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Modeling Interference Risk

Propagation and Other Uncertainties

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Outline

Risk assessment

- Motivation, outline of method

Case study

- MetSat/LTE in AWS-3

Modeling challenges

- Complexity, sensitivity analysis, known unknowns, bugs

Motivation

Demand for spectrum rights leads to

- Squeezing services together ever more tightly
- Ever-tougher trade-offs when making allocation choices

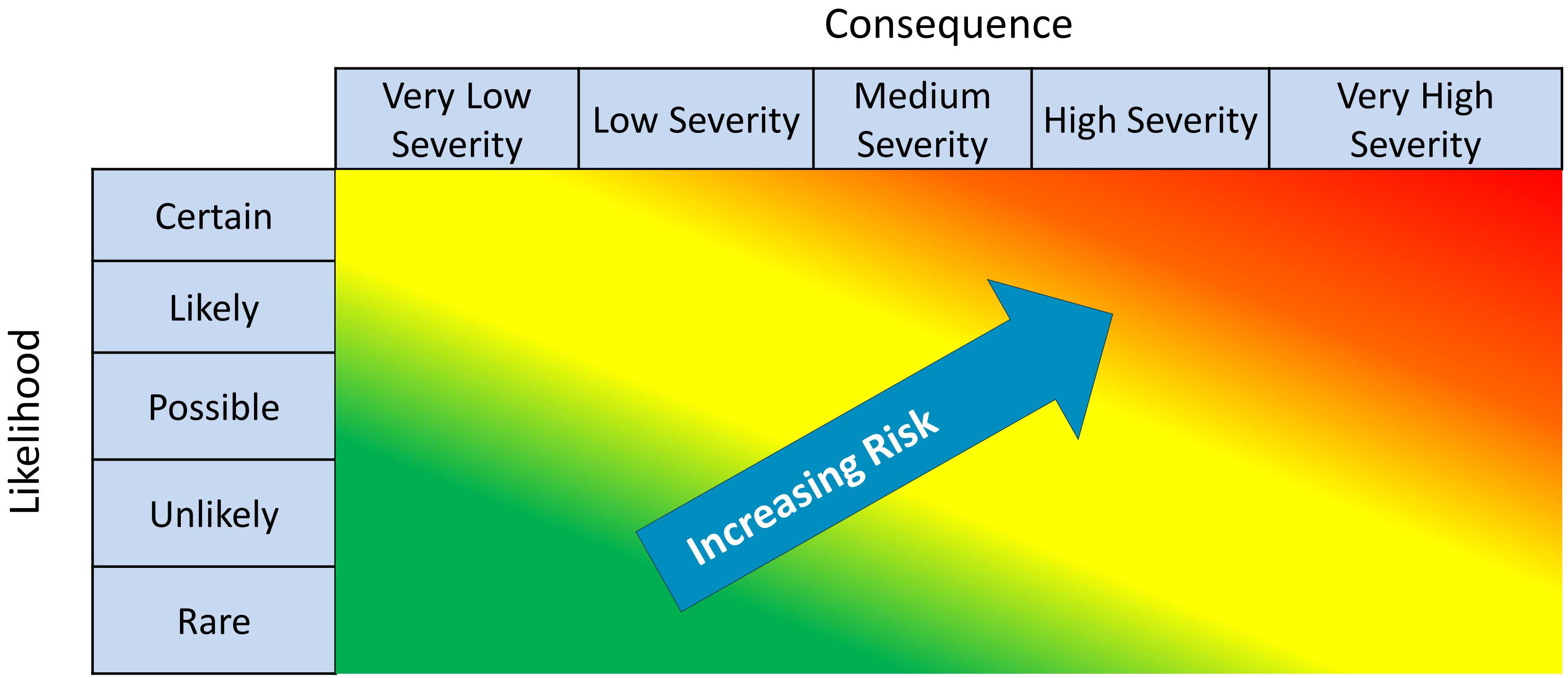
But traditional (especially worst-case) analysis often too conservative

- More protection for incumbents than they need
- Not enough headroom for entrants

Risk-informed Interference Assessment (RIIA) can help spectrum managers make better-informed trade-offs

Applications so far: MetSat/LTE, LTE-U/Wi-Fi, non-GEO satellites

Engineering risk assessment: A well-trodden path



The "risk triplet"

1. What things can go wrong?
2. What are the consequences?
3. How likely are they?

Worst case

1. One hazard
2. Most severe consequence
3. Ignore probability

A method

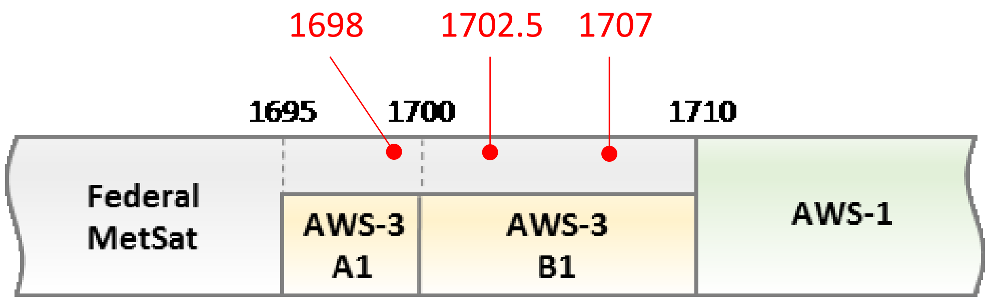
1. Make inventory of hazards
2. Define consequence metric
3. Assess likelihood & consequence for various interference modes (hazards)
4. Aggregate results

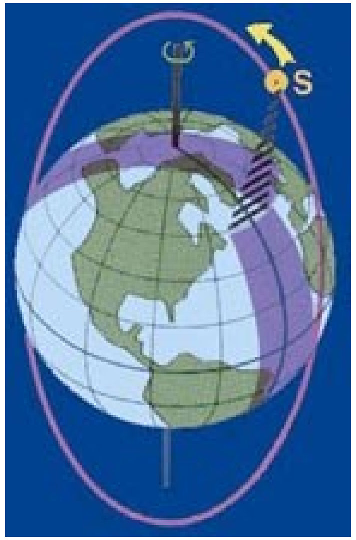
Case study: Weather Satellite/LTE coexistence

h/t Paul McKenna, Ed Drocella

De Vries, Livnat & Tonkin, "A risk-informed interference assessment of MetSat/LTE coexistence," *IEEE Access*, 2017

MetSat/LTE coexistence





Incumbents

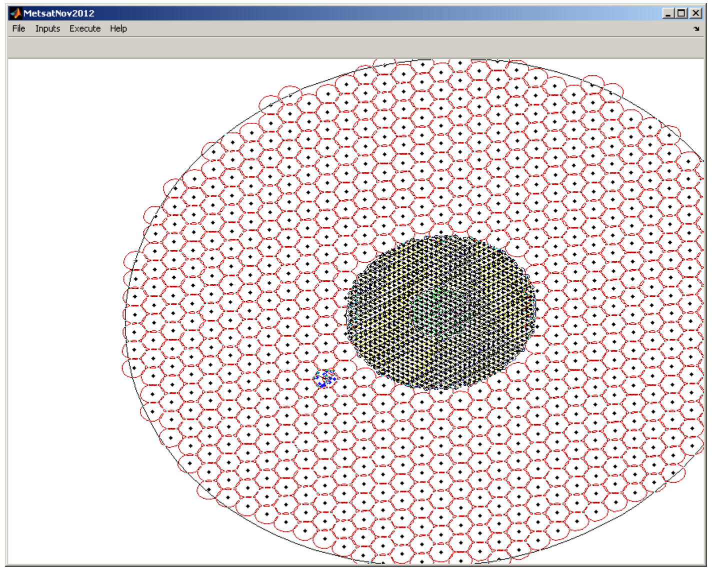
- Polar and geostationary meteorological satellites (MetSat)

