(MARCUS): Measurements of Aerosols, Radiation and CloUds Over the Southern OCeans

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What is MARCUS?

- **What?** MARCUS targets observations of clouds, aerosols, precipitation and radiation over the Southern Ocean (SO)
- **Where?** The Australian Antarctic supply vessel Aurora Australis (AA) will make routine transits between Hobart, Australia and the Antarctic stations Mawson, Davis and Casey, and Macquarie Island.
- **How?** AMF-2 installed on AA will measure CCN and INPs at surface, retrieve profiles of macrophysical and microphysical properties of liquid and mixed-phase clouds, downwelling radiation, etc. , and launch soundings
- **When?** 7-month period between September 2017 to April 2018 centered on summer
- **Why?** Measurements in cold waters at latitudes poleward of 55˚S are sparse and climatologically important since there are large GCM biases in modeled SW absorption, and supercooled and mixed-phase clouds are frequent & not well retrieved

More information at https://www.arm.gov/campaigns/amf2017marcus/

Outline

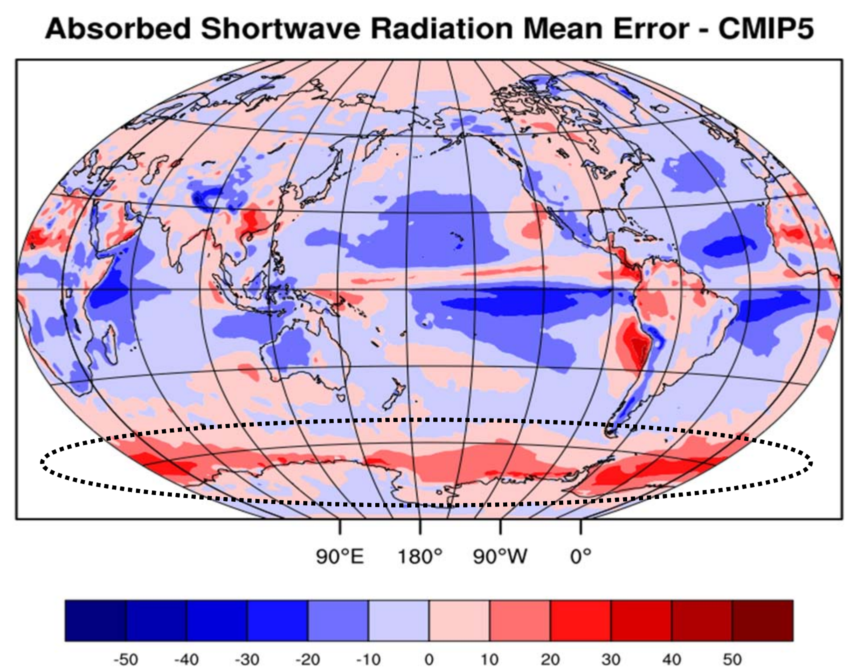
1. Motivation for MARCUS
2. MARCUS Science Themes & Testable Hypothesis
3. Planned Measurements for MARCUS
4. Planned Analysis Strategy
5. Information about planned coincident SOCRATES campaign

Motivation

- SO one of cloudiest region on Earth
- Earth's climate sensitive to representation of SO clouds
  - Impact on global energy budget , simulated global cloud feedbacks & carbon-cycle feedbacks on climate change
  - Location of tropical rainfall belts
  - SO surrounds Antarctic & interacts with ice shelves whose stability to climate change is unknown
- Remoteness from anthropogenic & natural continental aerosol sources makes SO unique testbed for understanding cloud-aerosol interactions in liquid & ice clouds

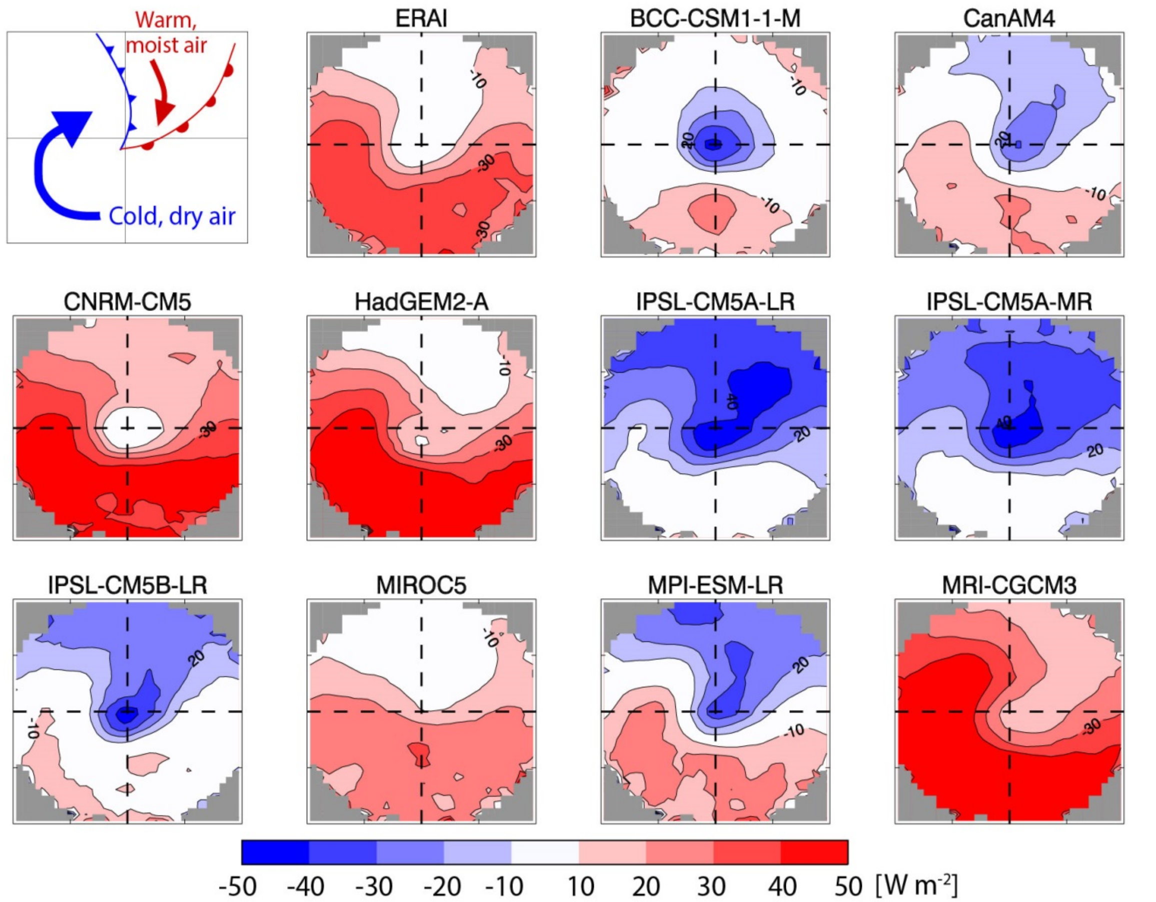
Climate model biases & observational knowledge gaps

