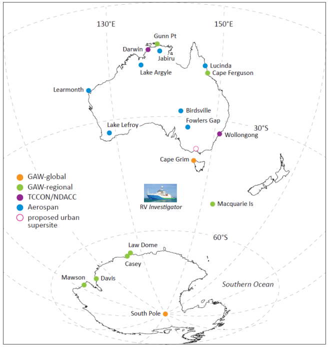
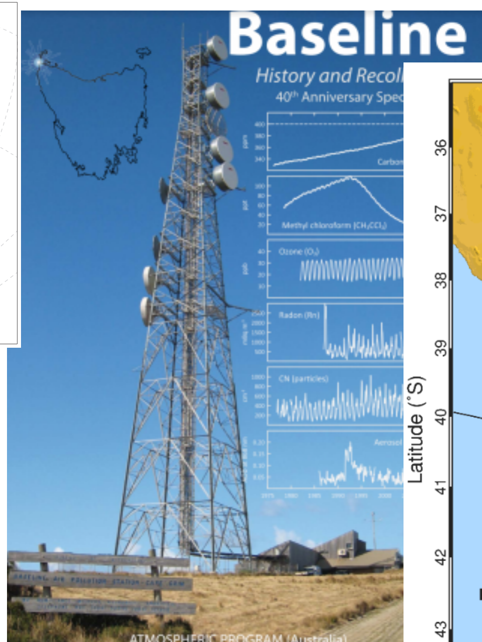
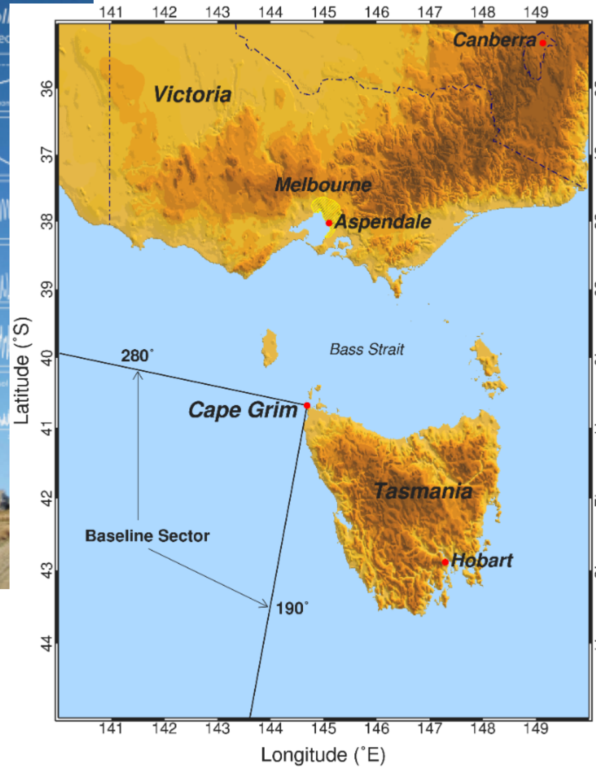
Long term aerosol observations at Kennaook Cape Grim and CAPE-k

Melita Keywood

Kennaook Cape Grim Baseline Station







Kennaook Cape Grim is a joint responsibility of the Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (CSIRO)

BoM funds and operates the Kennaook Cape Grim atmospheric observational facility.
CSIRO provides scientific capability and leadership

Kennaook Cape Grim Science Programs

- Radon Alistair Williams ANSTO
- Greenhouse gases and ozone depleting substances (GGODS) – Paul Krummel, Zoe Loh and Ray Langenfelds CSIRO
- Aerosols, Reactive Gases and Multiphase Atmospheric Chemistry (ARGMAC) Melita Keywood, Erin Dunne and Ruhi Humphries CSIRO
- Radiation Joanna Turner Southern Queensland University

ARGMAC Aerosols

- Aerosol microphysical properties (CN3, CN11, size distribution, CCN)
- Aerosol optical properties (scattering, absorption)
- Aerosol chemical composition (PM10, PM2.5, tofACSM)
- Rainwater chemical composition

CSIRO

ARGMAC Program Goals

Investigates the nature, sources and processes of production and evolution of climatically important particles over the Southern Ocean

Characterise

Southern Ocean marine boundary layer aerosol and the processes that relate aerosol to climate change

Identify

trends in our long-term data sets (particles and gaseous elemental mercury)

Contribute

data and information to data centres and assessments

data and information that will lead to the improvement/assessment of aerosol and multiphase atmospheric chemistry schemes in models

Kennaook Cape Grim record gives us a window into SO marine aerosol

Long term monitoring

Process studies

Long term monitoring

Challenge regional or global numerical models that underpin climate projections

Contributes to Global Atmospheric Watch

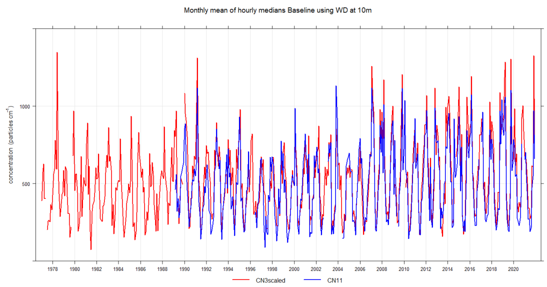
Demonstrate the effectiveness of interventions to protect the environment e.g. Minamata Convention on Mercury & Stockholm Convention on Persistent Organic Pollutant that Australia ratified in 2004

Long-term measurements in order to detect trends in global distributions of chemical constituents in air

Long term monitoring

Challenge regional or global numerical models that underpin climate projections

Contributes to Global Atmospheric Watch



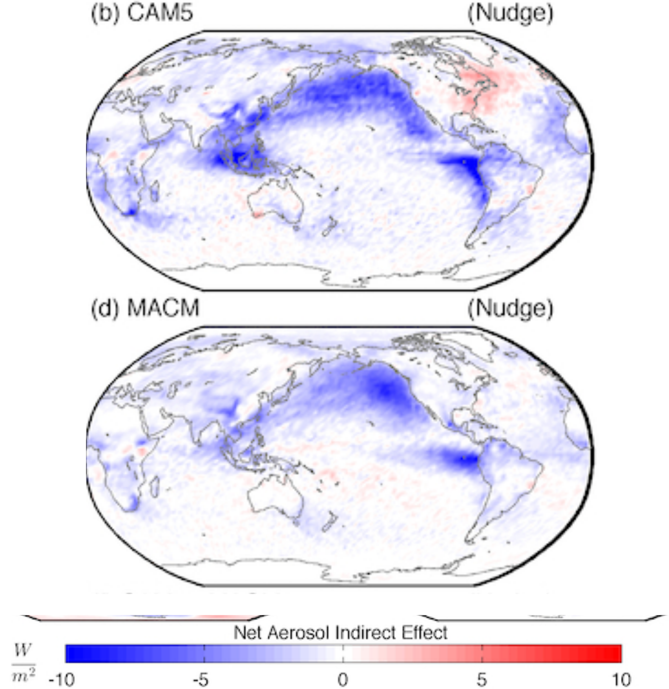
Long-term measurements in order to detect trends in global distributions of chemical constituents in air

Demonstrate the effectiveness of interventions to protect the environment e.g. Minamata Convention on Mercury & Stockholm Convention on Persistent Organic Pollutant that Australia ratified in 2004

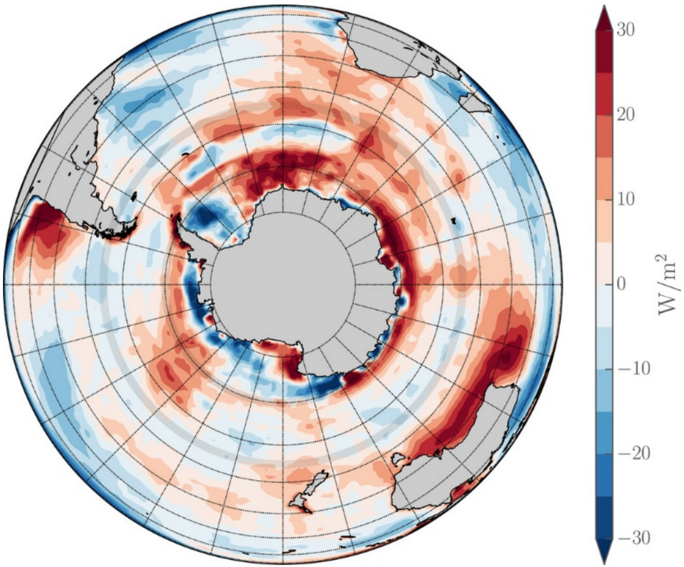
Marine aerosol is important

- Oceans cover 70% if the Earths surface
- Earth's radiative budget
- Biogeochemical cycling, impacts on ecosystems
- Regional air quality
- Southern Ocean aerosol is closest representation of natural aerosol on the globe due to relatively minimal impact of anthropogenic sources

Aerosol forcing associated with ACI over the SO is small relative to NH



Adapted from Kooperman et al. (2012)
Journal of Geophysical Research-Atmospheres, 117. doi:D23204
10.1029/2012jd018588

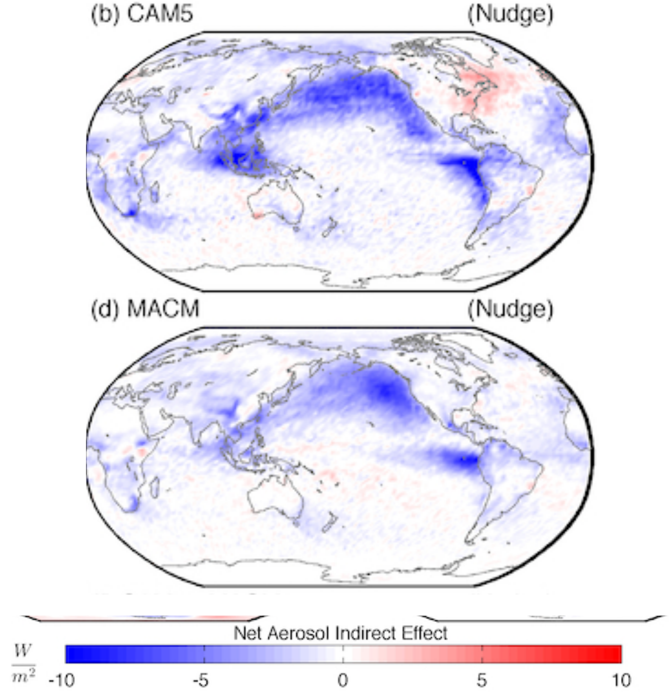


Mason et al., 2014 Journal of Climate 27, 16; [10.1175/JCLI-D-14-00139.1](https://doi.org/10.1175/JCLI-D-14-00139.1)

Marine aerosol is important

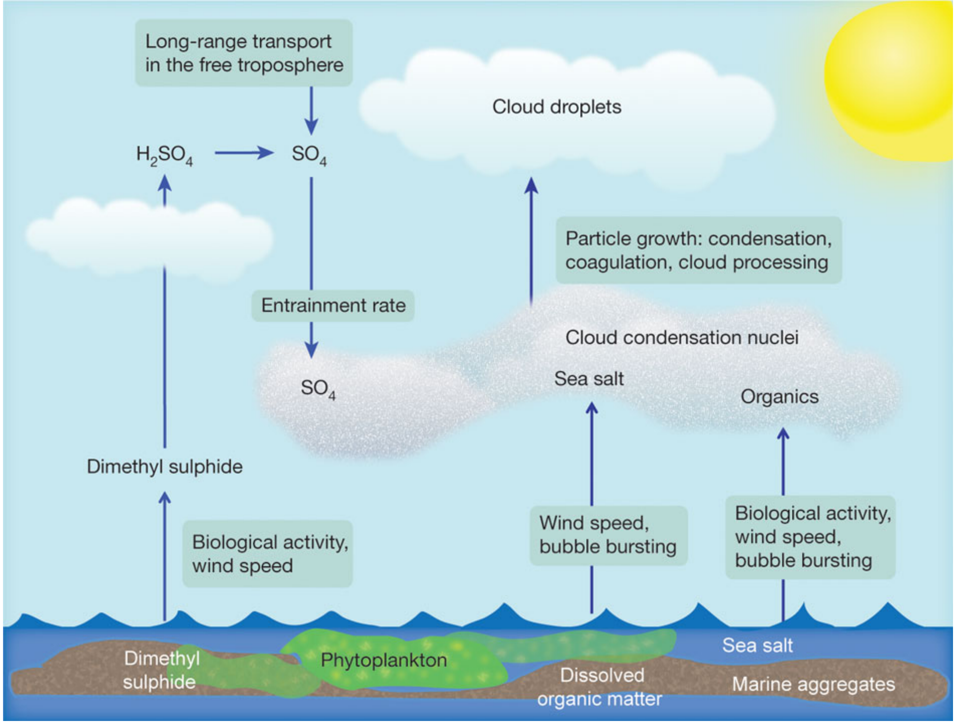
- Oceans cover 70% if the Earths surface
- Earth's radiative budget
- Biogeochemical cycling, impacts on ecosystems
- Regional air quality
- Southern Ocean aerosol is closest representation of natural aerosol on the globe due to relatively minimal impact of anthropogenic sources

