The Earth climate, its variability, and long-term change have become a critical issue in the past two decades; its impacts on society, ecological systems, and economy are widely recognized (e.g., Stern 2006; Parry et al. 2007). Societies need to anticipate climate change to successfully mitigate risks and to adapt to new conditions. The ability to plan critically depends on the available information of past and current climate conditions, as well as sound predictions of future conditions. Thus, the availability of accurate observations to characterize the climate system and to support the development and validation of prediction models is a key factor. Trenberth (2008) already stated the paramount importance of creating an information database of the climate system. The traditional ensemble of weather and climate variables (i.e., mean, minimum, and maximum values of temperature, precipitation, humidity, and wind speed at the surface) is not sufficient to describe and predict the variability, changes, and feedback mechanisms of the climate system.

The Global Climate Observing System (GCOS) formulated scientific requirements for climate observations (GCOS 2003), including a list of relevant parameters, the so-called essential climate variables (ECVs), with associated observation requirements. Eventually, more variables with more complete spatial and temporal sampling are necessary to determine how extremes are changing (Trenberth et al. 2013). The ECV list, associated requirements, and the corresponding implementation plan (GCOS 2010) are slowly evolving according to changes in needs and also due to improvement in observation technology and computing capacities.

The major requirements for long-term, global, homogeneous, and complete datasets are high
The aim of SCOPE-CM is the establishment of an international network of facilities for the continuous and sustained provision of high-quality products for climate monitoring. These satellite-based datasets, with the goal of detecting variability and trends of key climate variables, are referred to as CDRs. They are defined as a “time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change” (NRC 2004, p. 1) and can be divided into two classes: i) fundamental climate data records (FCDRs), a homogenous long-term dataset of radiances or brightness temperatures encompassing different sensors and platforms with spatial and temporal overlap; and ii) thematic climate data records (TCDRs), geophysical variables derived from the FCDRs that can be understood as the satellite product associated with an ECV. SCOPE-CM performs specific activities (see SCOPE-CM 2009) for the sustained generation of CDRs, through a coordinated network exploiting already available infrastructures and activities for cost effectiveness.

The concept of a network of regional centers focusing on a coordinated processing of satellite products for climate monitoring, named Regional/ Specialized Satellite Centres for Climate Monitoring (R/SSC-CM), was proposed in 2007 in the framework of the World Meteorological Organization (WMO) space program. The name SCOPE-CM was adopted during its first executive panel meeting held two years later, in particular for better referring to the global nature of the endeavors. This initiative is one component of an end-to-end system with the final objective of climate monitoring having the satellite observations represented by the WMO Integrated Global Observing System (WIGOS) at one end and the CDR user community at the other end (see Fig. 1). An effective exploitation of the huge amount of data provided by the meteorological and other environmental satellite systems, as well as the applicability of the resulting data products for climate studies, requires a consistent and careful sensor calibration and intercalibration. In particular, SCOPE-CM benefits from the related calibration activities of the Global Space-Based Inter-Calibration System (GSICS) (Goldberg et al. 2011). Although not available for all instruments, in general, calibration corrections produced in GSICS support the generation of FCDRs, used as data input for the processing of the TCDRs. For example, GSICS has launched an activity that studies different methods to perform intersatellite calibration in visible (VIS) channels (Chander et al. 2013). SCOPE-CM functions as a feedback mechanism to GSICS on the quality of such methods for the generation of surface albedo CDRs.

The sustained and coordinated generation of FCDRs and TCDRs is the main objective of SCOPE-CM. The current participants of the network are operators of meteorological satellites, such as
the China Meteorological Administration (CMA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the Japan Meteorological Agency (JMA), and the National Oceanic and Atmospheric Administration (NOAA). The SCOPE-CM stakeholders include the Committee on Earth Observation Satellites (CEOS), the Coordination Group for Meteorological Satellites (CGMS), the Global Observing System (GOS), GCOS, and the Global Energy and Water Cycle Experiment (GEWEX), one of the major projects of the World Climate Research Programme (WCRP). The direct link with those organizations ensures a high level of coordination between SCOPE-CM and other international initiatives and projects. The network is guided by the SCOPE-CM executive panel, while the coordination is a task of the SCOPE-CM secretariat (hosted by EUMETSAT).

