Deriving Technology Needs From Measurement Strategies

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Abstract—The Earth-Sun System Division in the Science Missions Directorate of NASA has seven science focus areas, which are oriented to gathering space-based data used in the decision-making process for National policy on the Earth environment. Science roadmaps, derived from the NASA strategic planning process, serve as the vehicle for deriving measurement strategies and remote sensing requirements. The technology requirements (instrument, information systems, and platform) are developed to fit the schedule and cost assessed against the proposed mission need dates. This paper[1] will discuss[2] and show the current state of this process.

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1. Science Roadmaps

The Earth-Sun Systems Technology Office (ESTO) works with each of the Program Scientists in the Earth-Sun System Division to develop technology needs in support of future near-term (today-2015) and far-term (2016-2035) mission needs[3]. The 7 science focus areas are:

- **Atmospheric Composition**
- **Carbon Cycle & Ecosystems**
- **Climate**
- **Earth Surface & Interior**
- **Sun-Earth Connection (currently Sun-Solar System Connection)**
- **Water & Energy Cycle**
- **Weather**

In this paper these focus areas will be addressed in appropriate examples to show the technology development process used to translate science mission needs into measurement strategies and finally into candidate technology options. The science roadmap is derived from the Agency strategic planning process. It is the tool used to support the science community needs from NASA as well as the budgeting process baseline. Figures 1-7 show the current science roadmaps.

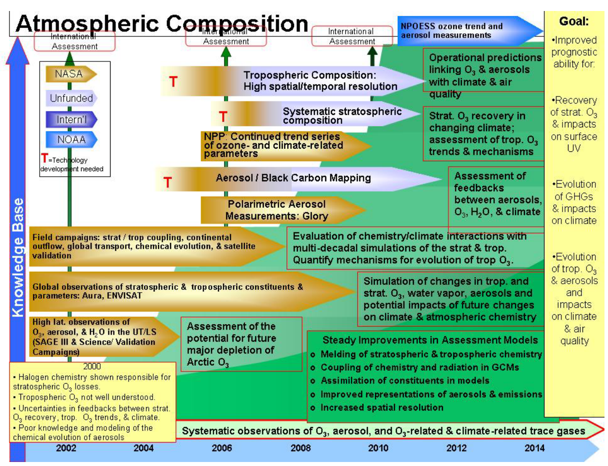

Figure 1 - Atmospheric Composition Science Roadmap

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[2] IEEEAC Panel 14.08, paper #2, Version 3, Updated January 27, 2005

