MARCUS: An Observational Campaign over the Southern Oceans for Determining the Roles of Clouds, Aerosols and Radiation On Climate

G. McFarquhar, U. Illinois
C. Bretherton, R. Wood & R. Marchand, U. Washington
S. Alexander, AAD
P. DeMott, CSU
A. Protat, Australian BoM
P. Quinn, NOAA
S. Siems, Monash University
& R. Weller, Woods Hole


VT


P&O
VNAA
AURORA AUSTRALIS
HOBART

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

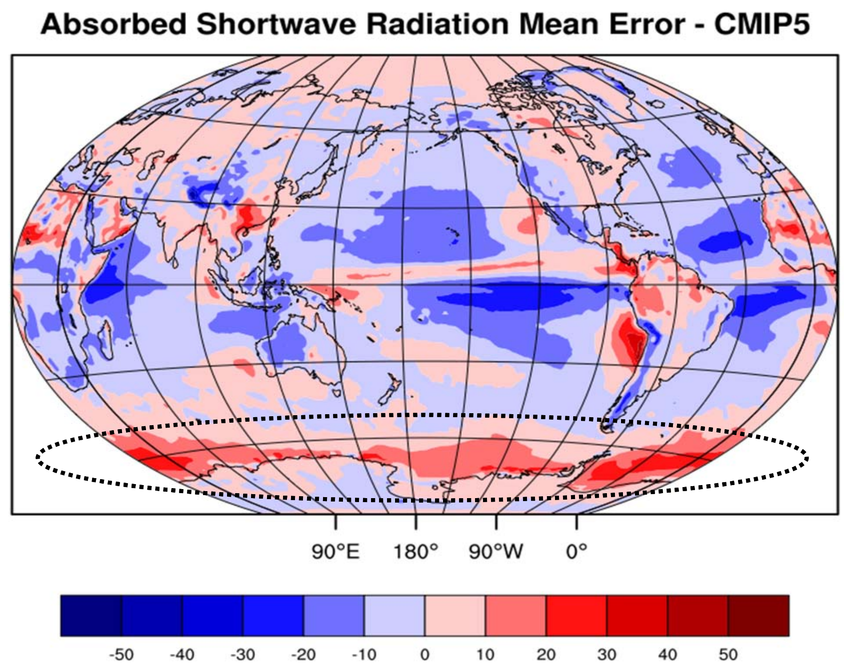
1. Motivation for Measurements of Clouds, Radiation and Aerosols over the Southern Oceans
2. Science Themes & Testable Hypothesis
3. Planned Measurements for
    - Measurements of Aerosols, Radiation and Clouds over the Southern Oceans (MARCUS)
    - Southern Ocean Cloud, Radiation, Aerosol Transport Experimental Study (SOCRATES) and
    - Macquarie Island Cloud Radiation Experiment (MICRE)
4. Planned Analysis and Collaborative Opportunities

Motivation

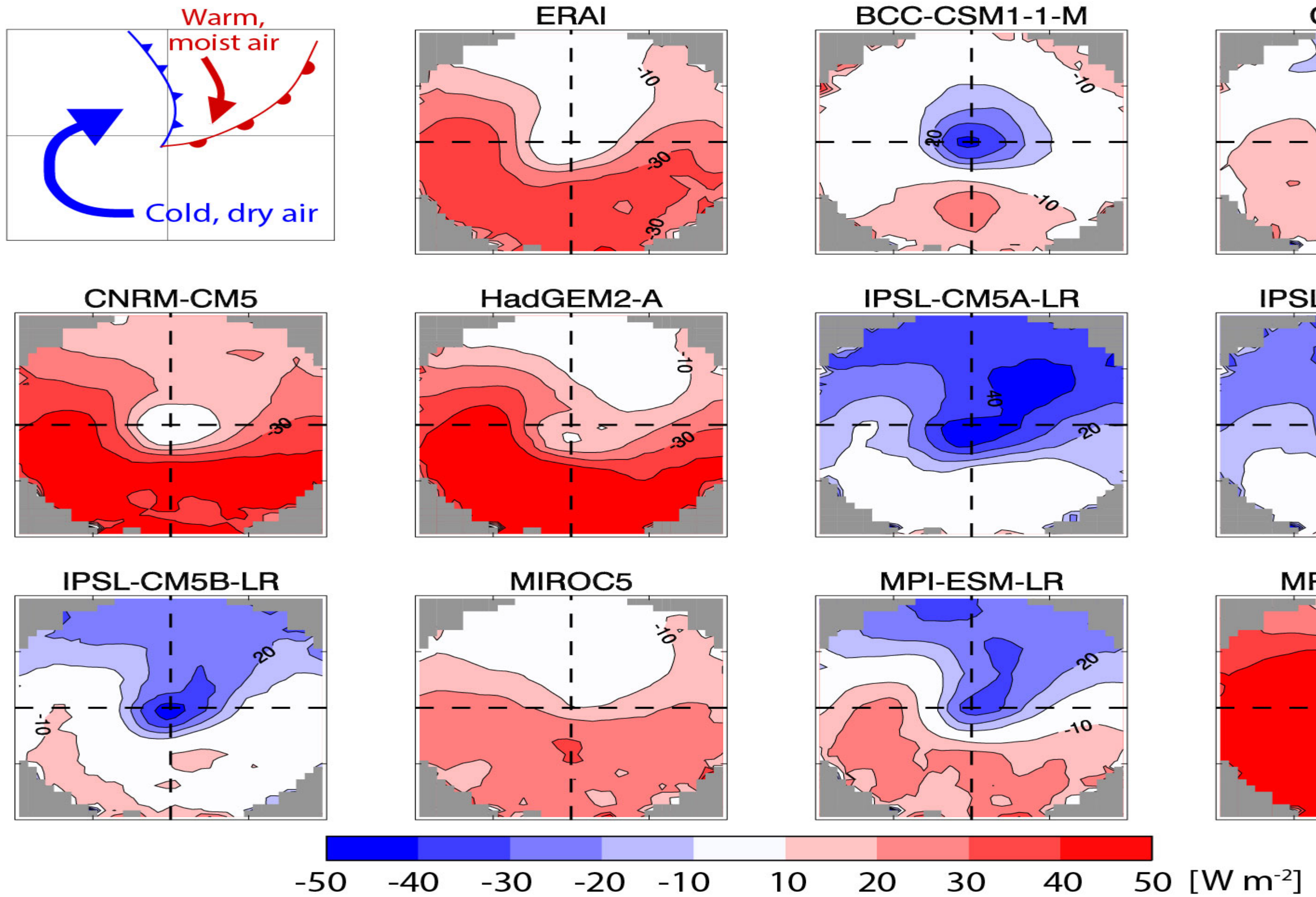
- Southern Oceans (SO) one of cloudiest regions on Earth
- Earth's climate sensitive to representation of SO clouds
  - Impact on global energy budget , simulated global cloud feedbacks & carbon-cycle feedbacks on climate change
  - Location of tropical rainfall belts
  - SO surrounds Antarctic & interacts 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
  - One of largest uncertainties in determining aerosol indirect effects for climate models is poor understanding of what is pre-industrial state

