CAPI Teaming Discussion

- 3:15: Purpose of session - Turner / Ghan
- 3:20: Z. Li - Aerosol induced invigoration of deep convective clouds
- 3:30: G. McFarquhar - Cirrus Aerosol Shallow Cumuli Atmos Radiation Study (CAESARS)
- 3:40: G. Feingold - Precipitation Susceptibility
- 3:50: J-C Dupont - Fog studies
- 4:00: R. Wood - Cloud effects on aerosol properties
- 4:10: A. Fridlind - CCN vs IN controls on LWP in mixed-phase stratiform clouds
- 4:20: X. Liu - aerosol effects on ice nucleation and ice clouds
- 4:30: M. Ovchinnikov - ISDAC model intercomparison
- 4:40: I. Gultepe - Proposed experiment on polar ice clouds (PIC3)
- 4:50: S. Biraud - Water vapor isotopes to look at cloud / precip processes

Cloud-Aerosol-Precipitation Interactions (CAPI)

- Steve Ghan and Dave Turner, Co-chairs
- Steering group: Sally McFarlane, Ann Fridlind, Graham Feingold, Rob Wood, and Xiaohong Liu
- Web page: http://asr.science.energy.gov/science/working-groups/capi
  - Mission Statement
  - Objectives
  - List of Primary Questions that the WG is trying to answer

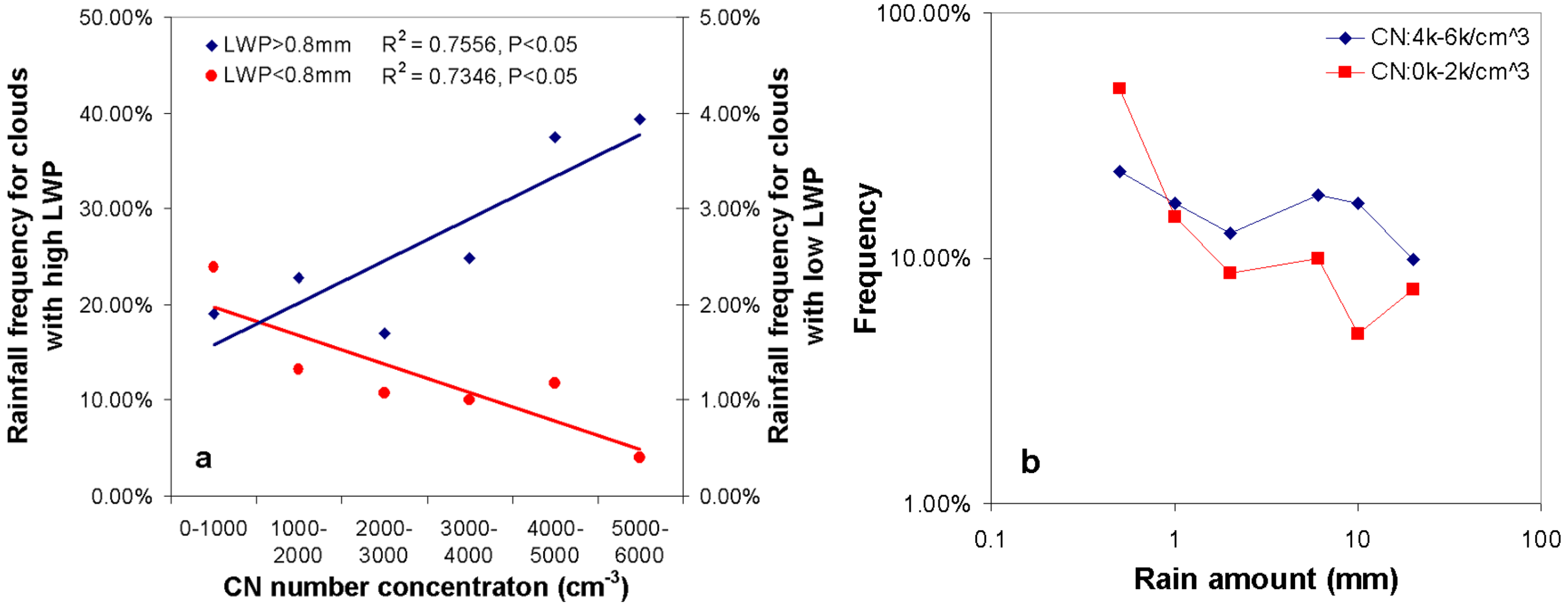
Li et al.

Aerosol induced invigoration of

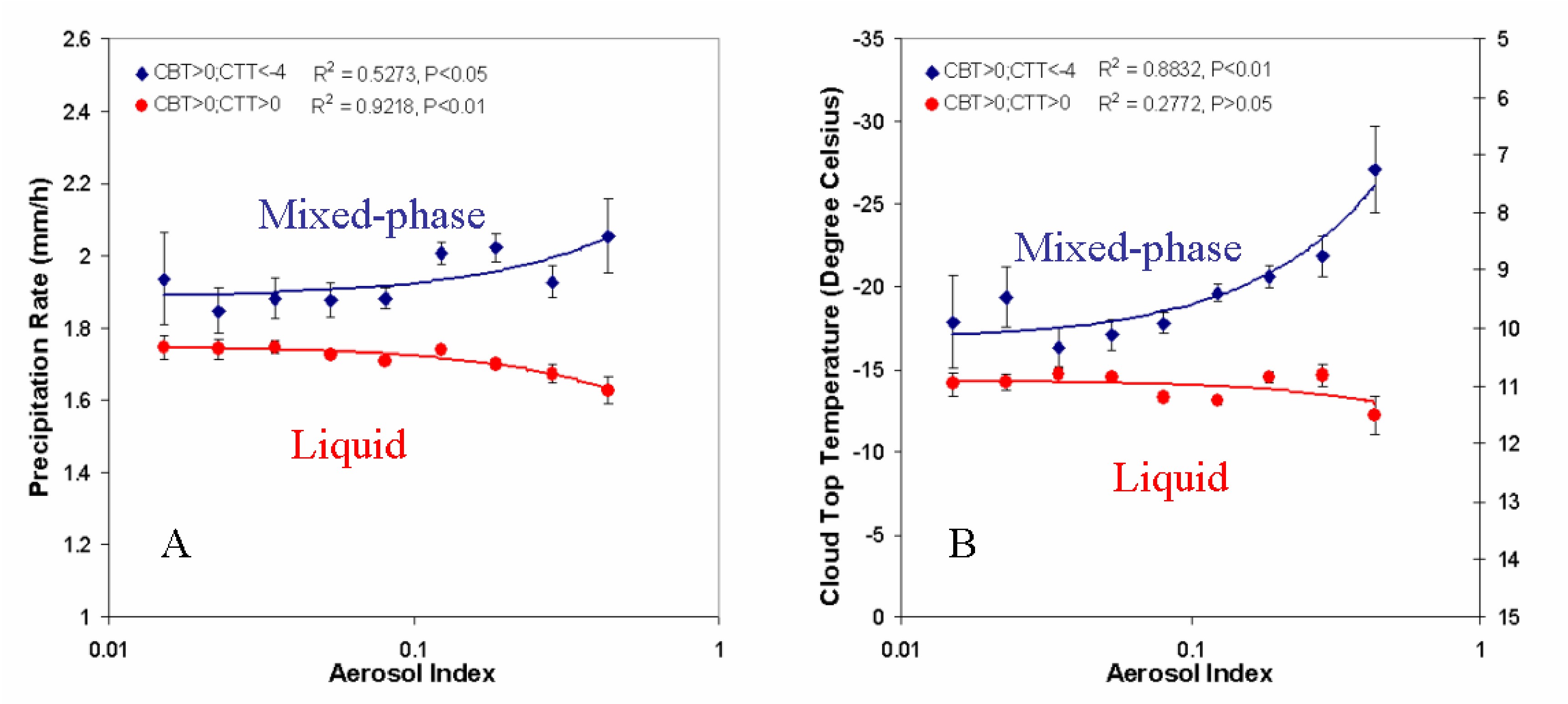
deep convective clouds

Detected two dominant modes of Aerosol Indirect Effects from 10-Year ARM

Influences on rainfall frequency and rain rate distribution



Detected two dominant modes of Aerosol Indirect Effects from A-Train Satellite



Tasks/Challenges for Modelers and Observers to Tackle the AIE

For modelers:

- Reproduce observed patterns for large ensemble simulations
  - Go beyond case-by-case studies
- Relative importance & frequency of occurrence for various mechanisms proposed
  - Go beyond isolated mechanism

For observers:

Critical measurements required to test various mechanisms

- Profiles of cloud phase
- Profiles LWC/IWC & latent heat
- Profiles of vertical wind
- Profiles of aerosol optical properties
- Profiles of cloud particle size

McFarquhar et al.

Cirrus Aerosol Shallow Cumuli

Atmospheric Radiation Study (CAESARS)

Cirrus AErosol Shallow cumuli Atmospheric Rad-iation Study (CAESARS)

McFarquhar, Mace, Jensen, Lawson, Mitchell, Liu, Ackerman, Muhlbauer, Um and ????

- Proposal to deploy AMF2 & AAF to area around Galapagos Islands, Ecuador (ship or island?)
- Goal: Collect long-term set of observations of cirrus & cumulus using in-situ & remote sensing platforms in eastern Pacific

Importance to CLWG/ASR

- Cirrus covers 20% of Earth
  - Balance between ir & solar radiative effects depends on microphysical & macrophysical properties
  - Controls of these properties must be determined
  - Need observations in undersampled regions (maritime Eastern Pacific)
- Boundary layer clouds have large radiative influence
  - Shallow cumuli ubiquitous over much of tropical oceans
  - Affect radiation, heat & moisture budget & circulations
  - Treatment in climate models demonstrably poor
  - Co-dependence on meteorology/aerosols poorly known
  - Little data because of remote oceanic location

Science Goals for CAESARS

1. Collect in-situ data on cloud microphysical & optical properties (cf. RACORO, SPARTICUS) in cirrus & shallow cumuli to aid in development/evaluation of retrieval algorithms.
2. Collect year-long data set of cirrus microphysical, thermodynamic & radiative properties in under-sampled region of maritime tropical environment (explore how large-scale dynamics & meteorology affects microphysical & macrophysical properties of cirrus)
3. Identify processes that influence formation, development & dissipation of shallow cumuli & evaluate factors that impact cloudiness, microphysical properties & diurnal cycles (including meteorology & aerosols)
4. Use in-situ & remote sensing data to develop parameterizations for cirrus & shallow cumuli & evaluate results of cloud resolving models & large-scale models

Feingold et al.

