Balloons in the Sky: Unveiling the Characteristics and Trade-offs of the Google Loon Service

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http://www.it.uc3m.es/pablo/

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uc3m | Universidad Carlos III de Madrid

About me

Dr. Pablo Serrano (IEEE SM)
Associate Professor, Univ. Carlos III de Madrid (UC3M)
Director of the Master in Connected Industry 4.0
Associate Editor of the IEEE Open Journal of the Communications Society

Current project:

- Hexa-X: A flagship for B5G/6G vision and intelligent fabric of technology enablers connecting human, physical, and digital worlds

Research interests:

- 5G / 6G, Wireless Communications, Performance Analysis, Energy Efficiency, Testbeds

Past visiting positions:

University Massachusetts Amherst (2007) – Jim Kurose,
Telefónica R+D Barcelona (2013) – Yan Grunenberger,
Trinity College Dublin (2015) – Doug Leith,
Universita degli Studi di Brescia (2016) – Francesco Gringoli,
University of Edinburgh (2017) – Paul Patras,
Universita degli Studi di Roma Tor Vergata (2020) – Giuseppe Bianchi

About UC3M

- Universidad Carlos III de Madrid (UC3M)
  - Act of the Spanish Parliament on 5 May 1989
  - First Chancellor was Professor Gregorio Peces-Barba
  - Approx. 20k students
  - Highest average grade achieved by students in Madrid
- Internationalisation
  - 20% of students at UC3M are foreign
  - Higher at both master's (30%) and doctoral (43%) levels.
  - 51% graduates have participated in international mobility programmes
- Among the top 150 best universities for employability
  - It has risen by 20 places in the QS Graduate Employability Ranking 2020
  - 90,6 % found work in less than 2 years after graduation.
- Amongst the best universities worldwide in 6 fields (incl. CompSci)

Contact

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Always looking for motivated people to collaborate with!

THE GOOGLE LOON PROJECT

Motivation

- Countries are heading towards the realization of the so-called Gigabit Society
- > 50% of the world population does not have any Internet connection
  - Many of those 4 billion people live in rural places
  - No network infrastructures
  - There are many terrestrial challenges to connectivity—jungles, archipelagos, mountains

Solution: Balloons

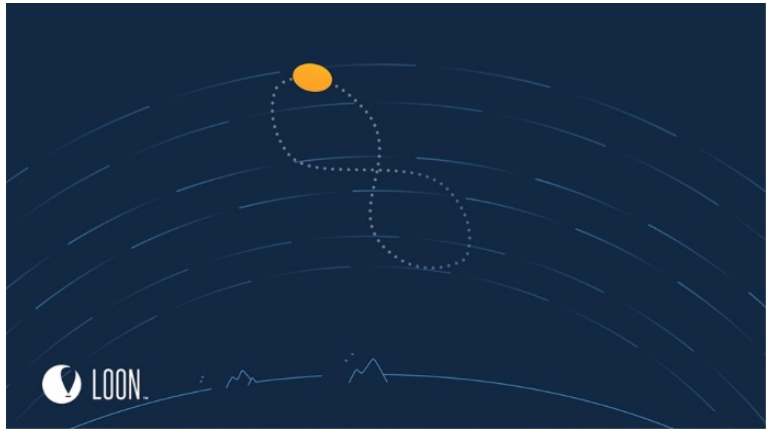
https://www.wired.com/2013/06/google-internet-balloons/

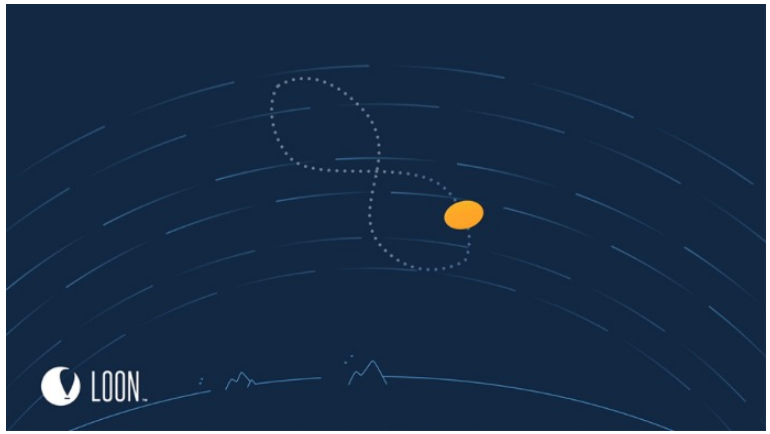
Introducing Project Loon

- Solution: use Balloons to beam Internet access

  https://blog.google/alphabet/introducing-project-loon/

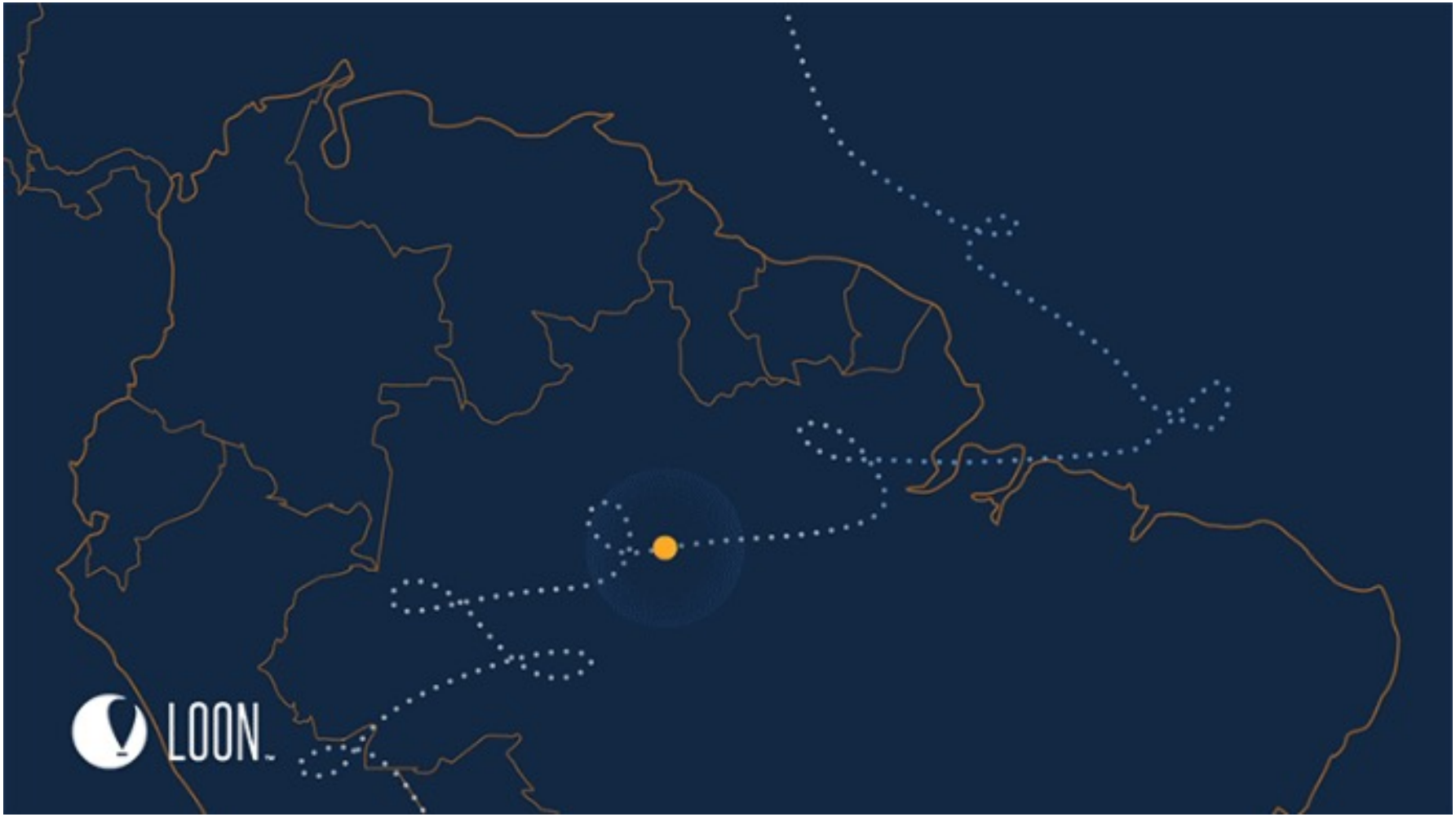
- Just wind and solar power: move the balloons up or down to catch the winds





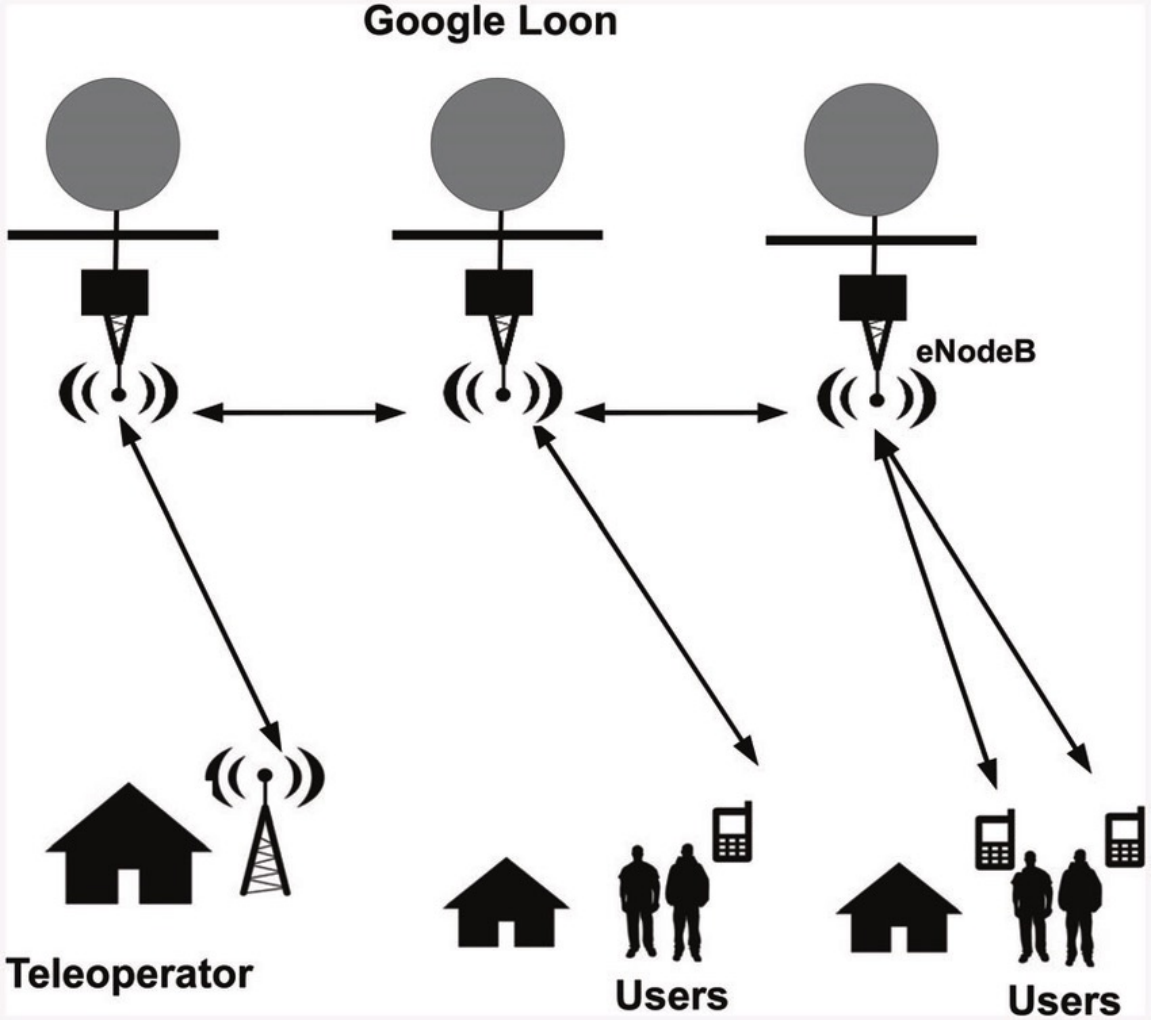
https://blog.x.company/1-million-hours-of-stratospheric-flight-f7af7ae728ac

