KALMAN FILTER RETRIEVAL OF SEA SKIN TEMPERATURE FROM SEVIRI: A COMPARISON CASE STUDY

Guido Masiello[1,2], Carmine Serio[1,2], Sara Venafra[1], Giuliano Liuzzi[1], Maria Grazia Blasi[1]

(1) Scuola di Ingegneria, University of Basilicata, Via dell'Ateneo Lucano 10, Potenza, Italy
(2) CINFAI, Piazza N. Mauruzi, 17, Tolentino (MC), Italy

Abstract

The high temporal resolution of data acquisition by geostationary satellites and their capability to resolve the diurnal cycle allow for the retrieval of a valuable source of information about geophysical parameters. To exploit this information we have developed a Kalman filter methodology for the retrieval of surface emissivity and temperature from radiance measurements made from geostationary platforms. The application of the retrieval methodology to SEVIRI (Spinning Enhanced Visible and Infrared Imager) infrared channels shows that we can simultaneously retrieve surface emissivity and temperature with an accuracy of ± 0.005 and ± 0.2 K, respectively. This performance is exemplified in this paper with a case study, which considers the retrieval of sea skin temperature for a target area of the Naples Gulf. Retrieval for temperature has been intercompared with similar products derived from AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectroradiometer) satellite sensors.

1 INTRODUCTION

Infrared instrumentation on geostationary satellites is now rapidly approaching the spectral quality and accuracy of modern sensors flying on polar platforms. Currently at the core of EUMETSAT geostationary meteorological programme is the Meteosat Second Generation (MSG). However EUMETSAT is preparing for Meteosat Third Generation (MTG). The capability of geostationary satellites to resolve the diurnal cycle and hence to provide time-resolved sequences or times series of observations is a source of information which could suitably constrain the derivation of geophysical parameters. Nowadays, also because of lack of time-continuity, when dealing with observations from polar platforms, the problem of deriving geophysical parameters is normally solved by considering each single observation as independent from past and future events. For historical reason, the same approach is currently pursued with geostationary observations, which are still now dealt with as they were polar observations.

To fill this gap, a surface temperature (T_s) and emissivity (ε) retrieval methodology for the atmospheric window infrared channels of the Meteosat Second Generation (MSG) SEVIRI (Spinning Enhanced Visible and Infrared Imager) has been recently developed in the framework of two projects EUM/CO/114600000996/PDW (Serio et al. 2012, Serio et al. 2014). The methodology exploits the Kalman filter (Kalman and Bucy, 1961, see also Rodgers 2000 for a discussion of the Kalman filter in the context of retrieval applications from satellite observations) to convey temporal constraint in the retrieval of surface parameters through time series of geostationary satellite data. To this end, it is worth mentioning that SEVIRI provides data every 15 minutes.

Even if the methodology works for the full disk, both for sea and for land, this paper focuses the attention on the sea skin temperature retrieved over a region centred on the Basilicata Region. To assess the quality of these retrievals they have been compared to AVHRR and MODIS operational products. In addition, a comparison with ECMWF (European Centre for Medium range Weather Forecasts) model has been provided.

