ROBUST NAVIGATION ISSUES IN THE EVENT OF GNSS FAILURES

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THE END OF HISTORIC NAVIGATION?

Welcome to the 21st century!

We have entered a brave new world of iPhones, Google maps, GPS navigation and never again do we need to trouble with astrolabes, sextants, nautical charts or LORAN…

Celestial navigation no longer taught at US Naval academy as of 1998, US, CA and RF LORAN operations ceased in 2010

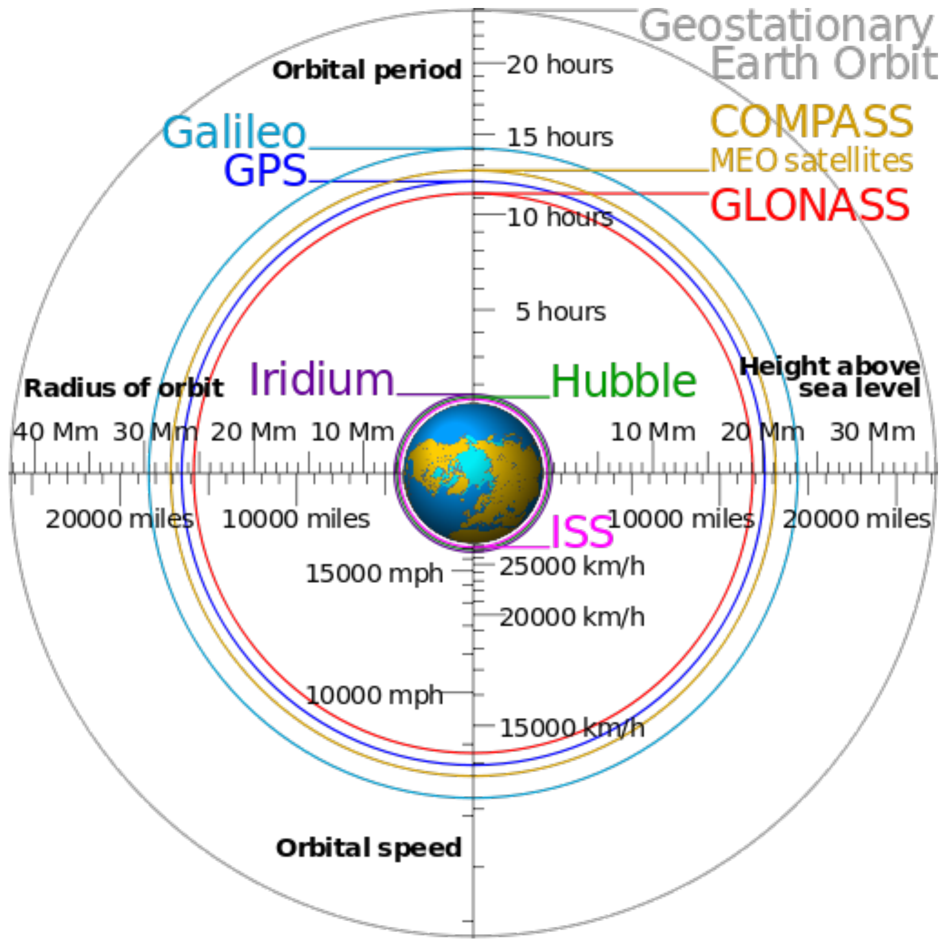
GPS is the future and GPS is eternal – or is it?

Artist rendering of GPS Satellite from GPS Satellite NASA art-iif.jpg via Wikimedia commons

GPS SATELLITE ORBITS ARE MEO

Sensibly, GNSS orbits minimize satellite needs with ~ 50 degree inclination orbits that cross over the equator (and magnetic equator)

