Exploring Total Column Water Vapor Retrievals from satellite-based NIR measurements in pre-convective environments

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Why use TCWV to monitor pre-convective environments

- Moisture is a key ingredient for deep convection and heavy precipitation
- Low-level moisture variability drives convective initiation
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Vertically integrated water vapor in kg/m^2
High sensitivity towards surface:

$$\boxed{\frac{L_{TOA}(0.9\ \mu m)}{L_{TOA}(0.865 \mu m)} \sim Total\ Column\ Water\ Vapour}$$

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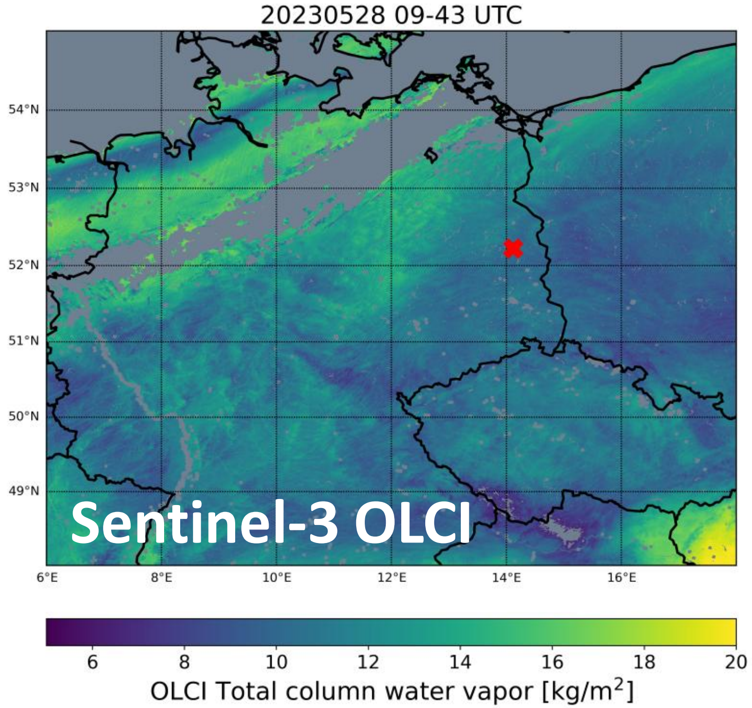

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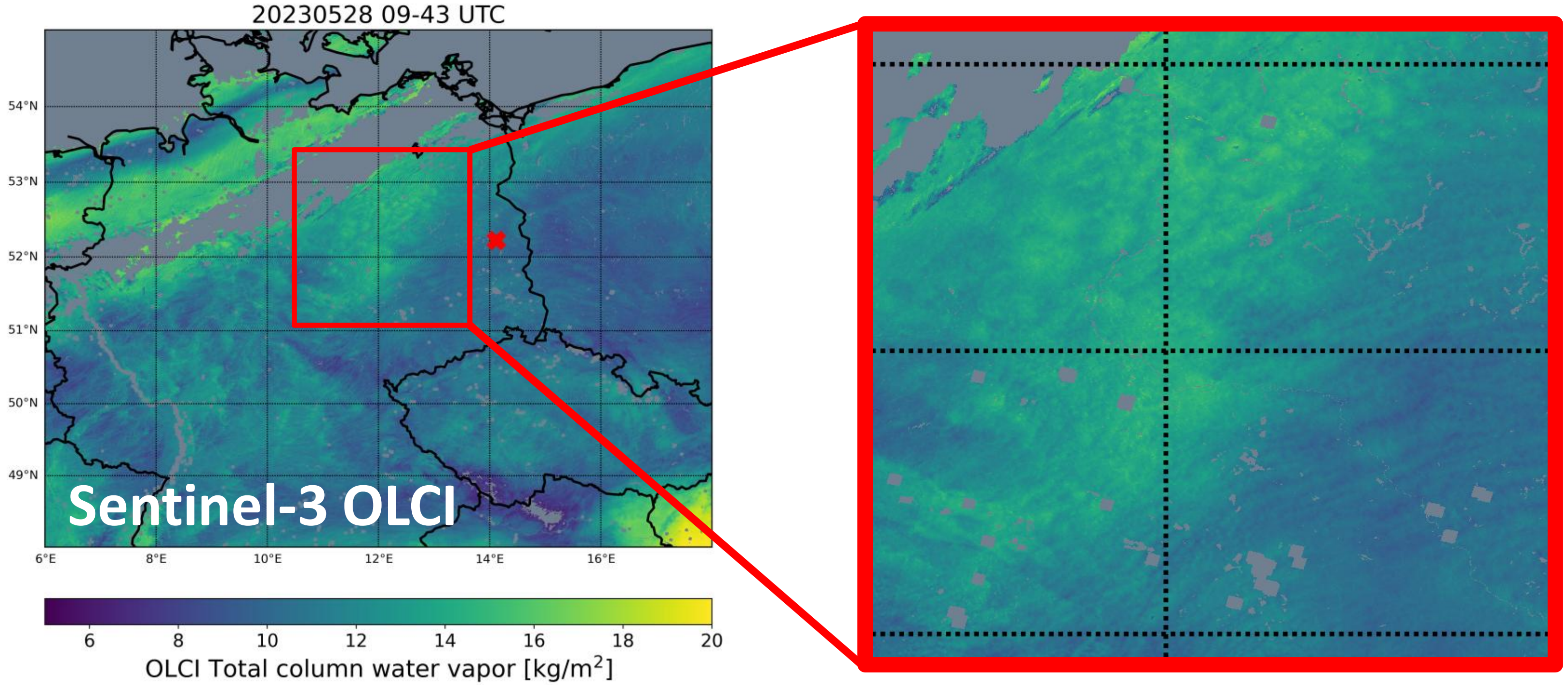

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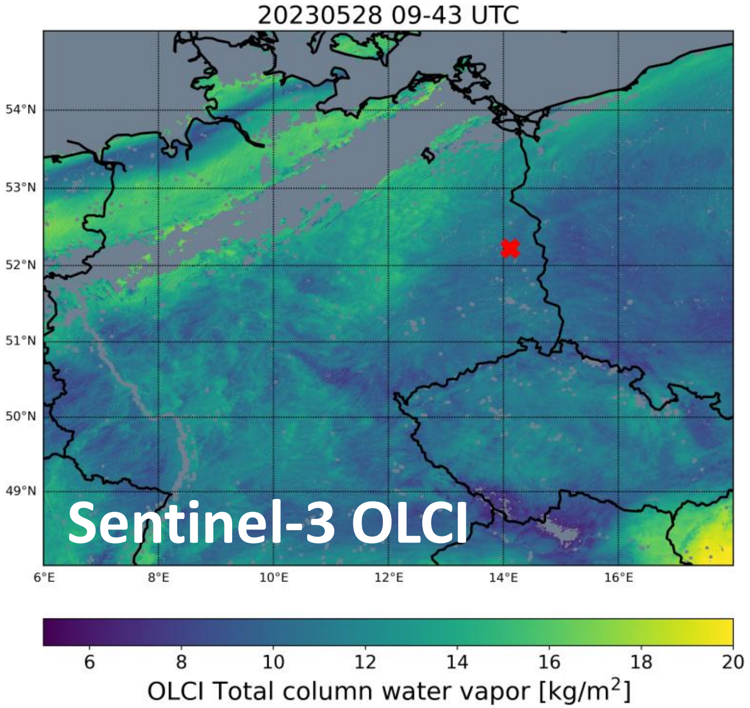

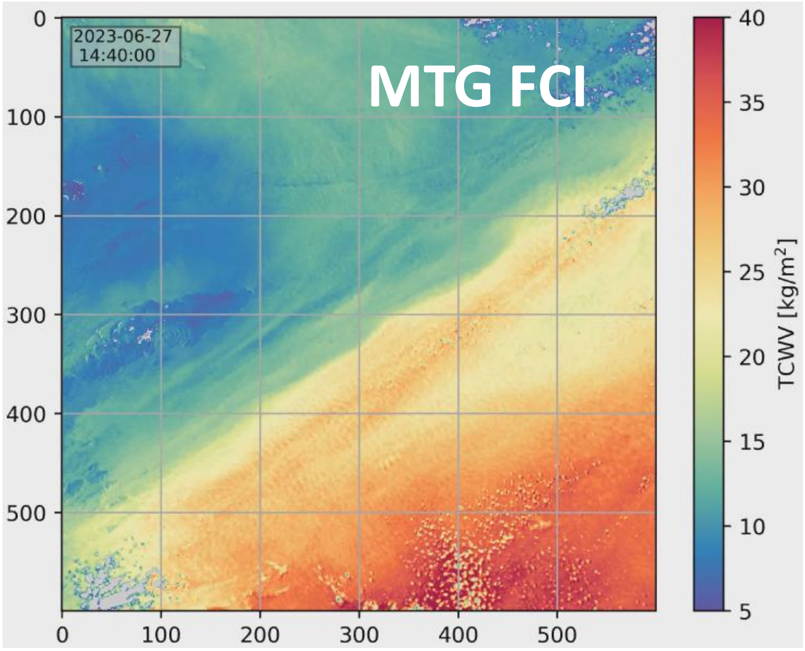

MTG-FCI

Figure Credit: Jan El Kassar

From moisture observations to convective potential

How to **feed this clear-sky TCWV information** into a parameter directly related to **convective potential**

