Implementation of a real-time Level 2 SEVIRI processor for the simultaneous physical retrieval of surface temperature and emissivity at global scale

Applied Spectroscopy

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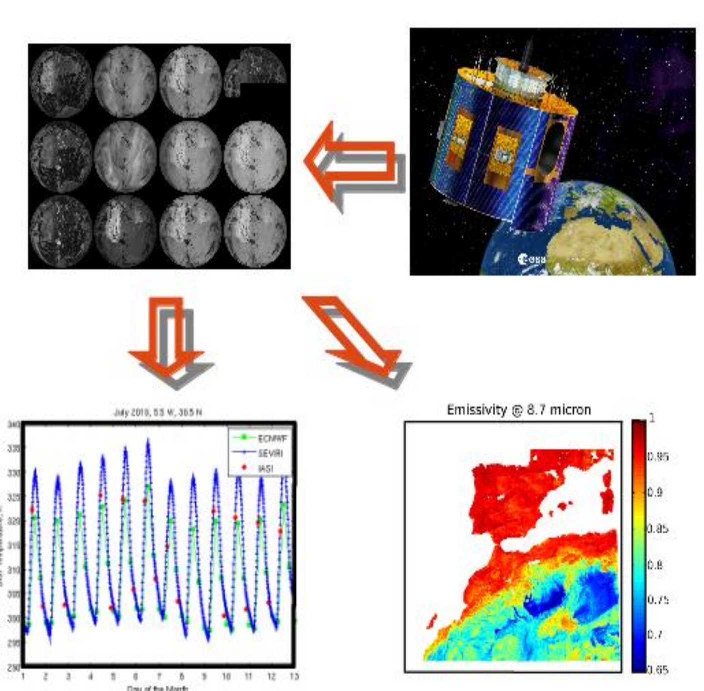
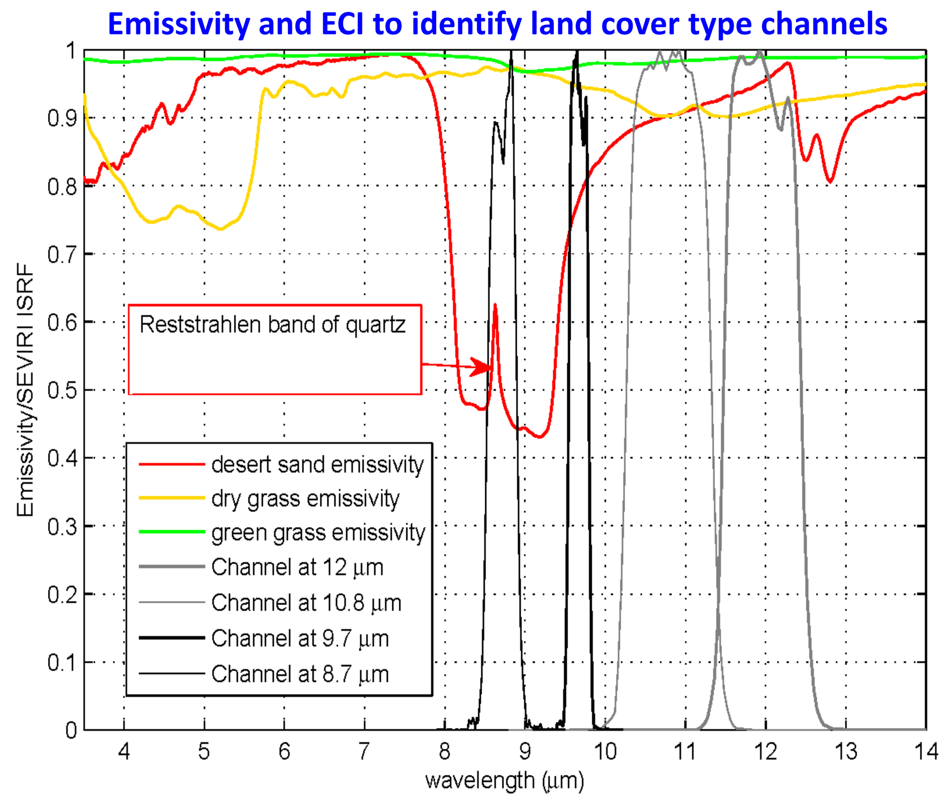
RATIONALE

