National Aeronautics and Space Administration

Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

UAS Control and Non-Payload Communication System Phase-1 Flight Test Results

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I-CNS
April 9, 2014

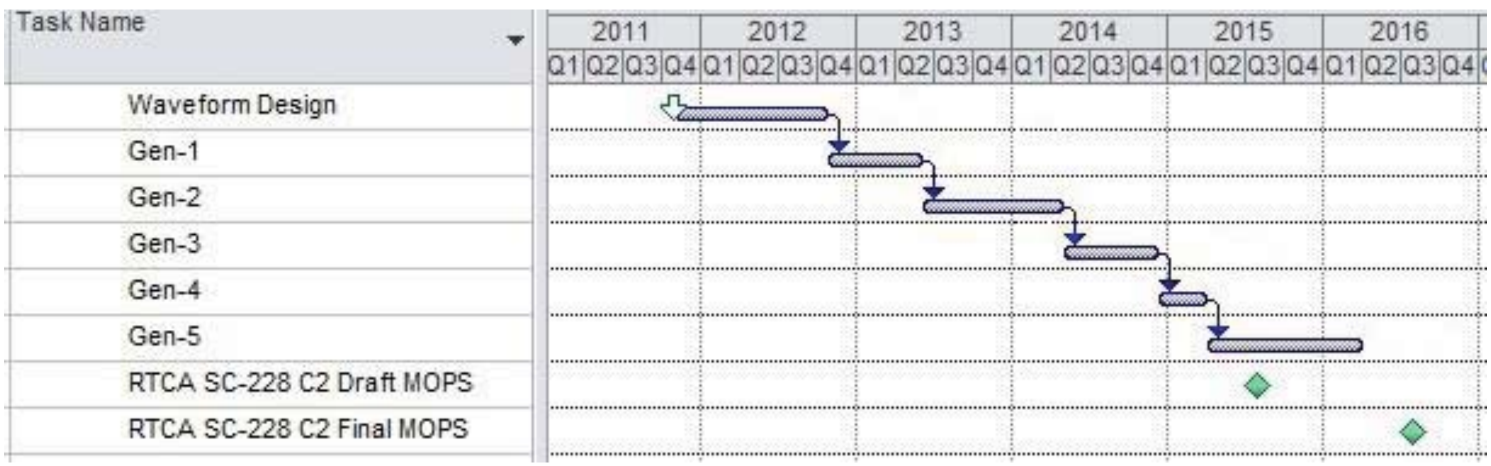
NASA – Rockwell Collins Cooperative Agreement

On Nov 1, 2011, NASA initiated a shared resource cooperative agreement with Rockwell Collins to demonstrate and support the further development of a Unmanned Aircraft CNPC System.

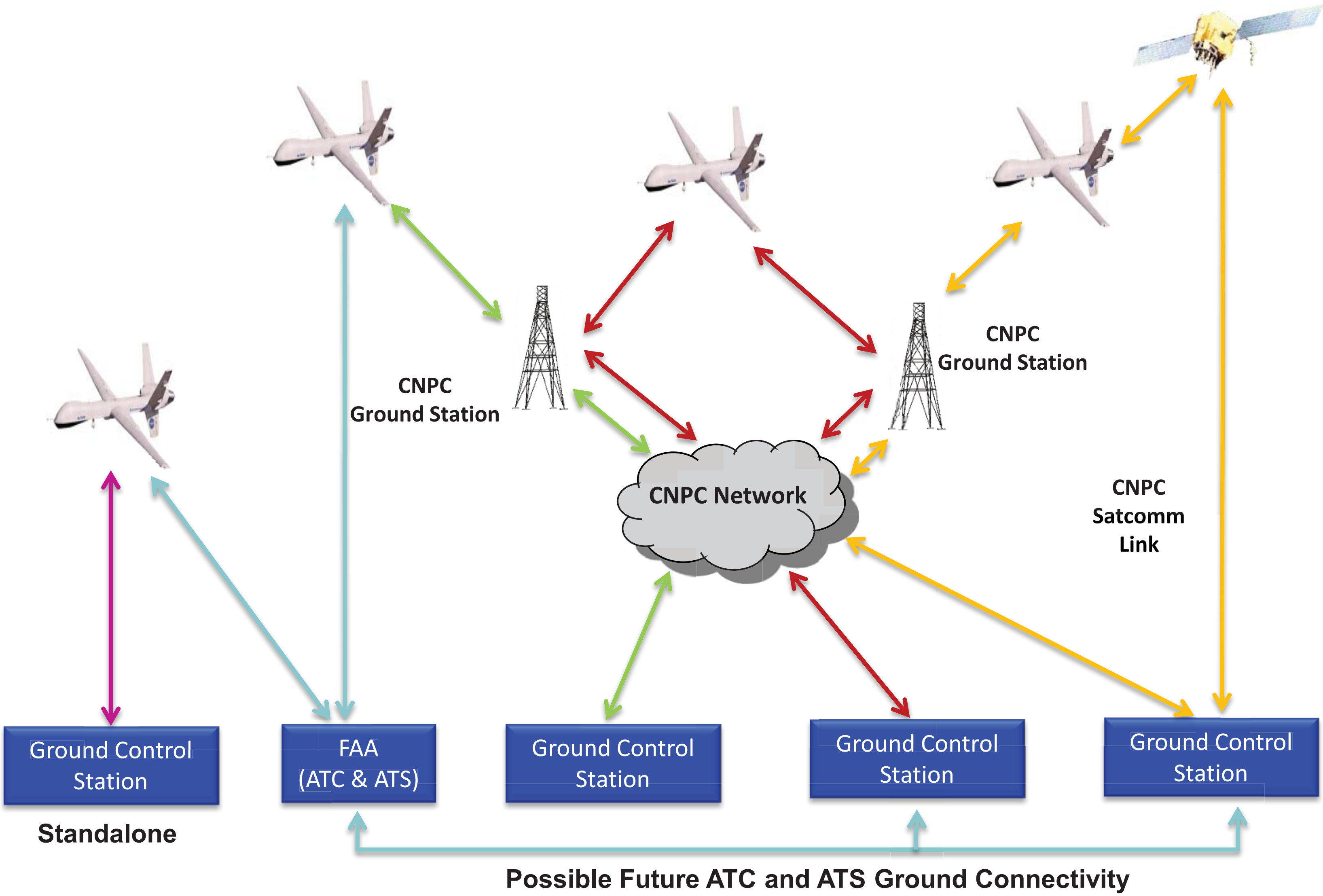
- Develop both ground and airborne prototype CNPC radios to provide a basis for validating and verifying proposed RTCA SC-203 (now SC-228) CNPC system performance requirements.
- Demonstrate a complete CNPC system, including interfacing to a ground based pilot station, transmission of CNPC data to/from more than one ground station, and onboard reception and transmission of CNPC data on more than one UA.

NASA – Rockwell Collins Cooperative Agreement

- The radios operate in UAS radio frequency spectrum
  - 5030 MHz – 5091 MHz (C band)
  - 960 MHz – 977 MHz (L band)
- The development of the prototype radios and associated CNPC system will be accomplished during a series of sprials.