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CAPE: Convective Available Potential Energy
Strongly controlled by properties of the boundary layer

$$\mathrm{CAPE} = \int_{LFC}^{EL} g \cdot \left(\frac{T_{\mathrm{parcel},v} - T_{\mathrm{env},v}}{T_{\mathrm{env},v}} \right) dz$$

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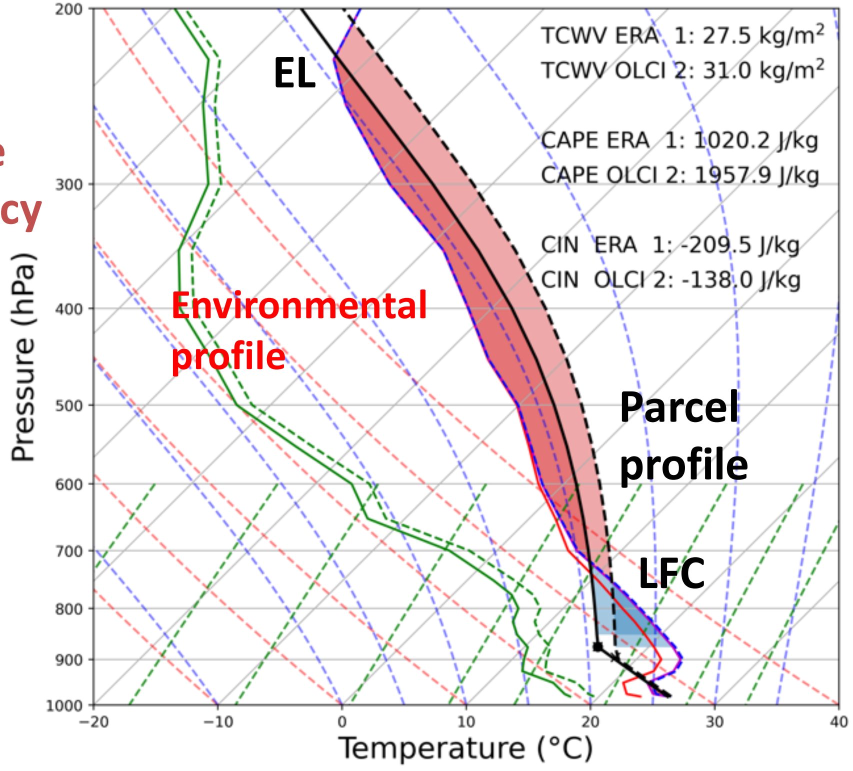
CAPE: Positive buoyancy



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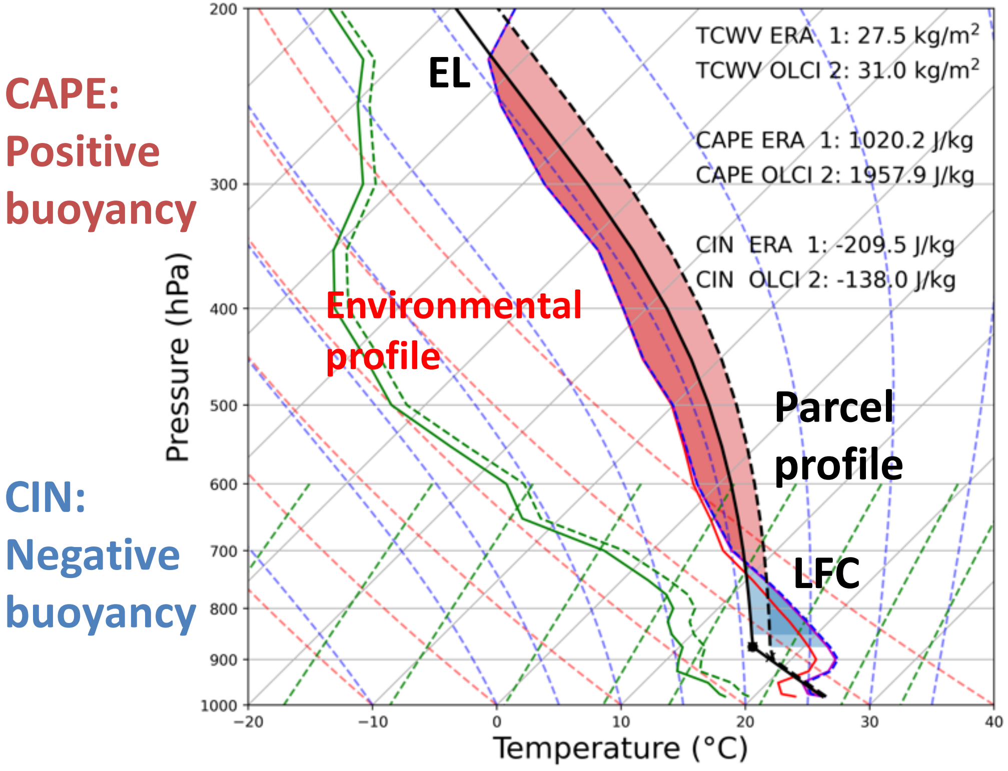
CIN: Convective inhibition

$$\mathrm{CIN} = \int_{SFC}^{LFC} g \cdot \left(\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}} \right) dz$$



CAPE/CIN Sharpening approach

For a fast and straightforward approach (Carbajal Henken et al, in prep), combine:

- NWP forecast temperature/humidity fields
- $\Delta TCWV = TCWV_{obs} - TCWV_{model}$

$$\frac{\partial CAPE}{\partial TCWV} = \frac{\partial CAPE}{\partial q} * \frac{\partial q}{\partial TCWV}$$

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CAPE/CIN Sharpening approach: Case study

Areas of interest:

- Robust OLCI TCWV retrievals over Germany in spring/summer time
- Dominant clear-sky conditions at satellite overpass times (~9 UTC, ~11 LT)
- Within 3 hours after satellite overpass: isolated/scattered convective development on local to region scales
  - → late morning/early afternoon convective cases
- Some convective potential present (non-zero CAPE values, low CIN values)

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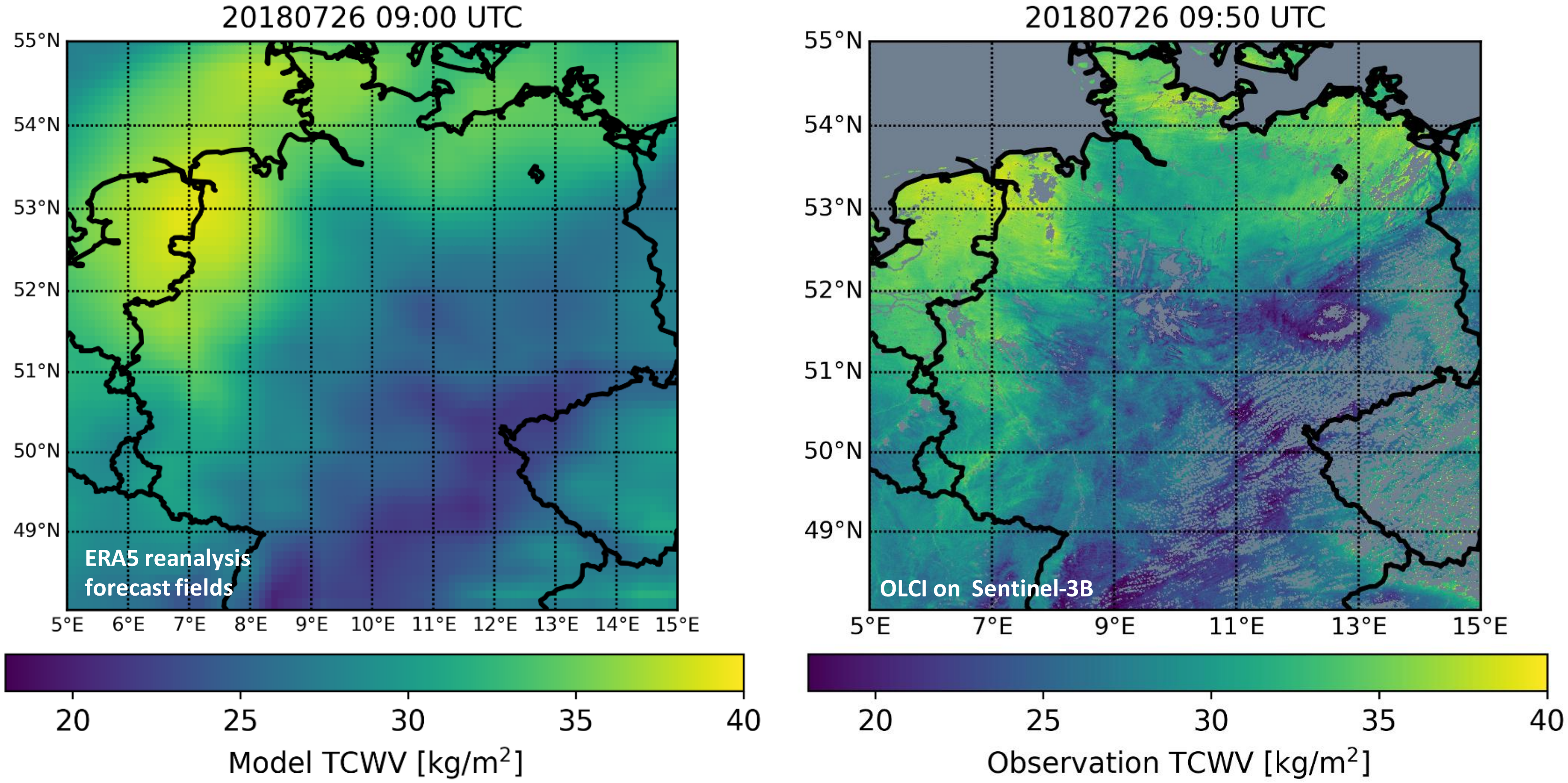