The real-time continuous monitoring of surface parameters is very important for different applications, like risk management, natural hazards and land surveillance. Geostationary platforms allow to provide series of satellite observations with a very high temporal resolution, able to resolve the diurnal cycle and to catch seasonal variability. In this work the development of a very fast multi-temporal and multi-spectral Level 2 processor is described. The processor exploits SEVIRI (Spinning Enhanced Visible and Infrared Imager) infrared radiances (8.7, 9.7, 10.8 and 12 µm) to retrieve surface temperature and emissivity simultaneously by means of a fast forward radiative transfer model (σ-SEVIRI) and an inversion procedure based on the Kalman filter approach. Further details on the adopted methodology are reported in recent works (Masiello et al. 2013 doi:10.5194/amt-6-3613-2013), together with validation exercises at regional and global scale both against in situ, analysis and equivalent satellite observations (Masiello et al. 2015 doi:10.5194/amt-8-2981-2015; Blasi et al. 2016 doi: 10.3369/tethys.2016.13.01). The software is capable to run in real-time also thanks to a code optimization and the usage of parallel computation. In detail, a single SEVIRI full disk slot time (15 minutes) can be processed in about 16 minutes exploiting 20 threads, providing surface temperature and emissivity estimations on land surface.

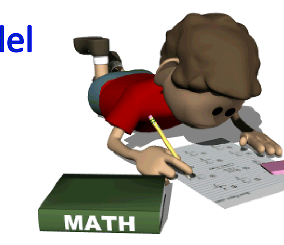
The SEVIRI instrument for the retrieval of Ts- ε



Emissivity and ECI to identify land cover type channels



METHODOLOGY



Forward Model: σ- SEVIRI, pseudo-monochromatic radiative transfer model

$$R(\theta_r,\varphi_r,\sigma)=\varepsilon(\theta_r,\varphi_r,\sigma)\tau_0(\theta_r,\varphi_r,\sigma)B(T_s)+R_u(\theta_r,\varphi_r,\sigma)+R_r(\theta_r,\varphi_r,\sigma)$$

$$R_u(\theta_r,\varphi_r,\sigma)=\int_0^{+\infty}B(T)\frac{\partial\tau}{\partial h}dh$$

$$R_r(\theta_r,\varphi_r,\sigma)=\tau_0(\theta_r,\varphi_r,\sigma)\int_0^{2\pi}d\varphi_i\int_0^{\frac{\pi}{2}}f(\theta_r,\varphi_r,\theta_i,\varphi_i,\sigma)R_i(\theta_i,\varphi_i,\sigma)\cos\theta_i\sin\theta_i d\theta_i$$

It takes into account both Specular and Lambertian reflection

New forward model: PCA (Principal Component Analysis) based approach to Radiative Transfer Model

$$\mathbf{R_{high}}=\mathbf{u}\cdot\mathbf{s}\cdot\mathbf{v}^t$$

$$\underset{[n_c\times 1]}{\mathbf{c}} = \underset{[n_p\times n_c]}{\mathbf{u}^t}\cdot\underset{[n_p\times 1]}{\mathbf{R_{high}}}$$

$$\underset{[n_l\times 1]}{\mathbf{R_{low}}} = \underset{[n_l\times n_p]}{\mathbf{W}}\cdot\underset{[n_c\times 1]}{\mathbf{c}}$$

About 7 times faster than older σ-SEVIRI version

Inverse Model: δ-SEVIRI, Kalman Filter + Persistence Model for the simultaneous retrieval of surface temperature and emissivity

$$\begin{cases}\mathbf{R_t}=F(\mathbf{v_t})+\boldsymbol{\varepsilon}_\mathbf{t} & \text{observation equation}\\ \mathbf{v_{t+1}}=\mathbf{H}\mathbf{v_t}+\boldsymbol{\eta}_\mathbf{t} & \text{state/evolution equation}\end{cases}$$

update or analysis (analysis at time t; forecast at time t)

