TEMPO/GEMS Joint Science Team Workshop (Aug 26-30, 2024; Kauilua-Kona, Hawaii, USA)

Current states of GEMS surface reflectance (SFC) algorithm and improvements

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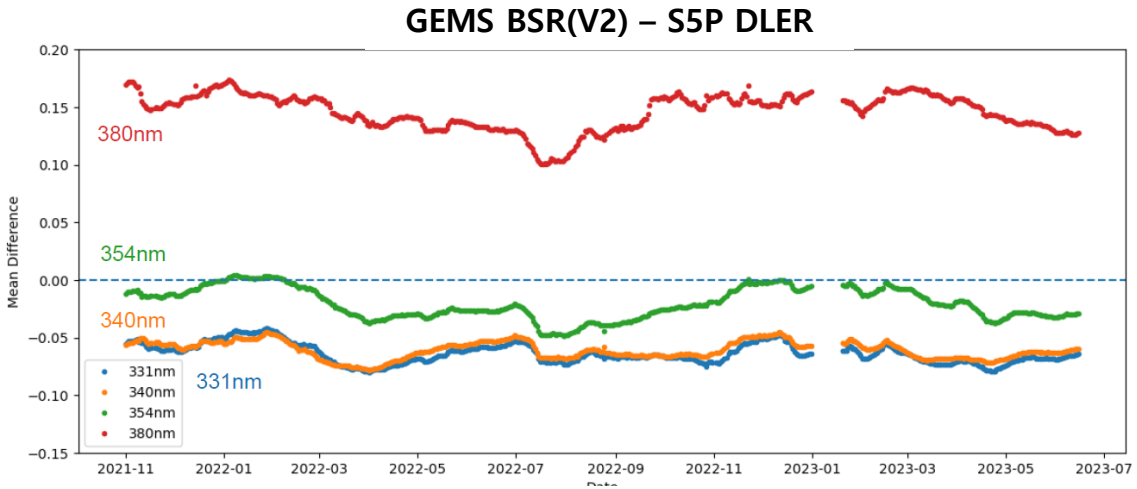
1. Introduction

Background Surface Reflectance (BSR)

- The product is an estimated (pseudo) reflectance based on observation conditions (Yeom et al., 2020; Lee et al., 2020)
- Reflectance is calculated to avoid contradictions in relationships with other L2 algorithms
- Many studies mainly use the minimum reflectance method to calculate BSR (e.g. LER*)
  - ✓ Recently, the new surface reflectance data considering the anisotropy based on preexisting LER database is produced
    (e.g. OMI Geometry-dependent LER (GLER), TROPOMI Directionally-dependent LER (DLER))
  - ➔ **In GEMS, the realistic BSR is calculated considering the surface anisotropy based on BRDF* modeling**

Issues present in current GEMS BSR (V2) product

- Under/Overestimation Issue of BSR
  - ✓ Underestimation at wavelengths below 400 nm
  - ✓ Overestimation issue in BSR at 380 nm



Difference between GEMS BSR and S5P DLER
(Image source : Pascal Hedelt, PEGASUS meeting 2023)

2. Improvements to the GEMS SFC algorithm

Interpolation of Radiance and Irradiance value

- GEMS dimensions→ Image x Spatial (2048) x Channel (1033)
  - ✓ Method: Scanning multiple images spatially (from east to west direction)
- Uniform wavelength within the same spatial domain, but with slightly different in each spatial

❖ Original approach (V2): Choose and utilize the channel with the wavelength closest to the target wavelength

❖ **Revised approach (V3): Linear interpolation by selecting the two values(channels) closest to the target wavelength**

Irradiance Data Change

- The existing GEMS IRR was excluded due to low values, resulting in an overestimation of TOA reflectance
- The available IRR at that time was from GEMS IRR and KNMI IRR, so V2 was calculated based on KNMI IRR.

❖ Original approach (V2): Used KNMI IRR

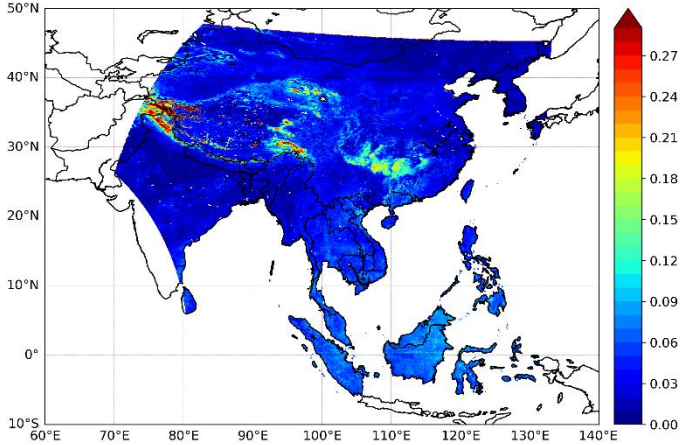
❖ **Revised approach (V3): Used GEMS IRR with BTDF correction algorithm applied**

2. Improvements to the GEMS SFC algorithm

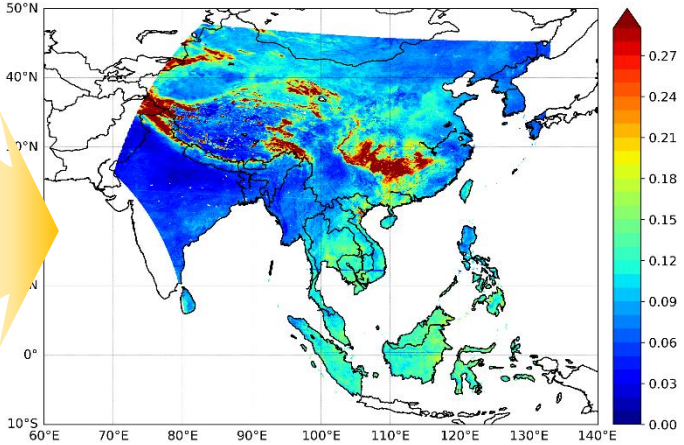
Improved underestimation and overestimation issues in GEMS BSR

