2 SOPS Anomaly Resolution on an Aging Constellation

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Overview

- Introduction
- SVN 15 and 18 glint firings
- SVN 29 Clock Heating due to Yaw Saturation
- SVN 19 Rubidium Frequency Standard End of Life
- SVN 16 Frequency Standards End of Life
- SVN 14 and 16 Simultaneous Anomalies
- Conclusion

Introduction

- **GPS Constellation Status**
  - **19 satellites past contractual mean mission duration (6 years)**
  - **15 satellites past design life (7.5 years)**
  - **5 satellites past updated mean mission duration**
    - **9 1/4 years for Block II**
    - **10 3/4 years for Block IIA**
    - **7 1/2 years for Block IIR)**
  - **16 satellites one component away from navigation mission failure**

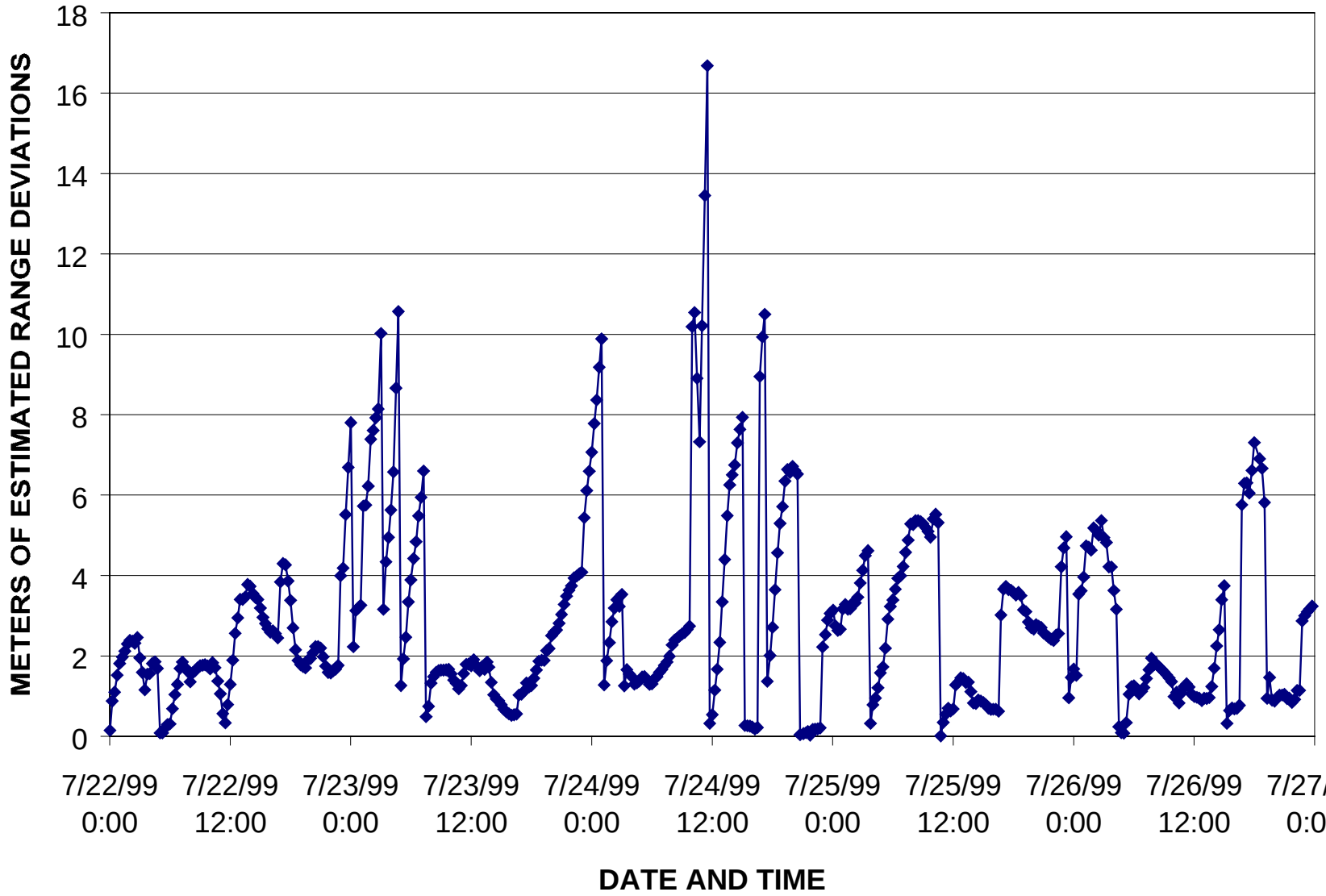
Introduction

- Air Force has no precise methodology for predicting when satellites will fail
- Satellites past their design life are causing anomalies that impact users
- Illustrate difficulties of operating such a constellation
- Highlight the drawbacks of maintaining “launch when failures occur” approach

