Engineering Team (ET)

2nd NASA PACE SDT Meeting

14 March 2012

Introducing the ET

- Chi Wu, Decadal Survey Missions Systems Engineer, Code 420 at GSFC.
- James (Jay) Smith, Chief Engineer for Instrument Systems, Code 550.0 at GSFC.
- Richard (Rick) Wesenberg, Senior MSE, Code 592 at GSFC.
- Angela Mason, PACE/Decadal Survey Tier II Mission Manager, Code 420 at GSFC.

Objective

1. Develop a generic baseline Ocean Color Instrument (OCI) instrument concept, optional enhancements and a mission concept;
2. Identify driving requirements; assess technical feasibility
3. Estimate cost of baseline instrument, baseline instrument with enhancements, and mission;

Ground Rules

- ET takes direction from the Program Scientist (PS) and Program Executive (PE) *only*.
- Members of the ET, ODL, IDL and MDL must sign the program NDA.
- Everything the ET produces **will** be made public, therefore:
  - *No* proprietary intellectual content;
  - *No* use of competition sensitive content;
  - *No* use of proprietary labor rates.

Key Trades

1. Ocean Color Instrument (Ground Sample Distance (GSD) (forward/aft 20° tilt for sun glint avoidance);
2. OCI + Atmospheric Channels: 940nm (25nm), 1380nm (10nm) and 2250nm (50nm).
3. OCI + Atmospheric Channels: GSD options of 500m or 250m.

Lab Schedule

- Optical Design Laboratory (ODL):
  - 3/14-4/18
- Instrument Design Laboratory (IDL):
  - 1k x 1k OCI and OCI + Atmospheric Ch: 4/9-13/12
  - Optional 2nd IDL: 4/23-27/12
- Mission Design Laboratory (MDL):
  - 5/14-18/12

PACE Engineering Team Schedule

3/12/12

	2012							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Engineering Team (ET) initial startup/meeting	26							
ET joins the Science Definition Team (SDT) tlecons (Ocean/Atmosphere)		9						
SDT Weekly Telecons		16 23	1 8 15 22 29	5 12 19 26	3 10 17 25 31	7 14 21 28	5 12 19 26	2
Optical Design Lab (ODL) Study			14	18				
ODL Weekly Tagup Meetings			9 14 21 28	6 13 18				
SDT Meeting, Arlington Va.			14 16					
Instrument Design Lab (IDL) Study				9 27				
Mission Design Lab (MDL) Study					14 18			
SDT Meeting, DC Area						TBD		
SDT Final Report							31	

Products ET Will Provide

- IDL Report & Cost Estimate: OCI;
- IDL Report & Cost Estimate: OCI + Atmospheric Channels;
- MDL Report & Parametric Cost Estimate: Mission + Instruments;
- Executive Summary (White paper or PowerPoint).

Concept Of Operations (CONOPs)

- Orbit Requirement: A sun-synchronous polar orbit that:
  - provides high illumination intensities for accurate retrievals from the relatively dark ocean,
  - minimizes atmospheric path lengths for improved atmospheric corrections,
  - minimizes the range of scattering angles for simplification of atmospheric corrections,
  - Maximizes repeat observations of high latitudes to improve probabilities of viewing cloud-free scenes each day, and
  - Minimizes contamination by sun glint
  - Global coverage 2 days or less; swath widths not to exceed 58°;
- Desired Implementation:
  - ***Good***: Sun-synchronous, polar orbit with an equatorial crossing time between 10:30 and 1:30, with orbit maintained to ±10 minutes over the lifetime of the mission, OR
  - ***Better***: Sun-synchronous, polar orbit with noon equatorial crossing time, 650 km altitude.

Concept Of Operations (CONOPs)

- Observatory Modes:
  - Normal Operations:
    - Global Area Coverage (GAC) Observing:
      - +/- 20 deg. tilt operations twice per orbit for sun glint avoidance
    - Local Area Coverage (LAC) Observing: Special mode supporting local area observations. Broadcast?
    - Science Data Downlink: Observe and downlink or observe only?
    - Safe Mode: Instrument off, thermal control.
    - Launch Mode: Instruments off, standby, caging/de-caging.