$$\begin{cases}\hat{\mathbf{v}}_\mathbf{t}=\hat{\mathbf{v}}_\mathbf{a}+\left(\mathbf{K_t^T}\mathbf{S}_\varepsilon^{-1}\mathbf{K_t}+\mathbf{S_a}^{-1}\right)^{-1}\mathbf{K_t^T}\mathbf{S}_\varepsilon^{-1}\left(\mathbf{y_t}-\mathbf{K_t}(\hat{\mathbf{v}}_\mathbf{a}-\mathbf{v_o})\right)\\ \mathbf{S_t}=\left(\mathbf{K_t^T}\mathbf{S}_\varepsilon^{-1}\mathbf{K_t}+\mathbf{S_a}^{-1}\right)^{-1}\end{cases}$$

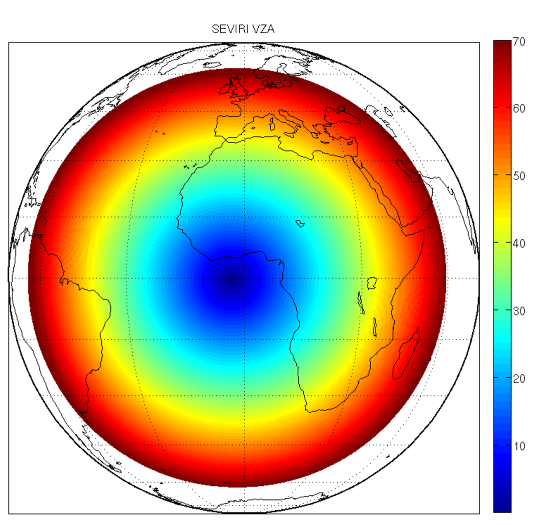
forecast

$$\begin{cases}\hat{\mathbf{v}}^\mathbf{f}_\mathbf{t+1}=\mathbf{H}\hat{\mathbf{v}}_\mathbf{t}\\ \hat{\mathbf{S}}^\mathbf{f}_\mathbf{t+1}=\mathbf{H}\hat{\mathbf{S}}_\mathbf{t}\mathbf{H^T}+\mathbf{S}_\eta\end{cases}$$

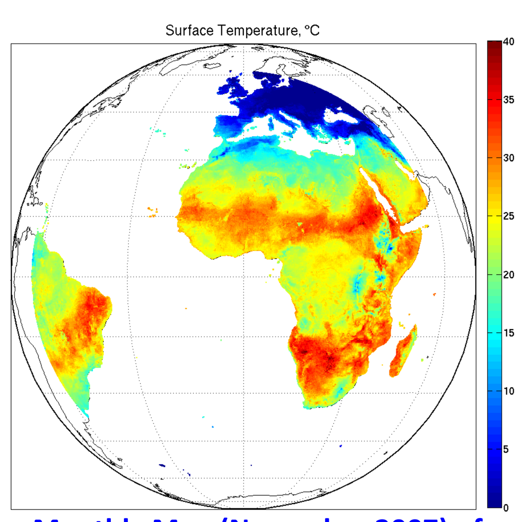
covariance of η_t

$$\begin{cases}\mathbf{v_a}=\hat{\mathbf{v}}^\mathbf{f}_\mathbf{t+1}\\ \mathbf{S_a}=\hat{\mathbf{S}}^\mathbf{f}_\mathbf{t+1}\end{cases}$$

