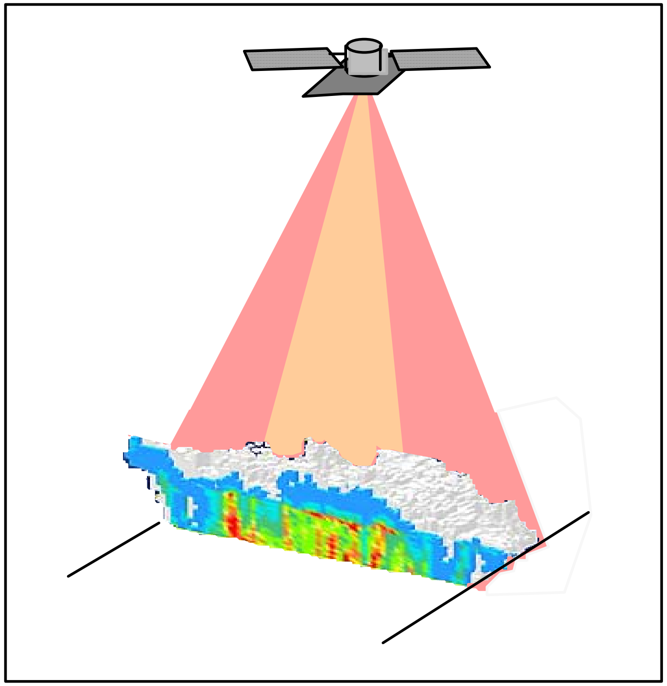
Dual Frequency Airborne Precipitation Radar (PR-2) Observations in CAMEX-4



E. Im
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PR-2 Background

- **Tropical Rainfall Measuring Mission (TRMM)**
  - The first spaceborne satellite dedicated for detailed rainfall measurements
  - TRMM carries a 14-GHz Precipitation Radar for measuring vertical profiles of rainfall rate

- **Global Precipitation Mission (GPM)**
  - GPM is the follow-on mission to Tropical Rainfall Measuring Mission (TRMM)
  - The core GPM satellite will carry 14/35-GHz dual-frequency radar package

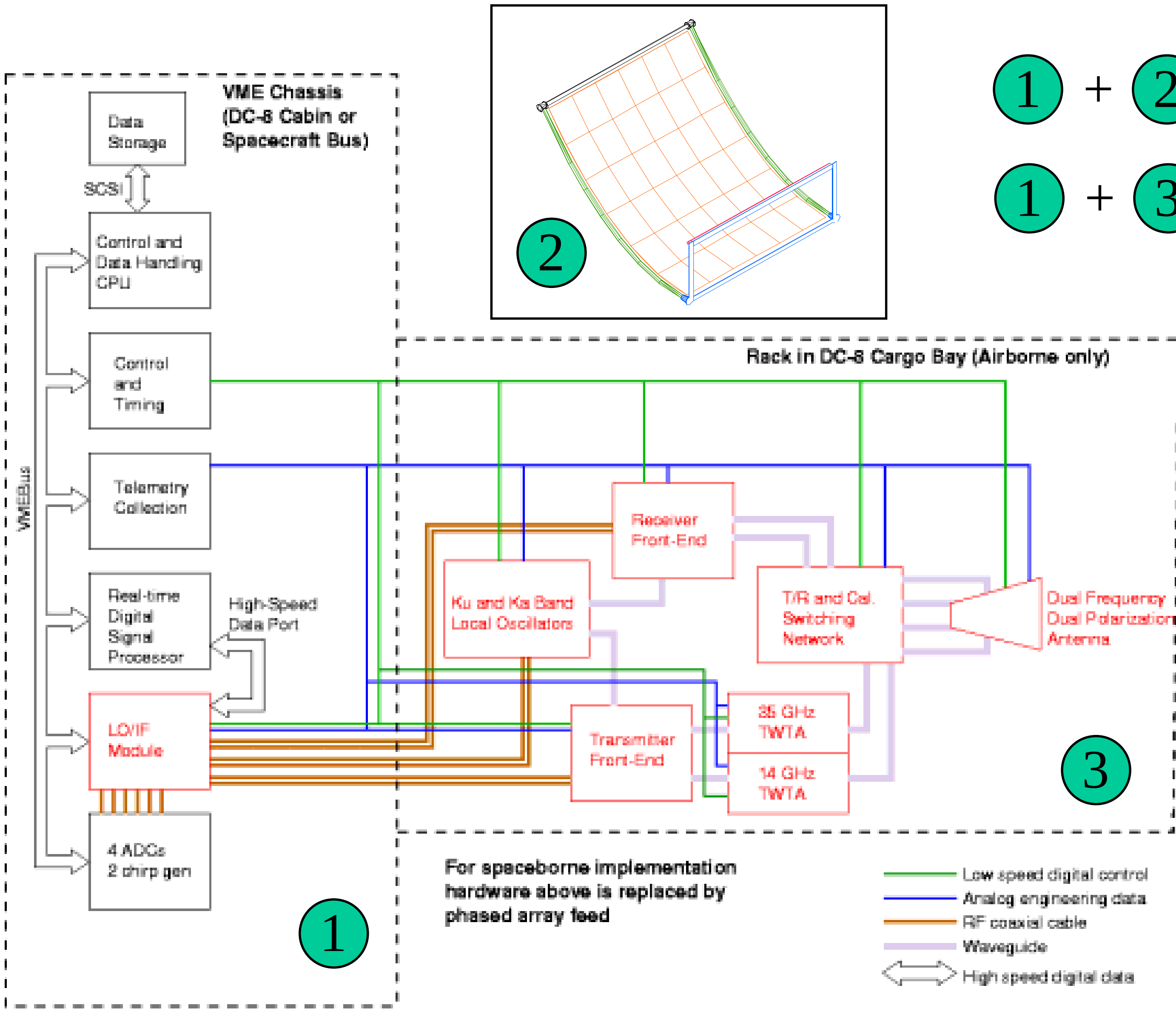
- **2nd-Generation Precipitation Radar (PR-2)**
  - PR-2 project, under NASA Instrument Incubator, develops advanced technologies for GPM dual-frequency radar
  - Innovations and Capabilities
    - **Use 14/35 GHz to improve dynamic range and sensitivity on rain measurements**
    - **2x improvement in radar resolution to reduce errors caused by rain beam filling**
    - **Dual polarization to differentiate between liquid and frozen hydrometeors**
    - **Doppler capability to obtain vertical motion structure**
    - **Cross-track adaptive scan over ±37^{O} to increase swath coverage**
    - **A factor of 2 to 3 mass reduction from TRMM PR using deployable antenna**

