Propagation Models for Spectrum Sharing

ITS Mission Statement:

- **Advance** innovation in communications technologies
- **Inform** spectrum and communications policy for the benefit of all stakeholders
- **Investigate** our Nation's most pressing telecommunications challenges through research that employees are proud to deliver

Rebecca Dorch, Billy Kozma, Paul McKenna,
Adam Hicks, and Michael Cotton

December 13, 2022

Boulder, Colorado • its.ntia.gov

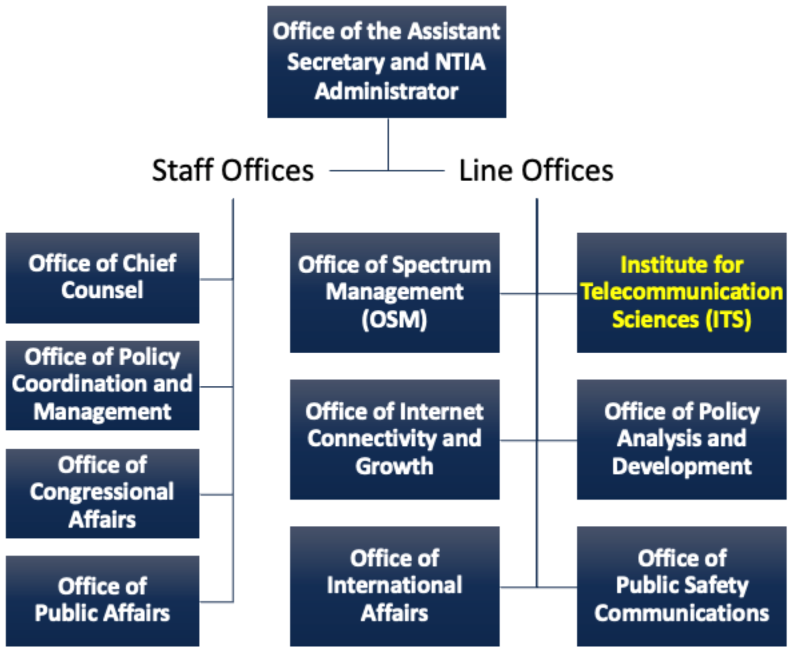
Agenda

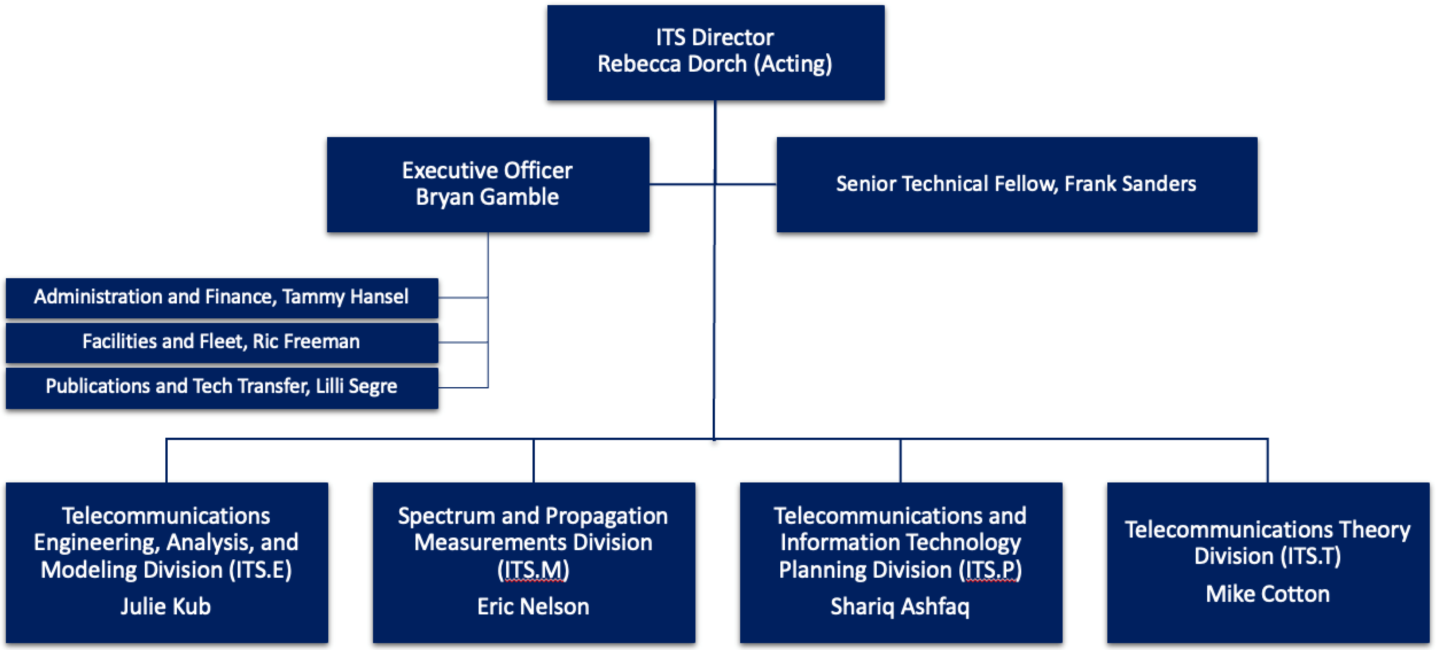
- Overview of ITS [10 mins]
- Problem Statement/Use Cases [15 mins]
- DoD CIO Mid-Band Project [15 mins]
- Measurements & Modeling [15 mins]
- Outreach & Collaboration [5 mins]
- Questions & Discussion [30 mins]

Overview of ITS

Rebecca Dorch

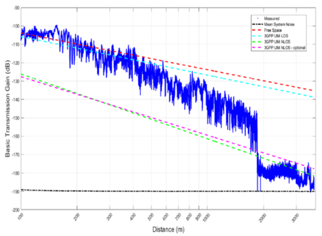
NTIA and ITS Organization Charts

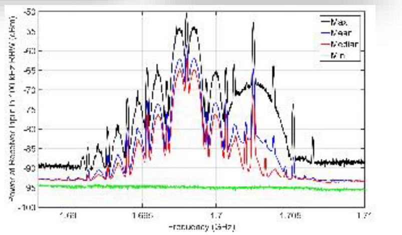


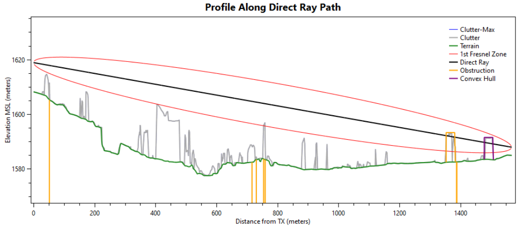


ITS Core Responsibilities and Activities

- Conduct telecommunications technology research programs for NTIA and provide research support for NTIA offices to support Administration and Agency needs
- Manage the Department of Commerce-owned Table Mountain Radio Quiet Zone and Advanced Communications Test Site
- Conduct research to solve other federal agencies' telecommunications and spectrum research needs via Interagency Agreements (IAAs)
- Work with industry and academia via Cooperative Research and Development Agreements (CRADAs)
- Engage with other stakeholders via OSTP, CSMAC, NITRD/WSRD, IRAC, PPSG, DoC 5G Working Group, National Spectrum Consortium, etc.
- Perform internally funded research programs to build core capabilities in:
  - Research, development, test & evaluation (RDT&E) of new and emerging telecom technologies
  - Radiofrequency spectrum occupancy and emission measurement
  - Electromagnetic compatibility analysis and interference protection criteria research
  - Radio propagation modeling and simulation

