Jet Propulsion Laboratory
California Institute of Technology

Observing atmospheric physics and dynamics from ~~small~~ NASA airborne platforms : experiences and considerations

Multi-instrument

Simone Tanelli

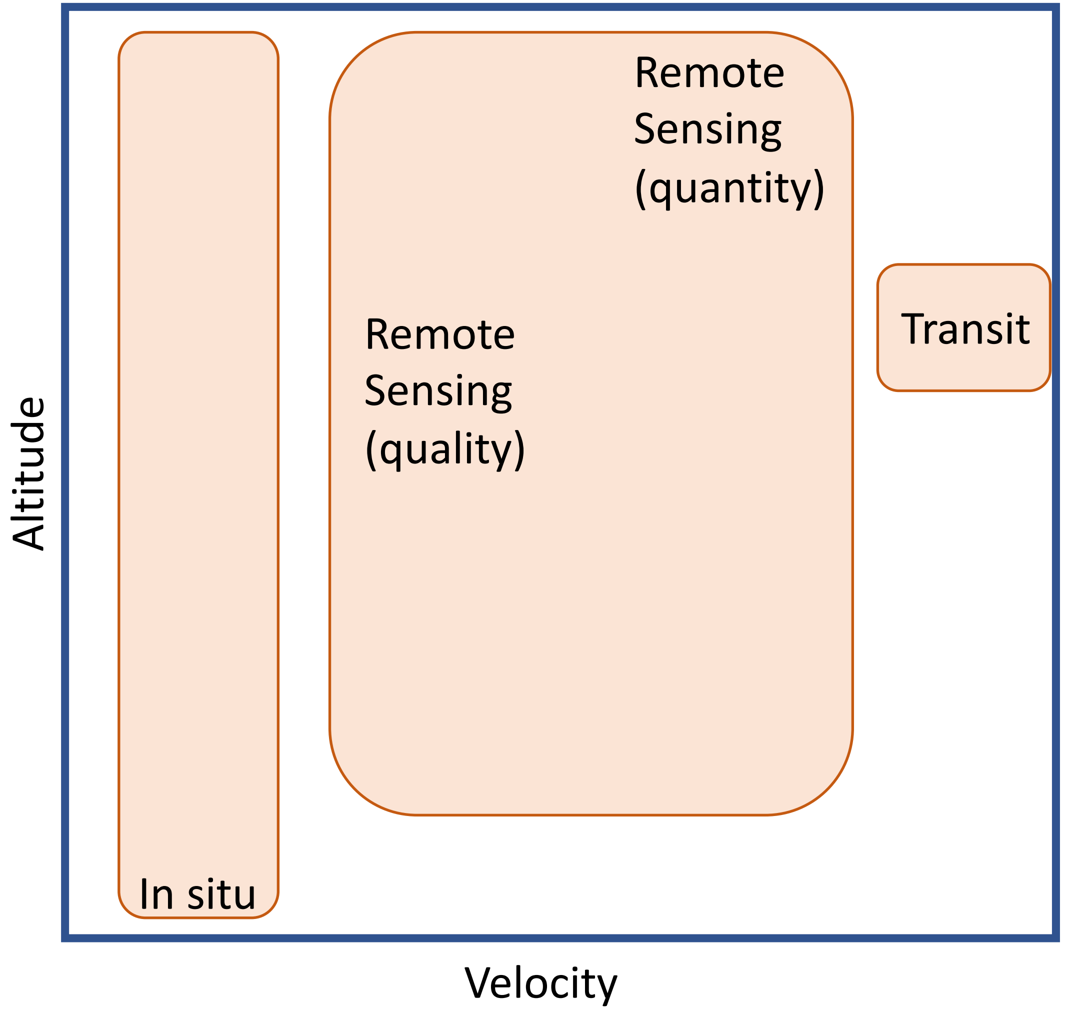
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA,

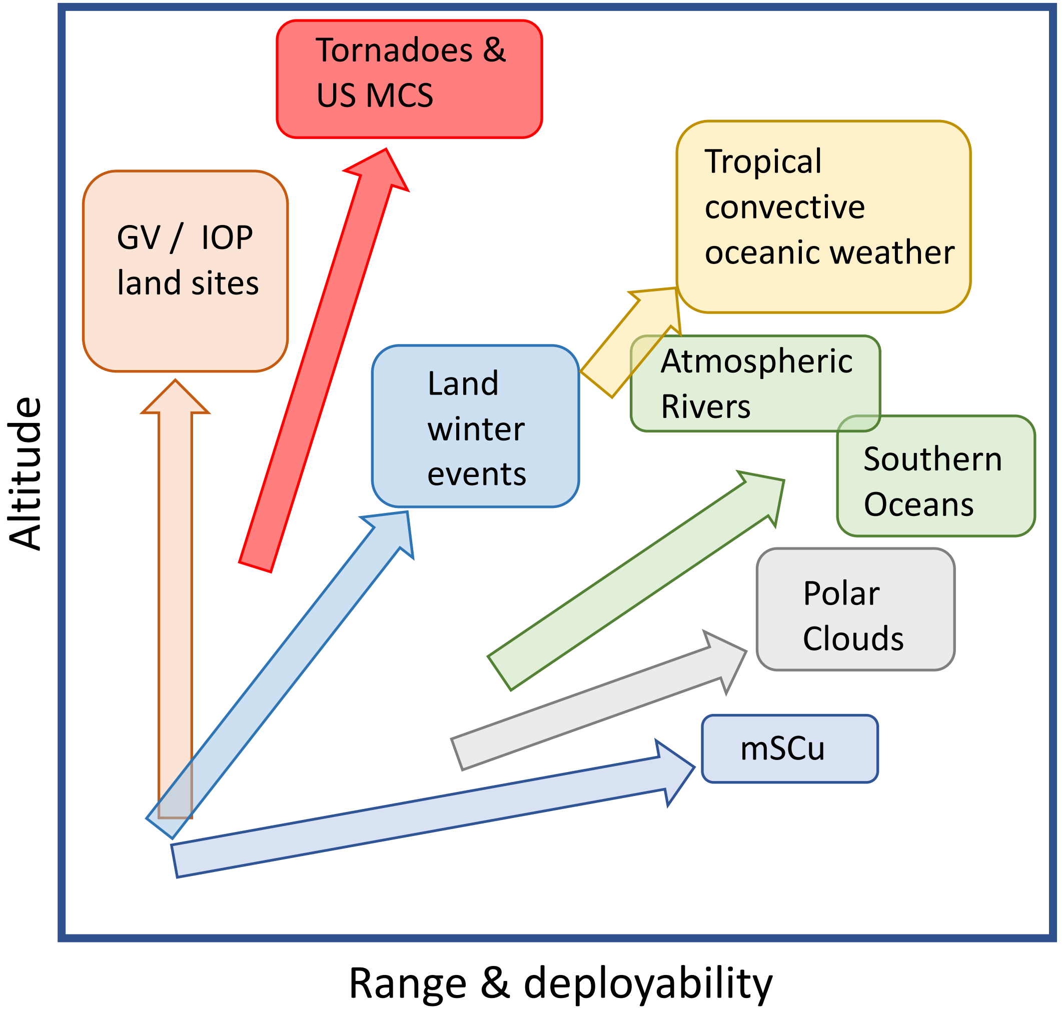
Bottomline upfront

1. Essential roles of airborne science within NASA
   A. **Complement** spaceborne observations
   B. **Enable** spaceborne observations
   C. **Validate** spaceborne observations
2. Essential role of the DC-8 within the NASA fleet specifically for atmospheric physics and dynamics
   A. **Reach:**
      Long legs, relatively “easy” logistics
   B. **Broad Envelope:**
      Wide range of altitudes, and flight speeds. Resilient.
   C. **Layout:**
      Crew-friendly & high capacity, hardware flexible layout

DC-8	Complement	Enable	Validate
REACH	**Reach remote weather**	**Significant Piggyback capacity, flying lab**	**Reach specific space-time coordinates**
BROAD ENVELOPE & ROBUST	**Flight modules compatible with wide range of weather scenarios**	Flexibility in the type of tech to be demonstrated	**Flexibility Remote Sensing vs in situ**
HUMAN + HW FRIENDLY LAYOUT	**Real time flight planning and mods in convective weather**	**Flexibility in the type of tech to be demonstrated**	Custom configurations for specific GV