- Climate models have uncertainties & biases in simulating SO clouds, aerosols & air-sea exchanges due to poor understanding of physical processes
- Clouds (particularly low-mid level clouds in cold sector) are poorly represented in GCM & NWP analyses
- Uncertainty in natural aerosol processes (CCN & INPs) are major source of uncertainty in radiative forcing from aerosols
- Large radiation biases interact with location of SH jet in GCMs, influence circulation and may correlate with climate sensitivity



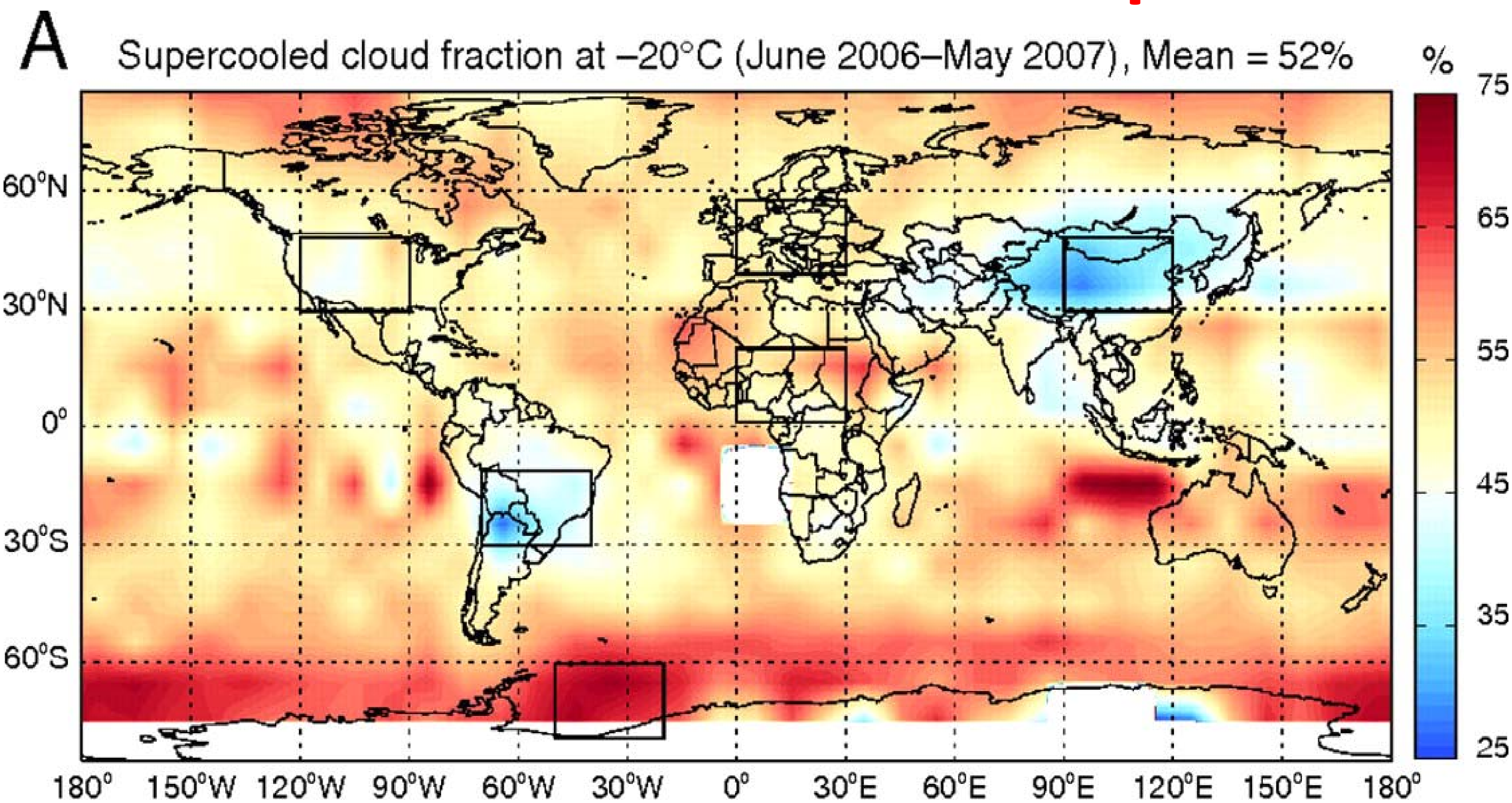
CMIP5 model clouds do not reflect enough sunlight over SO. Ensemble mean error for CMIP5 models in shortwave radiation absorbed by the Earth System. Positive values indicate too much shortwave radiation absorbed.

