Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure
and Water Management*

applications of GOES-GLM data at KNMI

Jos de Laat

Christian Wentink, Jasper Wijnands, Albert Jacobs

KNMI GEOWEB team
KNMI EWC team

Cor Veerman (Univ. Leiden)
Omid Tajalizdekhoob (Univ. Leiden, MSc student)

KNMI

(Royal) National Weather Service

hybrid operational and R&D institute with several research labs

strong background in Earth Observation; (co-) Principal Investigator of OMI, TROPOMI (Sentinel-5p), scatterometers & OSI SAF winds, space lidars (EarthCare, ADM-Aeolus)

Jos de Laat

senior scientist

KNMI R&D Satellite Observations (15+ years; 20+ years in EO; weather & climate scientist by training)

- national contact point AI/ML roadmap EUMETSAT

- contributed to EUMETSAT AI/ML Road Map [2022]

- co-author KNMI AI/ML strategy [2023]

- WMO "ad-hoc" task team "satellite nowcasting Africa" & white paper [2022]

- much more …

OUTLINE

context	• KNMI & GOES Global Lightning Mapper (GLM)
first results	• visualization • cases for discussing with KNMI weather forecasters • comparison with current use of lightning data by KNMI weather forecasters
added value	• short term prediction • nowcasting

next steps	• implementation
	• application development examples
	    o AI/ML near-real-time prediction
	    o auto-METAR
	    o KNMI Early Warning Center convective cell tracking & warnings

KNMI & GOES Global Lightning Imager: how it started …

motivation

KNMI "activity" development & deployment of satellite applications for operational weather forecasting

goals

- improve use of rapidly growing Earth Observation data in operational weather forecasting
- translate data into information (strong involvement by operational meteorologists)
- preparation for MTG

pilot projects (2020-now)

1. 2EWC   near-real-time scatterometer wind deviations from NWP model forecasts
2. SIMSAT   NWP model RGB's
3. GOES-GLM   lightning

GOES GLM lightning context for KNMI

- KNMI responsibility for Dutch overseas Carribean territories (incl. METAR)

- KNMI provides weather forecasts for Carribean islands Bonaire, Sint Eustatius, Saba (BES islands)

- last 10 years: develop "remote" volcanic observatory (St. Eustatius and Saba are volcanic)

- GOES/GLM already operational

- MTG readiness

- GeoWeb data portal (next generation KNMI web-based tooling for monitoring the atmosphere)

- KNMI started developing Early Warning Center (GeoWeb - based)

- KNMI Artificial Intelligence/Machine Learning strategy

GOES GLM lightning

KNMI **SATE** project: explore use of GLM data for weather applications (BES)

activities within project:

- explore literature, training, manuals, applications
- what data and information is available
- what is most useful for operational weather monitoring and forecasting

- where find operational GLM data
- obtain data, download options
- (Python) scripts for downloading & reading & processing data

- explore visualizations of data and information
- compare with existing source of lightning information

GOES GLM lightning

"first light" downloading, reading & visualizing data … (2019 day 240 = 28 August)

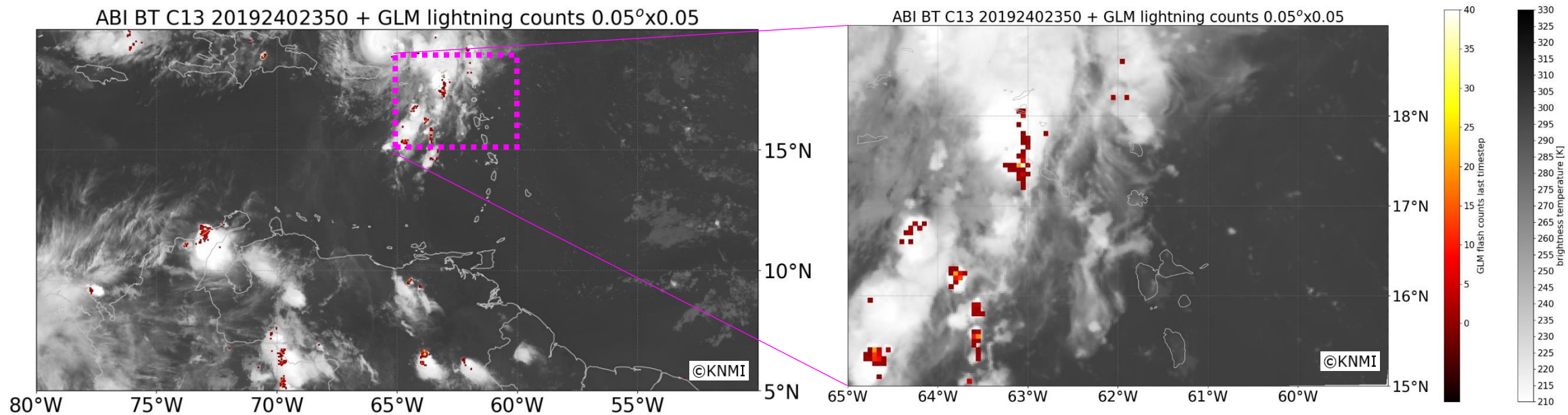Global Lightning Mapper lightning locations 2019240
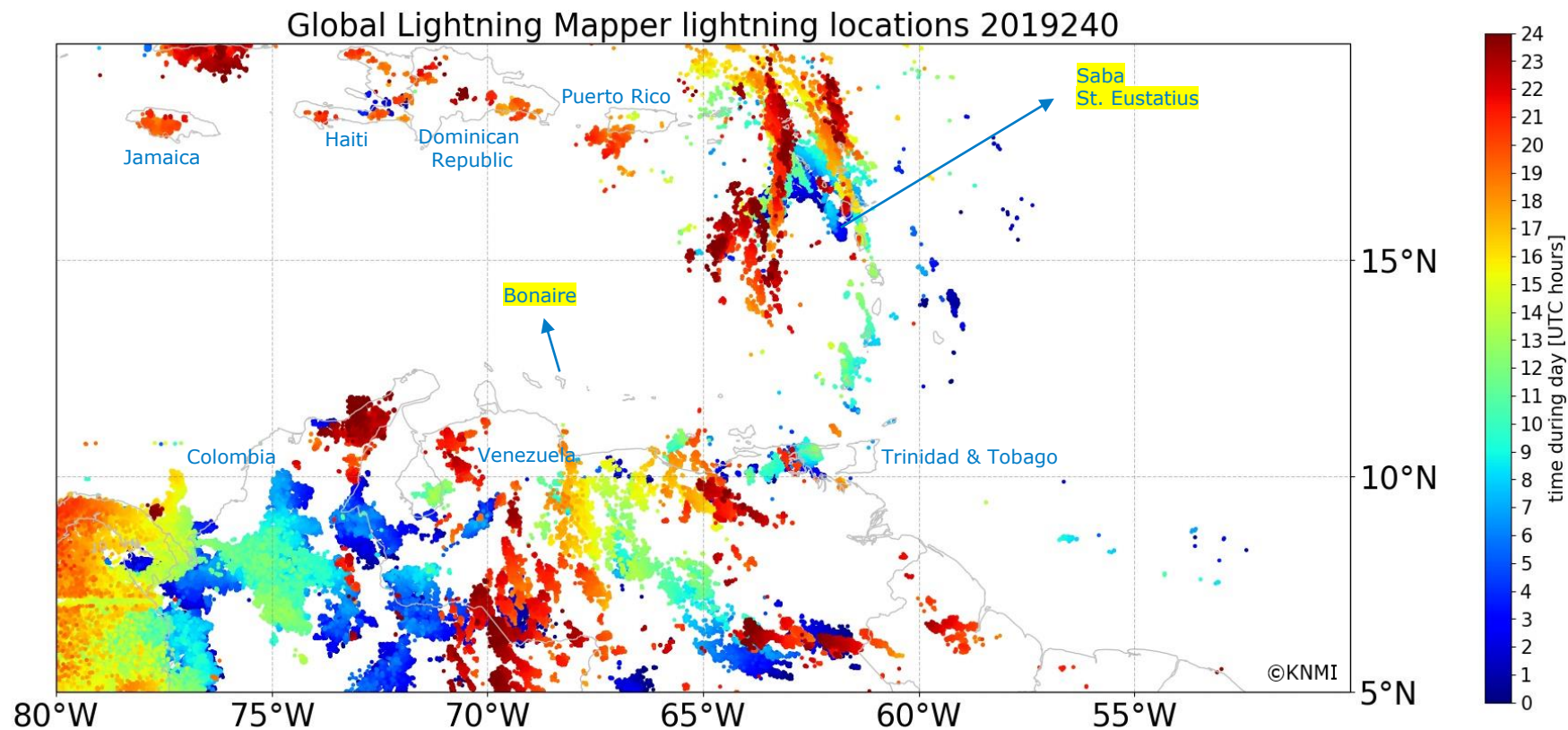
GOES GLM lightning comparison with existing lightning information sources
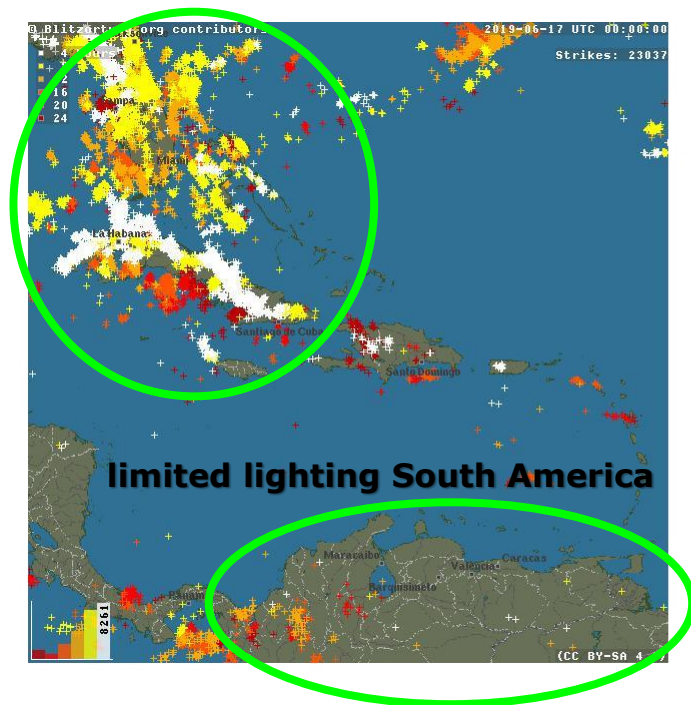
BlitzOrtung

