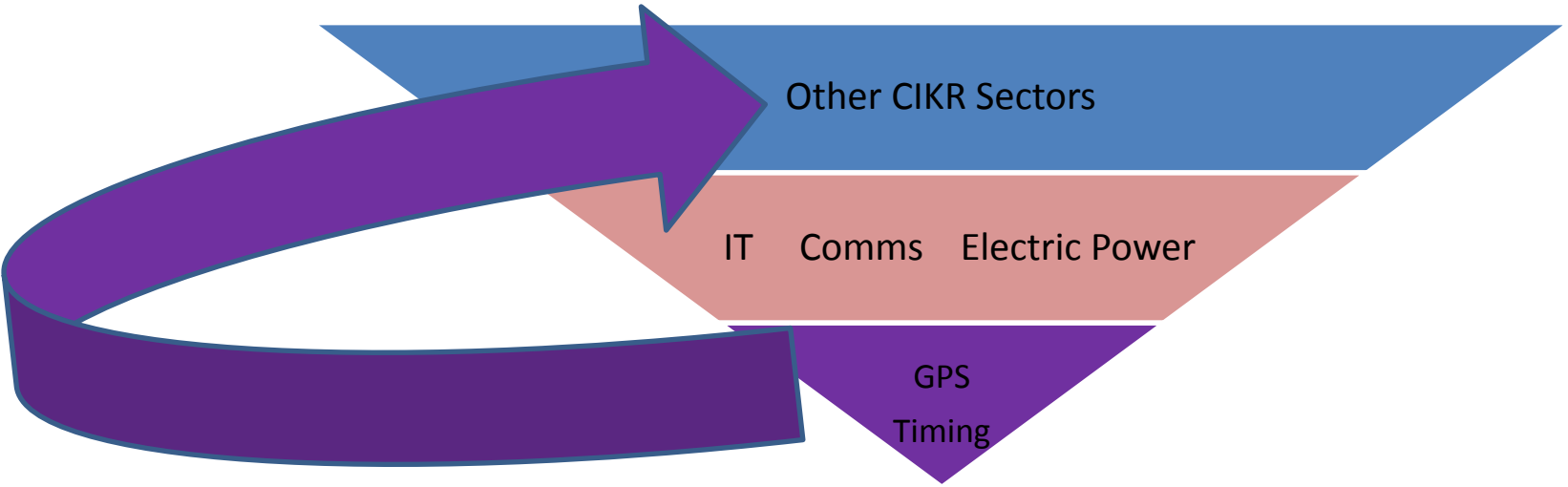
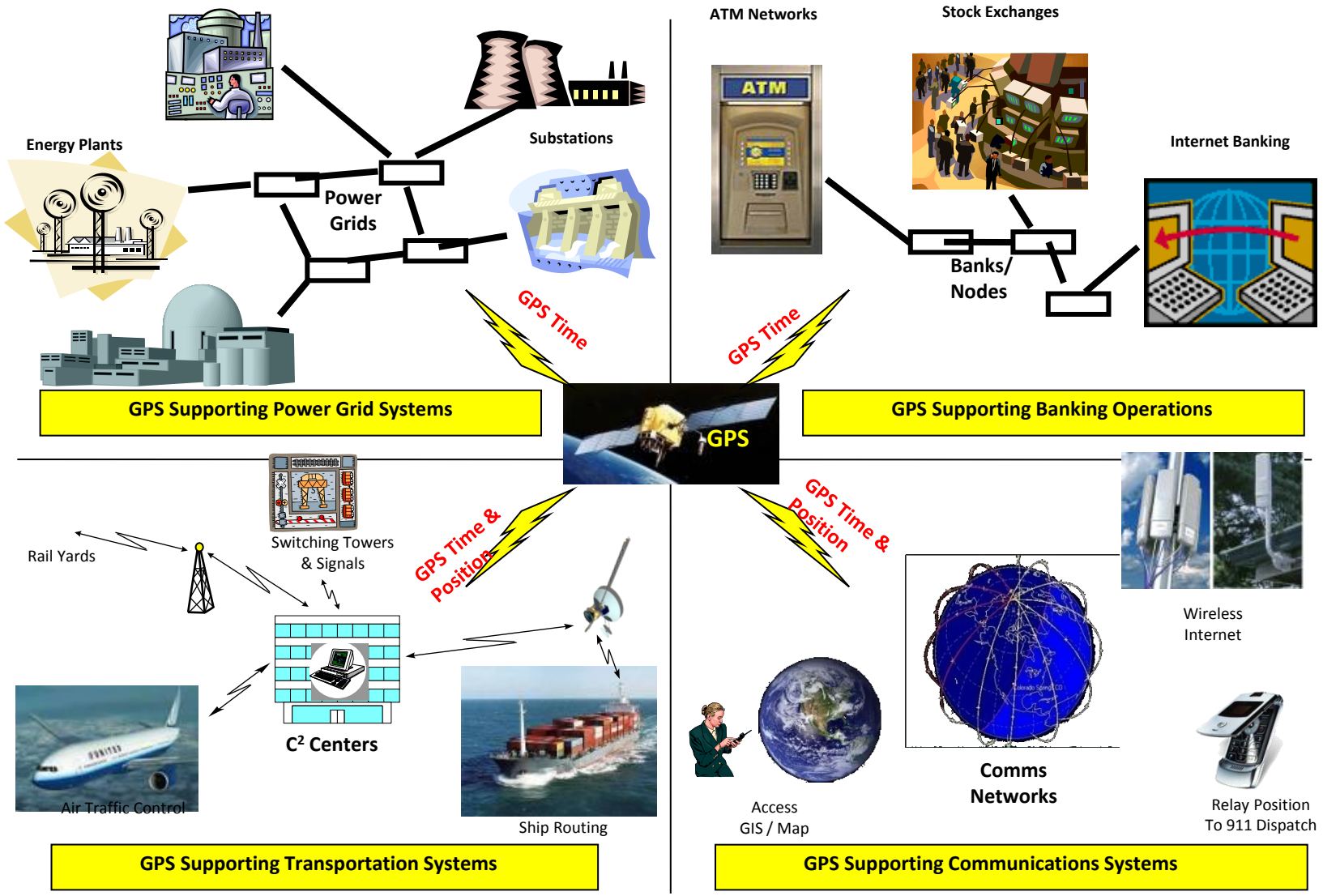
GPS Critical Infrastructure

