Aerosol-cloud-precipitation interactions in mixed-phase clouds over the Southern Ocean: Results from recent field campaigns

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ARM

Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study
SOCRATES

CIMMS
Cooperative Institute for Mesoscale Meteorological Studies

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1890

NSF

SOCRATES/MARCUS/MICRE/CAPRICORN Themes

Theme 1: Documenting the synoptically-varying vertical structure of SO boundary layers and clouds

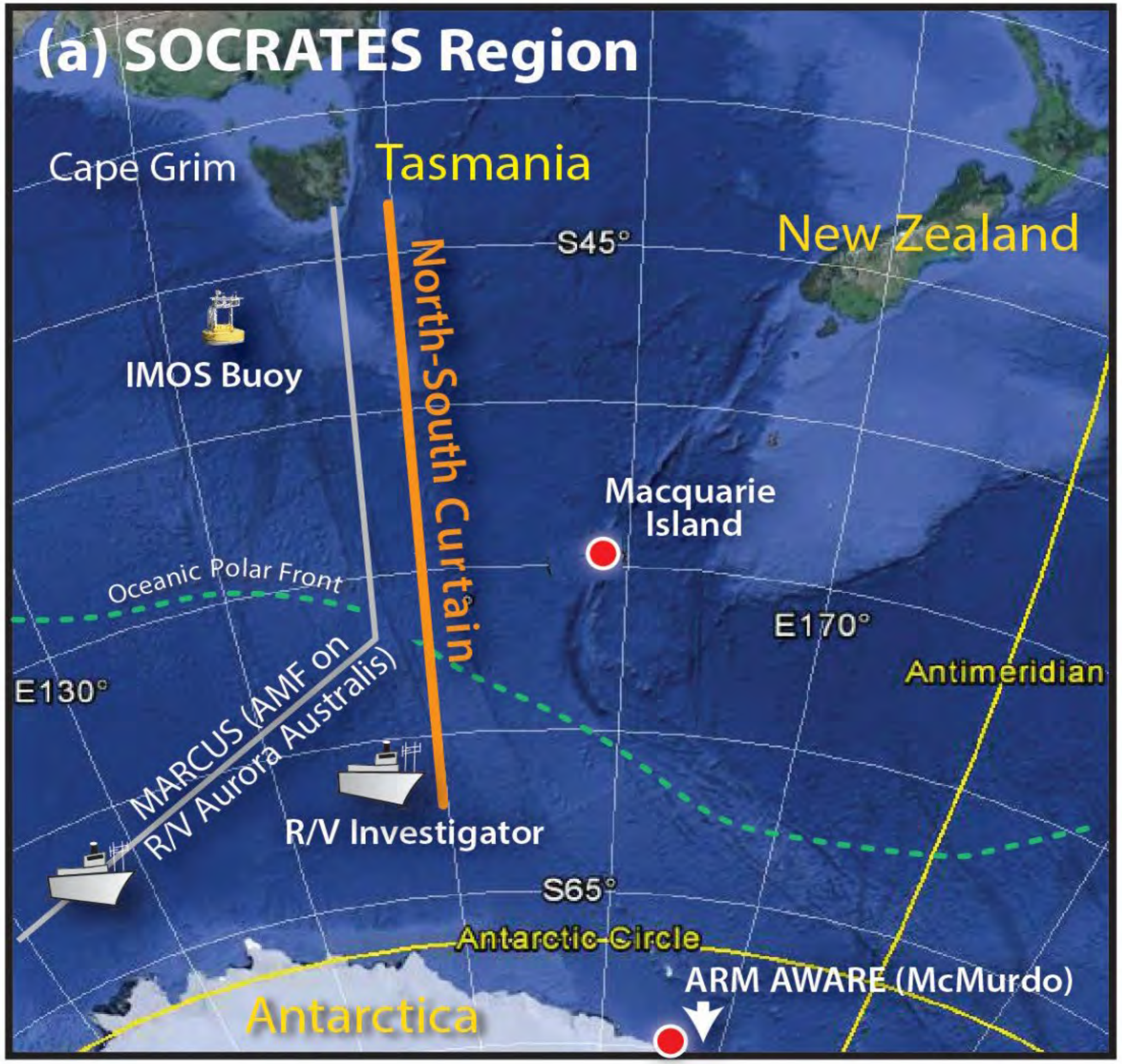
Theme 2: Variability of sources and sinks of SO CCN and INPs and role of local biogenic sources over spring, summer and fall

Theme 3: Supercooled liquid clouds over SO

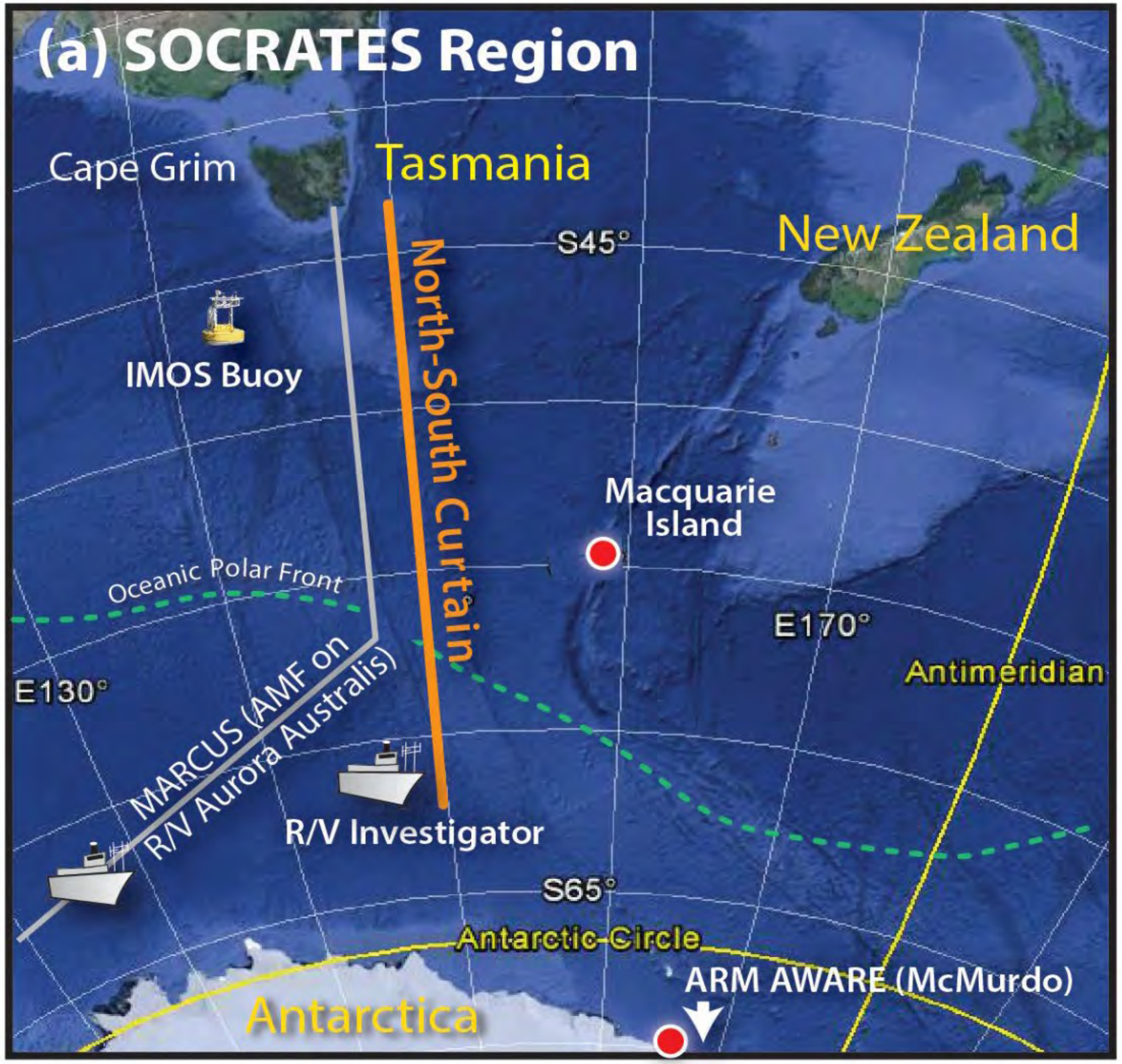
Theme 4: Retrieving the properties of mixed-phase clouds

For data to have broad impact on climate modeling, modeling community was integral part of project design so as to use data for systematic confrontation of leading climate models