Climate model biases & observational knowledge gaps

- Climate models have uncertainties & biases in simulating SO clouds, aerosols precipitation & radiation and their interactions 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 (cloud condensation nuclei CCN and ice nucleating particles INPs) major source of uncertainty in radiative forcing
- Large radiation biases interact with location of Southern Hemisphere jet in GCMs, influence circulation and may correlate with climate sensitivity

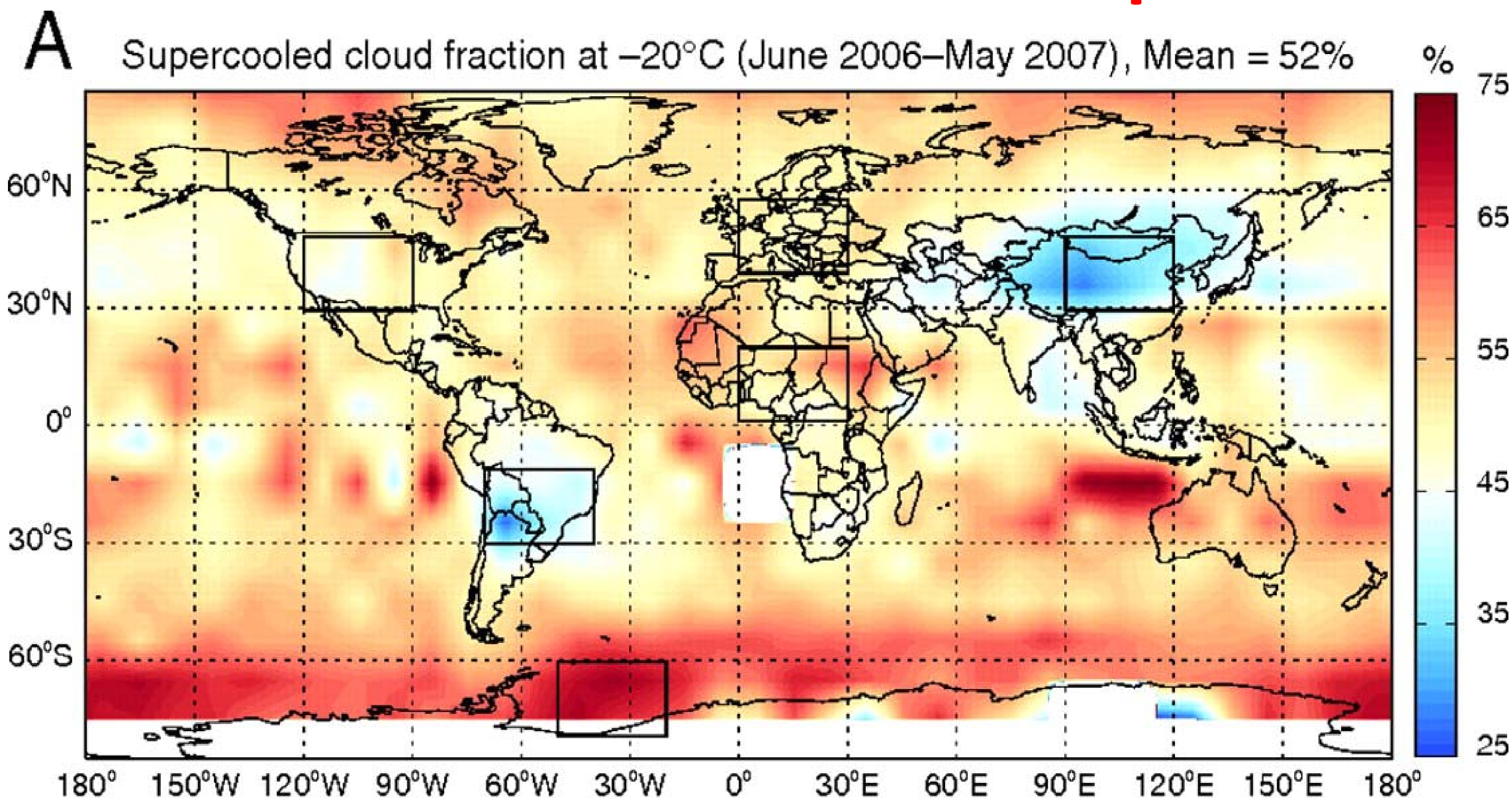


CMIP5 model clouds do not reflect enough sunlight over SO. Ensemble mean error for CMIP5 models in shortwave radiation absorbed by the Earth System. Positive values indicate too much shortwave radiation absorbed.

