Innovative surface reflectance retrieval from UVN satellites

Pascal Hedelt, Klaus-Peter Heue, Ronny Lutz, Fabian Romahn, Diego Loyola

German Aerospace Center (DLR), Remote Sensing Technology Institute - Atmospheric Processors (IMF-ATP)

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Introduction

Satellite-based trace-gas, cloud and aerosol retrievals require precise information about surface properties. Usually these are based on Lambertian equivalent reflectivity (LER) climatologies calculated from long-time satellite measurements. Typically these climatologies are based on previous satellite missions which usually have significantly lower spectral and spatial resolution than current and near-future missions and provide the LER only for certain predefined wavelengths. Moreover, most of the common climatologies do not take into account viewing-angle dependencies, which can be characterized by bidirectional reflectance distribution function (BRDF) effects.

We present here a new approach providing the so-called geometry-dependent effective Lambertian equivalent reflectivity (GE_LER, see Loyola et al. 2020), using the Full-Physics Inverse Learning Machine (FP_ILM) algorithm, which combines smart sampling, dimensionality reduction techniques with machine learning for efficient and extremely fast retrievals .

Based on 6 years of Sentinel-5P/TROPOMI data a new trace-gas specific climatology was generated providing effective surface albedos in the same wavelength range as the operational TROPOMI trace-gas/cloud property retrievals. Moreover, the same operational radiative transfer model was used in the generation, minimizing influences by different assumptions for the AMF calculation and its input surface albedo. Notably, with this climatology there is no longer any dependency on climatologies from other sensors with worse spatial resolution.

GE_LER retrieval algorithm

The effective surface albedo retrieval is based on the FP_ILM algorithm, which is a Neural Network approach involving smart sampling and dimensionality reduction techniques. It is already used in the operational TROPOMI O_3 VCD and cloud retrieval, see Loyola et al. (2020).

The algorithm is split into two parts—NN training (performed offline) and application to real data (online). The application of the trained NN operator to measured data is extremely fast yet accurate, since it involves only simple matrix multiplications.

1. Neural Network training (offline)
   - Generation of simulated reflectance spectra using (V)LIDORT (Spurr 2006, Spurr et al. 2008) for each trace gas/cloud fit window on a smart sampled grid (Loyola et al. 2016).
   - Dimensionality reduction: Either PCA or DOAS polynomial coefficients
   - NN training:
     - Input SO_2/HCHO: SZA, VZA, CSA, Surface Pressure, O_3 VCD, Principal Components
     - Input O_3/NO_2/H_2O: SZA, VZA, CSA, Surface Pressure, Polynomial Coefficients, SCD
     - Input Cloud (O_2 A band): SZA, VZA, CSA, Surface Pressure
     - Output: Surface albedo
2. TROPOMI GE_LER retrieval (online)
   - Application of trained NN to measured reflectance spectra from TROPOMI to retrieve effective (GE_LER) albedo for each L2 product listed in Table 1.

Table 1: Overview of TROPOMI L2 product for which a GE_LER surface albedo retrieval is performed, related wavelength range, dimensionality reduction applied, as well as related publications

Trace-gas/Cloud	Wavelength range	Dimensionality reduction technique	Reference
	311-326nm	PCA	
SO_2	325-335nm	PCA	Hedelt et al. (2024)
	360-395nm	PCA	
HCHO	328-359nm	PCA	Hedelt et al. (2024)
O_3	325-335nm	DOAS	Loyola et al. (2020)
NO_2	405-465nm	DOAS	Liu et al. (2021)
H_2O	435-455nm	DOAS	Chan et al. (2022)
Clouds (O_2 A band)	756-771nm	None	Loyola et al. (2020)

