ACE Mission Architecture

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Mission Architecture

ACE science requirements, as described by the STMs, define the overall ACE mission scope. The mission architecture, however, is based on the optimization of many factors including:

- Instrument alternatives
- International participation
- Orbit
- Number of platforms
- Science return and cost

ACE Mission Architecture Team evaluated 6 (+) mission concepts that meet the ACE science requirements and provide a number of viable options for mission implementation.

ACE Instruments

- The following core instruments were identified in the Decadal Survey:

  - HSRL Lidar for aerosol/ cloud heights and aerosol properties
  - Dual frequency, Doppler cloud radar for profiles of cloud properties and precipitation
  - Multi-angle, multi-spectral imaging polarimeter for aerosol and clouds
  - Ocean color multi-channel spectrometer for ocean ecosystems

- In addition, the ACE Science Definition Team recognizes the high science return from inclusion of the following instruments:

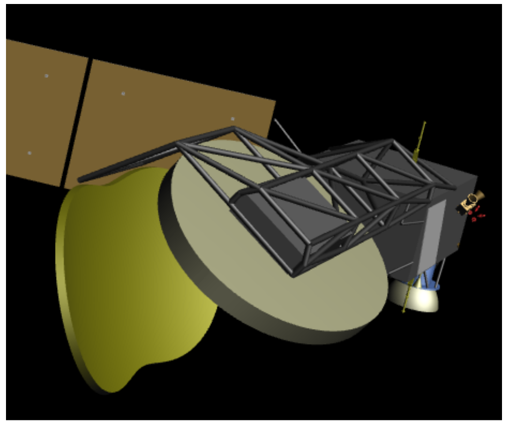
  - IR multi-channel imager for cloud temperatures and heights*
  - High frequency swath radiometer for cloud ice measurements
  - Low frequency swath radiometer for precipitation measurements

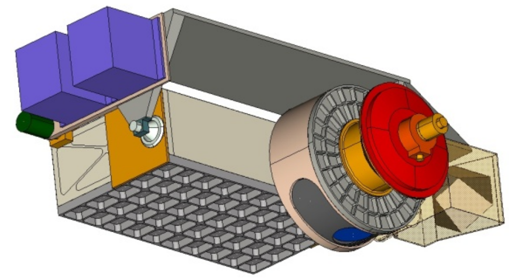
Several mission studies included accommodation of the additional instruments

* IR instrument is referenced in Chapter 9 of Decadal Survey as a necessary for ACE

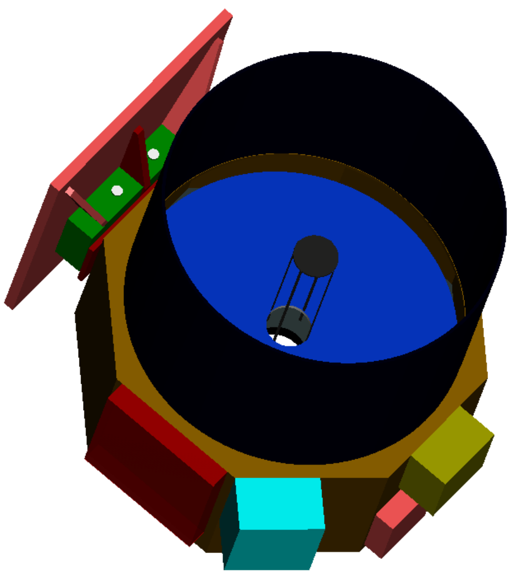
Instruments for Mission Studies

Cloud Profiling Radar

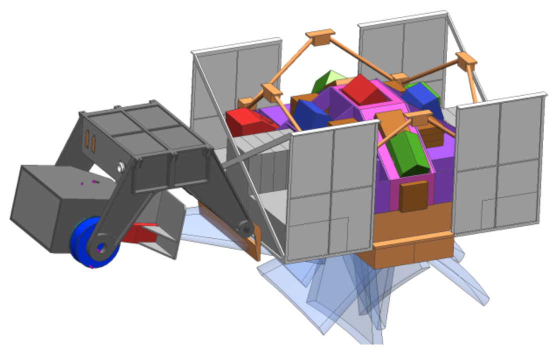




Ocean Radiometer for Carbon Assessment (ORCA)



High Spectral Resolution Lidar (HSRL)



Multiangle Spectro Polarimetric Imager (MSPI)

International Collaboration

ACE Mission Architecture Team conducted a preliminary assessment of potentially complementary science missions flying at the same time as well as potential contributed instruments

- Additional study is required to incorporate recommendations for ACE architecture although time frame for several opportunities is relatively near term

- Results from on-going discussions between NASA and CNES, and CSA regarding potential collaboration on instruments and missions, including PACE, will likely influence recommendations for the ACE architecture

