Global Magnetometer Coverage Efficacy During Geomagnetic Disturbances: A Case Study of the 2003 Halloween Storm

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GEM

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What are Space weather impacts?

1. What is space weather?

   Space Weather is the phenomenon of solar storms and other events in space that can impact Earth.

2. Why is space weather important to our modern society?
   a. Extreme space weather events can damage critical infrastructures, which may result in failures across key services such as electric power, communications, water supply, healthcare, and transportation.
   b. Billion-dollar economic impact: e.g. 1989 geomagnetic storm in QuebecIt. It could cause catastrophic damage if happened in New York area.
3. How do we understand and monitor space weather impacts?
   a. observation: satellites and ground based instruments, e.g. magnetometers, radars
   b. modelling: mathematical descriptions of the conditions of the space environment, based on statistical analysis of past and current observations of the space environment.

Key Questions:

Are the current magnetometer observations providing enough spacial coverage for monitoring the localized feature during geomagnetic disturbed periods?

1. are there any localized features during Halloween Storm?
2. are these features captured by the current magnetometer observations?

Methodology

To investigate if the coverage is sufficient, we performed the error analysis of the Global GMD model (Hu and Xu, 2024). If the error is high, it means the coverage is not good enough.

A short introduction of the Global-GMD model:

a. Algorithm: Applying Kriging interpolation with global magnetometer observations (dBh) other than the location of interest. Then, compare the interpolated value to the observed value at the location of interest.
b. Data: magnetometer data, solar wind/global indices.

Case study: First storm period during Halloween Storm 2003

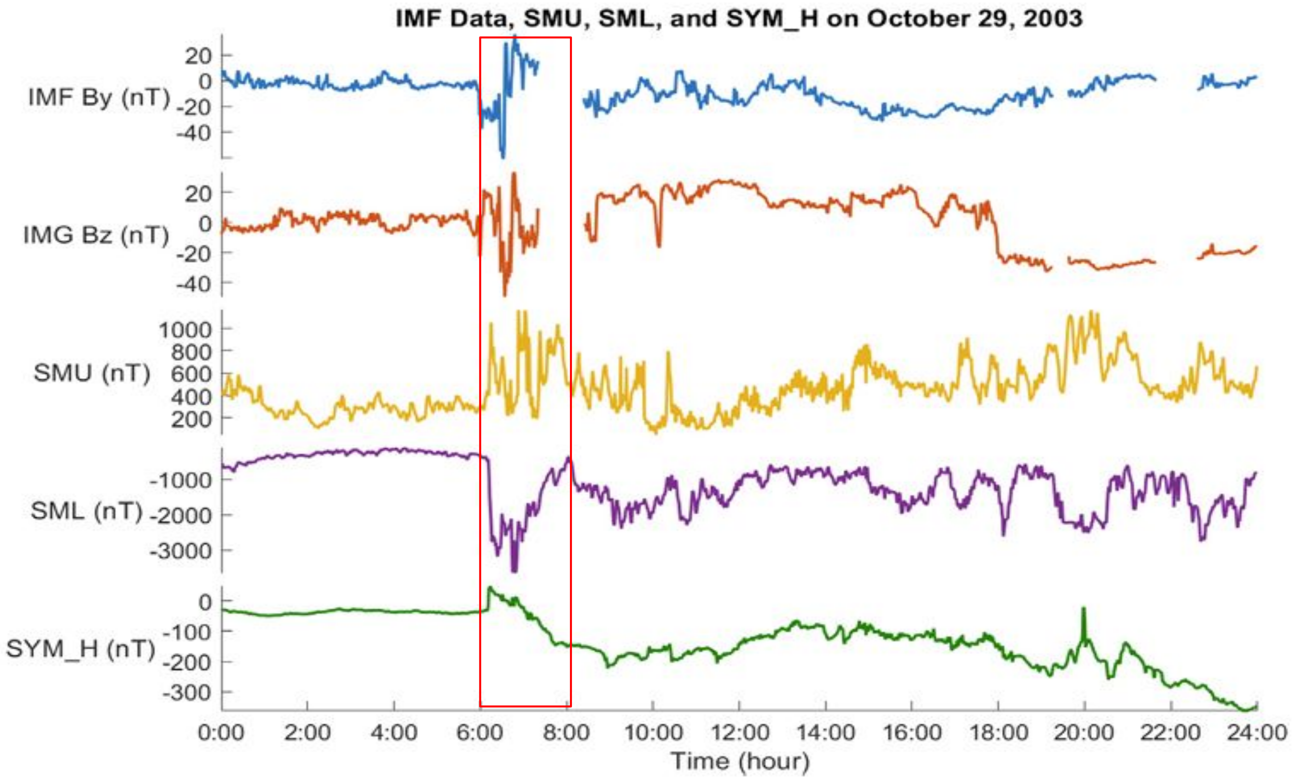
1. 06:00-08:00 UTC on 29th Octobor 2003
2. Data from 200+ magnetometer stations globally
3. Simulation (sim_dbh) VS observation (data_dbh)
4. Different geo-locations comparison:

   -high latitude regions (near auroral zones, including Norther Europe, Alaska, Canada)

   -mid latitude regions (US main continent)