Python-generated BlitzOrtung emulation

note: more research is needed to identify the cause of the lack of lightning over South America in BlitzOrtung

data exploration & combining data

"heat map" or flash extent density (gridded) ©KNMI

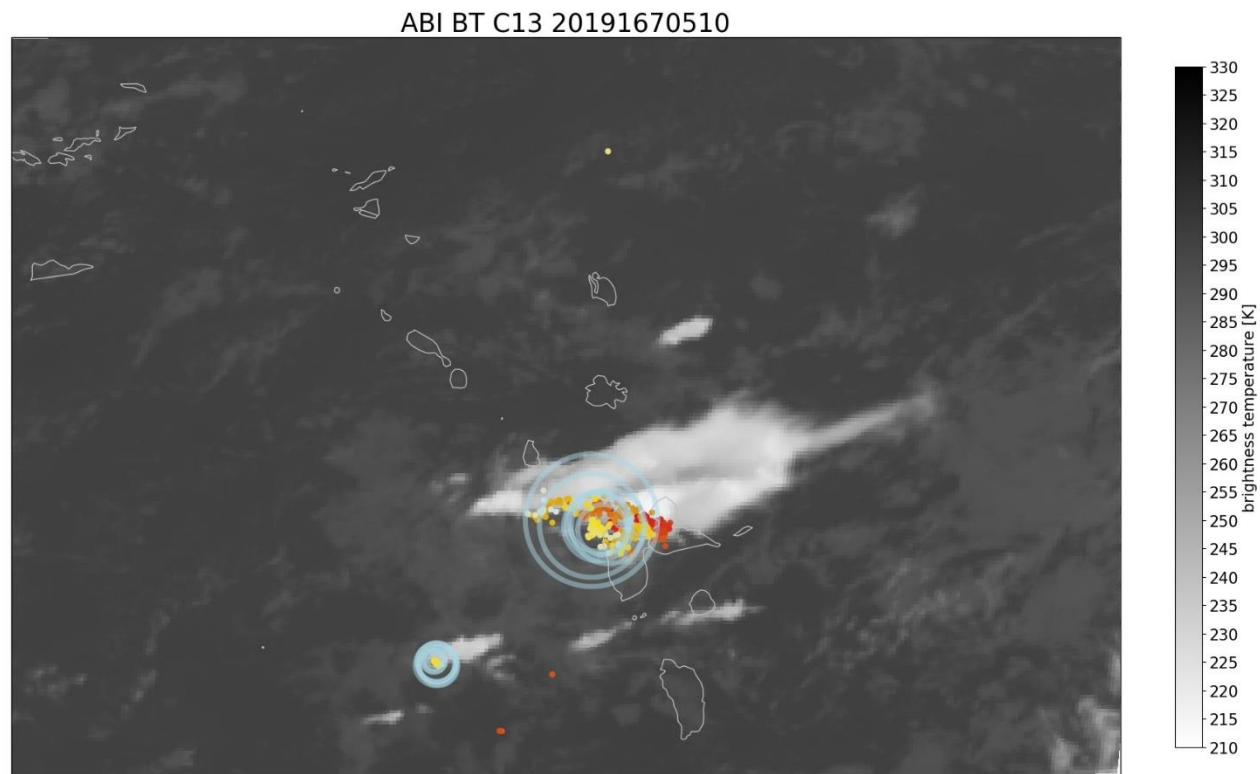GLM number of flashes per 0.05° grid within last 10 minutes, combined with ABI 10.3 µm

GOES GLM lightning visualization example: combine 3 types of information

Flashes last 10 minutes (blue; circles indicate flash "area" coverage)

Flashes last 2 hours (colors: red to yellow with red most recent)
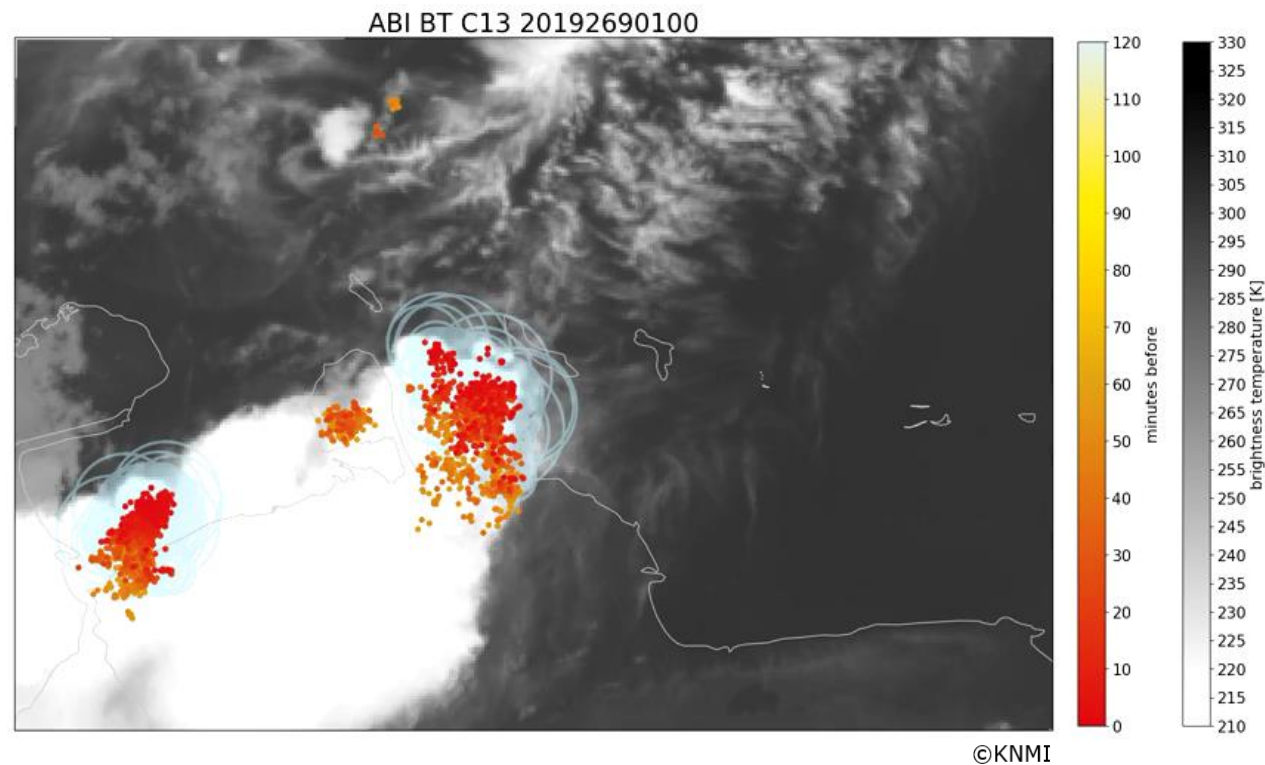
ABI 10.3 µm brightness temperatures

