**Overall Summary**

This is the 12th year of the GLM science team meeting. The meeting was held September 8-10, 2020 in an entirely virtual format this year due to COVID-19. Nearly 80 participants and 41 presentations were given. This year there were six topical sessions related to performance and instrument updates, GLM validation studies, science and application studies, operational uses, and data assimilation of GLM data to improve short-term forecasts. The meeting was led by Dr. Scott Rudlosky of NOAA/NESDIS and supported by Dr. Steve Goodman (NOAA/NASA) and Dr. Christopher Schultz (NASA MSFC). We thank all of those that participated in this meeting and look forward to GLM Science 2021.

* Session 1 focused on the Programmatic aspects of the GLM, preparations for FM3 (GOES-T, planned launch date of December 7, 2021; GOES-U planned launch in April, 2024), and the GOES-R Follow-on Program for 2030-2050 referred to as GEO-XO (Geostationary and extended orbits). Enhancements of current instruments (higher spatial resolution and greater coverage) and other candidate instruments are in the mix (GEO infrared and microwave sounders, ocean color, atmospheric composition).
* Session 2 focused on the separation of system level and meteorological contributors to detection efficiency. This has an impact on GOES-T/U and any future mission related to GEO-XO. The question remains of “what is a flash” and how to accurately represent the different physics of lightning measured by multiple observing techniques. The goal of these talks is to enrich the understanding of flash processes related to the meteorology, while also providing a sound basis for validation lightning detection performance. Many of these studies include ground and spaces based lightning measurements and cross validation.
* Session 3 examined the science and applications of GLM data to understand weather and climate processes which lightning plays a large role. Topics covered ranged from an overview of GLM, tropical cyclones, bolides, volcanic eruptions and new science mission to measure lightning from space.
* Session 4 continued to examine the science and applications of GLM data to understand weather and climate processes which lightning plays a large role. Topics covered ranged from fundamental lightning physics, to data storage, to modeling light output through cloud top.
* Session 5 focused on the operational uses of GLM directly from NWS forecasters. Also included are tools being developed by NOAA, NASA, and University partners to be placed within the operational environment in the next several years. Significant discussion occurred during this session around how the GLM was being used and the techniques that forecasters have implemented to effectively use GLM in their day-to-day operations. Additionally training methods and query tools were presented which should benefit the operational community.
* Session 6 focused on the new use of GLM data for assimilation into weather models. The main focus are on short term forecasts given that much of the early work in GLM DA shows the most potential improvement in that 0-6 hour time frame. Value was added in radar sparse regions and in cellular convection when GLM was added to other DA types (e.g., radar).

**Recently Awarded GLM funding: NASA ROSES Amendment A.33 – GLM selections**

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC and NOAA National Environmental Satellite, Data, and Information Service, Silver Spring, MD, have selected proposals for the Earth Science Research from Operational Geostationary Satellite Systems in support of the NASA Earth Science Division (ESD) and NOAA GOES-R Program. The solicitation seeks advanced research and practical applications using data derived from instruments aboard U.S. and international geostationary satellites including NOAA’s Geostationary Operational Environmental Satellite R series (GOES-R) of satellites and international geostationary satellites, such as the Japan Meteorological Agency’s Himawari and Korean GEO-KOMPSAT-2A satellite systems. The selected proposals achieve the goals through the generation of data products and/or the utilization of data products in scientific research and operational applications.

The research and development projects selected through this solicitation included tropospheric state and weather monitoring, convective storms, air quality, studies of aerosol characteristics, volcano monitoring and land surface vegetation characterization and phenology studies.

The NASA ESD has selected 9 out of a total of 83 proposals for the funding of $5.7M over three years. The NOAA GOES-R program has selected 18 out of 69 proposals received in response to this solicitation for the funding of $9.6M over three years. The combined total funding for these investigations, over a period of 3 years, is approximately $15 million

**Selected GLM Proposals:**

**Stephanie Stevenson, NWS/NHC**, *Enhancing forecast applications of the GOES-R GLM in tropical cyclones using multi-platform data fusion and AI to assess environment and storm structure*

**Daile Zhang, Univ. of Maryland**, *Downscaling of GLM Lightning Observations Using ISS-LIS Data*

**Kristopher Bedka/Langley Research Center,** *Automated Detection and Analysis of Severe, Tropopause-Penetrating Convective Storm Patterns Using Remote Sensing Data Fusion and Deep Learning*

