Marine Meteorology and Space Weather ONR Code 322MM

27 June 2023

Ocean, Atmosphere, and Space Research Division

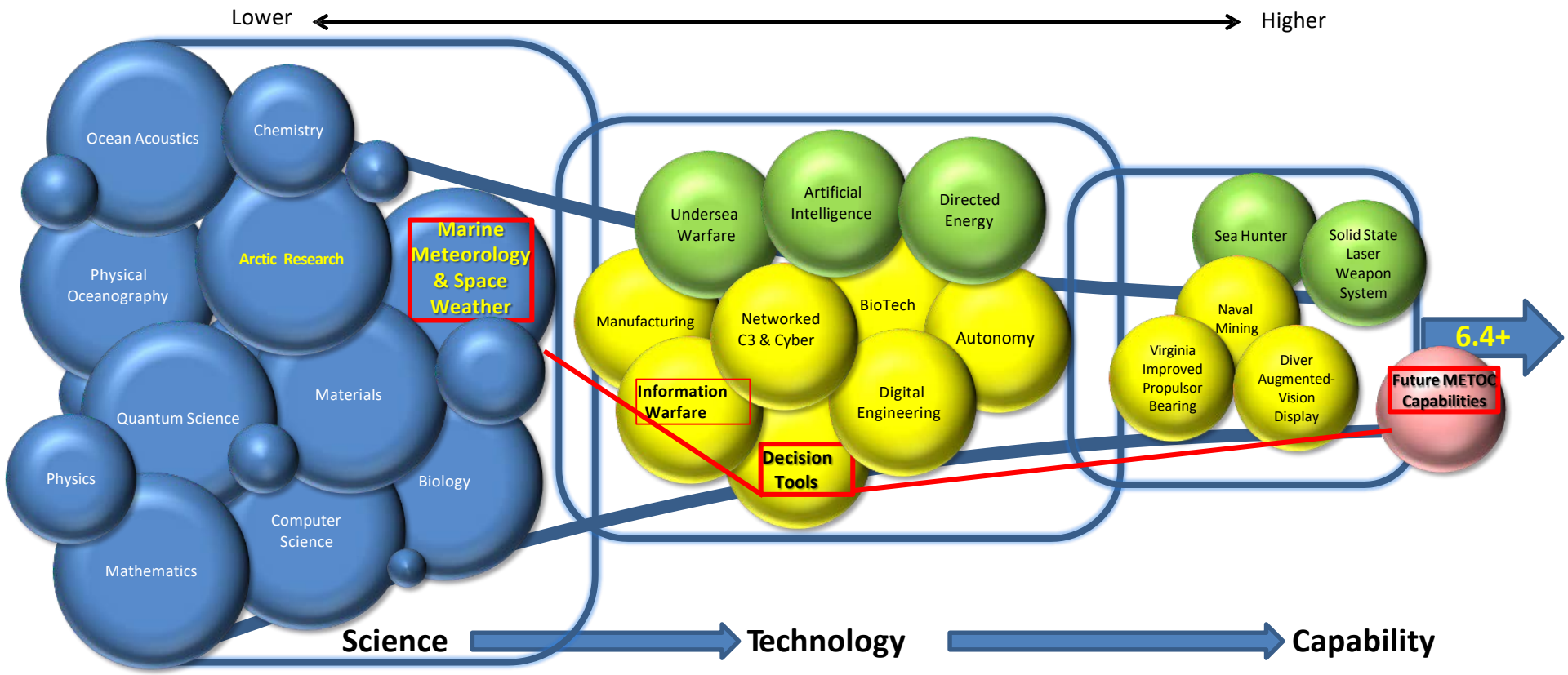
Naval Research - Team

Technical Maturity

ONR Code 322MM Program Officers

- Daniel P. Eleuterio
  - daniel.p.eleuterio.civ@us.navy.mil
- Joshua H. Cossuth
  - joshua.h.cossuth.civ@us.navy.mil
- Katherine L. Mulreany
  - katherine.l.mulreany.civ@us.navy.mil
- Bruce A. Fritz
  - bruce.a.fritz4.civ@us.navy.mil

Naval Research - Portfolio



- Basic and early Applied Research (BAR - 47%)
- Disruptive Technology (Innovative Naval Prototypes - 14%)
- Enabling Capabilities (Tech Candidates - 7%, Future Naval Capabilities - 13%, Tech Maturation - 16%; Total - 36%)
- Advanced Component Development & Prototypes – 1.2%)

