Sentinel-3 Product Notice – SLSTR Level-2 Near Real Time Aerosol Optical Depth

Mission	Sentinel-3A & Sentinel-3B
Sensor	SLSTR-A & SLSTR-B

Product	Near Real Time (NRT) Level-2 (L2) Aerosol Optical Depth (AOD)
	• Operations:
	  ○ SL2_AOD at Near Real Time (NRT) timeliness exclusively.
	  ○ Granules of 5 minutes.
	• Reprocessed:
	  ○ SL2_AOD at Near Real Time (NRT) timeliness exclusively.
	  ○ Granules of 3 minutes.
	  ○ Limited set of reprocessed data available covering several months of 2019 & 2020.
	  ○ Full reprocessing to complete historic mission timeline being planned.

Product Notice ID	EUM/SEN3/DOC/20/1188082
Issue/Rev Date	11/08/2020
Version	1.0
Preparation	This Product Notice was prepared by EUMETSAT.
Approval	EUMETSAT Mission Management

Summary

This is the Product Notice (PN) for the Sentinel-3A and -3B Sea and Land Surface Temperature Radiometer (SLSTR-A and SLSTR-B) Level-2 (L2) Aerosol Optical Depth (AOD) products generated as Baseline Collection 1 with EUMETSAT Processing Baseline (PB) 2.70 (both A and B), Instrument Processing Facility (IPF) v2.0 deployed on 19/08/2020. It is exclusively applicable to products generated in Near Real Time (NRT), daytime, and global (ocean and land surfaces).

This Notice describes the L2 NRT AOD current status, the processing baseline, the product quality and known limitations for both SLSTR-A and SLSTR-B. This product deployment builds on the latest

SLSTR Level-1 Processing Baseline, operational since 15.01.2020, which provided major improvements to the SLSTR L1B product.

Users of the Copernicus Sentinel-3 L2 NRT AOD should note the following indications associated with this product version:

- The **AOD** over **ocean surfaces** is '**Preliminary Operational**'. Its scientific quality is considered to be approaching the expected requirements, nevertheless it is considered to have reached a level of maturity which can be safely exploited by users. To confirm the final operational status validation is being performed over longer time series with a larger set of ground-based measurements. The completion of this validation exercise is expected within a few months, with fine-tuning continuing for the evolution to the full 'operational' maturity level, *i.e.* matching the expected quality requirements, within the year.
- The **AOD** over **land surfaces** is currently considered '**Demonstrational**' as this is the first release of this parameter and its product quality is not yet within the expected requirements. It is noted that in this case it should be used with caution noting its known current limitations. The associated novel algorithm is still the subject of further improvements & optimisation by EUMETSAT. Its preliminary operational maturity is expected to be reached in March 2021. A broader audience of users will be then invited to perform a more in-depth quantitative evaluation.

EUMETSAT Processing Baseline		
	S3A	**S3B**
Processing Baseline (PB)	PB 2.70	PB 2.70
IPFs version	SL_2_AOD IPF version: 02.00 NRT	
Product Baseline Collection (BC)	BC 1	
Explanation about the PB nomenclature: • The collection of IPF version and static Auxiliary Data Files (ADFs) is known as the PB. The PB number is the same for S3A and B. The PB is primarily internal and specific to the EUMETSAT Sentinel-3 Payload Data Ground Segment (PDGS) centre. The BC is the product version. A collection of several PBs that do not change the mission dataset in a significant way does not modify the BC.		

Current Operational Processing Baselines		
IPF	**IPF Version**	**Into operations since**
S3A SL2	02.00	NRT mode: 27/08/2020 with early products from 19/08/2020 available only on ODA and the EUMETSAT Data Centre
S3B SL2	02.00	NRT mode: 27/08/2020 with early products from 19/08/2020 available only on ODA and the EUMETSAT Data Centre

Status of the Processing Baseline

This PN covers the Near Real Time (NRT) SLSTR-A & SLSTR-B Level-2 (L2) Aerosol Optical Depth (AOD) products, both generated from the Instrument Processing Facility (IPF) version 02.00 and EUMETSAT PB.270.

This baseline was deployed in the EUMETSAT Sentinel-3 PDGS on 27/08/2020 for both SLSTR-A and SLSTR-B (early products generated from 19/08/2020 are also available only on ODA and in the EUMETSAT Data Centre). It is declared as follows:

- **Preliminary Operational** for **AOD** over **ocean** surfaces.
- **Demonstrational** for **AOD** over **land** surfaces.