- **PR-2 airborne simulator (used in CAMEX-4)**
  - It is the PR-2 prototype model that has most of capabilities, with the exception of the large, active (T/R module) scanning, deployable antenna

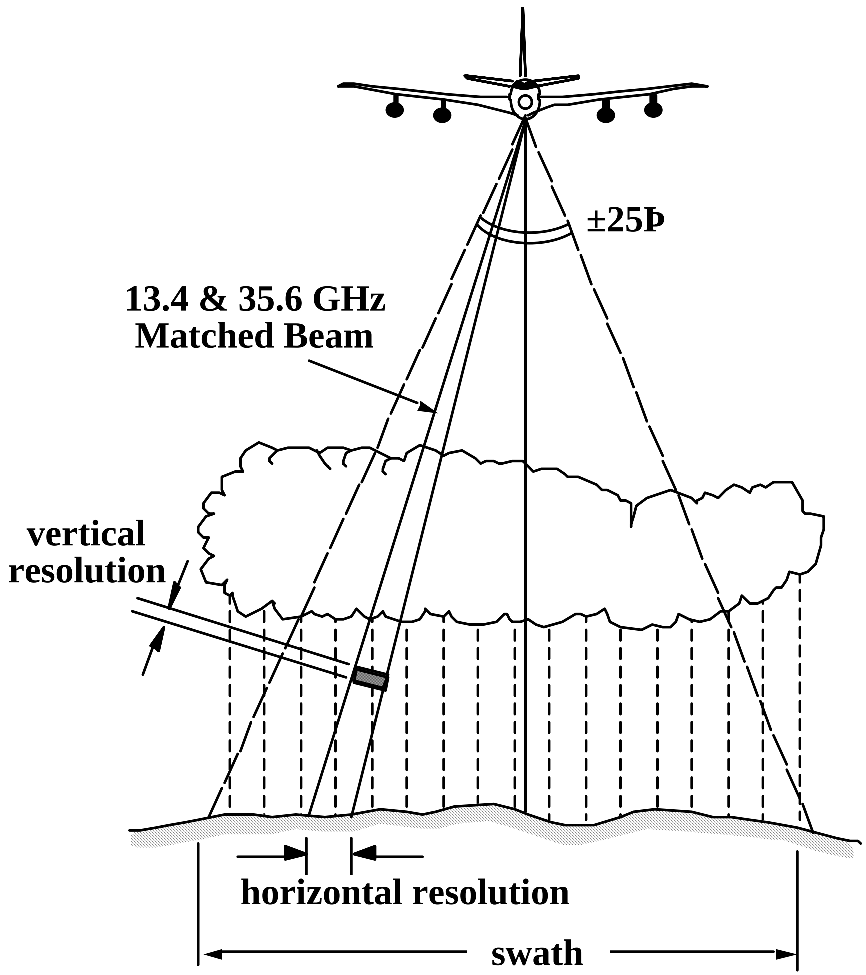
PR-2 Spaceborne Design vs. Airborne Simulator

1 + 2 = PR-2

1 + 3 = PR-2 simulator



PR-2 Airborne Operational Geometry



PR-2 Data Collection in CAMEX-4

- PR-2 development was begun in early 1999 and completed June-July 2001
- No Ka-band data was obtained prior to CAMEX-4 due to problem with off-the-shelf traveling wave tube amplifier (TWTA)
  - worked on ground but faulted in flight; sent to Texas for repair
- Ka-band TWTA was re-installed prior to 3rd flight; exhibited same fault while in flight; operated sporadically throughout remainder of mission
- For last three flights a remote control capability for the Ka-TWTA was added, allowing it to be reset remotely
  - allowed substantially more Ka-band data to be collected

Flight No	Date	Comments
010406	8/18/01	Ku-band only, some isolated convective cells
010407	8/20/01	Ku-band only, TS Chantal
010408	8/25/01	Clear air, first Ka band return from ocean surface
010409	9/03/01	Ka sporadic but obtained first dual-freq returns from rain; Ka for several minutes around 1638 and 1705 UTC

Data Collection (Cont’d)

Flight No	Date	Comments
010410	9/06/01	Ku-band, some Ka over rain (1704-1712, 1749-1800, 1820, 1840); problem with antenna scanning
010411	9/07/01	Ku-band, some Ka over rain (1759-1810); problem with antenna scanning
010412	9/09/01	Ku-band over stratiform rain; Ka 1826-1831; problem with antenna scanning
010413	9/10/01	Clear air flight around Hurricane Erin (little or no precip)
010414	9/15/01	Ku and some Ka (2240-2250) data in TS Gabrielle
010415	9/19/01	Mostly Ku-band in isolated cells; Ka 1729-1731, 1920
010416	9/22/01	Ku and some good Ka (2146-2155) data in TS Humberto
010417	9/23/01	Ku and some Ka (near 0020 UTC) in Hurricane Humberto
010418	9/24/01	Ku with Ka from 0011 to 0028, in Hurricane Humberto

Work Since Field Experiment

- Development of operational calibration software
  - includes noise estimation and subtraction
  - corrects antenna angles for scan non-linearities
  - uses updated calibration parameters
- Development of post-processing software
  - reads output of calibration software
  - performs some "clean-up" functions
  - ingests DC-8 navigation data
  - puts Level 1 B data in HDF format for archiving
- Examination of engineering data to ascertain radar performance
  - ocean surface backscatter
  - ocean surface Doppler (due to a/c motion) versus prediction from DC-8 data
- Operational data processing
  - all 40 GB raw data on disk
  - most processed to Level 1 B
  - expect to deliver preliminary Level 1 B data set to archive by end of March
  - Level 1 B data expected to be ~6 GB