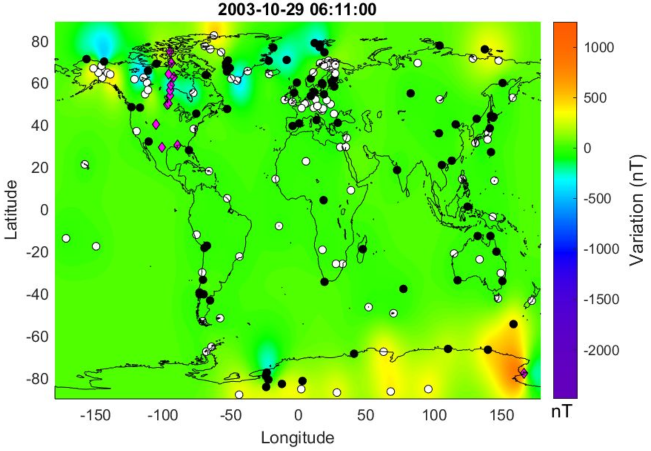
   -low latitude regions (Japan, South America)

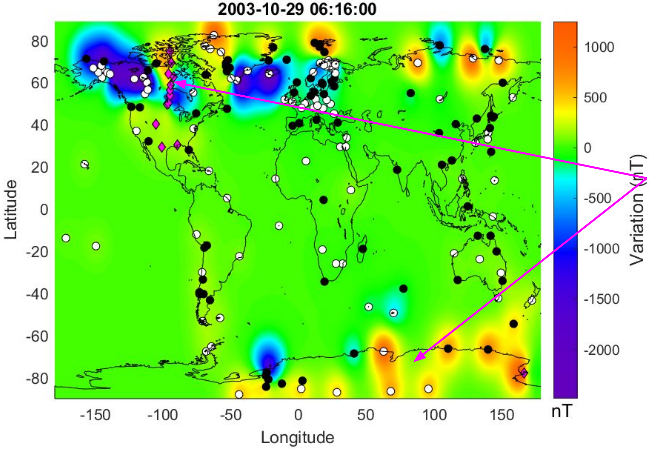
Overall global impacts of Halloween Storm 2003



Global GMD maps by Global-GMD model during the storm

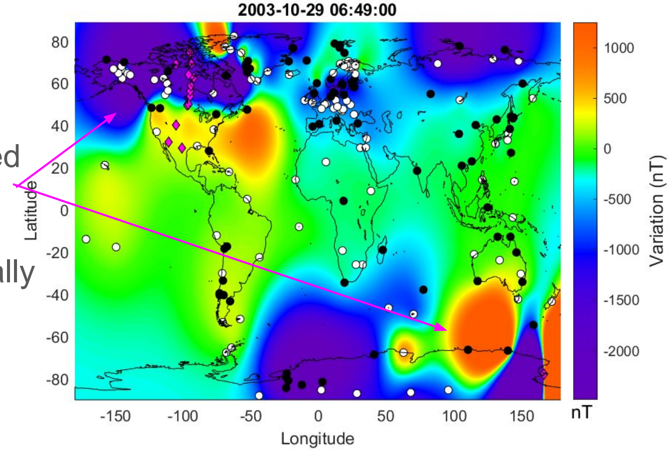
Quiet Time
(06:11 UTC)

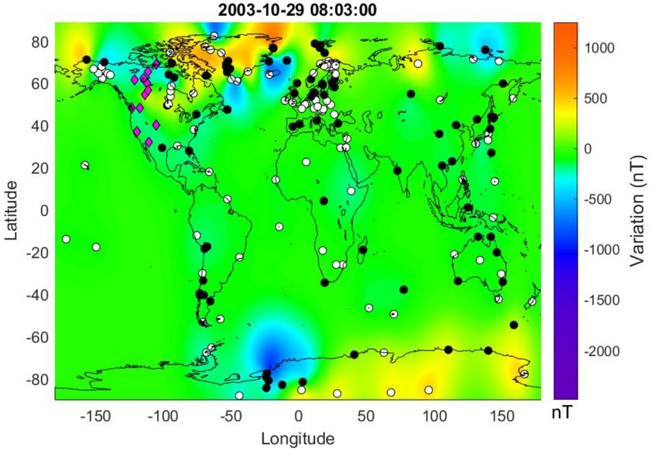




Geomagnetic Disturbances (GMDs) started at high latitude regions

Max Storm Intensity reached at high latitude regions, GMD expanded globally

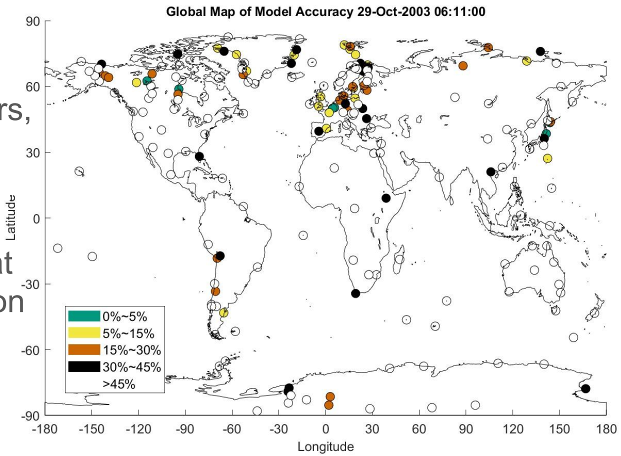


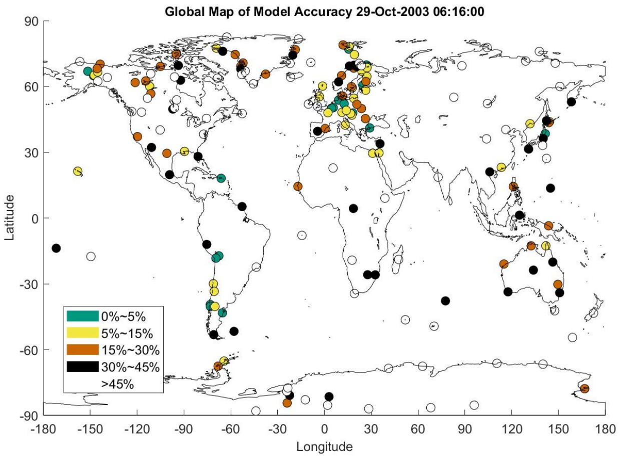


Mostly recovered
(08:03 UTC)

