



Southern Thunder Workshop  
(11-14 Jul 11)

**Unclassified**

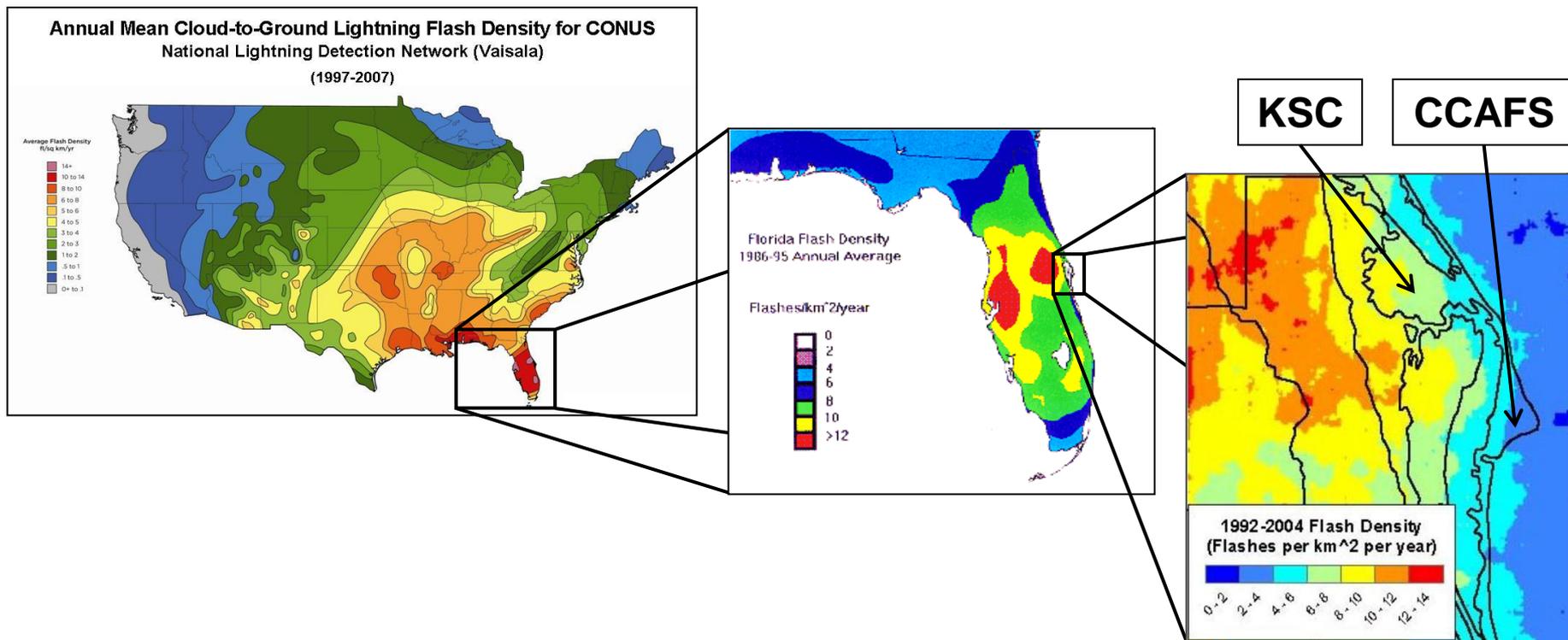
*Status and Plans for the  
Four Dimensional Lightning  
Surveillance System (4DLSS)*

Mr. William P. Roeder  
Meteorologist  
45th Weather Squadron



# Lightning and Space Program in Florida

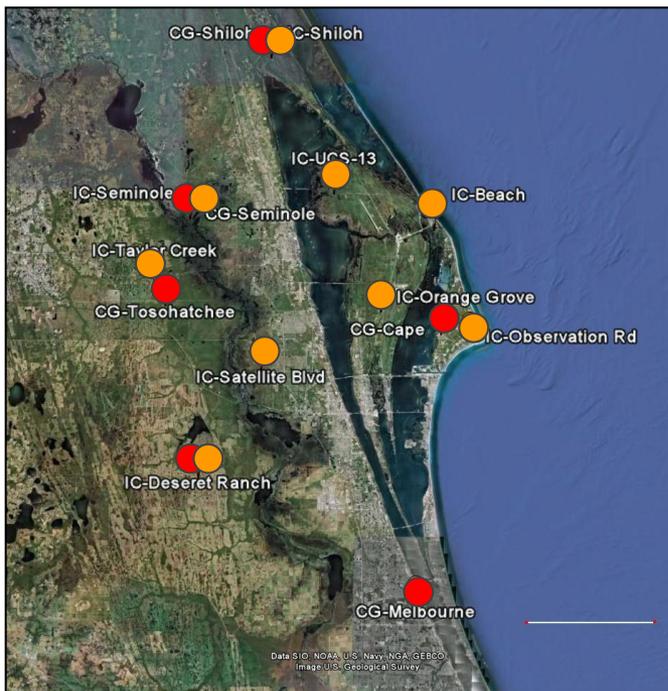
- America's Space Program in Florida
  - Cape Canaveral AFS and NASA Kennedy Space Center
- Central Florida is U.S. "Lightning Alley"





# 4DLSS -- Overview

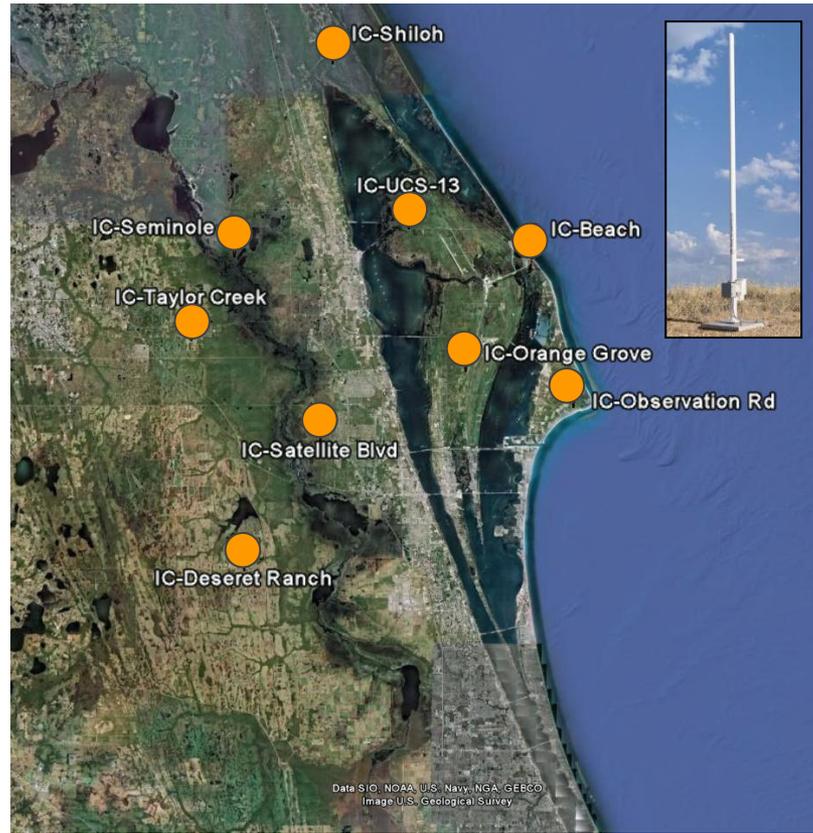
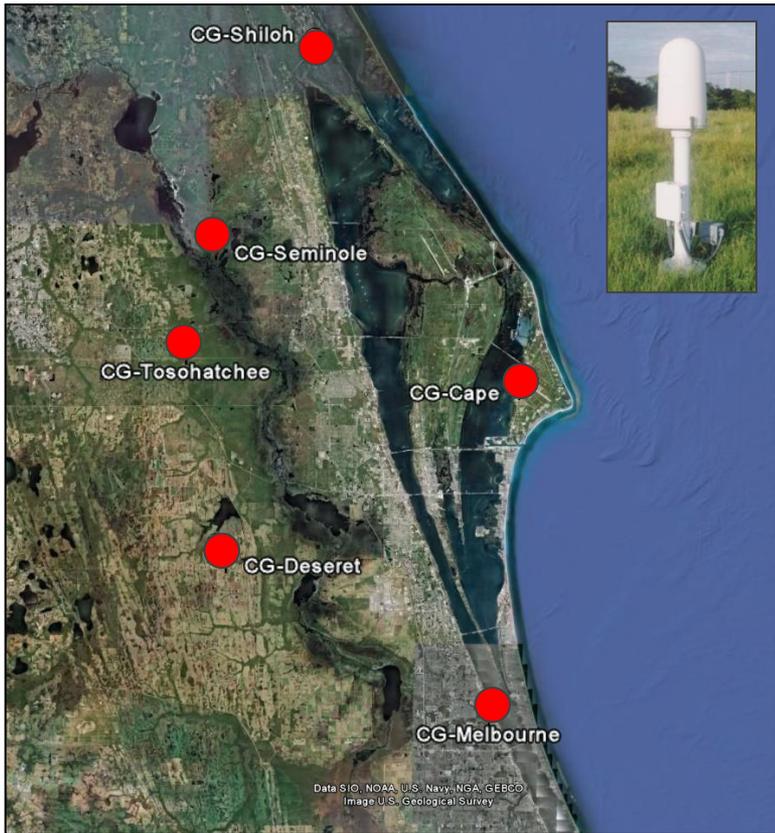
- **Four-Dimensional Lightning Surveillance System (4DLSS)**
  - **Cloud-to-Ground Lightning Surveillance System (CGLSS-II)**
  - **Lightning Detection And Ranging (LDAR-II)**
  - **Integrated into 4DLSS in April 2008**