Concept Of Operations (CONOPs)

- Observatory Modes (cont'd):
  - Calibration:
    - Monthly characterization: Change in all instrument detectors and Earth-viewing optical components through measurement of a stable illuminated source (e.g., moon, constant phase angle) through the Earth viewing port.
      - characterization of instrument spectral drift to within 3 nm.
    - Daily/Weekly Solar Calibration: Solar illuminated internal test targets (at least three ; Nadir pointing - 0° tilt) at or near orbit terminator crossings to provide temporal tracking of radiometry and spectral drift sensitivity;
    - Vicarious Earth based observations when opportunities arise.

Concept Of Operations (CONOPs)

- Communication:
  - Command and Observatory Status
  - Data to ground
  - Broadcast service?
- Mission Operations:
  - Where should we assume MOC is located?
- Science Operations:
  - Where should we assume SOC is located?
  - Capacity for full reprocessing of PACE data at a minimum frequency of 1 – 2 times annually.

Key Observatory Requirements

- SC & Instruments: Class B per NPR 8705.4
- Prop sub-system required for station keeping.
- Complete ground station download and archival of 5 nm data.
- Pointing knowledge: Known to within TBR arcsec.
- Pointing control: Image stable within TBR pixel over TBR msec. (Jitter spec?)

Measurement Requirements OES 1k x 1k

Measurement Parameter	Spec	Limits, tolerance, qualifiers
OCEANS		
Global Coverage:		
Surface coverage %	100% in 2-days	
Solar zenith angle range of data collection	75°	
Sun-sync or inclination preferences?	Sun sync	
Asc./dec. equatorial crossing – time of day	±1.5 hr from noon	Merits of ascending or descending TBD
Ground track repeat/sampling at equator		No stringent orbit repeat requirement
Spatial Coverage:		
Orbit altitude preferences?	~650 km	
Sample measurement size	1 km	Suborbital track at 20° tilt
Along track sample spacing	1 km	
Cross-track sampling swath	~2000 km	2-day coverage at 650 km altitude (corresponds to a ±51° viewing range. 1-day global coverage is possible at 650 km with viewing angles of ±58°.
Glint Avoidance	Yes	±20° (same as SeaWiFS)
Measurement Channels:		
Measurement center wavelengths – λ_o	Table 1	26 multispectral bands defined for SNR, Ltyp, Lmax, and specific data products
FWHM – $\Delta\lambda$	Table 1	Variable

λ sampling interval (fixed $\Delta\lambda$ or spectrometer)	spectrometer	5 nm resolution: 340-780 nm
Ltyp Radiances per λ_o	Table 1	
Nonsaturating Lmax Radiance per λ_o	Table 1	
On-orbit Calibration Observations:		
Surface Vicarious	yes	Single year-round ocean site minimum
Lunar (direct view)	0.1% radiometric accuracy (mission-lifetime)	Lunar view through Earth-viewing optics only, once per month at 7° lunar phase angle (same as SeaWiFS)
Solar Diffuser	0.1% radiometric accuracy (up to 6 months)	Dual diffusers similar to MERIS
Performance Specifications:		
SNR's per λ_o at Ltyp	Table 1	
Spatial sampling jitter	0.1 pixel	
Polarization sensitivity	< 1%	All multispectral & 5 nm bands Must be characterized to < 0.2% accuracy prelaunch
Saturation	No saturation	All multispectral & 5 nm bands
Other parameters: Out-of-band response, optical & electronic crosstalk, straylight, image striping	Specifications TBD	These effects are to be minimized to the greatest extent possible. Meister et al. (2011) provide recommendations.
ATMOSPHERE		
Same as Above - ???		

