The Los Alamos Dual Band Lightning Array: A new tool for mapping VLF and VHF lightning in the Gulf of Mexico

Can we probe D-region disturbances using lightning?

Christopher A. Jeffery

(cjeffery@lanl.gov)

Technical Staff Member

Space and Remote Sensing Sciences (ISR-2),

Los Alamos National Laboratory

LA-UR-08-3119

Los Alamos NATIONAL LABORATORY

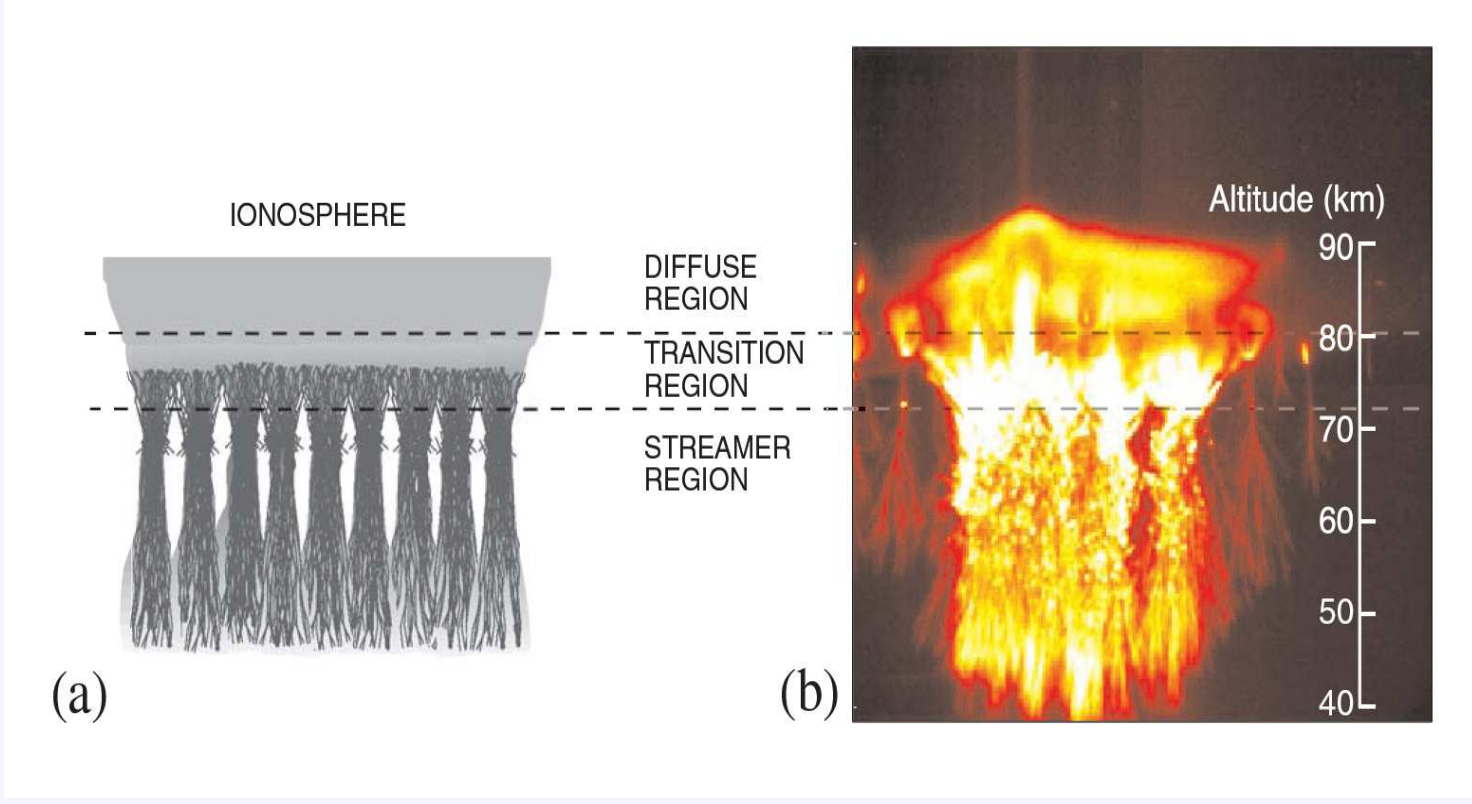
Overview

Goal of today's presentation is to present a new dual VLF-VHF lightning mapping capability in the Gulf of Mexico.

- Motivation: Impact sprites on VLF propagation: VLF sprites.
- What can dual VLF-VHF lightning mapping tell us about ionospheric disturbances above thunderstorms?
- LANL new hurricane lightning project.
- The goal of our project is too improve hurricane intensity forecasts: RF lightning observations, cloud electrification modeling and data assimilation.
- **The Los Alamos Dual Band Lightning Array.**
- Summary: Table questions for tomorrow's discussion.

Motivation

Thunderstorms affect the ionosphere!



Model and photograph of a red sprite [from Pasko, 2002].

Red sprites last milliseconds but what about the D-region perturbation?

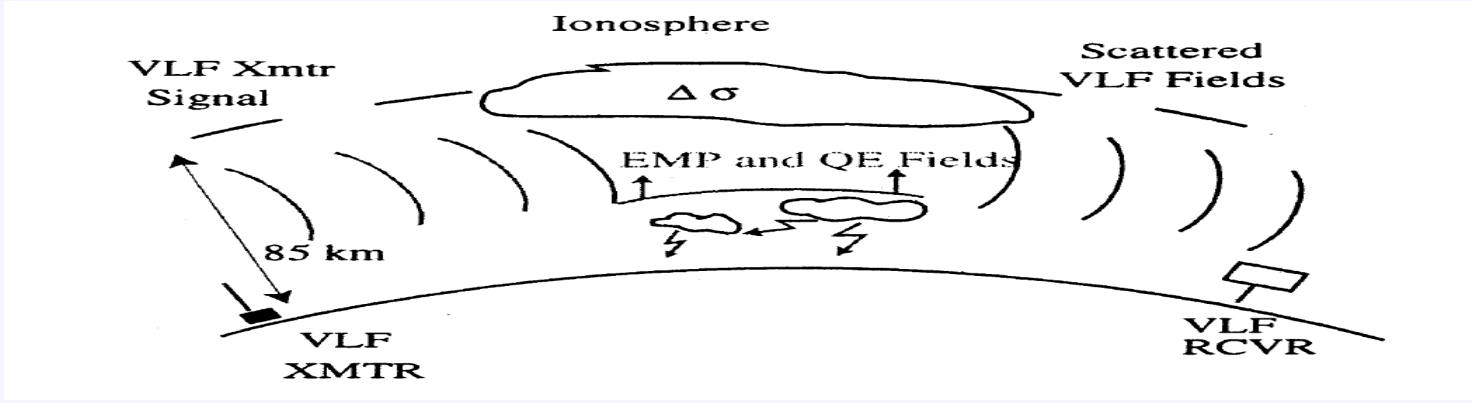
Ionospheric Modification

- Indeed, the ionospheric perturbations associated with sprites and other lightning processes lasts several minutes.
- We can study these ionospheric disturbances using VLF transmissions.