PR-2 Level 1 B Format

- File header, 72 bytes
- ScanTime , 4 bytes, nscan
- DC8_Lat, 4 byte, nscan
- DC8_Lon, 4byte, nscan
- DC8_Alt , 4 bytes, nscan
- Ray sequence number, 2 bytes, nscan x nray
- Range to 1st bin, 4 bytes, nscan x nray
- Surface Bin Number , 4 bytes, nscan x nray
- Number pulses averaged, 4 byte, nscan x nray x 4
- Look vector, 8 bytes, nscan x nray x 3
- Radar surface Doppler, 4 byte, nscan x nray
- Surface Doppler from DC8 Nav., 4 bytes, nscan x nray
- Zhh at Ku-band, 2 bytes, nscan x nray x nbins
- Doppler at Ku-band , 2 bytes, nscan x nray x nbins
- LDR at Ku-band , 2 bytes, nscan x nray x nbins
- Zhh at Ka-band (if available), 2 bytes, nscan x nray x nbins

nscan=no. scans in file

nray=no. rays in a scan

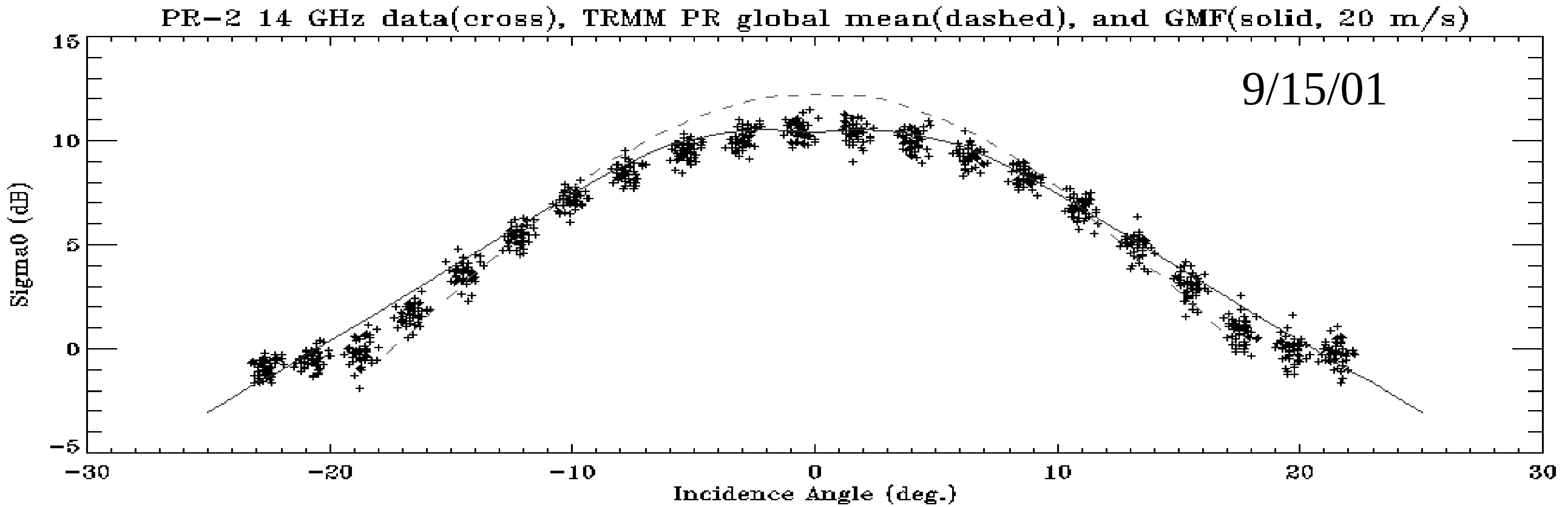
nbin=no. bins in a ray

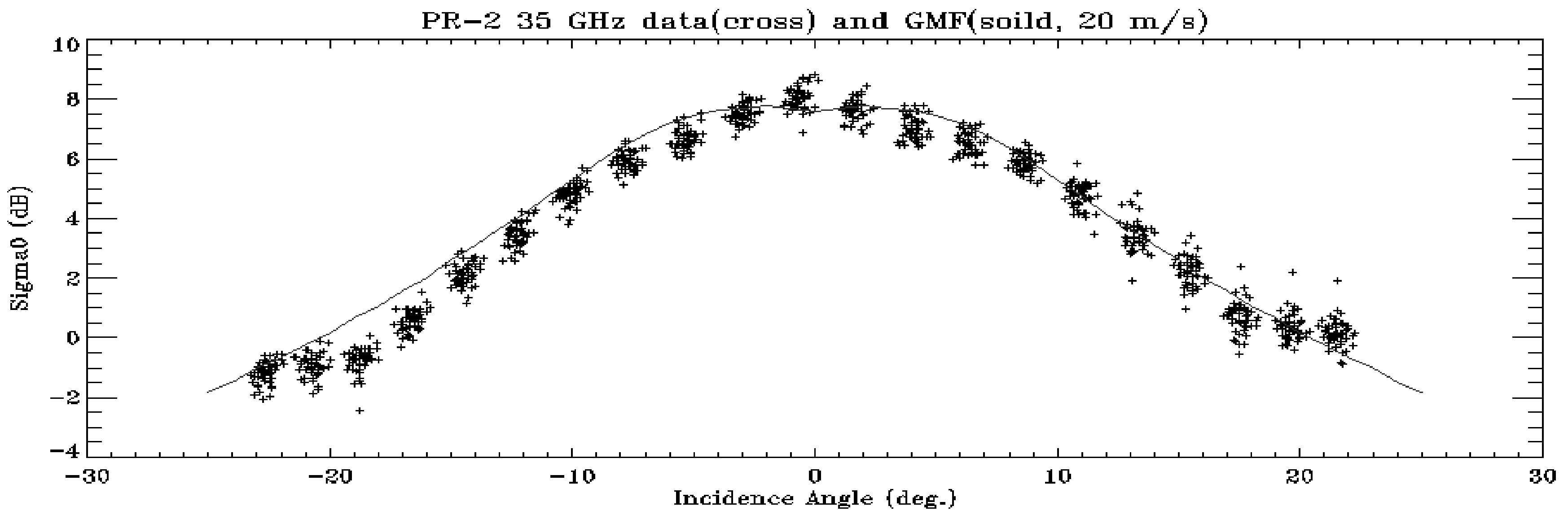
1st 5 items are vdata; others are SDS

File Header Contents

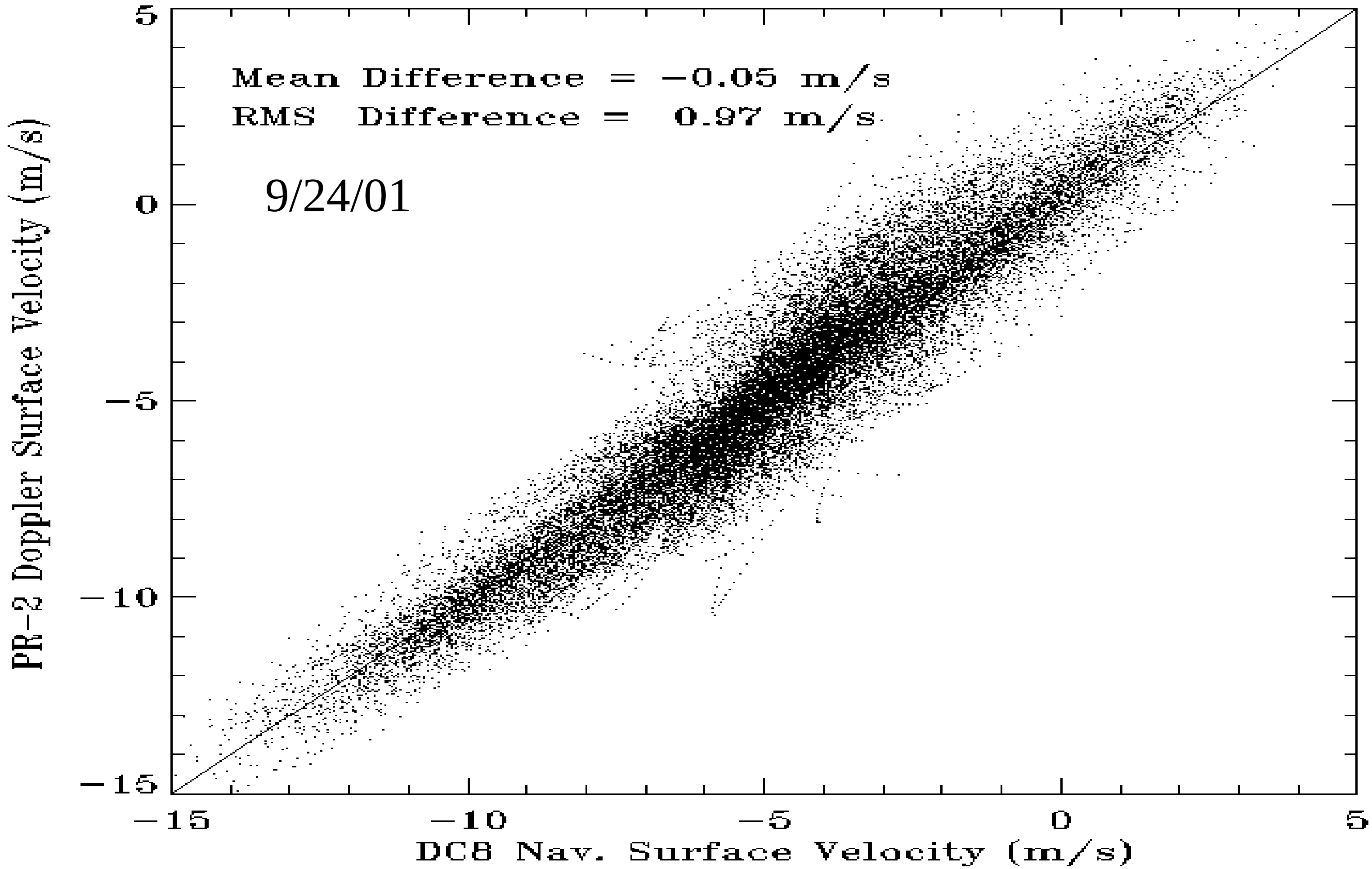
	Name	Format	Description
1	PRF	4-byte integer	Pulse repetition frequency in Hz
2	Pulse Length	4-byte integer	Radar pulse length in 1 us units
3	Antenna Left	4-byte integer	Antenna scan left-limit in deg.
4	Antenna Right	4-byte integer	Antenna scan right-limit in deg.
5	Scan Duration	4-byte integer	Scan time for antenna in second * 100
6	Return Duration	4-byte integer	Antenna retrace time in second * 100
7	Ncycle	4-byte integer	Number of pulse averaged by Wildstar board
8	AZ Average	4-byte integer	Number of blocks averaged in a beam or ray
9	Range average	4-byte integer	Number of 30m range cells averaged in a bin
10	Scan average	4-byte integer	Number of scans averaged
11	Number of Bins	4-byte integer	Number of range bins in the ray
12	Number of Beams	4-byte integer	Number of rays in each scan
13	Range Bin Size	4-byte integer	The vertical resolution of range bin
14	Z scale factor	4-byte integer	Factor multiplying reflectivity
15	V scale factor	4-byte integer	Factor multiplying Doppler
16	Valid Ka scan begin	4-byte integer	Scan number where the valid Ka data begin
17	Valid Ka scan end	4-byte integer	Scan number where the valid Ka data end
18	CalVersion	4-byte integer	Version number of the calibration table