True of existing and planned GNSS constellations



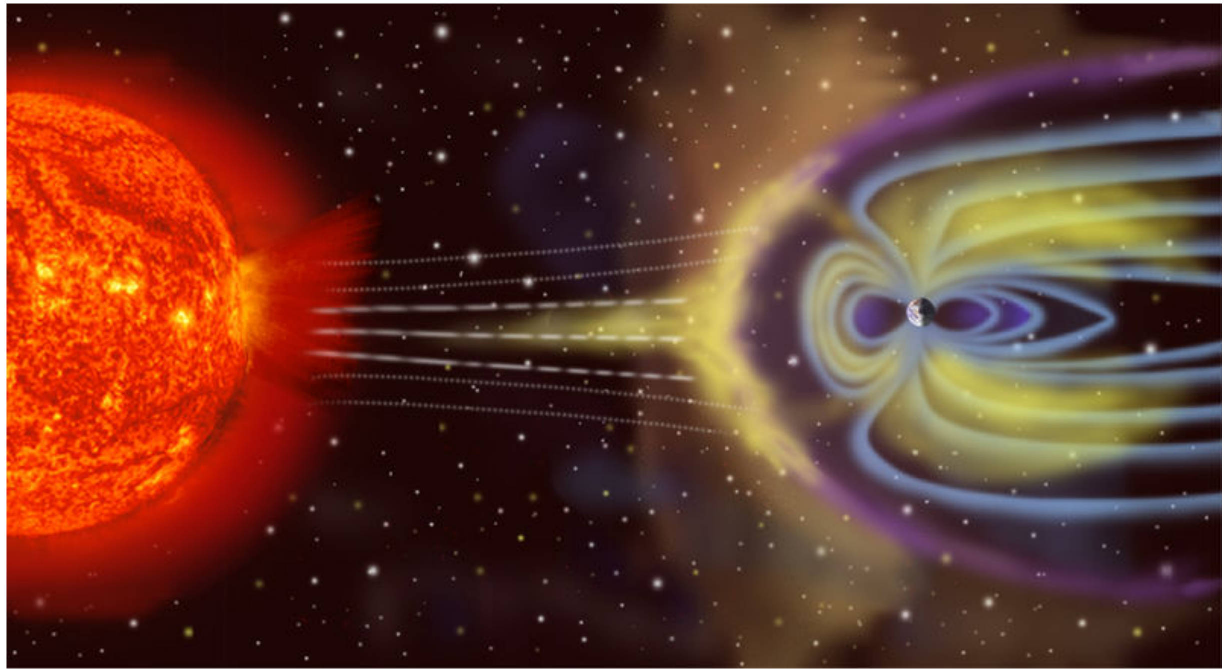
Comparison_satellite_navigation_orbits.svg
from Wikimedia commons

GNSS ORBITS CROSS THE OUTER VAN ALLEN RADIATION BELT

One operative term, oops!

Not really, this is a known aspect of the operating environment and satellite lives are calculated with a nominal expectation of radiation exposures.

