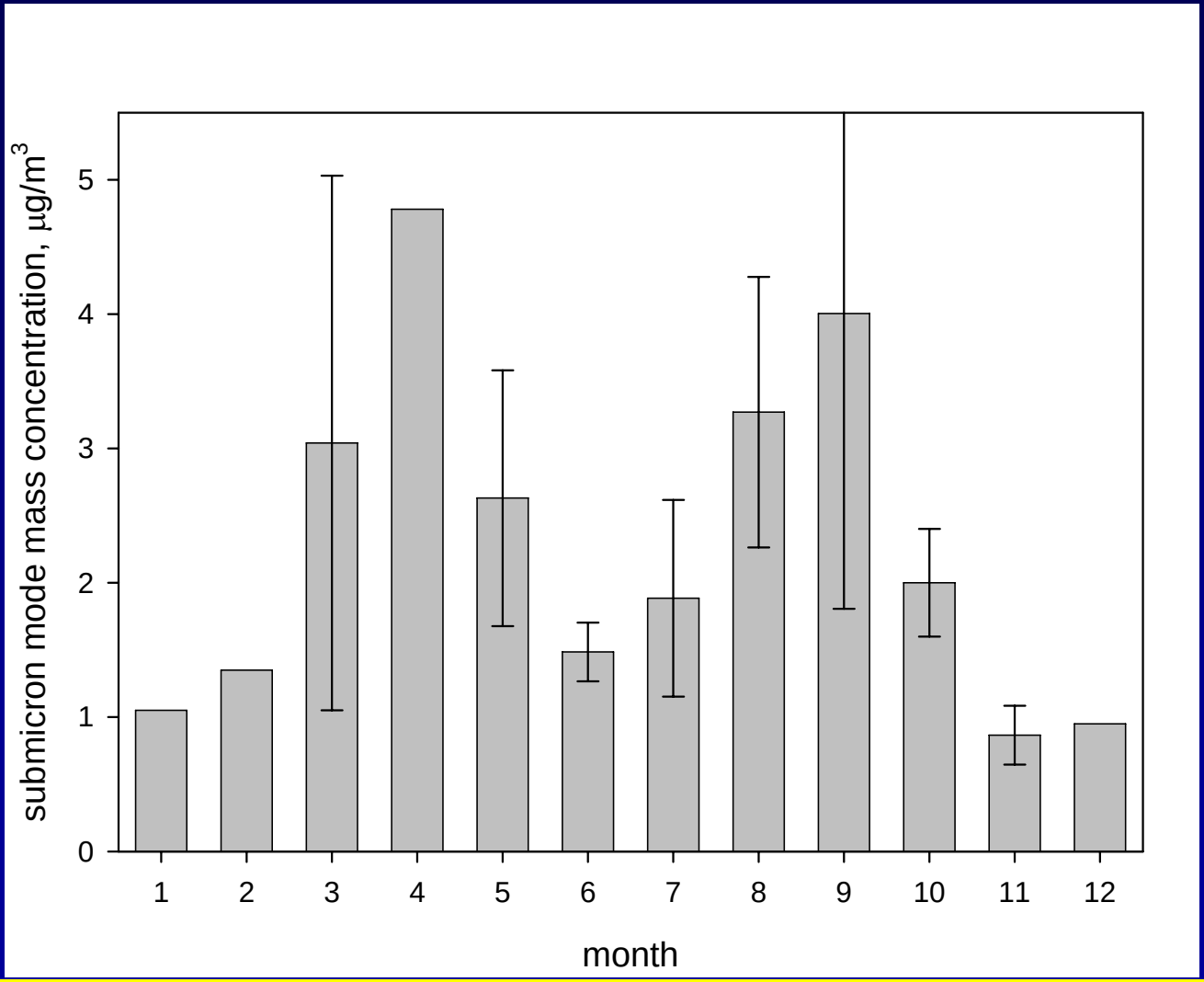
Seasonal log-normally fitted aerosol size distributions over the period from January 2002 to June 2004 at Mace Head

