SEMANTIC CLOUD SEGMENTATION MODELS FOR SOLAR APPLICATIONS WITH SYNTHETIC DATA

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25.09.2025

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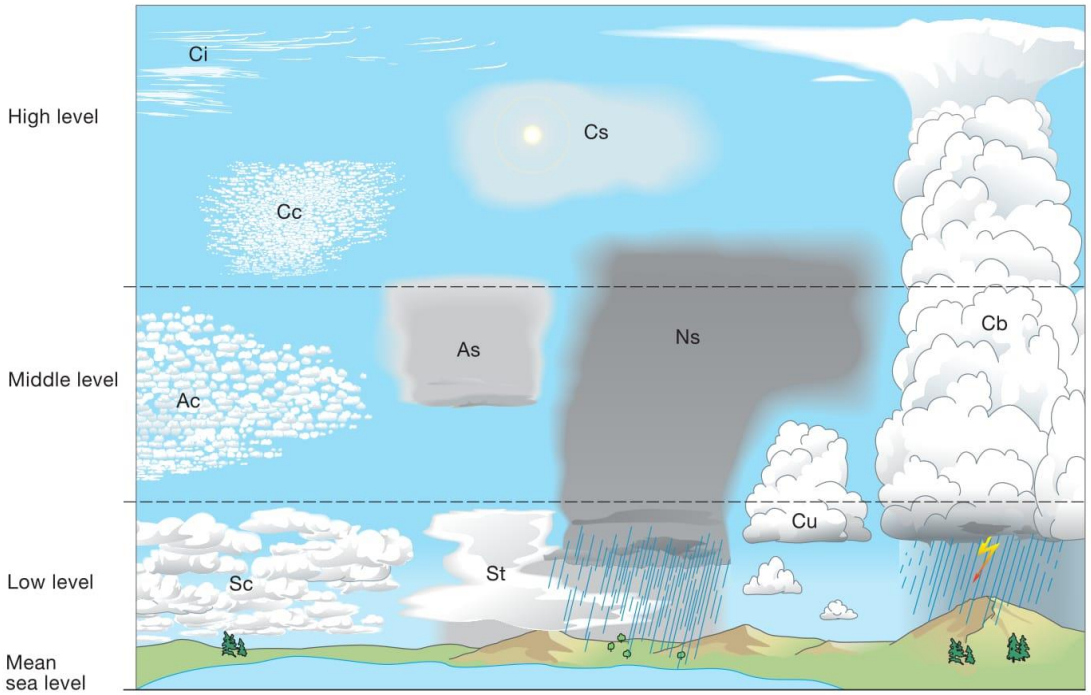
Agenda

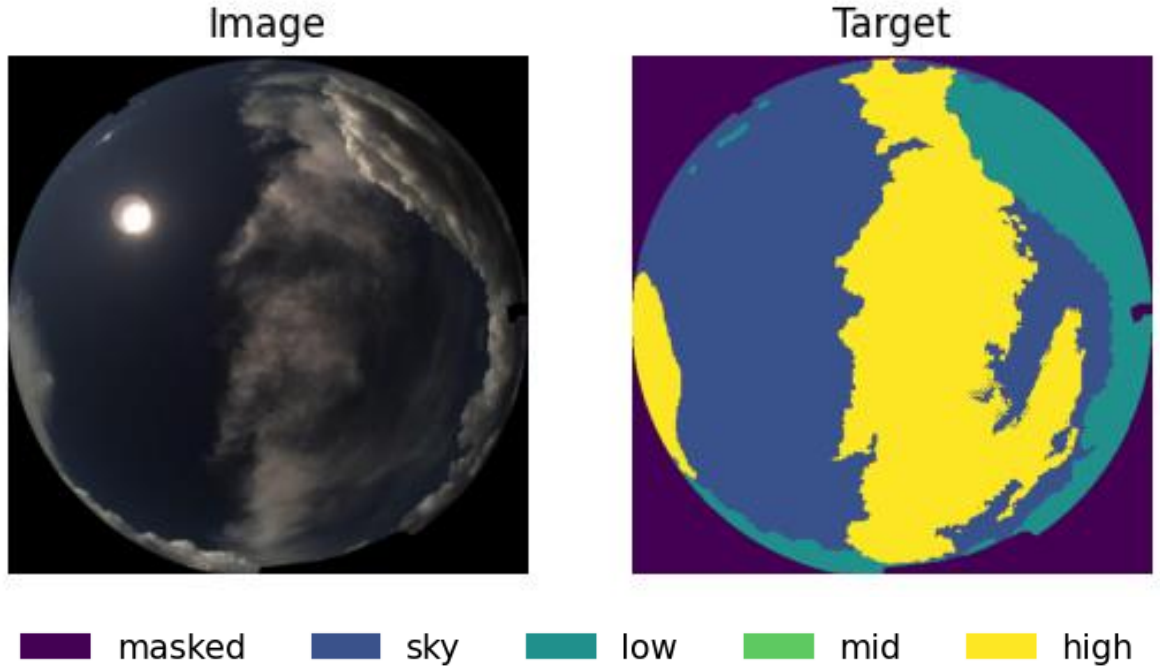
1. **Problem definition**
2. Existing datasets
3. Ground-truth data generation via Semi-supervised Video Segmentation
4. Experimental results
5. Conclusion and outlook

Problem definition

Motivation: Cloud detection for solar irradiance nowcasting systems to optimize operation of solar power plants and electrical grids.