Level 1 Product:

- Please see the Sentinel-3 A and B Product Notice – SLSTR Level-1B, S3.PN-SLSTR-L1.07 v1.0, issued on 15/01/2020.

Level 2 Product:

NRT AOD retrieval algorithm - Air quality, long-range transport & threat monitoring of air suspended particles

The Copernicus Sentinel-3 (S3) NRT AOD product quantifies the abundance of aerosol particles, and monitors their global distribution & long-range transport, at the scale of 9.5 x 9.5 km^2. All observations are made available in less than 3 hours since the SLSTR observation sensing time. It is only applicable during daytime.

The current S3 NRT AOD product is the first release as Baseline Collection 1. The users are strongly advised to note the recommended precautions and the differing maturity labels for the retrievals over ocean and land surfaces. Further improvements to the S3 NRT AOD product are planned, including the optimisation of the spectral constraints over land continents in case of unfavourable dual-view geometry, a comprehensive global validation, and additional updates following feedback from selected Sentinel-3 NRT atmospheric composition experts.

AOD Ocean & Land – Commonalities

Algorithm capabilities:

- Prior to the Level 2 processing, a correction of the radiometric calibration is applied to all the SLSTR L1B Top Of the Atmosphere (TOA) radiances in the solar channels S1-S6 (S4 being excluded) at the original sampling of 500 m. The correction is based on multiplicative radiometric coefficients derived from SLSTR-A summarised in S3MPC.RAL.TN.020-i1r0.
  Note that the same correction coefficients are equally applied to SLSTR-B since the radiometric consistency of both sensors have been aligned due to the tandem Sentinel-3 A-B activities that occurred in June-October 2018.
- All Level 2 NRT AOD parameters are provided at the super-pixel scale built by aggregating a block of 19 x 19 L1B SLSTR pixels. The super pixel resolution is about 9.5 x 9.5 km^2 close to nadir.
- The aerosol retrieval is exclusively achieved during daytime with solar zenith angles lower than 80 deg considered.

- Prior cloud screening is ensured by the SLSTR basic cloud mask available in the original L1B product. If less than 50% of the 19 x 19 L1B SLSTR pixels are cloud and glint-free, the super-pixel is then considered as invalid for L2 aerosol retrieval attempt.
- All cloud-free and glint-free L1B radiances are then arithmetically averaged out for each nadir and oblique view.
- The log(AOD) is fitted at the reference waveband of 550 nm. The actual AOD(550 nm) value is then derived *via* an exponential conversion avoiding then any negative values.
- *A posteriori* AOD filtering is achieved after the L2 AOD retrieval encompassing screening of cloud residuals, sediments in coastal areas, and other artefacts.
- The prior surface pixel classification is provided by the land / water mask available in the original L1B product.
- The set of aerosol models is based on the European Space Agency (ESA) aerosol Climate Change initiative (CCI) recommendations: two coarse mode (sea salt, desert dust), and two fine mode (weakly & strongly absorbing). All assume spherical particle properties computed with Mie code, except for desert dust which assumes spheroid properties computed with T-matrix code (Dubovik *et al.*, 2006).
- The reference parameter to be used is 'AOD_550' which gives the best quality of AOD(550 nm) only over ocean surfaces, *a posteriori* filtered out of retrieval defaults.
- In addition, the following parameters are provided: AOD(550 nm) over land with and without *a posteriori* filtering, spectral AOD at other wavelengths, spectral AOD uncertainty, Angstrom exponent between 550 & 865 nm, single scattering albedo (SSA), absorbing AOD(550 nm), dust AOD(550 nm), fine mode AOD(550 nm), spectral surface reflectance, and Aerosol Free Ratio Index (AFRI) for land continents (Karnieli *et al.*, 2000). Error estimate in AOD(550 nm) is based on 1 standard deviation assumption.

AOD Ocean – Preliminary Operational

Algorithm capabilities:

- All available views are used as independent spectral measurements in the retrieval state vector. Hence, the retrieval can either be performed with both views or only one if the other one is not available as done on AATSR by the original SU algorithm (Prof. Dr. Peter North).
- The spectral wavebands used in aerosol retrieval are: S2, S3, S5, and S6. S1 is excluded.
- The ocean surface reflectance is not jointly retrieved with aerosol, but estimated *via* the traditional surface model combining spectral reflectance from (Koepke *et al.*, 1984), foam fraction from (Monahan & O'Muircheartaigh, 1980), and the glint specular reflection from (Cox & Munk, 1954).
- Ocean AOD(550 nm) non *a posteriori* filtered is available as 'AOD_550_Ocean_NonFiltered'. The difference with 'AOD_550' will show the pixels screened by the *a posteriori* filtering.

