

Geometrical Cloud Characterization via Data Fusion

IEA PVPS Task 16, 17th Task Meeting

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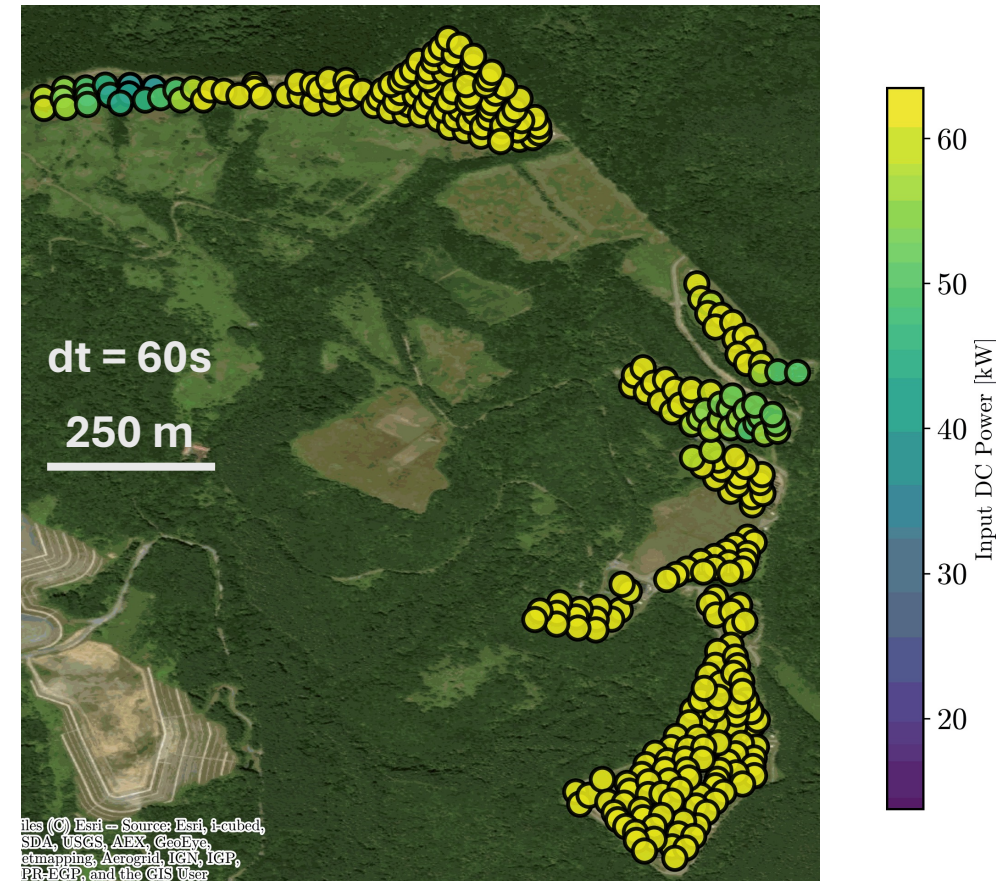
October 16, 2025 – Neuchâtel



Solar energy: a variable resource

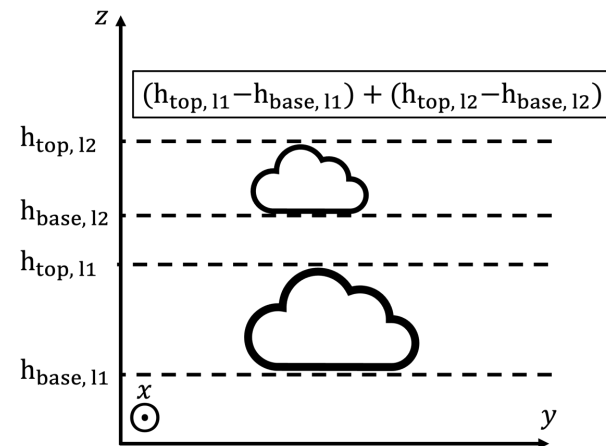
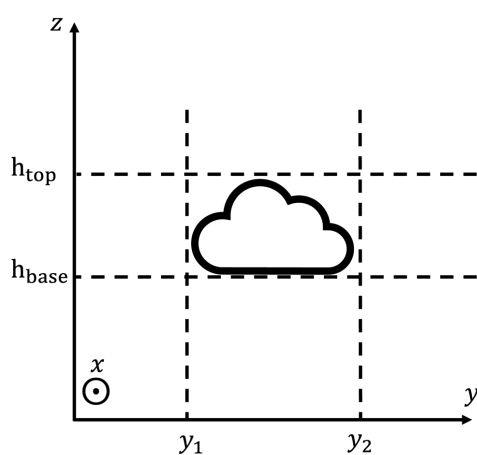
- **Clouds** can significantly reduce the amount of solar radiation reaching the ground.
- This **variability** affects the production of photovoltaic (PV) systems.
- It is both **spatial** and **temporal**.

PV production at the inverter level
(TotalEnergies 25 MW plant, Japan, May 2024)



Research Problem

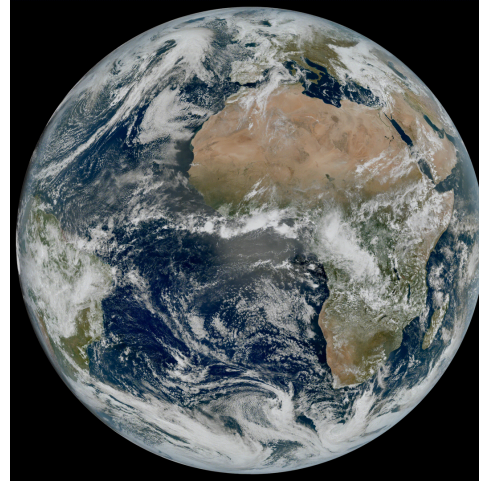
- **Scientific challenge:** The lack of fine-scale information on the state of the atmosphere limits high-resolution short-term forecasting of solar radiation.
- **Research objective:** Develop a real-time, local, 3D approach for cloud characterization with high spatial and temporal resolution.



Top-down view of a cloud field: illustration of the spatial variability of solar radiation (shaded and sunlit areas).

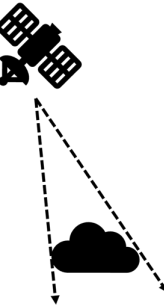


Complementary Observation Means

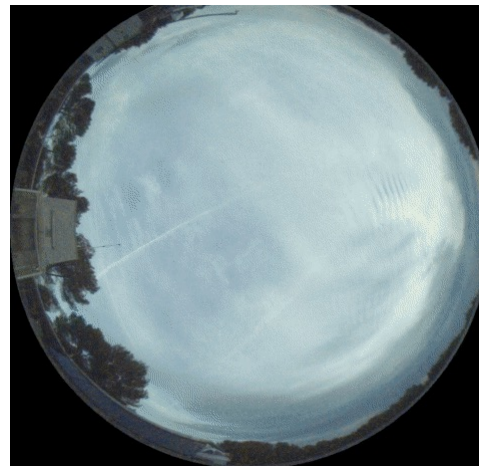


European Third-Generation Geostationary Satellite (MTG/Meteosat-12)

- Commissioned in January 2025, it provides multi-spectral observations of cloud cover and atmospheric dynamics.
 - Spatial resolution $\sim 10^3$ m
- (Source: EUMETSAT)

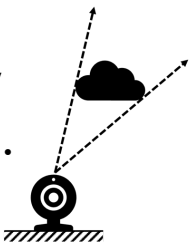


2025-10-16



All-sky Imagers (ASI)

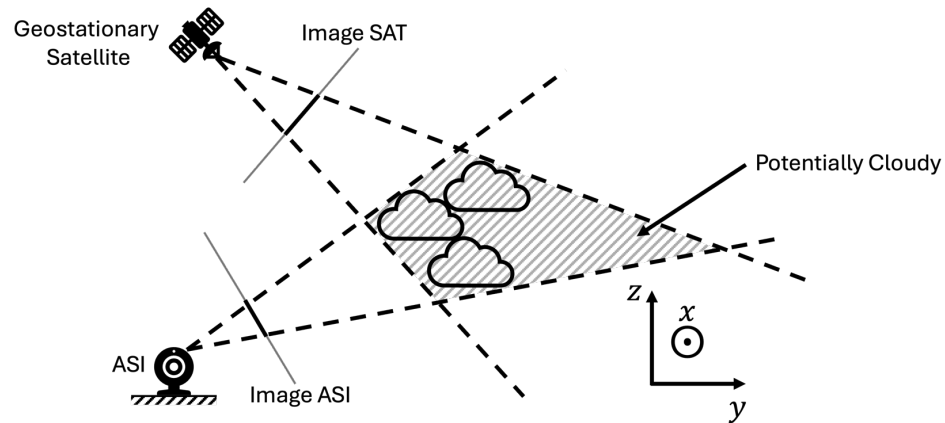
- View of the sky from the ground, used to locally observe cloud dynamics at very high resolution.
 - Spatial resolution ~ 10 - 10^2 m
 - Low cost (CAPEX $< \text{€}10\text{k}$, OPEX $\sim \text{€}0$)
- (Source: Chaire SciDoSol – Mines Paris)