SOCRATES/CAPRICORN/MICRE/MARCUS Coordinated Observations

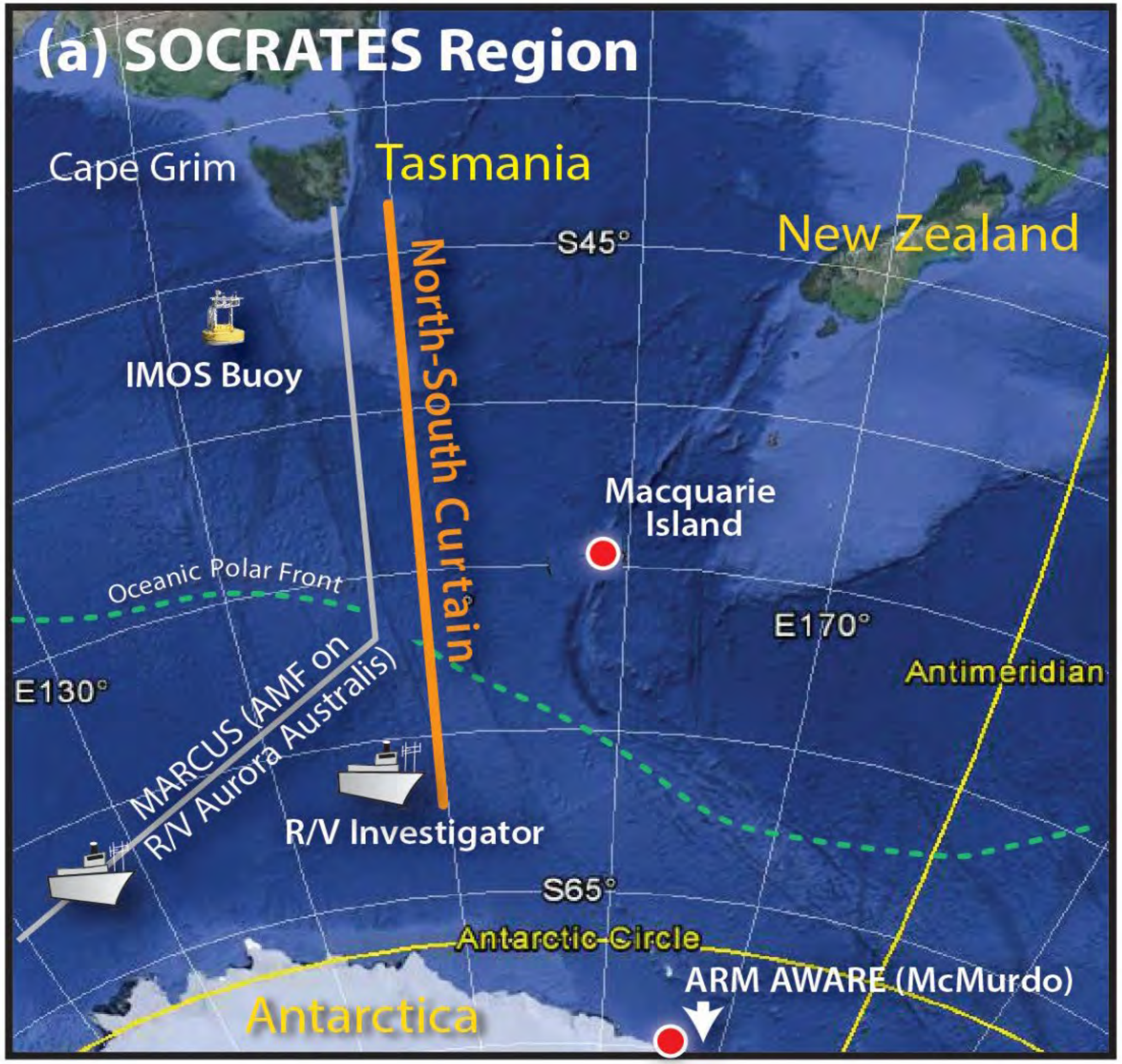


SOCRATES/CAPRICORN/MICRE/MARCUS Coordinated Observations



SOCRATES (Jan 15-Feb 26 2018):
NSF G-V deployment

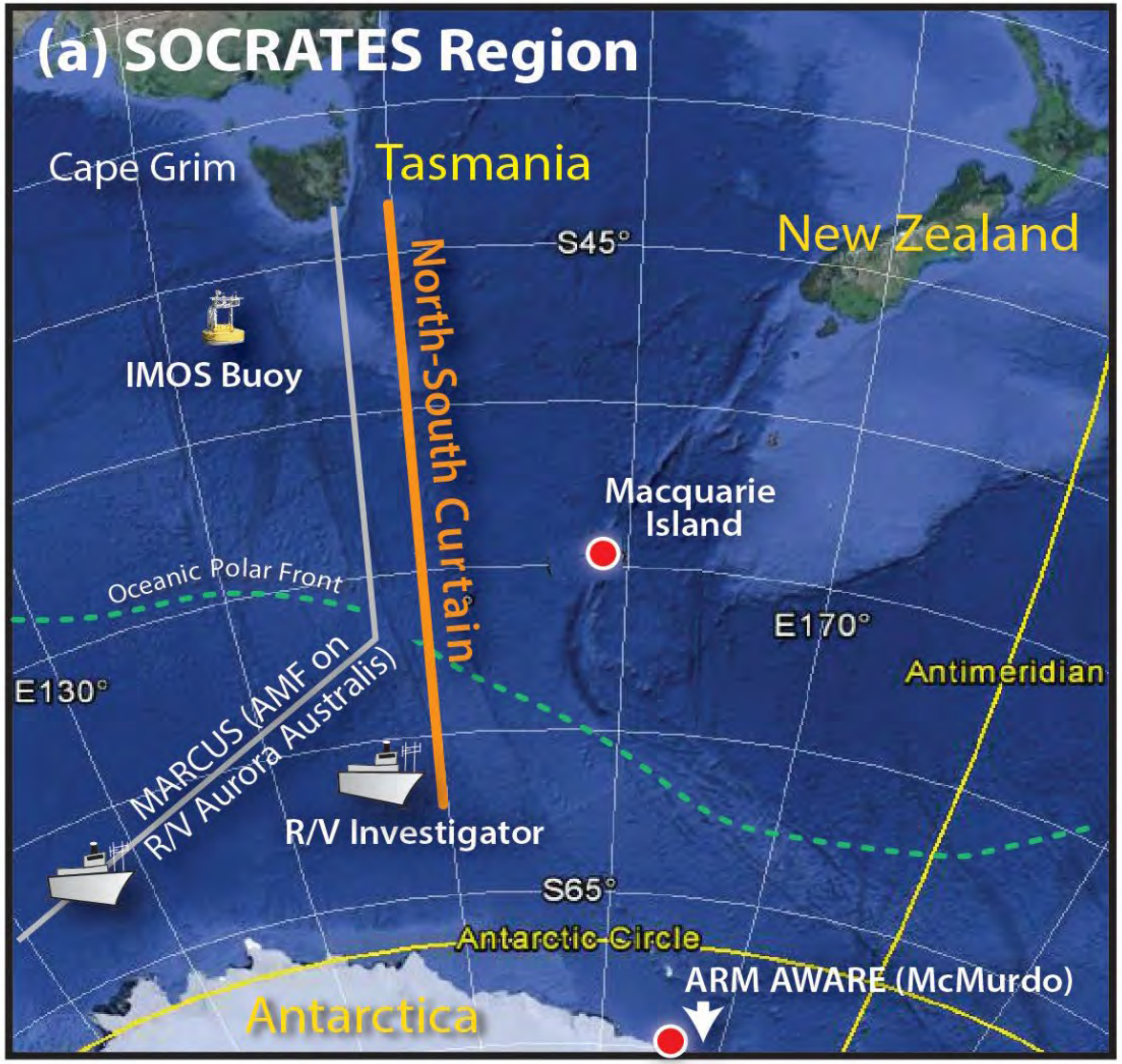
SOCRATES/CAPRICORN/MICRE/MARCUS Coordinated Observations



CAPRICORN (2016-2018):

Australian R/V Investigator

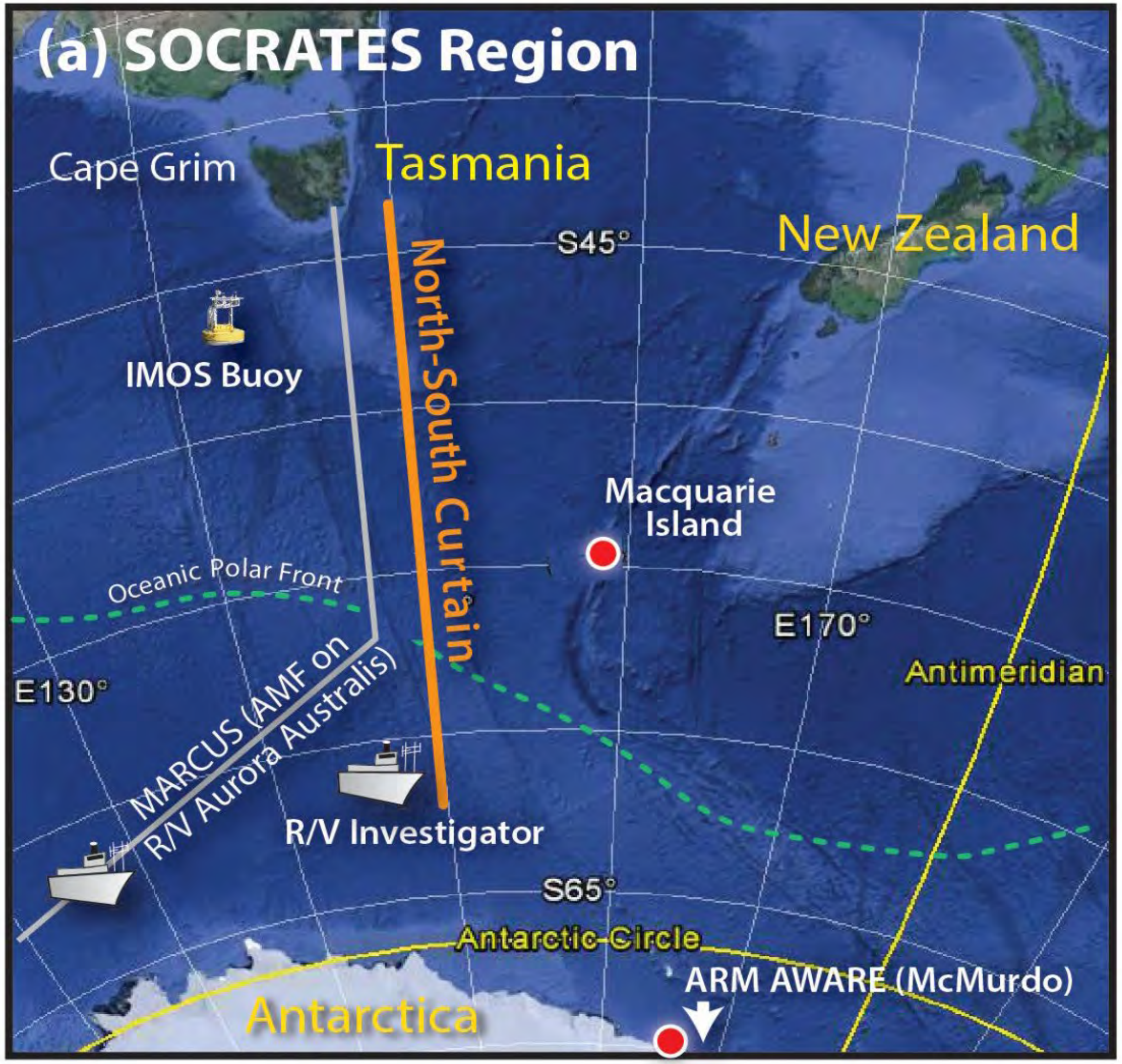
SOCRATES/CAPRICORN/MICRE/MARCUS Coordinated Observations



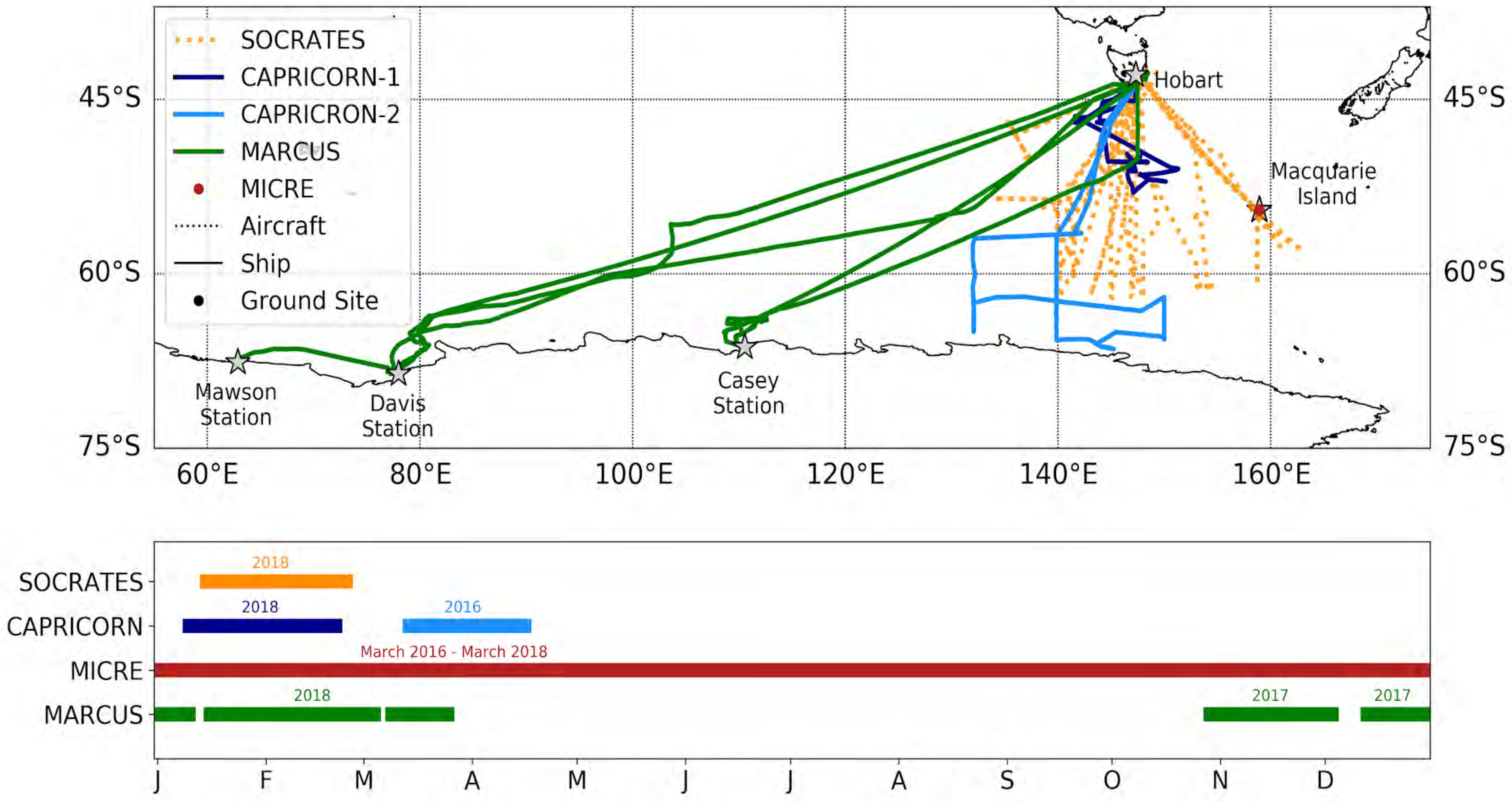
MICRE (2017-2018):

