Airborne Radar Systems for Research

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Wen-Chou Lee – *NCAR*
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*use of material from chapter of book: Airborne Measurements for Environmental Research – Methods and Instruments, Manfred Wendisch & Jean–Louis Brenguier, Eds. (release imminent)

Pros/Cons of Airborne Radar

- Allows studies over inaccessible regions
- Complementary sensors carried by aircraft (in-situ sensors, remote sensors)
- View from multiple angles
- Most studies are "snap-shots" (i.e., limited on-station time)
- Radars are short-wavelength (X-band or shorter) with necessary trade offs about attenuation, non-Rayleigh scattering, etc.

Survey of Systems/Platforms

Radar Name	Hurricane Surveillance	NOAA P-3	ELDORA (Electra Doppler Radar)	WCR (Wyoming Cloud Radar)
Owner	NOAA (ESSA)	NOAA	NSF/NCAR	Univ. Wyoming
Platform	DC-6	P-3 Orion 4-engine turboprop	Electra, NRL P-3	King-Aire, C-130
Scanning	RHI – scan tied to drift angle	RHI-Fore-Aft ±20° normal to heading	RHI-Fore-Aft ±20° normal to heading	Vertical or horizontal dual-beam
Radar type	Non-coherent	Doppler	Doppler	Doppler, dual-pol
Freq	X-band	X-band	X-band	W-band
Years	1964?-1975	1977-present	1992-2012	1995-present

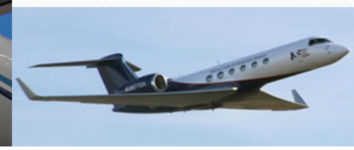
Survey of Systems/Platforms

Radar Name:	EDOP (ER-2 Doppler Radar)	CRS (Cloud Radar System)	HIWRAP (high-altitude imaging rain and wind profiler)	EXRad (ER-2 X-band Radar)
Owner	NASA	NASA	NASA	NASA
Platform	ER-2	ER-2	WB-57, Global Hawk	ER-2
Scanning	Dual-beam (fixed, nadir & +35°)	nadir	Nadir conical, dual-beam	dual-beam: conical or cross- track scan about nadir; fixed nadir
Radar type	Doppler, dual-pol (LDR)	Doppler, dual-pol (LDR)	Doppler	Doppler
Freq (band)	X	W	K_u, K_a	X
Years	1993-present	2002-	2010-	2010-

Survey of Systems/Platforms

Radar Name:	**SPIDER** (Super Polarimetric Ice-crystal Detection and Explication Radar)	**EC CPR** (Environment Canada Cloud Profiling Radar	**RASTA** (Radar SysTem Airborne)	**NAWX** (NRC Airborne W and X-band Polarimetric Doppler Radar
Owner	Japan	Canada	France	Canada
Platform	Gulfstream-II	Convair-580	Falcon 20, ATR-42	Convair 580
Scanning	-40 to +95 degree scan across flight direction	Fixed zenith and nadir- looking	3 down beams, 2 up beams. ±15 degrees sector	Vertical & Side looking
Radar type	Doppler, dual-pol	Non-coherent	Doppler	Doppler, dual-pol
Freq (band)	W	K_a	W	X, W
Years	1998-present	1999-	2000-	2006-