Climate model biases & observational knowledge gaps



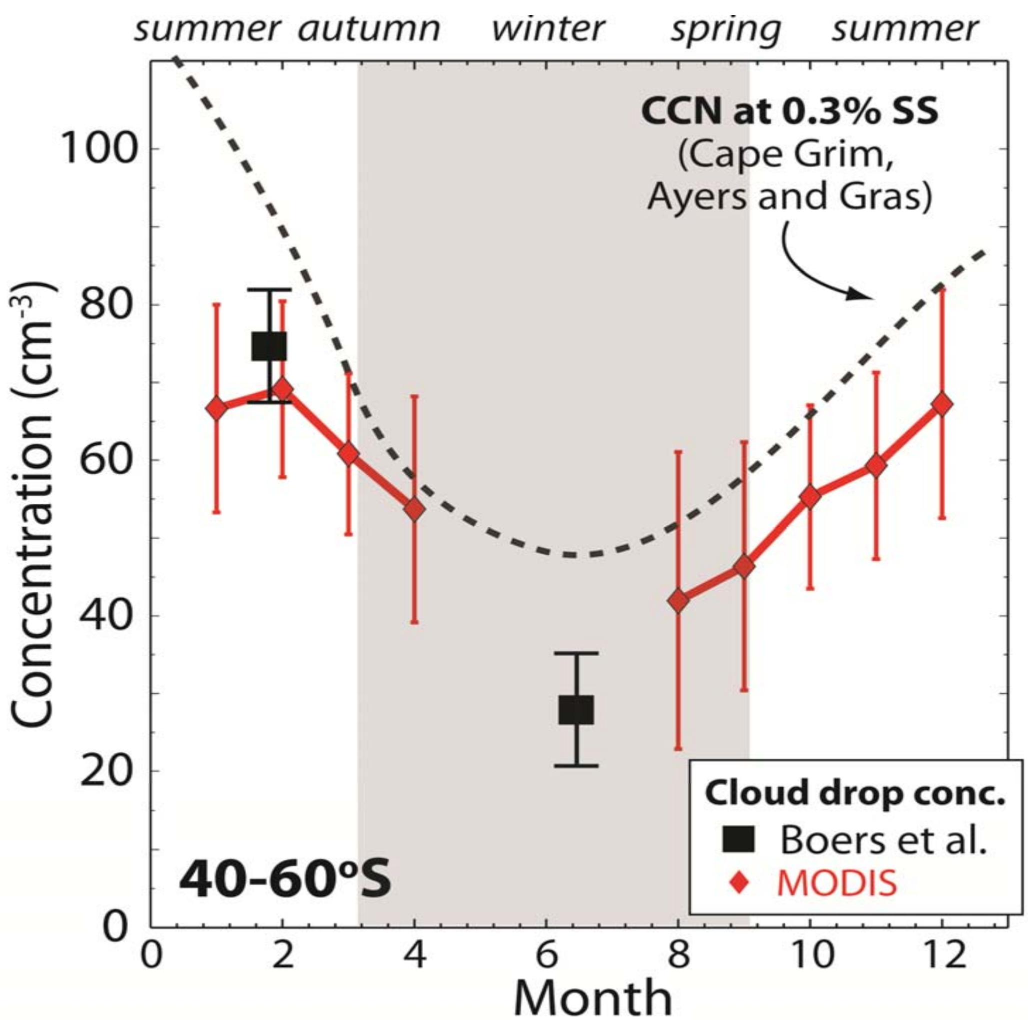
Cyclone compositing indicates consistent patterns of insufficient reflected shortwave in the cold, dry regions of the cyclones.

SO Cloud and Aerosol Properties



Large fraction of cloud-tops at temperatures near -20˚C contain supercooled liquid water, *as retrieved using CALIPSO depolarization measurements (Choi et al. 2010); GCMs have broad range of sensitivities to liquid vs. ice partitioning to temperature in SO clouds showing need for in-situ observational constraints*

SO Cloud and Aerosol Properties



Large seasonal cycles of cloud droplet & CCN concentrations exist over the SO. Biogenic sources are believed responsible, but much unknown about aerosol composition and underlying physical processes, especially at more southerly latitudes.

MARCUS observational and modeling requirements

MARCUS observational requirement	To enhance knowledge of SO aerosols, clouds & their interactions in variety of synoptic settings and to narrow uncertainties in representing key processes in GCMs, a comprehensive dataset is needed that documents BL structure, and associated vertical distributions of liquid and mixed-phase cloud and aerosol (including CCN and INP) properties over the SO under a range of synoptic settings.
MARCUS modeling requirement	For such a dataset to have broad impact on GCMs, the modelling community must be an integral part of the MARCUS design and be involved in a systematic confrontation of leading GCMs with MARCUS data, e.g. using short-term hindcasts as in VOCALS (Wyant et al. 2014).

MARCUS Science Themes

Theme 1: Synoptically-varying vertical structure of SO BL clouds and aerosols

Theme 2: Variability of sources and sinks of SO CCN and INPs and role of local biogenic sources over spring, summer & fall.

Theme 3: Supercooled liquid clouds over SO

Theme 4: Advancing retrievals related to clouds, precipitation, and aerosols, over SO

Specific testable hypotheses proposed for each theme

MARCUS Platform: Aurora Australis

- During each operational season (Oct. – Mar.), AA traverses SO ~ 4 times to resupply coastal East Antarctic bases(Mawson, Casey & Davis) and Macquarie Island.
  - Not dedicated research vessel (minimal influence on tracks)
  - Typical voyage ~ 10 to 14 days traversing SO (depending on ice conditions) and ~ 1 week moored at coast for resupply
- Space on AA for 2 AMF2 shipping containers to be installed for the entire operational season.
  - One will be located forward of bridge on port side, second aft of bridge on bridge deck
  - additional space on monkey deck above bridge to locate instruments requiring clear view of sky


P&O
AURORA AUSTRALIS

- **AA ran aground during blizzard at Mawson on Feb. 24, 2016 in 70 knot winds; refloated 2 days later but did have breach in hull**
- **Due back in Hobart on 10 May 2016 having been undergoing sea trials in Singapore where was in dry dock**