Known performances:

- The global ocean performance retains a very good consistency with MODIS Terra AOD(550 nm) Dark target Ocean Collection 6.1 over open remote oceanic areas. Near-simultaneous & spatially collocated L2 AOD pixel match-up over 1 year (2019) showed correlation in the range of 0.89:0.96 in the Atlantic oceans (North & South), and 0.74:0.83 over Indian & South-Pacific oceans. Current reprocessing with processor v2.0 has so far showed similar trends over Winter 2019-2020.
- Preliminary validation of the SLSTR AOD(550 nm) with AERONET over 2 months (December 2019 – January 2020) shows a very high correlation of 0.83 and a Root-Mean-Square Error (RMSE) of 0.08 for all ranges of AOD values. It has to be emphasized that these numbers mix both open remote oceans and coasts without further distinction.
- SLSTR AOD(550 nm) is systematically lower than MODIS Terra & Aqua AOD(550 nm) Dark target Ocean Collection 6.1: average difference of -0.03:-0.05. MODIS Terra (and somehow Aqua as well) AOD(550 nm) ocean (open and/or coasts) seems to have a positive bias of +0.04 (Levy *et al.*, 2018).
- Note that with the new processor v2.0, a light decrease of SLSTR AOD(550 nm) values in open oceans of the order 0:01:0.03, depending on the regions and seasons, has been observed as the consequence of the radiometric calibration correction for both views primarily, and the fitting of log(AOD) instead of (AOD) secondly.
- The radiometric calibration correction, especially in the SWIR, is expected to have reduced the AOD(550 nm) bias in case of large abundance of coarse particles (sea salt & dust): *e.g.* up to -0.04 over thick Saharan dust plumes transported over the Atlantic in December 2019 and April 2020. Further analysis is on-going to complete the assessment impact of the full radiometric calibration correction.
- Most of sediment contamination in the vicinity of estuaries and rivers, such as close to India, Thailand, East China & North-East of South America coasts are well removed thanks to the *a posteriori* filtering.

AOD Land – Demonstrational

Algorithm capabilities:

- The NRT aerosol retrieval over land surfaces is a linear weighted combination of two different methods:
  - a geometry method combining the dual-view angular view.
  - a spectral method exploiting each view independently and deriving the surface reflectance in the visible from the SWIR TOA reflectance.
- The weights on the geometry *vs.* spectral functions are primarily distinguished depending on the sampled dual-view geometry and the surface type.
- The overall tuning of the exploitation of the SLSTR geometry is based on the estimated aerosol information content as a function of the dual-view geometry variable across latitude, across nadir & oblique swath longitude, and Earth inclination (season). Such an analysis is supported by B. Fougnie *et al.*, 2020 "Aerosol Retrieval from Space – How does Geometry of Acquisition Impact our ability to Characterize Aerosol Properties) submitted to Journal of Quantitative Spectroscopy and Radiative Transfer, JQSRT_2020_490.

- The land cover type is primarily estimated *via* the AFRI from the TOA radiances in the S3 NIR (865 nm) and S6 SWIR (2.25 um). An AFRI of 1 indicates a very well developed and healthy vegetation, while values lower than 0.2 are associated with bright bare soils such as deserts. Values from 0.4 to 0.8 indicates a mix of beginning of vegetation, urban & other hybrid soils.
- The SLSTR dual-view geometry is considered as favourable when the minimum sampled scattering angle across both views is lower than 110 deg.
- The land surface model in the geometry module is the multi-angular model developed by the Swansea University (SU) and successfully applied to the (A)ATSR sensors (North *et al.*, 1996, 1999, 2002). Spectral channel weights are applied depending on surface type & sampled geometry in order to 1) minimize spectral surface brightness (*e.g.* too bright vegetation at 550 nm & 865 nm), and 2) mitigate uncertainties in the spectral shape of the land Bidirectional reflectance distribution function (BRDF) (*e.g.* high vegetation spectral anisotropy at 550 nm in case of large scattering angle).
- The land surface model in the spectral module is mostly applicable over surfaces with AFRI larger than 0.4. It takes benefits of the known spectral relationships between the TOA reflectance in S6 and benchmark surface reflectance in S2 as successfully applied by the NASA Deep Blue team on MODIS C6, SeaWIFS v3 and VIIRS (Hsu *et al.*, 2013, 2019). The SLSTR spectral coefficients are, at this stage, empirically tabulated as a function of AFRI inspired by the VIIRS enhanced deep blue ones (Hsu *et al.*, 2019).
- The use of the S6 channel (1.6 um) is overall minimal, and only restricted to bare soils with NDVI SWIR < 0.2 to ensure spectral SWIR consistency across S5-S6 channels.
- The empirical smoke index relies on the differences between AFRI and the visible spectral radiances. It is current only available over vegetated lands, at the experimental stage.
- The AOD parameters are given in 'AOD_550_Land_Experimental_NonFiltered' and 'AOD_550_Land_Experimental_PostFiltered'. The difference between both parameters being the AOD pixels removed by the *a posteriori* filtering.