Measurement Requirements OES 1k x 1k (cont'd)

Wavelength	Maximum Bandwidth	Ltyp	Lmax	SNR-spec
350	15	7.46	35.6	300
360	15	7.22	37.6	1000
385	15	6.11	38.1	1000
412	15	7.86	60.2	1000
425	15	6.95	58.5	1000
443	15	7.02	66.4	1000
460	15	6.83	72.4	1000
475	15	6.19	72.2	1000
490	15	5.31	68.6	1000
510	15	4.58	66.3	1000
532	15	3.92	65.1	1000
555	15	3.39	64.3	1000
583	15	2.81	62.4	1000
617	15	2.19	58.2	1000
640	10	1.90	56.4	1000
655	15	1.67	53.5	1000
665	10	1.60	53.6	1000
678	10	1.45	51.9	1400
710	15	1.19	48.9	1000
748	10	0.93	44.7	600
765	40	0.83	43.0	600
820	15	0.59	39.3	600
865	40	0.45	33.3	600
1245	20	0.088	15.8	250
1640	40	0.029	8.2	180
2135	50	0.008	2.2	100

Table 1: Specs for required 26 multispectral bands. The bands can be aggregated from 5 nm hyperspectral bands where appropriate. Radiance units are mW/cm^2 µm sr. The maximum bandwidth is specified for achieving the SNR-spec.

Meister, G., C. McClain, Z. Ahmad, S. W. Bailey, R. A. Barnes, S. Brown, G. E. Eplee, B. Franz, A. Holmes, W. B. Monosmith, F. S. Patt, R. P. Stumpf, K. R. Turpie, and P. J. Werdell, Requirements for an Advanced Ocean Radiometer, NASA T/M-2011-215883, NASA Goddard Space Flight Center, Greenbelt, Maryland, 37 pp., 2011.

Measurement Requirements OES + Atmos 1k

PACE atmosphere team measurement requirements (draft, 2 Mar 2012)

Global coverage

As for ocean requirements (i.e., "OES Measurement Requirement_CRM_22Feb12"), except:

1. Solar zenith angle range of data collection: ≥81.5° (cosine ≤ 0.15) for continuity with L2 products from MODIS/VIIRS.

Spatial coverage

As for ocean requirements, except:

1. Sample size: Goal of 250m in selected channels (see table below)
2. Along track sample spacing: Goal of 250m in selected channels (see table below)

On-orbit Calibration

As for ocean requirements

OES channels and performance

As for ocean requirements, with exception of following additional channels and/or modifications/clarification to baseline OES specs.

Measurement Requirements OES + Atmos 1k (cont'd)

CW (µm)	BW (FWHM, nm)	Rmax [a] (μ_0=1)	Lmax [a] (W/m^2-sr-µm)	Rtyp [a,b] (μ_0=1)	Ltyp [b] (W/m^2-sr-µm)	NEdR@Rtyp	SNR@Ltyp [a]	Spatial Resolution (m) [Threshold, Goal [c]]
Augmentation to baseline OES								
0.940	25	0.80	210	0.03	7.8	0.0002	130	1000
1.378	10 [d]	0.80	95	0.03	3.5	0.0003	90	1000
2.250 [e]	50	0.90	21	0.03	0.7	0.0003	90	1000 250
		Additional info. and/or modification to baseline OES channels						
0.665								1000 250
0.865								1000 250
1.640								1000 250
2.135								1000 250
0.763	5nm; CW tolerance: ±2.5nm; BW/CWL knowledge: < 0.1 nm							1000 250

Table notes:

a. Values consistent with Lmax, Rmax, and S/N@Ltyp for MODIS at native resolution (0.5–1 km); VIIRS SWIR channel S/N's ≈40% less (750 m).
b. Rtyp corresponds to cirrus optical thickness of ~0.2–0.3
c. "Goal "spatial resolution for reduction of low cloud heterogeneity biases. SDT report calls out for further specific studies in Phase A.
d. MODIS 30 nm BW found to be too large for adequate cirrus detection. VIIRS: 15 nm found to be significantly better.
e. For cloud phase and VIIRS/ABI cloud microphysics continuity