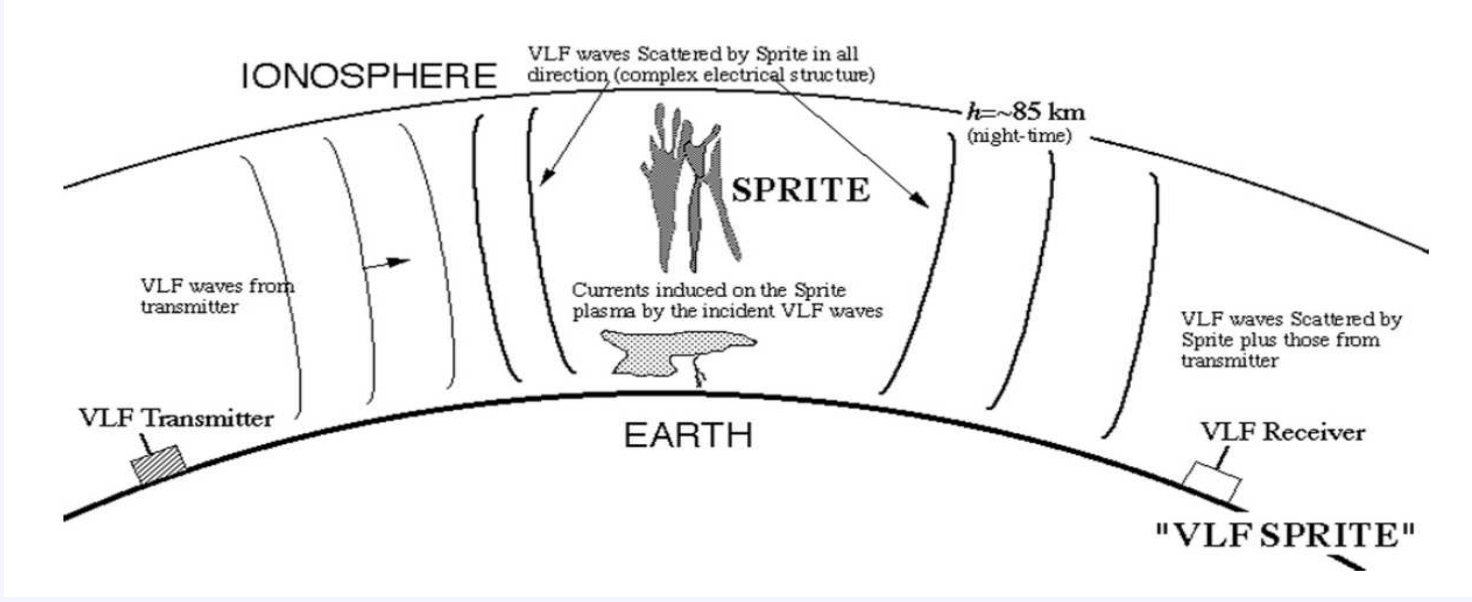
VLF Sprites: VLF perturbations due to relatively small, dense, ionospheric perturbations caused by red sprite discharges.

Early Trimpi: VLF perturbations due to ionospheric modification caused by the decay or build up of thunderstorm charges after a lightning discharge.

VLF Sprites vs Early Trimpi



Early Trimpi [from Rodger, 2003]



VLF Sprite [from Rodger, 2003]

VLF Sprites & D-Region Modification

Modeling and observational studies of (VLF) sprites indicate:

- Sprites caused by both EMP and QE thunderstorm fields from “spider lightning”.
- Ionospheric disturbance is structured enough to cause **significant VLF back-scatter**.
- This suggests that luminous structure is present in the electrical structure.
- Remarkably, fine-scale luminous structure has been observed on scales less than 30 meters.
- Modeling studies suggest that observed back-scatter is consistent with ionization variability of 10^5 per cc on 10 meters scales.

What can we learn about D-region disturbances above thunderstorms from LANL’s VHF lightning mapping capability?

Los Alamos NATIONAL LABORATORY

For Tomorrow's Discussion

LANL Lightning Geolocation Capability:

- Space-based VHF lighting geolocation capability.
- Ground-based VLF lighting geolocation capability.
- New ground-based VHF lightning geolocation capability.

How can we leverage this capability for Stefan's program?

Thesis: Use lightning events, occurring in the first several minutes after "spider-lightning" creates a severe D-region disturbance, to probe the disturbance.

- Direct line-of-sight measurement and geolocation of VHF source.
- On-orbit measurement of VHF source modification and scattering.
- Thunderstorm charge layer mapping (VHF) and VLF analysis (NBE).

LANL's Hurricane Lighting LDRD Project: New dual VLF-VHF capability in the Gulf

Los Alamos NATIONAL LABORATORY

< > - +

Science & Technology Framework

Two Broad Science & Technology Grand Challenges:

- Perform real-time 3D mapping of **convective events in the hurricane eyewall** using lightning as a proxy, and enabled by the **new LANL dual VLF-VHF lightning mapping array** deployed in the Gulf of Mexico.
- Demonstrate that rapid **hurricane intensification**, the sudden *large-scale* transition and reorganization of a vastly multiscale system, can be **accurately forecast** using a novel model that **assimilates real-time knowledge** of critical *small-scale* processes.

