“Precipitation” data assimilation at ECMWF

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with contributions from Mark Fielding, Marta Janisková and Alan Geer

H-SAF/HEPEX Workshop, 27/11/2019, ECMWF

Outline

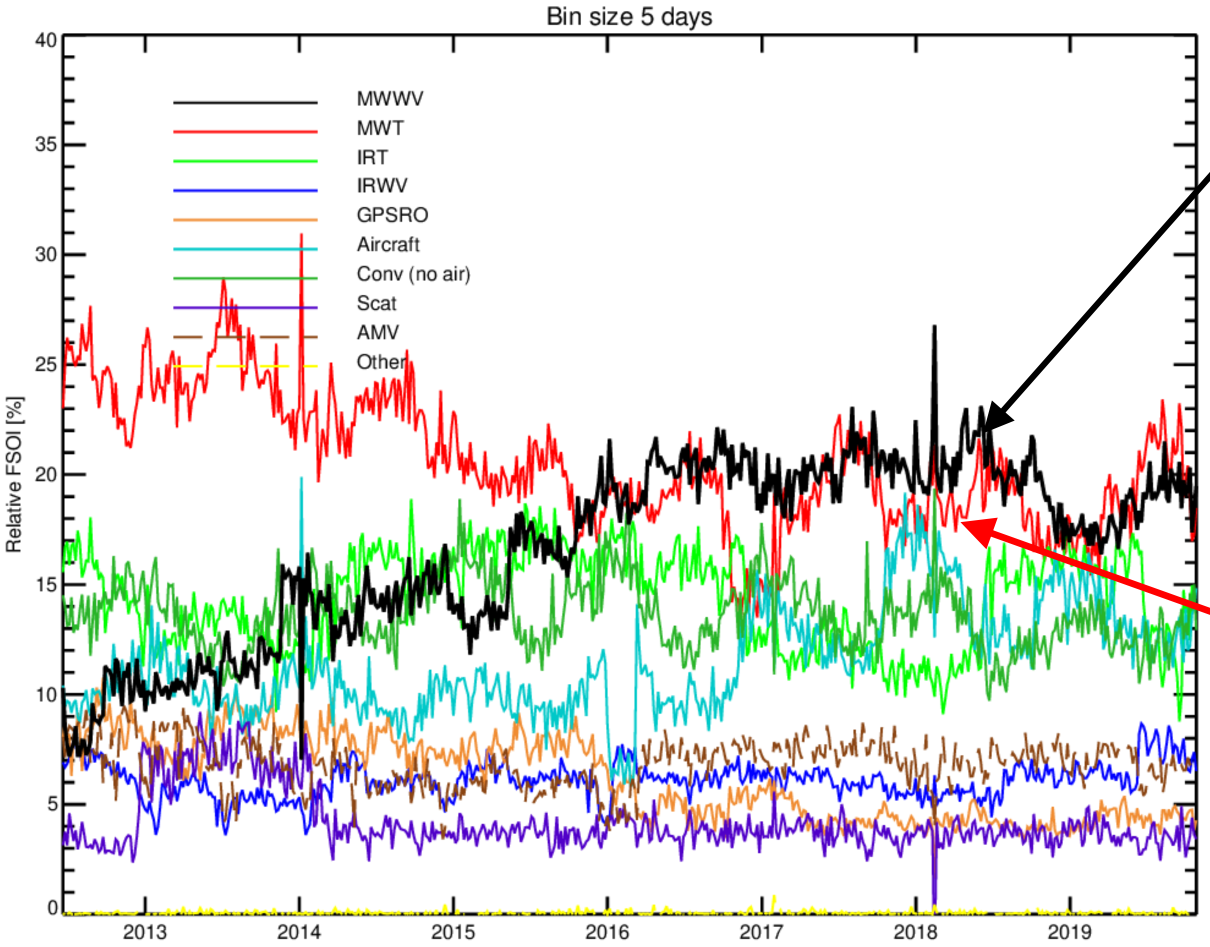
4D-Var data assimilation:

- **Satellite all-sky microwave radiances.**
- **Ground-based radar precipitation composites (NCEP Stage IV, OPERA).**
- **CloudSat radar and CALIPSO lidar observations.**
- **Lightning observations (GOES-16 GLM).**
- **Summary and plans.**

Operational assimilation of satellite all-sky microwave radiances

All-sky radiances sensitive to water vapour, cloud and precipitation (SSMIS, MHS, GPM GMI, ATMS, AMSR-2, FY-3x MWHS2) are now one of the most important observation types in ECMWF's IFS:

Relative forecast impact at 24h range (computed using adjoint)



2013 Year **2019**

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Microwave radiances sensitive to water vapour, cloud and precipitation:

- **8 sensors in all-sky conditions.**
- **3 sensors only in clear-sky.**

Microwave radiances sensitive to temperature:

- **assimilated in clear-sky only.**

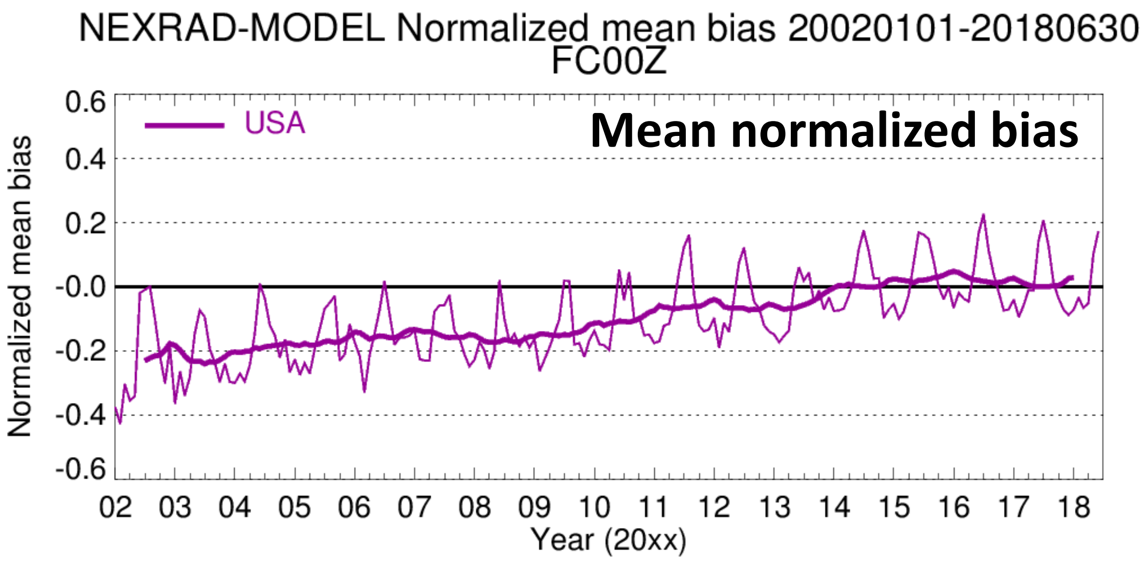
Geer et al., 2017, QJRMetSoc: The growing impact of satellite observations sensitive to humidity, cloud and precipitation.

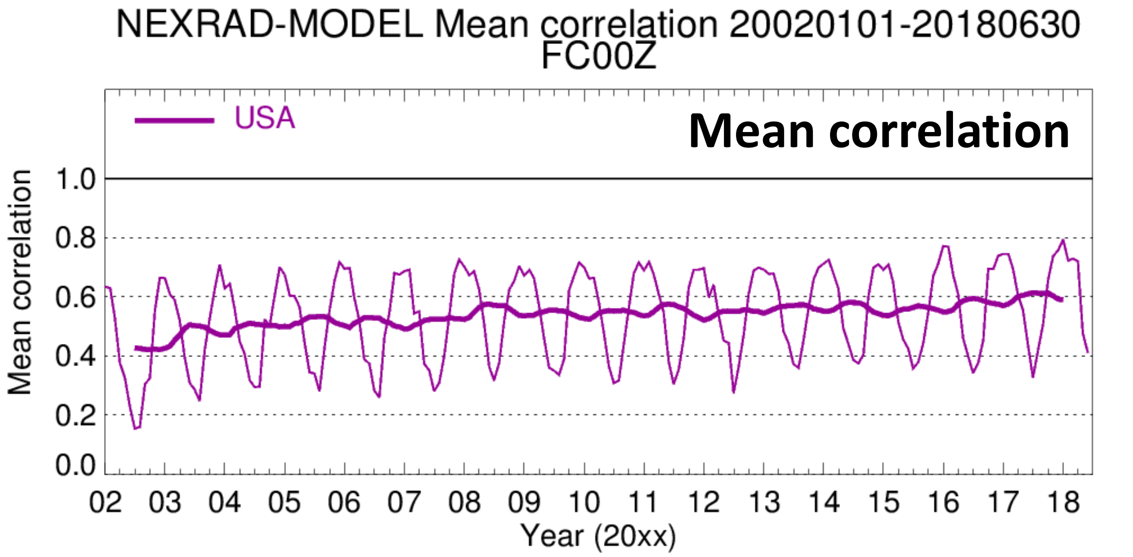
Operational 4D-Var assimilation of NCEP Stage IV precipitation composites (USA)

- NCEP Stage IV = NEXRAD (radars) & rain gauges.
- NCEP Stage IV precipitation composites have been assimilated in ECMWF's operations since November 2011.
- In 4D-Var, we assimilate 6-hourly precipitation amounts (computed from the original hourly composites) to avoid too strong non-linearities and reduce occurrences of zero-precipitation in the model (→ no sensitivity in adjoint).
- Past experimentation demonstrated that the positive impact on short-range forecast scores over the USA can propagate downstream towards Europe during the following days (esp. in higher-troposphere).

Lopez (2011), MWR

ECMWF's 24h forecasts versus NCEP Stage IV:





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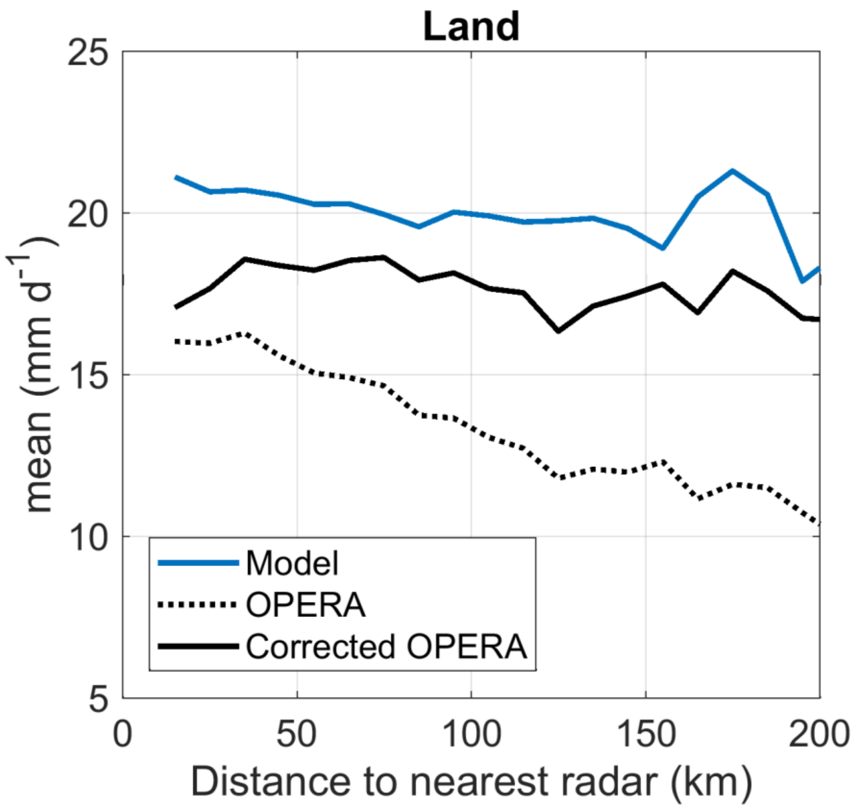
Experimental 4D-Var assimilation of OPERA precipitation composites (Europe)

