



Structural Monitoring and Evaluation Tools at Caltech: Instrumentation and Real-Time Data Analysis

S C Bradford, T H Heaton, J L Beck
California Institute of Technology

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Overview

- Dynamic properties of an instrumented Caltech building:
 - Natural frequencies temporarily *decrease* by 4% during strong winds!
 - Natural frequencies temporarily *increase* by 5% during rainfall!
 - The natural frequencies vary on several time scales.
- Analysis of Real Time Data
- Caltech Online Monitoring and Evaluation Testbeds (**COMET**)
- Implications for Structural Health Monitoring techniques that infer damage based on changes in modal parameters



Robert A Millikan Memorial Library



Millikan Library, one of the world's most heavily researched and instrumented buildings, has been studied extensively since its construction in the mid 1960s. Very stiff 9-story reinforced concrete building with one basement and no foundation piles.

A synchronized vibration generator (“shaker”) is installed on the roof for forced vibration tests.

USGS/Caltech **Dense Instrumentation Network** installed in 1998 -- 36 FBA-11 instruments, three horizontal stations on each floor (basement-roof) and three vertical stations in the basement. Digitized with two parallel systems:

- Mt Whitney digitizer/datalogger records triggered events
- Digitexx digitizer system streams real-time data to client computers

California Integrated Seismic Network (CISN) station **MIK** installed in 2001. Three-component episensor on 9th floor, Quanterra datalogger (this station is part of the **COMET** system).



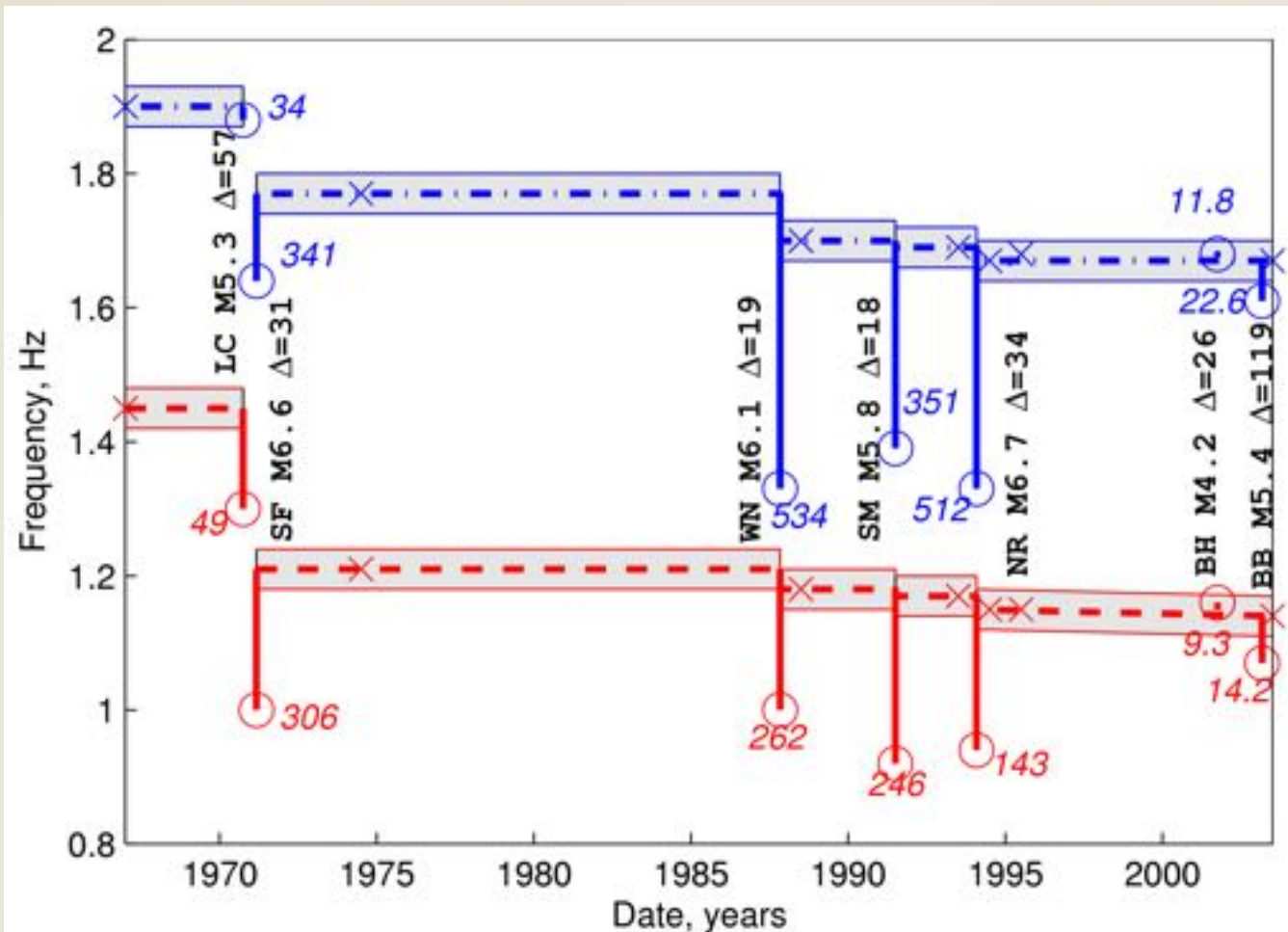
Historical Behavior of Millikan Library

Fundamental **EW** and **NS** modes of Millikan Library since construction.

