UAS-Based Passive Microwave Sounding and Imaging

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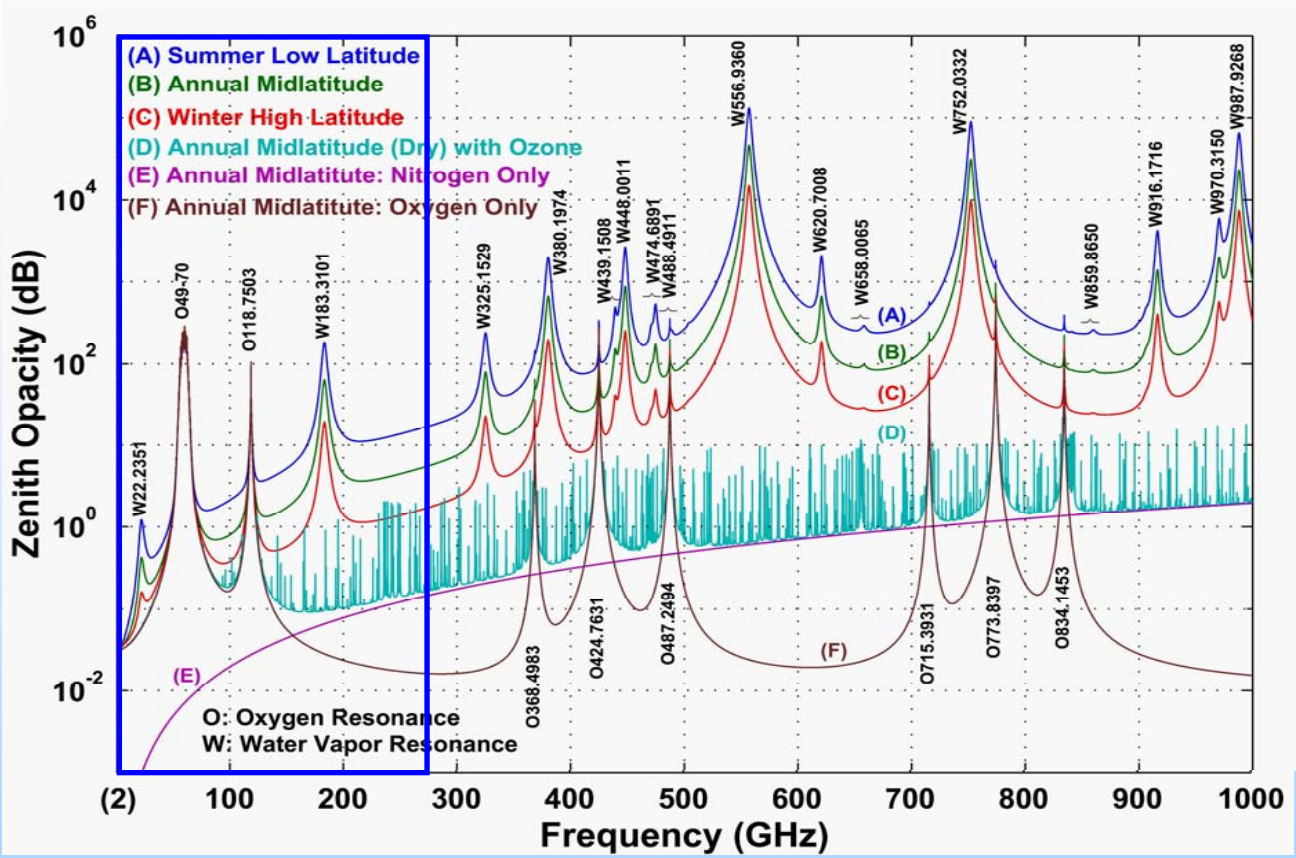
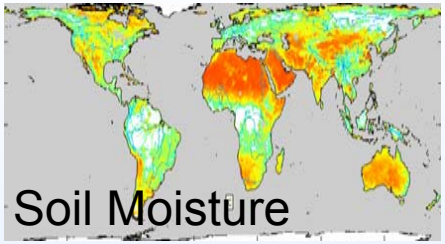
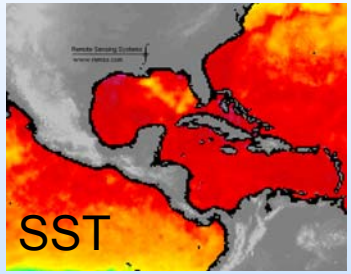
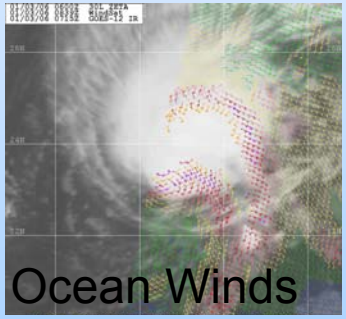
Passive Microwave Observables

Resolution: ~10-50 km (LEO satellite) or ~50 m – 2 km (Aircraft)

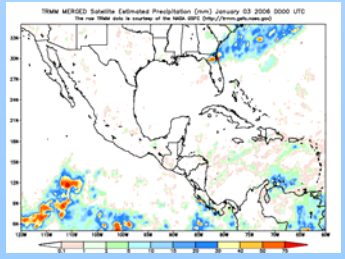




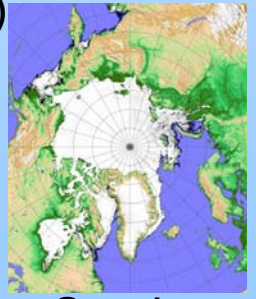




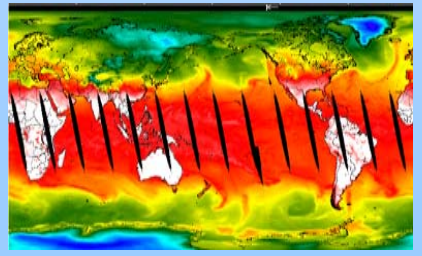
(Passive + Radar)



