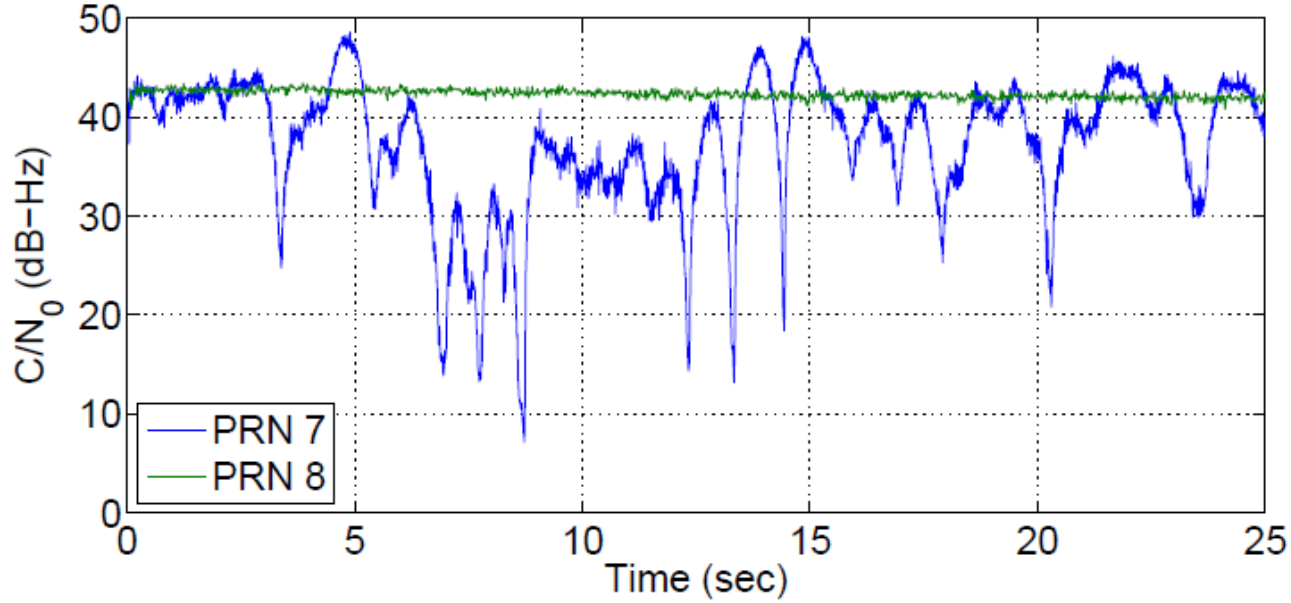
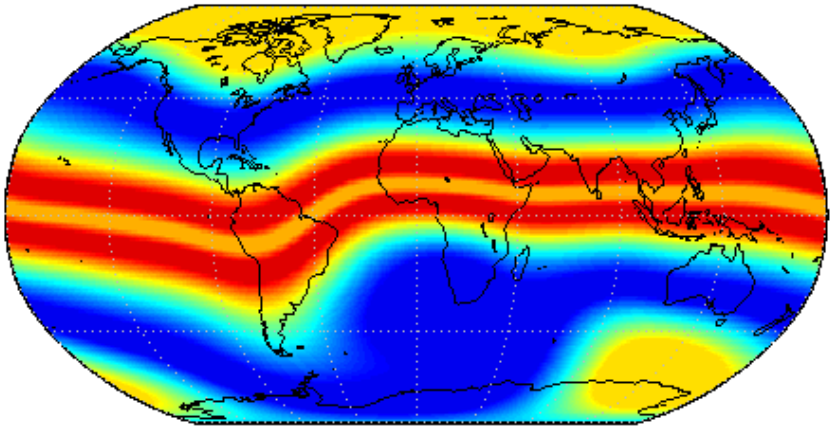
GPS, GNSS, and Space Weather
A Look Into the Future



Take Aways

- GPS is vulnerable
  - Space Weather
  - Spoofing
  - Jamming
- GPS is safe if
  - It is operated at mid-latitudes
  - Only 99.9% availability is required
- If above two conditions are violated, you need to speak with me.