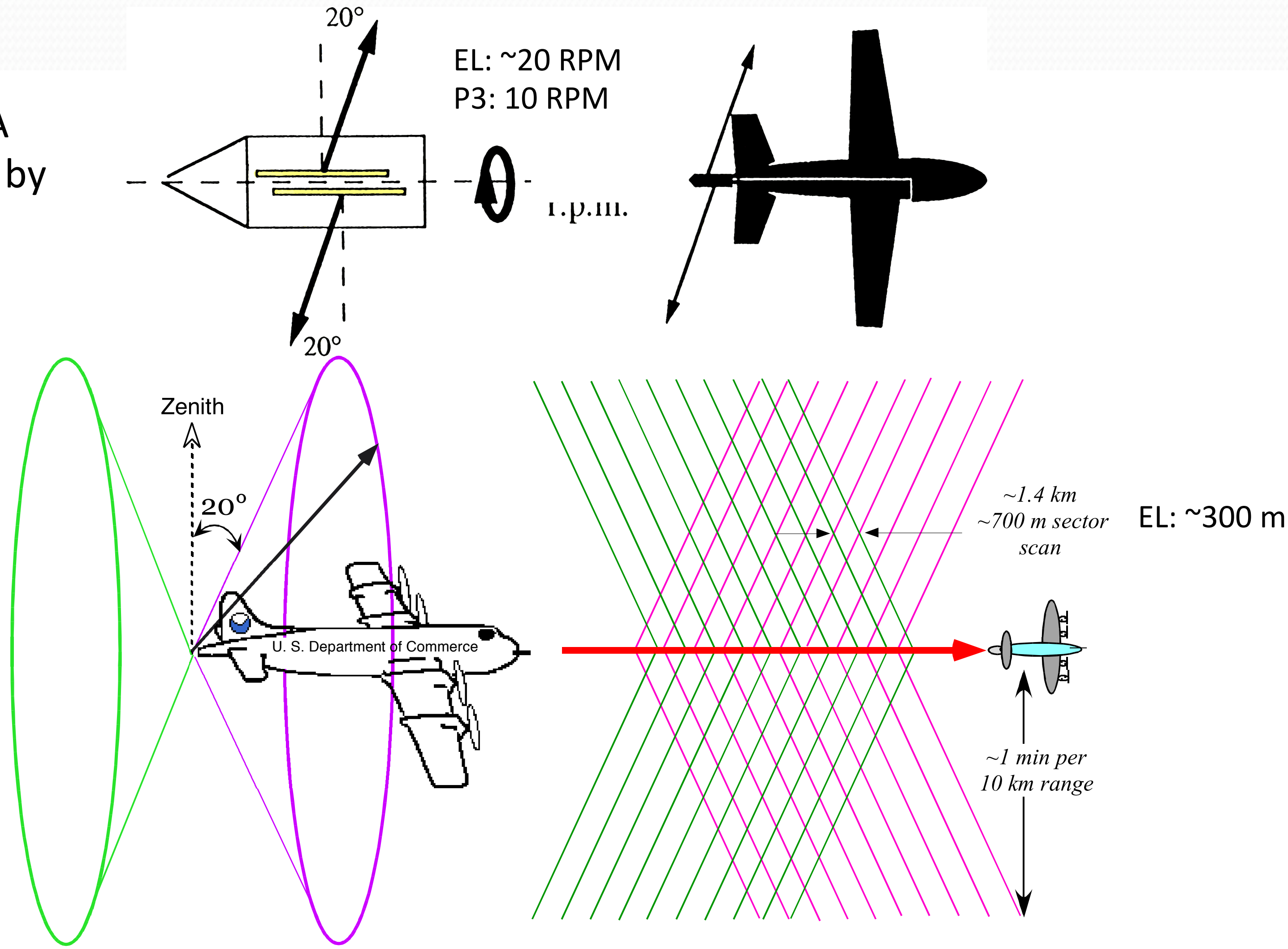
Survey of Systems/Platforms

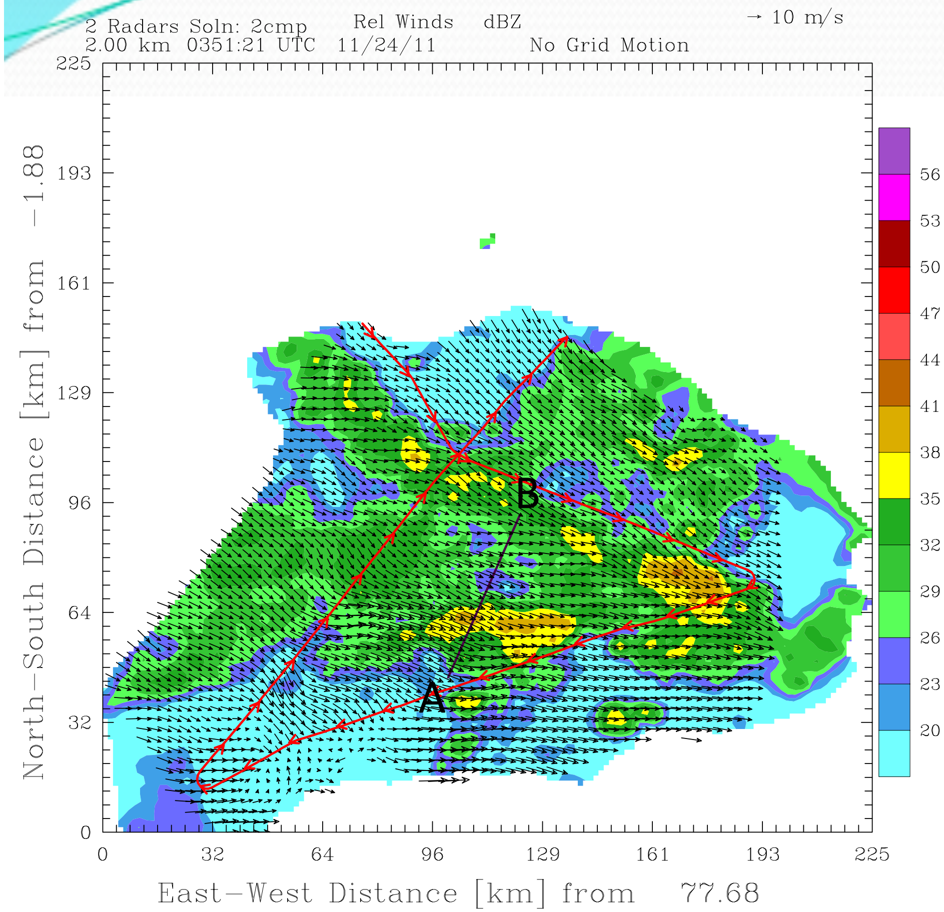
Radar Name:	G-IV Tail Doppler Radar	HCR (HIAPER cloud radar)	ACR (Airborne Cloud Radar)	IWRAP (Imaging Wind and Rain Profiler
Owner	NOAA	NSF/NCAR	NASA	NOAA
Platform	G-IV	G-V	NASA P-3, DC-8	P-3
Scanning	RHI-Fore-Aft ±20° normal to heading	RHI	Nadir	conical scan about nadir, quad- beam (30, 35,40 and 50 deg)
Radar type	Doppler	Doppler, dual-pol	Doppler, dual-pol	Doppler, dual-pol
Freq (band)	X	W	W	C, K_u
Years	2010	2013-	1995-	2002-

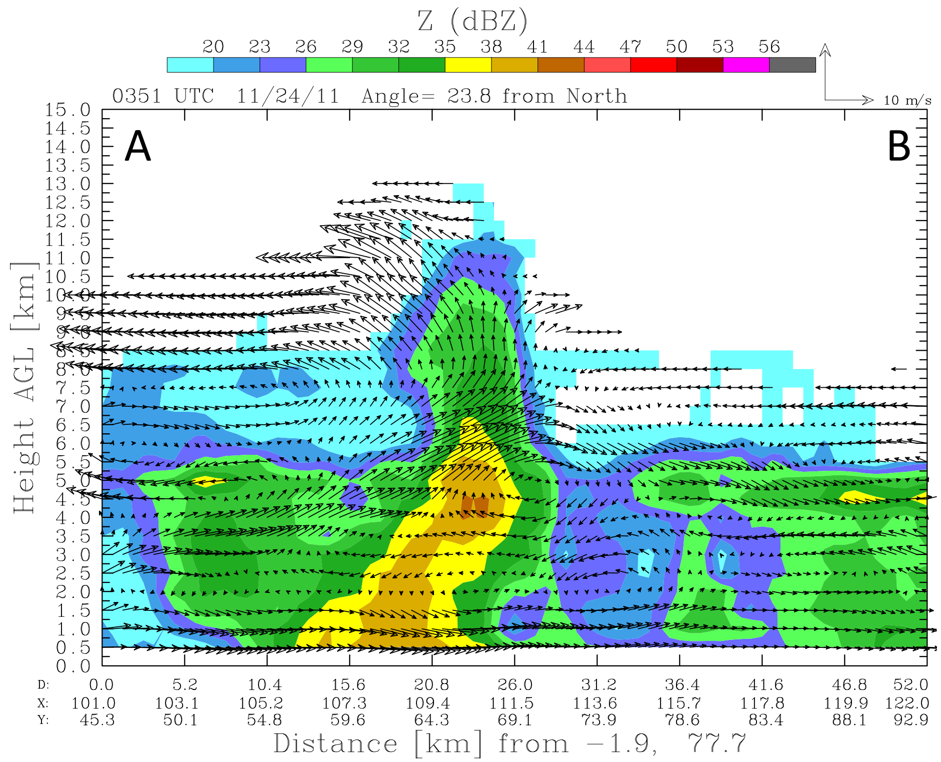
Fore-Aft Scanning "Mesoscale" Doppler Radars: NOAA P-3s & ELDORA

