NASA Advisory Council
Climate Priority Focus Area

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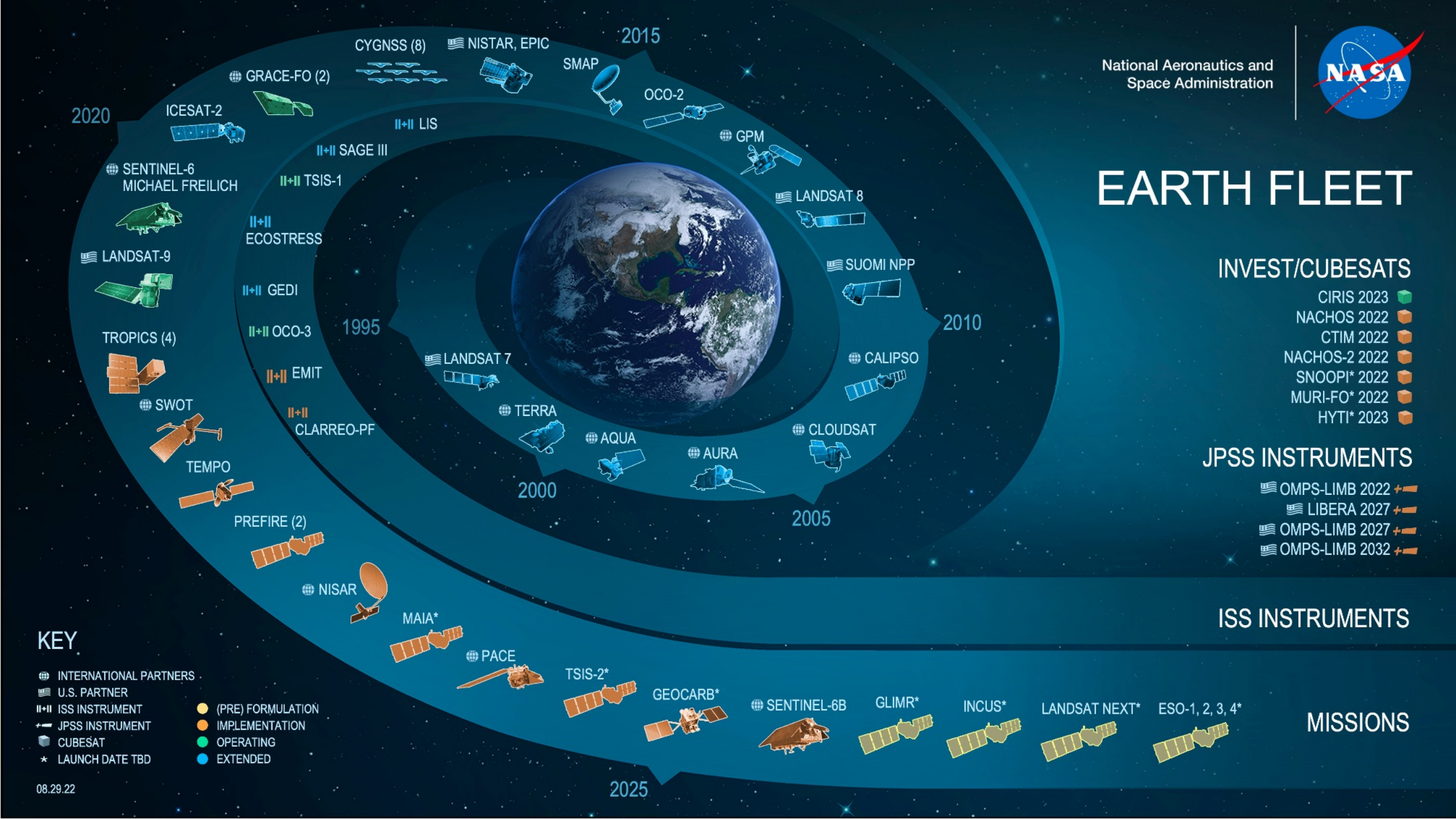
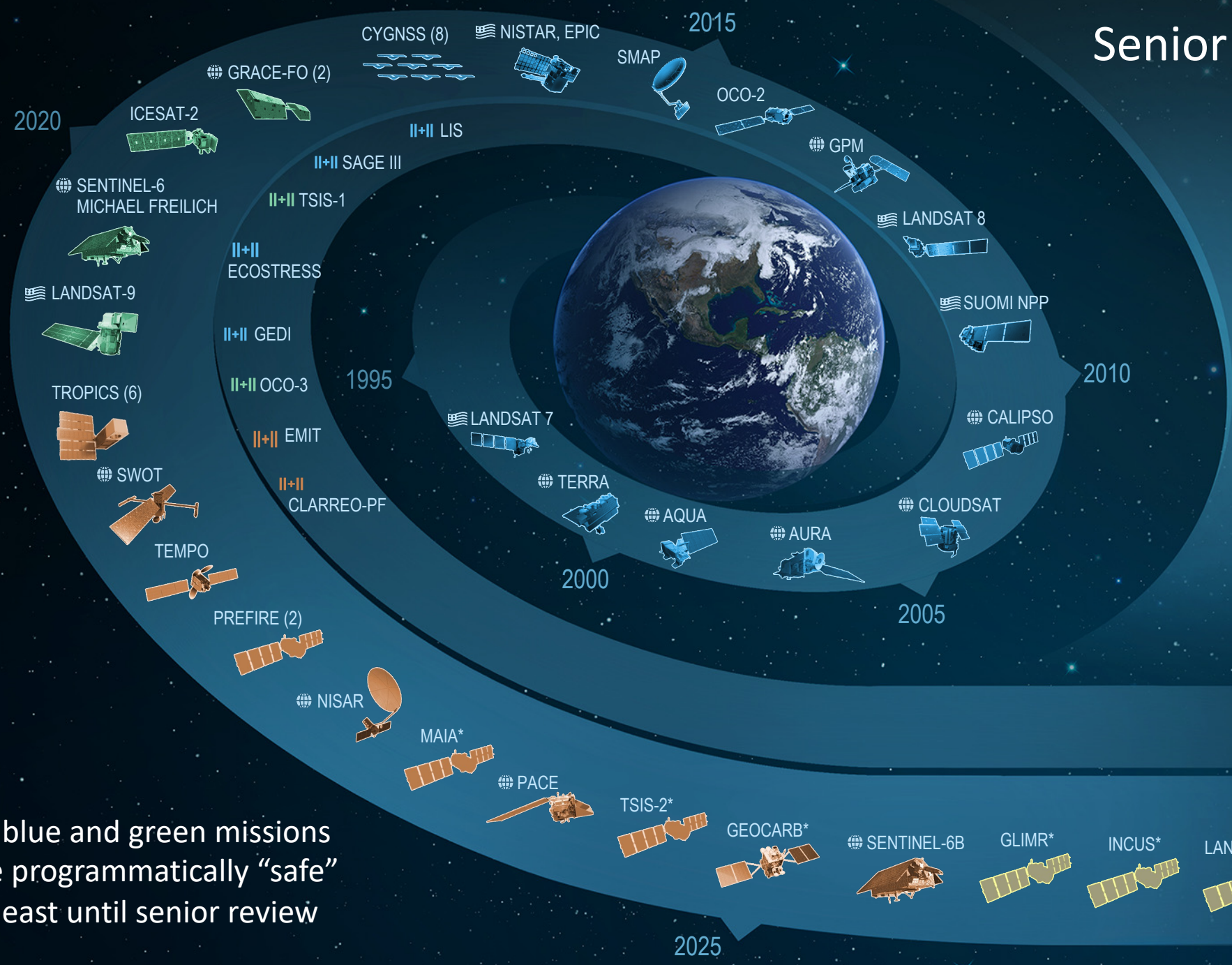

