1st ACCORD ASW
12-16 April 2021

# Assimilation of Meteosat Third Generation (MTG) Lightning Imager (LI) pseudo-observations in AROME-France – Proof of Concept


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# Lightning occurrence

- Cloud electrification due to the interaction of cloud particles
- Charge regions with the potential for **discharge processes**

Cloud-to-ground (CG)

Inter-/Intra-cloud (IC)

**CG + IC = Total Lightning**

# Motivation

- Predictability of **deep convection** and related weather phenomena

*From https://www.flickr.com/photos/okweatherwatch/42186567924/in/photostream/, accessed 14/12/2019*

*From https://de.wikipedia.org/wiki/Sturzflut, accessed 14/12/2019*

- NWP with need of **storm-scale data assimilation**
  - Currently only radar observations for length-scales <200km (Brousseau et al. 2016)
- **Total lightning** activity to locate deep convection
- Optical satellite sensors to monitor total lightning
- Geostationary (GEO) **Meteosat Third Generation (MTG)** satellites with a **Lightning Imager (LI)** end of 2022

# GEO lightning observations: MTG-LI

- **Optical** imager (**777.4 nm** or 886.3 nm)
- Spatial resolution: 4.5 (7) km nadir (France)
- **Total** (CG+IC) **lightning** activity
- Cloud illumination mapping as optical lightning extent

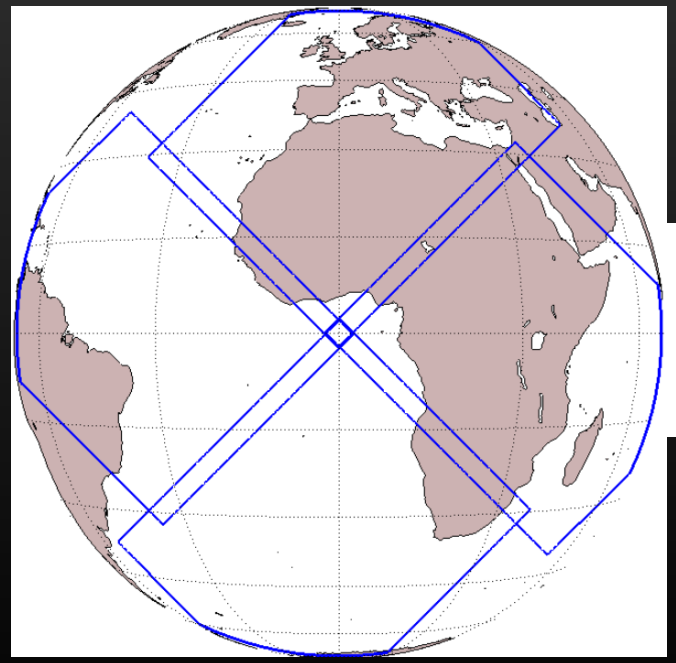
**Advantages** of MTG-LI:

- Large region coverage – land and sea
- Independence of topography – no (beam) blockage
- High temporal resolution – 1 ms

(a)

*Adapted from Peterson et al. (2020)*

(b)



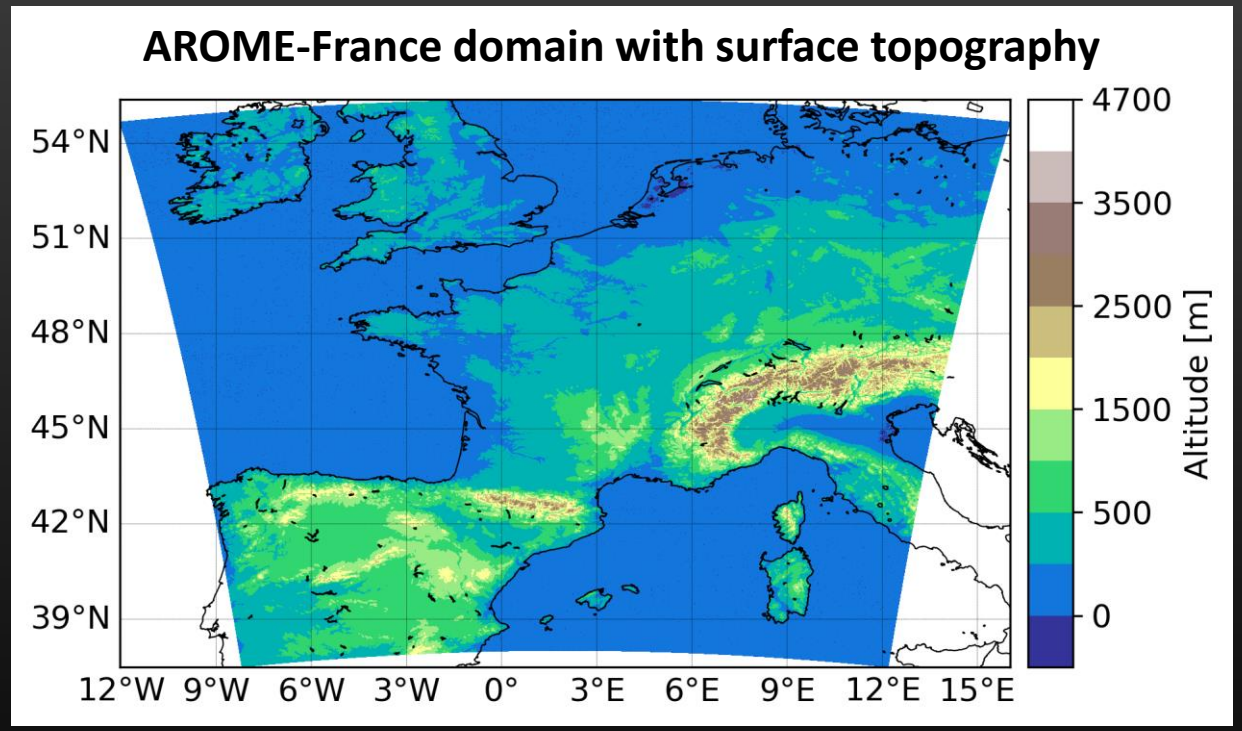
**Projected field of view (4 LI cameras)**

*From http://www.eumetrain.org/data/3/362/362.pdf, accessed 01/12/2020*

# The numerical weather prediction (NWP) model AROME-France

- Model domain French territory – assimilation only for European domain
- AROME version **al42_arome-op2.41**
- **Horizontal** grid of **1.3 km resolution**
- 90 vertical layers
- Deep convection resolved
- Control variables
  - vorticity, divergence, temperature, surface pressure, and **specific humidity**
- **Microphysical** scheme ICE3
  - Classes: Cloud water, Rain, Ice crystals, Snow, **Graupel and hail**
- **3DVar assimilation** with hourly cycles

*(Details in Seity et al., 2011, and Brousseau et al., 2016)*



# Concept of the lightning data assimilation (LDA)

| Tasks | Solutions |
| --- | --- |
| 1. MTG-LI data not before end of 2022 | →Generation of **pseudo-observations** |
| 2. No lightning diagnosis in AROME-France | →Define a **lightning observation operator** |
| 3. Lightning not related to the control variables | →Adapt the **1DBay+3DVar** scheme (Caumont et al., 2010, and Borderies et al., 2019) used operationally for radar reflectivity |

# 3DVar assimilation method for lightning data

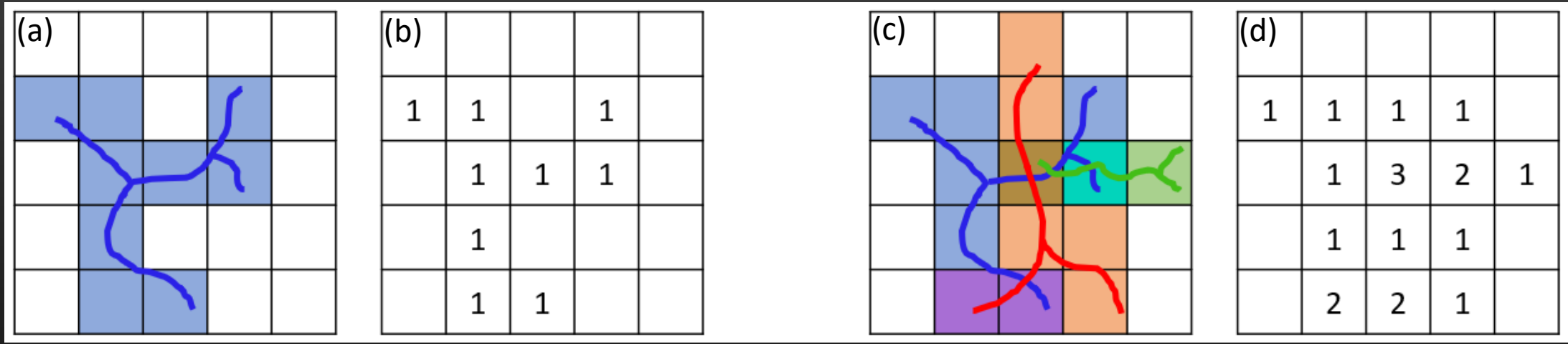
- Successful **3DVar LDA** with the **relative humidity (RH) profile**
  *(e.g., Fierro et al., 2019, Hu et al., 2020, and Liu et al., 2020)*
  - **RH** increased where lightning was observed
  - **Precipitation forecast skill:**
    LDA = radar data (radial velocity and radar reflectivity) assimilation (RDA) > reference experiment (no RDA, no LDA)
  - **Wet bias** reported due to spurious convection, missing approach to remove humidity

- Approach similar to radar reflectivity assimilation (*Caumont et al., 2010*, and *Borderies et al., 2019*)
  - 1D Bayesian (1DBay) to retrieve a **RH profile**
  - **FED-based 1DBay** to increase or decrease the background humidity

