ARM Atmospheric Radiation Measurement Program

RACORO

Routine

Aerial Vehicle Program (AVP)

Clouds with Low Optical Water Depths (CLOWD)

Optical

Radiative

Observations

RACORO Website:

http://acrf-campaign.arm.gov/racoro/

Organizational Structure

AVP Program Manager	**Rick Petty**
AVP Technical & Mission Science Director	**Beat Schmid**
AVP Chief Scientist	**Greg McFarquhar**

RACORO Steering Committee

Andy Vogelmann, Greg McFarquhar, Dave Turner, Jennifer Comstock, Graham Feingold, Chuck Long & John Ogren

Atmospheric Radiation Measurement Program

AVP Goals and Instrument Requirements

Greg McFarquhar

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Three Goals of AVP

1. **Routine observations** of clouds, aerosols and radiative properties
2. **Participation in IOPs** designed to contribute to our fundamental understanding of clouds, radiation and aerosols and their effects on global change
3. **Foster instrument incubator program** where miniaturized in-situ and remote sensing instruments will be purchased or developed,
   - small size and modularity of instruments will make them amenable to UAVs and larger aircraft

Role of RACORO

- First attempt at routine observations of clouds
  - Suggested as first mission of AVP in original proposal for development of AVP
- 9 month observational campaign of low liquid clouds over Oklahoma
- Statistics important for retrieval development and model evaluation, with application to projects like CLOWD
- Instruments to be used need to be proven, reliable, ease to use, not requiring a lot of maintenance
- Will be challenging to conduct this new paradigm for field observations, but payout will be great

The RACORO Instrument Suite Design

Routine observations requires a simple aircraft payload for cost effectiveness

Probes must have

- A track record of reliability,
- Require minimal maintenance and
- Relatively routine processing by automated means.
- Small weight & low power consumption for smaller & cheaper aircraft

Preference for

1. Slow aircraft speeds,
2. Fast instrument response times, and
3. If possible, large particle sampling volumes.

RACORO Science Overview

Andy Vogelmann &
Jennifer Comstock

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Introducing the RACORO Steering Committee

Andy Vogelmann	**Science coordinator, CLOWD co-chair**
Greg McFarquhar	**AVP Chief Scientist, *In situ* cloud obs**
Dave Turner	**CLOWD Co-chair, Surface retrievals**
Jennifer Comstock	**CLOWD Translator, Surface retrievals**
Graham Feingold	**Cloud-aerosol interactions**
Chuck Long	**Aircraft radiometers & flux analyses**
John Ogren	***In situ* aerosol & cloud obs (7 yrs, 2x wk)**

Cloud LWP Frequencies

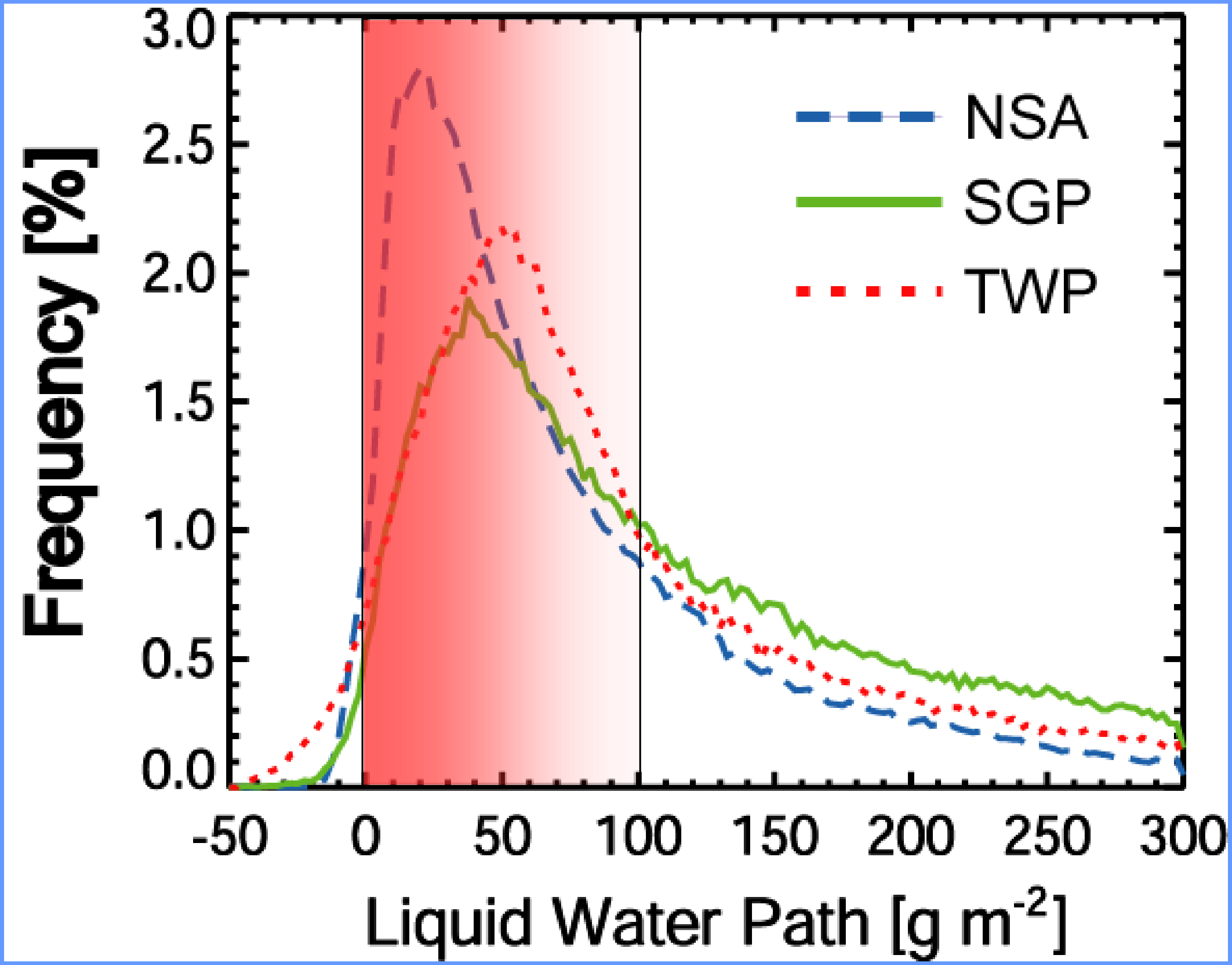
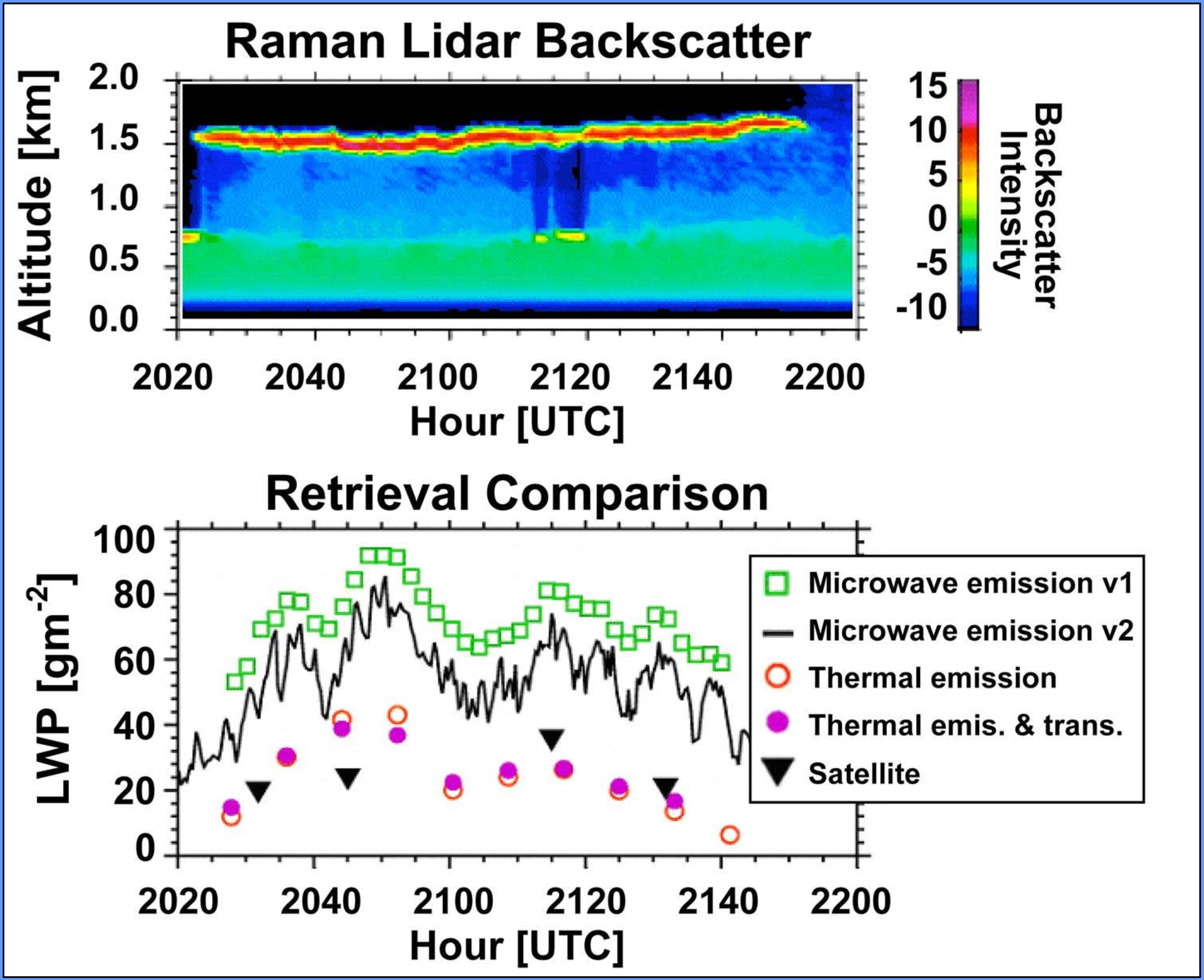


Figure adapted from Turner et al. (*TGARS*, 2007)

CLOWD BAMS Paper



Turner and 21 Co-Authors (BAMS, 2007)

Related Topic Areas

Modeling continental boundary layer clouds

- Poor agreement w/ observations (Lenderink et al., 2004)
- Subgrid scale to boot!

