Earth Science Mission Design Tools for Harnessing Satellite Signals of Opportunity

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Motivation for Pursuing Use of Signals of Opportunity (SoOps) other than GNSS

- To date, very few signals of opportunity have been harnessed for Earth remote sensing. These include:
  - SATCOM (P-band, 25 kHz BW): root zone soil moisture [Garrison et al., 2016]
  - GNSS (L-band, 2-20 MHz BW, RCP): ocean winds, soil moisture, sea ice [various]
  - Satellite Radio (Sirius-XM) (S-band, 1.8 MHz BW, LCP): ocean winds, SWH [Shah et al., 2011]
  - DBS digital television (K-bands 24 MHz BW, R/LCP): ocean winds, SWH [Shah et al., 2015]
- **Many thousands of other satellite signals at various frequencies, bandwidths, polarizations, and power levels are being actively transmitted and have the potential to be used to remotely sense Earth properties using bistatic radar and radio occultation techniques.**
- CYGNSS is demonstrating the utility and benefits of using bistatic radars to perform ocean scatterometry, and these could replace traditional scatterometers. Using other signals (freq., bandwidths, polarizations) either alone or in a multi-frequency approach, other valuable Earth science could be performed (cryosphere, terrestrial hydrology, mesoscale altimetry, etc.)
- Receiver and antenna technology are advancing quickly, and it's conceivable that multi-frequency antennas and reconfigurable radios could be developed into a versatile remote sensing instrument.

The International Telecommunications Union Bureau of Radiocommunication Databases

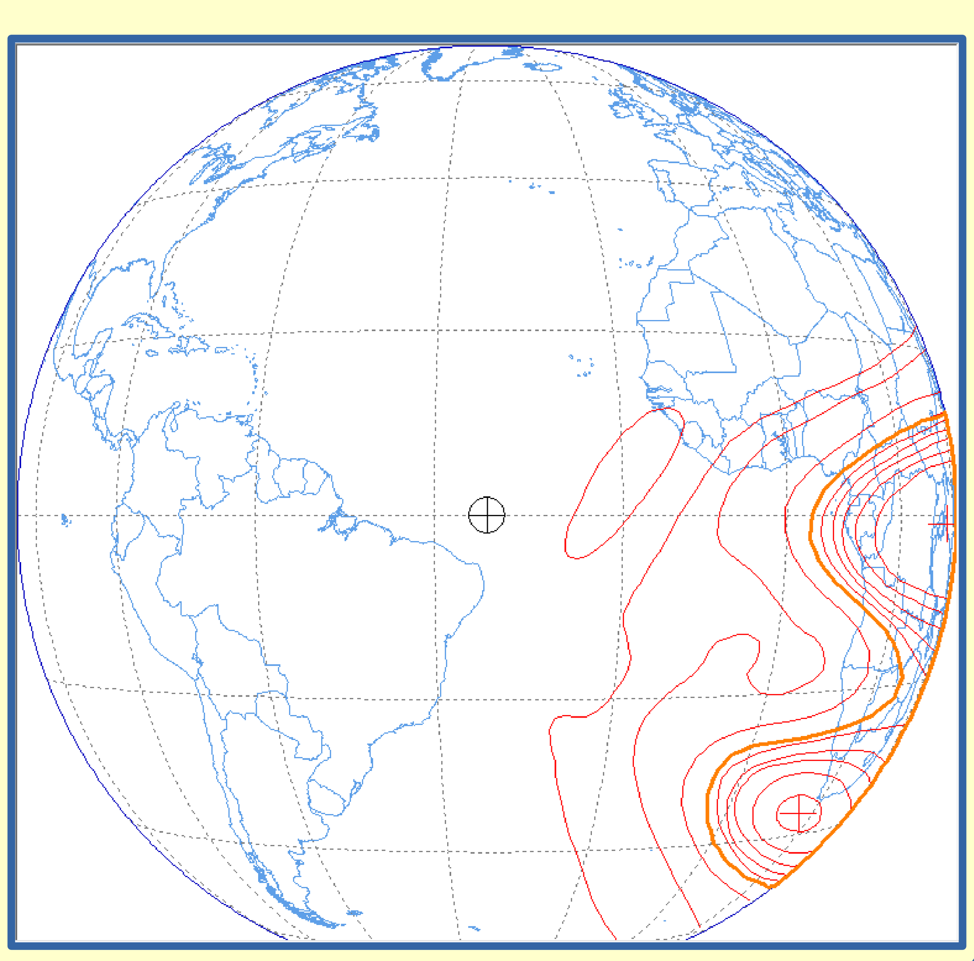
- The International Telecommunications Union (ITU) Bureau of Radiocommunication tracks all of the space and Earth-based transmitters and receivers to maintain radio spectrum quality and to avoid signal conflicts. Every two weeks, it publishes the International Frequency Information Circular (IFIC). The IFIC contains a Master Record database (srsxxxx.mdb), a graphical information database (grefxxxx.mdb), and other network update databases.
- A subscription to the IFIC costs 2340 CHF (Swiss Francs)
- IFIC databases are available on DVD-ROMs only as password-protected, Microsoft Access (.mdb) and can be queried only via proprietary software from the ITU.
- The SRS Database contains heirarchical information on satellite transmitters, including:
  - satellite name, antenna beams, frequency groups, carrier freq., bandwidths, max. envelope power levels, orbits, polarizations
- The GIMS Database is linked to the SRS Database and contains graphical information:
  - antenna beam gain contours (geosynchronous sats)
  - signal spectrum plots