GNSS/Sp Wx History

- 1995 GPS operational
- 1997 Galileo announced
  - 2003 goal for operational status
- 2000 SA turned off
  - 100m ➡ 15m errors
- 2001 scintillation shown to cause loss of lock
- 2001 first TEC images show ionospheric storms at mid-latitudes (over the USA)
- 2001 FAA “Volpe” report acknowledges Sp Wx threat to GPS

GNSS/ Sp Wx History- 2

- 7/2003 WAAS activated, 15 m errors ➡ 5m
  - 10/2003 ionospheric storm causes WAAS to fail
- 2005 Fugro-Chance talks about ionospheric storms as threat to business
- 2005 GPS launches first modernized satellite
- 2006 Galileo launches first test satellite with secret codes
  - 2 months later Cornell publishes codes

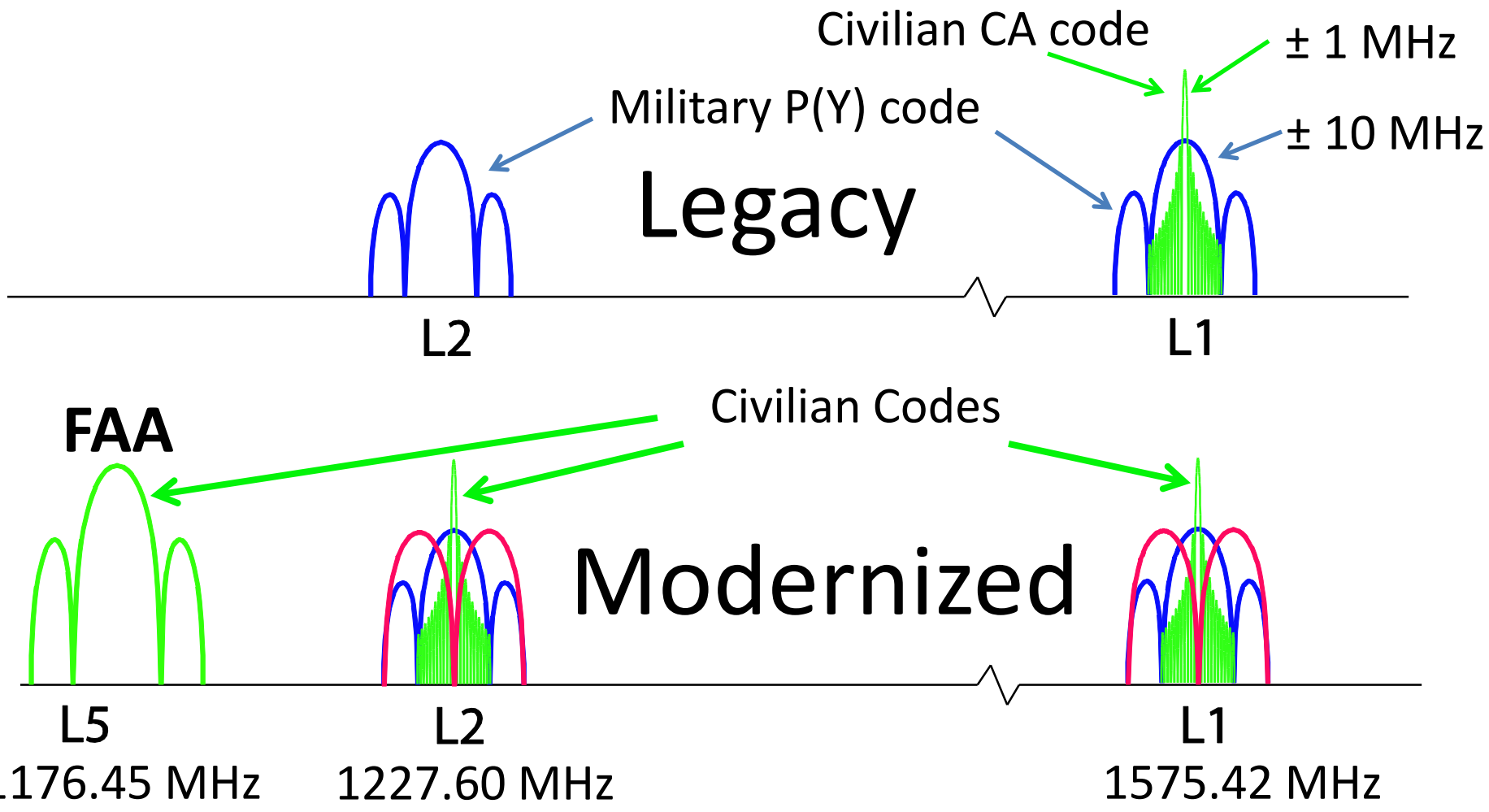
GNSS/Sp Wx History- 3

- 2006 solar radio burst threatens GPS globally
  - RSTN found to have serious limitation