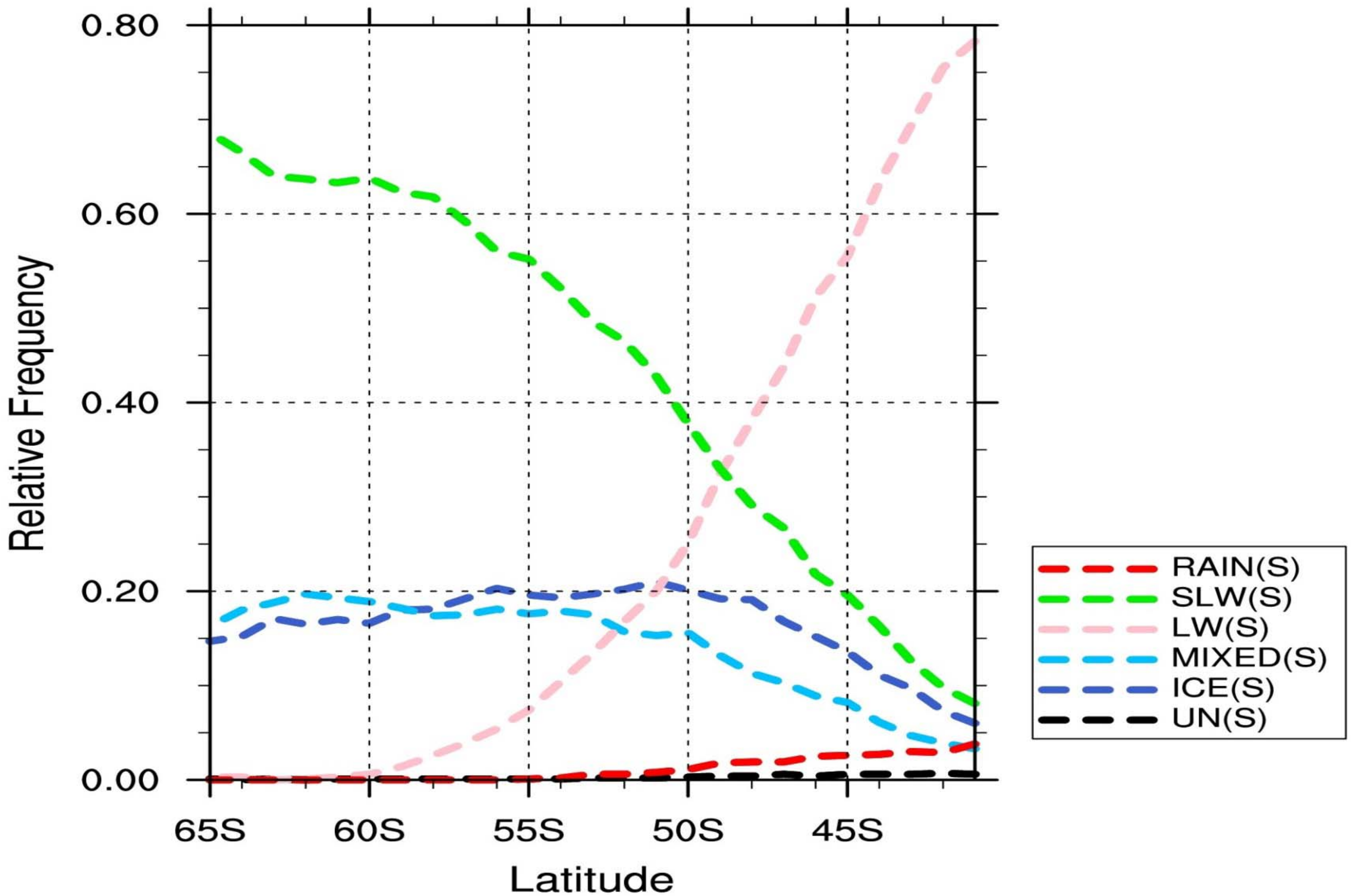


Cyclone compositing indicates consistent patterns of insufficient reflected shortwave in the cold, dry regions of the cyclones. *Figure shows bias in absorbed shortwave radiation for AMIP models from Bodas-Salcedo et al. (2013).*

SO Cloud and Aerosol Properties

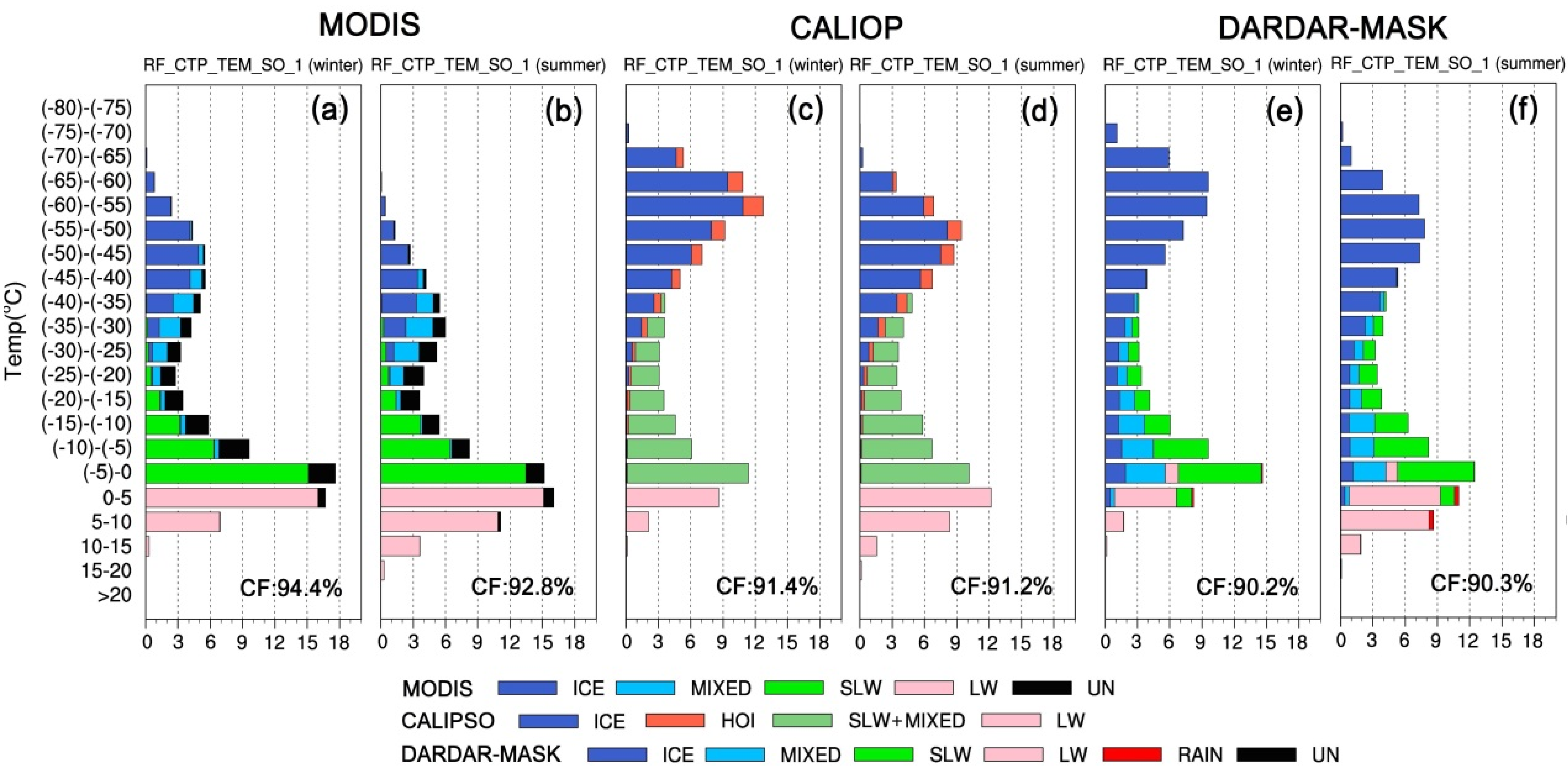


Large fraction of cloud-tops at temperatures near -20˚C contain supercooled liquid water, *as retrieved using CALIPSO depolarization measurements (Choi et al. 2010); GCMs have broad range of sensitivities to liquid vs. ice partitioning to temperature in SO clouds showing need for in-situ observational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



