An Empirical Evaluation of Longitudinal Anycast Catchment Stability

RIPE 91 - Bucharest, Romania

October 21, 2025

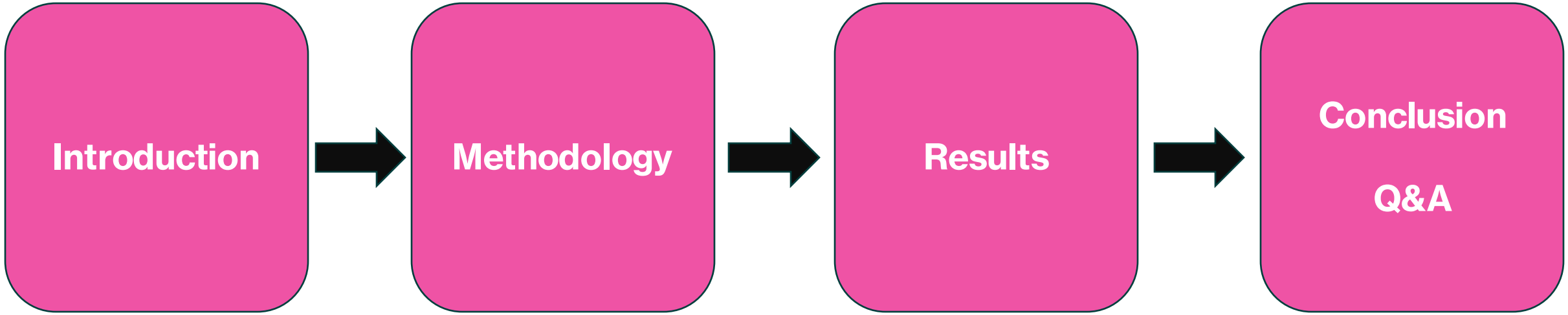
Remi Hendriks, Bernhard Degen, Bas Palinckx,

Raffaele Sommese, Roland van Rijswijk-Deij

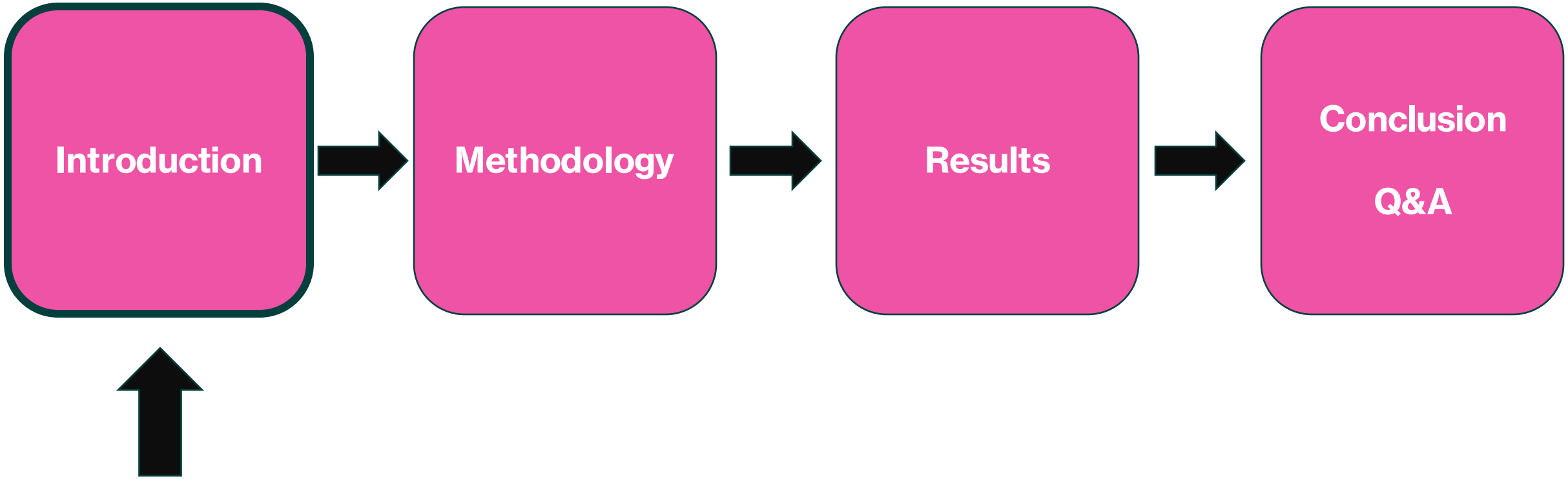
UNIVERSITY OF TWENTE.

DACS
Design and Analysis of Communication Systems

Structure



Structure



Introduction
Catchment mapping

- Anycast: announcing an IP prefix at multiple Points of Presence (PoPs)
  - BGP directs clients to different PoPs (often nearest)
  - Example usages: CDNs, DNS
- To assess client distribution, **catchment** mappings are used
- **Catchment**: the set of IP addresses that route to a particular anycast PoP
- Verfploeter [1] allows for actively measuring catchments



K-root anycast deployment

[1] Broad and load-aware anycast mapping with Verfploeter, de Vries et al. IMC'17

Introduction
Catchment mapping

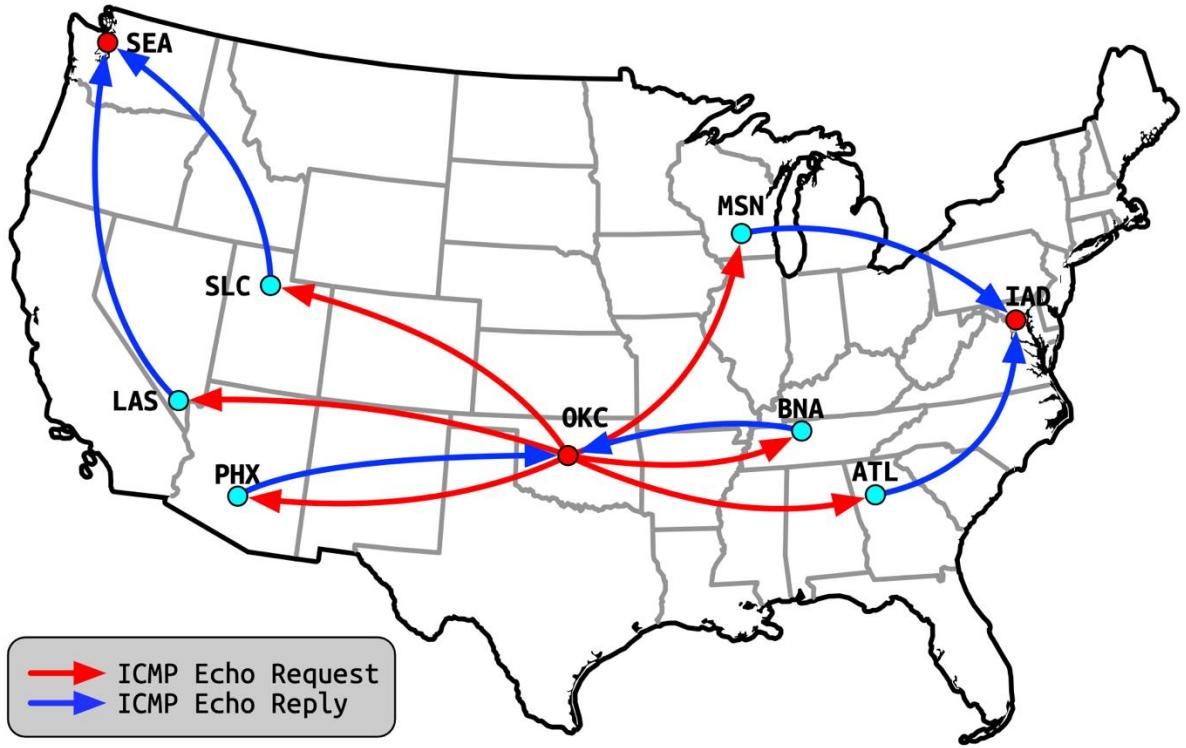


Fig. 1: The Verfploeter [18] method; an anycast site (red) sends ICMP probes to a hitlist, responses from clients (blue) end up at the "closest" anycast site.

Introduction
Problem statement

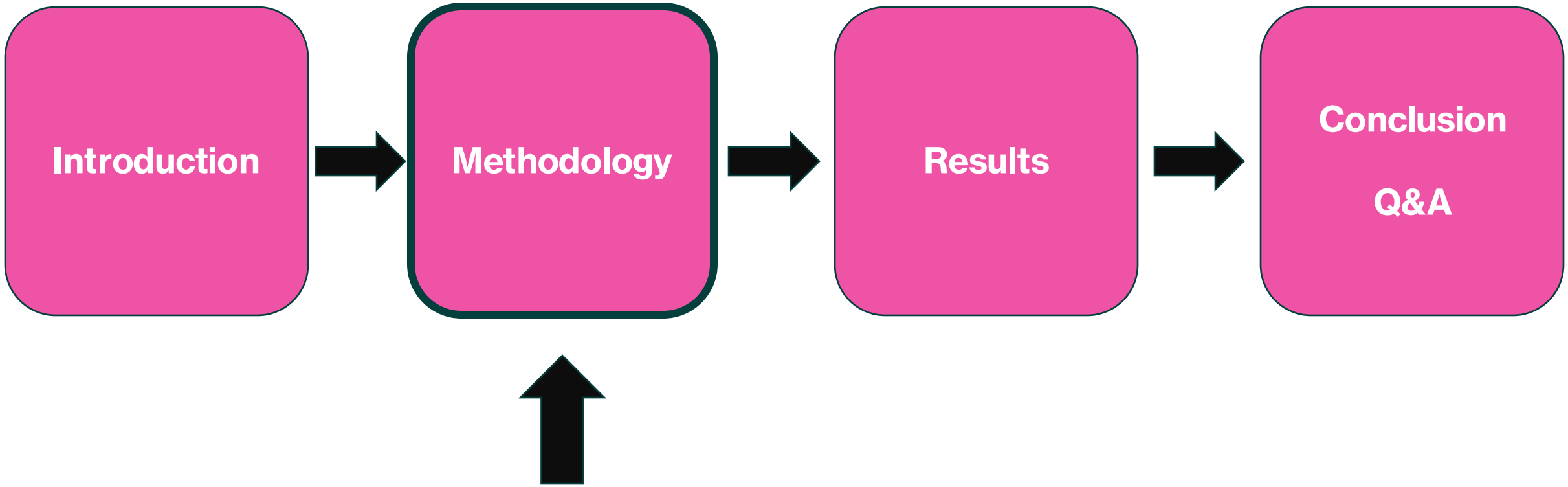
- Catchment mappings are useful
  - Gives insights in the performance of anycast networks
  - Allows for troubleshooting sub-optimal routing
    - *E.g.,* network region routing to distant PoP when a nearby PoP is available

