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Intercomparisons of liquid water path based on SEVIRI images and gradient boosting regression trees with in-situ observations and satellite-derived products

Miae Kim*, Jan Cermak, Hendrik Andersen, Julia Fuchs, and Roland Stirnberg
*miae.kim@kit.edu

Institute of Meteorology and Climate Research and Institute of Photogrammetry and Remote Sensing, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

What is liquid water path (LWP)?

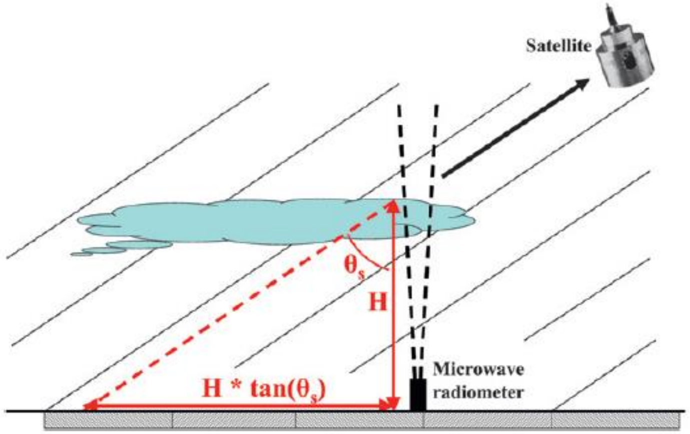
- LWP is defined as the integral of the cloud water content in the vertical column (unit: g/m^2).
- LWP can promote an enhanced or reduced net downward flux of radiation at the surface, acting to alter the Earth's climate.
- Changes in LWP :
  - link to changes in aerosol concentrations
  - are used in prediction of radiation and precipitation of climate models

Data and Methods

- LWP prediction model
  - Gradient Boosting Regression Trees (GBRT)
- Input features
  - MSG-2 SEVIRI channels : IR016 (Infrared 1.6 µm), IR039 (3.9 µm), IR087 (8.7 µm), IR108 (10.8 µm), IR120 (12.0 µm), IR134 (13.4 µm), VIS006 (Visible 0.6 µm), VIS008 (0.8 µm)
  - Satellite viewing geometry : Solar zenith angle (SZA), Azimuth angle (AZA)
- Target
  - CloudNet data
    - Leipzig, Lindenberg, and Juelich in Germany from 2011 to 2015
    - It is a part of the European Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) project (http://devcloudnet.fmi.fi/; https://actris.nilu.no/).
    - LWP is one of the level-2a Cloudnet retrieved meteorological parameters at 30-s temporal resolution and the vertically integrated liquid water content in clouds.
- CM SAF products
  - CMA (Cloud Mask)
    - Cloud filled and contaminated pixels were used.
  - CWP (Cloud Water Path)
    - Used to compare results

Data and Methods

- Homogeneous and Inhomogeneous data
  - Method from Greuell and Roebeling, 2009
  - Two subsets of CloudNet LWP data are created:
    - One containing relatively homogeneous cloud fields
    - The other containing relatively inhomogeneous cloud fields.
- Feature selection vs. No feature selection
- Parallax correction
  - Most of sites have a parallax displacement as approximately 3.5 km on average. So, for example, the pixel right above the center of the SEVIRI pixel that contains the Cloudnet location is used.



Source: Greuell and Roebeling, 2009

"… Because of the parallax, a cloud observed by a ground-based MWR with its vertical view direction is horizontally displaced in a satellite image by a distance H$\tan\theta_s$*, where H is cloud-top height. …"*