Goal: Provide a pixel-wise classification (semantic segmentation) of clouds in all-sky images in 3 layers defined by WMO.





Problem definition

Approach:

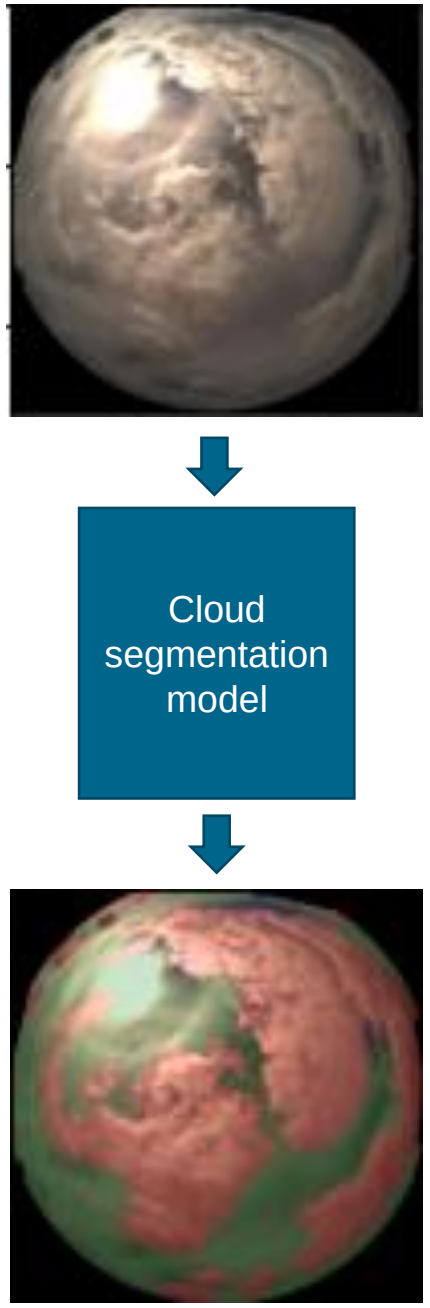
- Deep Learning based methods have been established

Challenges:

- High-quality pixel-level annotated datasets are required
- Lack of a large amount of ground truth readily available
- Expert annotations are time intensive

Solution:

- Automatic extension of manually annotated dataset.



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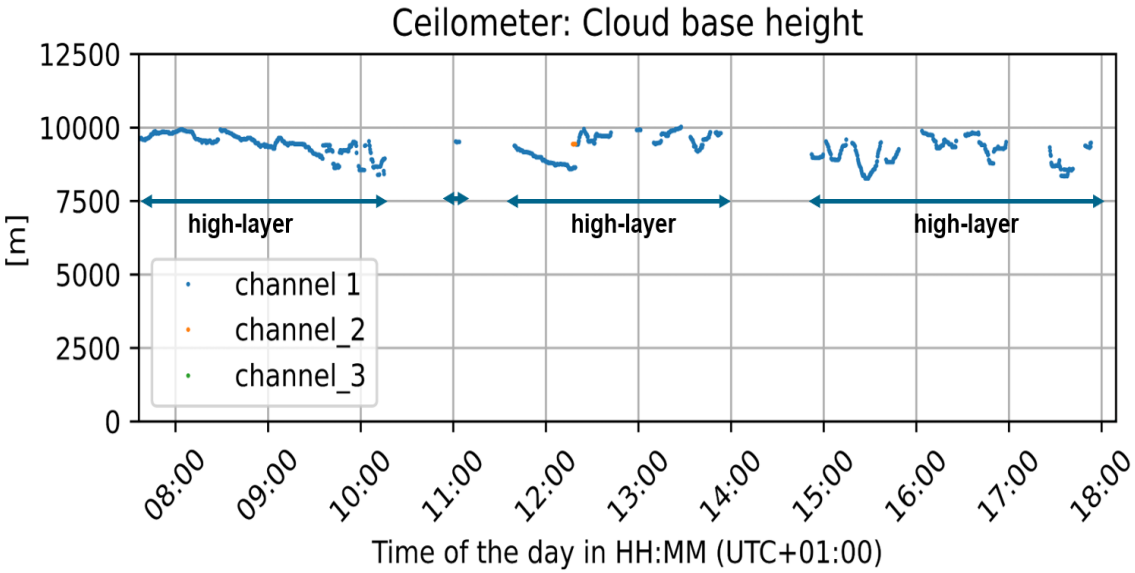
Datasets