ITU IFIC Database Characteristics

- Over 2 million transmit/receive frequencies
- Over 46000 satellite beams
- Most emissions contain frequency, bandwidth, polarization, power for both geo and non-geo
- Modulation characteristics (although allowed, rarely stored)
- Beam gain contour information available for geosynchronous satellites
- Active versus non-active transmission flagging

Translating the ITU BRIC into a SoOps Research Quality Database

- Goals:
  1. Convert the Microsoft Access database formats to an open source format (SQLite)
  2. Add spatial query functionality to the SQLite database using Spatialite
  3. Convert the the GIMS graphical antenna beam contour data to Spatialite polygons
  4. Link the SRS and GIMS SQLite databases via common queries
- We used the open source Kexi software to convert the .mdb files to .sqlite files
- To allow spatially-aware queries, e.g., "Find all antenna beams which contain a particular geographic region or coordinate," we added Spatialite enhanced metadata to the .sqlite files
- The GIMS database contains antenna bean contour data in an unknown BLOB format, so we used a call to the proprietary GIMS API library to extract the contour data and store into the .sqlite files
- The GIMS database also contains
- embedded image files (as BLOBs) which we extracted using mdbtools and created entries in the SQLite data tables

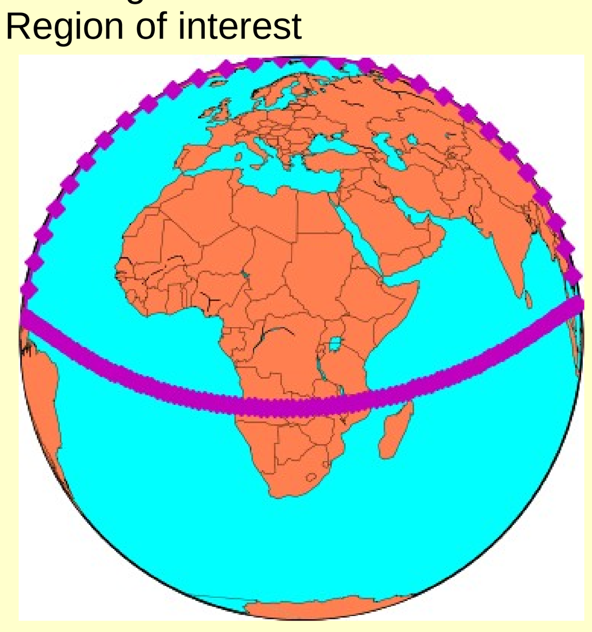


Example graphical antenna beam contour contour information (IntelSat8 325.5 E) available from the ITU GIMS database.

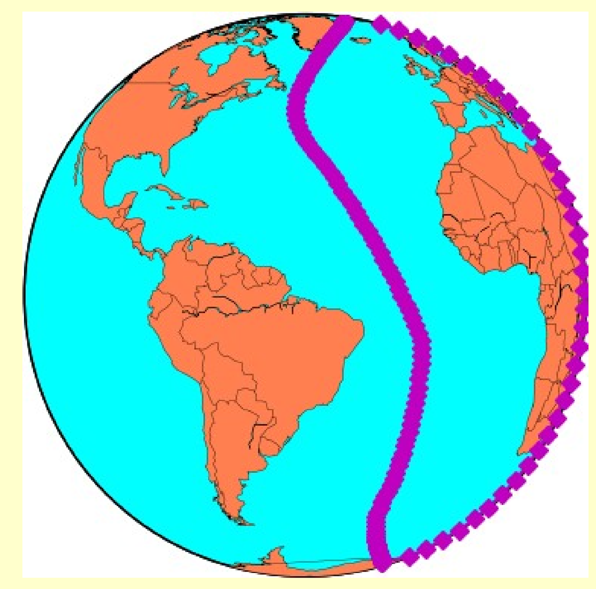
Interacting with and Querying the SoOps Database