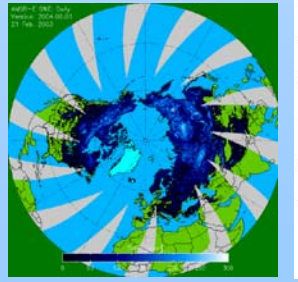
Precipitation



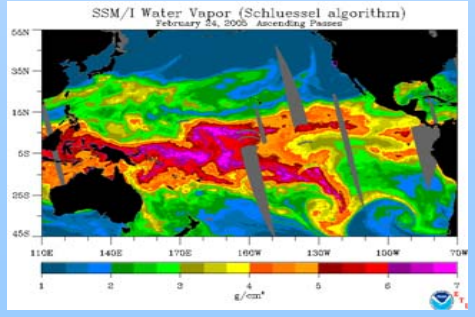
Sea Ice



Temperature



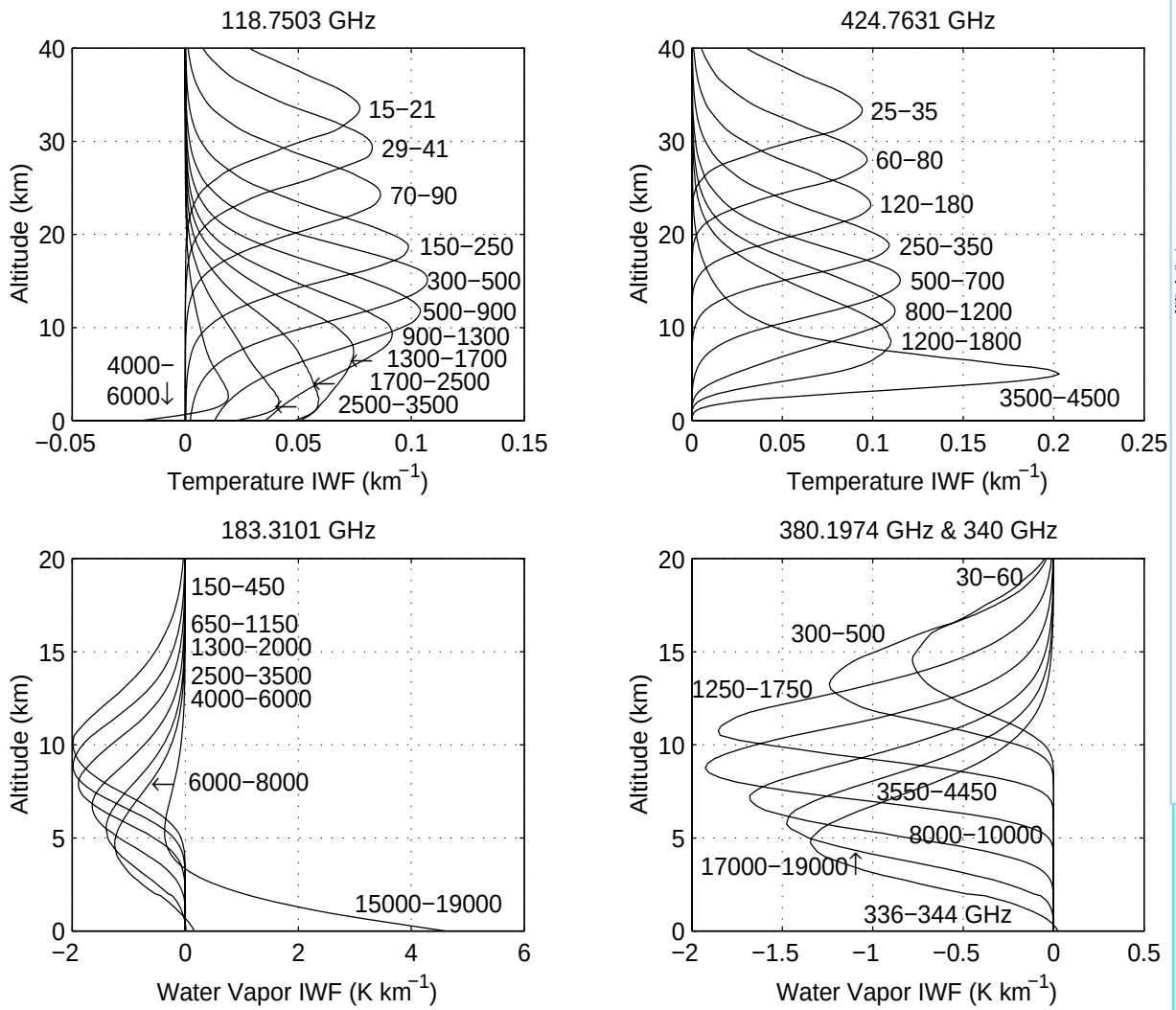
Snow Cover

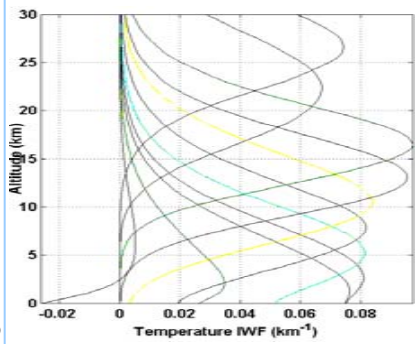


Water Vapor

Sounding Channel Vertical Response

- Clear Air -

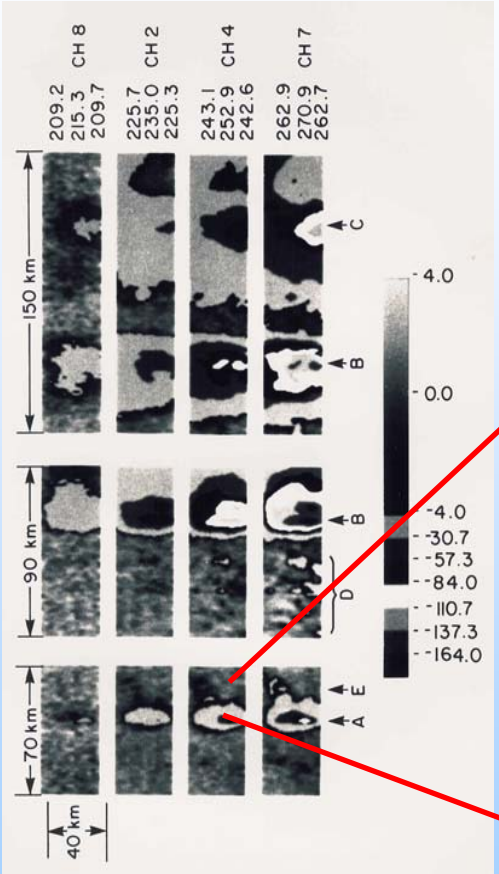


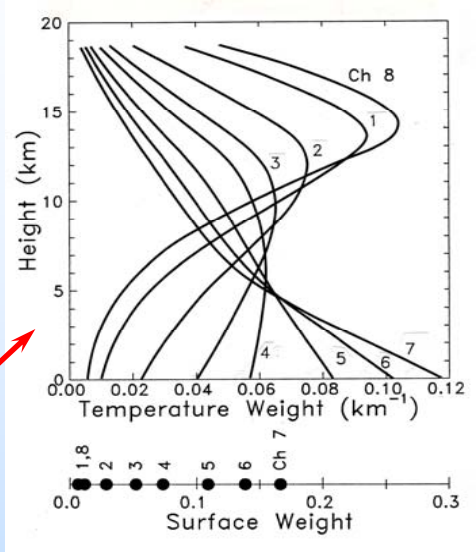


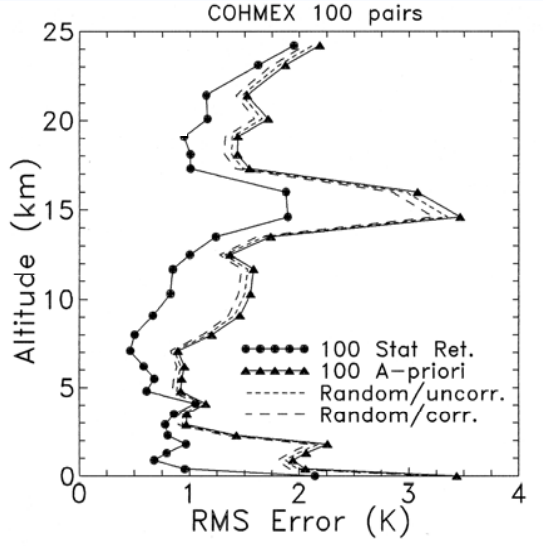
AMSU
5-MM

Klein & Gasiewski,
JGR-ATM,
July 2000

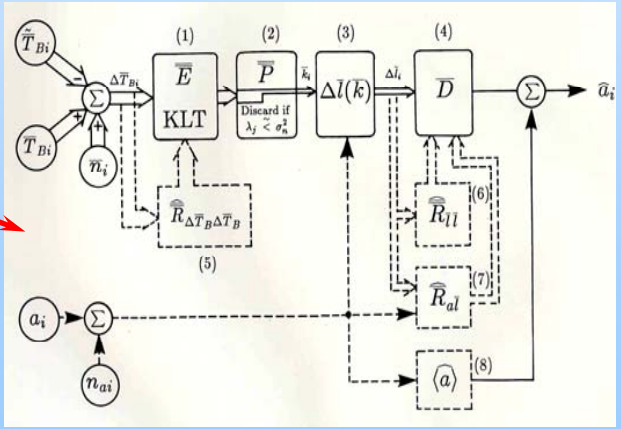
118-GHz Temperature Profiling & Cloud Top Altitude Retrieval

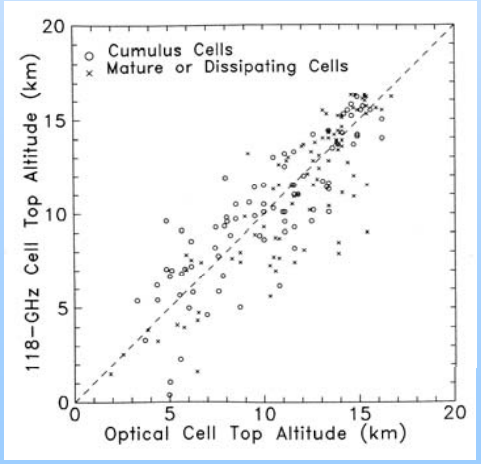






Clear-Air





Convection

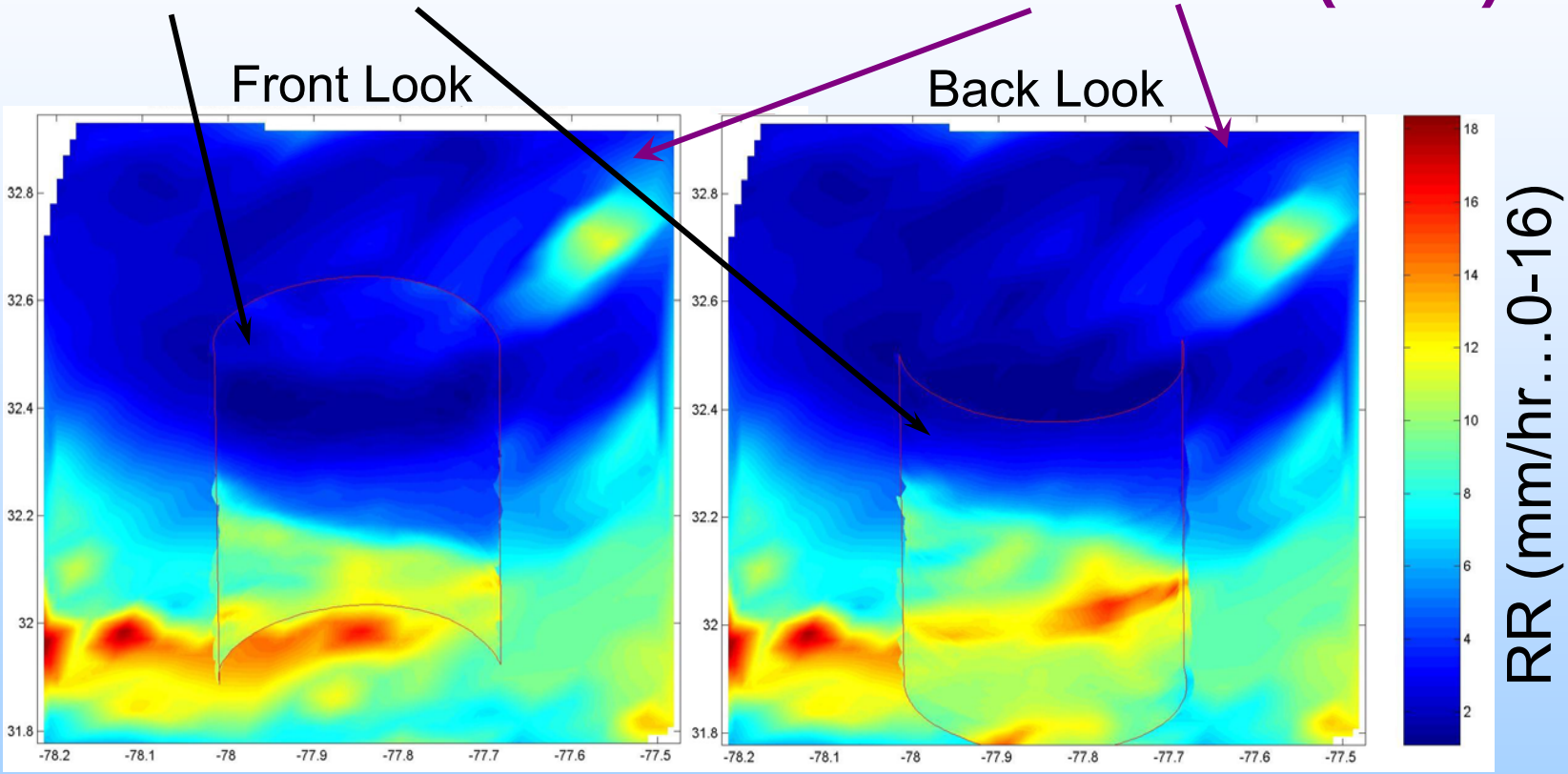
Gasiewski & Johnson
TGARS, January 1993

Gasiewski & Staelin
JGR, December 1989

PSR Airborne Studies

PSR Emission Algorithm vs TMI

PSR/A 10.7H GHz Rain Rate vs TRMM TMI (2A12)