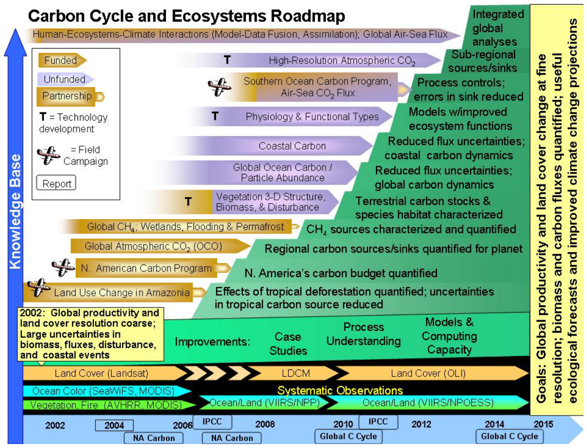


Figure 2 - Carbon Cycle & Ecosystems Science Roadmap

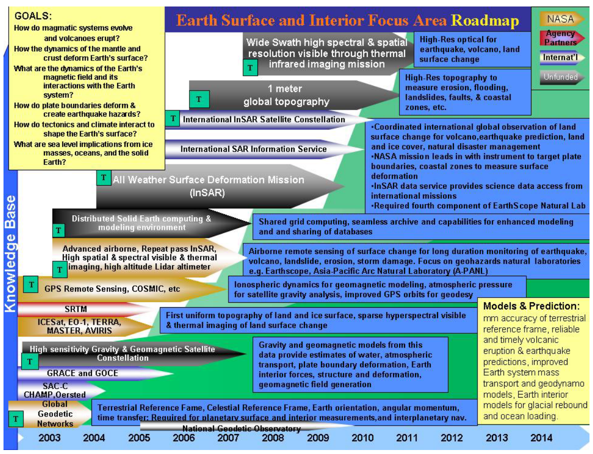


Figure 3 - Earth Surface & Interior Science Roadmap

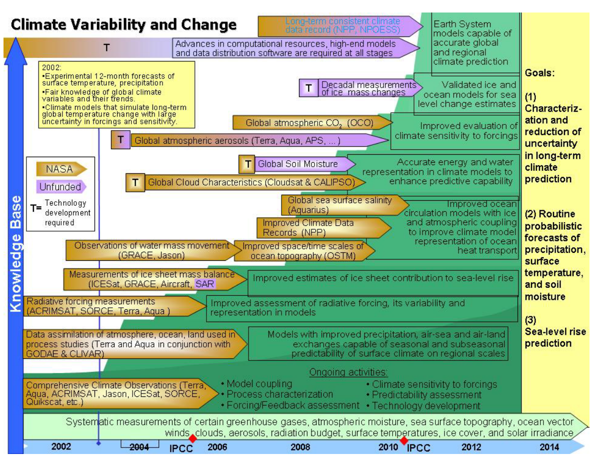


Figure 4 - Climate Science Roadmap

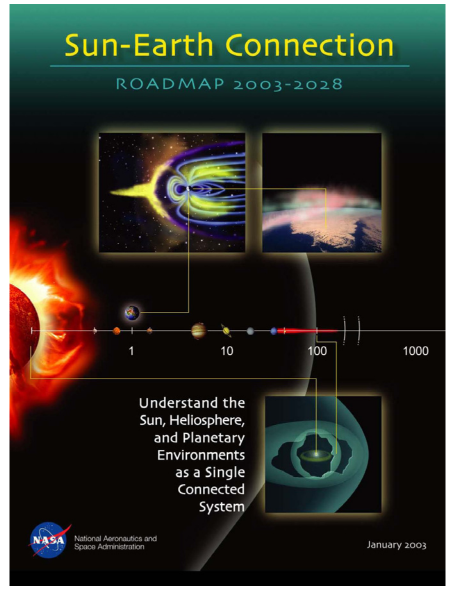


Figure 5 - Sun-Earth Connection Science Roadmap

Figure 5 is a complete document[4] published in a pre-Agency transformation Office of Space Science.

Although the presentation of the science roadmaps differs minimally, the layout tells many stories all on one page. The purpose of these roadmaps restricts their planning to the near-term (today to 2015) timeframe as viewed along the bottom of the page. The science questions to be answered are addressed in the green or blue background area,

