

# Whitespace Evaluation Software (WEST) and its applications to whitespace in Canada and Australia


Kate Harrison, Vidya Muthukumar, and Anant Sahai  
UC Berkeley

# Whitespaces are gaining momentum

<b>Federal Communications Commission</b>		<b>FCC 14-30</b>
<b>Before the Federal Communications Commission Washington, D.C. 20554</b>		
In the Matter of	)	
	)	
Revision of Part 15 of the Commission's Rules to	)	ET Docket No. 13-49
Permit Unlicensed National Information	)	
Infrastructure (U-NII) Devices in the 5 GHz Band	)	
	)	
<b>FIRST REPORT AND ORDER</b>		
<b>Adopted: March 31, 2014</b>	<b>Released: April 1, 2014</b>	

US 5 GHz NPRM  
April 2014

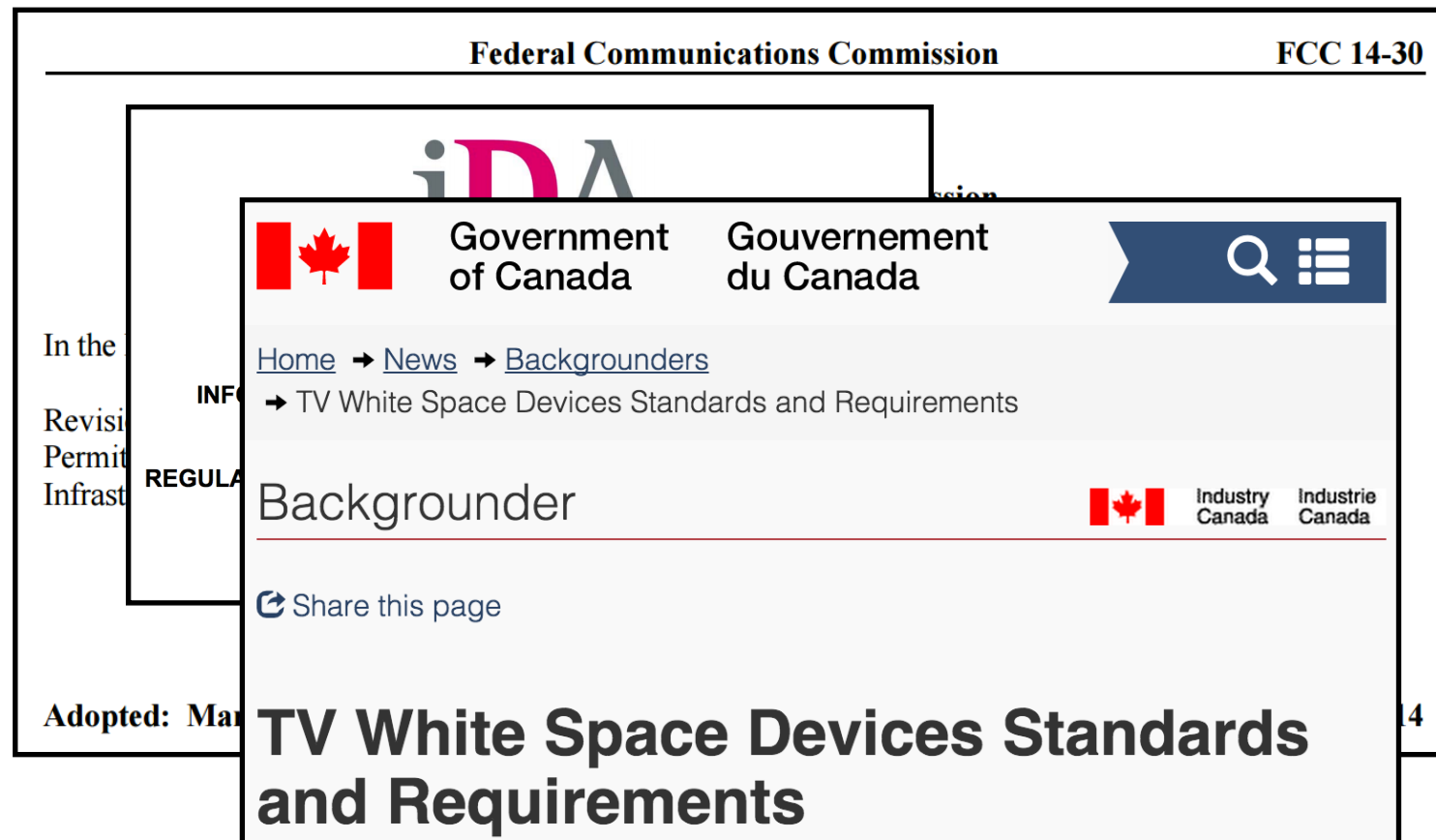
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Federal Communications Commission		FCC 14-30
In the Revisi Permit Infrast		ssion
	DECISION PAPER ISSUED BY THE INFO-COMMUNICATIONS DEVELOPMENT AUTHORITY OF SINGAPORE	ket No. 13-49
	REGULATORY FRAMEWORK FOR TV WHITE SPACE OPERATIONS IN THE VHF/UHF BANDS	
	16 June 2014	
FIRST REPORT AND ORDER		
Adopted: March 31, 2014		Released: April 1, 2014

US 5 GHz NPRM  
April 2014

Singapore TVWS  
June 2014

# Whitespaces are gaining momentum



US 5 GHz NPRM  
April 2014

Singapore TVWS  
June 2014

Canada TVWS  
February 2015

# Whitespaces are gaining momentum

The collage features three overlapping document covers:

- Top Cover (FCC 14-30):** Federal Communications Commission. It includes the iDA logo and the text "In the Matter of".
- Middle Cover:** Government of Canada / Gouvernement du Canada. It features the Canadian flag and a search icon.
- Bottom Cover (FCC 15-47):** Federal Communications Commission. It is titled "Before the Federal Communications Commission Washington, D.C. 20554". The text reads: "In the Matter of", "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band", "GN Docket No. 12-354", "REPORT AND ORDER AND SECOND FURTHER NOTICE OF PROPOSED RULEMAKING", "Adopted: April 17, 2015", and "Released: April 21, 2015".

US 5 GHz NPRM  
April 2014

Singapore TVWS  
June 2014

Canada TVWS  
February 2015

US 3.5 GHz  
April 2015

# Whitespaces are gaining momentum

The image shows a stack of four overlapping Federal Communications Commission (FCC) document covers, illustrating the progression of white space regulations. The covers are for FCC 14-30, FCC 15-47, FCC 15-99, and a final report and order from August 2015.

**Federal Communications Commission FCC 14-30**

**Government of Canada / Gouvernement du Canada**

**Federal Communications Commission FCC 15-47**

**Federal Communications Commission FCC 15-99**

**Before the Federal Communications Commission Washington, D.C. 20554**

**Adopted: March 16, 2015**

**TV and**

**REF**

**Adop**

In the Matter of )  
)  
Amendment of Part 15 of the Commission's Rules ) ET Docket No. 14-165  
for Unlicensed Operations in the Television Bands, )  
Repurposed 600 MHz Band, 600 MHz Guard )  
Bands and Duplex Gap, and Channel 37, and )  
)  
Amendment of Part 74 of the Commission's Rules )  
for Low Power Auxiliary Stations in the )  
Repurposed 600 MHz Band and 600 MHz Duplex )  
Gap )  
)  
Expanding the Economic and Innovation ) GN Docket No. 12-268  
Opportunities of Spectrum Through Incentive )  
Auctions )

**REPORT AND ORDER**

**Adopted: August 6, 2015** **Released: August 11, 2015**

US 5 GHz NPRM  
April 2014

Singapore TVWS  
June 2014

Canada TVWS  
February 2015

US 3.5 GHz  
April 2015

US TVWS rule update  
August 2015

How do we quantify  
whitespaces?

# How do we quantify whitespaces?

## Summary Analysis – White Space in Sample of U.S. Media Markets

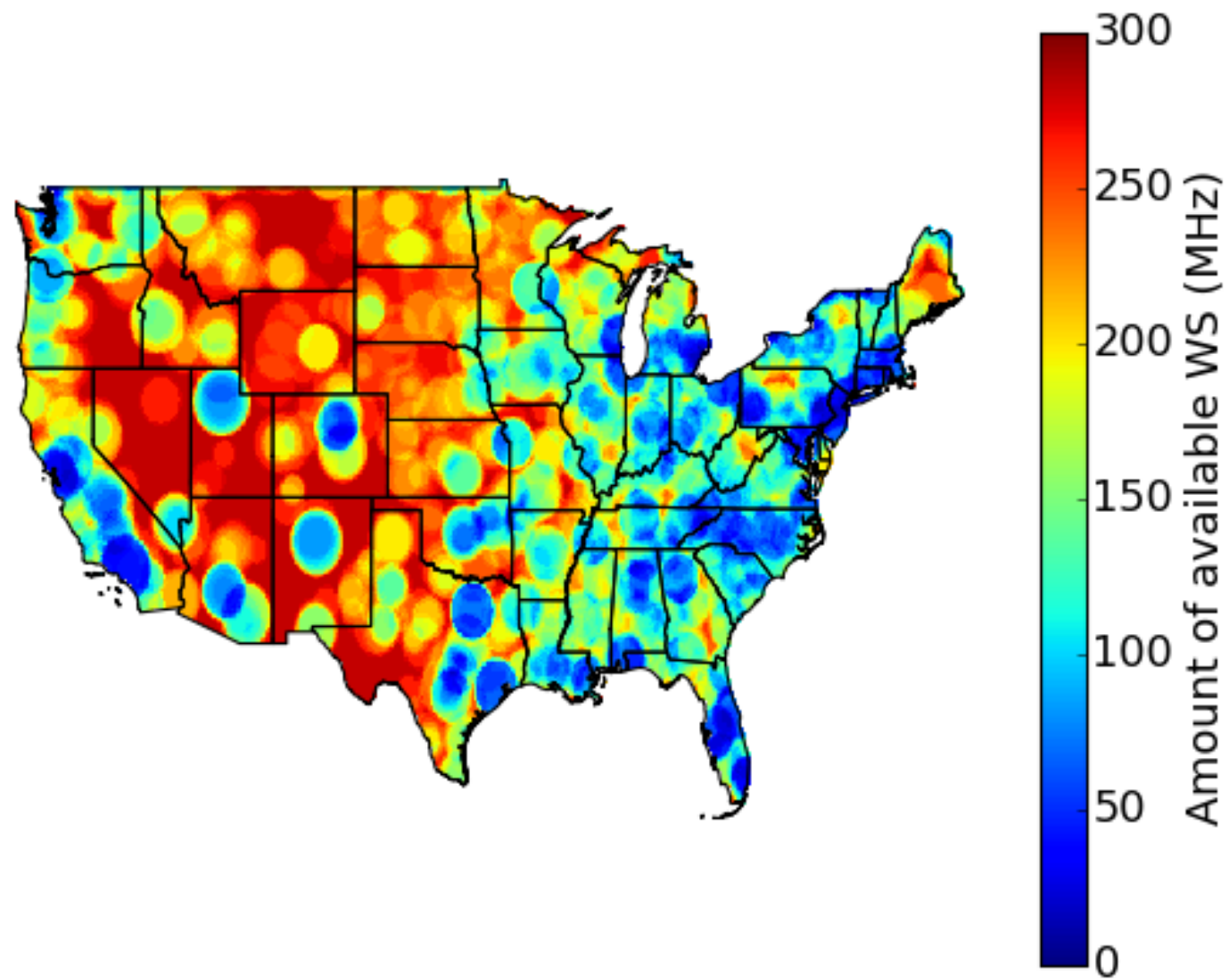
(The full analysis of each market with channel data is available at [www.spectrumpolicy.org](http://www.spectrumpolicy.org).)

Market	No. of Vacant Channels Between Chs. 2-51 After DTV Transition	Percent of TV Band Spectrum Vacant After DTV Transition
Juneau, Alaska	37	74%
Honolulu, Hawaii	31	62%
Phoenix, Arizona	22	44%
Charleston, West Virginia	36	72%
Helena, Montana	31	62%
Boston, Massachusetts	19	38%
Jackson, Mississippi	30	60%
Fargo, North Dakota	41	82%
Dallas-Ft. Worth, Texas	20	40%
San Francisco, California	19	37%
Portland, Maine	33	66%
Tallahassee, Florida	31	62%
Portland, Oregon	29	58%
Seattle, Washington	26	52%
Las Vegas, Nevada	26	52%
Trenton, New Jersey	15	30%
Richmond, Virginia	32	64%
Omaha, Nebraska	26	52%
Manchester, New Hampshire	23	46%
Little Rock, Arkansas	30	60%
Columbia, South Carolina	35	70%
Baton Rouge, Louisiana	22	44%

“Measuring the TV “White Space”  
Available for Unlicensed Wireless  
Broadband”  
(New America Foundation, 2006)



# Whitespace maps



# How do we quantify whitespaces?

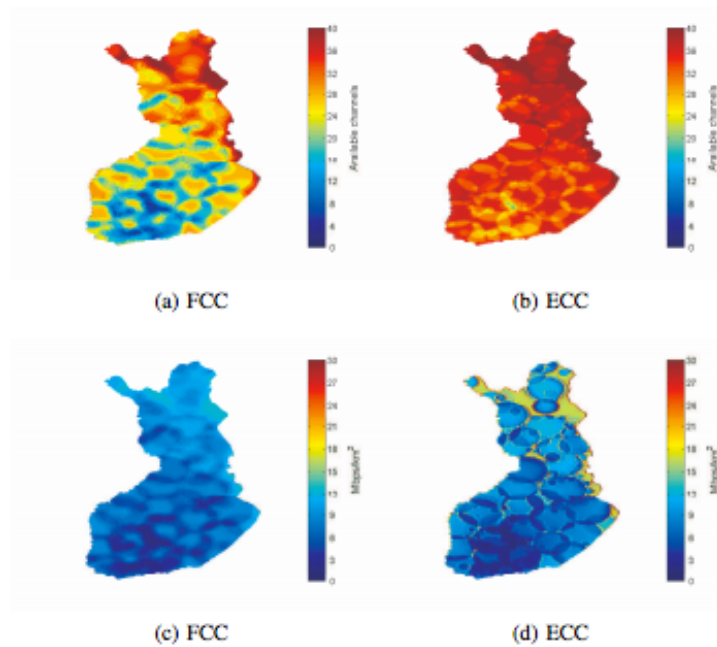


Fig. 1: Spatial distribution of available channels by using (a) FCC (b) ECC rules. Capacity per area for secondary cell size  $d = 2$  km and antenna height  $h = 30$  m calculated based on (c) FCC rules (d) ECC rules. For FCC the protection distance for the co channel is 14.4 km and for the adjacent channel 0.74 km. For ECC the margins are  $MI+SM = 10$  dB, and the outage probability is  $O_n = 10\%$ .

“Aggregate interference with FCC and ECC white space usage rules: case study in Finland” (Jäntti, et al. 2011)

# How do we quantify whitespaces?

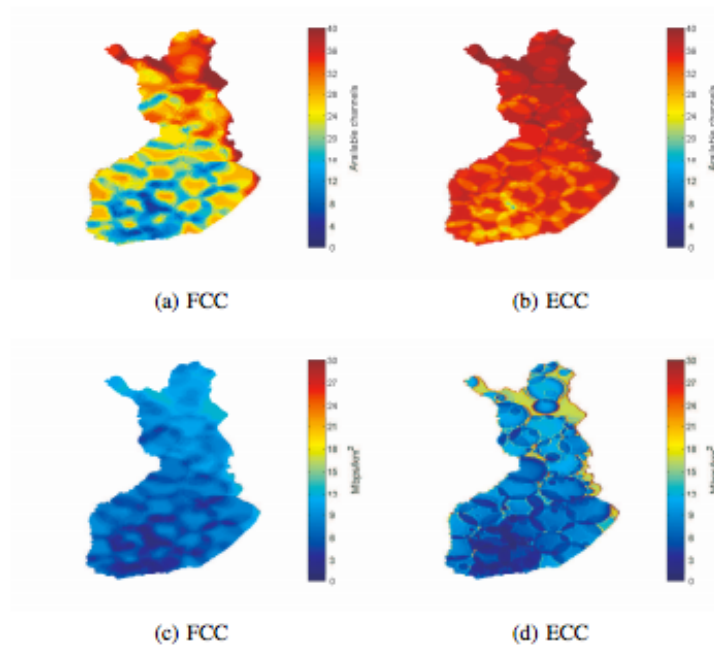


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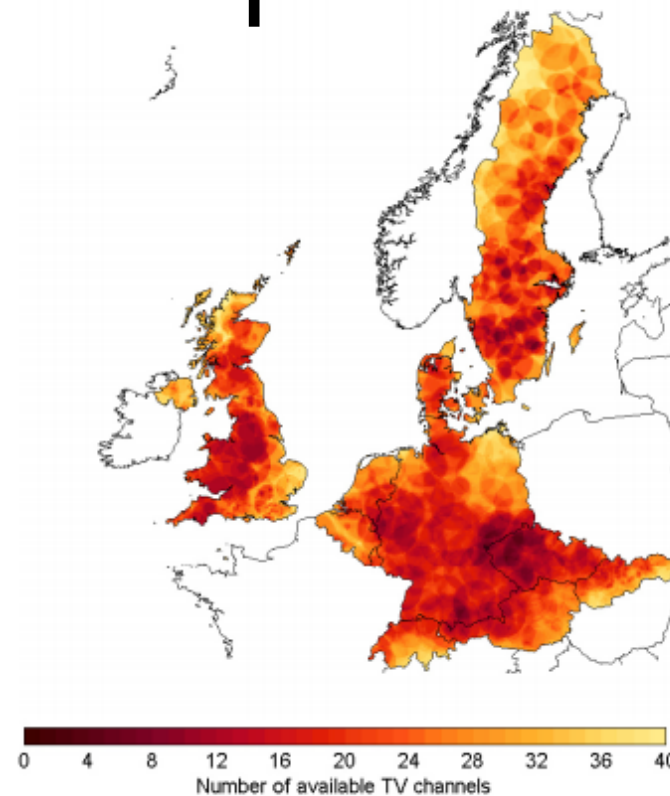


Fig. 2. White space map of  $S(x)$  for 11 European countries.

“UHF white space in Europe — A quantitative study into the potential of the 470–790 MHz band” (Beek, et al. 2011)

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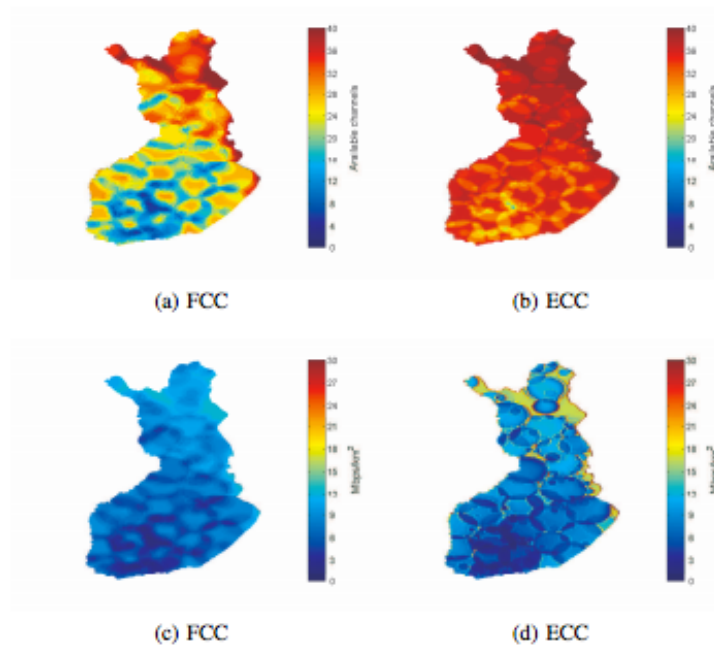


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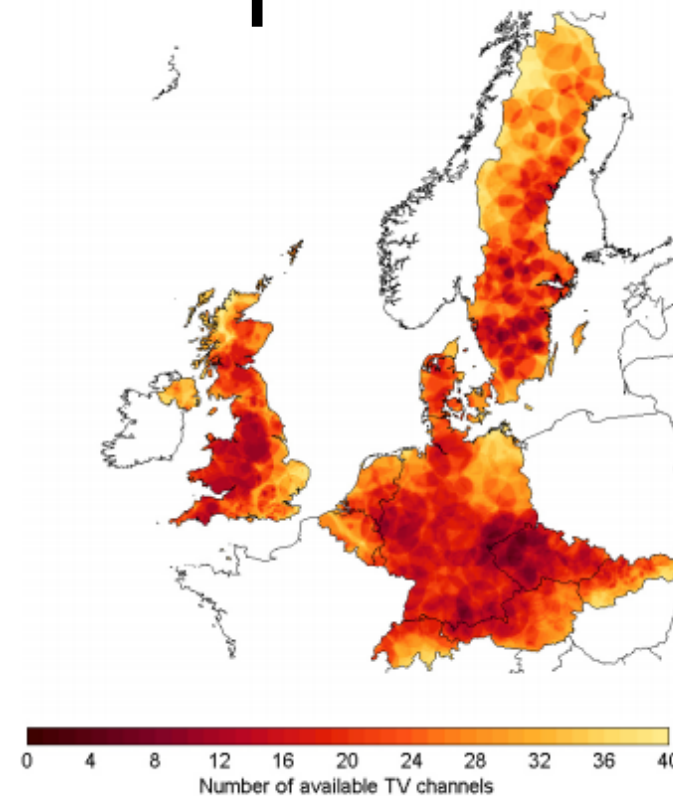
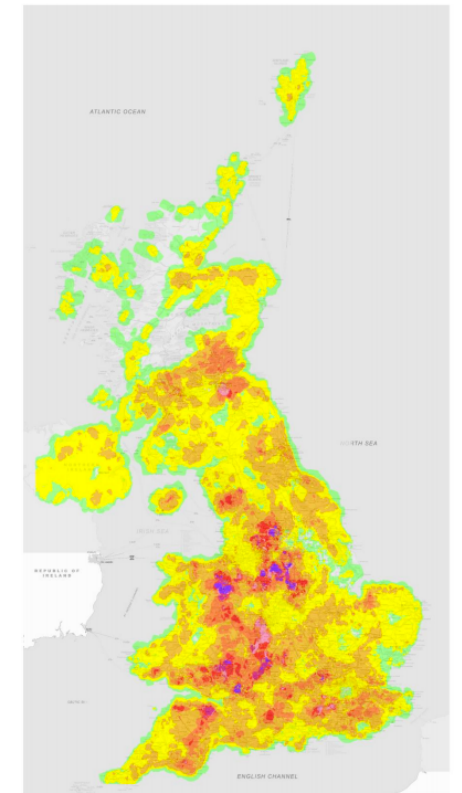


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Ofcom 2013 consultation



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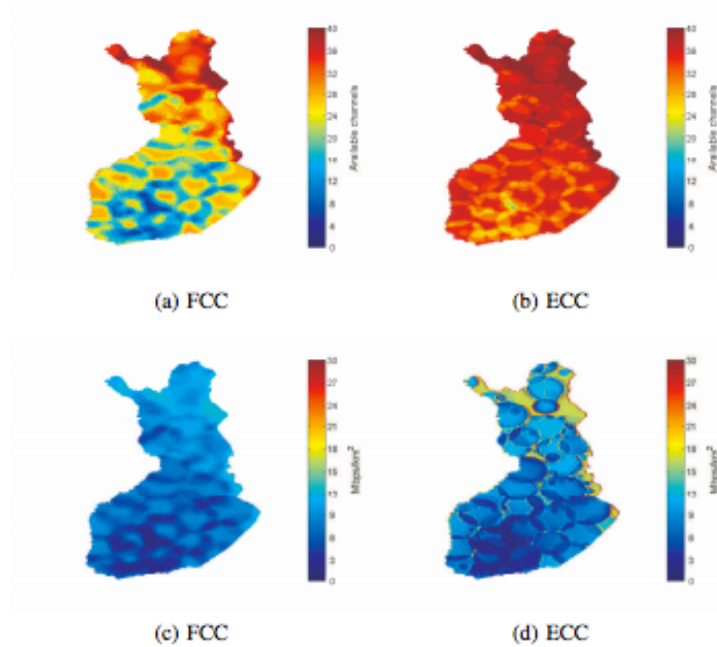


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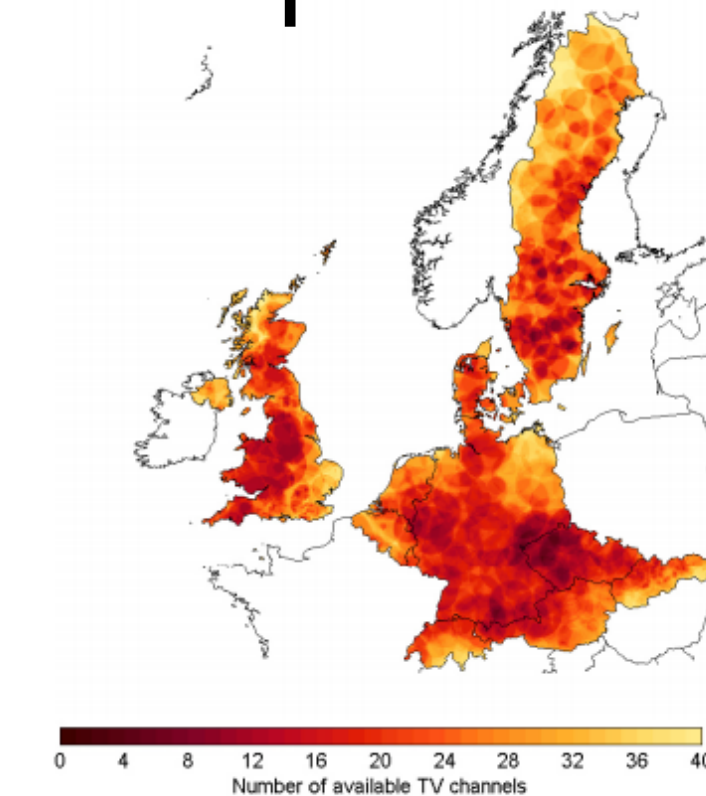
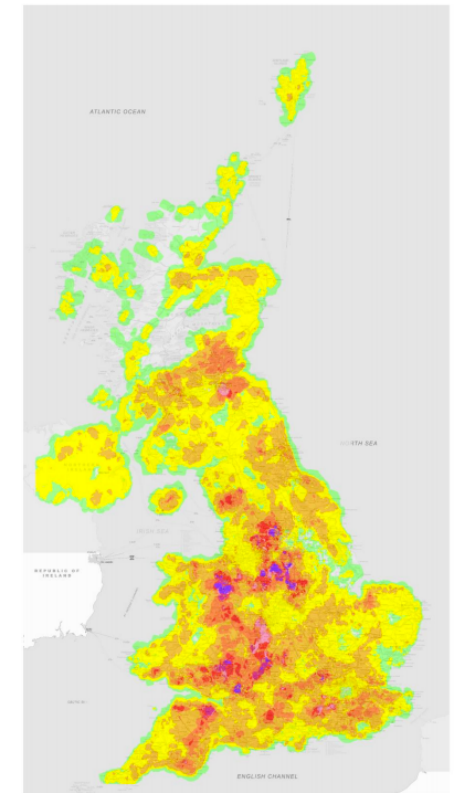


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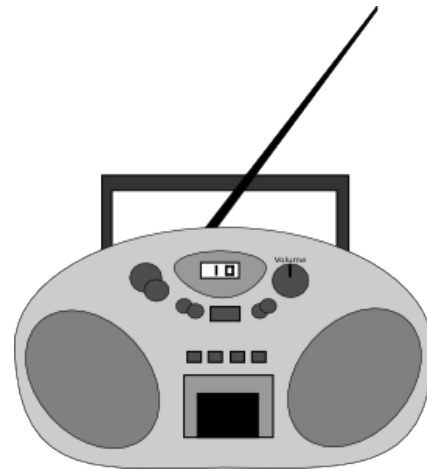
**“Opportunities for white space usage in Australia”  
Freyens and Loney, 2011**

Making it easier to  
quantify whitespaces

# Motivating example



+



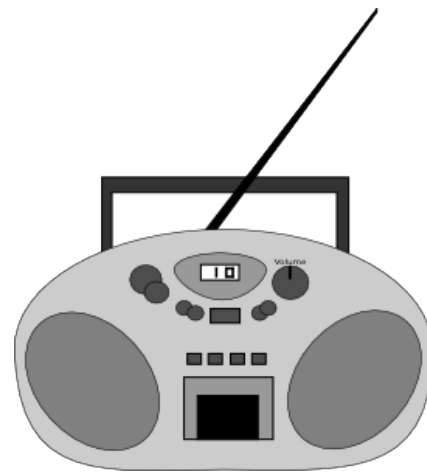
AM/FM whitespace



# Motivating example



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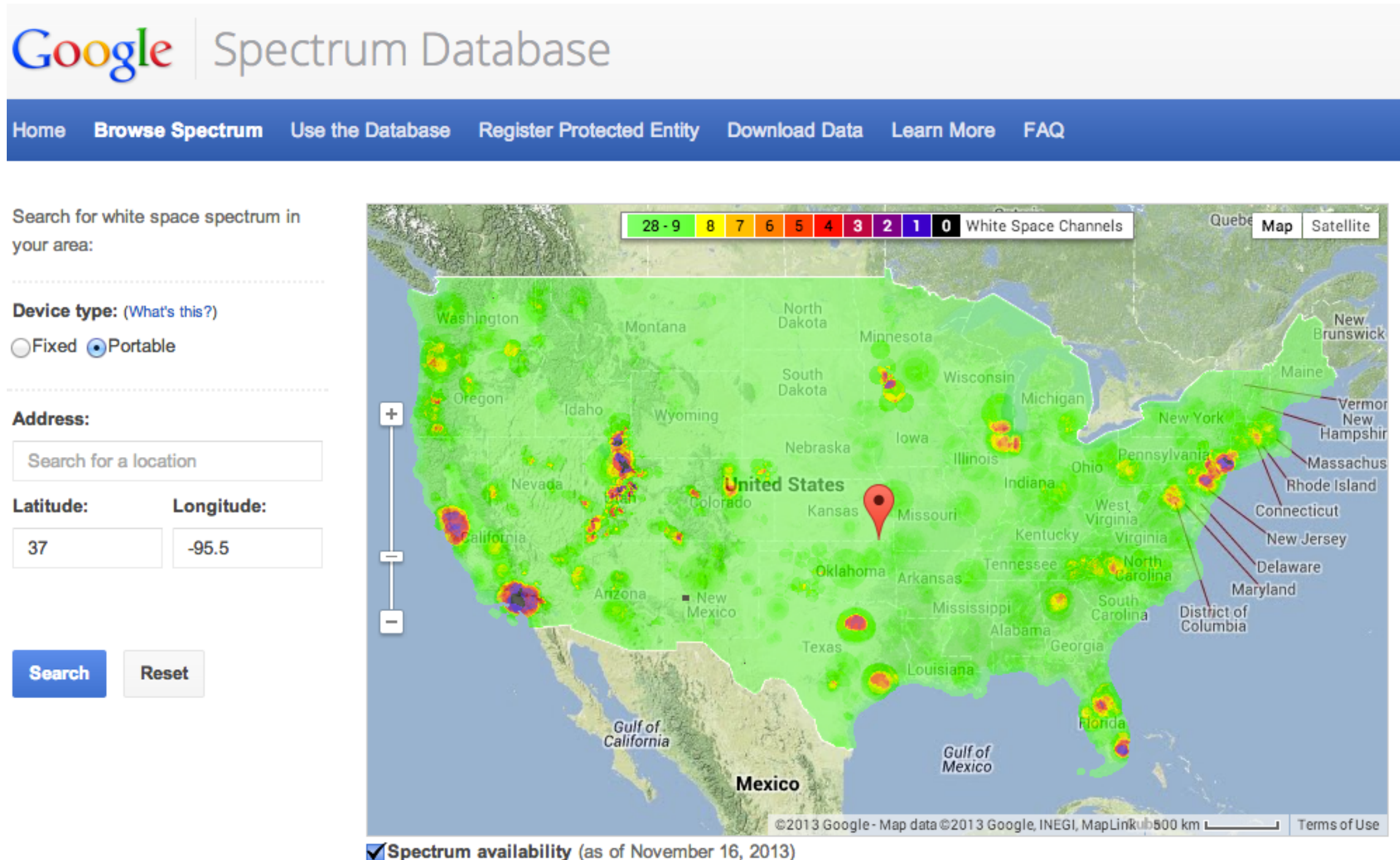
AM/FM whitespace