Precipitation Susceptibility

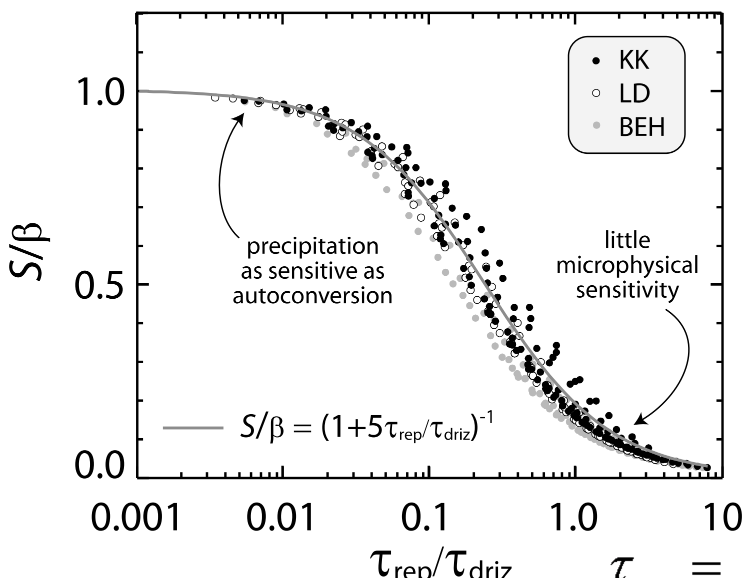
Precipitation Susceptibility

Hypothesis: Clouds within a limited range of conditions are susceptible to aerosol (vis-à-vis precipitation)

$$S_o = -\frac{d\ln R}{d\ln N}$$

R = rainrate

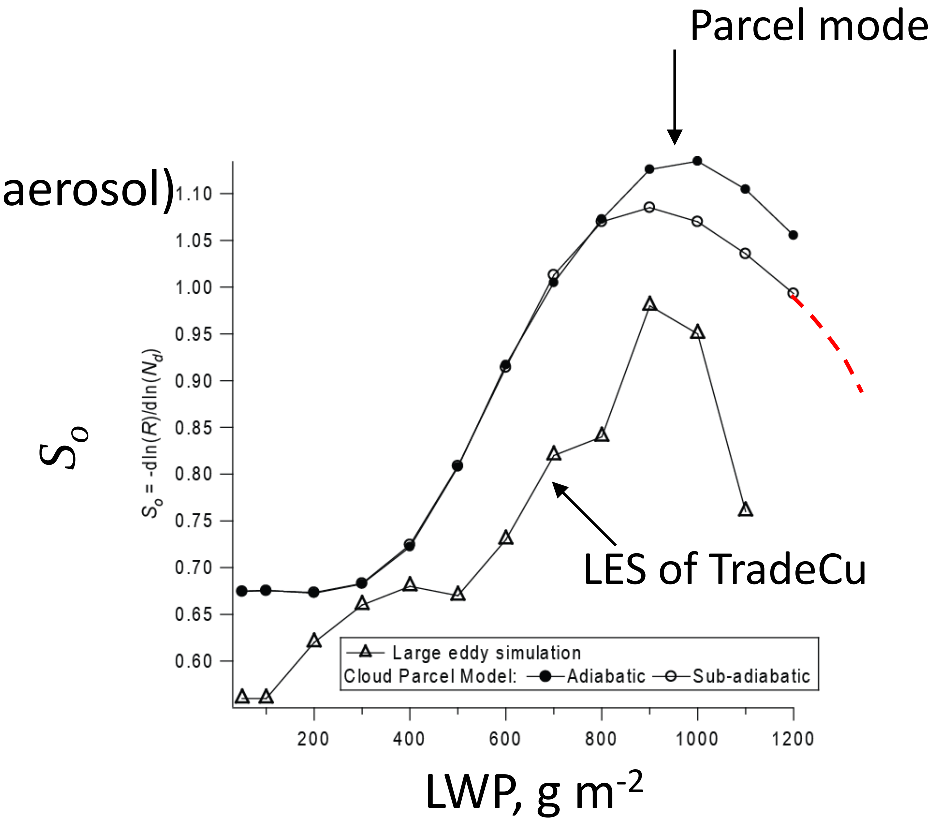
N = drop conc. (or aerosol)



τ_{rep} = replenishment time scale

τ_{driz} = drizzle time scale

Wood et al. 2009

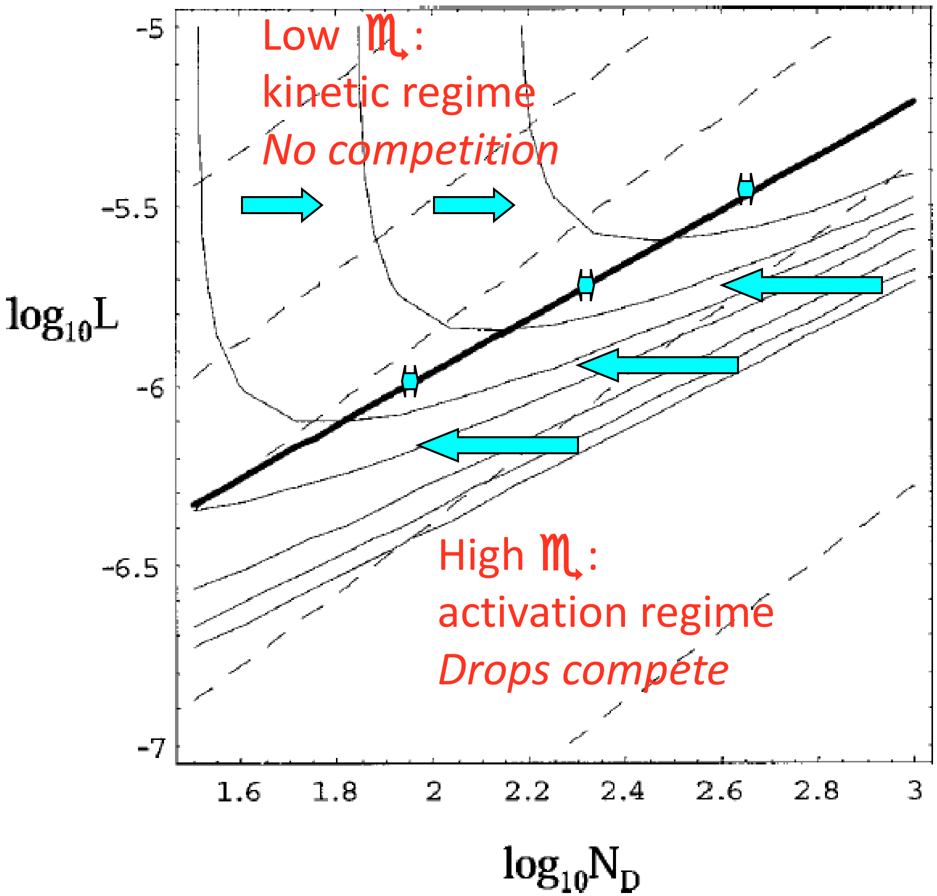


Feingold and Siebert 2009

Soorooshian et al. 2009

Nucleation Analog Robert McGraw (PRL 2003; 2004)

Contours of constant drizzle formation rate (radius 50 micron)



$$\left(\frac{\partial \ln J_{ss}}{\partial \ln N_D}\right)_L = \frac{9}{4} - \frac{v_c}{\bar{v}}$$

Arrows, point in direction of increasing rate depict sign and magnitude of the relative rate sensitivity

The thick line marks the cross-over boundary:

$$\varepsilon = \left(\frac{v_c}{\bar{v}}\right)^2 = \left(\frac{9}{4}\right)^2$$

$\bar{v} =$ mean cloud droplet volume

$v_c =$ critical cloud droplet volume

$N_D =$ cloud droplet number conc.

$J_{ss} =$ steady state drizzle rate (drops/cc-s)

$L =$ liquid water fraction

$\varepsilon = (v_c / \bar{v})^2$

Dupont et al.

Fog Studies

The Parisfog research program (2006, 2010-2013)

At SIRTA Observatory (France, 48.7°N – 2.2°E)

26 Oct. 2010

Jean-Charles DUPONT

IPSL/SIRTA
jean-charles.dupont@ipsl.polytechnique.fr

ASR Science team Meeting
CAPI Working group, March 31st, 2011

OBJECTIVES

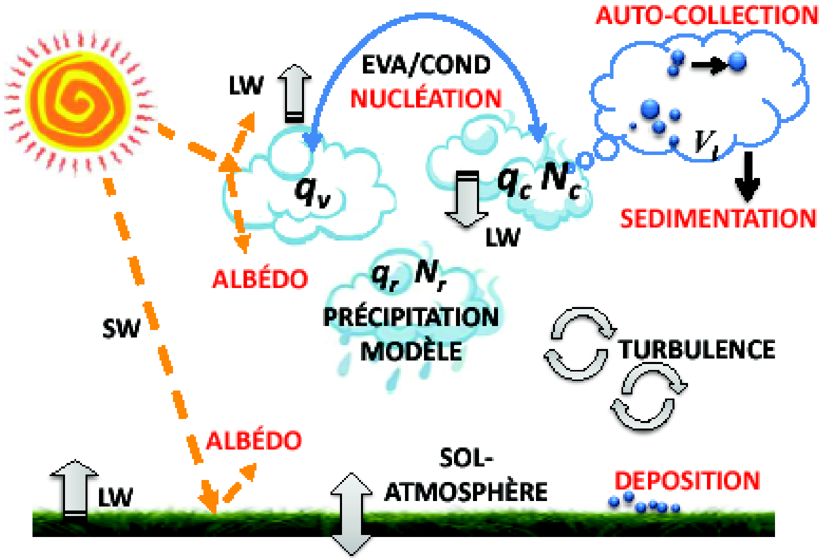
<u>Key science questions for FOG are</u>:

1. **How do competing** radiative, thermodynamic, microphysical, dynamical and chemical processes **interact with each other ?**

2. **Do key parameters** such as aerosol concentration, supersaturation, radiative cooling rates, turbulent mixing, **take on critical values to reach a particular balance that result in fog formation or dissipation ?**

3. **Is there a hierarchy in these processes**, or a single dominating process whose behavior must be better quantified ?

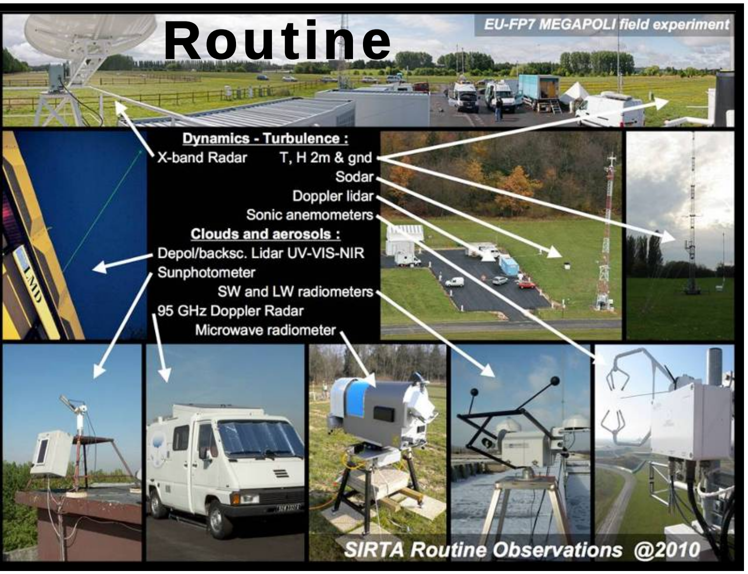
It relies on field experiments carried out at the SIRTA observatory to (1) monitor simultaneously all important processes and (2) sample a large range of conditions during several winter seasons (2006 to 2013).