Concept Civil UAS Communication Architecture



Waveform Trade Study

Seed Requirements (SC-203)

Requirement	Source
Radios must operate in frequency bands 960 – 977 MHz (L band) and 5030 – 5091 (C band)	NASA Contract SOW
L band and C band operations must be independent	NASA Contract SOW
RF link availability for any single link >= 99.8% Availability for simultaneous operation of L band and C band >= 99.999%	RTCA SC-203 CC016
Non-proprietary waveform	NASA Contract SOW
Must operate both air-to-ground and ground-to-air modes	NASA Contract SOW
Aircraft density assumptions Small UAs = 0.000802212 UA/ km^2 Medium UAs = 0.000194327 UA/ km^2 Large UAs = 0.00004375 UA/ km^2	ITU-R M.2171 P.54
Cell Service Volume Radius = 75 miles (L-Band)	RTCA SC-203 CC016
Maximum number of UAs supported per cell = 20 (basic services) Maximum number of UAs supported per cell = 4 (weather radar) Maximum number of UAs supported per cell = 4 (video)	RTCA SC-203 CC016
Tower height = 100 feet	RC Assumption
Uplink Information Rates (Ground-to-Air) Small UAs = 2424 bps Medium and Large UAs = 6,925 bps	ITU-R M.2171 Table 13
Downlink Information Rates (Air-to-Ground) Small UAs (basic services only) = 4,008 bps Medium and Large UAs (basic services only) = 13,573 bps Medium and Large UAs (basic and weather radar) = 34,133 bps Medium and Large UAs (basic, weather radar and video) = 234,134 bps	ITU-R M.2171 Table 13
Frame rate must support 20 Hz to enable real time control	ITU-R M.2171 Table 23/24
Aviation Safety Link Margin = 6 dB	RTCA SC-203 CC016
Airborne radio transmit power = 10 W	RTCA SC-203 CC016

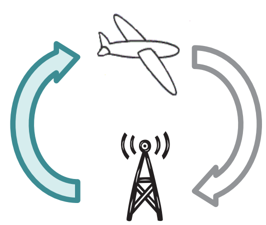
Technology Candidates, Criteria, & Scoring

Evaluation Criteria	System Level Factors Addressed	Downlink Multiple Access Candidates		
		CDMA	FDMA	TDMA
Link Margin at Full Capacity	Availability	Unacceptable	Reference	-13 dB for identical PA
Airborne Transmitter Power	SWAP, Cost, Complexity	10 Watts peak	10 Watts peak	200 Watts peak
Multipath Mitigation	Availability, Cost, Complexity	Link margin, spreading, RAKE processing	Link margin	Link margin, adaptive equalization
Synchronization Required	Cost, Complexity	None beyond that required for TDD	None beyond that required for TDD	Tight synchronization for low guard time overhead
Power Control Required	Cost, Complexity	Tight control mitigates near-far problem, 10-20% added complexity	Gross control mitigates near-far problem	Gross control beneficial but not required
Ground Signal Processing Complexity	SWAP, Cost, Complexity	10-20% added complexity	10-20% added complexity	Reference

Results

Ground-To-Air Link

Time Division Multiple Access
Constant Envelope
Binary Modulation Order



Air-To-Ground Link

Frequency Division Multiple Access
Constant Envelope
Binary Modulation Order

Time Division Duplexing

Datalink Technology Evaluation

Evaluation Criteria

Category	Criteria
Air/ground comm	Taxi / Surface / Preflight / Postflight Takeoff / Landing / Terminal En Route
Data Transmission	Addressed capability Repetition rate Command/Control Command/Control and ATC relay Command/Control, ATC relay, and surveillance
Mobility	Handoff Dynamic power control Adaptive modulation rates Active QoS retuning
Security	Confidentiality Integrity Availability
Traffic QoS	Traffic cross-carrier distribution Traffic priority Traffic classes Traffic reliability/ARQ Dynamic bandwidth allocation RF statistics reporting
Certification / complexity	Technology Readiness Level Certification Risk Robustness Determinism Link Layer Compatibility
Waveform	Duplexing (TDD/FDD) Uplink multiplexing Downlink multiplexing Uplink modulation Downlink modulation

Technologies

Technology Family	Candidates
Cellular Telephony Derivatives	TDMA (IS-136), CDMA (IS-95A), CDMAone (IS-95B), GSM/GPRS/EDGE, CDMA2000, EV-DO, EV-DV, UMTS (W-CDMA, TD-CDMA, TD-SCDMA), LTE, DECT, Mobitex, Flash-OFDM
IEEE 802 Wireless Derivatives	IEEE 802.11, 802.15, 802.16, 802.20, ETSI HiperPAN, HiperLAN, HiperMAN
Public Safety and Specialized Mobile Radio	P-25, P-34, TETRA, TETRA Release 2 (TAPS, TEDS), TETRAPOL, EDACS, iDEN, IDRA, Project MESA
Custom Civil / Aeronautical Solutions	HF Data Link, ACARS, VDL Mode 2, VDL Mode 3, VDL Mode 4, VDL Mode E, E-TDMA, ADL, B-VHF, UAT, Mode S, Gatelink, AMACS, LDL, L-DACS 1, L-DACS 2, STANAG 4660
Military	JTIDS/MIDS/JRE (Link 16), SINCGARS, EPLRS, HAVEQUICK, JTRS
APC Telephony	Airphone, AirCell, SkyWay

Scoring

No datalink technology is a perfect match for the CNPC system

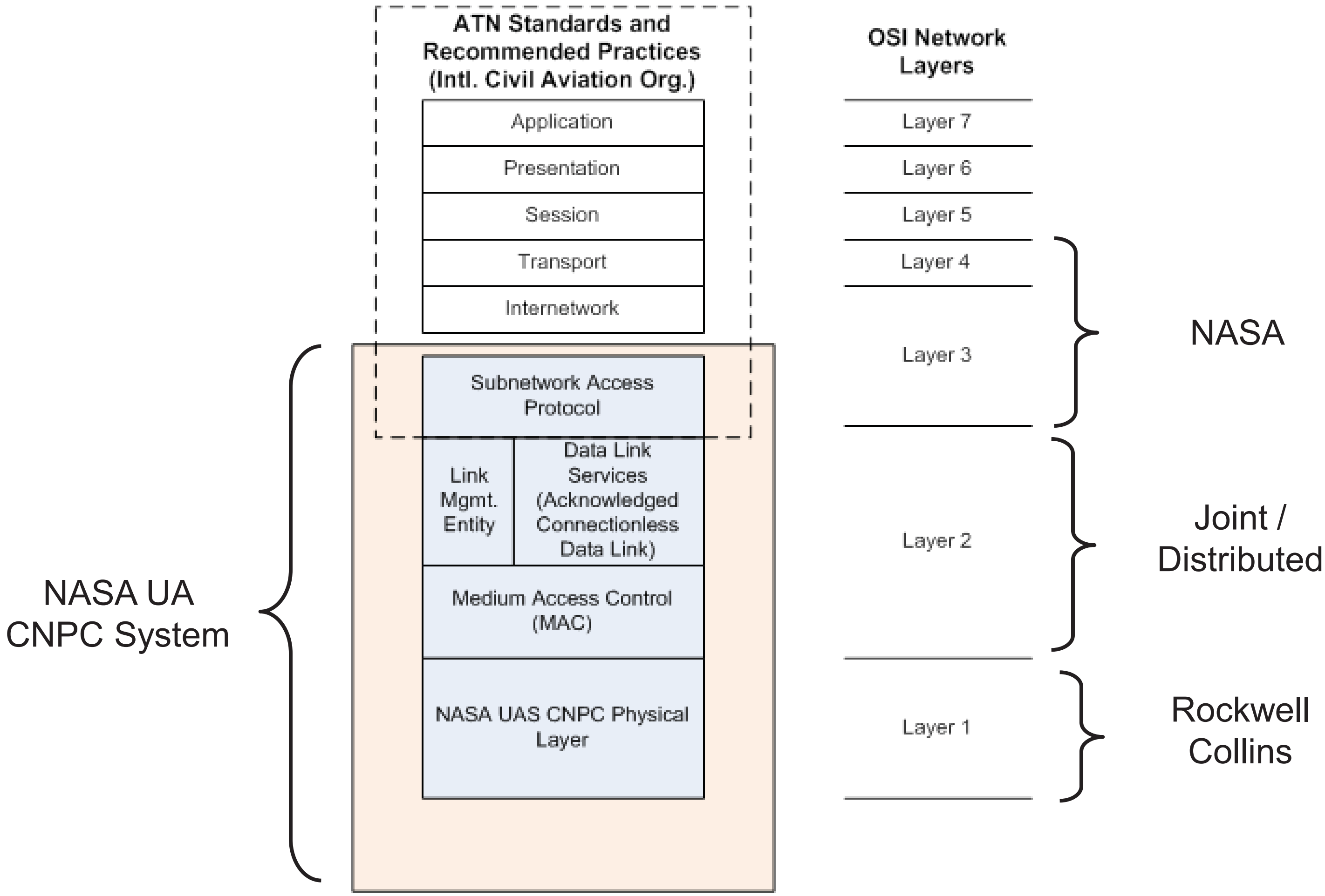
- All technologies must be modified to match the proposed waveform