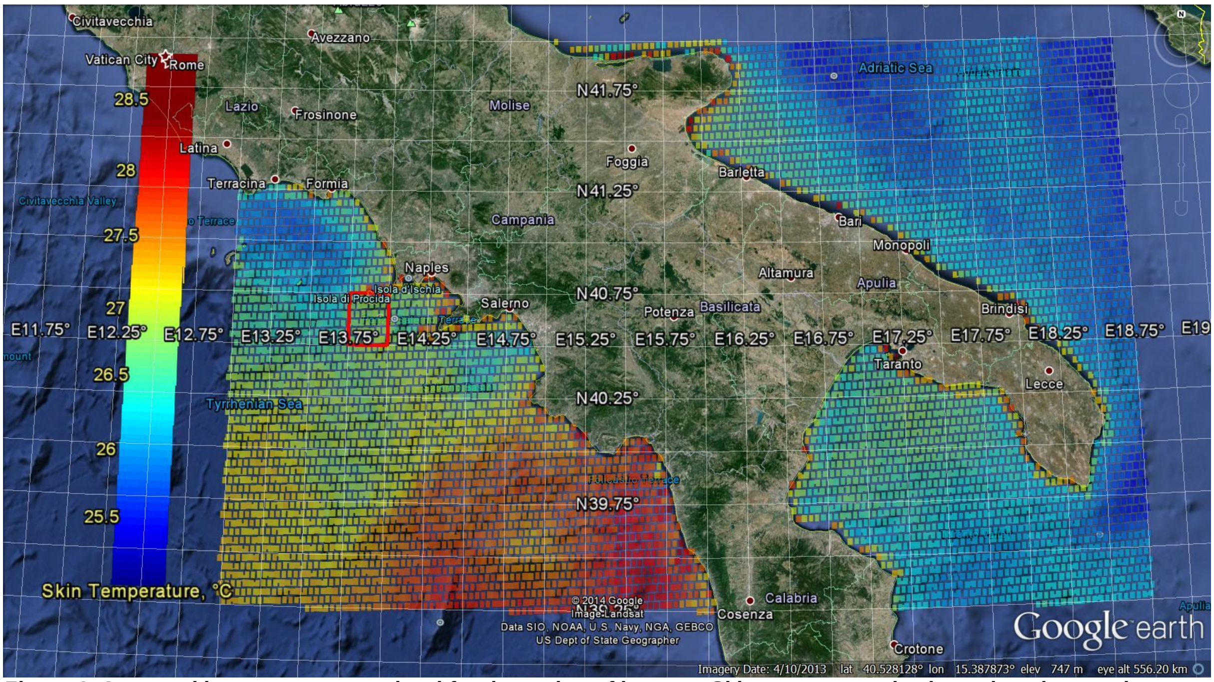

Figure 1: **August skin temperature retrieval for the region of interest. Skin temperature is shown in colour scale super-imposed to Google Earth. The red square indicates the gulf of Naples target area used for comparison with other satellite products.**

This paper is organized as follow: sections 2 and 3 describe respectively the data and summarize the methods used to retrieve surface emissivity and temperature. SEVIRI retrieved skin temperatures are compared with similar products in section 4. Conclusions are shown in section 5

2 DATA

SEVIRI observations have been acquired for the whole year 2013 over the target area shown in Figure 1, which extends from 13° to 18.75° degrees East longitude and 39.25° to 42° North latitude. The target area which includes Mediterranean Sea (Tyrrhenian, Ionian and Adriatic Seas) contains overall 9643 SEVIRI pixels. Among these pixels 5671 are over the sea. Figure 1 also shows the SEVIRI August map of skin temperature.

For the purpose of comparison, MODIS Sea Skin Temperature and AVHRR Sea surface temperature (SST) analysis were acquired for the same date and location.

The level 2 MODIS data products are produced and distributed by the NASA Goddard Space Flight Center's Ocean Data Processing System (ODPS). The data are available from the web site http://oceandata.sci.gsfc.nasa.gov. Both satellites AQUA and TERRA have been used.

The AVHRR data are not direct satellite observations. These data are indeed better referred to as AVHRR OI (optimal Interpolation) SST (Sea Surface Temperature) analysis ([9], because they are the results of an optimal interpolation scheme which combines AVHRR, buoys and ships data to form daily averages. The data are available at the web site ftp://eclipse.ncdc.noaa.gov/pub/OI-daily-v2/NetCDF/ and they are provided on a regular grid of 0.25 × 0.25 degrees.

For the whole target area shown in Fig. 1, we have also acquired ECMWF analysis products for the sea skin temperature at the canonical hours 0:00, 6:00, 12:00 and 18:00. ECMWF model data points are provided on 0.125°×0.125° (lat,lon) grid. They are time-space interpolated to SEVIRI pixels.

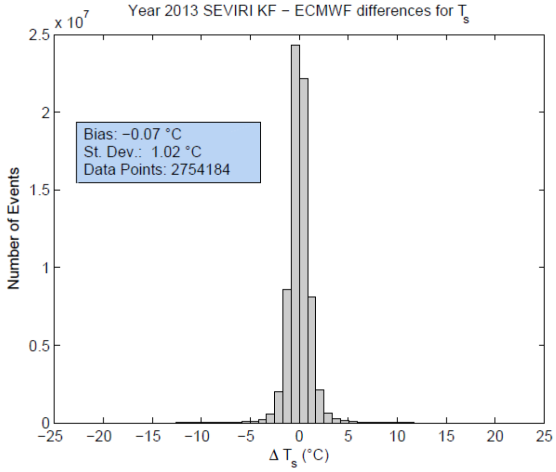

Figure 2: **Histogram of the differences $T_s^{SEVIRI} - T_s^{ECMWF}$.**

3 METHODOLOGY

The T_s-ε retrieval methodology we have applied to SEVIRI observations has been developed by Amoroso et al 2013, Masiello et al 2013a. The technique exploits the unique high temporal resolution of data acquisition by geostationary satellites and their capability to resolve the diurnal cycle. A Kalman filter approach was implemented for applying temporal constraints on the retrieval of surface emissivity and temperature. A persistence state model was used for the state vector. By properly tuning the parameters of the state equation, the different time scales of emissivity and temperature were modelled and hence a method which allows one to separate the radiative effects of the two parameters was developed.

