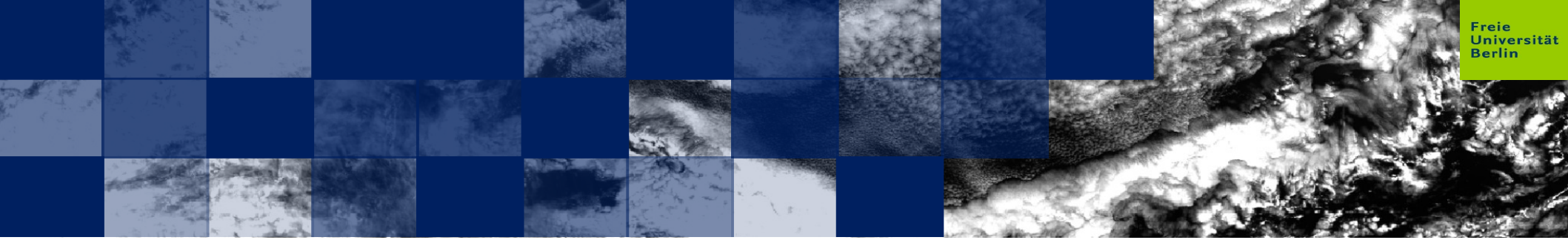


EUMeTrain Water Vapour Event Week

TCWV from OLCI, SLSTR, SEVIRI, FCI and its relationship to CI

Cintia Carbajal Henken, Jan El Kassar, Rene Preusker

Towards a Near Infrared Total Column Water Vapour Retrieval for MTG-FCI

Results from MSG-SEVIRI, S3-OLCI/SLSTR in preparation of a MTG-FCI Algorithm and their applications

Event Week "Application of water vapour products for analysis and nowcasting", 13.12.2022

J. El Kassar, C. Carbajal Henken, R. Preusker, J. Fischer

Freie Universität Berlin, Institute of Meteorology, Berlin, Germany

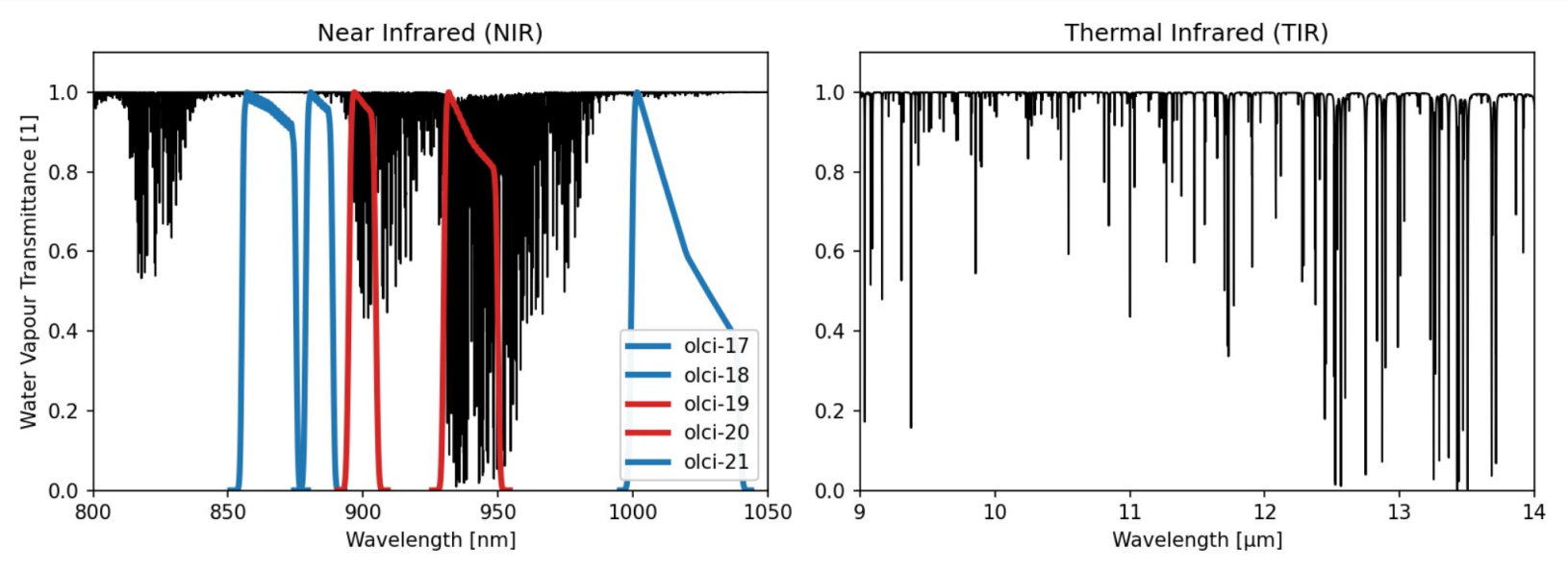
Structure

1. TCWV from the $\rho\sigma\tau$Bands (NIR) of Sentinel3 OLCI
2. TCWV from the Split Window Bands of MSG SEVIRI and S3 SLSTR
3. TCWV from the Combination of NIR and TIR of S3 OLCI/SLSTR
4. Comparison between NIR,TIR and NIR-TIR TCWV
5. Conclusions

TCWV from the $\rho\sigma\tau$Bands (NIR) of Sentinel3 OLCI

The Basics - TCWV from NIR: S3 OLCI

- very sensitive to TCWV and used in common clear-sky-TCWV retrievals (e.g. for MODIS, MERIS, OLCI)
- at least one window (e.g. at 865, 885 nm) and at least one absorption band (e.g. at 900, 940 nm)
- the "pseudo transmittance" $log(\frac{R_{absorption}}{R_{window}})$ correlates with water vapour content



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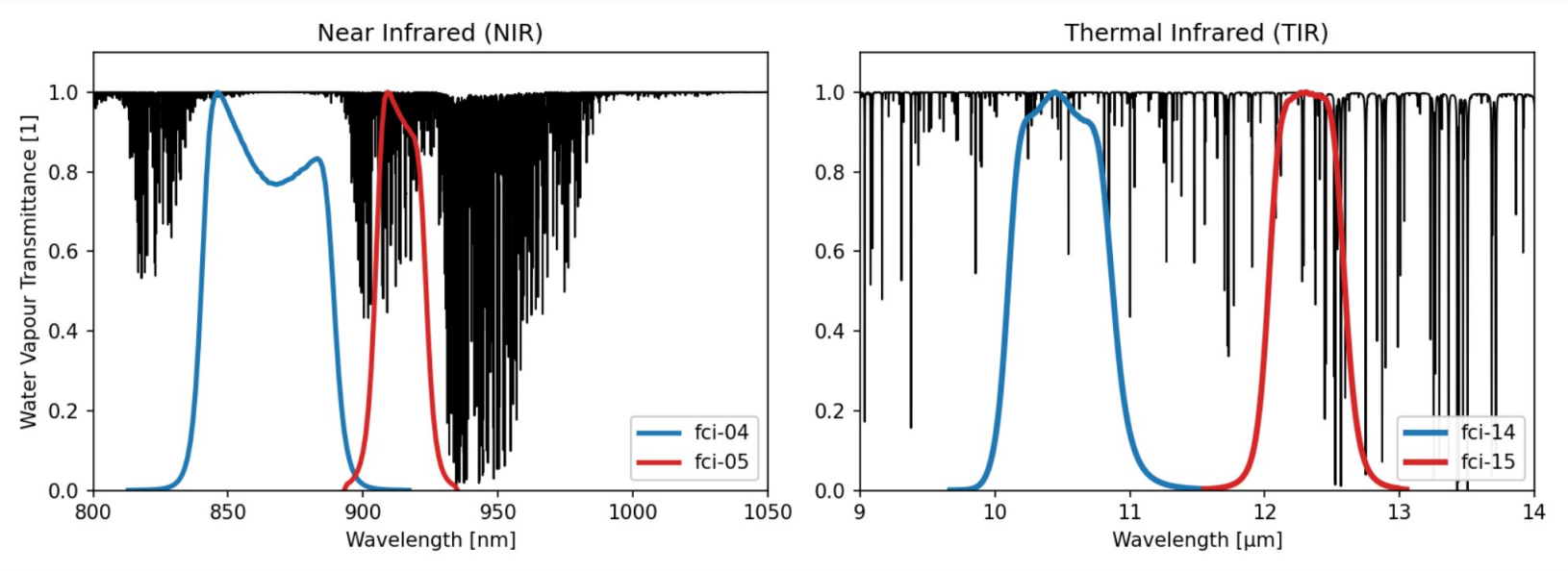

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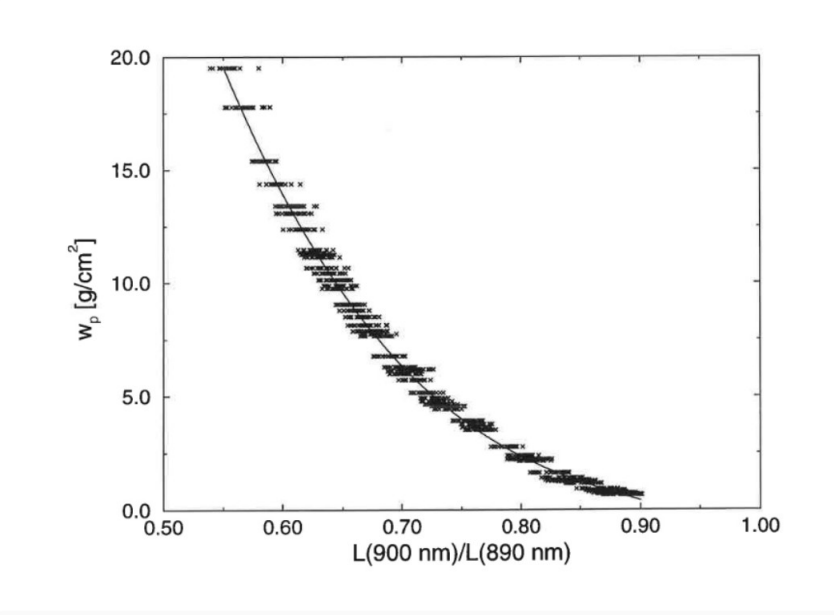


ratio vs. TCWV, taken from Bartsch and Fischer, 1996[1]

[1] Bartsch, B., Fischer, J. 1997, *Max-Planck-Institut für Meteorologie*

The Algorithm - TCWV from NIR: S3 OLCI

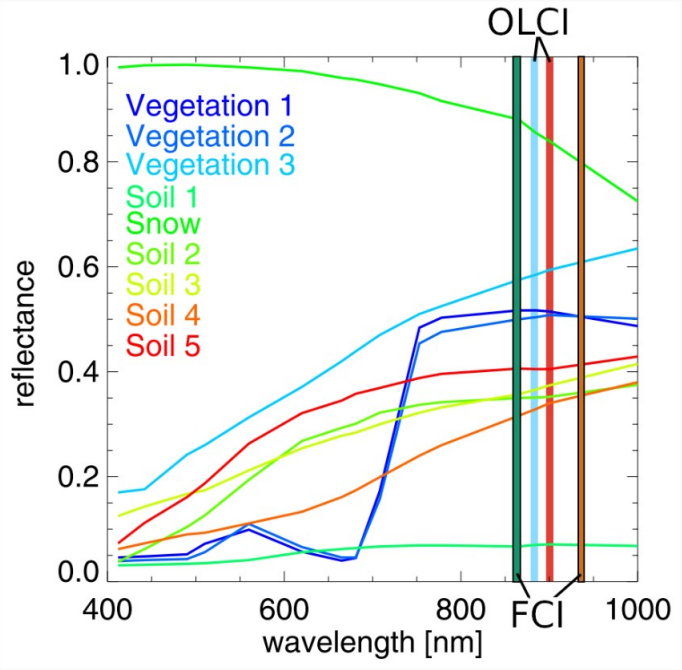
- we can simulate measurements for different atmospheric conditions, etc. $\Rightarrow$ Look-up-Table (LUT)
- our NIR-LUT is based on MOMo simulations (Hollstein und Fischer 2012[2])
- using 1D-Var/Optimal Estimation (Rodgers 2000[3]) we can find the optimal "state" describing our "measurment" with an associated uncertainty

[2] Hollstein, A., Fischer, J. 2012, *J. Quant. Spectrosc. Radiat. Transf.*
[3] Rodgers, C. D. 2000, *World Sci.*

The Algorithm - TCWV from NIR: S3 OLCI

Short Description over Land Surfaces

- we iterate: over *TCWV*, *surface albedo*$_{window}$
- prior knowledege taken from ERA5 (e.g. wind speed, surface pressure, etc.)
- details: Copernicus Sentinel-3 OLCI Water Vapour product (COWa) (Preusker et al. 2021[3])



examples for spectral albedo, adapted from Leinweber (2010)[4])), ASTER spectral library (Baldridge, 2009 [5]))

[3] Preusker, R. et al. 2021, *Remote Sens.*
[4] Leinweber, R., 2010, *Freie Universität Berlin*
[5] Baldridge, A., et al. 2009, *Remote Sens. Environ.*

The Algorithm - TCWV from NIR: S3 OLCI

Short Description over Ocean/Water Surfaces

- we iterate over *TCWV*, *aerosol optical depth*, *wind speed*
- prior knowledege taken from ERA5 (e.g. wind speed, surface pressure, etc.)
- details: Copernicus Sentinel-3 OLCI Water Vapour product (COWa) (Preusker et al. 2021)

[6] Cox, C.S. and Munk, W.H. 1954, *J. Mar. Res.*

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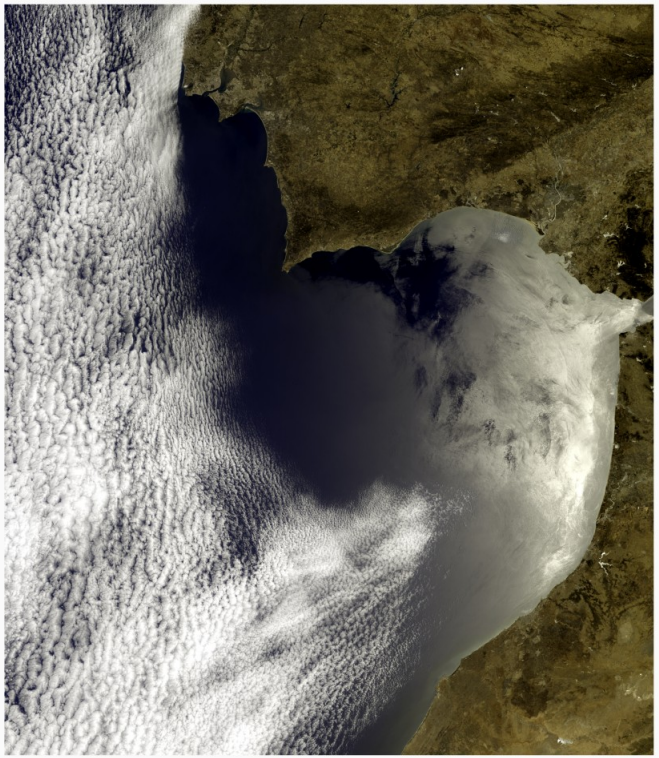