*Percentage of PB22

Space Weather

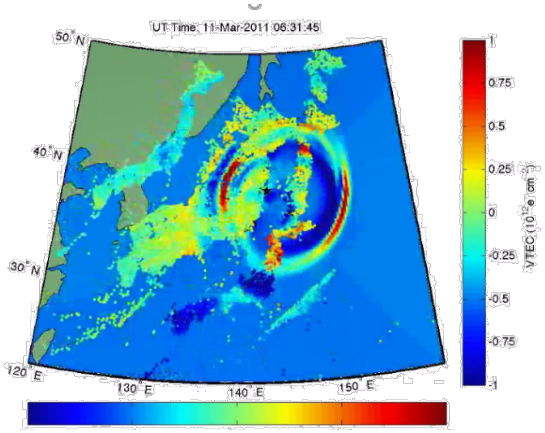
Research Area

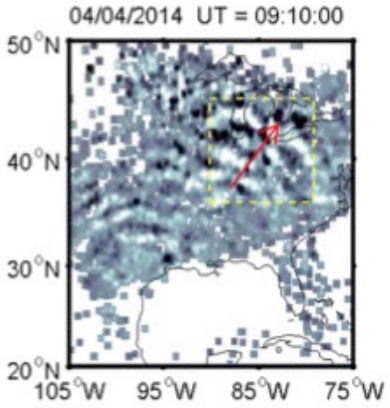
- **Impact**
  - Civil and other DoD ionospheric research does not sufficiently address the Navy's needs for Bottom-Side Ionospheric (BSI) conditions in regional maritime applications for HF Radar and Communications applications.
- **Hard Problems**
  - Improved prediction of Sporadic E, Equatorial Spread F, Polar Auroral clutter, transient effects of TIDs.
  - Improved sensing of regional conditions using nontraditional means.
- **Key Stakeholders**
  - Research partners, Naval Information Warfare Forces, Navy METOC

- **Research thrusts**
  - Understanding and prediction of low latitude and high latitude irregularities away from ground-based observing systems
  - Ionospheric drivers from below/ coupling between the stratosphere and thermosphere
  - Global assimilation of non-traditional ionospheric measurements
  - Space-based and maritime remote sensing applications
  - Communication applications
  - Low cost innovations (Cubesats, secondary payload sensors)
  - High latitude modeling (future focus)

Past Projects

- Ocean2Space Couplings (BRC 2012-2015)
  - The Couplings BRC addressed fundamental, multidisciplinary scientific and mathematical questions about coupling and upward energy propagation from earth, oceans, and troposphere that contributes to ionospheric variability.
  - PIs: J. Makela, P. Lognonne, D. Fritts, O. Buhler, S. Llewellyn-Smith, N. Zabotin
- Bottom Side IONosphere, BSION (2016-2019)
  - Four years of BSION 6.1 research on basic coupled, integrated tropospheric, stratospheric and ionospheric modeling suite was transitioned to the DARPA Space Environment Exploitation (SEE) program as well as 6.2-6.4 ONR projects including the further development of the Next Generation Ionosphereic Model (NIMO) planned for operations at FNMOC
  - PIs: T. Yuan, C. Valladares, F. Robey, J. Emmert, S. Eckermann, S. McDonald, D. Broutman, E. Miller, T. Fuller-Rowell, J. Retterer, V. Eccles, A. Coster





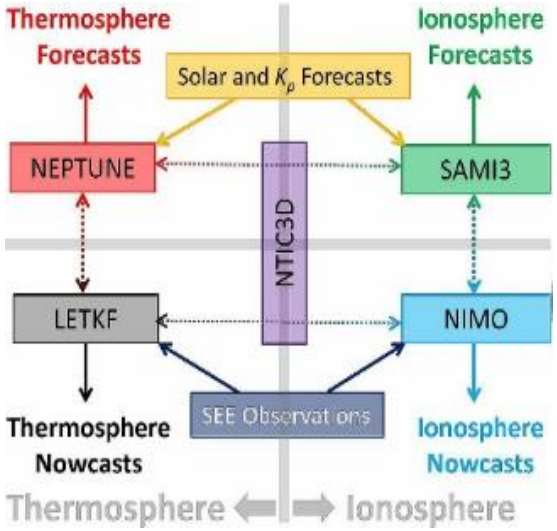
GPS TEC data.
From Azeem et al. (2015, GRL)

Horiz. Wavelength ~ 250 km.
Wave period ~ 20 min.

