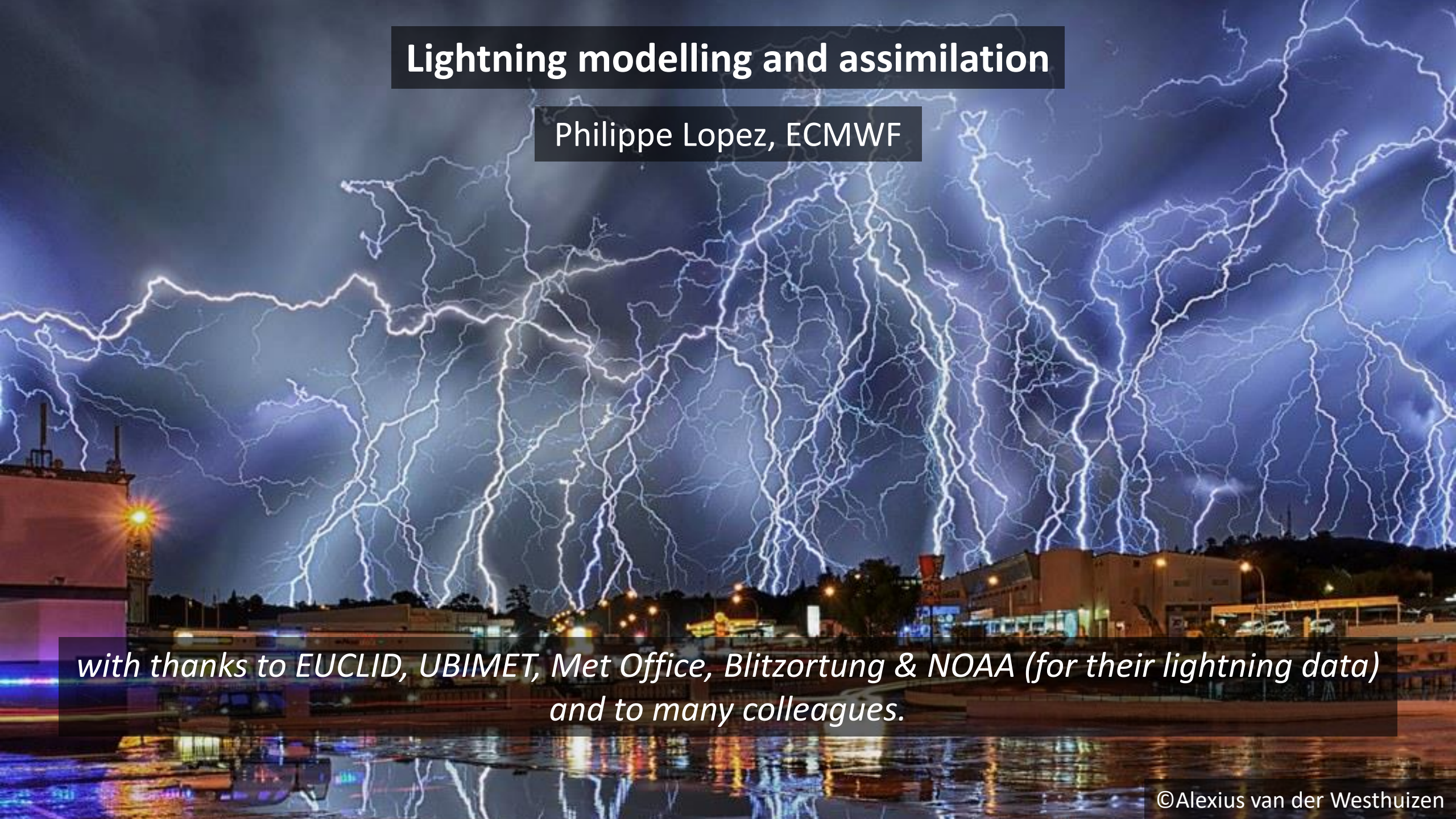
Lightning modelling and assimilation

Philippe Lopez, ECMWF



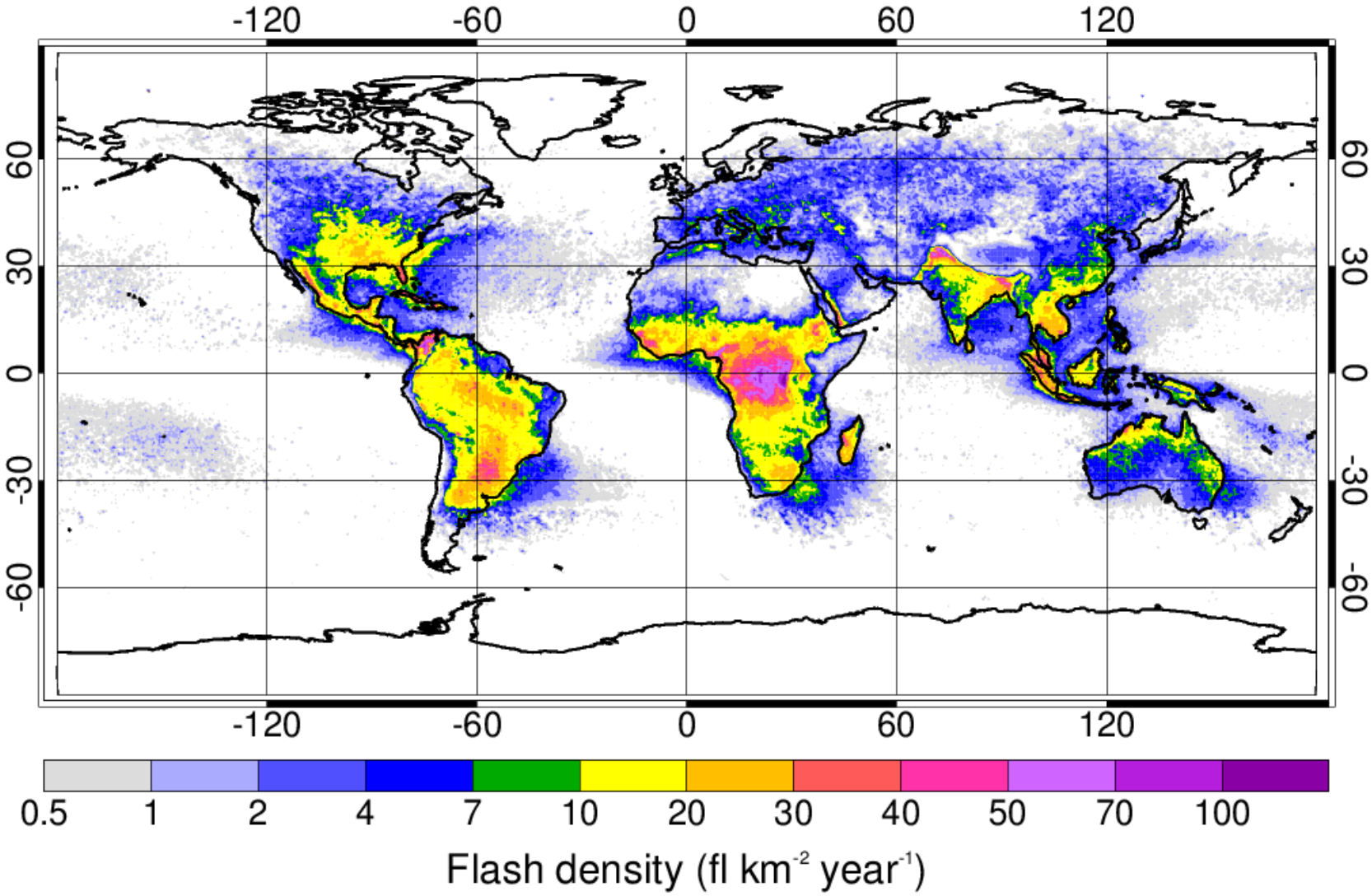
with thanks to EUCLID, UBIMET, Met Office, Blitzortung & NOAA (for their lightning data) and to many colleagues.

Outline

- Lightning parameterization in the IFS.
- Examples of its validation in forecasts.
- Lightning data assimilation: first experimentation with GOES-16 GLM.
- Summary and plans.
- A little bonus…

Lightning climatology

Annual mean lightning flash densities from LIS/OTD (1995-2010; Cecil et al. 2014):



Global mean = 2.86 flashes km^{-2} $year^{-1}$ ≈ 46 flashes s^{-1}.

ECMWF

The new parameterization predicts <u>total (CG+IC) lightning flash densities</u> from a set of predictors diagnosed from the convection scheme of the IFS:

$$f_T = 37.5\, Q_R \sqrt{CAPE} \left[min(z_{base}, 1.8) \right]^2$$

where

$$Q_R = \int_{z_{0°C}}^{z_{-25°C}} q_{graup} \left(q_{cond} + q_{snow} \right) \overline{\rho}\, dz$$

Proxy for the charging rate (collisions btw. hydrometeors)

with

$$q_{graup} = \frac{\beta\, P_f}{\overline{\rho}\, V_{graup}}$$

graupel content [kg kg^{-1}]
graupel fall velocity set to 3.0 m s^{-1}

and

$$q_{snow} = \frac{(1-\beta)\, P_f}{\overline{\rho}\, V_{snow}}$$

snow content [kg kg^{-1}]
snow fall velocity set to 0.5 m s^{-1}

$CAPE$ = convective available potential energy [J kg^{-1}]
P_f = convective frozen precipitation flux [kg m^{-2} s^{-1}],
z_{base} = convective cloud base height [km],
q_{cond} = convective cloud condensate content [kg kg^{-1}],
β = 0.7 over land and 0.45 over ocean (graupel/snow partitioning).

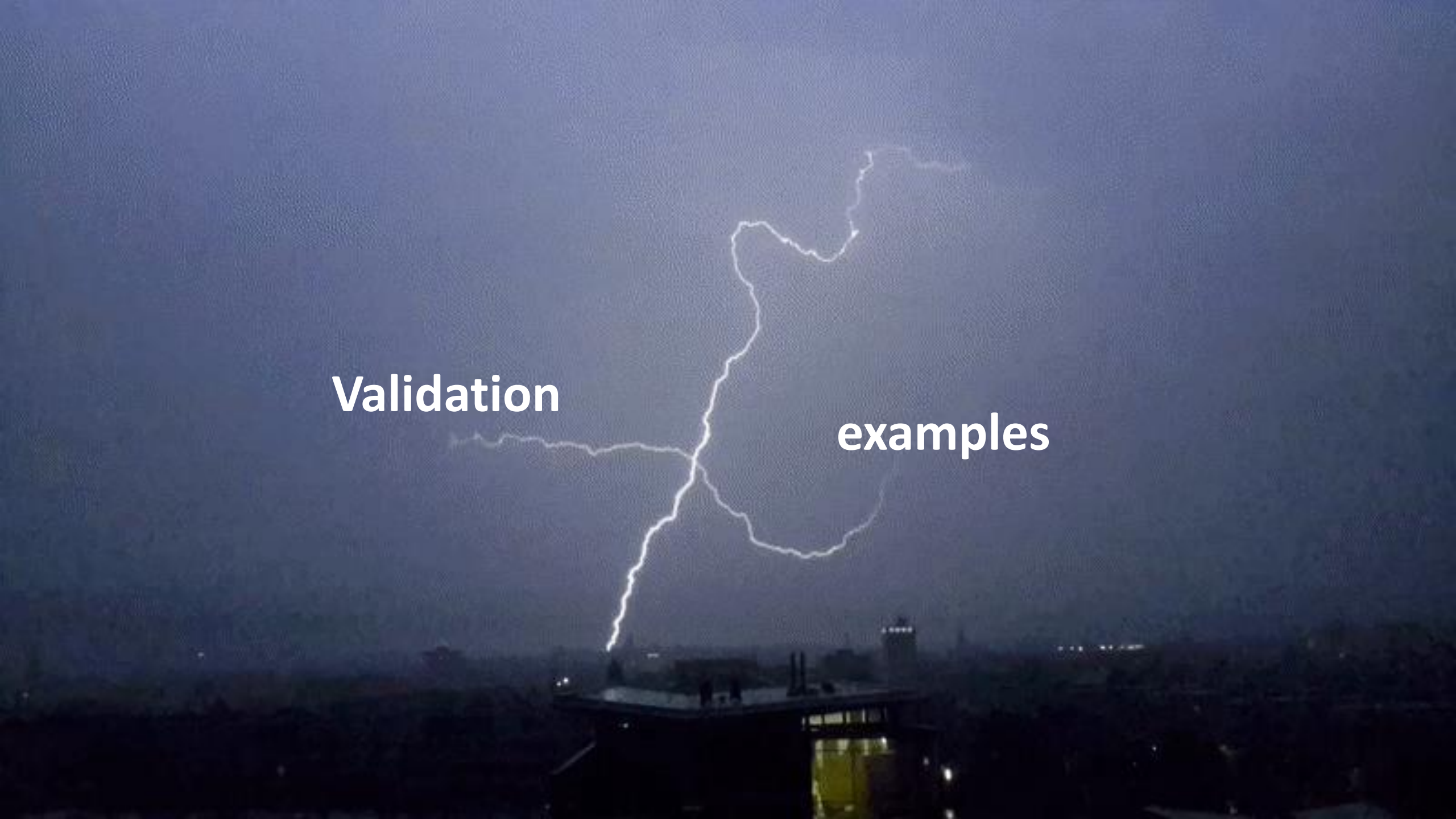
Lopez 2016, MWR

Lightning parameterization in the IFS

- The parameterization became operational in both deterministic (9-km resolution) and ensemble (18-km resolution) forecasts on 7 June 2018.