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- Problem statement:

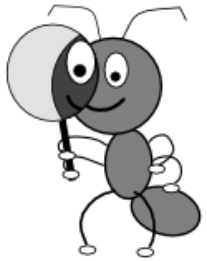
  Stability of catchment mappings (and anycast routing) largely unknown
  - How often should operators assess catchment mappings?
  - *E.g.,* is my catchment mapping from today valid for tomorrow?
    - What about next week? Next month? ...

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Methodology
Measurement set-up

- Daily Verfploeter catchment mappings spanning 6 months
- Targets
  - IPv4: USC/ISI hitlist [2]
  - IPv6: TUM's public IPv6 hitlist [3] + OpenINTEL [4] AAAA record addresses
- Probing strategy
  - One target per smallest propagated BGP prefix size (IPv4: /24, IPv6: /48) as representative
  - 3.5M responsive /24s and 0.5M IPv6 /48s responsive throughout the entire analysis period



Technical University of Munich

Open INTEL

[2] USC/LANDER project: Internet Addresses Survey Dataset. isi.edu/ant/lander

[3] Clusters in the Expanse: Understanding and Unbiasing IPv6 hitlists. Gasser et al. IMC '18

[4] A High-Performance, Scalable infrastructure for Large-Scale Active DNS Measurements. van Rijswijk-Deij et al. IEEE Journal '16

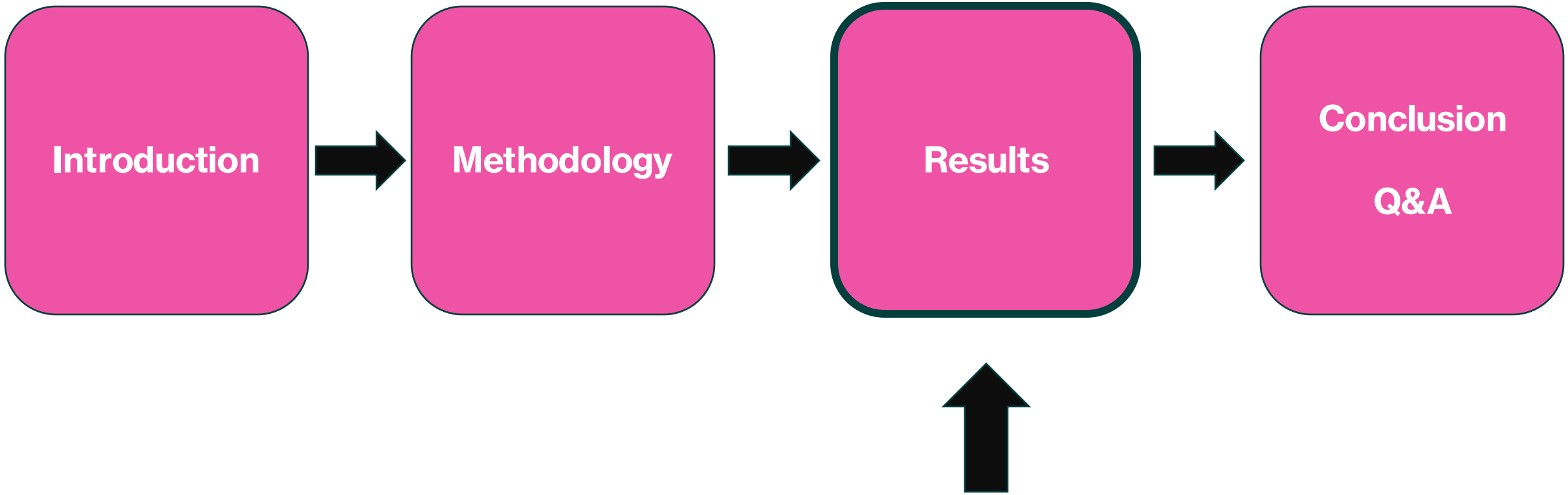
Methodology
Measurement set-up

- Anycast testbed comprising 32 PoPs
  - 20 countries; 6 continents
- Daily mappings at 00:00 UTC