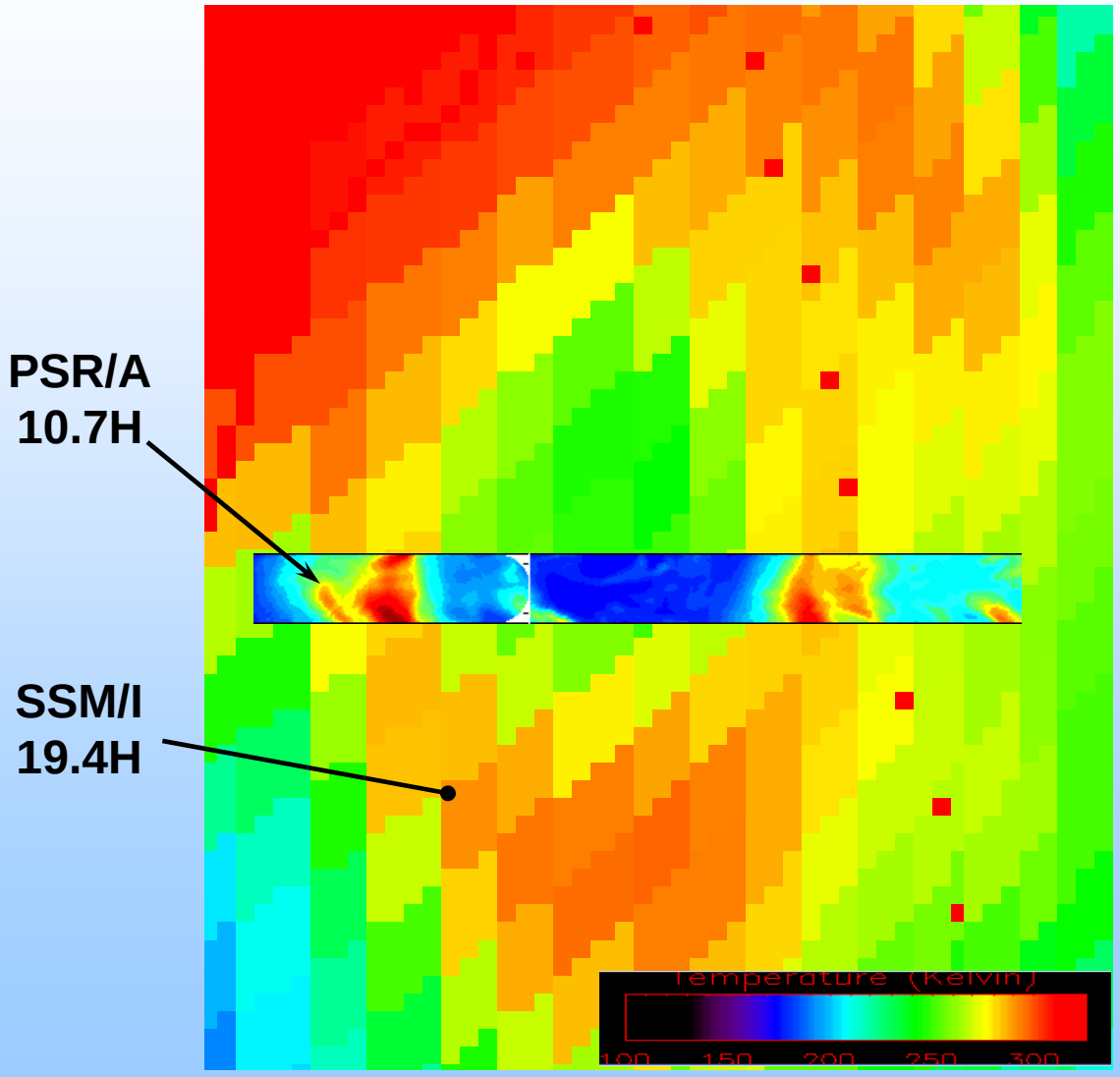


CAMEX3 - Hurricane Bonnie near landfall, August 26, 1998, NASA DC-8 Aircraft

Due to limited spatial resolution satellites miss many rain band features

Hurricane Bonnie at Landfall

Airborne vs. Satellite Microwave Imagery

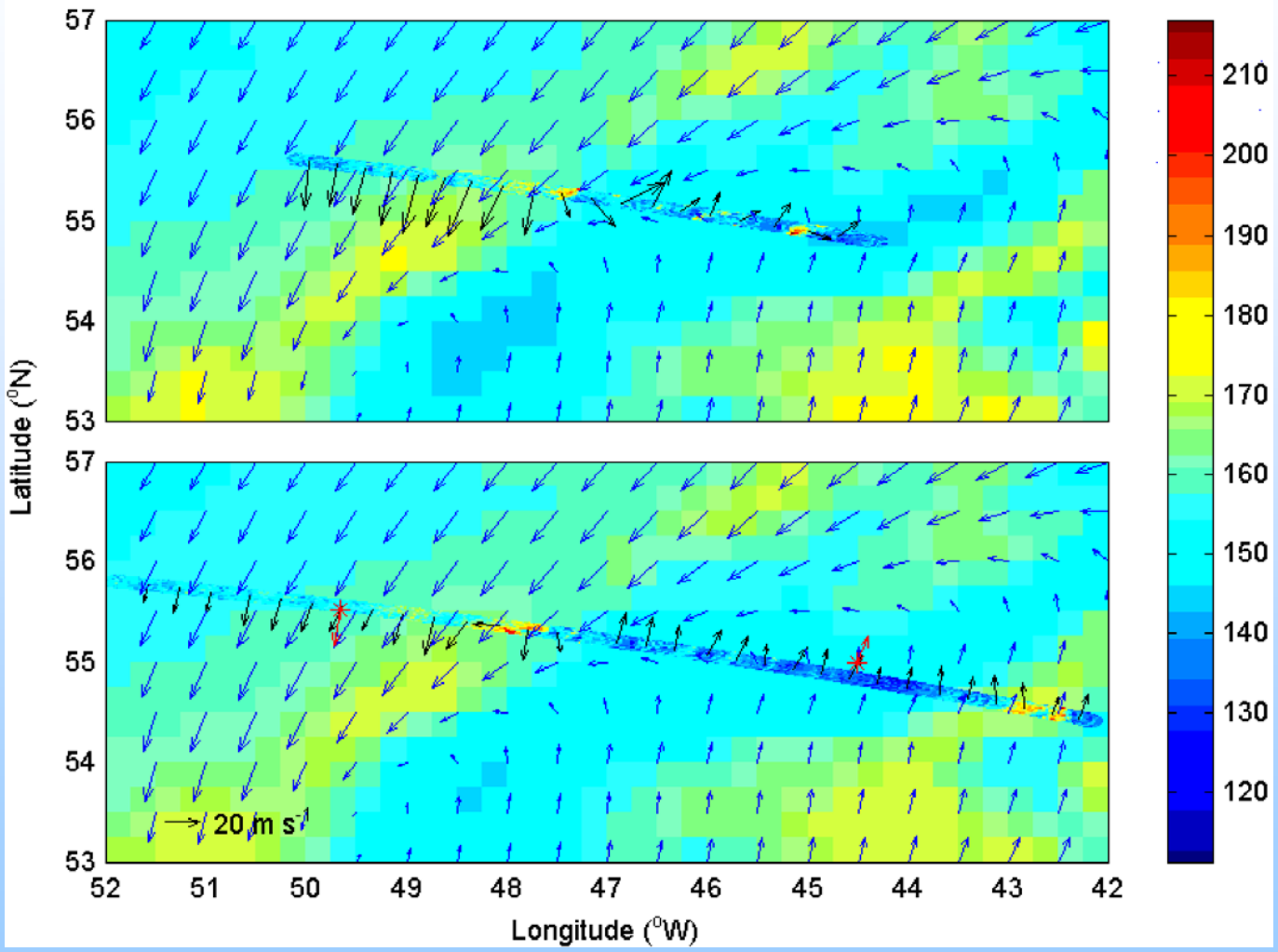


PSR/A 10.7H GHz imagery from an aircraft overpass of hurricane Bonnie at 1400-1425 GMT overlaid on 19.4H GHz DMSP F14 SSM/I imagery at 1358 GMT (August 26, 1998).

High-resolution airborne imagery clearly reveals - over a limited region - many submesoscale details of rainband precipitation structure that are absent in the satellite imagery.

Microwave Wind Vector Imaging

Labrador Sea Cold Cyclone PSR/D March 7, 1997

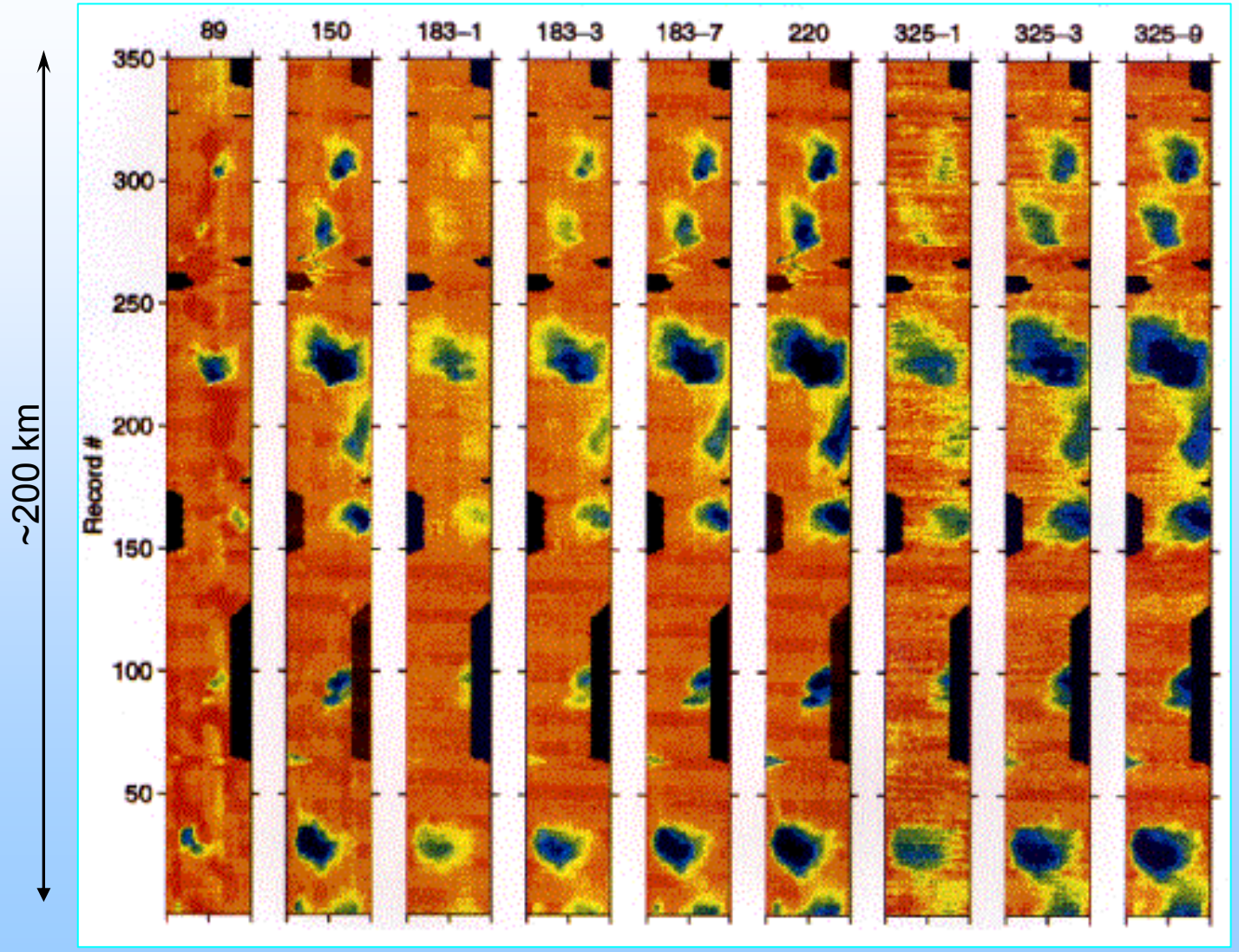


Full-scan passive microwave wind vector retrievals during two crossings of a cold cyclone centered in the Labrador Sea.

Retrieved wind vectors are overlaid onto PSR and SSM/I 37H GHz imagery. The blue arrows are wind data from the NCEP Eta analysis, dropsondes are orange arrows.

Cyclonic rotation of the retrieved and model wind fields about the center of rotation is clearly seen.

SMMW Cloud Ice & Precipitation Measurement



Maritime convection observed at 20 km altitude

Many cells missed at 89 GHz!

Gasiewski, et al, Proc. 1994 IGARSS, Pasadena, USA.

Evolution of Passive Microwave Sensors

Sensor	Characteristic: Operating Period	Type	Scan Strategy	No. of Channels	Frequencies (GHz)	Resolution FOV's (km)**	Swath Width (km)
SMMR	1978 - 1997	imager	conical	10	6.6 - 37	22 - 122	780
MSU	1978 - present	sounder	cross-track	5	50.3 - 57.95	110 - 200	2000
SSM/I **SSM/T1** **SSM/T2**	1978 - present	imager sounder sounder	conical cross-track cross-track	7 7 5	19.35 - 85 50.5 - 59.4 92 - 183	15 - 69 SSM/T1 (SSM/T2) 174 (48 - 120) at nadir 309 (85 - 213) at limb	1400
TMI	1997 - present	imager	conical	9	10.65 - 85.5	5 - 50	780
AMSU	1998 - 2020[1]	sounder	cross-track	20	50 - 183	AMSU-A (AMSU-B) 45 (15) at nadir 150 (50) at limb	2200
AMSR-E	2002 - present	imager	conical	14	6.9 - 89	5 - 50	1600
SSMIS	2004 - 2015[1]	imager & sounder	conical	24	19 - 183	12 - 55	1700
WindSat	2003 - present	imager	conical	22	6.8 - 37[2]	11 - 55	1025
CMIS[3]	future NPOESS	imager & sounder	conical	83	6.6 - 183	11 - 50	1700
ATMS	future NPP & NPOESS	sounder	cross-track	22	24 - 183	16 - 75 at nadir 68 - 323 at limb	2300