**Bin Guan/University of California, Los Angeles,** *Lightning and Wind Structure of Atmospheric Rivers Affecting the Continental US Observed by GOES-16/17*

**Steve Miller, CIRA/CSU*,*** *Advanced Concepts Enabling Situational and Hazards Awareness via Imagery (ACES HAI)*

**Session 1: Program and Instrument Updates** - Tuesday 8 September 2020

* Mark Rafal (GOES-R Program/NASA GSFC) – FM3 and FM4 on track. Expect FM3 (GOES-T) increased performance vs FM1 and FM2 based on mitigations (electronics, stray light) made by Lockheed.
* Tewa Kpulun (Lockheed Martin) – Increased performance in FM3 and 4 as RTEP boundary issues are mitigated (e.g., Bahama Bar). This leads to a larger dynamic range and lower thresholds to mitigate issues with overshoot/undershoot.
* Dan Lindsey (GOES-R Program/NESDIS)– GEO-XO on schedule to launch by 2032. A GLM follow-on instrument is being considered in the trade space, along with multiple orbital configurations inder consideration.
* Michael Peterson (LANL)– Re-clustering of the operational GLM datas has allowed for long duration flashes to be reconstructed. A key result was the identification of new world record lightning flash duration and size. This was documented in a recent GRL article and highlighted by AGU https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020GL088888
* Scott Rudlosky (NOAA/NESDIS/STAR) – A GLM value assessment for GEO-XO has been developed and due to NOAA to quantify the societal and economic benefit value of GLM and its impact to society. This assessment will be used to prioritize GEO-XO needs and budgets as GEO-XO is formulated in the next year. A presentation is planned for the “Community Meeting on NOAA Satellites” September 29-October 2 (https://www.nesdis.noaa.gov/sat-community-2020).

**Session 2: GLM Validation Studies**

* Timothy Lang (NASA/MSFC) – Overview of RELAMPAGO campaign and the involvement of GLM and the portable NASA MSFC LMA. Overall, collected a great LMA dataset during the RELAMPAGO campaign with over 1000 hours of 1-min ABI MDS rapid scan data collected. Similar GLM DE issues as with Colorado and Oklahoma deep, high radar reflectivity core storms observed in the Campaign. This will be summarized in an accepted article to JGR.
* Vanna Chmielewski (OU/CIMMS)– Used technique to identify the strongest and most accurately located LMA source information to generate the best flash information from the OKLMA combined network. This has potential impact to detection efficiency and flash area calculations.
* Eric Bruning (TTech)– Main message to develop robust studies and training to illustrate how information from multiple flash datasets can be used to maximize scientific understanding and operational diagnosis of different weather phenomenon. Highlights the challenges when data are misclassified.
* Katrina Virts (UAH)– Discussed DE from the perspective of GLM, ENTLN, and ISS. Using computer methods to generate error maps for GLM and evaluating the performance of various spatio-temporal matching methods.
* Robert Holzworth (U. Washington) - Very weak relation between GLM energy and WWLLN energy. There were no matches of bright groups to any >100kJ WWLLN strokes from a study of “superbolts”..
* Carlos Morales (U. Sao Paulo)– Working to merge multiple lightning datasets at a known tower location to understand the sequence of events relative to different lightning measurements to understand IC:CG ratio. They’ve also worked to use lightning jumps to predict severe weather occurrence, and provided a case that worked and did not work.
* Ken Cummins (U, Arizona) - G16 and G17 do not always report the same groups and flashes. G16 and G17 do not report all GLD360 CG strokes. Thus an exploration tool has been developed to
  + 1) Explore/confirm absolute frame time accuracy
  + 2) Relate stroke location to pixel splitting
  + 3) Deduce light-source size, temporal “shape”, and duration for millions of selected reports
  + 4) Explore impact of viewing angle for perfect time matches (to-west and to-east) and
  + 5) extend detection modeling based on these sources and pixel splitting