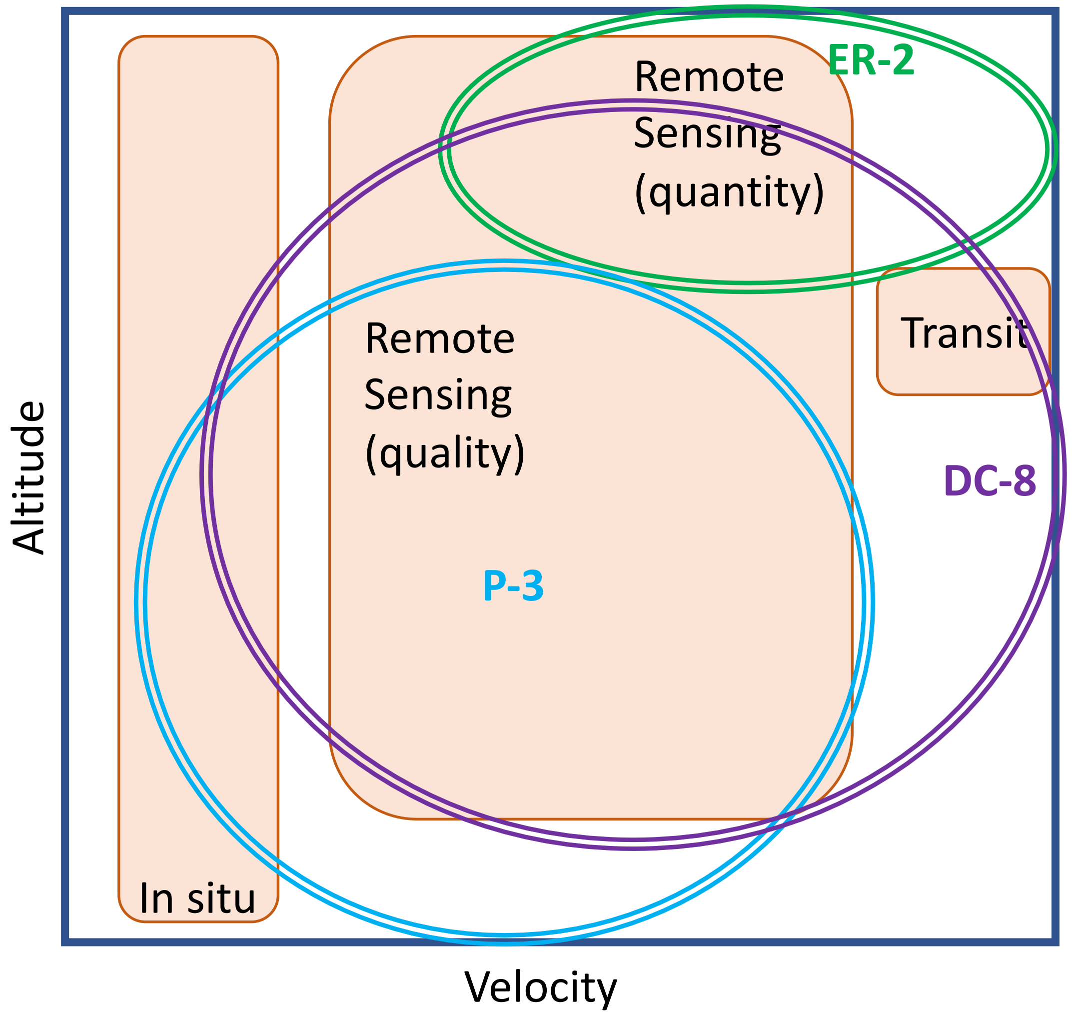
Performance envelope

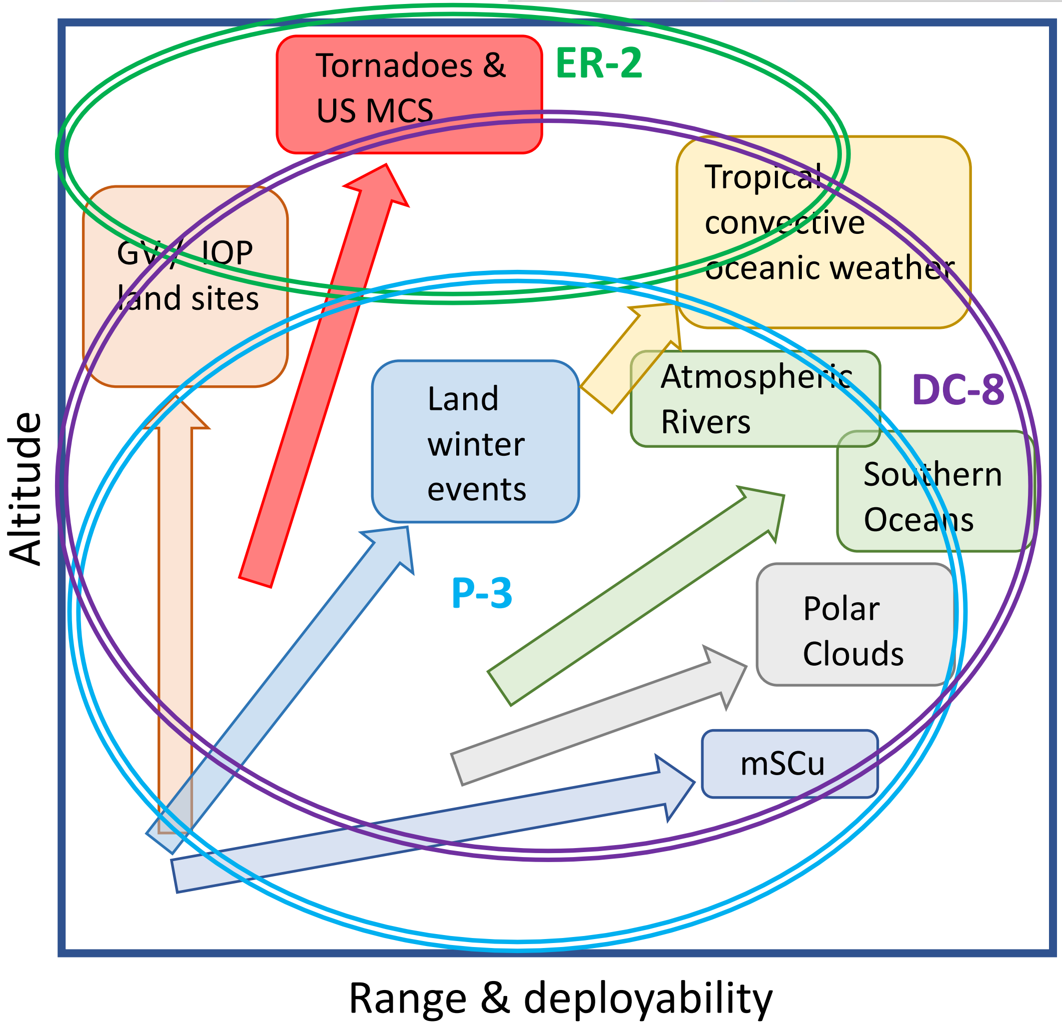




Performance envelope

Approximate envelopes of three multi-instrument NASA airborne platforms





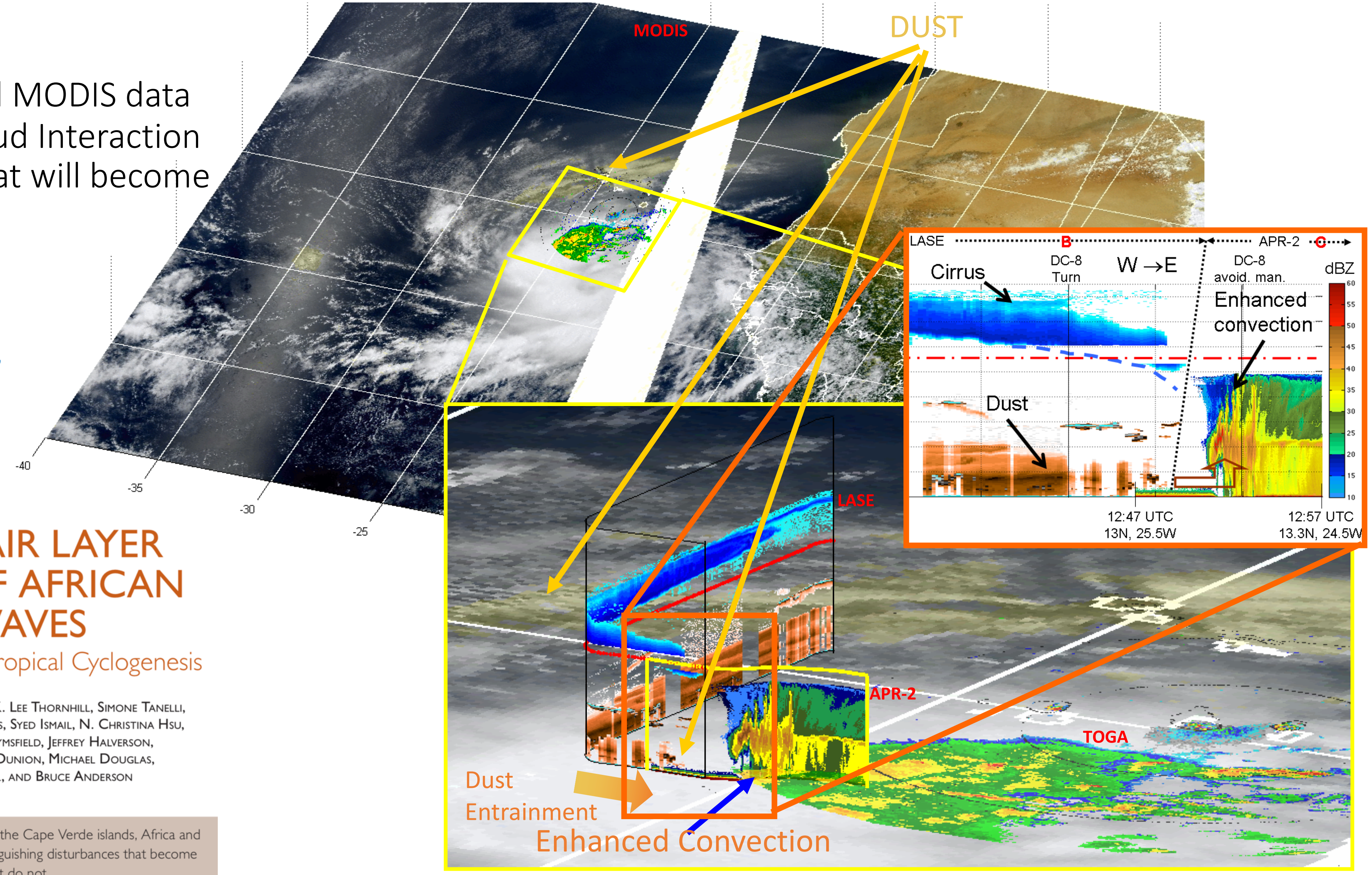
Cloud-Aerosol interactions & remote tropical weather events

Example #1 of need to fly high and low, far, long, and with several large and small instruments.