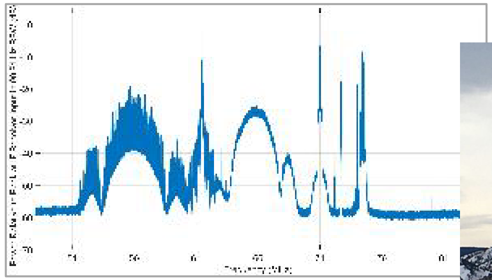


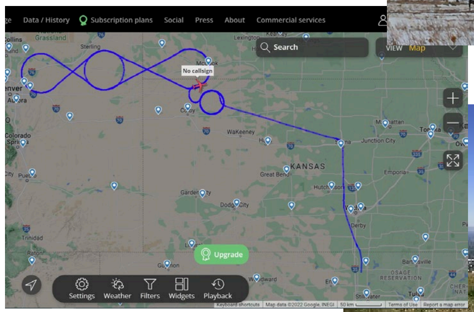




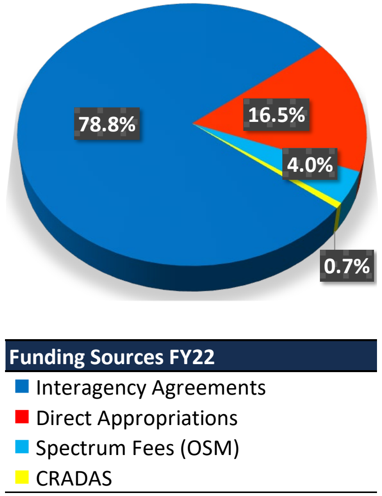
Significant Other Agency Programs

- **OSM Spectrum Management R&D** – Conduct research to support science-, technical-, and data-based spectrum sharing decision making.
- **DoD Mid-Band Propagation Modeling** – Establish an improved and community-accepted mid-band (i.e., 3.1–4.2 GHz) RF propagation model framework for diverse geometries
- **DoD Spectrum Sharing with 5G** – Research interactions between 5G base stations and radar, including USAF airborne radars such as AWACS and radio altimeters
- **DoD 5G Challenge** – Collaboration with DoD OUSD R&E to accelerate the adoption of open interfaces, interoperable subsystems, and modular, multi-vendor 5G solutions by fostering a large, vibrant, and diverse vendor community
- **NOAA Spectrum Sharing and 5G (RFIMS)** – Assess RFIMS capabilities and interference protection criteria for NOAA weather systems based on key performance indicators correlated to image degradation
- **NSF Spectrum Innovation Initiative** – Provide SME in spectrum engineering, spectrum management, and radio science in support of NSF's mission to promote the progress of science and to provide leadership in advancing research and education
- **DoD DSO via NASCTN** – Sharing Ecosystem Assessment with focus on CBRS
- **DoT CV2X** – Measurements and analysis of emerging communications technologies in the transportation sector

