ATSR-WFA NEW ALGORITHMS FOR HOT SPOT DETECTION

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Abstract
Two new algorithms have been developed and tested for the ATSR World Fire Atlas. A first one based on basic threshold on the 1.6 Micron channel in order to fully exploit the ATSR-1 time series back to 1991 and called Algo 3; a second one based on geographic and time adaptive threshold called Algo 4. The two algorithms have been prototyped and tested under different conditions, and their results are discussed in respect to Algo 1 and Algo 2 implemented since 15 years. Pros and cons of using the results of Algo 3 and Algo 4 instead of (or in synergy with) Algo 1 and Algo 2 are discussed depending on the land cover and season.

1. INTRODUCTION

During his long history the ATSR-WFA [1] demonstrated its usefulness in many research areas. The basic ALGO1 and ALGO2 approaches have been recognised to be extremely efficient and related results satisfactorily accurate. In order to complement the actual algorithms and to take benefit from the ATSR-1 we developed a new retrieval scheme, ALGO3, based on the analysis of ATSR family 1.6 \( \mu m \) band radiances.

In order to more efficiently use the TIR bands, particularly for boreal zones, a further and more complex scheme was developed, ALGO4. In this context the processing software was completely recoded, making the processing more efficient and expandable.

New processor features are:

1. Extraction of the tie-point coordinates for each orbit for off-line coverage checking
2. Extraction of brightness temperature orbit values (re-sampled to tie-point resolution) for long term analyses
3. Creation of detailed orbit and monthly log files
4. New hot spot detection schemes

The re-sampled brightness temperatures will be used for long term analysis of WFA data.

With “new algorithms” we indicate the re-coded ALGO1 and ALGO2 algorithms, based on fixed thresholds for the 3.7 \( \mu m \) band radiances, the fixed threshold for band 1.6 \( \mu m \) band algorithm (ALGO3), and the still under development adaptive threshold algorithm which will make use of 3.7 and 10.8 \( \mu m \) band radiances simultaneously (ALGO4).

The results reported in this paper are the results of the analysis of the reprocessed AATSR TOA products relative to the period July 2002 – December 2007.

2. ALGO3

A global picture of the ATSR-WFA hot spot density for the 2002-2007 period is given in Fig. 1, in which the colour scale indicates the number density from blue (low) to red (high).

![Figure 1 ATSR-WFA ALGO1 and ALGO2 density](image)

One of the ALGO1 and ALGO2 limitations is the dependence of the 3.7 \( \mu m \) BT values from the background temperature, i.e. from the temperature of the non burning area. In fact, being the total radiance reaching the satellite instrument the combination of the contributions of both burning and non burning fractions of the ground pixel, a fixed threshold for the hot spot detection cannot account for seasonal variations of the contributing background.

To overcome this problem a new approach is proposed here, named ALGO3. It is based on the investigation of the 1.6 \( \mu m \) band behaviour during night-time observations.

At this wavelength the contribution of background is negligible (far below the noise level of the ATSR band) while it can be demonstrated that a useful signal is
detected for active fires even for very small fire fractions. The ALGO3 method is based on the detection of 1.6 μm band reflectance values larger than a fixed threshold (=0.1) which is twice the detector noise level.

Fig. 2 shows the ALGO3 spot density for the 2002-2007 time range (colour scale as in Fig. 1).

The following observations can be made:

1. The solar proton and electron flux produces a quantity of spurious spots in the region interested by the South Atlantic Anomaly (SAA) [2], and for high latitudes.
2. Outside SAA the spot density is very similar to that of ALGO12 (Fig. 1)

Observation 1 could lead to the conclusion that ALGO3 cannot be used for global fire monitoring because Southern America, a small portion of South Africa, and high latitudes are impacted by the solar flux. This is certainly true if we limit the analysis to the nadir looking radiances. A refinement of ALGO3, in which both nadir and forward looking radiances are used, will allow the discrimination between spurious and “real” 1.6 μm band spots.

