Open Source Developments for the Joint Assessment of Cloud Characteristics in Simulations and Satellite Observations

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Leibniz Institute for Tropospheric Research - TROPOS

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Leibniz Association

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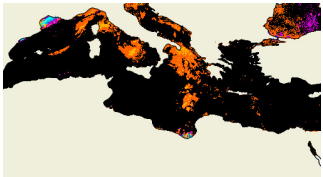
Outline

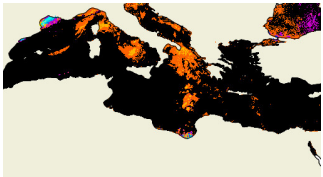
What Comes Next?

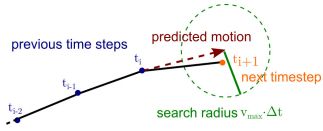
- **CTyPyTool**
  - ML-based emulator for cloud typing
  - fair comparison of cloud occurrences between observations and simulation



What Comes Next?

- **CTyPyTool**
  - ML-based emulator for cloud typing
  - fair comparison of cloud occurrences between observations and simulation
- **Tobac**
  - cloud tracking based on object detection & linking
  - flexible, modular & extendable



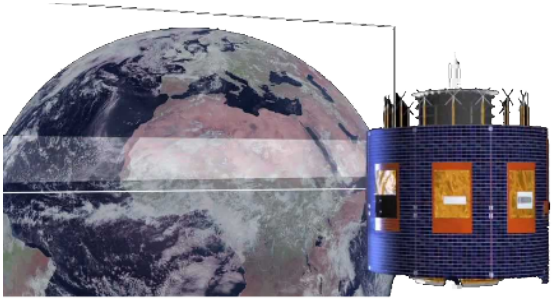


Outline

CTyPyTool: Research Questions

1. How well are cloud types and their characteristics represented in regional models?
2. What is the impact of different cloud parameterization choices (e.g. microphysics and convection) ?

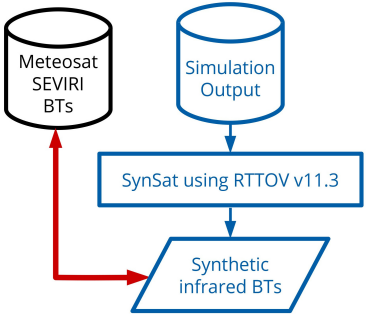
Simulation and Observation Data



- pairing Meteosat observations with simulated clouds.

How to Compare?

The Challenge

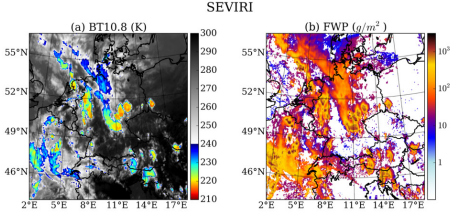


- **Synthetic Observations**
  - synthetic IR radiances from forward operator (SynSat, RTTOV)
  - **pro:** fair & direct comparison of BTs
  - **con:** sometimes ambiguous & hard to interpret

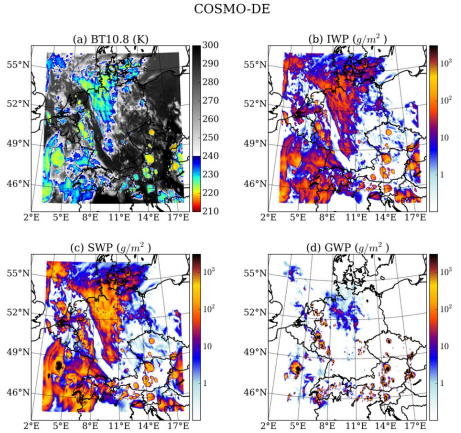
How to Compare?

A Few Examples

- **Comparing BT Images**
  - spatial distribution of "cold" clouds can be compared



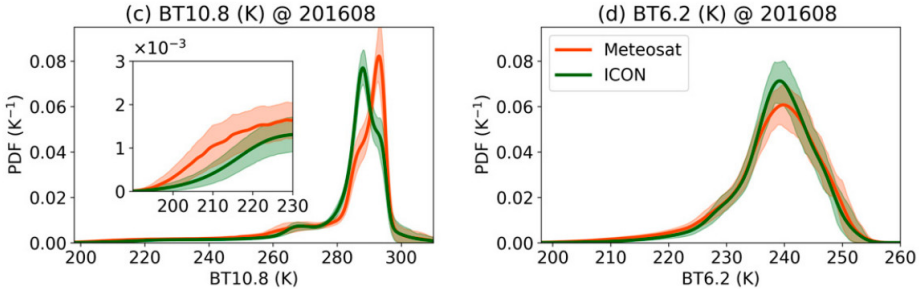
Senf and Deneke (2017b)



How to Compare?

