RESEARCH AND DEVELOPMENT TOPIC

Forward Scatter and Its Effects on Atmospheric Correction

Note

CMAC is patented technology developed by Advanced Remote Sensing, Inc., commercialized as RESOLV™

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Summary

- *Forward scatter is a natural phenomenon governing atmospheric changes to imagery of secondary influence to the pinwheel effect. Both are corrected by the CMAC algorithm in RESOLV. As in our journal papers, we use the name Closed-Form Method for Atmospheric Correction (CMAC) here because we are discussing the algorithm, not the service.*

- *Described in an earlier RESOLV Development topic paper, the pinwheel effect influences atmospheric change of reflectance primarily through interaction with aerosol particles. These changes increase the reflectance of dark targets due to backscatter and decrease bright reflectance due to attenuation. Secondarily, forward scatter illuminates aerosol particles from below and is a property of the greater reflected energy from bright targets acting upon the concentration of atmospheric aerosol.*

- *The pinwheel effect and forward scatter are the major influences degrading the reflectance signal recorded in satellite image data. These factors affect each band differently and, along with each sensor's relative spectral response, are accommodated through calibration.*

- *Mapped as the first step in the CMAC workflow, the Atm-I grayscale readily displays the effects of forward scatter that are reversed by CMAC processing.*

Introduction

An earlier RESOLV Development topic paper describes how the Atm-I model uses scene statistics to assess the overall atmospheric effect spatially across each image in the form of a grayscale. A subsequent topic paper then describes application of the Atm-I grayscale raster to scale the reversal of the atmospheric effect spatially. Here we introduce the subject of forward scatter and describe additional observations, measurements and analysis.

A simple definition of forward scatter in the context of atmospheric correction can be made from the observer's point of view: the illumination of atmospherically suspended particles from a light source behind them. A common earthbound example is the light of oncoming traffic on an unpaved road that illuminates dust in the air. Flip the axes to look down with a satellite or airborne imager: forward scatter is then the illumination of aerosol particles from below by the energy source of the light reflected by ground targets. The brighter that reflectance, the greater the effect of forward scatter.

Forward scatter is a subject deserving additional research focus, especially for its role in atmospheric correction over water and is introduced here to demonstrate additional complexity for the problem of atmospheric correction. Forward scatter plays a strong role for atmospheric correction over water and is of interest because CMAC applications for ocean surveillance would be promotional for smallsat application. Over terrestrial environments, the CMAC workflow now automatically accommodates forward scatter through generation of Atm-I grayscales that capture and reverse forward scatter effects.

Evidence of Forward Scatter

A first indication of forward scatter was observed while we were developing the Atm-I model. The resulting grayscale output systematically showed locations that the model indicated were affected to a greater degree than would have been expected. Bright rooftops, rock outcrops, bare soil and water bodies were portrayed much brighter in the Atm-I grayscale than would be expected were backscatter from atmospheric particles the sole mechanism at work. The finer-scaled Atm-I features evident in Figure 1 would not be expected if the contributing aerosol was as well mixed as it appears to be across much of the top-of-atmosphere reflectance (TOAR) view if forward scatter was not in play.

