THEMATIC GROUP

TOSCA COMMITTEE (SOLID EARTH, OCEAN, CONTINENTAL SURFACES AND ATMOSPHERE) (TOSCA – TERRE SOLIDE, OCÉAN, SURFACES CONTINENTALES, ATMOSPHERE)

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The Earth is a complex system whose various components (atmosphere, ocean, cryosphere, continental surfaces, solid earth) interact with each other through geological, physical, chemical and biological processes that take place on a wide range of spatial and temporal scales and are, moreover, affected by human activity. Understanding the Earth system requires a global approach to observe and understand its different components and their interfaces, couplings and interactions (Fig. 1). Most of the major scientific questions involve these interfaces, requiring scientific approaches that integrate the various components and disciplines.

Fig. 1. Observation of the Earth system, its components and interactions.

Earth observation sciences aim to understand and predict the planet's evolution, to distinguish between anthropogenic effects and natural variability and to better understand and anticipate the risks and hazards on human activities in a very wide range of environments. They deal with changes in the major climate cycles (energy, water, biogeochemistry) and the stocks and fluxes between the various components of the Earth system. The research focuses on physical and biogeochemical processes, complex feedback mechanisms, scale interactions and exchange and coupling mechanisms between the atmosphere, ocean, cryosphere and continental surfaces; it also aims to understand the mechanisms behind the formation and evolution of the solid Earth, its composition and thermal structure, its internal dynamics, the generation of the Earth's magnetic field and couplings with its external envelopes.

The sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC) clearly indicates that unprecedented changes are occurring in the Earth's climate. Since this report was published, the key indicators on the state of the planet (Fig. 2) show a clear acceleration in changes and this requires strong mitigation and adaptation measures. It is quite appropriately referred to as a climate emergency. As a result, 2023 was a record year for mean global and ocean temperatures. There are major impacts on ecosystems and biodiversity that are subject to other human pressures (e.g. population growth, pollution), as reported by the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). The three crises of climate change, biodiversity loss and pollution are threatening the implementation of the sustainable development objectives and putting enormous pressure on societies. These major societal challenges are recognised at the highest political levels: the United Nations 2030 Agenda and the Sustainable Development Goals, the COP (Conference of the Parties) on climate and biodiversity and, more recently, the United Nations Ocean Conferences. Meeting these societal challenges through measures to mitigate and adapt to climate change,

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and to reduce pollution and the impact of human activities, requires science-based approaches to provide the most appropriate solutions. Earth observation plays a key role in this respect.

While Earth observation satellites are indispensable and unique tools, understanding the Earth system requires an integrated approach based on both satellite and in-situ observations and modelling. Satellite observations provide a global and repeated view at high spatial resolution. In-situ observations and ground measurements play an essential role in validating and calibrating satellite measurements and in observing key parameters that cannot be observed by satellites (e.g. the ocean interior) or at complementary acquisition intervals. Modelling is fundamental to explaining phenomena, integrating satellite and in-situ observations to describe the state of the planet and predict its evolution for periods ranging from a few weeks to a season or longer (decadal forecasts, climate projections) and developing scenarios (digital twins).

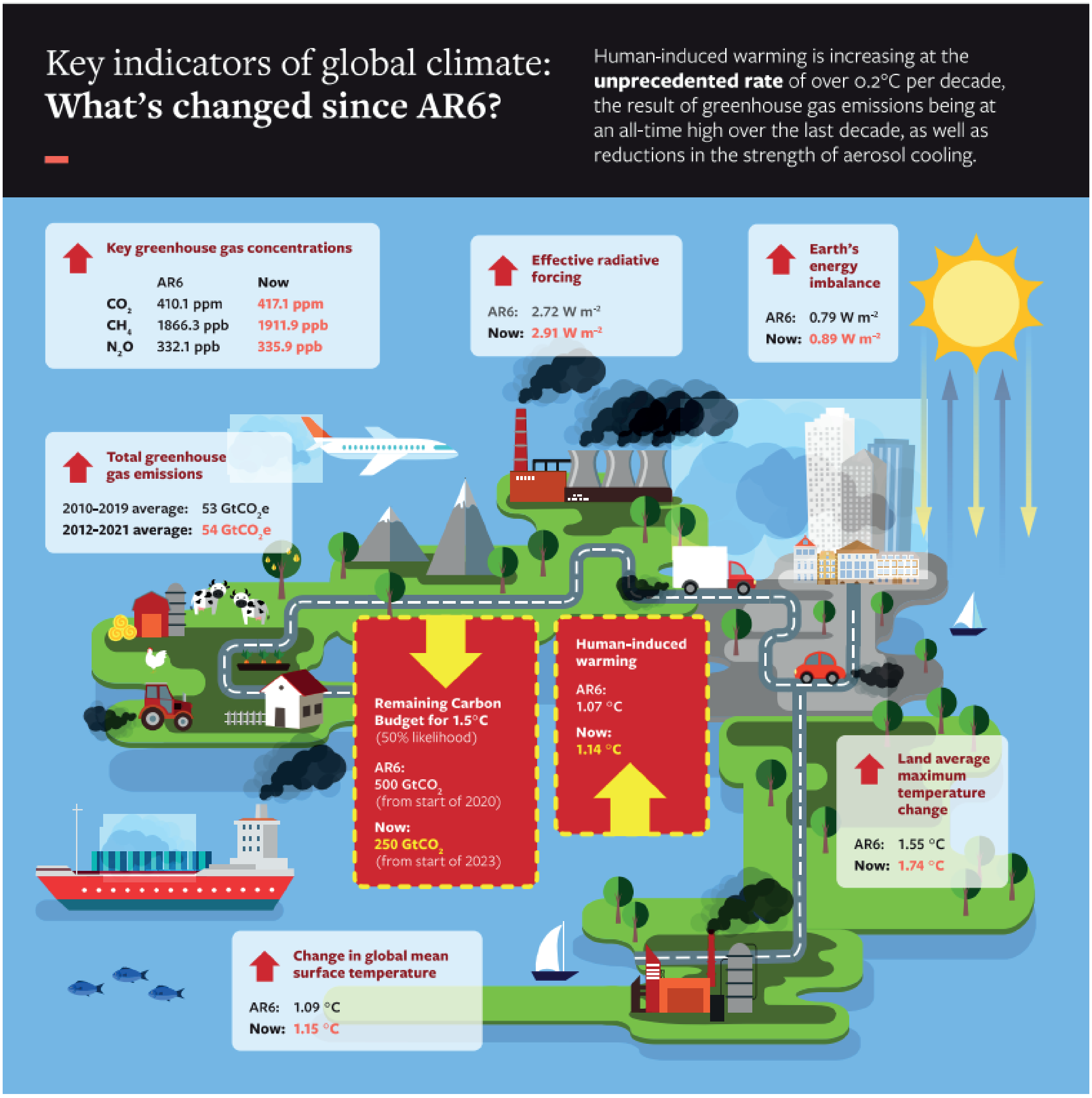

Fig. 2. Changes in climate indicators since the publication of the IPCC's sixth report (Forster et al., 2023)

Tosca integrates all Earth Science themes and is based on four thematic groups covering the compartments of the Earth system and their interfaces, couplings and interactions: Solid Earth, Ocean, Continental Surfaces and Atmosphere.