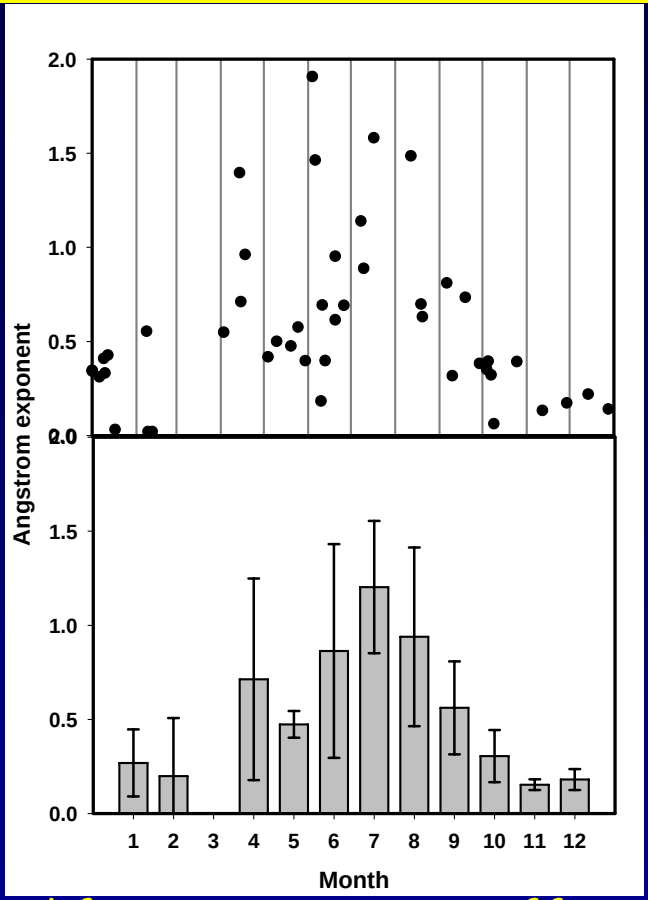


Seasonal differences in aerosol mass size distribution spectra measured by the MOUDI impactor in clean marine air. The MOUDI D_{50} inlet efficiency is estimated for a wind speed of 7 ms^{-1}, to be 5μm.

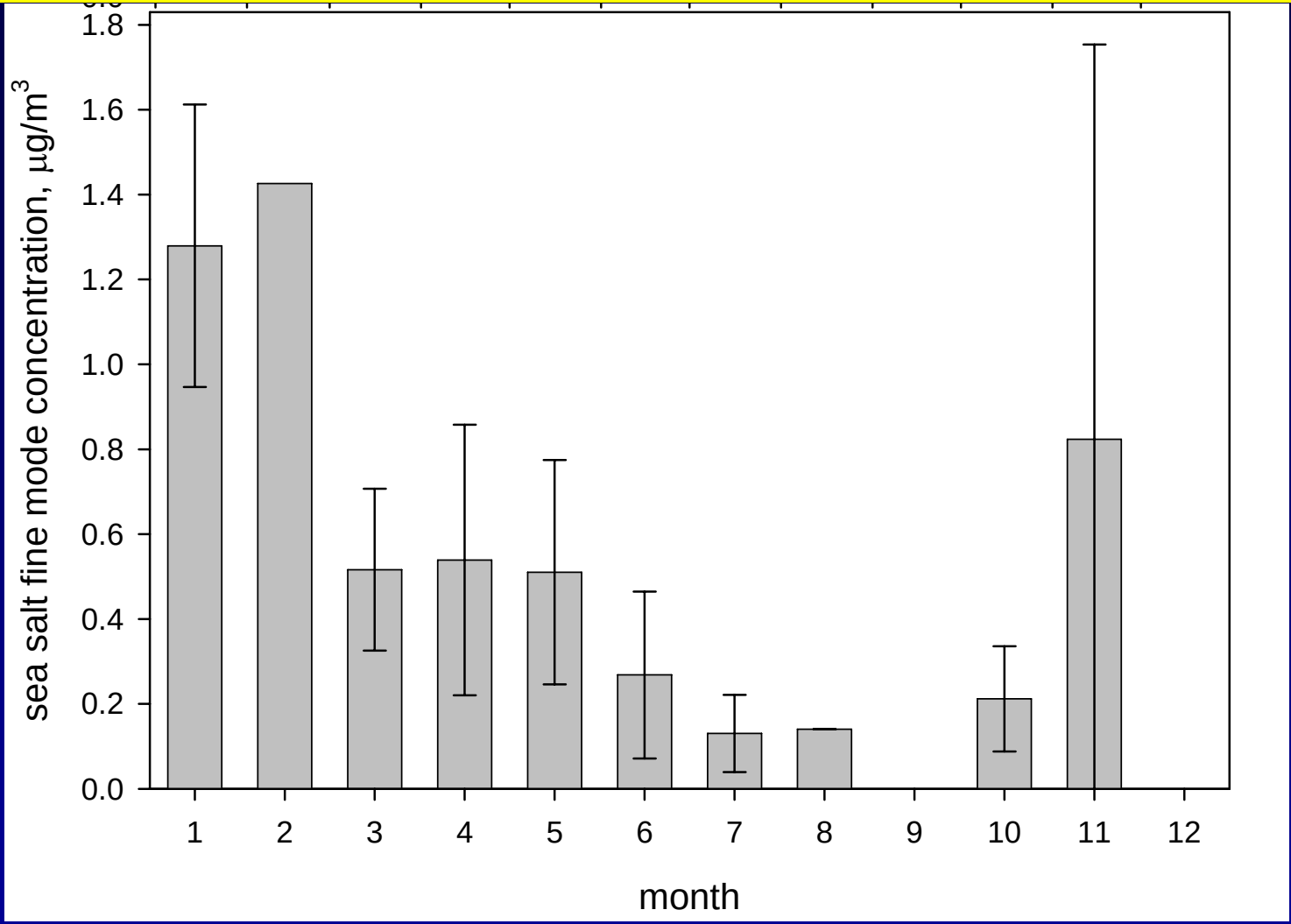
Insert figure is to highlight aerosol mass distribution between 1 and 6 μm, with a linear Y-axis

