Predicting thunderstorm risk using neural networks

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1st year PHD

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Context and objectives :

https://www.albatros-horizon.eu/

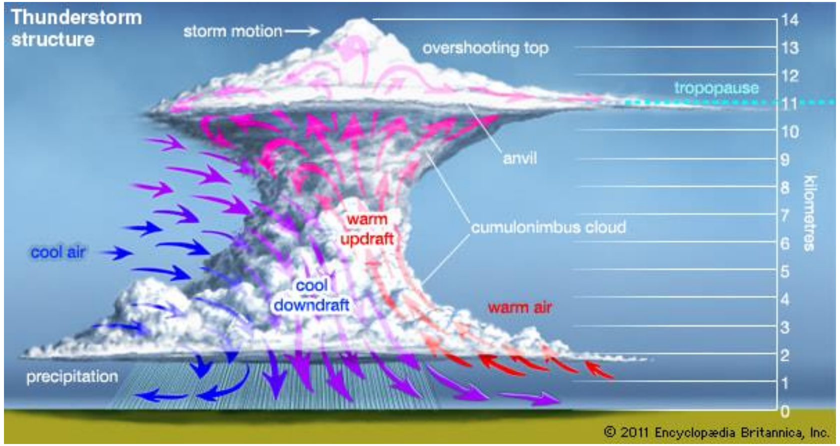
ALBATROS (Advanced systems and soLutions for Better practices Against hazaRds in the aviatiOn System) → **Reinforce air safety.**

Develop safety risk models to predict and prevent emerging hazards in aviation.

Cumulonimbus → Main lightning generator **(hazard).**

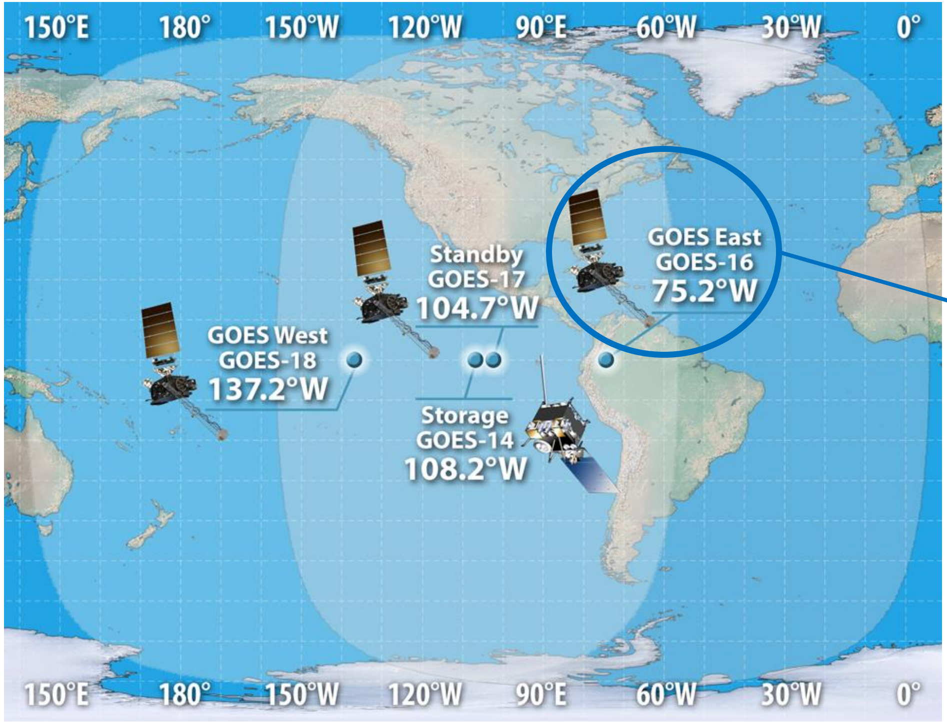
Presence of updrafts, downdrafts, turbulences in and around the cloud, but also heavy rain and hail → **Hazards for planes.**

Objective : define a methodology for predicting storm risk areas at very short term (<1h and every 5 minutes) by using deep neural networks