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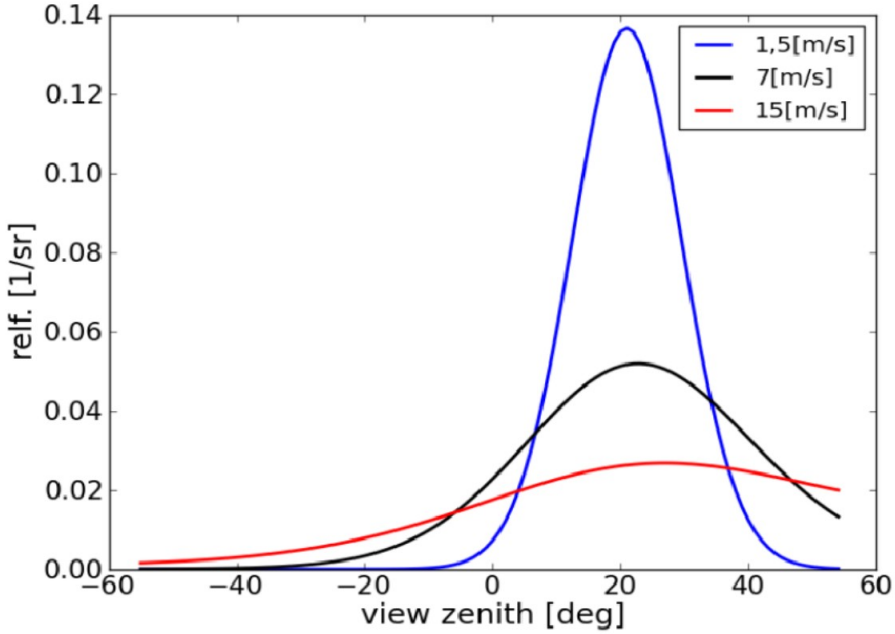
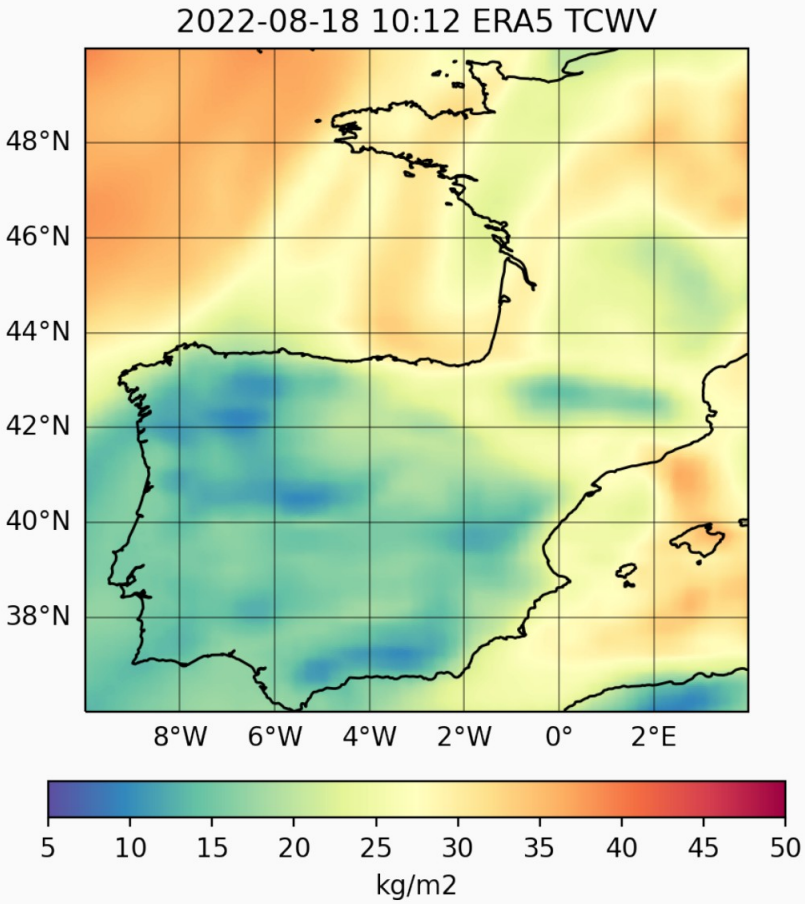
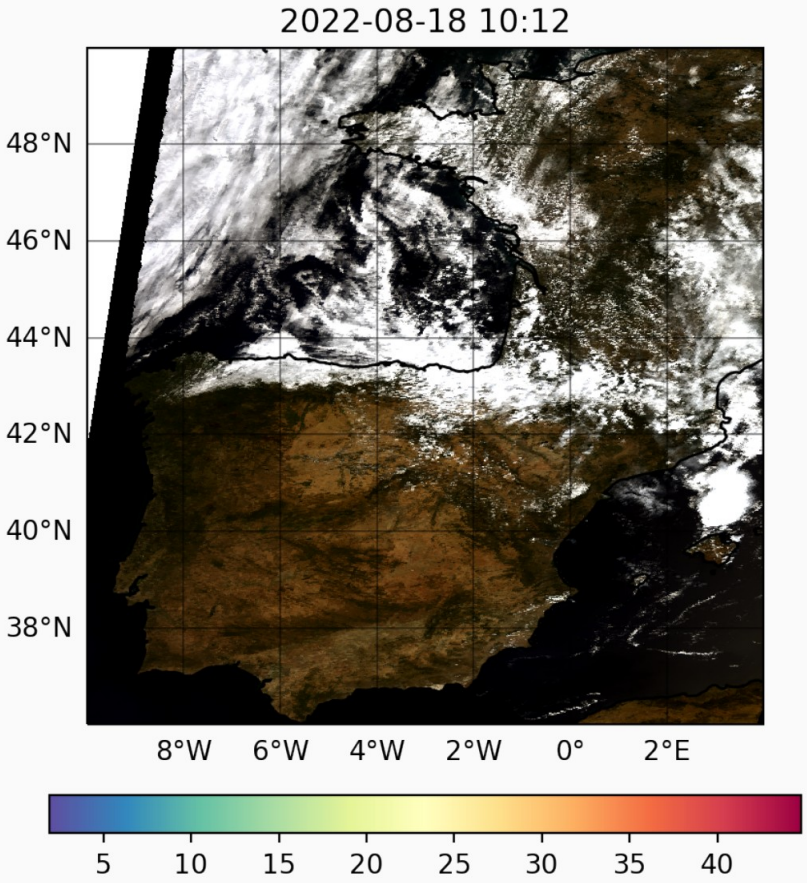


ocean surface reflectance vs. wind speed/ geometry, calculated from Cox and Munk, 1954.

[6] Cox, C.S. and Munk, W.H. 1954, *J. Mar. Res.*

Example - TCWV from NIR: S3 OLCI: Spain, 18.08.2022 10:10 UTC





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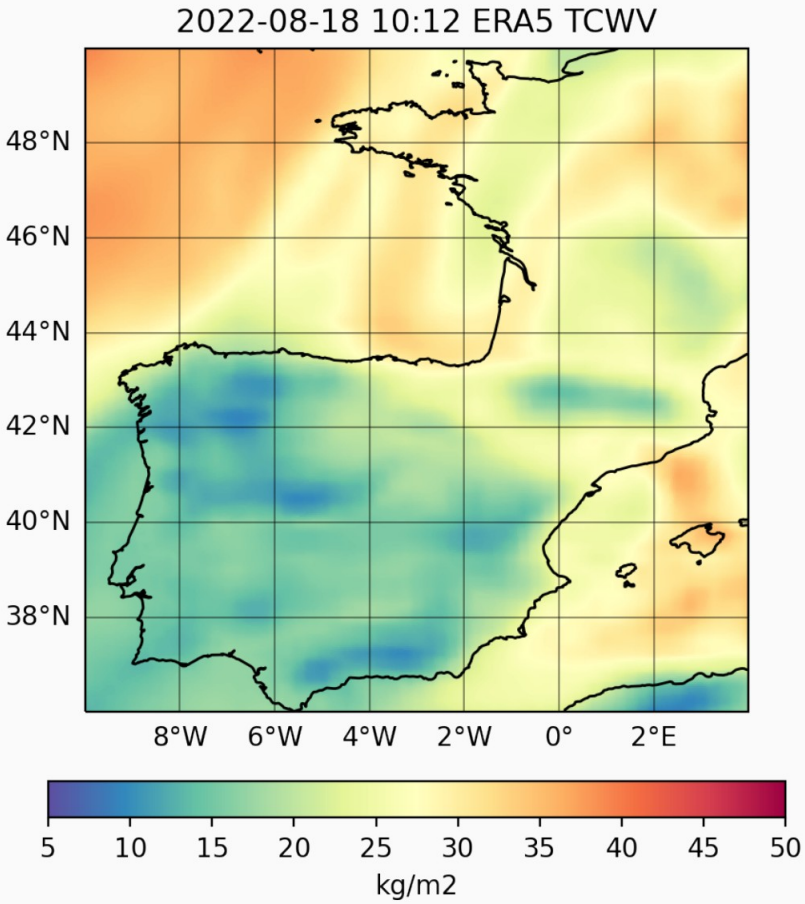

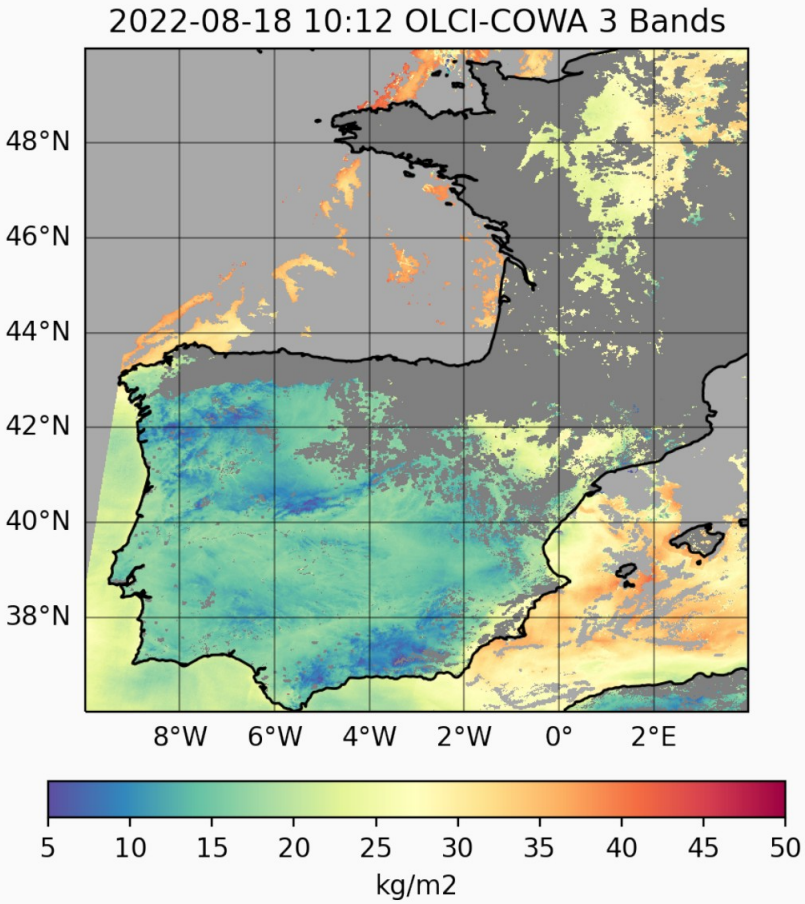

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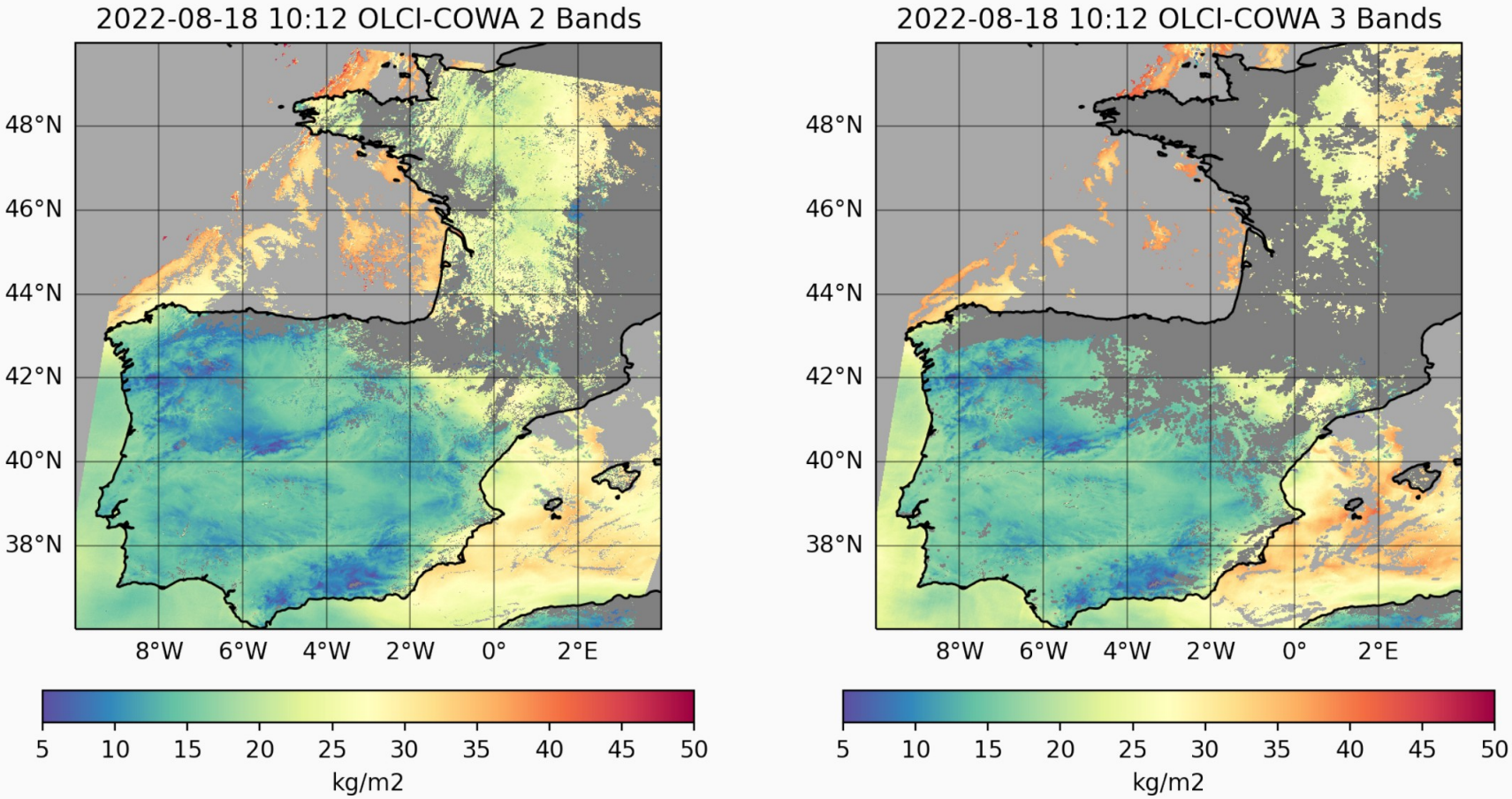


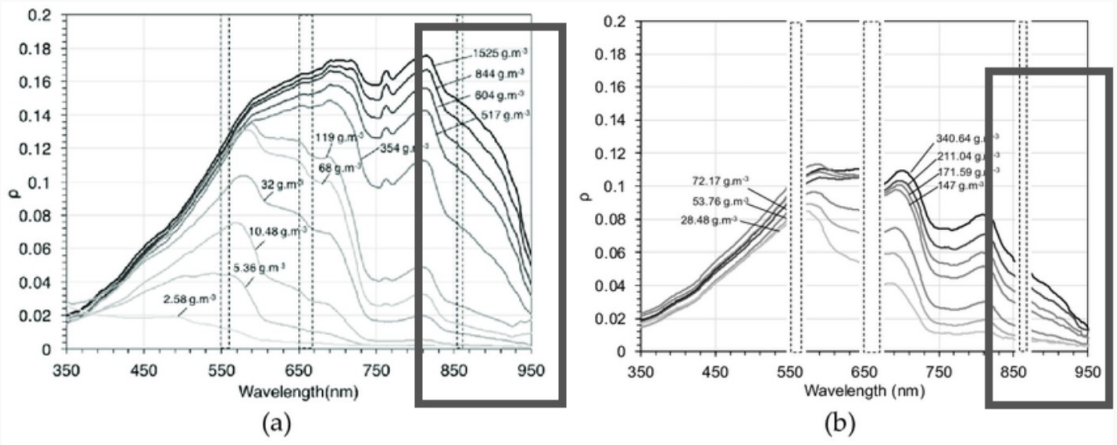
- over land very similar ⇒ no significant loss in quality
- over water surfaces 2-band COWA reliest stronger on apriori

Caveats for TCWV from NIR measurements

Challenges/issues:

- for FCI window and absorption band are far apart: surface albedo!!
- over water surfaces: aerosol vs. glint? (2 measurements vs. 3 state variables)
- over dark surfaces sensitive to thin clouds: good cloud masking!

Caveats for TCWV from NIR measurements



in situ remote sensing reflectance spectra at two french coastlines. Novoa et al. (2017)[7]

Concerning the discontinuities at the coasts:

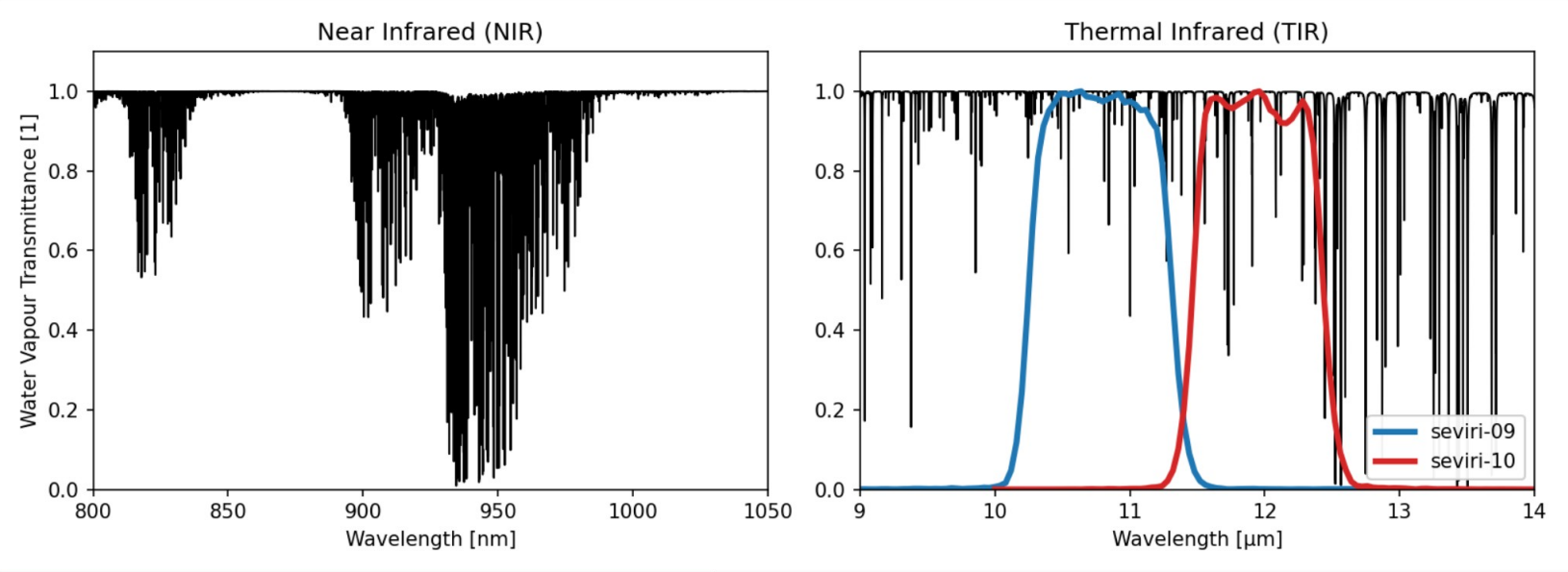
- sediment reflects more light at 865/885 than 900/940
- this increases the ratio despite no changes in TCWV

[7] Novoa, C.S. et al., 2017, *Remote Sens.*

TCWV from the Split Window Bands of MSG SEVIRI and S3 SLSTR

The Basics - TCWV from TIR: MSG SEVIRI, S3 SLSTR

- *split-window* has a "clean" (11 μm) and "dirty" (12 μm) band in the Thermal Infrared (TIR)
- the difference (SWD) roughly correlates with the moisture content
- forward simulation is done with Radiative Transfer for TIROS Operational Vertical Sounder (RTTOV) v12 (Saunders et al. 2018[8])



