CGMS SWCG Task Group on Ionospheric Radio Occultation System Optimisation

Task Group Lead: Erin Lynch (NOAA)

Coordination Group for Meteorological Satellites

CGMS Structure

PLENARY
Hosting partner (+ CGMSSEC)

CGMS SECRETARIAT
(EUMETSAT)

WGI – SATELLITE SYSTEMS & OPERATIONS

- D KIM (KMA) – Co-chair
- J Donnellon (NOAA) – Co-chair
- K Nikolova (EUM), vacant – Rapporteur

WGII – DATA & PRODUCTS

- N Xu (CMA) – Co-chair
- vacant – Co-chair
- A Heidinger (NOAA), P Ruti (EUM) – Rapporteurs

WGIII – CONTINGENCY & CONTINUITY

- S Tang (CMA) – Co-chair
- I Parker (NOAA) – Co-chair
- H Pohjola (WMO), A Taube (EUM) acting – Rapporteurs

WGIV – DATA ACCESS & END USER SUPPORT

- K Bessho (JMA) – Co-chair
- vacant – Co-chair
- S Elliott (EUM), N Donoho (WMO) – Rapporteurs

SWCG – SPACE WEATHER COORDINATION GROUP

- T Nagatsuma (NICT/Japan) – Co-chair
- E Talaat (NOAA) – Co-chair
- A Monham (EUM), J Andries (WMO) – Rapporteurs

WGClimate – CEOS-CGMS JOINT WORKING GROUP ON CLIMATE

- J Privette (NOAA) – Chairperson
- W Su (NASA) – Vice-chair
- Y Meijer (ESA) – GHG Task Team Lead

WGI Task Groups:

- TG on low latency data access
- TG on satellite data and codes
- TG on data collection services
- TG on space environment sustainability (+ link to SWCG)
- TG on RFI detection, monitoring and mapping
- Frequency management issues

Link to CGMS International Science Working Groups:
ITWG, IROWG, ICWG, IWWG, IPWG, IESWG, WGClimate + GSICS EP

WGIV Task Groups:

- Expert Group on cloud services
- TG on data access and exchange
- TG on metadata
- TG on user readiness (+ link to VLab)
- Task Group on cyber security – in abeyance

SWCG Task Groups:

- TG on spacecraft anomaly database
- TG on improving data access
- TG on ionospheric RO optimisation

Status: 14 June 2024

Current CGMS Structure Related to Space Weather

WGI: Satellite Systems & Operations

- NEW **Space Environment Sustainability TG** — *TG Chair:* ***Andrew Monham (EUMETSAT) / Juha-Pekka Luntama (ESA)***

SWCG: Space Weather Coordination

- **Spacecraft Anomaly Database TG**
- **Improving Data Access TG**

  TGs Chair: ***Andrew Monham (EUMETSAT)*** (for the two groups above)

- **Ionospheric RO Optimisation TG** — *TGs Chair:* ***Erin Lynch (NOAA)***

Co-Chair: ***Tsutomu Nagatsuma (NICT), Elsayed Talaat (NOAA)***
Rapporteur: ***Andrew Monham (EUMETSAT), Jesse Andries (WMO)***

GSICS GRWG Space Weather Subgroup — *Subgroup Chair:* ***Tsutomu Nagatsuma (NICT)***

Coordination Group for Meteorological Satellites

GSICS Global Space-based Inter-Calibration System

CGMS

Ionospheric RO System Optimisation Task Group

The Task Group on Ionospheric Radio Occultation System Optimisation was formed at CGMS-50 to address the full scope of item 6.4 in the High Level Priorities Plan:

> *In coordination with IROWG establish requirements for and recommend an implementation of an optimised system for radio occultation observations for ionosphere monitoring*

The Task Group benefits from the support of ionospheric RO experts, representatives of the CGMS RO data providers, and coordination with IROWG.

Since the TG formation, significant progress has been made in documenting the capabilities of current RO missions, reviewing methods to geolocate plasma bubble scintillations, and initiating Observing System Simulation Experiments (OSSEs).

