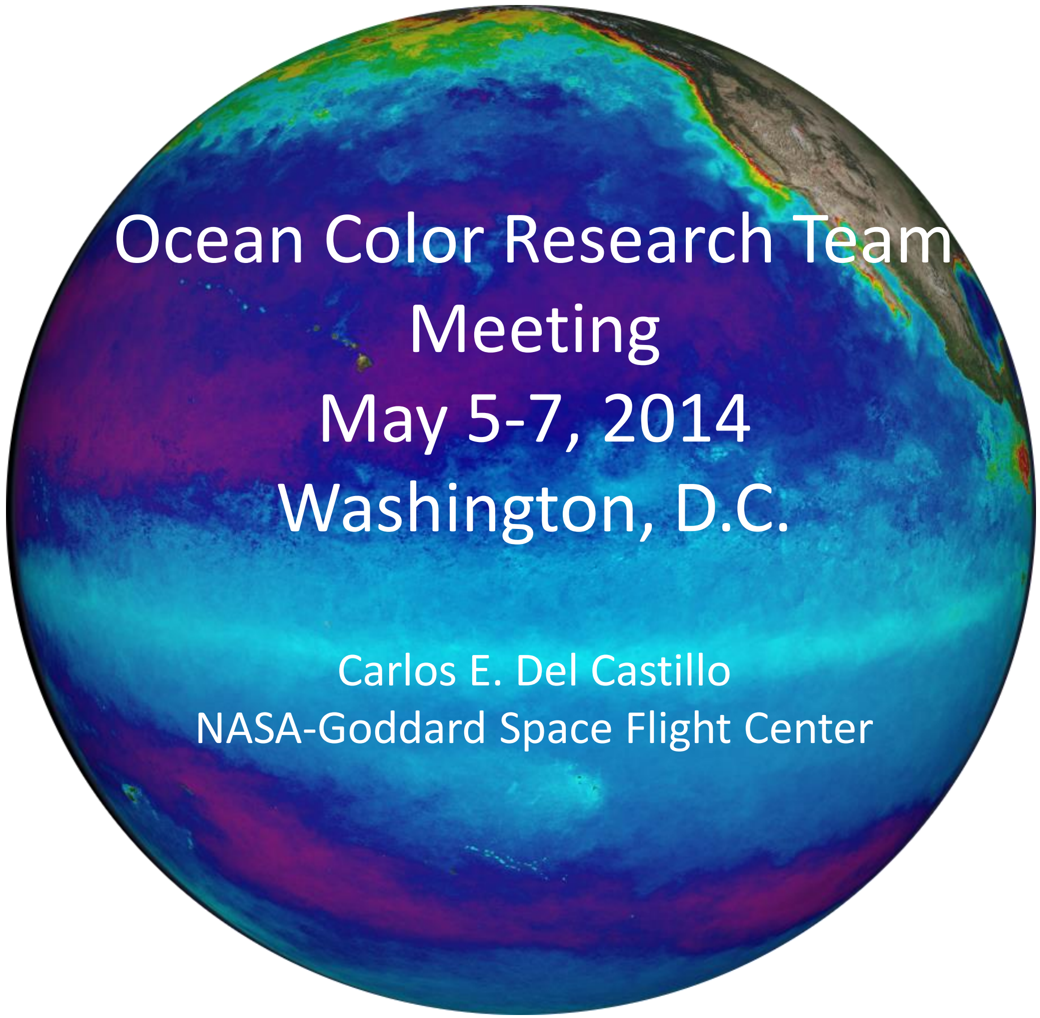
PACE *Pre-Aerosol, Cloud, and ocean Ecosystem Mission*

and beyond….

What PACE can and cannot do



Ocean Color Research Team Meeting
May 5-7, 2014
Washington, D.C.

Carlos E. Del Castillo
NASA-Goddard Space Flight Center

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

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and beyond….

Objectives

- Gather ideas to contribute to:
  - Advanced planning for OBB
  - White paper on ocean research needs (as only NASA can) to the next decadal survey.
- Primer for the next presentations on requirements for biogeochemical models, coastal research, and applications.