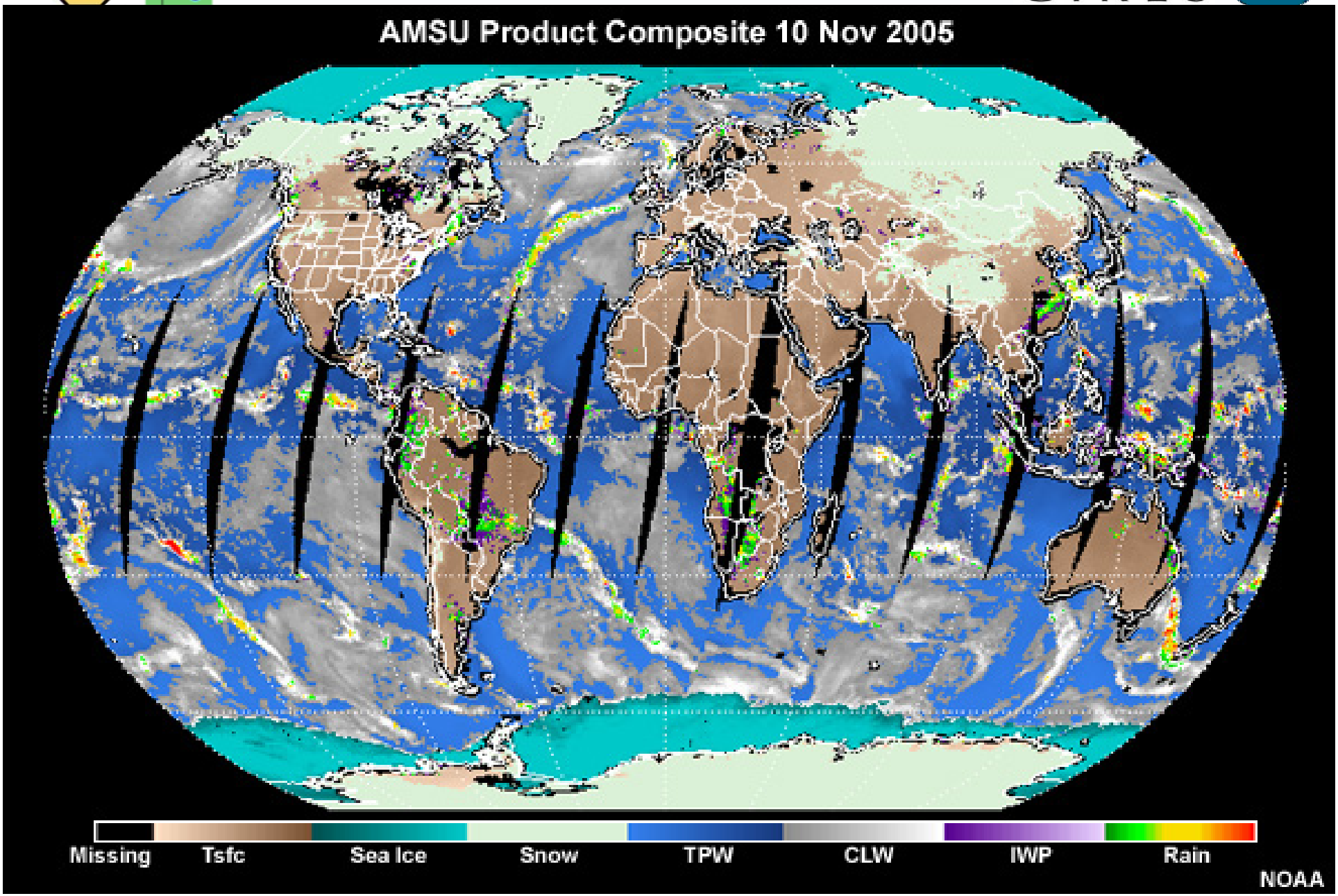
**Sensor resolution is proportional to frequency

1 Projected dates
2 WindSat channels at 10.7, 18.7, 37 GHz are fully polarimetric
3 **CMIS:**
- Channel at 18 GHz is fully polarimetric
- Reflector diameter 3.5 times larger than TMI
- Longer period of performance - 7 versus 3 years for previous sensors

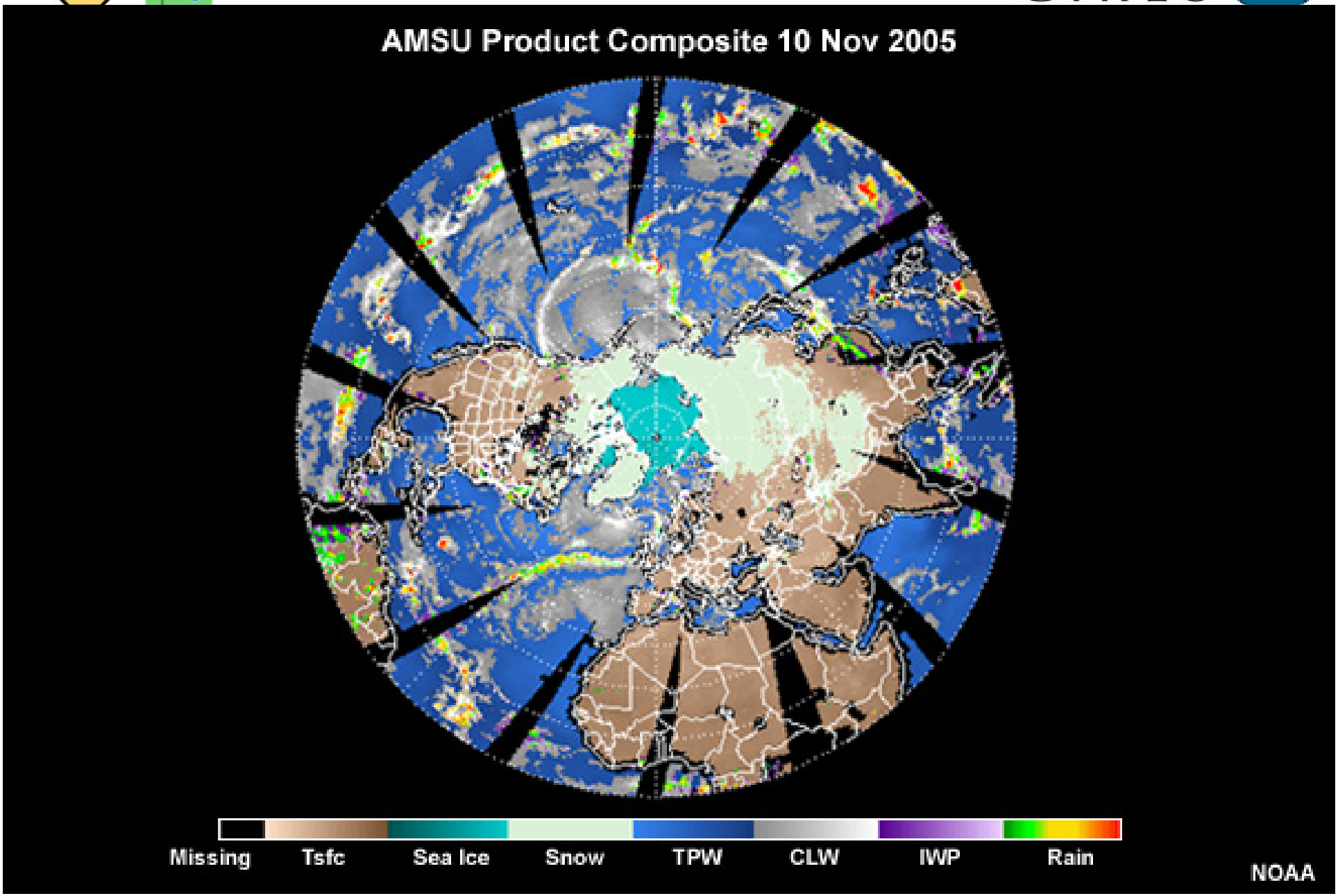
Sensor includes fully polarimetric channels
Sensor includes dual polarimetric channels
FOV: Field of view

NPOESS / IPO

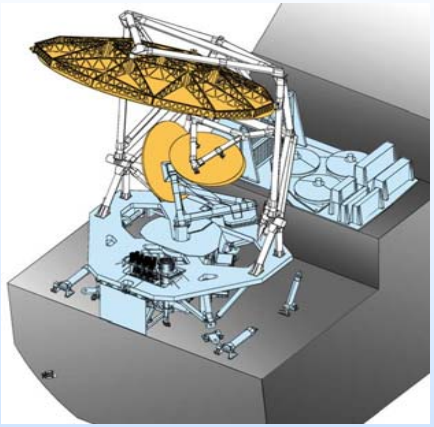
NOAA AMSU-A/B Products



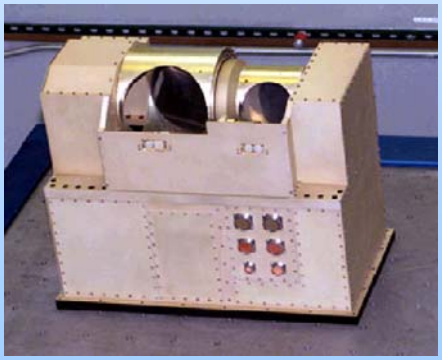
NOAA AMSU-A/B Products



NPOESS Microwave Sensors



- **Conical Scanning Microwave Imager/Sounder (CMIS, descoped June 2006).**
  - 2.2 m antenna
  - RF imaging at 6, 10, 18, 36, 90, and 166 GHz
  - Profiling at 23, 50 to 60, 183 GHz
  - Polarimetry at 10, 18, 36 GHz
  - 1700 km swath width



- **Advanced Technology Microwave Sounder (ATMS)**
  - CrIS companion cross track scan
  - Profiling at 23, 50 to 57, 183 GHz
  - Surface measurements at 31.4, 88, 165 GHz
  - 1.1, 3.3, and 5.2 deg (SDRs resampled)
  - 2300 km swath width

NPOESS EDR-to-Sensor Mapping
55 Product Sets [RDRs, SDRs, EDRs]

☆ Atmospheric Vertical Moisture Profile	Cloud Top Pressure	Precipitable Water
☆ Atmospheric Vertical Temp Profile	Cloud Top Temperature	Precipitation Type/Rate
☆ Imagery	Downward Longwave Radiance (Sfc)	Pressure (Surface/Profile)
☆ Sea Surface Temperature	Downward Shortwave Radiance(Sfc)	Sea Ice Characterization
☆ Sea Surface Winds	Electric Field	Sea Surface Height/Topography
☆ Soil Moisture	Electron Density Profile	Snow Cover/Depth
Aerosol Optical Thickness	Energetic Ions	Solar Irradiance
Aerosol Particle Size	Geomagnetic Field	Supra-Thermal-Auroral Particles
Aerosol Refractive Index	Ice Surface Temperature	Surface Type
Albedo (Surface)	In-*situ* Plasma Fluctuations	Wind Stress
Auroral Boundary	In-*situ* Plasma Temperature	Suspended Matter
Auroral Energy Deposition	Ionospheric Scintillation	Total Water Content
Auroral Imagery	Medium Energy Charged Particles	Vegetation Index
Cloud Base Height	Land Surface Temperature	
Cloud Cover/Layers	Net Heat Flux	
Cloud Effective Particle Size	Net Solar Radiation (TOA)	
Cloud Ice Water Path	Neutral Density Profile	
Cloud Liquid Water	Color/Chlorophyll	
Cloud Optical Thickness	Ocean Wave Characteristics	
Cloud Particle Size/Distribution	Outgoing Longwave Radiation (TOA)	
Cloud Top Height	Ozone - Total Column/Profile	

- VIIRS (23)
- CMIS (19)
- CrIS/ATMS (3)
- OMPS (1)
- SES (13)
- GPSOS (2)
- ERBS (5)
- TSIS (1)
- ALTIMETER (3)
- APS (4)

☆ Environmental Data Records (EDRs) with Key Performance Parameters

Global Hawk as a "Vectored" Earth Observing System

Aerial VEOSs

vs.