Usage/Loss Impacts/Backups/Mitigation



R. James Caverly
April 27, 2011

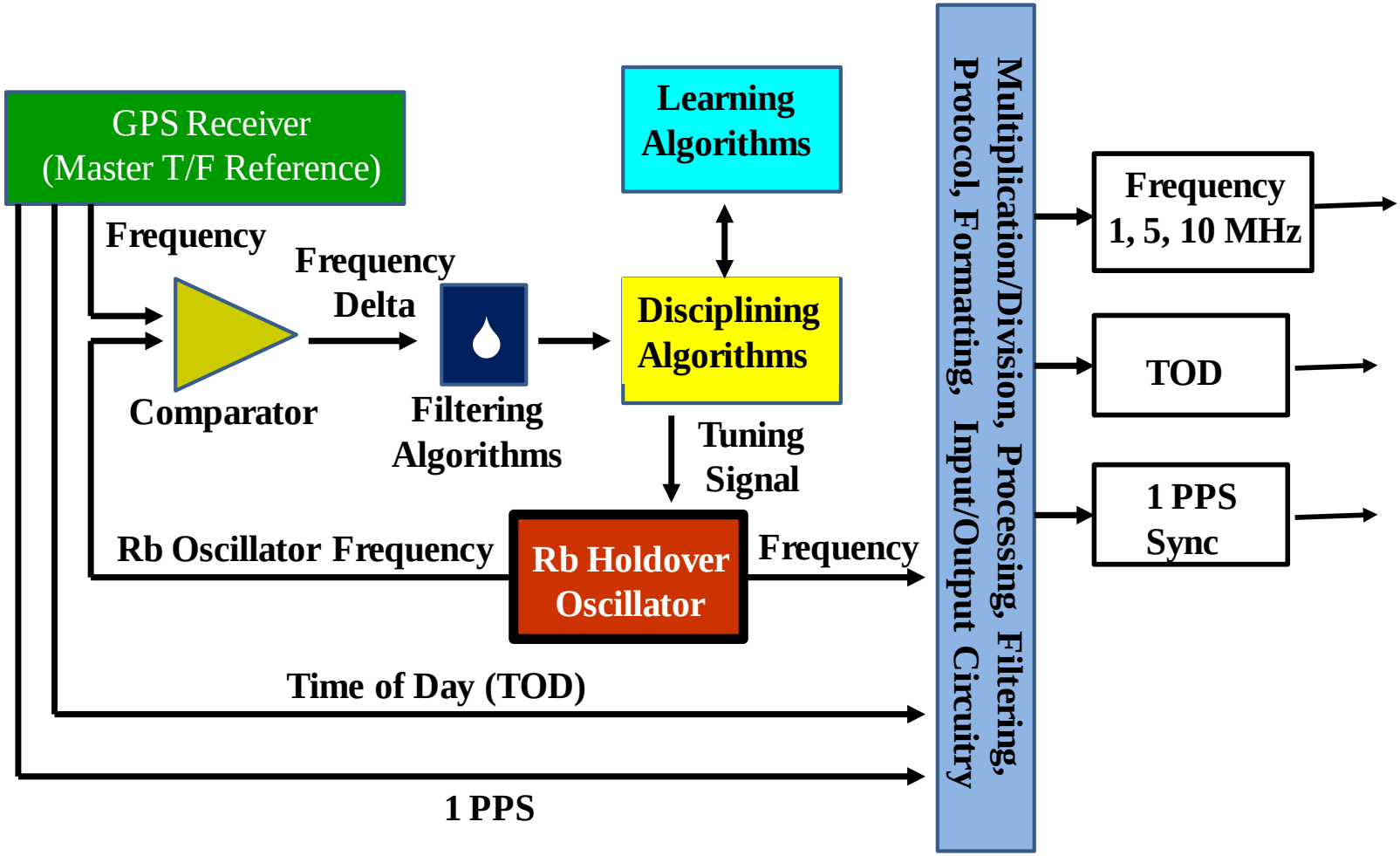
Critical Infrastructure GPS Dependencies



Summary of CI GPS Timing Usage

- Of the 18 CIKR sectors, 15 use GPS timing
- Major uses of GPS timing are for:
  - Network and phase synchronization in wireline and wireless networks (Communications/IT Sectors) used in multiple critical infrastructures
  - Precise frequency generation and stabilization for single frequency wireless networks (LMR simulcast)
  - Phase synchronization in Electric Power, Nuclear Power, and Dams/Hydroelectric power sectors/subsectors
  - Process scheduling, control, and synchronization in Oil and Natural Gas/Chemical/Critical Manufacturing/DIB sectors
