

Lights Out!

Climate Change Risk to Internet Infrastructure

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I'm a climate change skeptic...

I've looked at the data...

Things are much worse than is being reported.

Overview

- **Climate change is most significant issue facing mankind**
- **General objectives of our work: **assess risks**, potential impact, and mitigation strategies for the internet**
- **Today's talk**
 - **Climate change overview**
 - **Approach for assessing risk to internet infrastructure**
 - **Results of our analysis**

Climate change

- **Definition: *shifts in worldwide weather phenomena associated with increased global average temperatures, attributed largely to human activity over the past century***
- **Scientific evidence for warming of the climate system is unequivocal (Intergovernmental Panel on Climate Change)**

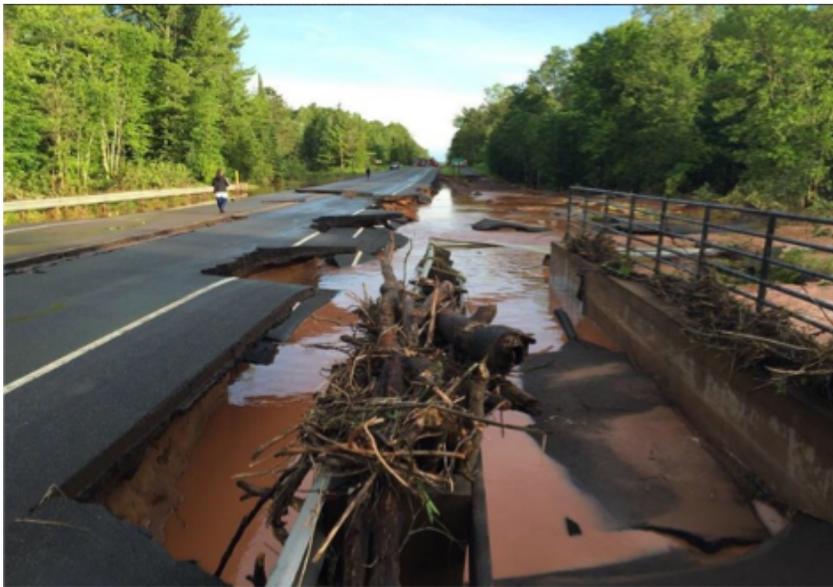


Source: NASA

Effects of increased CO2

- **CO2 is a greenhouse gas**
 - Traps heat in the atmosphere
- **Record average/maximum temps**
 - See recent NYT interactive feature (sobering)
- **Extreme weather events are more common**
- **Sea levels are rising**
- **Secondary effects could be significant**
 - Food security, loss of property, displaced populations, habitat loss

Fires, floods and storms



Sea level rise



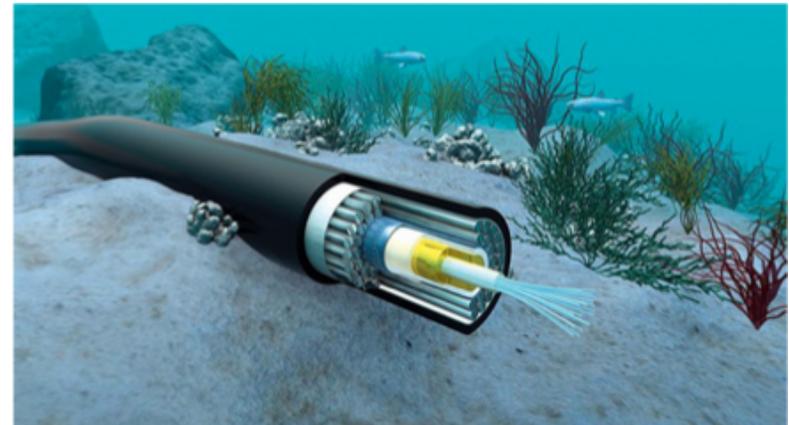
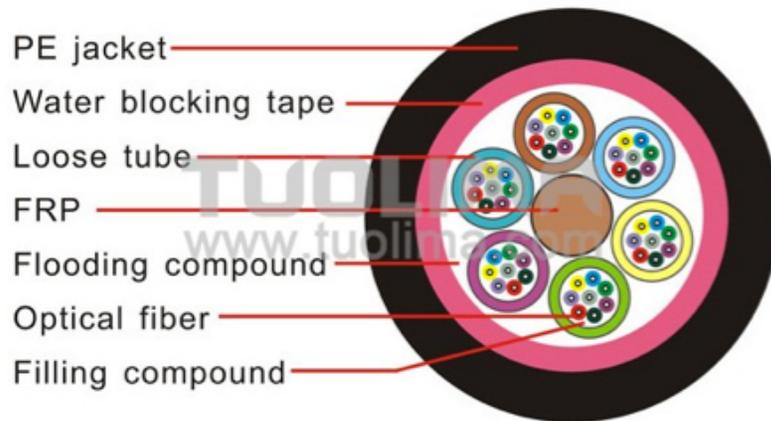
Research question

