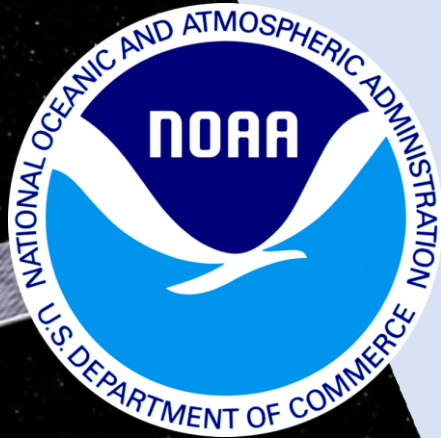


# Remote Sensors - RFI detection, monitoring and mapping



September 16, 2024

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JHU APL for NOAA



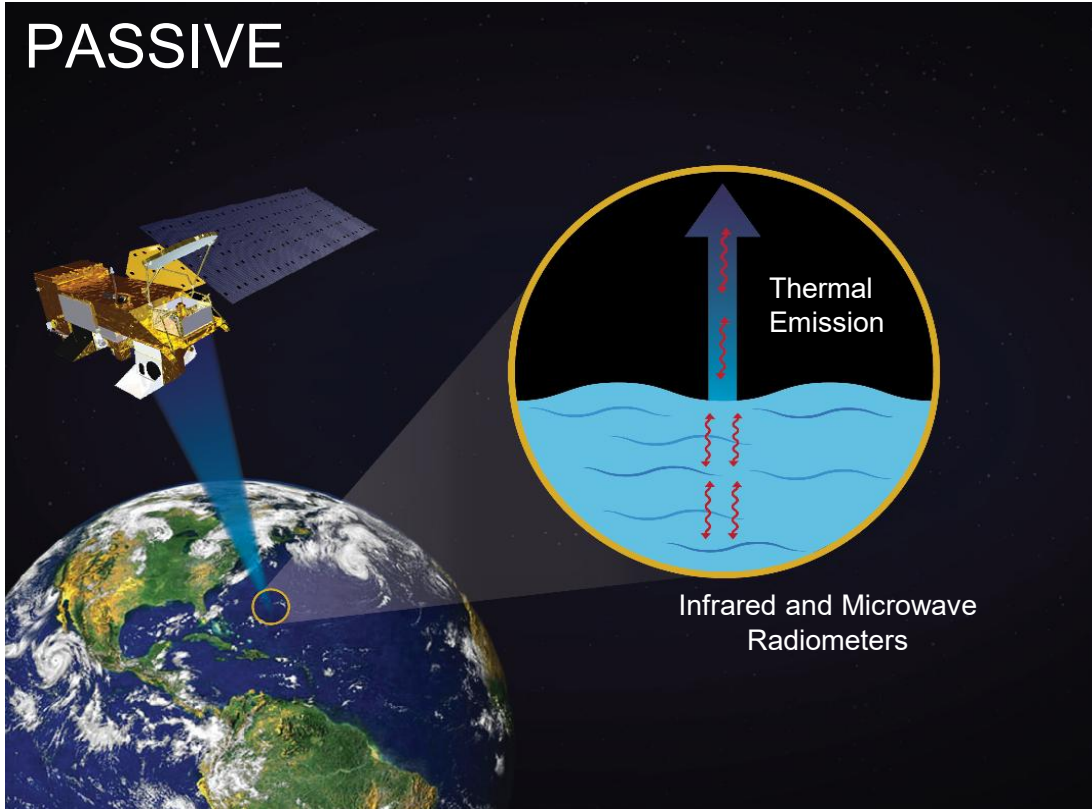
# Working with International Partners, we are utilizing a global observing network

Access to data from this constellation enables us to produce an incredible breadth of multi-sensor, multi-satellite products.

- JAPAN
- SOUTH KOREA
- CANADA
- SPAIN
- USA
- FRANCE
- NOAA
- EUMETSAT
- EUROPEAN COMMISSION
- TAIWAN SPACE AGENCY (TASA)
- EUROPEAN SPACE AGENCY
- NASA
- DEPARTMENT OF DEFENSE
- COMMERCIAL DATA PURCHASE



# How it Works: Microwave Remote Sensing



## 1. Universal Spontaneous Emission

Every physical body (water, soil, clouds, trees, people... literally everything on Earth) continuously and spontaneously emits electromagnetic radiation.

## 2. Measurement via Sounders

These naturally occurring thermal emissions are captured and measured from space by high-precision microwave sounders (radiometers).

## 3. Extremely Weak Signals

The emitted energy is proportional to temperature and is exceptionally faint:

- **Standard Object (100 K):** Emits only 0.1 pico-Watts ( $= 10^{-13}$  W) within 100 MHz.
- **Signal Fluctuation:** On the order of 0.1-K  $\rightarrow$  0.1 femto-Watts ( $= 10^{-16}$  W).

### Critical Spectrum Requirement

The extreme sensitivity required makes it essential to maintain protected allocations and to properly manage use of the spectrum near these bands.