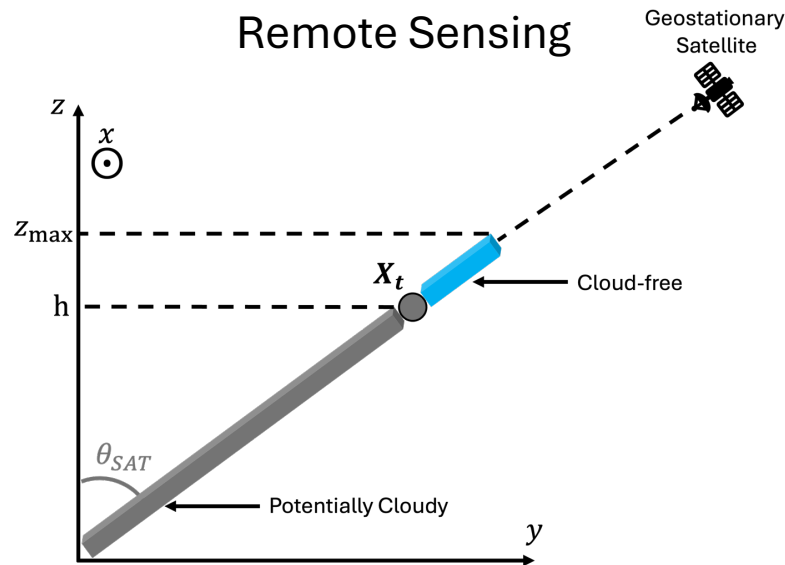
Proposed Approach

We propose a 3D cloud field reconstruction approach that integrates **three different techniques** using **readily available geostationary satellite data** and **a single ASI**:

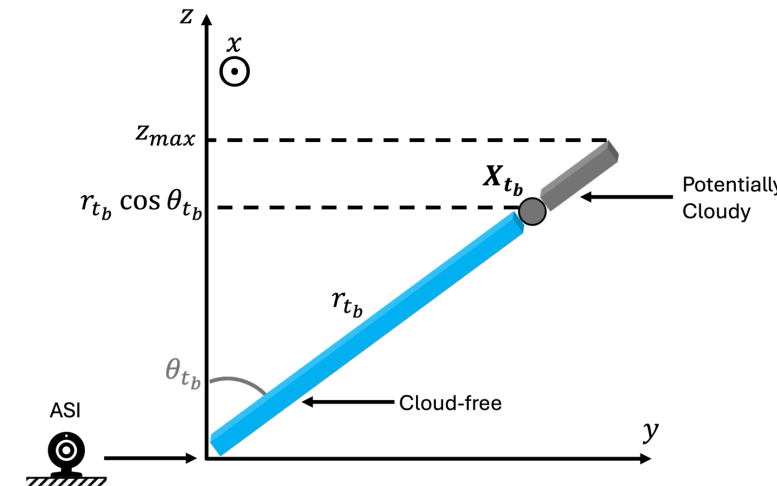
1) Shape-From-Silhouette



2) Passive Satellite Remote Sensing



3) Velocities combination

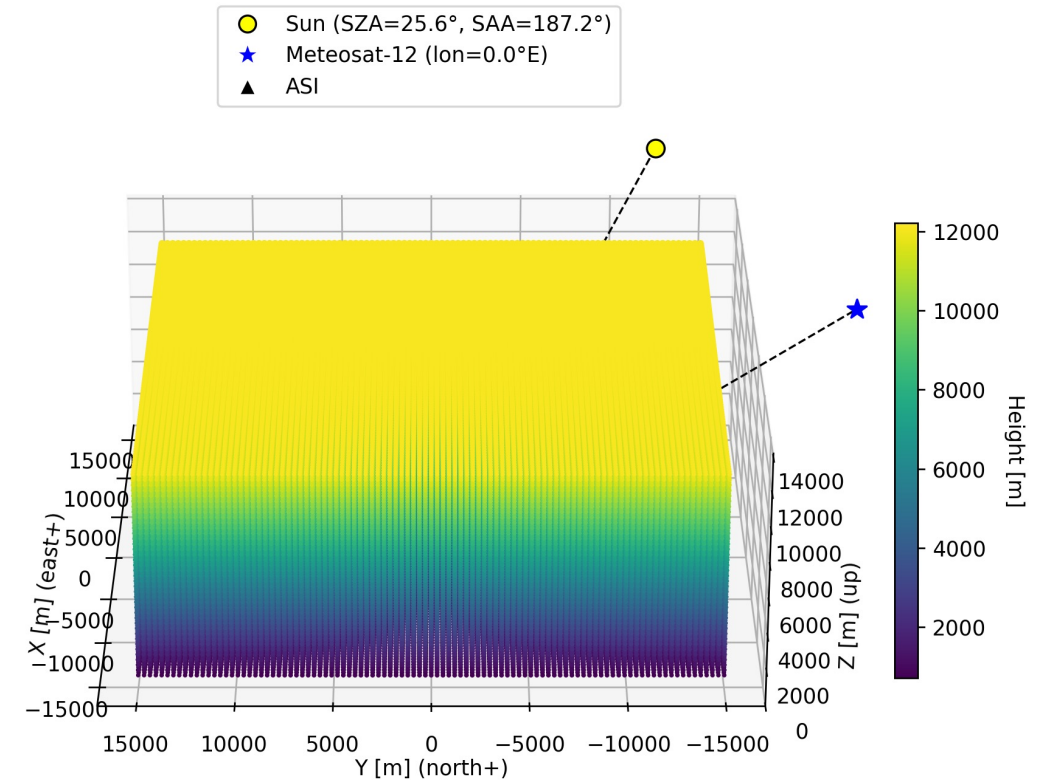


3D Cloud Characterization: Setup

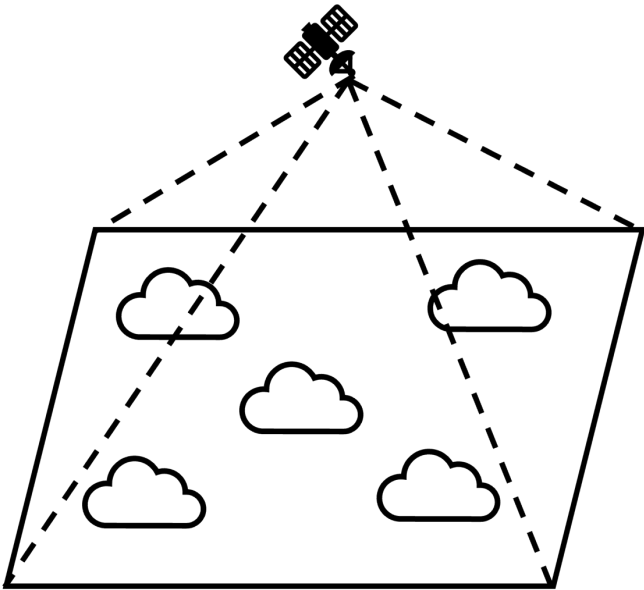
To characterize the relevant atmosphere, the following parameters are required:

- Grid geographic center
- Base radius
- Cloud height range
- Spatial resolution
- Grid time
- All-sky imager position
- Geostationary satellite position
- Earth shape parameters
- Solar position

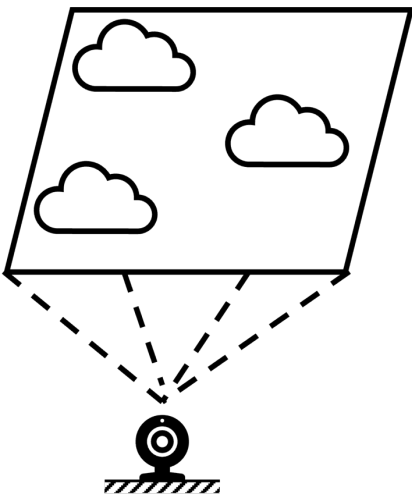
2025-06-28T12:08:00 UTC - (2.2077°E, 48.7120°N)



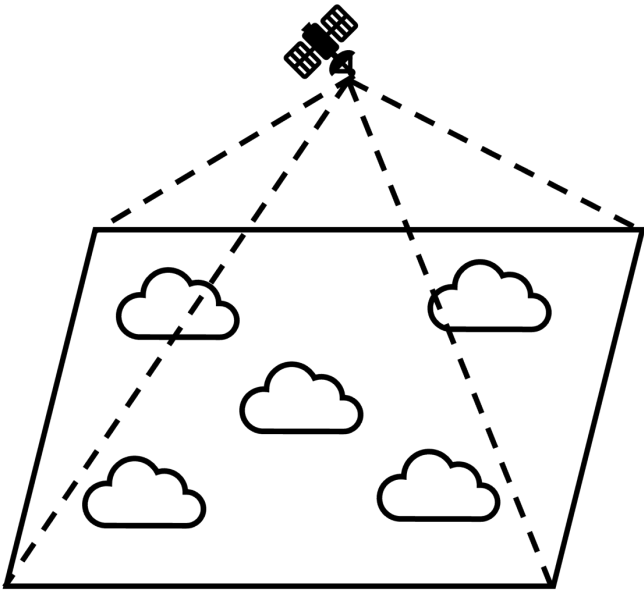
Example: base radius = 15 km; spatial resolution = 100 m;
cloud height range: 500–12,000 m,
resulting in **10,509,716 voxels** for characterization.