Aerosol forcing associated with ACI over the SO is small relative to NH



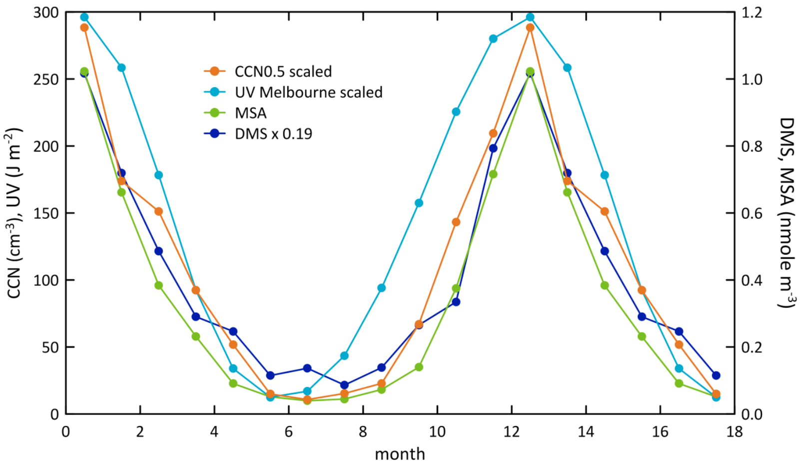
Adapted from Kooperman et al. (2012)
Journal of Geophysical Research-Atmospheres, 117. doi:D23204 10.1029/2012jd018588

Marine aerosol sources

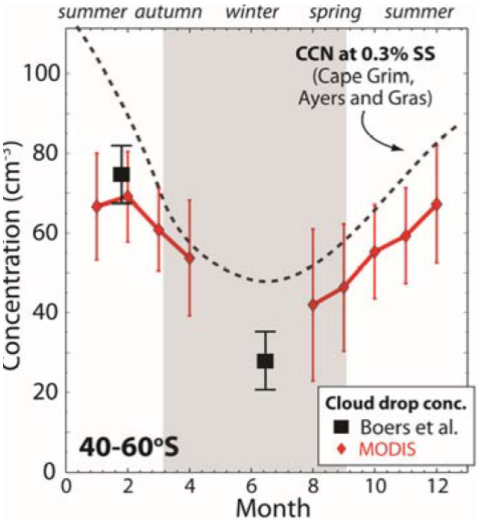


Quinn and Bates 2011 *Nature, 480*(7375), 51-56. doi:10.1038/nature10580

Cloud Condensation Nuclei



Gras and Keywood 2017Atmos. Chem. Phys., 17(7), 4419-4432. doi:10.5194/acp-17-4419-2017



SOCRATES white paper

CCN are not a particular type of particle, but a highly variable subset of the aerosol population.

The sources and sinks of CCN over the SO are actively researched

Achievements- long term records

A 45-year record of ultrafine particle number concentration (CN3)

A 33-year record of particle number concentration (CN10)

A 25-year (1981-2006) manual baseline CCN record (monthly median CCN (1.23%, 0.96%, 0.71%, 0.47% and 0.23 %SS) 2-6 days per month measured in baseline wind sector (190-280)

A 15-year record of cloud condensation nuclei concentration (CCN) measured continuously (0.5%SS)

A 31 -year record of black carbon concentrations (BC) (aerosol absorption)

A 16-year record of forward aerosol scattering at 3 wavelengths

A 46-year record of soluble ion concentrations in ~ PM10 including MSA, sea-salt and non-sea salt sulfate (NSSS)

A 20-year record of gravimetric mass and soluble ion concentrations in PM2.5 for MSA, sea salt and NSSS

A 37-year record of soluble ion concentrations in weekly baseline rainfall including sea salt and NSSS

19-year record of annual passive POPs concentrations (GAPS network, a collaborative program with Environment Canada)

~ 10 year record of gaseous elemental mercury via continuous measurement.

Da

Parameter	Description	Link
CN11	Particle number (CN10) hourly averages 2011-2021 TSI3010 Note CN data (2006-2010) submitted to WDCA in NARSTO format	WDCA -unique link
CN3	Particle number (CN3) hourly medians 1977 to 2007 using the Automated Pollack Counter	CSIRO DAP – https://doi.org/10.25919/xd4e-b034
CN3	2007-2021-various TSI instruments	CSIRO Servers
Aerosol scattering	Aerosol forward scattering at 450 nm, 525 nm and 635 nm 2011-2021 using Ecotech 3000 Nephelometer	WDC Aerosols- unique link
Aerosol scattering	Polar Nephelometer 2018-2021	CSIRO servers
Aerosol Absorption	Aerosol Absorption at hourly averages 637 nm 2011-2021 using MAAP and AE33	WDC Aerosols-unique link
BC	Hourly medians BC old aethalometer	Commitment to submit to CSIRO DAP
CCN 0.5%SS	CCN hourly averages 2012-2021	WDC Aerosols -unique link
CCN 1.2%, 0.96%, 0.71%, 0.47% and 0.23% SS	Manual monthly CCN medians 1981 to 2002 using the static thermal diffusion chamber	CSIRO DAP- https://doi.org/10.25919/bzkn-pq93
PM10ish composition	Soluble ion composition weekly baseline samples 1989-2003 using the Gold Top sampler	KCG Archives and CSIRO servers Commitment to submit to CSIRO DAP
PM10 and PM2.5 Composition	2003 onwards	CSIRO servers
Precipitation composition		KCG Archives and CSIRO servers
Gaseous Elemental Mercury	2011-2022	Commitment to submit to DAP in 2023 for use in Minamata Effectiveness Evaluation
Aerosol size distribution	2019-2021	CSIRO Servers
PM1 composition	2020-2021	CSIRO Servers
Mercury wet deposition	2013-2014	GMOS

Da

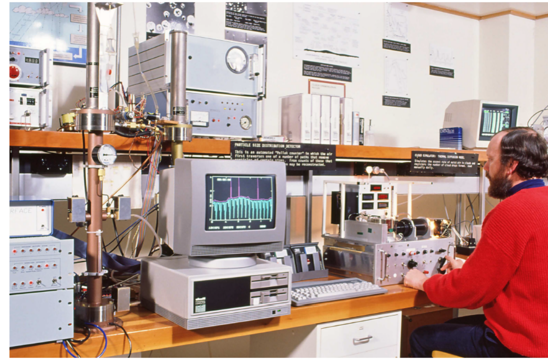
Parameter	Description	Link
CN11	Particle number (CN10) hourly averages 2011-2021 TSI3010 Note CN data (2006-2010) submitted to WDCA in NARSTO format	WDCA -unique link
CN3	Particle number (CN3) hourly medians 1977 to 2007 using the	CSIRO DAP https://doi.org/10.25919/xd4e
CN3		
Aerosol s		
Aerosol s		
Aerosol A		
BC		
CCN 0.5%		
CCN 1. 0.71%, 0.23% S		
PM10ish		
PM10 a Composit		
Preci composit		
Gaseous Elemental Mercury	2011-2022	Commitment to submit to DAP in 2023 for use in Minamata Effectiveness Evaluation
Aerosol size distribution	2019-2021	CSIRO Servers
PM1 composition	2020-2021	CSIRO Servers
Mercury wet deposition	2013-2014	GMOS

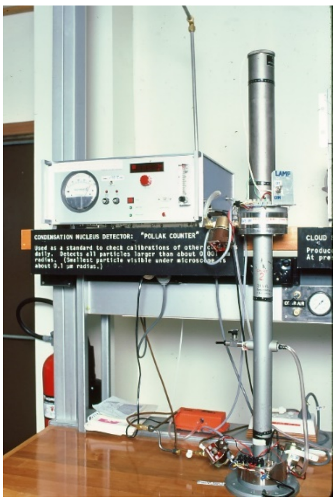
2011-2021 WDCA CN10, CCN, scattering and absorption