Crosses indicate frequencies from forced vibration tests.

Circles indicate natural frequency estimates from recorded earthquake events, and numbers in italics are peak roof accelerations from the event (cm/s^2).

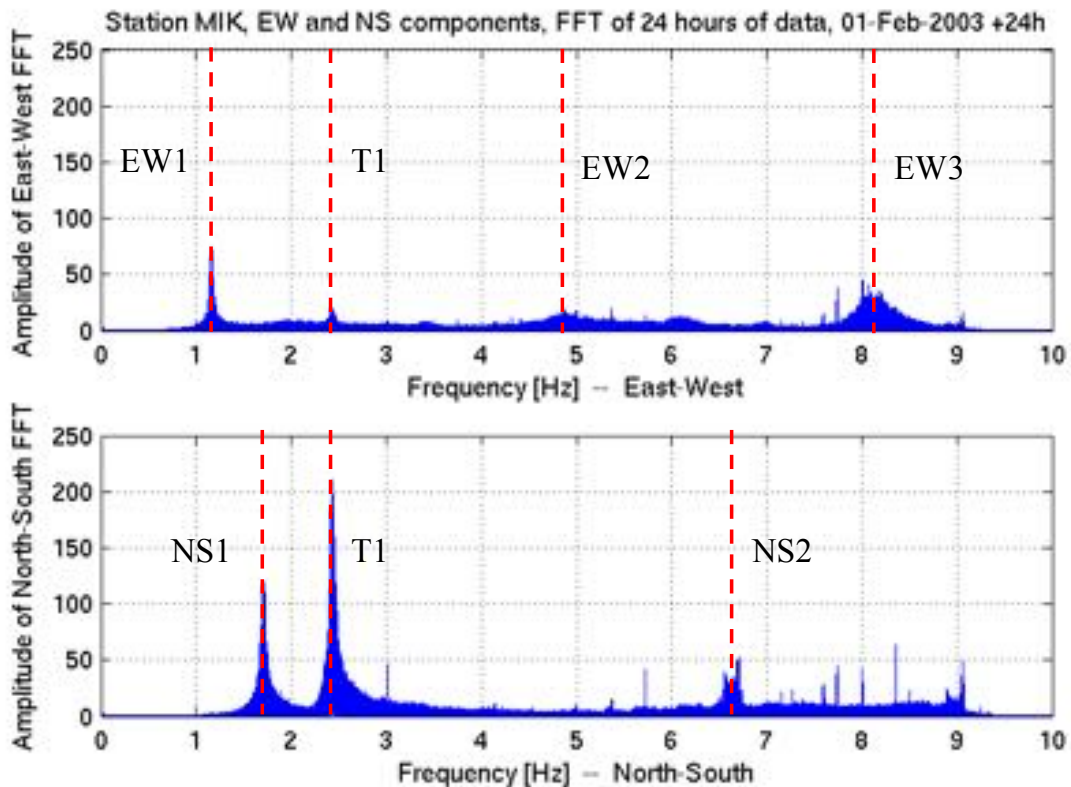
Dashed lines represent the observed natural frequencies of the library, and the shaded region is the likely variance from such factors as weather conditions, weight configuration of the shaker used for forced vibration tests, and experimental error.



[Earthquake Abbreviations: LC: Lytle Creek, SF: San Fernando, WN: Whittier Narrows, SM: Santa Monica, NR: Northridge, BH: Beverly Hills, BB: Big Bear] - (Clinton, 2004)



Frequency Domain



From one day of ambient data, an FFT shows the fundamental frequencies of the library.

The characteristics of an FFT (including the fundamental frequencies) change on several time scales.