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1. REVIEW AND PROGRESS SINCE THE 2019 FORESIGHT

1.1 SCIENTIFIC ADVANCES

The SPS2019 highlighted three major challenges for Earth Observation and Research: improving our understanding of the Earth system (water cycle, biogeochemical cycles, cryosphere and coastal zone), detecting and quantifying global changes (climate change, anthropogenic effects, Earth dynamics and shape), and identifying and quantifying environmental issues and risks (sustainable development objectives, atmospheric pollution, extreme events and biodiversity). Meeting these challenges meant ensuring the continuity of measurements and using long time series, improving spatial and temporal resolution, and combining measurements from one or more satellite missions, while incorporating *in-situ* and airborne measurements.

Continuity of measurement is imperative to enable monitoring of the essential variables that provide information on global change, identifying the dynamics of these changes, and trying to anticipate their impact as effectively as possible. It must be accompanied by monitoring and calibrating the measurements themselves, to ensure the quality of the final geophysical data. Over its 17 years of operation (2006-2023), the **Calipso** mission has enabled unprecedented monitoring of clouds and aerosols, leading to the identification of various climate feedback processes, such as the 'stability' or 'Iris' effect, which consists of a reduction of the surface of anvil clouds during local warming. Thanks to their exceptional spectral and radiometric stability (of the order of one hundredth of a Kelvin per year), monitored on a day-to-day basis by Cnes, Eumetsat and the laboratories, the three **Iasi** instruments have made it possible to monitor sixteen key variables for the atmosphere as a single instrument, over 17 years, making it the international benchmark for thermal infrared observations.

French teams also played a major role in leading the reanalysis of space geodesy measurements, which mobilised dozens of teams around the world to process data acquired with the four techniques, covering periods of 28 years **(Doris)**, 27 years **(GNSS)**, 41 years **(VLBI)** and 38 years **(SLR)**. This work led to the ITRF2020 (International Terrestrial Reference Frame), which is the best-performing implementation to date in terms of coverage, density, precision and stability, with the accuracy of the long-term origin and temporal evolution estimated at 5 mm and 0.5 mm/year respectively.

The combination of the Copernicus programme and Eumetsat's operational meteorology programme, for which France's centres of excellence are making a major contribution to commissioning of the satellites, means that we now have unprecedented continuity of observations of a large number of variables that are essential for studying the Earth system. The extension of the precise altimetry series **(Topex/Poseidon**, **Jason-1, 2** and **3**) with the launch of **Sentinel-6** in November 2020 and ongoing efforts to reprocess past data, improve algorithms and characterise errors have revealed a clear acceleration (~0.08 mm/year^2) in the rise in mean sea level, which is now more than 4 mm/year. In addition, the French scientific community has made leading contributions to the analysis and interpretation of altimetry data combined with gravity data **(Grace** and **Grace-FO**) and in-situ data **(Argo)** to monitor mean sea levels and the planet's energy imbalance. This work has confirmed the significant acceleration in the rise in sea level since 1993, essentially due to the accelerated mass loss from the Greenland and Antarctic ice caps. This type of multi-sensor combination has also led to improved knowledge of the multi-annual water budget of major river basins such as the Amazon and the Congo, as well as the hydrodynamics of estuaries. The data provided by **Sentinel-1** and **-2**, combined with that from the **Smos** and **Pleiades** missions, have also enabled numerous advances in knowledge of the cryosphere, the estimation of irrigation volumes and the study of soil moisture.

Improving spatial, temporal and spectral resolution is essential for understanding various scientific issues, such as spatial heterogeneities in observed trends, extreme events or the study of interfaces between environments (coastal/shoreline, urban/rural environments, etc.) and between ecosystems. The launch of **Swot** in December 2022 marked a revolution in the fine-scale study of the ocean, which plays a vital role in transporting energy and matter. For these studies, only satellite observations provide data that are both global and high-resolution.

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As part of the Calibration/Validation (Cal/Val) of **Swot**, more than twenty international oceanographic campaigns were coordinated by French teams worldwide in 2023, illustrating the effectiveness of such actions in federating large-scale international programmes. Regarding the mapping of continental surfaces, significant progress has been made in the classification of agricultural classes (from 2 types of summer/winter crops to 8 classes of annual crops) in the land cover maps, which now include 24 classes on a national scale. Studies are under way on seasonal and near-real-time mapping, using a combination of **Sentinel-2** series and very high spatial resolution images from satellites such as **Pleiades** or **Spot 6/7**. The mapping of coastal areas has also been explored, such as the study of the risk of flooding in Asian deltas.

The growing availability of high spatial resolution data has also facilitated the scientific study of the impact of human activities on the major biogeochemical cycles, by providing access to data on the metric to decametric scales at which humans interact with their environment (e.g. the impact of agricultural practices on soil carbon stocks). Taking advantage of advances in Artificial Intelligence (AI) to meet operational challenges or resolve complex ecological issues, the monitoring of terrestrial ecosystems draws on all fields of remote sensing to map, characterise and monitor the biodiversity of species and habitats. Progress has also been made over the last five years in the study of extreme events, particularly earthquakes. The joint use of **Sentinel-1** and **GNSS** measurements has improved our understanding of slow earthquakes, which last from a few weeks to a few months, and the distribution of frictional heterogeneities along subduction zones.

A particularly interesting case study highlights the cross-disciplinary nature of the issues addressed in studying the Earth system, linking internal and external envelopes: the eruption of Honga-Tonga on 15 January 2022. The waves generated propagated through the ground and the atmosphere as far as the ionosphere. The footprint of atmospheric disturbances has been characterised on a planetary scale by networks of measurements taken on the ground, on satellites **(Goes**, **GNSS**, **IASI**, **Pleiades**, **Sentinel-1** and **-2**) or airborne platforms **(Stratéole-2**), demonstrating the contribution of interdisciplinary analyses to investigation of the impulse response of planetary fluid shells (atmosphere, ocean) to an eruption of exceptional intensity.

1.2 REVIEW OF 2019 FORESIGHT PRIORITIES AND RECOMMENDATIONS

The programming context of the last five years has undergone profound upheavals: a difficult national budget context which has led to a pause in the development or implementation of several missions, the unavailability of European launchers (Ariane 6 and Vega C) and of Soyuz, which has led to delays in the start of certain programmes, the development of Esa programmes and the Copernicus programme, plus the emergence of new players in the space sector supported in particular by France2030, not forgetting Covid.

1.2.1 REVIEW OF HIGH AND VERY HIGH PRIORITY MISSIONS

The table below gives an overview of the missions, ranked as high or very high priority in SPS2019. Lower priority missions are detailed in the thematic group reports. Taking into account the changes in the space landscape, the 2019 ranking showed a clear separation between large and small missions, the latter being based on the use of nanosatellites.