“Strange” flying paths



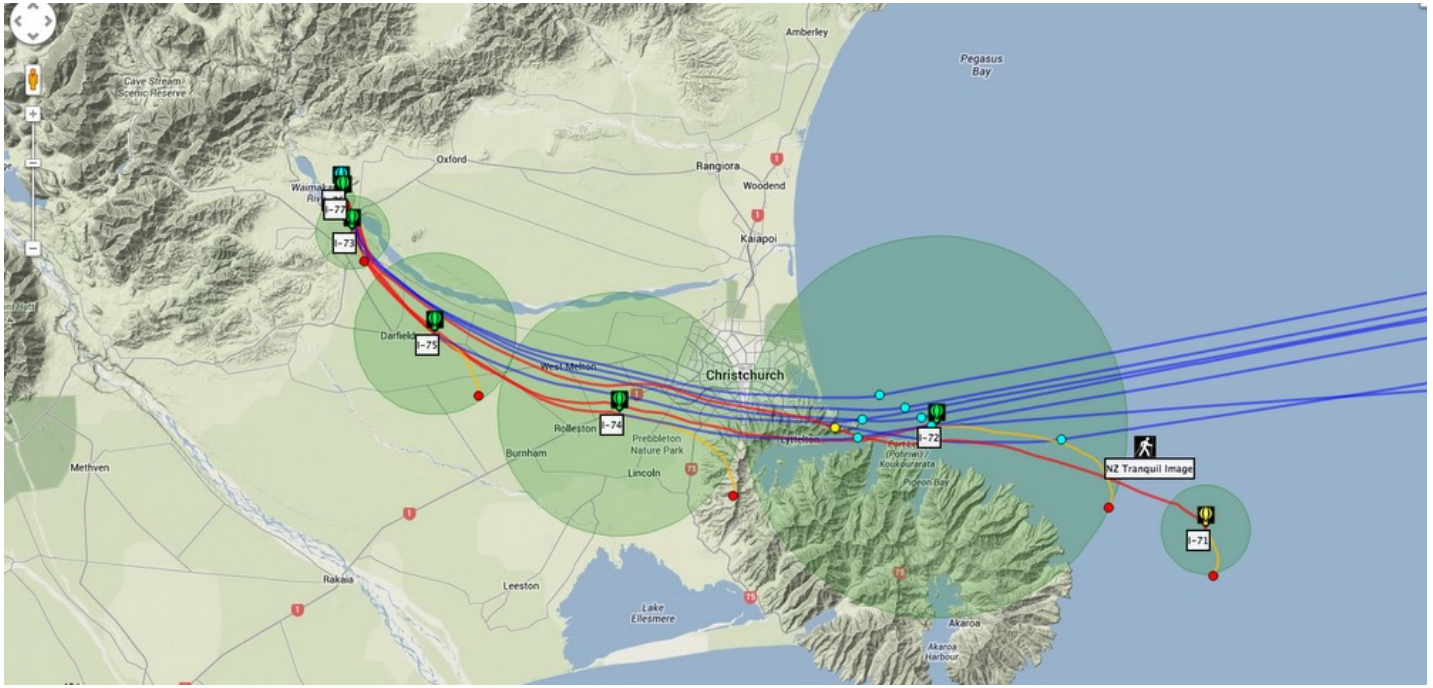
Architecture

- Technology
  - Initially ISM
  - Switched to LTE
- Box: 10 kg
  - Batteries, circuit boards, navigation hw
  - LTE equipment (Unibuiti Networks Rocket M2)
- Each balloon: ~ 40 km of coverage radius
- Inter-balloon links: up to 100 km



Official Launch

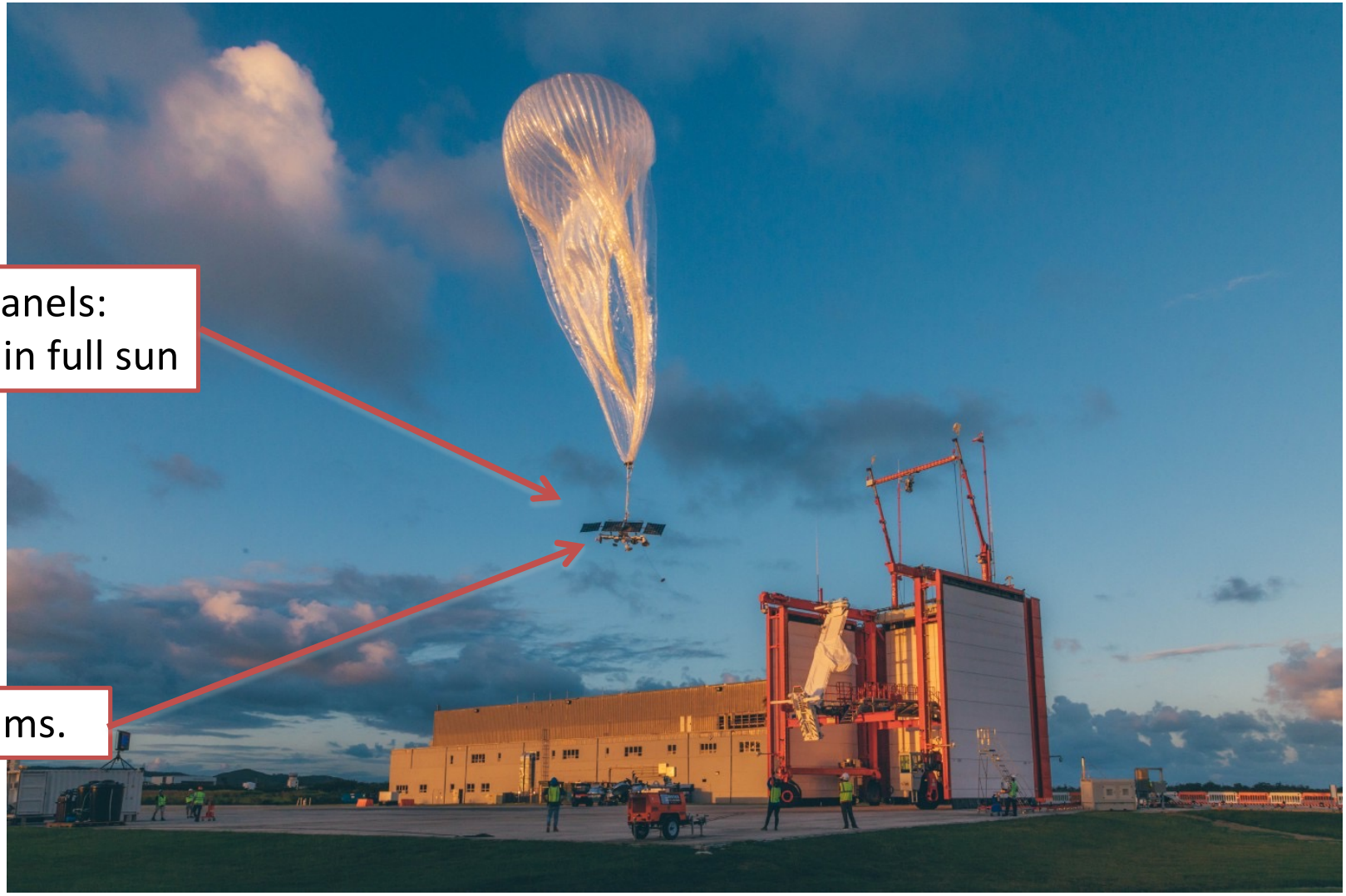
- June 2013: 30 balloons launched to connect 50 receivers



https://blog.google/alphabet/introducing-project-loon/

Launch (New Zealand)

Launch site (Nevada)



https://blog.x.company/loon-draft-c3fcebc11f3f

Lifespan

- Can operate for hundreds of days. Record: 312 days
  - **HBAL703** launched from Puerto Rico in May, 2019
    - Service for 3M / circumnavigation / 7M in the Pacific / landed in Mexico

https://medium.com/loon-for-all/312-days-in-the-stratosphere-5c50bd233ec5

Some issues – as of June 2014

- Google's Project Loon suffers accident as balloon takes out power lines
  - "Google has no way of ensuring its balloons won't wreak havoc once they're closer to the ground"

https://www.theverge.com/2014/6/3/5777182/google-project-loon-balloon-takes-out-power-lines

- Google Loon Wi-Fi balloon creates panic in New Zealand
  - "Rescue helicopter dispatched for what was thought to be a crashing plane"

https://www.theverge.com/2014/6/20/5826988/google-loon-balloon-crash-new-zealand

Balloons sightings

- “A Brief History of People Thinking Google's Loon Balloons Are UFOs”

https://gizmodo.com/a-brief-history-of-people-thinking-googles-loon-balloon-1661296616

https://www.bbc.com/news/world-latin-america-39265813

Research Question

- How effective and stable can be the service provided by Loon?

- Steps
  1. Gather data
  2. Identify use cases
  3. Derive performance figures: coverage

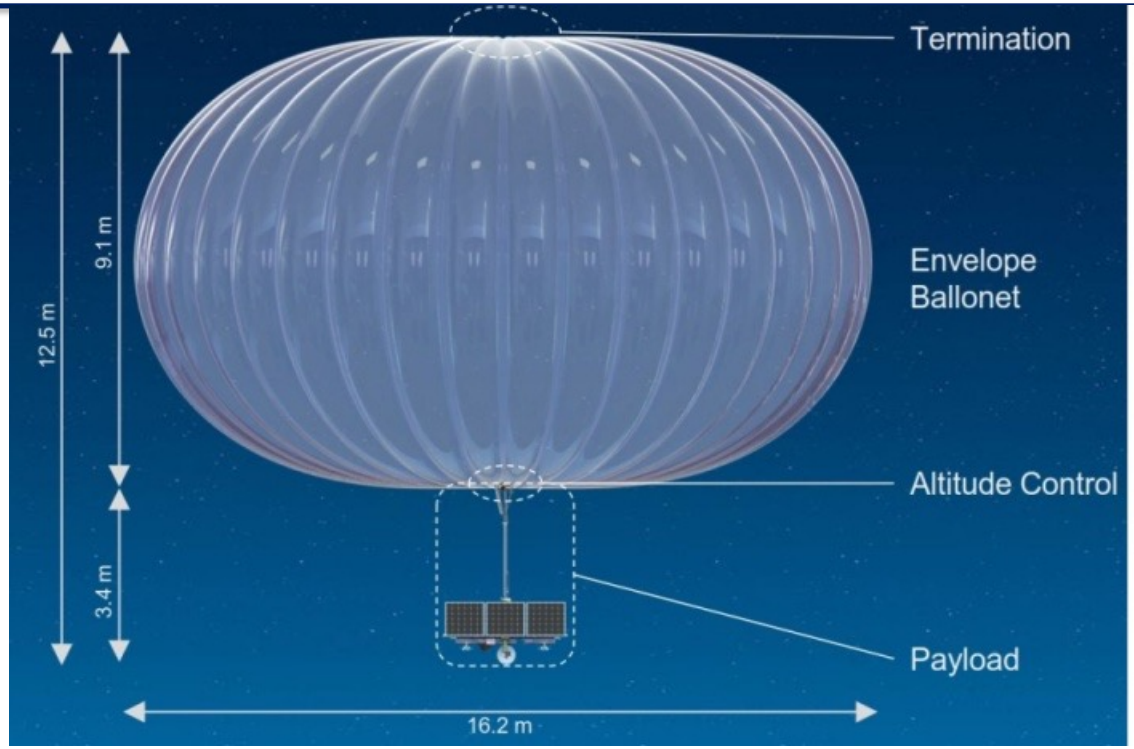
GATHERING DATA: TRACKING LOONS

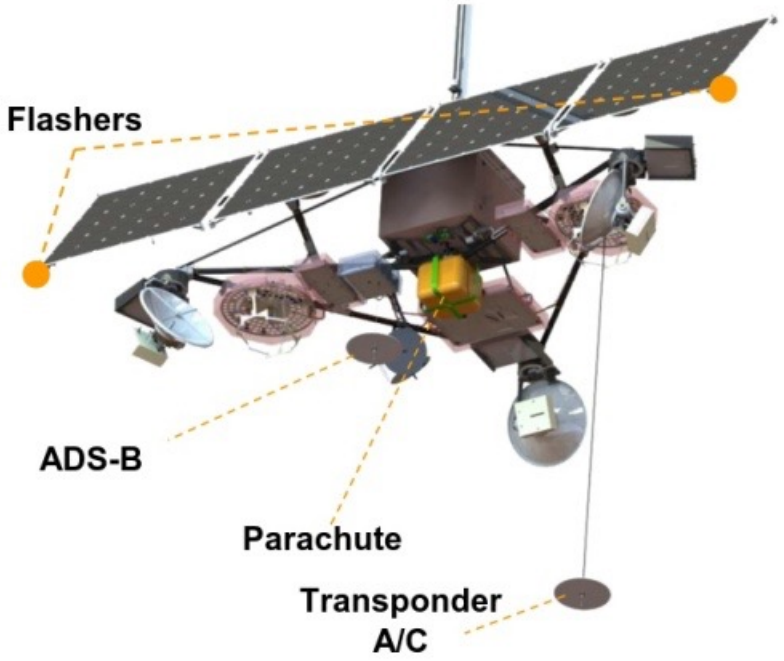
Tracking balloons (1/2)

- Each Loon is equipped with a Mode-S transponder, a secondary radar system used to support the Automatic Dependent Surveillance–Broadcast (ADS-B)
- The transponder is provided with a unique International Civil Aviation Organization (ICAO) address
- Thanks to ADS-B, an aircraft broadcasts
  - 24-bit ICAO address
  - An estimation of its position, speed, altitude,
  - The callsign, also known as the flight number
- For Loon, flight numbers start with “HBAL "

https://www.flightradar24.com/blog/keep-your-eye-on-the-hbal-tracking-project-loon-balloons/