Issues

- Justification for 5 nm spectral resolution from 350 to 750 nm, in addition to spectral bands for atmospheric corrections. ;
  - How is this related to spectral resolving power ($R=\Delta\lambda/\lambda$)?
- Match between geophysical parameter list and bands requested.
  - See following two charts, marked with a red “x”.
- Commercial or custom SC bus

Geophysical Parameter List

	Geophysical Parameter	Symbol	λ (nm)	Baseline range		Threshold Range		Units
				1%	*99%*	*5%*	*95%*	
X	Remote sensing reflectance (Rrs)	Rrs	340	0.0015	0.0200	0.0020	0.0150	sr^{-1}
X	Remote sensing reflectance (Rrs)	Rrs	380	0.0017	0.0200	0.0030	0.0170	sr^{-1}
	Remote sensing reflectance (Rrs)	Rrs	412	0.0011	0.0330	0.0035	0.0280	sr^{-1}
	Remote sensing reflectance (Rrs)	Rrs	443	0.0016	0.0240	0.0038	0.0210	sr^{-1}
	Remote sensing reflectance (Rrs)	Rrs	490	0.0023	0.0140	0.0042	0.0120	sr^{-1}
	Remote sensing reflectance (Rrs)	Rrs	510	0.0026	0.0110	0.0036	0.0080	sr^{-1}
X	Remote sensing reflectance (Rrs)	Rrs	531	0.0021	0.0100	0.0027	0.0060	sr^{-1}
	Remote sensing reflectance (Rrs)	Rrs	547	0.0014	0.0090	0.0019	0.0050	sr^{-1}
	Remote sensing reflectance (Rrs)	Rrs	555	0.0014	0.0080	0.0018	0.0050	sr^{-1}
X	Remote sensing reflectance (Rrs)	Rrs	670	0.0000	0.0020	0.0001	0.0010	sr^{-1}
	Remote sensing reflectance (Rrs)	Rrs	678	0.0000	0.0020	0.0001	0.0010	sr^{-1}
	Remote sensing reflectance (Rrs)	Rrs	683	0.0000	0.0120	0.0000	0.0010	sr^{-1}
	Total Absorption	a	412	0.020	2.0	0.03	0.8	m^{-1}
	Total Absorption	a	443	0.020	1.8	0.03	0.7	m^{-1}
	Total Absorption	a	555	0.650	1.5	0.08	0.6	m^{-1}
X	Total Absorption	a	676	0.460	1.8	0.47	0.8	m^{-1}
	Phytoplankton absorption	a_{ph}	443	0.003	1.2	0.007	0.7	m^{-1}
	Detrial absorption	a_d	443	0.0004	0.6	0.001	0.3	m^{-1}
	Colored dissolved organic material absorption	a_{CDOM}	443	0.002	0.9	0.003	0.5	m^{-1}
	Backscatter coefficient	b_{bp}	443	0.0003	0.1	0.001	0.003	m^{-1}
	Beam attenuation	c	412	0.03	10.0	0.1	0.5	m^{-1}
	Beam attenuation	c	443	0.03	10.0	0.1	0.5	m^{-1}
	Beam attenuation	c	555	0.08	10.0	0.1	0.5	m^{-1}

Geophysical Parameter List (cont'd)