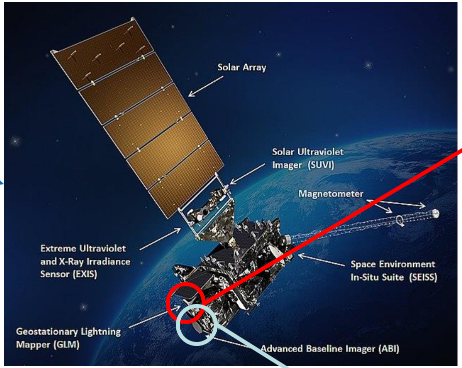
https://www.britannica.com/science/thunderstorm

The GOES-R satellite and its sensors :



https://www.goes-r.gov/mission/mission.html

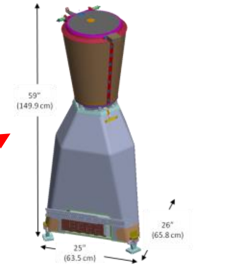
GOES Constellation field of view



https://fr.wikipedia.org/wiki/Geostationary_Operational_Environmental_Satellite

Geostationary Operational
Environmental Satellite
(GOES-R)

Geostationary Lightning
Mapper (GLM)



https://www.goes-r.gov/spacesegment/glm.html

Advanced
Baseline Imager
(ABI)

https://spaceflight101.com/goes-r/goes-r-instruments/

The sensors used :

Advanced Baseline Imager (ABI)

- Spectrometer/Radiometer
- Spatial resolution of 0,5 km in visible
- 2 km resolution for IR
- 16 wavelenght bands
- Band 13 : 10,3 µm, more sensitive to cloud classification
- Images every 5 minutes

Geostationary Lightning Mapper (GLM)

- Photonic/optical detector (camera)
- 8 km spatial resolution
- Observe lightnings
- 70-90% lightnings detection
- Works day and night (better)
- 3 types of products : here flashs are used
- Images every 20 seconds

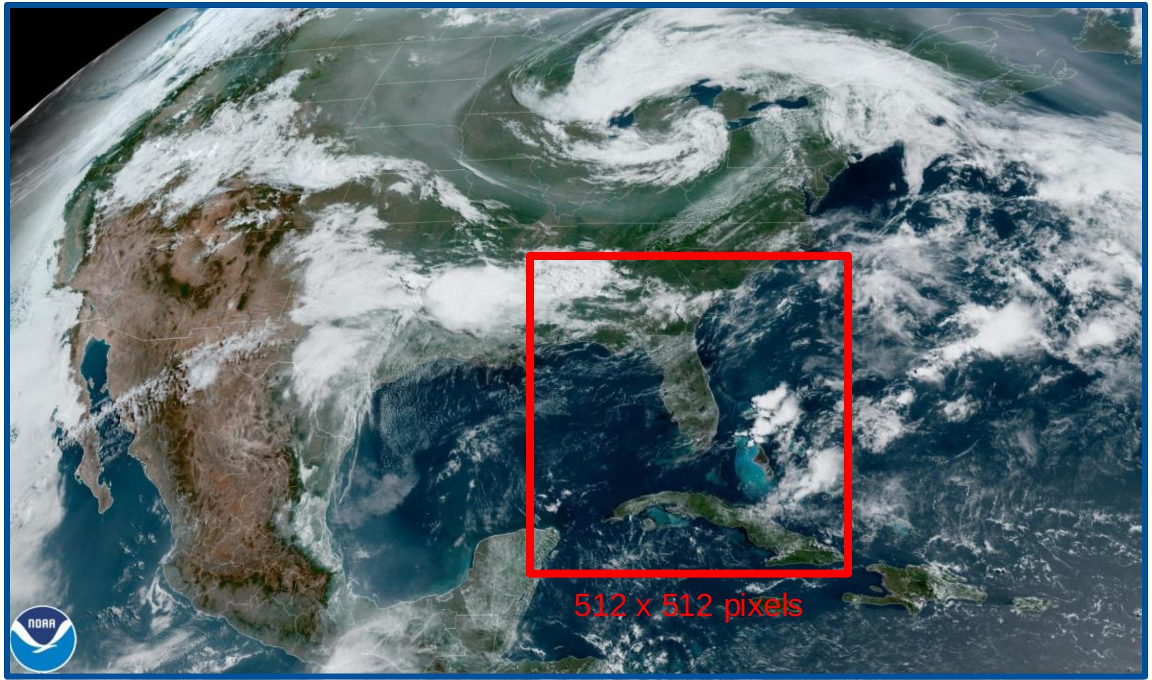
The geographical area studied :

Why CONUS ?