The study identified the 4 best datalink technologies

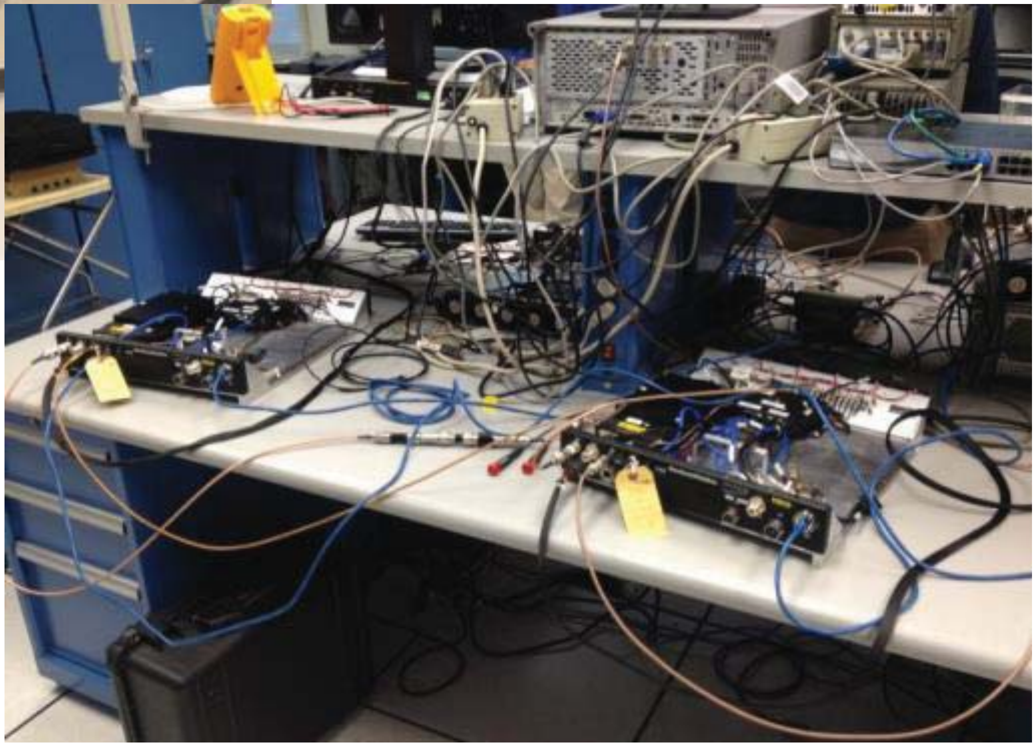
- LTE and IEEE 802.16 scored highest, P-34 and TEDS scored next best.

IEEE 802.16 was selected as the preferred datalink technology and will be used as the basis for development of the prototype CNPC system.

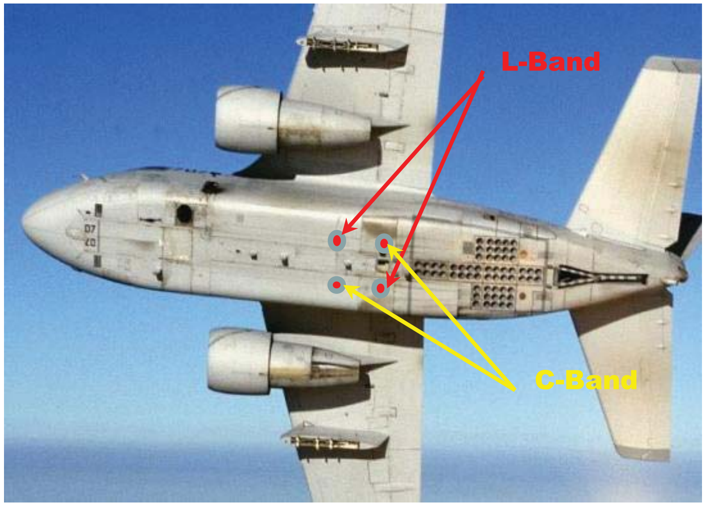
Rockwell Collins / NASA Design Lead Allocations