Orbiting Earth Observing Systems (POES, GOES)

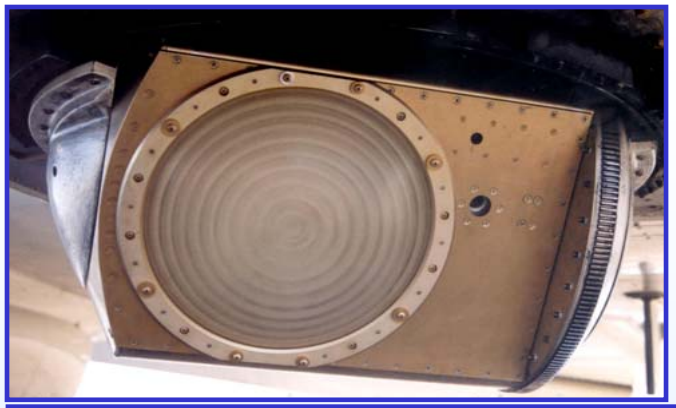
- "Random" access control/vectoring over long intervals
- Safe altitude (45,000+') for Wx & air traffic avoidance
- Optimal altitude for microwave spatial resolution
- Appropriate speed for precision wide-area imaging
- Extended (but finite) flight duration

=> Very high resolution local coverage complimentary to the capabilities of satellites

UAS-based Passive Microwave Applications

- Thermodynamic state variables within clouds and at abrupt frontal boundaries
- Sounding curtains (w/raobs) for nowcasting and forecasting (e.g., west coast landfalling jets)
- CLW & CIW loading & response to aerosols
- Hurricane precipitation rate, surface winds, rainband structure
- Targeted observations for NWP model initialization (e.g., THORPex)

The PSR System



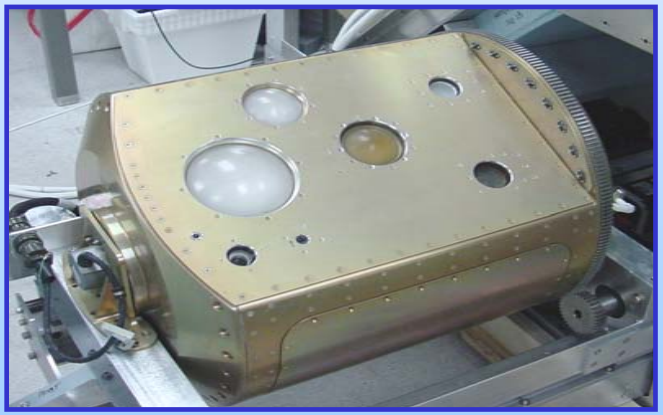
PSR Scanheads

Previous
Operational
Currently in Development

PSR/CX:	5.82-6.15	(v,h)	10º
1999 (C)	6.32-6.65	(v,h)	10º
	6.75-7.10	(v,h,U,V)	10º
	7.15-7.50	(v,h)	10º
2002 (CX)	10.6-10.8	(v,h,U,V)	7º
	10.60-10.68	(v,h)	7º
	10.68-10.70	(v,h)	7º
	10.70-10.80	(v,h)	7º
2004 (CXI)	5.5-7.7 GHz spectrometer		10º
	9.6-11.5 um IR (v+h)		7º

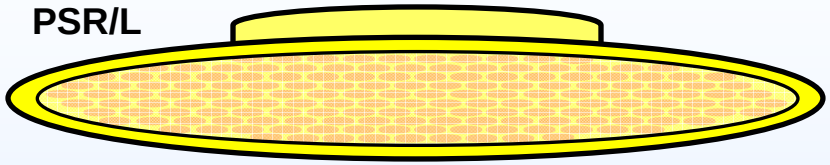
PSR/A:	10.6-10.8	(v,h,U,V)	8º	
1997 (D)	18.6-18.8	(v,h,U,V)	8º	
1998 (A_1)	21.4-21.7	(v,h)	8º	H_2O
2000 (A_2)	36-38	(v,h,U,V)	2.3º	
2002 (A_3)	86-92	(v,h,U)	2.3º	
	9.6-11.5 um IR	(v+h)	7º	

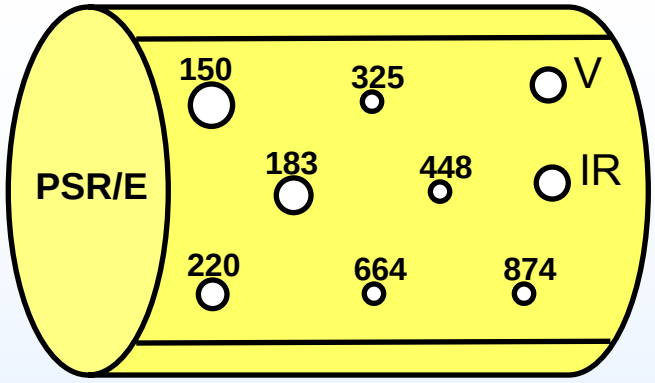
PSR/S:	18.6-18.8	(v,h,U,V)	8º	
2005	21-24x3	(v,h)	7º	H_2O
2006	36-38	(v,h,U,V)	7º	
	52.6-57.5x7	(v)	3.5º	O_2
	86-92	(v,h,U)	3.5º	
	118.750 x 7	(v)	3.5º	O_2
	183.310 x 7	(v)	1.8º	H_2O
	337-343	(v,h,U)	1.8º	
	380.197 x 3(5)	(v)	1.8º	H_2O
	424.763 x 5	(v)	3.5º	O_2
	9.6-11.5 um IR	(v+h)	1.8º	



Polarimetric Scanning Radiometer
Compatible Series of Scanheads
Channels • Polarizations • Beamwidths

PSR Scanheads Currently Under Design

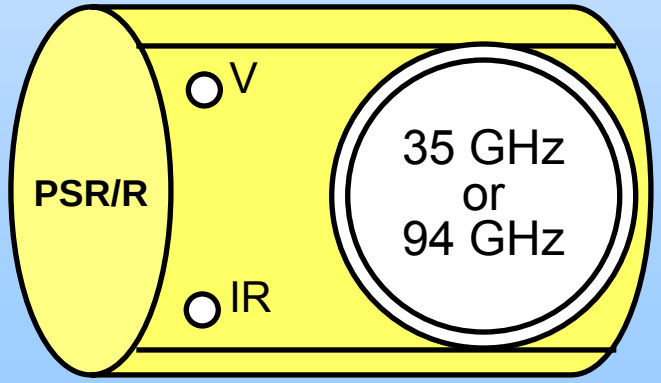




(V=RGB Video)

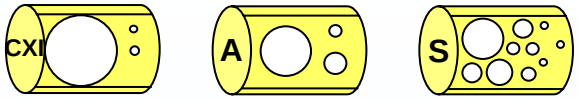
PSR/L:	1.400-1.406	(v,h)	10º
~2006-	1.407-1.413	(v,h)	10º
-2007	1.414-1.420	(v,h)	10º
	1.421-1.427	(v,h)	10º
	1.400-1.427	(v,h,U)	10º
	9.6-11.5 um IR	(v+h)	7º
	1.45 Scatterometer	(vv,hh,vh)	10º
	RGB Video		

PSR/E:	149-151	(v,h)	1º
~2007-	183.310 x 4	(v)	1º H_2O
-2009	218-222	(v,h)	1º
	325.153 x 4	(v)	1º H_2O
	448.001 x 3	(v,h)	1º
	660-668	(v,h)	1º
	870-878	(v,h)	1º
	9.6-11.5 um IR	(v+h)	7º
	RGB Video		

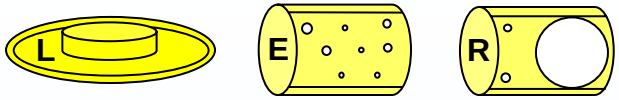


PSR/R:	35/94 Doppler Radar	(vv,hh)	2º
~2006-	9.6-11.5 um IR	(v+h)	7º
-2007	RGB Video		

Polarimetric Scanning Radiometer
Compatible Series of Scanheads
Channels • Polarizations • Beamwidths

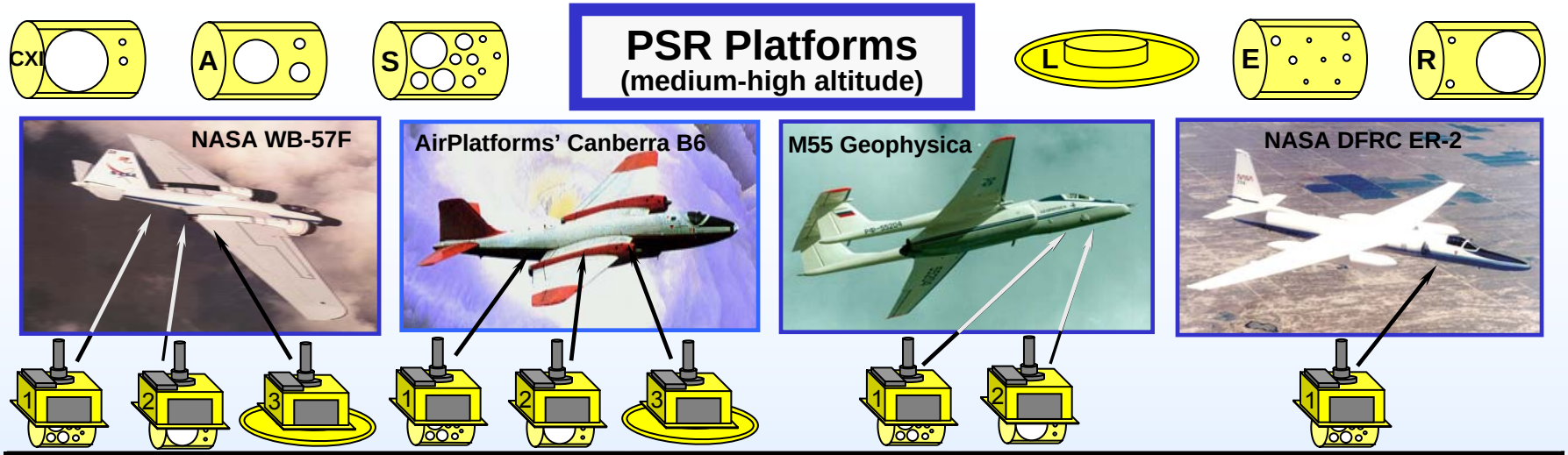


PSR Platforms
(low-medium altitude)



	NASA P-3B	NAWC P-3C	NRL P-3 (#674)	NASA DC-8
Altitude (ft / km): Range (nmi): Maximum Endurance (hrs):	500-30,000 (0.15-9 km) 2400-3800 8-12	500-30,000 (0.15-9 km) 2400-3800 8-12	500-30,000 (0.15-9 km) 2400-3800 8-12	1,000-41,000 (~0.3-12.5 km) 2400-5500 6-12
Relative Operating Costs:	Medium	Medium	Medium	Medium-High
Operating Restrictions:	Low	Low	Low	Low-Medium
PSR Location(s):	Bomb bay fairing	Bomb bay fairing	NRL Bomb bay fairing	Nadir-7 & Nadir-2 ports
Maximum # PSR Scanheads:	1 (1997), 2 (2003)	1 (2000), 2 (2006*)	2 (2004)	1 (1998), 2 maximum
Available Scan Modes:	Software-selectable conical, cross-track, along-track, nadir stare, and side view. Elevation angles from 0° to 70° WRT nadir. Attended or unattended operation. Synchronized scanning when using two scanheads.			
Sky/Limb View: (horizon+35°)	Yes (60° roll)	Yes (60° roll)	Yes (60° roll)	Yes (60° roll)*
Geophysical Sensitivity:	1. Ocean & Land Surface 2. Sea Ice 3. Low-Altitude Clouds & Precipitation 4. Soil Moisture & Salinity			1. Medium Altitude Clouds & Precipitation 2. Surface to Middle Tropospheric Temperature & Moisture Profiles 3. Ocean & Land Surface
Simulation Capability: Satellite sensor and associated PSR scanhead configuration SSM/I &TMI AMSR-E AMSU-A/B WindSat SSMIS ATMS CMIS GEM	PSR/A PSR/A & PSR/CXI -or- PSR/CXI & PSR/L PSR/S -or- PSR/S & CXI PSR/A & PSR/CXI PSR/S & PSR/CXI PSR/S -or- PSR/S & CXI PSR/S & PSR/CXI -or- PSR/CXI & PSR/L PSR/S -or- PSR/S & PSR/CXI -or- PSR/S & PSR/R			
Complimentary Instruments:	C-, Ku-Scat, PMS, ROWS, SRA, SAR, RAR, AVAPS, Lidar …			Scanning HIS, ARMAR, AIRSAR, LASE, PMS, MACAWS, Dropsondes …