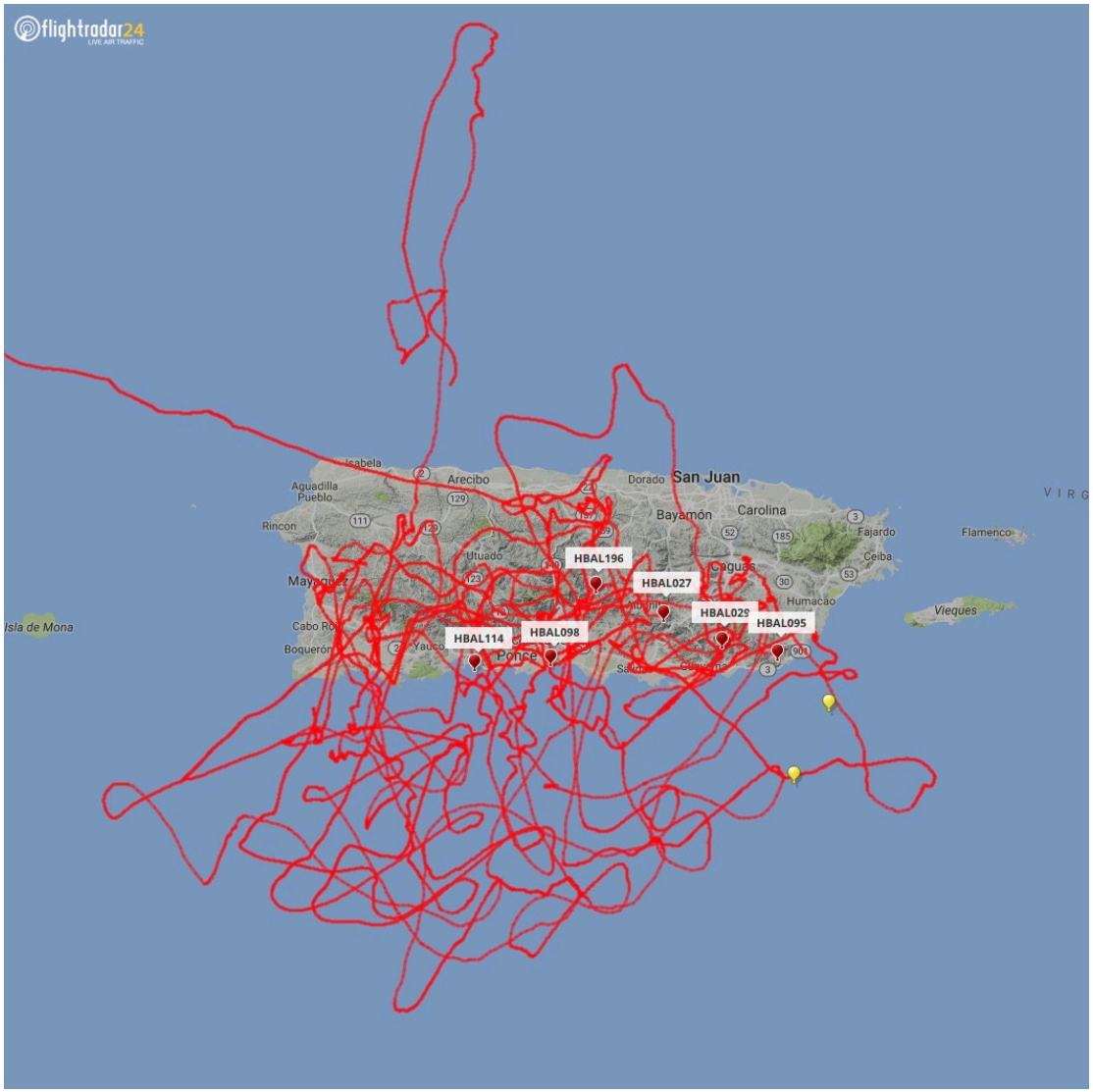
Tracking balloons (2/2)





- ADS-B messages can be received with DVB-T USB sticks
- This has fostered several crowd-sourced initiatives

Loons over Puerto Rico on 22 January 2018



My ADS-B receiver

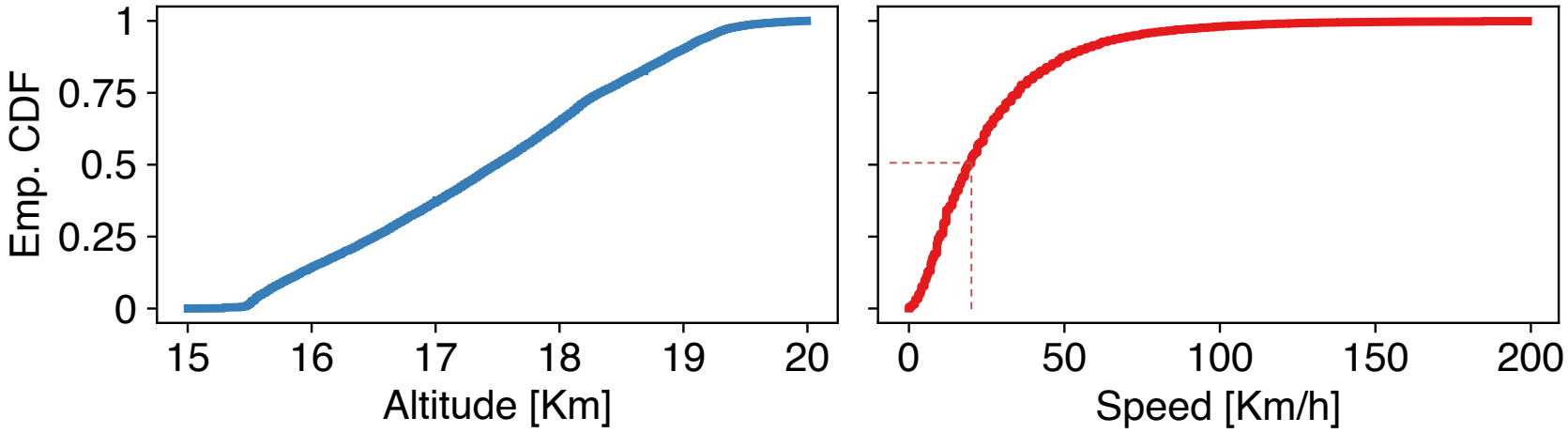
GATHERING DATA: SOME GENERAL STATS

Altitude and Speed

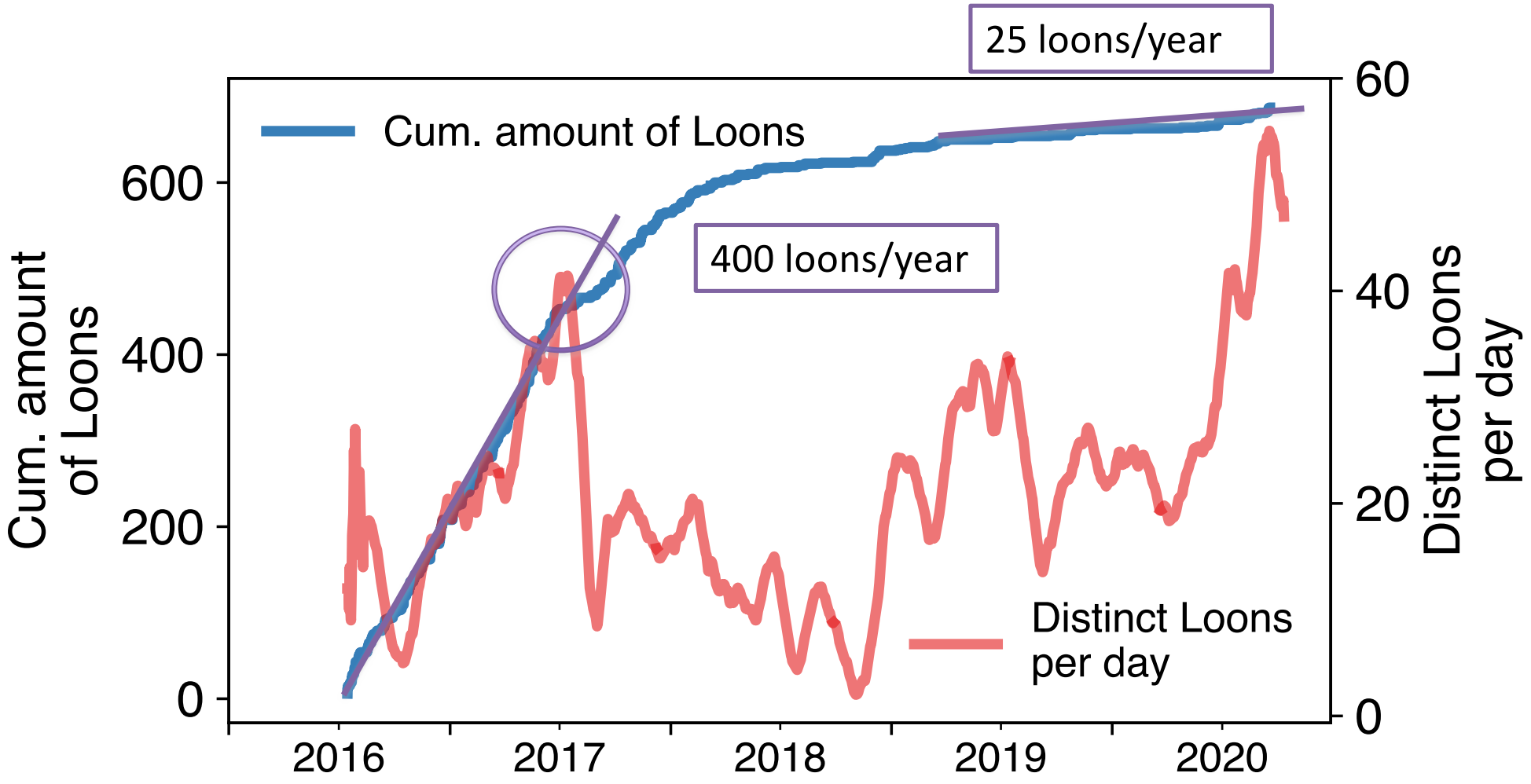
- Altitudes between 16 km and 20 km: Stratosphere
  - Stratosphere can reach 220 km/h in the Southern polar vortex
  - “Relatively low speeds (10 km/h to 30 km/h) and minimal turbulence”

https://xedknowledge.com/Coverstory_Demo.aspx?id=qJZ85UM6v6RmN6IFBF+t1Q==

- According to our data

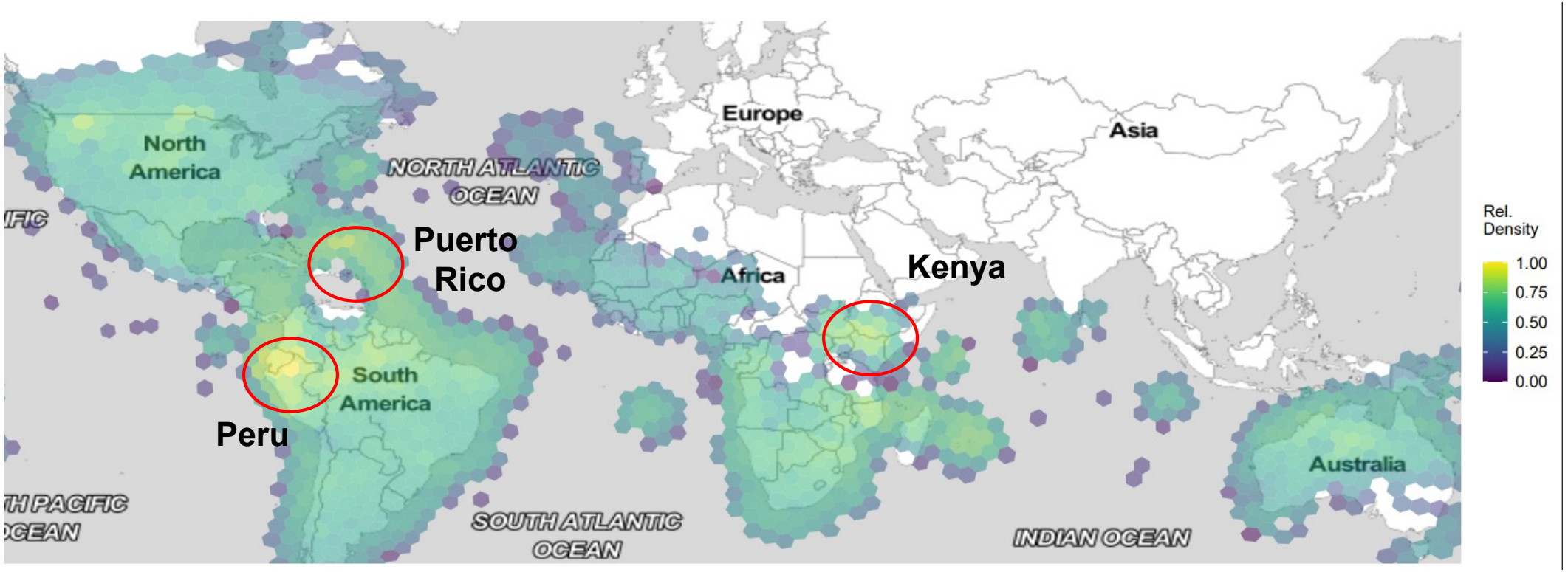


Number of Loons over time



Relative loon density

- Note: crowdsensing uses ground stations



- Deployment time
  - From Ceiba to Perú: appro. 20 h, to Kenya: 5 days

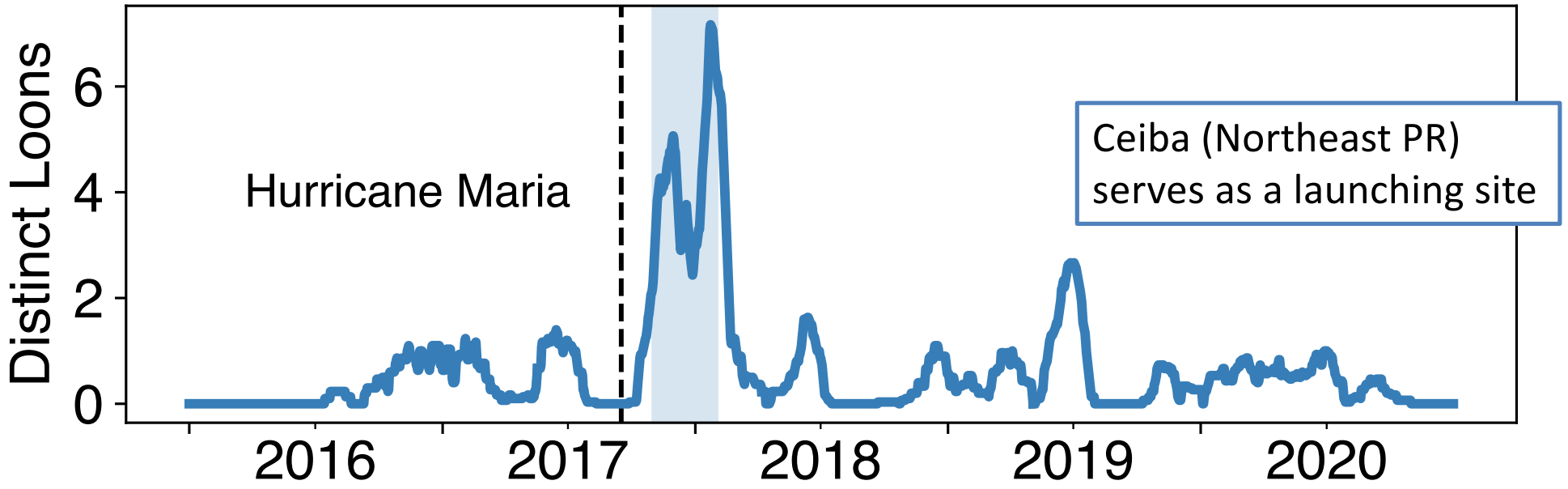
IDENTIFY USE CASES

Loon use cases

- There are no "official" use cases
- We rely on those that have been extensively covered by media
- We study areas with > 30 days of "minimal coverage" (>2 h/day) for > 3 months
- For each area, we count # of loons and represent its 30-day average