Current Projects

- Core Space Weather
  - Re-started in 2020, budget is very small
  - Wide variety of topics including modeling, data analysis, and instrument development
  - PIs: S. Smith, L.C. Tsai, J. Mabie, L.J. Nickish, S. McDonald, A. Nicholas, S. Budzien, D. Hickey, J. Helmboldt, A. Chartier, S. Kaeppler
- NIMO
  - NIMO is an ionospheric specification and short-term climatological forecast model that will began transition to operations at Fleet Numerical Meteorology and Oceanography Center (FNMOC) in FY22
  - Consists of an ionospheric data assimilation system (IDA4D), coupled to a physics-based ionosphere forecast model (SAMI3)
- HiFIOS
  - Low latitude implementation of NIMO
  - Field campaign in Palau currently in works

The Limb-Imaging Ionospheric and Thermospheric Extreme Ultraviolet Spectrograph (LITES) and the GPS Radio Occultation and Ultraviolet Photometer Co-located (GROUP-C) experiments on the International Space Station in February 2017. Photo courtesy of NASA



Future Work

- PRISM
  - High latitude, regional implementation of NIMO
  - PIs: A. Burrell, D. Themens, M. Cohen, E. Thomas, R. Moore, R. Varney, A. Coster, J. Morton, G. Perry
- [Unfunded] project on Gravity Wave impact on the ionosphere
  - Coupling processes between the troposphere/ stratosphere and the thermosphere/ionosphere are an emerging area of exciting science and are underinvested due to the cross-disciplinary nature of the problem and relative paucity of constraining observations. New space-based sensors and global ground-based observation networks are changing this and providing new opportunities to advance the state of the science. A larger scale effort by a focused team of investigators is needed to address this opportunity.
  - SEND US YOUR WHITE PAPERS!

Polar, Regional Ionosphere Sensing and Modeling (PRISM)

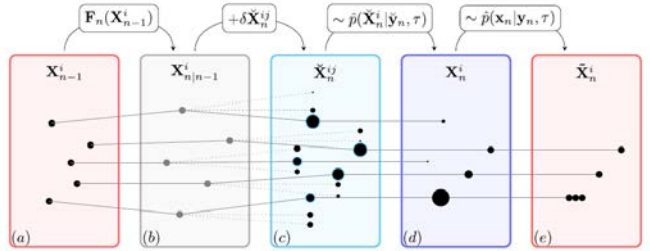
6.2 Tech Candidate

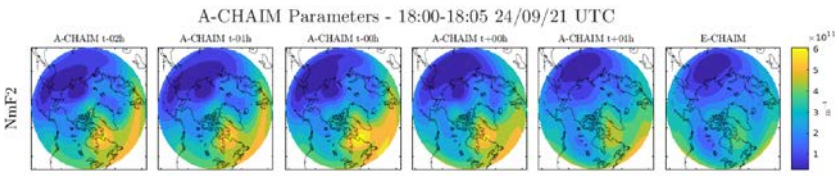
Objective: PRISM will improve polar ionosphere for NORTHCOM and EUCOM needs and will replace outdated empirical polar ionospheric models with a regional full physics ionospheric model leveraging recently available observations from new instruments and techniques

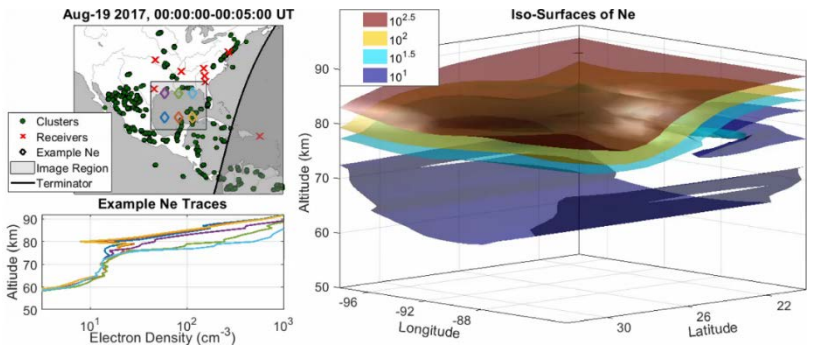
- **Demo capability is based on:**
  - High latitude extension of NIMO (see previous slide)
  - Full physics ionosphere model SAMI3
  - Respective ionosphere and thermosphere data assimilation systems