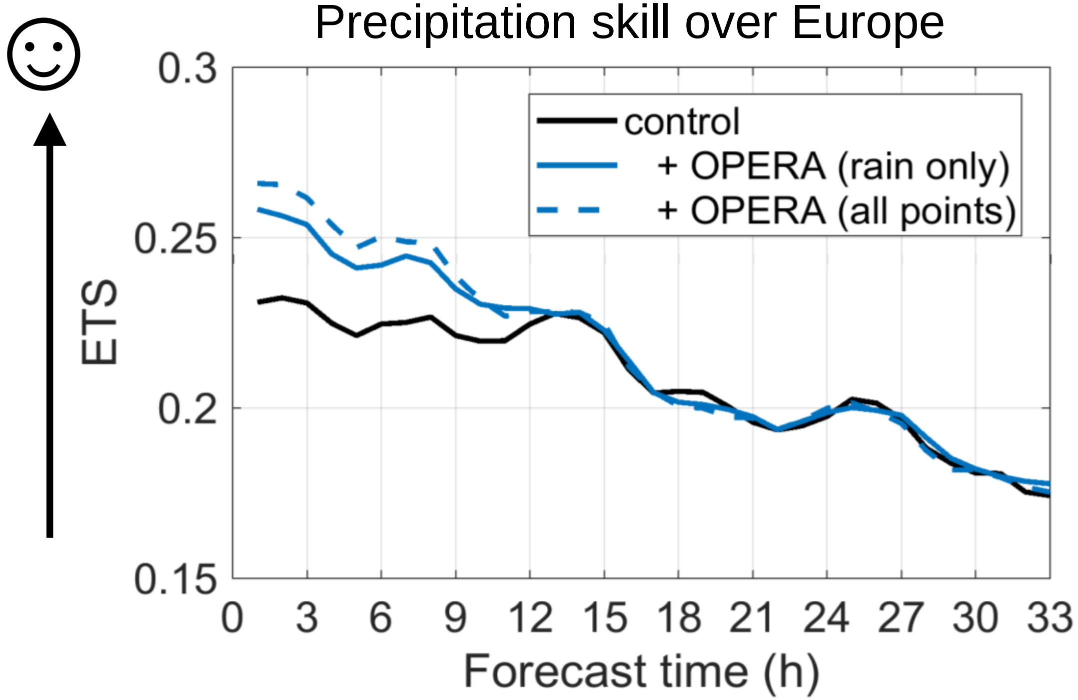
→ Recent developments: **Improved screening** & **attenuation correction applied to obs**.

Impact of attenuation correction:
Mean precip vs radar range



4D-Var assimilation experiments, May-July 2018:

Precipitation skill over Europe



Precipitation forecast skill improves up to 12h range → interesting for flood nowcasting.

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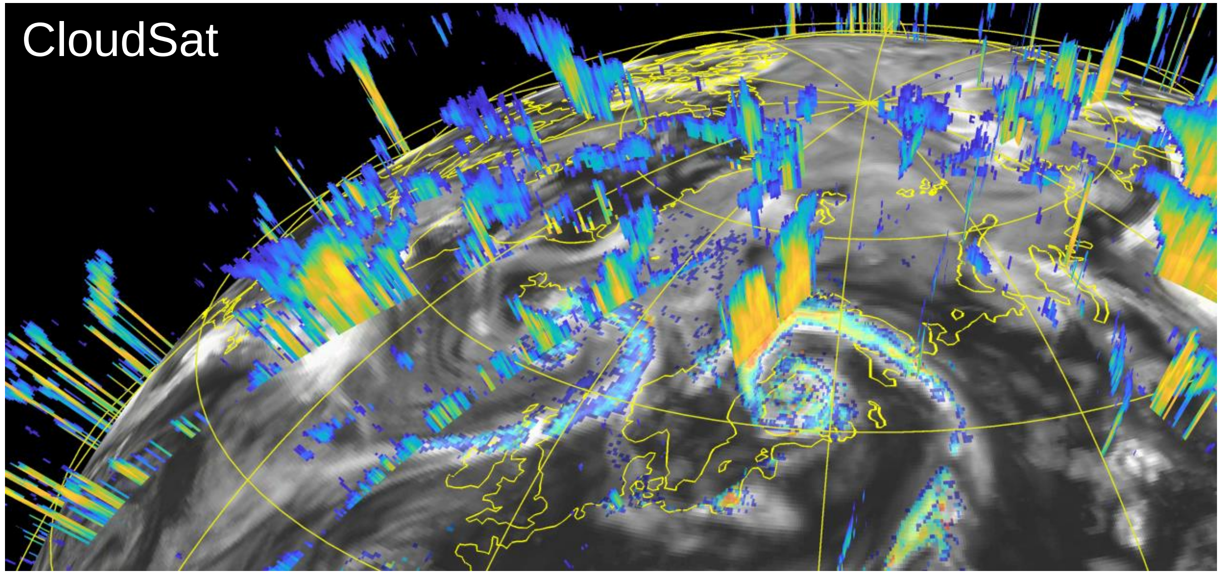
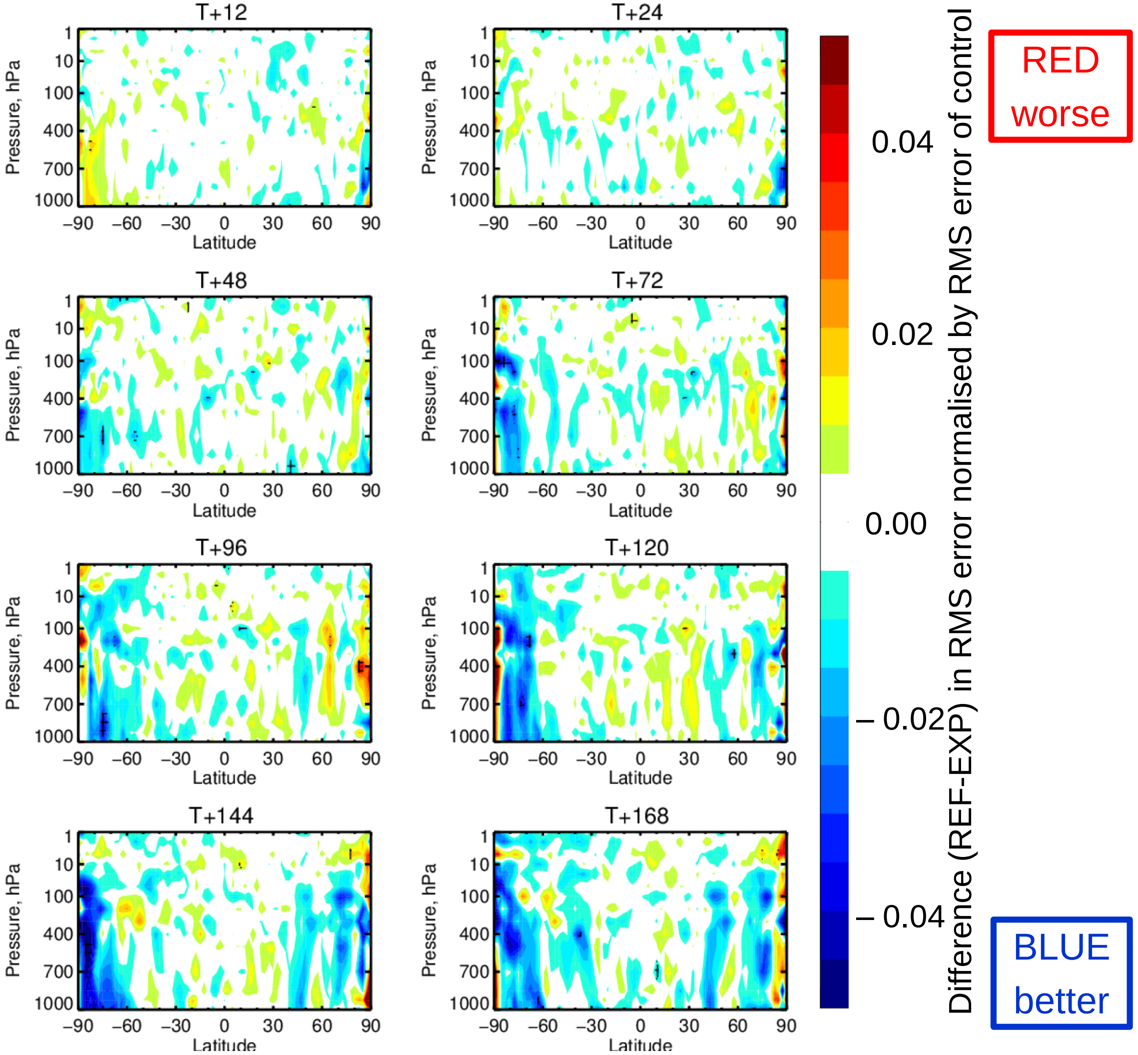
M. Fielding and P. Lopez

SMUFF
Seamless probabilistic multi-source forecasting of heavy rainfall hazards for European flood awareness

Experimental 4D-Var assimilation of CloudSat radar and CALIPSO lidar observations



Impact on Temperature Root Mean Square Error for various forecast ranges: +12h → +168h. 1 August – 31 October 2007



Along-track observations averaged to 72-km resolution:

- **CloudSat: cloud radar reflectivity (at 94 GHz),**
- **CALIPSO: cloud lidar backscatter (at 532 nm).**

→ Successful assimilation in 18-km resolution 4D-Var experiments (12h window; together with all other obs).

→ Preparation for the assimilation of future EarthCARE radar and lidar observations (2022?).

esa ECMWF EARTHCARE

M. Janisková and M. Fielding (2018)

Lightning parameterization

The new parameterization predicts total (CG+IC) lightning flash densities from a set of predictors diagnosed from the convection scheme of the IFS (operational since June 2018):

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

where

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

Proxy for charging rate

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).

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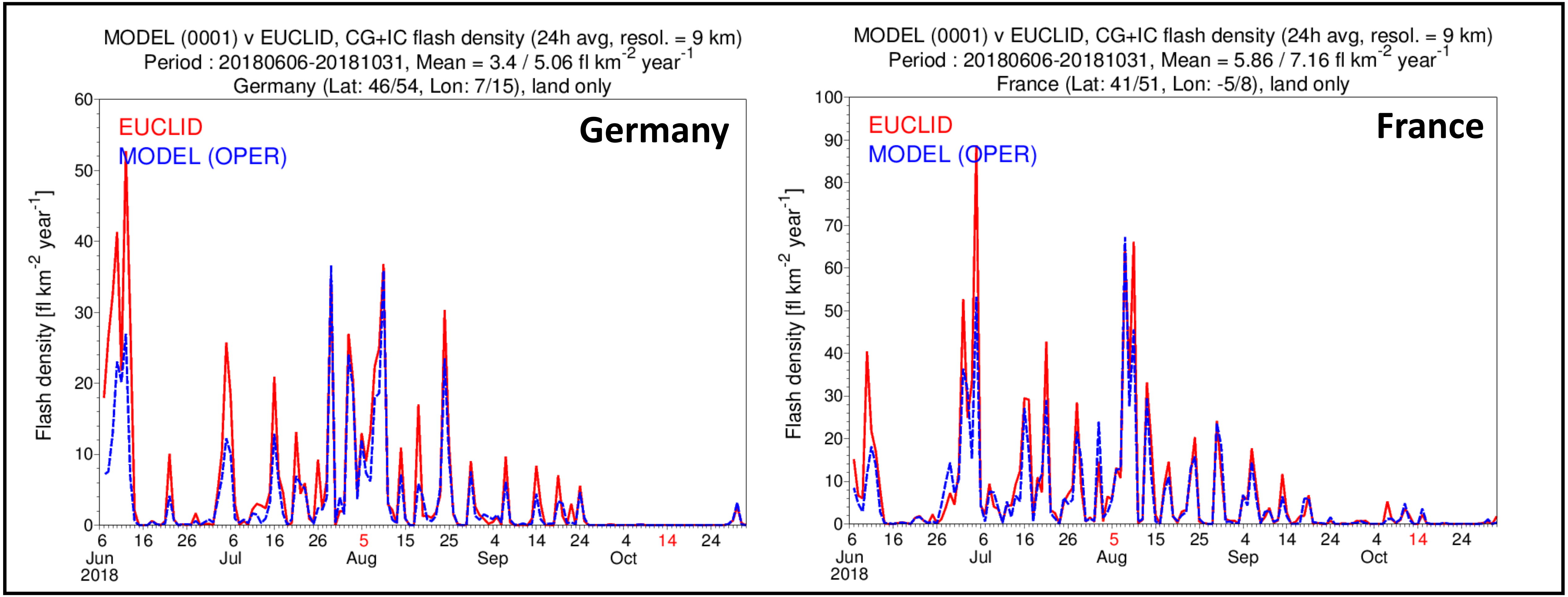
Lopez (2016), MWR

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).