INSTRUMENTS

SITE INSTRUMENTAL DE RECHERCHE PAR TÉLÉDÉTECTION ATMOSPHÉRIQUE

Sciences de l'environnement Institut Pierre Simon Laplace

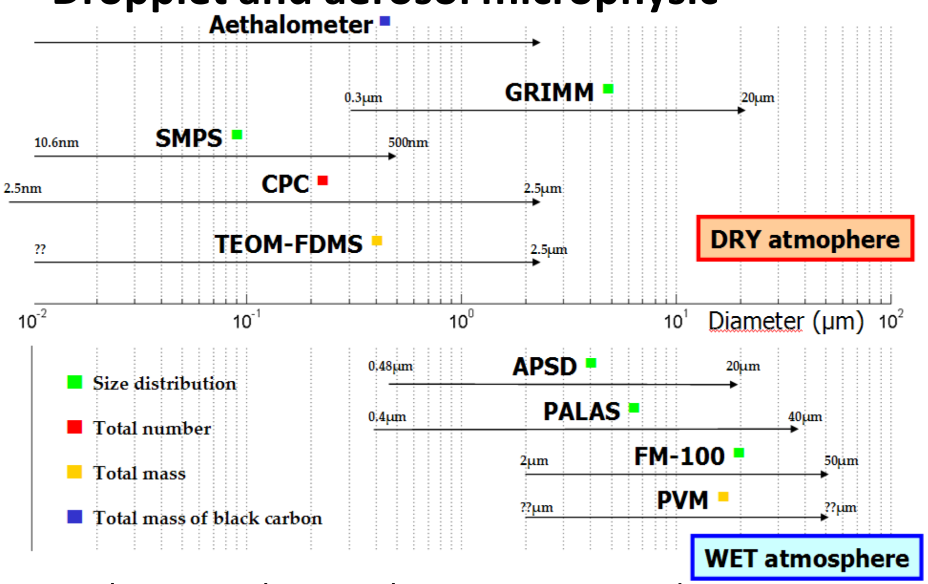


A 6-month IOP

Additionnal instruments

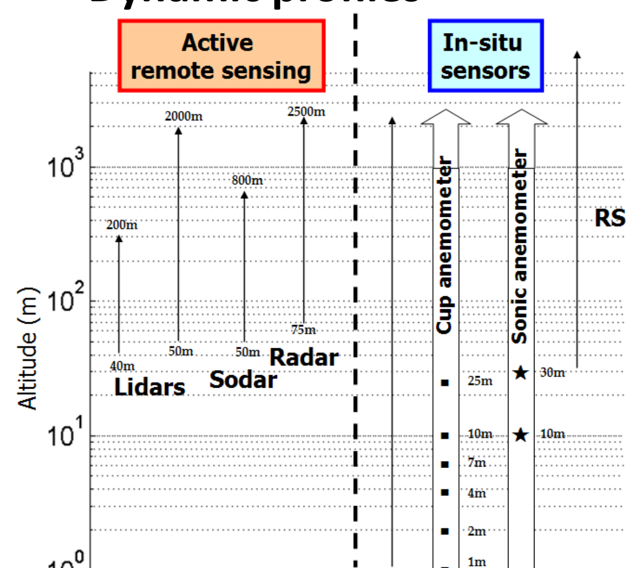
TYPE	MEASURE	INSTRUMENT	LAB & LOCATION
Lidars	Atmospheric dynamic	Wind lidar WLS7, v2	CEREA, Z1
		Wind lidar WLS70	CEREA, Z1
In-situ sensors	Aerosol and droplet distribution	CPC	CNRM, Z1
		TSI SMPS	CNRM, Z1
		DMT APSD	CCA, Z1
		Grimm OPC	LSCE, Z1
		CCNC-100	CNRM, Z1
		PALAS WELAS-2000	CNRM, Z1
		DMT FM100	CNRM, Z1
	Fog water content	Gerber-PVM	CNRM, Z1
	Scattering and absorption	Aethalometer at 7 wave-lengths	LSCE, Z1
	Mass concentration	PM2.5 TEOM-FDMS	LSCE, Z1

Dropplet and aerosol microphysic



Complete granulometry between 10nm and 50µm

Dynamic profiles

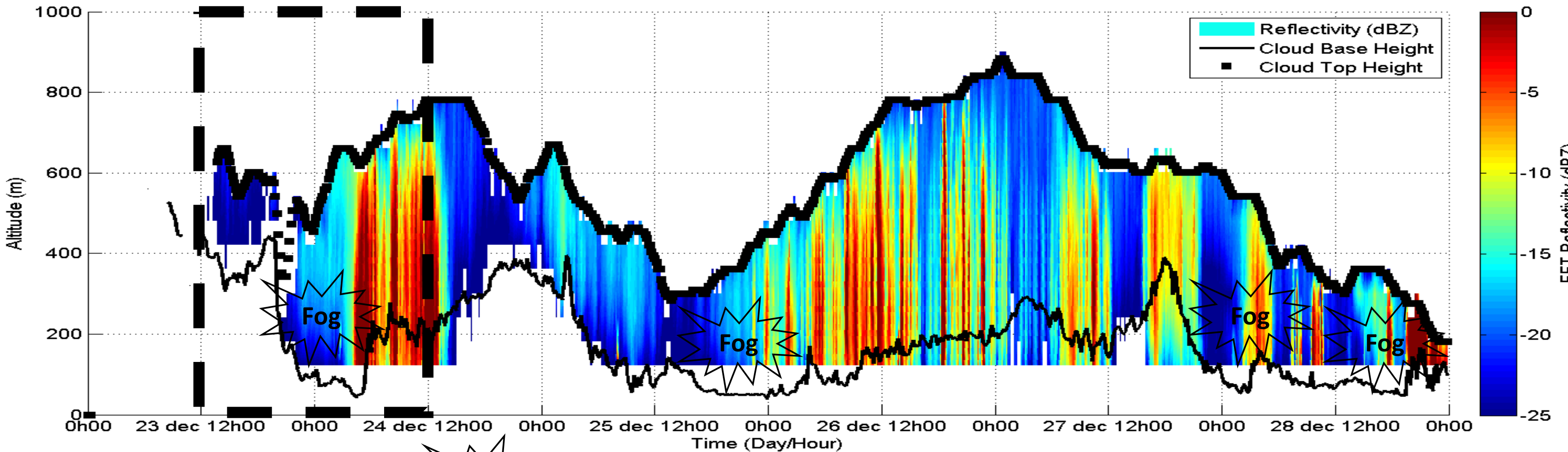


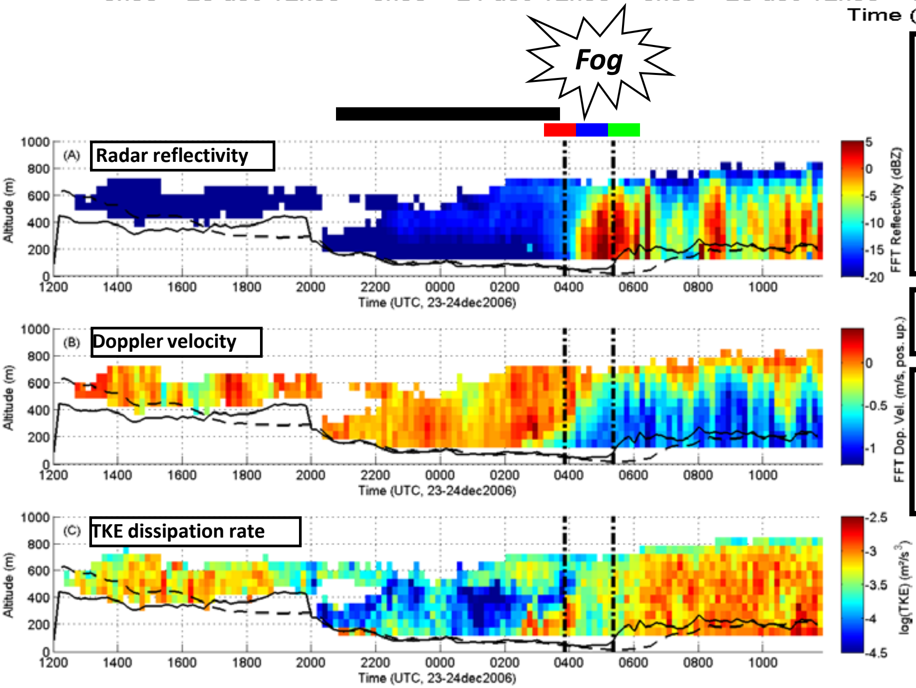
Complete dynamic profile between surface and 2500m

SIRTA
SITE INSTRUMENTAL DE RECHERCHE PAR TÉLÉDÉTECTION ATMOSPHÉRIQUE

FIRST RESULTS
(Process study)

Sciences de l'environnement
Institut Pierre Simon Laplace





Top LW cooling
(-160W/m²)
Top droplet growth
(Z~-15dBZ)
Low sedimentation
(~0m/s)

Evaporate cooling inside clouds

Lowering stratus until the surface
(Homogenous mixing)
Fog formation

Incloud droplet growth
(Z~-8dBZ)
Increase fall velocity
(-0.8m/s)

Droplet fall on the ground
+ limitated LW cooling at cloud top
(inversion of the Z vertical gradient)
Decrease of the LWC

Lifting stratus
(inhomogenous mixing)
Fog dissipation

Wood et al.

