NOAA Space Weather (SWX) Program: Thermosphere-Ionosphere Requirements

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Thermosphere-Ionosphere SW Effects

- Ionosphere – impacts on radio wave propagation
  - HF *communications, OTH radar, geolocation* 3 – 30 MHz: D-region ionosphere absorbs radio waves; structure, gradients, undulations, and tilts scatter and deflect signals
  - GNSS PNT precise point *positioning*, satellite *navigation*, and *timing*: line of sight total electron content (TEC) delays and refracts signals; plasma irregularities, structure and gradients diffract signals, causing amplitude and phase scintillations and sometimes complete loss of signal
  - Satellite *communications*: plasma irregularities and structure cause scintillations and loss of signal
- Neutral density
  - Satellite drag in low-Earth orbit (LEO): space traffic management, orbit prediction, conjunction prediction, collision avoidance, re-entry (neutral mass density, winds, structure, waves)

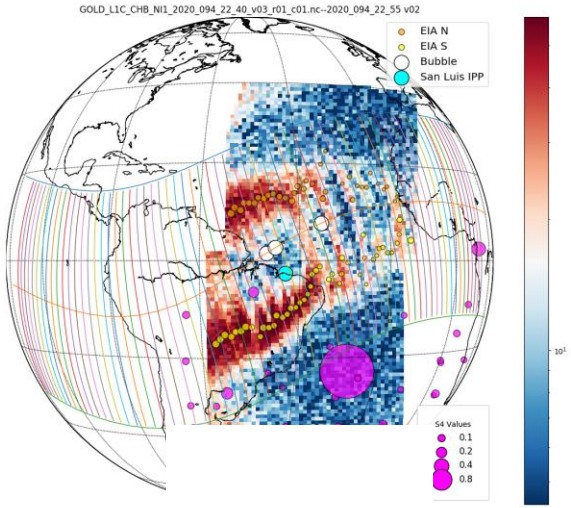
Trade Space: Measurement Objectives

Objectives (SPRWG #):

1. Ionospheric plasma density, structure, and irregularities (N_e, TEC, ΔN_e, S_4, σ_ϕ, rate-of-TEC index ROTI) (B15)
2. Neutral density ρ in LEO (B18)
3. Observations required for physical model drivers:
    a) solar EUV spectrum (related to B3)
    b) auroral imager (B16) / precipitating auroral particles /magnetosphere energy input (Poynting flux)
    c) plasma drifts V_i (B19)
    d) neutral composition O/N_2 (B17)
    e) neutral winds V_n (related to A13)

POR 2025 Continuation Priorities: N_e (and derived TEC, ΔN_e, V_i; B15) and solar EUV (B3)

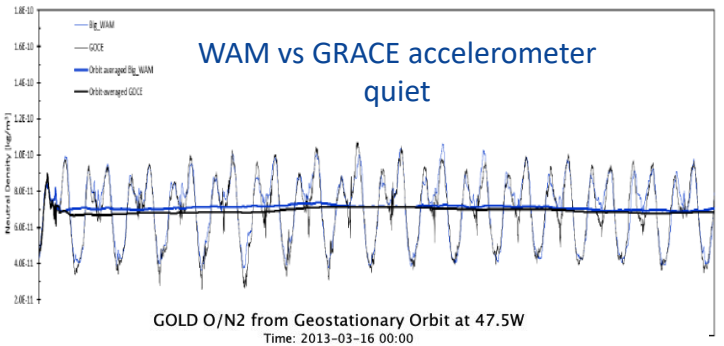
- Maintain the low-inclination LEO RO and plasma drift capabilities similar to those provided by COSMIC-2; reduce latency towards SPRWG goal.
- Augment with the high-inclination, polar orbiting RO constellation with plasma drift (similar to the earlier planned constellations) with low latency
- Augment with GEO nightside airglow imager(s) similar to GOLD. Note that such observations also provide O/N_2
- Additional:
  - Expand GNSS ground-based networks
  - Refine method to geolocate irregularities along ray path and combine ground and space based GNSS observations
  - Ingest into Glo-TEC and ROTI operational product and develop physics-based data assimilation capability
  - Maintain broadband EUV sensor capability

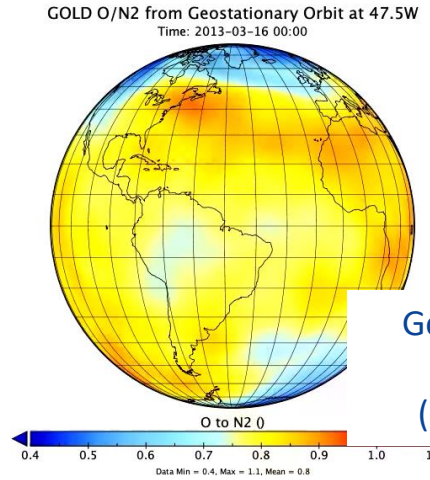


GOLD 135.6nm nightside image Courtesy Richard Eastes

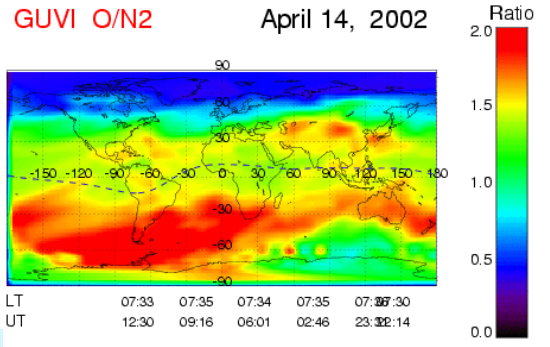
New SPRWG Capabilities: Neutral density (B18) and composition (B17)

