MISTIGRI, a microsatellite project associating high spatial resolution and high revisit frequency in the thermal infrared

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ABSTRACT- *This paper presents the MISTIGRI project of a microsatellite developed by the French space organisation CNES in cooperation with Spain. MISTIGRI is a precursor mission designed to combine a high spatial resolution (~50m) with a daily revisit in the thermal infrared (TIR). The scientific goals and expected applications of the mission are first described: they deal with (i) agriculture and hydrology, (ii) monitoring of urban areas and (iii) monitoring of coastal areas and continental waters. The spatial resolution and revisit specifications are justified. The choice of the orbit is discussed. The other mission specifications are briefly examined and rapid overviews of the instrumental concept and of the proposed mission architecture given.*

1 INTRODUCTION

As it is a key signature of the surface energy budgets, the surface temperature (Ts) appears as a crucial variable to monitor and understand the interactions between the continental or maritime surfaces and the atmosphere, and their contribution to the drifts currently being observed in relation with global change (Climate Change 2007: Synthesis report IPCC). But in the field of thermal infrared (TIR) remote sensing, researchers and users have to face a dilemma between spatial and temporal resolution: systems such as AVHRR, MSG, MODIS provide daily observations at low resolution on the one hand, while systems such as Landsat or ASTER on the other hand provide high resolution images, but with poor revisit capabilities of about 2 weeks. Significant improvements in the modelling and monitoring of the surface/climate system, particularly at local scale, and in applications dealing with agriculture, hydrology, climatology…are now expected from the availability of new spaceborne observational techniques in the thermal infrared that provide both (i) high revisit capabilities and (ii) high spatial resolution. This is the goal of the MISTIGRI (**MI**cro **S**atellite for **T**hermal **I**nfrared **GR**ound surface **I**maging) mission initiated by CNES in collaboration with Spain, and designed to associate a resolution of 50m and a 1 or 2 day-revisit (http://www.cesbio.ups-tlse.fr/fr/indexmistigri.html). After a two year phase 0, the project entered a phase A (2009-mid 2011) for a possible launch in 2015.

2 SCIENTIFIC OBJECTIVES

2.1 Monitoring of energy and water budgets of the continental biosphere

The energy and water fluxes over continental biosphere govern the status of vegetation and the biogeochemical cycles (CO_2 particularly) and are strongly impacted by the interactions between the surface and the atmosphere. The first objective of

MISTIGRI is to contribute to the monitoring of the water cycle, with a particular emphasis on the assessment of the rapid changes in land surface water status (after rainfall or irrigation) at the local (field) scale. The MISTIGRI data will be used in conjunction with models with the scope of either deriving surface fluxes, or improving and developing related methodologies. Several approaches can be used to estimate the evapotranspiration (ET). Simplified algorithms based on the analysis of the relationhips between Ts and albedo (or NDVI) can provide direct estimates of ET from Ts (Kalma et al., 2008) with further interpolation of ET between dates when TIR data is available to ensure a continuous monitoring of water status. Other methods are based on the use of bio-physical soil-vegetation-atmosphere transfer models (SVAT) associated to inversion (Jacob et al., 2006) and assimilation procedures (Crow et al., 2008). The expected main fields of application deal with:

- *agriculture*: monitoring of the growth, impact of agricultural practices on water use, detection of stress with application to irrigation or forest fire risk…
- *hydrology*: water budgets of watersheds, monitoring of water tables
- *biogeochemical cycles*: assessment of carbon fluxes and budgets using vegetation models.
- *meteorological forecasting*, through the improvement of the parameterization of the surface processes in the meso-scale models.