Orbit Considerations

- Orbit: sun synchronous
- 450km preferred by active instruments
- 705 km preferred for international and interagency contributions via formation flying
- Observation fusion for data products, like in the A-Train CloudSat/ CALIPSO/MODIS, will be required
- Separate vs. Shared platform
  - Impact of flying active instruments on single versus multiple platforms (i.e. radar/lidar measurement overlap)

Summary of Options

One Platform

RLOP

Notation:
Radar (R)
Lidar (L)
OES (O)
Polarimeter (P)

Two Platforms*

ACE 1: O
ACE 2: RLP

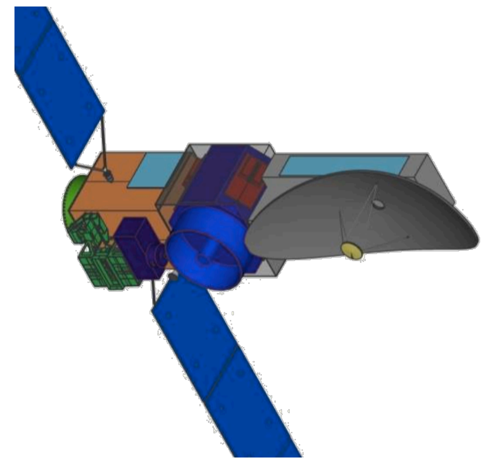
ACE 1: OP
ACE 2: RL

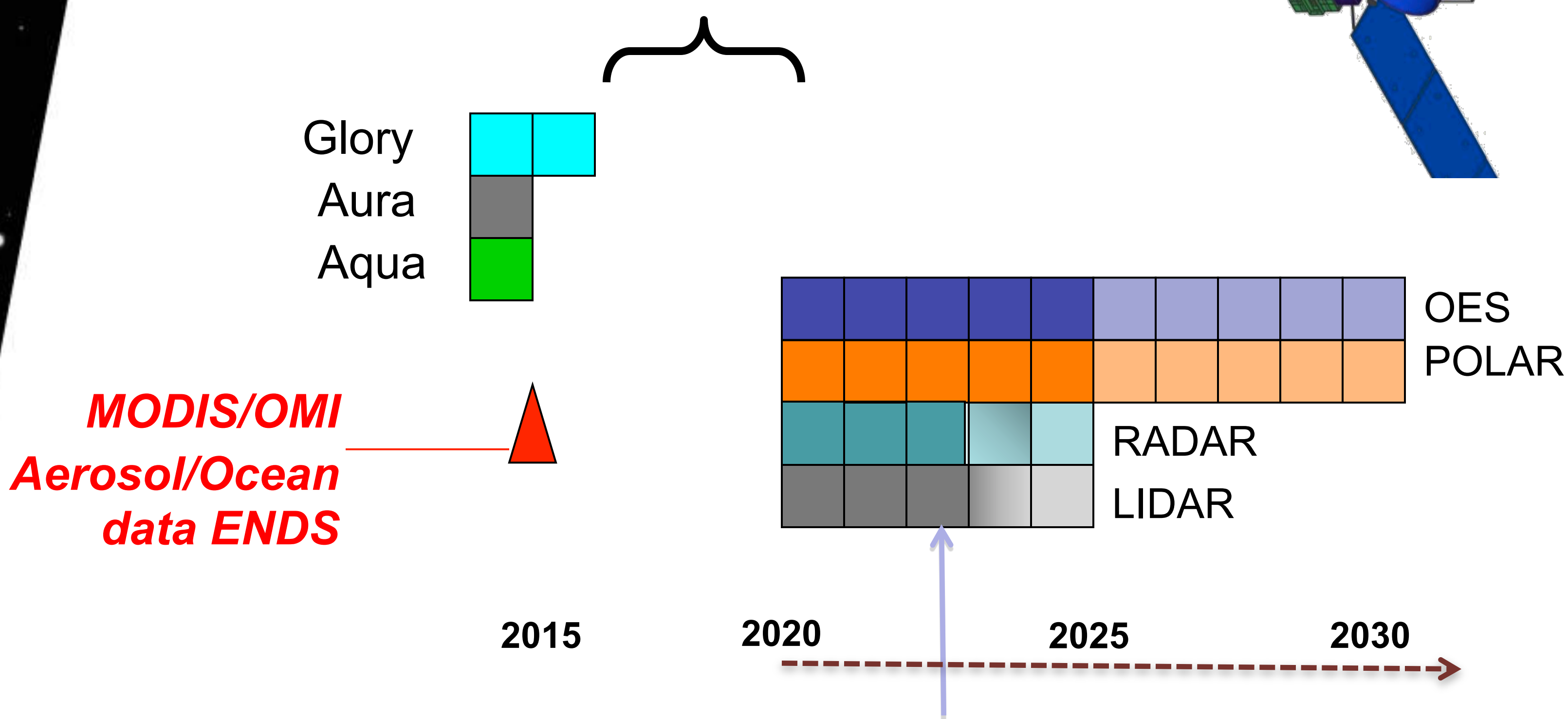
ACE 1: O
ACE 2: RLP + IR + submm + microwave