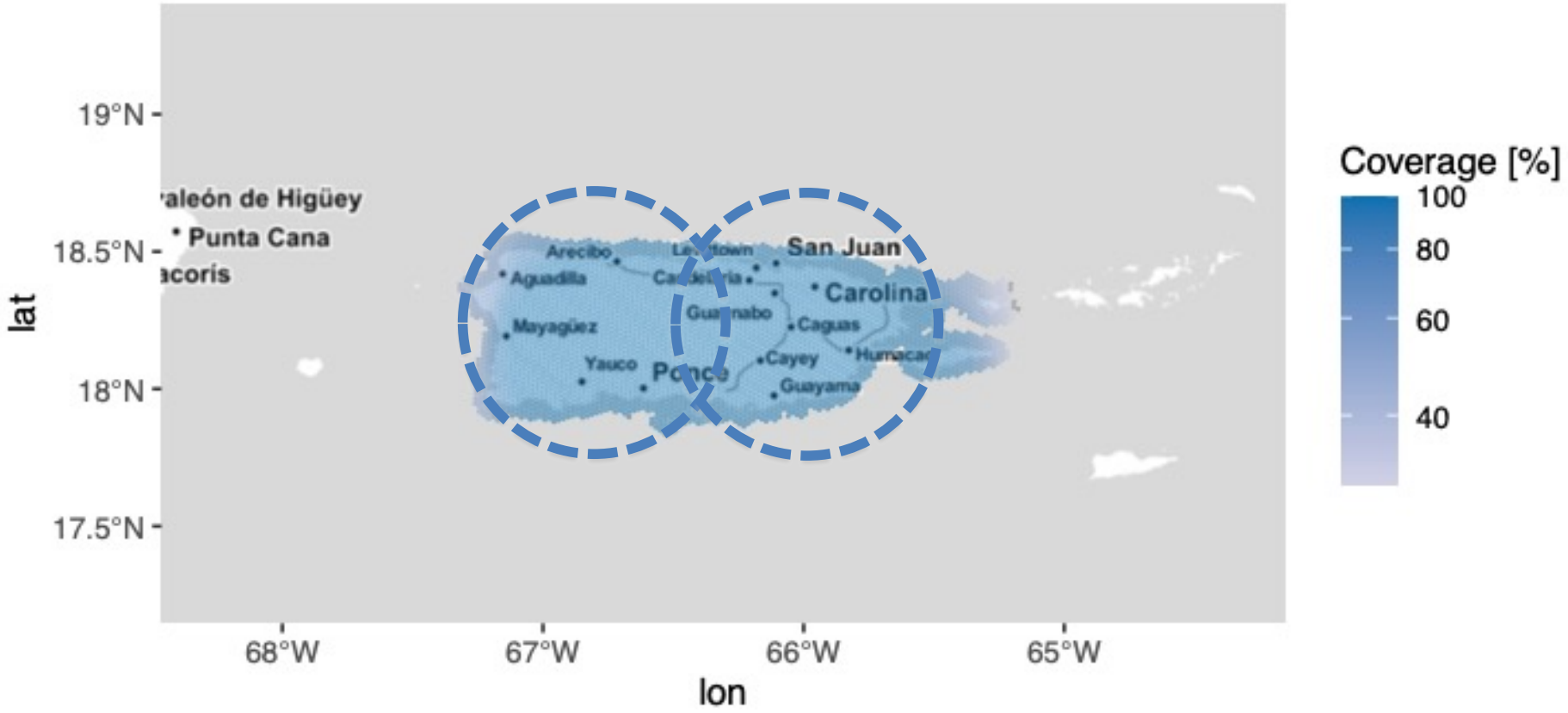
Puerto Rico

- Hurricane Maria: from Sep. 20 until Oct. 2.
- Oct. 6: authorized by the FCC to provide coverage
- Oct. 21: partnership with AT&T and T-Mobile
- Nov. 9: More than 100K people were provided basic connectivity
- Mar 2: service over the island would start to “wind down”



Puerto Rico

- Area: 9 104 km^2 (i.e., approx. 2 Loons)

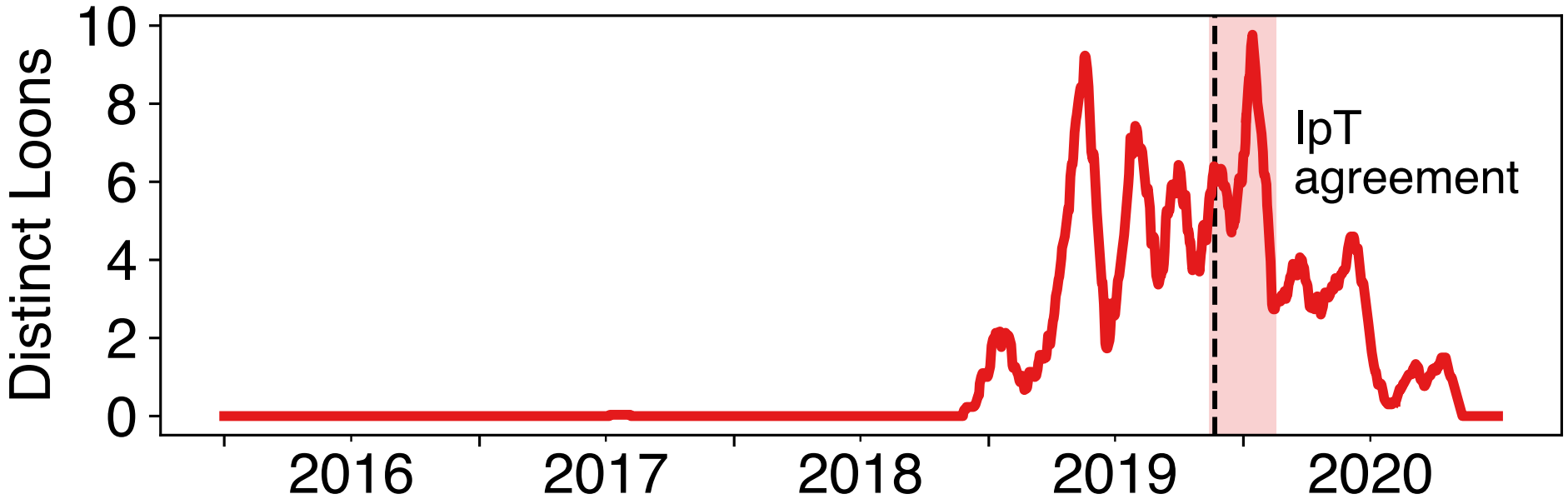


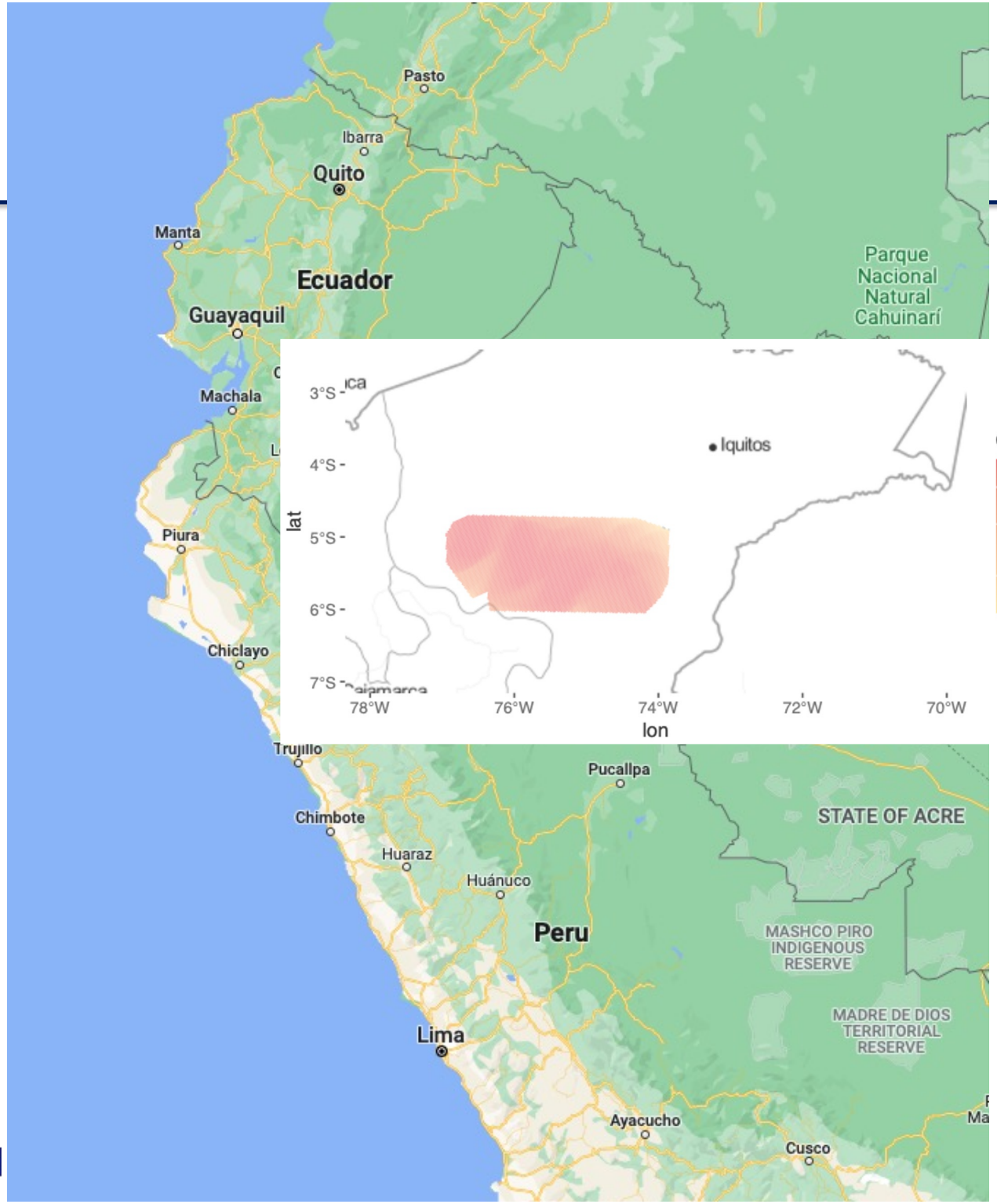
Perú – Loreto region

- 2014: Loon and Telefónica started collaboration
- May 2017: El Niño flooding (Piura, Chimbote, Lima)
- May 2018: 8.0 magnitude earthquake (Acari)

Coast

- Nov. 2019: Service over of the Loreto Region → Amazonas
  - Neutral-host Internet Para Todos (IpT) operator

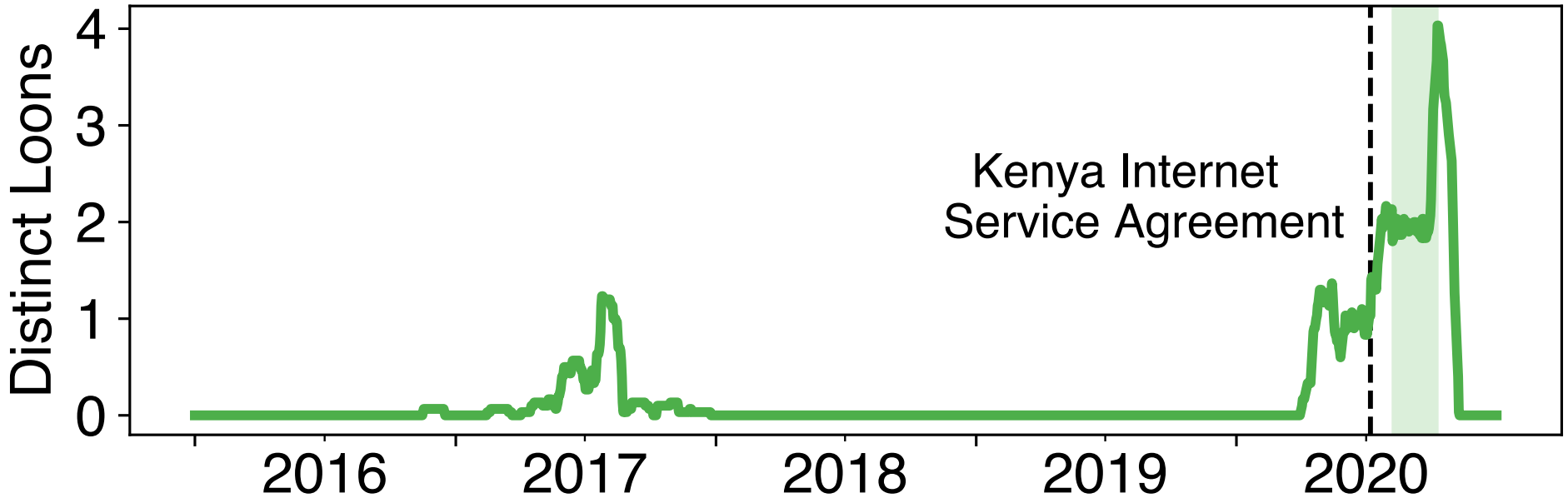



Pasto
Ibarra
Quito
Manta
Ecuador
Guayaquil
Parque Nacional Natural Cahuinarí
Machala
Piura
Chiclayo
Trujillo
Pucallpa
Chimbote
Huaraz
Huánuco
Peru
STATE OF ACRE
MASHCO PIRO INDIGENOUS RESERVE
MADRE DE DIOS TERRITORIAL RESERVE
Lima
Ayacucho
Cusco
Iquitos
3°S
4°S
5°S
6°S
7°S
lat
78°W
76°W
74°W
72°W
70°W
lon
Coverage [%]
100
80
60
40