DOE, AUS instruments on Macquarie Island

SOCRATES/CAPRICORN/MICRE/MARCUS Coordinated Observations



MARCUS (2017-2018):
AMF-2 on Aurora Australis



SOCRATES
CAPRICORN-1
CAPRICRON-2
MARCUS
MICRE
Aircraft
Ship
Ground Site
Hobart
Macquarie Island
Mawson Station
Davis Station
Casey Station
45°S
60°S
75°S
60°E
80°E
100°E
120°E
140°E
160°E
SOCRATES
CAPRICORN
MICRE
MARCUS
2018
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March 2016 - March 2018
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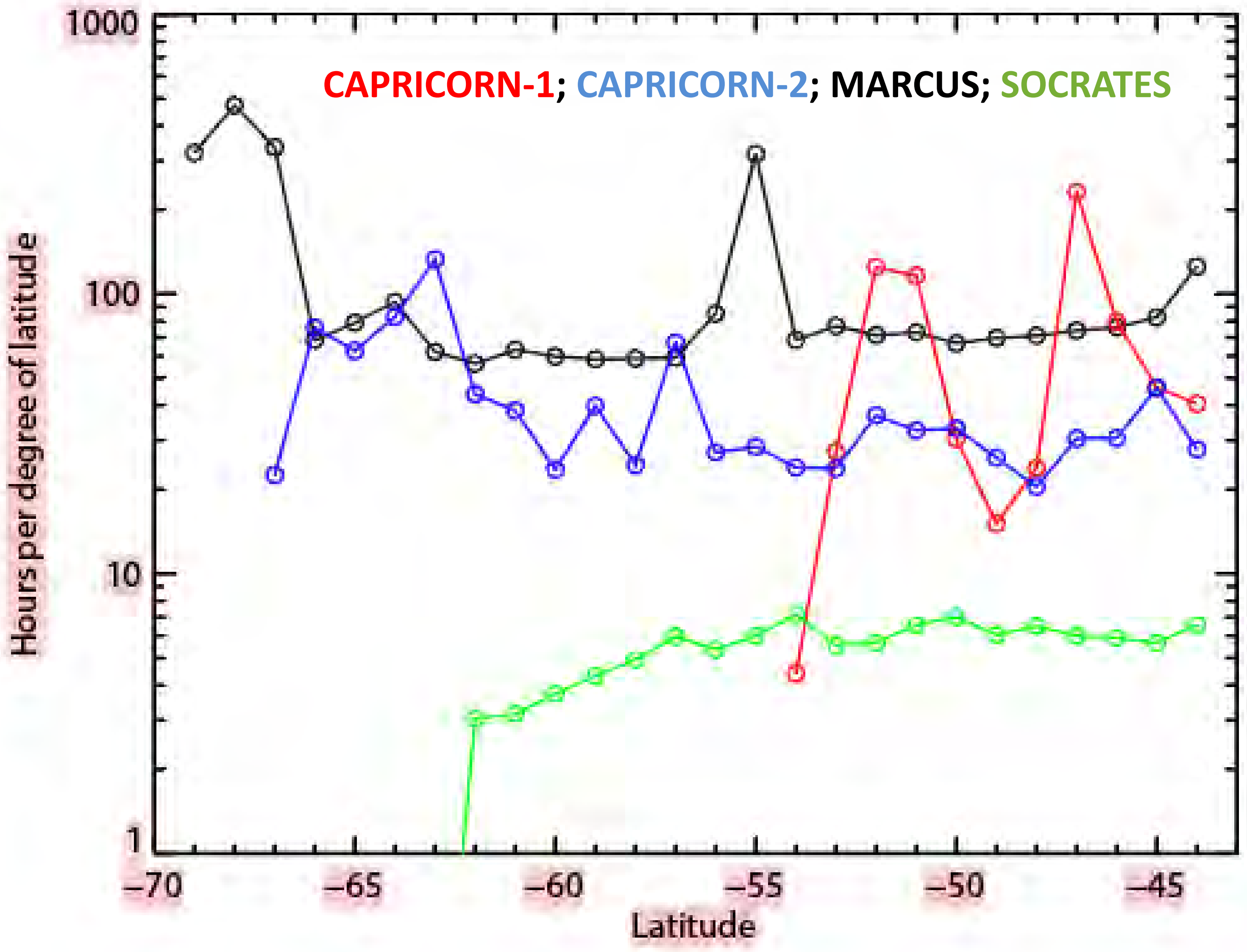
Synergy between projects



Campaign Advantages

MICRE: Long seasonal sample

CAPRICORN: More detailed oceanographic, aerosols & surface flux measurements

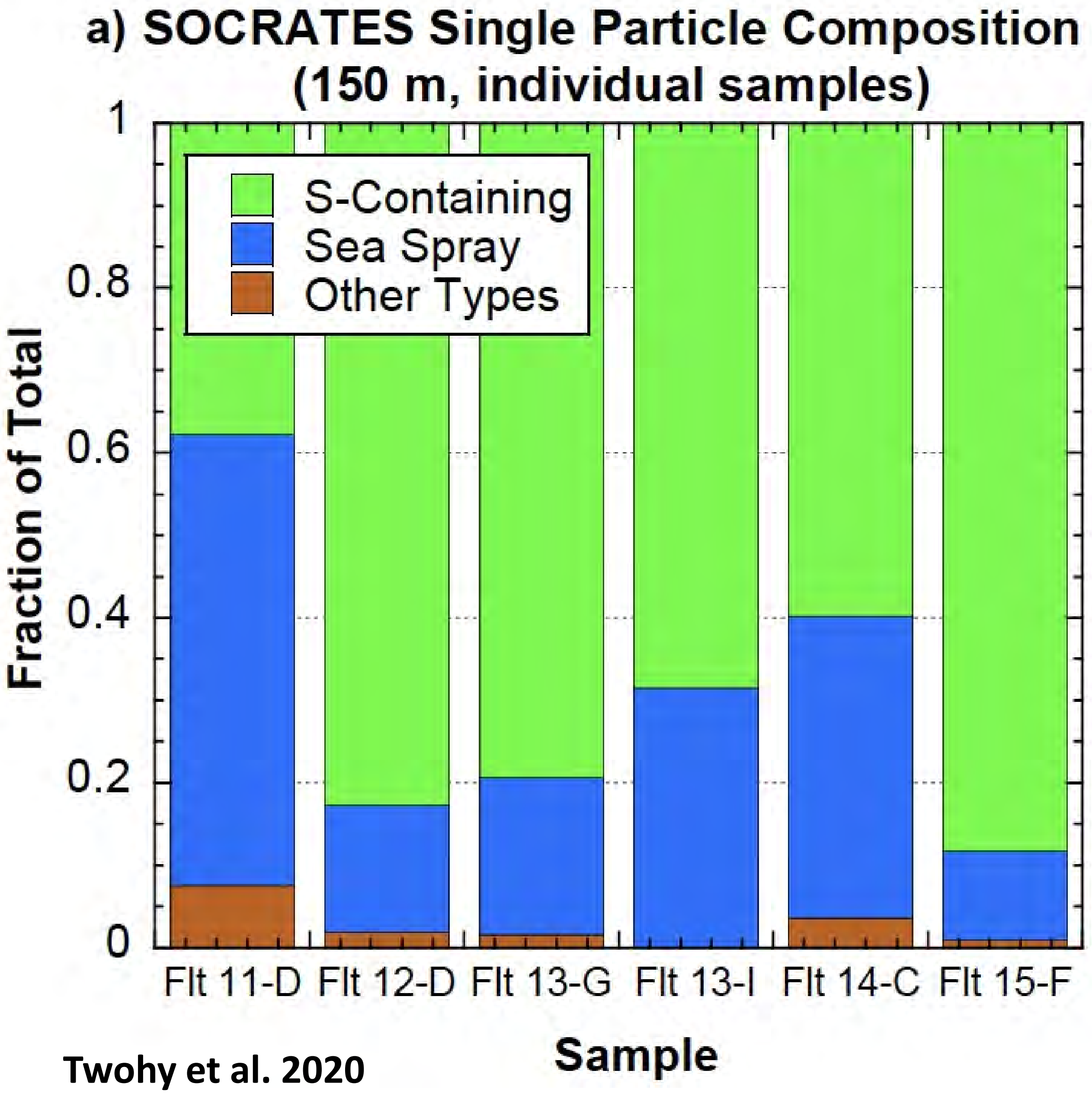
MARCUS: Seasonal cycles poleward of 60˚S

SOCRATES: Process studies and remote sensing evaluation

Preliminary Results

1. Surface Aerosol Observations
2. BL Aerosol and CCN Observations
3. INP Data
4. Ship and Ground-based Remote Sensing of Clouds
5. In-situ Measurements of Clouds