ACE 1: LOP + IR
ACE 2 R

*3 and 4 platform options have also been considered and several options merit further study

Option 1
Single Platform Architecture





1 year blocks – life times are worst case Instrument life, likely to be much longer based on experience

Option 1

Single Platform Architecture

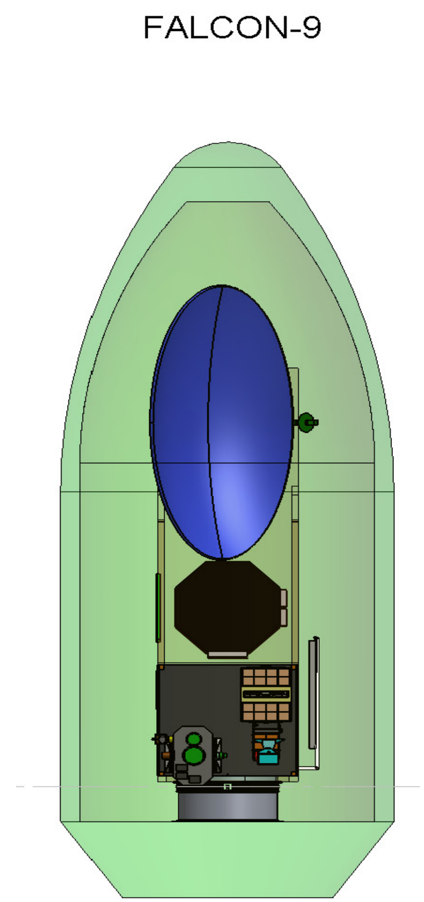
- ACE Core instruments:
  - Radar, Lidar, Polarimeter, OES
- Instrument life expected to exceed 3 year minimum mission based on CALIPSO and CloudSat experience
  - Lidar and Radar lifetimes can be lengthened by hardware enhancements, such as multiple laser units as done with CALIOP
- Custom built spacecraft as well as modified RSDO spacecraft meet requirements
- 450 km sun synchronous orbit
- Delta IV/Atlas V/Falcon 9 launch vehicles meet mission requirements
- Advantages:
  - Fulfills NRC Decadal Survey requirements for full ACE mission
  - Optimizes orbit for atmospheric science and improves atmospheric measurement sensitivity compared to higher altitude orbit
  - Minimizes launch vehicle costs and reduces overall operational complexity
- Disadvantages
  - Requires significant funding in Phase B to fund multiple instrument development
  - Limits post-launch flexibility

