

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

**Fabian Senf**, and the Tobac Developers Team

Leibniz Institute for Tropospheric Research - TROPOS

19. May 2022



# Outline

Introduction

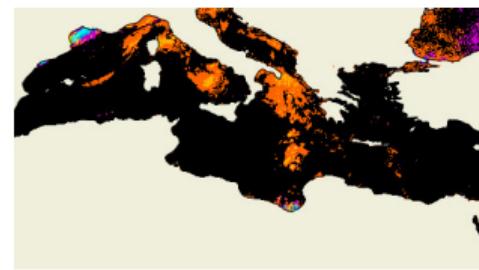
CTyPyTool

Tobac

Summary

# What Comes Next?

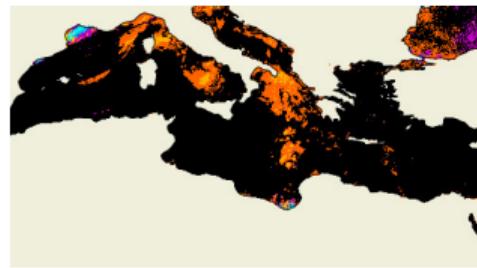
- **CTyPyTool**
  - ▶ ML-based emulator for cloud typing
  - ▶ fair comparison of cloud occurrences between observations and simulation



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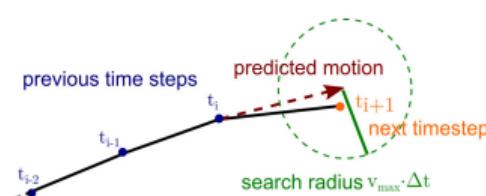
- **CTyPyTool**

- ▶ ML-based emulator for cloud typing
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- **Tobac**

- ▶ cloud tracking based on object detection & linking
- ▶ flexible, modular & extendable



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CTyPyTool

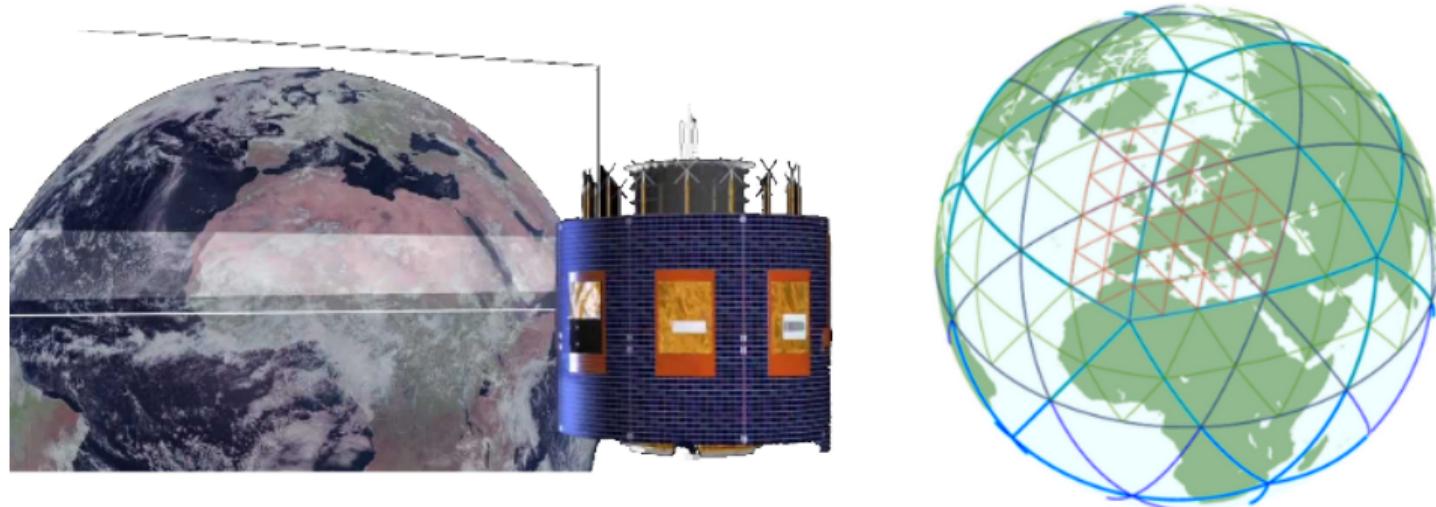
Tobac

Summary

## 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) ?

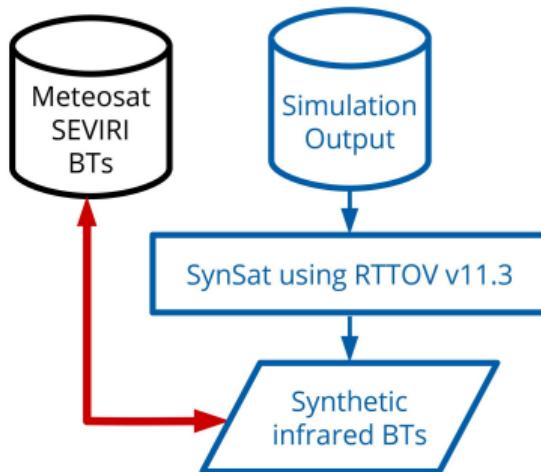
# Simulation and Observation Data



- pairing Meteosat observations with simulated clouds.