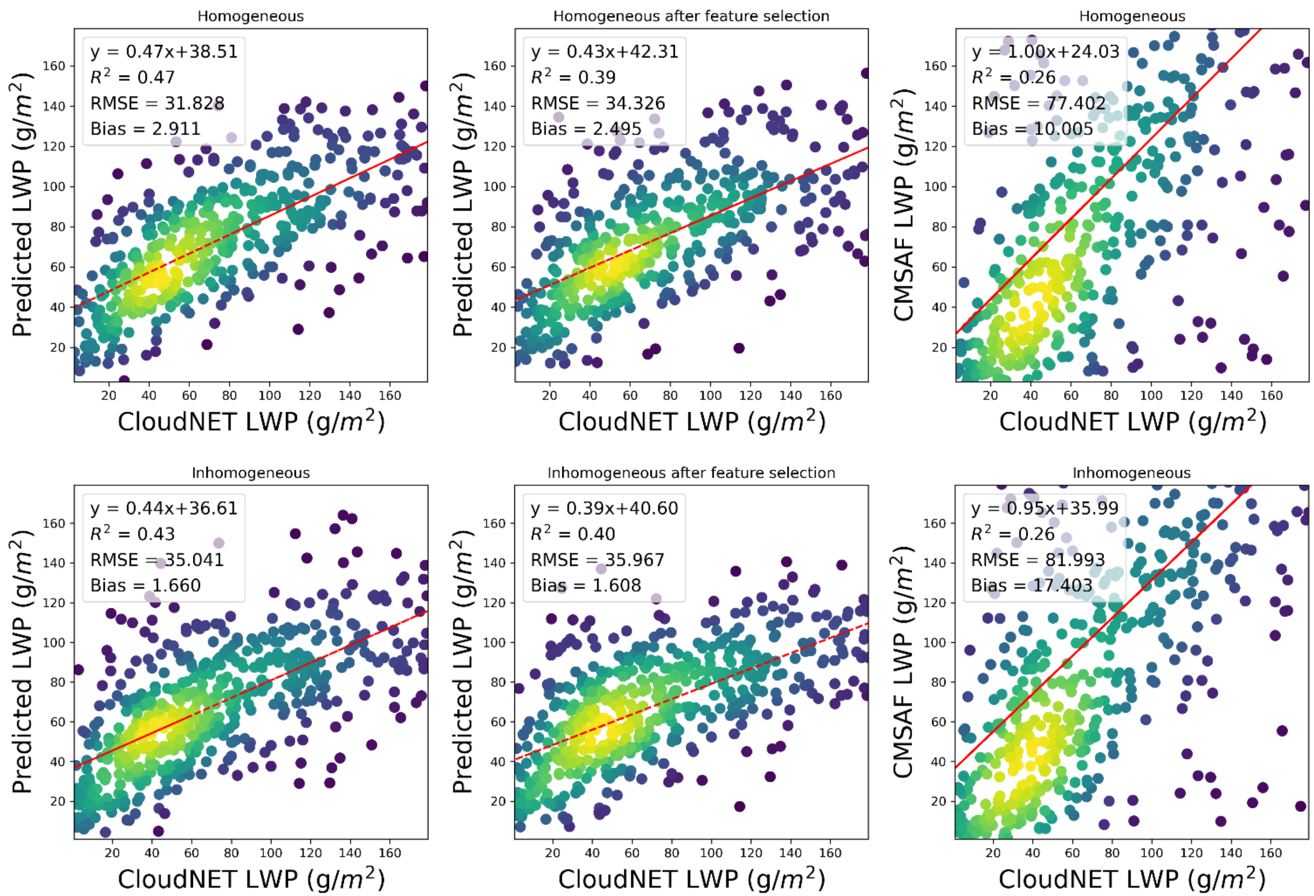
Results and Discussion

- Scatter plots between CloudNet LWP and predicted LWP for Leipzig

No feature selection | After feature selection | CM SAF LWP

Homogeneous

Inhomogeneous



Results and Discussion

- Model evaluation for LWP retrieval

Situations	Sites	Linear relation of LWP_{GBRT} - LWP_{gr}					
		n	R^2	RMSE (g/m^2)	Slope	Intercept	Bias (g/m^2)
Homogeneous	Leipzig	450	0.47	31.83	0.47	38.51	2.91
	Lindenberg	1207	0.34	36.65	0.33	36.76	-0.52
	Juelich	412	0.46	34.43	0.46	43.67	0.61
Homogeneous after feature selection	Leipzig	450	0.39	34.33	0.43	42.31	2.49
	Lindenberg	1207	0.20	40.36	0.20	44.26	0.03
	Juelich	412	0.37	37.58	0.32	54.46	1.30
Inhomogeneous	Leipzig	528	0.43	35.04	0.44	36.61	1.66
	Lindenberg	1415	0.31	38.95	0.31	34.64	-1.46
	Juelich	482	0.36	38.82	0.38	44.78	-0.20