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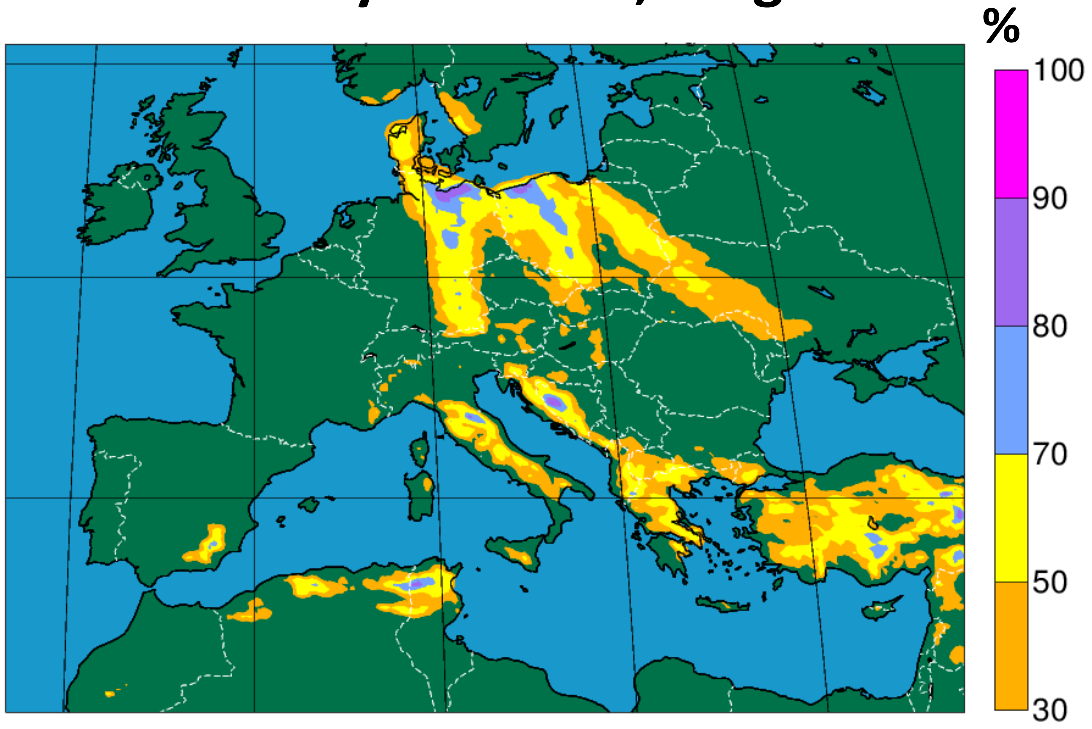
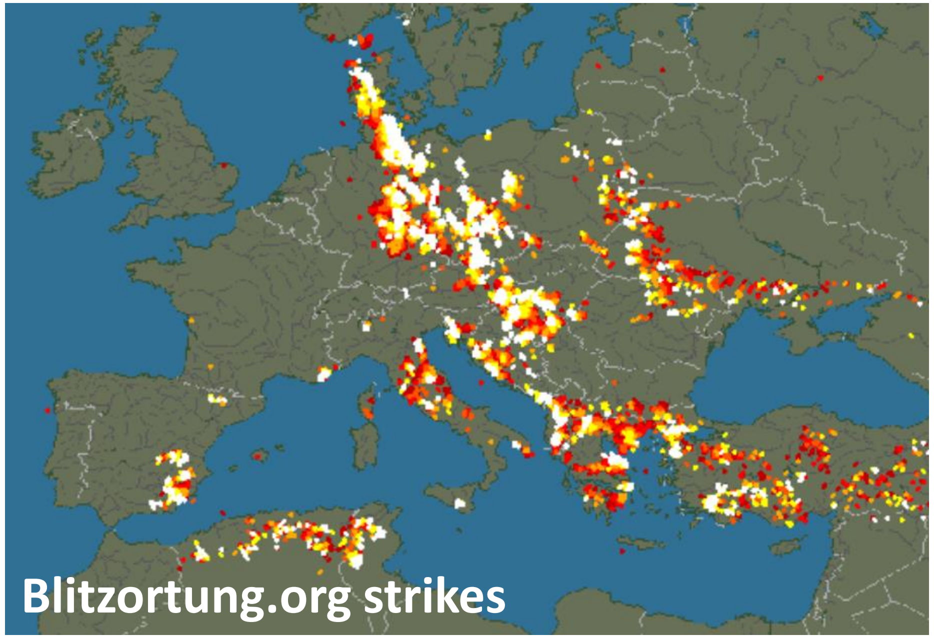
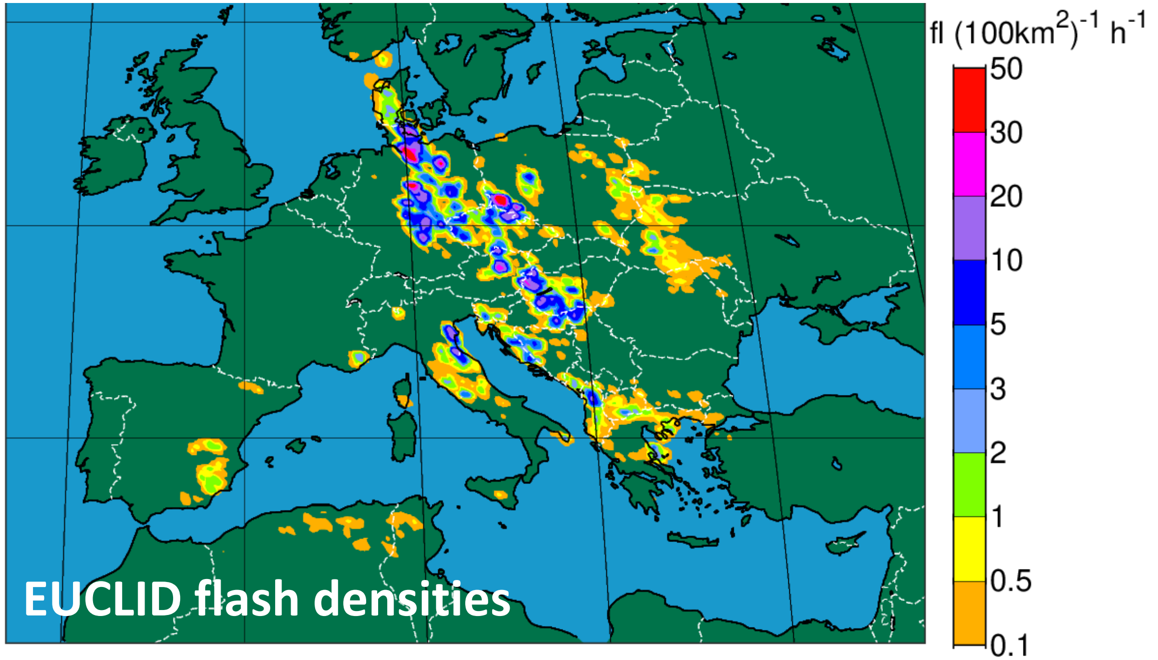
Ensemble forecasts can be used to deal with the random and discrete nature of lightning.

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



Observations, 10 May 2018 15Z





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

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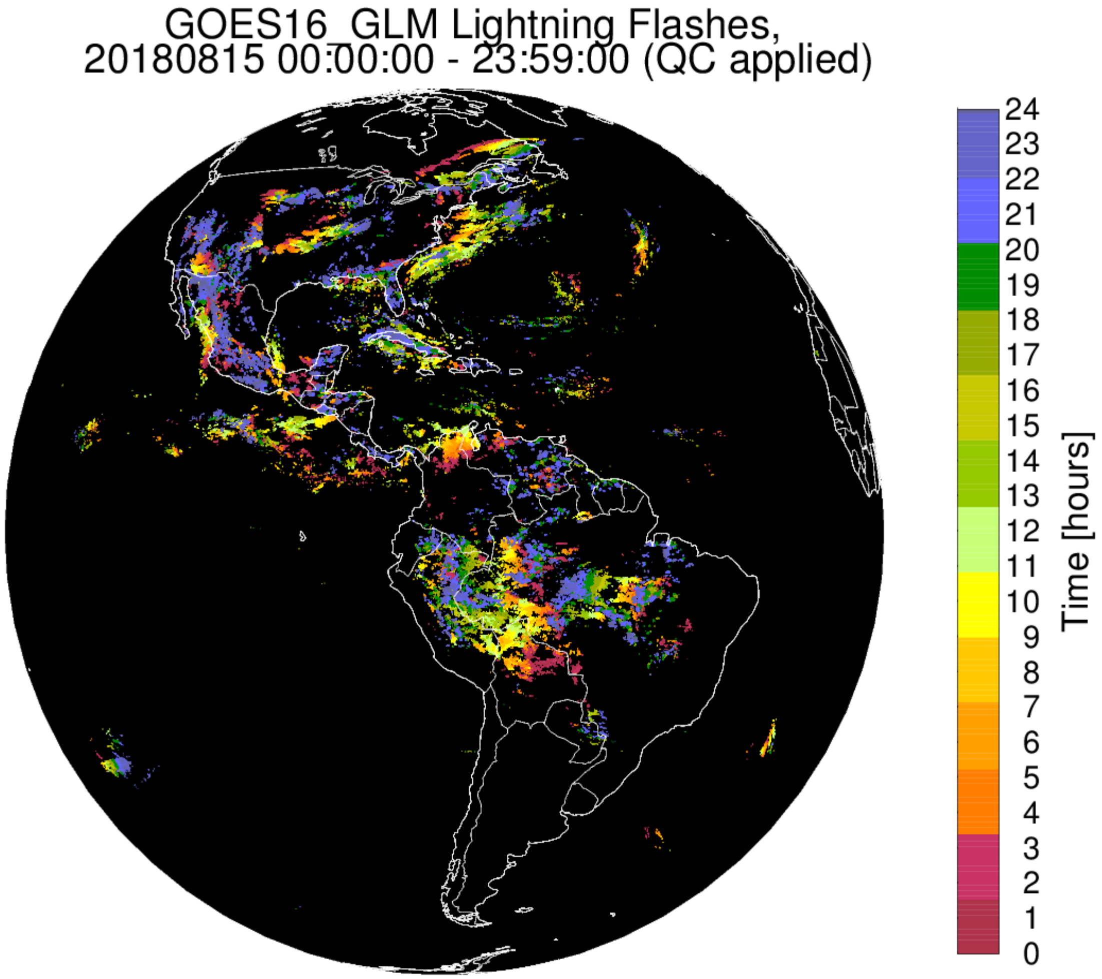
4D-Var assimilation of GOES-16 GLM lightning flash densities

- **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).**
- **Lightning observations can provide a direct constraint on convective precipitation during the 4D-Var assimilation process (much more difficult to obtain when using precipitation observations).**