# How to Compare?

## The Challenge



- **Synthetic Observations**

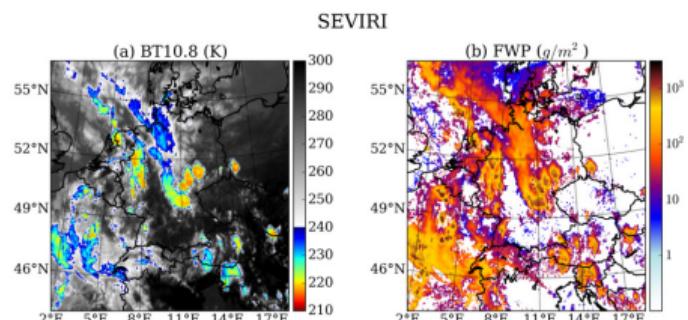
- ▶ synthetic IR radiances from forward operator (SynSat, RTTOV)
- ▶ **pro:** fair & direct comparison of BTs
- ▶ **con:** sometimes ambiguous & hard to interpret

# How to Compare?

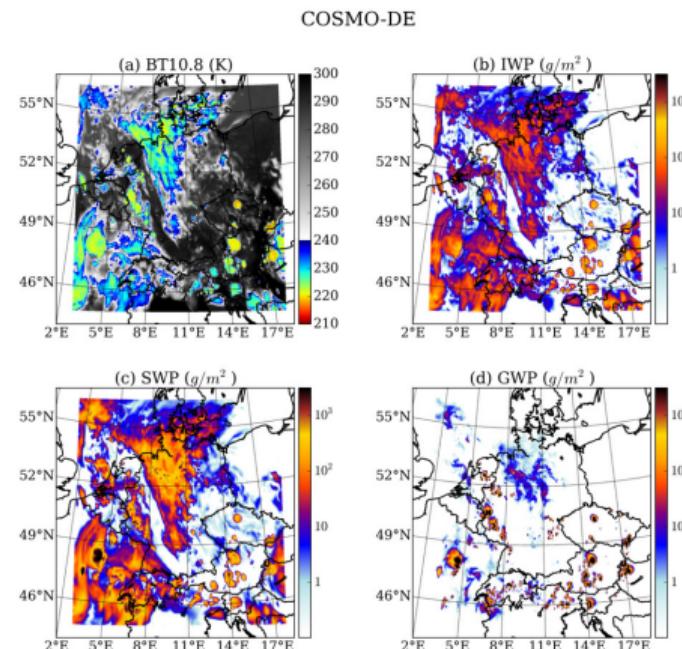
## A Few Examples

- **Comparing BT Images**

- spatial distribution of “cold” clouds can be compared



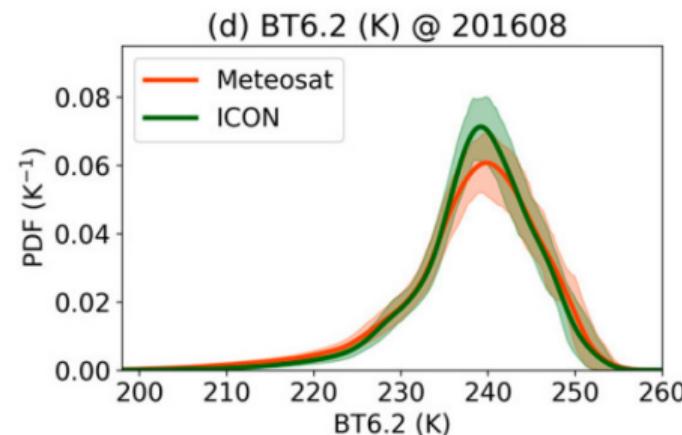
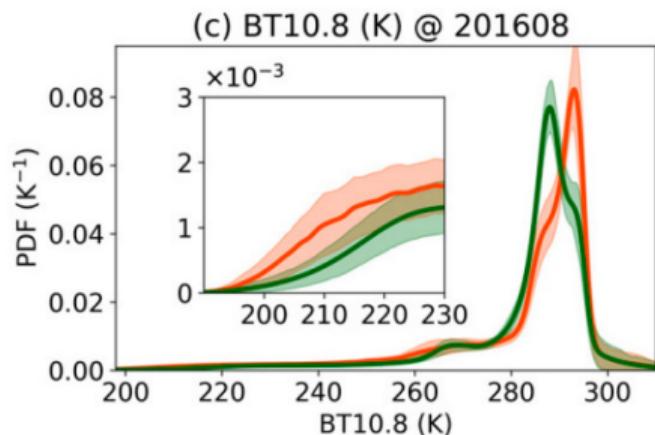
Senf and Deneke (2017b)



