ER-2 in TC-4
science, objectives, logistics

ER-2 instrument team:

G. Heymsfield, M. King, J. Myers, M. McGill, P. Pilewskie, J. Wang, F. Evans, A. Bucholtz, R. Hood, H. Revercomb

&

P. Newman, S. Platnick

TC-4 Science Team Meeting

April 25, 2007

Outline

- ER-2 overview
- TC4 payload
- Instrument descriptions
- Integration & Test strategy

Key personnel

Project office lead: Marilyn Vasques

Project office ER-2 lead: Mike Gaunce

ER-2 mission manager: Mike Kapitzke

ER-2 lead pilot: Dave Wright

Mission scientists: P. Newman, S. Platnick

NASA ER-2
Airborne Science Program
Dryden Flight Research Center

Aircraft: 2 Crew: 1 pilot

Length: 62 ft., 1 in. Wingspan: 103 ft., 4 in.

Payload: Nose (600 lbs.), Q-bay (750 lbs.), Wing pods (1360 lbs.), Centerline pod (350 lbs.)

Cruising altitude: ~ 70,000 ft., 20 km (increases as fuel is burned off)

Cruising speed: ~ 410 knots, 210 m-s^{-1}, 12.6 km-min^{-1}, 756 km-hr^{-1}

Time to altitude: ~30-45 min depending on payload

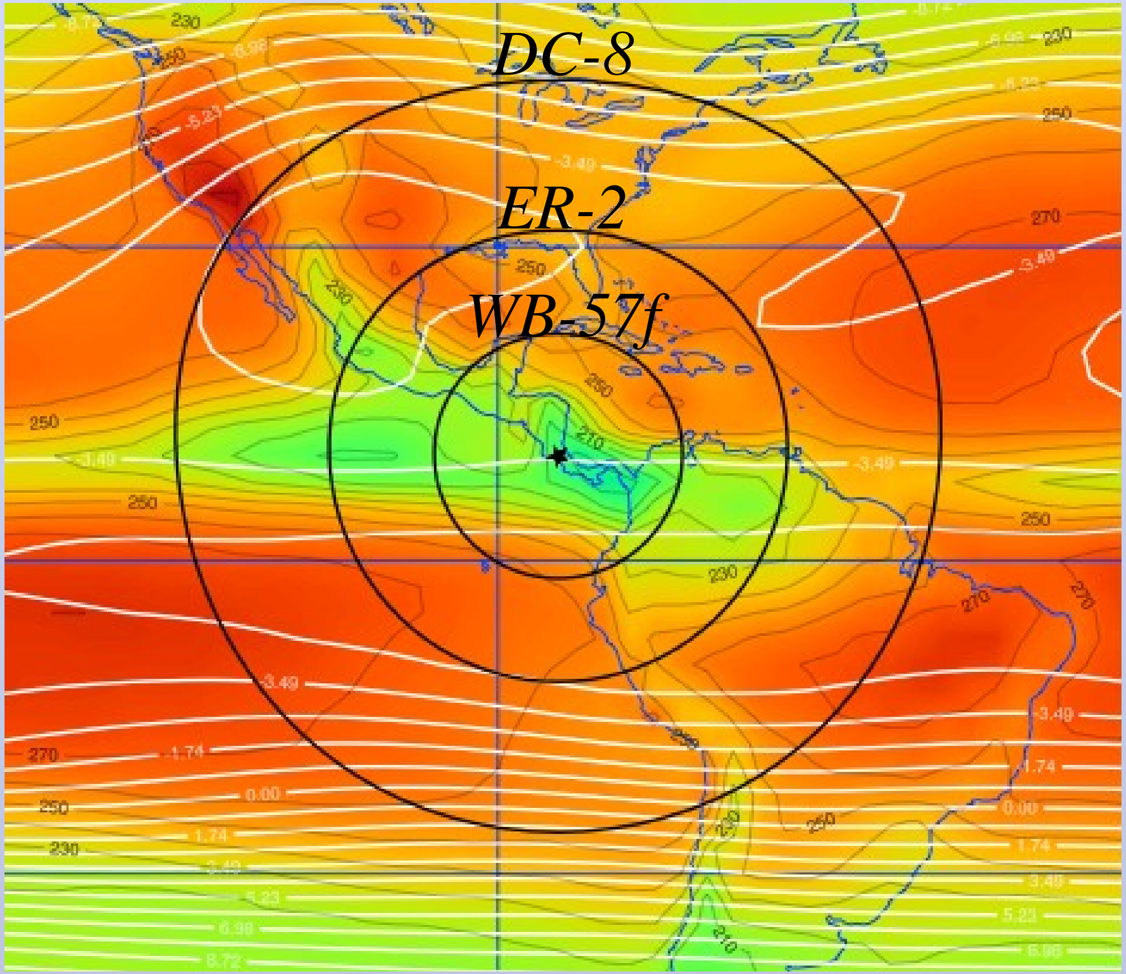
Descent initiated: ~ 30 min prior to landing

Required runway winds: < 15 knt crosswind

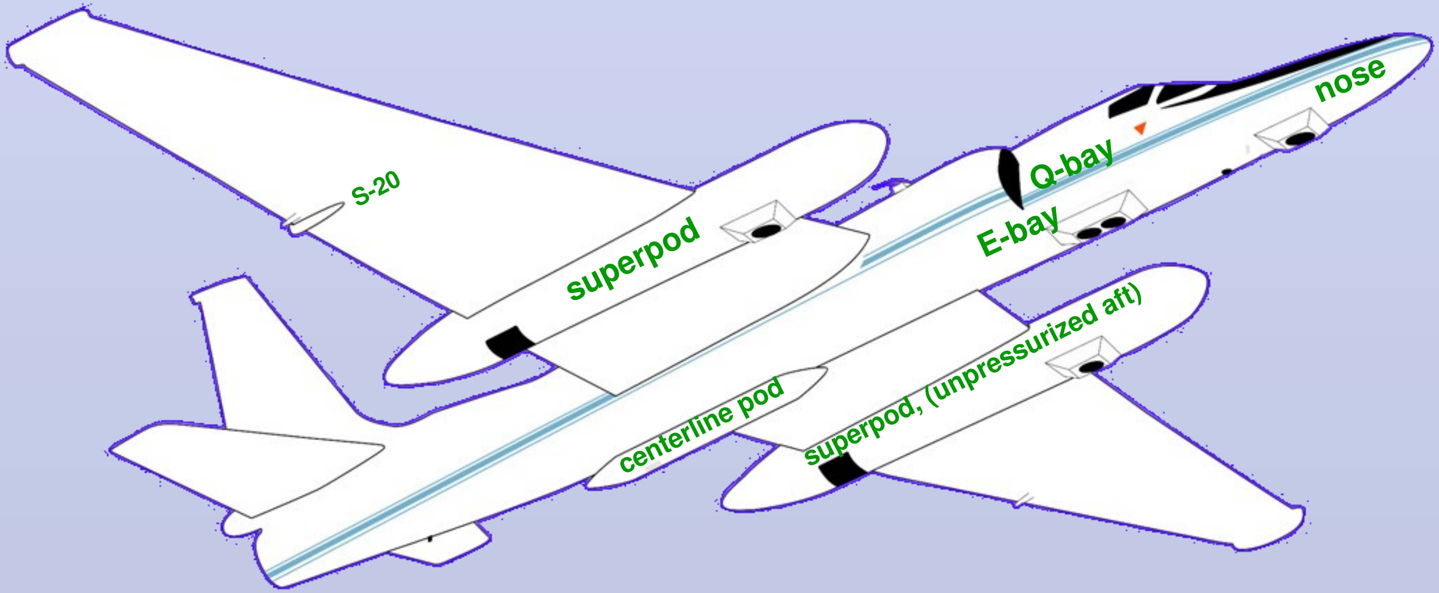
ER-2 mission manager: Mike Kapitzke
ER-2 lead pilot: Dave Wright

Pietersburg, South Africa. August 2000

Aircraft ranges



TC4 ER-2


S-20
superpod
Q-bay
nose
E-bay
centerline pod
superpod, (unpressurized aft)

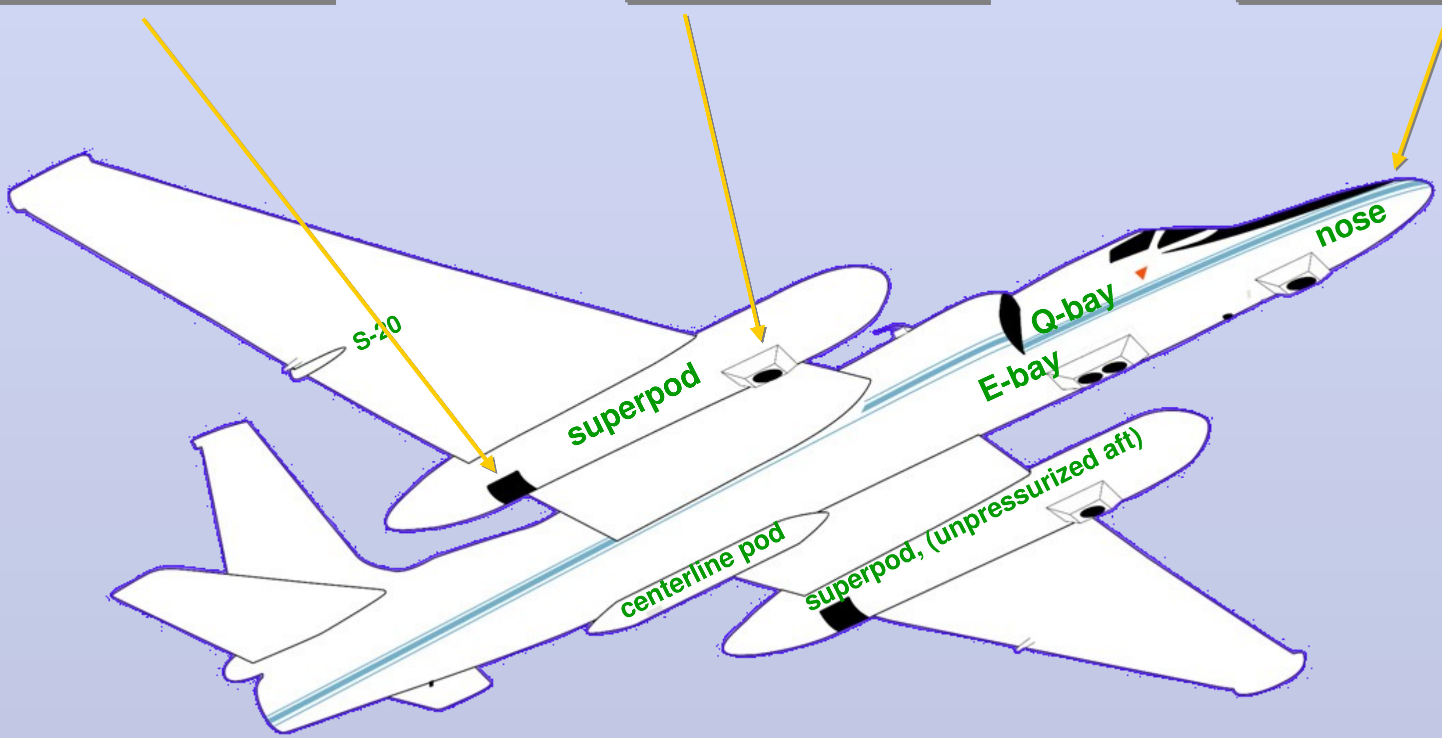
TC4 ER-2 Instrument Payload

Active Sensors

Cloud Radar System (CRS)

Cloud Physics Lidar (CPL)

ER-2 Doppler Radar (EDOP)