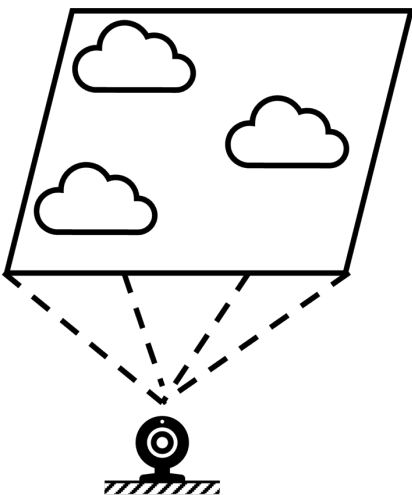
● $p(x, y, z)$



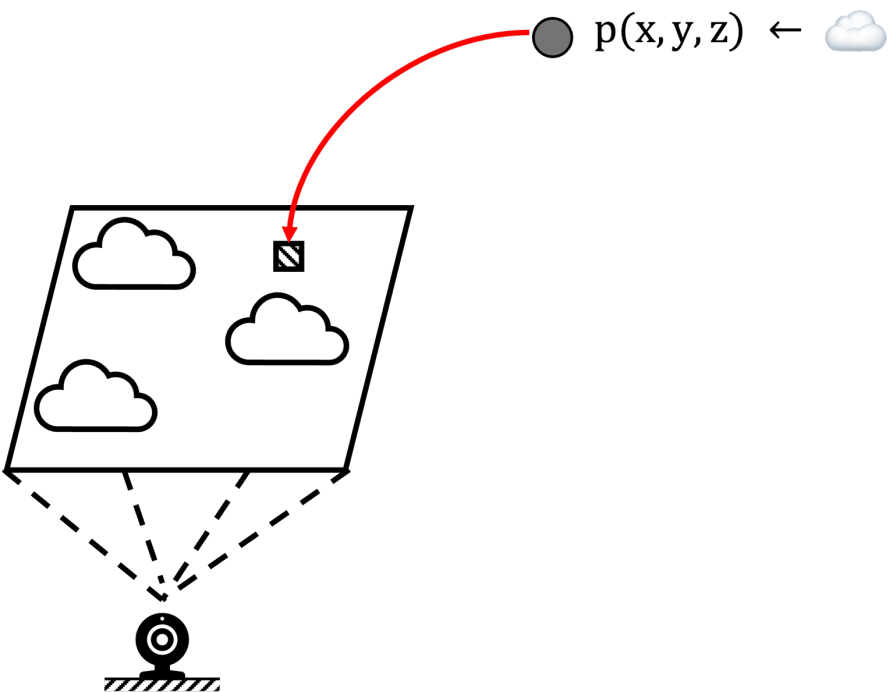
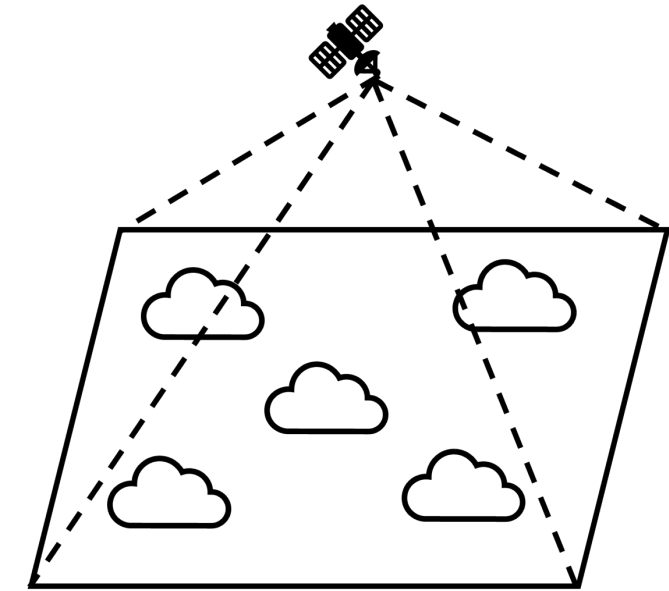
Initialization



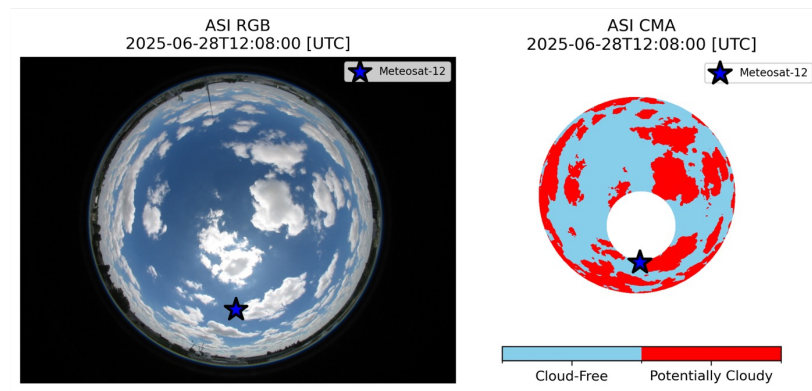
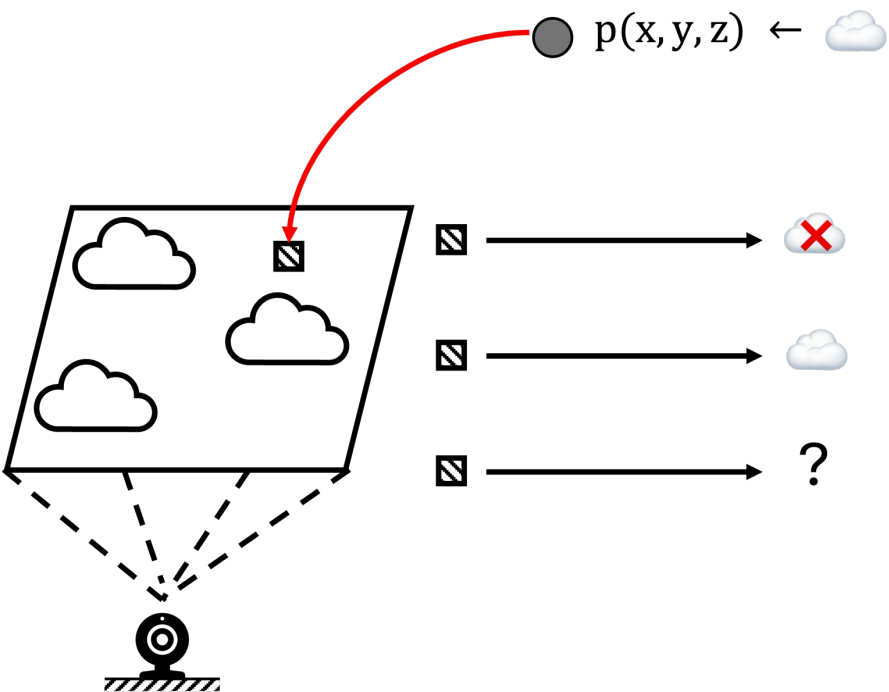
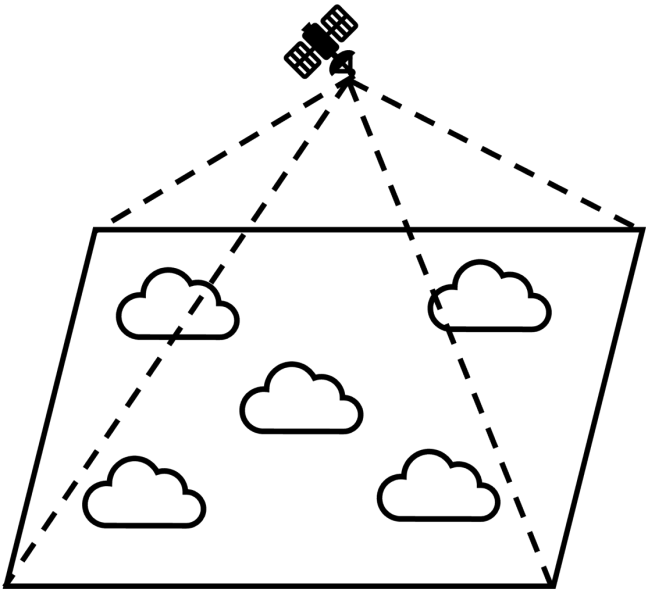
● $p(x, y, z) \leftarrow$ ☁



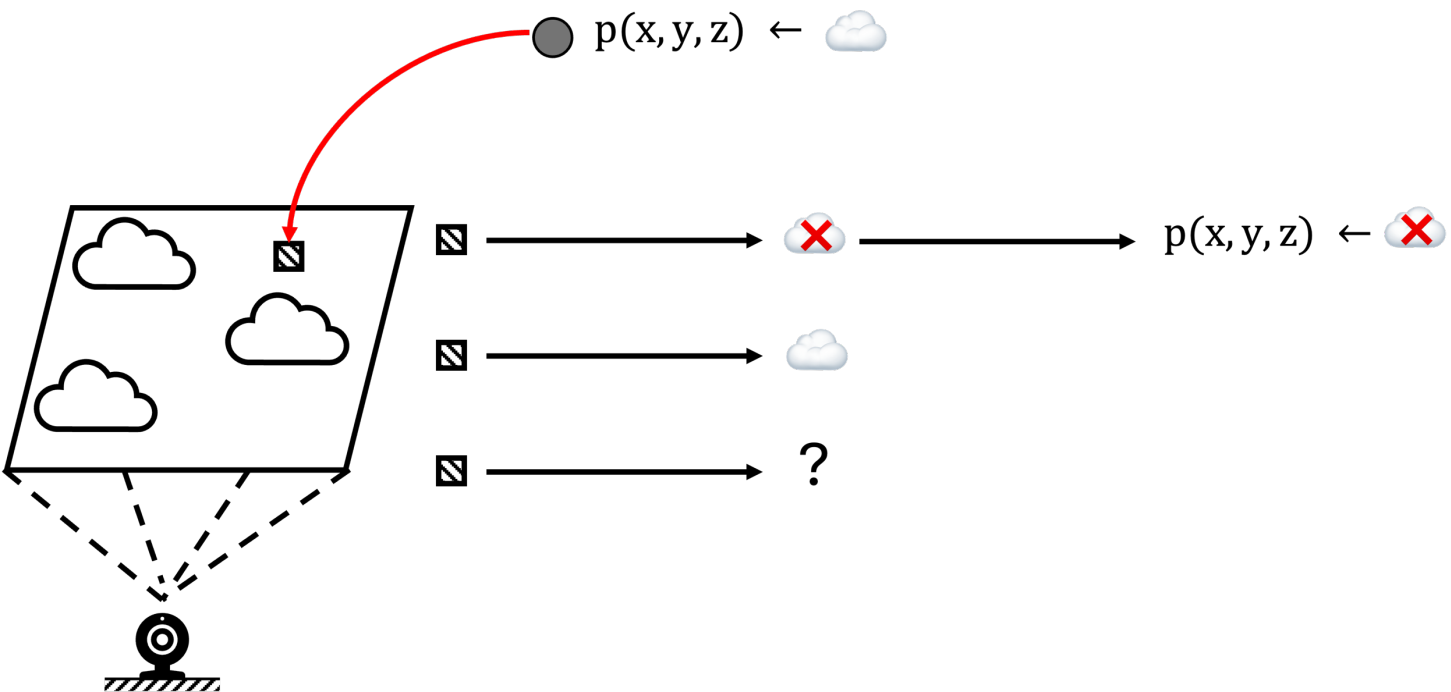
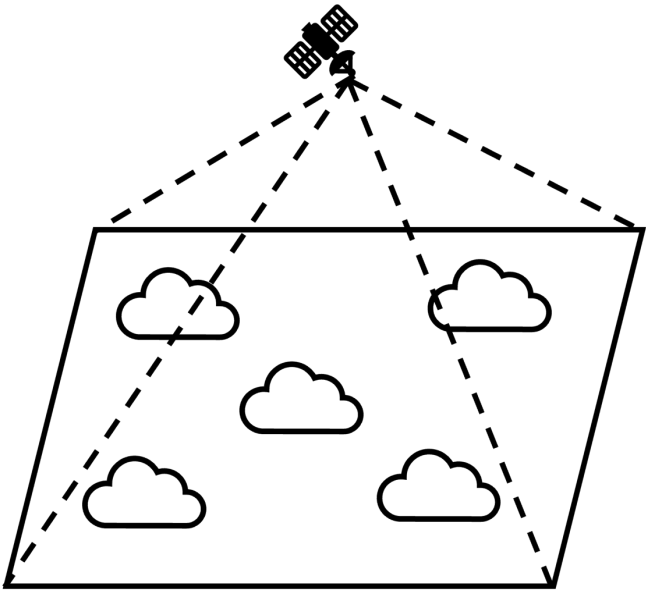
Initialization