Guiding Action and Rationale for the Task Group

Actionee	AGN item	Action #	Description	Deadline	Status	HLPP
SWCG (RO TG)	Joint WGI-WG-IV-SW CG/4	SWCG/A50.03	In coordination with IROWG, establish requirements for and recommend an implementation of an optimized system for radio occultation observations for ionosphere monitoring	CGMS-52	OPEN	6.4

Task Group Objectives:

- Establish requirements for:
  - Data latency
  - Number of ionospheric measurement counts for the whole system
  - Geographic and local time coverage requirements
- Observing System / System Simulation Experiments to address sensitivity of operational applications to changes in the latency or counts in order to establish requirements
- Access to commercial RO in support of the requirements

Task Group Membership

NOAA	Erin Lynch (Lead), Elsayed Talaat, Irfan Azeem, Christian Naylor, Ron Smilek
EUEMETSAT	Andrew Monham, Christian Marquardt, Riccardo Notarpietro
NICT	Tsutomu Nagatsuma
CMA	Cong Huang
DLR	Mainul Hoque
IROWG	Paul Straus (Aerospace), Bill Schreiner (UCAR), Riccardo Notarpietro, Tony Mannucci (JPL-NASA)
ROM-SAF	Manuel Hernandez-Pajares, Victoria Graffigna (IEEC & UPC, Barcelona)
WMO	Heikki Pohjola, Jesse Andries
Met Office	Edmund Henley
ISES	Mamoru Ishii

Observers:

- Kent Bækgaard Lauritsen (DMI-Denmark, PM on ROM SAF), Sean Healy (ECMWF), Hui Shao (NOAA), Estel Cardellach (ICE-CSIC-Spain)

Task Group Activities Summary

Task List from the Terms of Reference:

1. **Review current implementation systems**
    a. Number of ionospheric measurement counts
    b. Orbital planes (extent of global coverage)
    c. Latencies achieved
2. **User requirement definition**
    a. How user requirements are currently expressed
    b. Possible improvements to requirement definitions to drive optimised system (e.g. expression of temporal coverage per geographic zone, prioritisation of geographic zones, etc.)
3. **Definition of Observing System Simulation Experiments (OSSE) and Observing System Experiments (OSE) to address sensitivity of operational applications to changes in latency / counts in order to establish requirements.**
4. **Consider potential improvements in CGMSS Member RO measurement capabilities and / or data access in support of the requirements.**
5. **Consider potential impact of commercial RO in support of the requirements.**

NOAA Activities in Support of Task Group Efforts

- There is interest among the international community in understanding the requirements for radio occultation (RO) observations, often expressed as a count per day, particularly for ionospheric observations
  - The CGMS SWCG Task Group on Ionospheric Radio Occultation System is addressing the requirements for radio occultation observations for ionosphere monitoring.
  - The IROWG is conducting the ROMEX experiment to understand RO count requirements for the lower atmosphere.
- NOAA wants to understand the needs for ionospheric RO observations to
  - Set requirements for commercial data buys
  - Assess the requirements for a potential RO backbone
- This is a preliminary assessment of the number of ionospheric RO observations needed to support modelling as well as some future work to further refine this estimate

NOAA Consolidated Observation User Requirements List (COURL)

WRN-SWX – Slant Total Electron Content of the Ionosphere

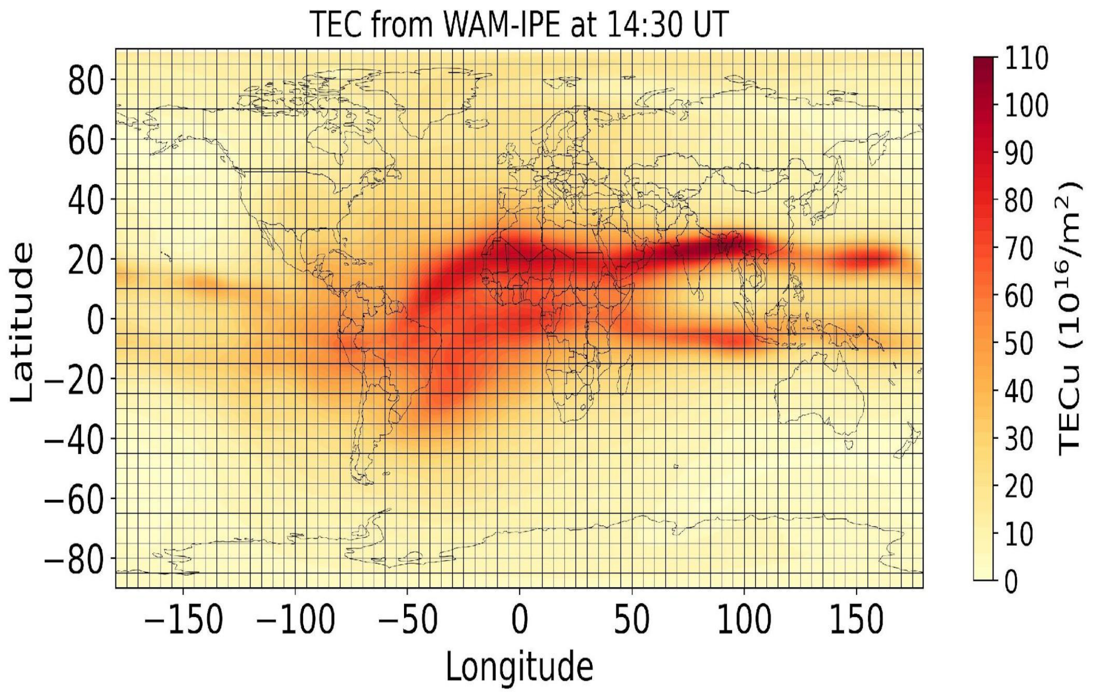
Attribute	Threshold	Objective
Geographic Coverage	Global	
Measurement Accuracy	3 TECU 0.3 TECU	
Sampling Interval	12,000 obs/day	50,000 obs/day
Data Latency	60 min	5 min
Measurement Range	1 – 200 TECU	1 – 400 TECU
Vertical Range	90 – 1500 km	