Outside the SAA zone of influence ALGO3 results much more efficient than ALGO1/2 in detecting gas flares from oil-gas industrial sites.

As an example of this capability, the North Sea area has been selected for testing and the related ALGO3 hot spot locations are shown in Fig. 5. The map of exploration lease in the same area is shown in Fig. 6 for qualitative comparison.

The time series of monthly hot spots for ALGO1 (blue line) and ALGO3 (red line) for the North Sea area is shown in Fig. 5. The ALGO3 data have been divided by 10 to overlap with the ALGO1 numbers, i.e. ALGO3 seems to be ten times more efficient than the 3.7 μm algorithms.

As a further example, the time evolution of the western coast of Africa monthly spots is reported in Fig. 6 where, again, ALGO3 data are divided by 10.
One of the major advantages of ALGO3 is that the analysis can be brought back to summer 1991, including the ATSR-1 mission data. This is not possible for the ALGO1 approach because the thermal bands of ATSR-1 suffered a fatal failure six months after launch, while band 1.6 \( \mu m \) operated almost continuously during the mission. In practice, 18 years of data will be available for long term analyses.

The use of ALGO3 is not limited to the active fire detection. In fact, the spurious pixels could be considered as proxy measurements of the proton and electron solar flux at 800 km altitude (the satellite flying height) and studies on SAA could benefit of this additional long term information.

### 3. FIRE PARAMETERS

Once a “hot spot” is detected using one of the above described methods (except when 3.7 \( \mu m \) saturates), it is possible to estimate some fire parameters [3], in particular the fire pixel fraction \( f \) and the related flame temperature \( T_f \).

The procedure requires that the signal from bands 1.6, 3.7 and 10.8 \( \mu m \) is available (i.e. not saturated or valid), and is practically an extension of the ALGO3 approach.

The retrieval is based on the following considerations. Equation (1), which describes the radiative budget for a single wavelength:

\[
R_s = (1-f) \cdot \varepsilon_b \cdot R_b + f \cdot \varepsilon_f \cdot R_f
\]

where subscript ‘\( s \)’ stands for “satellite”, ‘\( b \)’ for “background” and ‘\( f \)’ for “fire”.

For ATSR typical pixel size the fire fraction values range between \( 10^{-6} \) to \( 10^{-3} \), and flame emissivity can is here assumed to be close to 1. We can write:

\[
R_s \equiv \varepsilon_b \cdot R_b + f \cdot R_f
\]  

Values of surface emissivity vary between 0.93 and 1.0, and a first guess value can be obtained, for example, from the MODIS emissivity database. In practice, equation (2) will reduce to:

\[
R_s \equiv R_b + f \cdot R_f
\]

In equation (3) the surface background radiance has been multiplied by the initial guess for emissivity.

The Planck function:

\[
P(\lambda, T) = \frac{a}{\lambda^2} \cdot \frac{1}{e^{b/T} - 1}
\]

where \( a = 2 \cdot h \cdot c^2 \) \( b = h \cdot c / k \) (\( h = \) Planck constant, \( k = \) Boltzmann constant, and \( c = \) speed of light).

Given that for 1.6 and 3.7 \( \mu m \) \( \frac{b}{\lambda T} \gg 1 \) even at high temperatures, equation (4) can be approximated with:

\[
P(\lambda, T) \approx \frac{a}{\lambda^2} \cdot e^{b/\lambda T}
\]

Now, assuming that the signal at 10.8 \( \mu m \) is practically not influenced by the presence of flames (due to low fire fractions and reduced sensitivity to temperature changes), it is reasonable to assume the brightness temperature at this wavelength as a good estimate of the background temperature, \( T_b \).

Now, using the 1.6 and 3.7 \( \mu m \) radiances we can write the following system:

\[
\begin{align*}
R_s(\lambda_1) - P(T_b, \lambda_1) &= \frac{f \cdot a}{\lambda_1^2} \cdot e^{-b/\lambda_1 T_f} \\
R_s(\lambda_2) - P(T_b, \lambda_2) &= \frac{f \cdot a}{\lambda_2^2} \cdot e^{-b/\lambda_2 T_f}
\end{align*}
\]

The indices 1 and 2 are relative to band 1.6 and 3.7 \( \mu m \) respectively, while \( P(T_b, \lambda) \) indicates the Planck function at given wavelength and temperature \( T_b \).