P-3 & ELDORA antenna built by France

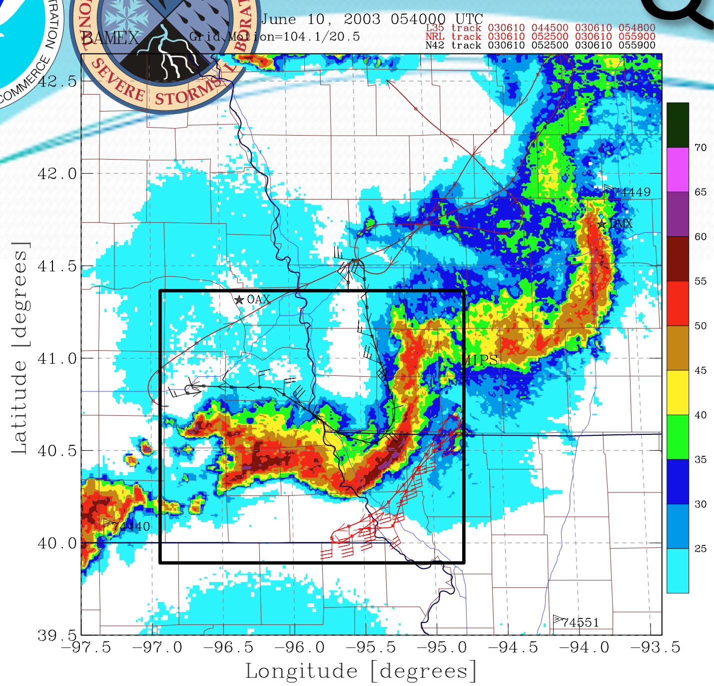


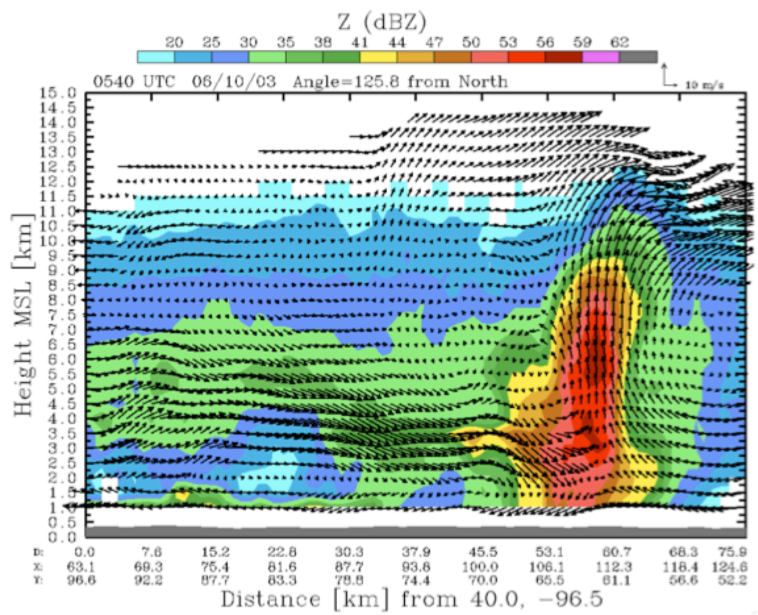
DYNAMO: Nov 24–Active Phase

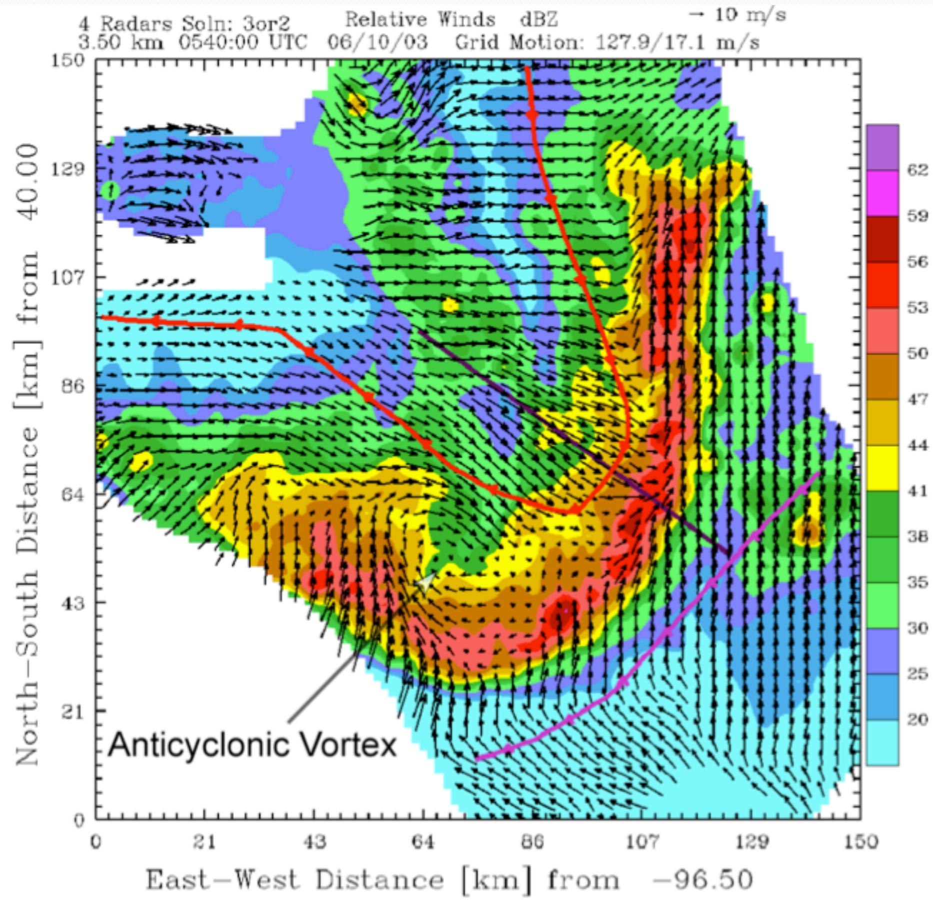




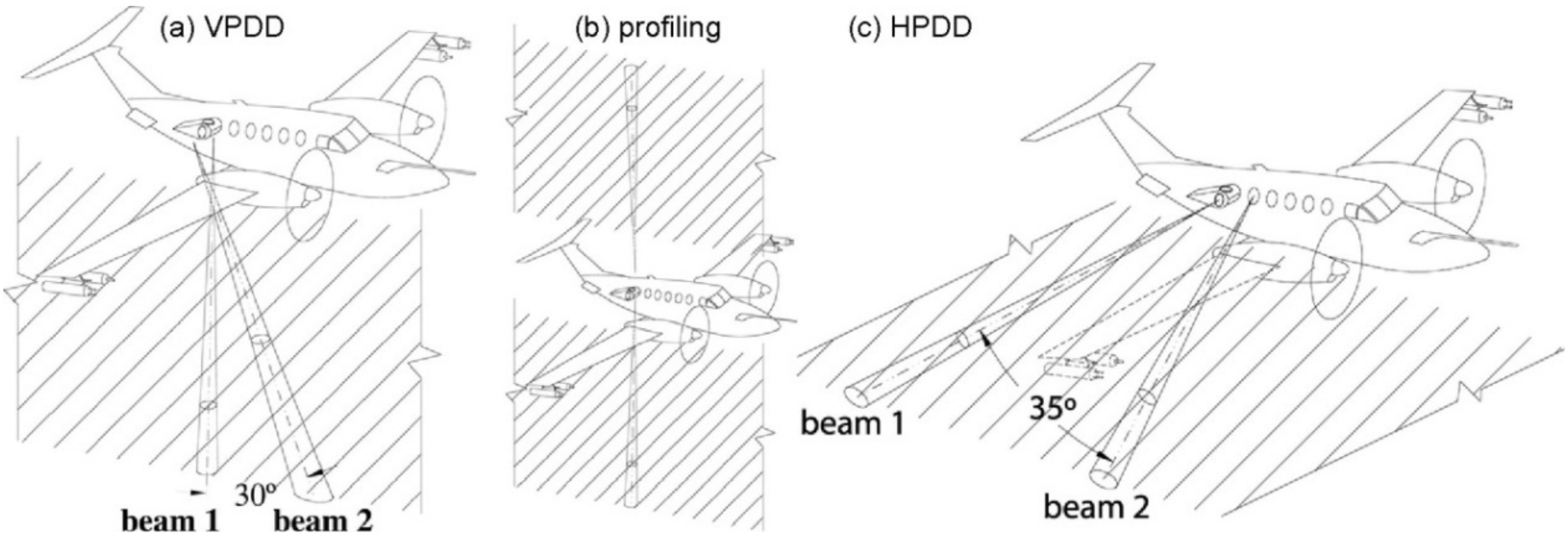
Quad-Doppler Example: BAMEX