The implementation of SCOPE-CM objectives is planned in three phases. The first phase focuses on the establishment of a coordinated network of space agencies and organizations. The main task during this phase is the creation of interagency partnerships and the establishment of the network, for which five pilot projects have been started. Other objectives of this phase are the assessment of the current satellite capabilities for climate monitoring, agreement on principles and standards, and the establishment of feedback mechanisms from stakeholders and the scientific community. In the second phase, currently in preparation, the partnerships created in the previous step will be consolidated and extended in order to move into sustained environments for the generation of FCDRs and TCDRs. In particular, increased collaboration and interaction with research institutions will be fostered. The currently proposed life cycle for a CDR within SCOPE-CM, planned for implementation in phase 2, consists of three levels:

i) SCOPE-CM pilot project stage: where the CDR is identified, accepted, and a prototype according to one or multiple agreed on method(s) is developed.
ii) SCOPE-CM CDR generation: transition to a sustained structure (e.g., cooperation of satellite operators) for processing, validation, and documentation. This includes a review process guided by the SCOPE-CM secretariat.
iii) CDR independent assessment: the CDR is assessed by external and independent experts and groups.

The third phase of the SCOPE-CM implementation plan will focus on a full deployment of sustained
systems. Today, few satellite sensor families [for instance, the Advanced Very High Resolution Radiometer (AVHRR) on NOAA and EUMETSAT polar orbiters as well as geostationary satellite sensors] allow construction of multidecadal satellite data records. Combining data from geostationary and polar-orbiting satellites can create a true global climatology. SCOPE-CM is envisioning such a development in the near future utilizing AVHRR data. The polar-orbiting satellites have the advantage of sensing Earth’s entire surface but with a limited daily sampling. In contrast, the geostationary satellites have the advantage of acquiring data for the same scene many times each day, but with the strong limitation of sensing only a portion of Earth’s surface enclosed within a radius of approximately 70° from the subsatellite point (SSP). The exploitation of an ensemble of geostationary satellites can partly remove this limitation (see Fig. 2). Following this approach, some problems arise, as pointed out by Knapp et al. (2011); in particular, the data are archived in different countries and stored in different formats. SCOPE-CM focuses on these issues, promoting the interagency cooperation and the homogeneous generation of FCDR according to agreed standards. Common issues for the generation of CDRs are the presence of gaps in the data time series and the intermittent substandard quality of metadata records (a file of information that captures the basic characteristic of the data itself). Space agencies hold long-term data records, in some cases starting in the late 1970s (see Fig. 3), that can be used for the generation of FCDRs and TCDRs. The exploitation for climate monitoring of those archives is itself a challenge. In particular, the availability and quality of the corresponding metadata is a key factor for success.

SCOPE-CM can facilitate methods for analyzing the quality of time series (detection of inconsistencies and their causes) and strategies for a shared methodology of handling metadata. Another benefit resulting from this initiative is the high potential for exchanging and consolidating retrieval algorithms and tools, preventing unnecessary duplication of effort. It will also foster complementary CDR generation in sustained and configuration-controlled processing environments. These aspects are currently considered within the SCOPE-CM pilot projects, where experts from the participating organizations are working together on specific FCDRs and TCDRs.

**THE GSA PILOT PROJECT.** One of the five SCOPE-CM pilot projects concerns land surface albedo retrieval. The geostationary surface albedo (GSA) algorithm has been proposed for the generation of this ECV. It can use imagery acquired by five geostationary satellites—Geostationary Operational Environmental Satellite (GOES): two orbits over the American continents/Pacific region,

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![Fig. 2. Processing area for the geostationary satellites used in the GSA method consolidation phase. From west to east: GOES-10 (west), GOES-8 (east), Meteosat-7, Meteosat-5 (IODC), and GMS-5. The common area between two adjacent satellites can be used for intercomparison.](image-url)
Meteosat: two orbits over Europe/Africa and the Indian Ocean, GMS: one orbit over East Asia and Oceania—to retrieve land surface albedo for the entire Earth, except for the poles (see Fig 2 and Table 1 for details). The currently available temporal and spatial coverage of geostationary satellite inputs for the GSA is depicted in Fig. 3. The GSA algorithm has been developed from a method proposed by Pinty et al. (2000a,b) at the Institute for Environment and Sustainability of the Joint Research Centre (IES-JRC) for joint retrieval of land surface albedo and aerosol load. The separation of the contribution to the signal at the top of atmosphere due to the surface reflectance and the aerosol is not a trivial problem, especially for bright surfaces (Sinyuk et al. 2007). The retrieval technique relies on the daily accumulation of geostationary satellite data. Assuming that the reciprocity principle is applicable at the spatial resolution of the imager on board those platforms (Lattanzio et al. 2007), the daily radiometric accumulation can be interpreted as an angular sampling of the surface. This is a central point because it allows for proper characterization of both the reflectance level and the contribution due to the surface anisotropy, which is a relevant part in the correct estimation of the surface albedo and for monitoring its heterogeneity. The retrieval is performed daily at the sensor pixel resolution; however, to minimize the effect of cloud coverage, especially over tropical regions, the product is delivered as a 10-day composite.