It holds:

\[
\begin{align*}
R_s(\lambda_1) - P(T_b, \lambda_1) &= \frac{f \cdot a}{\lambda_1^2} \cdot e^{-b/\lambda_1 T_f} \\
R_s(\lambda_2) - P(T_b, \lambda_2) &= \frac{f \cdot a}{\lambda_2^2} \cdot e^{-b/\lambda_2 T_f}
\end{align*}
\]

Or:

\[
\begin{align*}
R_s(\lambda_1) - P(T_b, \lambda_1) &= \frac{f \cdot a}{\lambda_1^2} \cdot e^{-b/\lambda_1 T_f} \\
R_s(\lambda_2) - P(T_b, \lambda_2) &= \frac{f \cdot a}{\lambda_2^2} \cdot e^{-b/\lambda_2 T_f}
\end{align*}
\]
Problem (8) can be simply solved, giving the following expression for $T_f$:

$$T_f = \frac{1}{\lambda_2} - \frac{1}{\lambda_1} \cdot b \ln \frac{R'_1}{R'_2} + 5 \ln \frac{\lambda_1}{\lambda_2}$$

(9)

The fire temperature is, then, inversely proportional to the natural logarithm of radiances ratio.

The value of $T_f$ from equation (9) can be used in one of the two equations in (8) to give:

$$f = \frac{R'_1 \cdot \lambda_1^5}{a} \cdot \frac{b}{\lambda_2\lambda_f^4}$$

(14)

In practice, the assumptions to be satisfied in order to get a sufficiently accurate estimate are:

1. $f \ll 1$ (always true due to typical size of ATSR ground pixels)
2. $\frac{b}{\lambda T} \ll 1$ (always true at any temperature for 1.6 and 3.7 μm band)
3. $\varepsilon_b$ known (or set to an average value, which is always possible)
4. $\varepsilon_f = 1$ (assumption that is not easy to verify: weakness of the method!)
5. $T_b \approx$ brightness temperature of 10.8 μm band

Fig. 7 shows the correlation between fire fraction (abscissa) and fire temperature (ordinate) for ten days of AATSR measurements (10-19 June 2006). Each couple of fire parameters is indicated with a red dot, while the dashed lines indicate the sensitivity limits of bands 1.6 (lower curve) and 3.7 μm (upper curve, assumed background temperature = 283 K).

According to the sensitivity curves it is not possible to retrieve valuable information on fire parameters for fractions $f > 5 \cdot 10^{-4}$ (3.7 μm band saturates) and for temperatures $T_f < 800$ K (1.6 μm band signal too low).

In practice, only small fractions and high temperature fires can be evaluated with this method. In Fig. 8 and Fig. 9 the histograms of fire fractions and fire temperatures for the selected data are respectively shown.

The above described method could, in principle, be used to discriminate industrial flares from wild fires, assuming that the former are characterised by smaller fire fractions and higher temperatures with respect to the latter.
A confirm of the validity of these assumptions is given in Fig. 10, showing the $f$ and $T_f$ histograms, and the $f$ vs. $T_f$ scatter plots for North Sea (left) and Canada (right) fires relative to the July 2002-December 2007 time period. The two areas have been selected because are located approximately at same latitudes and, hence, the possible differential water vapour contributions should be minimised (see ALGO4 paragraph for a detailed discussion).

In the scatter plots the dashed lines represent the sensitivity limits for 1.6 and 3.7 μm bands, the latter being evaluated for background temperatures estimated as the mean 10.8 μm brightness temperatures. The North Sea flame temperatures modal value exceed 2000 K with typical fire areas of few square meters, while the Canada fires, which are typically forest fires, are, as expected, “colder” and wider.