NAMMA, 2006:

APR-2, LASE, TOGA and MODIS data document Aerosol-Cloud Interaction in the formation of what will become Hurricane Helene

Microwave & Optical, Active and Passive



Adapted from Zipser et al. (Bullet. Amer. Meteor. Soc., 2009)

THE SAHARAN AIR LAYER AND THE FATE OF AFRICAN EASTERLY WAVES

NASA's AMMA Field Study of Tropical Cyclogenesis

BY EDWARD J. ZIPSER, CYNTHIA H. TWOHY, SI-CHEE TSAY, K. LEE THORNHILL, SIMONE TANELLI, ROBERT ROSS, T. N. KRISHNAMURTI, Q. JI, GREGORY JENKINS, SYED ISMAIL, N. CHRISTINA HSU, ROBBIE HOOD, GERALD M. HEYMSFIELD, ANDREW HEYMSFIELD, JEFFREY HALVERSON, H. MICHAEL GOODMAN, RICHARD FERRARE, JASON P. DUNION, MICHAEL DOUGLAS, ROBERT CIFELLI, GAO CHEN, EDWARD V. BROWELL, AND BRUCE ANDERSON

The objectives of an extensive field campaign based from the Cape Verde islands, Africa and Barbados during August–September 2006 included distinguishing disturbances that become tropical cyclones from those that do not.

Tropical storms & multi-role, multi-aircraft

Example #2 of need to fly high and low, far, long, and with several remote sensing and in situ instruments.

GRIP, 2010:

APR-2, HIWRAP, Dropsondes and CloudProbes : microphysics & storm structure ⟷ lightning

Understanding the Relationships between Lightning, Cloud Microphysics, and Airborne Radar-Derived Storm Structure during Hurricane Karl (2010)

BRAD REINHART,* HENRY FUELBERG,* RICHARD BLAKESLEE,+ DOUGLAS MACH,# ANDREW HEYMSFIELD,@ AARON BANSEMER,@ STEPHEN L. DURDEN,& SIMONE TANELLI,& GERALD HEYMSFIELD,** AND BJORN LAMBRIGTSEN&

** The Florida State University, Tallahassee, Florida*
+ NASA Marshall Space Flight Center, Huntsville, Alabama
 # Earth System Science Center, University of Alabama in Huntsville, Huntsville, Alabama
@ National Center for Atmospheric Research, Boulder, Colorado
& Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California
*** NASA Goddard Space Flight Center, Greenbelt, Maryland*

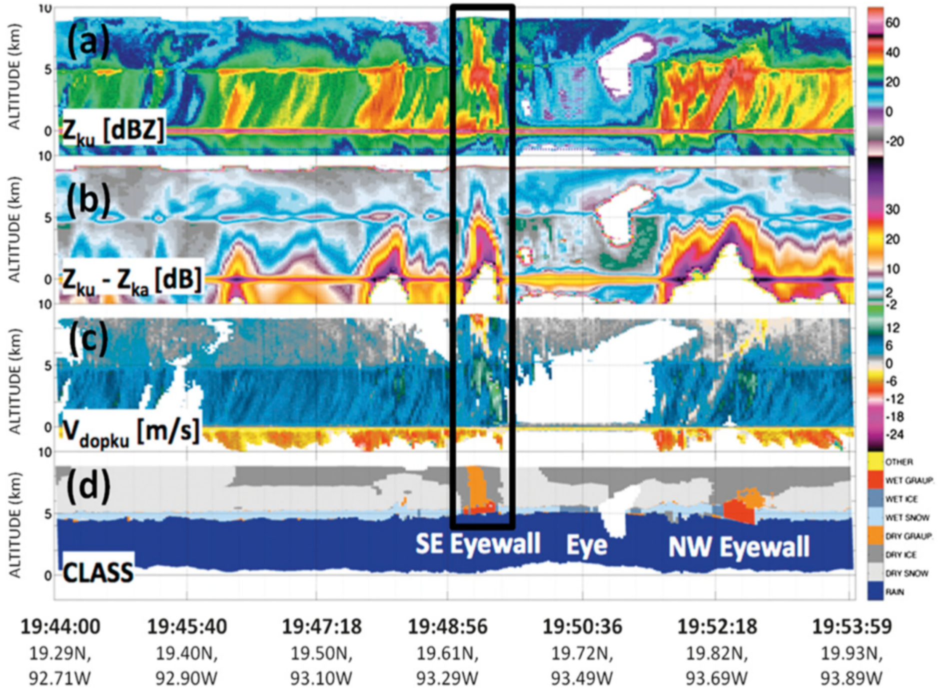


FIG. 12. APR-2 data from a southeast to northwest pass through Karl between 1944:00 and 1953:59 UTC. (a) Ku-band reflectivity. (b) Dual wavelength ratio (difference between Ku-band and Ka-band observed reflectivities). (c) Total Doppler velocity, with negative values representing upward vertical motion. (d) APR-2 experimental microphysics classification product. The black box highlights the electrified convective region of interest.

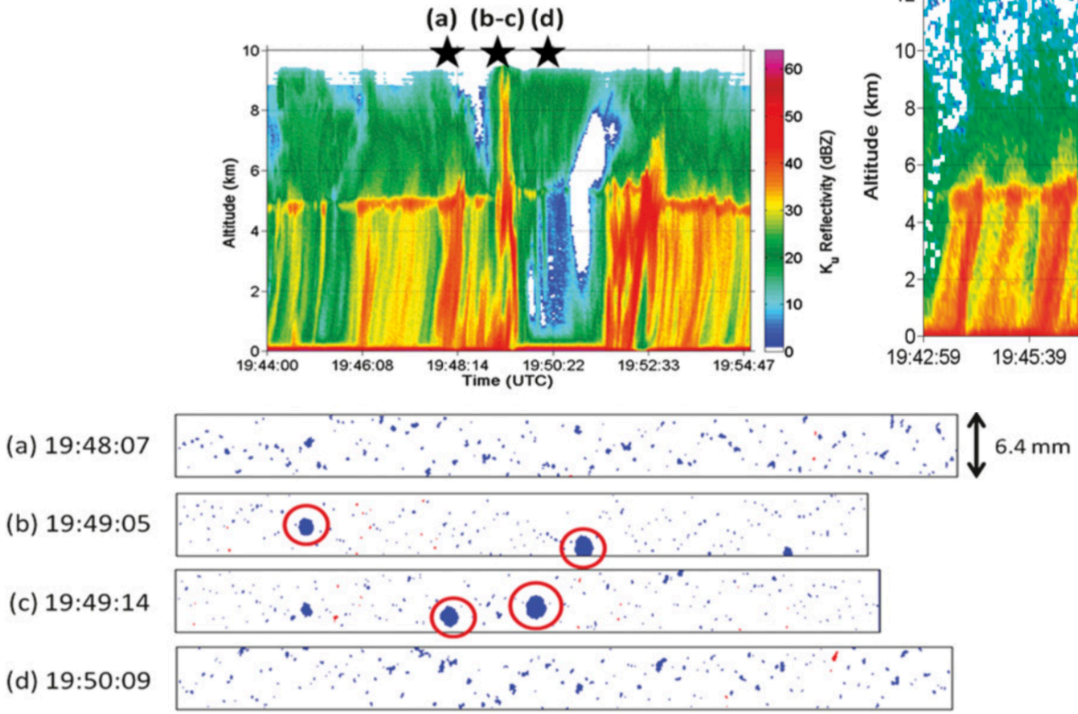
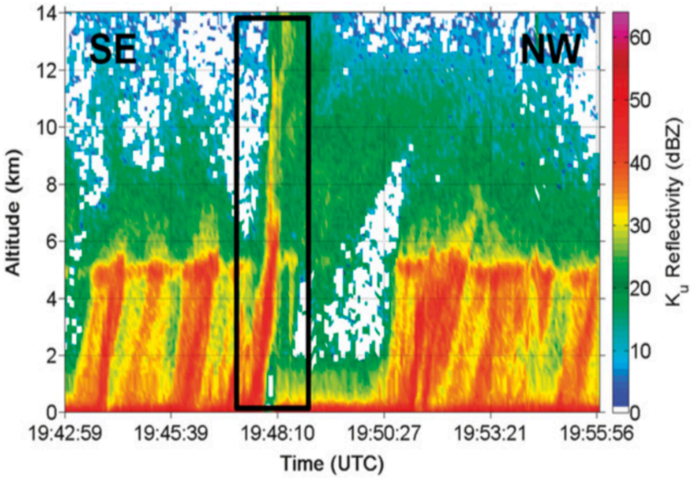


FIG. 17. PIP particle images from the southeast eyewall of Karl: (a) 1948:07, (b) 1949:05, (c) 1949:14, and (d) 1950:09 UTC. The black stars on top of the radar scan indicate the approximate location where each particle image was taken. Red circles identify graupel particles present in the convective region.

FIG. 13. Ku-band HIWRAP reflectivity data between 1942:59 and 1955:56 UTC. The black box denotes the electrified convective region of interest. Recall that the tilted appearance of the reflectivity is due to the scan geometry of HIWRAP.