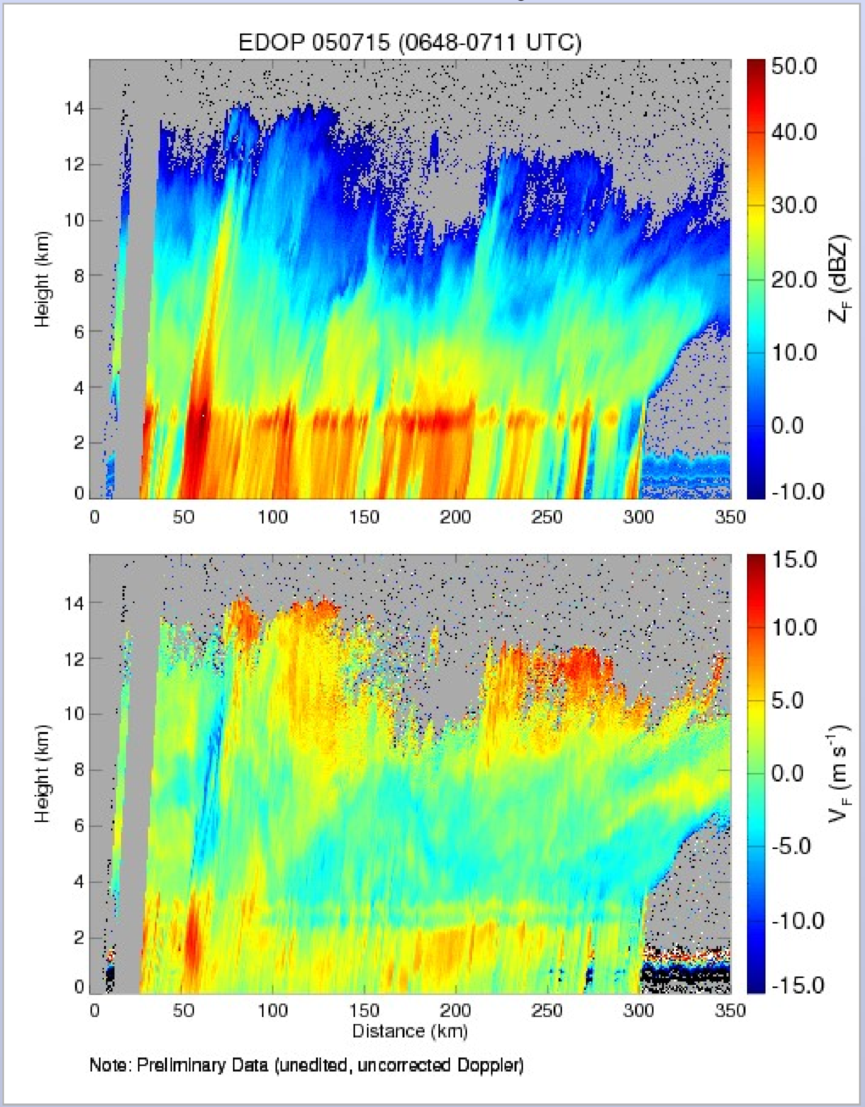
EDOP Nose

G. Heymsfield et al.

ER-2 Doppler Radar (**EDOP**)

- *Frequency:* **9.6 GHz**
- *Location:* SLR Nose
- *Antenna:* 3° fixed **nadir**
  3° fixed **forward** (35°)
- *Measurements:* reflectivity
  Doppler
  Doppler width
  linear depol. (LDR)
- *Resolution:* **37.5 m** vertical
  ~**1.1 km** footprint at surface
- *Sensitivity:* MDS ~ 0 dBZ_e
  (4.4 kHz PRF,
  0.5 s average,
  10 km range)

TCSP, 15 July 2005

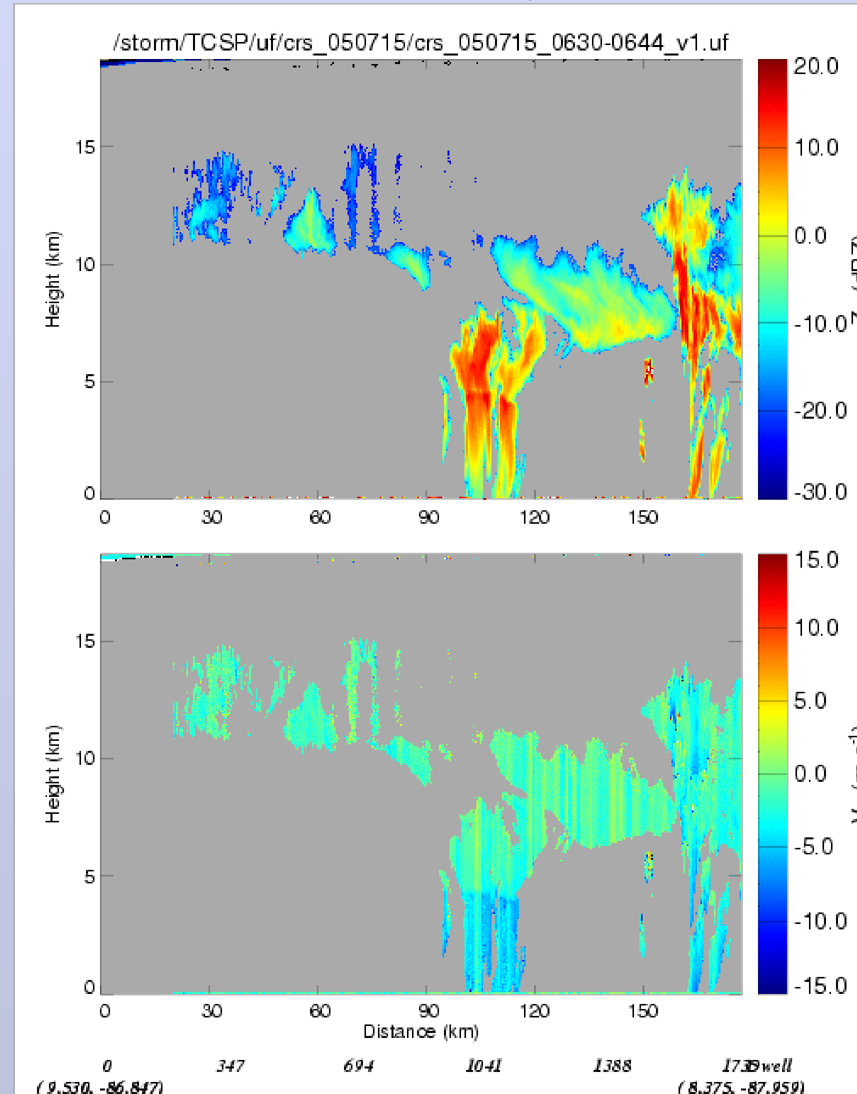


G. Heymsfield et al.

ER-2 Cloud Radar System (CRS)

- *Frequency:* **94 GHz**
- *Location:* superpod aft
- *Antenna:* 0.6° x 0.8° fixed **nadir**
- *Measurements:* reflectivity, Doppler, Doppler width, linear depol. (LDR)
- *Resolution:* **37.5 m** vertical, ~ **300 m** footprint at surface
- *Sensitivity:* MDS ~ -30 dBZ_e (4.4 kHz PRF, 0.5 s average, 10 km range)

TCSP, 15 July 2005



G. Heymsfield et al.

EDOP & CRS data and products

- **In the field**:
  - Quicklook images (*Z*, *v*), selected vertical profiles of *v*, *Z* with preliminary calibration
- **Post-mission**:
  - Calibrate & reformat data into radar Universal Format (UF) readable with IDL libraries.
  - Attenuation and aircraft motion corrections (EDOP); CRS (TBD)
  - Derived products: cloud layer and cloud top heights, *IWC*, vertical air motions, histograms/statistics, along-track (2D) winds
  - ER-2 instrument synergy: **CPL**, **MAS**, **CoSSIR**

Flight coordination & constraint

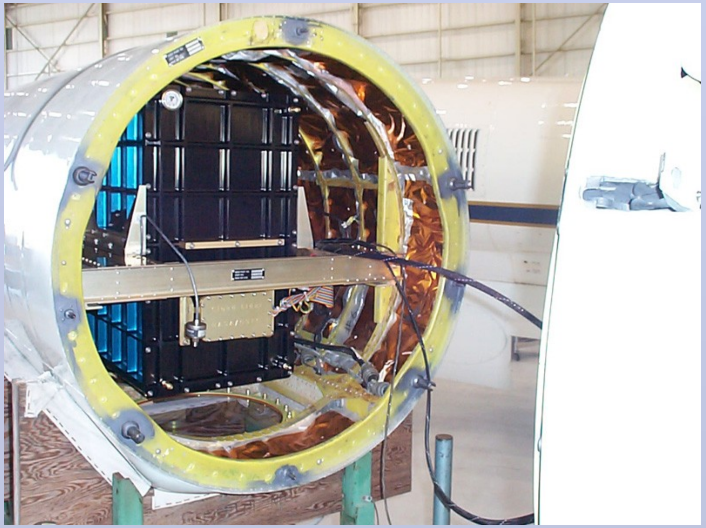
- Straight and level flight legs covering convection and associated anvil.
- Aircraft motions due to course changes and or gravity wave over thunderstorms directly affect Doppler measurements; reflectivity unaffected.
- Radars operate only above 50 kft due to safety considerations.

Cloud Physics Lidar (CPL)

Matthew McGill / Goddard Space Flight Center, Code 613.1
Dennis Hlavka, William Hart / Science Systems & Applications, Code 613.1

CPL is a **3-wavelength lidar** (1064, 532, 355 nm) using solid state photon-counting detectors.

ER-2 campaigns: SAFARI, CRYSTAL-FACE, THORPEX, AVE, CC-VEX



CPL instrument in flight configuration

CPL data products

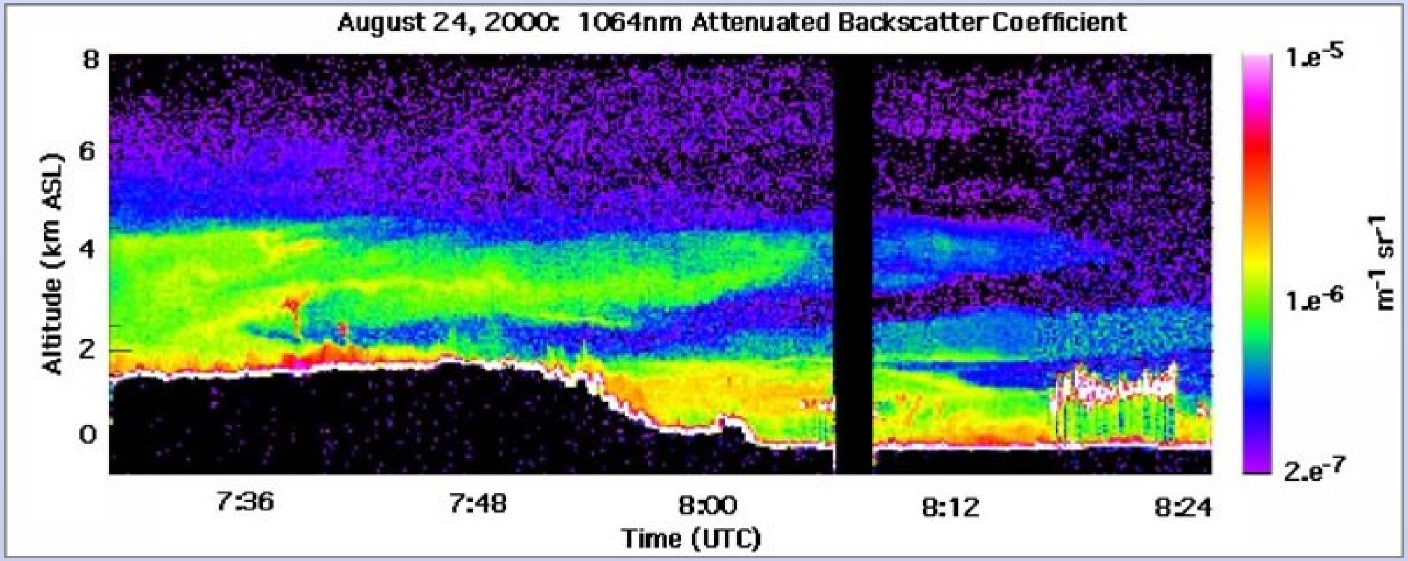
- Quicklook summary images for each flight.
- **Layer boundaries** for PBL, elevated aerosol layers, clouds
- **Optical properties**, including
  - layer extinction-to-backscatter ratio (S) from Rayleigh attenuation
  - layer extinction profile
  - layer optical depth
  - images for extinction and optical depth
  - depolarization ratio
  - layer transmission profile

Preliminary data products available **24 hours after data collection**, *except* extinction profiles which take longer to properly calculate. All data products are 1 second averages produced from the raw 1/10 second data, and for each wavelength (355, 532, 1064 nm).

ER-2 instrument synergy: lidar-radar data combination using Cloud Radar System (**CRS**).