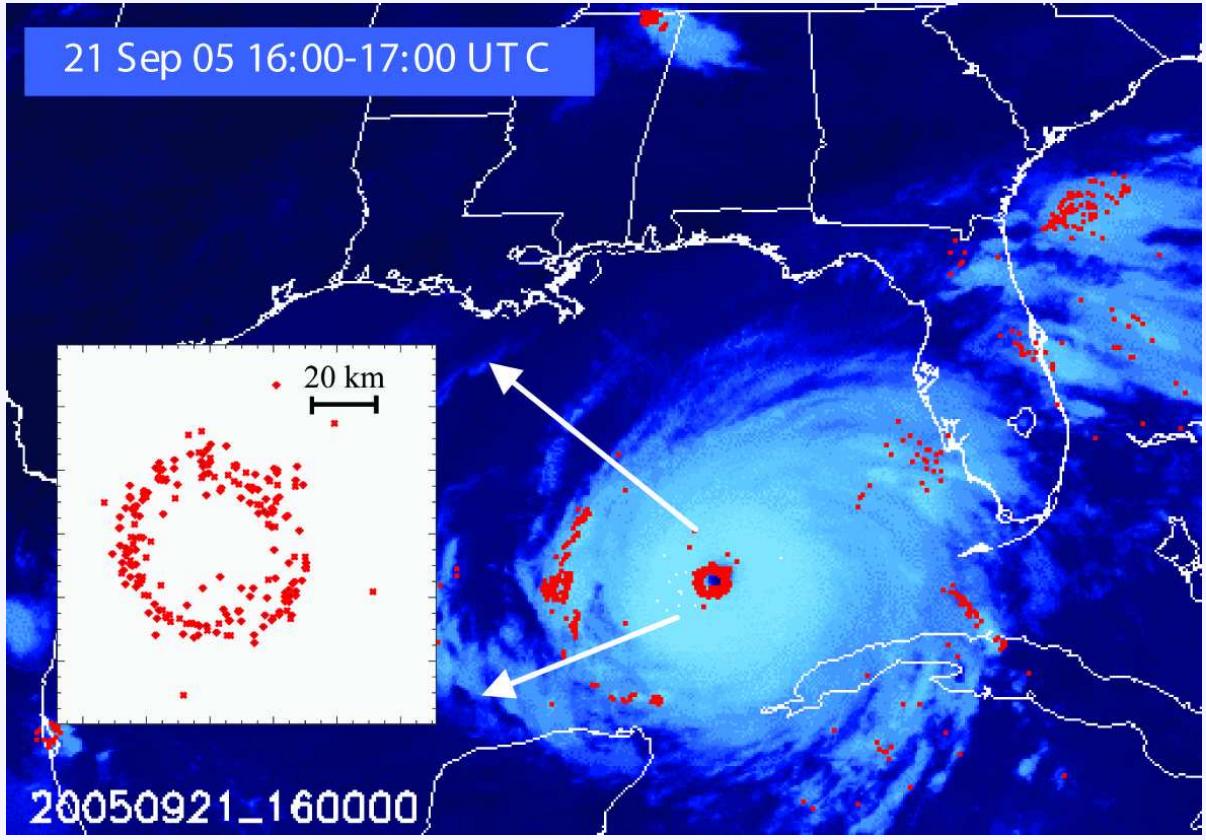
Metric of Success

Our metric of success is a national standard established by NOAA's Hurricane Intensity Research Working Group:

> . . . achieve a *10 knot improvement in 48-hour intensity forecasts* of hurricane-strength storms in *5 years* by the application of
> 1. *advanced numerical models*,
> 2. *novel methods of data assimilation*, and
> 3. *improved observations*
>
> through a focused applied research and development program.

Improved Observations

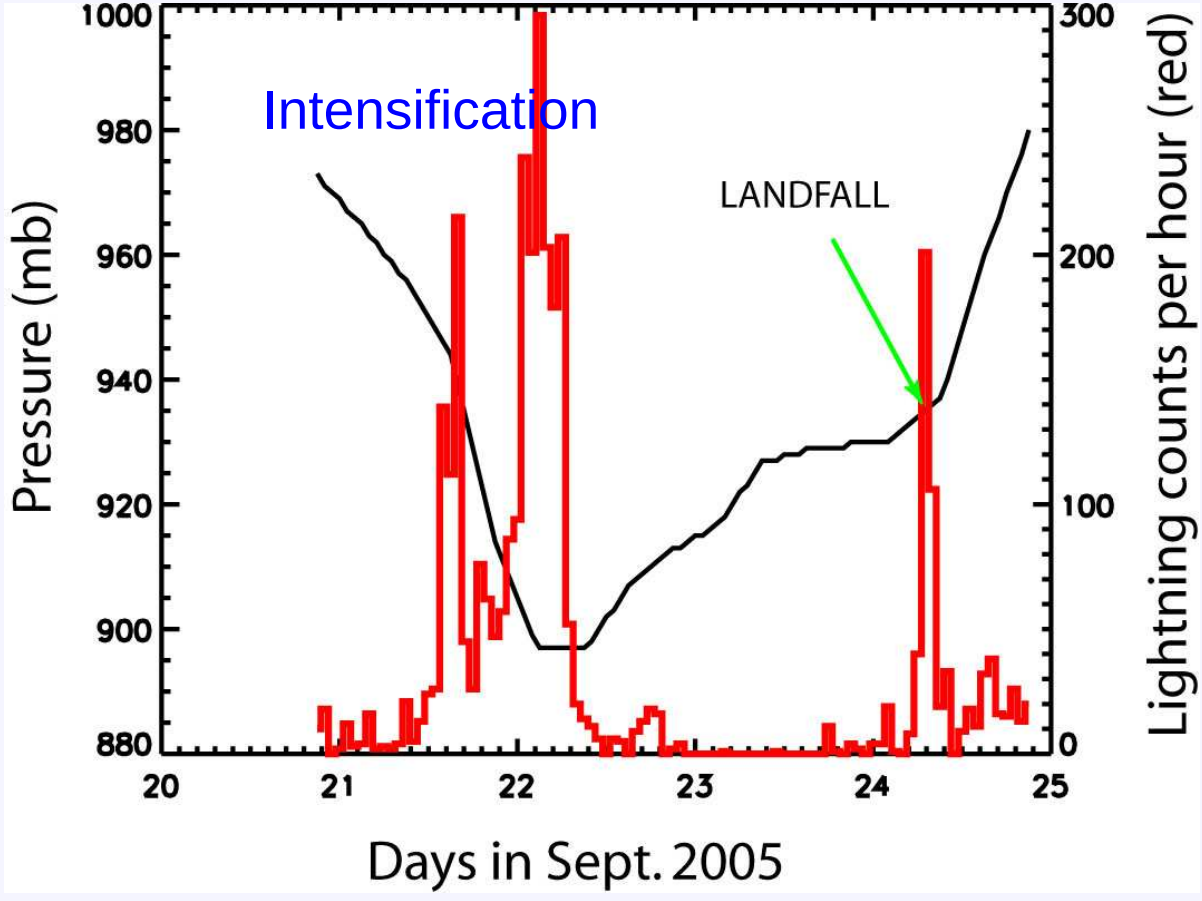
Lightning activity from Hurricane Rita.



- Motivates need for new 3D “total lightning mapping” array.
- What is the charge structure of hot towers in the eyewall?
- How is lightning activity influenced by intensification?

Los Alamos NATIONAL LABORATORY

Improved Observations (II)



- Hurricane Rita's intensification is coincident with onset of lightning activity.
- Eye pressure is calculated a-posteriori from a reanalysis.

Los Alamos NATIONAL LABORATORY

< > - +

Context for a New Lightning Array in Gulf

Two paradigms for lightning detection and geolocation:

VLF Detection: Record RF radiation in 10-20 KHz band.

- Long-range (2000+ km) detection, and 2000+ km array baselines.
- NLDN (used by NWS) only detects cloud-to-ground (CG).
- LANL technology records sferic (EMP pulse); detects both intra-cloud and CG lightning.
- NLDN data has no vertical resolution; LANL system may provide some height info via ionospheric modeling.

VHF Detection: Record RF radiation in 1-70 MHz band.

- Very accurate (100 m) height retrieval.
- Signal is attenuated over land.
- Line-of-sight detection; short 50 km baselines.
- Technology pioneered by NM Tech, for periodic campaigns.