>400 hrs >150 hrs >150 hrs >100 hrs

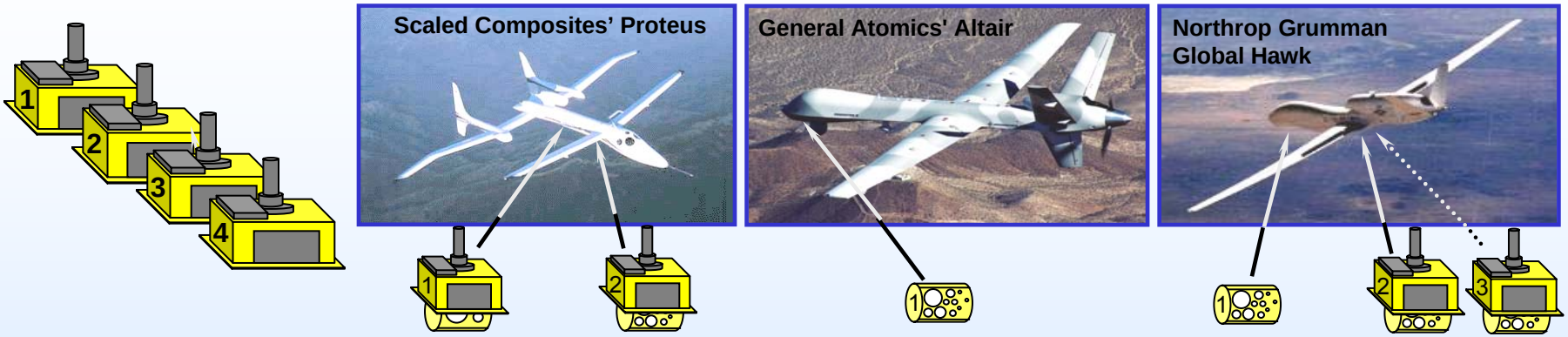


PSR Platforms
(medium-high altitude)

		NASA WB-57F	Canberra B6	M55 Geophysica	NASA ER-2
Altitude (ft / km): Range (nmi): Maximum Endurance (hrs):		30,000-65,000 (9-20 km) 2500 6	30,000-55,000 (9-17 km) 2000 (3000/extended tanks) 4.5 (6/extended tanks)	55,000-69,000 (17-21 km) 2000 5	60,000-70,000 (18-21 km) 3200 8
Relative Operating Costs:		Medium	Medium	Medium	High
Operating Restrictions:		Medium	Medium	Medium	High
PSR Location(s):		Bomb bay pallets	Bomb bay pallets*	Bay # I or II	Q-bay
Maximum #PSR Scanheads:		1 (2002) 2 (2005*) 3 (2006*)	3 maximum	2 maximum	1 maximum
Available Scan Modes:		Software-selectable conical, cross-track, along-track, nadir stare, and side view. Elevation angles from 0° to 70° WRT nadir. Attended or unattended operation. Synchronized scanning when using two or more scanheads.			
Sky/Limb View: (horizon+35°)		Yes (60° roll)	Yes (60° roll)	Yes (60° roll)	Yes (60° roll)
Geophysical Sensitivity:		1. High-Altitude Clouds & Precipitation 2. Surface to Lower Stratospheric Temp & Moisture Profiles 3. Ocean & Land Surface 4. Soil Moisture & Salinity		1. High-Altitude Clouds & Precipitation 2. Surface to Lower Stratospheric Temp & Moisture Profiles 3. Ocean & Land Surface	
Simulation Capability: Satellite sensor and associated PSR scanhead configuration	SSM/I &TMI AMSR-E AMSU-A/B WindSat SSMIS ATMS CMIS GEM	PSR/A PSR/A & PSR/CXI -or- PSR/CXI & PSR/S, & PSR/L PSR/S -or- PSR/S & CXI PSR/A & PSR/CXI PSR/S & PSR/CXI PSR/S -or- PSR/S & CXI PSR/S & PSR/CXI -or- PSR/S & PSR/CXI & PSR/L PSR/S -or- PSR/S & PSR/CXI -or- PSR/S & PSR/R		PSR/A PSR/A & PSR/CXI PSR/S -or- PSR/S & CXI PSR/A & PSR/CXI PSR/S & PSR/CXI PSR/S -or- PSR/S & CXI PSR/S & PSR/CXI PSR/S -or- PSR/S & PSR/CXI - or- PSR/S & PSR/R	PSR/A PSR/A or PSR/CXI PSR/S PSR/A or PSR/CXI PSR/S or PSR/CXI PSR/S PSR/S or PSR/CXI PSR/S or PSR/R
Complimentary Instruments:		NAST-I & M, Dropsondes		NAST I & M	NAST-I & M, HIS, MIR, CLS, EDOP MMW Cloud Radar

Anticipated Performance or Capability

PSR Platforms
(UAS)



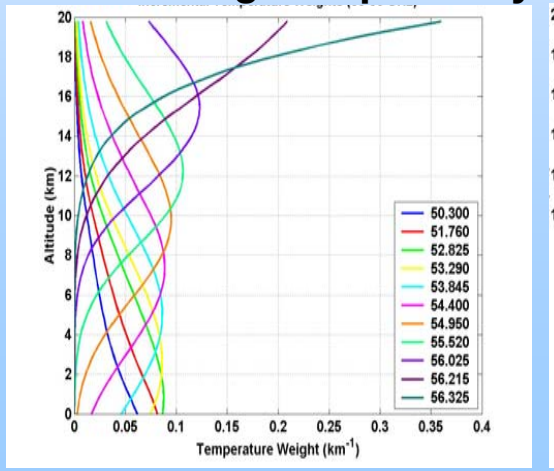
		Proteus	General Atomics Altair	NG Global Hawk
Altitude (ft / km): Range (nmi): Maximum Endurance (hrs):		500-65,000 (0.15-20 km)* ~2000* 2-7 (altitude dependent)*	500-45,000 (0.15-15 km) 3000 24	500-65,000 (0.15-20 km) 12,000 35
Relative Operating Costs:		Medium*	High	High*
Operating Restrictions:		Low	High	Medium*
PSR Location(s):		Fuselage pod	Fuselage fairing (scanhead only)	Fuselage fairing
Maximum # PSR Scanheads:		2 maximum	1 (2005)	2 maximum (1 cross track, 1 conical)
Available Scan Modes:			Nadir stare mode Potential for cross-track scanning	Nadir stare mode Cross-track scanning Potential for conical scanning
Sky/Limb View: (horizon+35°)		Yes (60° roll)	No	Possible (60° roll)
Geophysical Sensitivity:		1. Medium-High Altitude Clouds & Precipitation 2. Surface to Upper Tropospheric Temperature & Moisture Profiles 3. Ocean & Land Surface	1. Temperature & Humidity Profiles 2. Low-Altitude Clouds & Precipitation 3. Ocean wind direction	1. High-Altitude Clouds & Precipitation 2. Surface to Lower Stratospheric Temp & Moisture Profiles 3. Ocean & Land Surface
Simulation Capability: Satellite sensor and associated PSR scanhead configuration	SSM/I &TMI AMSR-E AMSU-A/B WindSat SSMIS ATMS CMIS GEM	PSR/A PSR/A & PSR/CXI PSR/S -or- PSR/S & CXI PSR/A & PSR/CXI PSR/S & PSR/CXI PSR/S -or- PSR/S & CXI PSR/S & PSR/CXI PSR/S & CXI -or- PSR/S & R	PSR/CXI or PSR/A PSR/CXI or PSR/A PSR/S PSR/CXI or PSR/A PSR/S PSR/CXI or PSR/A or PSR/S PSR/S	PSR/CXI or PSR/A PSR/CXI or PSR/A PSR/S PSR/CXI or PSR/A PSR/S PSR/CXI or PSR/A or PSR/S PSR/S PSR/S and PSR/R
Complimentary Instruments:		NAST I & M (others TBD)		NOAA In-situ & EO/IR (others TBD)

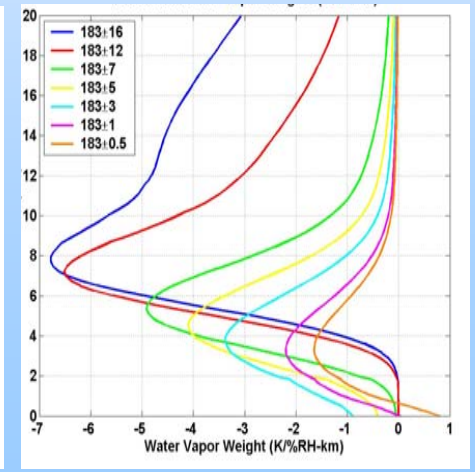
Anticipated Performance or Capability

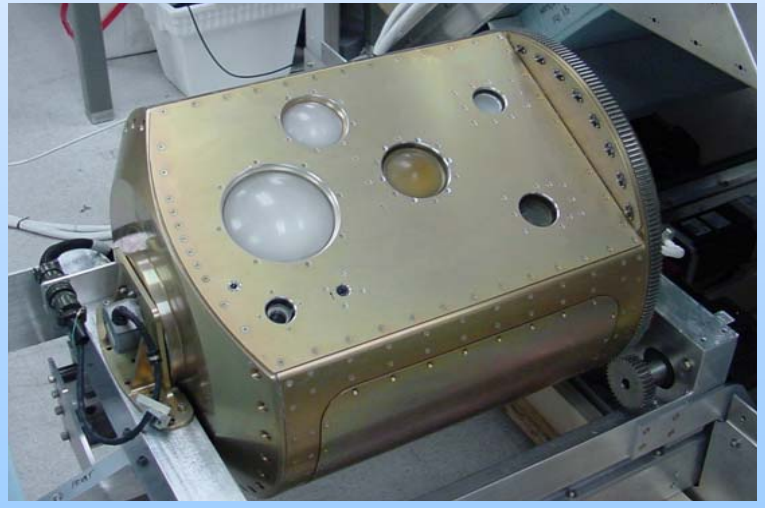
Passive Microwave Vertical Sounder

NOAA/ETL spectrometer modules with internal fast-switched absolute calibration.

Above spectrometers (plus two more under development) provide full AMSU-A/B and NPOESS CMIS and ATMS tropospheric sounding compatibility.

