ACE Mission Architecture

JPL: Armin Ellis, Deborah Vane, Simone Tanelli
GSFC: Dave Starr, Lisa Callahan, Rick Wesenberg
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.
• 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

High Spectral Resolution Lidar (HSRL)

Ocean Radiometer for Carbon Assessment (ORCA)

Multiangle Spectro Polarimetric Imager (MSPI)
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

Aerosol and OES data gap

MODIS/OMI
Aerosol/Ocean data ENDS

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

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Mass (Kg)</th>
<th>Orbit Average Power (W)</th>
<th>Raw Science Data Rate (Mbps)</th>
<th>Data Compression Output Data Ratio</th>
<th>Observation Duty Cycle</th>
<th>Orbit Avg Data Rate (Mbps)</th>
</tr>
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<tbody>
<tr>
<td>Polarimeter</td>
<td>132</td>
<td>152</td>
<td>15.5</td>
<td>2:1</td>
<td>60%</td>
<td>4.65</td>
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<tr>
<td>Lidar</td>
<td>515</td>
<td>658</td>
<td>11.06</td>
<td>2:1</td>
<td>100%</td>
<td>5.53</td>
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<tr>
<td>CPR</td>
<td>480</td>
<td>700</td>
<td>20</td>
<td>4:1</td>
<td>100%</td>
<td>5.0</td>
</tr>
<tr>
<td>OES</td>
<td>137</td>
<td>132</td>
<td>12</td>
<td>2:1</td>
<td>40%</td>
<td>2.4</td>
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<tr>
<td><strong>Payload Total</strong></td>
<td><strong>1,264</strong></td>
<td><strong>1,642</strong></td>
<td><strong>58.56</strong></td>
<td><strong>24.28</strong></td>
<td><strong>17.58</strong></td>
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</table>
### Option 1
**Single Platform Architecture**

<table>
<thead>
<tr>
<th>Launch Vehicle</th>
<th>ACE Observatory Wet Mass</th>
<th>Capability to 450 km</th>
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<tbody>
<tr>
<td>Taurus II</td>
<td>3762 kg</td>
<td>3200</td>
</tr>
<tr>
<td>Atlas V (501)</td>
<td>3762 kg</td>
<td>6030</td>
</tr>
<tr>
<td>Delta IV (4250-14)</td>
<td>3762 kg</td>
<td>6860</td>
</tr>
<tr>
<td>Falcon 9</td>
<td>3762 kg</td>
<td>8400</td>
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</table>
Option 1
Ground System Functional Architecture

Mission Ops Center (GSFC)
- RT health/safety processing
- Commanding
- Mission planning & scheduling
- Instrument data handling
- Trending/Analysis
- Orbit determination/control
- Network & contact schedule
- S/C monitor/control
- MOC testing
- Level 0 product processing
- Level 0 Data Archive

Science Op Center (GSFC)

Basis of cost study in red.
Legend:
HK=House Keeping data
CMD:=Commanding
TLM=Telemetry data

Legend:
HK=House Keeping data
CMD=Commanding
TLM=Telemetry data

Direct Broadcast for OES
X-band
3 Mbps

Various

Poker Flat, Svalbard, and Wallops (back-up only)

S-band
Real-time HK: 8 kbps
CMD: 2Kbps

TLM, HK

White Sands

Ka
500 Mbps TLM
SSA
8 kbps Real-time HK
2 kbps CMD

Coordination

Level Zero TLM,HK Data Products
Two Platform Options

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

<table>
<thead>
<tr>
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<td>Pre-Phase A Formulation</td>
<td>MCR</td>
<td>KDP A</td>
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<tr>
<td>Phase A Formulation</td>
<td></td>
<td></td>
<td>MDR</td>
<td>KDP B</td>
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<tr>
<td>Phase B Definition</td>
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<td>PDR</td>
<td>KDP C</td>
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<tr>
<td>Phase C/D Implementation</td>
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<td></td>
<td>CDR</td>
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<tr>
<td>Phase E Operations</td>
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</tbody>
</table>

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

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

*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
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).
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

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

<table>
<thead>
<tr>
<th>EC+ACE1</th>
<th>ACE</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-Band Doppler</td>
<td>W and Ka-Band Doppler</td>
<td>ACE radar sensitive to larger particles and precip.</td>
</tr>
<tr>
<td>3MI</td>
<td>MSPI or equiv.</td>
<td>More accurate polarization, more wavelengths</td>
</tr>
<tr>
<td>OES</td>
<td>OES</td>
<td>Same</td>
</tr>
<tr>
<td>BB IR</td>
<td>-</td>
<td>Crude ERB measurement</td>
</tr>
<tr>
<td>MSI</td>
<td>OES+IR imager</td>
<td>ACE has more wavelengths, ACE pixels slightly larger</td>
</tr>
<tr>
<td>ATMS</td>
<td>models</td>
<td>Nadir µwave sounding unit, T and Humidity, cloud properties</td>
</tr>
<tr>
<td>HSRL 1 λ</td>
<td>HSRL-3λ</td>
<td>ACE HSRL has 3 wavelengths vs EC 1 wavelength</td>
</tr>
<tr>
<td>-</td>
<td>HF µ radiometer</td>
<td>Scanning - cloud ice properties</td>
</tr>
<tr>
<td>ATMS</td>
<td>LF µ radiometer</td>
<td>Scanning - cloud precip properties</td>
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ACE+EarthCARE Observing Geometry
## Potential Instrument Providers*

<table>
<thead>
<tr>
<th></th>
<th>Radar</th>
<th>Lidar</th>
<th>OES</th>
<th>Polarimeter</th>
<th>submm</th>
<th>IR</th>
<th>microwave</th>
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<td>x</td>
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*Not exhaustive
Option Comparison, Power

<table>
<thead>
<tr>
<th>Mode Duration(hours)</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
<th>Option 5</th>
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<tbody>
<tr>
<td>Eclipse + Insts + Comm</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
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</tbody>
</table>

- Power differences among Options were driven by changes in the Power and Thermal subsystems
  - Array sizes -- Opt 1: 27.9 m^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

Phase A
- Preliminary Analysis
- Mission Definition & Observ. Contract Procurement

Phase B
- Definition
- System Definition
- Preliminary Design

Phase C
- Design
- Final Design

Phase D-1
- S/C Bus Fab. & Assembly, Observatory I&T & Launch Preparations
- S/C Bus Fab., Assembly & Test 12 mo.
- Observ. I&T 13 mo.
- Prep. for Launch 3 mo.

Phase D-2
- Launch & Checkout
- Schedule Reserve

Phase E/F
- Operations & Disposal
- Primary Mission Ops
- Extended Mission Ops

KDP A
- Mission Phase A Start
- 4/2015

KDP B
- Phase B Start
- 1/2016

KDP C
- Preliminary Design Review (PDR)
- 1/2017

KDP D
- Critical Design Review (CDR)
- 1/2018

KDP E
- Launch
- 10/2020

End of Mission
- 12/2025

End of Primary Mission
- 12/2023

Schedule Reserve
- 5/2020

Transition To Operations
- 12/2020

Instrument Delivery
- 1/2019

Schedule Reserve
- 1/2017

Time-line not to scale

Required Funded Reserve: 5 months