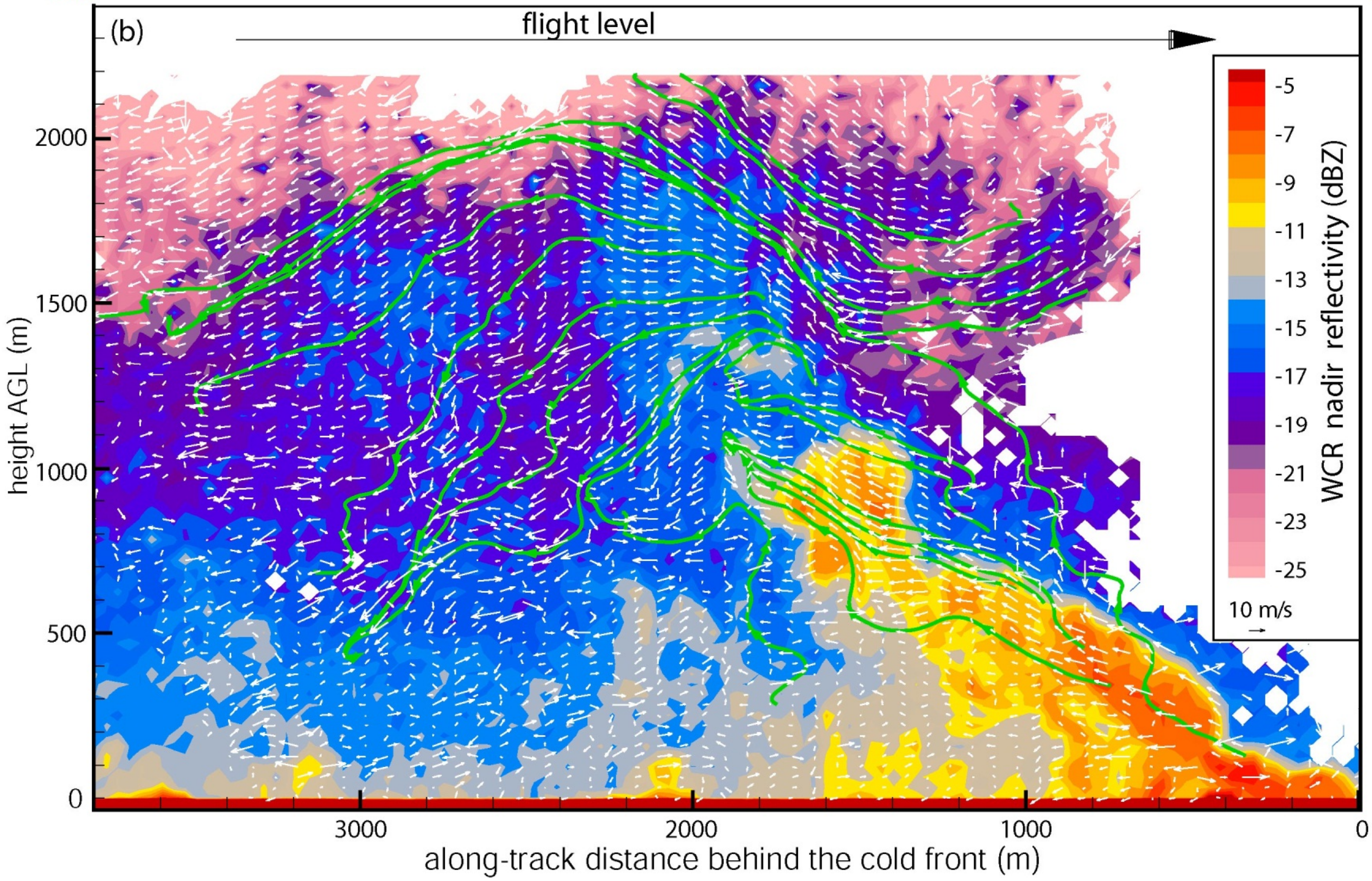


Wyoming Cloud Radar (3 mm, 95 GHz, W-band): Cloud Scale Features



WCR antenna options aboard the UWKA (from Damiani et al. 2006). The acronym VPDD (HPDD) refers to vertical (horizontal) plane dual-Doppler.