SVN 15 and 18 Glint Firings

- Five satellites with only 3 reaction wheels
- Satellites operated in a different mode
- Creates possibility for glint firing during eclipse season
  - Satellite's Earth sensor misinterprets the sun's reflection off the Earth's surface as an attitude error
  - Leads to thruster firings which can perturb the satellite's orbit
  - Can cause significant ranging errors

SVN 15 and 18 Glint Firings



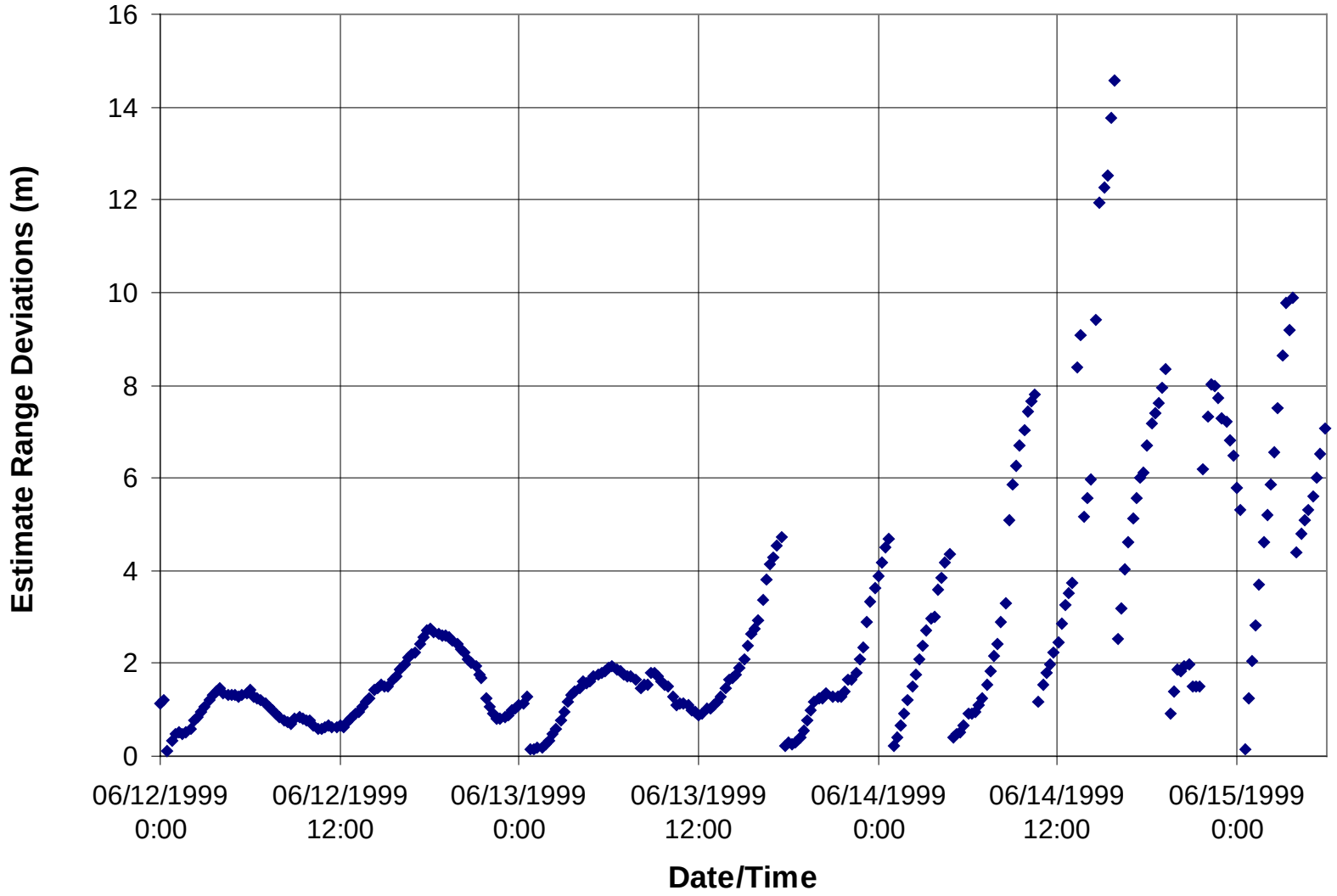
SVN 15 and 18 Glint Firings

- **Ranging errors**
  - **Exceeded 6 meters during 48 fifteen minute intervals and 10 meters during 8 fifteen minute intervals**
  - **Resulting in three dimensional errors of up to 23 meters**
- **Solution to this problem is modified Jet Control Logic (JCL) cycling**