[8]Saunders, R. et al. 2018, *Geosci. Model Dev.*

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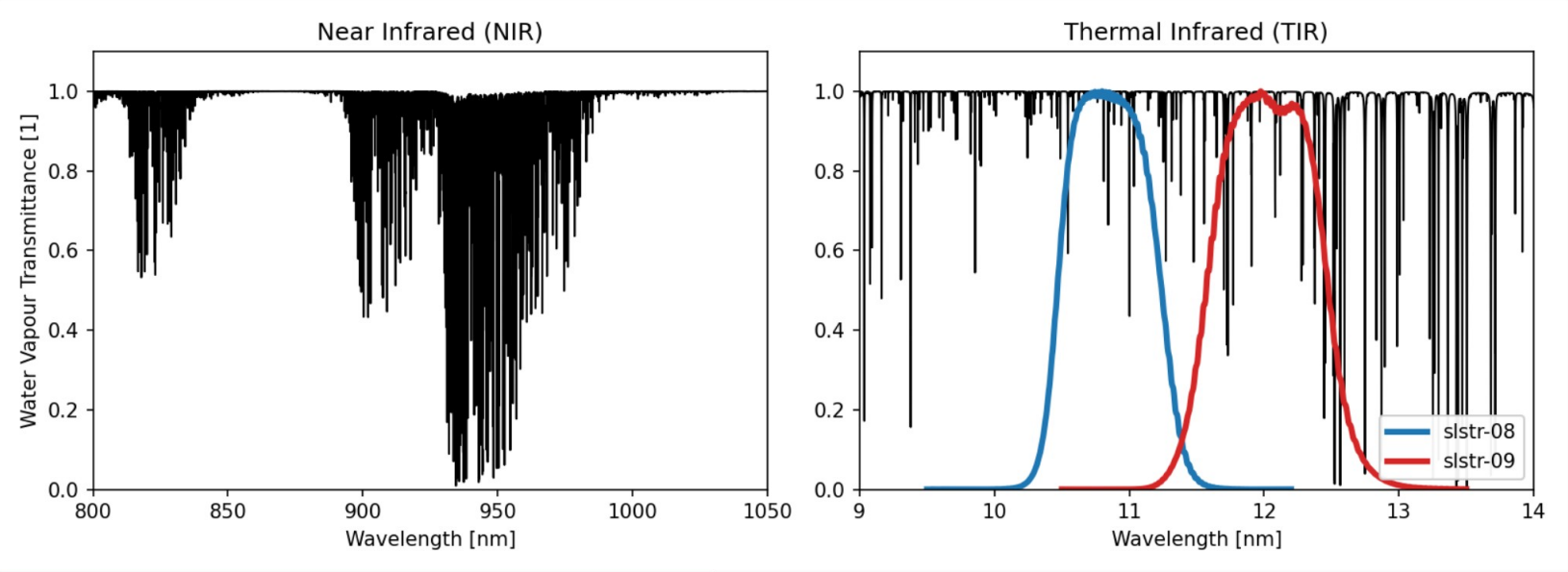

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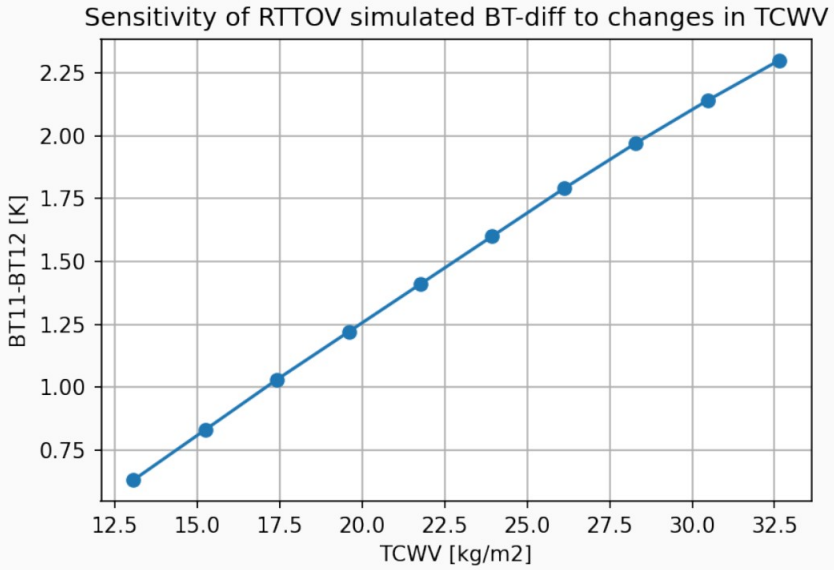
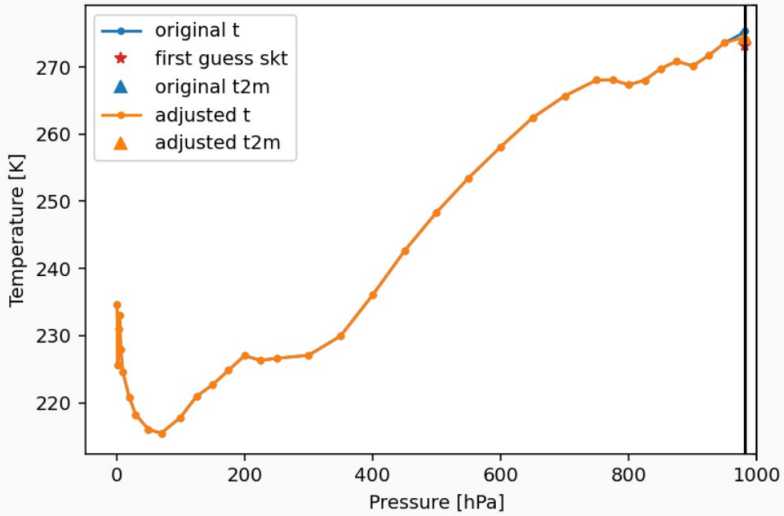
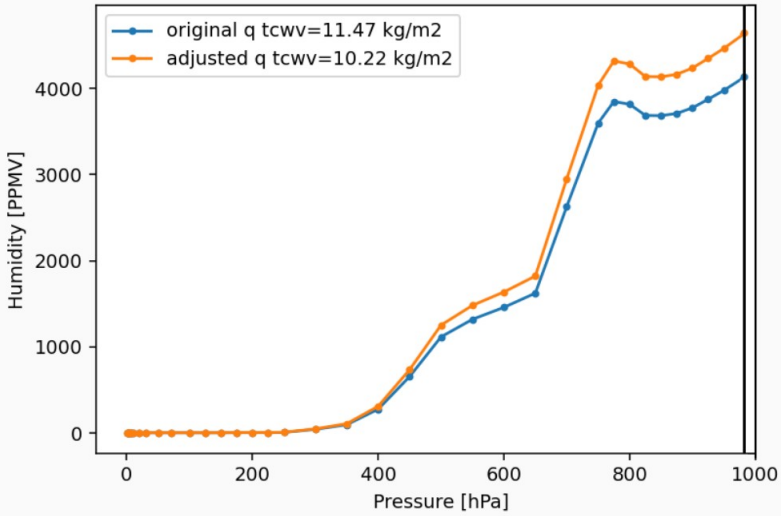


[8]Saunders, R. et al. 2018, *Geosci. Model Dev.*

Short Description:

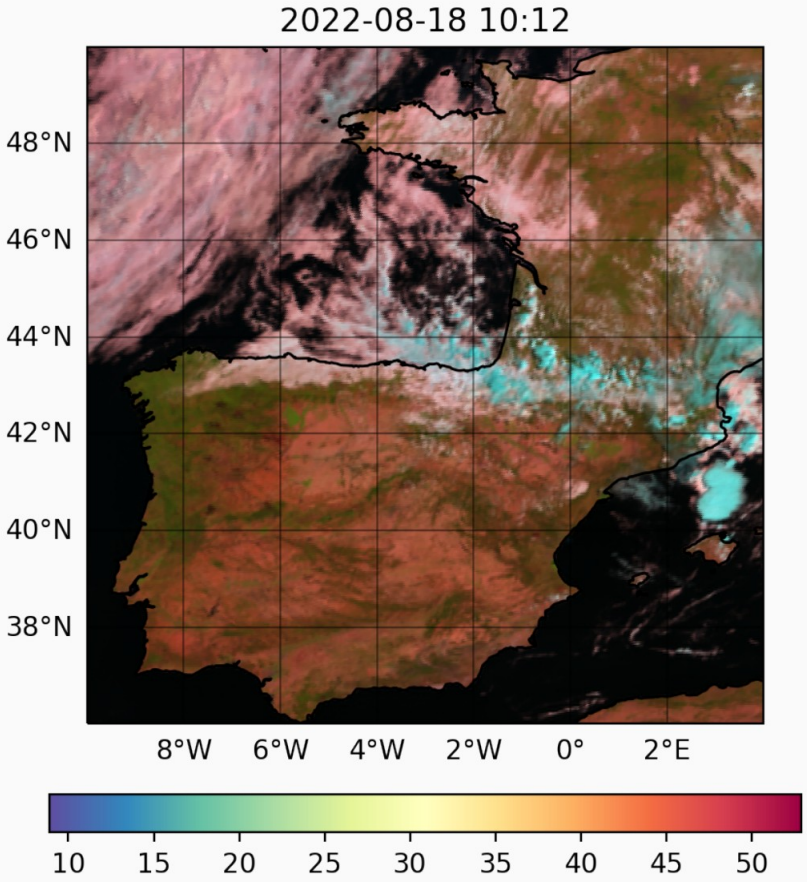
- optimal estimation $\Rightarrow$ iterative change of $TCWV$ and $T_{surface}$
- prior knowledge is based on ERA5 (reanalyses or forecasts)
- pixel-by-pixel radiative transfer with RTTOV as implemented by El Kassar 2021[9]

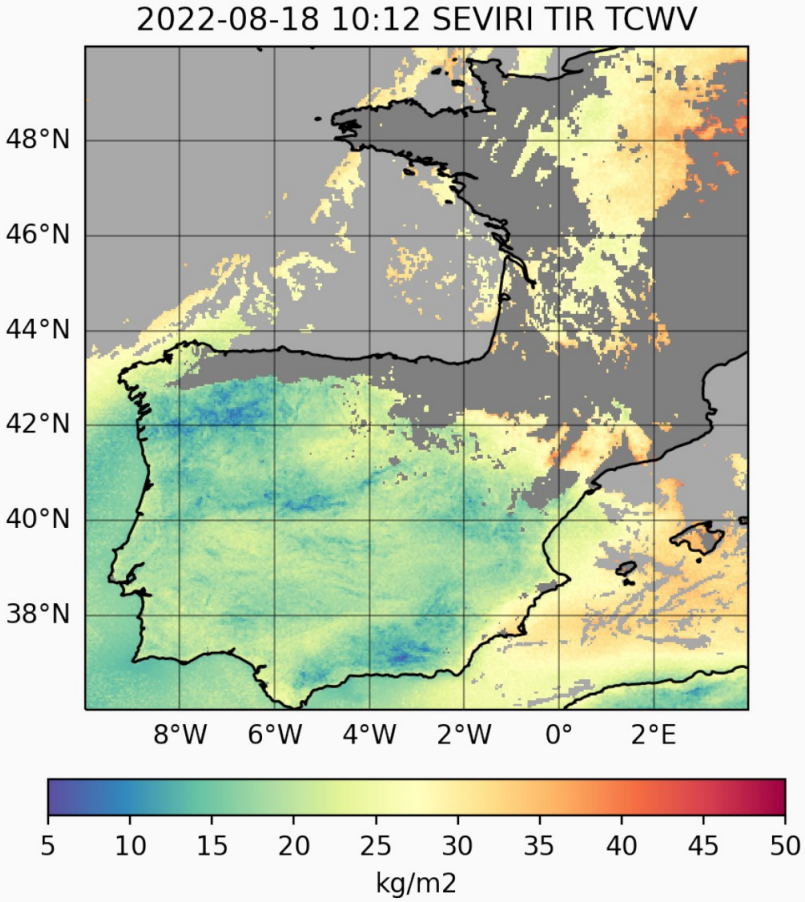




[9] El Kassar, J. et al. 2021, *Atmosphere*

Examples - TCWV from TIR: MSG SEVIRI: Spain, 30.08.2020 10:10 UTC





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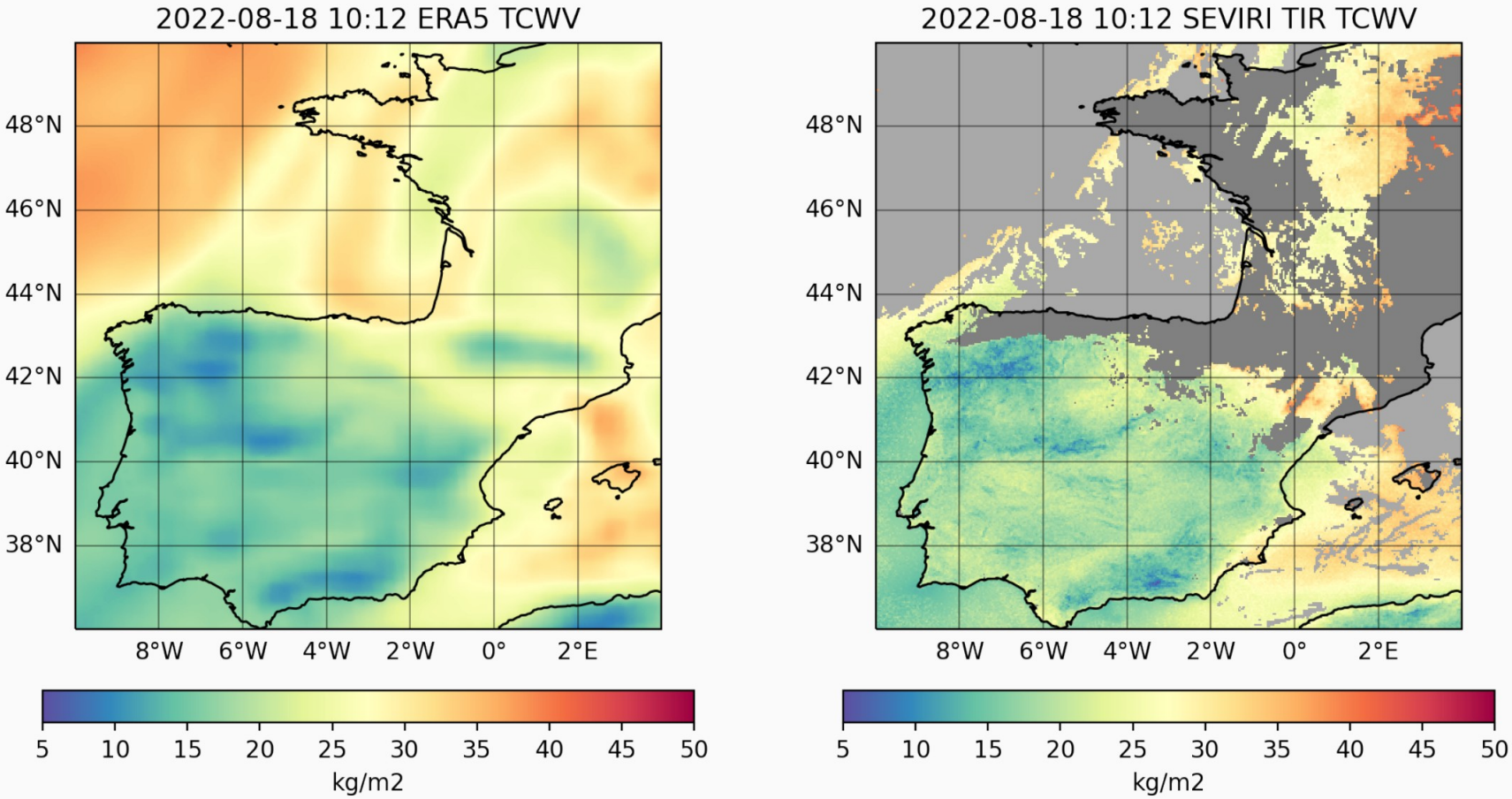