A Few Examples

- **Comparing Distribution Statistics**
  - identify biases in occurrence rates

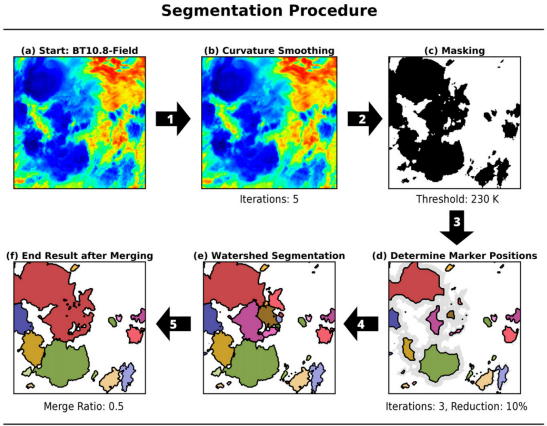


Senf et al. (2018)

How to Compare?

A Few Examples

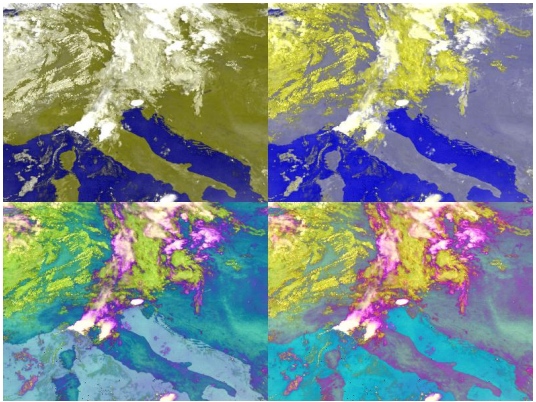
- or **Comparing Object Characteristics**
  - cell sizes distributions
  - growth rates
  - pair distances, ...



Rempel et al. (2017); Senf et al. (2018)

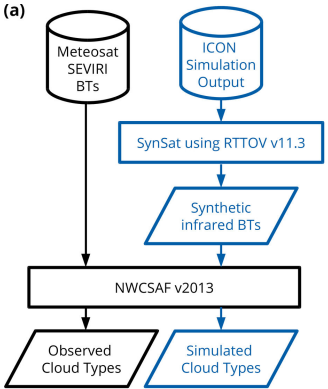
How to Compare?

However, all BT-based comparison are typically based on a single channel and miss the wealth of multi-spectral information!



Does Cloud Type Information Help?

Interfacing to NWCSAF

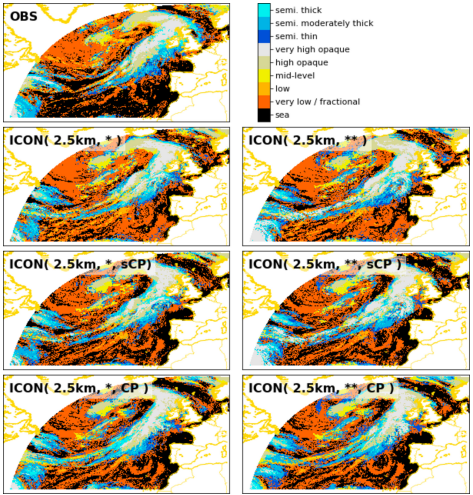


- **Cloud Classification**
  - synthetic IR radiances from forward operator (SynSat, RTTOV)
  - night-mode classification for observed and simulated IR fields with NWCSAF software
  - **con:** my interface is not user-friendly & only works over the oceans!!!

Does Cloud Type Information Help?

Interfacing to NWCSAF

- cloud type images are relatively easy to interpret



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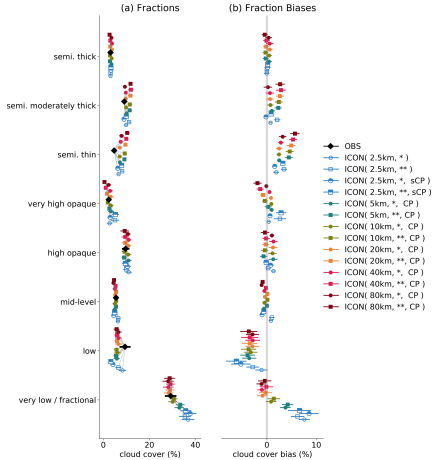
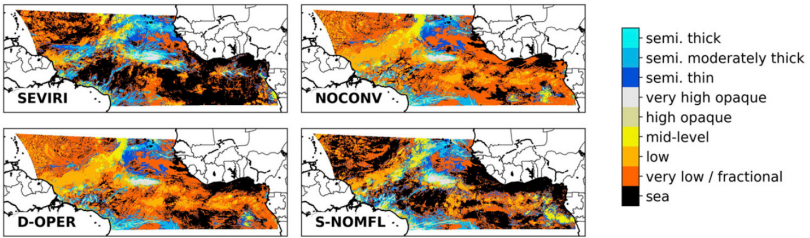


