CGSIC 49th Meeting Savannah Georgia

Reference Station Networks: Beyond Surveying."

SHM

Structural Health Monitoring

Managing the nations' bridge infrastructure

Advance technology for safety, productivity, and low costs

James Stowell

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CANARY SYSTEMS

A (very) Brief History

•Company Formed Jan 1997

Mission: Provide System Integration Services for Geotechnical Engineering Market with Integrated Software

- "Multilogger" released Nov 1997
- "MultiloggerDB" released 2001
- "MLWeb" released 2006

What Are We Doing?

- Building Campbell/Data Based Systems
- Developing Hardware Peripherals (control box)
- Developing Integrated Software (GPS/TPS/IPS)
- Connect over 800+ instruments “simultaneously” and alarming

Customers

Software: MultiLogger licenses 750+ (customers)

Hardware: Managing 3000 MCU's, (box Controller)

Top 100 hundred Engineering Companies World Wide

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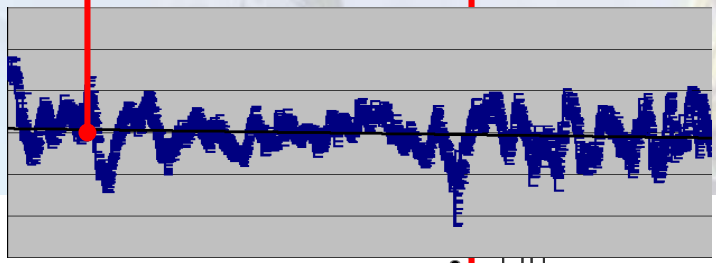
Who Are We Doing It For?

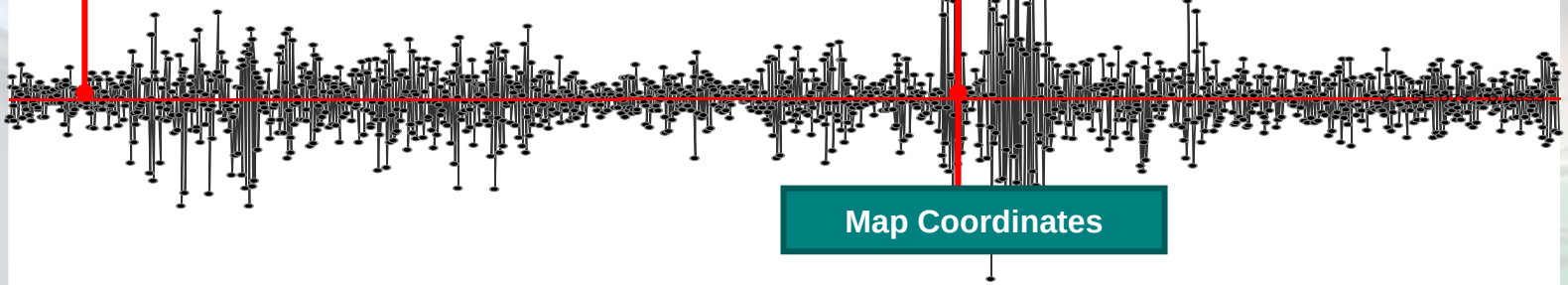
- Government – USACE/ USA
- Consulting Engineering Firms
- Engineering Companies/ URS/ ARCADIS
- Utilities - TVA/PG&E/etc.
- State DOTs

IPS

GPS

TPS





Map Coordinates

1 hour

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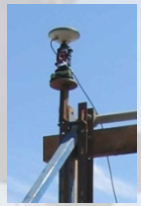
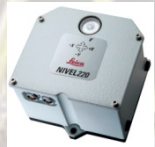
Canary Connections

- Same instruments
  - GPS
  - TPS
  - IPS (inclinometers)
  - Weather stations

  + over 100 different types of Geotechnical Instruments





"Bridging the Gap Geodesy to Civil Engineering"

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Chickamauga Lock Project Example

Instrumentation Includes (approximately):

- (44) Vibrating Wire Crackmeters
- (128) Vibrating Wire Extensometers
- (30) Vibrating Wire Growthmeters
- (180) Vibrating Wire Inclinometers and Tiltmeters
- (10) Vibrating Wire Jointmeters
- (12) Applied Geomechanics Tiltmeters
- (44) Vibrating Wire Piezometers and Uplift Cells
- (135) Vibrating Wire Stressmeters
- (258) Vibrating Wire Overcore Stress Cells
- (10) RXTX Optical Pendulums
- (13) CR10X & CR1000 Based Monitoring Systems
- (2) VW Comm Module Wireless Vibrating Wire Systems
- (1) Leica TCRP1201 Total Station with 20 Circular Prisms and 2 Reference Prisms
- (24) Manually Recorded Survey Markers

CANARY SOFTWARE

INTEGRATED SOFTWARE SOLUTIONS

DATA ACQUISITION SYSTEMS AND SOFTWARE FOR DEMANDING ENVIRONMENTS SINCE 1997

DATA ACQUISITION SYSTEMS AND SOFTWARE FOR DEMANDING ENVIRONMENTS SINCE 1997

CANARY SOFTWARE

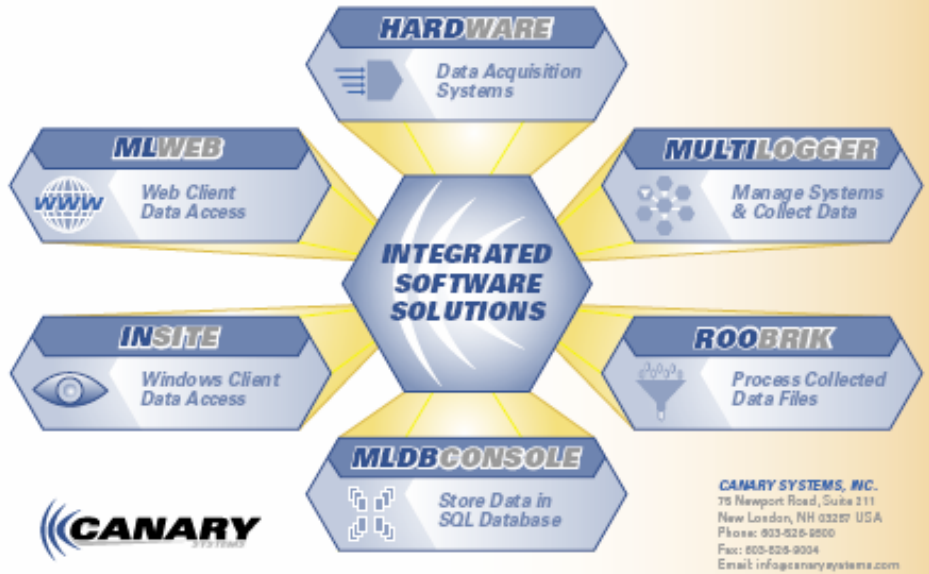
Canary Systems Integrated Software Solutions

Canary Systems MLWeb

One of the key components to deliver the value of the investment in your monitoring system is the software to make it all work. With decades of collective experience working with instrumentation and systems of many types deployed at hundreds of projects world-wide we have the experience to understand how the software should work to maximize this value. We develop in-house all of the software we sell, with the exception of the Firebird SQL database server, and are continually enhancing it to provide better value with each new version. We also understand that it isn't just about developing world-class software, but providing support after the sale that further enhances the value of your investment. We stand behind our work and look forward to helping you with your monitoring systems and software!

Visit www.CanarySystems.com to find out more and download demo software.

CANARY SYSTEMS SOFTWARE INTEGRATION

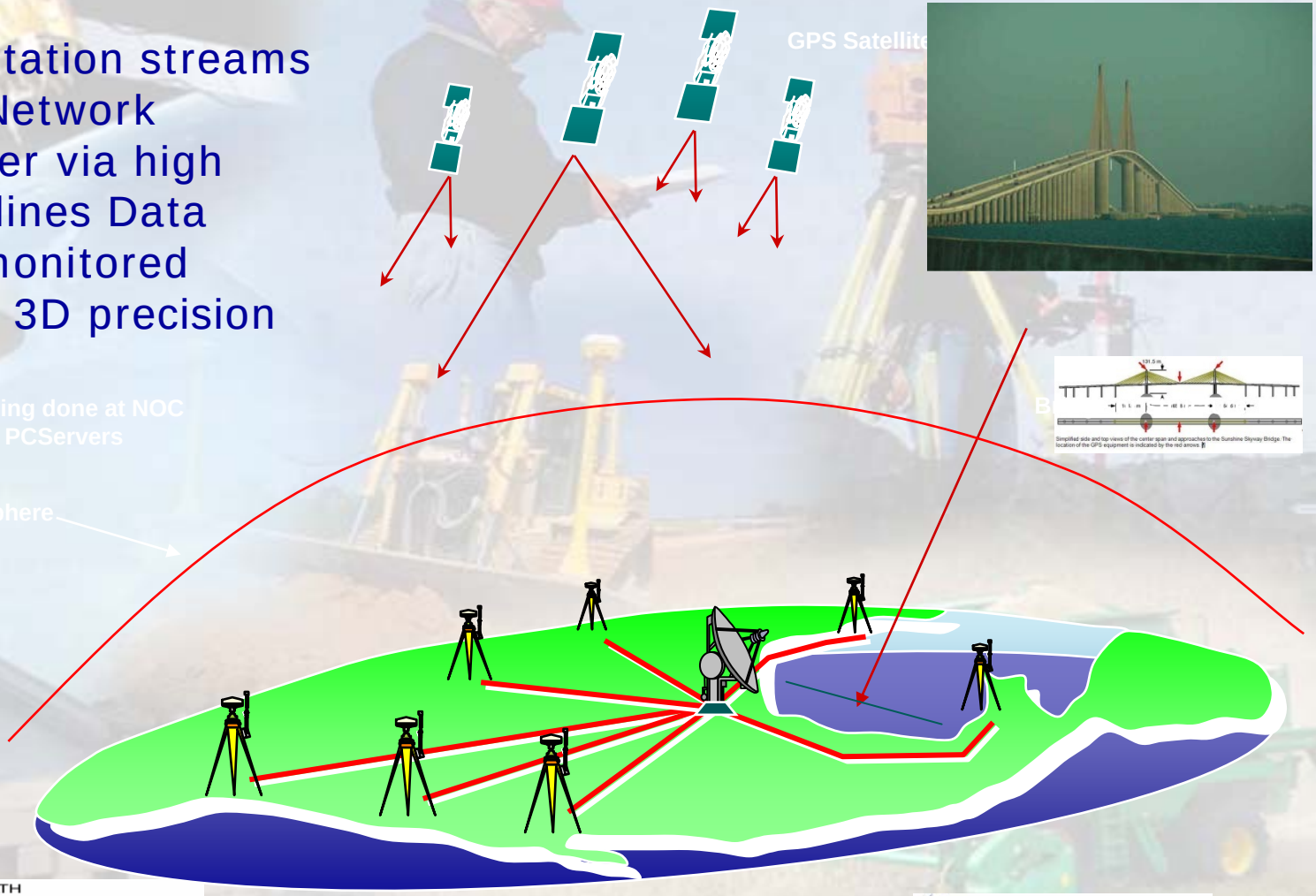


CANARY SYSTEMS

CANARY SYSTEMS, INC.
75 Newport Road, Suite 311
New London, NH 03257 USA
Phone: 603-526-9500
Fax: 603-526-9004
Email: info@canarysystems.com

Real Time Monitoring

- A Network Control Center
- Each GPS Station streams data to the Network Control Center via high speed data lines Data integrity is monitored continuously 3D precision ±10 mm



