The Johns Hopkins University
APPLIED PHYSICS LABORATORY

The Pre-Aerosol Clouds and ocean Ecosystem Mission
PACE

http://decadal.gsfc.nasa.gov/pace.html

by:

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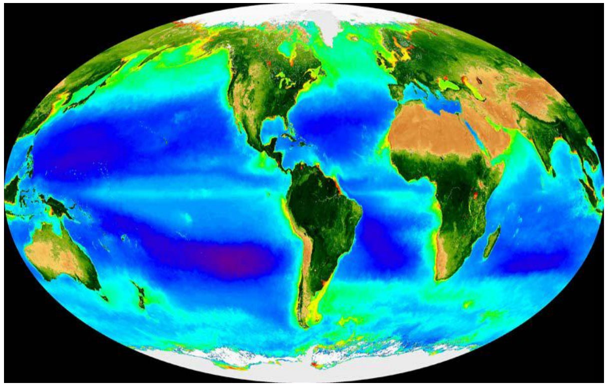

Summary

1-What is the PaCE Mission?

-Motivations

-Goals

2-The PaCE Science Definition Team (SDT)

-Charter

-How it was selected and who are the members?

-How it operated?

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-Recommendations

4-NASA Flight Project Lifecycle and PaCE

-What is it?

-Budget?

-Where is PaCE in the Flight Project Lifecycle?

What is the PACE mission?

•In 2010 NASA HQ decided to implement PACE due to the outstanding issues for continuity of MODIS products for ocean color, aerosol, cloud from NPP and JPSS VIIRS. The guiding document is: Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space

http://science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf

•The PACE mission will make global ocean color measurements that are essential to understand the carbon cycle and its interrelationship with climate change, and to expand our understanding about ocean Biogeochemistry and Ecology.

•The PACE mission will also continue the collection ocean climate data that are necessary to differentiate between natural and anthropogenic climate variability.

•The PACE mission was envisioned as an advanced Ocean Color Sensor provided by NASA and a Polarimeter (3MI) provided by CNES or ESA. CNES recently declined to provide the 3MI sensor. NASA is in conversations with ESA.

The PACE Science Definition Team

Charter:

•Define the science content of the PACE mission and defend its scientific value.

SDT Selection:

•25 July, 2011 NASA issued a Dear Colleague Letter inviting proposals for Science Definition Team (SDT) membership.

•18 October, 2011 – NASA issued selection letters for the SDT.

•First meeting – November, 2011

•Second Meeting – March, 2012

•Last meeting – June, 2012

The PACE Science Definition Team

Ocean Biology and Biogeochemistry:

Antoine, David – LOV, France
Balch, Barney – Bigelow Lab
Behrenfeld, Mike – Oregon State Univ
Boss, Emmanuel- Univ of Maine
Del Castillo, Carlos –JHU-APL (Chair)
Franz, Bryan- NASA GSFC
Frouin, Robert – UCSD-SIO
Gregg, Watson – NASA GSFC
McClain, Chuck – NASA GSFC
Meister, Gerhard- NASA GSFC
Mitchell, Greg – UCSD-SIO
Muller-Karger, Frank – Univ of S. Florida
Siegel, David – UC-Santa Barbara
Wang, Menghua – NOAA NESDIS
Werdell, Jeremy- NASA GSFC (SSAI)

Atmosphere Aerosols & Clouds:

Cairns, Brian – NASA GISS
DaSilva, Arlindo – NASA GSFC
Diner, David – NASA JPL
Dubovik, Oleg – Univ. of Lille, France
Kahn, Ralph – NASA GSFC
Marshak, Sasha – NASA GSFC
Massie, Steve – NCAR
Platnick, SteveNASA GSFC (Deputy Chair)
Reidi, Jerome – Univ. of Lille, France

Atmosphere/Ocean:

Chowdhary, Jacek – NASA GISS

Terrestrial:

Huemmrich, K. Fred – NASA GSFC

Instrument Engineering:

Puschell, Jeffery – Raytheon

Commercial Data Use:

McNaughton, Cameron – Golder Associates, Canada

SDT Operation

•The SDT held three public workshops and ~ weekly teleconferences.