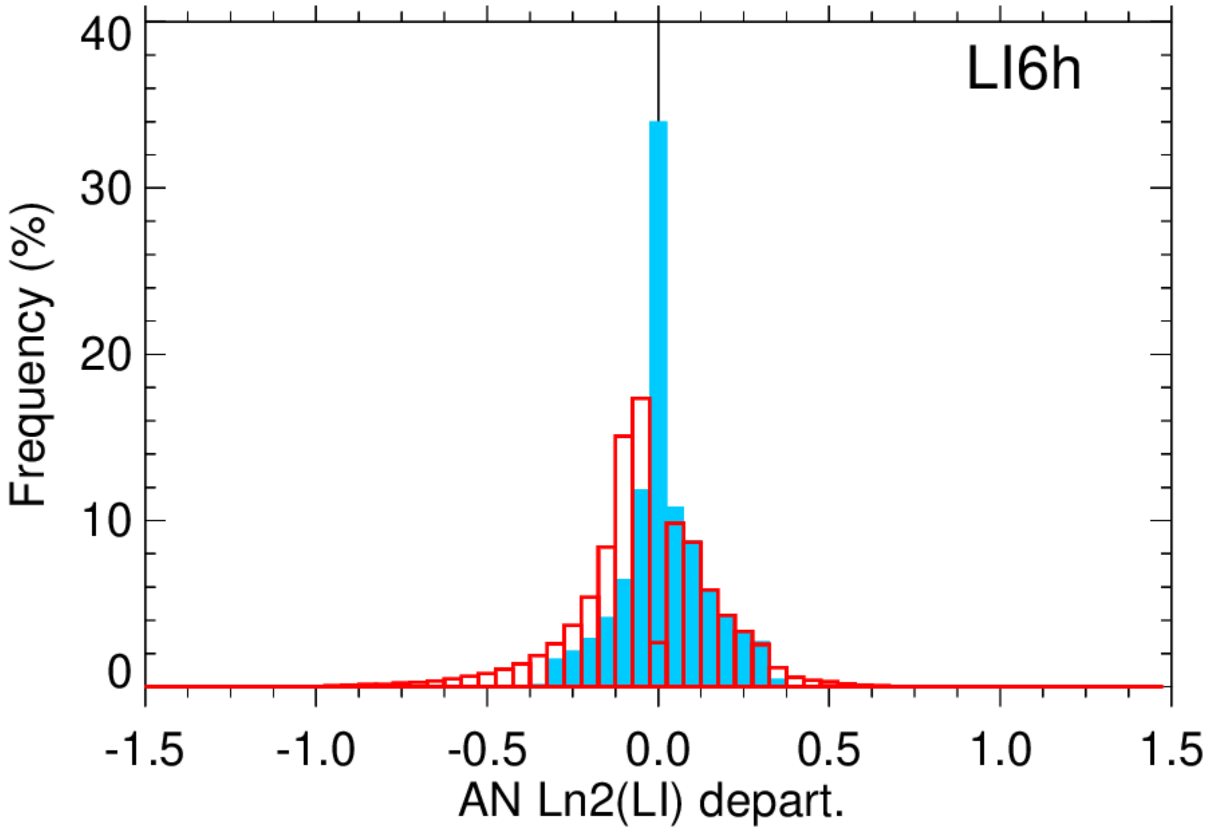
Example of GOES-16 GLM flash data coverage (over one day; colour-coded according to time).

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.**

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Summary and plans for "precipitation" assimilation

Current status:

- Satellite all-sky MW radiances: operational (major source of information).
- NCEP Stage IV precipitation composites: operational.

- OPERA precipitation composites (Europe): some work/testing still needed.
- CloudSat radar and CALIPSO lidar: promising results in 4D-Var assimilation.
- GOES-16 GLM lightning flash densities: good progress toward 4D-Var assimilation.

Plans (focusing on new observations)**:**

- New ESA project (PEARL) on assimilation of space-borne radar & lidar (for EarthCARE).

- Finalize GOES-16 GLM lightning assimilation (Americas).

- Extend lightning assimilation to GOES-17 GLM (Pacific), MTG-LI (EUMETSAT; 2022?) and possibly to continental-scale/global ground-based lightning detection networks.

- Assimilation of GPM Dual-frequency Precipitation Radar data.

- Assimilation of visible reflectances from geostationary and polar-orbiting satellites.

Thank you!

References: (Ctrl + click to follow links)

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

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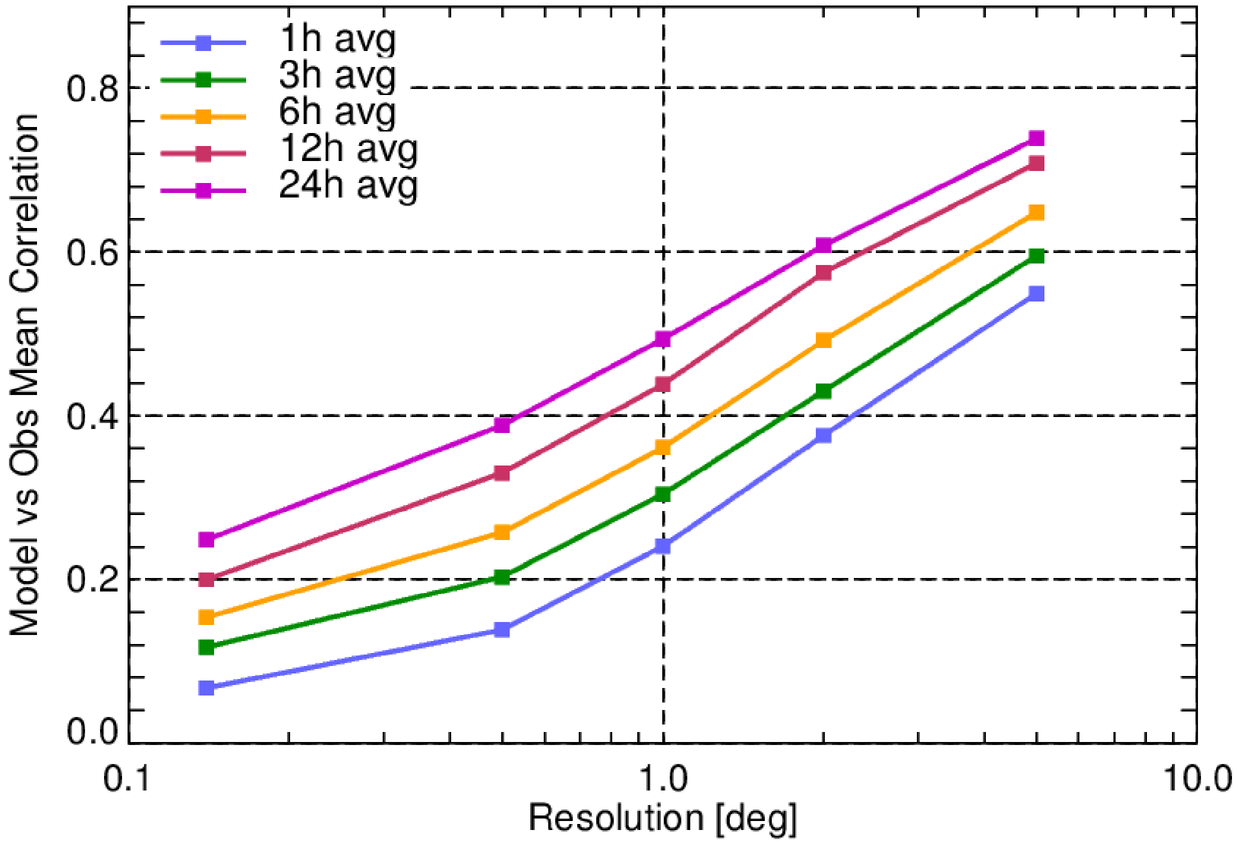
ECMWF model vs UBIMET LDS observations

Mean correlations (between maps of flash density) for various averaging scales in time and space.

Based on 0-24h forecasts (16-km resol.) over Europe in summer 2015.



Model and observations correlation improves for wider temporal and spatial scales → Implications for DA?

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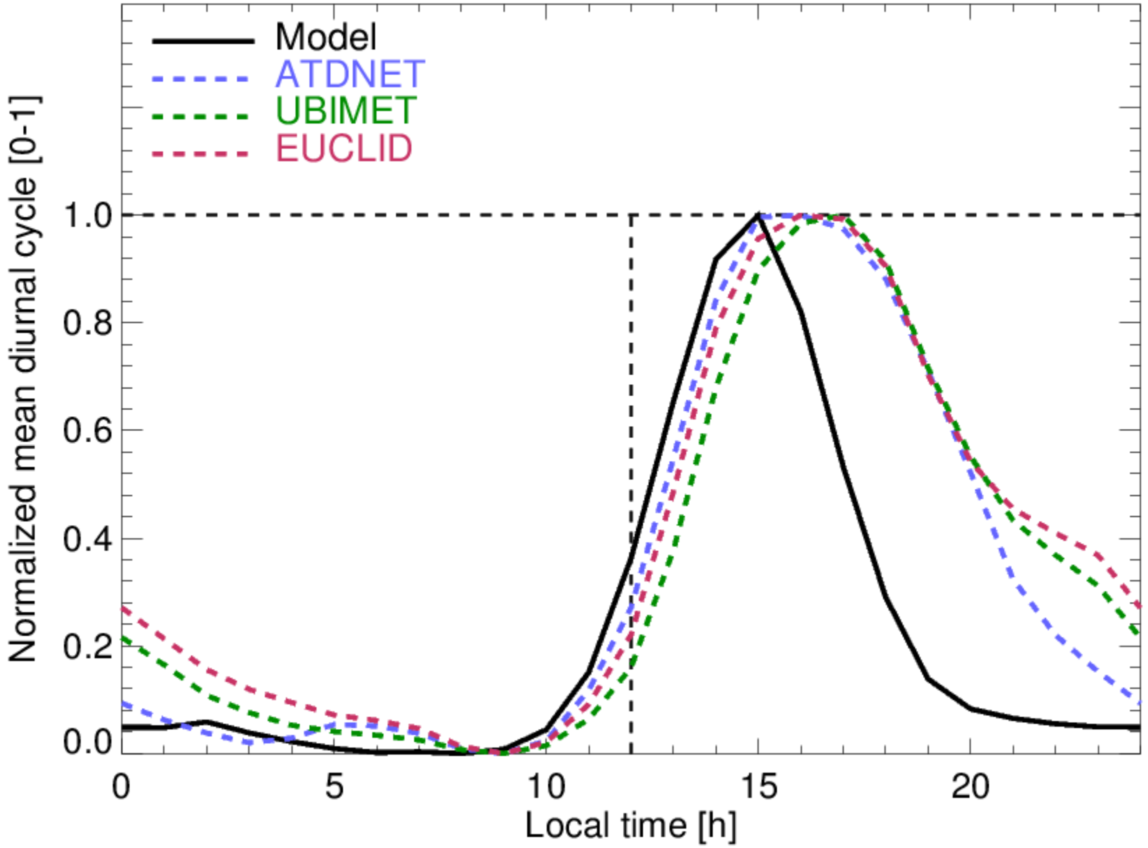
ECMWF model vs various ground-based lightning networks

Diurnal cycle of mean flash densities (normalized by amplitude).

Based on 0-24h forecasts (16-km resol.) over Europe in summer 2015.



Predicted lightning declines too early in the afternoon.
→ Consistent with previous studies focusing on precipitation.

