Effectiveness of Satellite Imagery Cloud Removal using Multi-Modal Deep Learning in Downstream Applications

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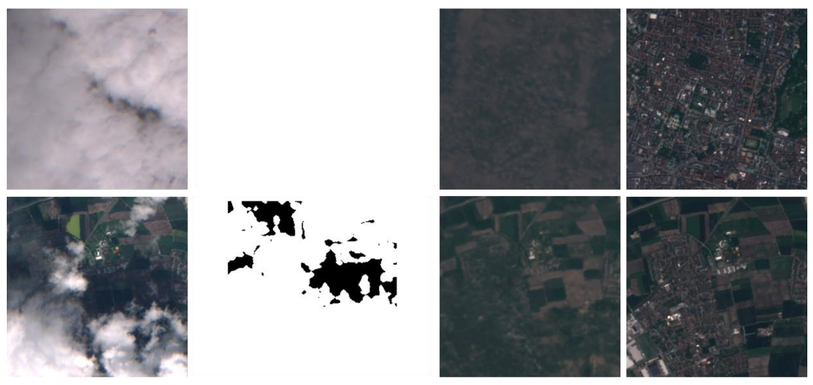
Motivation

- 67% of the Earth's surface is covered with clouds at any given time, obstructing visibility for satellite imagery
- Easy solution: Discard cloudy images
- Traditional methods for cloud removal rather limited, especially with thick cloud cover
- Idea: Combine synthetic aperture radar (SAR) as auxiliary data source with Deep Neural Networks to perform multi-modal cloud removal
- Recent approaches achieve good results in terms of PSNR / SSIM
- Currently no performance evaluation of cloud-removed compared to cloud-free data on downstream tasks



- Using Land Cover Classification, compare performance of cloud-removed images of SoTA DNN and proximity of distributions

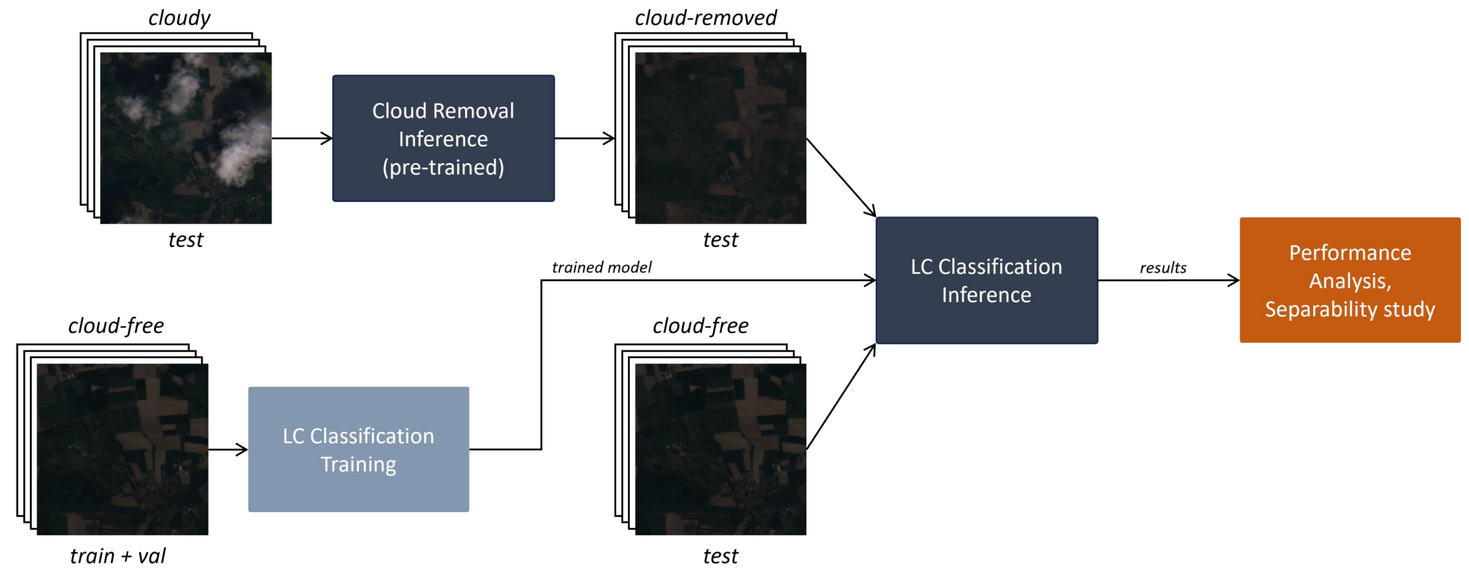
Related Work

- Mono- vs. multimodal: Use auxiliary data, e.g. SAR (less impacted by clouds)
- Mono- vs. multitemporal: Use multiple cloudy patches to predict cloud-removed
- SEN12MS-CR: Paired cloudy + cloud-free multispectral images from Sentinel-2 with SAR data from Sentinel-1 mission [1]
- Gu et al. [2] show that explicit cloud removal improves performance in downstream task compared to learning w. cloudy data
- Gawlikowski et al. [3] show issues arising from using cloudy data in downstream tasks, incl. overconfident mispredictions and clear separability of cloudy and cloud-free data based on model logits

