WIND SPEED RETRIEVAL FROM DIGITAL COMMUNICATION AND GPS SIGNALS

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Outline

- **Background**
  - Past Heritage with GNSS-R
  - Motivation
- **Objective**
- **Recent Demonstration with S-Band Signals**
- **Retrievals from Simulation**
- **Description of Flight-Certified Instrument**
- **Summary and Future Work**

Ocean Roughness/Wind Speed

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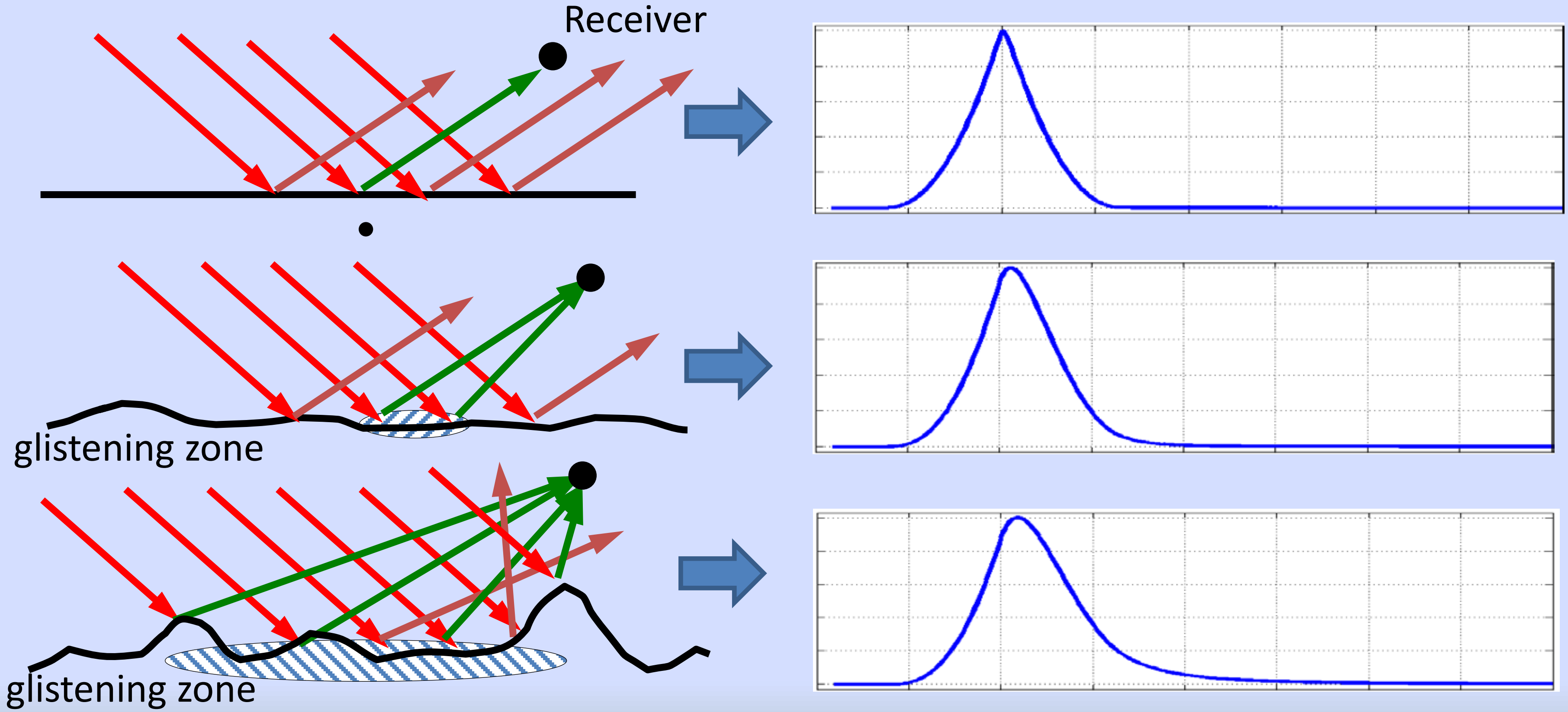
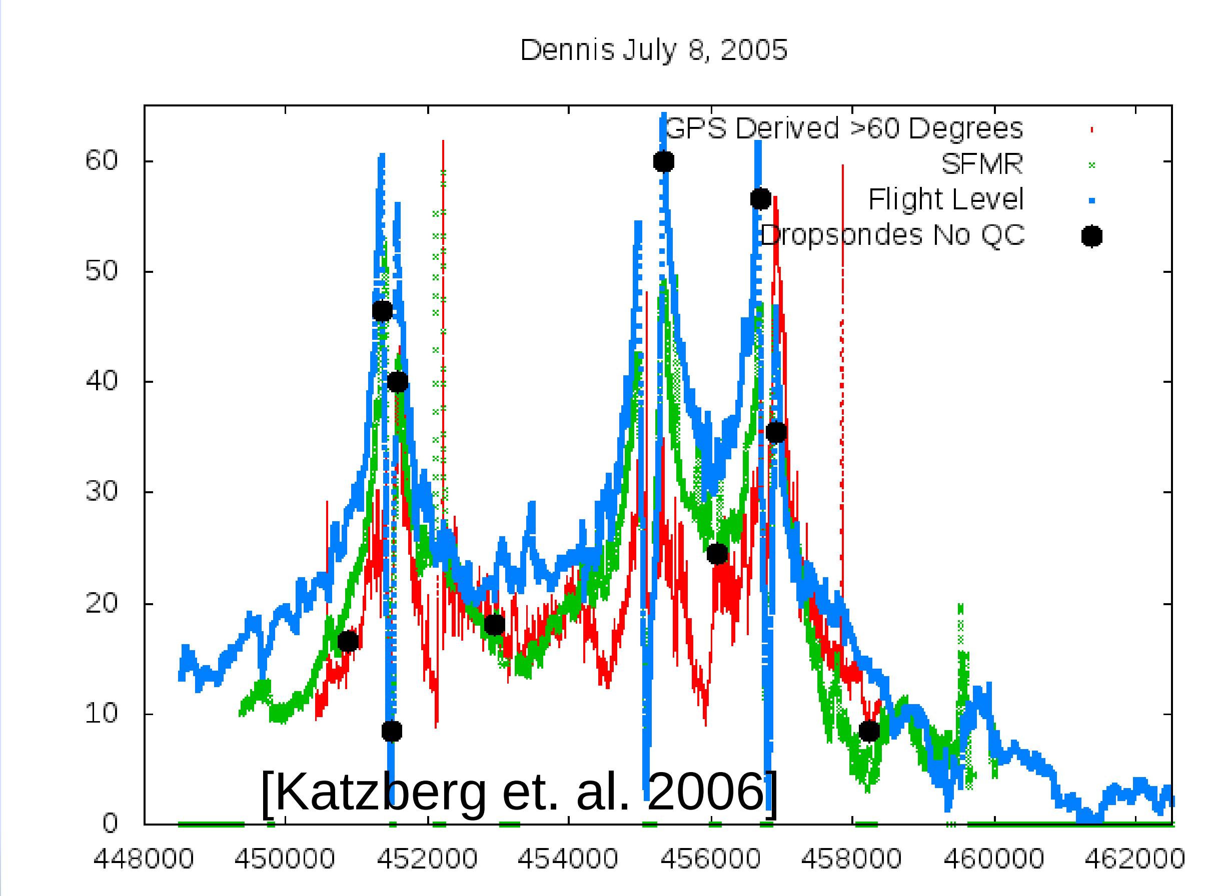
Fundamental Physics:

Rougher surface = larger distribution in path delays



GNSS-R Experience

- GNSS-R receivers on NOAA flights since 2000
- Calibration with wind speed up to Hurricane speeds.