Inhomogeneous after feature selection	Leipzig	528	0.40	35.97	0.39	40.60	1.61
	Lindenberg	1415	0.20	42.25	0.17	42.19	-0.67
	Juelich	482	0.29	41.11	0.30	49.88	-2.06
		Linear relation of LWP_{CMSAF} - LWP_{gr}					
	Leipzig	528	0.26	81.99	0.95	35.99	17.40
	Lindenberg	1411	0.12	122.60	0.90	57.97	21.97
	Juelich	482	0.09	134.73	0.90	28.33	-6.06

- Welch's t-test with 95% confidence interval

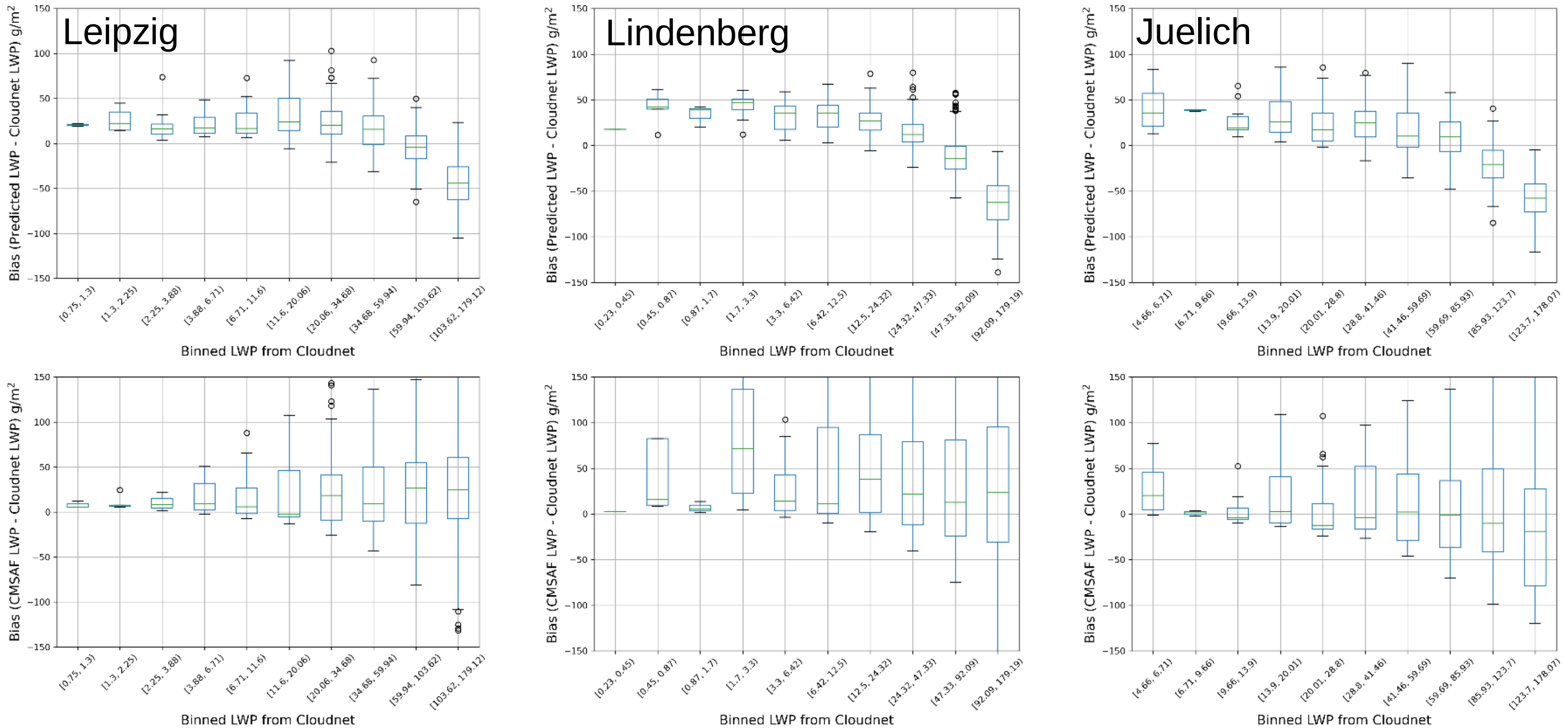
Situations	Statistics	Leipzig	Lindenberg	Juelich
Homogeneous vs. Homogeneous fs	t-statistic	-0.51	1.09	0.32
	p-value	0.609	0.274	0.747
Inhomogeneous vs. Inhomogeneous fs	t-statistic	-0.00	1.47	0.87
	p-value	1.000	0.142	0.386
Homogeneous vs. Inhomogeneous	t-statistic	2.99	3.72	2.76
	p-value	0.003*	0.000*	0.006*
Homogeneous fs vs. Inhomogeneous fs	t-statistic	3.65	5.40	3.89
	p-value	0.000*	0.000*	0.000*