Ocean Surface Backscatter Measurements



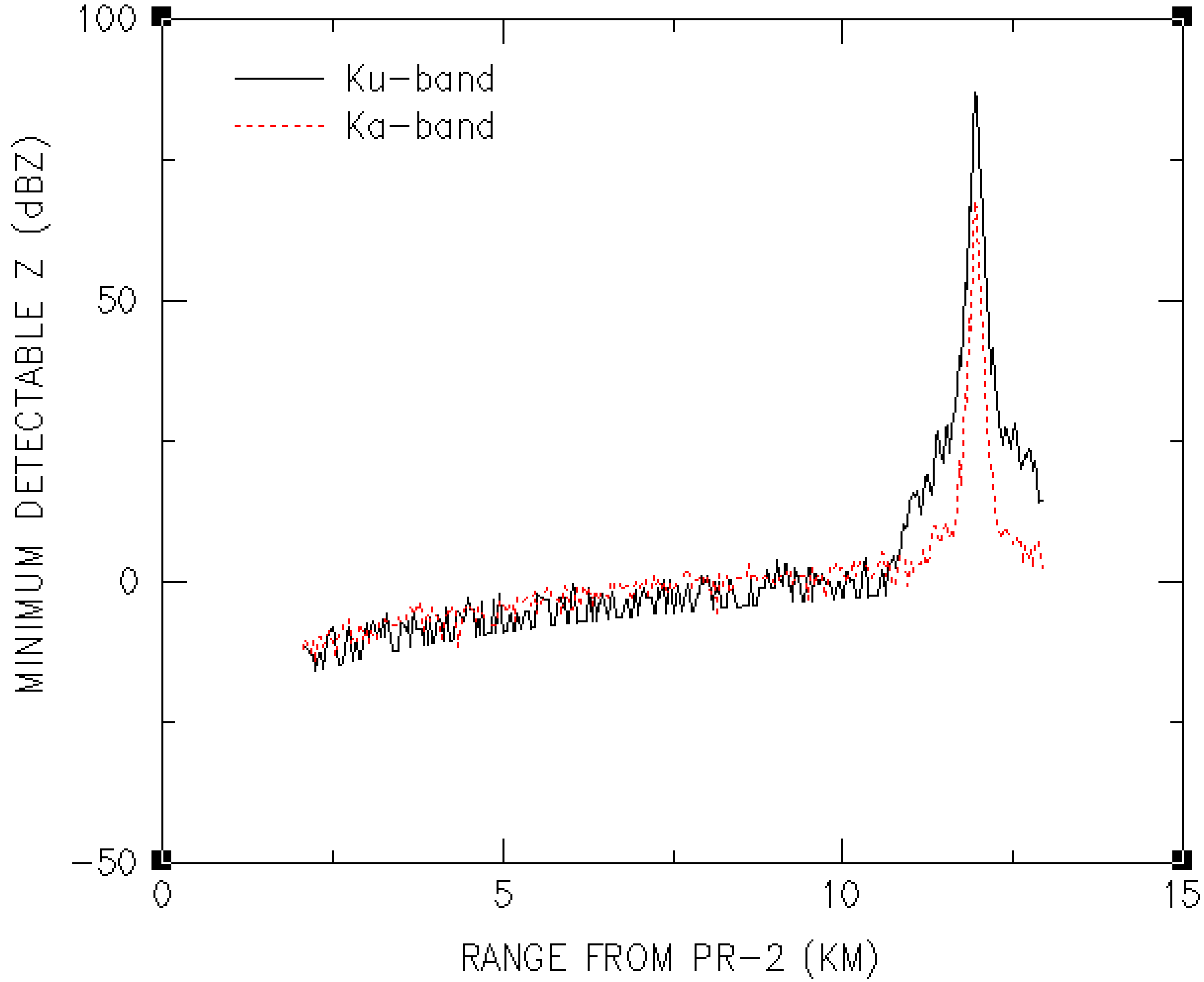


Ocean Surface Doppler Measurements



- Outliers are generally related to aircraft maneuvering

Measured Sensitivity After Noise Subtraction

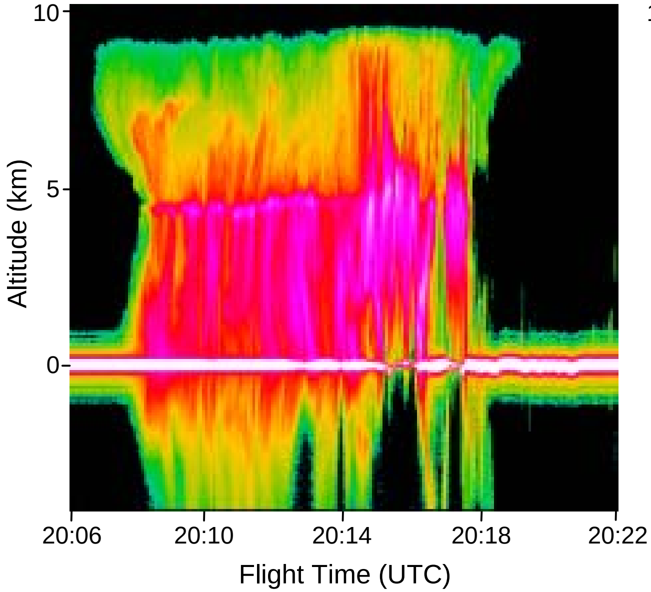


Data Quality Assessment

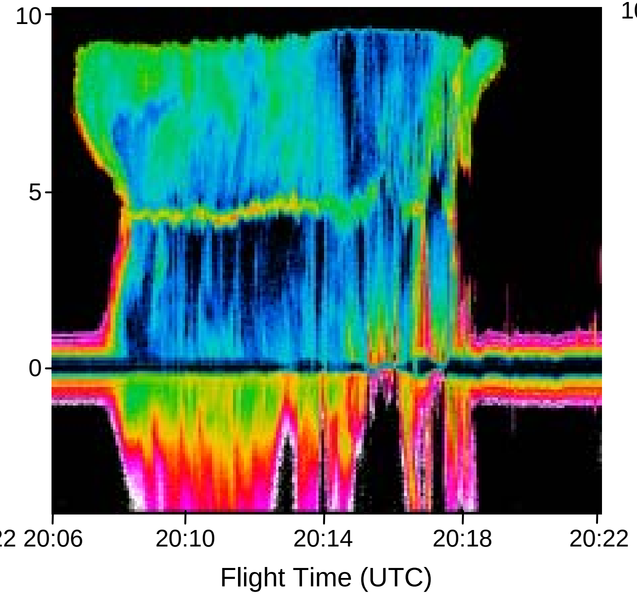
- Ku-band data were acquired on all flights
- Ka-band data were acquired on a number of flight legs
- Ocean backscatter indicate that the calibration is reasonably accurate (1-2 dB)
- Sensitivity after noise subtraction better than 5 dBZ at 10 km range
- Doppler Ku-band measurements of the ocean compare well with predictions when flying straight and level
  - Ka-band Doppler appears to work properly, although has poor accuracy by design
  - Ka-band antenna is under-illuminated to get matched beams, making Ka-band Doppler spectral width large relative to the PRF
- Known problems
  - Ka-band TWTA had repeated faults, allowing limited data collection
  - 9/6, 9/7, and 9/9 flights had “stuck” antenna scanner
  - LDR requires inter-channel calibration; still has moderate uncertainty at this point