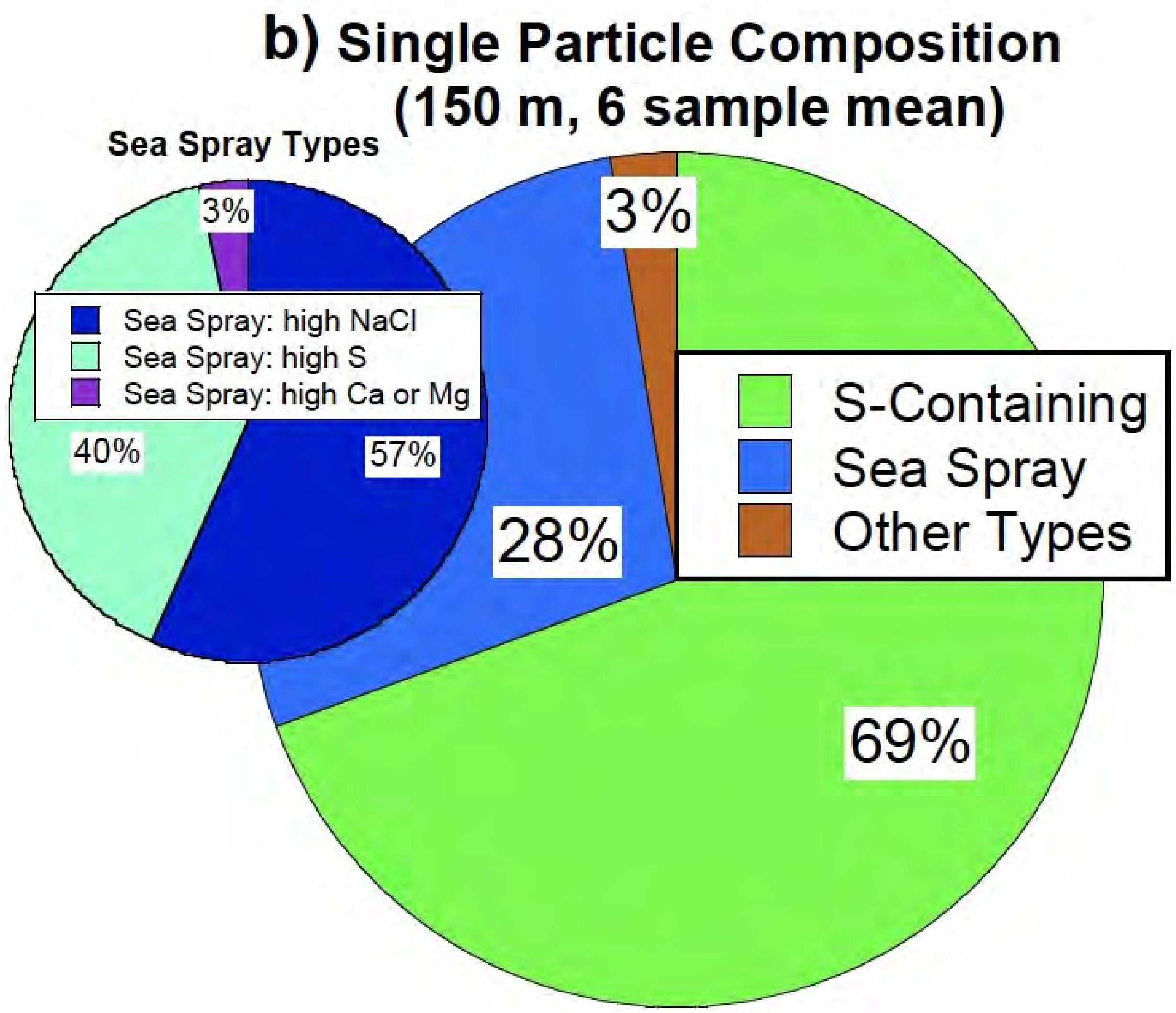
BL Aerosols: What controls number and composition?



Twohy et al. 2020

- Aerosols sampled 150 m above ocean by CVI ($0.1 < D < 5\ \mu m$) stored frozen for analysis by TEM and X-ray spectroscopy
- Dominated by sulfur-based particles primarily biogenically-produced sulfuric acid
- Second-most frequent particle type in this size range (mean 28%) was salt-based sea-spray

BL Aerosols: What controls number and composition?

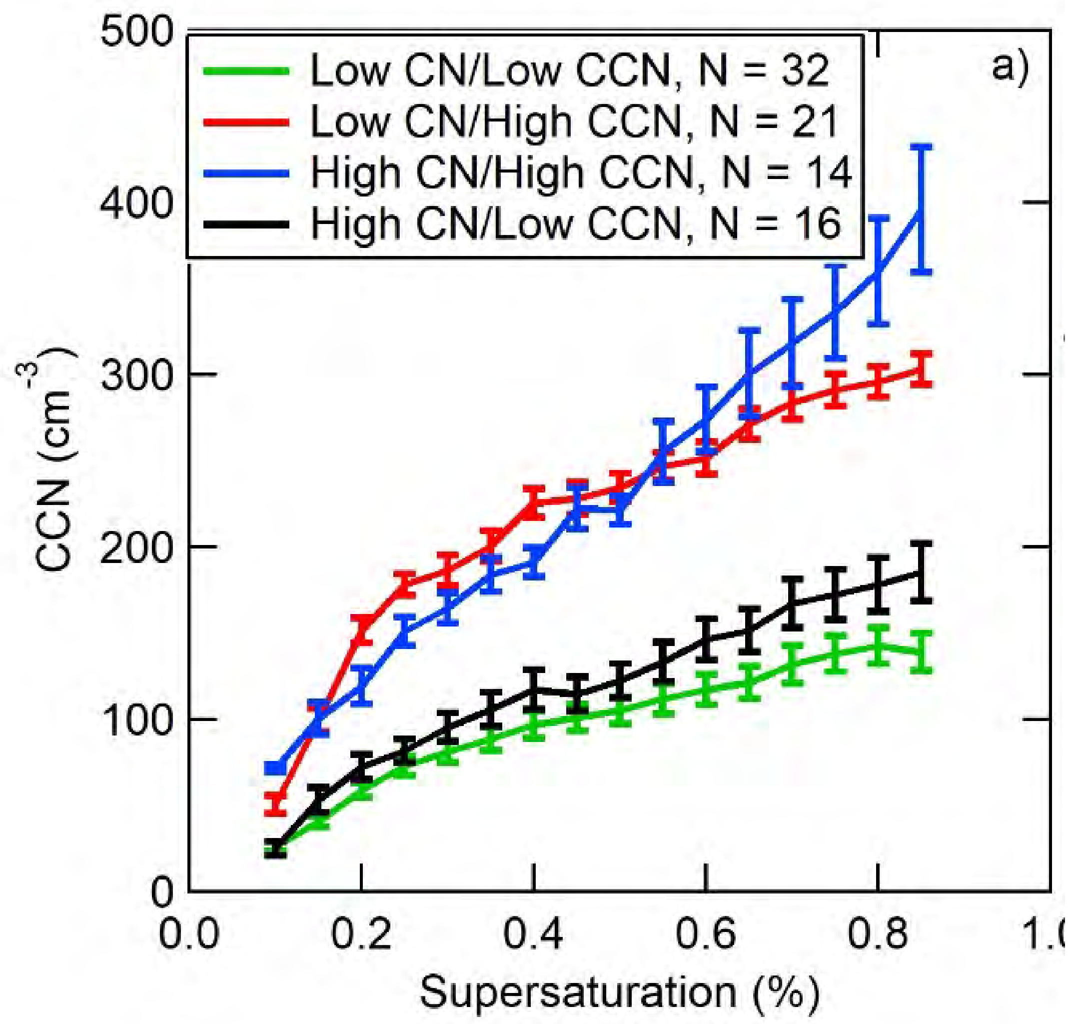


- Salt-based sea-spray dominated by unprocessed, sodium chloride-based sea-spray particles

- Many of the large sea-spray particles had detectable carbonaceous coatings, which may be important in ice nucleation

Twohy et al. 2020

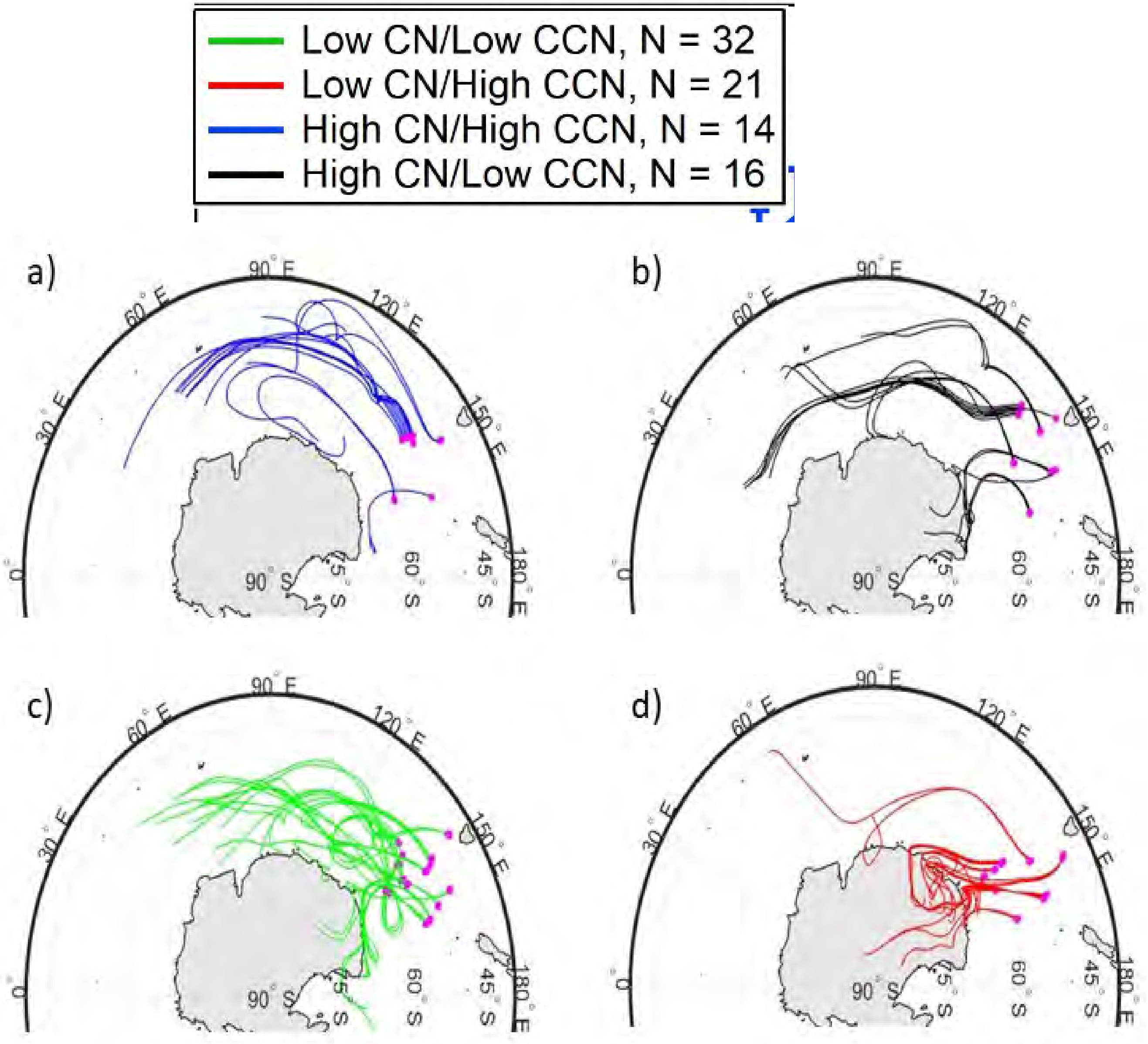
BL CCN: What controls number?