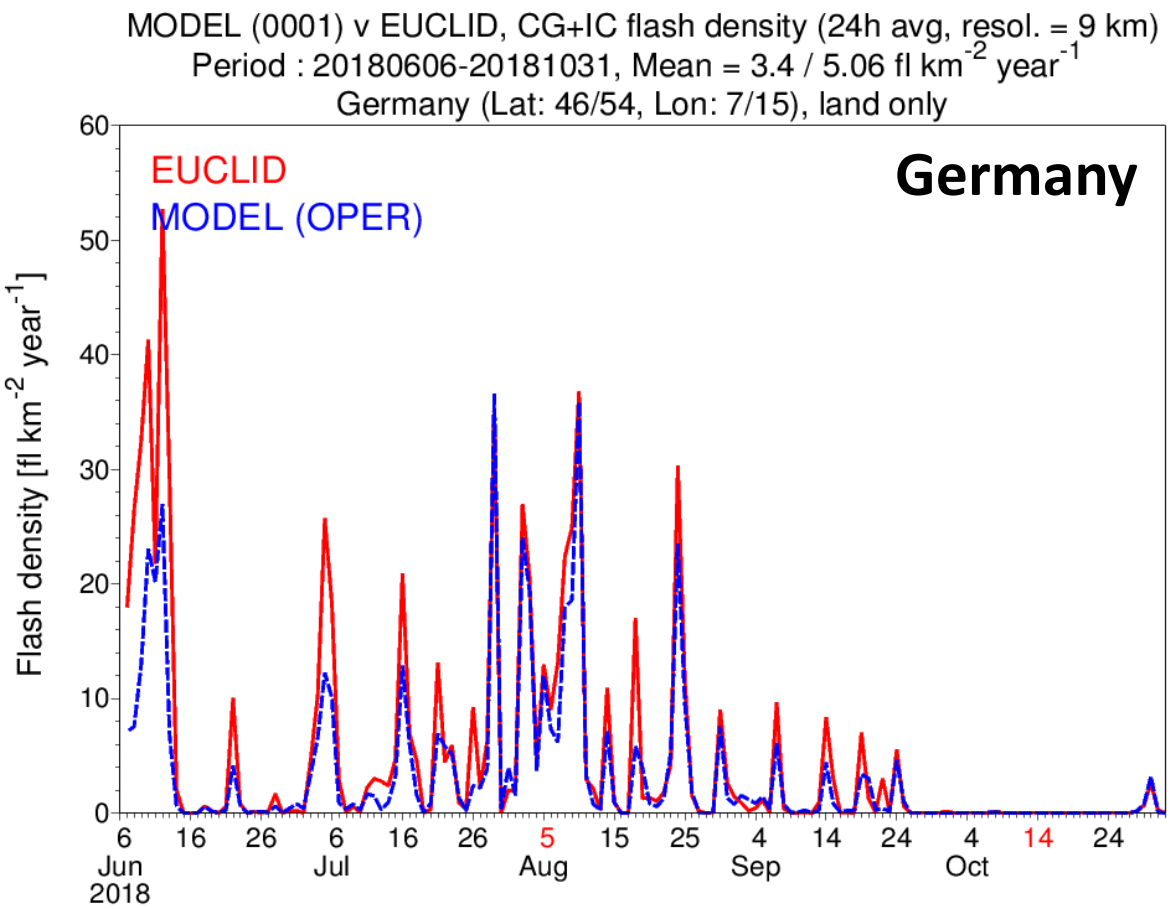
- It outputs total lightning flash densities that are both “instantaneous” (over a model time step) and averaged over 1, 3 and 6 hours (all expressed in flashes/km^2/day).

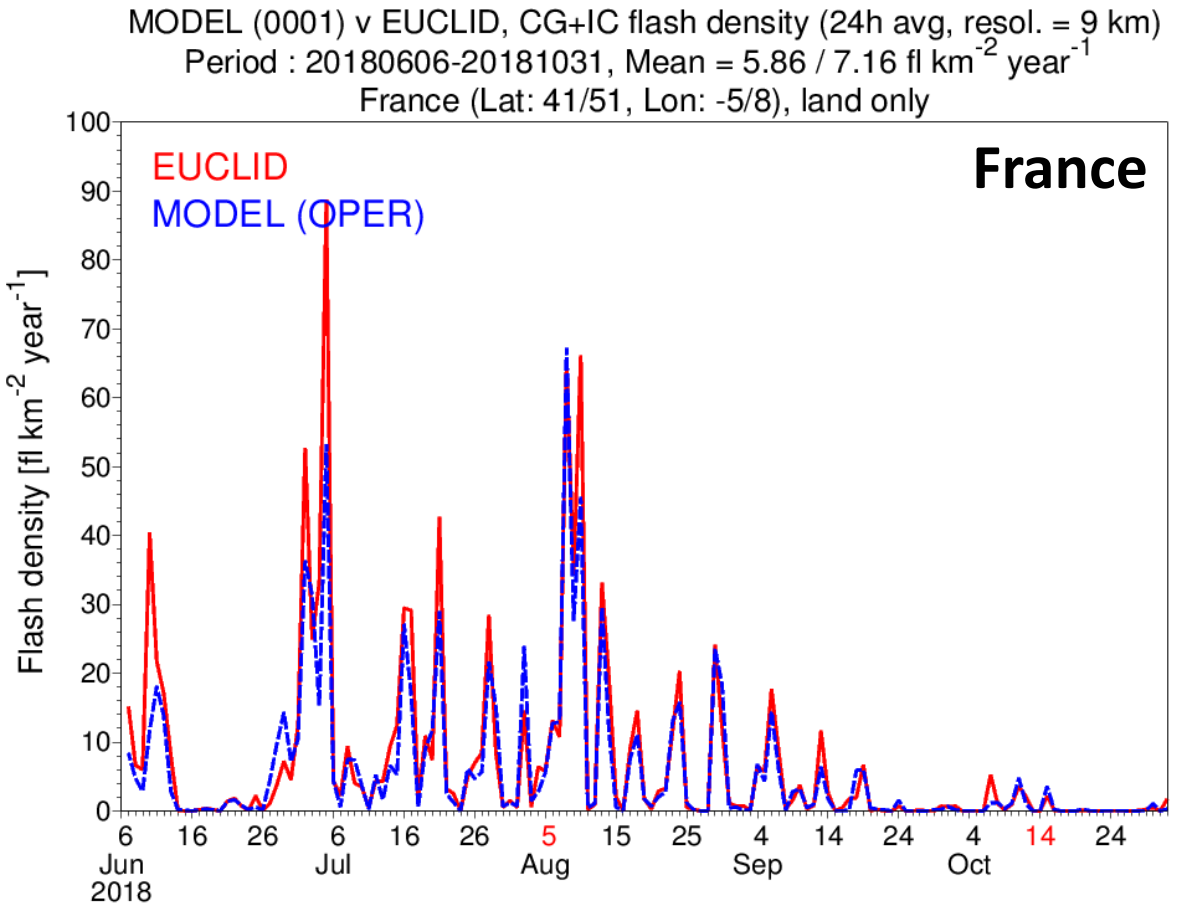
- It is also being used to forecast:
  - lightning-triggered wildfires,
  - atmospheric NOx emissions from lightning (CAMS chemistry model).


Validation
examples

Comparison of ECMWF MODEL with EUCLID (lightning flash densities)

Time series of daily mean flash densities over various European land subdomains during the period 6 Jun-31 Oct 2018: ECMWF model (blue; 9 km) against EUCLID observations (red).



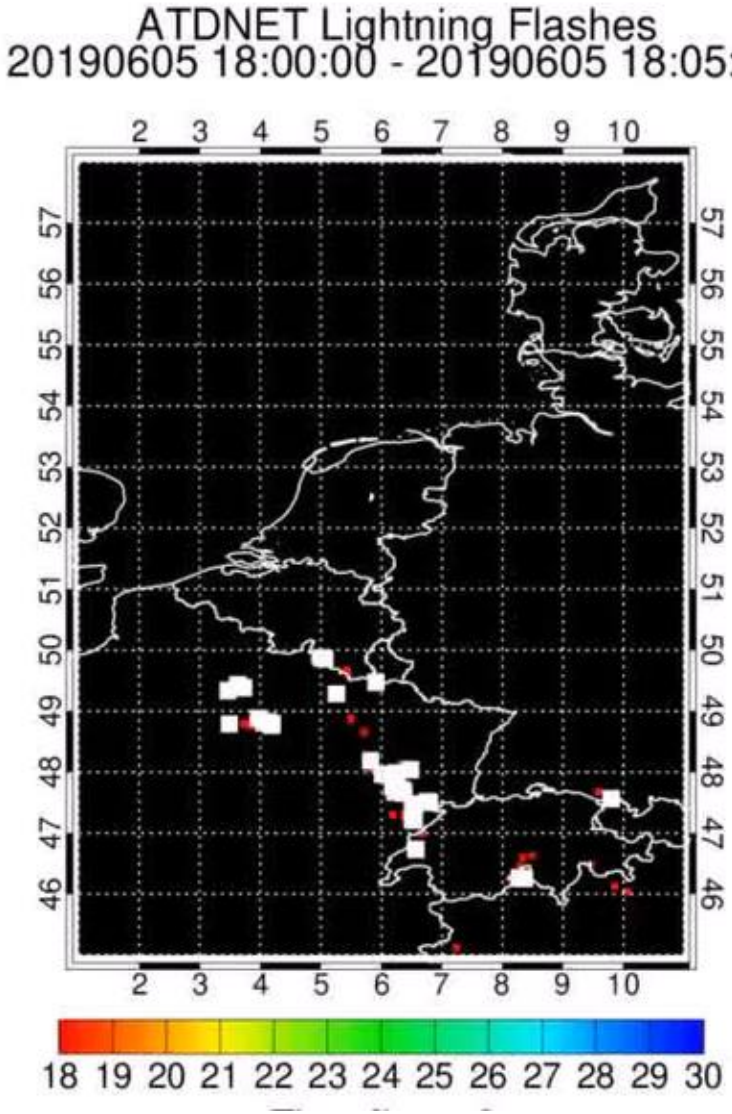


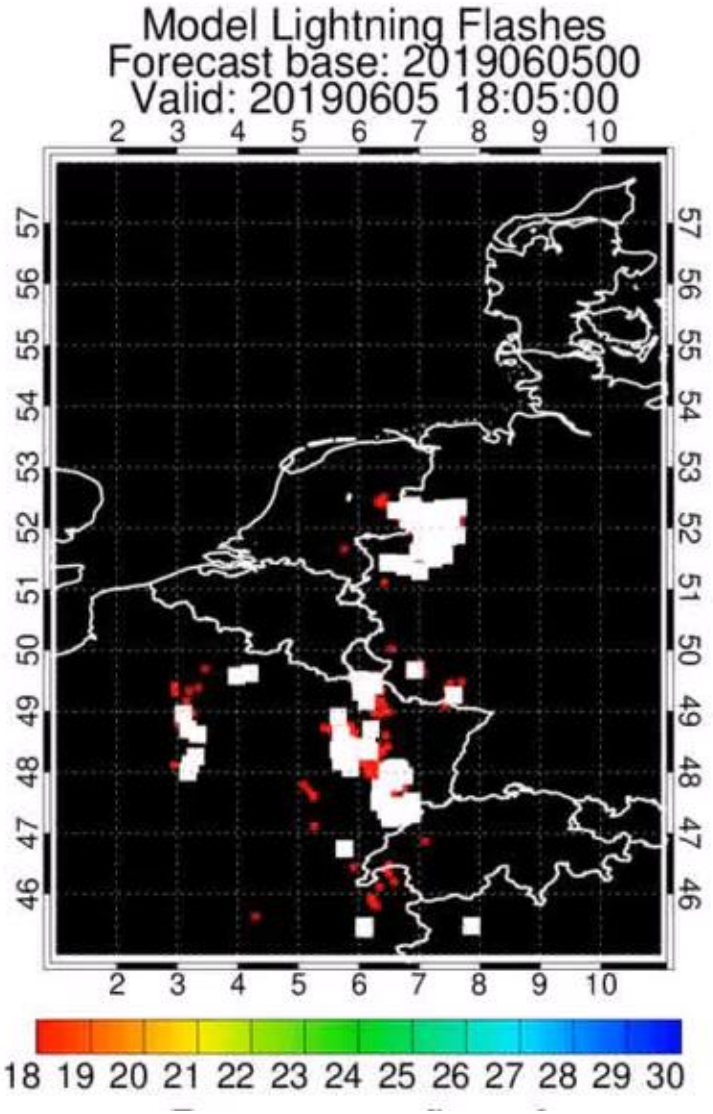
ECMWF

Comparison of model with ATDnet lightning flashes

12h animation of 2-mn flash data starting from 5 June 2018 at 12Z.

9-km resol. L137 model forecast: +18h to +30h range.



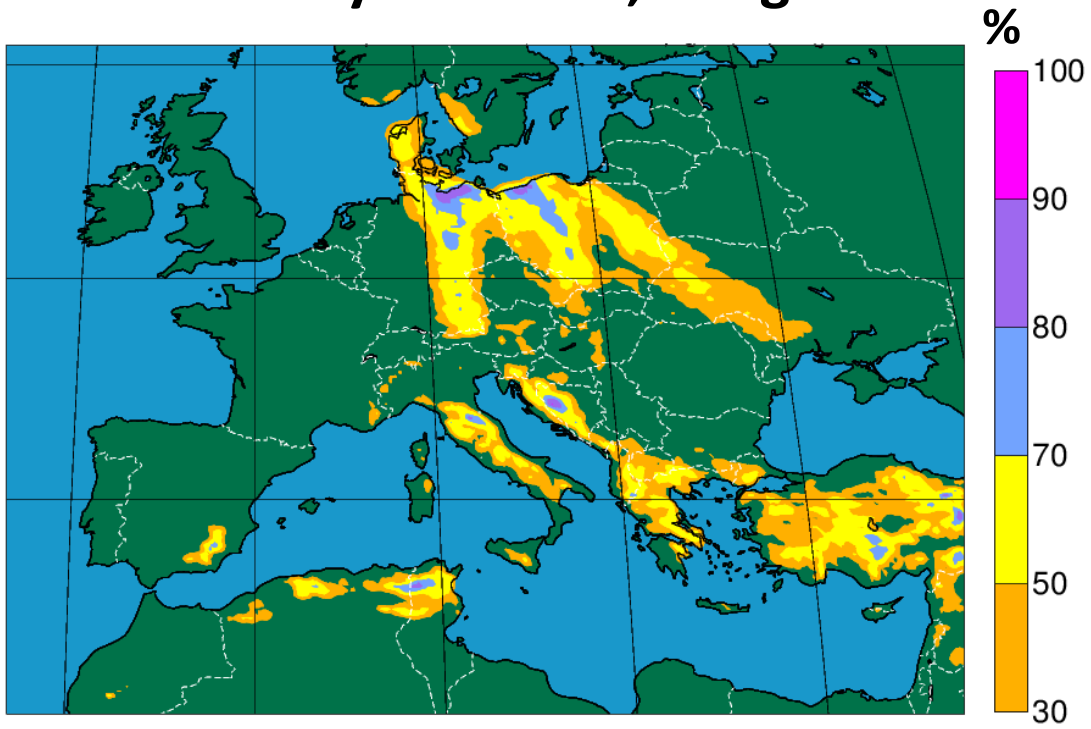


Model flashes were randomly generated to match the simulated flash densities.

ECMWF

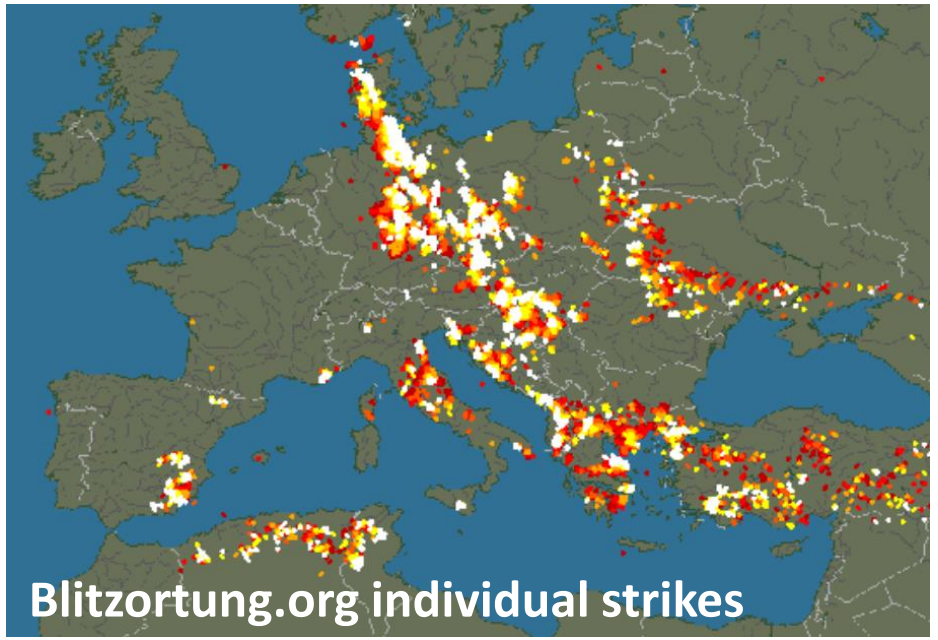
Ensemble forecasts can be used to deal with the random and discrete nature of lightning.