DC-8 serving simultaneously as Remote Sensing and In Situ platform, with the GH overhead

Tropical storms & multi-role, multi-aircraft

Example #3 … the next day, over land, in a foreign country

…where dropsondes cannot be used and flight permissions are more complex

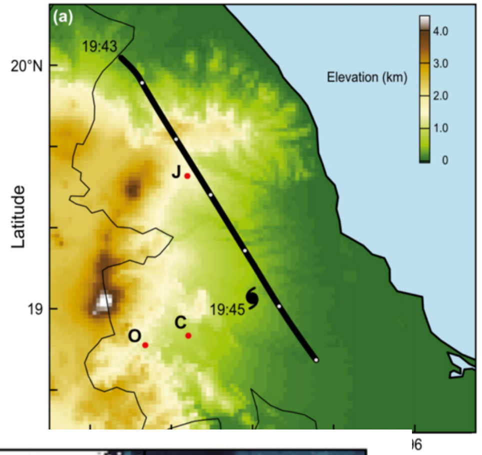
Orographic Modification of Precipitation Processes in Hurricane Karl (2010)

JENNIFER C. DEHART

Department of Atmospheric Sciences, University of Washington, Seattle, Washington

ROBERT A. HOUZE JR.

Department of Atmospheric Sciences, University of Washington, Seattle, and Pacific Northwest National Laboratory, Richland, Washington



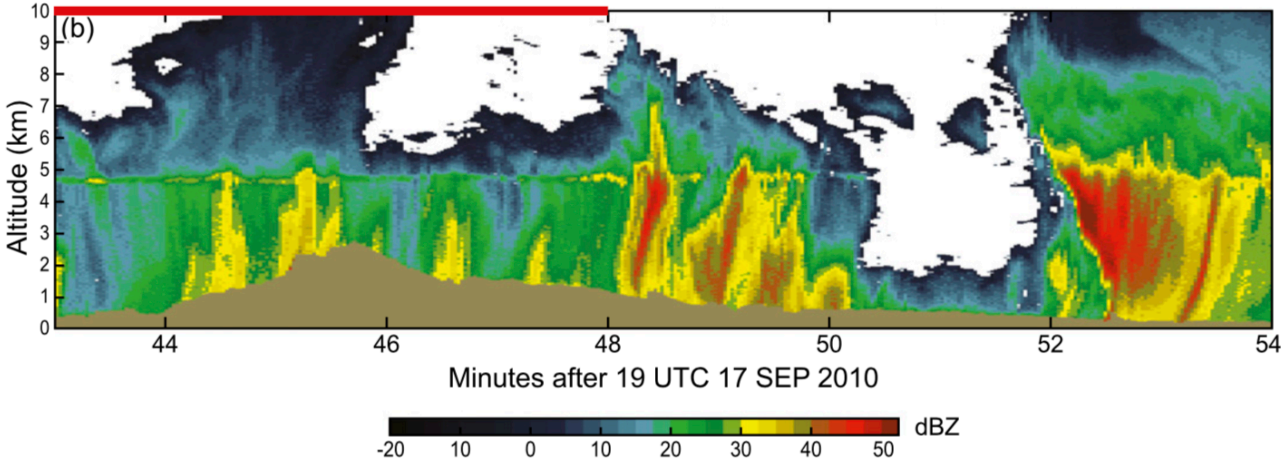
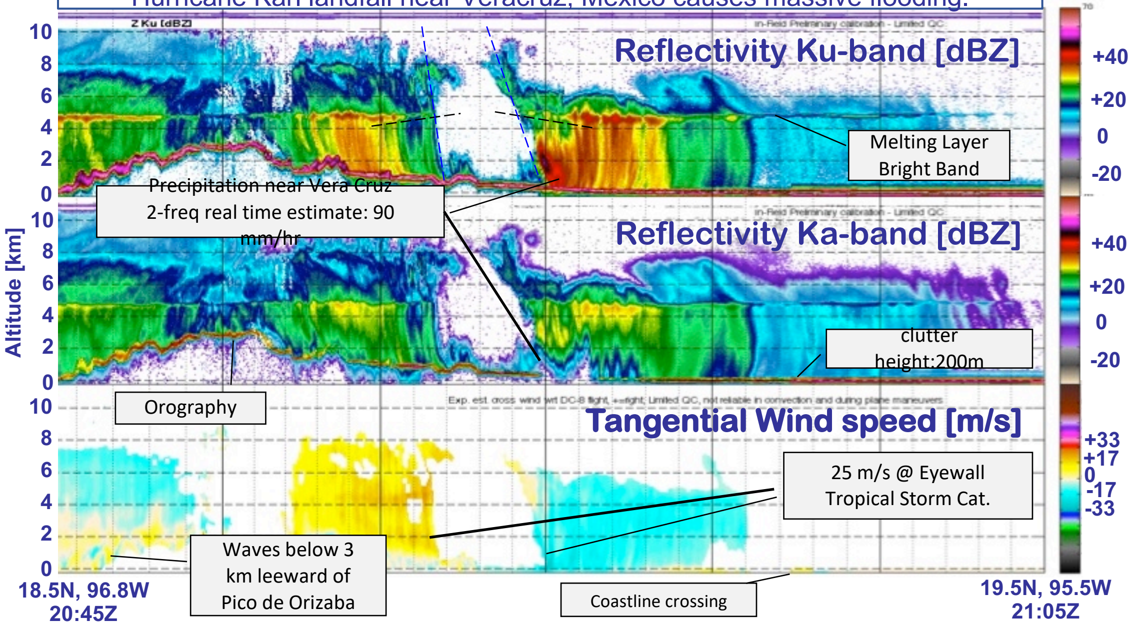


FIG. 7. (a) DC-8 flight segment on 17 Sep beginning at 1943 UTC and the corresponding center of Karl as interpolated from the NHC best track data. Time next to the hurricane symbol indicates the time to which the best track data were interpolated. Time next to the flight track indicates the starting point of the track. White dots indicate the position of the plane at every even numbered minute along the track. Locations of Jalapa, Córdoba, and Orizaba are labeled with their first initial. (b) Reflectivity cross section for the segment shown in (a). Thick red line corresponds to the red line of leg 3 in Fig. 8a.

Karl after landfall from the DC-8



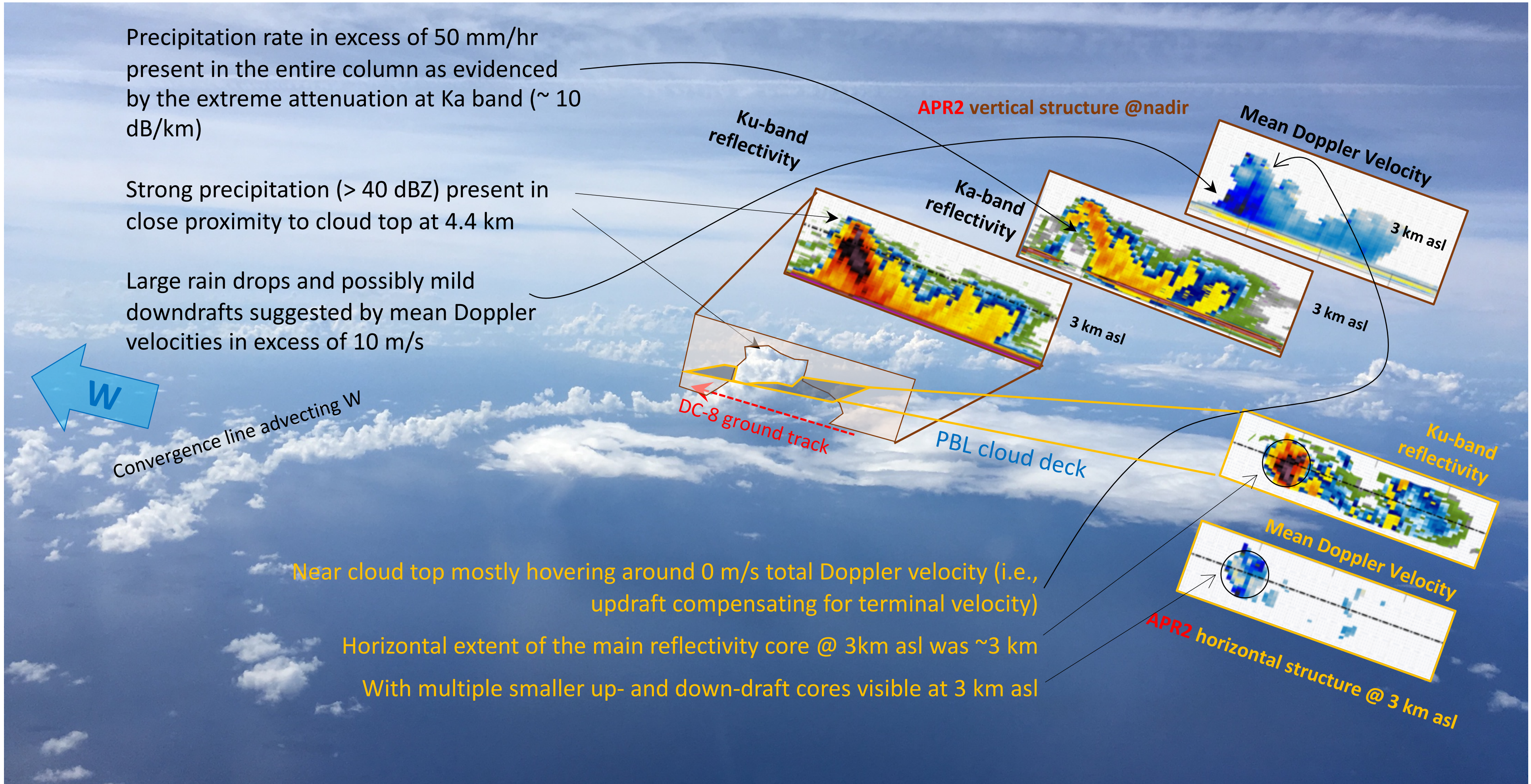
”Small” Oceanic weather phenomena

Example #4 : long range necessary even close to home

CPEX, 2017:

Intense shallow isolated convection

Multiple forms of oceanic tropical convection do not require necessarily to go very high or very far, but they do require time to be found, time to refine appropriate flight modules, and flexibility to operate over, around and inside them



On June 23, 2017, between 1920Z and 1940Z, @25.9N, 73.3W the DC-8 performed 3 passes over a fairly unimpressive-looking warm rain cloud.
The vast majority of isolated clouds visited on that day were producing little or no precipitation.
This one was different…it had been attached to a shallow deck for hours while advecting westward with the winds along a small line of convergence. Was the cloud deck its “plume”? Was it moisturizing the PBL?