Option 1
Payload Summary

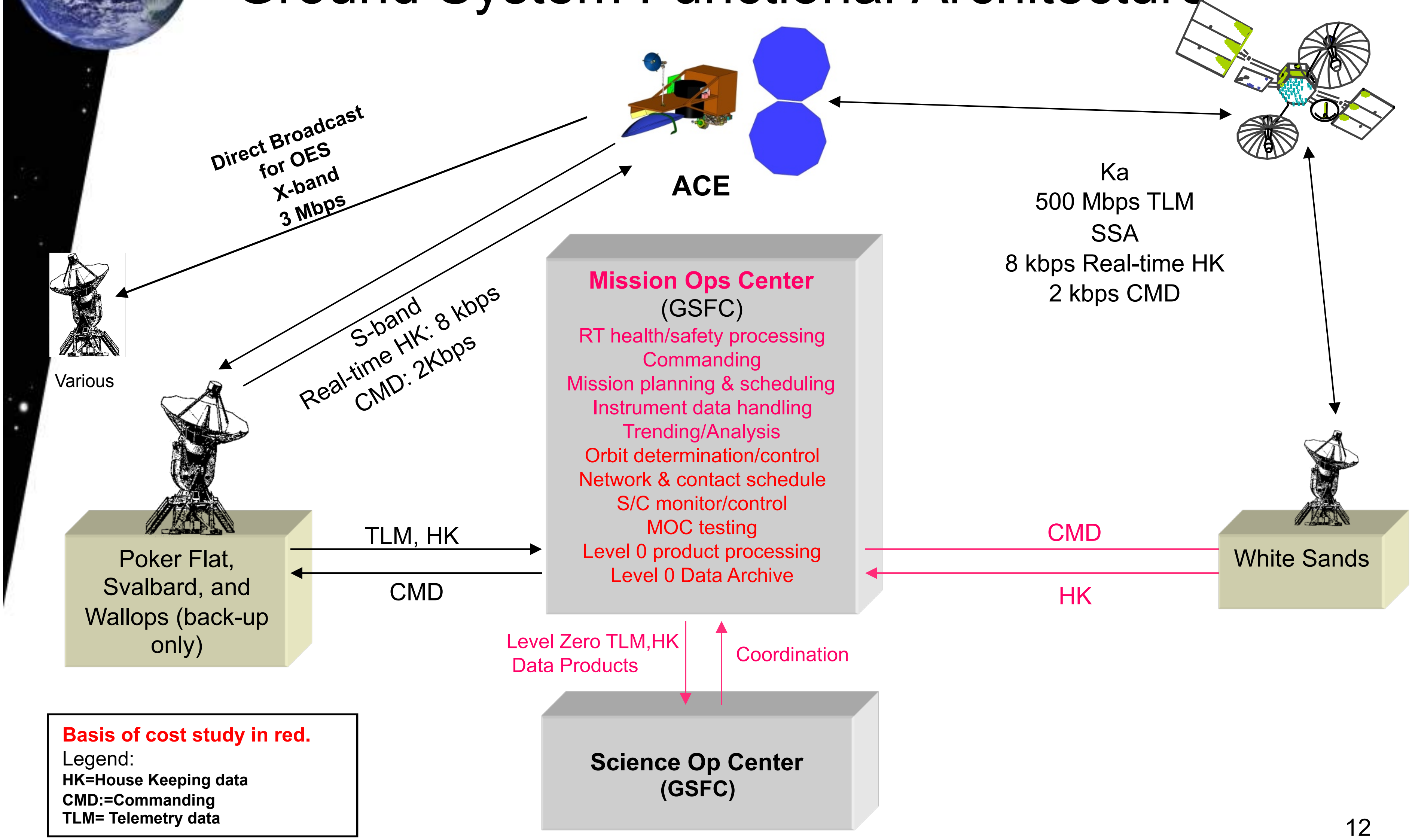
Instrument	Mass (Kg)	Orbit Average Power (W)	Raw Science Data Rate (Mbps)	Data Compression Ratio	Output Data (Mbps)	Observa-tion Duty Cycle	Orbit Avg Data Rate (Mbps)
Polarimeter	132	152	15.5	2:1	7.75	60%	4.65
Lidar	515	658	11.06	2:1	5.53	100%	5.53
CPR	480	700	20	4:1	5.0	100%	5.0
OES	137	132	12	2:1	6.0	40%	2.4
Payload Total	**1,264**	**1,642**	**58.56**		**24.28**		**17.58**

Option 1
Single Platform Architecture

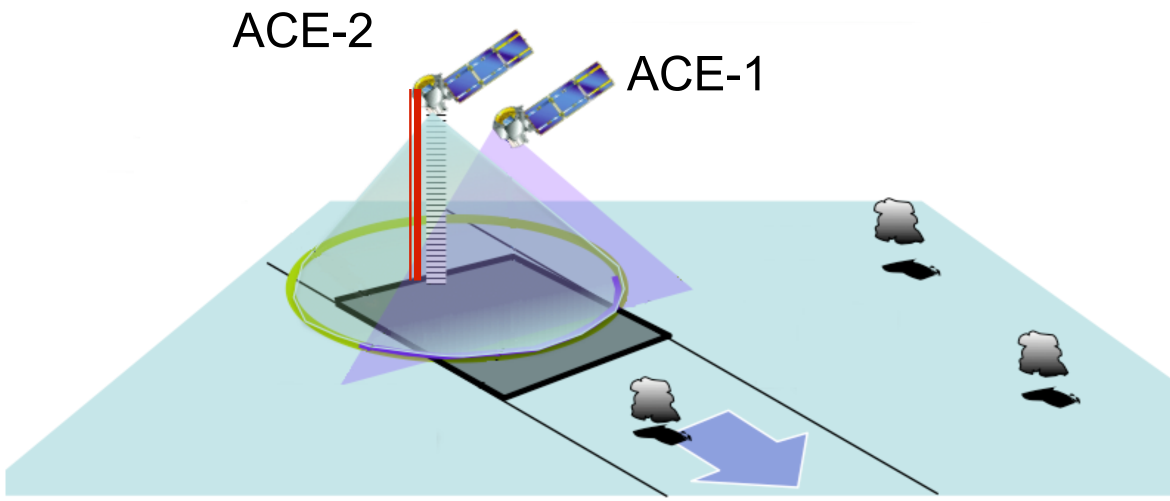
Launch Vehicle	ACE Observatory Wet Mass	Capability to 450 km
Taurus II	3762 kg	3200
Atlas V (501)	3762 kg	6030
Delta IV (4250-14)	3762 kg	6860
Falcon 9	3762 kg	8400