ABI BT C13 20191670510

©KNMI

GOES GLM lightning animations

Flashes last 10 minutes (blue; circles indicate flash area coverage)

Flashes last 2 hours (colors: red to yellow with yellow most recent)

ABI 10.3 µm brightness temperatures

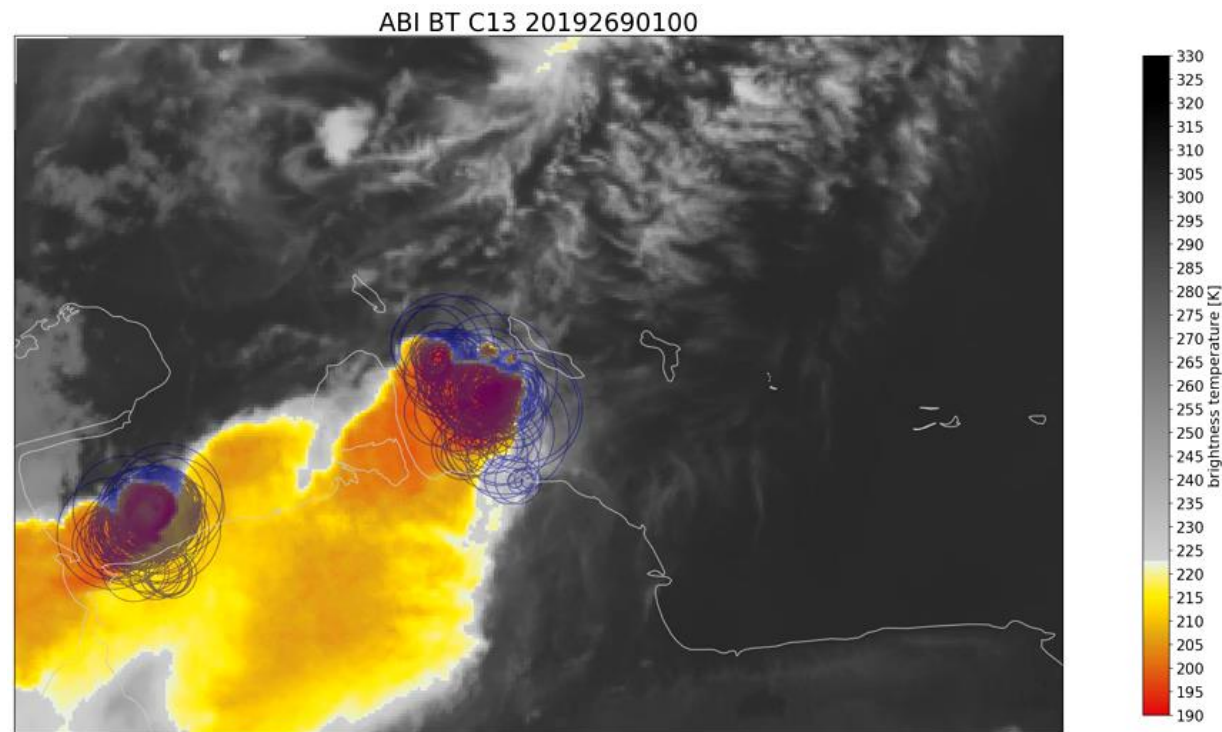ABI BT C13 20192690100

©KNMI

GOES GLM lightning animations

Flashes last 10 minutes (blue; circles indicate flash area coverage)

ABI µm micron BT (colors: yellow to red 223K (-50°C) to 190K)
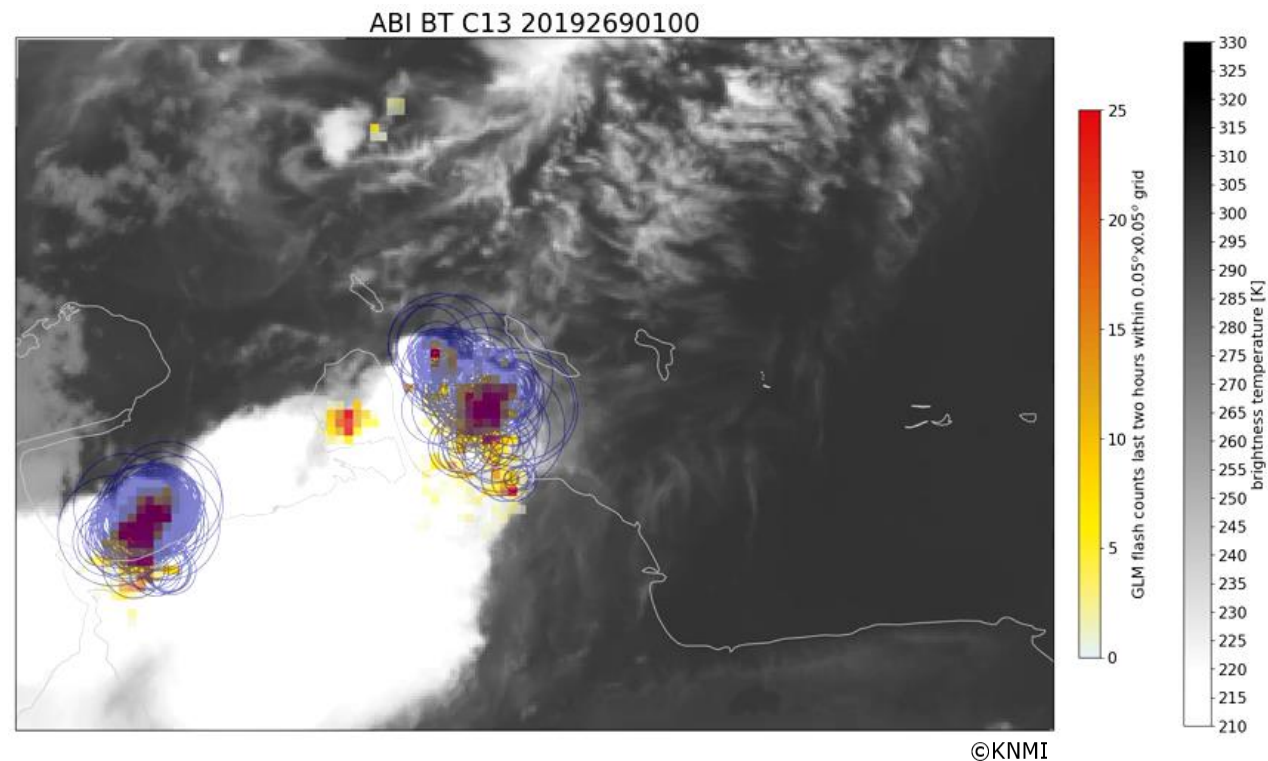

©KNMI

GOES GLM lightning animations

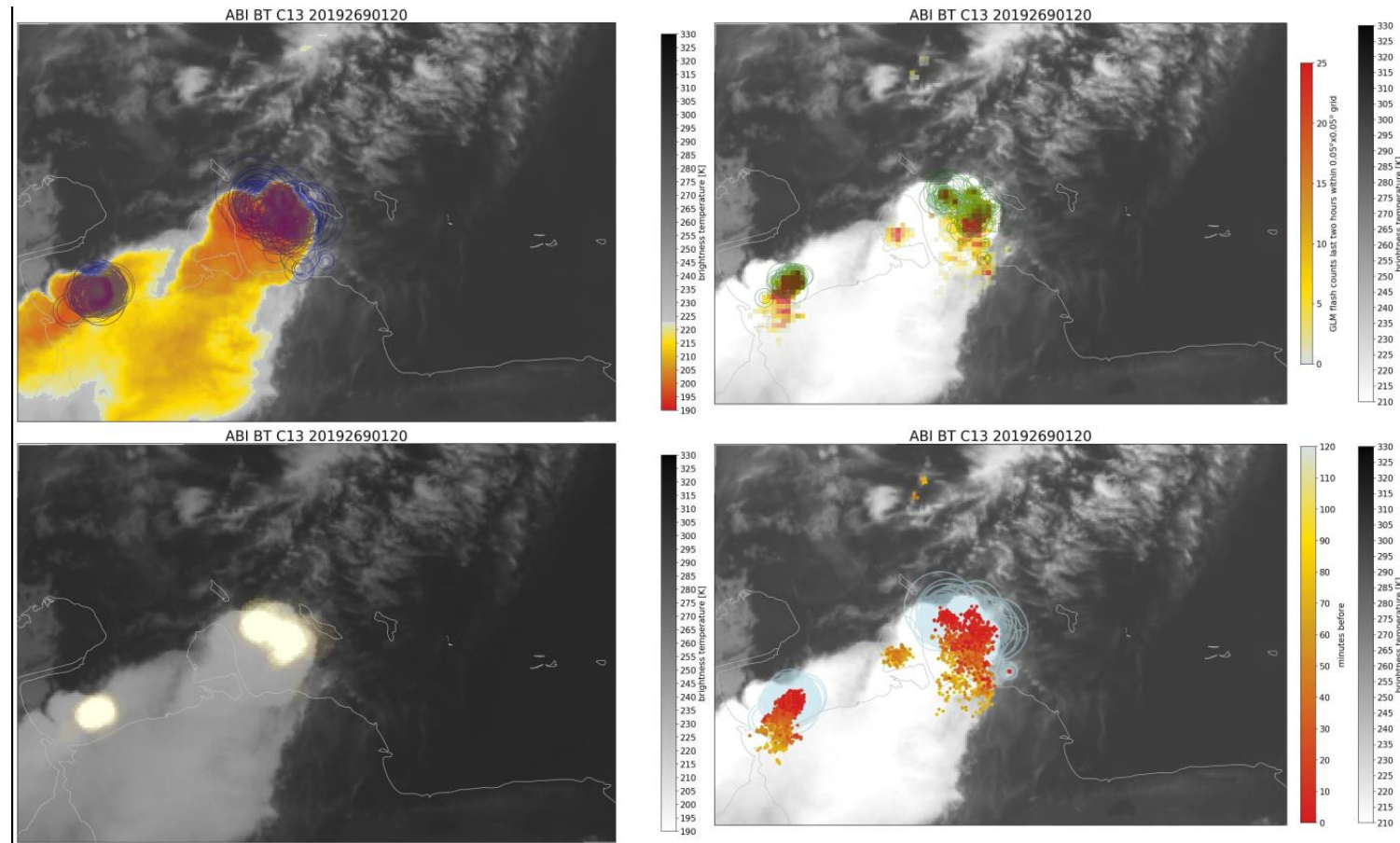Flashes last 10 minutes (blue; circles indicate flash area coverage)