# 4DLSS -- Overview

- **CGLSS-II: Six IMPACT Sensors In and Around CCAFS/KSC**
- **LDAR-II: Nine LDAR-II Sensors In and Around CCAFS/KSC**





# 4DLSS -- Status

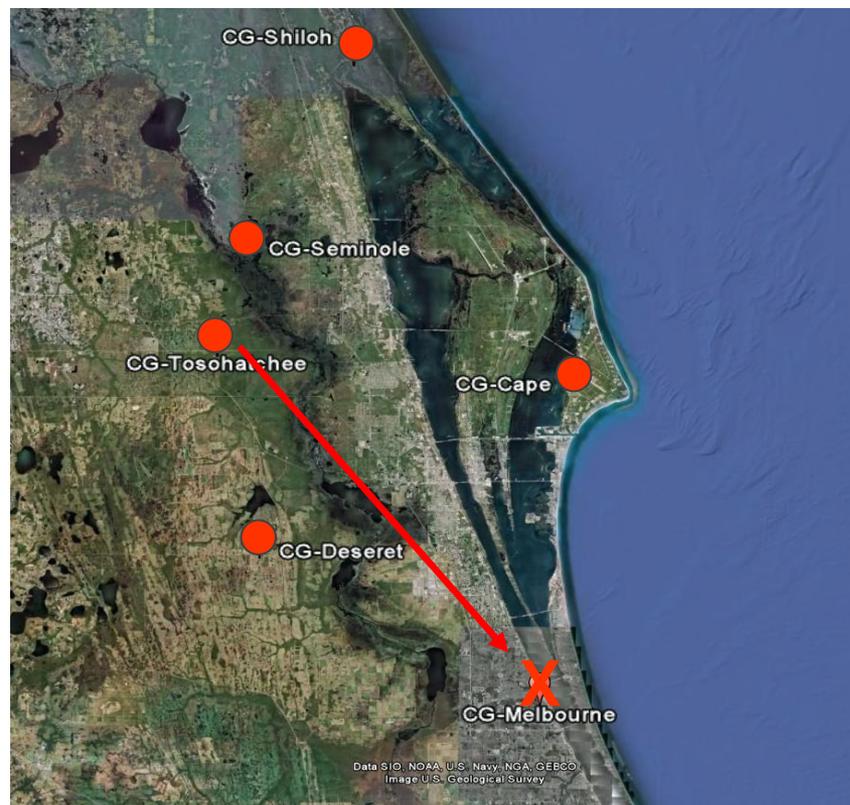
- 4DLSS Status – Bad News, Worse News, Worst News
  - **Long-term sustainability failing for CGLSS-II and LDAR-II**
    - IMPACT sensors no longer produced for CGLSS-II
      - No spare parts!
    - LDAR-II sensors no longer produced for LDAR-II
      - Spare parts purchased for 1-2 Years (through 2012)





# 4DLSS -- Status

- 4DLSS Status – Bad News, Worse News, Worst News
  - **CGLSS-II Melbourne sensor broken by lightning July 2009**
    - CGLSS-II degraded from 6-sensor to 5-sensor Network
      - No spare parts!
    - Tosohatchee sensor moved to Melbourne
      - Optimize network geometry for 5-sensors





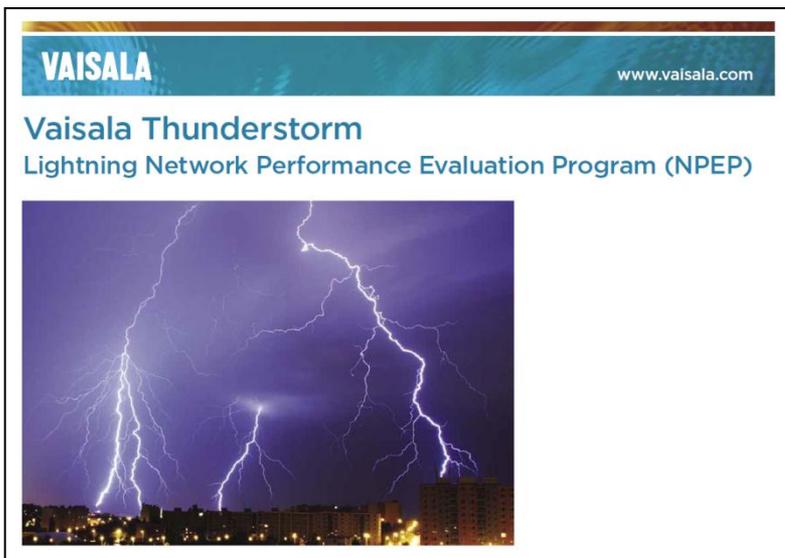
# 4DLSS -- Status

- **4DLSS Status – Bad News, Worse News, Worst News**
  - **CGLSS-II performance degraded much more than expected after sensor moved from Tosohatchee to Melbourne**
    - **Median error ellipses doubled in area**
      - **0.1 nmi<sup>2</sup> to 0.2 nmi<sup>2</sup> for 95% confidence ellipses**
    - **Discovered Jan 2010**
  - **Maintenance program to download optimized configuration settings doesn't download the values**
    - **Discovered Feb 2010**
  - **Maintenance program fixed; correct settings downloaded (Feb 2010)**