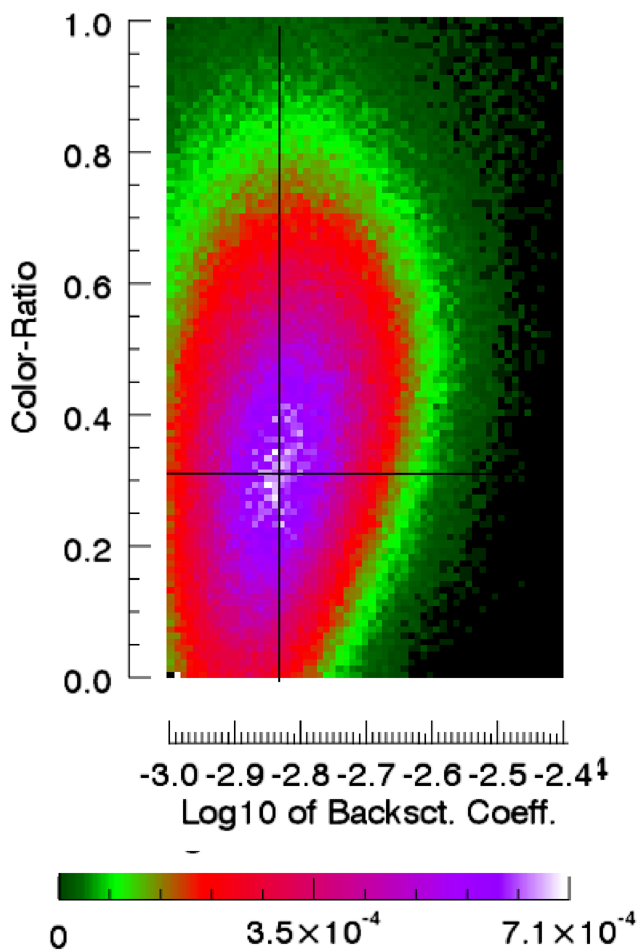
Cloud effects on aerosol properties

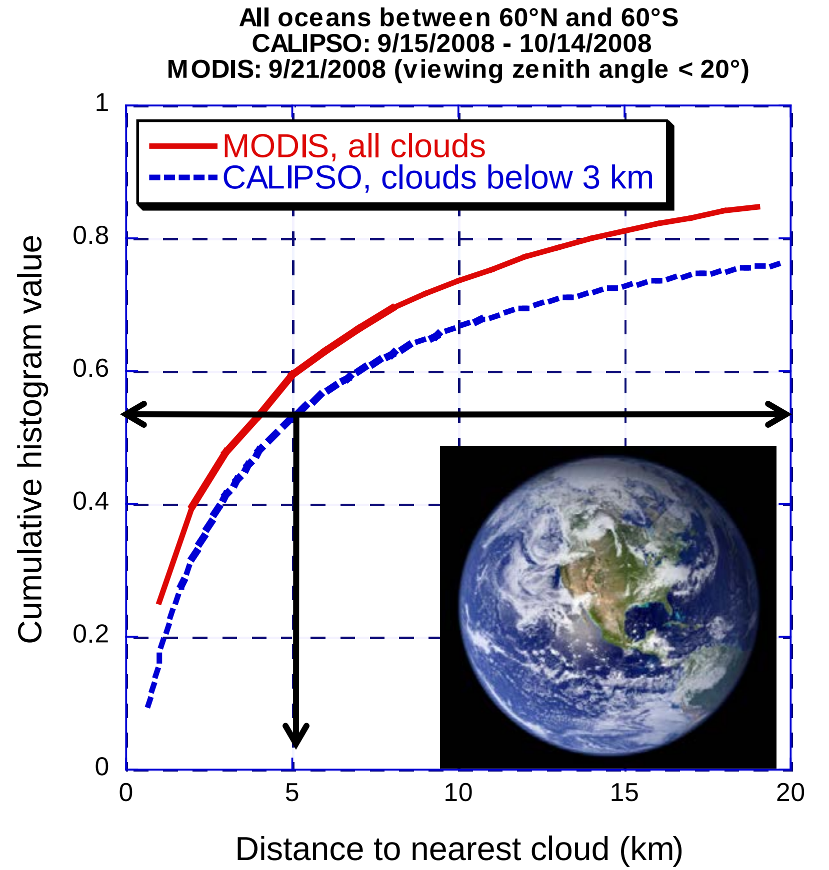
Cloud effects on aerosol: The challenges

- Clouds exert major influences on the physical, chemical and optical properties of aerosols.
  - a large fraction of aerosol mass (including possibly SOA) is produced in clouds via aqueous phase processes. Many of these processes are not well understood and represented in models.
- Clouds, via precipitation formation, are the primary sink for cloud condensation nuclei and a major sink of nucleation mode aerosol
  - true even in environments with very low precipitation rates, e.g. marine stratocumulus. The effects on aerosols are not well quantified globally and obfuscate conclusions drawn from aerosol-cloud correlative studies
- The presence of clouds makes it challenging to learn about aerosol properties via remote sensing
  - clouds exist in anomalously humid microenvironments and aerosol radiative properties close to them will differ from those at far-field. Poses challenges for interpretation of aerosol-cloud property correlations.

Cloud impacts on aerosol remote sensing

Near clouds / Far from clouds





from **MODIS**: 60% of all clear sky pixels are located 5 km or less from all clouds

from **CALIPSO**: 50% of all clear sky pixels are located 5 km or less from low clouds

Cloud effects on aerosol: ASR Opportunities

- In-situ observations
  - state-of-the-art physicochemical aerosol measurement technology within ASR program to examine chemical and physical signatures of cloud processing
  - Airborne platforms, new CVI on G-1.
- Remote sensing
  - ARM remote sensing Facilities (e.g. new HSRLs) provide remote sensing data on the cloud-clear sky boundary at much higher spatial resolution than is typically available from space
  - Precipitation radars can help quantify aerosol loss rates in a variety of environments
- Modeling
  - Process scale modeling to examine aerosol processing rates in clouds (e.g. explicit microphysics LES coupled with chemistry)
  - WRF-Chem, CAM, and MMF models for regional and global assessment

Fridlind et al.

CCN vs IN controls on LWP in mixed-phase stratiform clouds

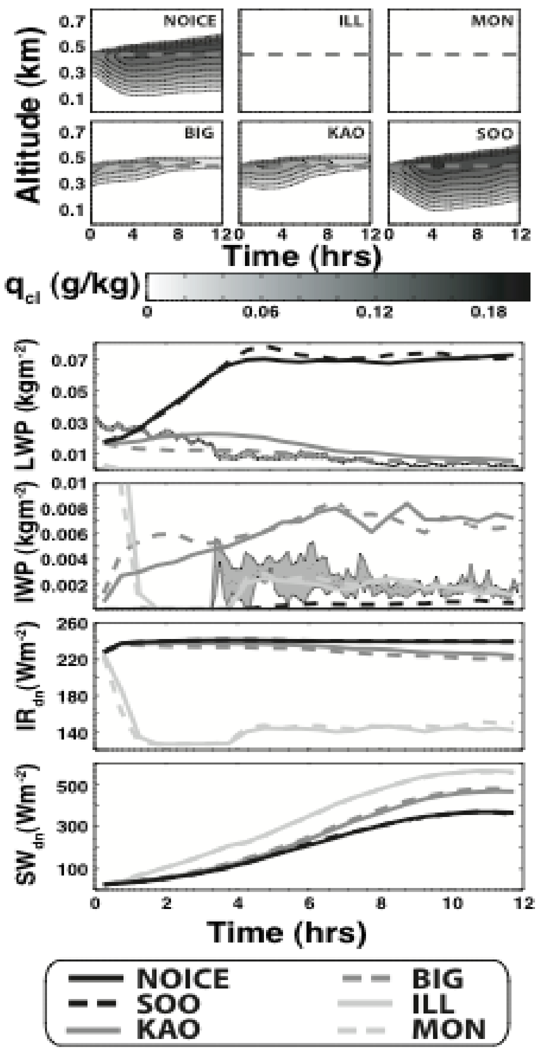
CCN versus IN control on LWP (and thus radiative impacts) of mixed-phase stratiform clouds in the Arctic

Ann Fridlind, NASA GISS

Gijs de Boer, LBNL

Andy Ackerman, NASA GISS

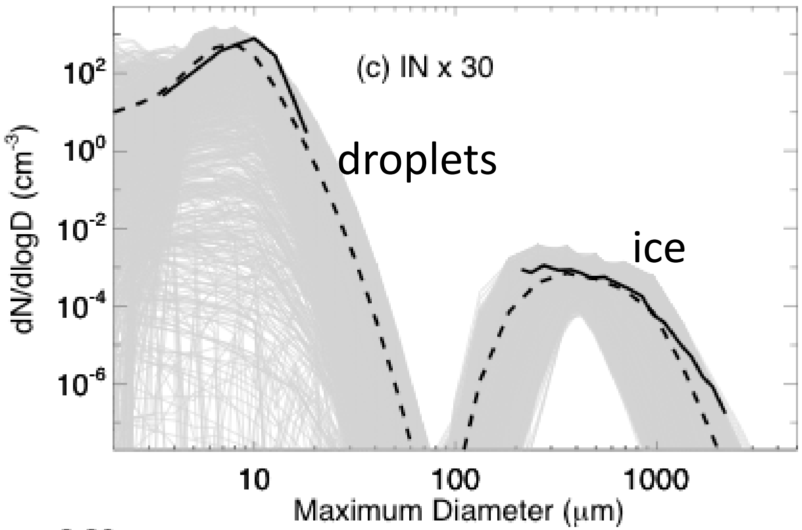
Immersion Freezing Example from SHEBA case study



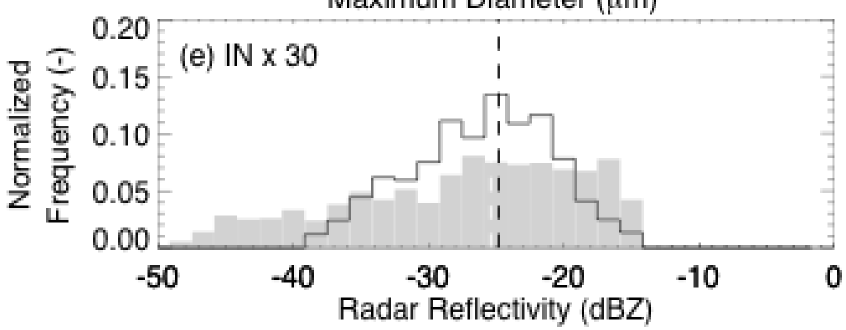
(de Boer et al., 2011)

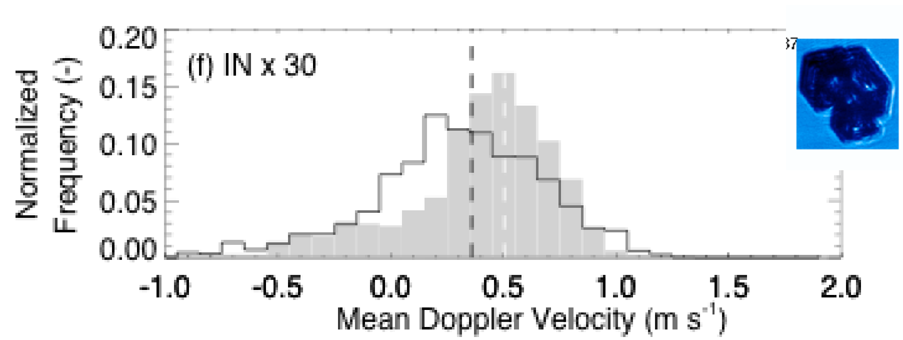
- Numerical study shows changing insoluble mass component of CCN has large impact on cloud lifecycle as governed by immersion freezing
- Cloud water eliminated very rapidly when assuming aerosol composition with high freezing efficiency (e.g. Illite, Montmorillonite)
- Wide variability surrounding often used Bigg parameterization based on insoluble mass type
- These impacts control surface short- and longwave radiation via LWP
- Second order effects from soluble mass fraction and aerosol concentration shown
- What about other ice nucleation mechanisms??