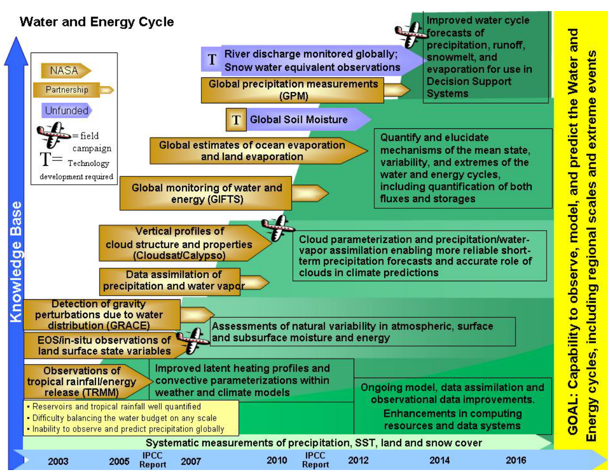


Figure 6 - Water & Energy Cycle Science Roadmap

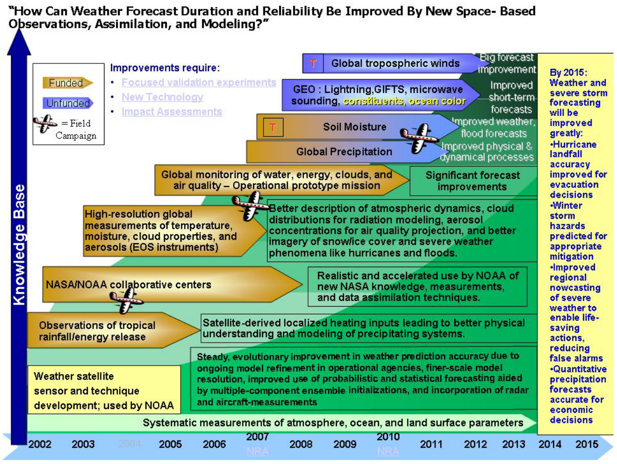


Figure 7 - Weather Science Roadmap

while the candidate mission needs are shown by the shaded arrows to the left of the green/blue fields. Of particular note for the purposes of this paper are the **'T'** preceding some of the candidate mission arrows. These are the areas where technology development is perceived to be required in order to achieve the science measurements needed to fulfill the mission science.

A different formatting of the science questions into a summary chart for near and far-term mission planning proved to be useful in fulfilling our far-term technology development needs. A sample from one of the pages of the Carbon Cycle & Ecosystems focus area is shown in **Figure 8.**

Carbon Cycle & Ecosystems Science Questions	Carbon Cycle & Ecosystems Scientific Outcomes	Carbon Cycle & Ecosystems New Measurements & Activities	Mission Target Date	Near-Term Measurements	Far-Term Measurements (2016 & Beyond
What changes are occurring in global land cover and land use, and what are their causes?	Models with improved ecosystems functions	Physiology & Functional Types	2011	**Physiology & Functional Types 2011**	Photosynthetic Efficiency
	Process controls and errors in Southern Ocean sink reduced	Southern Ocean Carbon Program; Air-Sea CO2 Flux	2012		
	Sub-regional carbon sources and sinks	High-Resolution CO2	2013		High Resolution CO_2
What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?	Reduced carbon flux uncertainties and coastal carbon dynamics	Coastal Carbon Mission	2011	**Coastal Carbon 2011**	GEO Coastal Carbon
	Integrated global analyses of consequences	Global Models with Human-Ecosystems-Climate Interactions	2013		
How do ecosystems, land cover, and biogeochemical cycles respond to and affect global environmental change?	Reduce uncertainties in tropical carbon source	Land Use Change in Amazonia Field Campaign	2006		
	Quantify North America's carbon budget	North American Carbon Program (Field Campaign)	2007		
	Quantify regional carbon sources/sinks on Earth	Orbiting Carbon Observatory Mission	2008	**OCO 2008**	High Resolution CO_2
	Species habitat Characterized	Vegetation 3-D Structure, biomass, & Disturbance	2010	**Vegetation Vertical Structure 2010**	Advanced Land Cover Change

Figure 8 - Sample Near/Far Term Measurement Needs

Figure 8 shows the science question down the ordinate in the green field (column) to the left. The central column defines the 'New Measurements & Activities' to address a particular scientific outcome, e.g. **Physiology & Functional Types** which has a near-term mission need in 2011, but a follow-on far-term technology development need to support a **Photosynthetic Efficiency** mission beyond 2016[3].

The science roadmaps and the measurement/mission needs derived charts provide the basis for discussing the details of the new science measurement strategies required to fulfill the science requirements in the near and far-term technology development planning.

2. TRANSLATING MEASUREMENTS

Determining the need for new measurement strategies from the existing science roadmap technology development requirements occurs via two primary vehicles. ESTIPS(the Earth Science Technology Integrated Planning System can be found at http://estips.gsfc.nasa.gov. This system was developed several years back to support the existing NASA Earth Science Enterprise in translating science questions and measurements into new measurement scenarios and their associated technology requirements. **Figure 9** shows an example from the Carbon Cycle & Ecosystems database on ESTIPS[2].