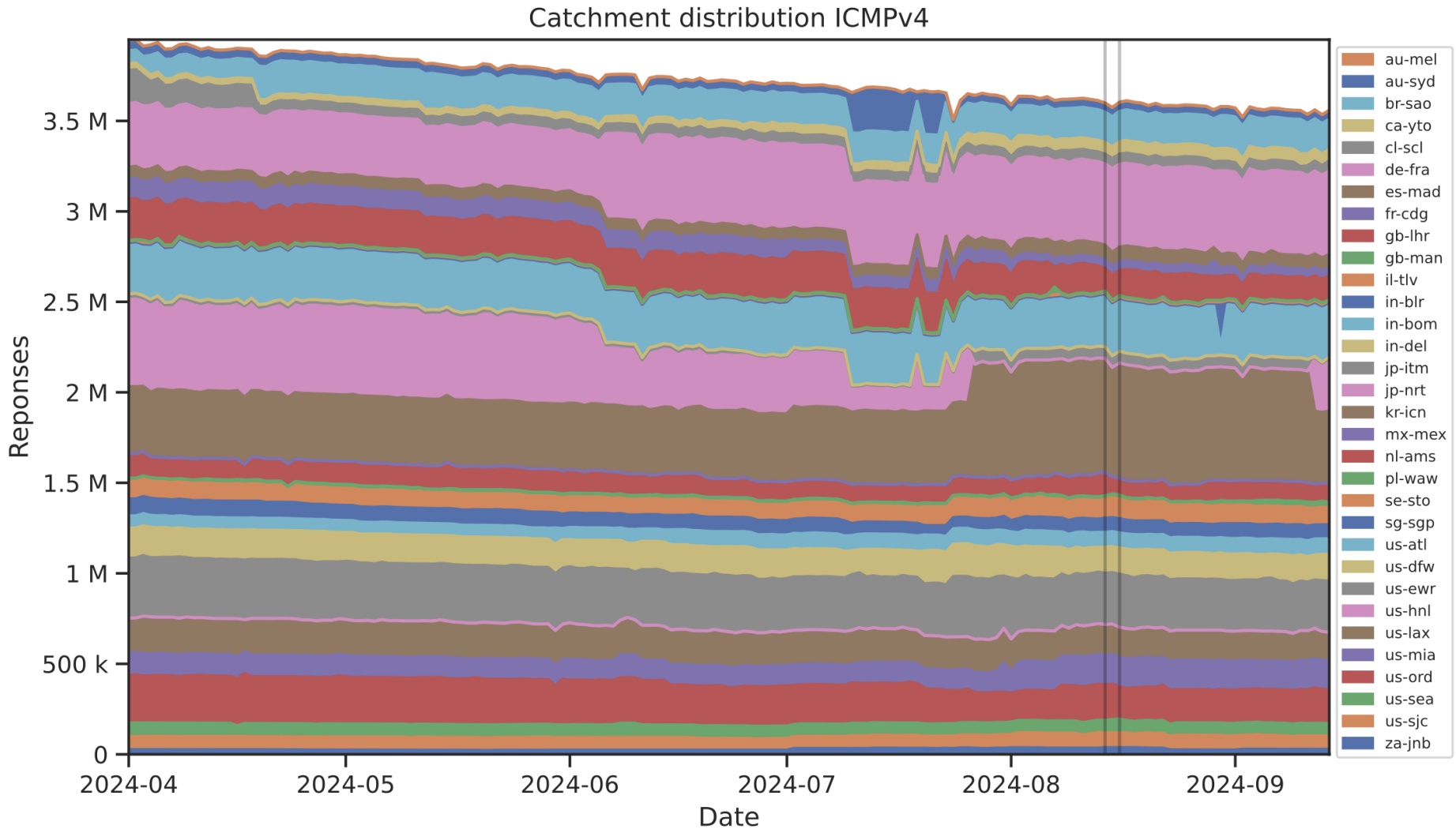


Vultr datacenter locations
https://www.vultr.com/features/datacenter-locations/

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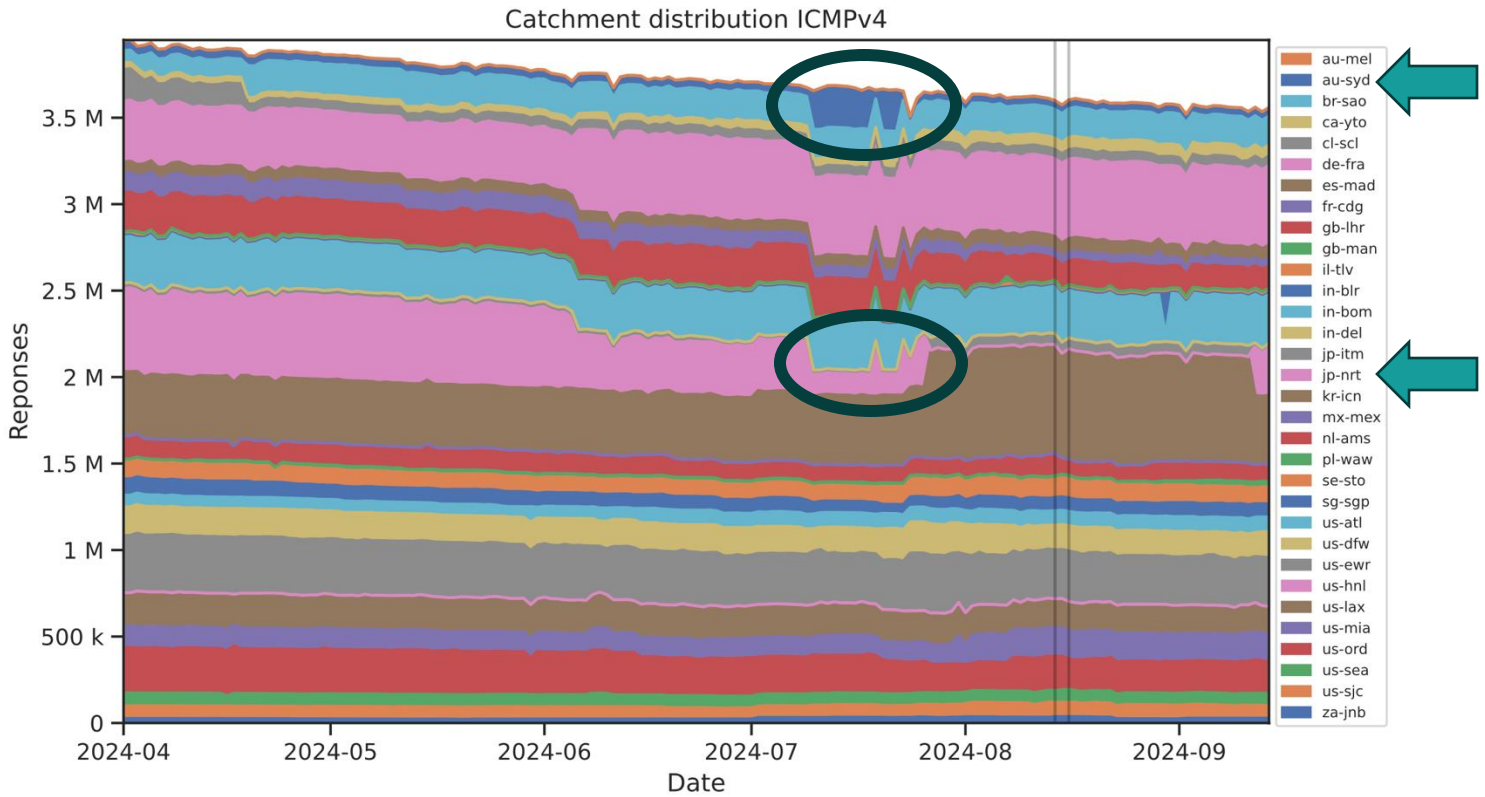


Results
Longitudinal catchment distribution



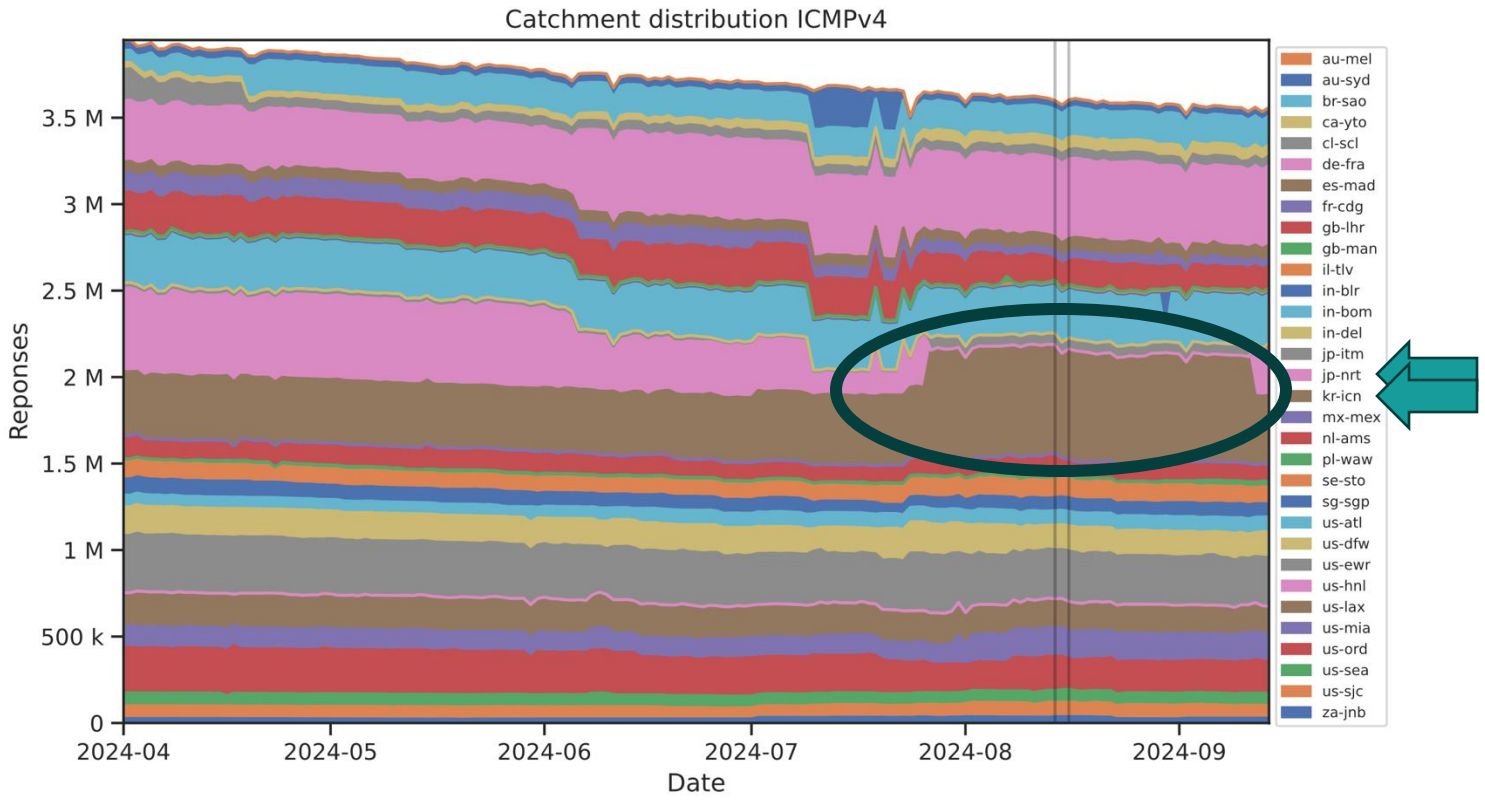
Results
Longitudinal catchment distribution

- July 10
  - jp-nrt (Tokyo) loses most traffic
  - au-syd (Sydney) expands five-fold



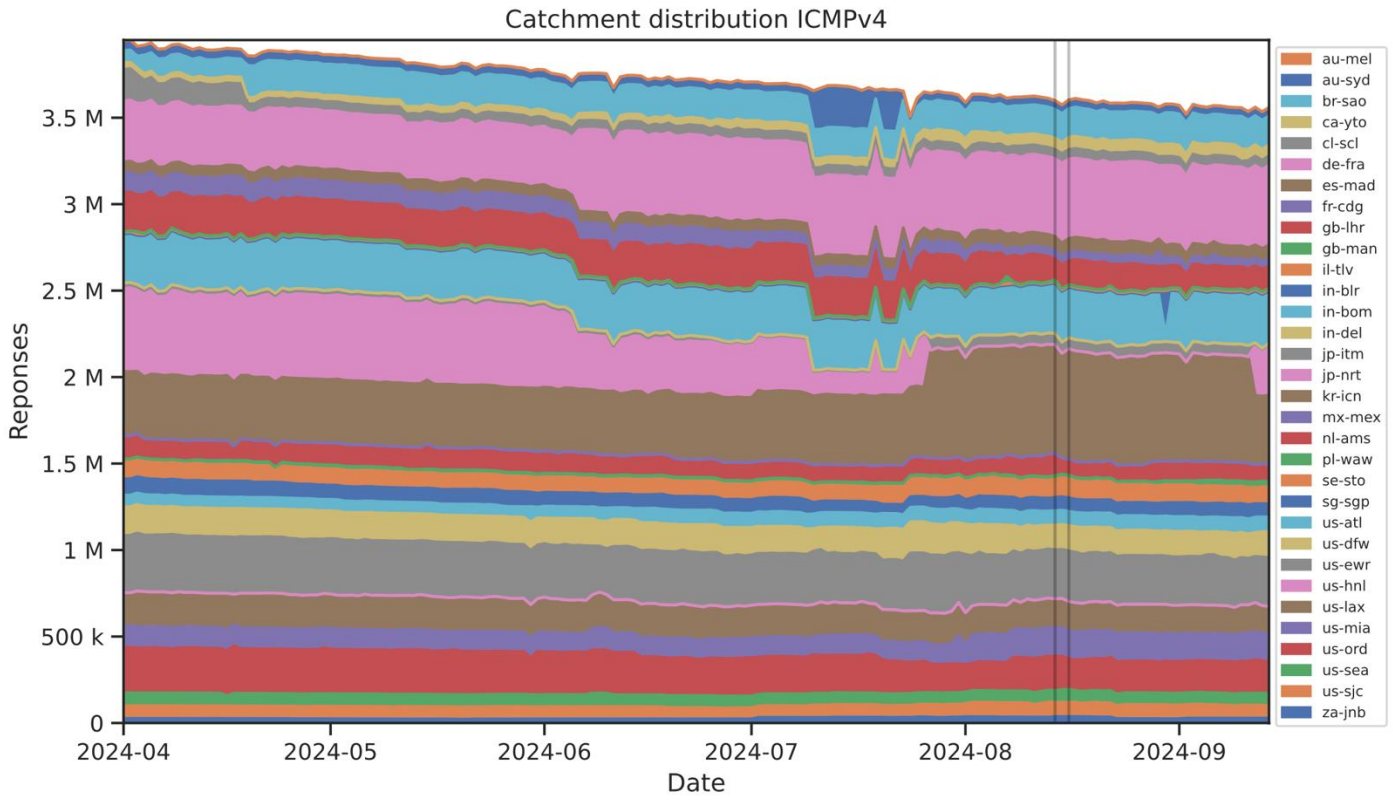
Results
Longitudinal catchment distribution