46 157 km^2

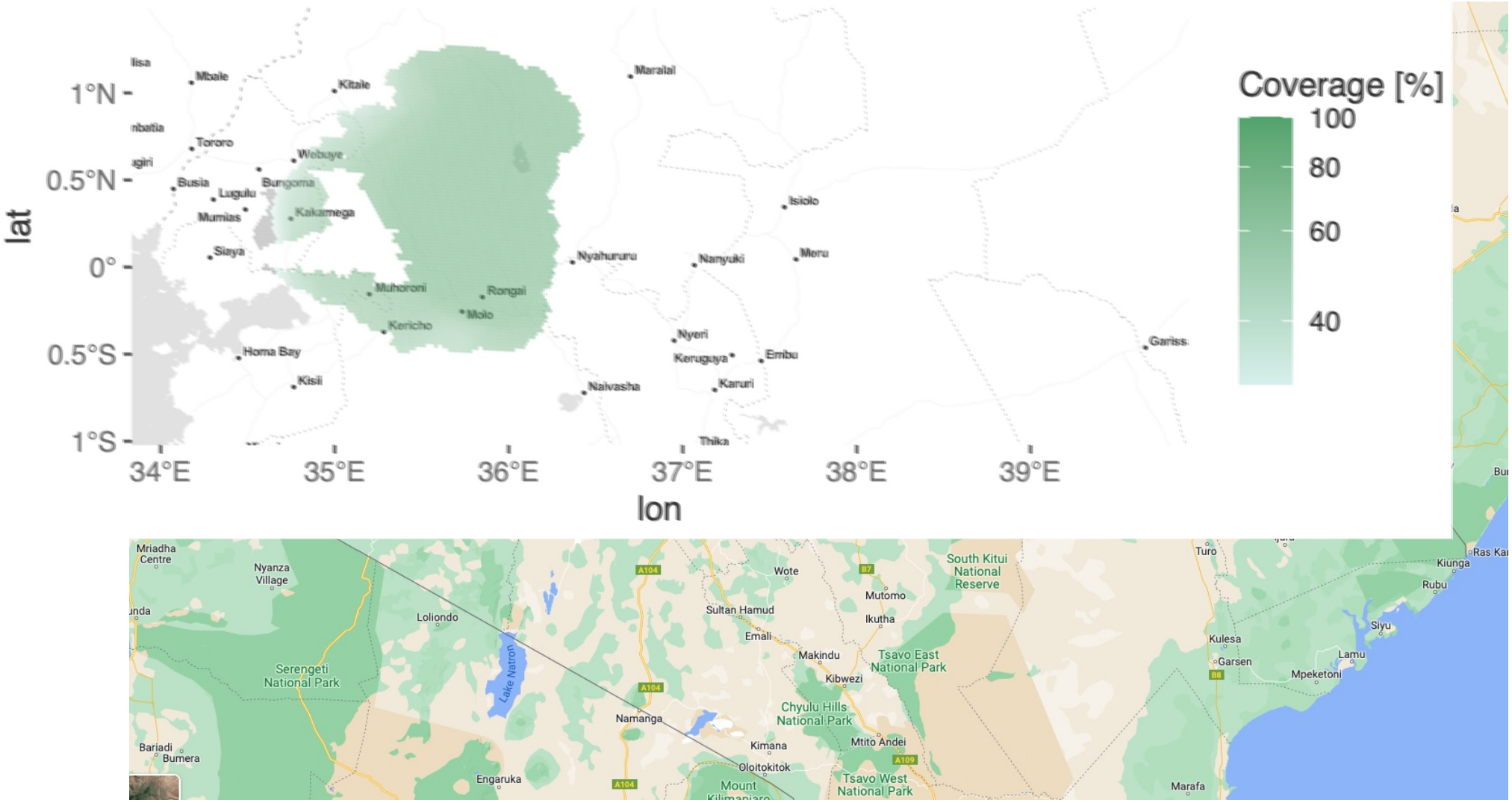
Kenya

- July 2018: the service would start in 2019
  (Some activity seems to be taking place in 2017)
- No activity during 2018 and 2019
- March 2020: Kenyan government gave approval
- July 7, 2020: service announcement. Target: 35 loons



Kenya

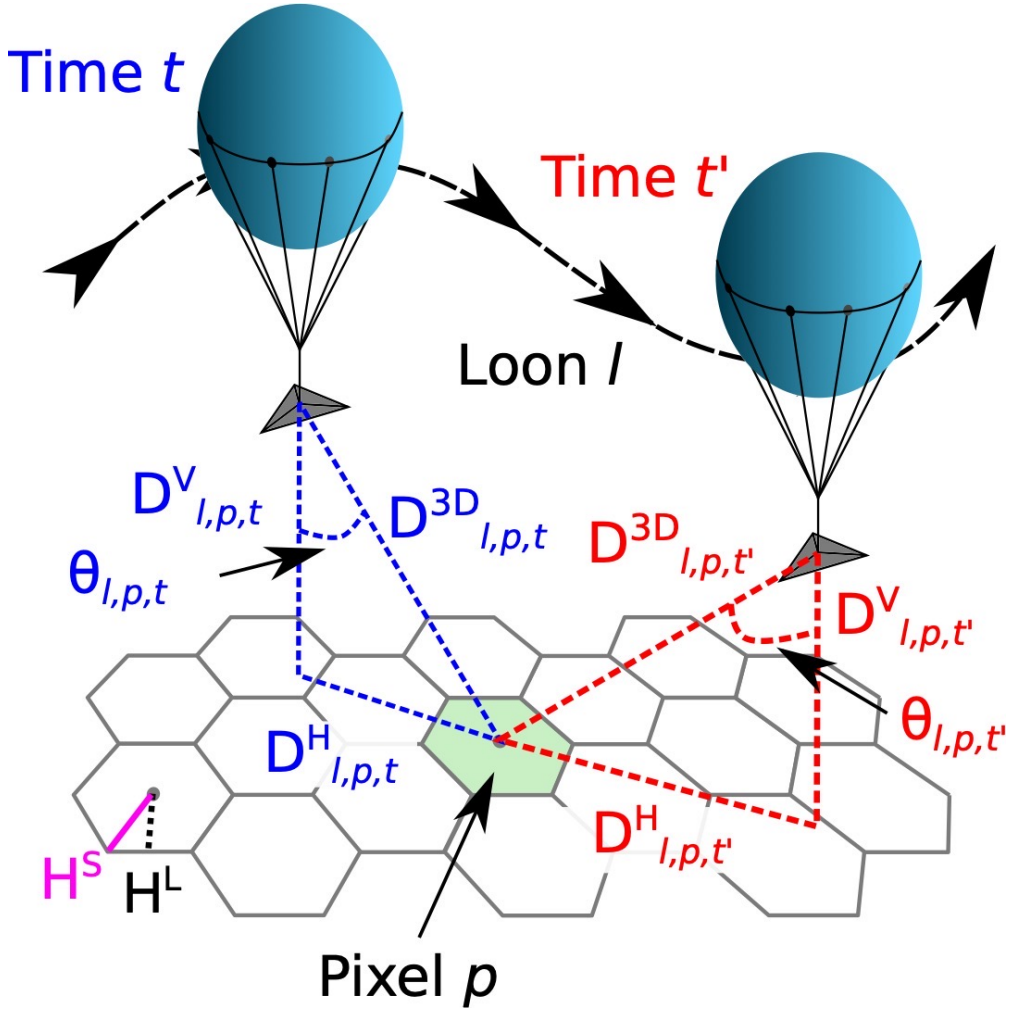
27 800 km^2



PERFORMANCE FIGURE: COVERAGE

Computing coverage

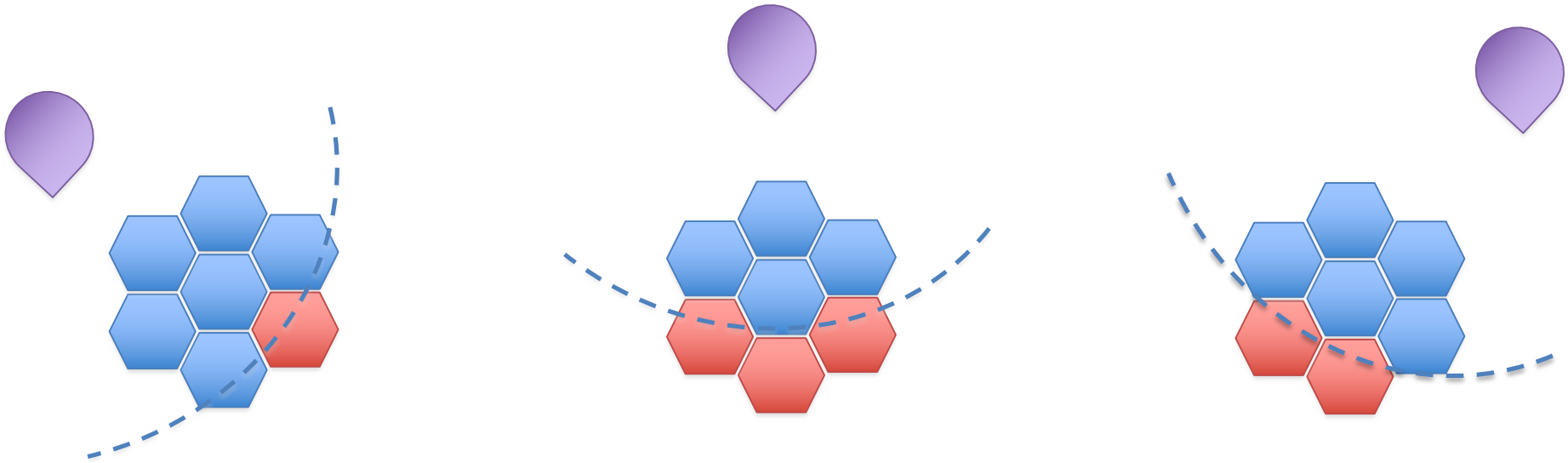
- Downlink only
- Free-space loss
  - f: 800 MHz
  - P_{TX}: 37 dBm
  - G_{UE}: - 10 dB
  - G_{TX}: [1]
- Coverage
  - Rsens: - 100 dBm



[1] S. Ananth et al. "System design of the physical layer for loon's high-altitude platform," EURASIP Journal on Wireless Communications and Networking, vol. 2019, no. 1, Jun. 2019.

Tessellation and discretization

- We discretize time and space



t = 0

6/7 ≈ 85%

t = 1’

4/7 ≈ 57%

t = 2’

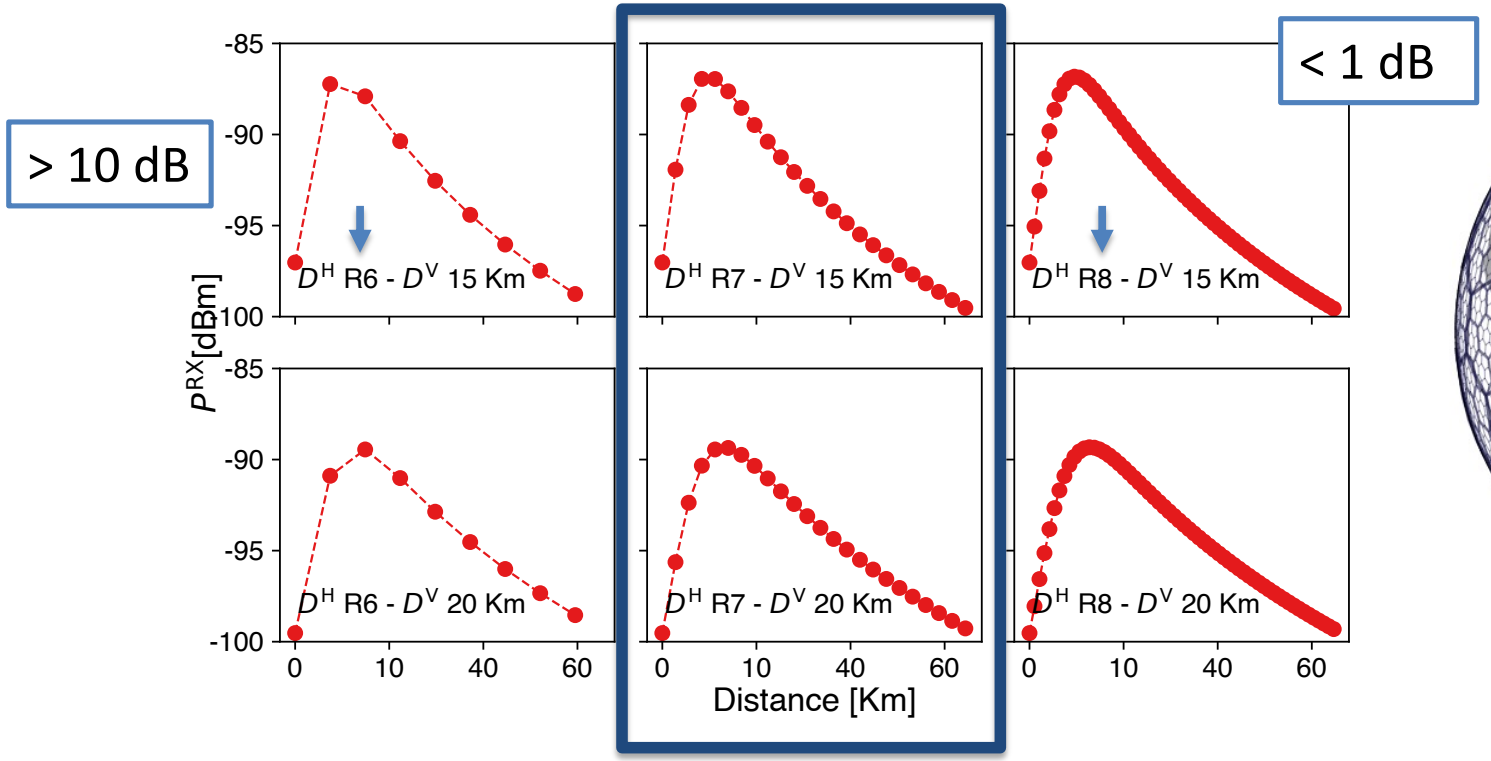
5/7 ≈ 71%

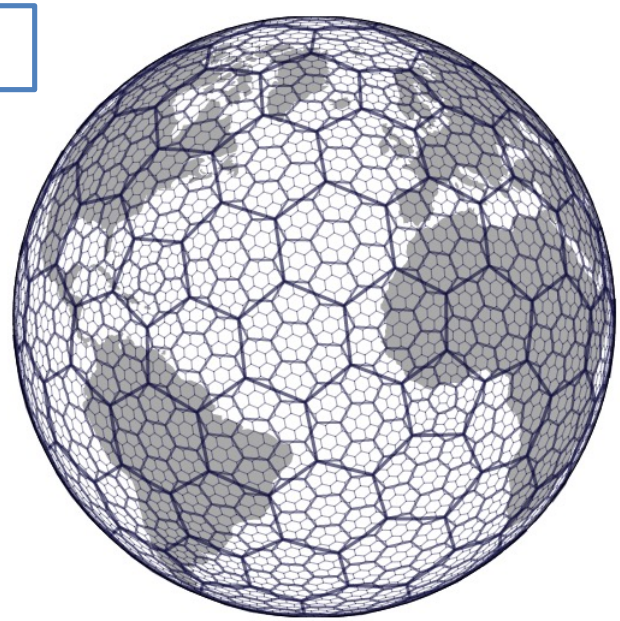
- Average coverage: (6/7 + 4/7 + 5/7)/3 ≈ 71%