Marine boundary layer (MBL) clouds

- MBL cloud albedos poorly simulated (Zhang et al., 2005; Bender et al., 2006; Zhu et al., 2005)
- Main source of uncertainty in GCM tropical cloud feedbacks (Bony and Dufresne, 2005)

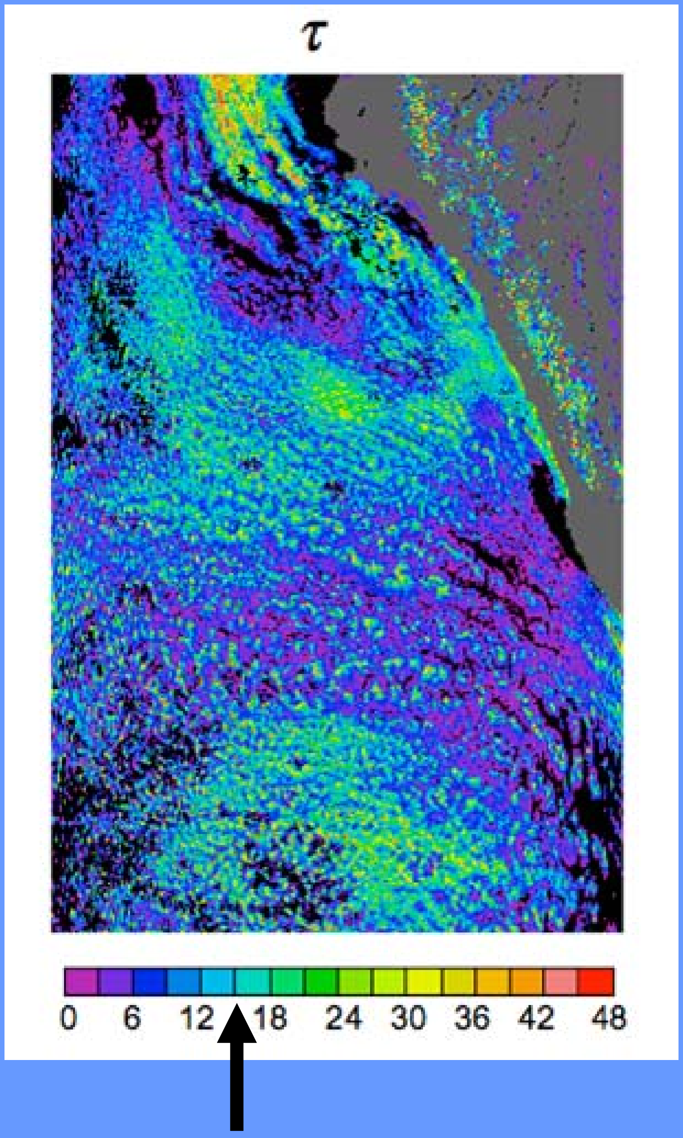
Aerosol Indirect Effects (AIE)

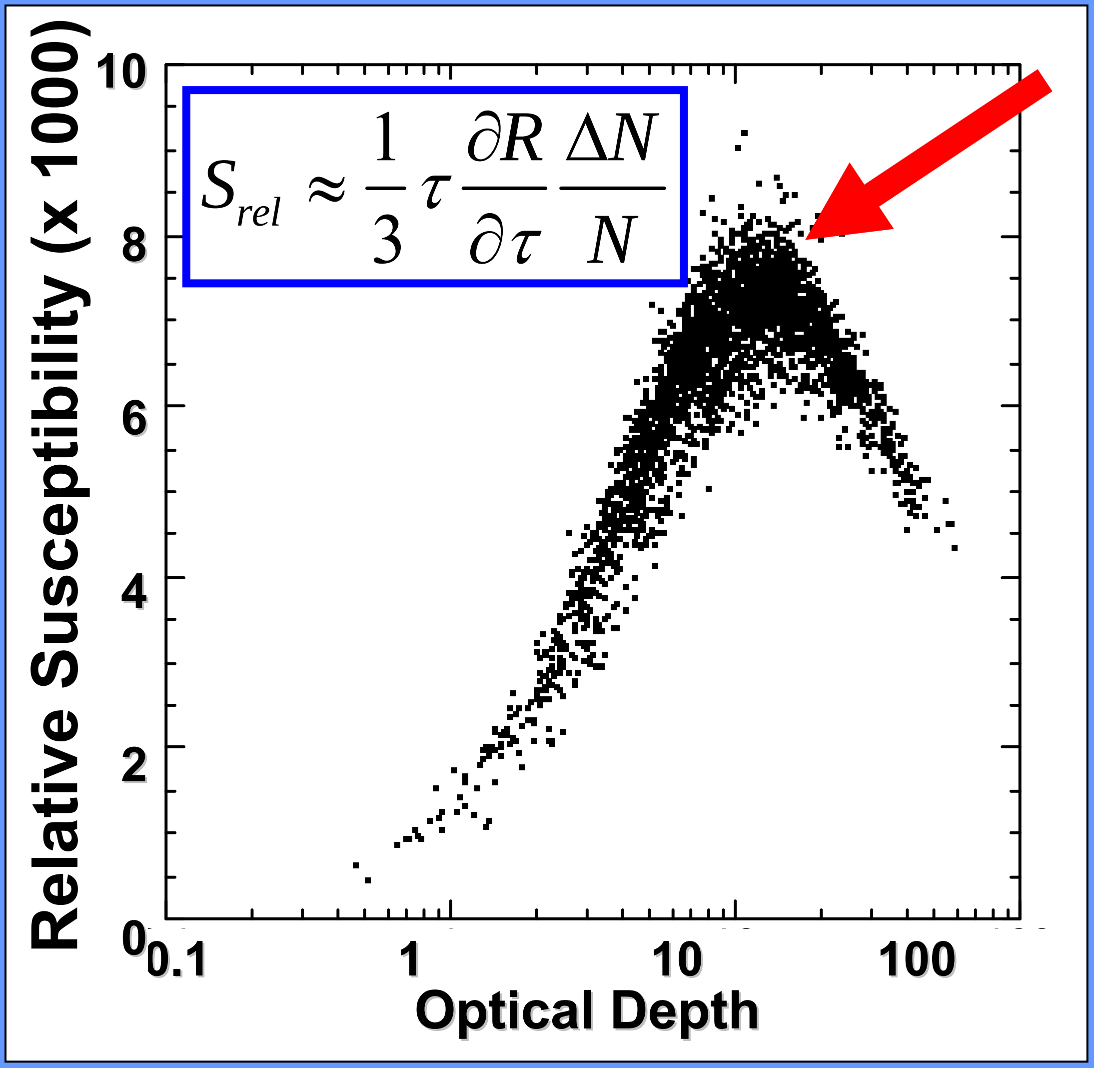
- AIE has greatest uncertainty range (IPCC, 2001)
- AIE least saturated for thin and developing cloud

➢ **MBL broken cloud fields & Rapid transitions (Rifts zones or POCs)**

  - Large impact on the global radiative energy budget
  - Difficult retrieving cloud properties within broken fields

Cloud Relative Susceptibility





Platnick and Oreopoulos (*JGR*, Submitted)

RACORO Overview

- Conduct long-term, routine flights in boundary layer, liquid-water clouds at SGP to measure
  - Microphysical properties
  - Optical properties and radiative fluxes, and
  - Associated aerosol prop. & atmospheric state
- Long-term statistics needed because these clouds are thin and/or broken, which make retrievals uncertain
  - Help develop & evaluate ARM retrievals
  - Improve our understanding of how boundary layer clouds interact with aerosols & radiative fluxes

General Approach

Fly at SGP; Target boundary layer, liquid-water clouds

The SGP is easily accessible

Ample personnel to support a long-term field program

Extensive complement of state-of-the-art surface retrievals

Boundary layer clouds

Common at the SGP year around

About 1/2 of them are CLOWD-type clouds

$\Rightarrow$ High probability catch

Low-altitude clouds

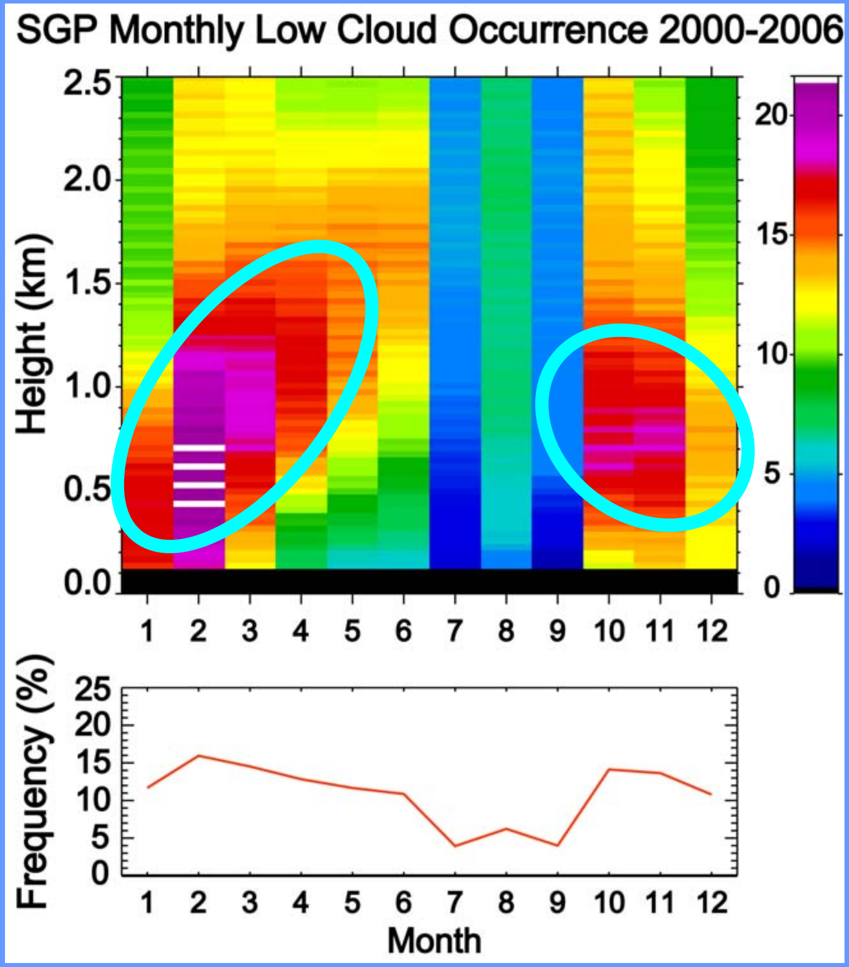
More easily accessible by aircraft

$\Rightarrow$ cheaper to sample than higher altitude clouds

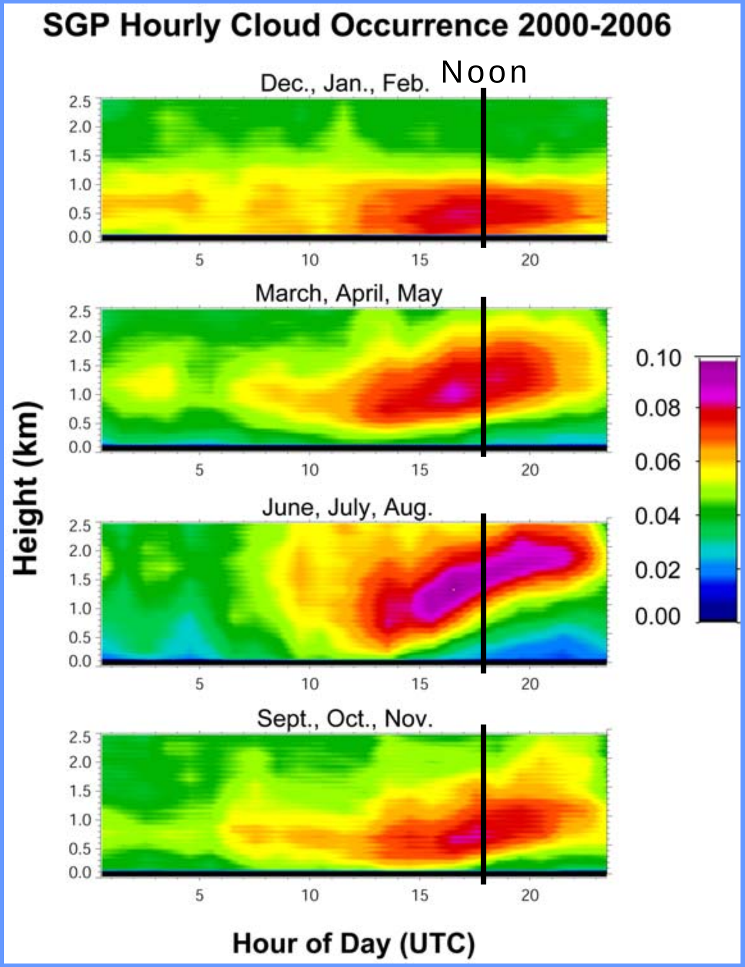
Liquid-water cloud probes developed for decades