GE_LER Climatology generation

1. Generation of daily TROPOMI GE_LER results
   - Input: 6 years of (partly reprocessed) TROPOMI L1 v2.1 data
2. Viewing-angle correction
   - Conversion from effective, viewing angle dependent GE_LER albedo to LER albedo
   - GE_LER albedo is parameterized as a polynomial function of the viewing angle ϑ
   - The correction factor is dependent on the surface type: Land / Water / Snow-Ice
3. Climatology generation
   - Cloud screening (cf < 0.01)
   - Removal of sun-glint affected or aerosol contaminated pixels
   - Gridding of monthly LER values to common 0.125x0.125° Lat/Lon grid
   - Determination of LER value for each grid cell for each month:
     - Land/Water scenes: Mean of lowest 10% LER values
     - Snow/Ice scenes: Remove lowest 10% LER values and determine mean
4. Postprocessing
   - Gaps and missing data are filled with values from other months with valid values.
5. End product
   - Monthly surface albedo climatology
     - for Clear (Land/Water) and Snow/Ice surfaces
     - for each TROPOMI L2 product listed in Table 1
   - Monthly correction factors to convert LER to scene (GE_LER) surface albedos

Results

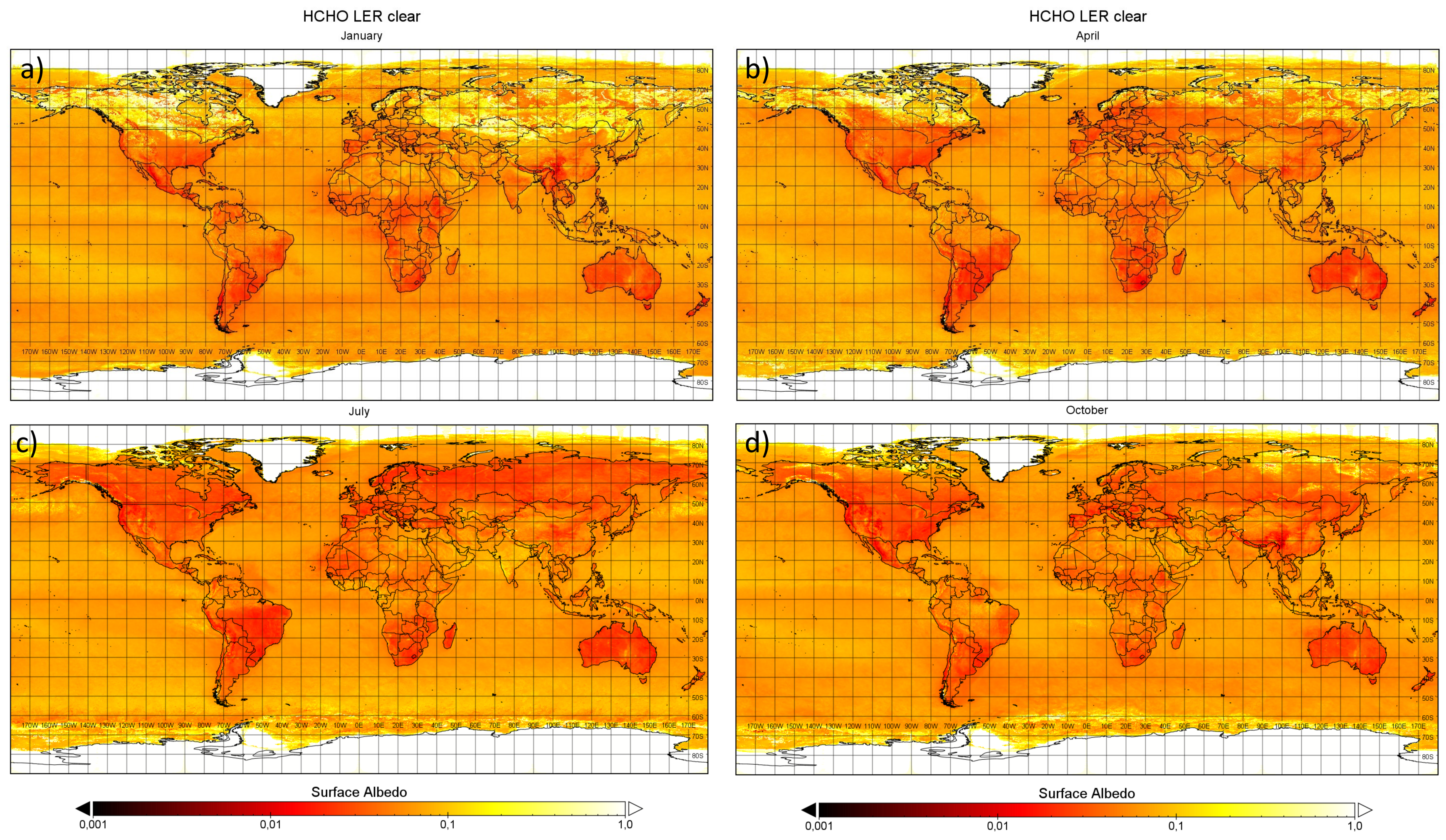

Fig. 1: HCHO GE_LER climatology (328-359nm) for clear conditions for a) January, b) April, c) July and d) October

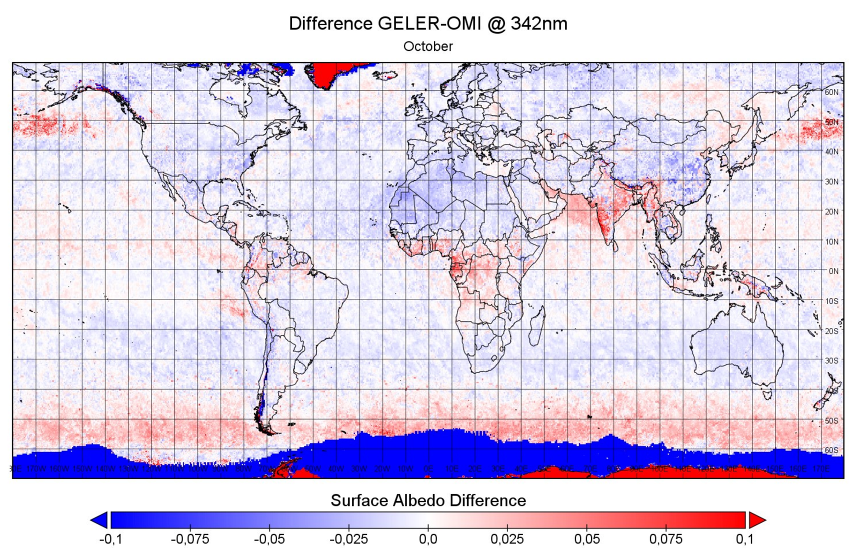

Fig. 2: Difference of HCHO GE_LER climatology (328-359nm) to OMI climatology (@342nm). Values exceeding |0.1| are due to fill values.

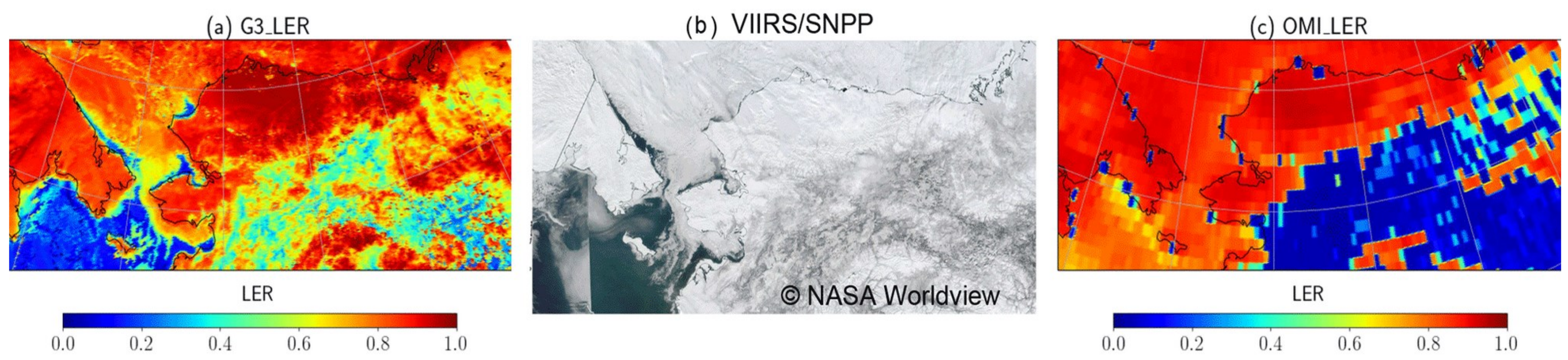

Fig. 3: Figure taken from Loyola et al (2020). S5P/TROPOMI O_3 GE_LER surface albedo measurements (a) on 1 April 2018 around the Bering Strait, agreeing well with the corresponding VIIRS/SNPP image (b) of coastal waters of Russia and Alaska. This region is not properly represented in the OMI LER climatology (c) showing snow/ice over this region.