Manually annotated dataset [1]**:**

- 770 annotated images

Weakly annotated dataset [2]**:**

- Ceilometer measures cloud height
- Measurements within certain thresholds represent single cloud layers
- Temporal stable single cloud layer conditions are identified
- Assign corresponding cloud layer as image-level weak label to binary cloud segmentations
- 47.000 segmented images



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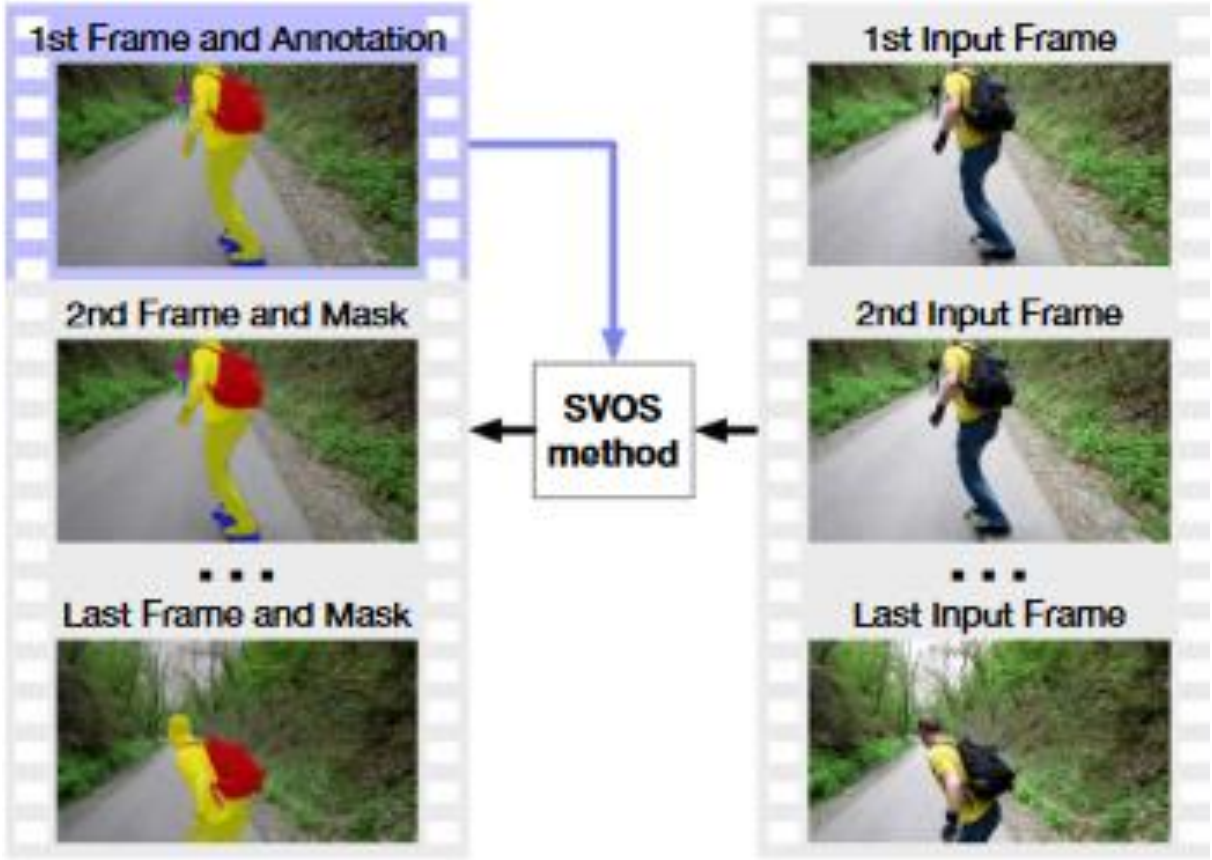
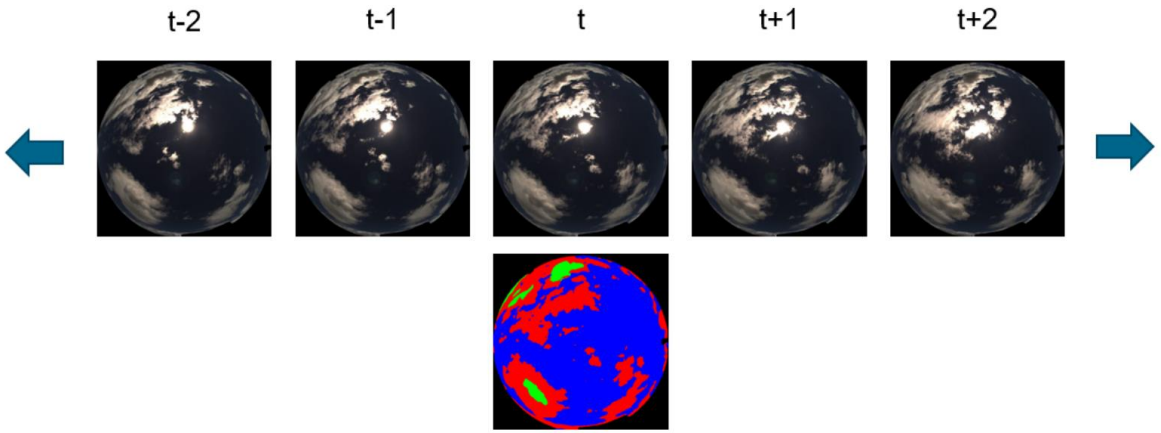
Ground-truth data generation via Semi-supervised Video Segmentation: Overview