Preliminary Assessment of Daily RO Requirements for Ionospheric Applications

- Initial approach is to address the RO requirements for resolving the background ionosphere to support modelling through data assimilation.
- Initial approach did not explore separate requirements estimates for geomagnetically quiet and disturbed conditions.
- A prior Observation System Simulation Experiment (OSSE) study has shown that observations improve biases between the nature run and the assimilation.
- The OSSE did not study constellation optimization (and number of RO occultations).

Ionospheric Modelling (Mid and Low Latitudes)

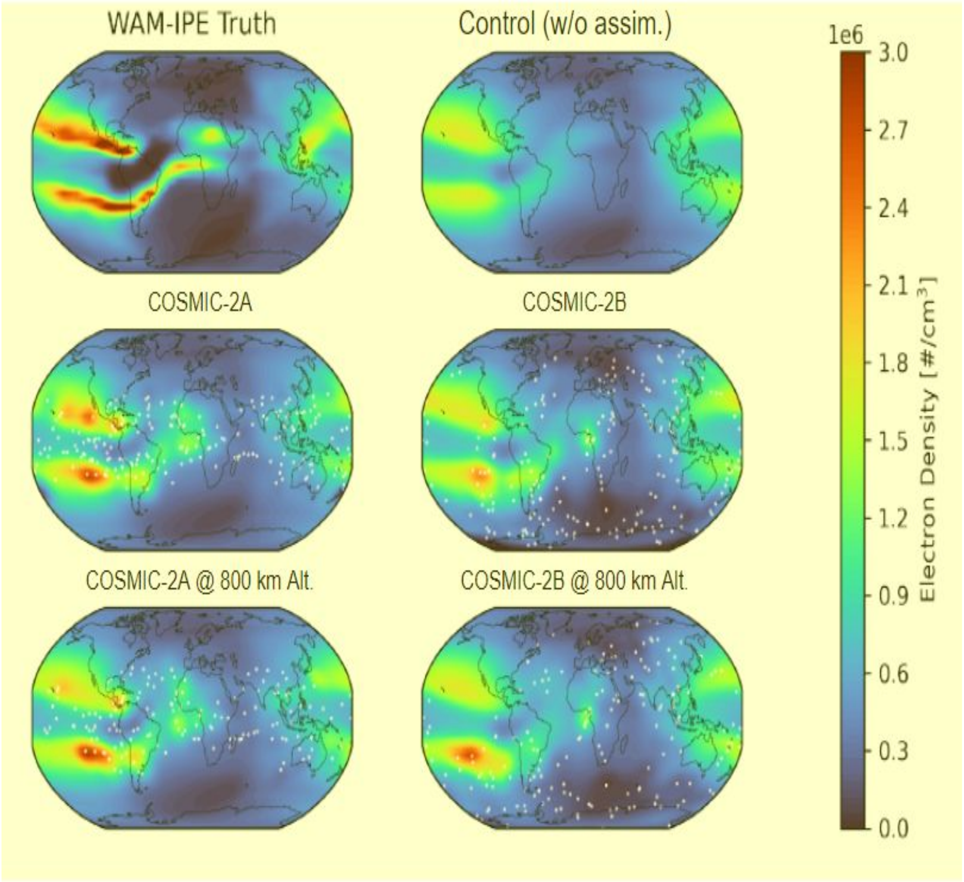
- Goal: Provide refresh of global TEC coverage for each assimilation cycle
- Assumptions:
  - 5˚x5˚ global model
    - [-90,90],[0:360]
  - Assimilation cycle = 2 hr