- **Capability demonstration via:**
  - Kickoff April 2023
  - Field Campaign: Winter 2025 – 26

PIs: Angeline Burrell, David Themens, Morris Cohen, Evan Thomas, Robert Moore, Roger Varney, Anthea Coster, Jade Morton, Gareth Perry







Funding Opportunities

- Long Range BAA N00014-23-S-B001 (via the 322MM Team Page)
  - https://www.nre.navy.mil/organization/departments/code-32/division-322/marine-meteorology-space
  - Formal Planning Letters/ Full Proposals encouraged by July 1 annually for the following Fiscal Year (Oct 1st)
- N00014-23-S-F002 FY24 Defense University Research Instrumentation Program (DURIP)
  - Posted 02/14/2023, Due Date: 12 May 2023
  - https://www.nre.navy.mil/work-with-us/funding-opportunities/fiscal-year-2024-defense-university-research-instrumentation
- SBIR / STTR
  - N23A-T022 Lightweight Mirrors for Microsatellites and Small Satellites
  - N231-070 Ultraviolet Solar Blind Sensors for Microsatellites and Small Satellites
  - N222-112 Low-profile High-Frequency Maritime Antenna (First RF Corp.)
  - N182-137 F-region (thermospheric) Dayside Neutral Wind Measurement from a CubeSat (SSRC)

Funding Opportunities
Early Career / Student

- N00014-23-S-F004 FY24 Young Investigator Program
  - Posted 03/29/2023, Due 7 July 2023
  - https://www.nre.navy.mil/work-with-us/funding-opportunities/fy-2024-young-investigator-program-yip
  - 2013-2015 Riccardo Bevilacqua – RPI - Measuring Spatio-temporal Variations in Upper Atmosphere via Nano Satellites and WINCS
  - 2022-2025 John Swoboda - MIT Haystack - Novel Ground-based Ionospheric Sensing
- NRL Pathways Internships (Quarterly)
  - https://www.nrl.navy.mil/careers/students/pathways/
- NRL-NRC Post-Doctoral Program
  - https://www.nrl.navy.mil/Careers/Post-Docs/NRC/
  - Application deadlines: February 1, May 1, August 1 and November 1
- ONR Undergraduate and Graduate Internships (NREIP and SEAP)
  - https://www.nre.navy.mil/education-outreach/undergraduate-graduate/nreip-naval-internship
  - (Open Application Period Aug 1 -Nov 1 for the following summer)
- NSF INTERN Program (see next slide)

NSF INTERN

Supplemental Funding Opportunity

- Up to $55K for up to 6 months of internship with host.
- PI must submit the supplemental request through an active NSF award
- Funds: travel, tuition and fees, health insurance, stipend, temporary relocation costs, materials + faculty co-mentoring.
- 250+ INTERNs supported each year

Dear Colleague Letter: Research Internships for Graduate Students at AFRL (NSF-AFRL INTERN)

There might be other INTERN opportunities in FY24, be on the lookout!

- Questions?

322MM Website:

Bruce A. Fritz

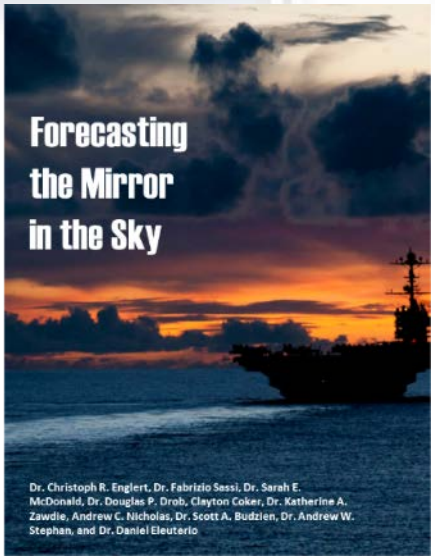
– bruce.fritz@nrl.navy.mil

Daniel P. Eleuterio

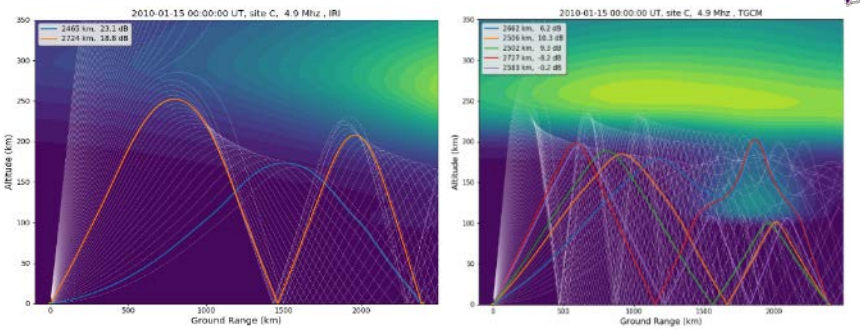
– daniel.p.eleuterio.civ@us.navy.mil

Backup

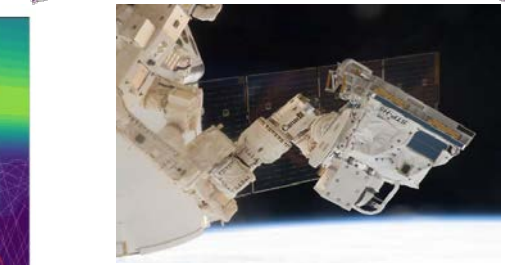
Space Environmental Analysis and Prediction



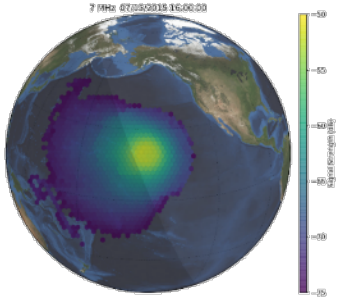
Englert, C. et. al. (2018). Forecasting the mirror in the sky. *Naval Science and Technology Future Force, 5, No. 1, 20-23*



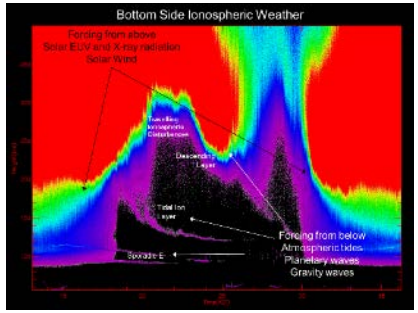
Example of the changes to the raytrace pathways using Modernized Jones-Stephenson/ Ionospheric Ray Trace (MOJO-IRT) for skywave HF communications for two different estimates of the Ionosphere at a particular time and place.

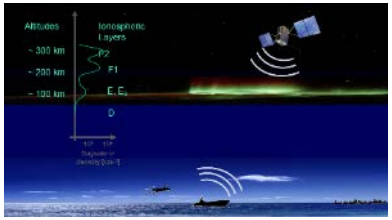


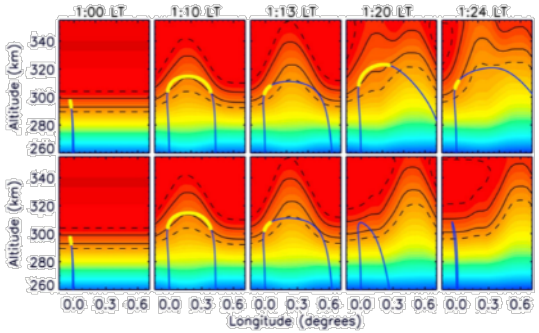
The Limb-Imaging Ionospheric and Thermospheric Extreme Ultraviolet Spectrograph (LITES) and the GPS Radio Occultation and Ultraviolet Photometer Co-located (GROUP-C) experiments on the International Space Station in February 2017. Photo courtesy of NASA



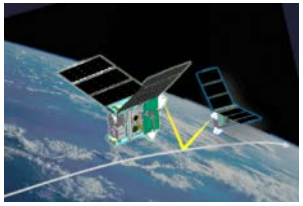
Real-time HF signal power estimates via full-physics range-dependent 3D ray calculations including the effects of magnetic field and plasma collision frequency.