•The SDT was not agnostic about cost – Used NASA engineering team and commissioned IDL and MDL studies to understand science and mission requirements tradeoffs.

•The SDT used findings by other groups (IOCCG, ACE, GEOCAPE, NRC reports, etc...), and the community's ~37 years of experience operating ocean color sensors.

•The SDT report is based on a whole mission concept. For an ocean color mission this means:

- -Post launch calibrations including vicarious calibrations.
- -Field campaigns including process studies.
- -Continual algorithm maintenance and re-processings.

•Science Questions->Measurements->Approaches->Instruments Requirements->Mission Requirements

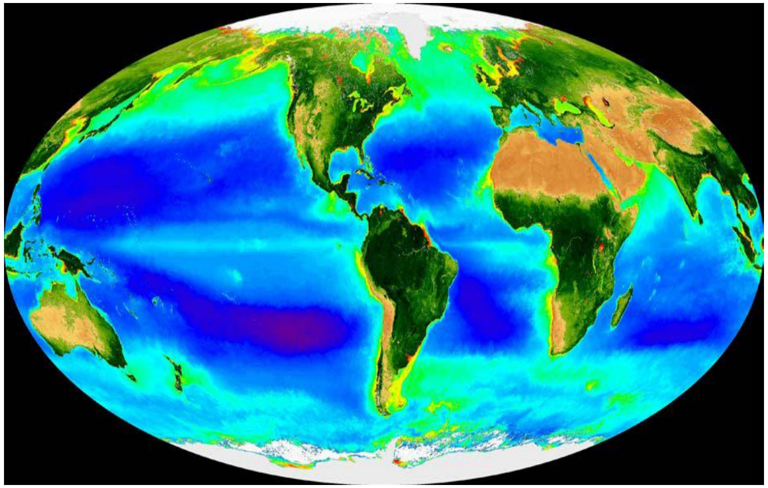
•Science Questions and Instrument and Mission Requirements where prioritized by Thresholds and Goals

Threshold = Must have for the success of the mission
Goals = Very nice to have
Achieving goals cannot compromise thresholds.

Status of SDT activities

Report was released on October 16, 2012

Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) Mission Science Definition Team Report



Threshold Requirements

Orbit	• sun-synchronous polar orbit • equatorial crossing time between 11:00 and 1:00 • orbit maintenance to ±10 minutes over mission lifetime
Global Coverage	• 2-day global coverage to solar zenith angle of 75° • sun glint avoidance • multiple daily observations at high latitudes • solar view zenith angles not exceeding ±60°
Instrument Performance Tracking	• characterization of all detectors and optical components through monthly observations through Earth-viewing port of stable, external illuminated source • characterization of instrument performance changes to ±0.2% within the first 3 years and maintenance of this accuracy thereafter for the duration of the mission • monthly characterization of instrument spectral drift to an accuracy of 0.3 nm • daily measurement of dark current and observations of a calibration target/source, with knowledge of daily calibration source degradation to ~0.2%
Instrument Artifacts	• Prelaunch characterization of linearity, RVVA, polarization sensitivity, radiometric and spectral temperature sensitivity, high contrast resolution, saturation, saturation recovery, crosstalk, radiometric and band-to-band stability, bidirectional reflectance distribution, and relative spectral response • overall instrument artifact contribution to TOA radiance of <0.5% • no image striping at sensor spectral radiance • crosstalk contribution to radiance uncertainties 0.1% at L_{typ} • polarization sensitivity of ≤1% and knowledge of polarization sensitivity to ≤ 0.2% • no detector saturation for any science measurement bands at L_{max} • RVVA of <5% for the entire view angle range and by <0.5% for view angles that differ by less than 1° •Stray light contamination < 0.2% of L_{typ} 3km away from a cloud • out-of-band contamination of <0.01 for all multispectral channels • radiance-to-counts relationship characterized to 0.1% over full dynamic range
Spatial Resolution	• Global spatial coverage of 1 km x 1 km (±0.1 km) along-track
Atmospheric Corrections	• retrieval of $[\rho_w(\lambda)]_N$ for open-ocean, clear-water conditions and standard marine atmospheres with an accuracy of the maximum of either 5% or 0.001 over the wavelength range 400 – 700 nm • two NIR atmospheric correction bands comparable to heritage • NUV band centered near 350
Science Spectral Bands	• 5 nm spectral resolution from 355 to 800 nm • complete ground station downlink and archival of 5 nm data.
Signal-to-noise	• spectral instrument SNR at L_{typ} as defined in Table 1 and Appendix I for all science measurement bands
Data Processing, Reprocessing, Distribution	• full reprocessing capability of all PACE data at a minimum frequency of 1 – 2 times annually.

