Lightning-corrected GSMaP Precipitation Measurements

Archie Veloria[1*], Yuuki Wada[1], Hitoshi Hirose[1], Daichi Kitahara[2], Syugo Hayashi[3], Tomoo Ushio[1]

[1] Department of Electrical, Electronic, and Infocommunications Engineering, Osaka University, Japan

[2] Department of Applied Physics and Physico-Informatics, Keio University, Japan

[3] Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan

大阪大学 OSAKA UNIVERSITY

* email: archie@se.eei.eng.osaka-u.ac.jp

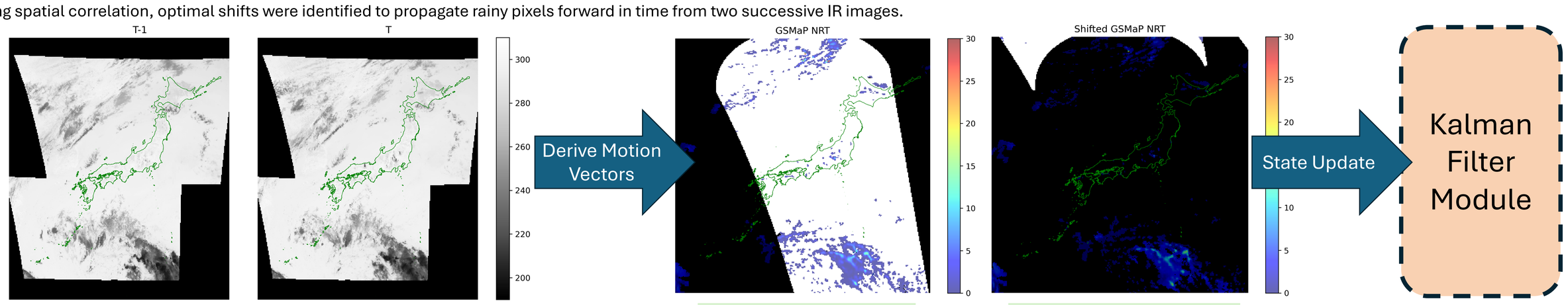
INTRODUCTION

Satellites have been widely used for monitoring rain globally. Through a top-down approach, satellites provide rainfall information even in remote areas. However, accurate rainfall measurements from microwave radiometers (MWR) are not always available. Because of this limitation, the Japan Aerospace Exploration Agency (JAXA) developed the Global Satellite Mapping of Precipitation (GSMaP) which provides hourly rainfall measurements from propagated MWR images with feedback information from the widely available brightness temperature data from geostationary satellites. This was done through a Kalman Filter approach (Ushio et al., 2009). Lightning and rainfall are usually associated with severe weather conditions. Considering the intrinsic relationship between lightning and rain, this study aims to improve GSMaP's accuracy by developing a new Kalman Filter approach that introduces lightning into the existing GSMaP rainfall measurements.

METHODOLOGY

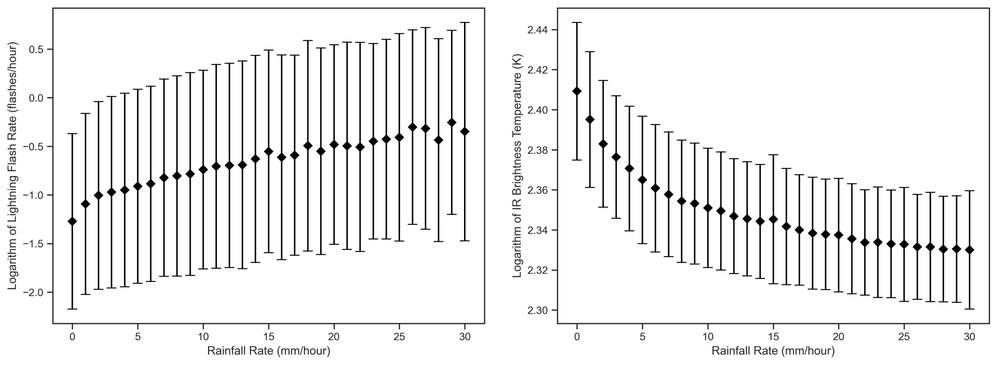
The study region is limited to the Japan area. The study period covers 1-month data from August 2019.

Using spatial correlation, optimal shifts were identified to propagate rainy pixels forward in time from two successive IR images.



Kalman Filter Design

The nonlinear and noisy relationship of rainfall rate with lightning flash rate and infrared brightness temperature was used to provide feedback information and update the rainfall rate measurements.