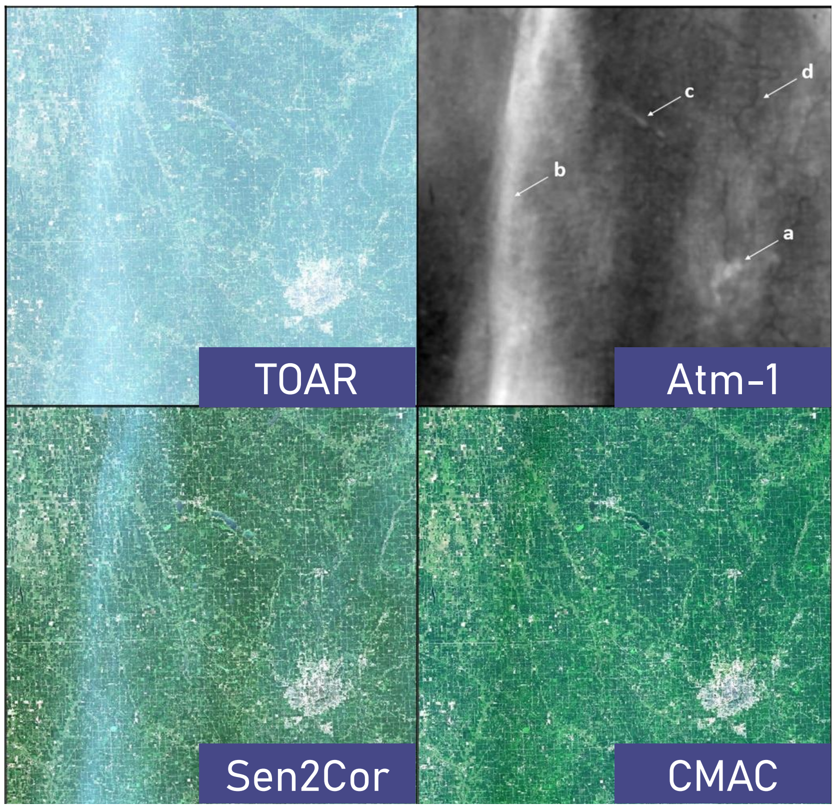

Figure 1 *Sentinel-2 tile of the Sioux Falls, South Dakota region (T14TPP 08-11-2019) affected by wildfire smoke. The annotated Atm-I grayscale shows elevated Atm-I with a north-south band of higher Atm-I smoke (b). Visible indicators of forward scatter are: (a) unexpectedly high grayscale values over Sioux Falls of the same brightness as a heavier smoke plume (b) and specular reflectance that enhanced the Atm-I response of lakes (c). Reduction of the Atm-I response occurred from dark riparian forest (d) of uncharacteristically low Atm-I. CMAC successfully corrected this image but state of the art Sen2Cor did not, thus providing evidence that the portrayal of atmospheric effect by the Atm-I model is correct and that forward scatter is a common phenomenon.*

Additional evidence of forward scatter became apparent during early CMAC development through observation of existing calibration targets that we intended to use. A common calibration target design juxtaposes dark and bright panels, white and black for the greatest dynamic response, arranged in a checkerboard pattern. Figure 2 provides views of such a target at the Salon de Provence, France airport.

Figures 2d and 2e illustrate forward scatter where the greater energy from bright panels can be seen to expand spatial extent to affect additional pixel areas well beyond the original panel borders. The contrasting response for the comparatively negligible energy from the dark panels shrank their spatial extent. For the 30-m target panels, the effect upon 10-m Sentinel-2 pixels was severe.

