Monte Carlo Simulations for Evaluating the Accuracy of GLM Detection Efficiency and False Alarm Rate Retrievals

Katrina Virts (UAH) and William Koshak (NASA)

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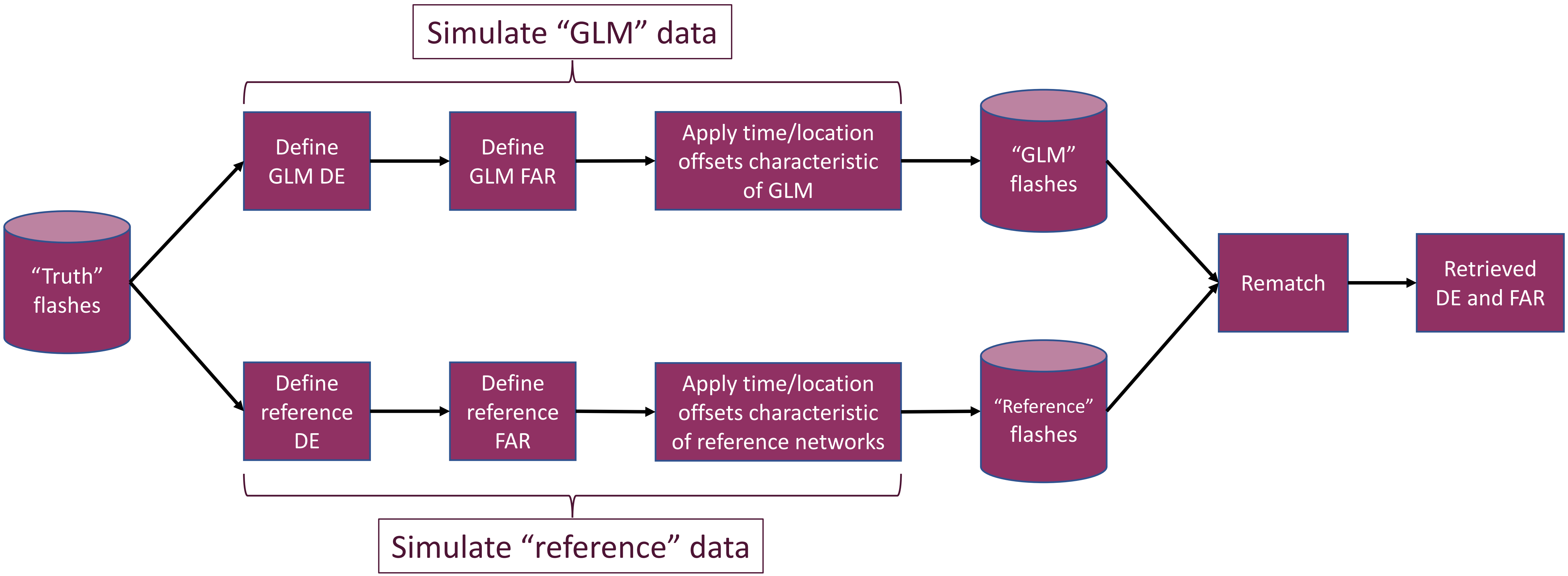
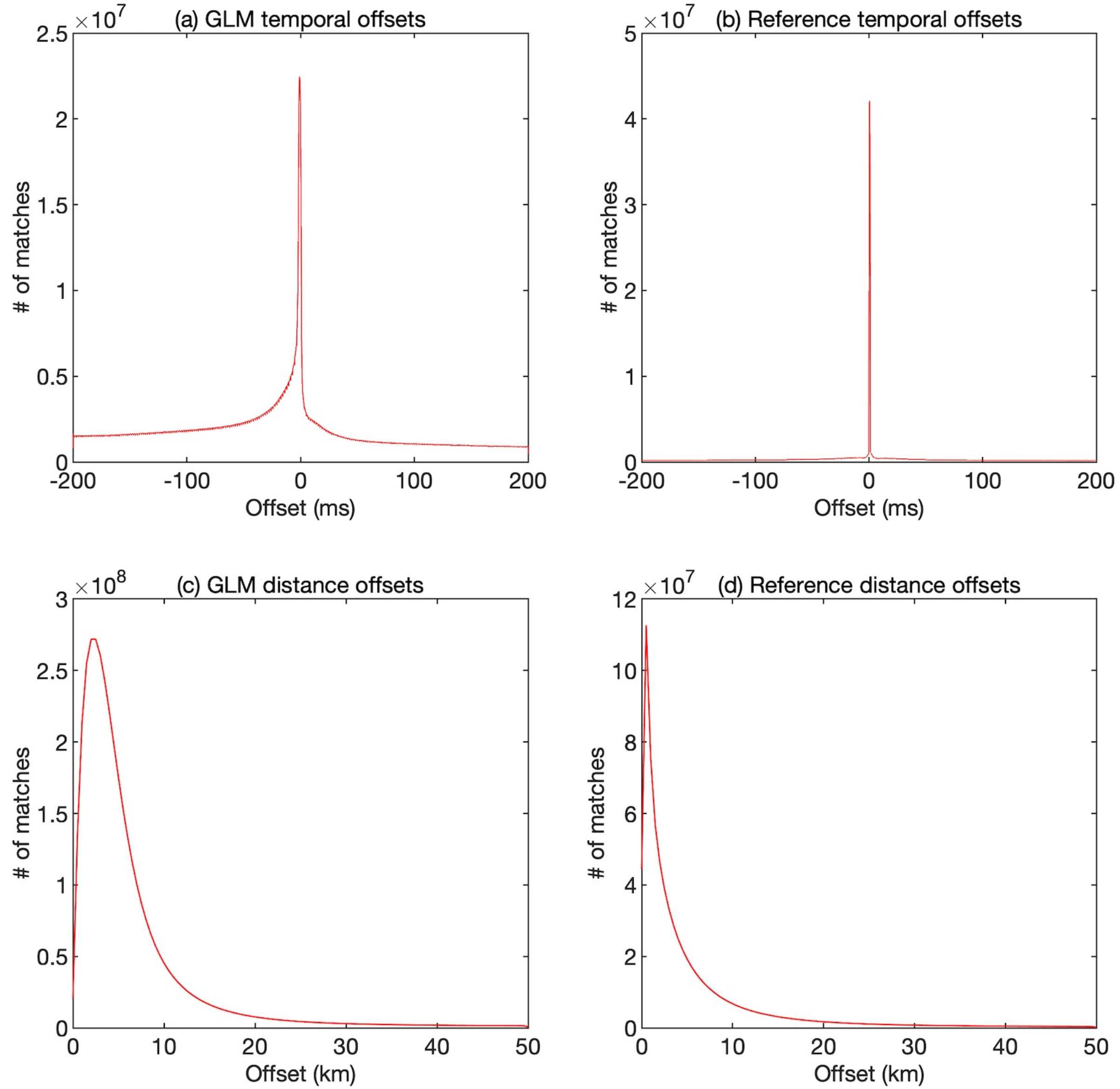
Estimating Errors in DE and FAR