# 1. Pseudo MTG-LI FED as lightning data for the assimilation (1/2)

- **Flash extent density (FED)** on regular grid and within a given time period

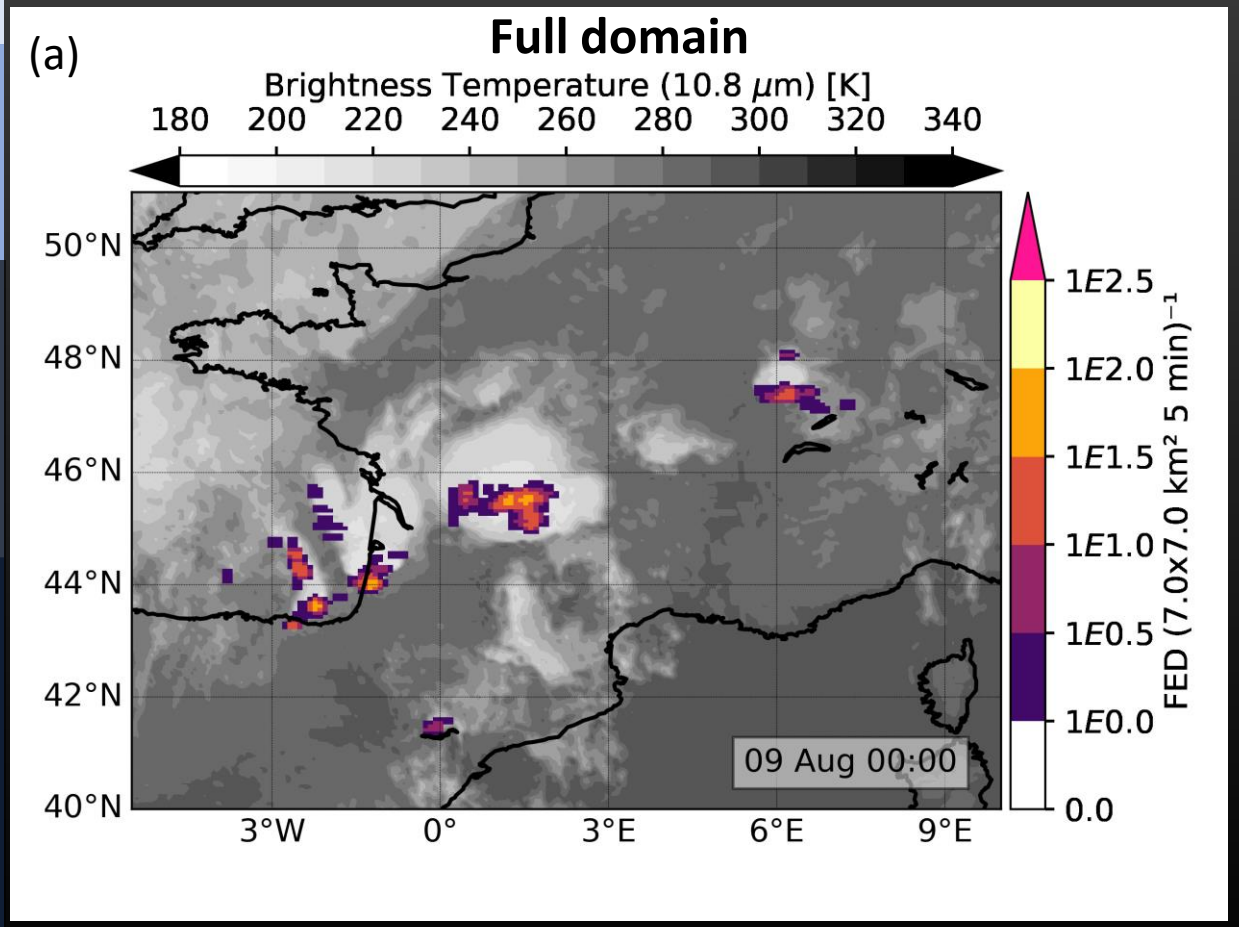
**Initial time step** **A given period of time**

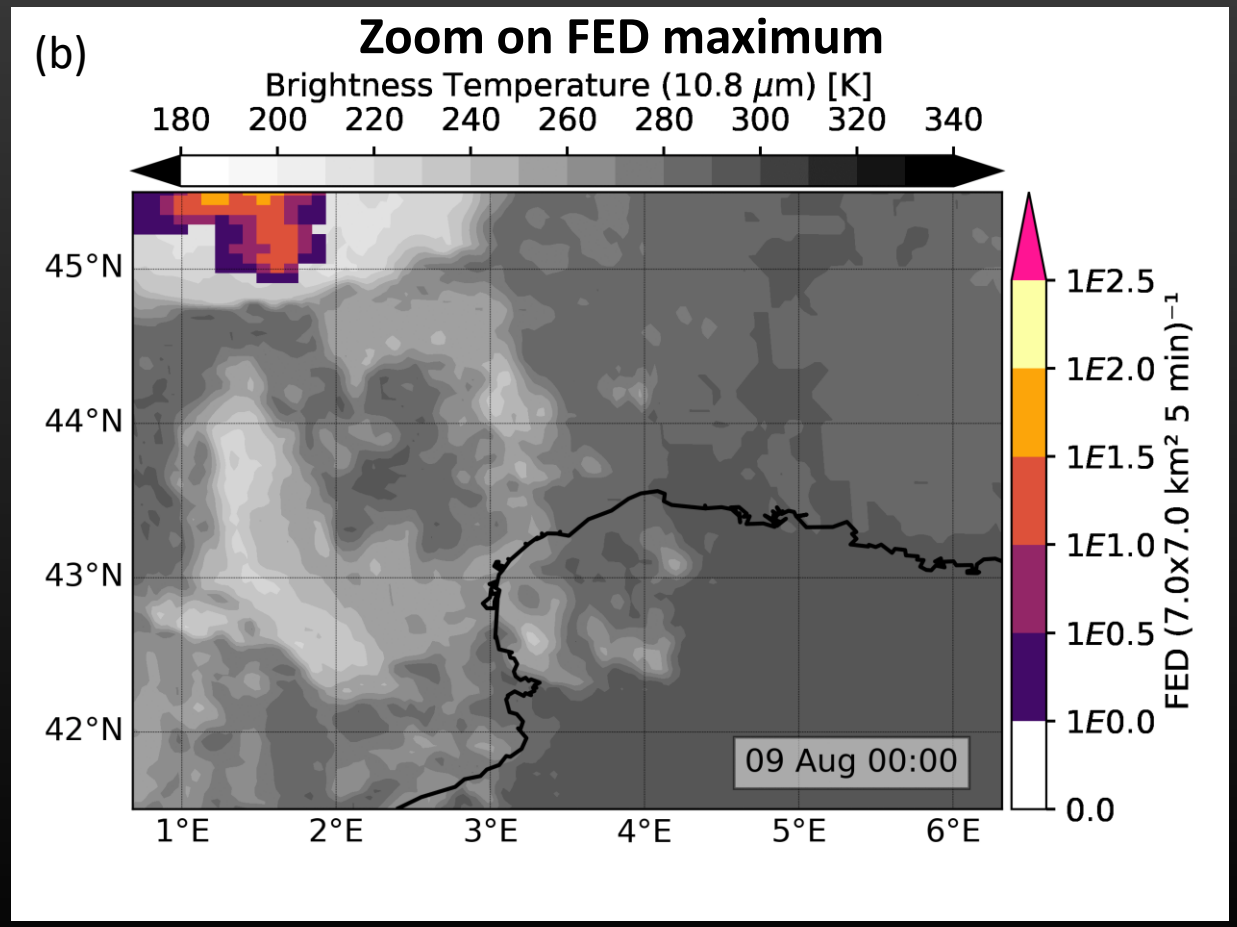



- GEO lightning pseudo-observation generator (Erdmann et al, in review for JTECH) for **MTG-LI spatial** and **temporal resolution**
- **MTG-LI** pseudo-observations of **FED** generated from ground-based Meteorage records

# 1. Pseudo MTG-LI FED as lightning data for the assimilation (2/2)

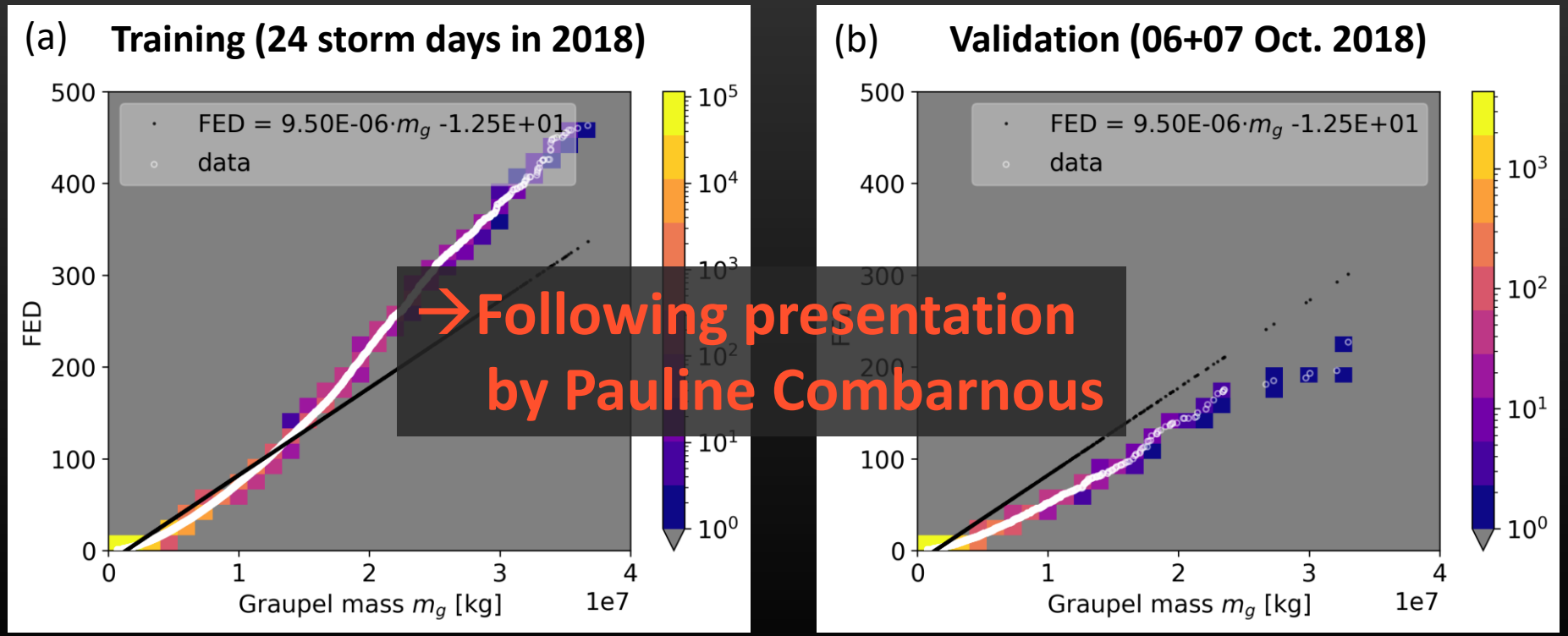
- Ex.: Pseudo **MTG-LI FED** based on Meteorage records + IR 10.8 µm MSG – SEVIRI images for 09 August 2018



# 2. FED forward operator

- Linear relationship between **proxy column graupel mass $m_g$** and **FED**
  *(e.g., Deierling et al., 2008, Barthe et al., 2010, and Bovalo et al., 2019)*
- FED for assimilation: 7 km x 7 km pixels, 10 min integration time windows
- Here: Proxy $m_g$ closest to FED pixel center selected to compare the distributions




→Following presentation by Pauline Combarnous

# 3. 1DBay for LDA (1/2)

- ***FED forward operator*** to create background FED
- **1D Bayesian retrieval** as linear combination of background profiles in a **given *vicinity***
- **Expected RH profile** for each FED observation

$$y_{po}^{RH} = \sum_i x_i^{RH} \frac{W_i}{\sum_j W_j}$$

$$with\ y_{po}^{RH}: Pseudo\ RH\ profile, x_i^{RH}: Background\ RH\ profiles, W_i: Weights$$

$$W_i = \exp\left(-\frac{1}{2}\frac{\left(FED - \boldsymbol{F}(x_i)\right)^2}{\sigma_o^2}\right)$$

$$with\ FED: Flash\ Extent\ Density\ observation\ [dB], \boldsymbol{F}: FED\ forward\ operator,$$

$$x_i: AROME\ background\ (here\ graupel\ mass),$$

$$\sigma_o: combined\ observation\ and\ observation\ operator\ error\ (here\ 2\ dB)$$