- CCN spectra in BL grouped in 4 clusters using k means clustering
- Clusters associated with bimodality in CN and CCN concentrations
- Division between low and high at approximately 750 cm^{-3} for CN and dependent on supersaturation for CCN

Sanchez et al. 2020

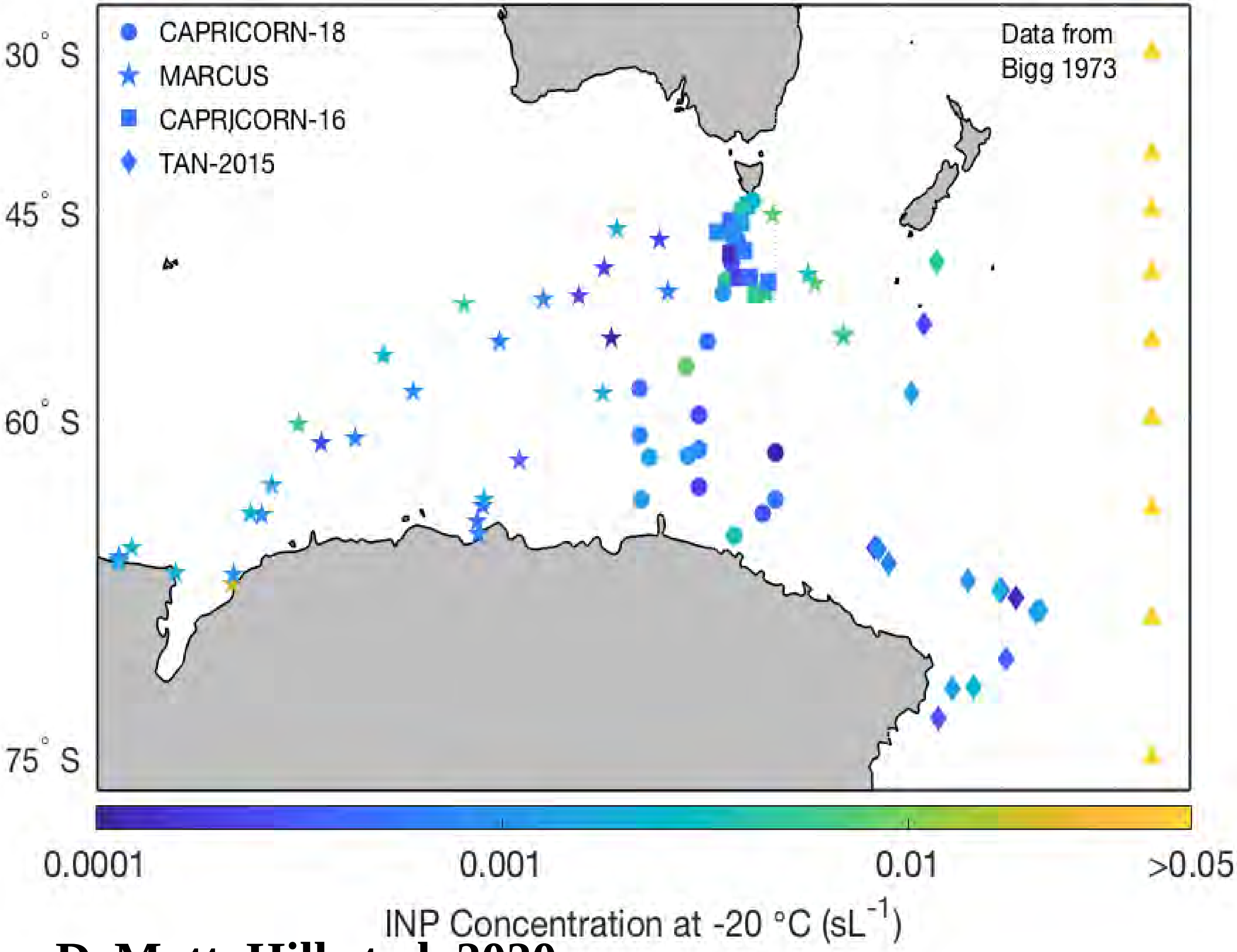
BL CCN: What controls number?



Sanchez et al. 2020

- Back trajectories performed to explain variability in CCN
  - Low CN/high CCN – southerlies influenced by Antarctic coastal biological productivity,
  - high CN/low CCN – westerlies characteristic of RPF low accumulation mode conctn.
  - High CN/high CCN – Similar as high CN/low CCN but with condensational growth of RPF to CCN sizes
  - Low CN/low CCN – aerosols scavenged by precipitation and lack RPF

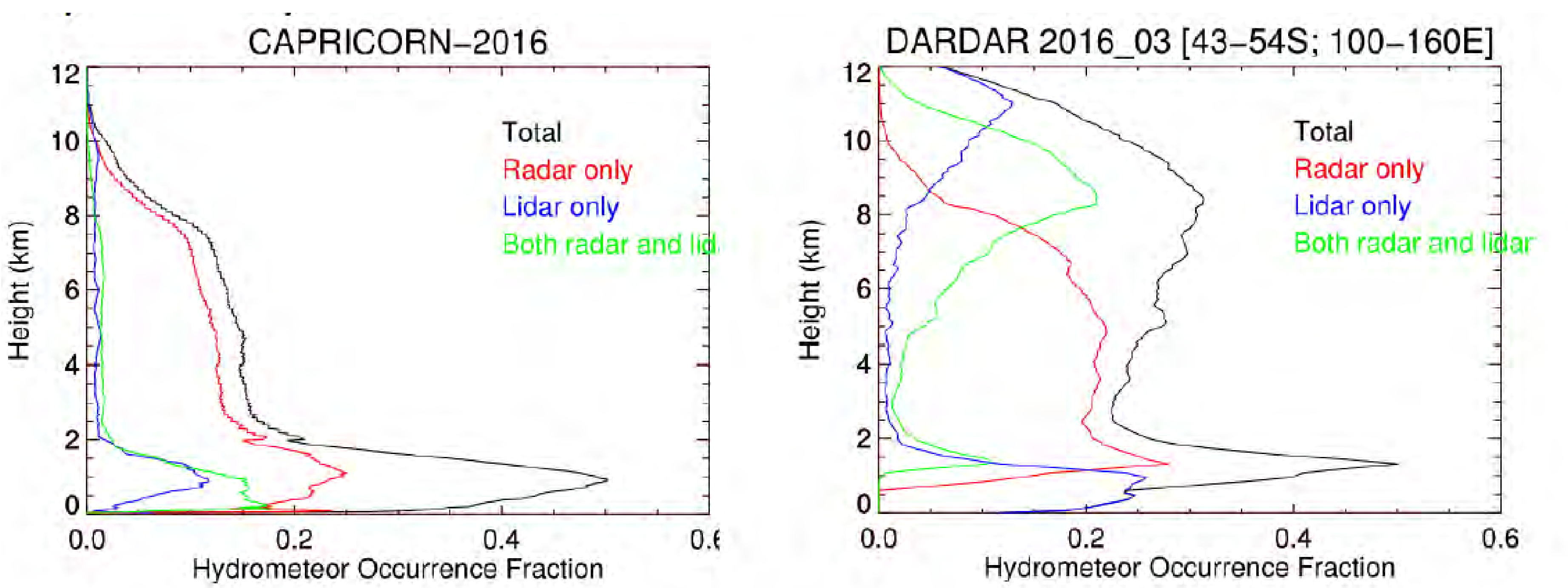
What are INP concentrations over SO?



DeMott, Hill et al. 2020

- INP concentrations at -20˚C collected by CSU IS measuring immersion freezing T spectra on bulk aerosol samples collected onto polycarbonate filters (pore size of 0.2 μm)
- Large variability, but generally low, INPC concentrations
- Weak overall dependence on latitude, with highest concentrations on land (especially towards Australia)

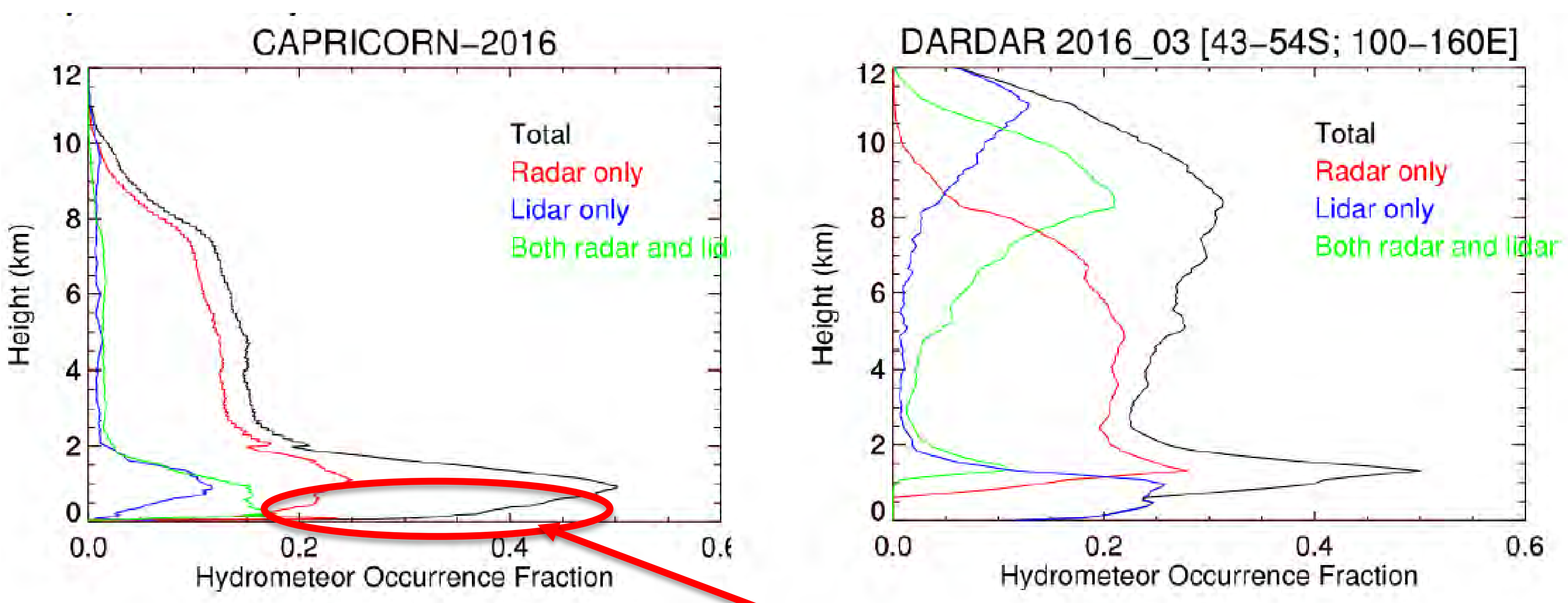
Clouds: Ship- and Ground-based Remote Sensing



Comparison of satellite & ship retrievals:

Alexander et al. 2020

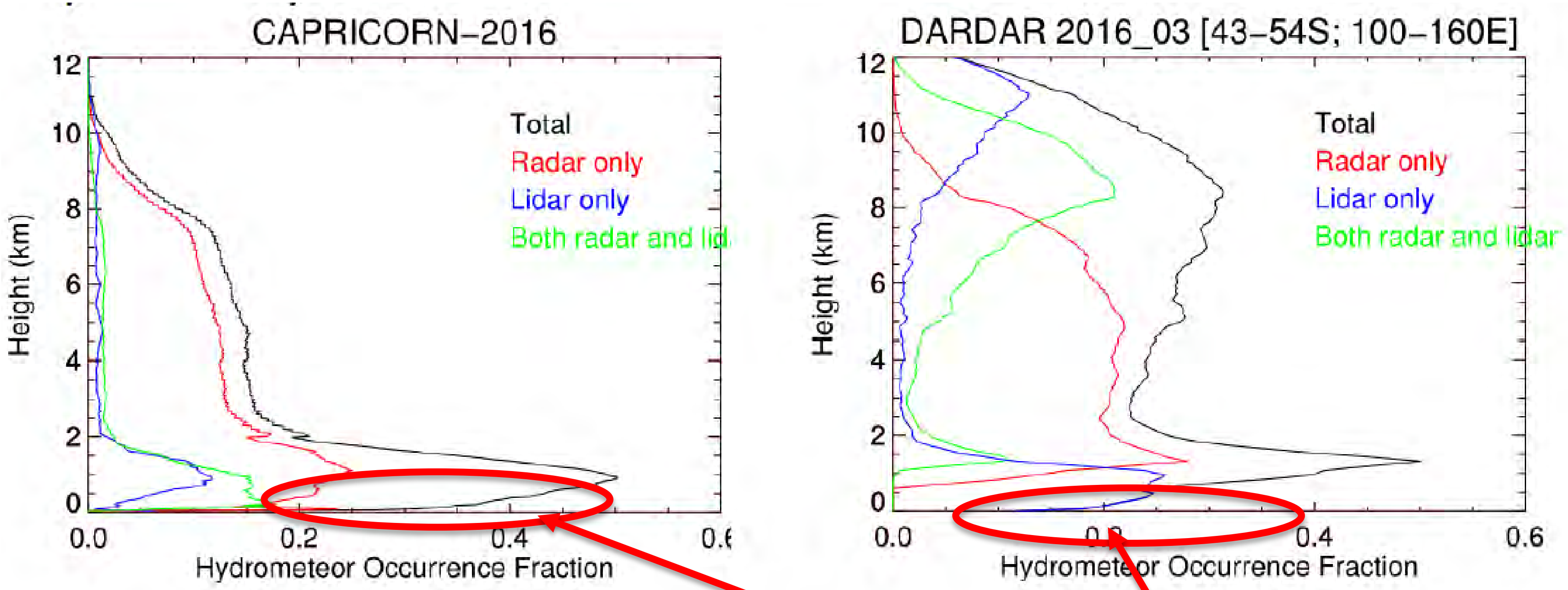
Clouds: Ship- and Ground-based Remote Sensing



Comparison of satellite & ship retrievals: **Ship-reported occurrence at 500 m**

Alexander et al. 2020

Clouds: Ship- and Ground-based Remote Sensing



Comparison of satellite & ship retrievals: **Ship-reported occurrence at 500 m is double that reported by satellite.**

Alexander et al. 2020

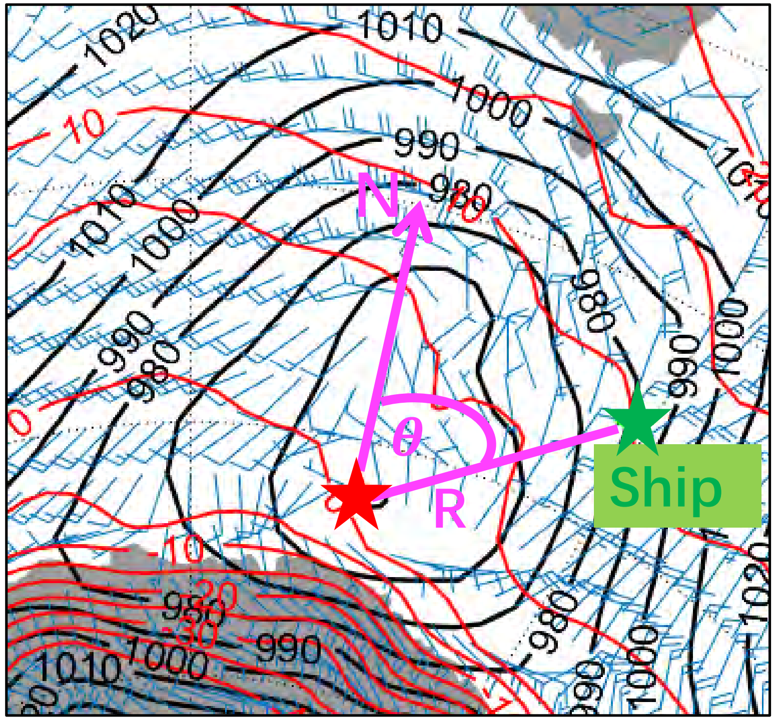
Clouds: Ship- and Ground-based Remote Sensing

- **Ding/McFarquhar VAP segregate data by environmental, geographic & meteorological conditions observed during MARCUS to identify controls of SLW**

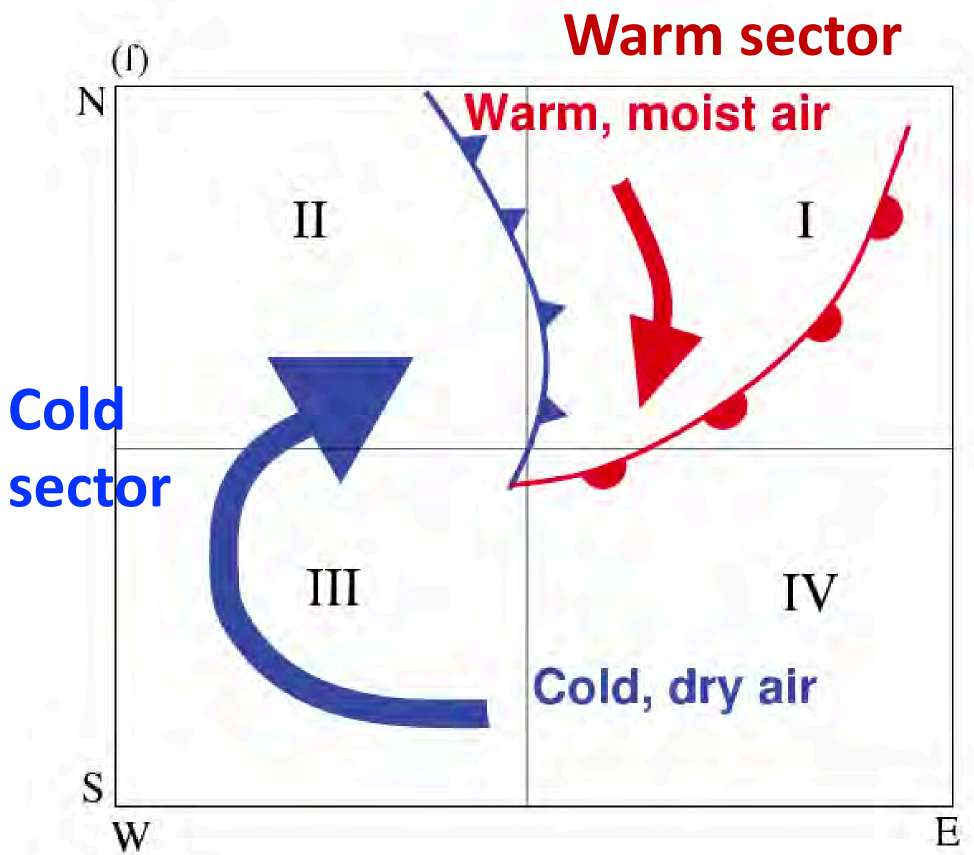
Variable	Source
Sea surface temperature (SST)	Infrared Thermometer
Cloud base temperature (CBT)	Cloud base height (CBH) from Ceilometer merged with T profiles from 6hourly sounding
Precipitating /non-precipitating clouds (PC/NPC)	Maximum column radar reflectivity dBZ_{max}>-15 dBZ is PC, -30<dBZ_{max} <-15dBZ is NPC (Huang et al., 2016)
Coupled /decoupled	$\triangle c_b$ = CBH – LCL, $\triangle c_b$ >300m is decoupled & $\triangle c_b$ <300m is coupled (Comstock et al., 2005)
North/ South of the ocean polar front (NPF/SPF)	Daily SST from AVHRR (Dong et al., 2006)
Air mass origin westerly/ easterly (W/E)	48hrs HYSPLIT back trajectory simulation
Location relative to cyclone	Sea level pressure (SLP)

4. Relative location in cyclone system

Conceptual models:

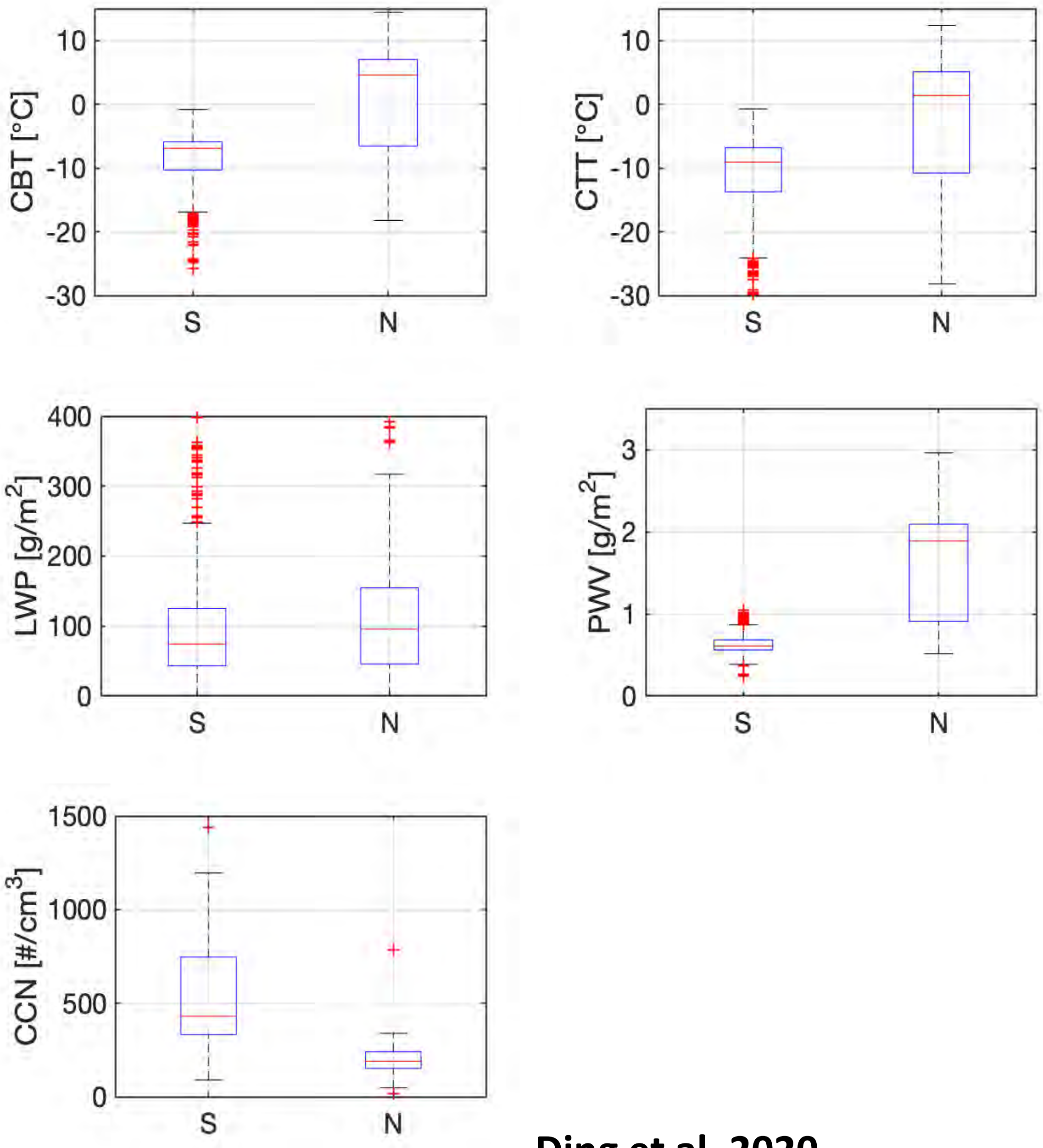


Ding et al. 2020



Bodas-Salcedo et al. (2016)
Lang et al. (2018)

Clouds: Ship- and Ground-based Remote Sensing



Ding et al. 2020

- How properties of single-layer, non-precipitating clouds with z_b < 3 km & > 500 km from nearest cyclone center varied whether north or south of 60˚S.