A prototype of the algorithm was implemented at EUMETSAT in 2001 for processing Meteosat Visible and Infrared Imager (MVIRI) visible channel data (Govaerts et al. 2004). During the last decade, the requirements for climate monitoring were quantified (Ohring et al. 2005; GCOS 2006), and a measurement of the uncertainty associated with any sensed variable became an essential piece of information. For this purpose a statistical method was developed by Govaerts and Lattanzio (2007) for estimating the retrieval error in the GSA processing scheme. It explicitly accounts for the measurement uncertainties and differences in the geostationary radiometer characteristics. The successive step was the extension

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**Table 1. Instrument details for the geostationary satellites used in the method consolidation phase.** The SSP position, the image acquisition repeat cycle (RC), the VIS band spectral width, the SSP instrument square pixel size (PS) and the digitization levels (DLs) are given.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Location (SSP)</th>
<th>RC (h)</th>
<th>VIS band (μm)</th>
<th>PS (km)</th>
<th>DL (bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMS-5</td>
<td>140°E</td>
<td>1</td>
<td>0.40–1.07</td>
<td>1.25</td>
<td>6</td>
</tr>
<tr>
<td>Meteosat-5</td>
<td>63°E</td>
<td>0.5</td>
<td>0.40–1.08</td>
<td>2.5</td>
<td>8</td>
</tr>
<tr>
<td>Meteosat-7</td>
<td>0°</td>
<td>0.5</td>
<td>0.40–1.08</td>
<td>2.5</td>
<td>8</td>
</tr>
<tr>
<td>GOES-8 (east)</td>
<td>75°W</td>
<td>3</td>
<td>0.52–0.72</td>
<td>1.0</td>
<td>10</td>
</tr>
<tr>
<td>GOES-10 (west)</td>
<td>135°W</td>
<td>3</td>
<td>0.53–0.77</td>
<td>1.0</td>
<td>10</td>
</tr>
</tbody>
</table>

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![Fig. 3. Temporal and longitudinal coverage of the geostationary platforms planned to be used for generating a land surface albedo product within the SCOPE-CM initiative.](image-url)
of the retrieval method to other geostationary platforms (Govaerts et al. 2008). During this phase the software code was redesigned and reengineered.

The SCOPE-CM collaboration activities began in 2008 with the integration of the GSA algorithm in the reprocessing environment at the JMA to generate land surface albedo datasets from the Japanese Geostationary Meteorological Satellites (GMSs). In the second half of 2011, the GSA code was integrated at NOAA’s National Climatic Data Center (NCDC) to accommodate GOES data. Currently, the same retrieval algorithm is integrated and running in the reprocessing environments of three different space agencies for the generation of land surface albedo at a resolution close to the MVIRI’s (~2–3 km). The GSA products generated with observations acquired by MVIRI can be requested at the EUMETSAT archive portal (at https://eoportal.eumetsat.int).

One albedo time series [expressed in terms of the directional hemispherical reflectance estimated with a sun zenith angle of 30° (DHR30) parameter] for a pixel in northeast Africa, and consisting of results from the complete MFG series, is shown in Fig. 4. The DHR30s for all Meteosats are spectrally converted using Meteosat-7 broadband albedo as a reference following the empirical method proposed by Loew and Govaerts (2010). The processing at NCDC [archived satellite data at NCDC can be requested at the Comprehensive Large Array-Data Stewardship System (CLASS) access point, www.class.noaa.gov] with GOES data will be made available after the processing and validation phases are complete.

After the successful implementation of the GSA code into the target reprocessing environments, the first planned and currently ongoing SCOPE-CM activity in the pilot project phase for the land surface albedo is the generation of a surface albedo dataset for a period of four years (2000–03) from the five individual geostationary platforms. The second planned and ongoing activity is the generation of a composite land surface albedo product for the same period, remapped to a monthly averaged 0.25° (~25–30 km) resolved spatial grid. This product will be provided in network Common Data Form (NetCDF4) with climate and forecast (CF) name conventions, a self-describing data format, that is easy to process and platform independent, according to the SCOPE-CM defined standards.