Storm dynamics inside and outside

Example #5 : elaborating on prior example

Remote Sensing instruments needed to simultaneously observe the volume inside the storm and the volume outside, at a variety of scales, preferably at the same time. DropSondes still necessary.

CPEX, 2017: Embedded deep convection, shallow cumuli and PBL dynamics

Joint Analysis of Convective Structure from the APR-2 Precipitation Radar and the DAWN Doppler Wind Lidar During the 2017 Convective Processes Experiment (CPEX)

F. Joseph Turk[1], Svetla Hristova-Veleva[1], Stephen L. Durden[1], Simone Tanelli[1], Ousmane Sy[1], Dave Emmitt[2], Steve Greco[2], Sara Q. Zhang[3]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91107 USA
[2]Simpson Weather Associates, Charlottesville VA 22902 USA
[3]Global Modeling and Assimilation Office (GMAO), Goddard Space Flight Center, Greenbelt MD 20771 USA

Correspondence to: F. Joseph (Joe) Turk (jturk@jpl.caltech.edu)

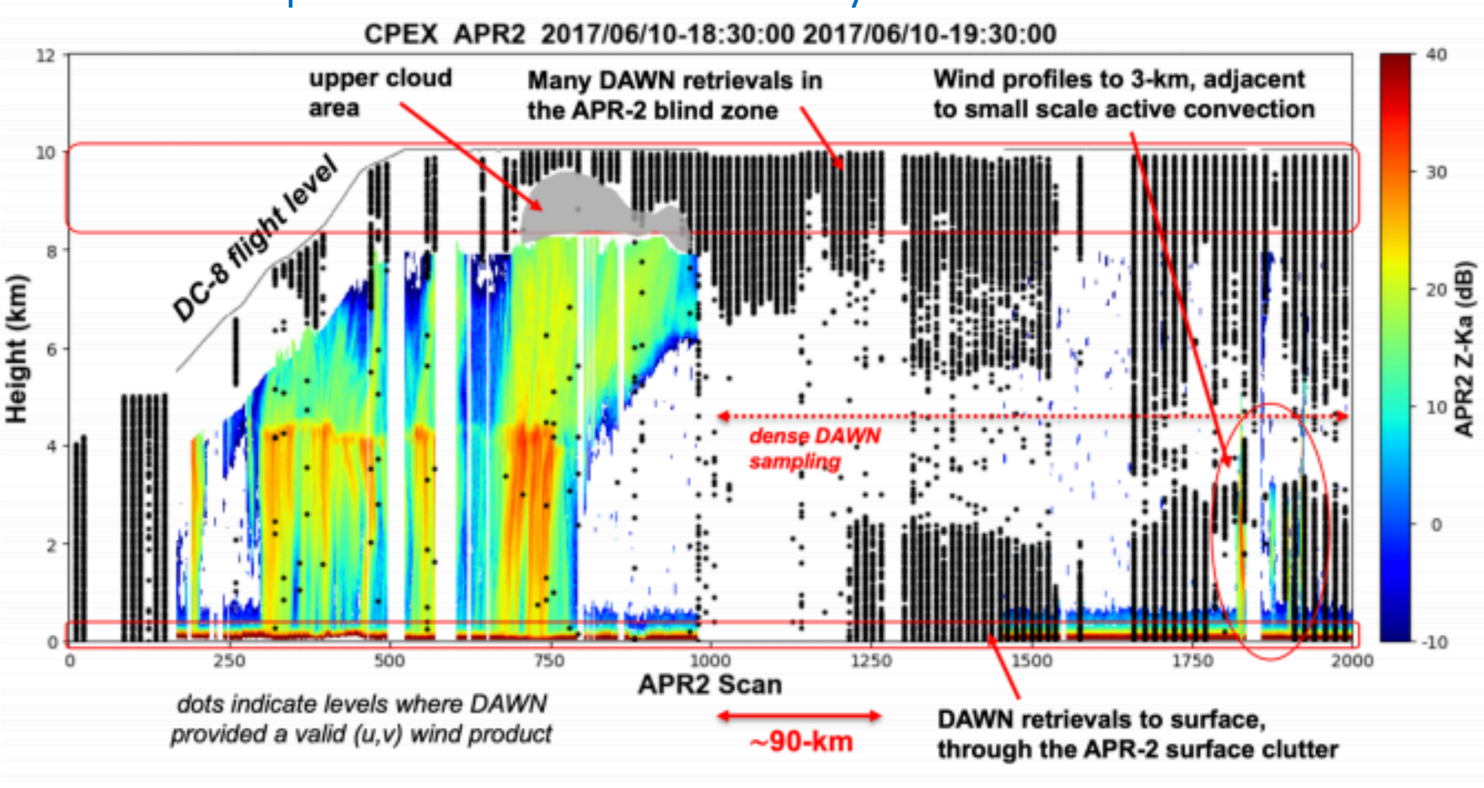


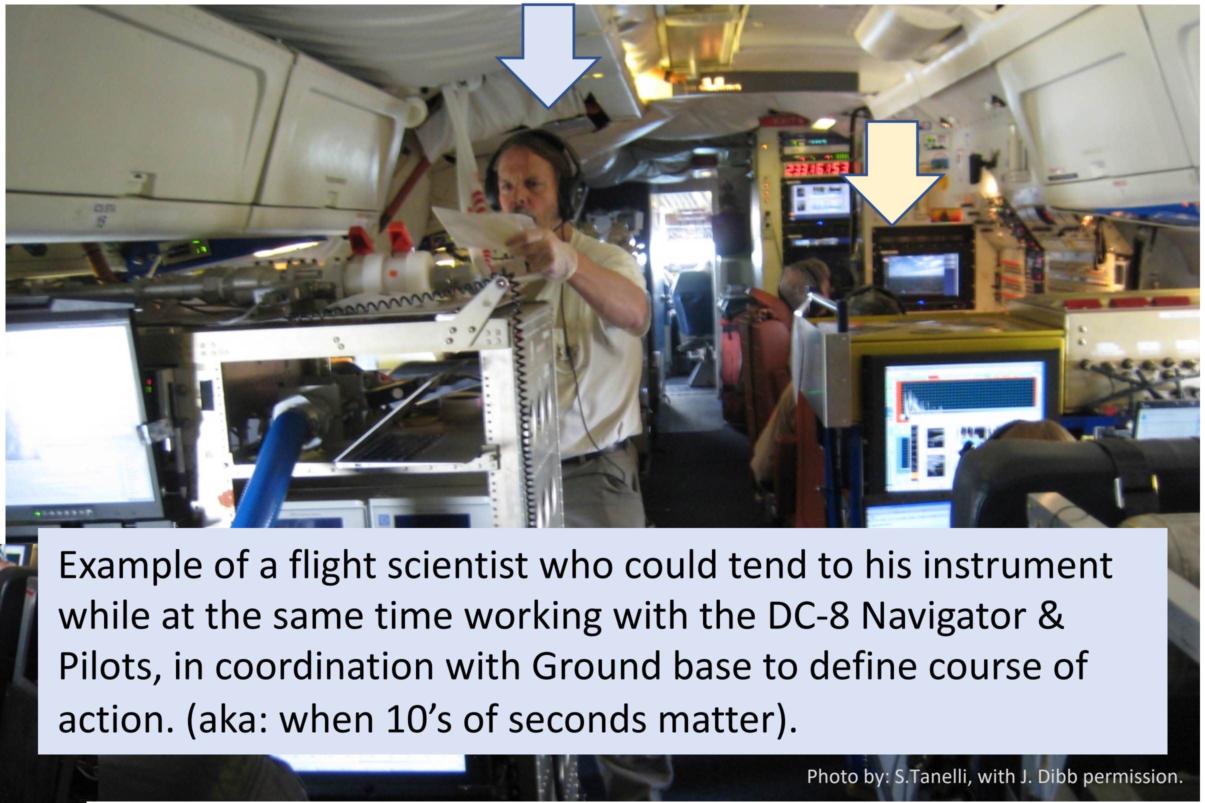
Figure 7. Cross-section of the APR-2 Ka-band reflectivity (color scale in dB to right) during Segment 1 (1830-1930 UTC). The x-axis represents the APR-2 scan number (2000 scans representing 720-km ground distance), and y-axis the height (km) above the ocean surface. The DC-8 reached its nominal 10-km flight altitude near 1840 UTC. The black points represent vertical locations of valid DAWN (*u*, *v*) wind vectors from the DAWN wind profiles obtained during processing of the LOS data. The gray "upper cloud" area shows an area where the clouds in the 1.8-km "blind zone" (where APR-2 does not receive any data) but whose cloud top is noted by the lowest-most level in the DAWN profiles.