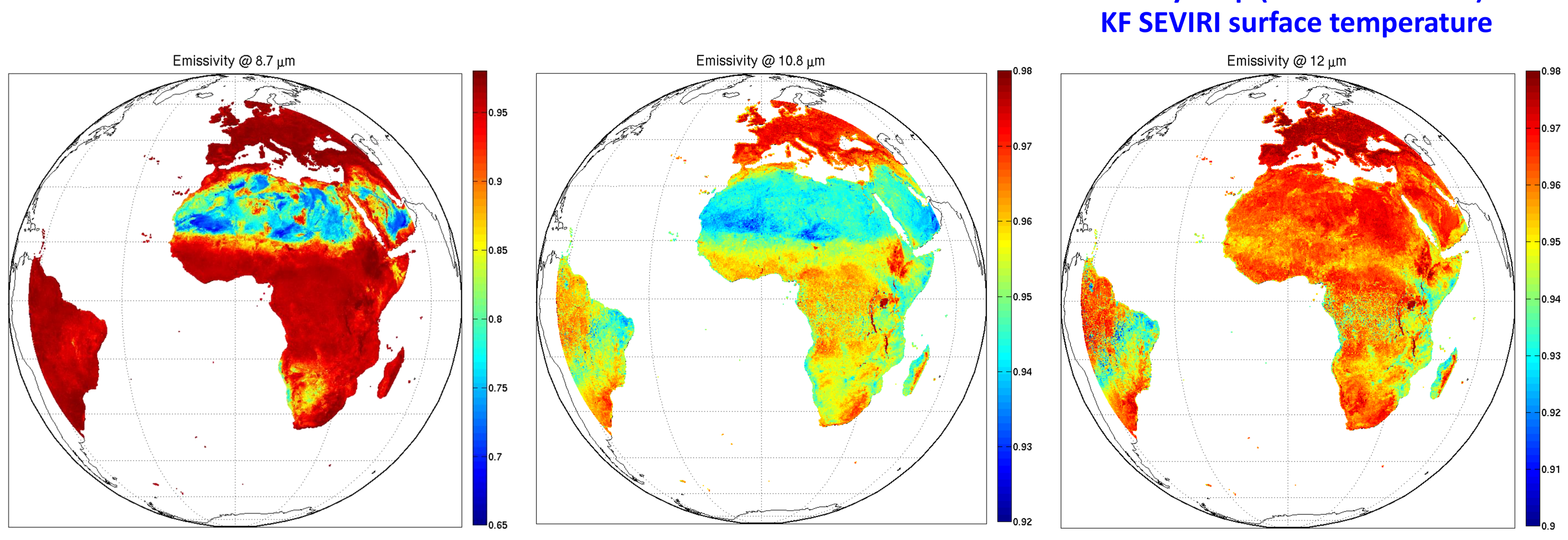
Results on Land Surface



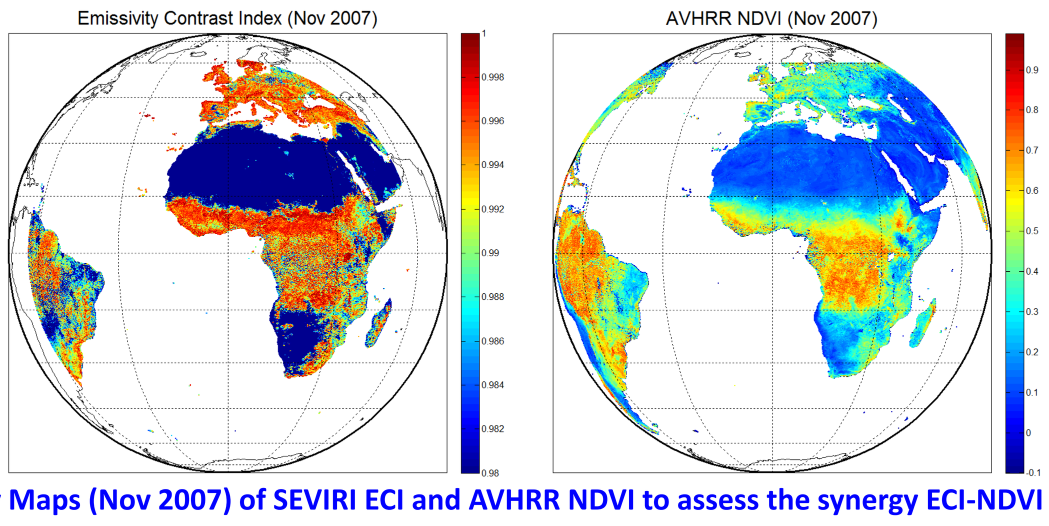
Full Disk (VZA<=70°): Total 3,545,871 pixels for Land 3,488,328 Land pixels 57,543 In Land Water pixels



Monthly Map (November 2007) of KF SEVIRI surface temperature



Monthly Maps (November 2007) of KF SEVIRI emissivity (8.7, 10.8 and 12 micron)