- Data every 5 minutes
- Easely retrievable online
- Free
- Near to the equator → hot and humid climate that favors thunderstorms and lightnings

Pourquoi cette zone précise ?

- Allows spatial restriction
- Easier pretraitement



13 Jun 2023 14:21Z - NOAA/NESDIS/STAR GOES-East - GEOCOLOR Composite - Day(0.47 um - blue, 0.64 um - red, and 0.86 um – near IR)

https://www.star.nesdis.noaa.gov/GOES/conus.php?sat=G16

Continental United States (CONUS)

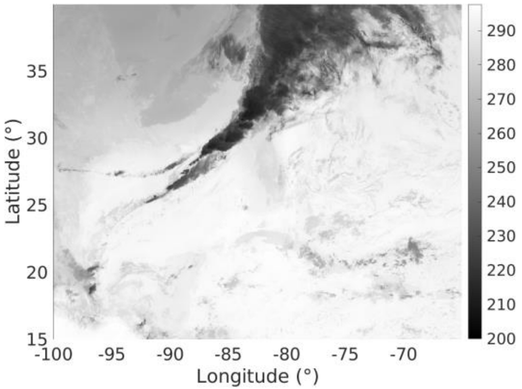
Data processing :

Temporal processing :
Cumulative flashes over 5 minutes
around the ABI time step

Spatial processing :
Mesh of 0,03x0,03°

Images with a 4,5 km spatial resolution
and a 5 minutes temporal resolution

13/01/23 à 02h06



Brightness temperature images (ABI)

Lightning position images (GLM)

<u>Data retrieved for :</u>

- Winter months (January, February, December)
- Between 00h00 and 05h00 am
- Years from 2020 to 2023

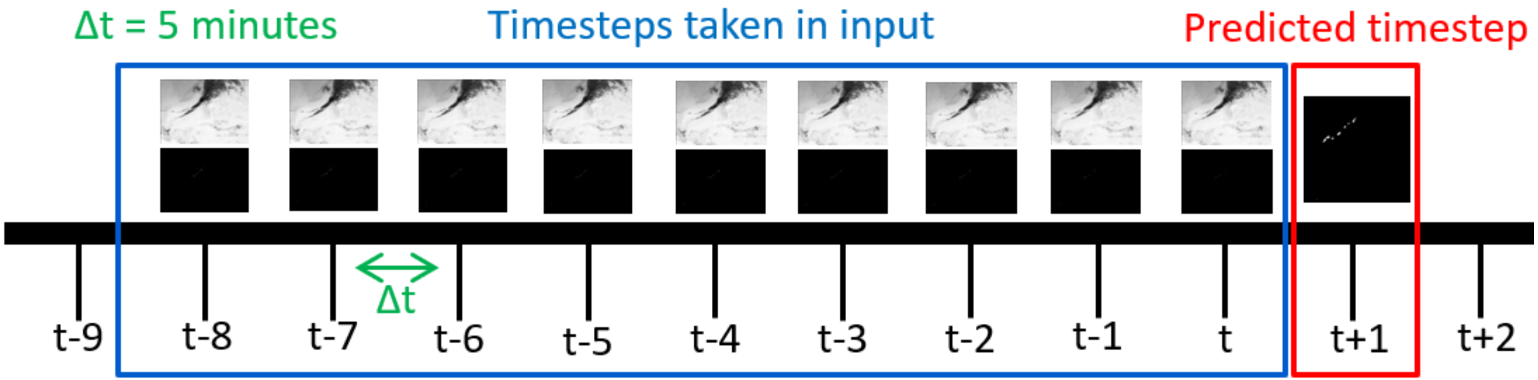
<u>Final database :</u>

- Approximatively 168 days recovered
- 10 080 input/target pairs (ABI/GLM)
- 20160 images

<u>Data distribution for the algorithm :</u>

- 70% train (14112 images)
- 30% test (6048 images)

Description of the learning process :