National Aeronautics and Space Administration
NASA
EARTH FLEET
2015
CYGNSS (8)
NISTAR, EPIC
SMAP
OCO-2
GPM
LANDSAT 8
SUOMI NPP
2010
CALIPSO
CLOUDSAT
AURA
AQUA
TERRA
LANDSAT 7
2005
2000
1995
2020
GRACE-FO (2)
ICESAT-2
LIS
SAGE III
TSIS-1
ECOSTRESS
GEDI
OCO-3
EMIT
CLARREO-PF
SENTINEL-6 MICHAEL FREILICH
LANDSAT-9
TROPICS (4)
SWOT
TEMPO
PREFIRE (2)
NISAR
MAIA*
PACE
TSIS-2*
GEOCARB*
SENTINEL-6B
GLIMR*
INCUS*
LANDSAT NEXT*
ESO-1, 2, 3, 4*
2025
INVEST/CUBESATS
CIRIS 2023
NACHOS 2022
CTIM 2022
NACHOS-2 2022
SNOOPI* 2022
MURI-FO* 2022
HYTI* 2023
JPSS INSTRUMENTS
OMPS-LIMB 2022
LIBERA 2027
OMPS-LIMB 2027
OMPS-LIMB 2032
ISS INSTRUMENTS
MISSIONS
KEY
INTERNATIONAL PARTNERS
U.S. PARTNER
ISS INSTRUMENT
JPSS INSTRUMENT
CUBESAT
LAUNCH DATE TBD
(PRE) FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED
08.29.22