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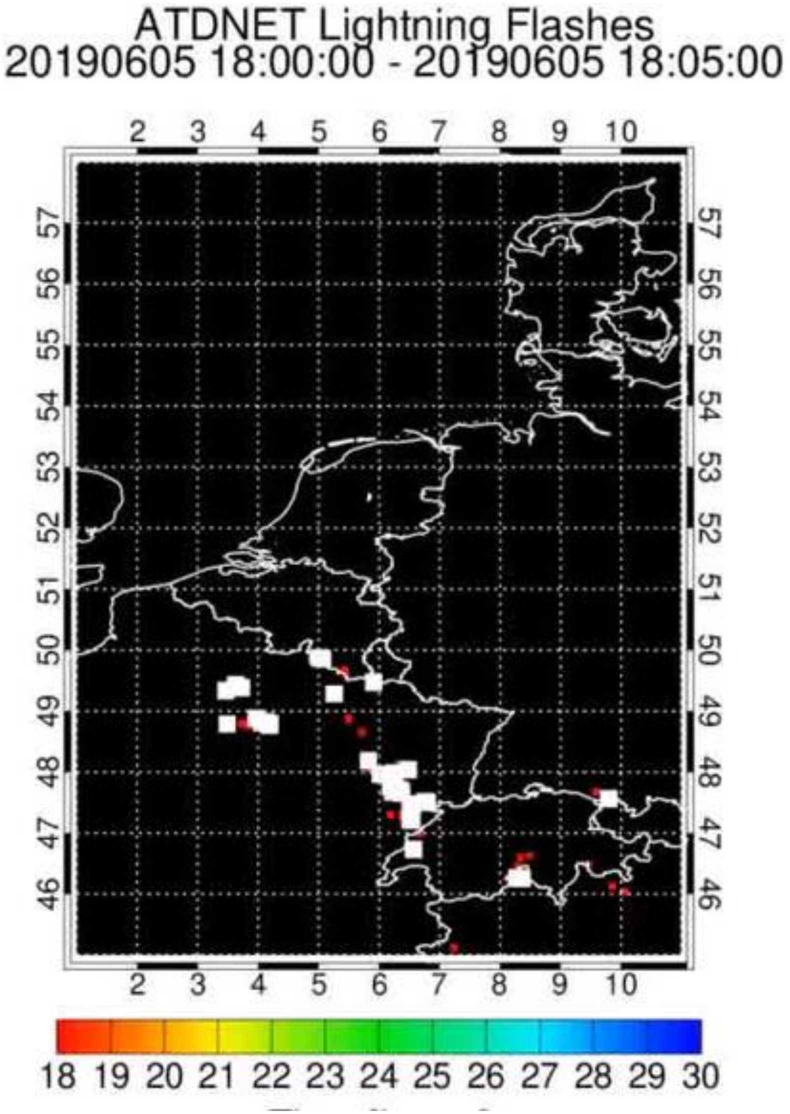
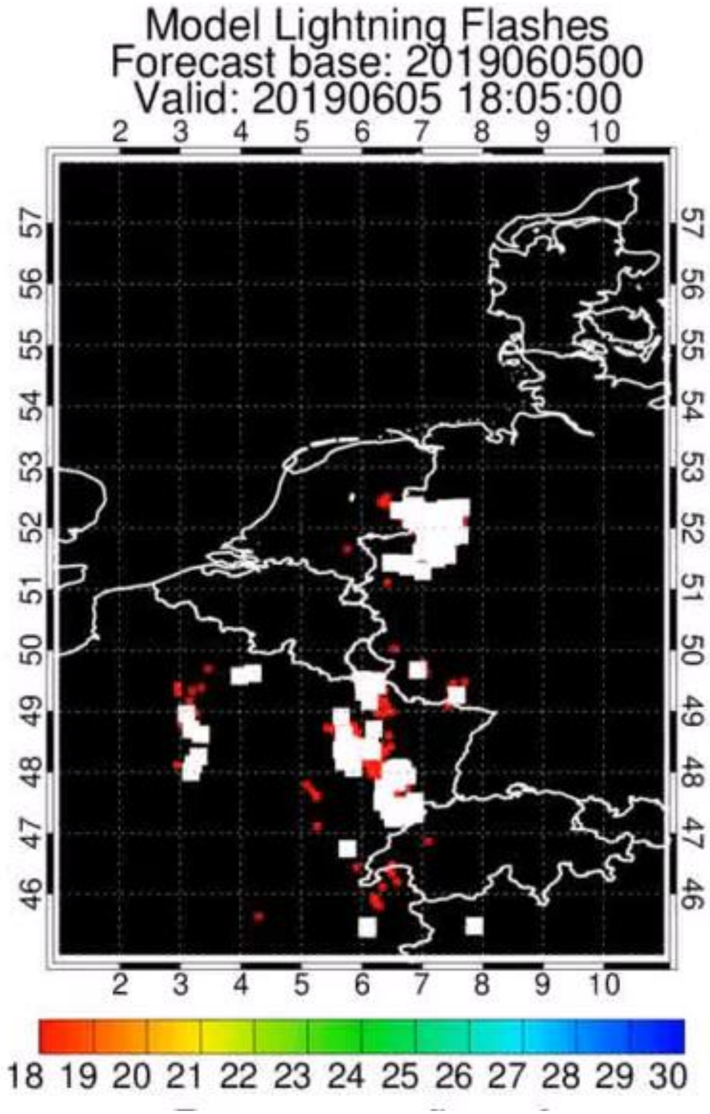
Comparison of model with ATDnet lightning flashes

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.

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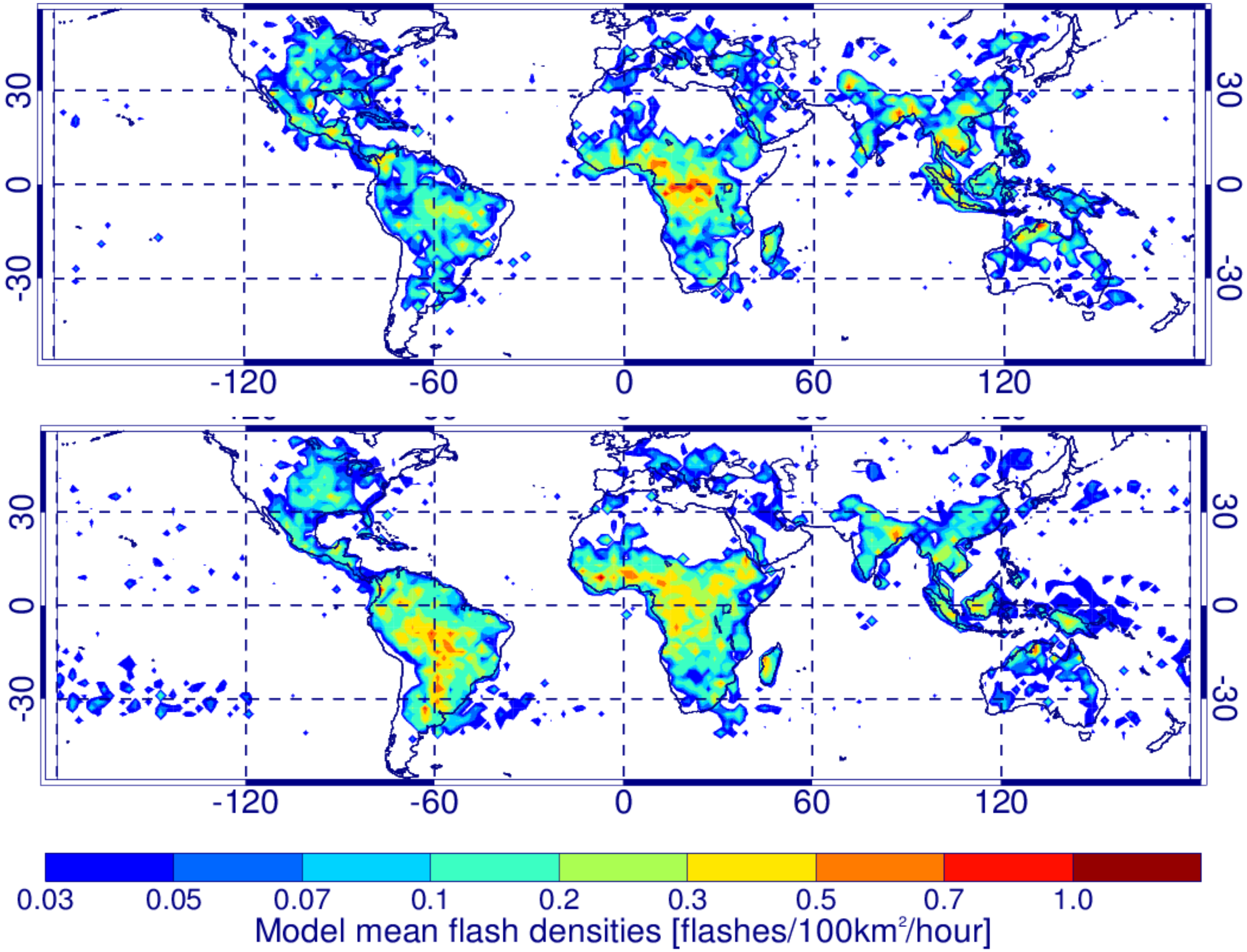
Simulated lightning against ISS-LIS observations

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.

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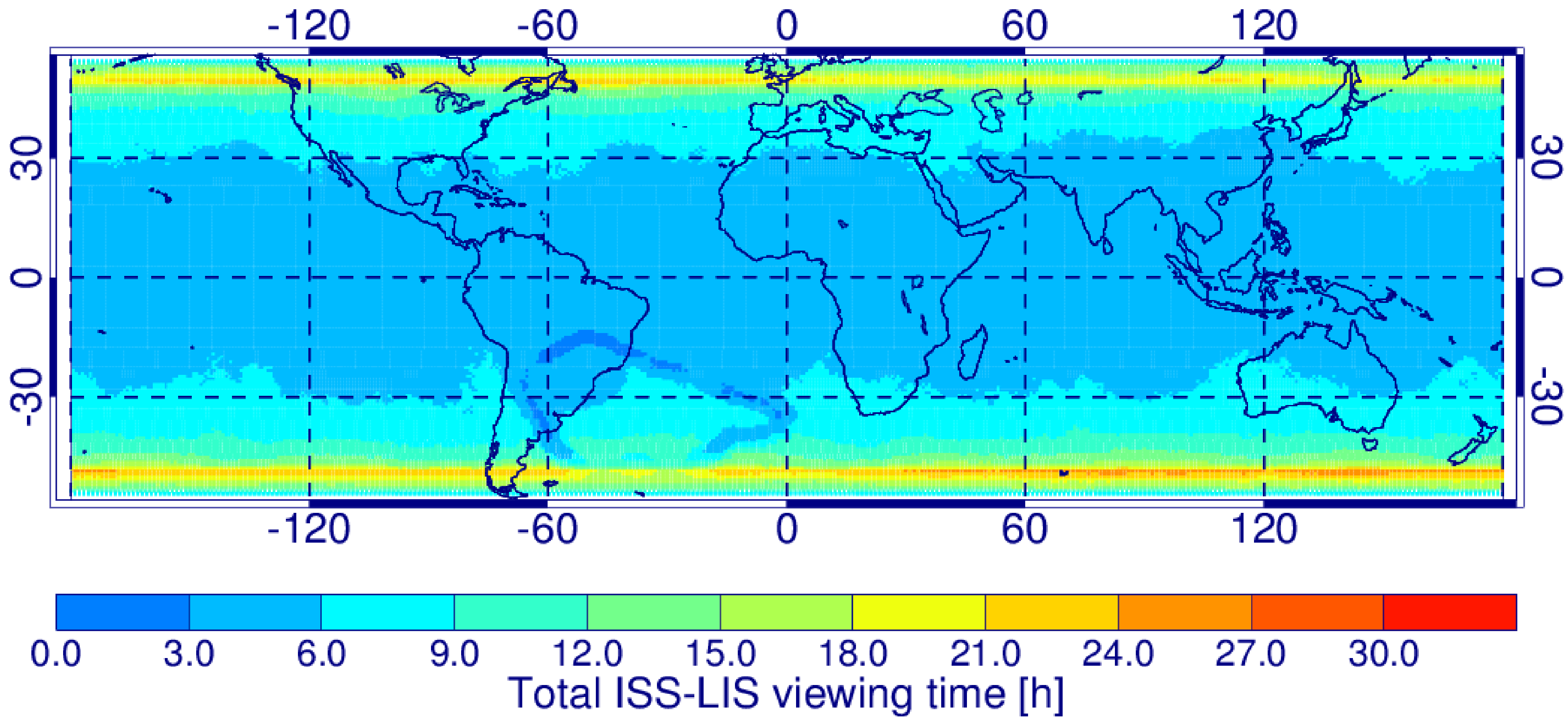
But beware: ISS-LIS sampling is rather limited!

