Seasonal variations of meteorological characteristics of clouds producing enhancements of energetic particle flux

Svechnikova E.K., Mareev E.A., Ilin N.V.

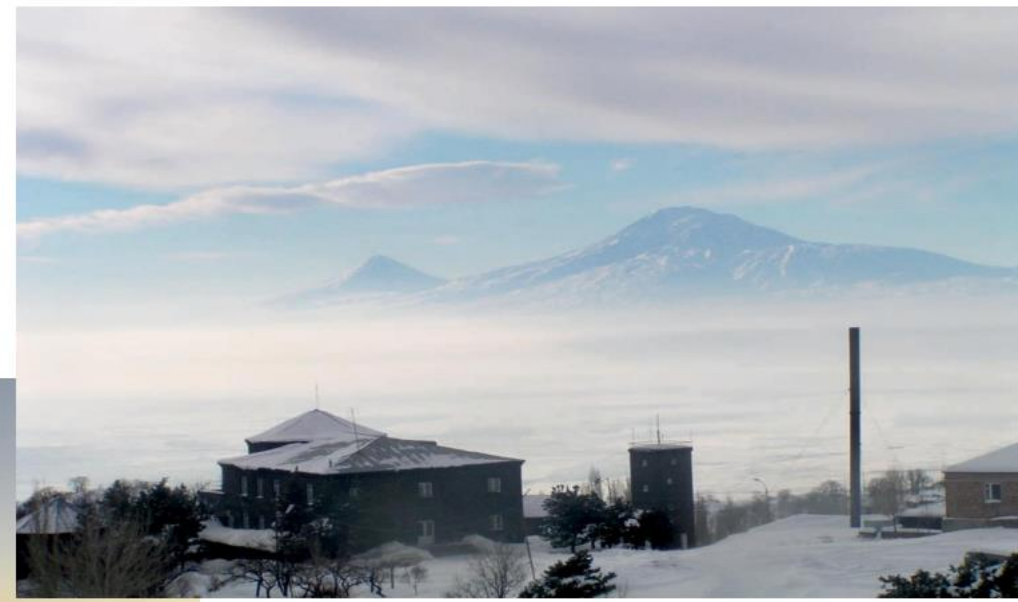
Institute of Applied Physics of the Russian Academy of Sciences (IAP RAS)

15.10.2019, TEPA-2019, Nor Amberd

Thunderstorm ground enhancements (TGEs)…
and **winter events of energetic particle flux enhancement**

Aragats Space Environmental Center

Aragats Station (Armenia, (40.4743N, 44.1806W), 3200 m a.s.l.)



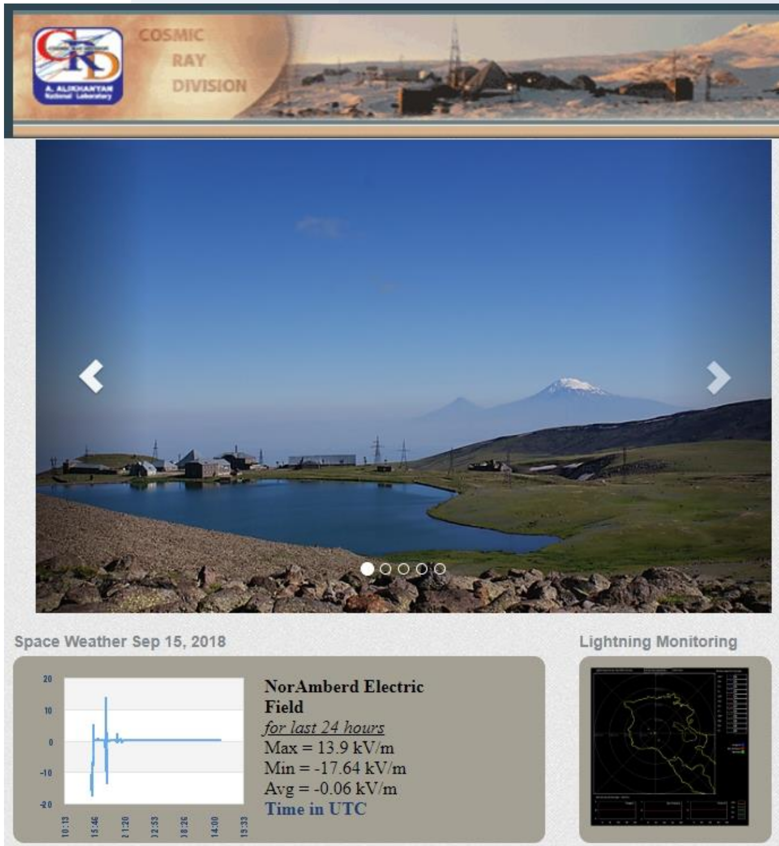
Near-ground values:

- **electric field**
- **energetic particle flux**

Outline

- Consideration of microphysics for understanding the TGE phenomenon.
- WRF-model for simulation of convective events.
- Clouds producing enhancements of energetic particle flux: typical features of “summer” and “winter” events.
- Comparison of the results with meteocharacteristics of clouds producing TGFs.

Motivation



Electric field and energetic particle flux disturbances

- **Mechanism of energetic processes in thunderstorms:**

  Relativistic runaway electron avalanche **(**RREA) ?

  Radon progenies ?

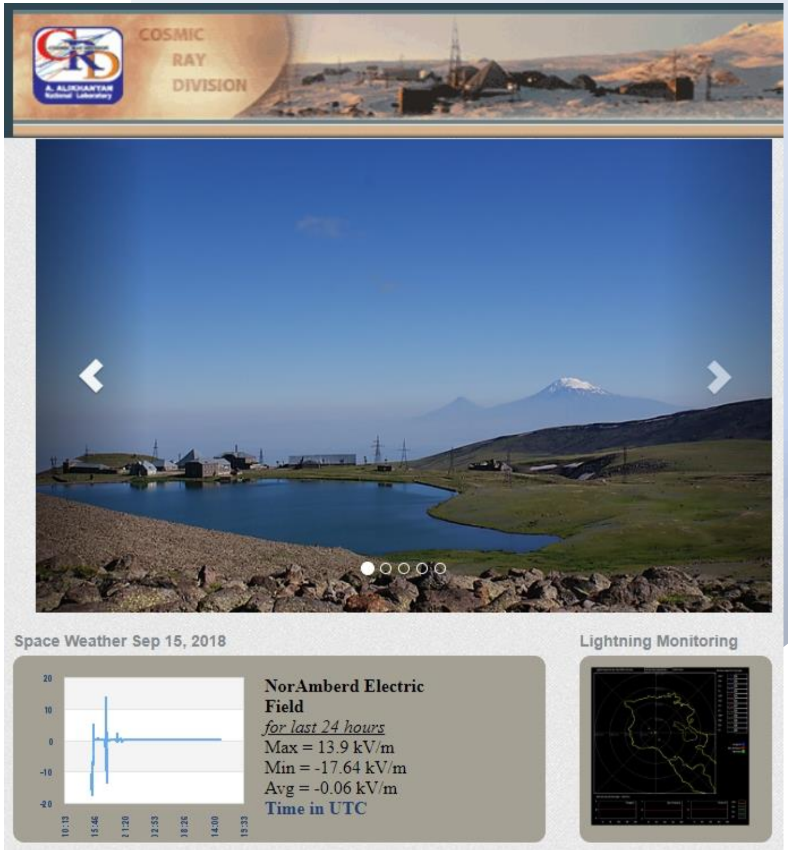
- **Structure of electric field in the cloud:**

  Parameters of avalanche development?

  Role of lower positive charge region?

  Conditions favorable for TGE development?