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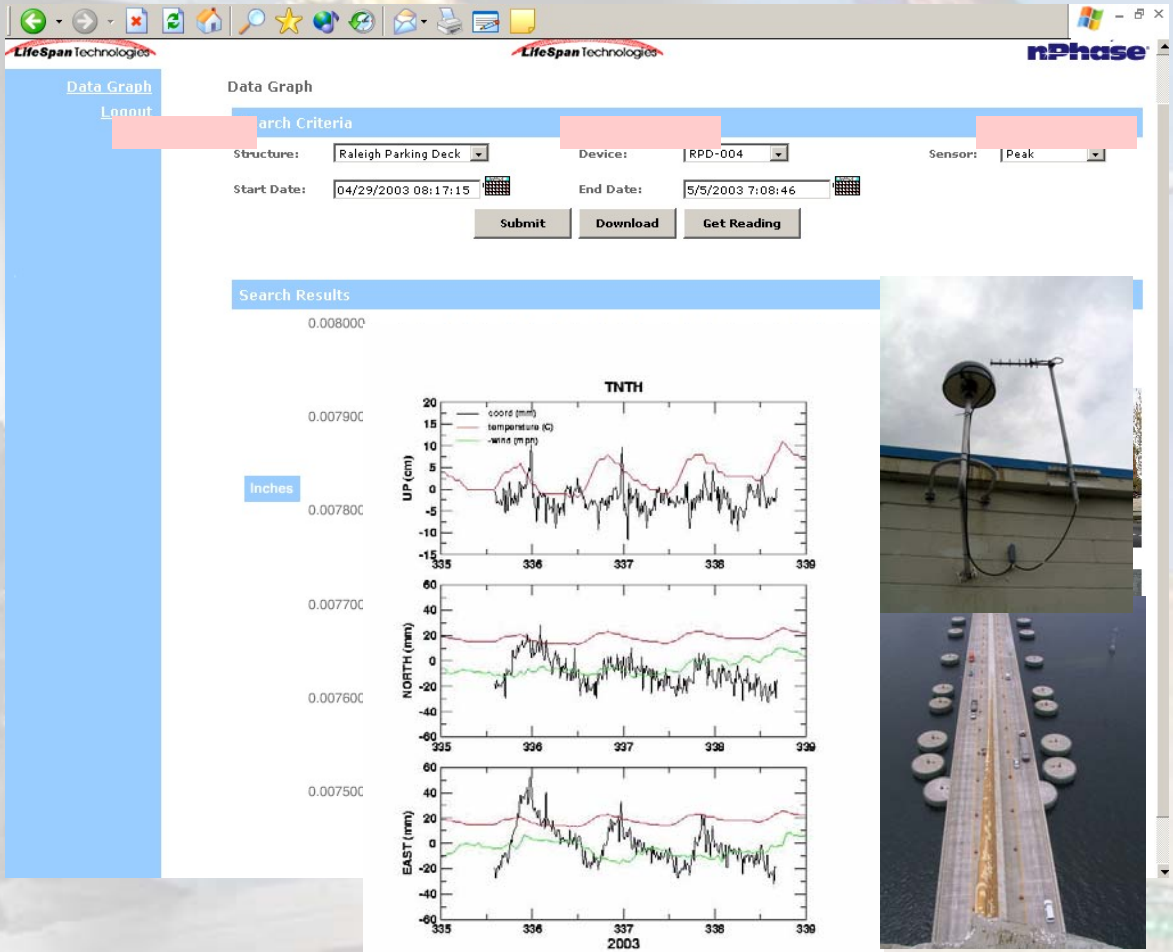
Data Sample



- Multiple structures per interface
- Selectable sensors
- Dynamic graphing based on date range desire
- Alarms by sensor
- Custom data display at sensor, structure, or structures levels

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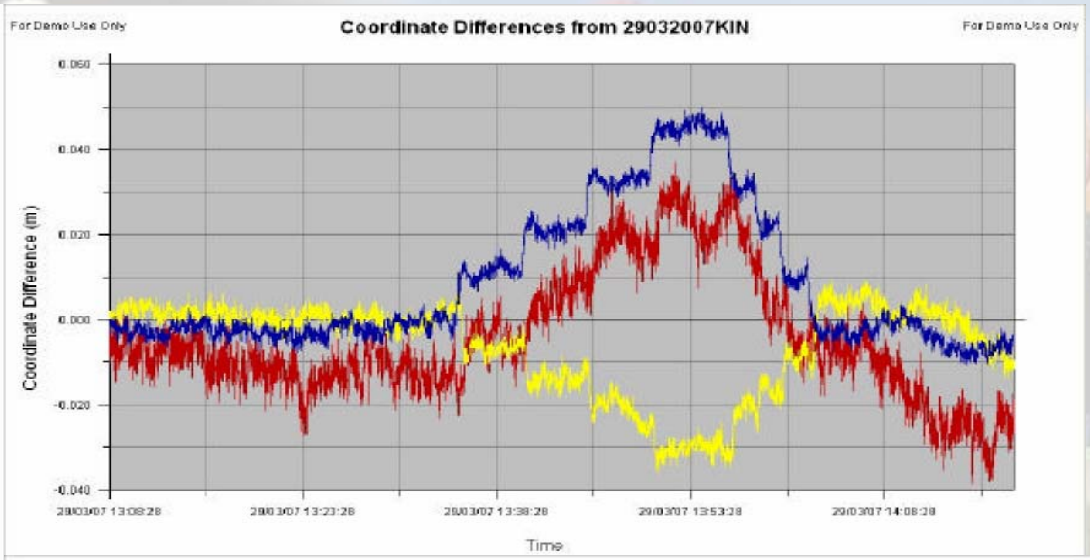
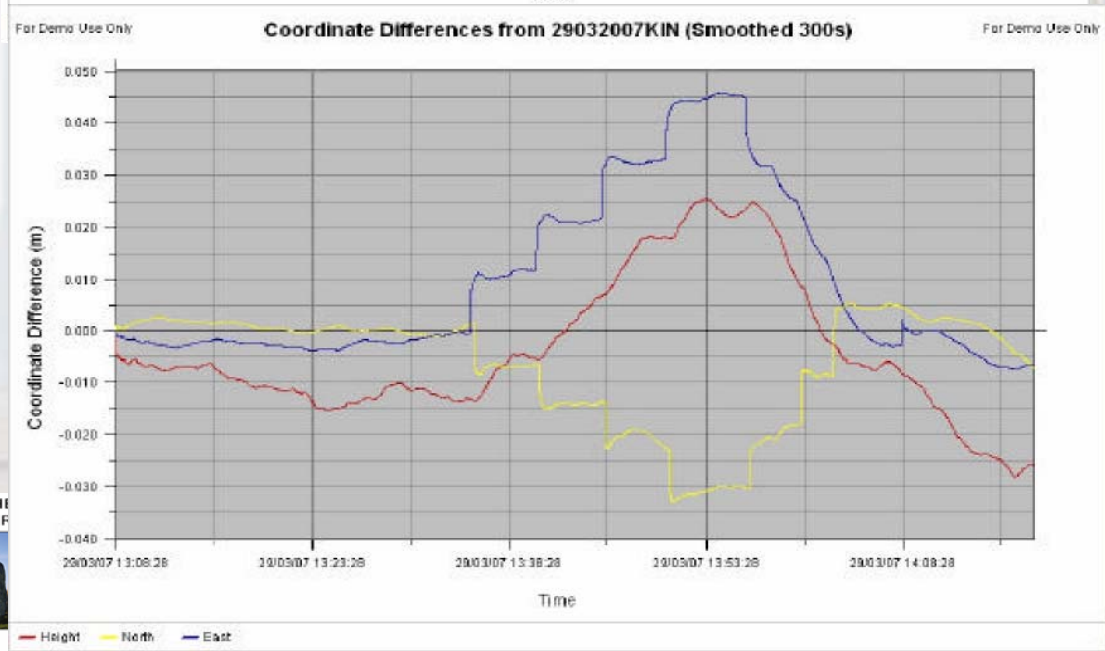
Real Time results unfiltered and resulting from a maximum displacement of 4 cm.





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Reference Station Networks

- Perfect environment
- Perfect Tool
- WYSWYG
- Perfect Opportunity

- Yeah baby, we have been waiting a long time!

CANARY SYSTEMS

Structural Health Monitoring

- **Start with a "GPS/IPS" (inclinometer positioning system) sensor system to clarify initial structural health concerns**
- **Additional sensor types can then be strategically added in suspect locations**
- **Structural engineers, using state-of-the-art analytics, can develop a final diagnosis quickly and efficiently with information from our sensor systems**
- **A definitive diagnosis leads to development of structure specific remedies and optimized Asset Management programs**

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Wikipedia

- Axiom VI: There is a trade-off between the sensitivity to damage of an algorithm and its noise rejection capability;
- Axiom VII: The size of damage that can be detected from changes in system dynamics is inversely proportional to the frequency range of excitation.

SHM Components [edit]

The sensory system consists of approximately 900 sensors and their relevant interfacing units. With more than 350 sensors on the Tsing Ma bridge, 350 on Ting Kau and 200 on Kap Shui Mun, the structural behaviour of the bridges is measured 24 hours a day, seven days a week.

The sensors include accelerometers, strain gauges, displacement transducers, level sensing stations, anemometers, temperature sensors and dynamic weight-in-motion sensors. They measure everything from tarmac temperature and strains in structural members to wind speed and the deflection and rotation of the kilometres of cables and any movement of the bridge decks and towers.

These sensors are the early warning system for the bridges, providing the essential information that help the Highways Department to accurately monitor the general health conditions of the bridges.

The structures have been built to withstand up to a one-minute mean wind speed of 95 metres per second. In 1997, when Hong Kong had a direct hit from Typhoon Victor, wind speeds of 110 to 120 kilometres per hour were recorded. However, the highest wind speed on record occurred during Typhoon Wanda in 1962 when a 3 second gust wind speed was recorded at 78.8 metres per second, 284 kilometres per hour.

The information from these hundreds of different sensors is transmitted to the data acquisition outstation units. There are three data acquisition outstation units on Tsing Ma bridge, three on Ting Kau and two on the Kap Shui Mun.

The computing powerhouse for these systems is in the administrative building used by the Highways Department in Tsing Yi. The local central computer system provides data collection control, post-processing, transmission and storage. The global system is used for data acquisition and analysis, assessing the physical conditions and structural functions of the bridges and for integration and manipulation of the data acquisition, analysis and assessing processes.

- Monitoring Hong Kong's Bridges Real-Time Kinematic Spans The Gap

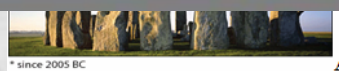
Structural Health Monitoring for bridges [edit]

In order to oversee the integrity, durability and reliability of the bridges, WASHMS has four different levels of operation: sensory systems, data acquisition systems, local centralised computer systems and global central computer system.

The sensory system consists of approximately 900 sensors and their relevant interfacing units. With more than 350 sensors on the Tsing Ma bridge, 350 on Ting Kau and 200 on Kap Shui Mun, the structural behaviour of the bridges is measured 24 hours a day, seven days a week.

Monitoring Applications
Tunnelling and Buildings

- Construction site near by the tunnel
- Deformation risk in bad soil
- Urban areas
- Multiple total stations needed
- GNSS used for reference point stability
- Geotechnical sensors
- Railways and Highways
- Construction
- Maintenance of structures



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Monitoring Applications
Dams and Landslide

- **Safety and risk management of important transport links and urban areas**
- **Landslide areas near by dam**
- **Glacier above water reservoir**

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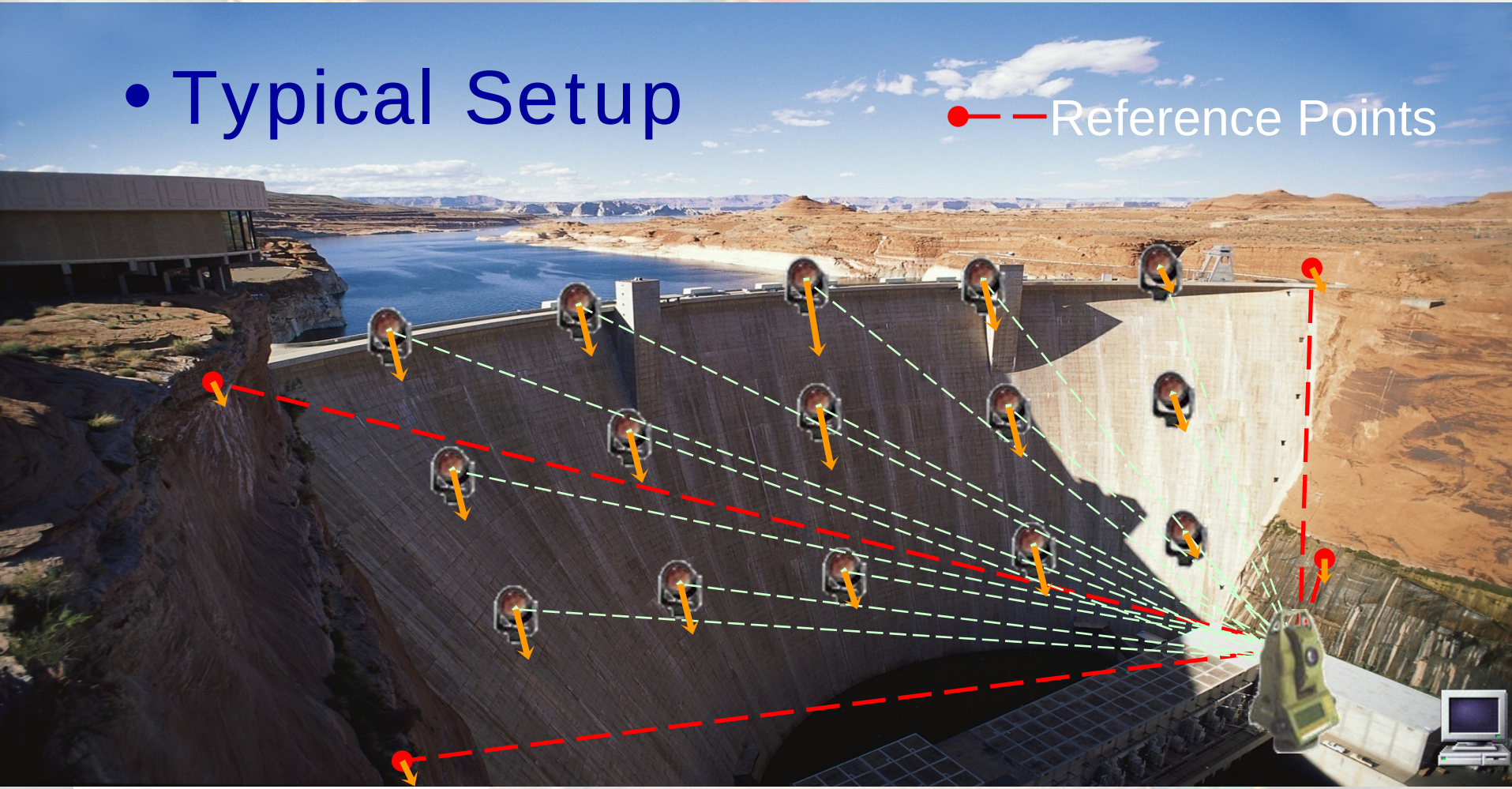
CANARY SYSTEMS

