Sentinel 3 Science Products: A US contribution

Proposal submitted in response to the solicitation NNH10ZDA001N-ESUSPI: Earth Science U.S. Participating Investigator

FINAL REPORT – June 2017

Principal Investigator: **Christopher Justice[1]**

Co-Investigators: **Luigi Boschetti[2]**, **Eric Vermote[3]**, **Louis Giglio[1]**, **Evan Ellicott[1]**

[1]University of Maryland, Department of Geographical Sciences, College Park, MD

[2] Department of Forest, Rangeland and Fire Sciences, University of Idaho, Moscow, ID

[3] NASA Goddard Space Flight Center, Greenbelt, MD

Introduction

The European Copernicus Program and the associated Sentinel missions provide important Earth observations for the international Earth science community. Sentinel-3 is an ESA mission primarily designed to support GMES (Global Monitoring for Environment and Security) services relating to the environment, with capability to serve numerous marine, land-, atmospheric- and cryospheric-based application areas. While Sentinel-3 is primarily intended as an ocean mission, the various sensors such as the SLSTR (Sea and Land Surface Temperature Radiometer), OLCI (Ocean and Land Color Instrument), SRAL (SAR Altimeter), and MWR (Microwave Radiometer) means its capabilities extend beyond oceans and include fire detection, forest cover mapping, and land change monitoring. This USPI proposal was focused on preparing for the Sentinel 3 SLSTR instrument which is an evolution from the ESA AATSR instrument see table below.

Table 6.1. Comparison of the Sentinel-3 SLSTR, AATSR and ATSR-1/2 instruments highlighting the steady evolution of capability and performance.

	Capability	SLSTR	AATSR & ATSR-1 & 2
Swath	Nadir view	>1400 km	500 km
	Dual view	>740 km	500 km
Global coverage revisit times	1 satellite (dual view)	1.9 days (mean)	3 days at mid-latitudes
	2 satellites (dual view)	0.9 day (mean)	–
	1 satellite (nadir view)	1 day (mean)	3 days at mid-latitudes
	2 satellites (nadir view)	0.5 day (mean)	–
Spatial sampling interval at SSP (km)		0.5 km VIS-SWIR 1 km IR-Fire	1 km
Spectral channel centre, λ (μm)	VIS SWIR MWIR/TIR Fire1/2	0.555; 0.659; 0.865 1.375; 1.610; 2.25 3.74; 10.85; 12 3.74; 10.85	0.555; 0.659; 0.865[a] 1.610 3.74; 10.85; 12
Radiometric resolution	VIS (A = 0.5%) SWIR (A = 0.5%)	SNR >20 SNR >20	SNR >20 SNR >20
	MWIR (*T* = 270K) TIR (*T* = 270K) Fire-1 (<500K) Fire-2 (<400K)	NEΔT < 80mK NEΔT < 50mK NEΔT < 1K NEΔT < 0.5K	NEΔT < 80mK NEΔT < 50mK
Radiometric accuracy	VIS–SWIR (A = 2–100%)	<2% (BOL) <5% (EOL)	<5%
	MWIR–TIR (265–310K) Fire (<500K)	<0.2K (0.1K goal) <3K	<0.2K
Design lifetime[b]		7.5 years	ATSR-1 & 2: 3 years AATSR: 5 years

A, albedo; BOL, beginning of life; EOL, end of life; SSP, subsatellite point; NEΔT, Noise-Equivalent Temperature Difference.
[a] These channels were present for the AATSR and ATSR-2, but not the ATSR-1.
[b] Some instruments remain in operation for much longer than their 'design lifetimes'. Launched in 2002, Envisat's AATSR, for example, was designed for 5 years, but continued to operate for almost 10 years until 2012. Similarly, ERS-1 has provided an uninterrupted series of ATSR-type data and data products since its launch in 1991.