# How to Compare?

## A Few Examples

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

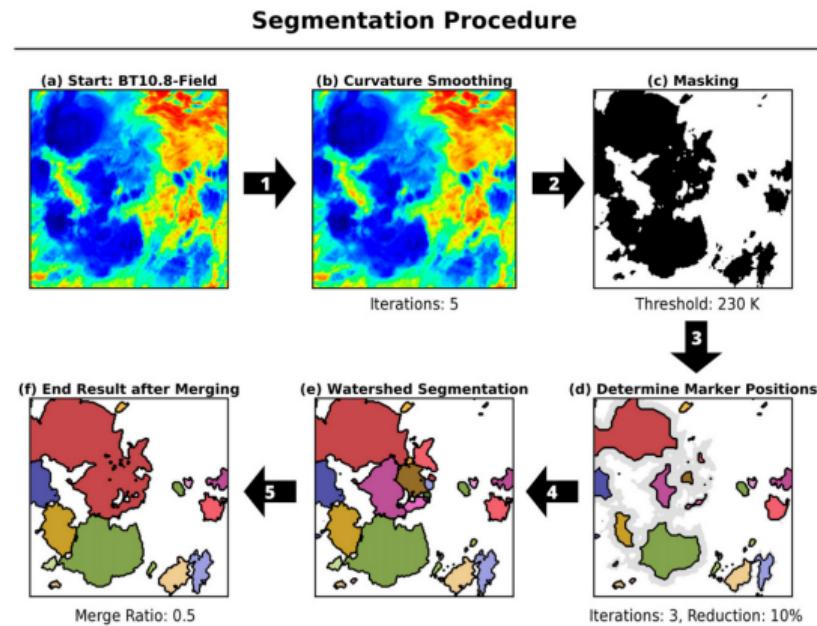


Senf et al. (2018)

# How to Compare?

## A Few Examples

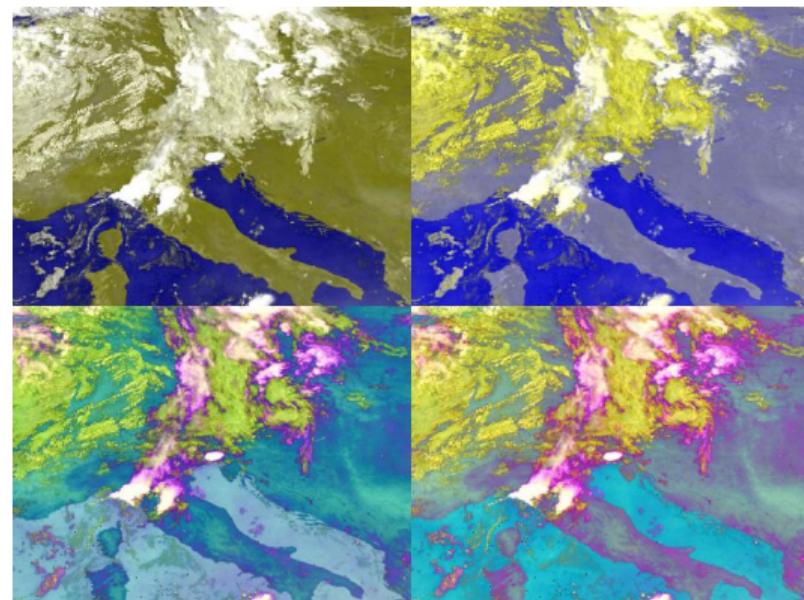
- or **Comparing Object Characteristics**
  - ▶ cell sizes distributions
  - ▶ growth rates
  - ▶ pair distances, ...