Senior Review 2023 & 2026



Panel is convened to evaluate the scientific performance of each mission and the continued relevance of each mission to the NASA Science Strategic Plan. Performance factors include scientific merit, national needs, the technical status of the mission, and budget requirements.

ISS INSTRUMENTS

MISSIONS

All blue and green missions are programmatically “safe” at least until senior review

Sustained Observables[1,2]

Observable	Mission(s)/Instrument(s)	Expected through[3]	Comments
High Res Land Cover	ASTER, Landsat 8, 9, Next	~2033	Since 1972; evolving to 25 bands
Radiation Budget	CERES (6), Libera (EV-C on JPSS-3)	~2032	Radiation budget measurements since 1997 (TRMM)
Total brightness and spectral Irradiance	TSIS-1, TSIS-2	~2028	continuation of irradiance measurements begun in 1978
SST, land characteristics, ice and snow, etc.	MODIS, VIIRS, SBG/ESO	~2037	Latest on record is JPSS-4; continuity since 1999
Sea surface height	Sentinal-6 Michael Freilich, Sentinel 6-B	~2030	Continues multi-decadal record of SSH and related parameters
Ozone	Aura, OMPS, TEMPO, SAGE-III, JPSS-2,3,4	~2037	Mix of stratosphere, troposphere, and profiling

1. I am oversimplifying
2. Observed parameter does not ensure it is observed the way it is desired for certain applications
3. Based on NASA's estimated launch dates of latest missions and five-year life

Sustained Observables[1,2]

Observable (DS Designated)	Mission(s)/ Instrument(s)	Expected through[3]	Comments
Cloud structure, height, optical properties, precipitation state	MISR, Cloudsat, Calipso, CCP/ESO	~2035	Other instruments observe cloud cover, cloud ice, etc.
Aerosol properties and profiles and cloud properties	MISR, Calipso, PACE, A/ESO	~2035	Other instruments observe aerosol optical properties
Changing mass distribution within and among the Earth's atmosphere, oceans, groundwater, and ice sheets	GRACE-FO, MC/ESO	~2035	Potentially no gap, depending on life and launch of Mass Change
Surface Deformation and Change: Earthquakes and landslides to ice sheets and permafrost	NiSAR, SDC/ESO	~2035	History of success with international partnerships.
Earth Surface Biology and Geology: ground/water, temperature, snow reflectivity, active geologic processes, vegetation traits, and algal biomass	MODIS, VIIRS, ASTER, SBG/ESO	~2035	Robust history of spectral imaging, limited history with hyperspectral

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3. Based on NASA's estimated launch dates of latest missions and five-year life