"The SLSTR is continuously calibrated using onboard and vicarious calibration techniques. Taking advantage of the instrument's conical scan concept, each scanner views alternately at every scan one of two identical calibration blackbody cavities kept at two different temperatures. The SLSTR also includes a solar diffuser for visible channel gain calibration that is viewed once per orbit. The SLSTR design allows for the spectral and radiometric integrity of all measurements because both the oblique and nadir measurements are made through common focal plane optics. Up to 2.25 μm, i.e. for channels 1–6, the instrument is calibrated on-board by observing a PTFE diffuser protected by a UV filter and illuminated by the Sun. This diffuser forms the core part of the visible calibration unit. Since the Sun is not visible all the time, this calibration takes place only once per orbit, just before the terminator crossing of the satellite in the Southern Hemisphere. Calibration of the infrared channels S7 to S9 and two fire channels is continuous (i.e. every second scan) by observing the two stable and highly accurate blackbody targets. One target floats at the temperature of the instrument optics enclosure, and the other is maintained at a higher temperature by active heaters. This combination provides two calibration points spanning the normal range of SSTs. Note that additional vicarious techniques are used to calibrate the upper range of SLSTR Fire channels, as this is beyond the operating temperature of the onboard blackbodies. The blackbodies for the SLSTR are based on a design already used for the (A) ATSR sensors. The viewed areas of the blackbodies have a very high emissivity ($e > 0.999$) and are spatially very uniform. The temperatures of the blackbodies are measured with high-accuracy platinum resistance thermometers calibrated on the ground against a transfer standard traceable to ITS-90, the international temperature scale of 1990. To ensure the stability and high quality of SLSTR data products, rigorous and accurate pre-flight characterization and calibration of the SLSTR blackbody sources are essential."

The Copernicus Missions are considered a source of data products, contributing to the international climate observation program. A continuing international technical interaction is therefore needed on terrestrial Essential Climate Variables (ECV) design, production, evaluation and validation. Subsequently, this project's goal was to emphasis the harmonization between US and ESA products from AVHRR, MODIS, VIIRS, ATSR, MERIS and Sentinel-3 to insure cross-platform product compatibility. We worked closely with our European counterparts on calibration strategies, product specifications, algorithm design, implementation, and shared product validation protocols. We focused on Level 1b (calibrated and geo-located radiances), cloud mask, surface reflectance, albedo, vegetation index, active fire and burned area products. Our efforts were organized in the framework of GTOS GOFC-GOLD and the CEOS LPV and ACIX in order to address technical interaction urgently needed on terrestrial Essential Climate Variables (ECV) design, production, evaluation and validation.

The collaborations achieved through this proposal contributed to international initiatives aimed at coordination of international land observations and the exposure of these activities to a broader international community. Members of the project team were actively involved in the CEOS Cal-Val Land Product Validation (LPV) group and the Global Observation of Forest Cover and Land Dynamics (GOFC-GOLD) program. Through this project, the validation of the fire products was taken up by Dr. Luigi Boschetti who co led the CEOS WGCV Land Product Validation Group on Fire. All these efforts contributed to standardizing approaches to product validation, collection and sharing of *in-situ* data, and highlighted the benefits of international cooperation.

USPI Approach

The USPI team worked with their ESA-funded counterparts on various products. Eric Vermote has established a relationship concerning Atmospheric Correction with Dr. Phillipe Goryl, ESA Sentinel-3 instrument lead, and through this collaboration set up the CEOS Cal Val

Working group Atmospheric Correction Inter-comparison Experiment (ACIX). Vermote participated in a previous Sentinel 2 USPI, which has now resulted in a close working relationship between ESA Sentinel 2, the Landsat Science Team (Vermote PI) and the NASA MuSLI program.

The longstanding relationship between USPI team members and Dr. Martin Wooster (Kings College London) and his team, provided ~~collaborative opportunities to work~~ collaboration on fire-related field validation experiments in Australia and Africa (Figure 1) in preparation for Sentinel 3. In addition, team members worked closely with colleagues through GOFC-GOLD Fire Implementation Team to provide~~d~~ justification and specifications for the fire detection capability on Sentinel-3. Preliminary evaluation of SLSTR fire detection capability was performed. The Fire Radiative Power product associated with the 1km detections developed by the Wooster group is now provided by the ESA *SL_2_LST* package.

Through the collaborations with ESA scientists, the project team leveraged its various international EO coordination activities to share the findings from the research and provide guidance, feedback, and insight.