Local feature analysis by simulations VS observations

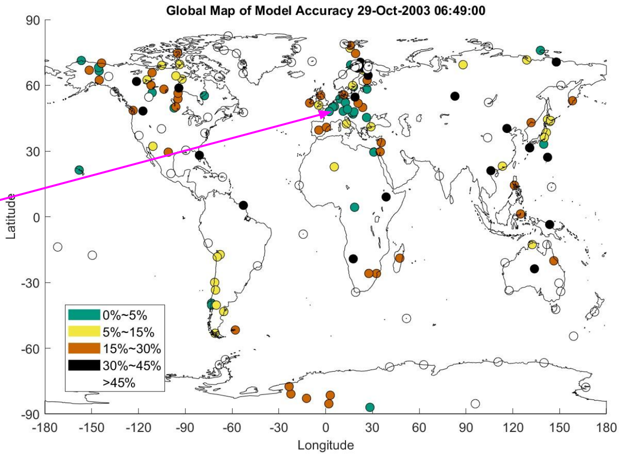
Most relative errors, $\left|\frac{Sim\_dbh - dat\_dbh}{dat\_dbh}\right|$ >45% because of smaller dat_dbh at quiet time condition

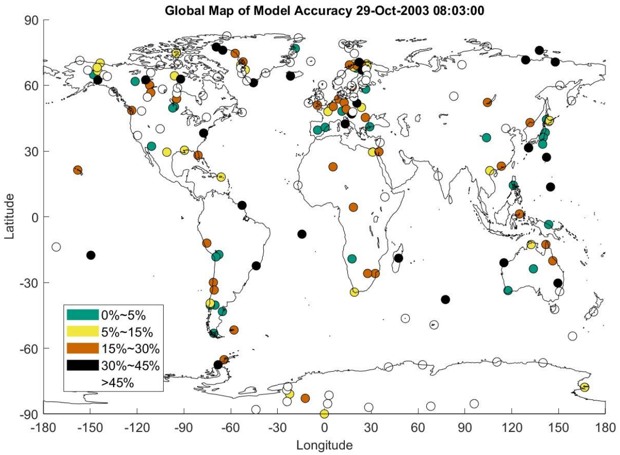




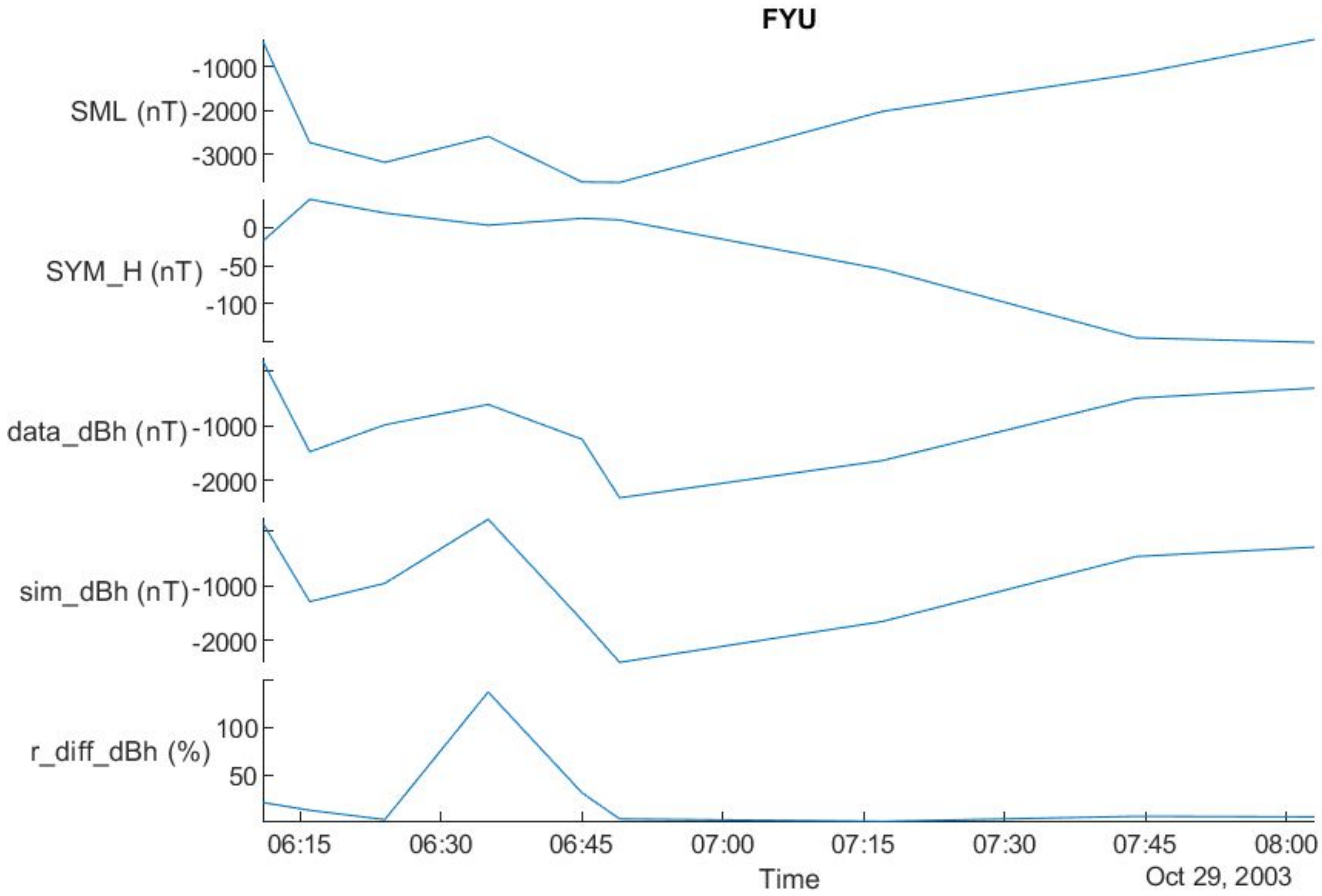
When GMD increasing, relative errors decreased at high latitude regions and the locations of good magnetometer coverages