  - **Turn off thrusters during eclipse to prevent thruster firing**
  - **Must maintain contact with the satellite during full eclipse - manning intensive operation**

SVN 29 Clock Heating due to Yaw Saturation

- **Problem with its attitude subsystem that requires a different operational mode**
  - **Requires manual momentum dumps**
- **Last summer, 2 SOPS found the satellite with both yaw and pitch momentum saturated**
  - **Caused clock panel to yaw into the sun**
  - **Rubidium frequency standard heating caused change in frequency drift from negative to positive**
  - **Difficult for the Kalman filter to model change from positive back to negative**
- **Modeling problems led to ranging errors**

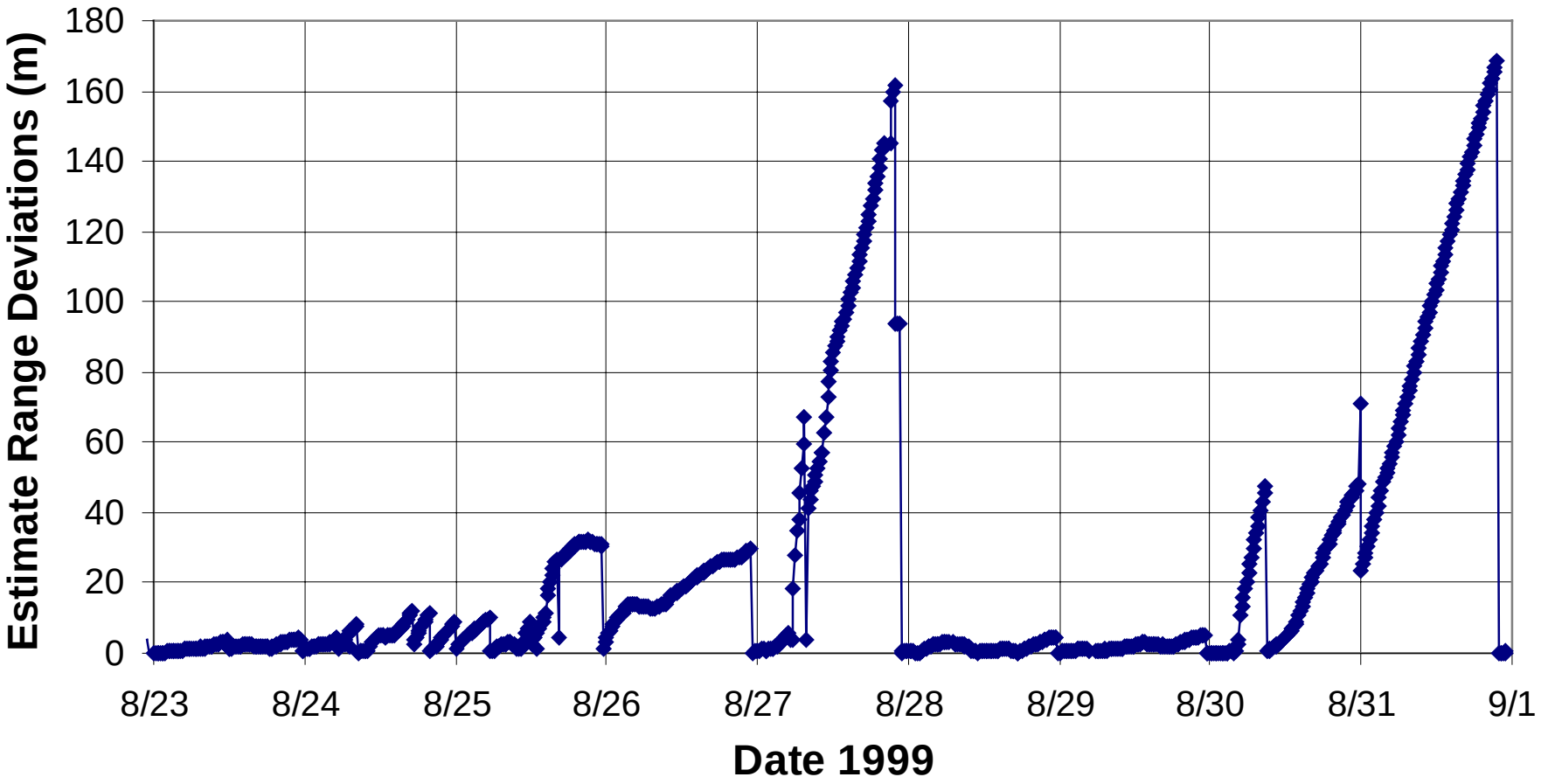
SVN 29 Clock Heating due to Yaw Saturation