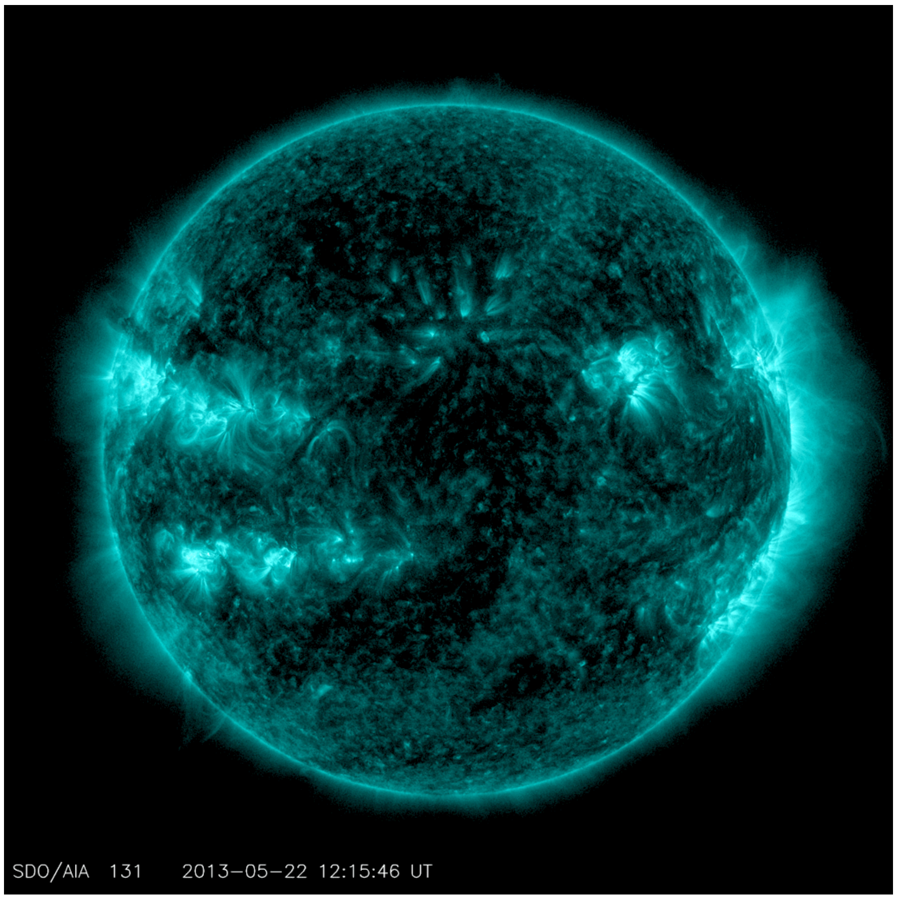
Nominal … what about this nominal term



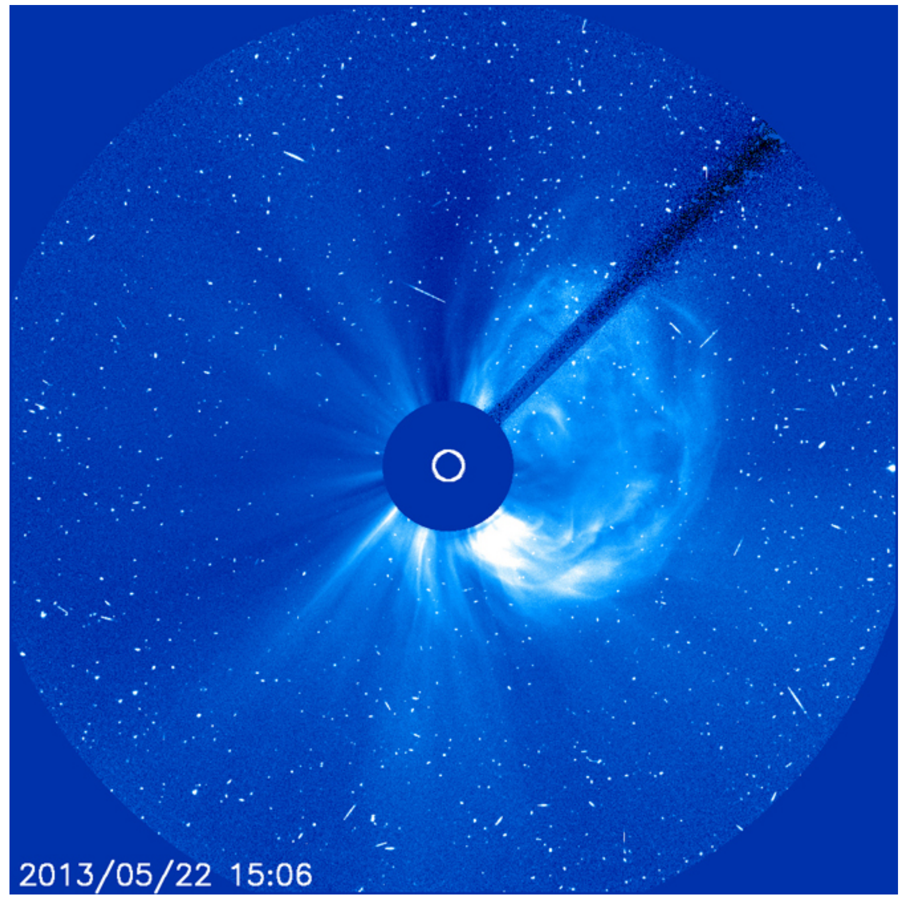
Credit: NASA Magnetosphere rendition.jpg via Wikimedia Commons

