Reviewers' comments:

Reviewer #1 (Remarks to the Author): ***see attachment***

Reviewer #2 (Remarks to the Author):

This is an excellent paper showing experimental observations of simultaneously occurring gammaray glows and TGFs. The relationship between gammaray glows and TGFs is not presently well understood. This topic is of broad interest to the scientific community.

I recommend this paper be accepted once the authors successfully revise their manuscript to address the following issues:

1) Primary Comment: The fundamental conclusion (presented in the title) that gammaray glows initiate TGFs is not supported by the observations. To be clear, the word "initiate" implies that cause and effect have been identified, and this is not the case (correct me if I am wrong). Instead, it seems that TGFs have the ability to quench gammaray glows (as accurately reported in the article). Although the authors state that they cannot experimentally determine whether the TGF or the glow quenching happened first, it is clear that the two are related, and this is a very important scientific result.

2) As noted by the authors, previous work has reported that lightning has been observed to quench gammaray glows. Is it possible that a TGF was associated with the lightning, but not observed? (Is it possible that a TGF actually quenched the gammaray glow instead of the lightning?)

3) Very minor editing for English is recommended. There are several places throughout the text where the word "the" could be inserted to help the reader, for example.

Overall, I recommend the authors change the title to more accurately reflect their conclusions and clarify the discussion of (1) and (2) throughout the manuscript.

***Editors Note: In order to clarify the significance of your results please define all error bars in the figure captions. Currently, Fig. 2 is the only figure where the error bars have been defined as 1 sigma.

Reviewer 1

Referee comments on the paper:
" Gamma-ray Glow initiating Downward Terrestrial Gamma-ray Flash" by Yuuki Wada, Teruaki Enoto, Yoshitaka Nakamura, et.al.

The paper describes “the first unequivocal simultaneous detection of a *gamma-ray glow* termination and a *downward TGF, observed from the ground*”. However, physical meaning of observed phenomena and terminology used should be clarified and corrected.

The term (concept) “downward TGF” is very confusing. The Term TGF (terrestrial gamma flash) was introduced in the 90-ths for the very short bursts of gamma radiation (less than few ms) detected by orbiting gamma observatories and coming from the direction of earth. These, very short bursts are associated with very strong thunderstorms in the equatorial regions. The origin of TGFs is accepted to be the relativistic runaway avalanches (RREA) unleashed in the strong electric fields of upper dipole between the main negative and the upper positive charge layers of the thundercloud. The seed electrons are from the ambient population of cosmic rays (CR) and possibly from the streamers or/and lightning leaders. Also, the several scenarios of the intensification of seed electron flux by a feedback schemes in the upper dipole are suggested.
The “inverse TGF” term, as it is used in the reviewed paper is absolutely another hypothetical phenomenon. It is ~200 ms long (2 orders of magnitude larger in time than TGF) burst of gamma rays detected on the earth’s surface. Thus, a possible origin of the observed phenomenon is electrons acceleration in the *lower dipole*, between the main negative and the lower positive charges, with characteristics completely different from ones in the upper dipole!

Previous few detections of the “inverse TGEs” in association with cloud-to-ground lightning flashes were reported by the Telescope Array (TA, [1]) group, and by group from International Center for Lightning Research and Testing (ICLRT, [2]). The duration of registered gamma bursts in both experiments did not exceed several hundred microseconds (2 order of magnitude less that reported in the reviewed paper). Thus, the “inverse TGFs” detected in these experiments are another type of phenomena. And we should agree that each group put specific meaning in their observations. Better use neutral term “burst of gamma rays” for denoting such observations until physical mechanism will be confirming or rejected.

In my opinion, the term “gamma glow” is also used not properly in the paper. Gamma glows are registered by gamma ray spectrometers located on balloons and recently on aircraft. Gamma glows originate in the upper dipole with all inherent peculiarities (high

altitude, very thin air, large charges of main layers, the screening layer attracted from the ionosphere, etc). For the electrons, gamma rays and neutrons observed on the earth's surface there is internationally accepted term: thunderstorm ground enhancement (TGE). TGEs propagate in the much denser lower part of the thundercloud; the atmospheric electric field in the lower dipole originates under conditions which are different from those in the upper one. RREA simulations with CR seed electrons reproduce quite well observed energy spectra of TGE particles. Thus, reserving of the special term TGE for "gamma glow" observed on the earth's surface is justified. Confusing terminology is not only a linguistic problem, neglecting the different physical conditions of the "same-named" entities can lead to mistakes in interpretation.

The structure of the electric field is the main entity underlying all measurements of particle fluxes and lightning initiations. The length of the field and its location above earth's surface was deduced from simulation trials with several tested models. The final choice of the electric field location was made by requiring to reproduce measured gamma-ray spectra and count-rate histories. In this way, it is possible to reject "very bad "models, however, it is questionable to approve a "good "model. The results will crucially depend on choice of other unknown parameters of simulation, for instance, assumed intracloud electric field strength (3.5 – 4 kV/cm) seem somewhat large. Thus, the procedure cannot be too precise and selection between 400 and 600 meters of cloud height seems to be rather arbitrary.