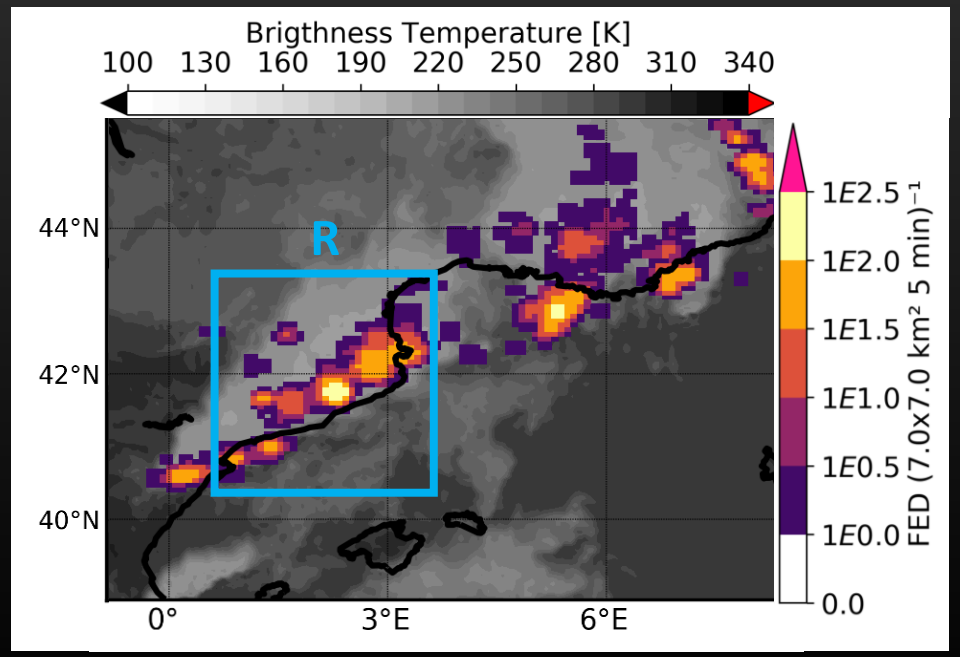
# 3. 1DBay for LDA (2/2)

## Thinning

- Avoid correlations of observation errors
- Regular reduction of assimilated RH profiles as observations
- *Thinning factor 2*

## 1DBay vicinity

- Vicinity size (R) of 160 km to **500 km**
- Difference of humidity and FED fields
- Cloud area estimated
- Selection of background profiles



# AROME-France experimental setup

## Temporal setup

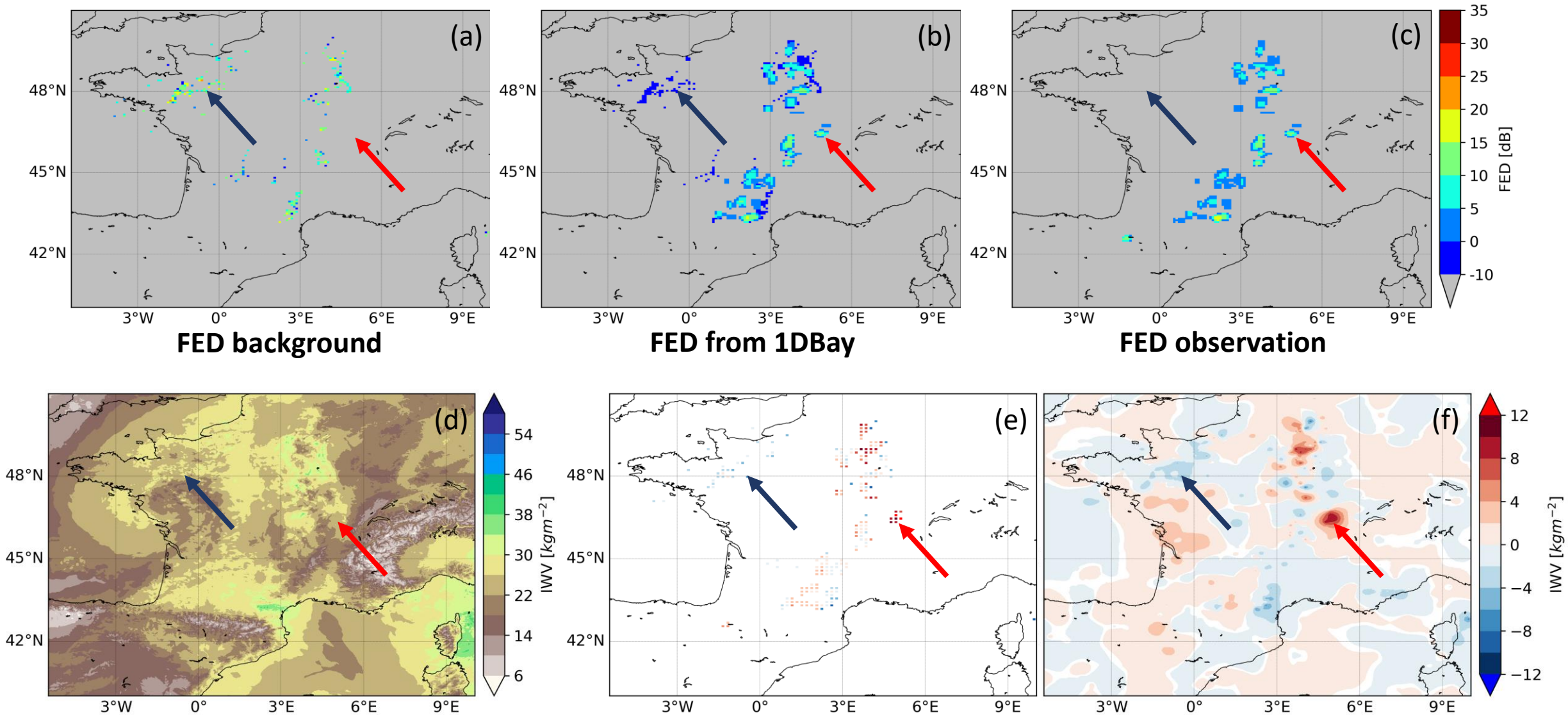
1. **24 hour** run with hourly data **assimilation**, e.g., 06 October 2018 00 UTC to 23 UTC
2. **30 hour free run**, e.g., 07 October 2018 00 UTC to 08 October 06 UTC

## Experiments

| | | |
|---|---|---|
| **CTRL** | Control | Assimilation without RDA and LDA |
| **RDA** | Radar Data Assimilation | CTRL + radar radial velocity and radar reflectivity |
| **LDA** | Lightning data assimilation | CTRL + FED |
| **RDA_LDA** | Radar and lightning data assimilation | CTRL + radar radial velocity and radar reflectivity + FED |

- LDA uses the cloud area estimation during the 1DBay
  (experiments without the cloud estimation were conducted but are not shown)

# Example: Effects of FED assimilation on the AROME-France analysis

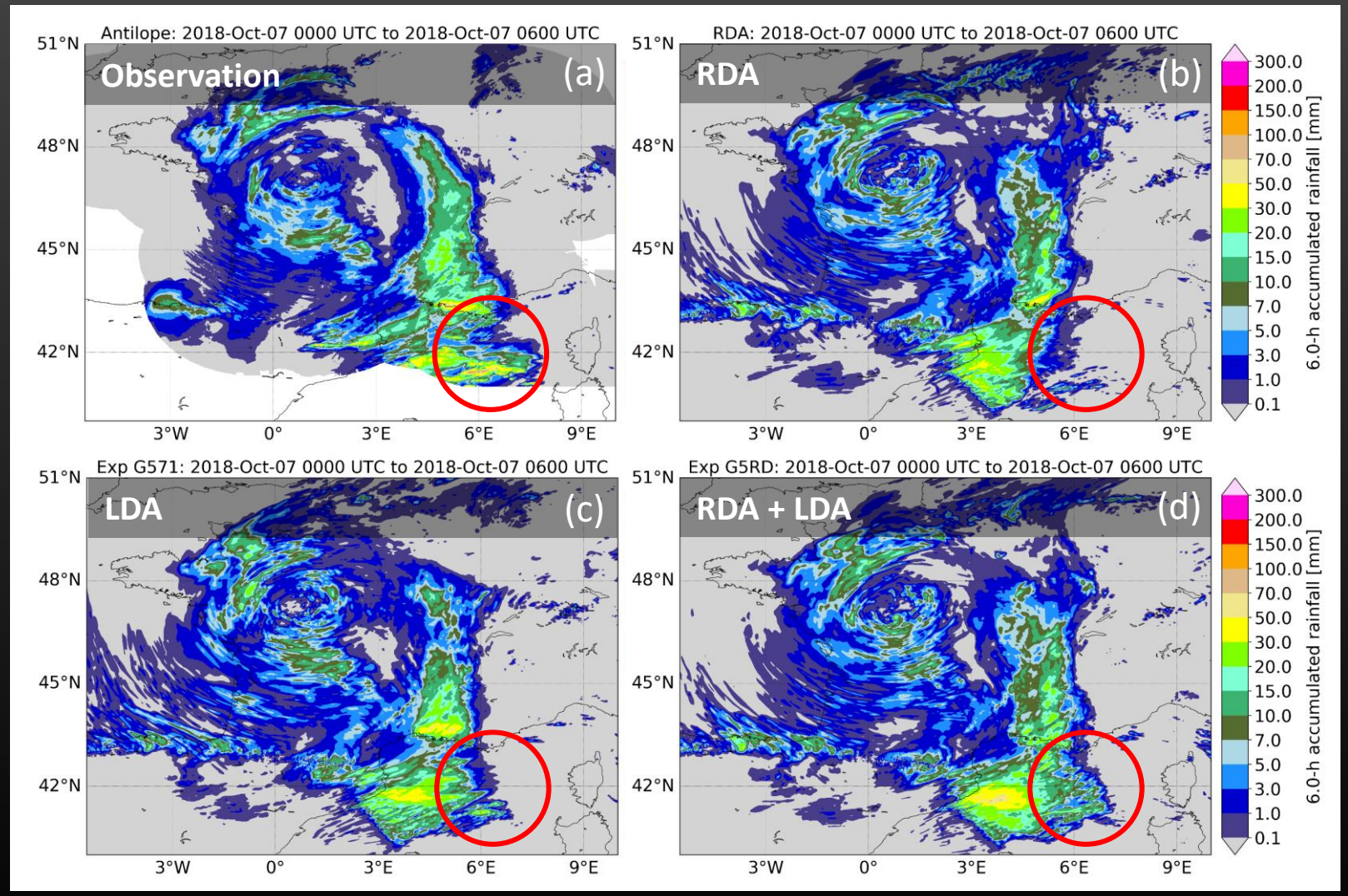



FED background | FED from 1DBay | FED observation

Integrated water vapor (IWV) background | IWV background change by LDA | IWV analysis - background