SVN 19 Rubidium Frequency Standard End of Life

- **Satellite was on its last unused frequency standard (a Rubidium) in the summer of 1999**
  - **It had been very stable**
  - **Errors in GPS time transfer performance indicated that something was destabilizing the GPS time scale**
  - **2 SOPS noticed that SVN 19's frequency standard had become significantly less stable**
  - **SVN 19 was removed from an estimating partition**
  - **Large number of contingency uploads and frequency steps indicated the problem was getting worse**
  - **Vehicle was set unhealthy because we could not keep errors below tolerance**

SVN 19 Rubidium Frequency Standard End of Life



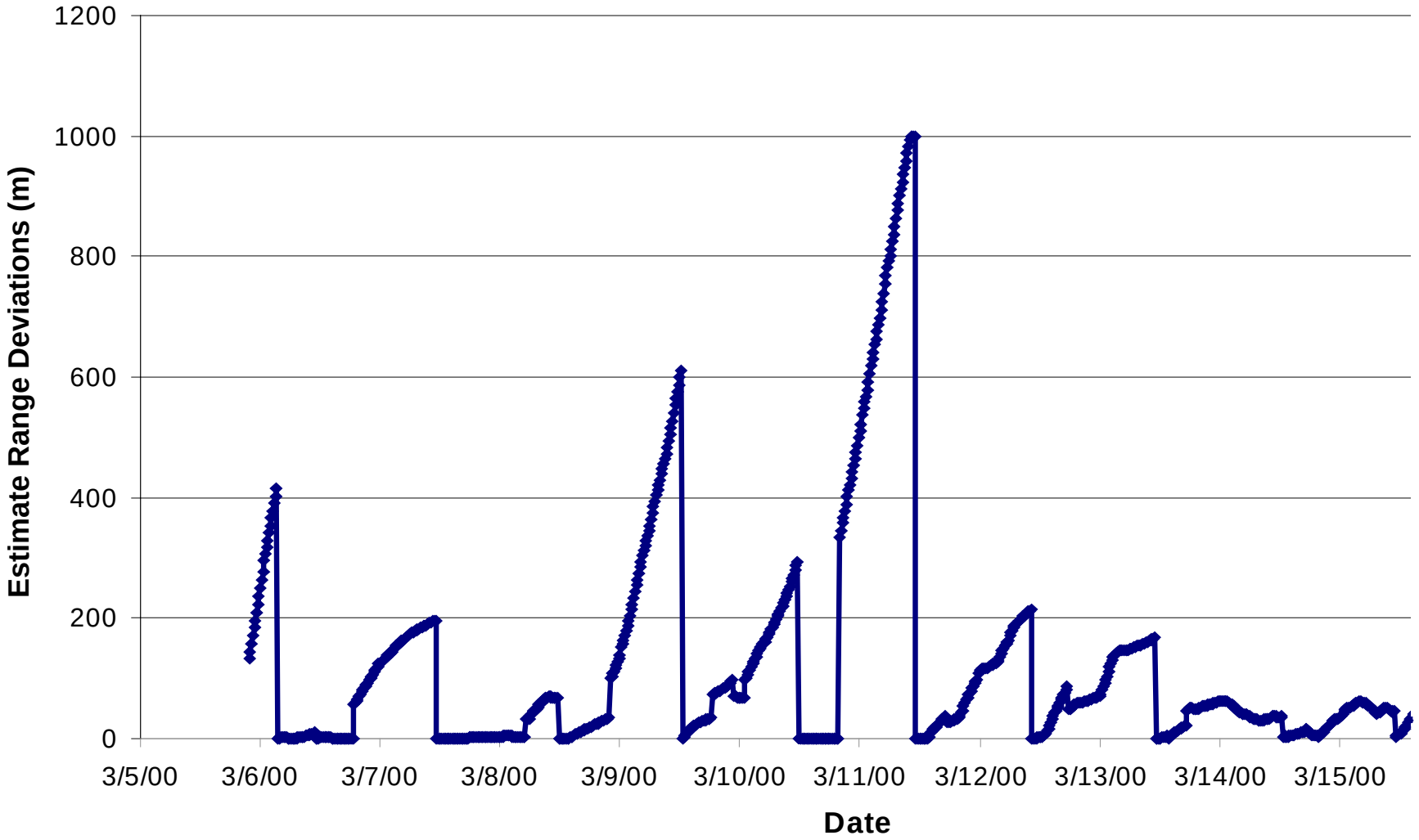
SVN 19 Rubidium Frequency Standard End of Life