Hardware Test Bed Setup
NASA Glenn Research Center



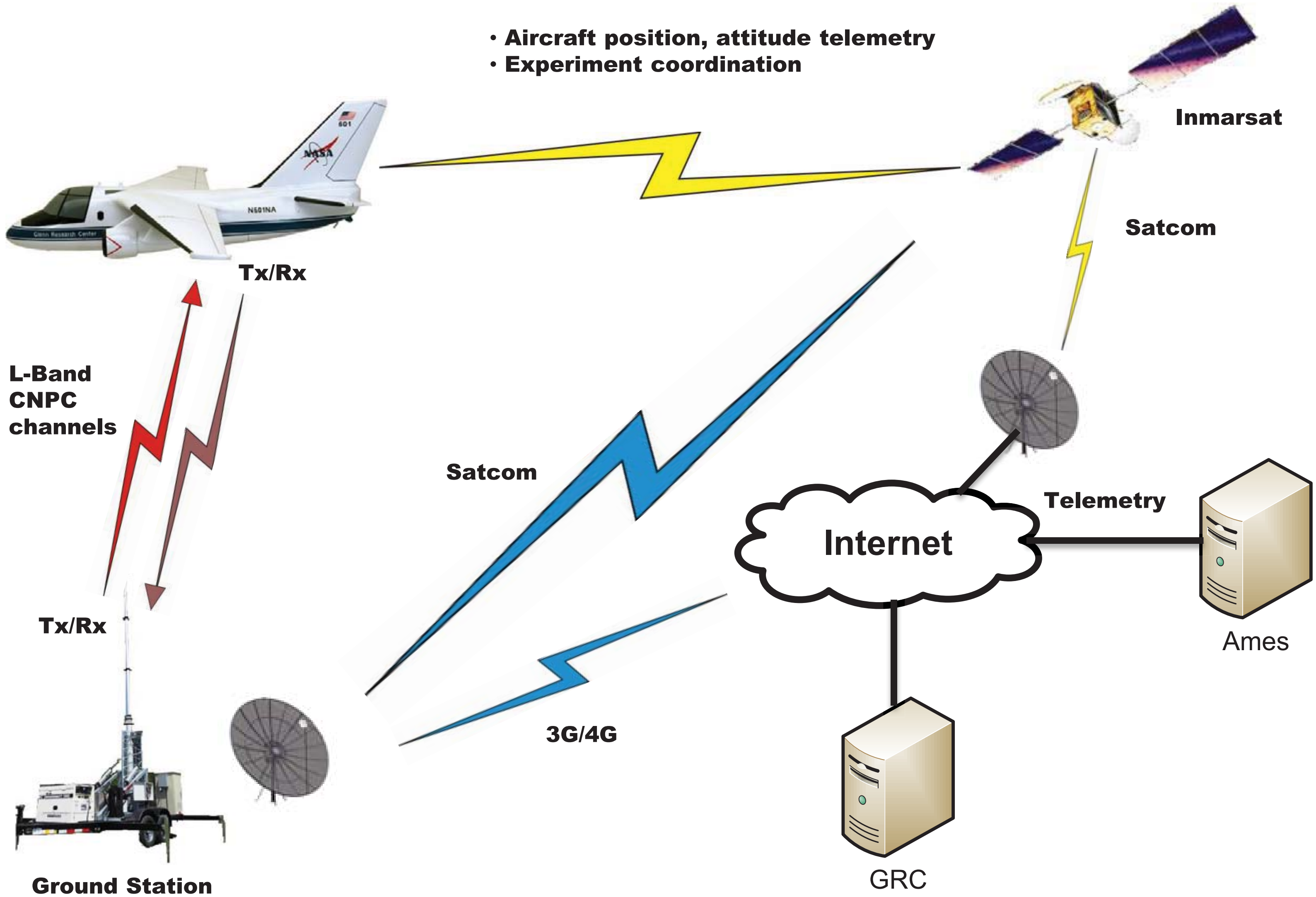
Aircraft & Ground Station



Flight Test – Gen 1
May 2013

- L-Band Radio only
- One Aircraft – One Ground Station
- Omni on aircraft, sector on the ground station (Flight testing will take into account ground antenna pattern)
- Limited live flight data from aircraft
- All other data emulated from script
- Without incorporating layers 3 and above
- No Security
- Capture parameters: Telemetry, RF, and Raw Data