- A python library was developed to interface with and query the SoOp spatialite database based upon different goals:

  1. Query SRS on satellite and signal charatceristics
     - Satellite name
     - Satellite type: geosynchronous or non-geosnyschronous
     - Signal carrier frequency
     - Signal bandwidth
     - Signal EIRP (where available in the original SNS)
     - Signal polarization
     - Actively in use
- 2. Query based on spatial information:
  - Beam contour
  - Beam gain
  - Region of interest



Queried ZOREH-2 satellite depicting its GK-2 beam at -6db gain



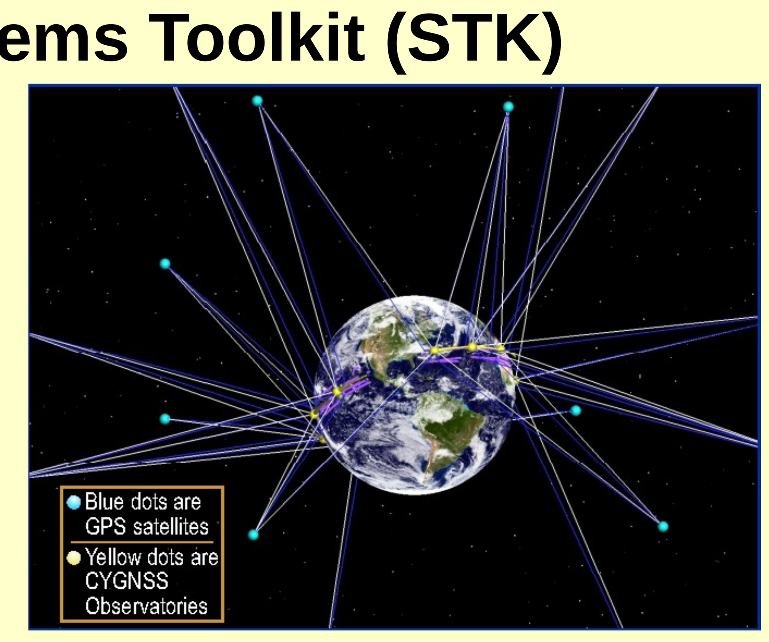
Queried GIBSAT-8B satellite depicting its KGBLR beam at -6db gain

Planning New Measurement & Mission Scenarios

- Targeting new Earth remote sensing applications and expanding the use of other SoOps is our goal.
- Science requiring measurements of different Earth surface properties can be enabled by analysis of SoOps frequencies, polarization ratios, bandwidths, etc.
- **Supplementing the SoOps database with more detailed information on signal characteristics (modulation structure) is required.**
- Possible applications include:
  - Sea ice extent/age
  - Soil moisture
  - Wetlands mapping/monitoring
  - Sea surface roughness
  - Sea surface altimetry
  - Ice sheet melt/height

Integrating with Systems Toolkit (STK)

- We have developed a python library which exports database queried satellite contours and orbits for use in AGI's System Toolkit (STK)
- Exported SoOp STK scenarios can be analyzed in STK with candidate bistatic receiver chain/access scenarios for new mission concepts



Example of STK-based scenario based on CYGNSS proposed concept [Ruf et al, 2011])

Next Steps & Future Work

- We plan to continue building higher-level functionality into the python library to allow more sophisticated querying of specific SoOps properties.
- The missing modulation information requires another source of determining if the signals have open or non-proprietary modulation schemes. This is required if a bistatic receiver does not perform cross-correlation of the direct and reflected signals.
- The initial work to export the SoOps satellite and beam information to STK has been performed, but more work is needed to effectively use the capabilities of STK to design receiver platform scenarios for specific science missions, such as polar-orbiting sea ice or ice sheet studies. Additionally, orbit information specific to non-geosynchronous platforms needs to be included from another source, e.g., NORAD TLEs.
- Non-geosynchronous satellite beam information is limited in the SoOps database and should be added from another source to be used in STK scenario analysis.

Acknowledgments

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