Entrants

- Cellular uplink (LTE UEs) → aggregate interference

Studied by NTIA in 2010, and CSMAC/NTIA in 2013

Bands assigned in 2015 cellular auction with rules based on CSMAC report



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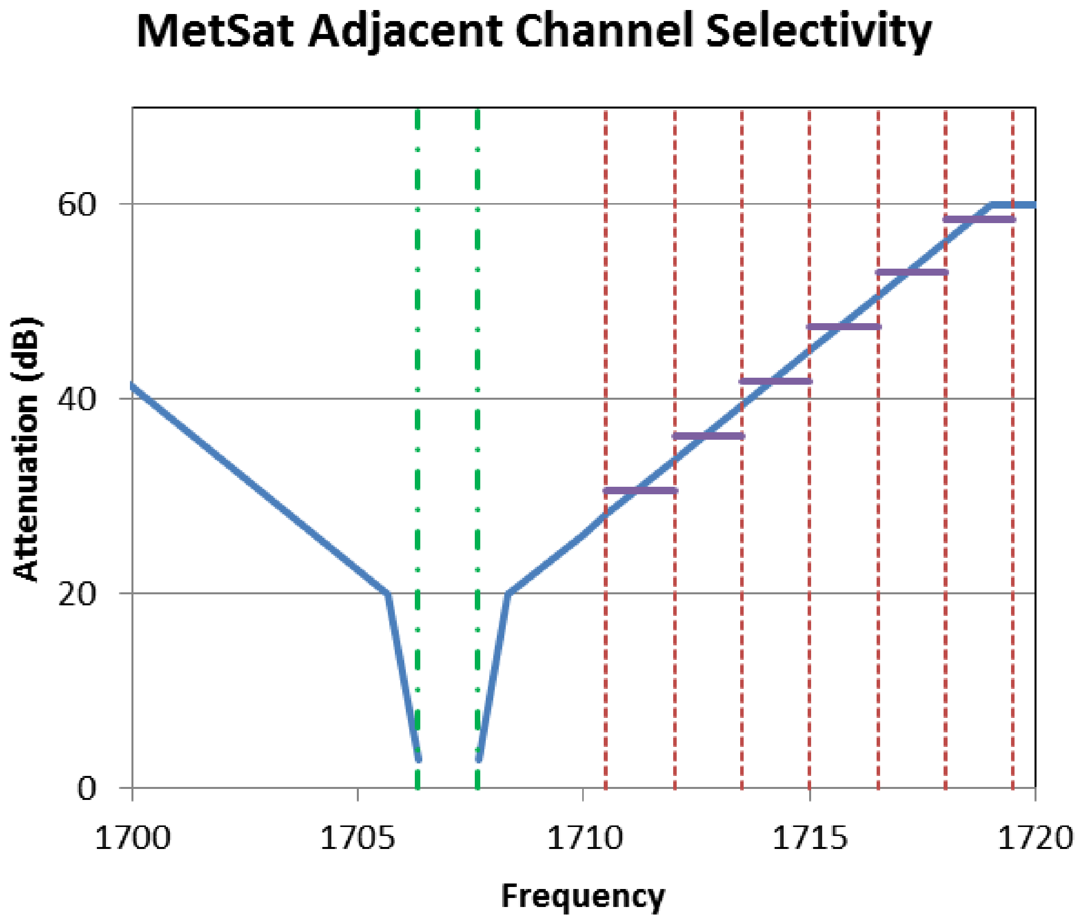
Step 1: Make inventory of hazards

Hazards

- Co-channel interferers
  - LTE mobiles outside exclusion zone
- Frequency-adjacent interferers
  - Existing AWS-1 cellular allocation – no exclusion zone

Ignored

- Intermod & spurious emissions
- Non-interference hazards
  - Desired signal fluctuation, component failure, human error



Step 2: Define consequence metric

Use ITU-R SA.1026-4 MetSat Interference Protection Criteria (IPC)

"Long-term" (occasional satellite signal fades)

- 5° earth station antenna elevation
- Interference power not-to-be-exceeded > 20% of time

"Short-term" (occasional strong interference)

- 13° elevation
- Interference power not-to-be-exceeded > 0.0125% of time

For HRPT service, 29.5 dBi antenna, 1.33 MHz receiver bandwidth, the IPCs are

- Long-term: -116.1 dBm, NTE > 20% of time
- Short-term: -114.1 dBm, NTE > 0.0125% of time

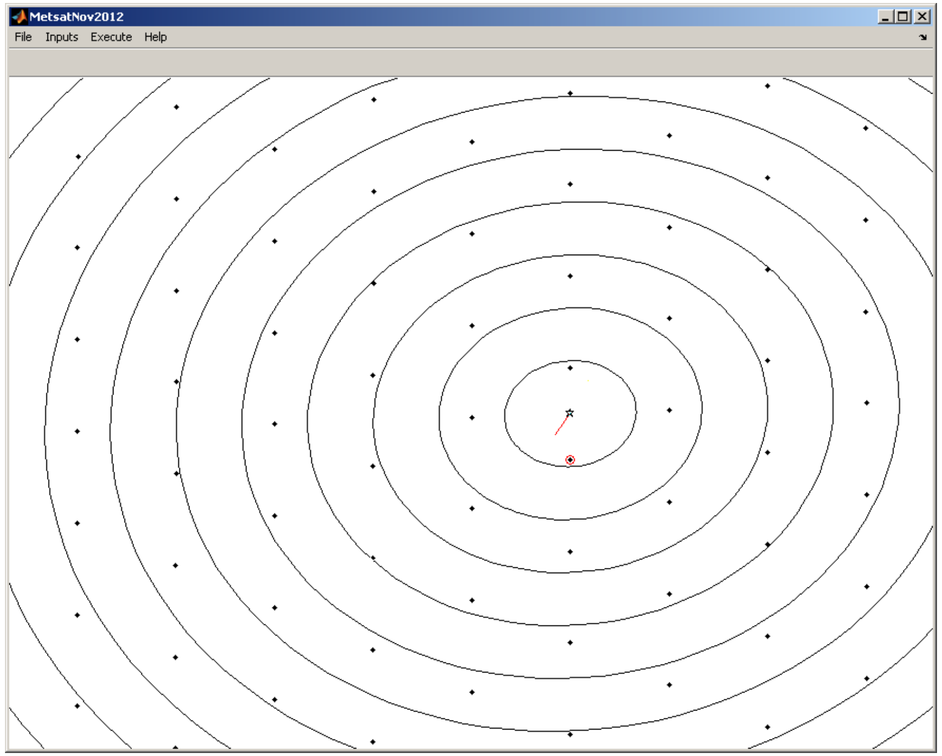
Step 3: Calculate likelihood/consequence

Assess likelihood & consequence for various interference modes using Monte Carlo modeling