# The "Golden Bands" of Meteorology

## Physics

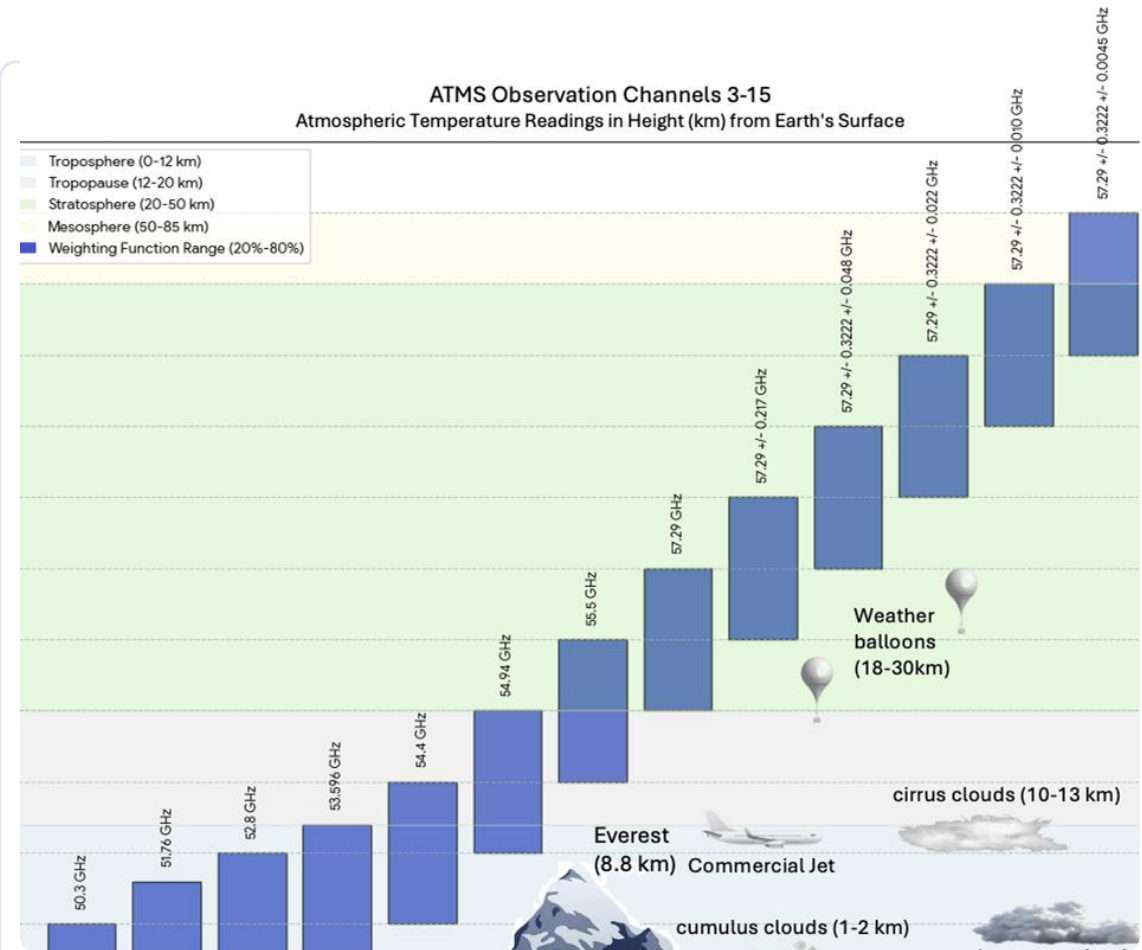
The Oxygen (O<sub>2</sub>) Absorption Complex (50-60 GHz).

## Concept

"Slicing the Atmosphere" – How opacity varies with frequency to yield 3D temperature profiles.

## Criticality

Why 50 GHz is the only way to see inside hurricanes (cloud penetration).





# The RFI Risk – Contamination of Data

## Interference Risks & RFI Types

As services in millimeter wave bands are implemented, there are potential, severe interference risks to passive sensors.

### Typical / Single-Source RFI

A single, powerful source of interference (e.g., radar) that causes obvious, identifiable RFI in SMOS or SMAP data.

### Aggregated RFI (AWS and Satellite Constellations)

Multiple interfering sources within each measurement area that aggregate, making detection and separation extremely difficult.

**Unintended Electromagnetic Radiation (UEMR)**—leaked electronic noise generated by active satellite constellations, power systems, and terrestrial hardware—bleeds into protected passive bands. Because remote passive sensors rely on measuring extremely weak, naturally occurring signals (e.g., thermal emissions from Earth or cosmic radio waves), even low-level UEMR can obscure or distort observation data, degrading the accuracy of weather forecasting, climate modeling, and space science measurements.

## Key Concerns from RF Advances

Commercial RF spectrum advances near remote passive sensing frequencies pose critical risks to essential climate and weather data:

### 1. Adjacent Band Contamination

Contamination of sensitive passive measurements is highly probable due to the rapid growth of adjacent band use.