- 2008 GPS Spoofing demonstrated
- 2009 Galileo rescinds receiver licensing requirement, agrees to open ICD
- 2009 Galileo lets contract for first 14 satellites
  - Announces it can not meet 2013 deadline for activation
- 2010 one of two WAAS satellites lost, single string

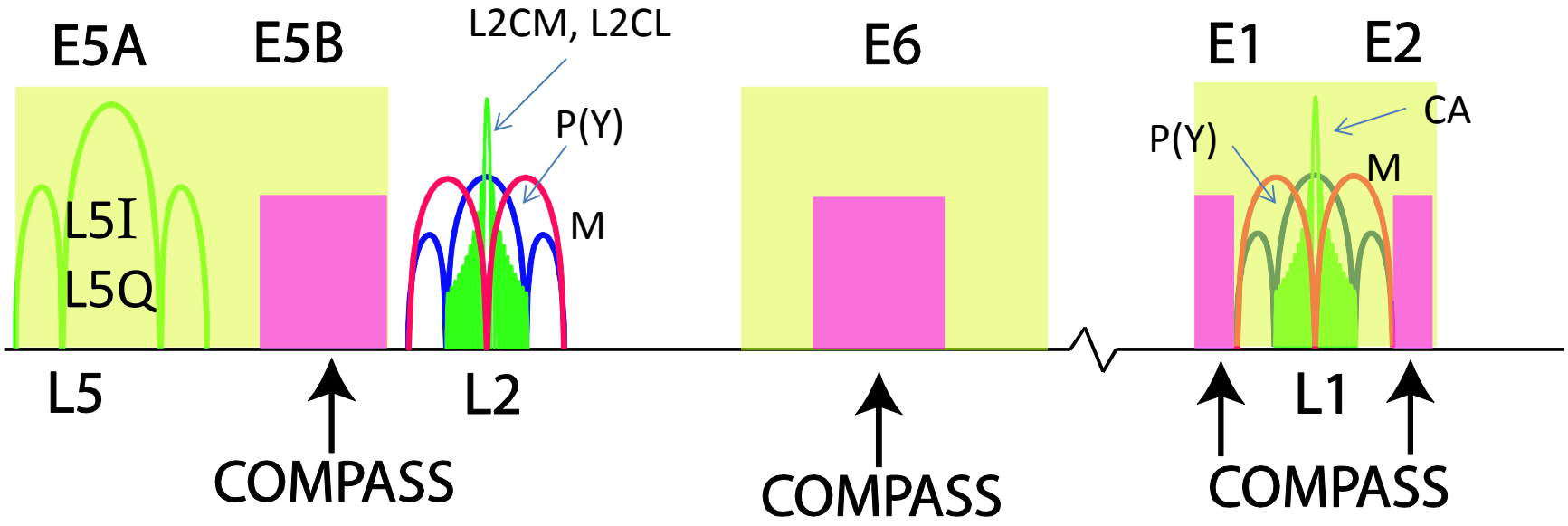
Galileo Is Taking Risks

- In Orbit Validation (IOV) satellites (4)
  - Launch 2011
  - Will not be in orbit long enough to test radiation survivability or other design flaws.
- The rush to design and launch operational satellites means that any lessons learned from IOV satellites cannot be incorporated into first operational satellites.
- The rush to create an operational system means that for the first block, consisting of 14 satellites, if one is vulnerable, all are vulnerable.