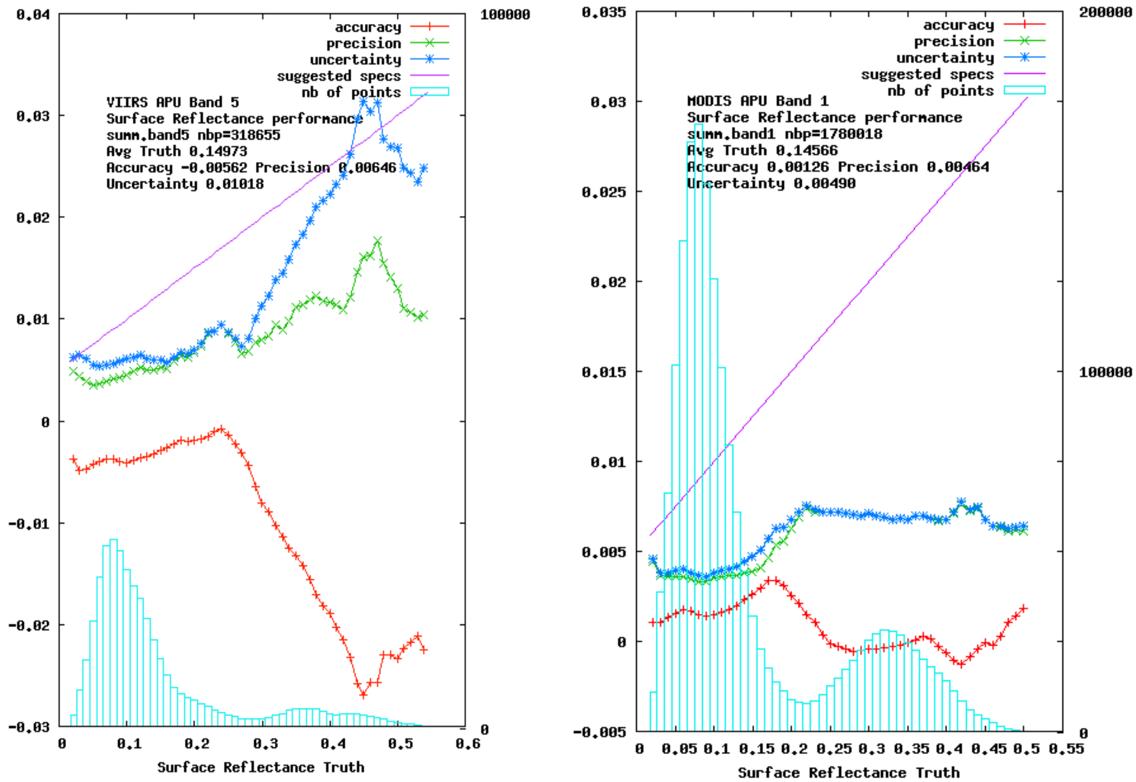
Figure 1. Validation and capacity building campaign in Kruger National Park, South Africa, in 2014. Members of this project collaborated closely with ESA counterparts, including Martin Wooster (center-left), technical lead for the SLSTR sensor's fire product development.

Calibration and Surface Reflectance

Accurate radiometric calibration is a prerequisite to creating a science-quality, time-series of BRDF corrected surface reflectance and consequently, higher order downstream products for Sentinel 3. Calibration errors can propagate directly into the surface reflectance and create artificial variations that can be misinterpreted as trends, especially if these variations are due to a slow decay in the calibration mechanism. We used the approach we originally developed for cross calibration of AVHRR with MODIS [Vermote and Saleous, 2006] to monitor the calibration in the visible to shortwave infrared bands and to provide correction terms as needed (e.g. Figure 2).