Seasonal variation in marine accumulation submicron mass concentration over the period January 2002 to June 2004

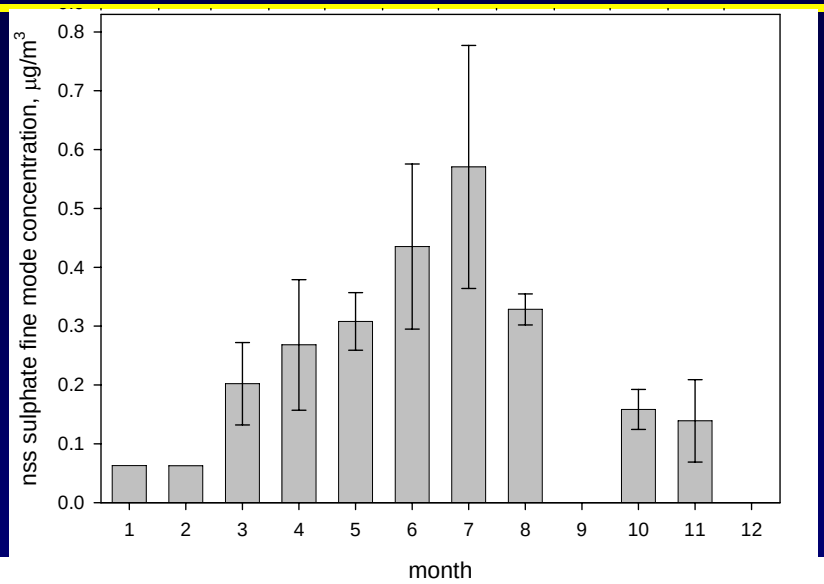


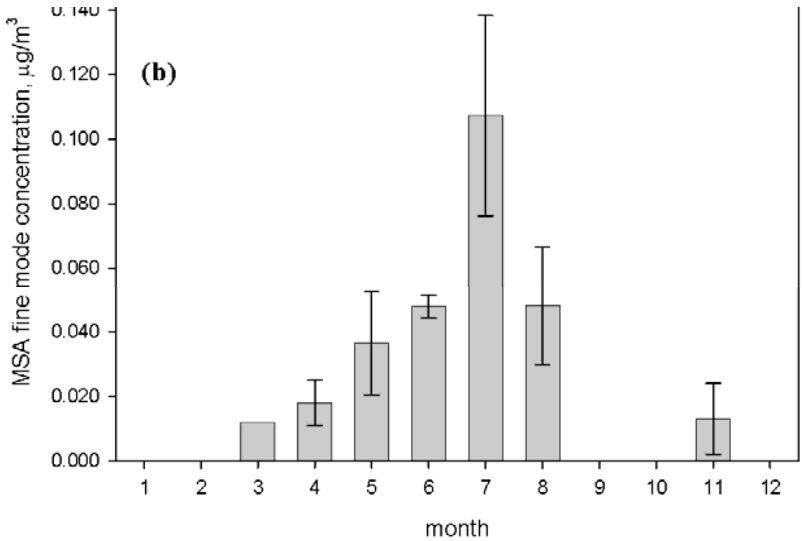


Angström exponent derived from scattering coefficient measurements (at wavelengths of 450, 550 and 700nm). Marine aerosol show larger Angström exponent values during late spring and summer, indicating a larger contribution of the fine or accumulation mode aerosol, compared to winter, which is likely due to organic sub-micron aerosol during biologically active seasons