When GMD reached peak intensity over -1500 nT in Europe, the error is smaller than 5% because of good spatial observation coverage.

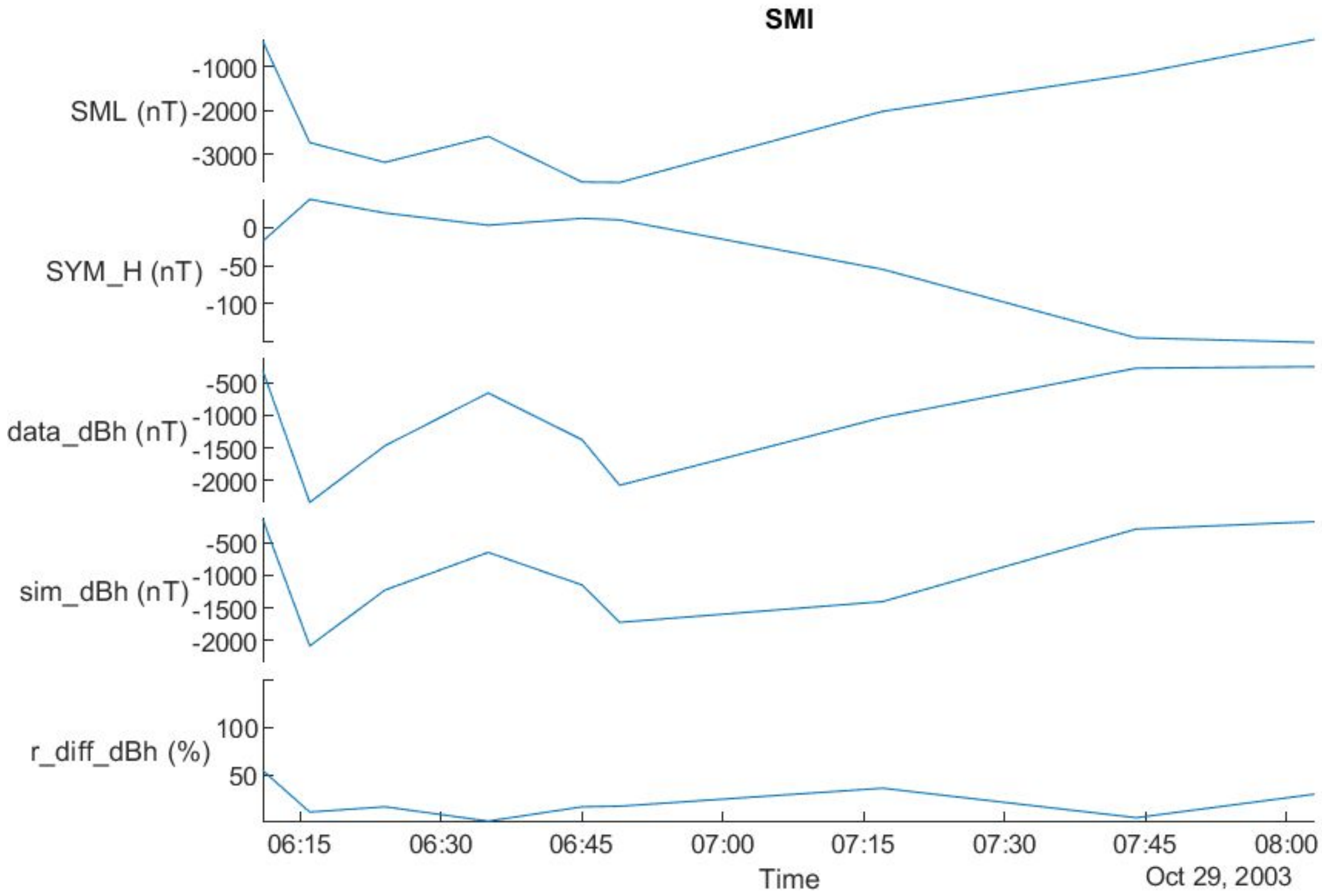




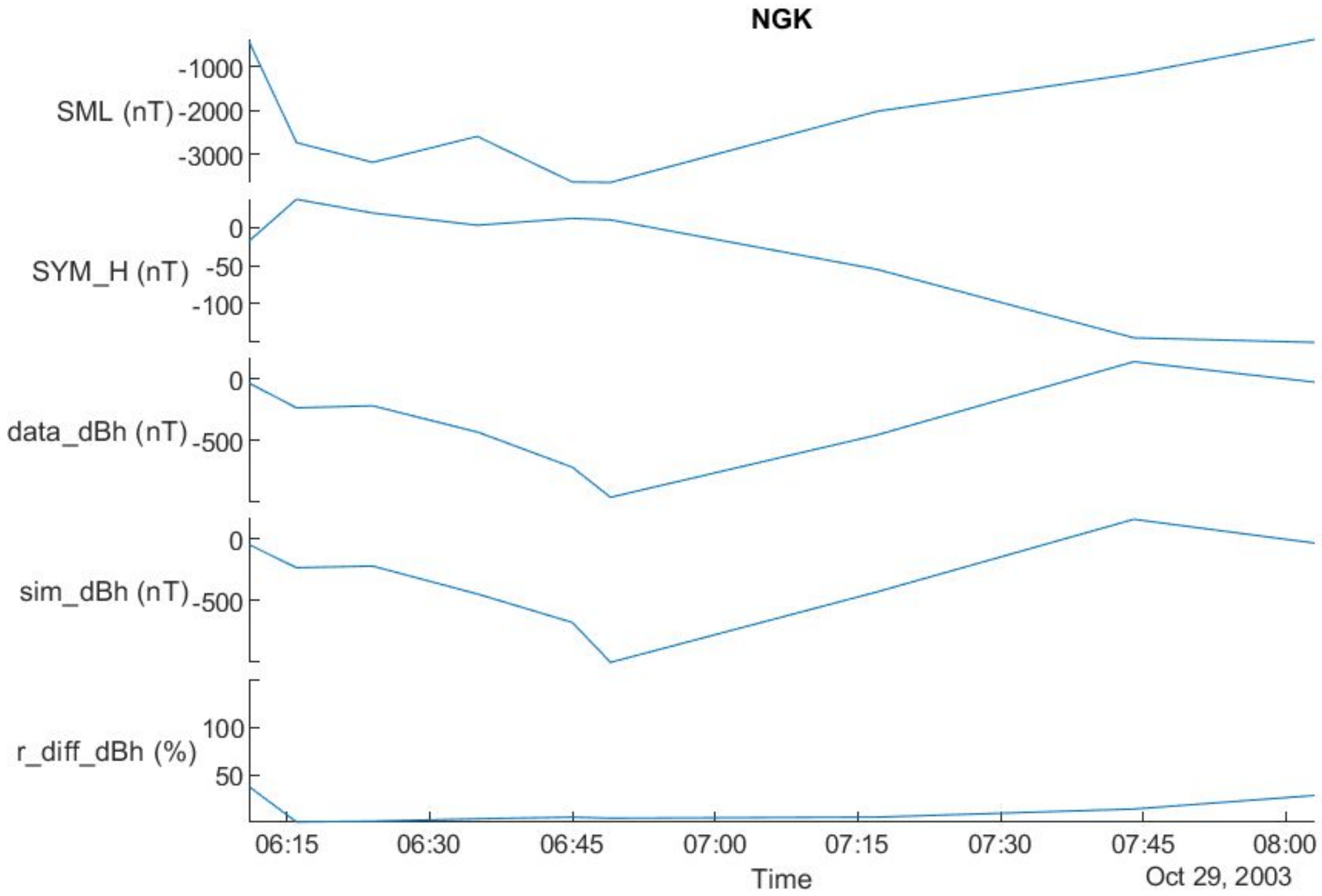
When storm recovered, the error level increased globally.