Surface reflectance is one of the key products used in developing several higher-order land products, such as Vegetation Indices, Albedo and LAI/FPAR, it is therefore seminal to detecting trends in the biosphere and land surface and has been classed by NOAA as a "Fundamental Climate Data Record (FDCR) for Land". Building a long-term surface reflectance data record of climate quality ~~implies~~ involves combining different instruments, sensors and satellites, accounting for different spatial resolutions and spectral characteristics, assuring consistent calibration, and correcting for atmospheric and directional effects. As the spatial resolution issue is addressed by aggregating the original data to a resolution still suitable for climate studies (e.g. 0.05º latitude, longitude), the instrument calibration becomes the first major hurdle one has to go through before being able to proceed any further. Several calibration techniques have been developed by our team, in particular combining the cloud spectral band inter-calibration with the BEnchmark Land Multisite ANalysis and Intercomparison of Products (BELMANIP) cross sensor calibration in the near-infrared. We used robust reflectance data records and inter-comparison methods that we have developed over the past several years (consisting of atmospheric correction, directional effect correction and spectral normalization) to establish and verify the inter-consistency of the reflectance products from the SLSTR and OLCI sensors on-board Sentinel 3, the MODIS sensors on-board Aqua and Terra and the VIIRS sensors on-board Suomi-NPP. We were particularly interested in the SLSTR providing continuity with MODIS Terra.

As a baseline we performed a comprehensive estimate of the performance of the MODIS/VIIRS Surface Reflectance over the AERONET sites. Some of the results are presented in Figure 2, for the VIIRS bands M5 (red), MODIS band 1 (red). Figures 2a-b shows the Accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty (i.e. the quadratic sum of Accuracy and Precision) (blue line) of the Surface Reflectance as well the uncertainty specification (magenta line) that was derived from the MODIS theoretical error budget (0.005+5%). It should be noted that the error budget was initially derived for V5 of the MODIS Surface Reflectance algorithm [Vermote and Saleous, 2006] and was revised as part of the further improvement of the validation protocol for V6. In particular, the early version did not attempt to make any determination of the aerosol model and the understanding of the different models was limited to a few studies (pre-AERONET era).



a) b)

Figure 2: Estimates of BRDF corrected surface reflectance Accuracy, Precision and Uncertainty performances for: a) VIIRS band M5 (red), and b) MODIS-Terra Band 1 (red). The surface reflectance 'truth' is computed using the 6S radiative transfer code and the AERONET data for the entire Terra or VIIRS mission.

Active Fire Detection and Burned Area Mapping

The SLSTR and MODIS (Collection 6) detection algorithms are quite similar, but nonetheless there are some nontrivial differences. The critical MIR, or "fire channel", is centered at 3.7 µm for SLSTR compared with 3.9 µm for MODIS. The former may therefore include some amount of atmospheric attenuation from CO2 and water vapor. Wooster et al. (2012) covered the inclusion of the shortwave IR (2.25) channel in the SLSTR algorithm to improve nighttime detection of small fires. However, this same channel for MODIS is not operational at night. The potential fire thresholds (thresholds used to exclude obvious non-fire pixels), for example, are calculated using different spatial sampling schemes.

During the performance period of this project we maintained regular communication with Martin Wooster, the ESA-sponsored SLSTR Science Team Lead for the active fire product, to discuss algorithm development and cal/val efforts. Regular, annual meetings, such as the GOFC-GOLD (Global Observations of Forest and Land Cover Dynamics) Fire Implementation Team (IT), offered us the opportunity to meet with our ESA counterparts to work on SLSTR fire product(s) development.

In addition, field campaigns (e.g. Fig. 3), offered unique and fruitful opportunities to work on cal/val efforts for numerous sensors, including VIIRS and MODIS, which was used to inform development of SLSTR.