$\Rightarrow$ should be well tested for routine observations

Atmospheric Radiation Measurement Program

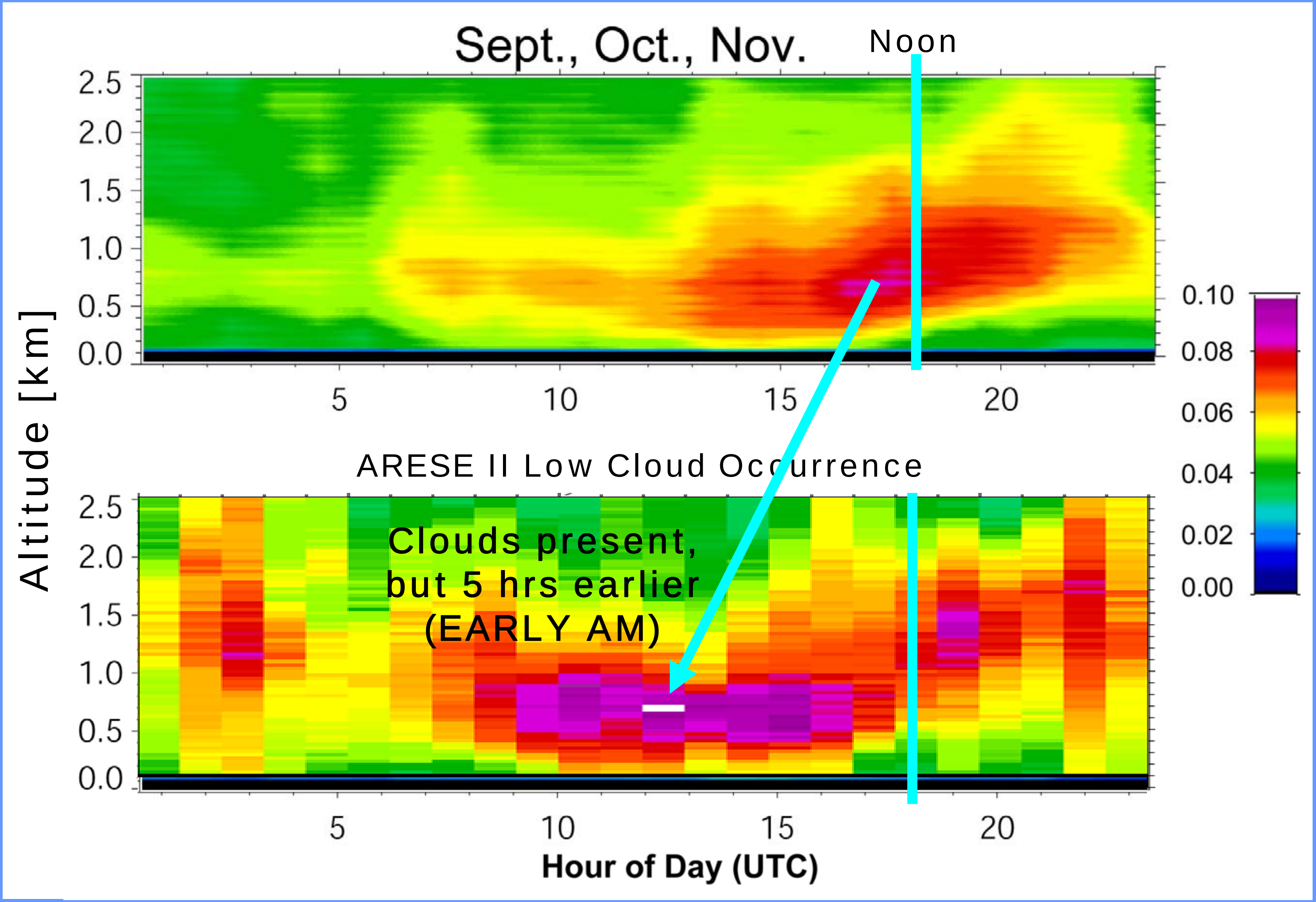


Seasonal freq. of SGP low clouds



Diurnal cycles of SGP low clouds per season.

Climatology Vs. ARESE II



Instrument Suite

Low-level, slow-flying aircraft observing:

- Cloud microphysics

  Size Distribution, bulk LWC, β_{ext}

- Radiometric quantities

  ↑↓ SW & LW radiometers, SW spectra to map surface albedo

- State parameters

  Fast-response Temp., H_2O_v, & turbulence

- Aerosol properties

  Size Dist (D > 50 nm), CN & CCN

(Further details follow)

RACORO Serves Crosscutting Interests of the ARM WGs

1. **CLOWD Working Group (WG)**
2. **Determine the radiative forcing of CLOWD clouds at the SGP, includes evaluations of their 3-D microphysical cloud structure and routine characterization of surface albedo (RPWG).**
3. **Ascertain the lower detectability limit of liquid-water contents for ARM radars and other remote sensors, and aid in the development of future radar specifications for improved observations of these clouds (CPWG).**
4. **Improve cloud retrieval algorithms so that the multi-year ACRF datasets may obtain long-term CLOWD statistics (CPWG).**
5. **Evaluate their impacts on the broadband heating rate profiles (BBHRP).**
6. **Quantify aerosol indirect effects in boundary layer clouds (AWG)**
7. **Improve model parameterizations of continental boundary layer clouds, whose developments have largely used maritime data (CMWG)**
8. **CLOWDs common in MBL ⇒ RACORO can aide design of 2nd AMF Facility that will be marine-capable**

Potential RACORO Science Questions

1. Do cloud property retrievals exhibit a diurnal cycle in their accuracies?
2. Radiative closure
   - Can radiative transfer calculations using the observed cloud fields attain agreement/closure with the observed surface radiative fluxes?
   - Which probability distribution functions (PDFs) of small-scale cloud property variations are needed to achieve surface radiative closure?
   - Can high-resolution models simulate those PDF seasonal variations?
3. Simple process modeling
   - Can parcel models represent aerosol activation observed in real clouds?
   - Is aerosol compositional complexity required to achieve closure on drop number concentration?
4. Cloud-aerosol interactions
   - What is the role of aerosol loading in varying the microphysical and macrophysical properties of boundary layer cloud fields?
   - Can the large sampling statistics from a year-long project isolate differences associated with different aerosol types and cloud types?

4\. What are the linkages between aerosol, cloud dynamics/microphysics, and the initiation of drizzle in warm, shallow clouds?

5\. How well do boundary layer models simulate the statistics of clouds and aerosol-cloud interactions?

Atmospheric Radiation Measurement Program

RACORO
Retrieval Algorithm Validation & Value Added Products

Jennifer Comstock

Dave Turner

Andy Vogelmann

- Vet Retrievals for Operational Use
  - Flux Closure via BBHRP-CLOWD
- Microphysics “Referee”
  - RACORO

Statistics, statistics, statistics…

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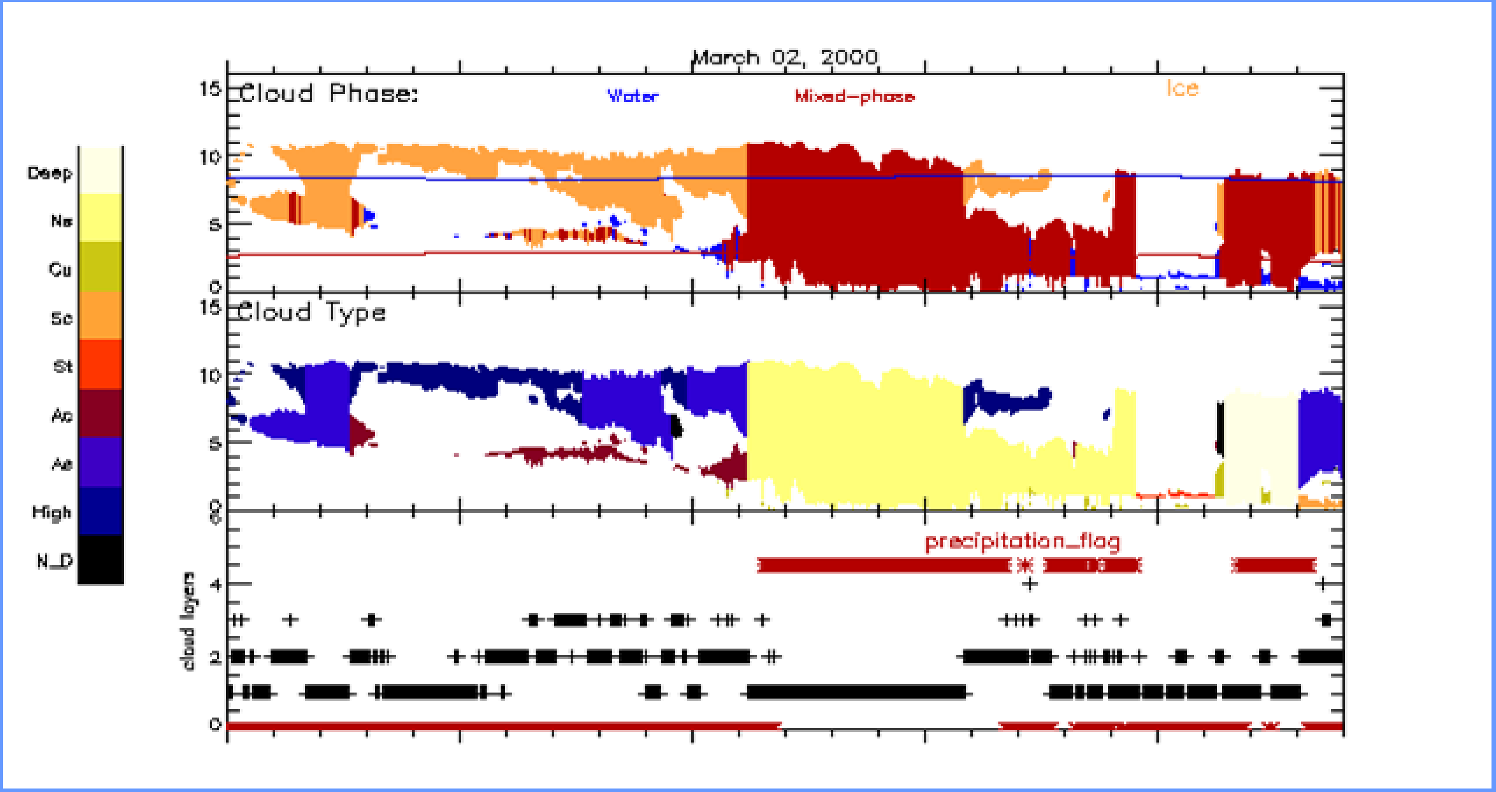
Value Added Products:
Cloud Classification

Cloud Phase and Type retrieval (Wang and Sassen 2002)



Surface Retrieval Algorithm Classes

- Microwave Radiometer (MWR)
  - Statistical Retrieval, Physical Retrieval
- Cloud Radar
  - Empirical methods, constant droplet number density
- Visible wavelengths
  - MFRSR, NFOV, Broadband
- Infrared
  - IR spectral measurements (8-13 μm; 3-5 μm)
- Lidar
  - MPL, Combined lidar-radar, Raman Lidar