Flash counts last 2 hours (colors: red to yellow: 1-25 counts)

ABI 10.3 μm micron brightness temperatures

ABI BT C13 20192690100
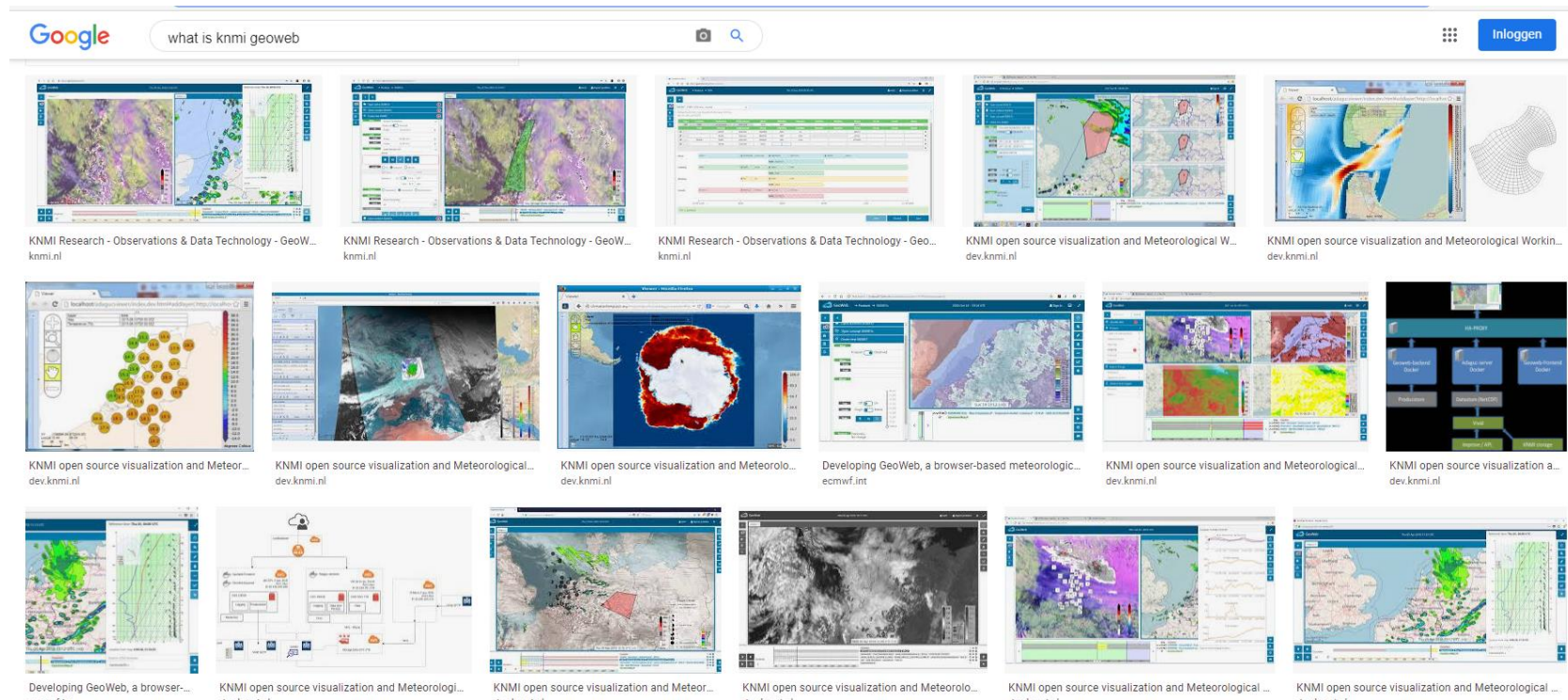
©KNMI

GOES GLM lightning animations

working towards operational implementation in KNMI GeoWeb data portal (& KNMI EWC)

GOES GLM lightning KNMI GeoWeb

- next generation tooling for monitoring the atmosphere
- Python & web-based flexible integrated data visualization system
- open source developed by/at KNMI
- forecasters, scientists and developers (incl. KNMI Early Warning Center)

https://www.knmi.nl/research/observations-data-technology/projects/geoweb-the-next-generation-web-based-tooling-for-monitoring-the-atmosphere

GOES GLM lightning

✓ existing operational data
✓ immediate use in KNMI operational weather forecasting (BES)
✓ very similar data to be provided by MTG
✓ should be easy to setup GOES data stream for use @KNMI
✓ could be made easy to use (present in familiar ways)

✗ no operational data stream yet in support of BES volcano dashboard
✗ automated alerting not yet developed

KNMI meteorologists note that for many of their non-specialist users information about lightning from data KNMI currently uses over the Netherlands suffices (BlitzOrtung & other sources). User needs often differ from meteorological needs and R&D needs, especially with non-specialist users.

➤ users indicate a strong interest in short-term predictability

discussion/feedback KNMI operational meteorologists

× less value knowing where lightning is once it has started to occur (persistence)

× less value in knowing where it moves (generally associated with cloud systems)

✓ **highly valuable to know where lightning occurs where it has not occurred before**
(actionable information for customers → e.g. airports, aviation)

probabilistic lightning prediction

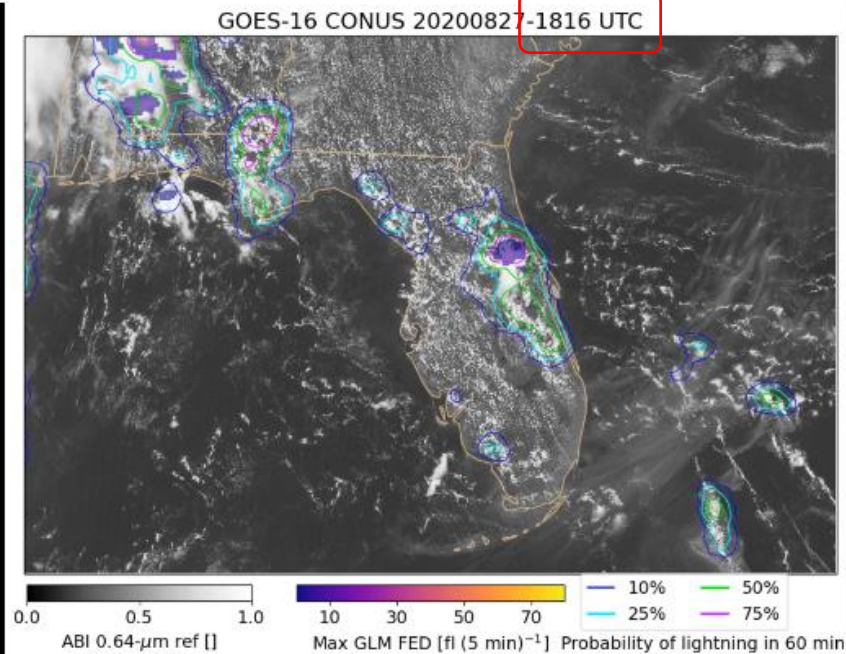## probabilistic lightning prediction

(NOAA/CIMSS; Cinetineo et al., 2018 10.1175/WAF-D-17-0099.1)

https://cimss.ssec.wisc.edu/satellite-blog/archives/38136

- deep-learning model to recognize complex patterns in weather satellite imagery

- predict the probability of lightning in the short term (~60 mins).