Monitoring Eastside GPS/TPS 460 prisms

- Typical Setup



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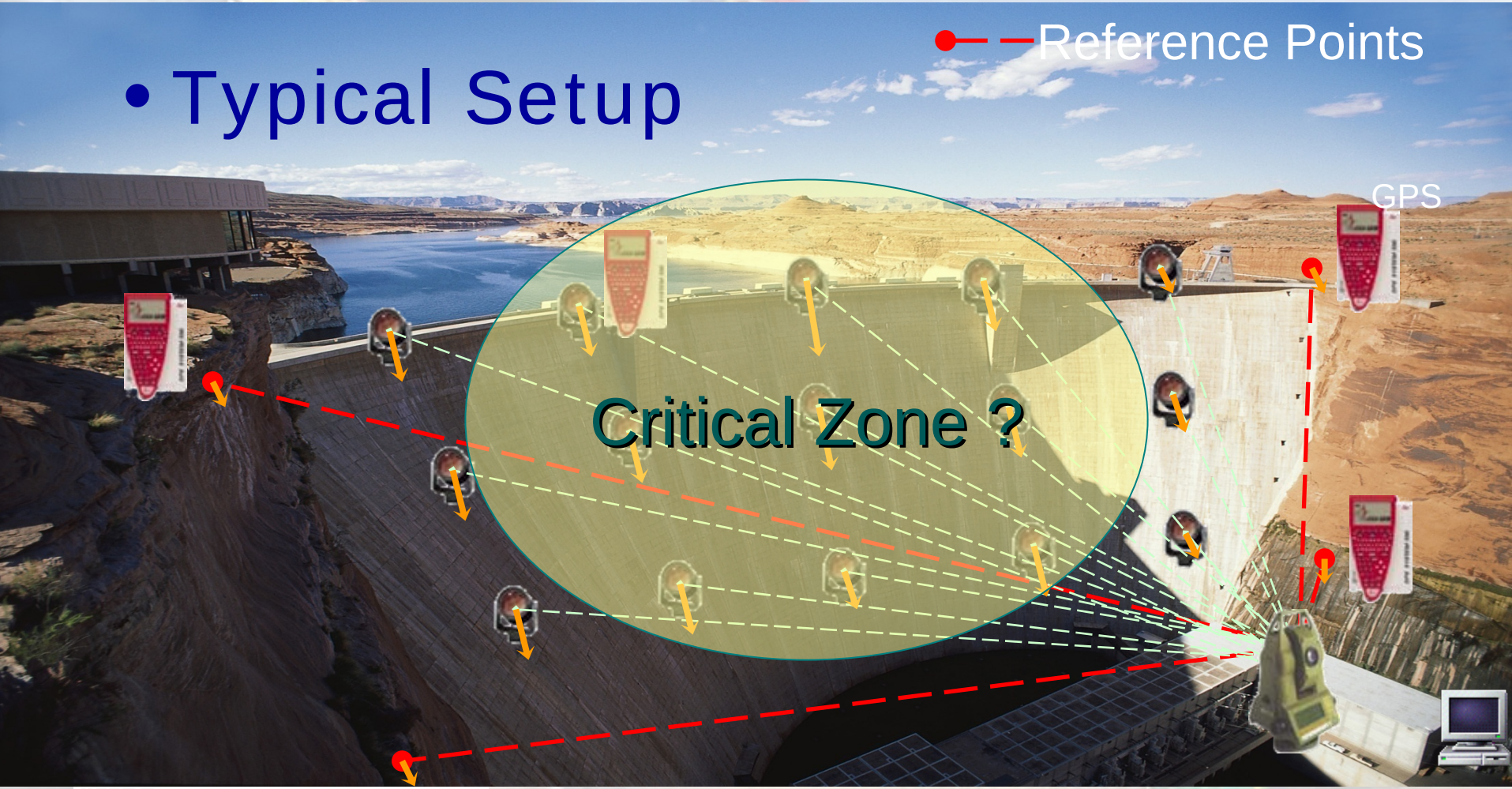
Monitoring

- Typical Setup



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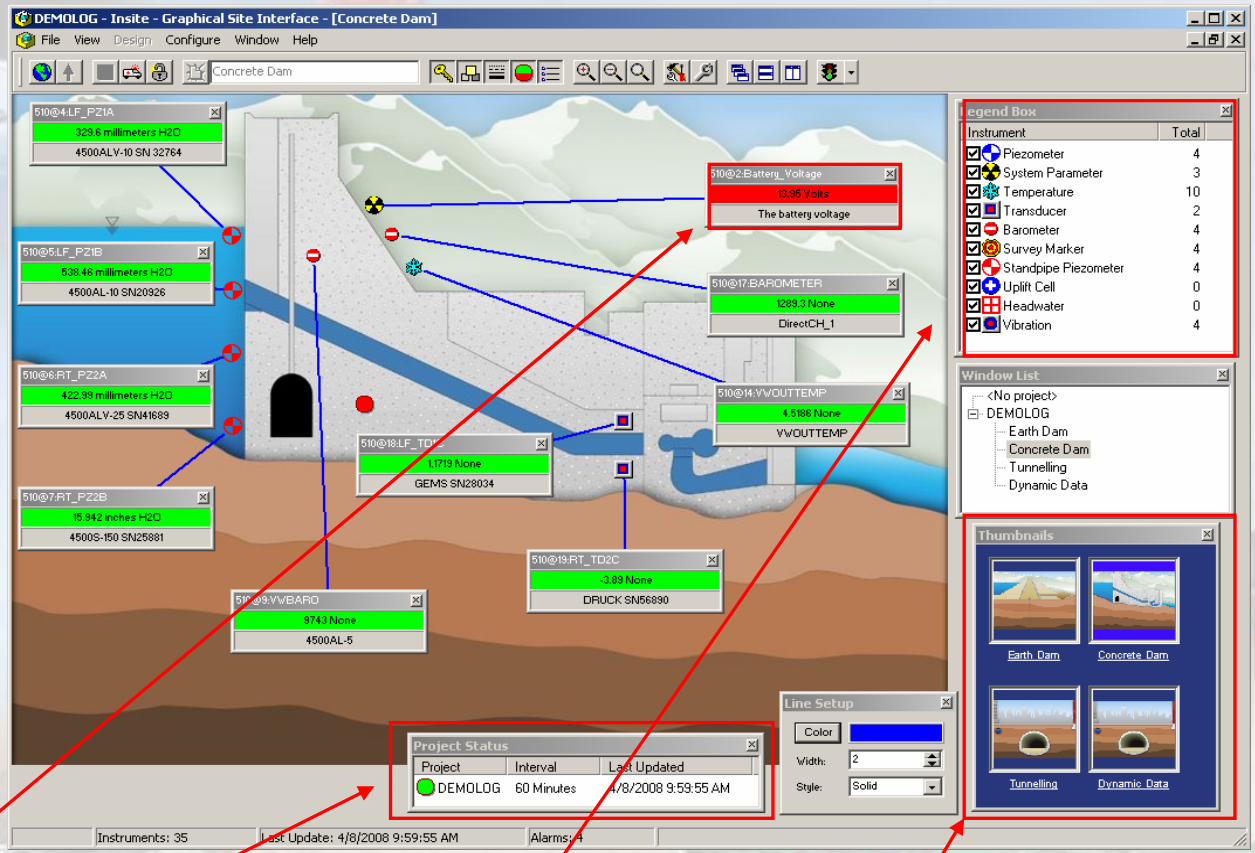
Data Acquisition Systems for Demanding Environments

MultiLoggerDB Project Interface

•Insite, the MLDB client software, is designed to present a project as a series of Project Views. This application includes extensive functionality in the viewing of the project and the output of data



•Readings Box showing current reading & status (yellow or red = alarm)

•Project Status

•Legend Box showing instruments and managing the display

•Thumbnail viewer for selecting Project View.

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Monitoring Applications
Open Pit Mining

- **3D deformation for slope stability control (prediction)**
- **Safety and risk management for staff and machinery**
- **Long term 3D survey as reference for other monitoring tools**
- **Total stations used for cost effective wide area coverage**
- **GPS, geotechnical and other monitoring systems used for added safety**

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Example – Mine

•Before

•After

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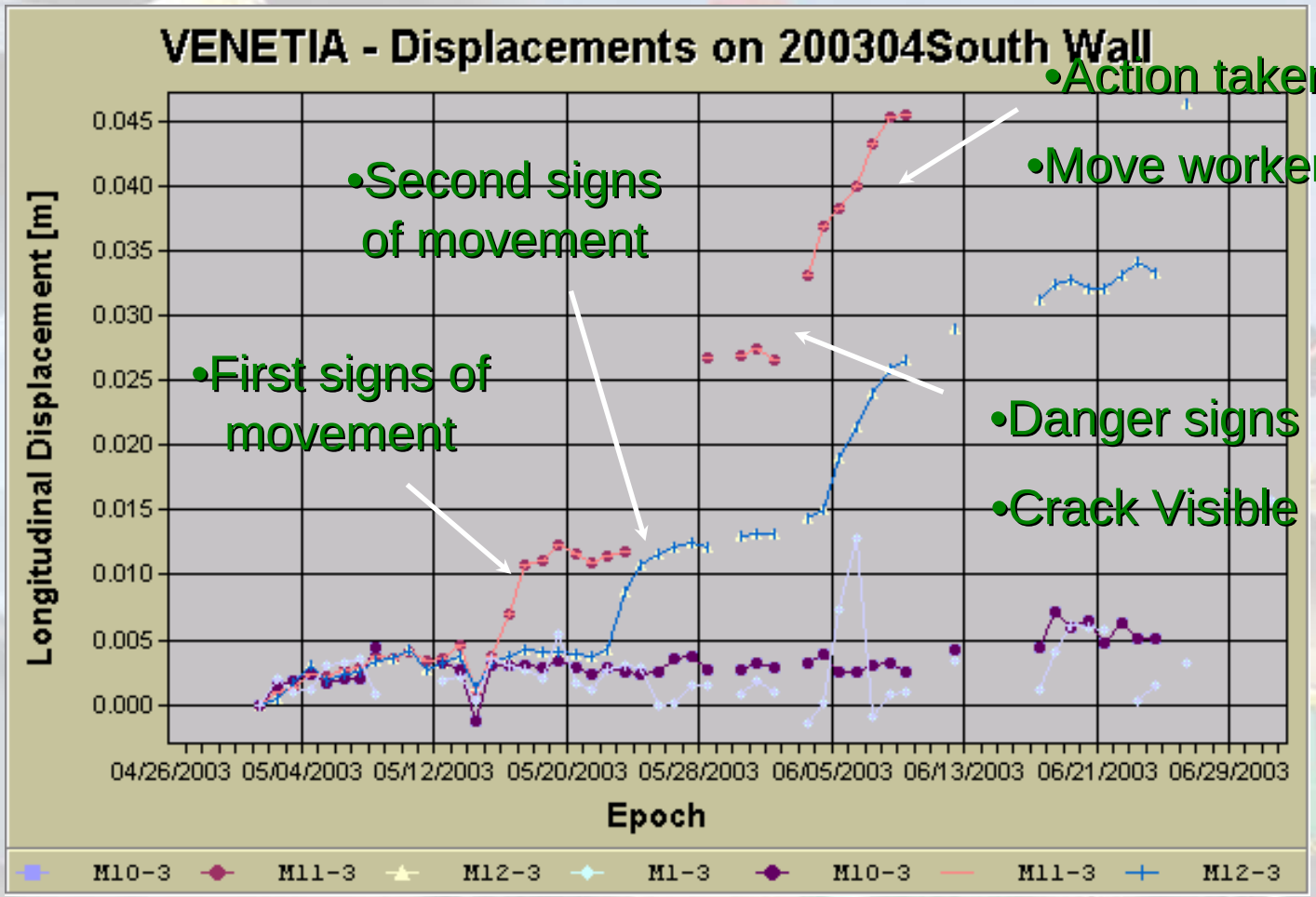
CANARY SYSTEMS