Retrieval Validation

Closure Experiments

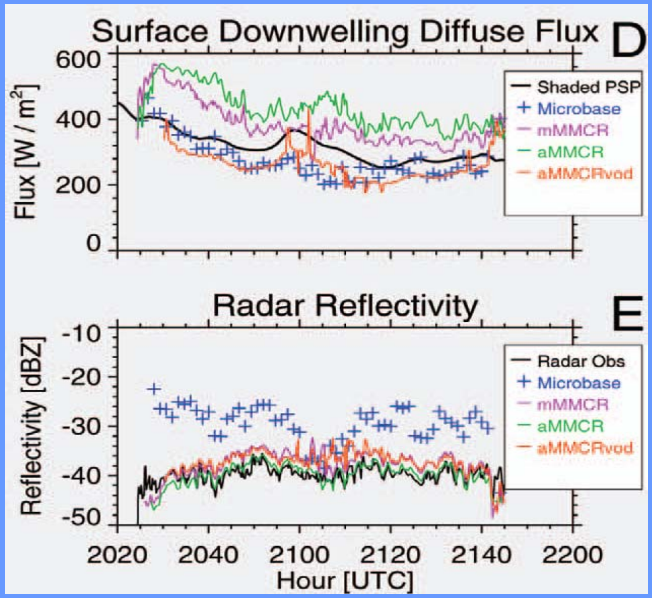
- **Broadband shortwave diffuse flux**
  - **Tests smaller particle limit**
- **Mean radar reflectivity**
  - **Test larger particle limit**

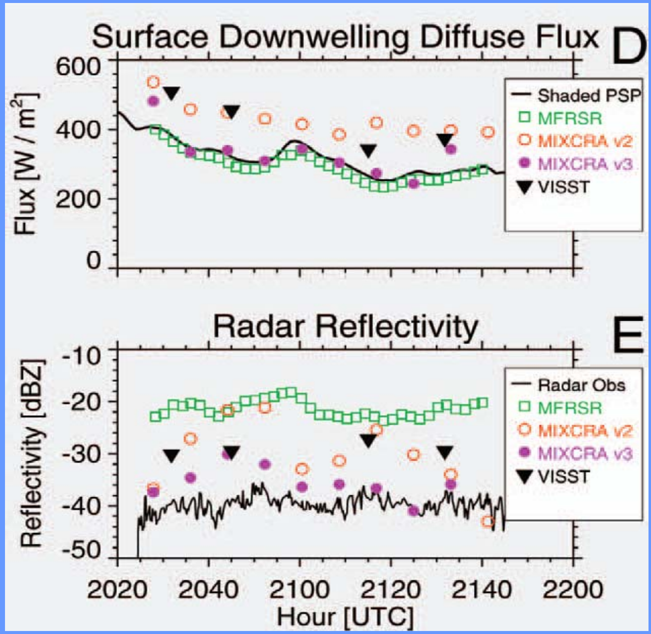
RACORO

- **Airborne cloud optical and microphysical properties**
  - **"Referee"**
- **Radiative fluxes**

❖ Statistical sampling
  - **Essential for thin & broken clouds**

Develop single CLOWD VAP





From Turner et al. BAMS (2007)

General Flight Plan & Measurement Strategy

Greg McFarquhar

Experiment

- Fly pre-determined flight tracks over the SGP 2 to 3 times/week for 1 year
- Flight legs envisioned:
  - Focus on low LWP clouds, but sample whatever clouds present to get representative statistics
  - Straight, ~20 km long legs at multiple heights where clouds are present
  - Bowtie, box and triangle patterns
  - Spirals over central facility
- Times may be planned with satellite overpasses
- Nighttime flights
- Routine observations must use instrumentation with very high reliability and "easy" processing

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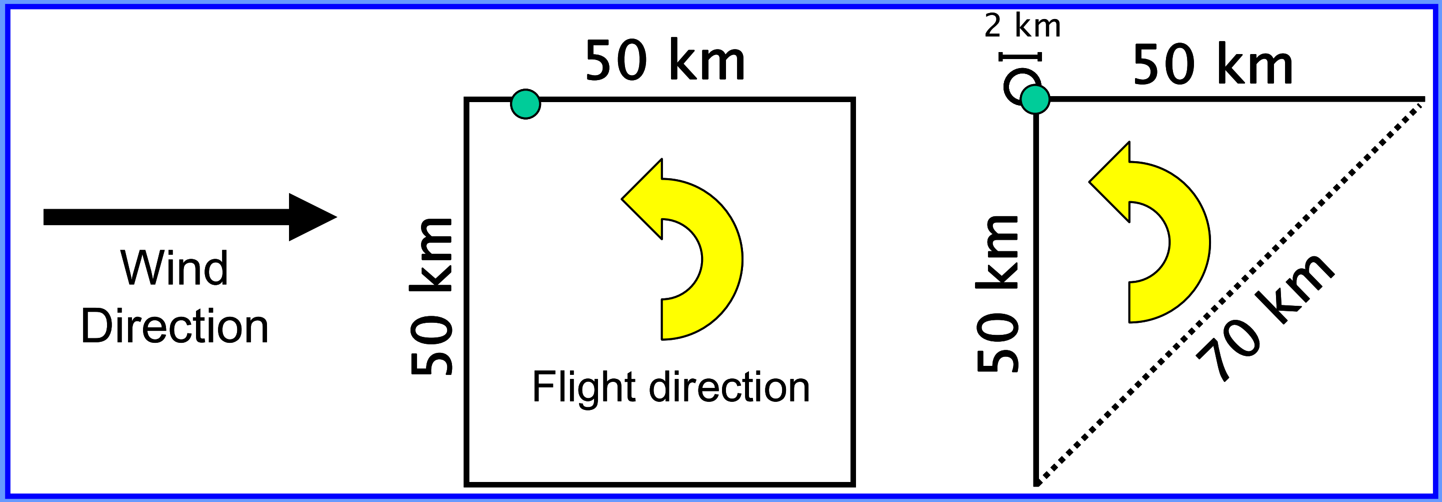
Flight Pattern Considerations & “Rules”

- **Flight patterns will use**
  - ➢ **Long, straight legs in**
  - ➢ **Simple flight configurations,**

  Minimizes in-flight pilot decisions and potential sampling biases.
- **Deviations from pre-determined legs only when a shift would significantly increase the cloud sample without biasing it.**
- **Sampling of cloud fields at multiple vertical levels.**
- **Spiral descents over the CF.**



Flight Evaluations

- On the fly
- Mid-program review

Evaluating:

- **Flight plans**
- **Instrumentation**
- **Achievement of sampling objectives**

Flight Timing

Need to come up with decision on when to conduct the flights

- Originally proposed table may not hold true when we carefully look at cloud diurnal cycles

We can only operate 9 months

- What months should we not operate in?
- We won't operate July and need at least 1 other month before October

Go/No-go & Delay Decisions

- Flight safety
- Cloud Coverage < 10% (plus just a couple clear-sky flights for calibration/reference)

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RACORO Sampling Evaluation

Chuck Long

Long-term field campaigns

- Different from "normal" paradigm
  - “Normal" 3-6 weeks of intensive effort by many, esp. aircraft IOPs
  - Long term less "effort per day", but includes persistent effort
    - BOTH PEOPLE AND INSTRUMENTS!!!
  - What can go wrong, will go wrong, usually at the most critical and inconvenient time
  - Some problems are clever, using subterfuge and patience to sneak up and bite you

My experience

- First: TSI instrument evaluation IOP
  - First time ARM dealt with long-term effort, decided best fit "IOP" funding path/paradigm
- Others: Nauru Island Effect Study, NSA Radiometer IOP, etc.
- In all cases, was determined that a review at the half way point was a good idea
  - Check instrument performance
  - Test whether experiment goals were being met

RACORO

- Purpose is to obtain representative statistics of cloud properties
  - Boundary layer liquid water clouds
- Propose to sample **CLOUD FIELDS** rather than cloud type (i.e. not chase clouds)
- Differing length scales (LWC scales of meters, aerosols on scales of km or 10s of km)
- Simple pre-determined flight patterns, progressing flight times (diurnal) for each season

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RACORO
Mid-experiment review

- Instruments
  - Obvious instrument problems handled as they occur
  - No better data QC than using the data for scientific purposes
  - Participants will perform preliminary analyses along the lines of the science goals
  - **Are the measurements adequate to the scientific goals?**

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Mid-experiment review

- Statistics
  - Have we adequately sampled each cloud field type?
  - Have we adequately sampled each parameter set type (clouds, aerosols, radiation, etc.)?
  - Are we missing something?
  - Or do we have enough of something, adjust to including something else?
  - **Examine the statistics and consider modifications to the flight/sampling/instrument strategy**

RACORO
Mid-experiment review

- People
  - Sustained efforts difficult, esp. in the context of our daily/weekly lives
  - Start with great enthusiasm
  - Segue into "yeah, I need to get around to that…"
  - **Mid-experiment workshops serve to re-invigorate the scientists as well as the science!**

Project Management & Execution

RACORO Operations Command Structure

- **AVP personnel conduct the flights and QC the data**
- **AVP will have a meteorologist on contract**
  - **Provide flight-planning information & go/no-go decision-making**

“Executive Board”

- **A subset of the RACORO Steering Committee**
- **Provide the requisite guidance and feedback on operations**
- **Interact through regular telecons & meetings**
- **Initial interactions frequent, and tail off to regular schedule**
- **RACORO Wiki site to contain archives of discussions and results**

This structure will serve as interim coordination in addition to the “halfway check”

ARM Atmospheric Radiation Measurement Program

CIRPAS Twin Otter & RACORO Measurements

Greg McFarquhar

CIRPAS Twin Otter recently selected

- RACORO will have approx. 200 flight hrs
- "Slow" flight speed, approx 55 m/s

Capable of deploying multiple instruments

- Up to 18 wing-mounted pods
  - Although max. reduces flight time by 1 hr per 300 lbs that's beyond a 1,500 lb payload that includes the operator
- Many instruments already available & integrated
- Enables potential redundancy for many critical measurements

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The RACORO Instrument Suite Design

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Instrument Suite

Low-level, slow-flying aircraft observing:

- Cloud microphysics
  - **Size Distribution, bulk LWC, β_{ext}**
- Radiometric quantities
  - **↑↓ SW & LW radiometers, SW spectra to map surface albedo**
- State parameters
  - **Fast-response Temp., H_2O_v, & turbulence**
- Aerosol properties
  - **Size Dist (D > 50 nm), CN & CCN**
- Aircraft telemetry
  - **Speed, pitch, roll**

CIRPAS: Twin Otter

- **Research Capacity: 1500 lbs**
- **Research Power: 5600 W at 28 VDC, 4000W 110VAC 60 Hz:**
- **Speed: 100-140 Kts**
- **Practical Ceiling: 18000 ft.**

ARM Atmospheric Radiation Measurement Program

TIER 1 - CRITICAL

ALL CRITICAL INSTRUMENTS ARE NEEDED. NO PRIORITIZATION POSSIBLE.

