

Objective characterization of mesoscale cloud patterns from graph theory and an Ising-like model (BICIM)

Supplementary Material

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Observed cloud field organizations

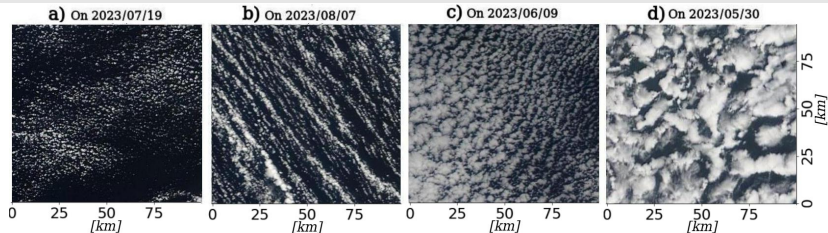


Figure: Example of satellite observations

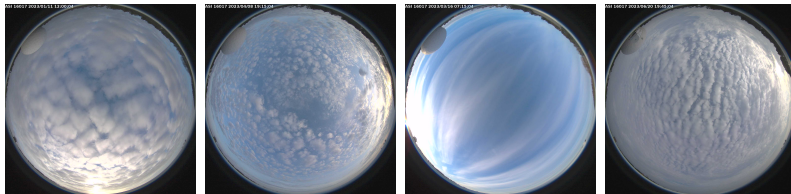


Figure: Example of ground-based observations (from a Sky Camera)

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Context: West Coast of Sweden

- Oceans play a major role in the climate system — **70%** of Earth's surface.
- Focus region: **North Sea, West of Sweden** (56° – 59° N, 3° – 12° E).
- Northern Europe = convergence zone for diverse air masses:
↪ mP, mT, cP, mA, cA
- Region strongly influenced by pressure oscillations (e.g., NAO).

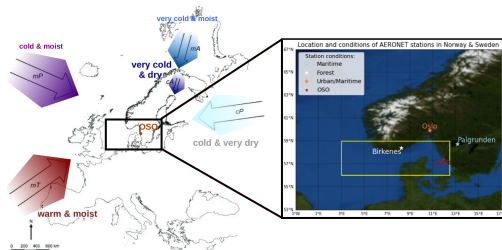


Figure: Left: Air mass types. Right: Study area

- Onsala Space Observatory (OSO):** ideal for atmospheric studies
↪ Located in "clean" air, land/sea interface

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① Modelisation (Bldimensional Cloud Ising Model)

- BICIM simulations & sensitivity tests using OSO measurements as input data
- Cloud Field Characterization via Graph Theory

② Observations

- To collect 250 satellite observations (or observations from Sky camera)
- Cloud Field Characterization via Graph Theory

③ MASCOL

- Automatic identification of similar cloud field organizations using the MASCOL metric.

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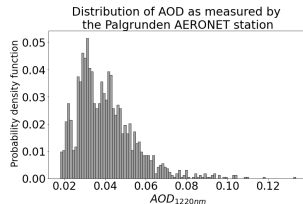
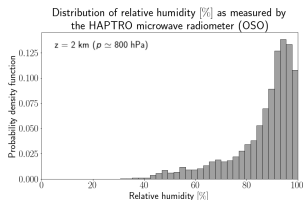
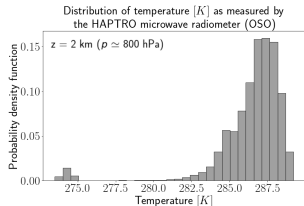
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Modelisation – Input Data for BICIM



Input data for BICIM simulations (I, II, III & IV → see Poster):



Input Data for sensitivity tests:

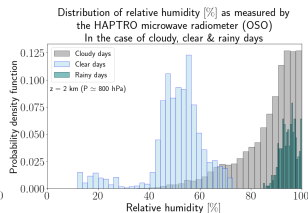
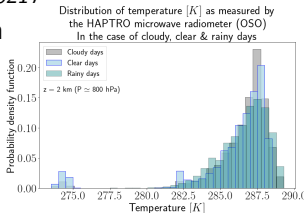
Day classification based on *Wei et al. (2021)*

→ **Clear:** $RH \leq 85\%$ from 0 to 10km

→ **Cloudy:** $RH \leq 85\%$ below 600m,
 $RH \geq 84\%$ above

→ **Rainy:** 20 min continuous rain
with $RH \geq 84\%$ from 0 to 10 km

Wei et al. (2021), Remote Sensing, doi: 10.3390/rs13132527



Modelisation – Sensitivity tests

- The model shows **consistent behavior** across all cases:
 - ↪ **100% cloudy grid**: more clouds for “cloudy” input; quick clearing for “clear”.
 - ↪ **Random grid**: “rainy” case → more clouds at first, then decrease (rain consumes clouds).
- Tests: each flux excluded one at a time:
 - ↪ **Conductive flux** $\Phi^{dif} = 0$: Slight delay in flocculation (+25k draws), but similar final state.
 - ↪ **Surface flux** $\Phi_s = 0$: small impact