- VOS (Video Object Segmentation) is an AI technique that segments and tracks objects frame by frame in a video.
- In Semi-Supervised VOS (SVOS) an initial mask of the object to be segmented in the first frame is given.



Ground-truth data generation via Semi-supervised Video Segmentation: Strategy

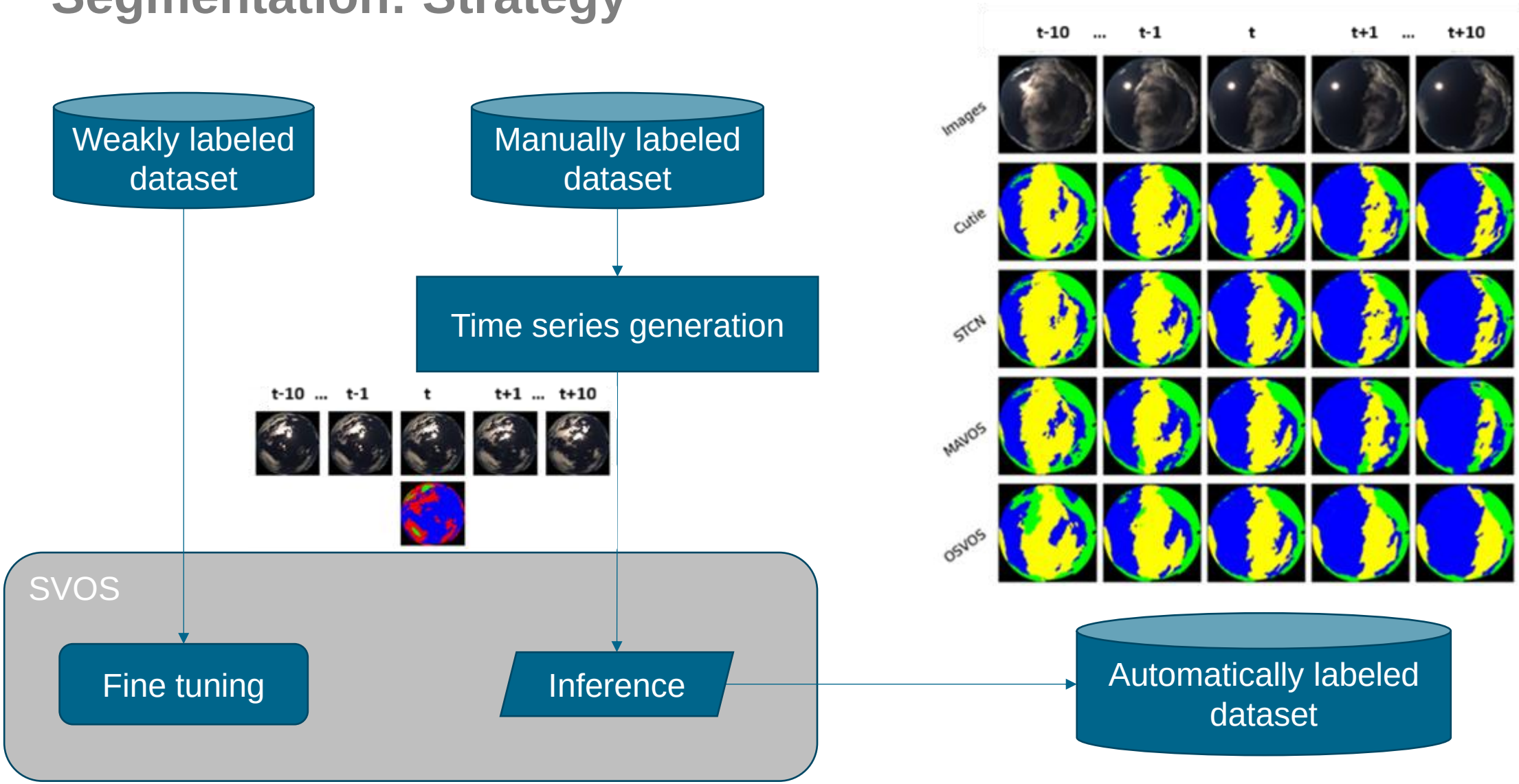
- **Goal**:
  - Expand the existing Manually annotated dataset
  - Study the degradation of quality in label propagation