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



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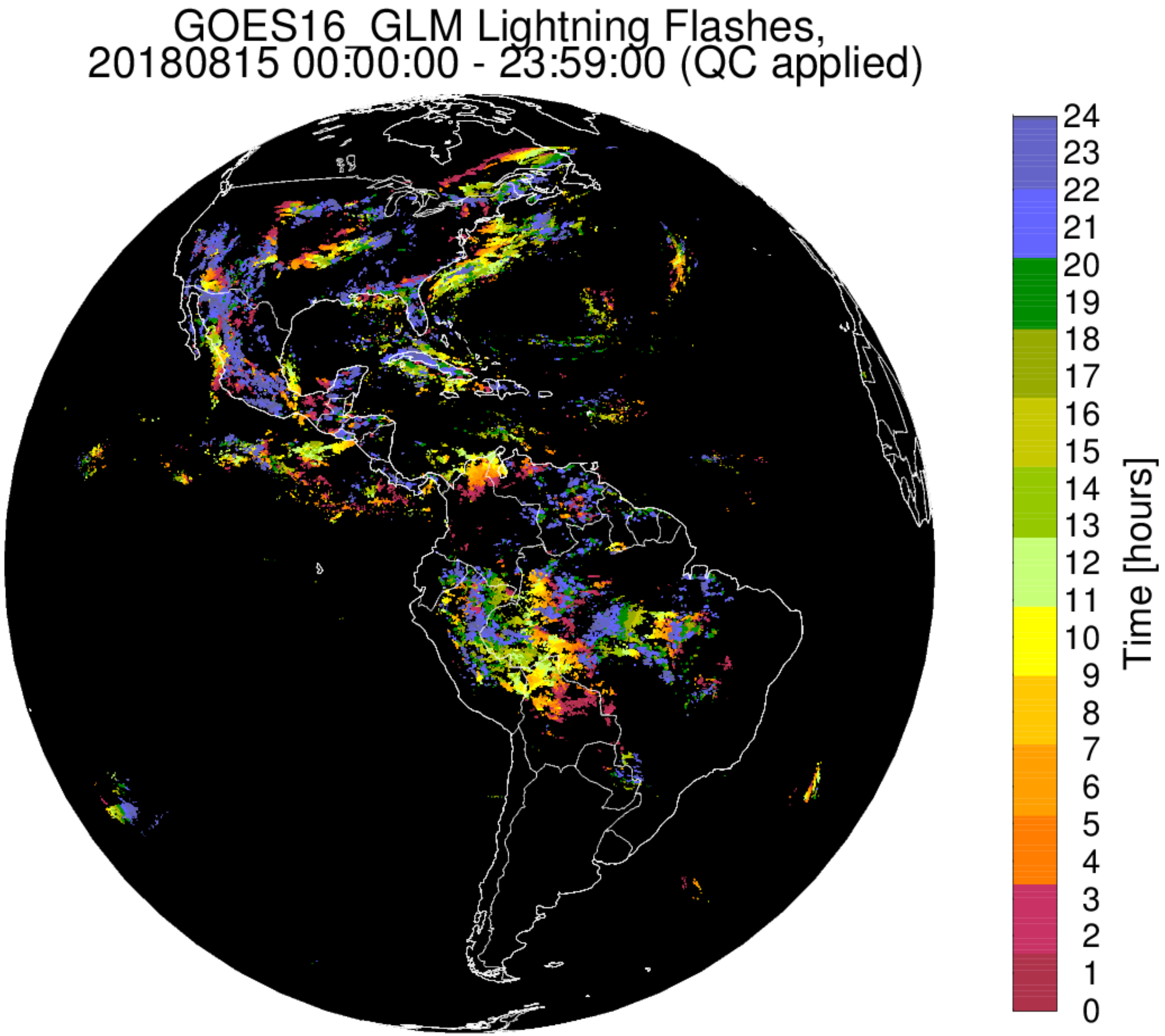
GOES-16 GLM flash data: Example of data coverage (15 Jun 2018)



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

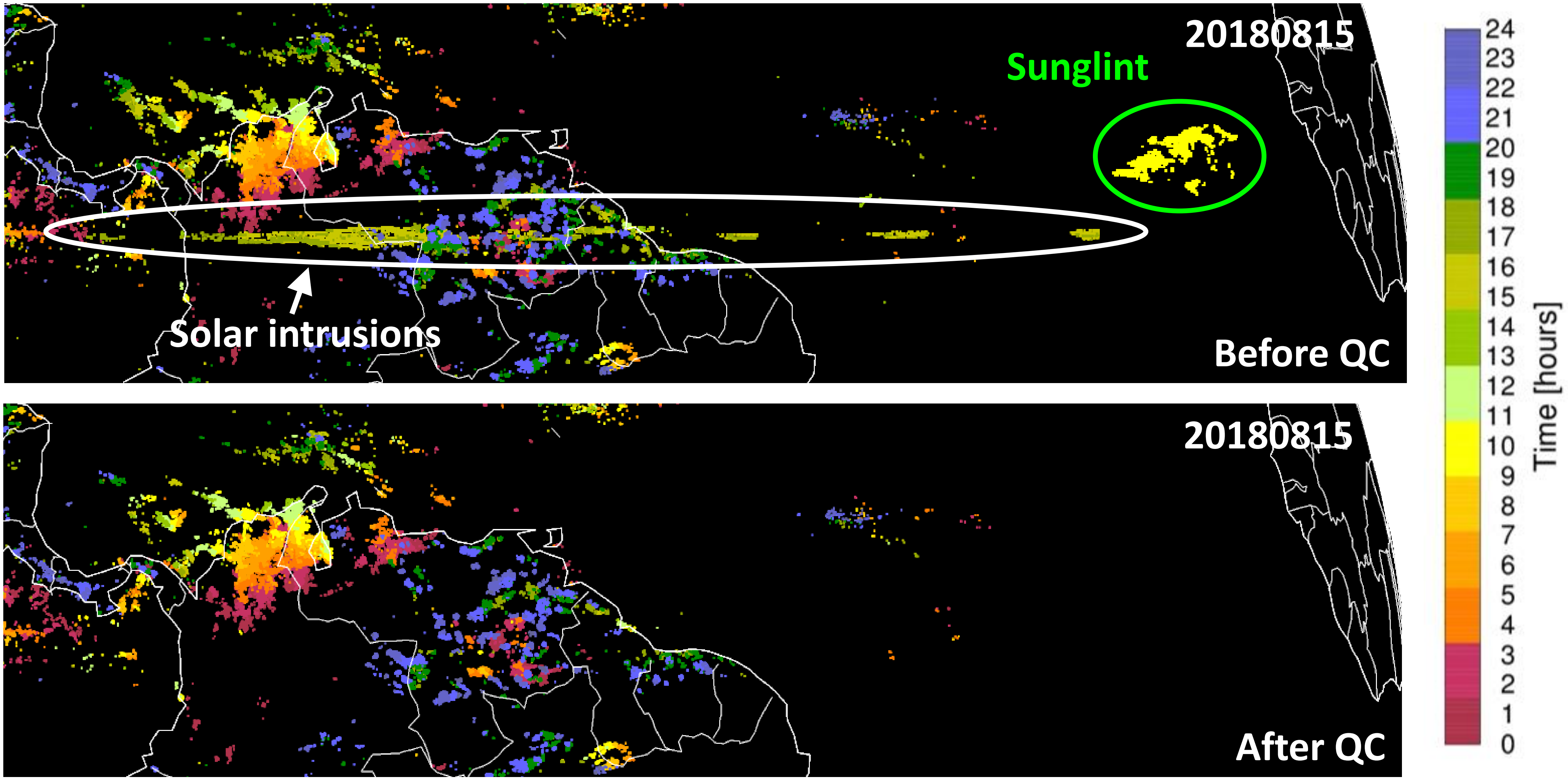
- Homemade quality control of the GLM flash product had to be developed:

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)