CATEGORY (Table)	ITEM NUMBER	OBSERVATION
Cloud Microphysics (C1)	1	Liquid-water content (LWC)
	2	Cloud drop size distribution from 3 to 640 µm (diameter)
Radiation (C2)	3	Uplooking hemispheric SW (pyranometer)
	4	Uplooking total/diffuse SW (SPN-1)
	5	Downlooking hemispheric SW (pyranometer)
Aerosol Instruments (C3)	6	Aerosol size distribution from 0.02-0.5 µm (diameter)
	7	Total CN [fast instrument also assists aerosol size measurement]
Aircraft state (C4)	8	True aircraft speed
	9	Aircraft geopositioning data (lat/long/alt/heading/pitch & roll)
Atmospheric state (C5)	10	Temperature, water vapor concentrations, pressure
	11	Updraft velocity

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- Gerber probe (has worked well in past)
  - May need upgrades before experiment
- Hot wire of CAPS probe
  - Noisier, but useful for redundancy

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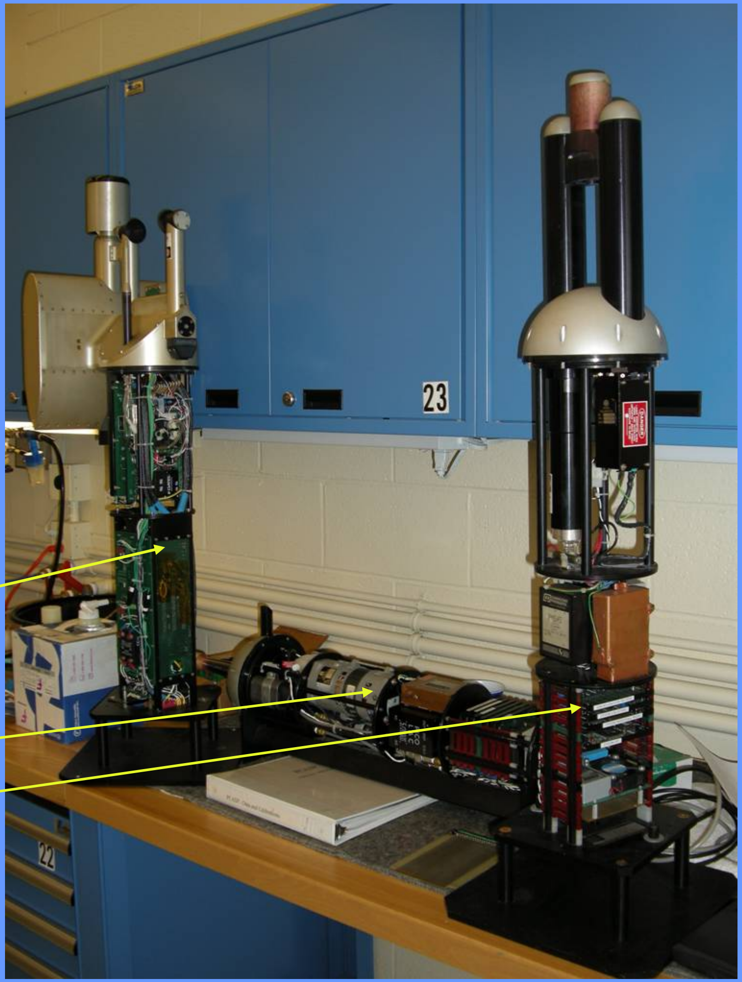
- 0.5 to 50 μm (2 probes owned by CIRPAS):
  - CAS (reliable in liquid clouds from past experiments)
  - FSSP-100 (needs more calibration that CAS as there are drifts in laser), good for redundancy
  - Haf will check if CAS can clock at 10 Hz to get faster response data
- D > 20 μm (2 probes owned by CIRPAS)
  - 1DC
  - 2DS (newer probe has worked well in past)
- D > 120 μm
  - CIP owned by CIRPAS; some concern with hollow images
  - 2DS fills range up to 1.28 mm (owned by CIRPAS)
  - Would be good to use a 2DC for redundancy and not as many problems with hollow images (need to acquire)

Aerosol and Cloud Spectrometers



CAPS
PCASP
FSSP-100

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- ↑↓ Epply PSPs gives hemispheric BB SW @ 1 Hz
- Upward-looking SPN-1 purchased (Chuck Long)
  - Direct and diffuse SW @ 10 Hz, but less acc. than PSP
  - Enables dir-dif partitioning from more accurate PSP
  - No moving parts
  - Avoids need for stabilized platform
    (Weight, reliability & maintenance issues)

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Aerosol Concentration

TSI 3010 CPCs
TSI 3025 UFCPCs

Aerosol Inlet

Sample caught before aircraft significantly bends flow lines. Flow slowed down at the intake by two diffusers having total area ratio of 1:10

Sample distributed to cabin instruments from nipples on the duct

- Could fly 3 CPCs to get fast size information
  - Sample at 1 Hz
  - D > 3 nm
  - D > 7 or 10 nm
  - D > 12 nm

- Investigating SEMS
  - Slower (50 sec) sampling but more accurate
  - Might be more labor intensive for analysis

Atmospheric Radiation Measurement Program

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Flight Path and Platform Attitude

- NovAtel: Lat, Long, Altitude, Ground Speed, Ground track.
- TANS Vector: Heading, Roll, and pitch angles.
- C-MIGITS-III: Lat, Long, Altitude, Pitch, Roll, Heading, E-velocity, N-Velocity, Up/Down Velocity.
- Collins ALT-50 Radio Altimeter: Altitude over ground.

- These instruments are available in CIRPAS core instruments sampling at 10 Hz.

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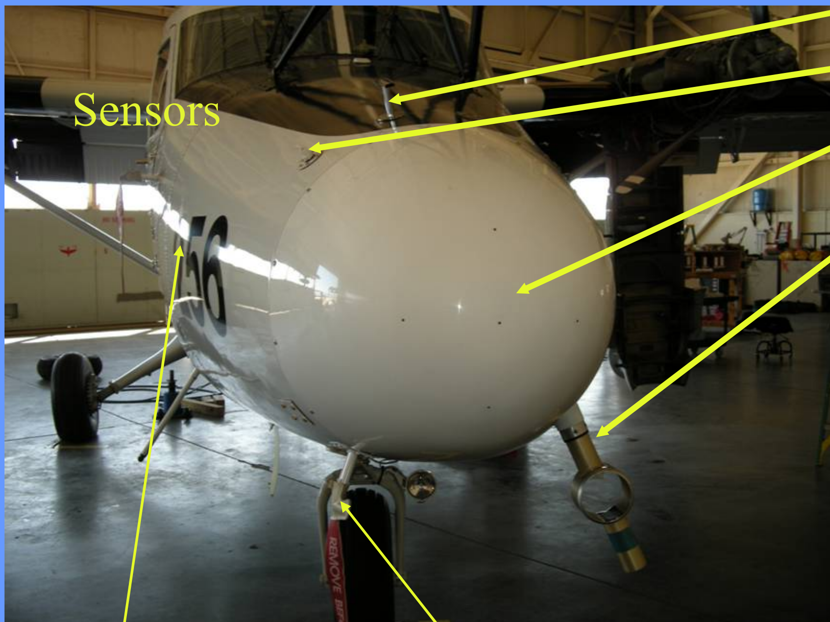
Met and LWC package

(Temperature, Humidity, Pressure, Wind, Surface temperature, and Cloud Liquid Water Content)

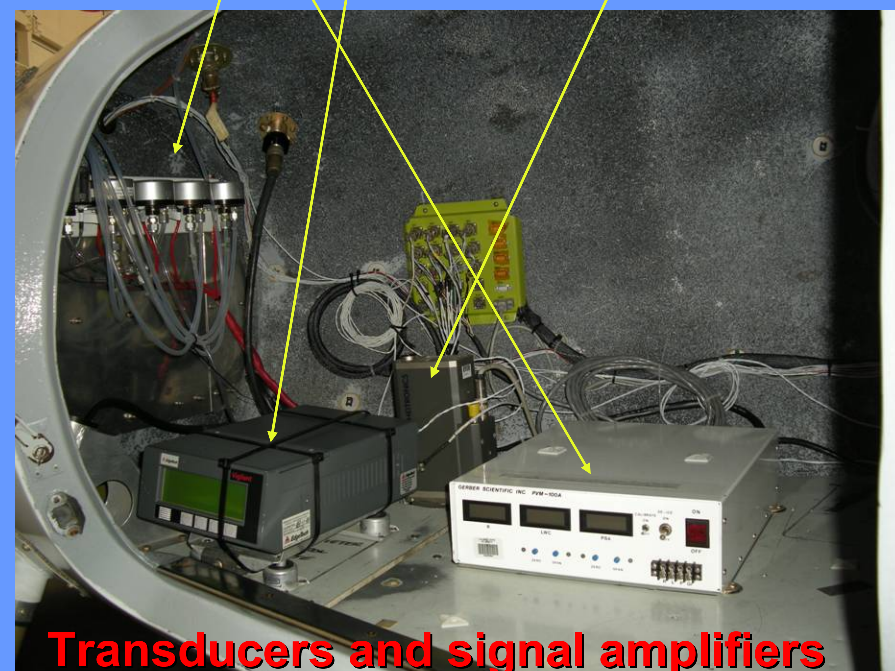
Thermometer
Dew Point
Gust probe
LWC

IR thermometer



Static Port

Pitotube



ARM Atmospheric Radiation Measurement Program

- Water vapor chilled mirror and simpler Vaisala system for redundancy on water vapor present on CIRPAS (few sec sampling)

- Investigating TDL hygrometer for faster response observations (50 Hz)

- Temperature from Rosemount meter EL102.
  In-cloud temp. measurements will be more uncertain (problem far beyond ARM)

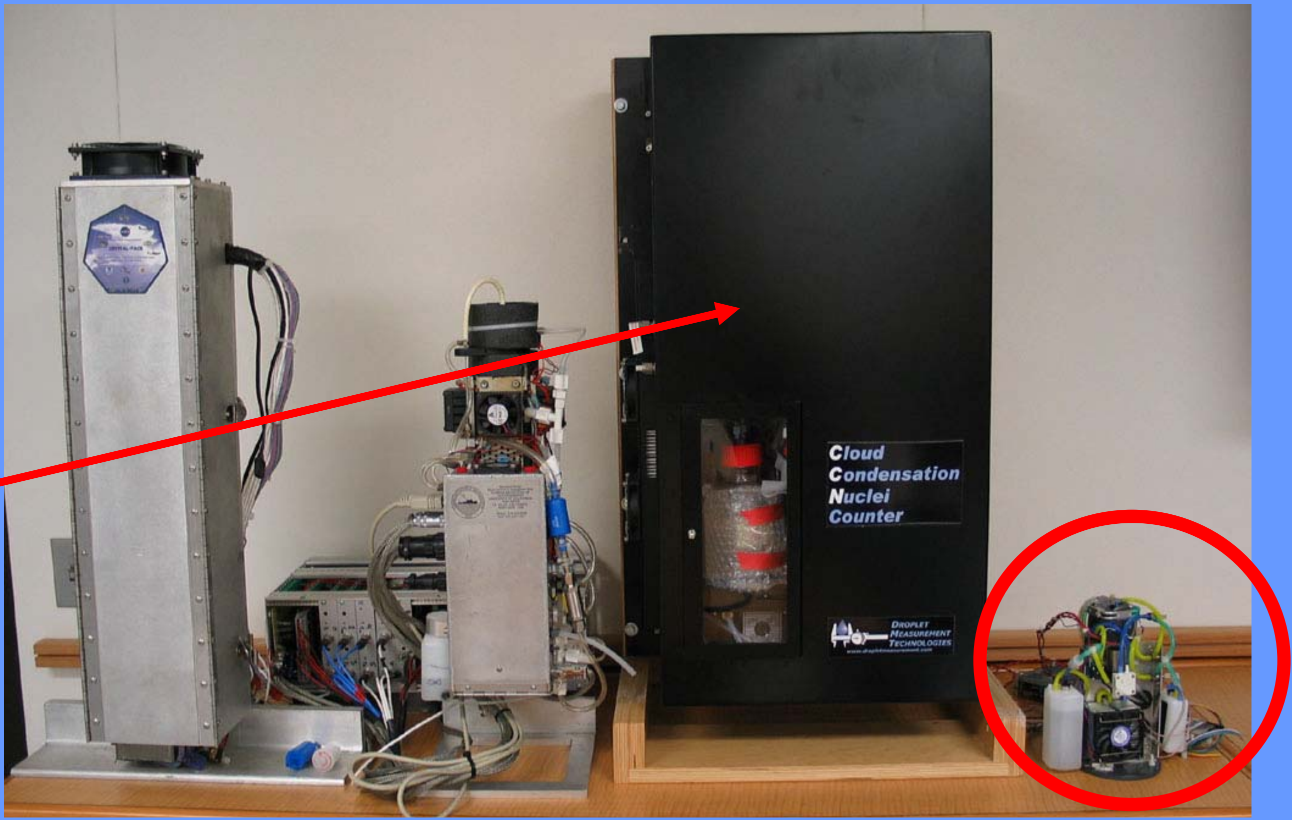
- Gust probe is a 3-d radome system (devel. by CIRPAS)
  - samples at 100 Hz, can ave. to 10 Hz or 40 Hz
  - potential problem of water getting in radome holes (even on the tarmac)