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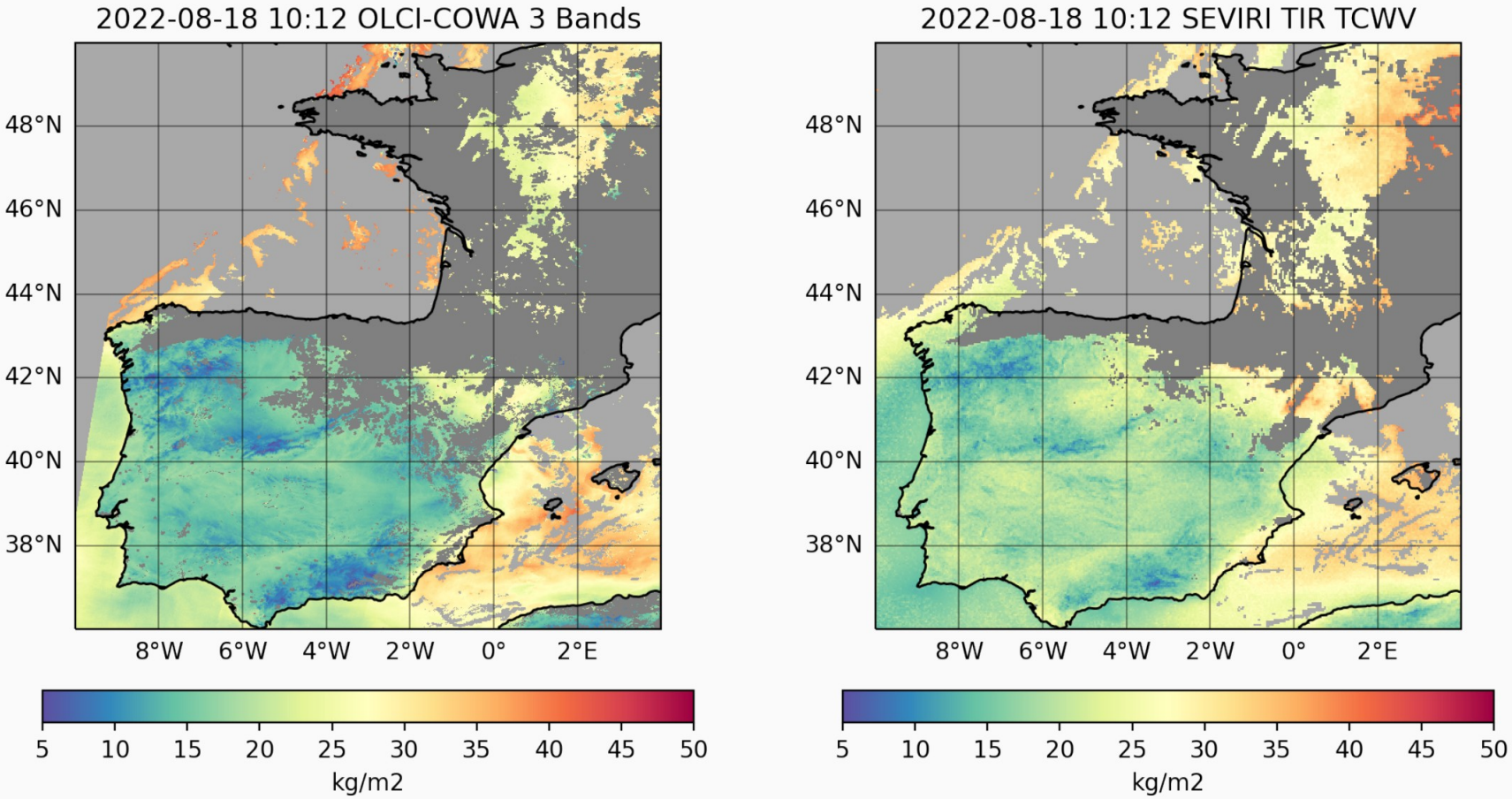
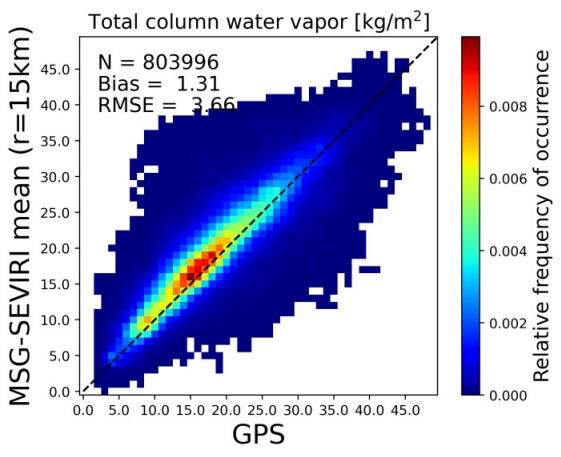
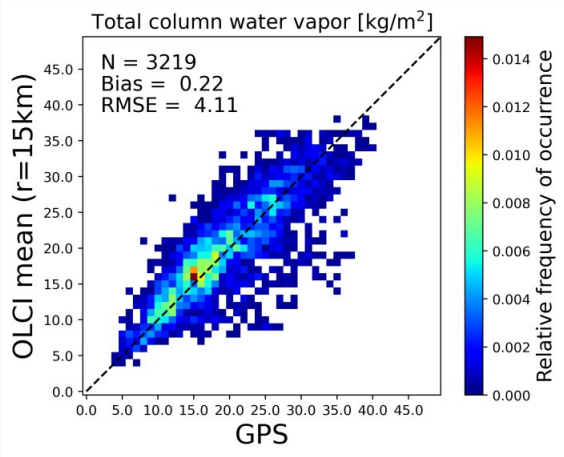
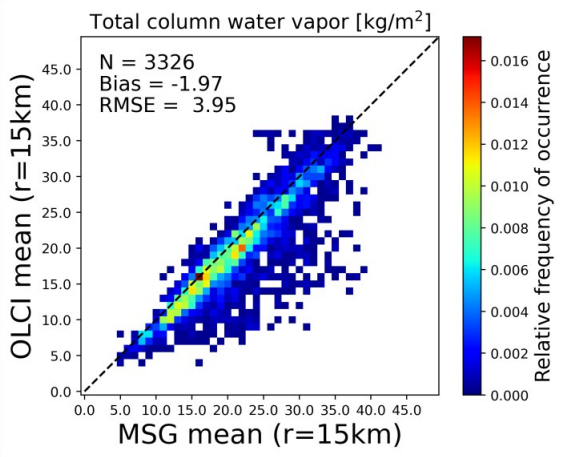


- wet bias in SEVIRI over land, over ocean COWa is higher
- COWa over land less sensitive to thin cirrus

Validation results over Germany







wet bias in SEVIRI TCWV against GPS and COWA TCWV but overall reasonable!

Caveats/challenges for TCWV from TIR measurements

Challenges/issues:

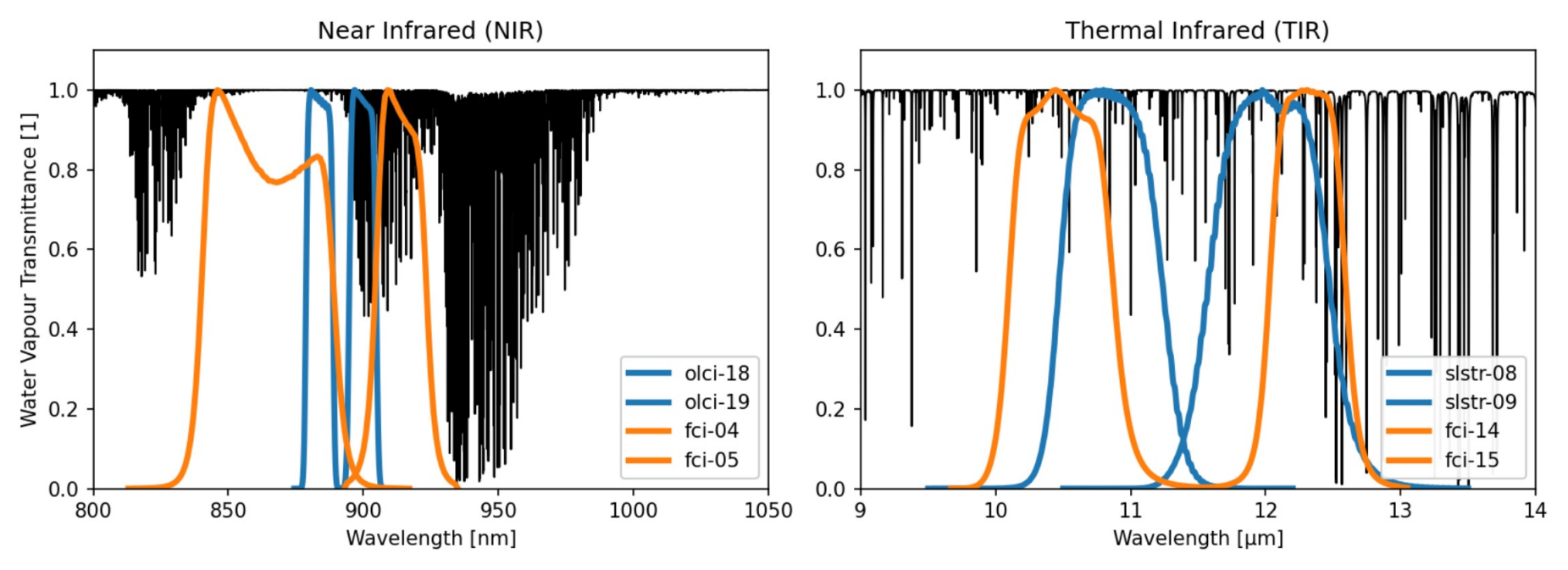
- prior knowledge of emissivities and shape of atmospheric profiles needed
- long processing time (1 ms/pixel)
- sensitive to thin clouds
- in some cases the averaging kernel (AVK) is low (= how much gain from the measurement vs. prior knowledge)

TCWV from the Combination of NIR and TIR of S3 OLCI/SLSTR

The Idea - TCWV from NIR and TIR: S3 OLCI/SLSTR

NIR and TIR's strengths and weaknesses seem to complement each other: why not combine them?

- use forward models of both presented algorithms
- profit from both complementing one another.



The Algorithm - TCWV from NIR and TIR: S3 OLCI/SLSTR

Advantages

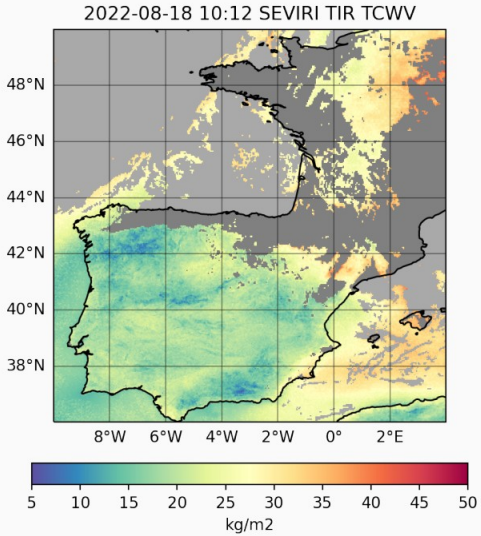
- complementing one another: sensitivity to small-scale TCWV over water and land surfaces.
- information from TIR can replace "missing" additional NIR-bands for surface characterization (e.g. over ocean)

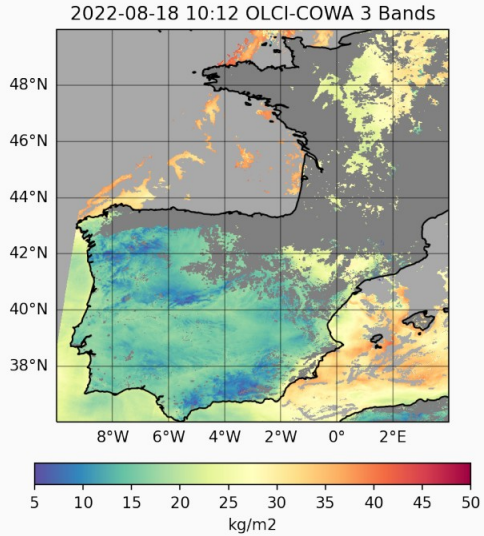
still work in Progress!

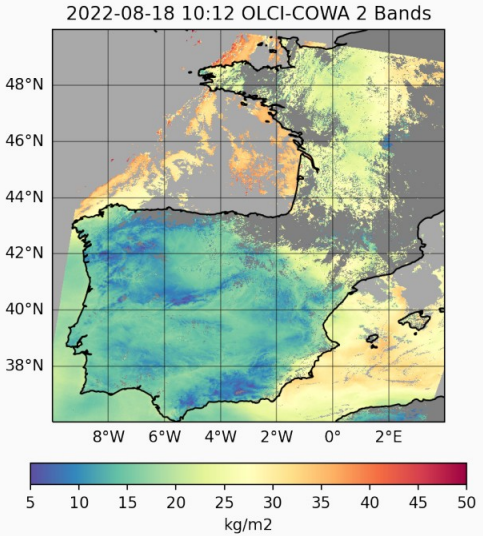
- only the first working prototype(s)
- more work towards FCI VIS/NIR bands necessary!

Comparison between NIR,TIR and NIR-TIR TCWV

The Comparison - TCWV from NIR and TIR: S3 OLCI/SLSTR

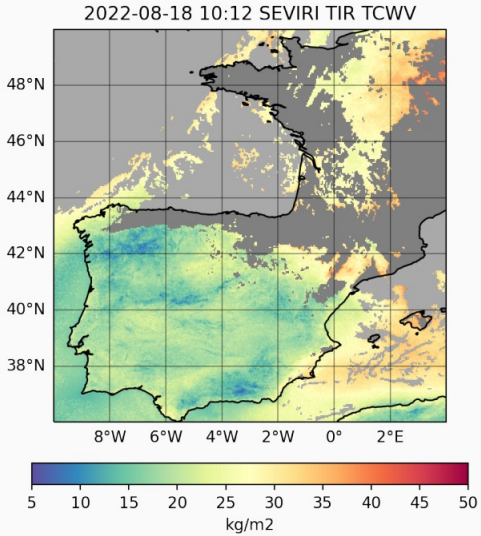


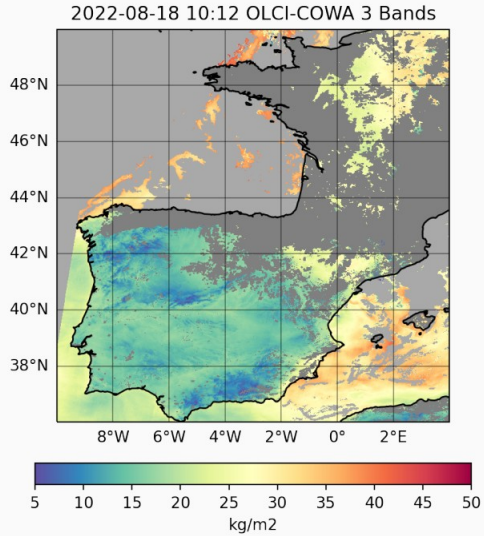


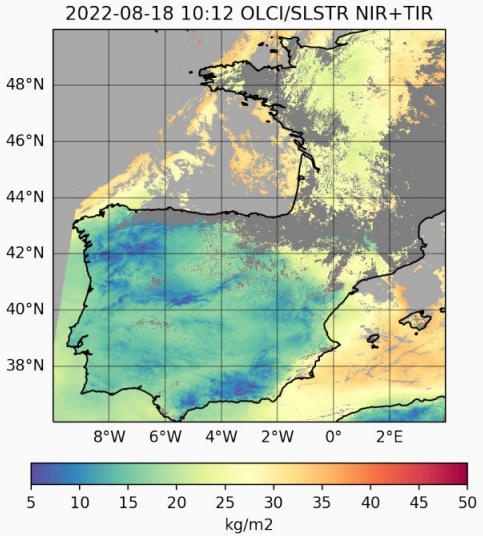


- "dynamic range" in TCWV values high over water and land surfaces
- gravity and lee waves visible over water and land surfaces

The Comparison - TCWV from NIR and TIR: S3 OLCI/SLSTR







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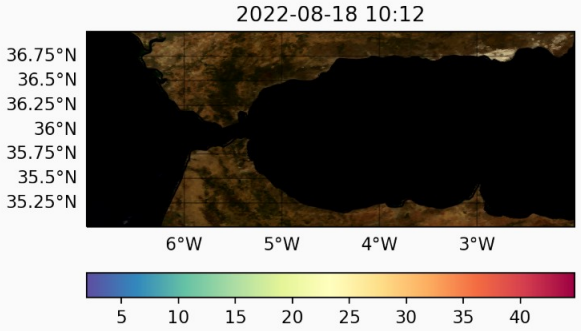
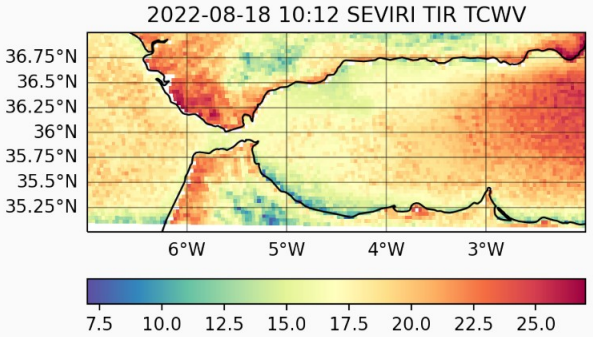
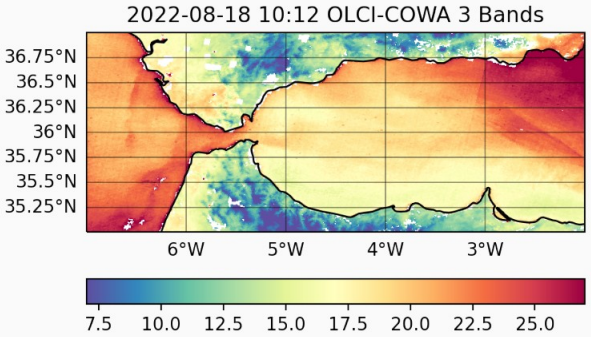
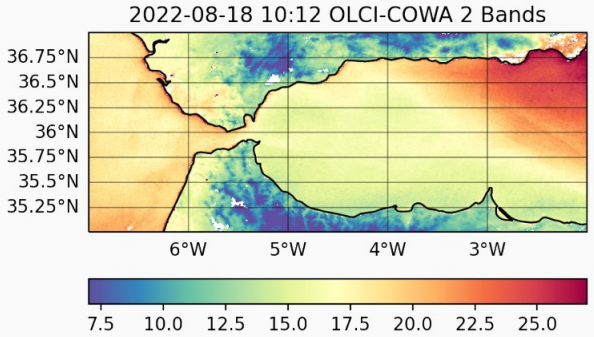
The Comparison - TCWV from NIR and TIR: S3 OLCI/SLSTR Zoom In









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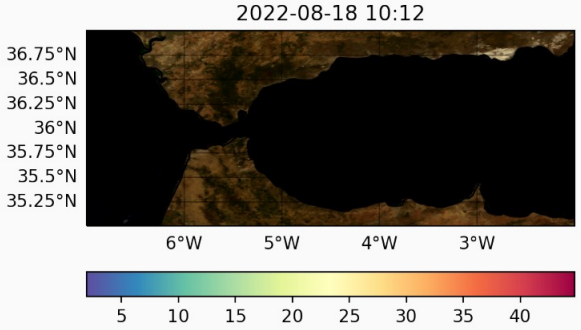
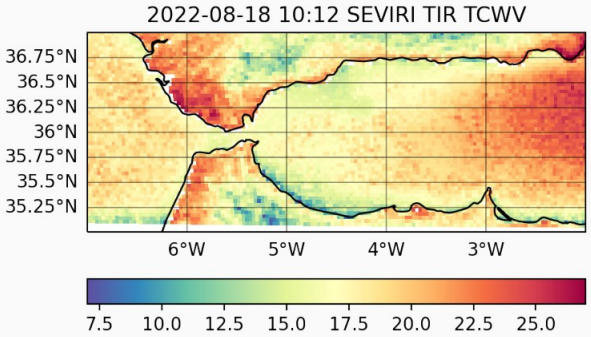
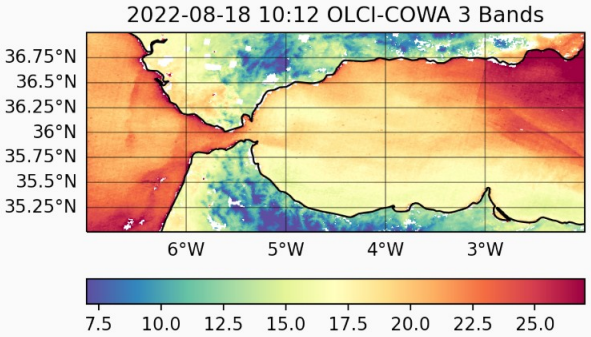
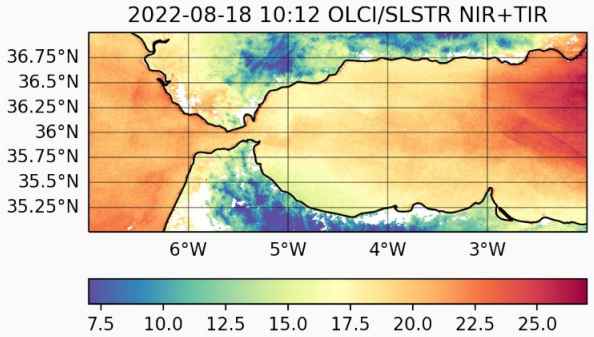
The Comparison - TCWV from NIR and TIR: S3 OLCI/SLSTR Zoom In