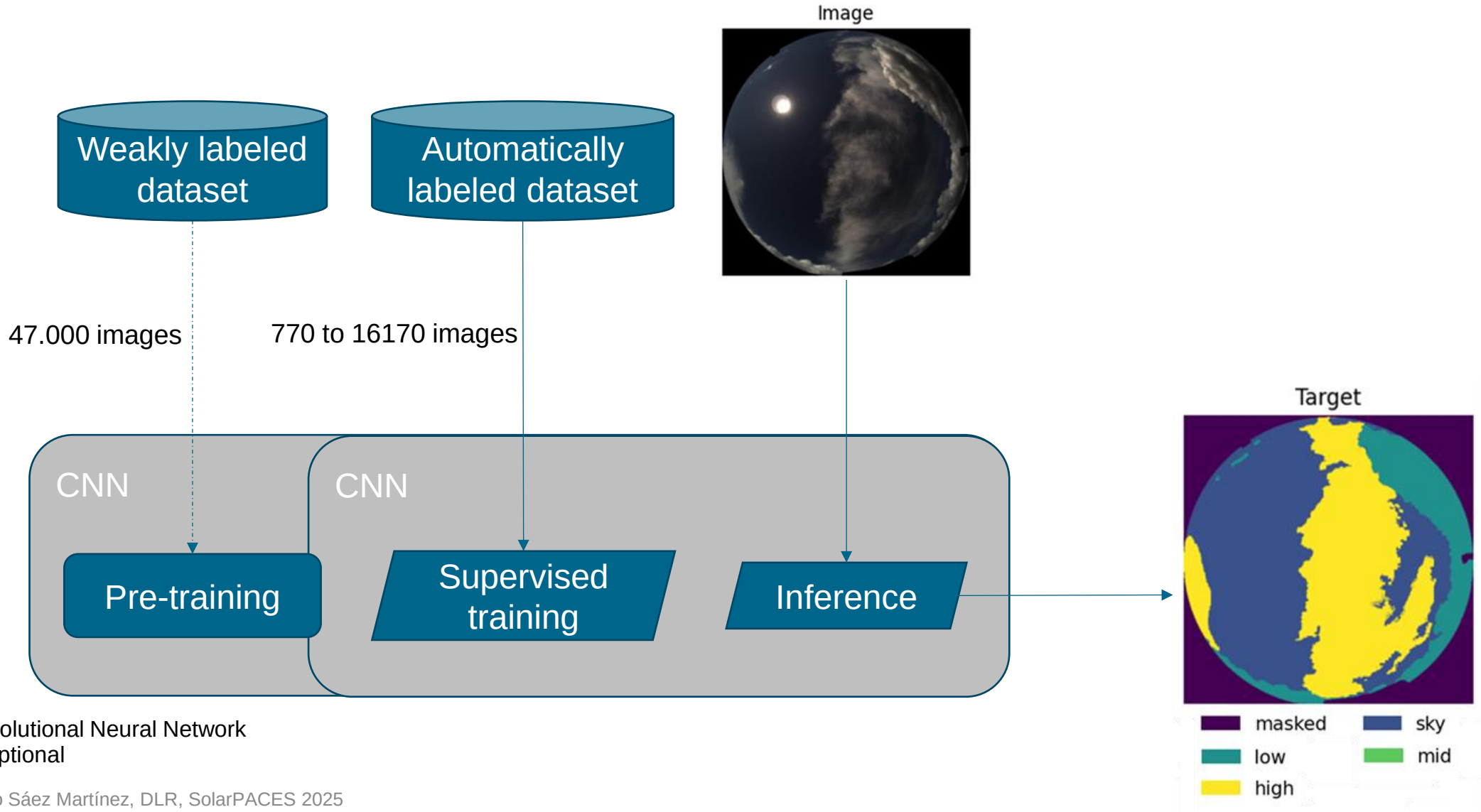
- Test 4 models:
  - OSVOS (2017) [3]
  - STCN (2020) [4]
  - Cutie (2024) [5]
  - MAVOS (2025) [6]