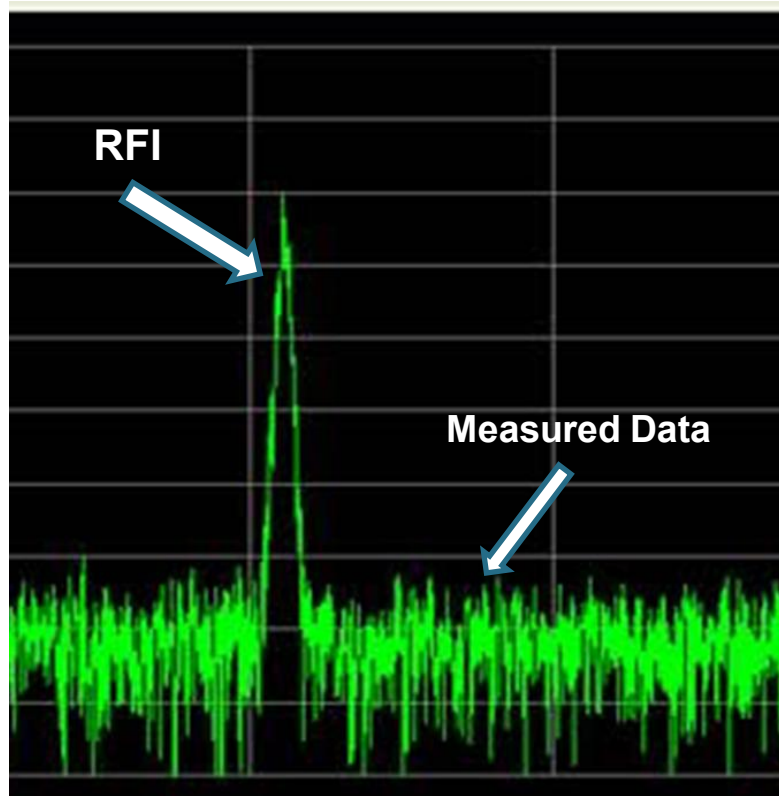
### 2. Manifestation Uncertainty

It remains highly uncertain exactly how the interference will manifest in observations and to what physical extent.