- # of grid cells: (180/5)x(360/5) = 36x72
- # of assimilation cycles per day: 24/2 = 12
- # of occultations per day: 36x72x12 = **31,104 occs/day**

NOAA Ionospheric OSSE: Set Up

- 2022 OSSE conducted by T. Matsuo et al. for SWO looked at assimilating EDPs in the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM)
- Constellations chosen to resemble COSMIC-2. Observations simulated using WAM-IPE nature run.
- Observations assimilated using Data Assimilation Research Testbed (DART) framework and Ensemble Adjustment Kalman Filter (EAKF) data assimilation scheme.
- Results for quiet and storm periods were assessed.
- The OSSE did not address ionospheric RO requirements in the context of global-scale modelling.

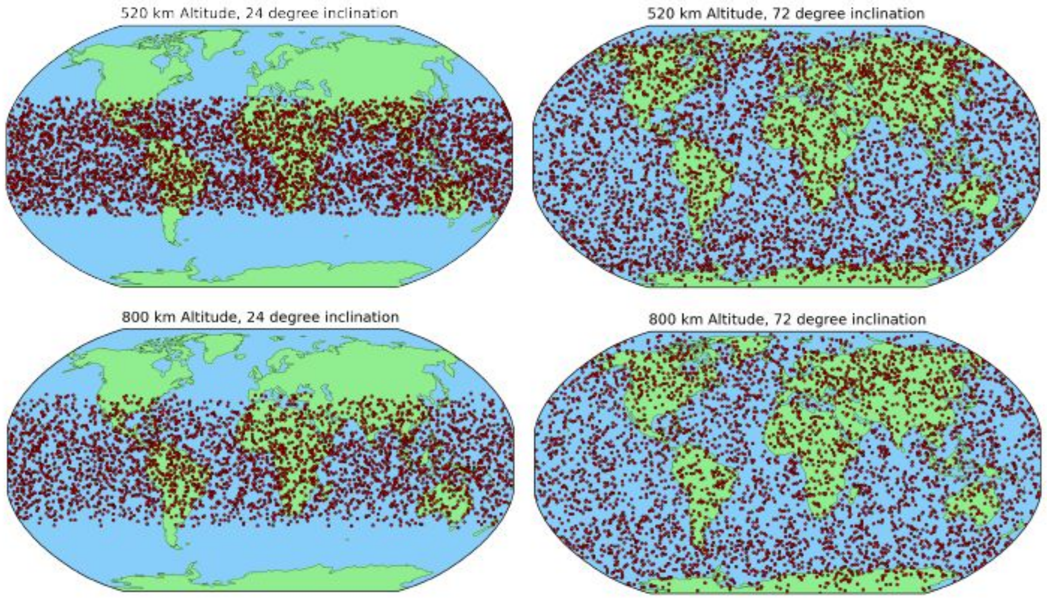


Figures courtesy of T. Matsuo (UC, Boulder)

NOAA Ionospheric OSSE: RO Constellations

- Four constellations of 6 satellites are simulated with varying orbital parameters.

- 520 km altitude and 24◦ inclination constellation
- 520 km altitude and 72◦ inclination constellation
- 800 km altitude and 24◦ inclination constellation
- 800 km altitude and 72◦ inclination constellation



Experiment Name	Included Constellations	Short-Hand Notation
OSSE 1	520 km alt, 24° inc	5024
OSSE 2	520 km alt, 72° inc	5072
OSSE 3	800 km alt, 24° inc	8024
OSSE 4	800 km alt, 72° inc	8072
OSSE 5	520 km alt, 24° inc & 800 km alt, 72° inc	5024 & 8072
OSSE 6	520 km alt, 24° inc & 520 km alt, 72° inc	5024 & 5072
OSSE 7	520 km alt, 24° inc & 800 km alt, 24° inc	5024 & 8024
OSSE 8	800 km alt, 24° inc & 800 km alt, 72° inc	8024 & 8072
OSSE 9	520 km alt, 72° inc & 800 km alt, 72° inc	5072 & 8072
OSSE 10	520 km alt, 72° inc & 800 km alt, 24° inc	5072 & 8024