14-GHz Vertical Cut Over Tropical Storm Chantal

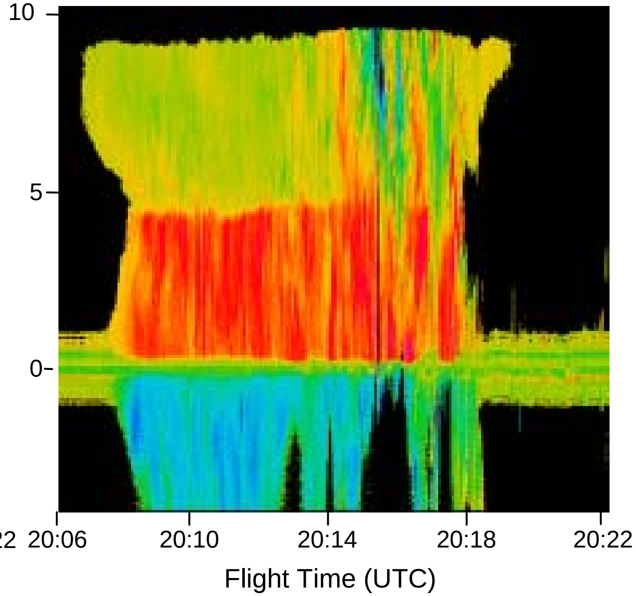
Co-polarized (HH) radar reflectivity



HV/HH radar reflectivity ratio

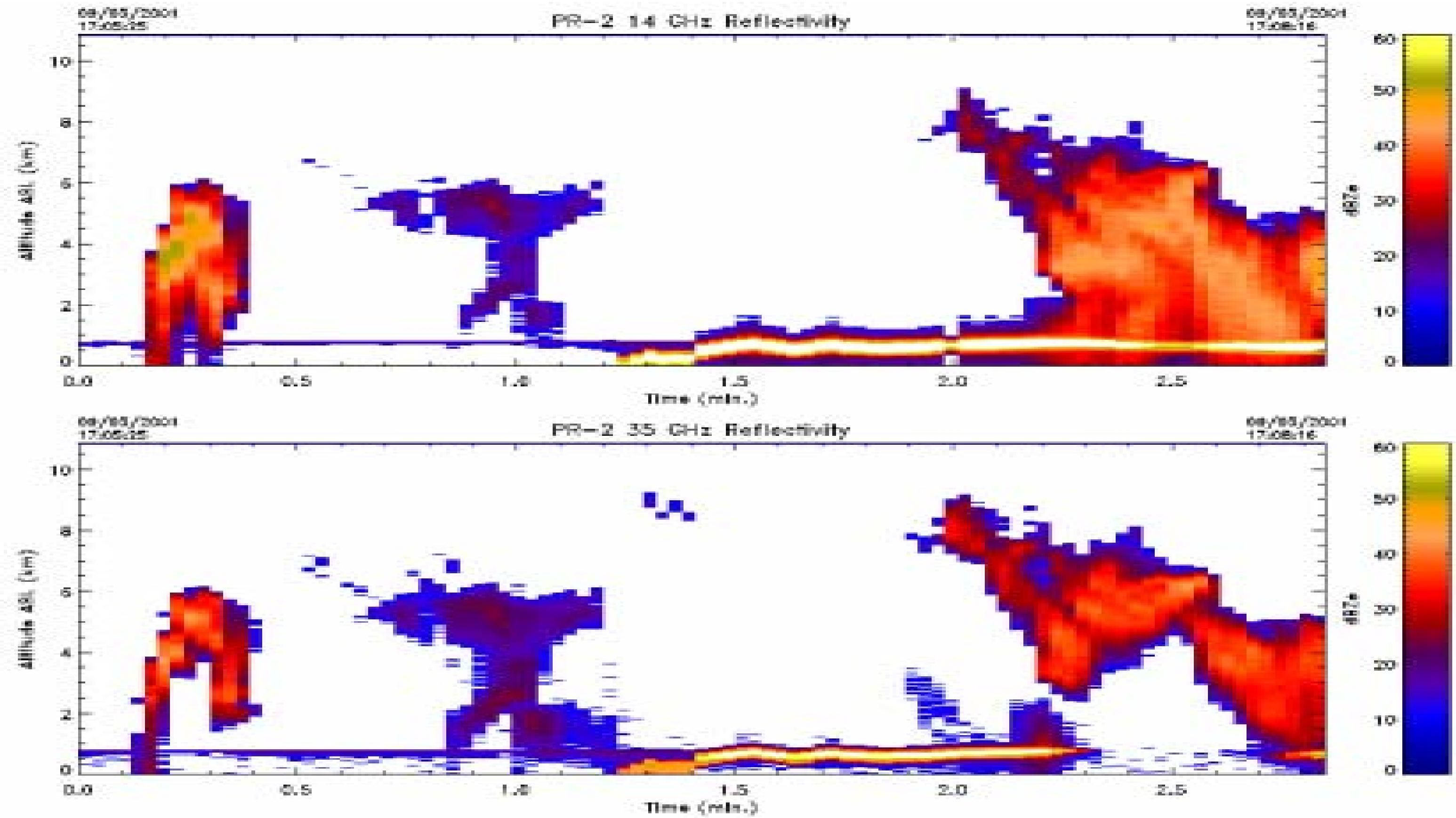


Co-polarized Doppler



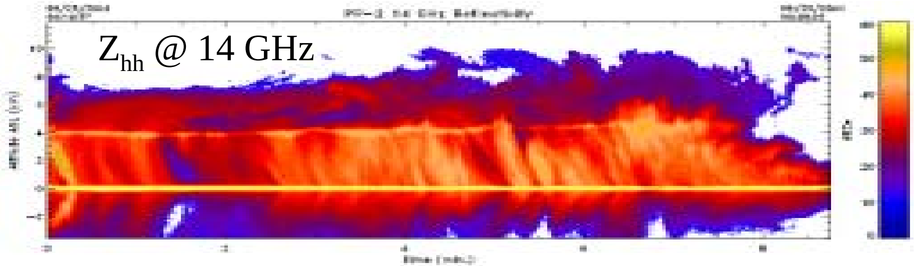
- Co-pol reflectivity showed detailed structures of both the melting layer (at left) and the intense convective region (at right) of Chantal. Image also showed the ocean surface returns and the mirror images (double bounces) of the radar returns from rain above the surface.
- Linear Depolarization Ratio (ratio of cross-polarized to co-polarized reflectivities) accentuated the ice particles at the melting layer.
- Doppler velocity image showed the velocity sharply changes at melting layer as the ice particles fall slowly and melt, increasing in speed to 5-10 m/s at lower altitudes. Much larger Doppler is seen associated with downdrafts and updrafts in the convective area.