# 4DLSS -- Status

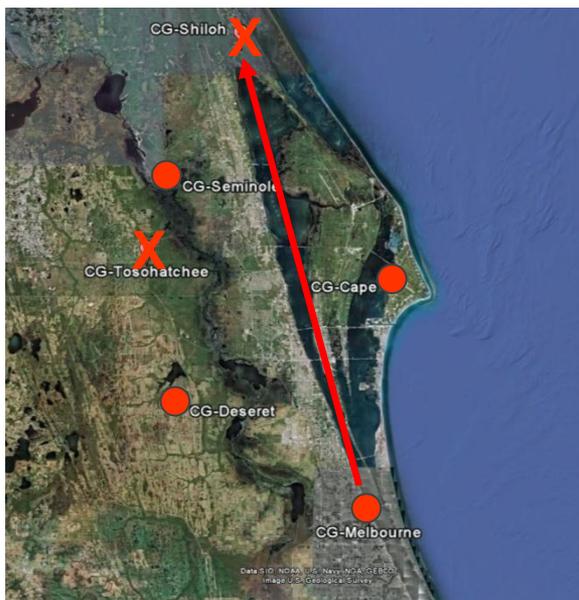
- 4DLSS Status – Bad News, Worse News, Worst News
  - Network Performance Evaluation Program (NPEP) conducted Nov 2010
    - Melbourne sensor needs improvement
      - Large metal building built near sensor unknowingly
    - **Melbourne sensor configuration updated Dec 2010**





# 4DLSS -- Status

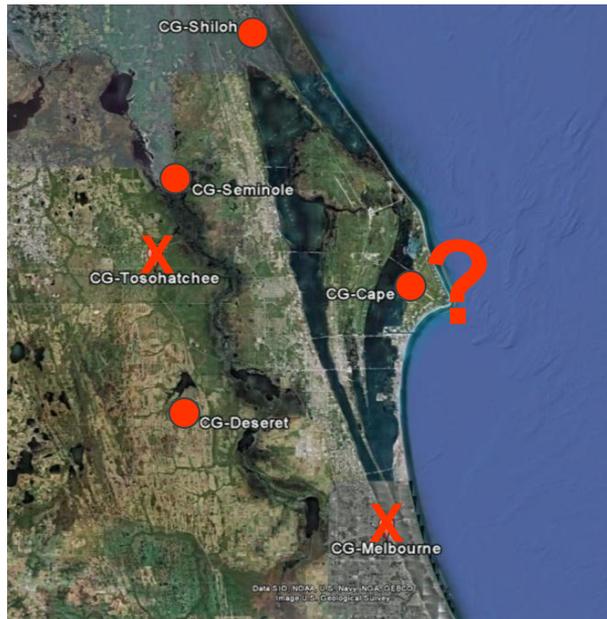
- 4DLSS Status – Bad News, Worse News, Worst News
  - **CGLSS-II Shiloh sensor broke Apr 2011**
    - CGLSS-II degraded to 4-sensor network
    - Melbourne sensor moved to Shiloh
      - Optimize network geometry for 4 sensors





# 4DLSS -- Status

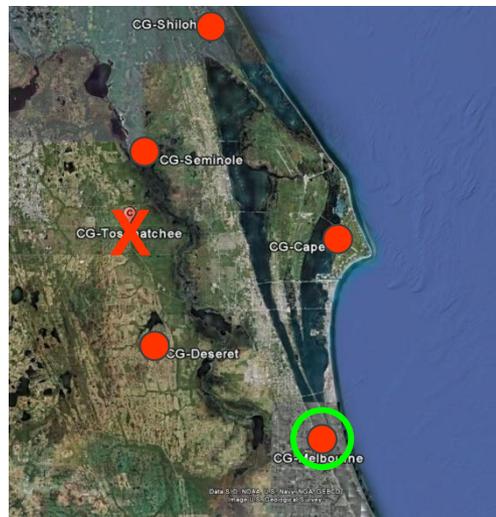
- 4DLSS Status – Bad News, Worse News, Worst News
  - **Discovered Cape sensor excluding negative strokes (Apr 2011)**
    - Allowable rise-time had incorrect setting
    - Negative strokes ~97% of total
    - Cape sensor essentially not being used
      - Cape most important to CGLSS-II performance
      - CGLSS-II has been essentially a 4-sensor network, now a 3-sensor network
    - Date configuration error occurred not known
  - **Cape Sensor Quickly Reconfigured (Apr 2011)**





# 4DLSS -- Status

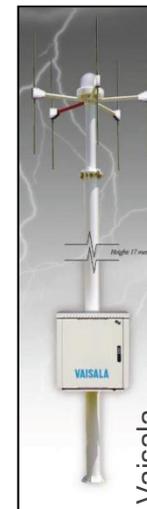
- **4DLSS Status – Bad News, Worse News, Worst News**
  - **Maintenance contractor (Computer Sciences Raytheon (CSR)) built a working IMPACT sensor from two broken sensors (Apr 2011)**
    - **Kudos to CSR!**
  - **Installed Apr 2011 at Melbourne**
  - **CGLSS-II back to 5-sensor configuration**
    - **Still no spare parts!**
  - **Possible 6th IMPACT Sensor from Space Lift Range System Contract (SLRSC)**
    - **CSR is testing the sensor**
    - **CGLSS-II might be back to 6 sensors!**
    - **Still no spare parts!**





# 4DLSS -- Plans

- **4DLSS Plans**
  - **Establish Sustainability – Option #1**
    - **Medium-term solution**
    - **Replace 4DLSS with LS-7001 and LS-8000**
      - **Purchased three LS-7001 sensors**
        - **Replace Tosohatchee sensor**
          - **Get back to full 6-sensor configuration**
        - **Replace Shiloh sensor**
          - **LS-7001 has better digital filtering that should help with radio noise at Shiloh**
      - **Have two spare sensors**
      - **Delayed by computer security issues**
      - **Currently pursuing computer security waiver**





# 4DLSS -- Plans

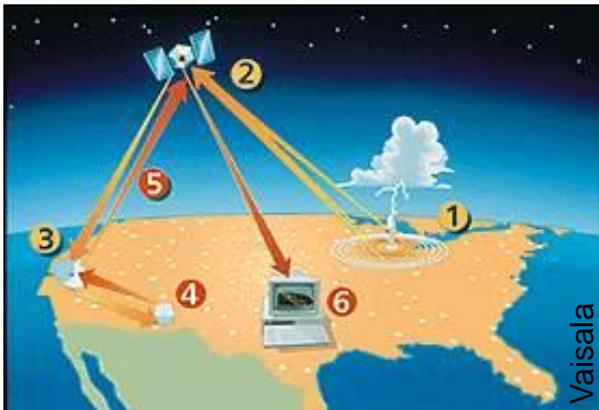
- 4DLSS Plans
  - Establish Sustainability – Option #1
    - Replace 4DLSS with LS-7001 and LS-8000
      - Replace rest of CGLSS-II with LS-7001 thereafter
      - Then begin replacement of LDAR-II with LS-8000 sensors
        - Hopefully with TOA 3-D location capability added
      - These follow-on parts of the plan superseded by Option-3





# 4DLSS -- Plans

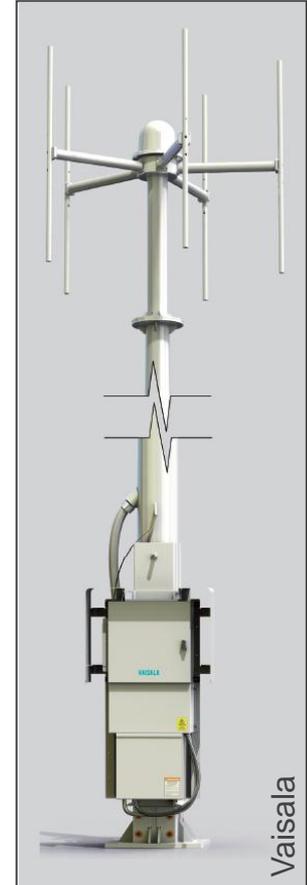
- **4DLSS Plans**
  - **Establish Sustainability – Option #2**
    - Short to medium-term solution
    - Purchase IMPACT Sensors being retired from NLDN
      - Won't have same IA issues as LS-7001 sensors
  - Not being pursued
    - Contractual issues
    - Superseded by Option #3