ARM Atmospheric Radiation Measurement Program

TIER 2 – IMPORTANT

Tier Ranking	Observation	Category	Overall Category Ranking
1	CCN	Aerosol	1
2	Turbulence	Atmospheric State	1
3	Drizzle drop size distribution (2DC)	Cloud property	1
4	Surface albedo (↑↓ SW NB, spectral, rapid sample)	Radiation	1
5	Uplooking hemispheric LW (pyrgeometer)	Radiation	2
6	Uplooking spectral NFOV SW (fast, 1^{o} FOV)	Radiation	3
7	Uplooking NFOV IR (IRT)	Radiation	4
8	Flagging of mixed-phase clouds	Cloud property	2
9	Large aerosol size distribution (0.5 to 3 mm)	Aerosol	2

CIRPAS owns this model that could be compared against mini-CCN: use both for redundancy



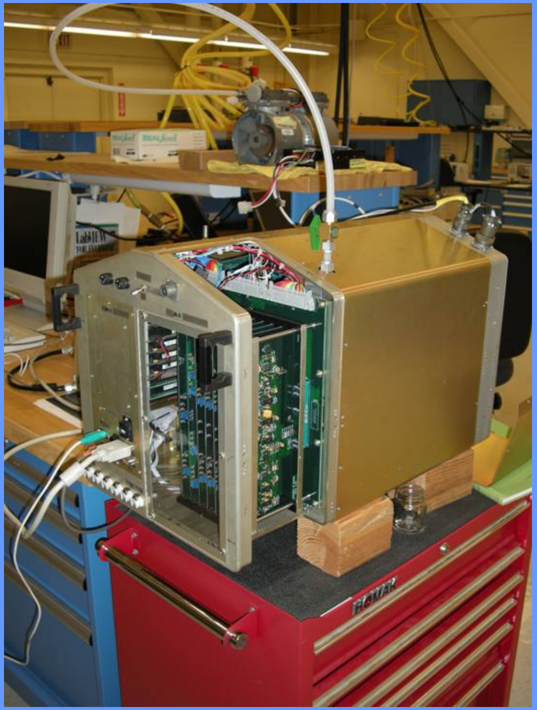
1st Prototype	2nd Prototype	DMT Version	Mini-CCN
2001	2002	2004	2006

Image Courtesy Greg Roberts, Scripps

Table D1. Comparison of the commercial CCN instrument and the miniature CCN instrument.

Instrument	Commercial CCN (DMT)	Miniature CCN
Dimensions (cm)	80 x 48 x 34	21 x 20 x 7
Weight (kg)	28	1.8 (without case)
Power (W)	420 (peak)	40 (peak)

Available Additional Instruments



Dual Column CCN Spectrometer DMT, Inc

SP2 Soot Photometer DMT, Inc.

NMASS Ultrafine Particle Size Spectrometer Univ. of Denver.

Atmospheric Radiation Measurement Program

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- ↑↓ MFRSR can be obtained inexpensively & will give surface albedo in 5 different channels (415, 500, 615, 673, 867 nm)
- Prefer rapid-sample mode (10 Hz)
- Upward-looking MFRSR data reduced using SPN-1 direct-diffuse data

TIER 2 – IMPORTANT

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ARM Atmospheric Radiation Measurement Program

- Kipp and Zonen radiometers available, but without dome/sink temperature sensors

- Eppley PIR commonly used in the field w/ temperature sensors, but need to locate candidate instruments

- Require input from RACORO radiometer mentor (TBD)

Atmospheric Radiation Measurement Program

TIER 2 – IMPORTANT

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7	**Uplooking NFOV IR (IRT)**	**Radiation**	**4**
8	**Flagging of mixed-phase clouds**	**Cloud property**	**2**
9	**Large aerosol size distribution (0.5 to 3 mm)**	**Aerosol**	**2**

- NIMFR cheap technology that works fine & will give radiance at MFRSR wavelengths
- Inclusion of a 1.6 μm channel would enable Reff retrievals. Cost is $2K plus (unknown) personnel installation & testing costs
- ASD option exists that will give full spectrum, but going beyond 1 μm (to get Reff) gets pricey.

TIER 2 – IMPORTANT

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9	Large aerosol size distribution (0.5 to 3 mm)	Aerosol	2

• CIRPAS has 2 IRT Heliotronics for fast ↑↓ IR sampling to interpret PIR BB data

ARM Atmospheric Radiation Measurement Program

TIER 2 – IMPORTANT

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8	**Flagging of mixed-phase clouds**	**Cloud property**	**2**
9	**Large aerosol size distribution (0.5 to 3 mm)**	**Aerosol**	**2**

- Would need Rosemount icing detector, don’t have: big problem might be power required

ARM Atmospheric Radiation Measurement Program

TIER 2 – IMPORTANT

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8	Flagging of mixed-phase clouds	Cloud property	2
9	Large aerosol size distribution (0.5 to 3 mm)	Aerosol	2

- CIRPAS has PCAPs that goes down to 0.1 µm and provides redundancy with lower level of CAPS (0.5 to 3 µm)
- OPC originally suggested in proposal

ARM Atmospheric Radiation Measurement Program

TIER 3 – USEFUL

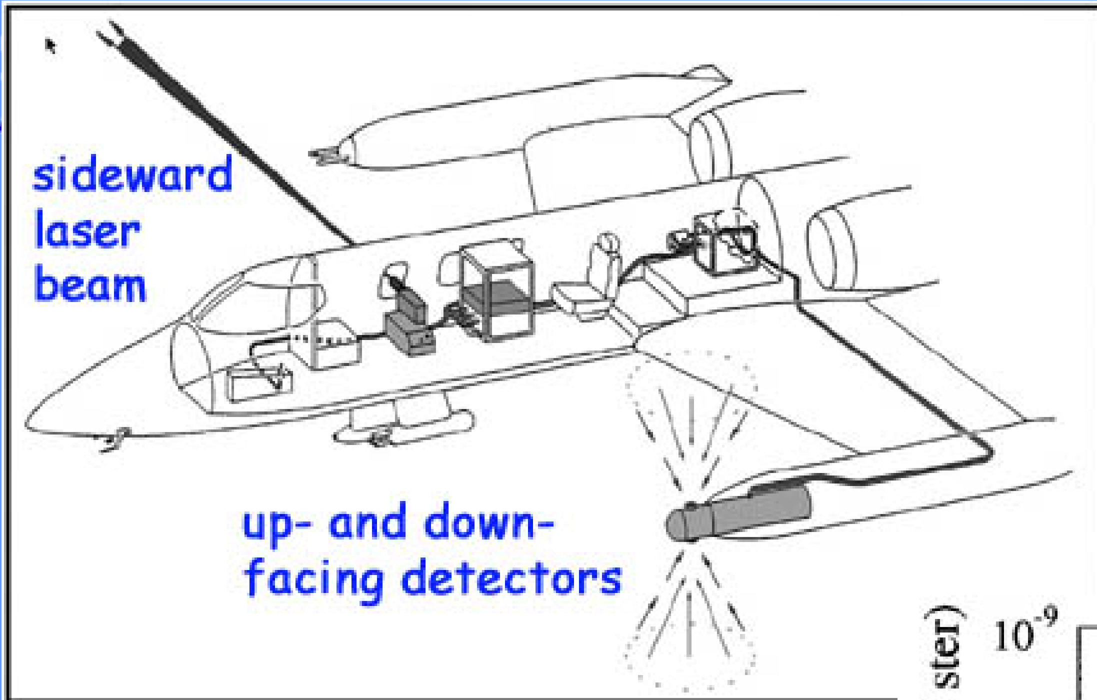
Tier Ranking	Observation	Category	Overall Category Ranking
1	**Downlooking hemispheric LW (pyrgeometer)**	**Radiation**	**5**
2	**Fast downlooking IR (IRT)**	**Radiation**	**6**
3	**Horizontal wind speed and direction at cloud level**	**Atmospheric State**	**2**
4	**Downlooking spectral NFOV SW (fast, 2π FOV)**	**Radiation**	**7**
5	**Fast downlooking SW (SPN-1, cloud albedo)**	**Radiation**	**8**
6	**Video of what flown**	**Atmospheric State**	**3**
7	**Redundant (bulk) LWC**	**Cloud property**	**3**