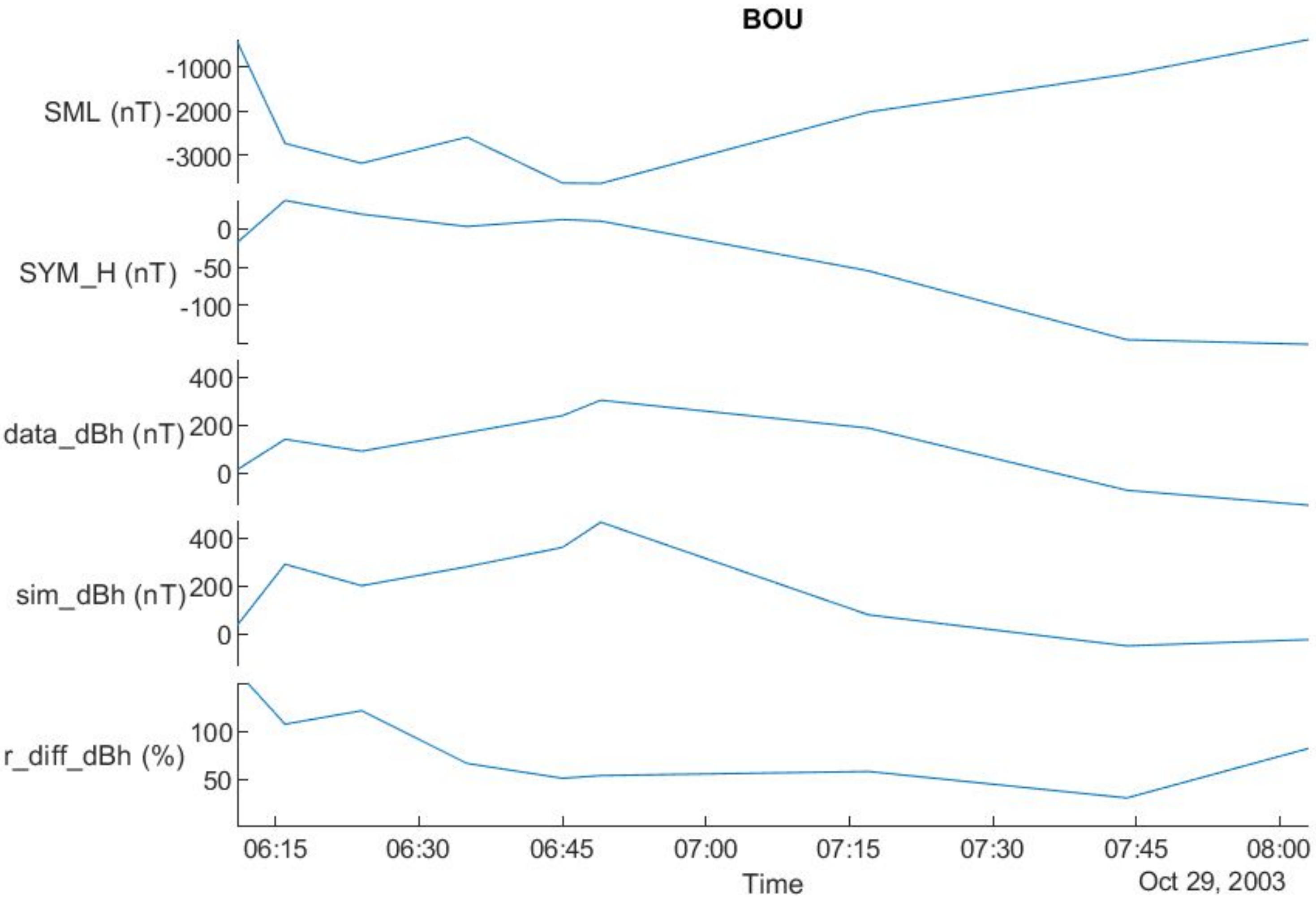
FYU,
Mag_lat=67.33
Mag_lon=-94.43,
is located at the center of magnetometer arrays in Alaska.