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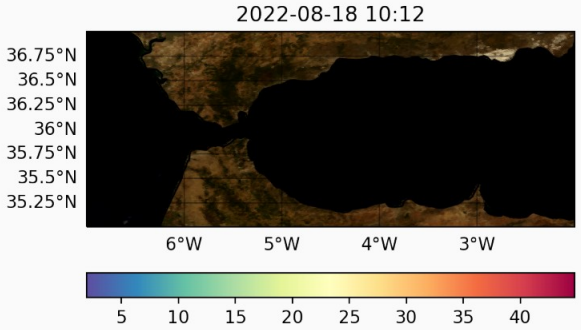
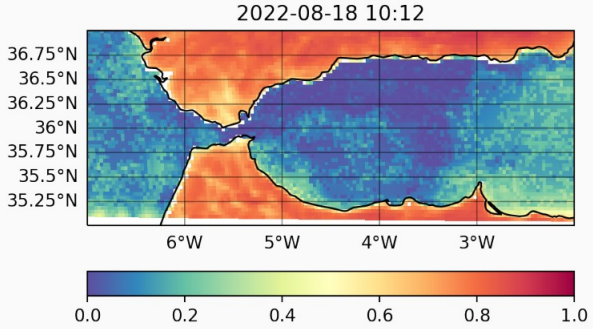
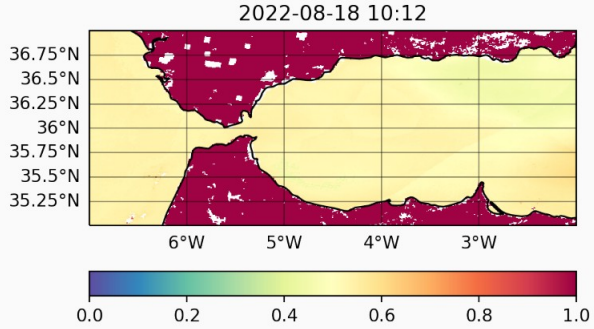
The Comparison - TCWV from NIR and TIR: S3 OLCI/SLSTR Zoom In

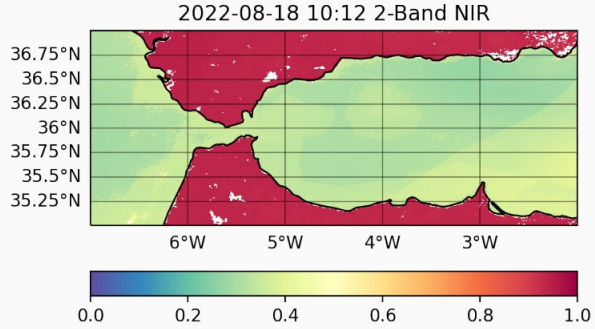




- AVK for SEVIRI over water close to 0 up to 0.5



- AVK for COWA over water between 0.4 up to 0.7



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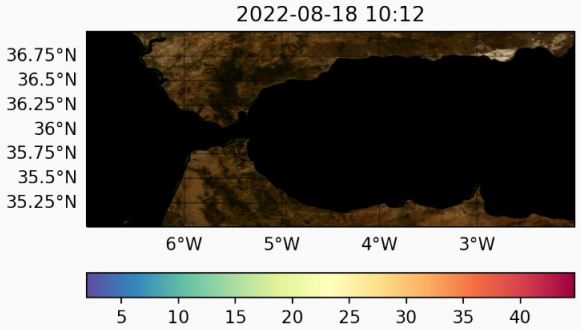

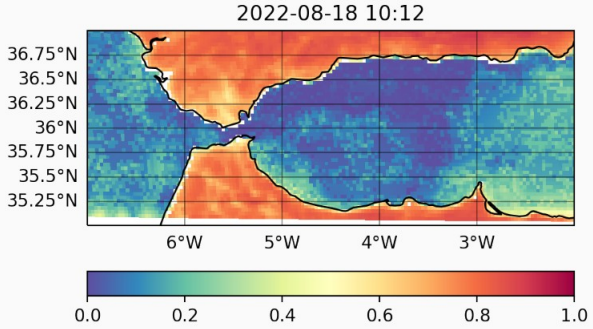

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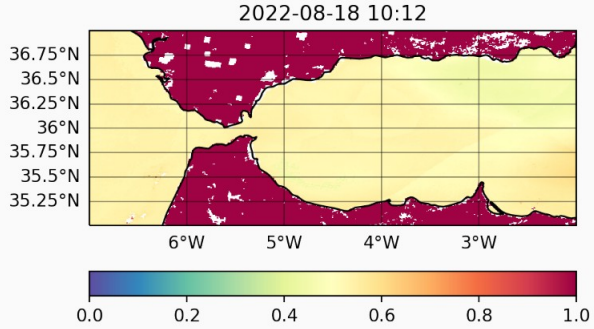

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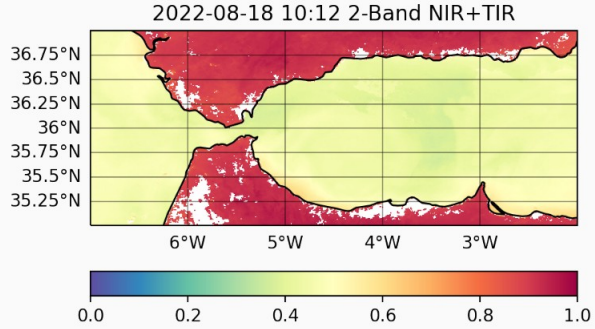


- AVK for OLCI/SLSTR over water close to 0.3 up to 0.5

Conclusions

Summary and Outlook

Conclusions

- working 0.885/0.905 micron prototype $\Rightarrow$ transfer to 0.865/0.905 micron
- TIR could complement FCI-NIR-TCWV
- synergy algorithm combines both strengths of NIR-TCWV and TIR-TCWV (e.g. more robust against aerosols?)
- at 1 km capable of revealing small-scale TCWV features both over land and water

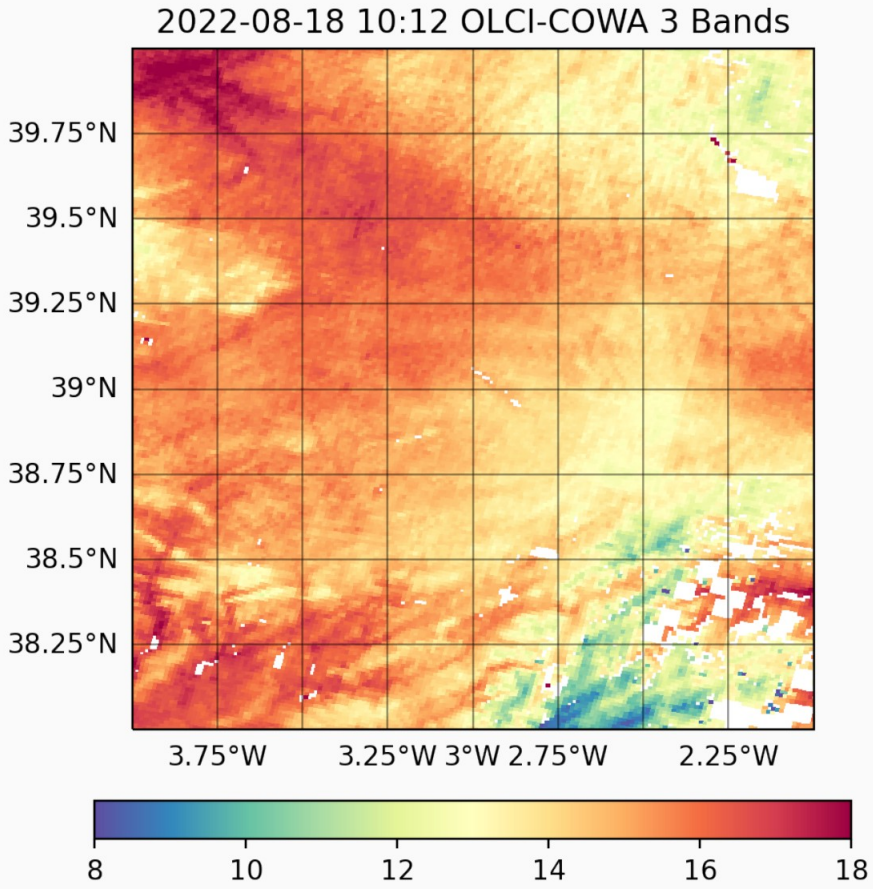
Outlook

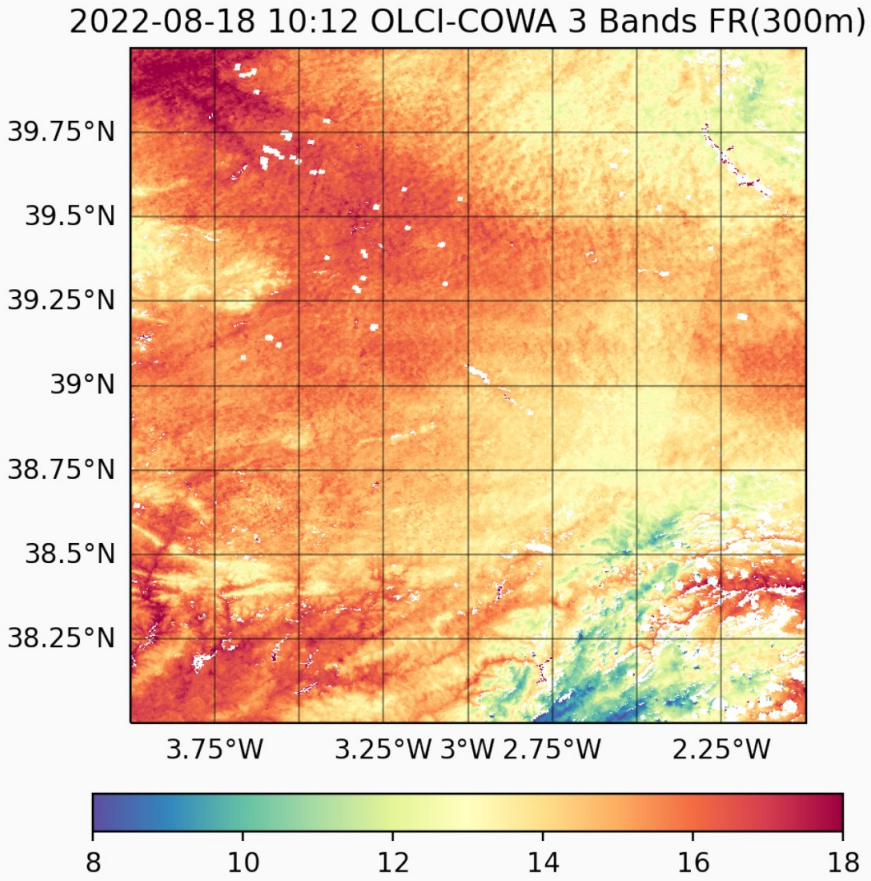
- analyse algorithm for possible weaknesses and correct deficiencies
  - parametrise the surface albedo in the absorbing band
  - stronger constraints over water surfaces
- extensive validation against ground-based station data, soundings

Jan El Kassar jan.elkassar@met.fu-berlin.de

Freie Universität Berlin

An even higher resolution...





TCWV and relation to convective initiation (CI)

Freie Universität Berlin

German RealPEP project: exploiting satellite-based observations of the (heavy) precipitation-generating atmosphere

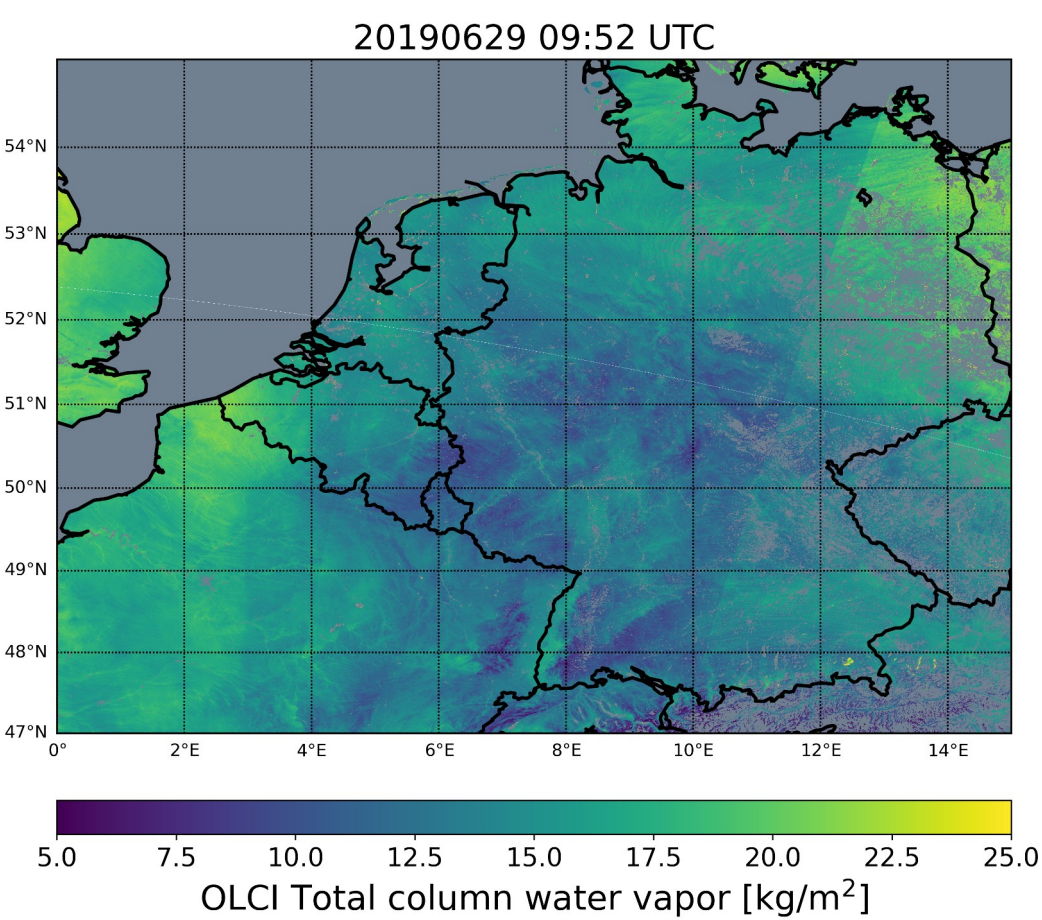
More specifically, we investigate the **potential/added value of satellite observations** of total column water vapor (TCWV) for **improving nowcasting of convective initiation (CI)**.

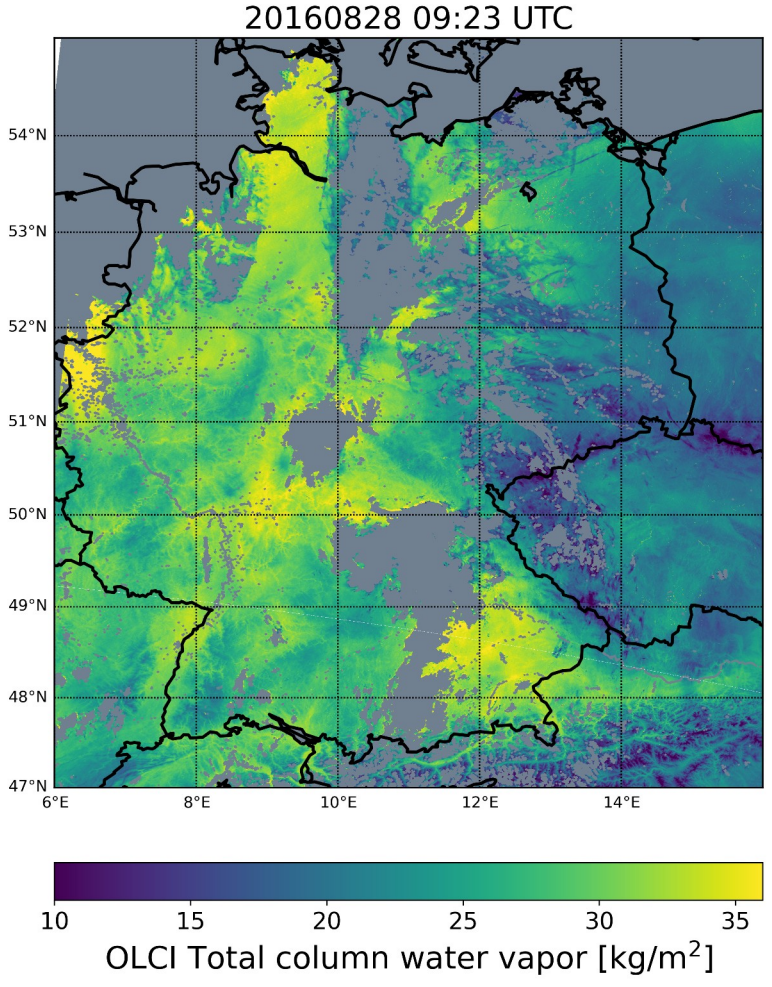
- **Develop, process and evaluate new high resolution satellite-based TCWV products**
  - OLCI: spatial information
  - SEVIRI: temporal information
  - Mimicking/preparing for MTG-FCI observations
- **Assess TCWV spatio-temporal variabilities in pre-convective environments.**
  - Determine suitable metrics for characterization/quantification of pre-convective environment
  - Use proxy's/features/predictors to translate information to CI probability (machine learning method?)
  - By creating large match-up dataset: multiple TCWV datasets & Cloud/CI/RDT parameters
- **Assess added value of new satellite-based TCWV product and CI information** in/wrt radar-based QPN and NWP assimilation methods.