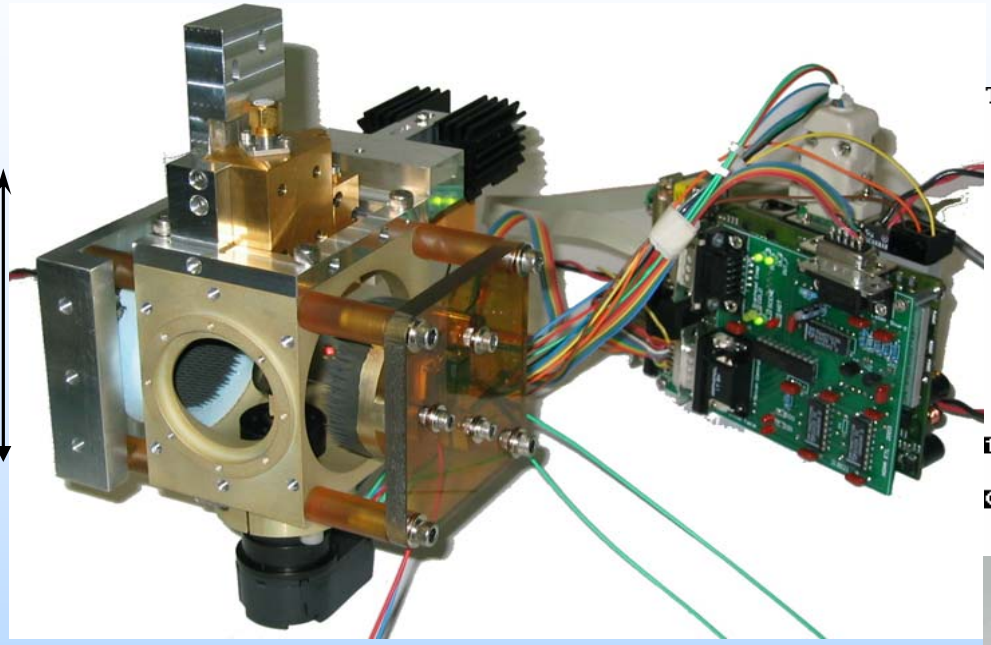


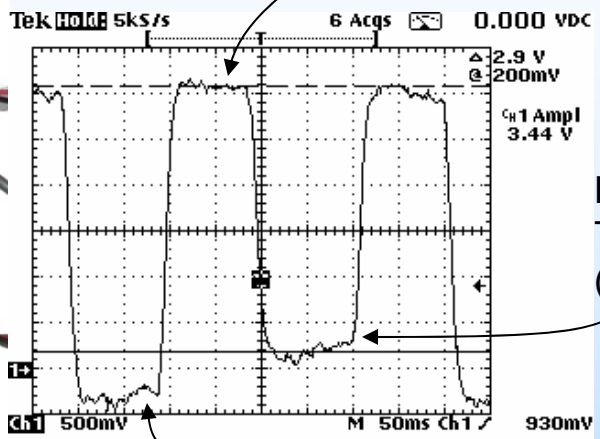


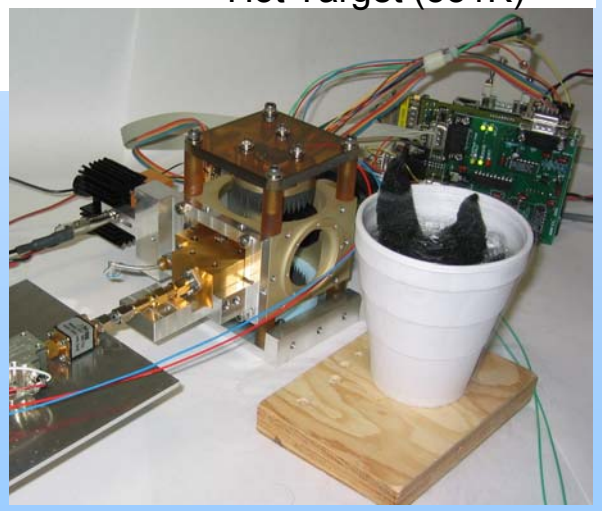


Microwave sounders as installed in NOAA PSR/S airborne radiometer sensor head

PSR/S 380 GHz Spectrometer





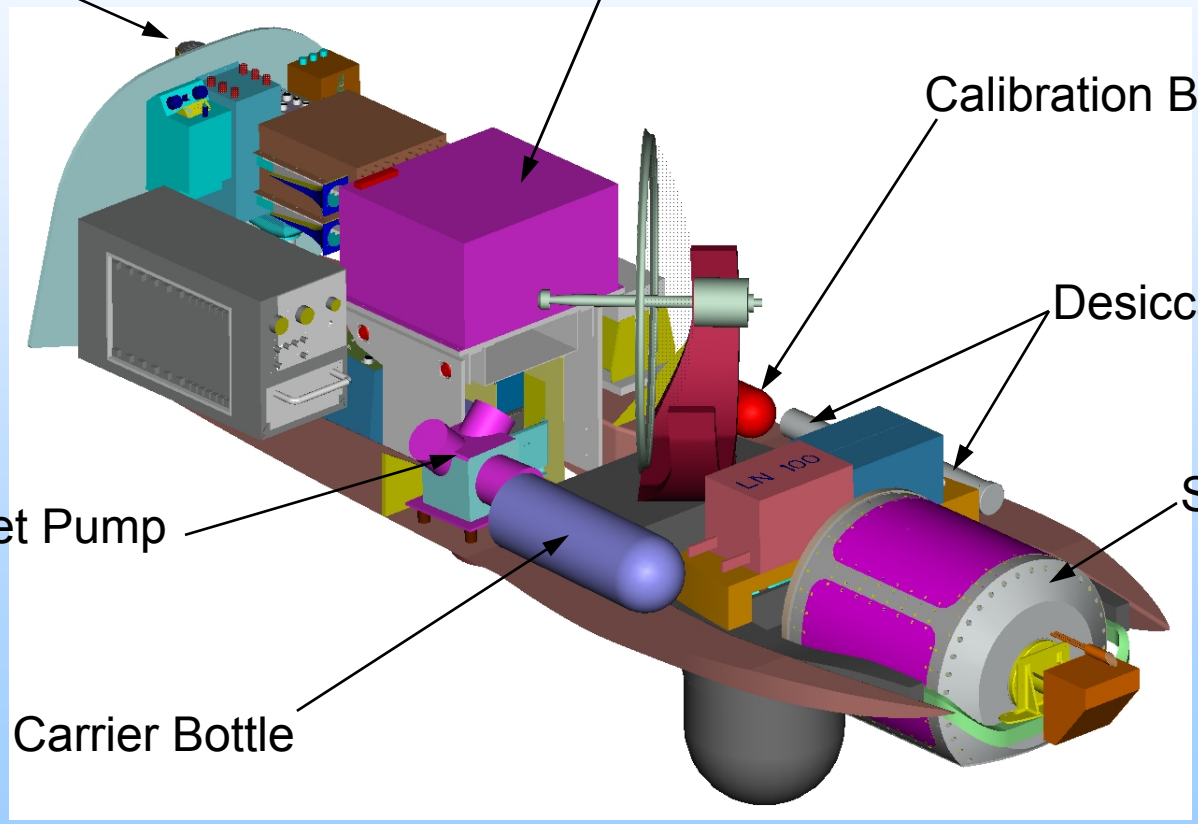


500 MHz wide IF band
Centered at 10.65 GHz

$\Delta T = 3.1$ K ➡ $T_{sys} \sim 4900$ K

Altair Integration

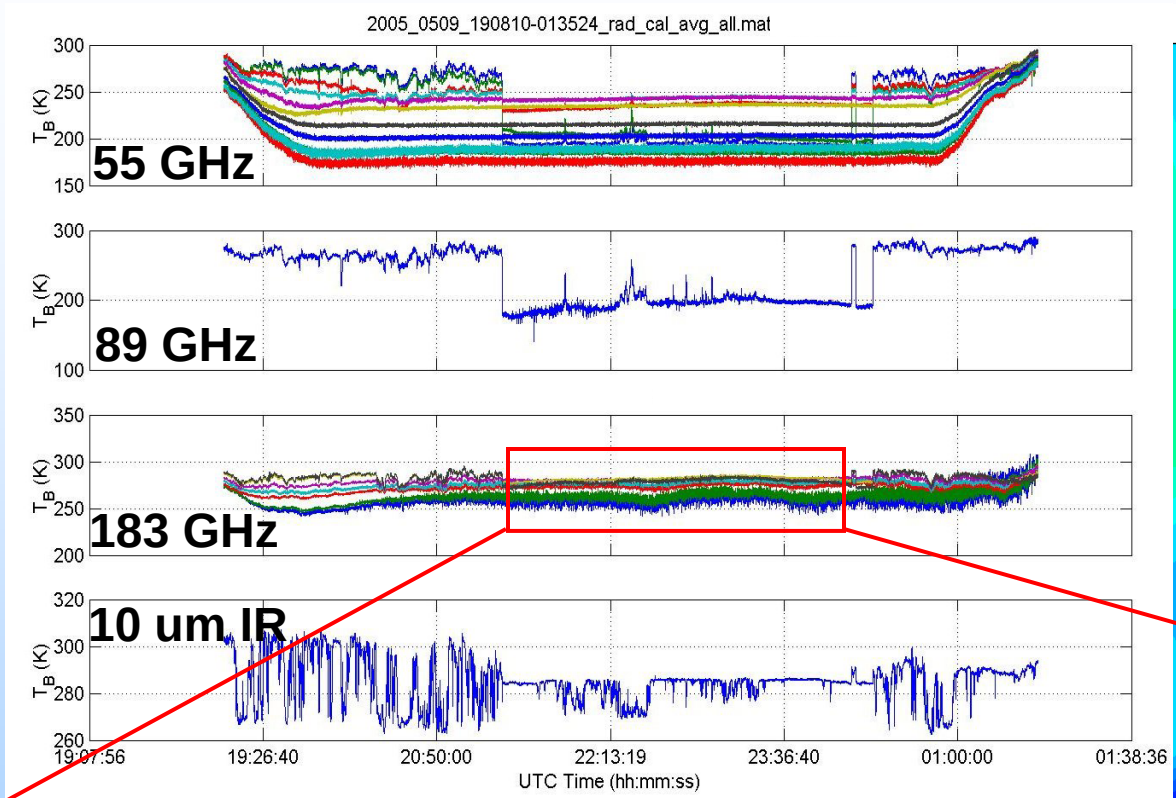
Right Front Iso View

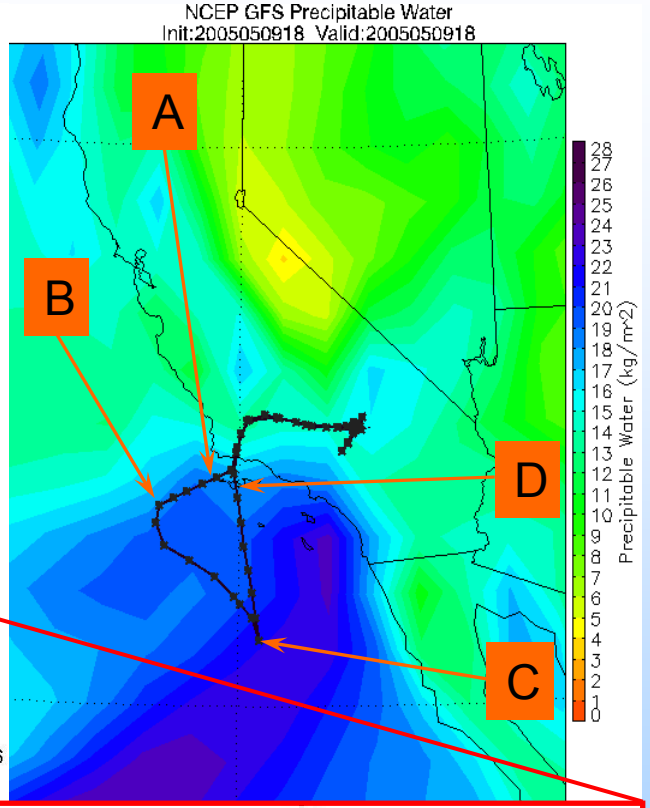


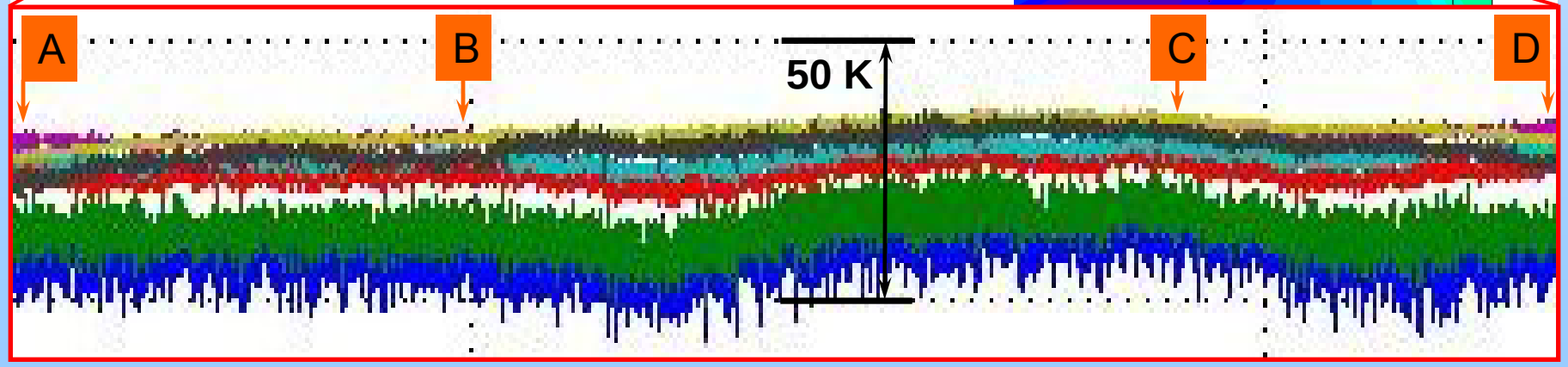
Altair Integrated Package

Atmospheric River Sounding Flight

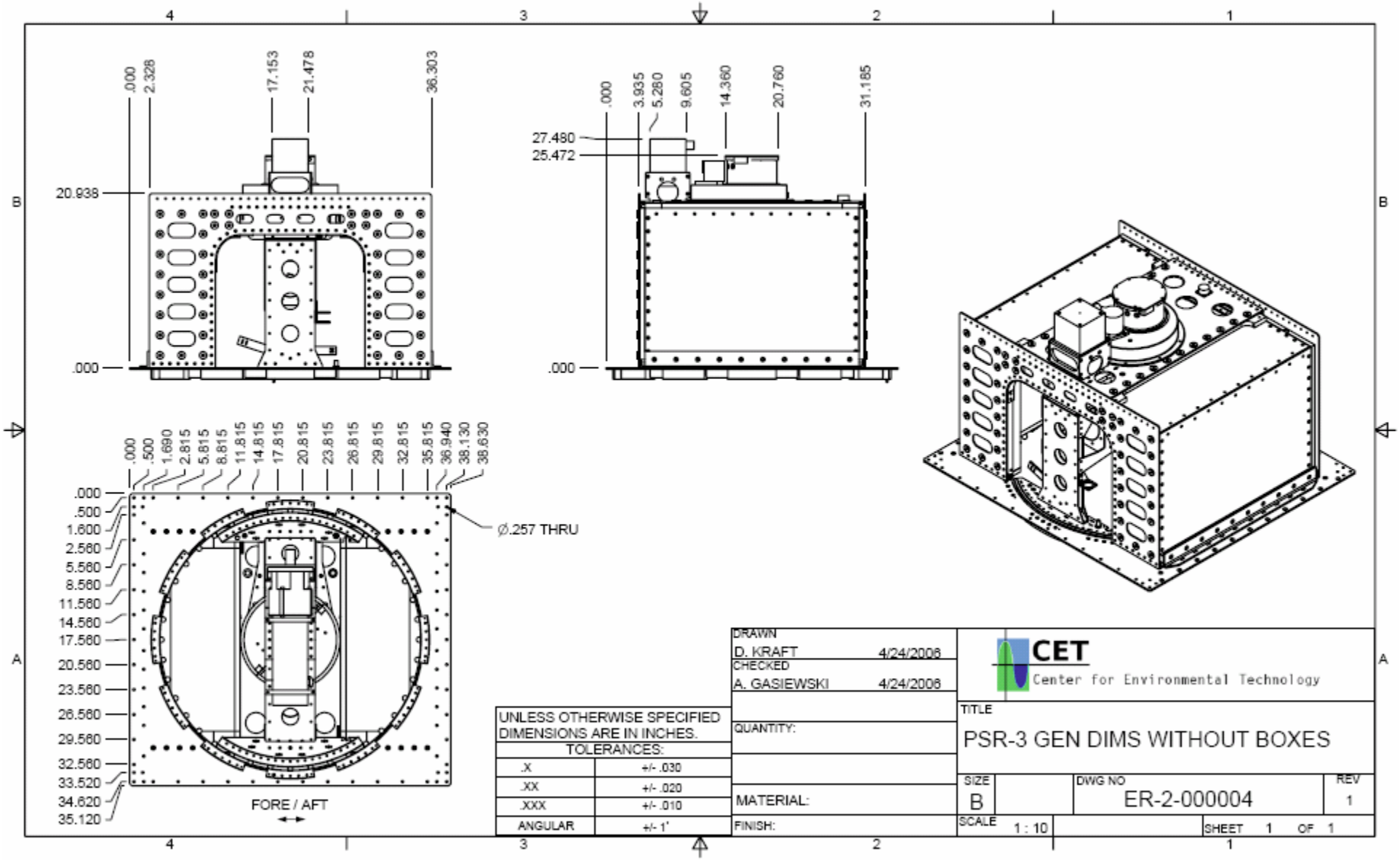
- Weak Atm River Penetrated on May 9, 2005 -

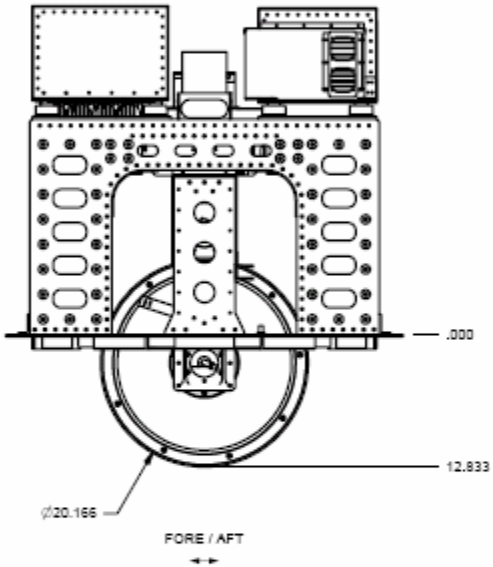


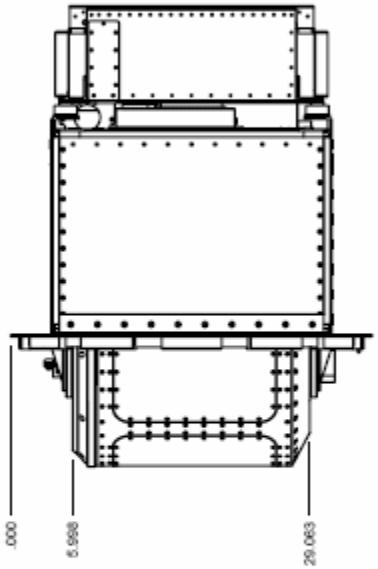


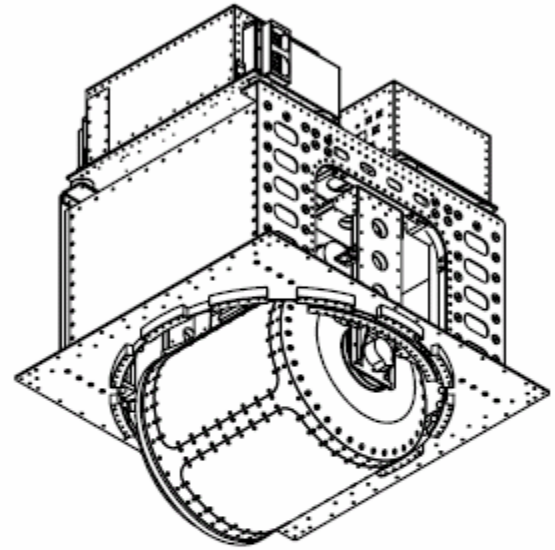


A PSR Global Hawk Integration


.000
2.328
17.153
21.478
36.303
20.938
.000
.000
3.935
5.280
9.605
14.360
20.760
31.185
27.480
25.472
.000
.000
.500
1.690
2.815
5.815
8.815
11.815
14.815
17.815
20.815
23.815
26.815
29.815
32.815
35.815
36.940
38.130
38.630
.000
.500
1.600
2.560
5.560
8.560
11.560
14.560
17.560
20.560
23.560
26.560
29.560
32.560
33.520
34.620
35.120
Ø.257 THRU
FORE / AFT
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.
TOLERANCES:
.X +/- .030
.XX +/- .020
.XXX +/- .010
ANGULAR +/- 1°
DRAWN
D. KRAFT 4/24/2006
CHECKED
A. GASIEWSKI 4/24/2006
QUANTITY:
MATERIAL:
FINISH:
CET
Center for Environmental Technology