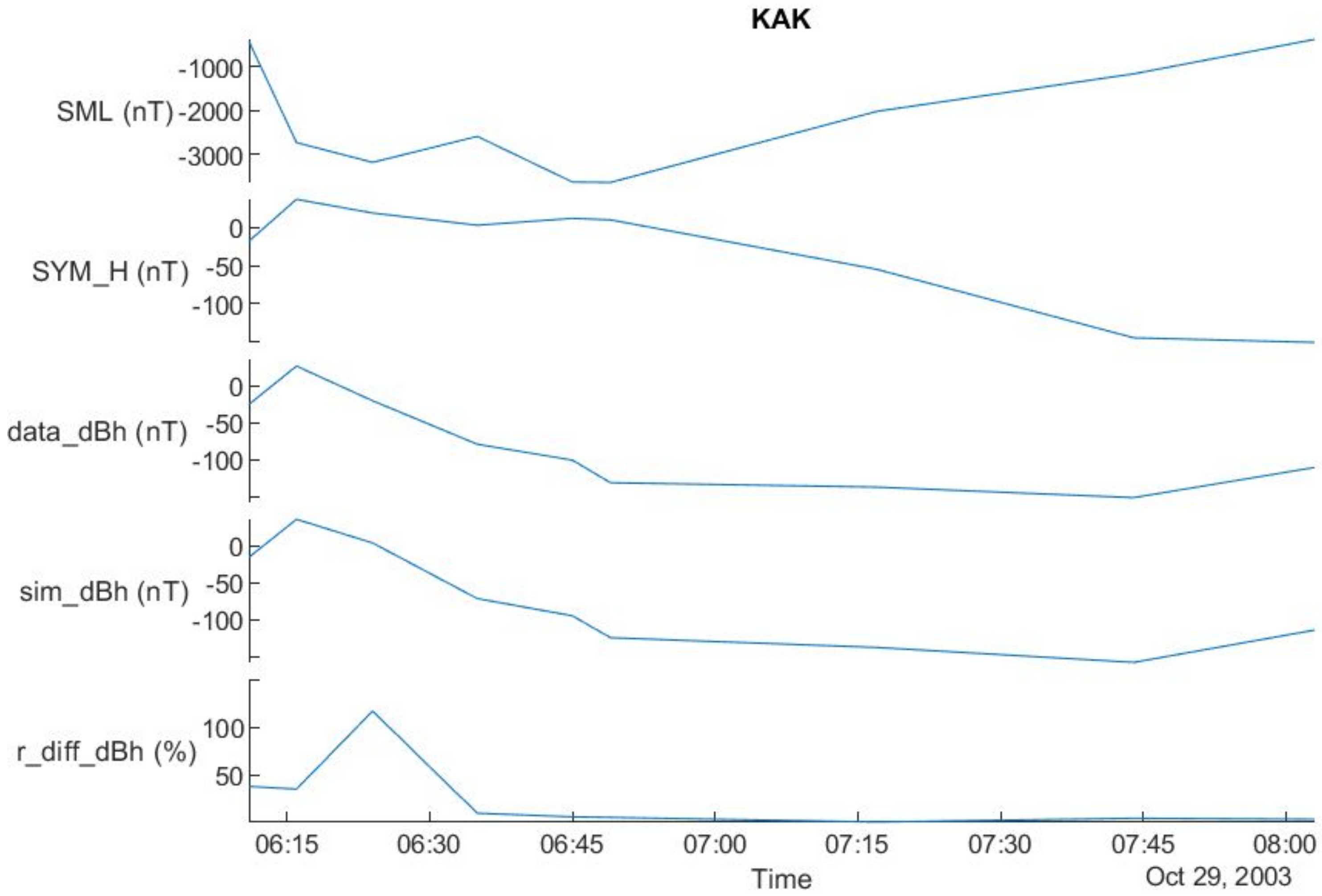
SMI, Mag_lat=67.51 mag_lon=-54.08, is located at the center of magnetometer arrays in Canada.