NOMINAL SOLAR MAX INCLUDES FLARES & CME'S

About a week ago, Mr Sun was blowing off a bit of plasma – not directly at us



131 Angstrom Wavelength Image
Credit: NASA/SDO/GSFC



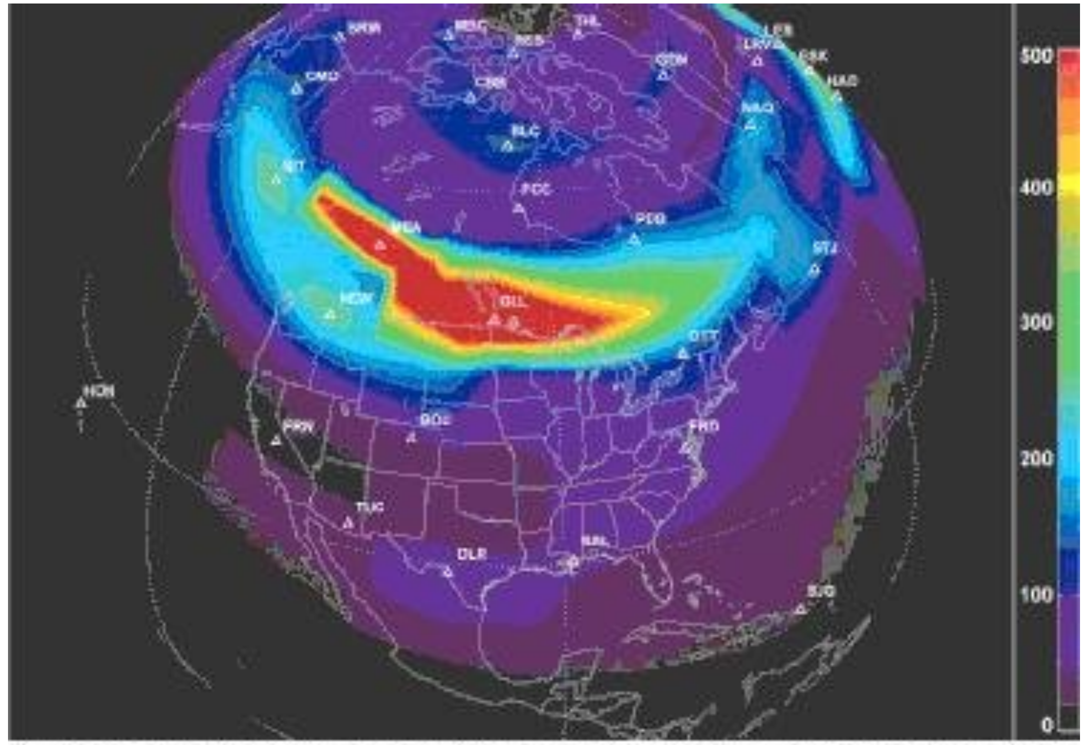
Credit: ESA and NASA/SOHO

CMEs DO HIT WITH ‘BAD’ RESULTS

While the failure of a major electric utility should not be understated, this CME was not large in the historic scale.

The 2003 Halloween event was similar size or a bit larger. The 2003 event had GPS disruptions and induced additional trapped particles.

The 1859 Carrington Super Flare produced strong auroras as far south as Cuba and Hawaii, shocked telegraph operators and let people read from the aurora light in Baltimore.



Geomagnetic field disturbance conditions, dB/dt (nT/min) over North America at time 7:45 UT on March 13, 1989