A New Dual VLF-VHF Lightning Observing System

We are developing a new

dual VLF-VHF lightning observing system

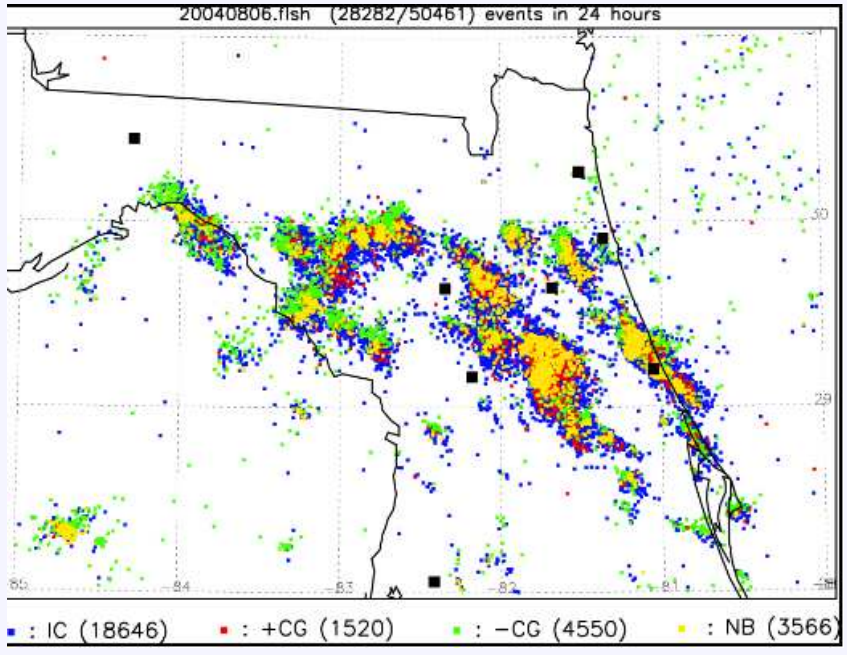
in the Gulf of Mexico, that exploits:

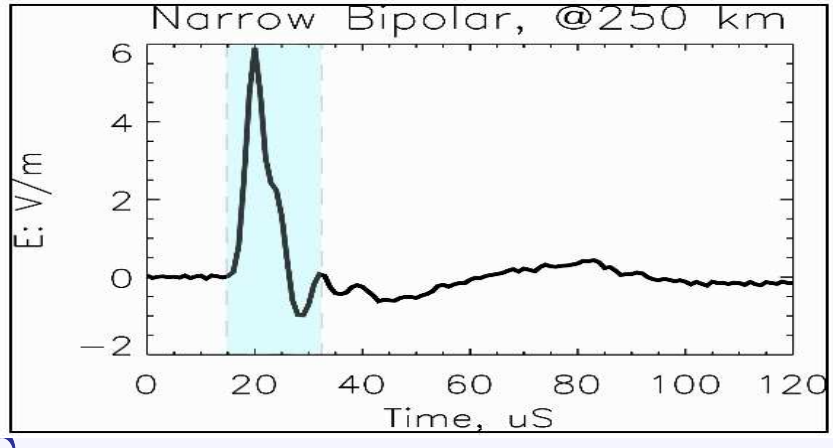
- Low VHF attenuation over sea water.
- Longer 150 km baselines for long-range (500 km) VHF detection.
- LANL capability to detect both CG and IC lighting.

Los Alamos NATIONAL LABORATORY

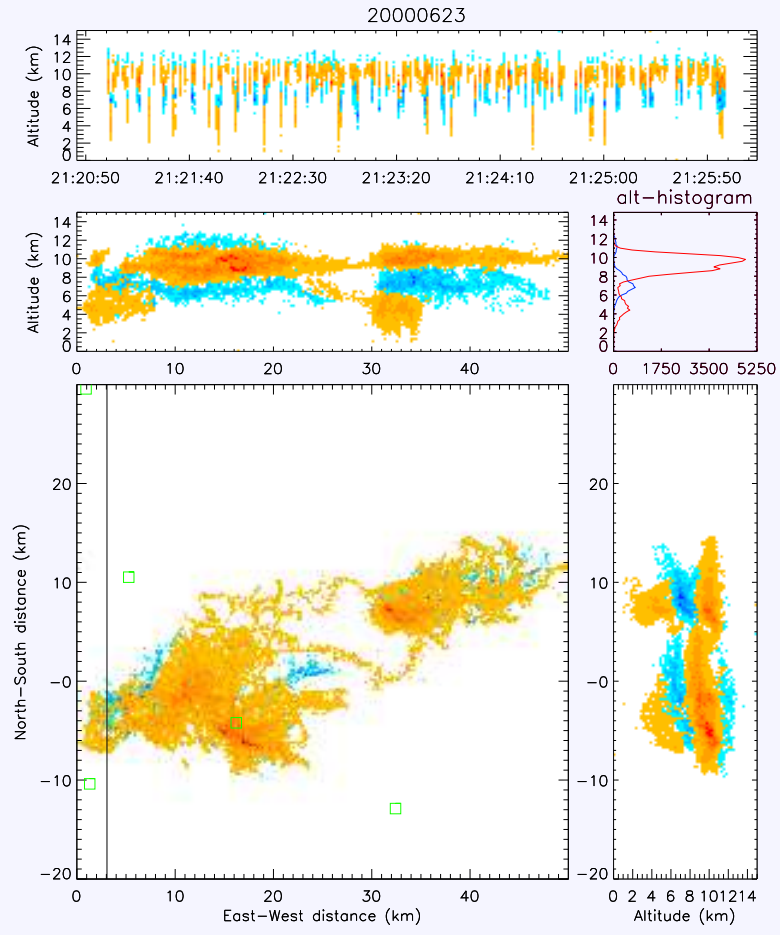
A New Dual VHF-VLF Lightning Observing System (II)

LASA VLF





VHF (from NM Tech LMA system)