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Mission	Scientific goals	Work carried out	Current status / Possible new framework
Very high priority			
Trishna	Water stress in ecosystems, urban areas, coastal areas	Surface temperature	Phase-C, scheduled for launch in 2026 in partnership with Isra
Mescal/ACCP	Aerosol speciation	Phase-0, not selected by Nasa	Discussions for participation in **Caligola** in partnership with Asi and Nasa
	Convective clouds and precipitation	Phase-0 then A	Phase-A, **C2omodo/AOS** in partnership with Nasa
High priority (large missions)			
Marvel	Gravity field	Phase-0, concept studied in partnership with DLR, Esa, Nasa but not retained	**Magic/NGGM** in phase B1 within an Esa/Nasa framework
	Reference system		**Genesis** as part of Esa NAV programme
Skim	High-frequency measurement of waves and surface currents	Phase-0, Cnes then phase-A, Esa (EE9), Stream proposal for EE11	**Odysea** accepted for competitive phase A for Nasa EE
Biodiversity	Essential variables for small-scale biodiversity	Phase-0, hyperspectral imaging, Galene (coastal and continental waters) not included in EE12	-
High priority (small missions)			
C3iel	Convective clouds and extreme events with NanoSat	Phase 0/A/B, mothballed due to budgetary constraints	Phase-C, scheduled for launch in 2027 in partnership with Isa
Ulid/Smos-Next	Salinity, soil moisture and thickness of fine ice	Phase-0/A, Fresch, not selected for EE12	-
NanoMagSat	Measuring the Earth's magnetic field	Phase-0/A	Selected as part of Esa Scout programme
DAMONA	High-resolution hydrology	Phase-0, Smash	Under study within the FR2030 framework

The results over the last five years have been mixed, largely due to the difficult national budget context, which has led to some developments being put on hold or halted. Thanks to the strong mobilisation of the scientific community and Cnes teams, which should be commended, several scientific priorities identified during SPS2019 have nevertheless been restarted and confirmed. On the other hand, half of the top priorities (P0) and the majority of the lower priorities (P1) of SPS2019 could not be retained.

Four high-priority missions have been selected for development. The **Trishna** thermal infrared mission, which has been a priority for the last twenty years, was upgraded to Phase-C at the end of 2019, as part of a joint project with Isro. Beyond the initial objective of studying terrestrial ecosystems, which is based on a dynamic and structured national community, an ocean component of **Trishna** has gradually been established. The **Marvel** gravimetry mission, another long-standing priority, was designed to meet two major objectives: obtaining precise knowledge for the reference system, and high-resolution gravity field observations. Although the proposed concept was not ultimately selected, the mission was adopted for two projects, on the one hand through the unexpected selection of the **Genesis** mission as part of Esa Navigation programme and, on the other, through the preparation of Esa and Nasa **Magic/NGGM** mission. Cnes and the French community are involved in both these missions. On the nanosat front, after their development was halted for budgetary reasons,

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the **C3iel** mission finally moved into Phase-C in 2024 for launch in 2027, and the **NanoMagSat** mission to study the Earth's magnetic field was selected in early 2024 by Esa as part of the second phase of its Scout programme.

The second very high priority of SPS2019, the **Mescal** mission, aimed to study aerosol speciation by adding a UV channel to an American lidar at the **ACCP** atmosphere observatory. Following a budgetary decision by Nasa, the concept was abandoned, as was the idea of carrying a lidar in the constellation's inclined orbit. The **C2omodo** mission, P1 of SPS2019, designed to study convective systems using a train of microwave radiometers, was then proposed and selected, ensuring not only French participation on the steering committee of this international observatory of the next decade, renamed **AOS**, but also giving the French community access to the entire data chain.

Several missions are currently competing for selection in various international programmes, the results of which should be known in 2024. Regarding high-frequency observation of ocean surface currents, following the non-selection of the missions **Skim** (EE9 finalist) and **Stream** (not selected for the EE11 call because it was considered to exceed the budget), the **Odysea** mission was proposed and selected for Nasa Earth Explorer call. About the study of salinity, soil moisture and the thickness of thin ice, the demonstrator mission for a 3rd generation L-band radar concept**, Ulid**, was abruptly terminated in 2021, leading to a refocusing of phase A studies around a 2nd generation **Smos-HR** concept, from which the **Fresch** concept is derived. This concept was submitted but not selected despite a very favourable evaluation in Esa EE12 call for proposals. Cnes has supported work to promote the development of a hyperspectral satellite for coastal observation. Finally, the concept of a very frequent revisit hydrology mission using a constellation of **Smash** (**ex-Damona**) nanosats is currently being evaluated as part of the France2030 programme.

1.2.2 REVIEW OF WORK AT THE EUROPEAN LEVEL

At Esa level, Cnes has provided support to French teams taking part in Earth Explorer (EE) missions. Since the last foresight seminar (SPS), the **Aeolus** (EE5) mission has been successfully launched, with the French community being heavily involved. Its three years of operation have demonstrated its capacity to improve our knowledge of wind fields (particularly in the tropics and in the lower stratosphere where convection induces large-scale circulation) with a very significant impact on the quality of wind forecasts from global models via data assimilation. Eumetsat has proposed to its member states an operational follow-up (**EPS-Aeolus** programme) for 2030. The **EarthCare** (EE6) mission was successfully launched in May 2024; the preparatory work benefited from the internationally recognised expertise of the French scientific community in the use of active measures to study clouds and aerosols. Preparatory work for forthcoming EE missions supported by Cnes has focused on the development of **Biomass** (EE7), the exploitation of future fluorescence measurements from the **Flex** mission (EE8) to study water stress in vegetation, and far-infrared spectroscopy studies for the **Forum** mission (EE9). Finally, Cnes has supported the preparatory work for the **Wivern** missions, a top priority for the Atmosphere group during SPS2019, with the aim of carrying out the first measurement of the wind inside clouds, one of the two finalist missions for possible selection for EE11, and the missions proposed for EE12 on the themes of radiation budget **(Eco**) and high-resolution salinity **(Fresch**).

In addition to this support for the French teams, Cnes pushed the French priorities at the 2022 ministerial conference, defined in conjunction with the national programme: an ambitious contribution to the **Future EO** envelope programme, the backbone of the European programme for the entire value chain from upstream to downstream, including Earth Explorers (EE), as well as the **Climate Space** and **Sentinel User Preparation** support programmes. However, the lack of commitment to the Future EO programme by Member States at the most recent ministerial meeting is a cause for concern and may limit the scope for implementing innovative and ambitious EE missions in the future. The possibility of setting up a new category of EE missions that are larger in scope but spread out over a longer period, needs to be considered. Finally, it should be noted that, although supported by the national community, the latter's participation in various Esa programmes aimed at exploiting space missions, has fallen short of expectations. An initial analysis

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shows that the complexity of the responses and the lack of administrative support are major obstacles to the participation of French teams.