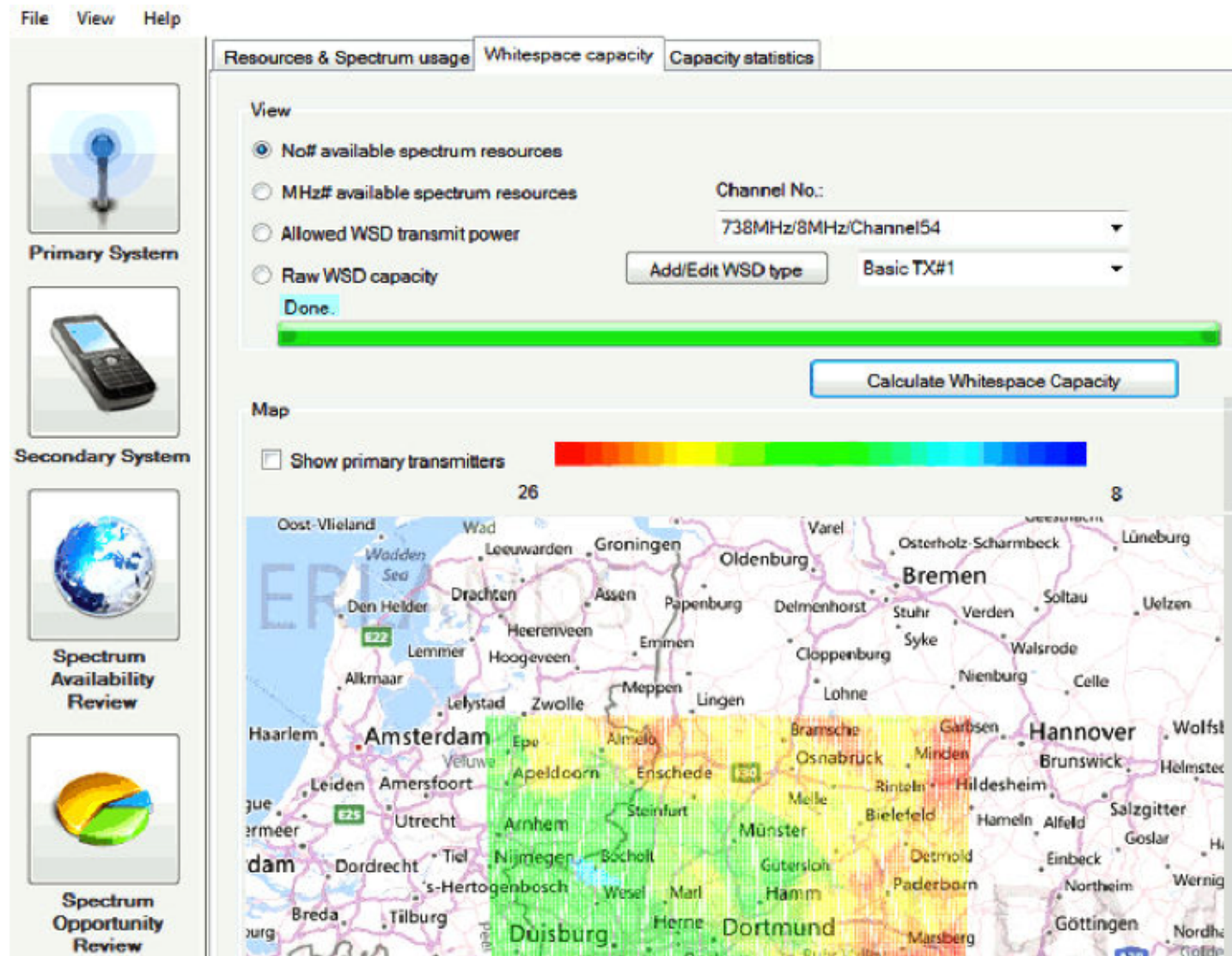
- Easy to use
- Free
- Reliable
- Flexible/extensible



# Existing tools



# Existing tools

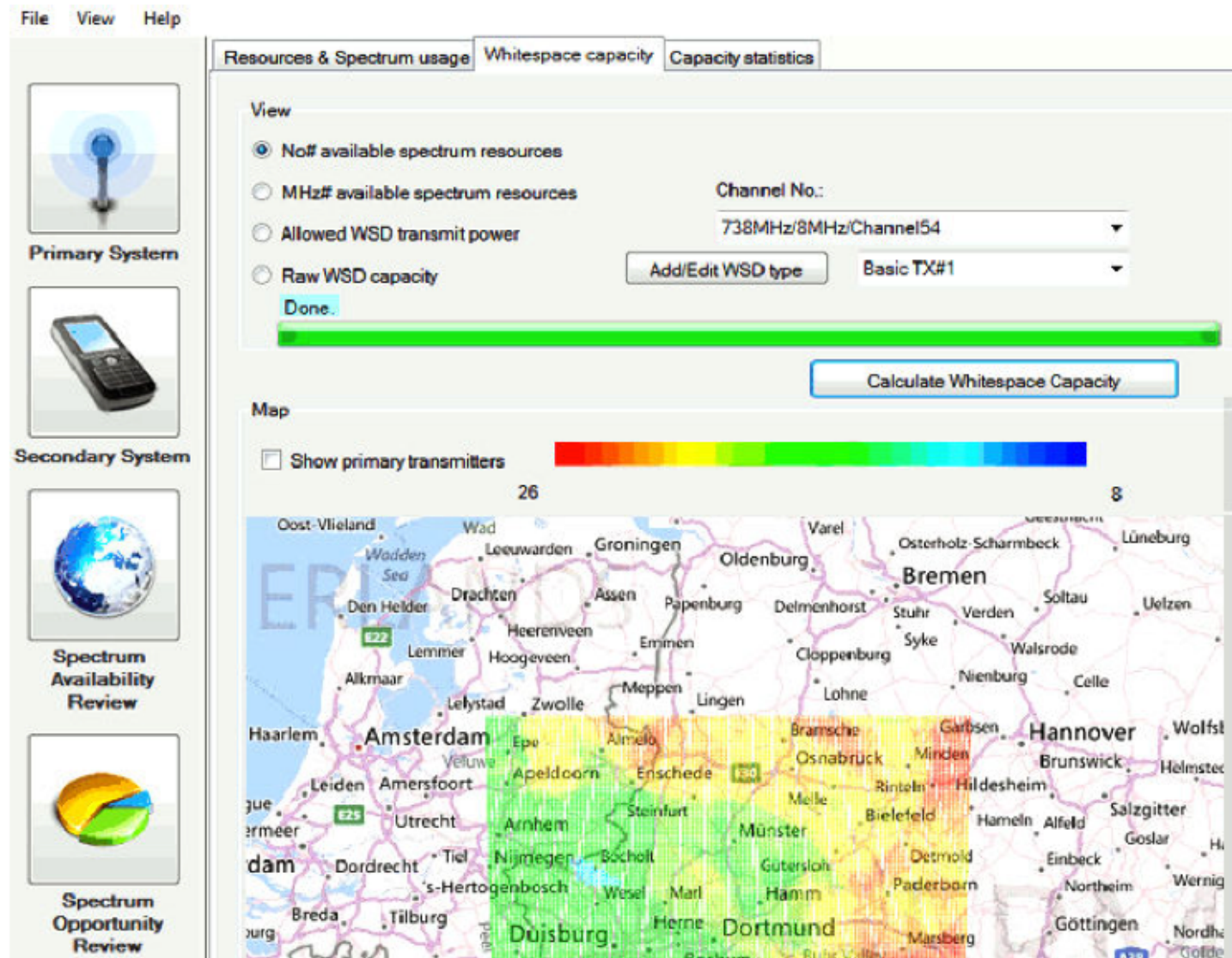


- Many tunable parameters
- Written in Matlab

“Software Tool for Assessing Secondary System Opportunities in Spectrum Whitespaces”  
(WoWMoM 2013)



# Existing tools



- Many tunable parameters
- Written in Matlab
- Not available for public use

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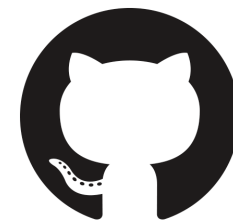
# WEST

(Whitespace Evaluation SofTware)

**Written in...**



**Posted on...**



**GitHub**

[west.kateharrison.net](https://west.kateharrison.net)

# Key features

- Extensible to other bands
- Free, easier to integrate (e.g. AWS)
- Modular, extensible
- Open-source with GPLv2

# The real test

WEST + first year grad student = 2 papers

## Whitespaces after the USA's TV incentive auction: a spectrum reallocation case study

Vidya Muthukumar, Angel Daruna, Vijay Kamble, Kate Harrison, and Anant Sahai  
Wireless Foundations, EECS, UC Berkeley

**Abstract**—Spectrum has traditionally been allocated for single uses and by now most of the “prime” spectrum has well-entrenched incumbent users. When a new service needs spectrum, there are two qualitatively distinct ways of making bandwidth available for it. A swath of incumbent users can be removed from a band, with the cleared band being reallocated for the new service. Alternatively, the new users can be allowed to utilize the interstitial spectrum holes (i.e. whitespaces) between incumbent users, with the requirement to protect the incumbents’ QoS. But these can also be used in combination by partially clearing a band and opening up the rest for whitespace-style sharing. In this case, the ability of regulators to “repack” incumbents, e.g. alter their operating channels, can reduce the need to evict them. An open question has been how whitespaces and partial spectrum clearing interact with each other and the ability to repack incumbents. Do efficient repacks completely eliminate whitespaces?

The USA FCC’s upcoming incentive auction in the TV bands is the first large-scale attempt to repack a major band of spectrum in order to clear spectrum for LTE. This auction is meant to navigate the tradeoff between incumbent TV services and LTE networks. In preparation, the FCC has made a large and complex data set of repacking constraints available for the first time. We have repurposed this data and built our own repacking engine in order to study a more general version of the tradeoff between whitespaces and cleared spectrum.

We conclude that (1) repacking enables clearing of significantly more spectrum than just removing incumbents; (2) the total amount of spectrum available for new uses is relatively insensitive to how incumbents are removed; (3) efficient repackings basically trade whitespace spectrum for cleared spectrum; (4) even the most efficient repackings leave plenty of whitespace — an amount that can be comparable with the amount of cleared spectrum.

### I. INTRODUCTION

TV spectrum has recently become a very popular topic due to its proximity to mobile spectrum as well as the TV whitespaces, which give access to spectrum necessary for economic development. There are many interesting aspects to the field of cognitive radio and whitespaces, such as coexistence techniques, network planning, system architecture, and security and robustness, whose unique challenges have been studied to varying degrees. However, few studies address a very simple question: when is it better to completely reallocate a band vs. to share it?

In fact, there are several different options for making “new” spectrum, as shown in Figure 1:

- 1) *Completely reallocate the band as a single-use band.* Until recently this was the standard way of reallocating

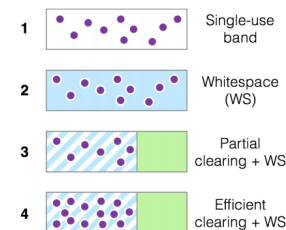


Fig. 1. An illustration of the various options for spectrum repurposing. Incumbents are shown as purple dots while whitespaces are blue and cleared spectrum is green. White represents unused spectrum (in the case of whitespaces, this is a buffer which is necessary to maintain the incumbent’s quality of service). The white and blue hashed pattern represents spectrum that could but need not support whitespace rules.

- 2) *Declare the entire band potential whitespace while preserving the quality-of-service of the incumbents via sharing rules.* This is becoming the de facto way of “generating” new spectrum, especially after the publication of the PCAST report<sup>1</sup> [1]. Whitespace regulations naturally have to navigate a tradeoff between quality-of-service for the incumbent vs. the secondary users. This has been explored in [2]–[4].
- 3) *Partial clearing of the band.* Pristine spectrum is created while a portion of the incumbents remain. The uncleared spectrum may be designated as either single-use spectrum or as whitespace with the incumbents as the primary users. Partial clearing is preferable when it is not possible or desirable to remove all of the incumbents.
- 4) *Efficient partial clearing of the band.* The spirit and use cases are very similar to scenario 3 except that this option maximizes the number of incumbents that remain after a partial clearing. Rather than remove the incumbents which were in the now-cleared spectrum, these incumbents are efficiently packed into the remaining (uncleared) spectrum whenever possible. This approach essentially sacrifices would-be whitespace in order to

<sup>1</sup>This report, submitted as a recommendation to the President of the United States by the President’s Council of Advisors on Science and Technology in 2012, emphasized the need to find at least 100 MHz of spectrum as soon

## Whitespace Evaluation SofTware (WEST) and its applications to whitespace in Canada and Australia

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Wireless Foundations, EECS, UC Berkeley  
{harriska, vidya.muthukumar, sahai}@eecs.berkeley.edu

**Abstract**—Spectrum whitespaces and dynamic spectrum sharing have become important and interesting topics in recent years. The USA authorized the use of TV whitespaces in 2008 and the UK and Canada followed suit in early 2015. In light of the PCAST report of 2012, additional bands are being evaluated for spectrum sharing in the USA and abroad.

With the increasing momentum of spectrum whitespaces, it is more important than ever to understand the consequences of regulatory decisions. For example, what is the effect of increasing the separation distance from 10km to 15km? Regulators need the ability to understand tradeoffs like this so that they can make informed decisions based on *actual*, not hypothetical or supposed, impact.

Despite the clear need, data-driven analyses appear to be quite rare among regulators, industry members, and researchers alike. Although the data is often freely available, employing it can be an onerous task. In order to reduce this barrier, we have created an open-source software package, WEST, that quickly allows a user to estimate the amount of whitespace in a given region.

For example, after collecting the requisite data, we produced estimates of the amount of whitespace in Canada in under an hour. To demonstrate the power of our software, we present novel results on whitespace availability in Canada and Australia. However, the true potential of WEST lies in the ability to configure it to use existing or hypothetical rulesets. We thus use WEST to compare the FCC and Industry Canada (IC) rulesets, showing that each citizen loses approximately one whitespace channel, mainly due to the increased size of IC’s separation distances as compared to the FCC’s. We also showed that although the effect of taboo channel exclusions (a notion introduced in the IC ruleset) is small in Canada, it would be much larger if applied to the USA. The identification of the real-world effects of these regulatory decisions was made possible by WEST’s ability to create “chimera rulesets,” i.e. mosaics of the IC and FCC rules, so that we could examine each variable in isolation.

Finally, we describe the high-level design of WEST. The modular design makes it easy for users to combine, replace, modify, or remove various components to achieve the desired effect. We sincerely hope that the community will use and contribute to WEST, turning it into an even more powerful tool than it is today. If real-world data were at your fingertips and easy to use, what would you do?

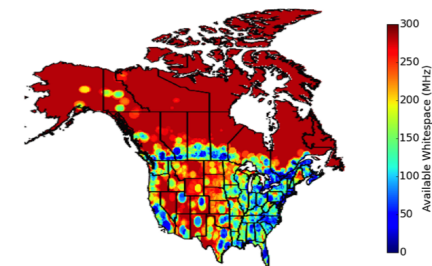


Fig. 1. Map showing the amount of whitespace (in MHz) available to a fixed device in North America under the FCC ruleset.

have shown that a large fraction of allocated spectrum actually lays fallow. Since it is not practical to make sweeping changes to existing allocations and deployments, dynamic spectrum access (DSA) is critical for harnessing this spectrum that is allocated yet unused [4].

The incarnation du jour of DSA is as TV whitespaces, the interstices between over-the-air TV stations. The Federal Communications Commission (FCC) in the USA made use of the whitespaces legal in 2008 [5] (with updates in 2010 [6] and 2012 [7]) and Singapore followed suit in 2014 [8]. Ofcom in the UK [9] and Industry Canada [10] did the same in early 2015. We fully expect that it is simply a matter of time before TV whitespaces around the world are legal to use.

At the same time, other bands are under consideration for spectrum sharing. In the USA, the 3550-3650 MHz and 5350-5470 MHz bands are undergoing sharing investigations [11], [12]. In other countries, GSM whitespaces [13] are already being used (albeit illegally).

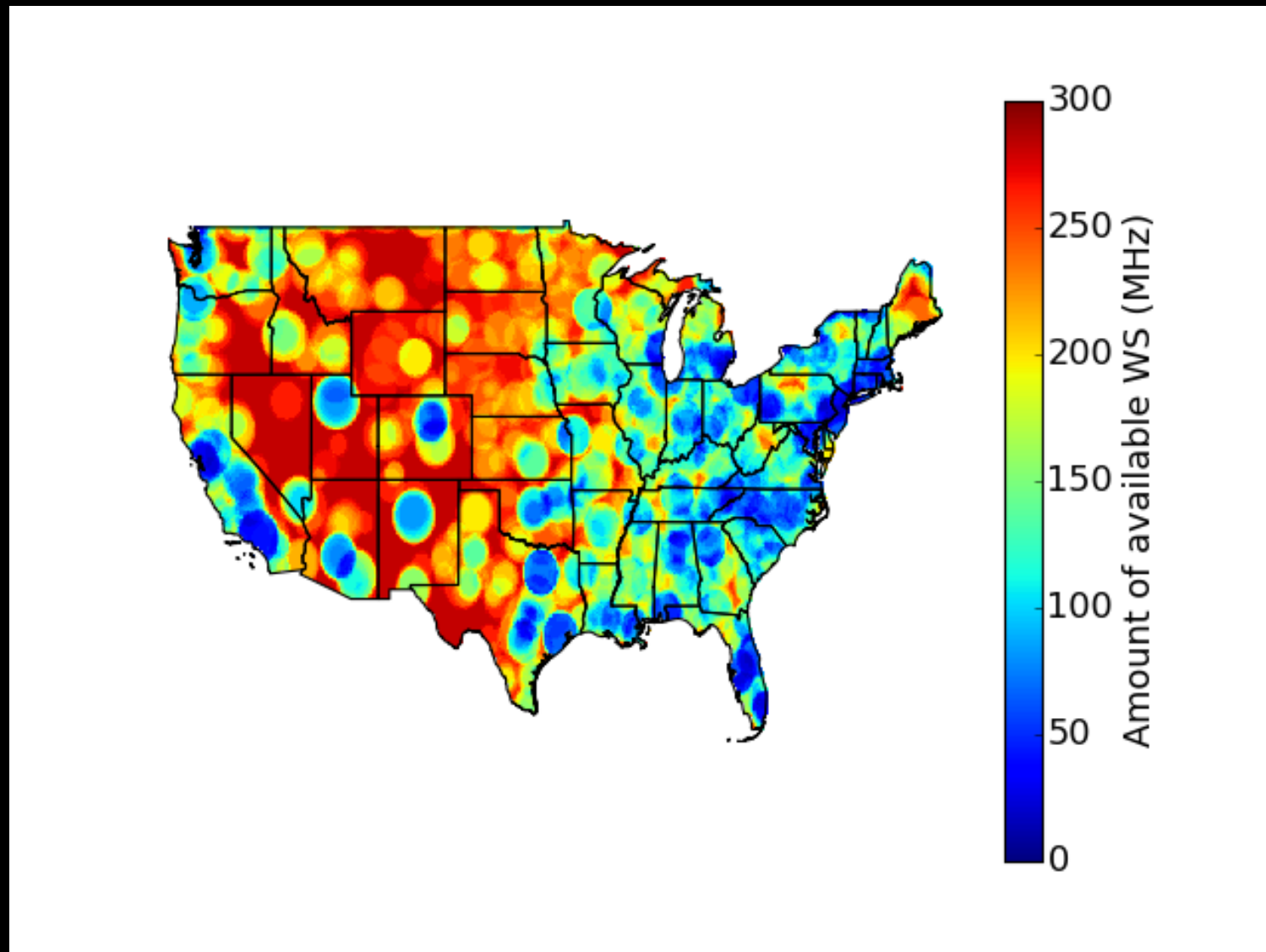
One of the most common questions asked when considering

# Using WEST to study...

- Whitespaces in Canada
- Differences between FCC and Industry Canada ruleset
- Whitespaces in Australia
- Amount of contiguous-channel whitespace



# Existing results: Whitespaces in USA

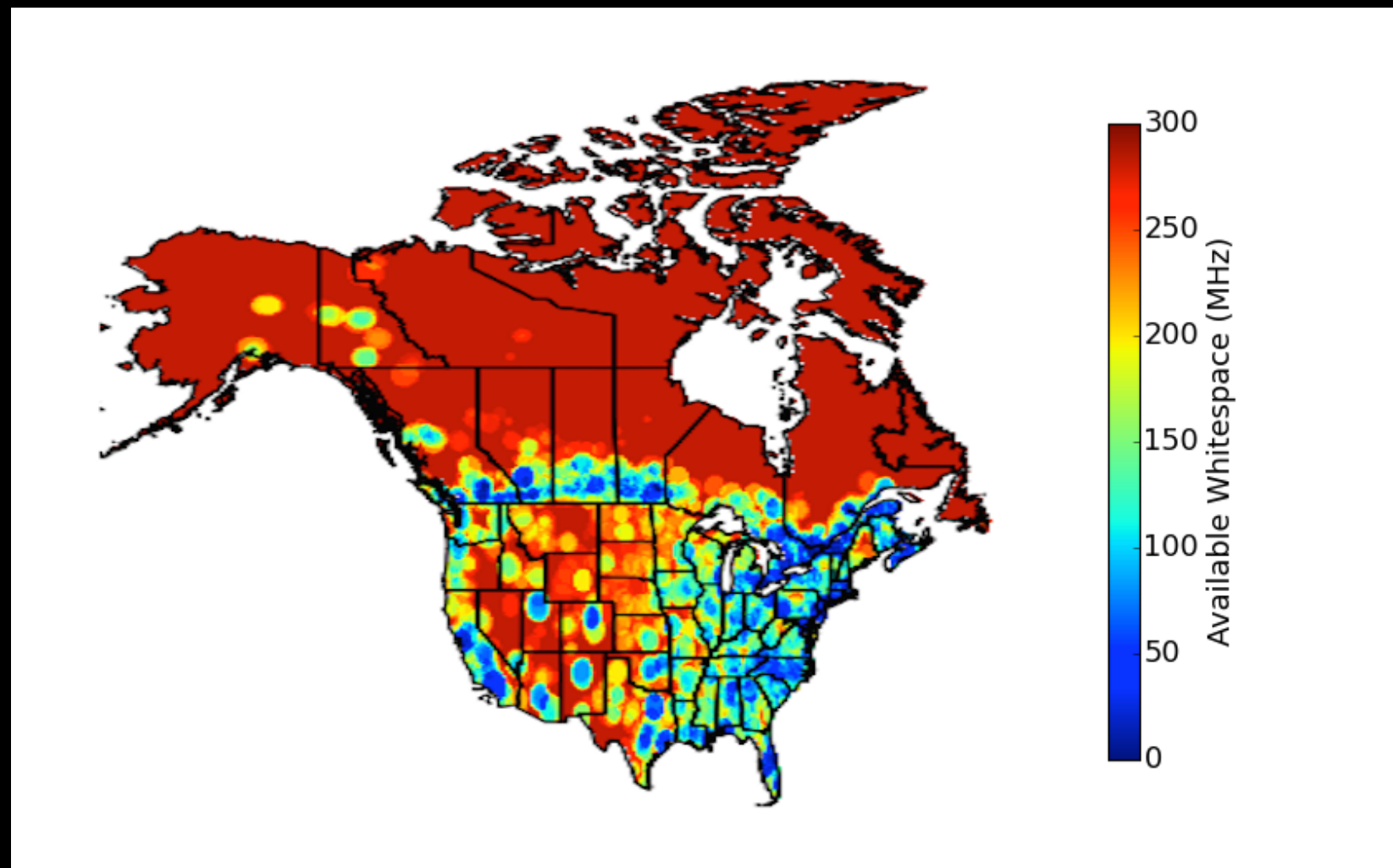


Urban areas — sparse in whitespace  
Rural areas — abundant in whitespace



# Applications of WEST:

## Whitespaces in Canada (under the FCC ruleset)

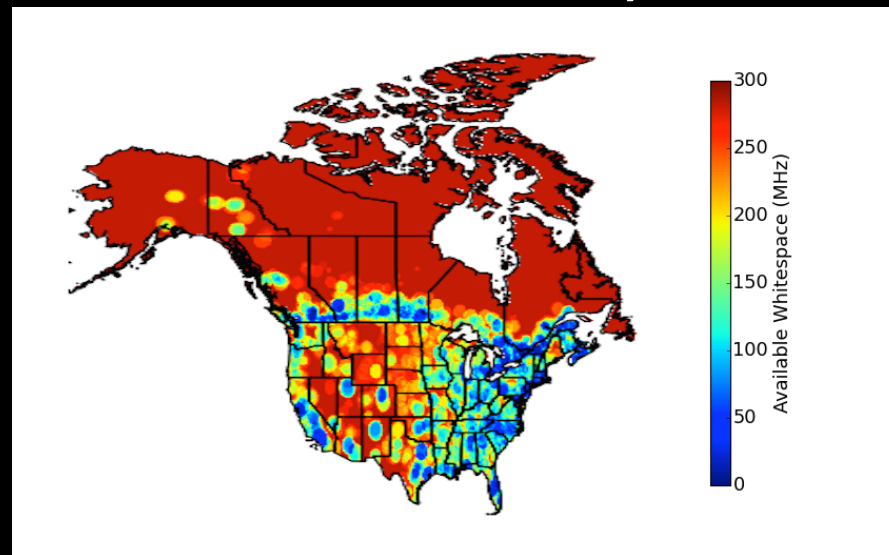


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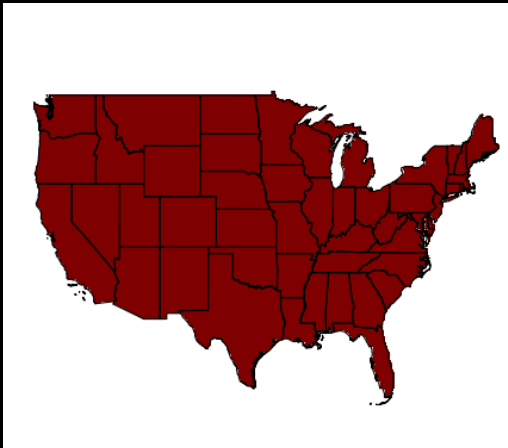
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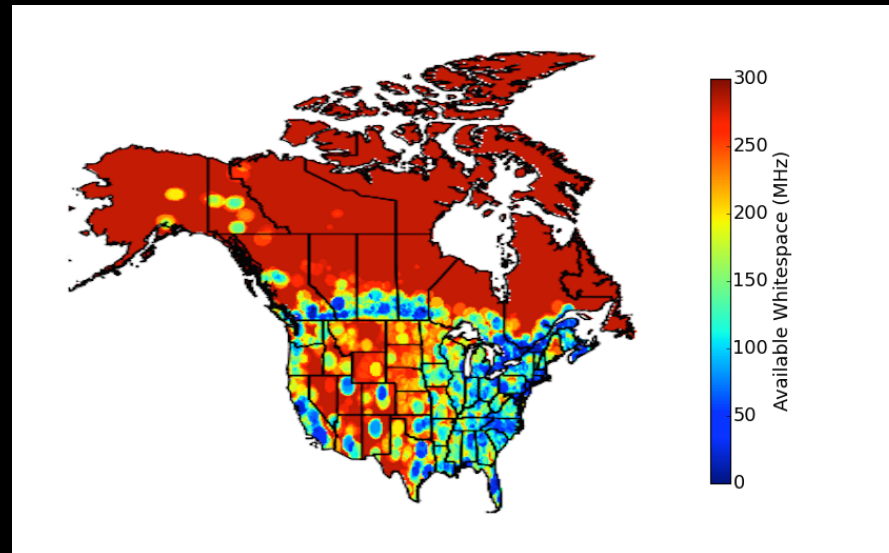


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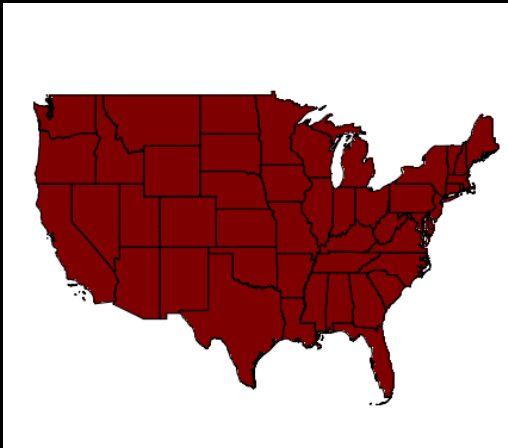


“Equal weight” map

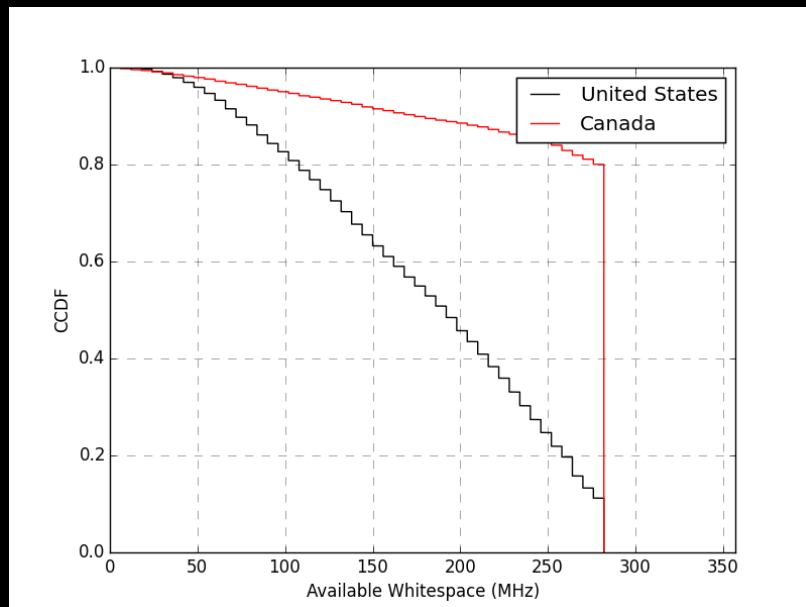
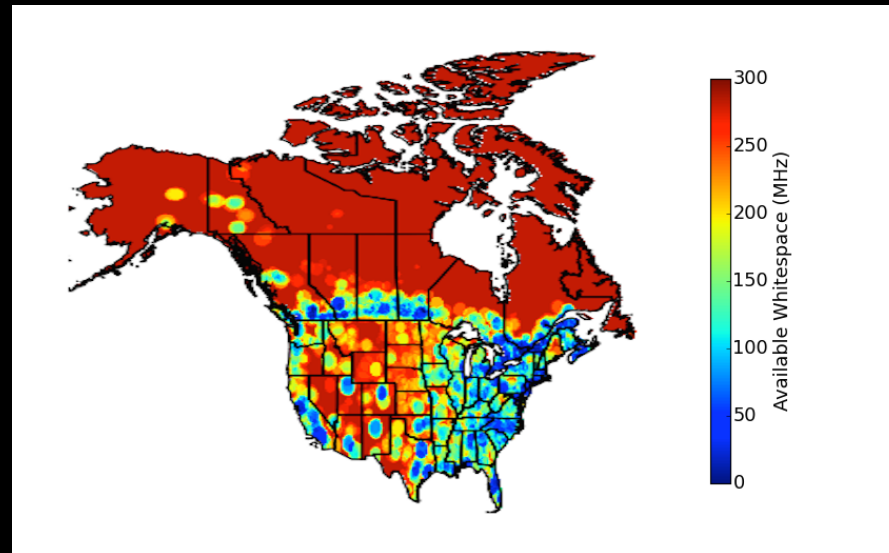