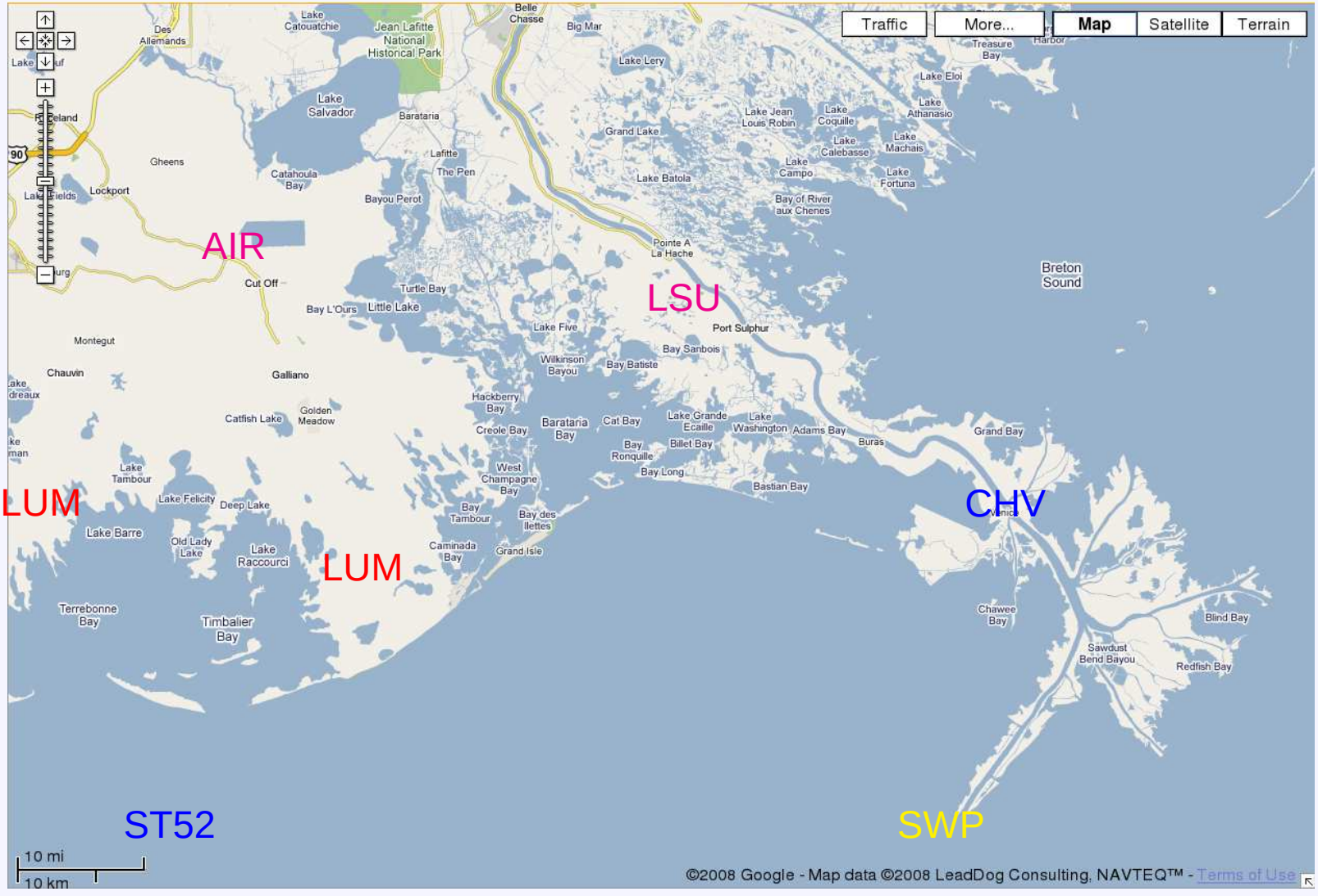


Charge transfer can be calculated from new dual VHF–VLF.

Los Alamos NATIONAL LABORATORY

Our New Gulf RF Lightning Array

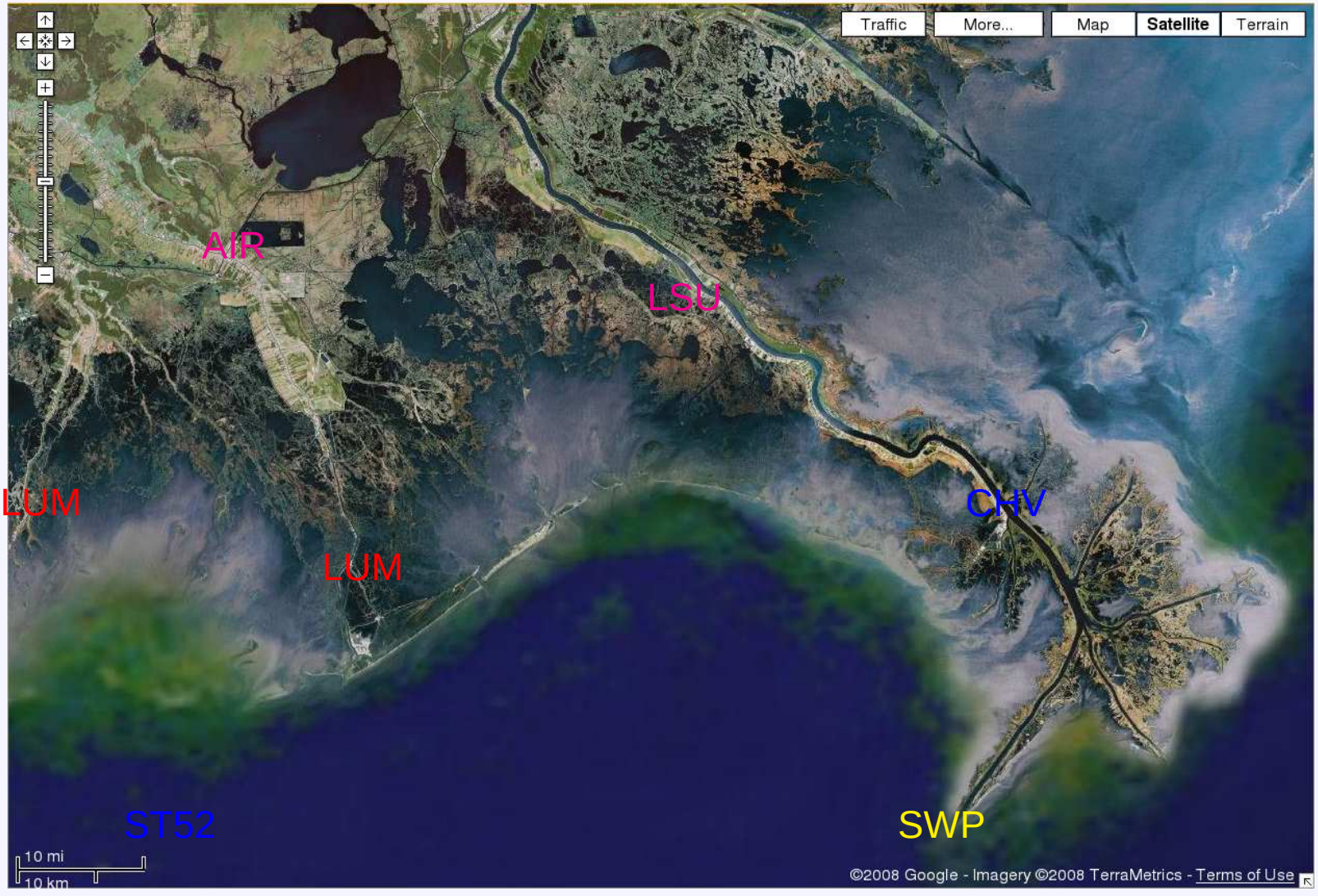
Sensor Array–New Orleans Area



Los Alamos NATIONAL LABORATORY

< > - +

Sensor Array–New Orleans Area



Los Alamos NATIONAL LABORATORY

< > - +

Why Hurricanes? Why Gulf of Mexico?

We are all aware of the enormous human tragedy inflicted by hurricanes Katrina and Rita.

But, these hurricanes also exposed the vulnerability of our energy security to hurricane disaster.