# Fractions skill scores (FSSs) for rainfall and FED (1/2)

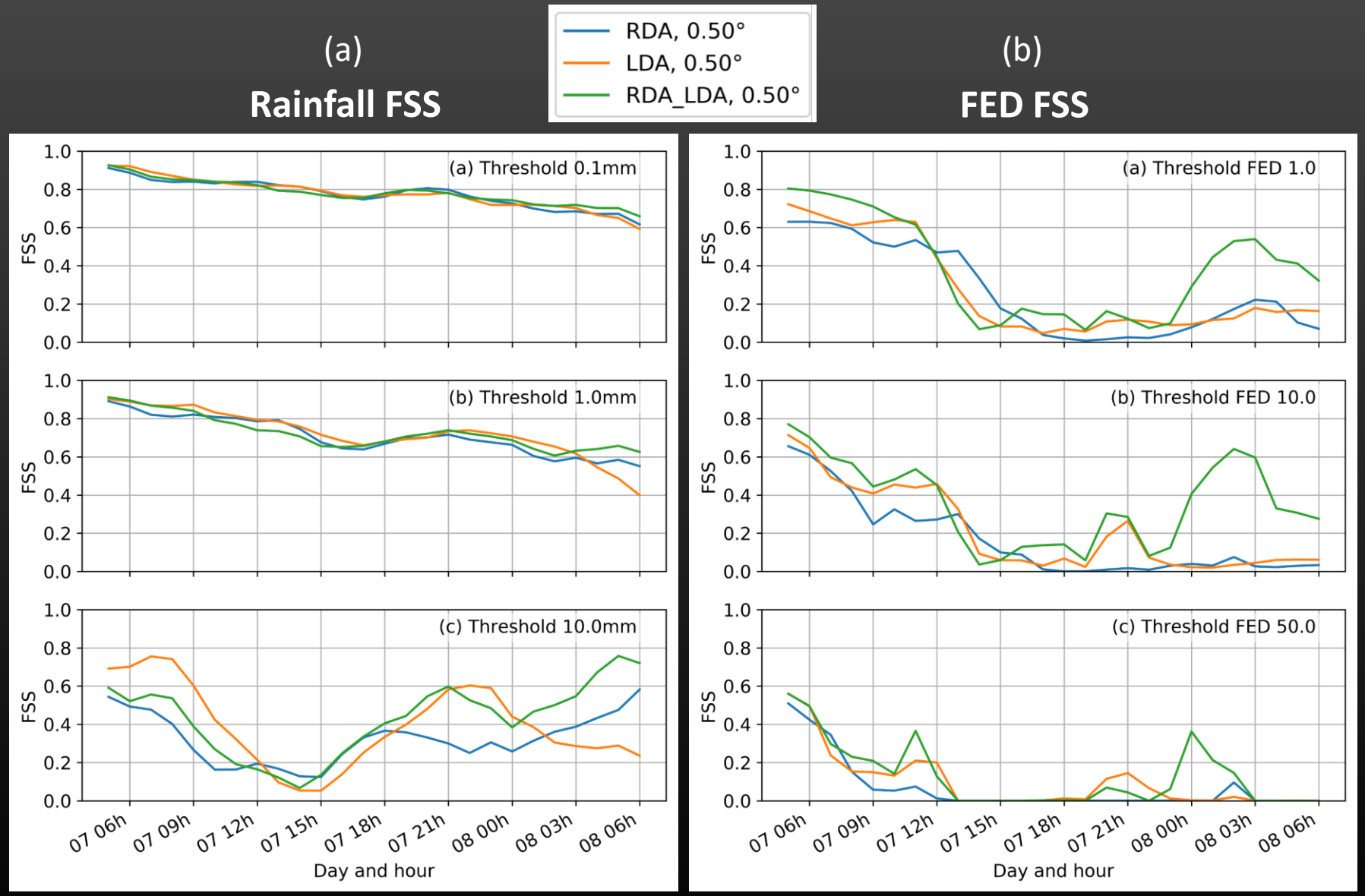
- 6 hour accumulated rainfall
- *Antilope* observations (rain gauges + radars)
- First 6 hours of free run, i.e, 07 Oct 00 UTC to 06 UTC
  - RDA
  - LDA
  - RDA + LDA



# Fractions skill scores (FSSs) for rainfall and FED (2/2)

- Compare two 2D-fields
- **Threshold** values for binary True-False information
- **Neighborhood** considered
- **FSS of 1** for **perfect** prediction for given neighborhood
- FSS of 0 for no skill

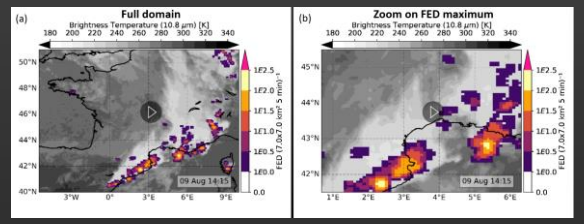
*(Roberts and Lean, 2008, and Faggian et al., 2015)*



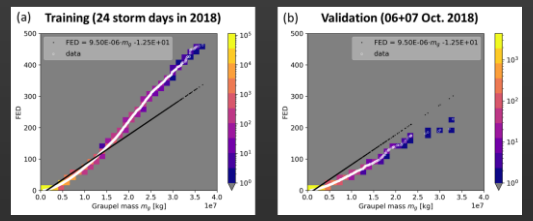
# Summary: MTG-LI FED assimilation in AROME-France

**LDA concept for AROME-France**

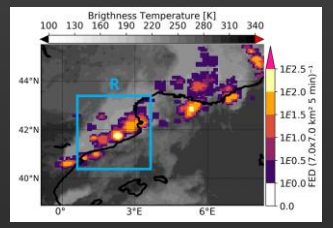
MTG-LI pseudo FED




Linear FED forward operator

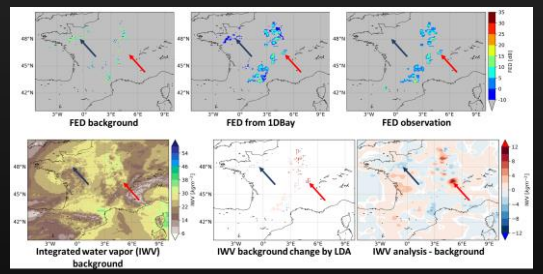



1DBay+3DVar LDA



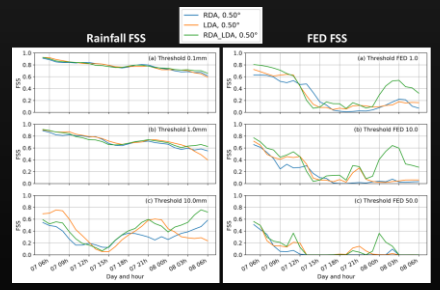
**4 case studies as proof-of-concept**

IWV: background → analysis:
**Increase** in regions of high obs. FED
**Decrease** where spurious AROME FED




FSS: **LDA skill** higher or lower than RDA skill → possible **improvements**:

- FED forward operator
- LDA cloud area estimation
- Coupled RDA-LDA approach




**Paper in preparation**

**Thank you for the attention!**

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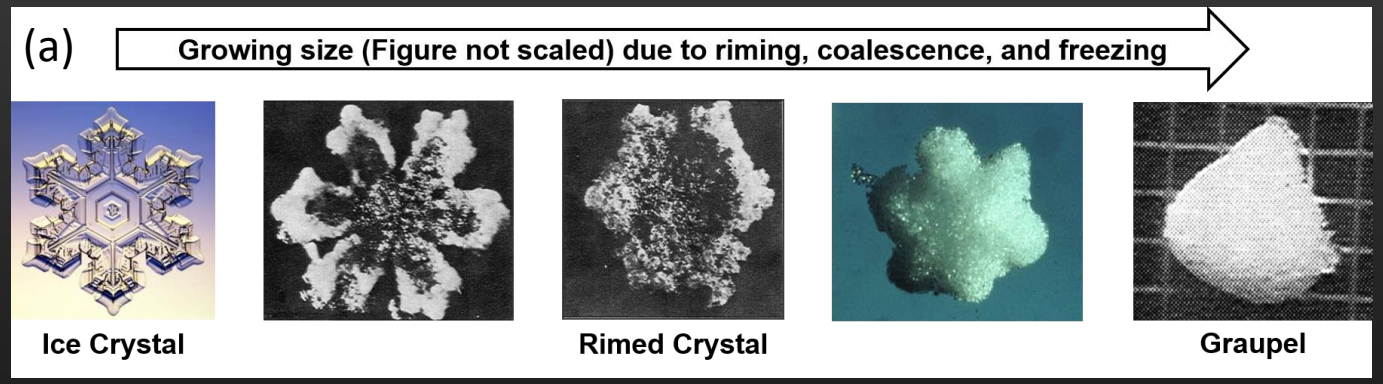
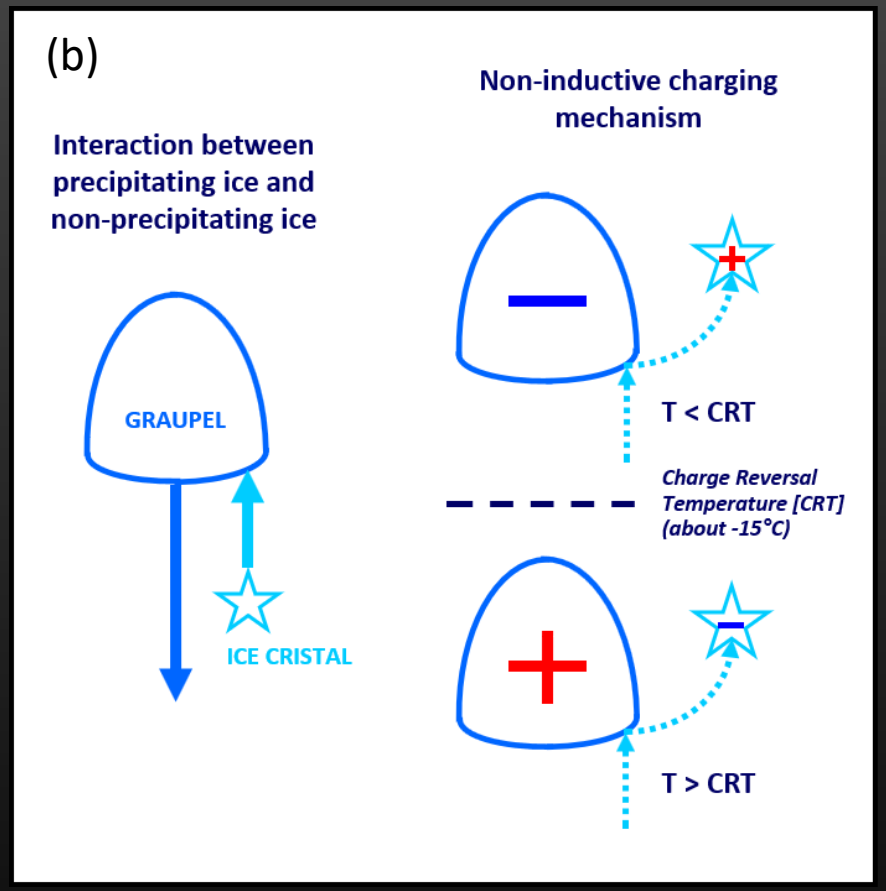
# Backup slides

# Cloud electrification

- Need of **electric field** sufficient to cause a **breakdown**
- **Non-inductive** graupel ice charging