What is the risk of sea level rise to the Internet infrastructure?



“Internet infrastructure” - links

- Fiber conduits deployed on land and under water



“Internet infrastructure” - nodes

- Nodes: locations where fiber conduits connect



Approach

- **Geographic overlap analysis of internet physical infrastructure vs. projected sea levels**
 - Projection and transformation tool in ESRI's ArcGIS
 - Challenge: varying formats of the two GIS datasets
- **Coastal Infrastructure Risk (CIR) metric quantifies geographic scope and infrastructure density**
- **Internet infrastructure from Internet Atlas**
 - See NANOG 61
- **Sea Level Rise Inundation models from NOAA's office of coastal management**
 - <https://coast.noaa.gov/digitalcoast/>

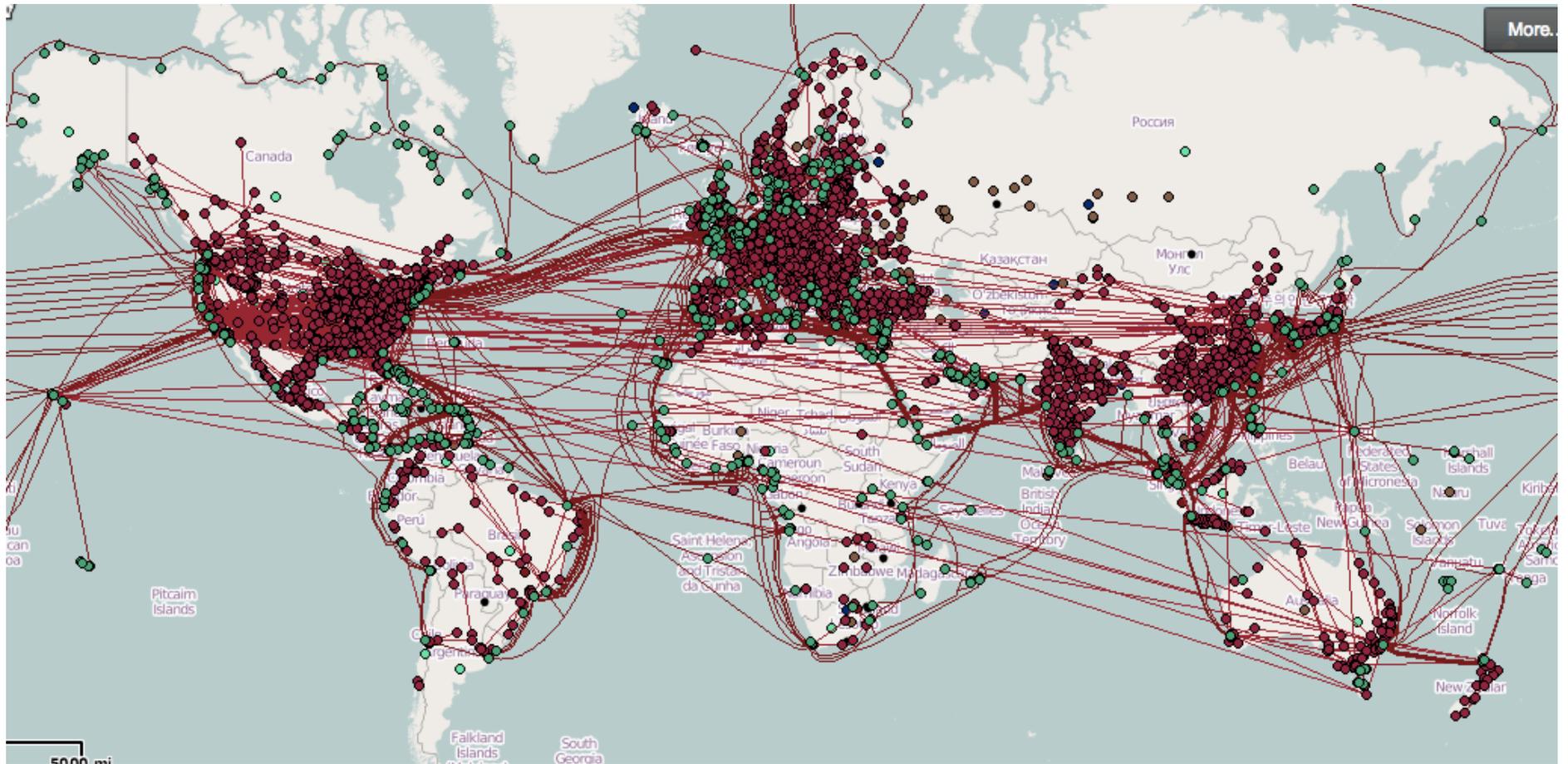
Internet Atlas in brief

- **Key features**
 - Largest database of *physical Internet infrastructure* (buildings that house PoPs, IXPs etc. and fiber conduits)
 - Web portal for visualization and analysis
- **Key differentiators**
 - Size: over 1,500 maps
 - Detail: all maps are geocoded
 - Functionality: maps + algorithms + measurement
- **Supported by the *DHS IMPACT*, NSA, NSF**