**Session 3: Science and Applications Part 1**

* Scott Rudlosky (NOAA/NESDIS/STAR)– Provided an overview of GLM performance and applications on GOES 16 and GOES 17. Highlighted gridded GLM products in AWIPS2, a visualization for storm intensity from M. Peterson, and a GLM storms concept.
* Chris Schultz (NASA MSFC) – Demonstrated how lightning during the 3 June 2018 Fuego Eruption had two distinct phases of activity. Also showed how GLM and ENTLN provided entirely different pictures of the electrical activity during the eruption. 91% of the lightning observed during the eruption was only observed by 1 of the 2 lightning sensors used.
  + Discussion: Just confirmed that EN realtime data includes WWLLN strokes. The ENTLN and WWLLN data are merged, though, and if ENTLN detects a WWLLN stroke the WWLLN stroke is not included in the realtime data to avoid duplicate reports.
* Chris Slocum (NESDIS/STAR) – using GLM data in assimilation to improve SHIPS-II model forecasts. The impact is that they are seeing short term gains in forecasting of tropical cyclones due to the inclusion of the GLM data. Higher temporal fidelity data (1-hour bins) could add information about sudden changes (would require a nonlinear ML algorithm to leverage this input into the SHIPS-II model).
  + Discussion: Potentially using radius of maximum wind relationships to GLM. In the absence of aircraft, the quality of the RMW is poor. So, we should see some important inside into how to interpret lightning with respect to RMW. But, until we can improve estimates of RMW operationally, it will be challenging to incorporate into something like SHIPS RII.
* David PeQueen (Texas Tech University) – Illustrated how Dorian had distinct shifts in flash area and flash energy information which followed the diurnal cycle. These shifts were not as pronounced in an E. Pacific storm (Erick). Are there differences between Atlantic and Pacific storms related to lightning?
* Randy Longenbaugh (DOE/Sandia National Lab) – using stereoscopic techniques to identify bolide events across the GOES-16/17 fields of view, as well as, using ABI to vet potential bollide detections. As a result they’ve Launched a new webpage to track these events: https://neo-bolide.ndc.nasa.gov/#/)
  + Discussion: Interesting to look at combined event data from 2 GLMs (3 when we launch G18 during commissioning PLPT. This is a bit different from Clem Tillier's suggestion for SuperGroups at the 2019 GLM meeting.
  + BRAMON tracks bolides in Brazil. [http://www.bramonmeteor.org/bramon/en/](https://meet.google.com/linkredirect?authuser=0&dest=http%3A%2F%2Fwww.bramonmeteor.org%2Fbramon%2Fen%2F)
  + Randy, will you or your Ames team plan to compare (stereo) MTG LI and GLM East in 2022 and compare LI with 4 km pixels at nadir at 1 msec temporal with GM at 8 km and 2 msec ? This could be useful input to the GEO-XO Lightning Mapper design.
* Erin Lay (LANL) – using RF to observe lightning from geosynchronous orbit. Planned mission called SENSER. Would like to understand the impact of the ionosphere, as well as, work with ground based LMAs to understand storm evolution.
* Bartolomeo Viticchie (EUMETSAT)– outlined the MTG-LI satellite and preflight performance of the level-2 data. The simulated lightning detection performances of LI are characterized by a strong variability The FDE varies from about 0.3 to 0.98, for a FFAR that can be as high as 24 flashes per second The detection threshold varies in [4, 15] µJ / (sr m2 ). Launch is in 2022-2023. Coverage is up as high as 70 N.