Motivation

- **Why Digital Communication Signals?**
  - Noise-like transmission - generates range-bins
  - Free transmitters > 400 satellites
  - Higher transmitted power: Better accuracy
  - Geostationary orbit: Fixed geometry
  - Low-Cost receiver (all consumer electronics)
- **Demonstrated using XM radio signals (S-band)**

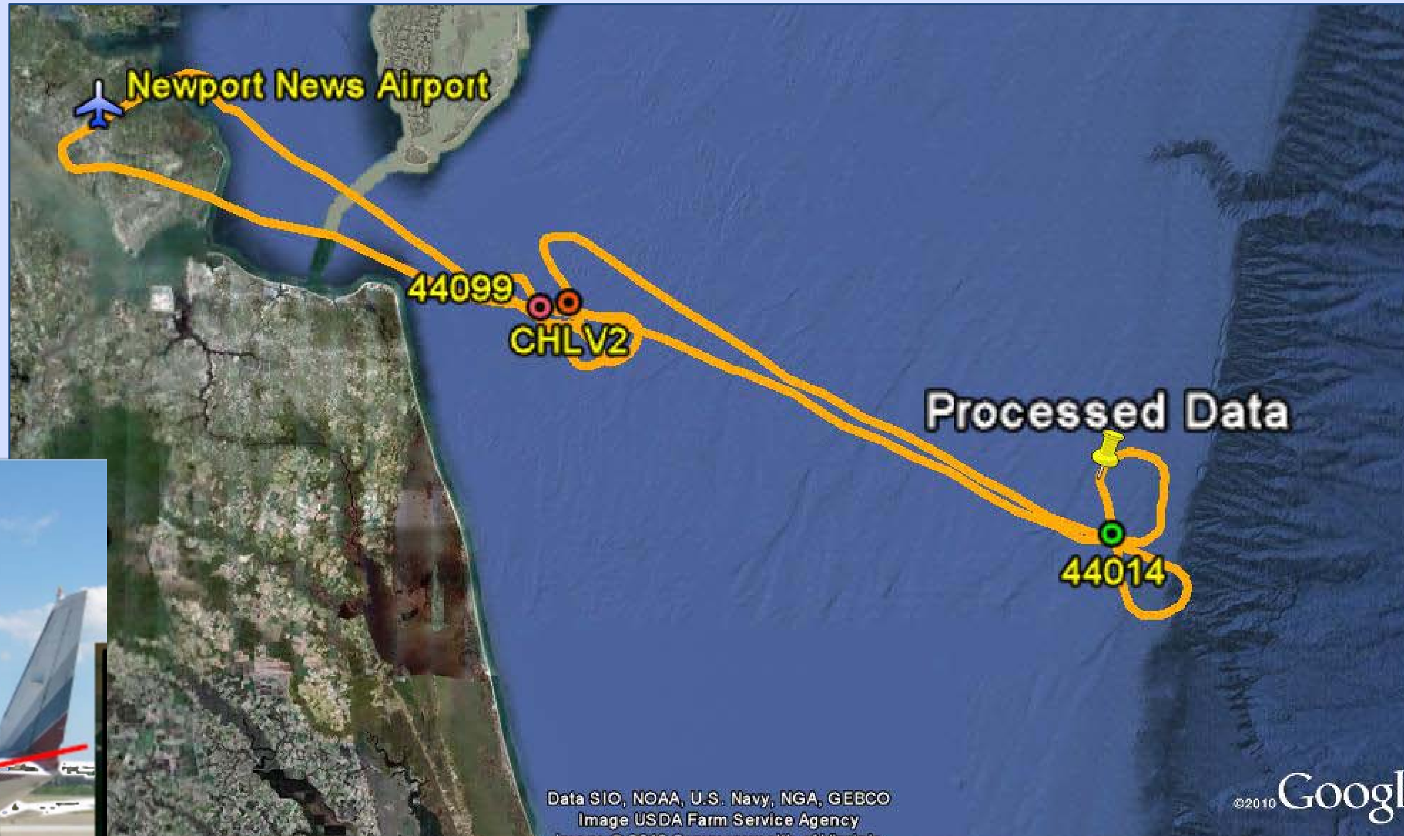
Objectives

- To demonstrate reflectometry with digital communication signals
- To quantify wind speed retrieval error:

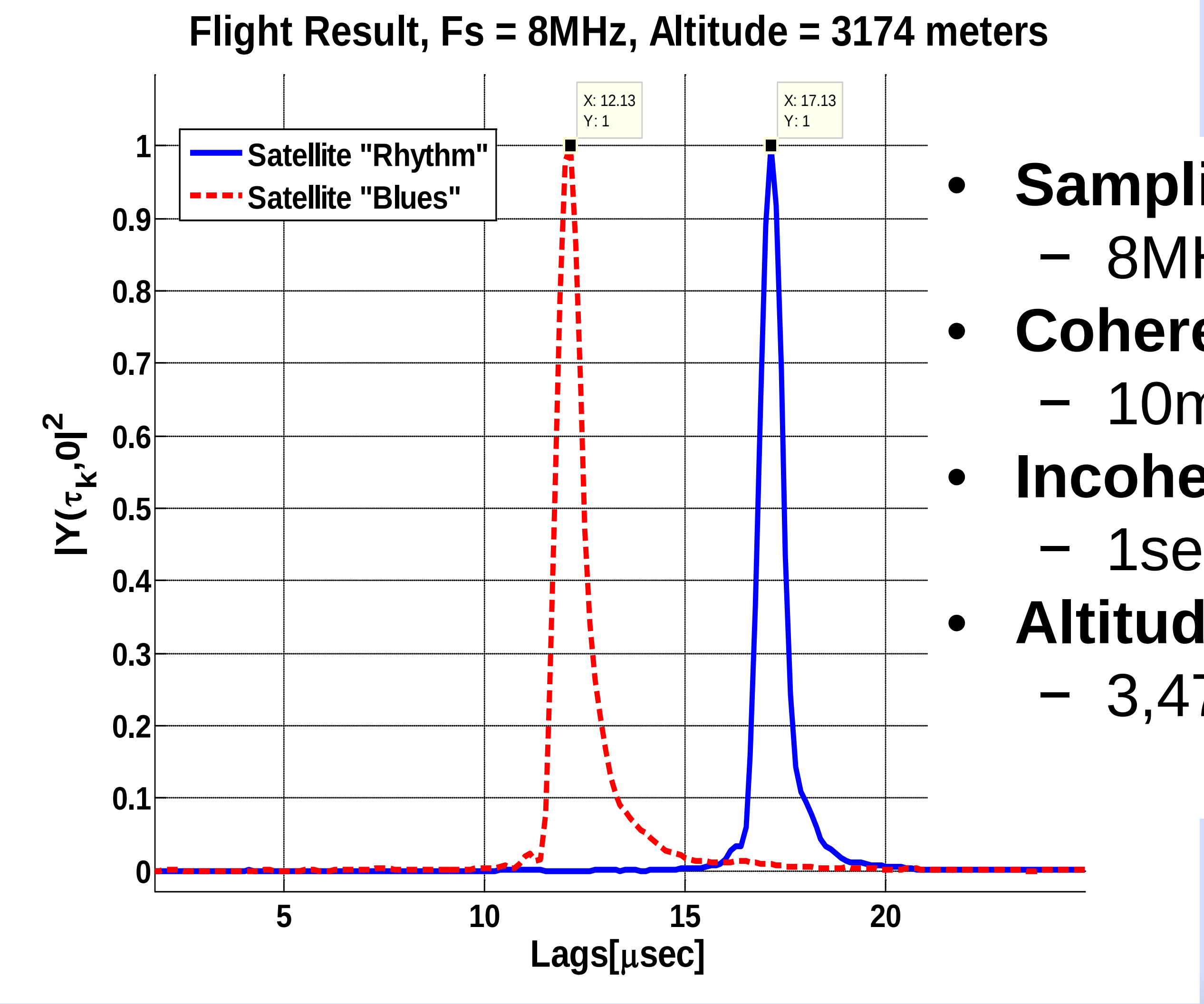
  GPS vs. XM

- Plan for high-speed retrieval from XM instrument

2010 Experiment



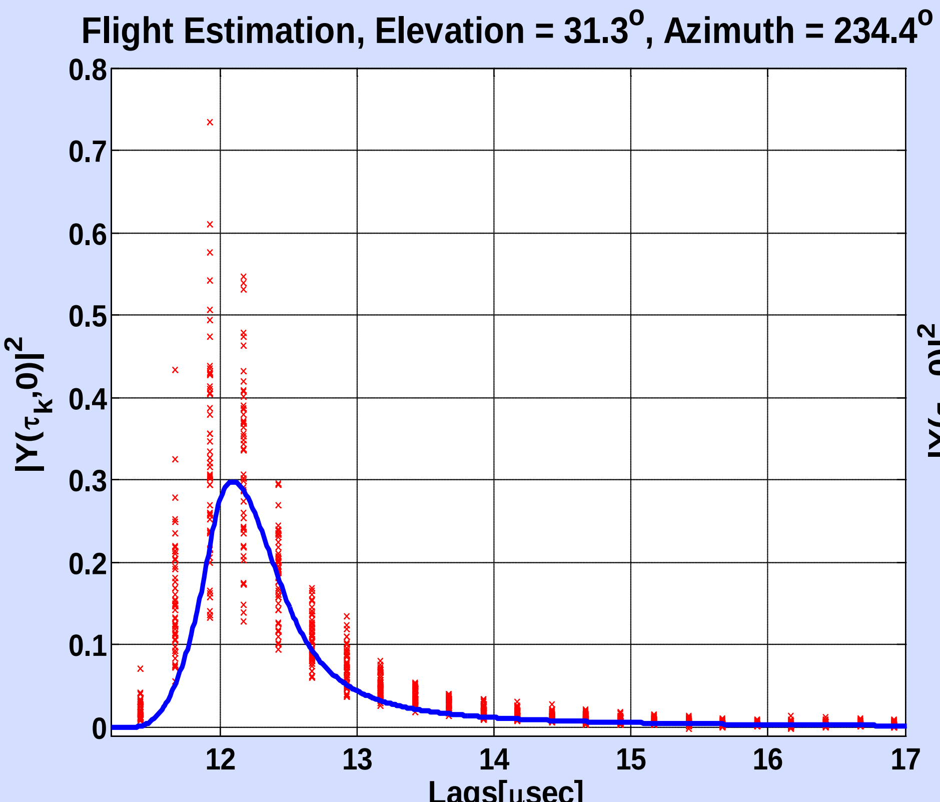
Waveforms (2010)

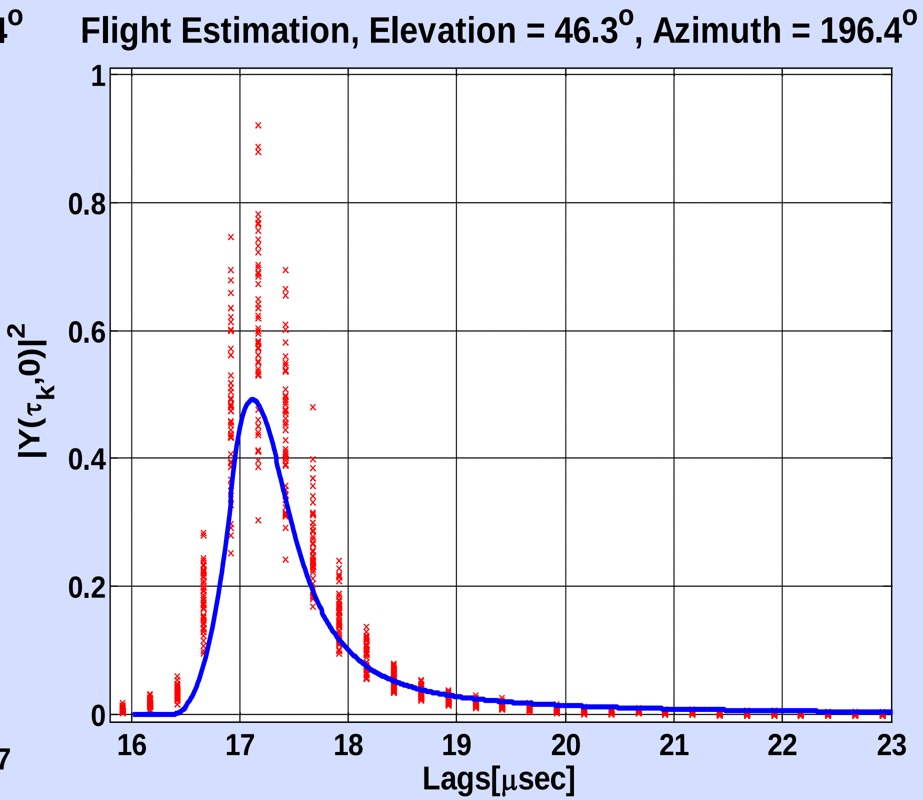


- **Sampling Frequency**
  - 8MHz
- **Coherent Integration**
  - 10ms
- **Incoherent Integration**
  - 1sec
- **Altitude**
  - 3,471 meters

Wind Retrieval (2010)

- Chesapeake Light (CHLV2): **7.5 m/s** (MSS = 0.0010)





Blues: **6 m/s**

(MSS = 0.0076)

Rhythm: **7.2 m/s**

(MSS=0.0098)

2012 Experiment

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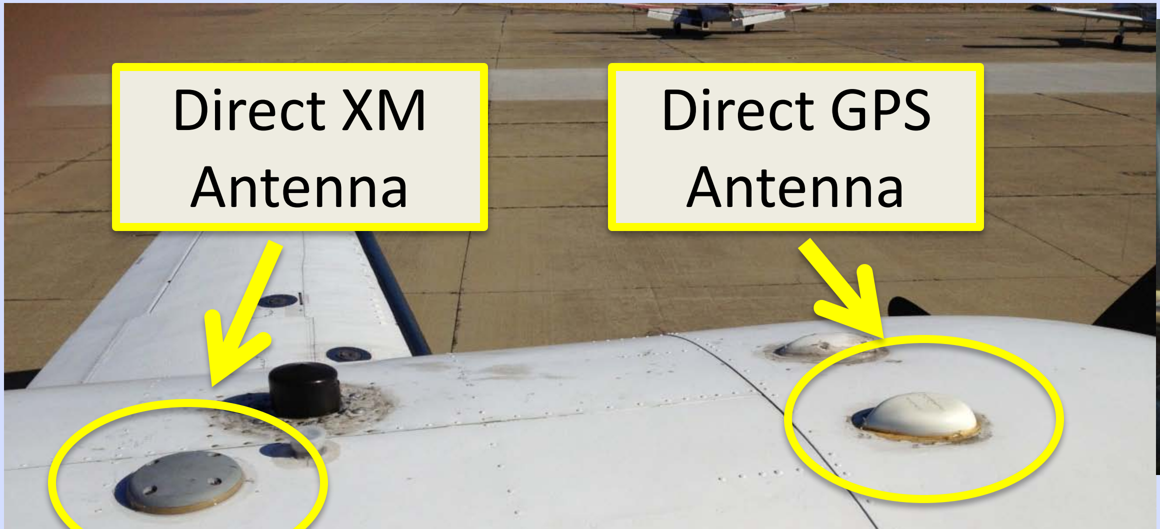


Direct XM Antenna

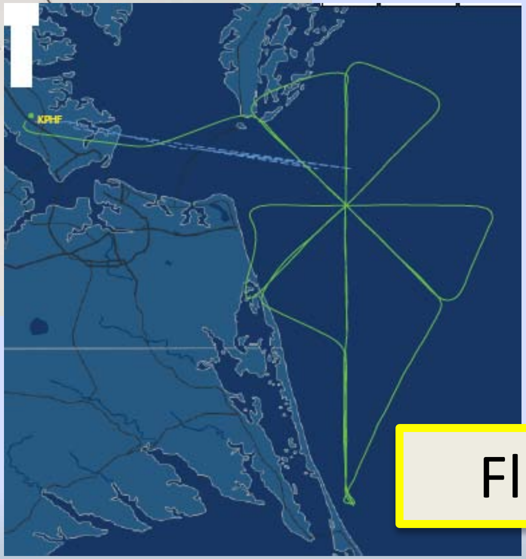
Direct GPS Antenna

GPS DMR

XM Recorder

Reflected GPS Antenna

Reflected XM Antenna



Flight Path

Waveforms (2012)