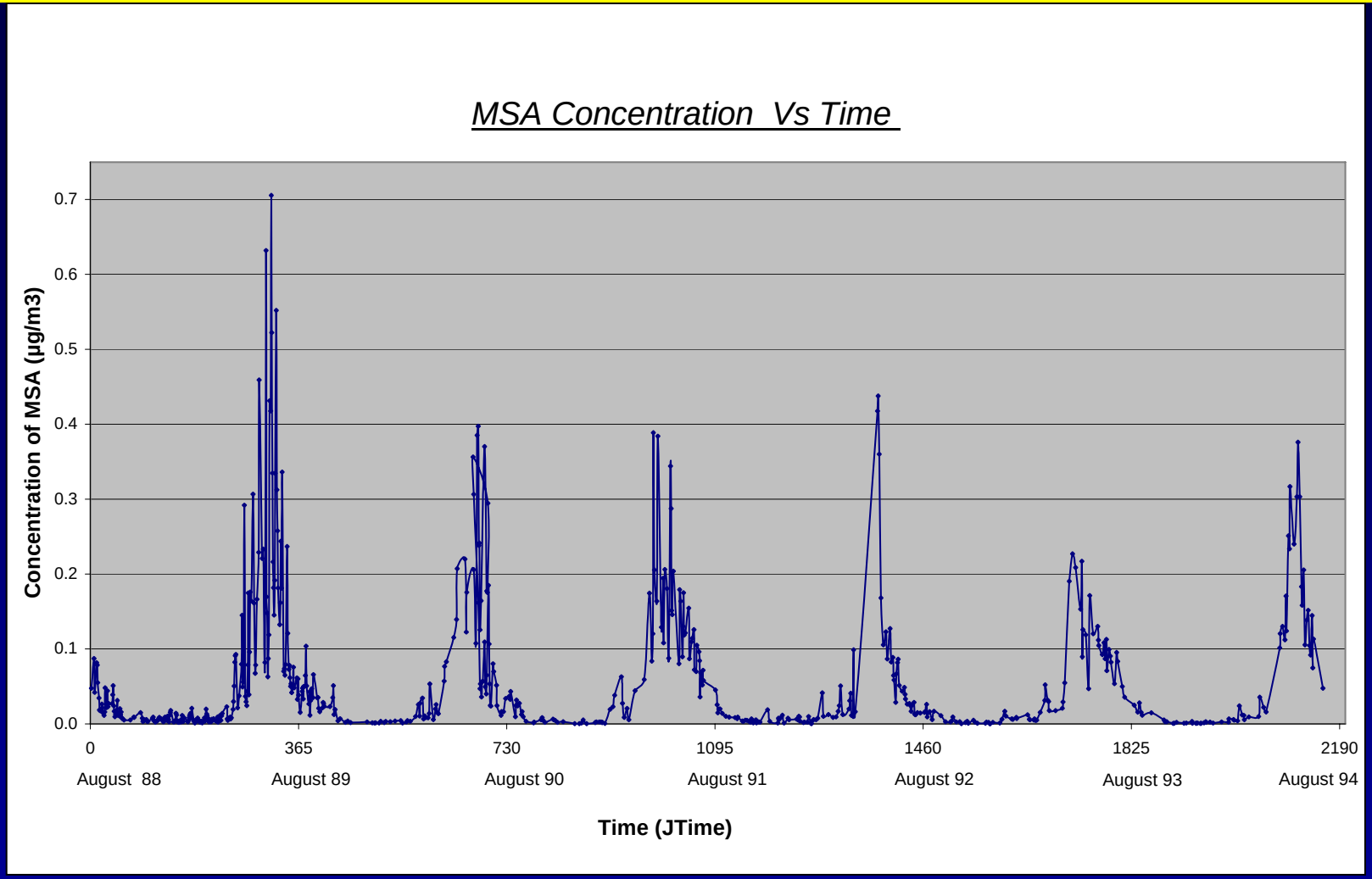


Seasonal variation of fine mode (< 1.5 μm diameter) sea-salt mass concentration, which shows a higher sea-salt loading in winter due to higher wind speeds