As part of the European Eumetsat programme for an operational meteorological satellite, Cnes has supported French teams developing the **EPS-SG** (polar orbit) and **MTG** (geostationary orbit) programmes, the launch of which has been delayed due to the unavailability of European launchers. In particular, the preparation of the **Iasi-NG** hyperspectral infrared sounder, developed by Cnes to be carried on the three **Metop-SG-A** satellites, has been finalised. This mission will follow on from **Iasi**, the international benchmark for infrared observation, in order to extend for 20 years the monitoring of the thermodynamic parameters that are essential for numerical weather forecasting, as well as many other variables that are essential for studying both the composition of the atmosphere and the climate, with greater accuracy and vertical coverage of the atmosphere. These observations will be supplemented by those provided by a family of instruments aboard the same platform, such as the **3MI** polarimeter (clouds and aerosols) and **Sentinel-5** (air quality). The synergistic use of all these instruments will enable us to better characterise the composition of the atmosphere. Diurnal variation will be studied by the instruments on board **MTG-I** and **MTG-S**, the latter carrying the **IRS** and **Sentinel-4** instruments which the French community has helped to develop.

The European Union's (EU) Copernicus programme has placed Europe at the forefront of global monitoring of the planet, based on a long-term space component (the Sentinel missions), in-situ observations and monitoring and prediction services for climate, the ocean, the chemical composition of the atmosphere, continental land masses and emergency monitoring. Since the last SPS, Cnes has supported the definition and implementation of the Copernicus programme by including French priorities and demands in the definition of the programme, defending the continuity of Sentinel missions that are of interest to the national community, and supporting the involvement of French laboratories in mission groups and data exploitation work. This is particularly the case for the study and monitoring of anthropogenic greenhouse gas emissions (**CO2M** mission) and evapotranspiration and surface temperature (**LSTM** mission), for which the **MicroCarb** and **Trishna** missions are precursors. Extensive consultations with the national community have led to the co-construction of French priorities for the implementation of New Generation Sentinel satellites. In particular, this led to the selection of wide-swath altimetry for the **Sentinel-3-NG-Topo** mission, illustrating the successful transition of innovative upstream missions resulting from decades of research into this operational, environmental-monitoring programme.

1.2.3 REVIEW OF AIRCRAFT AND BALLOONS

A very high priority for SPS2019 was the renewal of the high-altitude jet for the Safire unit (the French facility for airborne research). Thanks to strong mobilisation of the various stakeholders, the necessary budget was secured in early 2024, with commissioning planned for around 2030. The end of Falcon 20 operations in February 2022 has logically led to a sharp increase in the demand on the ATR 42 in recent years, resulting in incompatible overlaps between campaigns and weakening the Cal/Val possibilities for satellite missions scheduled for launch in the near future **(EarthCare**, **MicroCarb**, **Iasi-NG**, etc.). Rapid commissioning of the new jet therefore remains a priority.

More generally, just over twenty space-related campaigns using the Safire unit's fleet of research aircraft have been carried out over the last five years. Bringing together a total of some fifty laboratories, these campaigns have covered a wide range of scientific topics: anthropogenic greenhouse gases, the water and cloud cycle, air quality, aerosols, and also ocean and continental surface temperatures. Safire's resources have also been used to validate various space missions **(Aeolus**, **Cfosat**, **GNSS**, **Iasi**) or to prepare future missions **(Merlin**, **MicroCarb**, **Trishna**, **Scarbo**[1]).

As far as the balloon programme is concerned, the priorities identified during the SPS2019 have been followed. The StratoSciences campaigns using Open Stratospheric Balloons (OSBs) have continued annually and are part of the European **Hemera** project. Around forty experiments from

1 Space CARBon Observatory H2020 project

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13 countries have been carried out, with regular scientific output and a broadening of the balloon user community to include new themes (clouds, atmospheric electricity) or new instrument developments. In addition to the cooperation framework with Canada and Sweden for the use of the Timmins and Kiruna bases, a cooperation agreement was signed by Cnes and the Brazilian Space Agency in 2021 and 2023, to set up an equatorial launch site, a long-standing priority for the national community. Two major strategic projects have relied heavily on the balloon programme: **Stratéole-2**, for the study of the upper troposphere-lower stratosphere using atmospheric pressurised balloons, with two campaigns carried out (in 2019 and 2021); and the **Magic** initiative, combining six annual campaigns of Open Stratospheric Balloons (OSBs), light expandable balloons, research aircraft and ground-based instruments to study greenhouse gases. Lastly, the integration of balloons in the Cal/Val plans for space missions has been strengthened, both at the Aire sur l'Adour site (regular release of light balloons that can be expanded when a satellite of interest passes overhead): **Iasi**, **Sentinel-5P**, **Oco-2**, **Calipso**) or during OSB campaigns.

The setting up of the national infrastructure of instrumented aircraft and aerostats (SAFIRE) for **In-Air** research has been strongly supported by the French scientific community to facilitate measurement campaigns based on the joint use of aircraft and balloons, in addition to ground or satellite measurements, as shown by the first strategic campaigns (Magic or Eurec4a).

1.2.4 REVIEW ON DATA ISSUES

Since the last SPS, the Data Terra research infrastructure has been strongly structured around major projects such as the Equipex+ Gaia Data project, to accelerate the extraction, analysis, dissemination and intelligent use of data, indicators and models from national and international observation services/systems. The research infrastructure is based on four centres of data and services (Aéris, Odatis, ForM@Ter and Theia), corresponding to each of the four major compartments of the Earth system, whose operation has gradually become standardised and to which the National Biodiversity Data Cluster (PNDB) was added in 2024. However, the various centres still need to be coordinated. The definition of a scientific roadmap also needs to be finalised, so that Data Terra can be fully integrated into national space priorities.

New uses for satellite data have been developed. Over the last five years, there has been a particular development of downstream services, with the introduction of programmes **(Swot-Aval**, etc.) aimed at service-oriented use of satellite mission data, based to varying degrees on research work carried out for many years in laboratories. In response to the recommendations of SPS2019, a specific CNRS-Cnes measure has been taken to stimulate the development of innovative methods for the processing, analysis and scientific exploitation of satellite data, including for the preparation of future missions. Finally, an analysis of the increase in new actors, notably via the France2030 programme, raises the question of the contribution to science of market-oriented programmes driven by private companies. More generally, the success of these various programmes will depend very heavily on the quality of the data, access to the data, and the complementarity and interoperability of any new data in relation to existing data.

Created in June 2019, the Space Climate Observatory (Sco), which now brings together 47 signatories and 26 countries, has gradually structured itself around issues of adaptation to climate change, with the aim of facilitating the transition of research work from a demonstration phase to an operational service. However, the Sco positioning in relation to Cnes annual call for research projects remains to be defined, given the number of projects that still deal mainly with research issues, which illustrates the constant need for interaction between research and operations for a given application project.