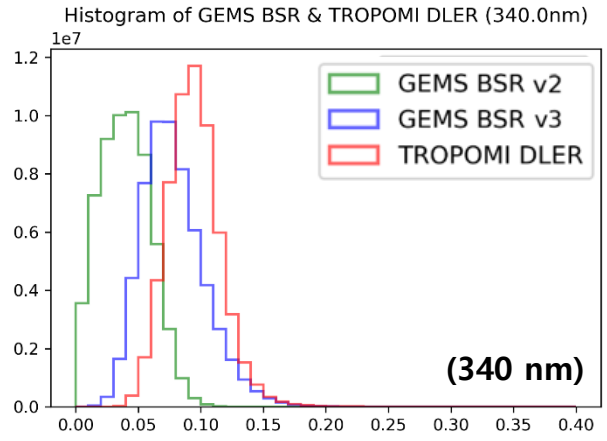
- The revised algorithm mitigates underestimation below 400 nm and overestimation at 380 nm in BSR

Initial GEMS BSR V2 (340 nm)

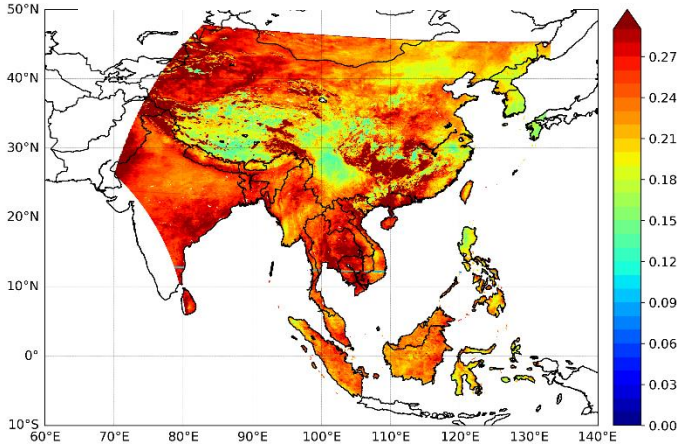


Updated GEMS BSR V3 (340 nm)

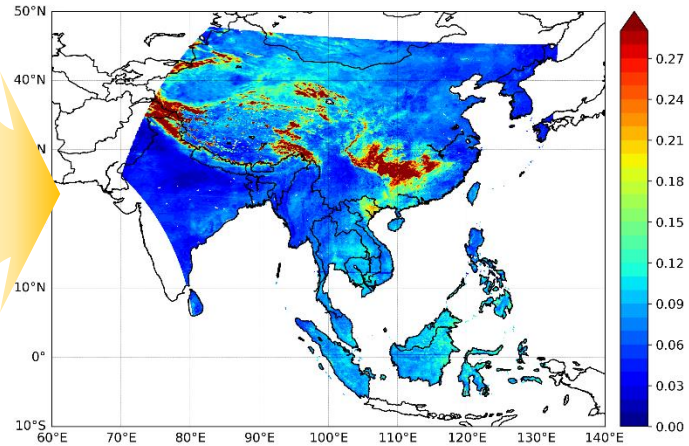


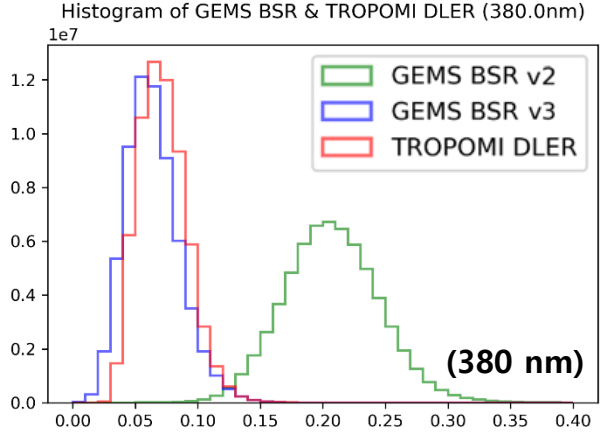


Initial GEMS BSR V2 (380 nm)



Updated GEMS BSR V3 (380 nm)