- Gulf of Mexico provides **29% of domestic oil supply** and **19% of domestic gas production**.
- Katrina, alone, destroyed **46 platforms** and **four jack-up rigs**.
- She inflicted severe damage on 37,000-ton, billion-dollar Shell Mars platform—**most prolific in Gulf** producing 148,000 barrels/day and designed for 140-mph winds/70 ft waves.
- Given current energy crisis, a hurricane in the Gulf this summer would have **dire consequences** for US economy and energy security.

Our University–Chevron–LANL Partnership

LUMCON: Louisiana Universities Marine Consortium.

(1) Headquarters,

(2) Fourchon.

Nicholls University:

Roof of the library.

River Pilot Association:

Base at tip of Mississippi.

Chevron:

(1) Venice on-shore base,

(2) Oil platform ST-52.

LSU:

Agricultural area.

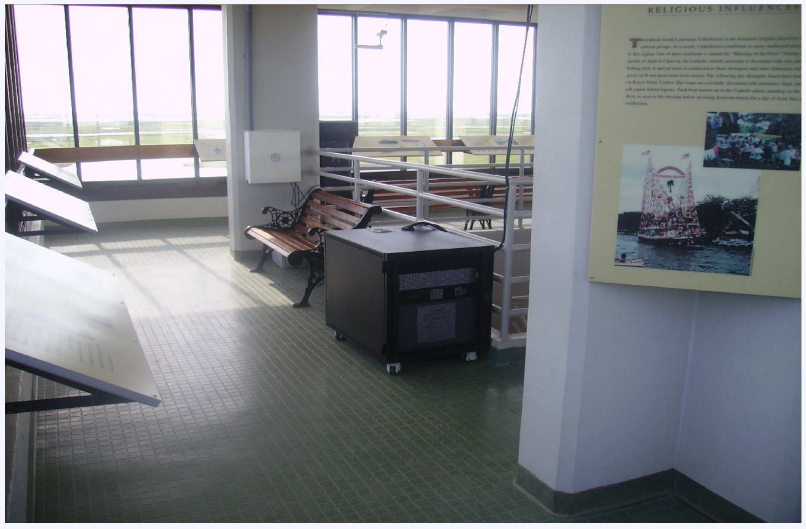
Fourchon Port Authorities:

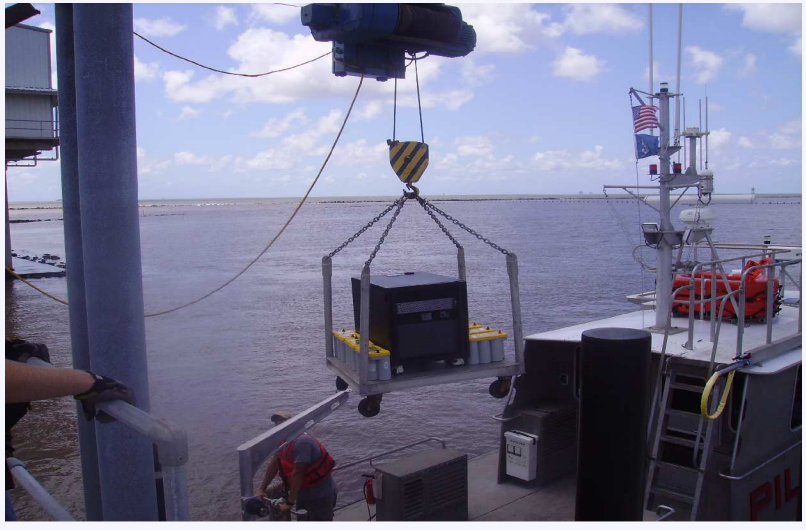
Airport.

Challenges of Building a Real-Time VHF Array in New Orleans

1. New sensor technology; requires new design and testing.
2. Rely on generosity of host.
3. Background VHF noise. Challenging in Mississippi delta with development along narrow bayous.
4. Internet access. Lightning sensors have high data rates (256–512 kbps). DSL service is often not available. SWP and oil platform are challenging. Satellite internet is “download” oriented & unreliable in severe weather.
5. Legal hurdles. LANL will not indemnify universities or corporations.

Challenge #1: New Sensor





Sensor unit consists of computer server, pull-out monitor, GPS unit, log amplifier, filters and UPS.

Challenge #1: New Sensor

Antenna is a 1m Rohde & Schwarz monopole with 10 khz–80 Mhz bandwidth.