Example – Mine



•Movement detected 2 weeks before visible Crack

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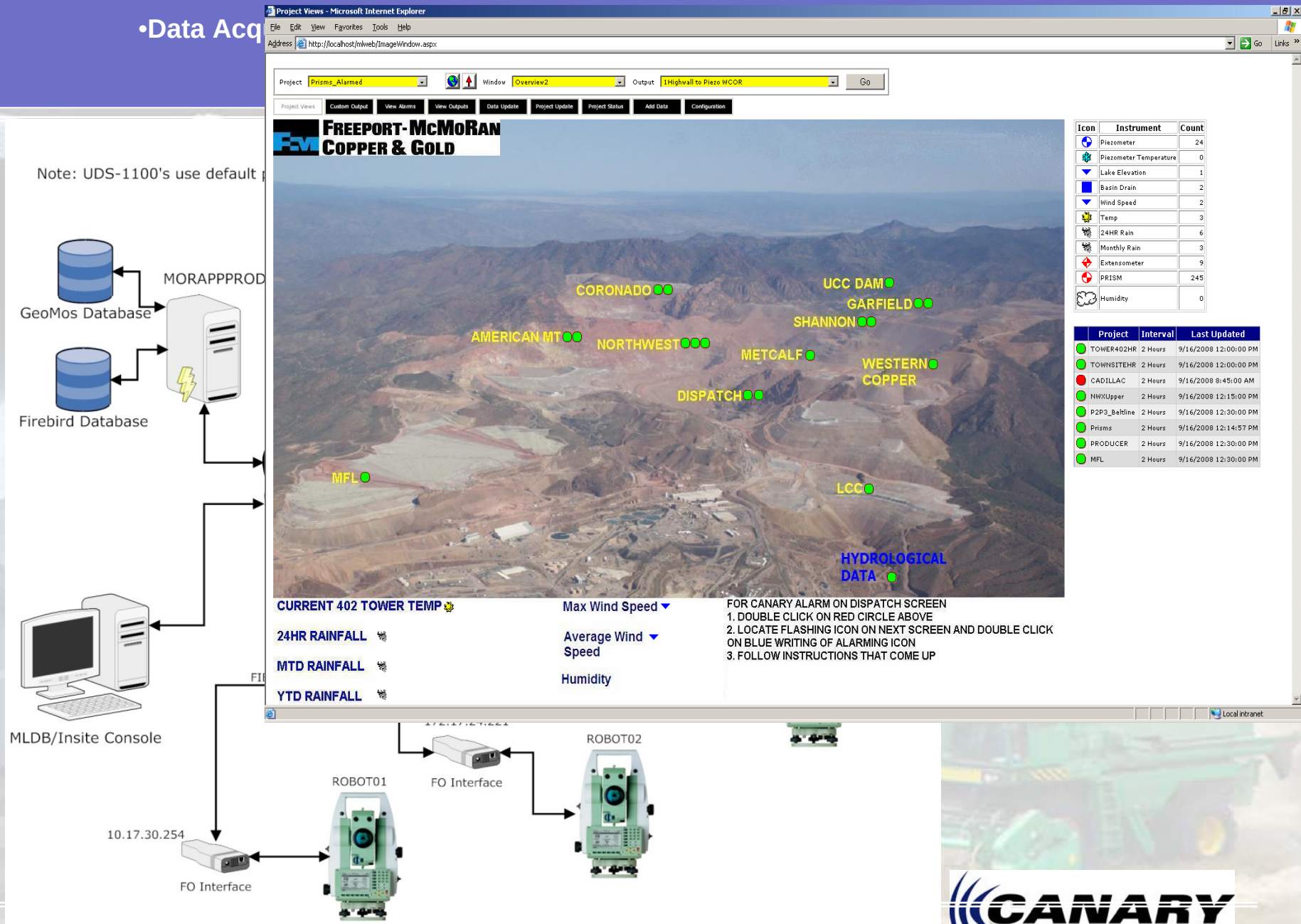
•Data Acq


Project Views - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://localhost/mlweb/ImageWindow.aspx
Project Prisms_Alarmed
Window Overview2
Output 1Highwall to Piezo WCOR
Go
Project Views
Custom Output
View Alarms
View Outputs
Data Update
Project Update
Project Status
Add Data
Configuration
FREEPORT-McMoRan COPPER & GOLD
CORONADO
UCC DAM
GARFIELD
SHANNON
AMERICAN MT
NORTHWEST
METCALF
WESTERN COPPER
DISPATCH
MFL
LCC
HYDROLOGICAL DATA
Icon
Instrument
Count
Piezometer 24
Piezometer Temperature 0
Lake Elevation 1
Basin Drain 2
Wind Speed 2
Temp 3
24HR Rain 6
Monthly Rain 3
Extensometer 9
PRISM 245
Humidity 0
Project
Interval
Last Updated
TOWER402HR 2 Hours 9/16/2008 12:00:00 PM
TOWNSITEHR 2 Hours 9/16/2008 12:00:00 PM
CADILLAC 2 Hours 9/16/2008 8:45:00 AM
NWXUpper 2 Hours 9/16/2008 12:15:00 PM
P2P3_Beltline 2 Hours 9/16/2008 12:30:00 PM
Prisms 2 Hours 9/16/2008 12:14:57 PM
PRODUCER 2 Hours 9/16/2008 12:30:00 PM
MFL 2 Hours 9/16/2008 12:30:00 PM
CURRENT 402 TOWER TEMP
24HR RAINFALL
MTD RAINFALL
YTD RAINFALL
Max Wind Speed
Average Wind Speed
Humidity
FOR CANARY ALARM ON DISPATCH SCREEN
1. DOUBLE CLICK ON RED CIRCLE ABOVE
2. LOCATE FLASHING ICON ON NEXT SCREEN AND DOUBLE CLICK ON BLUE WRITING OF ALARMING ICON
3. FOLLOW INSTRUCTIONS THAT COME UP
Local intranet
Note: UDS-1100's use default
MORAPPPROD
GeoMos Database
Firebird Database
MLDB/Insite Console
ROBOT02
FO Interface
ROBOT01
10.17.30.254
FO Interface

Monitoring Applications
Seismic and Subsidence

- **Measurement of tectonic movement, earthquakes, isostatic rebound, glacial flow, subsidence due to extraction of groundwater or mining**
- **1D or 3D deformation for understanding risks to infrastructure and for scientific study**
- **Measurement of movements over wide areas**
- **Often use a combination of GNSS and geotechnical instrumentation**

Monitoring Applications
Bridges and Structures

- **Safety and risk management of important transport links and urban areas**

- **Construction near by buildings (high rise buildings)**

- **Maintenance of Structures**
- **Insurance and Bonds**

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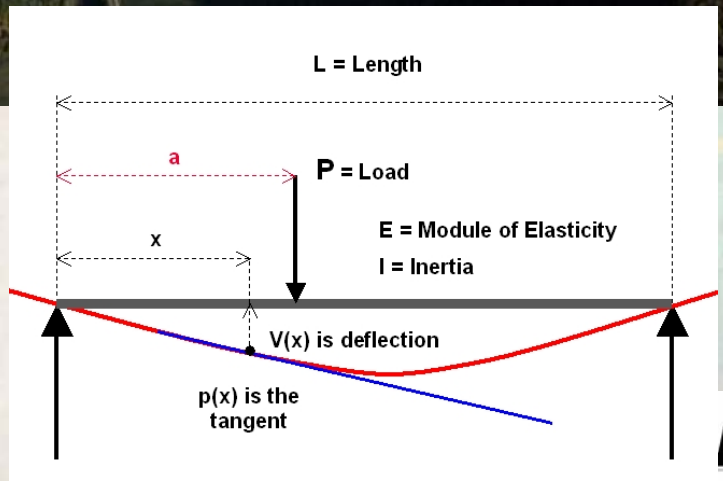
IPS Inclinometer Positioning System



Continuous Beam Deflection Monitoring Using Precise Inclinometer Data

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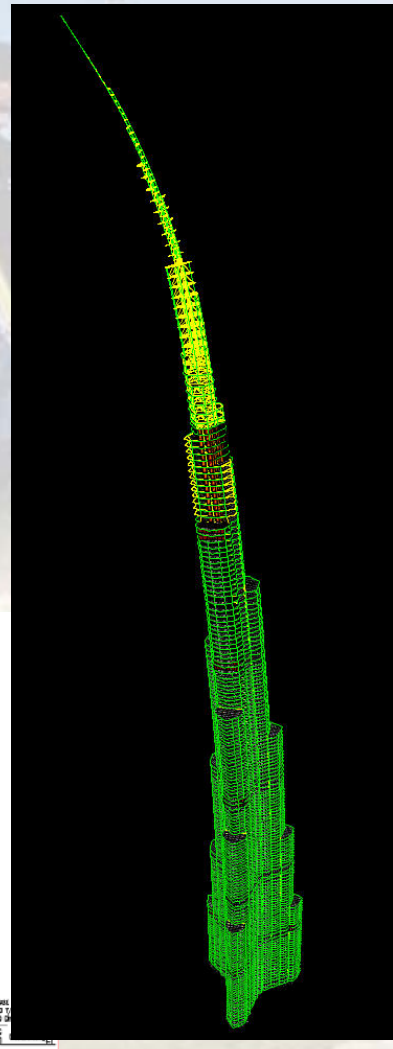
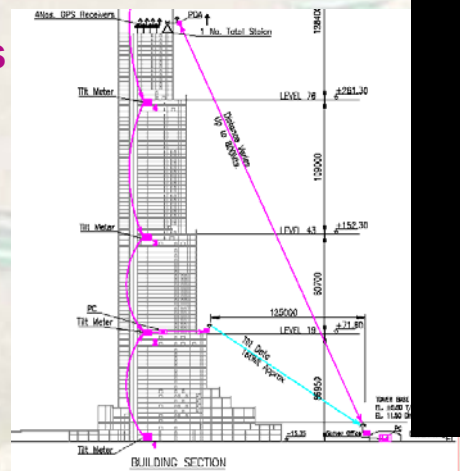
Integrated Monitoring System

- GPS
- TPS
- IPS



- **Traditionally a laser beam coupled with a ZNL is used to materialize the main verticale.**
- **The observed deviations are reported on the map coordinates.**
- Ground Map coordinates