- Analysis of GLM DE and FAR (Bateman et al. 2021; Lang et al. 2020; Murphy and Said 2020; Rutledge et al. 2020; Zhang and Cummins 2020; others in this section) has focused on GLM performance as a function of geography, storm type, cloud characteristics, time of day, flash size and duration, etc.
- Other factors that can affect the calculated GLM DE and FAR:
  - Reference network DE and FAR
  - Location and timing accuracy of GLM and reference networks
  - Geographic variations in reference network performance
  - Spatial and temporal matching criteria
- The challenge: Estimate uncertainty in the retrieved GLM DE and FAR as a function of these factors by means of Monte Carlo computer simulations

Monte Carlo Simulation Procedure



Characteristic Time/Location Offsets



Observed offsets derived from July 2019 – June 2020

GLM offsets derived by seeking “best reference match” for each GLM group

Reference offsets derived by matching reference pulses/strokes from two networks to each other

Analysis is “reference network-agnostic” – the simulated reference data contain characteristics of both real-world networks

“Truth” flashes = daily observed GLM-16 flashes from July – September 2020

Simulation: Vary GLM DE and FAR

Simulation specifics:

GLM DE = 0.4, 0.5, …, 1

GLM FAR = 0, 0.1, …, 0.4

Reference DE = 0.4, 0.7, 0.9

Reference FAR = 0.05

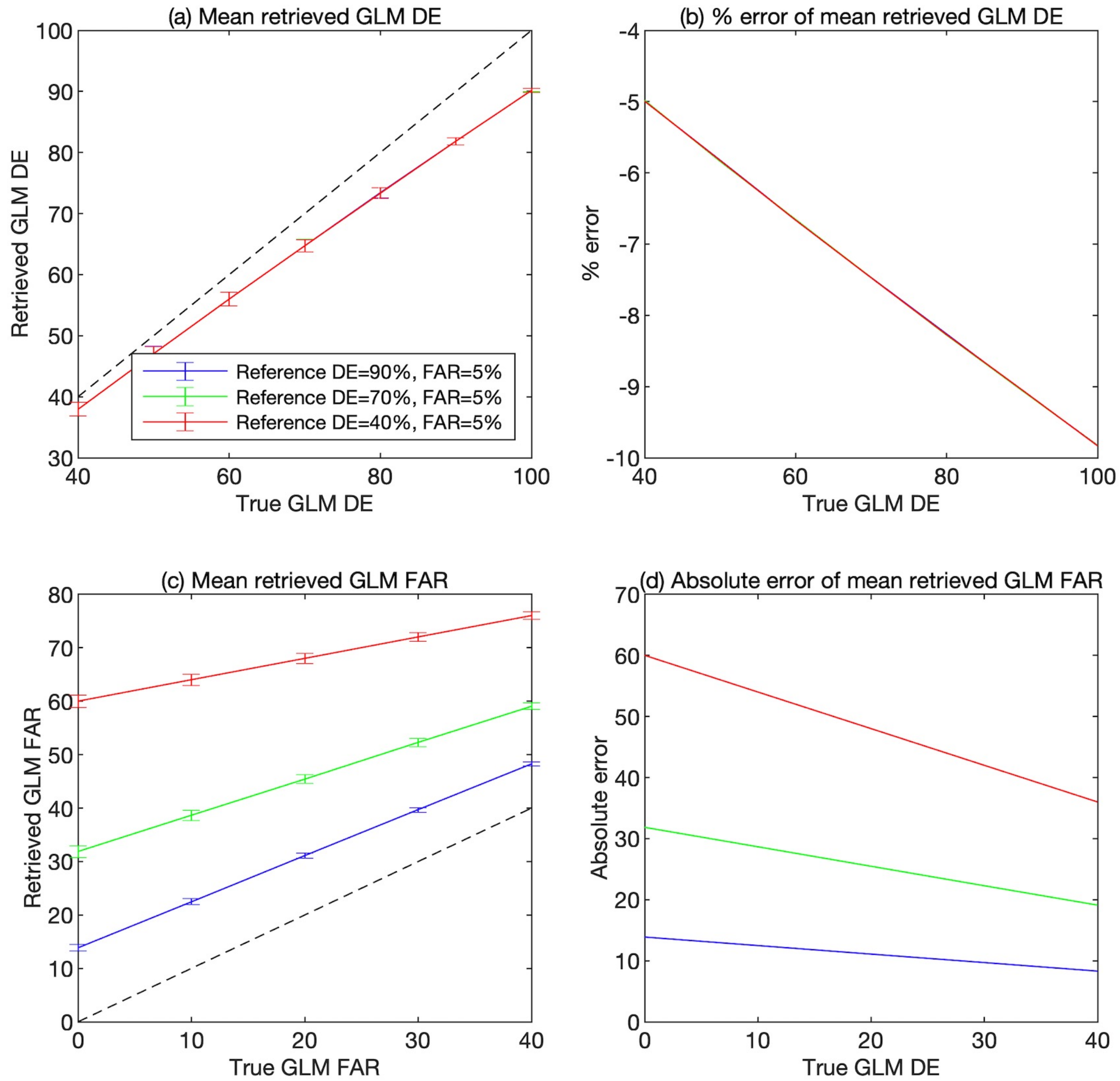
GLM offsets = observed

Reference offsets = observed

Matching criteria = standard

Results:

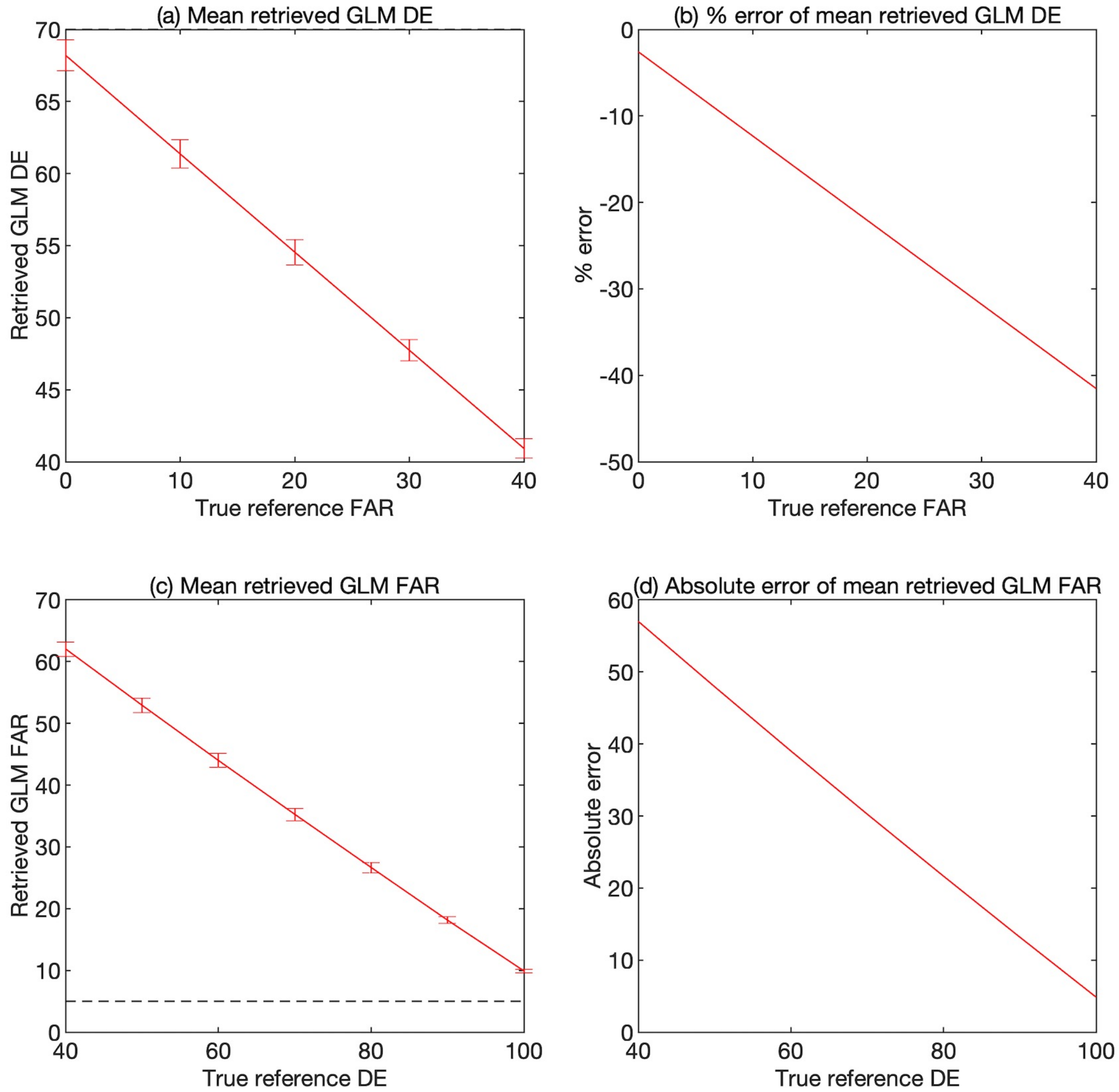
- Retrieved GLM DE is ~identical regardless of reference DE
- Retrieved GLM DE underestimates the true DE (% error from -5% to -9.8%)
- Retrieved GLM FAR varies with both true GLM FAR and true reference DE
- Absolute error of retrieved FAR ranges from 9-13% (when reference = great) to 35-60% (when reference = poor)