Geophysical Parameter	Symbol	λ (nm)	Baseline range		Threshold Range		Units
x Beam attenuation	c	676	0.47	10.4	0.5	0.9	m^{-1}
Diffuse attenuation coefficient for downwelling plane irradiance at 490 nm	kd	490	0.02	4.0	0.02	1.5	m^{-1}
Incident Photosynthetically Available Radiation (PAR): Instantaneous			0	2200	100	2100	μmol quanta m^{-2} s^{-1}
Incident Photosynthetically Available Radiation (PAR): 24-hour flux			0	60	10	55	mol quanta m^{-2} d^{-1}
1% PAR depth	$Z_{1\%}$		10	150	35	135	m
Particulate inorganic carbon concentration	PIC		$1.2\ 10^{-5}$	$5.3\ 10^{-4}$	$1.9\ 10^{-5}$	$3.3\ 10^{-4}$	mol m^{-3}
Particulate Organic Carbon concentration	POC		15	2000	20	500	mg m^{-3}
Dissolved Organic Carbon concentration	DOC		35	800	40	500	μmol L^{-1}
Suspended Particulate Matter Concentration	SPM		25	70000	45	15000	mg m^{-3}
Particle size characteristics (size range indicted here)			0.05	2000	0.8	200	μm
Total Chlorophyll-a concentration	TChl-a		0.015	40	0.030	25	mg m^{-3}
Other phytoplankton pigments			?	?	?	?	
Phytoplankton Carbon concentration	C_{phyto}		0.15	800	3.0	450	mg m^{-3}
Normalized Fluorescence Height	FLH		0.0001	0.025	0.0010	0.015	mW cm^{-2} μm^{-1} sr^{-1}
Fluorescence Quantum Yield	FQY		0.0003	0.05	0.001	0.02	flouresced ph $(\text{absorbed ph})^{-1}$
Net Primary Production	NPP		55	8500	90	4500	mg m^{-2} d^{-1}
Phytoplankton physiological properties: Chi-C			0.0005	0.3	0.001	0.1	mg mg^{-1} ?
Phytoplankton physiological properties: Growth rate			0.00	1.9	0.01	1.5	d^{-1}
Phytoplankton groups: microphytoplankton			0	0.9	0	0.7	1
Phytoplankton groups: nanophytoplankton			0	0.9	0.2	0.8	1
Phytoplankton groups: picophytoplankton			0	1.0	0	0.8	1
Trichodesmium concentration			0	10000	0	5000	filaments L^{-1}
Coccolith concentration			293	814930	760	314000	detached coccoliths ml^{-1}
?			34	3624	59	2066	plated coccolithophores per coccolith aggregates ml^{-1}

Instrument Design Laboratory (IDL)

- **Initial planning**
  - meeting approx. 1 month before study
  - Pre-work meeting 3 -4 days before study
- **Study execution**
  - Typically limited to 1 week in duration, with customer participation expected the first 3 days of the study, internally on 4th day, the fifth day for reporting to the customer
  - The IDL team also works internally 1 day following the study for wrap-up activities
- **Cost Estimation**
  - Typically the cost estimate, structural analysis results, and debris assessment are presented 7 business days after the study
- **Study products**
  - Provided 1 -2 weeks following study execution
  - Notional instrument block diagram, Point Design Summary (PDS) spreadsheet to summarize final instrument configuration , Optical model (s), Electrical architecture, Thermal model (based on a preliminary version of the instrument baseline that is published mid-week), Mechanical model, Structural analysis, if there is sufficient mechanical fidelity, Instrument performance verification (radiometric and optical), Reliability assessment, Pointing stability sensitivity assessment, Contamination assessment, Orbital Debris and/or micrometeorite assessment, Mass model (a.k.a. master equipment list (MEL)), Cost model

Mission Design Laboratory (MDL)

- **Initial Planning**
  - meeting approx. 1 month before study
  - Pre-work meeting 3 -4 days before study
- **Study Execution**
  - Typically limited to 1 week in duration, with customer participation expected the first 3 days of the study, internally on 4thday, the fifth day for reporting to the customer
  - The MDL team also works internally 1 day following the study for wrap-up activities
- **Cost Estimation**
  - Depending on the study, analogous, parametric and grass root cost estimation is offered;
  - MDL cost a custom spacecraft bus and may not provide cost estimates for commercial SC buses.
- **MDL Services**
  - End-to-end mission architecture concept development, existing mission/concept architecture evaluations , trade studies and evaluation, technology, risk, and independent technical assessments, requirement refinement and verification, mass/power budget allocation, cost estimation
- **Study Products**
  - Flight dynamics/orbit analysis and optimization, mechanical models, performance analysis, thermal model, analysis and concept design, power analysis, mechanism concept design, communication link analysis, ACS performance analysis and concept design, launch system accommodation and performance analysis, system engineering, I&T, mission and science operations analysis, scheduling, cost analysis, system block diagrams. Products are extensive and tailored to meet customer requirement.

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