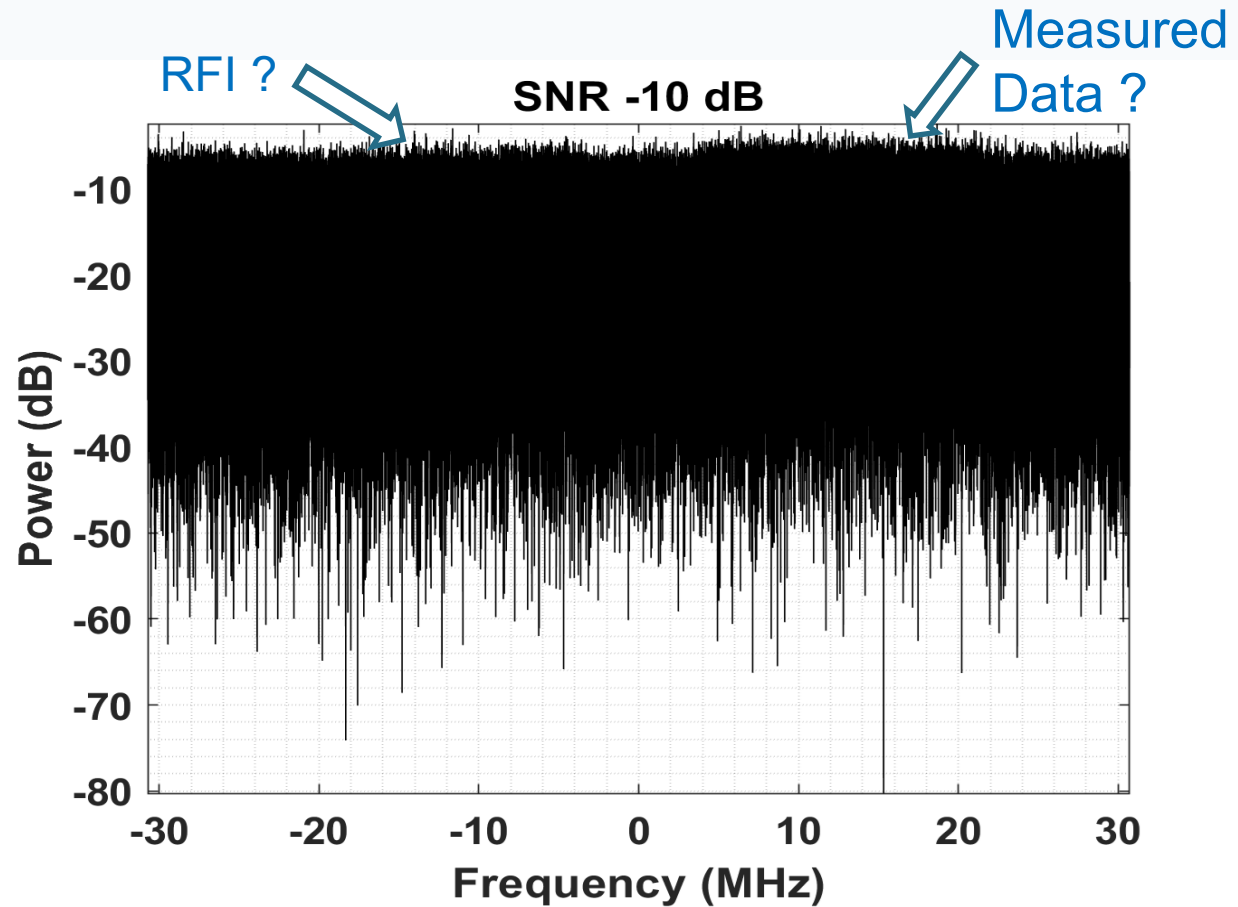
### 3. Mitigation & Impact Reduction

It is unclear how to best minimize these impacts, and how CGMS members can effectively safeguard overall global measurements.

This is NOT what passive remote sensor RFI looks like:



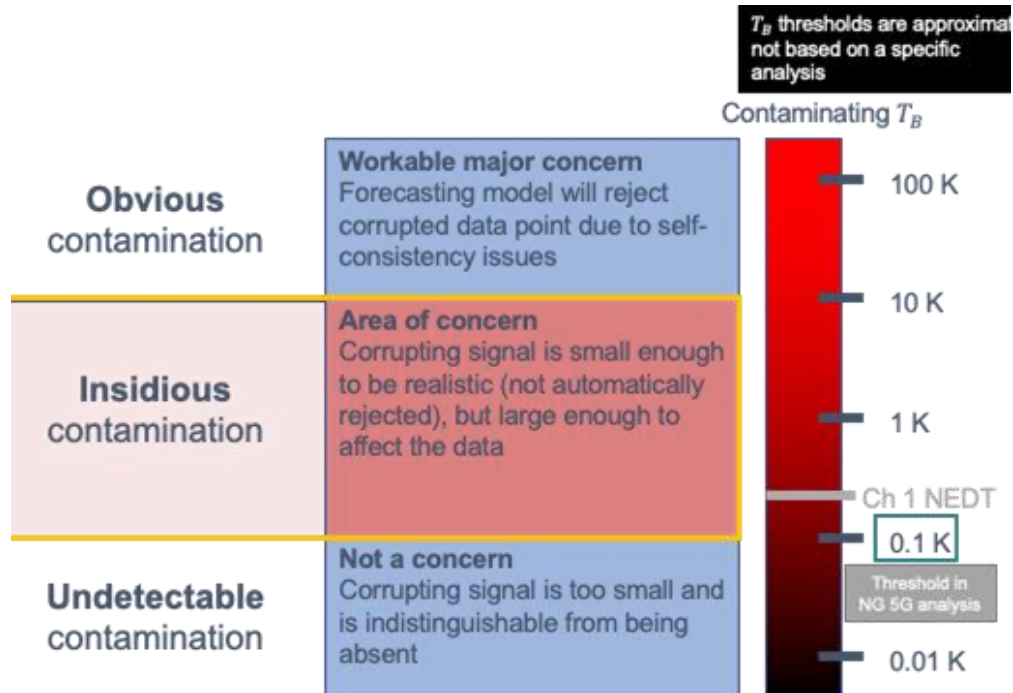
It's likely to look more like this:



*You can't see the difference!*

# RF Passive Band Situation *as we see it*

## Contamination Thresholds & Impact Levels



TB – Brightness Temperature

## Key Situation Insights

### 1. The Growing Threat

Non-natural RF contamination will only increase, both in overall intensity and across spectrum proliferation.

### 2. Resolution Complexity

Resolving RF contamination is highly challenging. It cannot simply be 'removed' from the background and must be identified and mitigated with multiple coordinated methods.

### 3. Path Forward: Tri-Pillar Effort

A broad and continuous effort is urgently required across three key dimensions:

- **Regulatory:** Global collaboration at both international and national levels.
- **Policy:** Developing agile frameworks to rapidly respond to environmental spectrum changes.
- **Technical:** Integrating advanced scientific and engineering robustness into next-generation satellite systems.

# The Regulatory Trap: "Light Licensing"

## Definition

Automated, database-driven licensing.