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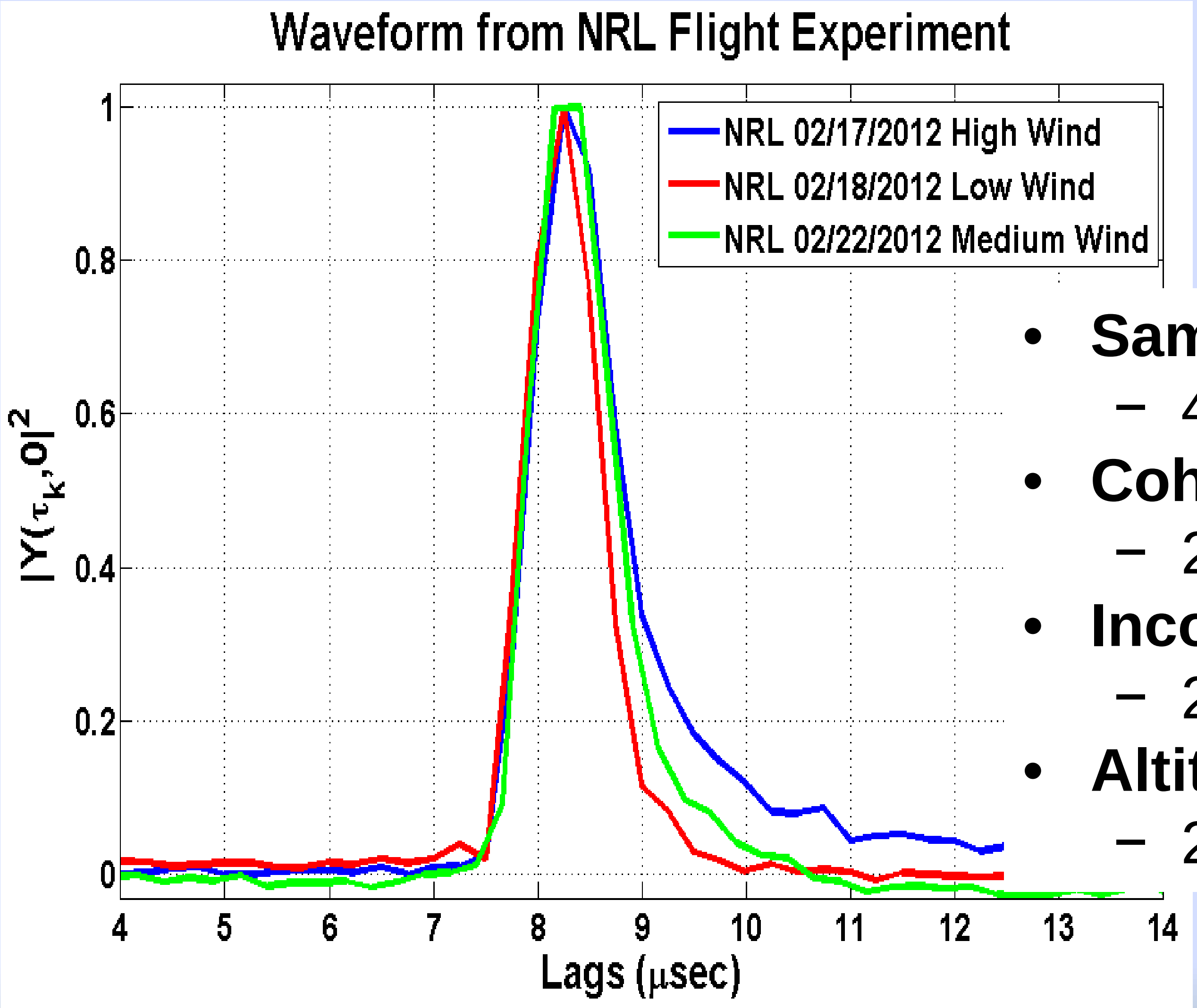
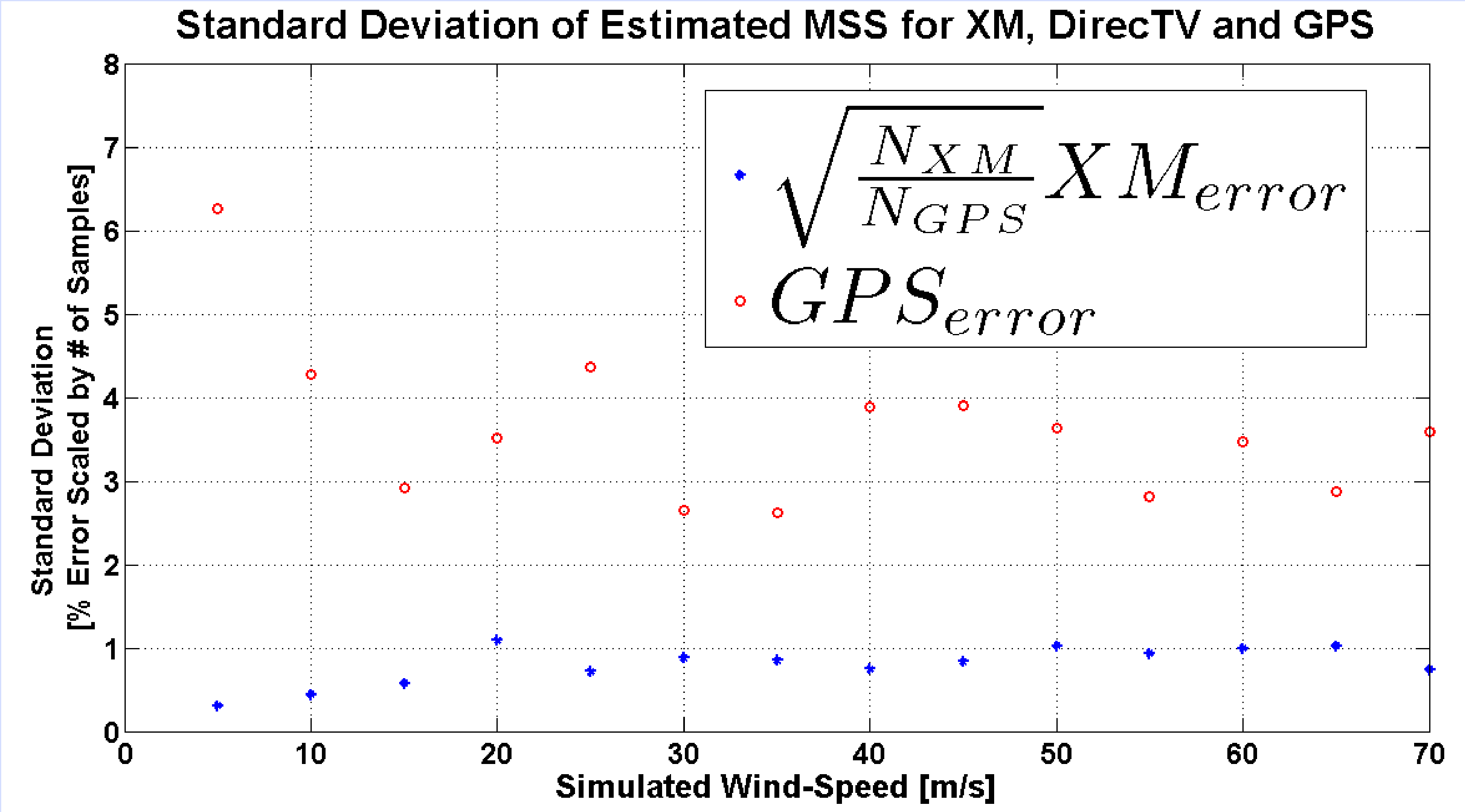


- **Sampling Frequency**
  - 4MHz
- **Coherent Integration**
  - 20ms
- **Incoherent Integration**
  - 2sec
- **Altitude**
  - 2,439 meters