System Model

$x_k = x_{k-1} + w_{k-1}$

Measurement Model

$BT_k = \alpha x_k + \sigma_{BT}$

$FR_k = \beta x_k + \sigma_{FR}$

Measurement Matrices

$H = \begin{bmatrix} \alpha \\ \beta \end{bmatrix}, z_k = \begin{bmatrix} BT_k \\ FR_k \end{bmatrix}$

Covariance Matrices

$Q = [w^2], R = \begin{bmatrix} \sigma_{BT}^2 & 0 \\ 0 & \sigma_{FR}^2 \end{bmatrix}$

The system is assumed to be in a steady state to simplify calculations.

Error Covariance

$\lim_{k \to \infty} P_k = P$

The discrete-time Riccati Equation can be expressed as

$P = A[P - PH^T(HPH^T + R)^{-1}HP]H^T + GQG^T$

$P = P - PH^T(HPH^T + R)^{-1}HP + Q$

After solving the matrix operations,

$P = \frac{QD \pm \sqrt{(QD)^2 + 4D(\sigma_{BT}^2 \sigma_{FR}^2 Q)}}{2D}$

where $D = \alpha^2 \sigma_{FR}^2 + \beta^2 \sigma_{BT}^2$

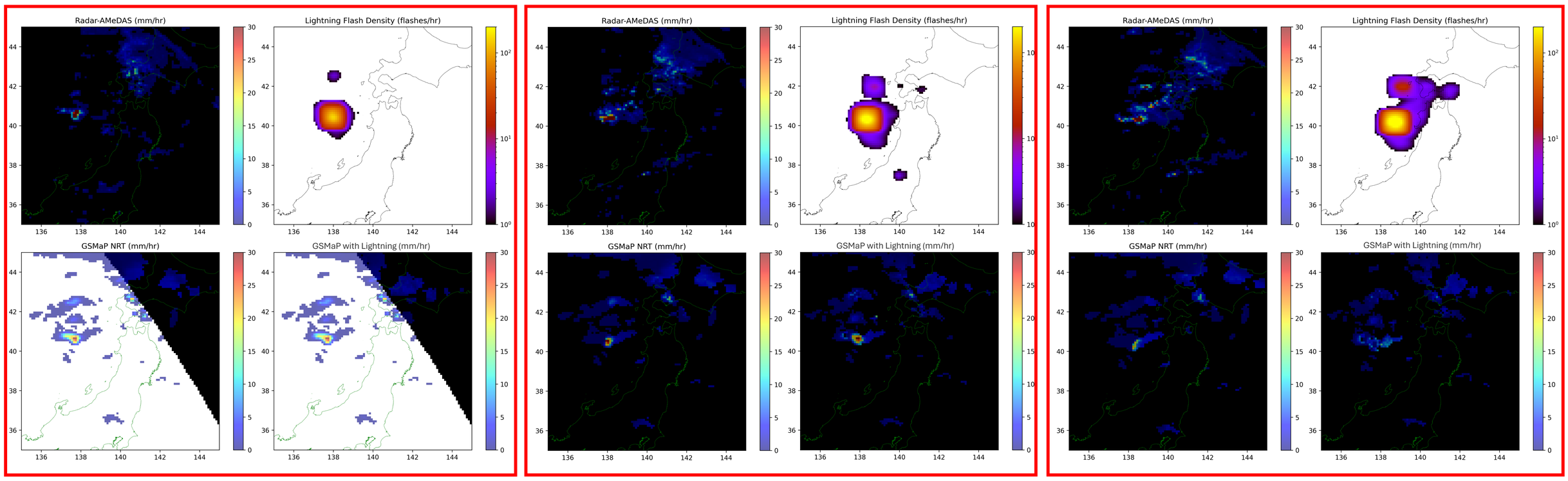
Kalman Gain

$K = PH^T(HPH^T + R)^{-1}$

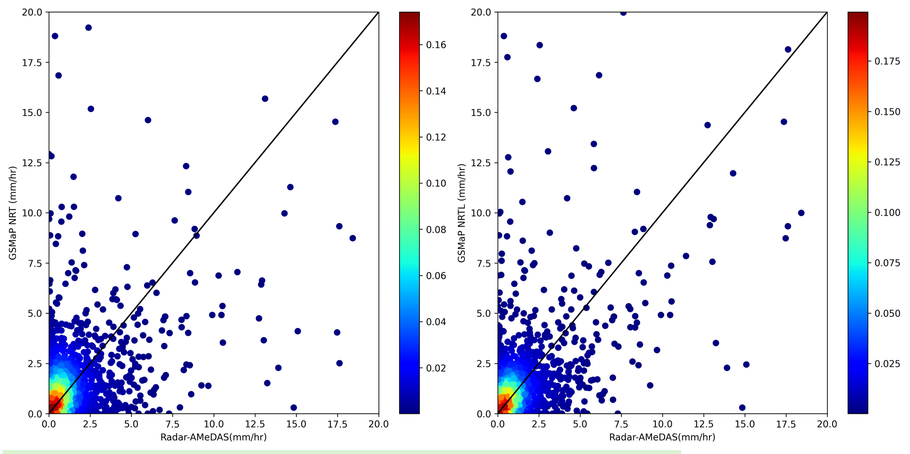
State Update

$\widehat{x_k} = x_k + K(z_k - H_k * x_k)$

RESULTS



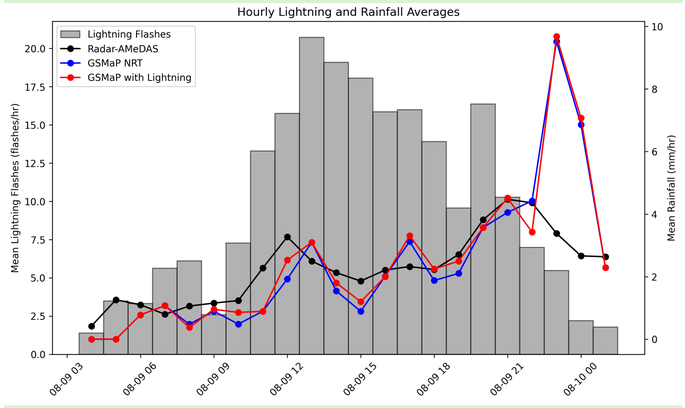
Comparison of Radar-AMeDAS with GSMaP NRT and GSMaP with Lightning



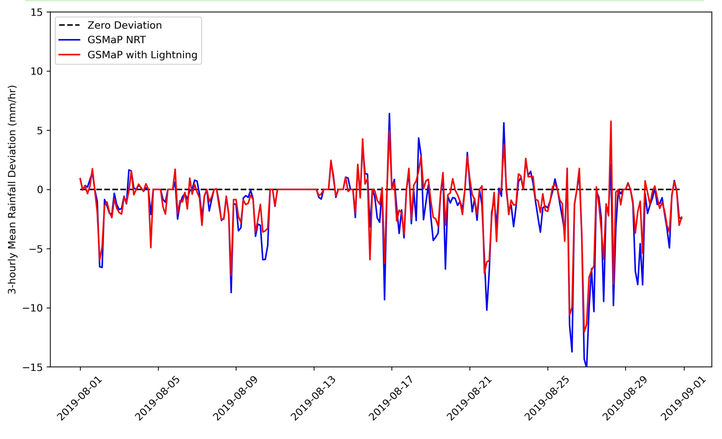
Performance of GSMaP Products with respect to Radar-AMeDAS at 0.5-degree

Resolution	Product	RMSE	MAE	Bias	Correlation
1-hr	NRT	7.6807	3.9751	-2.1965	0.3109
	NRTL	6.2120	3.4064	-1.5680	0.3206
3-hr	NRT	3.7158	2.4333	-1.9571	0.4604
	NRTL	2.9792	2.0270	-1.4650	0.4661
1-day	NRT	3.1060	2.2281	-2.2281	0.5934
	NRTL	2.5418	1.8329	-1.8329	0.5081

Time Series of Rainfall and Lightning during a Thunderstorm Case



Three-hourly Time Series of the difference between Radar-AMeDAS and GSMaP