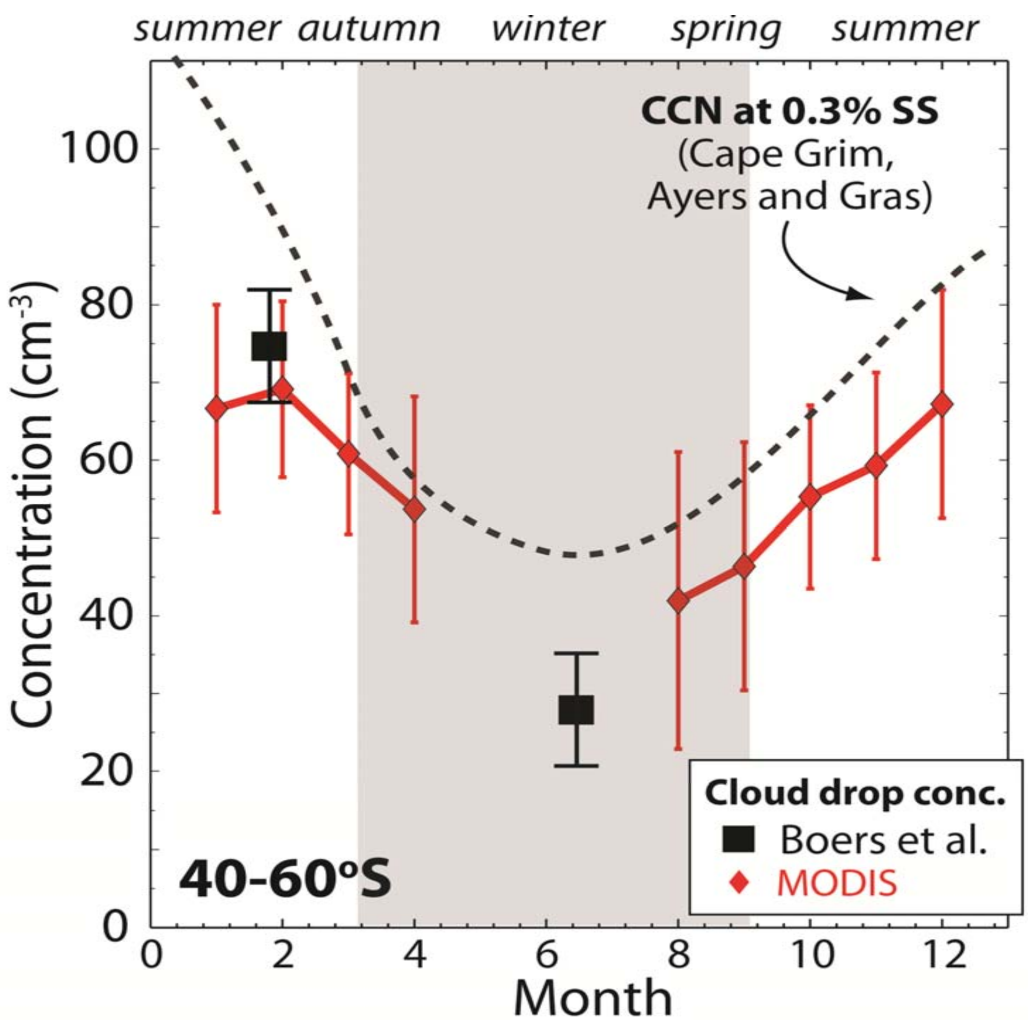
Relative Frequencies of cloud top thermodynamic phase classes of ice (ICE), mixed- phase (MIXED), liquid warm (LW), SLW, rain (RAIN) and uncertainty (UN) categorized by DARDAR-MASK during Austral summer (S). Relative frequencies of the cloud top phase classes for the single layer of the highest cloud tops (60 m) below 5 km. (Adapted from Huang et al. 2012b)

Retrievals of clouds, precipitation & aerosols, over SO

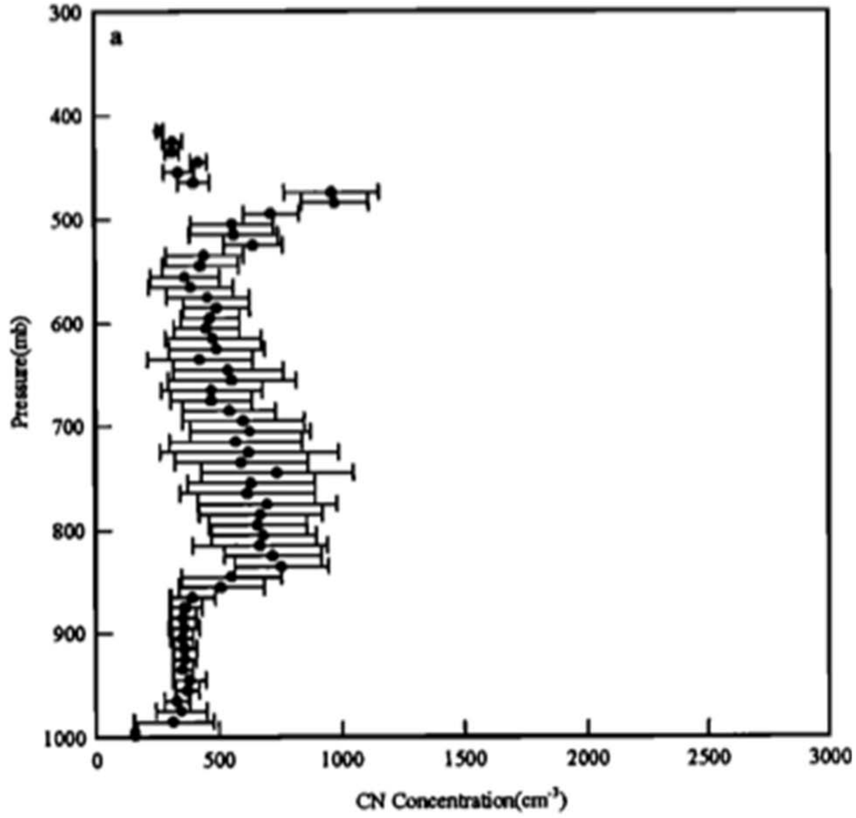


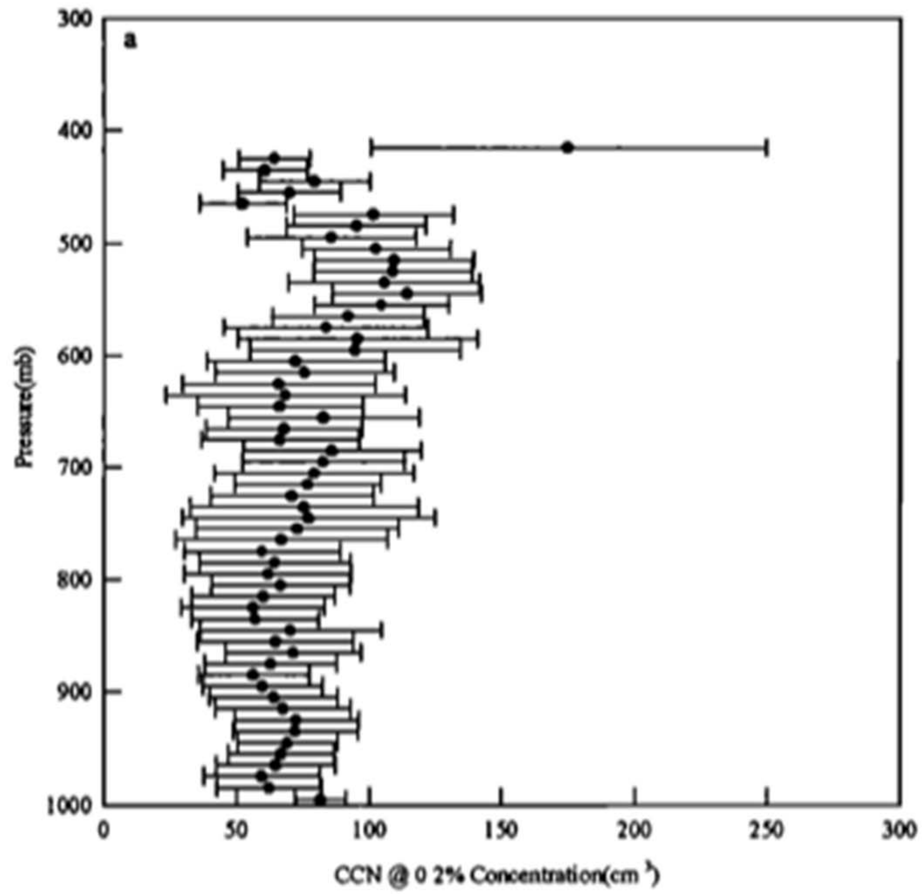
Vertical distribution of cloud top phase *retrieved from MODIS (Platnick et al. 2003), CALIOP (Hu et al. 2010) and DARDAR (Delanoë and Hogan 2010). MODIS shows less high cloud and a warm bias and less liquid water below -20°C. CALIPSO does not distinguish between supercooled water and mixed phase, while DARDAR gives ice-only at cloud-top between 0 & -30°C not reported by either CALIPSO or MODIS. From Huang et al (2014b).*

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.