- Follow CSMAC modeling assumptions

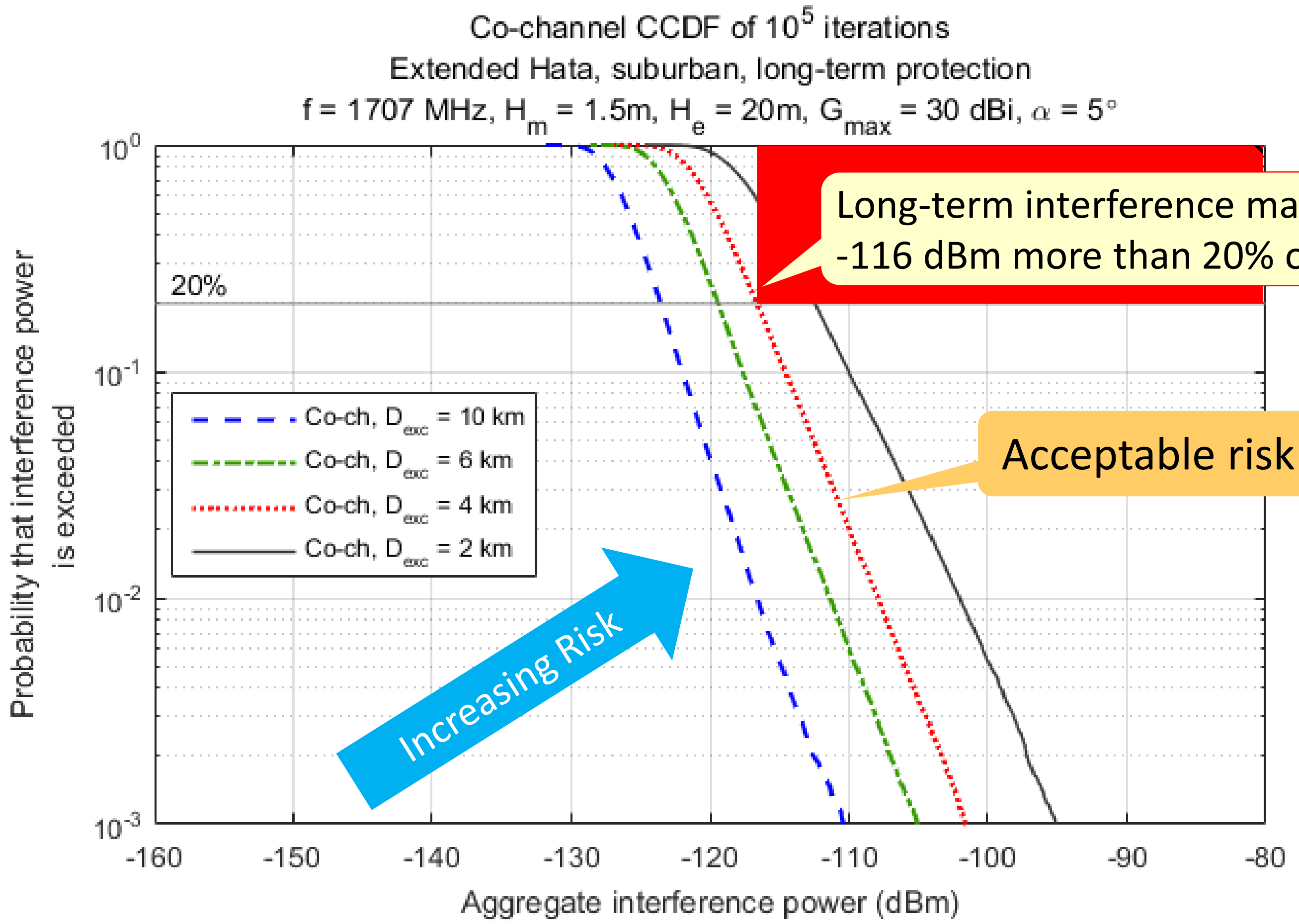
For each inner radius (exclusion distance)

- Do N times
  - Place UEs randomly between inner and max simulation radius; use suburban or rural density depending on location
  - Calculate net interfering power for each UE, and sum over all of them
  - N = 10,000 to 1 million, depending on time %
- Calculate probability distribution of aggregate interfering power



Long-term IPC (5°) requires 4 km exclusion

Likelihood: Exceedance probability



Long-term interference may not exceed -116 dBm more than 20% of the time

Acceptable risk with 4 km exclusion

Consequence: Aggregate interference power

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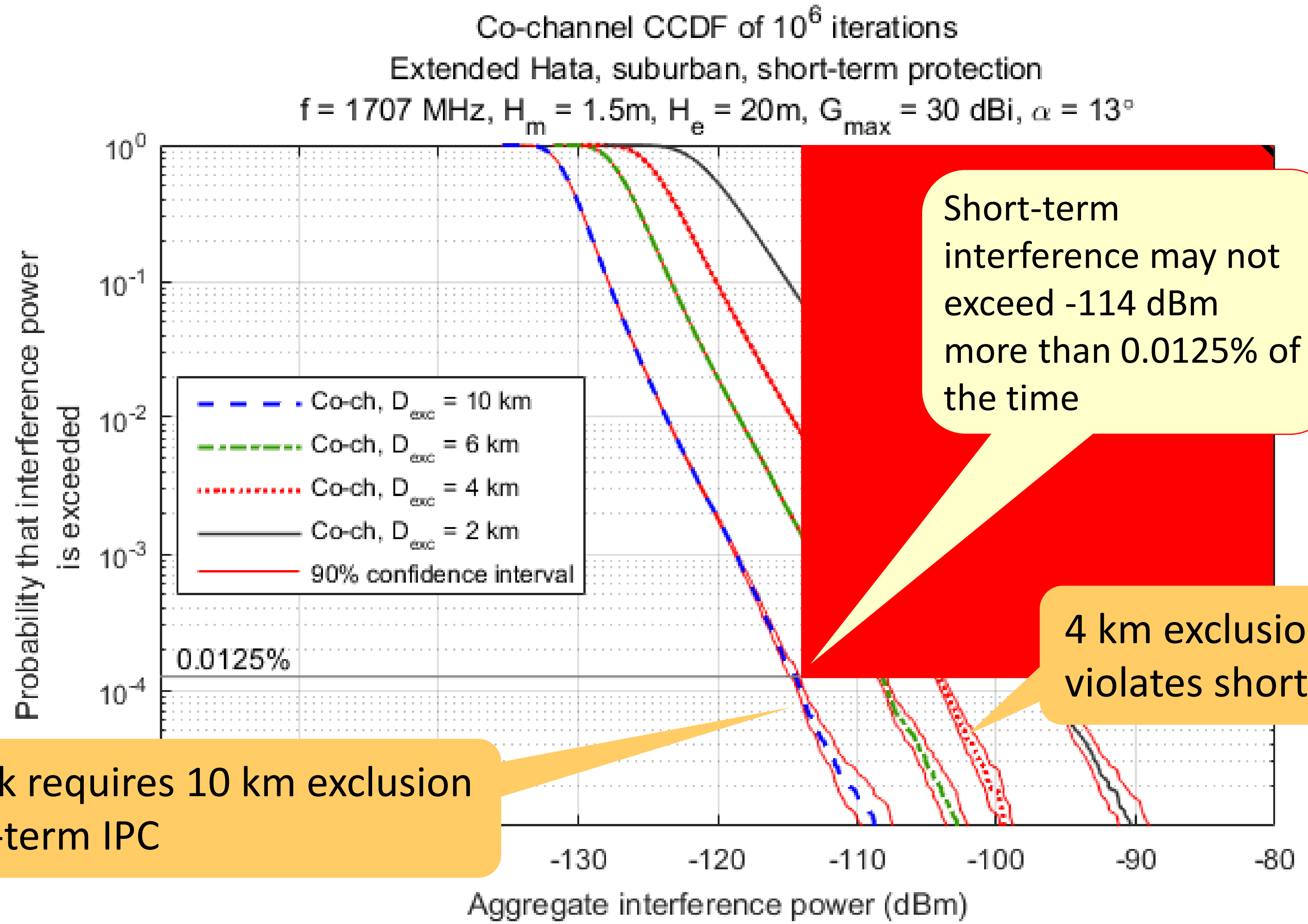
BUT: short-term IPC (13º) sets co-channel exclusion