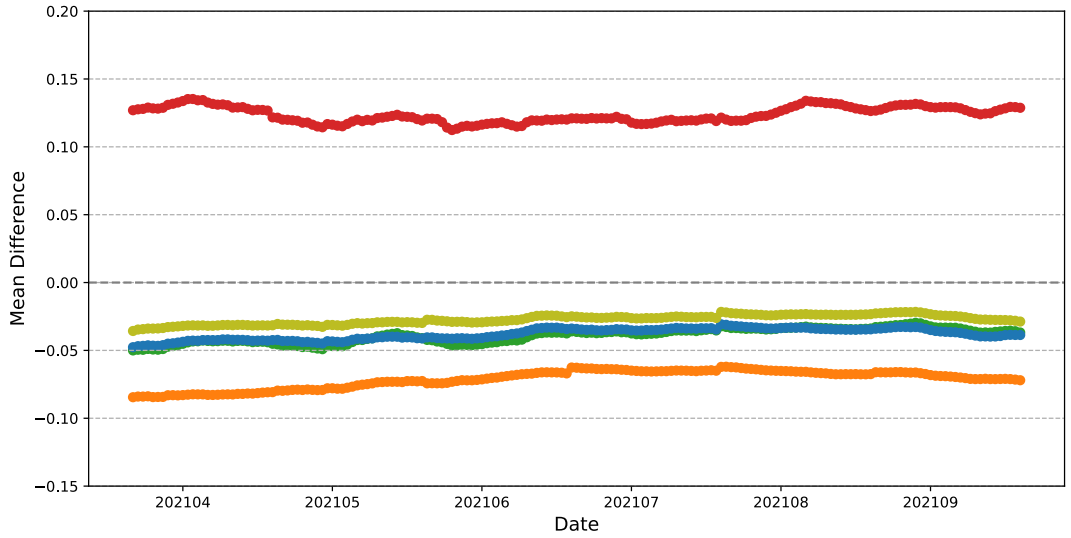


2. Improvements to the GEMS SFC algorithm

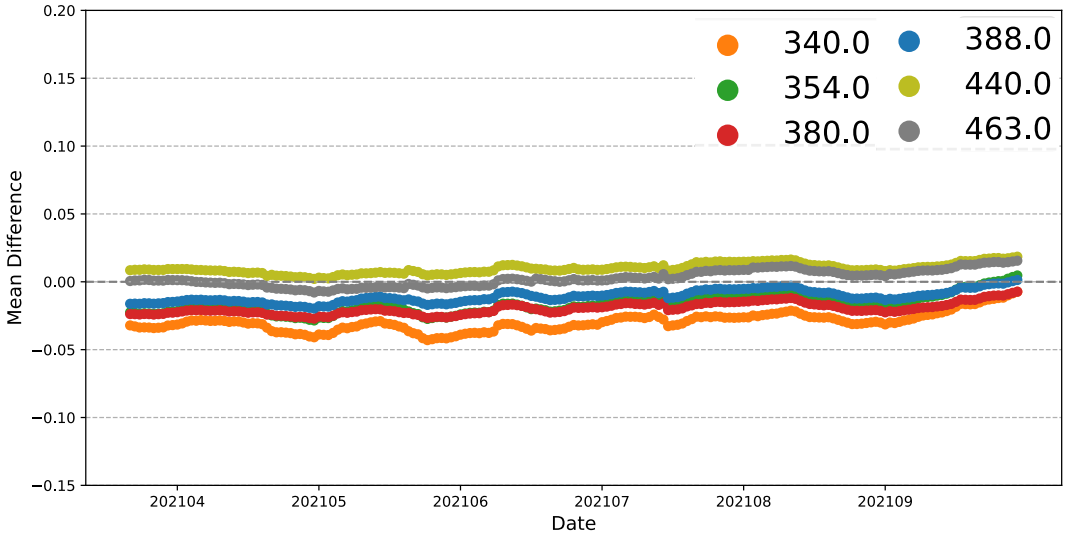
Comparison between GEMS BSR and TROPOMI DLER

- Select all clear pixels with quality flag=0, and both SZA and VZA is less than 70 degree
- Calculate mean difference (BSR – DLER) with same wavelength pairs (340, 354, 380, 388, 440, 463 nm)
  - ✓ BSR 463 nm only exists in V3 because it was added in V3 update
- Comparison period : 2021.04 ~ 2021.09 (7 months)
  - ✓ GEMS overpass at 4:45/5:45 UTC coincides with TROPOMI overpass time over Korea → Only 0445 UTC data are used to compare
- The difference with DLER was substantially reduced when employing BTDF Irradiance and interpolation method