- Maximum of +/- 10 frames is evaluated

Ground-truth data generation via Semi-supervised Video Segmentation: Strategy



Ground-truth data generation via Semi-supervised Video Segmentation: Strategy



CNN: Convolutional Neural Network

Optional

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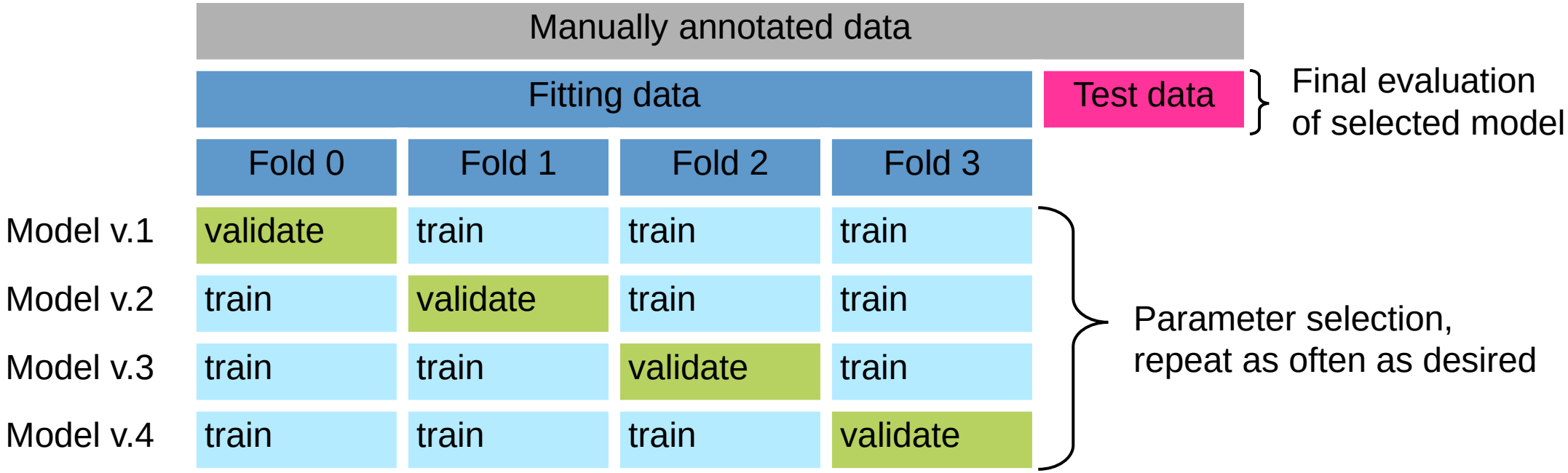
Experiment Results: Dataset – 4-Fold Cross Validation