Methodological progresses are also expected from MISTIGRI data, among which the study of aggregation processes and scaling (which should in turn contribute to an improved use of the low resolution data of the global cover sensors such as AVHRR or MODIS), the determination of emissivity and temperature-emissivity separation, and the study of directional anisotropy (Lagouarde et al., 2000, Kurz, 2009)…

2.2 Monitoring of the urban environment

The climate over cities is significantly affected by a number of characteristics proper to urban areas. The three-dimensional structure of urban canopies with important heterogeneities both at local scale (heights of buildings, orientation of streets…) and at larger scale (vocation of districts: settlement, industrial, commercial…), alter the roughness of the surface and the flow within the urban atmospheric boundary layer. The use of a large panel of artificial materials with contrasted surface properties also affects the radiative transfers, while the reduction of vegetated areas and the increase of impervious surface combine to modify water cycles drastically. Human activities also contribute to urban climate by several ways: urbanization, emission of pollutants, increase of energy consumption among others. It finally results in a strong variability of microclimates inside cities and in differences with surrounding rural climate, the well-known urban heat island phenomena.

The urban remote sensing remained focused on the description of the UHI for a long time (Arnfield, 2003), but recent progress on modeling opens new perspectives. Progress has been made not only on surface energy budgets and fluxes (Voogt et Oke, 2003) but also on the physics of the TIR signal itself: description of the directional anisotropy (Lagouarde et al., 2010), radiative transfer and aggregation processes of temperature and emissivity (Fontanilles et al., 2008). The possible fields of application of MISTIGRI deal with:

- *urban climatology and heat waves.* The increase of the frequency and intensity of heat waves expected as a consequence of the climate change makes necessary policies for mitigating their effects. A strong demand exists for building alert systems and improved urban planning.
- *urban hydrology r*equires improved methodologies for a better assessment of the water budgets of urban watersheds (Carlson and Arthur, 2000) and for urban planning.
- *monitoring of urban vegetation*. Vegetation plays a significant role for hydrology (by increasing water storage capacities of ground and limiting runoff) and for the welfare and health of inhabitants (humidification of air, shading effects and reduction of temperatures…).
- *diffusion of pollutants and air quality*. The surface temperature helps to validate the atmospheric flow and diffusion models used for forecasting the extension of pollution plumes.
- *anthropogenic fluxes* (industrial activity, air conditioning or heating of buildings, transport…) can be estimated through the closure of the surface energy budgets (Pigeon et al., 2007).

2.3 Monitoring of coastal and continental waters

Many additional research fields can take benefit of MISTIGRI data (vulcanology, geology, industrial hazards…). Among those we chose to emphasise applications dealing with coastal and continental waters in this paper. Data are needed to observe submesoscale activity -1 to100 km scale- characterized by fronts, filaments, which have a large impact on vertical transport of different properties (nutrients, CO_2…). In coastal area, several processes are responsible for intense and narrow SST gradients ~1 km (for instance fresh water coming from rivers or estuaries…) which have an influence on air-sea fluxes as well as winds (Chelton et al., 2007; Donlon et al., 2009). MISTIGRI will allow one to study such fronts displaying SST signatures not detected with current low resolution satellite data. A number of applications are expected:

• coastal oceanography (internal waves, etc), sea state (storm surge, etc)
• estuary hydrology
• land and coastal ocean exchanges, and contribution to carbon, nitrogen and other biogeochemical cycles; estimates of greenhouse gas fluxes (CO_2, N_2O, CH_4…) at the air-sea interfaces in coastal areas
• pollutant discharge from rivers, and exchanges (heat, pollutants…) over the tidally portion of rivers, estuaries and wetland
• coastal zone management, water quality monitoring
• algae blooms
• monitoring of halieutic resources,
• marine services

The high spatial resolution of the MISTIGRI data will also be used in a variety of applications dealing with continental waters (lakes and rivers), for instance study of confluence of rivers and lakes, monitoring of floods, thermal plumes of nuclear power plants… Surface water temperature of lakes has also been defined has Essential Climate Variable by GCOS and will be integrated in the future database (Hydrolare / Hydroweb) of the GTN-L list (Global Terrestrial Network for Lakes).