Source: Metatech Corporation, Applied Power Solutions

Geomagnetic Storm responsible for Quebec Hydro failure

Figure from Congressional Testimony – EMP commission

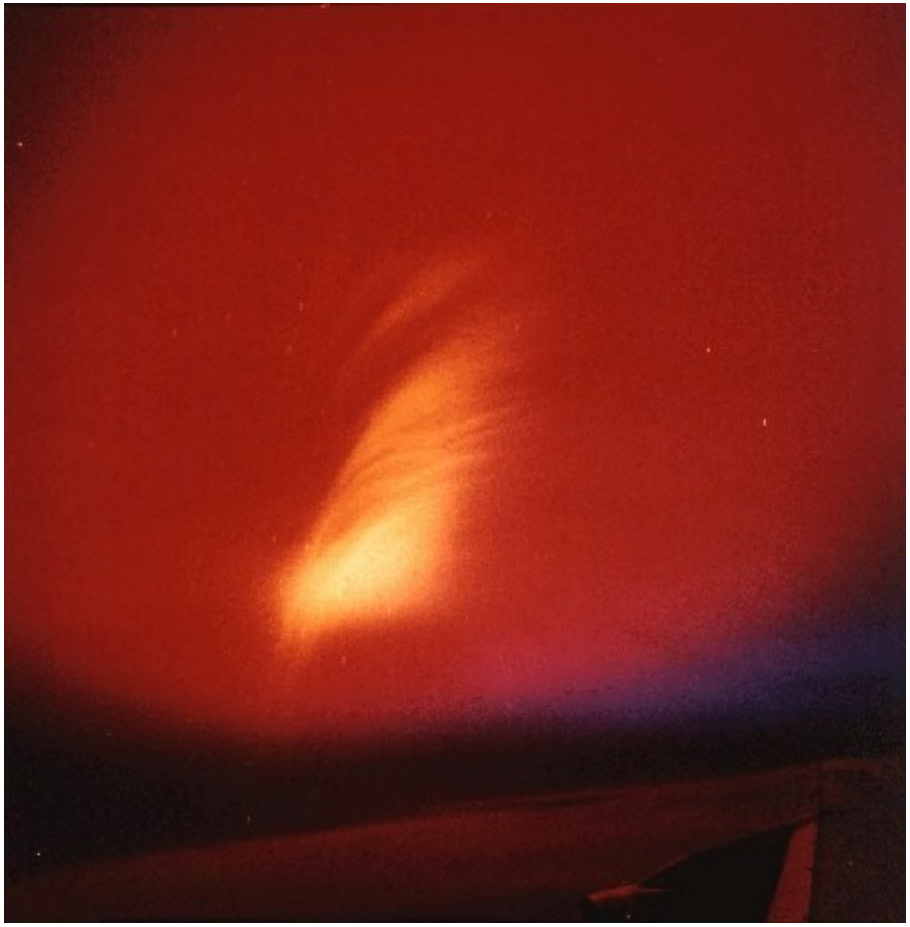
PRETTY AURORA PICTURE

While pretty, aurora represent energetic particles exciting the atmosphere and they indicate strong localized plasma effects are occurring nearby.

Strong aurora represent conditions of enhanced trapped radiation as well as difficult and non-uniform ionosphere conditions that render GNSS operations either degraded (inaccurate) or disrupted entirely.

NASA 533440main_halloweenstorm2003-aurora.jpg
The 2003 Halloween event produced this Aurora visible at Mt Airy Maryland