Simulated Retrievals



Flight Certified XM Instrument

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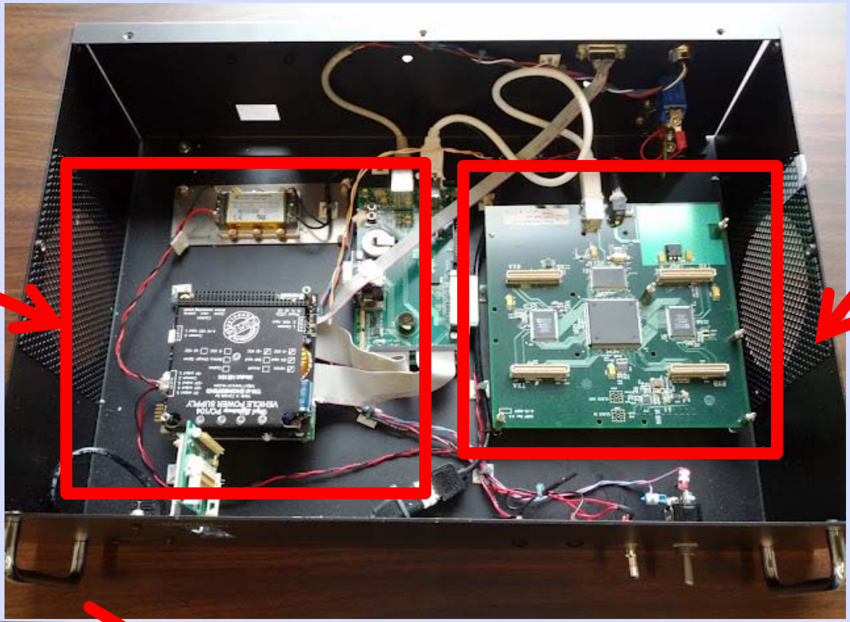
ANTENNA

AMPLIFIER

PC-104

USRP



19”

3U

FRONT VIEW

BACK VIEW

Summary and Future Work

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Summary

- GPS reflectometry heritage
- Recent demonstration with XM signal
    - +30 dB SNR increase
    - S-band vs. L-band
- Small, low power, autonomous instrumentation

Future Work (Proposed)

- Fly XM receiver during 2012 Hurricane Season

Acknowledgements

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- The authors would also like to thank Derek Burrage and Joel Wesson of the Naval Research Laboratory (NRL) for inviting our participation in the 2012 experiment.
- Nicole Quindara's participation in the 2012 experiment was partially supported by NRL.
- Flights and aircraft installation were performed by Rick Aviation, Newport News, VA.

Thank you for your attention!

Questions ?

References

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Backup Slides

XM: Ambiguity Function

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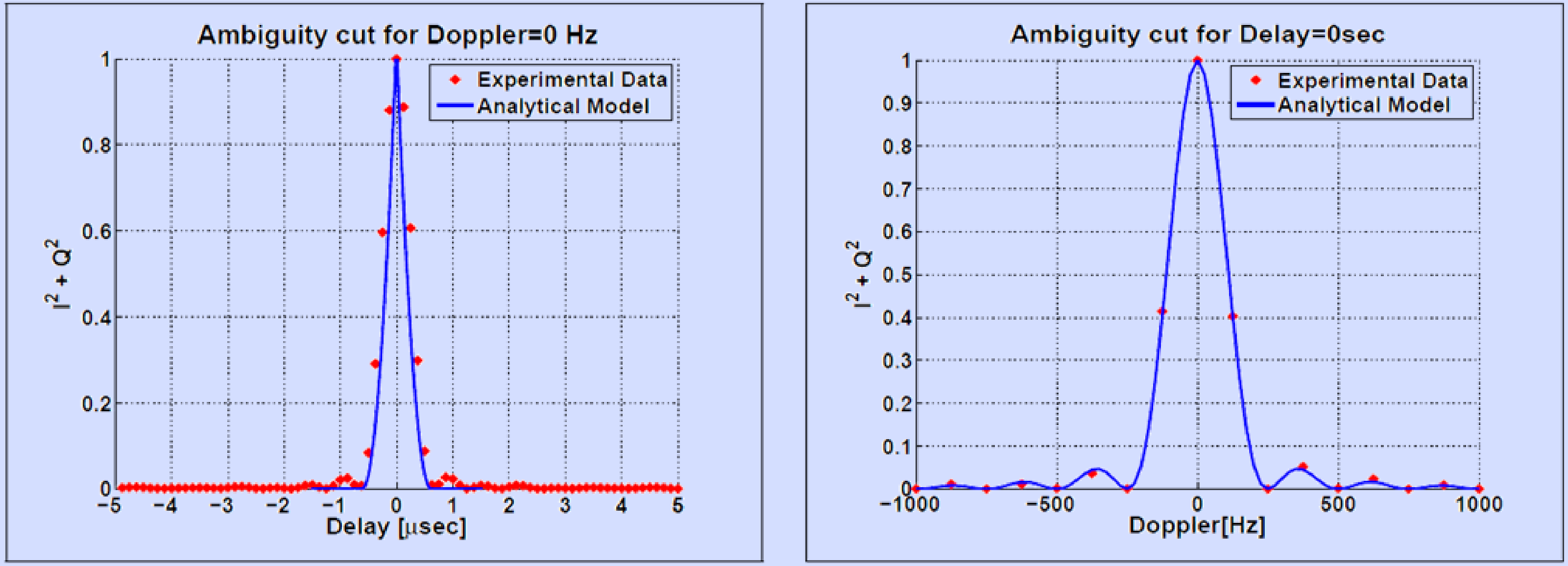
$$|\chi(\tau, f_c)|^2 = \left| \frac{1}{T_I} \int_0^{T_I} s(t) s^*(t-\tau) e^{(-j2\pi f_c t)} dt \right|^2$$



Delay Dimension $|\chi(\tau, 0)|^2$ **Doppler Dimension** $|\chi(0, f_c)|^2$

Assumption of long, random, uncorrelated data bit stream validated

Previous Work

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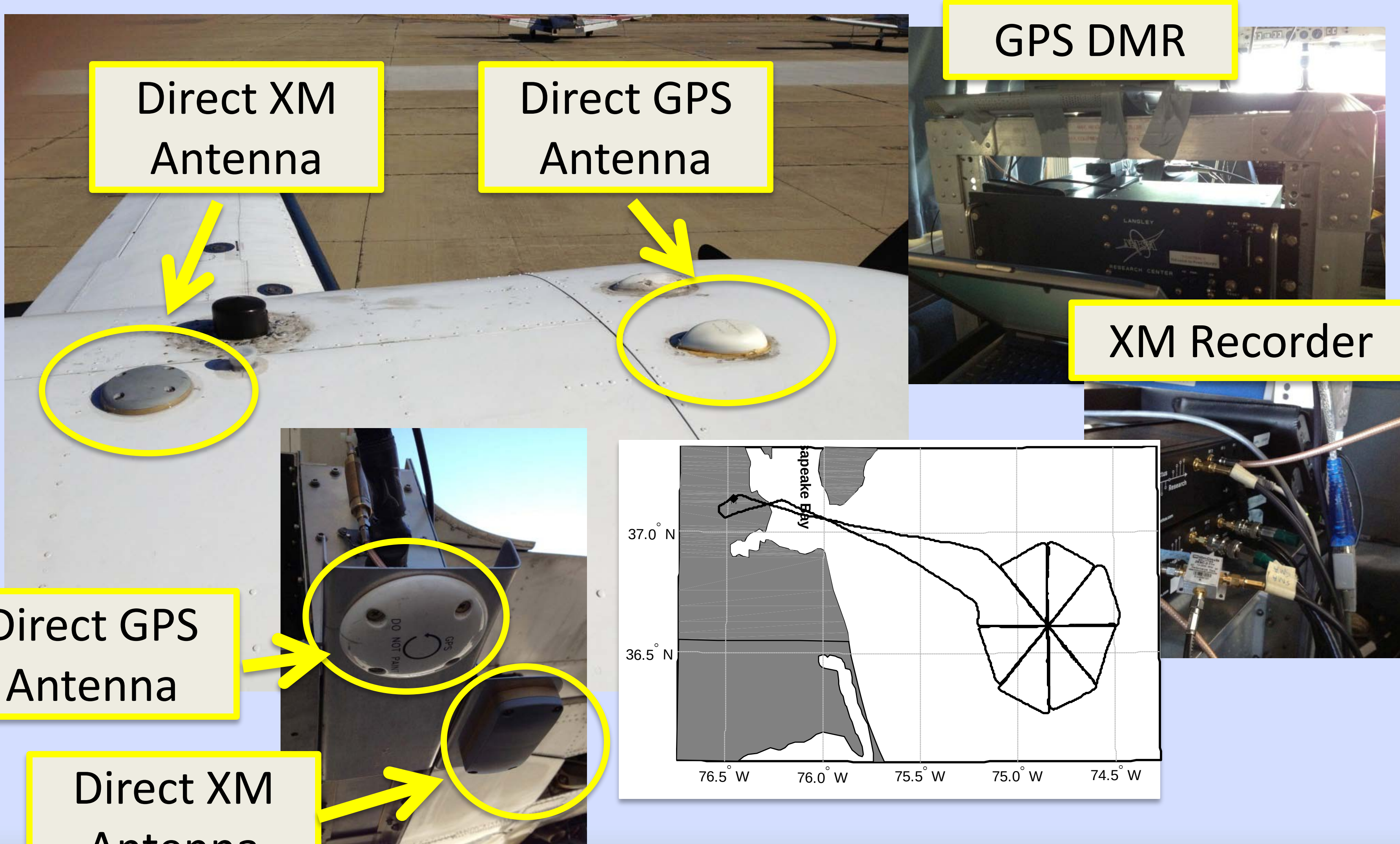
- **Global Navigation Satellite System Reflectometry (GNSS-R)**
  - First demonstration of remote sensing with “signals of opportunity”
  - Retrieval of ocean surface roughness, wind speed and direction
  - 12 Years of development: airborne (NOAA Hurricane Flights)
  - GNSS-R enabled by use of known pseudo-random noise (PRN) code
- **Digital Communication Signals Reflectometry**
  - Expand methods to other “signals of opportunity”
  - Demonstrated with XM digital radio
    - Commercial satellite radio system in the US