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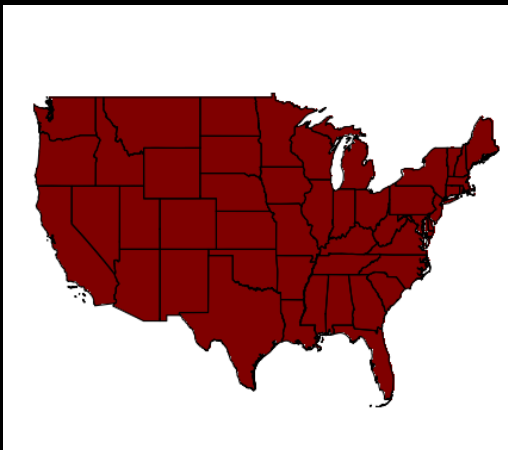
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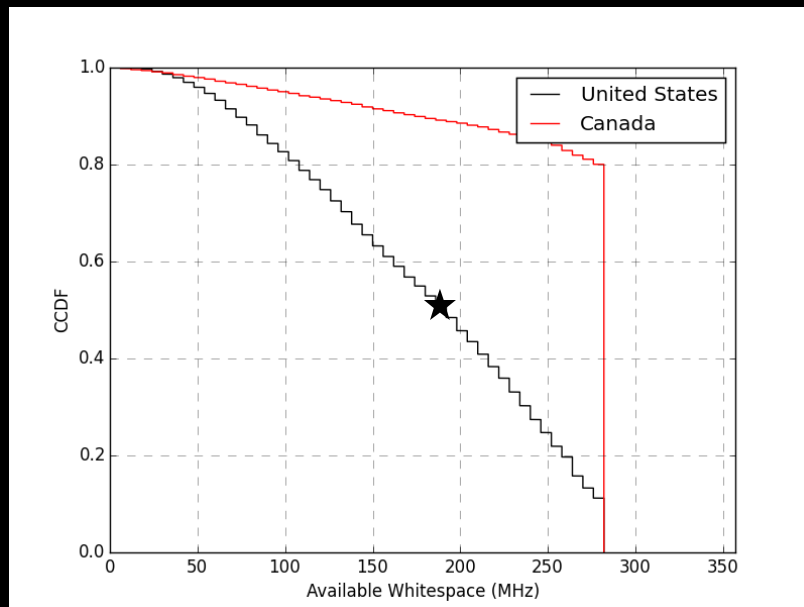
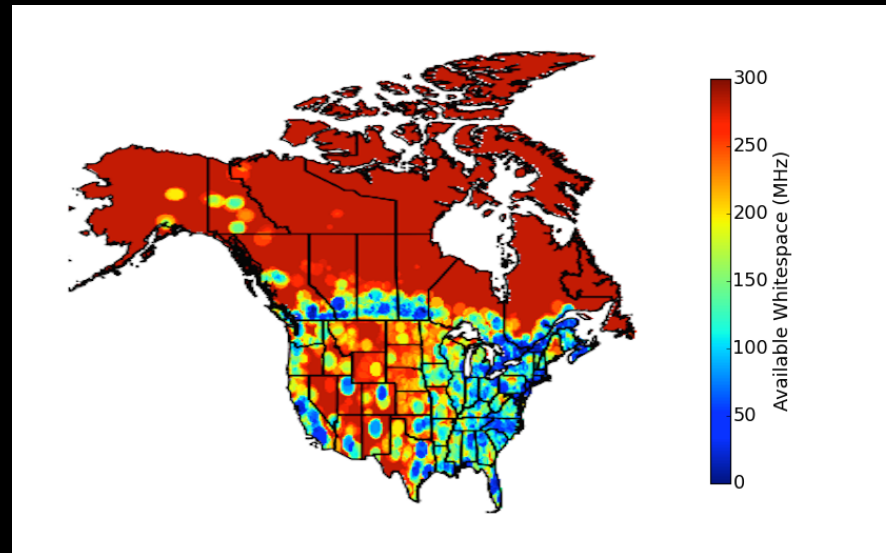
Canada has more  
**WS by area**

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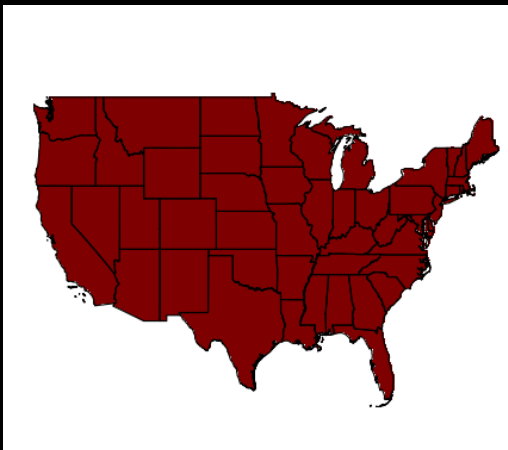
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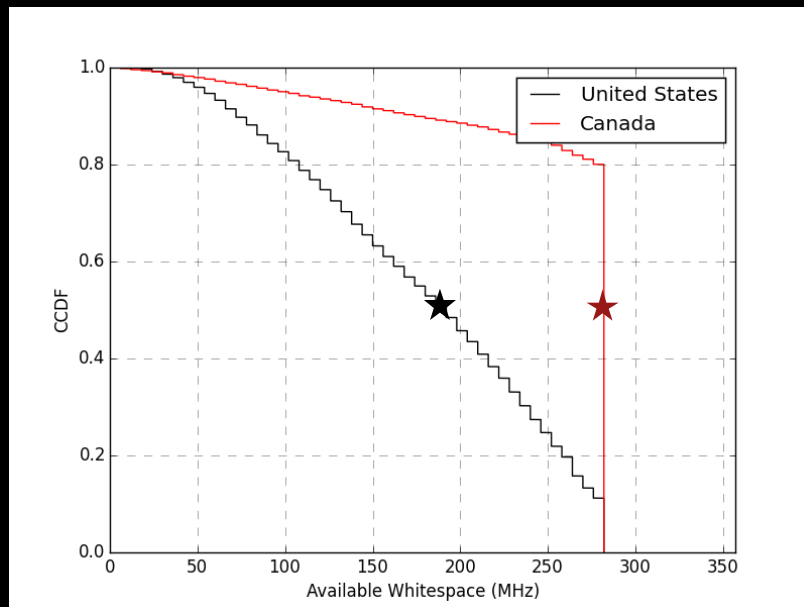
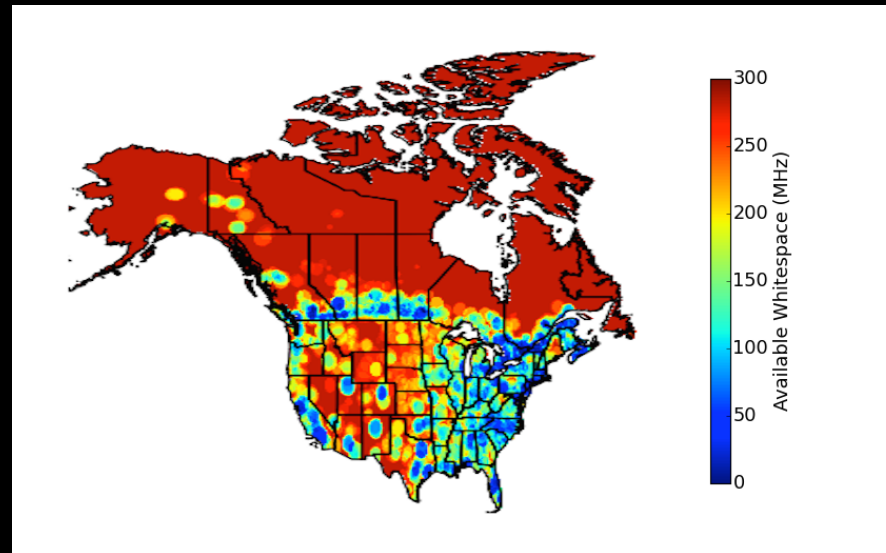
Canada has more  
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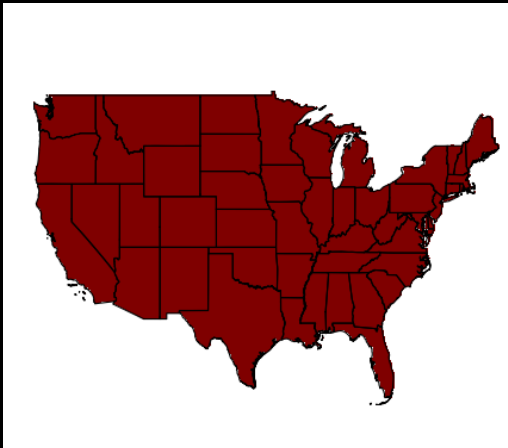
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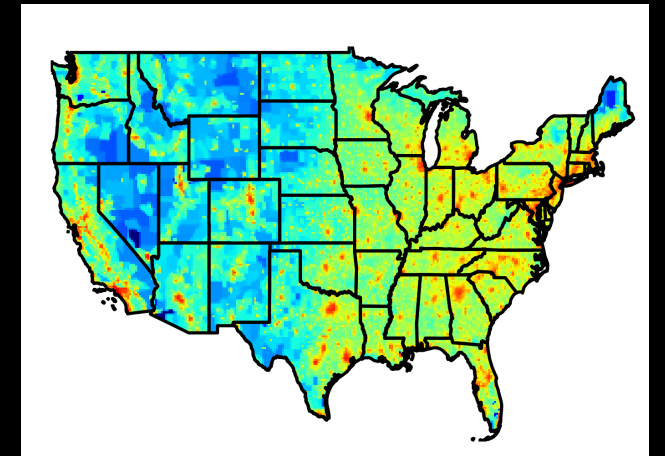
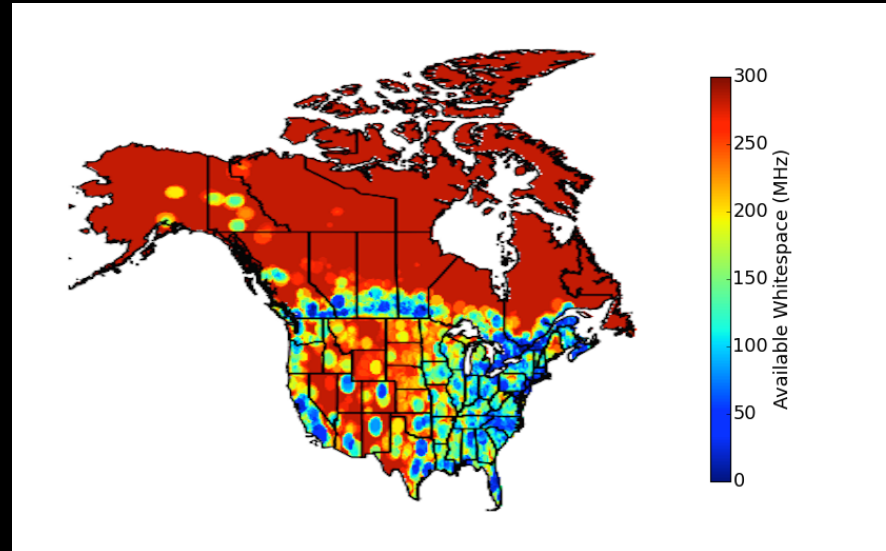
Canada has more  
**WS by area**

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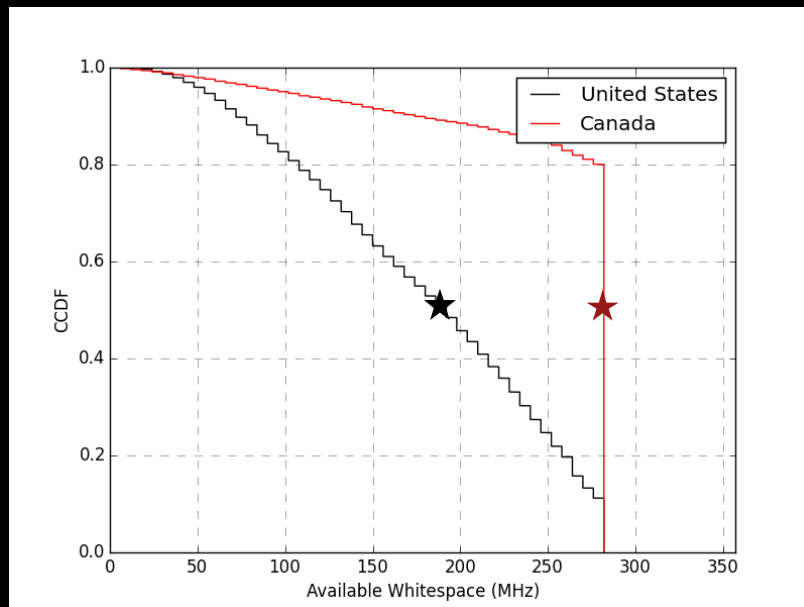
## Whitespaces in Canada (under the FCC ruleset)



“Equal weight” map



Population map

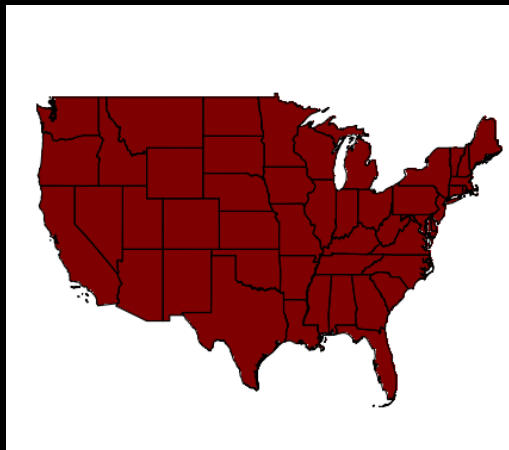


Canada has more  
**WS by area**

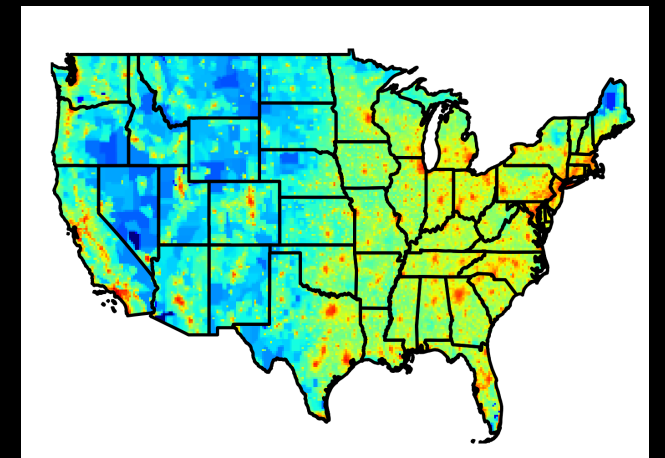
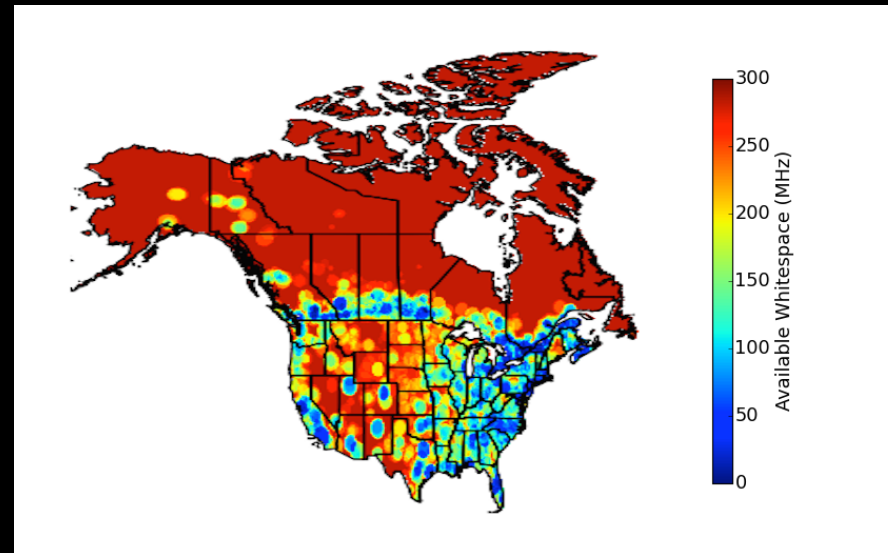


# Applications of WEST:

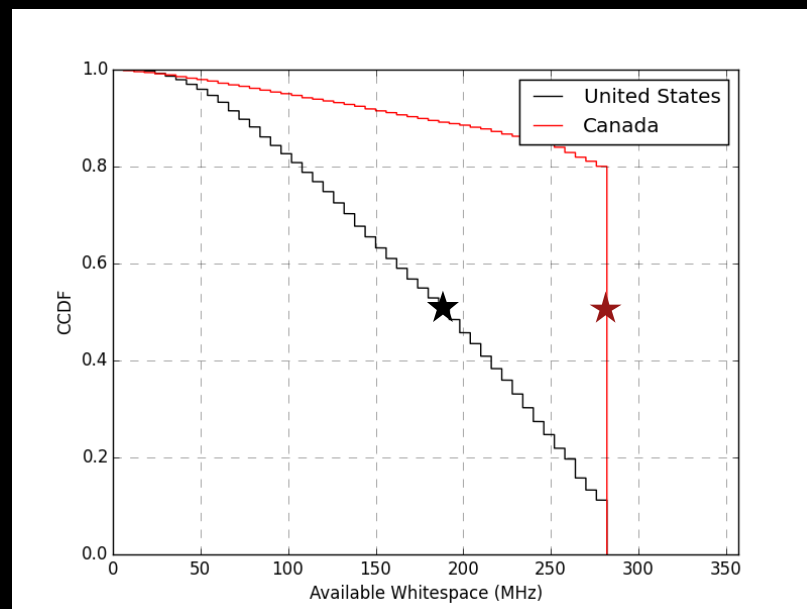
## Whitespaces in Canada (under the FCC ruleset)



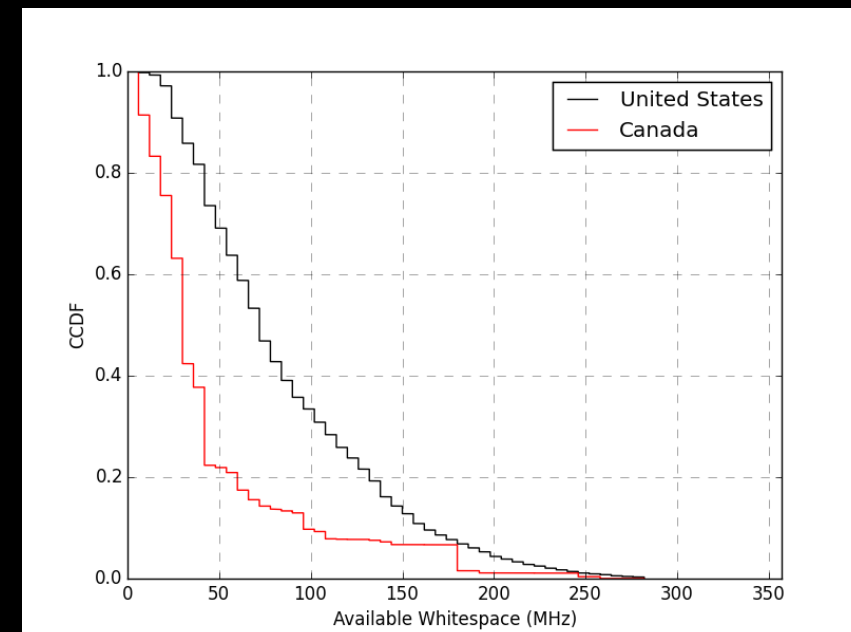
“Equal weight” map



Population map



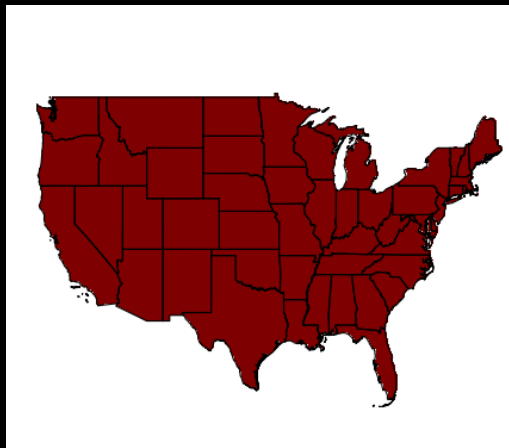
Canada has more  
**WS by area**



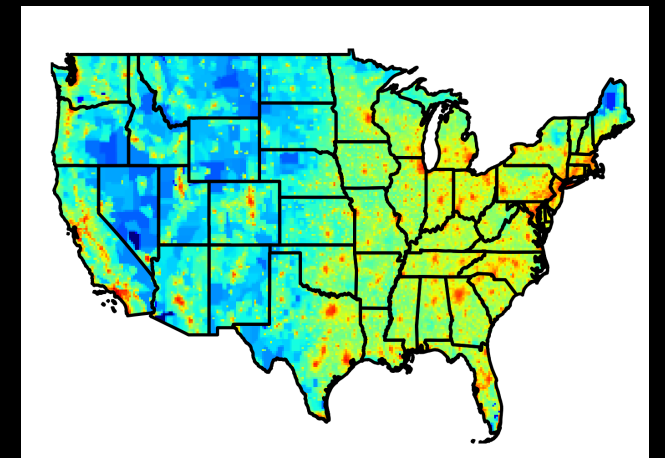
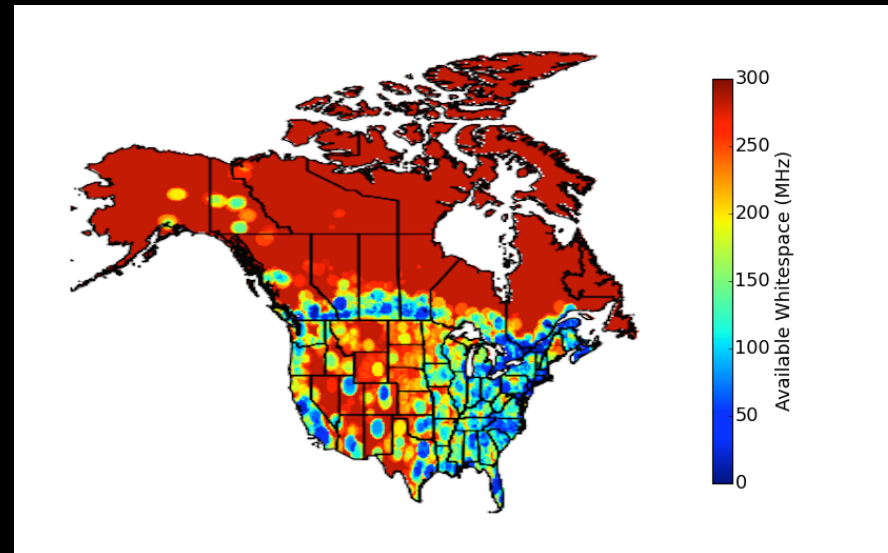
USA has more  
**WS by population**

# Applications of WEST:

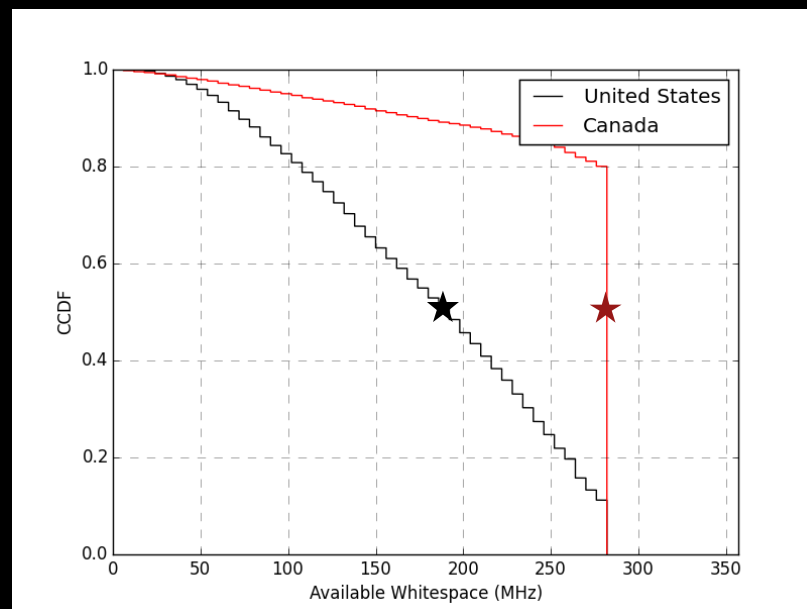
## Whitespaces in Canada (under the FCC ruleset)



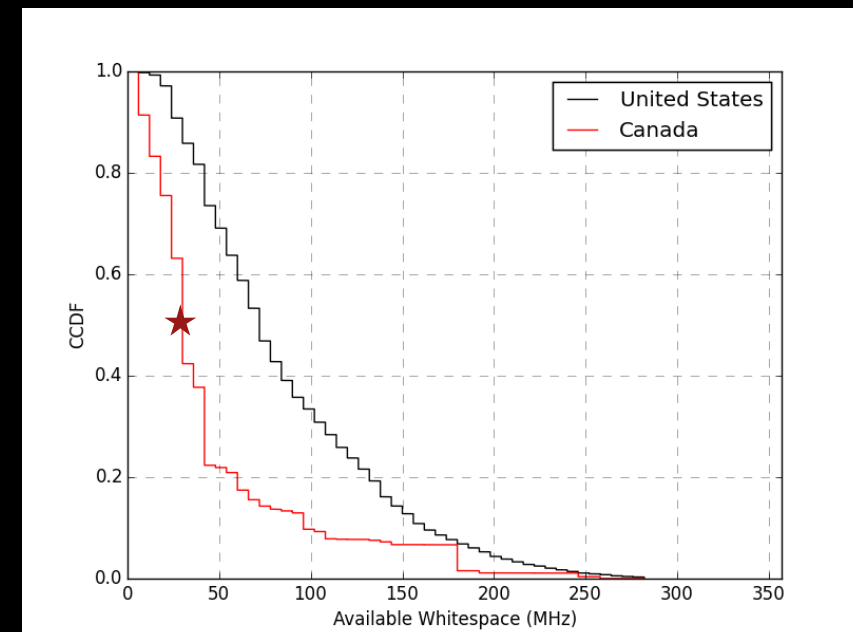
“Equal weight” map



Population map



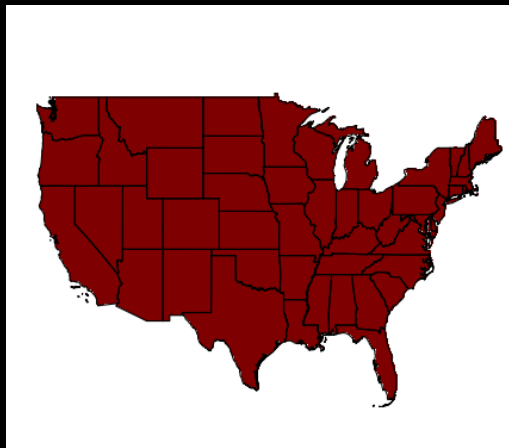
Canada has more  
**WS by area**



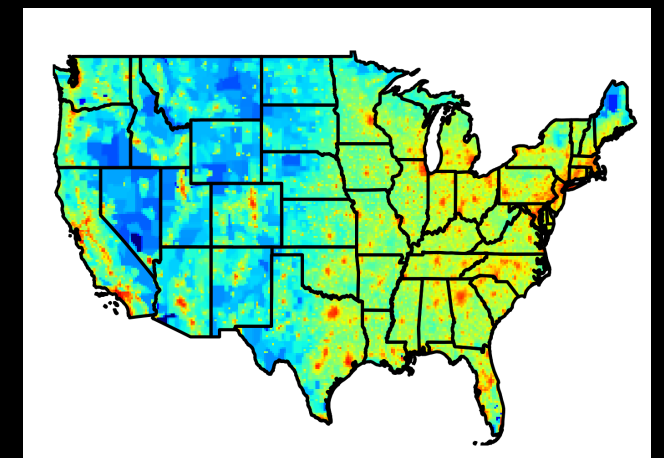
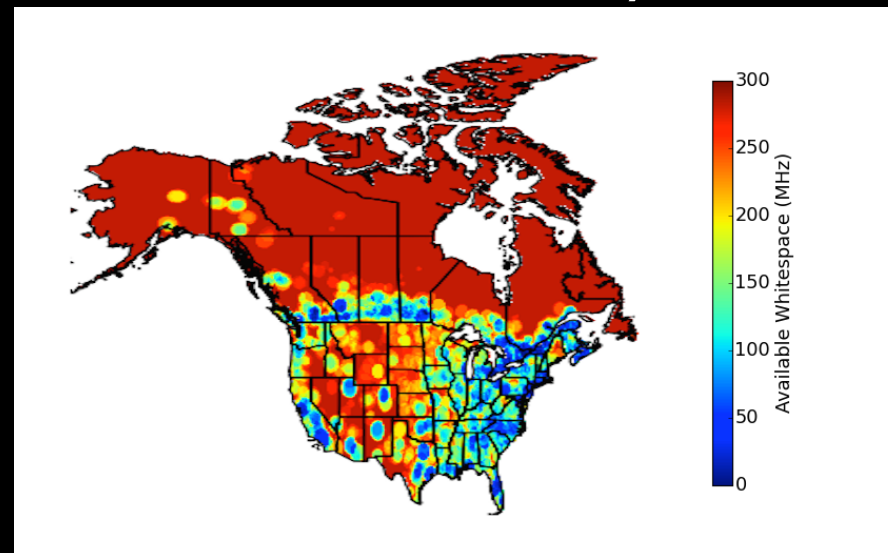
USA has more  
**WS by population**

# Applications of WEST:

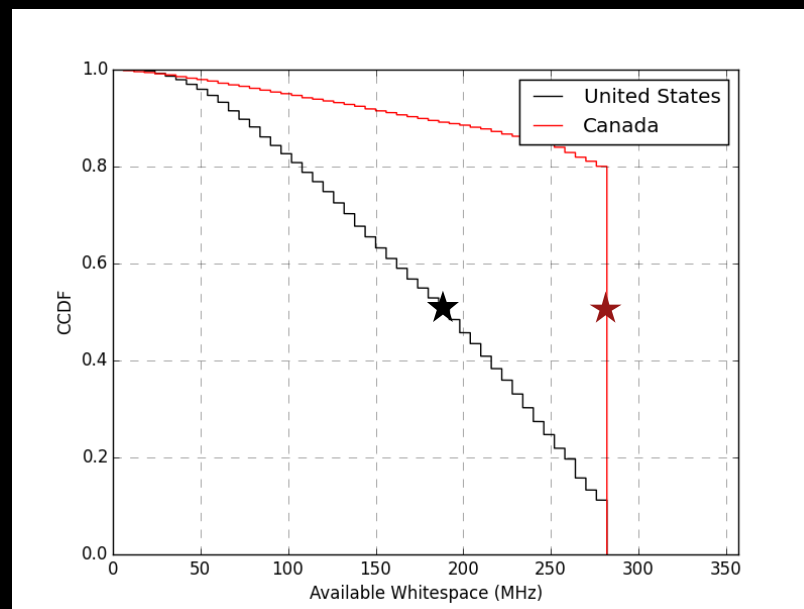
## Whitespaces in Canada (under the FCC ruleset)



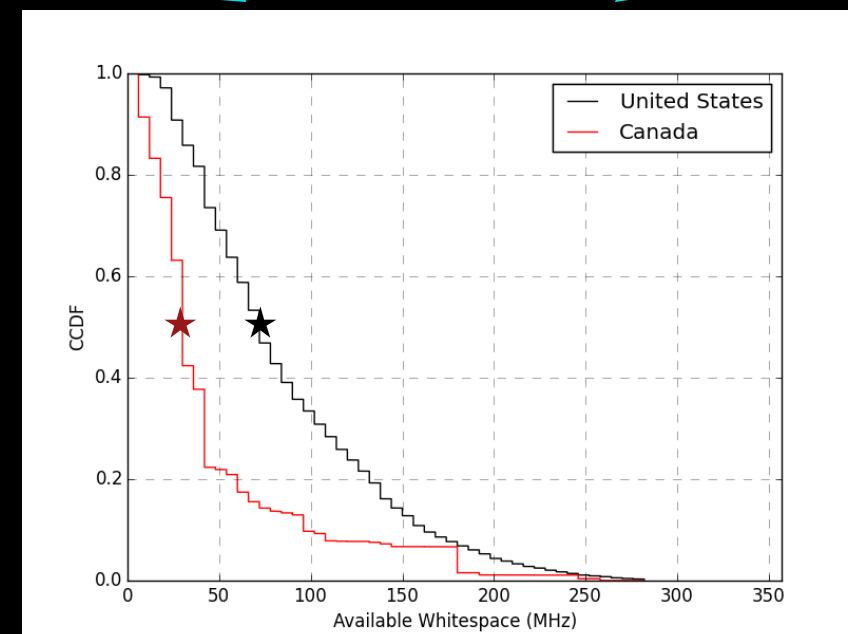
“Equal weight” map



Population map



Canada has more  
**WS by area**



USA has more  
**WS by population**

# **Applications of WEST:**

Whitespaces in Canada (under the FCC ruleset)

# **Applications of WEST:**

Whitespaces in Canada (under the FCC ruleset)