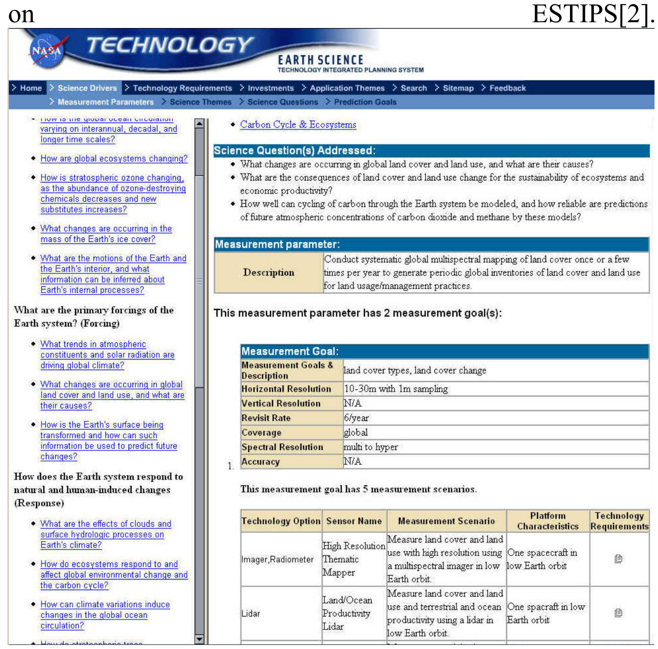


Figure 9 - ESTIPS Measurement Scenario Sample

The forcing function science question, *What changes are occurring in global land cover and land use, and what are their causes?,* is used in the sample to highlight a LIDAR-based measurement scenario as a candidate which was acceptable to the Carbon Cycle & Ecosystems science team in answering a substantive part of the science question. This leads to both a near (Physiology & Funtional Types) and a far (Photosynthetic Efficiency) term technology development effort. The ESTO technologists translate, with iterations in the science focus area teams, the candidate technology options for further development. One of the useful products of this process is the sample chart depicted in **Figure 10.**

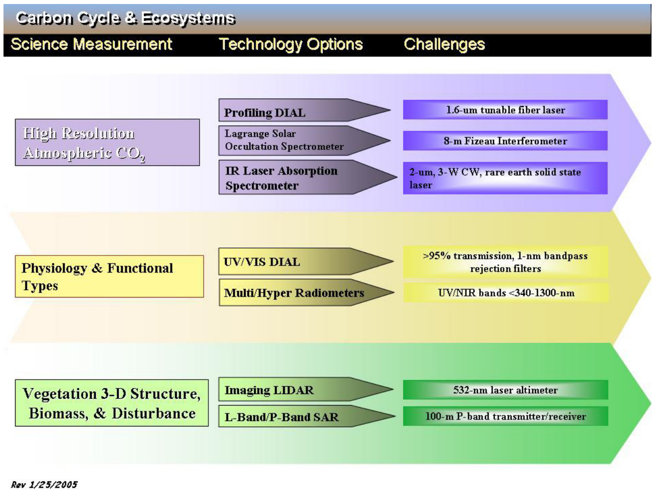
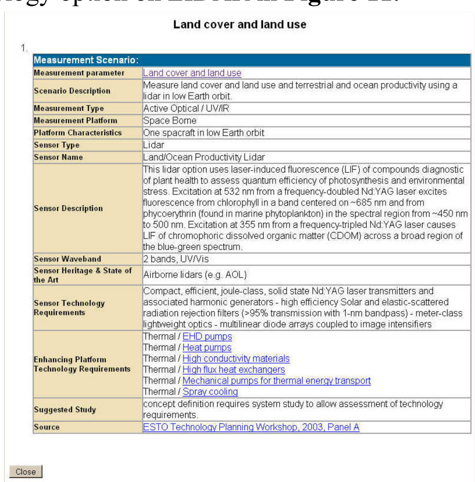


Figure 10 - Measurement To Technology

The Physiology & Functional Types measurement can be accomplished by two candidate technology options, one involving a differential absorption LIDAR instrument. As a one-page summary, the technology challenges shown to the right of *UV/VIS DIAL* are developed, in part, by the ESTIPS technology option on LIDAR in **Figure 11.**



Land cover and land use

1.