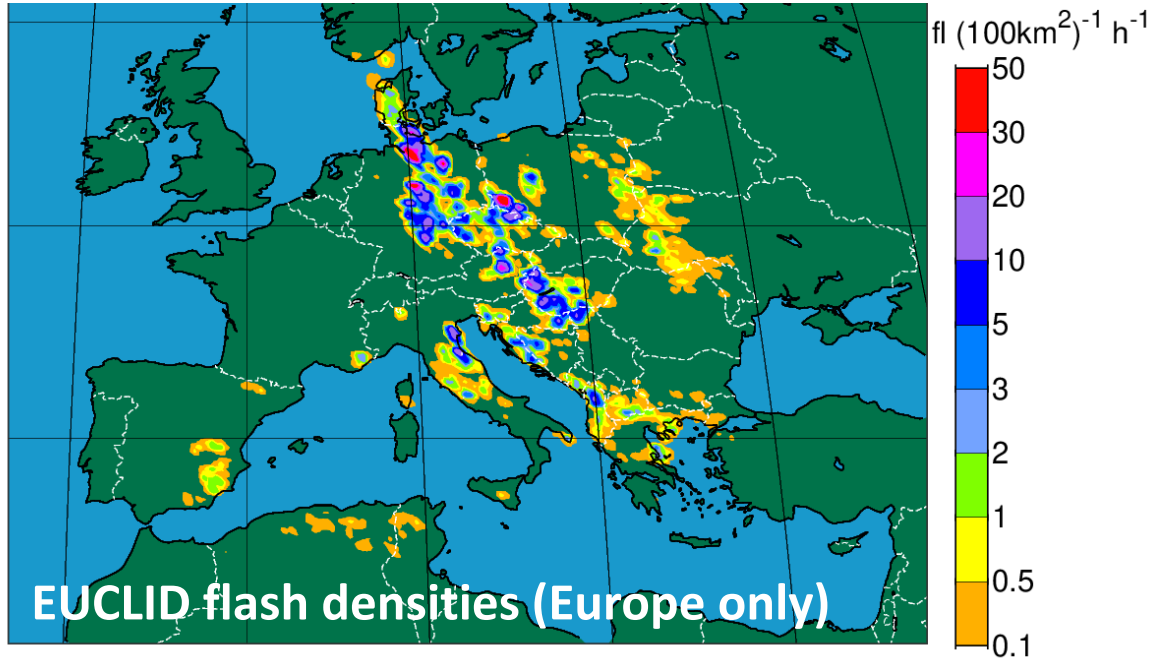
ECMWF ensemble forecast
Probability[flash density > 0.1 fl/100km²/h]
FC Base: 10 May 2018 00Z, Range: +60 to +63h.



→ **Ensemble lightning forecasts can offer useful guidance to forecasters up to day 3 (in mid-latitude regions).**

Ground-based obs., 10 May 2018 15Z



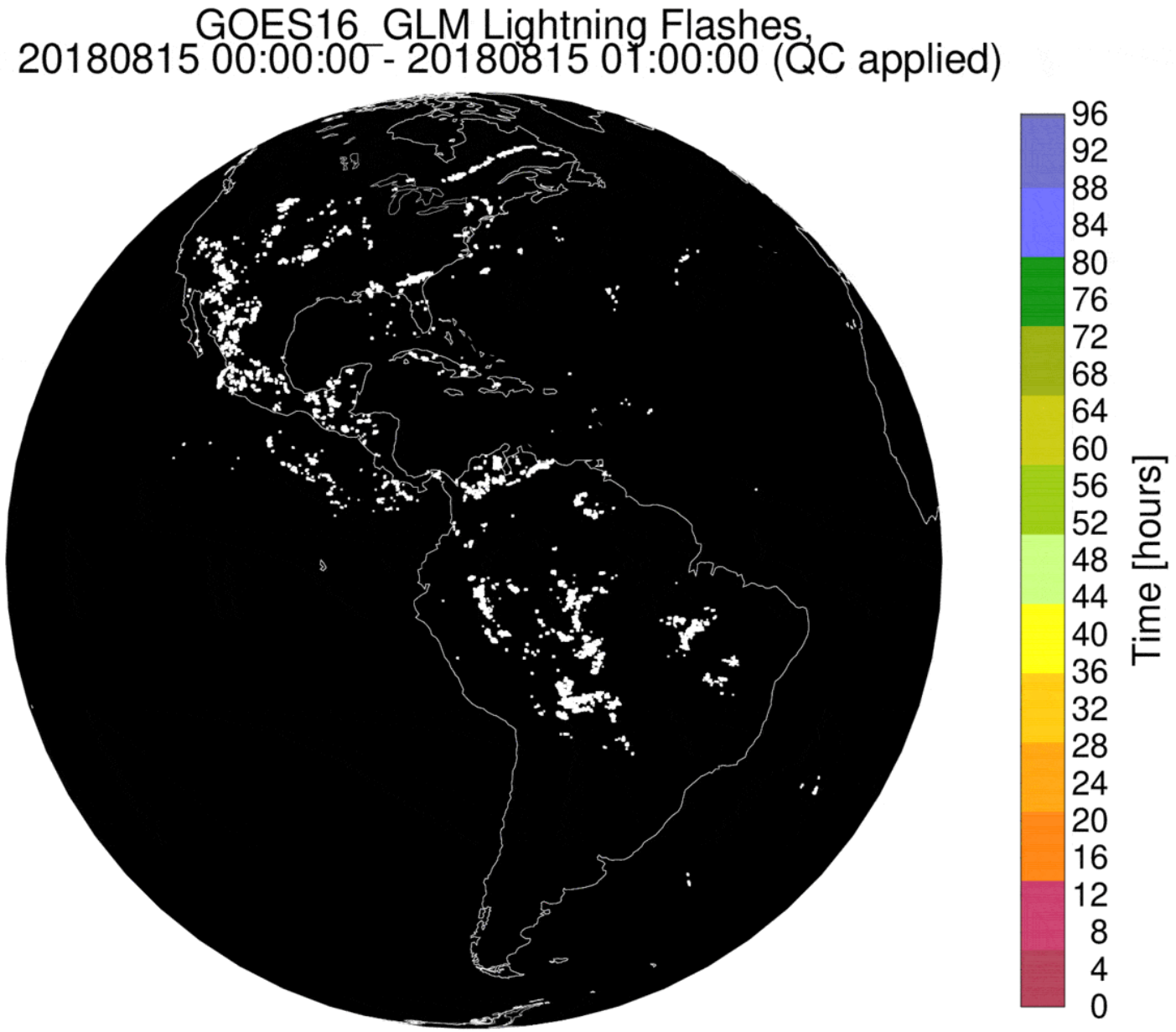


ECMWF


Data
assimilation

GOES-16 GLM lightning observations:

- The Geostationary Lightning Mapper (GLM) on board the new NOAA GOES-16 and 17 satellites provides continuous full-disk lightning observations at 8 km resolution (nadir) and in quasi-real-time.
- Lightning pulses are detected through their signature in the 777.4 nm oxygen band (lightning peak emission).



Animation of GOES-16 GLM lightning flashes over 4 days.

4D-Var assimilation of GOES-16 GLM lightning flash densities

- **Method: direct 4D-Var (like all other observations).**

- **Quantity to be assimilated:**
  - **Lightning flash density,**
  - **Averaged over a few hours (to reduce effects of non-linearities),**
  - **Logarithmic transform applied prior to assimilation (more Gaussian departures).**

- **Lightning observations can provide a direct constraint on convective precipitation within the 4D-Var assimilation process (much more difficult to obtain when using precipitation observations, which can be large-scale or convective).**

4D-Var assimilation of GOES-16 GLM lightning flash densities

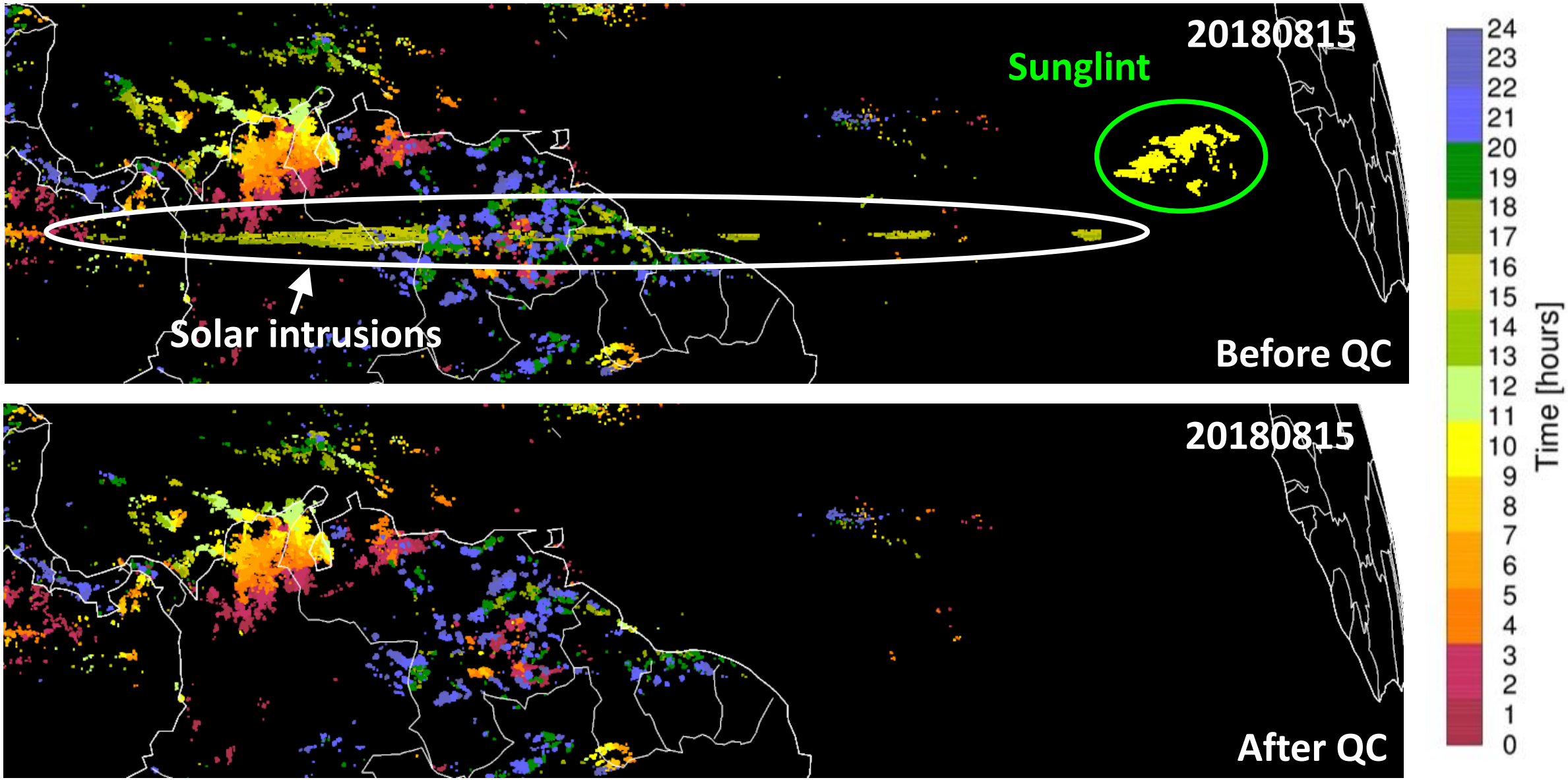
- Homemade quality control of the GLM flash product had to be developed:

Features to be removed	Screening method
Spurious flashes caused by sunglint	Remove all flashes inside sunglint region, throughout day
Persistent isolated lines of flashes (solar intrusion)	Convolution with line-identifying kernel
Flashes organized in short-lived regularly-spaced patterns (~ SSP noon; solar intrusion)	Convolution with comb-shaped function
Isolated flashes (e.g. due to detector noise, jitter)	Time and space criterion (±2 hr, ±80 km)

- Most technical developments needed to assimilate lightning obs have been made in the IFS (CY46R1):
  - include flash detection efficiency (75 to 88%, as a function of solar zenith angle);
  - averaging of obs over 6 hours and onto the model grid (outer loop);
  - obs quality control and screening;
  - new obs operator (incl. tangent-linear and adjoint);
  - logarithmic transform applied to flash density (more Gaussian distributions).

No bias correction used for the moment.

GOES-16 GLM flash data: Quality Control (example; zoom over South America)

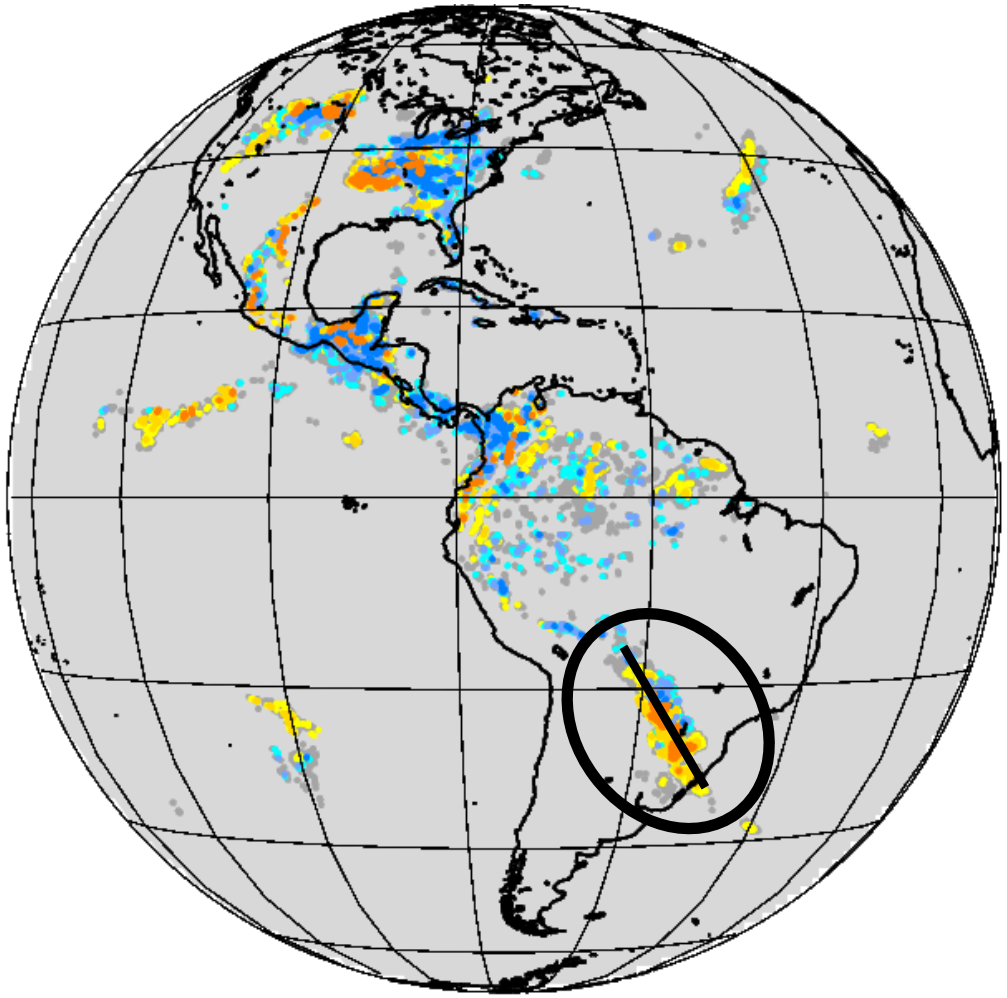


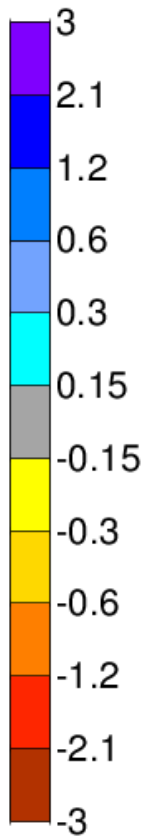
ECMWF

4D-Var assimilation of GOES-16 GLM lightning flash densities: First cycle.