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and beyond….

The Fundamental PACE Science Drivers-Oceans

WHY are ecosystems changing, **WHO** within an ecosystem are driving change, **WHAT** are the consequences & **HOW** will the future ocean look?

PACE will allow research into:

- Plankton Stocks– Distinguish living phytoplankton from other constituents and identify nutrient stressors from turbid coastal waters to the bluest ocean
- Plankton Diversity – Characterize phytoplankton functional groups, particle size distributions, and dominant species
- Ocean Carbon – Assess changes in carbon concentrations, primary production, net community production and carbon export to the deep sea
- Human Impacts – Evaluate changes in land-ocean interactions, water quality, recreation, and other goods & services
- Understanding Change – Provide superior data precision and accuracy, advanced atmospheric correction, inter-mission synergies
- Forecasting Futures – Resolve mechanistic linkages between biology and physics that support of process-based modeling of future changes

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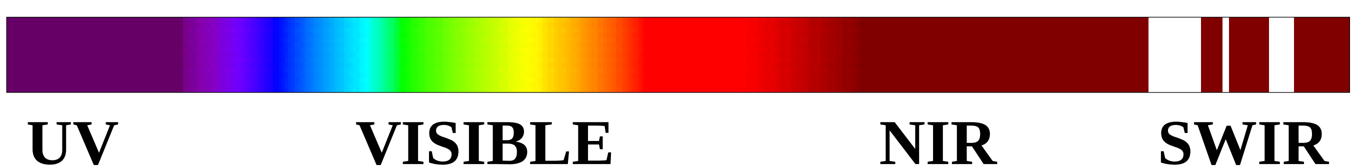
PACE will improve our understanding of ocean ecosystems and carbon cycling through its…

- <u>Spectral Resolution</u> – 5 nm resolution to separate constituents, characterize phytoplankton communities & nutrient stressors
- <u>Spectral Range</u> – Ultraviolet to Near Infrared covers key ocean spectral features
- <u>Atmospheric Corrections</u> – UV bands allow ‘spectral anchoring‘, SWIR for turbid coastal systems. A *<u>polarimeter</u> option for advanced aerosol characterization is TBD.*
- <u>Strict Data Quality Requirements</u> – Reliable detection of temporal trends and assessments of ecological rates
- PACE mission and operations concept will be **<u>similar to the successful SeaWiFS mission.</u>**



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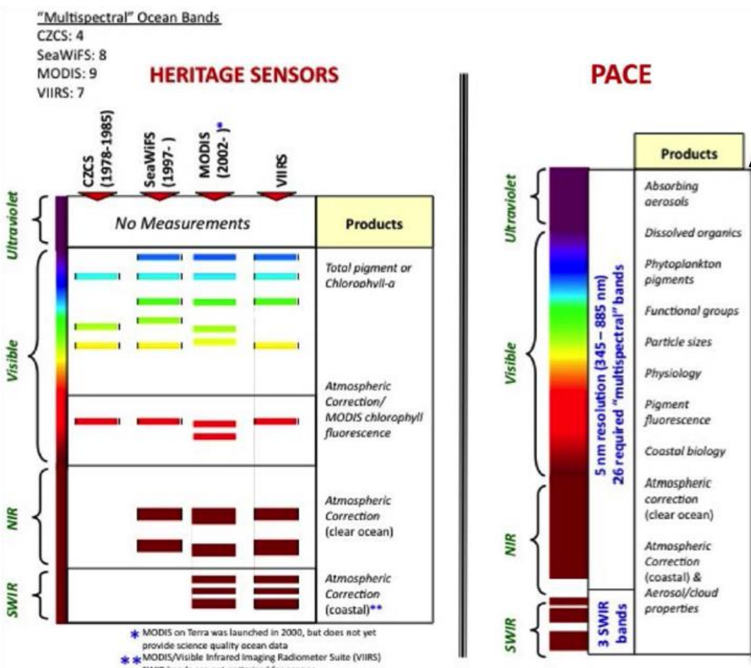
The PACE Advantage: Not just an instrument – a full mission concept

- A mission architecture that includes continual post launch calibration (including lunar and vicarious calibration), <u>algorithms development and maintenance, field validation and process studies.</u>
- Unprecedented spectral and radiometric requirements



Data will be downloaded at max resolution.