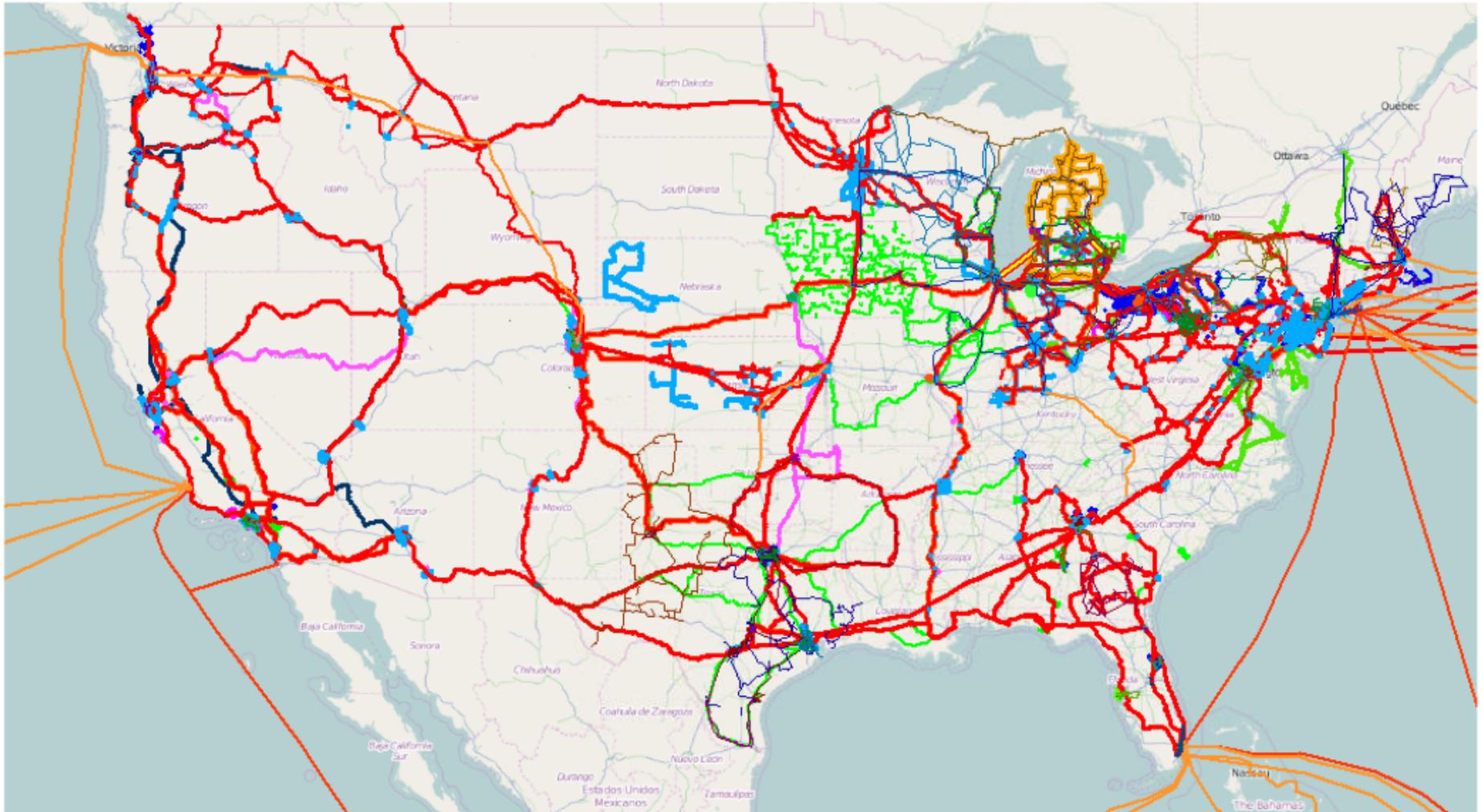
Snapshot of maps in Atlas



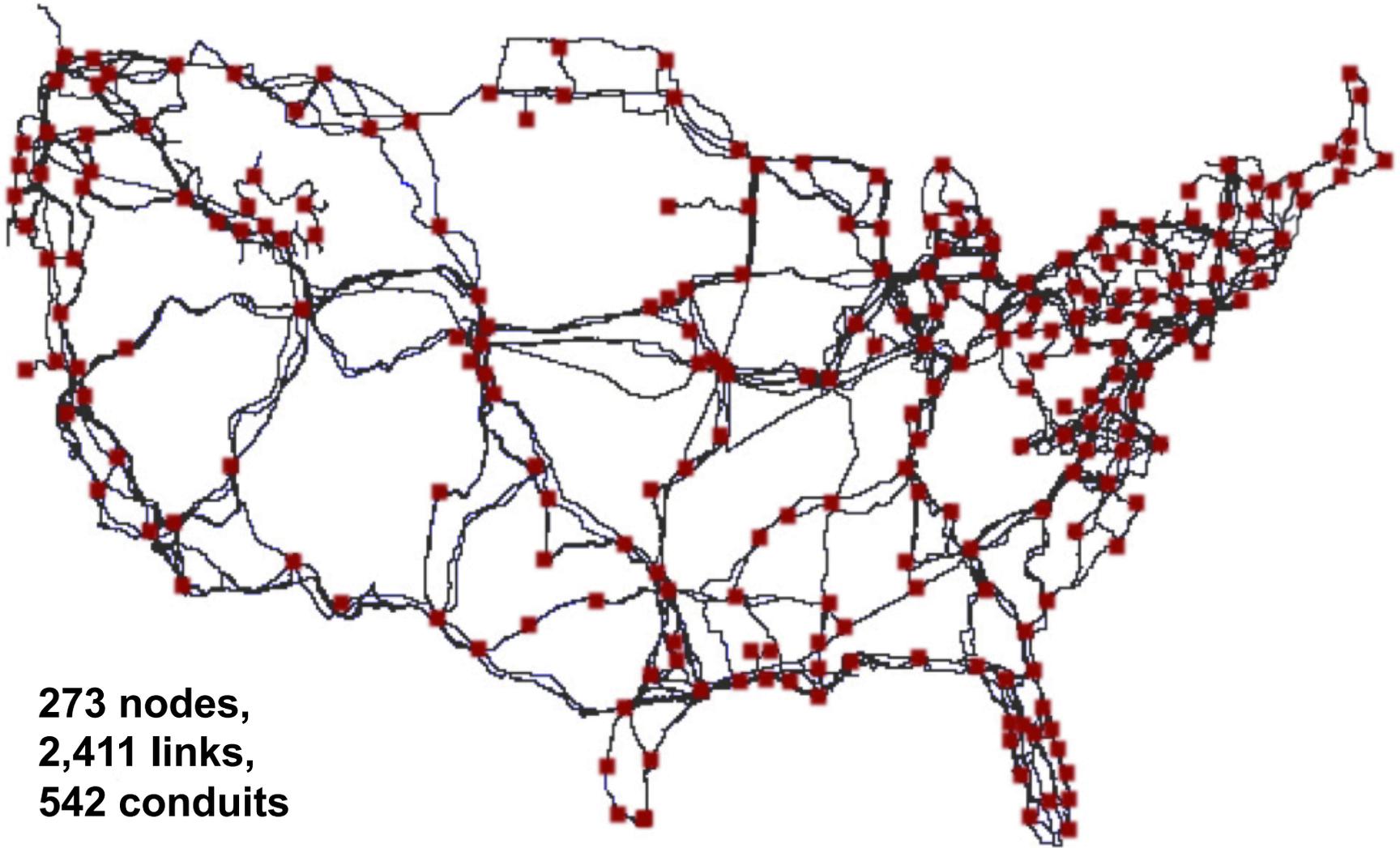
Internet Atlas – full view



US metro fiber infrastructure



US long-haul infrastructure



Sea level rise modeling

- **Sea Level Rise Inundation map data from NOAA's Office of Coastal Management**
 - **Projections of sea level rise scenarios (in ft.) for coastal counties over next 100 years**
 - **Modified bathtub approach**
 - **Consider local geographic features, tidal activity, hydrological features, and projected sea level rise (polar and glacial ice melt, thermal expansion, storage on land)**
- **We use highest mean rise scenario**