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

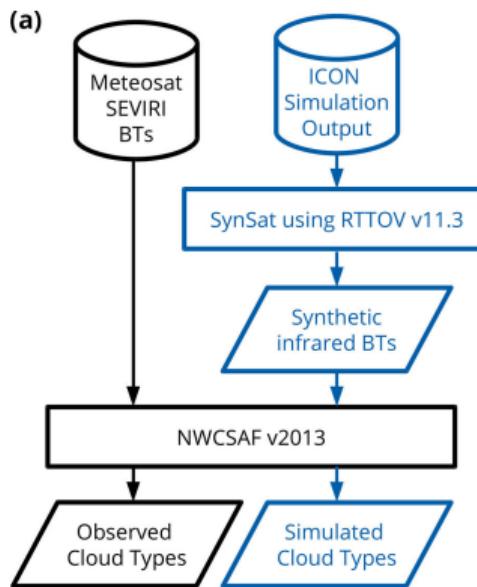
# How to Compare?

**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



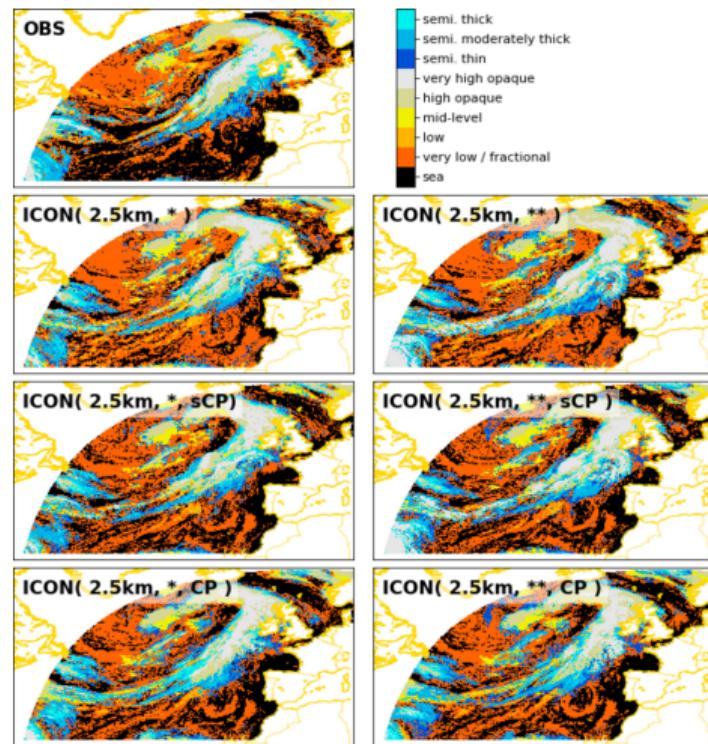
- **Cloud Classification**

- ▶ 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?