Missions in the NASA Program of Record

Mission	Observable	Measurement Approach	Date
Cloudsat	profiles of cloud: structure, liquid water, optical properties	Nadir-looking radar	≥ 2023
Calipso	profiles of cloud: structure, liquid water, optical properties	Atmospheric Lidar and Multipurpose imaging VIS/IR radiometer	≥ 2023
Suomi NPP	Atmospheric temperature and moisture profiles, ozone profiles, radiation budget, SST, Surface imaging	Broadband radiometer (CERES), SW scanning spectrometer (OMPS) and IR spectrometer (CrIS), imaging spectrometer (VIIRS), absorption band microwave radiometer (ATMS)	≥ 2023
GPM	precipitation	Microwave imager and precipitation radar	≥ 2023
OCO-2	Carbon Dioxide	High resolution spectrometer	≥ 2023
SMAP	Soil Moisture	Radiometer (active sensor failed)	≥ 2023
DISCOVR	Irradiance and outgoing radiation	Imaging vis/IR radiometer (EPIC); solar irradiance monitor (NISTAR	≥ 2023
CYGNSS	Ocean Roughness (windspeed); cyclone evolution and formation	Direct and reflected GPS signals	≥ 2023
GRACE-FO	Mass movement on Earth	Inter-satellite ranging	≥ 2023

Missions in the NASA Program of Record

Mission	Observable	Measurement Approach	Date[4]
ICESat-2	Ice elevation change, and sea ice thickness	Multi-beam laser altimeter	≥ 2023
Sentinel-6 Michael Freilich	Primary: Sea surface height; Secondary: tropospheric temp. and humidity	Radar Altimeter and GNSS	≥ 2025
SWOT	SSH and inland water height for 100-m rivers and 1 km2 lakes.	Ka-band radar interferometry.	≥ 2026
TROPICS	Thermodynamics of the troposphere and precipitation structure for storm systems	4 cubesats (originally six) in 2 planes - Absorption-band microwave radiometer/spectrometer	2023
TEMPO	monitor daily variations in ozone, nitrogen dioxide, and other key elements of air pollution	UV and visible spectrometer	2023
Prefire	Thermal emissions of cloud cover as well as sea ice and ice sheets meltwater	Miniaturized thermal infrared spectrometers on two CubeSat satellites	2024
NiSAR	Geology, Ice, movement, vegetation	L- and S-band SAR (interferometry)	2024

4. Blue boxes are currently operational missions and the dates given indicate expected end of mission science, contingent on functionality and outcomes of the Senior Review Process; Green boxes are planned missions and the dates given are planned launch dates.

Missions in the NASA Program of Record

Mission	Observable	Measurement Approach	Date[4]
MAIA	sizes, compositions and quantities of particulate matter in air pollution	Multi-angle Imager for Aerosols; Multichannel/direction/polarization radiometer	2024
PACE	Ocean color, clouds, and aerosols	Spectrometer and polarimeter	2024
TSIS-2	Total brightness and spectral irradiance	Solar irradiance monitor	2025
SENTINEL-6B	sea surface height; changes over time; seasonal changes; geoid	Radar Altimeter and GNSS	2026
GLIMR* Geosynchronous Littoral Imaging and Monitoring Radiometer	coastal phytoplankton; oil spills; etc. in region centered at Gulf of Mexico	Hyperspectral radiometer	2027
INCUS	Factors governing occurrences of convective storms, heavy precipitation, and clouds	Radar on three spacecraft, one also with a radiometer	2027