  - Precise time stamping of data, transactions/high-frequency trading in Banking & Finance/Postal and Shipping sectors
- In general, GPS timing used in *distributed* interconnected systems that require *synchronization* for monitoring, control, production, transaction tracking, and other functions
- Of the 15 GPS timing using CIKR sectors, GPS timing is deemed *Essential* in 11 of them
  - Essential in more than half of the Nation's CIKR Sectors
  - Dependence is growing over time

GPS Time and Frequency System (TFS) Holdover Oscillator



It is the TFS, not the GPS Receiver alone, that should be considered as the building block for timing, frequency, and time-of-day services.

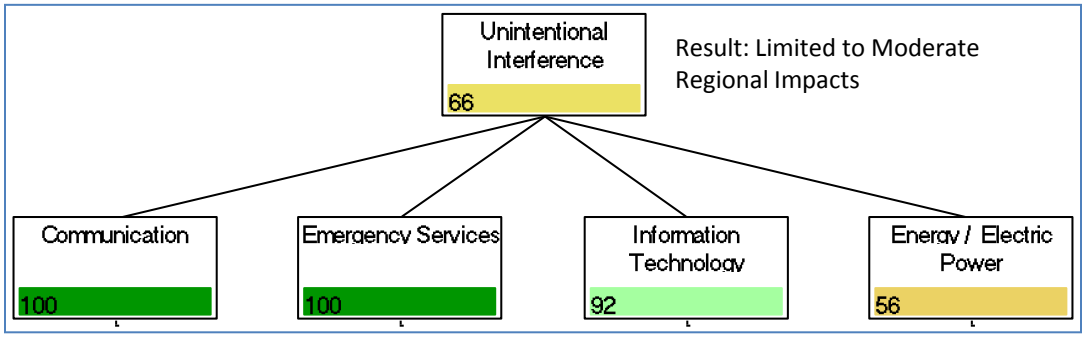
CIKR Sector Oscillators And Holdover Times