2012 Experiment



XM System

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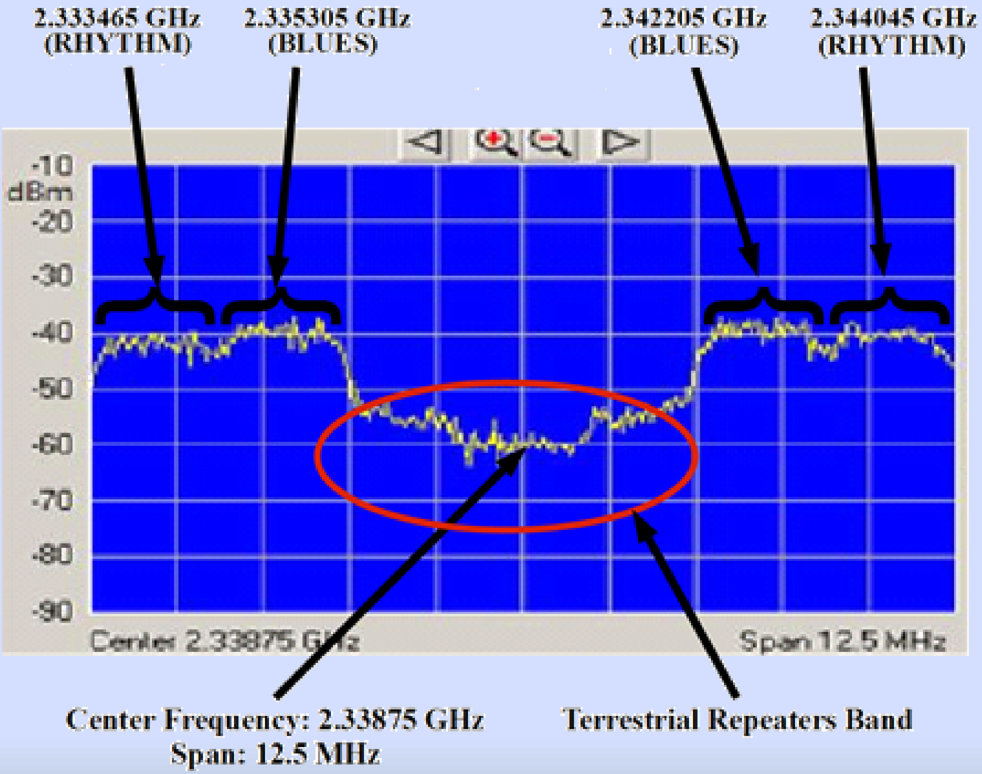
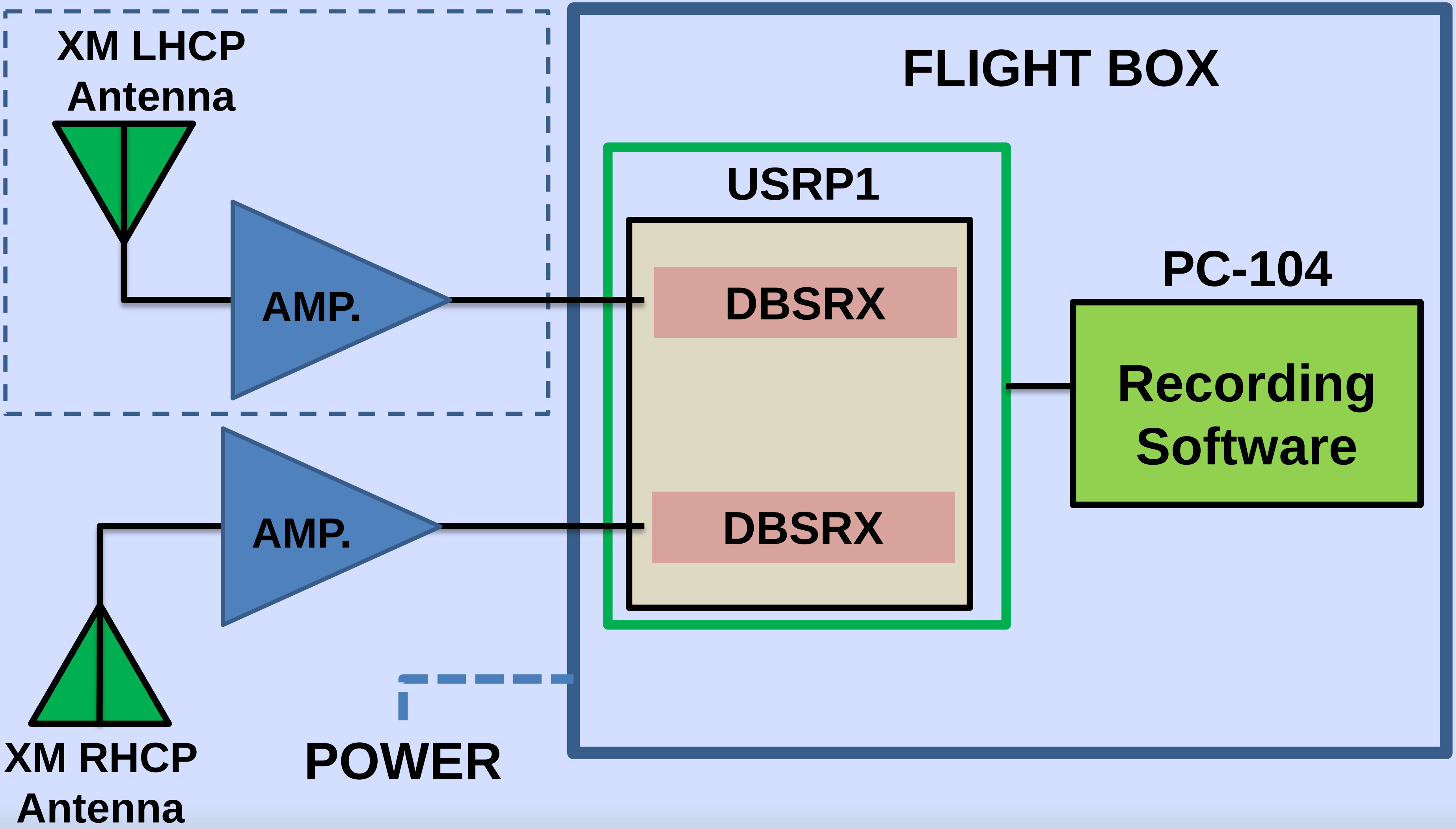
- **Two active** geostationary satellites:
  - Rhythm (85^{o}W), Blues (115^{o}W)
- **QPSK** Modulated, **LHCP** Signal

