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TROPOMI Geometry-dependent Lambertian-equivalent surface reflectivity (GLER) product for improved trace-gas retrieval

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Background

- Accurate information about the reflectivity of the Earth's surface is required for most satellite retrievals of atmospheric composition, and this information is generally taken from monthly surface reflectivity climatology that neglects angular dependence. The dependence of surface reflection on illumination and observation directions is described by the bidirectional reflectance distribution function (BRDF). Recently there have been studies to account for the surface BRDF effects in trace gas retrievals, such as Geometry-dependent surface Lambertian-equivalent reflectivity (GLER) by Vasilkov et al. (2017), Qin et al. (2019) and Fasnacht et al. (2019); Geometry-dependent Effective LER (GE_LER) by Loyola et al. (2020); Directionally dependent Lambertian-equivalent reflectivity (DLER) by Tilstra et al. (2021).
- We have developed global GLER products, previously for the Ozone Monitoring Instrument (OMI) and recently for Sentinel-5 Precursor (S5P) TROPOspheric Monitoring Instrument (TROPOMI) with several new improvements and updates, which include use of
  - ✓ near real time daily V006 MODIS MCD43C1 BRDF data and gap-filled with a daily BRDF coefficient climatology,
  - ✓ NASA's Global Modelling Initiative (GMI) hourly 0.25 x 0.25 deg Replay simulations for more accurate determination of pixel specific terrain pressure, and
  - ✓ 4-km near real time snow cover product from the Interactive Multi-sensor Snow and Ice Mapping System (IMS) by the U.S. National Ice Center (USNIC) to improve detection of seasonal snow/ice scenes.
- We also demonstrated how the use of GLER is beneficial to TROPOMI's high spatial resolution (up to 3.5 km x 3.5 km) measurements to monitor atmospheric trace gas pollutants down to the sub-city scale.

Methods

GLER is derived from the following equation

$$I_{TOA} = I_0 + GLER*T/(1 - GLER*S_b)$$

VLIDORT (vector linearized discrete ordinate radiative transfer model) is used to calculate the top of the atmosphere radiance (I_{TOA}) for a Rayleigh atmosphere over a **non-Lambertian surface**.