2.4 Strategy of the MISTIGRI mission

MISTIGRI is a precursor mission. Its first aim is to demonstrate the interest of combining high revisit and spatial resolution in the TIR for monitoring surface water status, and to develop the related methodologies. The strategy of the MISTIGRI mission is similar to that of Venμs (http://www.cesbio.ups-tlse.fr/fr/indexvenus.html), and associates a spatial system with experimental sites monitored by scientific teams at ground. The large number of existing long term programmes and networks for monitoring climate, ecology, hydrology processes (FLUXNET, ICOS, LTER, GEWEX programmes, NEESPI…) and the persistence of the scientific questions addressed ensures that a large panel of sites will be available in the future.

3 MAIN MISSION SPECIFICATIONS

3.1 Spatial resolution

As classically for VNIR channels, the choice of the spatial resolution is first constrained by the typical size of the units or fields studied. Proposing a unique value is obviously difficult, as it depends on the type of landscape studied. Nevertheless, we can refer to Kustas et al. (2004) who showed that a resolution lower than about 100 m was required to discriminate the contributions of 2 crops (soybean and corn) to actual evapotranspiration, in the case of Iowa plain where fields have a typical size of 100x100 m. Agam et al. (2007) confirmed this limit for agricultural applications. A similar conclusion was found by Garrigues et al. (2006) who quantified the spatial heterogeneity of the NDVI for 18 landscapes of the VALERI database (http://w3.avignon.inra.fr/valeri/) and similarly concluded that ‘the sufficient pixel size to capture the major part of the spatial variability of the vegetation cover at the landscape scale is estimated to be less tan 100m’. Another guideline is provided by an analysis of the size of fields in the case of a French typical hilly agricultural region (Gers department), according to information obtained from administration in the Common Agriculture policy framework: 75% of the surface is made of plots ≥ 150x150m², which corresponds to a typical 3x3 50 m pixel grid. We can also refer to the 100 m resolution of Landsat LDCM.

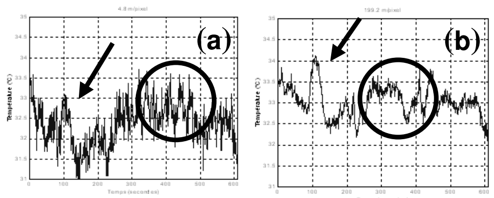

***Figure 1**. Ts temporal evolution above a maritime pine stand over a 600s period at 1 Hz for 5 m (a), and 200 m (b) resolutions. Low frequency fluctuations related to convection in the PBL (arrow) are present regardless of the considered spatial resolution, whereas high frequency fluctuations are smoothed by spatial integration at pixel scale. The Y axis ranges between 31 and 35°C (after Lagouarde et al., 1997).*

A particularity of the surface temperature is to display rapid time fluctuations in relation with the turbulent nature of the atmospheric flow (with wind speed in particular). High frequency fluctuations related to the surface boundary layer flow (which correspond to small scale eddies) are partly smoothed by the spatial integration performed at the pixel scale. On the opposite the planetary boundary flow induces lower frequency fluctuations (typically a few minutes) with a characteristic size (typically the kilometer) much greater than the pixel one. These cannot be reduced and contribute to the uncertainty on instantaneous satellite Ts measurements. Experiments performed over maritime pine stands using a helicopter-borne TIR camera (Lagouarde et al., 1997) indicate that a resolution lower than ~40m is not useful (Fig. 1). A confirmation is expected soon from recent experiments performed over a large range of surfaces (from bare soils to cities) in the South of France and from a numerical study using an improved version of the ARPS LES model. To our knowledge no similar results can be found in literature.

A resolution of about 50m finally allows one to obey the combined constraints imposed by land cover heterogeneity, minimum swath size required (25 km), and uncertainties induced by turbulence.

2.4 Revisit

The choice of the revisit is guided not only by the probability of cloudfree conditions which determines the number of data available, but also by the performances of the models used for deriving fluxes with the required accuracy. The reader will refer to a study (Lagouarde et al., 2011, same issue) presented in details is this issue, where it has been shown that a 1 day-revisit was necessary.