Year	2030	2045	2060	2075	2090	2100
Projected Rise (ft.)	1	2	3	4	5	6

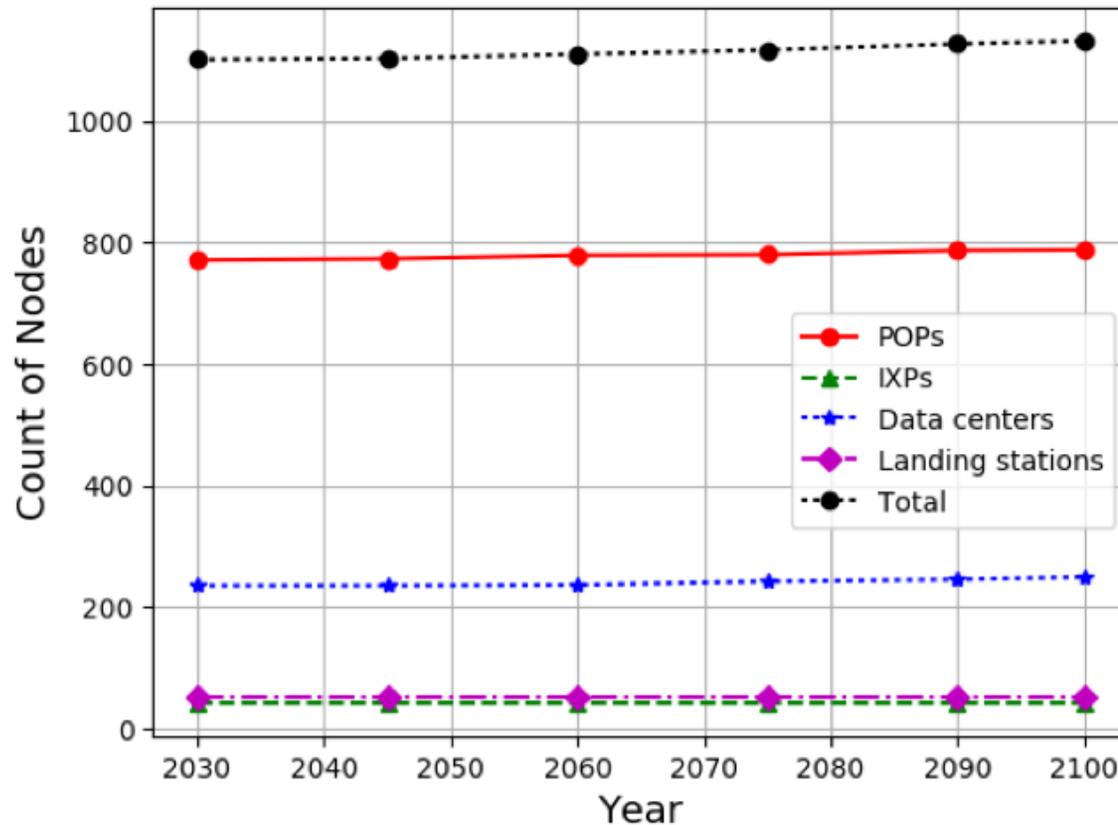
Sea level rise and the Internet

- **Water, humidity and ice are threats to fiber optics**
[Datwyler' 14]
 - **Signal attenuation/loss, corrosion damage and fiber breakage**
- **Observations**
 - **Infrastructure deployments are not designed to be *under water***
 - **Deployments are ~20 years old and are aging**
- **Potential risks to the Internet infrastructure**
 - **Physical damage**
 - **Buried conduits are prone to inundation and corrosion**