NOW FOR SOMETHING UNNATURAL

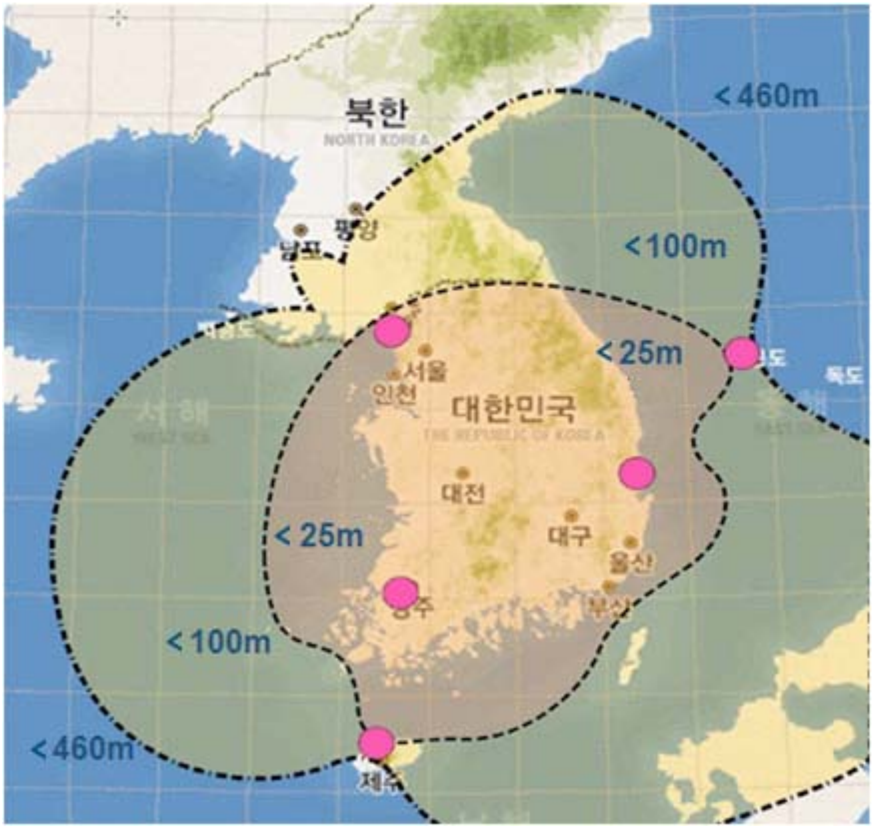


Operation_Dominic_Starfish-Prime_nuclear_test_from_plane.jpg from USG Photo via Wikimedia commons

Lets give them a HAND (High Altitude Nuclear Detonation). STARFISH was a local event that pumped the natural radiation belts (shortening satellite lives), created auroras, created localized persistent plasma effects (patch and striations) and finally added a threat to ground systems with discovery of the large Electromagnetic Pulse (EMP).

Prompt effects are not the concern of this paper however civil systems are largely not 'hardened' against EMP so such unnatural events threaten every aspect of a GNSS, the satellite radiation environment, the ionospheric propagation and finally the survival of the receiver unit.

DID SOMEONE MENTION JAM?



Projected accuracy and coverage of Korea's eLoran network. Ministry of Oceans and Fisheries of Korea

As a small signal, GNSS is subject to being overwhelmed either by high power source leakage (c.f. LightSquared network) or by nefarious behaviors with intentional jamming.

North Korea (DPRK) caused GPS disruption to both ships (> 250) and aircraft (>1000) to a level where ROK determined to restore LORAN support to a new 'enhanced' eLORAN standard.

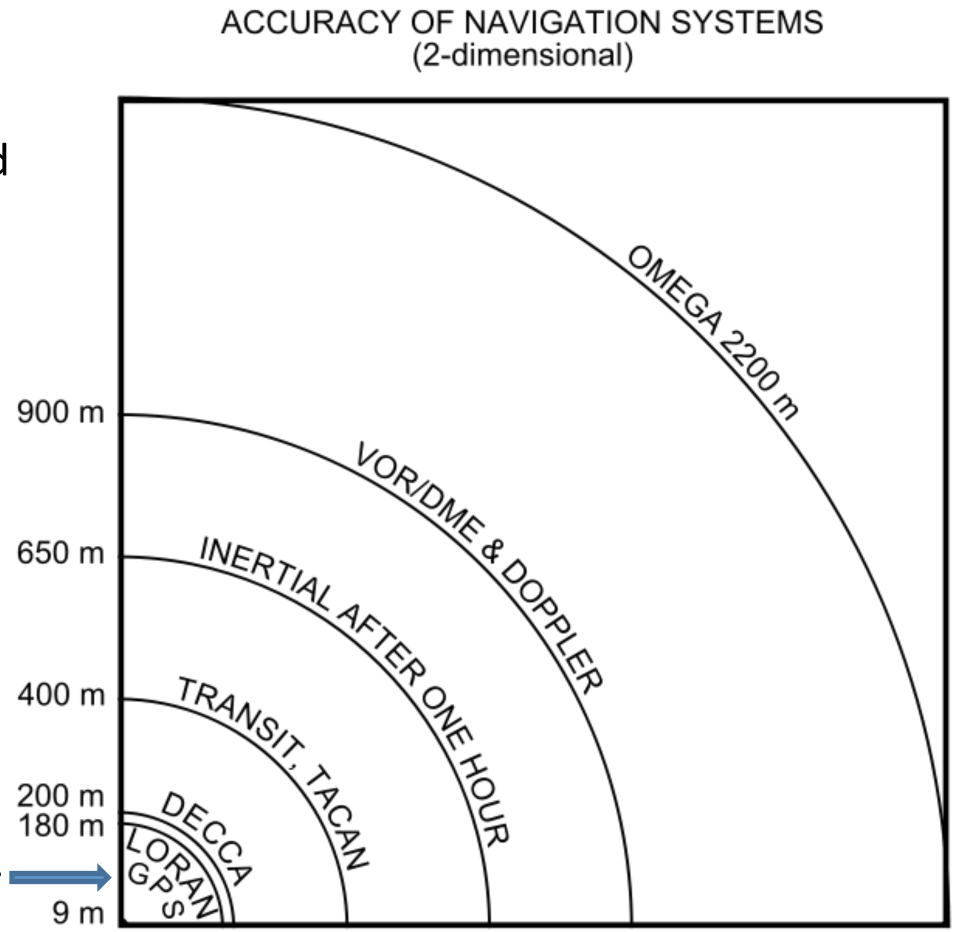
WHAT ACCURACY FOR BACKUPS?