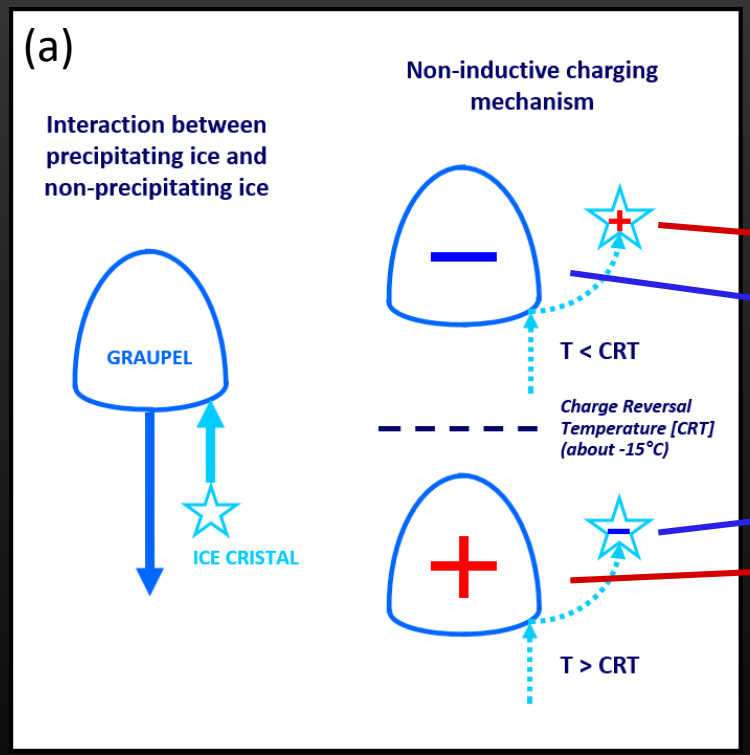

*From personal communication, S. Coquillat (2019)*

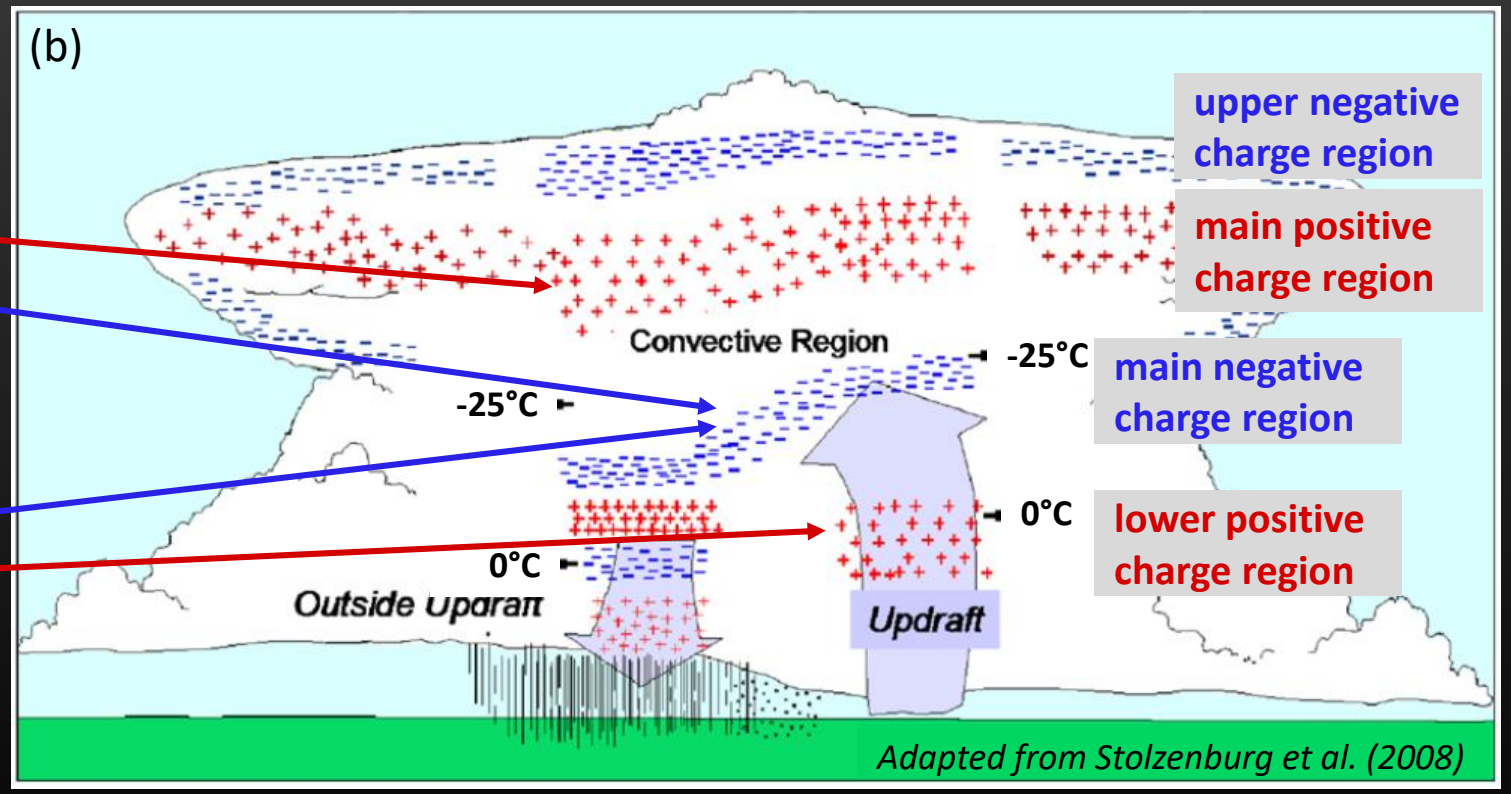



- **Other hypothesis**:
  - Inductive charging: particle-particle and ion capture
  - Convective charging: importance of the screening layer and corona discharges

# Cloud electrification

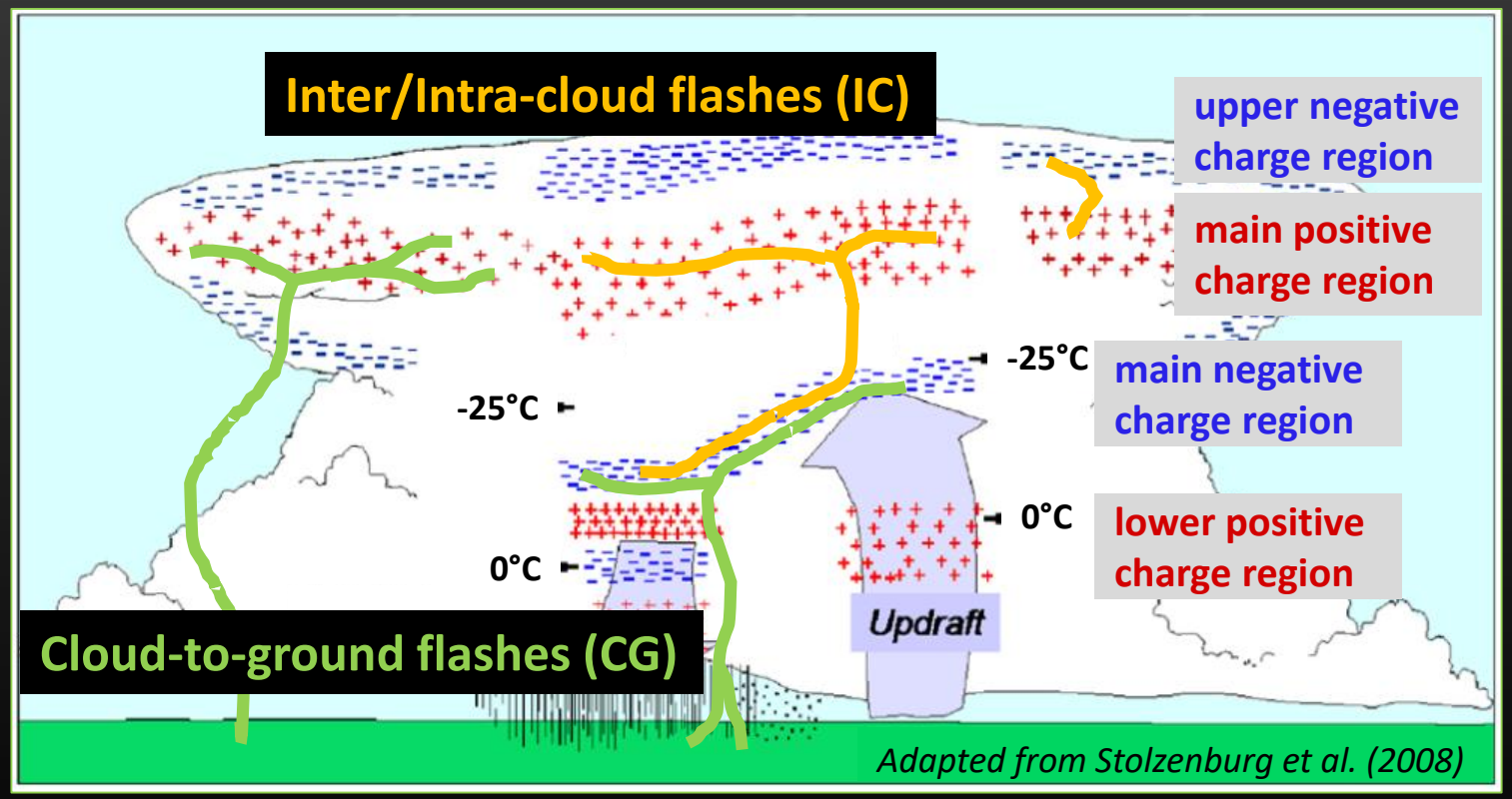
- **Transport** of charged particles → **Charge structure** within thunderclouds (normal polarity storm)



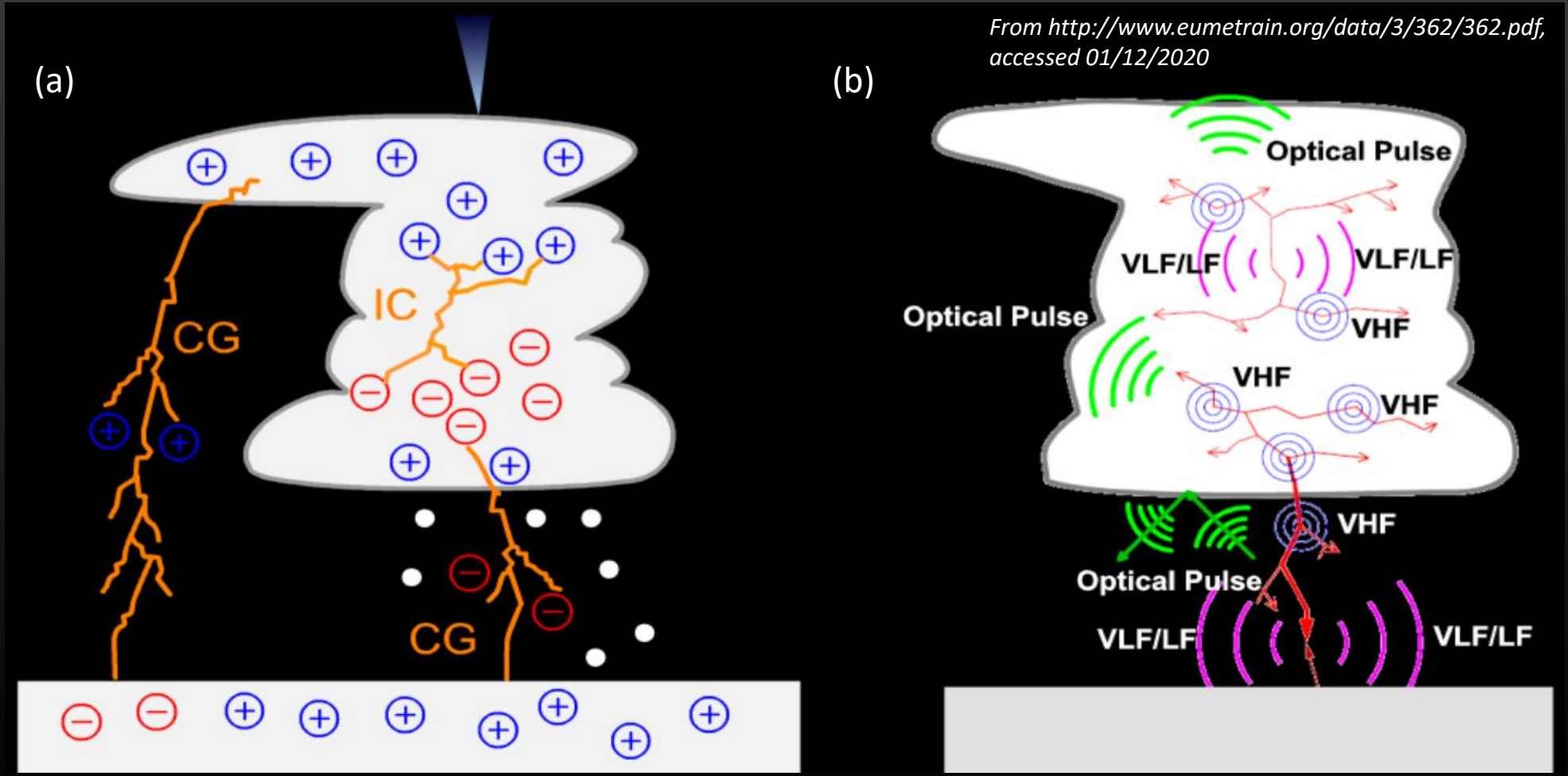
# Cloud electrification

- **Flashes** as discharges between charge regions of **the cloud and the ground** and **inside one cloud or between clouds**