In some cases, the SDT is very prescriptive in technical requirements and instrumental approaches. This is based on the experience that the OC community has accumulated from CZCS through present.

However, the SDT is mindful of not overprescribing in areas where technical innovation may offer novel approaches.

Ocean Science Measurement Goals (not ranked)

- *Accuracy*: Retrieval of normalized [*rw*(*l*)]N for open-ocean, clear-water conditions and standard marine atmospheres with an accuracy of the maximum of either 10% or 0.002 over the wavelength range of 350 – 395 nm
- *Aerosol heights*: Identified approach or measurement capacity for evaluating/measuring aerosol vertical distributions and type for improved atmospheric corrections.
- *Atmospheric correction*: SWIR atmospheric correction band at 2130 nm with a SNR of 100.
- *Coverage*: 1-day global coverage
- *Coverage*: Coverage to a solar zenith angle >75o
- *Crossing time*: Noon equatorial crossing time (±10 min)
- *Instrument artifact*: Overall instrument artifact contribution to TOA radiance retrievals of <0.2%.
- *Navigation and Registration*: pointing knowledge of 0.05 IFOV; band-to-band registration of 90% of one IFOV; simultaneity of 0.01 second
- *Nitrogen dioxide*: Identified approach for characterizing NO2 and ozone concentrations at sufficient accuracy for improving atmospheric corrections
- *Mission lifetime*: 10 years
- *Performance changes*: Characterization of instrument performance changes to ±0.1% within 3 years and maintenance of this accuracy thereafter
- *Saturation*: No detector saturation for any science measurement bands up to 1.2 × *L*max

Signal-to-noise: SNR for bio-optical science bands and/or atmospheric correction bands greater than those shown Appendix II

Spatial resolution: Spatial resolution of 1 km2 (±10%) at all scan angles

***Spatial resolution*: Along-track spatial resolution of 250 m x 250 m to <1 km2 for inland, estuarine, coastal, and shelf area retrievals for all bands or a subset of bands – OCI-C**

- *Spectral coverage*: 5 nm spectral coverage from 800 to 900 nm
- *Spectral sub-sampling*: Spectral sub-sampling at ~1-2 nm resolution from 655 to 710 nm for refined characterization of the chlorophyll fluorescence spectrum
- *Water vapor*: Spectral measurement band centered at 820 nm or 940 nm to determine water vapor content

Summary of the PACE SDT Recommendations

1-To address **threshold** PACE science questions dealing with global Ocean Biogeochemistry and Ecology the PACE mission must include:

•A well-characterized ocean color instrument covering the spectral range between 350 and 900 nm at ~5 nm resolution, plus three SWIR bands at a spatial resolution of 1 km^2 (nadir). This instrument option is called **OCI**.

•A mission architecture that includes continual post launch calibration (including lunar and vicarious calibration), algorithms development and maintenance, field validation and process studies.

λ	Band Width (nm)	Spatial Resolution (km^2)	L_{typ}	L_{max}	SNR-Spec
350	15	1	7.46	35.6	300
360	15	1	7.22	37.6	1000
385	15	1	6.11	38.1	1000
412	15	1	7.86	60.2	1000
425	15	1	6.95	58.5	1000
443	15	1	7.02	66.4	1000
460	15	1	6.83	72.4	1000
475	15	1	6.19	72.2	1000
490	15	1	5.31	68.6	1000
510	15	1	4.58	66.3	1000
532	15	1	3.92	65.1	1000
555	15	1	3.39	64.3	1000
583	15	1	2.81	62.4	1000
617	15	1	2.19	58.2	1000
640	10	1	1.9	56.4	1000
655	15	1	1.67	53.5	1000
665	10	1	1.6	53.6	1000
678	10	4	1.45	51.9	2000
710	15	1	1.19	48.9	1000
748	10	1	0.93	44.7	600
820	15	1	0.59	39.3	600
865	40	1	0.45	33.3	600
1240	20	1	0.088	15.8	250
1640	40	1	0.029	8.2	180
2130	50	1	0.008	2.2	50