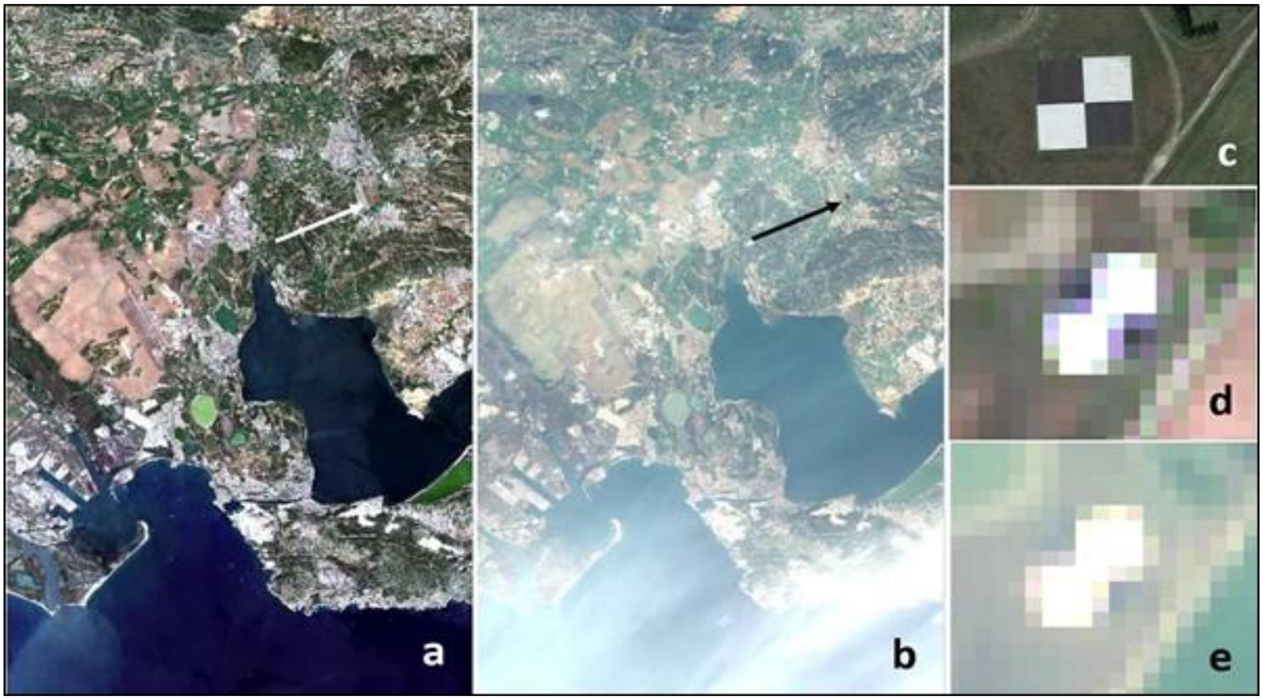

Figure 2 *Sentinel-2 views of the Salon de Provence, France region (T31TFJ): a calibration target (arrows) in TOAR regional images from June 16, 2021, under light haze (a, d) and March 8, 2021, under moderate haze from wildfire smoke (b, e). A Google Earth image (c) of the target shows the 30 m × 30 m black and white panels. Forward scatter may result in a permanent loss of information; however, artificial intelligence may be useful for restoring detail.*

Our understanding of forward scatter is a logical interpretation given the evidence we have seen. Because pixel values can be altered, perhaps irredeemably, due to forward scatter as in Figure 2, this subject deserves a great deal more investigation. By providing an initial definition of the problem here, the path becomes clearer for further investigation and correction that logically could employ machine learning tied to Atm-I level, individual pixel brightness and neighboring pixel brightness to reconstitute the image details otherwise lost.

Effect of Forward Scatter and Geometry in Applications of RESOLV

Calibration of RESOLV can be automated with application of a properly engineered calibration target, but not with use of the standard checkerboard design as shown in Figure 2. Instead, target panels can be separated, and the dark panel made larger than the bright panel. Additional considerations include creating a surface that is as Lambertian (perfectly diffuse reflection) as possible, a proximal water source to aid washing off accreted dust, north-south alignment, a gentle slope to the south for drainage, and periodic groundtruth measurements to assure the highest accuracy as the surface material ages. Another consideration is generation of a bidirectional reflectance model appropriate for any solar elevation/look angle that can quantify what proportion of incident light is lost, scattered away from the sensor at various viewing angles according to solar and look-angle geometry.

Design and deployment of a calibration target are critical for rapid and precise calibration and remain the subject for further research and development. In the interim, vicarious methods are sufficient to deliver verified accuracy and reliability for smallsat application. Competing methods based on radiative transfer need Sen2Cor and LaSRC output, however, these methods experience degraded accuracy under conditions of elevated Atm-I as documented in this series of RESOLV topic papers. Reliability for atmospheric correction using radiative transfer is questionable for regions of low spectral diversity as is reported in a subsequent RESOLV Verification topic paper examining Landsat 8/9 atmospheric correction for a low spectral diversity environment.

The concept of a viewing envelope is important for CMAC application over water. Water targets are especially prone to forward scatter from water-surface sky reflectance. This can be seen in Figure 3 for a portion of a nadir-look Sentinel-2 image of the Mexican Gulf Coast where CMAC correction worked well. CMAC results that yield appropriate atmospheric correction over water such as in Figure 3 have been attained for many satellite images, but not all. There are views over water that are uncorrectable. A glaring example is when the azimuth and viewing angle combine to produce sun glint that makes the image unusable. Sun glint is also produced by waveforms as can be seen in Figure 4 *(on page 6)*.