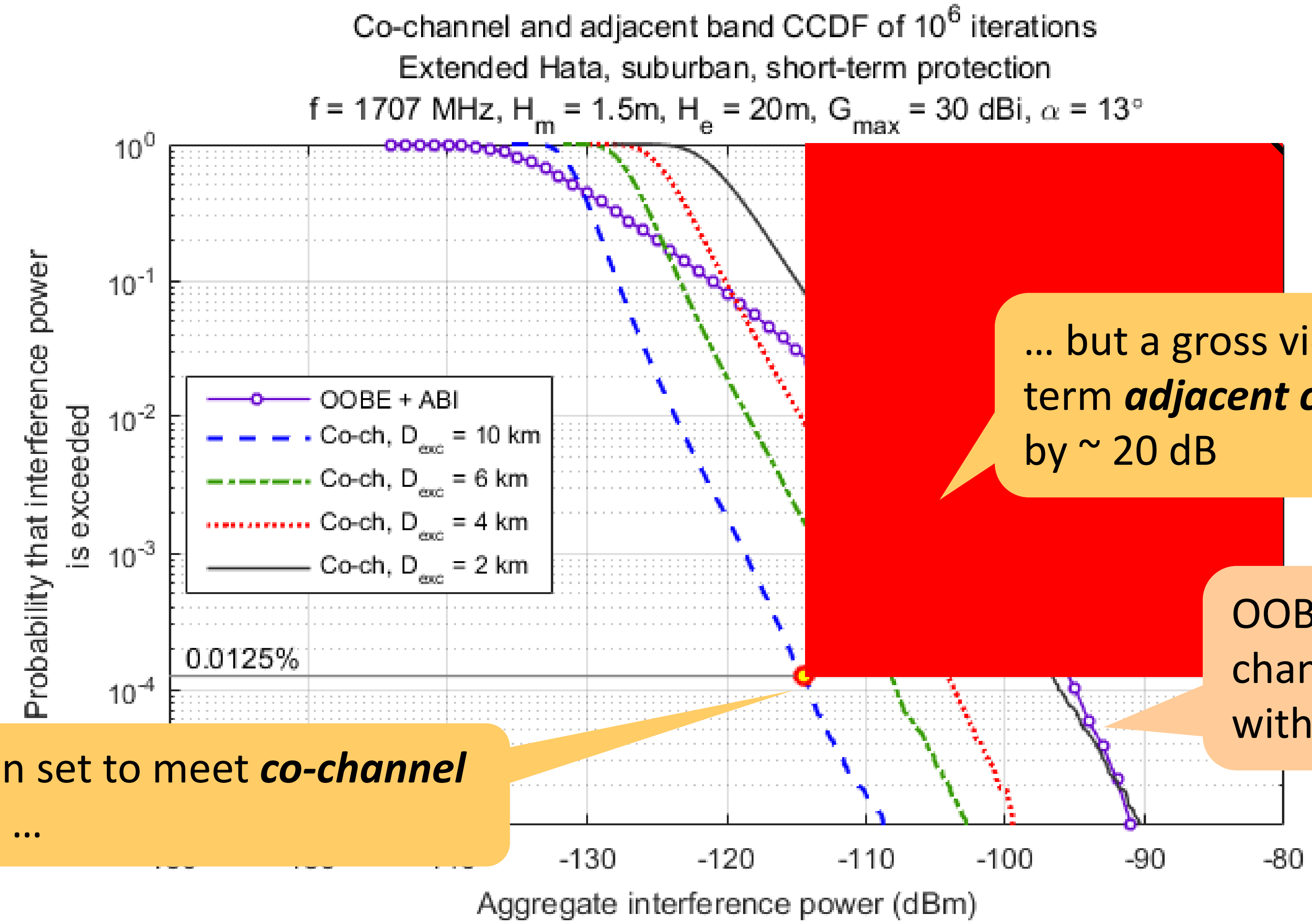


Short-term interference may not exceed -114 dBm more than 0.0125% of the time

4 km exclusion of long-term IPC violates short-term protection

Acceptable risk requires 10 km exclusion to meet short-term IPC

Step 4: Aggregate results with adj. band interferers



… but a gross violation of short-term ***adjacent channel*** IPC by ~ 20 dB

OOBE + ABI similar to co-channel interference with 2 km exclusion

10 km exclusion set to meet ***co-channel*** short-term IPC …

Modeling challenges

It's tough to make predictions, especially about the future

Yogi Berra

Modeling Challenges

1. Sensitivity to assumptions
2. Lots of parameters
3. Known unknowns
4. Bugs

Sensitivity analysis

Remember that all models are wrong;
the practical question is
how wrong do they have to be
to not be useful

– George Box

1. Sensitivity analysis

Which parameters strongly influence the outcome?

- Inform judgment about whether calculated risks are believable
- Provide insights about which mitigation strategies to pursue

For MetSat/LTE, explored the effects of

- Propagation modeling
  - Extended Hata vs. ITM, urban and suburban clutter, ITM terrain characterization, and location variability in Extended Hata
- Earth station antenna characteristics
  - Gain, elevation angle, height
- Out-of-band effects
  - OOBE filtering in mobiles, ACS of MetSat receivers

Propagation – most significant uncertainty

1 dB change in IX changes exclusion by order (1-2 km)

Model parameters

- Inapplicable model choice (e.g. baseline (rural) ITM in suburban area) can increase aggregate interference power by more than 20 dB increasing exclusion distance from 10 km to > 60 km
- Reducing ITM terrain roughness Δh from 90 m to 30 m decreases the path loss by 5 to 10 dB
- For like-to-like comparisons (e.g. Extended Hata and ITM, both with suburban clutter, Δh = 90 m in ITM), differences in path loss are less than 5 dB

Clutter model

- Path loss changes by tens of dB depending on whether rural, suburban, or urban conditions are selected

Location variability

- For the short-term IPC, increasing the s.d. of location variability by 2 dB leads increases aggregate interference power by 6 to 8 dB

Earth station characteristics

Knowable variability from one station to the next – not modeling uncertainty

- While these are fixed and known for a given location, the analysis gives an indication of how sensitive the results are to errors in the assumed parameter values

Increasing the antenna height or gain reduces aggregate interference power

- Height 20 m to 55 m reduce interference by up to 10 dB
- Gain from 30 dBi to 40 dBi reduces interference by 2.5 dB

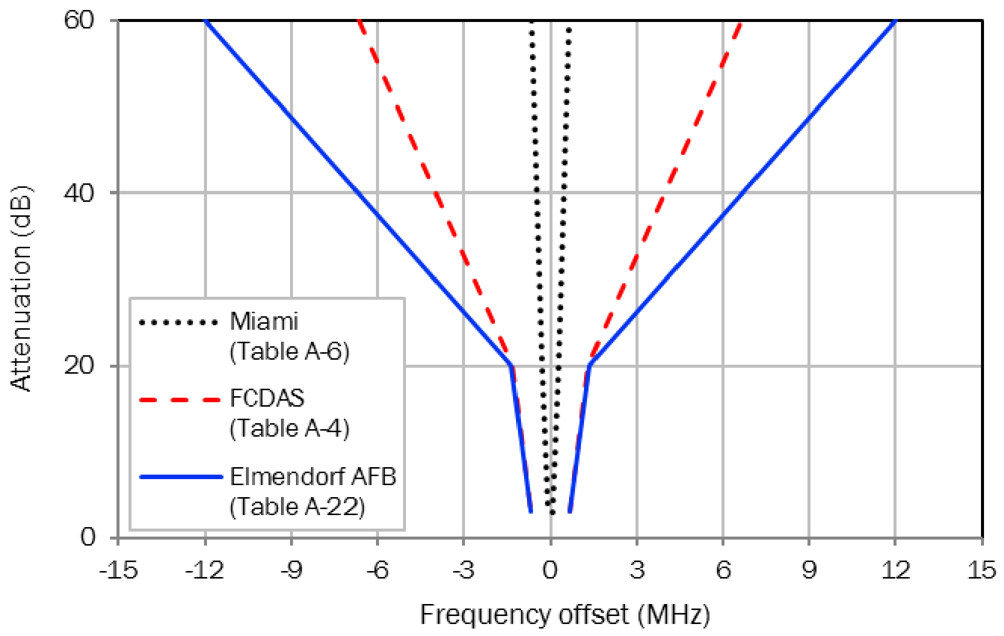
Out-of-band effects

LTE transmitter (~ Adjacent Channel Leakage Ratio)

- Baseline: ACLR uniformly distributed between 30 and 40 dB
- Sensitivity: all emitters to have 30 dB, or all have 40 dB ACLR
- → either leads to change of 3–5 dB in the aggregate interference power

MetSat receiver (~ Adjacent Channel Selectivity)

- Baseline: relatively wide ACS mask of Elmendorf AFB in Anchorage
- Narrower mask of FCDAS in Fairbanks → 10 dB decrease in interference power (@ 10 km exclusion)



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Lots of parameters

Any darn fool can make something complex;
it takes a genius to make something simple.