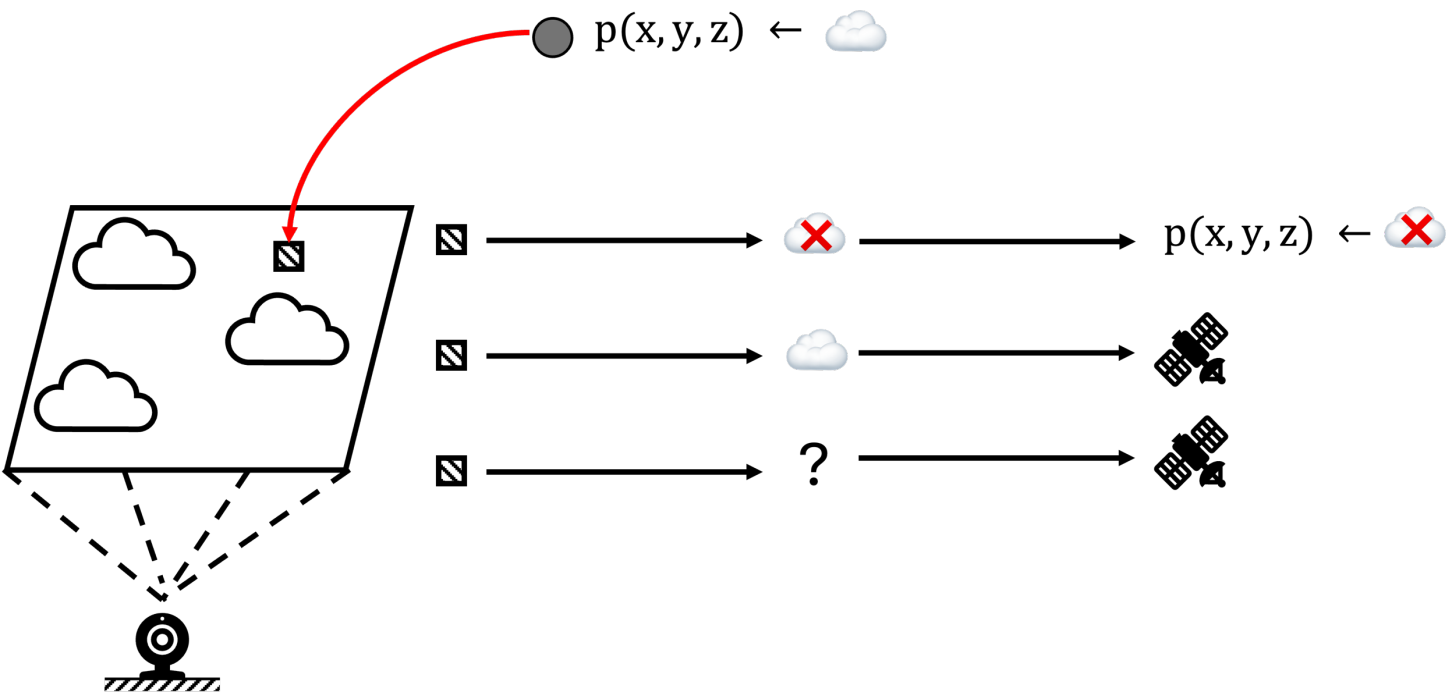
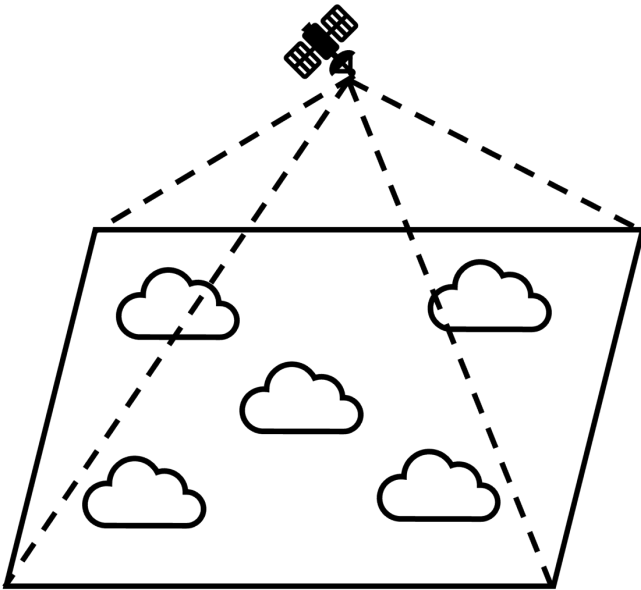
1) Shape-From-Silhouette