 - **Aging deployments are more vulnerable to damage, esp. if under water**

Quantifying effects of sea level rise

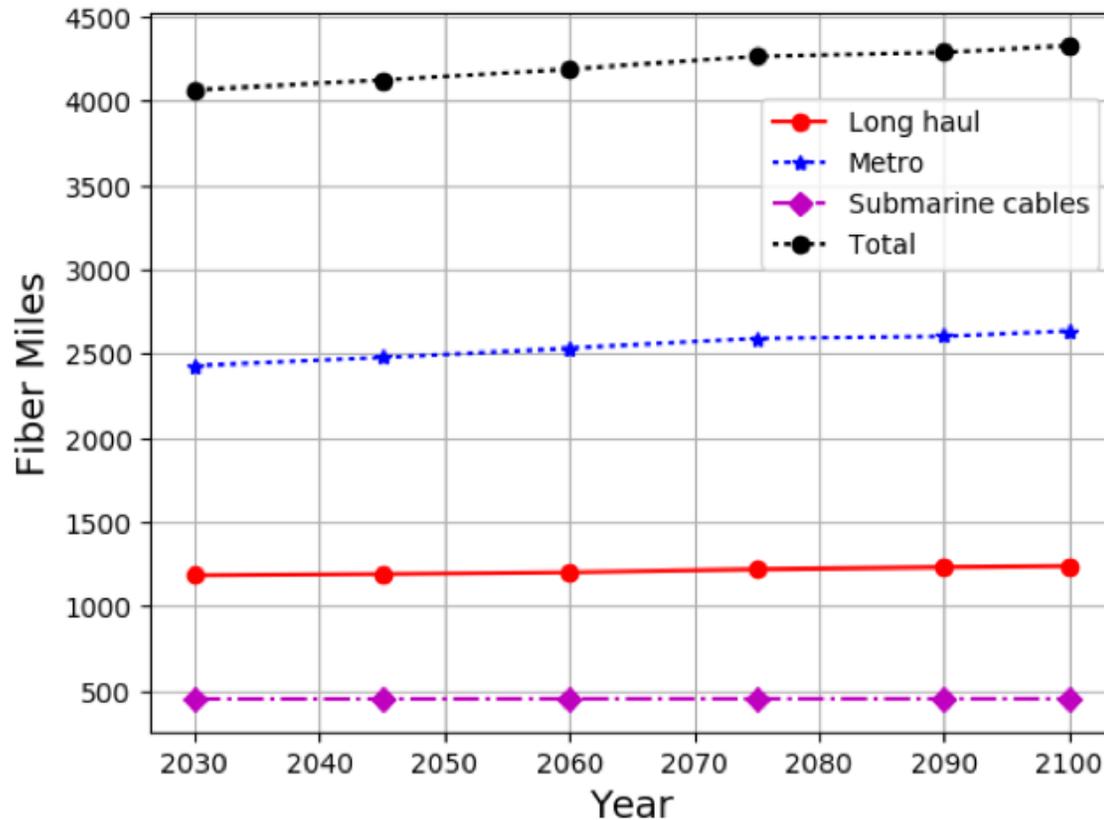
- **Overlap models to capture and analyze the risks of climate-change related sea level rise on nodes and links**
- **Coastal Infrastructure Risk (CIR) metric to highlight infrastructure under water per geographic location**
- **Temporally assess the impacts to identify top locations most at risk**
- **Implementation**
 - **Overlap tool to calculate the number of nodes, length of fibers (in miles)**
 - **Calculate CIR metric using kernel density tool**