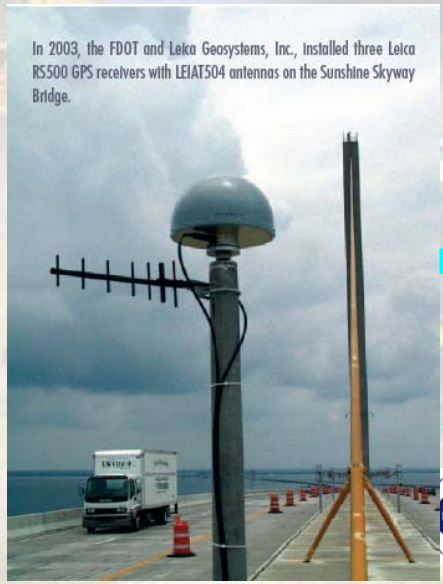
External Recognition of

GPS World Magazine

Feature Article and Cover

Sept 2003

Structural health monitoring using GPS



BRIDGES Magazine

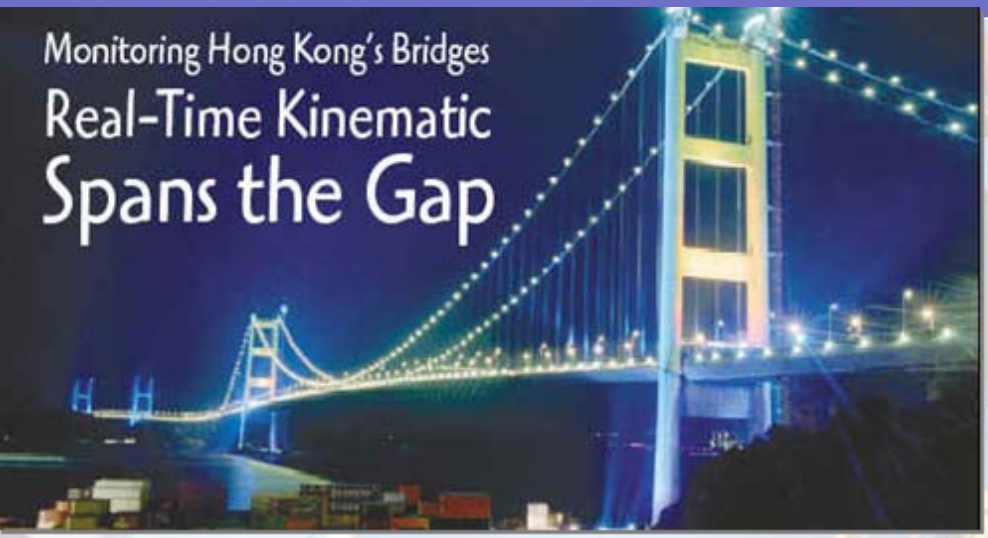
Feature Article and Cover

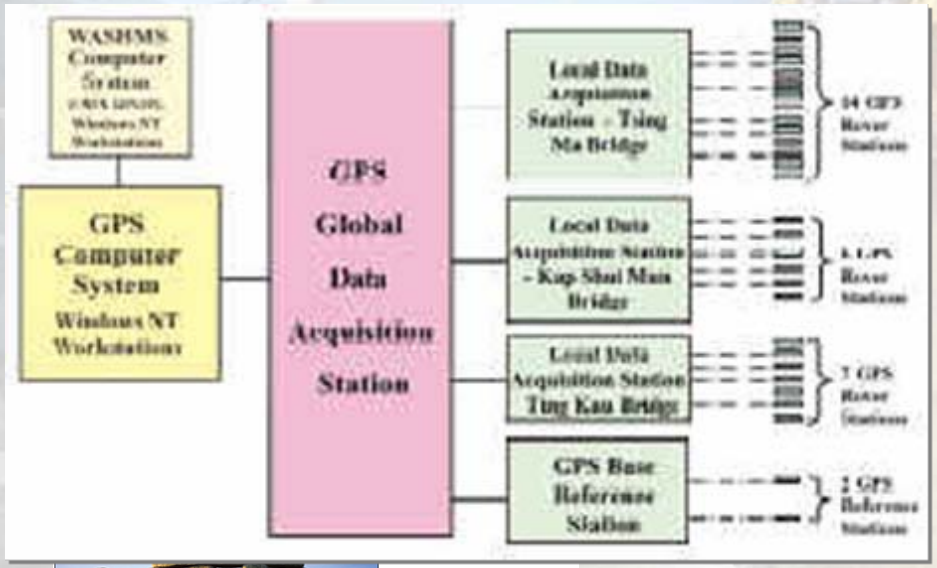
April 2006

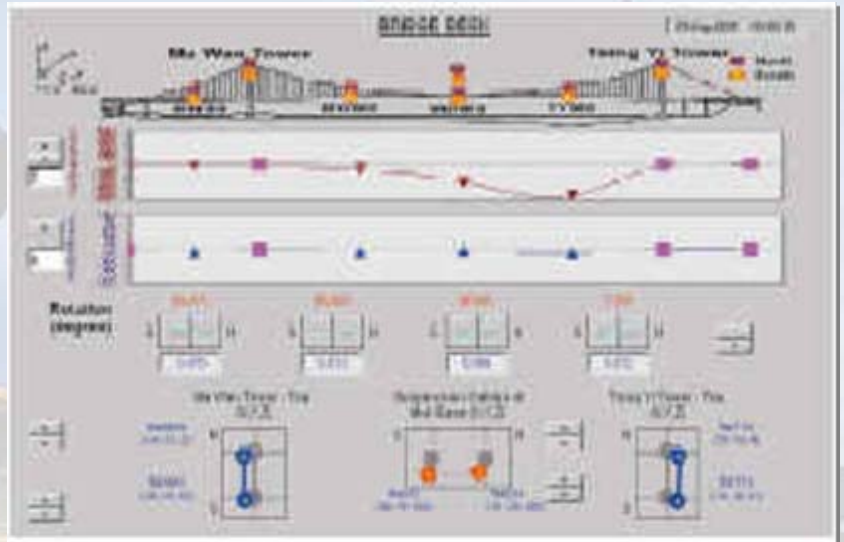
How did we get there?

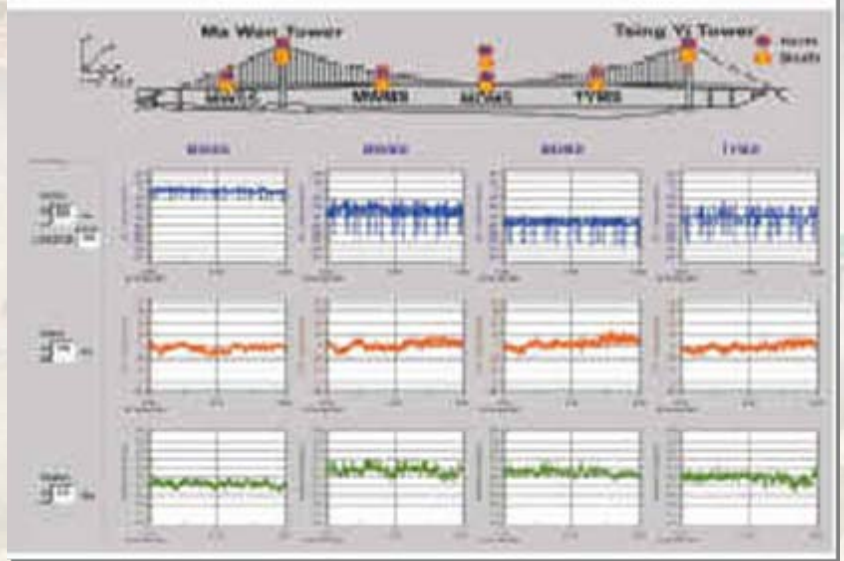
CANARY SYSTEMS

Example Hong Kong









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2009 ASCE Report Card for America's Infrastructure

Almost 27%, or more than one in four, of the nation's bridges are considered structurally deficient or functionally obsolete. In real numbers, this means that of the 600,905 bridges listed by the U.S. Department of Transportation in December 2008, 72,868 (12.1%) were categorized as structurally deficient and 89,024 (14.8%) were categorized as functionally obsolete. Even though the number of deficient rural bridges declined by 8596 from 2005 to 2008, the number of deficient urban bridges increased by 2817 during the same time period. Considering the higher level of passenger and freight traffic on these urban bridges, the impact is significant.

- 72,868 (12.1%) structurally deficient
- 89,024 (14.8%) were categorized as functionally obsolete.

- One in four, (1/4) count your bridges every 4th one could fail.

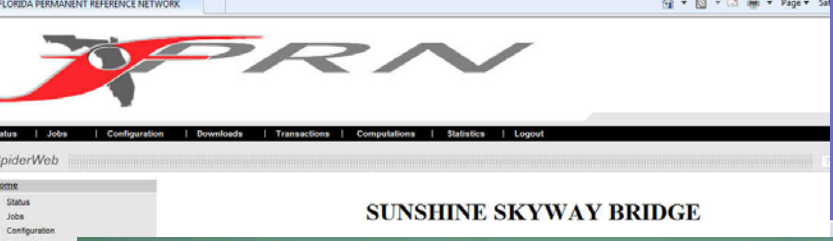
6 Dead in Minn. Bridge Collapse

Posted Aug 1, 07 9:20 PM CDT in US | Share

(Newser Summary) – A four-lane bridge over the Mississippi River in Minneapolis collapsed d
the evening rush, killing at least 6 people and injuring dozens. Witnesses say there were up to
cars on the bridge at the time, and as many as 50 were hurled into the river and onto the bank
rescuers rushed to triage victims and put out massive fires.

The FBI and Homeland Security have ruled
terrorism—the *Minneapolis Star-Tribune* re
construction crews had been repairing the
section of the I35W bridge that buckled for
several weeks. One semi reportedly burst i
flames, while some witnesses said that a sc
bus full of children was on the bridge while
collapsed, though it appears none of the ch
were injured.

—Greg



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At 7:25 a.m. on
May 9, 1980,
with th
Greyh
appro
Pinella
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the Su
Skyw
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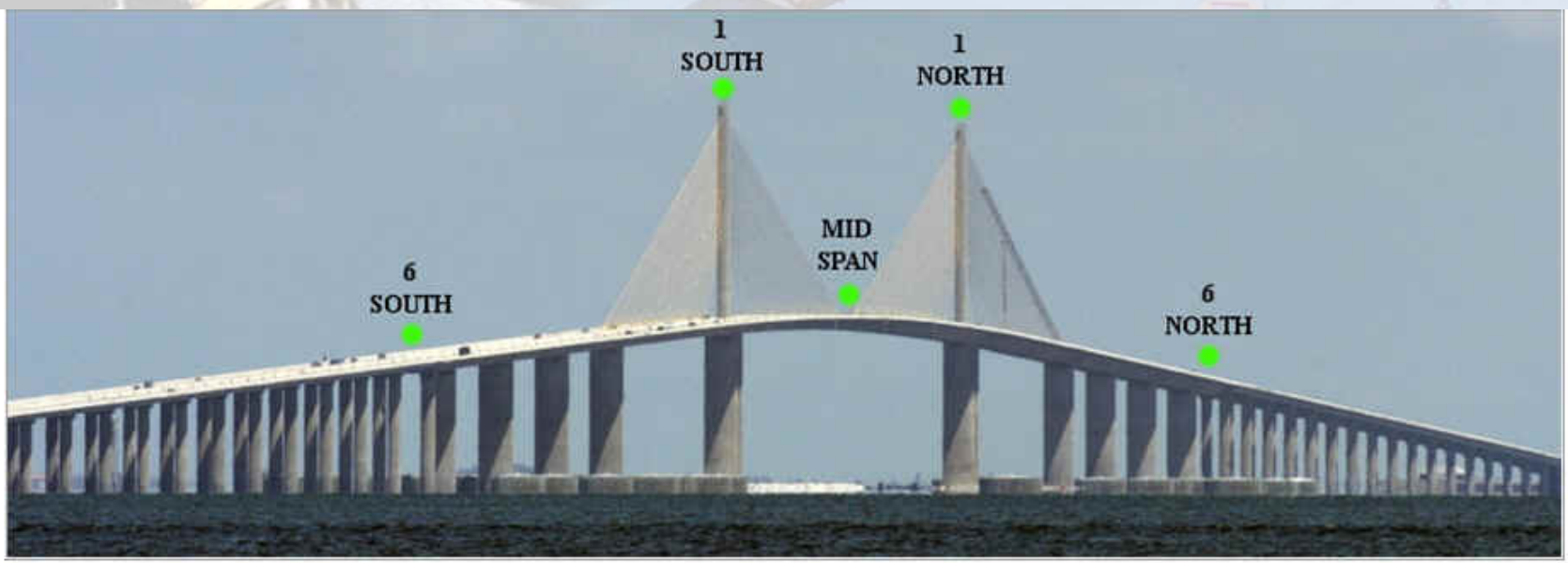
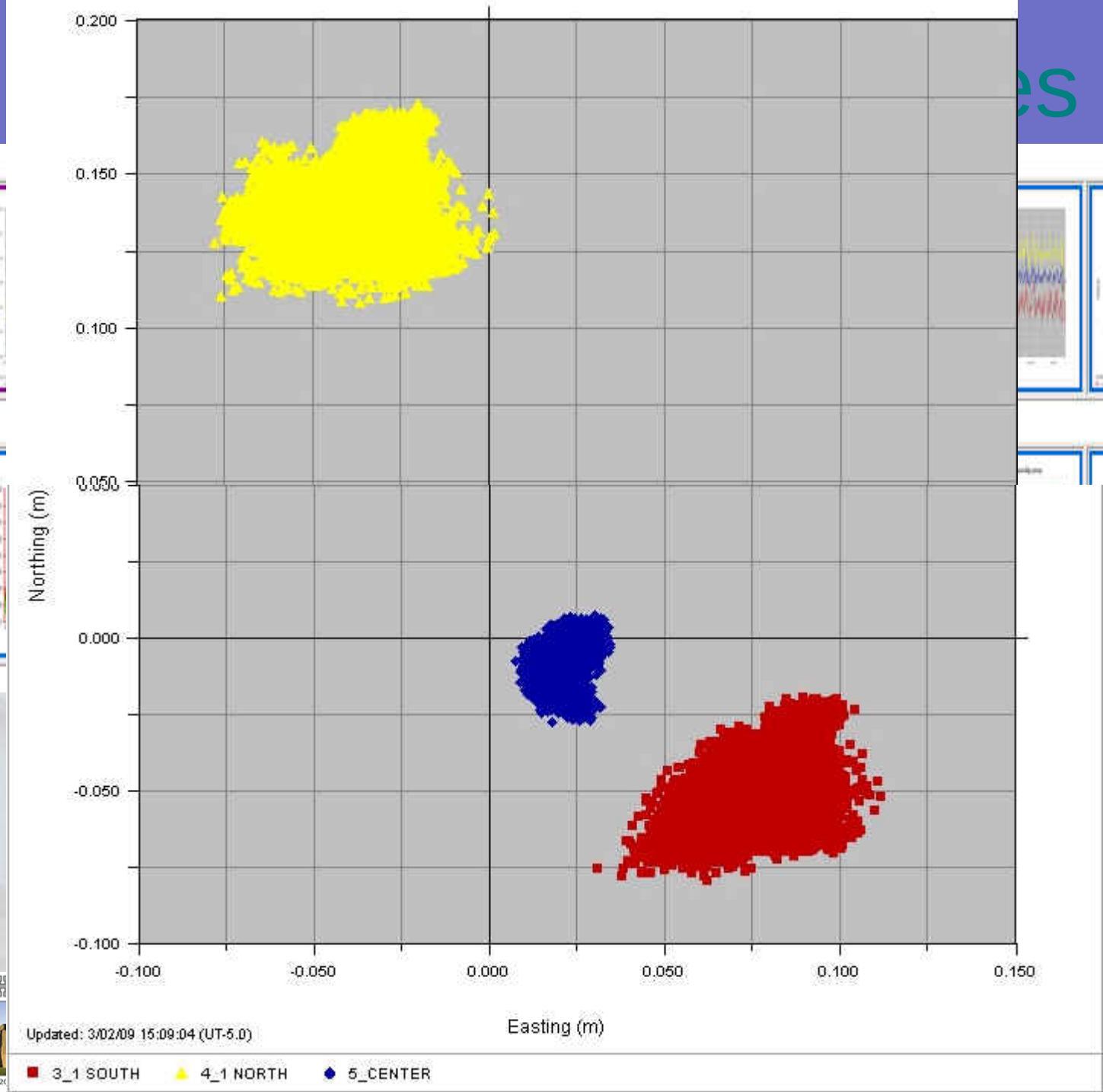
tensed
helm c
freight
Ventu
as lon