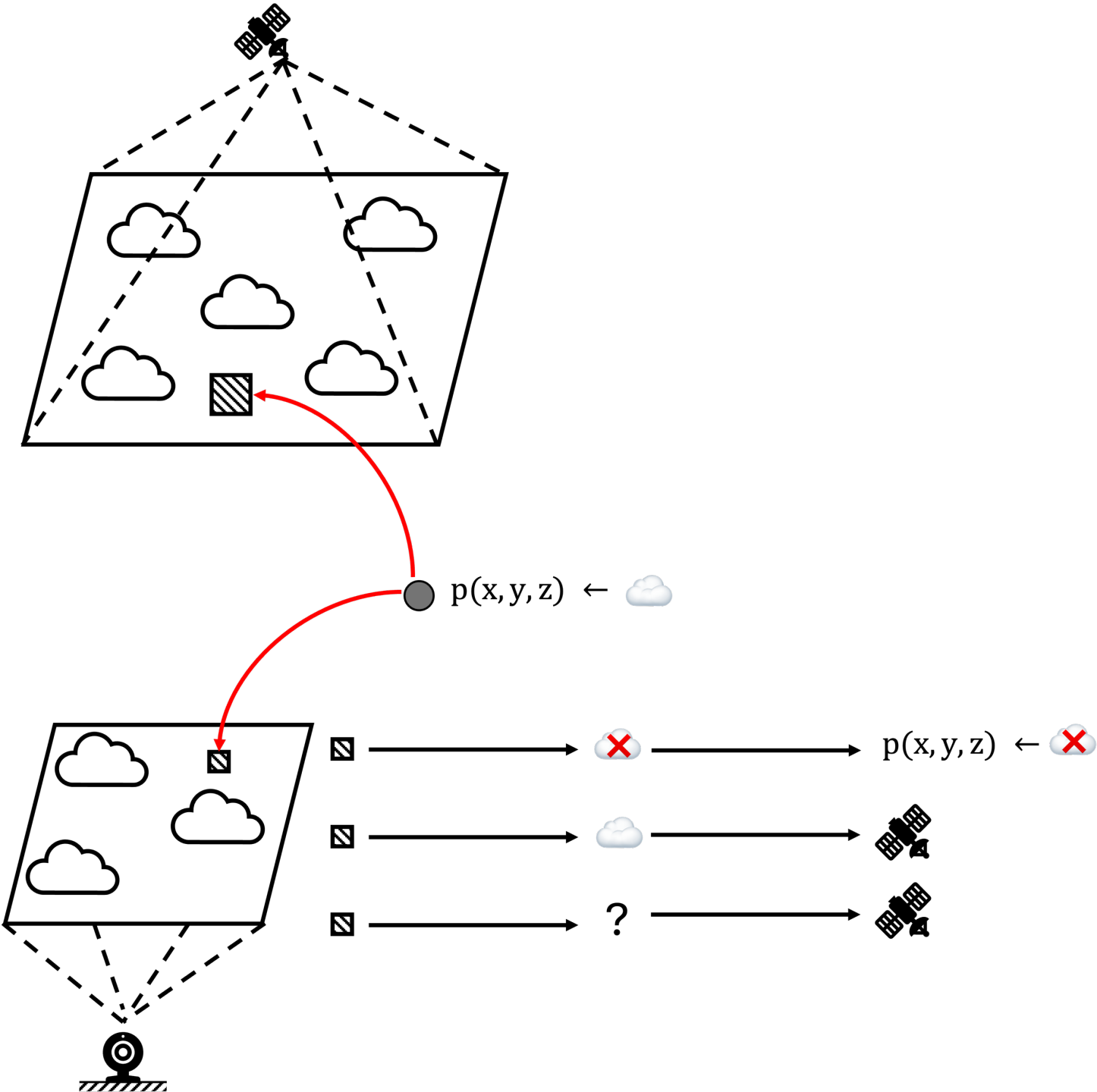
1) Shape-From-Silhouette



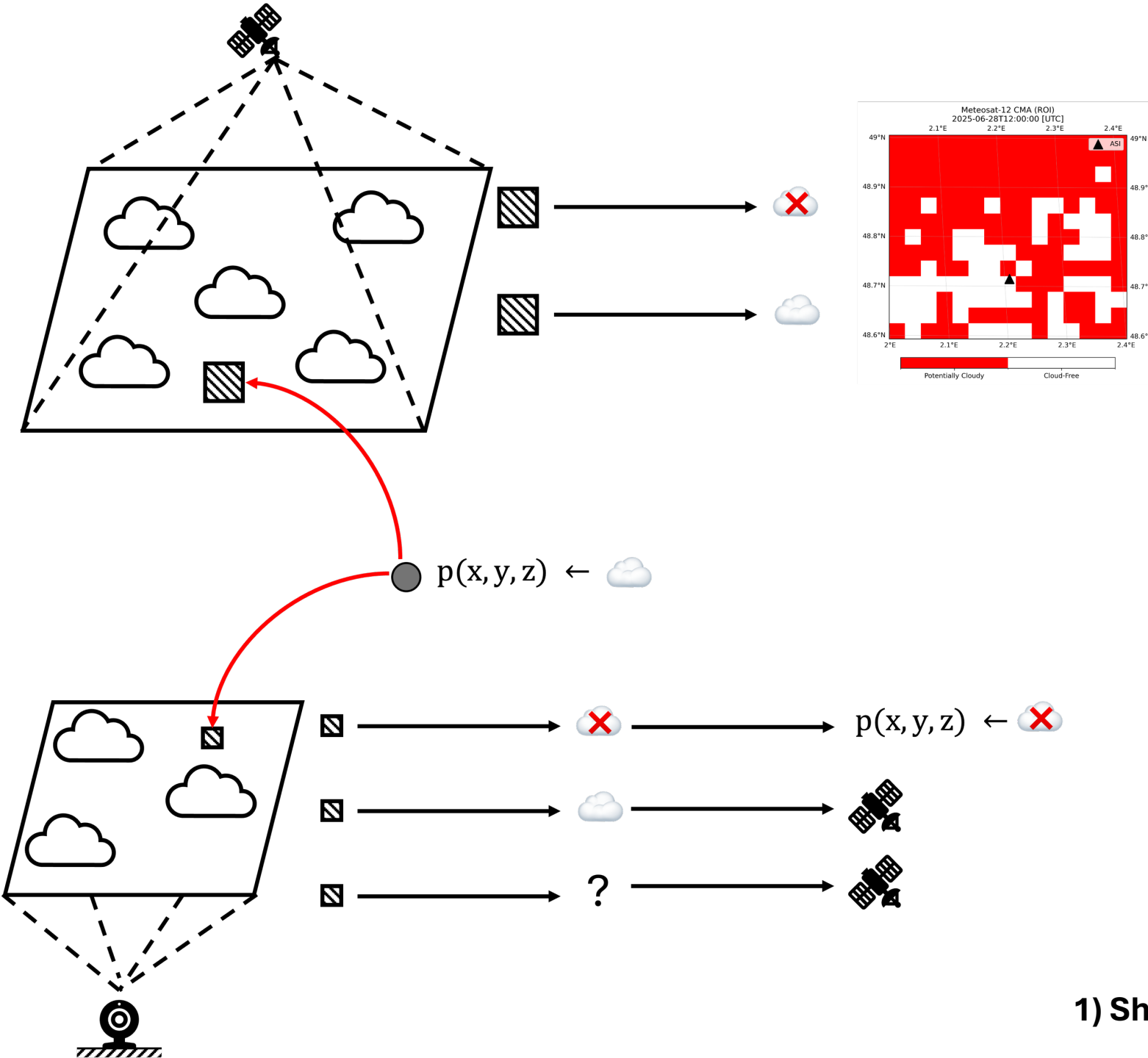
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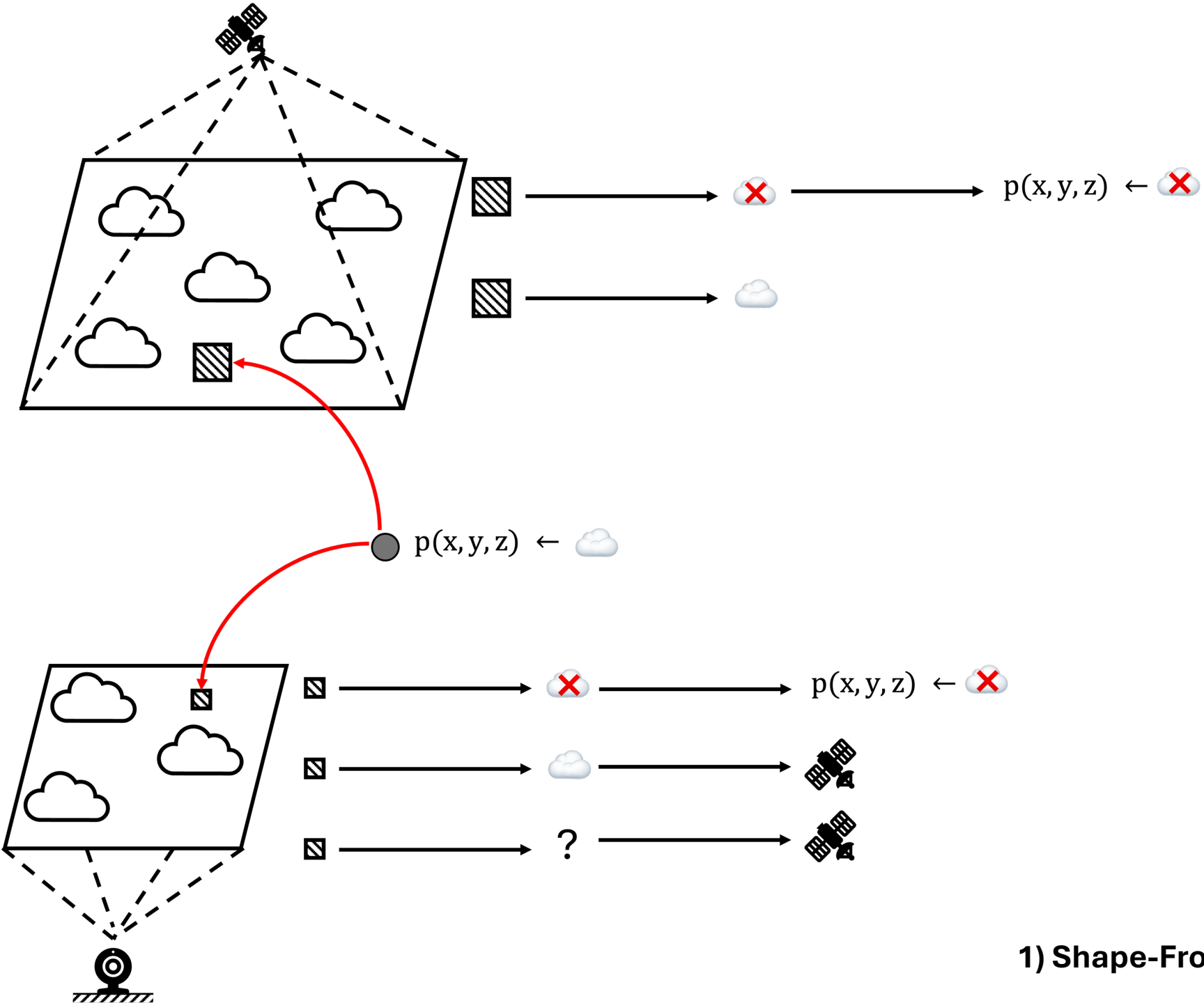
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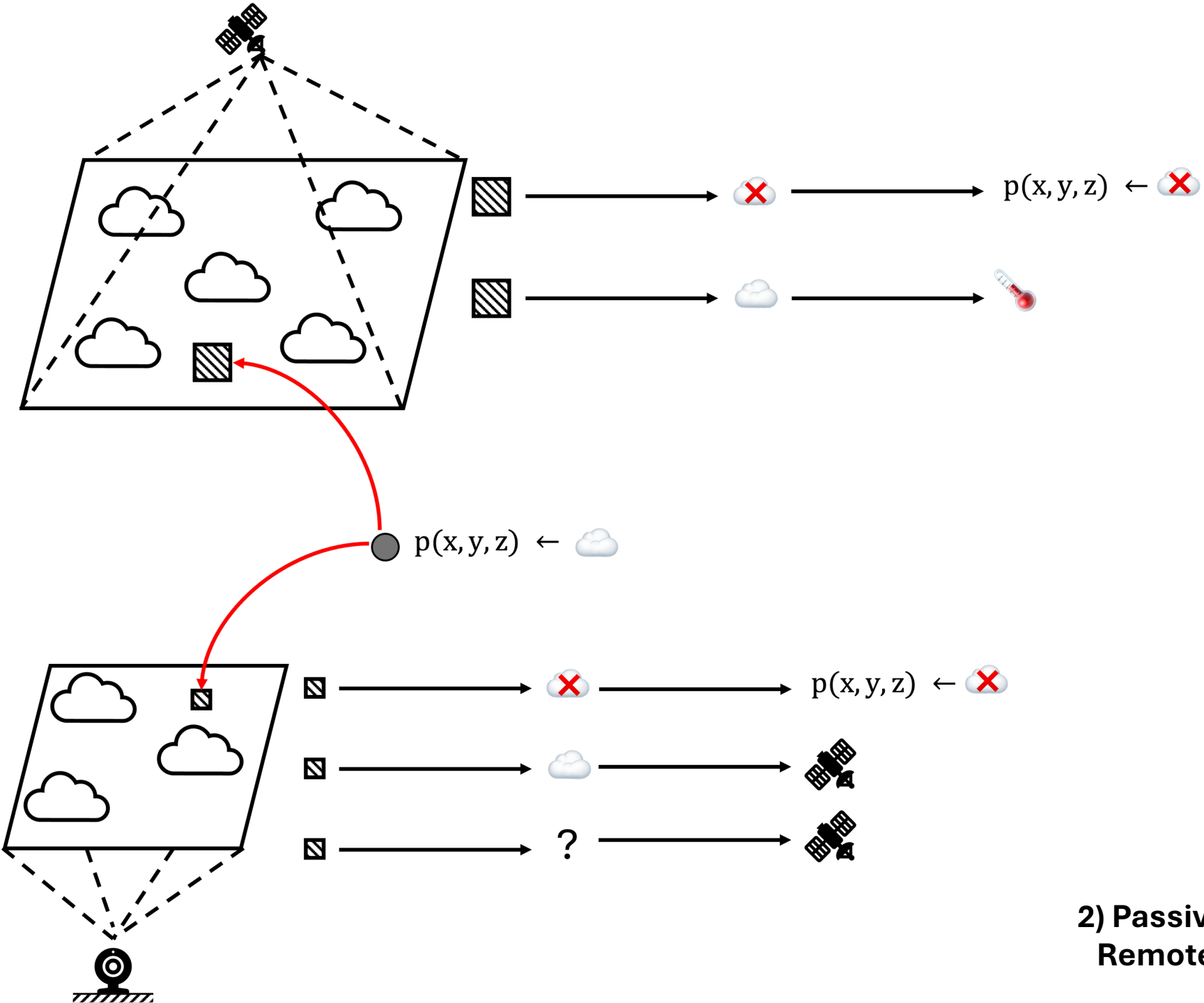
1) Shape-From-Silhouette