**Session 4: Science and Applications Part 2**

* Steven Goodman (GOES-R Program/TGA)– Developing a hierarchy to monitor climate related tendencies of lightning now that lightning is an essential climate variable according to GCOS. Methods, data storage, requirements for new lightning observation platforms, etc. must all be consistent to effectively monitor lightning as a climate variable. Task Team Members for (2020) are: Valentin Aich - GCOS/WMO, Geneva Caterina Tassone - GCOS/WMO, Geneva Robert Holzworth - U. Washington, USA Steven Goodman - GOES-R/TGA, USA Colin Price – Tel Aviv University, Israel Earle R Williams – MIT, USA Yuriy Kuleshov – BOM Australia Vasiliki Kotroni – NAO, Greece Bartolomeo Viticchie – EUMETSAT
  + Discussion: Regarding metadata, I've started a formal CF metadata standards request motivated by LIS, GLM, and other lightning datasets, focused on modeling the flash-group-event linkage (or source-flash, links to storm cells, etc.) at the metadata level . [https://github.com/cf-convention/discuss/issues/62](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fgithub.com%2Fcf-convention%2Fdiscuss%2Fissues%2F62) - your comments on the linked Google Doc are most welcome.
  + How long does the lightning record have to be in order to be really useful for climate studies? And, must IC and CG be in the record or is CG only sufficient?
* William Koshak (NASA MSFC)– developing methods to automatically classify GLM flashes as IC or CG. This builds upon work that has been done for the last decade. Has implications for lightning-NOx studies and indicates that CG flashes generate more NOx than their incloud counterparts
  + Discussion: even though there may be less NOx produced by IC compared to IC, the NOx produced by IC likely impacts the upper troposphere formation of Ozone more so than the NOx generated by CG's.
  + IC LNOx higher altitude which has greater impact on ozone. However, one still has to be careful since many (probably most) CGs have IC components, plus storm convection can still pull LNOx upward. In any case, I was only commenting on LNOx production, not impact.
* Daile Zhang (U. Maryland)– Overview of the new NASA ROSES A.33 project (see above) to downscale GLM data to the ISS LIS footprint to Improve GLM optical areas and energy estimation, and the detection efficiency of lightning.
* Nadia Ahmed and Marek Slipski (Frontiers Development Lab) – used Google Cloud information to formulate a real-time prediction algorithm to forecast severe weather occurrence 15-30 minutes ahead of time. 2018 and 2019 data were used as training and then compared to a limited sample of severe events from 2020. Overall they demonstrate in this limited dataset that the inclusion of the GLM specific information improves POD and FAR metrics and at a larger benefit than the inclusion of ENI data into prob severe (Cintineo et al. 2018).
  + Discussion: For the trained model, the equations are built to predict any given timeseries as severe or non-severe. And we can look at the features for a single example.
  + yes, the weights of the equation are stored in the computational graph upon training. The next steps are to explore these weights in the context of flow equations and other physics based models and parameters
  + For the time series analysis the equation is can be written as the fast fourier transform of the original data whose output is the input of the ridge regression classifier--the randomness is introduced in the number of components, frequencies, dilation, etc...
* Joan Montanyà (U. Catalonia, Spain)– Demonstrated the cross referencing of ASIM and an LMA located in Columbia to understand flash sequence from two different instruments. GLM detections of this flash are consistent with the ASIM video images and photometer radiances as well with the leader development provided by the Colombia-LMA.
* Mark Stanley (New Mexico Tech)– The general goal to better understand how light output at different wavelengths correlates in time with various lightning discharge processes Applying this to GLM, what factors determine which discharge events are detected at 777.4 nm and their optical amplitude? They observed a wide variation in optical output of Initial Breakdown Pulses (IBPs) for different IC flashes (and likely from storm to storm), particularly at the 777.4 nm wavelength of GLM. The ratio of blue (337 nm) to red (777.4 nm) is much higher for IBPs than events late in the flash (such as K-changes), consistent with IBPs being at least partly composed of fast negative non-thermal streamers. Even with the poor red output relative to blue, strong IBPs can still produce the brightest optical output within flashes.
  + Discussion: do you think you might run the INTF during the SENSER mission next year for joint comparisons with ASIM, GLM, LIS, ground based...
  + the INTF should still be running all of next year, so join comparisons with ASIM/GLM/LIS/... are possible.
  + great- we should include you in our Campaign Plan in preparation. Will follow up.
* Geoffrey Stano (GHRC/UAH)– illustrated how the GHRC is archiving various lightning data and then using that information to turn around climatological type analysis. They’ve incorporated the Peterson reclustering information and have worked to publish datasets using doi indexing.
  + Q: Geoffrey, Michael- 100 km flash definition is somewhat arbitrary (meso-alpha, beta, gamma)- or is there a value that better links to storm physics?
  + A: we're currently running with the Lyons et al (2020) paper for this particular definition. [https://doi.org/10.1175/BAMS-D-19-0033.1](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fdoi.org%2F10.1175%2FBAMS-D-19-0033.1). We certainly want to dig into these data more than I showed here so that we can start asking questions about the storm physics.
* Kelcy Brunner (NASA SPoRT/UAH ESSC)– Using model output to simulate optical path scattering from the light source to the cloud top. Scattering depth is the most important model control on light reaching cloud-top. WHERE and HOW your scattering concentration exists matters: they both factor into the mean free path, especially related to ice concentration. These simulations address a percentage of light reaching cloudtop: amplitude is king.
  + Q: can you validate or constrain your model with dual pol radar and hydrometeor id added (since dBZ is not unique ~ n(D) D^6).
  + A: we've definitely tried using hydrometeor id, it gets tricky because HiD doesn't give the same microphysical specificity we need. I suspect radar and HiD will become more useful as we transition the model to using satellite-based optical depth and effective radii (vs. and idealized WRF environment).
  + Using purely dual-pol variables for that kind of application would probably be more successful than HiD
* Kevin Thiel (OU/NSSL) - The combination of ABI data and GLM data provide complementary insight into thunderstorm morphology and meaningful lightning interrelationships with evolving storm characteristics. Areas with cloud -tops colder than 240 K typically produce lightning. The GOES -16 viewing angle to convective features complicates the interpretation of ABI data, especially cloud -top height. Increasing local flash density is strongly related to decreasing flash areas, higher cloud -top heights, and colder cloud -top temperatures.
  + Liquid Water Path is part of one of the GOES-R ABI L2 algorithms; see [https://www.star.nesdis.noaa.gov/goesr/documents/ATBDs/Baseline/ATBD\_GOES-R\_Cloud\_DCOMP\_v3.0\_Jun2013.pdf](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fwww.star.nesdis.noaa.gov%2Fgoesr%2Fdocuments%2FATBDs%2FBaseline%2FATBD_GOES-R_Cloud_DCOMP_v3.0_Jun2013.pdf) for details