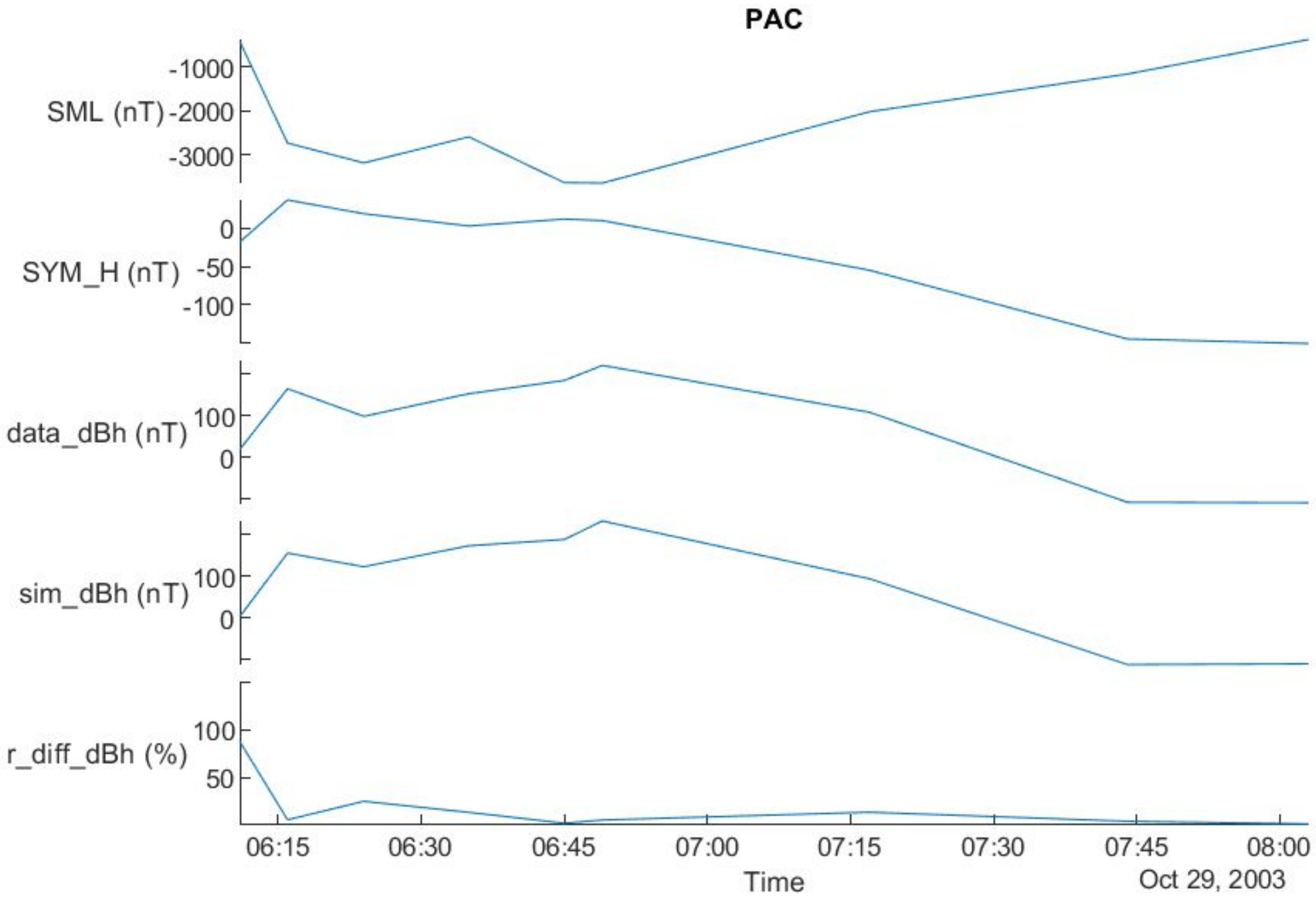
NGK, Mag_lat=48.08 Mag_log=89, is located at the center of magnetometer arrays in Europe. Overall, r_diff_dbh is small mostly < 10%.



BOU, Mag_lat=48.93 mag_lon=-40.05, is located at the center of magnetometer arrays in US.



KAK,
Mag_lat=29.35
mag_lon=-148.04,
is located at the
center of
magnetometer
arrays in Japan.



PAC,
Mag_lat=-26.69
mag_lon=1.52
, is located at the center of magnetometer arrays in South America.