GPS / GNSS systems are in the neighborhood of ~ 10m location accuracy under good conditions

LORAN tended to approach 100m location accuracy in good conditions

A suitable backup to GPS/GNSS failures should be no worse than LORAN and should substitute for GNSS in bad conditions

Thus an objective of 50 meters



50 meter target value

Credit: Accuracy of Navigation Systems.svg from Wikimedia commons

SOME NUMBERS FOR SYSTEM SCOPING ANALYSIS

50 meter errors drive useful issues:

Day / Night in clear conditions
- Implies filters for sun use
- Implies baffling needs

Angles: Sidereal earth rate at ~ 7.292E-5 rad/s * 0.1 s yields 7.3 µrad measurement error

- Implies optic size
- Constrains camera design
- Implies gimbal resolution
- Constrains gravity vector measurement

Timing: Sidereal earth rate at equator radius arm ~ 465 m/s

- Implies 0.1 second as upper limit for integration
- Implies UT1 knowledge to 0.1 second

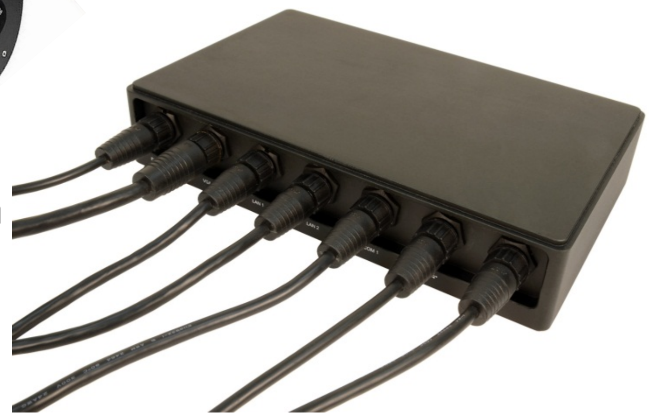
Requires IERS Bulletin A
- Implies computer periodic access of USNO IERS

Requires GPS coordinated local clock to 'ride through' outage

HOW HARD TO AUTOMATE?

Automated telescope – 10 cm

Digital camera



Weather-proof PC

Local clock-synched to UTC v GPS

Tiltmeter – vertical reference

Naturally significant software and hardware work needs to occur but the parts are in hand

How hard can this be?

PROOF OF CONCEPT

Ok, so a 35cm telescope with multiple IR cameras and real time processing isn't a prototype of a low cost automated backup navigation tool in the event of GNSS failure… We did the underlying technique during our development in 2003 and discerned the cockpit 'GPS' used pressure height when the celestial navigation did not align with GPS.

Time to get off the stage with the picture of my child…