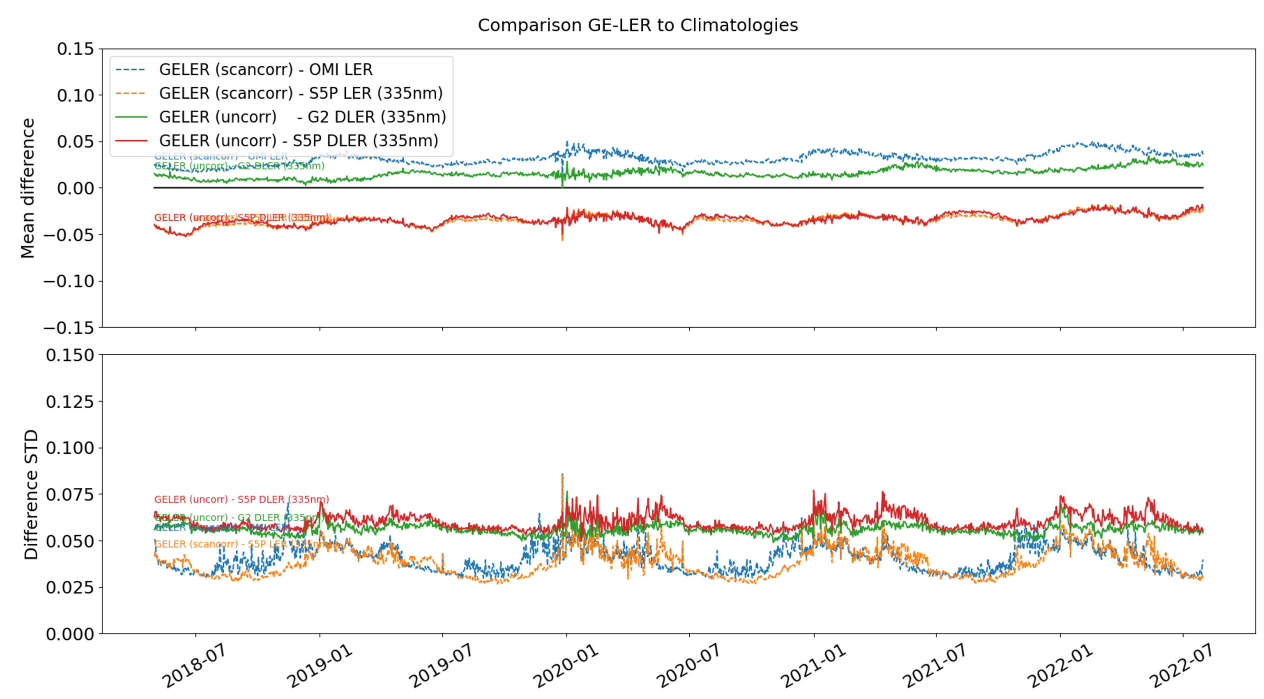

Fig. 4: Daily mean difference and standard deviation between O_3 GE_LER measurements and different climatologies.

Summary & Conclusions

- Generation of geometry-dependent effective surface albedo (GE_LER) based on 6 years of TROPOMI L1 v2.1 data
- Combined smart sampling, dimensionality reduction and Neural Network retrieval approach
- Machine learning approach allows for accurate near-real-time surface albedo retrieval
- NN training involves the same RT models as used in retrieval i.e. (V)LIDORT
- Generation of climatology for each S5P/TROPOMI L2 product in specific fit window range
  -> Avoids external dependency from databases of other sensors with worse spatial resolution
- GE_LER climatology shows good agreement with existing climatologies (e.g. OMI, Kleipool 2010)

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