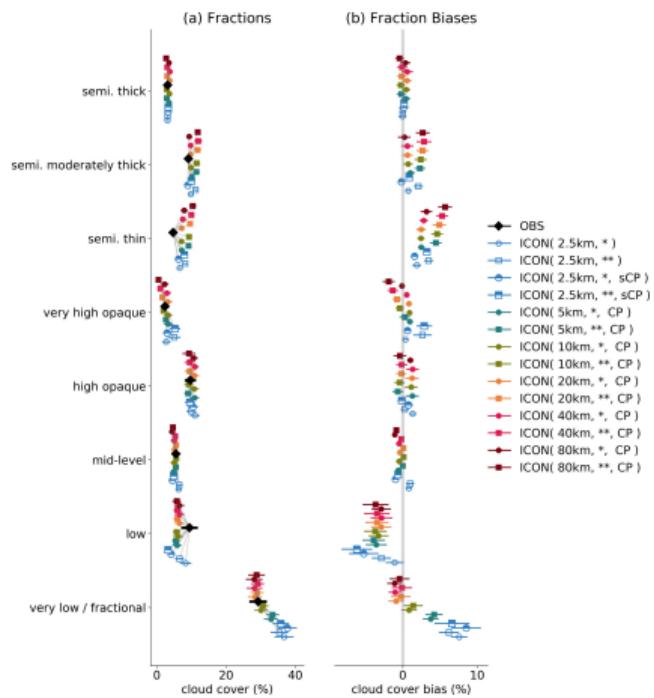
## Interfacing to NWCSAF

- cloud type images are relatively easy to interpret



# Does Cloud Type Information Help?

Interfacing to NWCSAF



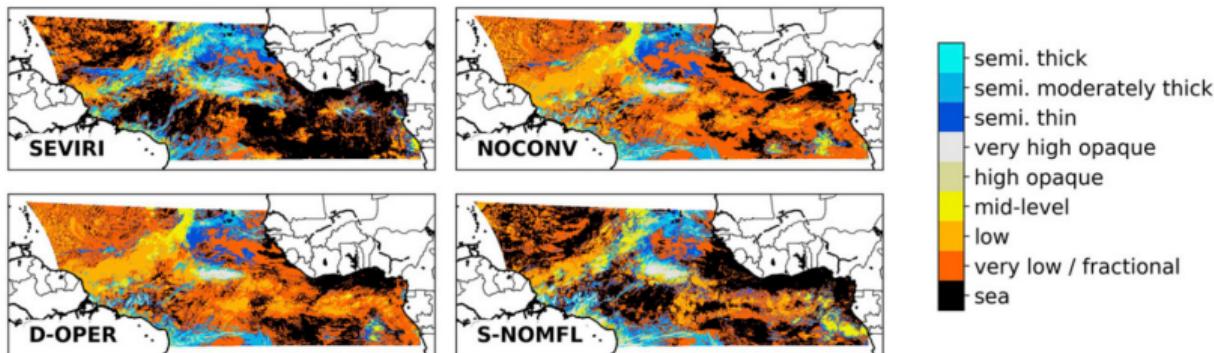
- **Cloud Fraction Biases:**

- ▶ 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  
→ a bit cheating is needed...
- ▶ NWCSAF cloud typing is decision-based  
→ 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

### The Machine-Learning based Cloud Typing Emulator **CTyPyTools**

**1 Why Machine Learning?**

- efficient emulation of classifiers
- easy to apply (once trained)

**2 Scientific Problem**

- How well can we simulate different cloud types and their amounts?
- How can a fair comparison to observations look like?

**3 Data Source**

- Meteosat images
- NWCSAF cloud types

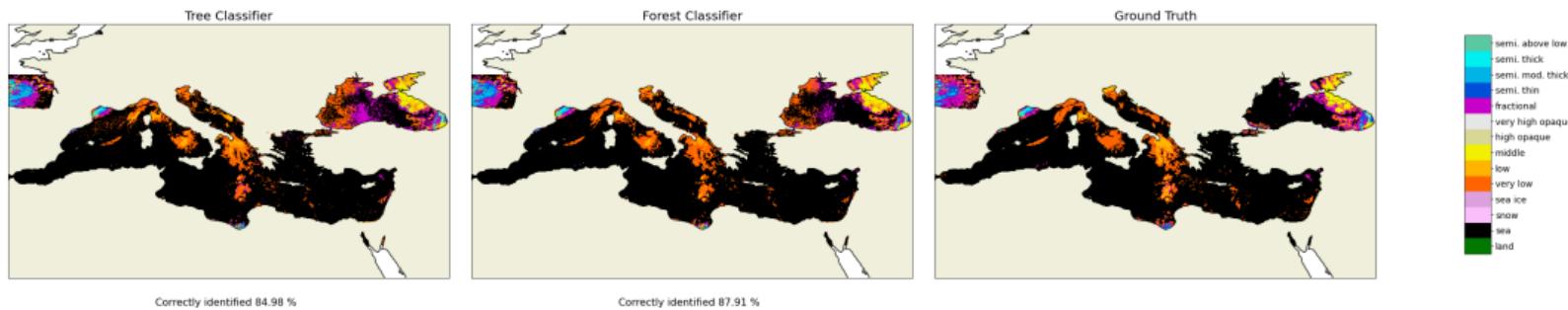
**4 Method**

- decision trees
- `sklearn.tree.DecisionTreeClassifier`

**TROPOS**

# 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 improve accuracy

# Can Machine Learning Make Life Easier?

CTyPyTool on GitHub

The screenshot shows the GitHub repository page for 'fsenf / CTyPyTool'. The repository is public and has 3 branches and 0 tags. The main branch has 106 commits. The commits list includes:

- fsenf Merge pull request #6 from fsenf/dev ... (247a0e6 19 days ago)
- recommit of bugfix #3 @ issue #5 (20 days ago)
- added getting started on jupyterhub to index (5 months ago)
- fixed undefined variabel being used (23 days ago)
- bugfix in requirements (5 months ago)
- Initial commit (5 months ago)
- added netcdf prerequisites to requirements (2 months ago)
- added updated pipfile.lock (2 months ago)
- Updated README to correct repository (3 months ago)
- added requirement.txt (2 months ago)

The repository has 0 stars, 1 watching, and 1 fork. It includes sections for About, Releases, Packages, and Contributors.