The flying lab with integrated flight planning suite.

SEAC^{4}RS, 2013: Cloud, Aerosol, Composition

Even the large capacity of the C-8 forced painful selections, and prompted renewed efforts to reduce the size and mass of instruments

This type of cross disciplinary paper requires all this



Example of a flight scientist who could tend to his instrument while at the same time working with the DC-8 Navigator & Pilots, in coordination with Ground base to define course of action. (aka: when 10's of seconds matter).

Photo by: S.Tanelli, with J. Dibb permission.

JGR Atmospheres

RESEARCH ARTICLE
10.1029/2019JD031957

Key Points:
- Formaldehyde and hydrogen peroxide scavenging efficiencies are consistent with literature, while methyl hydrogen peroxide is generally smaller
- Highly soluble hydrogen peroxide is mostly depleted between cloud base and the freezing level, that is, the warm region of the storm
- Retention of dissolved trace gases in frozen precipitation seems to be more important for moderately soluble trace gases

Vertical Transport, Entrainment, and Scavenging Processes Affecting Trace Gases in a Modeled and Observed SEAC^{4}RS Case Study

G. C. Cuchiara[1,2], A. Fried[1], M. C. Barth[2], M. Bela[3,4], C. R. Homeyer[5], B. Gaubert[2], J. Walega[1], P. Weibring[1], D. Richter[1], P. Wennberg[6,7], J. Crounse[6], M. Kim[6], G. Diskin[8], T. F. Hanisco[9], G. M. Wolfe[9,10], A. Beyersdorf[11,12], J. Peischl[3], I. B. Pollack[3,13], J. M. St. Clair[6,14,15], S. Woods[16], S. Tanelli[17], T. V. Bui[18], J. Dean-Day[18], L. G. Huey[19], and N. Heath[20]

[1]Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO, USA, [2]Atmospheric Chemistry Observations and Modeling Laboratory, National Center for Atmospheric Research, Boulder, CO, USA, [3]Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, CO, USA, [4]Chemical Sciences Laboratory, Earth System Research Laboratory, NOAA, Boulder, CO, USA, [5]School of Meteorology, University of

The flying lab as nursery of new technologies

Two examples close at hand and recent

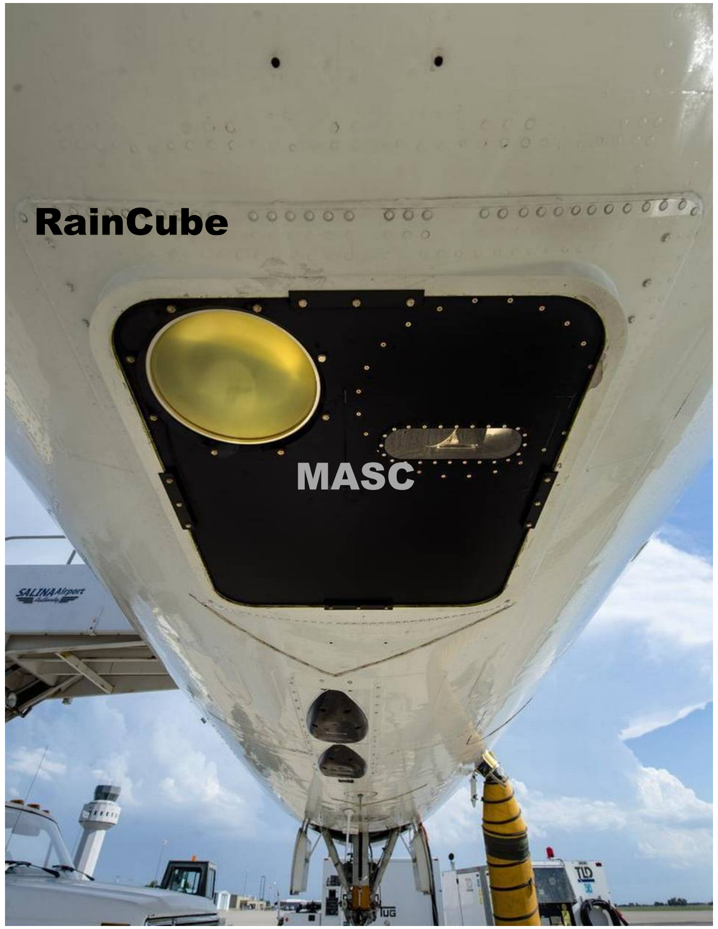
PECAN, 2015: RainCube & MASC

Both operated successfully on the NASA DC-8 for their **first airborne test and demonstration during PECAN (Jun. 28 – Jul. 11, 2015)**

They shared the nadir #2 port, and they had no funding for an independent flight demo campaign.

The DC-8 team helped identify a possible piggyback opportunity. The PECAN team gracefully adopted them. HQ supported the augmentation.

They were successfully demonstrated in orbit 3 years later.



Their demonstrated performance in PECAN is believed to be a fundamental step in them having had the chance to be launched…

OLYMPEX/RADEX'15, 2015: APR-3

In SEAC^{4}RS a highly desired cloud radar could not be included in the payload, (only the APR-2 precipitation radar was).

That type of need motivated the AITT'12 funding of APR-3 (a cloud + precipitation radar) that essentially occupies the same volume and ports as APR-2. APR-3's development schedule was not planned to complete until 2016, but the DC-8 environment, and its engineering team, enabled an <u>accelerated integration</u> of APR-3's early configuration and demonstration in OLYMPEX/RADEX'15.

The DC-8 main cabin and cargo bay environments facilitate rapid integration of relatively small technology development efforts. In both examples shown here timeliness of integration was essential

A not necessarily reasonable, experimenter wish-list for a "DC-8 replacement"

1. Essential roles of airborne science within NASA
   A. **Complement** spaceborne observations
   B. **Enable** spaceborne observations
   C. **Validate** spaceborne observations
2. Essential role of the DC-8 within the NASA fleet specifically for atmospheric physics and dynamics
   A. **Reach:** Long legs, relatively "easy" logistics
   B. **Broad Envelope:** Wide range of altitudes, and flight speeds. Resilient.
   C. **Layout:** Crew-friendly & high capacity, hardware flexible layout

DC-8	Complement	Enable	Validate
REACH	improved fuel efficiency **Reduced cost**	**Reduced cost** or scheduled "mass piggyback" opportunities	reduced runway length
BROAD ENVELOPE & ROBUST	enable slower speeds (100 m/s) at mid altitude ceiling increased to 50 kft		enable slower speeds (100 m/s) at mid altitude ceiling increased to 50 kft
HUMAN + HW FRIENDLY LAYOUT	Improved hazard assessment and avoidance	More RS ports (including fore-aft), wingtip or pylon pods	
	improved intercom, comms, and coffeemaker		Improved comms and multimedia awareness tools

An N-aircraft replacement for the DC-8 is viable, or even preferable, IF the joint cost of operation of the N platforms is comparable.

Backups

	Crew / IF	Long Range	High Altitude	Mid Altitude	Low ALtitude	Speed ctl	Deploy/ Logistics	Multi Instrument	RS+in situ	Access to instr	Unpress Instr
DC-8	++	++	+	++	+	+	+	++	+	++	+
P-3	+	+	--	++	++	+	++	+	++	+	+
ER-2	-	-	++	--	--	-	-	+	+	--	+
G-V								-			

	Crew	Long Range	High Altitude	Mid Altitude	Low ALtitude	Speed ctl	Deploy/ Logistics	Multi Instrument	RS+in situ	Access to instr	Unpress Instr
Sci – Hi Impact	H	H	H	H	L	M	H	H	L	M	V
Sci – Hydro/TCu	M	H	M	H	M	M	M	H	M	L	V
Sci - PBL	M	H	L	M	H	H	H	H	H	M	V
Demo - Instr	L	L	V	V	V	H	L	L	V	H	V
Demo - Technol	L	L	V	V	V	V	L	L	V	H	V
Demo - algo	V	V	V	V	V	V	V	V	V	L	V
GV	H	H	V	V	V	V	V	H	M	V	V

APR3 – HSRL2 – RSP Altitude Regimes

Target	Retrievals	Aircraft height above aerosol/cloud layer top	Rationale/Drawbacks
Shallow Cu microphysics and macrophysics	APR-2 high-res cloud retrievals; RSP cloud retrievals	600 ft above cloud tops	Limits impact of crab angle for RSP W-band OK; no Ku or Ka No data from HSRL
Shallow Cu cloud top microphysics	RSP cloud retrievals	1500 – 2000 ft above cloud tops	Limits impact of crab angle for RSP W-band OK; no Ku or Ka HSRL cloud data suspect.
Cloud top microphysics	RSP+HSRL CDNC retrievals	>3000 ft above cloud tops (4500 preferred)	Reduce impact of HSRL optical overlap function; get accurate measurement of aerosol backscatter for calibration of attenuated backscatter profile
Aerosol above cloud	Aerosol extinction and backscatter retrievals	> 4500 ft above top of aerosol layer	Radar gets wider swath. RSP OK for clouds larger than 1-km horizontal. Get fully beyond HSRL optical overlap range (1.5 km) + the thickness of the aerosol layer