- July 10
  - jp-nrt (Tokyo) loses most traffic
  - au-syd (Sydney) expands five-fold
- July 27 – September 12
  - kr-icn (Seoul) increases by 200k
  - jp-nrt (Tokyo) shrinks further



Results
Longitudinal catchment distribution

- Takeaways:
  - Large difference in catchment sizes (caused by topological differences)
  - Large catchment shifts visible (suggesting large re-routing events)



Results
Zooming in on jp-nrt (Tokyo)

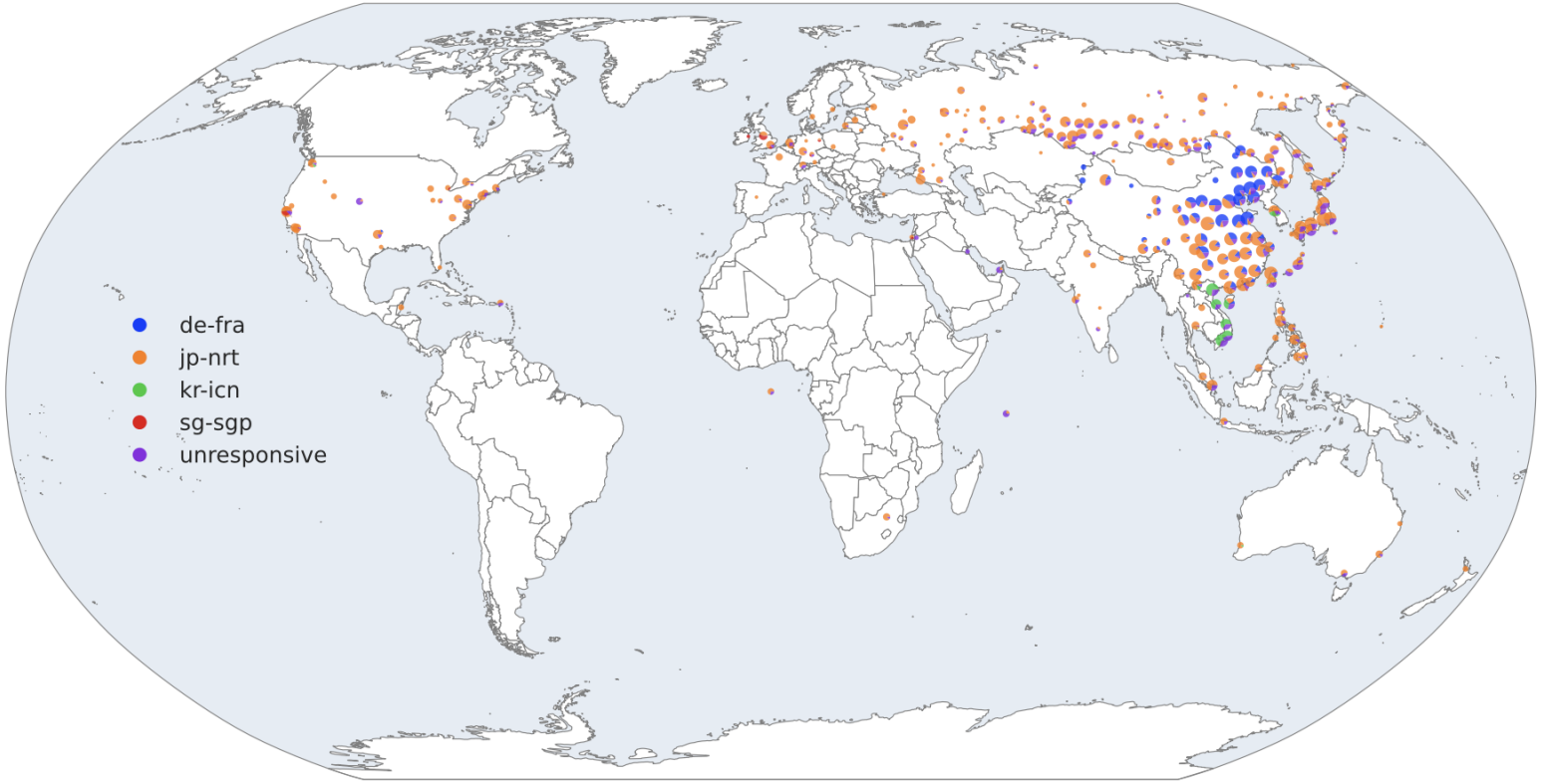
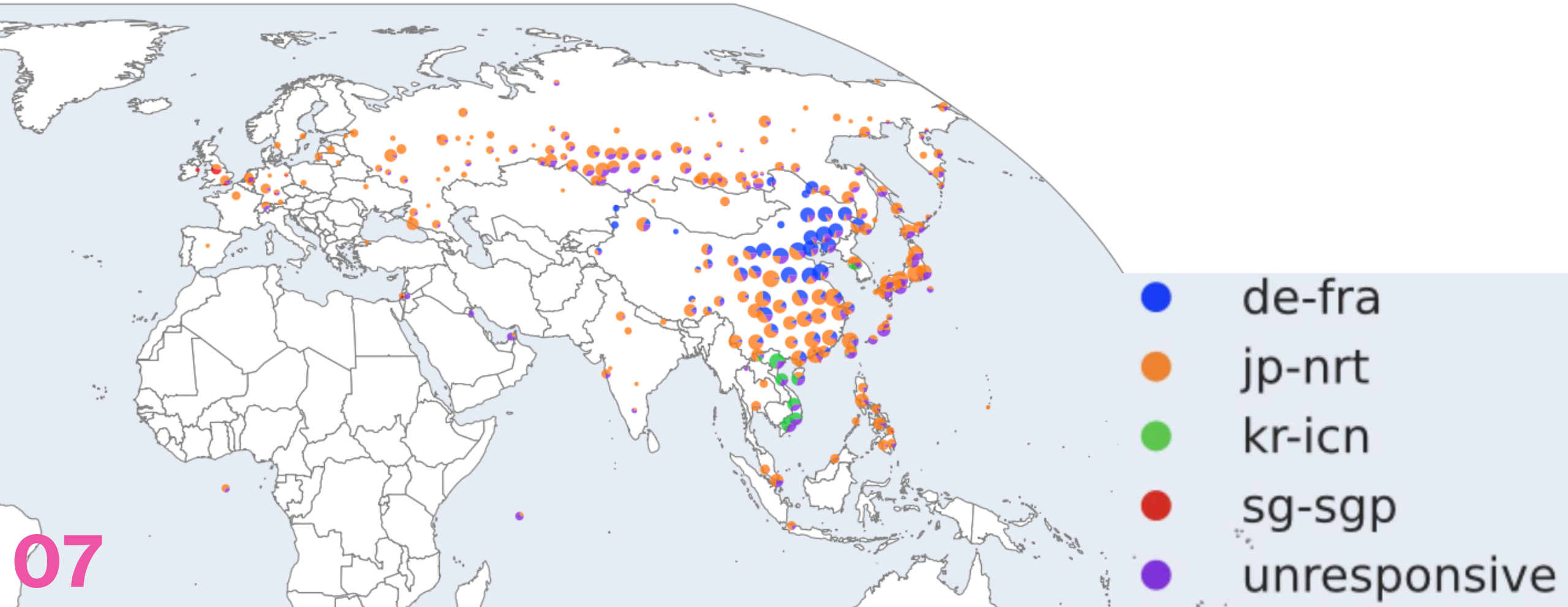
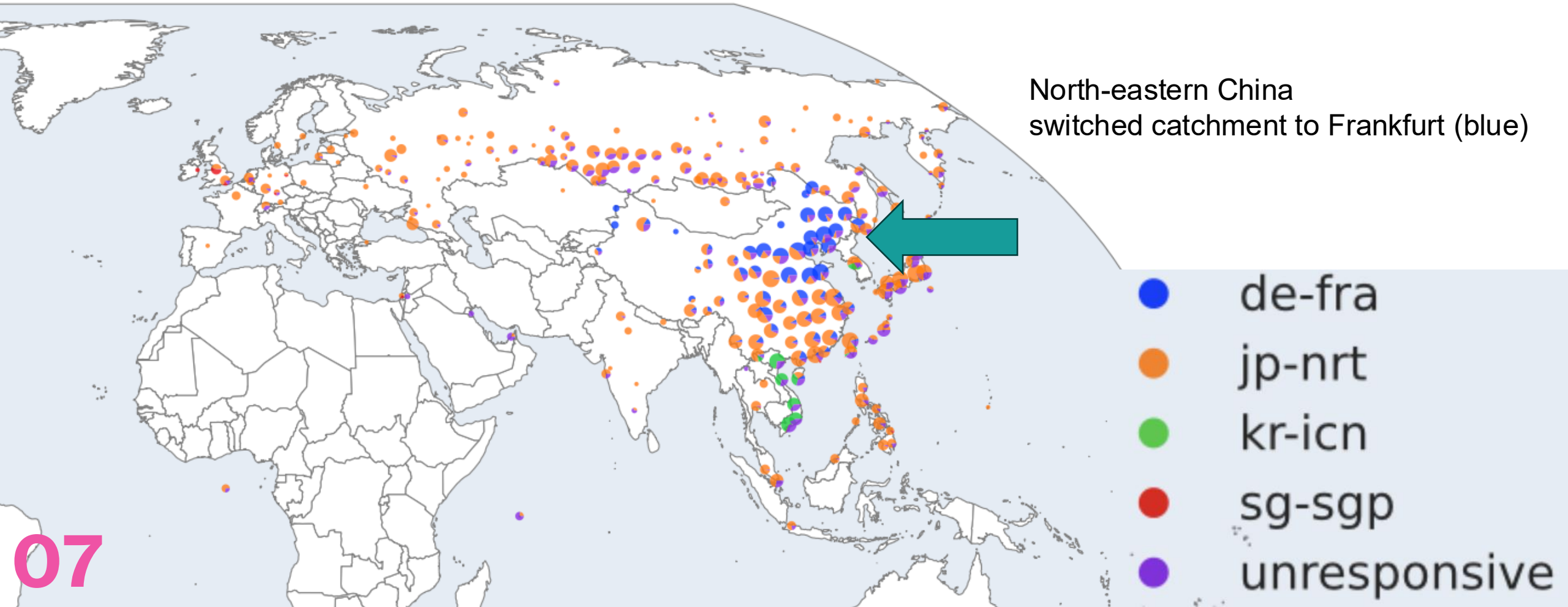