The forward model used in the procedure is a monochromatic radiative transfer code based on a look-up-table of pre-computed optical depth named σ-SEVIRI following the model developed for IASI radiance, σ-IASI (Amato et al. 2002, Masiello and Serio 2003). As for σ-IASI the look-up table for σ-SEVIRI has been developed from one of the most popular line-by-line forward model, that is LBLRTM (Clough et al. 2005). Actually, the σ-SEVIRI look-up table is obtained by down-scaling the wave number sampling rate with a procedure described in Liuzzi et al. 2013, 2014.

The inverse approach relies on suitable a-priori information for emissivity. To this end, for land surface, we have used the University of Wisconsin (UW) Baseline Fit (BF) Emissivity database (UW/BFEMIS database, e.g. http://cimss.ssec.wisc.edu/iremis/, Seemann et al., 2008, Borbas and Ruston 2010). The UW/BFEMIS database is derived from the monthly mean operational Aqua/MODIS (Moderate Resolution Imaging Spectroradiometer) products (called MYD11C3) using a conceptual model called the Baseline Fit method developed from laboratory measurements of surface emissivity. For sea surface emissivity we use Masuda's model (Masuda 1988).

4 RESULTS

4.1 Comparison with ECMWF analysis

The comparison with ECMWF model data for T_s (skin temperature) shows a very nice agreement with absolute monthly mean differences below 0.4 K and standard deviation around 1 K. Figure 2 shows the histogram of T_s differences for the whole year 2013. It is seen that the yearly average difference is only -0.07 K with a standard deviation of 1.02 K. The statistics has been compiled with 2,754,184 data points. In passing, this testifies the high reliability reached by the ECMWF sea skin temperature product. Figure. 3.a) show the spatial distribution of the yearly differences. It is seen that apart from SEVIRI pixels close to the coast, the difference is homogeneously zero everywhere.

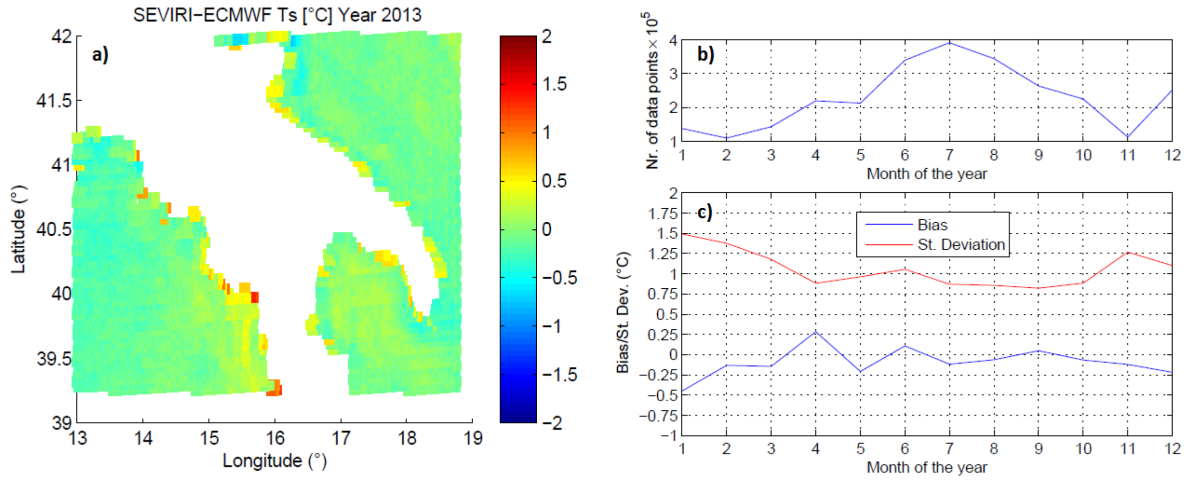

Figure 3: **Comparison of SEVIRI retrieved Skin temperature with ECMWF analysis. Panel a) Map of the yearly average difference $T_s^{SEVIRI} - T_s^{ECMWF}$. Panel b) Number of data points. Panel c), monthly bias (in blue) and standard deviation of the skin temperature difference (in red).**