Motivation



Electric field and energetic particle flux disturbances

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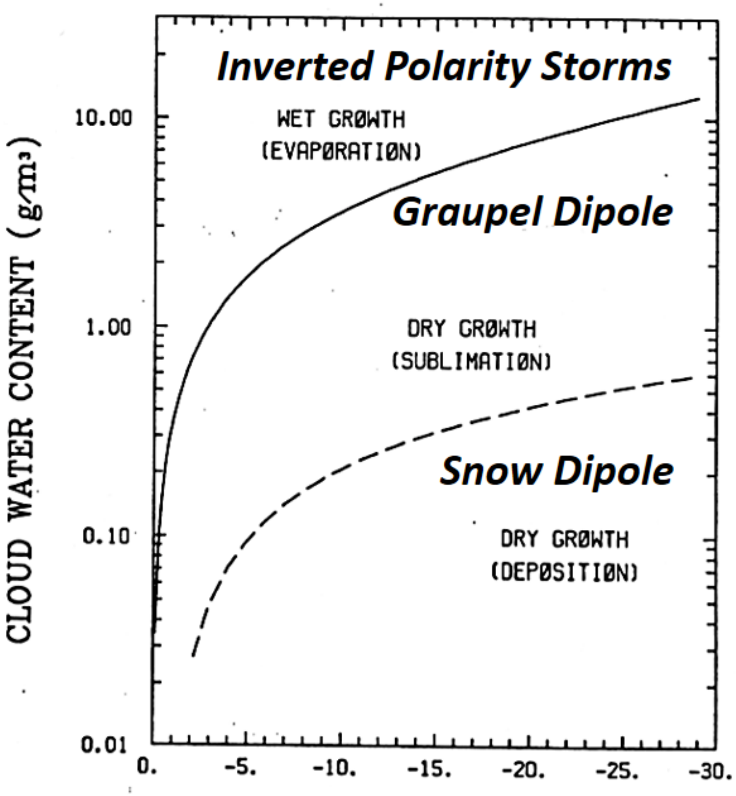
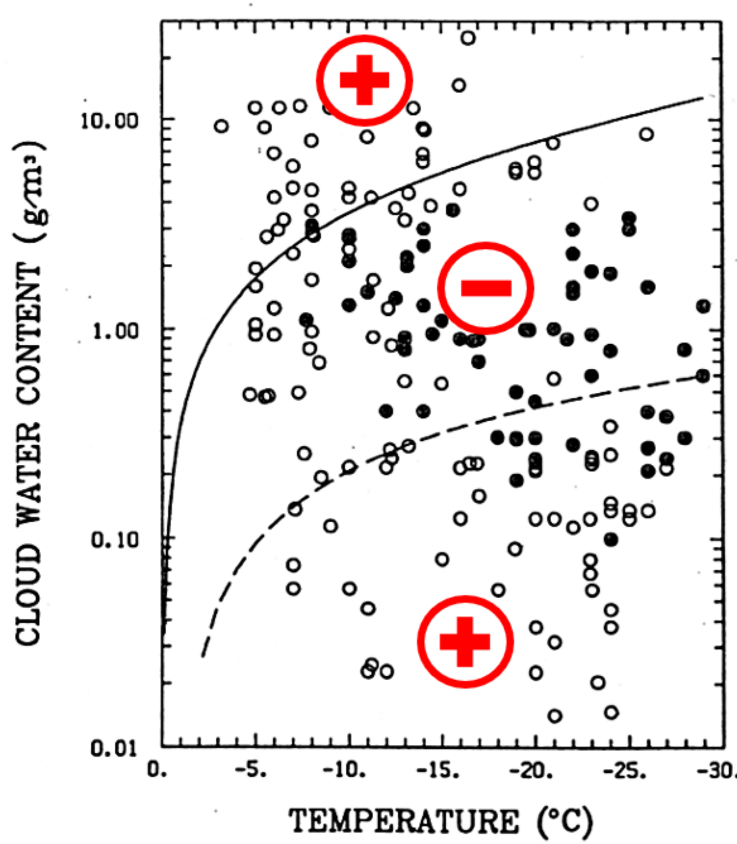
Object of the research: Distribution of cloud particles (hydrometeors) and aerosols

Microphysical bias of electrization processes



(Williams et al, 1991)



(Takahashi, 1978)

[Williams, 2019]

Weather Research and Forecasting Model

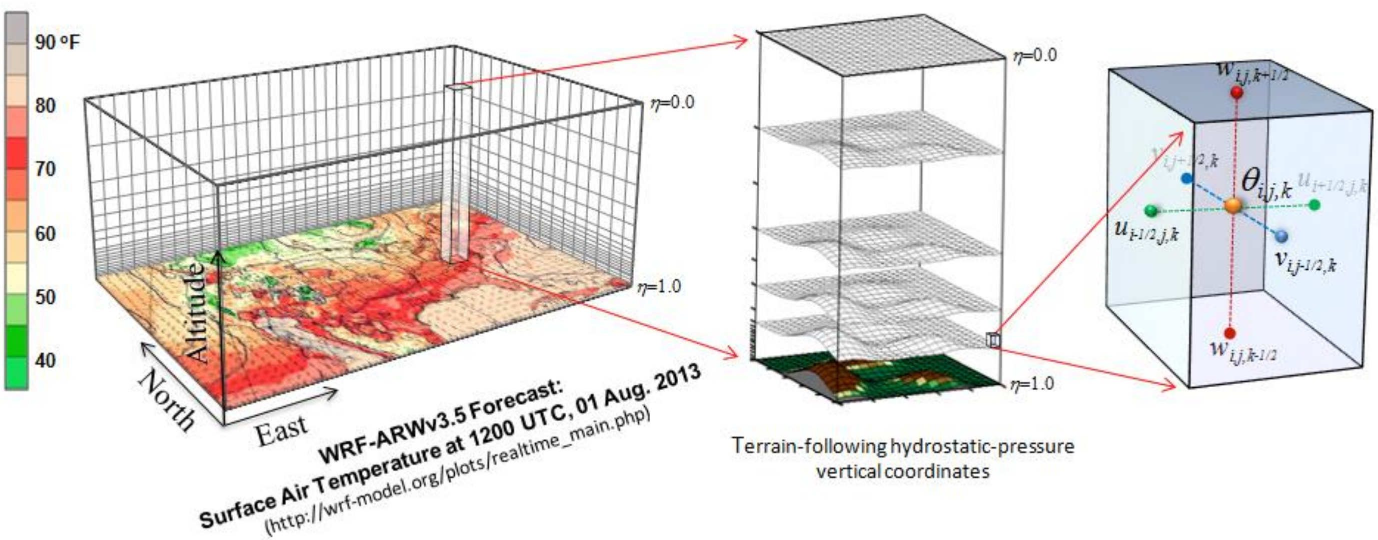
WRF – Open Source Project

- free software
- distributed development
- centralized support

WRF developers:

- **NCAR** (National Center of Atmospheric Research)
- **NOAA** (National Oceanic and Atmospheric Administration)
- **NCEP** (National Center of Environmental Prediction)
- **Universities**
- **other US government agencies**

- **Euler's non-hydrostatic equations for a fully compressible fluid**
- **High resolution (100 m - 10 km)**
- **Different models of cloud microphysics**
- **Initial and boundary conditions are necessary (global forecast models)**



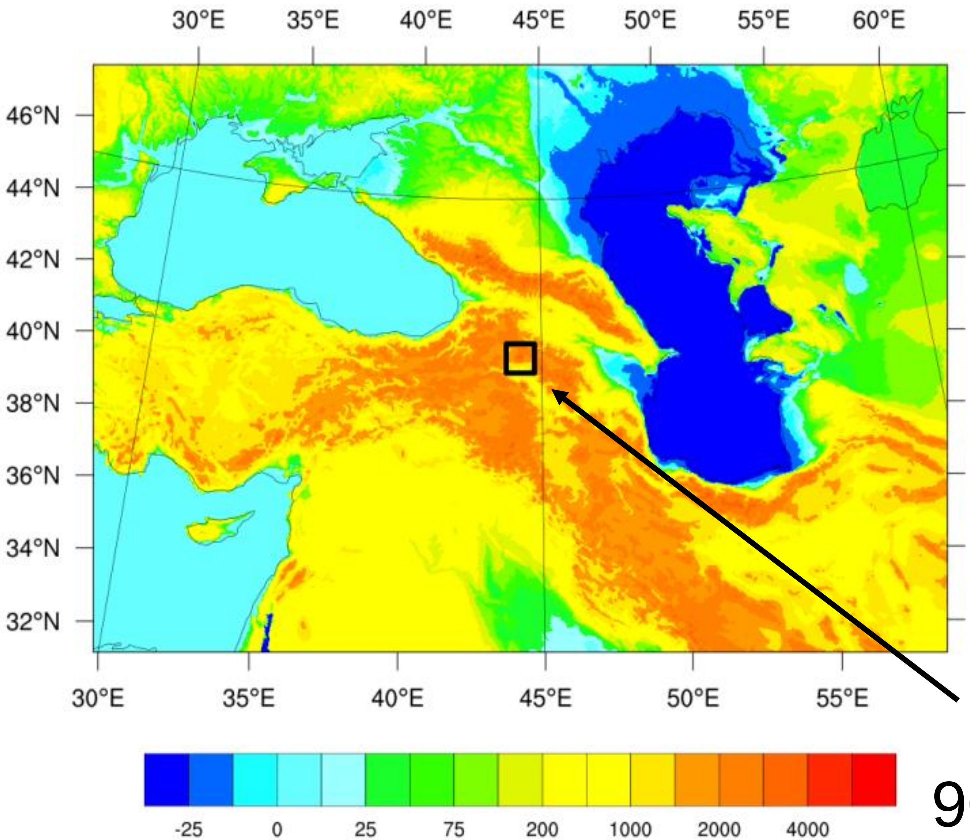
WRF for cloud dynamics consideration:

Pengguo Zhao, Yan Yin, Hui Xiao (2014) *"The effects of aerosol on development of thunderstorm electrification: A numerical study"*

Daniel T. Dawson II, Edward R. Mansell, Matthew R. Kumjian (2014) *"Does Wind Shear Cause Hydrometeor Size Sorting?"*