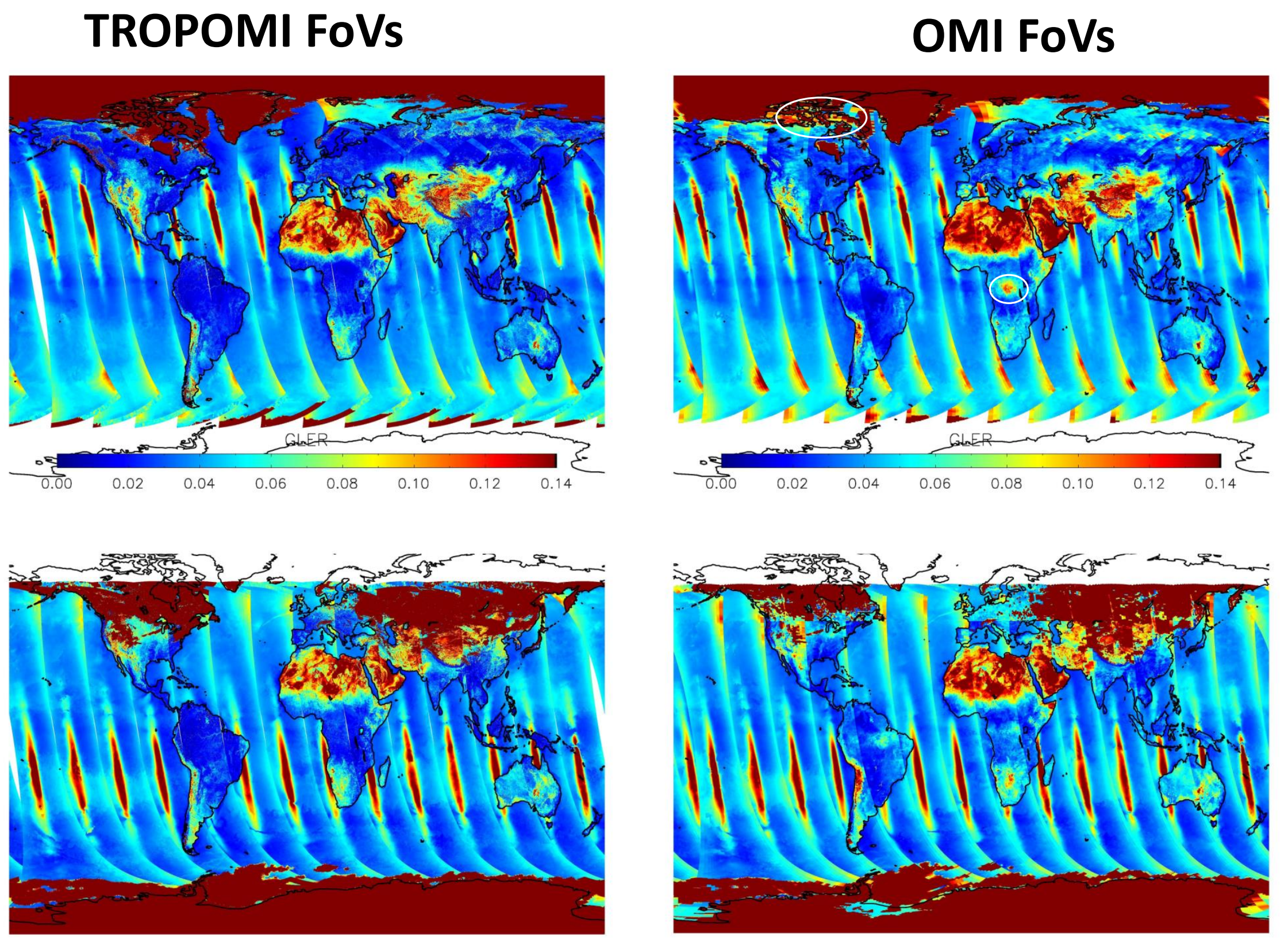
- **Over land**, the MODIS-derived BRDF function (RTLS) and BRDF product (MCD43C1) is applied and averaged over sensor's field of view (FoV).
- **Over ocean**, models to accounts for both light specularly reflected from the rough ocean surface (Cox-Munk slope distribution) and diffuse light backscattered by water bulk (i.e., contribution from water-leaving radiance).
- Look-up tables for I_0, T and S_b are generated also with VLIDORT.

Major updates for TROPOMI GLER

	TROPOMI	OMI (Col 3)
Land	MCD43C1 V006 (daily, 5-km reso. & near-real-time, with flags for data quality and gaps)	MCD43GF V005 (1-km reso but every 8-days, gap-filled, snow-free, up to 2015)
Ocean	VLIDORT 2.8.3	VLIDORT 2.7.6
GMI	Hourly, 0.25 x 0.25 deg	Monthly, 1 x 1 deg
Snow/ice	IMS (4 km resolution, N hemi only) by the U.S. National Ice Center	NISE (25 km reso) from NOAA National Snow and Ice Data Center

We do gap-filling of MCD43C1 data using the daily BRDF climatology created from V006 MCD43GF record. GMI data is used for pixel terrain pressure computation. VLIDORT 2.8.3 has improved accuracy in water-leaving radiance computation compared to the previous version.

GLER at 466 nm



06/21/2020

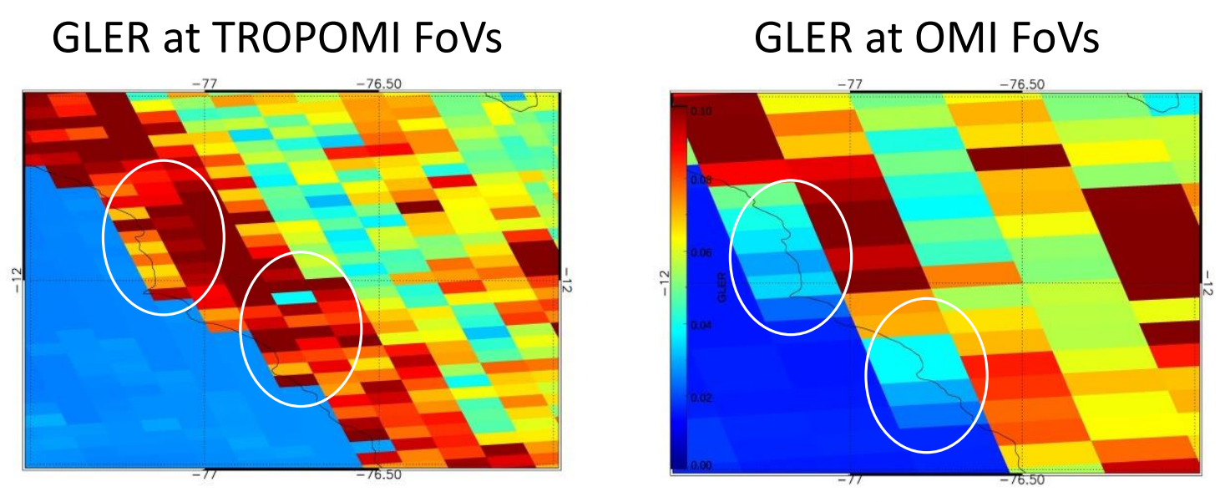
Both GLERs are similar in general except in a few areas (white circles in OMI map) due to different snow/ice data used (for that in N. Canada) and geometry difference (for that in C. Africa)