Single 4D-Var cycle (28-km resol., 137 lev.) using $\log^{(2)}$[6h-avg flash density] (no bias corr.) on 1 Jun 2018 at 00Z.
All operational observations also assimilated.

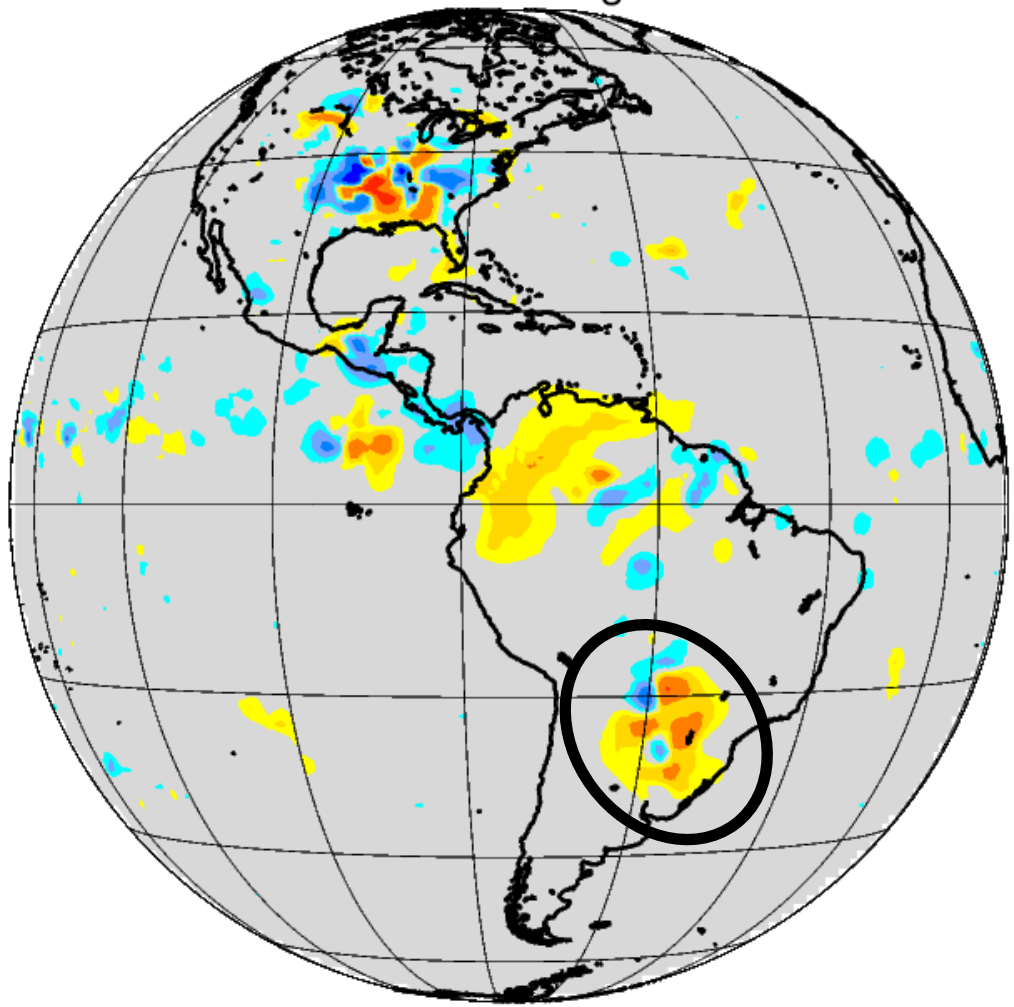
Background lightning departures

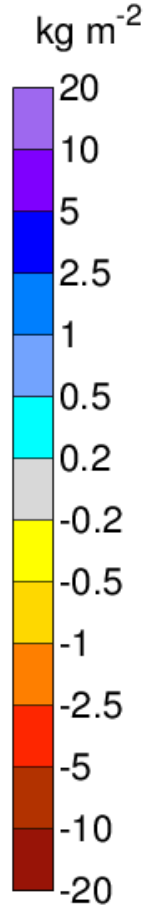




TCWV analysis increments due to lightning obs.

Mean = -0.03 kg m^{-2}

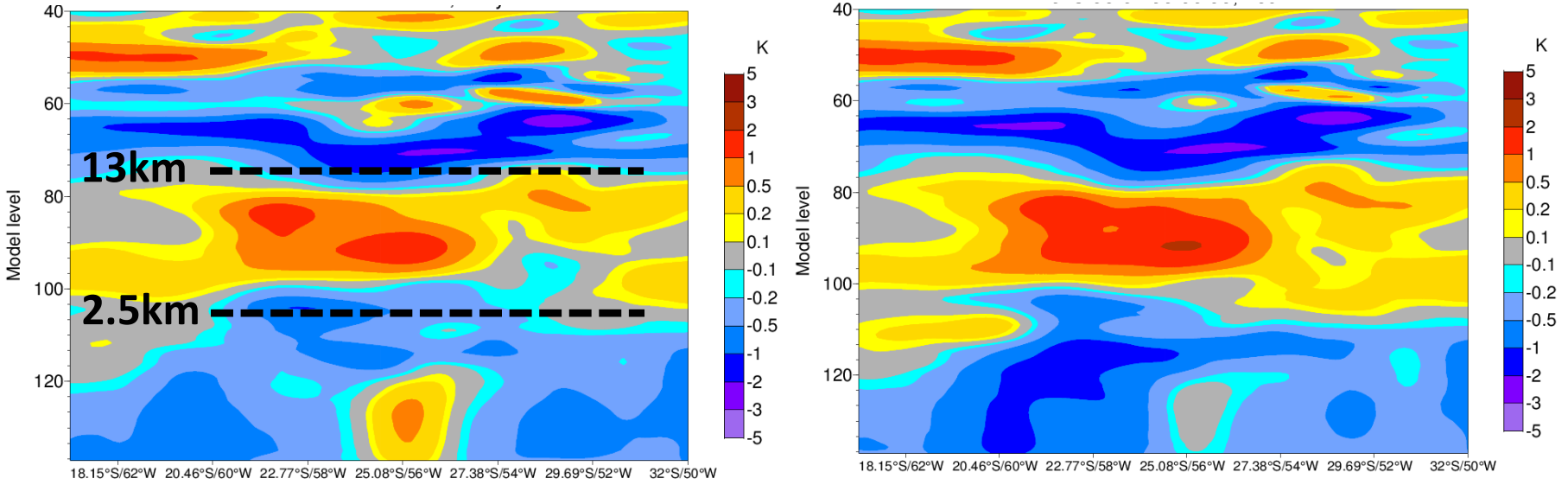




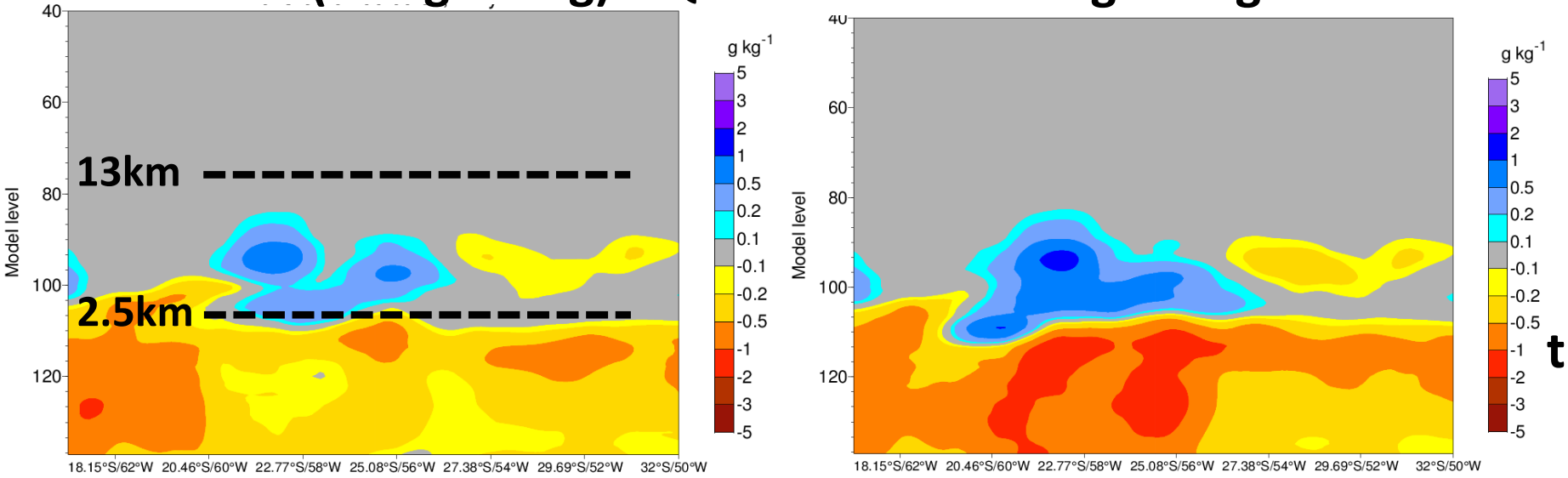
ECMWF

4D-Var assimilation of GOES-16 GLM lightning flash densities: First cycle.

Control (no lightning) T increm. With lightning assim.



Control (no lightning) Q increm. With lightning assim.



Cross-sections of T and Q analysis increments

→ Increments due to lightning assimilation are consistent with or strengthen those due to all other obs.

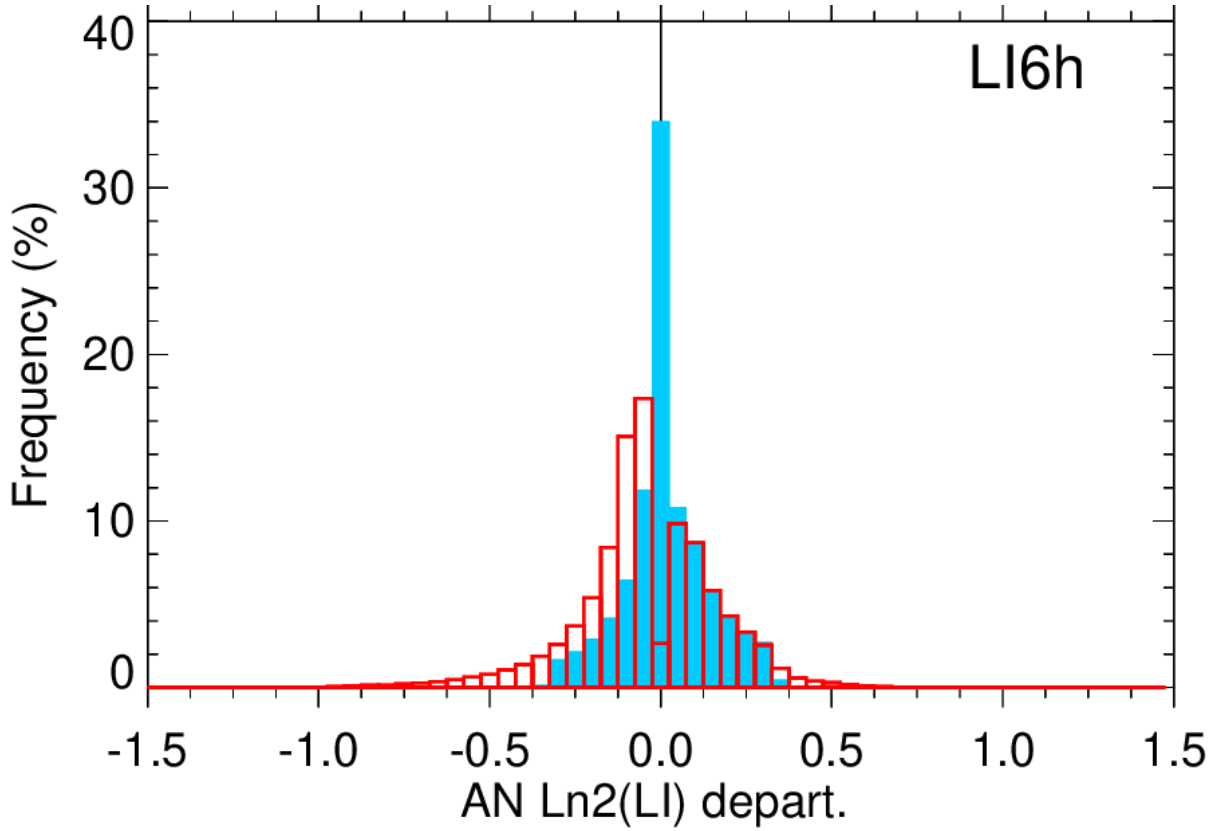
ECMWF

4D-Var assimilation of GOES-16 GLM lightning flash densities: First long experiment.

Histograms of obs–model lightning departures, before and after assimilation:

Before assimilation

After assimilation



4D-Var experiment with GOES-16 GLM lightning obs. Jun-Aug 2018 (25-km resol.)