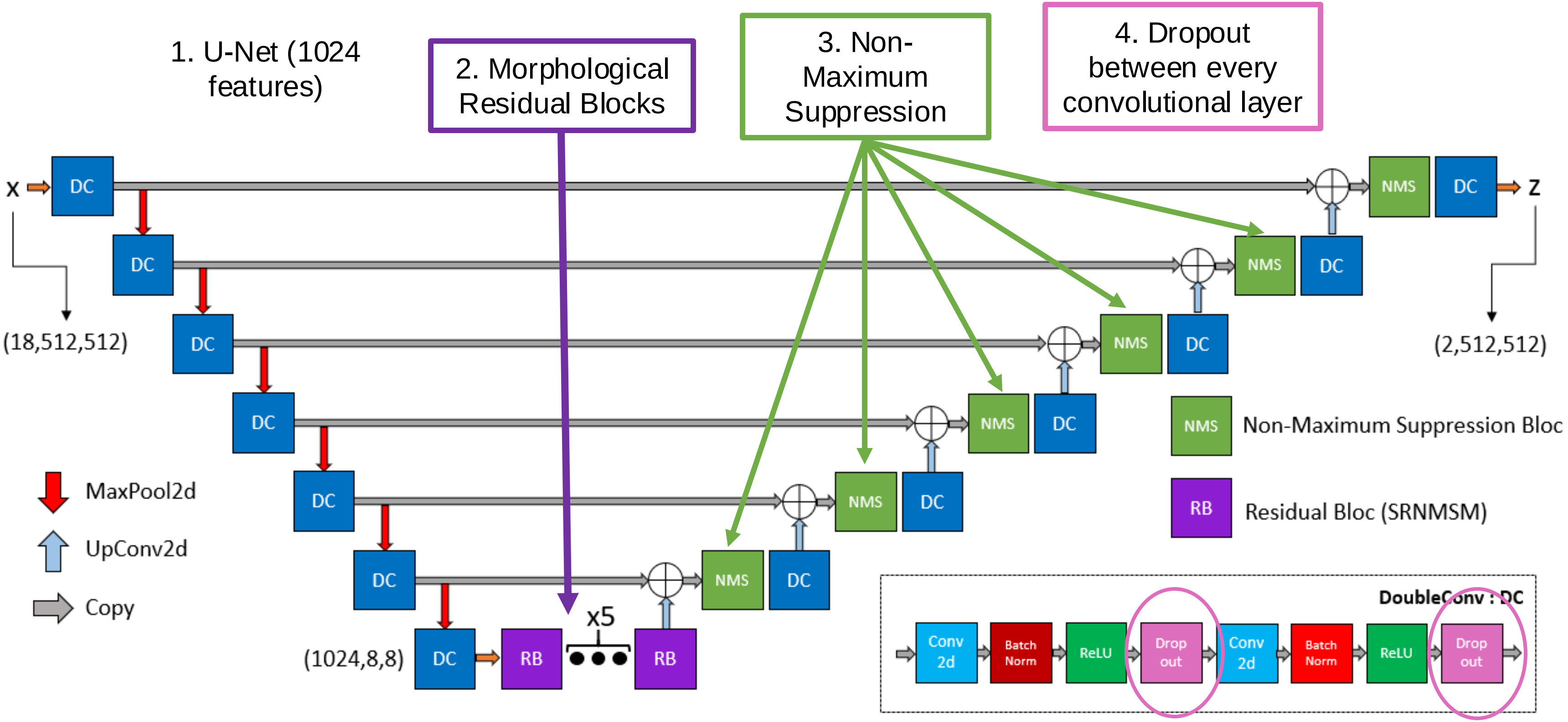
Prediction mask of the position of electrical activity for future timesteps

9 steps sequence as input : to keep the temporal dependance between images whithout having a high computer cost

Segmentic Segmentation :