NOAA Ionospheric OSSE: Ranking Metric

- A ranking metric is used as a high-level indicator of each OSSE's relative performance.
- Using the RMSEs at each latitude region for hmF2, NmF2, TEC, and altitude electron density, each OSSE is ranked.
- The ranking metric assigns a rank to each OSSE's RMSE, 1-10, with 1 having the lowest error and 10 having the highest error.
- The rank is calculated for each hour and then averaged over the period to give the ranking metric for the quiet or storm periods.

NOAA Ionospheric OSSE: Results

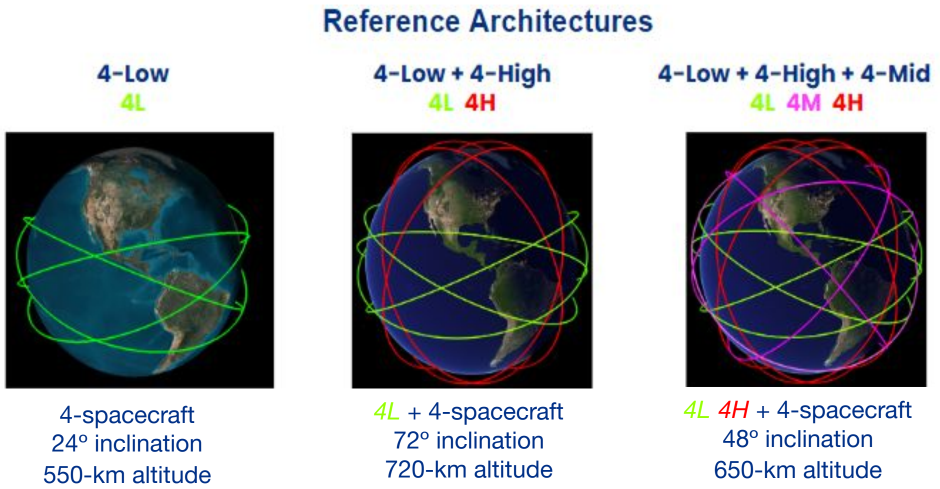
- Where there are more observations for a given latitude band, there is better performance.
- Thus, we generally see better performance from the 520 km altitude constellations than the 800 km altitude constellations.
- Observations improve the large model biases about the EIA that is present between WAM-IPE and TIEGCM.
- There is consistent improvement seen for NmF2 RMSE at low- and high-latitudes for the quiet and storm periods.