GEMS BSR (Initial; V2) – S5P DLER



GEMS BSR (Updated; V3) – S5P DLER

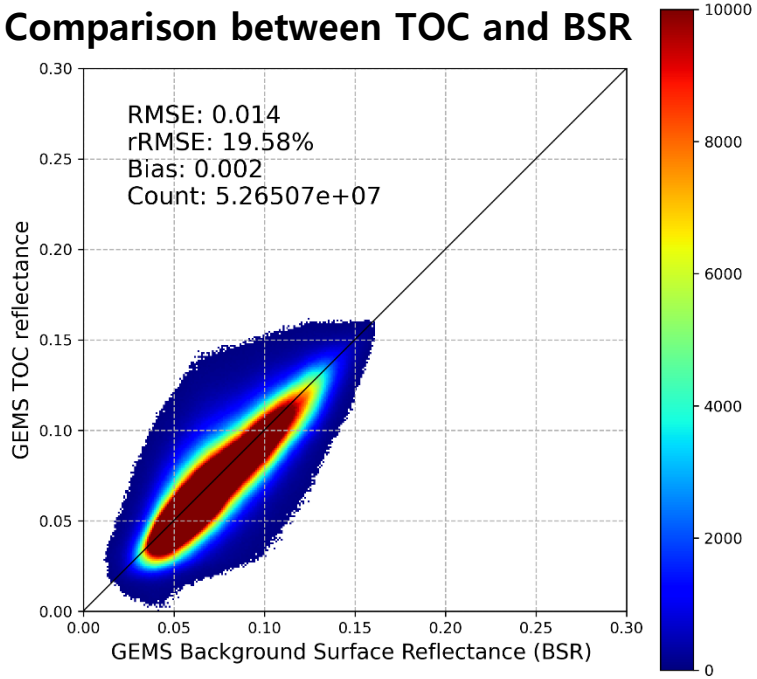


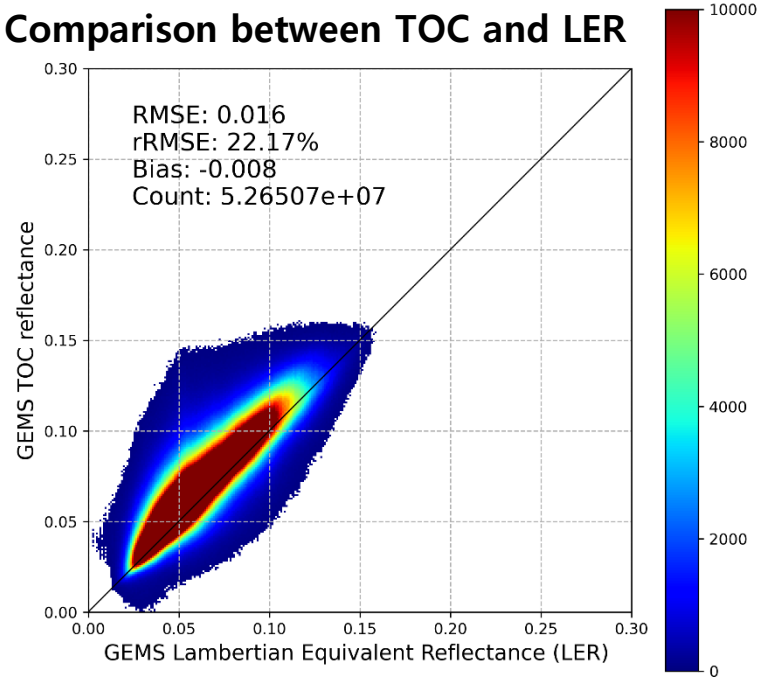
3. Intercomparison between GEMS BSR and LERs

TOC* = Top-Of-Canopy

Comparison between GEMS BSR and GEMS LER

- GEMS LER → Assumes Rayleigh atmosphere with AOD = 0, performs atmospheric correction, and applies minimum reflectance
  - ✓ The lowest reflectance occurring at the same pixel during the compositing period (Same as BRDF; 15-day) is selected
- Purpose of BSR and LER → Simulate reflectance similar to TOC* calculated based on actual outputs (AOD, CLD, O3T)
- Use GEMS TOC as a reference → Compare GEMS BSR and LER
- BSR shows approximately 3% higher rRMSE accuracy than LER, with a bias improvement of about 0.006

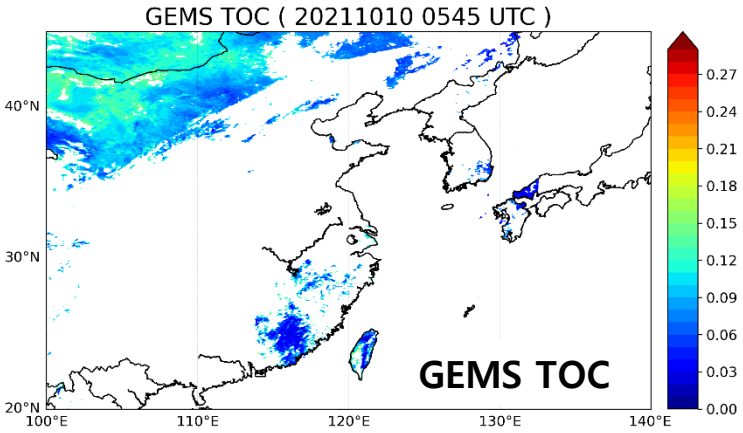


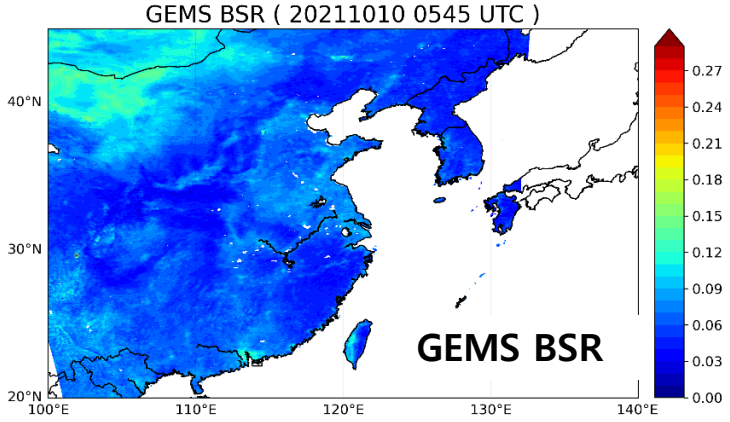


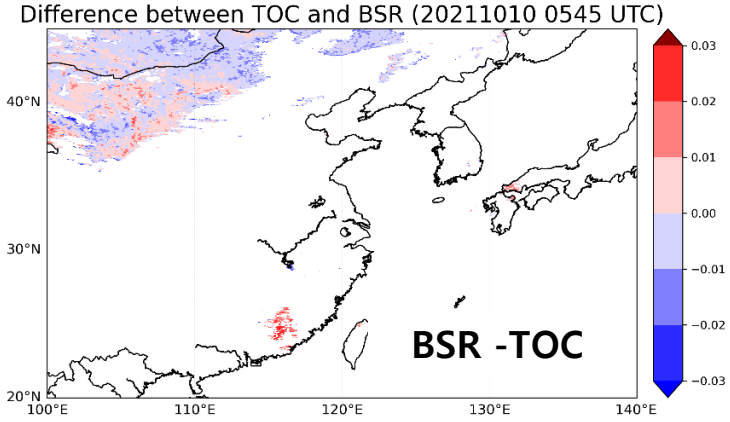
3. Intercomparison between GEMS BSR and LERs

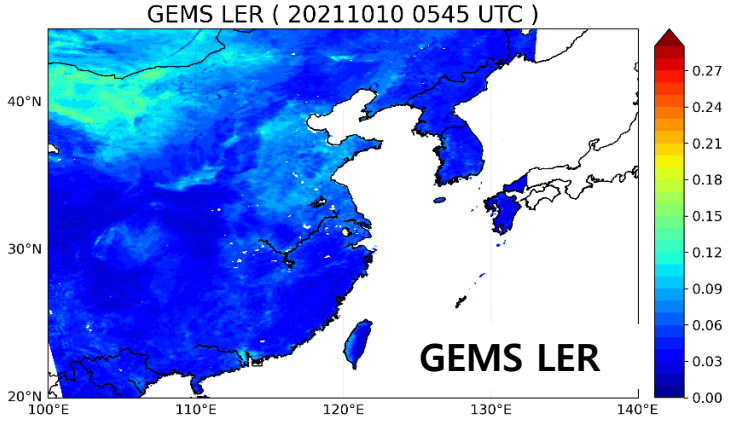
Comparison between GEMS BSR and GEMS LER