- integrated in ProbSevere[©NOAA/CIMSS] algorithm

    - *convolutional neural network (CNN)*

    - *the CNN currently uses four ABI channels: band 2 (0.64-µm), band 5 (1.6-µm), band 13 (10.3-µm), and band 15 (12.3-µm)*

    - *assign the probability of lighting in the next 60 minutes to each pixel in the image*

    - *very computationally efficient, only needing 30 seconds to process the ABI CONUS domain and 3 seconds to process an ABI mesoscale domain*
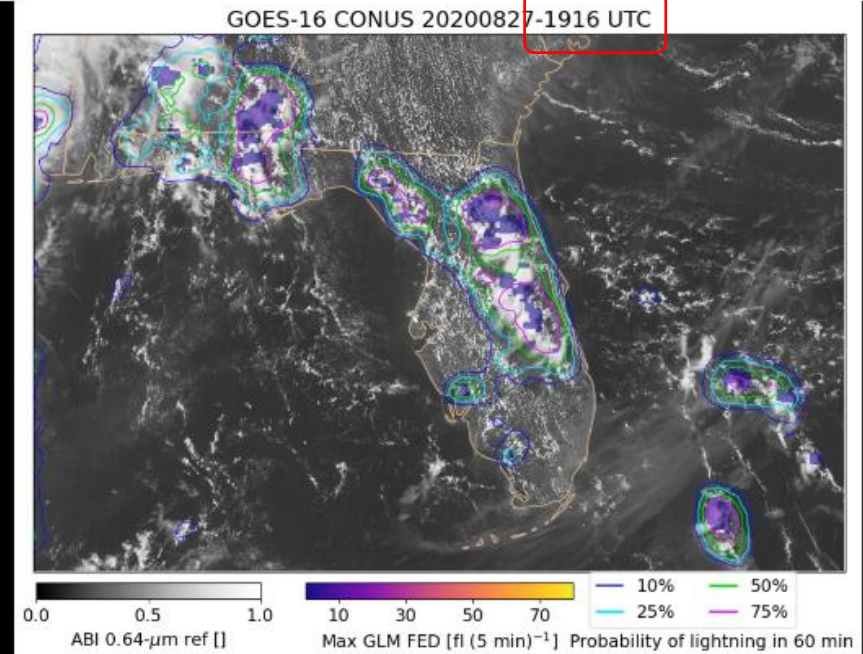
probabilistic lightning prediction (NOAA/CIMSS)

filled contours indicate observed flashes --- contours indicate probability of lightning < 60 minutes
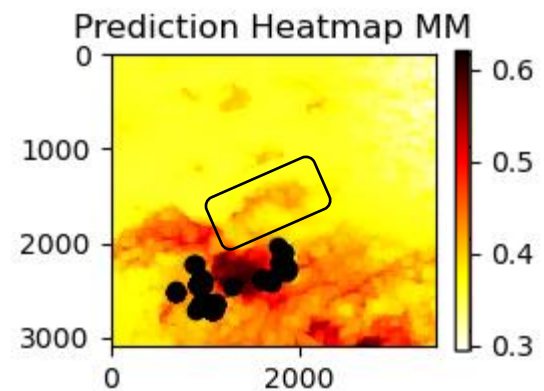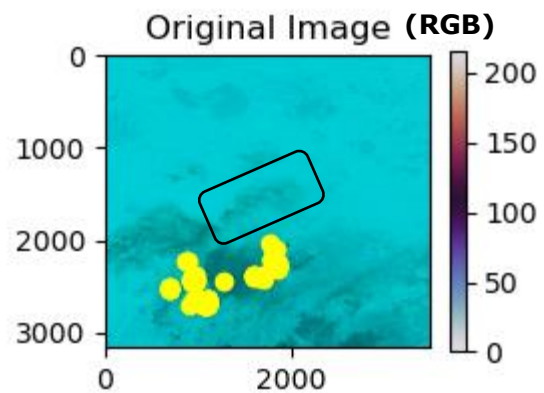
probabilistic lightning prediction @KNMI

master student project (University Leiden Center for Data Science); 2022-2023 (during COVID19)

- primary goal: build expertise developing a learning algorithm

- convolutional neural network (inspired by Cintineo et al. [2018])

- first aim: predict future lightning based on current cloud patterns

- predict lightning for the 20-30/30-40/50-60/80-90/170-180 minute intervals ahead in time

- three GOES-16 ABI channels (VIS 0.64 µm + IR 10.3 & 12.3 µm)
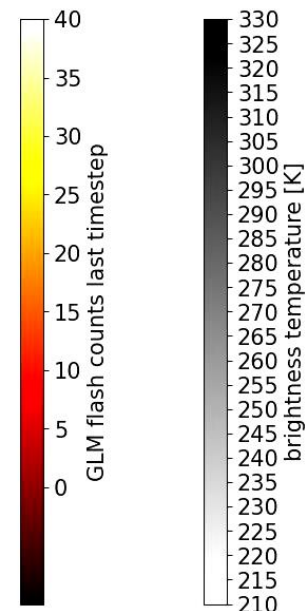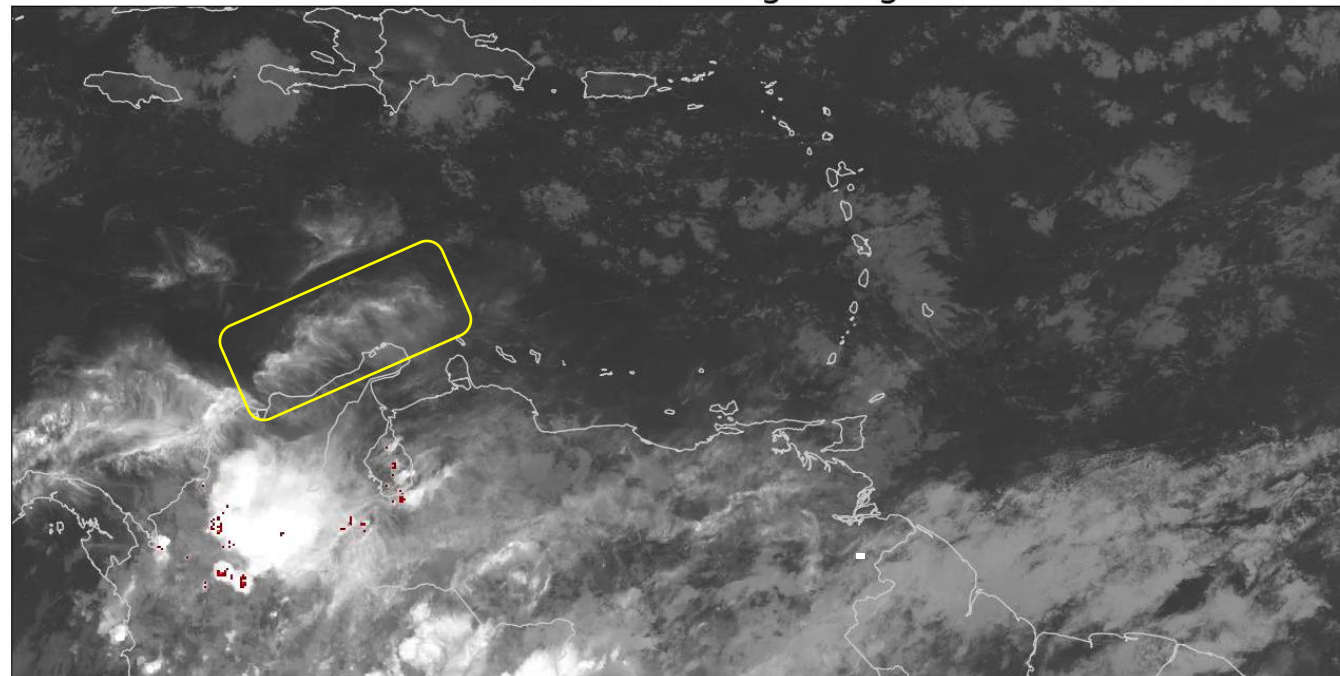
- region: Caribbean + northern South America