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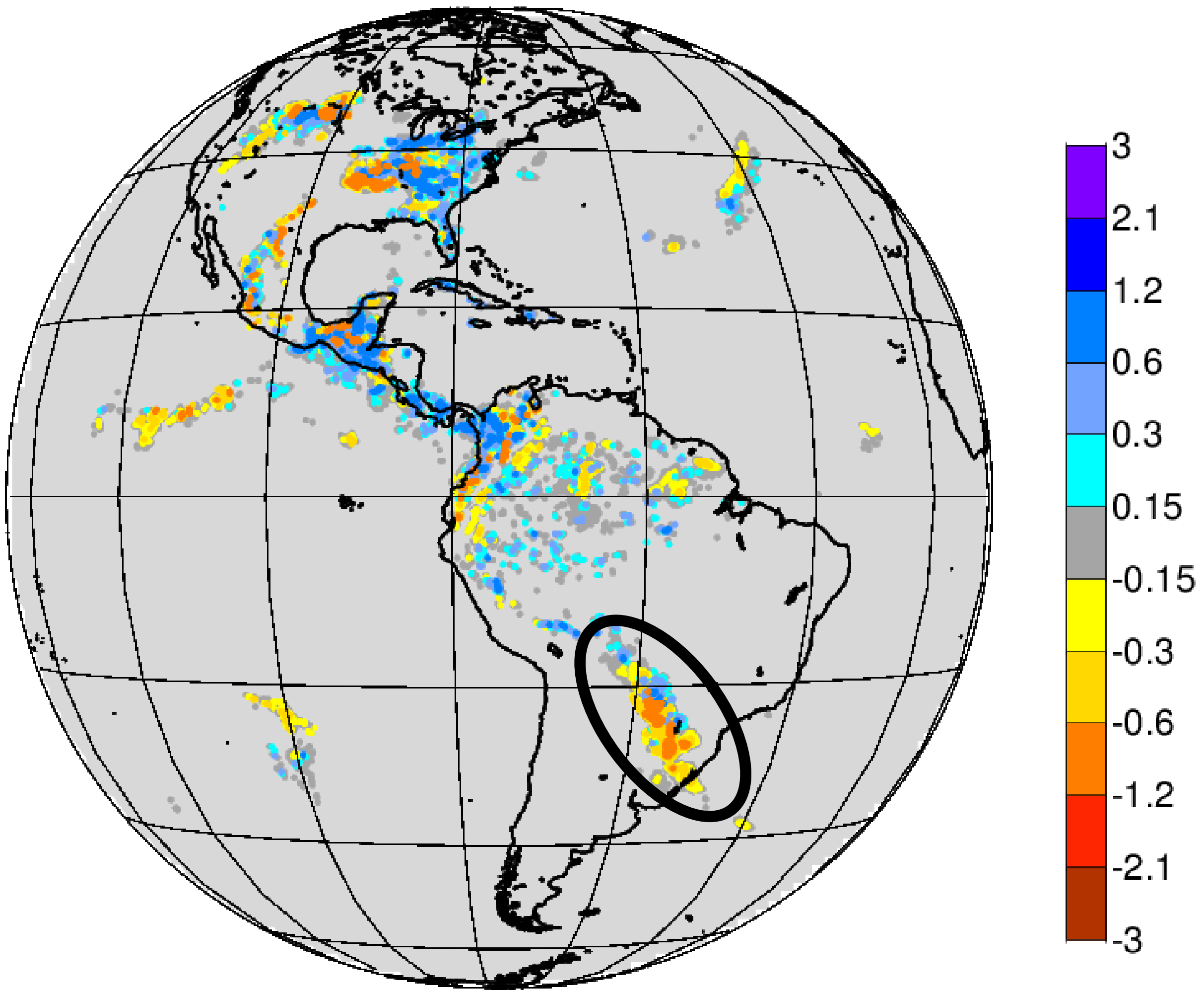
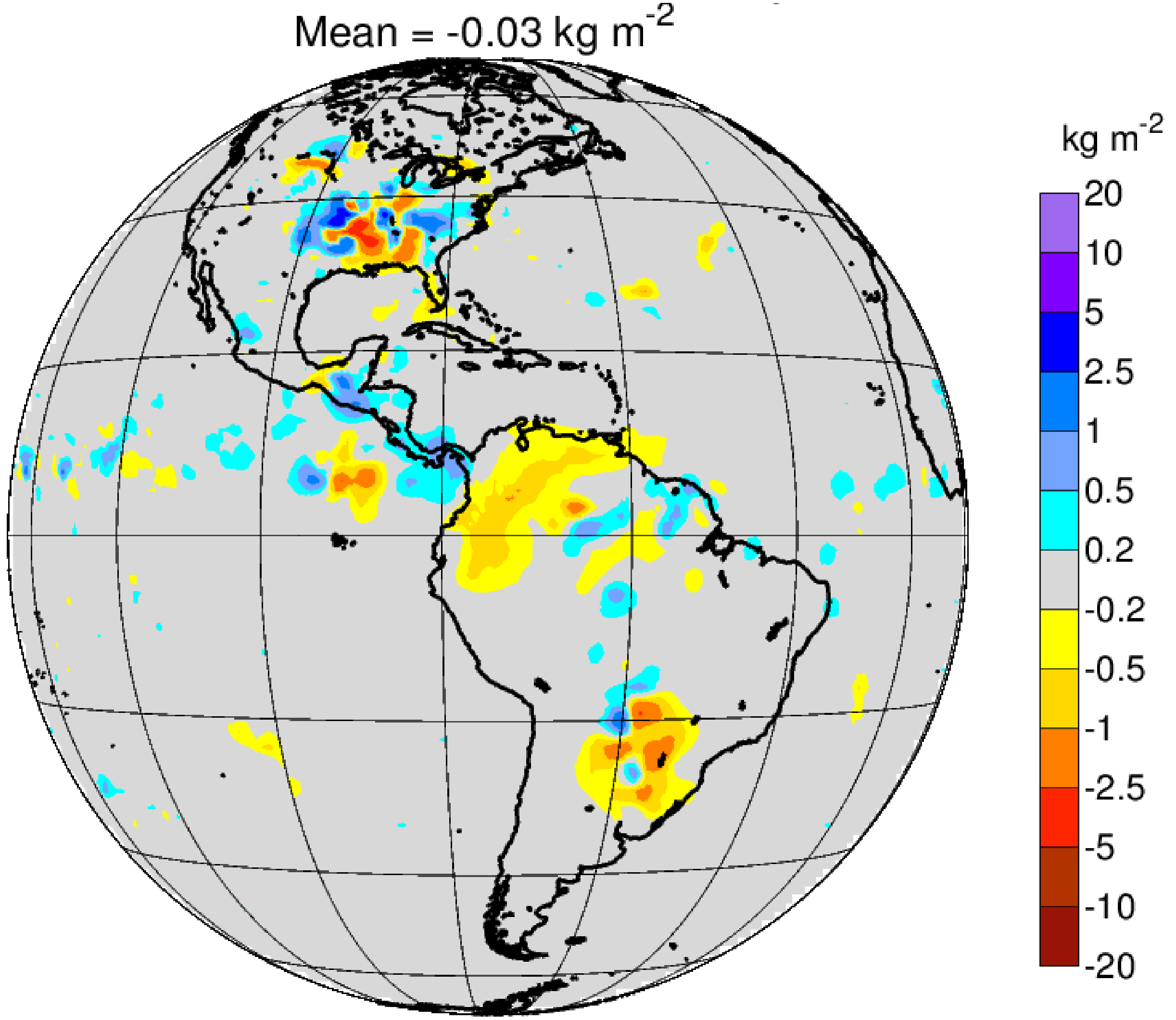
4D-Var assimilation of GOES-16 GLM lightning flash densities: First cycle.

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



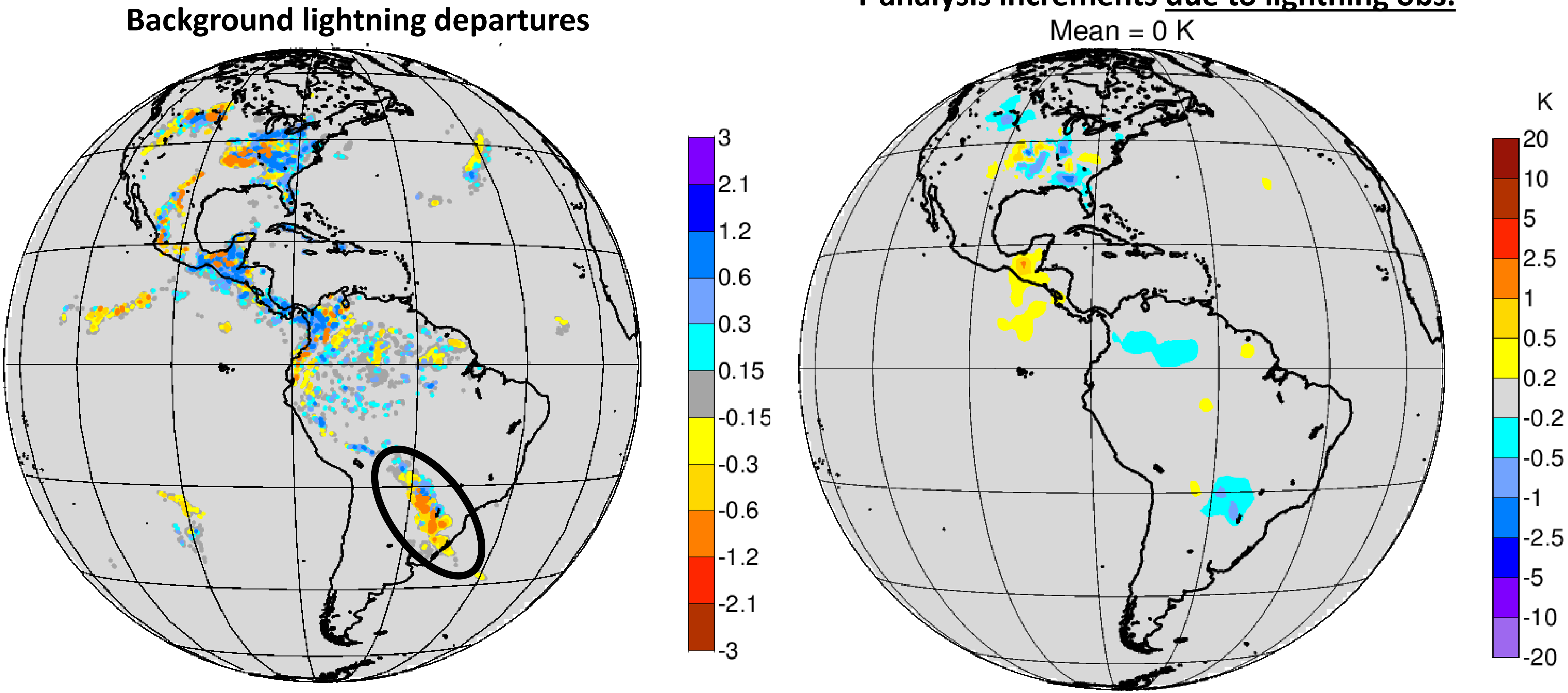
TCWV analysis increments due to lightning obs.



ECMWF

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.



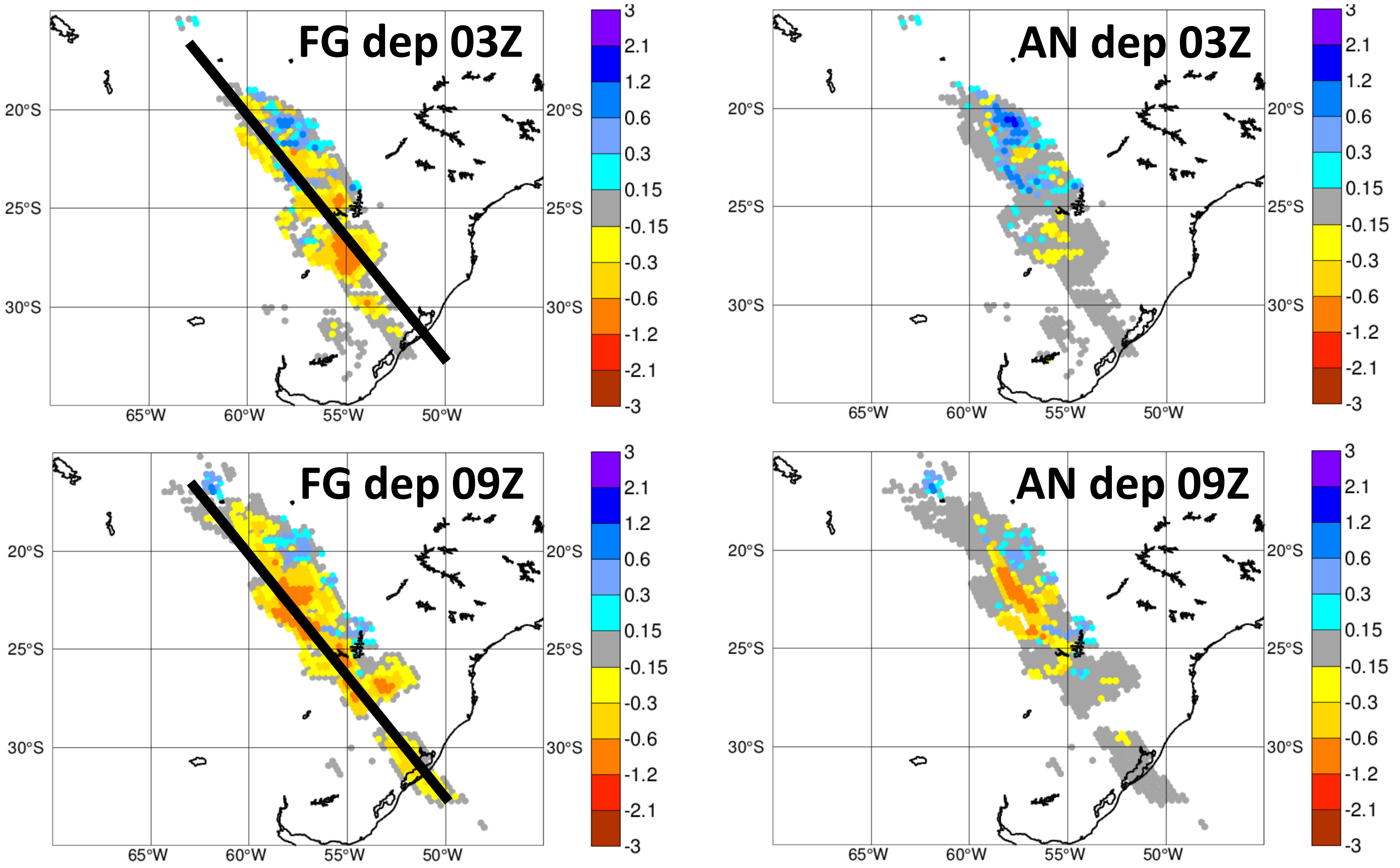
4D-Var assimilation of GOES-16 GLM lightning flash densities: First cycle.

Single 4D-Var cycle (28-km resol., 137 lev.) using log[(2)][6h-avg flash density] (no bias corr.).