- **Cloud Fraction Biases:**
  - coverage of simulated very low clouds is very resolution sensitive
  - simulated semi-transparent cirrus clouds are too abundant

Does Cloud Type Information Help?

Interfacing to NWCSAF

- **Parameterization Developments:**
  - cloud typing helps to support parameterization development
  - e.g. stochastic convection scheme (S-NOMFL) outperforms other approaches



Sakradzija et al. (2020)

Can Machine Learning Make Life Easier?

- **Some Thoughts:**
  - data interfacing is much easier in modern languages
  - NWCSAF software is not designed to run synthetic BTs from simulations
    $\rightarrow$ a bit cheating is needed...
  - NWCSAF cloud typing is decision-based
    $\rightarrow$ a perfect task for modern emulators

Can Machine Learning Make Life Easier?

CTyPyTool Methodology

- **Idea:**
  - tree-based emulation of NWCSAF cloud types
  - night-mode classification, BTs only
  - trained on regional observation

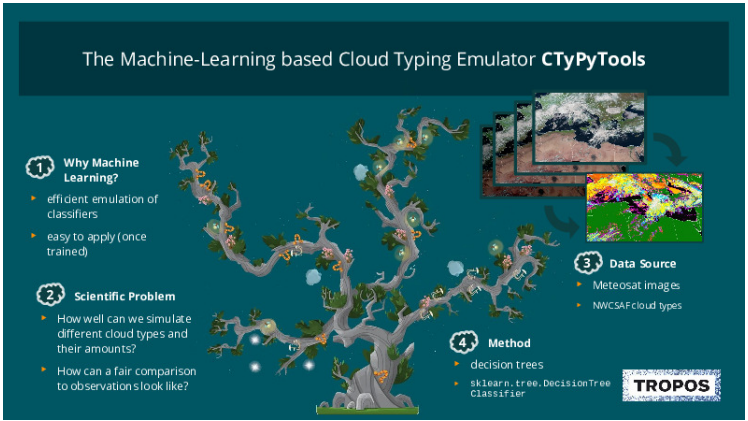
Can Machine Learning Make Life Easier?

CTyPyTool Methodology

- **Idea:**
  - tree-based emulation of NWCSAF cloud types
  - night-mode classification, BTs only
  - trained on regional observation
- **Status:**
  - experimental for the Mediterranean area, only over oceans
  - Open-Source: `https://github.com/fsenf/CTyPyTool`
  - Open-Docs: `https://ctypytool.readthedocs.io`

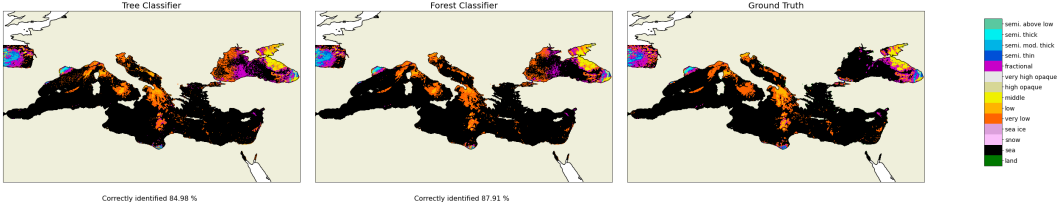
Can Machine Learning Make Life Easier?

CTyPyTool Methodology



Can Machine Learning Make Life Easier?

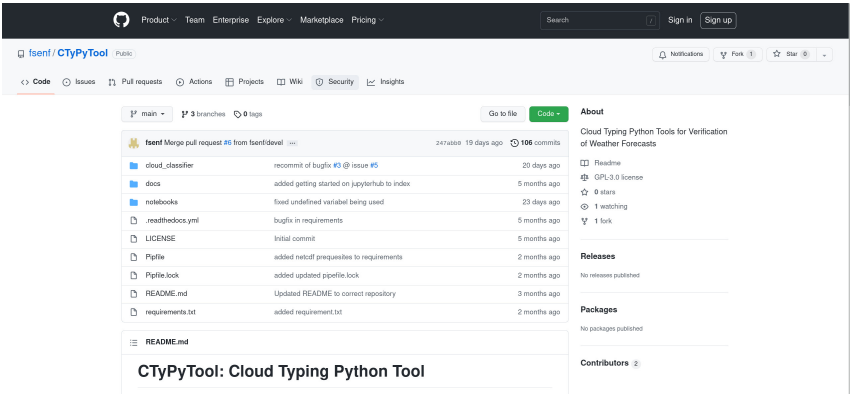
CTyPyTool Prelim. Results



- typical accuracy: around 80%
- only all-sky BTs included so far, clear-sky estimates are expected to improved accuracy

Can Machine Learning Make Life Easier?