More CN, and as many CCN in FT as PBL!

Observational and modeling requirements

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 boundary layer 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.
Modeling requirement	For such a dataset to have broad impact on GCMs, the modelling community must be an integral part of the experiment design and be involved in a systematic confrontation of leading GCMs with data, e. g. using short-term hindcasts as in VOCALS (Wyant et al. 2014).

MARCUS Overarching objectives

(i) To **characterize physical properties of lower-tropospheric cloud systems** around mid-latitude cyclones over complete seasonal cycle;

(ii)To characterize microphysical and chemical properties of aerosols and aerosol precursor compounds, including DMS, that may play a role in regulating CCN and INPs over SO and to investigate their significance for cloud and precipitation formation, and radiative properties;

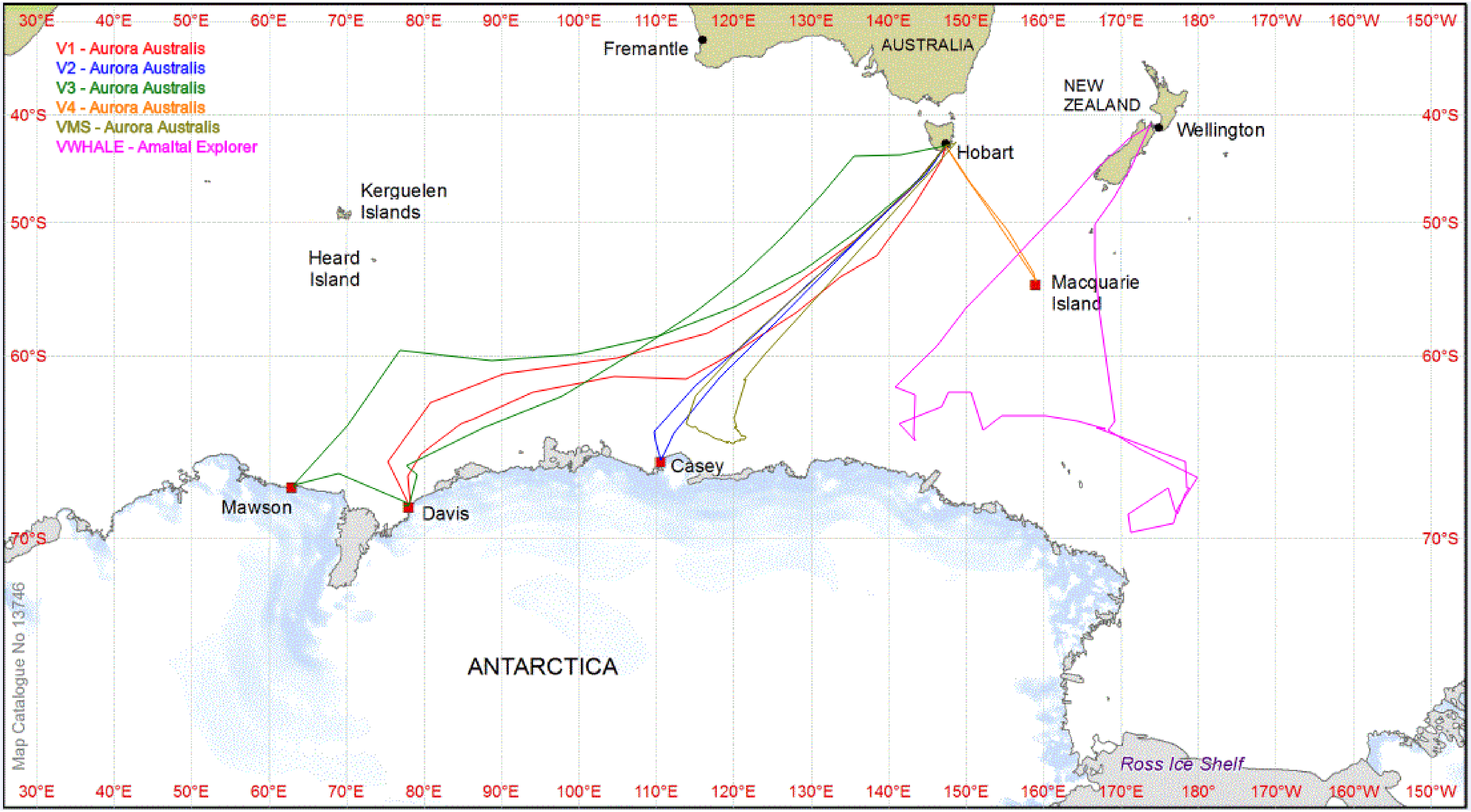
(iii)To assess the quality of satellite cloud, aerosol, precipitation, and upper ocean products, to develop new ones, and to use these products to address the science questions;

(iv)To evaluate & improve skill of models at different scales to reproduce observed properties of SO cloud systems, aerosol physicochemical properties, and aerosol-cloud-precipitation interactions, and to use such models to develop process-oriented understanding of mechanisms controlling properties