CPL web site: **http://virl.gsfc.nasa.gov/cpl/**

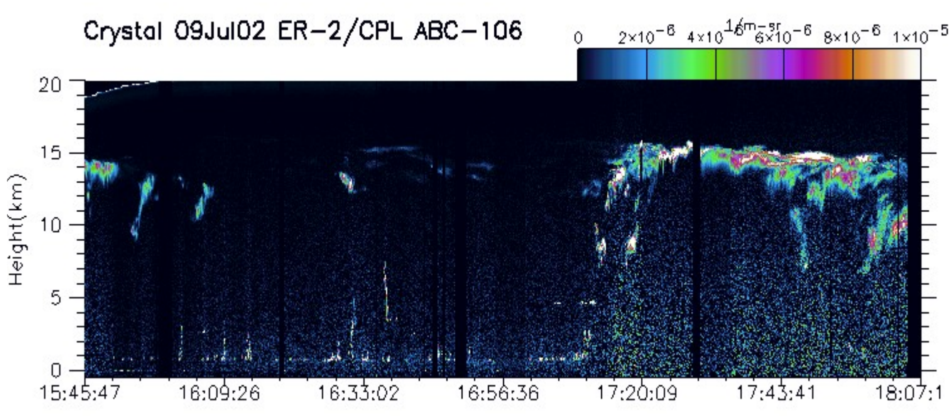
Cloud & Aerosol Profiling, 24 August 2000, SAFARI

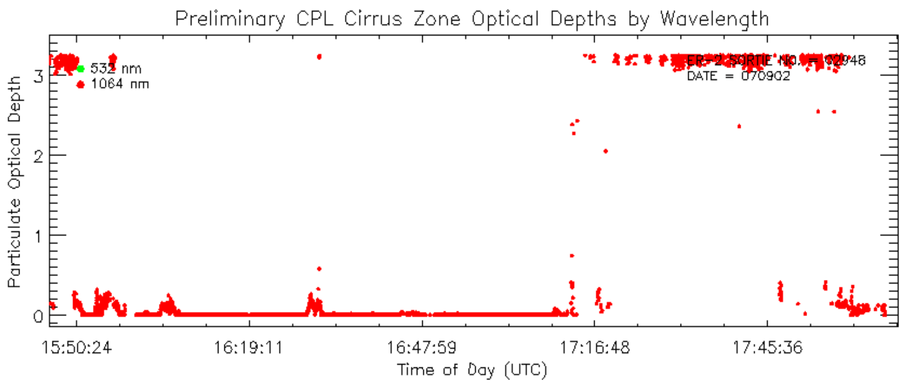


Cirrus Optical Depth Retrieval, 9 July 2002, CRYSTAL-FACE

1064 nm Attenuated Backscatter Profile

Cirrus Optical Depth (0-3.5)

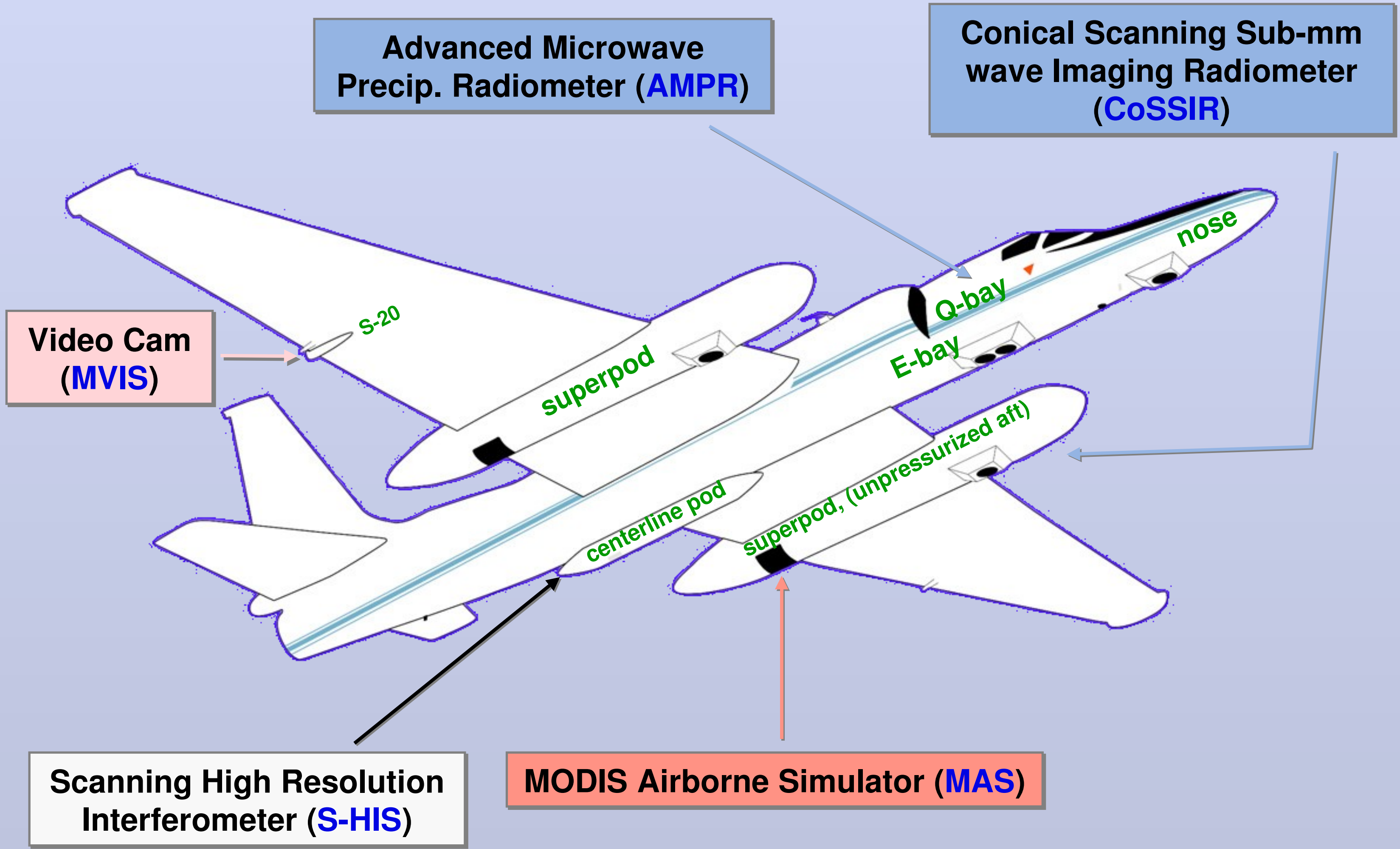




McGill et al.

TC4 ER-2 Instrument Payload

Passive remote sensing instruments



Advanced Microwave Precipitation Radiometer (AMPR)

Dr. Robbie Hood
NASA MSFC

INTRODUCTION:

Multi-frequency microwave imagery at 10.7, 19.35, 37.1, and 85.5 GHz.

Frequencies are well suited to the study of rain cloud systems, but are also useful to studies of various ocean and land surface processes.

AMPR frequencies provide satellite simulations of DMSP Special Sensor Microwave/Imager (SSM/I), the NASA Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), and Advanced Microwave Scanning Radiometer (AMSR-E).

INSTRUMENT DESCRIPTION:

The radiometer and accompanying data system are mounted in the Q-bay.

The radiometer is positioned in the lower Q-bay with the scanning mirror extending below the body of the aircraft into a hatch with a porthole open to the ambient atmosphere.

The data system is mounted above the radiometer in the upper Q-bay section.

The AMPR is composed of two adjacent antenna systems with one large scanning mirror accommodating both systems. One antenna system was designed to use a copy of the SSM/I feedhorn for the three higher frequencies. The second antenna system collects data at 10.7 GHz.

AMPR resolution and calibration

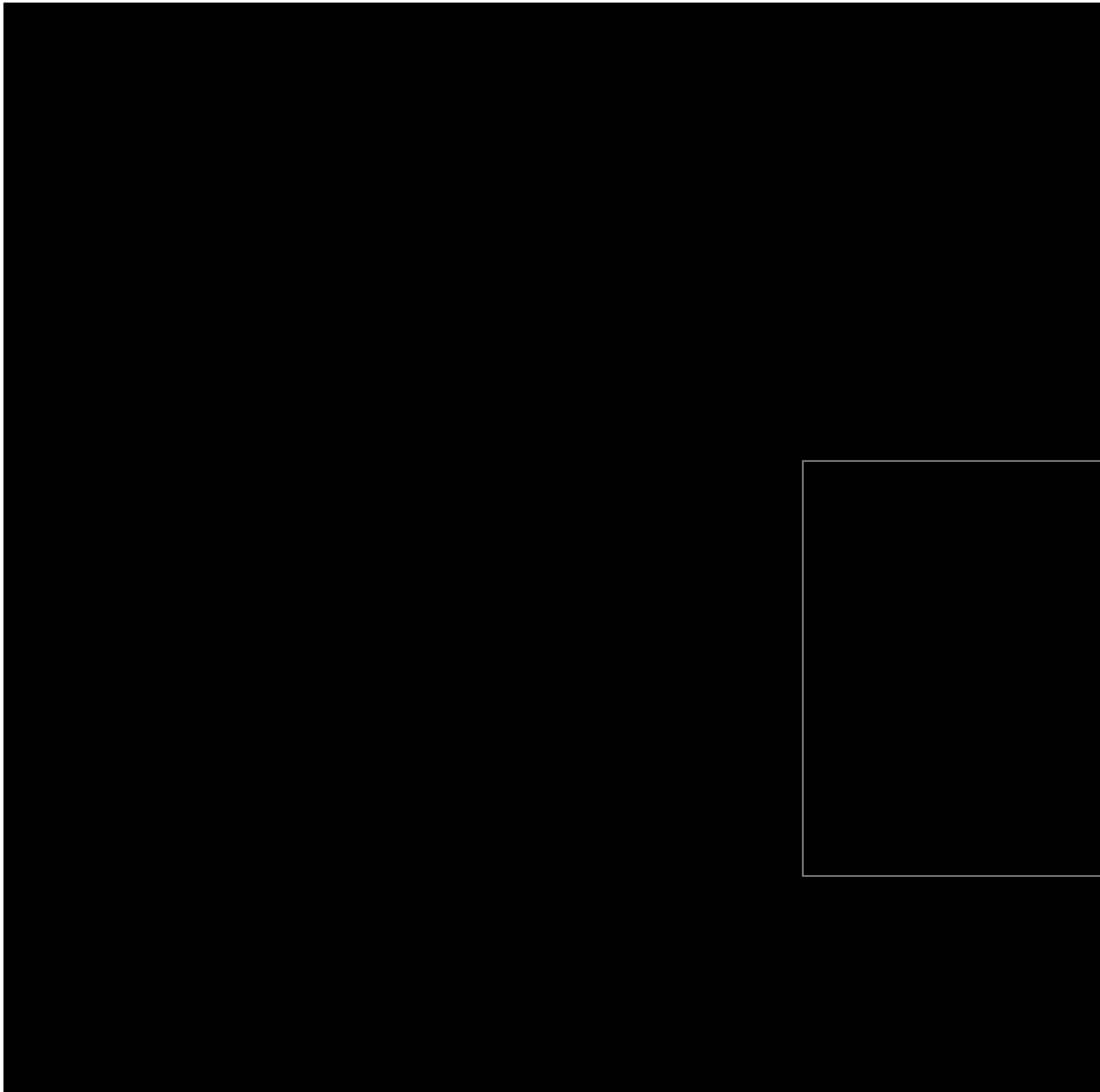
Ground spatial resolution of the nadir footprint from 20 km is 0.6 km for the 85.5 GHz channel, 1.5 km for 37.1 GHz, and 2.8 km for both the 19.35 and 10.7 channels

AMPR calibrates with external cold and warm loads after every fourth data scan.

A total calibration sequence or a total data scan are each performed in a three second time period. The AMPR scanner sweeps through a total 90˚ (±45˚ from nadir) data scan collecting a sample for each channel every 1.8˚ for a total of 50 samples per channel.

Based upon an aircraft altitude of 20 km and an aircraft speed of 200 ms^{-1}, this scan rate yields contiguous footprints for the 85.5 GHz channel within a 40 km wide swath. The other three channels will be over sampled. The alignment of the feed horns has been adjusted such that vertical polarization is received 45˚ to the left of nadir and horizontal is received 45˚ to the right of nadir. An equal mixture of vertical and horizontal polarizations is received at nadir.

AMPR



[redacted] strip images depict
[redacted] orm with a large
[redacted] a cirrus anvil
[redacted] en in four radio
[redacted] by AMPR aboard

Scanning HIS: 1998-Present
(High-resolution Interferometer Sounder, 1985-1998)

H. Revercomb et al.

U. Wisconsin

Characteristics

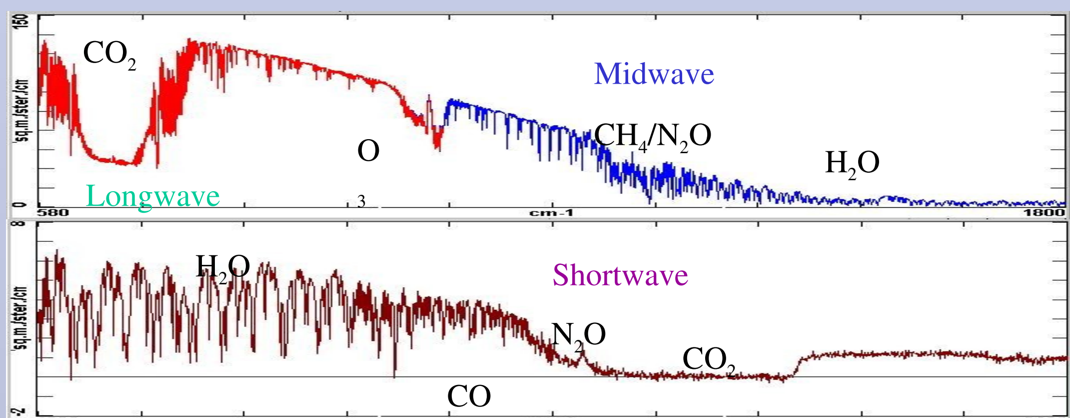
Spectral Coverage: 3.3-17 microns

Spectral Resolution: 0.5 cm^{-1}

Resolving power: 1000-6000

Footprint Diam: 2.0 km @ 20 km

Cross-Track Scan: Programmable including uplooking zenith view



Applications:

- Radiances for Radiative Transfer
- T & WV Vapor Profiles
- Cloud Radiative Prop.
- Surface Emissivity & T