CTyPyTool on GitHub

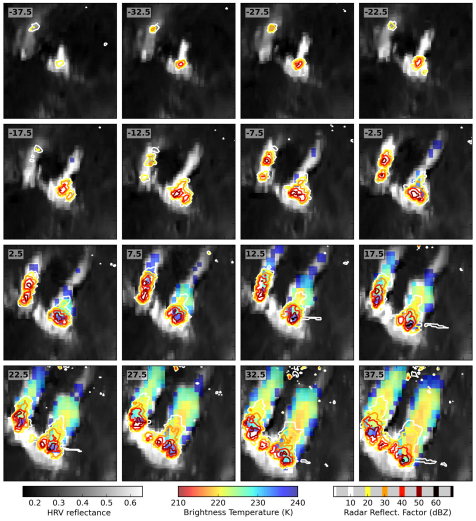


Outline

How to Follow Clouds?

The Lagrangian Perspective

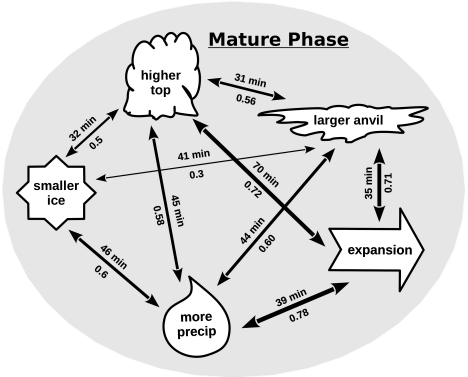
Clouds evolve and ...



How to Follow Clouds?

The Lagrangian Perspective

... some of their changes indicate potential future development.



Senf and Deneke (2017a)

Tobac: Research Question

How can we follow developing clouds and analyze their changing characteristics with a tool

- works automatically,
- is flexible, modular & not depended on a particular type of data?

How to Follow Clouds?

Tobac Methodology

- **Idea:**
  - develop an Open-Source Python Package

How to Follow Clouds?

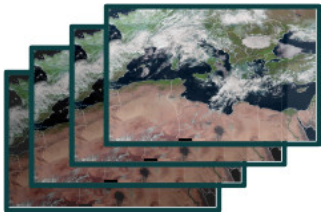
Tobac Methodology

- **Idea:**
  - develop an Open-Source Python Package
  - build upon established packages, e.g. `xarray` from the `https://pangeo.io` family

How to Follow Clouds?

Tobac Methodology

- **Workflow**
  1. Input
  2. Feature Detection
  3. Linking / Tracking
  4. Segmentation & Object-Based Analysis
  5. Plotting & Output



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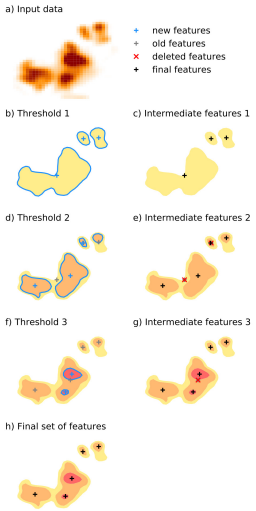

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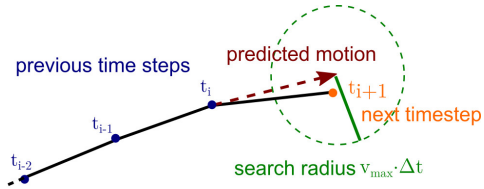
soft-matter/**trackpy**

Python particle tracking toolkit

25 Contributors | 113 Used by | 321 Stars | 108 Forks



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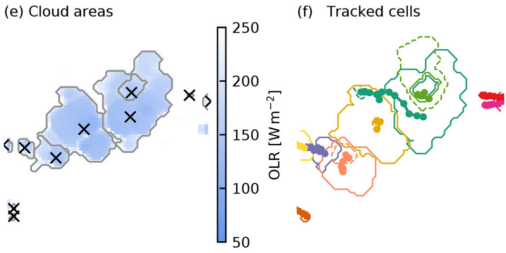