– Pete Seeger

2. Very high-dimensional parameter spaces

Lots of parameters

- **Link**, e.g. frequency, weather, path length, …
- **Device specs** e.g. transmit power, antenna pattern, ACLR, ACS, …
- **Deployment**: location types, device density, topology, …
- **Business**: who deploys what, when
- **Operation**: channelization, duty cycle, # active devices, …
- **Consequence metrics**: aggregate inference (absolute or ratios); throughput (Tp) or degradation of througput (DTp), mean %DTp, percentile %DTp; mission/business metrics

Generating results is easy; the challenge is to make sense of, communicate, and act on them

Responses

Pick one case

- Often worst case, unlikely to be socially optimal

Boil answers down to a single (binary ;-) number

- The world isn't like this

Scenario planning

- Often generates 70–80 key factors
- Package results as 3–5 alternate futures
- Policy should ideally be robust across scenarios

Policy gaming

- Build interactive models for decision makers

Known unknowns

There are no facts about the future

– David Hulett

3. Epistemic uncertainty

Examples

- Device characteristics
  - e.g. depend on technology, could be different in future
- Deployment
  - e.g. geo density of LTE handsets
- Unforeseen use cases
  - e.g. drones in AWS-3

Many semi-equivalent distinctions

- Aleatory variability (frequentist) vs. epistemic uncertainty (Bayesian)
- Risk vs. uncertainty (Frank Knight)
- Ergodic vs. non-ergodic
- Stationary vs. non-stationary

Responses

Guess first, fix later

- Hard to change once interests have vested
- Policy is a "wicked problem"; decisions can't be unwound

Risk management as well as risk assessment

- On-going rules maintenance based on modeling and experience

Bayesian Belief Networks to model causal relationships

- Given current knowledge, calculate probability of specified outcomes

Humility

Bugs

There are two ways to write error-free programs; only the third one works

– Alan Jay Perlis

4. Mistakes and errors

As more modeling is used in spectrum management, there will be more mistakes

- MetSat example, TAC → IEEE paper: found error in antenna pattern

Responses

Revert to back-of-the-envelope calculations

- But: a reasoned, wrong answer is still better than a WAG

Insist on reproducibility

- “Show Your Work”
- Disclose assumptions, data, methods, code
- Disclose interests

When modeling leads to rules, what happens when errors are discovered?

- What if there were errors in CSMAC analysis that set MetSat protection zone distances?

Responses

Live with it

- But if a wrong answer is OK, why struggle to get a right answer?

Let the market fix it

- Needs clear-enough initial rights assignment, and liquid market

Revise rules

- Ad hoc change, or sunsets
- “Dynamic” rules

Wrap-up

Too soon old, too late smart

Themes

Risk-informed interference assessment works

- Required tools/techniques widely used, just requires a different mixture for RIIA
- Can be applied to real-world spectrum cases: MetSat/LTE, LTE/Wi-Fi, inter-satellite
- Yields useful insights

Limits of statistical modeling; responses?

- Pick one case, report results as yes/no
- Plan for surprise
- Scenario planning, Bayesian Belief Networks, …
- Fix it later
- etc.

Questions

How to communicate results of high-dimensional spaces so information is actionable?

- Pick one case, scenario planning, policy gaming, …?

How to handle model sensitivity order(10 dB)?

- Worst case, design margin, …?

How to deal with epistemic uncertainty?

- Bayesian Belief Networks, ex post rather than ex ante, plan for surprise, …?

How to respond *post hoc* to material modeling errors ?

- Give up modeling, require reproducibility, ongoing risk management , …?
- Live with the outcome, let the market adjust, revise rules, dynamic rules, …?

Backup

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MetSat/LTE Sensitivity Analysis Results

Propagation

Antenna

Parameter / Value	Co-channel exclusion distance (km): From IPC	Co-channel exclusion distance (km): Match OOBE+ABI
Baseline analysis	10	2
Propagation model and clutter (baseline: Extended Hata, suburban)		
Extended Hata, urban	5	<1
ITM, Dh = 10 m, rural, base ITM case	60	10
ITM, Dh = 30 m, rural, base ITM case	67	11
ITM, Dh = 30 m, suburban, 15 dB correction	39	8
ITM, Dh = 30 m, urban, 27 dB correction	18	3
ITM, Dh = 90 m rural, base ITM case	65	11
ITM, Dh = 90 m, suburban, 15 dB correction	27	5
ITM, Dh = 90 m, urban, 27 dB correction	11	<1
Location variability (baseline: 8 dB)		
6 dB	6	2
10 dB	18	4
12 dB	29	7
Antenna height (baseline: 20 meters)		
15 meters	8	2
35 meters	16	4
55 meters	22	7
Antenna gain / short-term protection limit (baseline: 30 dBi / -114 dBm)		
40 dBi / -105 dBm	4	2
Antenna elevation (baseline: 13 degrees)		
20 degrees	8	2

Note: sensitivity analysis did not change the basic conclusions (i.e. short-term IPC is the binding constraint; adjacent channel interference is much higher than co-channel)

Corrections to ITM for “urban” areas

Table 2. Urban Factor: A(Okumura)-A(Longley-Rice) dB

	Frequency							
d km	100	150	200	300	500	1000	2000	3000 MHz
10	16.2	17.4	20.6	22.9	26.6			
20	13.4	15.9	18.2	20.6	24.1	29.4	36.3	
30	11.5	14.3	16.4	19.1	22.7	27.4	34.0	38.3
40	10.9	13.4	15.3	17.9	21.5	26.0	31.9	35.7
50	10.0	12.8	14.8	17.5	20.7	25.3	30.7	34.2
60	9.3	12.1	13.5	16.4	19.4	24.0	29.1	32.2
70	8.6	11.2	12.8	15.3	18.2	22.5	26.2	28.8
80	8.0	10.6	12.0	14.2	16.4	20.0	22.7	24.3
90	7.3	9.4	10.7	12.0	13.8	16.9	18.5	19.4
100	6.5	7.7	8.3	10.0	11.2	13.5	14.1	15.2

$h_1 = 200$ m, $h_2 = 3$ m

A. G. Longley, "Radio propagation in urban areas,“ OT Report 78-144, Mar. 1978.

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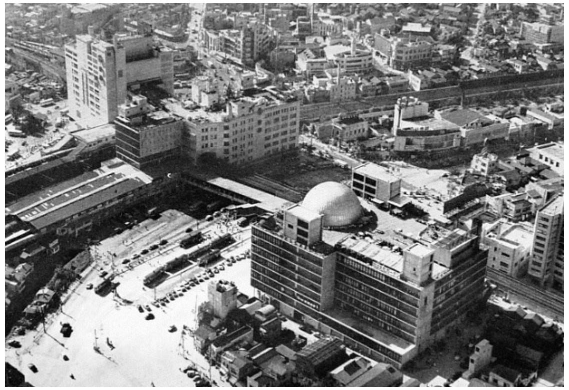
Beware terminology – what's "urban"?