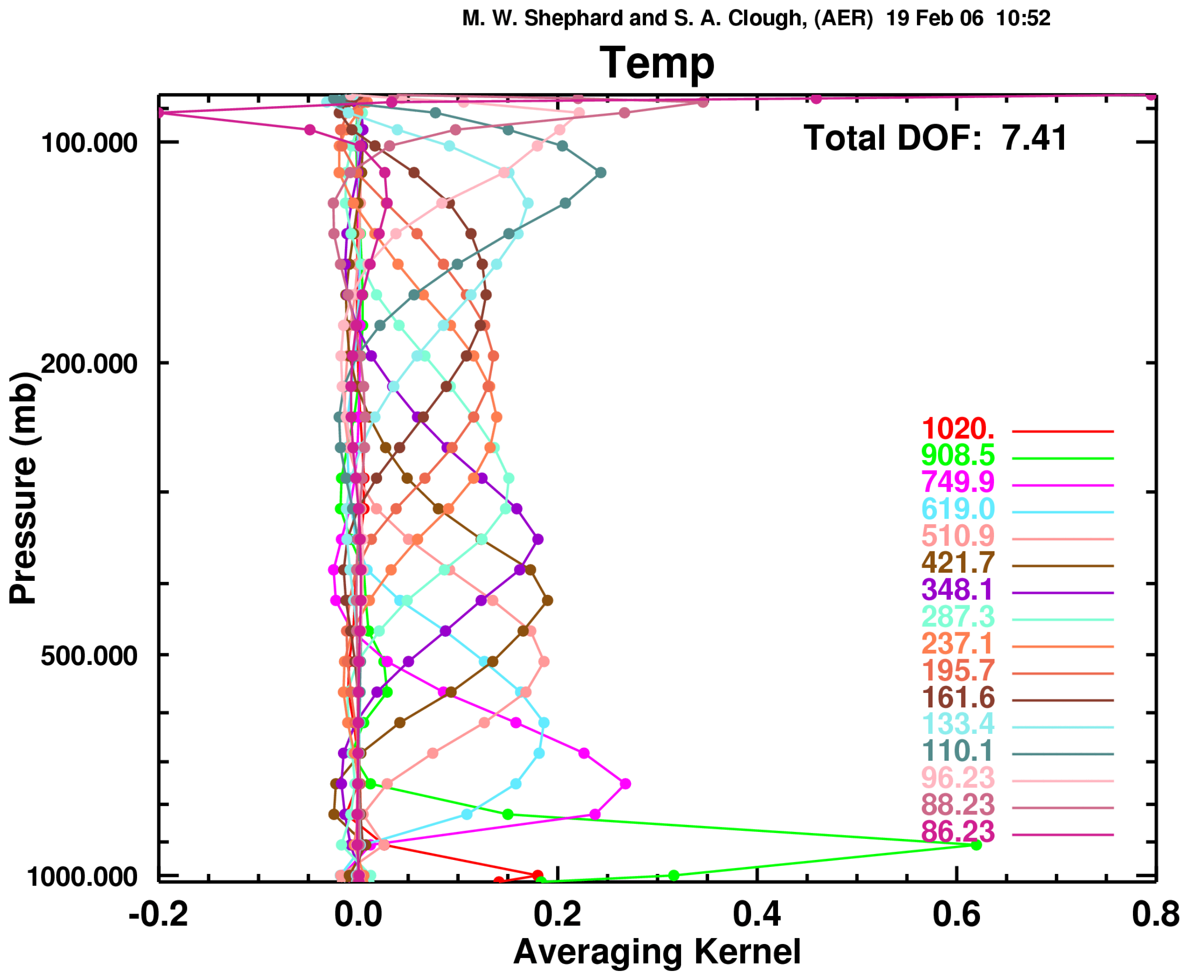
Temperature Averaging Kernels for S-HIS

100 mb

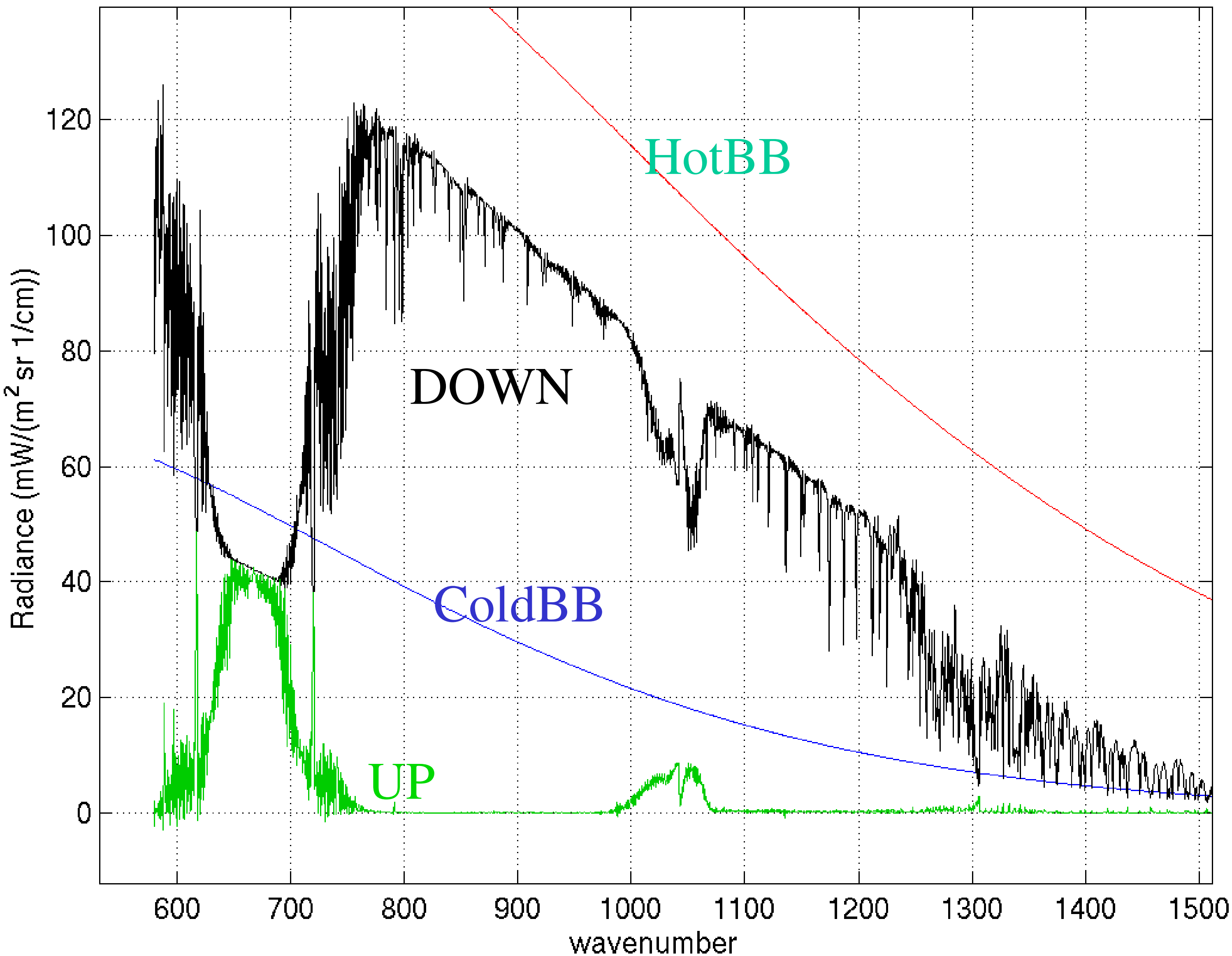
200 mb

500 mb

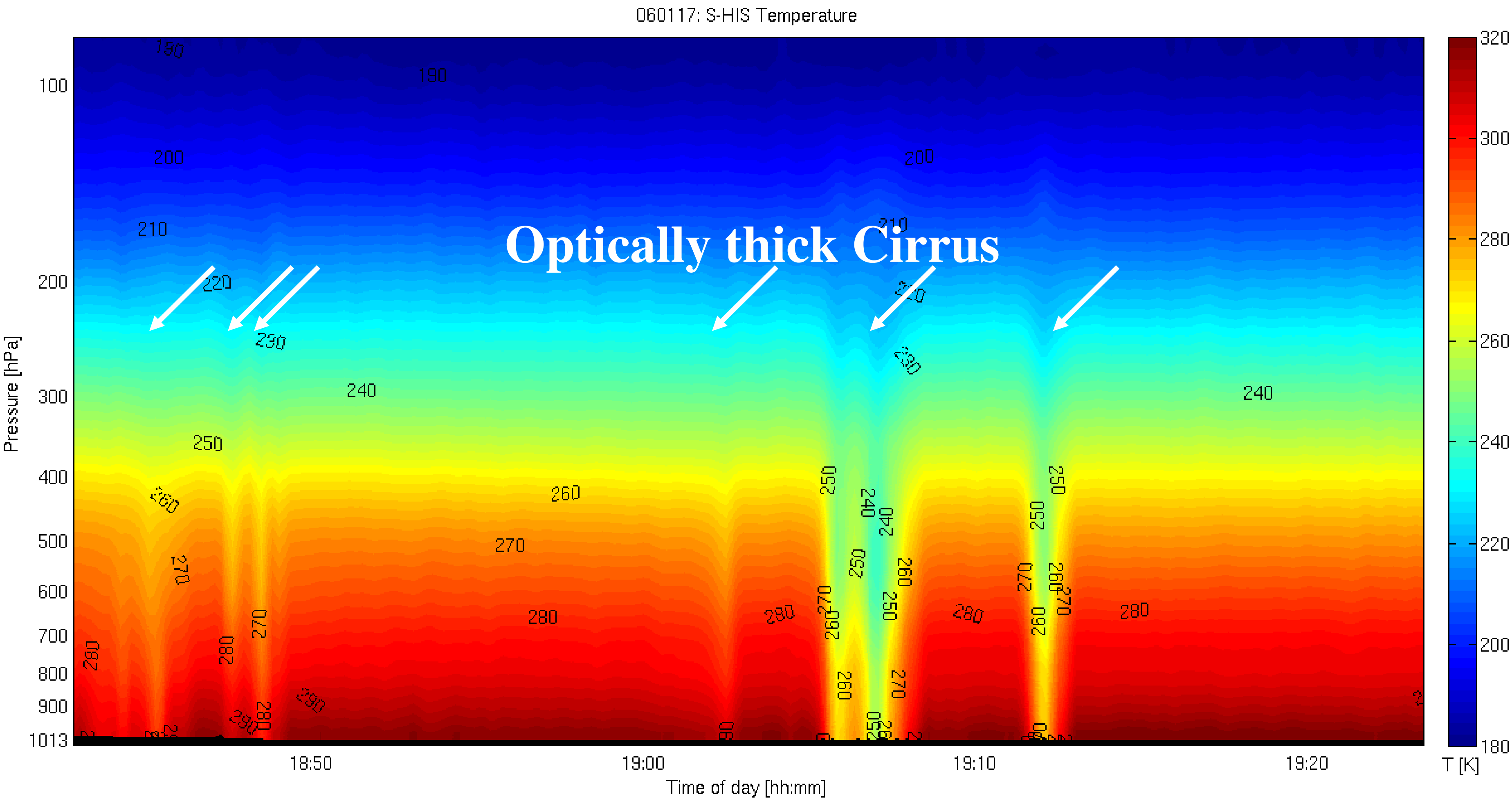
1000 mb



S-HIS zenith and cross-track scanning Earth views

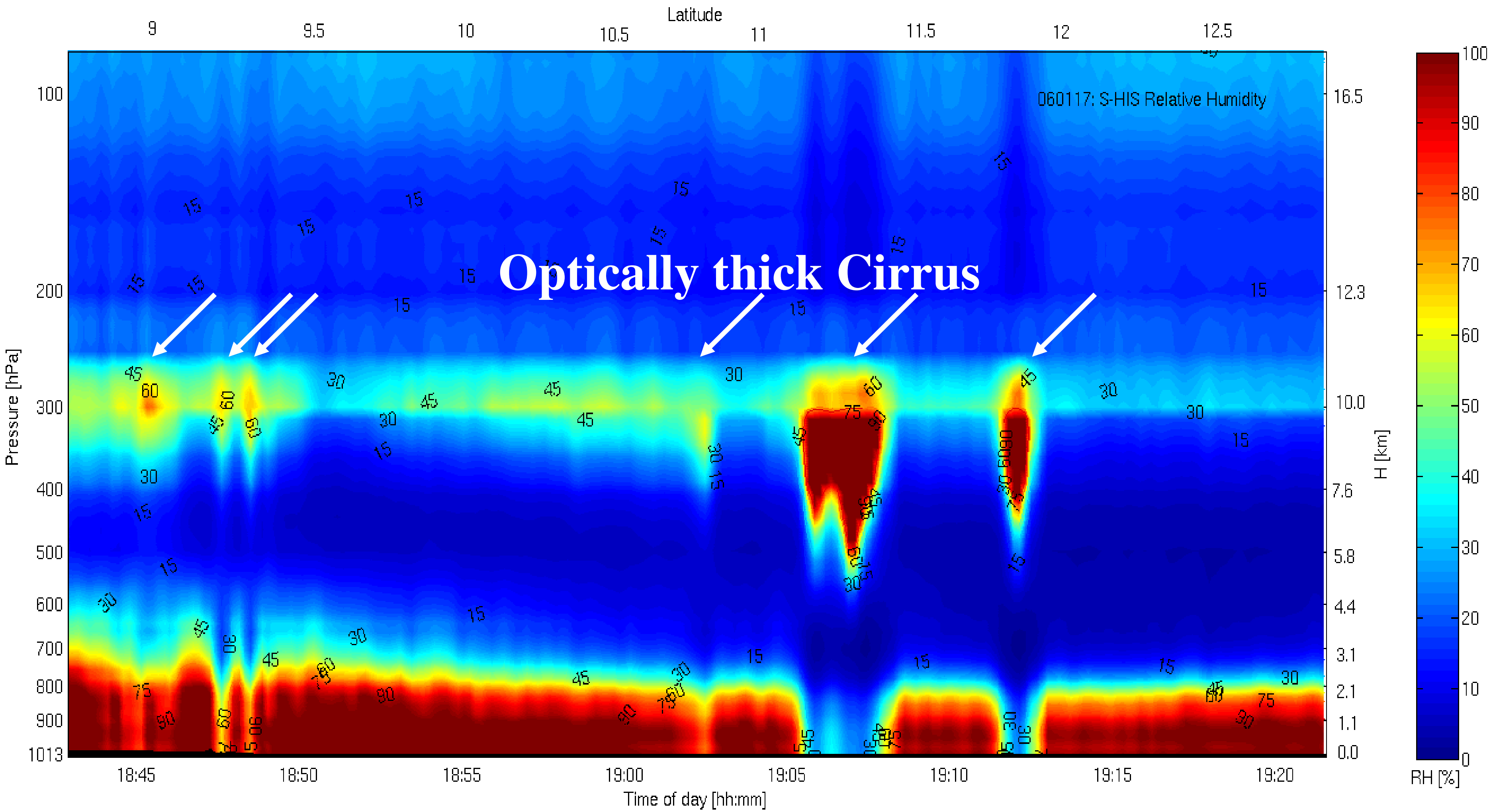


Scanning HIS Temperature Retrieval
from TES Flight on 17 January 2006



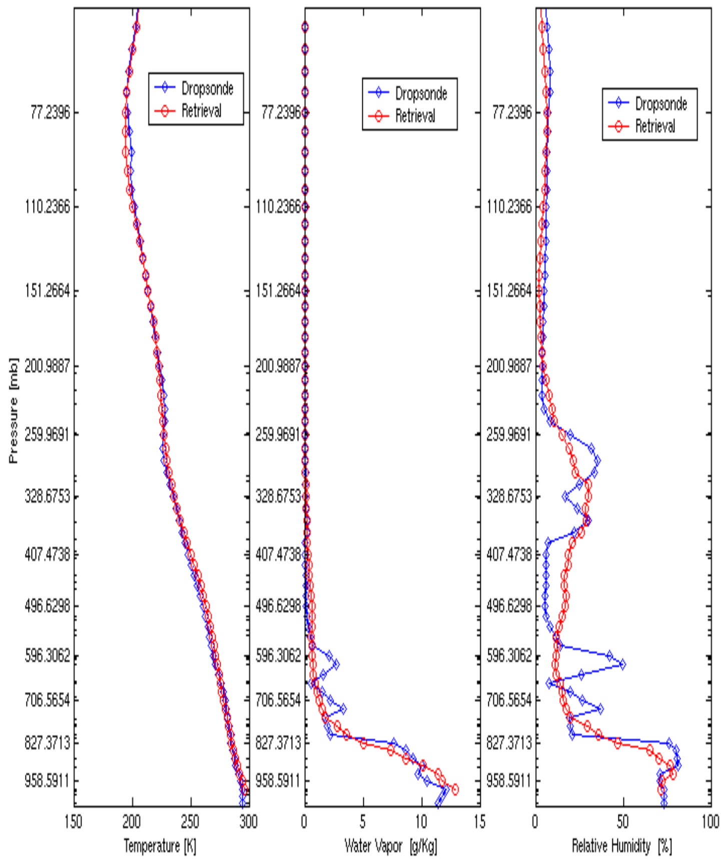
Scanning HIS Relative Humidity Retrieval

from TES Flight on 17 January 2006

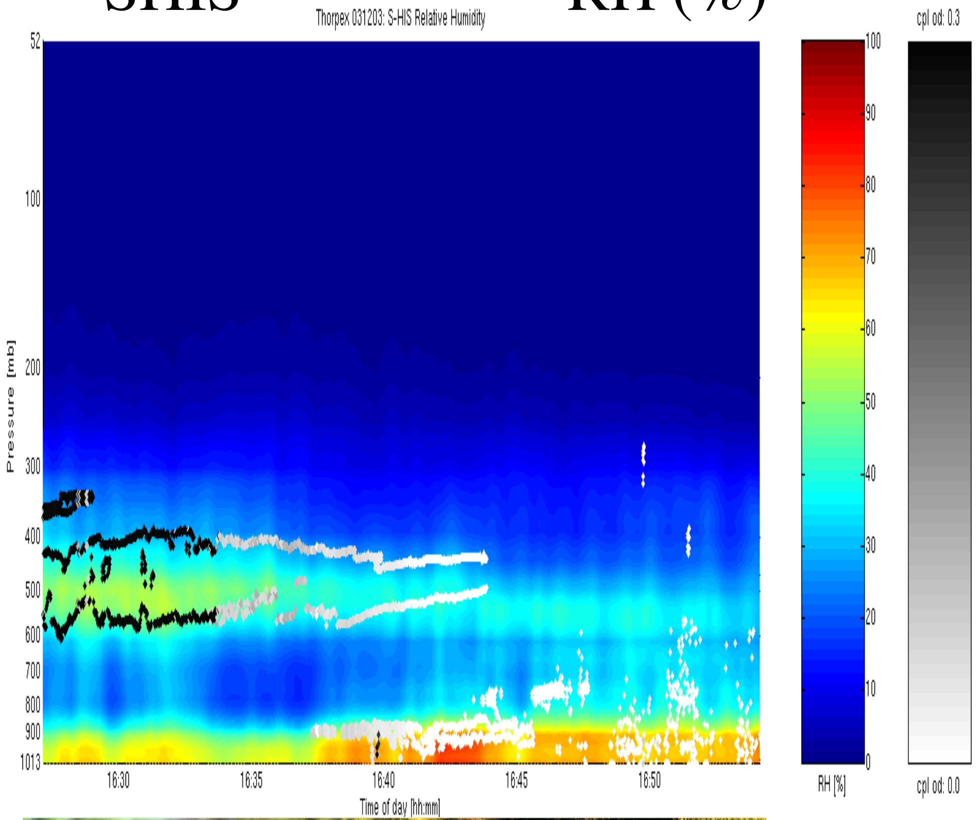


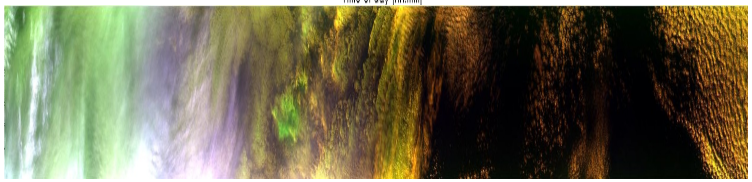
S-HIS Retrieval of Cloud Boundaries and CPL

Dropsondes & Retrieval



SHIS RH (%)





MAS

Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)