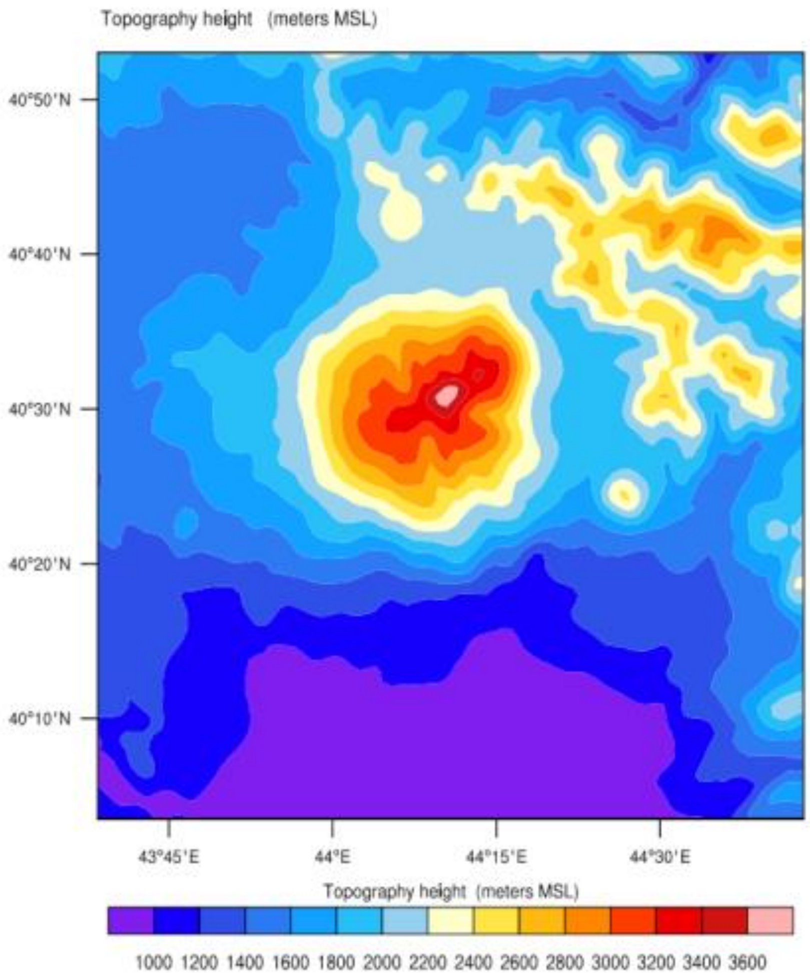
Two domain approach

The Weather Research and Forecasting (WRF) Model



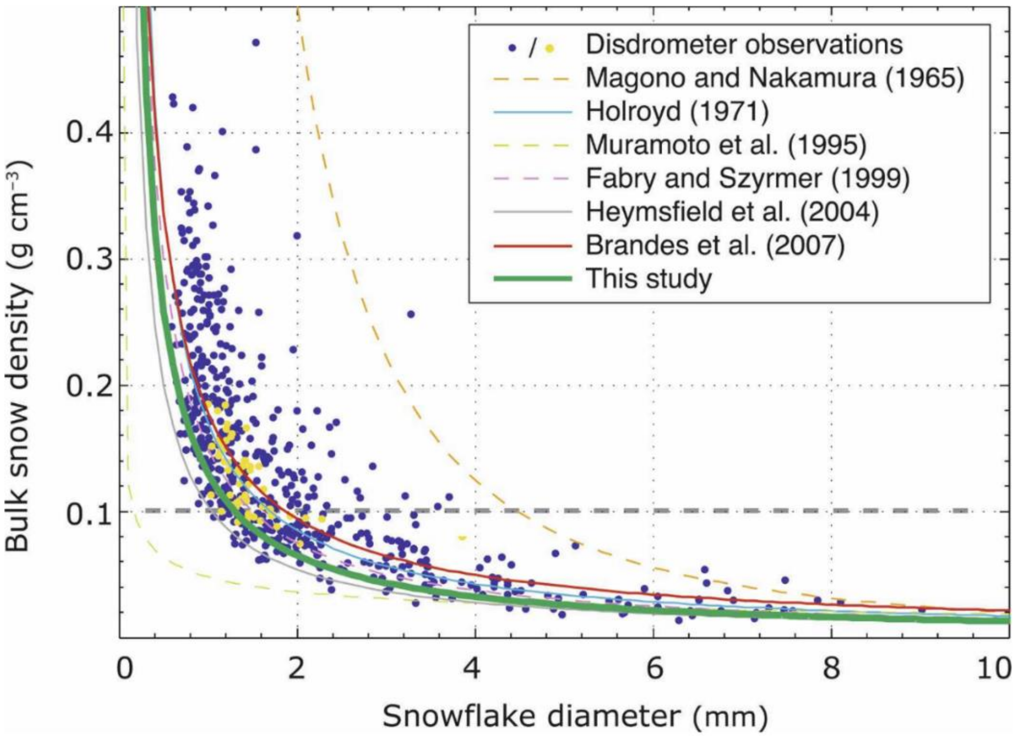
2700×1800 km

90×90 km



Microphysics: cloud particles types

Bulk distribution: one function of size



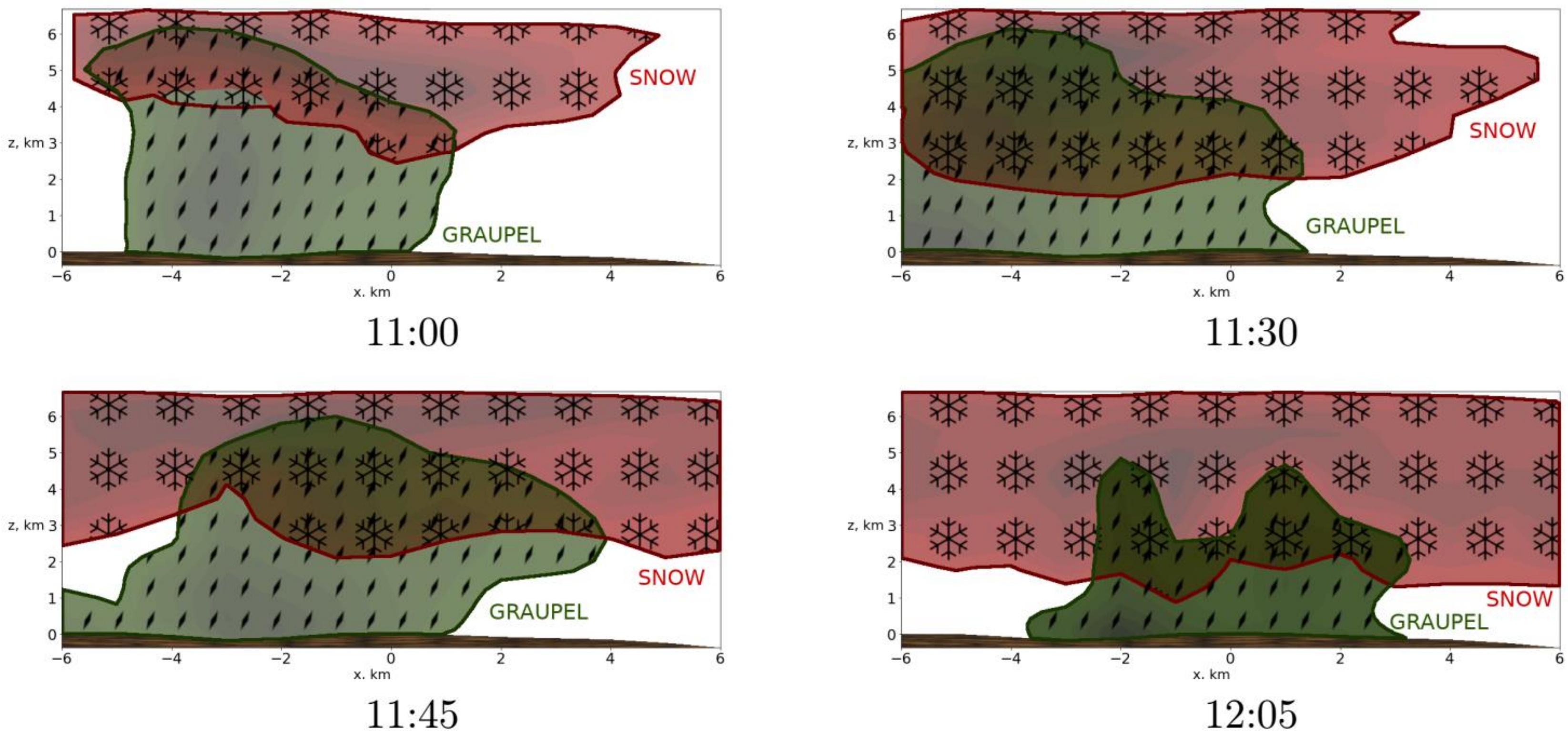
CLOUD	**< 50 µm**
RAIN	**> 500 µm**
ICE	**0.001 - 1000 µm**
SNOW	**< 10 mm**

Thompson Scheme Thompson, Gregory, Paul R. Field, Roy M. Rasmussen, William D. Hall, 2008: Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part II: Implementation of a New Snow Parameterization. *Mon. Wea. Rev.*, **136**, 5095–5115.

NSSL 2–moment Scheme Mansell, E. R., C. L. Ziegler, and E. C. Bruning, 2010: Simulated electrification of a small thunderstorm with two–moment bulk microphysics. *J. Atmos. Sci.*, 67, 171–194.