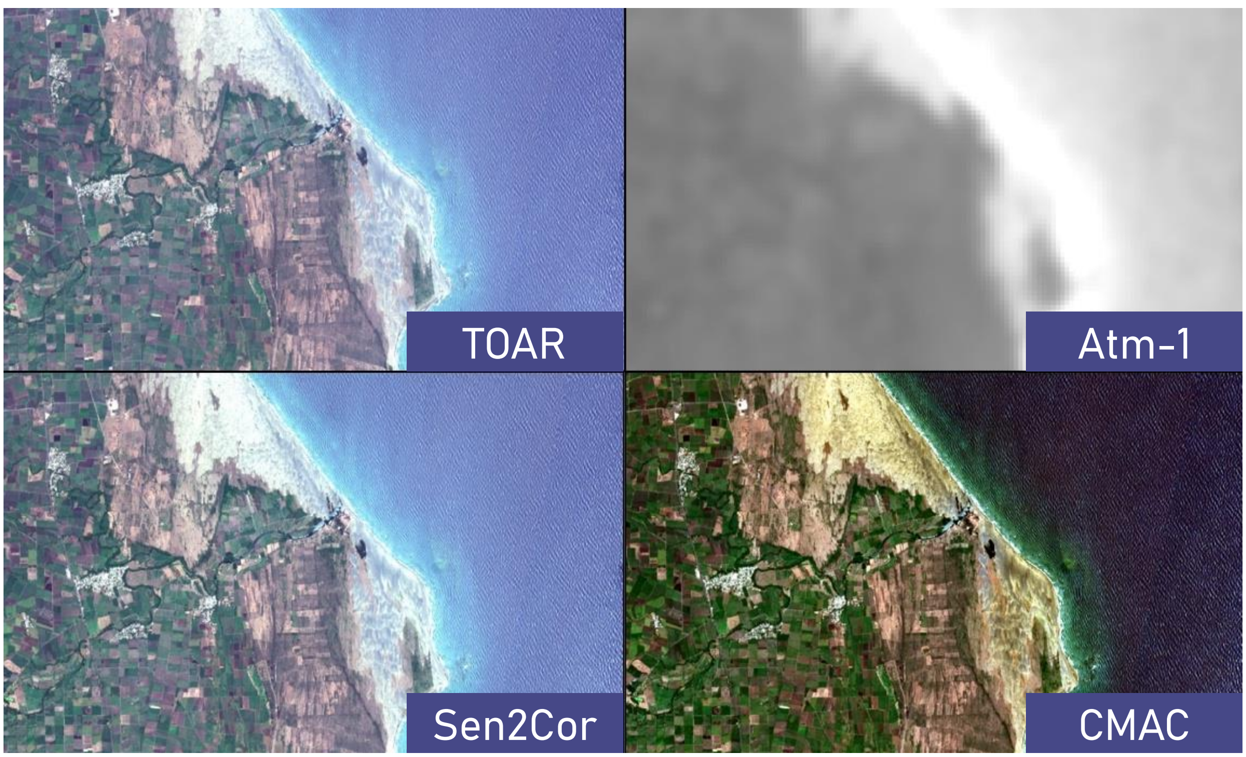

Figure 3 *Sentinel-2 (T14QQG, 05-03-2021) views of the Mexican Gulf Coast and dunes of the peninsula north of Playa Chachalacas, Mexico. Note the very bright signature of the Atm-I grayscale that reversed the specular reflectance causing the bright blue in TOAR and Sen2Cor views. The Sen2Cor correction is an example of the present state-of-the-art provided for a perspective on the promotional role of Atm-I capturing forward scatter effects over water.*

Complex problems such as over-water correction can be solved by dividing the issue into smaller pieces, accordingly, starting with image geometry. Attaining appropriate results from CMAC as in Figures 3 and 4 can be best assured through use of an envelope to define and avoid problematic geometry where solar elevation/azimuth and satellite look angle/azimuth preclude correction. Such an envelope could be particularly important for planning pointable views of hotspots; if you can't capture the image as you are approaching, get it after you pass.