J. R. Wang [1], K. F. Evans [2], B. Monosmith [1]

[1] NASA/GSFC, [2] U. Colorado

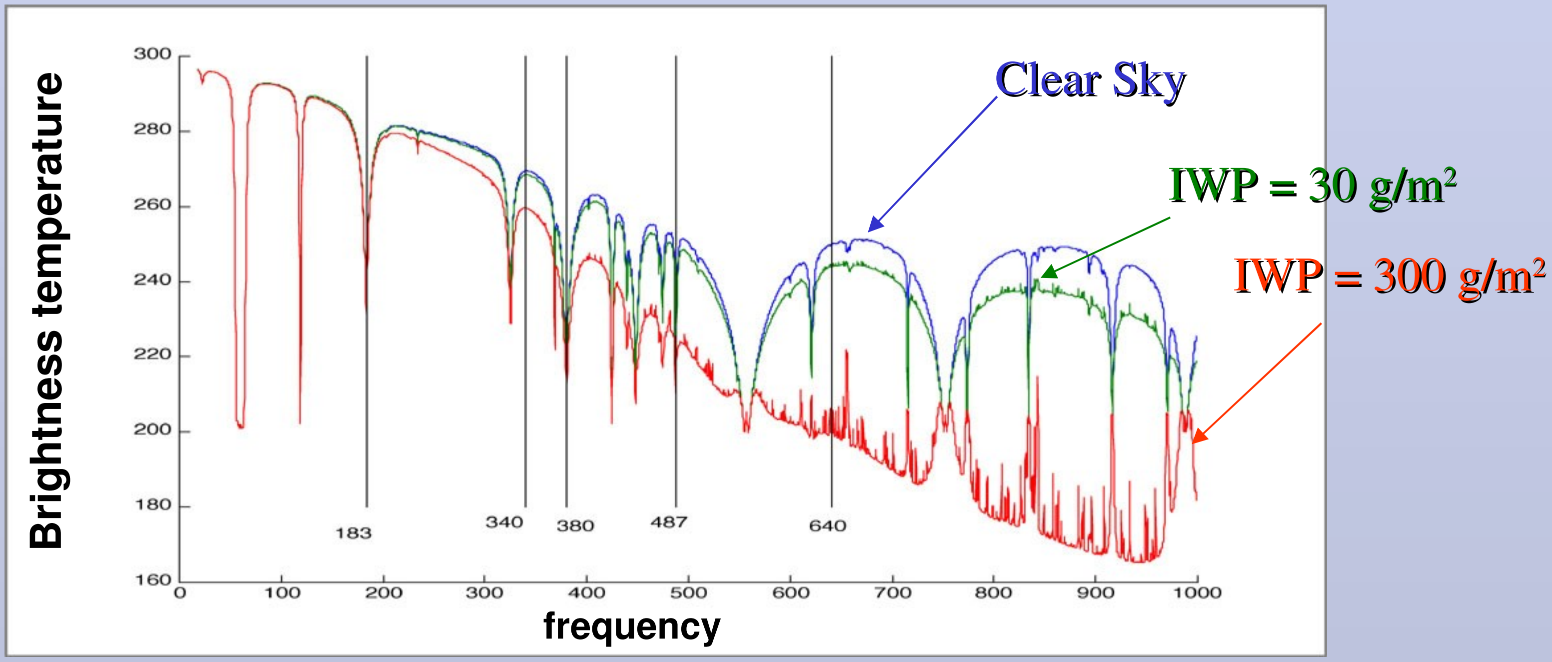
Scientific Objectives:

- Develop and evaluate a promising **new** cirrus remote sensing techniques
- Provide accurate cirrus **retrievals**, **with error bars**, for validation of existing satellite cirrus sensing algorithms (e.g., from MODIS).
- Provide **water vapor profiles** and cirrus ***IWP*** (Ice Water Path) and $\boldsymbol{D_{me}}$ (median mass diameter) to the TC4 community for constraining cirrus cloud models
- Measure **spatial pattern** of *IWP* and D_{me} from the edge of anvil to precipitating regions to improve understanding of the connection between deep convection and the the production of anvil cirrus.