GPS Modernization



GPS is now GNSS
Signals at end of next Solar Maximum



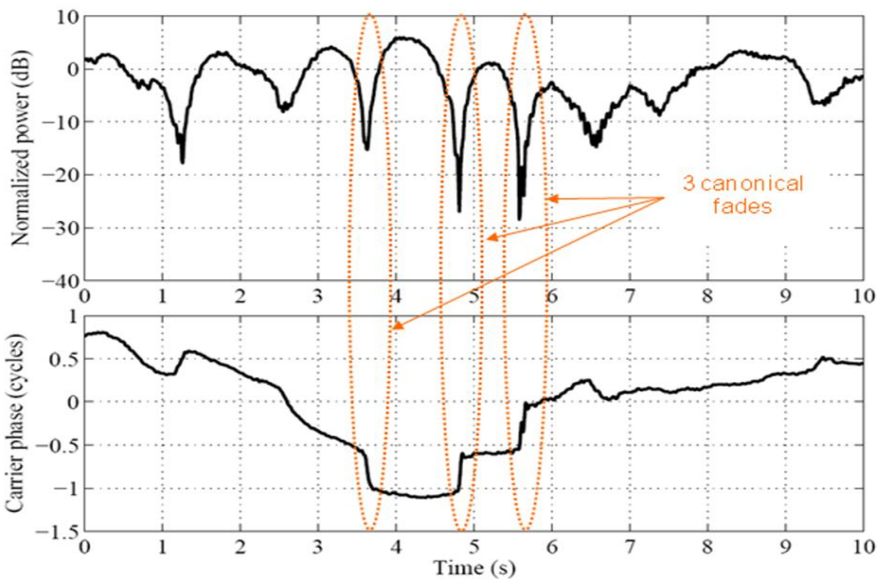
Plus space based augmentation systems (WAAS, EGNOS etc.) and GLONASS and Iridium(???) and L1C

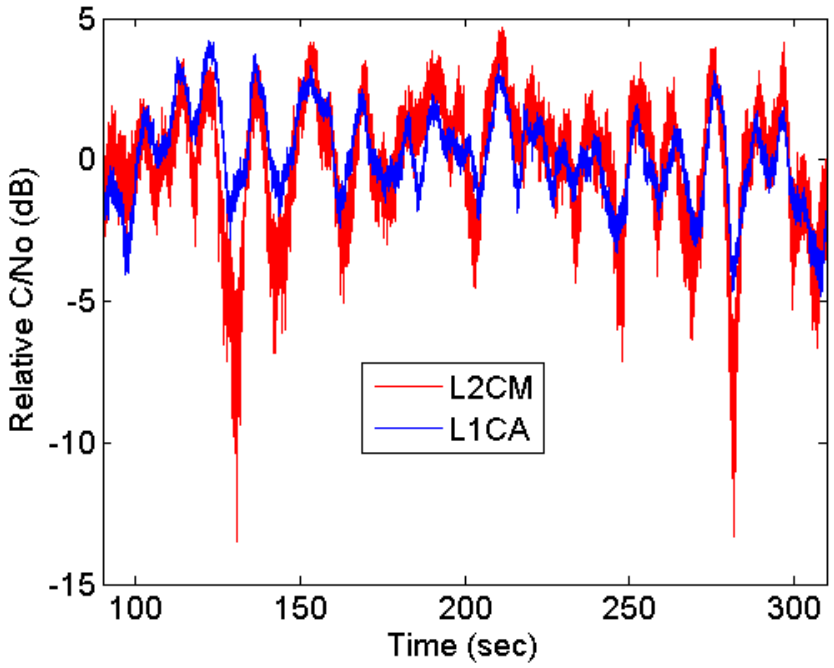
New Signals and Space Weather

- New codes designed to be more robust in the presence of scintillation
  - Dataless pilot signals
- Lower frequencies of new signals will be more vulnerable to scintillation.
- But absolute TEC will not be easily calculated with civilian codes,
  - Need two 10 MHz signals and only one available for both Galileo and GPS (civilian)
- Iono. ranging errors will continue to be an issue