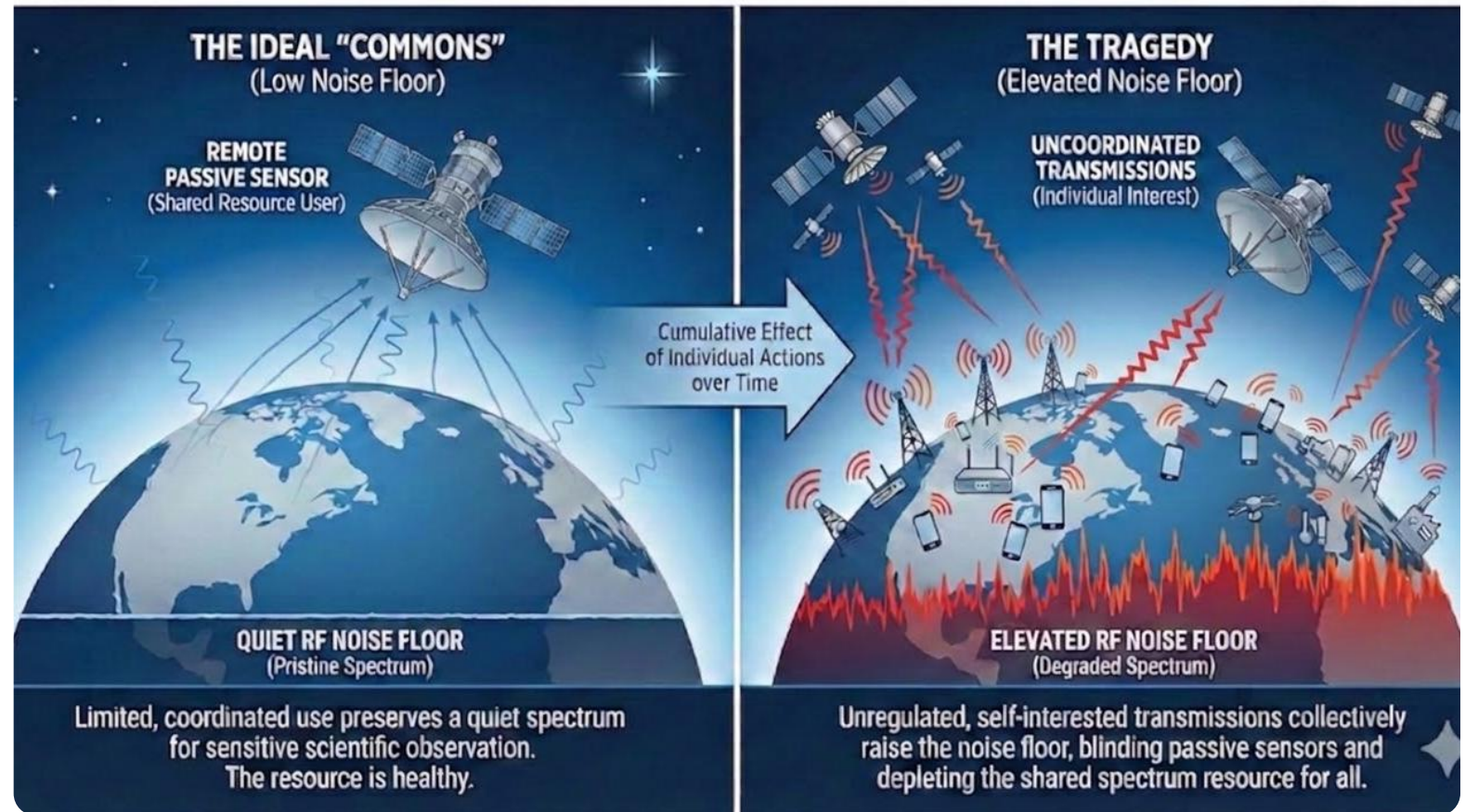
## The Flaw

Designed for active-to-active protection (jamming). **Fails** for active-to-passive protection (noise floor integration).