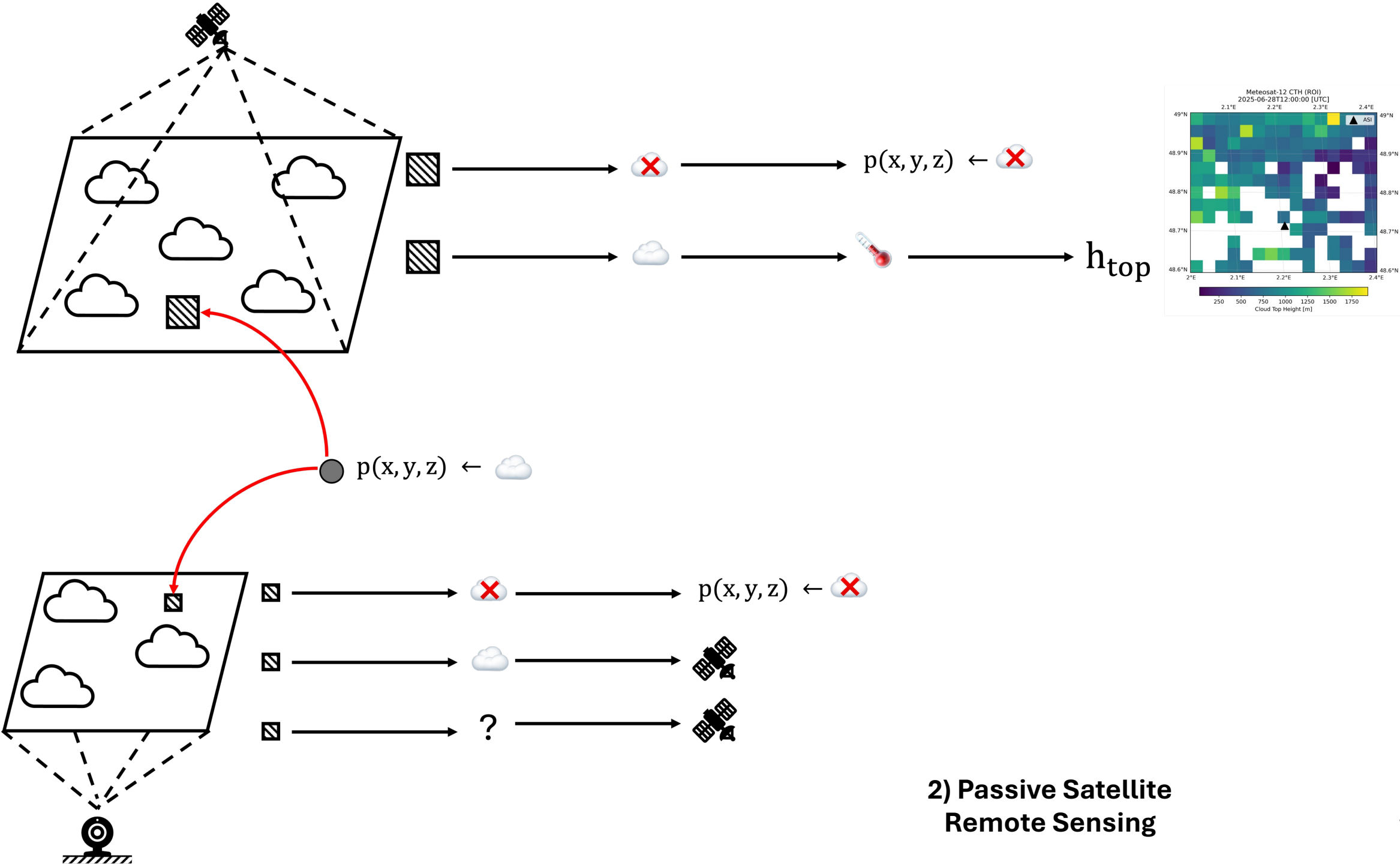
1) Shape-From-Silhouette



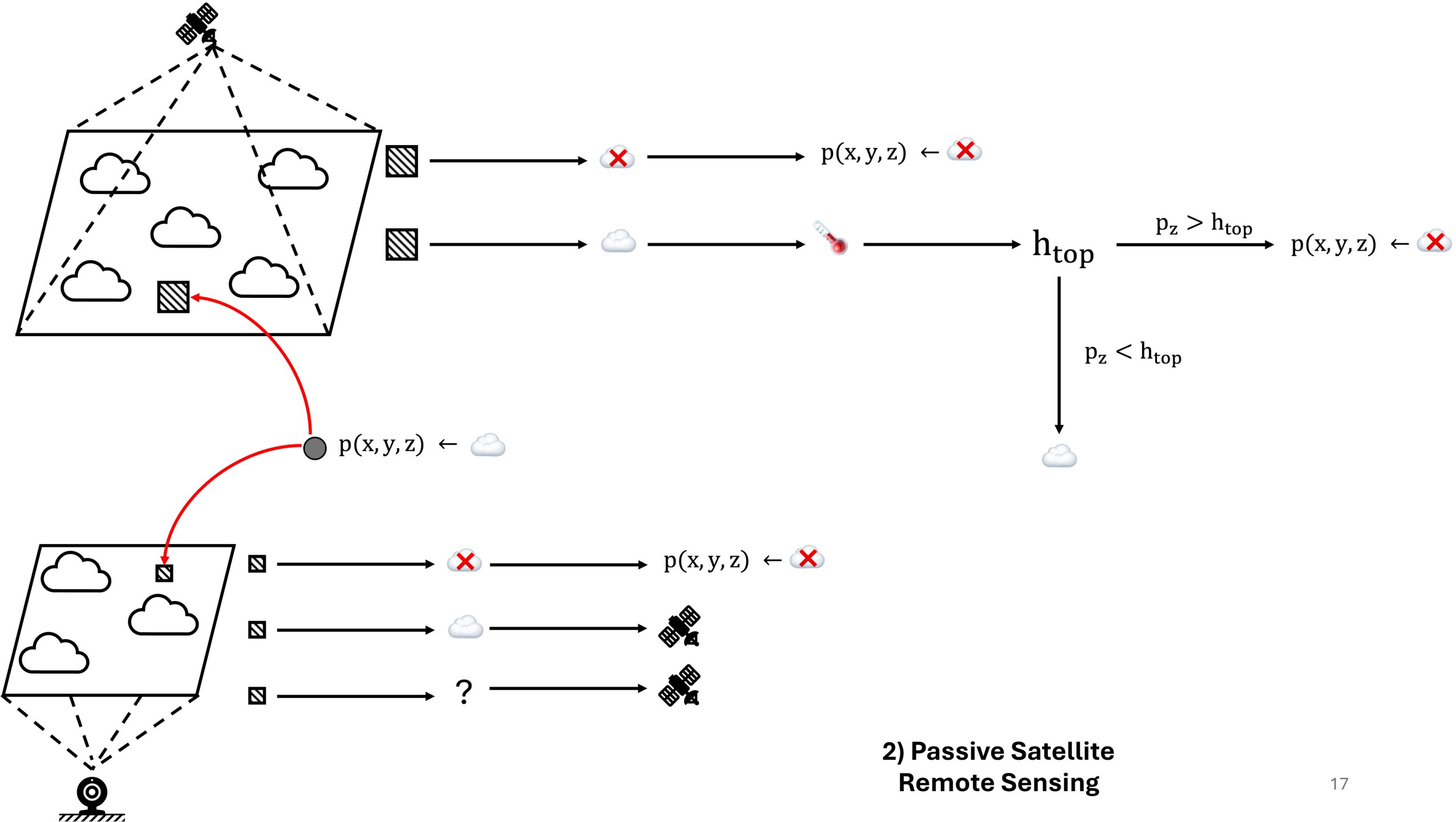
1) Shape-From-Silhouette

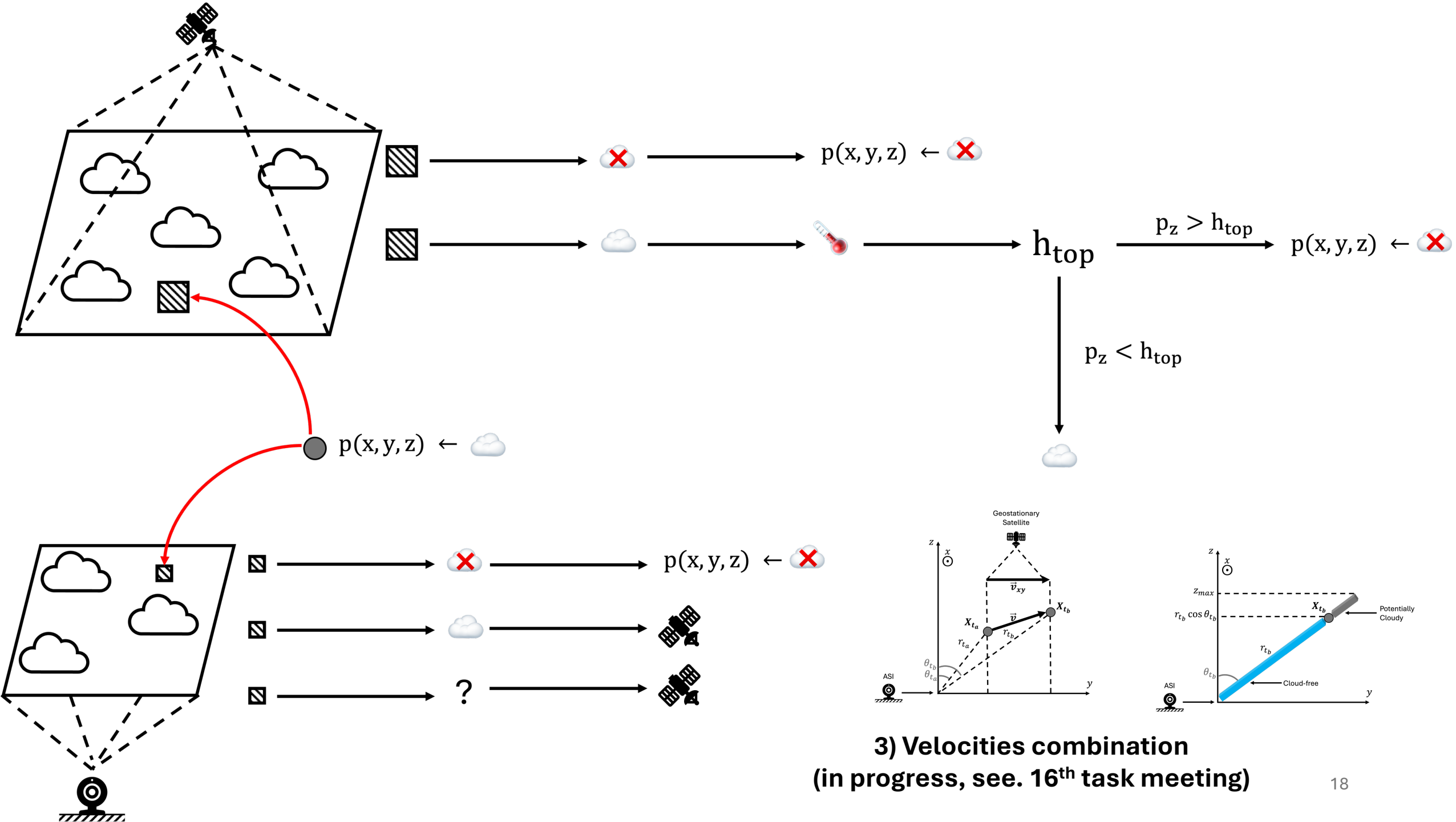


2) Passive Satellite Remote Sensing

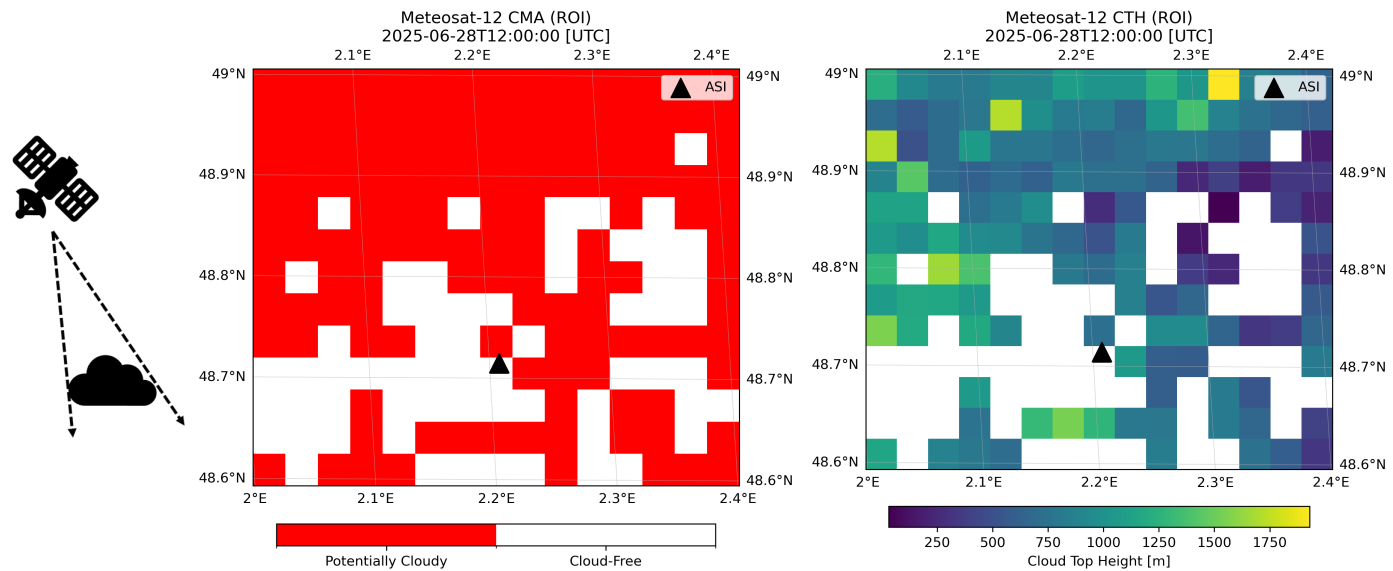