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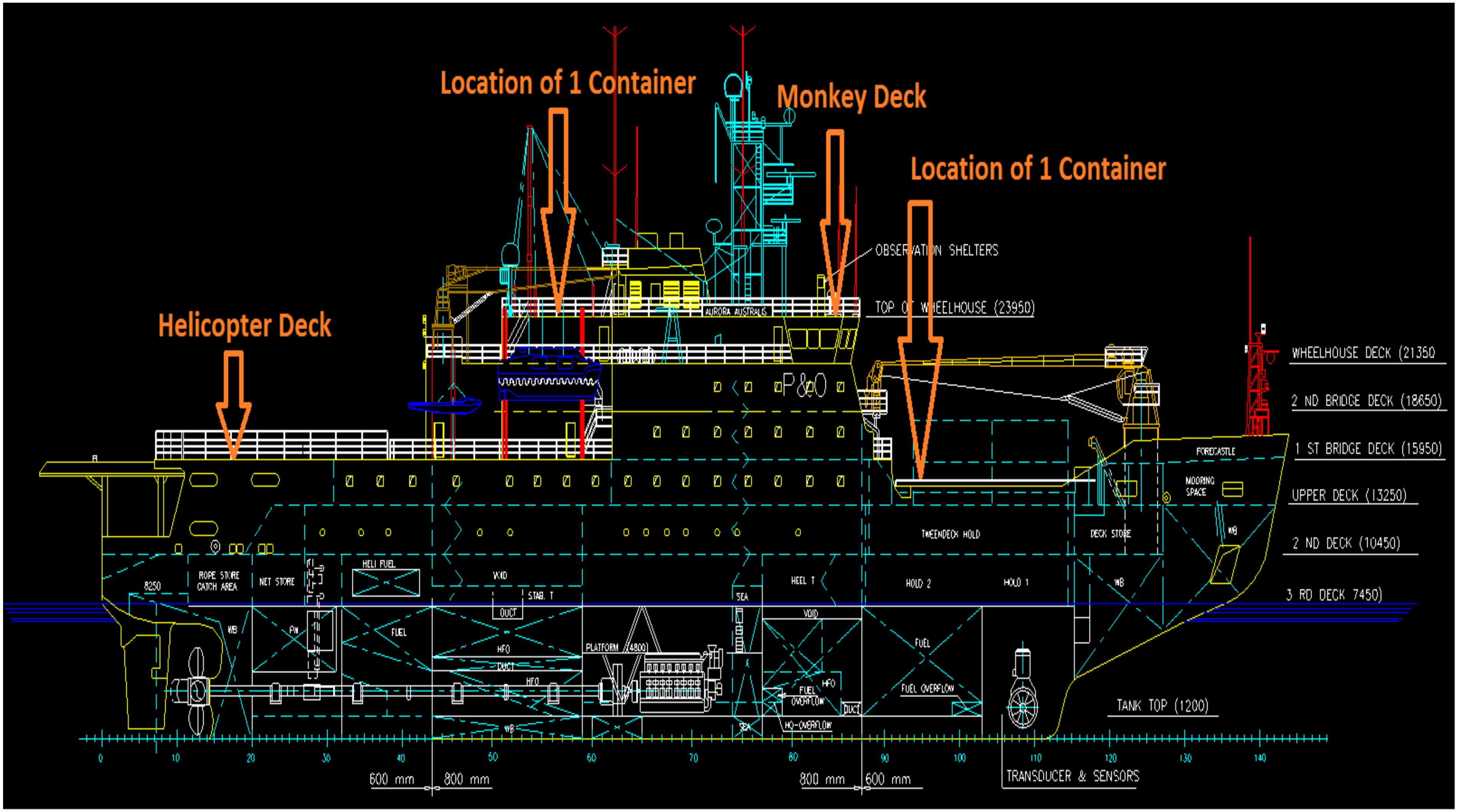
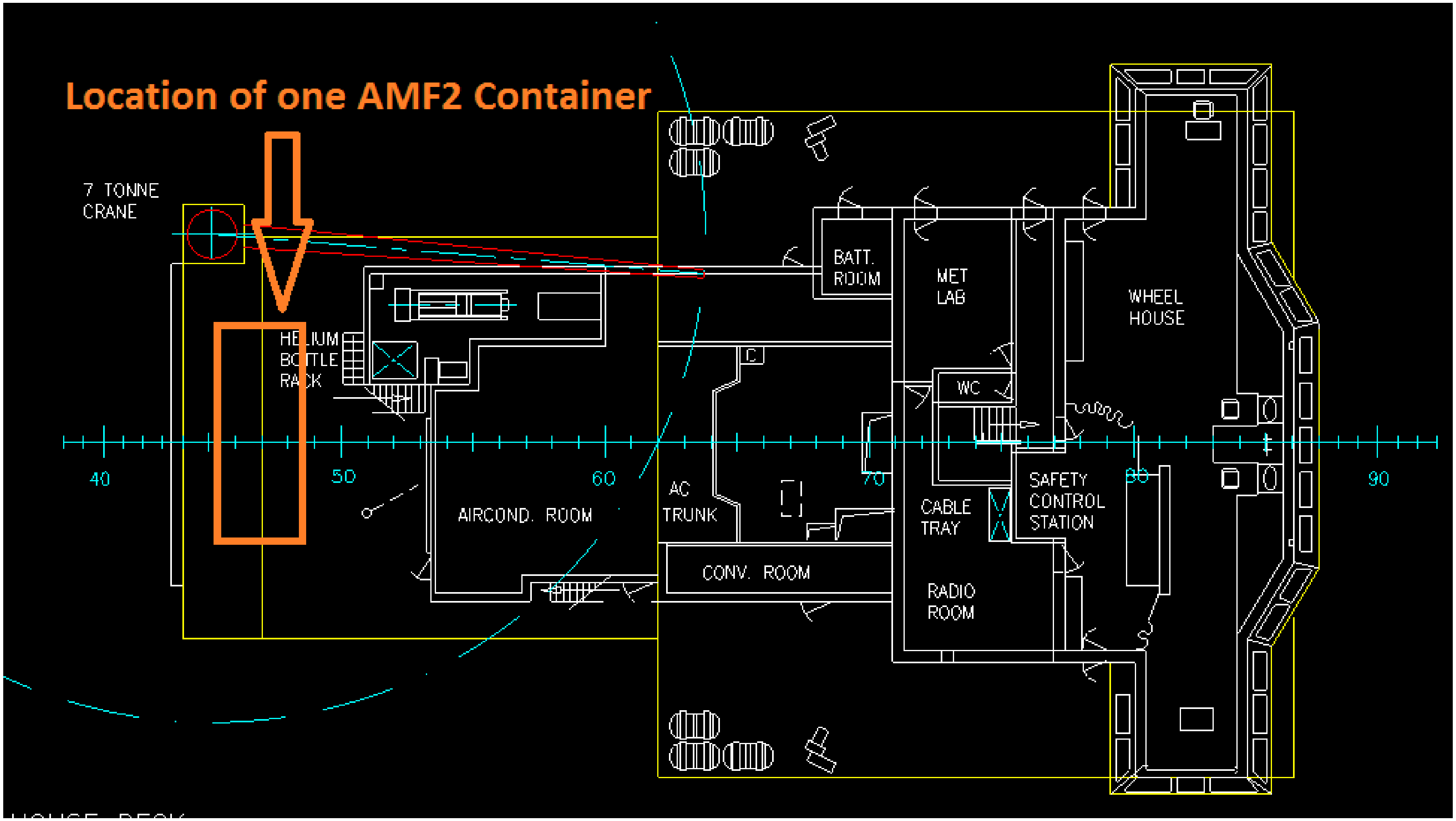
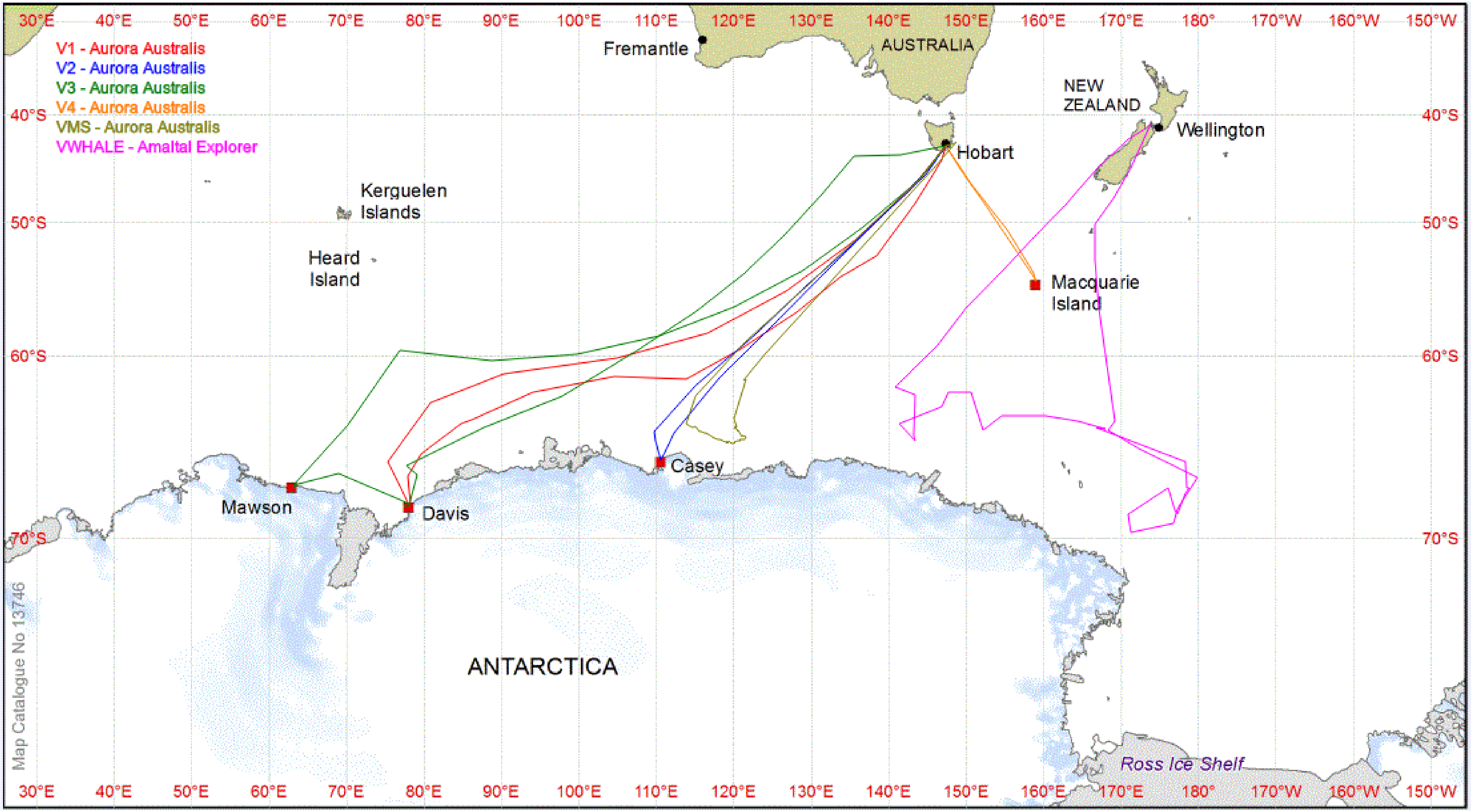