1.2.5 REVIEW OF SUPPORT FOR SATELLITE MISSIONS

Cnes annual call for research projects and the PhD and post-doctoral programmes provide essential support for space activities and are still very popular with laboratories, whether for preparing future missions, exploiting data or linking up with applications. Recent years have seen the emergence of new themes (forest dynamics, human impact on the environment, biodiversity, anthropogenic emissions, etc.) and increased needs for new algorithmic approaches. However, this increase in re-

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quests for support raises serious concerns about the human resources available in the laboratories, which appear to be inadequate to contribute to the many missions planned in the short term, particularly in the fields of measurement physics, data analysis and instrument design.

Since SPS2019, Tosca has stepped up its exchanges with all its national academic partners (CNRS-Insu-OA/Sic/TS, Inee, Météo-France, Onera, CEA, IRD, Ifremer, etc.) at its own committee meetings, during the inter-agency committee meetings organised for each national or bilateral mission, and during the seven mission extension reviews **(Calipso**, **Cfosat**, **Jason-2**, **Megha-Tropiques**, **Saral**, **Smos**, **Venµs**) for which the scientific evaluation has been harmonised. Strategic workshops have also been set up with the national community on various subjects (Copernicus, hydrology, methane, atmospheric lidar) to co-construct the space roadmap for Earth Observation and Research.

2. SCIENTIFIC PRIORITIES

Earth observation capabilities must be developed in the coming years to improve our knowledge and understanding of the Earth system and to meet the new societal challenges posed by the acceleration of climate change, the decline in biodiversity and pollution. In particular, the aim is to gain a better understanding of how the climate and the major climate cycles (water, energy, biogeochemistry) are changing, and to monitor and anticipate tipping points in the climate system. The effectiveness and effects of mitigation policies need to be measured, and the impacts of climate change need to be quantified and understood to guide strategies for adapting to climate change. Monitoring and understanding changes in biodiversity and characterising the exposure, vulnerability and dynamics of socio-ecosystems are key for increasing our knowledge and resolving societal issues. Many scientific questions also concern the dynamics of the solid Earth and its interaction with the Earth's external envelopes, the atmosphere, ocean, cryosphere and hydrosphere. Finally, it is essential to better characterise and anticipate extreme events, risks and natural hazards.

Tosca scientific priorities have been defined in line with the various national foresights (e.g. CNRS-Insu, Inee, Météo-France, Ifremer) and considering European (ESA, Eumetsat) and international (e.g. Nasa, Geo) ones. The questions selected are naturally those for which Earth observation makes or can make a major contribution.

These priorities have been grouped into six cross-cutting themes, which are then broken down into scientific priorities. They are based on the scientific priorities and issues detailed by each of the Tosca groups, synthesising and prioritising them within an Earth system vision:

- Theme 1: Climate variability and cycles
- Theme 2: Coupling, interfaces and scale interactions
- Theme 3: Land-sea continuum
- Theme 4: Socio-ecosystems and biodiversity
- Theme 5: Prediction, digital twins and hazards
- Theme 6: Interactions between the Earth's interior and its external envelopes

2.1 CLIMATE VARIABILITY AND CYCLES (T1)

Unprecedented changes are taking place in the Earth's climate. How will the **climate evolve over the next few decades, and what are the likely tipping points** or irreversible changes in certain climate variables? What are the underlying processes and how can we detect the risks of going beyond tipping points, anticipate them and provide society with the information it needs to be better prepared? To meet this challenge, we need to maintain and optimise long observation series for the essential climate variables. New missions will shed light on research into the water cycle **(Swot**, **Trishna, Cimr, Cristal**), the carbon cycle **(Flex**, **Biomass**) and the estimation of GHG fluxes **(MicroCarb**, **CO2M**, **Merlin**, **Iasi-NG**, **Sentinel 5P** and **5)**. However, there will still be challenges before we can fully understand **the hydrological budget at the spatial scales of water management**. The **regional variation in groundwater stocks** also remains the great unknown in the terrestrial water cycle. On climate time scales, the main uncertainty about the amplitude and speed of the rise in sea level is linked to changes in the polar ice caps. It is

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vital to gain a better understanding of **the evolution of the internal properties of the Antarctic ice cap**, for which glaciological models diverge significantly due to non-linear effects (tipping points) in their response to climate forcing.

We also lack understanding of certain key processes linked to the water cycle. This is particularly the case for **cloud formation mechanisms and deep convection processes in the atmosphere**. The aim is to understand how the mixing and properties of anthropogenic and natural aerosols affect cloud formation processes, their radiative properties and precipitation, and how to improve our understanding of deep convection. Convective activity can be characterised by vertical velocity and mass fluxes. To date, these two variables have not been measured on a global scale, which is an obstacle to modelling these phenomena.

Another area of research concerns our planet's radiation budget. The study of its evolution incorporates the combined effects of changes in GHG concentrations in the atmosphere and the various feedback effects within the Earth system. How can we **measure the Earth's radiative energy imbalance accurately enough** to provide an additional indicator of the effectiveness of climate policies?

2.2 COUPLING, INTERFACES AND SCALE INTERACTIONS (T2)

Understanding the planet as a coupled system requires measurements at the air-sea interface, where the ocean meets the atmosphere. In this transition zone between the ocean and the atmosphere, clouds form, storms are triggered, carbon dioxide from the atmosphere is absorbed by the ocean and nutrients are transported to ocean ecosystems. **These interactions need to be better understood, which requires simultaneous measurement of surface wind, surface currents** and ideally waves. In the absence of surface current measurements, the details of these couplings still elude us, and controversies over the underlying physics remain unresolved.

Continental shelves and areas on the edge of ice are subject to significant variations in salinity, due to the inflow of freshwater from rivers or melting ice. The polar zones are subject to very rapid variations with feedback affecting the climate of the planet. There are still many unknowns. **Where, when and by what mechanisms do freshwater fluxes enter the ocean? How do they affect the stratification of ocean surface layers, and how do the strong density gradients they induce contribute to coastal and polar circulation? How does the export of low-salinity water offshore by eddy dynamics structure the distribution of salinity at the mesoscale**, with consequences for ocean-atmosphere exchanges of heat, energy and gases and for ocean circulation?

The interfaces between the different components of the Earth system are areas of exchange (e.g. heat, water, nutrients) that occur on a wide range of spatio-temporal scales that interact with each other. Understanding and modelling these couplings at different scales is a major scientific challenge. Sub-mesoscale observation and modelling have highlighted the important role of fine scales in ocean dynamics. **To better understand and take into account the couplings between these small-scale ocean dynamics and the large scale**, along with marine biogeochemistry, we need to continue making and improving fine-scale observations. **Observing cloud-aerosol interactions and fine-scale convection is also important for characterising 'multi-scale' interactions and their role in aerosol mixing, convection and global atmospheric circulation**.

2.3 LAND-SEA CONTINUUM (T3)

Coastal and littoral regions are increasingly influenced by changes in the global ocean, atmospheric forcing and highly anthropogenic continental inputs, with consequences for the diverse ecosystems they shelter. **What are the land-sea fluxes (water, matter, chemistry), their interactions with coastal dynamics and the open ocean, and how can we meet the challenges of adaptation and risk management in coastal and littoral zones?** Monitoring and forecasting their evolution requires a better understanding of their dynamics, the interactions between physical processes, biogeochemistry, sediments and the distribution of pollutants due to human activities, as well as continued observations from catchment areas to the coastal ocean (from the coast up to the watershed) and the deep ocean. An approach that considers

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the land-sea continuum can better estimate variations in water volume, fluxes and the various components of circulation, as well as their spatial and temporal variability.