## CTyPyTool: Cloud Typing Python Tool

# Outline

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CTyPyTool

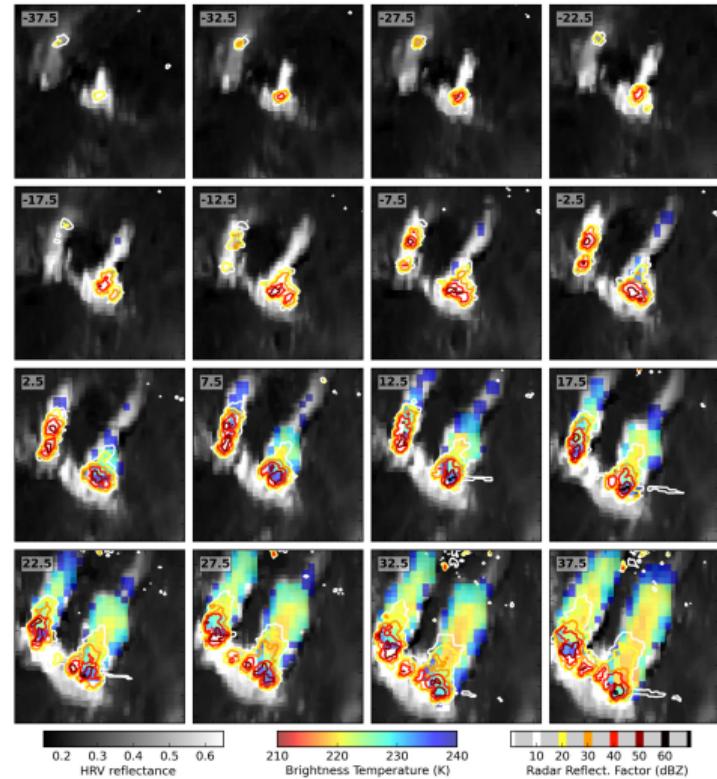
Tobac

Summary

# How to Follow Clouds?

The Lagrangian Perspective

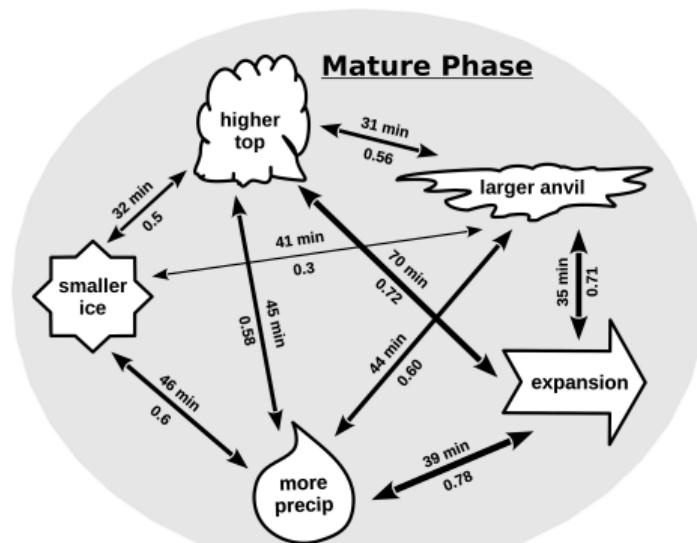
Clouds evolve and ...



# 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

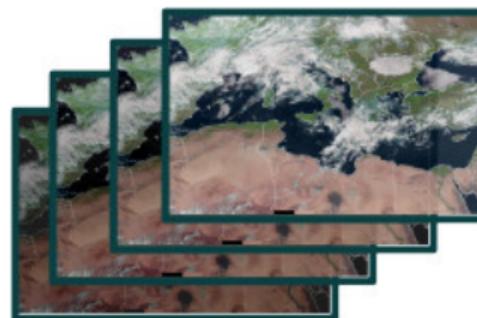


# How to Follow Clouds?

## Tobac Methodology

- **Workflow**

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

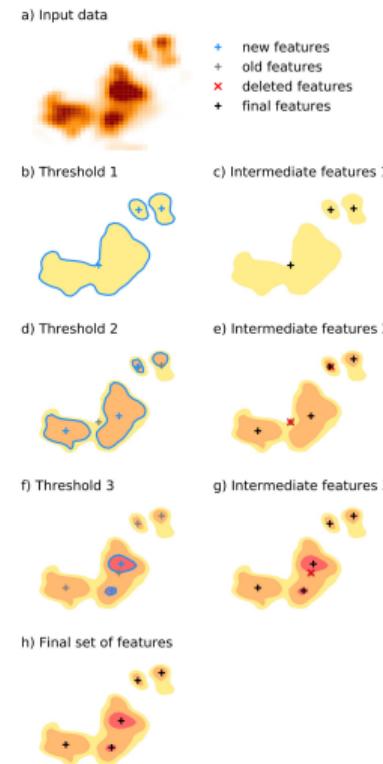


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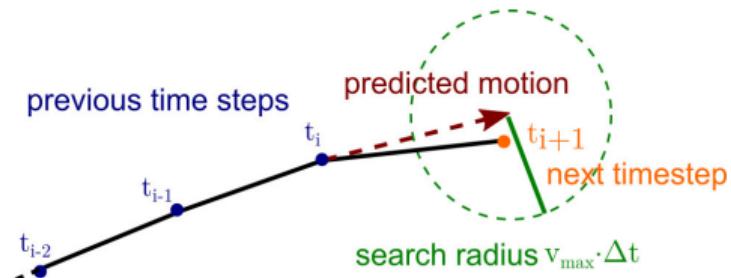
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soft-matter/**trackpy**