Option 1
Ground System Functional Architecture



Two Platform Options

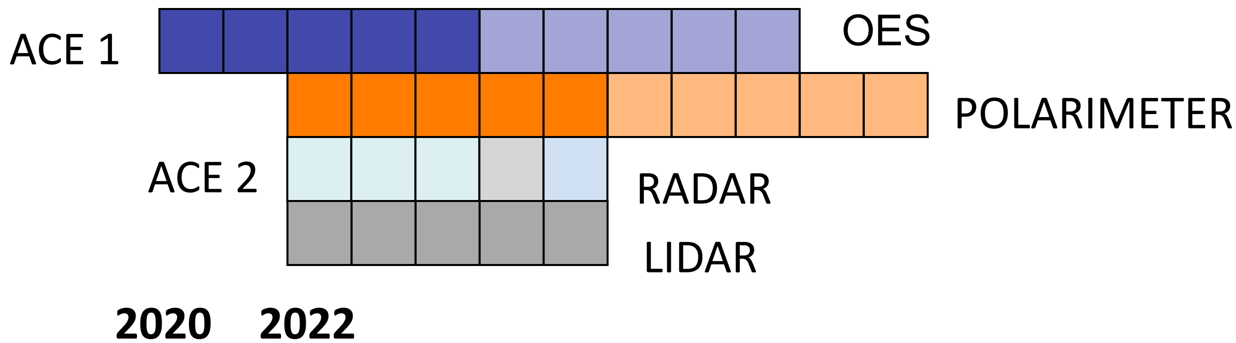


Two platforms to fly in formation

Advantages:

- Total cost is spread out over a longer period of time and reduces budget stress
- Provides more opportunity for international collaboration

Option 2a



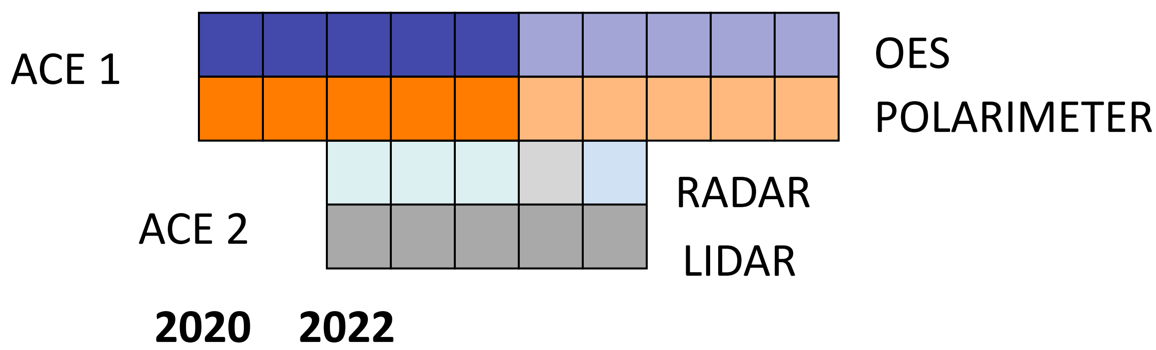
Advantages:

•Early acquisition of ocean ecology data

•Potential international collaboration with ACE 1 flying in formation with EarthCARE mission and/or a CNES provided polarimeter on ACE 1

•Potential for 10+ years of measurements

Option 2b



Advantages:

•Polarimeter provides context for aerosol and cloud measurement
•Potential international collaboration with ACE 1 flying in formation with EarthCARE mission
•Potential for 10+ years of measurements