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

Instrument threshold requirements

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

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PACE Threshold Ocean Mission Science Traceability Matrix (STM)

Science Questions

1. What are the standing stocks, compositions, and productivity of ocean ecosystems? How and why are they changing?
2. How and why are ocean biogeochemical cycles changing? How do they influence the Earth system?
3. What are the material exchanges between land & ocean? How do they influence coastal ecosystems and biogeochemistry? How are they changing?
4. How do aerosols influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere?
5. How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics?
6. What is the distribution of both harmful and beneficial algal blooms and how is their appearance and demise related to environmental forcings? How are these events changing?
7. How do changes in critical ocean ecosystem services affect human health and welfare? How do human activities affect ocean ecosystems and the services they provide? What science-based management strategies need to be implemented to sustain our health and well-being?

Approach

Approach	Maps to Science Question
Quantify phytoplankton biomass, pigments, optical properties, key groups (functional/HABS), & estimate productivity using bio-optical models, chlorophyll fluorescence, & ancillary physical properties (e.g., SST, MLD)	1, 4, 2, 5, 3, 6
Measure particulate &dissolved carbon pools, their characteristics & optical properties	2, 3
Quantify ocean photobiochemical & photobiological processes	2, 4
Estimate particle abundance, size distribution (PSD), & characteristics	1, 3
Assimilate PACE observations in ocean biogeochemical model fields to evaluate key properties (e.g., air-sea CO_2 flux, carbon export, pH, etc.)	2, 4
Compare PACE observations with field- and model data of biological properties, land-ocean exchange, physical properties (e.g., winds, SST, SSH), and circulation (ML dynamics, horizontal divergence, etc)	3, 4, 5, 6
Combine PACE ocean & atmosphere observations with models to evaluate ecosystem-atmosphere interactions	4
Assess ocean radiant heating and feedbacks	5
Conduct field sea-truth measurements & modeling to validate retrievals from the pelagic to near-shore environments	1, 4, 2, 5, 3, 6
Link science, operational, & resource management communities. Communicate social, economic, & management impacts of PACE science. Implement strong education & capacity building programs	7

Measurement Requirements

- water leaving radiance at 5 nm resolution from 350 to 800 nm
- 10 to 40 nm wide atmospheric correction bands at 350, 820 (or 940), 865, 1240, 1640, and 2130 nm
- characterization of instrument performance changes to ±0.2% in first 3 years & for remaining duration of the mission
- monthly characterization of instrument spectral drift to 0.3 nm accuracy
- daily measurement of dark current & a calibration target/source with its degradation known to ~0.2%
- Prelaunch characterization of linearity, RVVA, polarization sensitivity, radiometric & spectral temperature sensitivity, high contrast resolution, saturation, saturation recovery, crosstalk, radiometric & band-to-band stability, bidirectional reflectance distribution, & relative spectral response
- overall instrument artifact contribution to TOA radiance of < 0.5%
- image striping to < 0.1% in calibrated top-of-atmosphere radiances
- crosstalk contribution to radiance uncertainties of 0.1% at L_{typ}
- polarization sensitivity ≤ 1%
- knowledge of polarization sensitivity to ≤ 0.2%
- no detector saturation for any science measurement bands at L_{max}
- RVVA of < 5% for entire view angle range & < 0.5% for view angles differing by less than 1°
- Stray light contamination for the instrument < 0.2% of L_{typ} 3 pixels away from a cloud
- Out-of-band contamination < 0.01 for all multispectral channels
- Radiance-to-counts characterized to 0.1% over full dynamic range
- Global spatial coverage of 1 km x 1 km (±0.1 km) along-track
- Multiple daily observations at high latitudes
- View zenith angles not exceeding ±60°
- Standard marine atmosphere, clear-water $[r_w(l)]_N$ retrieval with accuracy of max[5%, 0.001] over the wavelength range 400 – 710 nm
- SNR at L_{typ} for 1 km^2 aggregate bands of 1000 from 360 to 710 nm; 300 @ 350 nm; 600 @ NIR bands; 250, 180, and 15 @ 1240, 1640, & 2130 nm
- Absolute calibration to 2% pre-launch and 5% on-orbit (before vicarious calibration)
- 3 hour data latency and direct broadcast of aggregate spectral bands
- Simultaneity of 0.02 second