Historical data sets CSIRO DAP or CSIRO servers

New instruments –data submission protocols under development

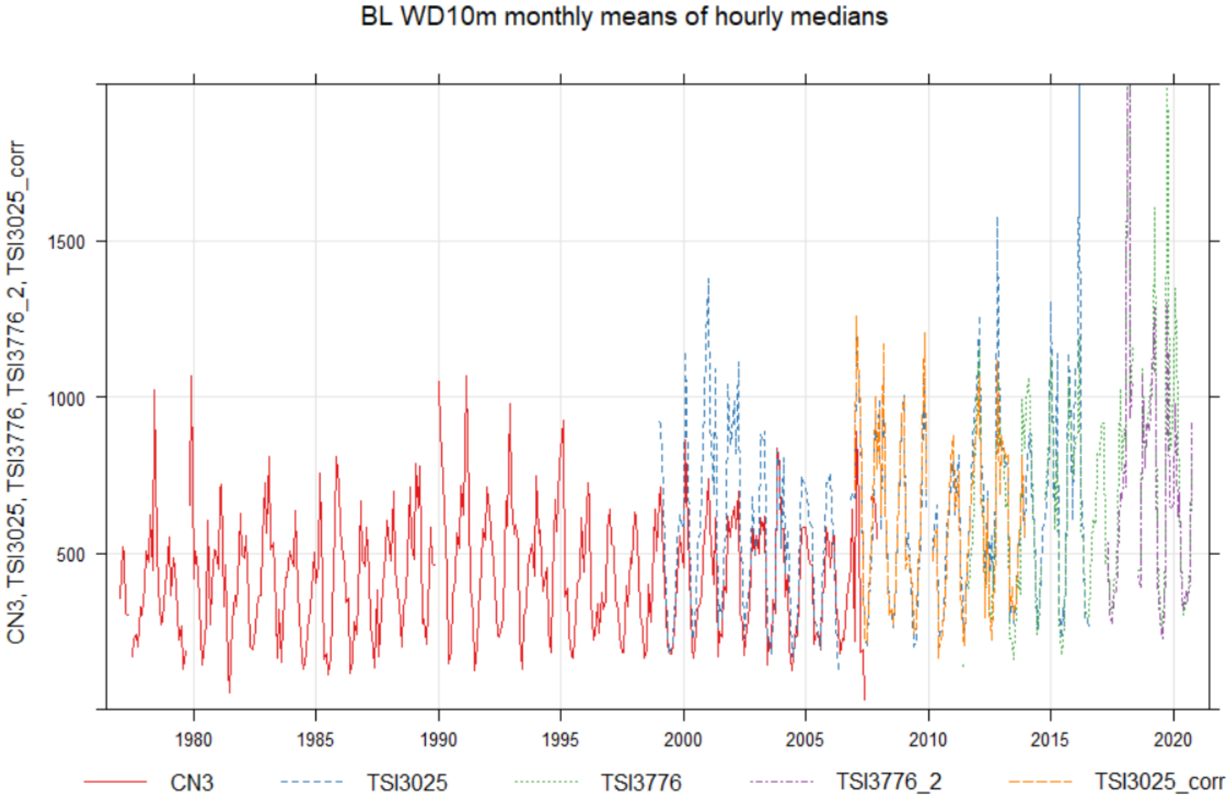
Particle number concentrations





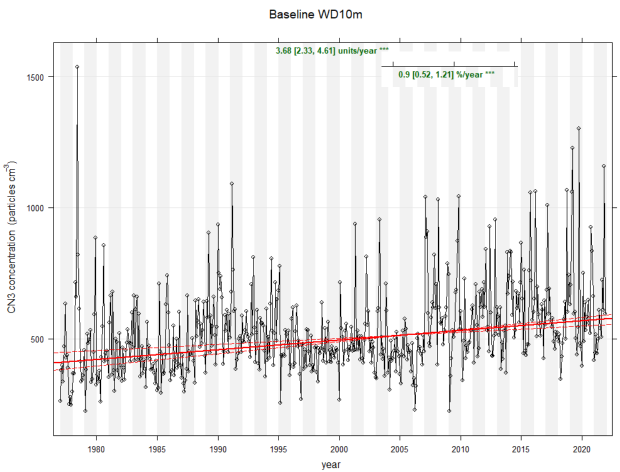
1977-1998

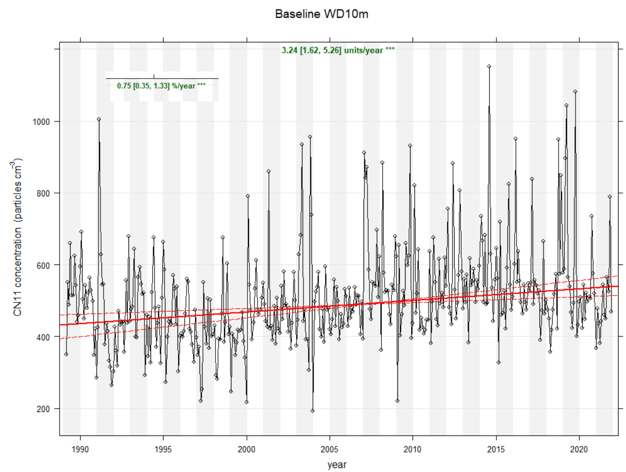
1998 to present


BL WD10m monthly means of hourly medians
CN3, TSI3025, TSI3776, TSI3776_2, TSI3025_corr
500
1000
1500
1980
1985
1990
1995
2000
2005
2010
2015
2020
CN3
TSI3025
TSI3776
TSI3776_2
TSI3025_corr

14

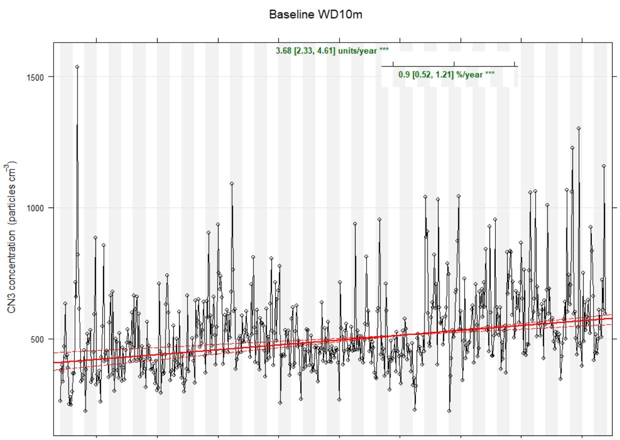
CN trends

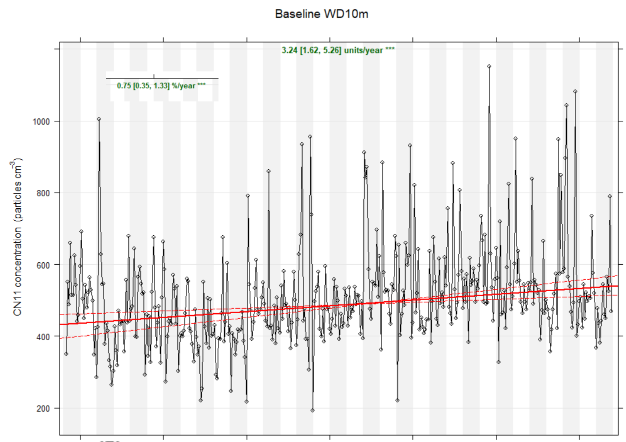




- Deseasoned and autocorrelation, hourly data (note that TS averages to monthly before calculating trend)
- solid red line shows the trend estimate
- dashed red lines show the 95 % confidence intervals for the trend based on resampling methods
- 1.1% [0.56,1.66] %/year

CN trends

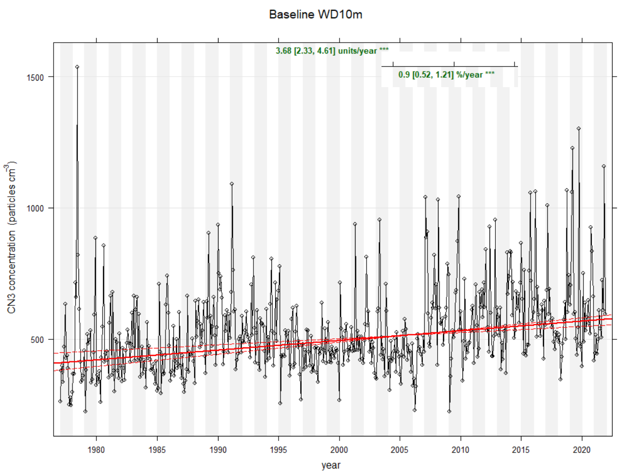


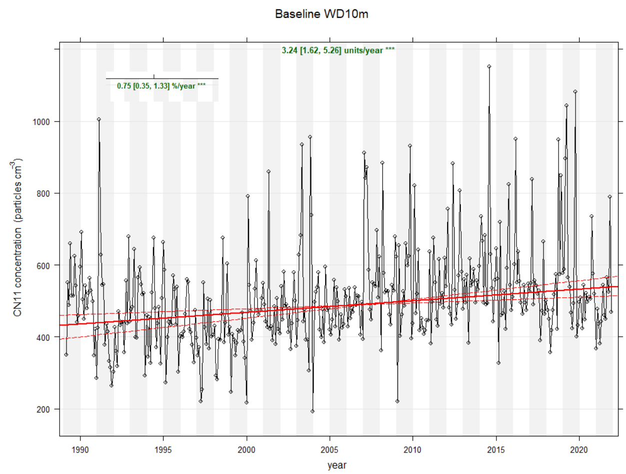


OpenAir Thielsen procedure Carslaw, D. C. and K. Ropkins, (2012) openair --- an R package for air quality data analysis. Environmental Modelling & Software. Volume 27-28, 52-61

- Deseasoned and autocorrelation, hourly data (note that TS averages to monthly before calculating trend)
- solid red line shows the trend estimate
- dashed red lines show the 95 % confidence intervals for the trend based on resampling methods
- 1.1% [0.56,1.66] %/year

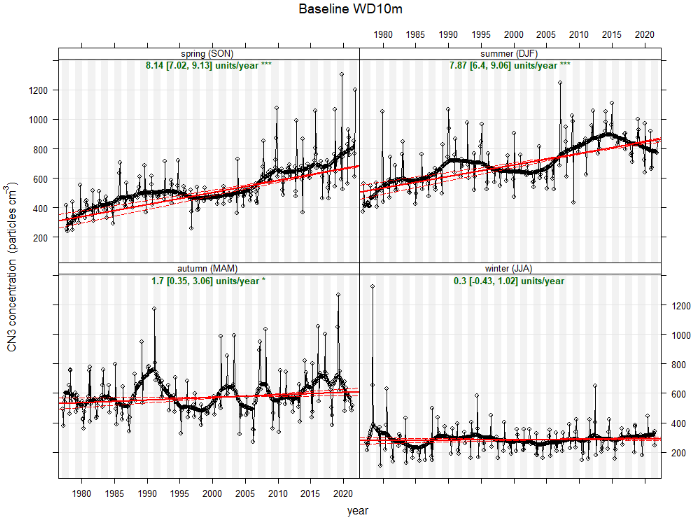
CN trends

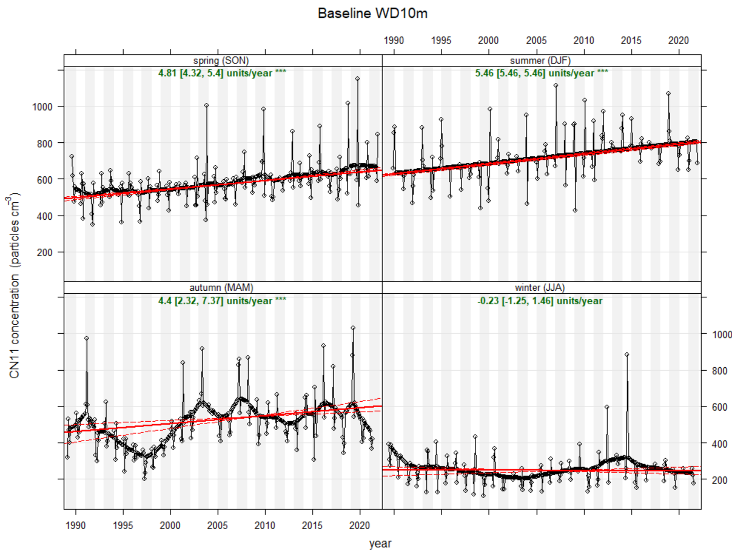


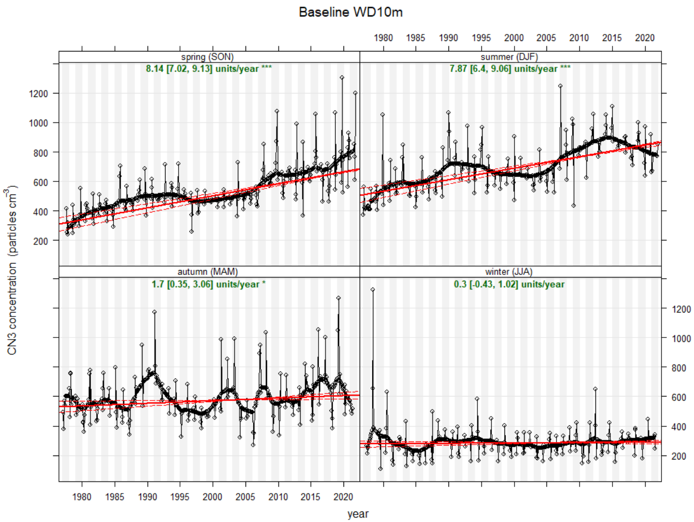


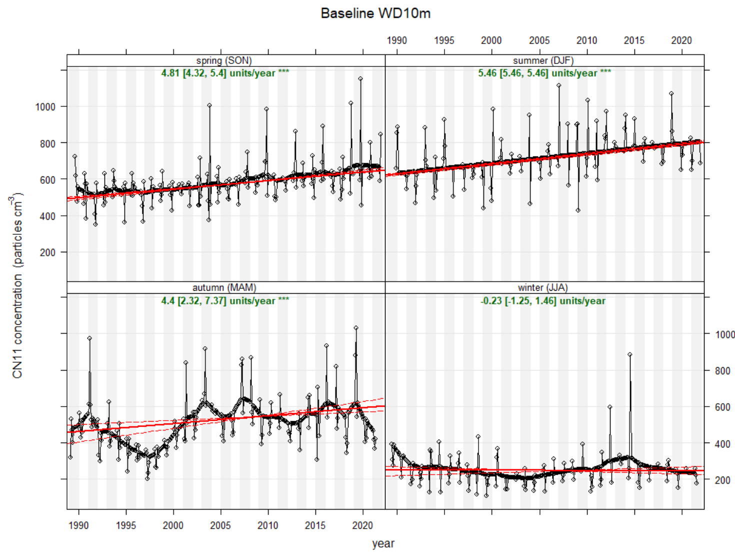
- Deseasoned and autocorrelation, hourly data (note that TS averages to monthly before calculating trend)
- solid red line shows the trend estimate
- dashed red lines show the 95 % confidence intervals for the trend based on resampling methods
- 1.1% [0.56,1.66] %/year