## Key Concept

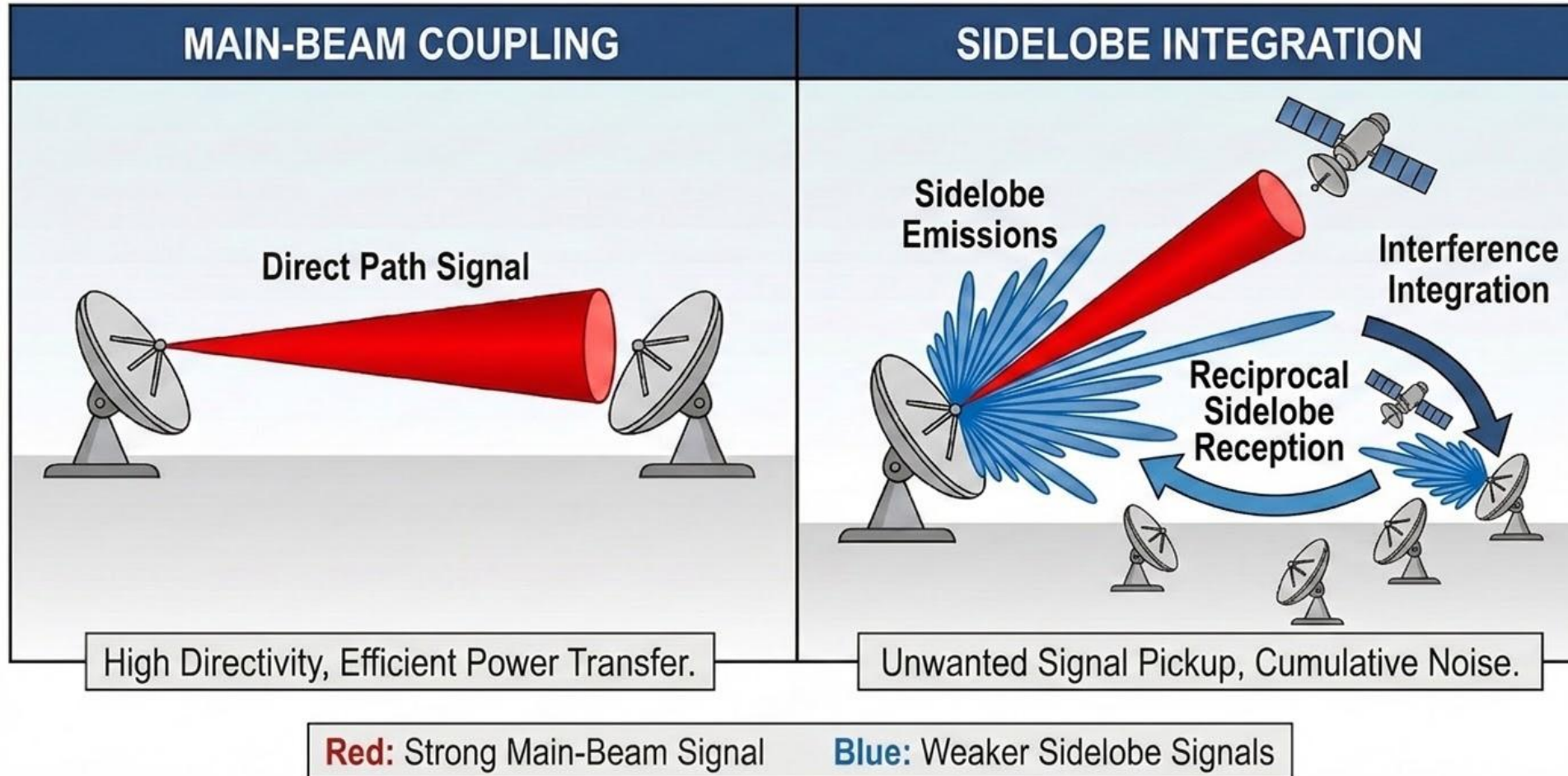
"The tragedy of the commons" applied to the noise floor.

## THE TRAGEDY OF THE RF COMMONS: A Passive Sensor's Perspective



# Aggregate Interference Mechanics

## SATELLITE RF LINK COUPLING MECHANISMS





# Why is this a problem for MW Sounders?

## The Fundamental Flaw

### Total Power Measurement

As designed, microwave (MW) sounders only measure the **total amount** of radiative power entering the antenna.

They cannot natively filter or separate individual source contributions within the same frequency band.

## The Contamination Dilemma

### Indistinguishable Cases

Case A: Contaminated Signal

$$230 \text{ K (Env)} + 5 \text{ K (RFI)} = 235 \text{ K}$$

Case B: Normal Signal

$$235 \text{ K (Env)} + 0 \text{ K (RFI)} = 235 \text{ K}$$

*These two entirely different scenarios look identical to current MW sounders.*

## Spectral Impact

### Adjacent Band Interference

Adjacent band signals and energy spillover will constantly change due to external factors:

- Outside environmental temperature
- Active frequency usage fluctuations
- Varying transmitter power levels

**To the instrument, these dynamic changes mimic natural environmental changes in 'K'.**

# Economic & Safety Impact

## Economic Value

# \$160B / Year

Global economic benefit derived directly from accurate meteorological forecasting.

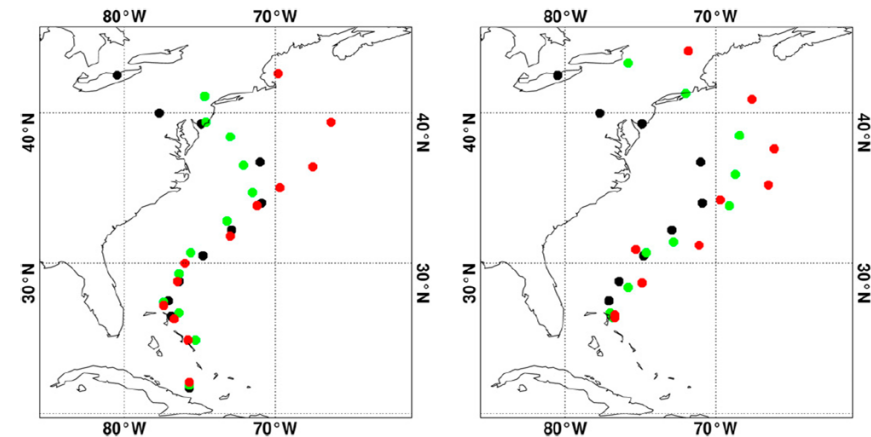
## Safety & Prevention

# Lead-Time Saves Lives

A direct correlation exists between warning lead-time accuracy and the number of lives saved during major tornado and hurricane events.