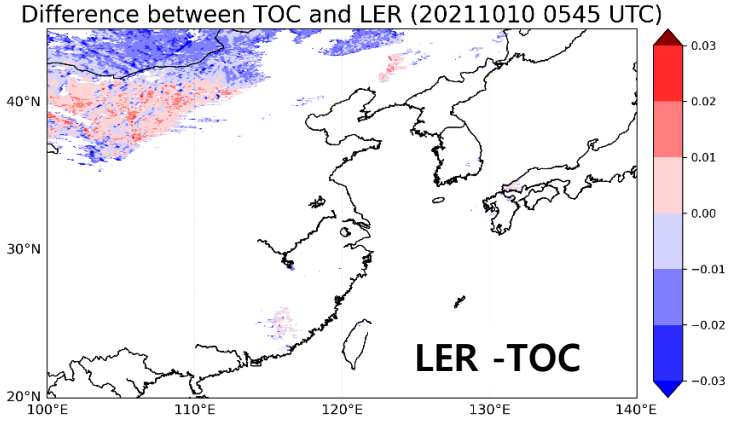
- Qualitative verification of BSR and LER based on GEMS TOC reflectance (2021. 11. 10. 0545 UTC)
- Both LER and BSR show similar trends compared to TOC, but the magnitude is exaggerated in LER
- Even with the minimum reflectance method applied, there may be an overestimation → Highlights the importance of BRDF









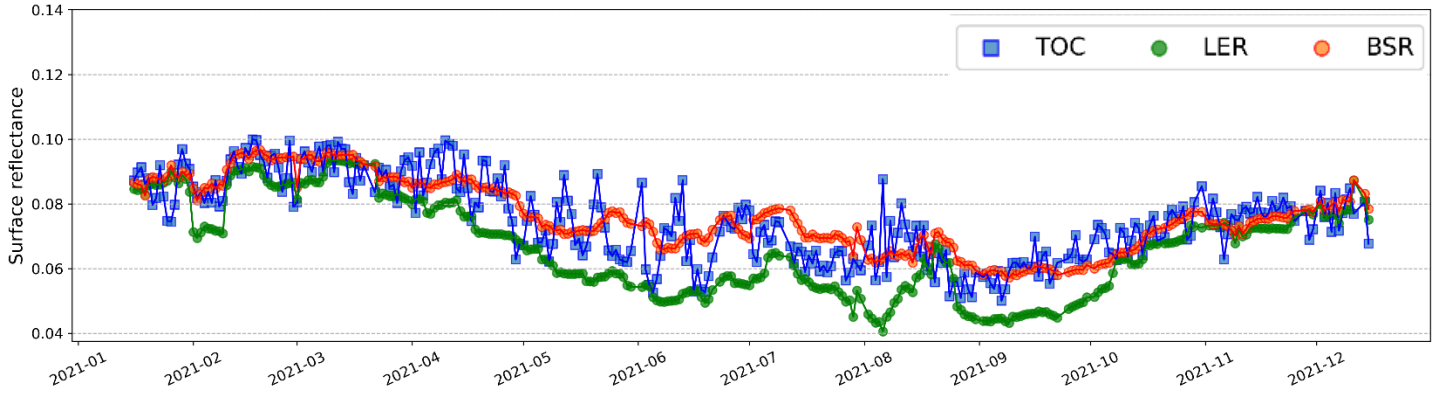


3. Intercomparison between GEMS BSR and LERs

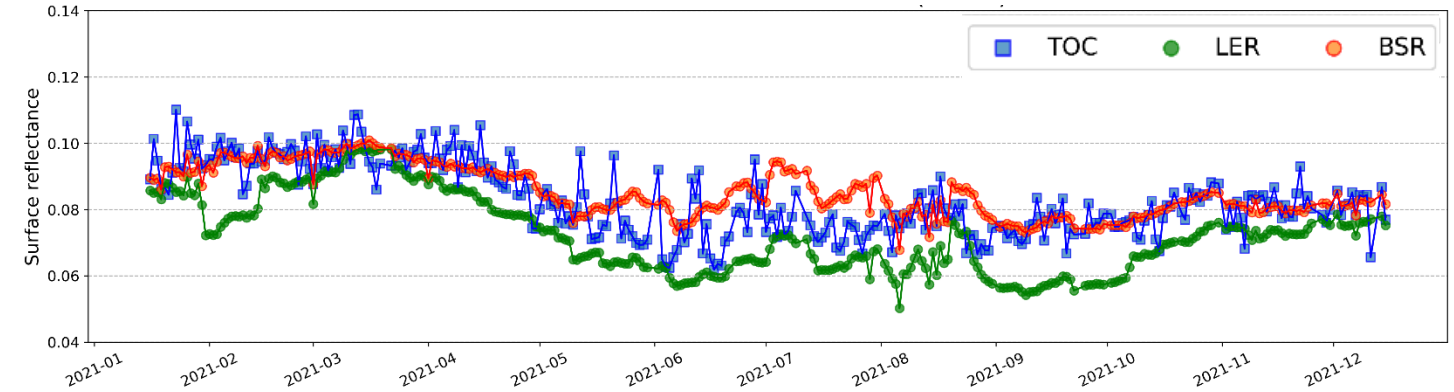
Analyzing surface reflectance variation across land types (GEMS BSR & LER)