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D00J14, doi:10.1029/2009JD013302, 2010

Influence of turbulence parameterizations on high-resolution numerical modeling of tropical convection observed during the TC4 field campaign

Antonio Parodi[1] and Simone Tanelli[2]

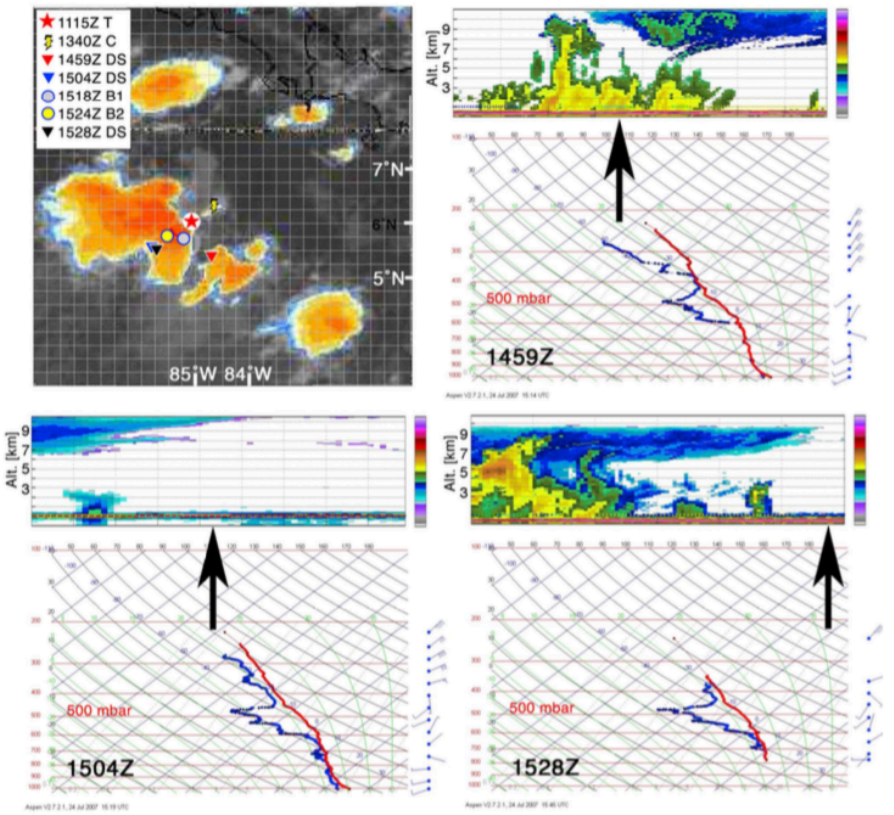


Figure 3. (top left) GOES image at 1528 Z and position of dropsonde releases and APR2 observations of convective cores during the time period 1340–1530 Z. (top right and bottom) Dropsoundings at 1459, 1504, and 1528 Z are shown together with an approximate position with respect to APR-2 imagery (nadir beam, radar reflectivity between the surface, and 10 km altitude). Core C, not used in this analysis, is the one that was penetrated at around 20 kft and where the DC-8 was struck by lightning. Core B1 is shown in Figure 4. Core B2 is used in the analysis but is not shown in the figures.

Multi aircraft (DC-8 with ER-2 and WB-57)

Good example of DC-8's resilience (we entered that cell at a not ideal altitude and got zapped – mission continued).

Multiple role of atmo modeling in these endeavors.

Dropsondes.

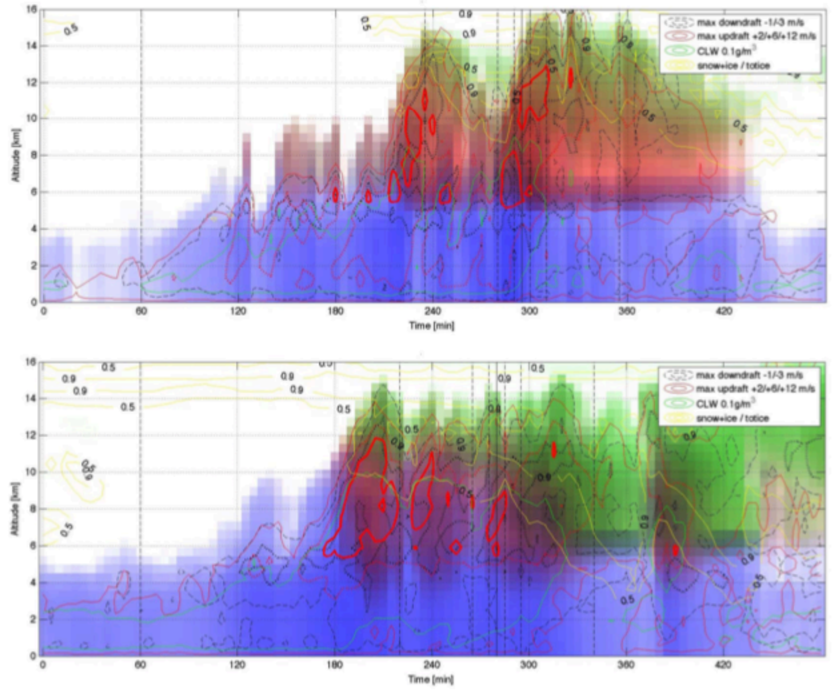


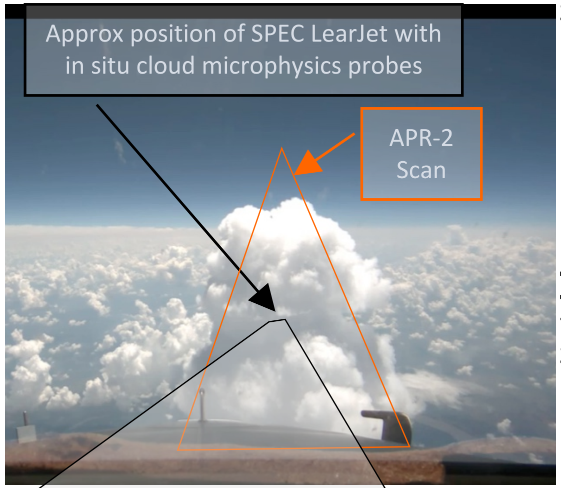
Figure A1. Convective cell history. Blue is amount of rainwater, red is graupel, and green is snow. (top) One example from IW. (bottom) One example from IT. The time origin is set at 1000 Z.

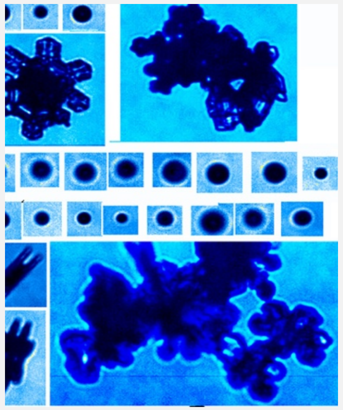
The Airborne Precipitation Radar 2nd Generation (APR-2) in the SEAC4RS Field Campaign 2013

S. Tanelli, S. L. Durden, S. Hristova-Veleva, J. Turk, W. Chun, S. Tauch

- **APR-2** was developed (ESTO IIP '99 E. Im, PI) to support the science of **GPM** and to demonstrate **advanced radar techniques to monitor precipitation from space**.
- APR-2 is currently deployed on the NASA DC-8 to contribute high quality **3-D depictions of convective clouds** for the SEAC4RS experiment.
- One of **SEAC4RS** goals is to advance our understanding of weather-pollution interactions to enable improvements in **climate and chemical transport models**.
- Data acquired by APR-2, other remote sensing and in situ instruments on NASA ER-2, SPEC LearJet, and UAH and AERONET ground facilities during SEAC4RS will enable objective performance **assessment of current models in representing cloud-aerosol-chemistry interactions**.

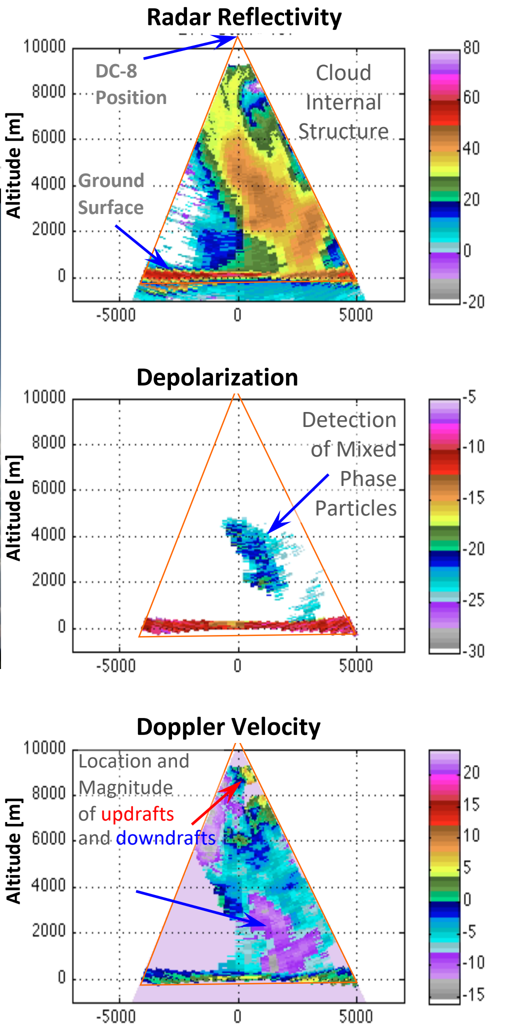
NASA DC-8 forward camera view of convective tower a few seconds before was overflown in Aug 2013 over Alabama