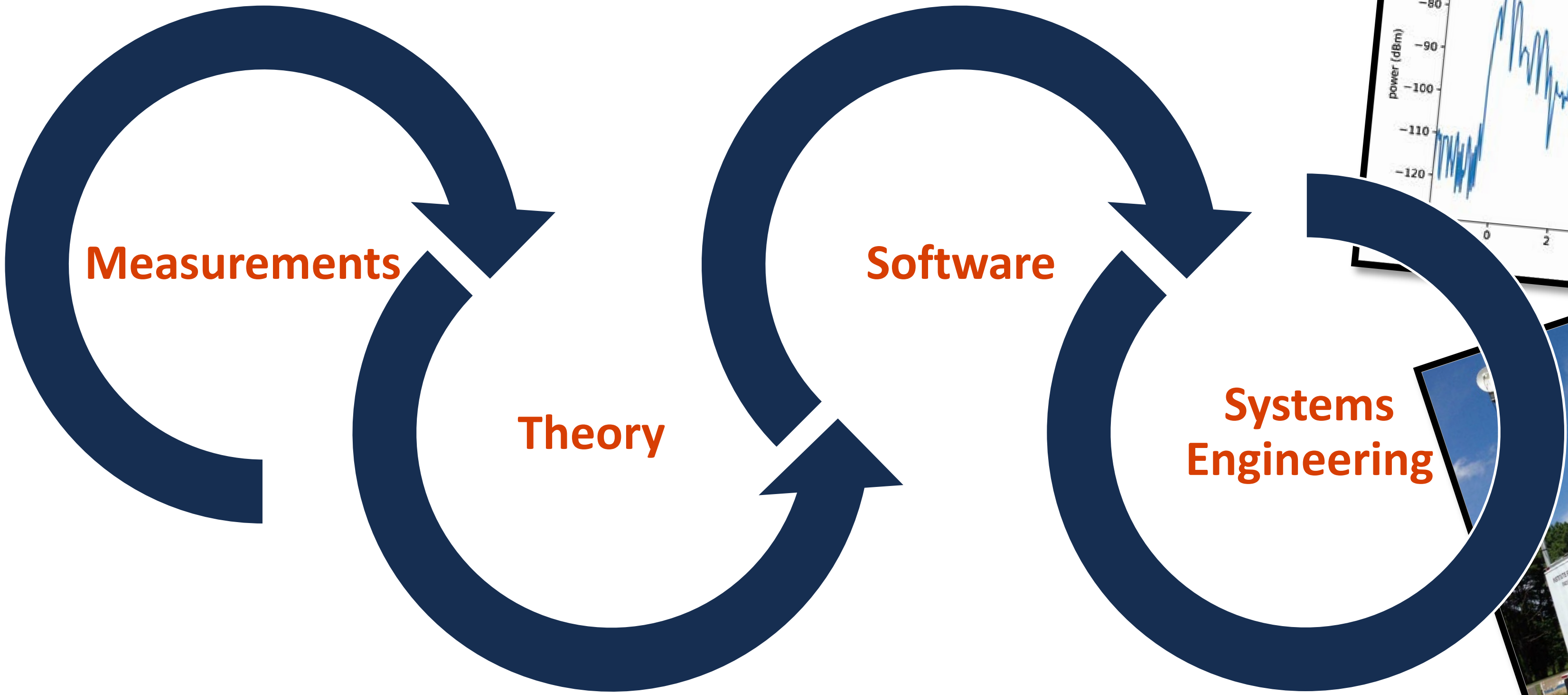


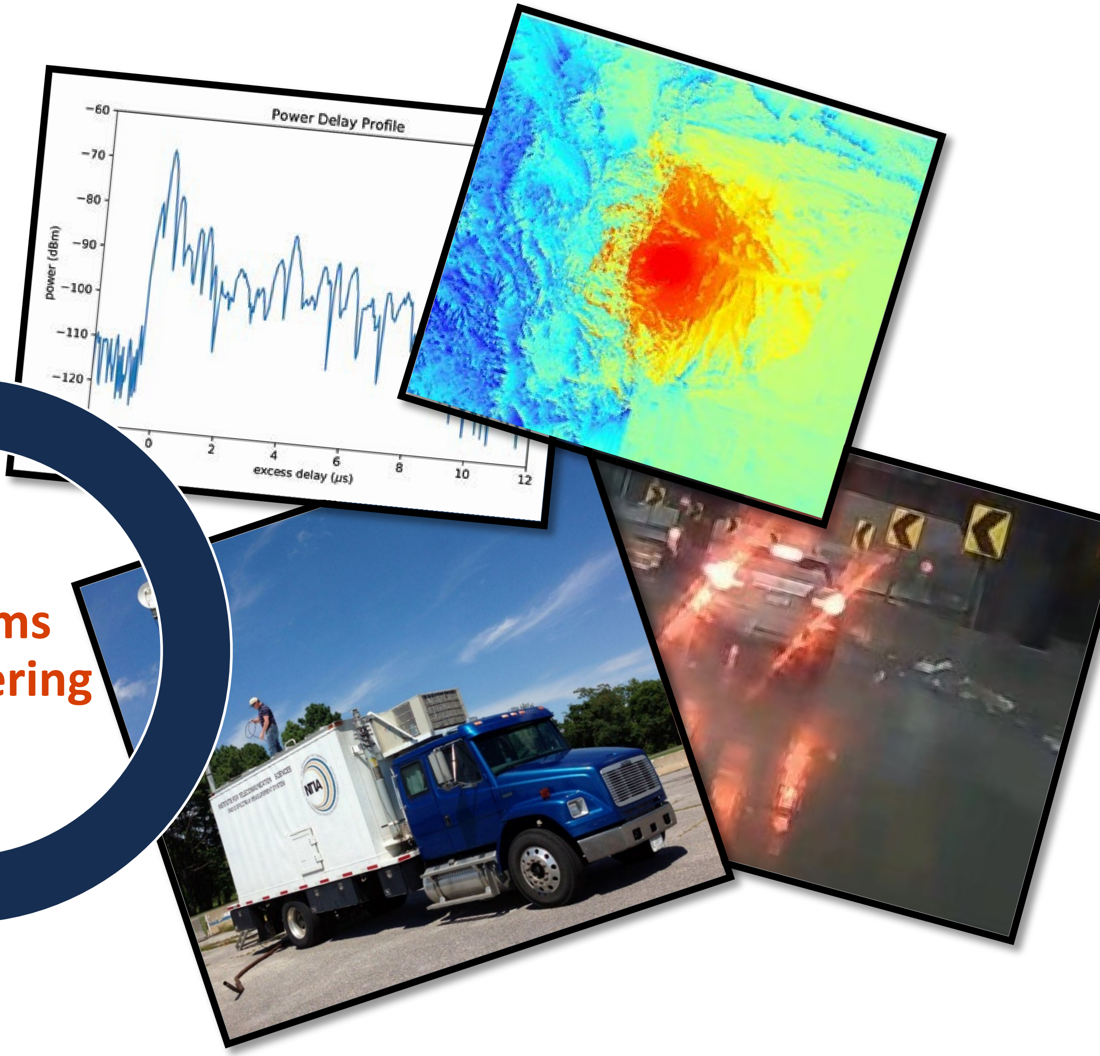


46 active IAAs & CRADAs in FY22

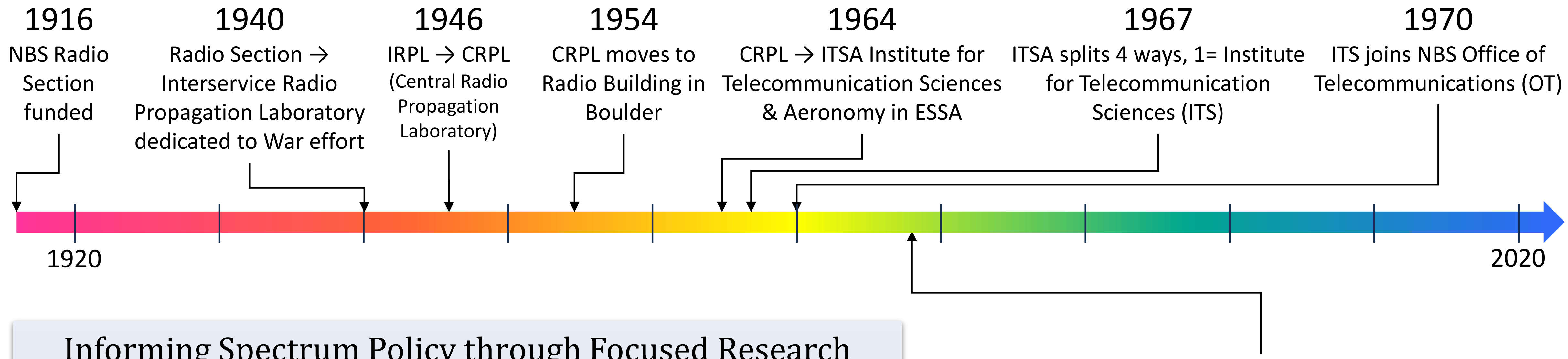


Our Teams


Measurements
Theory
Software
Systems Engineering


Power Delay Profile
power (dBm)
excess delay (μs)

100+ Years of Trusted Research



Informing Spectrum Policy through Focused Research

"There is a critical need for competent and effective telecommunications and information research and analysis and national and international policy development, advice, and advocacy by the Executive Branch of the Federal Government."

NTIA Organization and Authorization Act, 47 USC 8 §901(b)(4)

1978

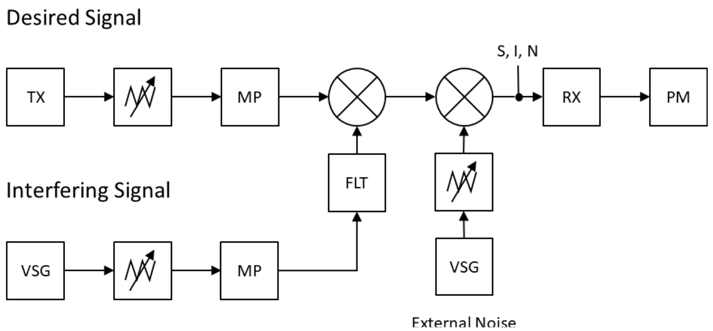
NBS Institute for Telecommunication Sciences + White House Office of Telecommunications Policy = National Telecommunications and Information Administration

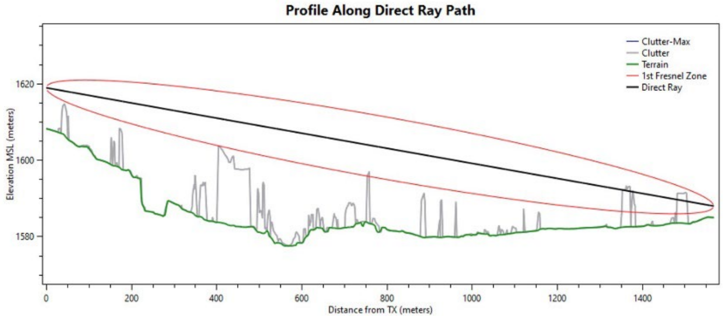
Problem Statement/Use Cases

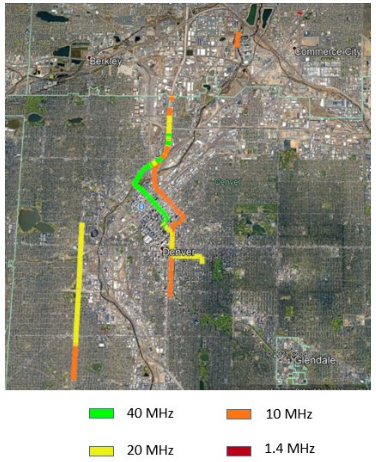
Paul McKenna and Michael Cotton

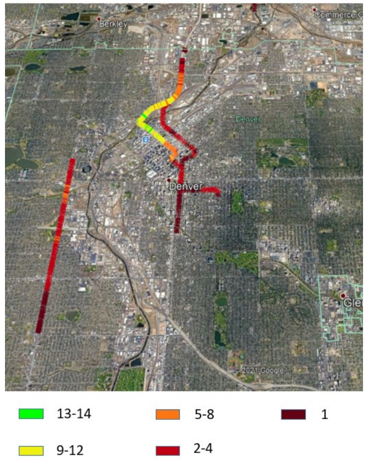
NTIA Spectrum Management R&D

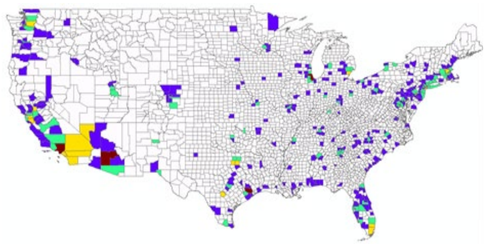
- **Goal:** To provide planned R&D (i.e., science, models, data, analyses, and software) and Quick-Reaction SME to advance NTIA spectrum management processes and decisions
- **Approach:** Planned R&D Projects
  - Clutter propagation modeling
  - Propagation Code Library (PropLib)
  - ITU-R Study Group 3
  - mmWave propagation measurements and modeling
  - RSEC modernization
  - Spectrum Quantification, Verification, and Characterization
  - Interference analyses





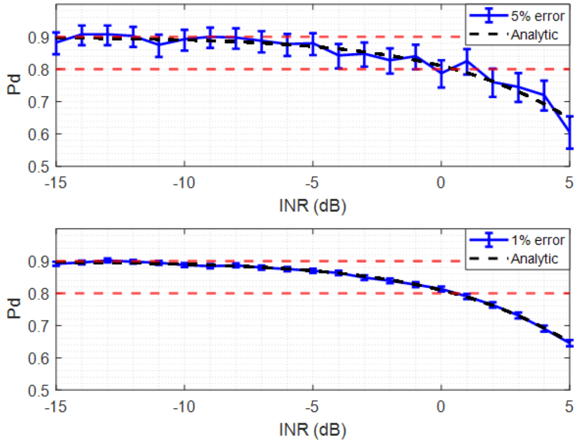






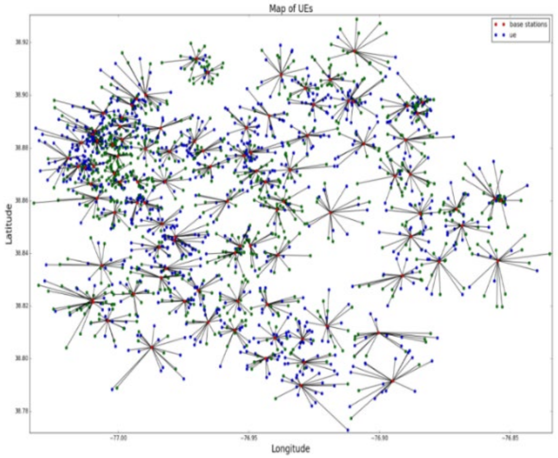
NTIA Interference Analysis

- **Goal:** Provide first-principals theory for electromagnetic compatibility modeling
- **Approach:**
  - Link- and system-level simulation
  - Interference protection criteria (IPC)
  - Aggregate modeling
  - Specialization in high-priority verticals, e.g., radar, mobile comms, SAS, intelligent vehicle
  - Theoretical basis for real device testing — DSRC, C-V2X