✓ **Histogram of (obs – model) departures becomes narrower after assimilation → good.**

× **However, noticeable asymmetry between (obs > model) and (obs < model) cases: it is always easier to decrease model lightning than the opposite.**

Summary and plans

So far:

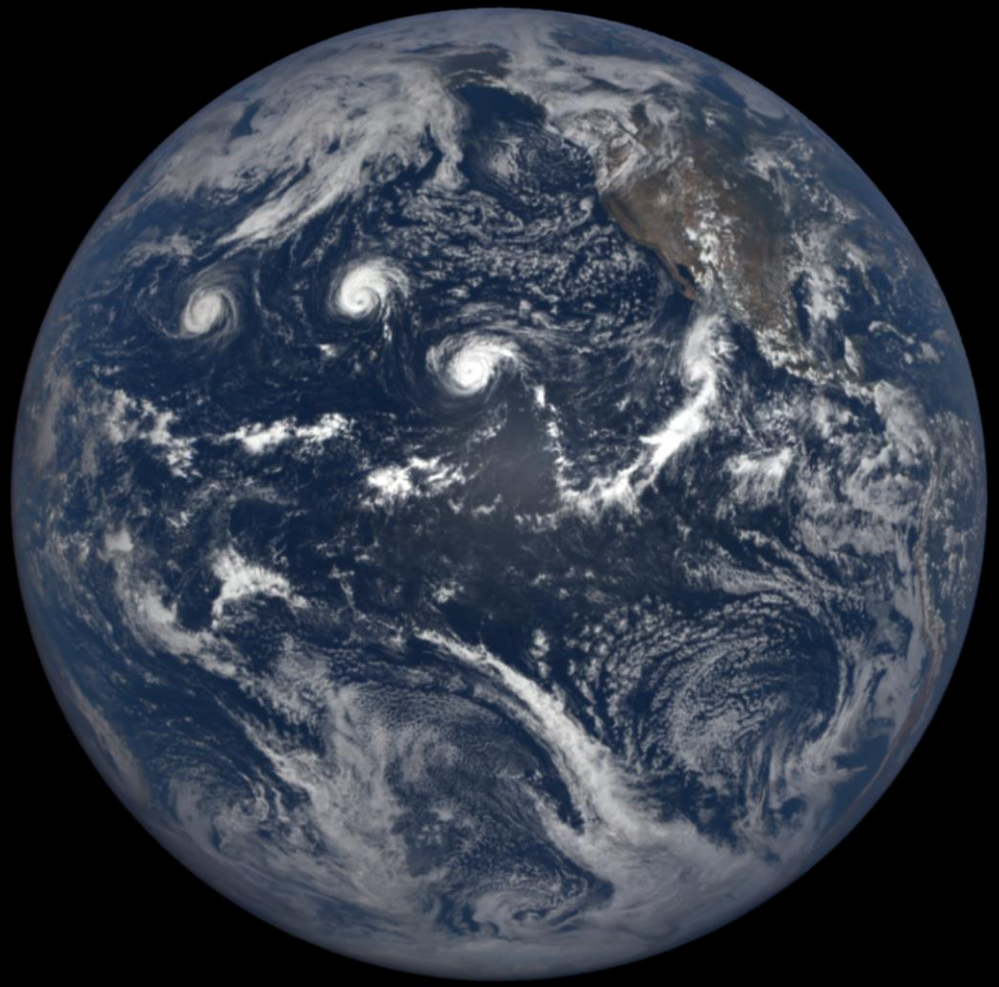
- Operational prediction of lightning flash densities since June 2018.
- 4D-Var assimilation of GOES-16 GLM lightning flash densities is being tested (research).

Plans:

- Revise lightning parameterization to reduce identified biases (new predictors?).
- Improve specification of background and obs error statistics for lightning flash densities.
- Introduce some bias correction (model and obs).
- Try to reduce asymmetry between “model > obs” and “model < obs” cases.
- Assess impact on meteorological scores.
- Extend the assimilation to GOES-17 GLM (Pacific) and MTG-LI (2022?) and possibly to ground-based networks.

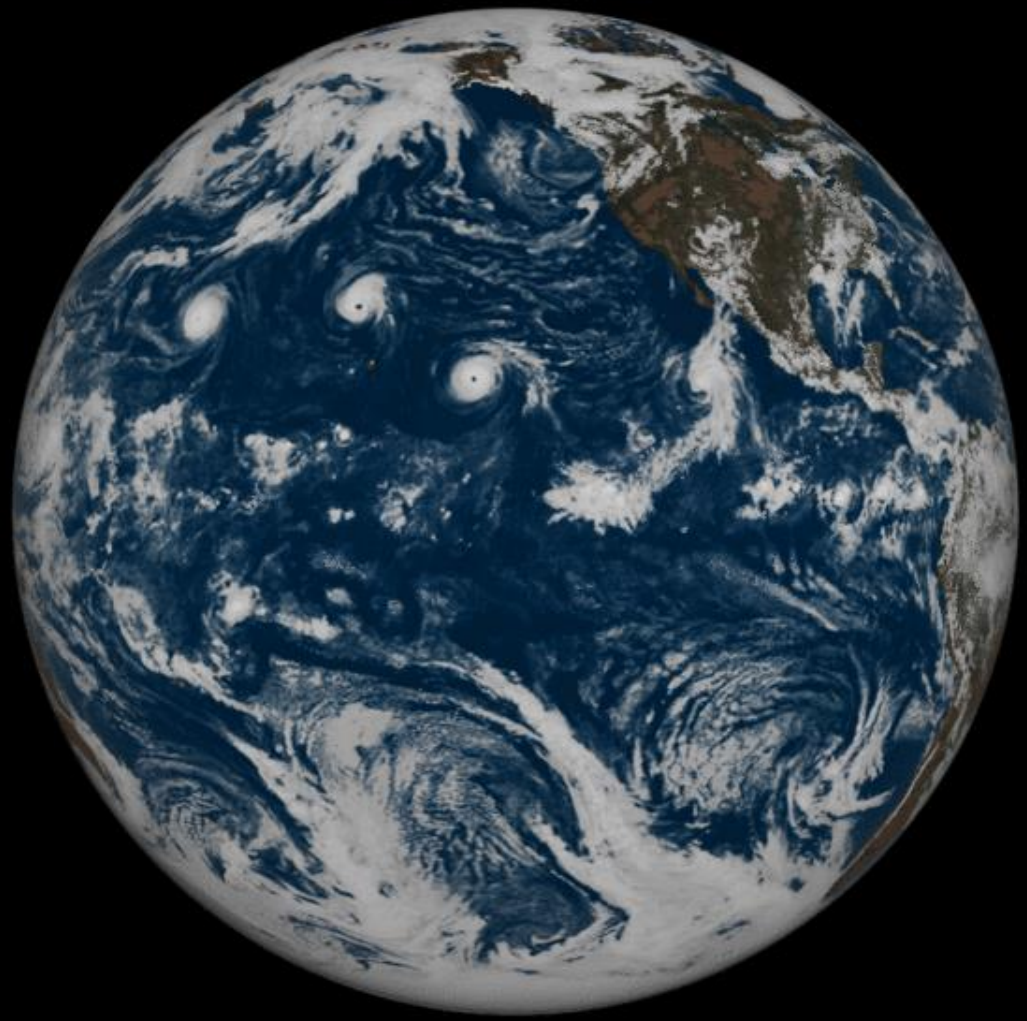
2 September 2015

NASA's DSCOVR satellite (valid: 21:11Z)



ECMWF 9-km forecast 00Z +9h → +33h (visible, infared and lightning)

2015090200+21:05:00



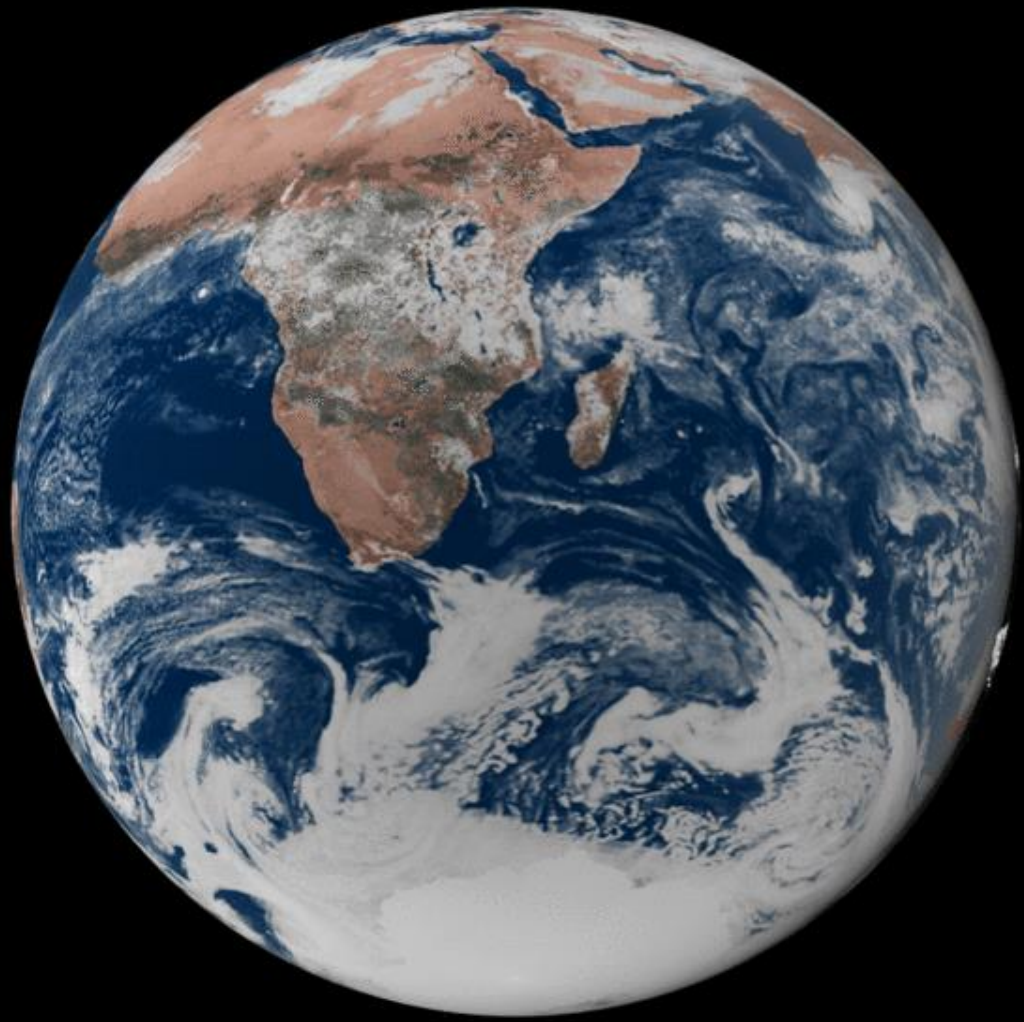
ECMWF

7 December 1972

NASA's Apollo 17 "Blue Marble" (valid: 10:39Z)

ECMWF 9-km forecast 00Z +48h → +72h (initialized from ERA5)

1972120500+58:37:30 (hc28)



Lopez 2020 (submitted to BAMS)

ECMWF

Thank you!

References: (Ctrl + click to follow links)

Lopez, P., 2020: Forecasting the Past: Views of Earth from the Moon and beyond, *Bull. Amer. Meteor. Soc.* (submitted).

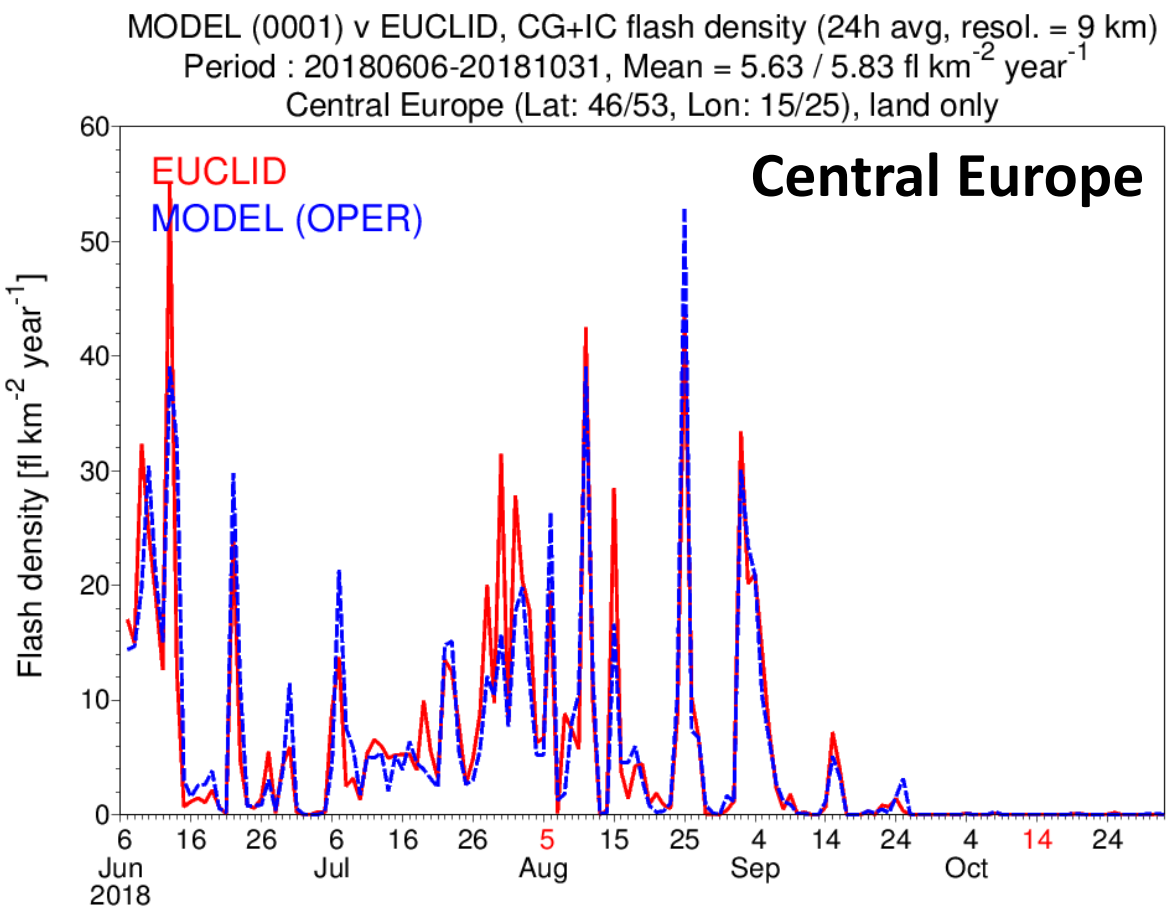
Lopez, P., 2018: Promising results for lightning predictions, *ECMWF Newsletter 155*, *Spring 2018*, 14-19.