Implementation Requirements

Vicarious Calibration: Ground-based R_{rs} data for evaluating post-launch instrument gains. Features: (1) Spectral range = 350 - 900 nm at ≤ 3 nm resolution, (2) Spectral accuracies ≤ 5%, (3) Spectral stability ≤ 1%, (4) Deploy = 1 yr prelaunch through mission lifetime, (5) Gain standard errors to ≤ 0.2% in 1 yr post-launch, (6) Maintenance & deploy centrally organized, & (7) Routine field campaigns to verify data quality & evaluate uncertainties

Product Validation: Field radiometric & biogeochemical data over broad possible dynamic range to evaluate PACE science products. Features: (1) Competed & revolving Ocean Science Teams, (2) PACE-supported field campaigns (2 per year), (3) Permanent/public archive with all supporting data

Ocean Biogeochemistry-Ecosystem Modeling

- Expand model capabilities by assimilating expanded PACE retrieved properties, such as NPP, IOPs, & phytoplankton groups & PSD's
- Extend PACE science to key fluxes: e.g., export, CO_2, land-ocean exchange

Platform Reqmts.

- 2-day global coverage to solar zenith angle of 75°
- Sun-synchronous polar orbit with equatorial crossing time between 11:00 and 1:00
- Maintain orbit to ±10 minutes over mission lifetime
- Mitigation of sun glint
- Mission lifetime of 5 years
- Storage and download of full spectral and spatial data
- Monthly lunar observations at constant phase angle through Earth observing port
- System-level pointing accuracy of 2 IFOV and knowledge equivalent to 0.1 IFOV over the full range of viewing geometries
- System-level pointing jitter accuracy of 0.01 IFOV or less between any adjacent spatial samples
- Spatial band-to-band registration of 80% of one IFOV between any two bands, without resampling

Other Needs

Capability to reprocess full data set 1 – 2 times annually

Ancillary data sets from models missions, or field observations:

Measurement Requirements
(1) Ozone
(2) Water vapor
(3) Surface wind velocity and barometric pressure
(4) NO_2

Science Requirements
(1) SST
(2) SSH
(3) PAR
(4) UV
(5) MLD
(6) CO_2
(7) pH
(8) Ocean circulation
(9) Aerosol deposition
(10) run-off loading in coastal zone

Atmosphere

With just an ocean color radiometer:

ASQ-1 - In combination with data records that were begun with heritage/existing imagers, what are the long-term changes in aerosol and cloud properties that can be continued with PACE and how are these properties correlated with inter-annual climate oscillations?

With an ocean color radiometer + a multi-angle polarimeter :

ASQ-4 - What are the magnitudes and trends of Direct Aerosol Radiative Forcing (DARF), and the anthropogenic component of DARF?

ASQ-5 - How do aerosols influence ocean ecosystems and biogeochemical cycles?

Challenges of PACE

PACE main instrument will be a passive ocean color UV-VIS-SWIR radiometer flying on a sun-synchronous low Earth orbit.

- No science that may require active sensors
  - No LIDAR
- Limits to coastal research
  - LEO results in low dwell time, low signal. Researchers may have to choose between spatial an spectral resolution.
  - Same time of day revisit + cloud cover limits observation of processes – use in special events (e.g. spills, HABS).
  - Limits to atmospheric correction if we don't fly a polarimeter.