# 4DLSS -- Plans

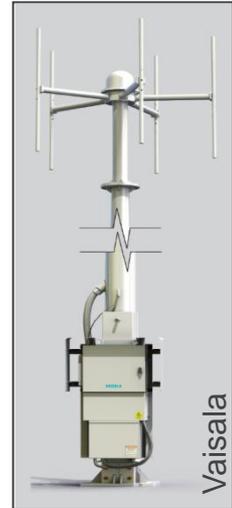
- **4DLSS Plans**
  - **Establish Sustainability – Option #3**
    - Long-term solution
    - Replace CGLSS-II & LDAR-II with new TLS-200 Sensors
      - Long-term sustainability
        - Reduced maintenance cost
        - 8-12 Sensors of one brand new type vs. 15 sensors of two out-dated types
      - Lightning aloft detected, but only x-y location
        - Loss of LDAR-II z-location capability
        - 45 WS can live with it
  - **\$3M funded by KSC**





# 4DLSS -- Plans

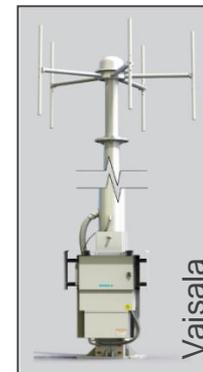
- 4DLSS Plans
  - Establish Sustainability – Option #3 (*con't.*)
    - Integrate 9 in-range NLDN sensors in real-time
      - May overcome problem of CGLSS-II missing ~4% of strong local strokes due to sensor saturation
        - But is sensor saturation causing of the problem?
        - Comments?
      - Robustness when fewer local sensors not used in stroke solution
      - Little loss in performance when many local sensors used in solution



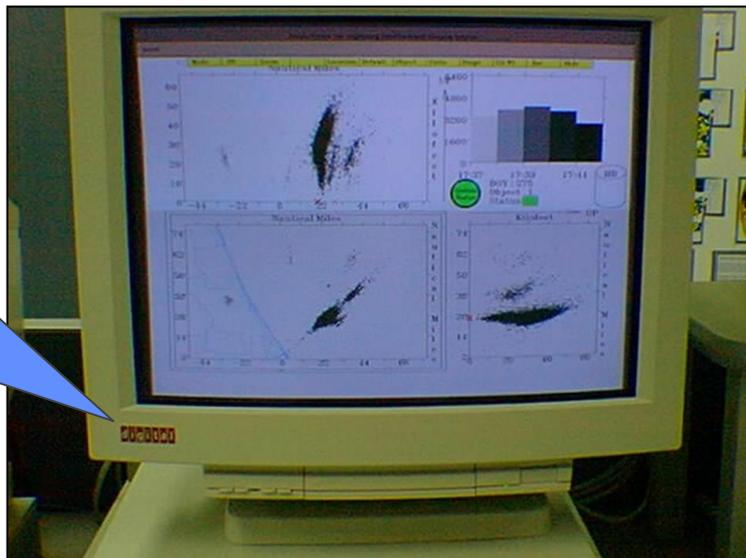


# 4DLSS -- Plans

- 4DLSS Plans
  - Establish Sustainability – Option #3 (con't.)
    - New LDAR-II display
      - Current display software unsustainable
        - Requires VAX proprietary operating system
      - Can't display all activity under high flash rates



*Hill? What hill?  
I don't remember  
going over any hill?!*



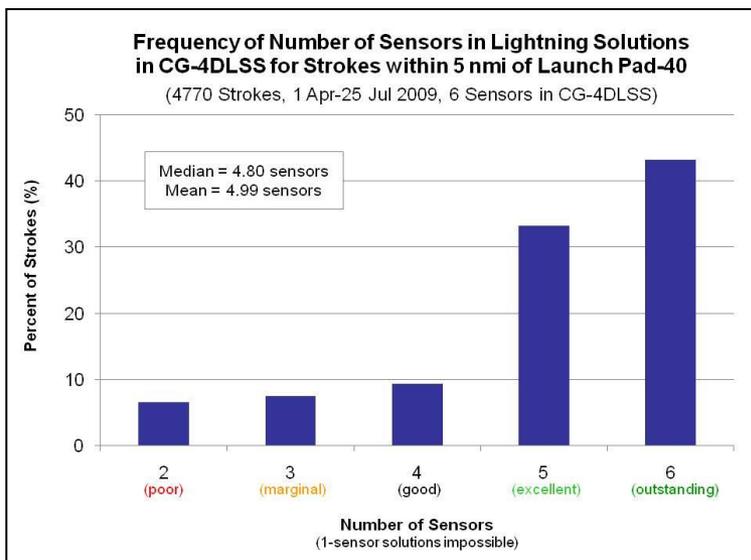
*I'm soooo tired!*



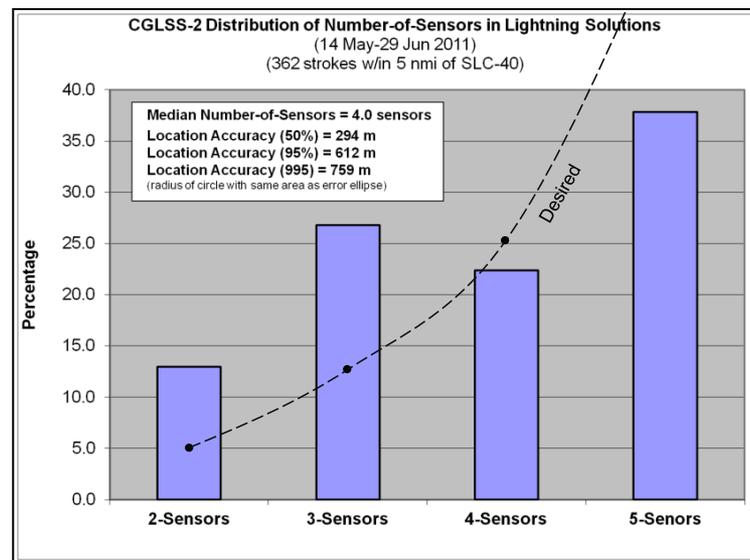
# 4DLSS -- Plans

- 4DLSS Plans
  - Monitor Performance Better
    - Weekly review of CP-8000 performance flags by CSR
      - Depending on local lightning frequency
    - Annual NPEPs by Vaisala
      - May change to biennial if CGLSS-II proves stable

**DESIRED**



**ACTUAL**





# 4DLSS -- Plans

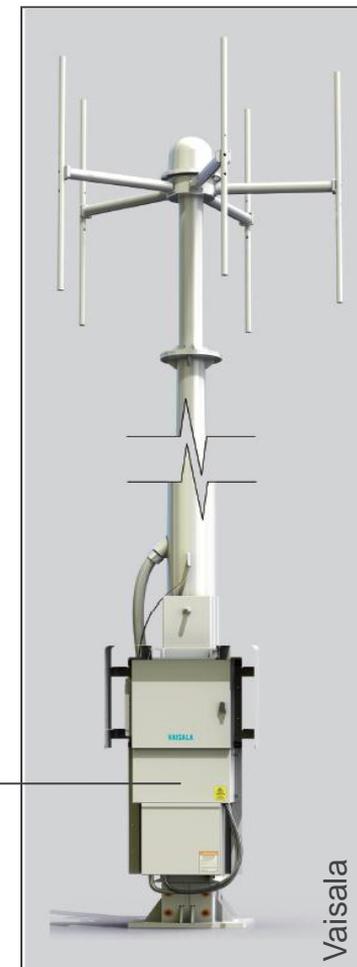
- 4DLSS Plans
  - Move Shiloh CGLSS-II sensor
    - Participates in relatively few lightning solutions to the south
      - Near or including critical launch pads
    - Blockage by nearby radar site?
      - Comments?
    - Radio noise?
      - Might be mitigated by LS-7001 digital filtering