12/21/2020

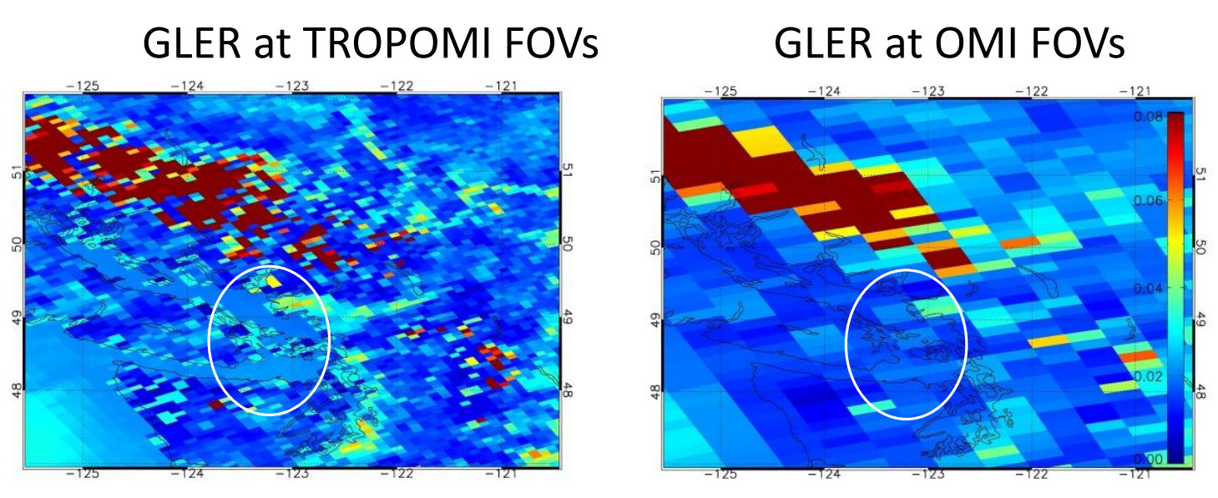
Similar patterns of difference observed to these in 6/21/20. The lower GLER of OMI than TROPOMI over the Larsen ice shelf need more investigation.