# Electromagnetic emissions from lightning

- **Radio frequency**, e.g., for **Meteorage** low frequency (LF) **ground-based network**
- **Optical pulses**, e.g., seen by **satellites**



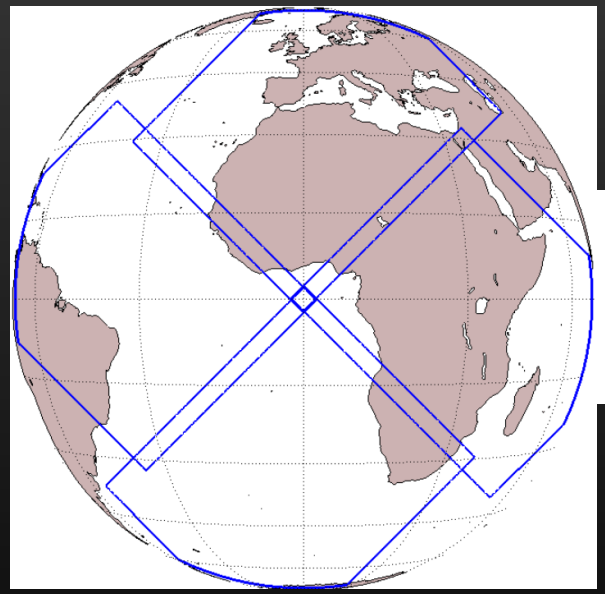

*From http://www.eumetrain.org/data/3/362/362.pdf, accessed 01/12/2020*

# Lightning observations

## Spaceborne sensors on Geostationary (GEO) and low Earth orbit (LEO)

- E.g., GEO **Meteosat Third Generation (MTG) Lightning Imager (LI)** coverage

(a)



**Projected field of view (4 LI cameras)**

*From http://www.eumetrain.org/data/3/362/362.pdf, accessed 01/12/2020*

(b)

(c)

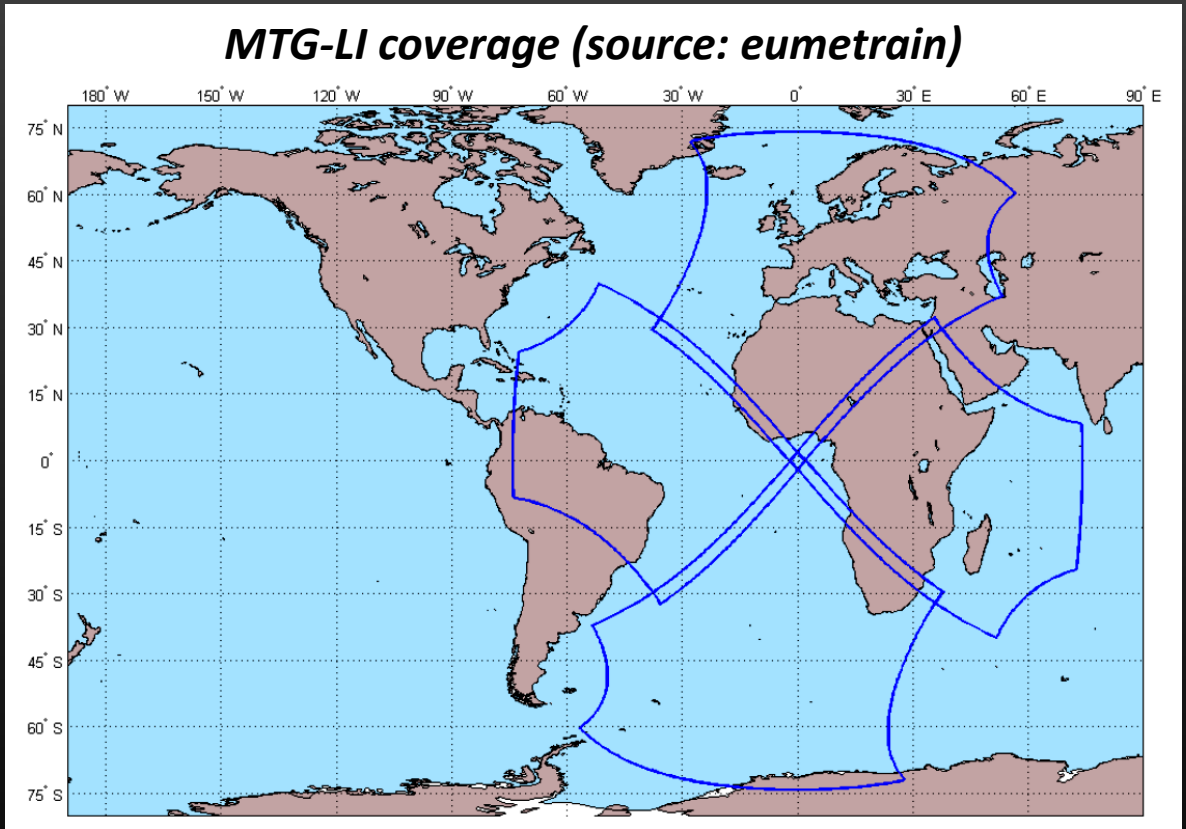
*From https://directory.eoportal.org/web/eoportal/satellite-missions/iss-lis, accessed 05/04/2020*

(d)

## Ground-based lightning locating systems (LLSs), e.g., French **Meteorage** network

# MTG-LI

- 777.4 nm oxygen band optical sensor
- 1 ms temporal resolution
- Spatial resolution of 4km nadir and about 7 km over France



# GLM and NLDN data - GEO lightning pseudo-observation generator (2/4)

**Ground-based LF stroke-type data**

## Training Input

- 6 NLDN **features** per flash:
  - Extent,
  - Stroke+pulse number,
  - Duration,
  - Mean absolute current,
  - Maximum current,
  - CG ratio
- 3 observed GLM **targets** per flash:
  - Extent,
  - Event number,
  - Duration

## 1. Pseudo-GEO target generator

- LF observation flash features
- Machine learning based target generator
- Simulated pseudo-GEO targets

## 2. Simulation of pseudo-GEO events

- Use simulated pseudo-GEO targets
- Pseudo-GEO events on regular lat-lon grid

## Test

- Statistics of distributions of observed and pseudo-GLM flash characteristics
- Comparison of observed GLM FED and simulated FED

**GEO Flash Extent Density (FED)**

- Submitted paper to JTECH: **Erdmann et al.** [Erdmann, F., Caumont, O., and Defer, E.: A geostationary lightning pseudo-observation generator utilizing low frequency ground-based lightning observations, submitted to the Journal of Atmospheric and Oceanic Technology in October 2020]