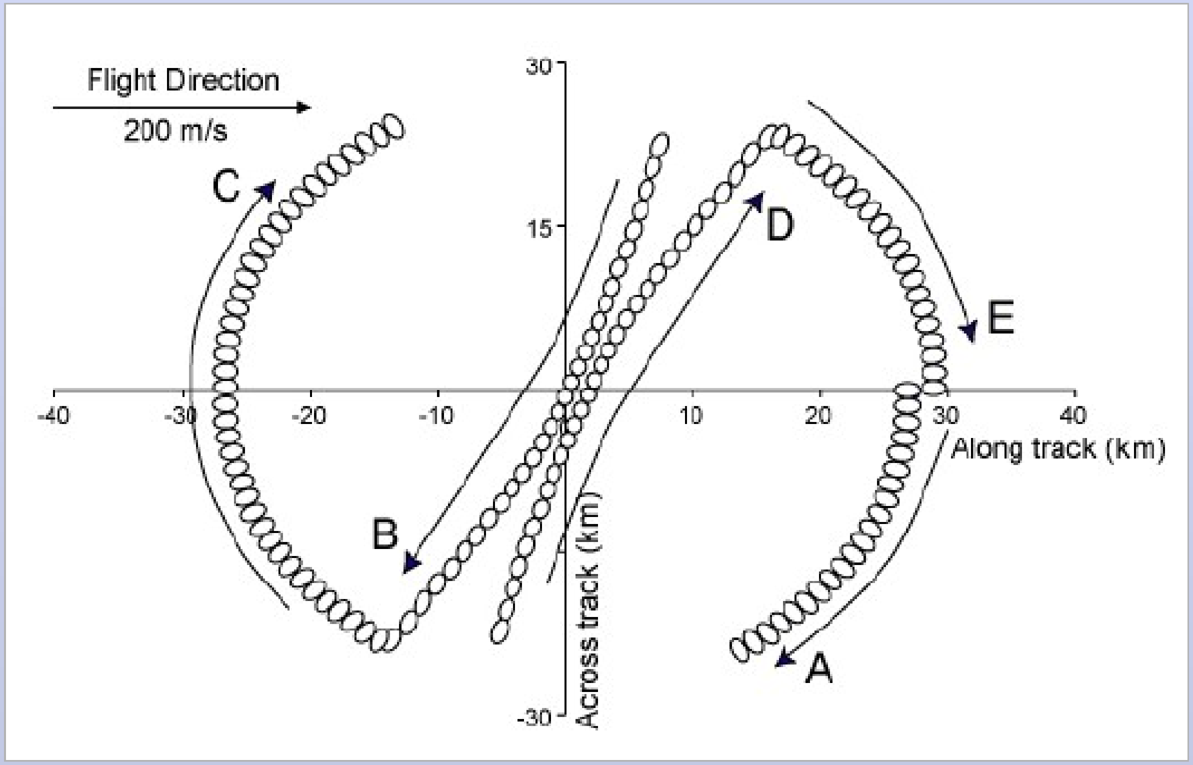
CoSSIR: 11 channels between 183-874 GHz

f (GHz) *physics*	Channels (GHz)	Polarization
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Modeled Response of Upwelling Radiation to Cirrus Clouds



Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)

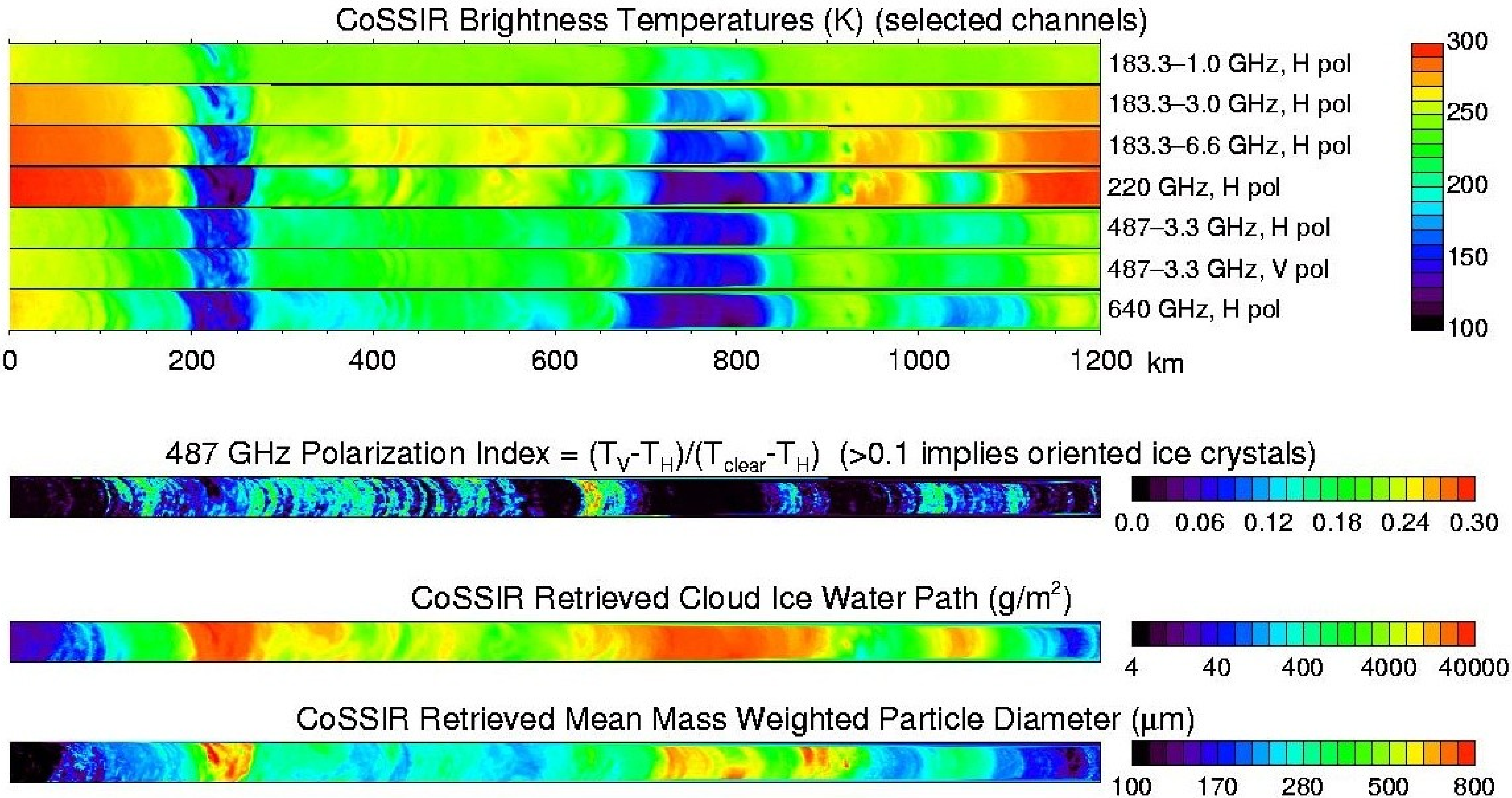


Scan Geometry includes conical
and cross-track (~ 10s repeat)

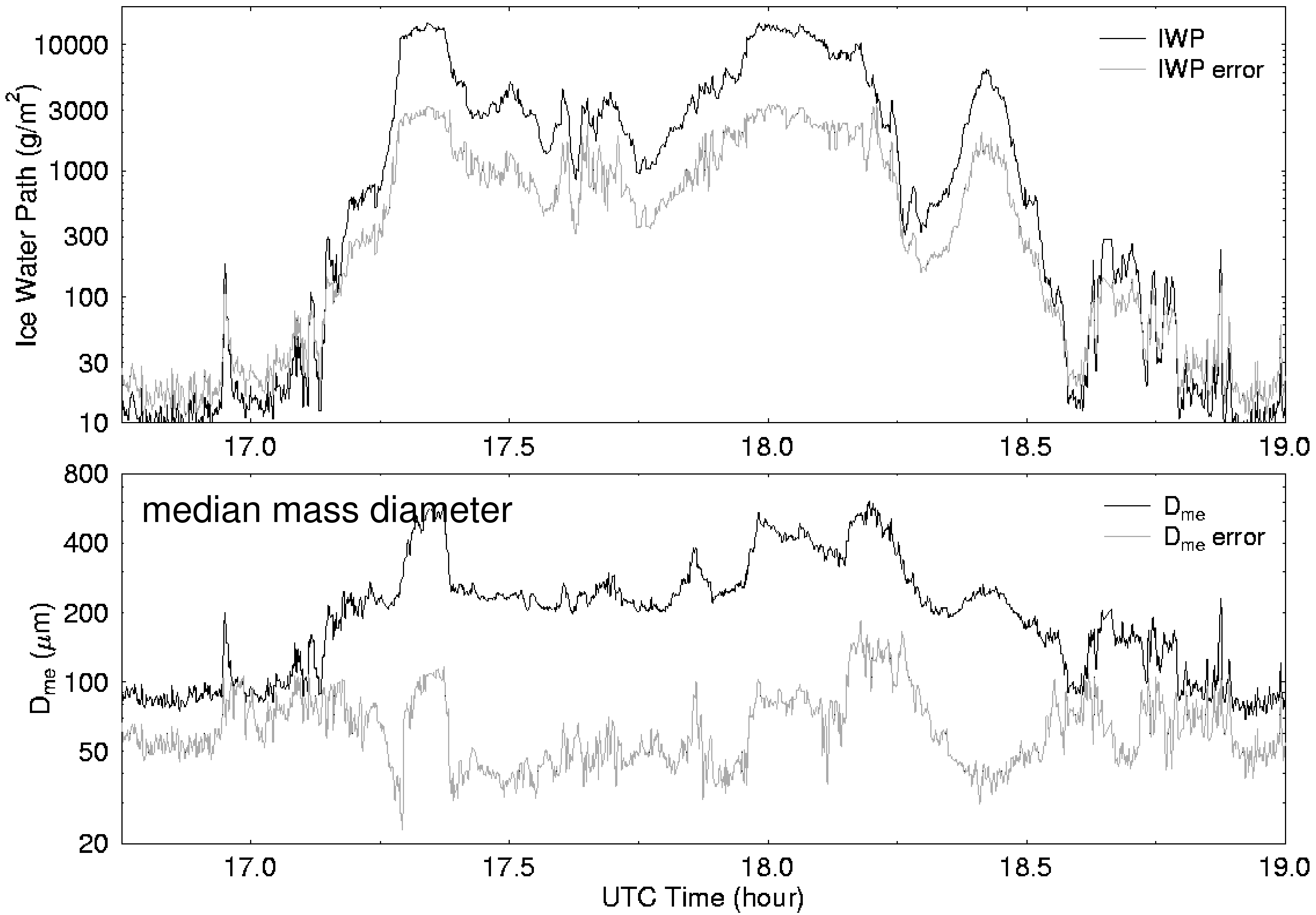
FOV: 1.4 km at nadir, 2.3x3.9 km at 53° scan
Swath: ~ 46 km

Compact Scanning Submillimeter-wave Imaging Radiometer

Results from CR-AVE (January 27, 2006)



CoSSIR Retrieved Nadir IWP and D_{me}



MODIS Airborne Simulator (MAS)

M. D. King (NASA/GSFC)

NASA Ames Sensor Facility instrument:

J. Myers, R. Dominguez, M. Fitzgerald, et al.

Sensor Characteristics:

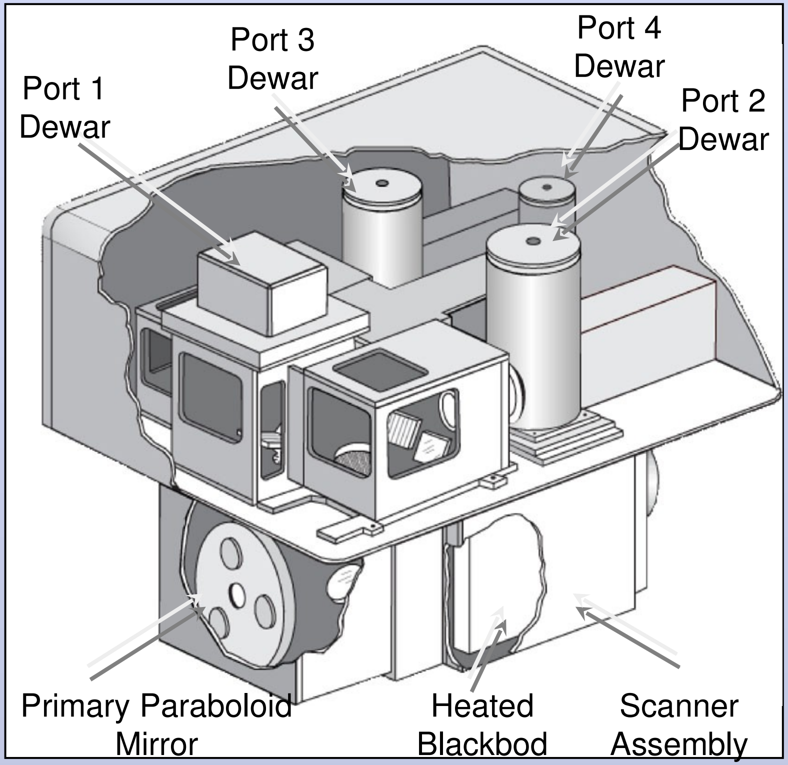
- **50 spectral bands**, from 0.47 to 14.3 µm
- instantaneous field of view: 2.5 mrad, **50 m at nadir** (from ER-2 flight altitude)
- scan ±43°, 716 pixels in scan line, ~ **37km swath**
- scan rate 6.25 Hz, 16 bits per channel, 1.72 GB hr^{-1}
- Calibration:
  - solar bands: integrating sphere
  - thermal: 2 on-board blackbodies

Products: cloud mask (S. Ackerman), thermodynamic phase, optical thickness, particle size (effective radius), and water path

Phase from MAS SWIR spectral features, IR techniques, cloud mask tests

Optical thickness, size, water path use solar reflectance technique, VIS through MWIR

Non-absorbing bands at 0.65, 0.86; absorbing bands at 1.6, 2.1, 3.7 µm



MODIS Airborne Simulator (MAS)

Products: cloud mask (S. Ackerman), thermodynamic phase, optical thickness, particle size (effective radius), and water path

- Phase from MAS SWIR spectral features, IR techniques, cloud mask tests
- Optical thickness, size, water path use solar reflectance technique, VIS through MWIR
  - non-absorbing bands at 0.65, 0.86; absorbing bands at 1.6, 2.1, 3.7 µm