Number of nodes affected



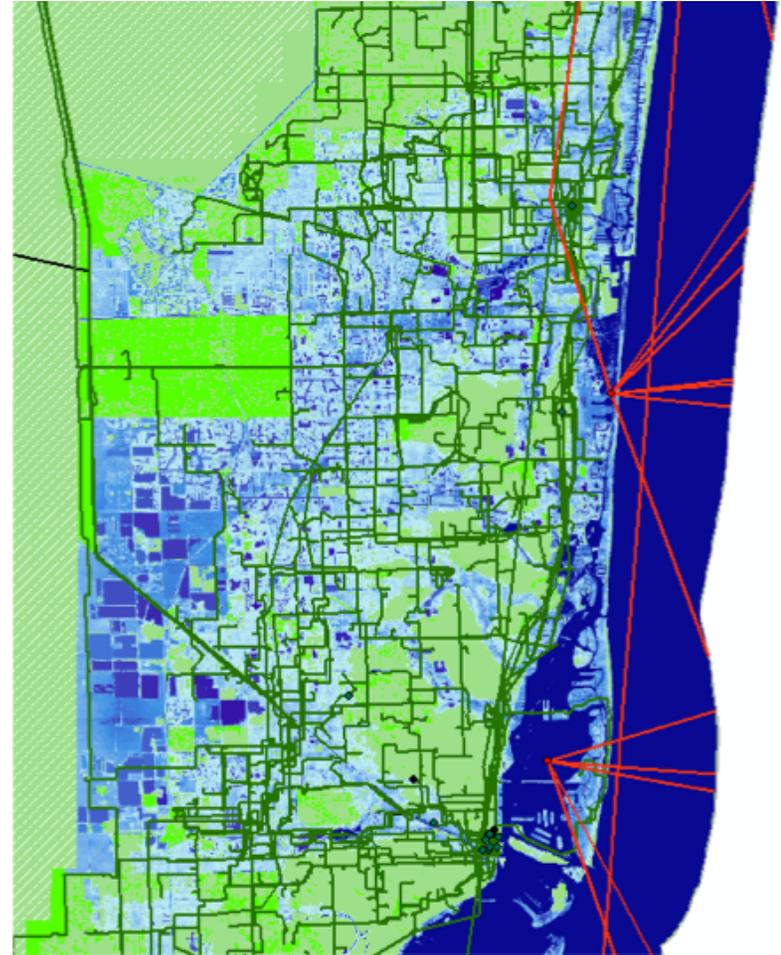
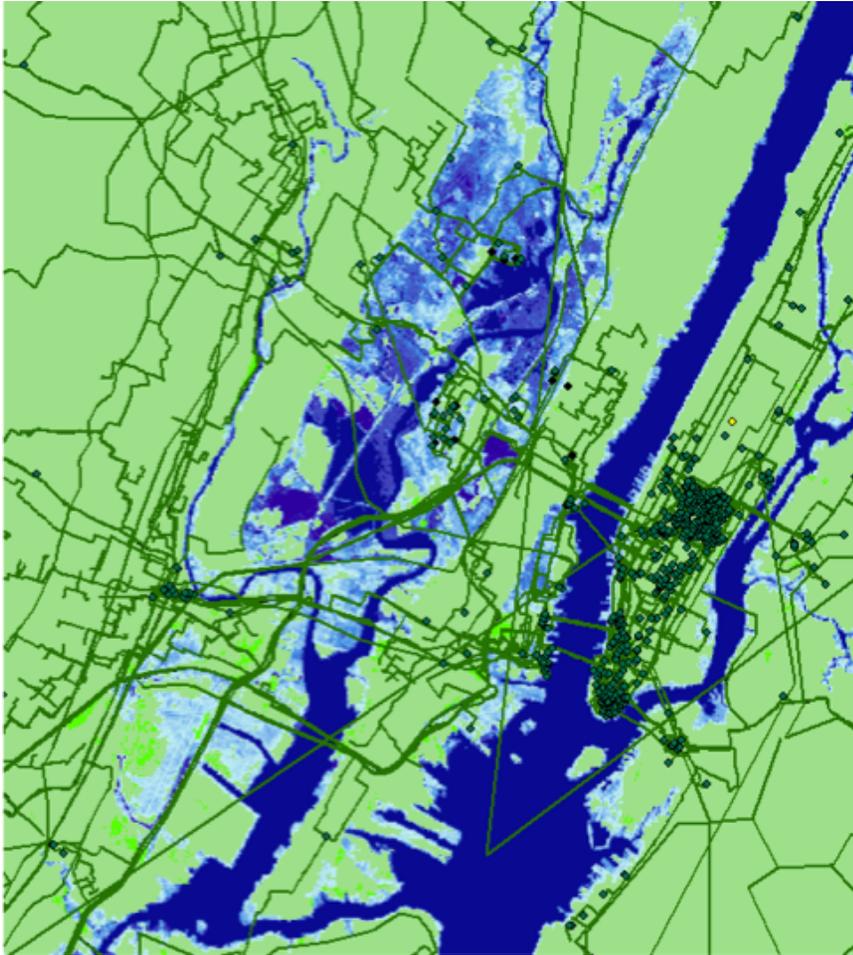
**771 POPs, 235 data centers will be affected by a 1 ft. rise
788 POPs and 249 data centers by the end of the century**