# Overview: Concept of the lightning data assimilation (LDA)

**NWP: AROME-France background, $x_b$**

**FED forward operator, $F$**

**Background FED**

**Pseudo MTG-LI FED**

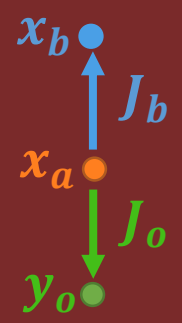
**1D Bayesian (1DBay) retrieval**

**Pseudo relative humidity (RH) profiles**

**NWP: AROME-France forecast**

**Assimilation cycle**

**NWP: AROME-France analysis, $x_a$**

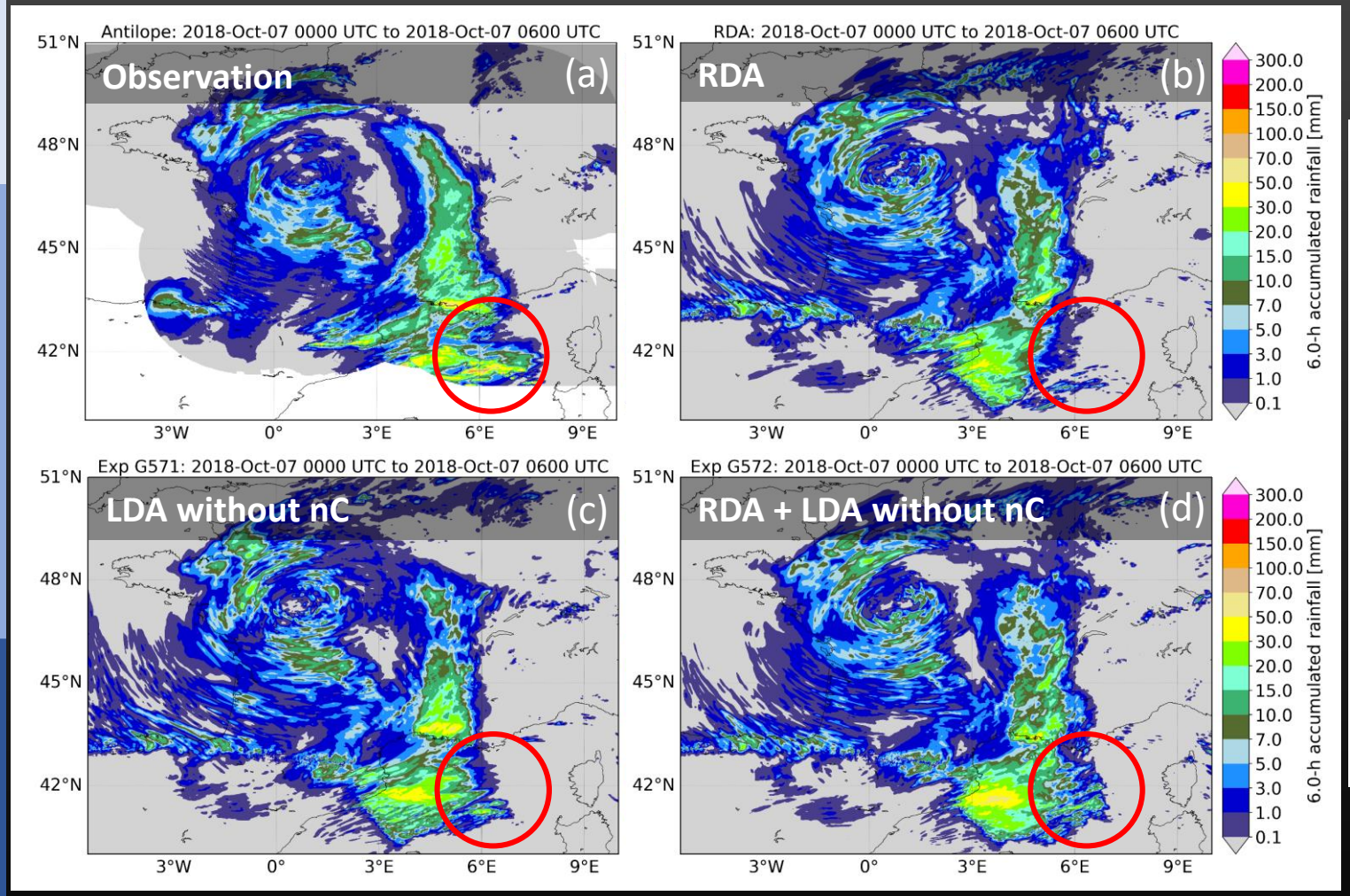


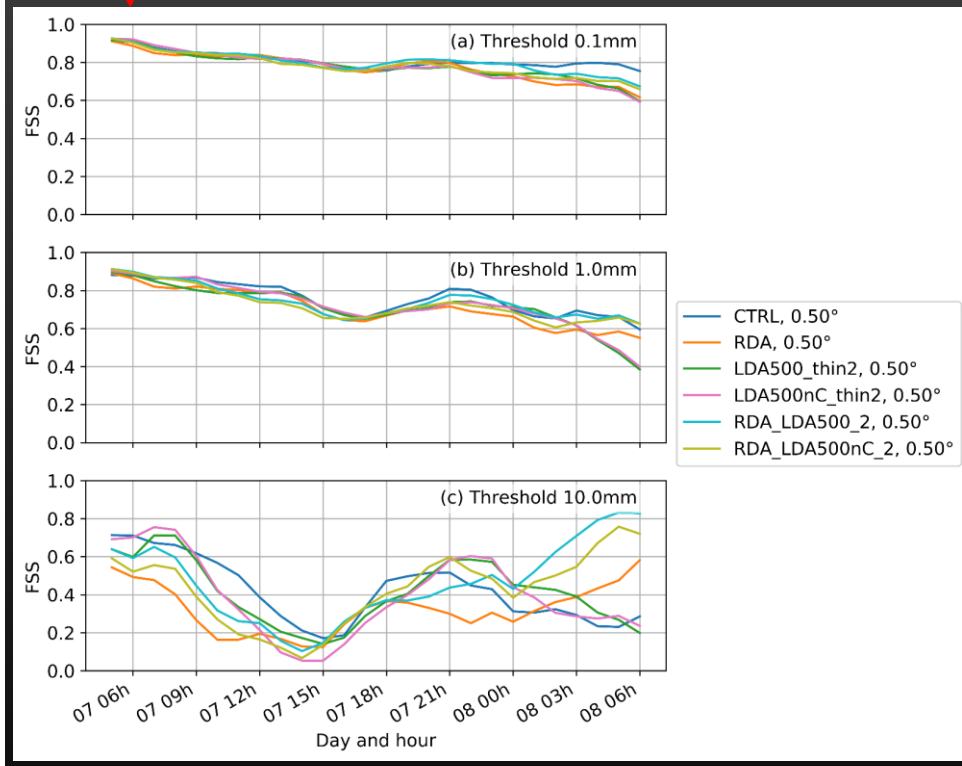

**3D Variational (3DVar) Assimilation** with *cost function J*

$$J(x) = \frac{1}{2}(x - x_b)^T \mathbf{B}^{-1}(x - x_b) + \frac{1}{2}[y_o - H(x)]^T \mathbf{R}^{-1}[y_o - H(x)]$$

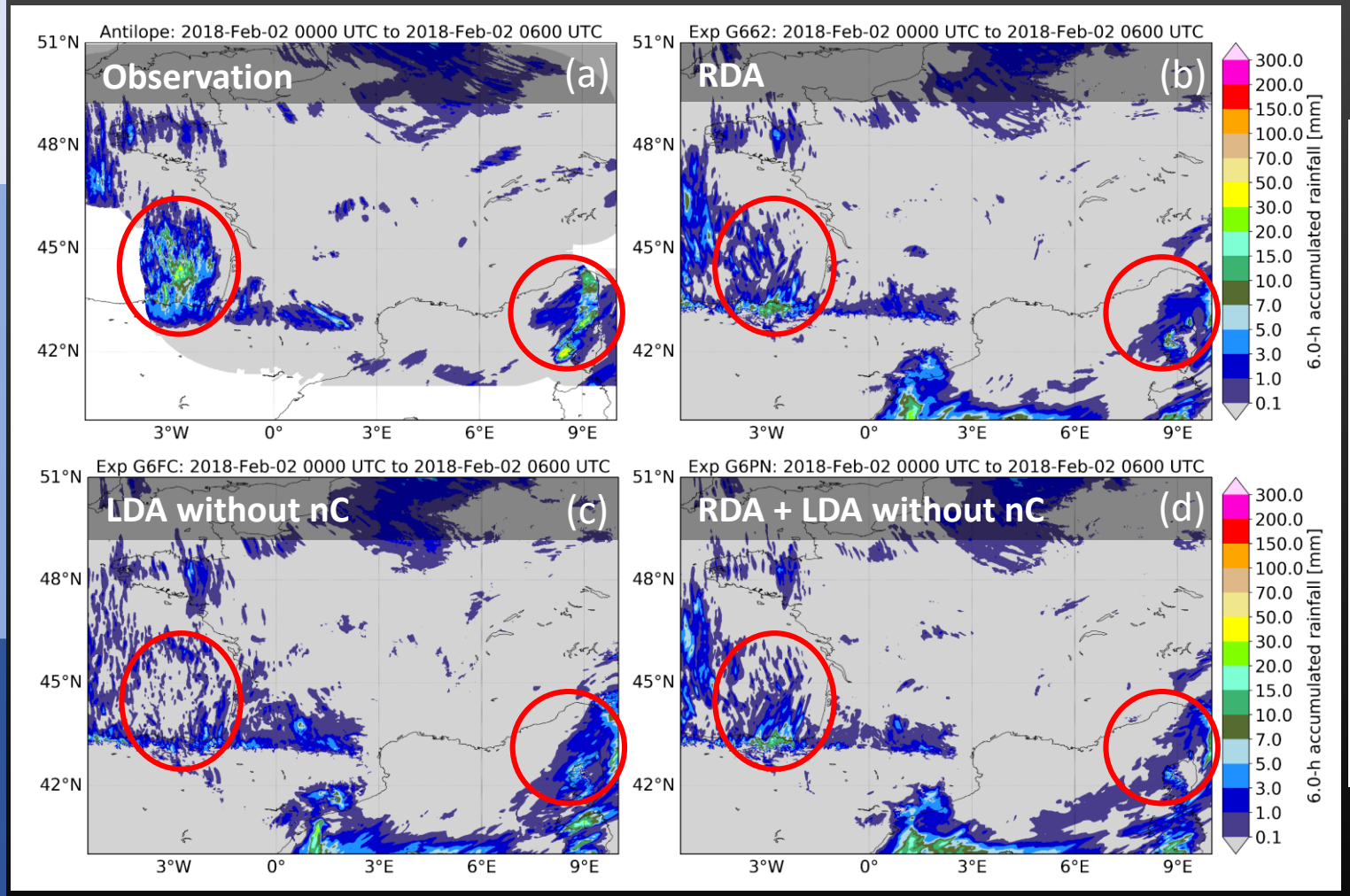
*with $x$: state vector, $x_b$: background state,*
*$\mathbf{B}$: background error covariance matrix, $y_o$: observation vector,*
*$H$: observation operator, $R$: observation error covariance matrix*