TGE event 2016-06-11: recovered hydrometeor distribution

For “summer events”: a cloud consists mainly of GRAUPEL and SNOW hydrometeors



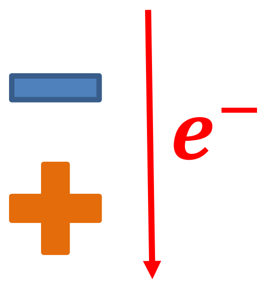
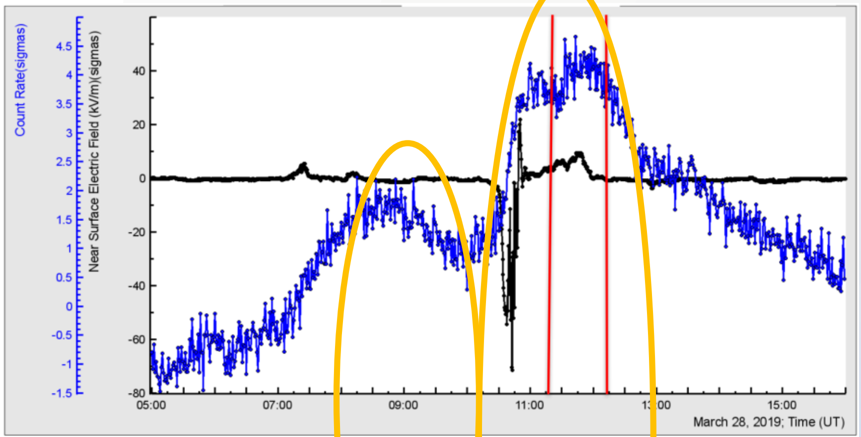


Figure 3: The spatial distribution of cloud particles in the densest clusters at the moments of its passage over the Station, recovered by WRF-modeling. Zero horizontal and vertical coordinate values corresponds to the location of the Station.

Typical cloud height: 0 – 6 km;
liquid water content: 0.0001 g/m^3 and more

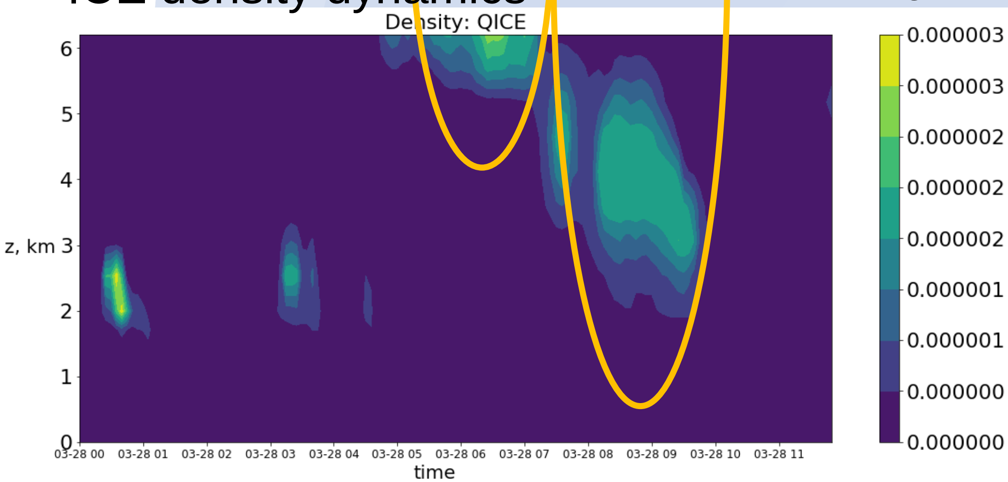
2019-03-28



Great correlation of dynamics of count rate and ice density, almost «ice-only» event!