...Summary of the PACE SDT Recommendations

2- To continue legacy imager-based aerosol and cloud data records initiated during the EOS era with MODIS, the **OCI** must be augmented to include:

•Three additional SWIR bands at 1 km^2 spatial resolution. This instrument options is called **OCI+**

λ	Band Width (nm)	Spatial Resolution (km^2)	L_{typ} (w/m^2-sr-µm)	L_{max} (w/m^2-sr-µm)	SNR-Spec
350	15	1	7.46	35.6	300
360	15	1	7.22	37.6	1000
385	15	1	6.11	38.1	1000
412	15	1	7.86	60.2	1000
425	15	1	6.95	58.5	1000
443	15	1	7.02	66.4	1000
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665	10	1	1.6	53.6	1000
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748	10	1	0.93	44.7	600
820	15	1	0.59	39.3	600
865	40	1	0.45	33.3	600
1240	20	1	0.088	15.8	250
1640	40	1	0.029	8.2	180
2130	50	1	0.008	2.2	50
940	**25**	**1**	**7.8**	**210**	**150**
1378	**10**	**1**	**3.5**	**95**	**100**
2250	**50**	**1**	**0.7**	**24**	**150**

...Summary of the PACE SDT Recommendations

3-To address goal science questions and applications regarding global coastal and estuarine environments as well as inland water bodies, the PaCE mission, in addition to threshold requirements, should have:

•A goal of hyperspectral (5 nm) observations at a spatial resolution better than 500 x 500 m. This instrument option is called **OCI coastal (OCI-C)**

λ	**Band Width (nm)**	**Spatial Resolution (m)**	**SNR-Spec**
350	?	< 500x500	?
355	?	< 500x500	?
360	?	< 500x500	?
365	?	< 500x500	?
390	?	< 500x500	?
395	?	< 500x500	?
400	?	< 500x500	?
.	?	< 500x500	?
.	?	< 500x500	?
.	?	< 500x500	?
900	?	< 500x500	?
1240	20	1	250
1640	40	1	180
2130	50	1	50

λ	**Band Width (nm)**	**Spatial Resolution (km^2)**	**L_{typ} (w/m^2-sr-μm)**	**L_{max} (w/m^2-sr-μm)**	**SNR-Spec**
350	15	1	7.46	35.6	300
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748	10	1	0.93	44.7	600
820	15	1	0.59	39.3	600
865	40	1	0.45	33.3	600
1240	20	1	0.088	15.8	250
1640	40	1	0.029	8.2	180
2130	50	1	0.008	2.2	50

Achieving OCI-C cannot compromise OCI performance thresholds.

...Summary of the PACE SDT Recommendations

4-To address **goal** science questions regarding the effect of aerosols on ocean productivity, the PACE mission should have:
A multi-angle polarimeter (3M) in addition to ocean threshold requirements. This option is called **OCI-3M.**

5- To address **goal** science questions regarding how aerosols affect cloud properties, the PACE mission should include the **OCI+** option and:
A multi-angle polarimeter (3M) and select atmospheric bands at 250m spatial resolution. I call this option ***"The whole enchilada" .***