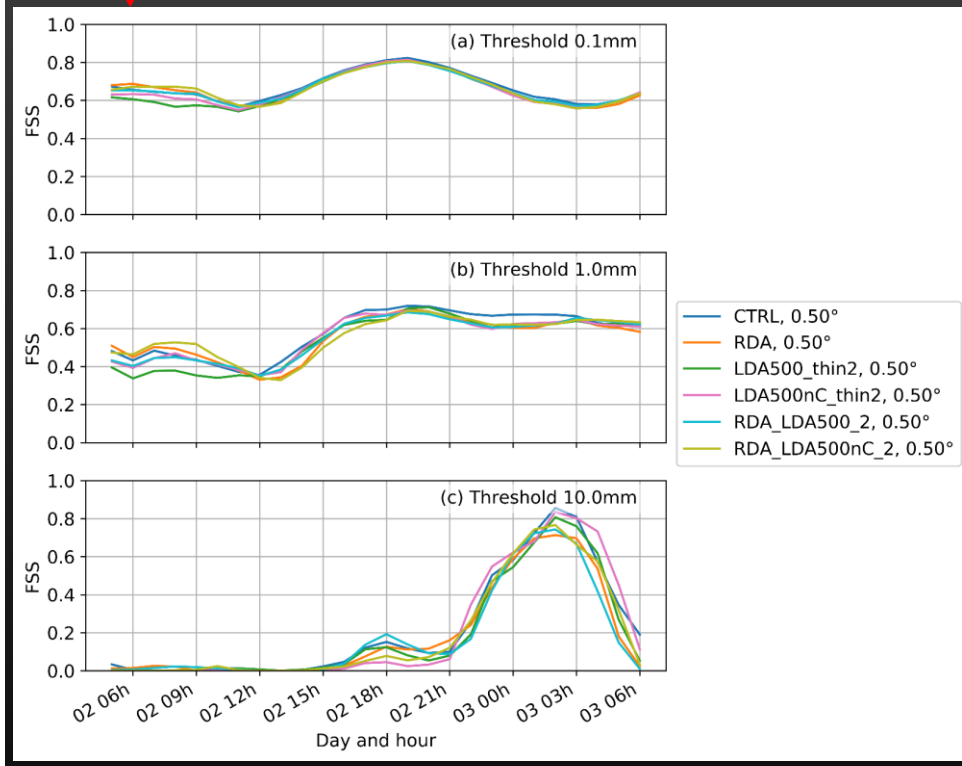
# Case 1: 07-08 October 2018



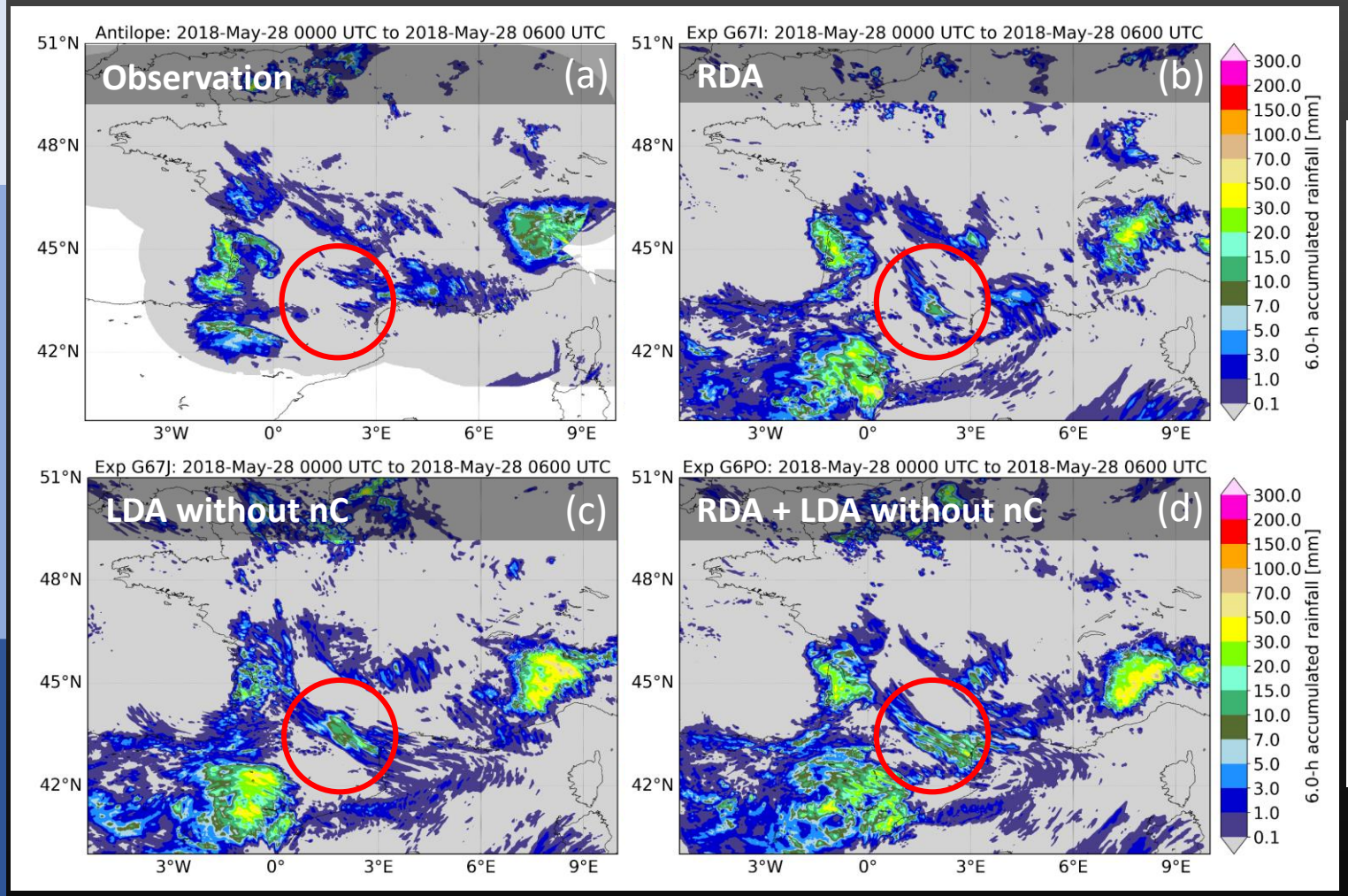



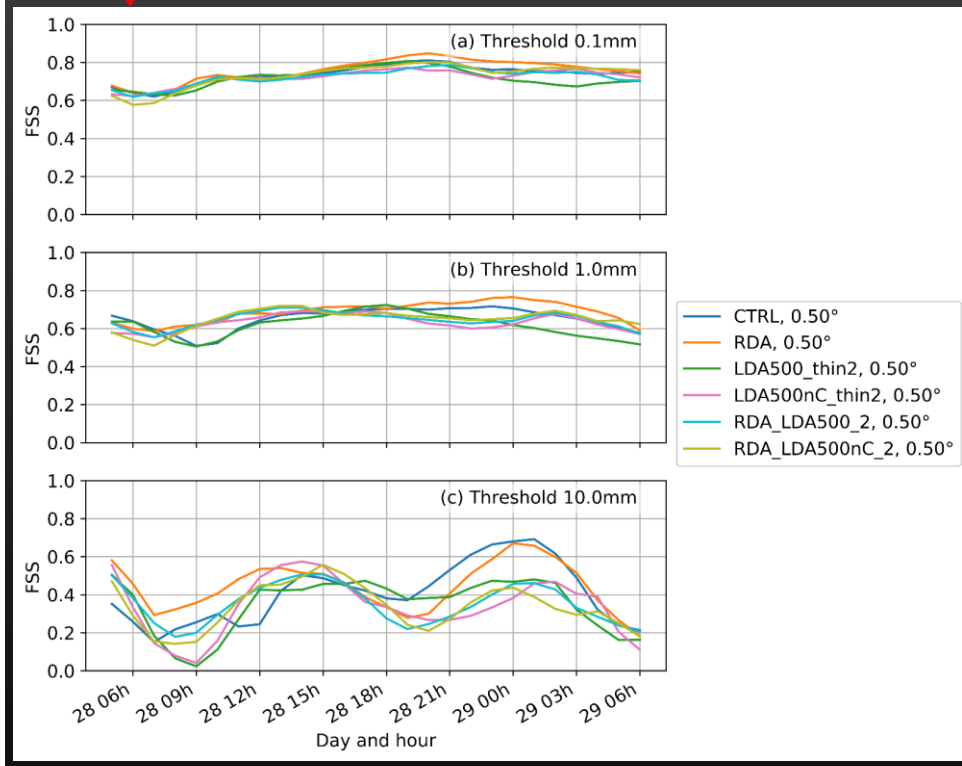
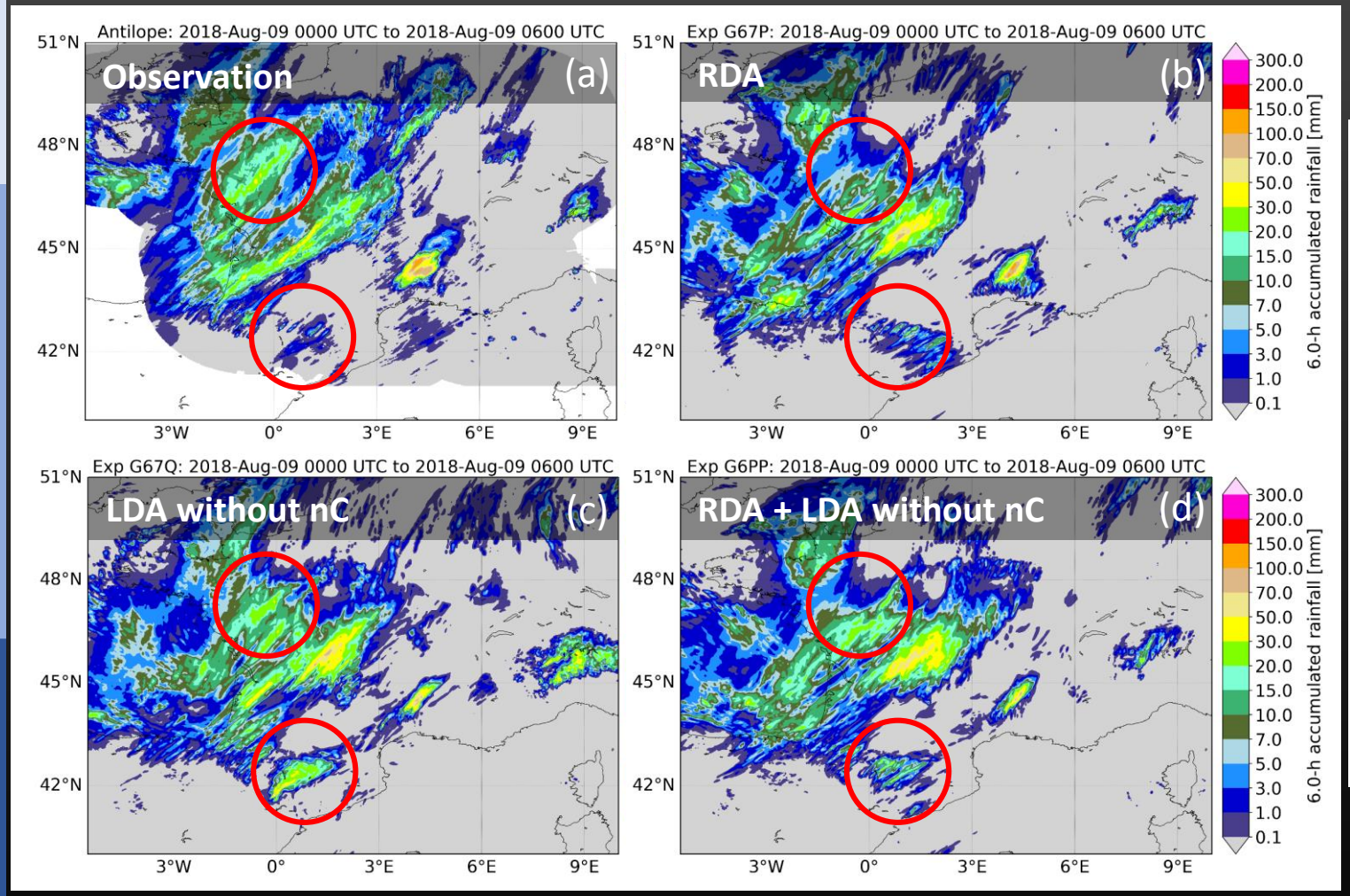
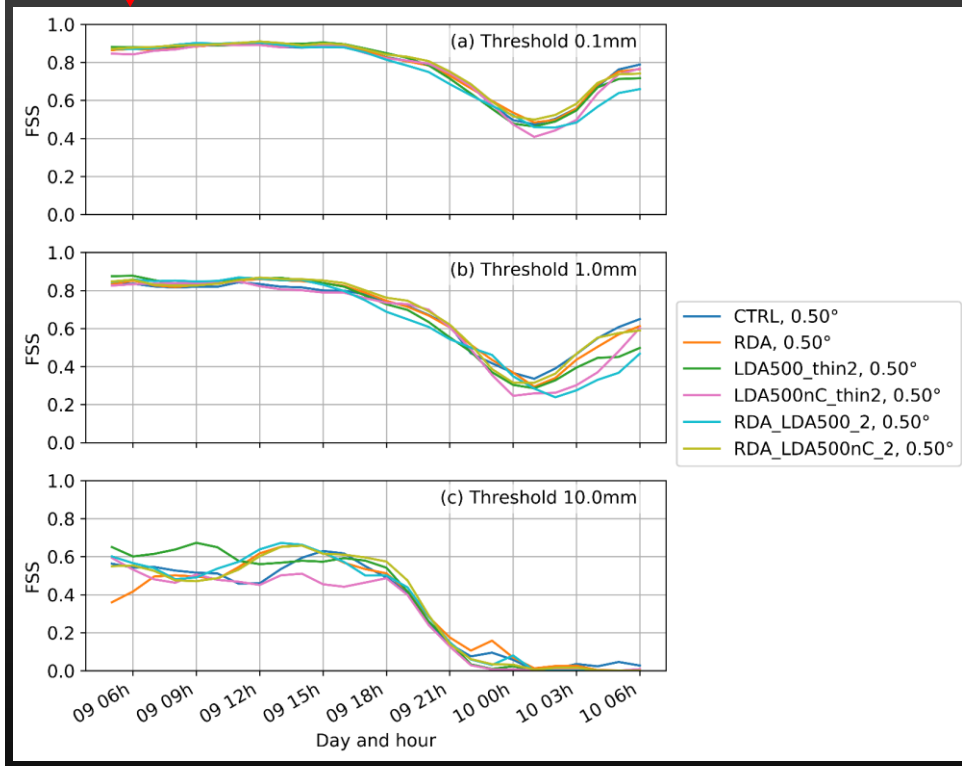
# Case 2: 02-03 February 2018



# Case 3: 28-29 May 2018






# Case 4: 08-09 August 2018