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# The Very First Multi-Temporal and Multi-Spectral Level-2 SEVIRI Processor for the Simultaneous Physical Retrieval of Surface Temperature and Emissivity

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**Abstract.** The estimation of surface parameters yields important information in several applications on regional and global scale. Because of their high temporal resolution, infrared instruments on board geostationary platforms are capable to provide time sequences of observations, which fully resolve the diurnal cycle. To exploit multi-temporal information, a Kalman filter (KF) methodology has been implemented in order to retrieve simultaneously surface temperature and emissivity from SEVIRI (Spinning Enhanced Visible and Infrared Imager) infrared data. Because of its sequential nature, the Kalman filter methodology yields a very fast software implementation, which can be applied to the SEVIRI full disk for off-line analysis. The software can run in real-time at the regional scale, which makes it very attractive for different applications such as land surveillance, natural hazards, risk management, and so on. The paper will show the basic methodology and applications at regional and global scale.

## INTRODUCTION

In two recent studies [1, 2], the high temporal resolution of data acquisition by geostationary satellites and their capability to resolve the diurnal cycle has been exploited for the retrieval of surface temperature and emissivity. We have examined the case of SEVIRI (Spinning Enhanced Visible and Infrared Imager) Meteosat-9 high rate level 1.5 image data. A suitable Kalman Filter (KF) approach [3] has been developed and demonstrated on the basis of suitable case studies encompassing a variety of surface features (sea and land surface). The results have been quite recently documented in the science literature [1, 2, 4, 5, 6]. In [1, 2], we pursue a genuine dynamical strategy which exploits the sequential approach of the Kalman filter. This results in an algorithm which does not need to increase the dimensionality of the data space, e.g., because of time accumulation of observations, while preserving the highest time resolution prescribed by the repeat time of the geostationary instrumentation (e.g., 15 min for SEVIRI).

A thorough validation of the KF scheme has been already performed and shown in [1, 2, 4, 5, 6]. The analysis has shown that the KF approach is robust and is not affected by large data voids because, e.g., of clouds. The physical retrieval provides a very accurate estimation of surface temperature and emissivity. For temperature, the root mean square (RMS) error is better than 1.5 K and 1 K for land and sea surface, respectively. For emissivity, the RMS error is of the order of ± 0.005.

The present paper is aimed at reviewing recent results/achievements and exemplifying the capability of KF approach to deal with the global and regional scale, sea and land surface. To this end, two suitable case studies have been set up, analyzed and presented in this paper.

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## DATA AND METHODS

The SEVIRI imager on board Meteosat-9 allows for a complete image scan (full Earth scan) once every 15 min period with a spatial resolution of 3 km for 12 channels (8 in the infrared), over the full disk covering Europe, Africa and part of South America. Infrared channels range from 3.9 $\mu$m to 13.4 $\mu$m and their definition in terms of channel number is given in Tab. 1. The SEVIRI cloud mask used in the analysis is that operational. SEVIRI radiances and associated cloud mask were downloaded from the EUMETSAT Data Centre through the Unified Meteorological Archive Facility (UMARF). With the purpose to show that the KF approach is able to run at global and regional scale, two case

**TABLE 1.** SEVIRI infrared channels

| SEVIRI channel number | wave length ($\mu$m) |
|---|---|
| 4 | 3.9 |
| 5 | 6.2 |
| 6 | 7.3 |
| 7 | 8.7 |
| 8 | 9.7 |
| 9 | 10.8 |
| 10 | 12.0 |
| 11 | 13.4 |

studies have been set up in this paper. The first example refers to a SEVIRI full disk data set (land and sea surface) for November 2007. The second example concerns the Basilicata region (39.25°N-42°N, 13°E-18.75°E), for which SEVIRI radiances were acquired for the whole year 2013 (again sea and land surface types have been analyzed).

The basic KF approach involves the use of a *data equation or model*, which relates the data (spectral radiances in our case) to the state vector and a *state equation* which governs the time volution of the state vector. The state vector is made up by the surface temperature, $T_s$ and the emissivity for channels at 12, 10.8, 9.7 and 8.7 $\mu$m. The data equation is the radiative transfer equation, which is parameterized through a forward model, which has been purposely developed for SEVIRI [7, 8, 9, 12]. For the state equation we use a simple statistical model, which consists of a persistence equation with a suitable stochastic noise term (again see [1] for details).