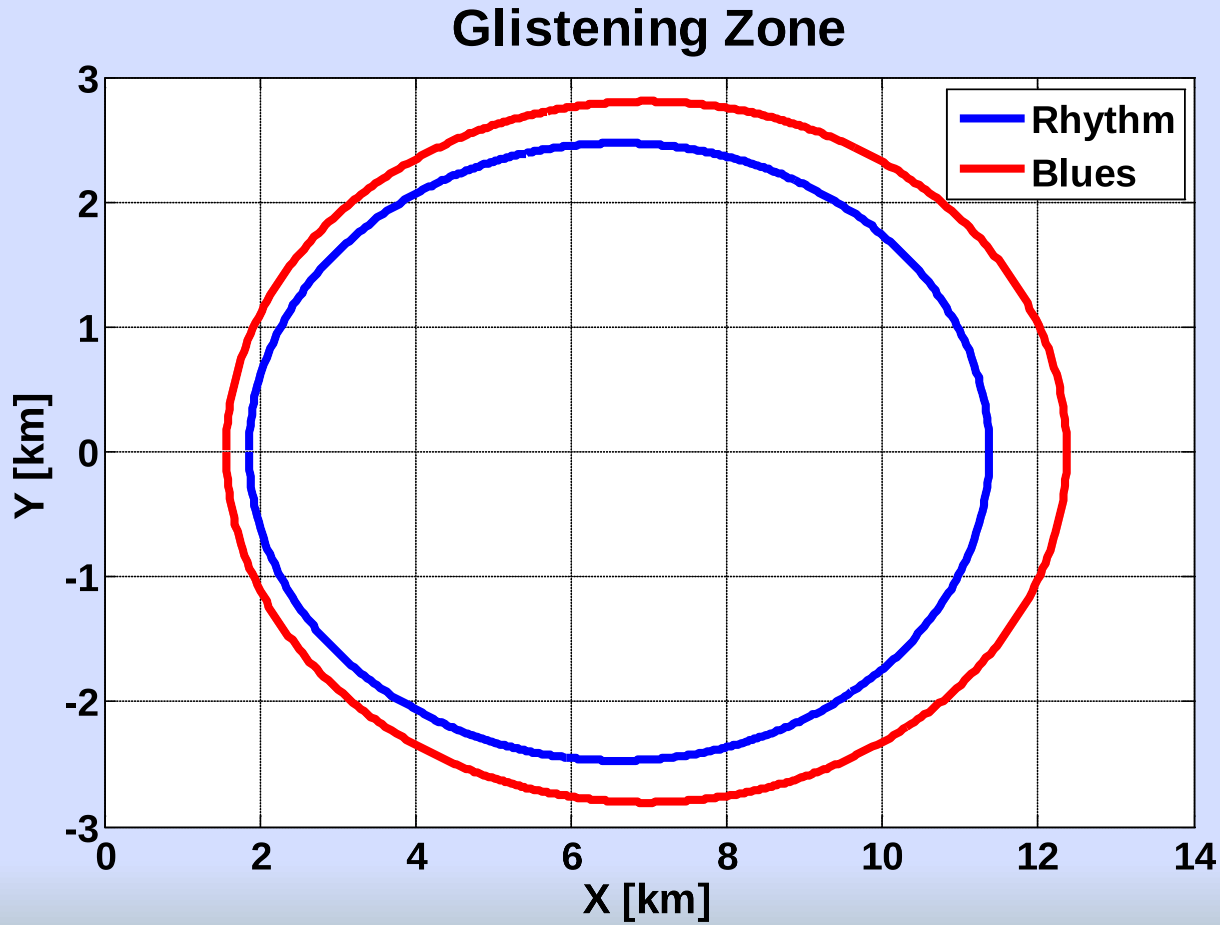


Instrument for NOAA Flights



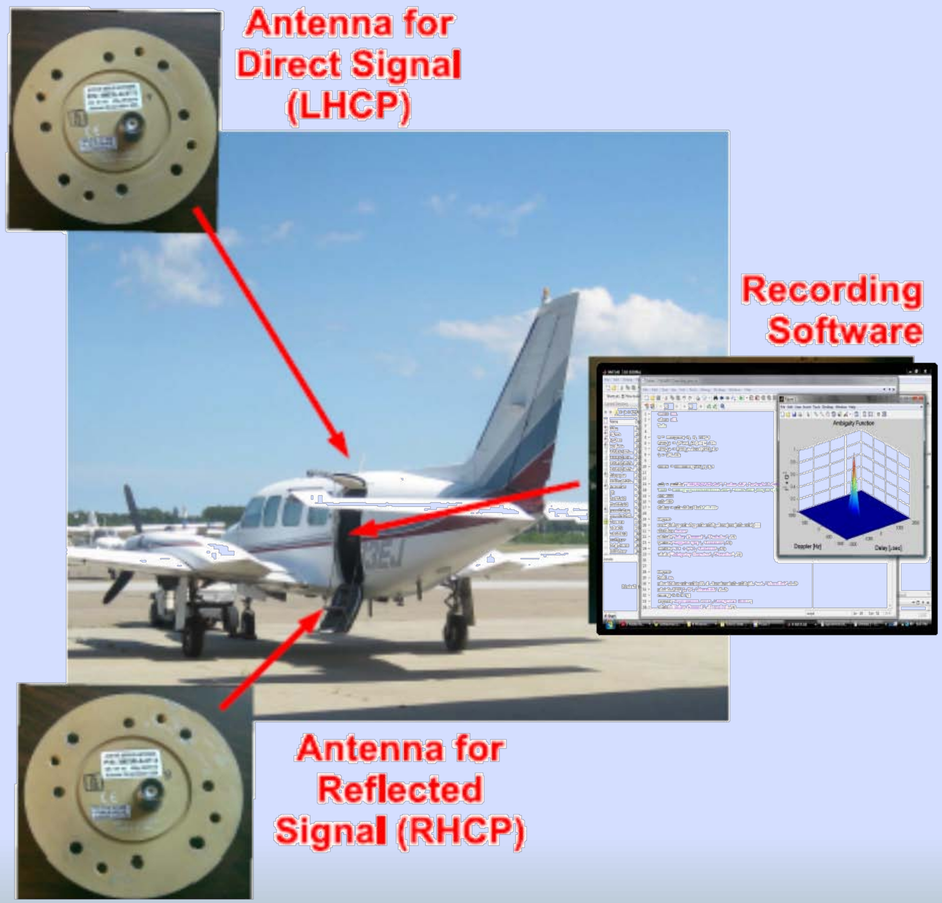
Glistening Zone

- **Blues:** Semi-major = 4.76km, Semi-minor = 2.47km
- **Rhythm:** Semi-major = 5.40km, Semi-minor = 2.80km



Airborne Experiment: Geometry

- Experiment conducted: 02-July-2010 in Piper Navajo
- Experiment time period: 07:51AM EDT - 09:19AM EDT



Data Processing

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- Estimation process for Wind Speed
  - Isotropic normal PDF assumed
  - Nonlinear least squares estimation

$$J_{SV}(\boldsymbol{X_{SV}}) = \sum_k \left(|Y_{SV}(\tau_k, 0)|^2 - \left| Y_M\left(\tau_{k,}, 0; \boldsymbol{X_{SV}}\right) \right|^2 \right)^2$$

$$\boldsymbol{X_{SV}} = \left\{ {\sigma^2}_{ISO_{SV}}, S_{SV}, \tau_{0_{SV}} \right\}$$

${\sigma^2}_{ISO_{SV}}$= Mean Square Slope (MSS)

S_{SV} = Scale factor (remove variation in signal power)

$\tau_{0_{SV}}$ = Delay offset (adjust small uncertainties in delay)

  - Independent estimate for each satellite

Simulation of Waveform

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- Assume no bin-bin correlation
- Assume inphase and quadrature phase component to be independent normally distributed random variables
- Assume isotropic Gaussian distribution for PDF
  - ($\sigma_{ISO} = \sigma_u = \sigma_c$)
- Voltage signal:

$$Y_s\left(\tau,0;P_{\vec{v}}\right)=\sqrt{\frac{\left|Y\left(\tau,0;P_{\vec{v}}\right)\right|^2}{2}}Z_s+\sqrt{\frac{N_0}{2T_I}}Z_n$$