# 4DLSS – *Future Possibilities*

- **Future Possibilities**
  - **Add z-location capability to TLS-200 sensors**
    - **45 WS suggested precise timing already in interferometry, so why not combine with TOA algorithm for z-location**
    - **Vaisala willing to develop subject to funding & manning**
    - **Maybe combine TOA x-y locations with interferometry x-y locations for more reliable final x-y location?**



*Modify software  
to get 'z' capability*



# *4DLSS – Future Possibilities*

- **Future Possibilities**
  - **Improve estimation of peak current and peak current error**
    - **Current peak current algorithm old and not extensively verified**
    - **Goal: Peak current error tailored to each stroke**
    - **45 WS has some ideas for new approach for peak current error tailored to each stroke**
    - **Any researchers interested?**

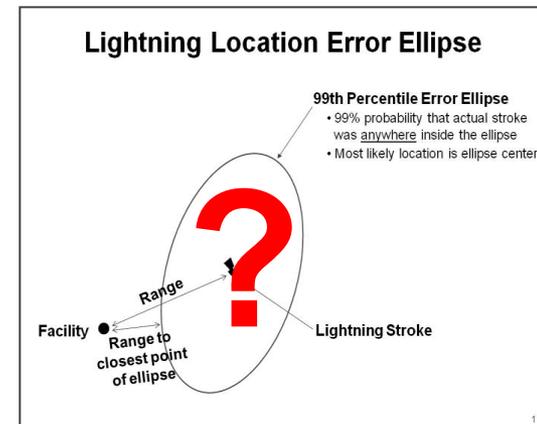


# 4DLSS – Future Possibilities

- Future Possibilities

- Verify error ellipses

- Do half of strokes occur outside the 50% error ellipses?
      - 5% outside the 95% error ellipse?
      - 1% outside the 99% error ellipse?
      - I.e. is the distribution bi-variate Gaussian?
      - Limited anecdotal evidence suggests error ellipses might be a bit too small
    - Any previous verifications of error ellipses? How well done?
    - Requires lots of ground truth with independently proven locations
      - See new lightning detectors at SLC-39B

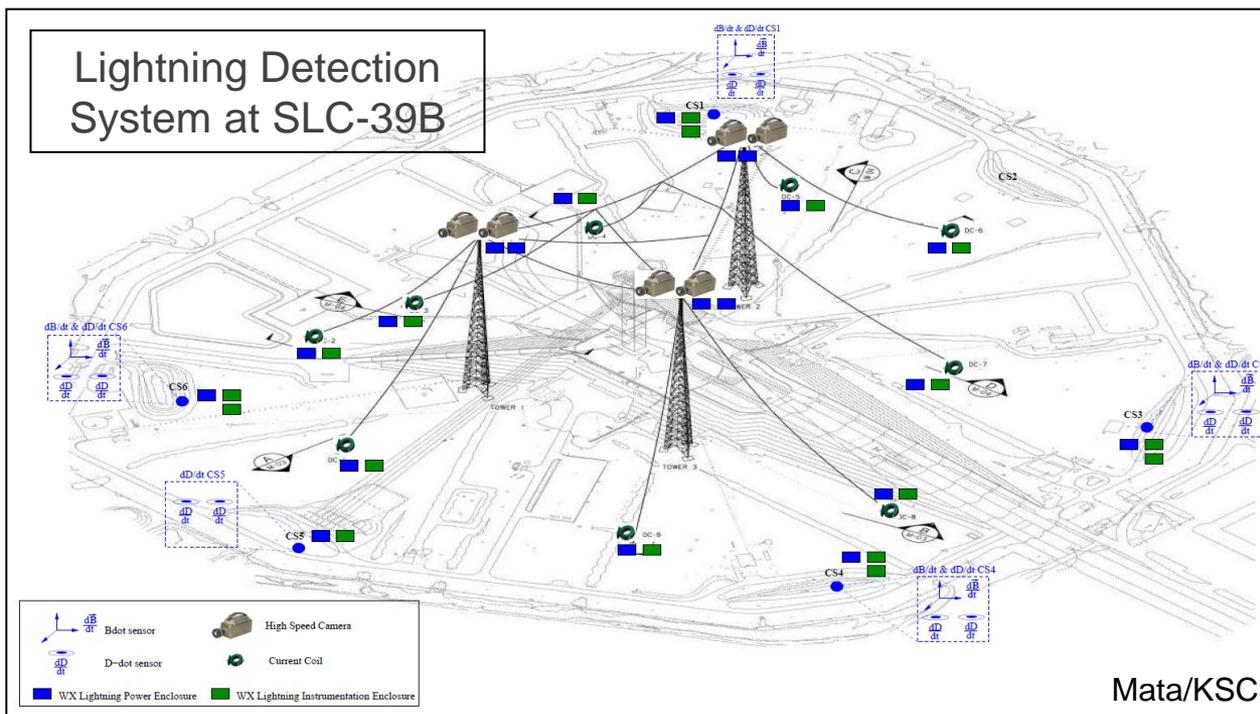




# 4DLSS – Future Possibilities

- Future Possibilities

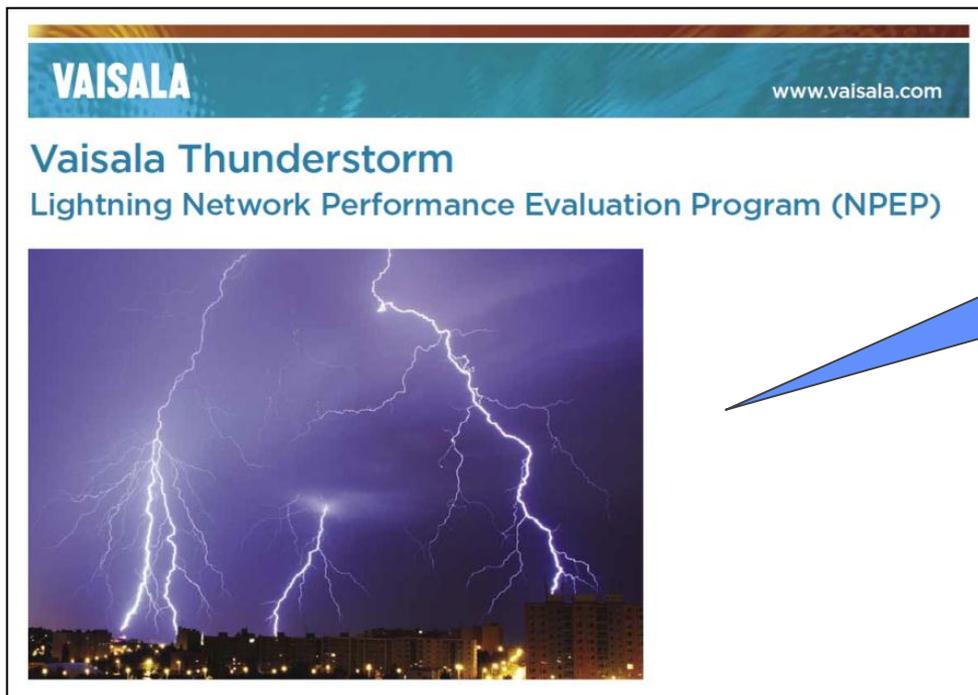
- Use new lightning sensors at KSC launch pad 39B to verify/improve detection rate, location accuracy, error ellipses, and especially peak current/peak current error





# 4DLSS – *Future Possibilities*

- **Future Possibilities**
  - **Develop NPEP for lightning aloft detection networks**
    - **Might be part of Vaisala's TLS-200 plans**
    - **Vaisala, care to comment?**