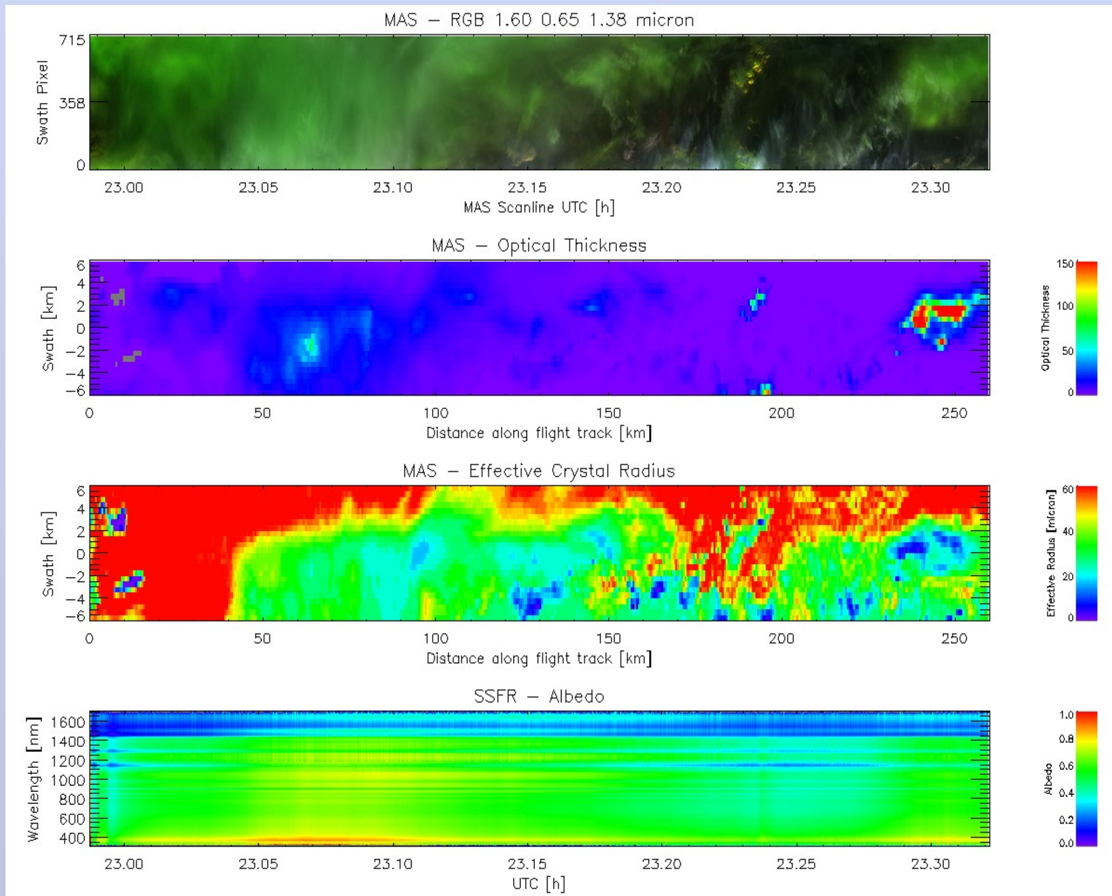
Flight plans: **Aqua/Terra** coordination; **in situ validation**

Field products: preliminary calibration L1B files & quicklook imagery (~24 hrs), selected retrievals (~48 hrs)

TC4 inst. synergy: Cloud *IWP* with **CoSSIR**, **CRS**; LWP with AMPR; τ with **S-HIS**, **CPL;** retrieval consistency with solar spectral flux measurements from **SSFR** (ER-2, DC-8)

MAS CRYSTAL-FACE examples

Figure 2. MAS cloud optical thickness and effective radius, and SSFR albedo along a leg of 350 km (UTC 1835-1902) on July 9, 2002, mostly above a thick cirrus cloud. MAS optical thickness and effective radius are shown for 500 m horizontal cloud resolution.



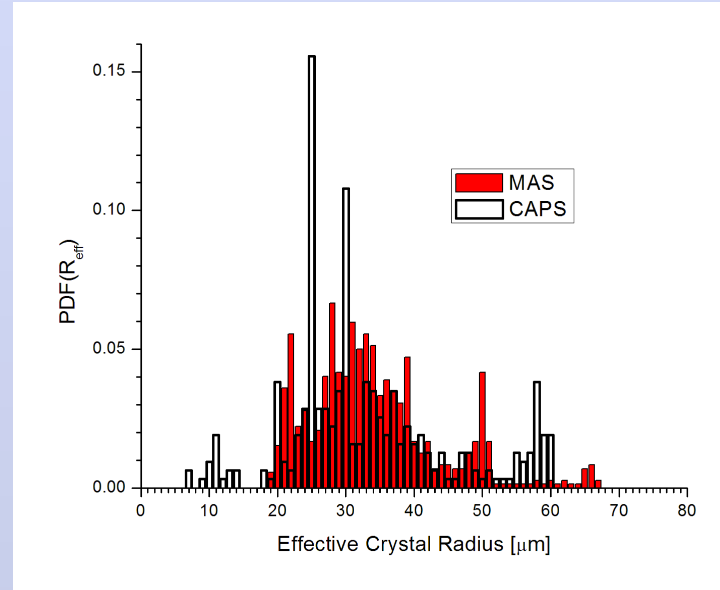
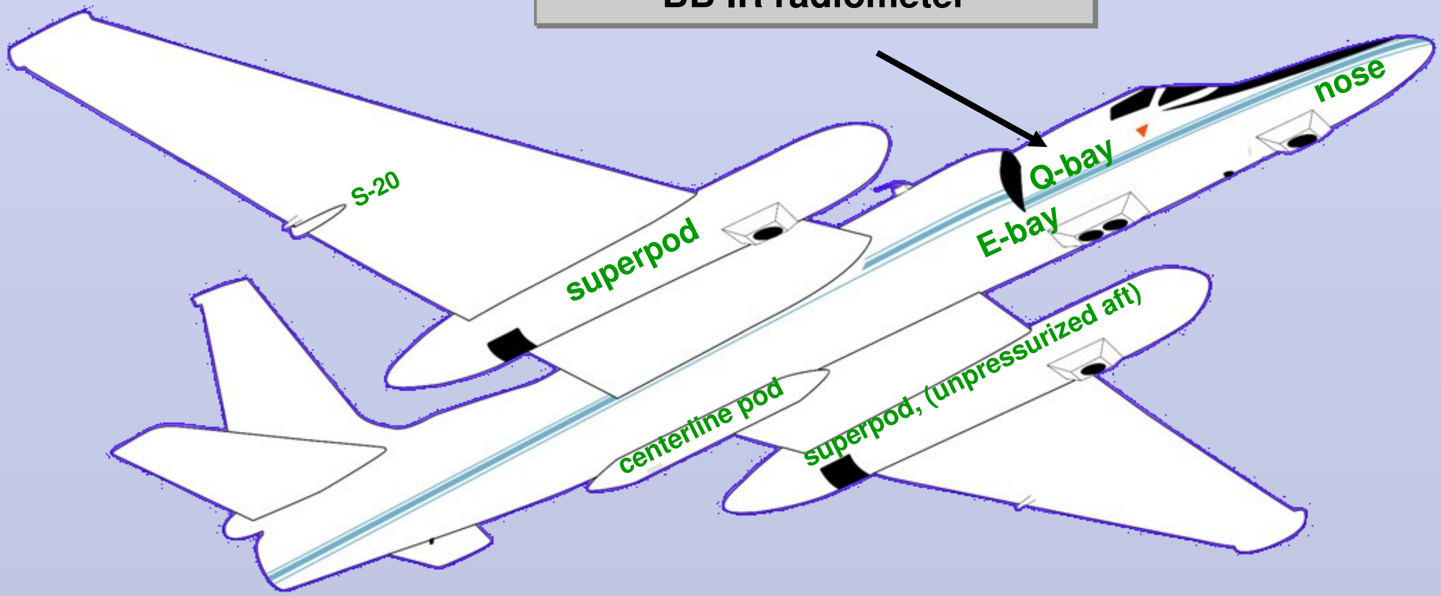


Figure 1. Comparison of effective radius as retrieved by MAS on ER-2 (red columns) and measured by CAPS on WB-57 (white columns) on July 23, 2002. Maximum horizontal displacement between ER-2 and WB-57 was 2 km.

from Schmidt, Pilewskie, Platnick, et al., *JGR*, 2007 (submitted)

TC4 ER-2 Instrument Payload
Broadband/spectral flux instruments

Q-bay/E-bay: Solar Spectral Flux Radiometer (SSFR), BB IR radiometer



Solar Spectral Flux Radiometer (SSFR)

also on DC-8

P. Pilewskie, W. Gore, S. Schmidt, et al.

- Hemispheric FOV
- Wavelength range:
  300 nm to 1700 nm
- Spectral resolution: 8-12 nm
- Simultaneous zenith and nadir viewing
- Accuracy: 3-5%; precision: 0.5%
- **Measure Quantities**: Upwelling and downwelling spectral Irradiance
- **Derived Quantities**: spectral Albedo, net flux, flux divergence (absorption), fractional absorption
- **Retrieved Quantities**: particle size, optical thickness, LWP

ER-2 heritage:

FIRE-ACE (1998)

SAFARI-2000 (2000)

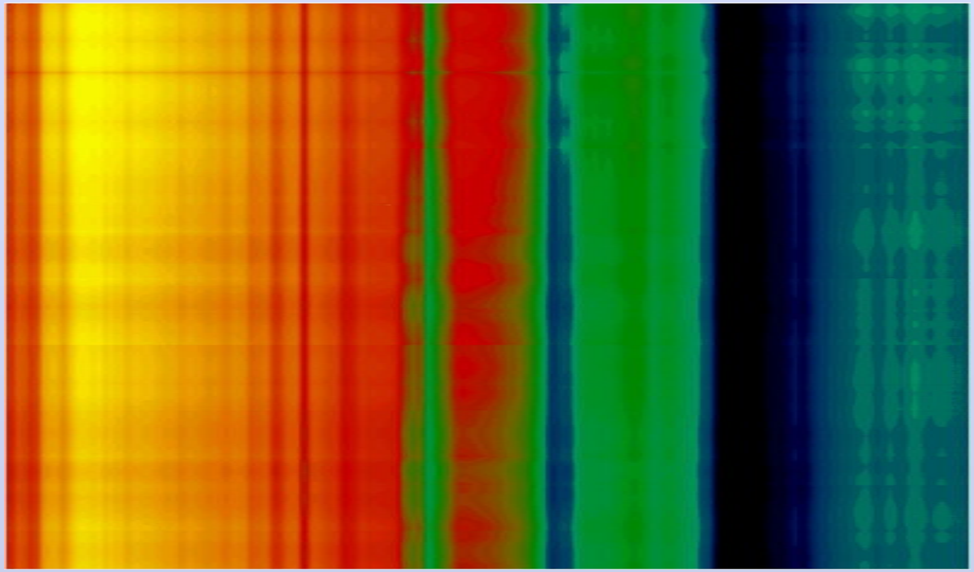
CRYSTAL-FACE (2002)

Solar Spectral Flux Radiometer (SSFR)

- **Measure Quantities**: Upwelling (F↑) and down- welling (F↓) spectral Irradiance
- **Derived Quantities**
  - Spectral Albedo: F↑/ F↓
  - Net Flux: F↓- F↑
  - Flux Divergence (absorption): $(F\downarrow - F\uparrow)_{top} - (F\downarrow - F\uparrow)_{bottom}$
  - Fractional absorption: $(F\downarrow - F\uparrow)_{top} - (F\downarrow - F\uparrow)_{bottom} / F\downarrow_{top}$
- **Retrieved Quantities**: particle size (r_e), optical thickness (τ), LWP

SSFR ARESE-II Example
(Twin Otter, 29 March 2000)