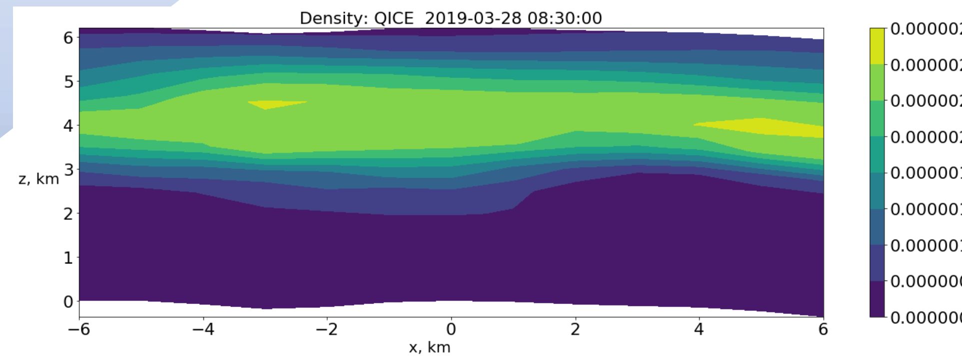
ICE density dynamics

g/m^3



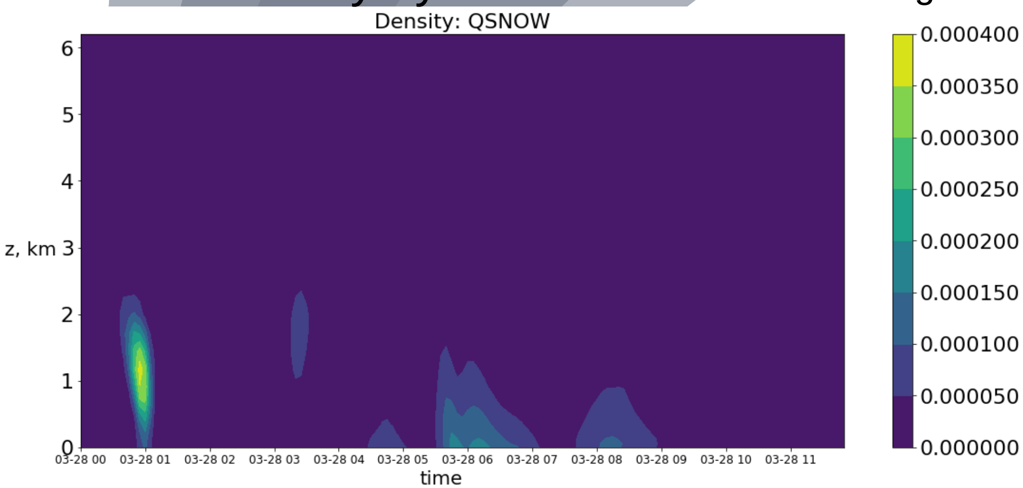
ICE density spatial distribution

g/m^3



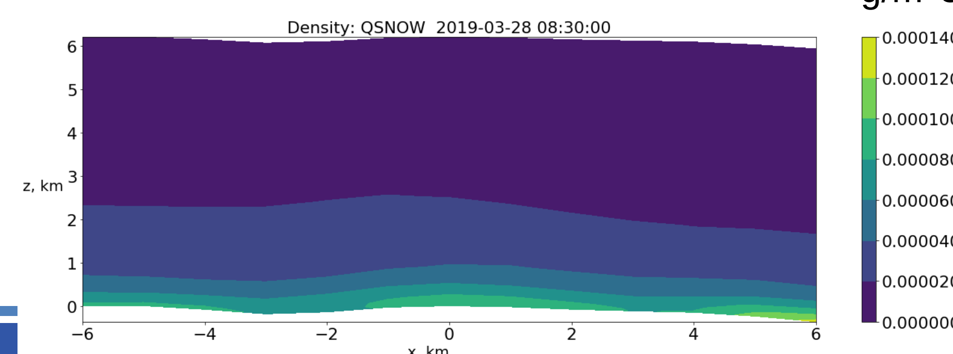
SNOW density dynamics

g/m^3



SNOW density spatial distribution

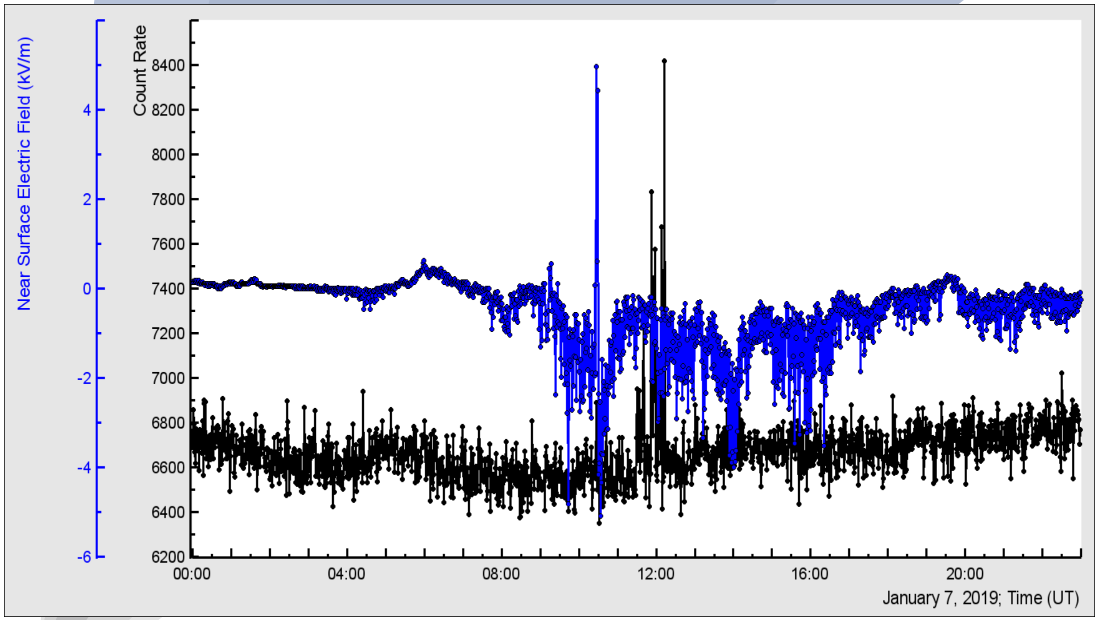
g/m^3



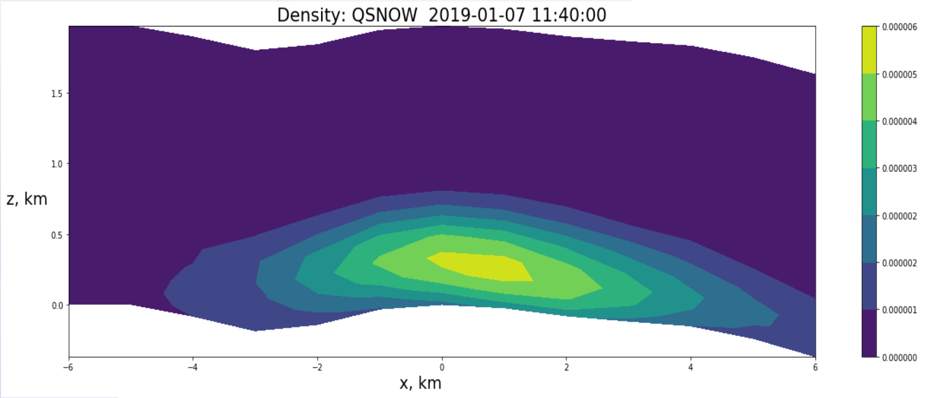
Winter event of flux enhancement: January 7, 2019

2019-01-07
Only GRAUPEL, ICE and SNOW particles are present above the Station.

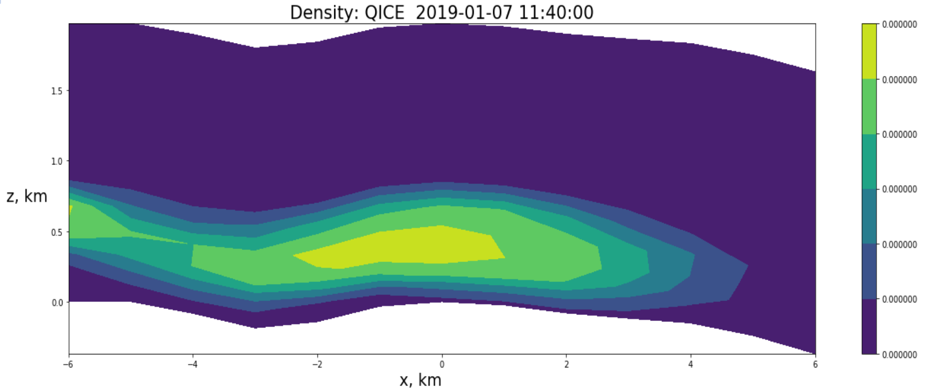
EUMETSAT data: cloud top height is about 0.5 — 1 km; before and after the event — higher, with **ice particles on cloud top**.



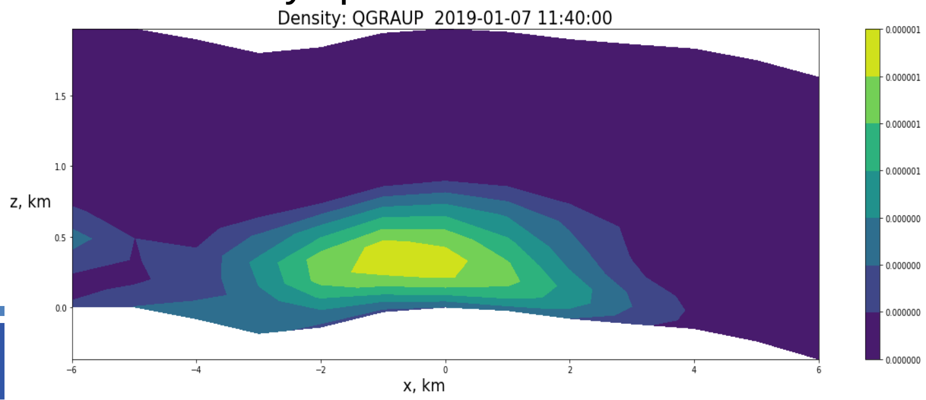
SNOW density spatial distribution



ICE density spatial distribution



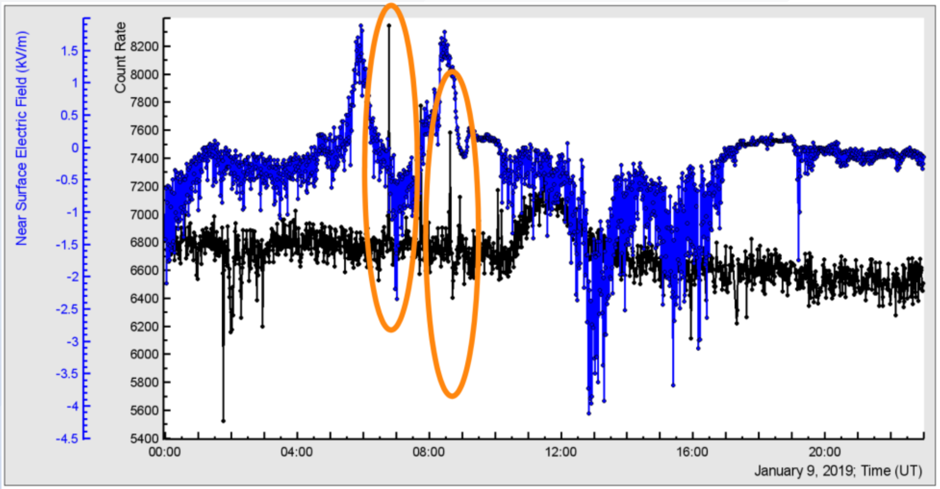
GRAUP density spatial distribution



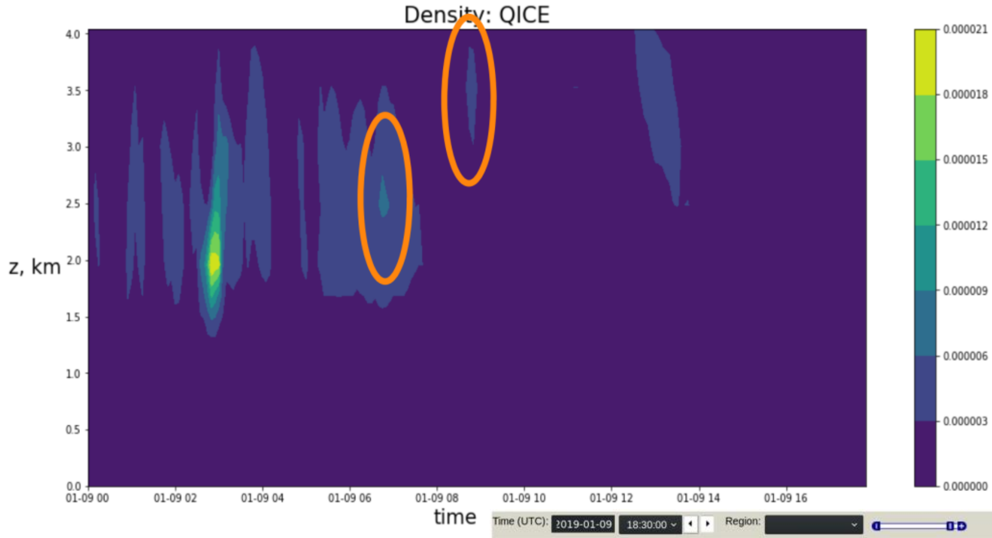
Winter event of flux enhancement: January 9, 2019

2019-01-09
All the count rate sharp increces show **an excellent correlation with SNOW- and ICE-clusters dynamics** (no significant GRAUPEL particles concentration)

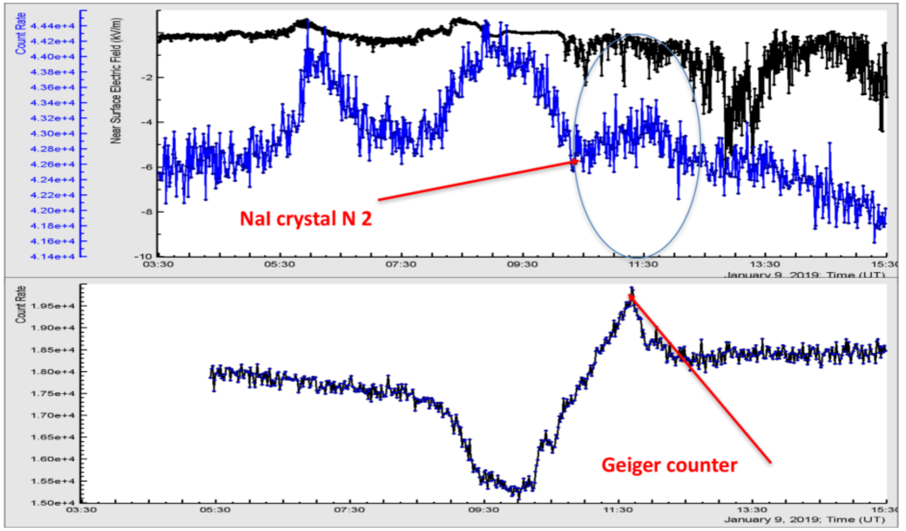
7:45 and 8:15 UT
Apparent correlation with ICE.
No significant SNOW-clusters!
11:30 «electron TGE»
Concentration of SNOW particles is two orders of magnitude greater than that of ICE.