Having a big variety of mapping arrays and radar network (see below) it will be much better to use radar observations (confirmed by LF and JLDN data) and compare particle flux models with experimentally measured location of the charged layers forming the lower dipole.

"Lightning discharges were monitored by a broadband low-frequency (LF: 0.8–500 kHz) lightning mapping network (hereafter LF network), for which detectors are installed along Toyama Bay and in Noto peninsula. Another set of receivers at the extreme-low-frequency (ELF: 1–100 Hz) band are installed at Kuju, as summarized in "Methods: Radio Observations". We also utilized lightning location data of Japanese Lightning Detection Network (JLDN) operated by Franklin Japan Co., Ltd.";

X-band radar has a shorter wave length and can measure shape of raindrops by transmitting 2 types of waves (horizontal and vertical) and estimates rainfall from flattening of raindrops [3]. Radar can recognize the shape of raindrops and resolve the sizes of raindrops with ~2 mm accuracy. These excellent characteristics surely will allow to estimate with high accuracy the height of differently charged layers in the thundercloud.

Thus, this referee offers to estimate the location of the cloud charge layers (i.e. the extension of the electric field, relative location above detectors, and the height above the surface where the field terminates) from the excellent measurements with facilities described above and then use experimentally obtained parameters in simulations.

"Our observation cannot clarify whether the glow termination or the downward TGF took place first because these phenomena seemed to be slightly overlapped."

"we speculate that the avalanche electrons of the gamma-ray glow can behave as seed electrons of the downward TGF" + "the highly-electrified region responsible for a gamma-ray glow can be a dominant source of seed electrons for a TGF which occurs in the close proximity of a gamma-ray glow"

The RREA avalanche continue~~d~~ as long as conditions for the "runaway" regime in the cloud are met. The separation of the "overlapped" avalanche into glow and TGF seems to be somewhat artificial. 200 ms is somewhat large time and you can interpret both bursts as a TGE interrupted by lightning flash and then restarted, without dividing the observation to TGE and short burst? There are several publications on TGEs terminated by the lightning flashes and restarted again and again (you can find these publications in your citations list).

Recommendations

1. **Use proper terminology: avoid term "inverse TGE" for naming not well established yet hypothetical gamma ray emission accompanied by lightning flashes. Better use term "gamma ray bursts", to distinguish from reported previously microsecond duration "inverse TGFs". Instead of gamma glows use TGE term, that refers to the RREA process in the lower dipole.**
2. **In the introduction cite the previous reports on "inverse TGFs". The past research on the same topic and using the same terms should be mentioned.**
3. **Try to acquire information from radar for estimation from the direct measurements the location of the charged layers in thundercloud. Measurements always are much better than data obtained from alternative simulations estimates. Simulations always contain simplifications and arbitrary parameters.**
4. **To confirm cloud charge structure, invoke the data from the near-surface electrostatic field measurements by electric field mills. Explicitly describe**

the lower dipole where the electron acceleration took place: as we understand from the paper authors assume the dipole formed by the main negative and lower positively charged regions (LPCR).

5. **Consider the model of TGE interrupted by the lightning flash (simplest model) for describing observations.**

References

1. Abbasi, R. U., Abu-Zayyad, T., Allen, M., et al., (2018). Gamma Ray Showers Observed at Ground Level in Coincidence With Downward Lightning Leaders. Journal of Geophysical Research: Atmospheres, 123(13), 6864–6879. doi:10.1029/2017jd027931
2. Hare B.M., M.A. Uman,M.A., Dwyer J.R., et al., Ground-level observation of a terrestrial gamma ray flash initiated by a triggered lightning, Journal of Geophysical Research Atmospheres 121(11) DOI: 0.1002/2015JD024426
3. http://www.mlit.go.jp/river/pamphlet_jirei/pdf/xrain_en.pdf?0930

Summary of changes made to the manuscript entitled "Gamma-ray Glow preceding Downward Terrestrial Gamma-ray Flash"

We deeply thank the referees for careful reading of our manuscript and helpful comments. We have revised the manuscript by taking their comments into account. In our manuscript, modified descriptions are shown in red.

Reviewer #1 (Remarks to the Author):

1. Use proper terminology: avoid term "inverse TGF" for naming not well established yet hypothetical gamma ray emission accompanied by lightning flashes. Better use term "gamma ray bursts", to distinguish from reported previously microsecond duration "inverse TGFs". Instead of gamma glows use TGE term, that refers to the RREA process in the lower dipole.