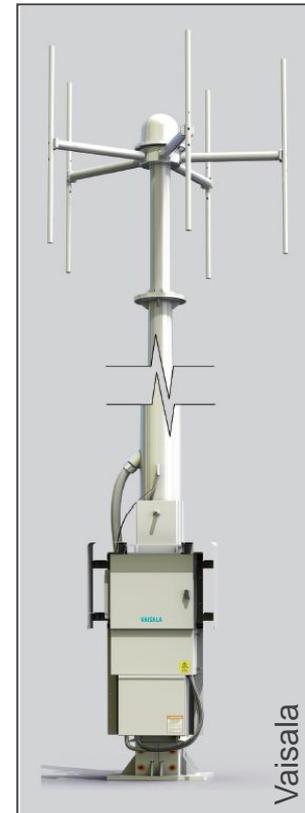


**NPEP for lightning aloft networks, e.g. TLS-200?**



# *4DLSS – Future Possibilities*

- **Future Possibilities**
  - **NLDN to convert in-range sensors to TLS-200s**
    - **Improve total lightning coverage in and around Florida**
    - **Improve 45 WS evaluation of Lightning Launch Commit Criteria**
    - **Many other applications**
      - **Lightning Safety!**
    - **Vaisala, care to comment?**





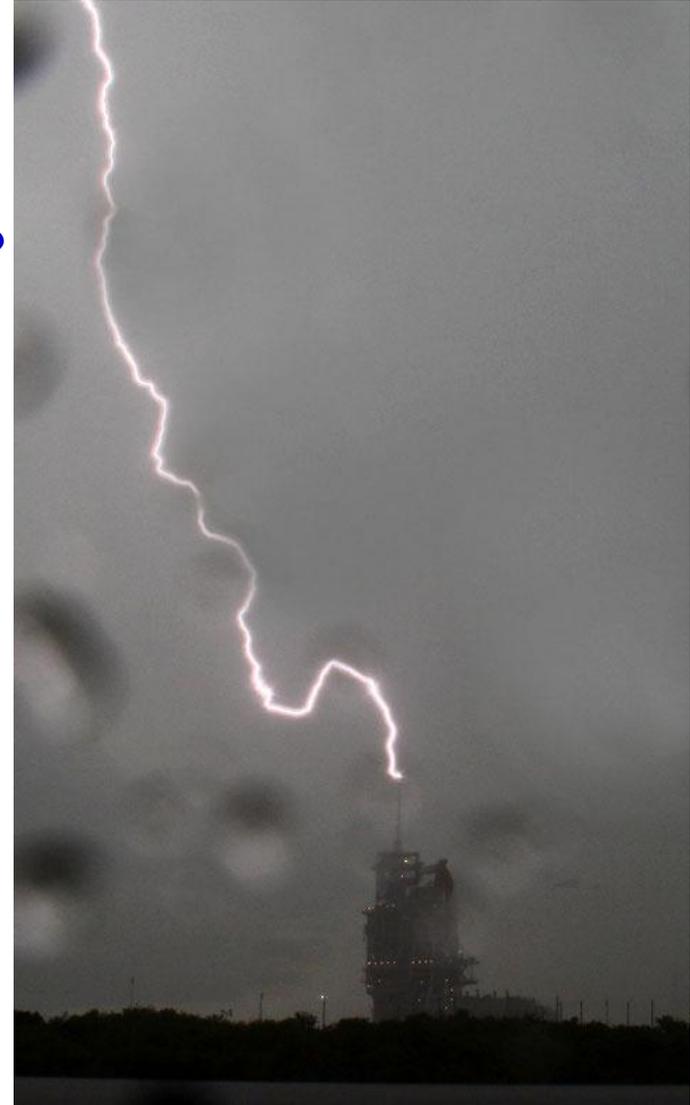
# *4DLSS – Future Possibilities*

- **Future Possibilities**
  - **Develop capability to detect stroke rise-time**
    - **Induced current damage is a function of peak current and rise-time**
    - **Customers need to determine how to use this in their decision process to inspect for induced current damage**



# *4DLSS – Future Possibilities*

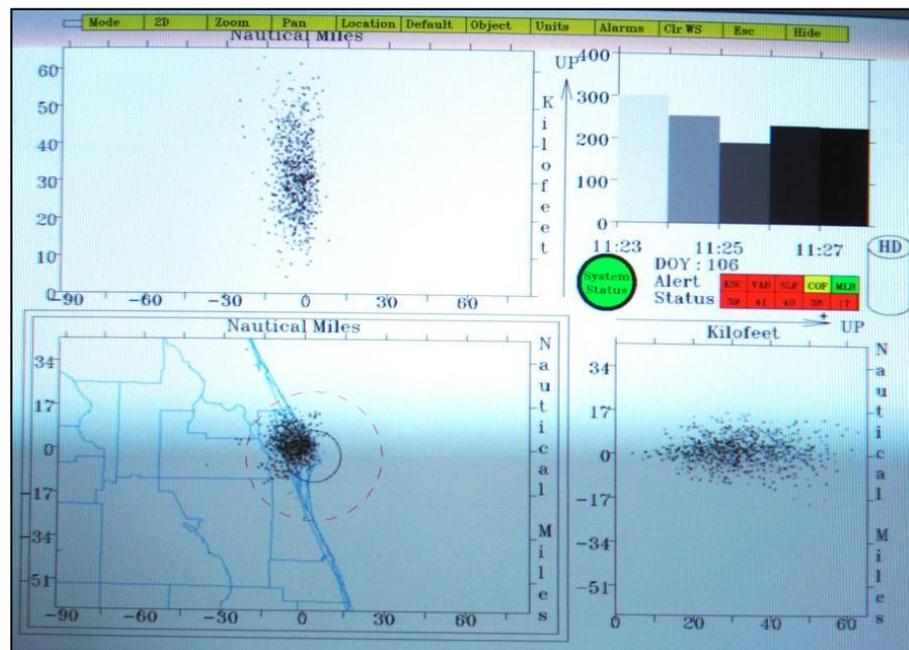
- **Future Possibilities**
  - **Does CGLSS-2 detection rate decrease for strokes to tall objects?**
    - What is detection rate vs. height above ground?
    - Above what height does the effect become important?
    - Is there any way to compensate for the issue?
      - Replay data with increased sensitivity?





# 4DLSS – Miscellaneous

- 4DLSS -- Miscellaneous
  - Previous problem of LDAR noise on cold mornings
    - Much less frequent and much less intense than in past
      - Presumably due to switch to digital TV
    - Minor Inconvenience
    - Occurs when lightning not expected and no deep convective clouds are present
    - No action required