2) Passive Satellite Remote Sensing

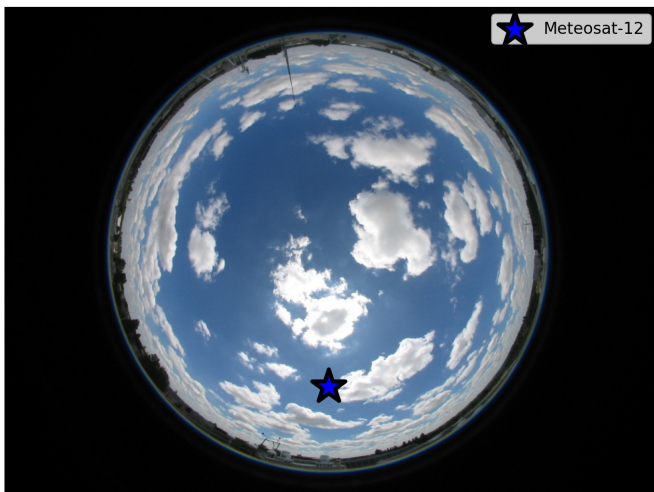




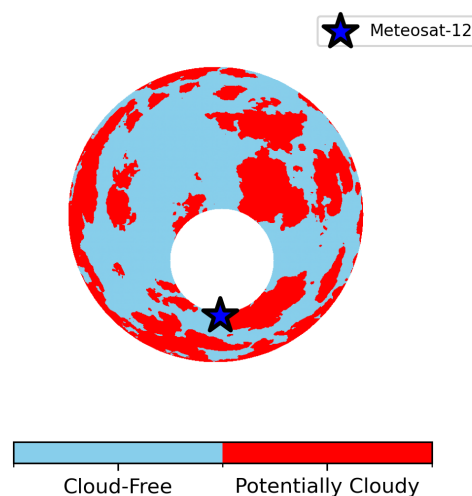
Simultaneous observation: ASI and satellite 2025-06-28 at 12:08:00 UTC in Palaiseau



ASI RGB
2025-06-28T12:08:00 [UTC]



ASI CMA
2025-06-28T12:08:00 [UTC]