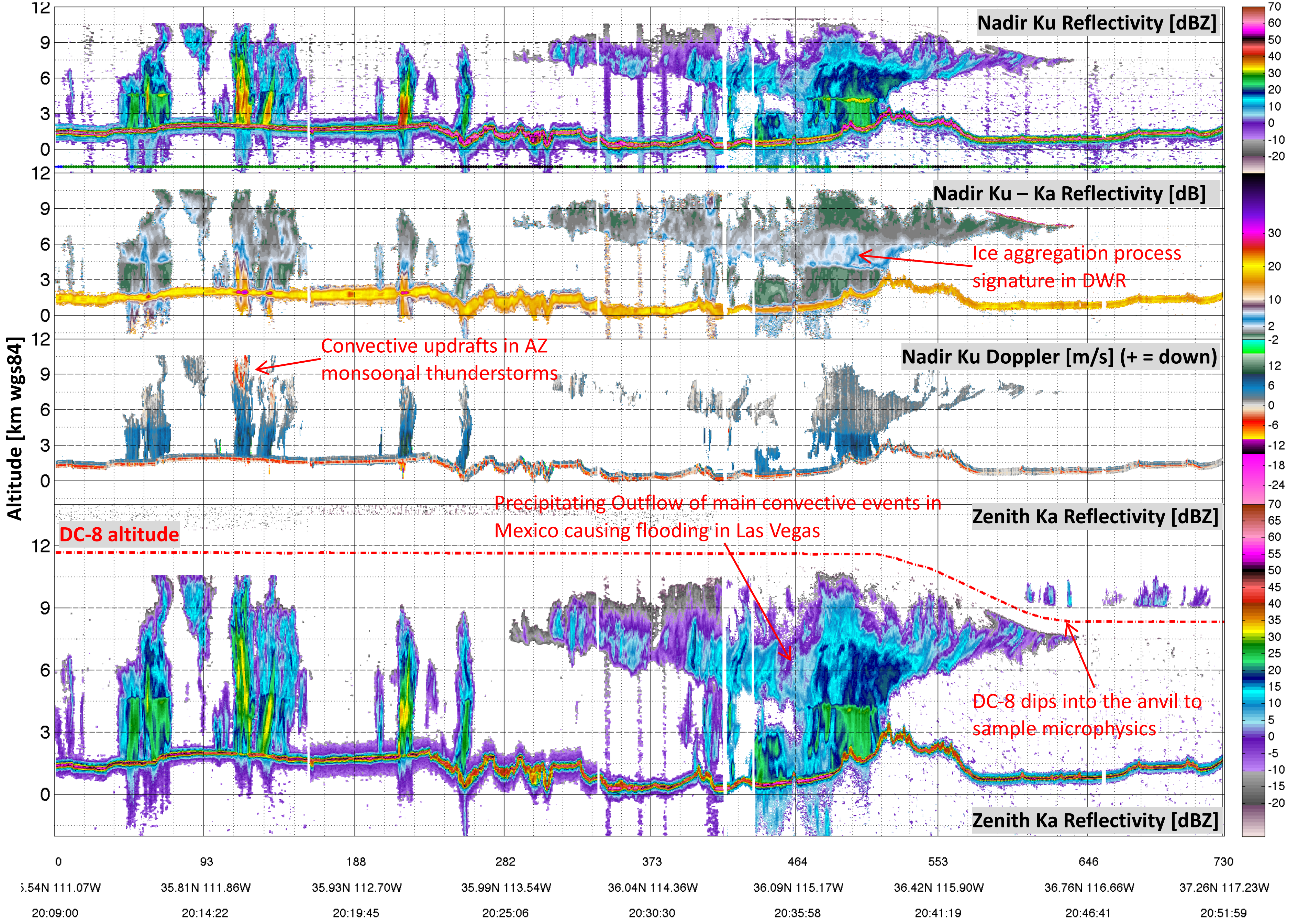
Cloud particles observed by in situ probes

SPEC Image Courtesy of P. Lawson and R. Bruntjes



APR-2. Radar reflectivity, signal depolarization and Doppler velocity provide a high resolution view of the thundercloud where the in situ samples were collected.

Cloud environment awareness & in situ probes.



Within NASA, airborne radars are developed specifically when tied to a spaceborne mission or mission concept

① Initial demonstration of new C&P Radar concepts, designs, technologies, algorithms

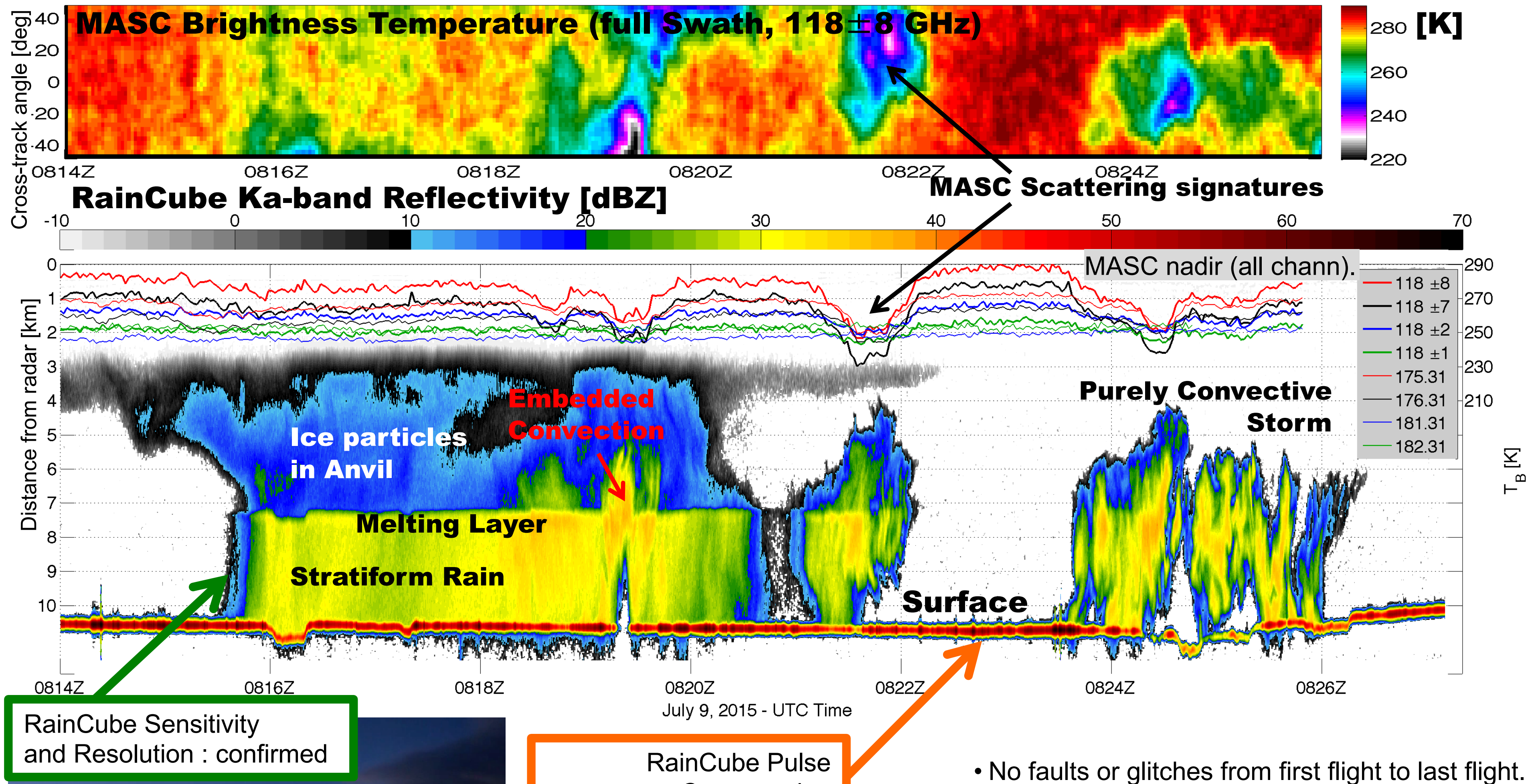
- Necessary to demonstrate novel measurement principles or techniques, or preliminary proof of form and fit, or novel aspects of processing techniques.
- Airborne is considered a "relevant environment" for some aspects of a new technology development.
  - Not adequate to address the specific challenges tied to space environment (e.g., thermal, radiation, etc.)
  - Sub-optimal proxy when it comes to platform velocity and attitude: not always adequate in representing effects of a LEO platform velocity (~ > 6 km/s) relative to Earth's surface, but generally overly conservative when it comes to attitude and location related uncertainties (accuracy , precision and control in v and attitude are order(s) of magnitude finer in spaceborne platforms wrt airborne).

② "Ground Validation" centerpieces

- Because of the similarity in look direction (downward) and the high mobility to target specific underflights

③ Complementary sources of data to programs or spaceborne assets

- To target specific measurements that cannot yet be achieved from space, but are necessary to develop either the science, the algorithms or the technologies.



- No faults or glitches from first flight to last flight.
- Fine calibration and science analysis: in progress.
- Coordinated operations with ground based weather radars

Acknowledging:

- AFRC: excellent coordination and rapid implementation
- PECAN Science Leadership: outstanding flexible and creative collaboration
- OU ARRC: coordinated deployment of X-band ground based weather radars
- Weather Focus Area Leads: additional flight hours to PECAN for RainCube and MASC