2.4 SOCIO-ECOSYSTEMS AND BIODIVERSITY (T4)

The study of socio-ecological systems and their capacity to adapt is hindered by a lack of data at the local scale where interactions between living species take place. **It is essential to improve characterisation of the exposure, vulnerability and dynamics of socio-ecosystems in response to global change**. Biophysical and anthropogenic mapping of continental surfaces at this scale, requires metric-scale imagery and imagery with high spectral richness – in addition to the time series of **Sentinel** images – to meet the need to characterise the distribution and abundance of plant species, habitat fragmentation, phenology and biophysical variables of vegetation, coastal and urban areas and continental waters.

Scientists still need to further their understanding of the way marine biodiversity evolves in response to global change. **Improving our knowledge of marine biogeochemistry and its coupling with physics is necessary to understand better the evolution of primary production, higher trophic levels and, more generally, marine biodiversity**. This improved understanding should enable us to identify and monitor ecological 'hotspots' to support sustainable exploitation and conservation policies, particularly through developing marine protected areas.

2.5 PREDICTION, DIGITAL TWINS AND HAZARDS (T5)

New observations are needed to **improve weather, ocean and sea ice prediction and to support the evolution of models and the development of** very high-resolution **digital twins** (to within a kilometre on a global scale, to within one hundred metres on a local scale). In particular, there is a need to **improve forecasting of extreme events** such as cyclones, heatwaves, droughts, marine heatwaves, floods, coastal flooding and toxic algal blooms. The development of new satellite observations and their complementarity with in-situ measurements requires to synthesise them using increasingly powerful numerical models and artificial intelligence techniques. It is essential to qualify the data before they are integrated into models.

Anticipating natural hazards (earthquakes, tsunamis, volcanic eruptions, gravity instabilities) remains a significant challenge. It involves identifying the underlying processes and detecting infrequent, low-amplitude precursor signals, often mixed with signals that may be associated with natural or anthropogenic surface disturbances. In this context, observing and modelling of environmental risk components (hazards, exposure and vulnerability) must be carried out at compatible and interoperable spatial and temporal resolutions.

2.6 INTERACTIONS BETWEEN THE EARTH INTERIOR AND ITS EXTERNAL ENVELOPES (T6)

The study of the Earth's interior and its external envelopes is a multidisciplinary theme. Related research includes **the feedback between isostatic adjustment and the recent melting of the ice caps, mass transfers at the Earth's surface, changes in sea level, the occurrence of earthquakes**, crustal deformation caused by variations in groundwater levels, the effects of volcanism on atmospheric chemistry and the Earth's radiation budget, and the interactions between internal and external magnetic fields and their impact on the atmosphere and flora and fauna.

For this research, creating a **terrestrial reference frame that is as accurate and stable as possible is essential**. The target for the accuracy and stability of the ITRF, as put forward by the International Association of Geodesy, is an accuracy of 1 mm and a stability of 0.1 mm/year.

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3. FORESIGHT AND SUMMARY OF RECOMMENDATIONS

3.1 PROGRAMMATIC CONTEXT

The Copernicus programme marks a paradigm shift for Earth observation in Europe. The European Copernicus programme put Europe at the forefront of global monitoring of the planet, based on a long-term space component (the Sentinel missions), in-situ observations and monitoring and forecasting services for the climate, the ocean, the chemical composition of the atmosphere, continental land masses and risk monitoring. The more recent development of the EU's Destination Earth and Esa Digital Twin Earth programmes, based on the new capabilities of cloud services and HPC (High Performance Computing) resources, are providing new capacities for modelling the Earth system and developing scenarios to better guide decisions for sustainable management of the planet.

The space component of Copernicus will be ramped up over the next few years with the Sentinel Expansion and Sentinel NG programmes. Copernicus should be operating more than 20 satellites by 2030. Eumetsat will be completely renewing its fleet of Earth observation satellites with the **EPS-SG** (polar orbit) and **MTG** (geostationary orbit) programmes. Concurrently, a large number of Esa Earth Explorer scientific missions, in which the national community is heavily involved, are concerned with this foresight, namely: **Earthcare**, **Biomass**, **Flex**, **Forum**, **Harmony**, **Cairt** or **Wivern** (EE11), EE 12.

In this context, Cnes must make proposals and drive development for scientific missions or innovative concepts that may or may not eventually be integrated into the long-term observation programmes of Copernicus and Eumetsat. It must continue to play a major role in defining and implementing Copernicus in collaboration with Esa and Eumetsat, and help French laboratories participate. Cnes involvement in the **Swot** mission is an excellent example of its specific role in missions involving technological breakthroughs with high scientific stakes and upstream of long-term observation programmes.

3.2 PRIORITIES FOR SPACE MISSIONS

The priorities for space missions are based on the six cross-cutting themes and the associated priority scientific issues. These include an analysis of the gaps with respect to missions that have already been decided upon or are in orbit, particularly in the context of Copernicus, Eumetsat and Esa Earth Explorer. These priorities mainly concern missions undertaken by Cnes alone or under bilateral agreements. They also include recommendations for missions carried out as part of Copernicus (EU), the Esa Earth Explorer programme and Eumetsat. They can be broken down into one or more objectives: continuity of measurements, improved accuracy of measurements, improved spatial and temporal resolution, measurements of new parameters, simultaneous measurements of several parameters.

The major priorities are organised according to how they relate to a priority theme, indicating any contributions they might make to other themes.

3.2.1 CNES-ALONE OR BILATERAL INITIATIVES

<u>Theme 1: Climate variability and cycles</u>

- **C2omodo / AOS.** The C2omodo mission, led by Cnes as an instrumental contribution to the AOS observatory, is based on observations by a tandem of microwave radiometers. It meets the need to better document the internal dynamics of deep atmospheric convection on a global scale. This issue was raised in the 2019 foresight, and the community would like to reiterate the priority status of the C2omodo mission within the AOS international observatory. The Italian Space Agency's Caligola mission, conducted as part of the AOS programme, could offer interesting features for aerosol speciation and marine biogeochemistry, thanks to its onboard lidar. It will be important for the French community to be ready to exploit these data, although no French contribution to an instrument has been envisaged.
- **Smash.** Tosca reiterates its strong support for the **Smash** mission for frequent-revisit hydrology observation, which can be implemented in the very short term as part of New Space-type

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constellation projects. With daily observations of water levels in rivers, lakes and reservoirs via a constellation of compact nadir radar altimeters, **Smash** will help to reduce uncertainties about the water cycle and meet major application challenges.