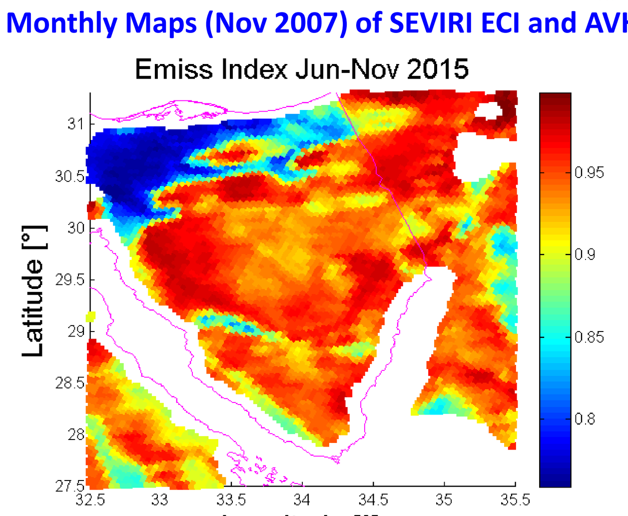
δε=Max(ChEmiss)−Min(ChEmiss)
We define the Emissivity Contrast Index (ECI) as 1−δε.
ECI varies in range [0,1]:

ECI≈1, NDVI ≈1: Green Vegetation

ECI≈1, NDVI ≈0: Dry Vegetation

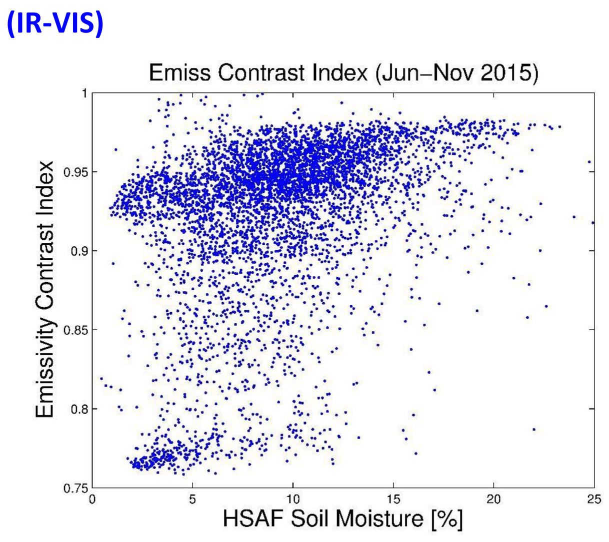
ECI≈0, NDVI ≈0: Bare Soil

Monthly Maps (Nov 2007) of SEVIRI ECI and AVHRR NDVI to assess the synergy ECI-NDVI (IR-VIS)