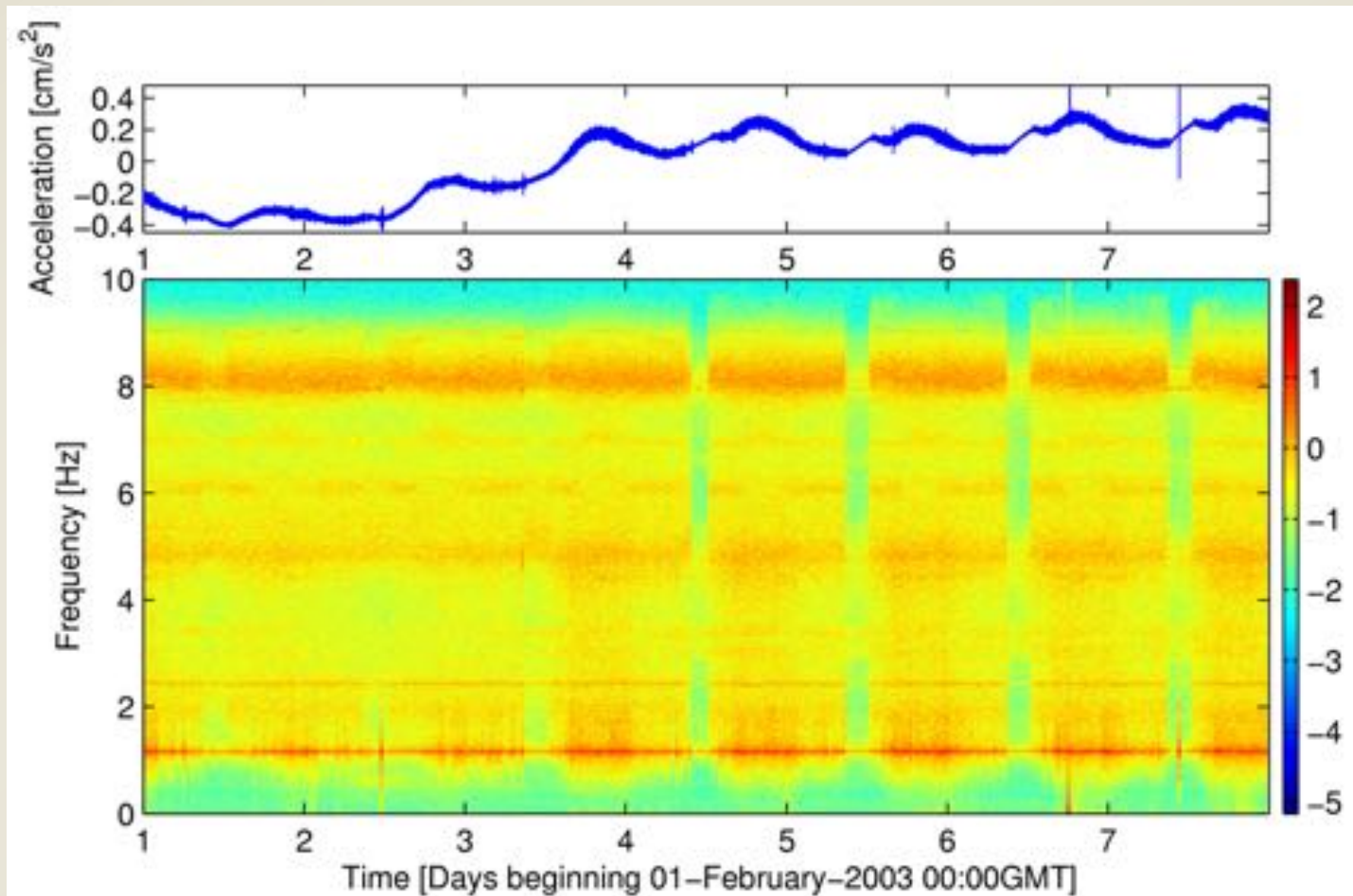


One Week of Data

A spectrogram of **MIK** (EW component) consisting of one week of data, with a running FFT of one hour.

Colorbar indicates log amplitude of FFT.

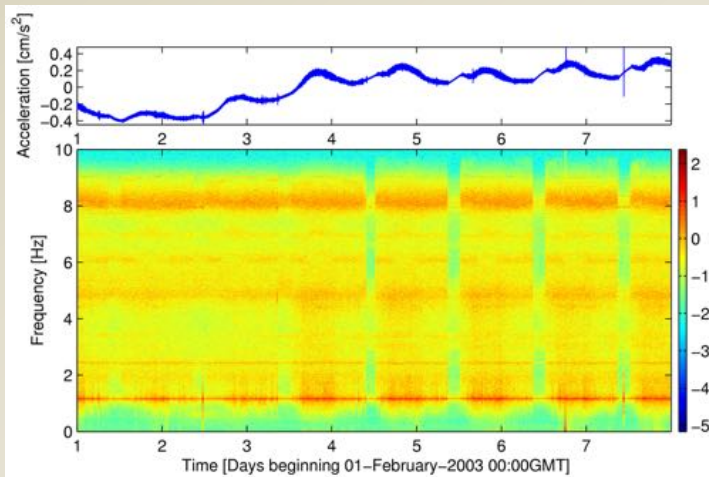
The vertical stripes in the spectrogram are quiet periods, the AC system turns off nightly from Midnight-4AM.



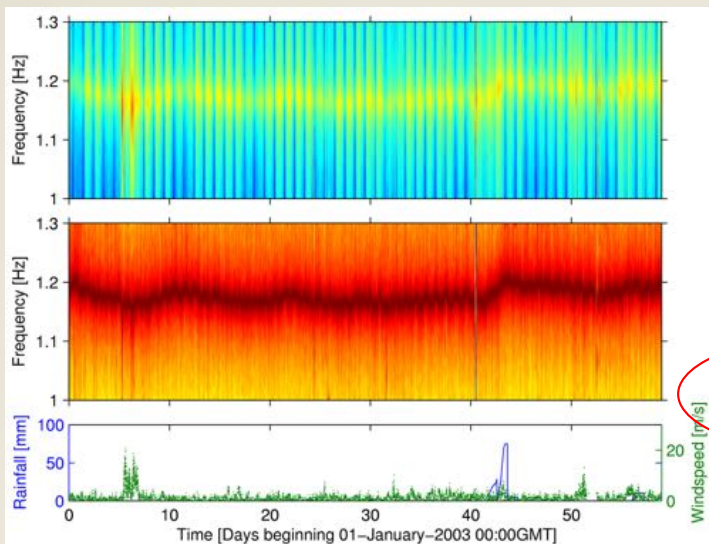


Dynamic Properties of Millikan Library vary on different timescales:

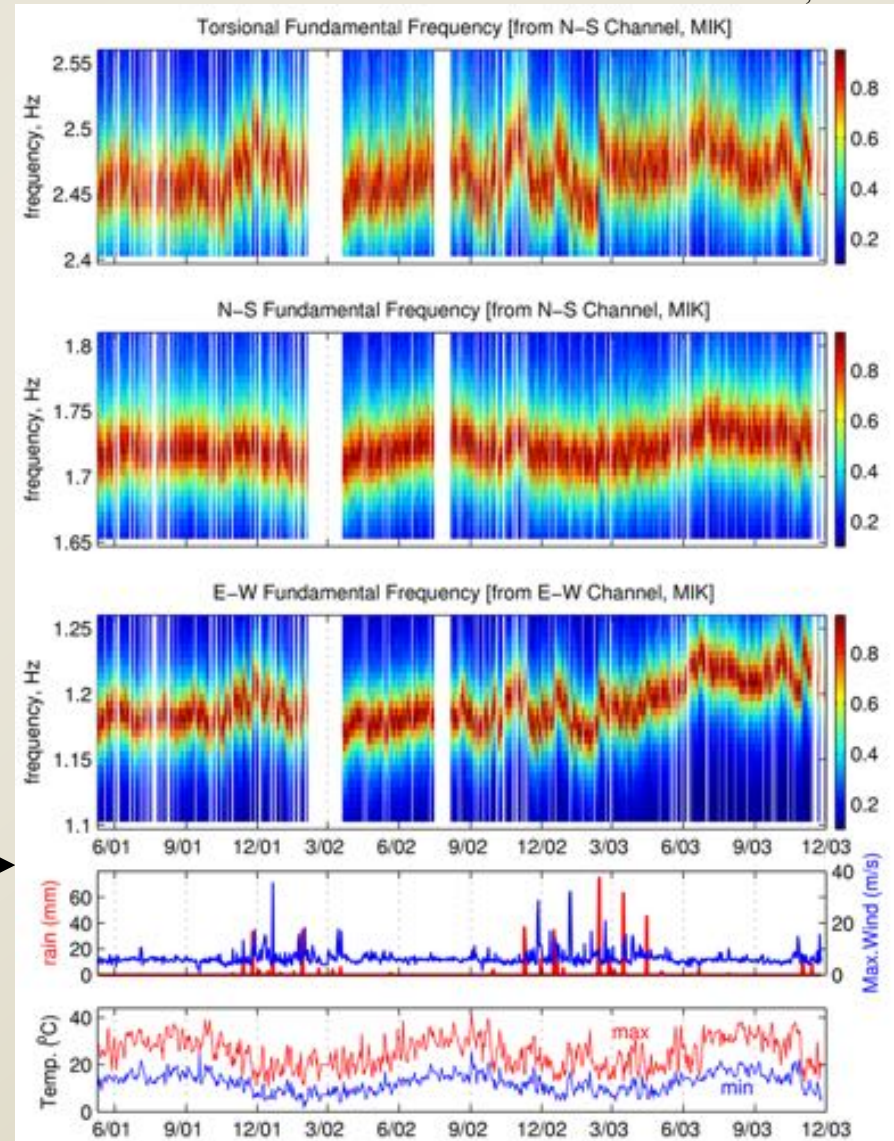
Clinton, 2004



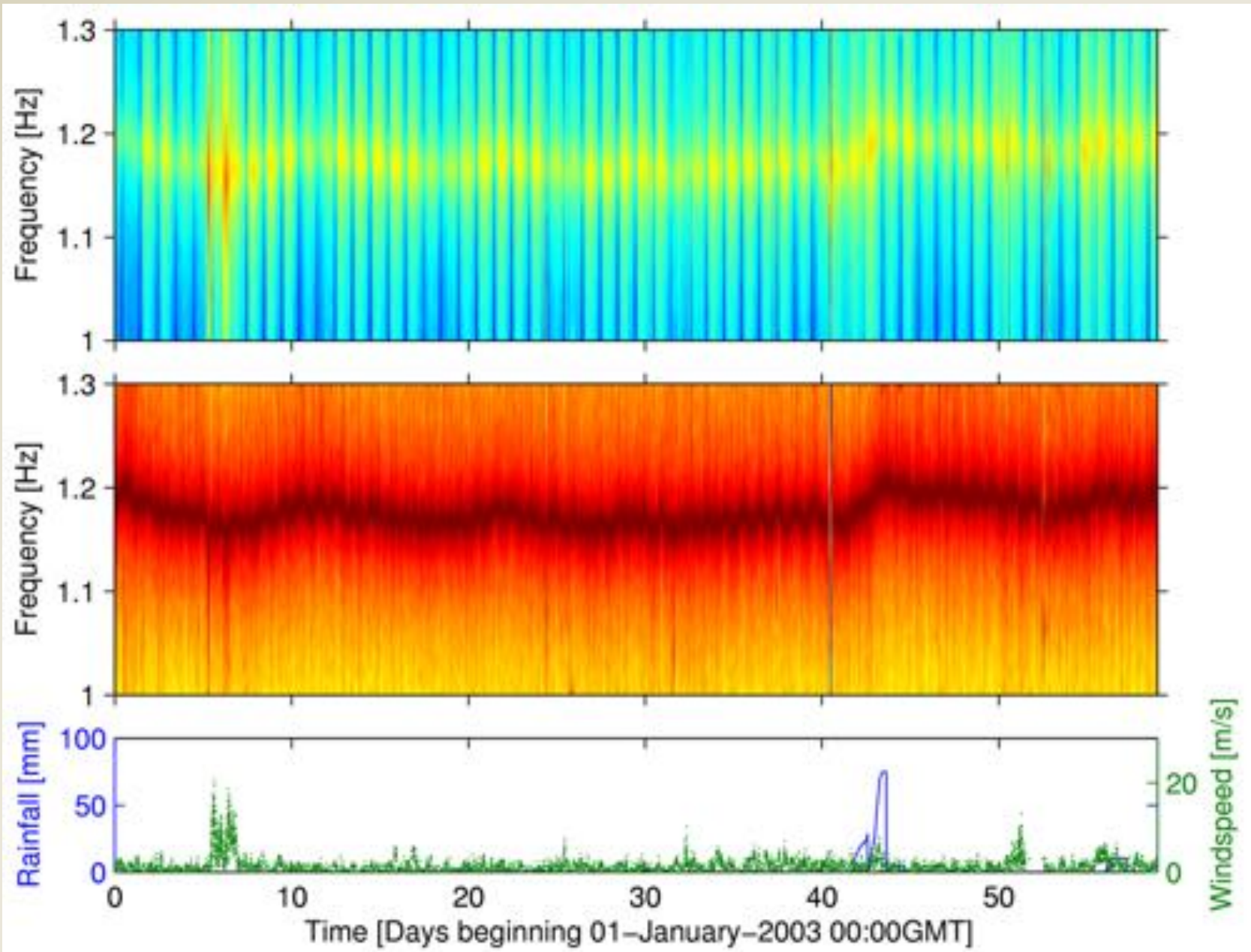