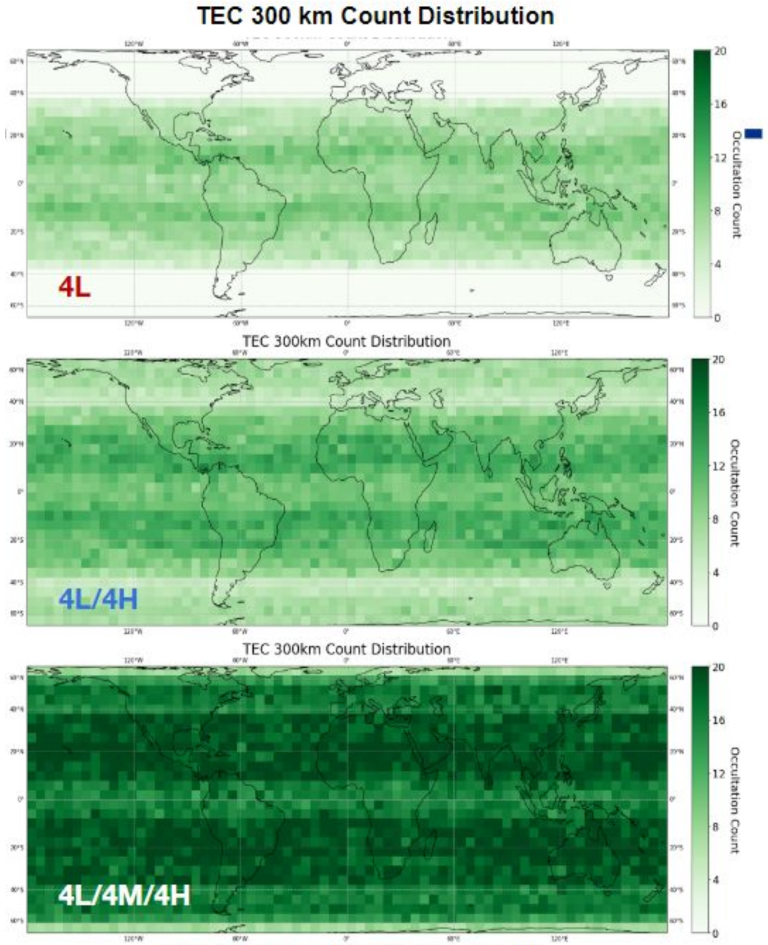
Altitude	Experiment Name	Constellations	Quiet: Low Lat	Quiet: Mid Lat	Quiet: High Lat	Quiet: Global	Storm: Low Lat	Storm: Mid Lat	Storm: High Lat	Storm: Global
200 km	OSSE 1	5024	5.12	7.53	8.36	8.3	4.64	7.15	7.85	7.79
300 km			5.24	9	8.49	7.97	5.18	8.09	8.55	7.21
400 km			4.71	8.76	8.38	5.33	5.52	8.73	8.52	6.91
500 km			3.81	8.79	7.57	4.36	5.79	7.85	6.88	6.33
200 km	OSSE 2	5072	2.72	3.77	4.28	2.77	5.61	5.42	4.09	4.3
300 km			8.63	3.34	3.71	6.99	8.91	5.61	3.58	7.73
400 km			9.18	5.9	5.28	9.18	9.21	4.48	4.03	8.3
500 km			9.1	6.68	5.48	9.1	8.39	4.55	4.67	7.67
200 km	OSSE 3	8024	4.22	8.22	7.72	8.38	4.61	7.85	8.18	7.67
300 km			5.34	9.4	9.05	8.47	5.39	8.48	9.21	7.88
400 km			6.32	8.94	8.12	6.79	6.52	7.61	9.24	7.21
500 km			5.51	8.47	7.48	5.87	5.15	6.24	6.88	5.55
200 km	OSSE 4	8072	2.53	6.06	5.32	4.51	5.09	5.73	4.36	5.12
300 km			9.11	5.87	4.48	8.34	8.67	7.33	5.33	8.61
400 km			9.82	7.13	4.21	9.82	9.67	5.61	4.58	9.03
500 km			9.9	6.93	4.77	9.9	9.21	5.3	4.88	8.7
200 km	OSSE 5	5024 & 8072	7.29	6	5.2	5.81	5.85	4.27	5.18	5.03
300 km			4	5.04	5.22	3.5	4.7	4.52	5.27	3.76
400 km			3.65	3.69	3.98	3.33	3.82	5.73	4.33	3.67
500 km			4.52	3.65	4.4	4.19	5.18	6.3	5.21	5.09
200 km	OSSE 6	5024 & 5072	8.12	3.28	5	4.37	6.42	4.12	4.48	4.67
300 km			4.38	3	4.15	2.39	4.06	2.88	3.3	2.82
400 km			3.13	2.86	5.05	2.82	3.06	4.58	3.76	2.64
500 km			3.26	3.51	5.03	3.03	3.91	5.27	4.85	3.82
200 km	OSSE 7	5024 & 8024	7.62	7.5	8.2	9.02	5.7	6.61	9.03	7.94
300 km			2.16	8.12	9.36	5.85	2.15	6.27	8.7	4.64
400 km			1	6.83	7.87	1.35	1.42	7.64	8.79	3.64
500 km			1.02	6.76	7.04	1.11	2.73	7.21	6.79	3.91
200 km	OSSE 8	8024 & 8072	6.11	5.77	4.77	5.52	5.39	5.03	5.12	4.88
300 km			4.26	5.57	5.05	3.87	4.36	5	5.67	3.79
400 km			5.01	4.21	3.63	4.66	4.55	4.55	4.91	4.12
500 km			5.63	3.5	4.32	5.33	4.18	4.79	5.33	4.45
200 km	OSSE 9	5072 & 8072	4.28	3.57	2.05	2.03	5.76	3.64	2.21	3
300 km			7.38	2.63	1.5	5.02	7.61	4	1.73	5.88
400 km			8	3.55	3.84	7.85	7.42	2.76	2.82	6.21
500 km			8	3.54	4.09	7.96	6.73	3.09	4.82	6.09
200 km	OSSE 10	5072 & 8024	7	3.7	4.1	4.29	5.94	5.18	4.48	4.61
300 km			4.2	3.35	3.98	2.6	3.97	2.82	3.67	2.7
400 km			4.18	3.13	4.64	3.87	3.82	3.33	4.03	3.27
500 km			4.29	3.18	4.82	4.15	3.73	4.39	4.7	3.39