A Vertical-plane dual-Doppler cross section across a cold front in West Texas. Wyoming Cloud Radar data collected as part of the IHOP campaign

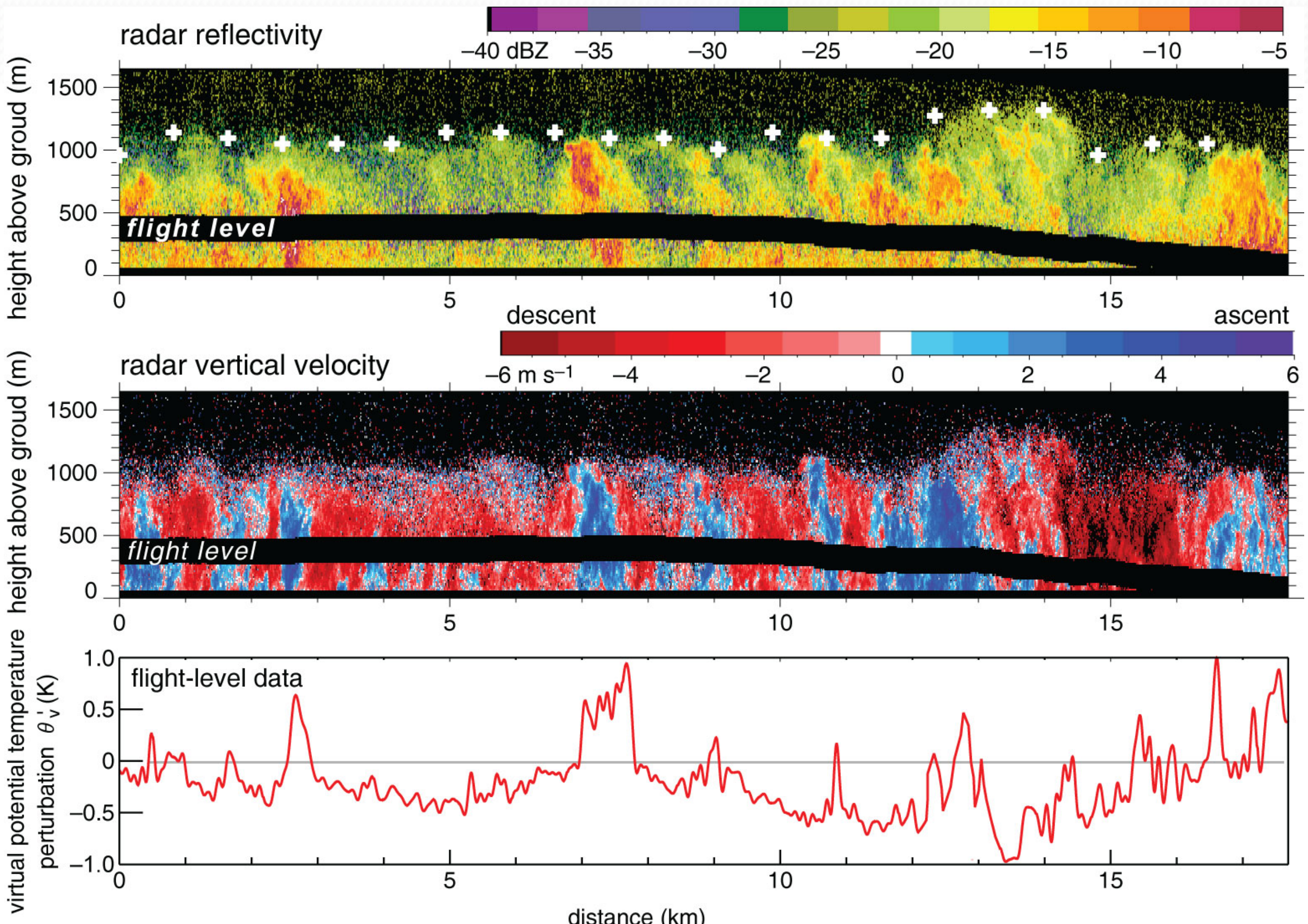


research topic:
mm-wave radar

from:

Geerts, B., R. Damiani, and S. Haimov, 2006: Fine-scale vertical structure of a cold front as revealed by airborne radar. *Mon. Wea. Rev.*, **134**, 251–272.

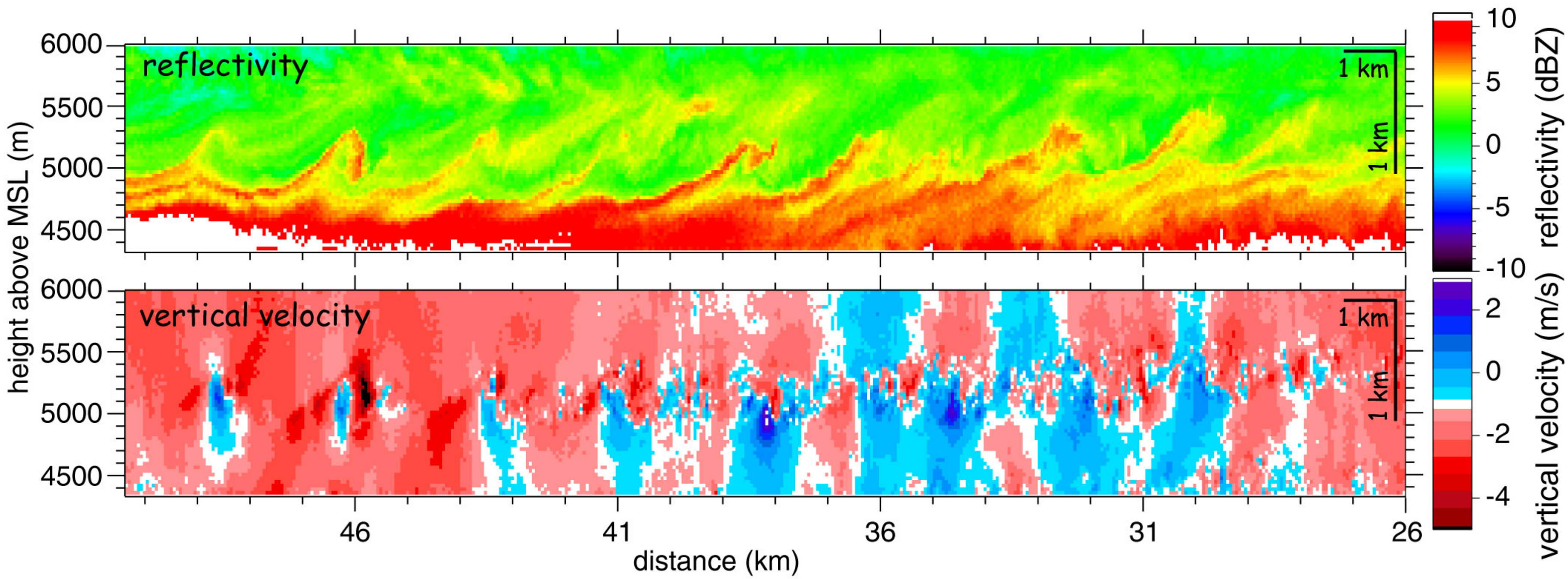
WCR vertical cross section of reflectivity and vertical velocity in a daytime convective boundary layer in Oklahoma. The echoes are high concentrations of small insects. The flight-level θ'_v shows that most insect plumes are buoyant