P&O
AURORA AUSTRALIS

MARCUS AMF on Aurora Australis

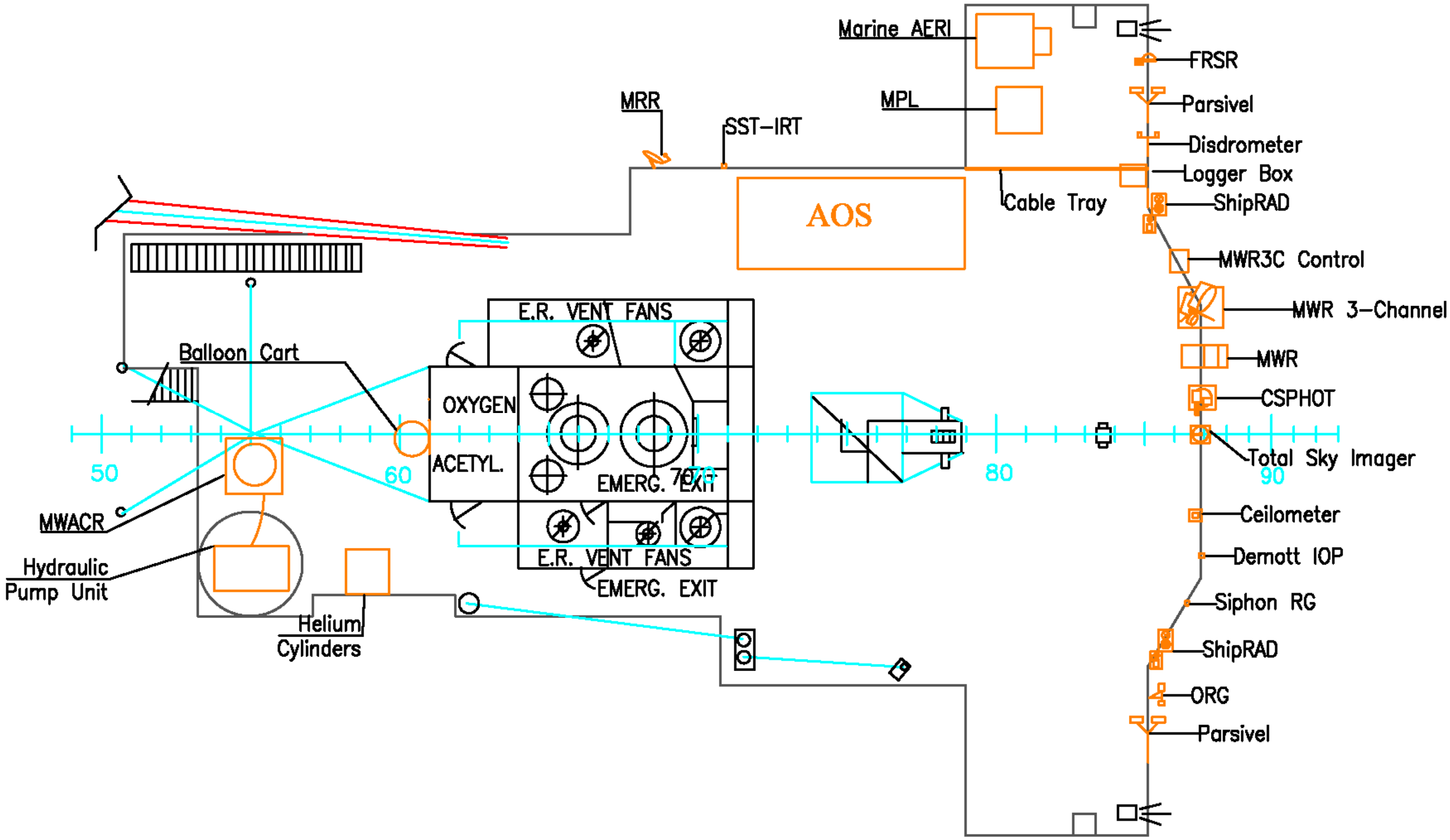
- During each operational season (Oct. – Mar.), AA traverses SO ~ 4 times to resupply coastal East Antarctic bases(Mawson, Casey & Davis) and Macquarie Island.
  - Not dedicated research vessel (minimal influence on tracks)
  - Typical voyage ~ 10 to 14 days traversing SO (depending on ice conditions) 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



- 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.

Observations for MARCUS

- Aerosols, CCN, INPs and O_3 at ship
- 4/day soundings
- 95 GHz radar, lidar, 2 microwave radiometers, sun photometer, disdrometer, radiation measurements, ceilometer, marine atmospheric emitted interferometer, total sky imager, meteorological measurements



Marine AERI
FRSR
MPL
Parsivel
MRR
SST-IRT
Disdrometer
Logger Box
Cable Tray
AOS
ShipRAD
MWR3C Control
MWR 3-Channel
E.R. VENT FANS
Balloon Cart
MWR
CSPHOT
OXYGEN
ACETYL.
EMERG. EXIT
50
60
70
80
90
Total Sky Imager
MWACR
Ceilometer
Hydraulic
Pump Unit
E.R. VENT FANS
Demott IOP
EMERG. EXIT
Siphon RG
Helium
Cylinders
ShipRAD
ORG
Parsivel

ARM

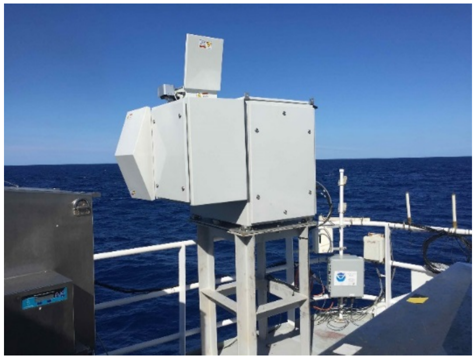
CLIMATE RESEARCH FACILITY

Instrument Payload

Instrument Name	Instrument	System	Install To:
Condensation Particle Counter	CPC	AOS	AOS van
Cloud Condensation Nuclei (CCN100)	CCN	AOS	AOS van
Hygroscopic Tandem Mobiity Analyzer	HTDMA	AOS	AOS Van
Dry Nephelometer	NEPH	AOS	AOS Van
Ultra High Sensitivity Aerosol Spectrometer	UHSAS	AOS	AOS Van
WXT520	AOS Met	AOS	AOS Stack
CO Detector	CO	AOS	AOS van
Ozone	O3	AOS	AOS Van
Particle Soot Absorption Photometer	PSAP	AOS	AOS Van
Balloon Borne Sounding System	Sonde	BBSS	Deck
Micropulse lidar	MPL	Lidar	OPS van
Ceilometer	CEIL	Lidar	Deck
Disdrometer	PARS	Met	Handrails
Disdrometer	PARS	Met	Handrails
Marine met	Anemometer	Met	Super Structure
Marine met	Barometer	Met	Super Structure
Marine met	ORG	Met	Handrails
Marine met	T/RH probe	Met	Handrails

Instrument Name	Instrument	System	Install To:
Infrared Thermometer	IRT	MET	Handrails
Sea Surface Temperature IRT	SST-IRT	Met	Handrails
Microwave Radiometer 2-channel	MWR-2C	MWR	Handrails
Microwave Radiometer 3-channel	MWR-3C	MWR	Handrails
Marine W-band ARM Cloud Radar	MWACR	Radar	Deck
Beam Steerable Radar Wind Profiler	BSRWP	Radar	Top of OPS van
Atmospheric Emitted Raiance Interferometer	MAERI	Radiometry	Deck
Fast-Rotating Shadowband Radiometer	FRSR	Radiometry	Handrails
ShipRad - Downwell short/longwave, VectorNAV	Shiprad	Radiometry	Handrails
Cimel sunphotometer	CSPHOT	Radiometry	Handrails
Sea Navigation	SeaNav	Systems	OPS van
platform for MWACR	Stable Table	Systems	Deck
Total Sky Imager	TSI		Handrails
Micro Rain Radar (Alexander IOP)	MRR	IOP	Handrails
OceanRAIN Disdrometer (Alexander IOP)		IOP	Handrails
Filter Sampler (DeMott IOP)	TSI		Handrails

Instruments



MAERI

Micro Pulse Lidar

Total Sky Imager

Cimel Sun Photometer

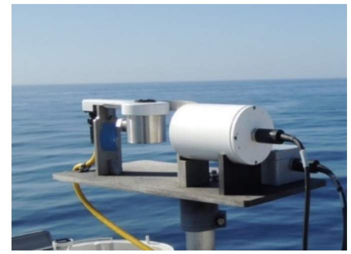
Ceilometer

Sea Surface Temperature
(Infrared Thermometer)