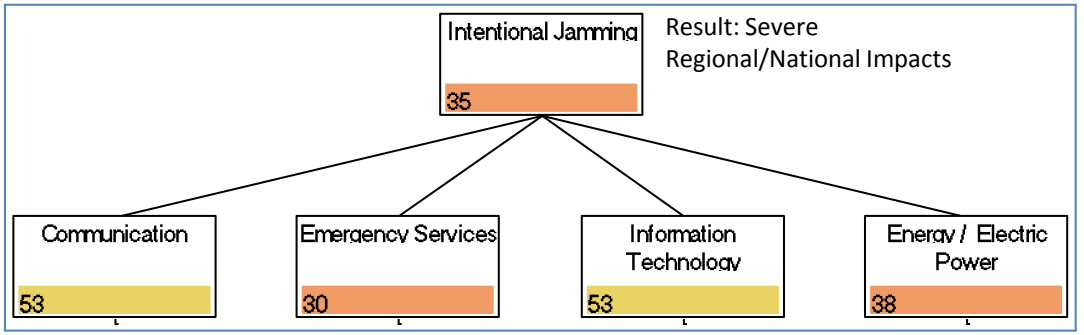
GPS Timing Essential CIKR Sector	Timing Accuracy Requirements*	Oscillators Used**			Least Robust Oscillator	Osc. Holdover Time (Hours)
		TCXO	OCXO	Rb		
Communications Sector	~ Nanoseconds (SONET, CDMA)		X	X	OCXO (HS)	24 +
Emergency Services Sector	~ Nanoseconds (CDMA E911, LMRs)		X		OCXO (HS)	24 +
Information Technology Sector	20 to 100 Nanoseconds (PTP)*		X		OCXO (MS)	1
Banking and Finance Sector	Millisecond- Microsecond (HFT)^	X	X	X	TCXO	< .24 -1.7
Energy/Electric Power Subsector	1-4.6 Microsecond (Synchro-Phasors; Fault Loc.)		X		OCXO (MS)	1
Energy/Oil and Natural Gas Sector Subsector	Microsecond (exploration, SCADA)		X	X	OCXO (MS)	1
Nuclear Sector	1 Microsecond (Synchro-Phasors)		X		OCXO (MS)	1
Dams Sector	1 Microsecond (Synchro-Phasors)		X		OCXO (MS)	1
Chemical Sector	Sub Microsecond-Microsecond		X		OCXO (MS)	1
Critical Manufacturing Sector	Millisecond	X	X		TCXO	1.7
Defense Industrial Base Sector	Millisecond	X	X		TCXO	1.7
Transportation Sector	~ Nanoseconds (Wireless modal comms)		X	X	OCXO (HS)	24 +