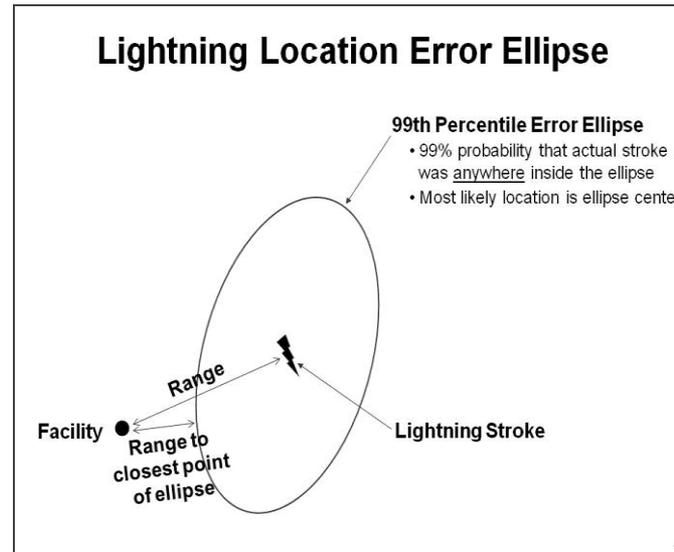


Extreme case – ~once per year



# 4DLSS – Miscellaneous

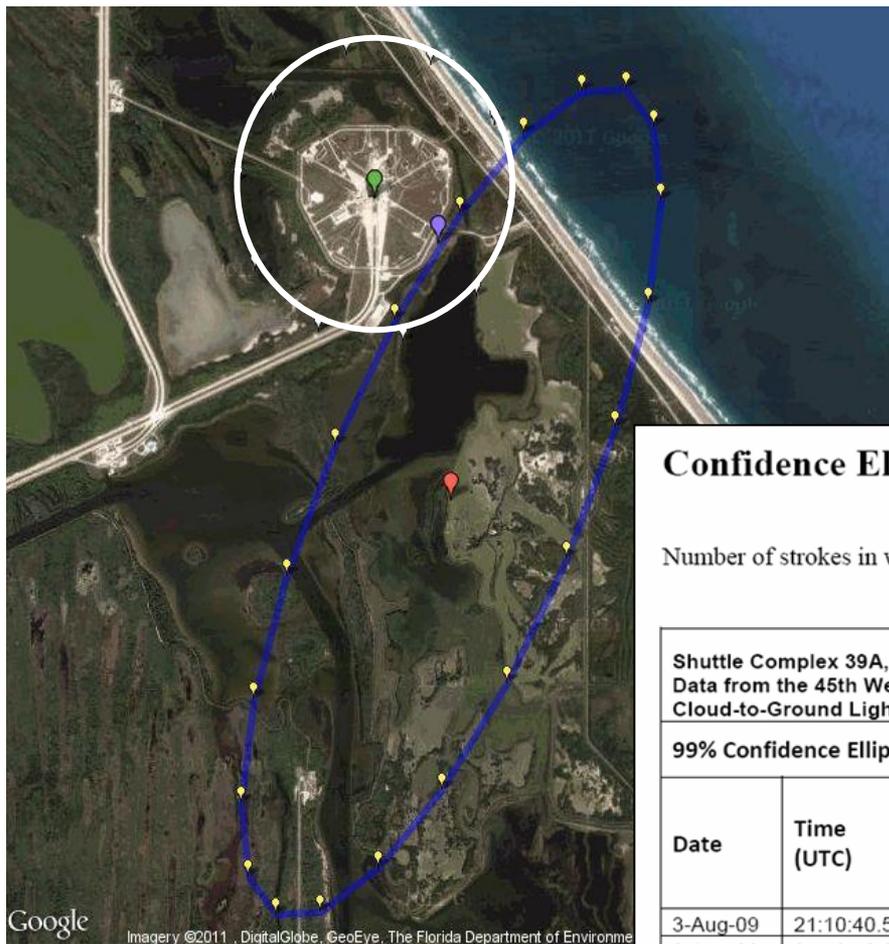
- 4DLSS – Miscellaneous
  - Error ellipses provided to customers
    - 95% or 99% error ellipses depending on launch customer
      - Scaled from 50% error ellipses provided by CP-8000
    - Distance from key facility to most likely location
    - Distance from key facility to closest edge of ellipse





# 4DLSS – Miscellaneous

## Example of CGLSS-II Error Ellipse Product



### Confidence Ellipse Data

Number of strokes in which the center of the launch complex is inside the 99% confidence Ellipse: 3

Shuttle Complex 39A, 3 August 2009  
Data from the 45th Weather Squadron  
Cloud-to-Ground Lightning Surveillance System II (CGLSS II)

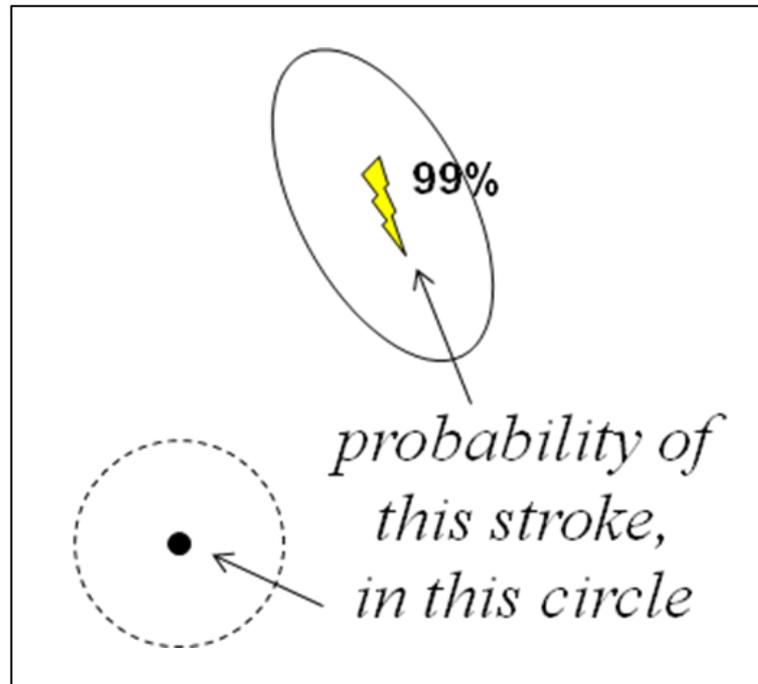
#### 99% Confidence Ellipse Data

Date	Time (UTC)	Magnitude (kA)	Azimuth	Range (NM)	Azimuth (to Ellipse*)	Range (to Ellipse*)	Magnitude (kAmps)	Target Inside Ellipse*?	Sensors in Solution
3-Aug-09	21:10:40.527	-39.8	288.4	0.46	26.3	0.11	-39.8	Yes	3
3-Aug-09	21:10:40.601	-32.2	296.4	0.42	53.3	0.42	-32.2	Yes	2
3-Aug-09	21:10:41.240	-49.1	292.9	0.61	101.9	0.09	-49.1	Yes	4