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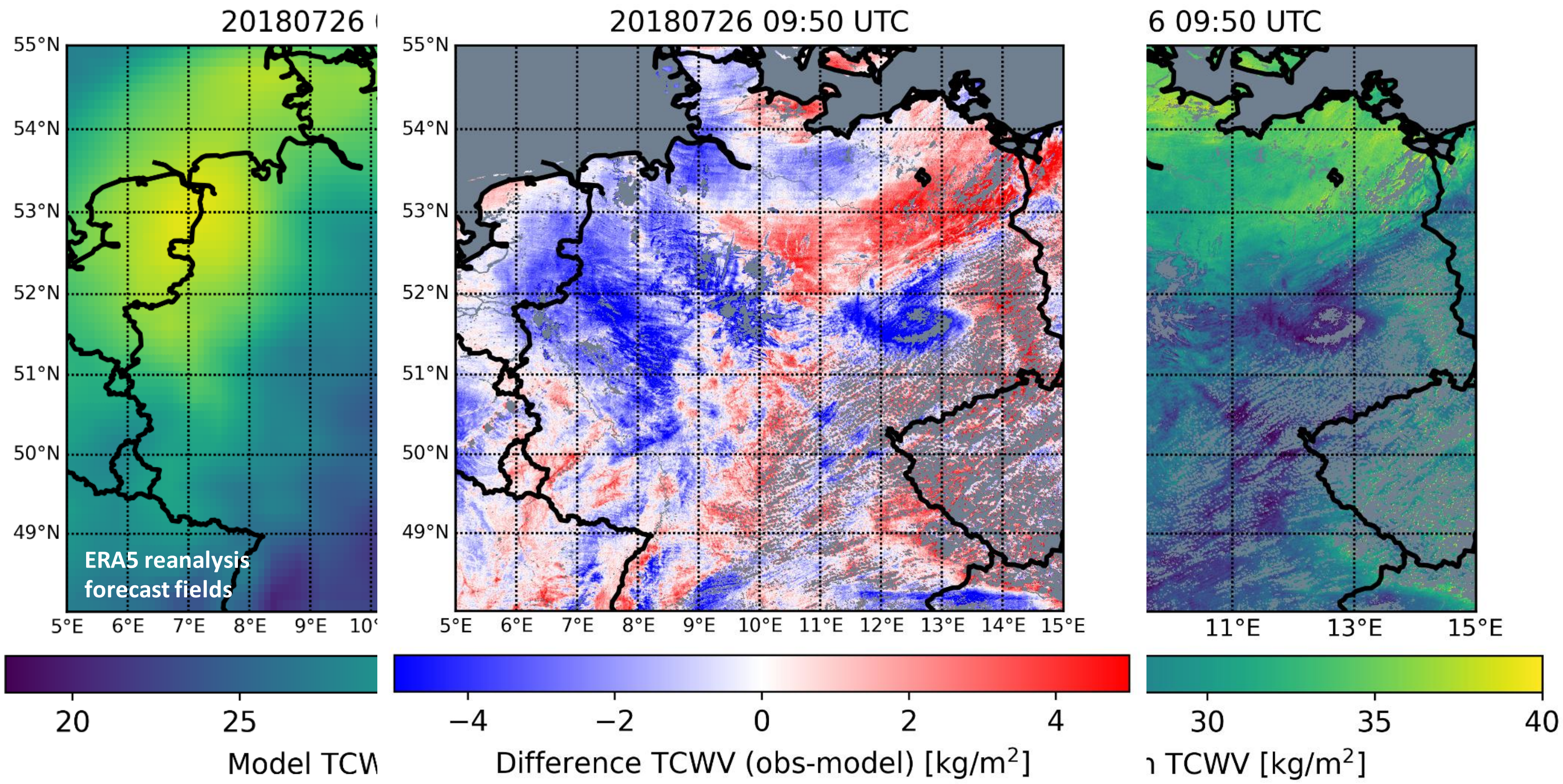

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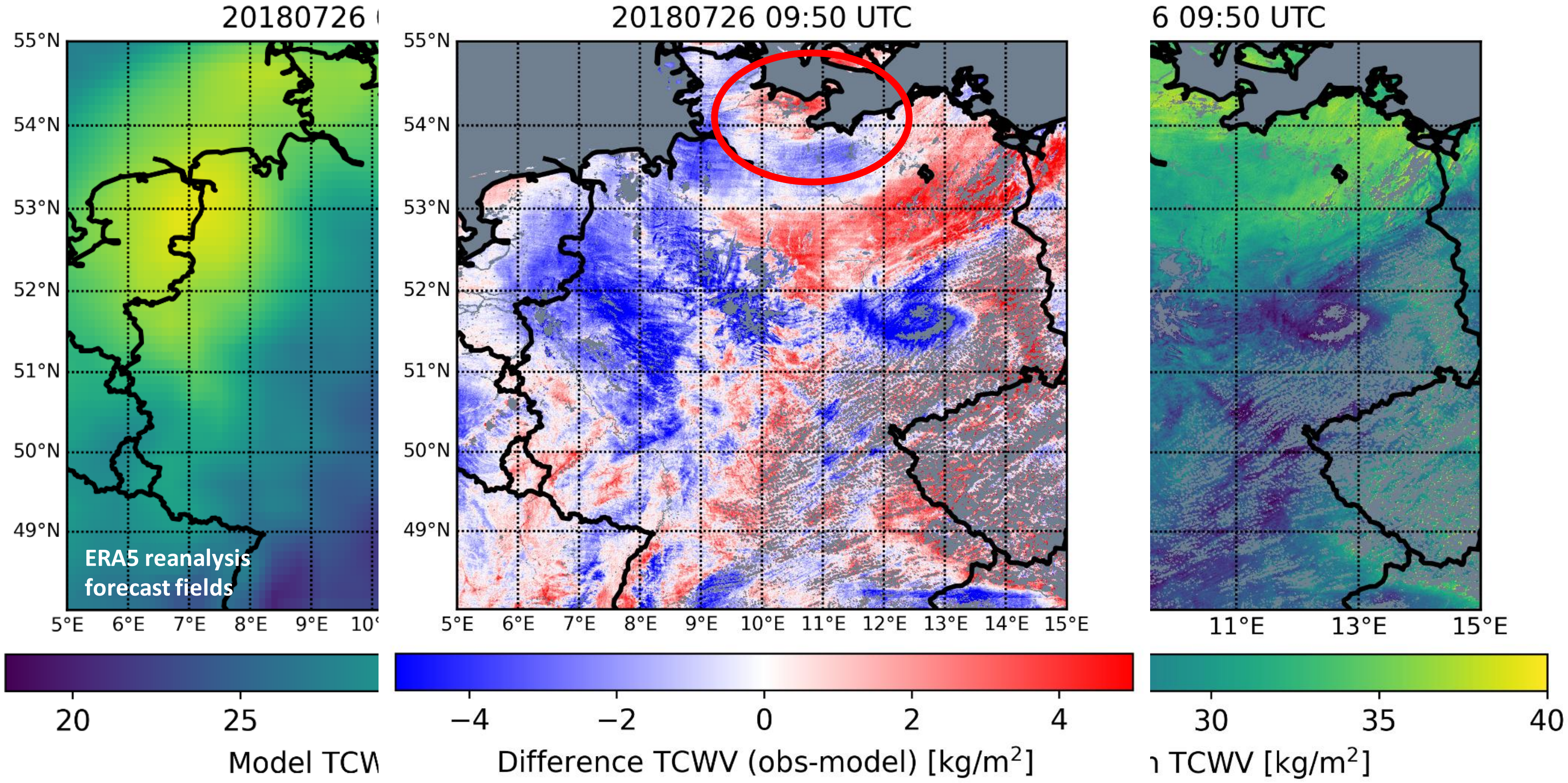