probabilistic lightning prediction @KNMI

Original Image **(RGB)**

Prediction Heatmap MM

year 2019 day 108 hour 10:00
prediction future 30-40 minutes

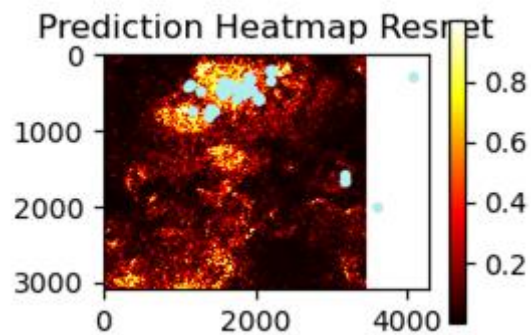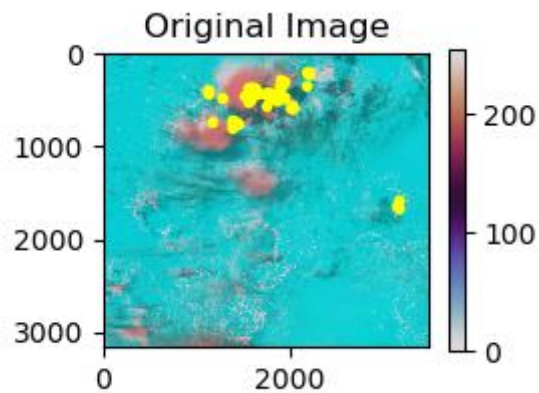ABI BT C13 20191081040 + GLM lightning counts 0.05°x0.05

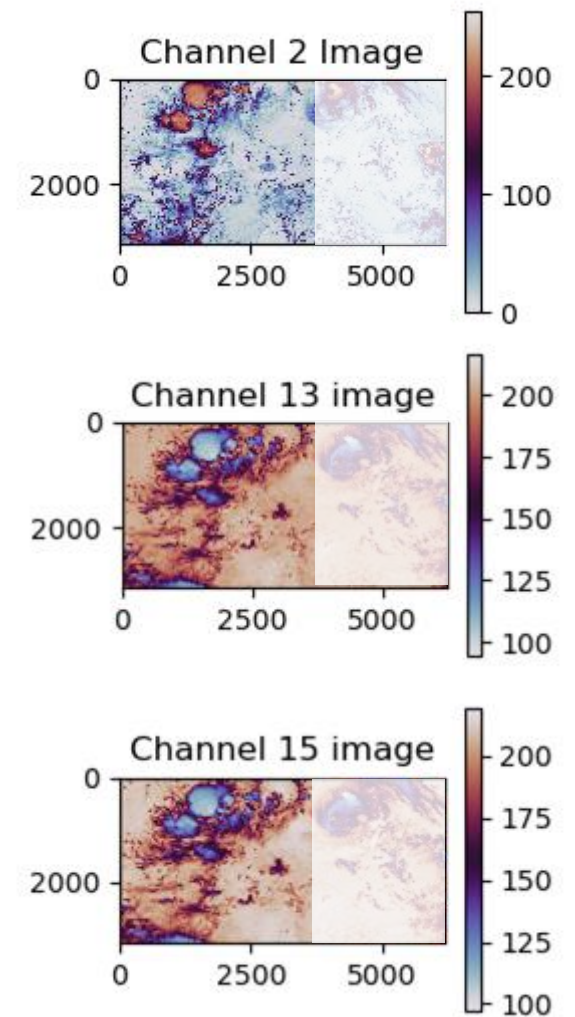(not shown: performance/verification statistics are very good)

probabilistic lightning prediction @KNMI

year 2019day 263hour 15

Original Image
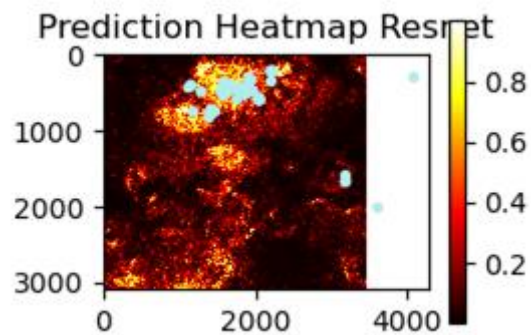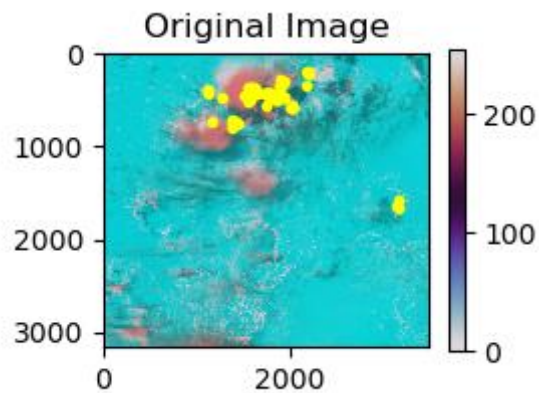
Prediction Heatmap Result

- algorithm was asked

future lightning based on **current** cloud patterns

no time dependence
binary prediction: lightning or no lightning

- algorithm learned to recognize (explainability)

- optically thick clouds
- cold clouds
- cloud patterns/clusters

- physically makes sense

- lightning associated with formation of graupel
- graupel → precipitating clouds
- graupel → sufficient water (optically thick)
- graupel → sufficiently cold (high clouds)

Channel 2 Image

Channel 13 image

Channel 15 image

probabilistic lightning prediction @KNMI

year 2019day 263hour 15

Original Image

Prediction Heatmap Resmet

Questions **not** asked to algorithm:

- future **amount** of lightning based on **current** cloud patterns

- future **chance** of lightning based on **current** and **past** cloud patterns

- future **amount** of lightning based on **current** and **past** cloud patterns
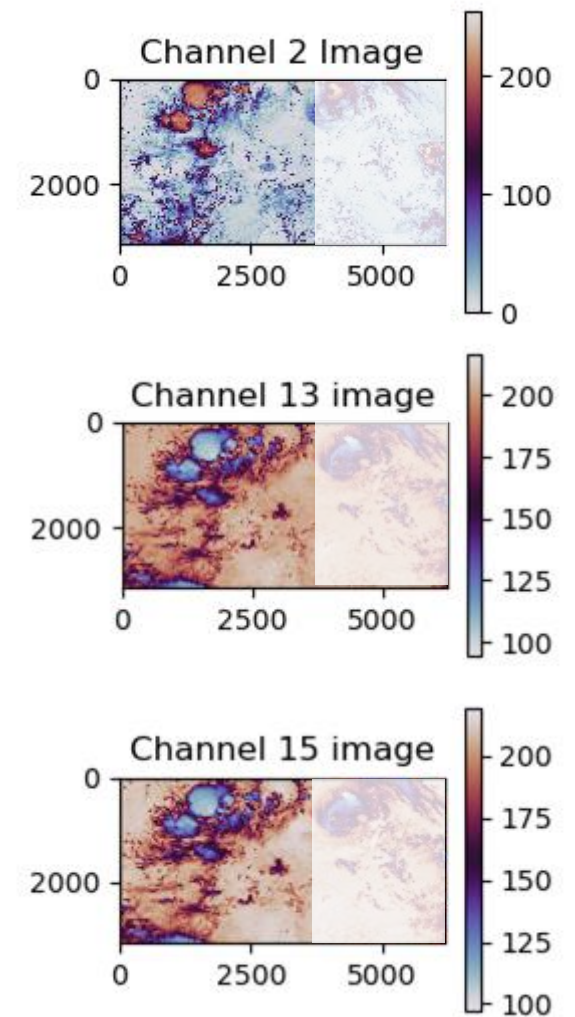
+ time evolution

+ use all GOES (or MTG) channels rather than three channels

+ train on number of lightning flashes
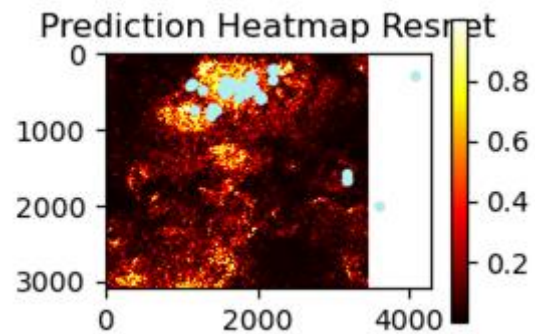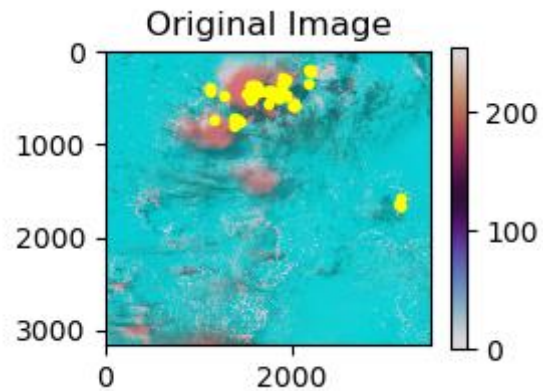
+ train on lightning energy

+ train on lightning area

preparation data for training network takes a ton of time !!!!