Option 2c

ACE 1: OES
ACE 2: Radar, Lidar, Polarimeter, IR, sub-mm, and microwave

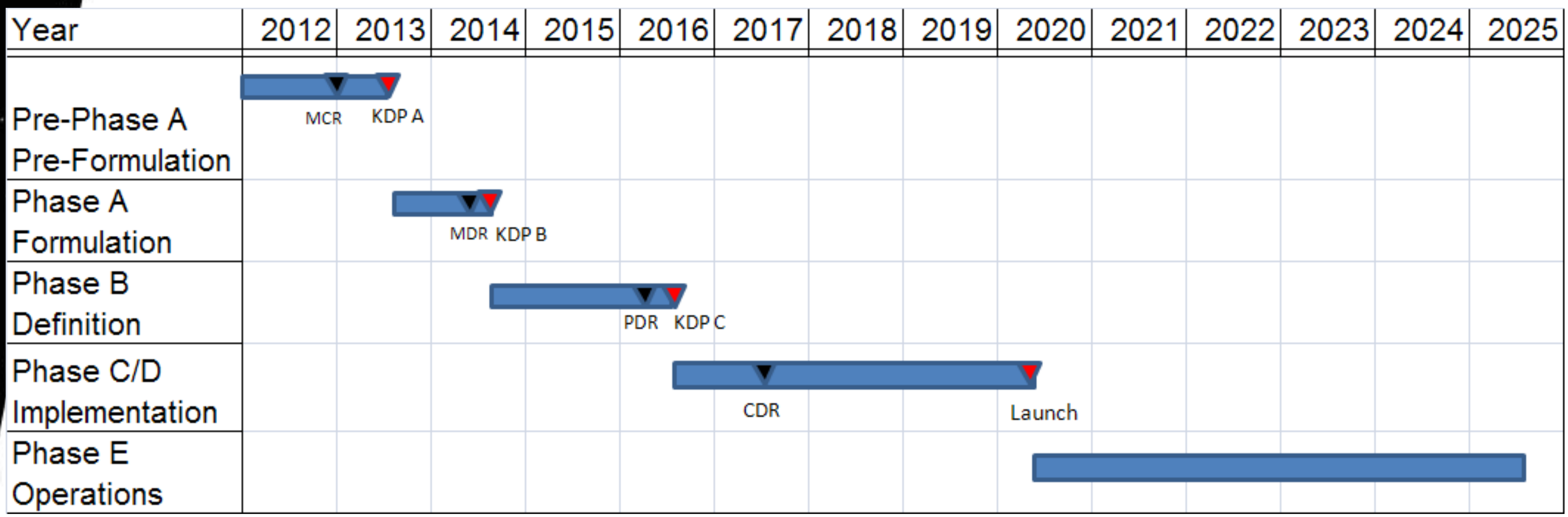
Advantages:
- Full suite of instruments to achieve science as described by ACE Science Definition Team
- Potential international collaboration with ACE 1 flying in formation with EarthCARE mission and/or a CNES provided polarimeter on ACE 1

Option 2d

ACE 1: OES, Lidar, Polarimeter, IR
ACE 2: Radar

Advantages:
- Polarimeter provides context for aerosol and cloud measurement
- Full suite of instruments necessary to achieve science described in Decadal Survey

ACE Notional Schedule
Single Platform (Option 1)



Phase A: 12 months

Phase B: 24 months -- assumes competitive instrument procurement and instrument PDRs 3-6 months prior to Mission CDR

Phase C/D: 48 months

Phase E: 60 months

ACE Mission Options Summary

Option	Description	Estimated Cost*	Comments
1	RLOP	**0.74 x A**	Fulfills NRC Decadal Survey requirements for ACE mission
2a	O RLP	**A**	Early ocean ecology data Flattens funding profile requirements Increases potential for international participation Potential CNES-provided polarimeter on ACE1
2b	OP RL	**1.01 x A**	Polarimeter with OES provides context for aerosol and cloud measurement
2c	O RLP + IR + submm + microwave	**1.27 x A**	Enhanced science capability Increases potential for international participation
2d	LOP + IR R	**1.15 x A**	Fulfills NRC Decadal Survey requirements for ACE mission

*Cost estimates have not been reconciled between MDL/Team X, FY$, Class B vs C+ and mission duration. For this public release to the science community, it was decided that ROM information about relative costs would still be useful, but to not provide an absolute scale until these factors are better normalized.

Mission Summary

- ACE mission requirements are well known and strongly coupled to the STMs
- JPL and GSFC have evaluated 6 (+) mission concepts that include a single mission scenario as well as multiple platform options that provide earlier data acquisition and longer data collection
  - All mission concepts satisfy Decadal Survey requirements for ACE science
  - Recommendation on ACE architecture or identification of additional studies is dependent on the outcome of on-going discussions regarding potential international collaboration on ACE and PACE as well as Agency decisions on the science scope of PACE
- Based on the instruments technology readiness the ACE mission can proceed with a LRD as early as 2020

Mission Architecture
Path forward

- Select baseline architecture and perform more detailed design on mission implementation
  - Pursue international collaboration consistent with mission concept and orbit analyses
  - Initiate independent cost estimate
  - Continue and expand mission systems engineering activities including Risk definition

Back up

Mission Concept Study History

2007 ACE Mission Concept Study: MDL Study

- MSPI + ORCA + Lidar + IRCIR

2009 ACE Core: MDL Study

- MSPI + ORCA + Lidar + CPR'

ACE 1 (aka PACE): MDL Study

- ORCA + 3MI + ATMS

Multiple Platforms Options:

- Radar only platform: Team X Study
- Radar and Lidar platform: Team X Study
- Lidar only platform: Team X Study