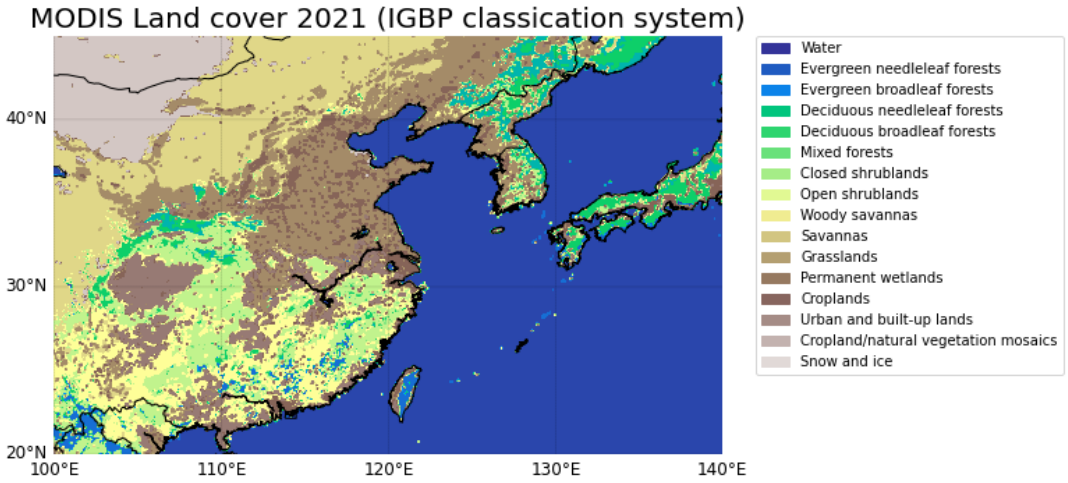
- Performed time-series distribution analysis for Cropland and Urban areas (using 2021 Landcover data (MCD12C1))
- The time-series analysis shows that BSR follows the TOC trend better than LER across both land cover types

Surface reflectance time series (Cropland)



Surface reflectance time series (Urban)





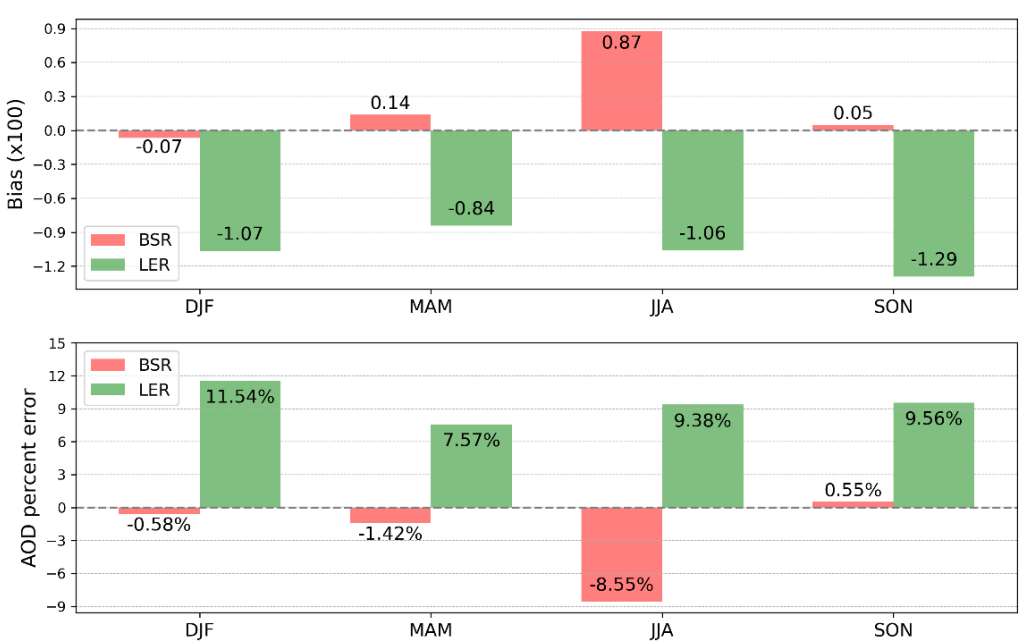
MODIS land cover (MCD12C1)

3. Intercomparison between GEMS BSR and LERs

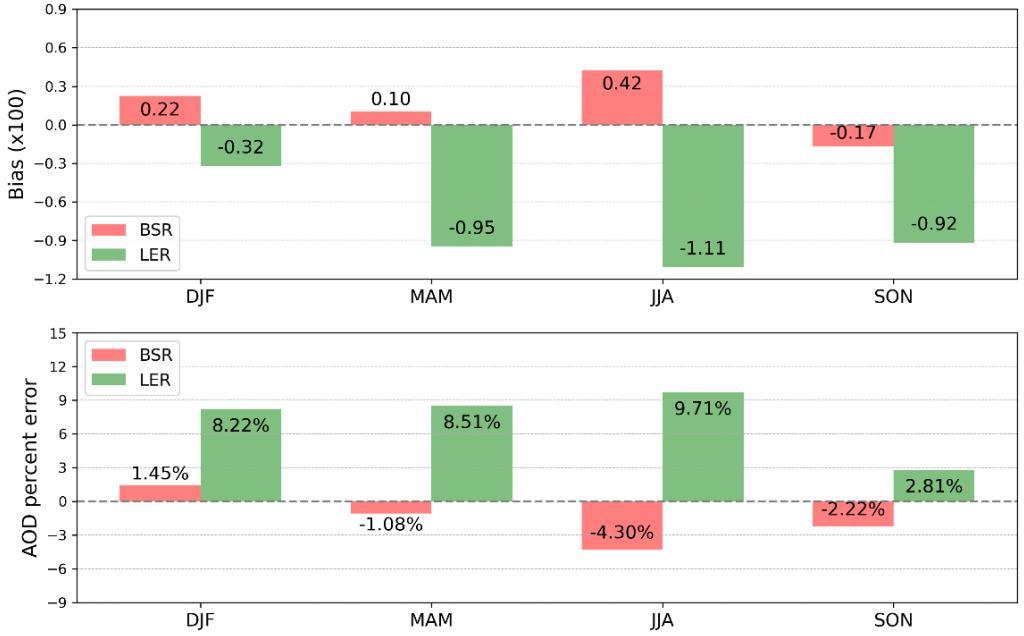
Analyzing surface reflectance variation across land types (GEMS BSR & LER)