**Session 5: Science and NWS Integration and Operational Uses**

* Jonathan Wynn Smith (U. Maryland/NESDIS STAR) – Demonstrated the operational gridded products generated for NWS purposes. Looking forward there is a goal to integrate glmtools into CSPP-GEO to compute official GLM gridded products at each GRB site. Migrate to the product generation to NESDIS generation and distribution of the GLM gridded products.
  + Jonathan mentioned our NESDIS CSPP -GEO Project, developed and managed at UW-CIMSS in Madison. This is an alternative to the GOES-R ReBroadcast (GRB) to receive experimental products- [https://cimss.ssec.wisc.edu/csppgeo/](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fcimss.ssec.wisc.edu%2Fcsppgeo%2F)
  + European users are waiting for the data to be on NESDIS so that it is redistributed through EUMETSAT, but the python package provided by Bruning has been used by some users as an interim solution - very nice
  + The European Caribbean countries use GLM in operations. We learned of this at the Barbados VLab las year
* K. Magee (NWS Huntsville) Forecasters at NWS Huntsville find GLM as an invaluable tool that provides more operational use that ground based networks. Has been utilized for severe weather operations, airport weather warnings, and impact-based decision support. Forecaster challenges include parallax correction during widespread convection and there is uncertainty in how to use the flash area and flash energy products.
  + Q: Katie, is the GLM trend in Svr Storm Interrogation primarily the refresh rate vs radar or other (easy to digest, added situational confidence) since you can already interrogate the vertical structure of the VCP?
  + Q: Katie, have any forecasters noticed any issues/instances where the GLM color curve was pegged on the high end hindering use for lightning jumps?
    - I've had to shift the default range multiple times both in warning operations and watching elsewhere, especially with supercells. FED default range I've had to bump up to 1024 at times (trying to keep the log scale as I best I could), Average Flash Area I've had to bump up to 10000km^2 at times with large squall lines.
    - we have had the same issue with high lightning events. We have been playing with the color curves as well. I am trying to create curves that fit high lightning events better so the color changes when jumps or drops occur to be more noticeable to the forecast. Logarithmic curves don't always work in these events though once the lightning reads 300 or greater. Was making sure this is not a regional issue though.
    - Okay, thanks. I would not be surprised if it will happen more when you have a strong dry area in the mid-levels creating a high hail event with strong latent heat release. We have noted very high lightning rates with significant hail events.
    - We used to see very large jumps in the old LMA data in significant hail events. And we probably push the limits on the default curve in very significant events with any elevated mixed layers, but haven't noticed this much here...at least that's been my experience.
    - I've noticed differences in GLM color curves/thresholds depending on whether you load 5-min FED or 5-min with 1-min update FED. With the 5-min option, the color curve has much higher thresholds than the 1-min update. To echo Linda's presentation, figuring out how to adjust the color curve would be a great task for the mesoanalyst, if that is required for the warning environment due to higher rates.
    - Katie, et al GLM is well integrated in Tulsa as well in the mesoanalyst role primarily. We use it not just for identifying LJ's but to also note decrease in activity or upticks in FED for warning decisions. We communicate this on NWSChat routinely as well.
* Linda Gilbert (NWS Marquette) enhances the warning decision process for marginal and high impact events using a fusion of environmental parameters as a metric for utility of GLM.
  + Really like how MQT is combining environment with the lightning data. low topped environments limit the depth of the mixed phase region, and thus robust lightning is not expected. This is based on cool season environments we've worked with in the southeast.
  + check in with Stephanie Stevenson at NHC- here NASA/NOAA ROSES proposal will look at marine weather, including ongoing collaboration with Michael Folmer at OPC.
* Jason Jordan (NWS FDTD) – Developed methods to use GLM to assist in ground based lightning detection differences (ENI, NLDN). Why is this important? Decision Support Services. – Ground says here OR there, GLM says yes, no, or maybe. When everything lines up the forecaster has higher confidence to communicate the threat of lightning to partners. Also highlighted is using the ground networks to identify data dropouts from GLM when rates are really high.
  + Q: how often does the dropout occur?
  + A: very rarely, once every few years. This case was unique because of the east/west orientation of the line hitting the same parts of the ccd.
  + To clarify, yes long stratiforms can commonly cause isolated overflows, but sustained overflows (making a big dent in DE) are rare
  + A more common issue in big stratiform flashes is that they exceed 10000 km^2 and the current ground system implementation wraps the area to negative values, which causes problems with product generation in glmtools. We worked around that over the summer, if I recall, but still waiting on a fix that is in work in the ground system.