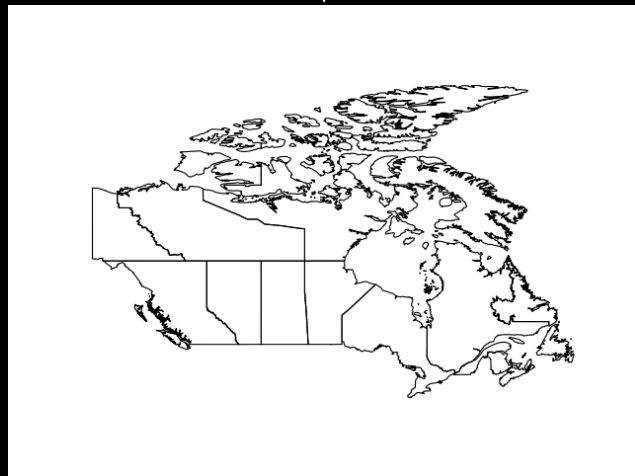
- **Part 1: Importing data** (2 hrs, ~200 lines of code)
- **Part 2: Evaluating WS** (~7 lines of code)

# Applications of WEST:

Whitespaces in Canada (under the FCC ruleset)

- **Part 1: Importing data** (2 hrs, ~200 lines of code)

Boundary file  
(.SHP file),  
readable by  
WEST



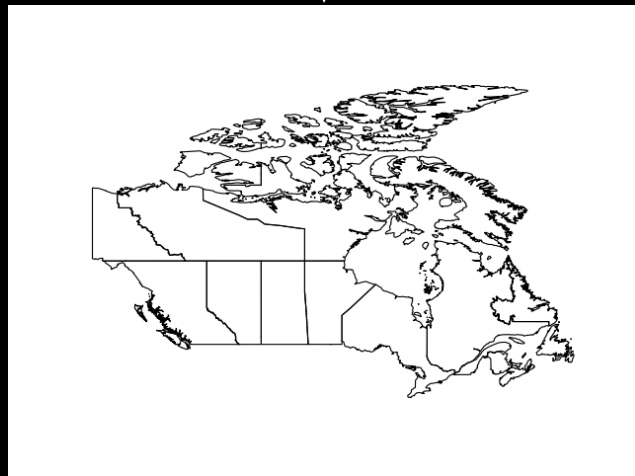
- **Part 2: Evaluating WS** (~7 lines of code)

# Applications of WEST:

## Whitespaces in Canada (under the FCC ruleset)

- **Part 1: Importing data** (2 hrs, ~200 lines of code)

Boundary file  
(.SHP file),  
readable by  
WEST



Listing of Canada TV  
Stations

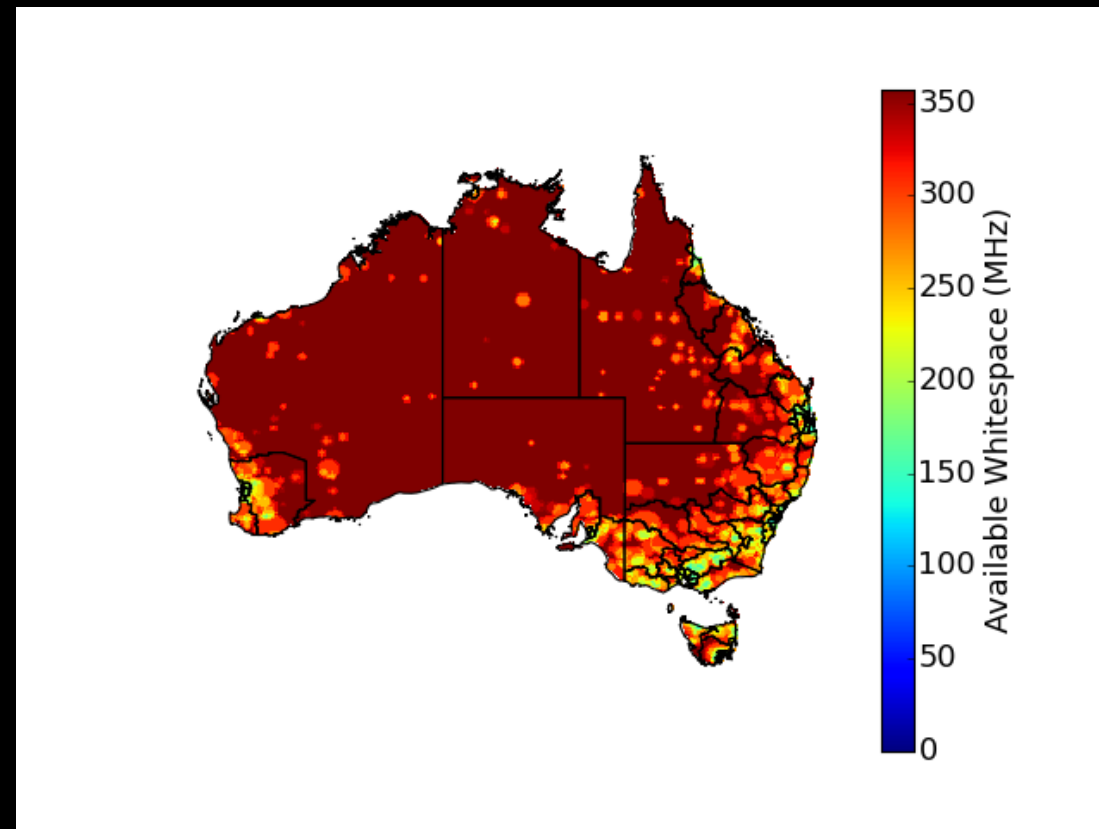


TV station	
Location	Call sign
Height	Tx type (D/A)
Frequency	Tx power

- **Part 2: Evaluating WS** (~7 lines of code)

# Applications of WEST: Whitespaces in Australia

- Procedure similar to Canadian exercise
- Whitespace evaluated under FCC ruleset



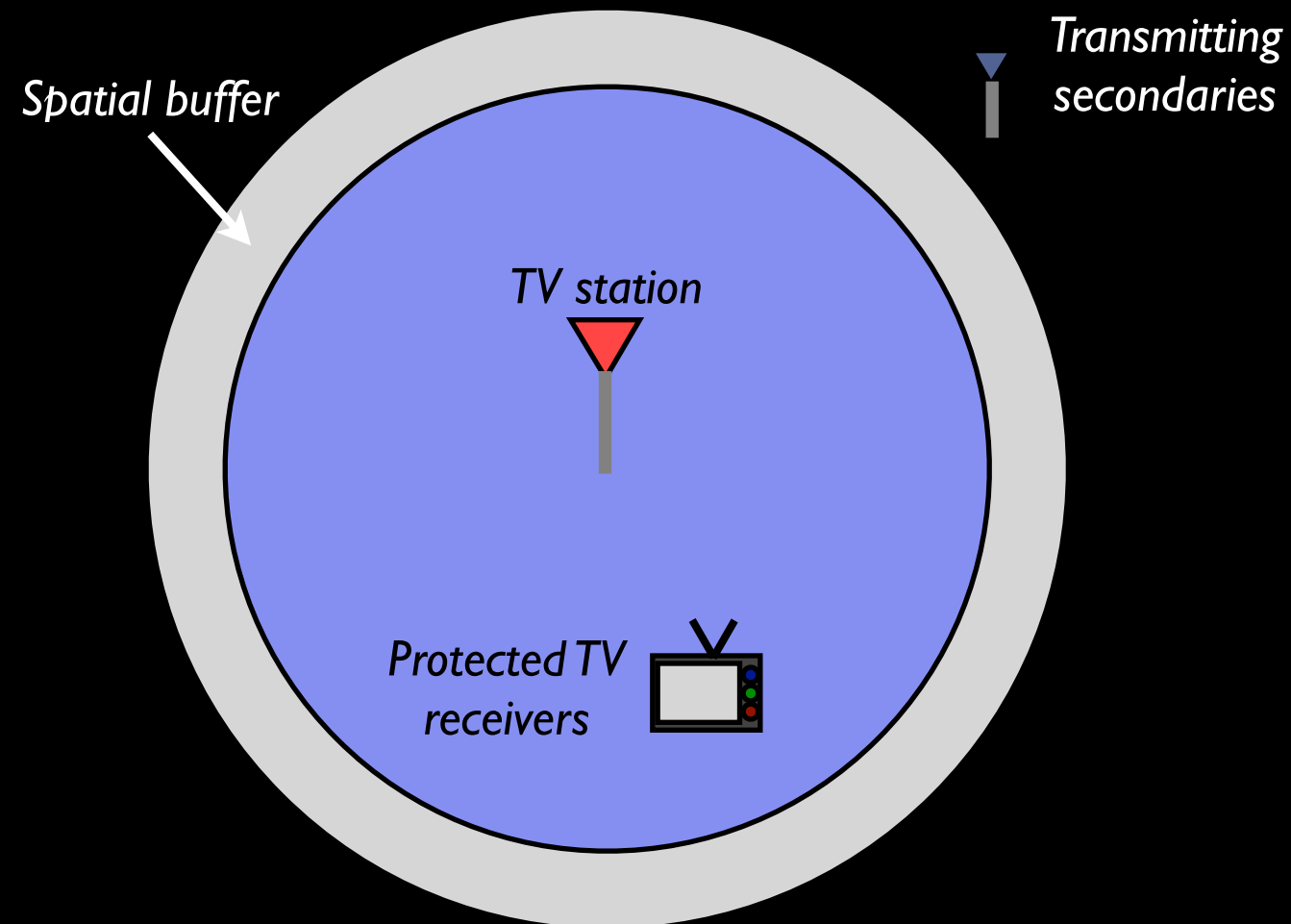
- WS in Australia more plentiful (some channels are vacant)
- No candidate ruleset yet



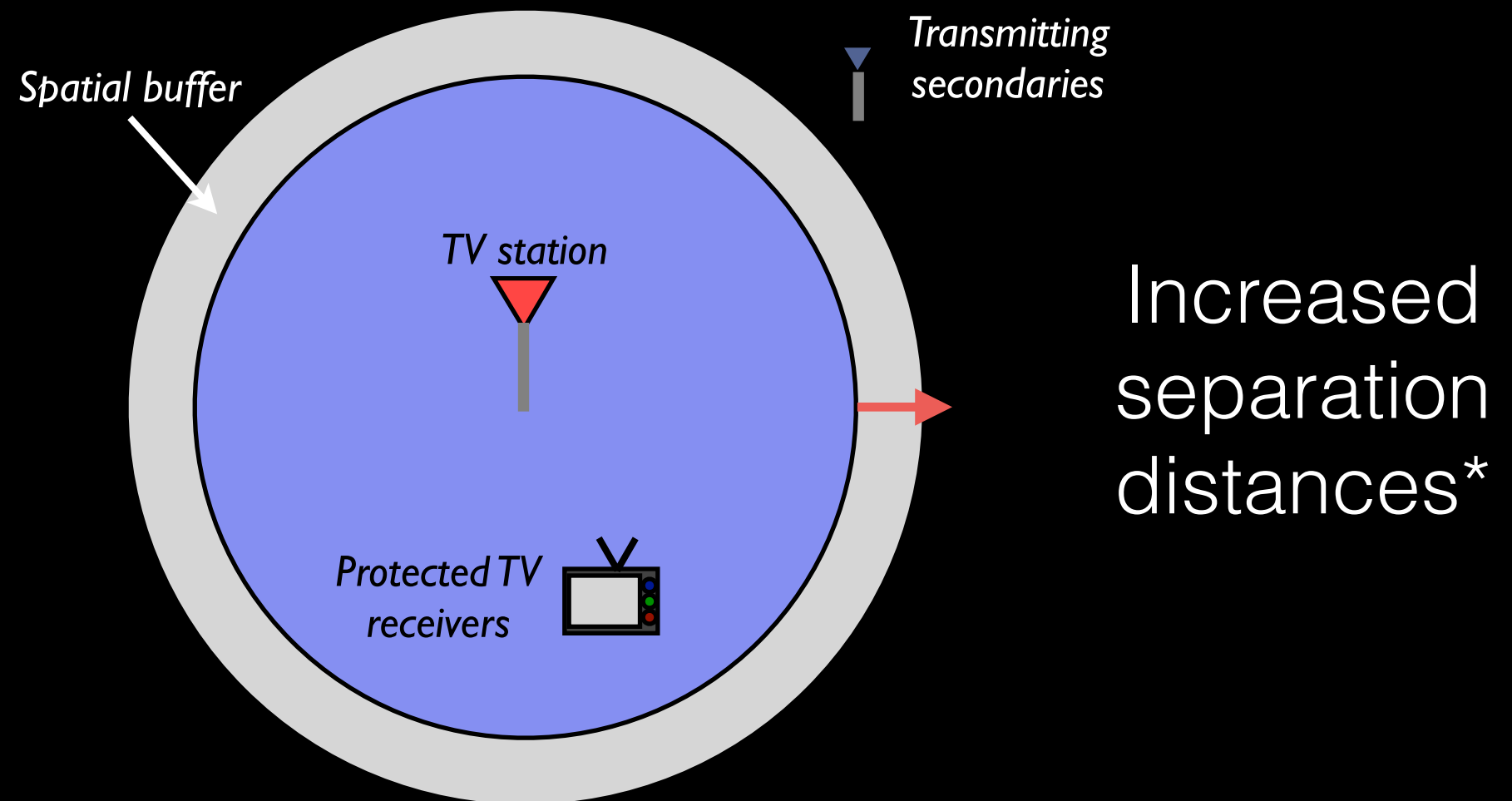
**Industry Canada (IC) ruleset**, released  
early 2015

How does it compare with FCC's ruleset?

# The FCC Ruleset

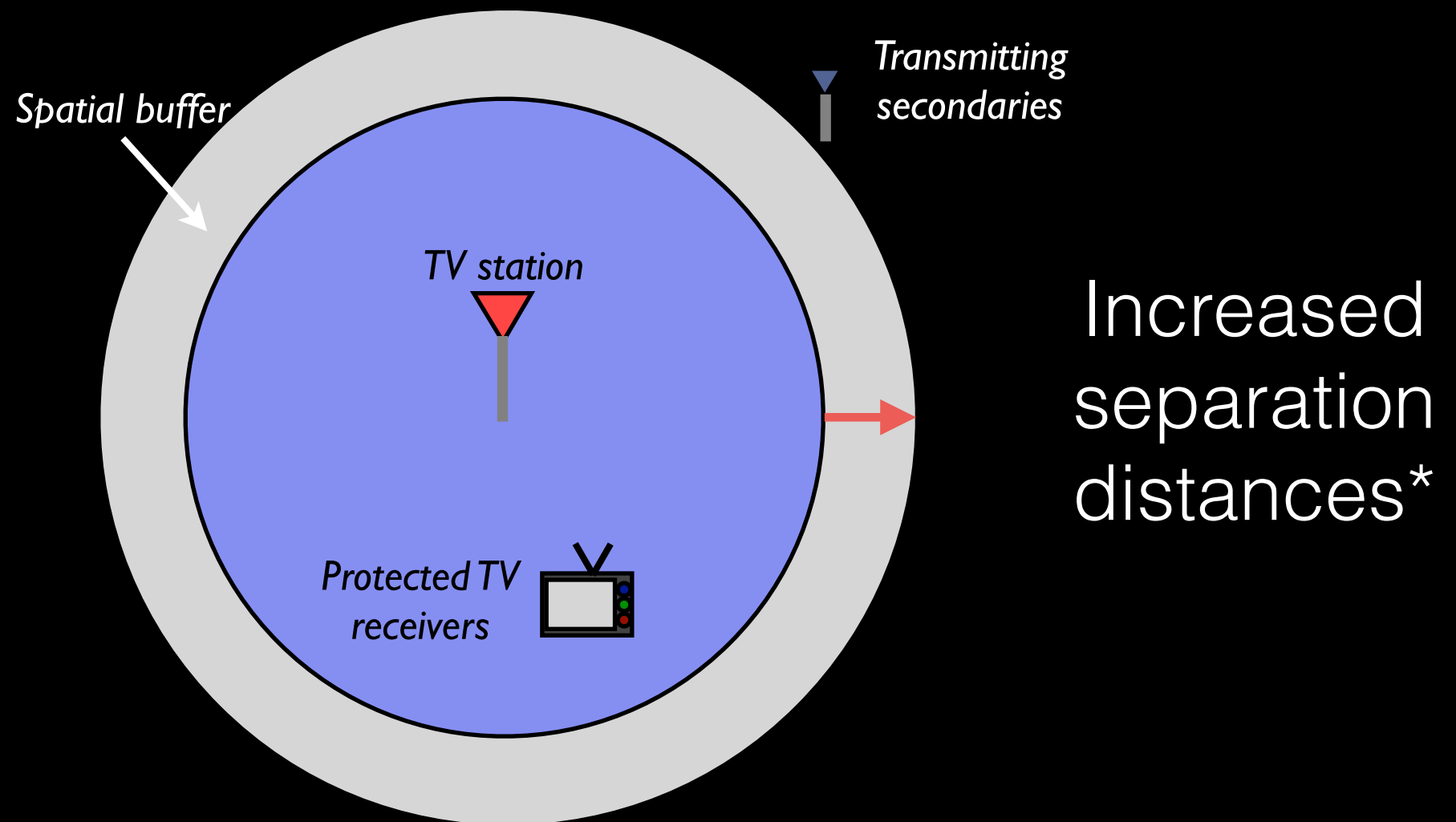


# FCC vs IC: Separation Distances



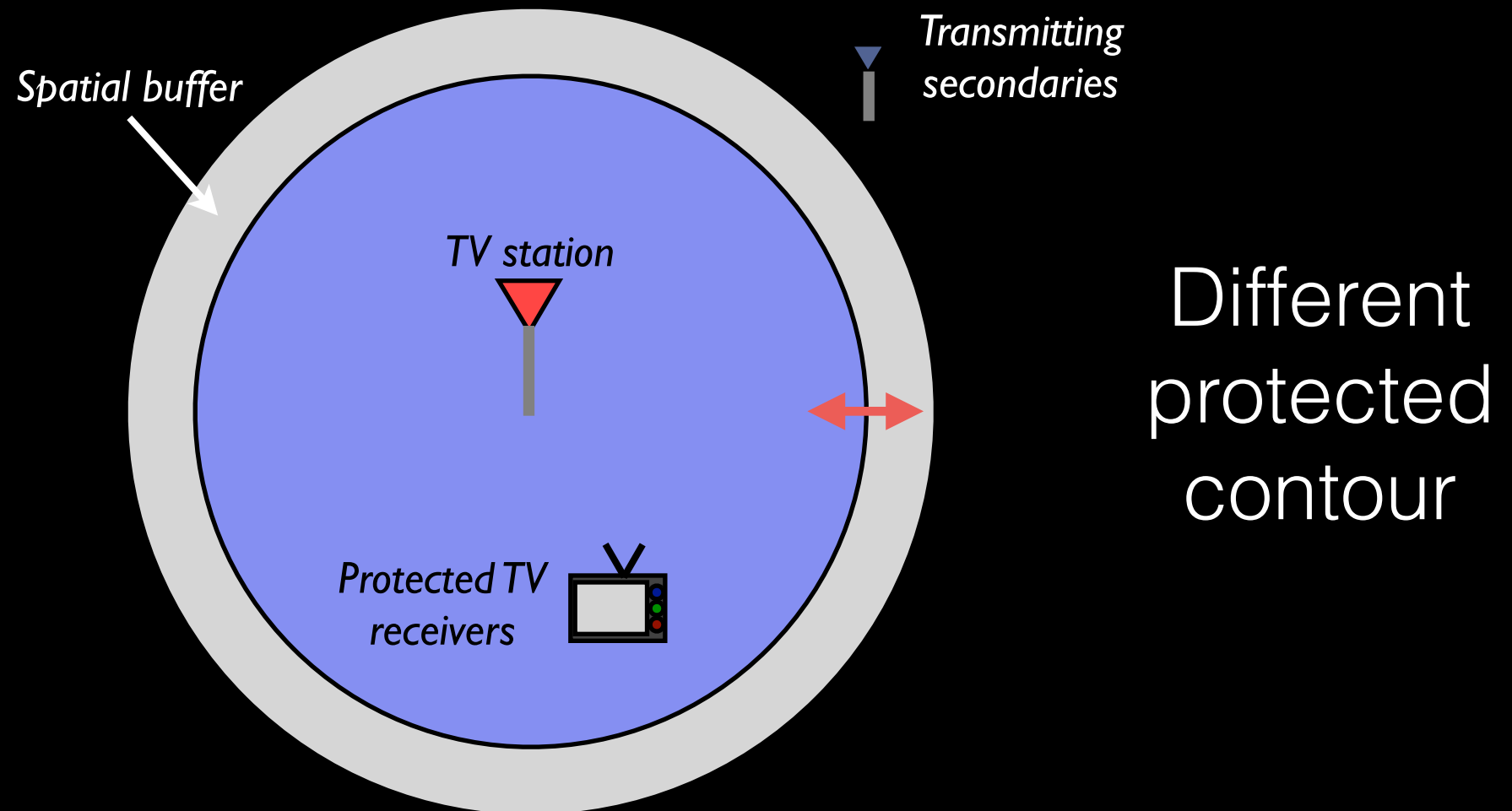
\*for almost all TV stations

# FCC vs IC: Separation Distances

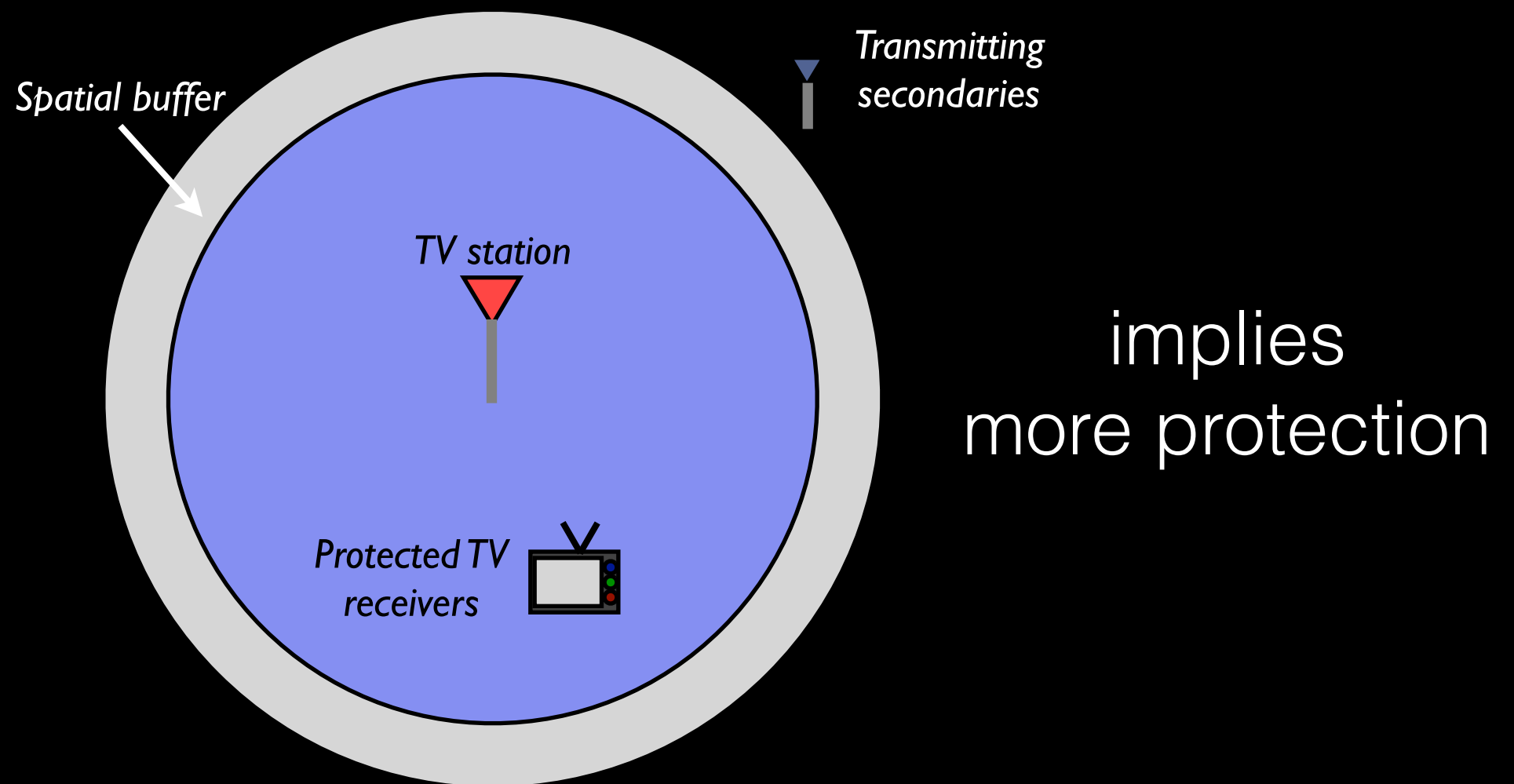


\*for almost all TV stations

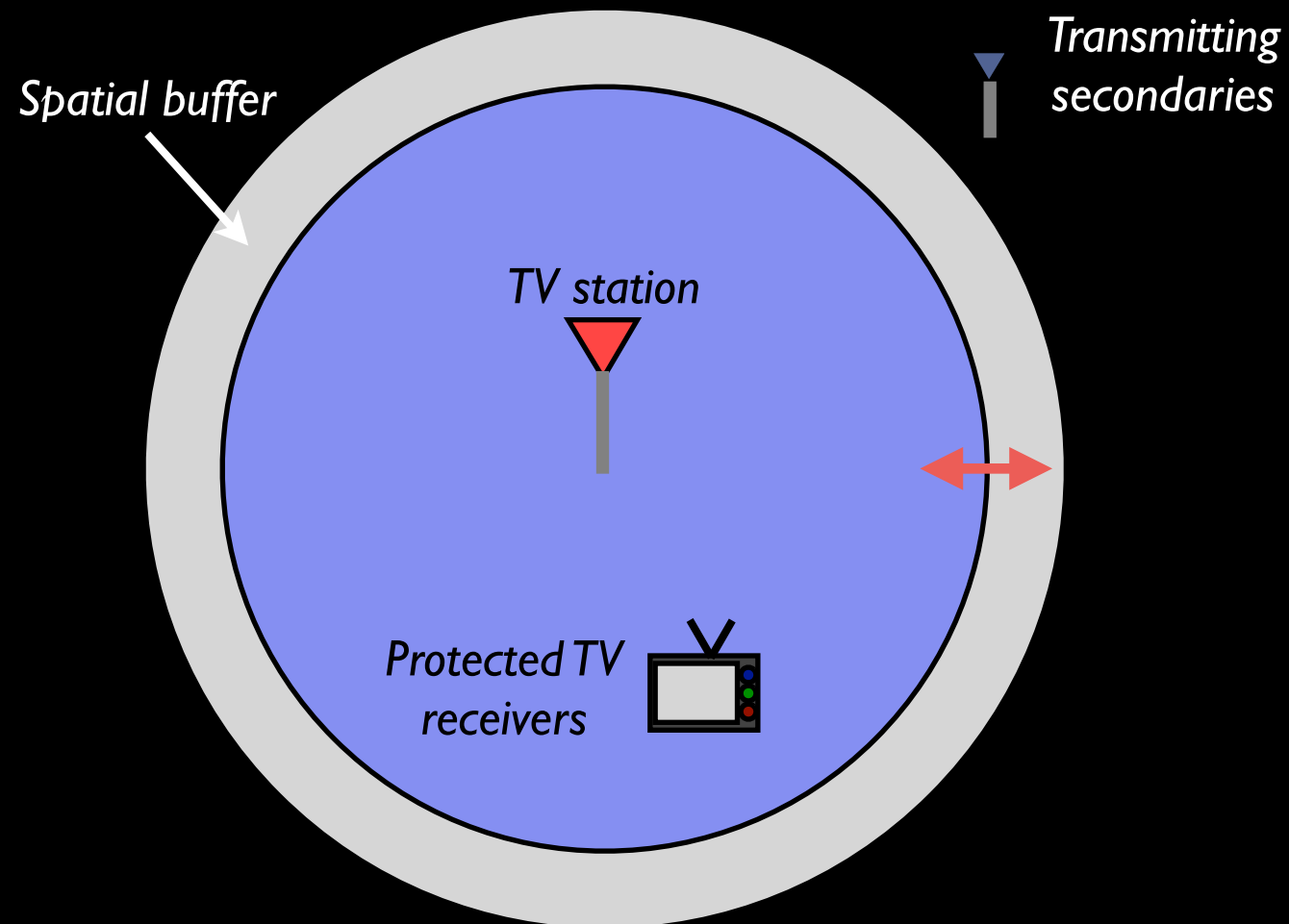
# FCC vs IC: Protected Contour Definition



# FCC vs IC: Protected Contour Definition

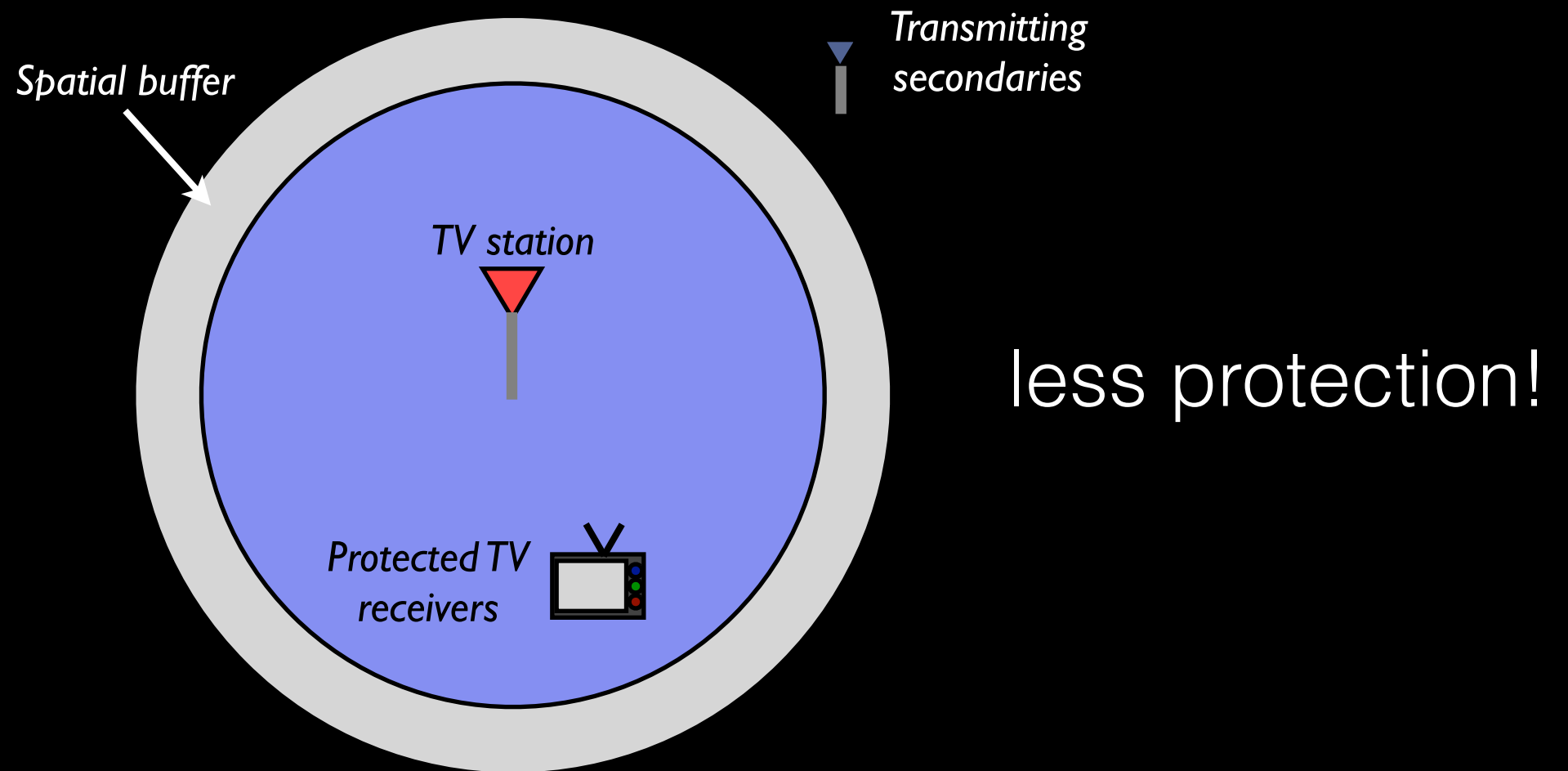


# FCC vs IC: Protected Contour Definition



OR

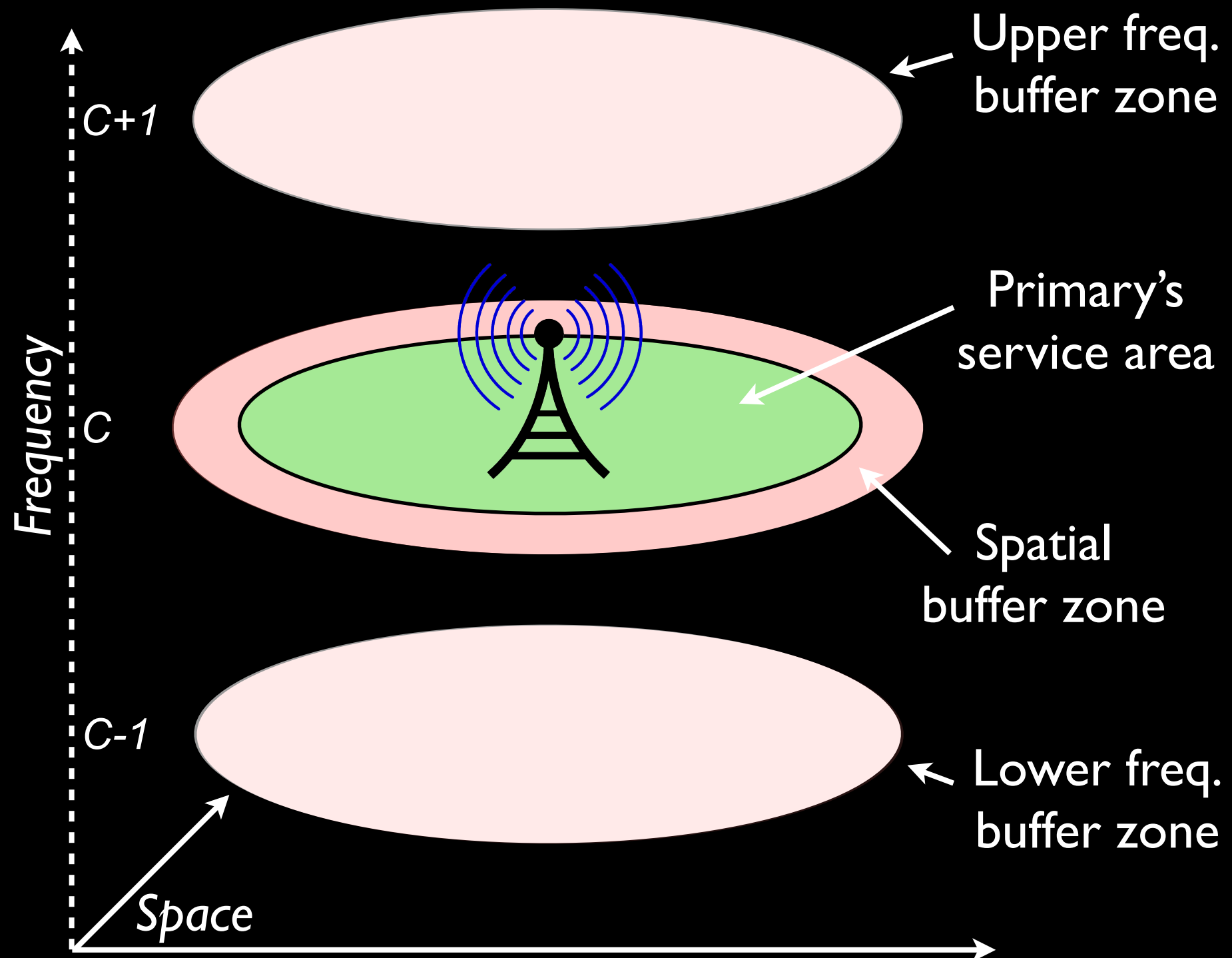
# FCC vs IC: Protected Contour Definition