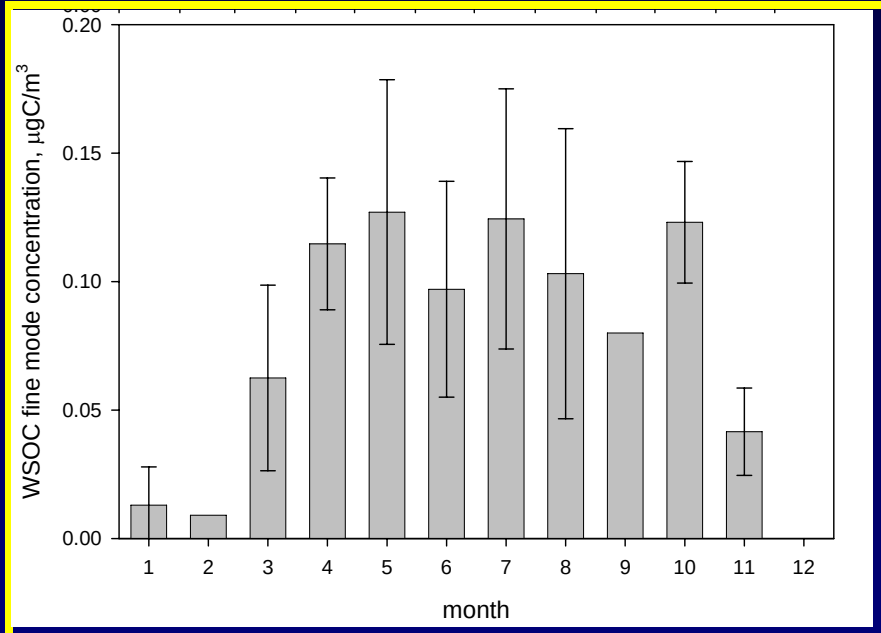


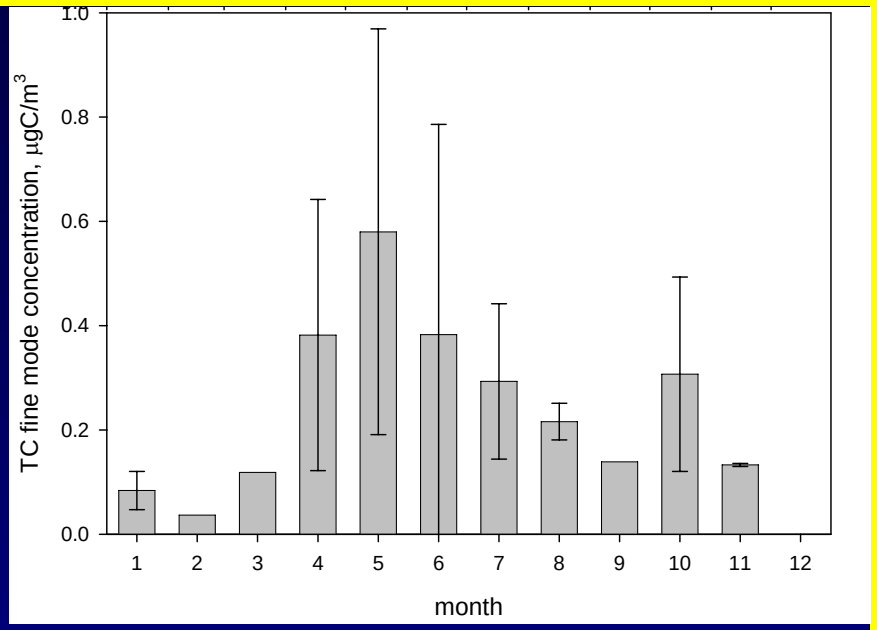


Methanesulfonate (MSA) and non sea-salt sulphate (nssSO4) fine mode mass concentration seasonal pattern.



Methane sulphonate (MSA) mass concentration measurements at Mace Head (1988 – 1994) from Prospero et al., RSMAS, University of Miami.