- Rubidium frequency standard never stabilized
- 2 SOPS was forced to resort to a Cesium frequency standard
  - Cs had been turned off in the past for poor service
  - Beam current of 1.8 nanoamps when 2 SOPS operational limit is 2.0 nanoamps
  - Since swapping to this frequency standard, it has been the worst performer in 7 out of 7 months
  - Its beam current is down to 1.39 nanoamps
  - Only a short matter of time before this last frequency standard fails

SVN 16 Frequency Standards End of Life

- In late Feb, failure of its Cs frequency standard
  - Running off its VCXO, ranging error of 450 meters in 1 1/2 hours
  - Satellite taken off the air before errors grew too large
  - Cs recovered and satellite monitored for two days before being set healthy to users
  - Two weeks later: same failure, except ranging errors grew to 1300 meters within 1 1/2 hours
  - Cs recovered again, but judged an integrity-monitoring problem
- Satellite had an unused Rb frequency standard
  - FS was never stable enough to set operational

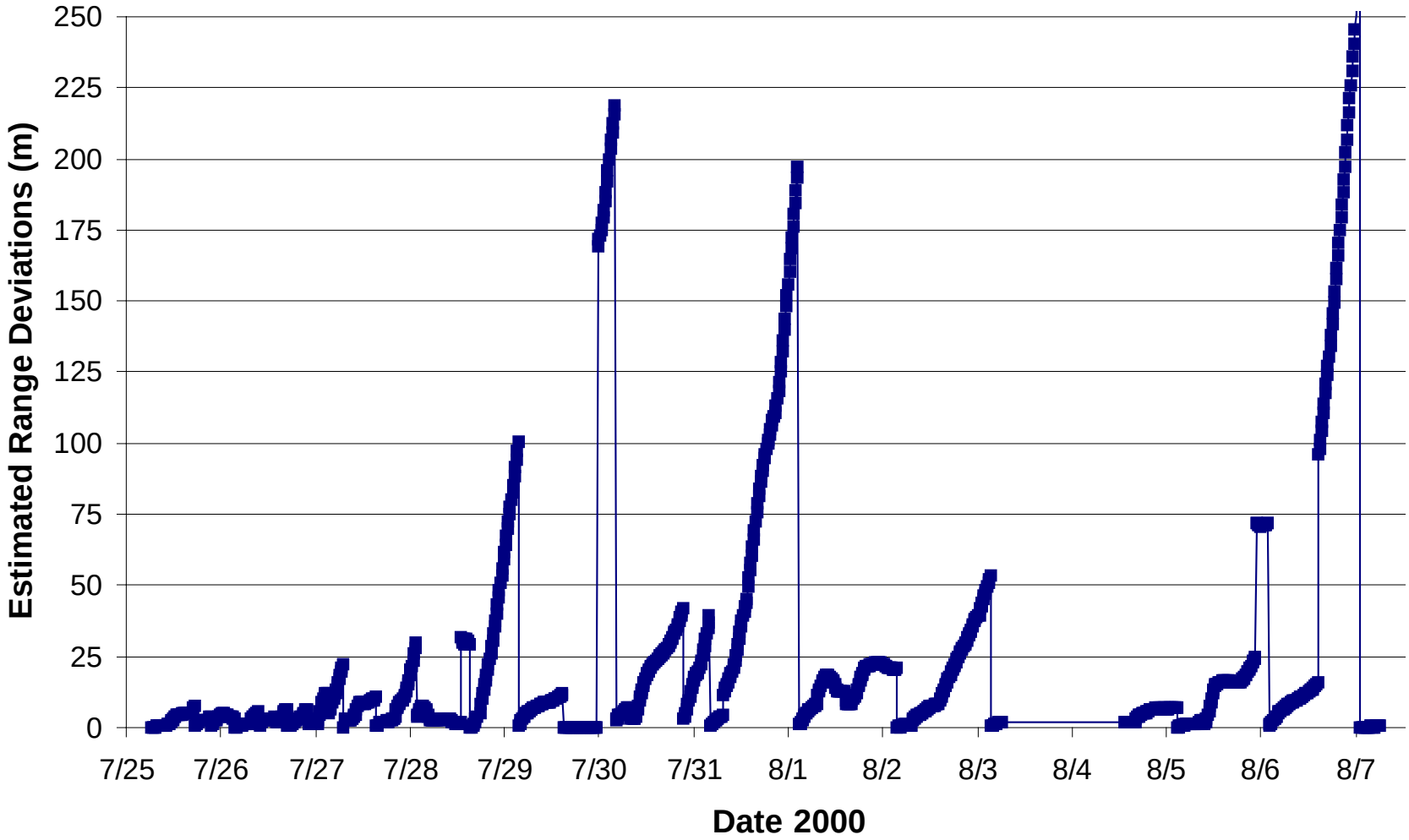
SVN 16 Frequency Standards End of Life



SVN 16 Frequency Standards End of Life

- **Satellite now in the same situation as SVN 19**
  - **All frequency standards had been operated and selected as unfit for operational service**
  - **Only options: Unstable Rb or Cs with a beam current of 0.8 nanoamps**
  - **Unstable Rb chosen as less risky option**
  - **Rb operated poorly, but within tolerances for 3 1/2 months**
  - **Became unstable and satellite was set unhealthy**
  - **Swapped to Cs FS on August 14, 2000**
  - **2 SOPS assessing its performance**

SVN 16 Frequency Standards End of Life



SVN 14 and 16 Simultaneous Anomalies

- Two days before 2 SOPS switched to SVN 16's last Rubidium, SVN 14 experienced its second reaction wheel failure
  - SVN 14 could no longer point at Earth