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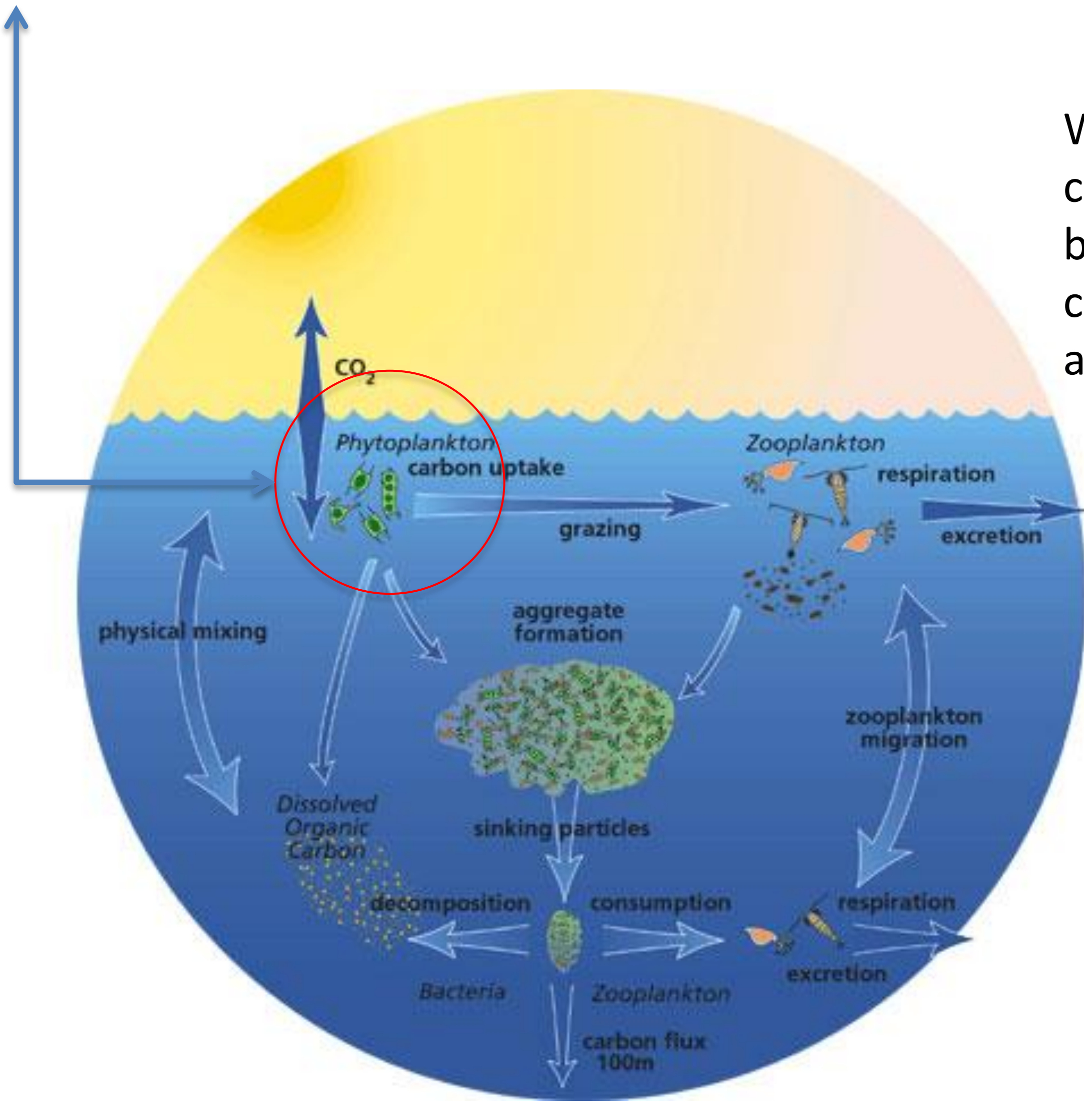

What other components of the biological pump could be addressed as only NASA can??