2010 ACE 2: Team X Study

- CPR, HSRL, MSPI, SM4, IRCIR, GMI

Smallsat accommodation of multiple ACE platforms: JPL Study 2010

ACE Radar-Lidar Co-alignment I

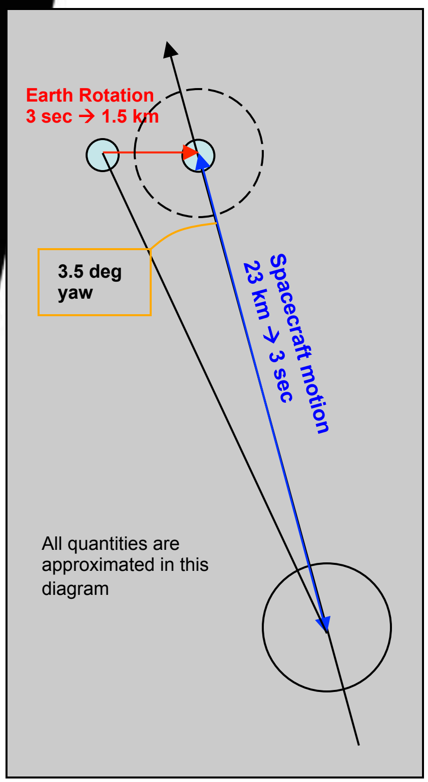
Geodetic vs. Geocentric reference

- Geodetic
  - Nadir is normal to the Earth's surface, not to the spacecraft trajectory
  - Minimizes contamination from horizontal wind components along line of sight
  - Doppler shift from platform motion can vary by about 50 m/s (i.e., 280 MHz shift variation at 355 nm and 31 kHz at W-band).
- Geocentric
  - Nadir is normal to the spacecraft trajectory, not the Earth's surface
  - Minimizes fluctuation of Doppler shift from platform motion
  - Incidence angle on Earth's surface swings about +/- 0.2 degrees. Occasional high-level jet stream can reach 100 m/s: if perfectly aligned along direction of sight, it can introduce a bias on Doppler measurements of 0.35 m/s. Such occurrence is rare and reported in GCM models (i.e., correction possible in ground-processing).

Geocentric is favored because geodetic causes a larger Doppler shift fluctuation

ACE Radar-Lidar Co-alignment II

Separate vs. Shared platform



- Separate platform is more flexible to perform in-orbit adjustments (e.g., CloudSat CALIPSO), but frequent maneuvers may be required to keep lidar footprint within radar nadir footprint track. Differential cross-section offered to drag and spacecraft mass are the main factors defining how frequent these maneuvers may have to be.
- Shared footprint requires orbit-period yawing to keep lidar footprint within radar nadir footprint track. Preliminary simulations show that a +/- 3.5 deg yaw at ascending and descending nodes are sufficient.
  - Preliminary feedback from bus providers indicates that this is feasible, but detailed analysis is required for specific spacecraft configurations
  - Additional Doppler shift fluctuation due to yaw maneuvering is less than 1 m/s (i.e., 5.6 MHz at 355 nm, 650 Hz at W-band)

International Collaboration

Partner	**Instrument/Contribution**	**Opportunity/ Mission**	**LRD/Orbit**
ESA	CPR, HSRL, MSI, BBR	EarthCARE	2015
			400+ km
CSA	Radar	APOCC/SnowSat	
	Polarimeter	APOCC/MCAP	
	Infrared camera	APOCC/TICFIRE	
JAXA	Submm	GCOM-W3	2018 700 km
	Science, data processing, and cal/val contributions		