15


Baseline WD10m
spring (SON)
8.14 [7.02, 9.13] units/year ***
summer (DJF)
7.87 [6.4, 9.06] units/year ***
autumn (MAM)
1.7 [0.35, 3.06] units/year *
winter (JJA)
0.3 [-0.43, 1.02] units/year
CN3 concentration (particles cm^{-3})
year

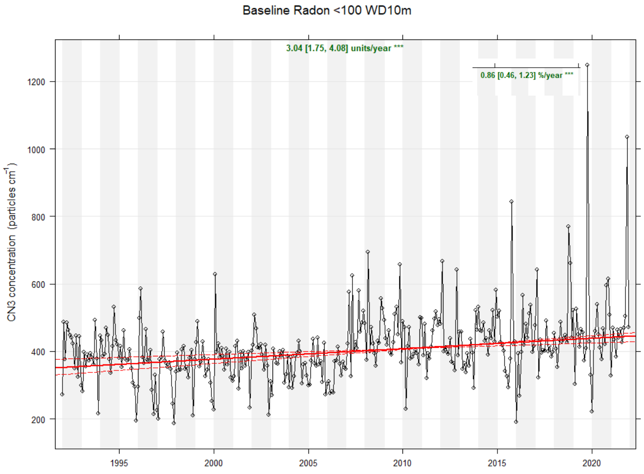

Baseline WD10m
spring (SON)
4.81 [4.32, 5.4] units/year ***
summer (DJF)
5.46 [5.46, 5.46] units/year ***
autumn (MAM)
4.4 [2.32, 7.37] units/year ***
winter (JJA)
-0.23 [-1.25, 1.46] units/year
CN11 concentration (particles cm^{-3})
year

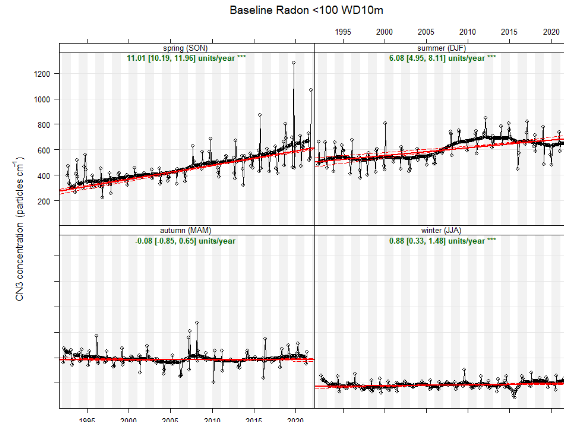


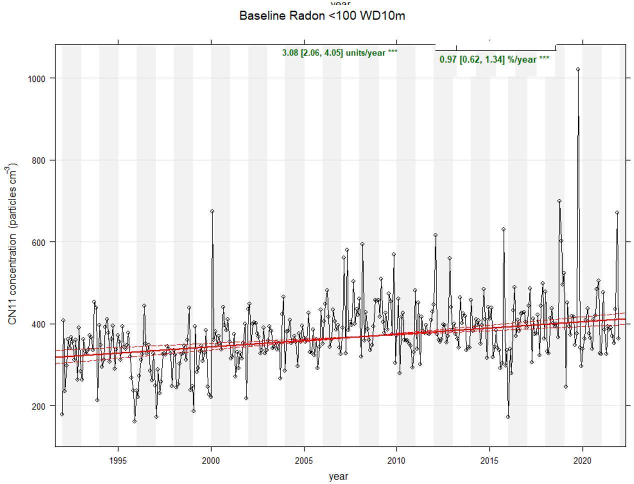


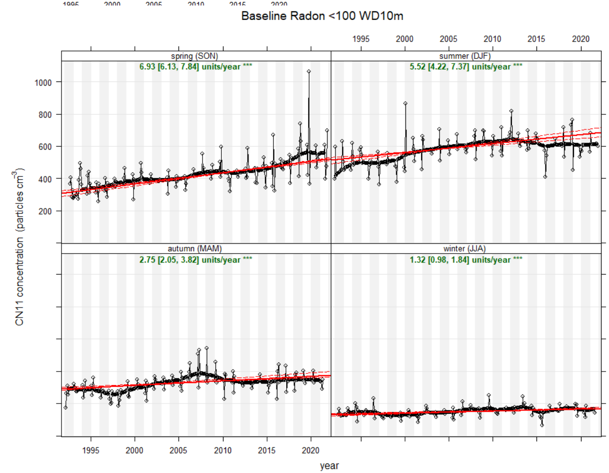
CN3 over 45 years that's an increase 135 -180 particles cm^{-3}

Almost a doubling of baseline summer and spring medians in 45 years


Baseline Radon <100 WD10m
3.04 [1.75, 4.08] units/year ***
0.86 [0.46, 1.23] %/year ***
CN3 concentration (particles cm^{-3})
year

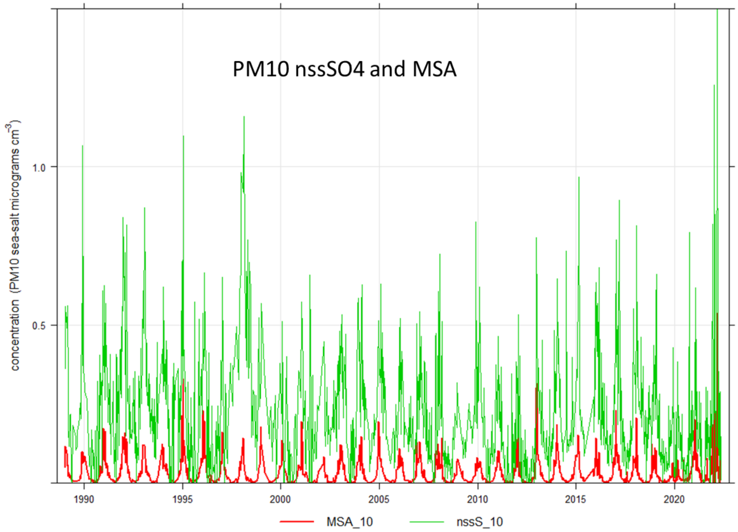

Baseline Radon <100 WD10m
spring (SON)
11.01 [10.19, 11.96] units/year ***
summer (DJF)
6.08 [4.95, 8.11] units/year ***
autumn (MAM)
-0.08 [-0.85, 0.65] units/year
winter (JJA)
0.88 [0.33, 1.48] units/year ***
CN3 concentration (particles cm^{-3})

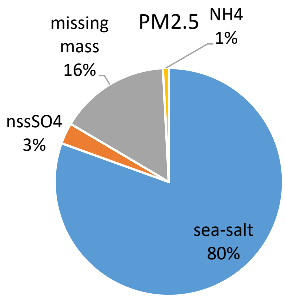

Baseline Radon <100 WD10m
3.08 [2.06, 4.05] units/year ***
0.97 [0.62, 1.34] %/year ***
CN11 concentration (particles cm^{-3})
year


Baseline Radon <100 WD10m
spring (SON)
6.93 [6.13, 7.84] units/year ***
summer (DJF)
5.52 [4.22, 7.37] units/year ***
autumn (MAM)
2.75 [2.05, 3.82] units/year ***
winter (JJA)
1.32 [0.98, 1.84] units/year ***
CN11 concentration (particles cm^{-3})
year

Aerosol chemical composition

- Weekly integrated samples show seasonal and annual information e.g. climatology's of sources
- How does chemistry influence CCN or optical properties?
- More information in the continuous records of aerosol microphysics





18

Continuous chemical composition -tof-ACSM

Time of flight aerosol chemical speciation monitor

- Inlet system –background subtraction
- Aerodynamic lens (70- 700 nm)
- Turbo pump- separates gas-phase from th particle beam
- Ionization chamber with vaporizer (600 C) particles flash vaporized and are ionized b electron impact
- Tof Ms separates ions according to their mass-to-charge ratio (MQ)
- The raw time-of-flight mass spectra are converted to unit mass resolution (UMR) spectra by integrating over each m/Q
- The mass spectral signals are converted to particle mass loadings (µg m^{-3}) using calibrated ionization efficiency (convert ions to mass) and flow rate (to determine volume of air sampled).

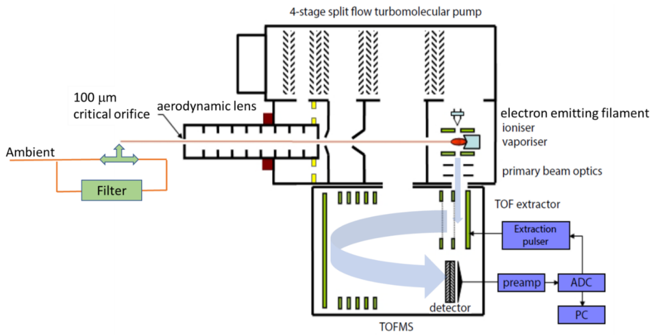
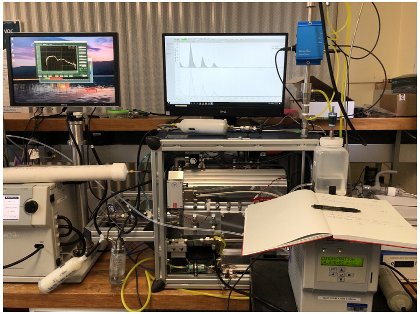


Figure 1. Schematic of the ToF-ACSM.

Frohlich (AMT, 2013)



19

Time of flight aerosol chemical speciation monitor

- Only non-refractory components – not crustal oxides or BC
- Frag tables for species e.g. MSA and now seasalt
- Organics lumped together here
- PMF to pull out different organic species
- Data for October 2020-June 2023