TITLE
PSR-3 GEN DIMS WITHOUT BOXES
SIZE
B
DWG NO
ER-2-000004
REV
1
SCALE
1 : 10
SHEET 1 OF 1



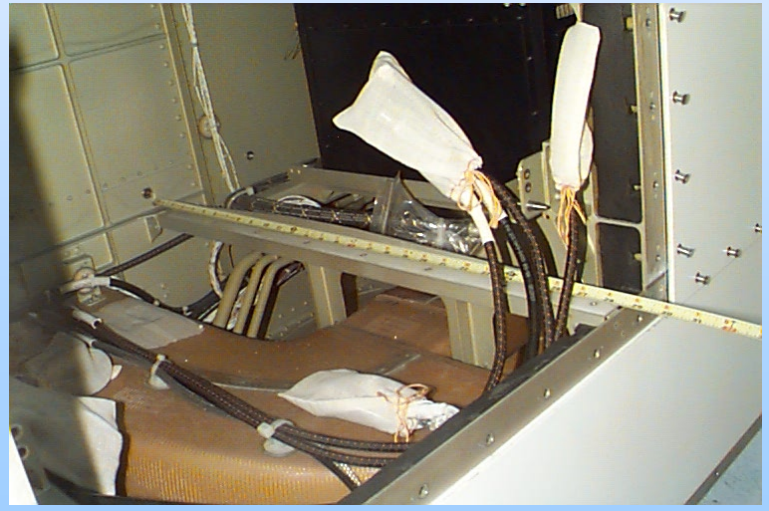




DRAWN			CET Center for Environmental Technology
D. KRAFT	4/25/2006		
CHECKED			
A. GASIEWSKI	4/25/2006		TITLE
			PSR-3 WITH SCANHEAD
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.	QUANTITY:		
TOLERANCES:			
.X	+/- .030		SIZE B / DWG NO ER-2-000005 / REV 1
.XX	+/- .020		
.XXX	+/- .010	MATERIAL:	
ANGULAR	+/- 1°	FINISH:	SCALE 1 : 10 / SHEET 1 OF 1

Center-Bay Conical Scanners

- One or (possibly) two PSR units -

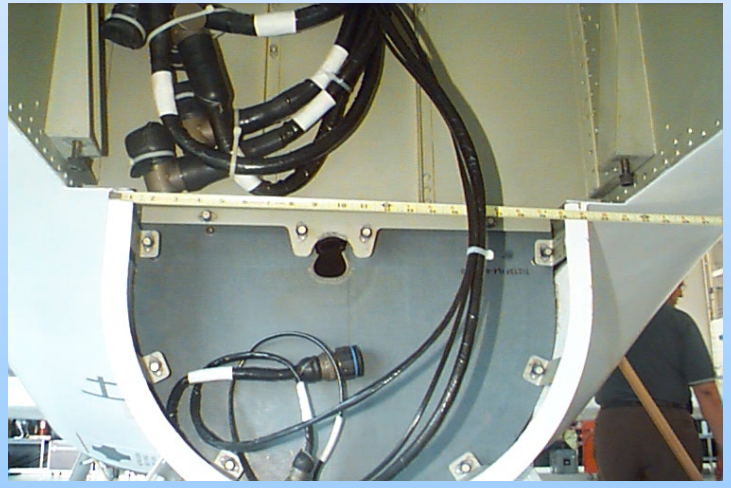


V-tail and upper intake design reduces likelihood of adverse vortex shedding from scanners

29” center-bay height (PSR positioner is 28” tall)

Cross-Track Nose Scanner

- Forward Fuselage Section -



22” diameter nose section (PSR scanheads are 20” diameter)

Summary

- All significant combinations of microwave bands for established sounding and imaging are available using the PSR system. The system provides all ATMS and CMIS measurement capabilities in a well tested and well supported flexible configuration of sensor components.

- We propose modifications for up to two PSR positioners in the GH center bay, along with one cross-track scanning PSR scanhead in the GH nose.

- PSR scanheads support a wide variety of microwave and other new instrumentation in an easily reconfigurable scanning package.