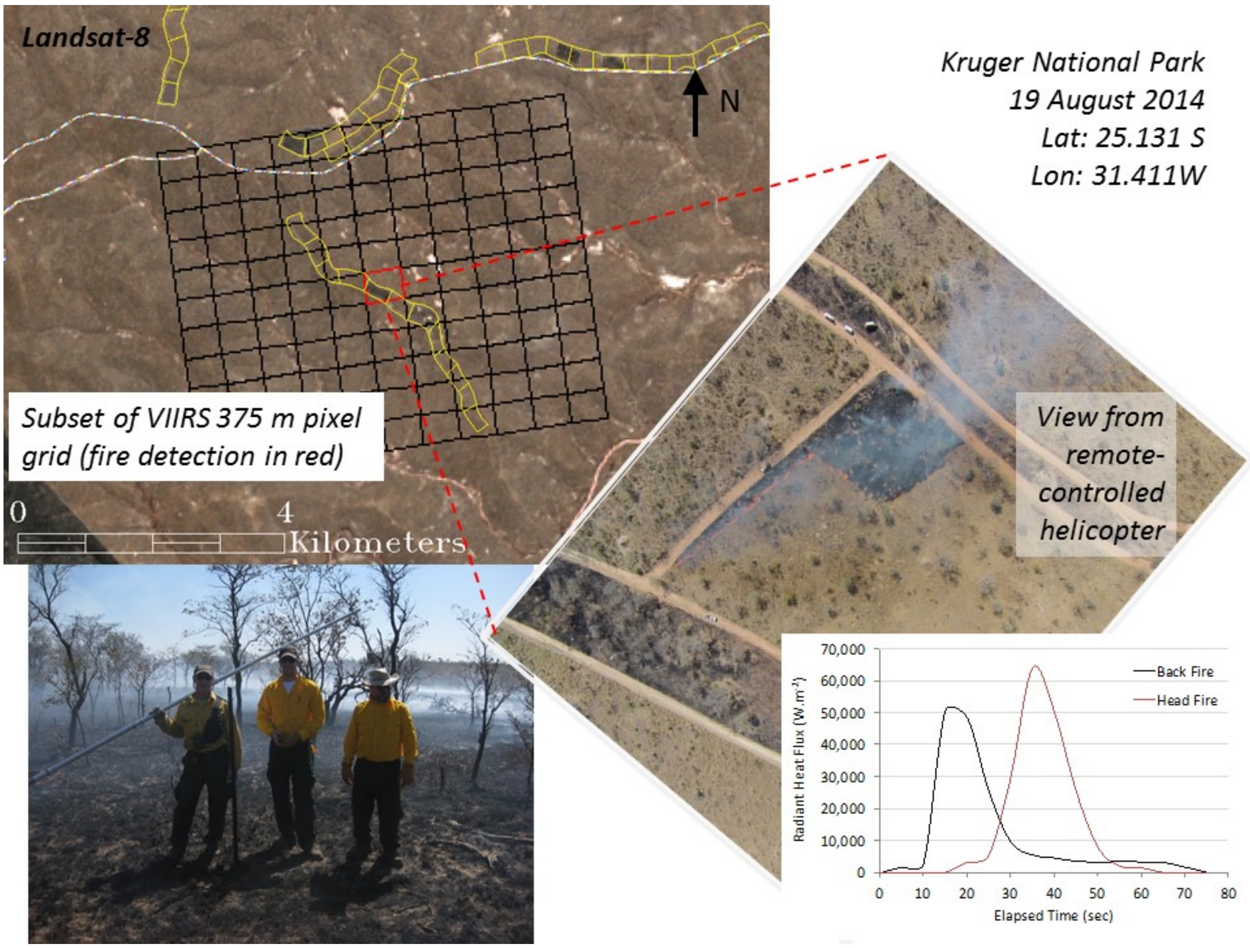


Figure 3. Field campaign in Kruger National Park, South Africa, in 2014. This effort offered a great opportunity to collaborate with members from numerous research and operation organizations, including members of the SLSTR development team.

As of early May, 2017, a new processing baseline had been updated for the SLSTR Level-1B data to improve nadir and oblique view geolocation accuracies which almost meet the mission requirements (<0.5 pixel). While most other channels are operating normally, a mis-registration between the S7 and F1 channels has been observed. This is due to the specific geometry of the F1 detector, which is designed to be sensitive to high radiances needed for fire detection.

Figure 4 provides an example of the SLSTR imagery generated from observing the large fire in Portugal in mid-June, which was responsible for over 60 deaths. The sensor overpassed the fire at 1045 UTC. The fire front, burn scar, and smoke are all present in the images. We note, however, that to date the Level-2 LST product, which includes the fire detection and FRP products is not yet available.