Known performances:

- The overall performance of the SLSTR NRT AOD(550 nm) over land must firstly be separated between "favourable geometry" (*i.e.* minimum scattering angle < 110 deg) and "unfavourable geometry" (*i.e.* minimum scattering angle > 110 deg).
- The best AOD(550 nm) performance is obtained in case of SLSTR "favourable geometry", occurring mostly on the half Eastern side of both nadir & oblique swaths for all latitudes during Winter time, and in the Southern latitude (*i.e.* < 20 deg North) for the whole oblique swath during Summer time.
- During Winter time 2019-2020:
    - Near-simultaneous & spatially collocated L2 AOD pixel match-up SLSTR(AOD 550 nm) – MODIS Terra Merged DT/DB Collection 6.1 exhibits very good correlation: >0.85 over India, 0.64 over Thailand. Average deviations are variable: between 0.06 (India) and 0.056 over Europe.
    - Preliminary regional validation with AERONET shows very high correlation over major polluted areas, impacted by heavy industrial / anthropogenic pollution and biomass burning: ~0.91 over India, ~0.74 over Thailand & Australia, ~0.5 over East China, ~0.62 over South-America. Lower correlations are expected over less polluted areas (such as

Europe, USA, etc..). Average differences vary between 0.02 (India) and 0.09 (Europe, South-America).
    - Preliminary worldwide validation with AERONET overall shows a good correlation of 0.63 and average differences of 0.09.
- During July 2020:
    - Worldwide near-simultaneous & spatially collocated L2 AOD pixel match-up SLSTR(AOD 550 nm) – MODIS Terra Merged DT/DB Collection 6.1 exhibits encouraging correlation, ~0.71.
    - Very high performance is expected over South-America such as during Amazonia forest fires (to be further verified).

Known Product Quality Limitations

SLSTR-A Level-1B Processing Baseline 2.37 and SLSTR-B Level-1B Processing Baseline 1.12 have the following known limitations relevant to SLSTR L2 NRT AOD:

VIS/SWIR Radiometric Calibration Information:

- Even if a correction of the SLSTR calibration has been proposed for the solar channels (S1-S6), the calibration remains under assessment and the root cause of some discrepancy, not yet determined, is still under investigation.
- The correction coefficients are estimated over bright desert sites from a consensus of 4 expert groups. Their validity over dark targets (*e.g.* vegetation, open remote oceans) is under further verification.
- These corrections should be used with caution as it is possible that the differences are scene dependent.
- Non-linearity effects at low radiance range is not yet fully characterized.

SLSTR-A L2 NRT AOD EUMETSAT Processing Baseline 2.70, Processor v2.0, Baseline Collection 1, has the following known limitations:

Commonalities:

- **#1 – Spurious night-time granules may be generated** sometimes, as a result of non-correctly screened large Solar zenith angle in the oblique view. They should be ignored by filtering out granules with solar zenith angle, in the nadir view, larger than 80 deg.
- **#2 – The quick-look *via* the COpernicus Data Access (CODA) includes some spurious night-time granules**, displaying hence artificial low AOD values.
- **#3 – The additional aerosol parameters such as uncertainty, angstrom, SSA, etc…, are not yet comprehensively validated**. Hence, they shall be used with great caution until the EUMETSAT validation is finalized and made available.
- **#4 – SLSTR-A and B AOD alignments remain to be verified.** SLSTR-A and B TOA radiances were aligned during the Tandem activity (June-October 2018). The benefits or possible residual impacts are under verification for L2 NRT AOD.