Okumura's measurements were performed in 1963 and 1965 in Japan

Therefore, "urban" clutter as measured by Okumura (1968) and as defined in the Extended Hata model is likely to represent propagation in present-day suburbia—not today's big cities

→ propagation in today's suburbs should be modeled as urban, not suburban, in terms of the Okumura-Hata model family

Yurakucho, Tokyo, ca. 1960



Shibuya, Tokyo, ca. 1960

Seattle, WA, ca. 2015

Kirkland, WA, ca. 2015

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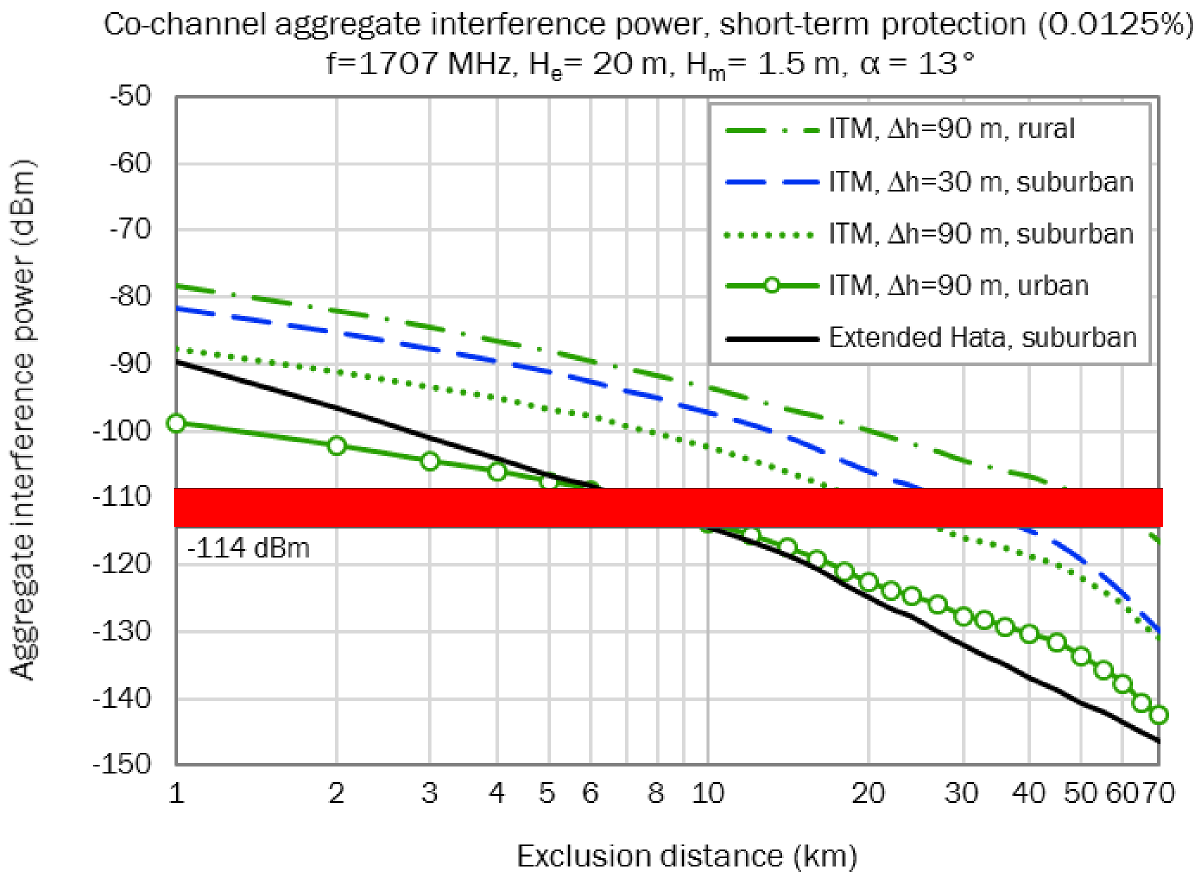
Propagation model parameters

Propagation model parameters can change exclusion distances dramatically

Terrain roughness Δh:
~ 90 m for average terrain,
~ 30 m for flat plains

ITM urban correction factors over rural follow Longley (1978):
Suburban 15 dB
Urban 27 dB



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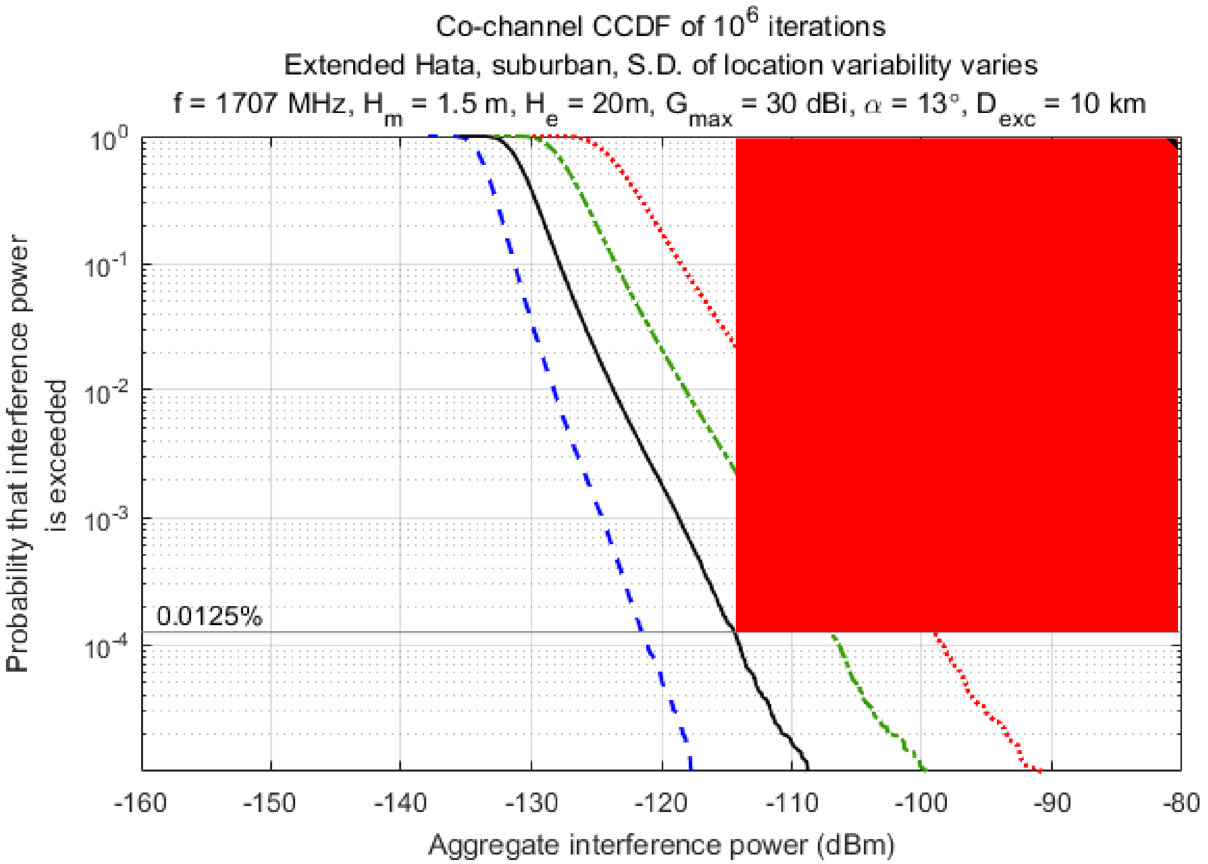
Location variability

Co-channel interference exceedance probability, short-term protection scenario, based on the Extended Hata suburban model with different values for the standard deviation of the location variability

The statistics of path loss, as well as the median value, must be considered in any interference analysis

As the exceedance probability decreases, the curves move farther apart → more sensitive to parameter choice at extreme values