Marker Peaks for Aerosol Species Identification

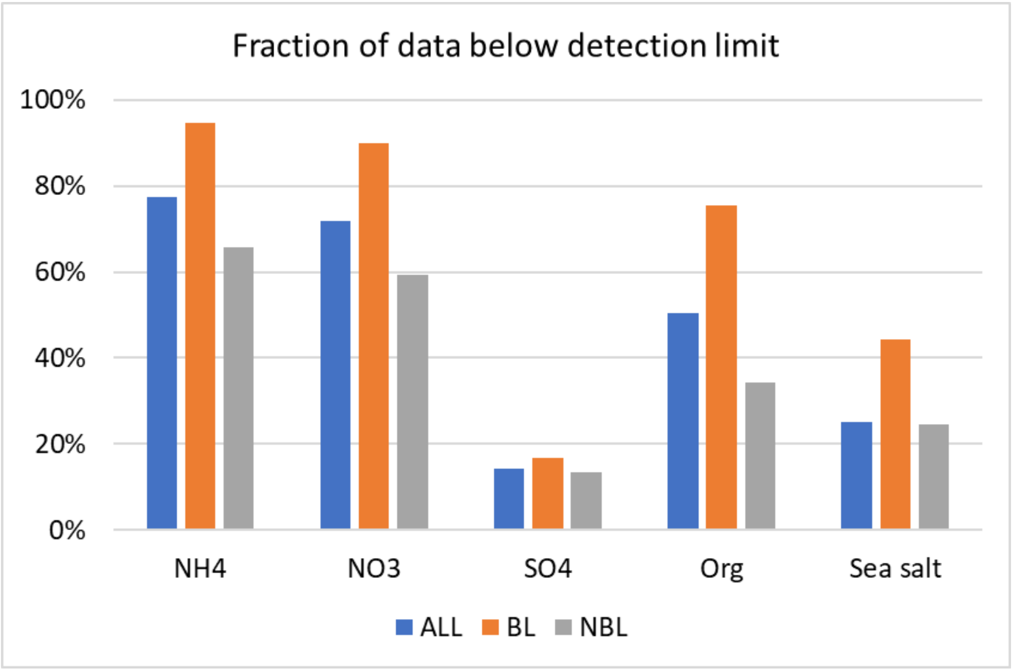
Standard AMS/ACSM colors

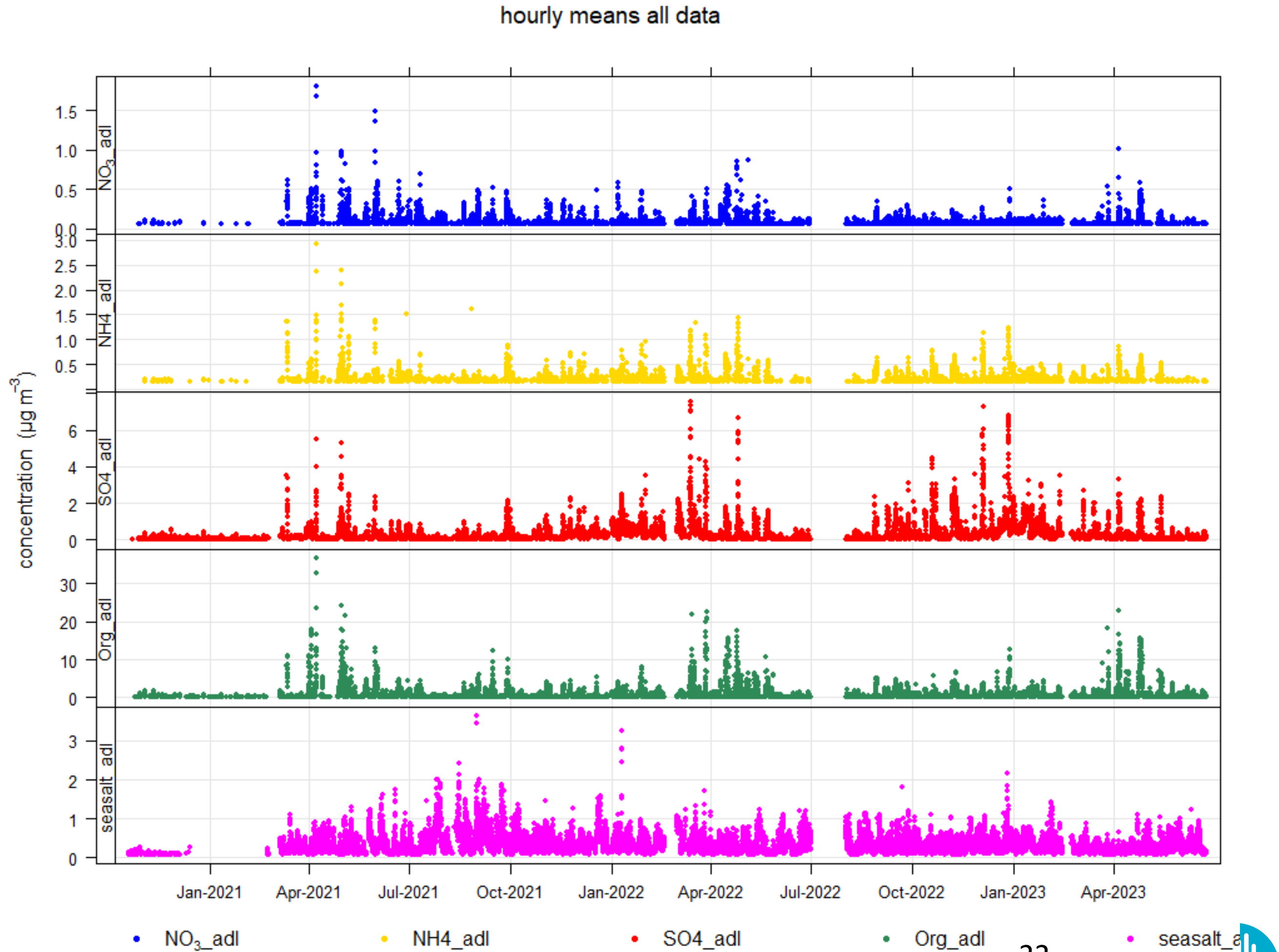
Group	Molecule/Species		Ion Fragments	Mass Fragments
Water	H_2O	$\xrightarrow{e^-}$	H_2O^+ , HO^+ , O^+	18, 17, 16
Ammonium	NH_3	$\xrightarrow{e^-}$	NH_3^+, NH_2^+, NH^+	17, 16, 15
Nitrate	HNO_3	$\xrightarrow{e^-}$	HNO_3^+, NO_2^+, NO^+	63, 46, 30
Sulfate	H_2SO_4	$\xrightarrow{e^-}$	$H_2SO_4^+$, HSO_3^+, SO_3+ SO_2^+, SO^+	98, 81, 80 64, 48
Organic *(Oxygenated)*	$C_nH_mO_y$	$\xrightarrow{e^-}$	CO_2^+ $H_3C_2O^+$, HCO_2^+, $C_{n'}H_{m'}^+$	44 43, 45, ...
Organic *(hydrocarbon)*	C_nH_m	$\xrightarrow{e^-}$	$C_{n'}H_{m'}^+$	27,29,41,43,55,57,69,71...

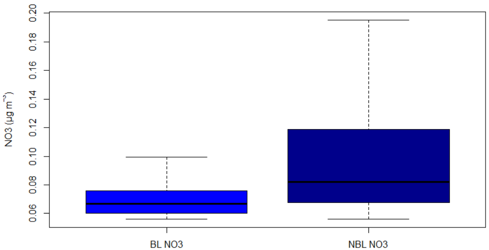
Standard electron impact ionization 70 eV

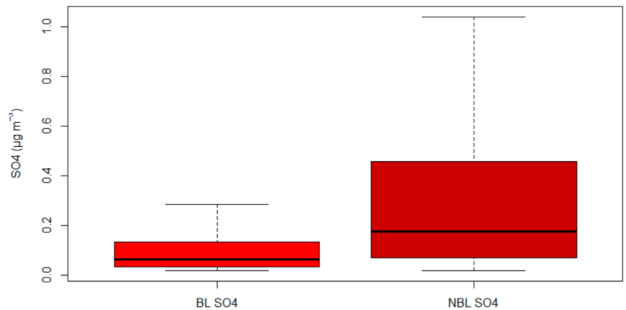
Detection limits

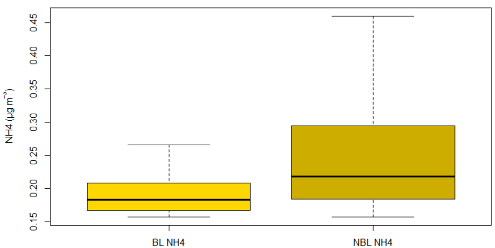
NH4	NO3	SO4	Org	Sea salt
0.157	0.056	0.018	0.164	0.078

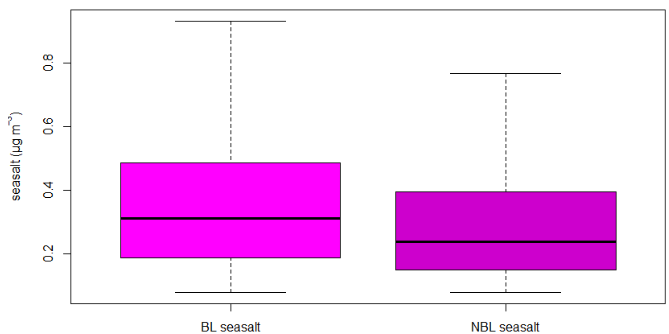


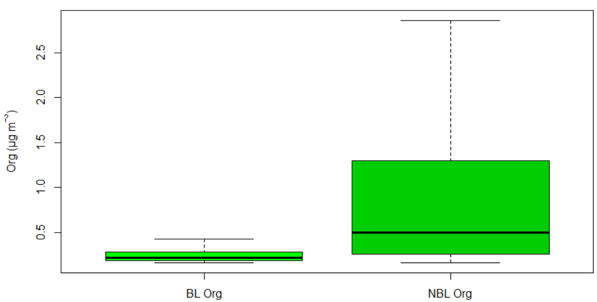

hourly means all data
concentration (µg m^{-3})
NO_3_adl
NH4_adl
SO4_adl
Org_adl
seasalt_adl
Jan-2021
Apr-2021
Jul-2021
Oct-2021
Jan-2022
Apr-2022
Jul-2022
Oct-2022
Jan-2023
Apr-2023
NO_3_adl
NH4_adl
SO4_adl
Org_adl
seasalt_a


NO3 (µg m^{-3})
BL NO3
NBL NO3

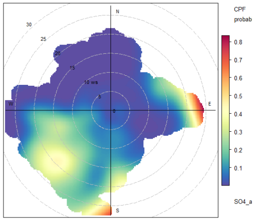

SO4 (µg m^{-3})
BL SO4
NBL SO4


NH4 (µg m^{-3})
BL NH4
NBL NH4


seasalt (µg m^{-3})
BL seasalt
NBL seasalt

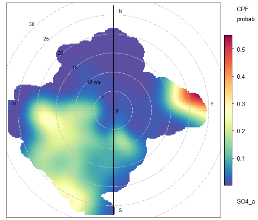

Org (µg m^{-3})
BL Org
NBL Org

0-10 percentile



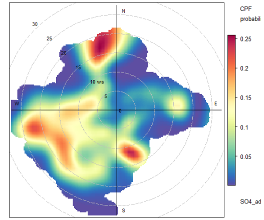
CPF (0.018 to 0.028)

10-20 percentile



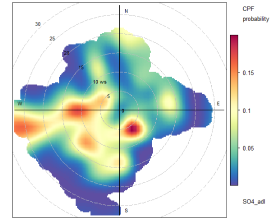
CPF (0.028 to 0.039)

20-30 percentile



CPF (0.039 to 0.054)

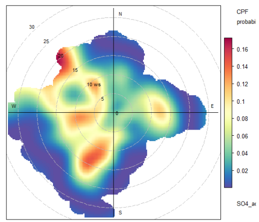
30-40 percentile



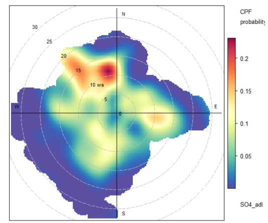
CPF (0.054 to 0.078)

SO4 Conditional Probability

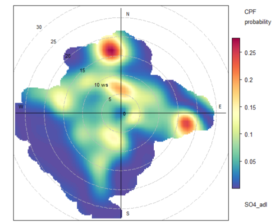
Low conc =low prob BL sector
High conc=easterly lower probability parts of BL sector



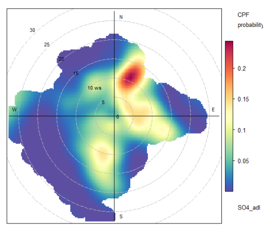
CPF (0.078 to 0.11)



CPF (0.11 to 0.16)

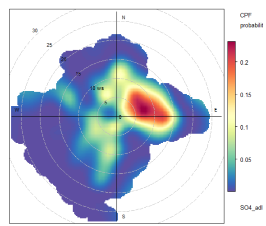


CPF (0.16 to 0.24)



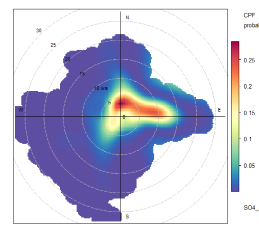
CPF (0.24 to 0.38)

70-80 percentile



CPF (0.38 to 0.67)

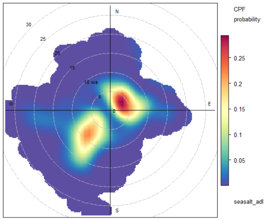
80-90 percentile



CPF (0.67 to 7.6)

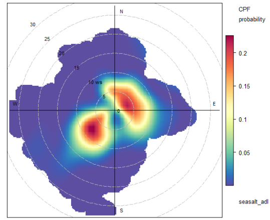
90-100 percentile

0-10 percentile



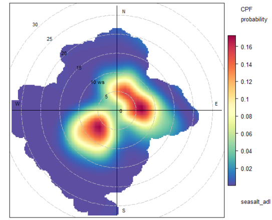
CPF (0.078 to 0.11)