Measurement Scenario:	
Measurement parameter	Land cover and land use
Scenario Description	Measure land cover and land use and terrestrial and ocean productivity using a lidar in low Earth orbit.
Measurement Type	Active Optical / UV/IR
Measurement Platform	Space Borne
Platform Characteristics	One spacraft in low Earth orbit
Sensor Type	Lidar
Sensor Name	Land/Ocean Productivity Lidar
Sensor Description	This lidar option uses laser-induced fluorescence (LIF) of compounds diagnostic of plant health to assess quantum efficiency of photosynthesis and environmental stress. Excitation at 532 nm from a frequency-doubled Nd:YAG laser excites fluorescence from chlorophyll in a band centered on ~685 nm and from phycoerythrin (found in marine phytoplankton) in the spectral region from ~450 nm to 500 nm. Excitation at 355 nm from a frequency-tripled Nd:YAG laser causes LIF of chromophoric dissolved organic matter (CDOM) across a broad region of the blue-green spectrum.
Sensor Waveband	2 bands, UV/Vis
Sensor Heritage & State of the Art	Airborne lidars (e.g. AOL)
Sensor Technology Requirements	Compact, efficient, joule-class, solid state Nd:YAG laser transmitters and associated harmonic generators - high efficiency Solar and elastic-scattered radiation rejection filters (>95% transmission with 1-nm bandpass) - meter-class lightweight optics - multilinear diode arrays coupled to image intensifiers
Enhancing Platform Technology Requirements	Thermal / EHD pumps Thermal / Heat pumps Thermal / High conductivity materials Thermal / High flux heat exchangers Thermal / Mechanical pumps for thermal energy transport Thermal / Spray cooling
Suggested Study	concept definition requires system study to allow assessment of technology requirements.
Source	ESTO Technology Planning Workshop, 2003, Panel A

Close

Figure 11 - ESTIPS Technology Option Sample

Since this is a sample of the kinds of information available in the ESTIPS requirements database, it should not be taken as the *de facto* level of detail, since the teams of scientists and engineers involved in filling in this data have provided more or less based on the complexity of the technology option.

Once the strategic science measurement has been translated into a technology option(s), it is time to iterate with the science team in the focus area, and to develop a high-level product for summarizing the potential results.

3. CONCURRENCE CHALLENGES

The concurrence process is aided by a quad chart that is prepared for each of the candidate new measurements/missions appropriate to a specific science focus area [3].

Figure 12 shows a summary of the Photosynthetic Efficiency mission, a far-term mission in support of the Carbon Cycle & Ecosystems focus area.