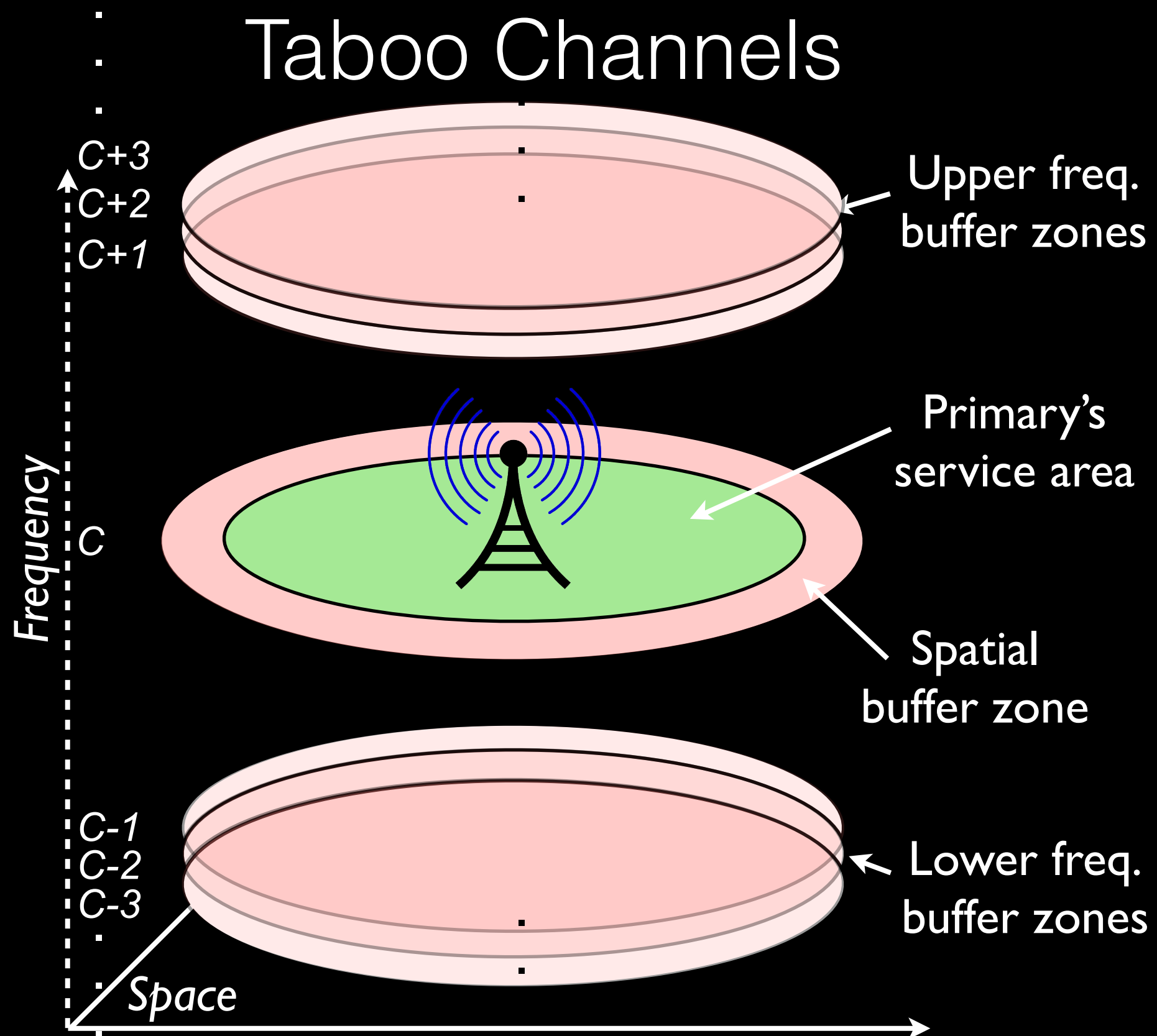
(depending on frequency of channel)



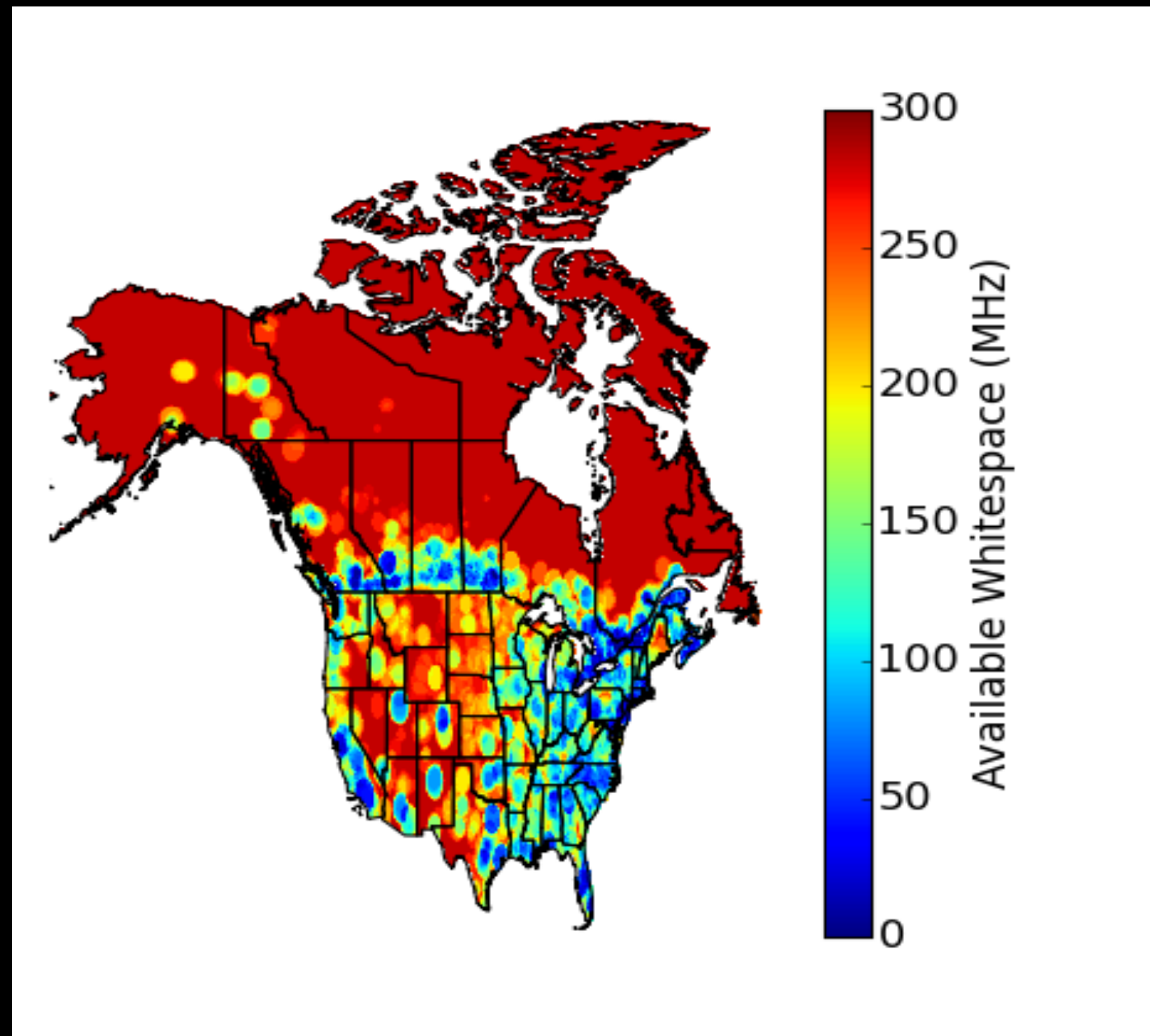
# FCC vs IC: Taboo Channels



# FCC vs IC: Taboo Channels

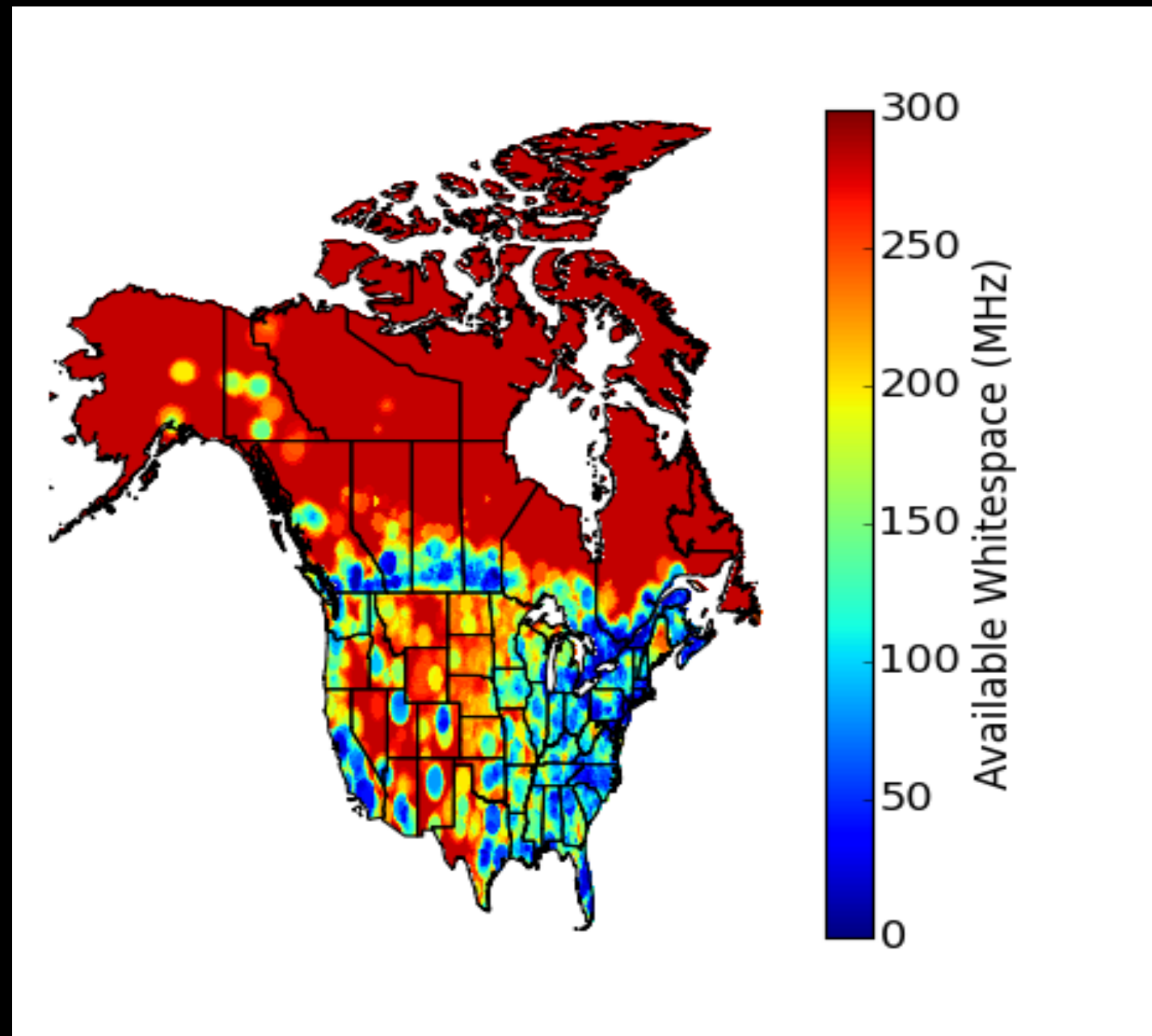


# Whitespaces in Canada — under the FCC ruleset



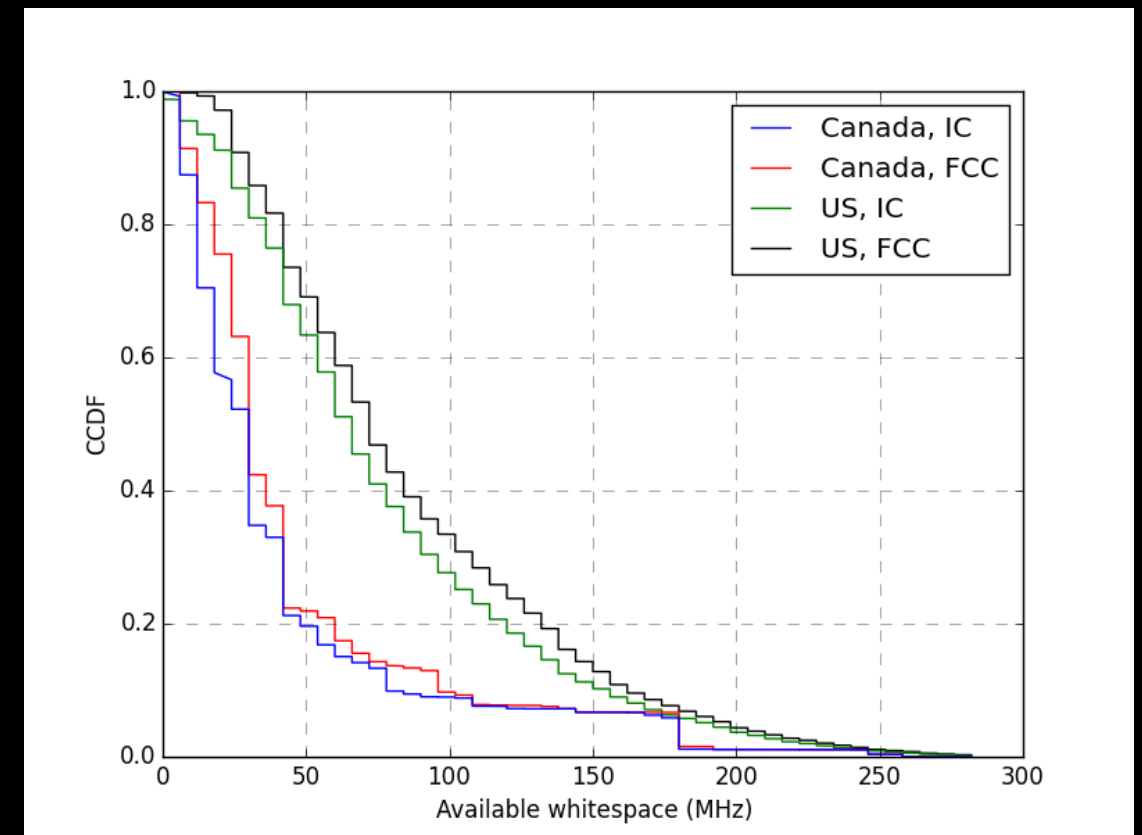
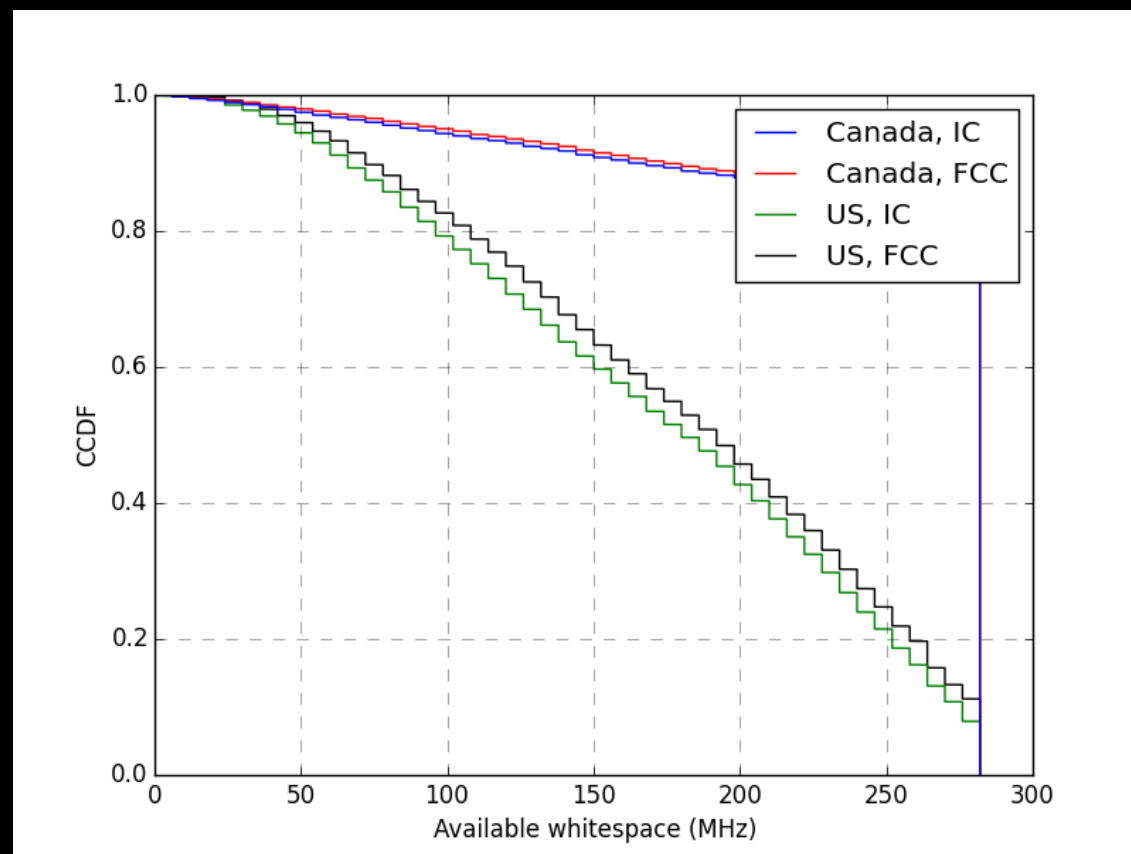
FCC ruleset

# Whitespaces in Canada — under the Industry Canada ruleset



IC ruleset

# Whitespaces in Canada — under the Industry Canada ruleset



# FCC vs IC: Chimera Rulesets

# FCC vs IC: Chimera Rulesets

**FCC**  
**ruleset**

# FCC vs IC: Chimera Rulesets

**FCC**  
**ruleset**

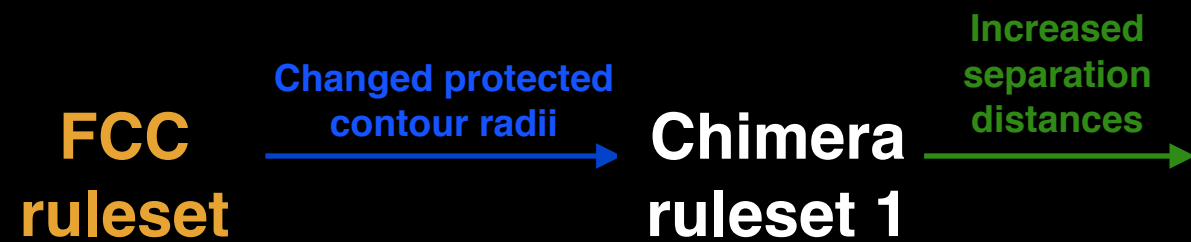
Changed protected  
contour radii →



# FCC vs IC: Chimera Rulesets



# FCC vs IC: Chimera Rulesets



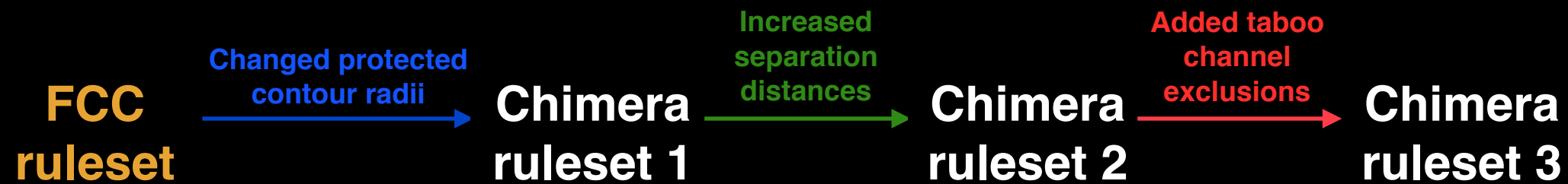
# FCC vs IC: Chimera Rulesets



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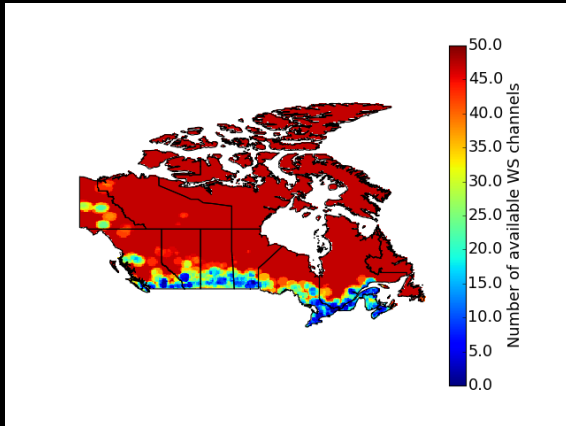
# FCC vs IC: Chimera Rulesets



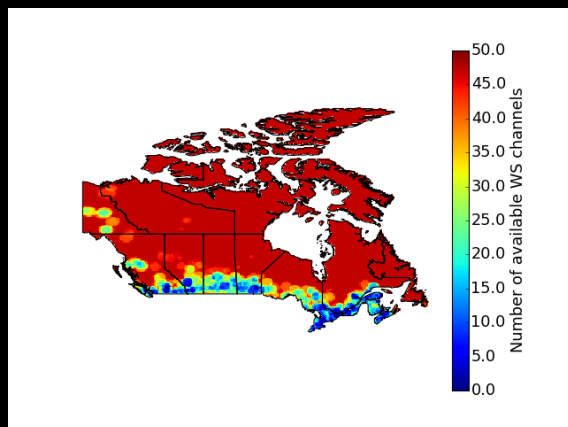


# FCC vs IC: Difference CCDFs

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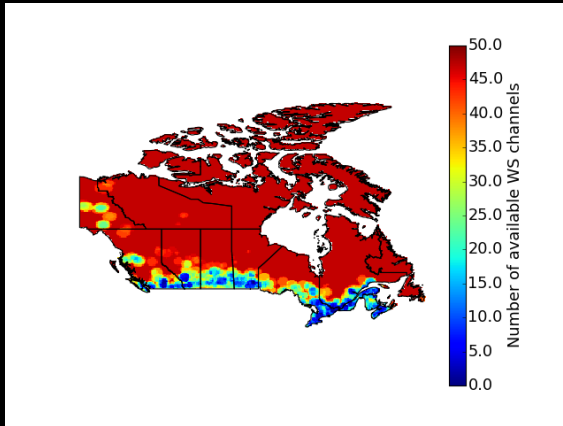


1. Whitespace map  
under chimera ruleset 1

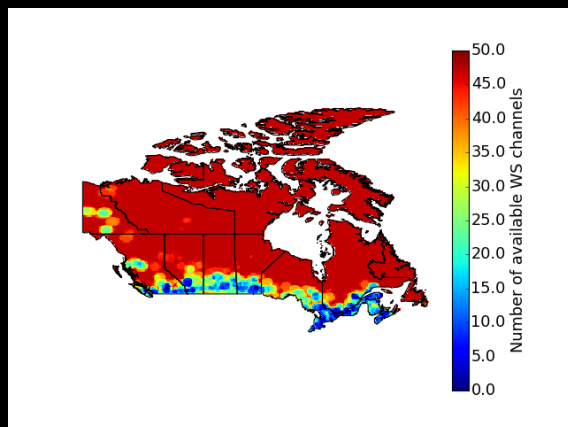


2. Whitespace map  
under chimera ruleset 2

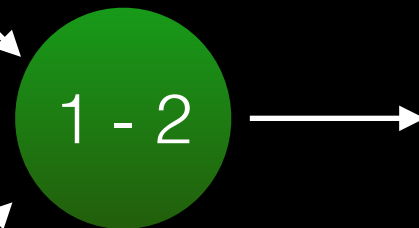
# FCC vs IC: Difference CCDFs



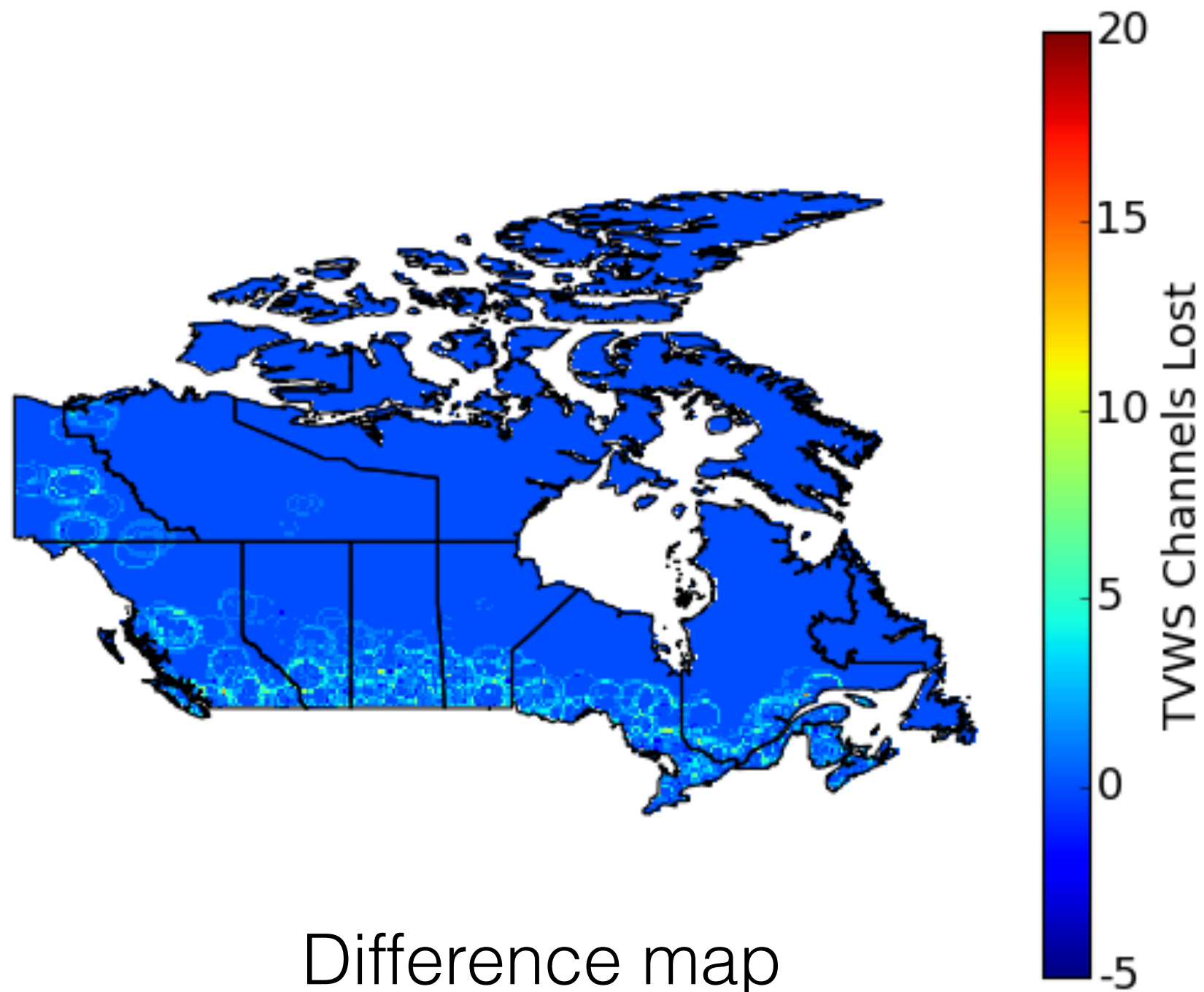
1. Whitespace map  
under chimera ruleset 1



2. Whitespace map  
under chimera ruleset 2



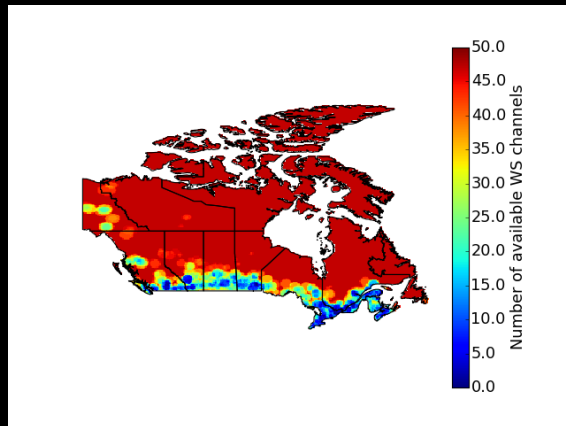
# FCC vs IC:



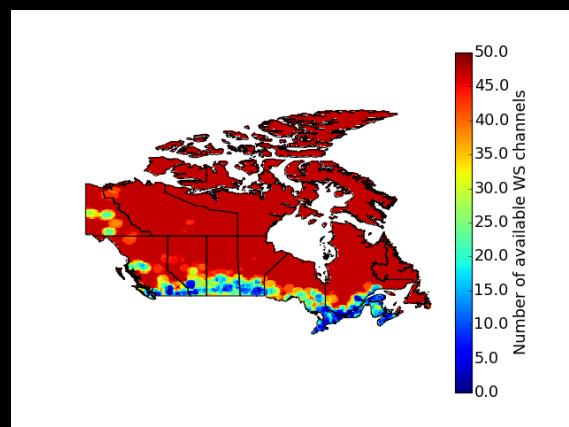
1. Wh  
under c

2. Wh  
under c

# FCC vs IC: Difference CCDFs



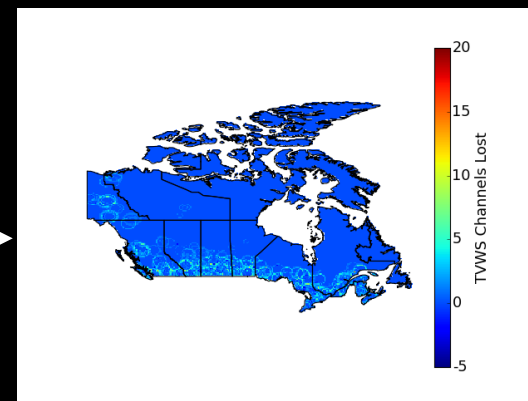
1. Whitespace map  
under chimera ruleset 1



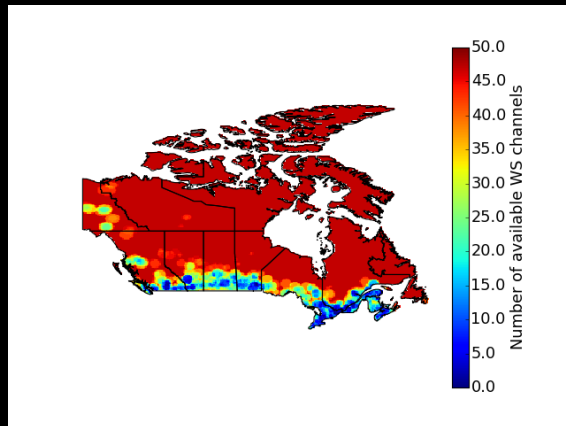
2. Whitespace map  
under chimera ruleset 2

1 - 2

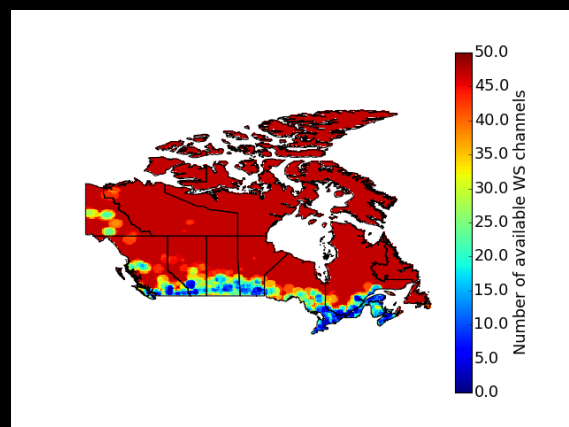
Difference map



# FCC vs IC: Difference CCDFs



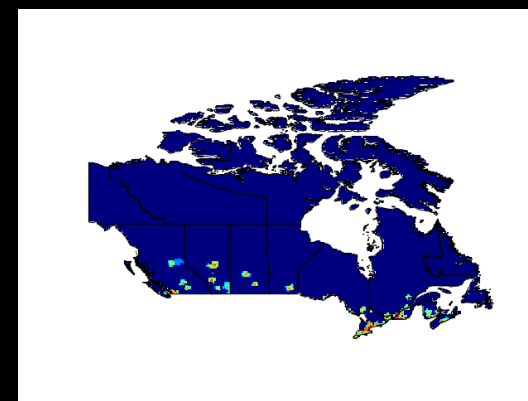
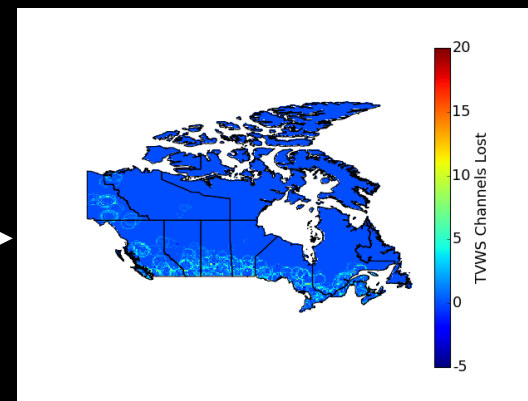
1. Whitespace map  
under chimera ruleset 1



2. Whitespace map  
under chimera ruleset 2

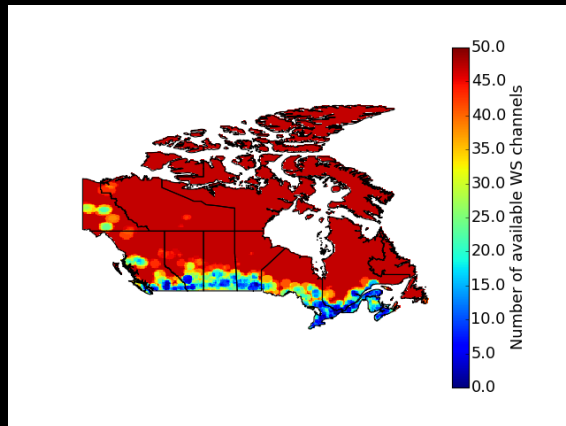
1 - 2

Difference map

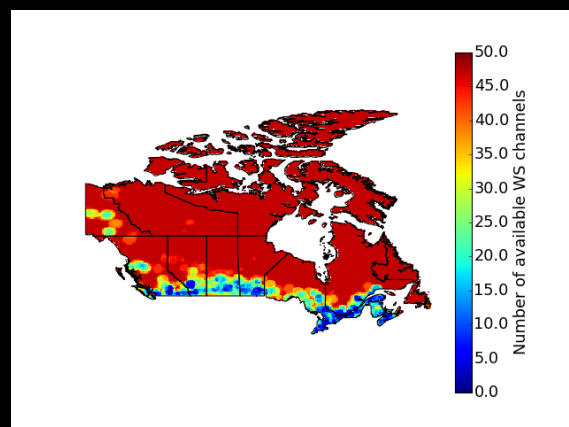


Population map

# FCC vs IC: Difference CCDFs



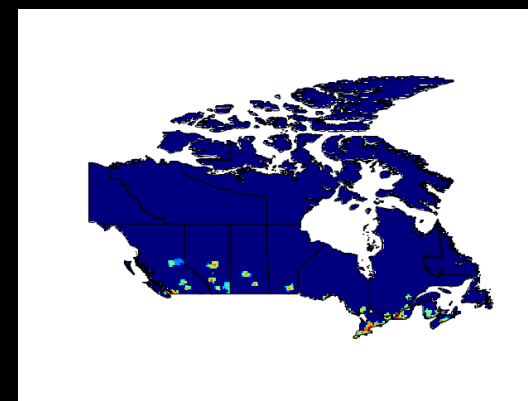
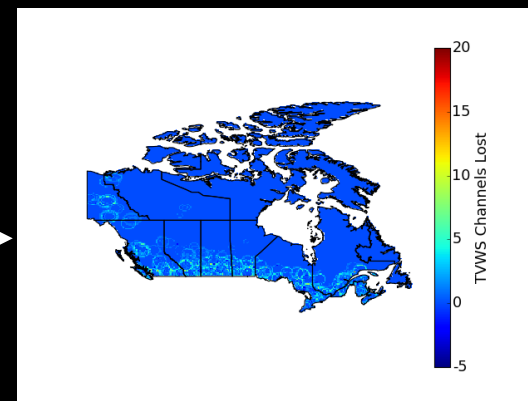
1. Whitespace map  
under chimera ruleset 1



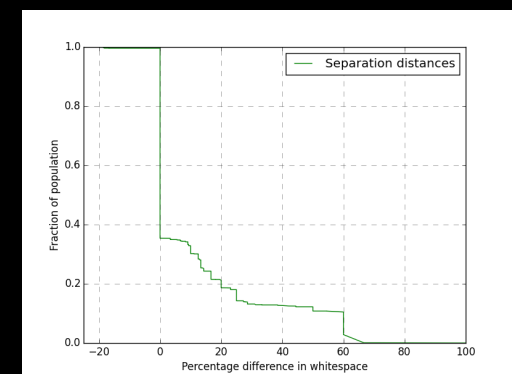
2. Whitespace map  
under chimera ruleset 2

1 - 2

Difference map

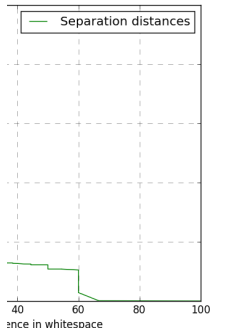
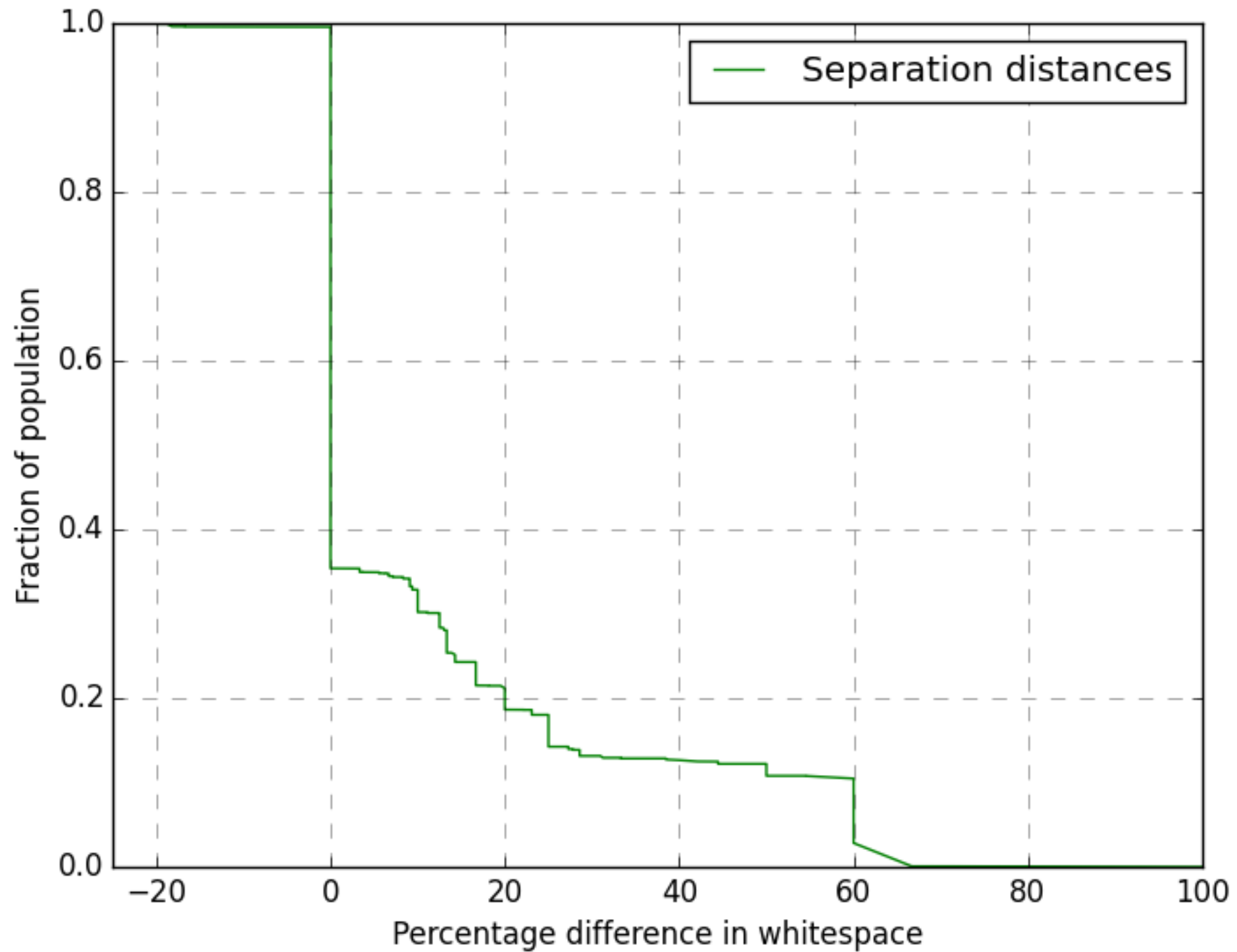


Population map



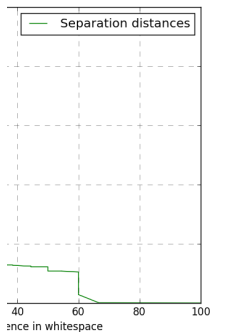
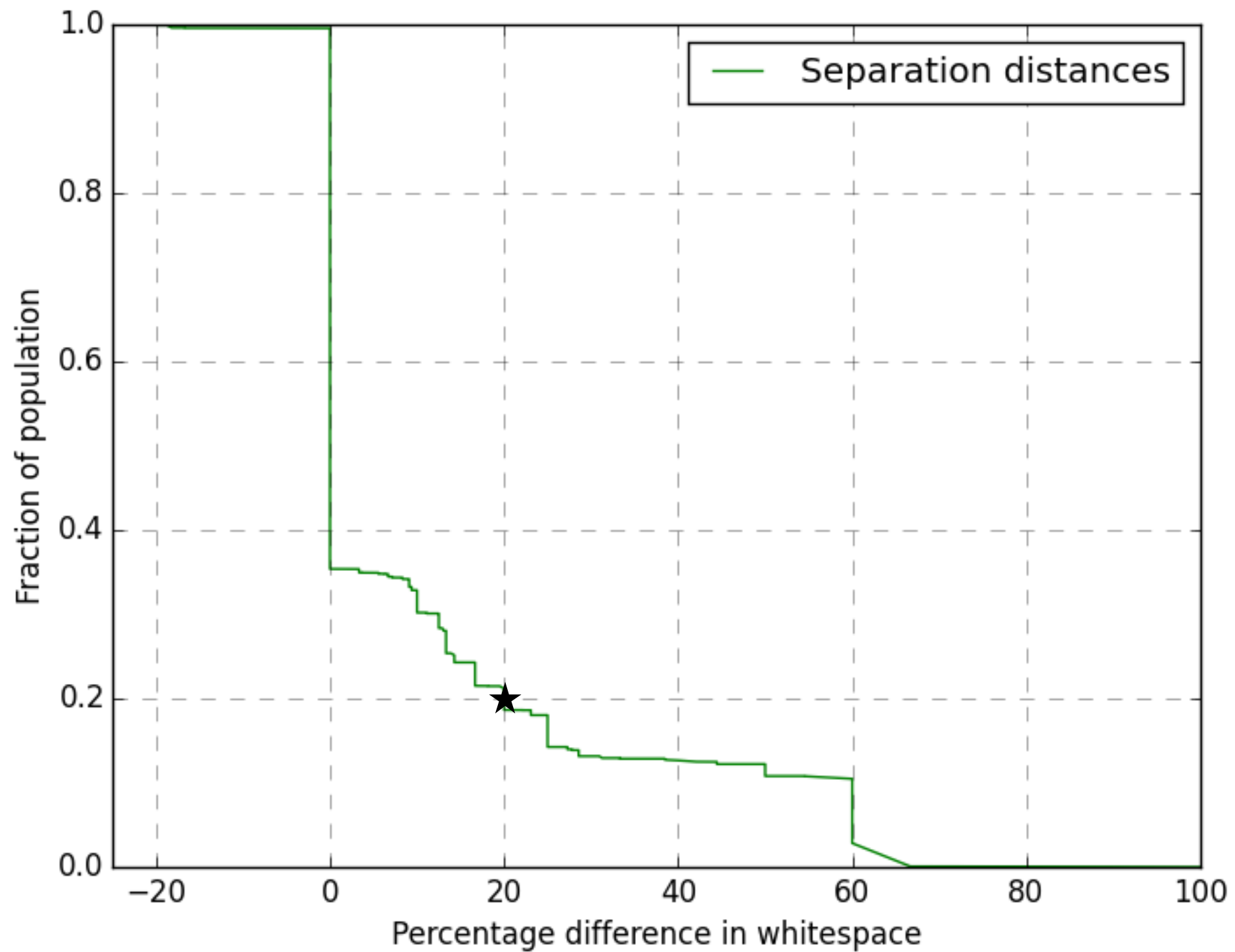


# FCC vs IC:



Population map

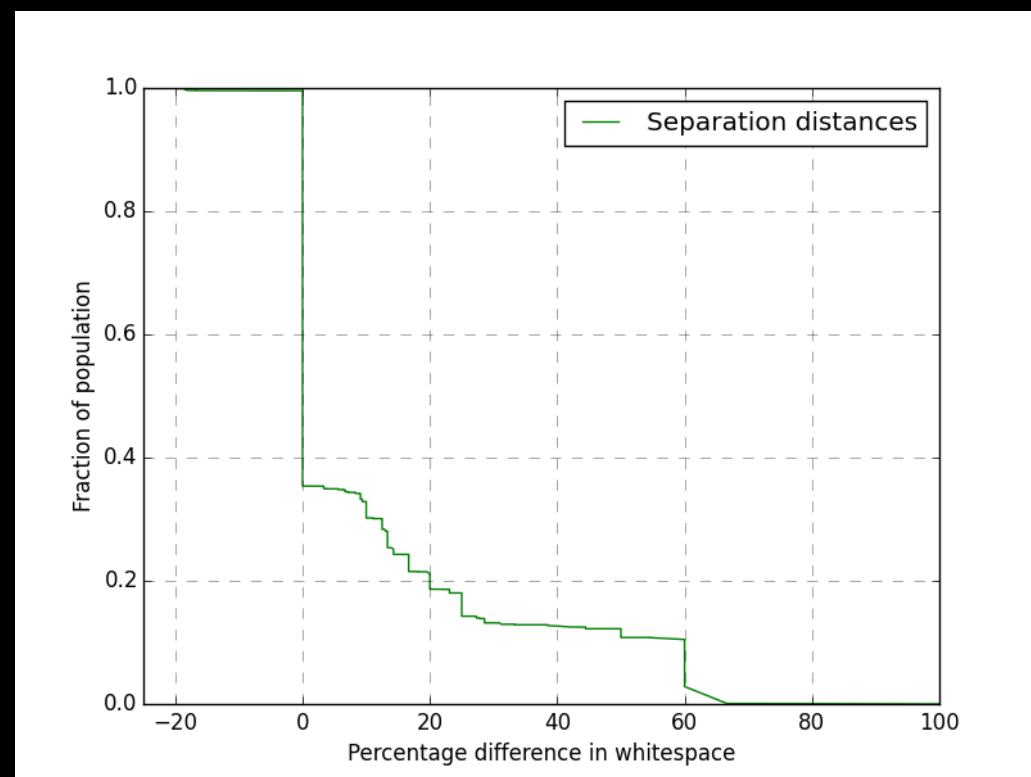
# FCC vs IC:



Population map

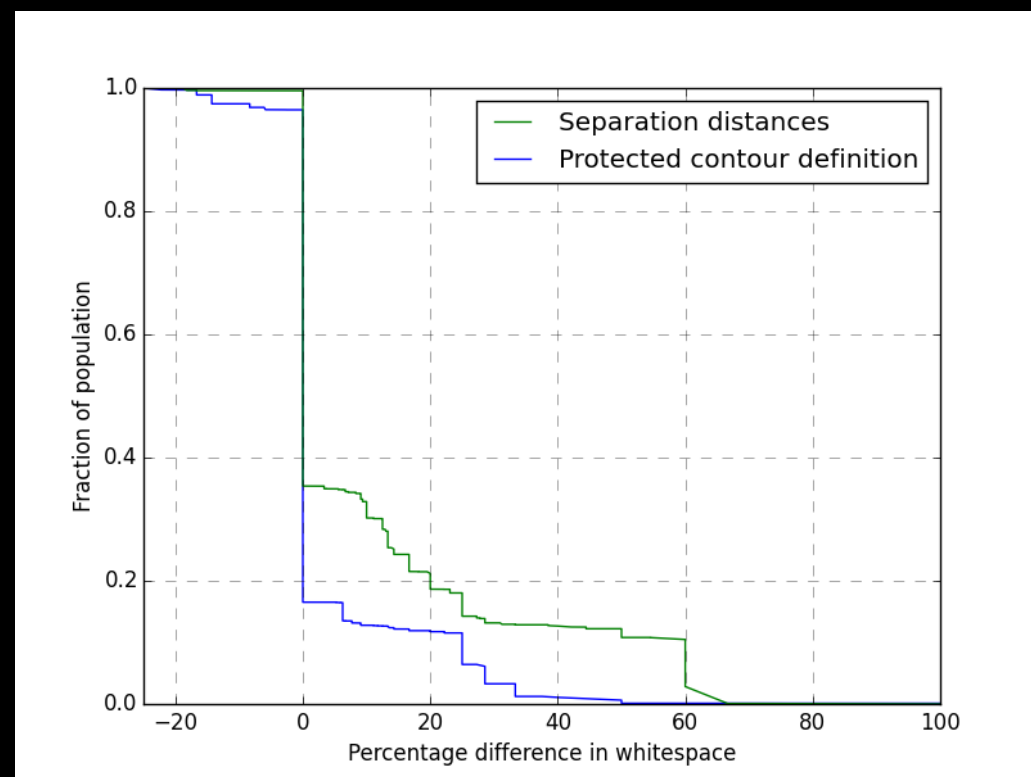
# FCC vs IC: Results

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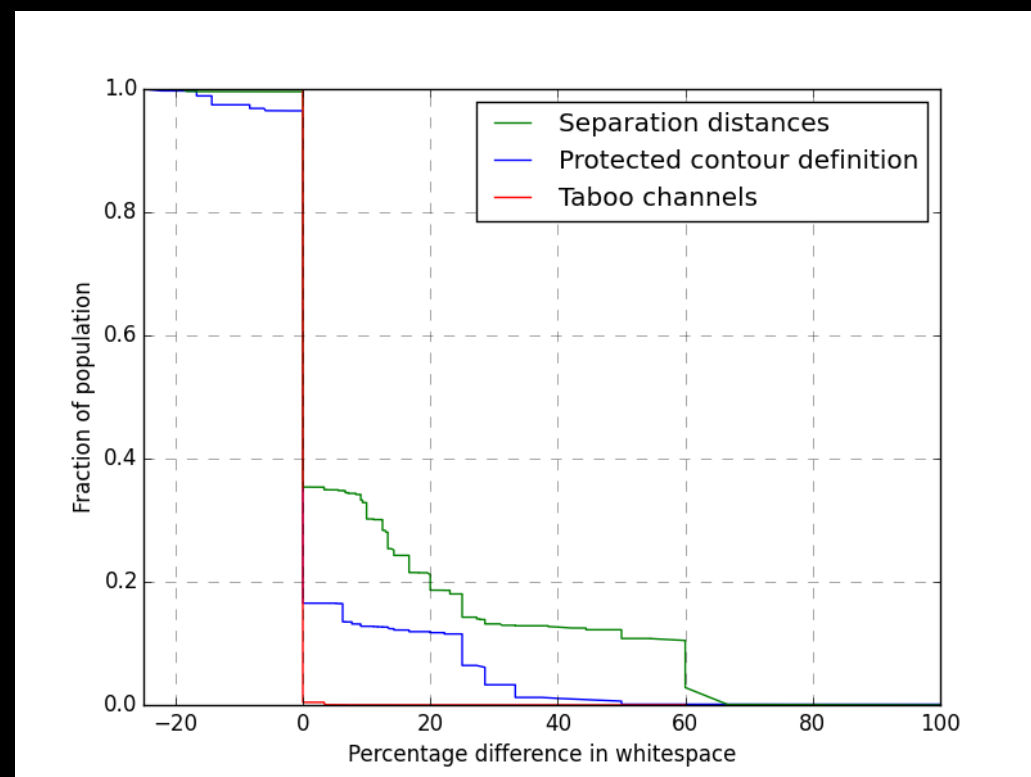
Canada