Values with asterisk are significant at $p < 0.05$

- Situations with no feature selection yielded better performance in accuracy, but no sites showed statistical difference.
- In the comparison of LWP from CMSAF and Cloudnet, the degradation in accuracy in all locations is observed.

Results and Discussion

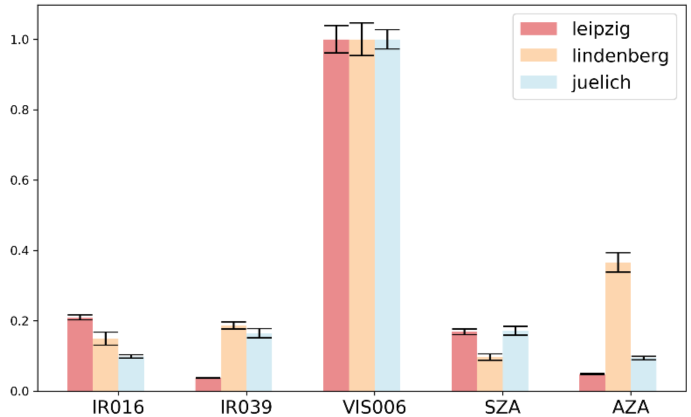
- Boxplots of bias
- Each bin segmented by Cloudnet LWP in logarithmic scale
- For inhomogeneous after feature selection situation for Leipzig
- GBRT model (upper) and CMSAF (lower)

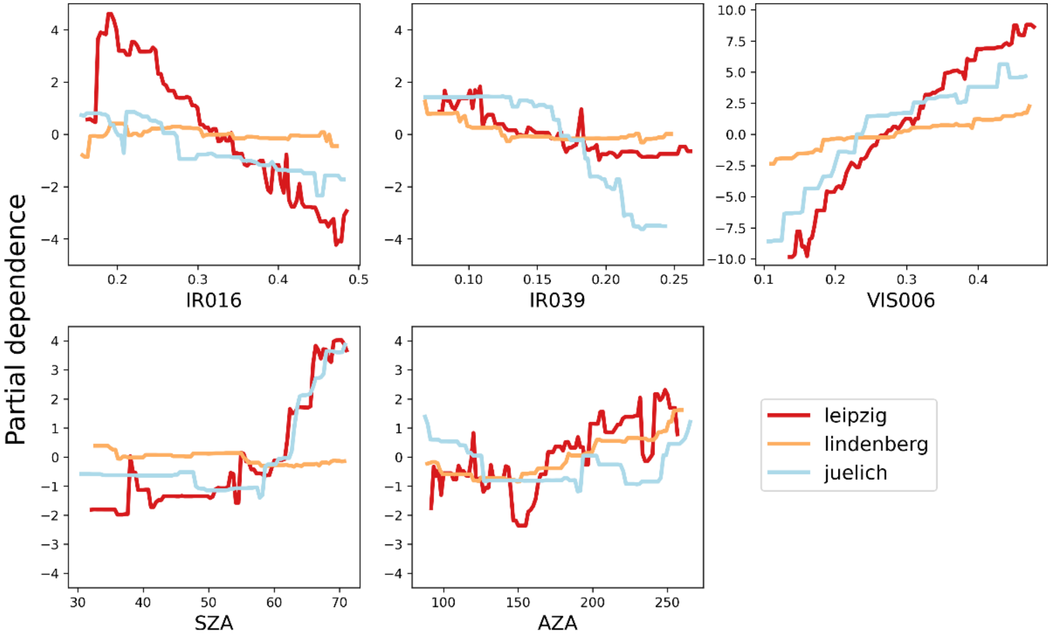


- Bias becomes larger as LWP values increase in all sites.