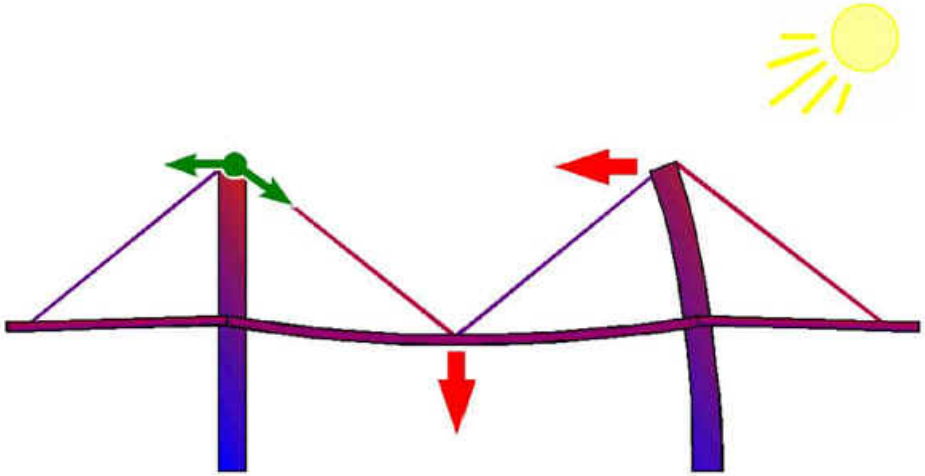
unforgettable scene



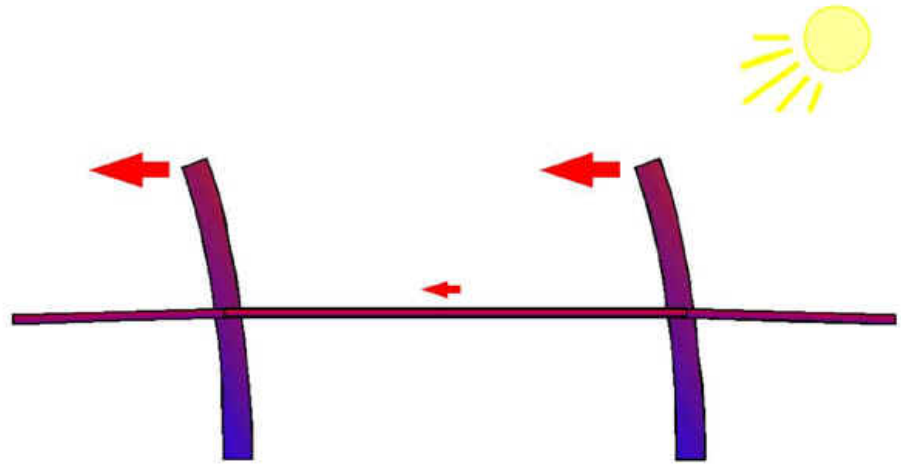
30 - DAY SERIES

SKYWAY SCHEMATIC
SKYWAY PHOTOS
REAL TIME SNAPSHOT PLOTS
POST PROCESSED SNAPSHOT PLOTS


0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
Northing (m)
-0.100
-0.050
0.000
0.050
0.100
0.150
Easting (m)
Updated: 3/02/09 15:09:04 (UT-5.0)
3_1 SOUTH
4_1 NORTH
5_CENTER

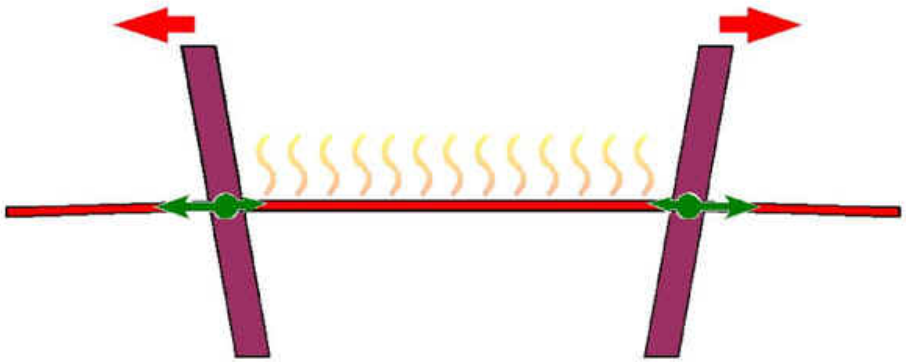


Solar effects: A simplified schematic showing more realistically the motions, red arrows, caused by the towers bending because of temperature differences through the towers caused by solar heating and forces, green arrows, transmitted through the cables.

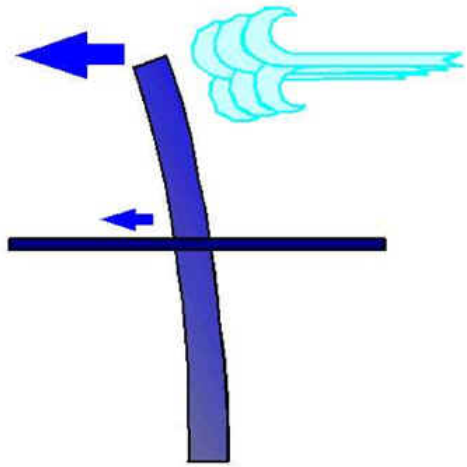


Wind Loading: A simplified schematic showing the motions, red arrows, caused by the towers bending because of temperature differences through the towers caused by solar heating.

Diurnal effects

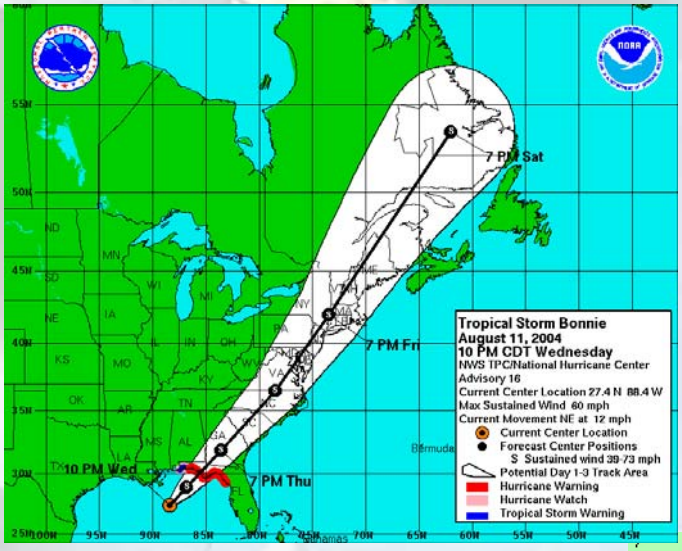


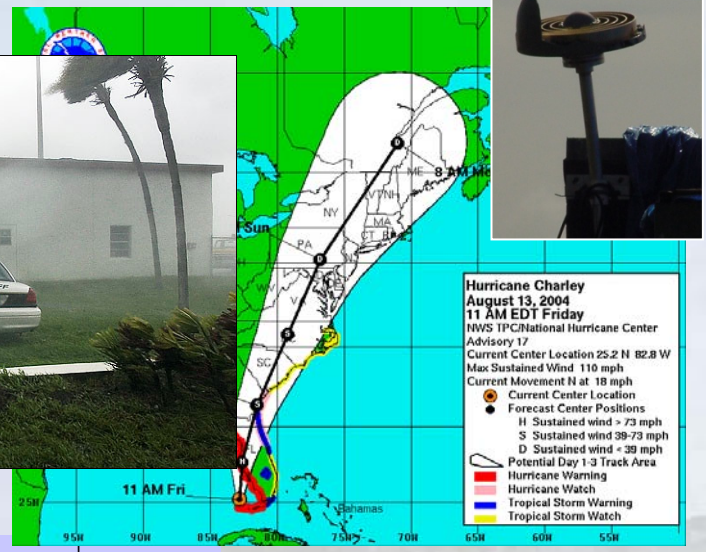
Deck expansion: A simplified schematic showing the motions, red arrows, caused by thermal expansion of the bridge deck spans and the resulting separation of the towers. Opposing forces are represented by the green arrows.

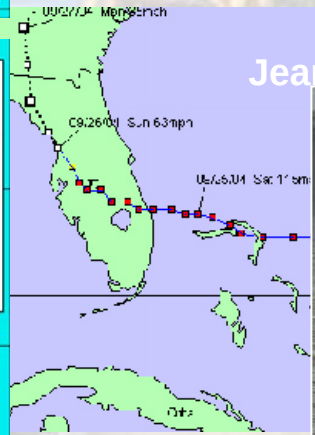


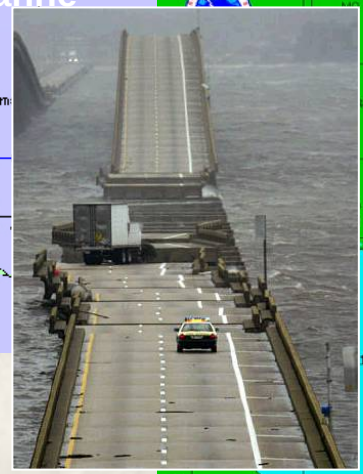
Wind Loading: A simplified schematic showing the motions, blue arrows, caused by wind loading.

