CNES contribution to Climate related space missions

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### The Essential Climate Variables

<table>
<thead>
<tr>
<th>Domain</th>
<th>Essential Climate Variables</th>
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| **Atmospheric** (over land, sea and ice) | - **Surface:** Air temperature, precipitation, air pressure, surface radiation budget, wind speed and direction, water vapour.  
- **Upper air:** Earth radiation budget (including solar irradiance), upper air temperature (including MSU radiances), wind speed and direction, water vapour, cloud properties.  
- **Composition:** Carbon dioxide, methane, ozone, other long-lived greenhouse gases, aerosol properties. |
| **Oceanic**                | - **Surface:** Sea surface temperature, sea surface salinity, sea level, sea state, sea ice, currents, ocean colour (for biological activity), carbon dioxide partial pressure.  
- **Sub-surface:** Temperature, salinity, currents, nutrients, carbon, ocean tracers, phytoplankton. |
| **Terrestrial**            | - River discharge, water use, ground water, lake levels, snow cover, glaciers and ice caps, permafrost and seasonally-frozen ground, albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation (fAPAR), leaf area index (LAI), biomass, fire disturbance, soil moisture. |
Programmes in operation

- Calipso
- Cryosat-2
- Hy-2A
- Iasi2/MetopB
- Swarm
- Jason 3
- Iasi1/MetopA
- Jason 2
- Smos
- Megha-Tropiques
- Saral-AltKa
- Sentinel-2A
- Sentinel-3A
Programmes being prepared or developed

- **2017**
  - Venus
  - Sentinel-2B

- **2018**
  - CFOSAT

- **2019**
  - IASI 3/MetopC
  - Microcarb

- **2020**
  - Biomass
  - Swot

- **2021**
  - Merlin

- **2022**
  - IASI-NG1/Metop SG A

CNES missions related to climatology
CNES missions related to climatology

Atmosphere:

-Megha-Tropiques (CNES-ISRO/India) launched in October 2011, studies the water and energy cycles in the tropical atmosphere with MW instruments (Saphir and Madras) and a broadband radiometer VIS/IR radiometer (Scarab).

-Calipso (NASA-CNES, A-Train) launched in April 2006, studies the properties of clouds and aerosols with a lidar (CALIOP, NASA) and an IR imager (IIR, CNES) on a platform provided by CNES. 10 Years Anniversary in June 2016 in Paris.

=> MESCAL (phase 0 study with NASA) as a FO mission of CALIPSO and Earthcare


=> 3MI on board Metop-SG (2021) will « continue » the measurement.
Megha-Tropiques

A better understanding of the water cycle in the tropics, a joint CNES/ISRO (India) project

A French-Indian mission to study atmospheric circulation, the water cycle and climate change in the tropics (monsoon variability, cyclone formation).

Its specific orbit provides five daily observations of any point of the globe in the tropical zone, which is essential for the study of extreme events. It has helped bring about remarkable progress in the forecasting of precipitation, cyclones, monsoons and drought.

Launched on 12 October 2011
Radiometers for atmosphere study

Megha-Tropiques mission launched in 2011, part of the GPM mission.

Megha-Tropiques : CNES/ISRO

- Three instrument:
  - MADRAS : microwave multi-channel imager
  - SAPHIR : multi-channel (6) swath radiometer (183 GHz)
  - SCARAB : cross-track multi-spectral rad.

- Orbit
  - Altitude = 867 km
  - Equatorial (20° incl)
Cyclone MARIA
from 19 to 21 September 2017 observed by Saphir
Atmosphere (continued):

-MERLIN (CNES-DLR) is a LIDAR satellite dedicated to the observation of the spatial and temporal gradients of atmospheric methane (CH4) columns. First IPDA Lidar in space

-IASI and IASI-NG (CNES-Eumetsat) infrared sounders on Metop then Metop-SG (2021-2040) to measure t°, water vapor, composition of the atmosphere. IASI-NG will succeed to IASI with improved performances. 10 years Anniversary of IASI-1 in October 2016 !!

-Microcarb (CNES) is intended for measuring CO2 column concentrations with a near-infrared dispersive grating spectrometer. Planned launch date: 2020
Atmosphere/Climate

Merlin

Monitoring methane, a greenhouse gas
A CNES/DLR cooperative project

The purpose of this microsatellite is to detect and measure methane found in the atmosphere, in order to map methane fluxes with unrivalled accuracy.

CNES is providing the Myriade Evolutions platform, and DLR (the German space agency) the innovative Lidar instrument.

Launch planned for 2021
Atmosphere/Weather

IASI and IASI-NG

Making breakthroughs for meteorology and determining the composition of the atmosphere
A CNES/EUMETSAT programme

An essential instrument in the payload of the 3 European polar-orbiting meteorological satellites, MetOp (A and B) and MetOp-SG, due to its Fourier transform interferometer.