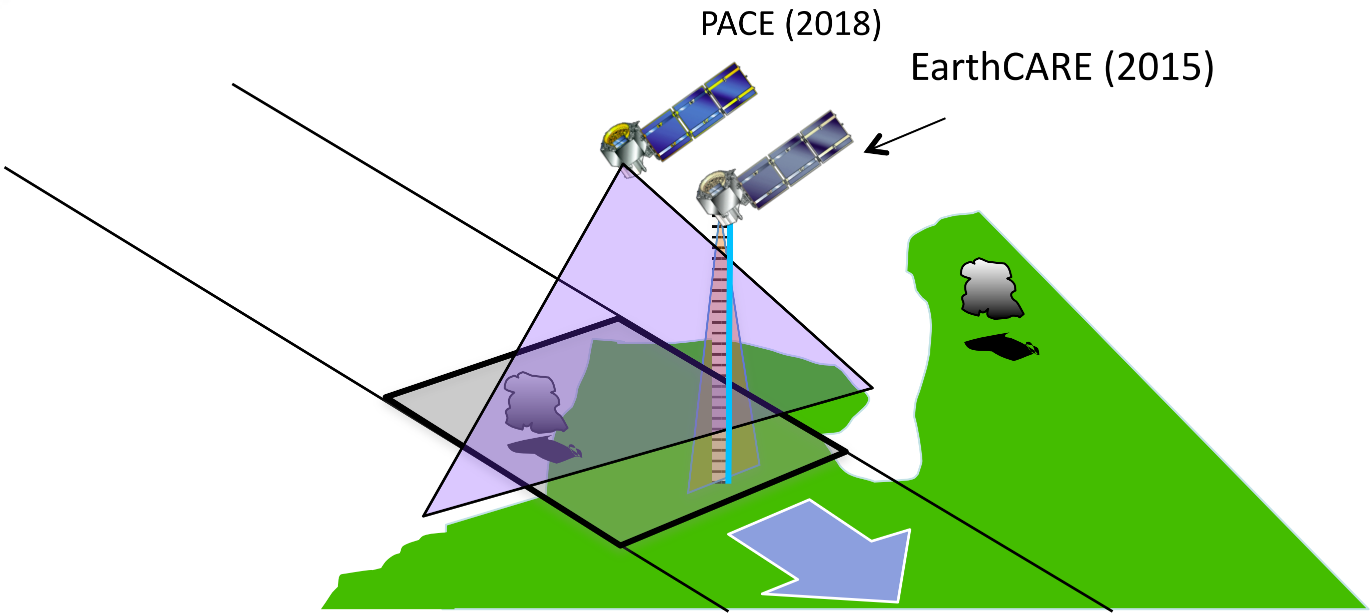
EarthCARE Option

- EarthCARE (LRD 2015) orbits at 400 km, PSS, 13:45 crossing time
- EC payload consists of
  - CPR 94 GHz -36dBz Doppler radar
  - HSRL (355nm) (ATLID)
  - Multi-angle BB (2 channel, 0.2-4μ radiometer)
  - MSI - 7 channel, 150 km swath imager (500m nadir: 0.66, 0.865, 1.6, 2.2, 8.2, 10.8, 12.)
- EC lacks a polarimeter and a wide swath multi-channel UV-visible radiometer
- Concept for ACE 1 to fly in formation with EarthCARE augmenting EC observations
- ACE 2 then launches the other instruments behind EC/ACE 1 later in the decade, but at a higher orbit (450km)
  - ACE 1 raises orbit to meet ACE 2

ACE and EarthCARE

EC+ACE1	ACE	Comment
W-Band Doppler	W and Ka-Band Doppler	ACE radar sensitive to larger particles and precip.
3MI	MSPI or equiv.	More accurate polarization, more wavelengths
OES	OES	Same
BB IR	-	Crude ERB measurement
MSI	OES+IR imager	ACE has more wavelengths, ACE pixels slightly larger
ATMS	models	Nadir μwave sounding unit, T and Humidity, cloud properties
HSRL 1 λ	HSRL-3λ	ACE HSRL has 3 wavelengths vs EC 1 wavelength
-	HF μ radiometer	Scanning - cloud ice properties
ATMS	LF μ radiometer	Scanning - cloud precip properties

ACE+EarthCARE Observing Geometry



Potential Instrument Providers*

	Radar	Lidar	OES	Polarimeter	submm	IR	microwave
JPL	x			x	x		
GSFC		x	x	x	x	x	x
LaRC		x					
ESA		x			x	x	
CNES				x		x	
JAXA	x				x		x
CSA	x					x	
US Industry/ Other	x	x	x	x	x	x	x

*Not exhaustive

Option Comparison, Power

	Option 2	Option 3	Option 4	Option 5
	Mode 1	Mode 1	Mode 1	Mode 1
	Power (W)	Power (W)	Power (W)	Power (W)
	Eclipse + Insts + Comm	Eclipse + Insts + Comm	Eclipse + Insts + Comm	Eclipse + Insts + Comm
Mode Duration(hours)	*0.6*	*0.6*	*0.6*	*0.6*
Payload on this Element				
ments	1629	1629	1754	1538
yload Total	1629	1629	1754	1538
ude Control	163	163	163	163
mand & Data	69	69	69	69
ver	329	334	356	310
pulsion1	16	16	16	16
lecom	115	115	115	115
hermal	124	140	124	121
Bus Total	818	839	845	796
pacecraft Total (Dry)	2447	2468	2599	2334
System Contingency	1052	1061	1117	1003
Spacecraft with Contingency	3499	3529	3716	3337

- Power differences among Options were driven by changes in the Power and Thermal subsystems
  - Array sizes -- Opt 1: 27.9m^2; Opt 2: 31.6 m^2; Opt 3: 29.7 m^2; Opt 4: 26.7 m^2
  - Option 2 (Baseline) power usage in Mode 1 is 3499 W
  - Option 3 (3529 W) has larger arrays to accommodate degradation over 10 yr lifetime
    - Small increases in Power and Thermal subsystems due to larger arrays
  - Option 4 (3716 W) uses more power due to addition of GMI
  - Option 5 (3337 W) uses less power due to substitution of skinny radar

ACE Project Lifecycle Schedule