Results and Discussion

- Feature importance (left) and partial dependence plot (right)
- For homogeneous after feature selection

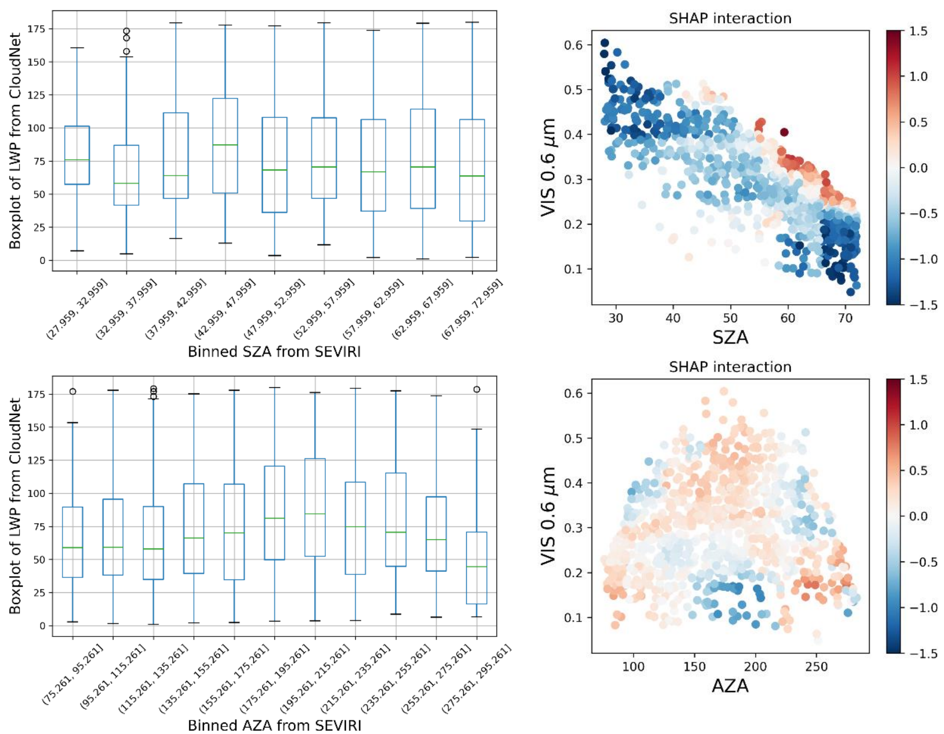




- The impact of VIS 0.6µm variable on the LWP estimation at all sites is clearly visible. The reflectance increases, as cloud optical depth, i.e., cloud thickness, increases, which then LWP increases.
- The larger the droplet size, the larger the LWP value, while the larger the droplet absorbs radiation. Therefore, the smaller the reflectance at the NIR, positive contributions to LWP estimation are expected. This is well seen in the partial dependence plots of the IR016 and IR039.

Results and Discussion

- Boxplot (left) : relationship between LWP and SZA and AZA
- SHAP interaction values (right) : VIS 0.6 µm and SZA and AZA



- SHAP plots can explore even deeper to explore individual differences and provide information about the relationship between input variables and predictions.

Summary

- GBRT model was developed to estimate LWP using Cloudnet LWP in-situ measurements and MSG-2 SEVIRI images.
- The model performed better than the existing satellite-based product.
- The response of satellite channels to LWP are well observed in the variable importance and partial dependency.
- Satellite viewing geometries such as SZA and AZA were not directly related with LWP but correlated with VIS 0.6 µm, together contributing to LWP estimation.
- Better estimation of LWP can give better information on cloud physical properties to climate models and various cloud properties-related studies.

Thank you for your attention.

Questions & comments are welcome!

Contact : miae.kim@kit.edu