DFG RealPEP

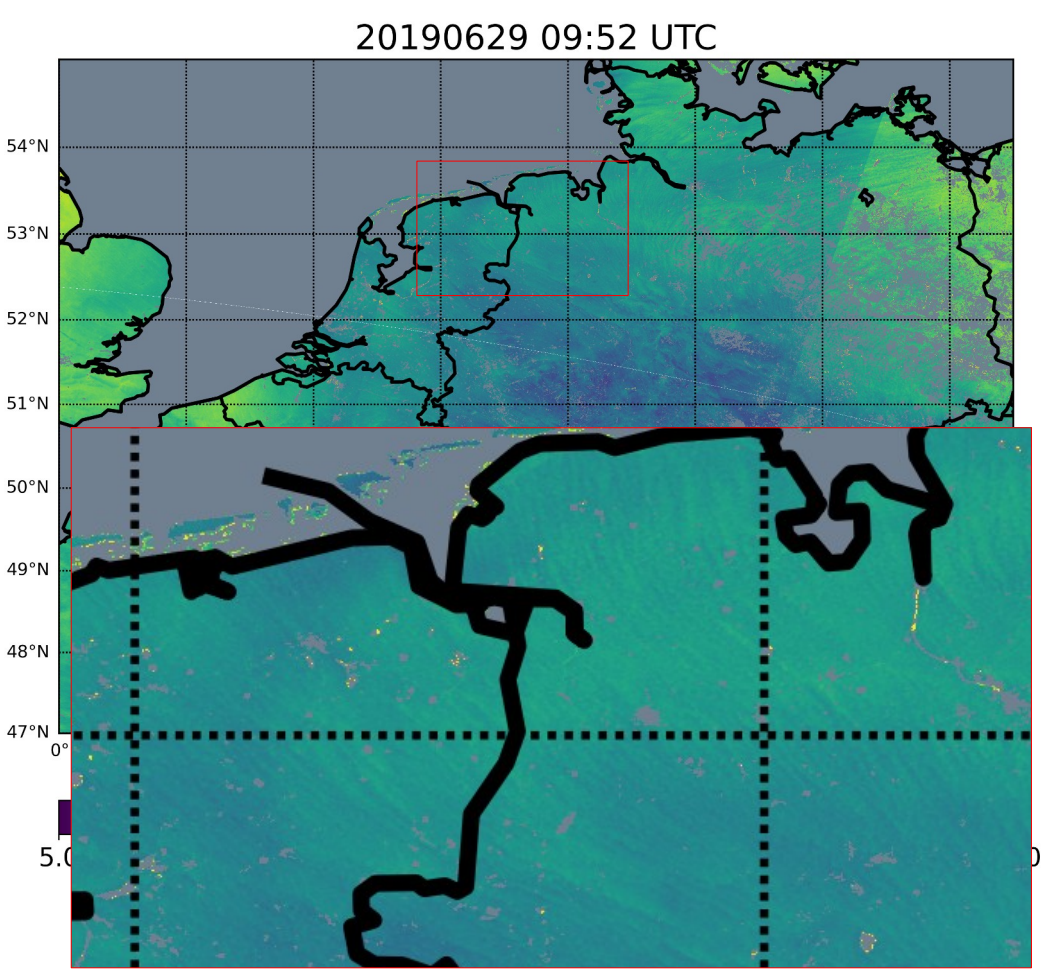
OLCI TCWV examples

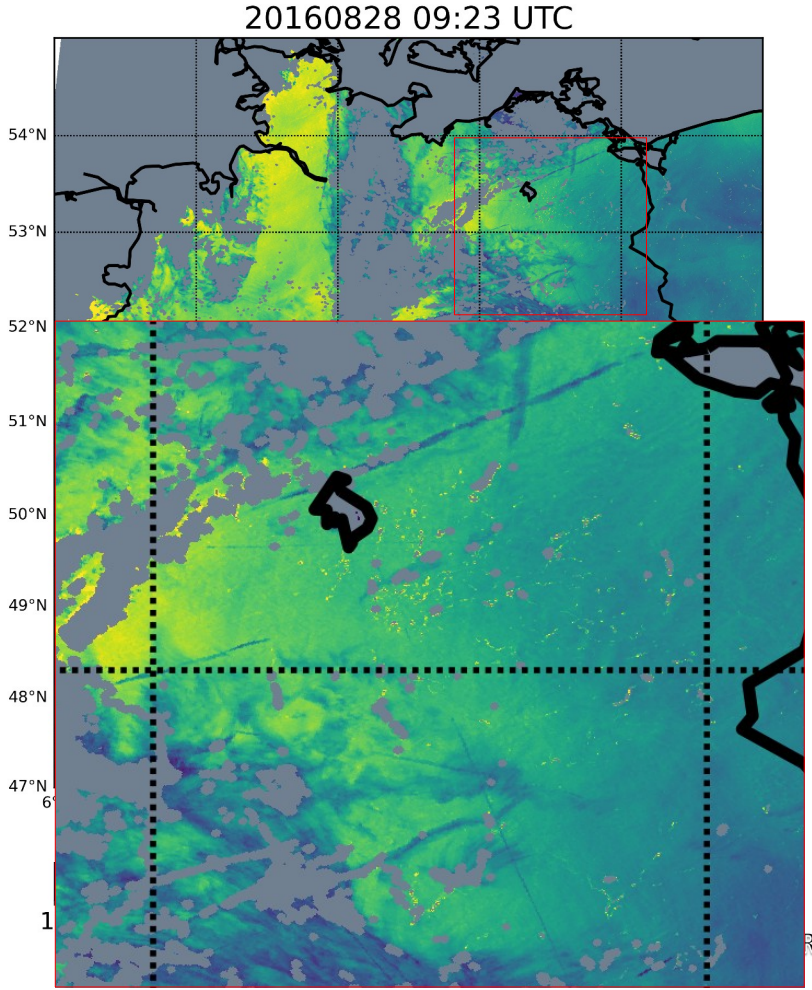
Freie Universität Berlin





OLCI TCWV examples





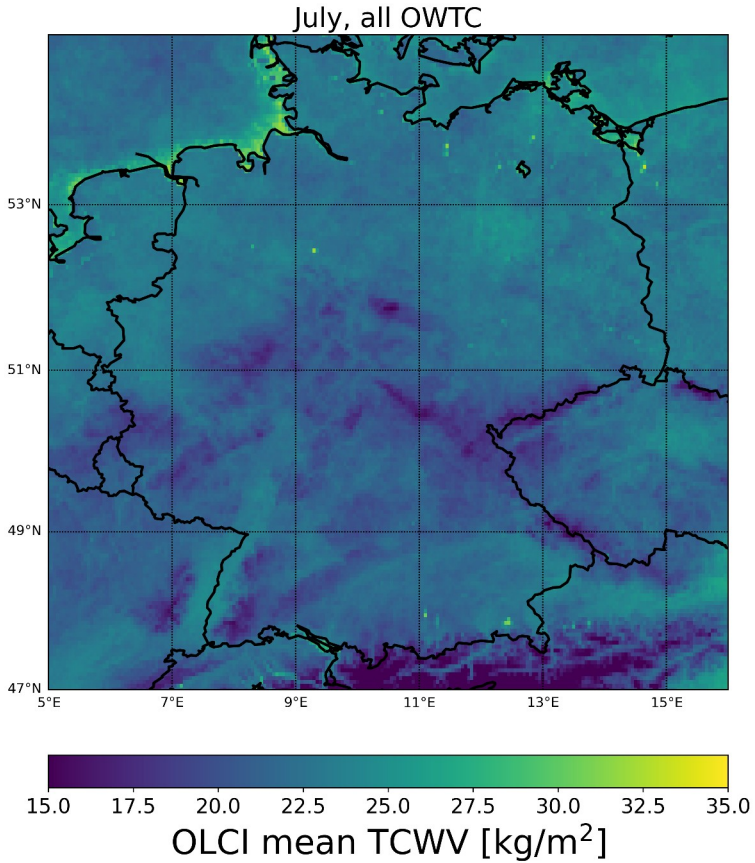
OLCI TCWV examples

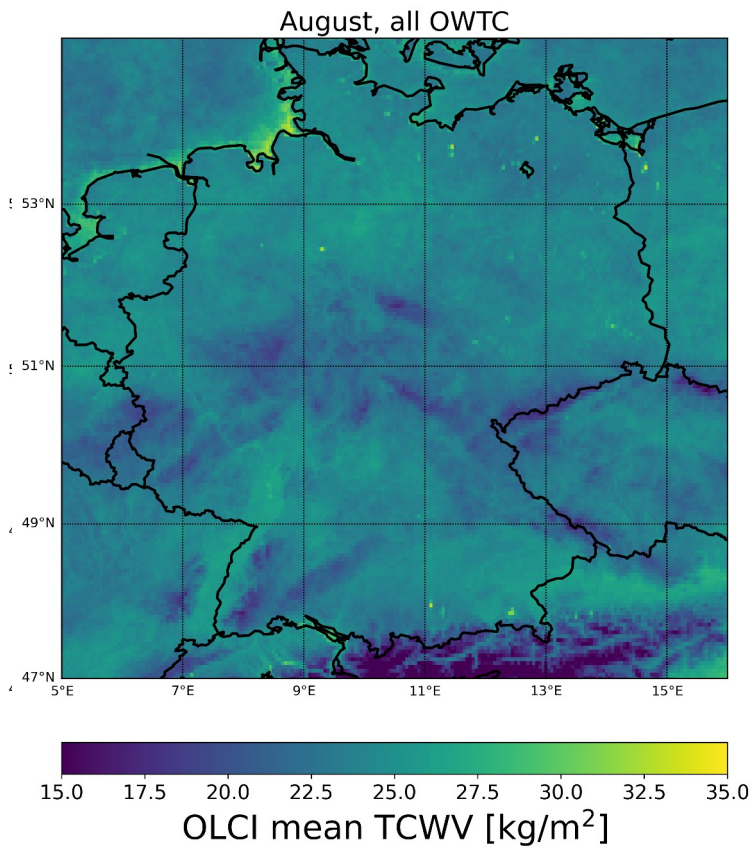
OLCI TCWV **montly/weekly climatology**

- based on obs from years 2016-2021
- cloud free areas
- morning time

OLCI TCWV anomaly =

$(TCWV_{pix}/TCWV_{clim}) * 100\%$





How to observe/quantify CI in TCWV fields

Freie Universität Berlin

Basic statistics (first/second orders)
- OLCI TCWV field: mean, std, percentiles (10, 50, 90)
- OLCI TCWV anomaly field: mean, std, percentiles (10, 50, 90)
- SEVIRI TCWV timeseries: mean, std, percentiles(10, 50, 90), jumps

Statistical approaches for analysis of image structures/texture:
spatial auto-correlation and texture measures
- Semivariogram/structure functions
- Local Morans I index
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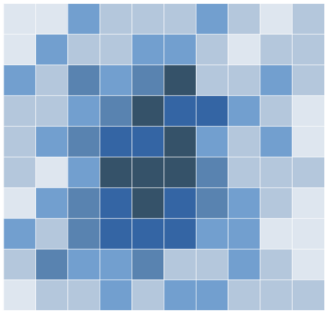
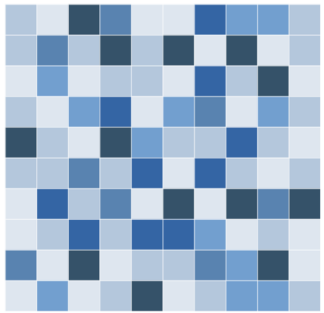
- GLCM





DFG RealPEP

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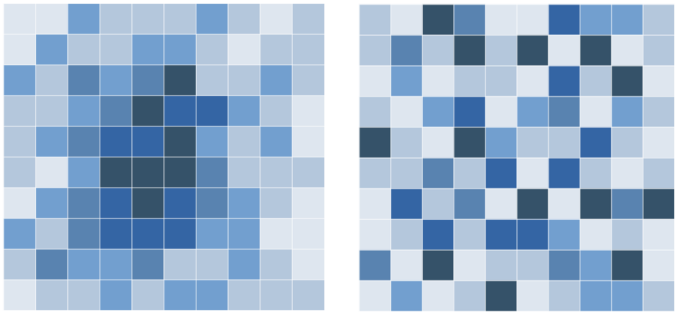

Spatial autocorrelation
Measures of contrast, homogeneity, correlation, orderliness...
- For varying pixel distances
- perpendicular/parallel to average BL wind direction (assymetry factor)

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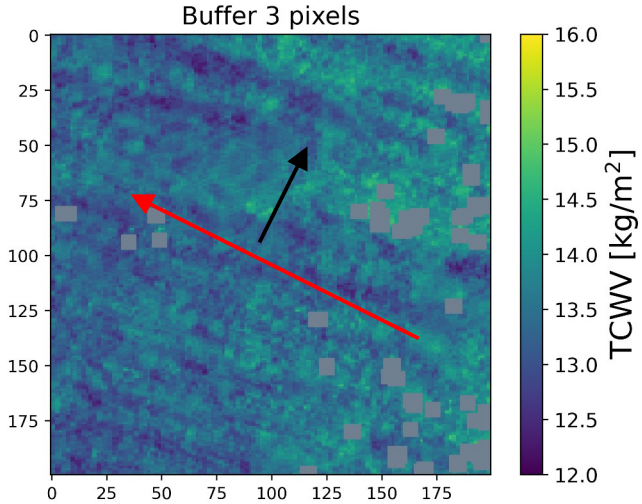

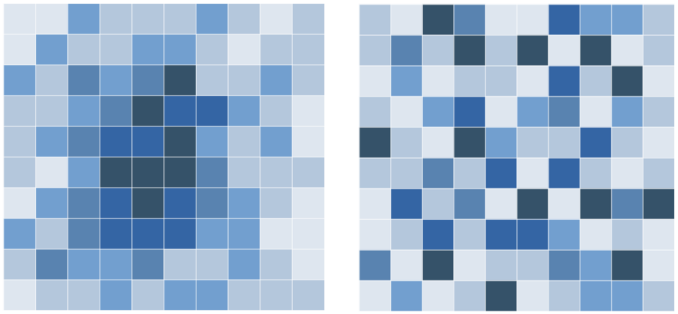

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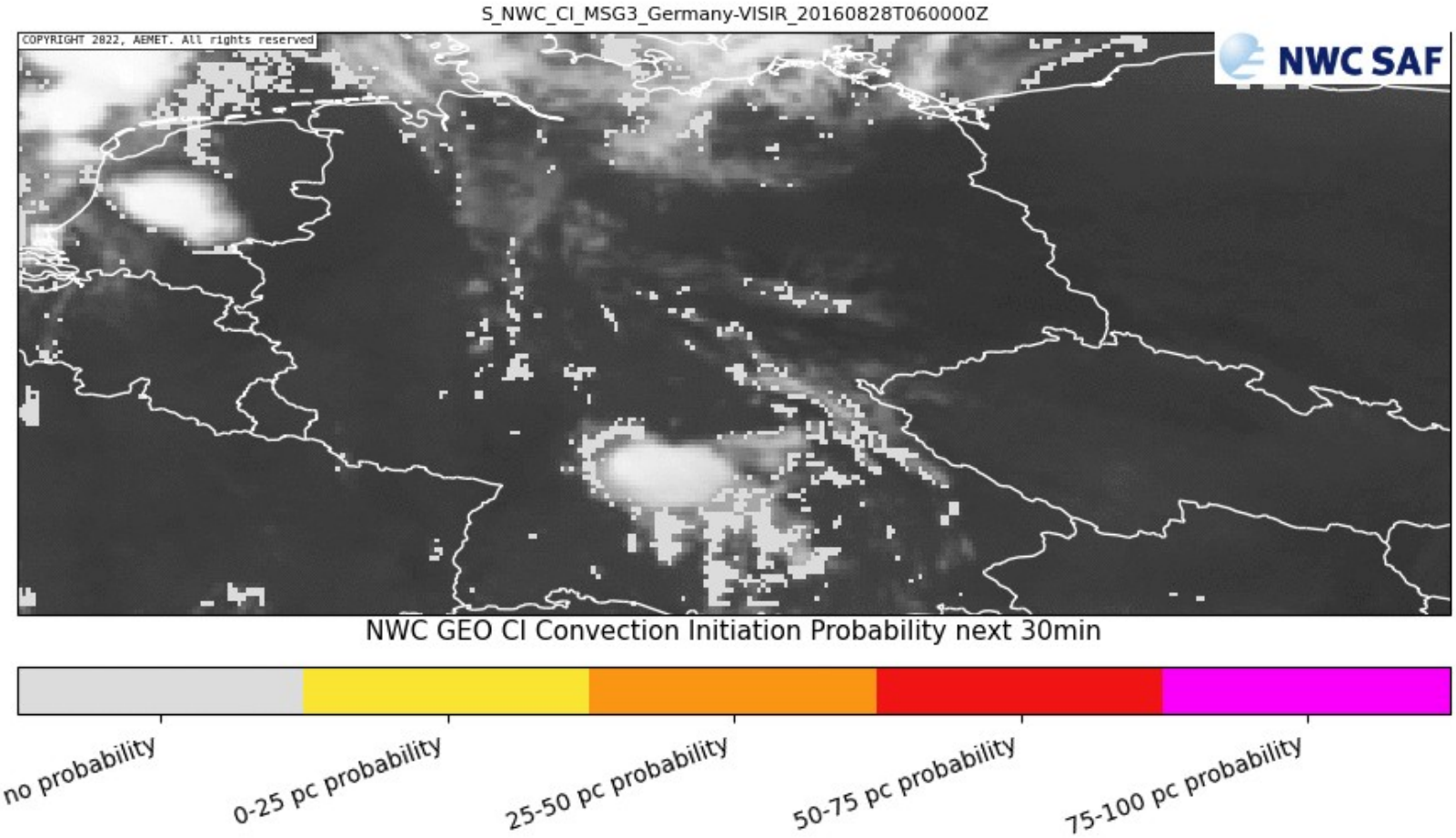
NWCSAF SEVIRI convective cloud products