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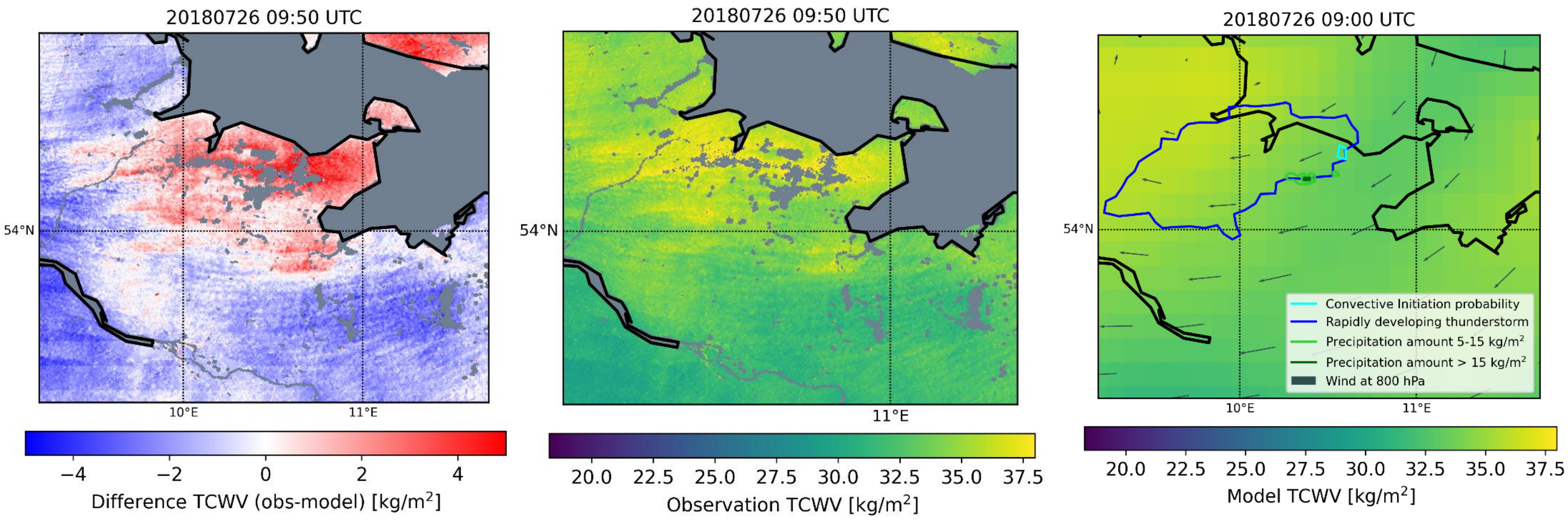

MODIS-TERRA at 10.04 UTC

MODIS-Aqua at 11.50 UTC

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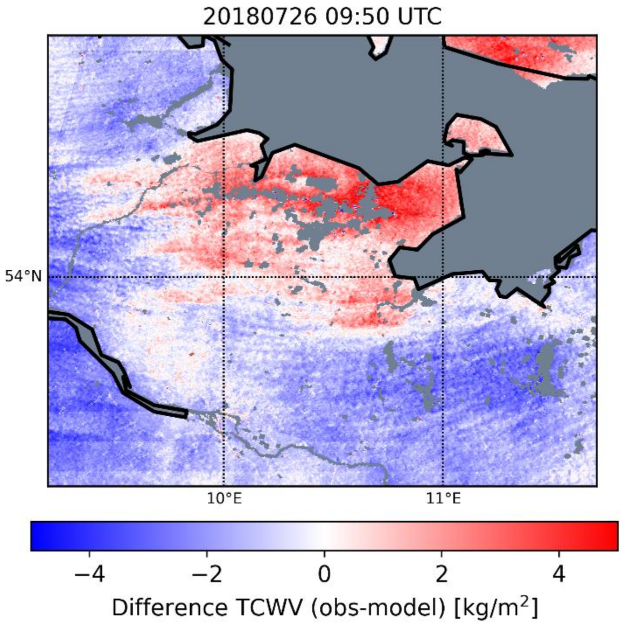
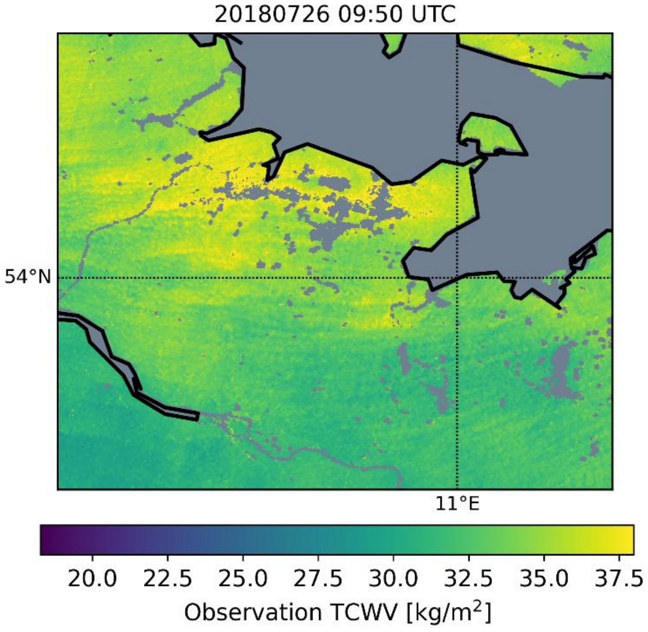
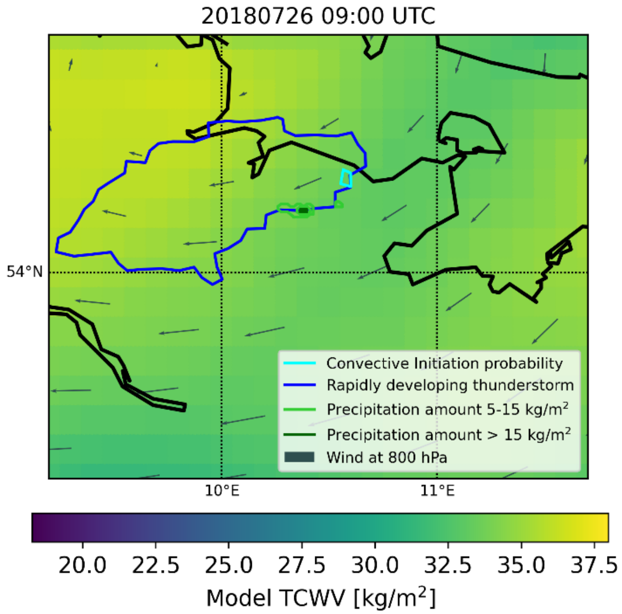




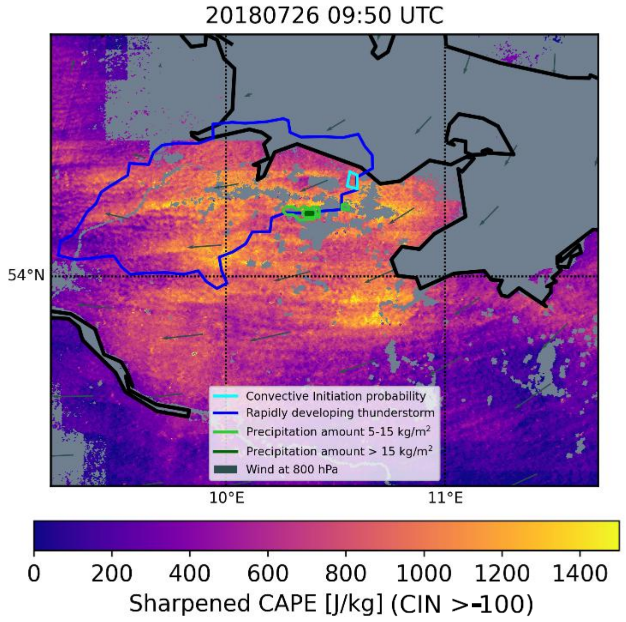


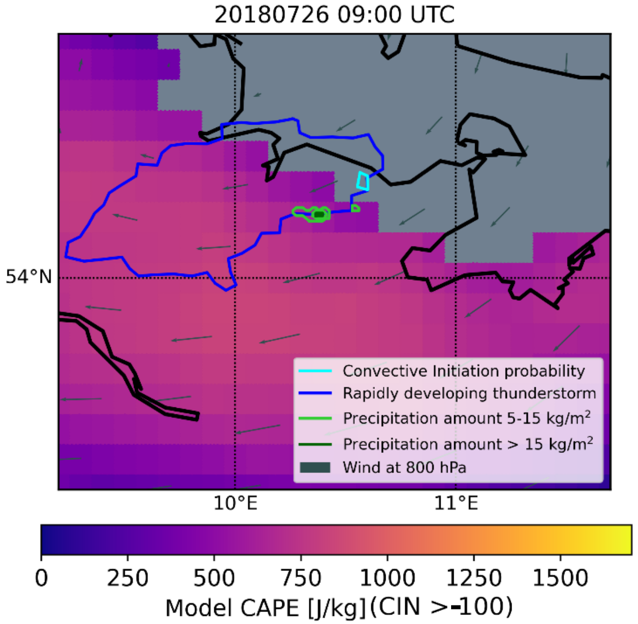
Contours:

NWCSAF Convective Initiation probability > 0

NWCSAF Rapid developing thunderstorm

RADOLAN Precipitation accumulation





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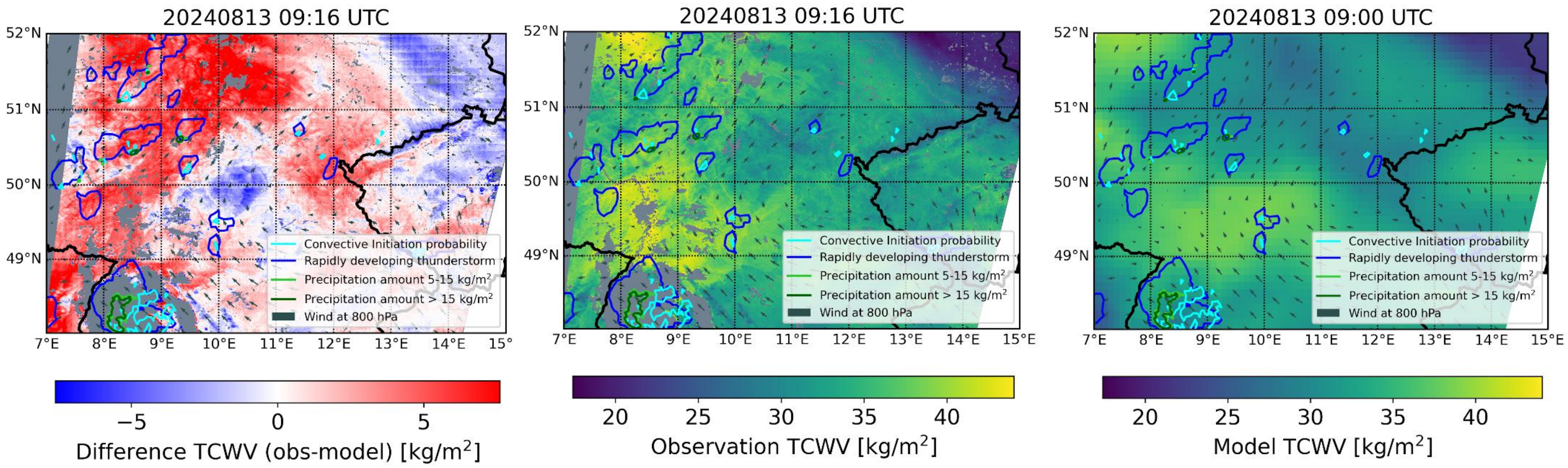