10-20 percentile



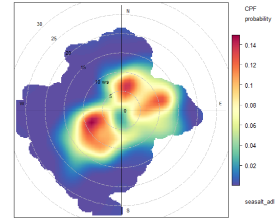
CPF (0.11 to 0.14)

20-30 percentile



CPF (0.14 to 0.18)

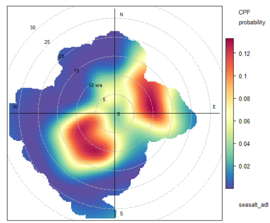
30-40 percentile



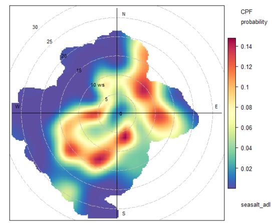
CPF (0.18 to 0.22)

Seasalt Conditional Probability

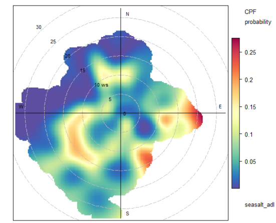
Low conc =low ws and bimodal
High conc=north-westerly 100% probability
Lower probability high ws BL



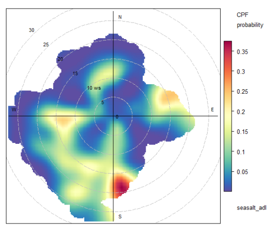
CPF (0.22 to 0.26)



CPF (0.26 to 0.32)

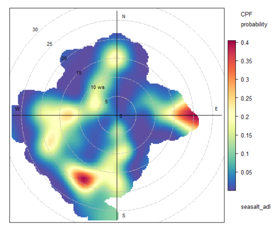


CPF (0.32 to 0.39)



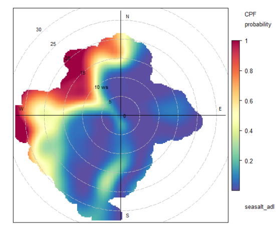
CPF (0.39 to 0.48)

70-80 percentile



CPF (0.48 to 0.64)

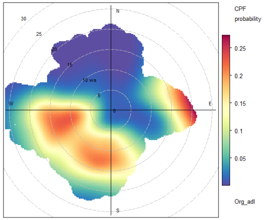
80-90 percentile



CPF (0.64 to 3.6)

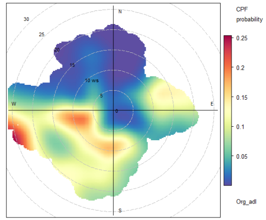
90-100 percentile

0-10 percentile



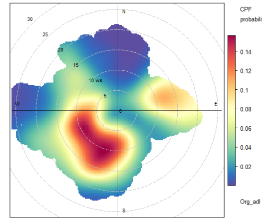
CPF (0.16 to 0.19)

10-20 percentile



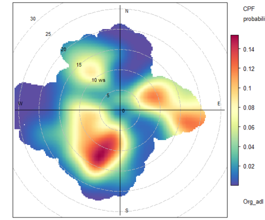
CPF (0.19 to 0.21)

20-30 percentile



CPF (0.21 to 0.24)

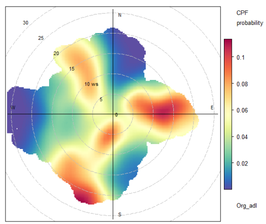
30-40 percentile



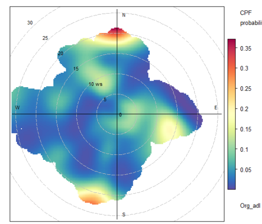
CPF (0.24 to 0.28)

Org Conditional Probability

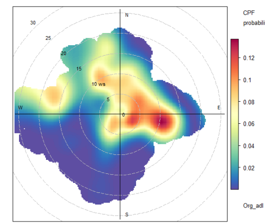
Low conc =BL
High conc=northeasterly,
Note
all probabilities are fairly low



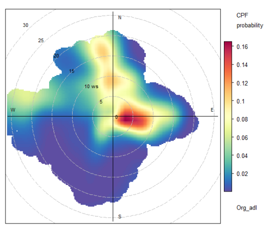
CPF (0.28 to 0.35)



CPF (0.35 to 0.49)

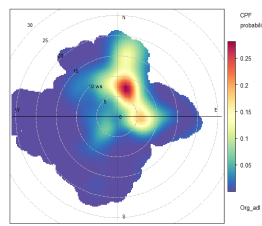


CPF (0.49 to 0.75)



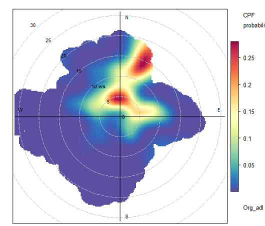
CPF (0.75 to 1.2)

70-80 percentile



CPF (1.2 to 2.4)

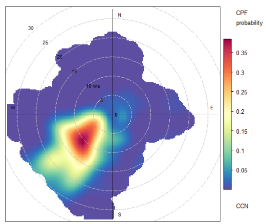
80-90 percentile



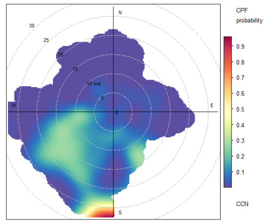
CPF (2.4 to 37)

90-100 percentile

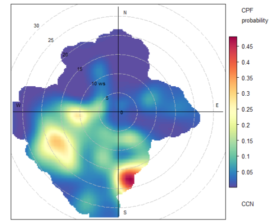
CCN Conditional Probability



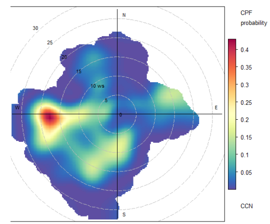
CPF (0.08 to 43)



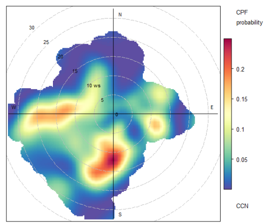
CPF (43 to 63)



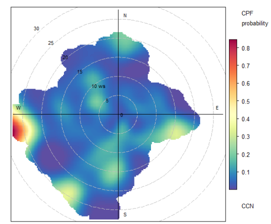
CPF (63 to 84)



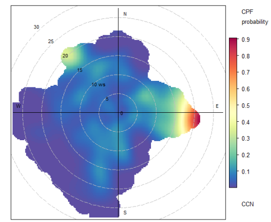
CPF (84 to 108)



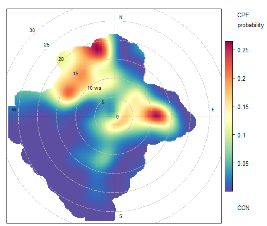
CPF (108 to 141)



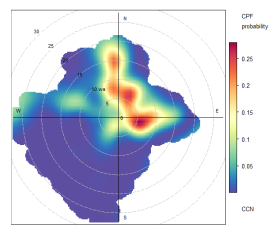
CPF (141 to 189)



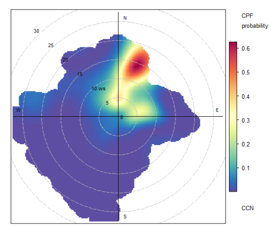
CPF (189 to 245)



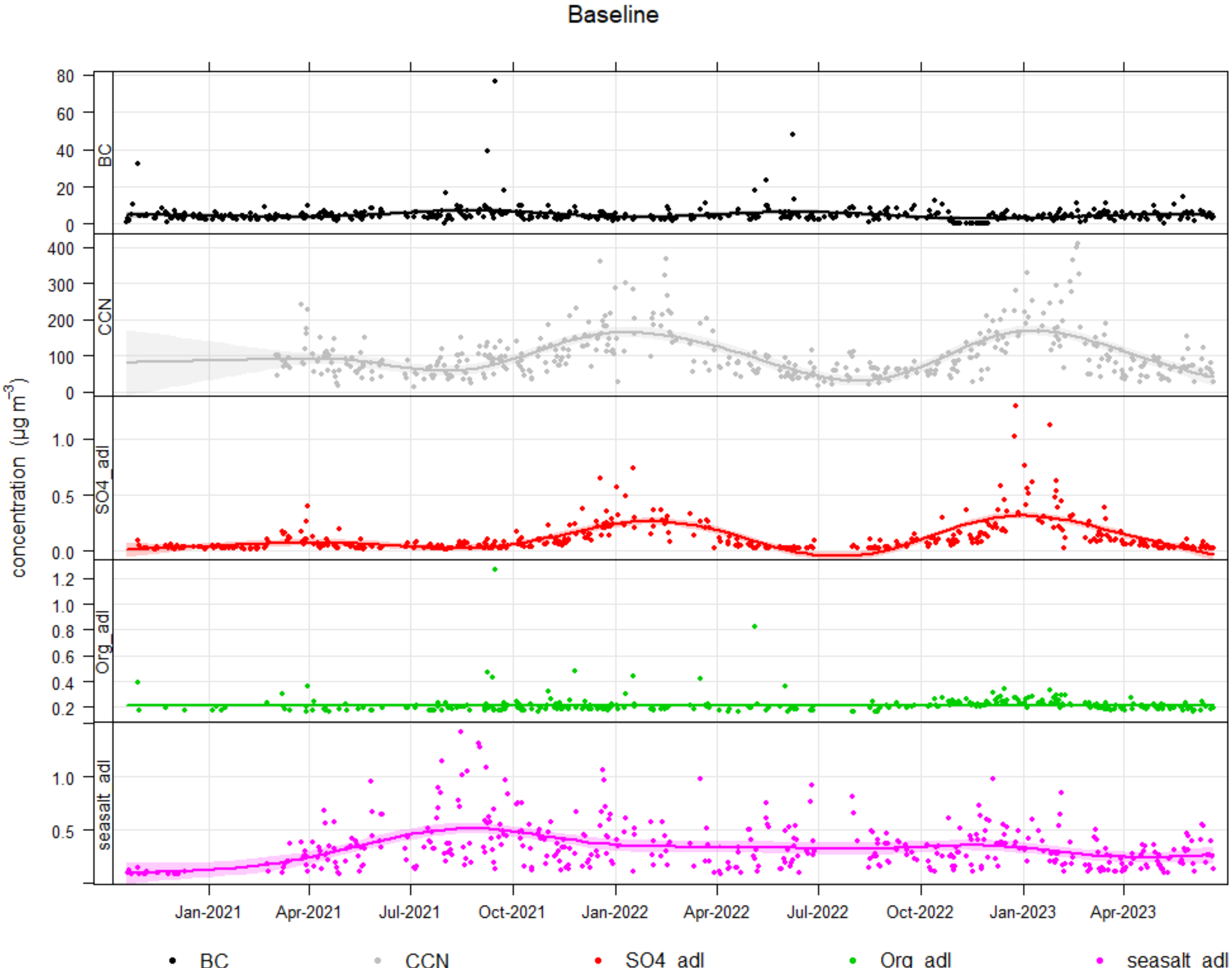
CPF (245 to 364)



CPF (364 to 697)



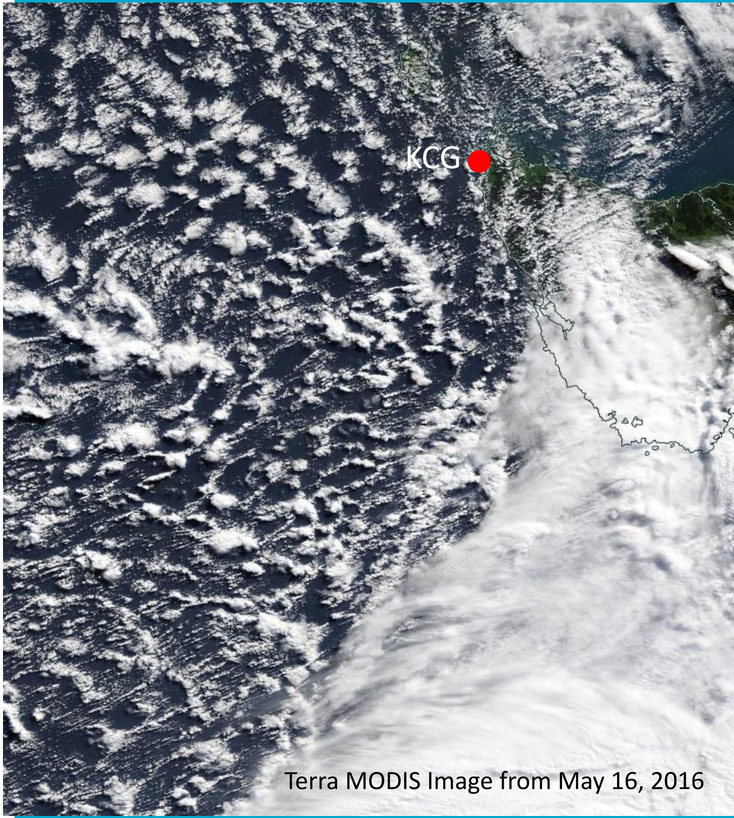
CPF (697 to 19575)