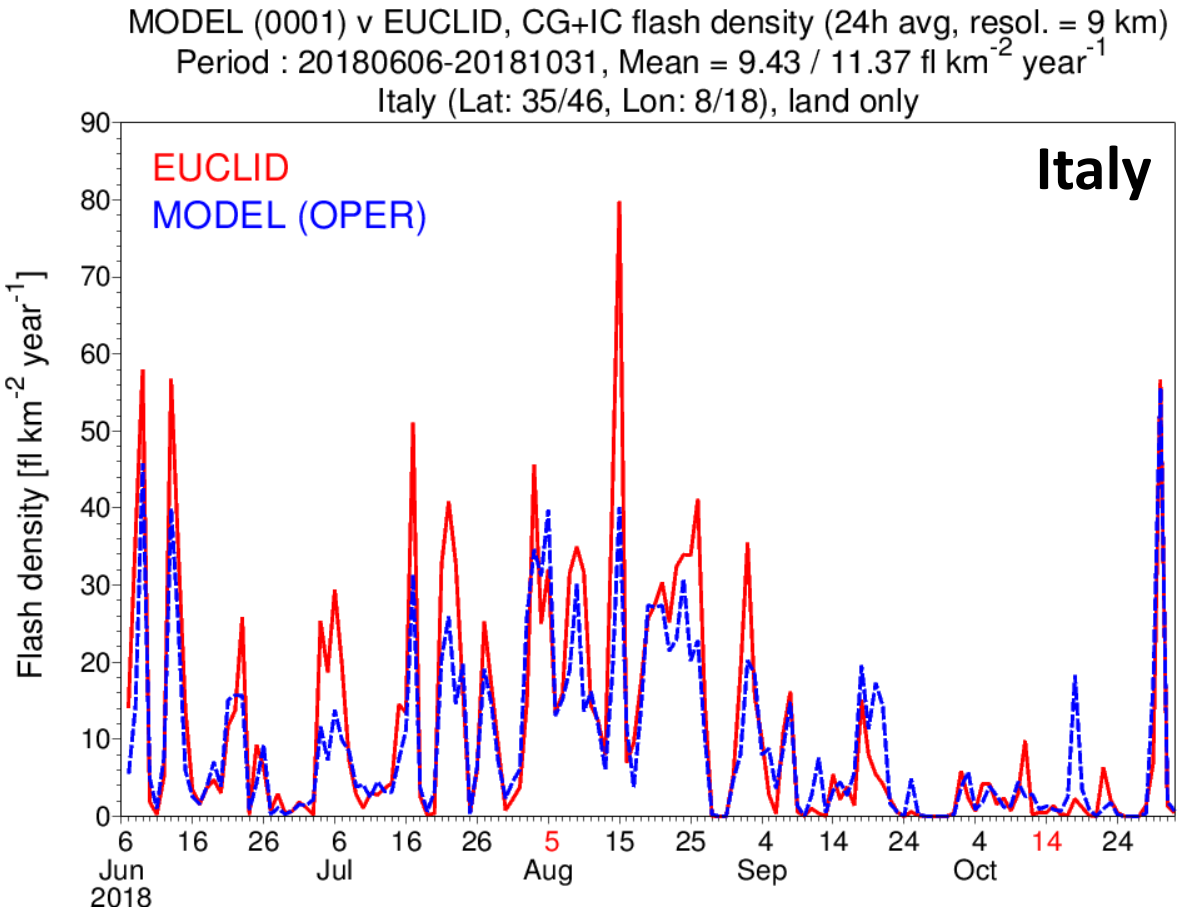
Lopez, P., 2016: A lightning parameterization for the ECMWF Integrated Forecasting System, *Monthly Weather Review*, **144**, 3057-3075.

Lightning parameterization implementation in ECMWF's IFS (model version 45R1, as of 2018): https://www.ecmwf.int/en/elibrary/18714-part-iv-physical-processes

Comparison of ECMWF MODEL with EUCLID (lightning flash densities)

Time series of daily mean flash densities over various European land subdomains during the period 6 Jun-31 Oct 2018: ECMWF model (blue; 9 km) against EUCLID observations (red).



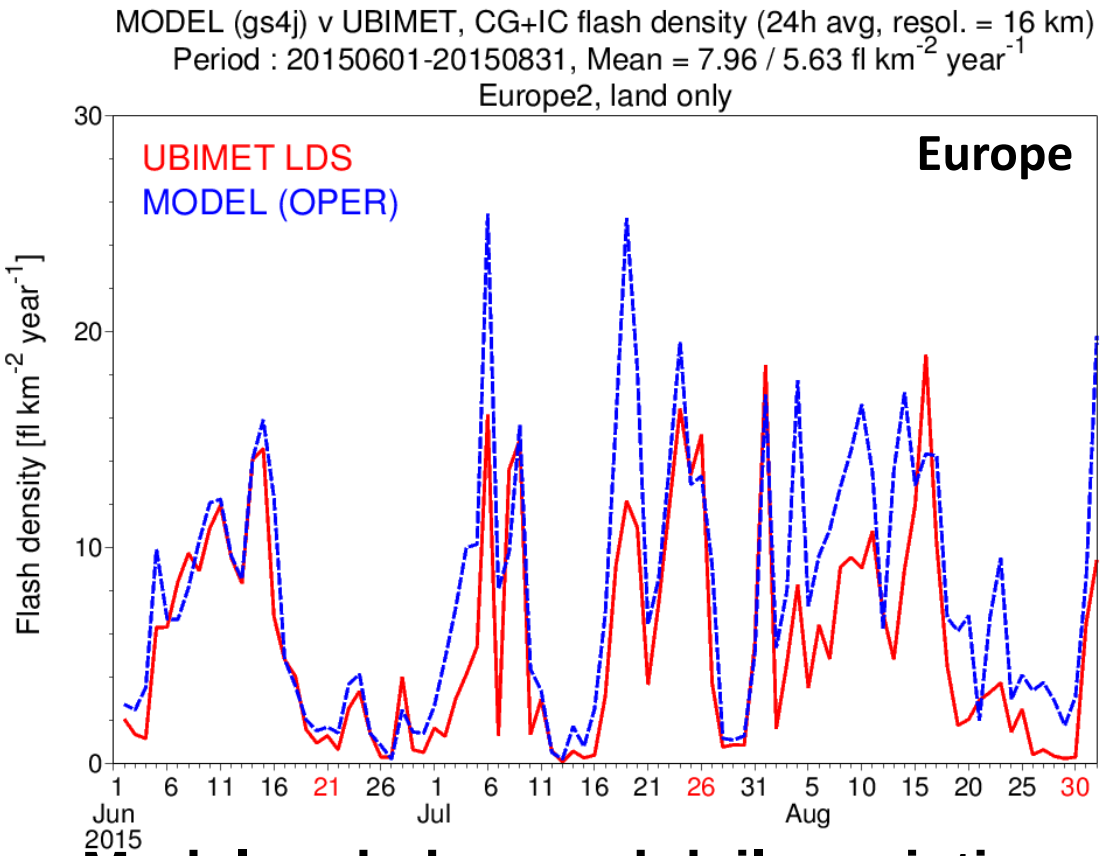


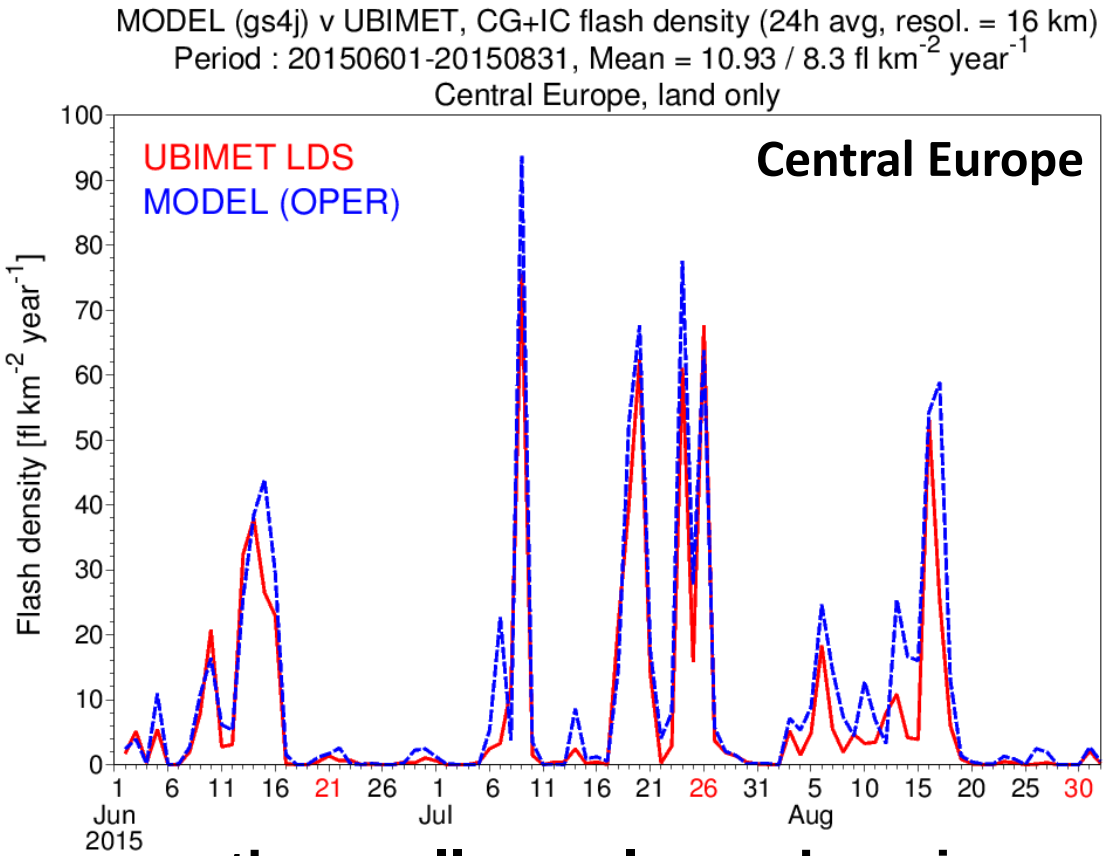
ECMWF

ECMWF model vs UBIMET LDS observations.

Time evolution of daily average lightning flash densities.

Based on 24h forecasts (16 km res.) over Europe in summer 2015.

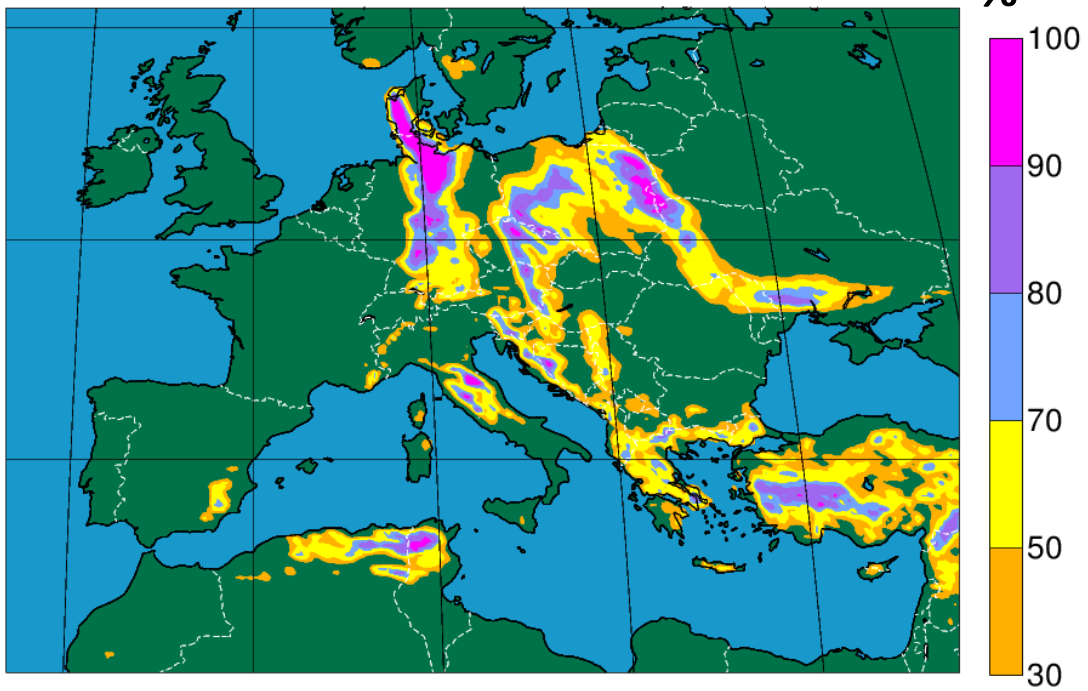




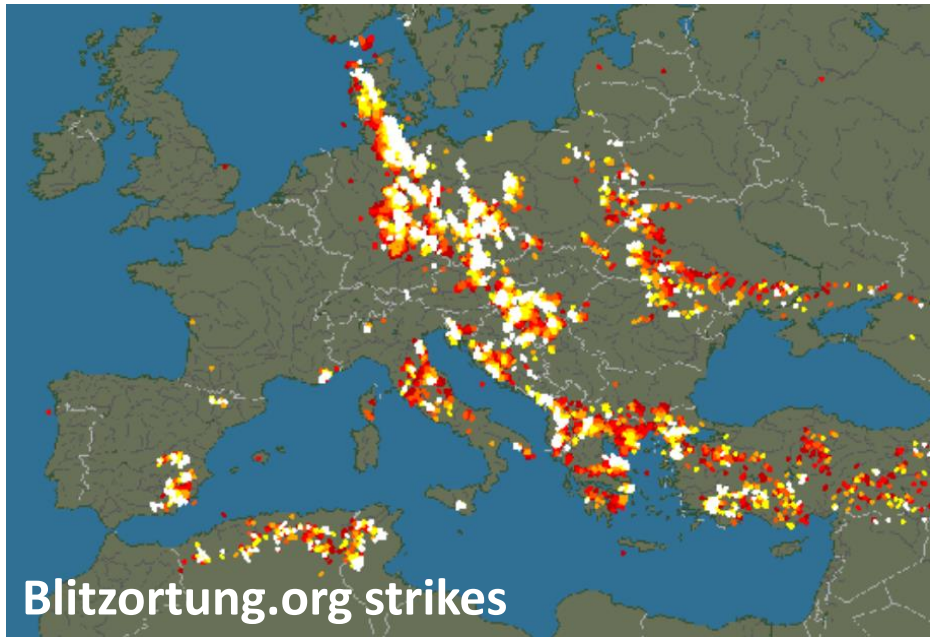
Model and observed daily variations agree rather well over large domains.

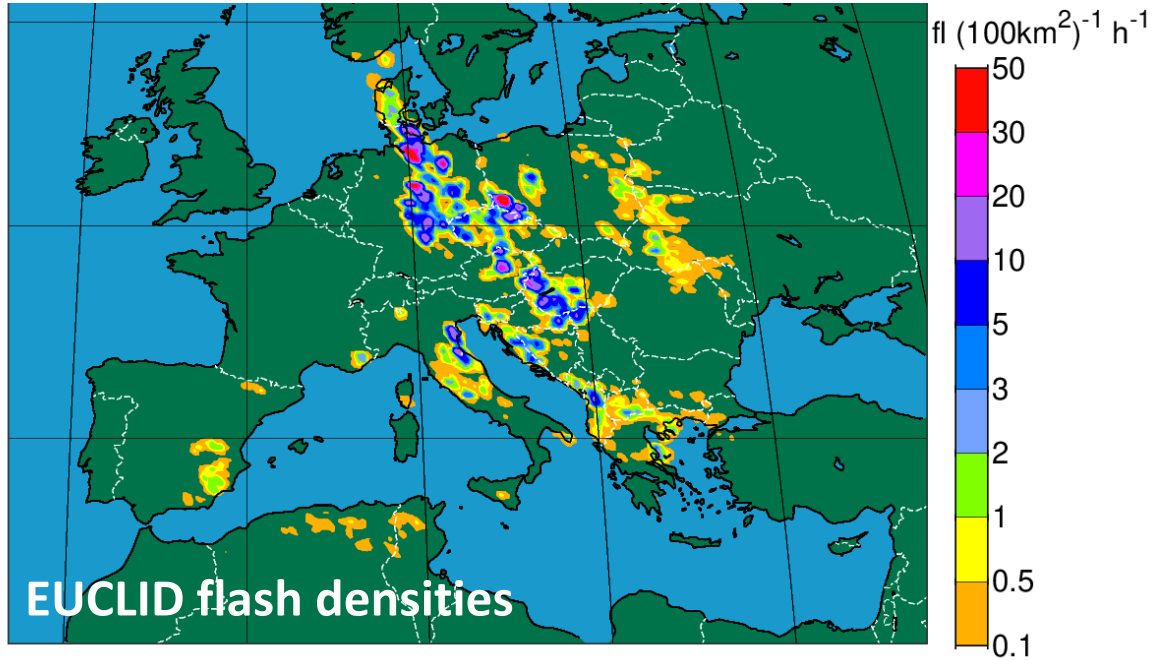
The ensemble forecast approach is particularly adequate to deal with the random and discrete nature of lightning.