Location of 1 Container
Monkey Deck
Location of 1 Container
Helicopter Deck
OBSERVATION SHELTERS
TOP OF WHEELHOUSE (23950)
WHEELHOUSE DECK (21350
2 ND BRIDGE DECK (18650)
1 ST BRIDGE DECK (15950)
UPPER DECK (13250)
2 ND DECK (10450)
3 RD DECK 7450)
TANK TOP (1200)
AURORA AUSTRALIS
P&O
FORECASTLE
MOORING SPACE
TWEENDECK HOLD
DECK STORE
HOLD 2
HOLD 1
HEEL T
SEA
VOID
FUEL
HFO
DUCT
FUEL OVERFLOW
HO-OVERFLOW
PLATFORM (4800)
STAB. T
HELI FUEL
ROPE STORE CATCH AREA
NET STORE
8250
FW
WB
600 mm
800 mm
800 mm
600 mm
TRANSDUCER & SENSORS



Location of one AMF2 Container
7 TONNE
CRANE
HELIUM
BOTTLE
RACK
BATT.
ROOM
MET
LAB
WHEEL
HOUSE
WC
C
AIRCOND. ROOM
AC
TRUNK
CABLE
TRAY
SAFETY
CONTROL
STATION
CONV. ROOM
RADIO
ROOM
40
50
60
70
80
90



- Voyages from 2012-13 season
  - Similar tracks expected for 2017-18
- Will be best set of data on clouds & aerosols south of 55˚S where cold SSTs and supercooled water expected to be ubiquitous.

AMF2 Aerosol Instruments

Instrument	Measurement	Priority
CCN Counter	CCN as function of supersaturation	1
Ambient nephelometer	Light scattering aerosol coefficient as function of RH	2
Wet nephelometer	As above, over range of RH	1
Condensation Particle Counter	Concentration of aerosols > 10 nm	1
Ultra-High Sensitivity Aerosol Spectrometer (USHAS)	Aerosols SDs (0.06 to 1 μm) at higher time resolution than from HTDMA	1
3-λ Particle Soot Absorption Photometer (PSAP)	Optical transmittance of particles at 3 λ	2
CO Detector	Good influence of anthropogenic influences	1
Local Meteorology	Wind Speed, Direction, T, RH, P and precipitation	1
Ozone	Part of AOS	3

AMF2 Priority 1 Instruments

Instrument	Measurement	Priority
Cimel Sunphotometer	Multi-channel radiometer (direct solar irradiance and sky radiance)	1
Balloon-borne Soundings	Vertical profiles of T, RH & winds (4/day)	1
Micropulse lidar	Vertical profiles of clouds/aerosols	1
Microwave Radiometer	Tb in channels sensitive to H20v and liquid (prefer 3 channel version)	1
Marine 95 GHz cloud radar on stabilized platform (SWACR)	Z, Vdop and spectral data	1
Vaisala Ceilometer	Detection of vertical cloud layers	1
Stability Platform	Corrects role, pitch & heave	1
Portable Radiation Measurement Package & Sun Pyranometer	PSP, PIR and Fast Rotating Shadow-band Radiometer (FRSR) and Sun Pyranometer	1 (for downwelling)
Ocean Temperature	Ocean Surface Temperature	1
Video or Parsivel Disdrometer	Raindrop size distributions	1
Inertial Navigation System	High accuracy motion data (SeaNav)	1