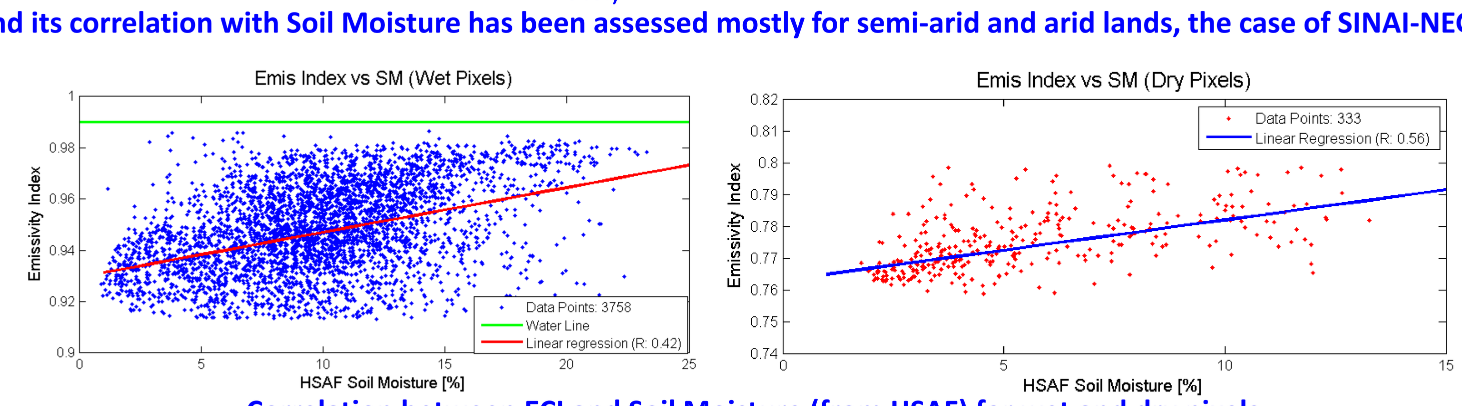


ECI variations

- For water ECI ≈ 0.99
- For bare soil ECI is between 0.7-0.8
- For green vegetation ECI is in the range 0.98-1 (high emissivity since it is structured and contains water)
- For dry or senescent vegetation, ECI is expected between 0.94-0.98 (in this case emissivity is more variable, especially in the 3-5 µm region, depending on the type and structure of cover type, the dryness, etc.)

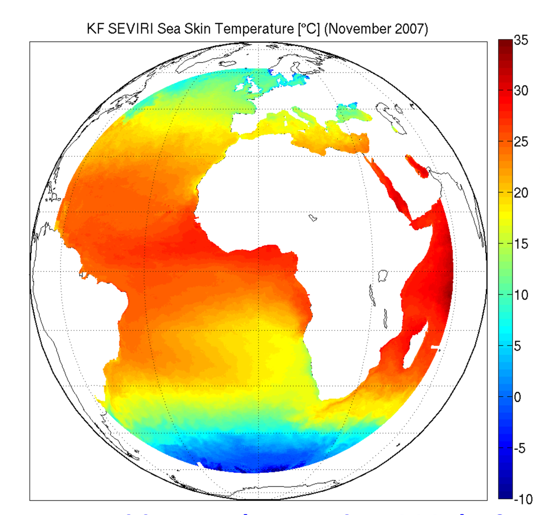


ECI and its correlation with Soil Moisture has been assessed mostly for semi-arid and arid lands, the case of SINAI-NEGEV desert