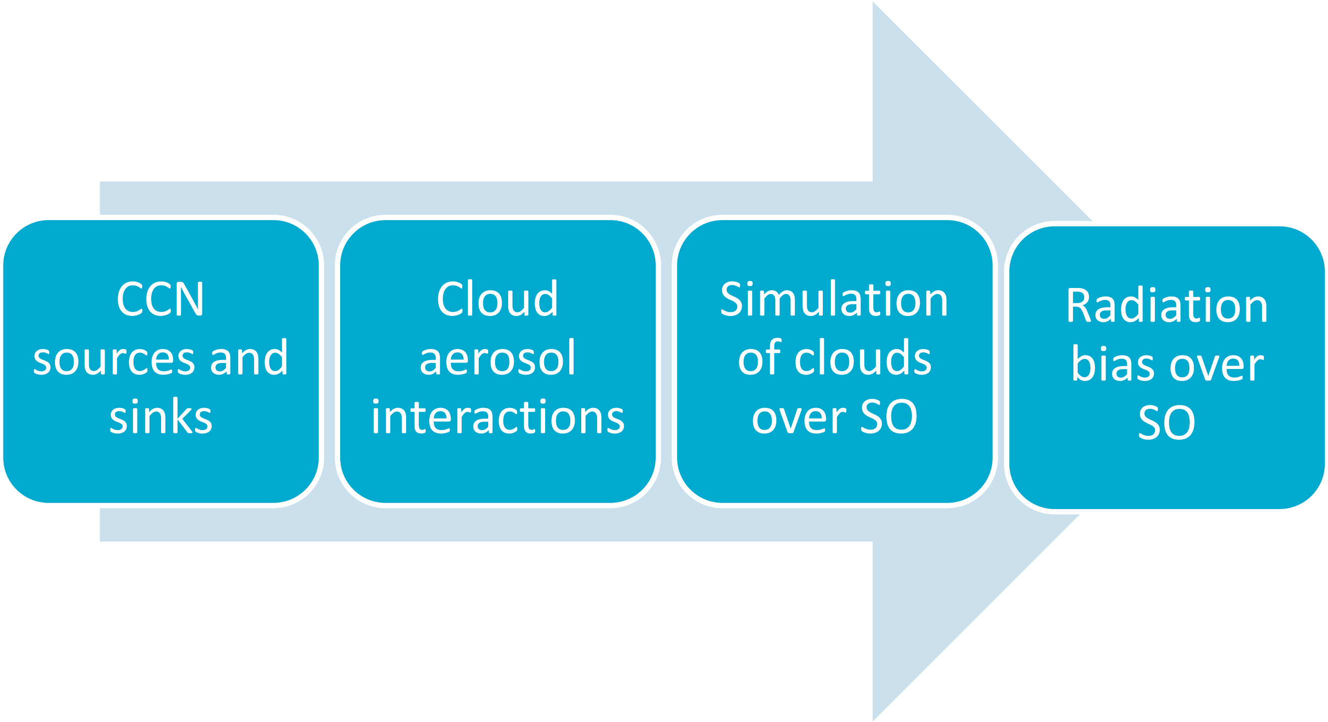

Baseline
concentration (µg m-3)
BC
CCN
SO4_adl
Org_adl
seasalt_adl
80
60
40
20
0
400
300
200
100
0
1.0
0.5
0.0
1.2
1.0
0.8
0.6
0.4
0.2
1.0
0.5
Jan-2021
Apr-2021
Jul-2021
Oct-2021
Jan-2022
Apr-2022
Jul-2022
Oct-2022
Jan-2023
Apr-2023
BC
CCN
SO4_adl
Org_adl
seasalt_adl

Cloud And Precipitation Experiment at kennaook (CAPE-k)

PIs: Jay Mace and Roger Marchand

CIs: Melita Keywood[3], Sam Cleland[4], Alain Protat[4], Ruhi Humphries[3]
Sonya Fiddes[5,6], Christina McCluskey[7], Steve Siems[8], Yi Huang[9], Peter May[8]




CCN sources and sinks
Cloud aerosol interactions
Simulation of clouds over SO
Radiation bias over SO

Why KCG is a good place to investigate radiative forcing?

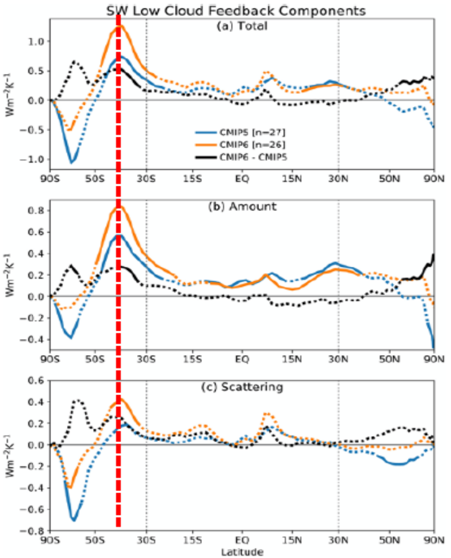


Fig. A1 - (a) Zonal mean SW low cloud feedback and its breakdown into (b) amount and (c) scattering components for the (blue) CMIP5 and (orange) CMIP6 multimodel means. Latitudes where at least 80% of the models agree on the sign of the feedback are plotted with a solid line. Multimodel mean differences are shown in black lines, which are solid where differences are significant ($p < 0.05$). Results are plotted against the sine of latitude to display uniform area weighting. The red line highlights the latitude of KCGBAPS. Figure taken from Zenlinka et al. [2020]. From CAPE-K proposal

- Low-clouds* are ubiquitous over the mid-latitude oceans of both hemispheres (Woods 2012)
- CMIP6 simulate strong latitudinal gradients in the response of low-clouds to increases in GHG in the Southern Hemisphere high and mid-latitudes
- Uncertainty in the low cloud feedback remains the largest source of intermodel spread in warming (climate sensitivity)
- Spread in uncertainty is pronounced at KCG latitude

*Low-altitude clouds with cloud-tops in or near the BL

CSIRO

Motivation

- Seasonal cycles in aerosol modulate cloud (and precipitation?) properties across the entire Southern hemisphere mid latitudes.
- KCG aerosol dataset is foundational for understanding Southern Hemisphere baseline air chemistry, aerosol, and radiation
- Great long-term record of aerosols at KCG, but no systematic observations of cloud-precipitation processes
- KCG provides an "accessible" location for a comprehensive deployment of modern ground-based remote sensors that can sample clouds in baseline air
- US organisations ASR (Atmospheric Systems Research) and ARM (Atmospheric Radiation Measurements) have a keen interest in midlatitude cloud feedbacks

32

CAPE-k

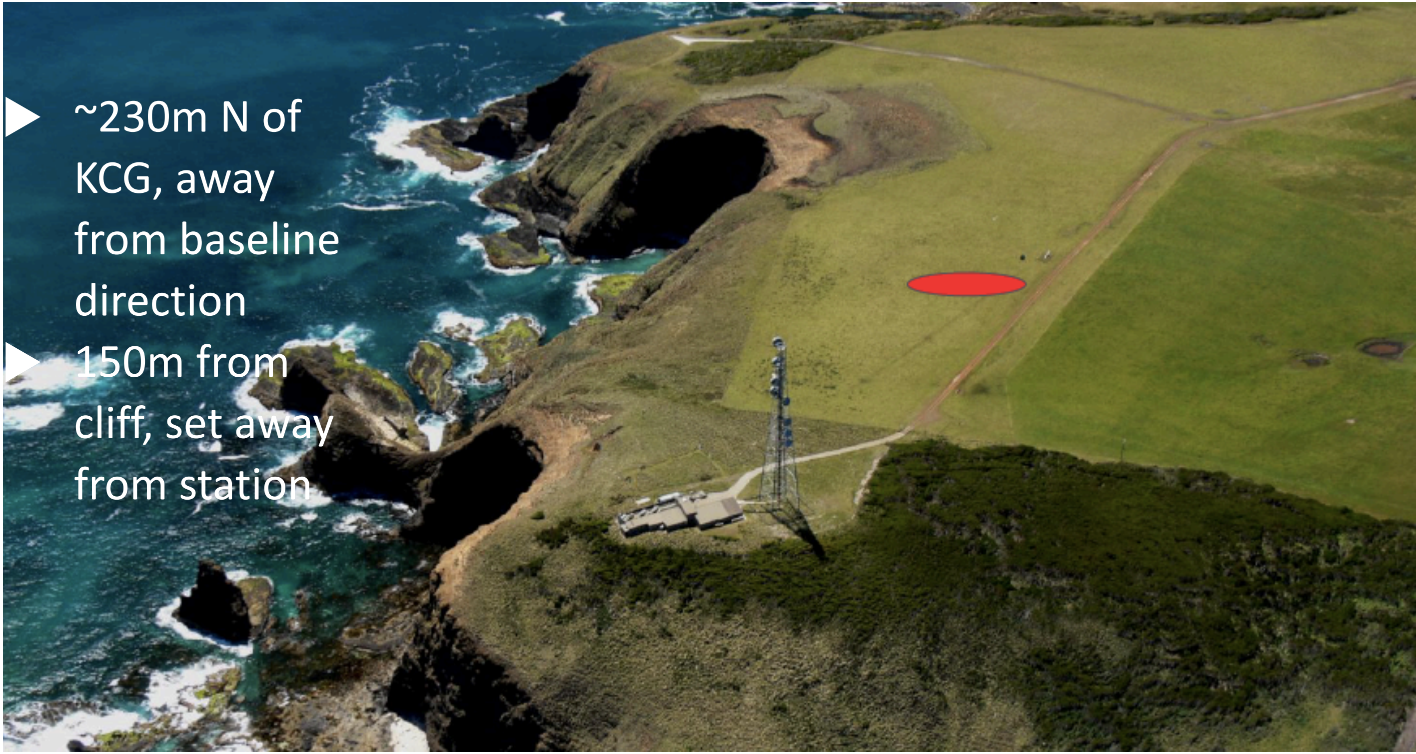
- **Main Theme**: Aerosol-Cloud-Precipitation Processes

- **Key Foci**:
- CDNC (Cloud Droplet Number Concentration) Budget and Albedo Susceptibility
- Precipitation Susceptibility to CDNC and Aerosol
- Precipitation Phase Partitioning
- Sensitivity of water budget to precip phase