Fig. 7: Visualization of the geolocation of prefixes in the catchment of jp-nrt on April 1st, and where they re-routed to on July 1st indicated with pie charts.

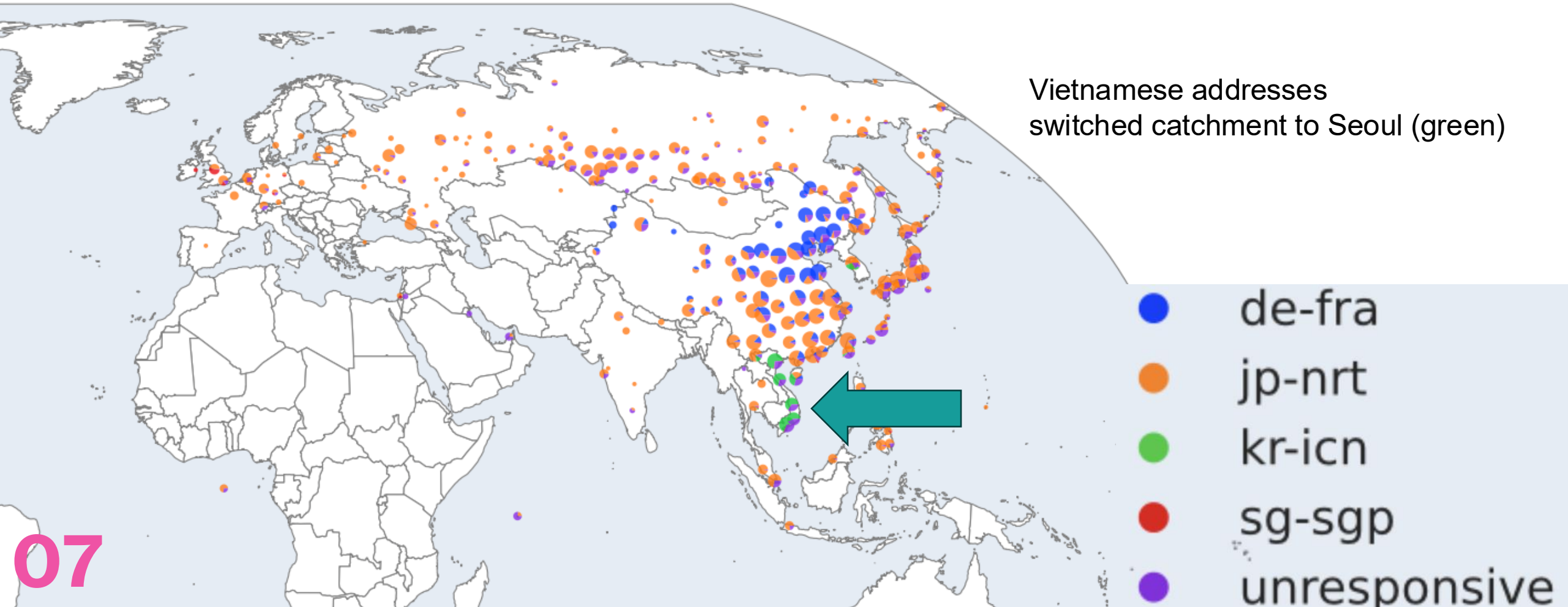
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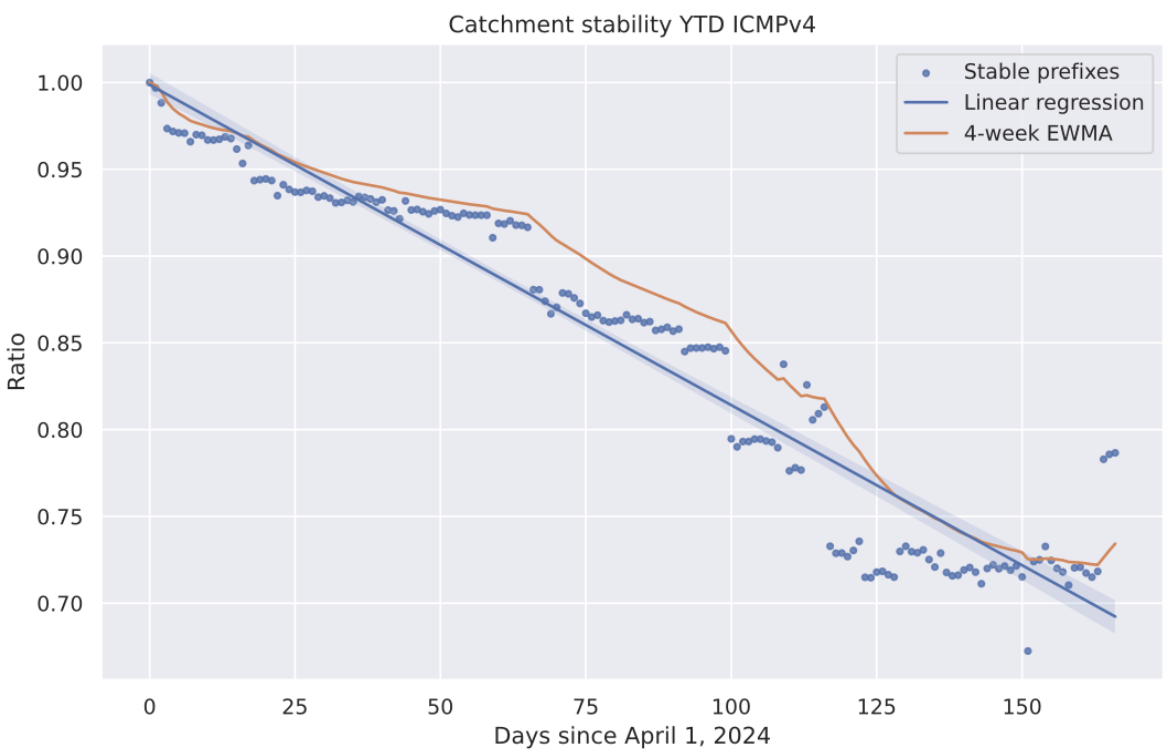
Vietnamese addresses
switched catchment to Seoul (green)

Results
Zooming in on jp-nrt (Tokyo)