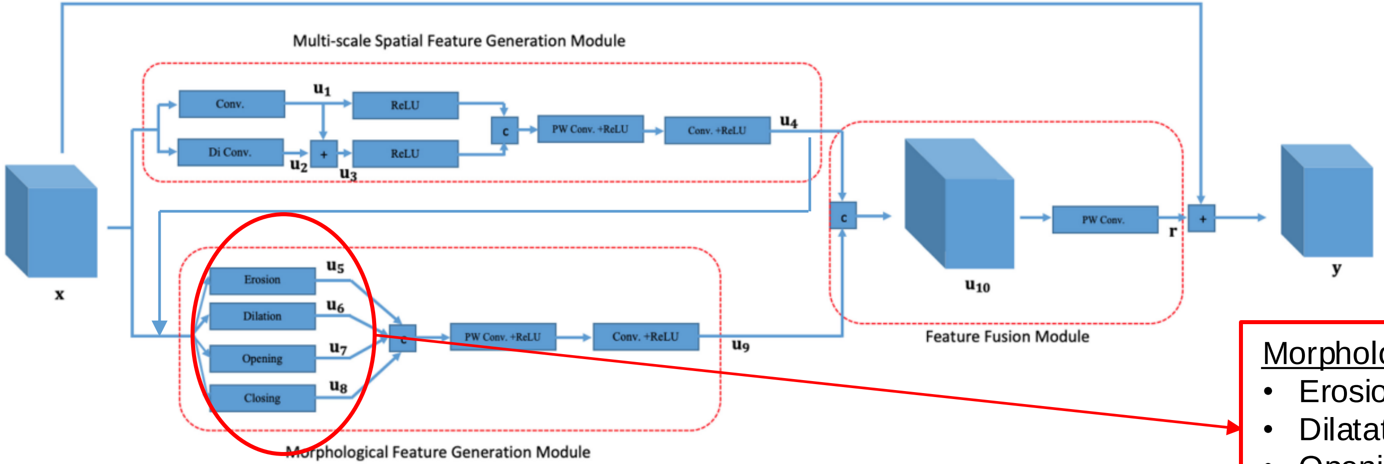
- At the end of the neural network, a class is attributed to each pixel of the output image

StrikeNet architecture :



Morphological residual SRNMSM bloc description :

Super Resolution Network using Multi-scale Spatial and Morphological features



Esmaeilzehi, 2022

Morphological operations :

- Erosion
- Dilatation
- Opening
- Closing

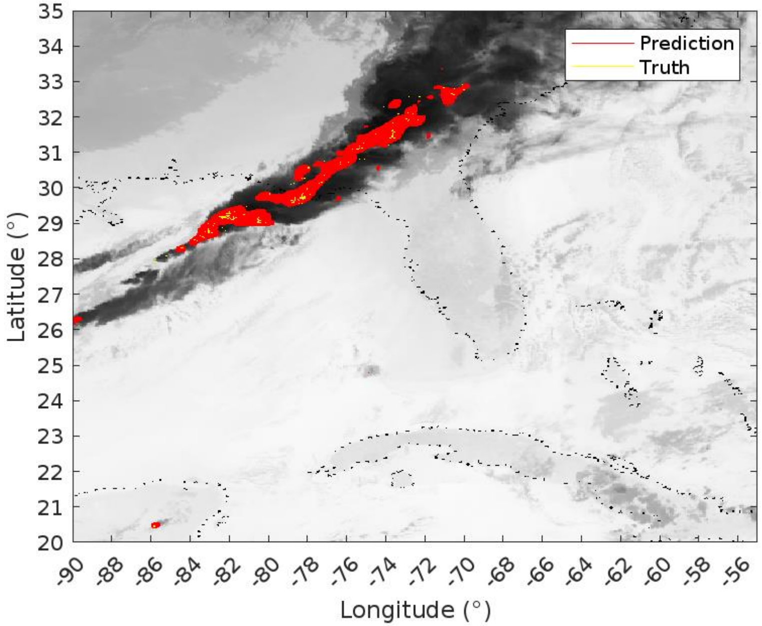
The addition of these blocks allows us to focus on the morphological characteristics of the images, in addition to the spatial processing carried out by the convolutions.

In our case, these blocks provide another analysis of the features extracted by the encoder, as well as the greater precision required given the size of the lightning flashes in the image.

Non-Maximum Suppression layers (NMS) :

13/01/23 à 02h06

Prediction with a simple U-Net model :



Predicted lightning risk areas (in red) too large regarding the ground truth

Non-Maximum Suppression technique (NMS) :

$$x_{i,j} = 10x_{i,j} - 9 \max_{di,dj \in \{-1,0,1\}} x_{i+di,j+dj}$$

0,98	0,15	0,56	0,49	0,71	0,86	0,55	0,15
0,30	0,69	0,75	0,68	0,14	0,61	0,30	0,69
0,48	0,08	0,89	0,36	0,05	0,44	0,48	0,12
0,25	0,78	0,69	0,95	0,60	0,28	0,47	0,15
0,38	0,13	0,10	0,50	0,09	0,45	0,30	0,52
0,99	0,87	0,54	0,43	0,16	0,89	0,33	0,08