2.4 Spectral bands

The baseline in the TIR is a configuration of 4 bands at 8.6, 9.1, 10.3 and 11.5 µm for obtaining surface radiometric temperature and emissivity using the TES algorithm (Sobrino et al., 2005). Merging the first two bands into a single one at 8.8 µm for a better NEDT is possible and its interest for MISTIGRI is currently being evaluated.

In the Visible and Near Infrared (VNIR) range, 4 bands have been selected at 450, 670, 865 and 910 nm. with an improved resolution of ~20m. Their objectives are: registration of TIR images, detection of low clouds, estimation of the integrated water vapor content, land cover, obtaining a first guess of emissivity for TES, possible disaggregation of TIR data… Many of these objectives require VNIR imagery to be acquired simultaneously to TIR. For these reasons, using other satellites (Sentinel 2 for instance) cannot replace a VNIR instrument onboard.

4 MISSION ARCHITECTURE

The mission architecture base line has been defined by integrating as many elements having a strong heritage as possible for reducing program costs and schedule risks.

4.1 Instrument

The TIR instrument is based on the use of a 640 x 480 uncooled microbolometer array with a pixel pitch of 25 µm developed by a French company ULIS. A trade off was made leading to the selection of this detector for the TIR instrument. Although the sensitivity of micro-bolometers is less than that of cryogenic detectors, such detectors have the main advantage of not needing a cooling system. The requirement for the swath is 25 km at least. The thermal time constant of microbolometers (9.2 ms) introduces a constraint to the satellite operation by making necessary a sampling time longer than the time constant in order to achieve a good MTF and linearity performances. This Time Delay Integration (TDI) acquisition mode requires a satellite slow down obtained by rotating the platform (varying the pitch angle) during the acquisition of the image. Moreover several lines of the array are used for each band to acquire the same line of the scene several times, thus allowing TDI-like image binning. NEDT values between 0.2 and 0.5K at 290K are finally expected.

An onboard calibration will be done using two internal blackbodies at 283 K and 313 K. This solution is preferred to blackbodies placed at the entrance of the instrument to reduce volume and to keep compatibility with the existing CNES MYRIADE platform. The goal is an absolute accuracy of 1K.

The VNIR instrument will be based on classical 1D CCD arrays, with a pushbroom classical imaging mode.

The design of the instrument results from technical studies and trade-off currently being done, and led by CNES with the support of TAS (Thales Alenia Space).

4.2 Platform

The MISTIGRI spacecraft architecture is based on the last version of the standard MYRIADE platform which allows fulfilling the mission needs with a large margin. MYRIADE is a multi-purpose flight proven platform developed by CNES in partnership with industry. It enables a total satellite mass of at least 200kg compatible with different launchers.

4.2 Orbit choice and acquisition capacity

The orbit will be Sun-synchronous to have the same overpass time. The 1 day-revisit specification imposes a one day repeat cycle orbit at an altitude of 561 km. The case of the 720 km (2 day-revisit orbit) has also been examined and is the option selected for the TIREX proposal (Sobrino et al., 2011, same issue): it requires a constellation of 2 satellites shifted by one day to fulfil the 1 day-revisit specification. Coverage and acquisition capacity are depending on the orbit choice. The coverage capacity (or potential accessibility to sites at ground) is defined by the ground area that can be seen by the satellite within the across track roll depointing limit of 30°. In the case of a 561 km altitude, the coverage is about 25% at the equator and reaches 42 % at 45° latitude. In case of the constellation at a 720 km altitude, the coverage is pretty satisfactory: 73% at the equator latitude and up to 100 % from the 43° latitude (Fig. 2).