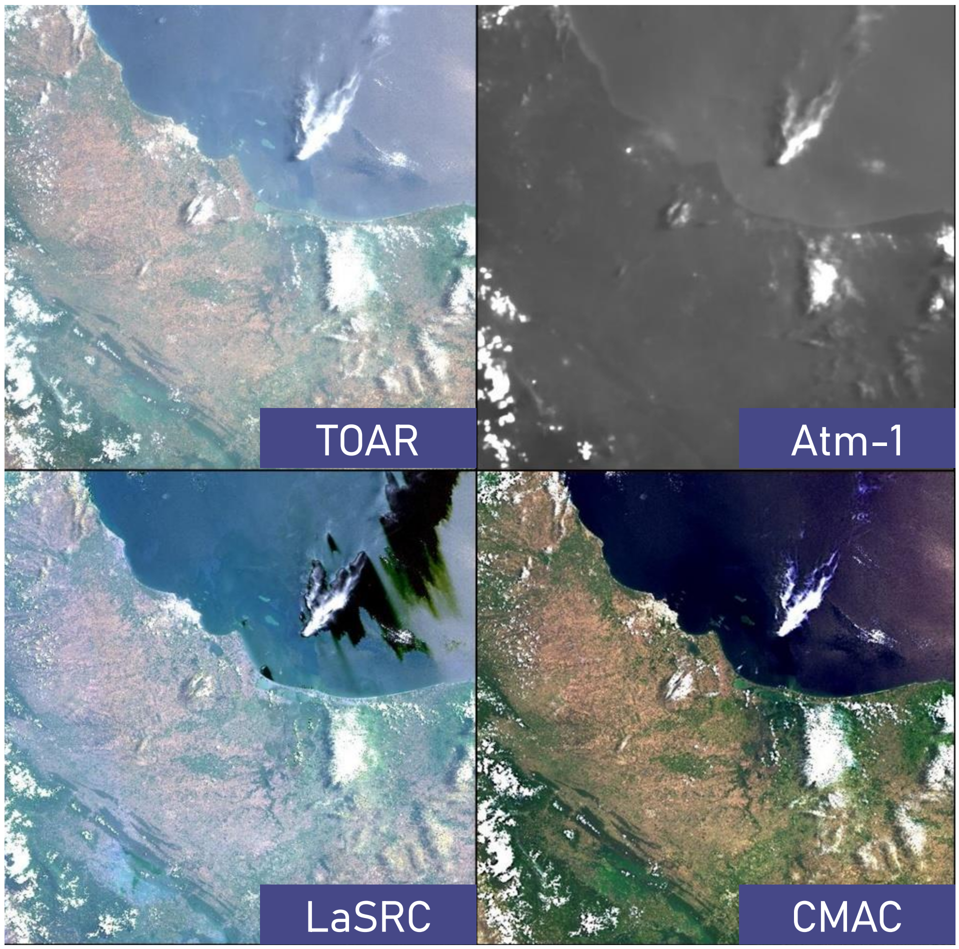

Figure 4 *Landsat 8 (P024R047, 05-12-2021) view of the Mexican Gulf Coast and atmospheric correction over water. A gradient in the color and the sun glint of the ocean demonstrates systematic spatial variability due to imaging geometry. The LaSRC scene is included as an indicator of the impact from high atmospheric levels of smoke over water and land.*

ABOUT THE AUTHOR

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Hello,

I'm Dr. David Groeneveld, founder and leader of RESOLV™. Our software atmospherically corrects smallsat data conveniently, accurately and reliably and does so in near real-time. The benefits of RESOLV™ go beyond its technical capabilities. Better accuracy helps researchers, scientists, and others make smarter choices to monitor and manage our planet.

Curious to learn more about RESOLV™, the science behind it and its potential for correcting smallsat images? Fill out this ***short form*** and I'll be in touch.

David G.