We are afraid that the reviewer might misunderstand our interpretation. The 200-ms-lasting short burst originates from de-excitation gamma rays of neutron captures. As previous papers (Bowers et al. 2017, Enoto et al. 2017) observationally demonstrated, lightning discharges can produce neutrons via photonuclear reactions in the atmosphere. We consider that such atmospheric photonuclear reactions are triggered by intense and brief (less than milliseconds) gamma-ray burst. In short, we presume that a TGF-like sub-millisecond burst preceded the short burst (neutron component), and call the former "downward TGF", separately from the "short burst".

We thank the reviewer for giving us an opportunity to revise our misleading manuscript. We have merged the Method section "Signature of a downward TGF" into the main text, and reworded the expression in the section "Detection of gamma-ray glow and photonuclear reactions by downward TGF" and the Method section "Gamma-ray emission originating from neutrons" to clarify our interpretation.

In the terminological issue, we consider that TGEs are intrinsically the same physical phenomena as gamma-ray glows, originating from electron avalanches termed RREAs (relativistic runaway electron avalanches), although there are some differences of direction, location, and meteorological conditions. Actually, we and another group use "gamma-ray glow" to point minute-lasting gamma-ray bursts from thunderclouds observed from the ground (Wada et al. 2018, Smith et al. 2018). Therefore, we retain to use the term "gamma-ray glow" throughout the present paper.

2. In the introduction cite the previous reports on "inverse TGFs". The past research on the same topic and using the same terms should be mentioned.

We had already cited papers on "downward TGFs" in the introduction section. The term "downward TGF" is more common in the scientific community rather than "inverse TGF" (e.g. Hare et al. 2016, Abbasi et al. 2018, Lyu and Cummer 2018).

3. Try to acquire information from radar for estimation from the direct measurements the location of the charged layers in thundercloud. Measurements always are much better than data obtained from alternative simulations estimates. Simulations always contain simplifications and arbitrary parameters.

As the reviewer pointed out, radar observations can give us useful information of cloud charges (e.g. Kelley et al. 2015, Hare et al. 2016). The X-band radar network operated by Japanese Ministry of Infrastructure, Land and Transportation can distinguish particle types in clouds by polarized microwave observations. However, their spatial resolution for altitude is ~1 km, less precise than the reviewer expects. In addition, winter thunderclouds have more compressed structures than summertime thunderclouds, which makes radar observations difficult. Therefore, we regret not to

use the radar data to estimate the cloud charge structure. We have explained this point in the Method section “Wind estimation with XRAIN”

Our simulation result well reproduces both the spectra and count-rate histories of the present gamma-ray glow event, and hence the obtained parameters should give us some meaningful physical interpretations. For example, the assumed values of the electric field, 0.35-0.4 MV/m are relatively high. However, such high electric fields are required to explain the high gamma-ray flux observed at detector B. Concerning this, we have added explanations in the section “Production mechanism of gamma-ray glow”

4. To confirm cloud charge structure, invoke the data from the near-surface electrostatic field measurements by electric field mills. Explicitly describe the lower dipole where the electron acceleration took place: as we understand from the paper authors assume the dipole formed by the main negative and lower positively charged regions (LPCR).

Unfortunately, we operated no field mills in the observation site. We presume that the electron acceleration took place at the lower part of the thundercloud as our simulation suggested (400 m altitude). However, whether the acceleration occurred between the main negative charged and the lower positive charged layers or not remains open question due to lack of near-surface electric field measurements (see also the discussion in Wada et al. 2018).

5. Consider the model of TGE interrupted by the lightning flash (simplest model) for describing observations.

The RREA avalanche continued as long as conditions for the “runaway” regime in the cloud are met. The separation of the “overlapped” avalanche into glow and TGF seems to be somewhat artificial. 200 ms is somewhat large time and you can interpret both bursts as a TGE interrupted by lightning flash and then restarted, without dividing the observation to TGE and short burst? There are several publications on TGEs terminated by the lightning flashes and restarted again and again (you can find these publications in your citations list).

As we explain in the response to the first remark, the 200-ms-lasting short burst is not of RREA origin, shown in the method section “Gamma-ray emission originating from neutrons”. Therefore, the reviewer’s idea is not the case in the present event.

Reviewer #2 (Remarks to the Author):

1) Primary Comment: The fundamental conclusion (presented in the title) that gamma-ray glows initiate TGFs is not supported by the observations. To be clear, the word "initiate" implies that cause and effect have been identified, and this is not the case (correct me if I am wrong). Instead, it seems that TGFs have the ability to quench gamma-ray glows (as accurately reported in the article). Although the authors state that they cannot experimentally determine whether the TGF or the glow quenching happened first, it is clear that the two are related, and this is a very important scientific result.

We appreciate the reviewer’s indication and understanding. We have reworded the title and modified the manuscript.