AMF2 Lower Priority Instruments

Instrument	Measurement	Priority
Total Sky Imager (TSI)	Time series of hemispheric images	2
High Spectral Resolution Lidar	Calibrated measurements of aerosol τ, volume backscatter coefficient, cross section & depolarization	2 (no space)
Dual-frequency (X-Ka) scanning cloud radar (KA-SACR; X-SACR)	Dual frequency scanning cloud radar measuring Z, Vdop	3 (no space)
Ka-band zenith radar (KAZR)	Millimeter wavelength cloud radar	2 (1 if stabilized platform)
Radar wind profiler (RWP)	Wind profiles & backscatter signal	2 (space uncertain)
Marine Emitted Radiance Interferometer (MAERI)	Thermal spectral radiance & measures of surface T & emissivity)	2-3

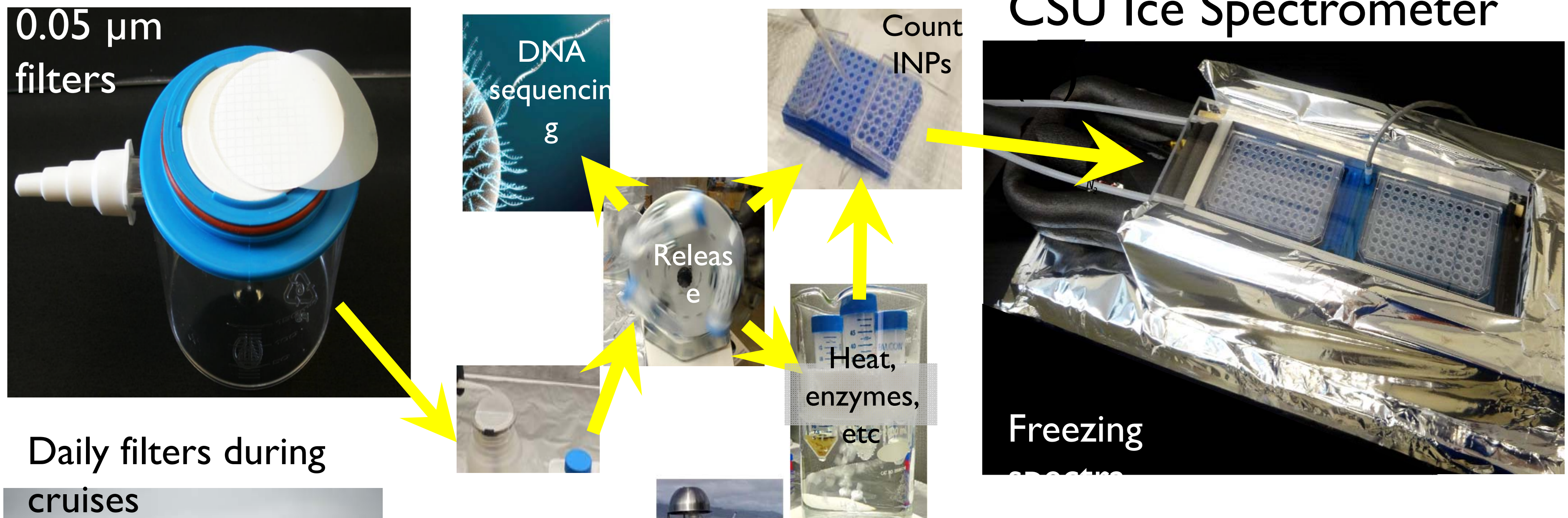
Additional observations for MARCUS

- CSU filter samples (funded)
- Aerosol chemical composition measurements (proposed): filter samples and heated/unheated SDs
- MICROTOPS measurements of aerosol optical depth

MARCUS ice nucleation measurements

Paul DeMott and Thomas Hill
Colorado State University

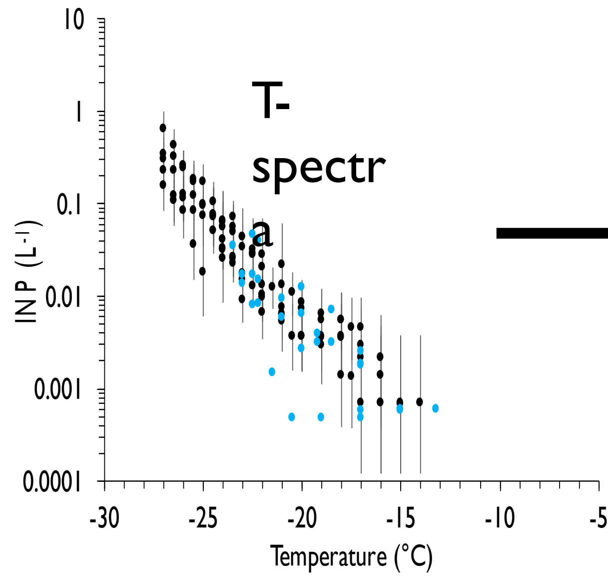
Ice nucleating particle measurements during MARCUS



Funded:
Standard processing, thermal treatment

Reserved samples for future:
Genomic analyses, enzymatic treatments

Processing data and integrating with AMF suite (example: ACAPEX)