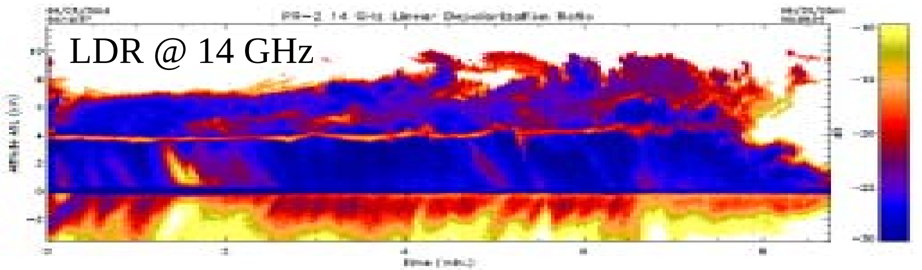
Dual-Freq Rain Data on 9/3/01

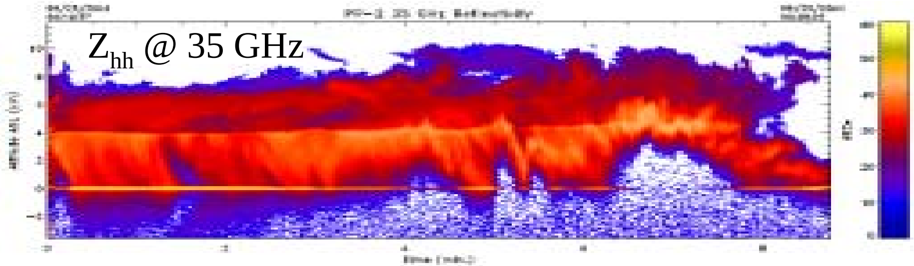


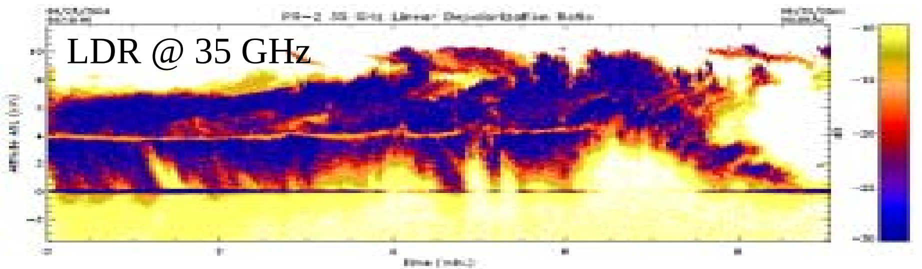
- During the 9/3/01 CAMEX-4 flight, we managed to make the 35-GHz TWTA to work continuously for more than 3 minutes. As such, dual-frequency vertical profiles of rain reflectivities at both 14 and 35 GHz were collected.

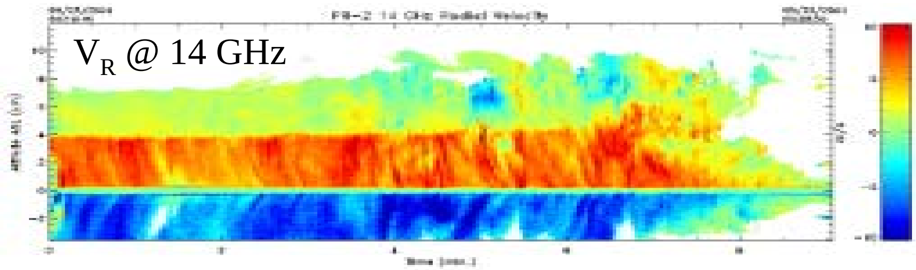
14- and 35-GHz Observations of Tropical Cyclone Humberto on 09/25/01

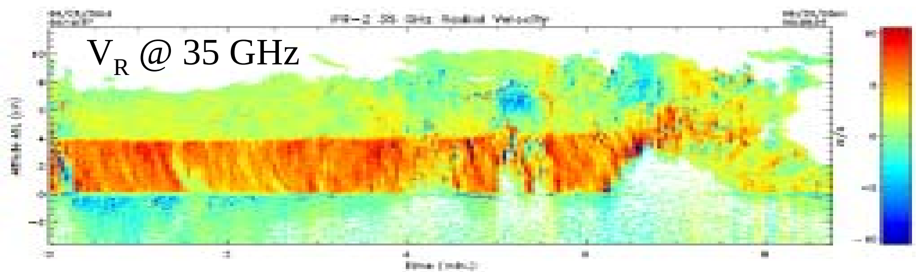








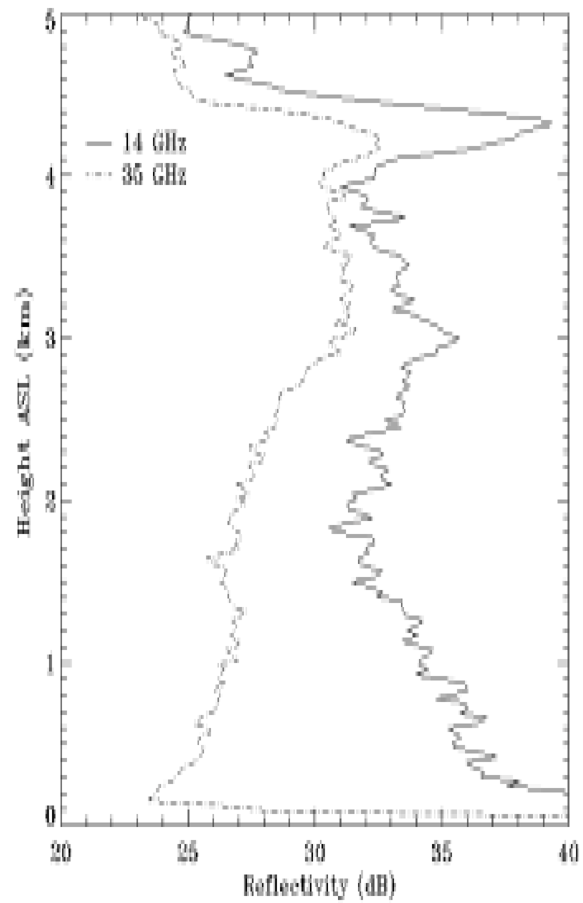




Vertical structures of Tropical Cyclone Humberto obtained at 14- and 35-GHz by PR-2 along the nadir-track.