TROPOMI GLER in inhomogeneous scenes

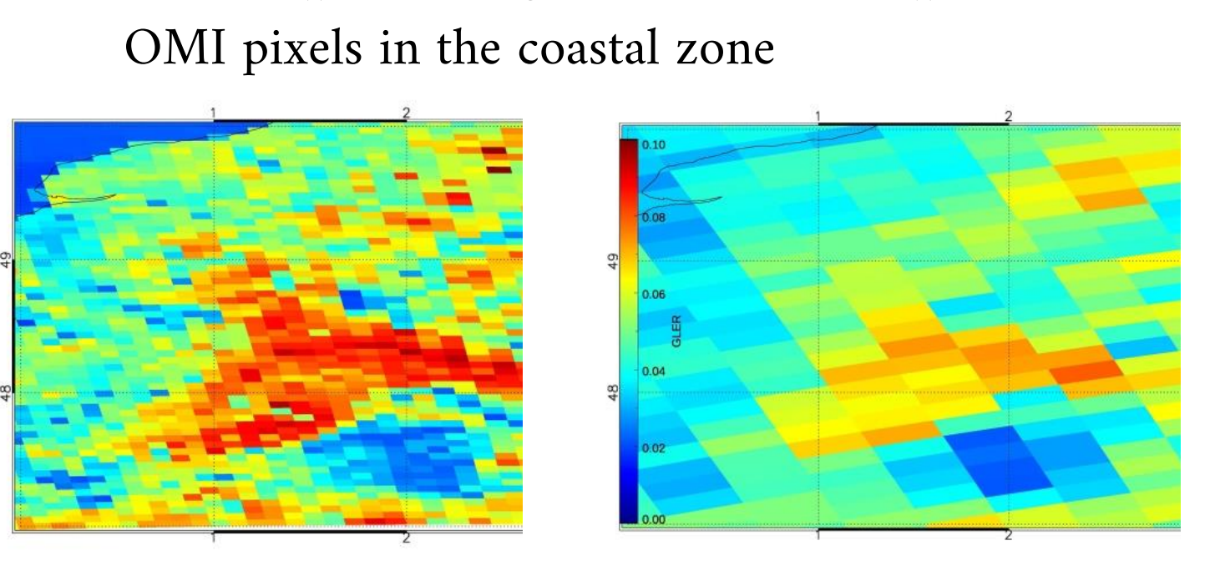
TROPOMI's high spatial resolution (3.5x3.5 km) GLER better characterizes the city boundary and structure



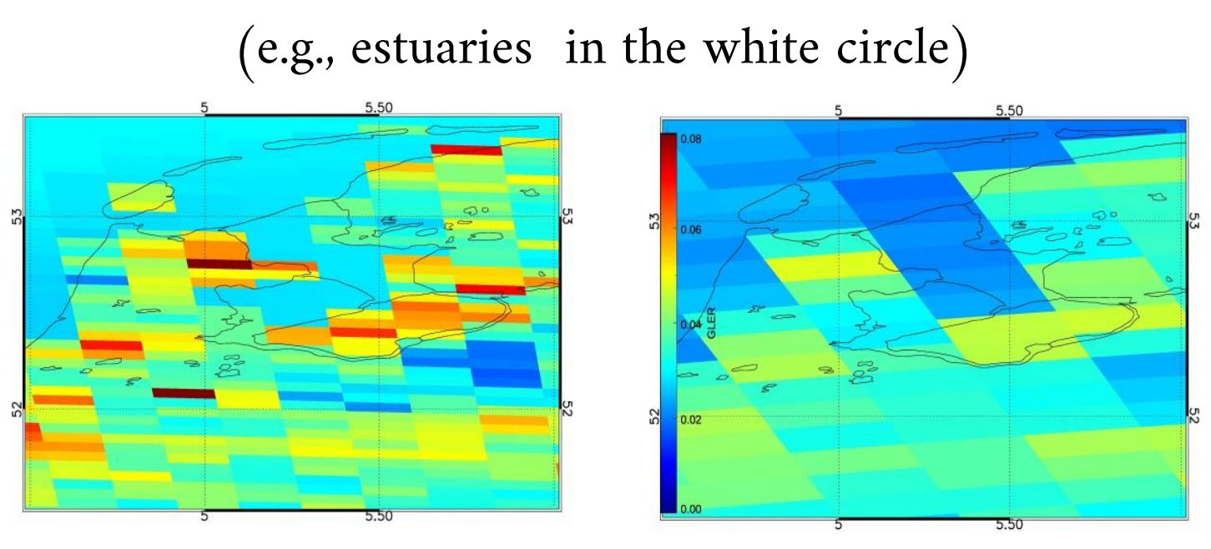
Lima, Peru (coast-mountain region), with much lower GLERs for mixed land-water OMI pixels in the coastal zone



Vancouver (complex landscape), with a lot of details smoothed out in OMI (e.g., estuaries in the white circle)