2) As noted by the authors, previous work has reported that lightning has been observed to quench gamma-ray glows. Is it possible that a TGF was associated with the lightning, but not observed? (Is it possible that a TGF actually quenched the gamma-ray glow instead of the lightning?)

Our previous publication reported a gamma-ray glow terminated by an in-cloud discharge, but without downward TGFs (Wada et al. 2018). We speculate that not all gamma-ray glows terminate with TGFs, however our present observations are not sufficient to demonstrate this speculation.

We have added this discussion in the section “Relation between gamma-ray glow and downward TGF”.

3) Very minor editing for English is recommended. There are several places throughout the text where the word "the" could be inserted to help the reader, for example.

Done.

Editors Note: In order to clarify the significance of your results please define all error bars in the figure captions. Currently, Fig. 2 is the only figure where the error bars have been defined as 1 sigma.

Done.

References

- Bowers et al., “Gamma ray signatures of neutrons from a terrestrial gamma ray flash”, *Geophysical Research Letters*, 44, 10063-10070 (2017)
- Enoto et al., “Photonuclear reactions triggered by lightning discharge”, *Nature*, 551, 481-484 (2017)
- Hare et al., “Ground-level observation of a terrestrial gamma ray flash initiated by a triggered lightning”, *Journal of Geophysical Research: Atmospheres*, 121, 6511-6533 (2016)
- Abbasi et al., “Gamma ray showers observed at ground level in coincidence with downward lightning leaders”, *Journal of Geophysical Research: Atmospheres*, 123, 6864-6879 (2018)
- Lyu and Cummer, “Energetic radio emissions and possible terrestrial gamma-ray flashes associated with downward propagating negative leaders”, *Geophysical Research Letters*, 45, 10764-10771 (2018)
- Kelley et al., “Relativistic electron avalanches as a thunderstorm discharge competing with lightning”, *Nature Communications*, 6, 7845 (2015)
- Wada et al., “Termination of electron acceleration in thundercloud by intracloud/intercloud Discharge”, *Geophysical Research Letters*, 45, 5700–5707 (2018).
- Smith et al., “Characterizing upward lightning with and without a terrestrial gamma ray flash”, *Journal of Geophysical Research: Atmospheres*, 123 (2018).

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

Referee second comments on the paper:
" Gamma-ray Glow initiating Downward Terrestrial Gamma-ray Flash" by Yuuki Wada, Teruaki Enoto, Yoshitaka Nakamura, et.al.

"As previous papers (Bowers et al. 2017, Enoto et al. 2017) observationally demonstrated, lightning discharges can produce neutrons via photonuclear reactions in the atmosphere. We consider that such atmospheric photonuclear reactions are triggered by intense and brief (less than milliseconds) gamma-ray burst. In short, we presume that a TGF-like sub-millisecond burst preceded the short burst (neutron component), and call the former "downward TGF", separately from the "short burst". "

This exotic scenario should be explained in more details. What is "downward TGF"? please, give an exact definition and exhausting description in the body of the manuscript.

I can say that 2-year monitoring of lightning flashes and particle fluxes synchronized on nanosecond time scale performed on Aragats do not give any coincidence [1]. Analysis of shapes of the simultaneously detected pulses of the fast wideband electric field produced by a lightning flash and pulses from particle detectors discloses that all additional detector pulses registered during lightning flash were the electromagnetic interference signals and not particles originated from the lightning bolt. There was no evidence of the production of electrons, neurons or gamma rays during a lightning flash.

References
1. A.Chilingarian , S. Soghomonyan , Y. Khanikyanc , D. Pokhsraryan , On the origin of particle fluxes from thunderclouds, Astroparticle Physics 105 , 54(2019).

Reviewer #2 (Remarks to the Author):

I am satisfied with the authors' responses to my comments. I recommend publication.

Summary of changes made to the manuscript entitled "Gamma-ray Glow preceding Downward Terrestrial Gamma-ray Flash"

We deeply thank the referees for careful reading of our manuscript again. We have revised the manuscript by taking into account their comments.

Reviewer #1 (Remarks to the Author):

"As previous papers (Bowers et al. 2017, Enoto et al. 2017) observationally demonstrated, lightning discharges can produce neutrons via photonuclear reactions in the atmosphere. We consider that such atmospheric photonuclear reactions are triggered by intense and brief (less than milliseconds) gamma-ray burst. In short, we presume that a TGF-like sub-millisecond burst preceded the short burst (neutron component), and call the former 'downward TGF', separately from the 'short burst'."

This exotic scenario should be explained in more details. What is "downward TGF"? please, give an exact definition and exhausting description in the body of the manuscript.

We have added an additional explanation of downward TGFs "**They, now called ``downward TGFs'', share several features with TGFs observed from space, such as coincidence with lightning, sub-millisecond durations, and energy spectra extending to >10 MeV.**" in the introduction section.