- Priority 1. Neutral density:
  - Accelerometer or GNSS POD from LEO constellation below ~550 km altitude with low latency and refresh to remove global bias (1-sat.) or regional bias (>1 sats.) in physical models
  - Implement physics-based data assimilation methodology in operations
  - Neutral density temporal variations can also be a good measure of magnetospheric energy deposition during a geomagnetic storm
- Priority 2. Neutral composition:
  - O/N_2 observations can be observed by airglow imaging on the dayside thermosphere from either GEO (e.g., GOLD) or LEO (e.g., GUVI, SSUSI)
  - From GEO one or more platforms as needed to increase maximum coverage and maintain low refresh
  - From LEO with several polar orbiting, high-inclination, equally spaced in local time
  - GOLD images were previously recommended as part of Ne and ΔNe (B15)
  - Develop physics-based data assimilation capability



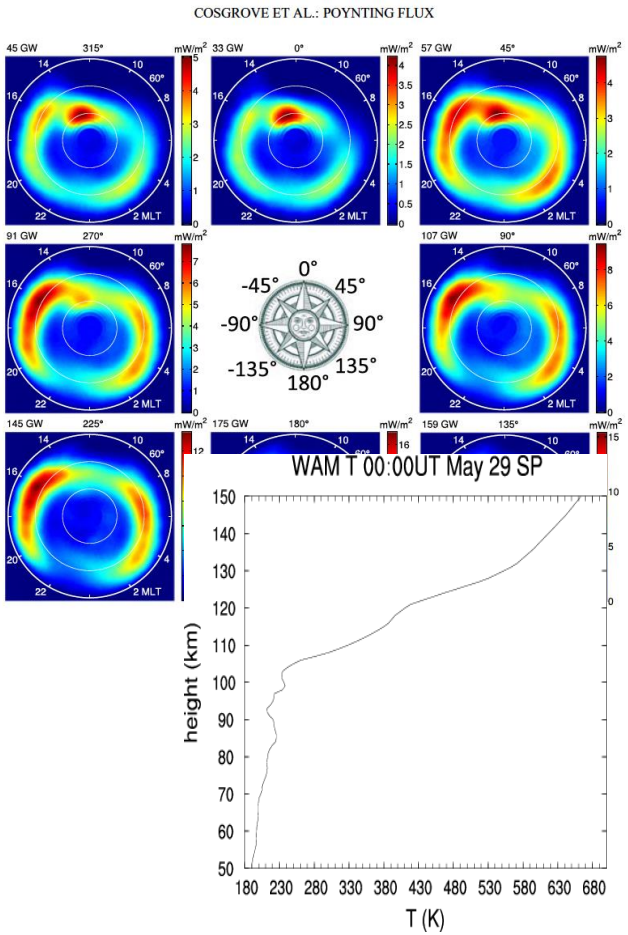


Geostationary imaging (e.g., GOLD)



Additional SPRWG-Based Objectives: Auroral imaging, Neutral winds

- Priority 2. Auroral imaging/magnetosphere energy deposition:
  - Provides location of auroral oval
  - Spectrally resolved auroral imaging can extract energy spectrum of auroral precipitation and ionospheric conductivity
  - Combined with plasma drifts to infer Joule heating – largest energy source for short-term variability during geomagnetic storms
- Priority 3. Neutral winds:
  - IR airglow remote sensing, dual view wind and temperature sensor 20-200 km altitude (e.g., DWTS)
  - Tidal winds in lower thermosphere drive neutral wind dynamo
  - Spectrum of waves propagating from the lower atmosphere and high latitudes impacts ionosphere and electrodynamics, including possible triggering of ionospheric irregularities
  - Satellite constellation for global coverage and refresh
  - Develop physics-based data assimilation capability



Summary

- Trade options have been identified and prioritized for satellite observation needs to improve operation products to mitigate space weather impact in the thermosphere and ionosphere. Several OSSEs are recommended to address the following issues:
  - a) Quantify how the accuracy of ionospheric scintillation specification improves as a function of spatial coverage for RO measurements and/or imaging the nightside ionosphere.
  - b) Quantify how the accuracy of neutral density specification and forecast varies as a function of the spatial and temporal coverage at LEO making either accelerometer or GNSS POD observations.
  - c) Quantify how the accuracy of TEC specification and forecast improves as a function of spatial and temporal coverage for dayside neutral O/N_2 measurements
- Satellite observations are one part of the required infrastructure and architecture to meet the needs of the future space weather impacts. Other components include:
  - Ground-based observation networks
  - Physical modeling go hand-in-hand to fill gaps in observations and enable forecasts
  - Need to enhance thermosphere-ionosphere physical model data assimilation capability (bias correction, driver estimation, ensemble Kalman filter)