from:

Geerts, B. and Q. Miao, 2005: The use of millimeter Doppler radar echoes to estimate vertical air velocities in the fair-weather convective boundary layer. *J. Atmos. Ocean. Tech.* , **22**, 225-246. [also Fig. 4.1 in Markowski and Richardson (2010), *Mesoscale Meteorology*]

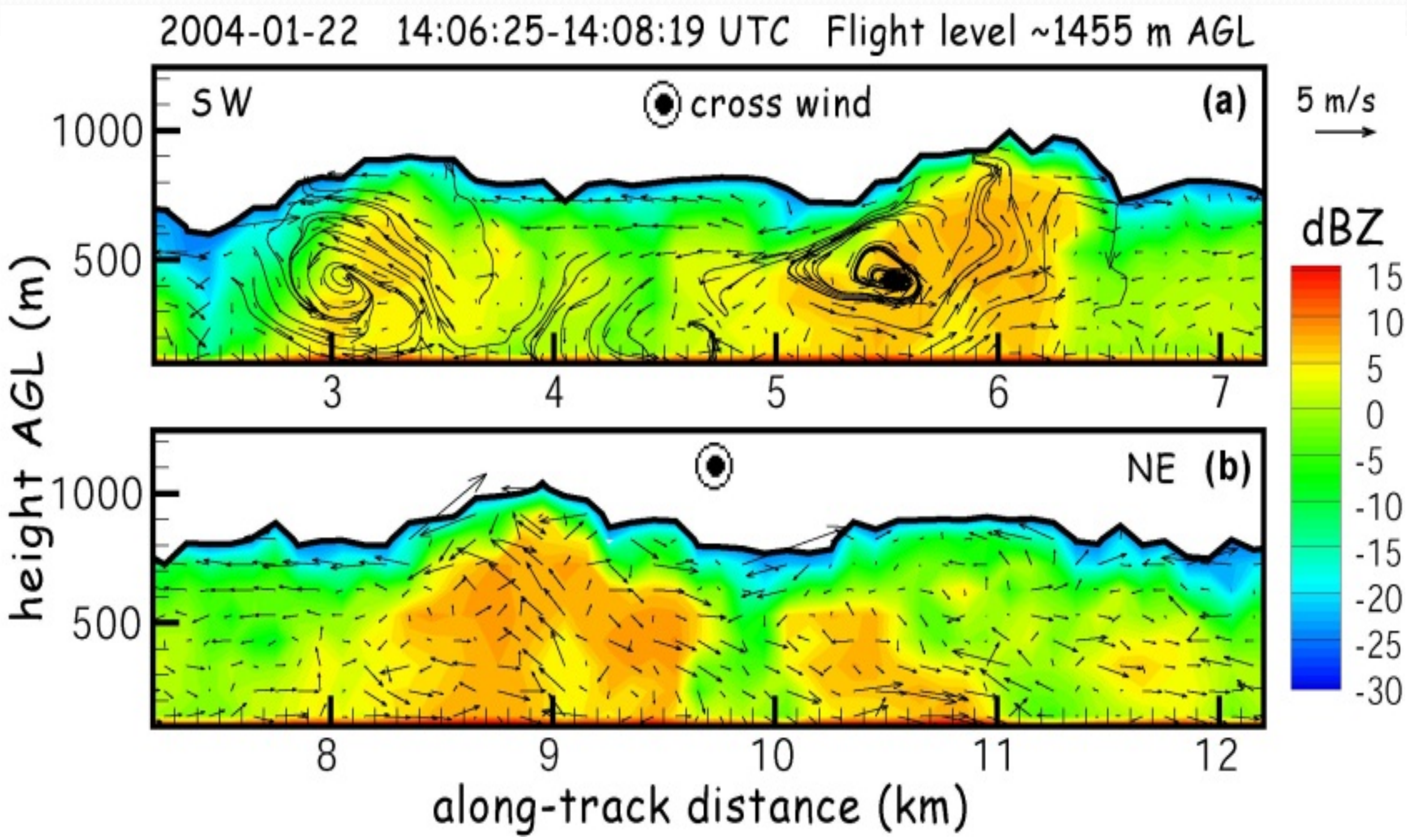
Wyoming Cloud Radar view of Kelvin-Helmholtz billows inside a winter storm over Wyoming



from:

Geerts, B., and Q. Miao, 2010: Vertically-pointing airborne Doppler radar observations of Kelvin–Helmholtz billows. *Mon. Wea. Rev.*, **138**, 982–986.