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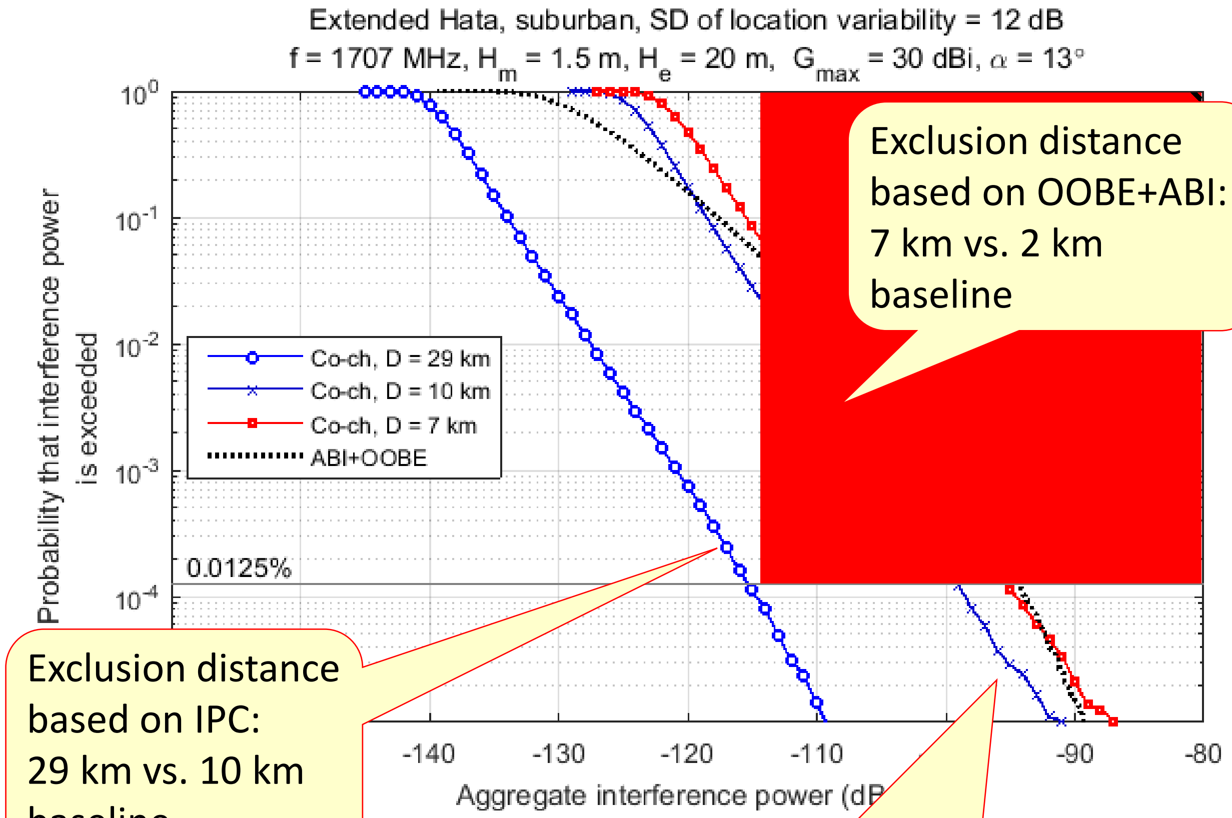
Location variability impact

Increasing s.d. of location variability from 8 dB baseline to 12 dB increases exclusion distance from 10 km to 29 km

Exclusion based on equalizing co-channel with OOBE+ABI increases from 2 km to 7 km

If 10 km exclusion had been chosen, aggregate interference would be 15 dB above the IPC

12 dB loc'n v'bility (baseline 8 dB)



Exclusion distance based on OOBE+ABI: 7 km vs. 2 km baseline

Exclusion distance based on IPC: 29 km vs. 10 km baseline

Co-channel at 10 km: -99 dBm
Δ = +15 dB from -114 dBm baseline

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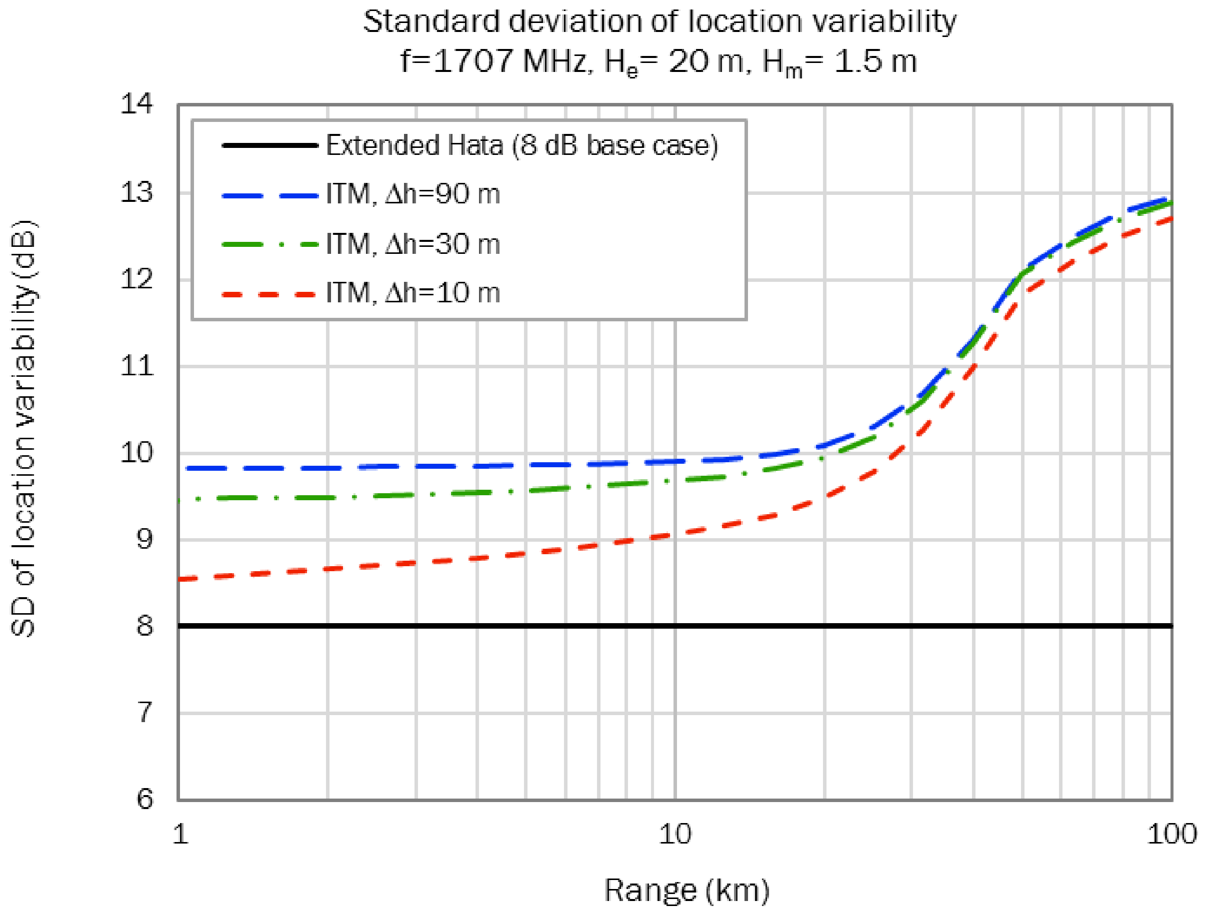
Standard deviation of location variability for ITM and Extended Hata



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Measures that would support good RIIA

Statistical protection criteria (signal level + probability) assist risk assessment