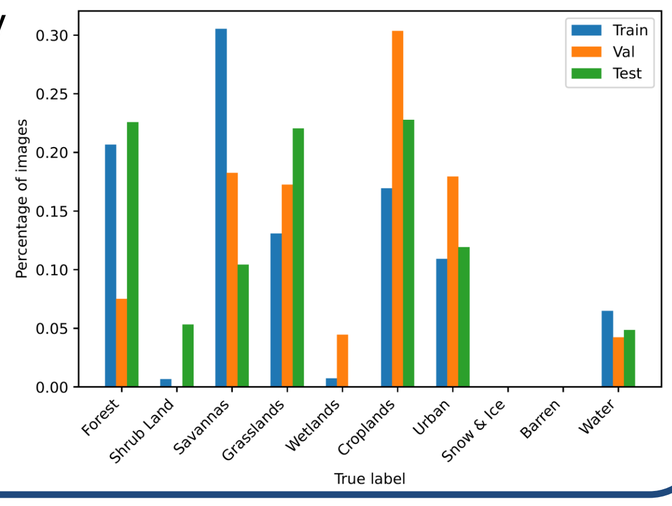
References

[1] A. Meraner, P. Ebel, X. X. Zhu, and M. Schmitt, "Cloud removal in sentinel-2 imagery using a deep residual neural network and saroptical data fusion," ISPRS Journal of Photogrammetry and Remote Sensing, 2020.
[2] J. Gawlikowski, P. Ebel, M. Schmitt, and X. X. Zhu, "Explaining the effects of clouds on remote sensing scene classification," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2022
[3] Z. Gu, P. Ebel, Q. Yuan, M. Schmitt, and X. Zhu, "Explicit haze & cloud removal for global land cover classification," 2022.
[4] P. Ebel, V. S. F. Garnot, M. Schmitt, J. D. Wegner, and X. X. Zhu, "Uncrtaints: Uncertainty quantification for cloud removal in optical satellite time series," 2023