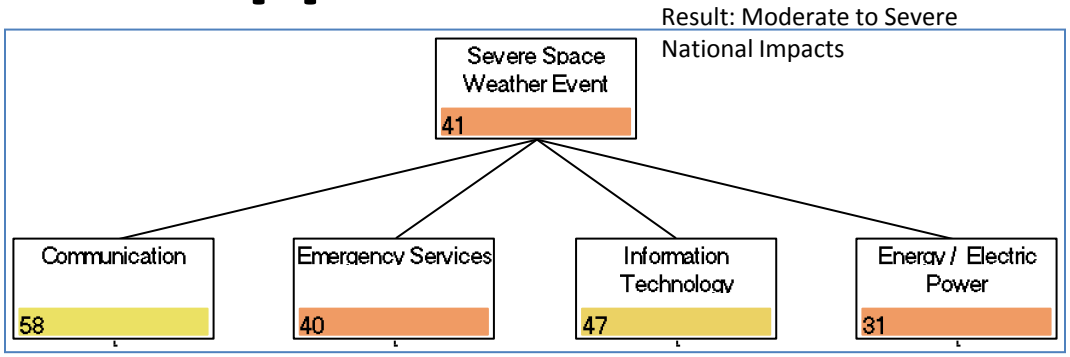
CIKR Impacts Under GPS Outage Scenarios

GPS Timing Essential CIKR Sector	Least Robust Oscillator	Holdover Time (hours)	Unintentional Interference impact: 8 hours (Y or N)	Intentional Jamming impact: Multiple Days (Y or N)	Space Weather impact: 16 hours (Y or N)
Communications Sector	OCXO (HS)	24 *	N	Y	N
Emergency Services Sector	OCXO (HS)	24 *	N	Y	N
Information Technology Sector^	OCXO (MS)	1#	Y	Y	Y
Banking and Finance Sector	TCXO	< .24 -1.7 #	Y	Y	Y
Energy/Electric Power Subsector	OCXO (MS)	1 #	Y	Y	Y
Energy/Oil and Natural Gas Sector Subsector	OCXO (MS)	1 #	Y	Y	Y
Nuclear Sector	OCXO (MS)	1 #	Y	Y	Y
Dams Sector	OCXO (MS)	1 #	Y	Y	Y
Chemical Sector	OCXO (MS)	1 #	Y	Y	Y
Critical Manufacturing Sector	TCXO	1.7 #	Y	Y	Y
Defense Industrial Base Sector	TCXO	1.7 #	Y	Y	Y
Transportation Sector	OCXO (HS)	24 *	N	Y	N