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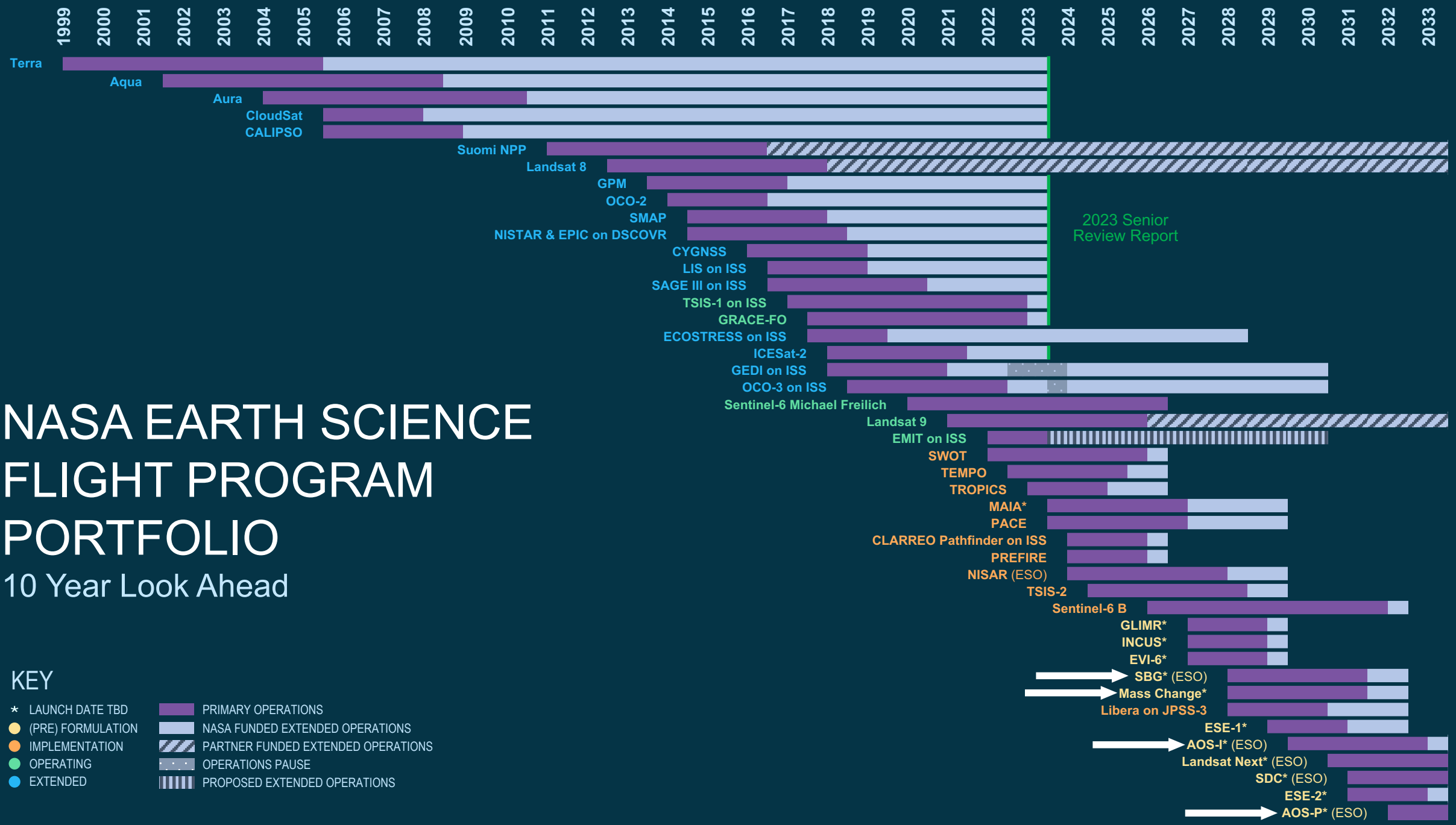
Missions on ISS in the NASA Program of Record

Mission	Observable		Date[4]
LIS	explore processes that cause lightning; building on 17-yr record from TRMM	Lightning imager	≥ 2023
SAGE-III	build on record dating back to 1979; monitoring ozone, primarily, plus aerosols, clouds, water vapor, pressure and temperature, nitrogen dioxide, nitrogen trioxide, and chlorine dioxide.	Limb-scanning SW spectrometer	≥ 2023
ECOSTRESS	plant–water dynamics and future ecosystem changes with climate	Thermal infrared radiometer	≥ 2023
GEDI	ecosystem structure and dynamics for carbon cycle and biodiversity; carbon balance	lidar	≥ 2023
OCO-3	Distribution and changes of CO2 from natural and urban sources	High resolution spectrometer	≥ 2023
EMIT	map the mineral composition of arid dust source regions via imaging spectroscopy in the visible and short-wave infrared. Will improve forecasts of the role of mineral dust in the radiative forcing (warming or cooling) of the atmosphere.	Visible and IR spectroscopy	≥2023
CLARREO-PF	Sunlight reflected from Earth Surface	Spectrometer	2024

4. Blue boxes are currently operational missions and the dates given indicate expected end of mission science, contingent on functionality and outcomes of the Senior Review Process; Green boxes are planned missions and the dates given are planned launch dates.