Example: ECMWF ensemble forecast
Prob[flash density > 0.1 fl/100km²/h]
FC base: 10 May 2018 00Z, range: +12 → +15h



Observations, 10 May 2018 15Z

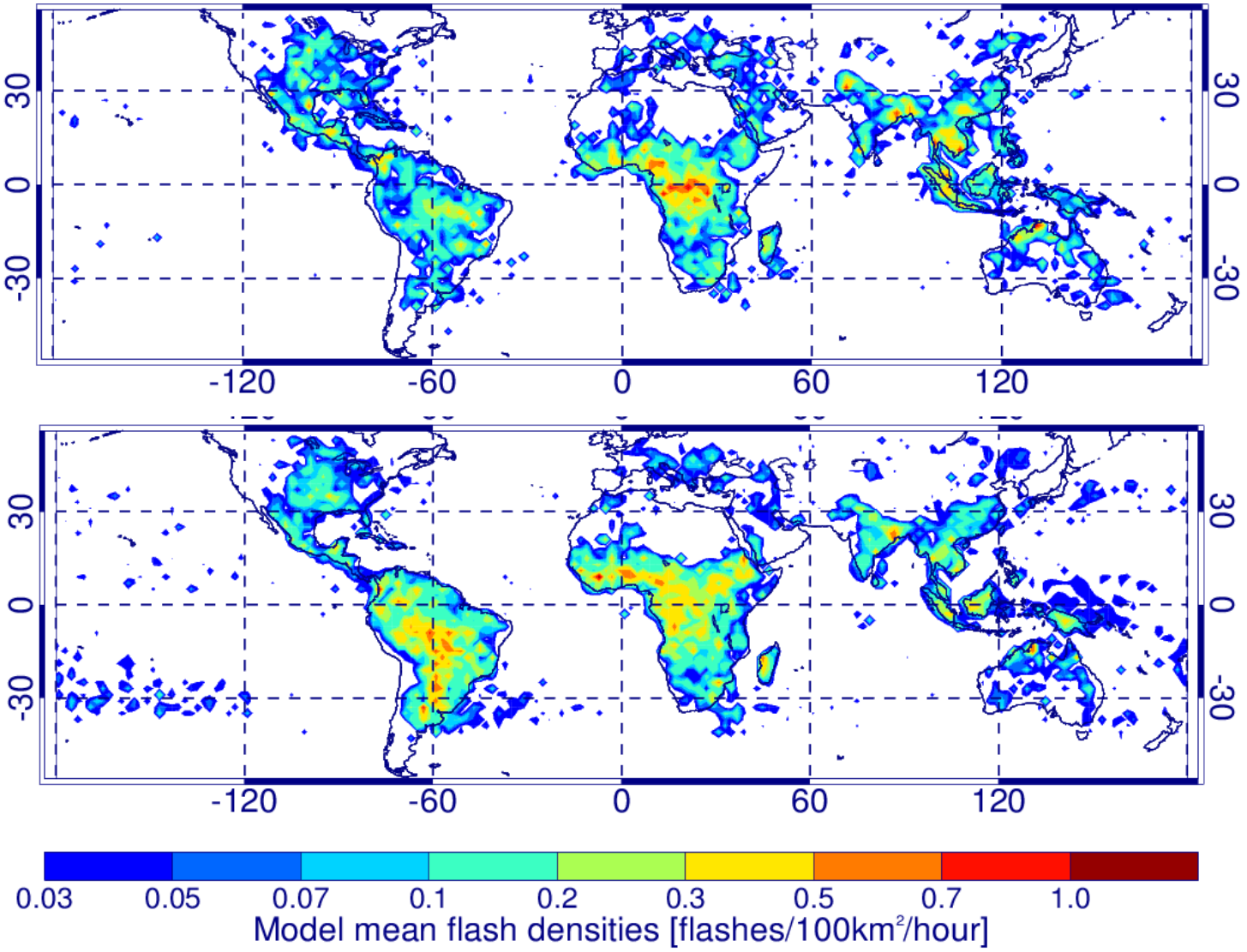




ECMWF

Simulated lightning against ISS-LIS observations

Mean lightning flash densities from 1 Aug 2017 to 12 Jun 2019 (on 2° grid).



ISS-LIS obs.
(Science data V1.0)

Model

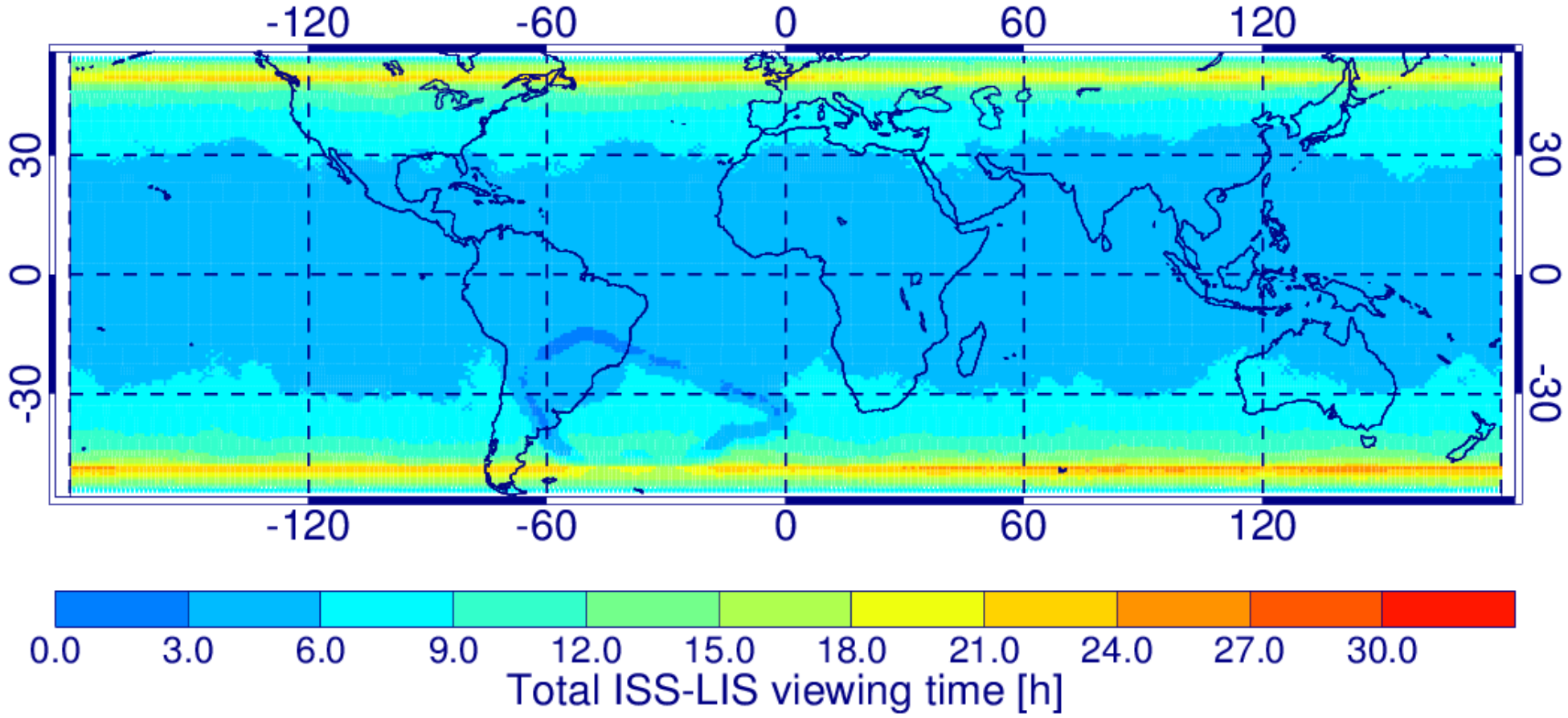
from TL255 (80 km resol.)
24h forecasts

→ **Spatial distribution OK.**
→ **Congo Basin: too low.**
→ **South America: too high.**

ECMWF

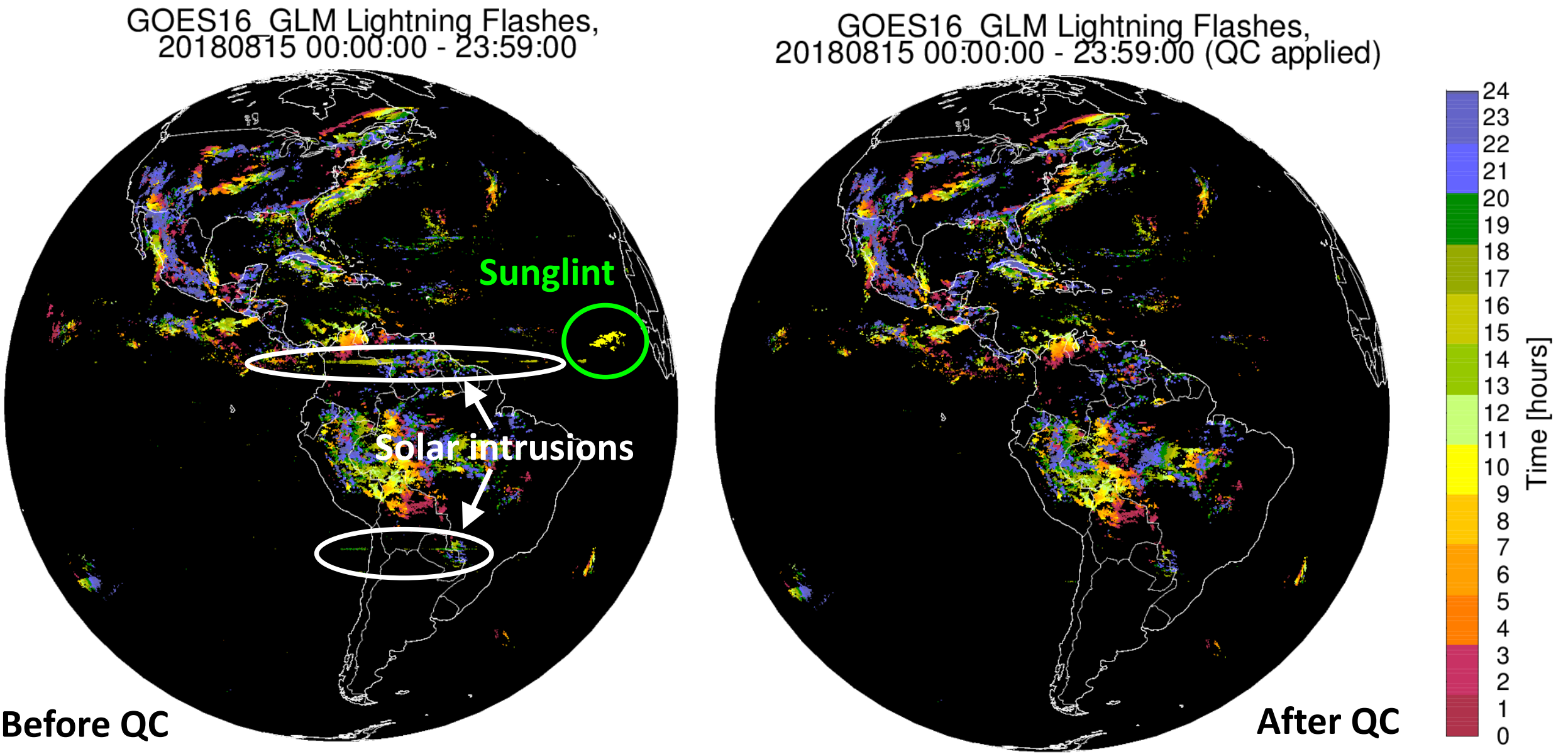
But beware: ISS-LIS sampling is rather limited!

But ISS-LIS total viewing time is limited:
Between 5 and 22 hours from 1 Aug 2017 to 12 Jun 2019.



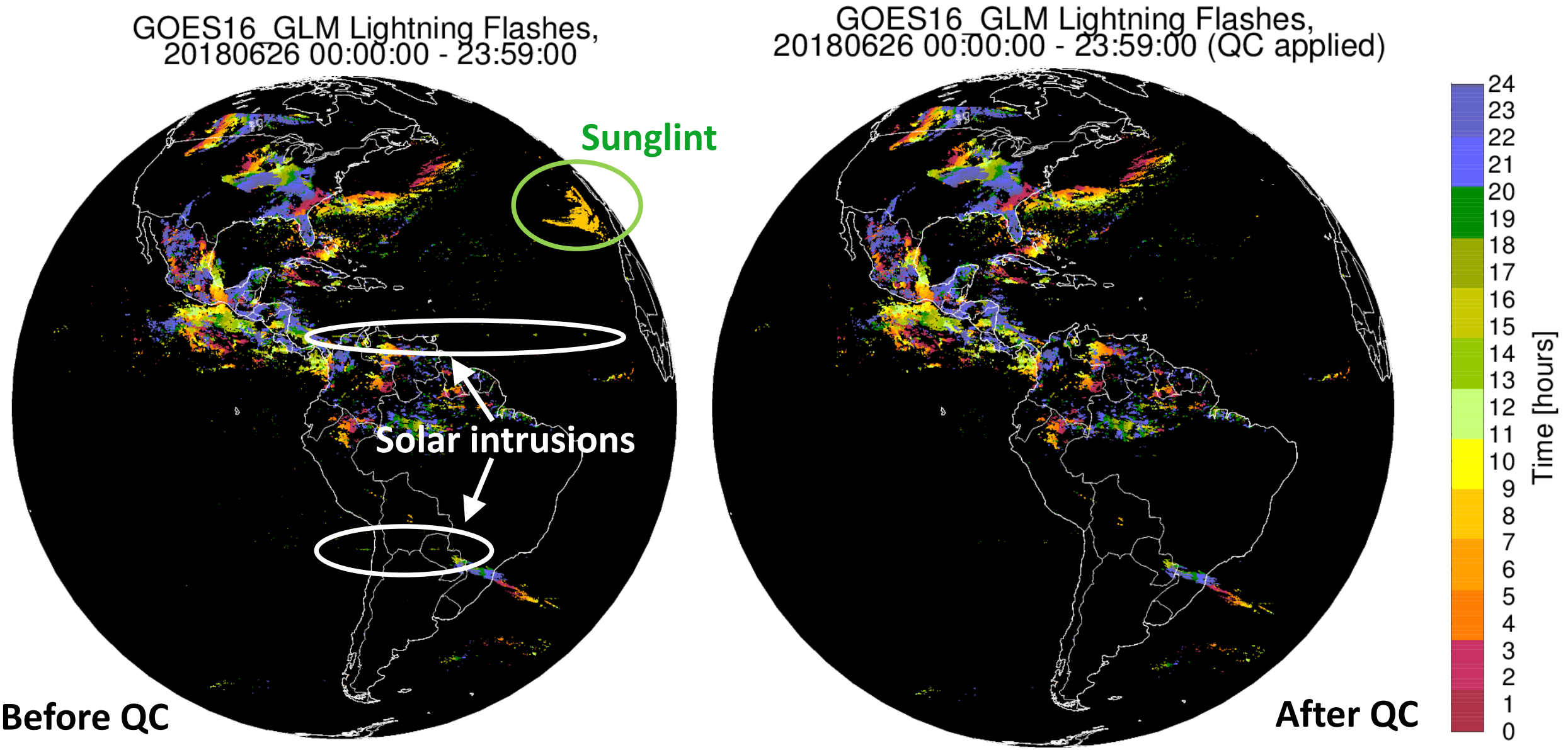
ECMWF

GOES-16 GLM flash data: Quality Control (example)