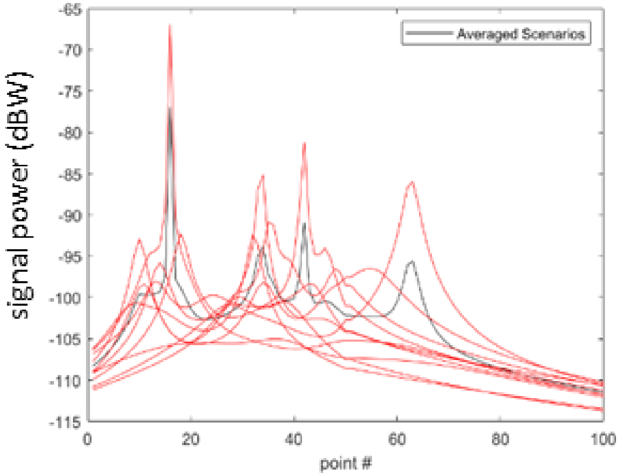


Results of long-range radar IPC test

Simulated RADALT flight path with 5G antenna models



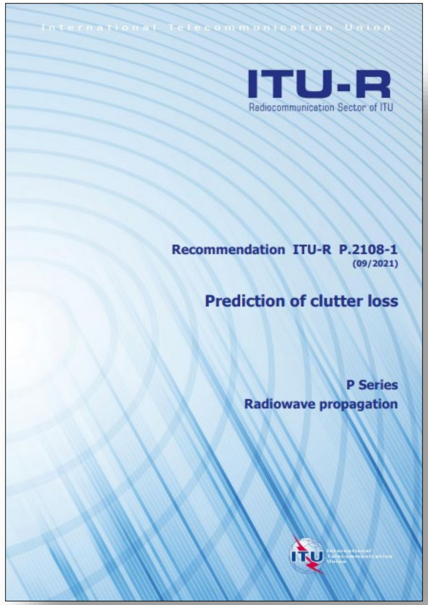
Aggregate AWS-3 LTE Basestations/UEs



Interference power along flight path

Existing Modeling Techniques

- ITM/Longley-Rice
  - Use of path “elevation statistics” to match prediction to ideal
  - Define full strata of variabilities (time/location/situation)
- TIREM/Rec.’s P.1812, P.452, P.2001
  - Each path is “unique”; heuristics/empiricism to derive the prediction for each path based on deterministic models (line-of-sight, diffraction, troposcatter)
- ITM in area mode/Rec. P.1546
  - Targeted towards “information sparse” environments; Site-general solutions
- Clutter models
  - Empirical families: Hata, eHata, P.2108 Sec 3.2/3.3
  - Deterministic families: Rec. P.1411, P.2108 Sec 3.1

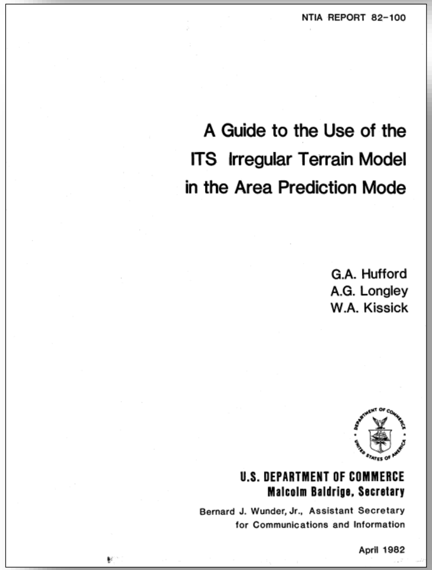

International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R P.2108-1
(09/2021)

Prediction of clutter loss

P Series
Radiowave propagation


NTIA REPORT 82-100

A Guide to the Use of the
ITS Irregular Terrain Model
in the Area Prediction Mode

G.A. Hufford
A.G. Longley
W.A. Kissick

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
Bernard J. Wunder, Jr., Assistant Secretary
for Communications and Information

April 1982

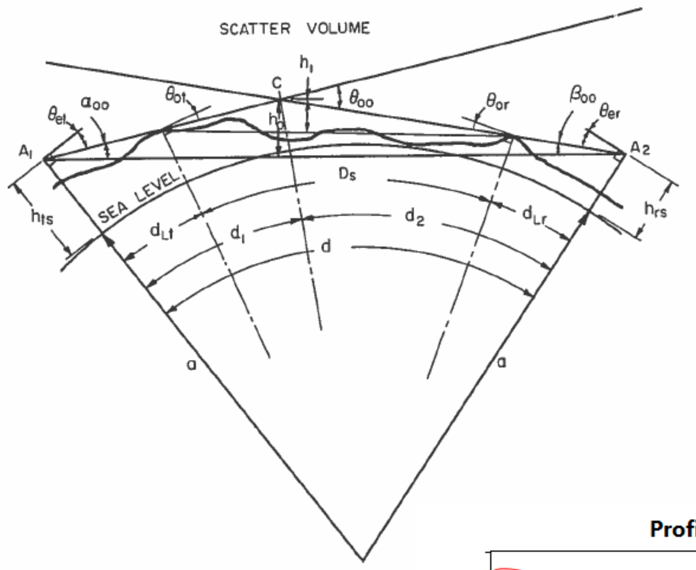
CSMAC EMC Improvements Subcommittee (2022)

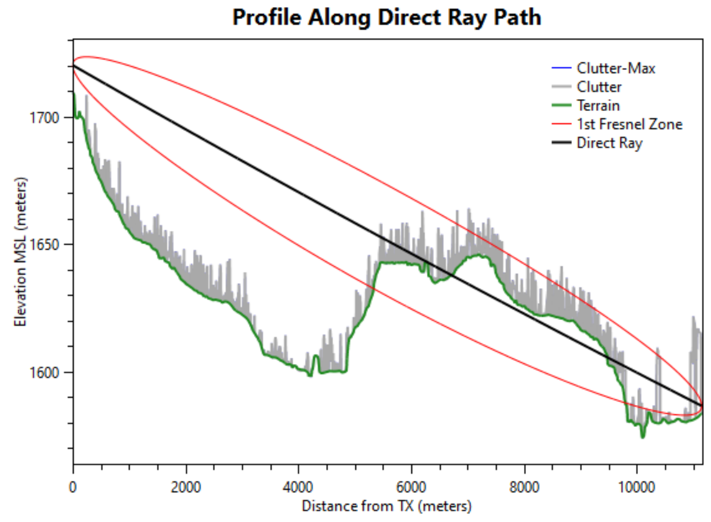
Takeaways from interview with ITS propagation experts to discuss limitations of existing propagation models:

- Existing models require expert users who understand the associated constraints and limitations to get a valid answer.
- Recognize that everything in radio science as it applies to real-world problems is nondeterministic; probabilistic uncertainties must be accounted for.
- Models that focus on narrowly-defined cases are likely to have lesser uncertainties than general models.
- Data-driven modeling in complex environments (e.g., LiDAR data to predict propagation through cluttered environments) is one area of needed study.
- Sensitivity and interpretation of input datasets (e.g., LiDAR, terrain, measurements) is another area of needed study.
- An expert system or handbook is needed to recommend an appropriate model and dataset to a given situation.
- Open-source measurement databanks with standardized collection methods would help validate models.
- Propagation model use cases and requirements should be chosen from possible deployments being considered for public policy action(s).
- Repeatable and documented experimental design/analysis is critical for the improvement and validation of predictive models.
- Forward-looking action should be taken to provide adequate time and funding for necessary and sufficient science and engineering results to underpin spectrum policy.
- A systematic approach involving stakeholders should be taken to standardize and evolve propagation models in the highest-priority frequency band. Once established, the approach should be extended to next-priority bands.