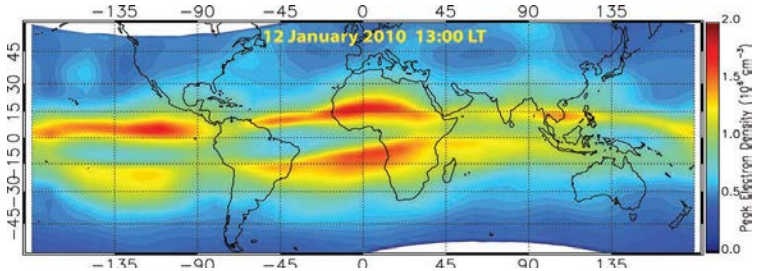






Zawdie, K. A., J. D. Huba, D. P. Drob, and P. A. Bernhardt (2015), A coupled ionosphere-raytrace model for high-power HF heating, *Geophys. Res. Lett.*, *42*, 9650–9656, doi:10.1002/2015GL066673.

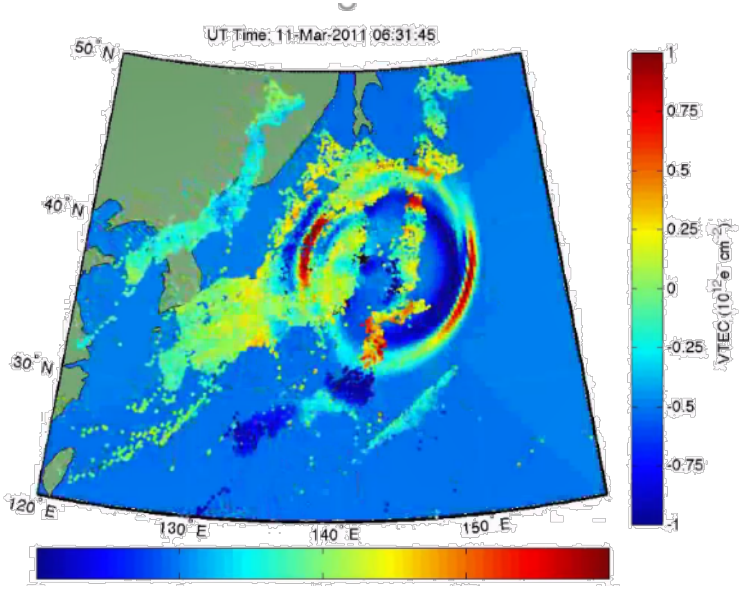




Preliminary results from a whole-atmosphere model, coupling the lower atmospheric meteorology to the upper atmosphere, where the ionosphere is formed. The color contours illustrate peak electron densities in the ionosphere. Photo courtesy of Naval Research Laboratory

Ocean2Space Couplings BRC

- Observations during the last decade demonstrate that large earthquakes generate large signals in the ionosphere
- Signals from the Tohaiku fault were detected in Hawaii about 10-40 min before the arrival of the tsunami. Could the ionosphere provide a global tsunami early warning system?
- ONR-funded research provided ***first*** airglow observation of a tsunami and has demonstrated the feasibility of predecessor event detection.

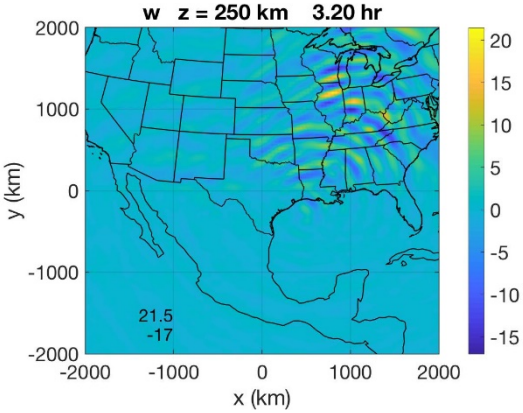


- J. Makela (Univ. Illinois), G. Crowley (ASTRA), S. Vadas (NWRA)
  - Visible Airglow, HF Sounder observations & modeling
- P. Lognonne (IPGP), K. Larmat (LANL), E. Okal (NWU)
  - GPS measurements, tsunami specification, & modeling
- D. Fritts (GATS, Inc.), J. Huba (NRL)
  - 3-D modeling of gravity waves into the ionosphere
- O. Buhler, E. Tabak (NYU/CIMS)
  - Modeling wave propagation in a complex atmosphere
- S. Llewellyn-Smith (UCSD/Scripps)
  - Real-time assimilation of tsunami-relevant data
- N. Zabotin, O. Godin, T. Bullett (CU/NOAA)
  - Dynasonde observations & modeling acoustic-gravity waves through “windows of transparency”