- Analyzed the impact of surface reflectance changes on AOD based on standards suggested by previous studies (Li *et al.*, 2012)
- Using TOC-derived AOD as the reference, error analysis of AOD when using GEMS BSR and LER (AOD fixed at 0.4)
- When reflectance is underestimated, AOD tends to be overestimated, with BSR causing lower AOD errors compared to LER
  - In particular, during the summer, there is about an 18% AOD percent error difference in Cropland and about 15% in Urban areas

Cropland (Bias of reflectance, AOD error)



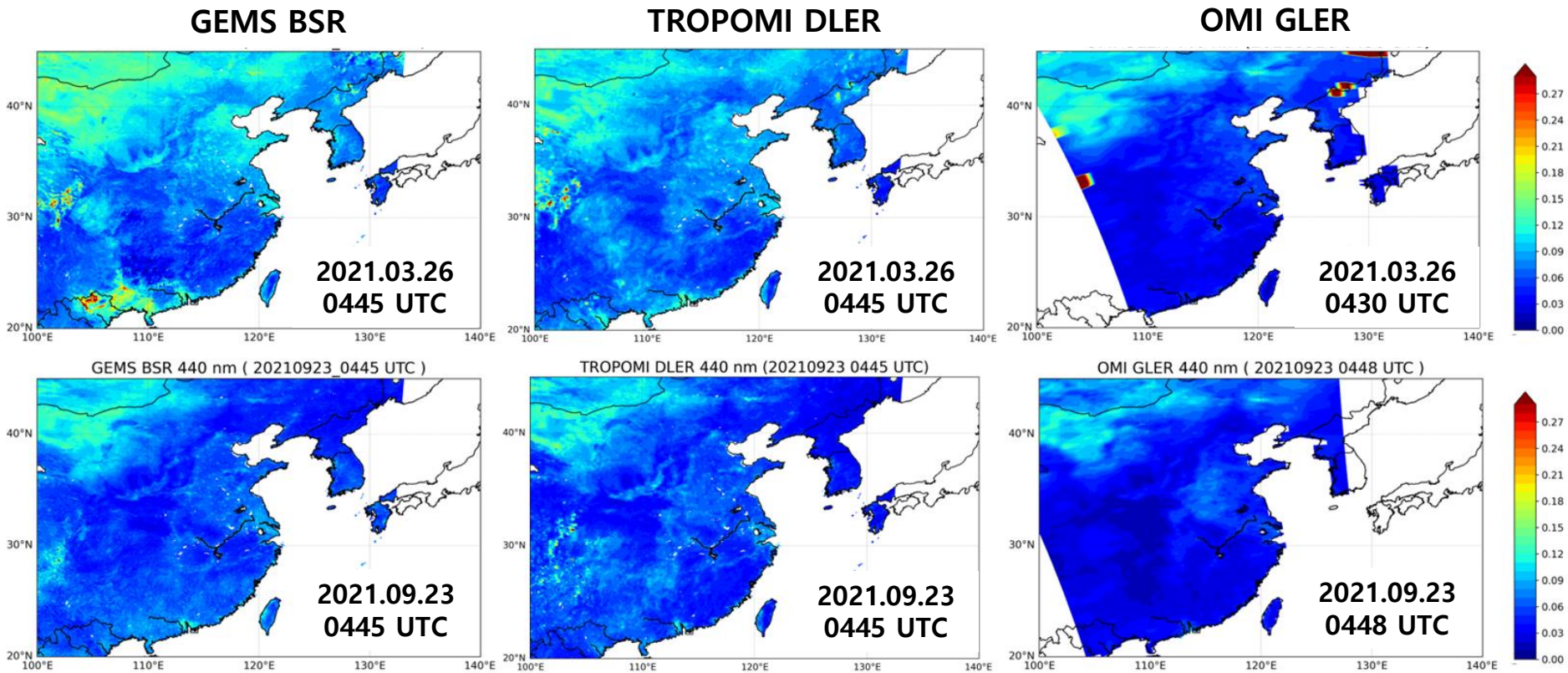
Urban (Bias of reflectance, AOD error)



3. Intercomparison between GEMS BSR and LERs

Qualitative comparison between GEMS BSR, GLER, and DLER (440 nm)

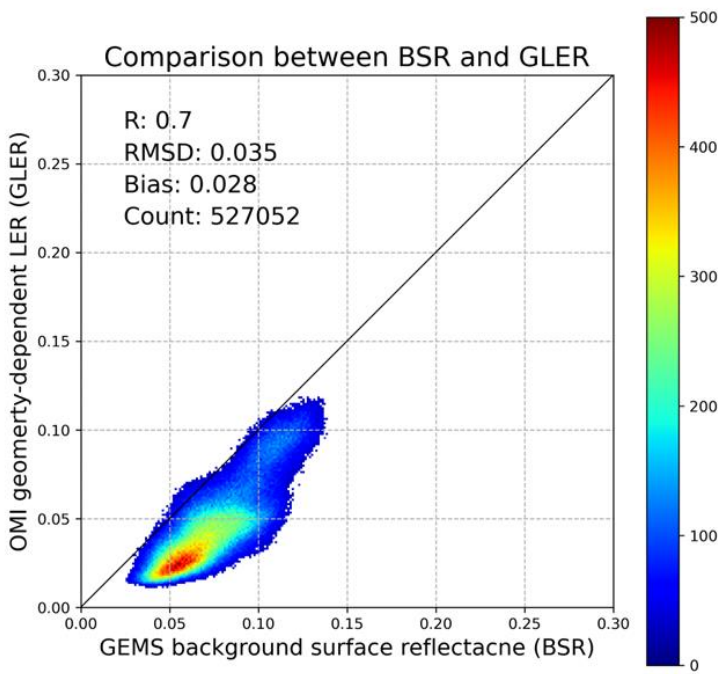
- All three datasets show similar distributions above 35° N, but GLER shows lower values in the eastern and western China
- GEMS BSR shows a distribution more similar to TROPOMI DLER than to OMI GLER
- Despite differences in reflectance values, the similar distribution suggests that BSR, like GLER and DLER, may consider BRDF