Modeling Preliminaries

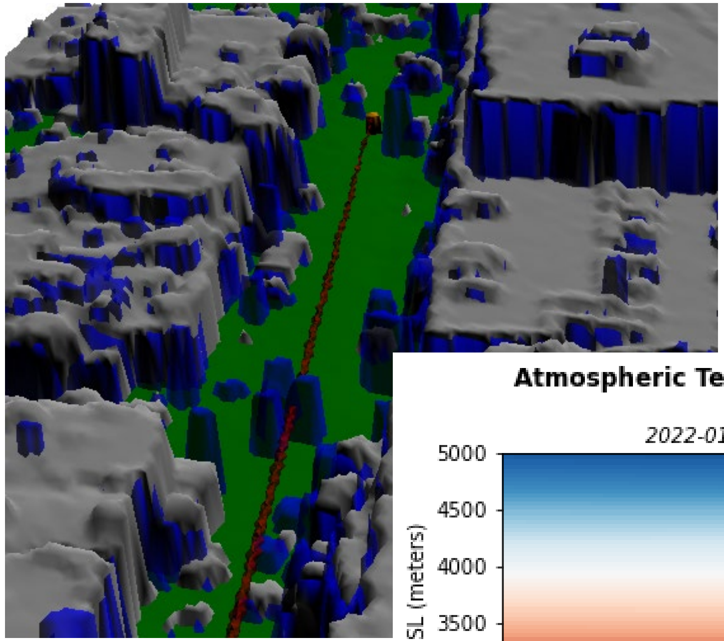
- General purpose
  - Not inherently limited by a service or use-case constraint
  - Capable of predicting both coverage and interference; "full" cumulative distribution function
- Anchored to first-principles and physics/theory
- Empiricism and statistics incorporated in rigorous manner
  - Encompasses variability of basic transmission losses
- Incorporation of all three core modes of propagation: Line-of-sight, diffraction, troposcatter
- Ability to account for simultaneous propagation phenomena along the path, e.g., clutter, terrain, atmospheric impacts
- Validation of propagation models and assumptions in priority scenarios with real-world spectrum-dependent systems

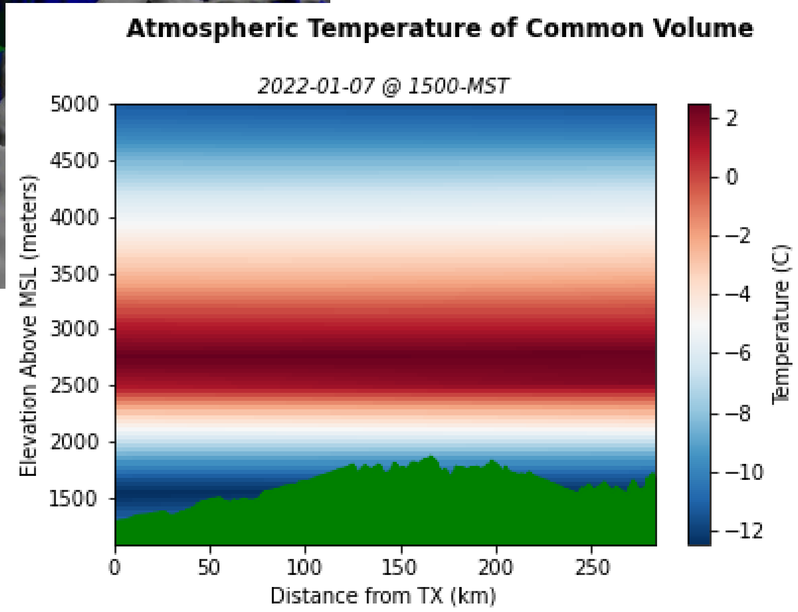




Priority Technical Areas of Improvement

- Clutter
  - End-point approximation vs full path effects
  - Screen vs knife-edge diffraction (lidar)
  - Parameterized statistical clutter details
- Ray theory and atmospheric stratification
  - Improve site-specific modeling through incorporation of meteorological data
  - Refinement of radio climates and effects on long term time variability
- Support improved interference analysis
  - Probability of interference events given improved information about TX/RX location(s)
  - Impact of antenna effects
  - Aggregation of emitters
  - Avoid “re-inventing the wheel”; leverage propagation model improvements achieved in other scenarios





DoD CIO Mid-Band Project

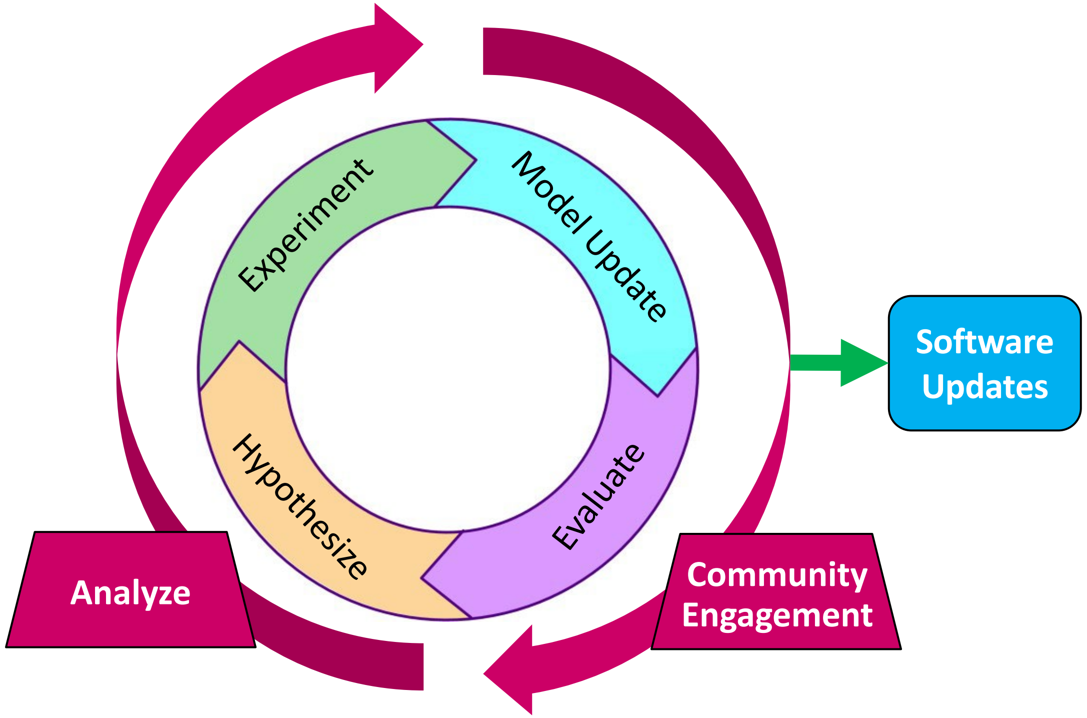
Billy Kozma

Overview

- **Goal:** To establish an improved and community-accepted mid-band (i.e., 3.1–4.2 GHz) RF propagation model framework for a diverse range of link geometries, e.g., clutter, terrain, air/ground, over-water, long distance
- **Approach:**
  - Bring the spectrum community together in an open collaborative way
  - Focus collective effort to improve modeling
  - Maintain a rigorous scientific process for improvements
  - Model development priorities drive experimental design and measurement requirements
  - Experimental results and measurement validations drive model updates
  - Model implementations delivered to community as trustworthy production-level software

5-Year Goals of the Program

- ITM2027
- LiDAR data-driven and statistical clutter propagation prediction
- Weather data driven troposcatter prediction
- Improved terrain diffraction prediction
- Improved prediction tools for interference analysis use cases
- Well-documented theory and measurement validation
- Community acceptance



ITS Propagation Library (PropLib)

https://github.com/NTIA

- **Goal:** To establish authoritative and widely-used propagation model software
- **Approach:** Define a modern software development process to ensure reliability and integrity of software research products. Once PropLib codes are released, improvements originate through (1) ITS scientific process and (2) open-source collaboration.
- **Process:**
  - In development
  - Internal production
  - Publicly released

In Development

- MPM
- P.1812
- P.526

- Actively developed
- Locally published (restricted users).

Internal Production

- Ohiopyle
- IF-77
- PropCore
- P.676
- P.835

- Suitable for stable dev
- Published NTIA-wide
- Okay for external shipping

Publicly Released

- ITM
- eHata
- P.528
- P.2108
- LFMF-SmoothEarth

- Fully open-source
- Publicly supported
- Code signed and formally citable

Short Descriptions of Projects

Program Management

- Objective: Provide overall program management of the DoD-Prop project
- Method:
  - Interface with DoD CIO and agency stakeholders
  - Equipment purchases for program
  - Community outreach and formalization of relationships, where appropriate
  - General programmatics (budget, scheduling, ITS management, &c)

Software and Data

- Objective: Provide software and data support of measurement and modeling activities
- Method:
  - Modeling: (A) Bring in IT assets to offload CPU-intensive tests, (B) Automate workflows as much as possible
  - Measurement: (A) Address known pain points, (B) Improve usability and reliability of the measurement software, (C) Implement data strategy, (D) Start refactoring the measurement code to a single codebase, (E) Explore options to remotely monitor and administer deployed measurement systems

Short Descriptions of Projects (cont.)