- Synthetic Waveform

$$\left\langle\left|Y\left(\tau,0;P_{\vec{v}}\right)\right|^2\right\rangle=\frac{1}{M}\sum_{i=1}^{M}Y_{s_i}(\tau,0;P_{\vec{v}})Y_{s_i}^*(\tau,0;P_{\vec{v}})$$

Link Budget

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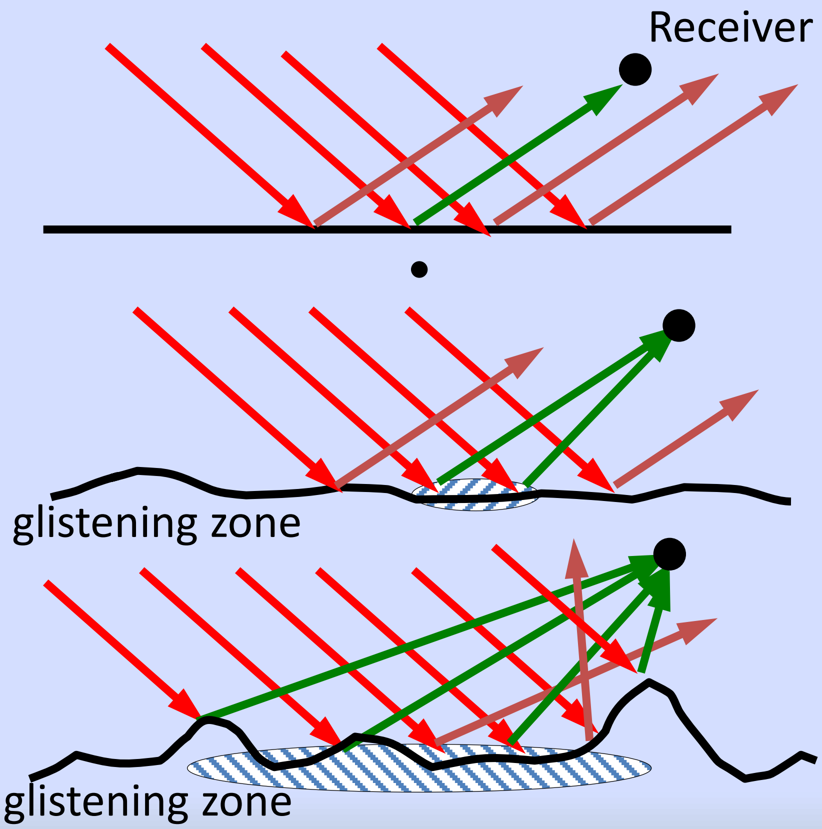
	XM (2)	GPS (1)	Unit
EIRP	**68.5**	**26.3**	**dBW**
Range	35888.0	22020.0	km
Path Loss	-162.1	-157.8	dB
Atmospheric loss	0.5	0.5	dB
Received Power Density	-94.1	-132.1	dBW/m^2
Effective Area	-28.8	-25.4	dBm^2
Received Isotropic Power	-122.9	-157.5	dBW
Antenna Gain	2.0	2.0	dBic
Received Signal Power	**-120.9**	**-155.5**	**dBW**
Noise Floor	-204.0	-204.0	dBW/Hz
C/N0	**83.1**	**48.5**	**dB-Hz**
Noise Figure	4.0	1.0	dB
Pre-Correlation, C/N0	**79.1**	**47.5**	**dB-Hz**
Bandwidth	62.7	63.1	dB-Hz
Pre-Correlation, S/N	**16.4**	**-15.6**	**dB**
Processing Gain	32.1	30.1	dB
Post Correlation, S/N	**48.5**	**14.5**	**dB**

Ocean Roughness/Wind Speed

Fundamental Physics:

Rougher surface =

larger distribution in path delays

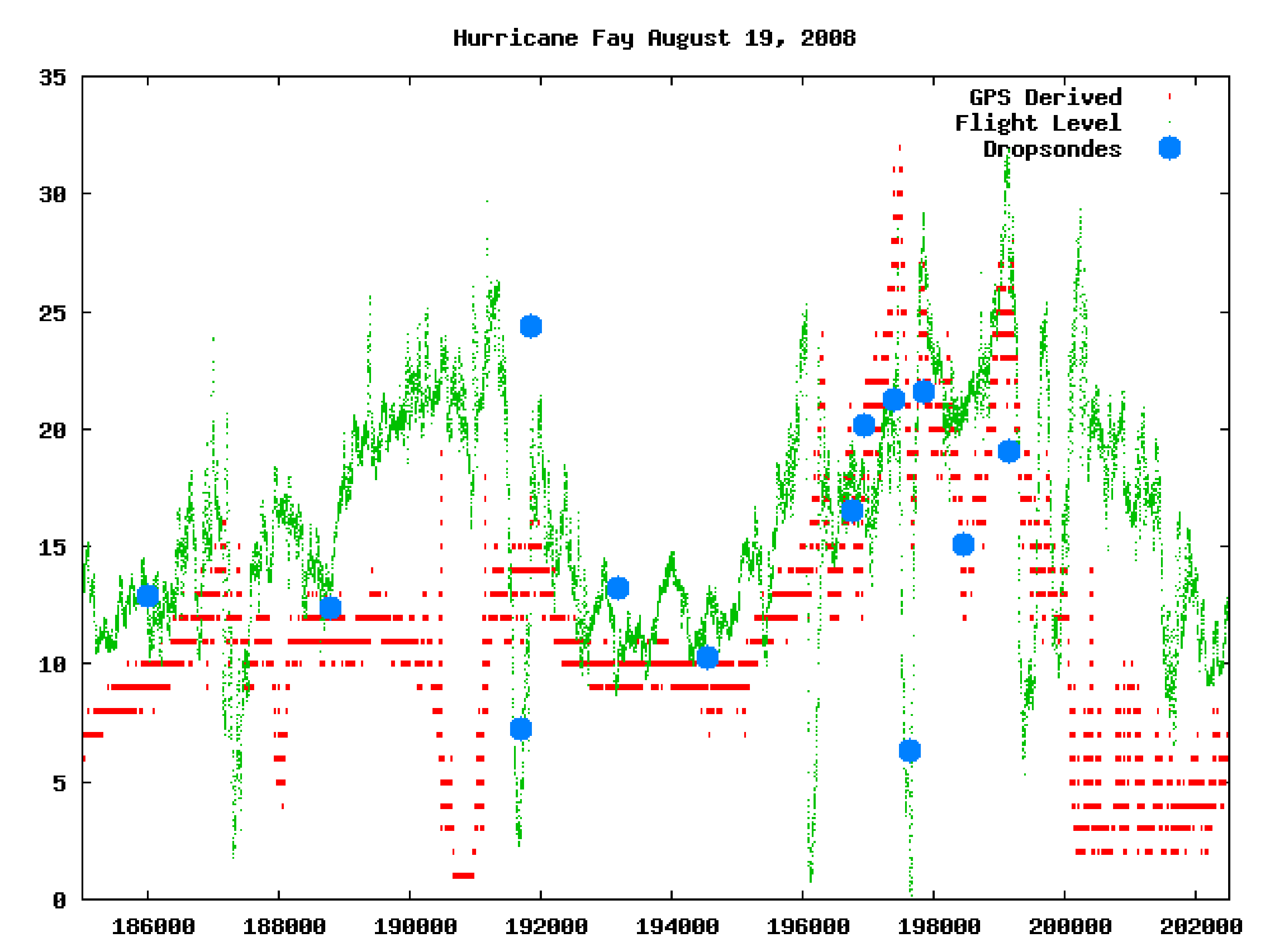


This phenomenon can easily be observed at sunset:

(water is calm inside the red ellipse)

(From Chapron and Ruffini, GNSS-R workshop, Barcelona. Photo taken at Le Conquet, Brittany)

GNSS-R Experience



GNSS-R Experience

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