## The Sandy Scenario

Re-running history without satellite microwave data (Forecast Failure)



*Without microwave data (red), the Sandy forecast made landfall in Maine several days out, instead of the actual track in New York / New Jersey (black).*

Source: McNally, et. al., ECMWF "Monthly Weather Review"

# RFI Detection Through Satellites & Constellations

## The Mapping Limit

### 2D Constraints

RFI monitoring from existing sensors is limited and currently restricted to two dimensions—time and geography.

- Global mapping requires satellite-based facilities.
- Raises key questions for standardization of monitoring systems.

## Comparison & Density

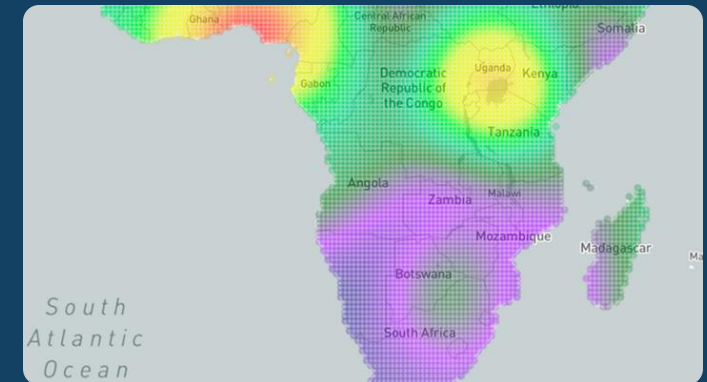
### Deployment Tracking

Deployment density can be monitored and compared over time against acquired instrument data.

- Comparison managed at ECMWF, STAR, or equivalent levels.
- Enables robust progress tracking over time.

## Global Standard

### RFI Assessment



*Procedures for reporting an RFI assessment need to be established and globally used in meteorological and climatological communities.*



# RFI Detection Through Sensor Technology

## Instrument-Level Flagging

### Embedded Sensors

Algorithms look for non-gaussian signal elements directly at the instrument level:

- Front-end radiometer and back-end spectral processors.
- Dual polarization and in-orbit mapping.
- Sensor calibration and bandwidth filtering to minimize external RFI.

## Advanced Mitigation

### On-Board Modules

Specialized physical modules designed to actively counteract corruption before downlink:

- Dedicated hardware embarked directly on satellite platforms.
- Discussed for upcoming missions to prove feasibility.
- Engineered to adapt to dynamically changing noise floors.

## Data Management

### Downlink Control

Intelligent on-board selection manages data limits based on satellite processing capacity:

- Strategic trade-off between absolute data transmission rates and localized RFI environmental details.
- Filters out highly corrupted files before wasting downlink bandwidth.
- Maximizes efficiency of deep-space and orbit-to-ground channels.



# Remote Sensing in RF Passive Bands

*Passive Band Sensors cannot discern between natural and anthropogenic spectrum emissions*

## RF Vulnerability

### Corruption Risk

EESS (passive) bands continue to be recognized as being at high risk for anthropogenic sourced corruption.

## Sensor Limitation

### Signal Confusion

Passive sensors are not able to differentiate between natural and man-made sources of signals.

## Weather Prediction

### Forecast Impact

An impact to weather models and forecasting accuracy is expected. AWS repeaters and satellite constellation growth may further corrupt bands.

## Future Standards

### Robust Design

Passive Band Sensors need an established set of standards to implement 'robustness' into their design to counteract interference.

MWS – Microwave Sounder | EESS – Earth Exploration Satellite Service



# RFI Detection Through Dedicated Instruments or Satellites

## Satellite Monitoring

### Global Facilities

Globally standardized satellite-based monitoring facilities map the overall spectrum landscape.

- Constellation of small satellites or drones to map the RF environment by area and time.

## Targeted Sensors

### Specific RFI Sources

Dedicated sensors focused on specific sources of interference, such as 5G identification sensors.

- In some bands, RF monitoring is already commercially available.
- Opportunity for "commercial" buys of RFI info to facilitate mapping and keep datasets current.

## Research & Development

### Ongoing Studies

Preliminary studies are actively addressing this detection approach and its associated technical challenges.

- Designed to cover various and larger RF bands.
- Scaling to encompass broader and more diverse geographical areas.



# Growing Commercial Presence in Space influences Spectrum Use

## 01. GLOBAL MARKET

### Economic Growth

Projected to reach **\$1.8 trillion by 2035** (up from \$630 billion in 2023), growing at roughly 9% annually.