Gen 1 Radio Flight Test Architecture

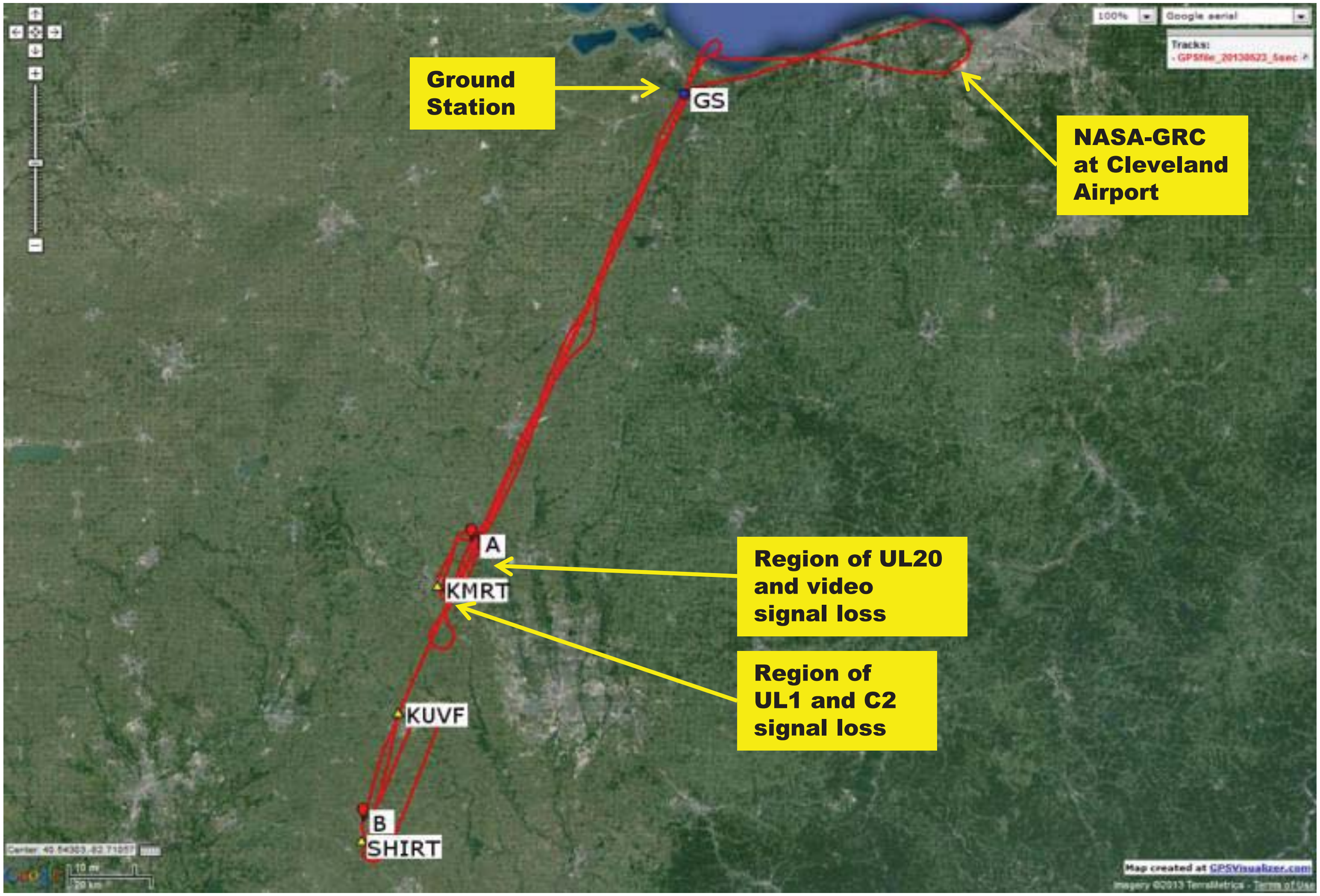


VHF 2-way voice communications link not shown

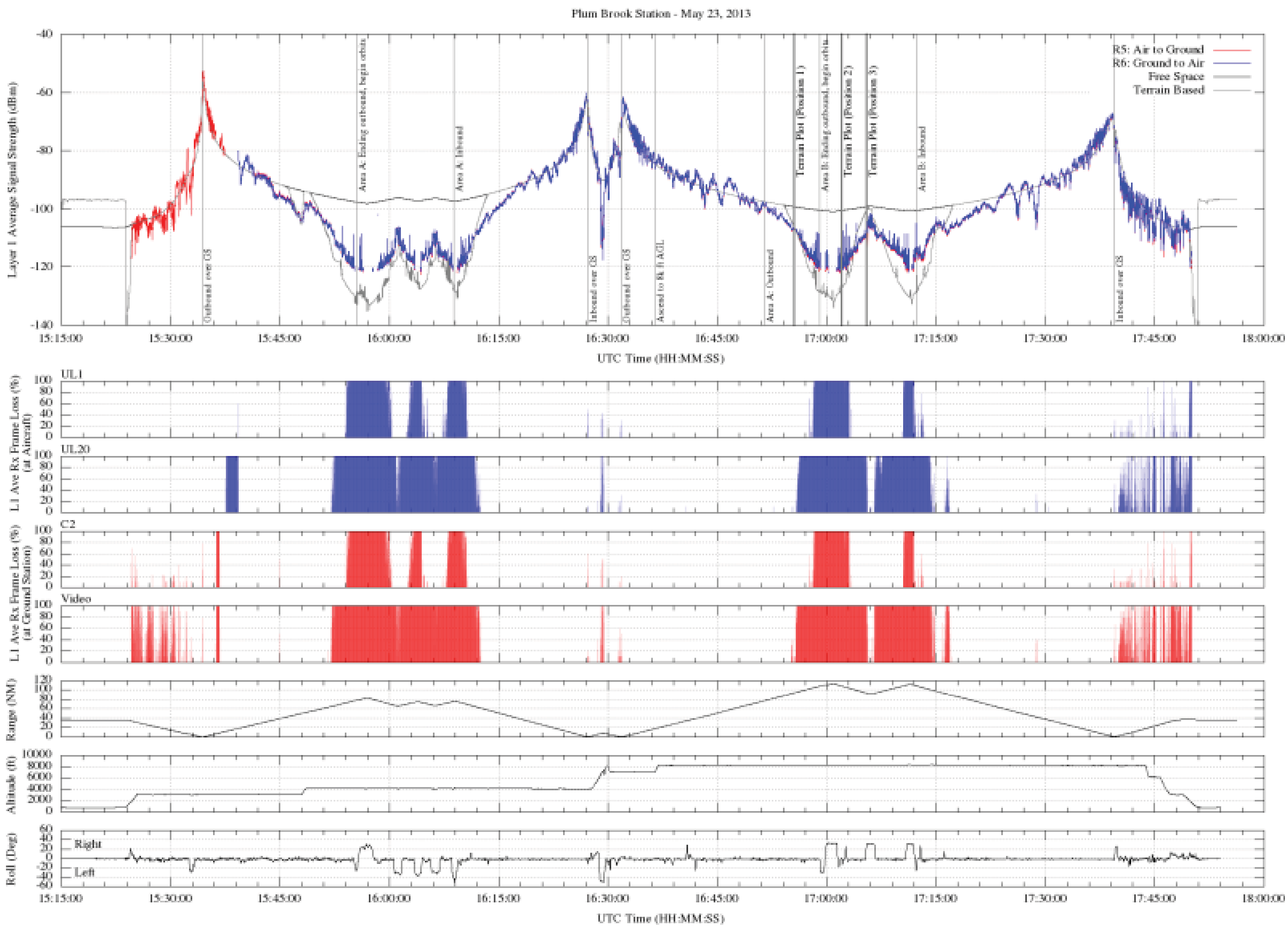
Rockwell-Collins Generation 1 CNPC Radio Testing

Test Number	Test Date	Ground Terminal Location	Tower Antenna Direction	Tower Position		Radio Config.	Filters	Comments
				Latitude	Longitude			
1	5/22/2013	GRC	312°	41° 24' 51.90"	-81 51' 34.86"	1, 2, and 3	Aircraft: (2) ceramic fliters. Ground: Rockwell tunable filter	Tower on hangar tarmac. Sounder flight patterns.
2	5/23/2013	PBS 1	212°	41° 20' 42.02"	-82° 38' 43.96"	5	"	PBS location 1. Aircraft flying in long-range flight corridor.
3	5/24/2013	PBS 1	212°	41° 20' 42.02"	-82° 38' 43.96"	5	"	PBS location 1. Aircraft flying in long-range flight corridor. Repeat of 5/23/13.
4	5/28/2013	PBS 2	178°	41° 20' 39.00"	-82° 38' 46.74"	5	"	PBS location 2. Aircraft flying approach tests into MFD.
5	5/29/2013	PBS 2	178°	41° 20' 39.00"	-82° 38' 46.74"	6	"	PBS location 2. Aircraft flying touch-and-go tests into MFD.
6	5/31/2013	PBS 1	212°	41° 20' 42.13"	-82° 38' 44.13"	6	Aircraft: (2) ceramic filters Ground: (2) ceramic filters	PBS location 1. Aircraft flying inside coverage area with live flight data in CPNC downlink stream.
7	6/18/2013	Cedar Rapids, IA	Omni	42° 2' 0.31"	-91° 38' 55.32"	7	Aircraft: (2) L-band ceramic fliters Ground: Rockwell tunable L-band fliter	L-Band omnidirectional antenna on 300-ft tower. Aircraft flight on 270 degree radial. 4 watts outbound, 0.2 watts inbound