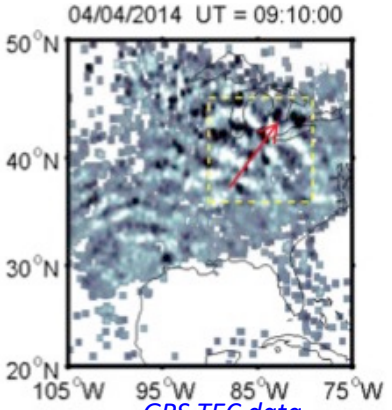
The Couplings BRC addressed fundamental, multidisciplinary scientific and mathematical questions about coupling and upward energy propagation from earth, oceans, and troposphere that contributes to ionospheric variability.

Bottom Side IONosphere (BSION)

- The stratosphere/thermosphere coupled Bottom Side IONosphere (BSION) project advanced the current state of the art in space weather effects beyond inherent limitations of current operational systems.
- After four years of BSION 6.1 research the basic coupled, integrated tropospheric, stratospheric and ionospheric modeling suite was transitioned to the DARPA Space Environment Exploitation (SEE) program as well as 6.2-6.4 ONR projects including the further development of the Next Generation Ionosphereic Model (NIMO) planned for operations at FNMOC.
- NIMO and the supporting basic and applied research continues to pursue the goal of high fidelity simulations and future forecasts of observed plasma field conditions including phase-resolved BSI variability on scales of minutes to hours and Travelling Ionospheric Disturbances (TIDs).



Fourier method with complex-ω ray-tracing driven from mesoscale COAMPS.
Broutman (2019)



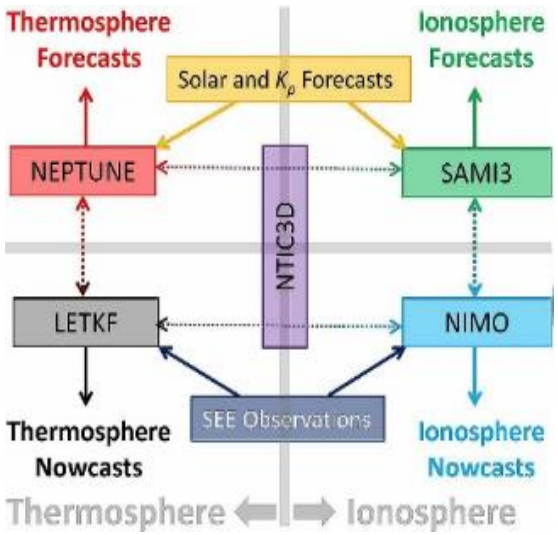
GPS TEC data.
From Azeem et al. (2015, GRL)

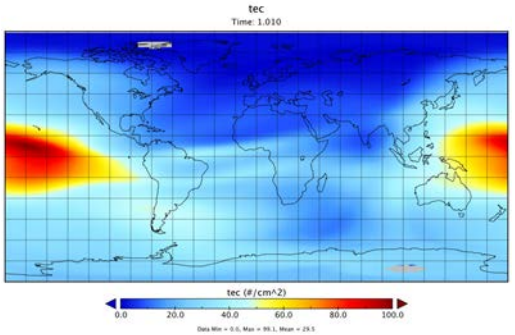
Horiz. Wavelength ~ 250 km.
Wave period ~ 20 min.

High Resolution, Whole Atmosphere Numerical Weather Prediction

Objective: Accurately predict space environment perturbations and disturbances down to horizontal scales of 100 km and out to 72 hours at a 1-hour cadence for operational DoD applications.

- **Demo capability is based on:**
  - High altitude extension of the Navy's next operational Numerical Weather Prediction (NWP) system, NEPTUNE
  - NIMO (see previous slide)
  - The full physics ionosphere model SAMI3
  - Respective ionosphere and thermosphere data assimilation systems.