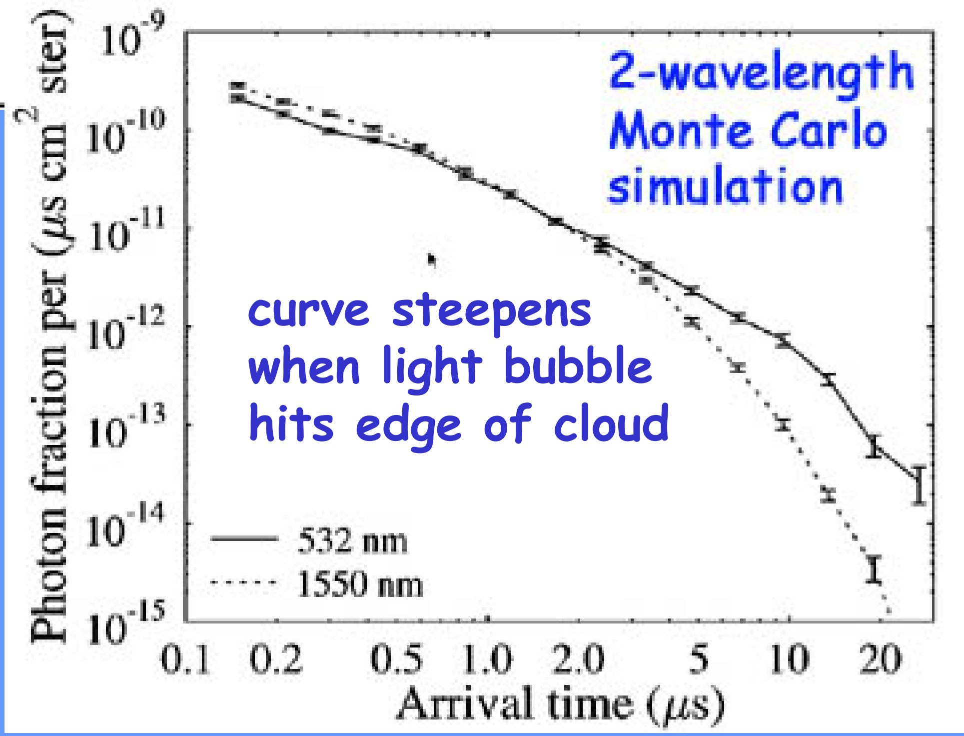
- CIRPAS has video/digital capabilities

Additional Instruments

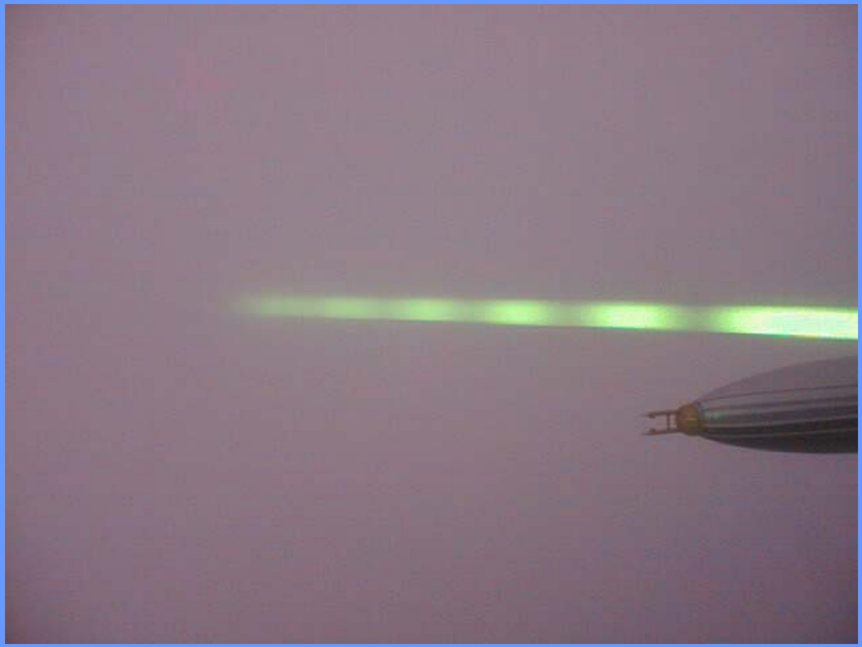
- In-situ lidar from SPEC
- Profiles of LW, PWV and temperature from CU
- Both would make good additions to project, require IOP-Rs

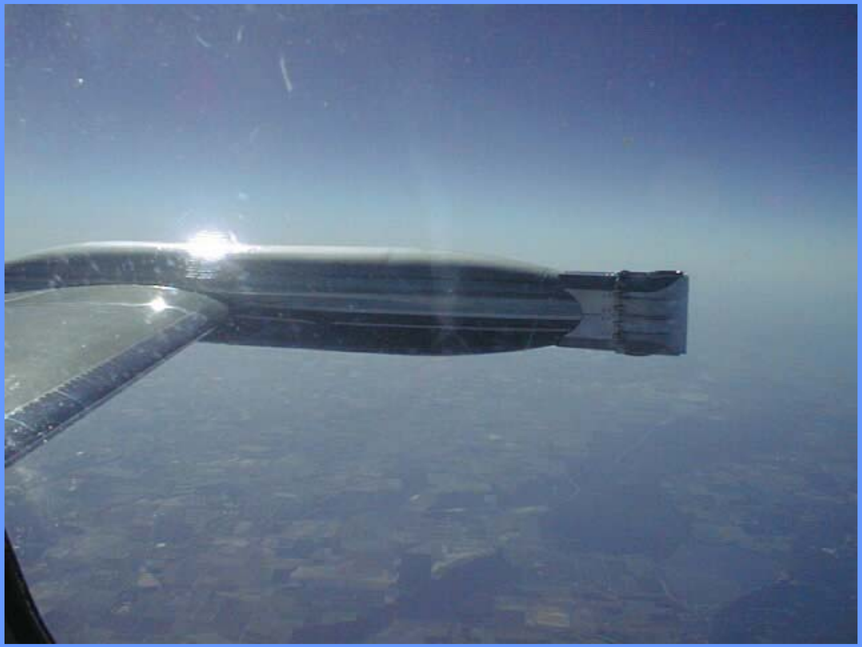
In situ lidar senses extinction in expanding spheres around aircraft





Maiden flight of in situ lidar





Proposal for Airborne Measurement of ILW, PWV and TP during ARM RACORO 2009 or Azores 2009 using Microwave Radiometry

A.J. Gasiewski
Vladimir Irisov
Vladimir Y. Leusky
Ed R. Westwater

CET CIRPAS Radiometers

- A dual-channel (23/31 GHz) cloud/water vapor radiometer and scanning 5-mm temperature profiling radiometer exist for ready integration onto the CIRPAS TO:
  - The dual-channel radiometer occupies a fairing that integrates onto a starboard window of the TO, and measures integrated cloud liquid water and precipitable water vapor both above & below the A/C
  - The scanning 5-mm temperature profiling radiometer integrates into a port-side wingtip pod and measures temperature profiles above and below the A/C
  - Either or both instruments are proposed for integration on the proposed RACORO or Azores ARM deployments in 2009 and autonomous operation

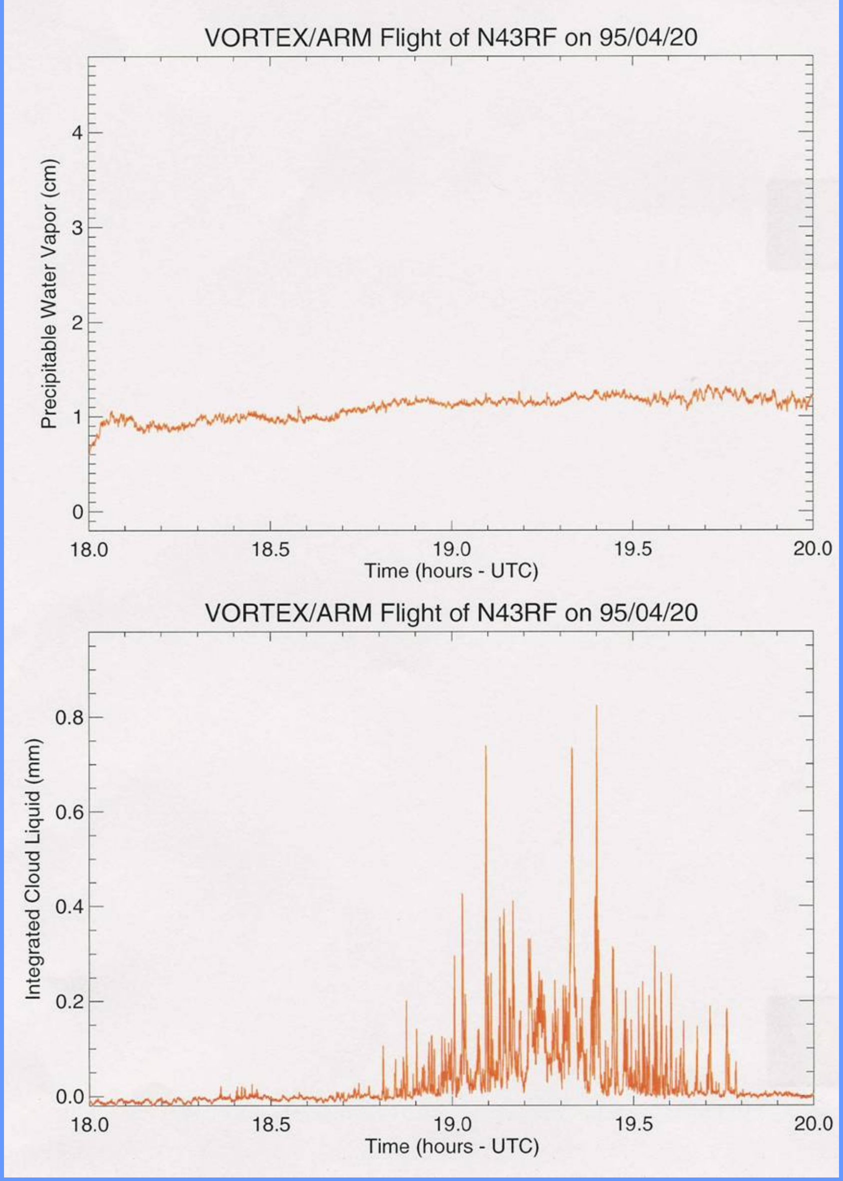
Dual-Channel (21/31 GHz) Radiometer

Starboard side fairing – Shoaling Waves Experiment (1999)

Seeking Photos from Archive…

Dual Channel Radiometer on NOAA WP-3D

Dual Channel Radiometer Retrievals

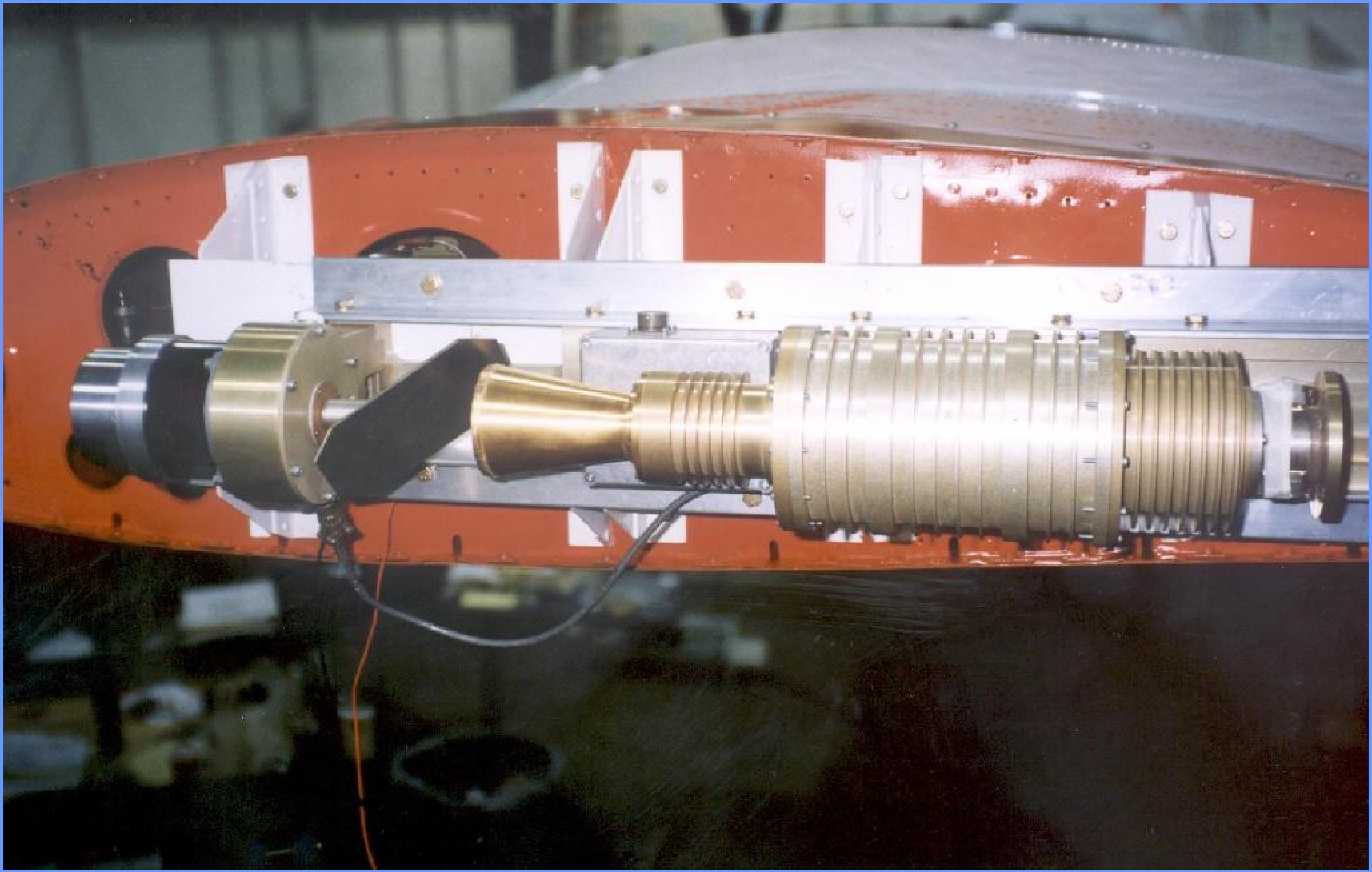


Scanning 5-mm Temperature Profiler

Port side wing tip – Shoaling Waves Experiment (1999)