The time frame of 2000–03 was chosen for two main reasons. First, this time leverages full longitudinal coverage with modern instruments on board geostationary platforms that are well characterized in terms of calibration and radiometric response. Second, the Moderate Resolution Imaging Spectroradiometer (MODIS) surface albedo products are available during this period and may be used as a reference for intercomparison. A proof of concept merged product at a spatial resolution of 0.25° for the period 1–10 May 2001 is shown in the top panel of Fig. 5. In the bottom panel of Fig. 5, the surface albedo retrieved from MODIS data for nearly the same period on a grid at a spatial resolution of 0.05° (~5.6 km) is shown. At least 75% of the MODIS albedo values are estimated through a full inversion and for a maximum of 25%, information is used from an archetypal bidirectional reflectance distribution function (BRDF) database. This MODIS quality control measure was chosen to approximate the same quality retrieved from the GSA algorithm shown in the top panel. This comparison shows that spatial coverage of albedo retrievals may be improved by utilizing geostationary data. The large-scale spatial structure of the albedo from both qualitatively appears similar, although some problems with residual cloudiness are visible in the geostationary product, for example, the difference in albedo over France and Spain. A more detailed quantitative analysis is needed as part of future validation activities within SCOPE-CM. A single set of products at pixel resolution, one for each of the five geostationary satellites, has already been compared with MODIS showing encouraging results (Govaerts et al. 2008). EUMETSAT, together with a European expert team, is currently developing an approach for a systematic and temporally coherent GSA dataset validation methodology that will take advantage of both other satellites and ground-based measurements, with the particular challenge related to the availability of suitable reference observations during the early period of the time series (1980s and 1990s).

It is evident that before the instruments shown in Fig. 3 can be processed into a consistent time series, the visible channel reflectances need to be intercalibrated considering the differences in their spectral response. As mentioned above, GSICS is investigating several methods (see special issue of GSICS Quarterly, 2012, Vol. 6, No. 1) that can be utilized. In particular, usage of deep convective clouds as the calibration target as described in Doelling et al. (2010) seems to be attractive because it can be applied to all geostationary satellites.

Thus, the SCOPE-CM land surface albedo climate data

1 Product identifier: Meteosat Surface Albedo—Meteosat First Generation (MFG)—0° (MSA1) and MSA1–Indian Ocean Data Coverage (MSA1-IODC).
The record will be based on a common calibration approach for all satellites in space and time. Additionally, the necessary algorithm inputs of total column values for water vapor and ozone need to be homogenized by using the same reanalysis dataset. A remaining issue is to address the presence of clouds in the albedo product, which is referred to as cloud contamination. This is the most important external factor limiting the quality of the retrieval, while the radiometric quality of the instrument is the internal one. Although radiometric quality can only be assessed, cloud coverage can be mitigated using ancillary information. Internal to the method is a cloud screening procedure (Pinty et al. 2000b), although it exhibits some deficiencies in properly detecting some cloud configuration patterns. To date, no external cloud mask information has been incorporated because past approaches seemed to be inappropriate; however, the algorithm interface easily allows the incorporation of an external cloud mask if a suitable method is identified. After the completion of those activities and an external CDR assessment, the processing will be ready to move into the sustained phase. (See the sidebar for information about satellite data archives.)

**Fig. 4.** (top) A DHR30 time series and its retrieved uncertainty derived from Meteosat (red: 0° mission, blue: IODC at 63°E). The DHR30s for all Meteosats are spectrally converted following the method proposed by Loew and Govaerts (2010). (bottom left) The location is in Sudan. (bottom right) The visible channel sensor spectral responses (SSRs) for the Meteosats.
THE GSA AS A MODEL WITHIN SCOPE-CM.

The pilot project concerning a land surface albedo record can be considered as the first success of the approach proposed in the SCOPE-CM framework. It clearly stated the importance of multiple international organizations united under the coordination structure and permanent link of SCOPE-CM to achieve a common objective. The GSA project helped develop a strong coordination and collaboration among the teams at JMA, NOAA, and EUMETSAT. This is an
An important factor that will facilitate the planning and preparation of other projects for generating a dataset for climate monitoring, for example, atmospheric motion vectors from geostationary observations to support reanalysis activities. During the development of the pilot project, some factors were found to be of great importance for the definition of common approaches for visible calibration and new future algorithms in order to generate climate data records. Common calibration and intersatellite calibration methodology for all sensors and common ancillary data will be used to minimize the impact of these external factors on the quality and homogeneity of the generated CDR. Usage of the same core algorithm, in terms of both the theoretical retrieval method and the software implementation, decreases processing-related problems. This unique processing approach is possible if, during the algorithm design, the data input and output handling and the core retrieval algorithm are separated and independent from each other. Another important feature is the need for an algorithm to easily adapt the methodology to additional similar satellites. This feature is paramount for increasing the temporal and spatial coverage of the generated dataset and for supporting the confidence in a previous retrieval. In the case of the GSA, the exploitation of other geostationary satellites is straightforward. Even if other approaches for surface albedo retrieval may be followed, the one proposed within the land surface albedo pilot project can be considered efficient and successful.

**SUMMARY.** The successful implementation of the GSA retrieval applied to geostationary satellite observations from three different data archives has been presented as an example of achievements possible within the WMO SCOPE-CM framework. It has been shown how and why it can be considered as a successful example of cooperation among different space agencies for climate monitoring activities. The experience gained from the GSA pilot project will be applied to other ECVs within SCOPE-CM and has great value for similar initiatives around the world.

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