Tessellation

- We use Uber's H3 library to tessellate the regions
  - 16 resolutions: HS(0) = 1 279 km, HS(15) = 0,58 m
  - Rx Power vs. distance for 2 altitudes (15 km, 20 km)

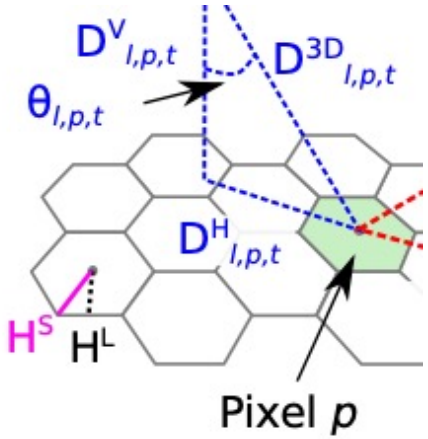
https://eng.uber.com/h3/





Time discretization

- Objetive: set a bound on $\Delta t = t[n] - t[n-1]$
- Aim: loon does not travel beyond $2H^S$ during Δt
- H^S: 1.4 km
- 99th percentile of speed: 100 km/h

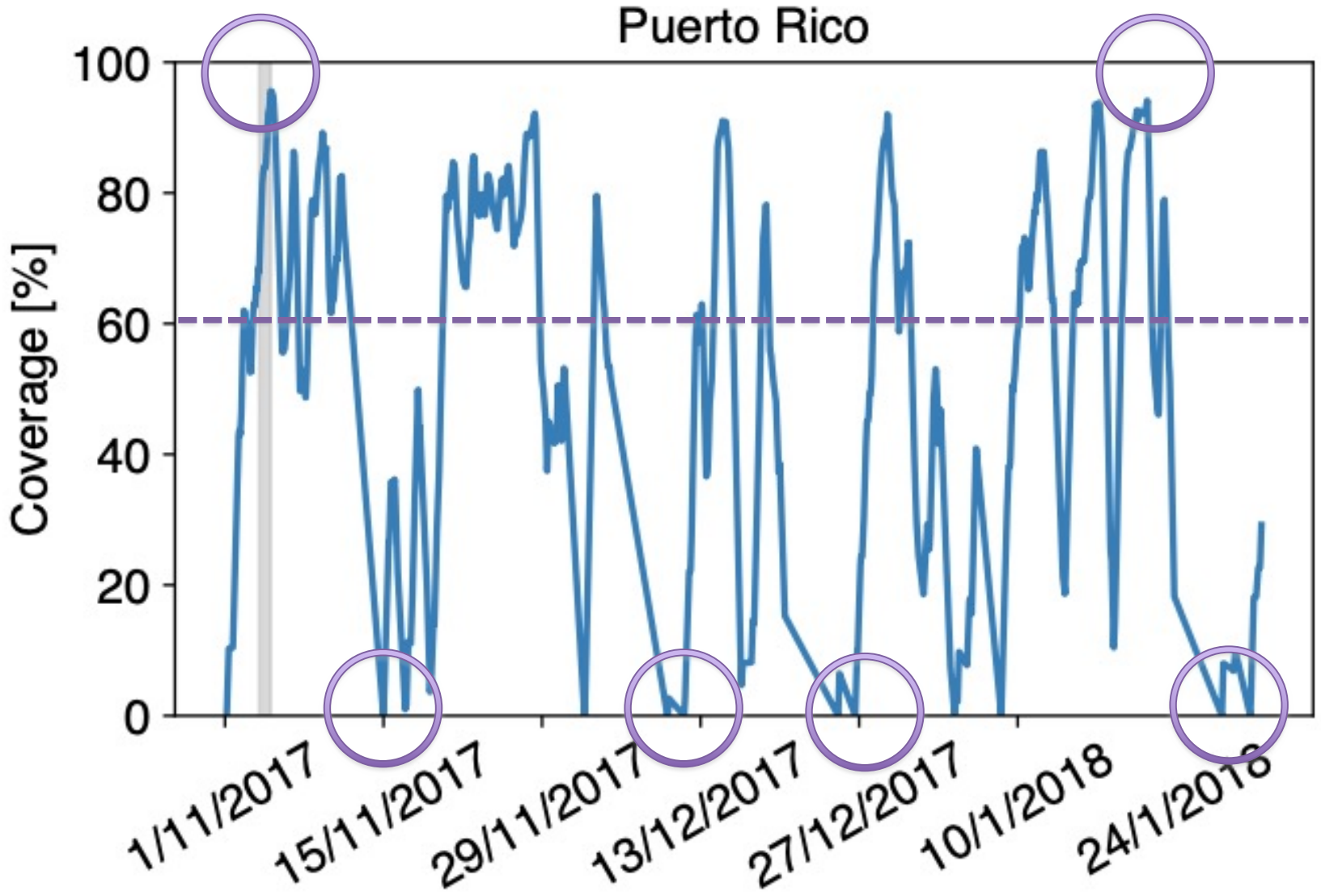


$$\Delta_t \leq \frac{2 \cdot H^S}{V^{99\text{-PCT}}} = \frac{2.8\ [\text{km}]}{100\ [\text{km/h}]} \approx 1\ \text{min}\ 26\ \text{s}$$

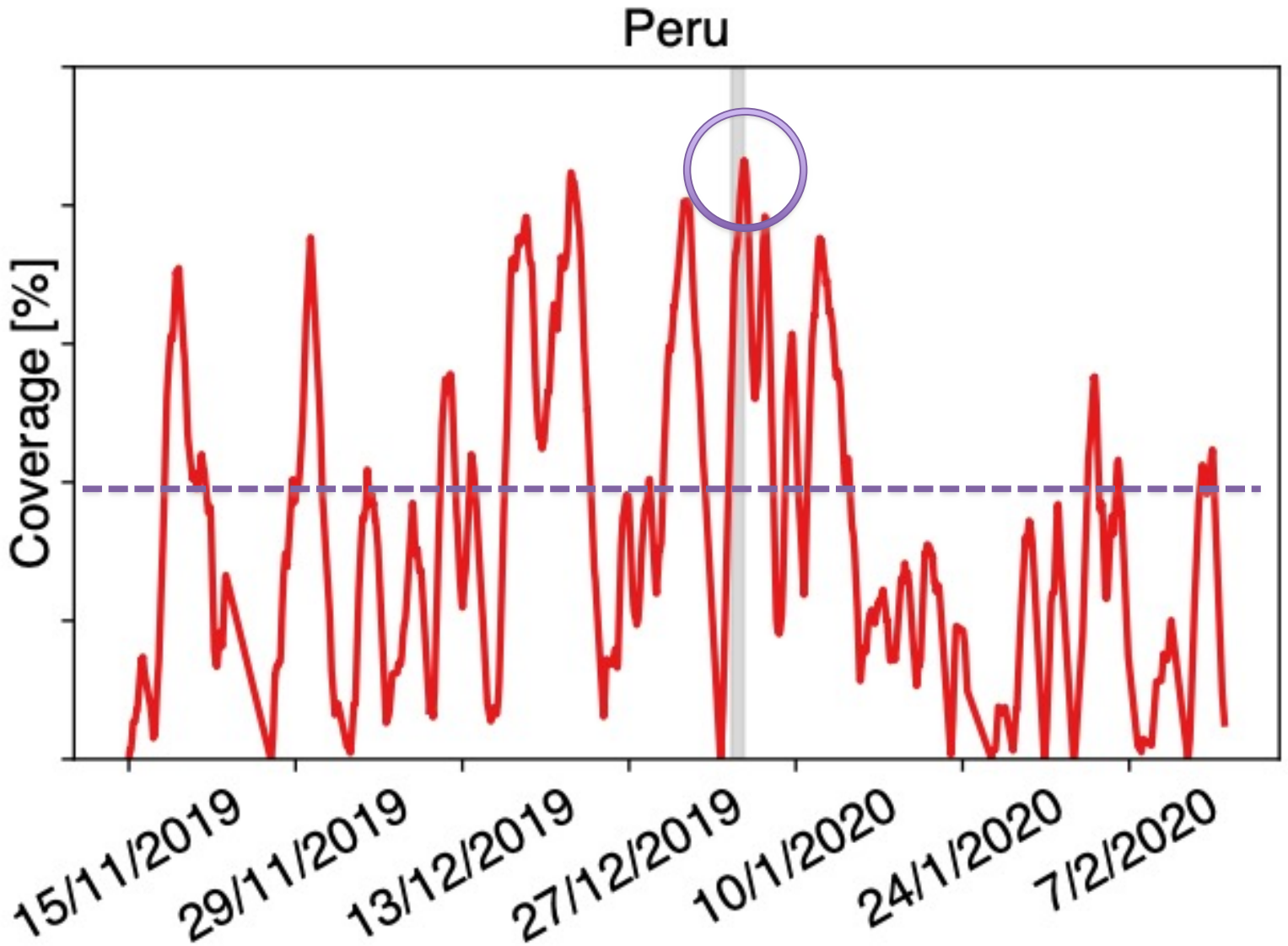
- We set Δt = 1 min

DAILY COVERAGE

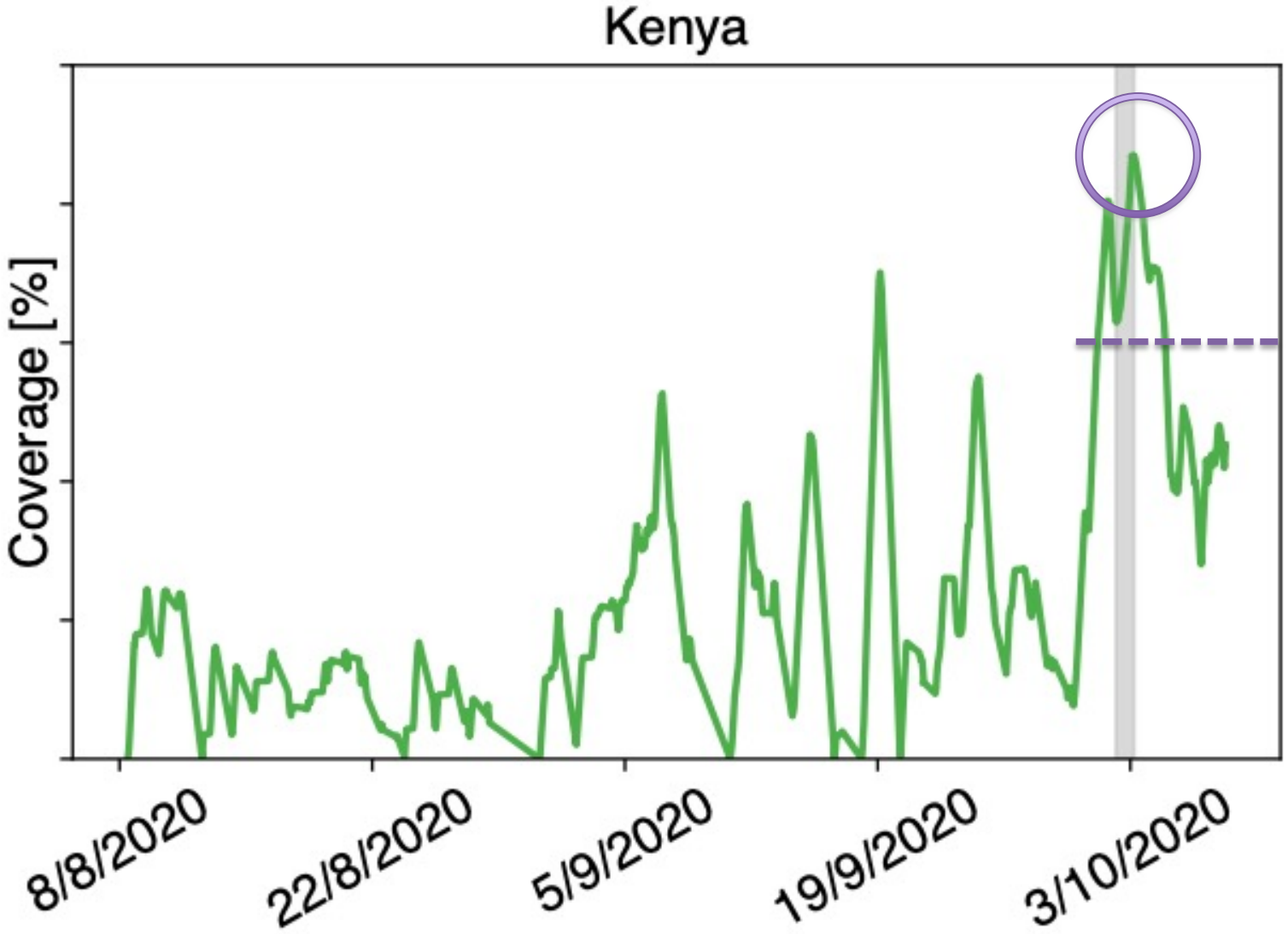
Puerto Rico: best 3 months



Perú


Peru
Coverage [%]
15/11/2019
29/11/2019
13/12/2019
27/12/2019
10/1/2020
24/1/2020
7/2/2020