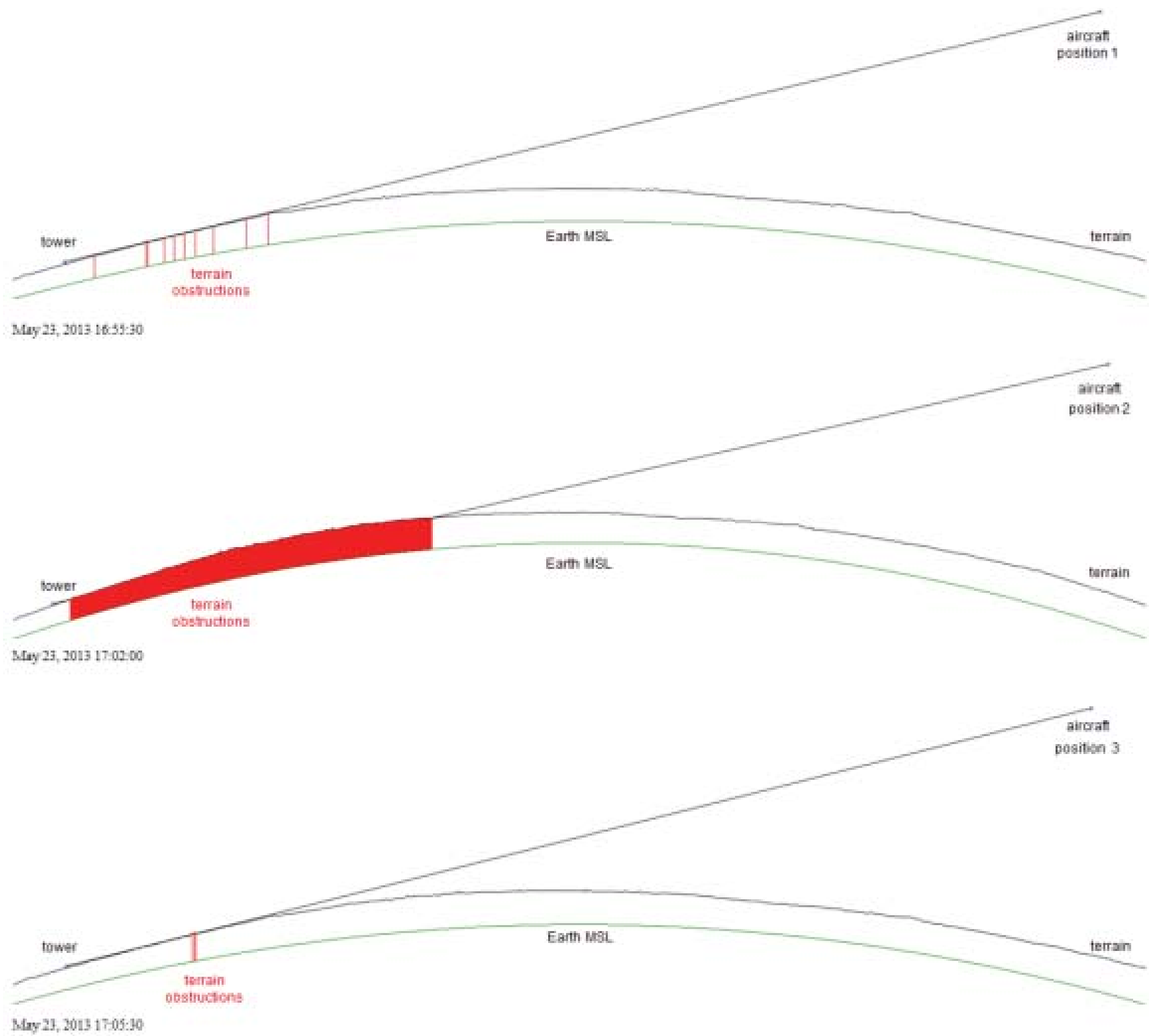
Research Flight Track – May 23, 2013



May 23, 2013 Flight Test – Plum Brook Station

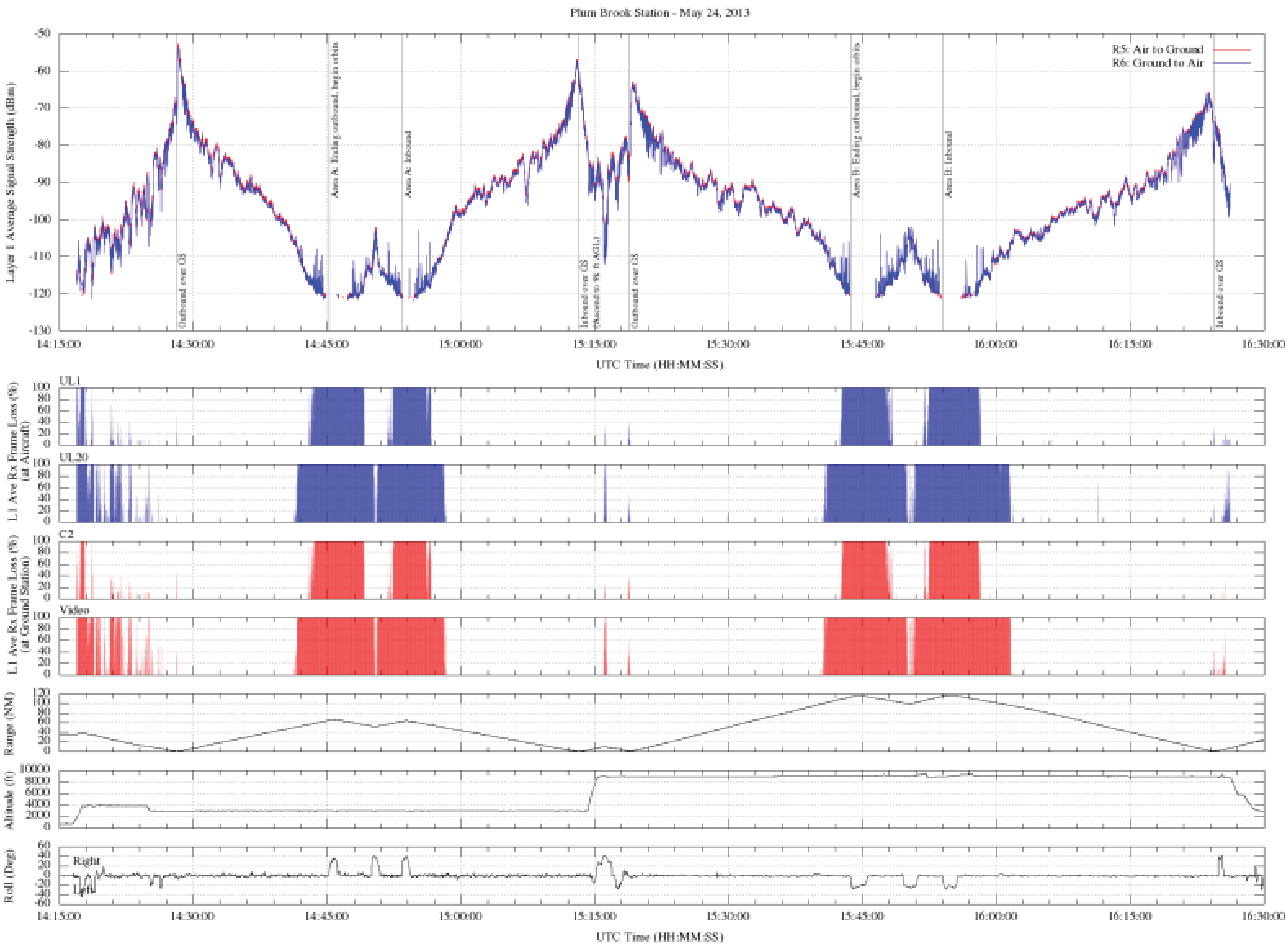