4 Hurricanes…….Structure Impact?

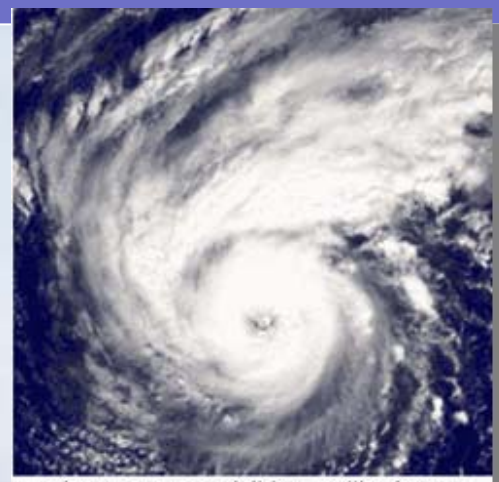




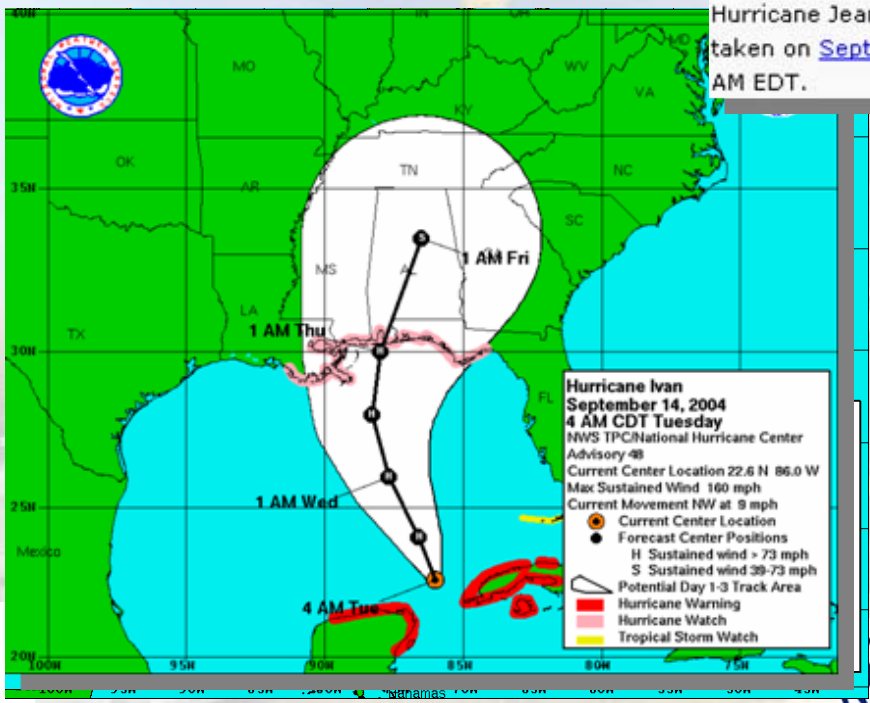


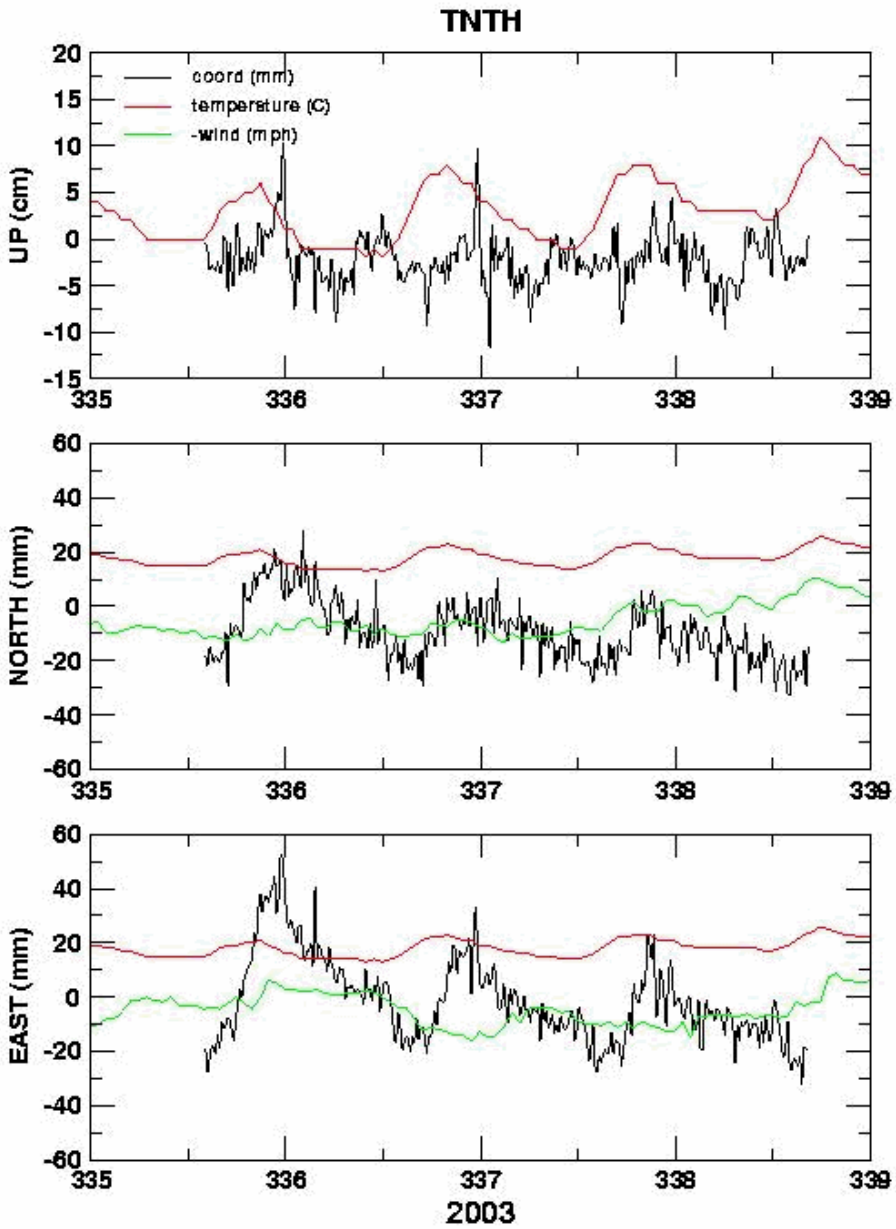


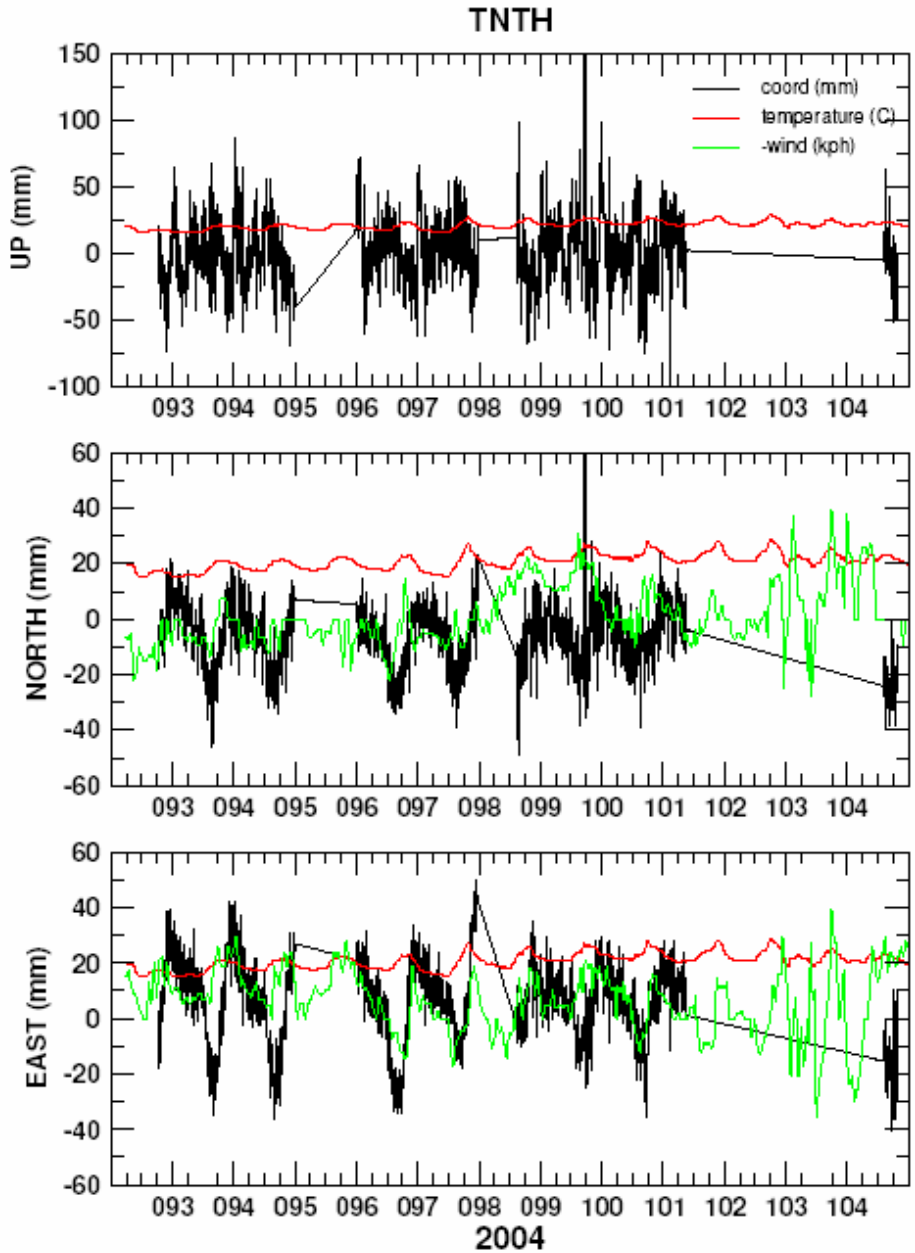
FLORIDA BLOWS!



Hurricane Jeanne visible satellite image, taken on September 22, 2004 at 11:15 AM EDT.