λ	**Band Width (nm)**	**Spatial Resolution (km^2)**	**L_{typ} (w/m^2-sr-µm)**	**L_{max} (w/m^2-sr-µm)**	**SNR-Spec**
350	15	1	7.46	35.6	300
360	15	1	7.22	37.6	1000
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583	15	1	2.81	62.4	1000
617	15	1	2.19	58.2	1000
640	10	1	1.9	56.4	1000
655	15	1	1.67	53.5	1000
665	10	1	1.6	53.6	1000
665	**2.5**	**250x250m**	**MODIS**	**MODIS**	**MODIS**
678	10	4	1.45	51.9	2000
710	15	1	1.19	48.9	1000
748	10	1	0.93	44.7	600
763	**2.5**	**250x250m**	**MODIS**	**MODIS**	**MODIS**
820	15	1	0.59	39.3	600
865	40	1	0.45	33.3	600
865	**2.5**	**250x250m**	**MODIS**	**MODIS**	**MODIS**
940	**25**	**1**	**7.8**	**210**	**150**
1240	20	1	0.088	15.8	250
1378	**10**	**1**	**3.5**	**95**	**100**
1640	40	1	0.029	8.2	180
1640	**2.5**	**250x250m**	**MODIS**	**MODIS**	**MODIS**
2130	50	1	0.008	2.2	50
2135	**2.5**	**250x250m**	**MODIS**	**MODIS**	**MODIS**
2250	**50**	**1**	**0.7**	**24**	**150**

...Summary of the PACE SDT Recommendations

Science Questions	Mission Options	Brief Description
Threshold Ocean Science Questions	OCI	Hyperspectral imager ~5nm resolution from 350-900 nm + 3 SWIR bands. 1 km^2 spatial resolution.
Legacy Atmosperic Science Questions	OCI+	OCI instrument plus 3 additonal SWIR bands at 1 km^2 spatial reolution.
Goal Science Questions-Coastal Oceans	OCI-C	OCI with spatial resolution better than 500x500 m.
Goal Science Questions Aerosols	OCI-3M	OCI and a 3M
Goal Science Questions Aerosols and Clouds	OCI-TWE	OCI+ sensor, selected atmospheric bands at 250 m x 250 m spatial resolution, and a 3M.