Theme 2: Coupling, interfaces and scale interactions

- **Odysea.** The concept proposed for the **Odysea** mission is a Ka-band Doppler radar with a very wide swath providing near-daily coverage of surface currents, an essential ocean variable that has not yet been measured from space and that plays a key role in the analysis of ocean/atmosphere coupling. **Odysea** fills a major gap in the monitoring of ocean winds and currents, and will change the game by providing a better understanding of how the ocean and atmosphere exchange gases, heat and energy. This was a major priority in the 2019 foresight.
- **Smos-HR.** Taking measurements of surface salinity with a resolution of ~10 km and an accuracy of 0.2 g/kg (improvement by a factor of 5 over **Smos**), **Smos-HR** will enable us to observe around 90% of the surface of continental shelves and eddy structures up to 60° latitude that are not observable with current or planned missions. This mission should provide a better understanding of **freshwater fluxes in exchanges between the ocean, atmosphere and cryosphere, and the associated role of eddy dynamics**. **Smos-HR** will also enable soil moisture to be characterised at 10 km resolution, and will contribute to the study of catchment hydrology, the estimation of precipitation and evapotranspiration (Theme 1) and numerical weather forecasting (Theme 5).
- **StratoFleet.** Documenting the coupling between phenomena on different scales, in particular aerosol mixing, convection and global atmospheric circulation, requires both global observations from space and local observations to analyse fine-scale processes. A layer of the atmosphere that is particularly concerned by these multi-scale interactions includes the upper troposphere and the tropical lower stratosphere, which is the scene of physical phenomena that are very important for our understanding of the global climate. This new balloon programme is designed to provide these new fine-scale observations using pressurised stratospheric balloons with an extended lifetime. An interesting international framework to support this work would be the **AOS** suborbital programme.

Theme 4: Socio-ecosystems and biodiversity

- **Biodiversity**. The priority is to improve observation capabilities for the study of socio-ecosystems. **Biodiversity**, already proposed as a major priority in the 2019 foresight, is a high spatial resolution (10 m) hyperspectral imaging system designed to monitor several key variables (species distribution, abundance and status) of terrestrial biodiversity and the state of health of emblematic ecosystems (tropical forests, savannahs, etc.). The features of this high-resolution hyperspectral imager also meet the need to characterise coastal environments (bathymetry, classification of shallow sea beds and habitats), industrial pollution (plumes of certain gases or aerosols), urban environments (more precise knowledge of land use) and geology (detection of minerals on bare rock).

Substantial priorities

Tosca notes the lack of a mission for wave monitoring and forecasting **(Cfosat-NG**) and the study of ocean/atmosphere coupling (Theme 2, Theme 5). This is a substantial priority. Cnes is encouraged to analyse bilateral opportunities for developing such a mission. The same applies to the **4D Earth** stereoscopic optical mission, which aims to provide systematic, global and monthly coverage of the Earth's surface at 2m resolution in four spectral bands, to characterise in 3D the impacts of human activities and the associated risks (themes 4 and 6). It is also strongly recommended that the development of the **Swot-Loac** (Land Ocean Aquatic Continuum) mission, which aims to quantify **land-sea fluxes (water, matter, chemistry) and their interactions with coastal dynamics and the open ocean** (Theme 3), be investigated as part of a longer-term perspective (post SPS2024).

3.2.2 EUROPEAN FRAMEWORK

Theme 1: Climate variability and cycles

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Copernicus missions: Sentinel, Sentinel Expansion and Sentinel New Generation (NG). Ensuring the continuity of measurements of essential climate variables is a **major priority** (Theme 1). The Sentinel missions provide some of the regular monitoring of these variables and will continue to do so over the next decade. Future **Sentinel Expansion** missions will be a major addition to these missions to monitor greenhouse gases, the Arctic and ice caps. In the longer term (post 2032), improvements will be made with the **Sentinel NG** programme. It is important that the needs of the scientific community be considered in these developments. Regular consultation meetings between Cnes, the Tosca groups and the national scientific community should be organised to identify French priorities. At this stage, the community has successfully mobilised around the design of **S3-NG-Topo**. Discussions are under way on the design of **S3-NG-Opt** to improve the spectral resolution of the water colour instrument, and on the design of **S2 NG** for high-resolution monitoring of continental surfaces and the coastal ocean. The development of the altimeter reference mission **(S6 NG**) has been highlighted for particular consideration to guarantee and improve its accuracy for monitoring the mean sea level and as a reference for other altimeter missions.

Theme 5: Forecasting, digital twins and hazards

Cmim (Constellation of mini sounders for weather forecasting). The aim is to meet the needs of future numerical weather forecasting models with very high revisit capability (of less than 3 hours) for observing processes in the lower layers of the atmosphere. Phase 0 of **Cmim** explored synergies between hyperspectral infrared sounders and microwave sounders to meet the need for observation in the lower layers of the atmosphere. The committee recommends that Cnes rapidly starts a Phase-A study to develop a proposal for observing systems (at instrument and constellation-architecture level), for potential future implementation in the Eumetsat programme.

S3-NG-Topo. With the choice of a wide-swath altimetry instrument, this mission will greatly improve the monitoring and forecasting of ocean circulation (Theme 5), and knowledge of the water cycle and the land-sea continuum (Theme 1, Theme 3). Its development will be based on **Swot's** experience, which means that Cnes will need to be heavily involved, in conjunction with Esa.

Theme 6: Interactions between the Earth's interior and its external envelopes

Genesis. Genesis is a mission decided by Esa as part of the FutureNAV programme for precise positioning. The aim is to produce a terrestrial reference frame with an accuracy of 1 mm and long-term stability of 0.1 mm/year (Theme 6). Through its support for the **Genesis** mission, Tosca recommends funding the **Doris-Neo** project, as the **Doris** receivers that are part of the on-board instruments will soon be obsolescent.

Magic is based on a constellation concept with a double tandem of gravimetric satellites. The expected performance improvements of around a factor of 10 compared with the **Grace(-FO)** missions will considerably extend the scope of applications for the study of the "Solid Earth", and for the "Continental Surfaces" and "Ocean" themes. By way of illustration, the **Magic** data will be used to search for precursor signals of earthquakes of magnitude 7.5 and above (around 55 events over 10 years), instead of 8.5 and above (around 1-2 events over 10 years) with **Grace(-FO**) (Theme 5). Major impacts are also expected on ocean, continental surface and climate-related themes (e.g. groundwater stocks, ice caps, ocean circulation, water mass exchanges, sea level, global energy budget) (Theme 1).

Carioqa. The aim of **Carioqa** is to test an atomic accelerometer in space to pave the way for ambitious space gravity missions based on cold atom interferometry, by 2035.

Substantial priorities

The **development of an ocean-colour geostationary mission has been a Tosca priority for several foresights**. Tosca recommends that a programmatic framework for such a mission be discussed with Eumetsat. The Tosca committee recommends that Cnes supports the participation of French teams in the preparation of the **Wivern** (observations of winds inside clouds at 1 km resolution – themes 1 and 5), **Eco** (measurement of the planet's energy imbalance – Theme 1) and **Cryorad** (low-frequency microwave measurements (0.4-2 GHz) to establish

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the temperature profile of the polar ice caps and monitor salinity in cold seas – Theme 1) missions proposed as part of Esa Earth Explorer programme.