← Days

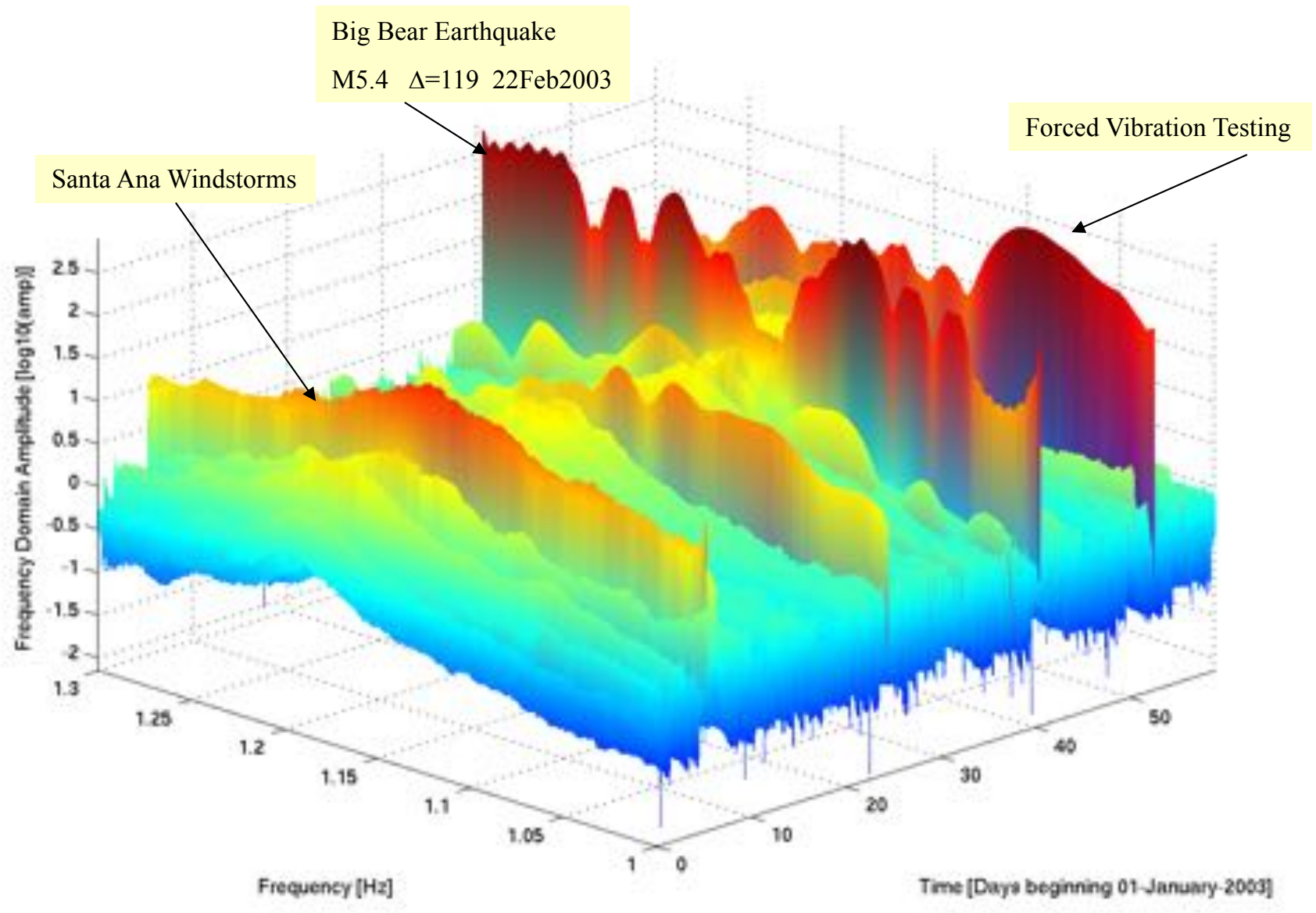


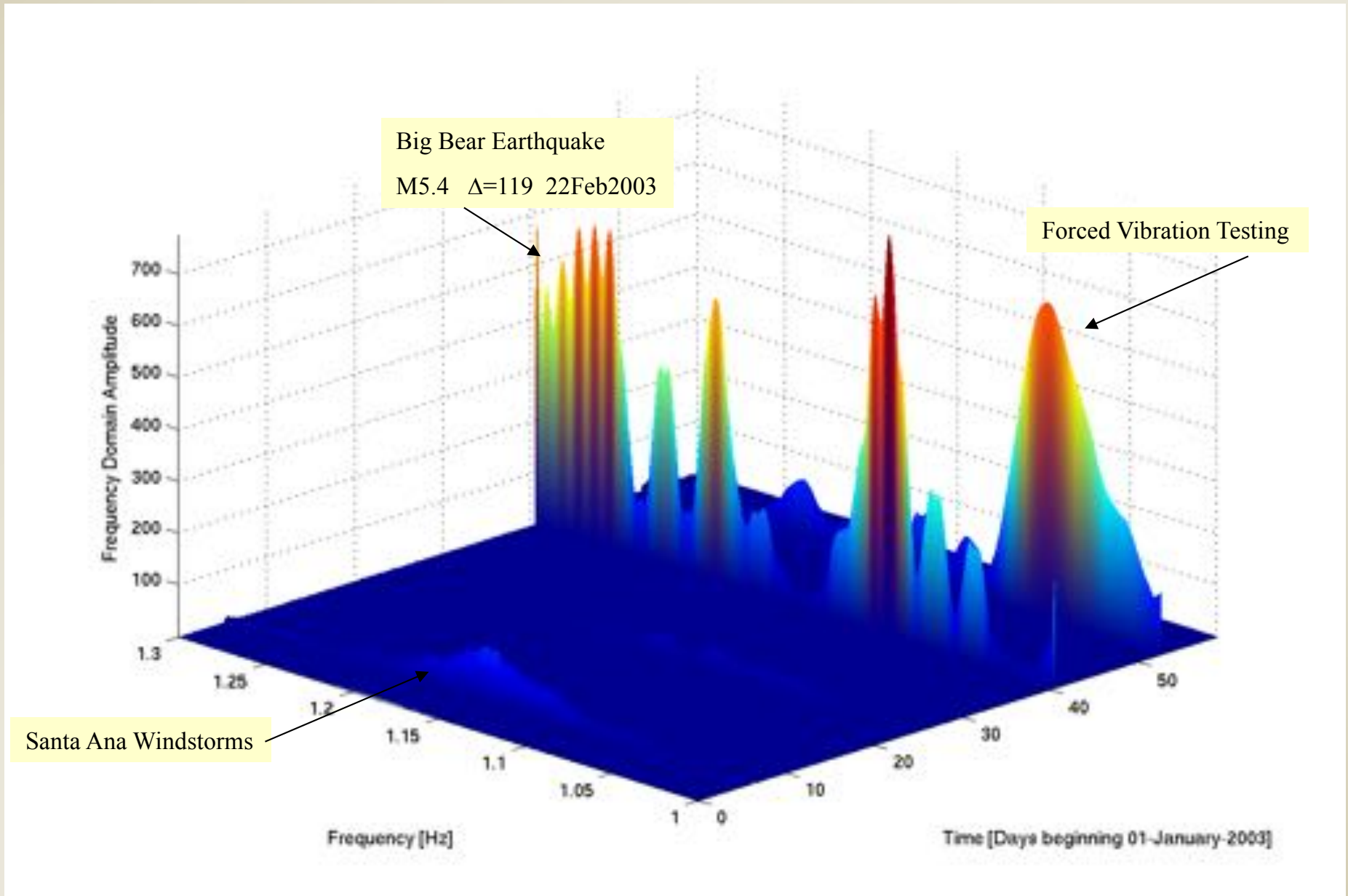