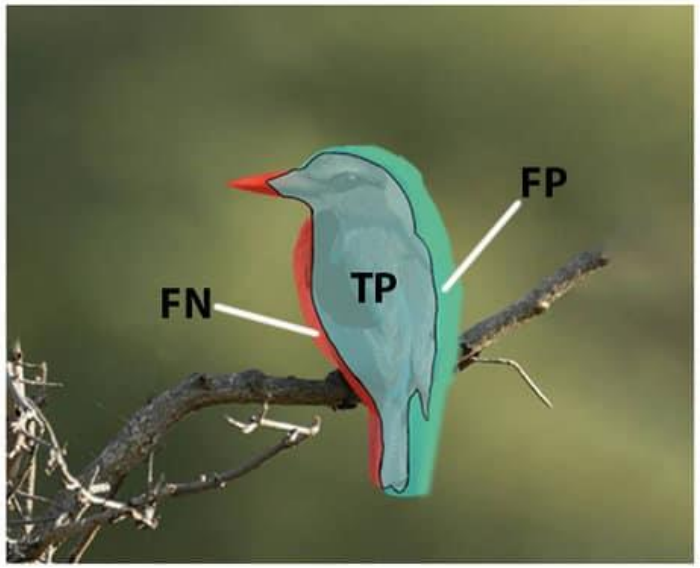


Analyze variance, avoids overfitting, uses all data

Experiment Results: Intersection over Union

Ground Truth Mask

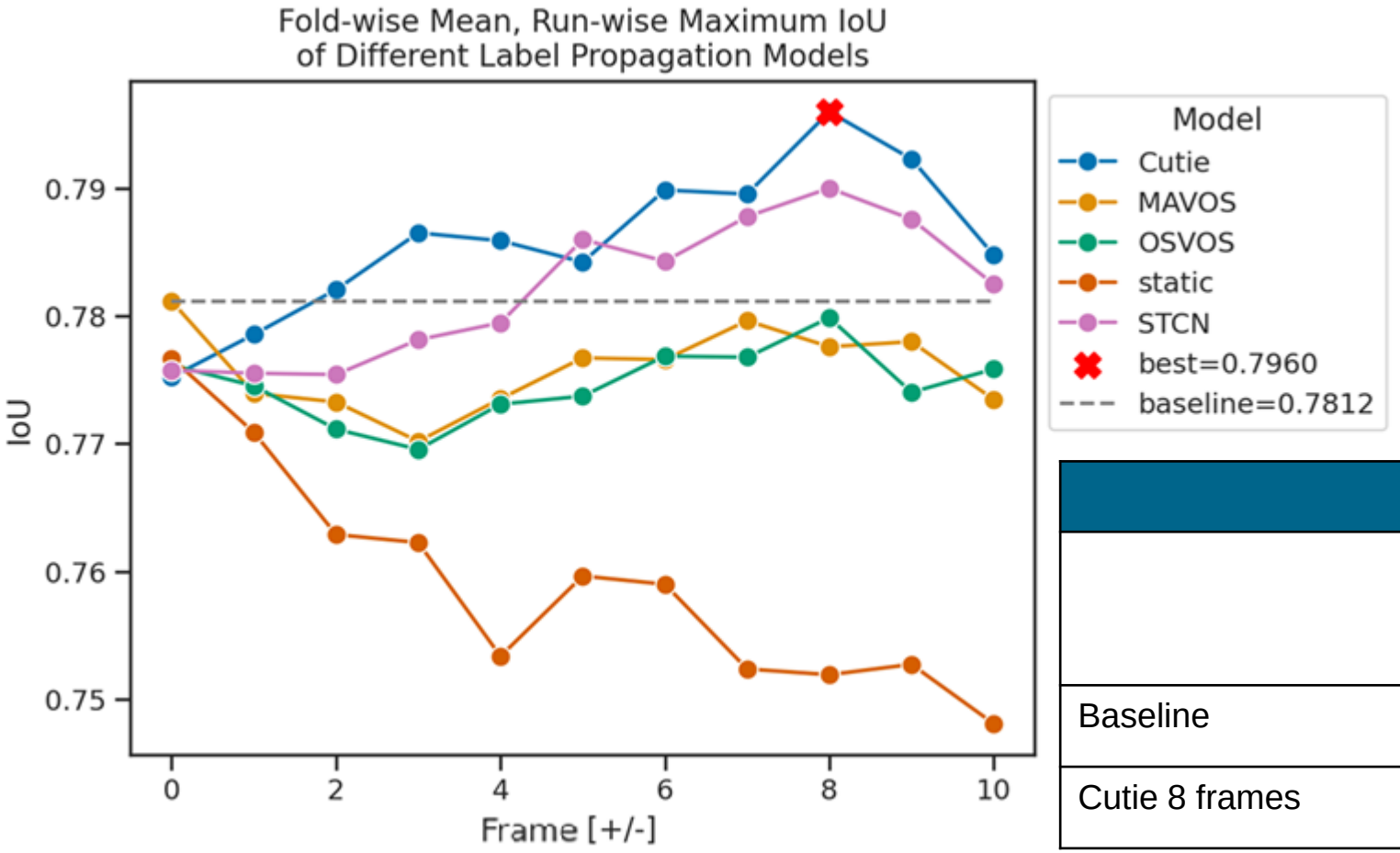
Predicted Mask



https://learnopencv.com/wp-content/uploads/2022/06/5-segmentation-iou.jpg

$$mean\ IoU = \frac{1}{|Classes|} \sum_{c \in Classes} \frac{Target_c \cap Prediction_c}{Target_c \cup Prediction_c} = \frac{1}{|Classes|} \sum_{c \in Classes} \frac{TP_c}{TP_c \cup FP_c \cup FN_c}$$