Budget

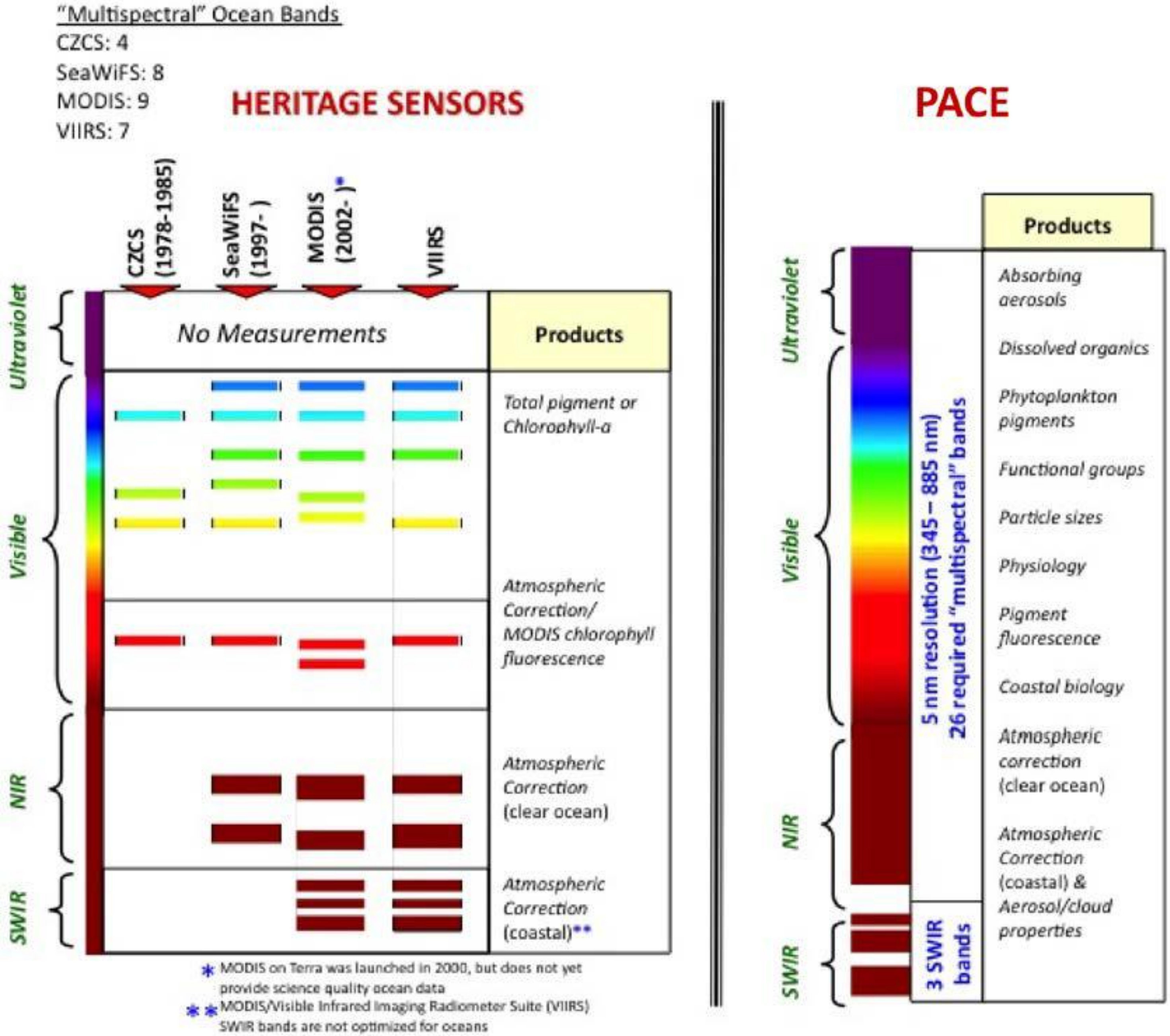
•~$750-$800 M

•~$150 M instrument

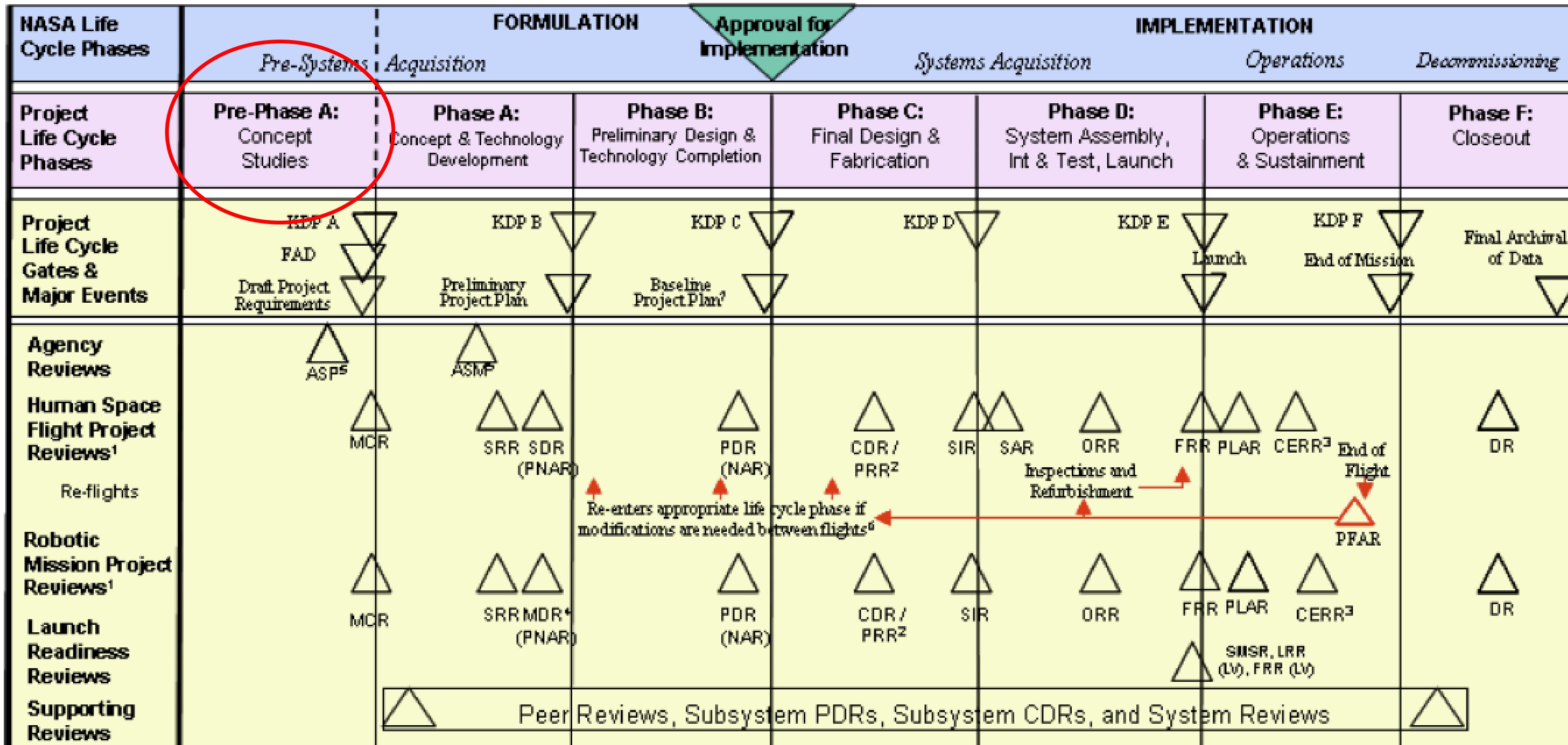
•~$150 M Launch

•~$450-$500 M for mission operations, vicarious calibration, science teams, paperwork, etc...

This is not an official NASA budget. These are estimates based on preliminary information provided by NASA during SDT meetings.


"Multispectral" Ocean Bands
CZCS: 4
SeaWiFS: 8
MODIS: 9
VIIRS: 7
HERITAGE SENSORS
CZCS (1978-1985)
SeaWiFS (1997-)
MODIS (2002-)*
VIIRS
Ultraviolet
Visible
NIR
SWIR
No Measurements
Products
Total pigment or Chlorophyll-a
Atmospheric Correction/ MODIS chlorophyll fluorescence
Atmospheric Correction (clear ocean)
Atmospheric Correction (coastal)**
* MODIS on Terra was launched in 2000, but does not yet provide science quality ocean data
** MODIS/Visible Infrared Imaging Radiometer Suite (VIIRS) SWIR bands are not optimized for oceans
PACE
Products
5 nm resolution (345 – 885 nm)
26 required "multispectral" bands
3 SWIR bands
Absorbing aerosols
Dissolved organics
Phytoplankton pigments
Functional groups
Particle sizes
Physiology
Pigment fluorescence
Coastal biology
Atmospheric correction (clear ocean)
Atmospheric Correction (coastal) & Aerosol/cloud properties