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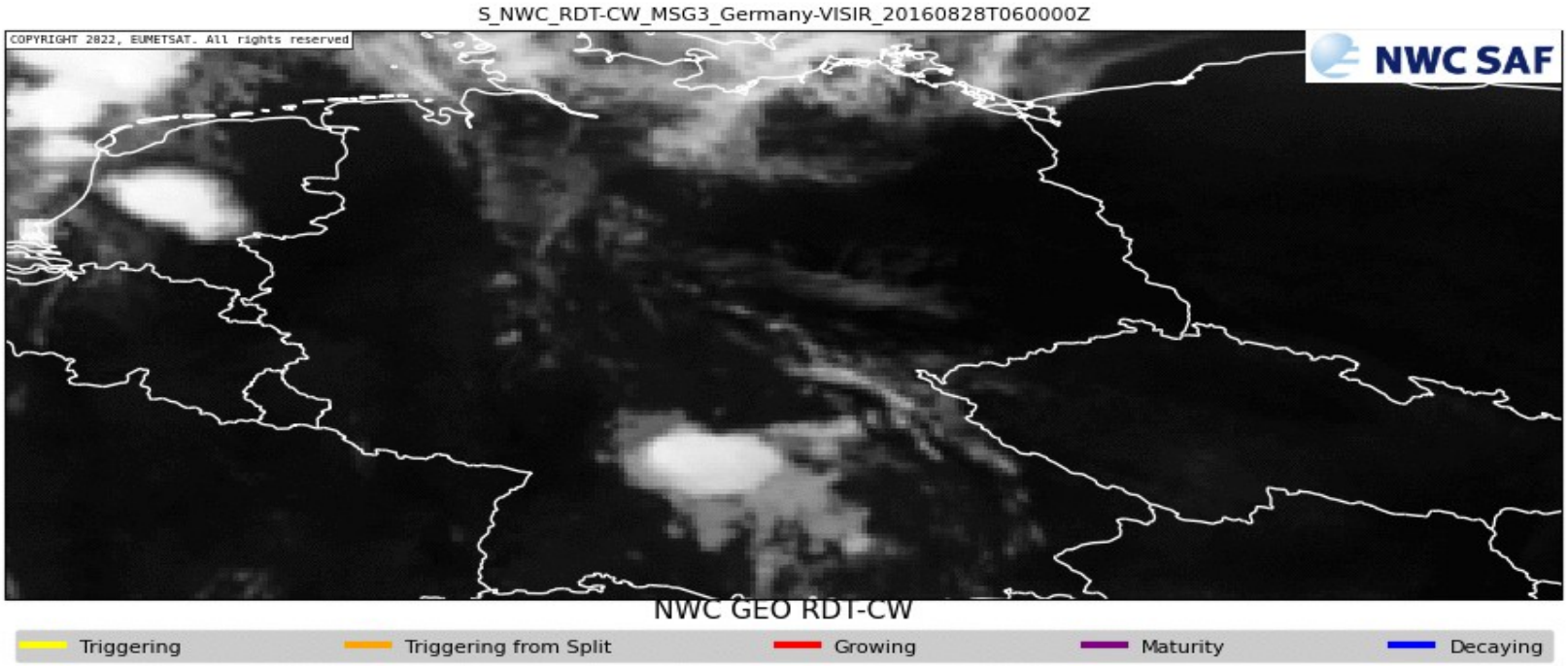
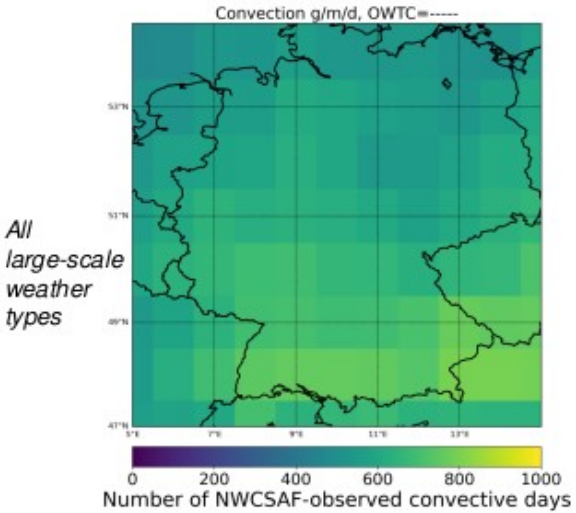


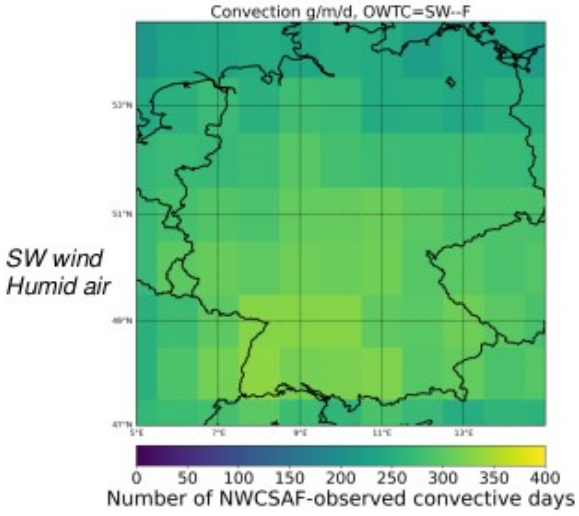
NWCSAF SEVIRI convective cloud climatology

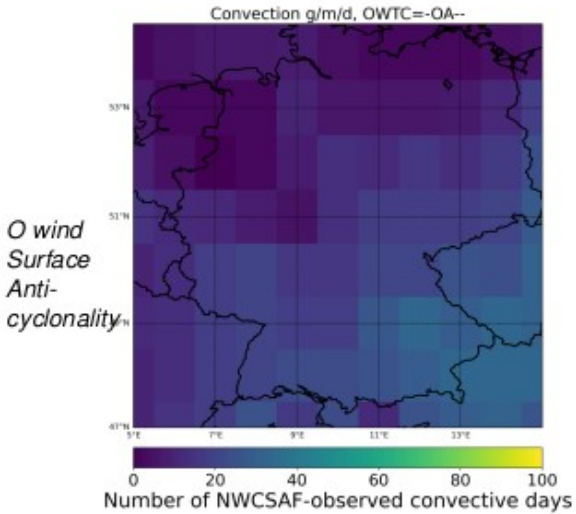
Based on NWC-SAF CI/RDT product using SEVIRI measurements in VIS/NIR/TIR + ERA5 parameters:

Convective cloud climatology for Germany 2016-2019

#days, onset, duration, cyclus, track, location, type, sevirity, for different large-scale weather types







TCWV-based metrics: examples

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for non-convective days and convective days (RDT), various start times and for each grid cell

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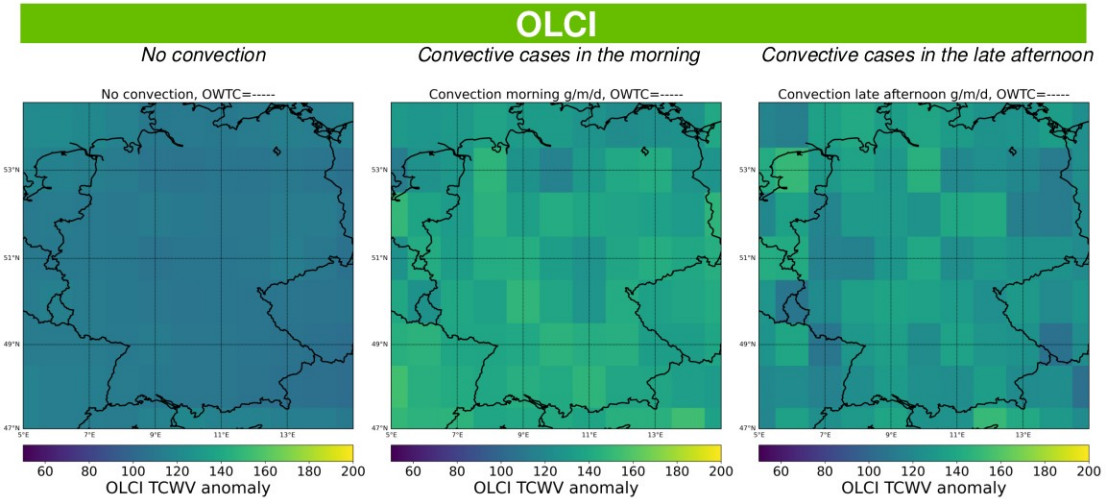

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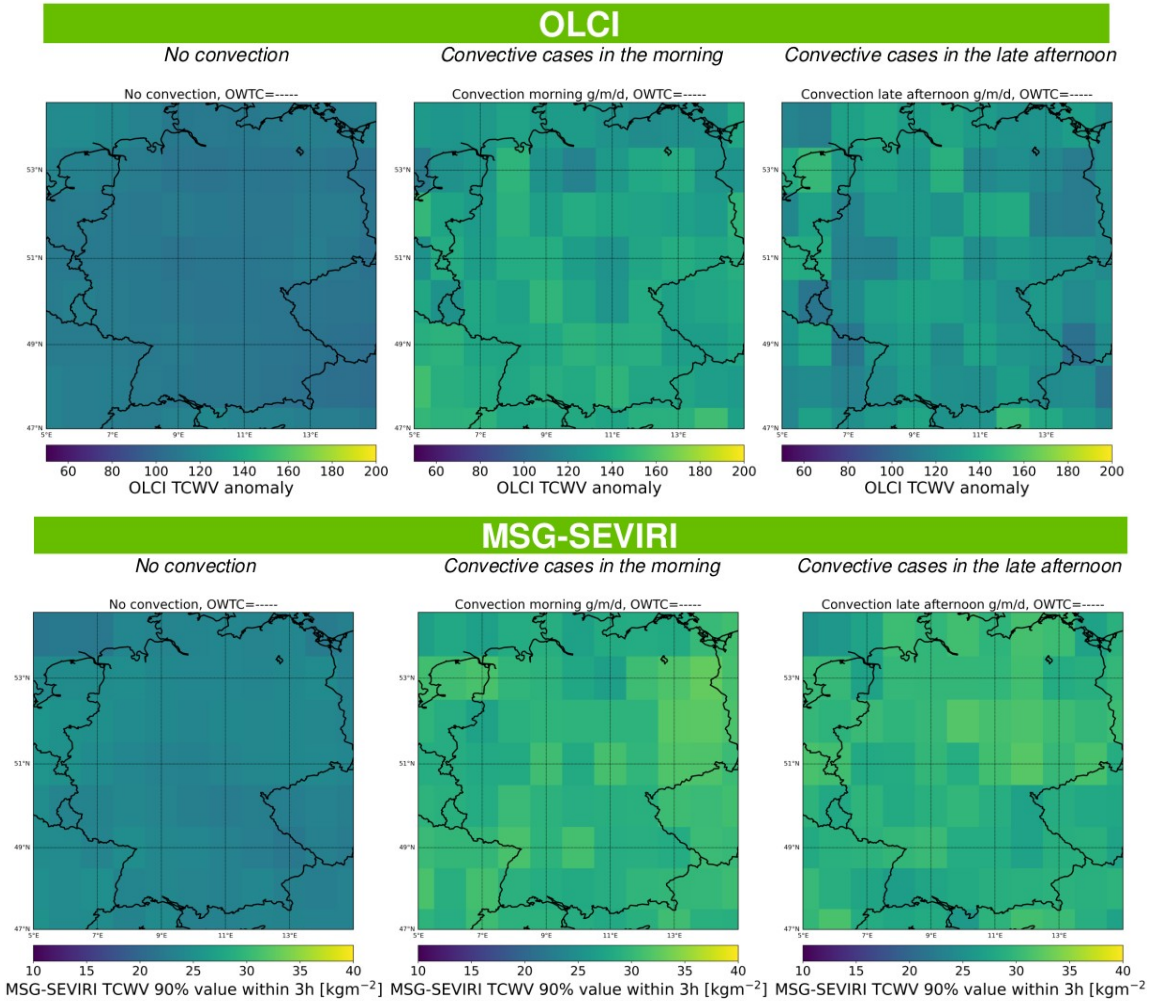
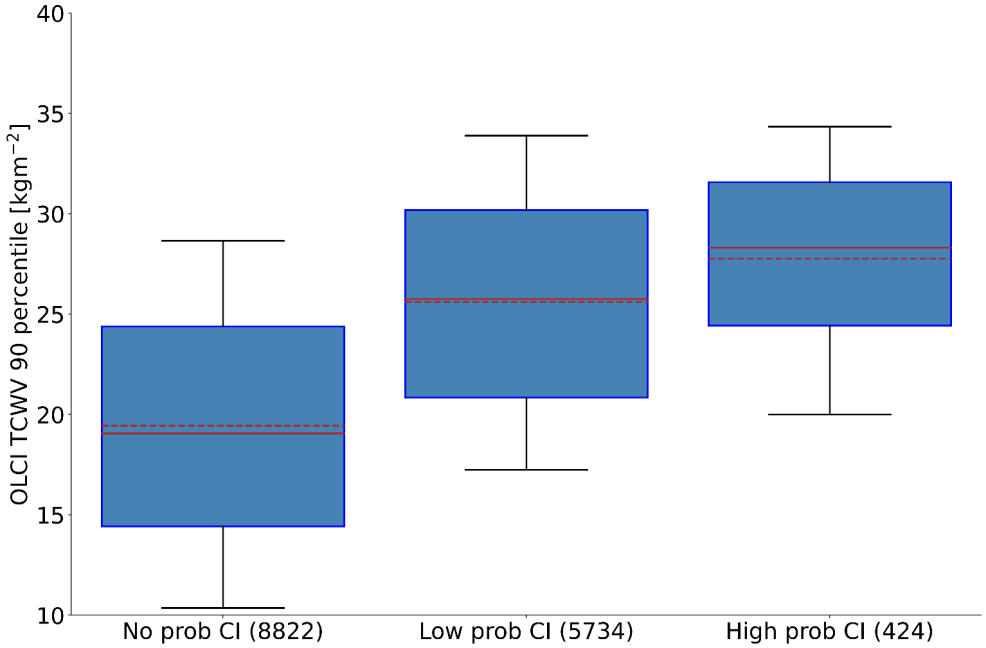


Discriminatory potential/power

Which TCWV-based parameters/metrics have discriminatory potential/power (pre-convective environment vs non-convective environment)

Distributions of TCWV-based metrics for:

- Germany: regions of 1 x 1 degrees
- Years 2016-2019, April-Sept
- Dominant morning clear-sky conditions
- All large-scale weather types
- All heights
- All convective cloud types



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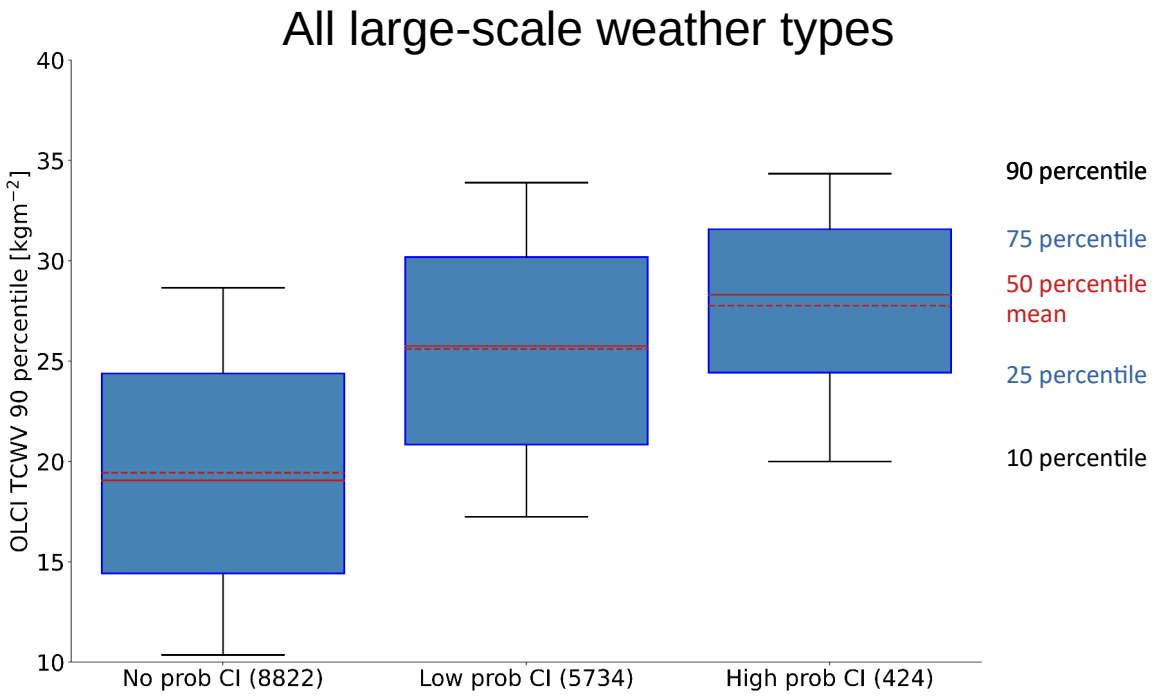
Mainly clear-sky situation in the morning