Channel 2 Image

Channel 13 image

Channel 15 image

year 2019day 263hour 15

Original Image

Prediction Heatmap Resnet
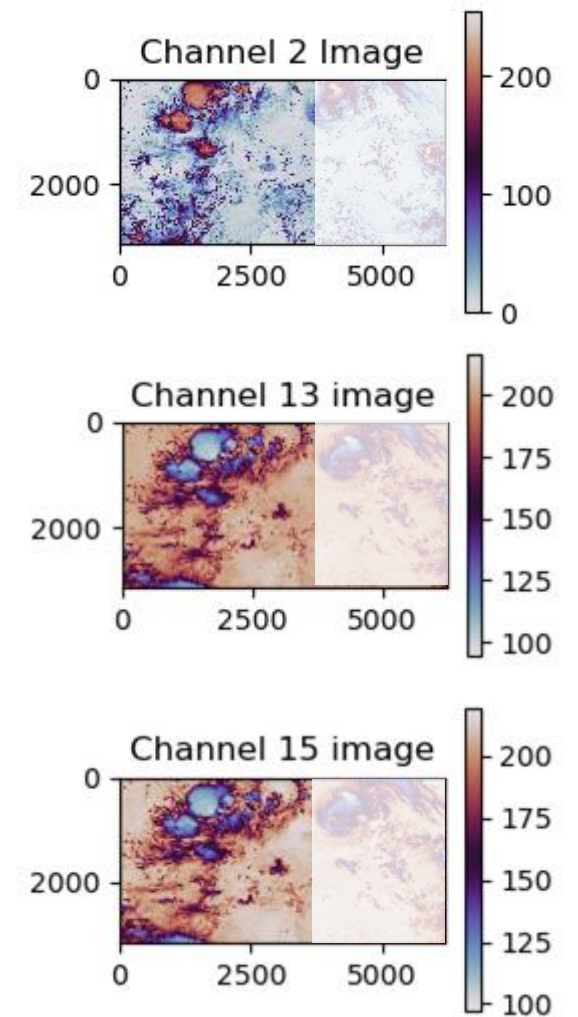
looking for funding for project:

develop generic AI/ML framework for similar problems

focus: severe weather over Europe

- lightning
- wind storms/gusts
- large hail
- heavy precipitation
- tornado's

input

✓ MTG FCI
✓ ESSL database
✓ MTG LI

Channel 2 Image

Channel 13 image

Channel 15 image

probabilistic lightning prediction

note: development of AI/ML severe weather applications is also done by several EU

National Weather Services and/or with support of EUMETSAT (FellowShips) and

promoted/stimulated by EUMETSAT as part of their AI/ML strategy.

auto METAR

2023 project GOES GLM lightning auto-METAR Bonaire International Airport

- ✓ KNMI responsibilities for Bonaire International Airport (Caribbean), incl. issuing METARs
- ✓ retiring group of local airport observers
- ✓ move to auto-METAR generation (incl. lightning → no local observation network)
- ✓ feasibility study started 2023 GLM lightning input for auto-METAR (incl. alerting)

create historical GLM time series for Bonaire:

How do observed and reported lightning compare?
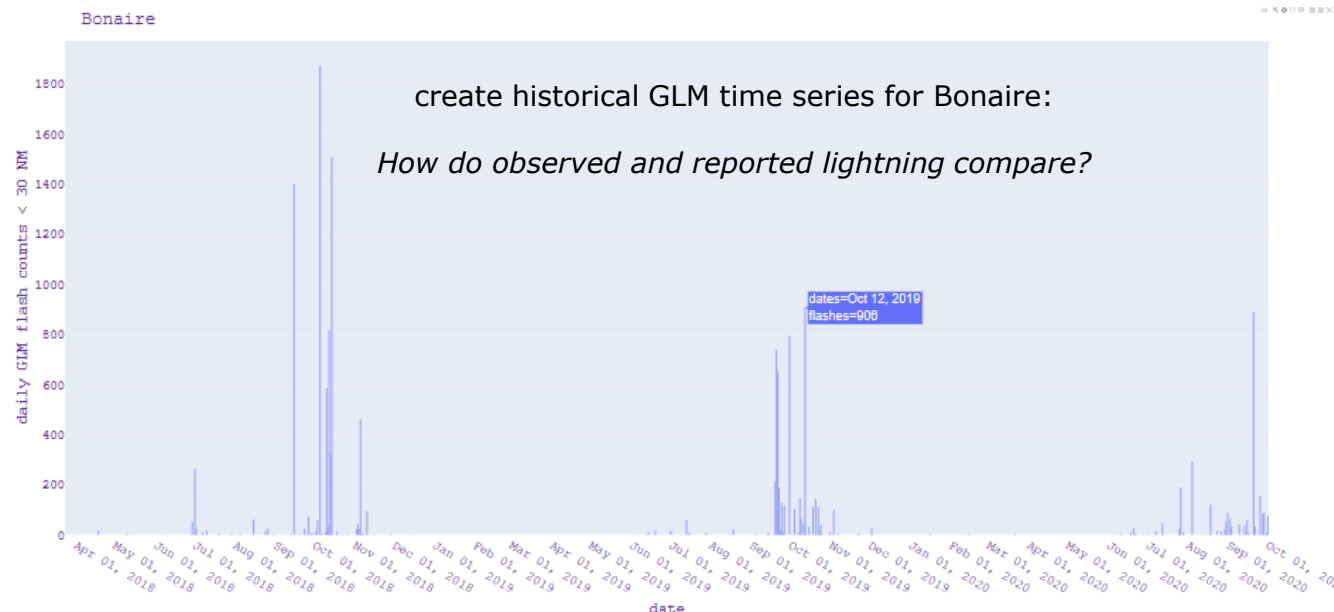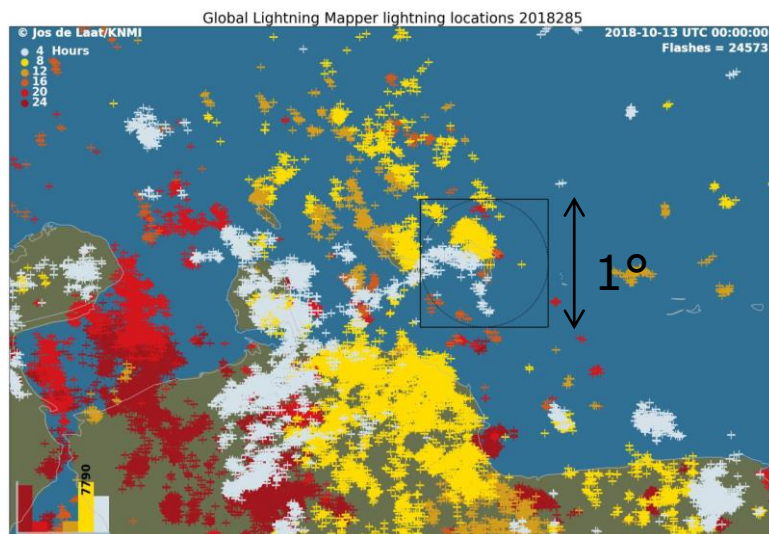
KNMI colleague Albert Jacobs: "at Bonaire lightning is rare"
(GLM: yes it is, within 5 NM less than 10 times a year)
(frequent lightning within 5 NM only a couple of times/year)

**KNMI Early Warning Center automated convective cell tracking**

2024 (?) MTG lightning imager link with KNMI warnings at "city scale"

✓ KNMI/EWC thunderstorm/severe weather cell tracking system (status: operational pilot)
✓ based on weather radar data
✓ provides NRT probability cones
✓ including cone warning color
✓ fully automated