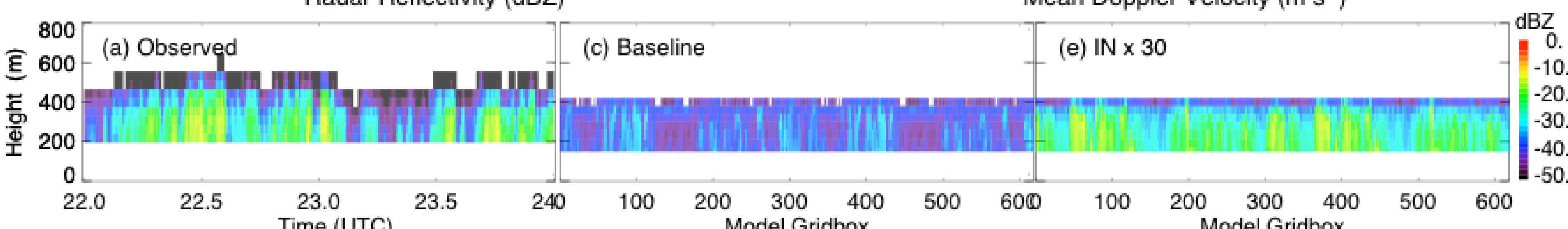
IN–N_{ice} closure: SHEBA ✗



- diagnostic treatment of 1.7/L IN overestimates ice formation in BL clouds
- steady-state solution for rapidly activated IN is $N_{ice} = w_e/v_f\ N_{IN} \approx 0.01\ N_{IN}$
- requires 30X more IN than estimated from measurements to explain ice, but horizontal variability still not explained

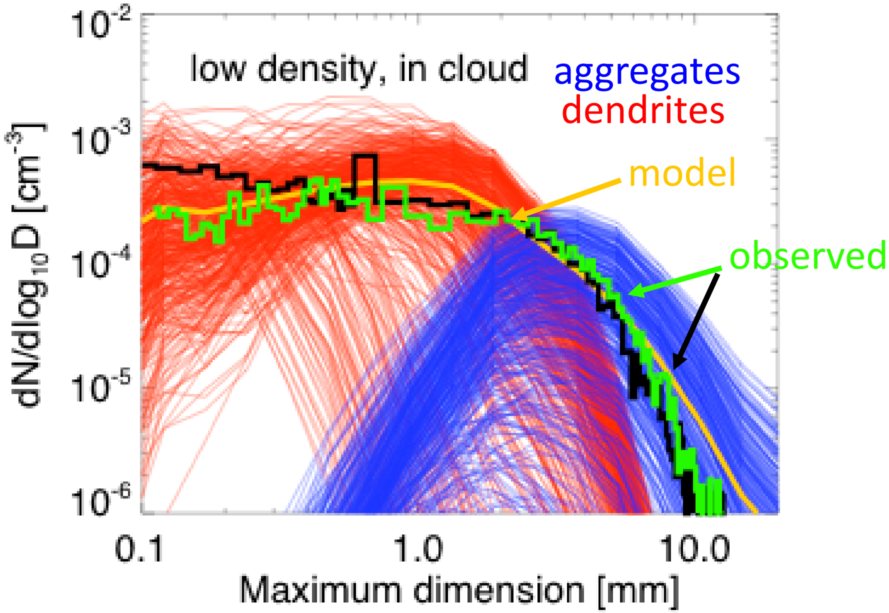




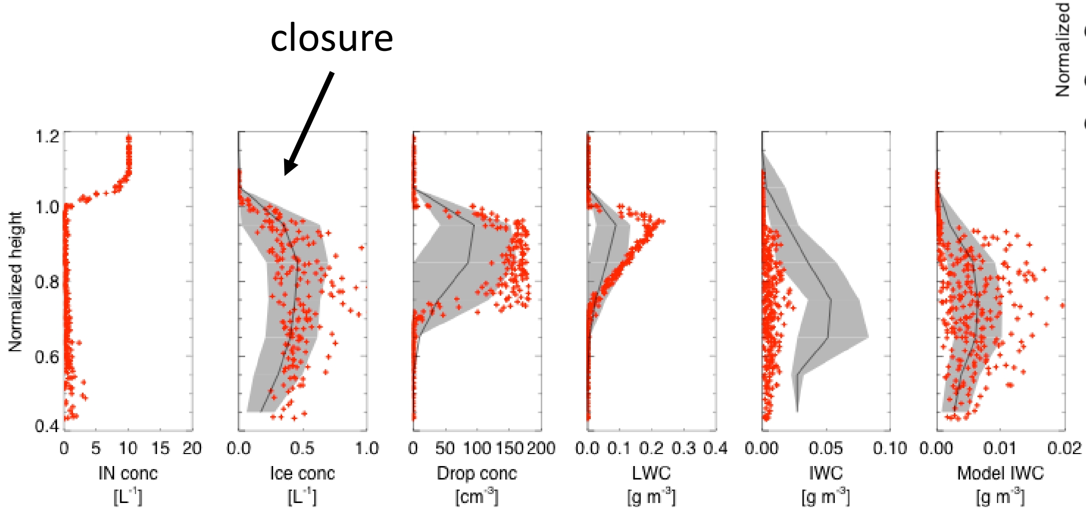


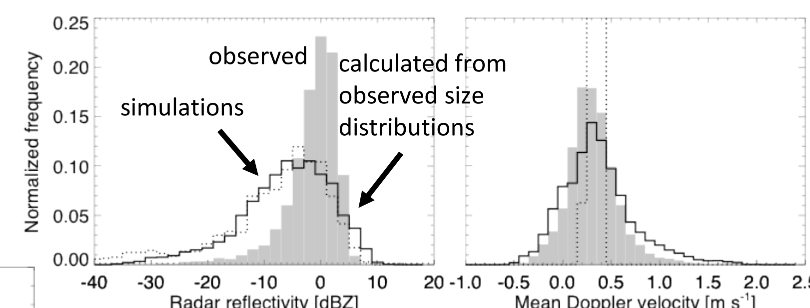
(Fridlind et al., submitted to JAS, 2011)

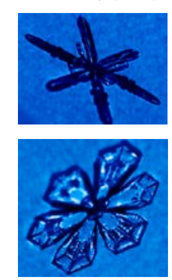
IN–N_{ice} closure: ISDAC ✔



- prognostic treatment of 10/L IN can explain observed N_{ice} concentration (!)
- no pronounced horizontal variability
- but ice *mass* closure is sensitive to unconstrained assumptions about ice particle properties (mass–D_{max}–A_{proj}–v_f relations) with spread of habit classes seen







(Avramov et al., submitted to JGR, 2011)

What is generally known

- increasing CCN in warm clouds
  - $N_{droplets}$ ↑
  - cloud droplet sedimentation and drizzle ↓
  - albedo and emittance ↑ or possibly neutral
  - LWP ↑ or ↓ depending upon Δw_e and overlying humidity
- liquid influence on surface radiative fluxes dominates that of ice (based on observed cases)
- but IWP modulates LWP (sedimentation sink)
- sensitivity of IWP to IN depends on ice and environmental properties (e.g., habit, fall speed, updraft velocity, RH)

What is generally not known

- what is the spatiotemporal co-variability of CCN and IN?
- how much overlap is there between CCN and IN via droplet freezing (activation in immersion mode)? What is the composition of those mixed particles?
- what are the details of IN activity spectra as f(T, S, dilution)?
- what microphysical processes are most important regionally and climatologically?
  - droplet and ice nucleation, ice aggregation, drizzle, riming, ice multiplication
  - spring (low LWP, higher CCN and IN) versus autumn (high LWP, lower CCN and IN)
- what is the dynamical coupling with microphysics?
- can models reproduce basic features of observed case studies within uncertainty bounds?
- are there any significant surface sources of IN?

An ASR focus area: Why + how

- long-term Arctic site with surface radiation measurements and soundings (NSA)
- excellent for complex boundary-layer processes
- history of Arctic IOP field programs measuring cloud properties, IN and (some) CCN: SHEBA, M-PACE, ISDAC
- programmatic focus on aerosol-cloud-radiation interactions
- expected impact of gas-to-particle conversion processes and aerosol/IN aging
- relevant to understanding rapid Arctic climate change
- policy relevance wrt regional emissions control strategies
- accurate incorporation of aerosol modules into GCMs requires understanding of global aerosol-cloud processes
- good challenge (hard, will lead to advances)

- generate short consensus position documents identifying outstanding problems and promising programmatic approaches, particularly as applied to GCMs, CRMs
- identify high-priority retrieval products
- identify high-priority instrument development efforts (e.g., IN activity, IN > 1 micron, CCN/IN composition)
- advocate for IOP field programs and development of relevant VAPs (from long-term data sets)