  + It happens with solar intrusion as well. It's particularly notable as missing groups in an otherwise continuous light curve. Figure 1 in [https://www.spiedigitallibrary.org/journals/Journal-of-Applied-Remote-Sensing/volume-14/issue-3/032402/Removing-solar-artifacts-from-Geostationary-Lightning-Mapper-data-to-document/10.1117/1.JRS.14.032402.full?SSO=1](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fwww.spiedigitallibrary.org%2Fjournals%2FJournal-of-Applied-Remote-Sensing%2Fvolume-14%2Fissue-3%2F032402%2FRemoving-solar-artifacts-from-Geostationary-Lightning-Mapper-data-to-document%2F10.1117%2F1.JRS.14.032402.full%3FSSO%3D1) shows a good example
  + That's why FED shows lightning but AFA does not, correct? Wouldn't this overflow make neither parameter populate?
  + Right. Actually it's not wrap-around, they're assigned as NaN, which makes it somewhat easier to catch. [https://github.com/deeplycloudy/glmtools/blob/master/glmtools/io/glm.py#L330](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fgithub.com%2Fdeeplycloudy%2Fglmtools%2Fblob%2Fmaster%2Fglmtools%2Fio%2Fglm.py%23L330)
  + For the buffer overflow issue, someone should quantify how this affects flash rate. I'm not convinced that it's such a big deal. Mostly impacting stratiform flashes that have such low rates that you won't miss anything
  + Q: Does it still occur at times of stray light contamination? I see to recall that some time ago, but it may have been fixed
  + A: The huge bursts of false events still occur during solar intrusion. The change that was made was to the ground system, preventing all that garbage from reaching L2
* Joseph Patton (U. Maryland/NESDIS STAR) – provided an overview of current and past training that has been developed to help folks understand and apply the GLM data. Looking forward, additional training will be needed as new techniques are developed and GLM is applied to various short-term forecasts.
  + Q: is there a need for more GLM vs ground based lightning trianing content- example, explanations?
  + Forecaster answer: I would say yes (my opinion only!!) but deeper than that. Really needs to be a series of modules on atmospheric electricity to understand how and why different sensor detect what they do. That should help mets understand better all the issues, strengths, weaknesses with all the detection methods.
  + A (from speaker): minimum flash area is a prime target for new training given the new grids are rolling out operationally soon.
  + Forecasters need a deeper understanding of what's going on related to atmos elect.
  + Could be a more nuanced round of training for "lightning" focal points, so to speak, who then goes on to train the rest of the staff...?
  + Most NWS meteorologists don't have Atmospheric Electricity courses available in their undergrad/Grad program. That's why a baseline series of atmospheric electricity modules would be needed.
  + I saw a really great talk from Kristin Calhoun during one of the NWS regional science calls, covering some basic physics all the way to detection differences, lightning jumps, and GLM applications. By far the most comprehensive presentation I've seen.
  + the message I often hear as a scientist is that forecasters want to be told what to do - but I also am aware of the difference it made in NEXRAD use in the early days when the focus switched from algorithmic warning to physical reasoning.
  + COMET MetED is starting new GLM trianing development so this is a good time to circle the wagons around gaps and needs on the lightning training. Kristin, Eric, Scott, me and others are helping.
  + Lightning Meteorology training video: [https://www.youtube.com/watch?v=hb0mpvibvTg&feature=youtu.be&ab\_channel=SciShare](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3Dhb0mpvibvTg%26feature%3Dyoutu.be%26ab_channel%3DSciShare)
  + [http://rammb.cira.colostate.edu/training/visit/training\_sessions/lightning\_meteorology\_1/](https://meet.google.com/linkredirect?authuser=0&dest=http%3A%2F%2Frammb.cira.colostate.edu%2Ftraining%2Fvisit%2Ftraining_sessions%2Flightning_meteorology_1%2F)
  + [http://rammb.cira.colostate.edu/training/visit/training\_sessions/lightning\_meteorology\_2/](https://meet.google.com/linkredirect?authuser=0&dest=http%3A%2F%2Frammb.cira.colostate.edu%2Ftraining%2Fvisit%2Ftraining_sessions%2Flightning_meteorology_2%2F)
* Idris Akala, J. Smith, and S. Rudlosky (U. Maryland/STAR)– This presentation outlined a query tool that can be used to grab past event information for lightning. [https://lightning.umd.edu/projects/website/query.html](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Flightning.umd.edu%2Fprojects%2Fwebsite%2Fquery.html)
  + Comment: Some WFOs get inquiries from first responders & other users about whether lightning may have been involved in fires and other issues--so this has some great potential. Thanks!
* Kelly Murphy (NASA SPoRT/UAH ESSC) – Tracking methods using a blended radar/GLM technique allows for tracking of storm features with on a combined radar/GLM field, radar alone, or GLM alone. The impact is that storm tracking can be done on CONUS and OCONUS. Currently have tracking methods at ARL 7, and are testing GLM alone tracking methods with NSSL.