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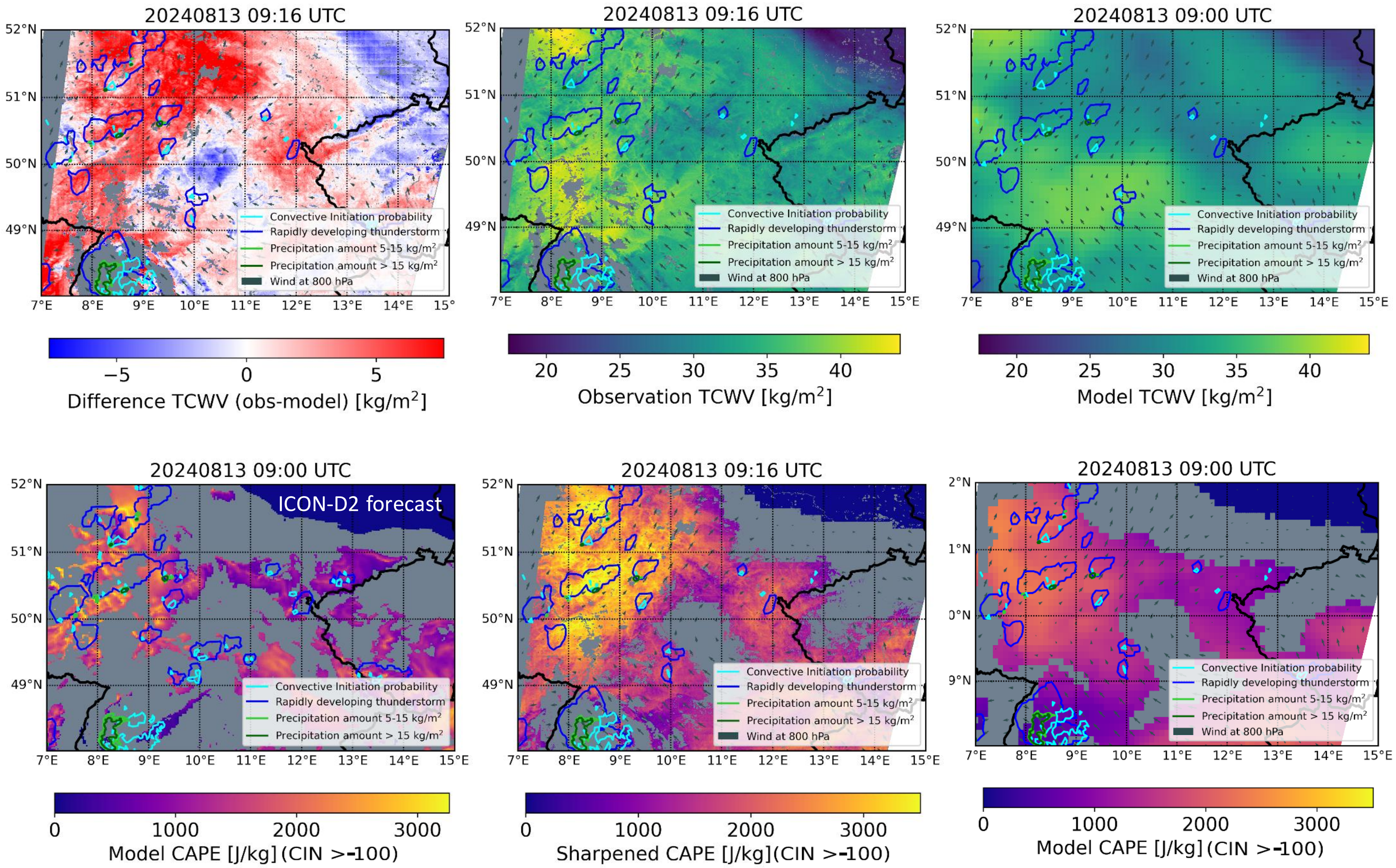

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CAPE/CIN Sharpening approach: Initial statistics

Initial statistical assessment on discriminatory power of CAPE to identify areas suscesptible to convection.

- **Aggregate data from 4 case study** days with widespread non-zero CAPE values in Germany
- To compare across days with different meteorological conditions

→ **CAPE anomaly** is pixel/grid cell deviation from regional mean value using a moving window with size ~ 100x100km^2

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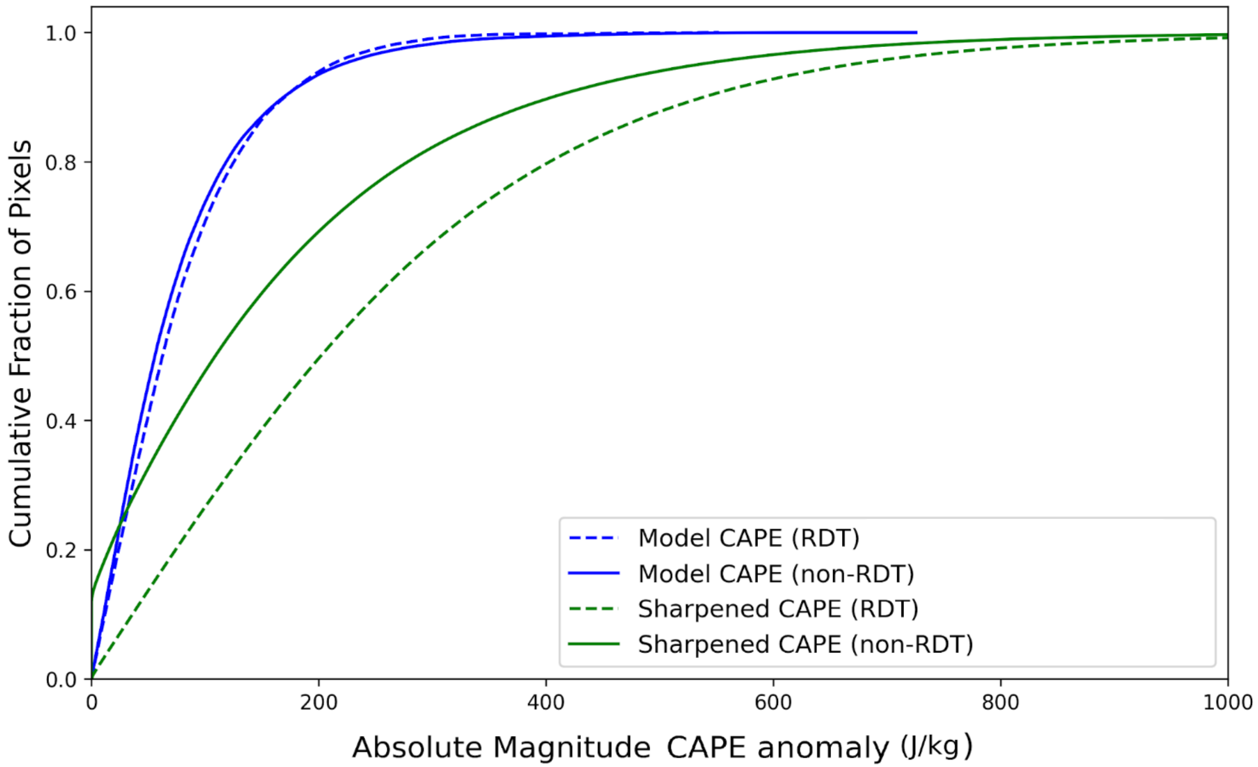

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Conclusions and Outlook

CAPE sharpening approach

- Fast and straight forward method, with one additional piece of information
- Works for subset of convective cases in Germany using ERA5 data
  - refines spatial
  - adds more variability in regions with convective development
  - better alignment with regions of convective development
- Relies strongly on shape of model atmospheric profiles
  - if baseline CAPE is low, their might not be a meaningful update of CAPE using satellite TCWV information

OLCI TCWV

- On polar-orbiting satellite,
  - high spatial resolution, capturing small-scale BL features that NWP models might struggle with
  - only one or two snapshots in the late morning time, no temporal evolution of moisture field
  - limits assessment of cases, e.g., no afternoon convective development

Conclusions and Outlook

Temporal evolution and vertical distributions of WV fields

- MTG-FCI TCWV retrieval framework, also using this NIR 0.9 micron WV absorption band
- Temporal resolution of 10 min, spatial resolution ~2 km for Germany (~50 OLCI pixels)
- Towards low-level moisture estimates
  - synergy with FCI Thermal Infrared bands to constrain better the vertical distrubtion of WV
  - synergy with MTG Sounder for information on vertical profiles
- Complement the more physically-based methods with AI-based methods