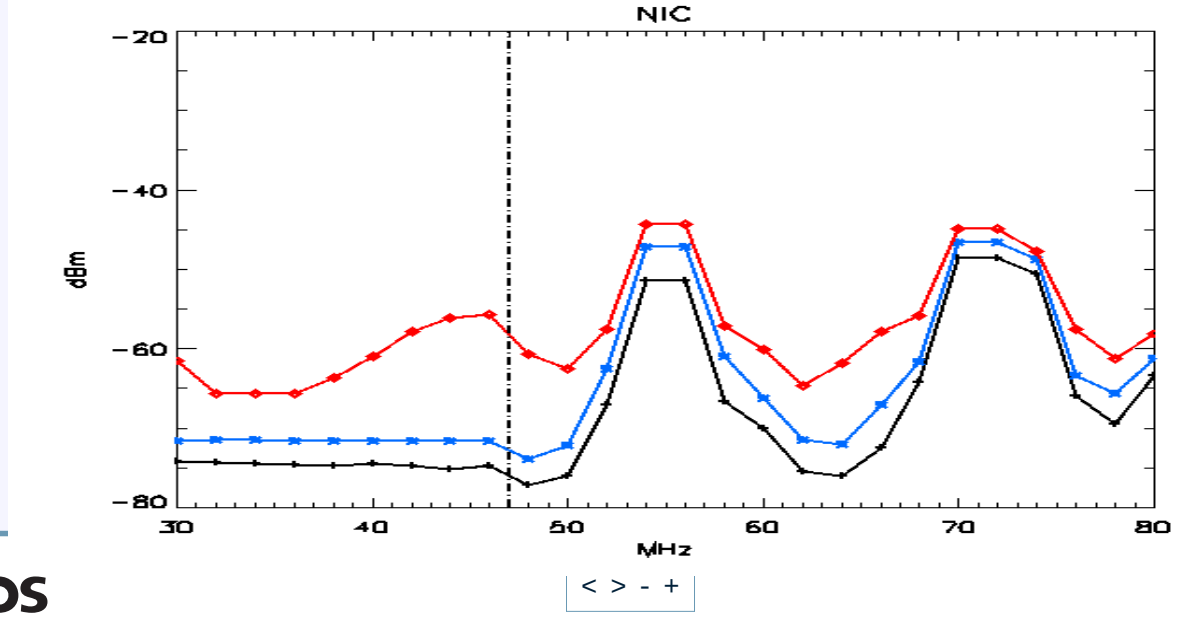
Los Alamos NATIONAL LABORATORY

< > - +

Challenge #2: Background Noise, Nicholls

Nicholls University

VHF Spectrum showing Channel 2 & 4

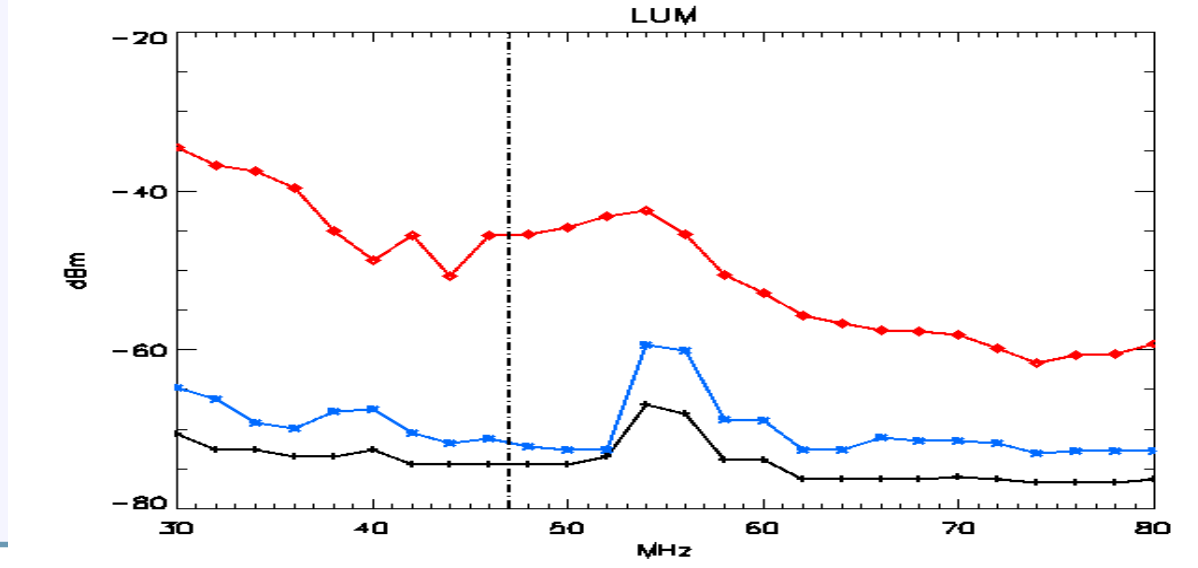


Los Alamos NATIONAL LABORATORY

Background Noise, LUMCON Headquarters

View from LUMCON

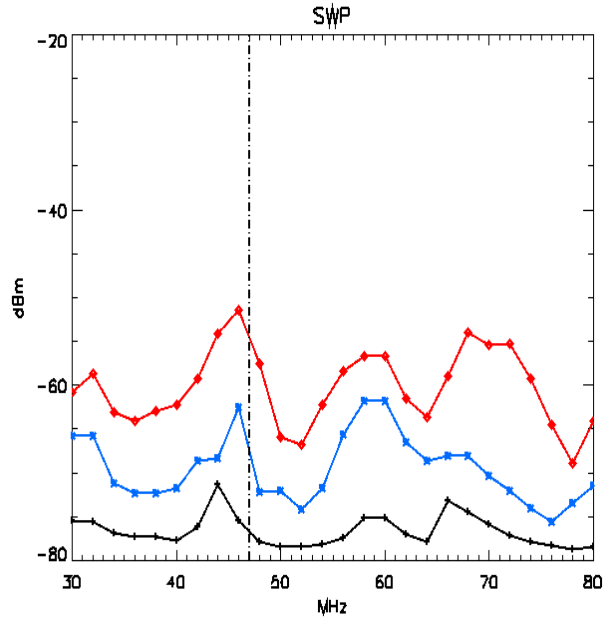
VHF Spectrum: Channel 2 & Equipment Noise