- **#5 – Software optimization w.r.t. low aerosol signal is under further consolidation** to better stabilize fraction AOD retrieval precision.

AOD Ocean:

- **#1 – The actual AOD ocean validation is not completed:** Although it benefits from the previous processor version, the actual from current processor v2.0 is under further completion by including longer time series of AERONET stations, Maritime Aerosol Network (MAN) ship-based measurements, and satellite inter-comparisons: primarily near-simultaneous collocated L2 with PMAP MetOp & MODIS Terra, and weekly/monthly aggregated MODIS Aqua and VIIRS.
- **#2 – The *a posteriori* filtering over remote oceans (far away from coasts) may be too stringent:** Fine-tuning to better disentangle good and bad AOD quality is on-going.
- **#3 – Potential minor negative bias:** AERONET validation over a 2-month period (December 2019 – January 2020) suggests a systematic negative deviation up to -0.04. Further analyses continue with regional and global ocean analyses in order to determine the nature of this potential bias, and whether it is specific to coasts and/or limited latitude regions.
- **#4 – Higher uncertainties in coastal areas as well as shallow lakes** are expected due to the challenge of disentangling the mix of shallow water & land surface brightness with aerosol scattering.
- **#5 – The overall assets and drawbacks of the oblique view in the AOD(550 nm) retrieval over ocean is under characterization**. As a potential impact, some North-South inconsistencies in the average (background) AOD values were originally identified. Although reduced in this release, this aspect remains under further verification.
- **#6 – Higher uncertainty in the Southern rough ocean** is expected due to the high difficulty to separate bright whitecaps and sea spray.

AOD Land:

- **#1 – Higher uncertainties over hybrid / urban soils and unfavourable geometry.** Associated AODs are too high due to inaccurate spectral coefficients used for this type of situations. Users are strongly advised to disregard aerosol pixels with AFRI values in the range of 0.6:0.8. This typically occurs during Summer time over Western Europe.
- **#2 – Positive bias of the order 0.1-0.15 for low AOD(550 nm) values (*i.e.* < 0.2) and unfavourable geometry** is suggested thanks to the validation with AERONET. Situations with favourable geometry may still exhibit such a bias, although seemingly at a lower magnitude.
- **#3 – Limitations due to remaining / unfiltered cloud residuals.** This mostly occurs in case of broken small clouds over warm surfaces (summer time over Europe, Asia, USA), and over the Amazonian forest (North & Eastern coast). This is a direct consequence of under detection by the SLSTR basic cloud mask, and unfiltered *a posteriori* AOD results. This leads to too high AOD outliers, and high standard deviation in SLSTR-AERONET AOD(550 nm) scatter-plots.
- **#4 – Too low AOD values over complex topography with low aerosol pollution**. Suspected root cause is Rayleigh correction inaccuracy w.r.t high surface altitude.

- **#5 – Too high AODs over very bright surfaces (deserts).** Such surfaces remain overall challenging due to the lack or contrast between aerosol signal and there underlying surface brightness (*e.g.* Sahara).
- **#6 – Transition Land/Ocean may be too sharp in some areas.**

Products Availability

☒ Copernicus Online Data Access (https://coda.eumetsat.int/), NRT

☒ EUMETCast (https://eoportal.eumetsat.int/), NRT

☒ EUMETSAT Data Centre (https://eoportal.eumetsat.int/), NRT

☐ FTP server address login: login password: password

☐ Other

Product	EUMETCast	ODA*	CODA**	EUMETSAT Data Centre
L2 AOD	NRT	NRT	NRT	NRT

*** ODA** is available only for Copernicus Services and S3VT users
**** CODA** is the service Copernicus Online Data Access and is available to all users

Off-line Products Availability

A series of S3 NRT AOD dataset produced off-line from SLSTR L1B NRT with the same processor v2.0 can be made available upon request (see EUMETSAT point of contact below). This includes the following:

- Global reprocessing of a couple of months in 2019 and 2020.
- Specific regionally and/or temporally limited reprocessing may be addressed upon user request;
- Possible other ancillary data and/or expert advice support.