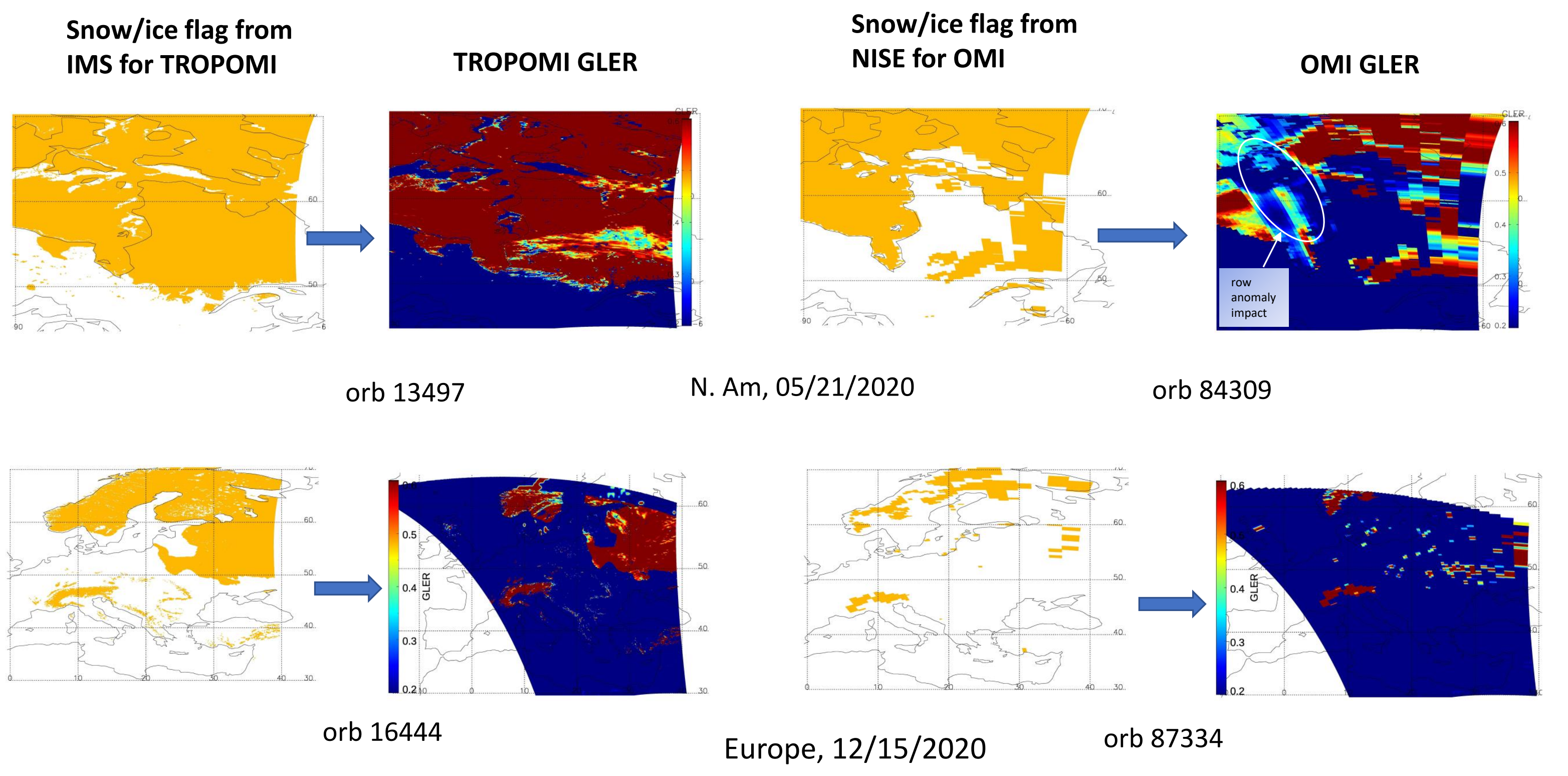


Paris, with OMI GLER smaller than TROPOMI due to different geomtries



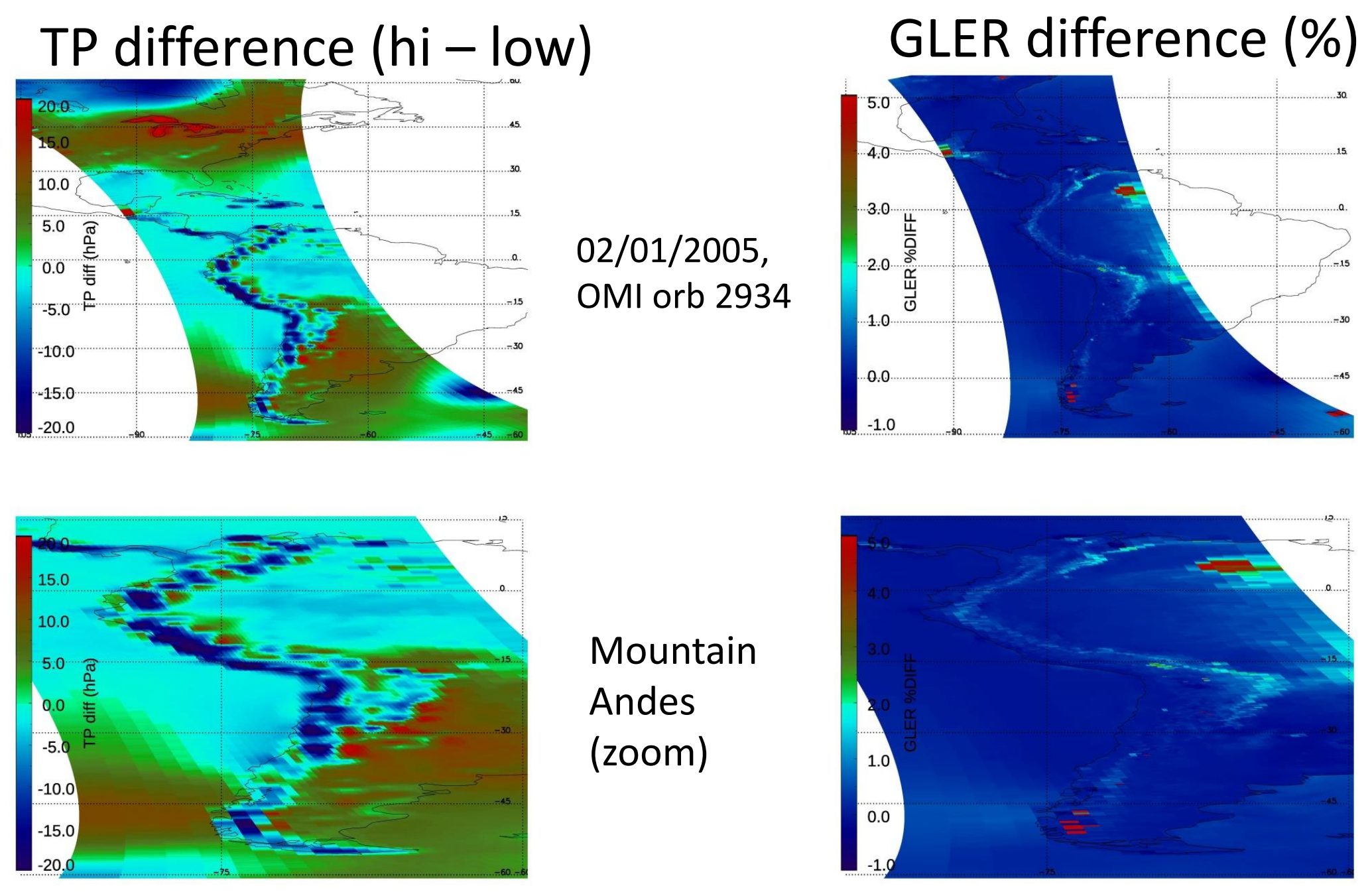
Amsterdam, small towns undetectable in OMI

GLER over snow and ice



- Detection of snow/ice cover is critical due to the dramatic difference between snow/ice and snow/ice-free GLER
- IMS detected continuous snow cover in north-east Europe but NISE missed most of them.
- Similar story in the north America (NISE missed some snow/sea ice cover in the east of Hudson bay).