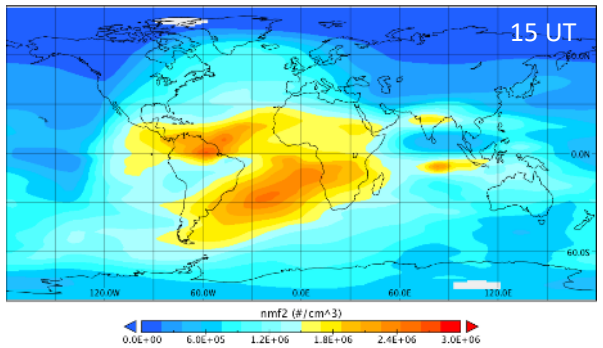
- **Capability demonstration via:**
  - Build phase ending April 2021
  - Validation phase May 2021 – April 2022

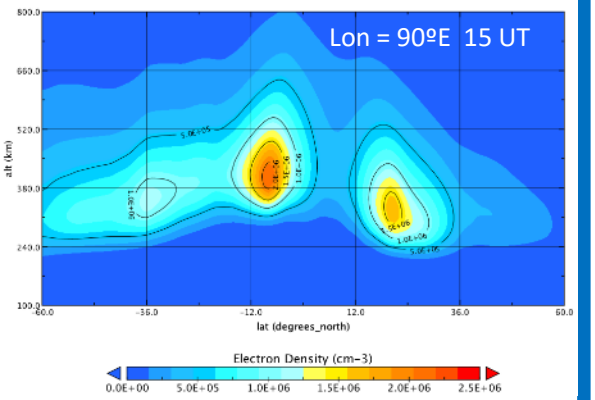
DARPA · ARL · NCAR · NPS · UTD · Los Alamos National Laboratory · APL Johns Hopkins

NextGen Ionosphere Model for Operations (NIMO)

Objective: Operational ionospheric specification and short-term forecast for warfighter applications

- NIMO is an ionospheric specification and short-term climatological forecast model that will begin **transitioning to operations** at Fleet Numerical Meteorology and Oceanography Center (FNMOC) **in FY21**
- Consists of an ionospheric data assimilation system (IDA4D), coupled to a physics-based ionosphere forecast model (SAMI3)
- Computationally-efficient and flexible architecture with interfaces built to support future improvements in ionospheric drivers (e.g. thermosphere, solar), data assimilation (DA) techniques, and data sources (e.g. UV sensors, cube-sats, HF datasets)
- **Will provide global and high-resolution regional specification and short-term (< 24 hour) climatological forecasts of electron density**





NIMO output consists of 3D electron density profiles that are updated every 15 minutes.

Warfighter Impact

- **DOD-owned ionospheric model** that produces forecasts of the ionosphere **for the prediction of the high frequency (HF) propagation environment**
- **Will support tactical decision aids for electromagnetic maneuver warfare (EMW) and HF communications performance predictions**

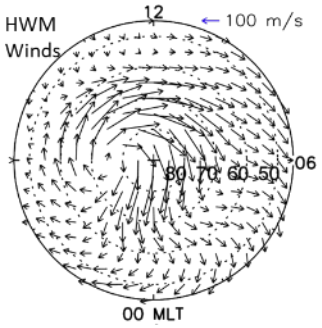
Operational Datasets for Global NIMO

Type	Source	Description	Notes
GPS TEC	JPL	TEC from ground GPS receivers	Also ingests RINEX
Radio Occultation	COSMIC	Long slant path TEC	Compatible with COSMIC-2, commercial RO
UV Radiance	DMSP SSUSI and SSULI	UV from Oxygen recombination emissions	Compatible with ICON, GOLD, future UV
In situ	DMSP SSIES	Electron densities at 850 km	
Ionosondes	USAF	Ionosonde frequency sweeps	Ingests electron density profiles (EDPs)

Empirical Models of the Atmosphere

Objective: Using data from decades of observations, construct empirical (climatological) representations of the atmosphere (NRLMSIS and NRLHWM)

- NRLMSIS 2.0 represents the average observed behavior of atmospheric temperature and 8 species densities as a function of location, day of year, time of day, solar activity, and geomagnetic activity.
- NRLHWM provides a time-dependent, observationally based, global empirical specification of the upper atmospheric general circulation patterns and migrating tides



- MSIS is used in a large number of operational (including GAIM-FP) and research applications, with over 5000 citations.
- NRLMSIS 2.0 is a major upgrade to NRLMSISE-00. Thermosphere species densities are now fully coupled to the entire temperature profile, and the model is based on extensive new atmospheric databases.
- The recalibration to recent new data is important, because the upper atmosphere is cooler and more contracted compared to the 1970s an 1980s data on which the old model is based.
- Currently working on adding a new species, nitric oxide (NO) to the model. NO is a major cooling agent of the thermosphere and ionosphere and is a key component of ionospheric D-region chemistry.