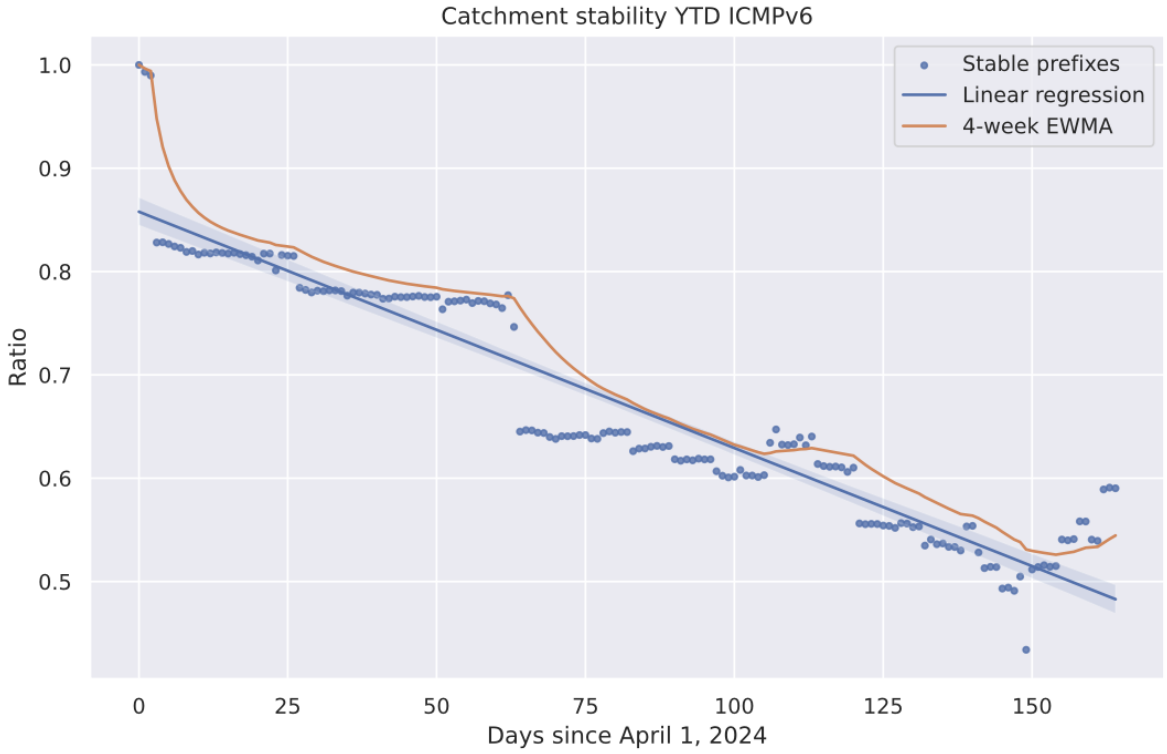
Table 1: Differences in RTT for the largest catchment changes observed at jp-nrt between April 1st and July 1st.

New site in July	Number of prefixes	Mean RTT to JP-NRT	Mean RTT to new site
de-fra	125,418	73.0 ms	255.3 ms (+250%)
jp-nrt*	296,304	89.5 ms	83.4 ms (-7%)
kr-icn	9,291	92.7 ms	99.4 ms (+7%)
sg-sgp	1,134	59.5 ms	43.5 ms (-27%)
Total	432,147	84.0 ms	141.1 ms (+68%)
unresponsive	78,153	81.7 ms	*n/a*

Results
Catchment stability over time



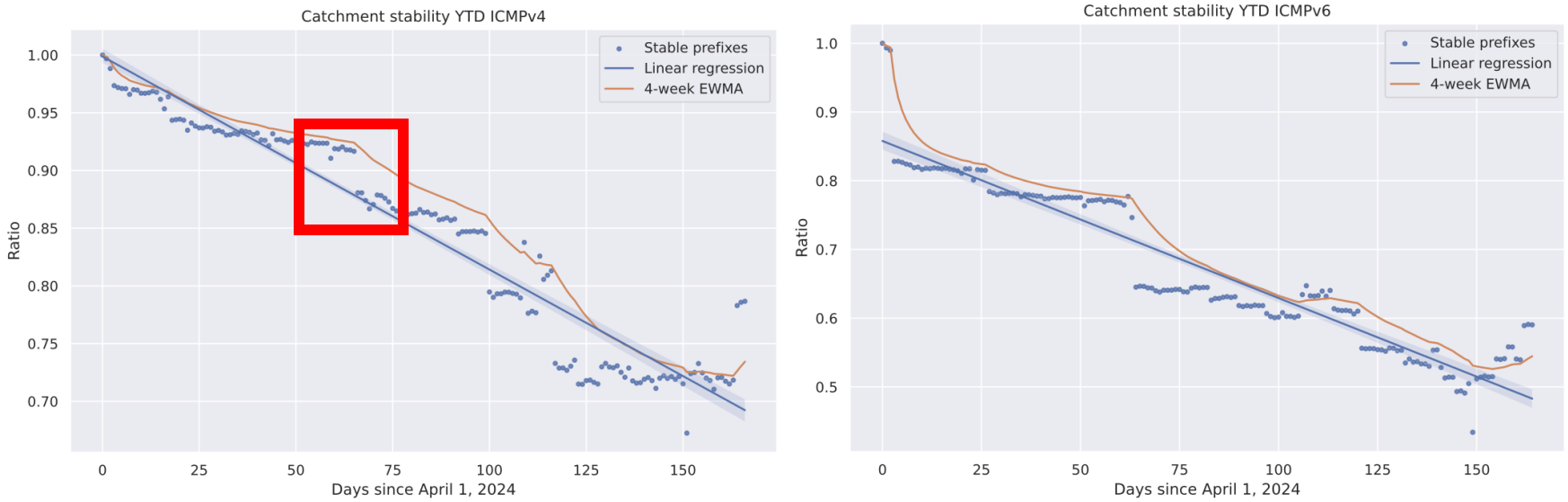
(a) ICMPv4



(b) ICMPv6

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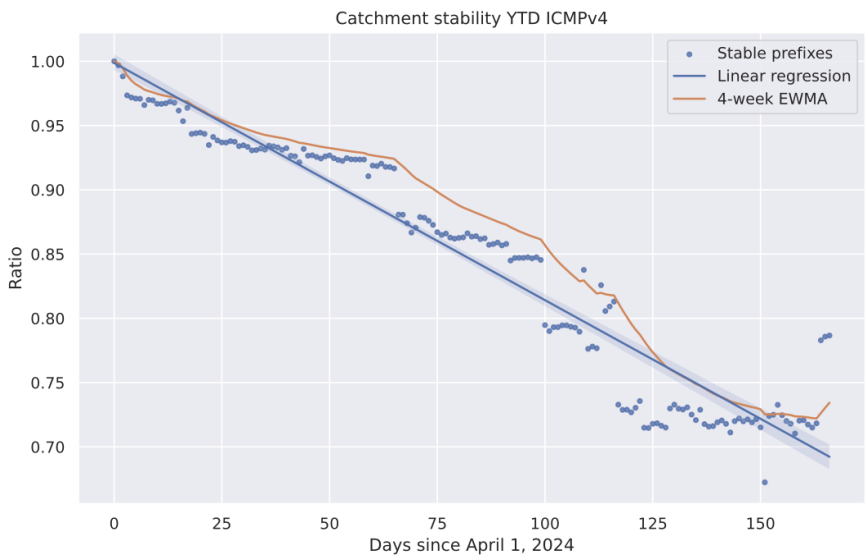
- Takeaways:
  - IPv4 mapping remains valid for 2 months (with an error rate of 10%)



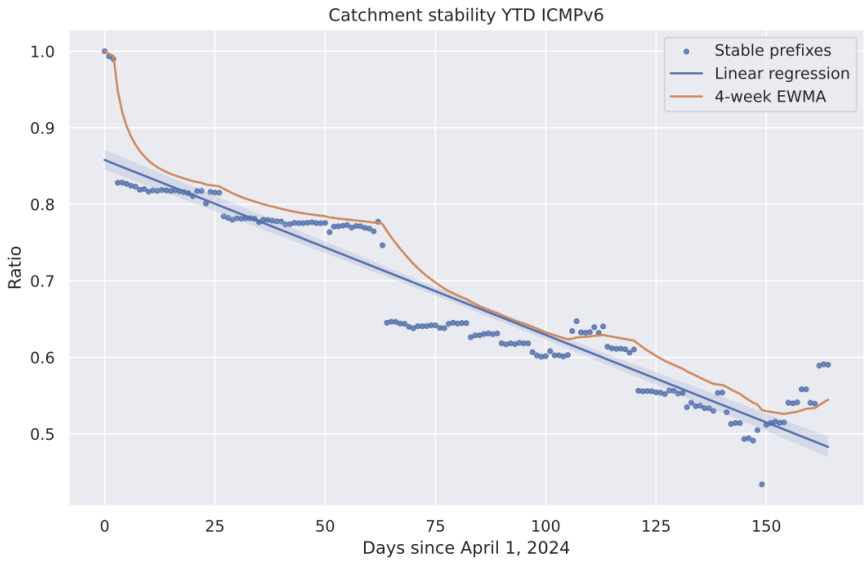
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  - Gradual decline with accelerations (likely due to re-routing events)