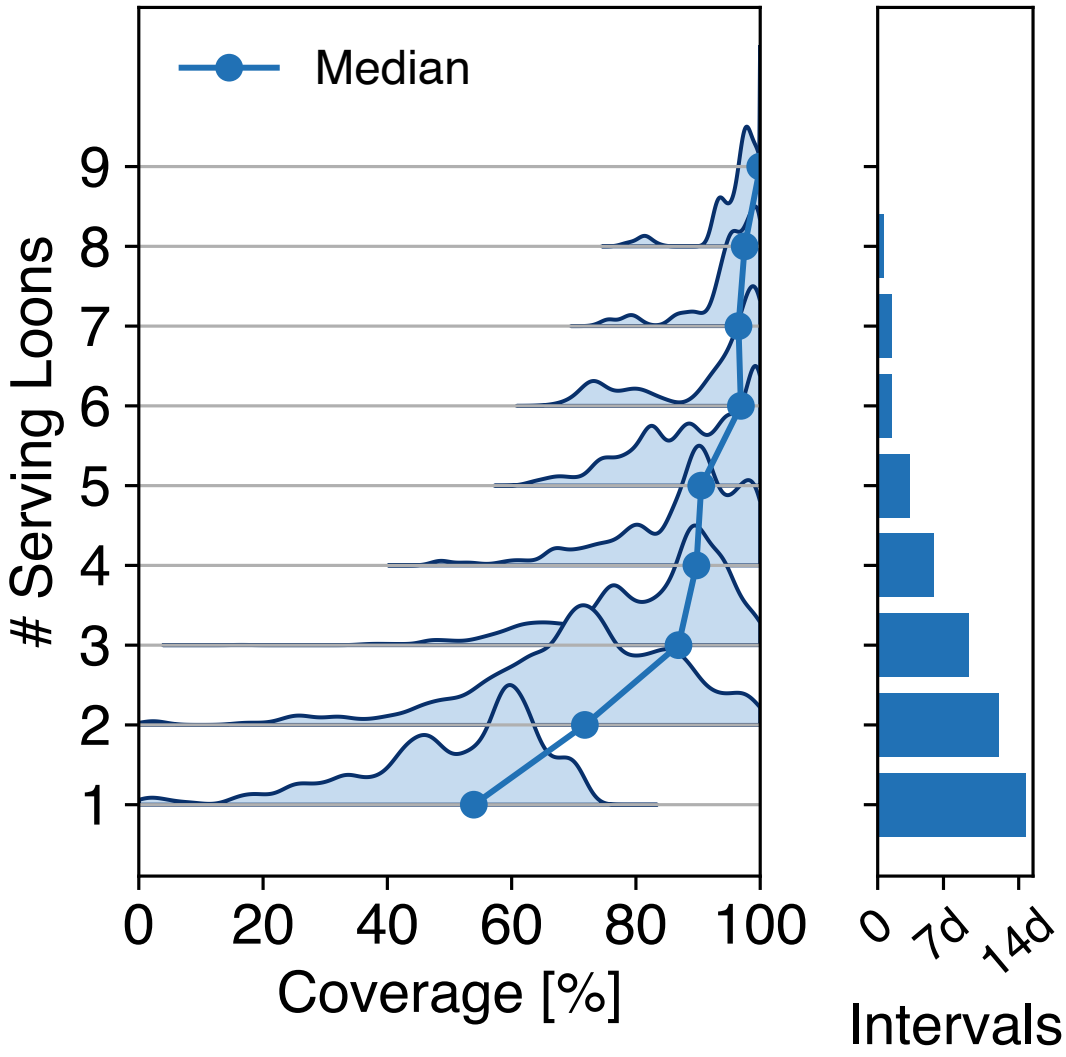
Kenya



“COST” OF COVERAGE

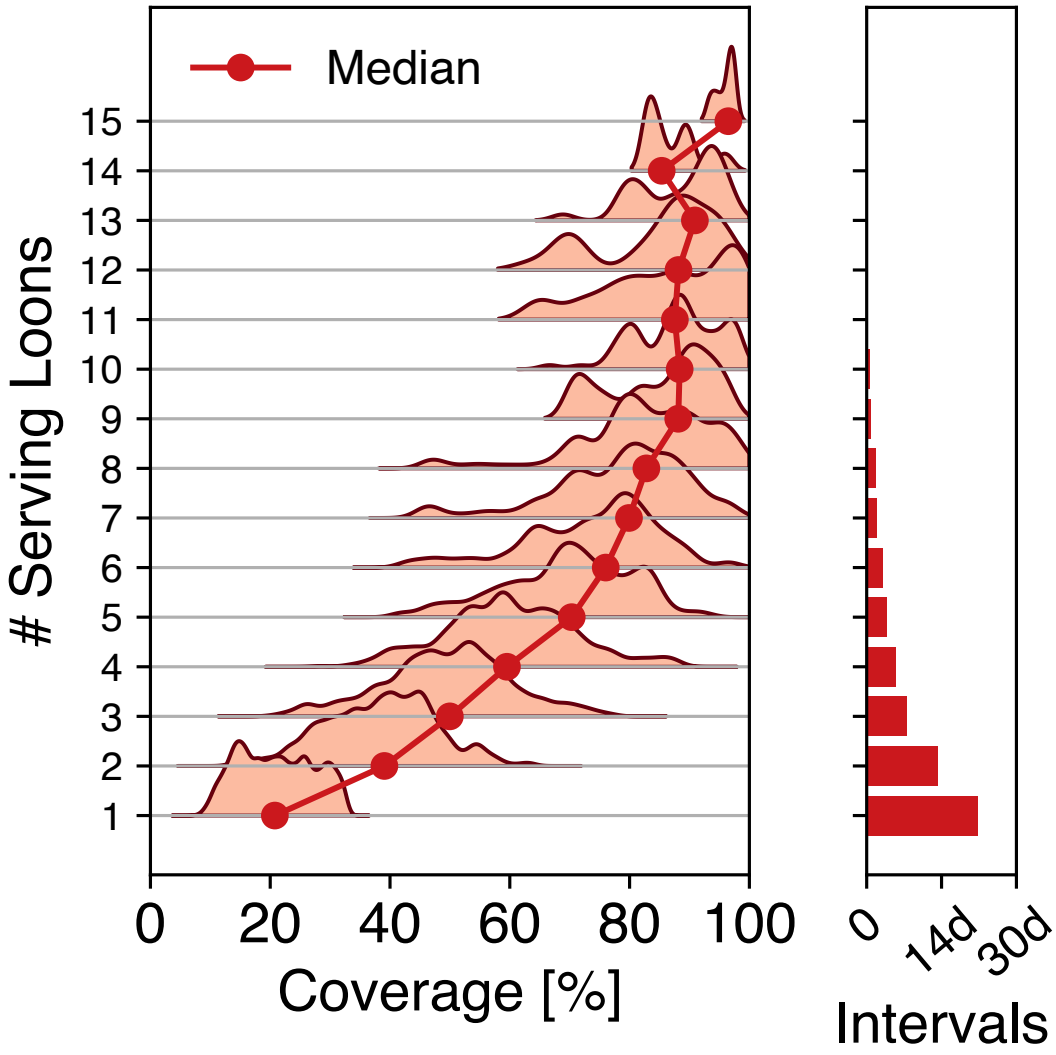
Puerto Rico

- Conditional density function of coverage
- With 2 loons
  - Median: 75%
- For ≥ 6 loons
  - Median > 90%



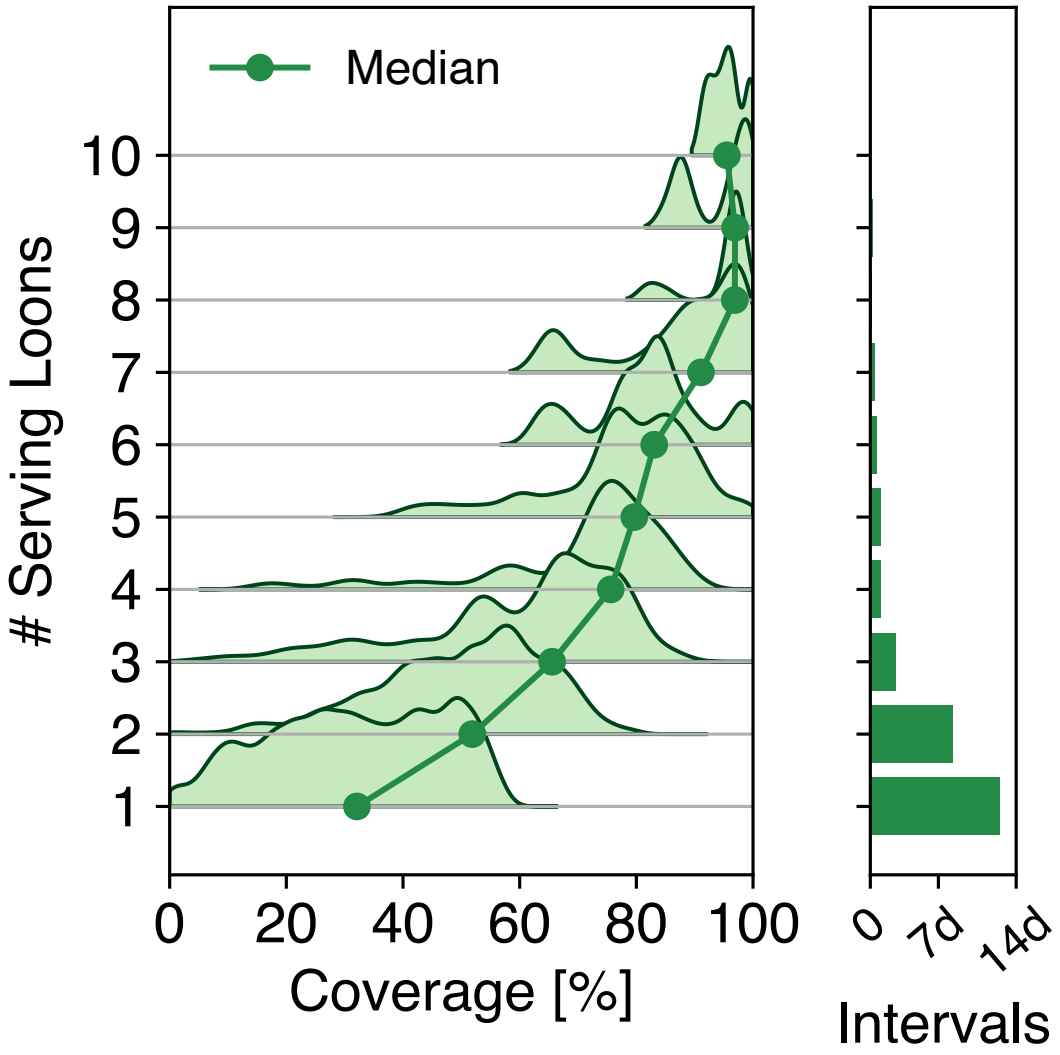
Puerto Rico

- Coverage only reaches 100% with ≥ 8 Loons
- Between 9 and 13: same median



Kenya

- Reaches 100% with 5 loons
- Extra loons improve coverage



ON THE BEST AND WORST SERVICE

Windowed maximal coverage

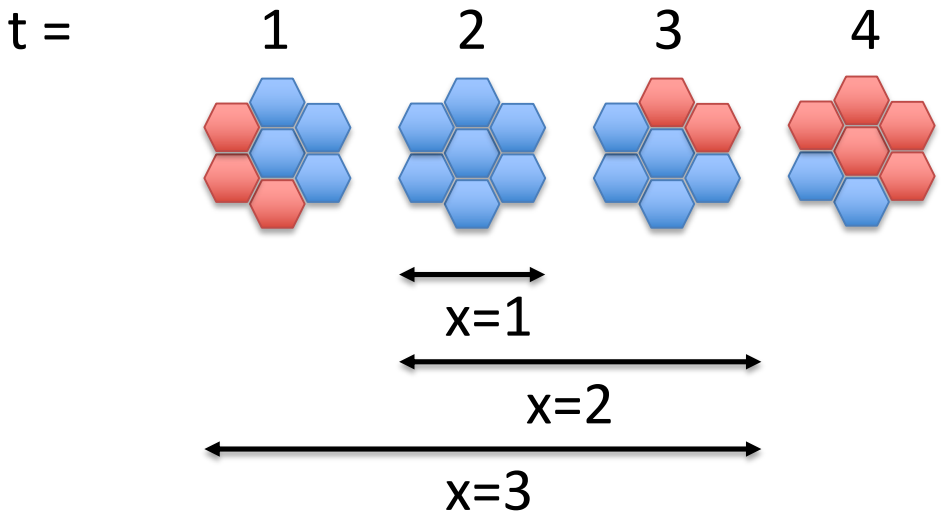
- Inspired by meaningful availability [1]
- Windowed max. coverage