NASA Flight Project Life Cycle



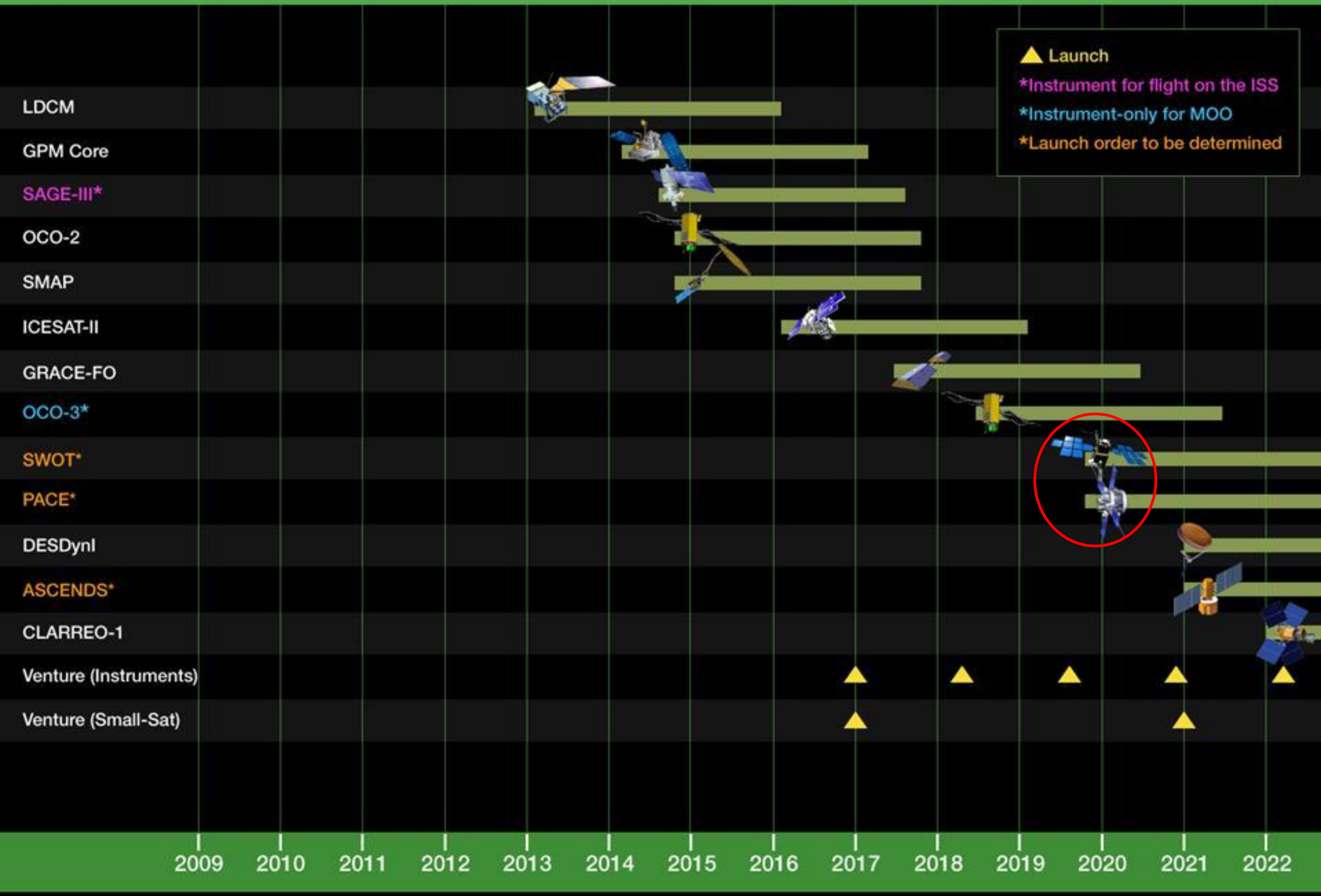
FOOTNOTES

1. Flexibility is allowed in the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan. These reviews are conducted by the project for the independent SRB. See Section 2.5 and Table 2-6.
2. PRR needed for multiple (≥4) system copies. Timing is notional.
3. CERRs are established at the discretion of Program Offices.
4. For robotic missions, the SRR and the MDR may be combined.
5. The ASP and ASM are Agency reviews, not life-cycle reviews.
6. Includes recertification, as required.
7. Project Plans are baselined at KDP C and are reviewed and updated as required, to ensure project content, cost, and budget remain consistent.

ACRONYMS

ASP—Acquisition Strategy Planning Meeting
ASM—Acquisition Strategy Meeting
CDR—Critical Design Review
CERR—Critical Events Readiness Review
DR—Decommissioning Review
FAD—Formulation Authorization Document
FRR—Flight Readiness Review
KDP—Key Decision Point
LRR—Launch Readiness Review
MCR—Mission Concept Review
MDR—Mission Definition Review
NAR—Non-Advocate Review
ORR—Operational Readiness Review
PDR—Preliminary Design Review
PFAR—Post-Flight Assessment Review
PLAR—Post-Launch Assessment Review
PNAR—Preliminary Non-Advocate Review
PRR—Production Readiness Review
SAR—System Acceptance Review
SDR—System Definition Review
SIR—System Integration Review
SMSR—Safety and Mission Success Review
SRR—System Requirements Review

NASA ESD Future Missions Timeline



Outstanding Issues …

-Atmospheric corrections – To what extend are data in the UV useful without having more information about aerosols? No clear consensus within the SDT. However, it is clear that the PACE mission will provide ground-braking science even with current atmospheric correction protocols

-Will NASA compete a vicarious calibration system?

-Launch vehicles- The longer a mission has to be planned without a well-defined launch vehicle, the higher the development cost. This is not an issue for the SDT, but it is an issue for the community.

Challenges

-PACE has moved from a technical phase into a political phase.

-The community is not enthusiastic about PACE.