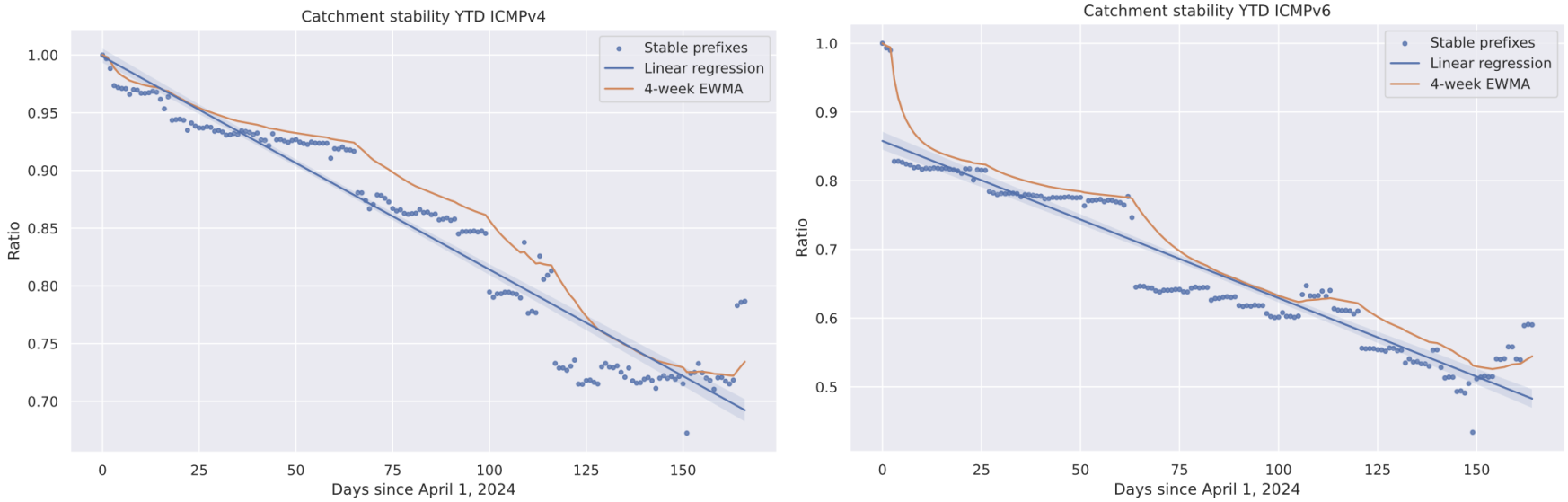
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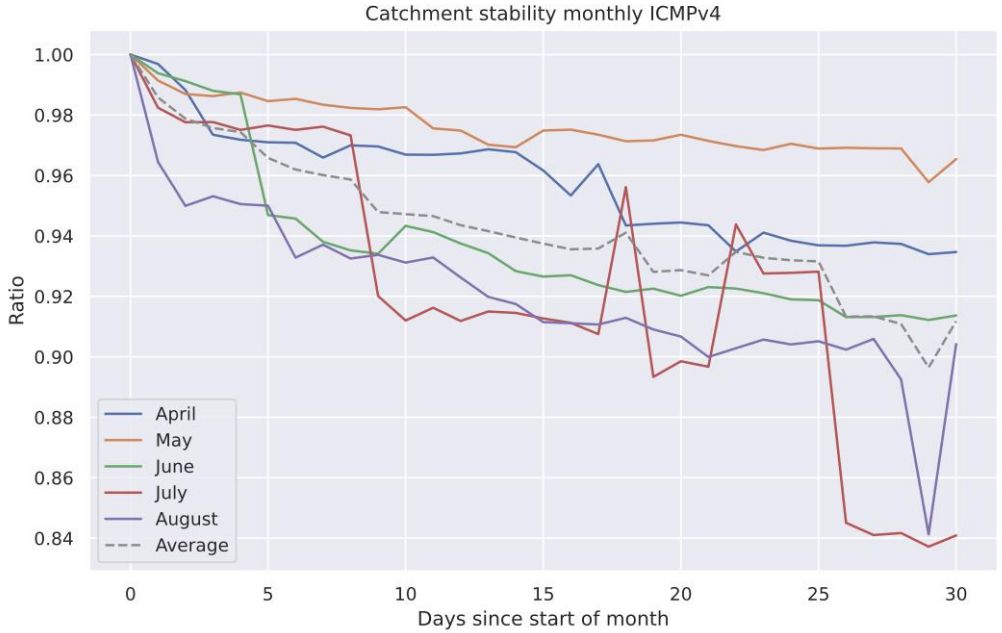
Results
Catchment stability over time

- Takeaways:
  - IPv4 mapping remains valid for 2 months (with an error rate of 10%)
  - Gradual decline with accelerations (likely due to re-routing events)
  - IPv6 more turbulent and less stable over time (*hitlist bias)

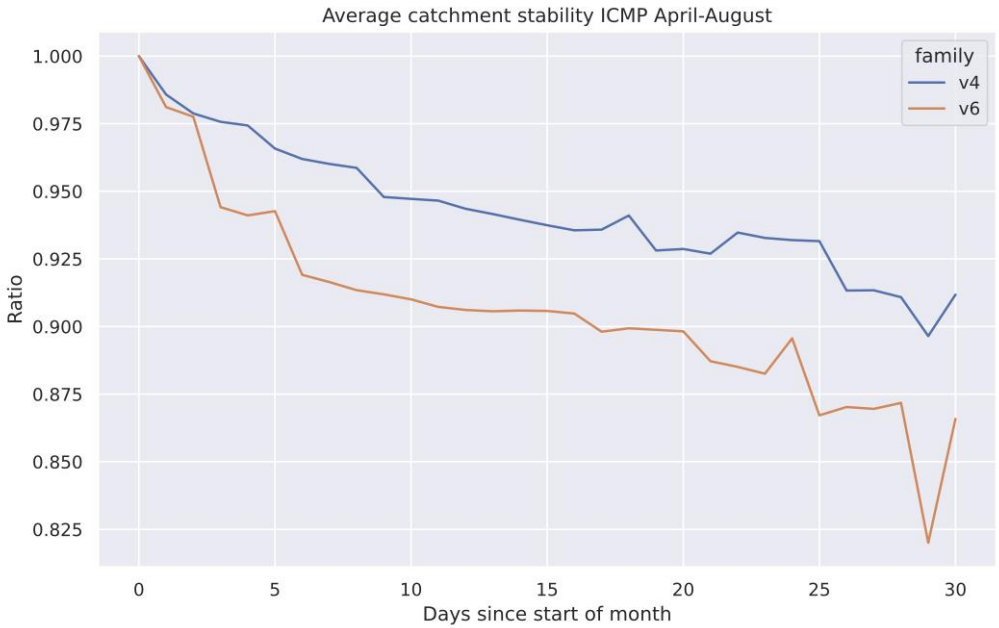


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Results
Monthly catchment stability



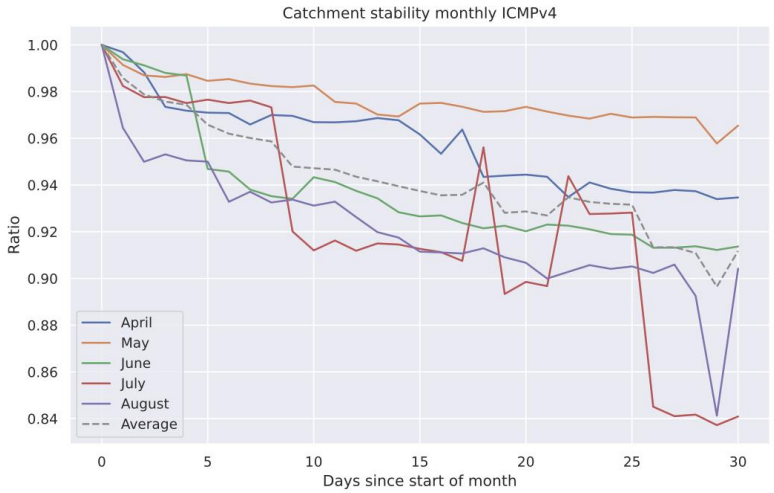
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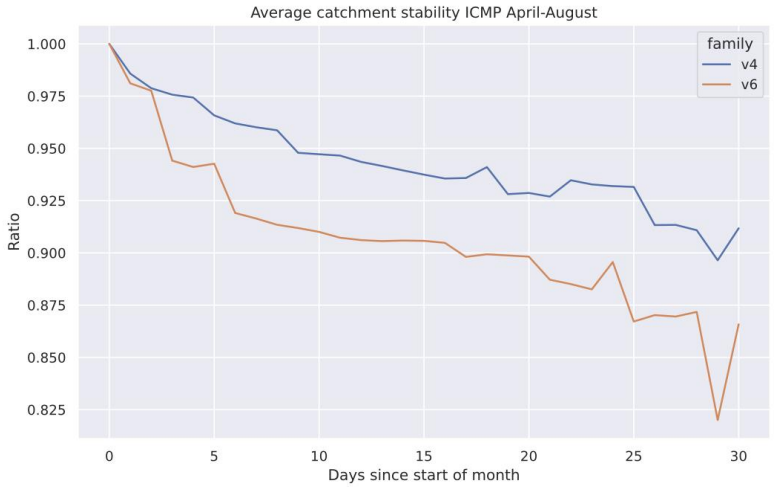
(b) Average monthly stability of ICMPv4 and ICMPv6 compared. We observe that IPv4 routing appears more stable on average and exhibits less variability.