NASA EARTH SCIENCE FLIGHT PROGRAM PORTFOLIO

10 Year Look Ahead



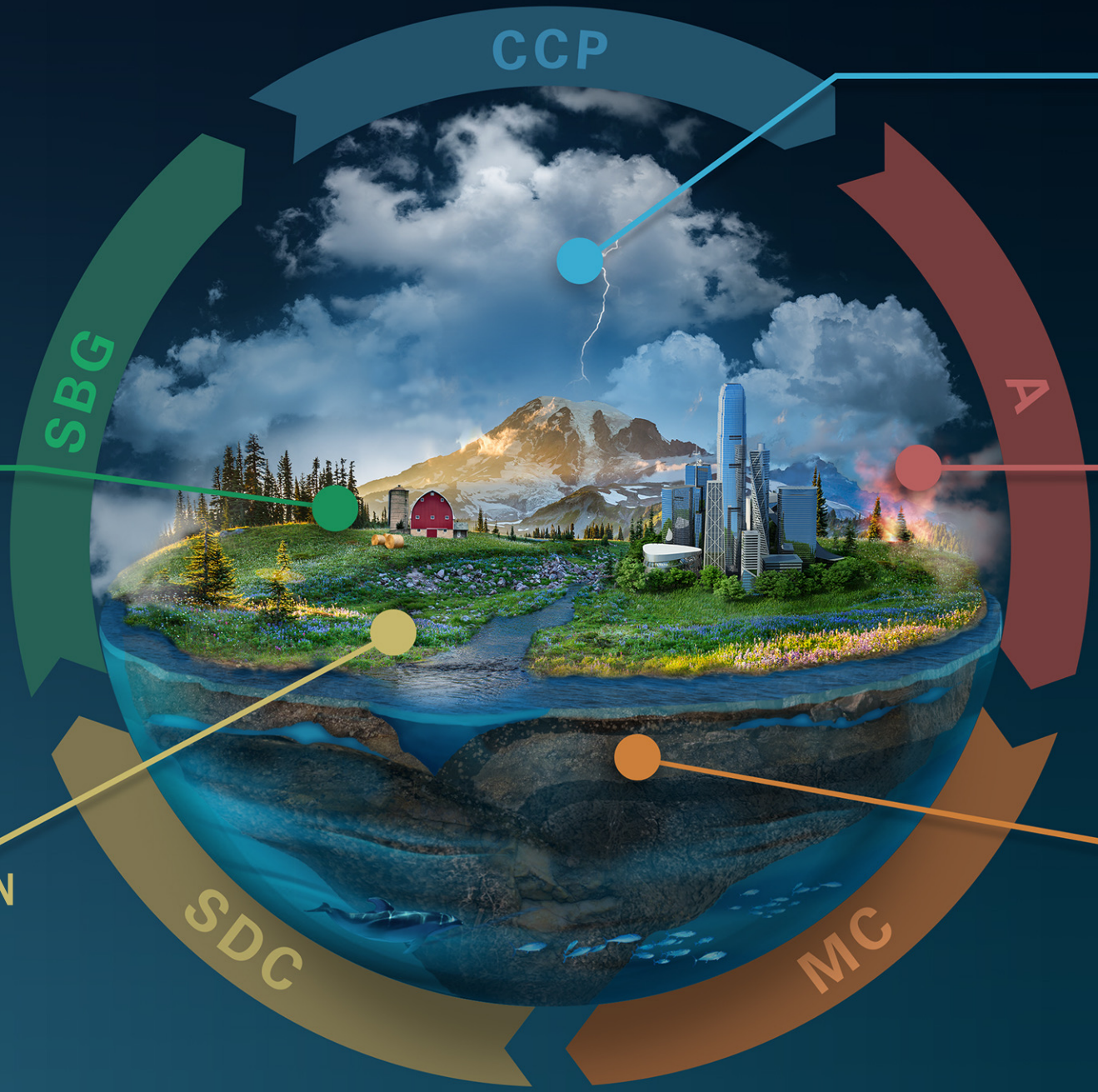
KEY

- ★ LAUNCH DATE TBD
- (PRE) FORMULATION
- IMPLEMENTATION
- OPERATING
- EXTENDED

- PRIMARY OPERATIONS
- NASA FUNDED EXTENDED OPERATIONS
- PARTNER FUNDED EXTENDED OPERATIONS
- OPERATIONS PAUSE
- PROPOSED EXTENDED OPERATIONS