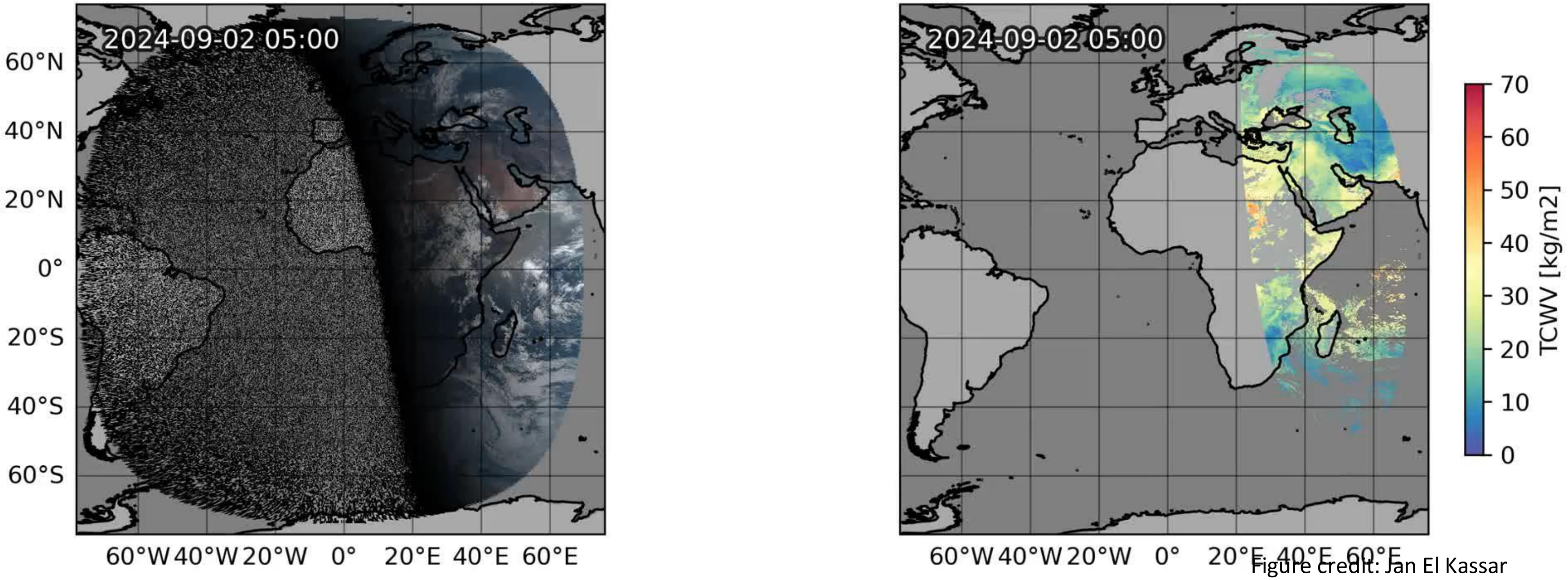

Figure credit: Jan El Kassar

First version of Retrieval Framework for MTG-FCI TCWV running on EWC (El Kassar et al., under review)

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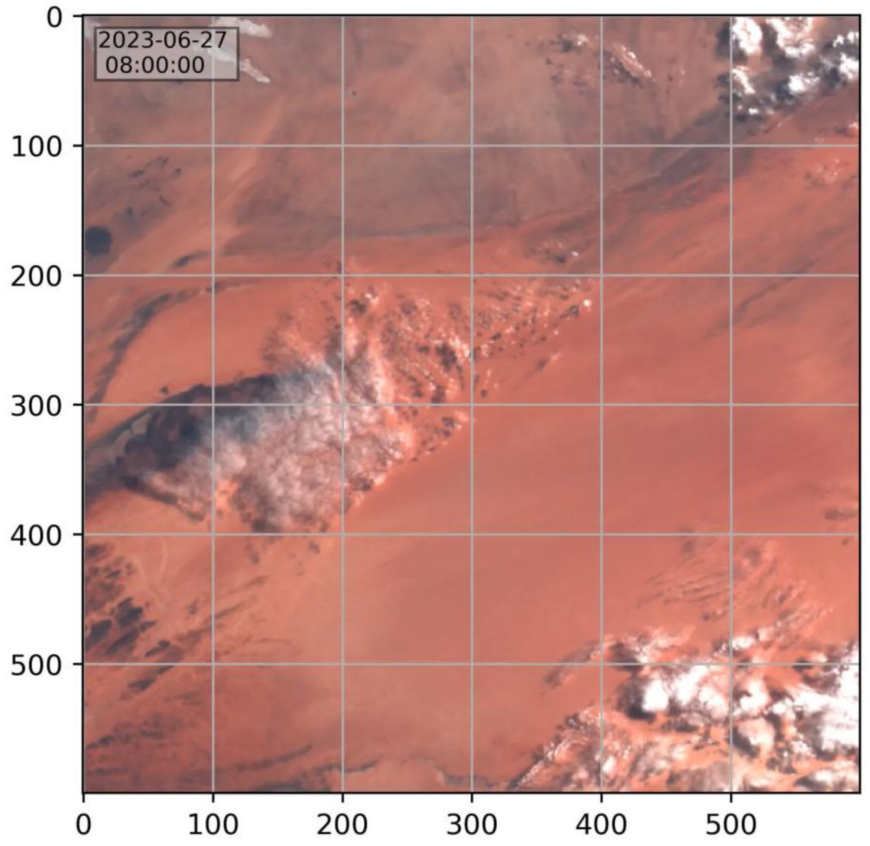
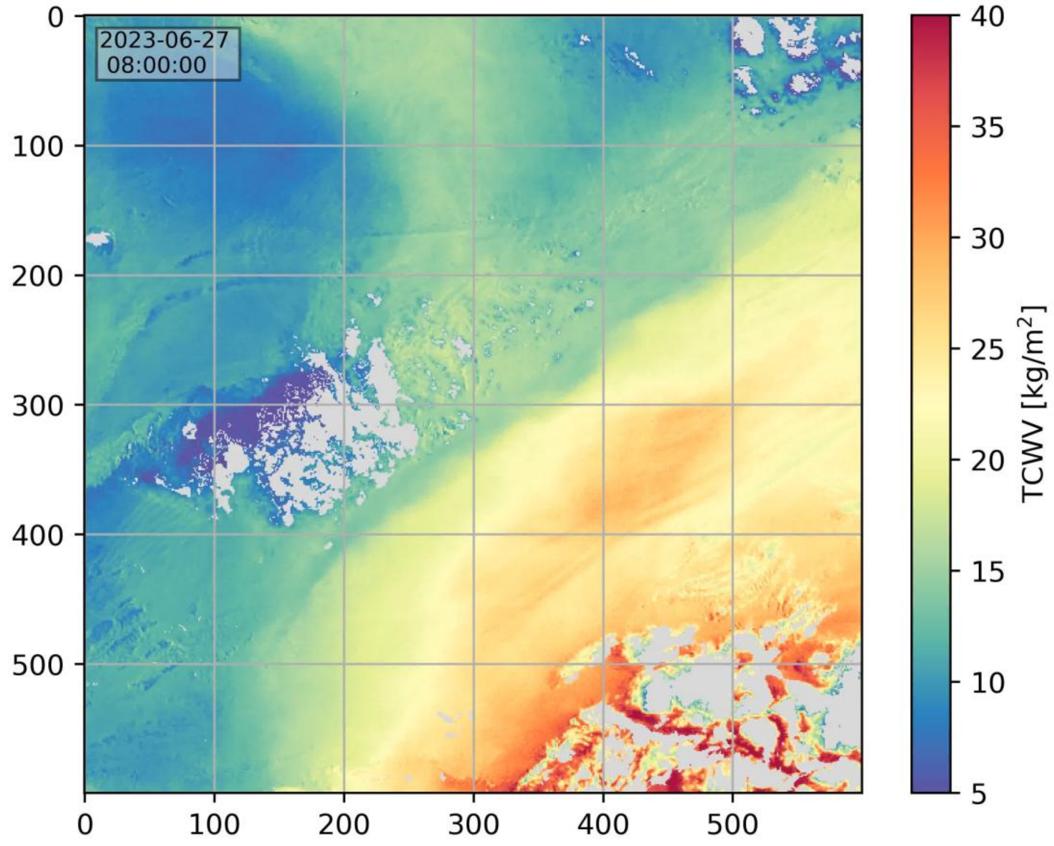
MTG-FCI TCWV