Simulation: Vary Reference DE and FAR

Simulation specifics:
GLM DE = 0.7 (spec)
GLM FAR = 0.05 (spec)
Reference DE = 0.4, 0.5, …, 1
Reference FAR = 0, 0.1, …, 0.4
GLM offsets = observed
Reference offsets = observed
Matching criteria = standard

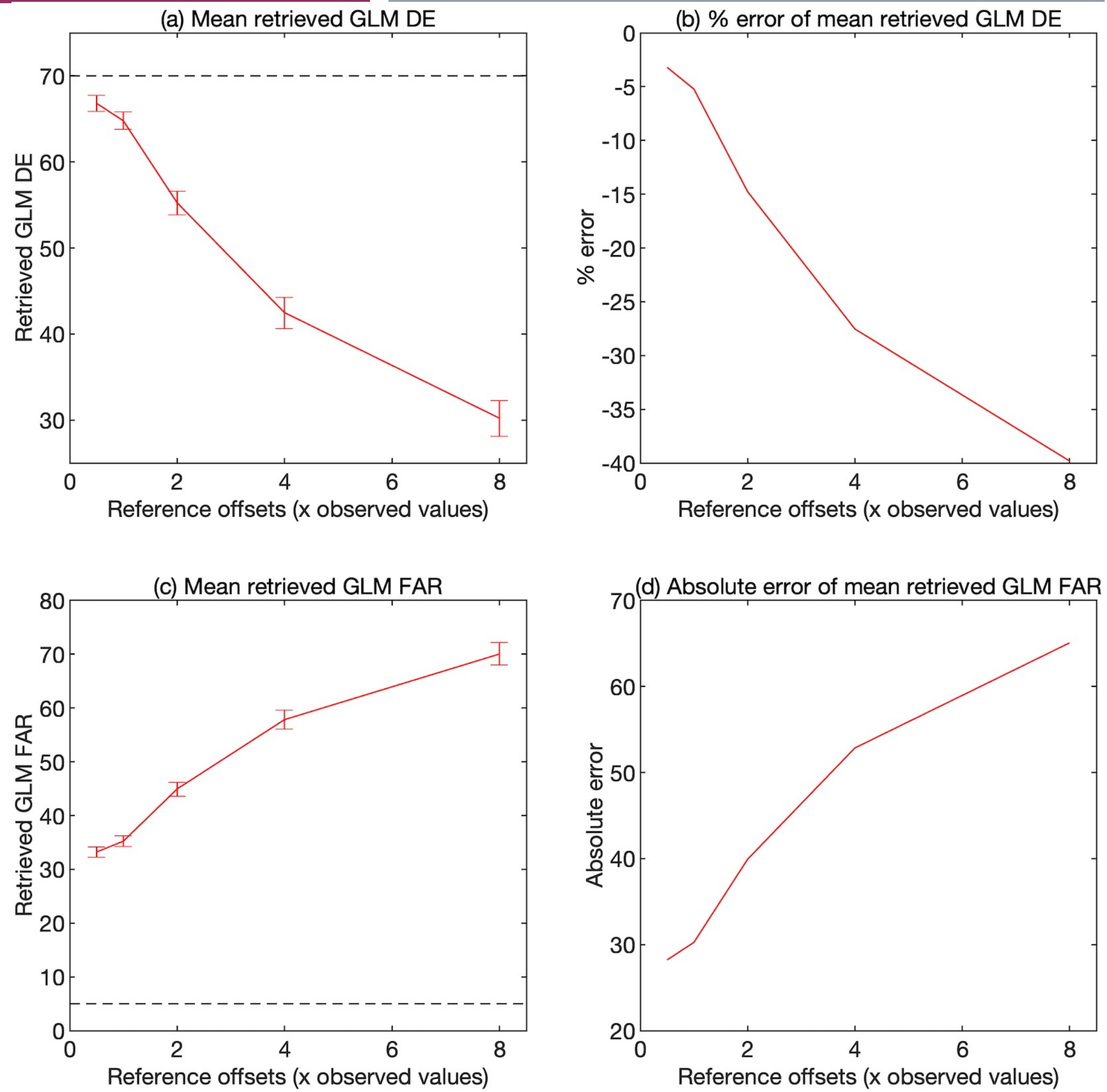
Results:
- Retrieved GLM DE underestimates the true DE (% error up to 41%)
- Absolute error of retrieved GLM FAR ~5% for true reference DE=100% but ranges up to ~57% for true reference DE=40%