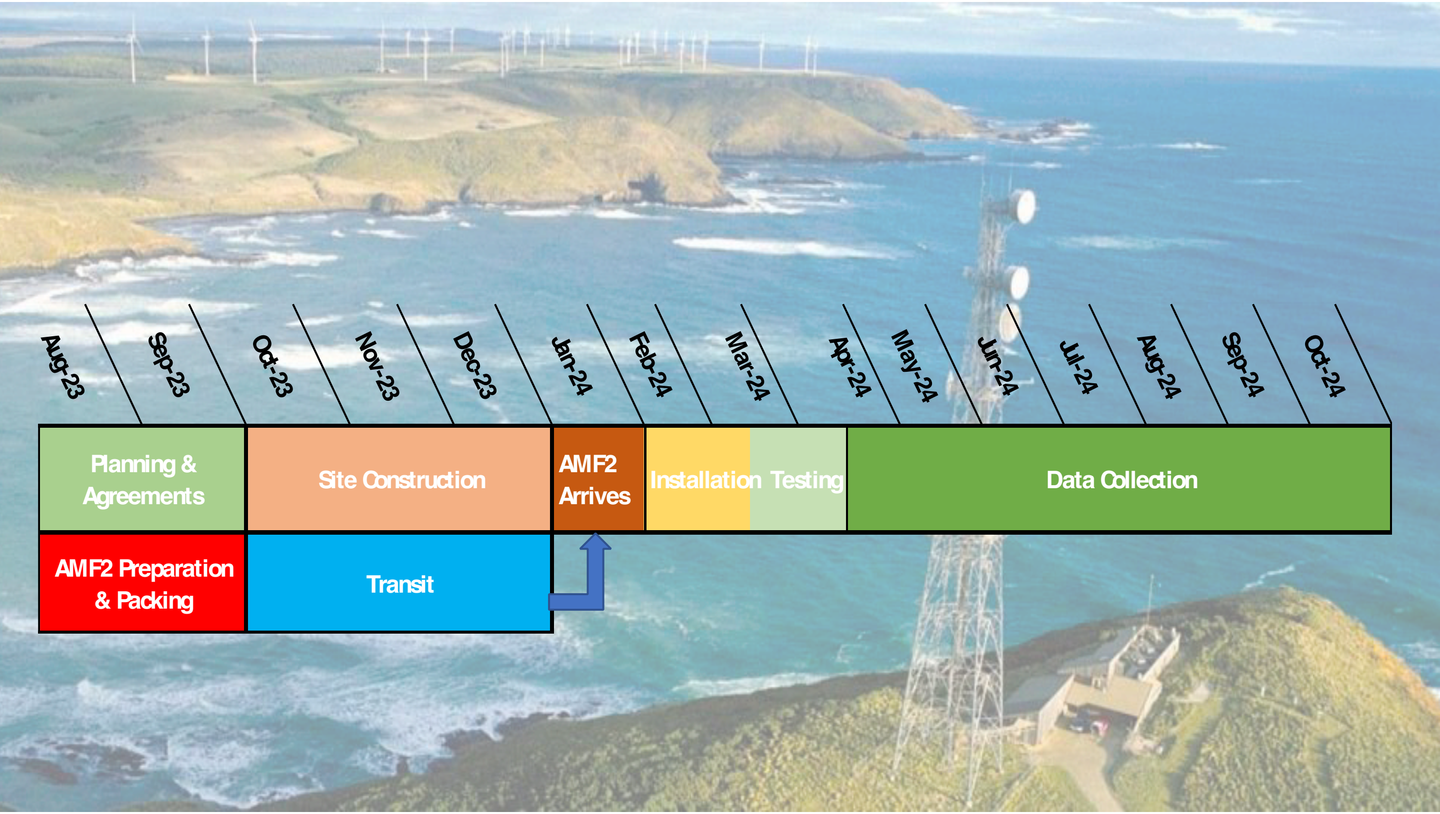
The campaign

- 17-month deployment of ARM cloud suite: 15 April, 2024-15 September 2025
- 3-4 IOP periods (enhanced radiosondes)
- Many, many instruments (9 shipping containers have arrived from the US!), but key ones for deriving cloud & precip. properties include:
  - W-Band Doppler Radar (WACR)
  - Ka-Band Doppler Radar (KAZR)
  - Microwave Radiometer
  - Micropulse Lidar

Bringing only 3 aerosol instruments to supplement our comprehensive aerosol suite


~230m N of KCG, away from baseline direction
150m from cliff, set away from station

CAPE-k Schedule



Guest Instruments (not ARM)

Instrument (institution)	Measured parameter	Deployment period	Comments
ToF-PTRMS	VOCs	Aug 23 → …	
CIMS (QUT)	VOCs	Aug 24 → Sep 25	ARC funded (incl QUT postdoc & UniMelb PhD)
NAIS (QUT)	Ion clusters	Aug 24 → Sep 25	
AMS (QUT)	Size resolved aerosol composition	Aug 24 → Sep 25	
LIF-SO_2 (Uni of York)	Trace-level SO_2	Apr 24 → Sep 25	
PINE (Leeds/KIT) + INP filters	Real-time INP concentrations	Apr 24 → Sep 25	NERC funded (incl dedicated postdoc)

+ others proposed but not confirmed

Aerosol Observing Shelter coming as space for guest instruments

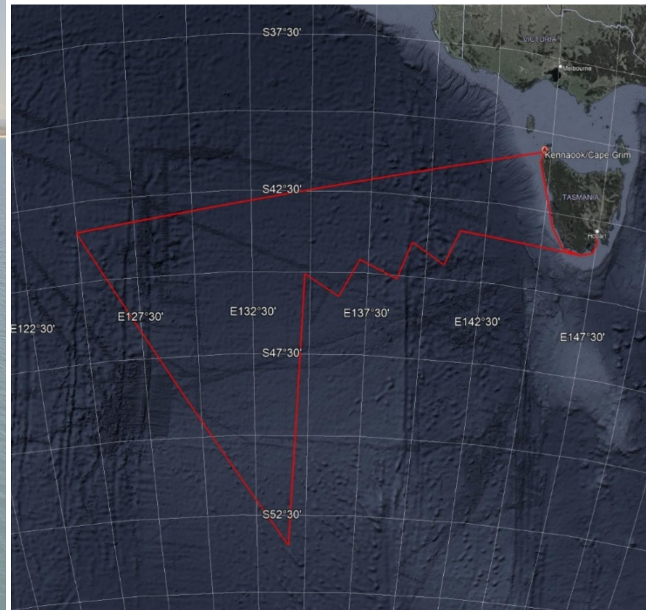
37

COAST-K

Clean Ocean Air Sampling upwind of Tasmania – Kennaook

Measuring the world's cleanest air – validating atmospheric measurements above the Southern Ocean.

- May 2025
- Hobart – Hobart, with ~1 week offshore Kennaook/Cape Grim, then going as far upwind as we have time for.
- Chief Scientist: Ruhi Humphries
- 22 berths available (let me know if you're interested in piggybacking!)



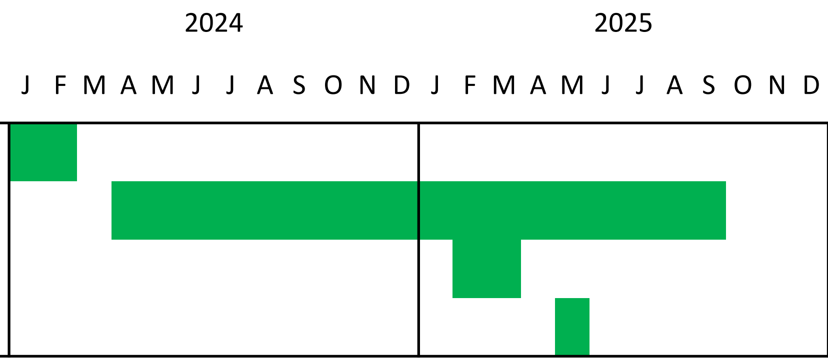
Part of a bigger Australian effort

Recent relevant Australian campaigns

- CAPRICORN – Mar/Apr 2016
- CAPRICORN2 – Jan/Feb 2018
- A multitude of piggyback voyages aboard RVI

Upcoming Australian campaigns

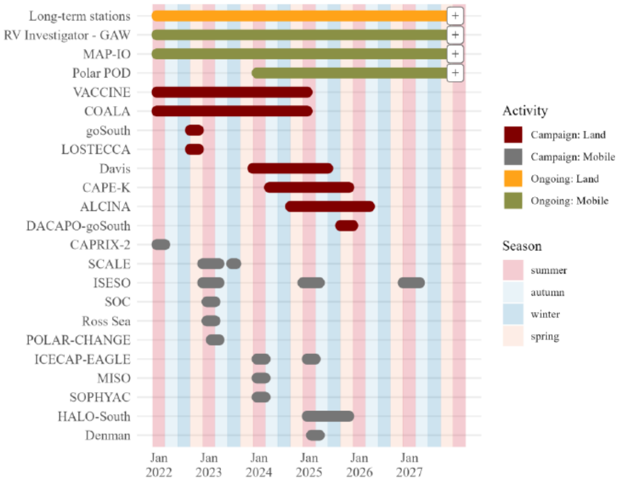
Campaign	Platform
MISO*	RV Investigator
CAPE-K	Kennaook/Cape Grim
Denman	RSV Nuyina
COAST-K*	RV Investigator

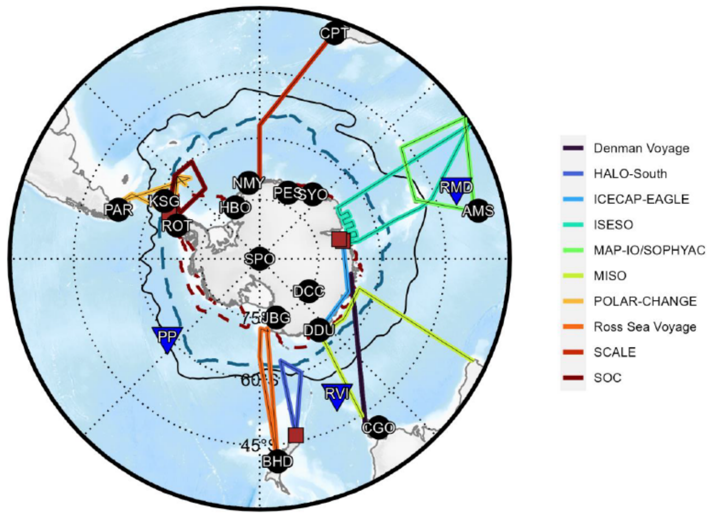


Not included here: CARINA, Davis 2024 and MICRE-II

Part of a bigger international effort

>22 international projects happening before end of 2025!





Goals

-Facilitate international collaboration and coordination

-Multiply & accelerate scientific impact

-Improve translation of observational science into model improvements

ELEMENTA
Science of the Anthropocene

Mallet, MD, et al. 2023. Untangling the influence of Antarctic and Southern Ocean life on clouds. *Elem Sci Anth*, 11: 1.
DOI: https://doi.org/10.1525/elementa.2022.00130

COMMENTARY

Untangling the influence of Antarctic and Southern Ocean life on clouds

Marc D. Mallet[1,*], Ruhi S. Humphries[1,2], Sonya L. Fiddes[1], Simon P. Alexander[1,3], Katye Altieri[4], Hélène Angot[5,6], N. Anilkumar[7], Thorsten Bartels-Rausch[8], Jessie Creamean[9], Manuel Dall'Osto[10], Aurélien Dommergue[6], Markus Frey[11], Silvia Henning[12], Delphine Lannuzel[13,14], Rémy Lapere[6], Gerald G. Mace[15], Anoop S. Mahajan[16], Greg M. McFarquhar[17], Klaus M. Meiners[1,3,14], Branka Miljevic[18], Ilka Peeken[19], Alain Protat[1,20], Julia Schmale[5], Nadja Steiner[21], Karine Sellegri[22], Rafel Simó[10], Jennie L. Thomas[6], Megan D. Willis[23], V. Holly L. Winton[24], and Matthew T. Woodhouse[1,2]

PICCAASO — Partnerships for Investigating Clouds and the biogeoChemistry of the Atmosphere in Antarctica and the Southern Ocean

KCG Project Team

Melita Keywood, Nada Derek, Jason Ward, Fabienne Reisen, James Harnwell, Jenny Powell, Ruhi Humphries John Gras CSIRO

Jeremy Ward, Nigel Sommerville, Cindy Spinks, Sarah Prior BoM

Alistair Williams and ANSTO Radon Team

CAPE-k Project team

PIs: Jay Mace and Roger Marchand

CIs: Melita Keywood, Sam Cleland, Alain Protat, Ruhi Humphries

Sonya Fiddes, Christina McCluskey, Steve Siems, Yi Huang, Peter May

Melita Keywood

Melita.Keywood@csiro.au