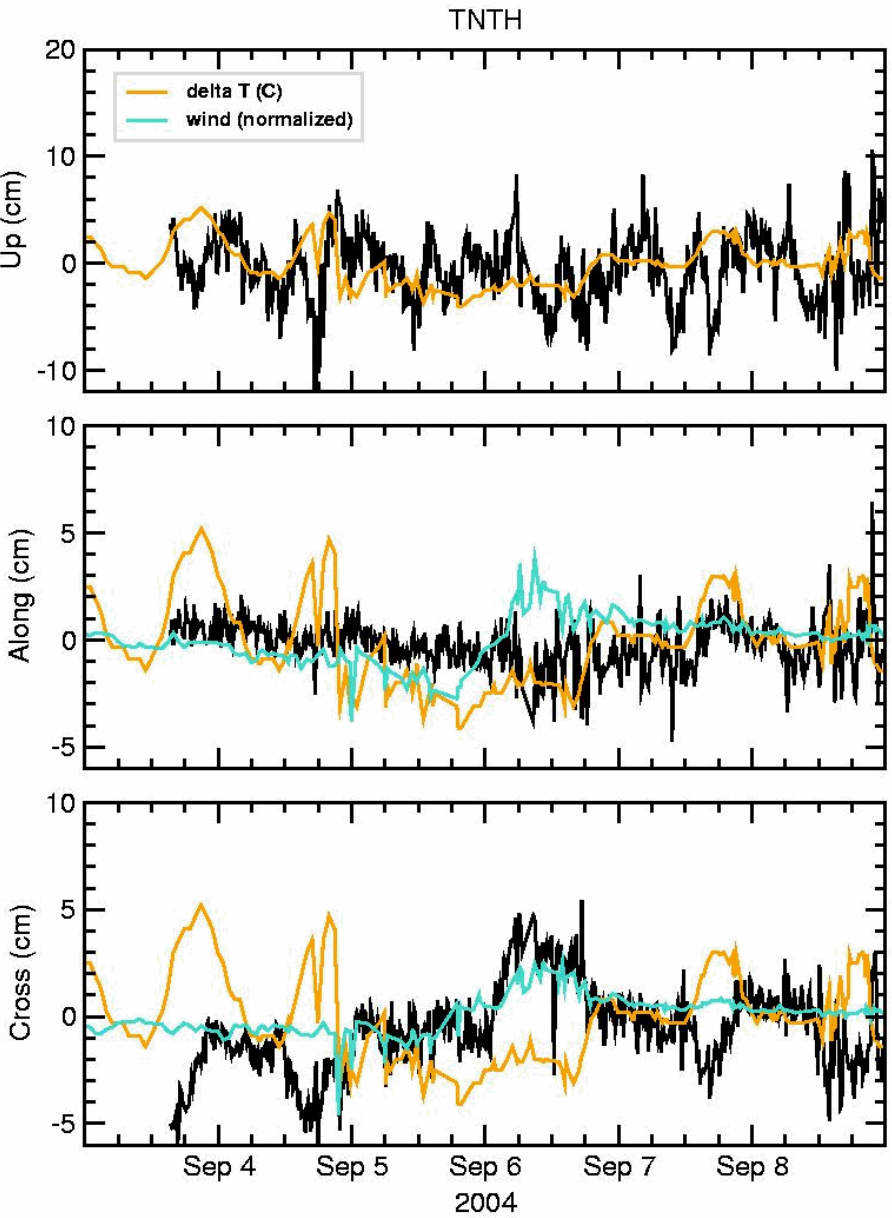

TNTH
coord (mm)
temperature (C)
-wind (mph)
UP (cm)
NORTH (mm)
EAST (mm)
2003

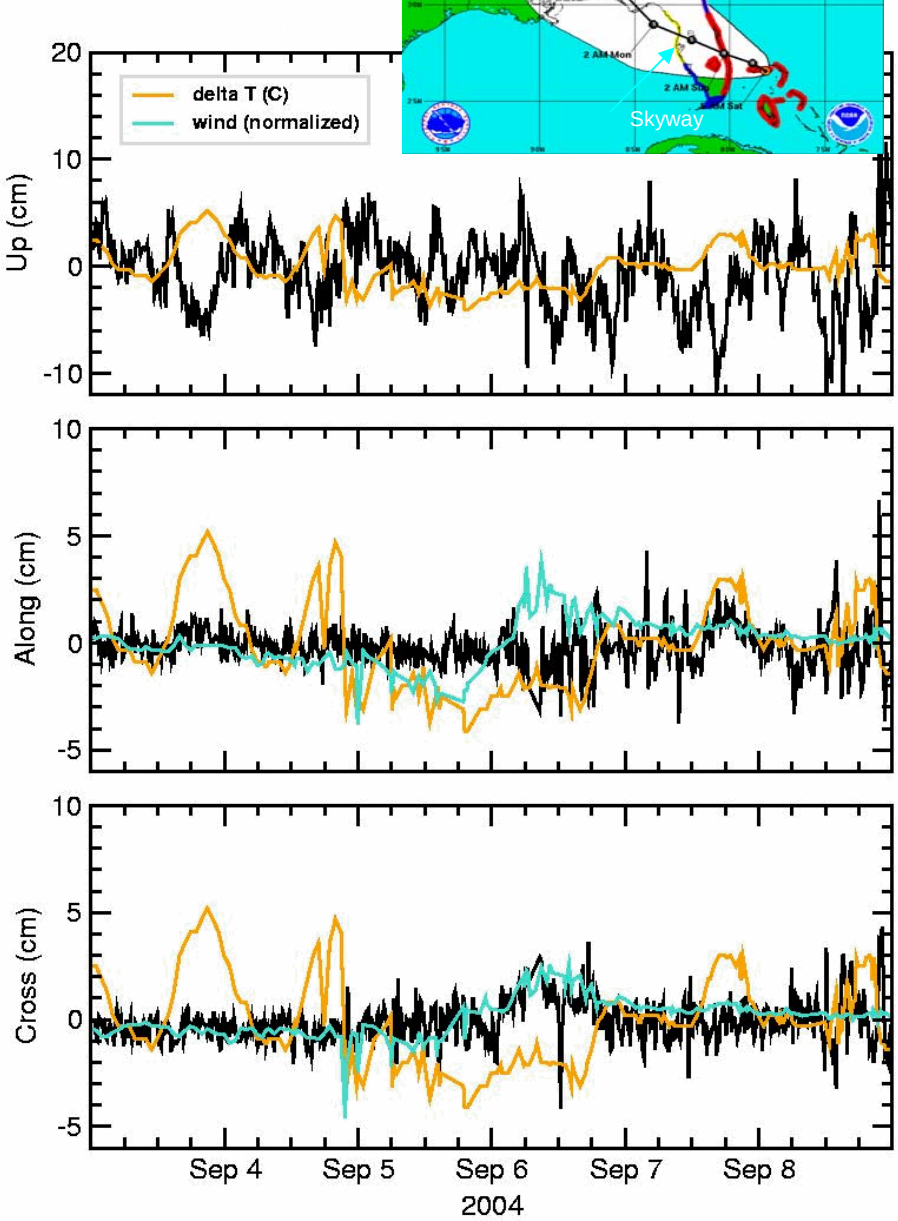

TNTH
coord (mm)
temperature (C)
-wind (kph)
UP (mm)
NORTH (mm)
EAST (mm)
2004

Crossing tracks of Frances, Jeanne, Charley

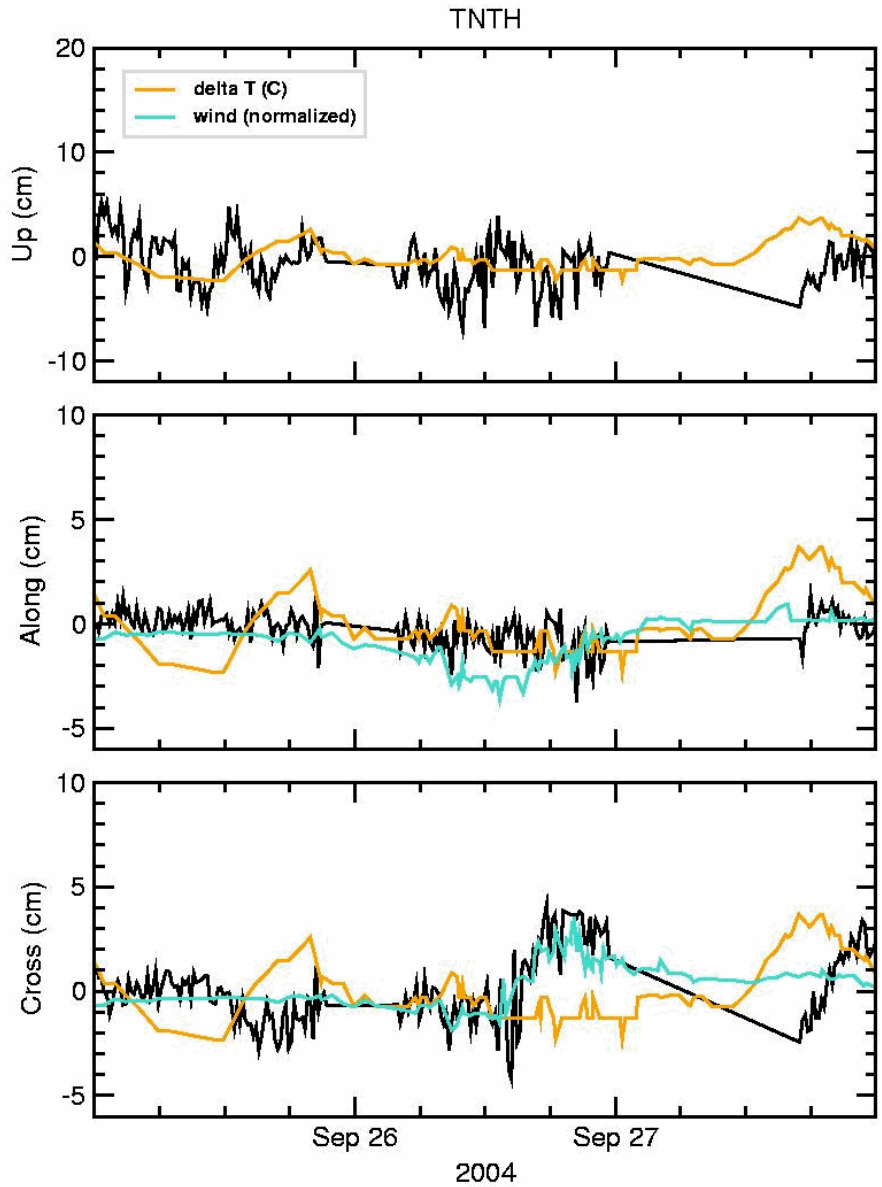
Skyway

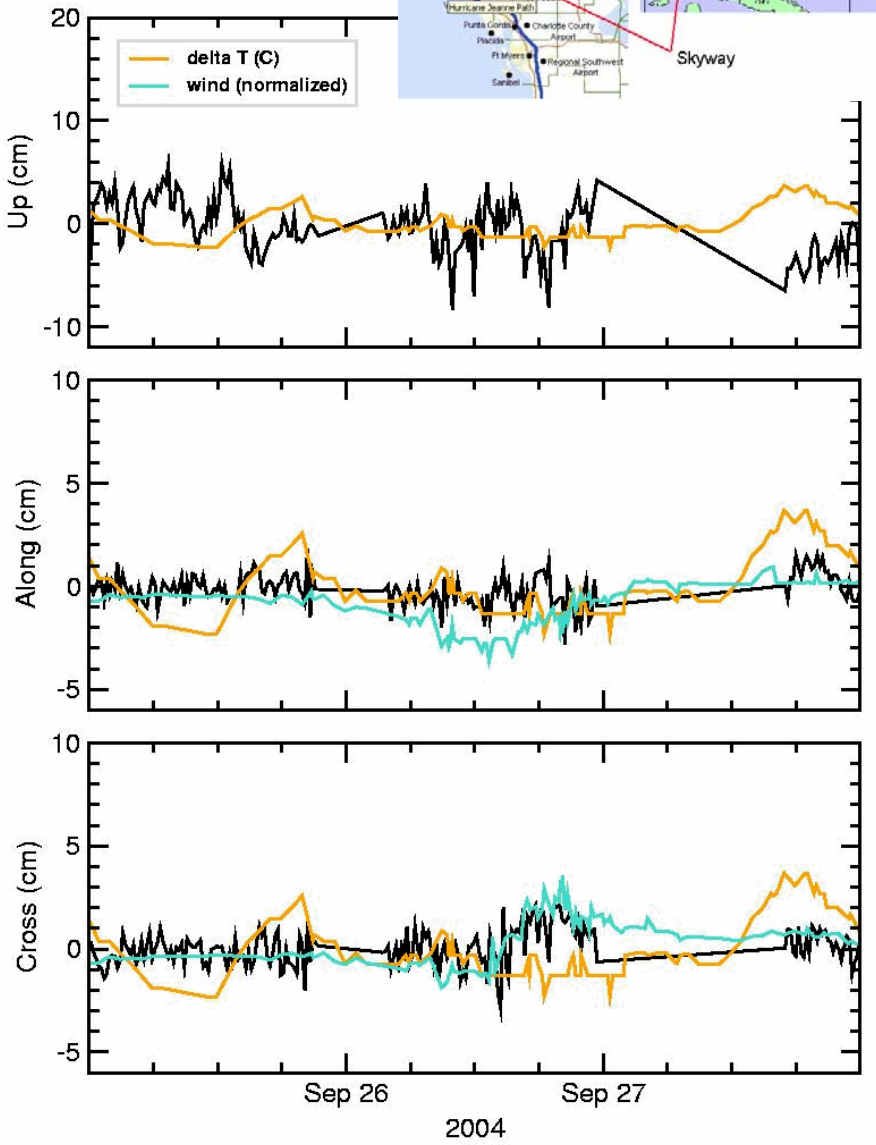
Hurricane Frances



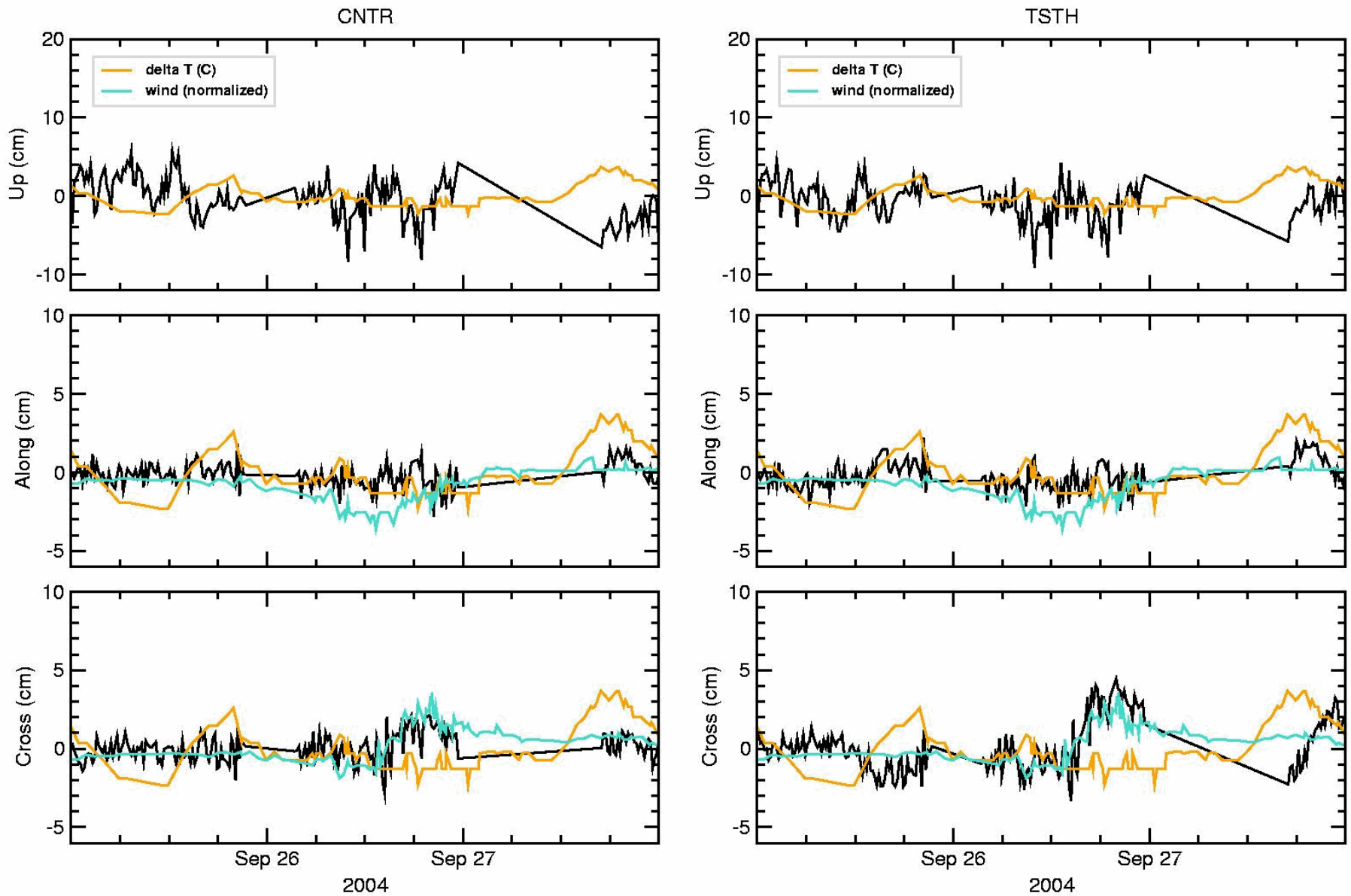


Hurricane Jeanne





Hurricane Jeanne



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Conclusions Close

"Refernece Stations have allowed this technology to enhanced tremendously."

Objective and quantitative information on exact structural asset condition and management- increase life cycle

Reduced costs, delays, and risks in maintaining its Building/ Bridge infrastructure- Safety enhanced

Improved use of cash and capital resources from making "just-in-time" repairs and replacement

Enhanced maintenance practices "objective criteria" instead of subjective Valued 24/7 health Monitoring Solutions

Higher accuracy and Precision

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Funding?
How to influence people and get money

- Educate
- Solicit
- Influence
- Show off your work

New Instruments

- TPS
  - 1 second/ remote
- Visual Targeting
  - Reflectorless
    - Reduced prisms
    - Coaxial optics
    - Reduces risk
    - remote
- Visual Scanning
  - Exceed Tolerance
    - Automatic Scanning
      - Course 10 x 10
      - Fine 1 x 1

3 in 1

1. TPS
2. Scanner
3. Coaxial Camera

Question

- Ask yourself
- Are you ready for a failure?

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Death toll rises to 13 in bridge collapse

Rain hampers recovery efforts

May 28, 2002 Posted: 10:23 PM EDT (0223 GMT)

A portion of the I-40 bridge where the barge struck it

WEBBERS FALLS, Oklahoma (CNN) -- Two days after a 600-foot span of Interstate 40 collapsed into the murky waters of the Arkansas River, the death toll rose to 13 Tuesday, with more bodies expected to be recovered, authorities said.

Rain slowed the recovery effort and the threat of lightning kept divers out of the water.

6 Dead in Minn. Bridge Collapse

Posted Aug 1, 07 9:20 PM CDT in US | Share

(Newser Summary) – A four-lane bridge over the Mississippi River in Minneapolis collapsed during the evening rush, killing at least 6 people and injuring dozens. Witnesses say there were up to 100 cars on the bridge at the time, and as many as 50 were hurled into the river and onto the banks; rescuers rushed to triage victims and put out massive fires.

The FBI and Homeland Security have ruled out terrorism—the *Minneapolis Star-Tribune* reports construction crews had been repairing the section of the I35W bridge that buckled for several weeks. One semi reportedly burst into flames, while some witnesses said that a school bus full of children was on the bridge while it collapsed, though it appears none of the children were injured.

—Greg Atwan

Thank you

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