LOS Propagation (UFED Modernization)

- Objective: Modernization of Undisturbed-Field, Empirically Derived (UFED) propagation model software
- Method:
  - Write a modernized C++ implementation of the UFED model
  - Ensure modular implementation, with "Undisturbed Field" and empirical components independently callable
  - Verify computations are equivalent to the pre-existing "engineering-code" FORTRAN implementation using limited set of existing test cases
  - Develop a new suite of test cases to further validate the code
  - Automate the running of these tests and document the code
- UFED assumptions:
  - Terminal above a ground plane with known properties
  - Terminal separation such that Earth curvature can be approximated to be flat
  - No terrain, No clutter
  - Antenna models

Clutter Propagation

- Objective: Development towards a clutter model for path geometries which are un-obstructed by terrain, through measurements and analysis.
- Method:
  - Focus on estimations of clutter loss for path geometries un-obstructed by terrain
  - Evaluate existing clutter models with 3.5 GHz measurement data
  - Develop new, or improved from existing, ITS modeling efforts
  - Form strong collaborative partnership with FCC
- Measurements:
  - Targeting 4-6 measurement campaigns (roughly 1 per quarter)
  - Measurement campaign = 1 week of measurements
  - Focused on urban and suburban environments
  - Focused on Rocky Mountain region (CO and neighboring states)
  - Biased towards AWS-3 measurements, where appliable
  - Explore/pursue partnership for aeronautical measurements in future years

Short Descriptions of Projects (cont.)

Terrain Diffraction Propagation

- Objective: Improve ITM and diffraction loss predictions models
- Method:
  - Compare prediction techniques, theory, and measurement data to improve ITM and diffraction models
  - Implement/improve support routines (FTF, MKE point detection, EAH, Earth curvature, etc.)
  - New/improved GitHub software repos
  - Obtain new measurement data over various diffraction paths of interest
- Note: Starting June 2023

Troposcatter and Anomalous Propagation

- Objective: Establish a baseline Troposcatter measurement link, while planning for second receiver node installation(s) and future anomalous paths. Explore some posed questions with spot measurements, relating data back to theory and existing models.
- Method:
  - Deploy system over dedicated link for long term capture and study. While system operates, begin site survey for potential secondary locations that best utilize the baseline link.
  - Spot measurements – test different configurations of interest as dictated by modeling/theory
  - Incorporate weather data into modeling approach
  - Once a long-term link is established, then next step to add a frequency

Measurements & Modeling

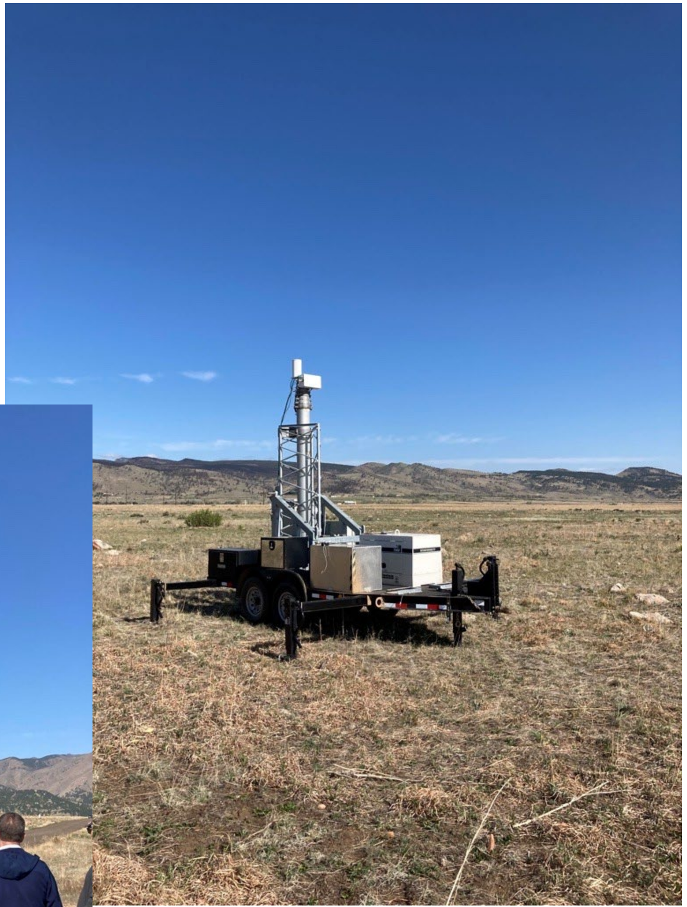
Adam Hicks

Overview

- Significant measurement activities within 3.5 GHz band
  - Clutter effects and characterization
  - Diffraction
  - Troposcatter
- Modeling-informed measurement
  - Targeted measurements meant to reflect theoretical scenarios in a real-world environment
- Closer look at clutter and troposcatter efforts
  - System validation
  - Baseline datasets

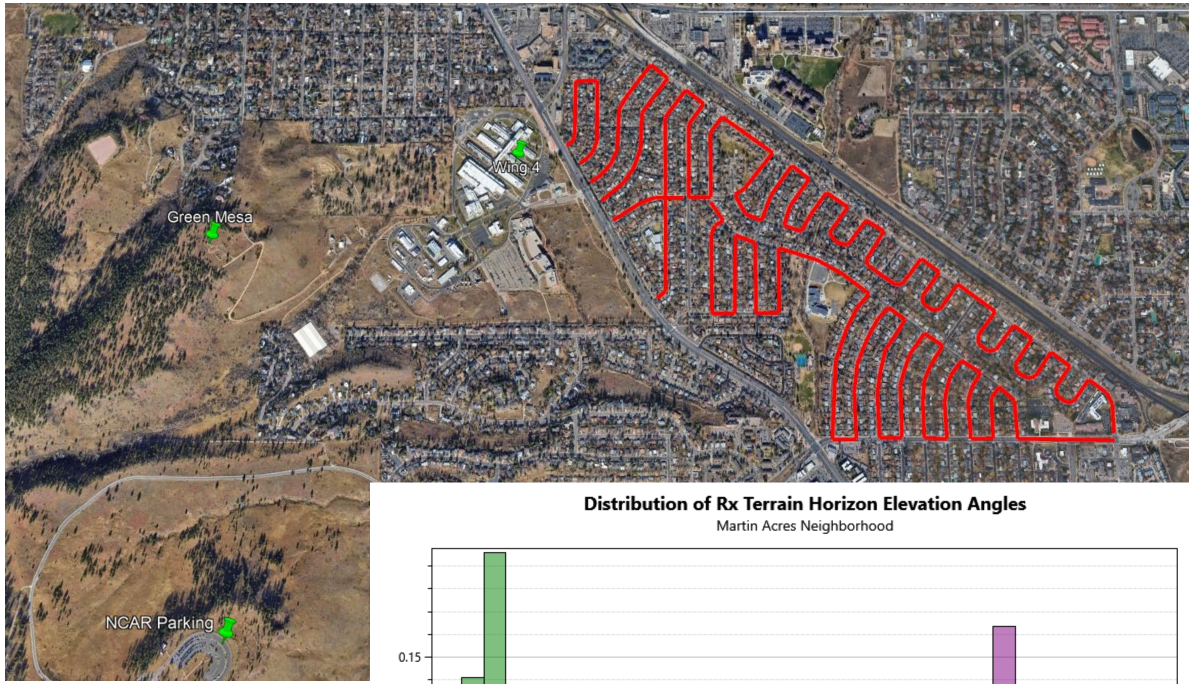
Clutter: System

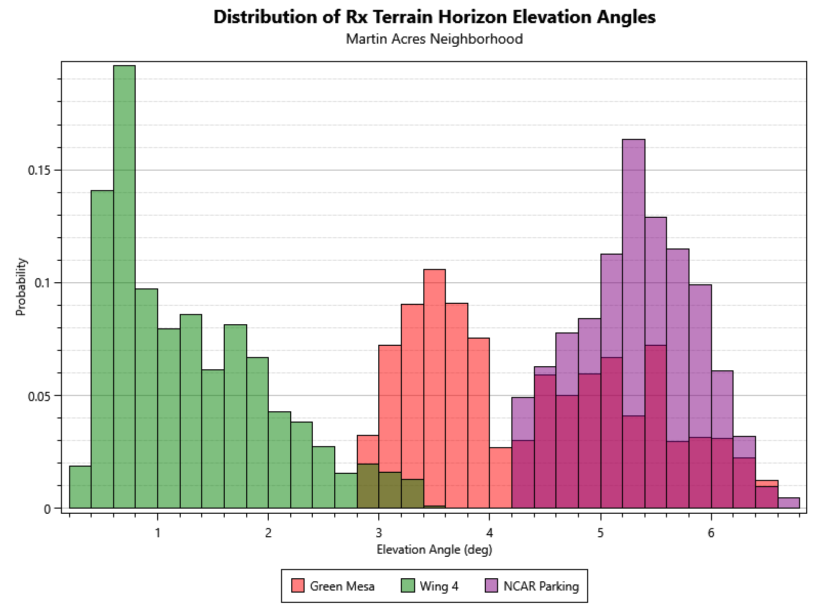
- Mobile measurement system
  - Omnidirectional antennas with preselection
  - Lab grade receivers and signal generators
  - Rubidium disciplined frequency references
- Newly redesigned based on 2020 ITS mmWave system
- Integration of high precision GPS system
  - Sub-meter positional accuracy in challenging environments
- Performed cross validation with previous system in 2021