GLER improvement with high resolution GMI



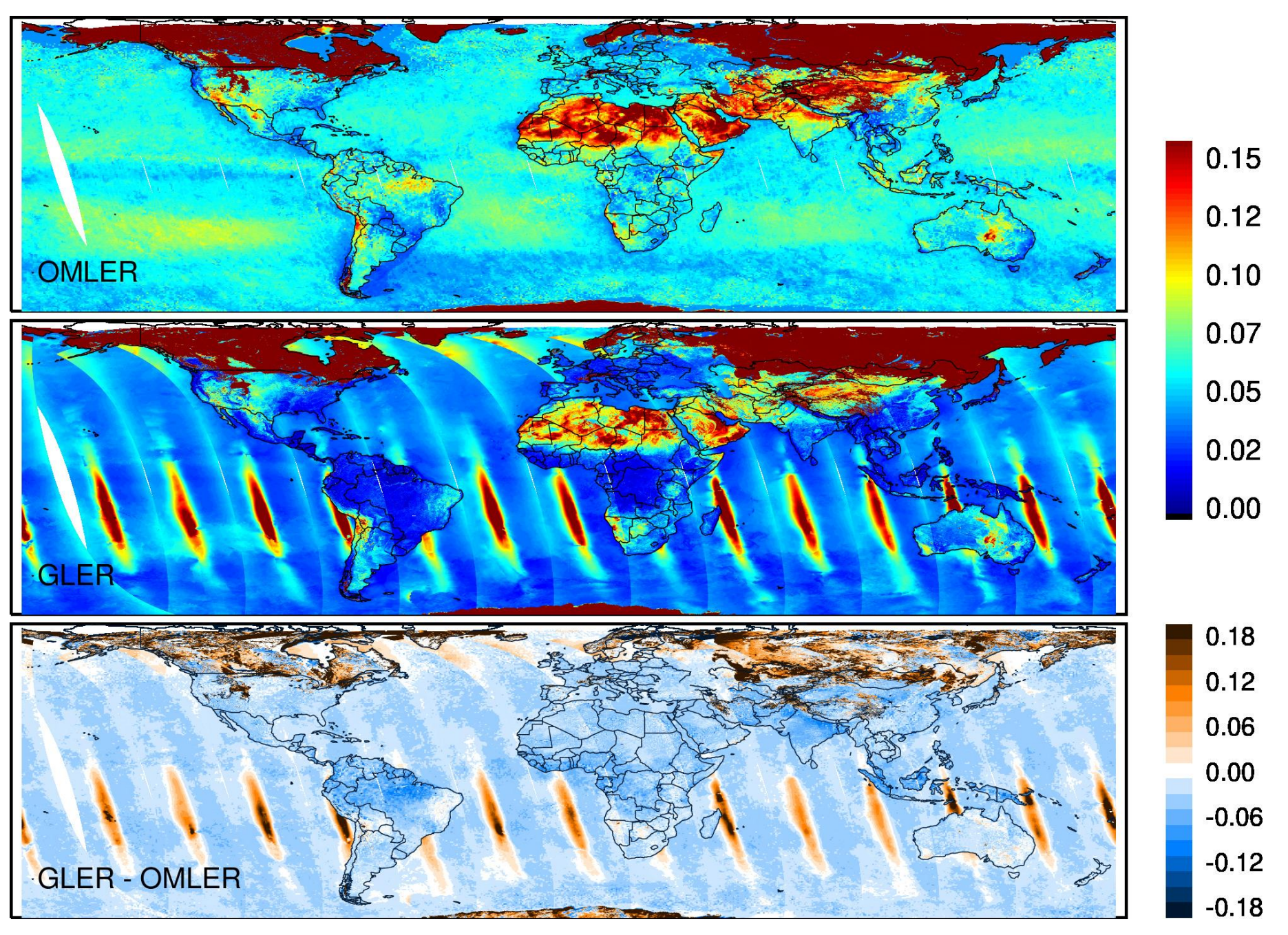
02/01/2005, OMI orb 2934

Mountain Andes (zoom)

- GLER can make upto 5% changes in complex terrains like mountains by switching to the high resolution (hourly, 0.25 x 0.25 deg) GMI data.

TROPOMI GLER vs LER Climatology (OMLER)