  - Anomaly occurred when Ascension monitor station was unavailable due to a comm failure
    - Situation was not recognized until hours later
  - SVN 14 never recovered attitude pointing capability

SVN 14 and 16 Simultaneous Anomalies

- **Both SVN 14 and 16 off the air and in view at the same time**
  - **Caused coverage problems and Dilution of Precision (DOP) spikes over the US and Kashmir**
  - **Coverage loss (lack of 4 satellites in view)**
    - **Oklahoma, Kansas, Nebraska and northern Texas lasting up to 18 minutes**
  - **DOP spikes as high at 888 (lasting < 1 minute)**
    - **Over the areas mentioned above and Nevada, Utah, Arizona, New Mexico and Colorado**

SVN 14 and 16 Simultaneous Anomalies

- **Solution: get 14 and 16 on the air or move another satellite to fill the gap**
  - **SVN 14 never usable, spun-up and boosted**
  - **16's Rubidium still warming up**
  - **Aerospace Corporation analysis concluded SVN 19 could most quickly fill the gap without negatively impacting other users**
  - **SVN 19 on borrowed time**
  - **SVN 44 launched to fill this gap (healthy Aug 00)**

Conclusion

- Anomalies caused by aging are creating large ranging errors, impacting users
- 2 SOPS was able to prevent most of these anomalies from severely impacting users
  - Depends on the availability of Ground Antennas (92% vis) and Monitor Stations (88% vis)
- Errors combined with poorly performing satellites, increased ground and satellite outages, and poor geometry can cause large navigation and time transfer errors

Conclusion

- The Air Force is addressing GPS sustainment policy
  - Consider replacing satellites before they fail and become an operational risk to users
  - The world's increasing dependence on GPS should increase our aversion to risk
- 60 day call-up may not be enough
- Risk may seem small, but it is important to address even a low level of risk