GPS Timing Impact Assessment Approach

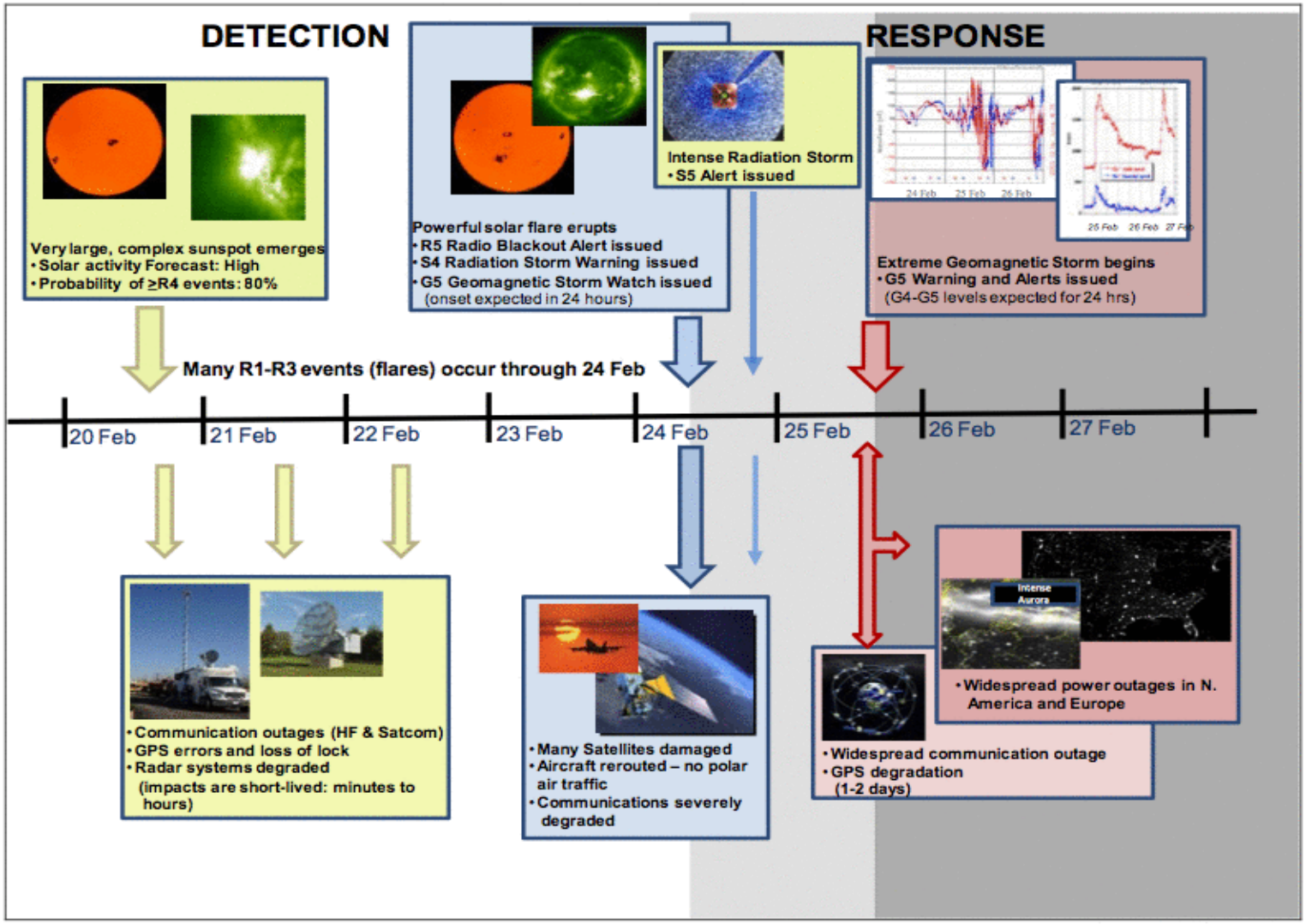






Operational Impact Level	Definition	Score
No impact	Full operational capability.	100
No - Lim		90
Limited	Infrastructure: Infrastructure is mildly impacted. Efficiency of some operations is reduced, workarounds are available, and the consequences are not important. Any degradations or impacts in service, costs, and risks that occur are localized (less than a metropolitan area) and do not extend to the regional level (metropolitan area or greater). Minor, localized public safety impacts.	80
Lim - Mod		65
Moderate	Infrastructure: Timing from GPS is not adequate to meet infrastructure needs over a significant region and time. Important portions of the infrastructure experience significantly degraded or complete loss of functionality as a result. Resulting degradations in the quality of infrastructure services and/or service impacts, costs, and risks that occur are significant to the region (metropolitan area or greater). Public safety impacts at the regional level.	50
Mod - Severe		40
Severe	Infrastructure: Timing from GPS is not adequate to meet infrastructure requirements over a substantial region and time period. Important portions of the infrastructure are severely degraded and there may be cascading effects within the infrastructure possibly cascading to other infrastructure sectors as well. Resulting impacts, costs, losses, risks that occur are significant to the nation. Public safety impacts over multiple regions and extended time periods.	25