Coordination Group for Meteorological Satellites

NOAA RO Backbone Study

- The distribution of TEC occultations will impact the desired global refresh.
- UCAR recently completed Phase 1 of a Backbone Study for NESDIS to explore RO architecture configurations to meet lower atmosphere requirements.
- TEC observations were simulated for the Phase 1 architectures, but the next phase will look more closely at space weather requirements.



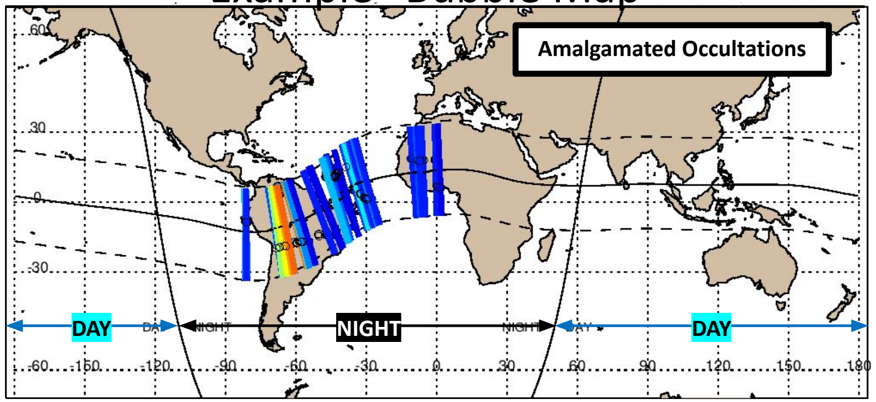


Figures courtesy of W. Gullotta (UCAR)

Scintillation Coverage and Refresh

- RO missions like COMSIC-2 that provide high-rate SNR and phase enable the geolocation of regions of irregularity causing scintillation. Once geolocated, a “Bubble Map” is created amalgamating all COSMIC-2 RO observations.
- However, scintillation only occurs when the line-of-sight of the GNSS signal passes within the apex altitude field line of the ionospheric bubbles. Only a fraction of occultation’s lines-of-sight provide effective scintillation coverage.
- Requirements for coverage and refresh of scintillation will be explored in future studies.

Example “Bubble Map”



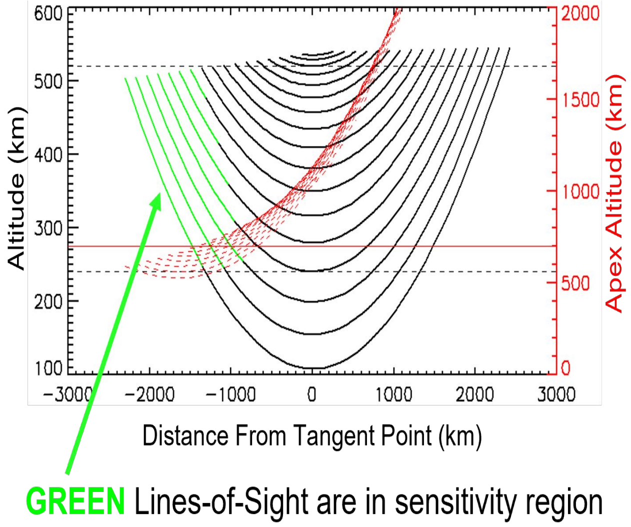


Figure courtesy of P. Straus (Aerospace Corp.)

Summary and Next Steps

- The Task Group has made significant updates to the table of Ionospheric RO capabilities and updates to WMO OSCAR data base are being made as a result of the cross comparison
- Commercial capabilities remain to be assessed
- There is word to be done defining and initiating OSSEs to aid in determining the number of required occultations (priority) and assess the sensitivity of operational applications to changes in latency / counts
- Looking forward to increased coordination and collaboration with IROWG and the Space Weather Sub-Group toward achieving our joint objectives.