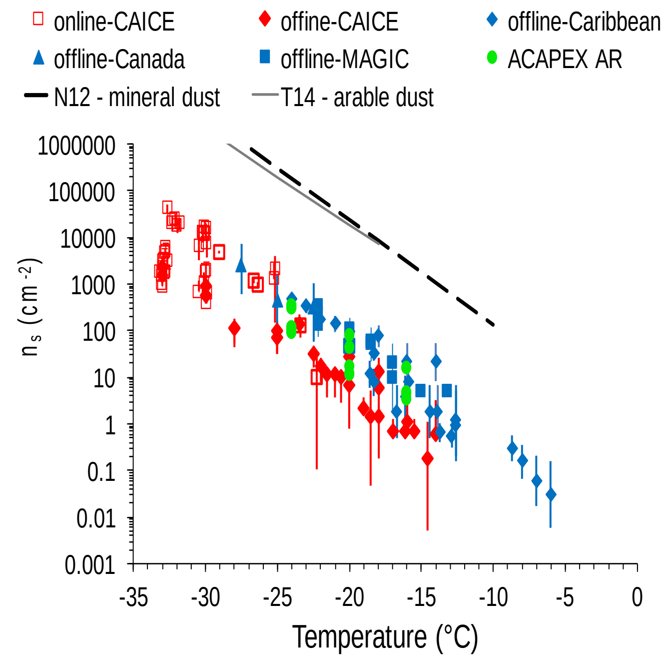


T-spectra

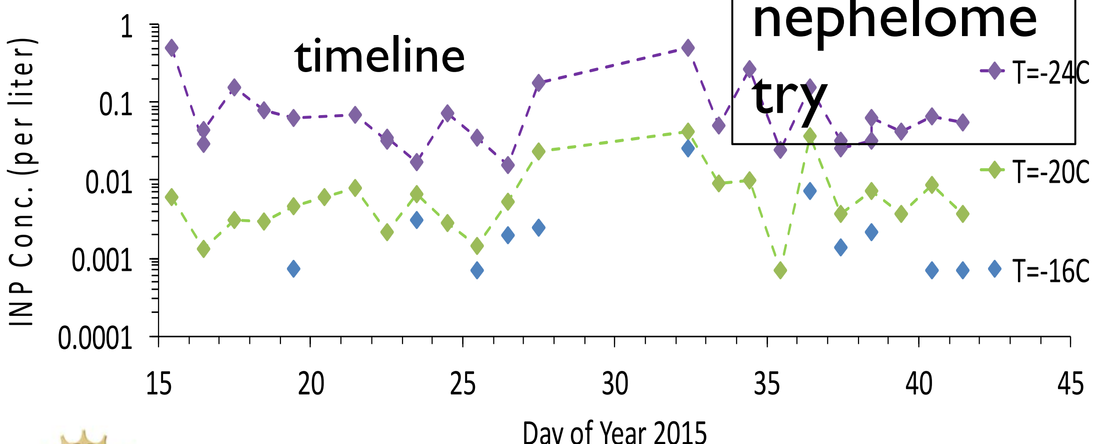
→

Aerosol surface area from size distribution or nephelometry

→



→ parameterization



timeline

Integration with SOCRATES and CAPRICORN

Green: completed or confirmed

- **First CAPRICORN sampling just completed (March 14-April 18): IS and continuous flow diffusion chamber (CFDC)**
- CAPRICORN intensive (Jan. 2018): IS and CFDC
- SOCRATES flights (G-V) January 2018: IS and CFDC
- MICRE annual cycle at Macquarie Island (2017-2018): IS

Proposed Aerosol Chemical Composition measurements for MARCUS: Quinn/Bates

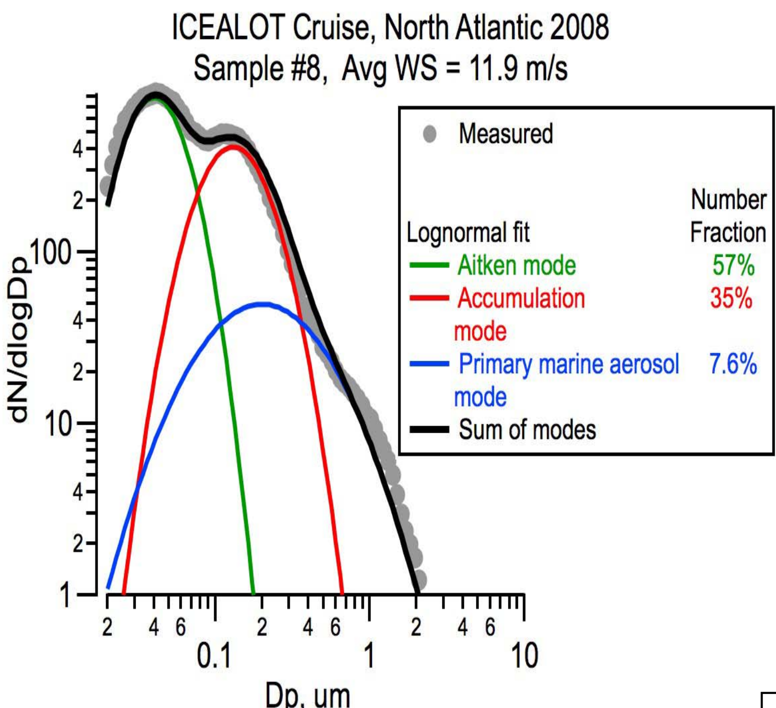
- CSU analysis detects presence of inorganics, but does not quantify them; also it does not detect temperature stable organics
- PMEL is proposing filter measurements with post chemical analysis and measurement of heated and unheated particle size distributions
- This will help assess importance of sources and sinks of CCN and INPs including role of local biogenic and sea salt sources over spring, summer and fall

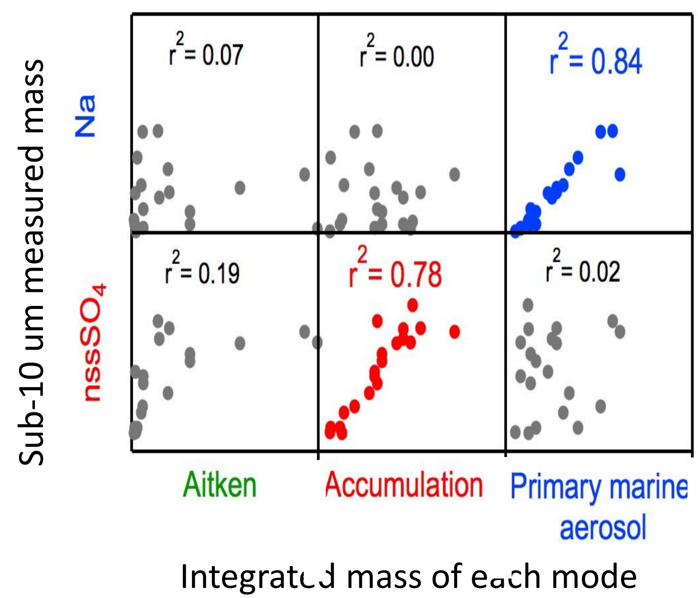
Aerosol chemical composition measurements proposed for MARCUS:
A two-pronged approach to fill a key measurement gap
(P.K. Quinn & T.S. Bates -- NOAA PMEL)

1.) Automated collection of filters for post chemical analysis of sea salt, ammonium sulfates and nitrates, MSA, calcium, and organic carbon for the sub-0.18, sub-1, and sub-10 um size ranges (same sampler as used at BRW & SGP)

Number fraction of each mode based on lognormal fits of number size distributions (ARM AOS)