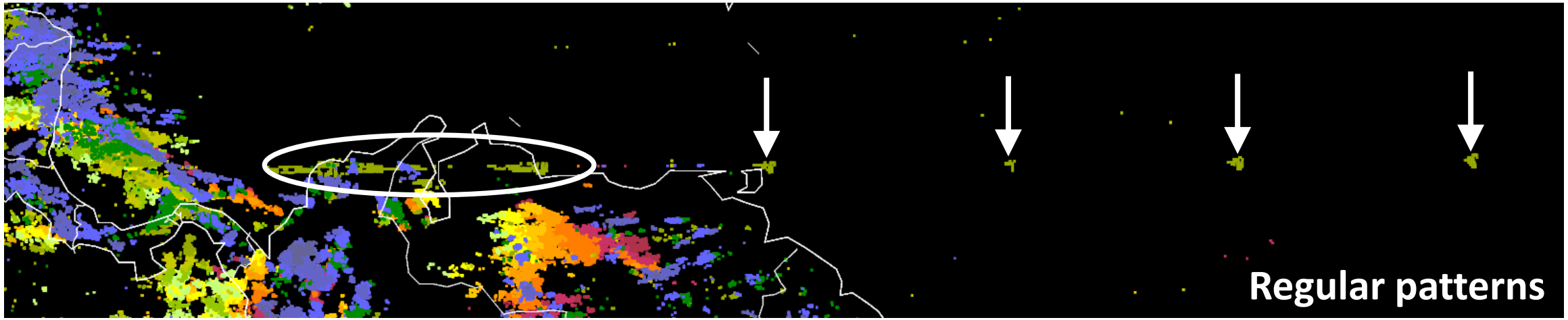
ECMWF

GOES-16 GLM flash data: Quality Control (example 1)

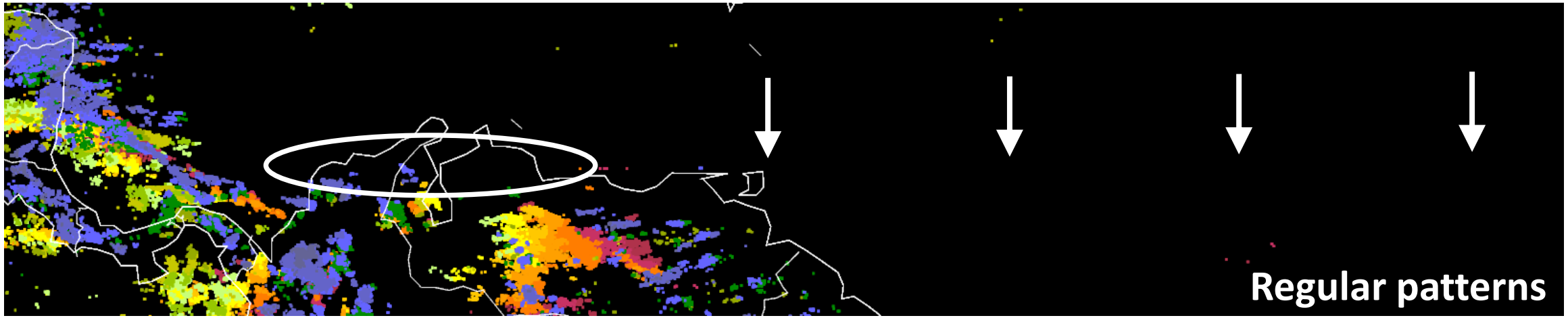


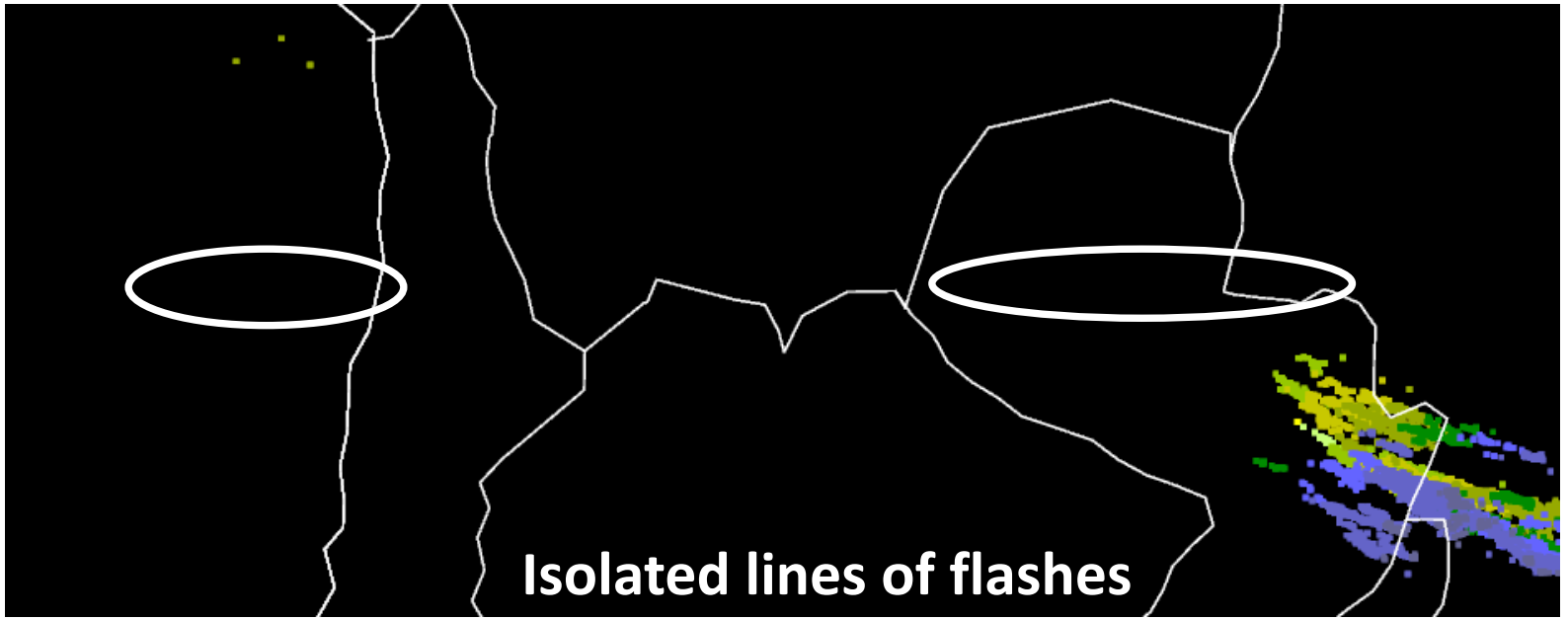
ECMWF

GOES-16 GLM flash data: Quality Control (example 1, zoom)



GOES-16 GLM flash data: Quality Control (example 1, zoom)

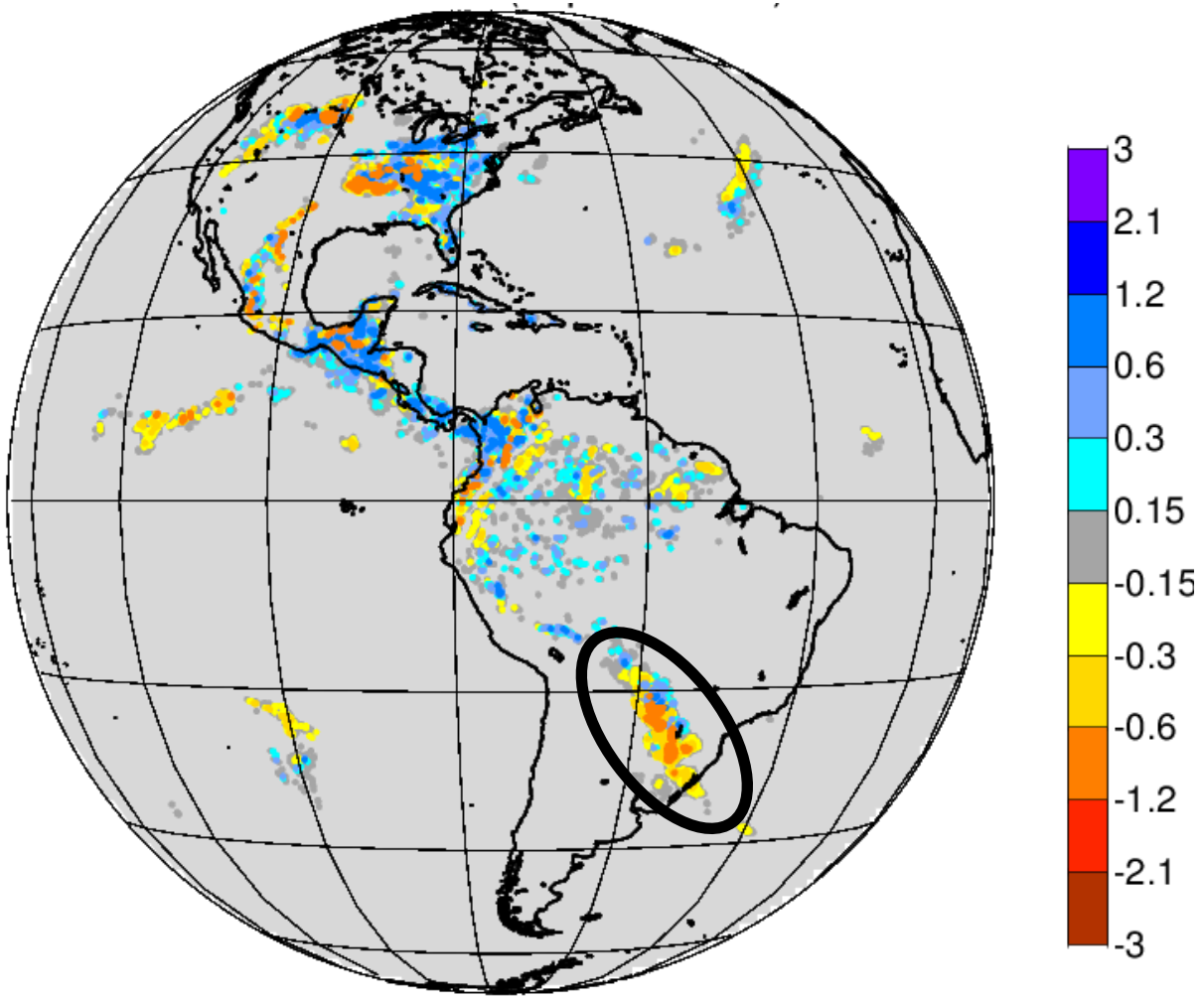




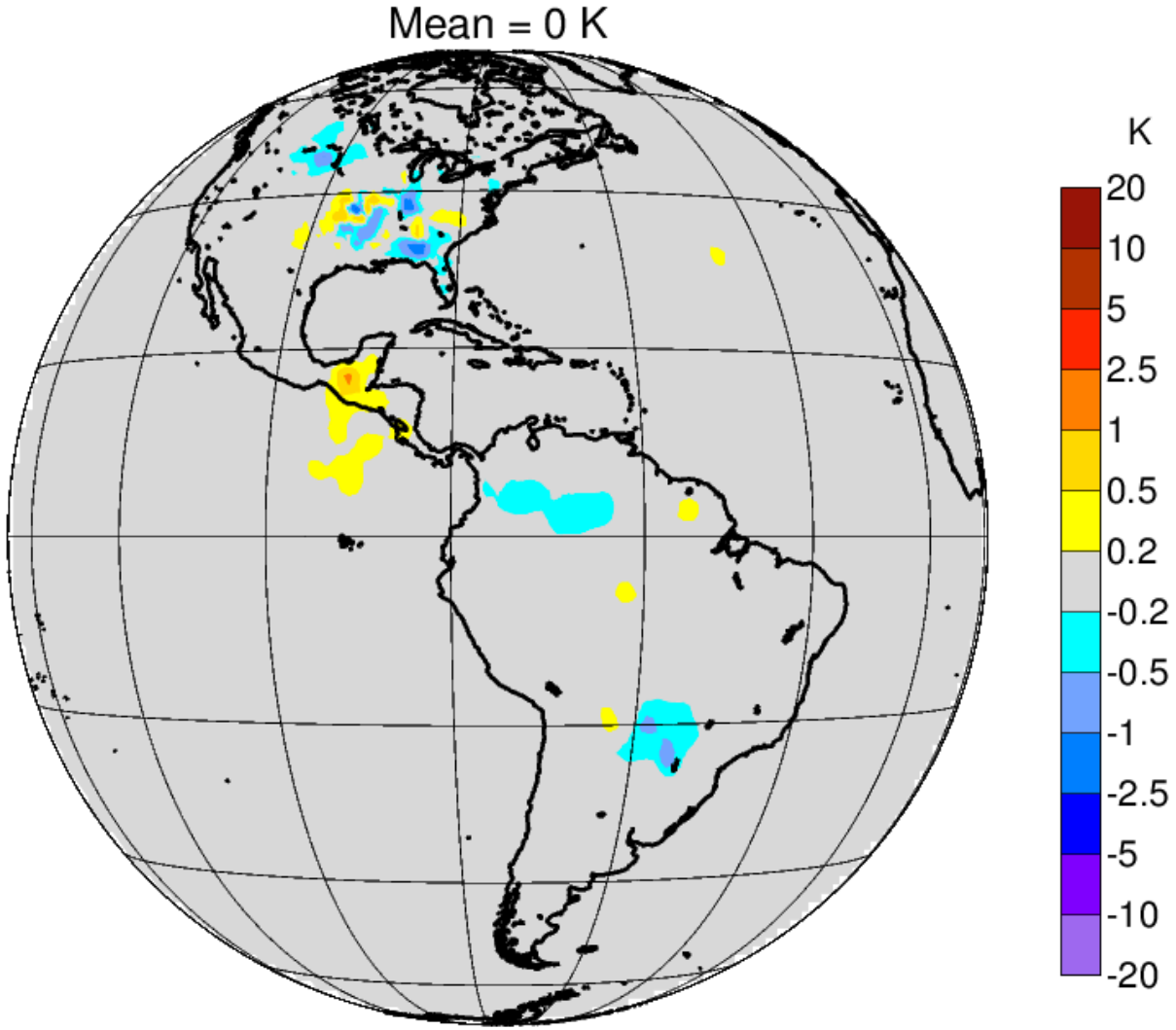
GOES-16 GLM lightning flash density assimilation: First attempt.

Single 4D-Var cycle (28-km resol., 137 lev.) using $\log^{(2)}$[6h-avg flash density] (no bias corr.) on 1 Jun 2018 at 00Z. All operational observations also assimilated.

Background lightning departures



T analysis increments due to lightning obs.



ECMWF

GOES-16 GLM lightning flash density assimilation: First attempt.

Logarithmic transform applied to lightning flash densities (F) before assimilation:

Ln(Ln(F+1)+1)

where F is in flashes/km^2/day.