Future

✓ allows for personalized warnings
✓ merge with weather MTG data
    ✓ lightning (actual)
    ✓ lightning (NRT probabilities)
    ✓ NRT severe weather probabilities
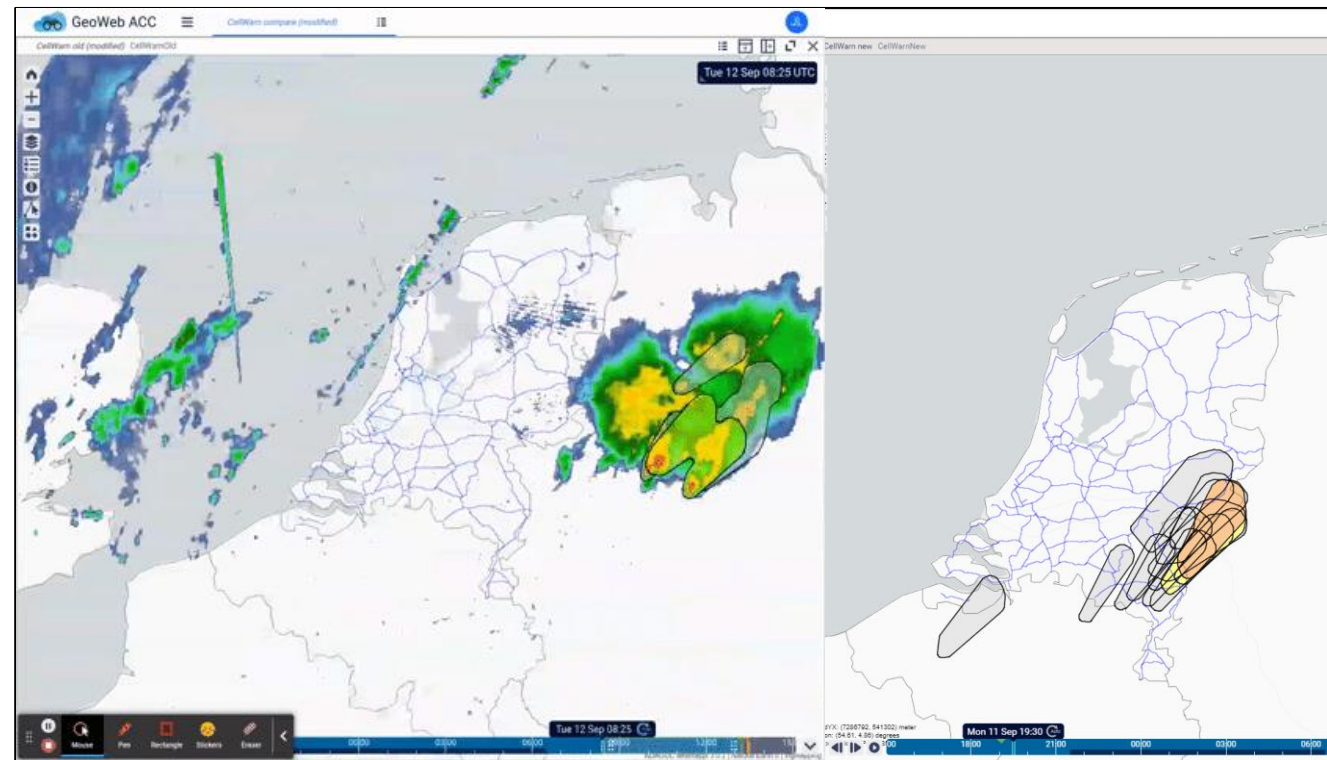
EUMETSAT/ESSL lightning workshop spring 2023

EUMETSAT Ligning Workshop (ESSL, Austria, spring 2023)

Kristin Calhoun of NOAA/National Sever Storms Laboratory

✓ it took many years before GLM was full integrated in NSSL operations

✓ GLM uptake still depends on/varies between forecasters

✓ particular interest in "early indicator" GLM data products

GLM Experiments in the NOAA Hazardous Weather Testbed

Kristin M. Calhoun
NOAA/National Severe Storms Laboratory

principal investigator on numerous projects within the NOAA Hazardous Weather Testbed

spinoff: lightning research with LOFAR

LOFAR = largest radio telescope operating at the lowest frequencies that can be observed from Earth
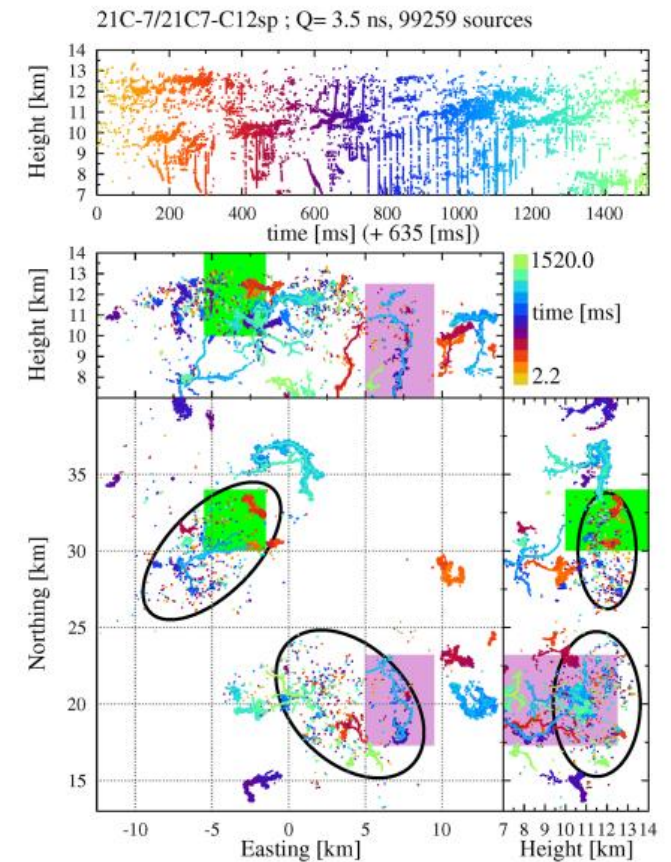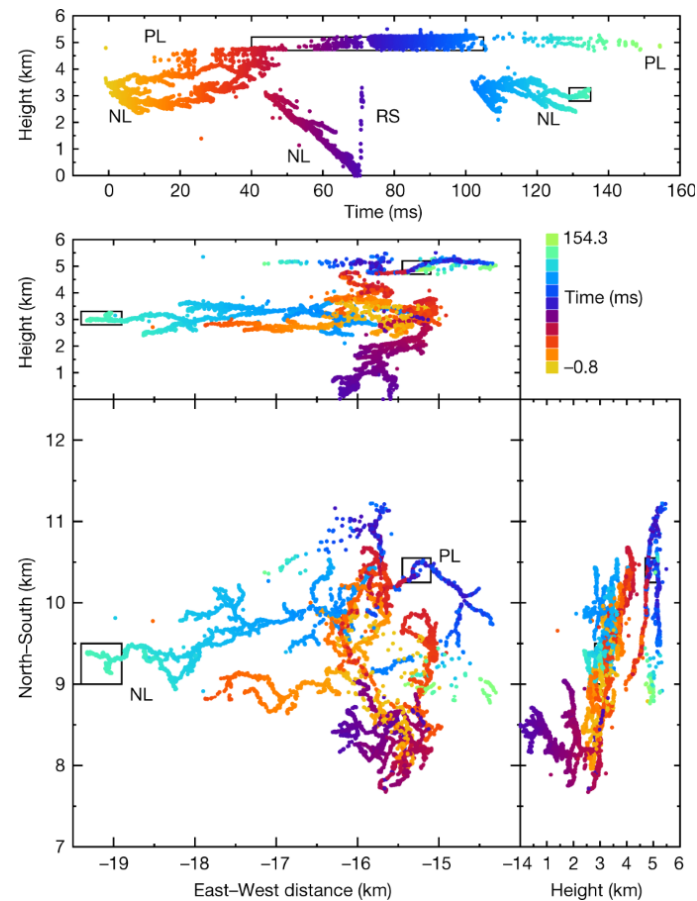
sensitive to lightning

reconstruct lightning and lightning-related phenomena with unprecedented accuracy and details

very fundamental research

Brian Hare (lead)
Olaf Scholten (ret. astrophysicist)

summary & lessons so far

lightning data applications at KNMI: **summary** & **lessons** learned so far

- developed GOES GLM expertise in preparation for MTG-LI

- explored data, visualizations, animations

- to be implemented in KNMI meteorological data portal (GeoWeb) also in preparation for MTG

- user feedback: geospatial **changes** in lightning are valuable ("actionable information")

- GOES/GLM-based method/algorithm exists for probabilistic lightning prediction

  - first steps AI/ML-based algorithm
  - research proposal for national funding
  - role for EUMETSAT/SAF's/EU NWS's?

- Bonaire auto-METAR application (incl. alerting)

- exploring more advanced use: searching for added value (data → information → action)

Q & A

There are many papers describing several aspects of the ProbSevere algorithm.

A good starting point is Cintineo et al. [2018]

https://journals.ametsoc.org/view/journals/wefo/33/1/waf-d-17-0099_1.xml

The list of papers referring to Cintineo et al. [2018] then provides further guidance to other ProbSevere papers as well as other research papers exploring the potential of using geostationary satellite data and AI/ML to identify and short term forecasting of risks of severe weather.