# FCC vs IC: Results



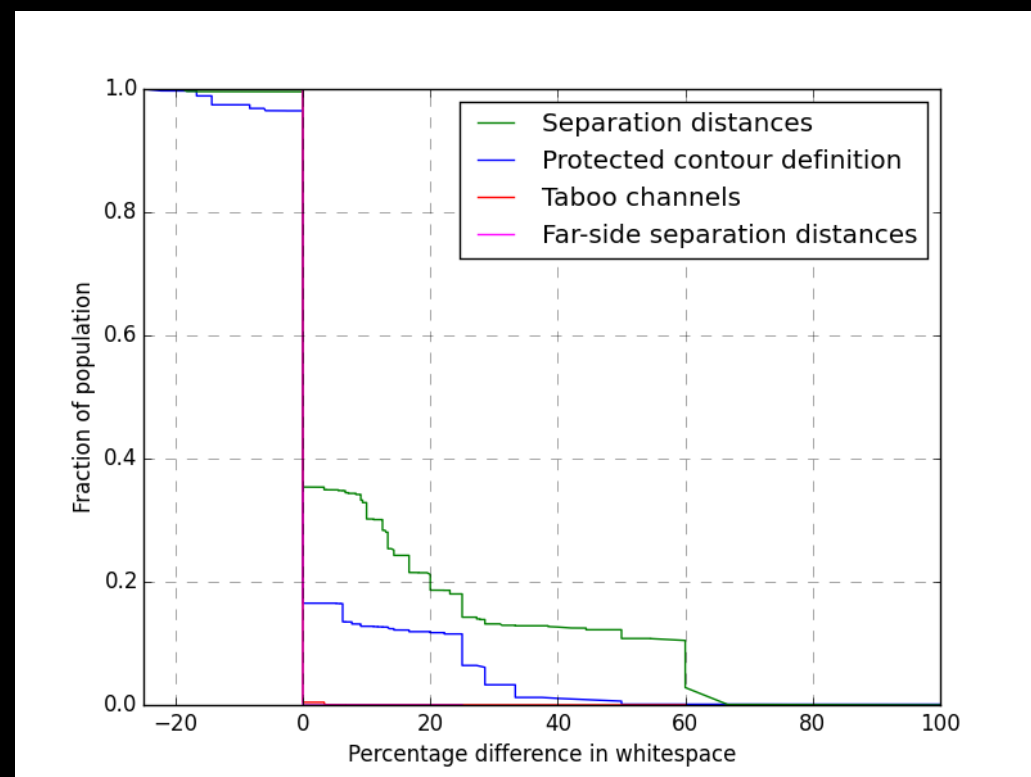
Canada

# FCC vs IC: Results



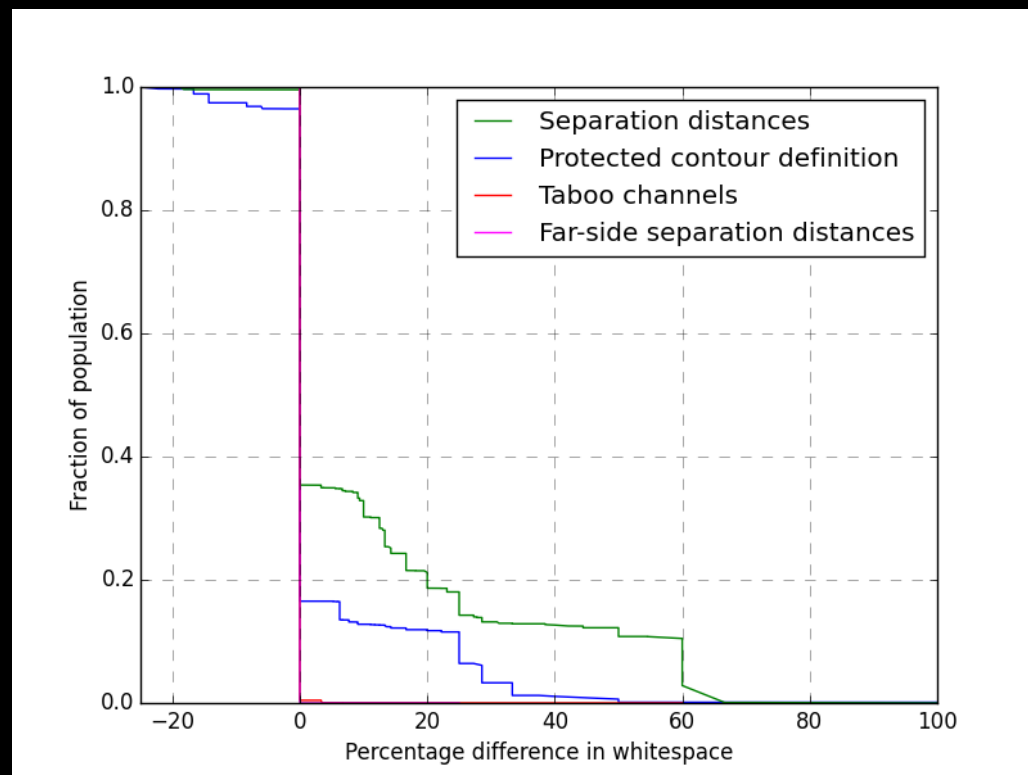
Canada

# FCC vs IC: Results

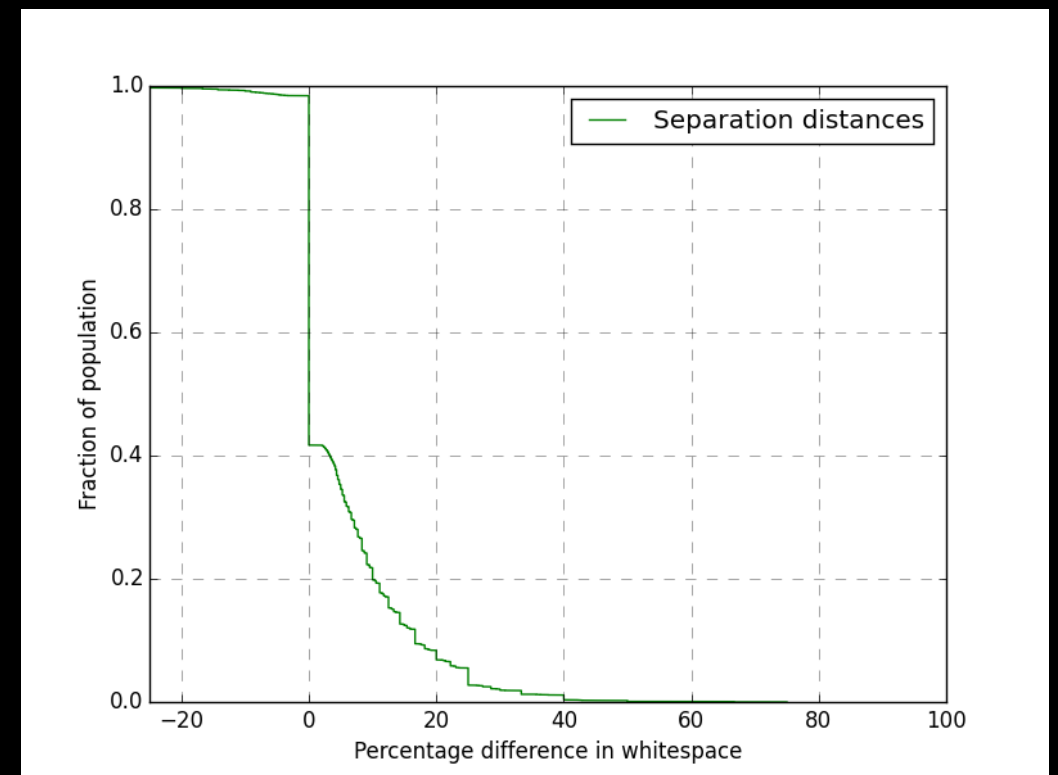


Canada

# FCC vs IC: Results



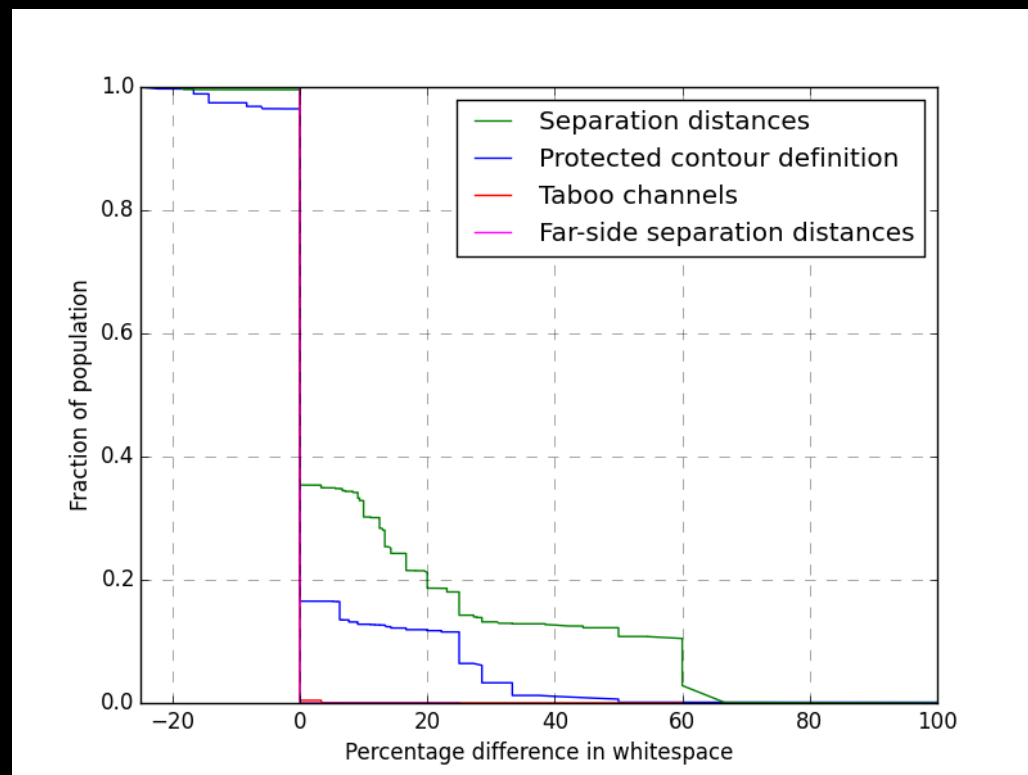
Canada



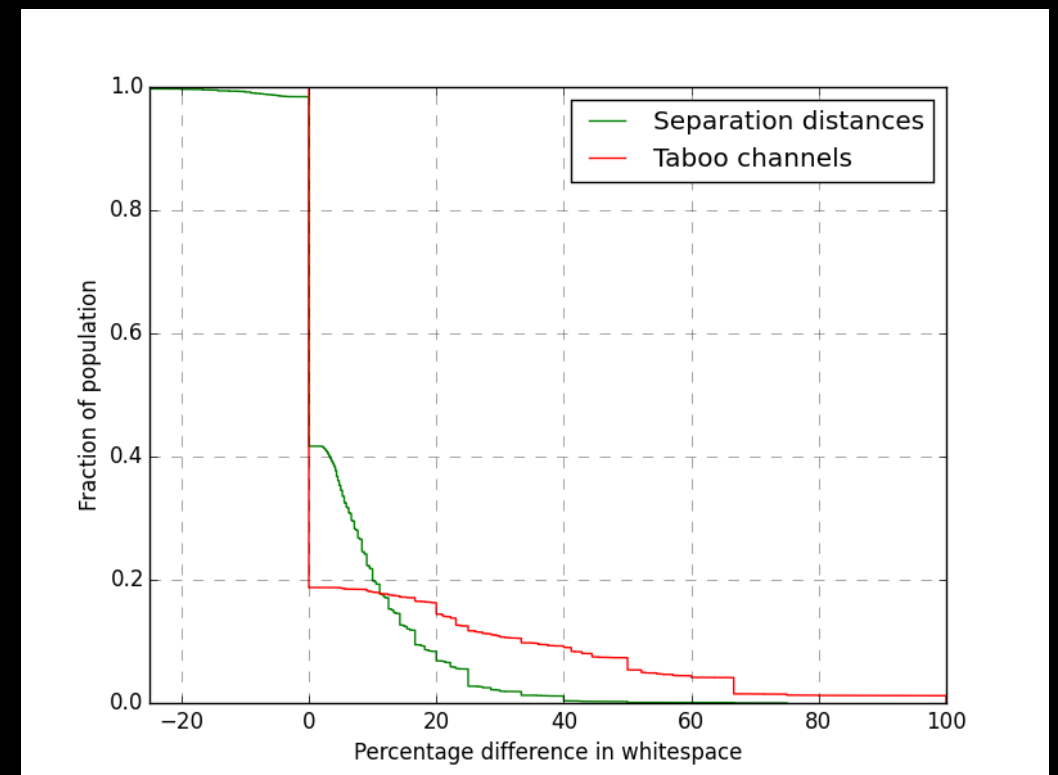
USA



# FCC vs IC: Results

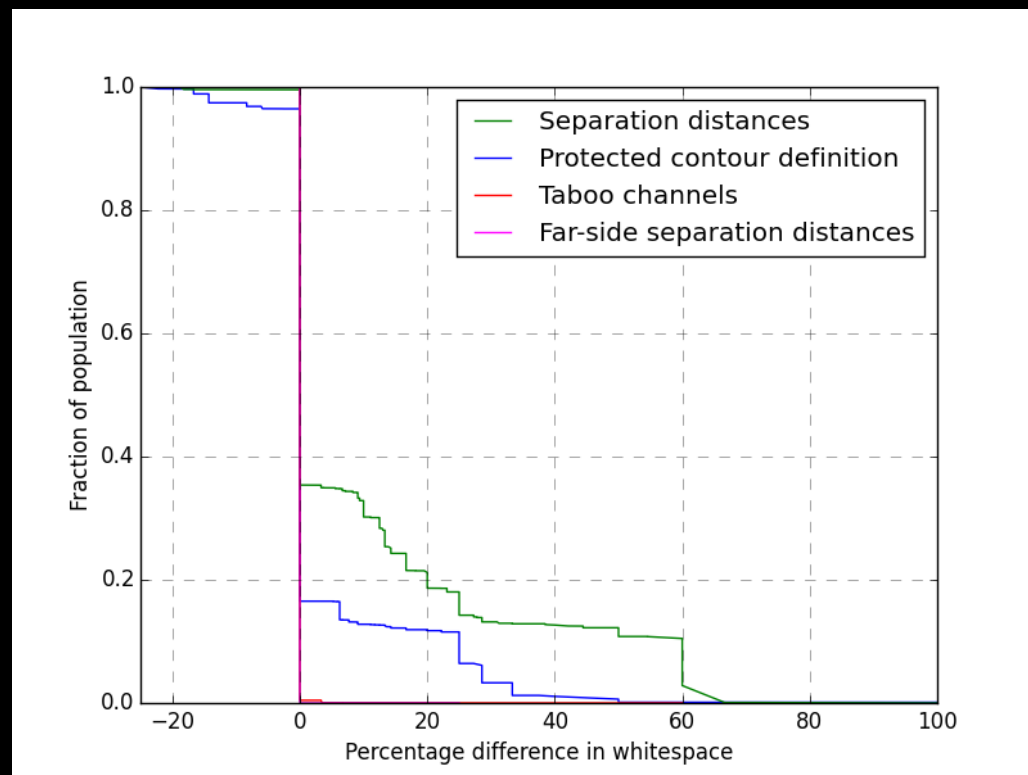


Canada

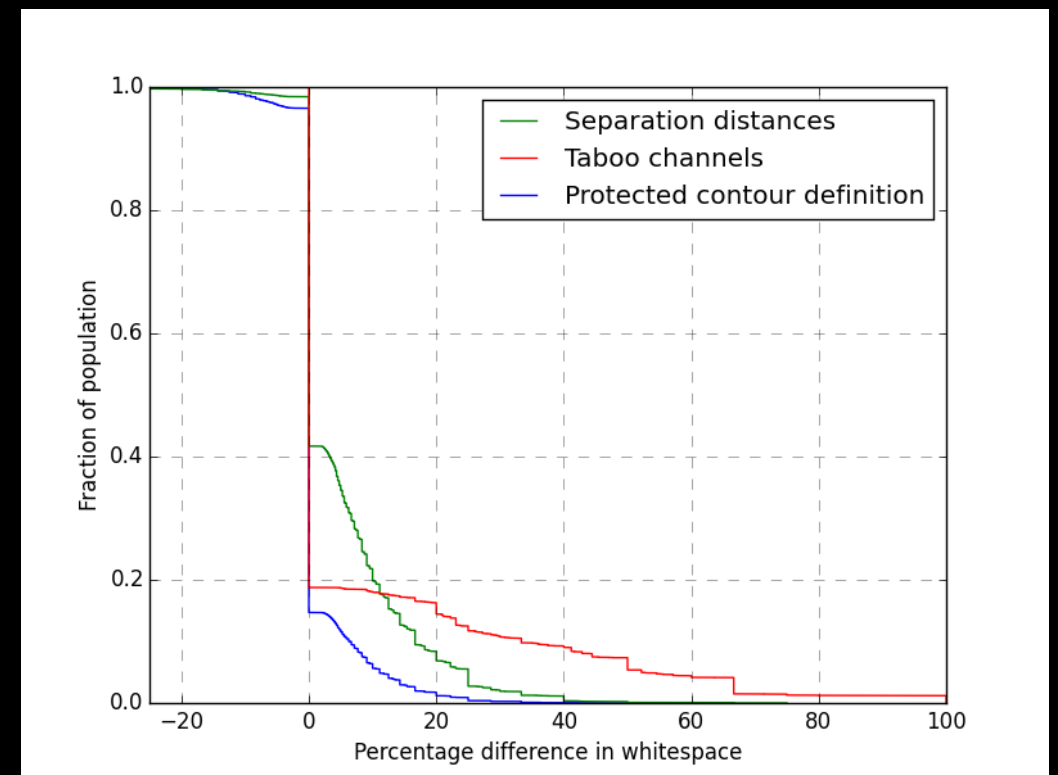


USA

# FCC vs IC: Results

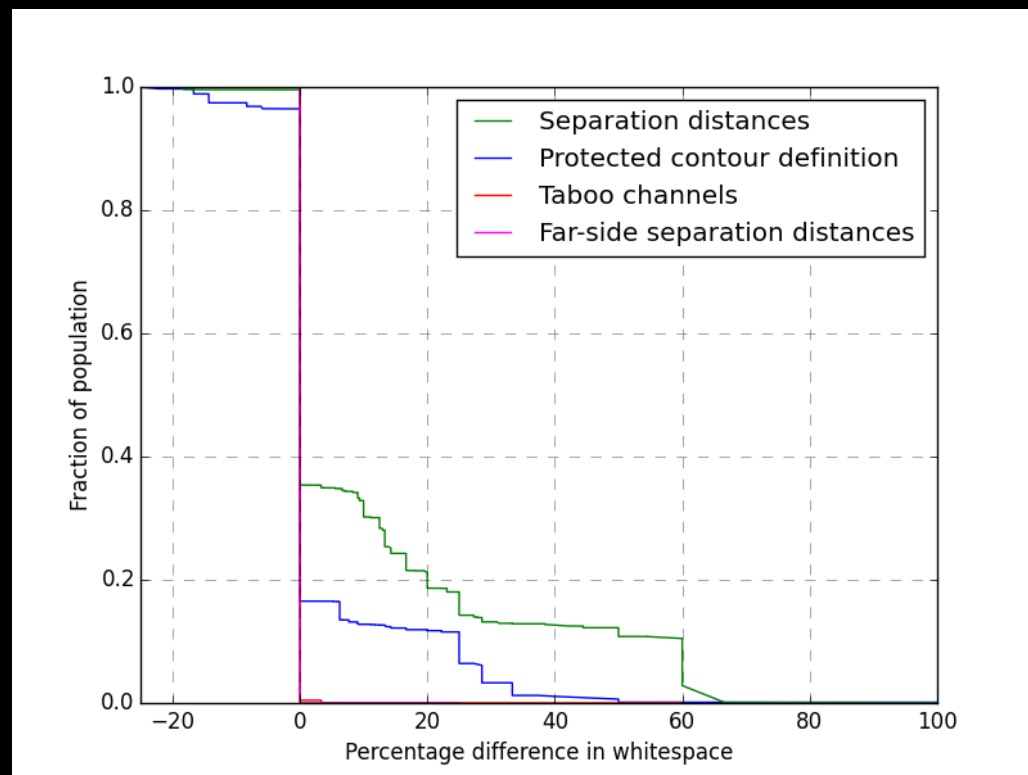


Canada

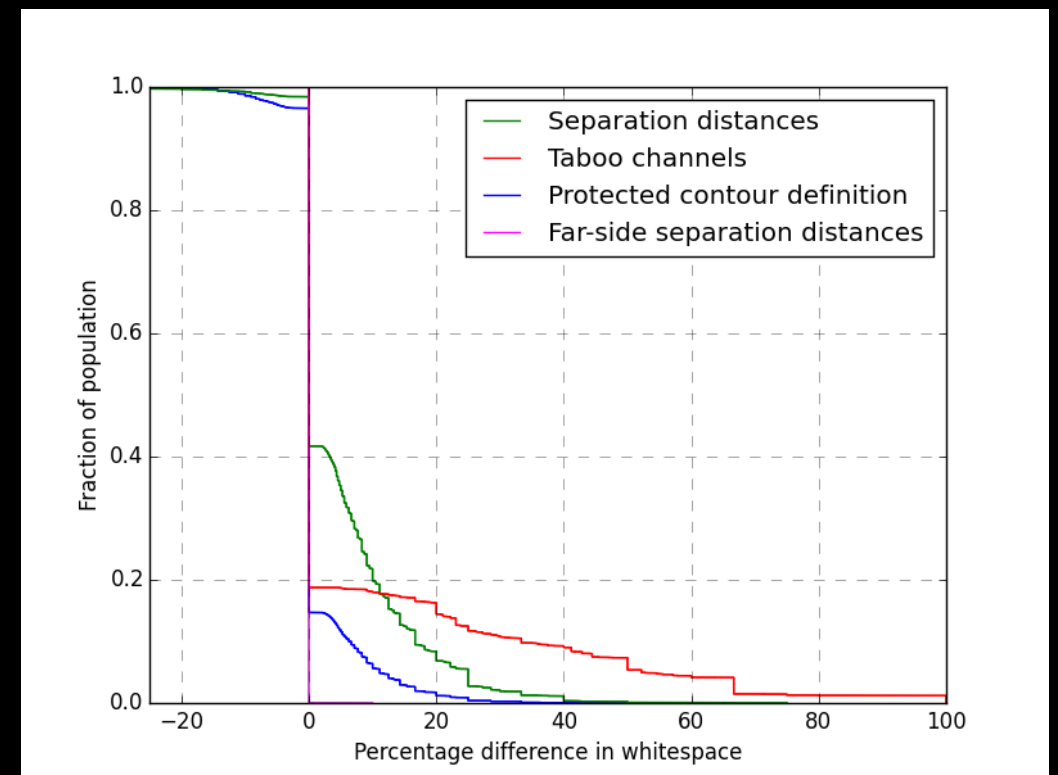


USA

# FCC vs IC: Results



Canada

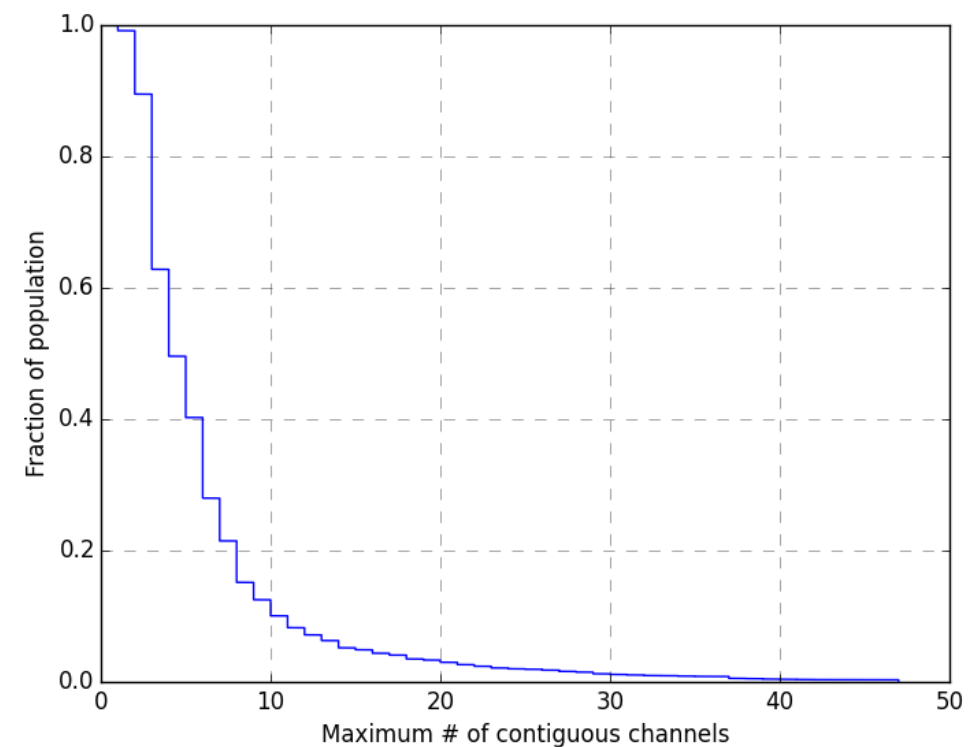
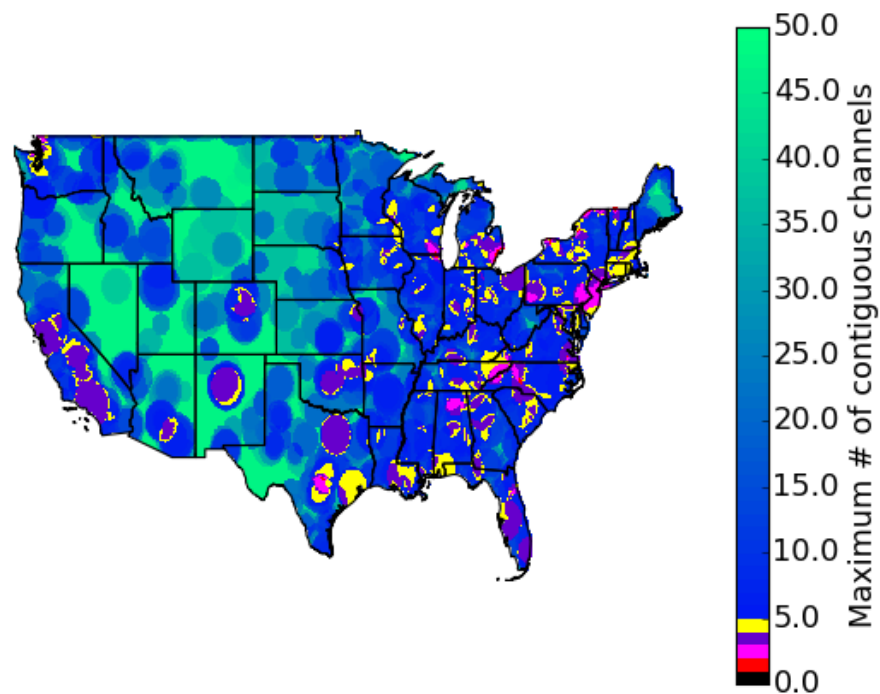


USA

# Applications of WEST:

## Contiguous channel whitespace availability

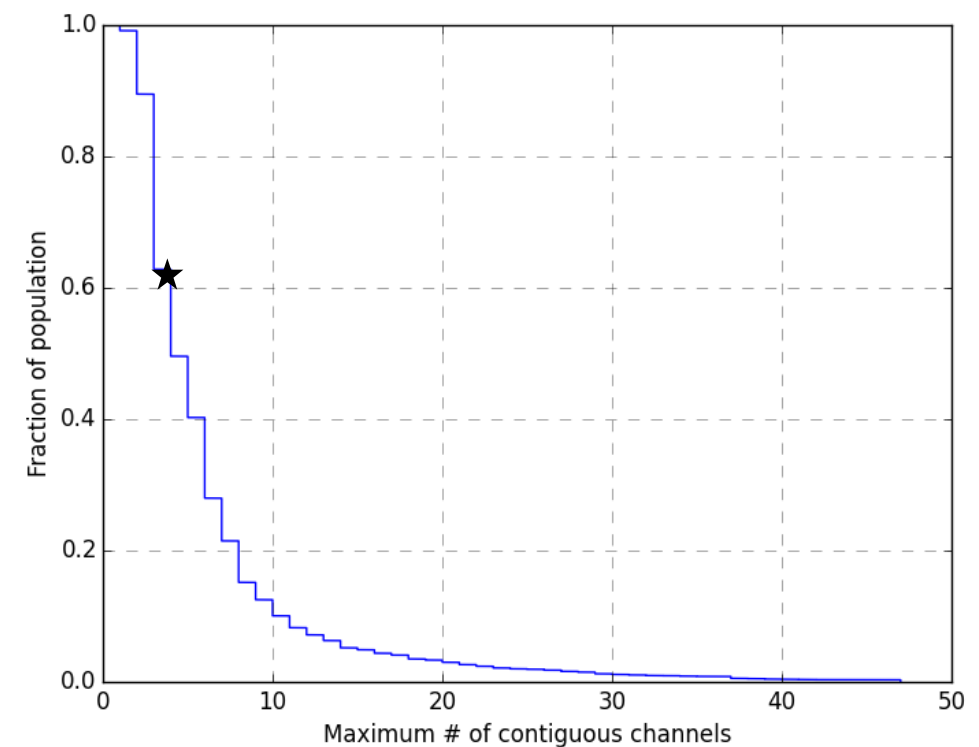
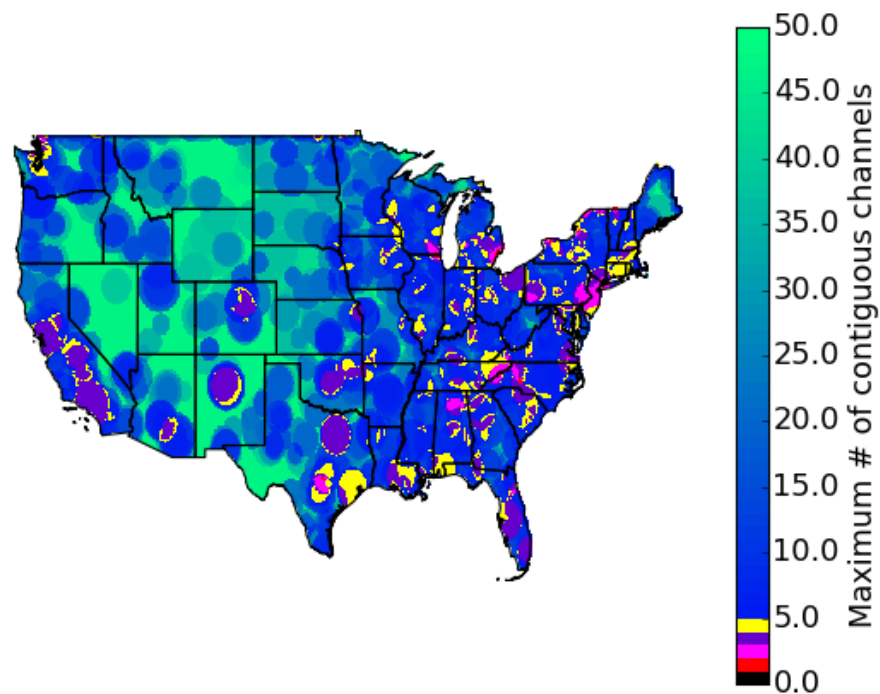
- Important for *practical implementation*
- < 50 lines of code



# Applications of WEST:

## Contiguous channel whitespace availability

- Important for *practical implementation*
- < 50 lines of code



# Other uses of WEST

- Comments to regulators (e.g. quantifying tradeoffs)
- Reproducible research
- New economic models

# Design

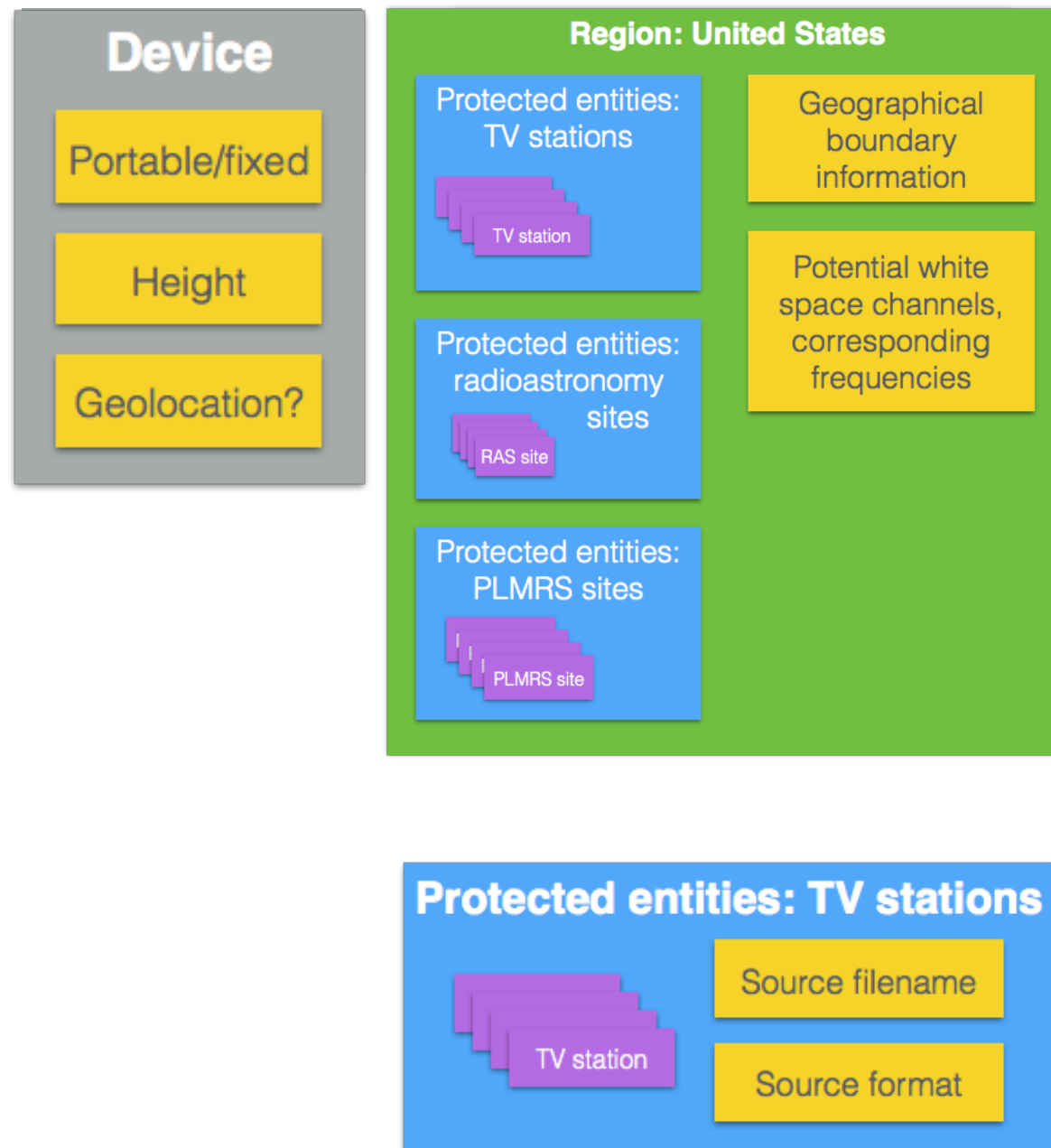
**Device**

Portable/fixed

Height

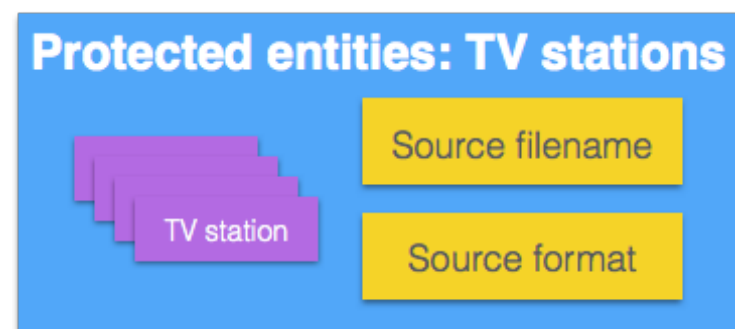
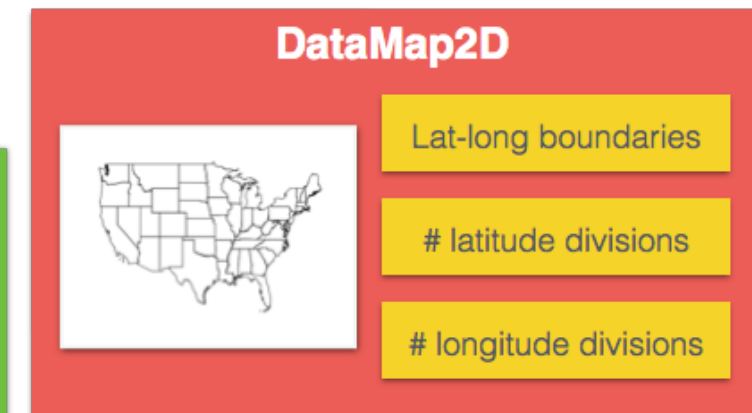
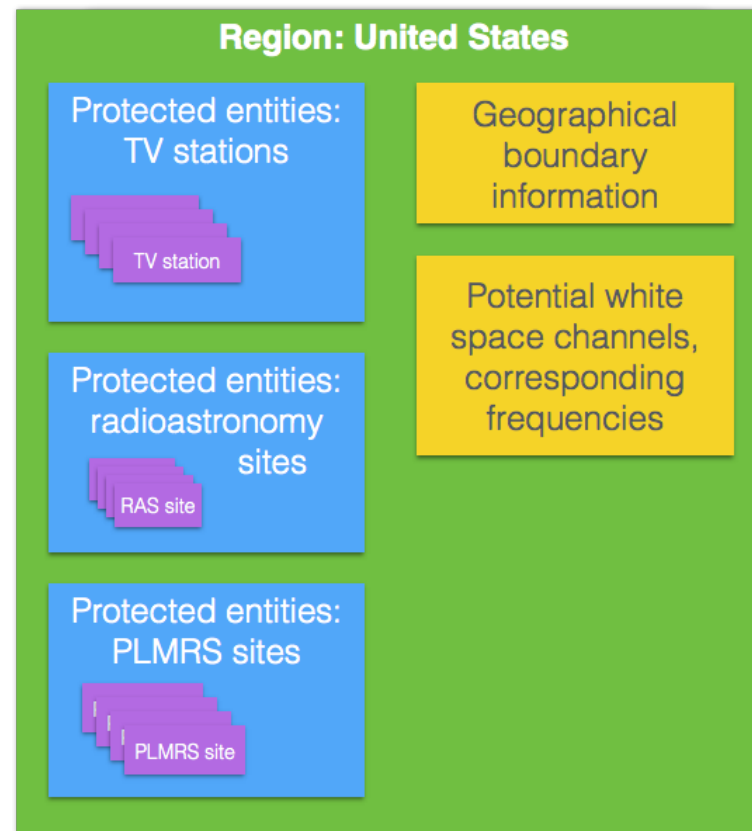
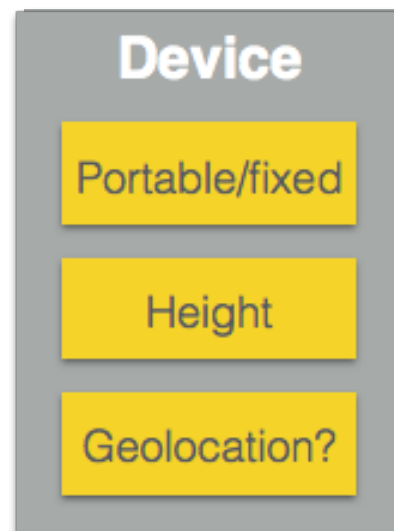
Geolocation?