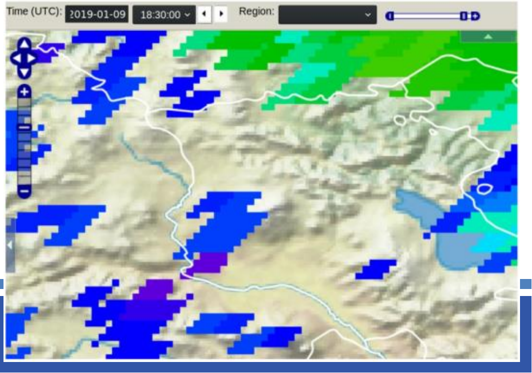


ICE density dynamics



Only NaI 2 registered small amount of gamma rays during "electron TGE"!



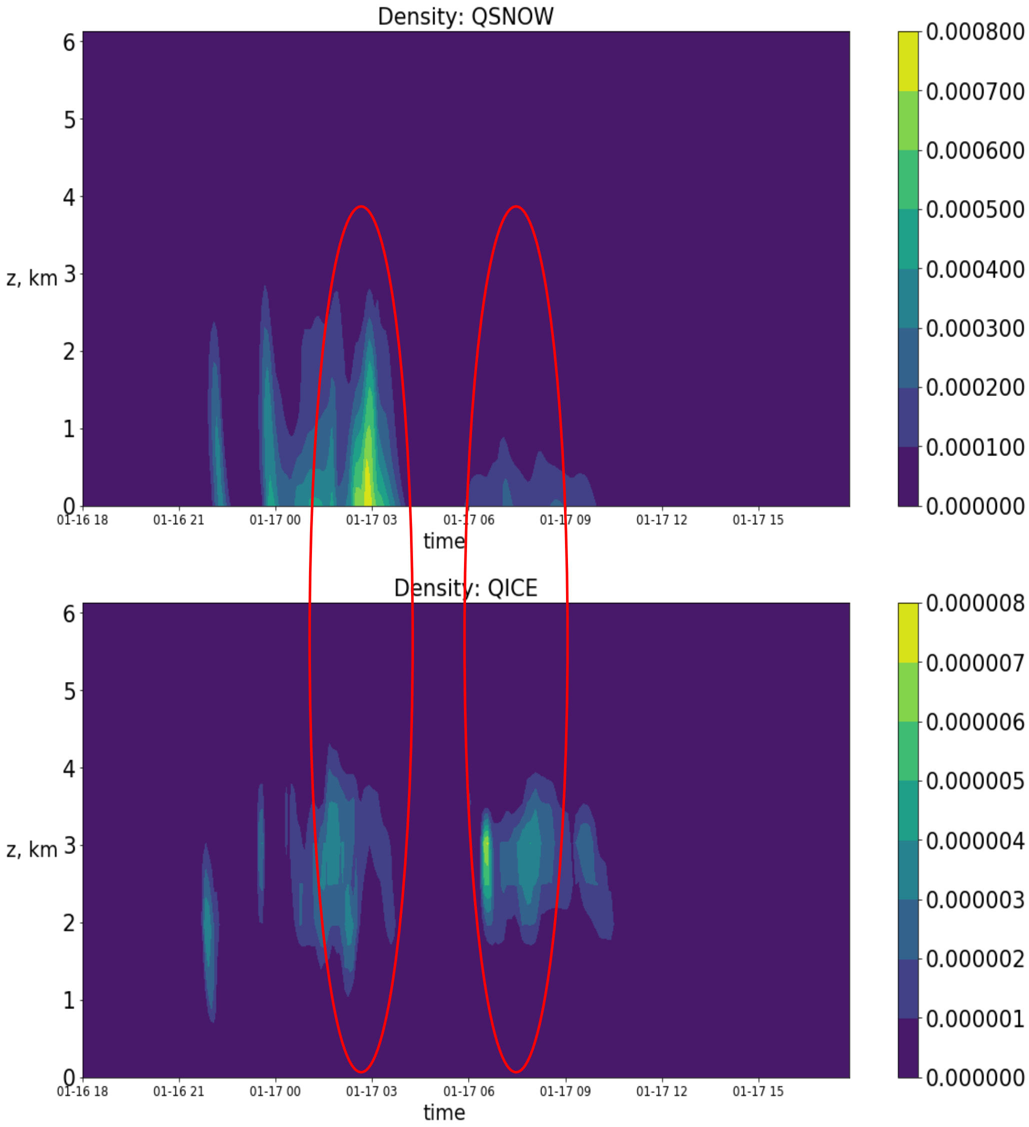


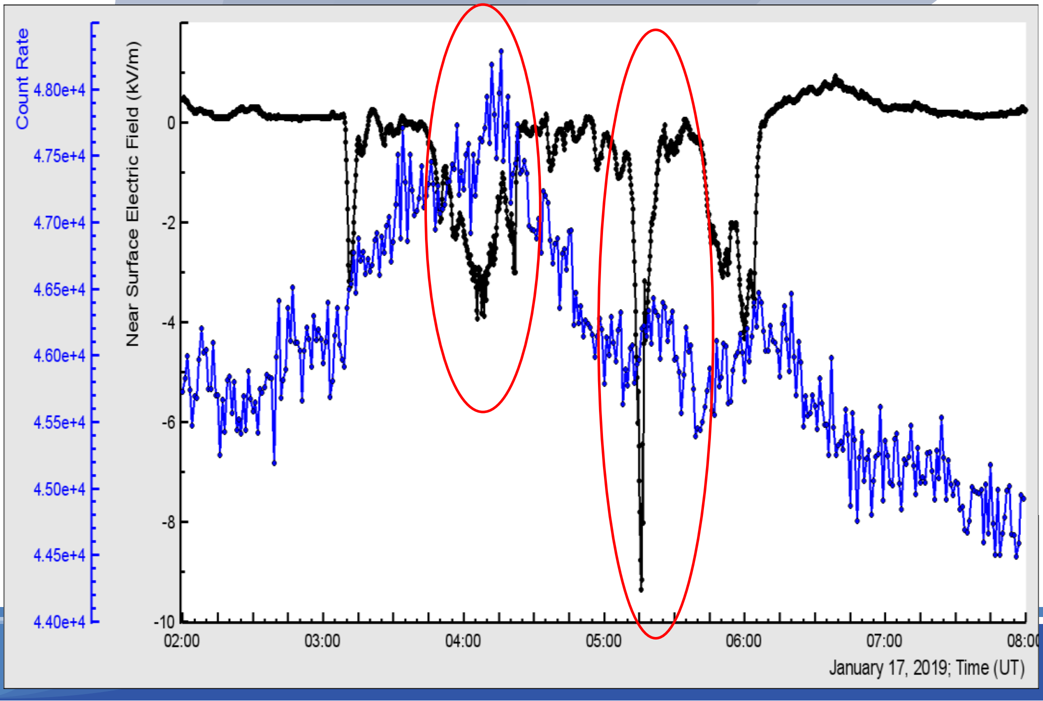
Winter event of flux enhancement: January 17, 2019

2019-01-17
Correlation with ICE-cluster dynamics!
(SNOW-cluster is located just above the ground, density of these particles is relatively low)

EUMETSAT: the top cloud height is about 4-5 km at the beginning of the event, then coming up to 10 km. Thin high level clouds at the beginning of the event are lately replaced by low- and mid-level clouds of snow. Thick, high and cold ice clouds are being replaced by thin mid-level clouds during the event.

Dynamics of SNOW and ICE density





Parameters of “summer” and “winter” events

Date of event	Count rate enhancement	Electric field, kV/m	Snow density mg/m^3	Graupel density mg/m^3	Ice density mg/m^3
2016-05-04	1.26	20	0.3	1.5	0.07
2016-05-11	1.15	15	2.0	1.0	0.02
2016-06-11	1.25	30	1.2	1.5	0.08
2016-07-28	1.38	25	1.2	0.5	0.005
2017-08-17	1.10	20	3.0	0.2	0.001
2017-09-29	1.14	15	2.0	0.2	0.002
2017-10-01	1.23	20	2.0	0.7	0.001
2017-10-10	1.19	20	1.5	0.3	less than 0.001

2019-01-07	1.15	5	0.06	less than 0.001	less than 0.001
2019-01-09	1.19	3	0.2	less than 0.001	0.005
2019-01-17	1.10	8	0.6	less than 0.001	0.002
2019-03-28	1.10	20	0.1	less than 0.001	0.002

Characteristic features of the winter events:

- ICE-density is significantly higher than in summer.
- Several events are caused by ICE-clusters only, without significant influence of other types of cloud particles.
- For some of events three types of hydrometeors are located in one and the same region.