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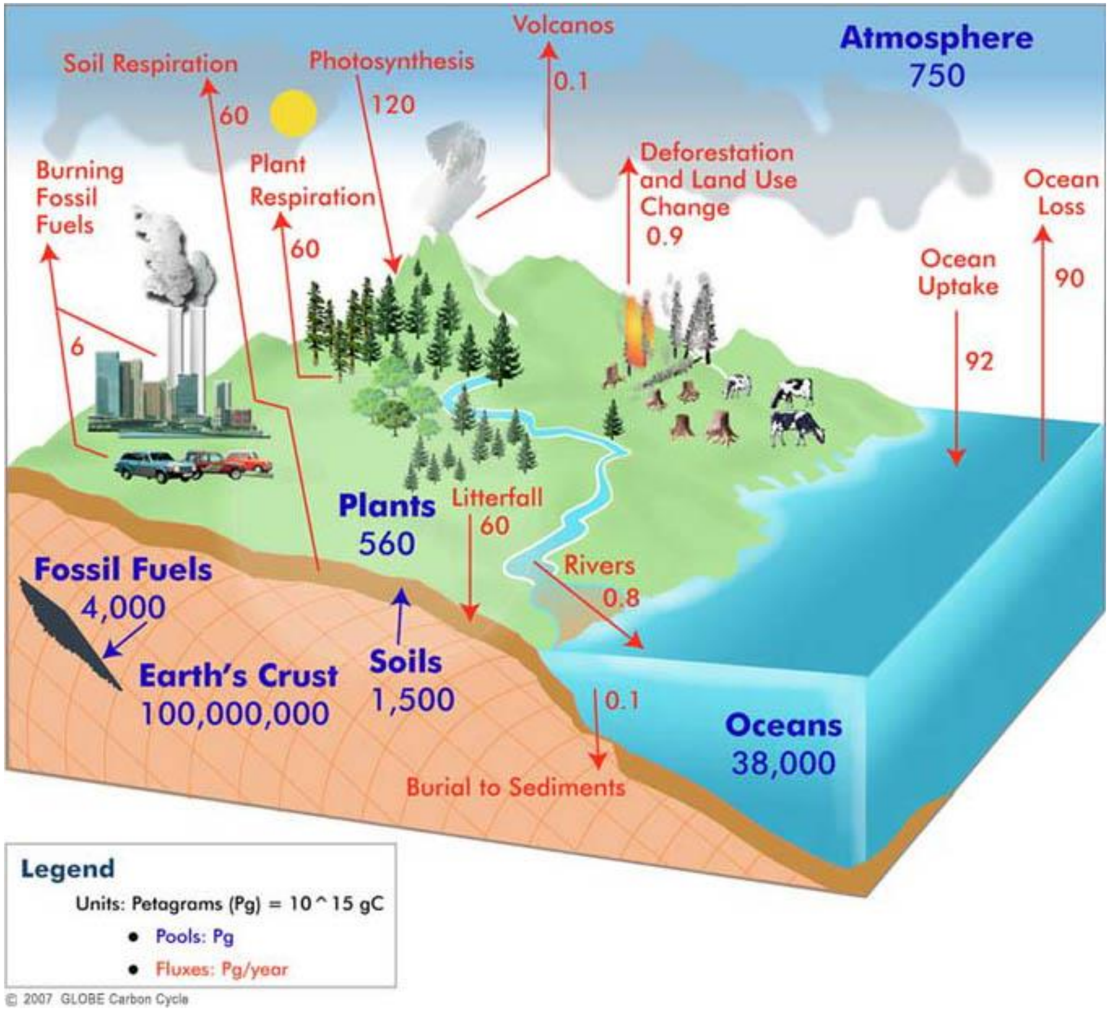

Final thoughts

- Think about science questions, not about the measuring technology
- Not all the science questions need or can be addressed from a large, complex mission – these are expensive and infrequent. Think about Earth Venture class missions. <u>Consider becoming a PI!</u>

EV Solicitation Schedule

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
EV-S-1	none	EVM-1	EVI-1	EVS-2; EVI-2	none	EVM-2; EVI-3	EVI-4	EVS-3	EVI-5	EVM-3; EVI-6	none	EVI-7

Key
EVS: Earth Venture Sub-Orbital solicitation
EVM: Earth Venture Full Orbital Mission solicitation
EVI: Earth Venture Instruments solicitation

http://science.nasa.gov/about-us/smd-programs/earth-system-science-pathfinder/

QUESTIONS ?????????????