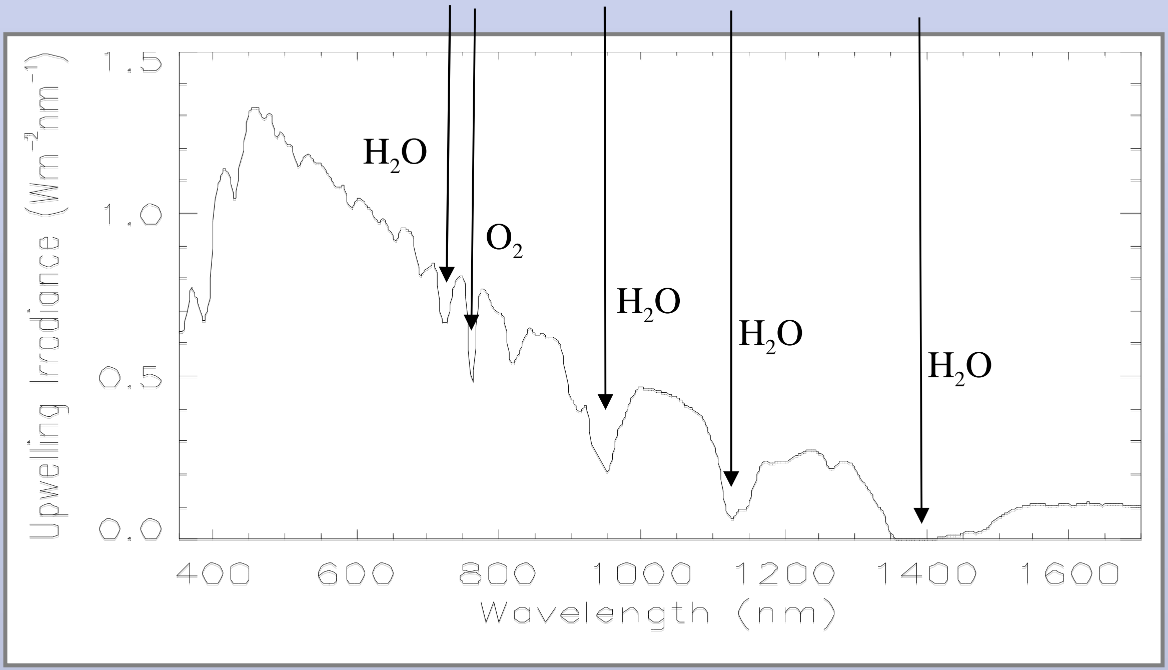
columns: 350 – 1700 nm



Start time = 18.6 UTC

rows: 4760 Spectra

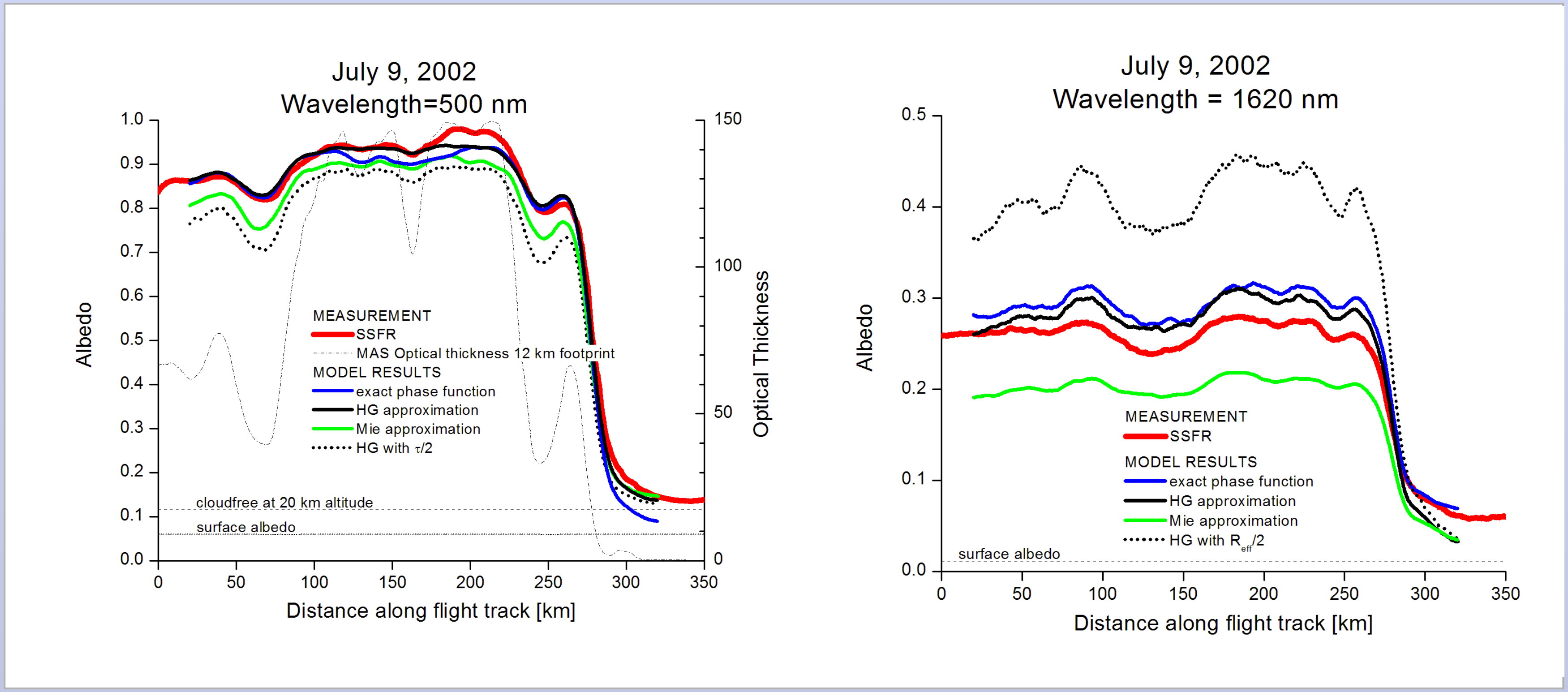
End time = 21 UTC



Pilewskie et al.

SSFR CRYSTAL-FACE Example

Measured and modeled (using MAS retrievals) albedo for July 9, 2002 for 500 nm (left) and 1620 nm (right).



from Schmidt, Pilewskie, Platnick, et al., *JGR*, 2007 (submitted)

Aircraft Measurements of IR Irradiance – Radiative Effects of Tropical Cirrus (Also on DC-8)

Anthony Bucholtz, Elizabeth Reid
Naval Research Laboratory, Monterey, CA

Basic quantities measured:

- Upwelling and Downwelling Broadband IR Irradiance
- Estimated accuracy: 3-5%

Derived quantities:

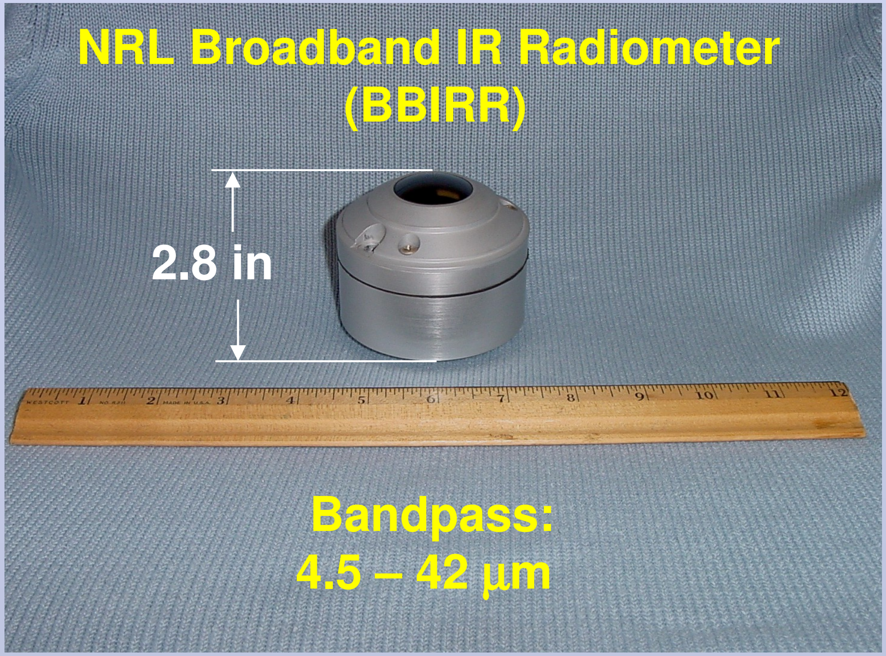
- Net IR Flux
- IR absorption and heating rates

TC4 Platforms:

- DC-8 and ER-2
- Up- and down-looking on both aircraft

Working in collaboration with SSFR:

- Pilewskie, Gore, et al.



BB IR Radiometer

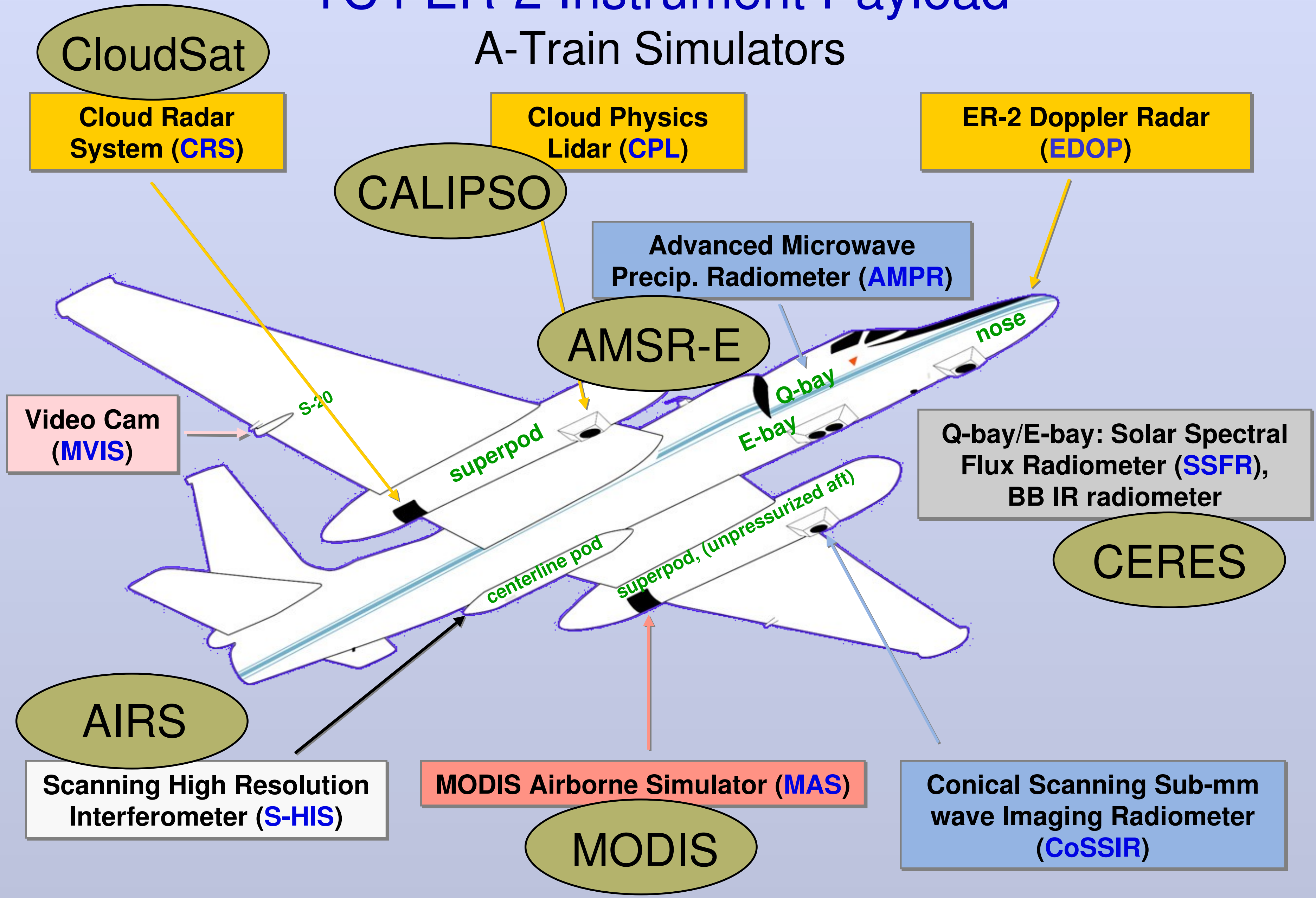
also on DC-8

PI: A. Bucholtz, co-I: Elizabeth Reid

- Upward and downward viewing broad band IR irradiance (W/m^2), layer heating rates when combined with DC-8
- CG-4 pyrgeometer
- 4.5-42 μm
- Silicon dome has a solar blind ellipse shape with a full 180° field-of-view with a good cosine response.
- Solar radiation absorbed by the window is effectively conducted away allowing accurate measurements in full sunlight
- Excellent dome to body thermal coupling eliminates the need for a dome thermistor and the calculation of the dome to body temperature

TC4 ER-2 Instrument Payload

A-Train Simulators



Payload

Inst.	Spectral	Spatial	Products
CPL	532, 1064 nm backscatter lidar	nadir only, 30 m vert., 200 m horiz.	Cloud/aerosol and layer information (top/base altitudes, extinction)
CRS	94 GHz	Nadir	Radar refl., Doppler velocities, cloud layer water content
EDOP	X-band	Nadir	Radar refl., Doppler velocities, precipitation
MAS	VIS/NIR/SWIR/IR grating spectr., 50 ch.	cross-track scanner, 37 km swath, 50 m .	Cloud prop., ice and water (cloud top, optical thickness, effective particle size, WP)
SHIS	IR Hyperspectral, 3.3-18 µm	cross-track scanner, 40 km swath, 2 km resolution	Temperature/ moisture profiles, cirrus cloud properties (top pressure, optical thickness, effective particle size, IWP)
CoSSIR	183 – 874 GHz, 15 channels	conical scanner (53° fwd and aft), 45 km swath	IWP, ice cloud median mass particle diameter
AMPR	V/H ch.: 10.7 GHZ, 19.4 GHz (window), 37 GHz (H_2O), 89 GHz (window)	cross-track scanner, 40 km swath, 0.6-2.8 km resolution	Precipitation Index
SSFR	VIS–SWIR, 10 nm resolution	Zenith and nadir	Solar spectral fluxes and layer heating rate (w/SSFR on DC-8), ice cloud optical/microphysical properties
BB IR	4.5 – 42 µm	Zenith and nadir	IR radiative fluxes and layer heating rate (w/similar instr. on DC-8)