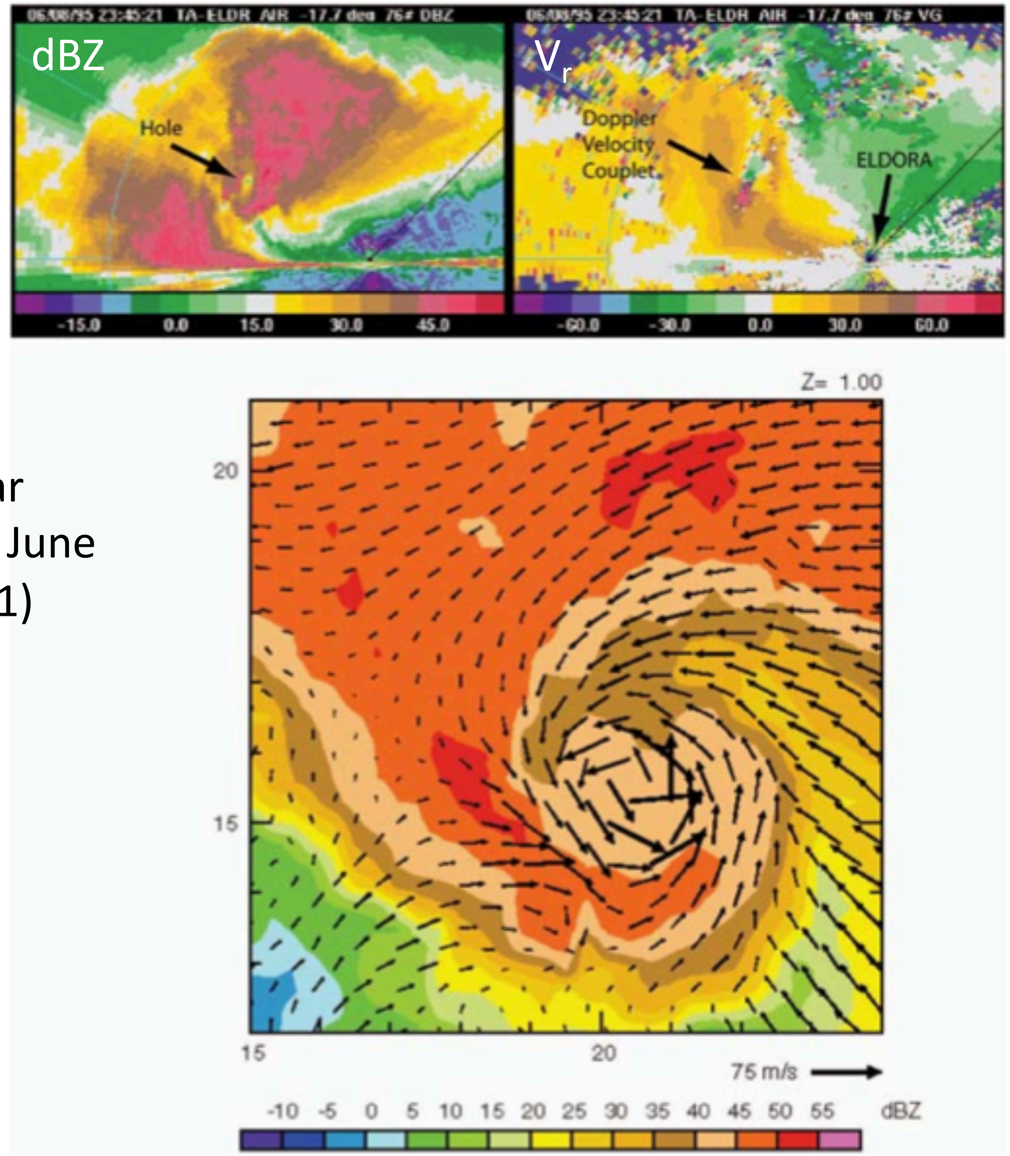
Wyoming Cloud Radar cross-section of vertical-plane reflectivity and winds on a UWKA flight track normal to the prevailing wind over Lake Michigan during lake-effect snow. Horizontal roll vortices can be seen



from:

Yang, Q., and B. **Geerts**, 2006: Horizontal convective rolls in cold air over water: buoyancy characteristics of coherent plumes detected by an airborne radar. *Mon. Wea. Rev.*, **134**, 2373–2396.

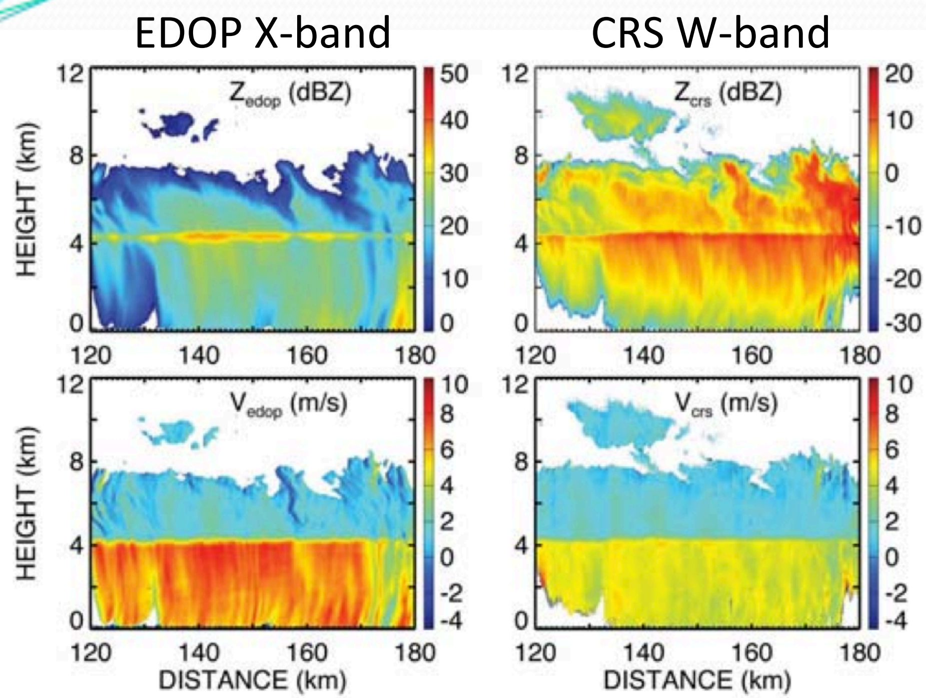
ELDORA: Convective Scale Analysis



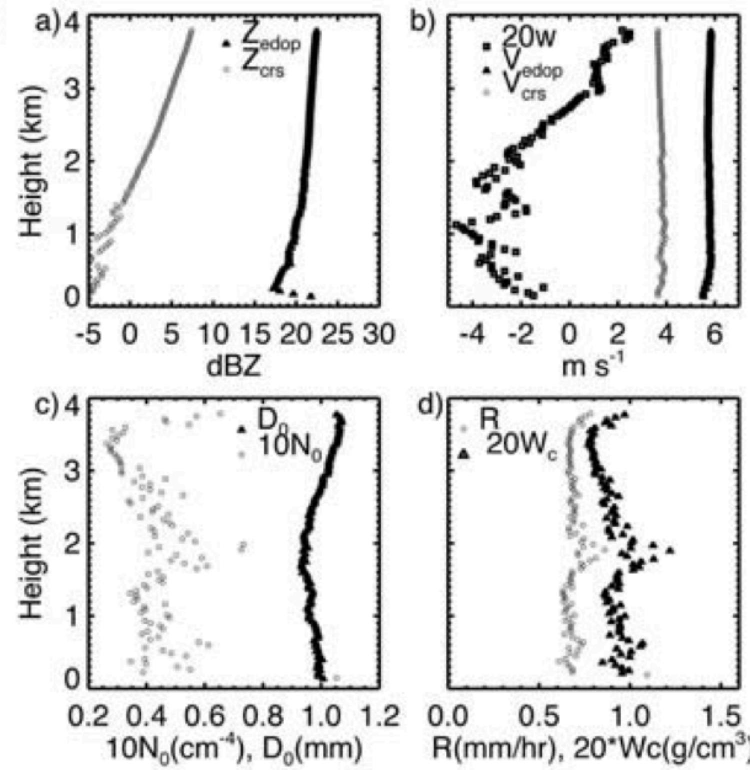
F5 tornado near Kellerville, TX on 8 June 1995 (VORTEX-1)