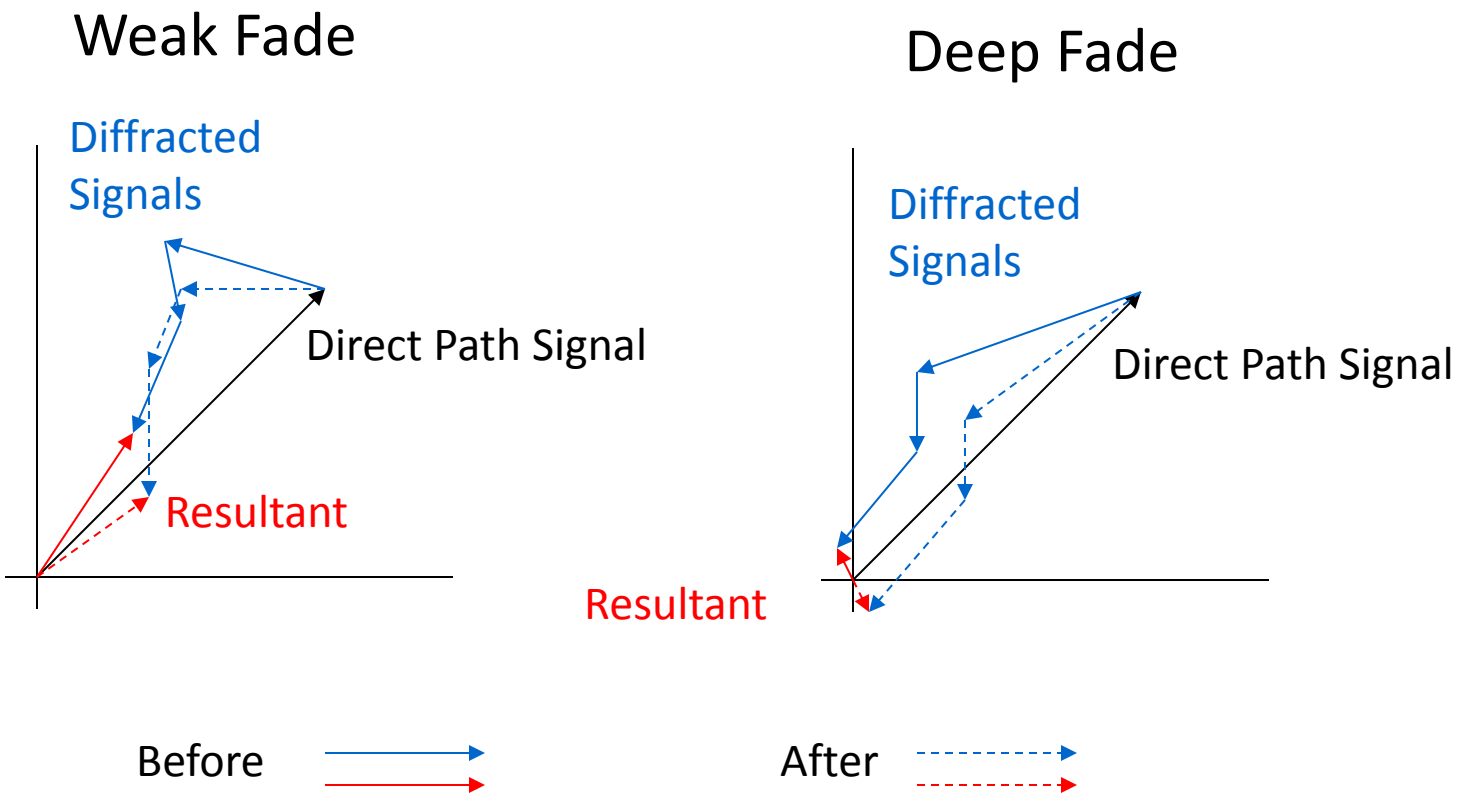
Scintillation is worse than we thought

- Amplitude and phase scintillation are not independent
- L1 and L2 fades are not independent
- L2 fades are larger