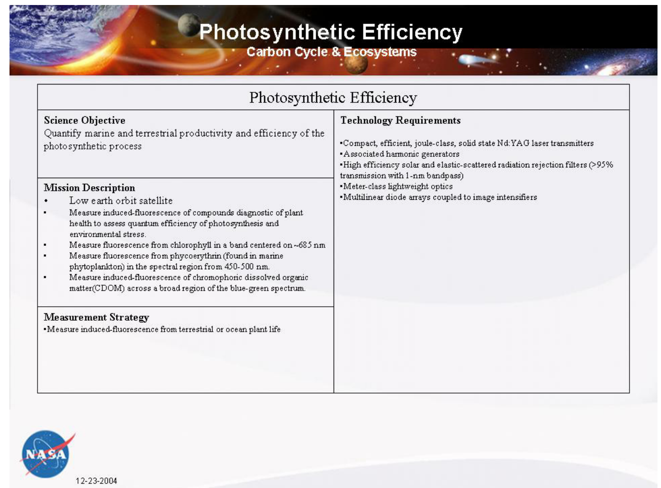


Figure 12 - Quad Chart Sample For Concurrence

This quad identifies the far-term measurement/mission is the particular science focus area. Four sectors, *Science Objective, Mission Description, Measurement Strategy, and Technology Requirements* are used to tie this quad to the previously addressed science question/outcome chart in **Figure 8.** Every possible attempt is made to keep the specific technology candidates neutral in addressing the *Technology Requirements* block.

4. TECHNOLOGY OPTIONS PROCESS

Once the science focus area teams have concurred on near and/or far term technology requirements, the ESTO technology development manager for the focus area team goes to work setting up technology options to meet the science mission needs. Each science focus area, we have found, chooses to present their approach differently, although we originally evolved a commonality in ESTO. This commonality was then tailored in regular discussions with the program scientists and their science team to meet the objectives they wish to portray for future missions.

Figures 13 -19 show samples from each of six focus areas on how they portrayed the technology options for a specific science measurement/mission.