Liu et al

Aerosol effects on ice nucleation

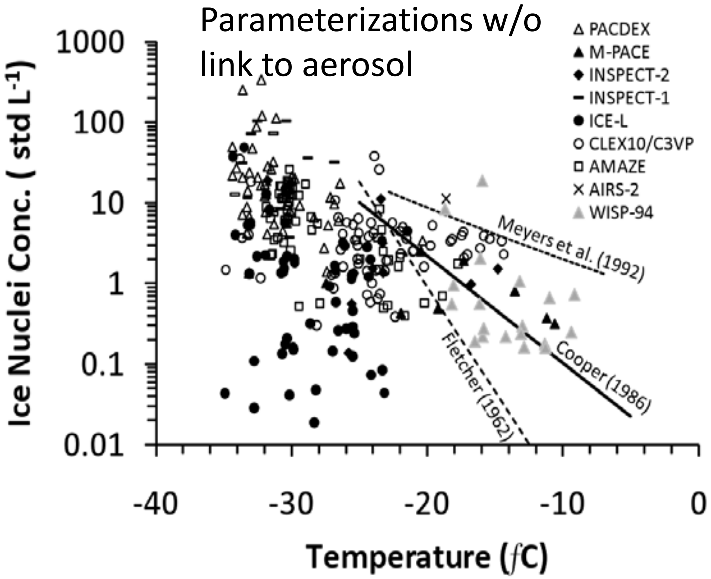
and ice clouds

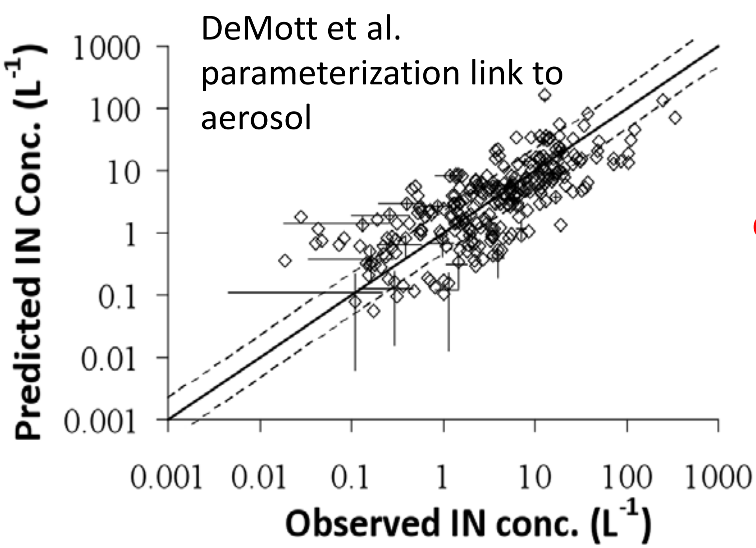
Aerosol – Ice Nucleation – Cloud Ice

X. Liu, P. DeMott, Z. Wang, G. de Boer

Challenges in modeling ice generation in ice and mixed-phase clouds

Parameterized vs. observed IN

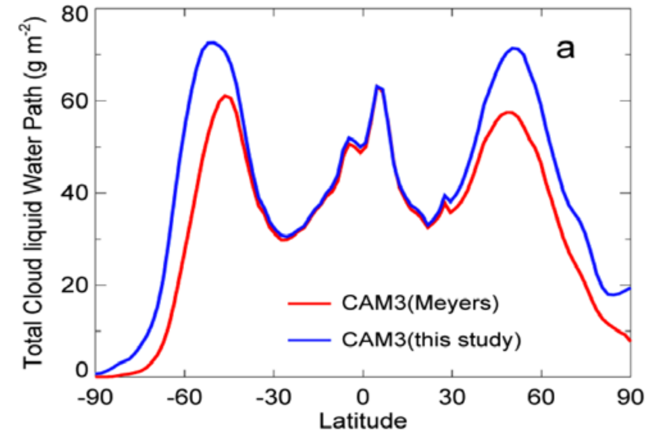


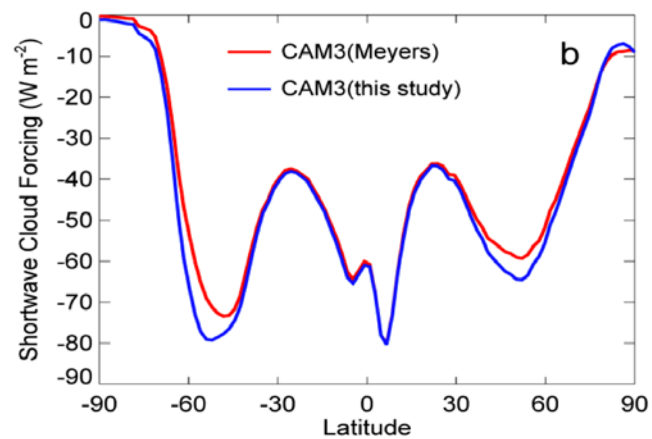


Multiple ice nucleation mechanisms related to aerosol & meteorological conditions

Uncertainties in IN parameterizations produce significant changes in CAM modeled LWP, cloud forcing and cloud fraction

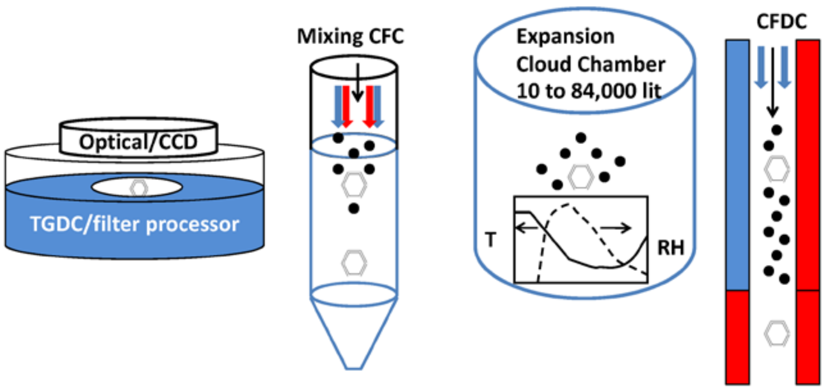
LWP and SWCF with two IN parameterizations

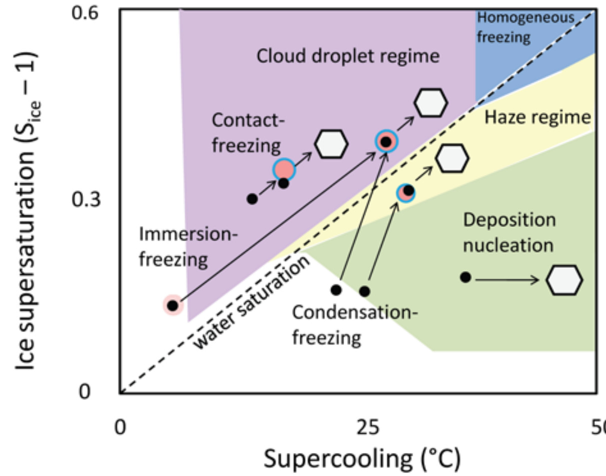




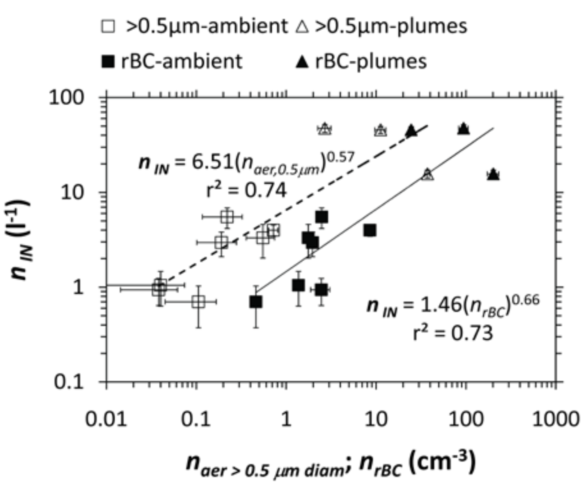
DeMott et al. (2010)

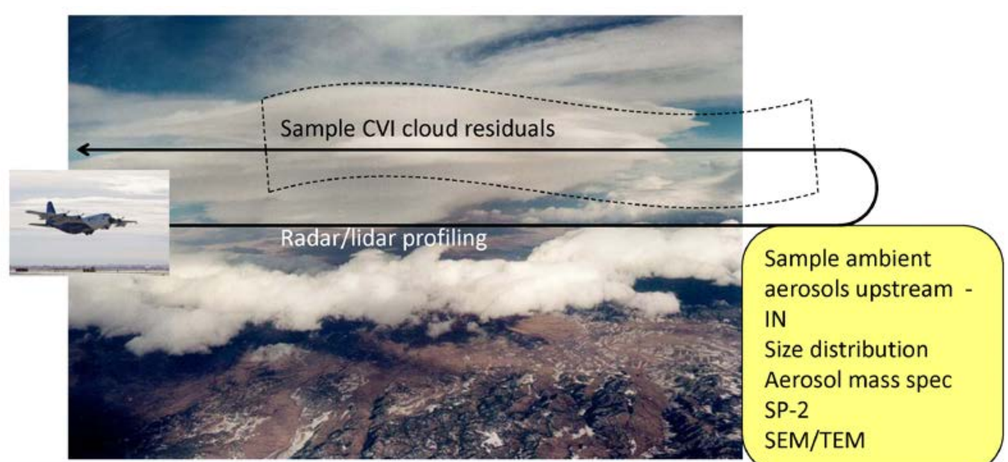
Challenges and issues in measuring ice nuclei, their link to aerosol properties, and their role in ice formation



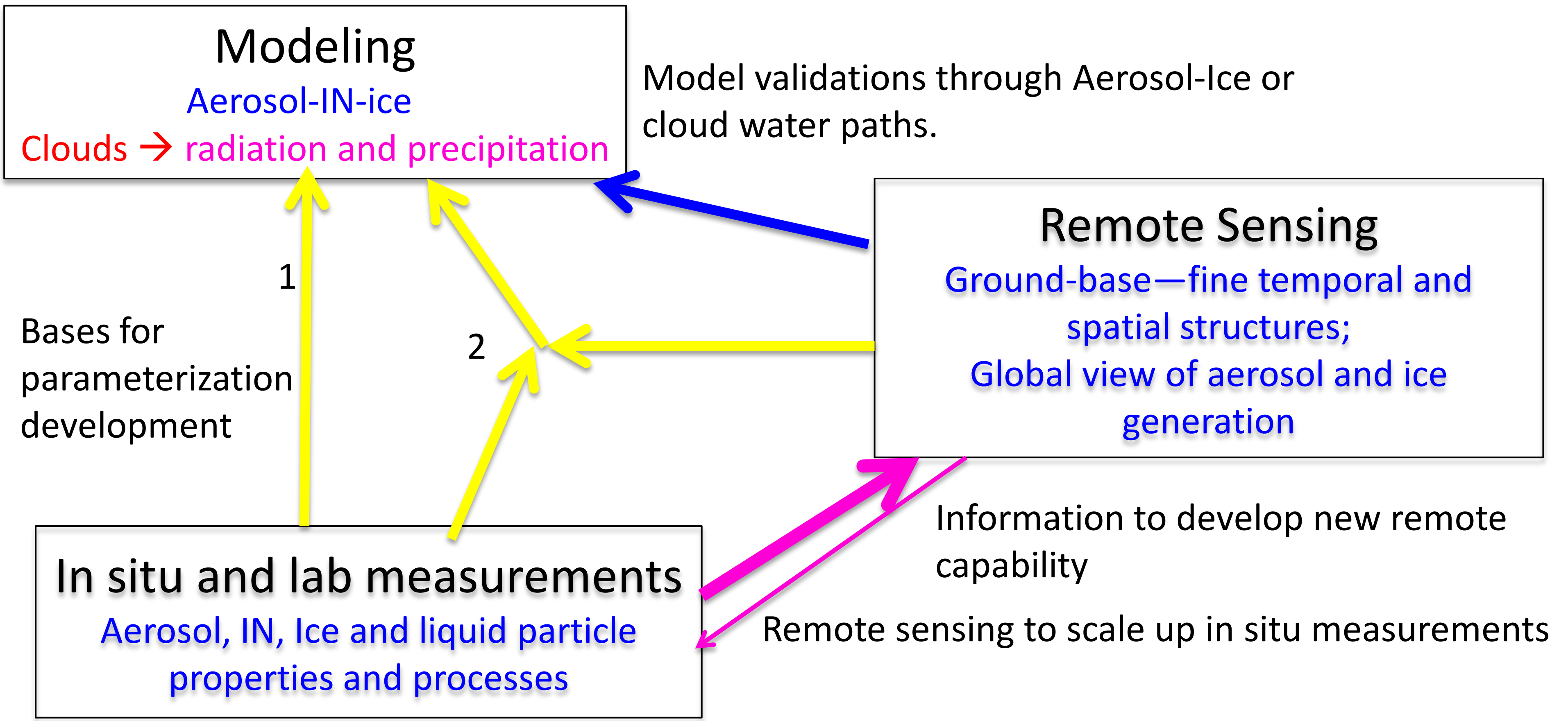


Many devices, need for calibration standards, uncertain role of time, multivariate and multi-mechanistic populations representing a very small fraction of total aerosols so relations to other aerosols require validation by difficult IN composition measurements, special cloud conditions required for directly relating IN to ice in clouds (e.g., role of secondary ice f





The Path forward



Science Tasks and Questions

1. Aerosol/meteorological conditions for different ice nucleation mechanisms
2. Roles of BC (e.g., from biomass burning) in the ice nucleation
3. Development of aerosol/meteorology dependent parameterizations
4. Scaling issues between in-situ (and even remotely sensed) measurements and GCMs

Ovchinnikov et al.