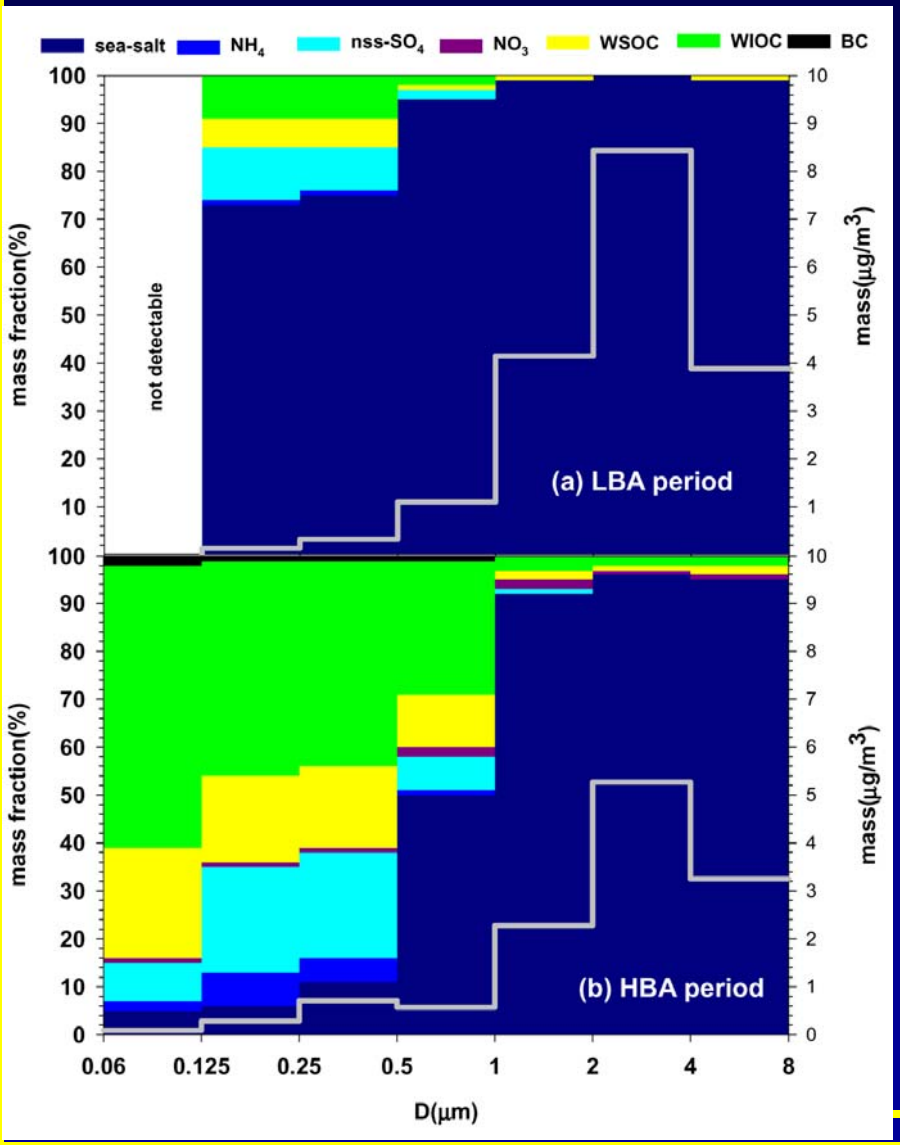


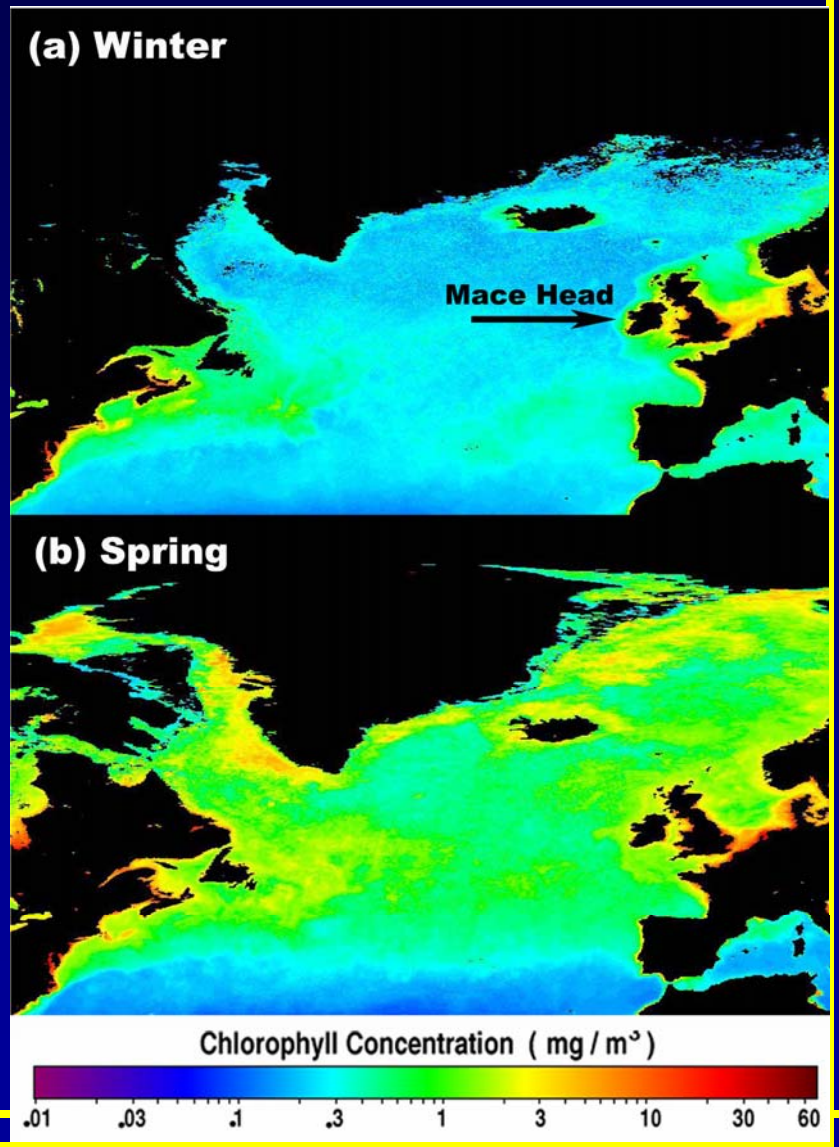


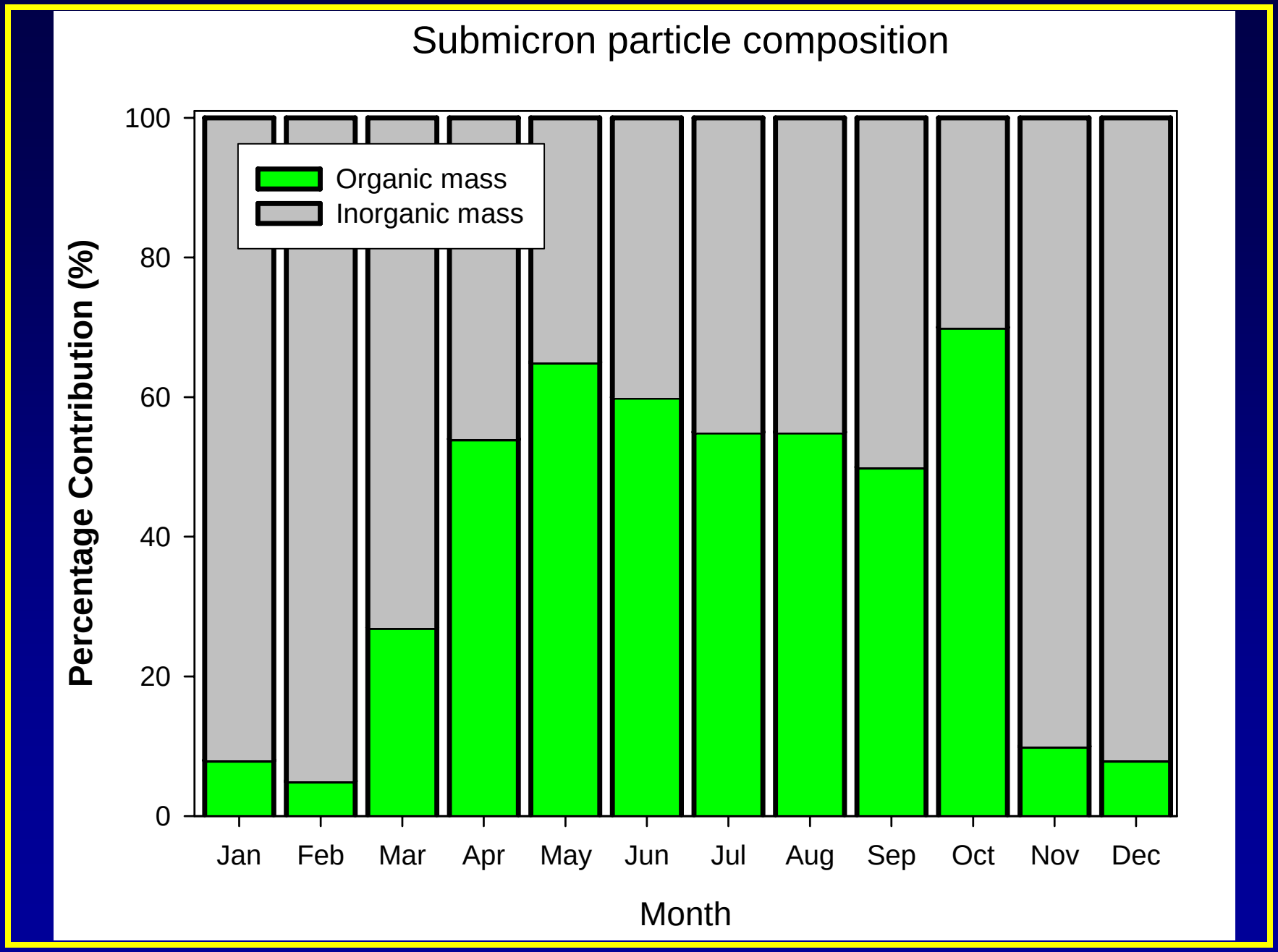
Seasonal variation of Water Soluble Organic Carbon (WSOC), shows highest concentrations during spring-to-autumn, which tracks higher phytoplankton biomass activity