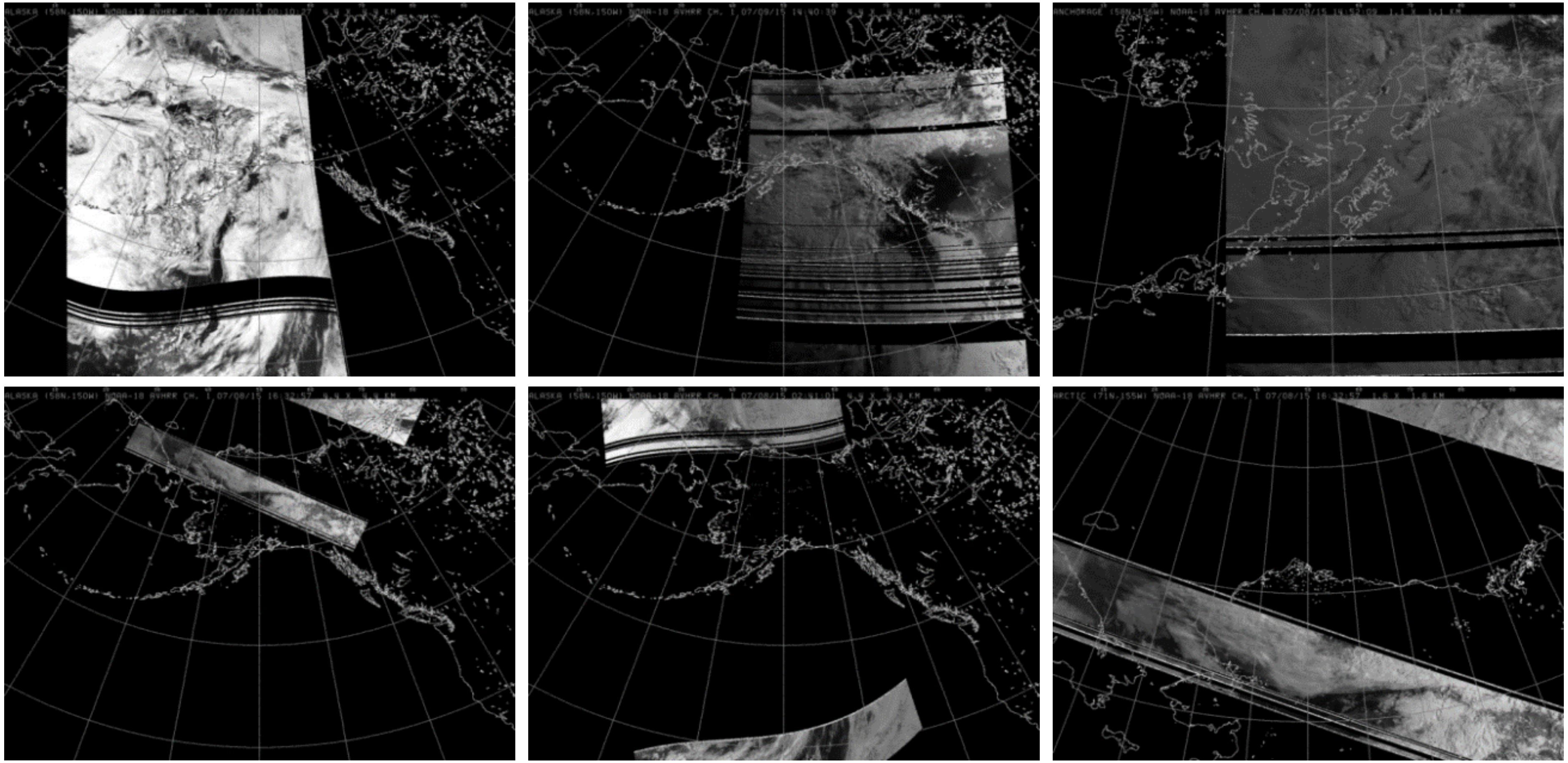
Better documentation of baseline performance data, assumptions/basis of recommendations

- Encourage (incentivize) services seeking protection to disclose baseline system performance information
- Encourage parties (petitioners and standards orgs) to disclose methods underlying interference criteria and coexistence assessments

Complement RIIA with economics, e.g.

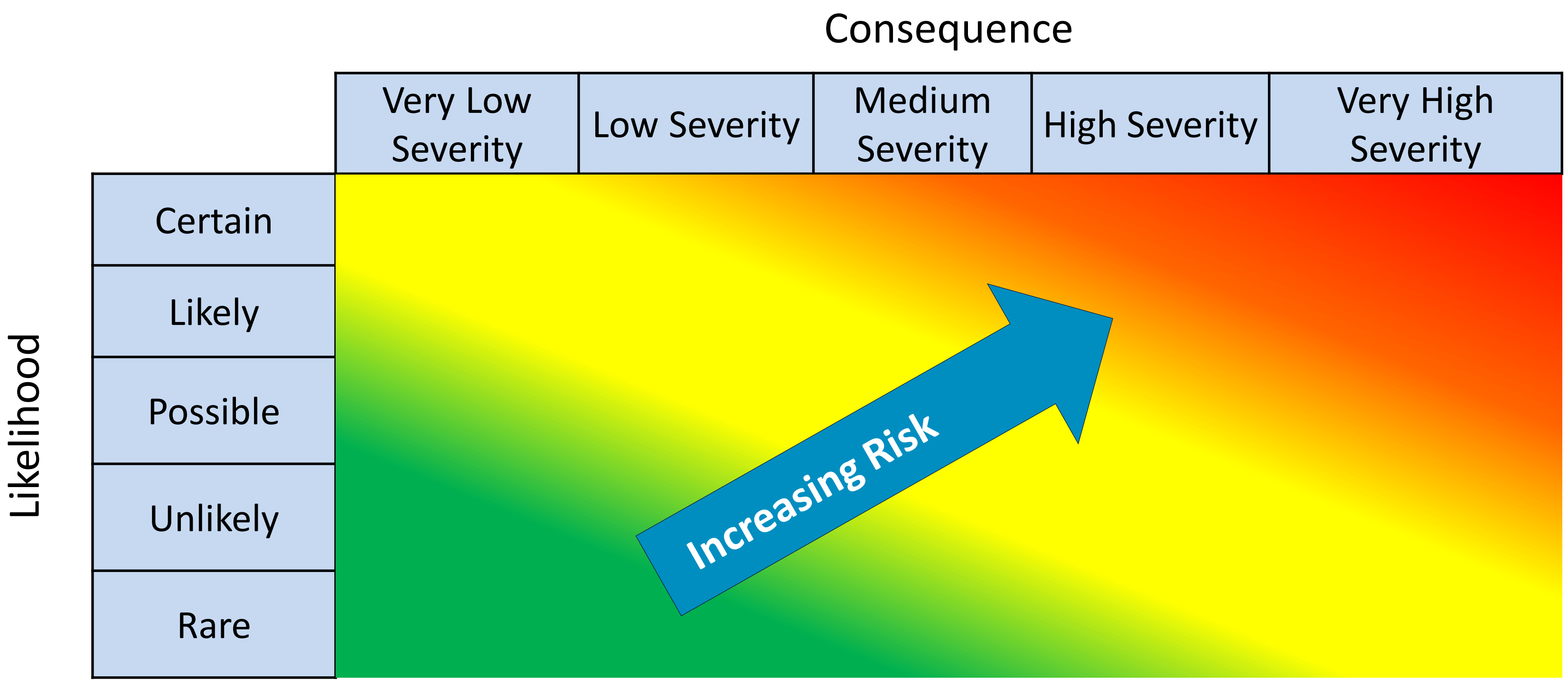
- Cost-benefit analysis
- Impact assessments

Baseline MetSat risk undocumented – but substantial



About 10% of images from NOAA in Juneau Alaska were like this in June 2015, *before* re-allocation

Engineering risk assessment: A well-trodden path



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Worst case

1. One hazard
2. Most severe consequence
3. Ignore probability

Time	Conditions	Temp.	Feels Like	Precip	Amount
3:00 pm	Showers	52 °F	50 °F	80%	0.01 in
4:00 pm	Showers	51 °F	50 °F	54%	0.01 in

A model should yield answers we believe to questions that matter

– Paul Romer