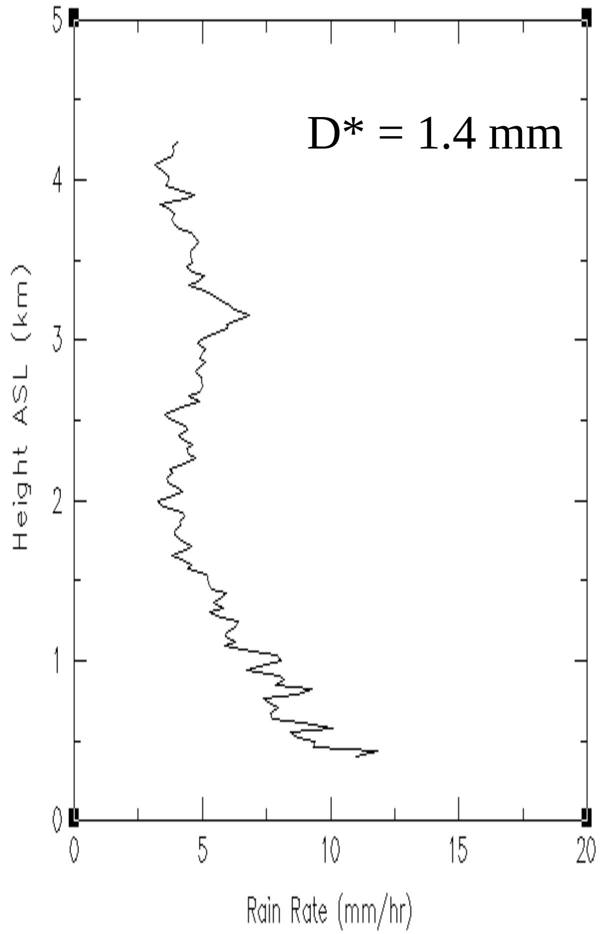
Dual-Frequency Rain Retrieval: TS Gabrielle

- Dual-frequency data were collected from 2240-2250 UTC in TS Gabrielle 9/15/01
- Have applied single and dual-frequency rain retrieval algorithms
  - Haddad et al. JAM, 1996, Extended Kalman Filter stochastic single frequency retrieval
  - Meneghini, et al., JTECH, 1992, dual-frequency deterministic algorithm
  - Currently working on extension of Kalman algorithm to dual-frequency
- At right are 14 and 35 GHz reflectivity profiles, measured by PR-2

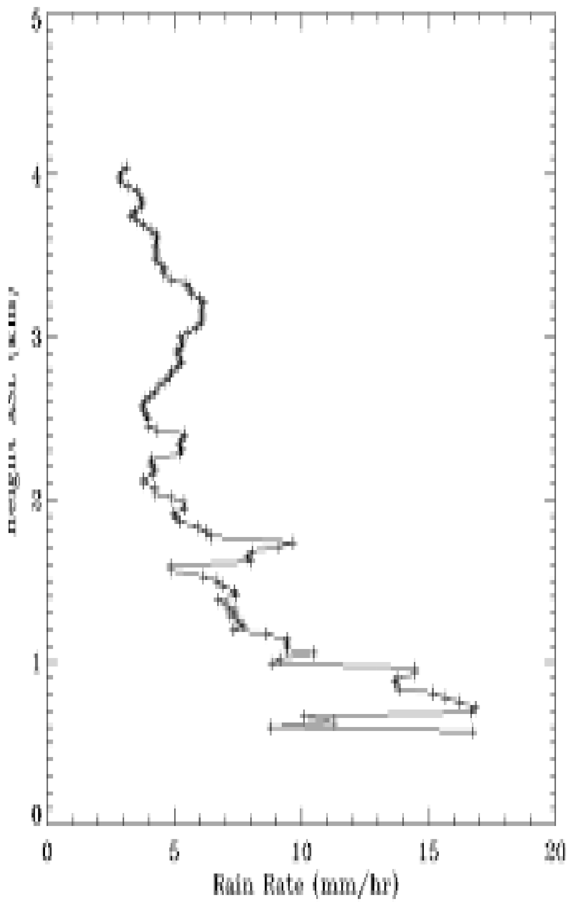


Dual-Frequency Results

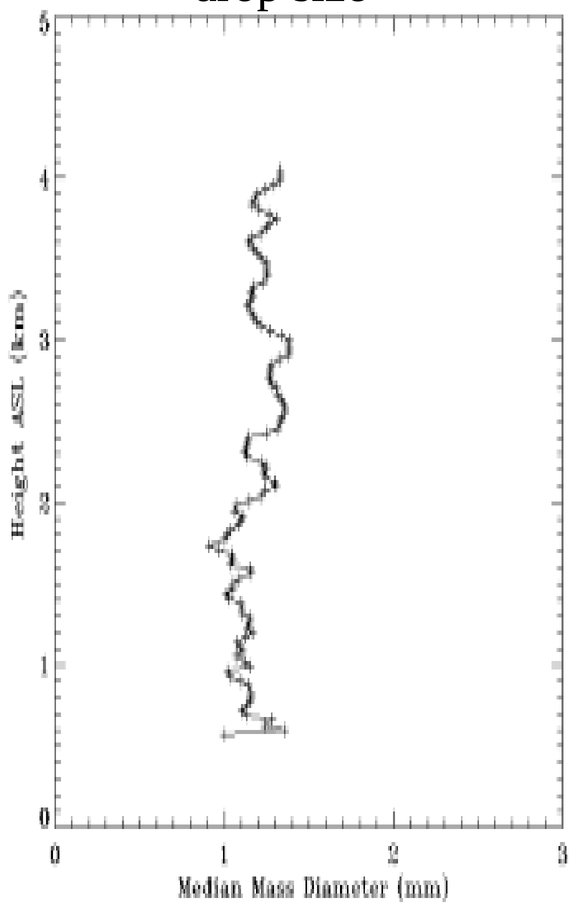
Single-freq rain



Dual-freq rain



Dual-freq median drop size



Summary

Accomplishments:

- Collected full set of Ku-band data on all CAMEX-4 flights
- Collected first Ku-/Ka-band dual-frequency data on some flight lines over both convective cells and in Tropical Cyclones Chantal, Gabrielle, and Humberto
- Revised and tested calibration software with new calibration parameters
- Developed software for combining calibration PR-2 data with DC-8 nav data and storing in HDF
- Used dual-frequency rain retrieval algorithm on Ku-/Ka-band data to retrieve rain profile

Future Work:

- Complete version 1 processing and deliver to archive
- Create documentation and sample read code for delivery to archive
- Perform more detailed engineering analyses of the version 1 data
- Re-process data and deliver new version
- Continue work on dual-frequency retrieval
- Compare and combine PR-2 data with that from other instruments