Fiber conduit miles affected



2,429 miles of metro fiber conduit affected by 1 ft of sea level rise
2,637 miles of metro fiber conduit will be affected in the next century

Coastal infrastructure risk



Infrastructure risk - nodes

City (POPs)	City (Data centers)	City (IXPs)	City (Landing Stations)
New York, NY (46)	New York, NY (43)	New York, NY (8)	Manasquan, NJ (2)
Miami, FL (31)	Newark, NJ (21)	Miami, FL (4)	Miami, FL (2)
Seattle, WA (28)	Seattle, WA (16)	San Francisco, CA (4)	Pacific City, OR (2)
Houston, TX (26)	Miami, FL (15)	Seattle, WA (4)	Tuckerton, NJ (2)
Washington, D.C. (23)	Palo Alto, CA (8)	Houston, TX (3)	Bandon, OR (1)

**Top 5 cities with high risk *nodes*
(number of nodes)**

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Infrastructure risk - links

City (Long-haul)	City (Metro)
Los Angeles, CA (89, 14.54%)	New York, NY (337, 19.8%)
New York, NY (79, 32%)	Seattle, WA (236, 23.6%)
Miami, FL (62, 5.3%)	San Francisco, CA (158, 9.43%)
New Orleans, LA (43, 22.51%)	Miami, FL (149, 13.27%)
San Francisco, CA (31, 7.4%)	Los Angeles, CA (138, 20.14%)

**Top 5 cities with high risk fiber *conduits*
(conduit miles and % under water)**

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Top 10 providers at risk

Rank	Provider
1	CenturyLink
2	Intelliquest
3	AT&T
4	BroadSky
5	TW Telecom
6	Verizon
7	PCCW Global
8	Cogent
9	Zayo
10	Sprint

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Summary

- **Climate change has many implications**
 - **Sea level rise, sever storms, fires, floods, etc.**
- **Focus of this work: assess risk to Internet infrastructure due to sea level rise**
- **We fuse infrastructure data from Internet Atlas and sea level rise models from NOAA**
- **~4.1k miles of conduits, ~300k of fiber and 1.1k colocation centers will be under water in the next 15 years**

Future

- **There is much to do!**
- **Expand sea level rise risk assessment to other countries**
- **Expand scope of threats**
- **Assess possible impacts of climate change-related threats**
- **Develop mitigation strategies**

Questions?

Acknowledgements:

Ram Durairajan
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References (<http://pages.cs.wisc.edu/~pb/publications.html>):

Durairajan et al. "Lights Out: Climate Change Risk to Internet Infrastructure",
In Proceedings of the ACM/IRTF/ISOC Applied Networking Research Workshop,
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Durairajan et al. "InterTubes: A Study of the US Long-haul Fiber-optic Infrastructure",
In Proceedings of ACM SIGCOMM, August 2015.

Portal: <http://internetatlas.org>