Clutter: Measurements

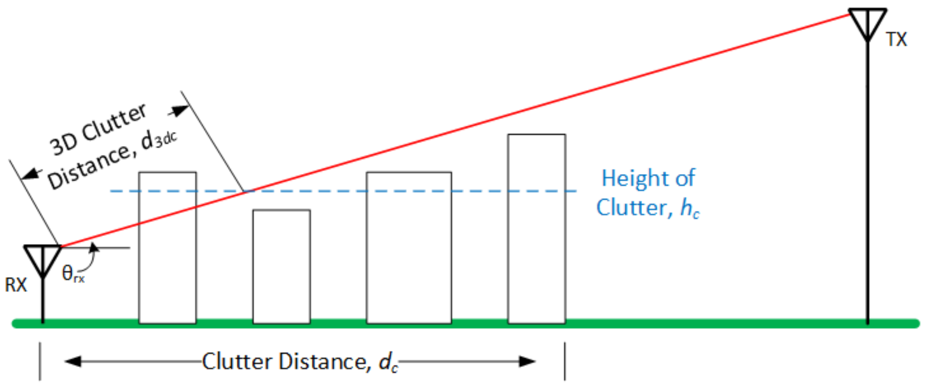
- Measurement system validation and verification in FY22
  - Lab and benchtop testing in Nov 2021
  - Mobile clutter measurements in Dec 2021
  - Longer distance diffraction measurements in May 2022
- Multiple transmitter experiment in Dec 2022
  - Simultaneous capture of 3 TXs during drive
    - Martin Acres
    - Drexel
  - Signal offsets of 3 kHz
- Targeting 4-5 clutter campaigns in FY23

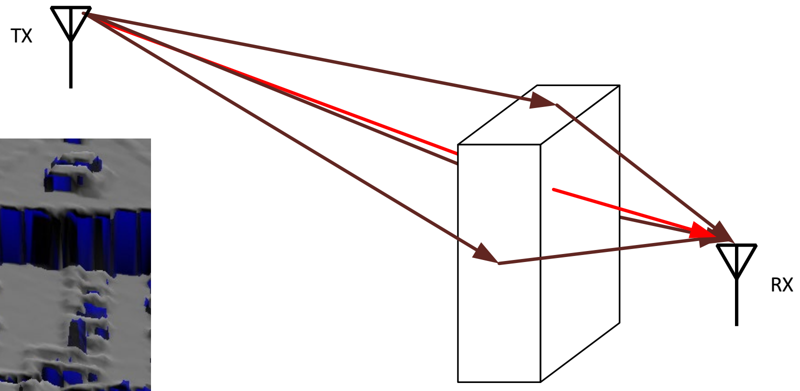


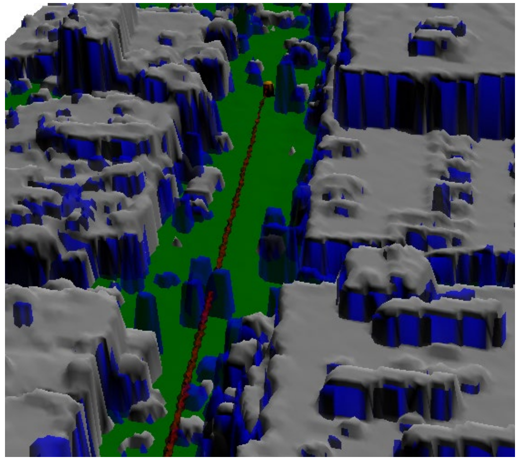


Clutter: Modeling

- Evaluation of existing clutter models
  - Identification of strengths and weaknesses
  - Description of inherent assumptions
  - Access to various models/codes
- Documentation of uses cases
  - Service coverage, interference, etc.
- Propose targeted measurement campaigns
- Development of both point-to-point and area-mode (statistical) models
- Priority on incorporation of variability statistics







Troposcatter: Measurements

Troposcatter: Measurement System

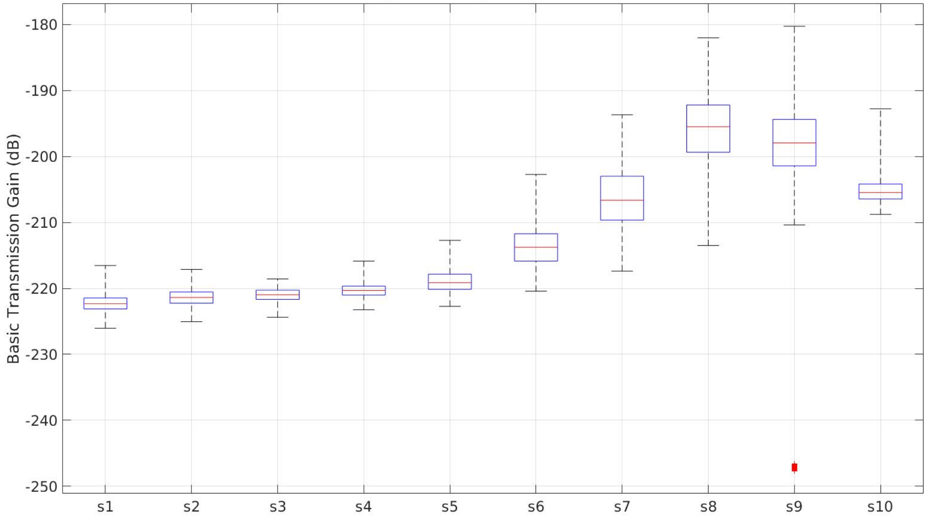
- June 2022: First Light
  - Signal establishment
  - System validation
  - Spot data collection and processing
- Variety of small experiments to exercise system
  - Various pointing angles
  - Polarization configurations
  - Antenna types
  - Measurement parameters

RX Subsystem	Parameter	Description
Antenna	Polarization	Vertical
	Gain, G_R	34.3 dBi (20 dBi)
	EL Beamwidth	3.3 Degrees (17)
	Cross-Polarization Loss, L_{pol}	30 dB
	Cable Loss, L_c	0.4 dB (4 dB)
Preselector	BPF – Frequency Range	3450-3500 MHz
	LNA – Gain	29 dB
	LNA – Noise Figure	1.3 dB
	LNA – 1 dB compression	13 dBm
Signal Analyzer	Frequency, f	3.475 MHz
	Detector	IQ
	Sample rate, f	1250 S/s
	Sample duration, T	8e-4 s
System	Gain, G	~24 dB
	Noise Figure, F_n	~4.5 dB

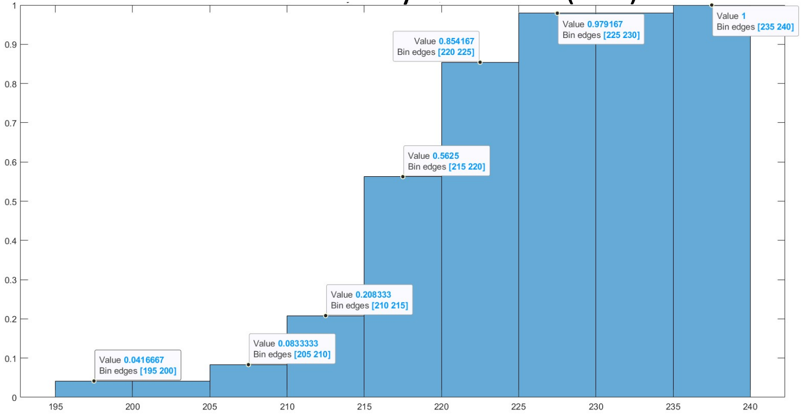
Troposcatter: Initial Measurements Results

- Aug 2022: Extended measurements
  - System stability
  - Antenna configuration
  - 48-hr capture
- Two antenna types
  - 34.3 dBi parabolic dish
  - 20 dBi standard horn
- Capture of data for preliminary analysis

Box and Whisker Plot (Aug. 25, 0000 to 1000 Hrs.)