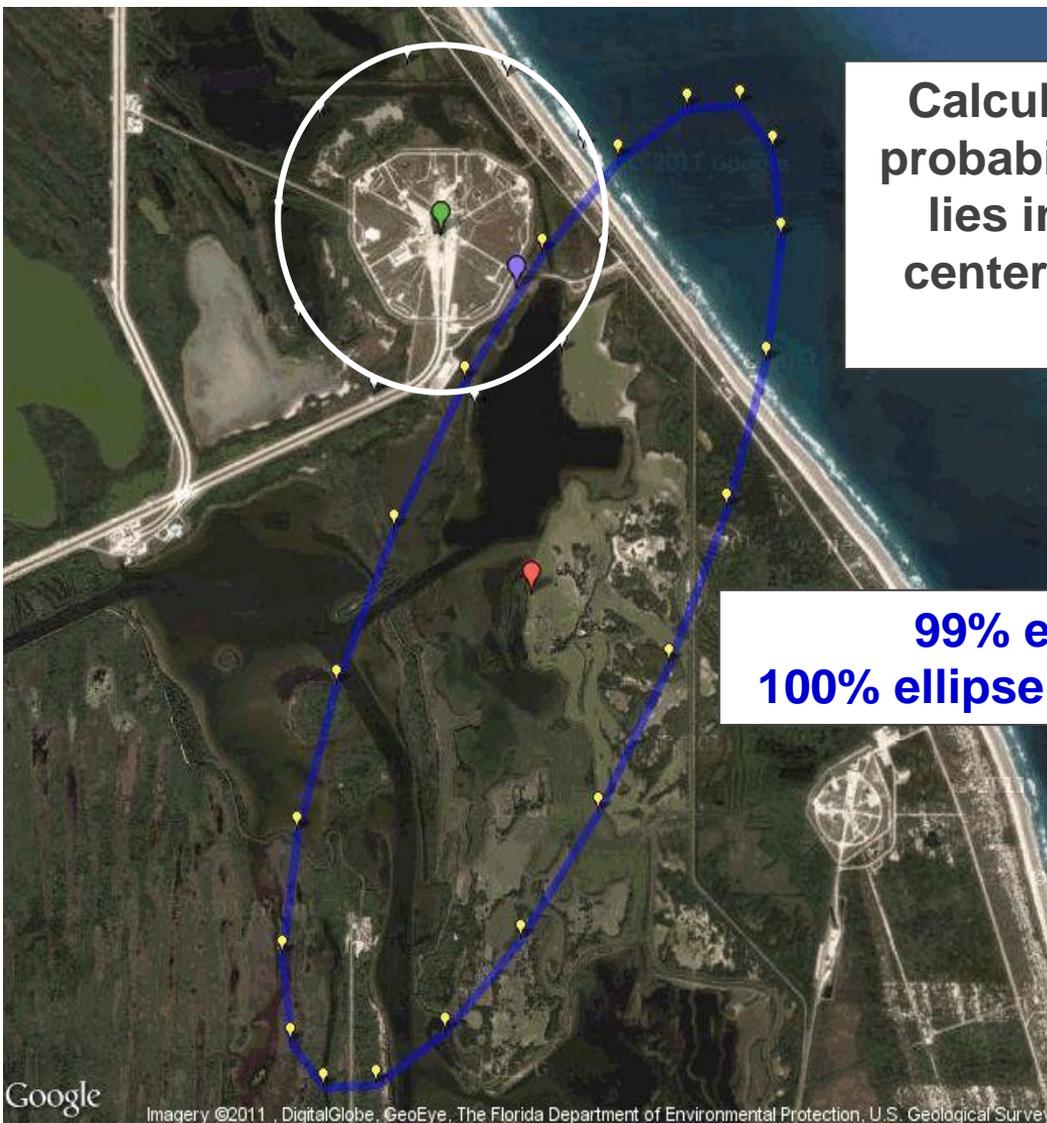
# 4DLSS – Miscellaneous

- 4DLSS – Miscellaneous
  - Technique developed for probability of any stroke being within key radii of key facilities
  - Now being provided to customers





# 4DLSS – Miscellaneous



Calculate how much of the probability field (blue ellipse) lies inside the key radius centered on the key facility (white circle).

**99% error ellipse.**  
**100% ellipse extends to infinity**



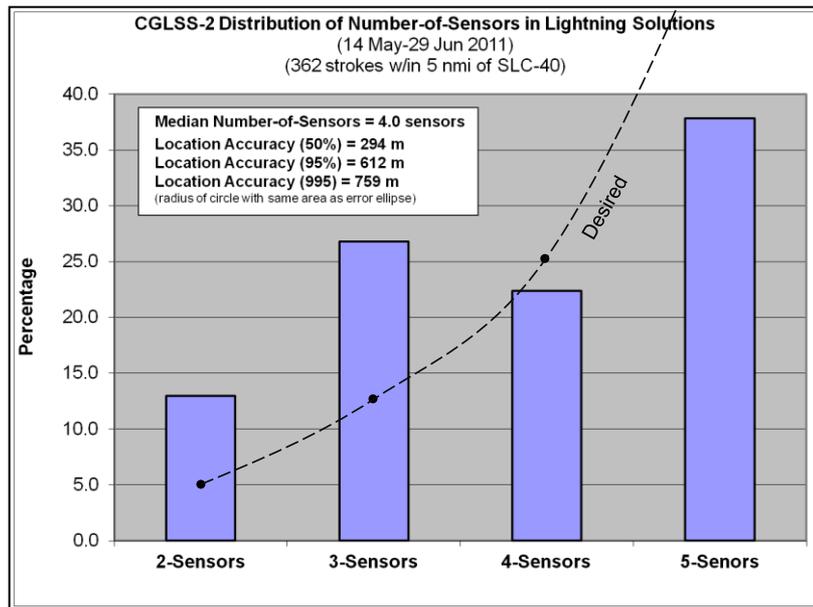
# *4DLSS – Miscellaneous*

- **4DLSS – Miscellaneous**
  - **Some customers incorporating peak current error in evaluating potential for induced current damage on payloads and space launch vehicle electronics**
    - **Use reported peak current + 20% to be cautious**
      - **In the future, we want peak current error tailored to each stroke, just as location error ellipses are now done**
        - **We have a proposal for how to do this**
        - **Anyone want to develop?**



# 4DLSS – Miscellaneous

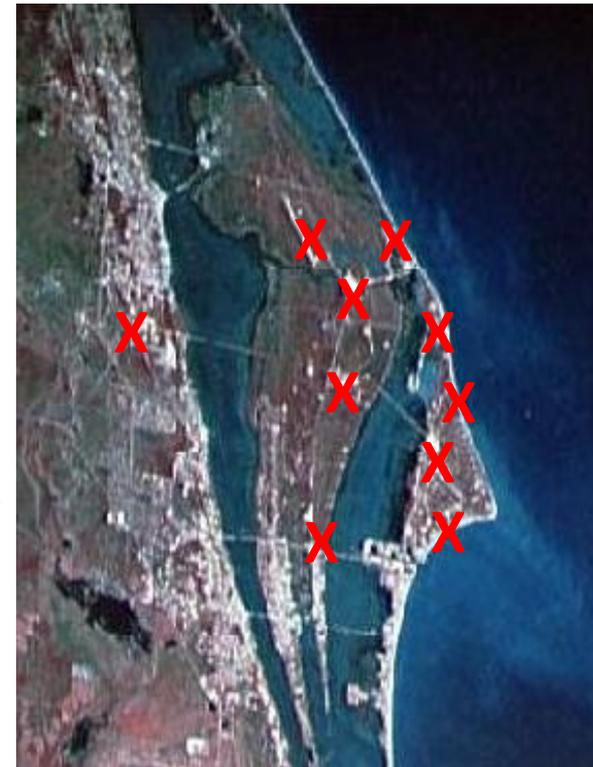
- 4DLSS – Miscellaneous
  - Frequency distribution of number of sensors in stroke solutions appears to be a powerful and easy diagnostic for system problems
    - If not a quasi-exponential distribution for a large number of strokes within the network, Then a problem exists
      - Doesn't tell you what the problem is, but at least you know to look for a problem





# 4DLSS – Miscellaneous

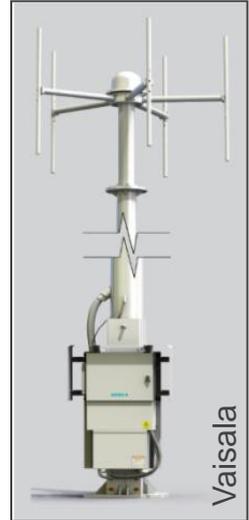
- **4DLSS – Miscellaneous**
  - **CGLSS-II high-precision performance estimate**
    - For 10 key locations
    - Being purchased from Vaisala
    - Useful to estimate detection rate vs. number of sensors used in the solution
      - A requirement for one launch customer
    - Useful to optimize sensor geometry when a sensor(s) is broken for an extended period





# Summary

- **4DLSS Is Unsustainable**
  - No spare parts for CGLSS-II and LDAR-II
  - Many maintenance challenges past 2 years
  - Solution -- Replace CGLSS-II & LDAR-II with new TLS-200 sensors
    - Integrate in-range NLDN sensors
- **45 WS providing new error products to launch customers**
  - Error ellipses provided and scaled to 95% or 99%
  - Probability of any stroke being within any key radius of any key facility
- **Future Possibilities**
  - Add z-location to new TLS-200 sensors
  - Improve peak current and peak current error estimates





# *Status and Plans for 4DLSS*

## Questions?

**william.roeder@patrick.af.mil**

- 1) Is saturation cause of CGLSS-2 missing some strong local strokes?
- 2) Is blockage by radar site likely cause of Shiloh sensor not participating in most lightning solutions to SSE?
- 3) Researchers interested in improving peak current/peak current error?
- 4) Previous verifications of error ellipses?
- 5) NPEP for IC-Ltg, in addition to CG-Ltg, e.g. for TLS-200s?
- 6) Change NLDN in-range sensors to TLS-200/integrate into 4DLSS?
- 7) CGLSS-2 detection rate vs. height of strike?