Bretmersky Earth-Enhanced Ranging Software

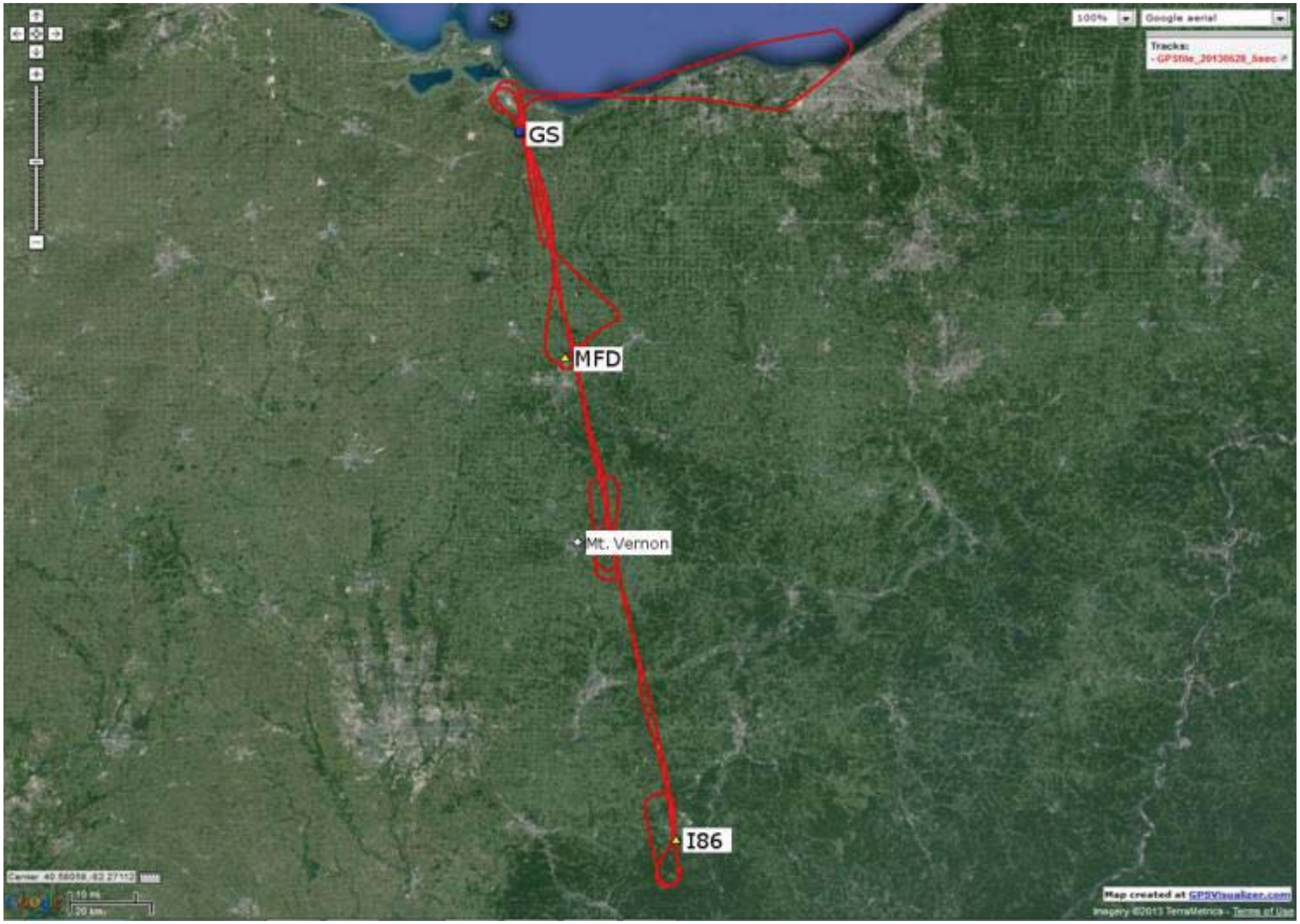


Research Flight Track – May 24, 2013

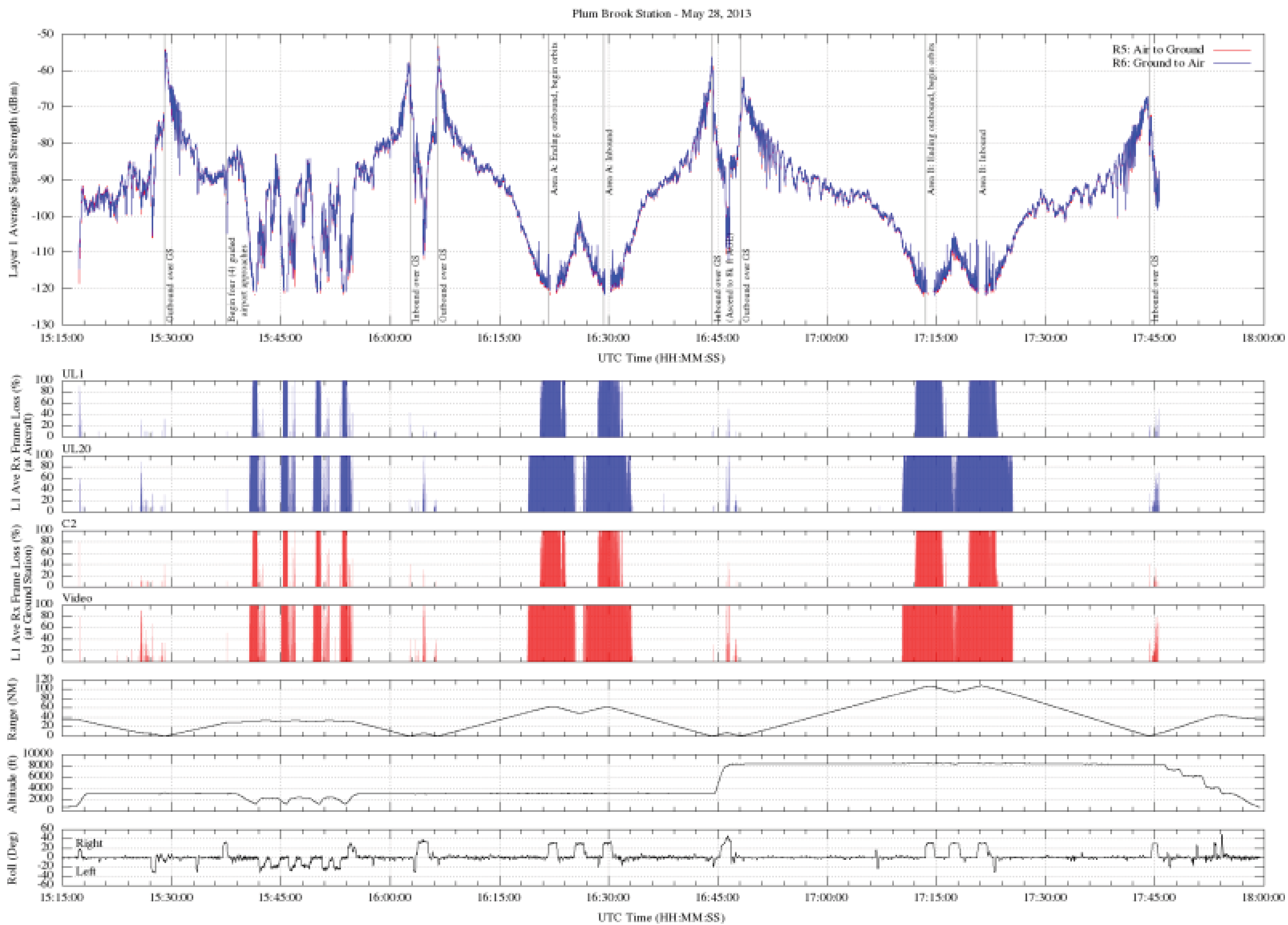
May 24, 2013 Flight Test – Plum Brook Station