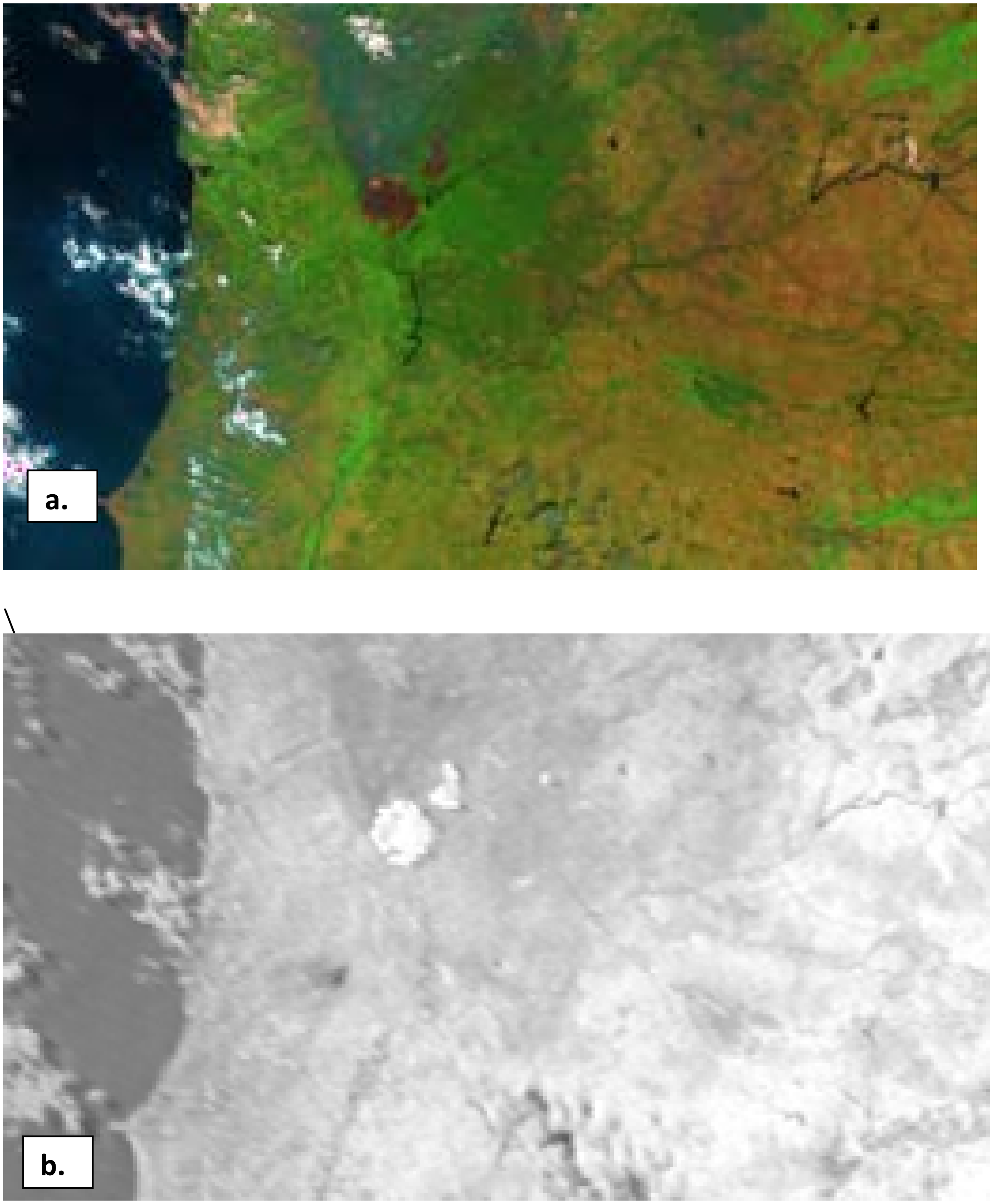


Figure 4: (a) Sentinel-3A SLSTR imagery from 18 June 2017 over Portugal wildfires. The image shows a false-color RGB (bands 6-3-1) and; (b) the F1 “fire channel” (3.74μm). The fire appears at the bright white object in the center-left.

References

Vermote, E. F., and N. Z. Saleous (2006), Calibration of NOAA16 AVHRR over a desert site using MODIS data, **Remote Sensing of Environment**, 105(3), 214-220.

Wooster, M. J., Xu, W., and T. Nightingale (2012), Sentinel-3 SLSTR active fire detection and FRP product: Pre-launch algorithm development and performance evaluation suing MODIS and ASTER datasets, **Remote Sensing of Environment**, 120(3), 236-254.