CDF of Hourly Medians (BTL)



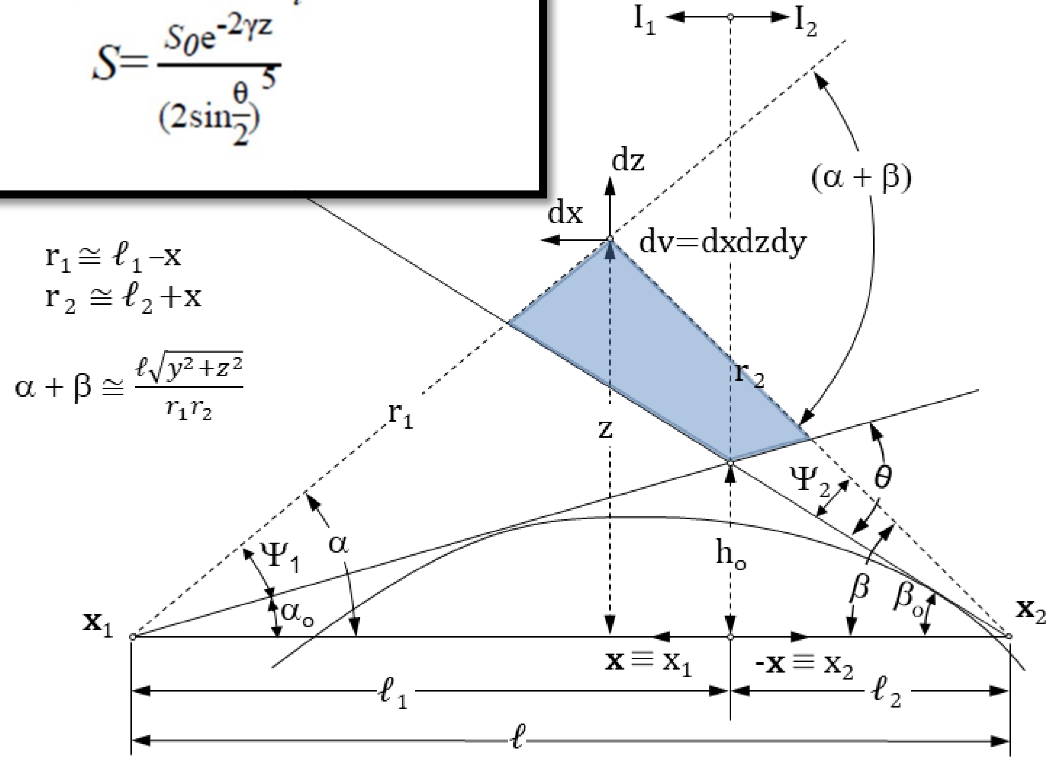
Troposcatter: Modeling

- Derivation of troposcatter model from first-principles
  - Dalke, R., "Tropospheric Scatter: Theory vs. Predictive Models," NTIA Technical Report TR-22-557, Feb 2022.
- Long-term measurement system
- Investigate empirical terms (S_0 and γ in S)
- Enhancement-side refinements
  - Targeted coastal measurement locations

$$V^2 = \frac{4l^2}{\pi^2 k} \iiint G_1 G_2 \frac{1}{r_1^2 r_2^2} S d\mathbf{x}$$

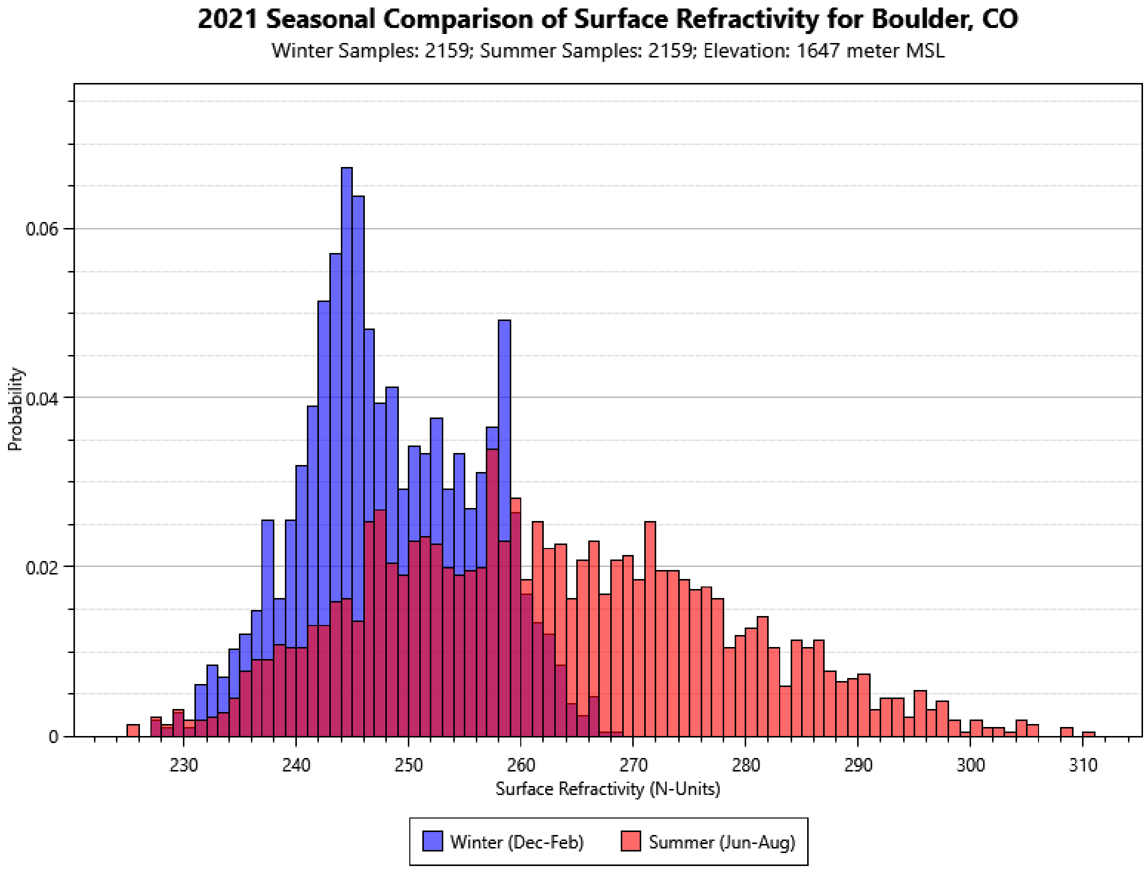
$$G_i = \sin^2(k h_{ei} \sin\psi_i), \quad i=1,2$$

$$S = \frac{S_0 e^{-2\gamma z}}{\left(2\sin\frac{\theta}{2}\right)^5}$$



Troposcatter: Utilize Meteorological Data to Improve Prediction

- NOAA High-Resolution Rapid Refresh (HRRR)
- 3-km resolution, hourly updated, CONUS atmospheric model
- Provides detailed vertically stratified data
- Applications to troposcatter theory and measurements through computation of time-varying and location-specific statistics
  - Atmospheric refractivity
  - Hydrometeors
  - Scatterers



Outreach & Collaboration

Michael Cotton and Rebecca Dorch

Red Team

- Reoccurring meetings to present and discuss approaches/results:
  - Frequency of meetings TBD
  - Data/information sharing
  - Technical contributions and technical review of work
  - Collaboration on specific measurement scenarios
  - Test, consensus building, and integration on common models and software tools
- Currently working with NTIA Legal on exact nature of agreement (CRADA)
- Organizations generally bring their own resources, use case(s), and specialization
- Likely single representative on Red Team, with support team
- ITS currently considering various gov/non-gov organizations for participation

- Invited Navy Red Team participation
  - Specialized in over-water propagation, anomalous propagation, meteorology
  - Current Navy Over Land Propagation project conducting propagation measurements
  - Mature propagation software, e.g.,
    - Interactive Scenario Builder (BUILDER)
    - Advanced Propagation Model (APM)
    - Tropospheric EM Parabolic Equation Routine (TEMPER)
    - Coupled Ocean/Atm Mesoscale Prediction Sys (COAMPS)
- Invited FCC Red Team Participation
- Specialized in clutter short-range clutter propagation
- Current project to improve propagation models for regulatory purposes, e.g., interference analyses
- Mature propagation software, e.g., Path Loss for Urban Model (PLUM)

NTIA Visiting Researcher and Intern Program (VRIP)

Designed to provide participants with opportunities to exchange views and align research with NTIA spectrum management R&D objectives.

Research areas
- Enhancing spectrum utilization
- Propagation modeling and software
- Electrical engineering
- Spectrum monitoring
- Telecommunications policy
- Improving telecom networks

Subject Matter Expert
Serve as a resource on topic(s) of expertise
Apply knowledge and experience to project

Intern
Be mentored by subject matter experts
Work on exciting projects in a team setting

Liaison
Conduct collaborative research in spectrum sharing and management

Questions & Discussion