If the pixel is the maximum among its neighbours :

- x = 10x0,98 – 9x0,98 = 0,98

If the pixel is not the maximum among its neighbours :

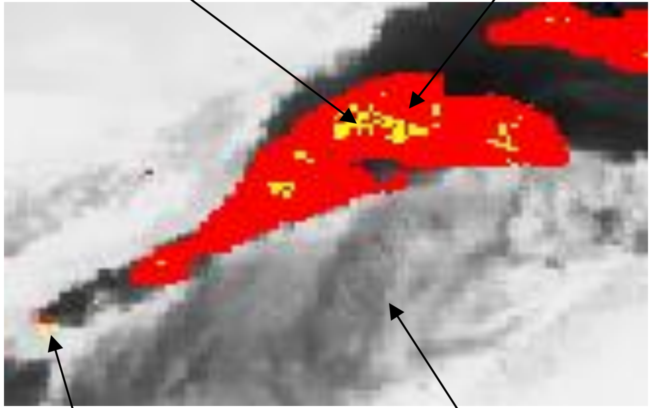
- x = 10x0,36 – 9x0,95 = -4,95

Allows to only give importance to the pixel that have a big chance to belong to the lightning class, and to decrease the importance of the others. This reduces the size of the risk area predicted.

Metrics :

FP = Lightning predicted instead of background (False Alarm)

VP = Well-identified lightning



VN = Well-identified background

FN = Missed lightning

Precision :

$$\boxed{Precision = \frac{VP}{VP + FP}}$$

Rate of well-identified lightnings out of all planned lightnings

Probability Of Detection :

$$\boxed{POD = \frac{VP}{VP + FN}}$$

Rate of well-predictied lightnings out of all real lightnings

F1-Score :

$$\boxed{F1_{score} = 2 * \frac{POD \; * précision}{POD + précision}}$$

Harmonic mean between accuracy and probability of detection

Evaluation and comparison between different models :

Persistance : Precision ↑, POD, F1-Score ↓

DeepLab : Precision, F1-Score ↓, POD ↑

U-Net : Precision, F1-Score ↓, POD ↑

ED-DRAP : Precision, F1-Score ↓, POD ↑

StrikeNet : Precision, POD, F1-Score ↑

	Metrics		
Models	***F1-Score***	***Precision***	***POD***
Persistence	0.43	**0.83**	0.29
DeepLab	0.11	0.06	0.82
U-Net	0.17	0.095	**0.95**
ED-DRAP	0.21	0.12	0.94
StrikeNet	**0.54**	0.42	0.78

- **Persistance** : prediction at t+1 = ground truth at t+2
- **DeepLab** : CNN with atrous convolutions
- **ED-DRAP** : CNN that uses spatial and sequential attention
- **StrikeNet** : Our deep neural network model

Conclusions :

✓ StrikeNet reaches better accuracy and FAR scores than the other models except for the persistence

✓ POD near to 80% → acceptable.

✓ Better F1-Score between all of the tried models.

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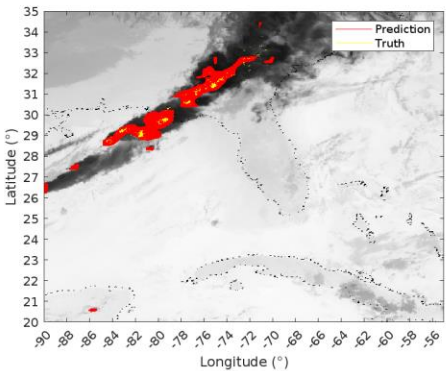
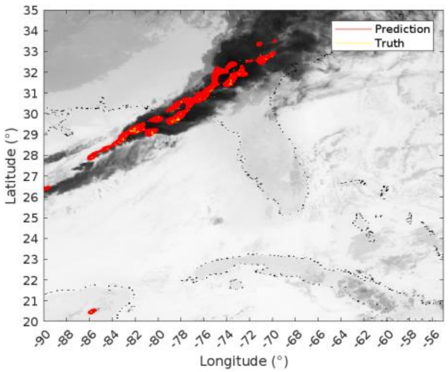
ALBATROS