Los Alamos NATIONAL LABORATORY

Background Noise, River Pilots at Southwest Pass

Channel 3 is Clear

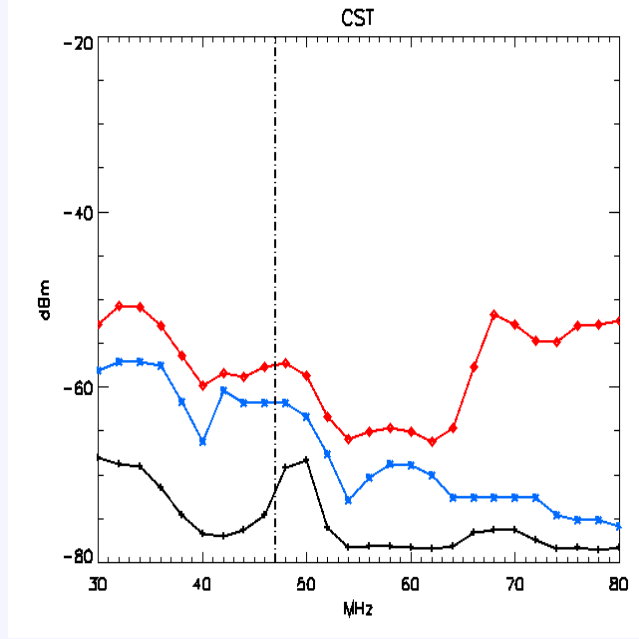


Los Alamos NATIONAL LABORATORY

< > - +

Background Noise, Oil Platform ST-52

Channel 3 is Clear



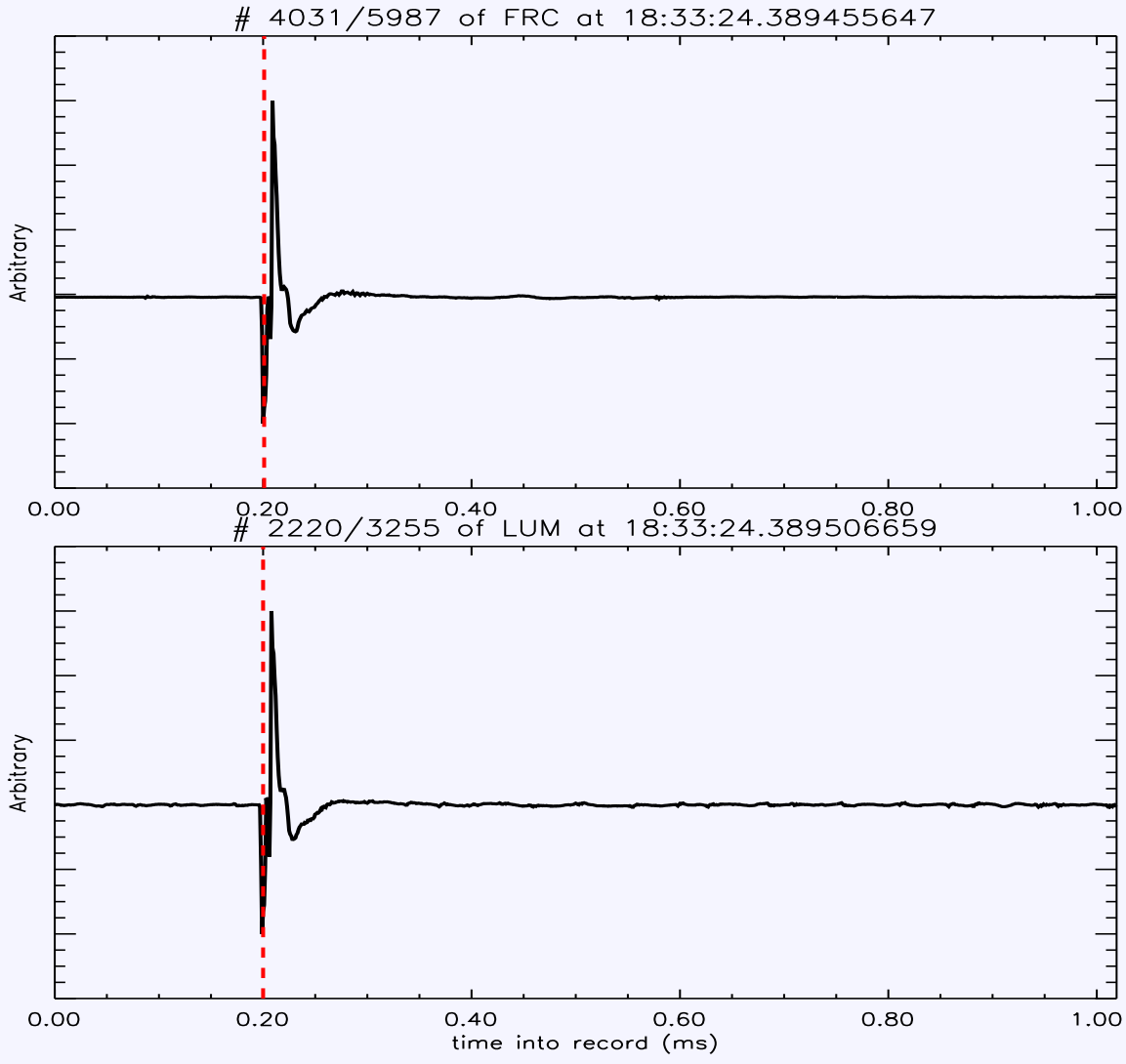
Los Alamos
NATIONAL LABORATORY

< > - +

Challenge #3: Internet Access

- Internet access is a primary challenge for our array due to high sensor data rates (256–512 kbps).
- Satellite internet appears promising, but (i) download oriented, (ii) fair-access policy throttles data, (iii) unreliable in severe weather.
- Stratos SGI operates an expensive microwave network in Gulf.

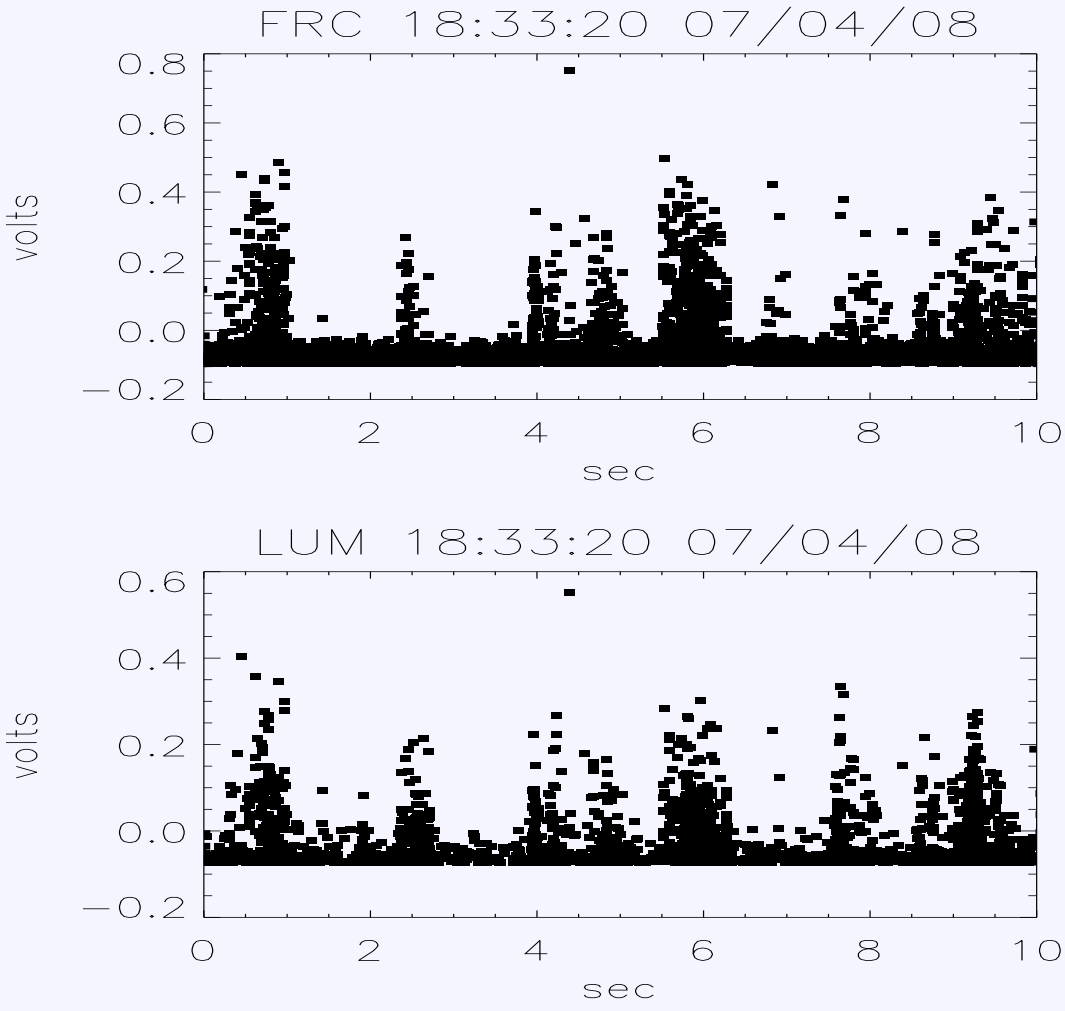
Preliminary VLF Array Data



Los Alamos NATIONAL LABORATORY

< > - +

Preliminary VHF Array Data



Accuracy from laboratory VHF pulse tests:

$\Delta x = (100\ ns) \times (3 \times 10^8\ m/s) = 33\ m$; Accuracy in field depends on # sensors, background noise etc.

Los Alamos NATIONAL LABORATORY

< > - +

Keeping up with the Jones'. . .

Los Alamos
NATIONAL LABORATORY

< > - +

For Tomorrow's Discussion

LANL Lightning Geolocation Capability:

- Space-based VHF lighting geolocation capability.
- Ground-based VLF lighting geolocation capability.
- New ground-based VHF lightning geolocation capability.

How can we leverage this capability for Stefan's program?

Thesis: Use lightning events, occurring in the first several minutes after "spider-lightning" creates a severe D-region disturbance, to probe the disturbance.

- Direct line-of-sight measurement and geolocation of VHF source.
- On-orbit measurement of VHF source modification and scattering.
- Thunderstorm charge layer mapping (VHF) and VLF analysis (NBE).