As already mentioned, assumption 5 is satisfied only at first approximation. In fact, in the above described method the radiance extinction is not accounted for. As will be shown in the paragraph dedicated to ALGO4, water vapour absorption plays a significant role in the atmospheric radiative transfer. In particular, the water vapour continuum strongly impacts the 10.8 μm band leading to an underestimate of $T_b$ and, hence an overestimate of $T_f$. This problem will be solved by simultaneously using ATSR nadir and forward looking measurements: the dual looking scheme will allow for the estimate of atmospheric and surface parameters and, hence, for a more affordable fire parameters estimate.

4. ALGO4

Although very efficient, ALGO3 approach allows for the detection of active/small-fraction fires only. This is due to the relatively large ground pixel size (1 km²) and to the S/N limit of 1.6 μm band.

To overcome this limitation, a new adaptive threshold algorithm, ALGO4, is under development. It is base on the simultaneous use of 3.7 and 10.8 μm band radiances, in which the latter should play the role, again, of background signal.

As stated above, the main problem to be tackled is the correct evaluation of the atmospheric transmissivity due to water vapour absorption in the two bands.

MODTRAN simulations of atmospheric transmissivity with varying water vapour total columns (TCWV) have been carried out and results are shown in Fig. 11. The exercise was carried out assuming a mid-latitude atmosphere and a nadir looking geometry. The TCWV values ranged from 1 to 10 g cm⁻² and related spectral transmissivity curves are indicated with different colours from blue to red (increasing TCWV order). Also reported are the AATSR spectral bands (grey areas). AATSR transmissivity curves are obtained by integrating the spectral transmissivity for each spectral band and for each TCWV value, and are reported in Fig. 13, where TCWV is the abscissa (0 to 6) and the transmissivity is the ordinate (0 to 1), band 3.7 μm is indicated in red, 10.8 μm in blue, and 12 μm in green.

It is evident that for TCWV values higher than 2 g cm⁻², the 3.7 and 10.8 bands are characterized by a very different water vapour absorption effect. This implies that, for TCWV > 2.5 g cm⁻², 3.7 μm brightness
temperatures at would be higher up to tens of K than those at 10.8 μm, even if no fires are present, resulting in undesired false alarms.

The new ALGO4 will make use of the (A)ATSR(-1/2) dual-view geometry (forward looking angle = 55°) in order to estimate a sensible correction for differential atmospheric extinction and surface emissivity and, consequently, to estimate a dynamic (adaptive) threshold for the 3.7 μm brightness temperatures.

To test the above described approach an exercise has been carried out using nadir and forward measurements from a single AATSR TOA product, and computing estimates of optical depths for bands 3.7 and 10.8 μm respectively. Optical depths have been used to correct the original radiances and, finally, corrected brightness temperatures have been computed. Results of this exercise are reported in Fig. 13, where the upper plot shows the optical depths and the lower plot the differences between brightness temperatures. Results are promising, especially for the tropical regions, where major problems are to be expected.

Finally, MODTRAN results indicate that the assumption that band 10.8 μm is a good estimate of the background temperature, used in the retrieval of fire parameters, is only valid for extra-tropical regions.

5. CONCLUSIONS

Two new hot spot detection algorithms have been designed for ATSR family instruments. In addition, a retrieval scheme aimed at the estimate of fire parameters has been put in place and tested. Preliminary results are very encouraging, although the maturity of ALGO3 and ALGO4 has to be reached yet, especially in terms of validation against independent data.

The use of ALGO3, which is based on the analysis of 1.6 μm radiances, will extend the WFA time range down to September 1991, resulting in the longest fire atlas worldwide. The ALGO3 limitations are linked to the influence of the energetic solar flux impinging the satellite and causing spurious signals in correspondence of South America, South Atlantic and the coasts of Antarctic (SAA), but future use of bi-directional measurements will reduce (hopefully eliminate) this factor.

The ALGO4 scheme, consisting in the synergistic use of 3.7 and 10.8 μm radiances, is still under development, being based on the extensive use of nadir and forward looking ATSR measurements.

6. REFERENCES