# Design





# Design



# Design

Device: fixed



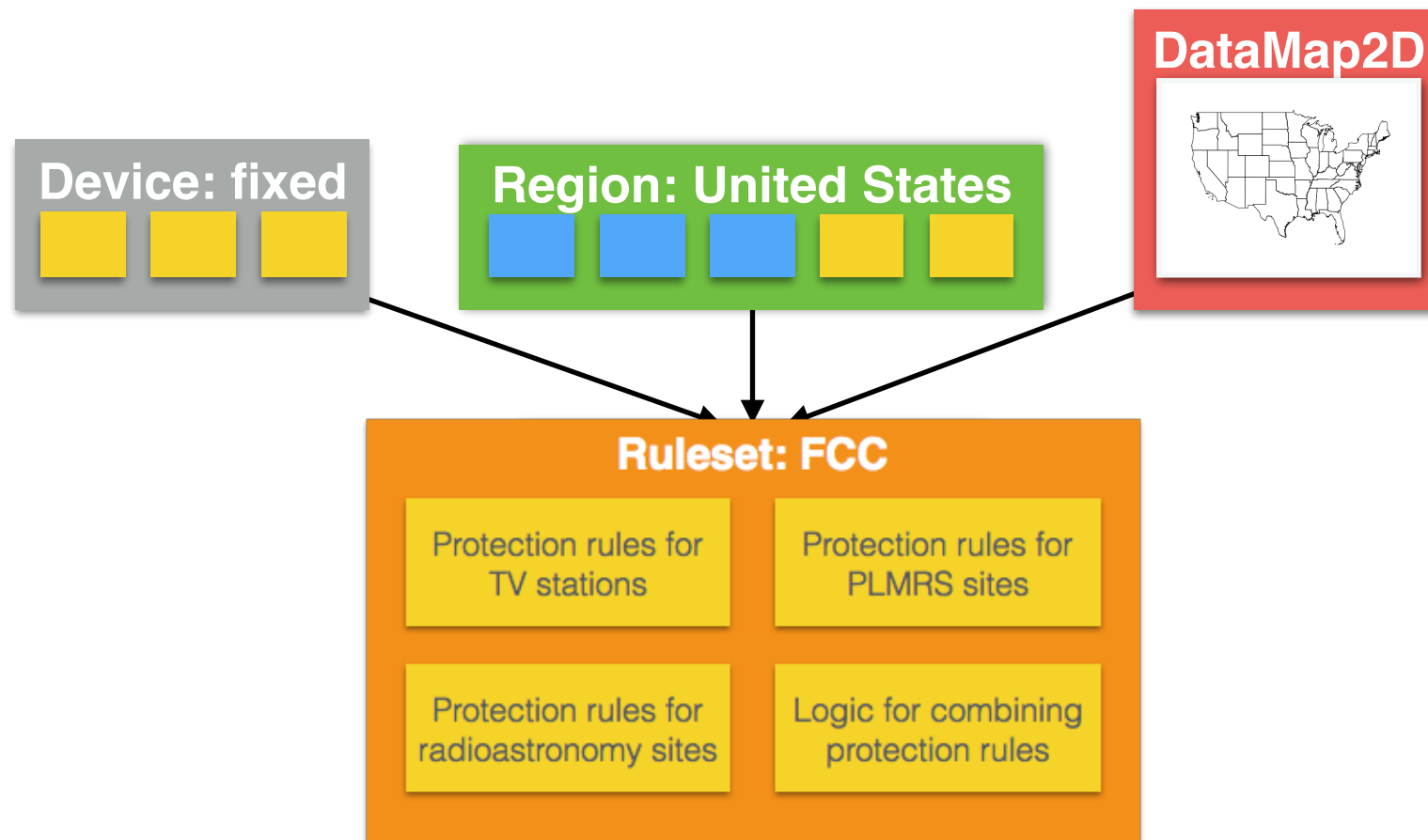
Region: United States



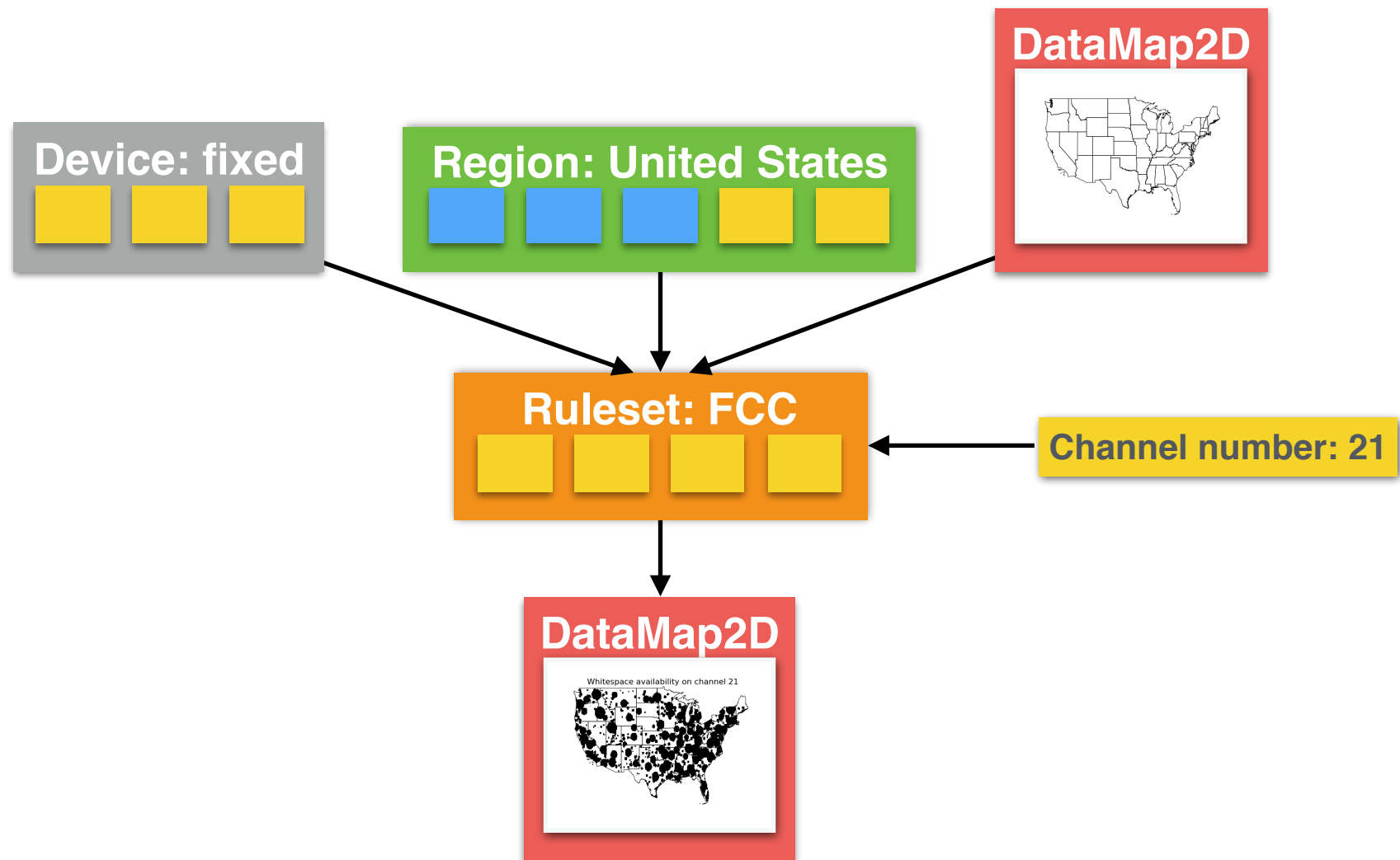
DataMap2D



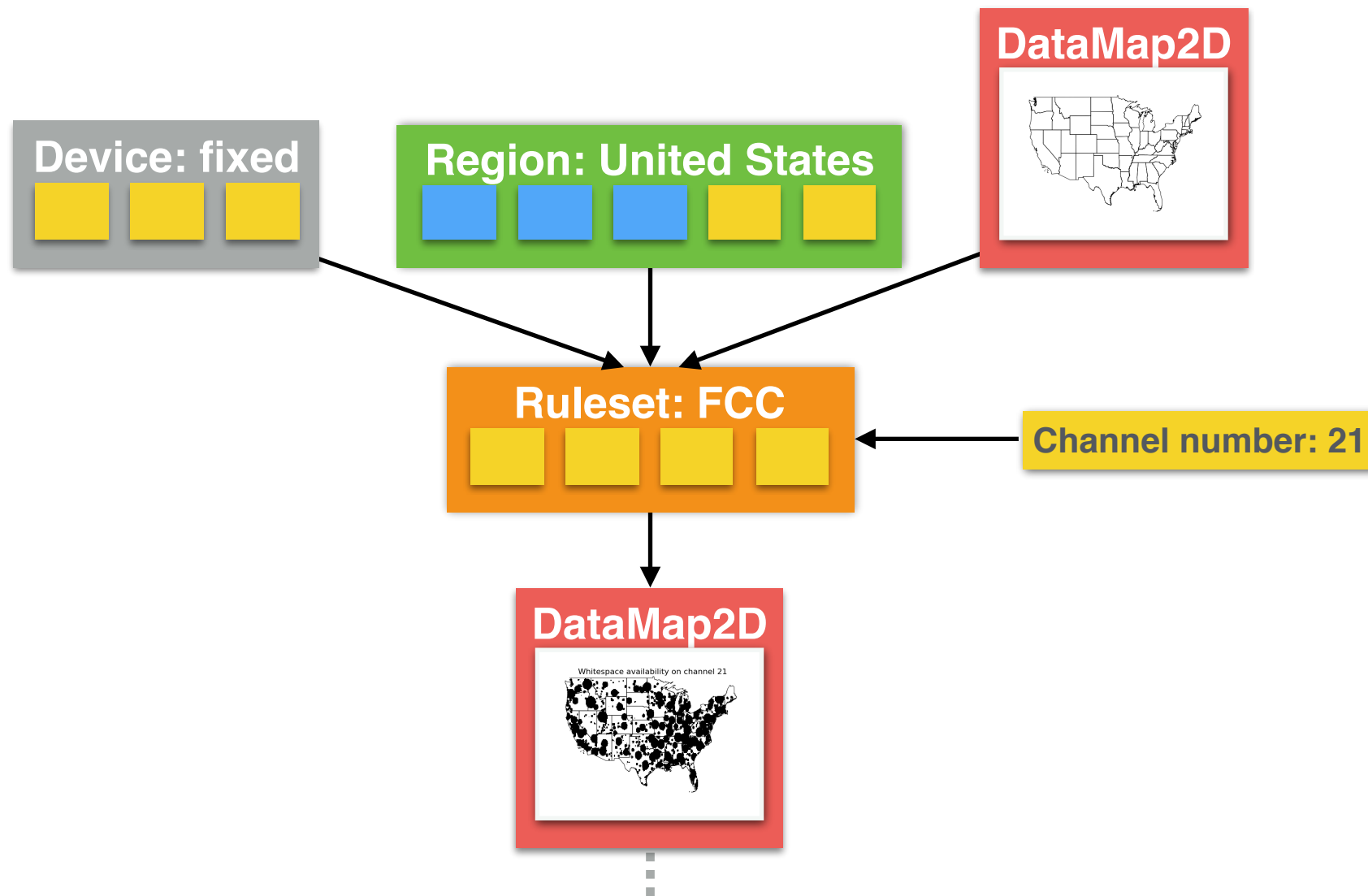
# Design



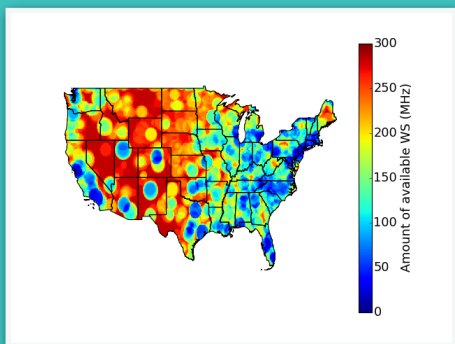
# Design



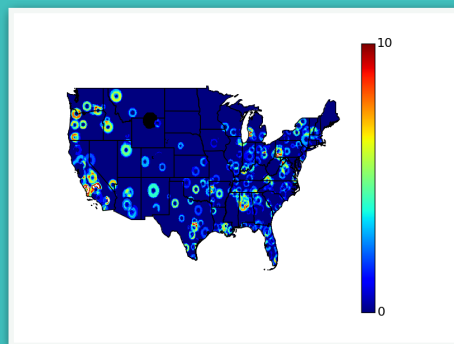
# Design



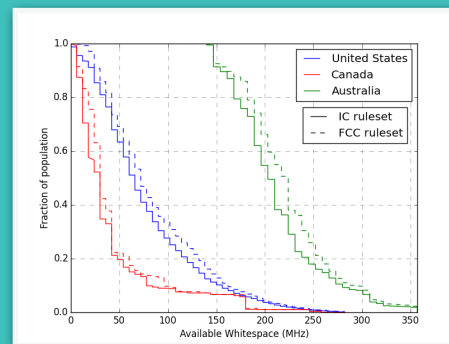
Whitespace channel count



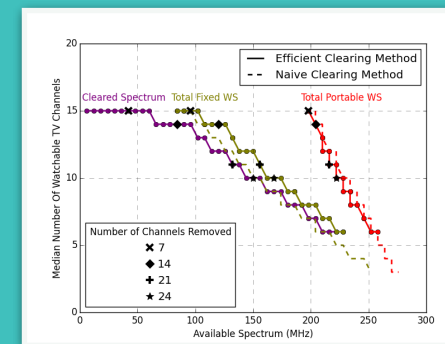
Whitespace delta map



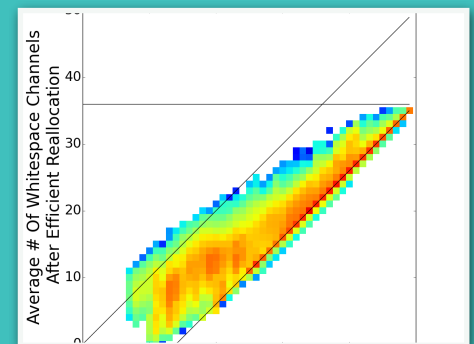
CCDFs by area, population



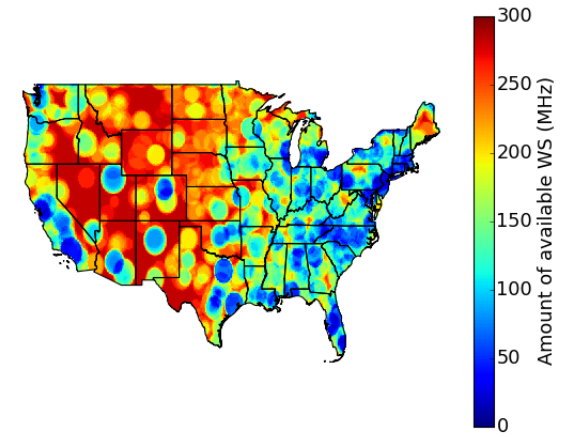
Pareto plots



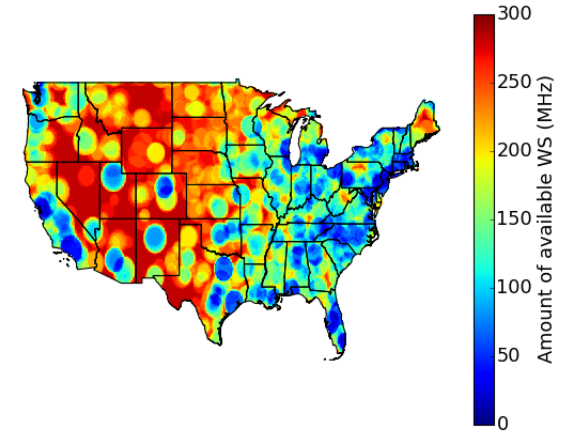
2D histograms



# Generating a whitespace map



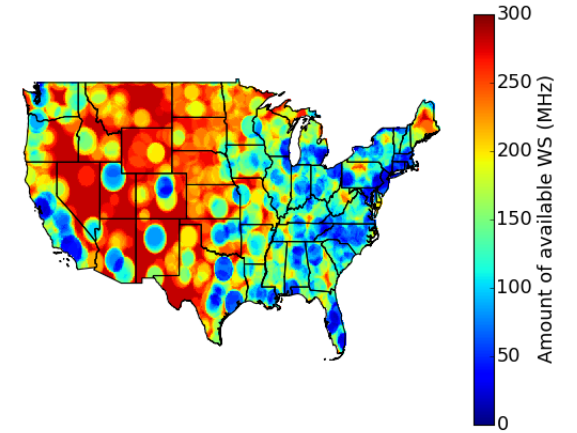
# Generating a whitespace map



```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device
```

Load WEST modules

# Generating a whitespace map



```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

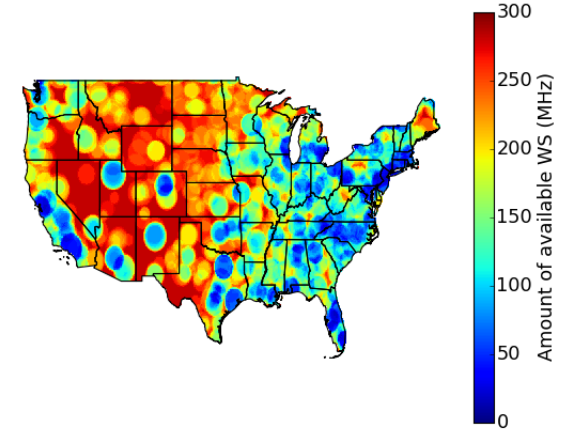
test_device = Device(is_portable=False, haat_meters=30)
```

## Specify the device

**Device**



# Generating a whitespace map



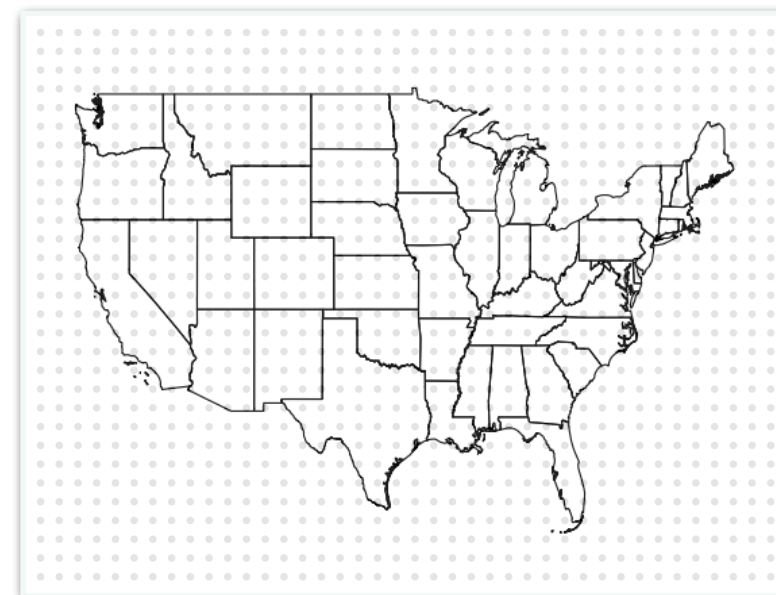
```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

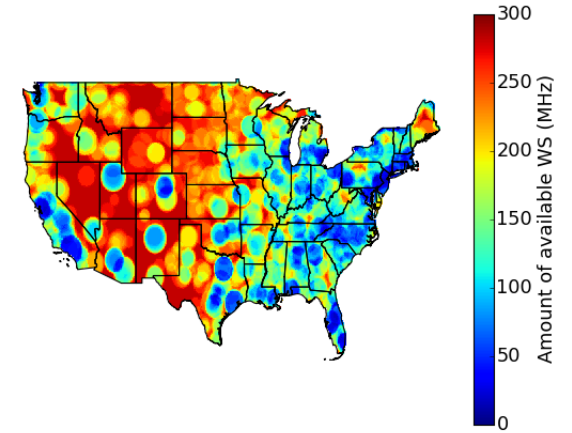
region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates,
                                          datamap_spec)
```

Define the  
grid we'll be  
working with



Continental US  
DataMap2D (original)

# Generating a whitespace map



```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

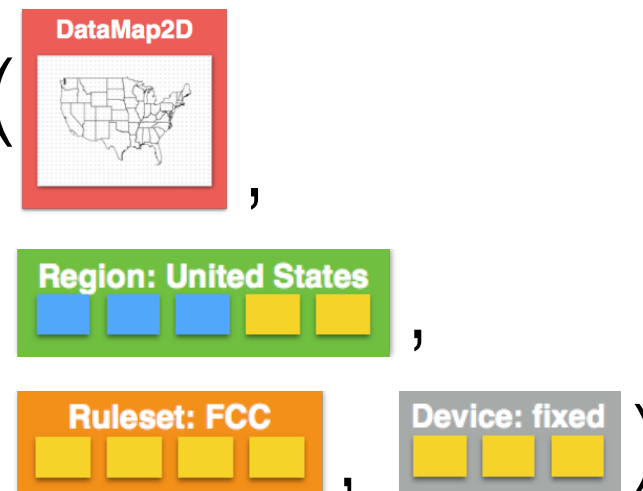
datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates,
                                          datamap_spec)

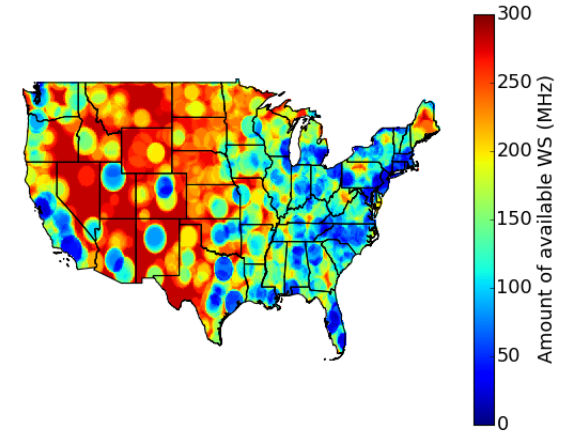
is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec,
                                                    RegionCanada,
                                                    RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()
```

generate\_whitespace\_map(



# Generating a whitespace map



```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

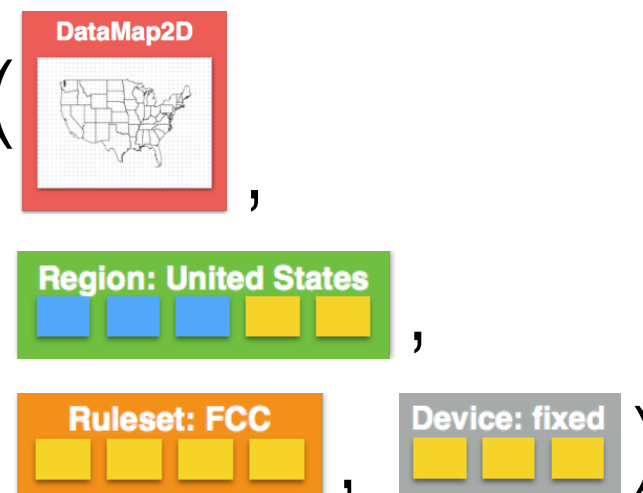
region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates,
                                         datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec,
                                                    RegionCanada,
                                                    RulesetFcc2012, test_device)

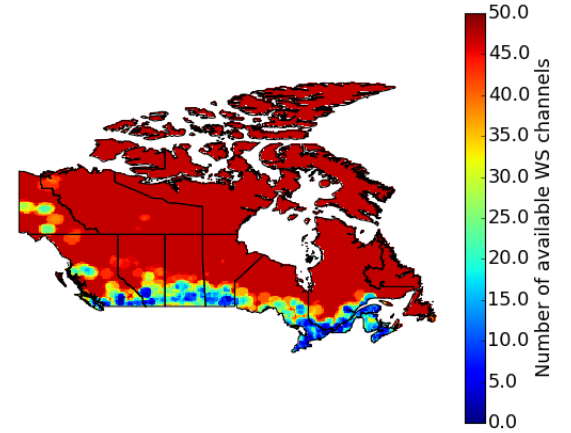
is_whitespace_map = is_whitespace_map_spec.fetch_data()
```

~~generate\_whitespace\_map(~~

“Specifications” are  
helpers that know how  
to generate data



# Generating a (Canadian) whitespace map



```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryCanada
from west.region_canada import RegionCanada
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

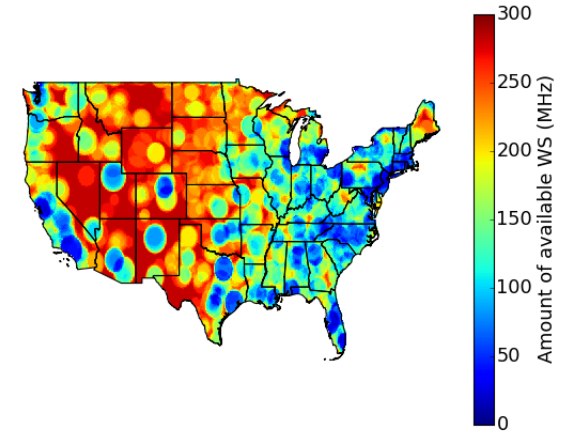
datamap_spec = SpecificationDataMap(DataMap2DCanada, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryCanada,
                                         datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec,
                                                    RegionCanada,
                                                    RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()
```

# Generating a whitespace map



```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

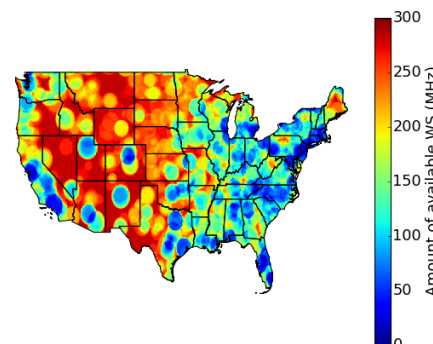
datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates,
                                         datamap_spec)

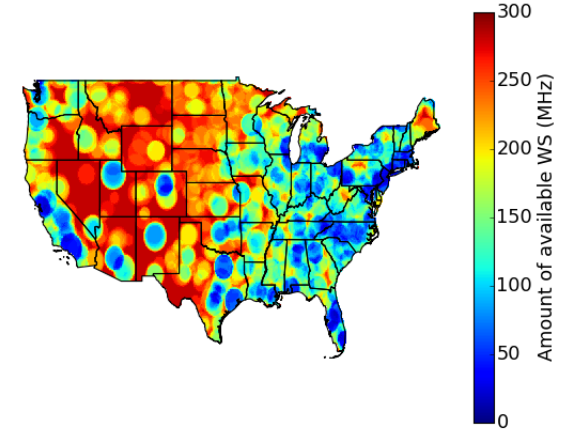
is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec,
                                                    RegionUnitedStates,
                                                    RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()
total_whitespace_channels = is_whitespace_map.sum_all_layers()

is_in_region_map = region_map_spec.fetch_data()
plot = total_whitespace_channels.make_map(is_in_region_map=is_in_region_map)
```



# Generating a whitespace map



```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates,
                                          datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec,
                                                    RegionUnitedStates,
                                                    RulesetFcc2012, test_device)

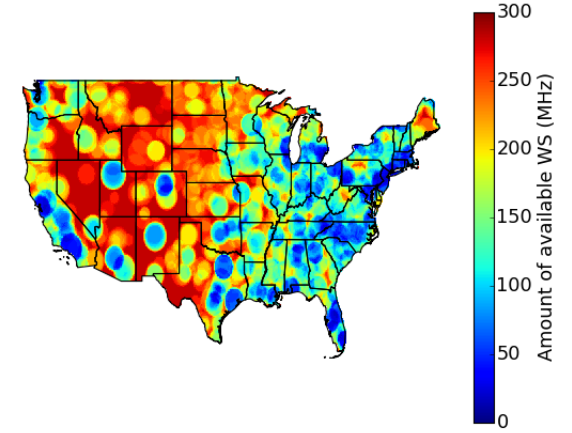
is_whitespace_map = is_whitespace_map_spec.fetch_data()
total_whitespace_channels = is_whitespace_map.sum_all_layers()

is_in_region_map = region_map_spec.fetch_data()
plot = total_whitespace_channels.make_map(is_in_region_map=is_in_region_map)

plot.add_boundary_outlines(boundary=BoundaryContinentalUnitedStatesWithStateBoundaries())
plot.set_boundary_color('k')
plot.set_boundary_linewidth('1')
```

Add the state outlines (in black)

# Generating a whitespace map



```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates,
                                          datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec,
                                                    RegionUnitedStates,
                                                    RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()
total_whitespace_channels = is_whitespace_map.sum_all_layers()

is_in_region_map = region_map_spec.fetch_data()
plot = total_whitespace_channels.make_map(is_in_region_map=is_in_region_map)

plot.add_boundary_outlines(boundary=BoundaryContinentalUnitedStatesWithStateBoundaries())
plot.set_boundary_color('k')
plot.set_boundary_linewidth('1')

plot.save("Number of TVWS channels in the United States.png")
```

Save the plot

# Important!

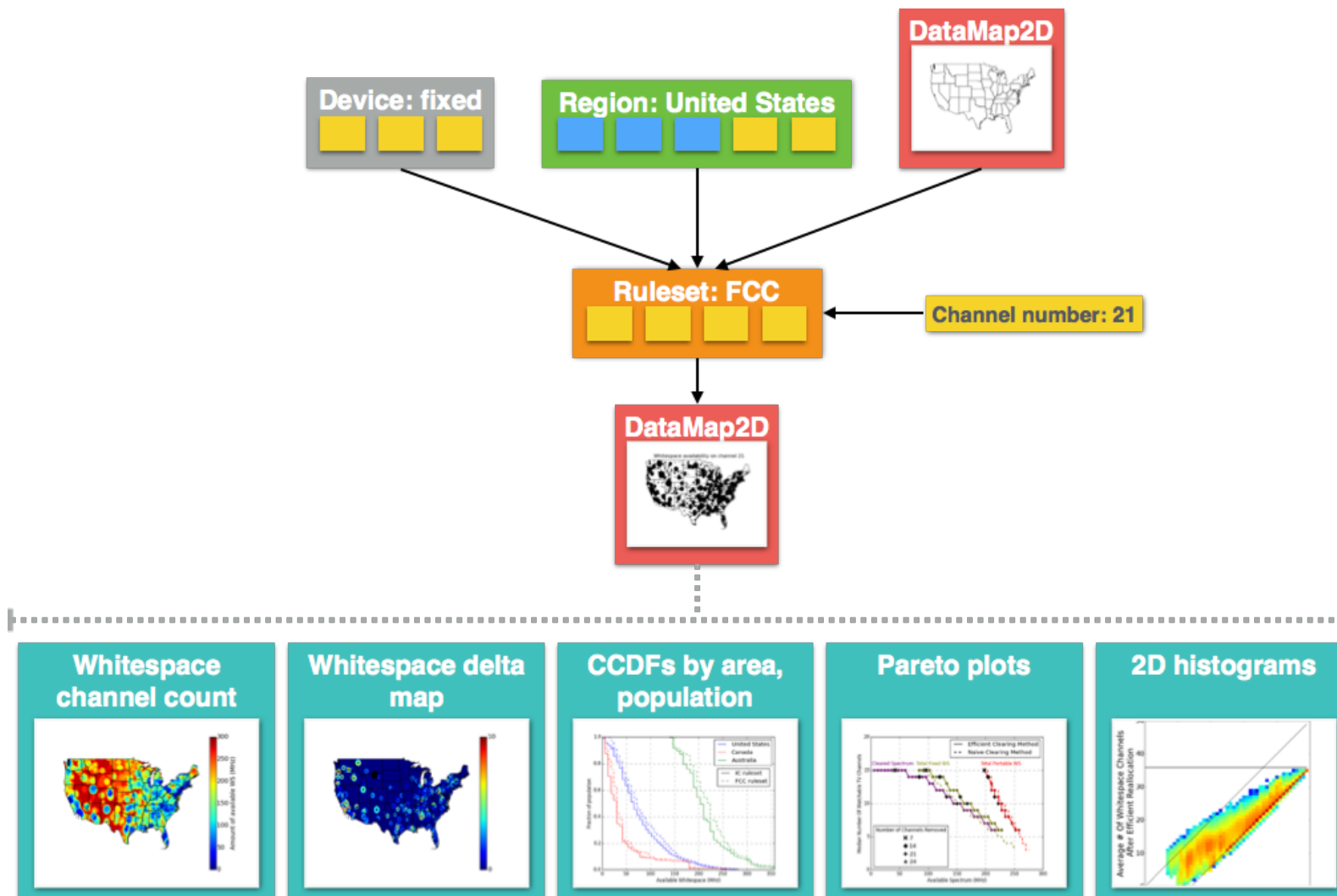
- WEST supports existing research
- Competition is good



# Many exciting directions

- Expand supported regions (“only” US, Canada, and Australia today)
- More propagation models (F-curves today)
- More rulesets (e.g. DSA model rules)
- Applied to another band
- New economic models
- Integrated with the cloud

# Questions?



[west.kateharrison.net](http://west.kateharrison.net)