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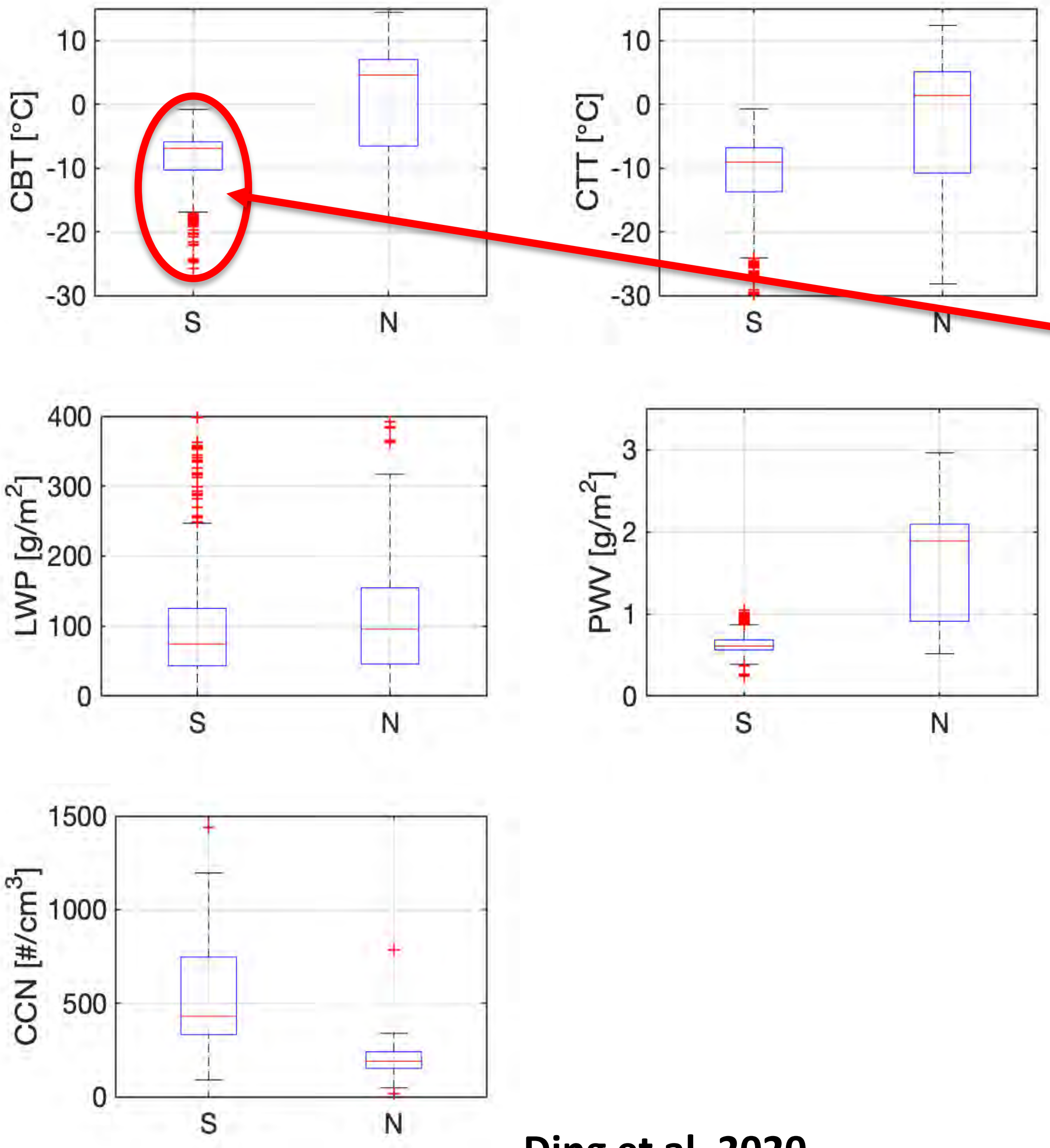

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- Average cloud base T ~ -10˚C S of 60˚S

Ding et al. 2020

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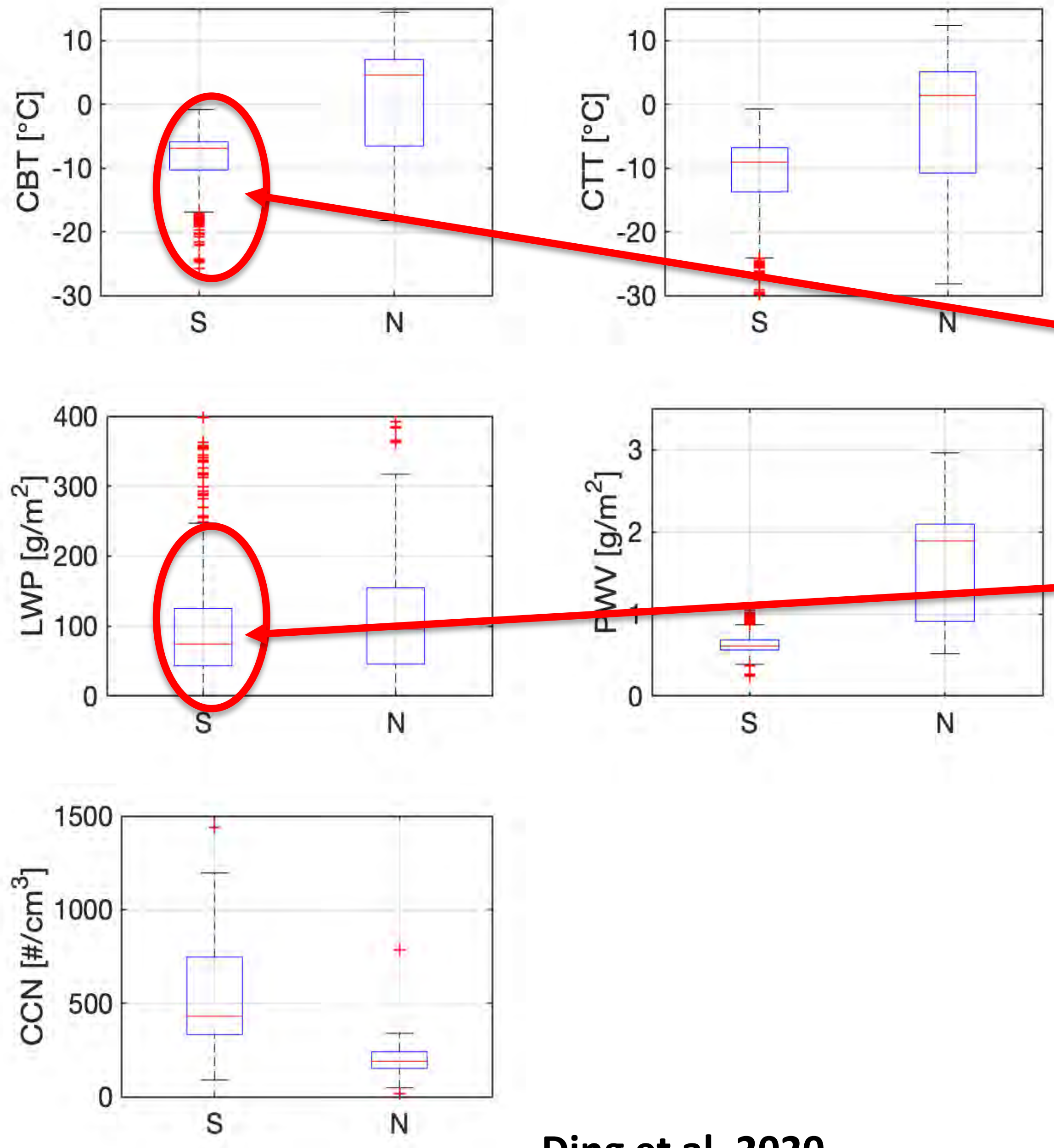

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  → SLW extensive south of polar front

Ding et al. 2020

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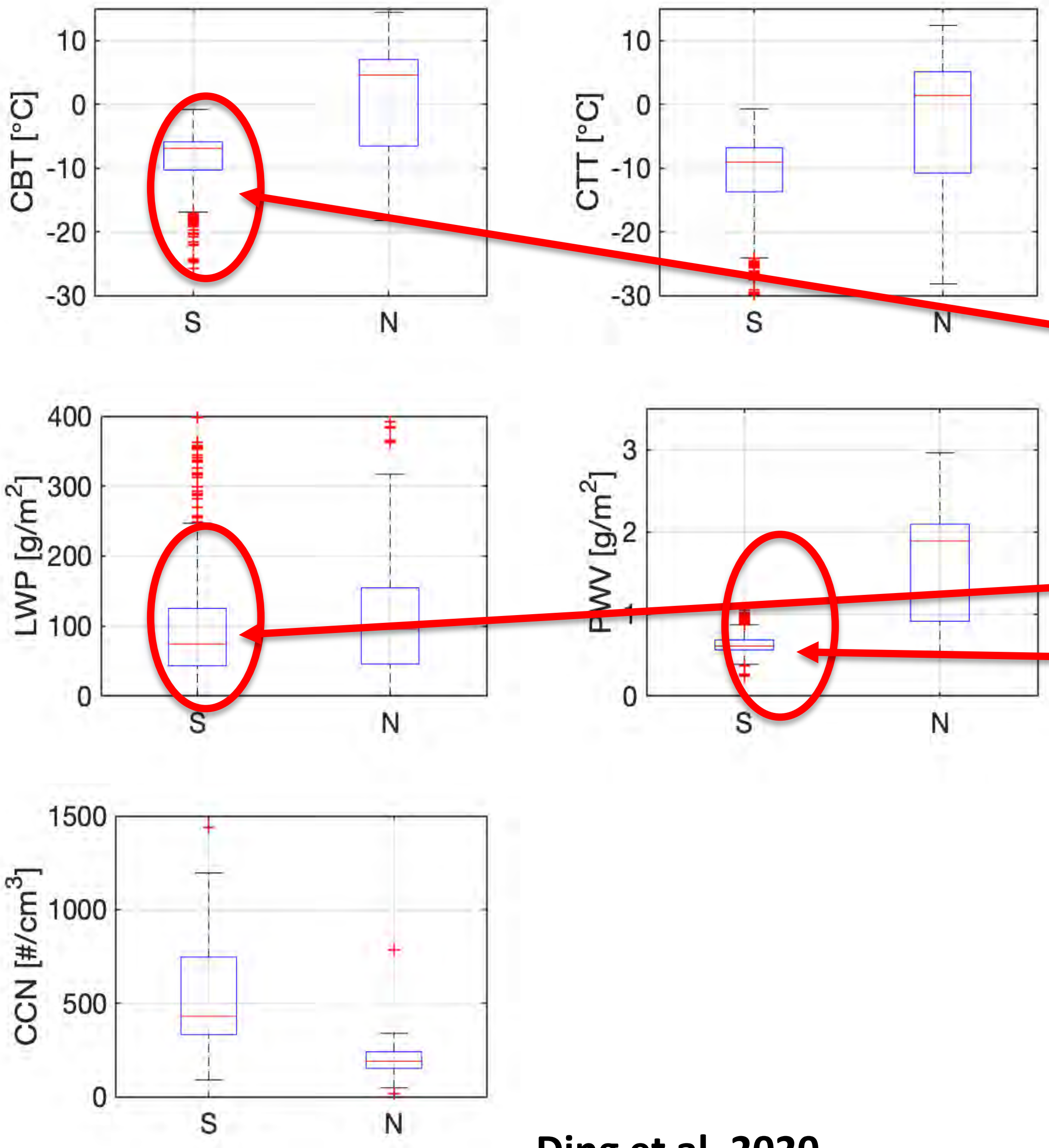