Simulation: Vary Reference Offsets

Simulation specifics:
GLM DE = 0.7 (spec)
GLM FAR = 0.05 (spec)
Reference DE = 0.7
Reference FAR = 0.05
GLM offsets = observed
Reference offsets = 0.5, 1, 2, 4, 8 x observed
Matching criteria = standard

Results:
- For offsets 50-100% of observed, % error of retrieved GLM DE is <5%. For offsets 800% of observed, retrieved GLM DE has a -40% error.
- Absolute error of retrieved GLM FAR ranges from ~30% for small reference offsets to ~65% for the extreme offset scenario.

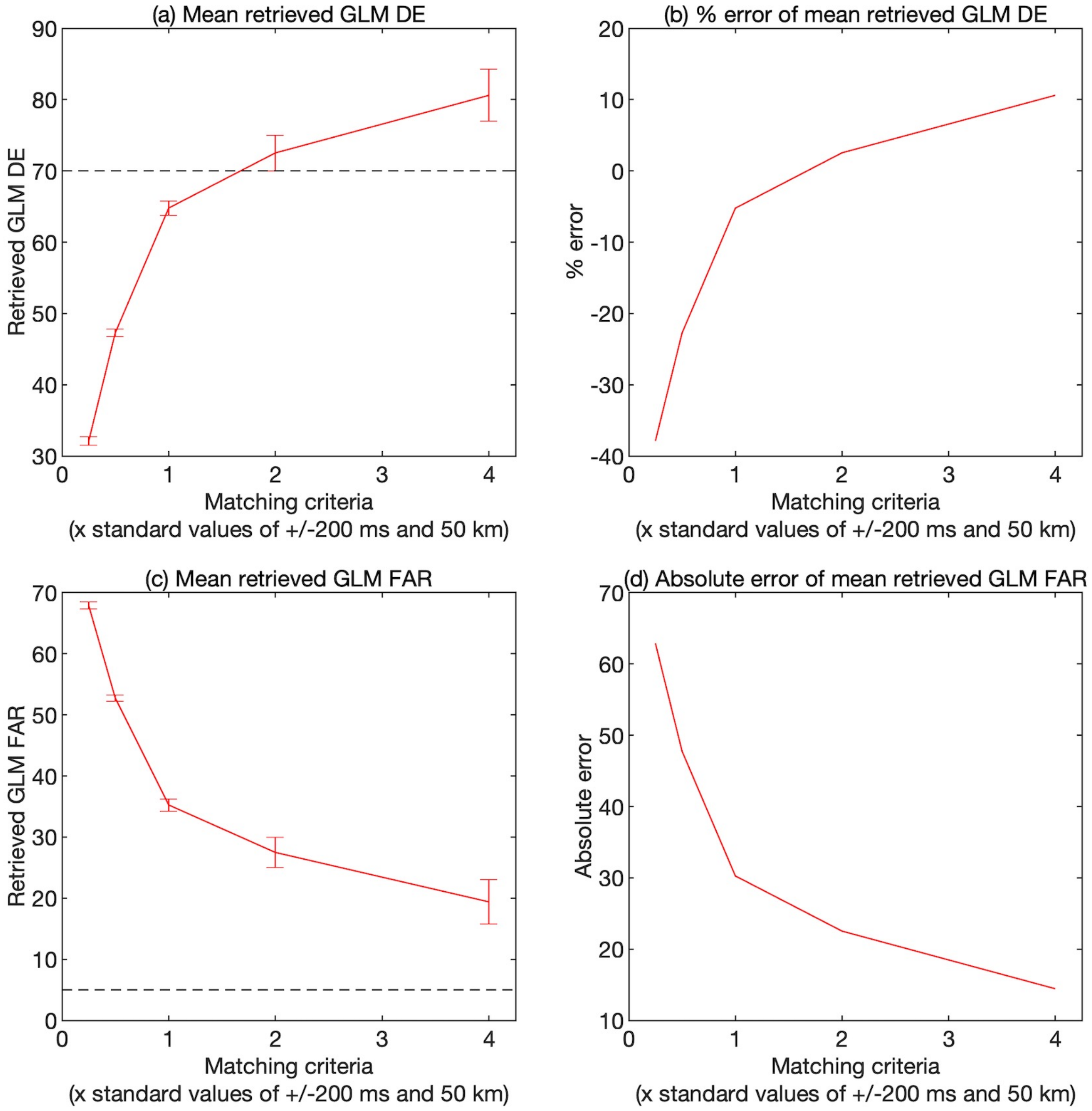


Simulation: Vary Matching Criteria

Simulation specifics:
GLM DE = 0.7 (spec)
GLM FAR = 0.05 (spec)
Reference DE = 0.7
Reference FAR = 0.05
GLM offsets = observed
Reference offsets = observed
Matching criteria = 0.25, 0.5, 1, 2, 4 x standard

Results:

- Strictest matching criteria underestimate true GLM DE by ~40%, with >60% absolute error in retrieved GLM FAR
- Broadest matching criteria overestimate true GLM DE by 10%, with 15% absolute error in retrieved GLM FAR
- The curve is steeper for more strict matching criteria
- Largest error bars are associated with the broadest matching criteria