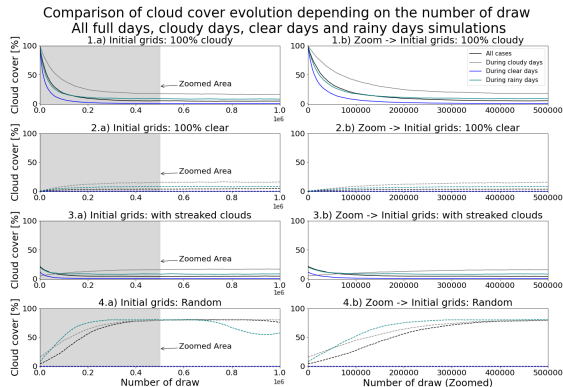


Figure: Cloud cover evolution depending on day type

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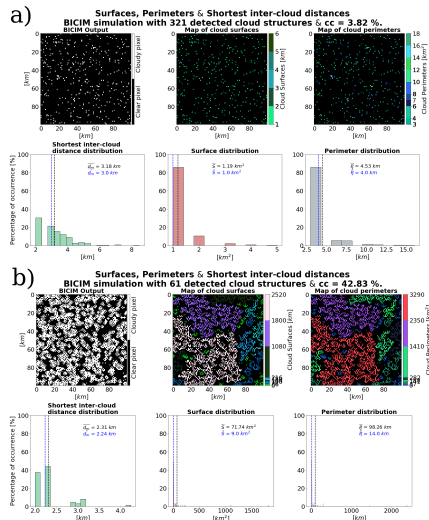
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Graph Theory

- **Graph theory** $\Rightarrow$ to objectively quantify cloud field organization.
 - $\hookrightarrow N_C$: Number of cloud structures
 - $\hookrightarrow CC$: Cloud cover (%)
 - $\hookrightarrow$ Distributions of cloud **surface areas** (S)
 - $\hookrightarrow$ Cloud **Perimeters** (P_r)
 - $\hookrightarrow$ **Shortest inter-cloud distances** (d_m)
- Example shown for 2 cloud fields: isolated clouds (a) vs. flocculated field (b):
 - $\hookrightarrow$ **Case a)**: CC , S , P_r lower; d_m , N_C higher
 - $\hookrightarrow$ **Case b)**: CC , S , P_r higher; d_m , N_C lower
- These metrics (CC , N_C , S , P_r , d_m) form the basis of our automatic identification method.



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Mascol metric

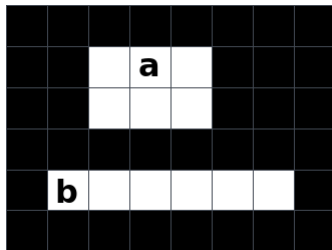


Figure: $S_a = S_b = 6 \text{ km}^2$, but $P_{r,a} < P_{r,b}$
 $\Rightarrow \frac{S}{P_r^2}$ higher for cloud a.

- Ratio S/P_r^2 informs about cloud compactness.
- Higher value $\Rightarrow$ more compact cloud.
- Lower value $\Rightarrow$ more spread-out shape.

Same cloud patterns, different scales $\rightarrow$ different CC and N_C

- Similar cloud shapes can have different spatial impact.
- Weighting CC and N_C emphasizes scale consistency.

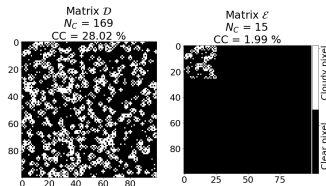


Figure: Cloud fields with similar structures but different scales.

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Metric for Assessing Similarity between Cloud Organization Layouts (MASCOL):

$$\mathcal{M} = \alpha KS_{S/P^2} + \beta KS_{dm} + \gamma D_{CC} + \delta D_{N_C} \quad (\alpha = \beta = 1, \gamma = \delta = 2)$$

- Cloud cover and number of clouds weighted more heavily (scale-sensitive)
- $\mathcal{M} = 0$: identical fields; $\mathcal{M} = 6$: totally different fields

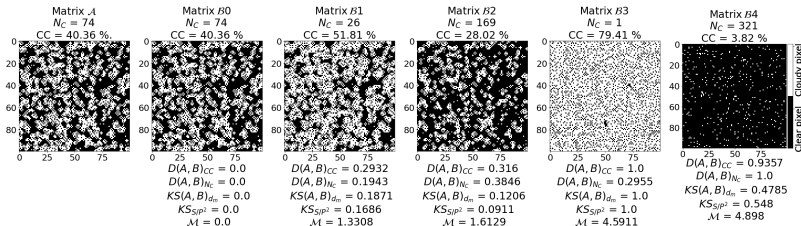


Figure: Example matrices with increasing $\mathcal{M}$ vs reference matrix A.