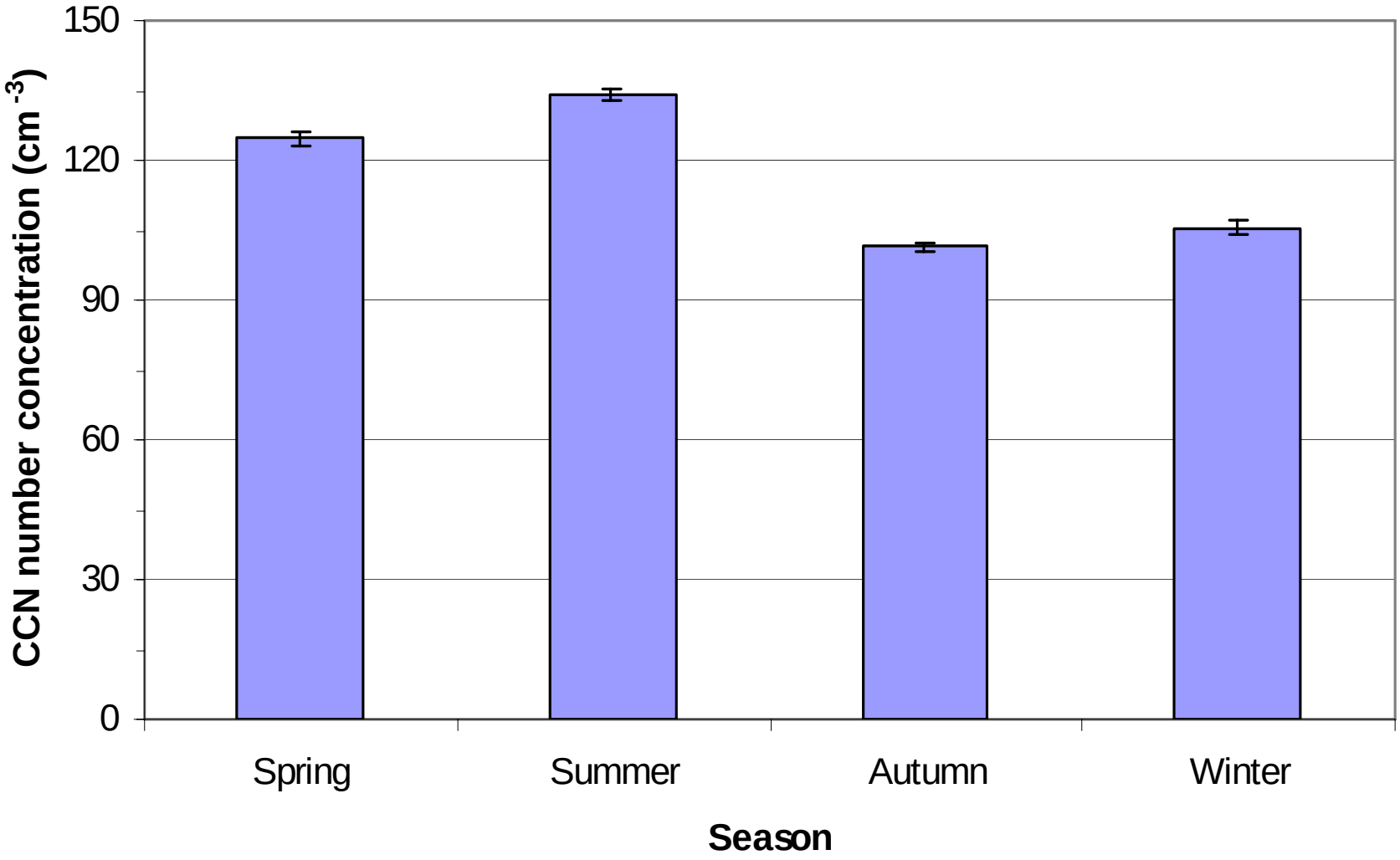
Total Carbon (TC): which includes WSOC, water insoluble organic carbon and elemental carbon, also shows a fairly similar seasonal pattern