Instruments

2-Channel Microwave Radiometer (MWR)

3-Channel MWR



Fast-Rotating Shadowband Radiometer

ShipRad - Downwelling Radiometer Suite

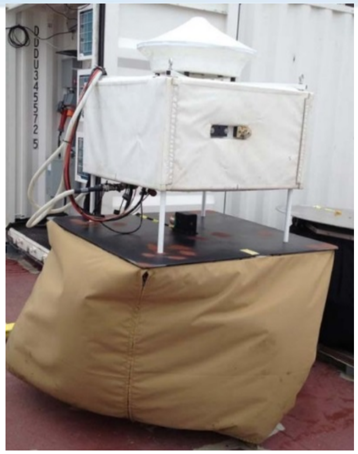
Laser Disdrometers

Siphon Rain Gauge

Optical Rain Gauge

Instruments

Radar Wind Profiler



Marine W-Band
Radar (MWACR)

Stabilized Platform
(for MWACR)

Balloon Soundings

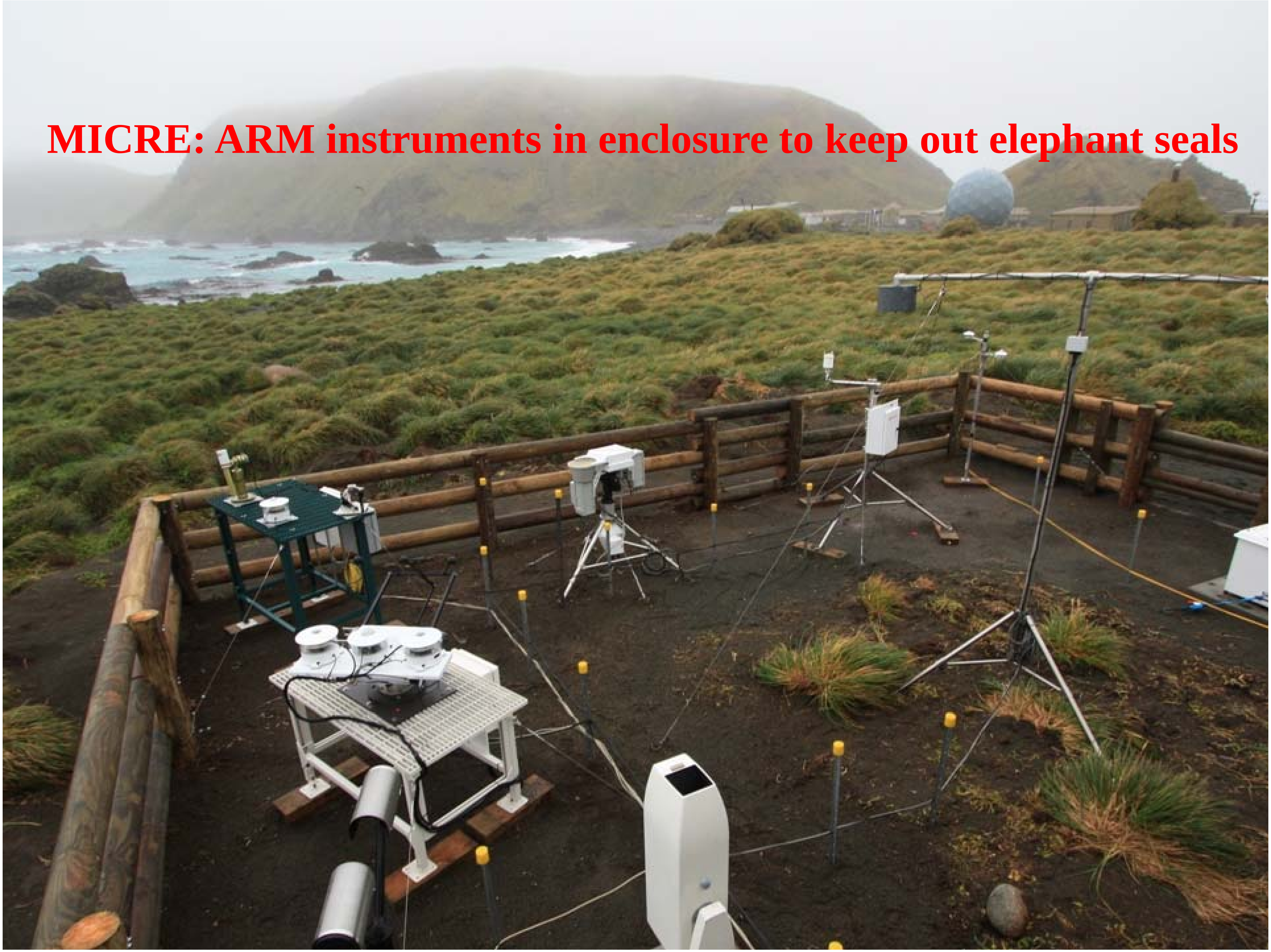
ARM
CLIMATE RESEARCH FACILITY

U.S. DEPARTMENT OF ENERGY | Office of Science

MICRE Project

- Deployment of following ground instrumentation to permanent research station at Macquarie Island (54˚S in SO storm track) from 03/16 to 03/18
  - Broadband radiometers (sky and ground radiation)
  - 3-channel microwave radiometer and ceilometer
  - Multi-Filter Rotating Shadowband Radiometer (MFRSR)
  - Precipitation disdrometer
  - Sun photometer for vis and ir narrow-field of view measurements
- Bureau of Meteorology deploying mm-λ cloud radar and cloud and backscatter lidar