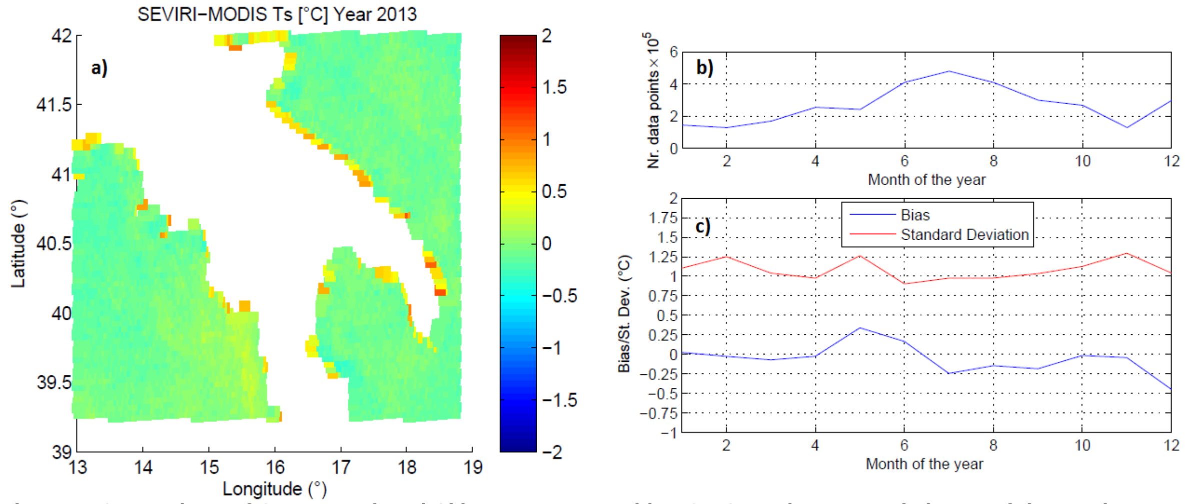

Figure 4: **Comparison of SEVIRI retrieved Skin temperature with MODIS products. Panel a) Map of the yearly average difference $T_s^{SEVIRI} - T_s^{MODIS}$. Panel b) Number of data points. Panel c), monthly bias (in blue) and standard deviation of the skin temperature difference (in red).**

To check for a seasonal dependence of the difference we have computed the monthly averages and standard deviations of the difference between SEVIRI and ECMWF. These are shown in Fig. 3.c). It is seen that the mean difference and standard deviation tend to decrease in the summer season, which is quite understandable because the frequency of cloud tends to diminish in summer. This has two positive concomitant effects: more data points and less cloud contamination.

4.2 Comparison with MODIS products

The comparison has been performed by using SEVIRI retrieval for T_s time-space colocated with MODIS overpasses.

Also in this case we have a very nice agreement with a yearly mean difference of -0.07 K and a standard deviation of 1.05 K. These two figures have been obtained with a statistics of 3230689 data points. Apart from the month of December 2013, the monthly mean difference is normally ≈ 0.2 K or below as it is possible to see from Fig. 4.c). The anomalous case of December 2013 is not understood at this stage, MODIS has an offset of some 0.5 K, with respect to SEVIRI, which is uniform over the target area. This behavior is not seen for other months.