Discussion

Different **phases** during the storm:

-Before storm happened: low disturbances, low accuracy in relative errors due to small observation values

-Storm initial to main phase:
In general, when the GMD is getting more intensive as storm, the localized features are enhanced at different regions, which led to higher accurate simulation results. The accuracy also depends on the spatial coverage of magnetometer observations in the regions.

-Storm recovering phase:
When the disturbances level decreased, the relative errors are increased.

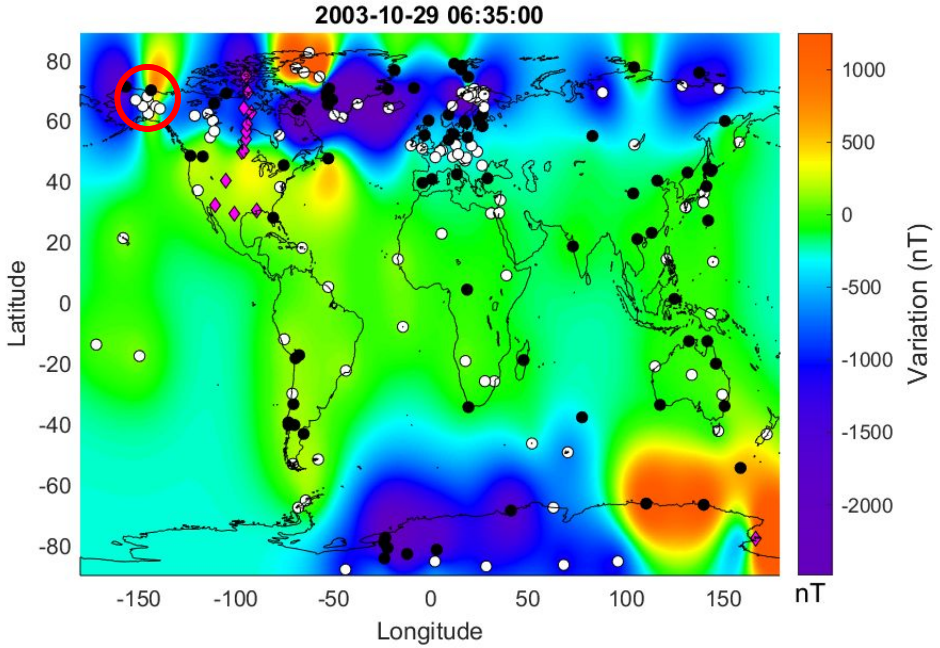
Discussion

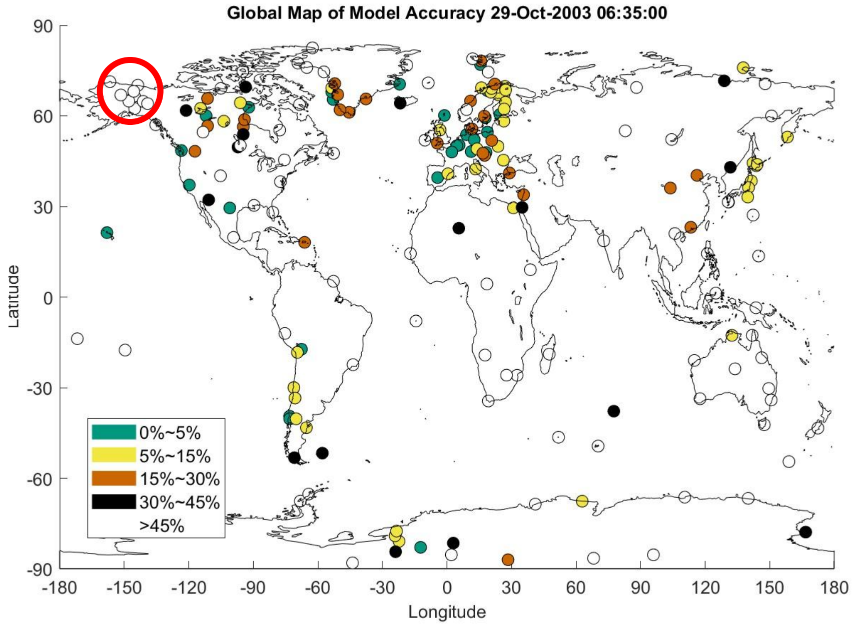
Different **spatial coverage** during the storm:

- The best spacial coverage can be seen in Europe where the relative error is consistently low.
- Canada and Alaska has slightly worse coverage. Though the estimations have been mostly accurate, the relative error increases at times when the region exhibits highly localized features. (see next slide)
- Low latitude regions such as Japan and South America also have relatively low errors due to relatively high coverage and less localized features as it is mostly impacted by ring currents. Relative errors do increase as the disturbance decreases.
- The Continental US stations are located at mid magnetic latitude regions with mild GMDs (200~400 nT) , they have the highest relative error because of its low spacial coverage.

Example of localized feature that is hard to catch

In Alaska, at 0635 UTC, the relative error is large (White color dots >45%) due to a localized feature (less than 100 miles) passing through the region. The stations were at locations between positive/negative disturburnces shown in the global GMD map.





Conclusion

Based on the error analysis from Global-GMD model during the first part of Halloween Storm 2003, it is shown

1. There are small scale local features less than 100 miles at high latitude regions (such as Alaska), especially during the highly disturbed periods.
2. To capture the localized features, spatial coverage of magnetometer observations is important.
3. The Continental US stations are located at mid magnetic latitude regions with mild GMDs (200~400 nT) , they have the highest relative errors because of low spacial coverage.
4. 2-D arrays are better than arrays only along longitude or latitude directions.