← Weeks

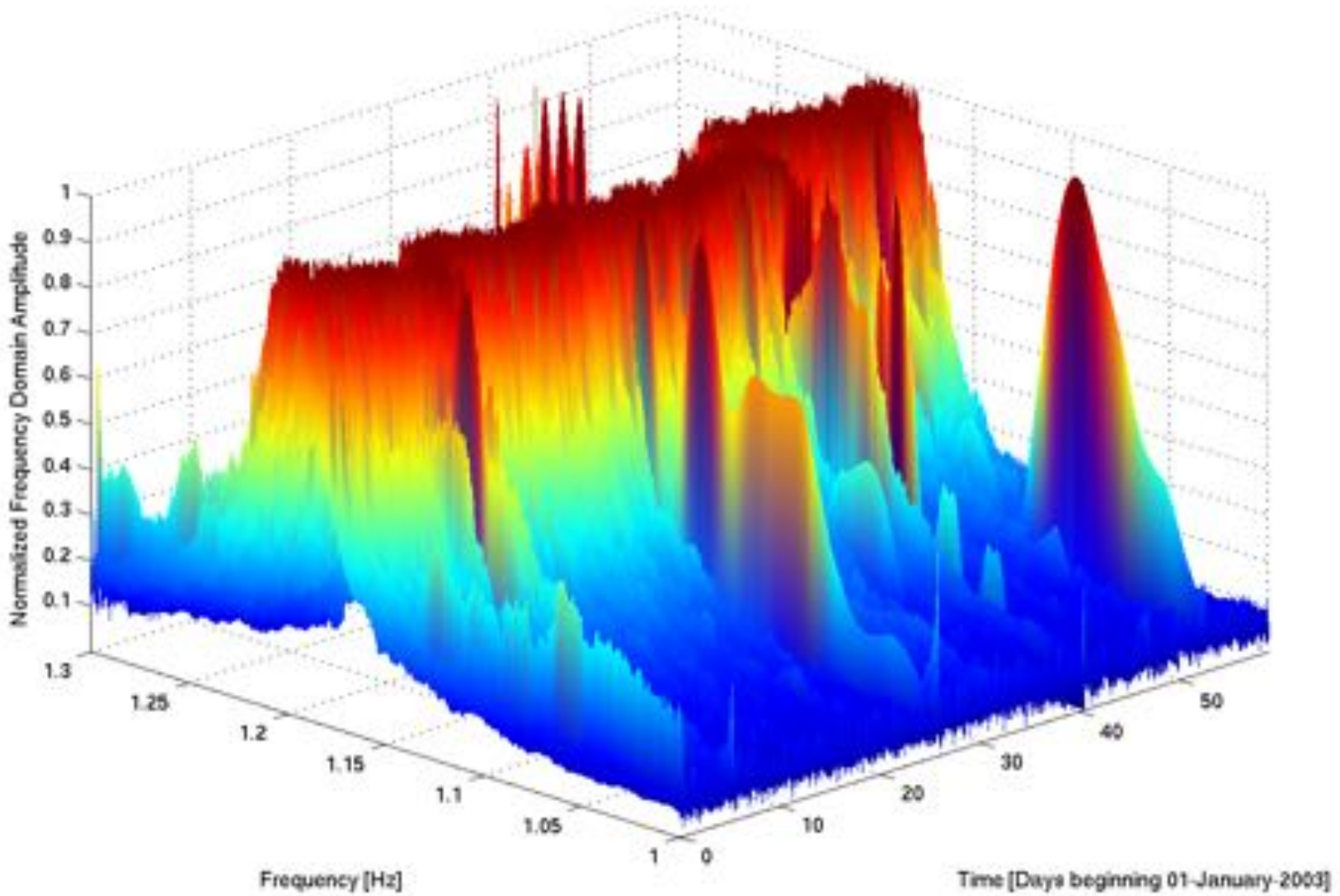


Years →