EARTH SYSTEM OBSERVATORY

INTERCONNECTED CORE MISSIONS



CLOUDS, CONVECTION AND PRECIPITATION

Water and Energy in the Atmosphere

AEROSOLS

Particles in the Atmosphere

MASS CHANGE

Large-scale Mass Redistribution

SURFACE DEFORMATION AND CHANGE

Earth Surface Dynamics

SURFACE BIOLOGY AND GEOLOGY

Earth Surface & Ecosystems

Independent Review Board (IRB) Findings

Atmosphere Observing System (AOS)

- Combination of Clouds Convection & Precipitation (CCP) and Aerosols (A)
- Aerosol properties, aerosol vertical profiles, and cloud properties and effects on climate and air quality
- Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes including cloud feedback
- Innovative science, some technologies pose high risk to cost and schedule
- IRB does not expect the current configuration to fit in the cost box

Surface Biology and Geology (SBG)

- Earth surface geology and biology, ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass
- Designed to meet science objectives with limited risks to cost and schedule
- Will likely fit in the mission cost box

Independent Review Board (IRB) Findings

Mass Change (MC)

- Large-scale Earth dynamics measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets
- High risk in the implementation (residual GRACE-FO Accelerometers, single string)
- Risk Mitigation will require additional resources (On the order of a few tens of $M)

Surface Deformation and Change

- Earth Surface Dynamics
- Remaining in extended study phase to take advantage of NISAR mission lessons learned
- Not examined by the IRB

Budget Challenges

- Lingering effects of COVID
- Cost risks associated with the Earth System Observatory
- Omnibus budget is >$200M less for Earth Science than President's Budget Request
- Prospect of Continuing Resolution in 2024 will present further budget challenges
- Extended missions come at a cost
- Resources not available to fully implement intended program
  - Delay planned missions?
  - Terminate extended missions?

Program Mitigation and Guidance from Decadal Survey

1. First delay large missions: ***delays have already occurred.***
2. Second delay medium-sized Designated missions, unless these delays threaten critical continuity measurements:
   a. ***Surface Deformation and Change***
   b. ***Mass Change: question about critical continuity***
3. Should continuity be threatened, the cadence of medium-sized competitive missions should be reduced but not to fewer than two competitions in the decade: ***already down to three from the envisioned four***
4. The budgets for Ventures and research and applications should not be reduced by more than 5% from their historical averages: ***not much in relative dollars to capture here***
5. For budget challenges that exceed this capacity, consultation with CESAS is required

Difficult Choices

- Routine vs. innovative measurements to advance science
  - Philosophical question for NASA
- Delay additional designated missions
  - Significant budget relief
  - Tremendous loss of much-needed information
- Further delay competitive missions
  - Lack of community opportunities
  - Reduced small-mission innovation potential
- Terminate extended missions
  - Not realizing the remaining benefits of past investments
- Increase risk posture
  - Carries great risk for climate measurements

Earth Science at NASA is Much More Than Missions

Research

- Turning observations into knowledge and understanding

Applications

- Translating products into usable information
- Working with stakeholders to identify needs and usable types of data

Earth Science Technology Office (ESTO)

- Developing and maturing technologies for future observations

Data Systems

- Maximizing use and usability of data acquired

Green Aviation

NASA's Sustainable Flight National Partnership

https://www.nasa.gov/aeroresearch/sustainable-aviation-np/

Hi-Rate Composite Aircraft Manufacturing (HiCAM)