Experiment Results: VOS Comparison

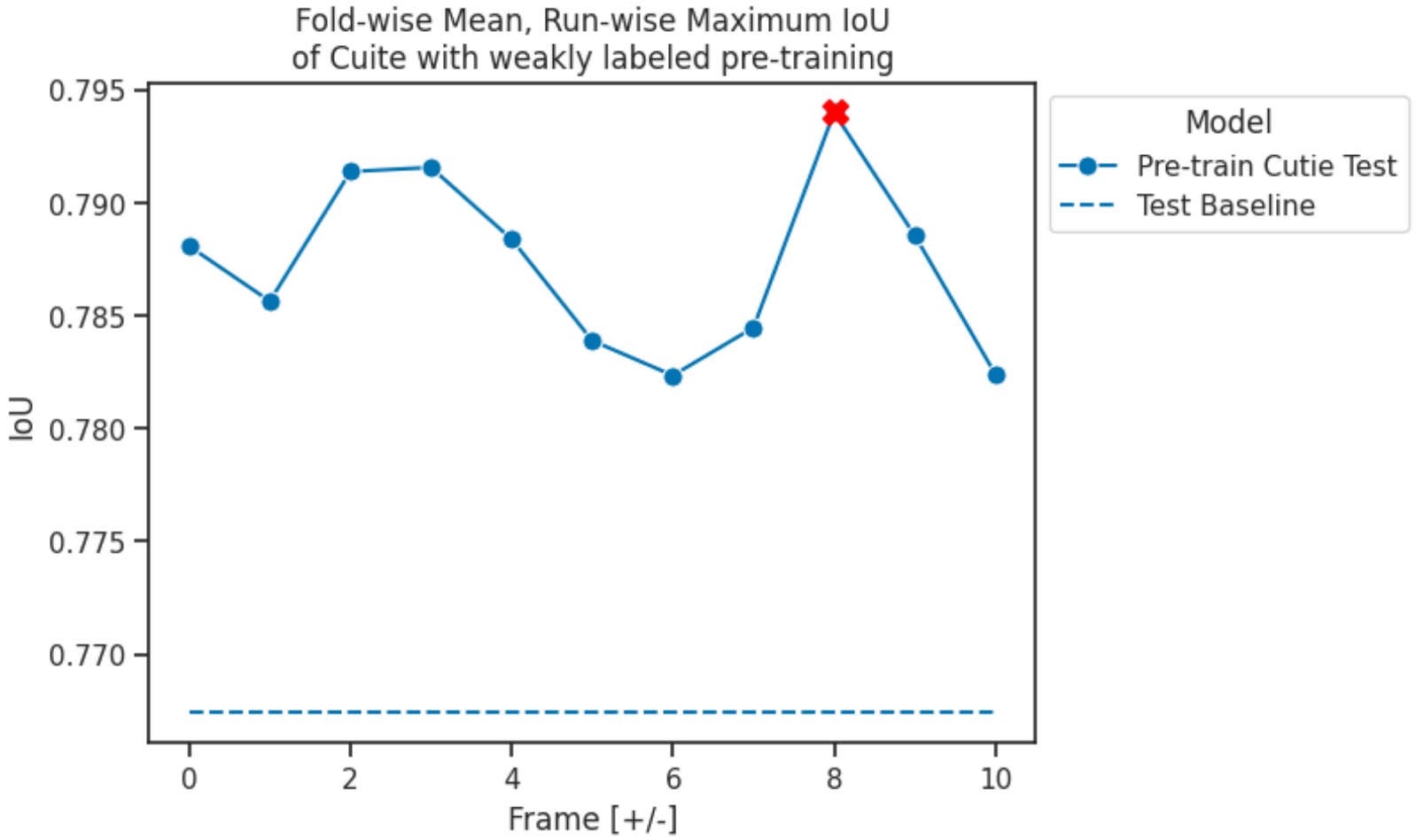


Results				
	Val. IoU	Val. IoU over baseline [%]	Test IoU	Test IoU over baseline [%]
Baseline	0.781	-	0.746	-
Cutie 8 frames	**0.796**	**1.9**	**0.767**	**2.8**

Pre-train: None.

Training: 4k iterations on the automatically labeled dataset.

Experiment Results: Pre-train Cutie



Pre-train: 4k iterations on the weakly labeled dataset (sun elevation above 10º).

Training: 4k iterations on the automatically labeled dataset.

Experiment Results

Results		
	Test IoU	Test IoU over baseline [%]
Baseline	0.746	-
Cutie 8 frames	0.767	2.8
Pre-train Cutie 8 frames (Short Pre-training)	0.776	4.0
Pre-train Cutie 8 frames (Extended Pre-training)	**0.794**	**6.4**

Short Pre-training:

- 4k iterations on the weakly labeled dataset (sun elevation above 20º).

Extended Pre-training:

- 4k iterations on the weakly labeled dataset (sun elevation above 10º).

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Conclusion and Outlook

Conclusion:

- SVOS are promising for segmentation tasks with limited labeled data as significant improvements are achieved against the baseline.
- Further improvement achieved by incorporating weakly labeled data in pre-training step.

Outlook:

- Use time series information
  - Allows more views on the same clouds without extra hardware
- Introduce confidence weighting (e.g. decreasing weights for label propagation)
- Introduce label relaxation to smooth class boundaries of propagated targets

References

[1] Y. Fabel, “Cloud Segmentation and Classification from All-Sky Images Using Deep Learning,” 2020.

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[3] S. Caelles, K.-K. Maninis, J. Pont-Tuset, L. Leal-Taixé, D. Cremers, and L. Van Gool, “One-Shot Video Object Segmentation,” 2017.

[4] H. K. Cheng, Y.-W. Tai, and C.-K. Tang, “Rethinking Space-Time Networks with Improved Memory Coverage for Efficient Video Object Segmentation,” 2021.

[5] H. K. Cheng, S. W. Oh, B. Price, J.-Y. Lee, and A. Schwing, “Putting the Object Back into Video Object Segmentation,” 2023.

[6] A. Shaker, S. T. Wasim, M. Danelljan, S. Khan, M.-H. Yang, and F. S. Khan, “Efficient Video Object Segmentation via Modulated Cross-Attention Memory,” in Proceedings of the Winter Conference on Applications of Computer Vision (WACV), Feb. 2025, pp. 8670–8679.

Thank you for your attention!

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