Has been able to improve 6-day weather forecasts. Provides air-pollution alerts 1 or 2 days in advance.


The three models of IASI-NG are under development. The optical setup of the new generation should increase the spectral resolution and instrumental signal twofold in comparison to IASI.

Launch of the third IASI model planned for 2018 and of the first IASI-NG model in 2021
The objective of MicroCarb is to create a global map of the sources and sinks of the main greenhouse gas, carbon dioxide (CO2). The mission aims to determine how the main carbon sinks of our planet – the oceans and forests – function, and to map them. At the same time, MicroCarb will measure how many tonnes of CO2 are emitted by all sources (especially human activities and vegetation) region by region.

CNES is the prime contractor for the system and the satellite, which are based on the Myriade network; The payload consists of a passive spectrometer in the near infrared developed by ADS.

This project is being carried out by CNES in cooperation with the British Space Agency (UKSA) and in close partnership with the Laboratory of Climate and Environmental Sciences (LSCE), the Laboratory of Dynamic Meteorology (LMD) Of the Institut Pierre Simon Laplace (IPSL).

Launch planned for 2020
**Microcarb product levels**

**Level 0** = downlink

**Level 1** = calibrated spectra
(+ imager data, geometry, housekeeping…)

**Level 2**
= CO₂ volume mixing ratio
(+ geophysical data, etc)

**Level 3**
= XCO₂ maps

**Level 4**
= Surface CO₂ fluxes
(typical resolution ≤ 200x200 km, ≤ week)

CNES responsibility

Laboratory responsibility

Inversion of the radiative transfer

Inversion of the atmospheric transport
Ocean:

Jason-2/3 (Eumetsat, NOAA, CNES, NASA) intended to provide high-precision data for the monitoring of sea-level.

Saral (CNES-ISRO/India), launched on 25 February 2013, embark the Ka-band radar altimeter AltiKa (sea level).

CNES is also involved in Sentinel-3 (2016) and Jason-CS (2018) (for sea level)

CFOSAT (CNSA/China-CNES), intended to provide sea wave spectrum (SWIM radar instrument from CNES), and sea surface wind (CNSA). Planned launch: 2018.
Oceanography/Hydrology

The Jason series

Towards operational oceanography
A CNES/NASA project (expanded to include NOAA and EUMETSAT).

Jason-2 has been able to demonstrate operational oceanography similar to operational meteorology.

Continuation of the Jason-3 programme, with many of the characteristics of Jason-2.

The follow-up to Jason-3 is already being planned. This will be the Jason CS (for "Continuity of Service"), the Sentinel 6 satellite of the Copernicus programme.

Jason-3 was launched on 17 January 2016
SARAL-AltKa

A high-precision oceanographic altimeter
In cooperation with India

Improved altimeter performance through the use of the Ka-band for measurements of coastlines, inland surfaces (lakes and rivers) and frozen surfaces (sea ice, glaciers, ice caps).

Complements the measurements from Jason-2.

Launched on 25 February 2013
Oceanography

**CFOSAT**

Precise measurement of wind and waves
In cooperation with China

First mission for the global measurement of wind and waves (distribution in size and direction) at the surface of the oceans.

This will complement measurements from altimetry missions.

Launch planned for 2018
SWIM instrument on CFOSAT mission

- SWIM (Surface Wave Investigation and Monitoring)
- Currently in phase D (on-going I&T in China)

CFOSAT: China France Oceanography SATellite

- Two payloads:
  - SWIM: wave scatterometer
  - SCAT: wind scatterometer

- Orbit
  - Altitude = 519 km
  - SSO (13 days repeat cycle)

- Mission: 3 years duration
R&D activity on scatterometer

- R&D activities to **SKIM** concept (EE9 proposal)
  - Evolution of SWIM in Ka-band (SWOT/KaRIn RFU heritage), with phase (Doppler) acquisition
  - A novel **wave + current** spectrometer (5 rotating beams from 6 to 12°) plus a very accurate **altimeter** (Ka-band, SAR mode, high PRF)
  - SKIM will give total surface current on each pass at high resolution and will resolve short waves (~20m)

- Study of bistatic configurations for current monitoring
  - Complementarities with JPL concept (DopplerScat)
CNES missions related to climatology

Land:

VEGETATION (CNES, European partners) intended to provide land cover with a multi-purpose VIS/IR imagery on SPOT 4/5. SPOT 5 launched on May 2002. End of Life 2015.

SMOS (ESA, CNES, CDTI/Spain) provides soil moisture and ocean salinity. Launched on November 2009.

PLEIADES (CNES) to study the glaciers, land use, vegetation. 2 satellites launched in 2011, 2012.

SWOT (NASA, CNES) will provide the collection and distribution of high-precision data for the monitoring of water level (sea, lakes, rivers). Planned launch : 2020.