Identification of composition (source) of each mode from chemical measurements

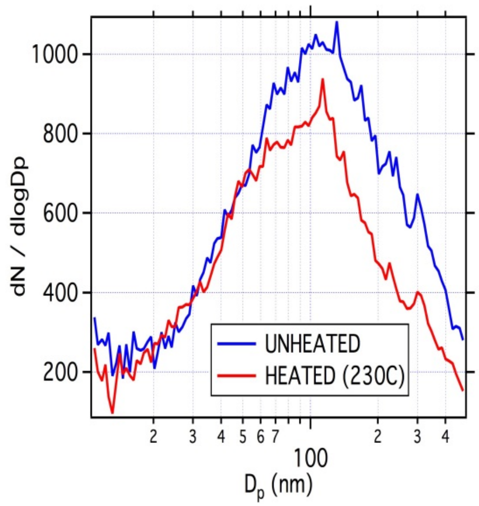




The addition of measured OC mass will provide further information on the composition and source of each mode

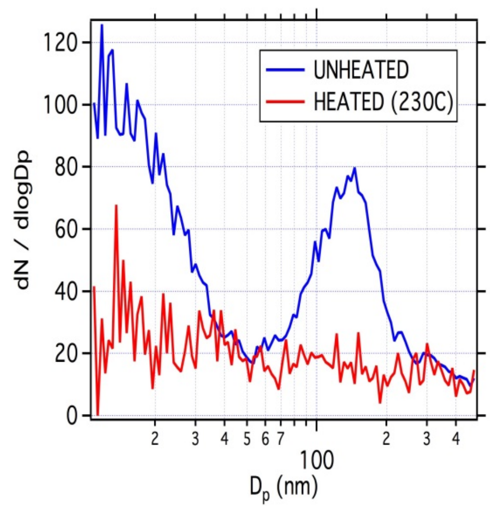
2.) Measurement of heated and unheated particle number size distributions using a thermal denuder upstream of an SMPS - examples from NAAMES cruise, N. Atlantic, 2015

Freshly generated sea spray aerosol from Sea Sweep



Primary aerosol with a small semi-volatile fraction

Ambient marine aerosol sampled during high winds

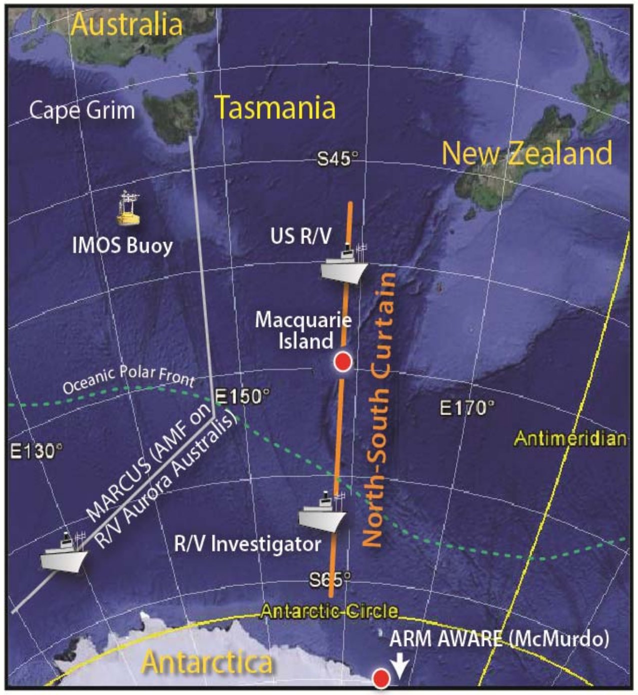


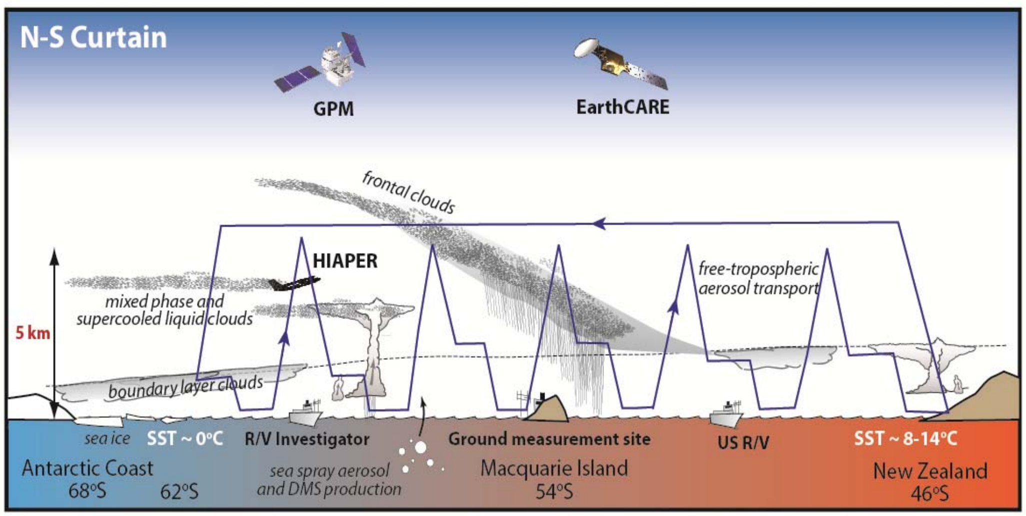
Mixture of secondary and primary aerosol components

Volatility measurements complement filter composition measurements by providing finer size and time resolution and the ability to differentiate between primary and secondary aerosol.

- Both systems (filter and thermal denuder) will have minimal footprints on the monkey deck (2x2x8’) and will be housed in weather proof enclosures.
- AMF2 technician time will be minimal (5 – 10 min per day at sea and 30 min total in port).
- These data, coupled with the AOS CCN data, will be available for an analysis of the contribution of biogenic and sea salt aerosols to the boundary layer CCN population over the course of the seasonal progression from spring to autumn and for testing and constraining modeled boundary layer CCN budgets over the Southern Ocean.

SOCRATES N-S Curtain:





Other Funded activities:

- *Australian R/V Investigator for 2016 and 2018*
- *DOE & Australian funded instr-uments on Macquarie Island*
- *IMOS Buoy in SOCRATES domain*
- *R/V Tangaro in Ross Sea*

Proposed Activities:

- *NSF G-V deployment*
- *U.S. Ship for Austral summer*

G-V Goal:

- *Characterize clouds, radiation, aerosols, and precipitation along SOCRATES curtain*
- SOCRATES data will be used to test and advance GCMs.

Issues to Consider

(i) analysis of ship orientation in timely manner is going to be very important

(ii) Consider location of all instruments carefully (aerosols fore of deck), need to know exact placement of instruments in relation to NAV instruments

(iii) Will it be problem if radiosondes launched into plume?