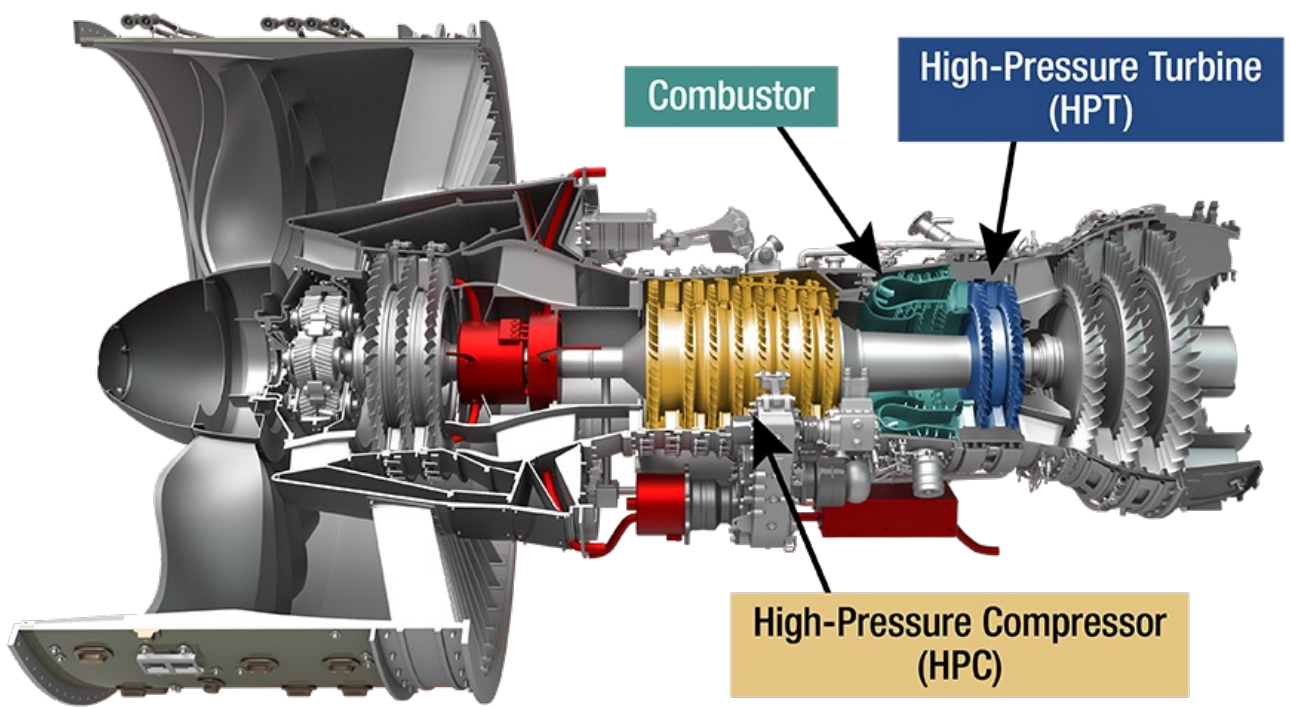
- Building lighter aircraft from composite materials increasing efficiency
- Strength and light weight of composites potentially allow for development of new aerodynamic shapes when compared to current metallic structures
- Anticipated number of new commercial aircraft in the next 20 years is 40,000, creating numerous opportunities

https://www.nasa.gov/aeroresearch/nasa-to-increase-sustainable-aircraft-manufacturing-with-hicam

Green Aviation

Hybrid Thermally Efficient Core (HyTEC)

- Development of a small-core turbofan jet engine to increase efficiency
- Less air enters the core to power the fan and more bypasses the core to provide thrust
- New core materials needed to operate at higher temperatures and pressures



Cross-section of a turbofan jet engine showing the components of the HyTEC project's smaller engine core, with the compressor, combustor, and turbine noted. By shrinking the engine core, better fuel efficiency can be achieved.
Credits: NASA

https://www.nasa.gov/aeroresearch/nasas-hytec-to-help-jets-burn-less-fuel

Green Aviation

Managing airport operations to improve efficiency of fuel use

- Series of three Airspace Technology Demonstration (ATD) projects
  - ATD-1: Better control of descent and increased predictability of landing times
  - ATD-2: Optimized management of operations from gate to sky to minimize time and energy usage
  - ATD-3: Efficient corrections to travel routes in the face of bad weather.

Credit: Getty Images

https://www.nasa.gov/feature/nasa-delivers-on-making-gate-to-gate-flights-more-efficient

Key Takeaways

- **NASA's Earth Science mission portfolio has provided and continues to provide highly valuable information on understanding and dealing with climate change**
- Long-standing measurements are approaching end of life, presenting data continuity challenges
- Resources are required to sustain existing missions into extended phases, which impacts the rest of the program
- Budget pressures put innovation and sustained measurements at risk
- Decadal Survey-recommended mitigation strategies have largely been exhausted
- Current budget will likely not sustain planned program
- Difficult choices to be made
- Encouraging and exciting activities on the Green Aviation front