BIOMASS (ESA) will provide the estimate of the global biomass and the terrestrial component of the carbon cycle. Planned launch : 2021.
SMOS

Measuring soil moisture, the water content of vegetation and the surface salinity of the oceans

The goal of the SMOS mission is to provide comprehensive and regularly updated mapping of soil moisture and the surface salinity of the oceans, key variables for studying hydrology, ocean circulation, meteorology and climate change.

SMOS data also offer very interesting perspectives for monitoring the thickness of sea ice in the polar regions and applications for crop forecasting, as well as for assessing the risks of flooding and drought, thus contributing to better management of food and water resources.

The satellite consists of a Proteus bus and an interferometric radiometer that measures the microwave electromagnetic radiation emitted by the surface of the earth, at a frequency very sensitive to water content (the L-band).

The SMOS mission has been selected by ESA as the second Opportunity mission of its Earth Explorer programme. It is run jointly by ESA, CNES and the CDTI (Centre for Industrial and Technical Development, Spain). CNES, which has provided the satellite bus, operates it from its centre in Toulouse. It has also developed the downstream SMOS Data Processing Centre (CATDS), which distributes Level 3 and Level 4 data to users as they become available.

Launched on 02 November 2009
**SWOT**

Level of the oceans and inland waters

A joint CNES/NASA project to map variations in the levels of inland and ocean waters.

CNES is providing the platform and cooperating with NASA on the instruments, in particular the Karin instrument (a highly innovative wide-swath altimeter).

CNES is also in charge of the satellite-control ground segment and is developing a mission ground segment for data processing. The French contribution is partly financed by the French future investments programme (PIA).

Launch planned for 2021
CNES – NASA mission; Launch foreseen in 2021

New technical concept: wide-swath interferometric radar (KaRIN)
- 2D Image / Swath 2 x 60 km
- 1 observation every 10 days at equator
- 1 observation every 5 days above 60°N
- Ka Band phase difference measurement on 2 antennas

Applications:
- **Oceanography**
  - Meso-scale study (Eddies > 10km),
  - Ocean/atmosphere coupling
- **Hydrology**
  - Cartography and water height monitoring over water surfaces as wide as 250 x 250 m²
  - Water height over rivers larger than 100m (target 50m), flow rates, estuary observation...
CNES Climate Change activities with French scientists also include:

Intercalibration of sensors from several agencies (example Infra red sounders like IASI, AIRS etc) and of sensors of a series of satellites (example = Jason series)

processing and reprocessing of data activities especially at the end of missions.

Inventory and delivery of existing ECV series derived from CNES missions, some ECV data are produced in CNES-CNRS thematic data centers (Théia = Land surfaces, Ocean, Form@Ter = Solid Earth, Atmospheric pole ICARE), over ECV are delivered through ESA Climate Change Initiative

Space data = inputs for Climate Service of Copernicus (European Program for Environment and Security)
CNES skills on vicarious calibration internationally recognized:

- ESA: SENTINEL-2 and SENTINEL-3
- EUMETSAT: 3MI
- NASA: calibration data and results exchange (LANDSAT-8, MODIS, SNPP VIIRS)
- NSPO: THEOS
- Airbus Defense and Space: SPOT6, SPOT7
The Calibration Pole

- Sounders cross-calibration: IASI-A, IASI-B, AIRS and CRIS
  - IASI is the reference for TIR sounding

- Sharing results with NASA and NOAA within GSICS
What about future Earth observation missions?

CNES R&D planned activities:

- Critical technologies for Lidar instrument (aerosols or IPDA lidars): APD, OPO, frequency comb, ...

Phase 0 study with NASA on MESCAL (CALIPSO Follow On)

- Thermal IR focal plane and detectors, SWIR detectors perfos improvements sensitivity/linearity, Straylight mitigation for spectrometers and radiometers ...

Phase A with ISRO on Trishna (CNES-ISRO IRT mission)

- Ka band compact SAR altimeter, compact wide swath radar interferometer (mixed constellation foreseen to complement Jason reference mission) ...

- SMOS new concepts study for higher space resolution (x4 times better SMOS HR or more SMOS Next)
What about future Earth observation missions?

New mission concepts to estimate physical parameters:

Specific phases 0 studies to investigate complementarity of sensors on various orbits with the help of research labs and data assimilation tools (OSSE: Observing System Simulation Experiments) to evaluate gain in performance.

A few targets:

- Smaller satellites in «Train» to combine different high resolution measurements of the same atmospheric cells (A-Train FO)

- Complementarity between microwave and optical sensors for water vapour

- Complementarity between active (lidar) and wide swath sensor for aerosols (3MI)

- Complementarity between nadir and wide swath radar altimeters for mesoscale ocean observation

Alert: Measurements not guarantied or not covered on medium/long term for:

- Microwave sea surface temperature (end of AMSR2/GCOM ?),

- Soil humidity/salinity (SMOS FO),

- Precipitation rate (GPM radar, microwave from GEO ?),

- Wind profile (ADM Follow on) ? => Sentinel expansion/new generation ?