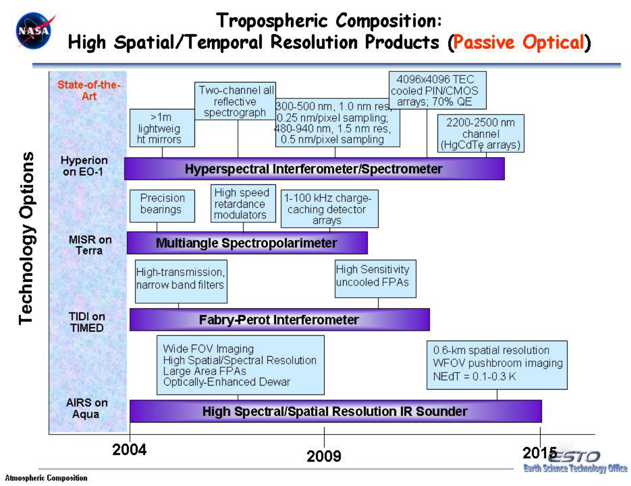


Figure 13 - Atmospheric Composition Technology

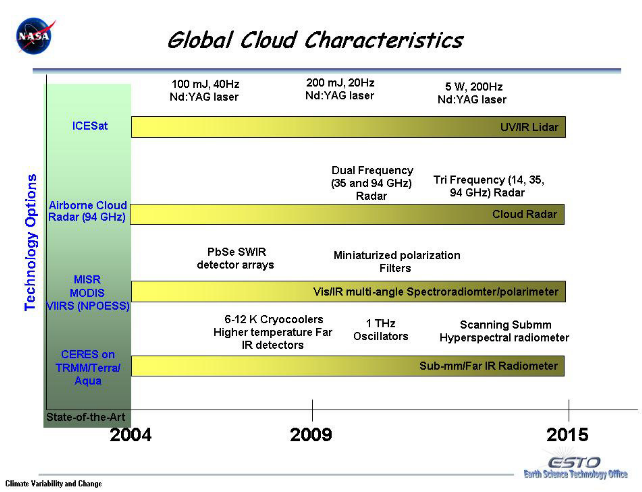


Figure 14 - Climate Technology

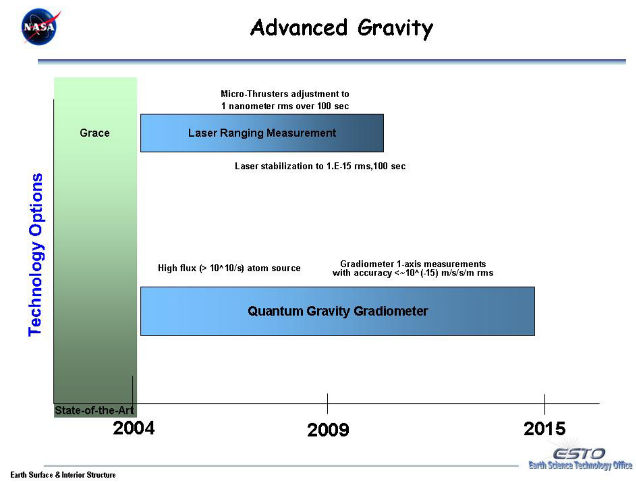


Figure 15 - Earth's Surface & Interior

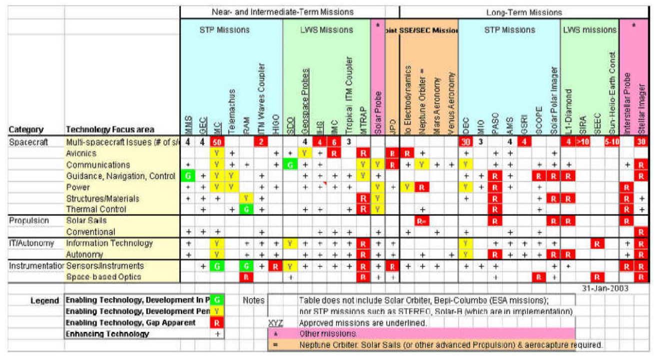


Figure 16 - Sun-Earth Connection Technology

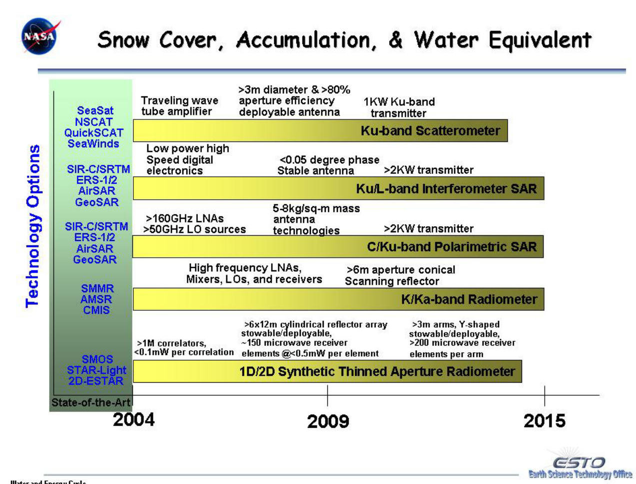


Figure 17 - Water & Energy Cycle Technology

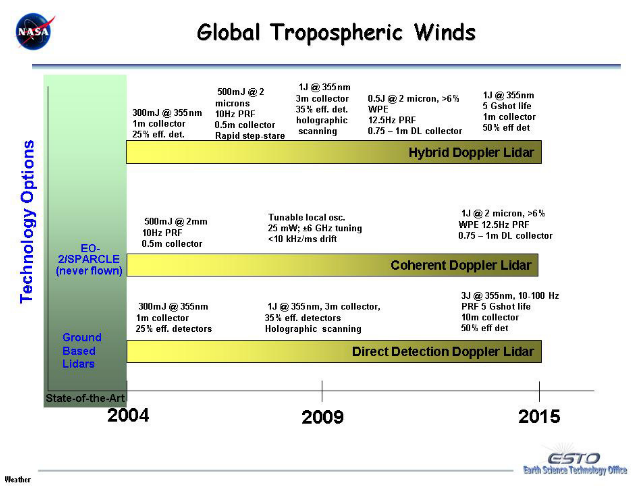


Figure 18 - Weather Technology

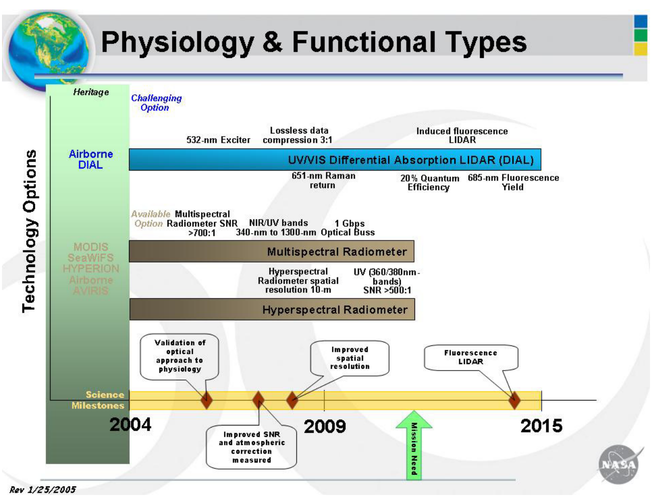


Figure 19 - Carbon Cycle & Ecosystems Technology

The *Physiology & Functional Types* mission technology options shown in **Figure 19** will be a good example for showing the product evolved by this process.

As in the science roadmaps, the bottom yellow horizontal bar reflects the timeline for this near-term "mission need." Additionally, and only implemented currently by this science focus area, are a series of science milestones in cartoons. These will be used to assess progress of the technology development, trade-offs if a flight-of-opportunity should arise, and a vehicle to assist in focusing the instrument technology development effort.

The ordinate (Technology Options) moving to the right show first a green shaded area which has the heritage of instrument technologies that follow. Blue shows "challenging option(s)" which usually will be used in the far-term mission since substantive work/costs would generally not make it ready for the science "mission need" date, in this case 2011. The brown instrument option(s), 2 shown, are likely technologies to invest in for fulfilling the near-term science mission.

Along the top and (sometimes bottom) of a horizontal blue or brown bar, are a few key component technology challenges to be met roughly correlated to the timeline and the science milestones. Quantitative objectives are the goal, so some of these will change as the development effort and the science assessment progress. As an example, the DIAL instrument needs on-board *Lossless data compression 3:1* in support of the *Photosynthetic Efficiency* far-term mission (see **Figures 8, 12**) since it is unlikely that the induced fluorescence LIDAR will be an available technology for the 2011 "mission need" date.