KEY FINDINGS

- The results of the Kalman Filter with feedback information from both brightness temperature and lightning show deviations from the rainfall rates of the current GSMaP NRT.
- In a Thunderstorm case, the GSMaP with Lightning tends to show closer rainfall rates to the Radar-AMeDAS than the GSMaP NRT.
- The GSMaP with Lightning product has lower RMSE, MAE, and Bias metrics than the GSMaP NRT when compared to the Radar-AMeDAS. This is true for the time resolutions of 1 hour, 3 hours, and 1 day. However, the correlation is almost similar.
- The 3-hour difference with Radar-AMeDAS reveals that the rainfall measurements from GSMaP with Lightning are closer to the ground truth.
- Overall, the GSMaP with Lightning product derived from the new Kalman Filter approach performed better than the GSMaP NRT product which was derived similarly, but only using brightness temperature as a feedback information.

NEXT STEPS

- Perform Kalman Filter with feedback information of lightning at different weather cases such as thunderstorms, frontal systems, and typhoons.
- Derive the product using satellite-based lightning mapper data.

ACKNOWLEDGMENTS

The GSMaP NRT data were obtained from JAXA and the lightning data were acquired from the Lightning Detection Network (LIDEN) operated by the Japan Meteorological Agency (JMA).

Reference:

Ushio, T., et al., 2009: A kalman filter approach to the global satellite mapping of precipitation (GSMaP) from combined passive microwave and infrared radiometric data. J. Meteorol. Soc. Jpn., 87 A, 137–151, https://doi.org/10.2151/jmsj.87A.137.