Scanning 5-mm Temperature Profiler

Port side wing tip – Shoaling Waves Experiment (1999)

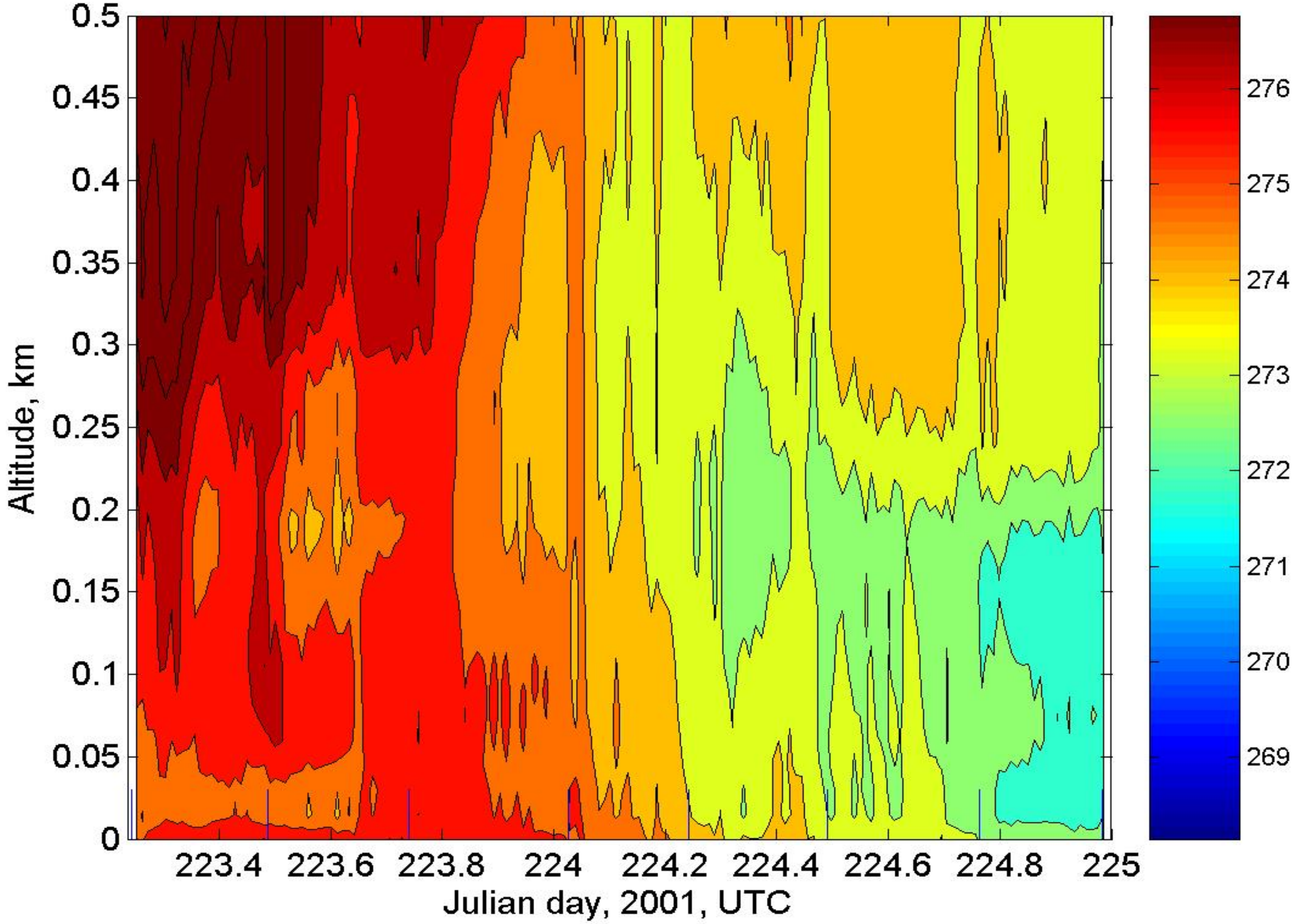


Scanning 5-mm Temperature Profiler

Shoaling Waves Experiment (1999)

Retrieved Temperature Profiles

Ship Based Temperature Profiles measured using the Scanning 5-mm Radiometer



Summary

• Extended deployment of either or both of the dual-channel and scanning 5-mm radiometers is proposed for inclusion during RACORO 2009 or the Azores 2009 ARM deployments under an ARM IOP-R.

• All hardware has been integrated and successfully flown on the TO during the Shoaling Waves Experiment in 1999. All hardware exists and is owned and managed by CU CET.

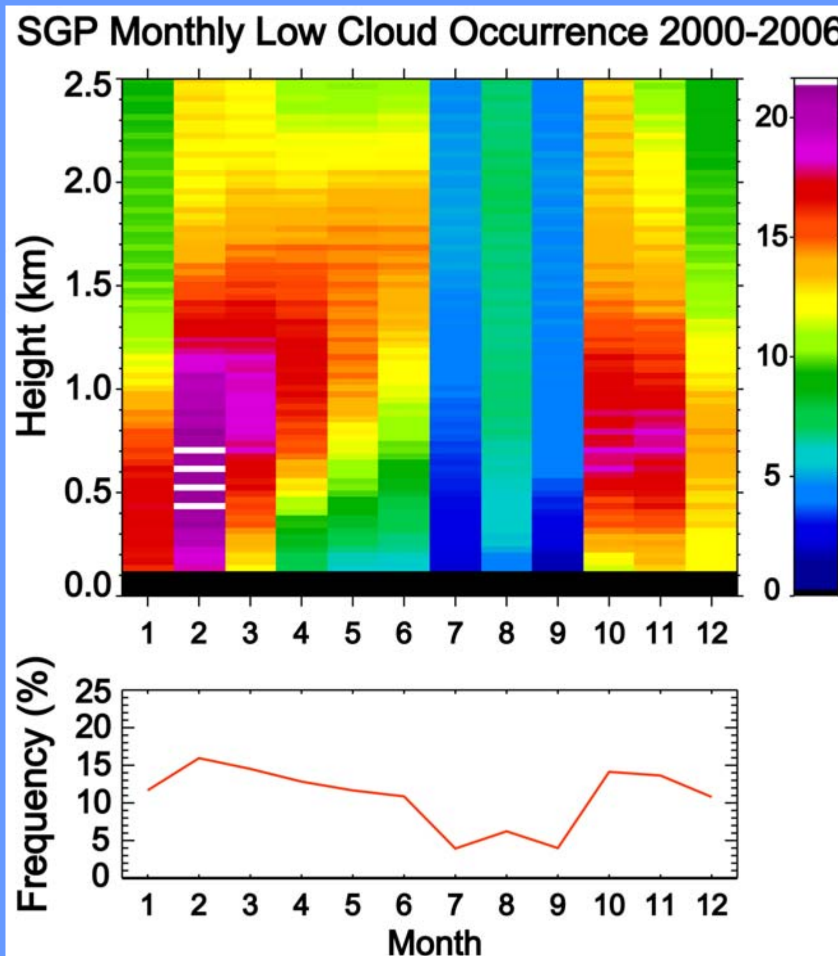
• Retrieval and calibration algorithms have been improved since the sensors were last used, and computer equipment for autonomous operation has been developed and will be integrated with these sensors.

Atmospheric Radiation Measurement Program

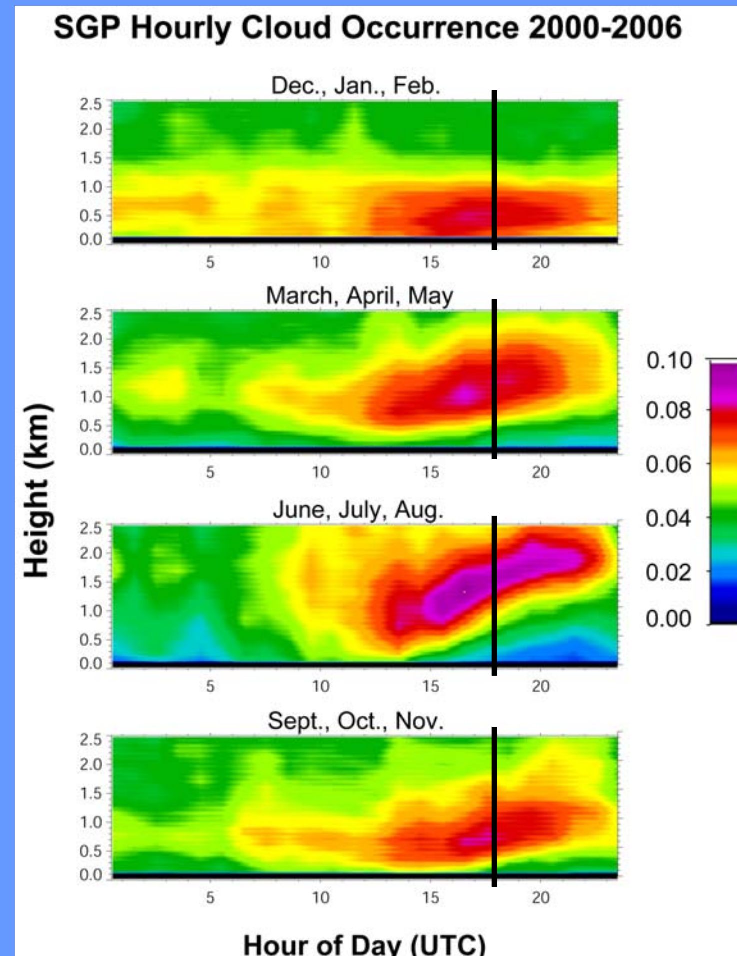
Discussion Items

- Down month selection
- Flight times
- Flight patterns

ARM Atmospheric Radiation Measurement Program



Seasonal frequency of SGP low Clouds



Diurnal cycles of SGP low clouds per season.

Courtesy Jen Comstock

ARM Atmospheric Radiation Measurement Program

Flight Timing

Example Season #1: 12 Weeks Starting 1 January

Week Number	Month Number	Week Departure Time	Comment
1	**Month 1**	8 AM	Progress 1 hr each week to capture the cloud frequency maximum in the early morning
2		9 AM	
3		10 AM	
4		11 AM	
5	**Month 2**	Noon	High solar zenith angle, which is between Terra and A-Train overpasses (1030, 1330)
6		Noon	
7		Noon	
8		Noon	
9	**Month 3**	3 PM	Later afternoon statistics
10		3 PM	
11		9 PM	Nighttime statistics (evening and morning)
12		6 AM	

Go/No-go & Delay Decisions

- **Flight safety**
- **Cloud Coverage < 10%**

Flight Pattern Considerations & “Rules”

- Flight patterns will use
  - ➢ Long, straight legs in
  - ➢ Simple flight configurations,

  Minimizes in-flight pilot decisions and potential sampling biases.
- Deviations from pre-determined legs only when a shift would significantly increase the cloud sample without biasing it.
- Sampling of cloud fields at multiple vertical levels.
- Spiral descents over the CF.