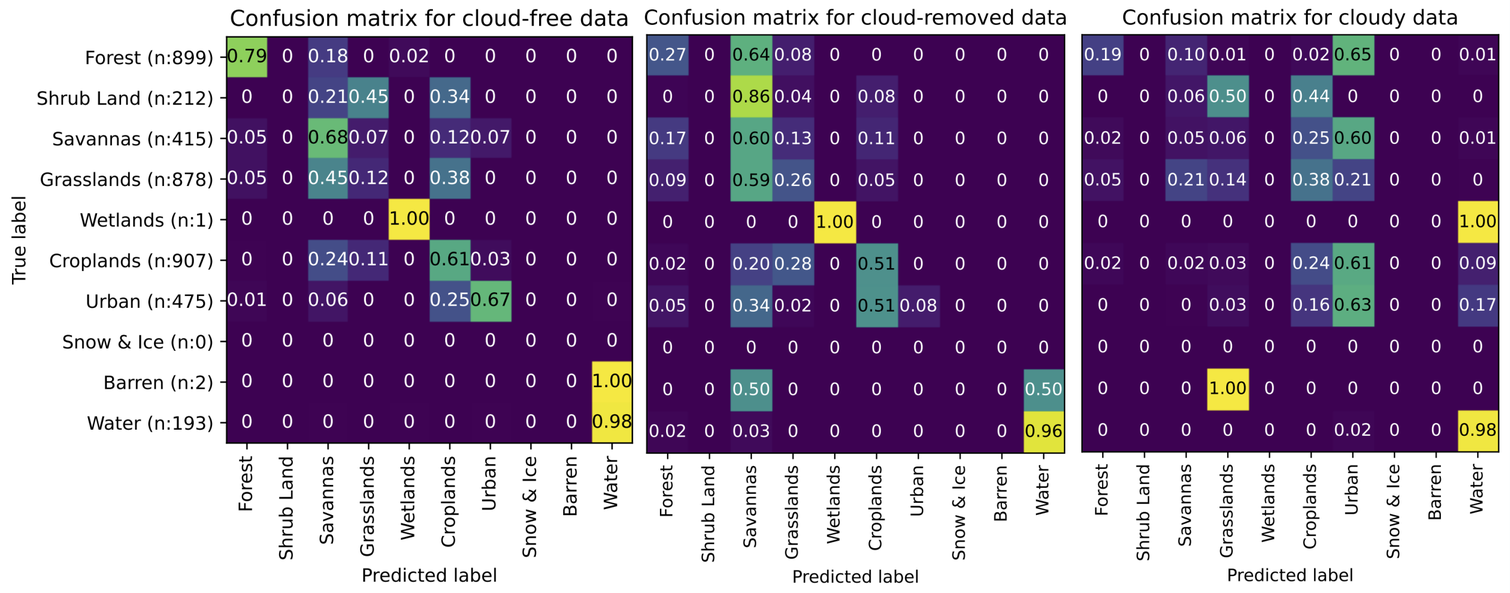
Methodology

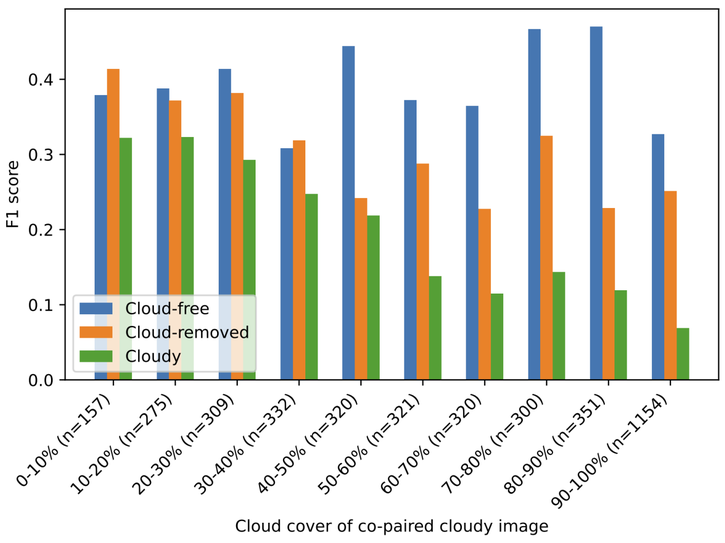


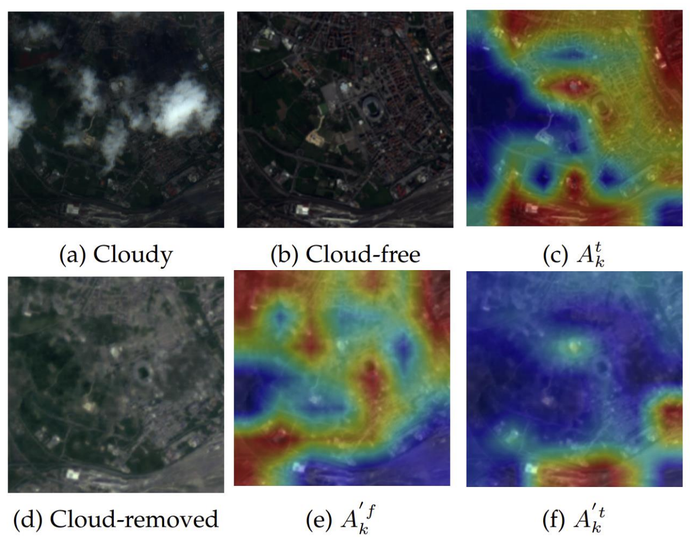
- Pair SEN12MS-CR with MODIS land cover maps from SENMS12
- Use SoTA pre-trained model UnCRtainTS [4] to obtain cloud-removed data
- Train ResNet50 classifier on cloud-free data
- Test classifier on cloud-removed, cloudy and cloud-free images
- Analysis
  - Predictive performance
  - Out-of-Distribution detection for separability of different data
  - Feature attribution study with GradCAM: Gradient-Weighted Class Activation Mapping

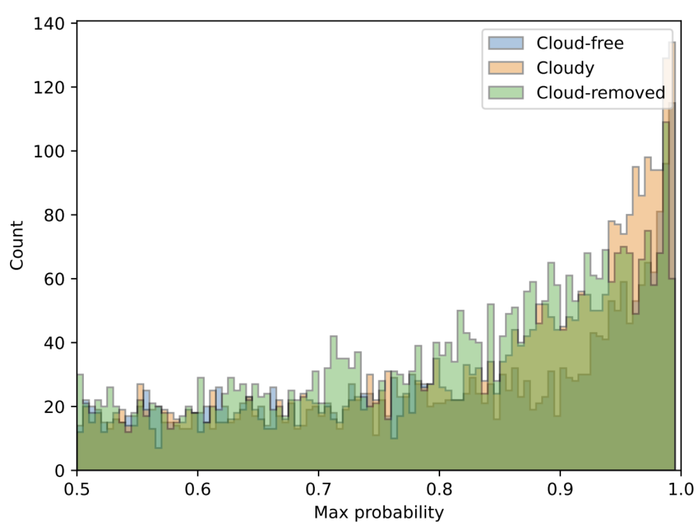


Experimental Results









- Bias and mispredictions towards low spatial frequency classes
- Performance drops with higher cloud cover, between cloud-free and cloudy
- Model expresses uncertainty by less confident predictions
- Mispredictions due to focus on cloud-removed areas