ISDAC model intercomparison

ISDAC – based model intercomparison

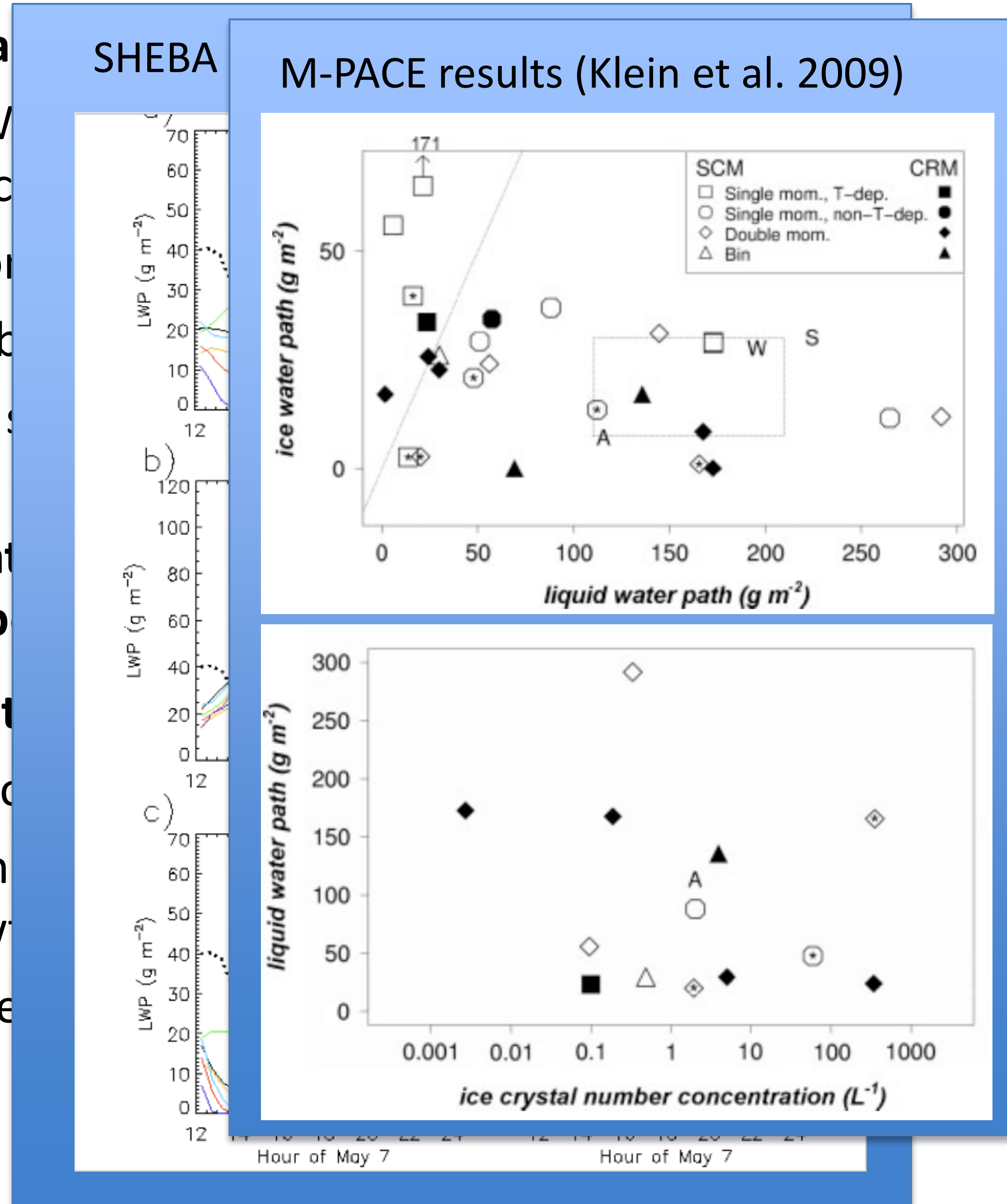
Build on previous intercompa

- Large spread of LWP and IW
  case, initial profiles, large sc
- Uncertainty in ice nucleatio
- … but constraining ice numb
- For many models there is a
  clouds when N_i is increased

Dynamics-microphysics-radiat
understood and modeled b

Possible approaches & next st

- Dynamics: Additional diagno … c.
- Microphysics: Constrain oth
  mass ratio, deposition growt
- Radiation: Unified paramete



ISDAC – based model intercomparison

Flight 31 case

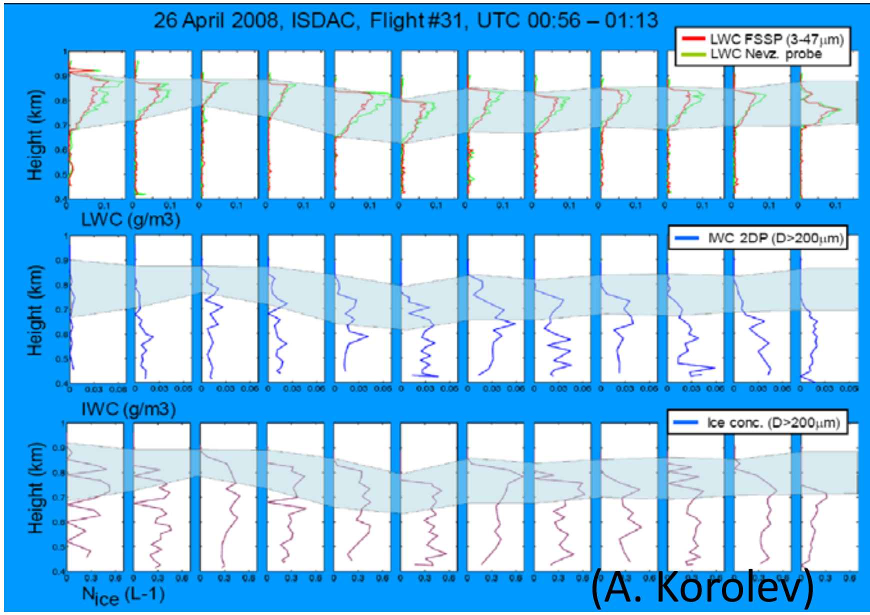
The simpler case the better

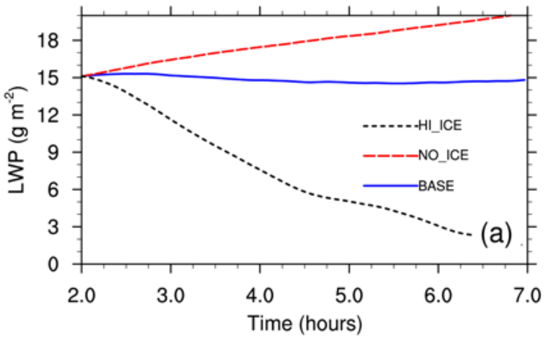
Long-lived mixed-phase stratus cloud

Elevated (decoupled) mixed layer with temperature inversion above and slightly stable layer below

Temperature inversion and cloud top height are near constant

Preliminary model simulations reproduce a quasi-steady state mixed-phase cloud





ISDAC – based model intercomparison

Plans, logistics, etc

ASR & GCSS

ASR: Data for initialization, forcing and evaluating the simulations

Align with a focus group

GCSS: Broader participation

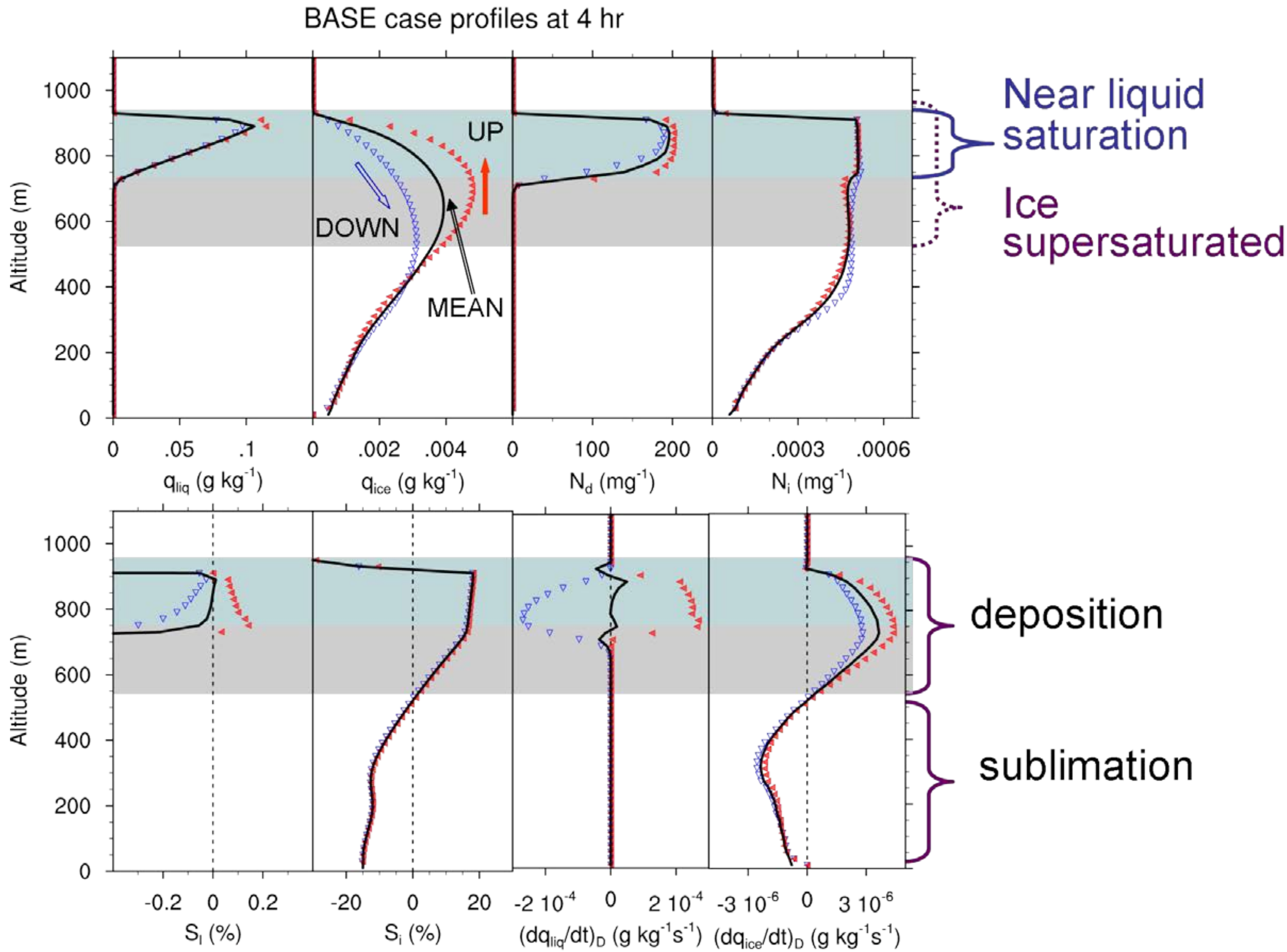
Vast model assessment and boundary layer modeling expertise

Target models: LES/CRM (? SCM, Regional ?)