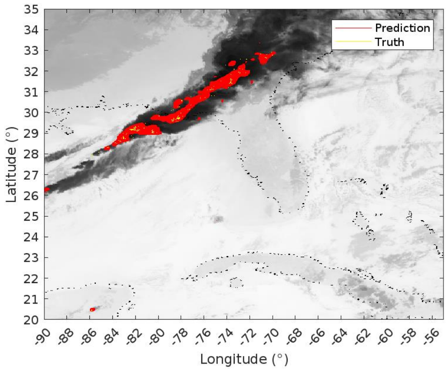
Graphical results comparison between models :



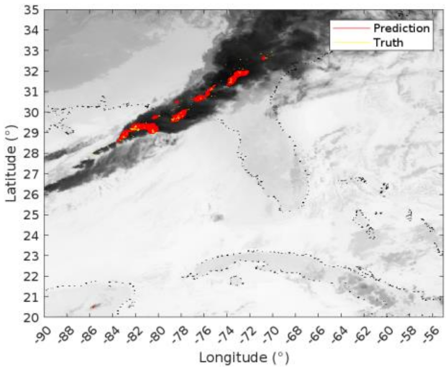
DeepLab



U-Net



ED-DRAP



StrikeNet

13/01/23 à 02h06

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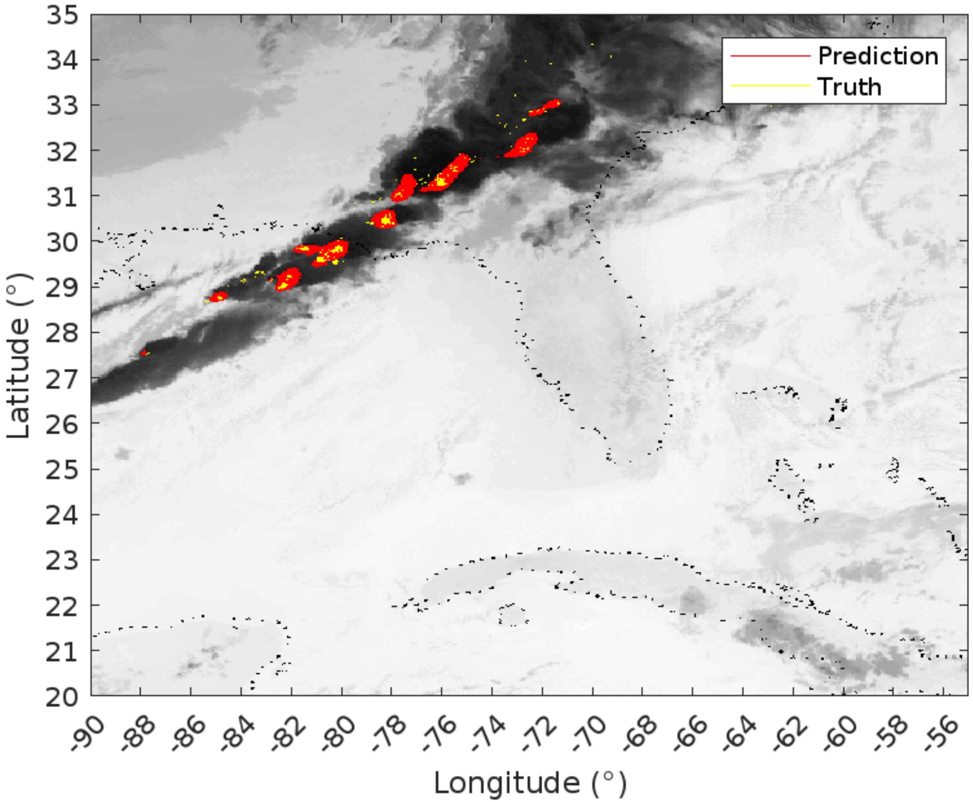
Graphical results for one precise day and moment :



Conclusion :

<u>What has been achieved :</u>

- ✓ Collection and preparation of satellite data to create a database
- ✓ Development of a neural network architecture specifically adapted to the problem
- ✓ Use of appropriate metrics to evaluate the model
- ✓ Satisfactory output results

<u>Perspectives :</u>

- ➢ Work on a GLM product other than flashes: groups
- ➢ Make forecasts for more timesteps : 5 instants, i.e. 25 minutes, with the aim of going up to 1 hour.
- ➢ Study and calibrate the probabilities of class membership obtained from the model output
- ➢ Use data from the new MTG satellite and its two similar sensors

Thank you for your attention

Any questions ?