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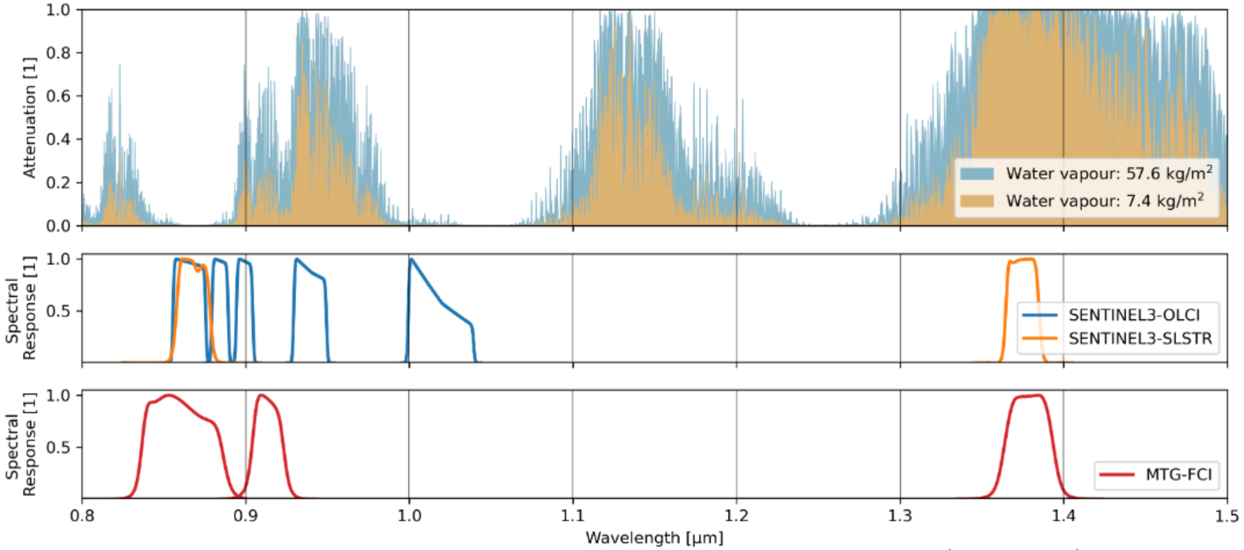
Thanks!

TCWV retrievals from NIR satellite measurements

- Daytime, clear-sky, over land surfaces
- Retrieval framework for instruments: MERIS, MODIS, OLCI, MTG-FCI (MetImage etc.)
- Use ratio of absorption at 0.9 micron to a near-by window channel
- Many validation exercises with well-established ground-based TCWV observations

more moisture
less moisture



From: El Kassar et al. 2025 in prep

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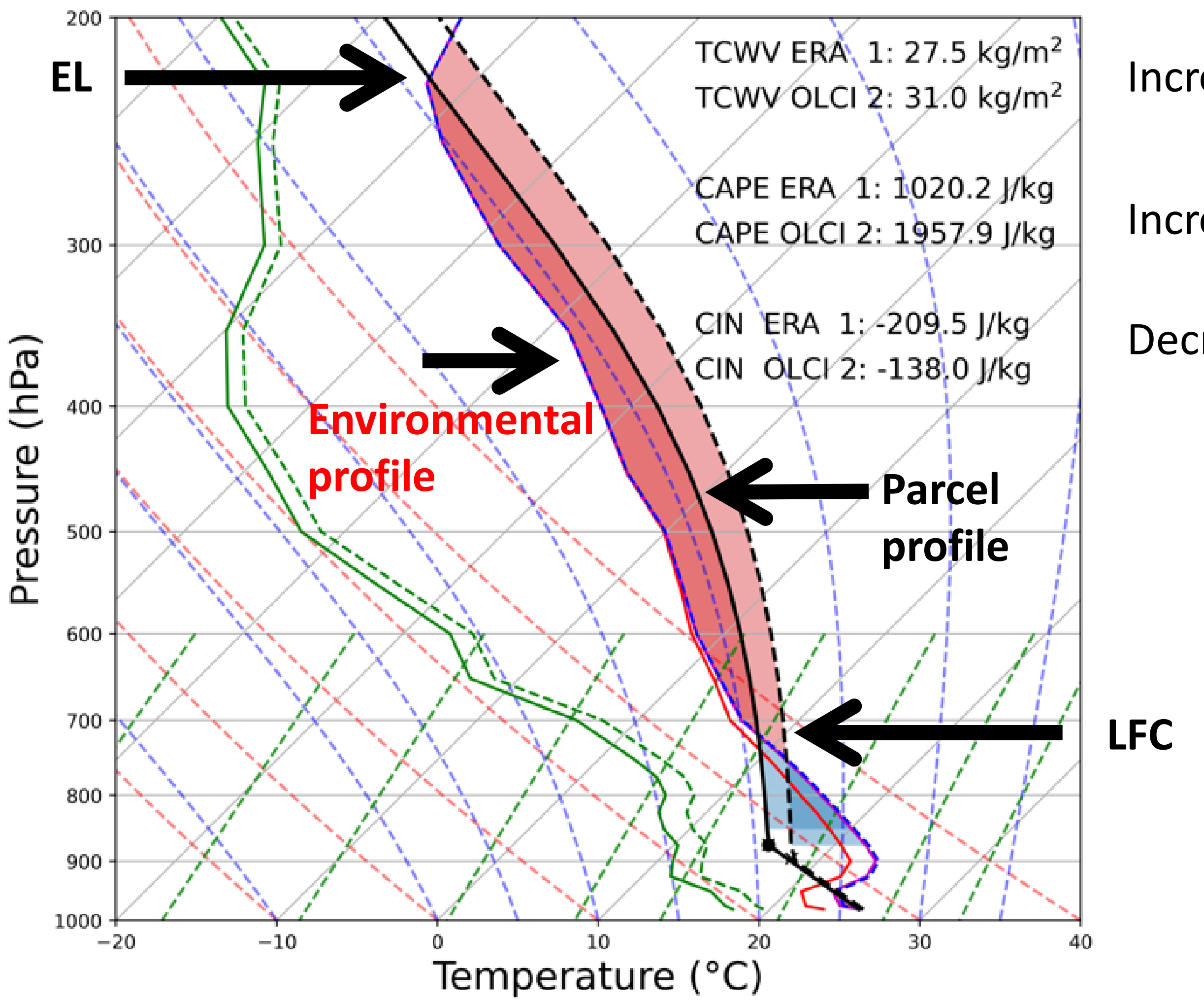
CIN: Negative buoyancy



Increase TCWV

Increase CAPE

Decrease |CIN|

T-skew, log-p diagram (metpy)

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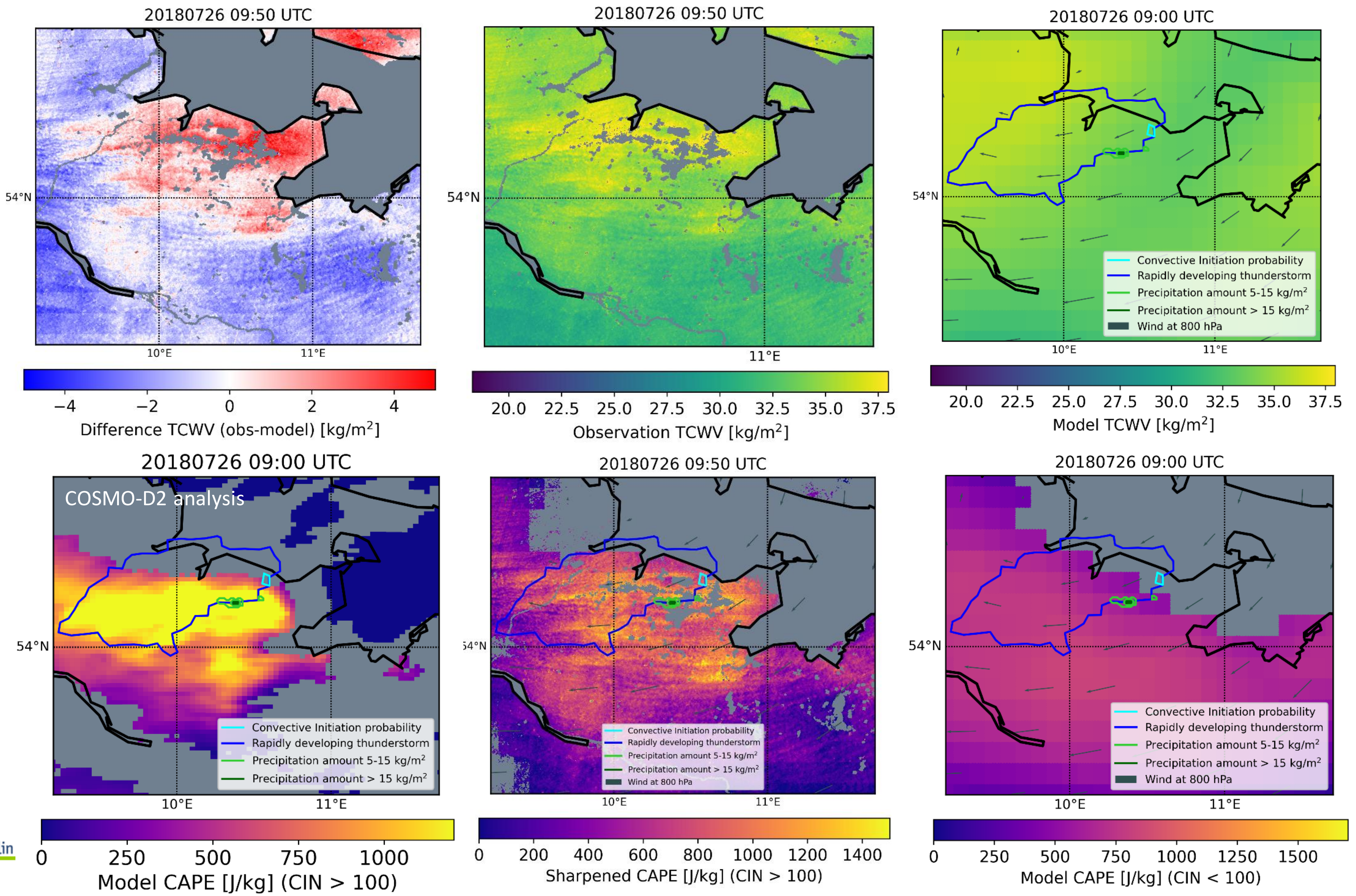
CAPE/CIN Sharpening approach: Case study