Lightning obs–model departures

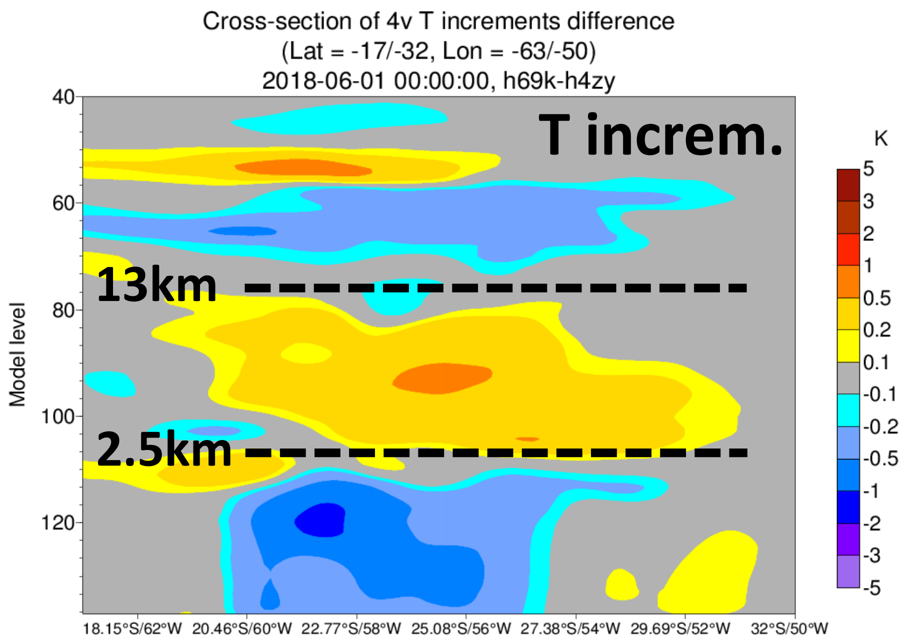
Zoom north of Argentina on 1 June 2018

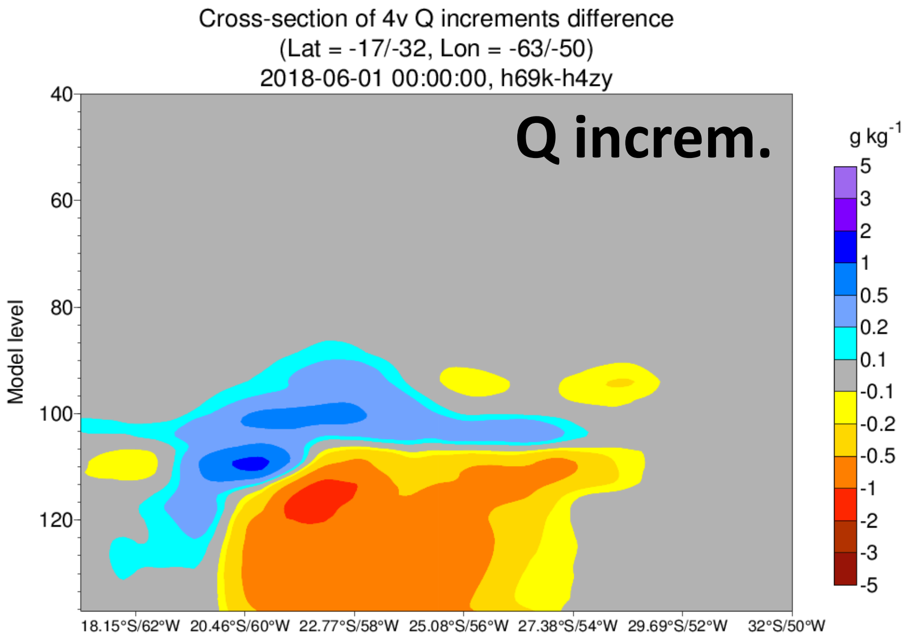
(2 time slots within 4D-Var window)



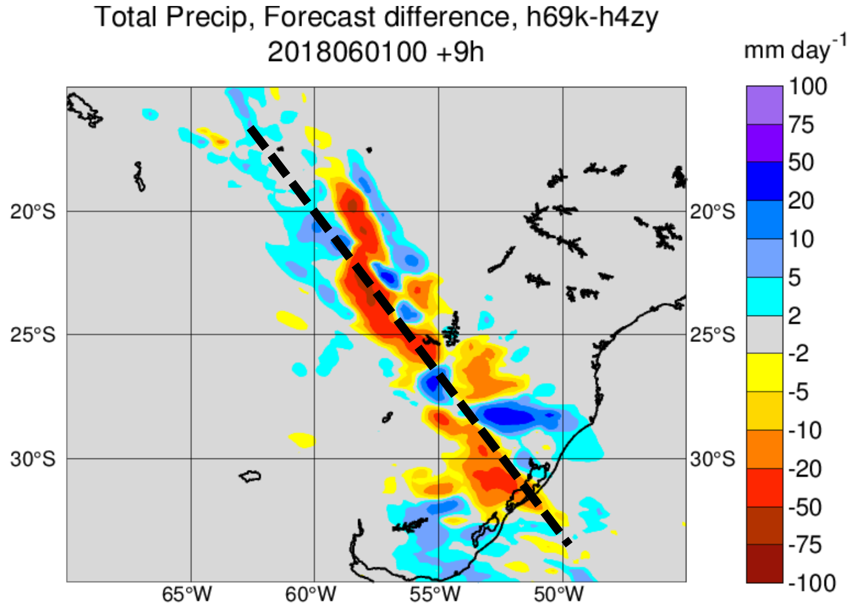
ECMWF

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





Cross-sections of T & Q analysis increm. due to lightning obs (north of Argentina).



← Impact on 9h total precipitation forecast (north of Argentina).

→ All these changes make sense to reduce lightning in the model.

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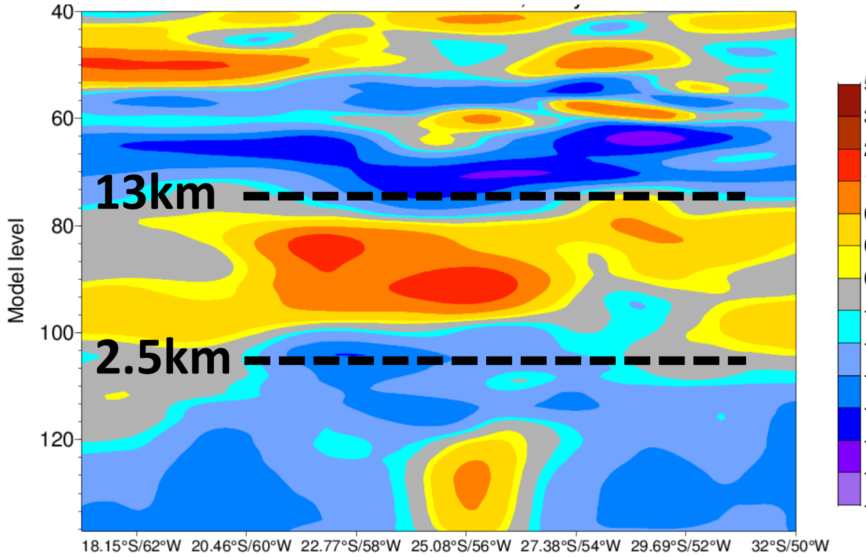
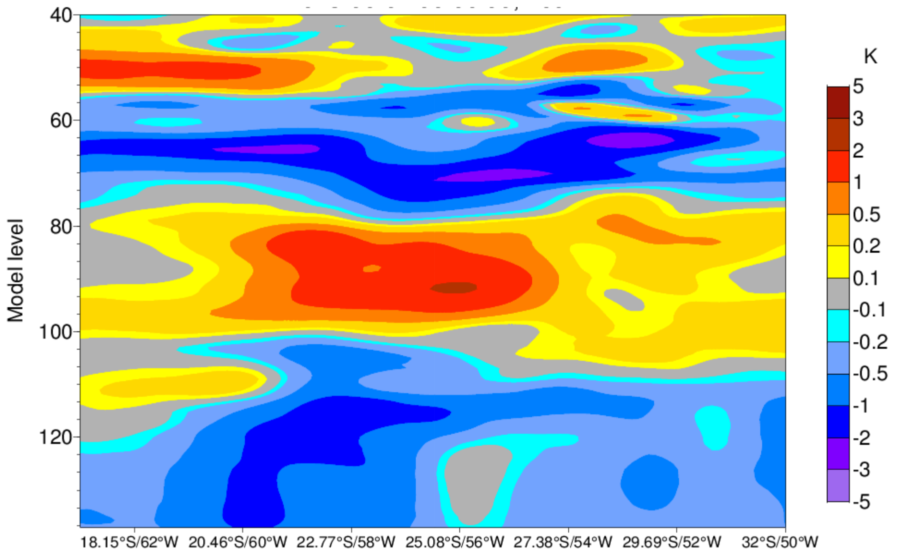
4D-Var assimilation of GOES-16 GLM lightning flash densities: First cycle.

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

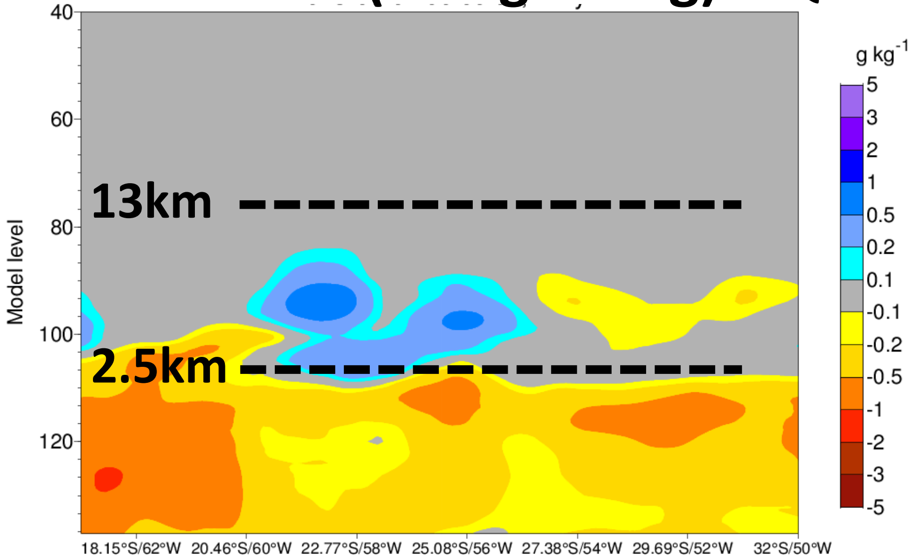


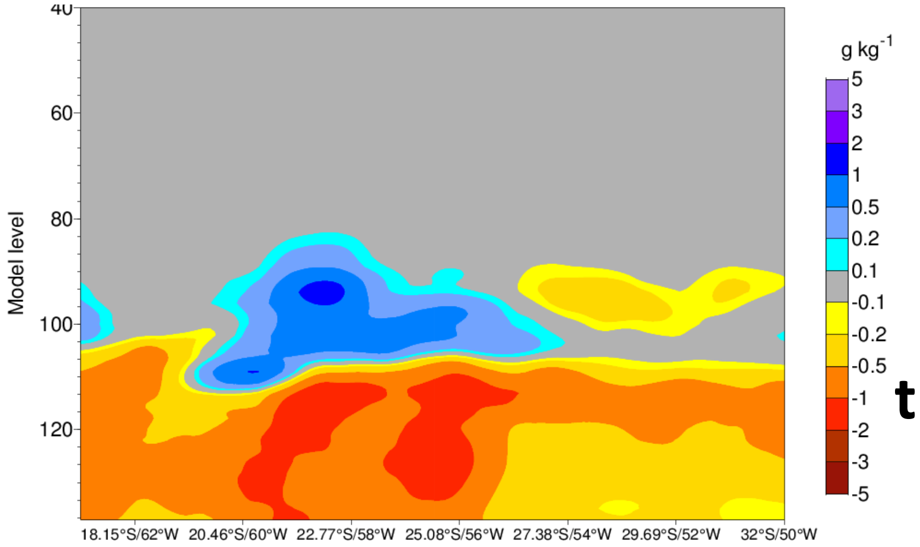


Cross-sections of
T & Q analysis increm.

(north of Argentina)

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





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