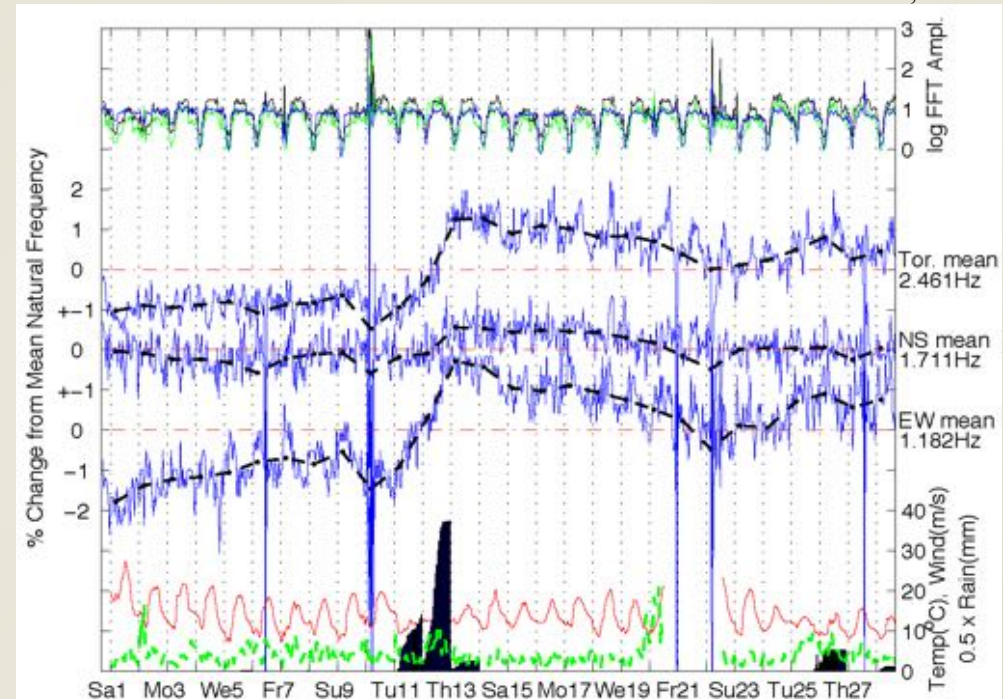
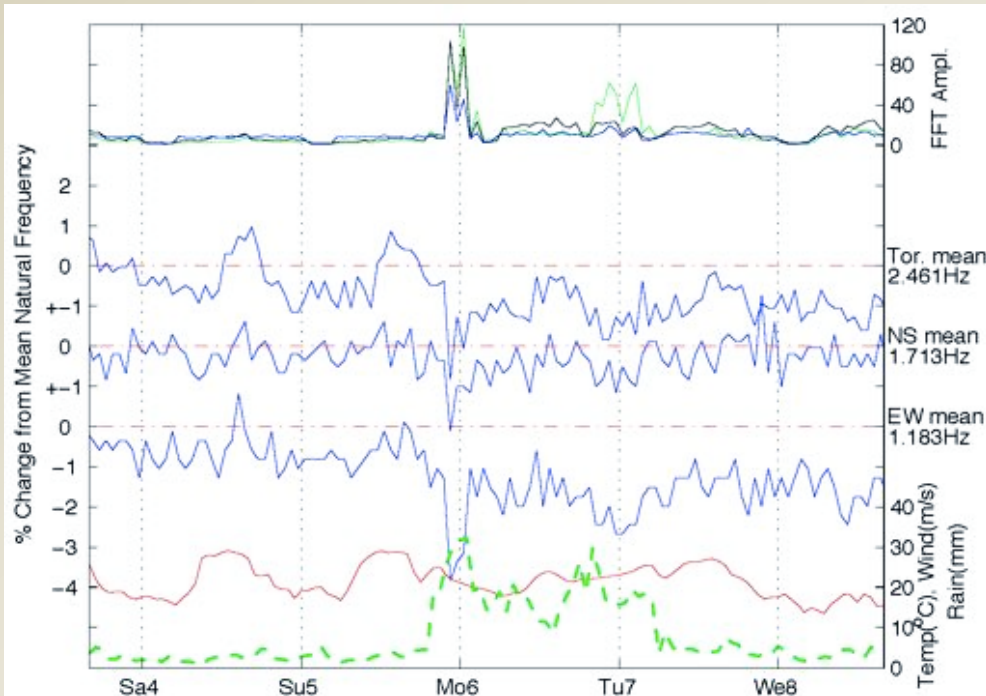