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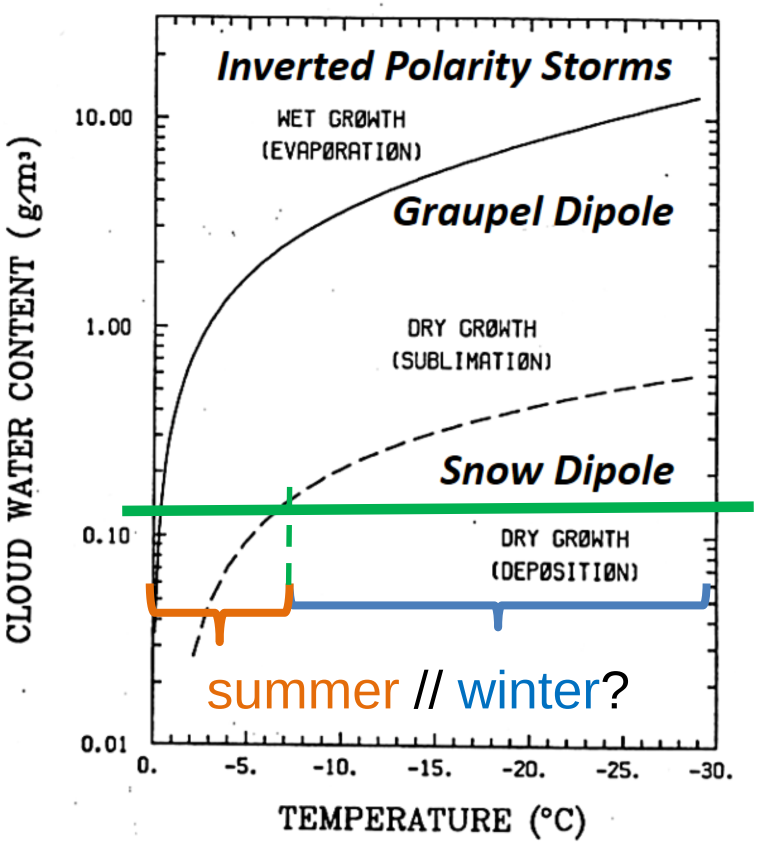
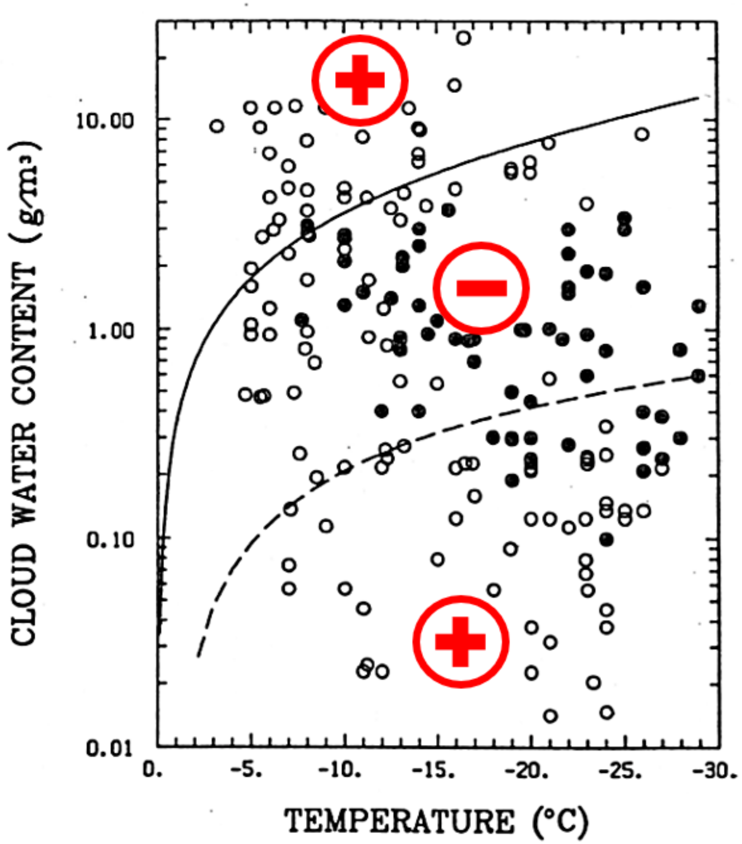
Microphysical bias of electrization processes



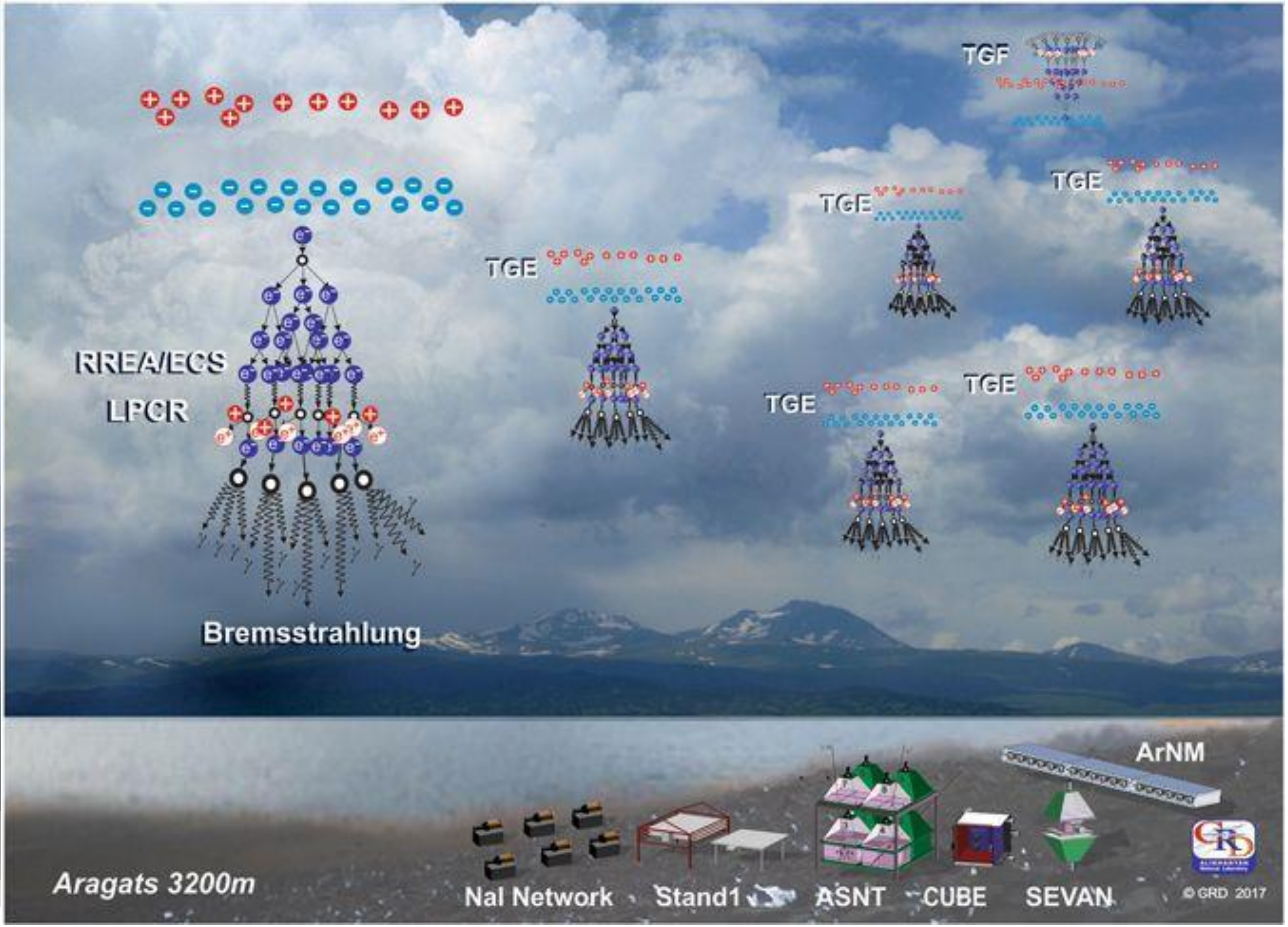
(Williams et al, 1991)



(Takahashi, 1978)

- ● Negative Rimer
- ○ Positive Rimer

TGFs (Terrestrial Gamma-ray Flashes) and TGEs (Thunderstorm Ground Enhancements)



High-energy atmospheric events and meteorological information: recent publication activity

Rendiconti Lincei. Scienze Fisiche e Naturali
https://doi.org/10.1007/s12210-019-00775-y

A DECADE OF AGILE

Check for updates

Gamma ray storms: preliminary meteorological analysis of AGILE TGFs

Meteorology of AGILE TGF observations

Alessandra Tiberia[1] · Stefano Dietrich[2] · Federico Porcù[3] · Martino Marisaldi[4] · Alessandro Ursi[5] · Marco Tavani[5]

Received: 26 July 2018 / Accepted: 21 January 2019

Characteristics of Thunderstorms that produce Terrestrial Gamma-ray Flashes

Article in Bulletin of the American Meteorological Society · July 2015
DOI: 10.1175/BAMS-D-14-00239.1

XV International Conference on Atmospheric Electricity, 15-20 June 2014, Norman, Oklahoma, U.S.A.