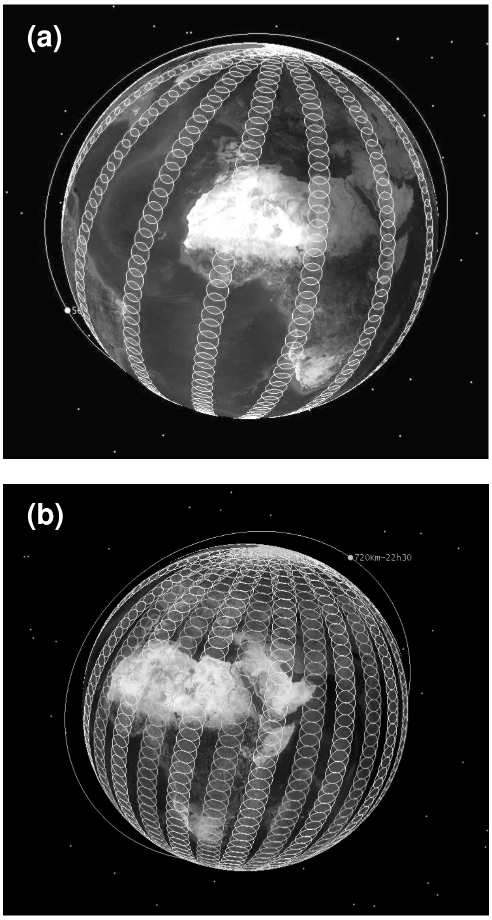

Figure 2. Potential accessibility at ground in the case of 1 satellite at 561 km (a) and of a 2 satellite-constellation at 720 km (b).

The acquisition of the sites is obtained by rotating the platform, across or along track. The acquisition capacity is therefore less than the coverage and limited by the time duration needed to achieve this rotation and by the image duration, taking into account a slow down ratio. As a consequence of the agility needs, the standard MYRIADE reaction wheels are to be replaced by more powerful wheels. A study performed at CNES has demonstrated the possibility to acquire imagery on sites in the most difficult case study of an orbit over western Europe including sites in Spain and France both sides of the track. For the 720 km altitude, the simulations show that 10 sites can be observed within a 310 s interval of time. Assuming sites spread over the land surfaces, an extension of this simulation leads to a number of 79 sites accessible on the daytime part of the orbit, and of 157 sites for the whole orbit. For the 29 revolutions flown during the 2 day-cycle, and taking into account a 29% cover of continental surfaces, a potential of about 665 (daytime only) and 1330 sites (daytime and nightime together) is accessible. The same computation leads to 60 (daytime) and 121 sites (whole orbit) per orbit with a 561 km altitude. For the 15 revolutions of the 1 day-cycle, about 260 (daytime) and 520 (day and night) sites can be observed with a 1 day-revisit. Despite obviously larger with the 720 km constellation, the number of potential reference sites at ground accessible with the 561 km orbit option remains quite compatible with the precursor character of the MISTIGRI mission.

The scientific data produced by the TIR and VNIR instruments are stored in the 16 Gbits Myriade Mass Memory and downloaded to a ground station located on a northern site. This location has a large visibility duration per day (~100mn) and allows to download up to 100 Gbits every day. This would also enable an additional systematic acquisition over boreal area and the constitution of an original dataset over such areas particularly affected by global change.

5 CONCLUSION

By filling the gap between high temporal /low spatial from one side and high spatial /low temporal resolutions from the other, which exists today in the context of the TIR missions, MISTIGRI is expected to bring an original information with a 1 day-revisit and ~50 m resolution. The scientific context is favourable, MISTIGRI being supported by an active scientific community having a large experience and a good maturity level in the TIR (models, experimental, spatial projects such as IRSUTE [Seguin et al., 1996] and SEXTET at CNES, PRISM and SPECTRA at ESA, FOCUS, BIRD at DLR, FUEGO in Spain…). The recent technological progress (uncooled microbolometers among others), and the fact the MISTIGRI architecture is constructed around elements having a strong heritage (platform) or being easily derived from other missions (for example the Venμs ground segment) all together significantly contribute to the feasibility of MISTIGRI. Finally, dealing with the general context of global change international programs, it appears that the development or reinforcement of long term federative initiatives and programs (such as FLUXNET, ICOS, GMES…) makes urgent an innovative precursor mission in the TIR such as MISTIGRI.

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