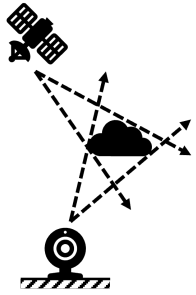


Simultaneous observation

1) Shape-From-Silhouette

2) Passive Satellite
Remote Sensing

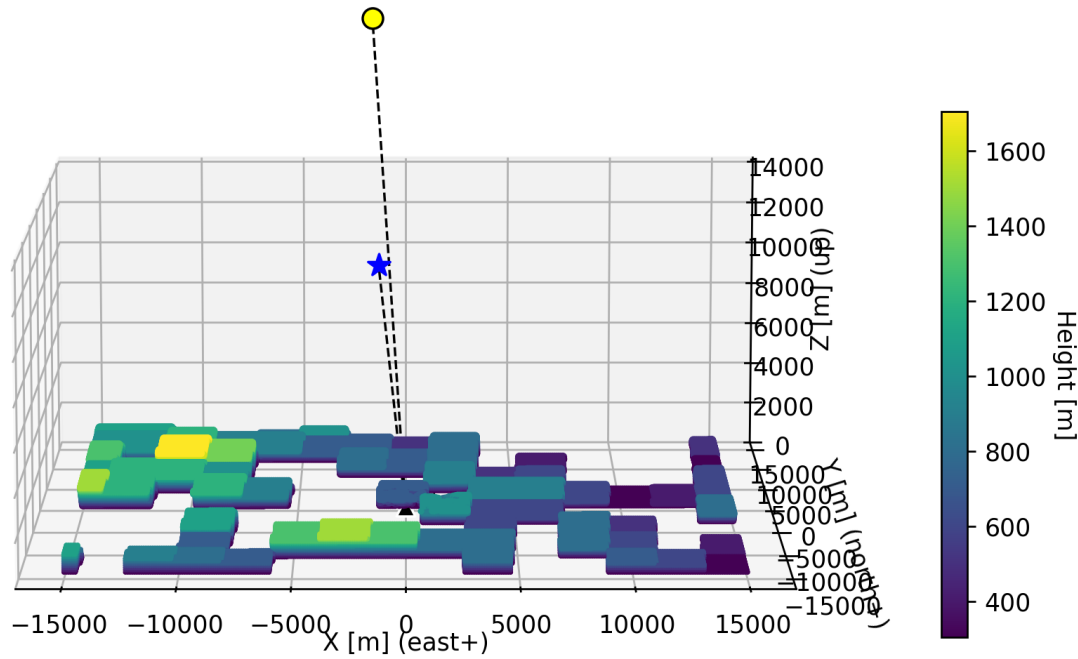
Results



View n°1

2025-06-28T12:08:00 UTC - (2.2077°E, 48.7120°N)

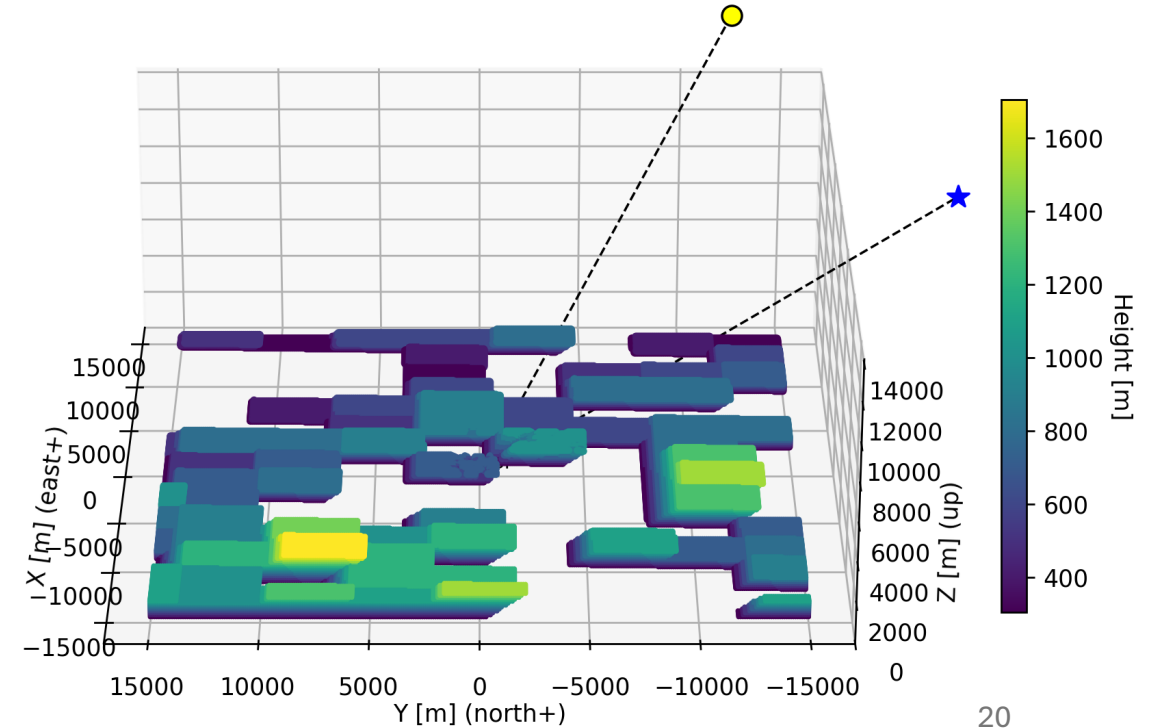
- Sun (SZA=25.6°, SAA=187.2°)
- ★ Meteosat-12 (lon=0.0°E)
- ▲ ASI



View n°2

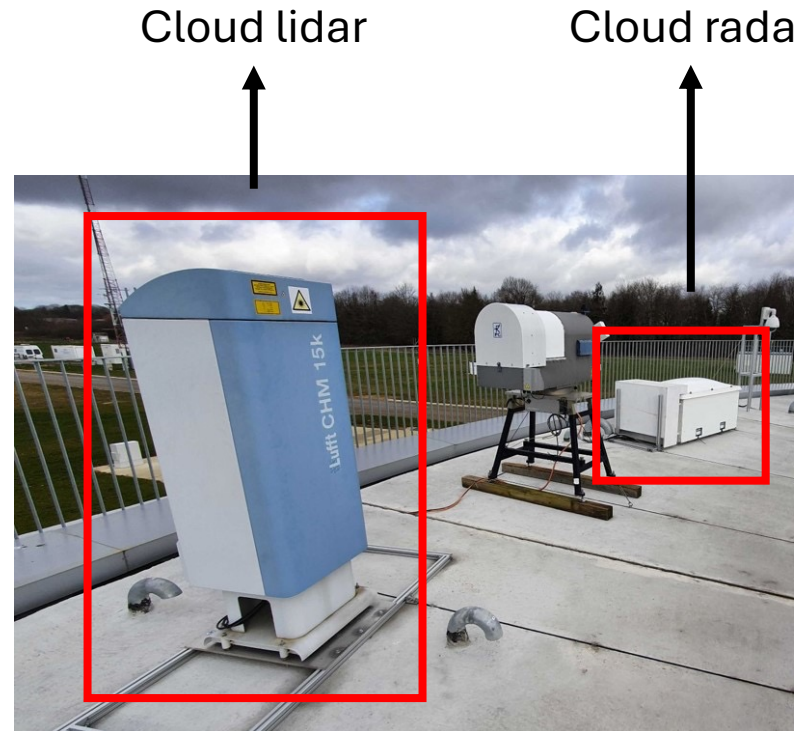
2025-06-28T12:08:00 UTC - (2.2077°E, 48.7120°N)

- Sun (SZA=25.6°, SAA=187.2°)
- ★ Meteosat-12 (lon=0.0°E)
- ▲ ASI

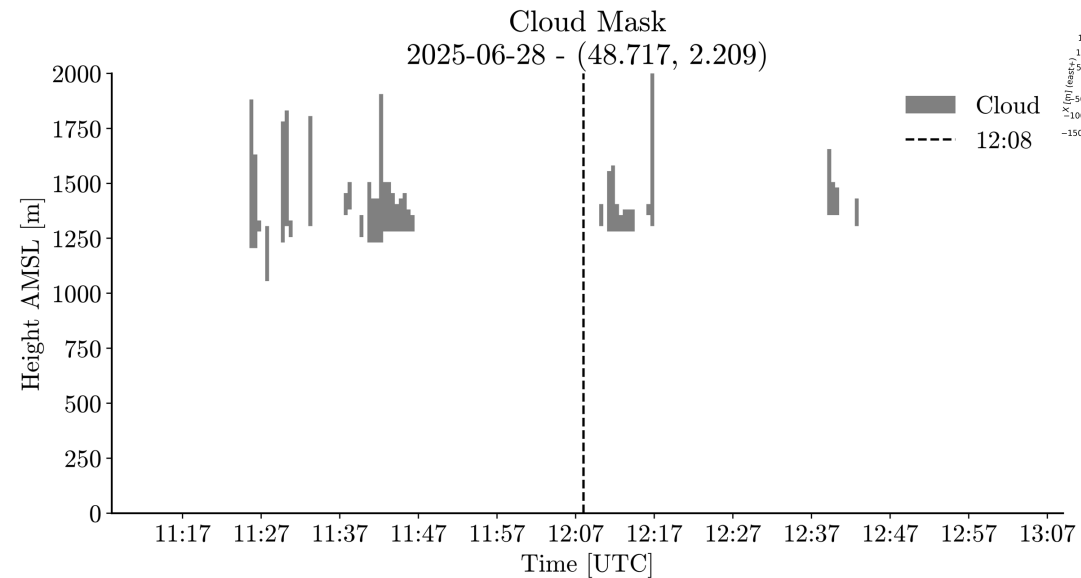


Reduction of cloud
uncertainty compared to
satellite only: **-42.92%**

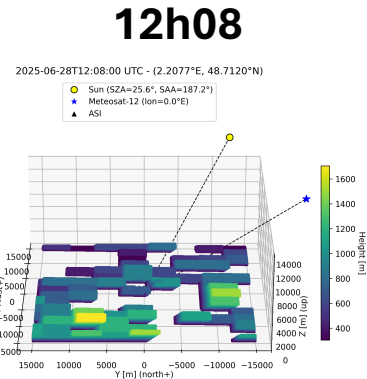
Scientific validation: a challenge in itself



Remote sensing systems at Sirta
(Palaiseau)



At 12:08, no cloud detected in the
vertical column.



Scientific challenge: use of 2D vertical profiles (time, altitude) from cloud lidar and radar for the validation of 3D cloud maps (longitude, latitude, altitude) derived from ground–satellite fusion.

Thanks for your attention!

Supercell seen by GOES-14 super rapid scan mode (1min)



- This work is funded by TotalEnergies and ANRT via a CIFRE grant (2023/1435).
- Data: SIRTa / ACTRIS Cloudnet / ICARE / AERIS / SATMOS / EUMETSAT
- Background image on the title slide: NASA
- ✉ amar.meddahi@minesparis.psl.eu