References

- Operational Algorithm Web - Copernicus Sentinel-3 Near Real Time (NRT) Aerosol Optical Depth (AOD) – *Air quality, long-range transport & threat monitoring of dangerous air particles*: https://www.eumetsat.int/website/home/Data/ScienceActivities/OperationalAlgorithms/CopernicusSentinel3NRTAerosolOpticalDepth/index.html (soon available);

- Daily monitoring of NRT AOD over oceans from S3A and S3B *via* the EUMETSAT Monitoring & Evaluation of Thematic Information from Space (METIS) NRT AOD website: http://metis.eumetsat.int/aod/index.html# (soon available);

- EUMETSAT Sentinel-3 NRT Atmospheric Composition webpage: https://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Sentinel3/AtmosphericComposition/index.html

- Sentinel-3 Mission Requirements Traceability Document (MRTD), C. Donlon, EOP-SM/2184/CD-cd, 2011: https://sentinel.esa.int/documents/247904/1848151/Sentinel-3-Mission-Requirements-Traceability

- Product Data Format Specification – SLSTR Level 1 & 2 Instrument Products, Ref: S3IPF.PDS.005.1, Issue: 2.7, Date: 06/02/2018: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/document-library https://www.eumetsat.int/website/home/Data/TechnicalDocuments/index.html

- SLSTR NRT AOD ATBD "Sentinel-3 Optical Products and Algorithm Definition – Near Real Time SLSTR Aerosol Optical Depth" written by J. Chimot, B. Fougnie (EUMETSAT), to be posted in the future.

- EUMETSAT – Copernicus Sentinel-3 SLSTR L2 NRT AOD Product Data Format (PDF) Specification, EUM/SEN3/DOC/20/1180730 v1.A, written by J. Chimot, 11/08/2020: https://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Sentinel3/AtmosphericComposition/index.html

- EUMETSAT – Copernicus Sentinel-3 SLSTR L2 NRT AOD Auxiliary Data Format (ADF) Specification, EUM/SEN3/DOC/20/1180728 v1.A, written by J. Chimot, 11/08/2020: https://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Sentinel3/AtmosphericComposition/index.html

- Further information and documentation about the SLSTR L1B product can be found at: https://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Sentinel3/SeaSurfaceTemperatureServices/index.html

- S3MPC.RAL.TN.020-i1r0 - S3 SLSTR Visible and Short Wavelength Radiometric Calibration Adjustments – issue 1.0, written by Dave Smith (RAL), 16/07/2020.

- Cox, C. and Munk, W. (1954) Measurements of the roughness of the sea surface from photographs of the Sun's glitter. J. Opt. Soc. Am., 44, 838–850.

- Dubovik, O., et al. (2006), Application of light scattering by spheroids for accounting for particle non sphericity in remote sensing of desert dust, J. Geophys. Res.,111, D11208, doi:10.1029/2005JD006619.

- Karnieli, A, Kaufman, YJ, Remer, L, Wald, A (2001). AFRI - aerosol free vegetation index. REMOTE SENSING OF ENVIRONMENT, 77(1), 10-21.
- Koepke, P. (1984). Effective Reflectance of Oceanic Whitecaps, Applied Optics, 23(11), 1816-1824. Koepke, P. (1984). Effective Reflectance of Oceanic Whitecaps, Applied Optics, 23(11), 1816-1824.
- Hsu, N. C., Lee, J., Sayer, A. M., Kim, W., Bettenhausen, C., & Tsay, S.-C. (2019). VIIRS Deep Blue aerosol products over land: Extending the EOS long-term aerosol data records. Journal of Geophysical Research: Atmospheres, 124, 4026– 4053. https://doi.org/10.1029/2018JD029688.
- Monahan, E.C. and O'Muircheartaigh, I. (1980). Optimal power-law description of oceanic whitecap dependence on wind speed, Journal of Physical Oceanography, 10(12), 2094–2099, 1980.
- North, P.R.J. (1996), Three-dimensional forest light interaction model using a Monte Carlo method, IEEE Transactions on Geoscience and Remote Sensing, 34(5), 946-956.
- North, P.R.J., Briggs, S.A., Plummer, S.E. and Settle, J.J., (1999). Retrieval of land surface bidirectional reflectance and aerosol opacity from ATSR-2 multi-angle imagery, IEEE Transactions on Geoscience and Remote Sensing, 37(1), 526-537.
- North, P.R.J. (2002a). Estimation of fAPAR, LAI and vegetation fractional cover from ATSR-2 imagery. Remote Sensing of Environment 80:114–121.
- North, P. R. J. (2002b). Estimation of aerosol opacity and land surface bidirectional reflectance from ATSR-2 dual-angle imagery: Operational method and validation, J. Geophys. Res., 107, doi:10.1029/2000JD000,207.

End of Product Notice