[1] T. Hauer et al. “Meaningful availability,” in NSDI 20, Feb. 2020

$$W^{\text{C-MAX}}(x) \equiv \max_{T_1<t_1<t_2<T_2} \{N^{\text{COV}}_{t_1,t_2} \mid t_2 - t_1 = x\}$$

$N^{\text{COV}}_{t_1,t_2}$ is the avg. # pixels with coverage during [t_1,t_2]

- Idea: find the best avg. coverage during ‘x’



W(1) = 7/7 = 100%
W(2) = 12/14 = 86%
W(3) = 16/21 = 76%
W(4) = 18/28 = 64%

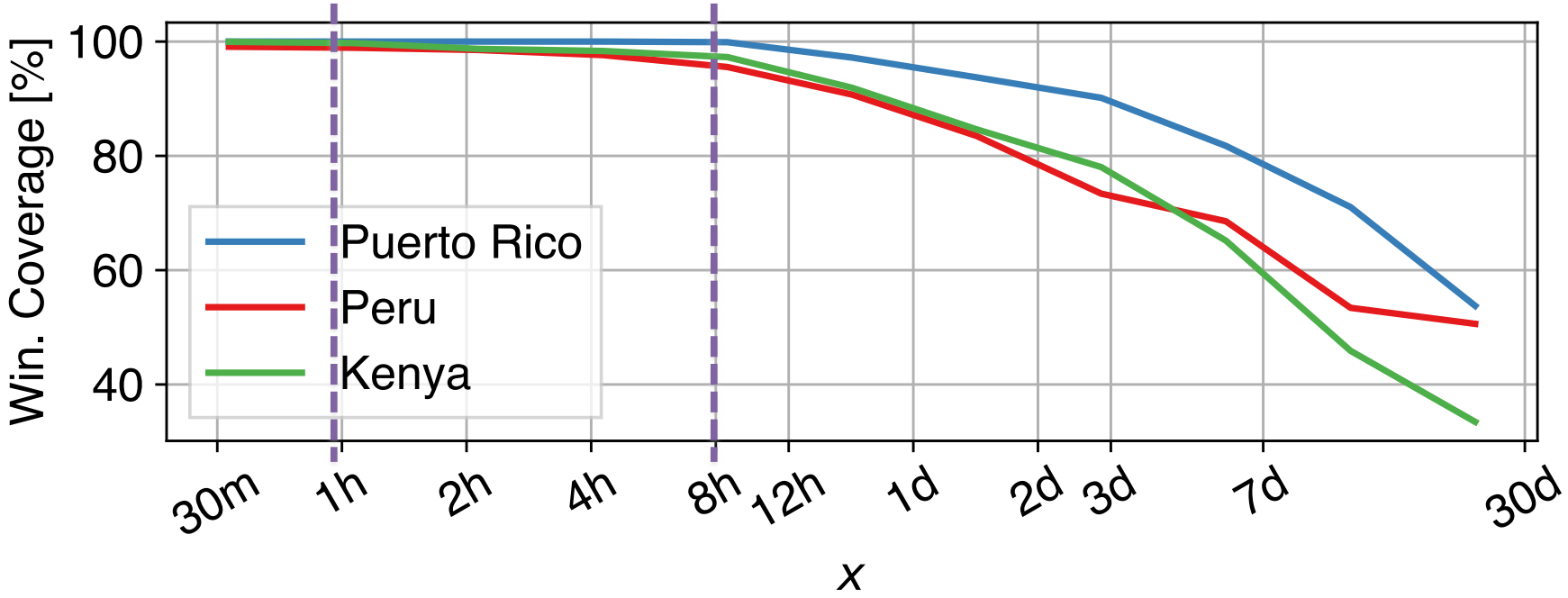
Windowed maximal coverage

- Inspired by meaningful availability [1]
- Windowed max. coverage

[1] T. Hauer et al. “Meaningful availability,” in NSDI 20, Feb. 2020

$$W^{\text{C-MAX}}(x) \equiv \max_{T_1<t_1<t_2<T_2} \{N^{\text{COV}}_{t_1,t_2} \mid t_2 - t_1 = x\}$$

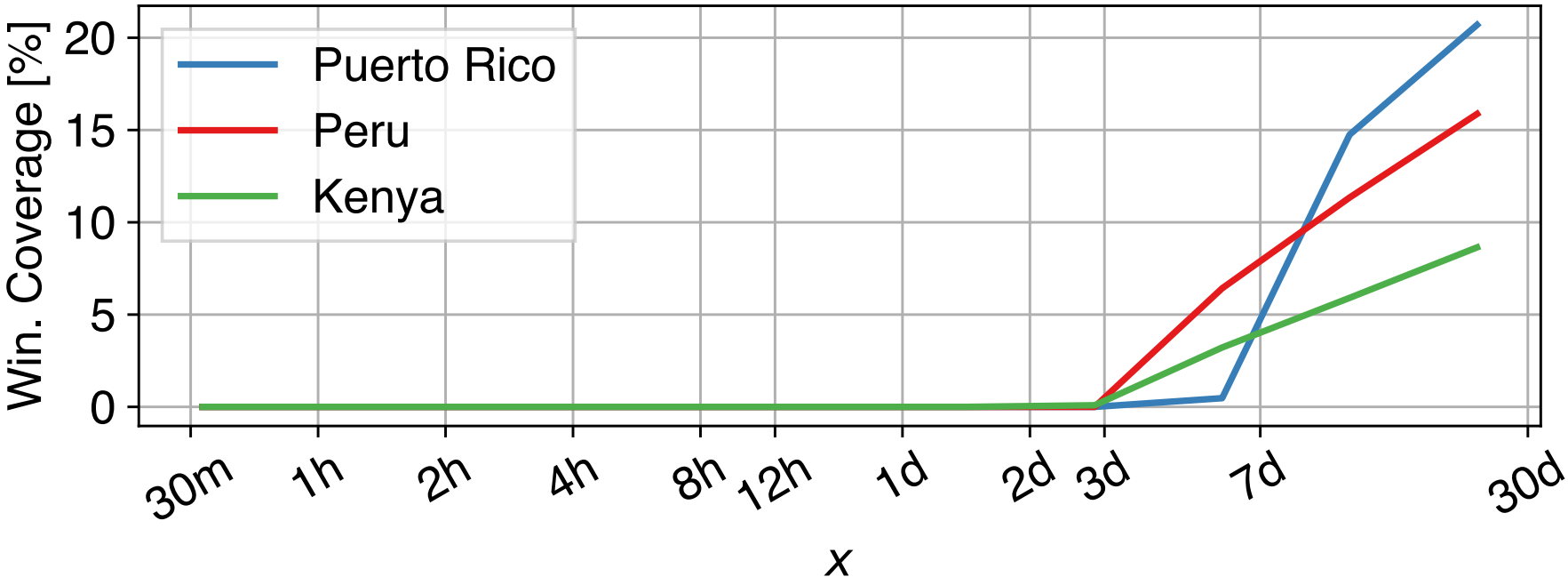
$N^{\text{COV}}_{t_1,t_2}$ is the avg. # pixels with coverage during [t_1,t_2]



Windowed minimal coverage

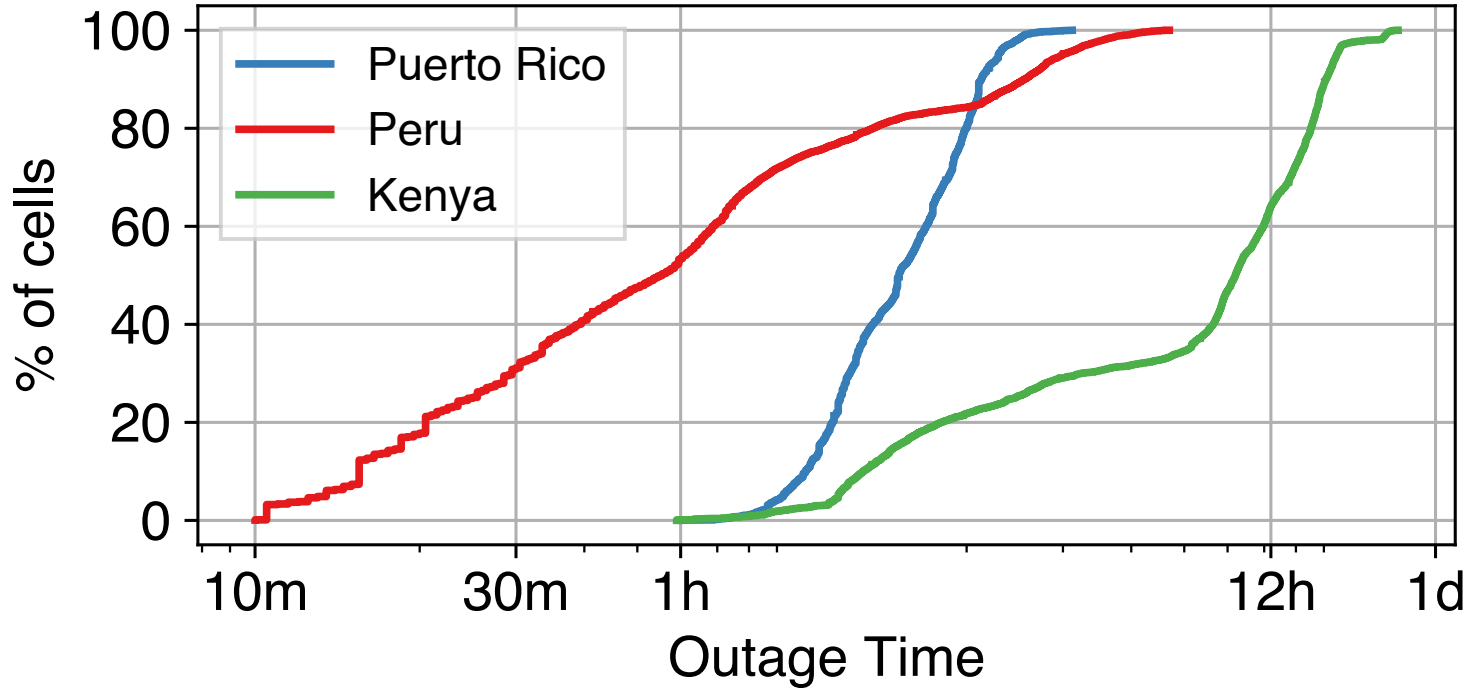
- Windowed min. coverage

$$W^{\text{C-MIN}}(x) \equiv \min_{T_1<t_1<t_2<T_2} \{N^{\text{COV}}_{t_1,t_2} \mid t_2 - t_1 = x\}$$



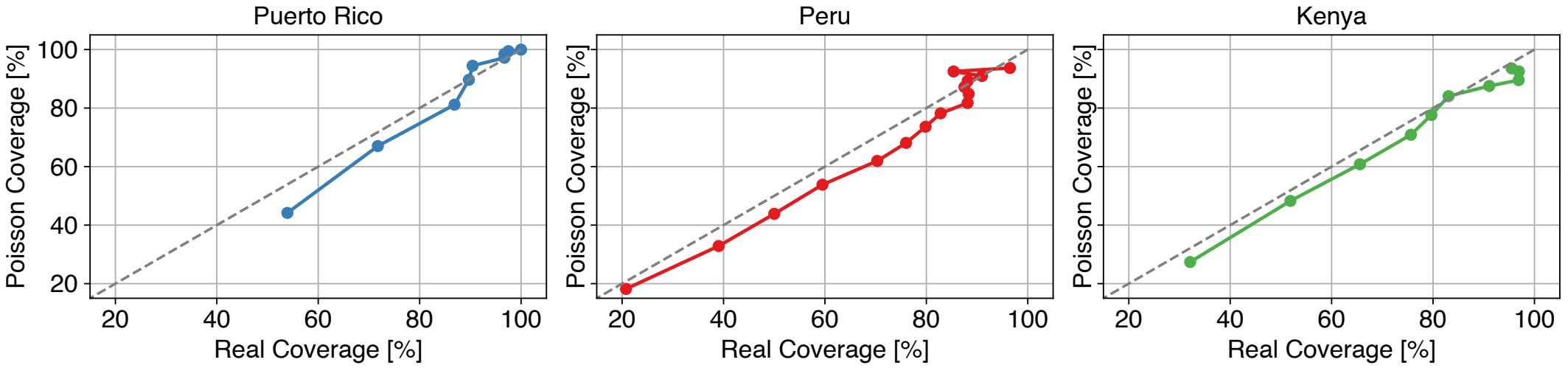
Outage time distribution

- Collect all downtimes per pixel (hexagon)
- Compute the median (per pixel)



Comparison vs. random deployment

- Median coverage with N loons
  - N loons (“real”) **vs.**
  - N randomly deployed loons (“Poisson”)



SUMMARY

Summary

- Study Loon service under optimistic assumptions
  - Channel model, interference, inter-loon links
  - Areas and times with certain coverage
- It is a better than nothing delay tolerant service
  - Outage periods > hours
- Significant challenges
  - Diminishing returns of adding extra loons
    - A 3x over provision
  - Performance similar to a random deployment

Saying goodbye to Loon

- Jan 22, 2021: “we haven’t found a way to get the cost low enough to build a long-term, sustainable business” https://blog.x.company/loon-draft-c3fcebc11f3f
- SoftBank acquired approx. 200 Patents from Loon

  https://www.softbank.jp/en/corp/news/press/sbkk/2021/20210930_03/
- Loon compiled a book about the experience

  https://www.scribd.com/document/528613645/The-Loon-Library
- Alphabet has open-sourced the data of 70 million kms or so of flight, including GPS and sensor data

  https://zenodo.org/record/3763022

Balloons in the Sky: Unveiling the Characteristics and Trade-offs of the Google Loon Service

Many thanks for your attention!

P. Serrano, M. Gramaglia, F. Mancini, L. Chiaraviglio, G. Bianchi, "Balloons in the Sky: Unveiling the Characteristics and Trade-offs of the Google Loon Service,"
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