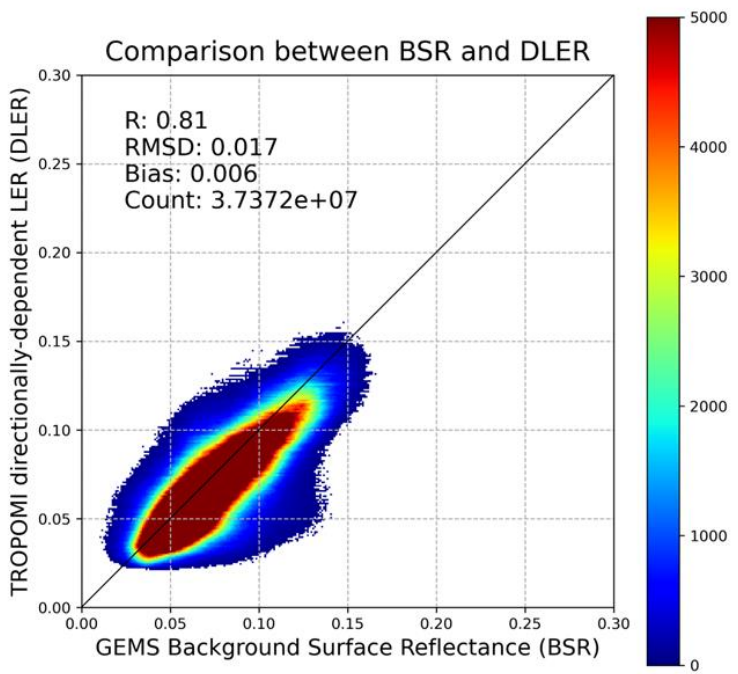
3. Intercomparison between GEMS BSR and LERs

Quantitative comparison between GEMS BSR, GLER, and DLER (440 nm)

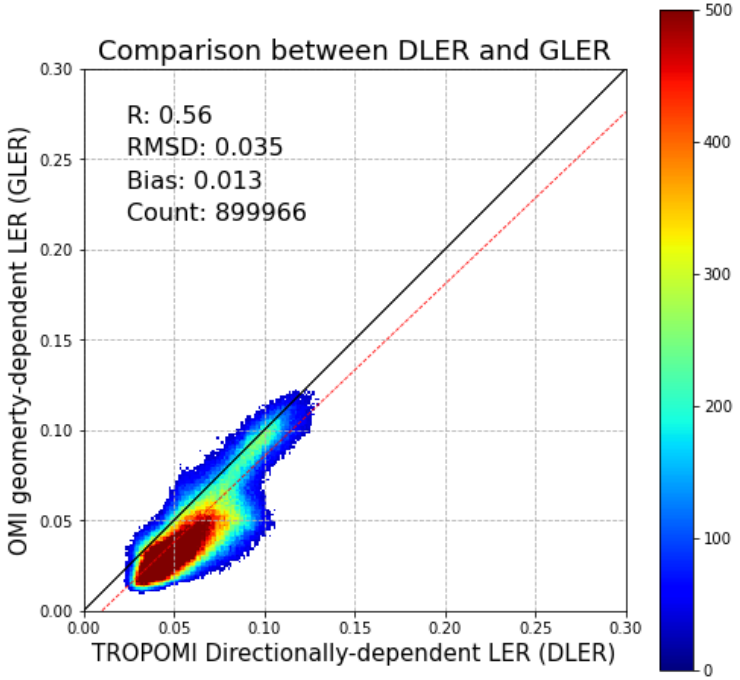
- Qualitative comparison between GEMS BSR, TROPOMI DLER, and OMI GLER → Utilizing data within a maximum of 15 minutes
- Reflectance values are highest in the order: OMI GLER << TROPOMI DLER < GEMS BSR
- All three datasets show some bias but similar distributions, confirming that they simulate similar BRDF distributions



GEMS BSR vs. OMI GLER



GEMS BSR vs. TROPOMI DLER



OMI GLER vs. TROPOMI DLER

4. Conclusion & Future plan

Conclusion

- Develop a BSR retrieval algorithm can reflect the anisotropic distribution characteristics of the surface through BRDF modeling
- Improve existing under/over-estimation issues through radiance/irradiance interpolation in V3 BSR product
- Confirmed that the V3 BSR product shows comparable or superior performance when compared with GEMS LER
- Confirmed similar distributions in comparisons with OMI GLER and TROPOMI DLER, suggesting that BSR can simulate BRDF

Future plan

- Conduct validation and comparison limited to the East Asia region → Plan to expand analysis across the entire GEMS domain
- Perform additional verification of BSR in the UV range and conduct sensitivity analysis on outputs sensitive to these wavelengths
  - ✓ Such as SO_2, HCHO, CHOCHO, Ozone etc.
- Provide feedback on issues arising from the use of BSR in the L2 algorithm

Thank you for listening :)

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