The retrieval scheme has to be initialized for the state vector. Furthermore, atmospheric parameters (temperature, $H_2O$ and $O_3$) have to be provided to account for the atmospheric radiative effects on spectral radiances. This *background* information is provided by ECMWF (European Centre for Medium-Range Weather Forecasts) analysis for surface temperature and atmospheric profiles of temperature, water vapour and ozone. The Masuda's emissivity model [10] is used for sea surface first guess and background, whereas for land the UW/BFEMIS University of Wisconsin Baseline Fit Global Infrared Land Surface Emissivity database [11] is used. Background emissivities have been re-mapped to SEVIRI infrared channels using a suitable algorithms, which is fully described in [1].

## RESULTS

This section describes the retrieval results obtained in the target areas defined in the previous section. As said, the case studies have been selected to exemplify the capability of KF scheme to run both at global and regional scale.

### SEVIRI Full Disk case study

The SEVIRI full disk case study includes pixels with a VZA (Viewing Zenith Angle) below 70°, since the forward model is not suitable for larger angles because it considers a plane parallel atmosphere. This assumption has been done taking also into account for the SEVIRI pixel size, which increases for higher VZA.

The application of KF at global scale is exemplified in Figure 1. which shows the surface temperature retrieval. In this figure the monthly average of retrieved skin temperature for November 2007 is shown. The expected latitudinal temperature gradients are well represented. Also the increase of temperature corresponding to desert areas, e.g., Sahara and Arabian deserts, is well reproduced. For the same period the retrieved emissivities at 8.7, 10.8 and 12 $\mu$m are shown in Figure 2. The SEVIRI channel at 8.7 $\mu$m is very useful to map desert areas because it is sensitive to the reststrahlen band of quartz. Normally, the other two channels (10.8 and 12 $\mu$m) are used to discriminate among

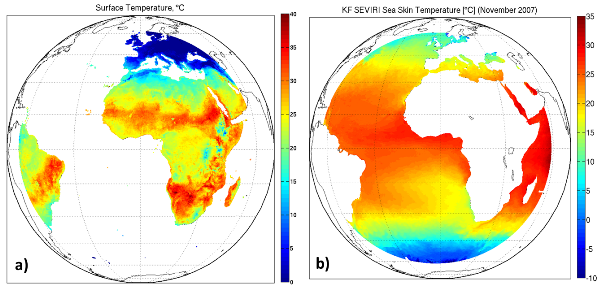


**FIGURE 1.** Monthly map (November 2007) of retrieved skin temperature for land (a) and sea (b) surface.

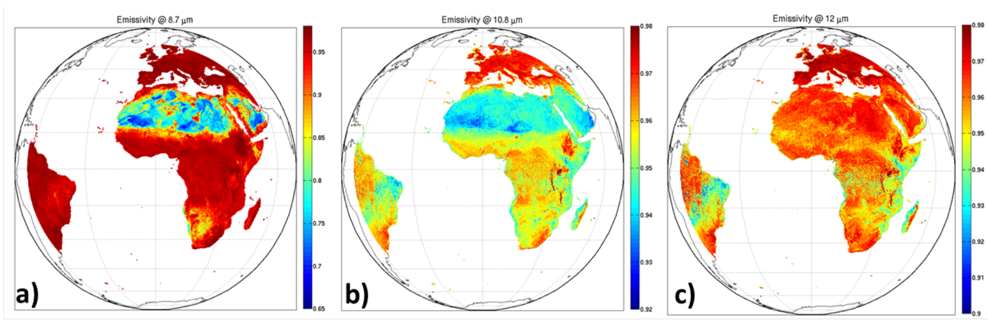


**FIGURE 2.** Monthly map (November 2007) of retrieved surface emissivity at 8.7 (a), 10.8 (b) and 12 $\mu$m (c).

different land cover types. The effectiveness of the 8.7 $\mu$m channel to map desert areas is well exemplified in Fig. 2a. It is seen that the sand "seas" of Sahara and Arabian regions are well reproduced because of the lower emissivity of sand at 8.7 $\mu$m.