Setup details under development:

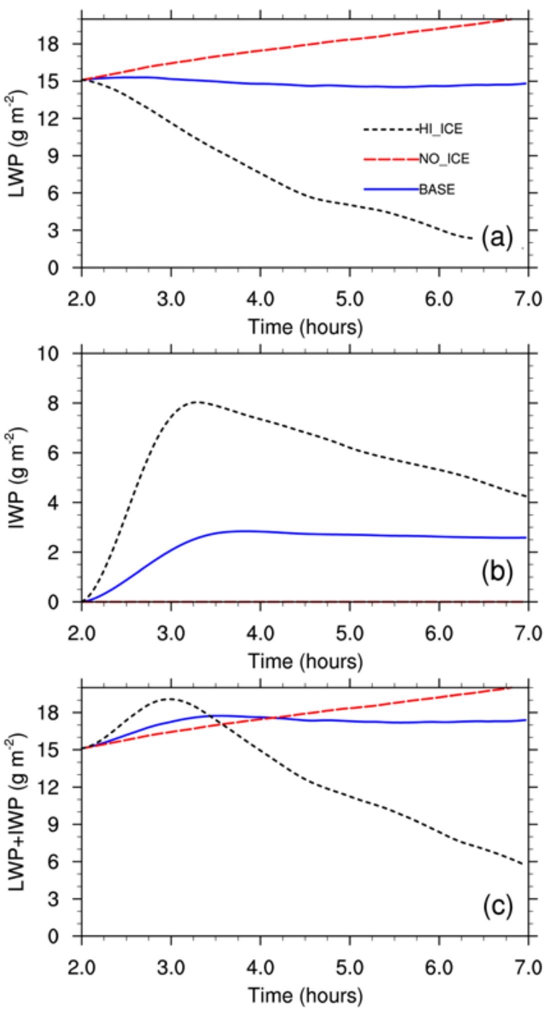
- Initial profiles, large-scale subsidence, spatial resolution
- Data format
- Timeline:
  - Case description (Spring 2011)
  - First model results (Summer/Fall 2011)
  - Follow-up at the working group meeting (Sept. 2011)

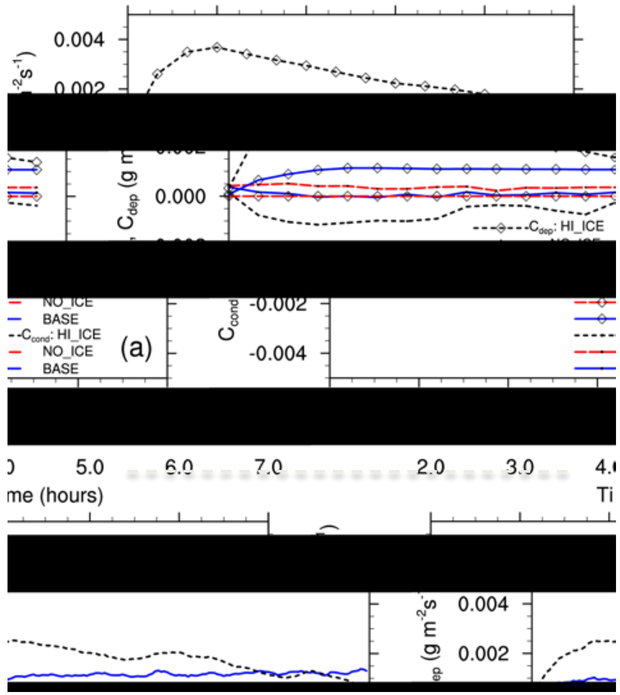
ISDAC FLT31: Base case cloud properties (N_i=0.5 L^{-1})

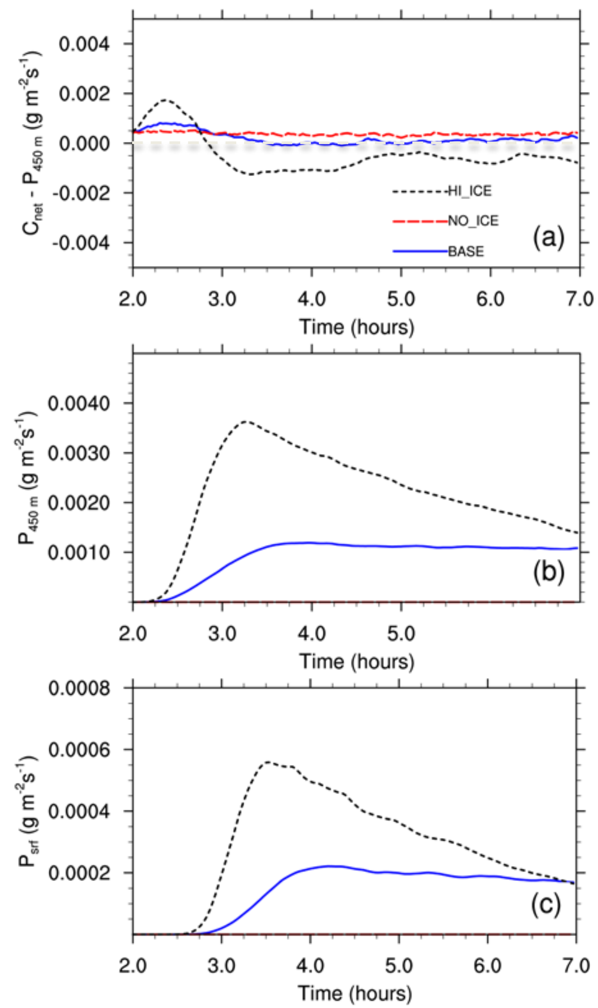


Sensitivity to N_i

Stable LWP for the BASE, increasing for NO_ICE, decreasing for HI_ICE







BASE: $N_i = 0.5\ L^{-1}$

NO_ICE: $N_i = 0\ L^{-1}$

HI_ICE: $N_i = 2\ L^{-1}$

Gultepe et al.

Proposed experiment on polar ice clouds (PIC3)

POLAR ICE CLOUDS AND CLIMATE CHANGE (PIC3)

I. Gultepe, J. W. Strapp[1], P. Liu[1], J. Verlinde[2], Z. Boybeyi[3], D. Lubin[4], D. Cziczo[5], J.P. Blanchet[6], P. A. Kucera[7], J. Sloan[8], T. Kuhn[9], E. Girard[6], S. Brooks[10], J. E. Cherry[11], M. Wendisch[12], P. Minnis[13], A. Zelenyuk[14] and K. Dethloff[15], J. Milbrandt[16], and X. Liu[17]

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AWI

ASR-CAPI breakout session

CURRENT ISSUES RELATED TO ICE CLOUDS/SNOW PRECIP

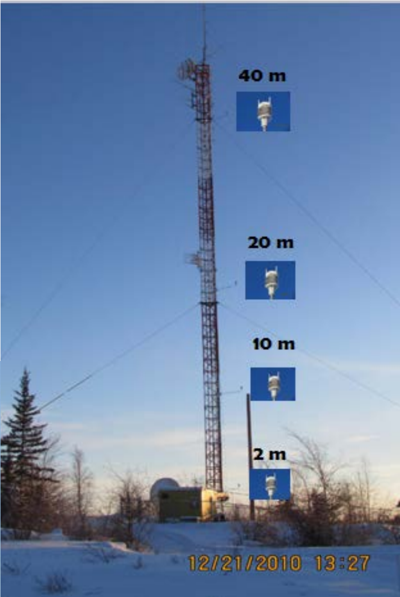
SITES

- NSA, Barrow, AL, US
- Yellowknife, NWT, CA
- AWI Polar-5 aircraft
- AMF2 mobile unit

○ **Overall, ice clouds and snow are important part of the hydrometeorological cycle, and they are directly related.**

- ○ Ice crystal concentration parameterizations and issues related small ice crystals, and nucleation processes
- ○ PR cannot be measured accurately if it is less than 0.5 mm/hr (~10 W m-2); snow rate is about 0.5 mm/hr overall in continental Arctic regions. Arctic precip rate will increase 3-4 times more than this of midlatitudes.
- ○ Ice crystal habit effects on mass and optical properties
- ○ Autoconversion from IWC to SWC
- ○ Ice crystal concentrations with size<100 micron
- ○ Usually low vertical air velocities
- ○ IN acidification and Arctic cooling
- ○ Ice particle spectra for various cloud types/habit
- ○ Spectral radiances for ice crystal types/retrievals

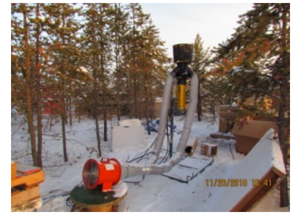
12/09/2010 12:32



Yellowknife to Barrow

Snow precipitation in Arctic regions

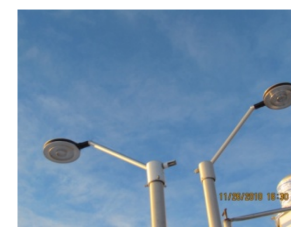





- Precip rates cannot be measured accurately if it is less than 0.5 mm/hr

- Weighing gauges do not work accurately in the Arctic regions because of their sensitivity to particle size and density, and wind effects

- Optical gauges are better than weighing gauges because their sensitivity is directly related to individual particle in a sampling volume



- Snow density is not well known during the precipitation to obtain accurate SWE.

- Hot plates (or capacitance sensors) can work better than others but no particle density info is provided

Biraud et al.

Water vapor isotopes to look at
cloud / precipitation processes