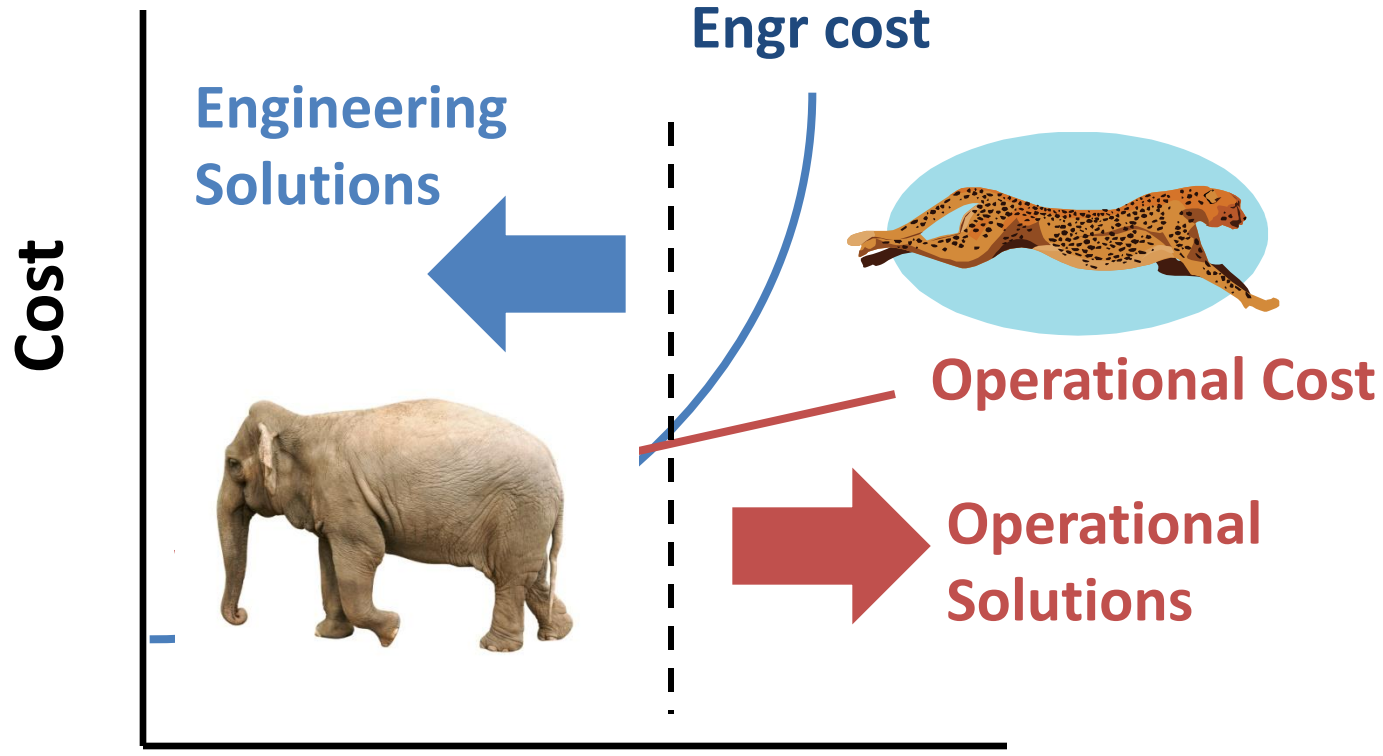
Why Should Deep Fades Have Half Cycle Phase Jumps?



New Application of GPS, Precision GPS

- Caterpillar **AccuGrade GPS Control System** for bulldozers
- For automated grading at 1 cm level
- Reference receiver with GPS receiver on blade
- Uses PHASE of GPS signal not range!

Two Approaches to Sp Wx



Availability, Integrity, Accuracy

Bottom Line For Next Solar Max

- New signals/codes for GPS/GNSS will generally not be in place by 2013
- PNT will dominated by legacy equipment using legacy GPS signals
- Perhaps by 2024 engineering solutions will make PNT more Sp Wx resistant (no P-code after 2020)
- During the next solar maximum we need to help GPS users “ride out” Sp Wx and we need to investigate the new signals to understand their vulnerability to Sp Wx (prediction and climate)

If you are a user…

- Know what the effects of space weather are on GPS and your product
- Recognize them when they impact your receiver
- Report impacts when sp wx causes problems
- Encourage (insist) that GPS receiver manufacturers include a space weather indicator

Good Luck During the Next Solar Maximum