Space Weather Planning Scenario



Impact on GPS and CI Feb 20 – 24 ≥ R4 Solar Event Scenario

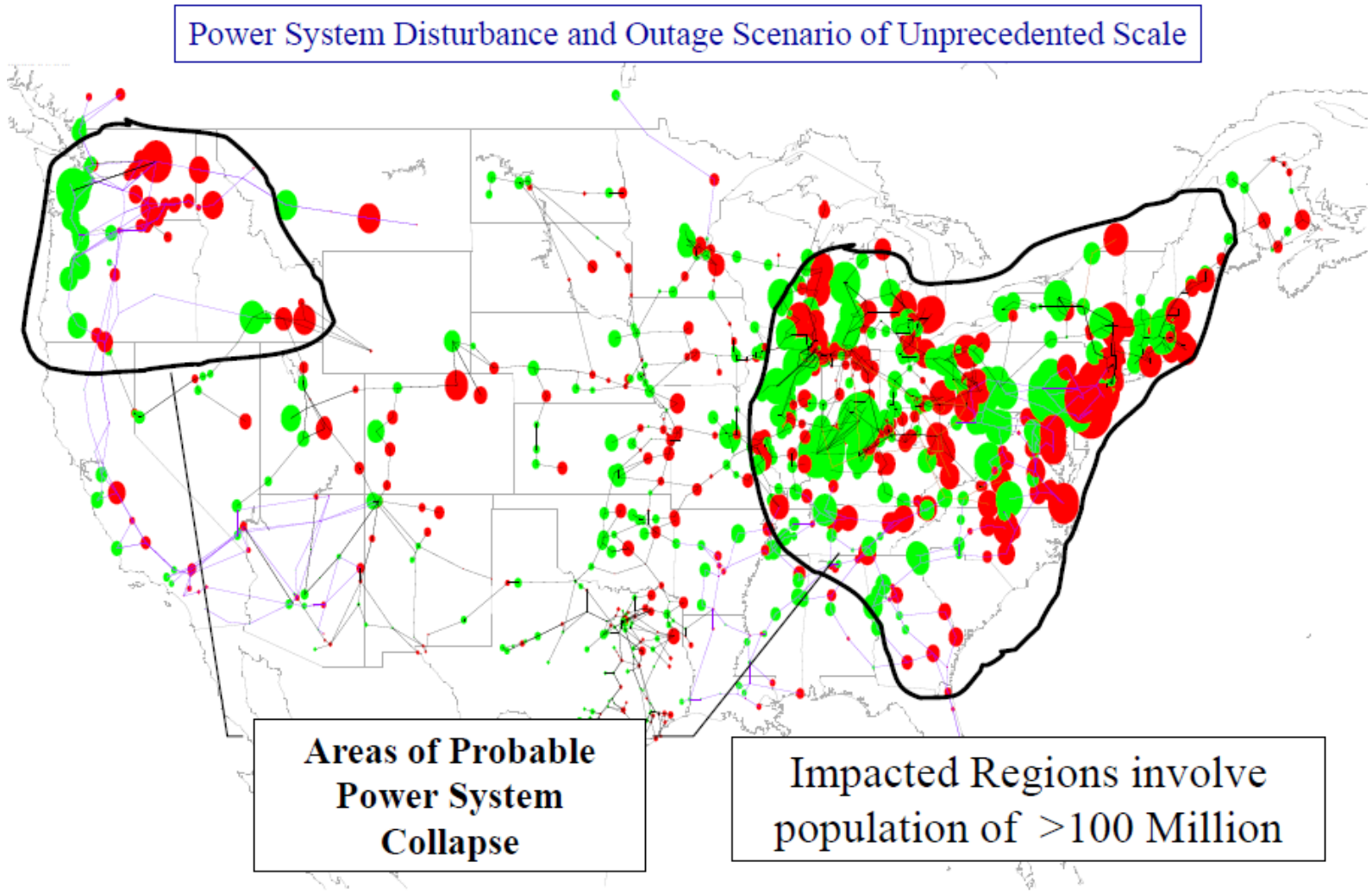
- An R4 event is caused by a disturbances of the ionosphere caused by X-ray emissions from the Sun.
  - A “Severe” (R4) High Frequency (HF) radio frequency event; HF radio communications blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time.
- GPS Impacts: Loss of signal due to:
  - Ionospheric plasma density irregularities
    - Refraction and diffraction of GPS signal propagating through the irregularity
    - Rapid amplitude and phase variations
  - Locations:
    - Night-time equatorial regions (severe, common)
    - Polar regions (usually mild, rare)
    - All latitudes during geomagnetic storms (severe, rare)
  - Time Duration of Event: 10s of minutes to multiple hours over multiple days
- Radar degradation due to similar causes as HF radio and GPS signal impacts described above

Impacts on GPS and CI from 25-26 FEB G5 Geomagnetic Storm Scenario

- **Electric Power outages due to:**
  - **Geomagnetic Storm induces ground currents and Earth surface potentials**
  - **Geomagnetically Induced Currents (GIC) at substations (damages equipment) and on power lines (causes faults\lines to trip out of service)**
  - **Loss of control caused by corrupted grid state estimation\situational awareness due to loss of GPS timing synchronization of data from SCADA and Synchrophasors**
- **Communications degradations consist of:**
  - **HF Blackouts**
  - **Satellite communications losses**
  - **CDMA Cellular and Land Mobile Radio Simulcast loss due to loss of GPS timing synchronization**
- GPS Impacts

Solar Storm Effect	Single Frequency GPS Timing Error (Range)	Single Frequency GPS Position Error (Range)	Time of Day	Duration of Event
TEC increase in ionosphere	Less than 100 ns Typical 10-30 ns	Less than 100 m Typical 10-20 m	Day side of the earth	Hours to days
-scintillation	Less than 100 ns for individual satellites	Loss of precision due to loss or corruption of individual GPS satellites	Worse in early evening	Individual events minutes but can persist for hours to days (diurnal)
-solar radio bursts	Severe events can deny GPS reception	Severe events can deny GPS reception	Day side of the earth	Minutes to hours (duration of the solar burst)

Geomagnetic Storm Caused Regional Power Outages



Source: Kappenman, J. 2010. "Electric Power Grid Vulnerability to Geomagnetic Storms."