Courtesy: Wen-Chau Lee (NCAR/EOL)

EDOP & CRS: High Level Cloud Perspective

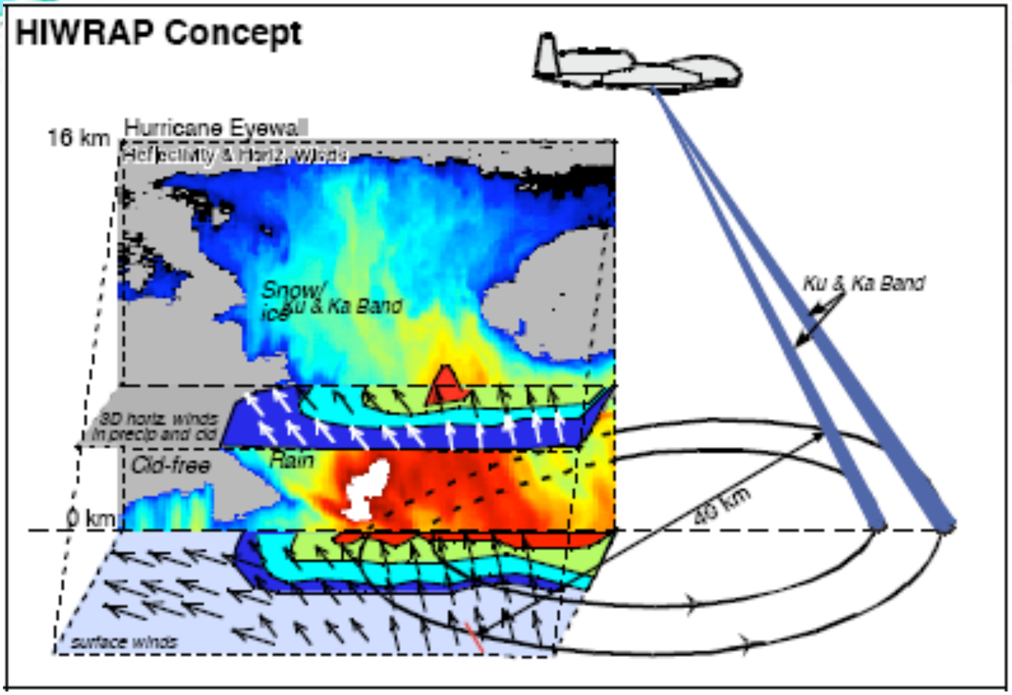


Stratiform rain observed with EDOP (upper panels) and CRS (lower panels) in July 2002 over Florida.



Averages for the entire rain fields: median volume diameter, D 0 , and the intercept parameter, N0, rainfall rate R, and rain water content W.

HIWRAP: Global Hawk



- HIWRAP Characteristics:
  - Simultaneous Ku/Ka-band Tx/Rx @ 30 and 40 deg.
  - Conically scanning
  - Precipitation & clouds as tracers.
  - Ocean surface vector wind scatterometer.
- NASA Global Hawk:
  - 19 km altitude.
  - ~ 30 hour missions.

- For the first time, provide capability to map the 3-D winds in precipitation/cloud regions and ocean surface winds in clear to light rain regions.
- Collect crucial data for hurricanes and tropical storm research.

Future

- The two NOAA P-3 and G-IV aircraft will be around for “a while” (new P-3 wings needed)
  - Upgraded to true dual-beam radars (2nd transmitter & receiver)
  - ~700 m along track spacing
  - G-IV radar critical for HWRF assimilation of storm structure → improved intensity prediction capability (operational demand)
- ELDORA needs a new platform
  - Critical gap in observational capability for convective scale research
  - Proposal to build new phased array radar for NSF/NCAR C-130 (decade away??)
- Airborne cloud radars (WCR, EDOP, HIWRAP, RASTA, SPIDER, etc) fill a nice niche
  - Scientific demand continues to grow
  - Capabilities continue to grow

NOAA P-3 Radar Upgrade Path

P-3 Radar Options and Comparison							
Characteristic	Current P-3 System with CRPE antenna	P-3 System with AOC dual flatplate antennas	P-3 System; AOC antennas; tandem magnetron xmtrs	P-3 System; AOC antennas; tandem magnetron xmtrs; 20 rpm	G-IV System; tandem TWT xmtrs	P-3 System; AOC antennas; tandem TWT xmtrs; 20 rpm	Eldora
Antenna beamwidth (deg)	1.8	2.0	2.0	2.0	2.7	2.0	1.8
Max Antenna Rotation (rpm)	10	10	10	20	15	20	24
Beam Scan Rate (sec/sweep)	12	12	6	3	4.5	3	2.5
Along-track sweep spacing (m)	1440	1440	720	720-360	1125	360	300
Peak xmt power (kW)	65	65	65	65	8	8	35
Duty cycle (%)	0.08	0.08	0.08	0.08	5	5	2.4
Average power (dBm)	47.2	47.2	47.2	47.2	56.0	56.0	59.2
Min detectable signal @10km (dBZ)	>0	>0	>0	>0	-9	-9	-12
Comments/Notes		Planned for N42RF in Spring 2013; N43RF in Spring 2014	Could be implemented in Spring 2014; est .5 person-yr and $100K	Requires motor replacement; est 1 person-yr and $400K		Replace xmtrs, receivers w/G-IV system; est 2 person-yrs and ~$1.5M	

Issues

- Common data exchange format (seems like a never-ending problem)
- Resource allocation for major field projects
- Expensive development, deployment, and maintenance costs
- Phased array technology shows considerable promise in providing dual-Doppler capability on aircraft that can’t carry scanning antennas (e.g., C-130) but currently fairly expensive