As can be seen by the varied approaches to refining the style of presentation, all of the science focus areas have tailored a basic concept to meet their particular needs.

5. Conclusions/Next Step

Moving a science requirement to a science mission is a long process when there is a technology development requirement. It is not easy, as those who have been there and done that, know, to get a handle on the near-term, let alone the far-term science measurement/mission needs. It is more difficult to translate and separate the science objectives/questions/measurements from the implementation details of the technology development and engineering.

It is truly a team effort and at NASA we have found that the technology development managers often need to put up a notional concept for the science team to refine and fashion into a credible, do-able pathway to success.

As we transform the Agency toward exploration of the moon, mars, and beyond, a succinctly stated roadmap to developing mission-level technologies will provide a measurable schedule for assessing the readiness for a particular technology and the mission-start criteria for a science measurement mission.

REFERENCES

[1] NASA/ESTO Web site http://esto.nasa.gov/

[2] ESTIPS, http://esto.nasa.gov .

[3] George J. Komar, "Deriving Measurement Strategies From Science, 2005 IEEE Aerospace Conference.

[4] Sun-Earth Connection Roadmap 2003-2028, NASA, January 2003.

BIOGRAPHY

William Stabnow is a Technology Development Manager for NASA. He is responsible for the development of component and instrument technologies in support of the NASA/Science Missions Directorate. He supports the Agency Program Scientist, responsible for the Carbon Cycle & Ecosystems focus area, in identifying, planning, and scheduling strategic technologies in support of future Agency missions. He has worked for the Department of Army, the National Institutes of Health, and the Federal Trade Commission during his federal service career. He also taught physics and chemistry in the State of Montana. He has a BS from the University of Maryland in Chemistry.