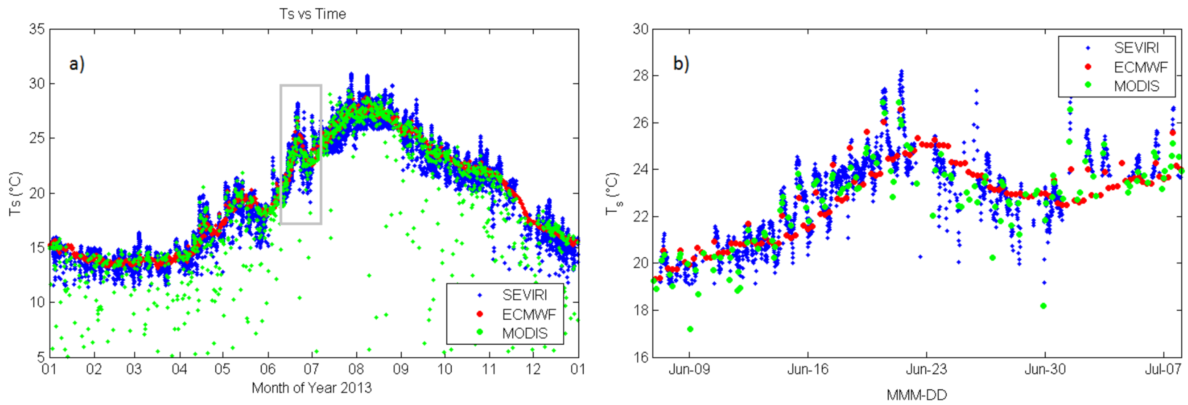

Figure 5: **Time behaviour of T_s along the whole year. The retrieval for T_s (in blue) is compared the ECMWF analysis (in red) and MODIS products. Panel b) is a zoom of the grey area in panel a).**

f

Figure 6: **Time sequence of the daily average for T_s. The retrieval is compared to that of the AVHHR OI SST.**

The Kalman filter we have developed for SEVIRI can also retrieve the year cycle with the same quality and accuracy shown from other satellite products as it is shown in Fig. 5 where we show the behavior of Skin temperatures retrieved from SEVIRI at its full temporal resolution superposed to ECMWF analysis and MODIS products. The figure refers to the region indicated by the red rectangle in Fig. 1 centered at lat/lon coordinates (40.625 N, 13.875 E) where RITMARE (*Ricerca ITaliana per il MARE,* Italian Research for the Sea) measurement campaigns took place (Budillon et al. 2014). The right panel shows 20 days zoom between June and July 2013. Between 22 and 23 June clouds cover the region and both SEVIRI and MODIS have no data. But when the clouds disappear the Kalman Filter methodology follows again the cycle.

4.3 Comparison with AVHRR products

For the case of AVHRR, the yearly cycle is also exemplified in Fig. 6 which shows the time evolution, along the year, of the daily mean surface temperature obtained from SEVIRI and AVHRR. The SEVIRI T_s compared to this product has been obtained by averaging over the day the correspondent value retrieved at the time step of 15 min. The comparison shown in Fig. 6 refers to one single SEVIRI pixel centered at lat/lon coordinates (40.625 N, 13.875 E).

The analysis evidences a yearly negative bias of SEVIRI of −0.30K, which is higher than the ≈ −0.07 −0.30K obtained with MODIS and the ECMWF analysis. This can be explained because the AVHHR OI SST is a surface temperature whereas our T_s is a skin temperature.

Satellite data, such as AVHRR, undergoes a de-bias procedure within the OI SST scheme which transforms the satellite skin temperature to that of the surface (Reynolds et al. 2007). From Fig. 6 we see that negative bias is quite homogeneous during the year, because the satellite senses the cool skin at the surface whereas buoys measure the warmer layer just below the surface.

5 CONCLUSIONS

We have developed a Kalman filter methodology for the retrieval of surface temperature and emissivity from SEVIRI radiances at the full spatial (3x3 km) and time (15 min) resolution. The SEVIRI retrieval for the skin temperature has been inter-compared with ECMWF analysis and MODIS skin temperature and with AVHRR OI-SST products. The intercomparison exercise has been performed for a target area of Southern Italy, which included the Gulf of Naples. The findings have shown a very good agreement between SEVIRI and the aforementioned products, with a bias (mean difference) less than 0.3°C and a standard deviation of ≈ 1° C.

AKNOWLEDGMENTS

This works has been performed under the projects, EUMETSAT EUM/CO/14/4600001329/PDW and RITMARE (CNR/MIUR), Italian Flagship project, Italian Research for the Sea.

REFERENCES

Amato U., Masiello G., Serio, C., Viggiano, M (2002). The σ-IASI code for the calculation of infrared atmospheric radiance and its derivatives. Environmental Modelling & Software, **17**, pp 651-667, doi: 10.1016/S1364-8152(02)00027-0.

Amoroso M, I De Feis, G Masiello, C Serio, S Venafra & P Watts, (2013). Spatio-temporal constraints for emissivity and surface temperature retrieval: Preliminary results and comparisons for SEVIRI and IASI observation. EARSeL eProceedings, **12** pp 136-148.