No CI probability

25 - 75% chance of in-cloud CI in next half hour

> 75% chance of in-cloud CI in next half hour

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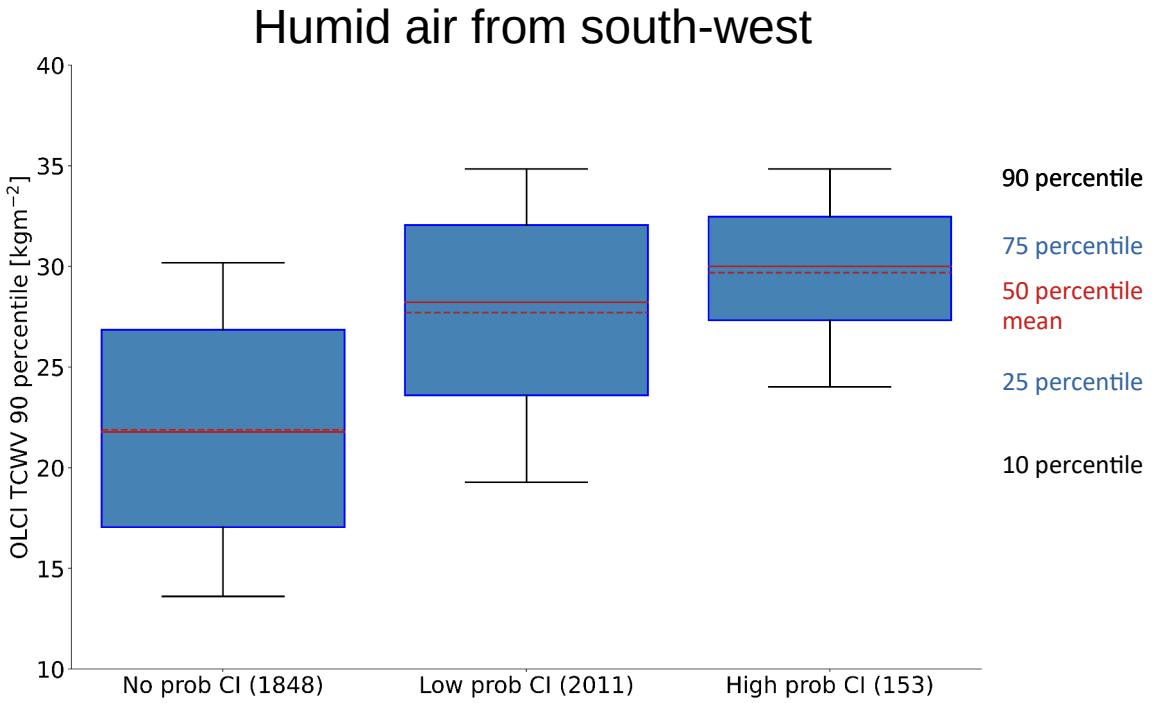

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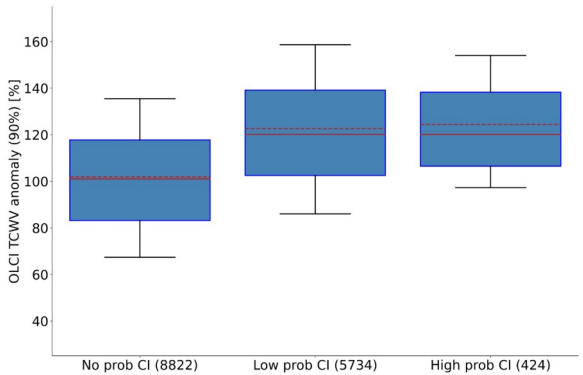
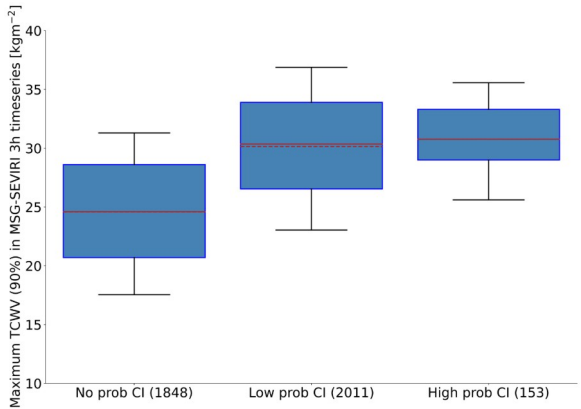
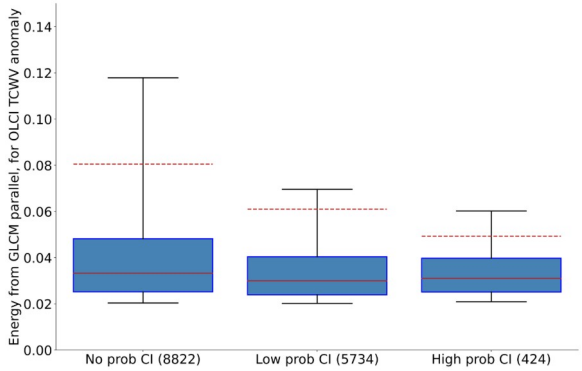
Spatial information (wrt climatology)

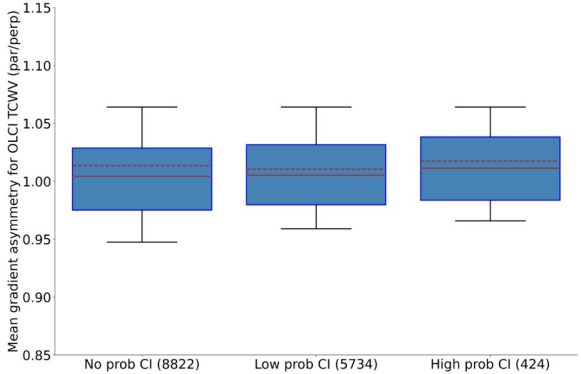




Temporal information

Measure of Orderliness

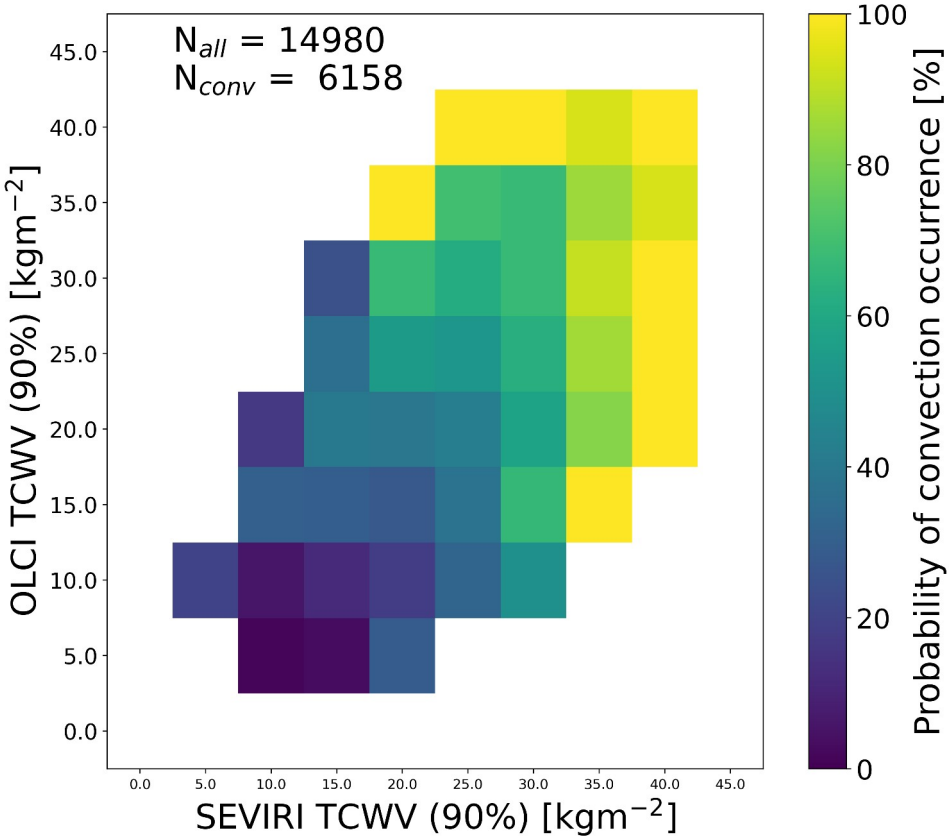




Gradient perpendicular/parrallel to BL wind direction

From diagnostic to prognostic potential

- **Characterize/quantify:** Define probability as relative frequency of CI occurrence within a certain time frame, within a certain region
  - period 2016-2019 April-September
  - regions in Germany
- Dependence on: time of year/day, large-scale weather, local weather situation, topography..?



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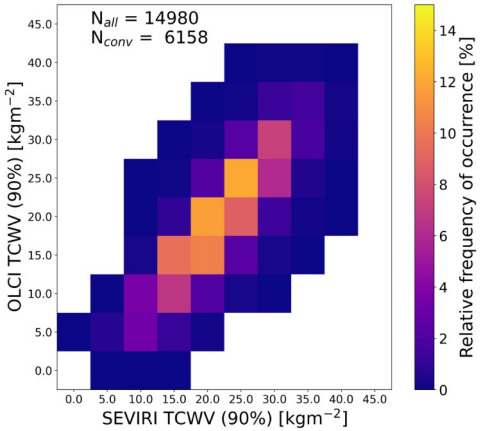
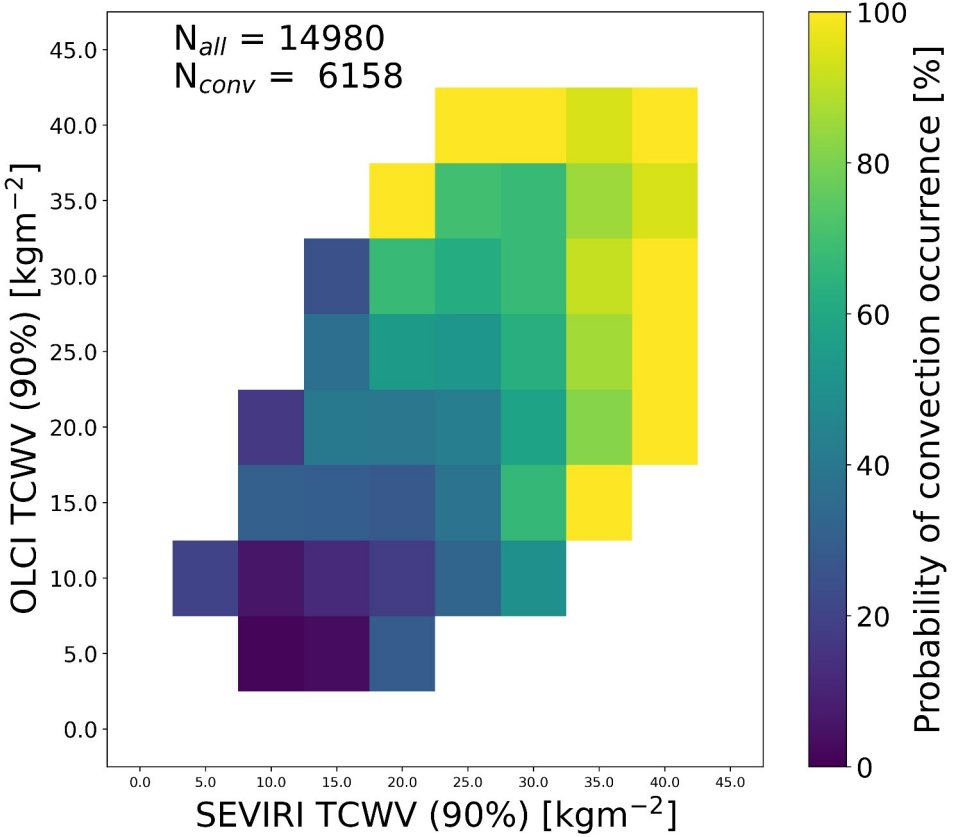
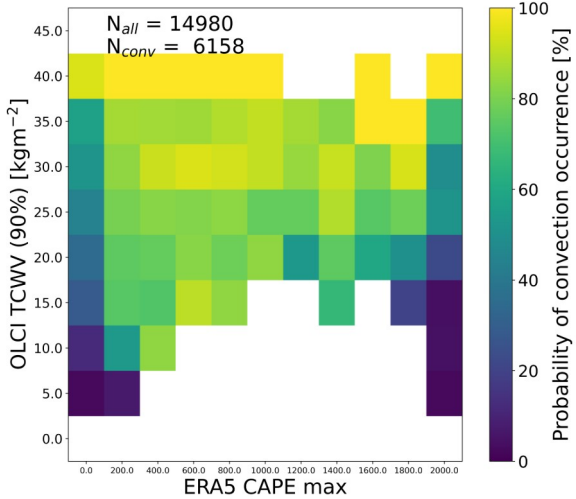


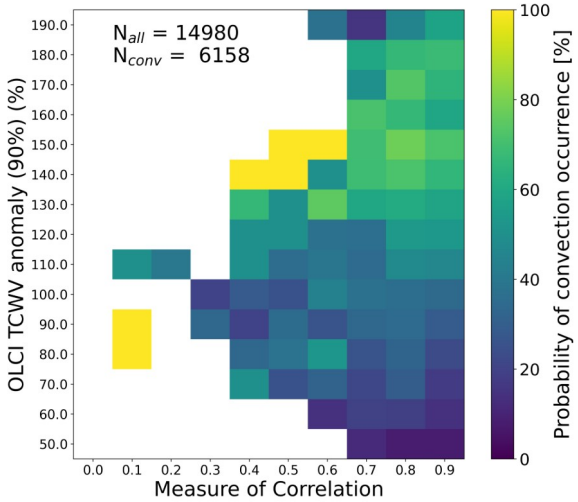
Spatial information

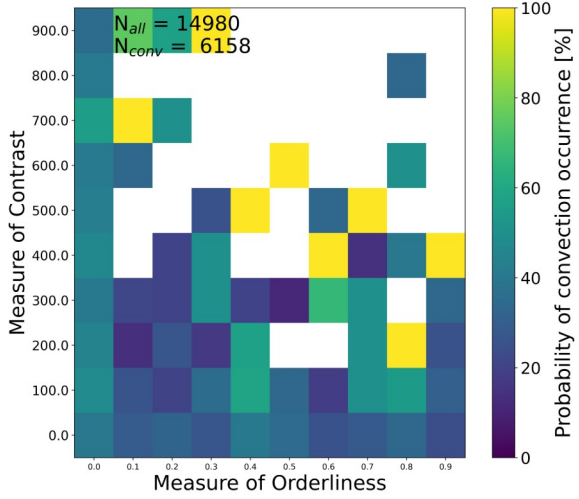


Temporal information

Towards a CI probability: examples

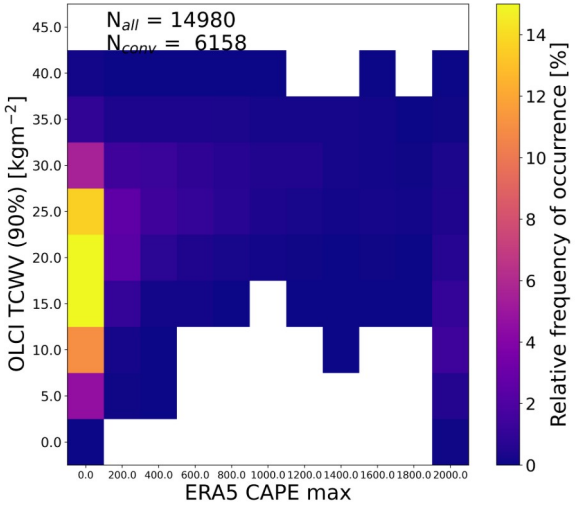


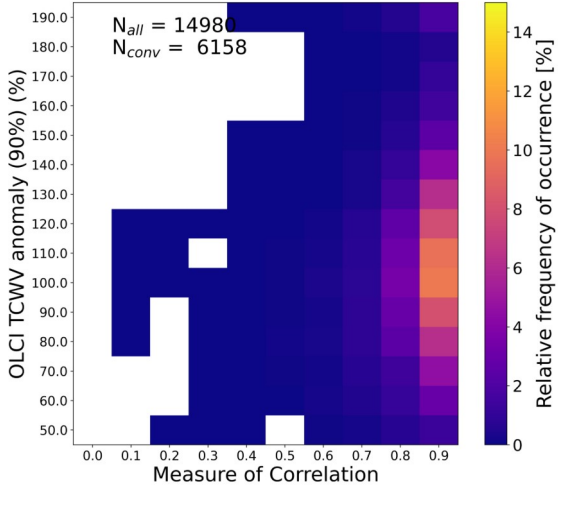


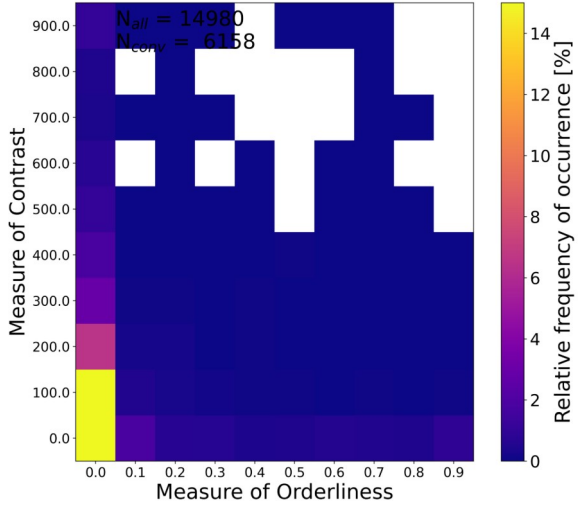


Play around with:

- Time of year
- Time of onset
- Large-scale weathe
- Type of convection
- Elevation
- ...







Summary

- **Study of satellite-based CI detection**
  - Big match-up dataset, including newly processed TCWV observations
    - challenges: higher resolution → more noise;
    - limitations: clear-sky + buffer, inland waters, morning time
  - Statistical analysis:
    - dozens of metrics based on spatial/temporal variabilities
    - varying distributions for (non-) convective environments
    - First straight-forward frequency based probability

Outlook

- **Study on satellite-based CI detection**
  - Extend match-up dataset until year 2022, use new NWCSAF software version cloud products
  - Tie observed CI to future RDT
  - Machine learning method to select best CI proxy's/predictors and produce a probability

- **Preparations for future MTG-FCI TCWV retrievals**
  - Tests with simulation data of MTG-FCI
  - Preparing for first real data in 2023
  - Include in-cloud CI detection and relation to (heavy) precipitation

Thank you!