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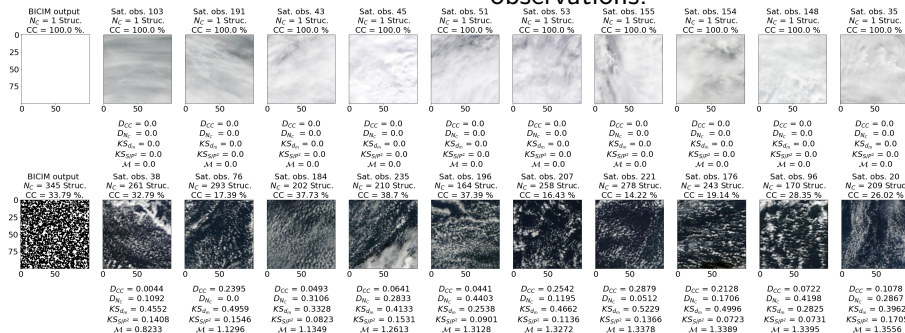
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First Results

- BICIM is used as a **reference**.
- We compare model outputs to satellite observations.
- **9 example outputs** from selected for comparison.
- Observations:
 - ↪ **250 satellite images** from NASA Worldview
 - ↪ Region: $56^{\circ}N$ – $59^{\circ}N$, $3^{\circ}E$ – $12^{\circ}E$
 - ↪ Timeframe: June 1–October 31, 2023
- Methodology applied to both model and observations.



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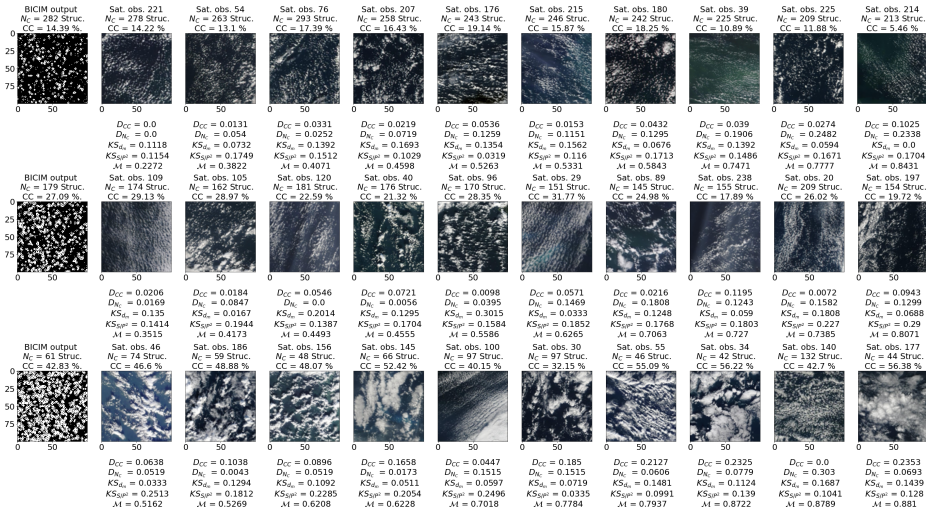
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- 9 categories of cloud fields from BICIM are defined (as an ex.).
- Satellite observations with $\mathcal{M} \leq 1.5$ are matched to the most similar category (minimal $\mathcal{M}$).
- If no match ($\mathcal{M} > 1.5$ for all), the observation is labeled as *Unclassified*.

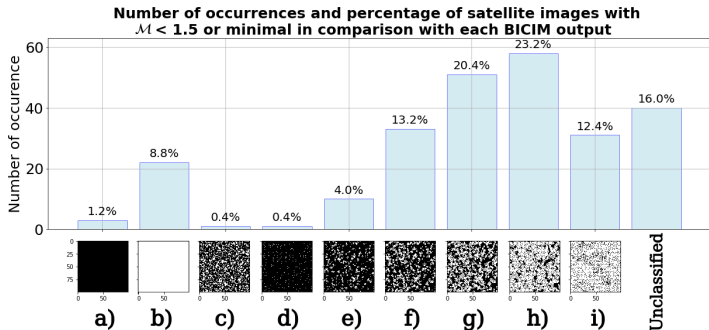


Figure: Number of satellite observations best matched (minimal $\mathcal{M}$) to each output. Last bar: unmatched observations.

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① Modelisation (Bldimensional Cloud Ising Model)

→ capable of generating cloud fields and reproducing their specific organizations
⇒ CC , N_C , S , P_r and d_m using Graph Theory

② Observations

⇒ CC , N_C , S , P_r and d_m using Graph Theory

③ MASCOL ($\mathcal{M}$)

→ Automatic identification of similar cloud field organizations

⇒ MASCOL allows for the *fast* (≤ 10 min) and *objective* identification of cloud organizations.

⇒ It is easily *adaptable* → possible to extend the region and study period.

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