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Ding et al. 2020

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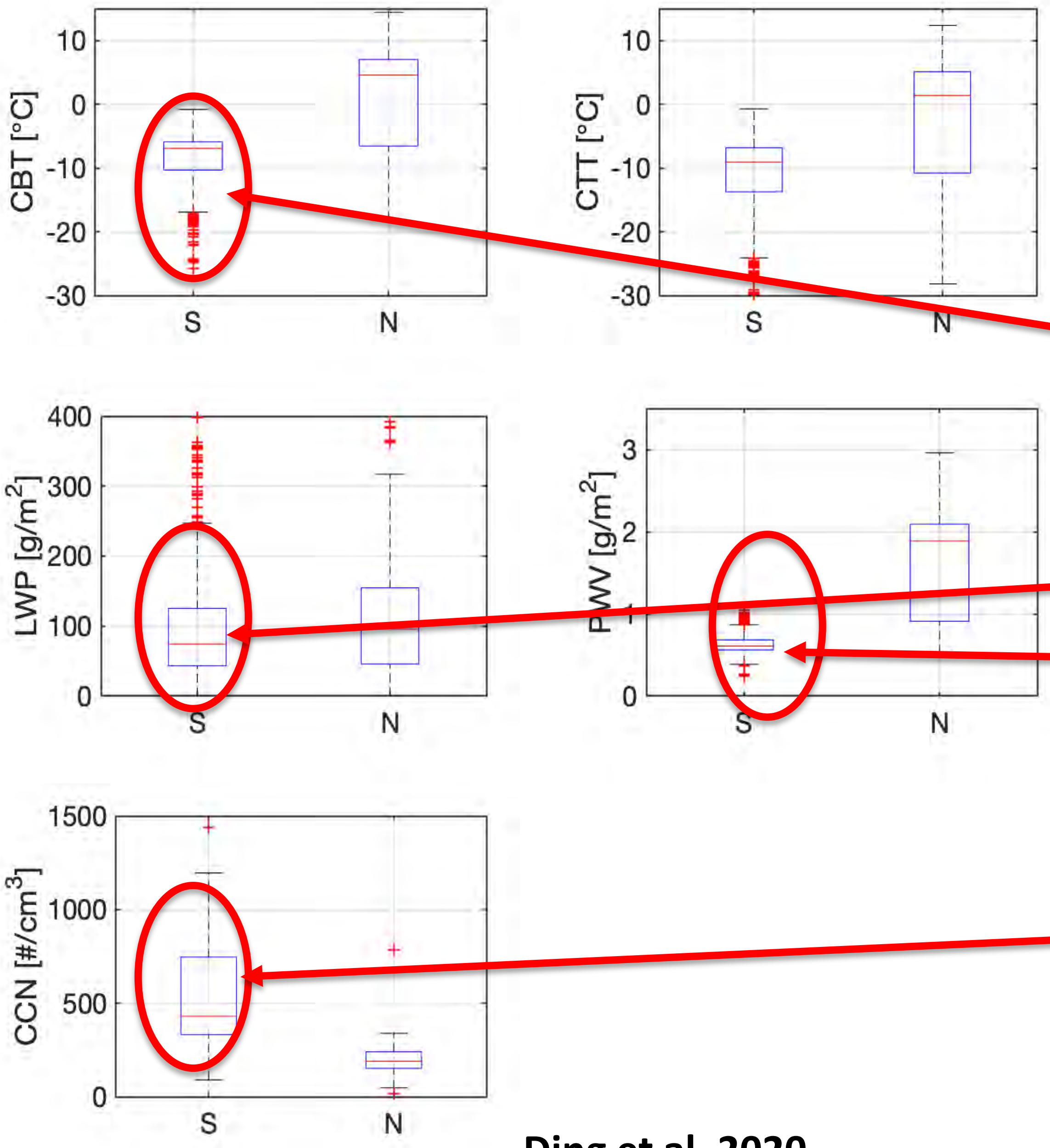

Ding et al. 2020

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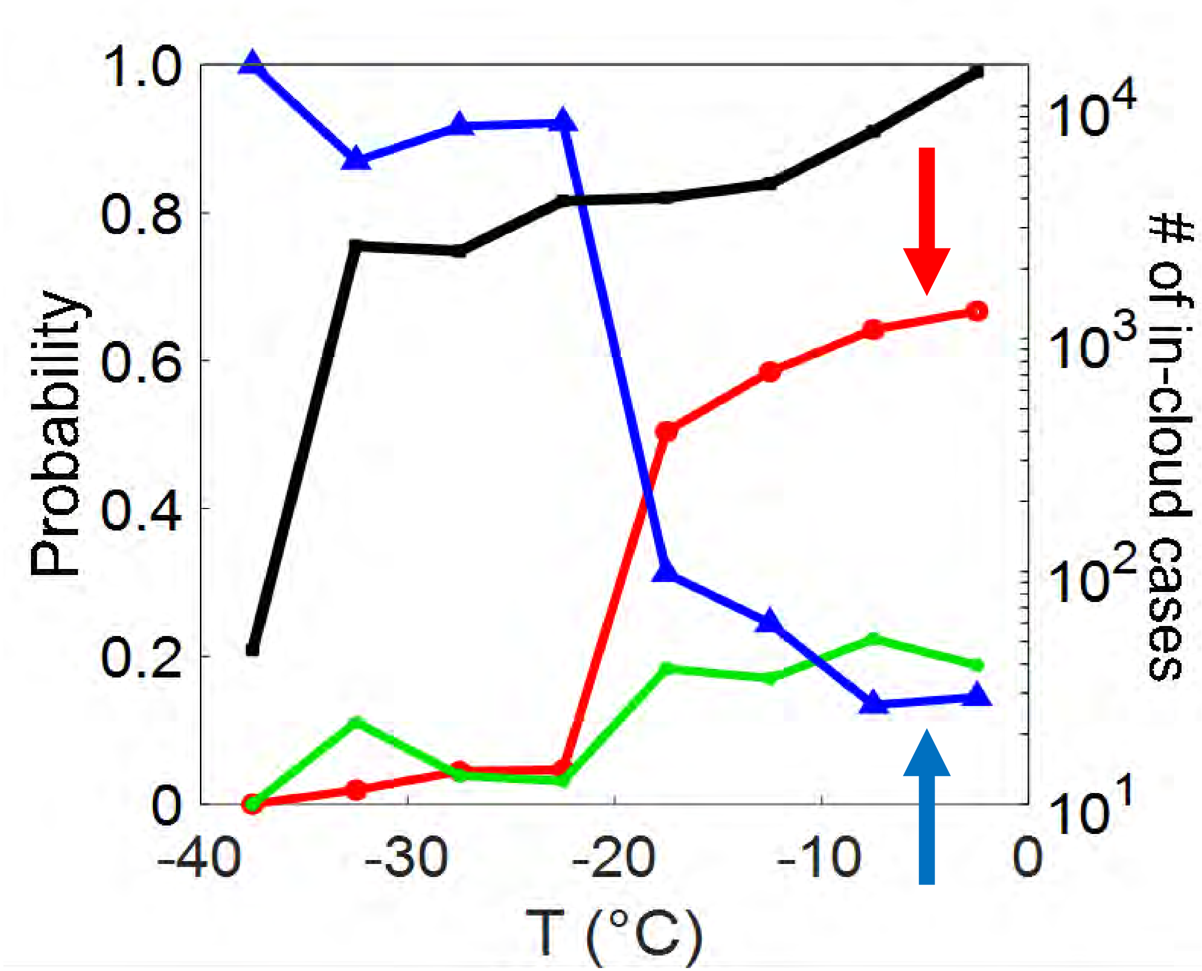
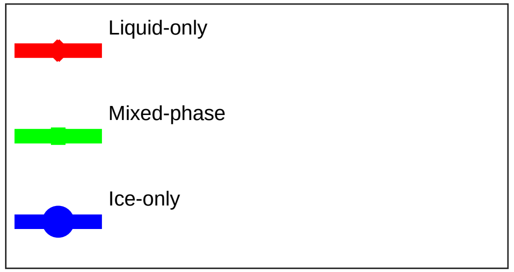
- Average cloud base T ~ -10˚C S of 60˚S → SLW extensive south of polar front even though less precipitable water
- CCN and retrieved N_c peaked in December and appear less south of 60˚S

Clouds: In-Situ Data and Process Studies

Relative phase occurrence frequency



Large frequency of SLW from -20° to 0°C
Ice-phase observed from -5° to 0°C



D'Alessandro et al. 2020

Summary

- Unique sets of data on SO clouds now available
  - 15 GV research flights
  - 4 voyages of Aurora Australis (spring, summer and fall)
  - 2 years of data at Macquarie Island
  - 2 cruises of R/V Investigator
- Initial findings
  - Pristine environment with numerous small and few large aerosols above cloud
    - → new particle formation & long-range transport from continents
  - Very few ice nucleating particles
  - High concentrations of aerosols over ocean where winds intense
  - Ubiquitous SLW in thin, multi-layer clouds with small-scale generating cells near cloud top
  - Variability of cloud properties and CCN associated with aerosols & meteorological conditions

Future

- **SOCRATES-II????**
  - **Alternate season: Explore observations in transition season where greater variability in blooms over course of project**
  - **Lagrangian rather than Eulerian experiment (try to trace how clouds evolve in subsequent flights)**
  - **Observations closer to Antarctic (suitcase flights to Antarctic?)**
  - **Two aircraft for coincident remote sensing/in-situ data**
  - **More comprehensive data on aerosol chemical properties**
  - **Holographic observations would have strengthened cloud data**