Python particle tracking toolkit



25 Contributors   113 Used by   321 Stars   108 Forks

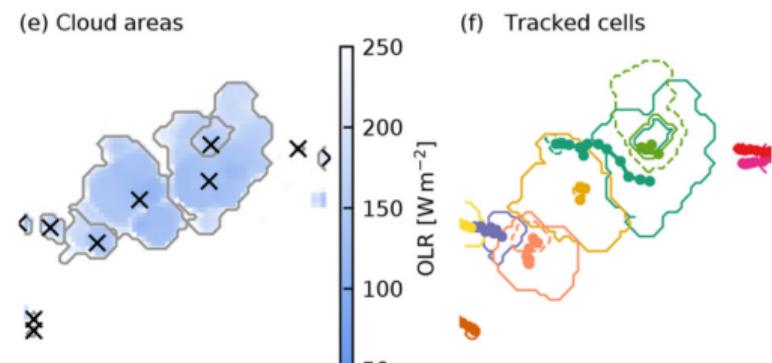


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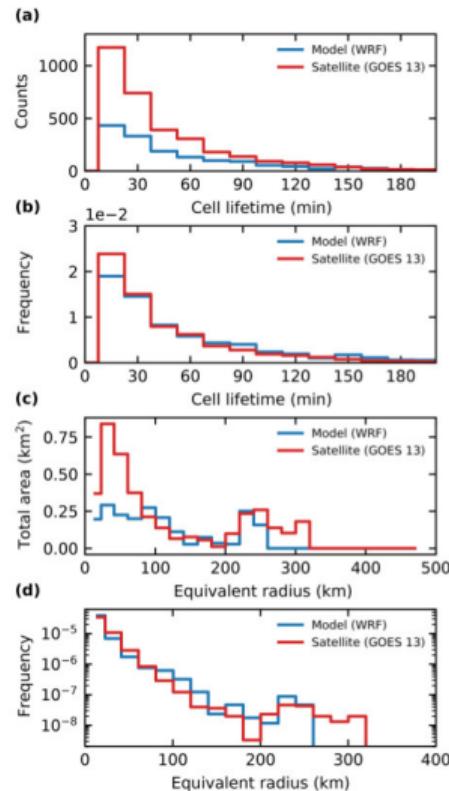


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Heikenfeld et al. (2019)

# 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

The screenshot shows the GitHub organization page for 'tobac-project'. At the top, there's a navigation bar with links for Product, Team, Enterprise, Explore, Marketplace, and Pricing. Below that is the organization's logo, a pink flower icon, and the name 'tobac-project'. There are tabs for Overview, Repositories, Projects, Packages, and People. The 'People' tab is selected, showing a table with five members. Each member has a profile picture, a GitHub handle, and a link to their profile. The members listed are Sean Freeman (freemansw1), fsenf, JuliaKukulies, Max Heikenfeld (mheikenfeld), and William Jones (w-k-jones).

| Member | Github Handle  | Profile Link                  |
|--------|----------------|-------------------------------|
|        | Sean Freeman   | <a href="#">freemansw1</a>    |
|        | fsenf          | <a href="#">fsenf</a>         |
|        | JuliaKukulies  | <a href="#">JuliaKukulies</a> |
|        | Max Heikenfeld | <a href="#">mheikenfeld</a>   |
|        | William Jones  | <a href="#">w-k-jones</a>     |