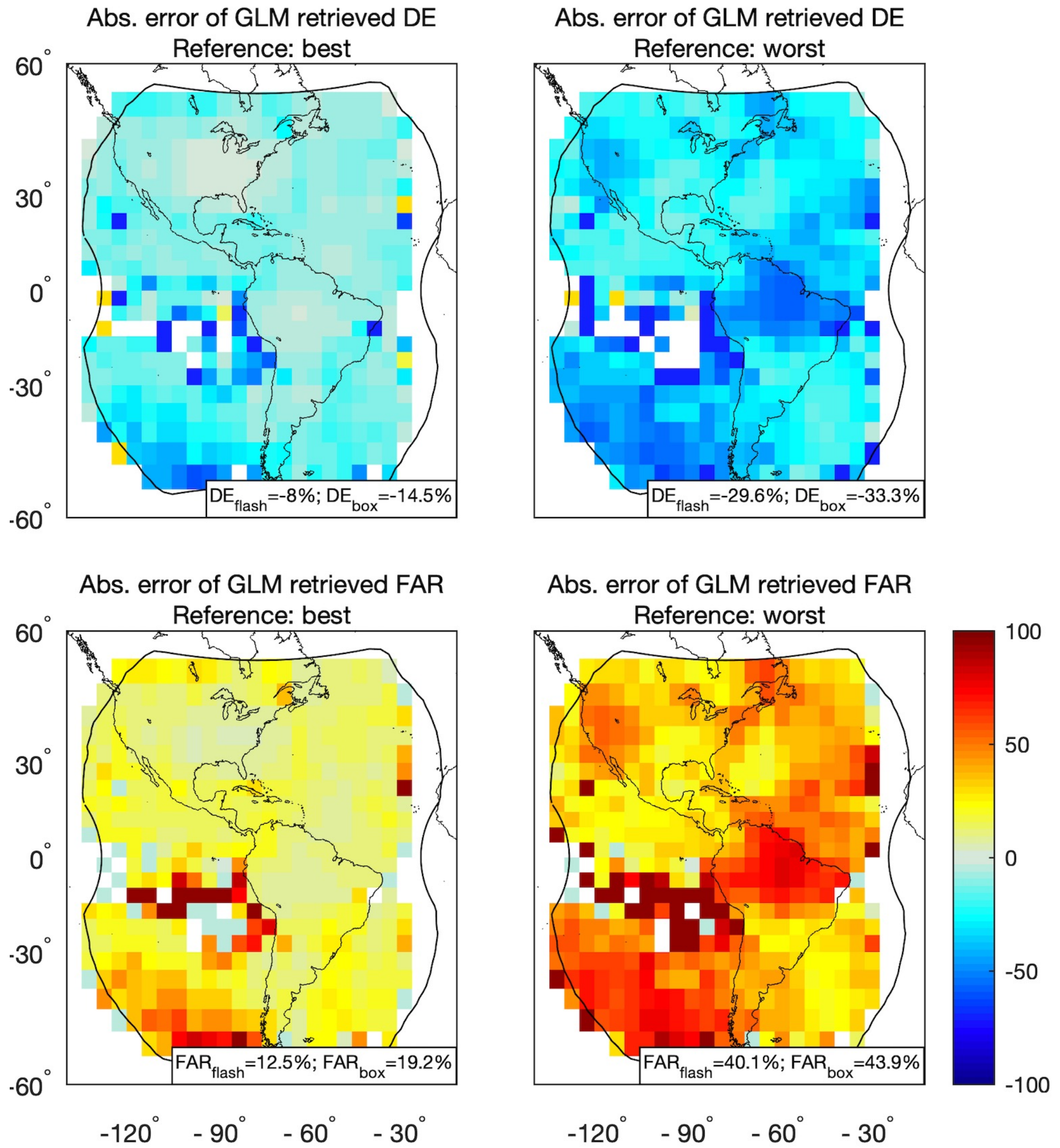
What About Geographic Variations?

- The simulations to this point have defined the "reference" network performance universally. In reality, this performance has a geographic dependence.
- Goal: Construct simulations in which the "reference" data performance varies in a geographically realistic manner
- Define a "best" and "worst" reference scenario at each grid point:
  "Best" = Higher DE and lower FAR
  "Worst" = Lower DE and higher FAR
- Analysis is "reference network-agnostic"
  - It does not matter which real-world network performs better in a given grid box
  - The important point is defining a realistic upper and lower bound on reference performance

Simulation: Vary Ref. Geographical Performance

Simulation specifics:
GLM DE = 0.7 everywhere (spec)
GLM FAR = 0.05 everywhere (spec)
Reference DE and FAR = "Best" and "worst" scenario at each grid box
GLM offsets = observed aggregate values
Reference offsets = observed at each grid box
Matching criteria = standard

Results:
- Retrieved GLM DE aggregated over all flashes ranges from 40% (reference = worst) to 62% (reference = best), implying absolute errors of -8 to -30%
- Retrieved GLM FAR aggregated over all flashes ranges from 17.5% (reference = best) to 45% (reference = worst), or absolute errors of 12.5% to 40%
- Geographic error patterns are evident, with GLM performance most severely underestimated in the Southern Hemisphere Pacific, where absolute errors **for the "best" reference scenario** range up to -30-60% (DE) and 30-70% (FAR)



Conclusions

- Monte Carlo simulations were conducted to analyze the impact upon retrieved GLM DE and FAR of:
  - Reference network performance (DE, FAR, location and timing errors)
  - Realistic geographic variations in reference network performance
  - Spatiotemporal matching criteria
- This analysis provides estimates of the error bars associated with retrieved GLM performance metrics
- Results illustrate that retrieved GLM performance is punished by imperfect reference network performance. In these simulations:
  - The retrieved DE for all flashes is anywhere from 8-30% lower than the true DE
  - The retrieved FAR for all flashes is 12-40% higher than the true FAR
  - GLM performance most severely underestimated in the S.H. Pacific