## Basilicata Region case study

This target area is very interesting because it includes different land cover types and sea surface, as well. Figure 3 shows the retrieval for land surface temperature and emissivity at 10.8 $\mu$m. For sea surface, the skin temperature is shown. Retrievals have been time-averaged over January 2013.

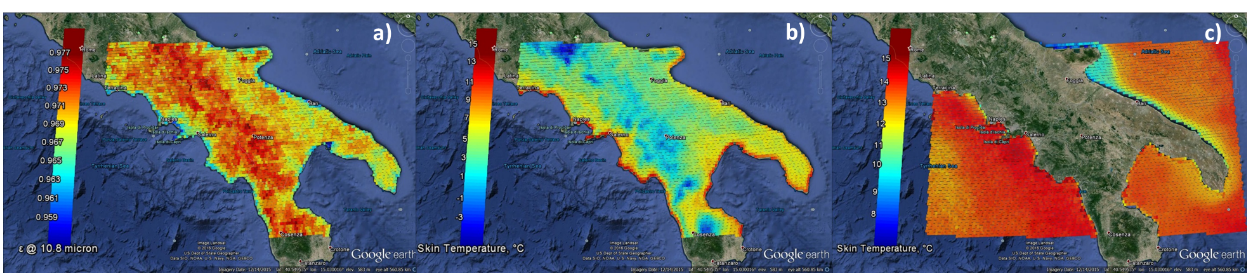


**FIGURE 3.** Monthly map (January 2013) of retrieved surface emissivity at 10.8 $\mu$m (a), and skin temperature for land (b) and sea surface (c).

For land surface, the retrieval for emissivity and temperature show the expected behaviour. In addition, although not shown for the sake of brevity, emissivity follows the expected seasonal cycle. Concerning the sea skin temperature, from Fig. 3 it is quite evident that the Tyrrhenian Sea (on the left-hand-side of the figure) is warmer than the Adriatic (on the right) [13]. Another interesting effect is seen for the Adriatic sea where the temperature is colder near the coast than offshore. This temperature gradient is in agreement with the known climatology [13] for the Adriatic sea and is named *cold-water* phenomenon. This phenomenon drives a vertical water flow with the up-welling of deeper water. The mechanism governs the biogenic activity/productivity of the Adriatic sea.

For the case study shown in Fig. 3, although not shown in the paper, a validation for the skin temperature has been performed by comparison with MODIS (Moderate Resolution Imaging Spectroradiometer), and ECMWF data [6]. Considering the full year 2013, a bias of -0.07 °C and a standard deviation of about 1.02 °C was found when comparing the KF retrieval to the ECMWF analysis; when comparing with MODIS, we found the same bias and a slightly larger standard deviation (1.05 °C).

Again for the case study at hand, the KF code has been also checked for timeliness. The code can process a single SEVIRI multi-spectral image (channels at 12.0, 10.8, 9.7 and 8.7 $\mu$m) within four minutes. These values can be scaled to different regions considering that in our case the target area is covered by 9643 SEVIRI pixels. Because the SEVIRI repeat time is 15 min, we have that for regional analysis the KF code can provide real-time scene analysis for $T_s$ and channel emissivity at at 12.0, 10.8, 9.7 and 8.7 $\mu$m.

## CONCLUSIONS

The very first multi-temporal and multi-spectral Level-2 processor for the simultaneous physical retrieval of surface temperature and emissivity has been presented in this paper. The KF scheme has been applied to different case studies and two of these, November 2007 SEVIRI full disk and Basilicata Region (year 2013) have been shown in this paper. We have shown how the methodology is capable to run at global and regional scale. The software is also very fast. We have shown that a fully physical retrieval scheme can process SEVIRI observations, in real-time and, hence, can be used for continuous monitoring of surface parameters, which could be used for the various purposes of tourism and agronomy, land surveillance, natural hazards and risk assessment analysis. The availability of simultaneous retrievals of surface emissivity and temperature from SEVIRI observations, would improve the exploitation of the European geostationary platforms and also lead to better, improved usage of other European satellite systems.

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