3.3 R&T PRIORITIES

Lidar technologies

There is a significant need for R&T in lidar technologies for various atmosphere applications (aerosol speciation, GHG measurements), oceanography (ocean colour, bathymetry) and continental surfaces (forest ecosystems). Continuing R&T activities around this technology is a priority, so that this type of instrumentation can be considered more easily in various programme frameworks.

High-resolution agile concepts

The use of hyperspectral missions with very high spatial resolution seems essential for quantifying anthropogenic GHG emissions. In response to these new challenges, the improvement of near infrared detectors and the agility of platforms, as well as miniaturisation for constellations, are avenues to be investigated.

3.4 NEW SPACE

New private sector players are positioning themselves as producers of Earth observation data and services. It will be necessary to monitor the progress of these New Space constellation proposals, share the results of the initial data qualification and analysis, and sum up the contribution of these constellations to research. As the quality of the measurements produced is crucial to their use in research, a focus on Cal/Val will be essential. Data-sharing policies will also need to be clearly explained and discussed.

3.5 PRIORITIES FOR IN-SITU INFRASTRUCTURE AND CAL/VAL ACTIVITIES

In-situ observation networks, by providing qualified and accurate data, play an essential role in Cal/Val activities and maintaining the quality of satellite measurements. Cnes must continue to support the observation work of Research Infrastructures (IRs) and National Observation Services (SNOs), which play a crucial role at the national level in conjunction with actions at the European and international levels.

In this context, support for **the In-Air infrastructure** comprising research aircrafts, balloons and drones is essential for validating many satellite missions scheduled for launch in the coming years (e.g. **MicroCarb, Iasi-NG, C3iel, AOS).** In particular, it is recommended that Safire's supervisory bodies start preparing to upgrade of the ATR aircraft.

Support for the national coordination of ocean observation **Fr-oos** (French Ocean Observing System) and associated IRs and SNOs is also needed to ensure that Cal/Val present/future needs for ocean missions (e.g. **Sentinels, Swot, Odysea, Smos-Hr**) are taken into account.

Tosca also recommends the deployment of **the *Observatoire Géodésique Géophysique Fondamental*** (OG^2F) in Tahiti, a unique facility in the South Pacific combining the four geodetic techniques, essential for improving coverage of the terrestrial reference system and complementary to the **Genesis** mission. Creating of a new-generation French SLR (Satellite Laser Ranging) station is the main challenge of this major Tosca priority.

Lastly, Tosca is supporting the **GravMagBallon** balloon mission project, which will acquire magnetic and gravimetric data at altitudes of between 10 and 30 km, enabling us to study the short-term evolution (< year) of the Earth's surface at regional scales and to improve the imaging of lithospheric structures.

3.6 DATA EXPLOITATION AND CLOUD/ HPC PLATFORMS

Cnes must continue to support French teams for innovative actions to develop algorithms and qualify, process and analyse data, in particular using artificial intelligence techniques and links with modelling. The reprocessing of long multi-sensor data series for all the essential climate variables (ECVs), the qualification of uncertainties and the scientific use of these time series is an essential component of climate studies. This work is being organised as part of the Esa Climate Space programme, in conjunction with the Copernicus programme for the operational aspects. Cnes has played and must continue to play a major role upstream of these actions to ensure continuous, state-of-the-art reprocessing of data (for example, for reprocessing of altimetry missions).

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The amount of satellite data available will increase considerably over the next few years, opening up new opportunities to push back the frontiers of knowledge. Exploiting this data will require easier access to data (levels 1&2) and products (levels 3&4) with tools and computing resources adapted to massive processing, assimilation and the use of artificial intelligence. At the national level, this will require that Data Terra be ramped up. Coherence between its four thematic clusters (Aeris, ForM@Ter, Odatis, Theia) and the new biodiversity cluster (Pndb) will need to be ensured to support transdisciplinary studies as part of an Earth system approach. Regarding scientific users, the services provided by Data Terra and the complementarity with those offered by the European platforms (Copernicus Data Ecosystem, WEkEO, Copernicus services, DestinE and DTE) must be clearly defined and explained.

3.7 SUPPORTING SPACE RESEARCH

Given the number of current and future missions (new missions carried out by Cnes or bilaterally, new missions under the Copernicus programme, new Earth Explorer missions, renewal of Eumetsat satellites, development of New Space), it is essential **to strengthen support for the French teams** involved in preparing future missions and exploiting data from in-flight missions, particularly in terms of long-term positions (researchers, engineers) in the laboratories.

4. CONCLUSION

The main priorities for space and balloon missions are summarised in the table below. The table separates the missions to be developed by Cnes alone or bilaterally and the missions already undertaken or to be undertaken within a European framework (Esa, EU/Copernicus, Eumetsat) which are a major priority for Cnes and require Cnes involvement to ensure their successful completion. The major priority for in-situ/ground infrastructure is also reiterated.

Cnes or bilateral missions		
Scientific issues	Observable	Current development framework
How do clouds form and develop in relation to their environment? (Theme 1)	Mass flow	**C2omodo / AOS** (Phase B0)
What are the interactions between atmospheric processes at large and small scales? (Theme 2)	Multi variables	**StratoFleet** (Stratéole Heritage)
How do current-wind couplings influence air-sea exchanges? (Theme 2)	Global currents	**Odysea** Shortlisted for Nasa EE
How does salinity structure eddies and land-ocean-ice exchanges? (Theme 2) Soil moisture and numerical weather prediction (Theme 1, Theme 5)	High resolution salinity, soil moisture	**Smos-HR** Phase A, Cnes, completed
Exposure, vulnerability and dynamics of socio-ecosystems in response to global changes (Theme 4)	Vegetation biodiversity, plant health, coastal environments	**Biodiversity**
The water cycle at the scale of water management needs (Theme 1)	Daily water levels for rivers, lakes and reservoirs	**Smash** France2030

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Missions in a European context: Esa, EU/Copernicus and Eumetsat		
Scientific issues	Observable	Current development framework
How can we better observe the atmosphere to improve weather forecasting? (Theme 5)	Temperature, Humidity	**Cmim** (Phase 0 Cnes)
Improving geodetic referencing (Theme 6)	Millimetric positioning	**Genesis**, Esa FutureNAV mission. ABCD phases to start in 2024
A better understanding of the planet's internal dynamics, extreme events and interactions between the inner Earth and its external envelopes (Theme 6, Theme 1)	Gravitational field	**Magic**, Esa-Nasa mission. B1 phase to start in 2024
Space instrumentation demonstrator (Theme 6). Interest in fundamental physics	Gravitational field	**Carioqa,** phase A launched in January 2024
Ocean, water cycle forecasting (Theme 5, Theme 1, Theme 3)	Sea level	**S3NG-Topo**
Ground infrastructures		
Improving geodetic referencing (Theme 6)	Millimetric positioning	**Tahiti Geodetic Geophysical Observatory**

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