Gamma-rays Associated with Nearby Thunderstorms at Ground Level

Rebecca Ringuette*, Michael L. Cherry, Douglas Granger, T. Gregory Guzik, Michael Stewart, John P. Wefel

Dept. of Physics & Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA

SCIENTIFIC REPORTS

OPEN

Thunderstorm charge structures producing gigantic jets

Levi D. Boggs[1], Ningyu Liu[2], Jeremy A. Riousset[1], Feng Shi[2], Steven Lazarus[3], Michael Splitt[4] & Hamid K. Rassoul[1]

Received: 23 February 2018
Accepted: 16 November 2018

Gigantic jets are atmospheric electrical discharges that propagate from the top of thunderclouds to the lower ionosphere. They begin as lightning leaders inside the thundercloud, and the thundercloud

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, A00E38, doi:10.1029/2009JA014622, 2010

Click Here for Full Article

Thunderstorm characteristics associated with RHESSI identified terrestrial gamma ray flashes

M. E. Splitt,[1] S. M. Lazarus,[1] D. Barnes,[1] J. R. Dwyer,[1] H. K. Rassoul,[1] D. M. Smith,[2] B. Hazelton,[2] and B. Grefenstette[2]

Received 3 July 2009; revised 28 November 2009; accepted 12 January 2010; published 23 June 2010.

A pipeline to link meteorological information and TGFs detected by AGILE

A. Ursi,[1,2] P. Sanò,[3] D. Casella,[3] M. Marisaldi,[4,5] S. Dietrich,[3] and M. Tavani[1]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, A00E49, doi:10.1029/2009JA014853, 2010

Terrestrial gamma ray flashes correlated to storm phase and tropopause height

D. M. Smith,[1] B. J. Hazelton,[1] B. W. Grefenstette,[1] J. R. Dwyer,[2] R. H. Holzworth,[3] and E. H. Lay[4]

Received 31 August 2009; revised 13 November 2009; accepted 4 January 2010; published 4 August 2010.

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2014JD021495

Key Points:
- Hydrometeor characteristics of TGF thunderstorms
- Hydrometeor characteristics of non-TGF storms
- TGF-related storms have higher hydrometeor content

A study of thunderstorm microphysical properties and lightning flash counts associated with terrestrial gamma-ray flashes

D. E. Barnes[1], M. E. Splitt[2], J. R. Dwyer[3], S. Lazarus[2], D. M. Smith[4,5], and H. K. Rassoul[1]

[1]Geospace Physics Laboratory, Physics and Space Science Department, Florida Institute of Technology, Melbourne, Florida, USA, [2]Department of Marine and Environmental Sciences, Florida Institute of Technology, Melbourne, Florida, USA, [3]Space Science Center (EOS) and Department of Physics, University of New Hampshire, Durham, New Hampshire, USA, [4]Santa Cruz Institute for Particle Physics and Physics Department, University of California, Santa Cruz, California, USA, [5]Space Sciences Laboratory, University of California, Berkeley, California, USA

A study of thunderstorm microphysical properties and lightning flash counts associated with terrestrial gamma-ray flashes

April 2015 Journal of Geophysical Research: Atmospheres
D. E. Barnes, M. E. Splitt, J. R. Dwyer, S. Lazarus, D. M. Smith, and H. K. Rassoul

Temporal and spatial coincident satellite passes between the Reuven Ramaty High Energy Solar Spectroscopic Imager and the Tropical Rainfall Measuring Mission

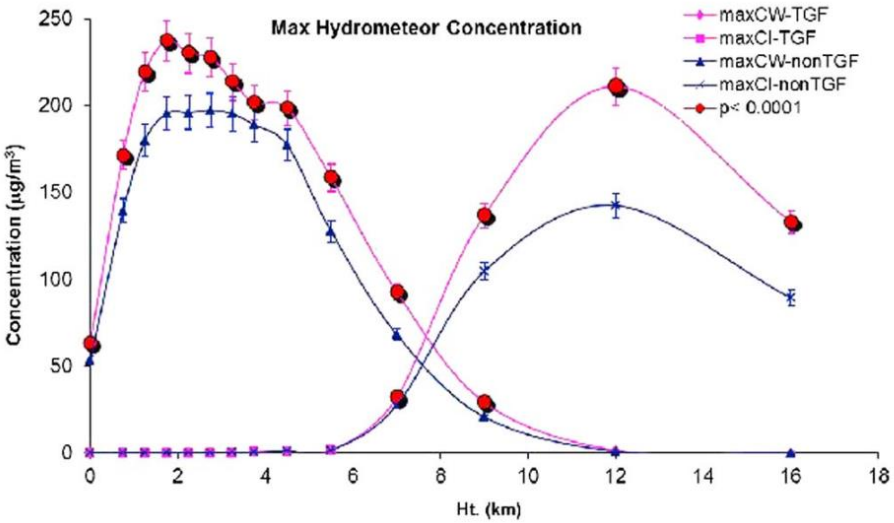


Figure 5. Maximum hydrometeor cloud water and cloud ice distribution of TGF and non-TGF cases referenced to geolocation. Statistically independent data represented by red filled circular overlays.

The TGF stands out dramatically from the non-TGF case for both CW and CI concentrations. The issues are that TGFs are more likely to be observed when there are a higher number of flashes and hence higher hydrometeor content.

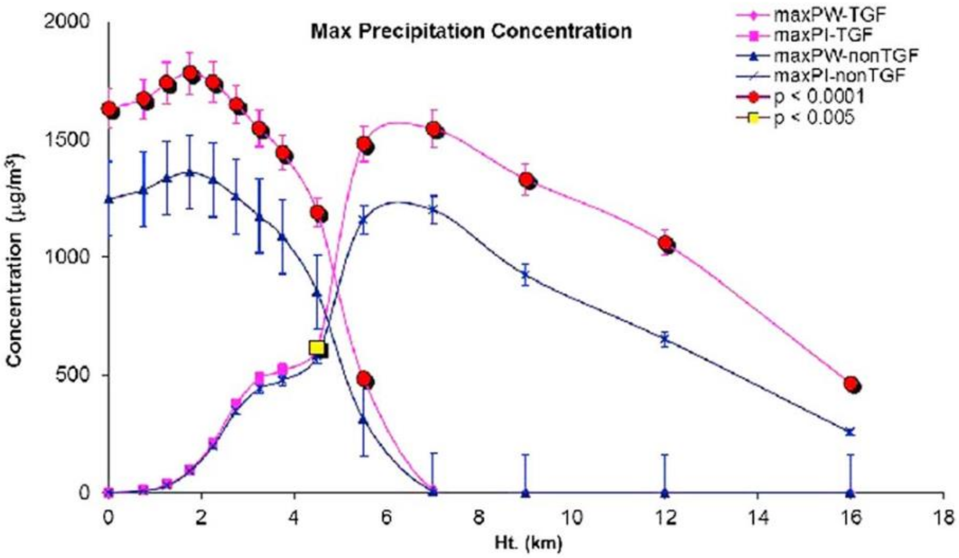


Figure 6. Maximum precipitation water and precipitation ice distribution of TGF and non-TGF cases referenced to geolocation. Statistically independent data represented by red filled circular and yellow filled square overlays.

Meteocharacteristic of TGF and TGE phenomena

- **Terrestrial Gamma-ray Flashes occurrence:**
- at an altitude of about 13 - 17 km
- within the maximum of flash rate or just after it
- in storms with size and convective strength in a wide range
- in the thunderclouds with relatively high liquid water content and ice content (lower bound of liquid density is VILD=0.54 g/m^3)

Observation bias: the selection bias toward the highest-altitude TGFs

Splitt M. et.al., 2010, JGR Atm. 115(A6), DOI: 10.1029/2009JA014622
Smith D. et.al., 2010, JGR Atm. 115, DOI: 10.1029/2009JA014853
Barnes D. et.al., 2015, JGR Atm.. 120, DOI: 10.1002/2014JD21495
Chronis T. et al., 2016, Bull. Amer. Meteor. Soc., 639, DOI: 10.1175/BAMS-D-14-00239.1
Tiberia A. et al., 2019, Rendiconti Lincei. Scienze Fisiche e Naturali, DOI: 10.1007/s12210-019-00775-y

- **Thunderstorm ground enhancements development:**
- at an altitude of about 0 - 6 km
- are usually terminated by a lightning flash, but sometimes may precede it; could occur without any lightning activity
- in storms with size and convective strength in a wide range
- in the thunderclouds with relatively high liquid water content and ice content (lower bound of liquid water content is 0.001 g/m^3)

Observation bias: low clouds (mountainous station) is needed

Conclusions

- Energetic particle flux enhancements occur in storms with size and convective strength in a wide range.
- Flux enhancements tend to occur in clouds with relatively high liquid water content.
- Clouds producing TGEs ("summer" events) have charges mainly on graupel and snow hydrometeors.
- Density of ice hydrometeors is significantly higher for winter events. (For several winter events electric field disturbance is caused by ice clusters only.)

Thank you !