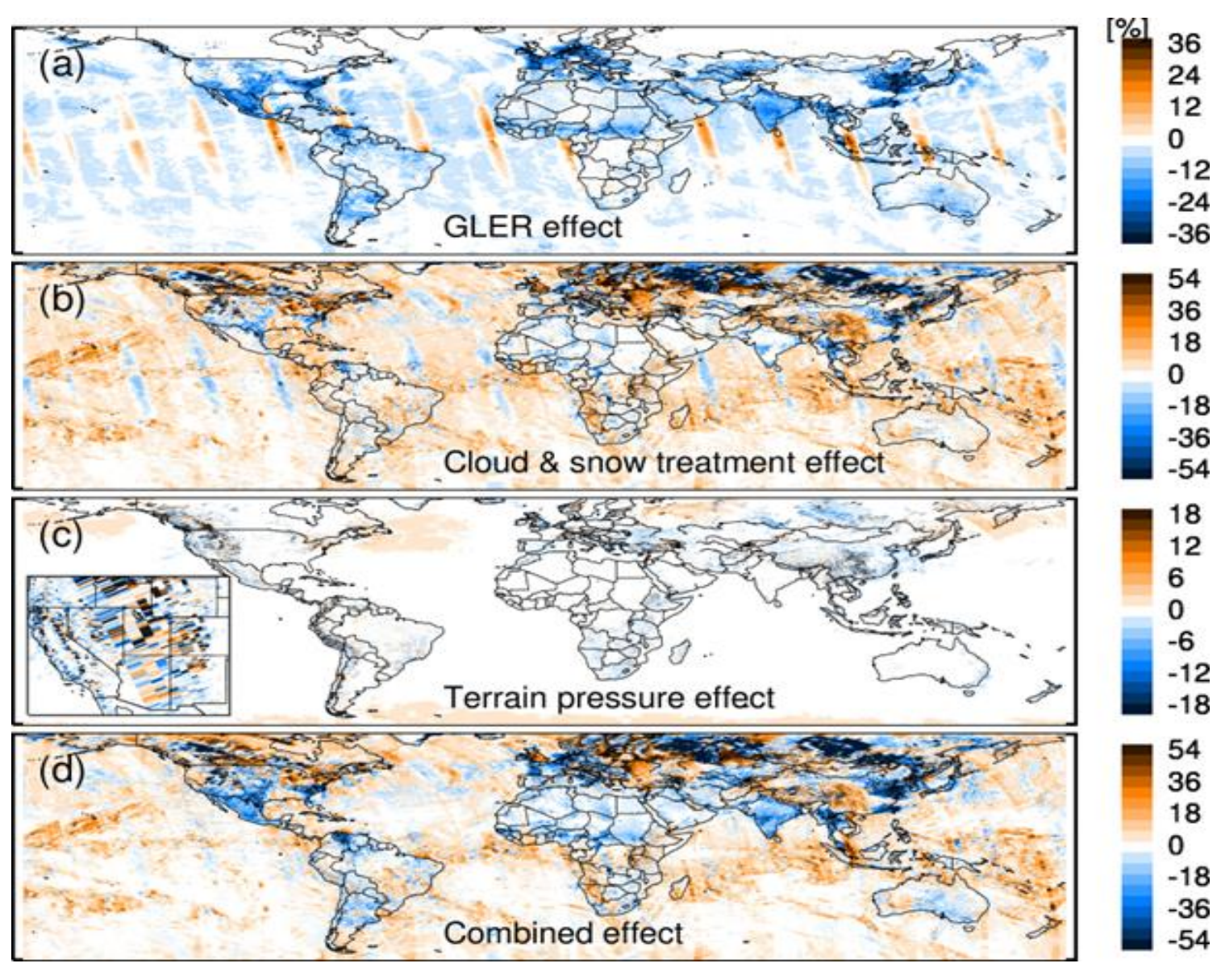
11/20/2019, 440 nm



- GLER is generally lower due to less aerosol and cloud contamination that affects the cloud retrieval (indirect effect on NO2 retrieval) as well as NO2 air mass factors
- The substantial difference between them arguing the need for a surface reflectivity database matching TROPOMI's high spatial resolution like GLER

Impact of GLER on tropospheric air mass factor of NO2

The impact (a) ranges from -50% to 25% for clear-sky scenes



Benefits of GLER approach

- captures solar and viewing angle dependencies,
- accounts for inter-annual surface changes,
- high spatial resolution accounts for inhomogeneous urban/suburban and coastal regions,
- requires no changes in operational cloud, aerosol and trace gas processors,
- provides L2 global surface reflectivity data without gap at individual sensor's FoV.

GLER approach is currently used for other satellite sensors (OMI, GOME, GOME-2) and future sensor(s) as well (e.g., TEMPO). Data is available via https://measures.gesdisc.eosdis.nasa.gov/data/MINDS/TROPOMI_MINDS_NO2.1.1

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