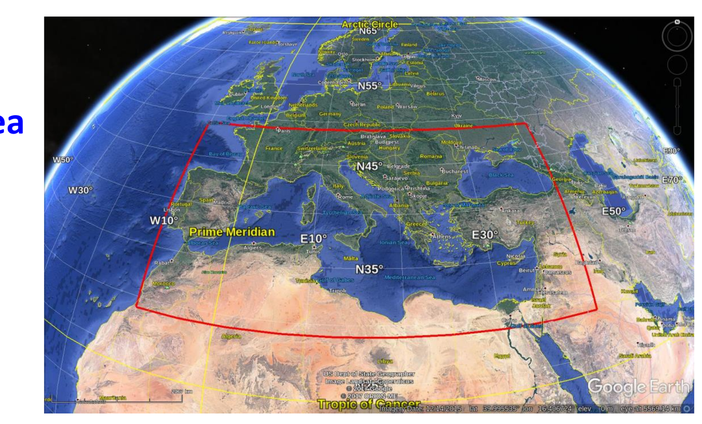


Correlation between ECI and Soil Moisture (from HSAF) for wet and dry pixels

Results on Sea Surface

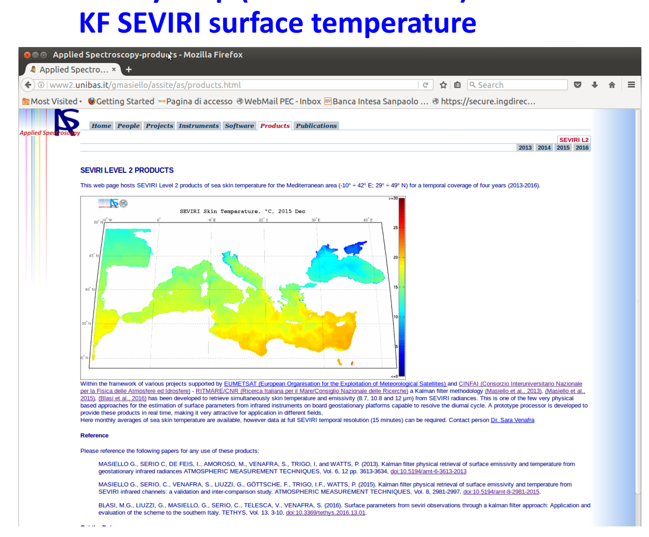


Full Disk (VZA<=70°): Total 5,519,207 pixels for Sea



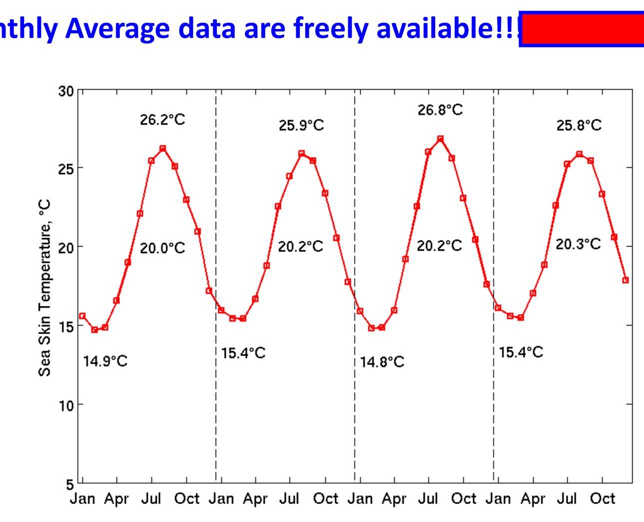
Monthly Map (November 2007) of KF SEVIRI surface temperature

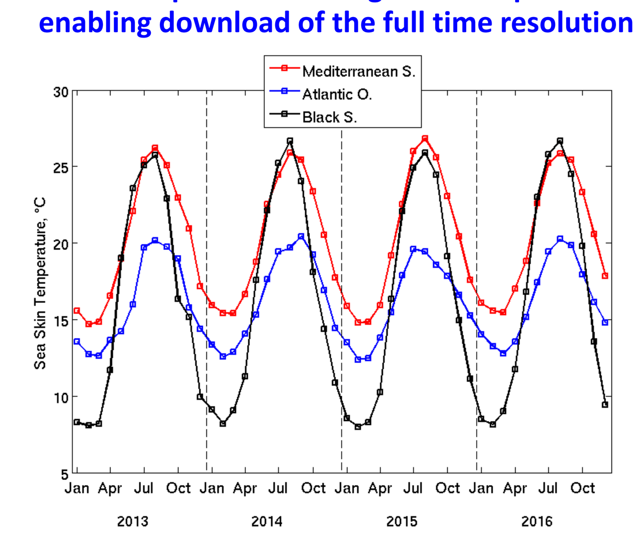
Application on the Mediterranean basin (Sea Skin Temperature for the years 2013-2016)



Monthly Average data are freely available!!

New web portal is coming: with simplified data request enabling download of the full time resolution results





2013-2016 SEVIRI Retrieved Monthly mean results for all the area and separating Mediterranean Sea from Atlantic Ocean and Black Sea

Computational Performances

A single SEVIRI FD run (for land pixels) takes about 30 minutes exploiting 8 threads and considering all pixels as clear sky (Ifort Compiler). For the Mediterranean area (232,898 pixels) it takes about 15 minutes exploiting one thread and considering all pixels as clear sky. These performances make this first fully based physical scheme very attractive for real-time applications.

CONCLUSIONS & FUTURE DEVELOPMENTS

- The physical simultaneous retrieval of surface emissivity and temperature has been applied to the SEVIRI full disk;
- The model has been improved and now it is about 7 times faster than previous version;
- The algorithm can be specialized for land or sea or both and a land-based version has been integrated and tested on IPMA LSA-SAF virtual machines for full disk retrieval of surface temperature and emissivity;
- The emissivity contrast index (ECI) can distinguish between bare soil and dry vegetation;
- There is a need to investigate ECI-NDVI synergy. In perspective this could improve SEVIRI capability to monitor vegetation stress and detect changes because of the global warming.

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