O'Dowd et al, Nature, 2004; Cavalli et al, J. Geophysical Research, 2005






Submicron particle composition
Organic mass
Inorganic mass
Percentage Contribution (%)
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

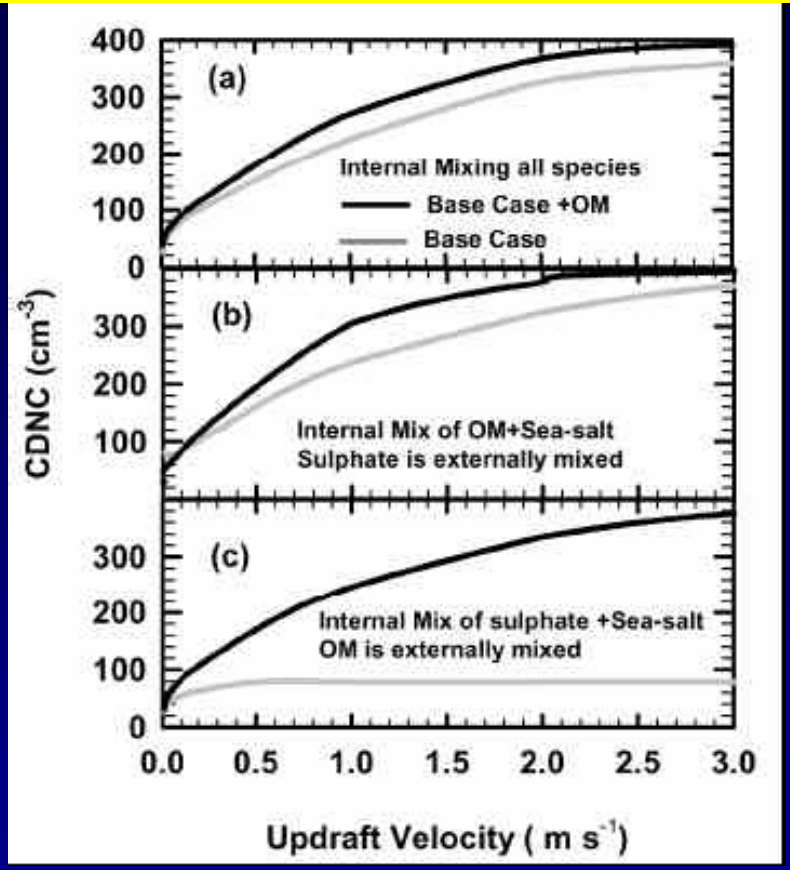


Seasonality of Cloud Condensation Nuclei (CCN), 1994 – 2003, at Mace Head.

Reade et al, Atmos. Res. (in press), 2006

O' Dowd et al,

Nature, 2004



15 – 20% increase

30% - > 100% increase

Use of a 1 D Lagrangian cloud parcel model, with different internal and external mixtures of inorganic species: sulphate + sea salt and of organic matter (OM) predicts :

An increase [black curve] in cloud droplet number concentration (CDNC) due to the addition of organic cloud condensation nuclei (CCN) above the baseline case – grey curve [for inorganic only cloud condensation nuclei - CCN]

Some Conclusions

- Seasonal characteristics of North Atlantic marine aerosols suggest an important link between marine aerosols and biological activity through primary production of marine aerosols, driven by variation in wind speed and organic matter concentration at the ocean surface

- Main feature observed from combined microphysical and chemical aerosol measurements is:
  During spring-summer, when biological activity is high, the aerosol is characterised by larger modal diameters and a maximum organic content

- Characterisation of the atmospheric aerosol at regional scale [for regions such as the North Atlantic] is key to improved understanding at the global scale, which ideally should incorporate fully characterised regional components

Future Requirements for Primary Marine Aerosol:

- Improved understanding of the role of surfactants in influencing bubble-mediated aerosol production
- Improved characterisation of marine aerosol chemical composition.
- Improved size-resolved flux measurements, including aerosol chemical species fluxes.
- Development of a Global Sea-Spray Source Function

17th International Conference on

Nucleation & Atmospheric Aerosols

August 13th – 17th 2007

National University of Ireland, Galway, Ireland.

Preliminary Scientific Programme:

- Nucleation Theory & Experiment
- Atmospheric Cloud Droplet & Ice Crystal Properties
- Tropospheric & Stratospheric Aerosols
- Aerosol-Cloud-Climate Interactions