- **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

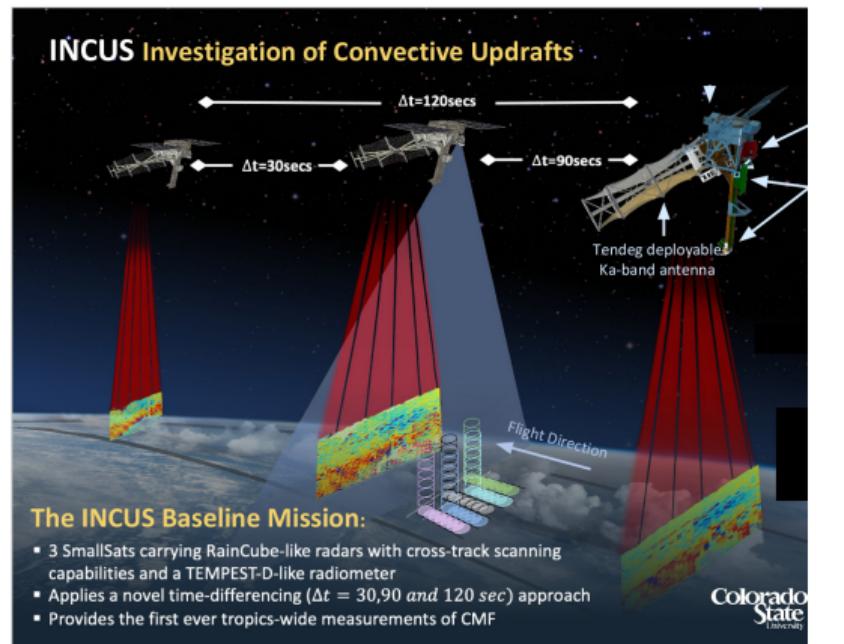
- **TRACER campaign:**

- ▶ 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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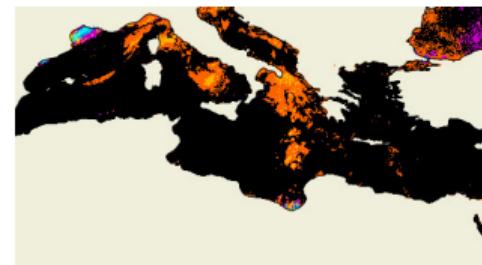
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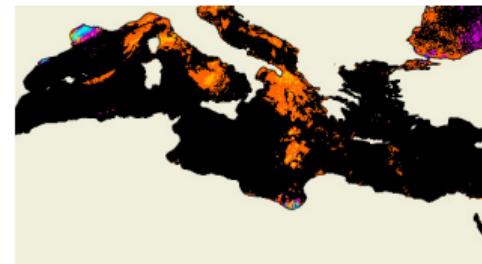
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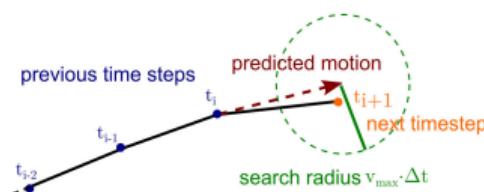
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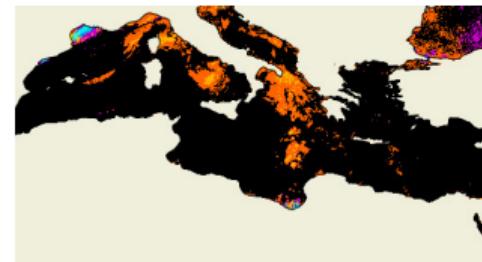
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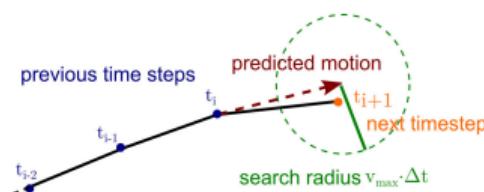
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**Thank you for your attention!**

# References I

Heikenfeld, M., P. J. Marinescu, M. Christensen, D. Watson-Parris, F. Senf, S. C. van den Heever, and P. Stier, 2019: tobac 1.2: towards a flexible framework for tracking and analysis of clouds in diverse datasets. *Geosci. Model Dev.*, **12 (11)**, 4551–4570, doi:10.5194/gmd-12-4551-2019, URL <https://www.geosci-model-dev.net/12/4551/2019/>.

Rempel, M., F. Senf, and H. Deneke, 2017: Object-based metrics for forecast verification of convective development with geostationary satellite data. *Mon. Wea. Rev.*, **145 (8)**, 3161–3178.

Sakradzija, M., F. Senf, L. Scheck, M. Ahlgrimm, and D. Klocke, 2020: Local impact of stochastic shallow convection on clouds and precipitation in the tropical atlantic. *Mon. Weather Rev.*, **148 (12)**, 5041 – 5062.

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

Senf, F., and H. Deneke, 2017b: Uncertainties in synthetic meteosat seviri infrared brightness temperatures in the presence of cirrus clouds and implications for evaluation of cloud microphysics. *Atmos. Res.*, **183**, 113–129.

Senf, F., D. Klocke, and M. Brueck, 2018: Size-resolved evaluation of simulated deep tropical convection. *Mon. Wea. Rev.*, **146** (7), 2161–2182.