Results
Monthly catchment stability

- Takeaways:
  - Catchments remain stable, on average, for an entire month



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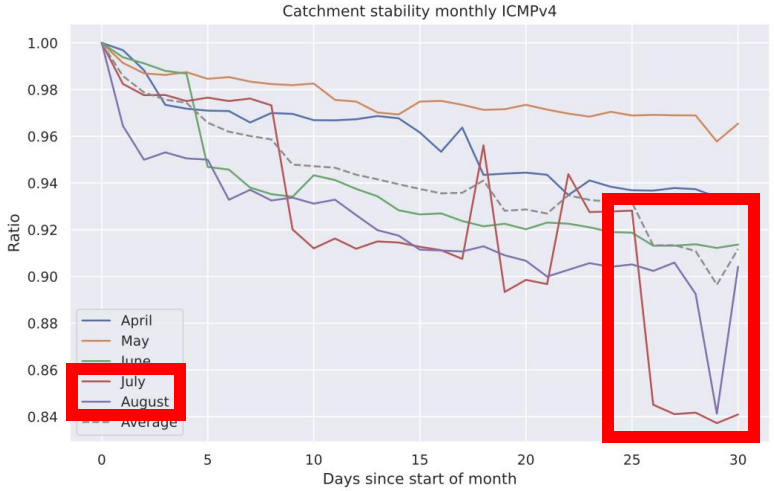


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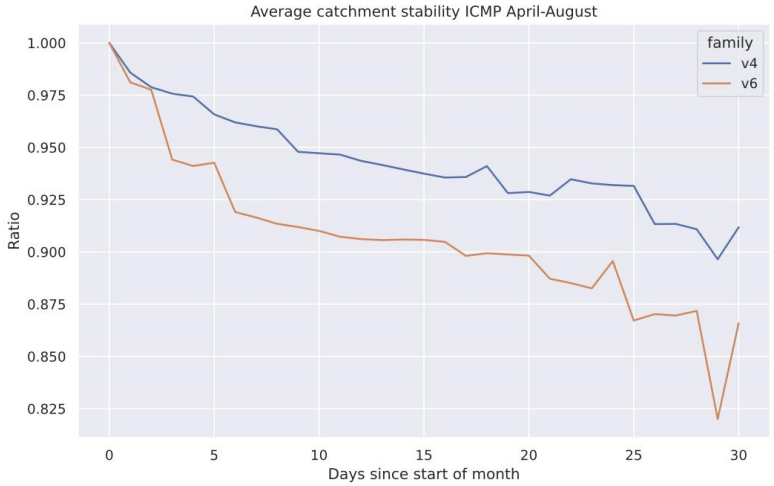
Results
Monthly catchment stability

- Takeaways:
  - Catchments remain stable, on average, for an entire month
  - Two outliers: July, August deteriorate quickly after the third week

    (caused by jp-nrt re-routing events)



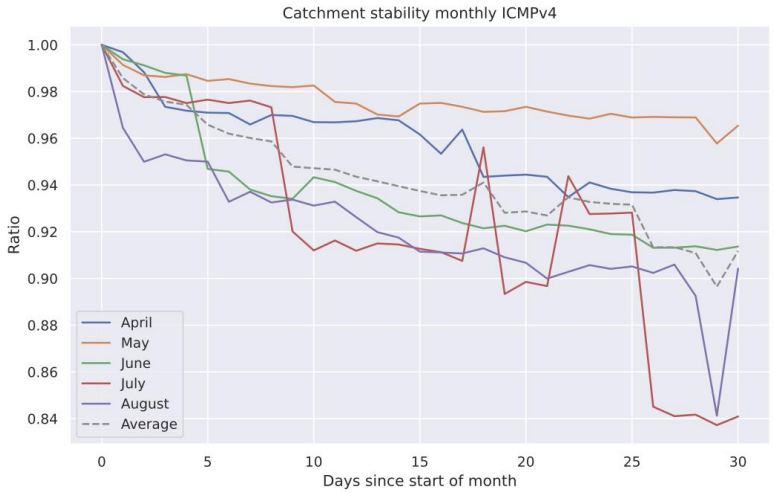
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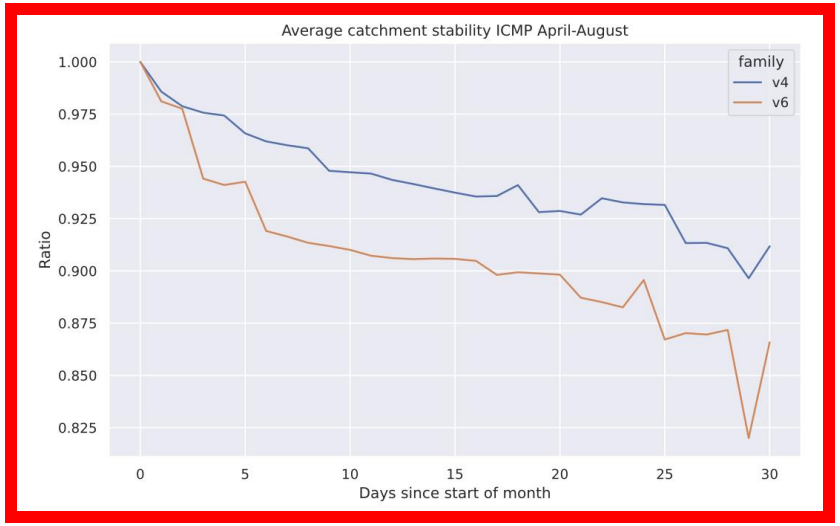
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  - Comparing IPv4 to IPv6; IPv4 routing appears more stable (*hitlist bias)

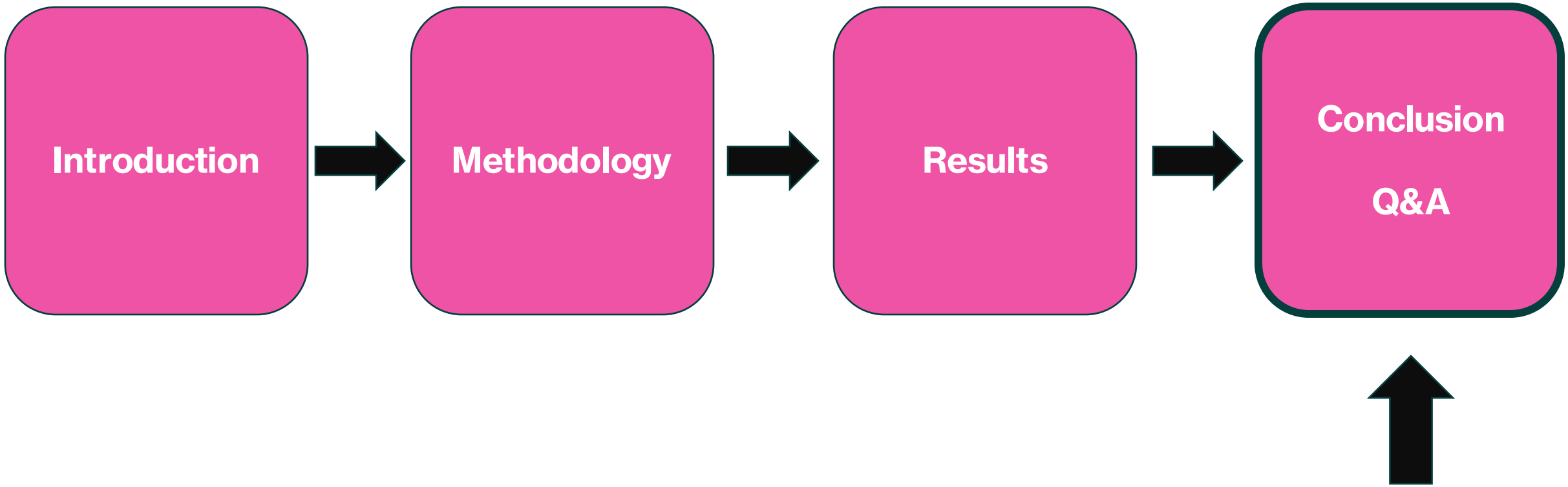


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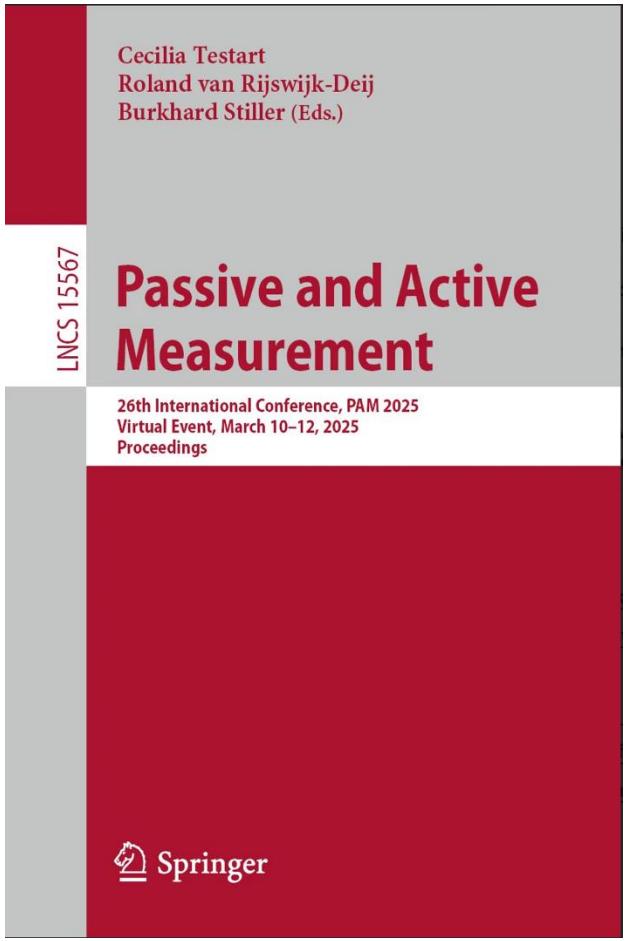
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Conclusion

- Catchment analysis helps operators improve their anycast services
  - Since Internet routing is dynamic; such analysis should be repeated
- Findings
  - Catchments are stable in the short term (day-to-day operations)
  - IPv4 catchments more stable than IPv6
    - However, IPv6 results biased by hitlist
  - Suggested frequency (coarse guideline)
    - Weekly catchment analysis for IPv4
    - And/or when large re-routing events are visible in passive traffic logs
- Future work
  - Understanding reasons for catchment shifts (BGP data, traceroute)
  - Spoofing and off-site traffic detection using catchment analysis



See our PAM'25 paper [6] for more details

[6] An Empirical Evaluation of Longitudinal Anycast Catchment Stability (PAM'25) - Hendriks, R., Degen, B., Palinckx, B., Sommese, R., van Rijswijk-Deij, R.

Q&A