General question to forecasters from Program Scientist Dan Lindsey

* In my mind as a non-forecaster, the key question on operational utility is: what value does the GLM provide on top of the existing ground network data? Another way to think about this is: what would the impacts to operations be if the GLM data feed stopped? I know there have been some presentations along these lines, and I appreciate those.
  + one of our next steps is to see how we can maximize GLM usage for marine operations/warnings, where data is sparse.
  + for me and in Lubbock, we know that the Detection Efficiency of ENTLN is different from the GLM where usually the ENTLN detects WAY more cloud flashes and CGs than GLD. BUT since the beginning of 2020, it seems that has flipped, GLD is reporting more than ENI. So far, the GLM has been fairly consistent at least from a visual perspective. Haven't dug into the data that much but Eric's group at TTU is looking into some of those differences.
  + I will echo what everyone else has been saying. GLM is well integrated into operations at our WFO and helps visualize lightning jumps more easily and catches the forecaster's eye. It is incredibly beneficial and would be greatly missed if the feed stopped.
  + From a forecaster/operator perspective, the addition of the GLM is big as it can give us a good idea of the rapid changes in the storm in question which radar can only do ever 6 min. If the feed stops, it will have an increasing impact as more operators start using and get an understanding of what it means. Right now, I view the GLM as a great addition and I think it will become more important as forecasters use it and more importantly, get use to it and understand what it really means.
  + GLM also gives spatial coverage/context in ways that the ground networks don't--really important for safety too.