Borbas E.E. and B.C. Ruston (2010), The RTTOV UWiremis IR land surface emissivity module, NWP SAF, EUMETSAT.

Budillon, G., Serio, C., Tramutoli, V., Aulicino, G., Bernini, G., Ciancia, E., Cotroneo, Y., Coviello, I., Di Polito, C., Fusco, G., Lacava, T., Liuzzi, G., Masiello, G., Paciello, R., Pergola, N., Satriano, V., Sileo, G., Venafra, S. (2014). Integration of satellite and UMV (Unmanned Marine Vehicle) based observations quality assessment and monitoring: preliminary results from the RITMARE project. Proceedings of 2014 EUMETSAT Meteorological Satellite Conference. Ginevra, Svizzera, 22 - 26 September 2014, Darmstadt, Germany: EUMETSAT.

Clough, S. A., Shephard, M. W., Mlawer, E. J, Delamere, J. S., Iacono, M. J., Cady-Pereira, K., Boukabara, S., and Brown, P. D., (2005). Atmospheric radiative transfer modeling: a summary of the AER codes, Journal of Quantitative Spectroscopy & Radiative Transfer, **91**, pp 233–244.

Kalman, R. E., and Bucy R.S. (1961) New Results in Linear Filtering and Prediction Theory. Transactions of the ASME - Journal of Basic Engineering **83**, pp 95-107.

Liuzzi, G., Masiello G., Serio, C., Fonti, S., Mancarella, F., Roush, T.L. (2013). Search for Martian methane with TES data: development of a dedicated radiative transfer code: first results. Proceedings of SPIE **8867**, 88670B, doi:10.1117/12.2025566.

Liuzzi, G., Masiello G., Serio C., Palchetti L., Bianchini G. (2014). Validation of H2O continuum absorption models in the wave number range 180-600 cm^{-1} with atmospheric emitted spectral radiance measured at the Antarctica Dome-C site. Optics Express, **22**, pp. 16784-16801 doi:10.1364/OE.22.016784.

Masiello G., Serio C (2003). An effective water vapor self-broadening scheme for look-up-table-based radiative transfer. Proceedings of SPIE, **4882**, pp. 52-61, doi: 10.1117/12.462580.

Masiello, G., C. Serio, I. De Feis, M. Amoroso, S. Venafra, I.F. Trigo, P. Watts (2013), Kalman filter physical retrieval of surface emissivity and temperature from geostationary infrared radiances, Atmospheric Measurement Techniques, **6,** pp 3613-3634, doi:10.5194/amt-6-3613-2013.

Masiello, G., Serio, C., Venafra, S., De Feis, I., and Borbas, E.E. (2014). Diurnal variation in Sahara desert sand emissivity during the dry season from IASI observations. Journal of Geophysical Research, **119** pp 1626-1638 doi:10.1002/jgrd.50863.

Masuda K, Takashima T, Takayama Y. (1988). Emissivity of pure and sea waters for the model sea surface in the infrared window regions. Remote Sensing of Environment, **24**, pp 313–329.

Reynolds, R.W., Smith, T.M., LIU, C., Chelton, D.B. Casey, K.S., and Schlax, M.G., (2007). Daily High-Resolution-Blended Analyses for Sea Surface Temperature, Journal of Cimate **20,** pp 5473-5496.

Rodgers C. D., (2000) Inverse methods for atmospheric sounding, Theory and Practice World Scientific, Singapore

Seemann, S.W., Borbas, E.E., Knuteson, R.O., Stephenson, G.R., and Huang, H.L. (2008), Development of a Global Infrared Land Surface Emissivity Database for Application to Clear Sky Sounding Retrievals from Multispectral Satellite Radiance Measurements, Journal of Applied Meteorology and Climatology, **47**, pp 108-123.

Serio C., Masiello G., Amoroso M., Venafra S., Amato U. and De Feis, I., (2012) Study on space-time constrained Parameter Estimation from Geostationary data, Final Report EUMETSAT (Contract EUM/CO/11/4600000996/PDW), EUMETSAT, Darmstadt, Germany, Revised by P. Watts.

Serio, C., Liuzzi, G. Masiello, Venafra, S, De Feis I., (2014) Kalman Filter estimation of surface temperature and emissivity from SEVIRI, Final Report EUMETSAT (contract EUM/CO/14/4600001329/PDW) EUMETSAT, Darmstadt, Germany, Revised by P. Watts.