Heikenfeld et al. (2019)

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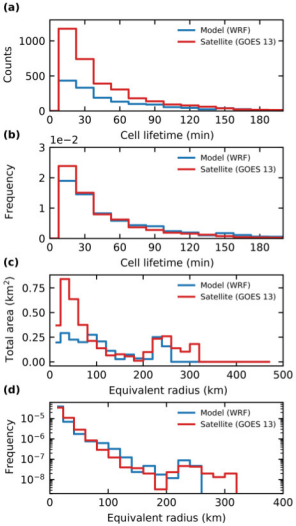


Heikenfeld et al. (2019)

How to Follow Clouds?

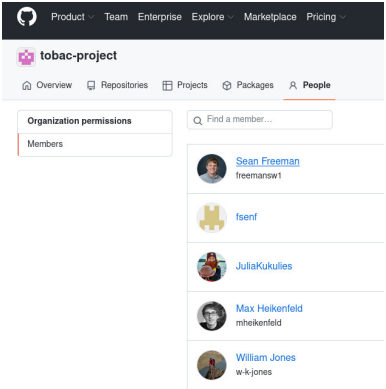
Tobac on GitHub & ReadTheDocs

- **Status:**
  - Open-Source: `https://github.com/tobac-project/tobac`
  - Open-Docs: `https://tobac.readthedocs.io`
  - User Tutorials: `https://github.com/tobac-project/tobac-tutorials`

How to Follow Clouds?

Tobac on GitHub & ReadTheDocs

- **Development:**
  - Latest Release in April 2022; Version 1.3
  - Active & International Community
  - Core developers from Uni Oxford, Colorado State Uni & TROPOS
  - many contributions from researchers at Argonne NL, Texas Tech & others



Tobac Core Team

How to Follow Clouds?

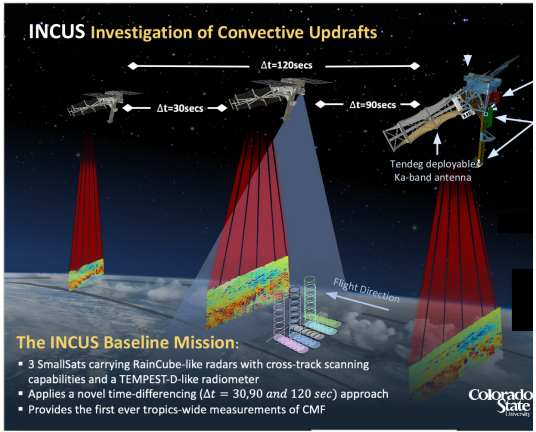
Tobac Research Applications

- **TRACER campaign:**
  - TRacking Aerosol Convection interactions ExpeRiment field campaign in Houston area
  - for studying climate-relevant processes and interaction in isolated deep convective systems
  - see `https://www.arm.gov/research/campaigns/amf2021tracer`

How to Follow Clouds?

Tobac Research Applications

- **Upcoming NASA missions:**
  - tracking utility for Atmosphere Observing System (AOS) mission as NASA's recent implementation of the NASEM decadal survey & for INCUS as a NASA Earth Venture Mission
  - `https://aos.gsfc.nasa.gov/` & `https://www.nasa.gov/press-release/nasa-selects-new-mission-to-study-storms-impacts-on-climate-models`



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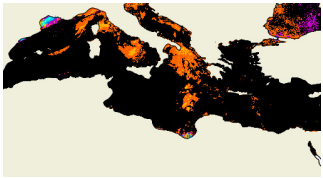

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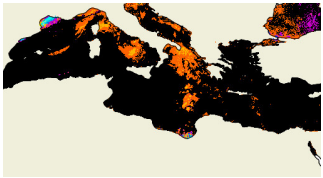

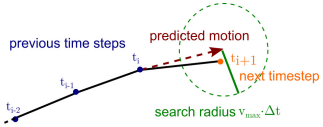

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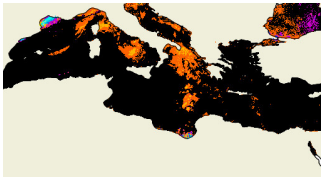

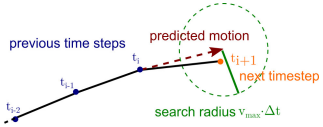

Thank you for your attention!

References I

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Senf, F., and H. Deneke, 2017a: Satellite-based characterization of convective growth and glaciation properties in relation to precipitation formation over central europe. *J. Appl. Meteor. Climatol.*, **56**, 1827–1845.

References II

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