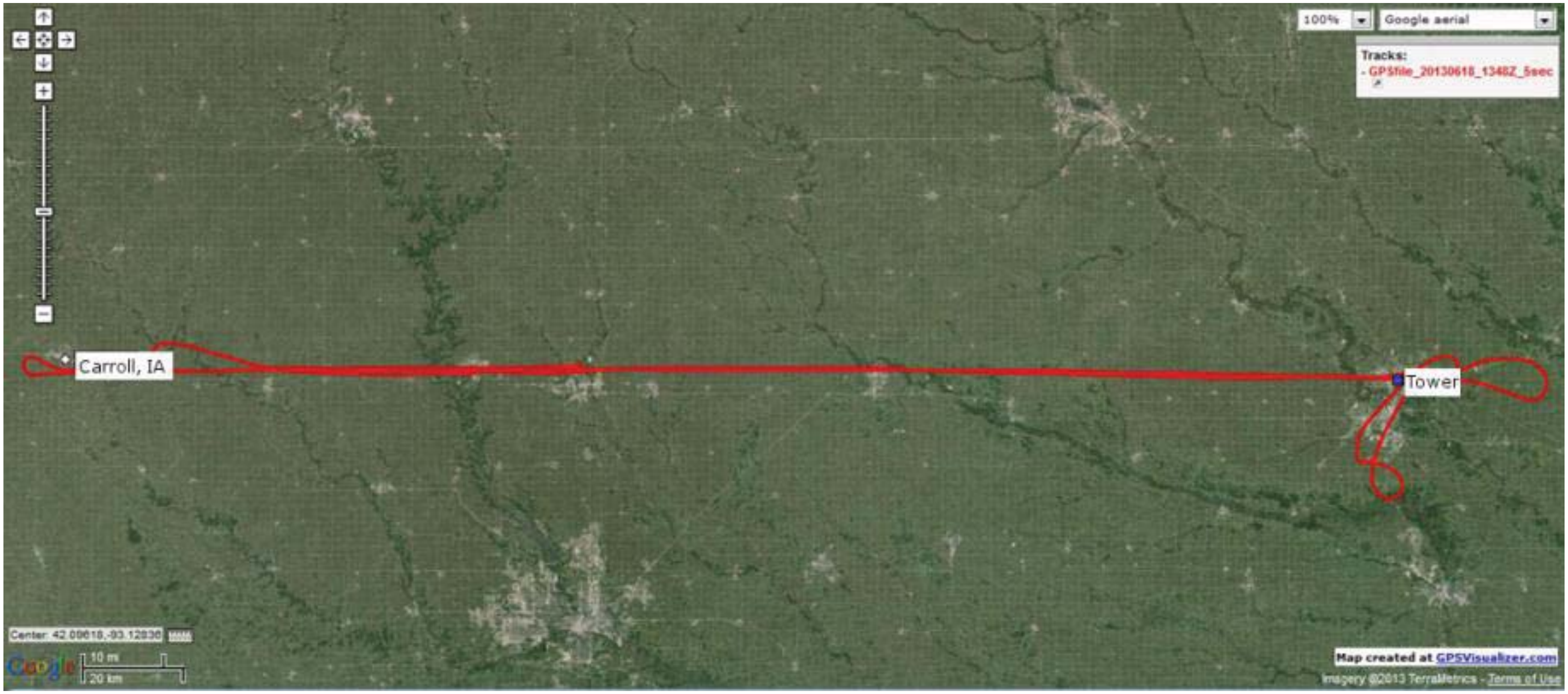
Research Flight Track – May 28, 2013



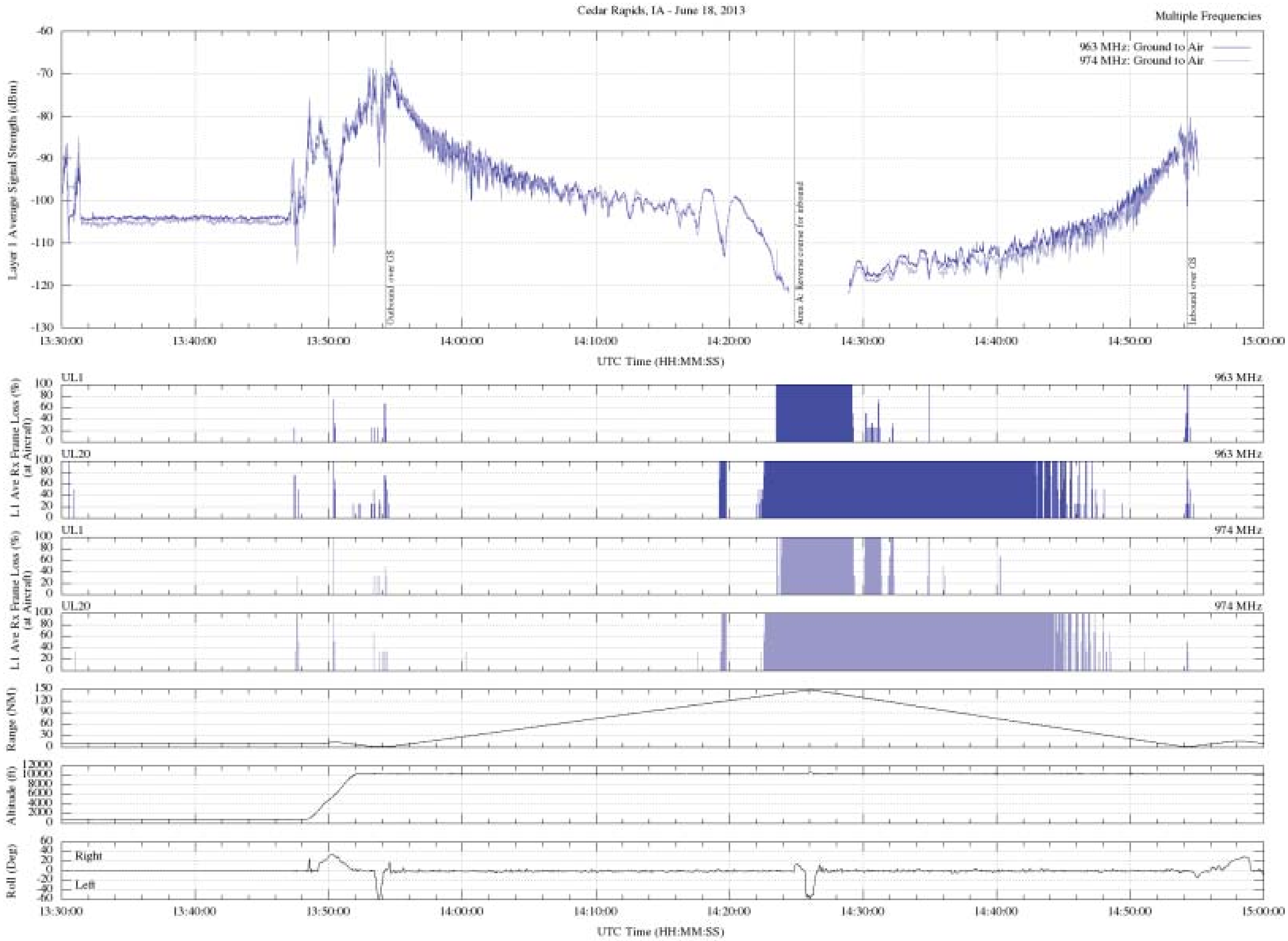
May 28, 2013 Flight Test – Plum Brook Station



Research Flight Track – June 18, 2013



June 18, 2013 Flight Test – Cedar Rapids, IA



Assessments/Thoughts

- The Generation 1 (L-Band) radios operate remarkably well: communications range is well beyond the target of 69 nmi.
- The GRC S-3 aircraft continues to be a flexible and effective research asset.
- All radio trays have been upgraded to become Generation 2 models, populated with both L-Band and C-Band radios. Additional radio trays have been purchased.

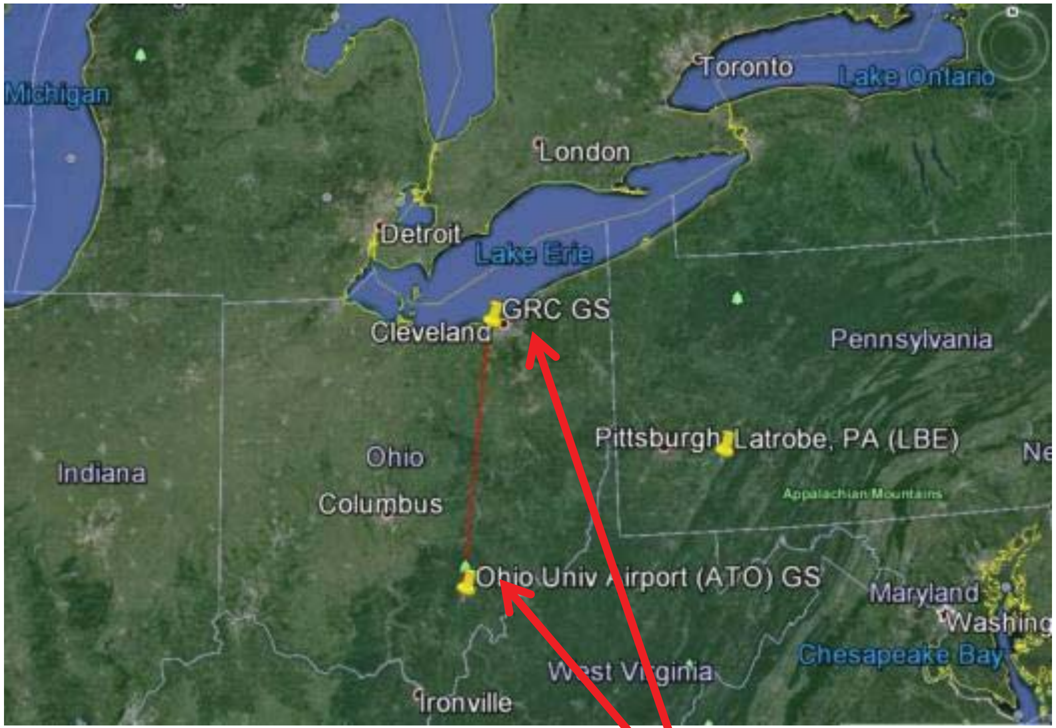
Flight Test – Gen 2
April 2014

- L-Band and C-Band Radios (simultaneous operation not required)
- One Aircraft – Two Ground Stations
- Omni on aircraft, sector on the ground stations (Flight testing will take into account ground antenna pattern)
- Expanded live data sent from aircraft
- All other data emulated from script
- No Security
- Basic handoff capabilities exercised
- IPv6 implemented, which will exercise IPv6 mobility
- Capture parameters: Telemetry, RF, Data, and mobility/handoff

Gen-2: "Hand-off" test

Transportable Ground Station

Installed Antennas at GRC



- Networked, remote-controlled ground stations
- Various hand-off decision scenarios
- Multiple service flow types
- Omnidirectional antennas