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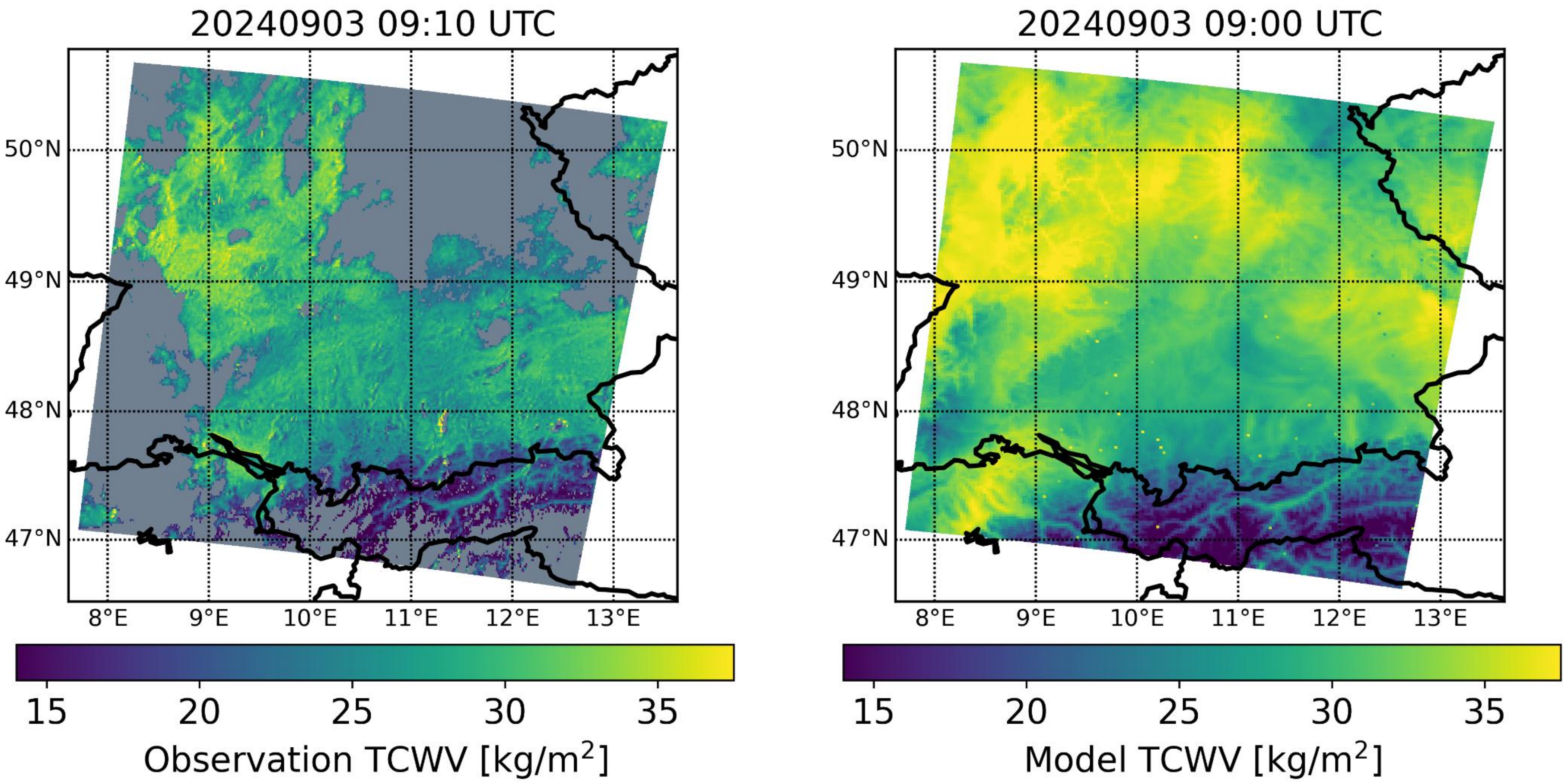
MTG-FCI TCWV observations vs model



ICON-D2

$\Delta x \sim 2$km

Effective spatial resolution?

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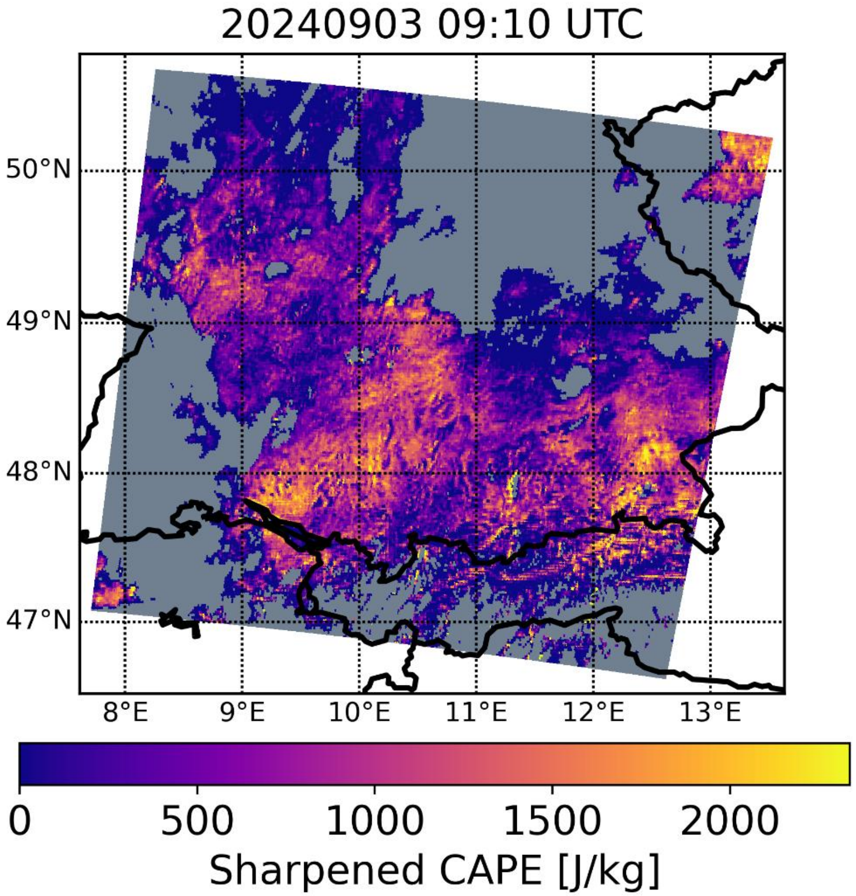
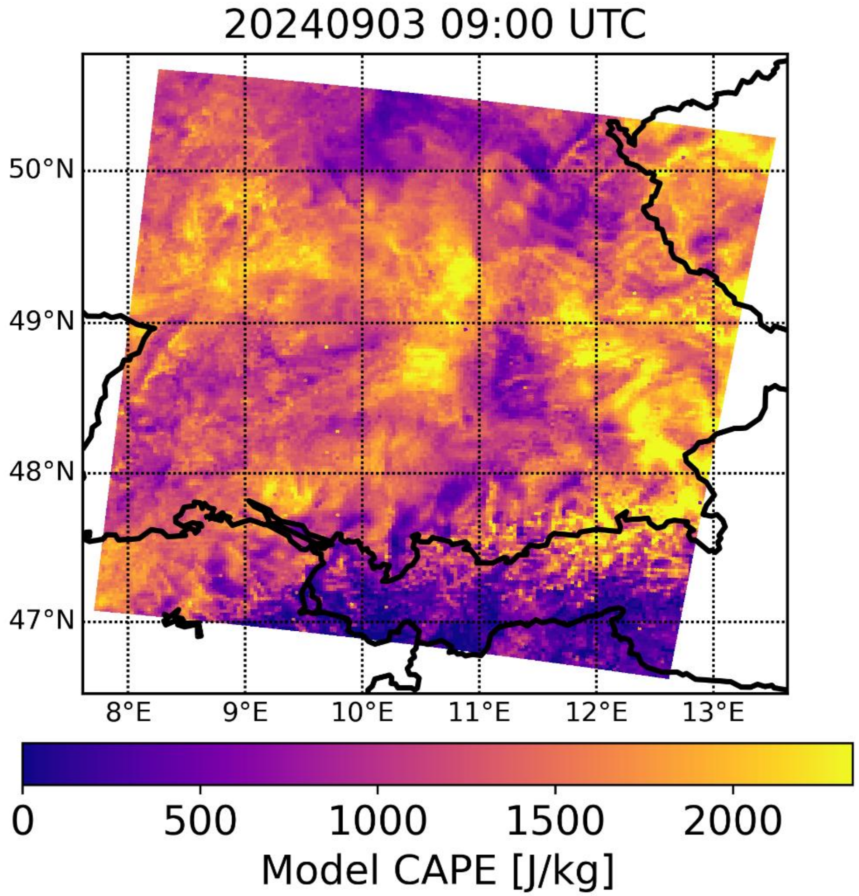
MTG-FCI TCWV in pre-convective environments

Observation



Model



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Δx ~ 2km

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