Key drivers are space-enabled capabilities, including high-bandwidth satcom, precision PNT, and real-time Earth observation.

## 02. VALUE SHIFT

### Non-Space Sectors

Value is shifting downstream from traditional hardware to **space-enabled services**.

Non-space platforms—such as autonomous logistics, ride-hailing, precision agriculture, and mobile finance—capture the majority of economic value.

## 03. CORE SECTORS

### Goods & People

Five primary sectors will generate **60% of the space economy** by 2035:

- Supply chain & transport
- Food & agriculture
- Defense & security
- Retail & digital comms

## 04. BROADER IMPACT

### Expanded ROI

Satellite infrastructure serves as the foundation for addressing **systemic global challenges**.

Yields critical non-financial returns: disaster early-warning, precise climate tracking, emergency response, and digital inclusion.

# Increasing Value in the Growing Space Sector

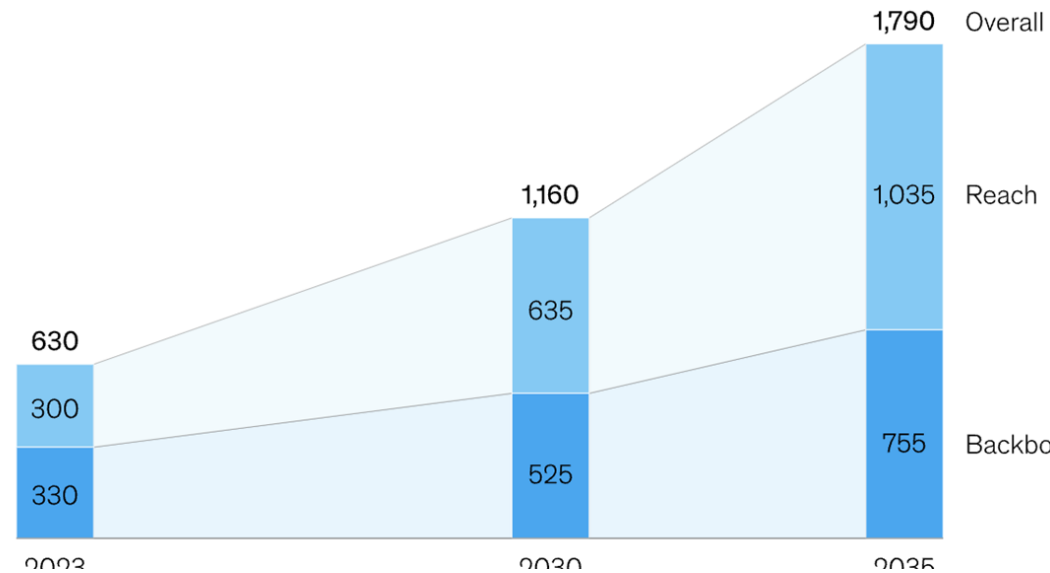
## Market Insight

### Global Growth

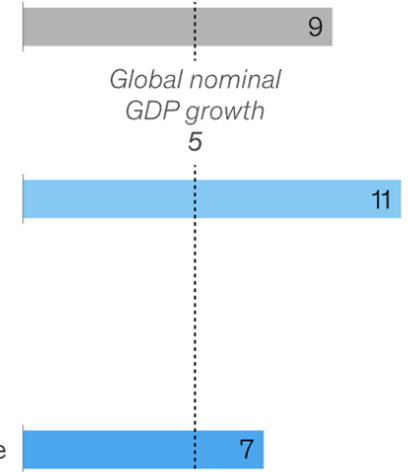
Space is a \$1.8 trillion opportunity for global economic growth, with applications growing faster than global nominal GDP.

April 8, 2024 | Report

Global space economy, \$ billion



CAGR, 2023–35, %



### "Backbone" Applications

Essential space infrastructure including satellites, launchers, and critical foundational services like broadcast television or GPS.

### "Reach" Applications

Downstream technologies enabling diverse commercial sectors to generate revenue, such as Uber leveraging satellite signals and mobile devices.



# Conclusion

## Summary

## Physics cannot be negotiated.

As mass market RF intensive applications approach, reach, or even exceed tolerable deployment numbers, sophisticated monitoring processes and systems will be needed.

## Call to Action

**Regulators must choose “Smart Licensing” (Aggregate-aware) over “Light Licensing” to prevent a degradation of global safety infrastructure.**

## RF Characterization & Thresholds

Spatial and spectral characterization of RFI requires selecting a threshold level above which data are flagged as contaminated. Any RF source characterization must include spatial and temporal descriptions.

## Collective Global Standards

Because data is acquired by a global network of sensors on meteorological satellites and fed into global forecast models, threshold selection and monitoring facilities should ideally be decided collectively.

## Critical Regulatory Gaps

The protection criteria in ITU-R Recommendation RS.2017 is only a starting point. Standards relevant to remote RF passive sensors do not currently exist for measuring, evaluating, and mitigating RFI affecting spaceborne Earth observation satellites.



# Thank You!