Weather Conditions

Clinton, 2004



Examining data from extreme weather events, we can see that both strong winds and heavy rains can affect the dynamic behavior of the library.

Heavy winds have been observed to temporarily decrease all fundamental frequencies by **2-4%**. The building recovers immediately after the wind event.

Rainfall causes an increase in the EW and Torsional fundamental frequencies of **3-5%**, the NS mode is less strongly affected by rain. Rain effects persist for 1-2 weeks, gradually reverting to pre-rain levels.



COMET

<http://comet.caltech.edu>

The **COMET** site acts as an interface to the CISN database for two Caltech stations: **MIK** (three channels from Millikan Library) and **CBC** (eight channels from the Broad Center).

24-bit data is stored at 80sps for **MIK** and 100sps for **CBC**.

Users can:

- Download data from the **COMET** archives
- Download real-time data
- Display data from the archives or in real time
- Run the MODE-ID application on archived or real-time data

COMET : HOME - [CMT: 02:47:36]
http://comet.caltech.edu/sn_home.asp

Home Help Link Login Signup

COMET
Hosted by Caltech!

[HOME] [About COMET] [Instrumentation] [News] [Contact]

Caltech Online Monitoring and Evaluation Testbeds (COMET)

COMET receives near real-time datastreams from the MIK (Caltech Millikan Library) station and CBC (Caltech Broad Center) station of the California Integrated Seismic Network, provided by the Southern California Earthquake Data Center.

In this website, you can download or display the near real-time vibration data from the sensors on Millikan Library and the Broad Center. This website also allows you to carry out modal identification of the vibration data. These functions can also be applied to past vibration data that is stored for twelve months in the data warehouse of COMET.

- **Signup** and you can download, display and analyze vibration data from this website!
- If you are new to COMET, please refer to **How to Start?** under the Help area for more information about how to use COMET.
- If you have used the system before, please **LOGIN**.



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The screenshot shows a web browser window with the address bar displaying http://comet.caltech.edu/sn_application_modeid.asp. The page title is "COMET : APPLICATION : Mode-ID - [GMT: 03-11-58]". The browser's navigation bar includes "Home", "Member", "Application", "Theory", "Help", "Link", and "Logout". The main content area has a blue header with "COMET" and "Hosted by Caltech!". Below the header, there are navigation links: "[DATA Warehouse]", "[Real Time DATA]", "[Display DATA]", and "[Mode-ID]". The main heading is "MODE-ID" with sub-links "[REAL TIME]" and "[DATA WAREHOUSE]". Under "Real Time Analysis", there are three bullet points:

- You can use **MODE-ID** to do modal analysis for **ALMOST** real time data in this website.
- Specify the duration of data and press the **Start** button, then the server will extract the latest vibration data with the duration you specify (with 30 sec time delay) and calculate the corresponding modal parameters.
- E.g. by selecting the duration to 10 sec and press the **Start** button at 10:00:00am, the server will do analysis on data from 09:59:20am to 09:59:30am.

The "Data Parameters:" section includes:

- Duration: minute(s) second(s)
- SCN:
-

At the bottom, there is a footer with the text: "You are visitor: 6972 since 01-August-2001. This website is maintained by Paul Lane. Please contact gsutton@caltech.edu for any comment or feedback. Last modified at: Wednesday, September 17, 2003 - 12:53:03 AM".



Conclusions

Ambient studies of Millikan Library have helped to quantify the changes in natural frequency that occur at several time scales.

Weather patterns strongly affect the behavior of the building:

- Temporary 4% decrease for strong winds, recovers immediately
- Temporary 5% increase for heavy rains, recovers over ~weeks

Caution is needed when applying Structural Health Monitoring techniques that use a change in fundamental frequencies to infer structural damage.