**Session 6: GLM Data Assimilation**

* Alex Fierro (OU CIMMS) - Performance diagrams aggregated over all 29 Spring Forecast Experiment days over CONUS for 1, 3 and 6-h forecast show a general improvement in forecast skill over CTRL for all DA runs; with the best results obtained for GLM+RAD. Individual cases reveal that assimilating GLM data showed benefit in radar-sparse areas such as the mountainous west, the Gulf of Mexico, East Coast and the Sierra Madre in Mexico. Complete analysis of HRRRv4 real time radar +/ GLM DA runs conducted during the SFE of Spring 2020.
  + Alex - did you look into the details of the radar limitations for the east-coast example case?
  + I'll add that the SE case was a 3-hour forecast and the storm may have been just starting at initialization time. I'd like to see what the obs and models looked like a 0 hours.
  + Alex, do you see particular benefits in GLM DA for the North America monsoon as storms are outside SW US radar coverage before coming into radar coverage? Monsoon follow-up. before storms reach US we do not have a good initial depiction- we were told this by RFC, also lack of gages. I think Pierre Kirstetter also looking into this issue for MRMS. So if GLM can give a better depiction before the radars really pick up on precipitation, then I would think for example the 3-6 forecast might be improved for the monsoon rainfall entering the US borders.
    - Yes; if you are interested, we could look in more details into some of these cases that had prominent GLM activity south of the border (mostly over the Sierra Madre) in which storms later evolved over the CONUS.
  + Alex- In earlier sessions we discussed GLM vs ground based networks- do you see a better result with ENGLN for example vs GLM? I know Alex has used ENGLN in the past.
    - RE: Alaska - EN has installed new sensors in Alaska since last year, and we are planning to add more in the near future, so ground network coverage up there is already improving and should continue to do so
* Yaping Wang (OU CIMMS)– Impact of GLM on the Warn-on-Forecast system. Without radar data, assimilating GLM data degrades the forecast skills by overly suppressing convection. ¬ With radar data assimilated, assimilating GLM data slightly improve the forecast skill of composite reflectivity and storm tracks. Assimilating GLM FED observations with/without radar data into the WoFS has the potential to improve the short-term forecast skills by better capturing the features of individual supercells, as well as better predicting storm tracks, but may struggle in mesoscale convective systems
* Rong Kong (OU CIMMS)– The goal of this work is to examine the impacts of GLM data with and without radar data. Overall, FED DA with GSI EnKF produces generally comparable results as radar DA. 2. When radar data are assimilated together with FED observations, the additional positive impacts of FED DA are relatively small but still present.
  + Kong, R., M. Xue, A. O. Fierro, Y. Jung, C. Cliu, E. R. Mansell, and D. R. MacGorman, 2020a: Assimilation of GOES-16 Geostationary Lightning Mapper Flash Extent Density Data in GSI EnKF for the Analysis and Short Term Forecast of a Mesoscale Convective System. Mon. Wea. Rev., 148, 2111-2133.
* Amanda Back (ESRL/CIRA) – Developed a DA system to examine how GLM can be used to improve forecasts over oceanic regions. Analysis of these experiments still underway. The GLM assimilation is permanently part of real-time RAPX/HRRRX following autumn code freeze. Pre-forecast hour for next-gen RRFS is in development. Other radar/lightning assimilation strategies are being evaluated and a formalized verification processes using satellite obs is being worked.

**Data Assimilation Discussion**: splinter meeting to discuss GLM DA moving forward.

FYI: 1. Joint Technology Transfer Initiative (JTTI) Weather Program Office, in collaboration with the NWS, developed the following three priorities (each with sub-priorities) for the JTTI Program. JTTI-1: In collaboration with the UFS community ([https://ufscommunity.org/](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fufscommunity.org%2F)) and/or the UFS/R2O Project ([https://www.weather.gov/media/sti/UFS-R2O-Project-Proposal-](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fwww.weather.gov%2Fmedia%2Fsti%2FUFS-R2O-Project-Proposal-) Public.pdf), further develop, test and enhance data assimilation techniques, develop and evaluate physics, improve model component coupling techniques and capabilities, and utilize Artificial Intelligence/Machine Learning (AI/ML) for improving forecasts:

JTTI-1(a): Test and improve methods for coupled data assimilation strategies for GFSv17/GEFSv13 or other applications within the UFS. This includes (i) developing and testing multi-scale hybrid EnVar (with Joint Effort for Data assimilation Integration (JEDI) if available) for UFS (particularly multi-scale covariance localization), (ii) developing and testing initialization and ensemble strategies for the Rapid Refresh Forecast System (RRFS) (e.g., multi-physics, stochastic physics etc.),

(iii) initializing regional nested, coupled domains for the Hurricane Analysis and Forecast System (HAFS), or (iv) further develop and/or improve quality control and bias corrections (utilizing machine learning) for high frequency remote sensing observations (radar, satellite radiance, lightning etc.). RE; JTTI, here is the full announcement and associated documentation: [https://www.grants.gov/web/grants/view-opportunity.html?oppId=328644](https://meet.google.com/linkredirect?authuser=0&dest=https%3A%2F%2Fwww.grants.gov%2Fweb%2Fgrants%2Fview-opportunity.html%3FoppId%3D328644)

Kyle Hillburn at CSU worked on a synthetic radar product based on GLM+ABI (derived by convolutional neural network) for DA purpose.