MICRE: ARM instruments in enclosure to keep out elephant seals



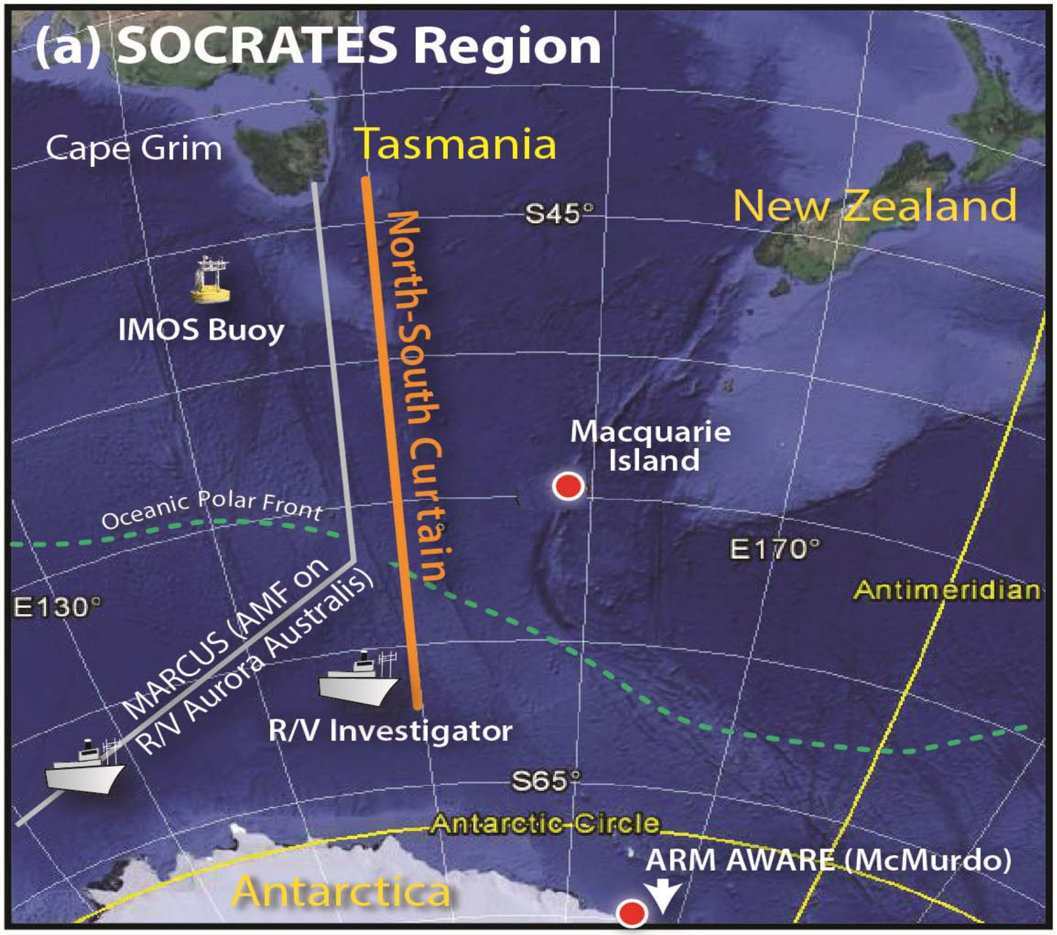
Green beam of AAD depolarization lidar

Timeline of Planned Activities

Table 3: Timeline of proposed SOCRATES activities (red shaded: already funded; blue: requested)

Platform (campaign)	2016				2017				2018				2019			
	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Macquarie Island observations (MICRE)																
Aurora Australis ship observations (MARCUS)																
Macquarie Island observations (ACRE)																
NSF OOI Climate Reference buoy																
Australian IMOS buoy																
R/V Investigator cruises (CAPRICORN)																
NSF/NCAR GV deployment																
NOAA P-3 Deployment																
R/V Tangaro (Deep South)																
ARM Mobile Facility at McMurdo (AWARE)																
Satellite observations																

Overview of Funded & Planned Observations



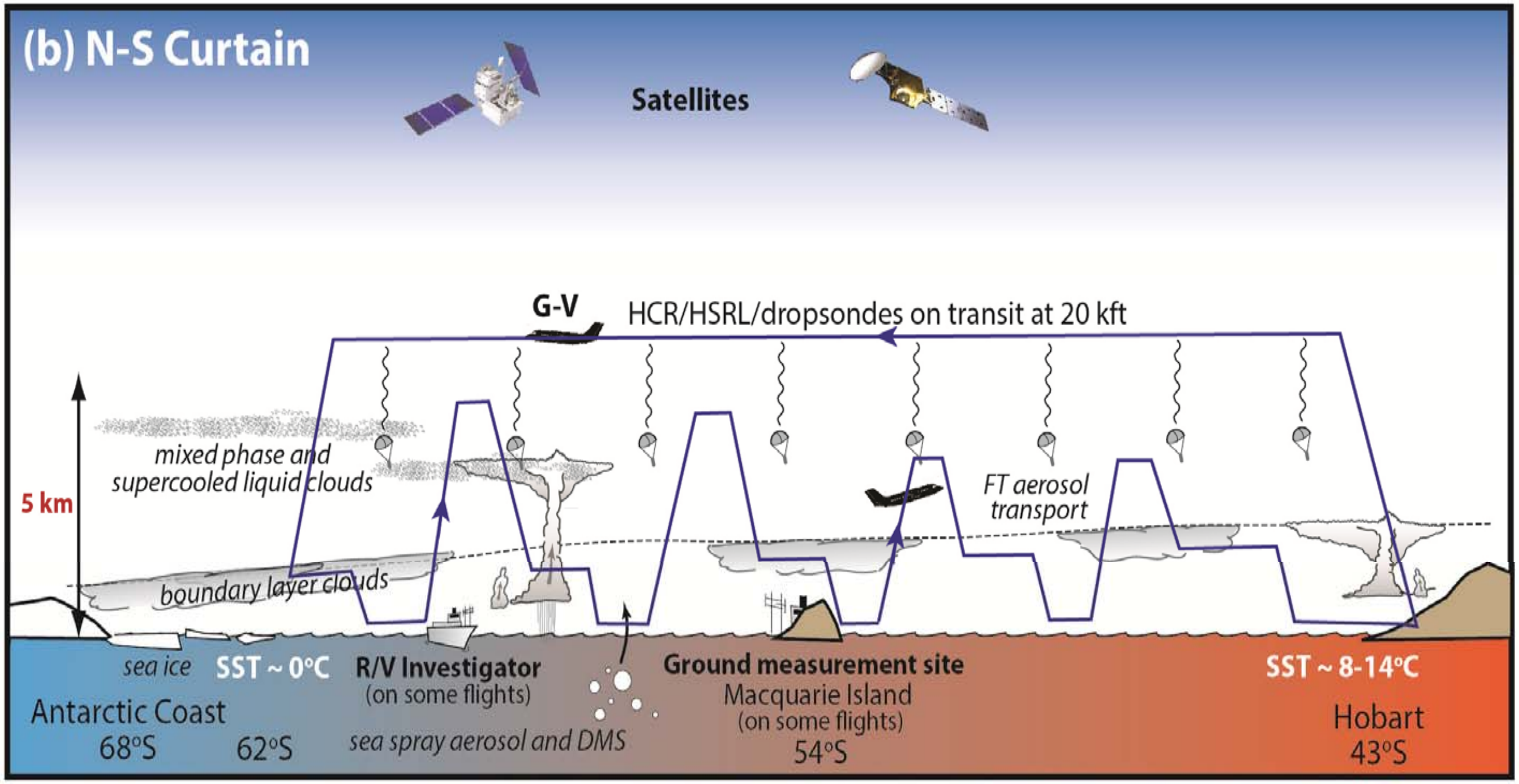
Funded Activities

- *ARM Mobile Facility on Aurora Australis icebreaker (MARCUS)*
- *Australian R/V Investigator for 2016 and 2018*
- *DOE & Australian funded instruments on Macquarie Island (MICRE)*
- *IMOS Buoy*
- *NSF G-V deployment (SOCRATES)*

Proposed Activities:

- *NOAA P-3 deployment*

Planned Aircraft Deployment : SOCRATES



G-V Goal:

- *Characterize clouds, radiation, aerosols, and precipitation along SOCRATES curtain using both cloud remote sensing and in-situ instrumentation (includes INP and aerosol size distributions)*

Planned Aircraft Deployment : SOCRATES