Geostationary Coastal and Air Pollution Events (GEO CAPE) Instrument Performance Study

Final Version

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Contents

Customer's Objective

- **The Ultimate objective of the GEO-CAPE 2014 study: Quantify the cost impact of very specific changes in instrument performance**
- **The customer has defined 4 instrument types they are notionally interested in:**
  - FR: Filter Radiometer
  - WAS: Wide Angle Spectrometer
  - MSS: Multi Slit Spectrometer
  - SSS: Single Slit Spectrometer
- **The customer has also defined the performance parameters that they want to examine across different ranges**
  - Spatial resolution: 250m, 375m, 500m
  - Spectral sampling resolution: 0.4nm and 2nm
  - Spectral range (UV, Vis, NIR, SWIR)
  - Ground coverage (scanning rate)
  - SNR performance
- **Maintaining SNR $\geq$1000 at all wavelengths was identified as the highest priority, ground coverage rate the second priority for the purpose of scaling the instrument concepts**
  - SNR calculated for 10nm bands in UV/Vis
  - The minimum scan coverage rate desired was 25,000km^2/min and the maximum was >100,000km^2/min

Customer Provided Instrument Performance Matrix

GEO-CAPE Ocean Sensor Requirement	Filter Radiometer (e.g., GOCI+)	Wide-Angle Spectrometer[1] (large detector array; >>2K x 2K)	Multi-Slit Spectrometer	Single-slit spectrometer[2]
Spatial GSD at Nadir	T = 375 m B = 250 m	D = 500 m T = 375 m B = 250 m	D = 500 m T = 375 m B = 250 m	D = 500 m T = 375 m B=250m
Spectral range[3] D = 350-900 nm T = 340-1050 nm	Multi-spectral[4] 16 or more bands	Hyperspectral D or T	Hyperspectral D or T	Hyperspectral D or T
SWIR Bands D = 1640 nm T = 1245, 1640 nm B = 1245, 1640, 2135nm	0, 1 (D) or 2 (T) bands	1 (D), 2 (T) or 3 (B) bands	1 (D), 2 (T) or 3 (B) bands	1 (D) or 2 (T) bands
UV/Vis/NIR Spectral Sampling/Resolution	D = 10 nm	T = 2/5 nm B = 0.4/0.8 nm	T = 2/5 nm B = 0.4/0.8 nm	T = 2/5 nm B = 0.4/0.8 nm
Scanning Rate[3]	B=>50k km^2/min	T=>25k km^2/min B=>50k km^2/min	T=>25k km^2/min B=>50k km^2/min	T=>25k km^2/min

T = Threshold requirements from STM (but not including the NO_2 requirements)
B = Baseline Requirements from STM (includes the NO_2 requirements)
D = Descope option
[1] for example, 8Kx2K to 4Kx2K detectors to permit large iFOVs
[2] with conventional size detector <=2K x 2K; use prior studies to explore as East-West sensor option only.
[3] SNR >1000 for UV-Vis (at 10nm FWHM) – see table on page 5
[4] Multispectral: ~MERIS bands plus 360, 385 & 1020 nm. SWIR additional. Does not meet threshold requirements.
On-Orbit Calibration for all instrument concepts: T = lunar monthly, B = lunar monthly + solar daily

Costing Assumptions for Out of House Instrument Cases

- **We used NICM to cost External Instruments (GOCI, GLIMR, GOI, COCOA, MOS) and to show the cost relative to the IDL Instrument References**

External Instrument	Mass Input	Power Input	Telemetry Input
GOCI	As-flown	As-flown	CBE of 2867kbps based on FR Case 8D
GLIMR, GOI, and COCOA*	CBE**	CBE	CBE
MOS	CBE	CBE was 139W (to be consistent with the other external instruments, we removed the 15% contingency from 160W)	CBE estimate assumes co-adding (data rate with no on-board co-adding is 2.4Gbps)

*The information for these instruments was based on customer input (Antonio Mannino) Strawman GEO-CAPE Coastal Ecosystem Sensor Preliminary Specification (CEM_sensor_table for_IDL_Feb18_2014)

****CBE**: Current Best Estimate

IDL Instrument Scaling

- **The optics were scaled based on spatial and spectral resolutions.**
  - For CEDI and COEDI, the integration time remained the same for the smaller, 250m, spatial resolution cases which results in a lower global coverage rate while the aperture was increased to maintain SNR above 1000 for the majority of wavelengths. The reduction in scan rate was then partially offset by increasing the detector array size to maintain the same north south IFOV. The integration time was maintained for the coarser 500m resolution which increased the coverage rate due to the larger IFOV.
  - For GEO-CAPE WAS, the integration time remained ~the same for the smaller, 250m, spatial resolution case which resulted in a lower global coverage rate while the aperture was increased to maintain SNR above 1000 for all wavelengths. The reduction was then partially offset by increasing the detector array size to maintain the same north south IFOV. The integration time was increased for the coarser 500m resolution, allowing a further decrease in aperture diameter while maintaining the coverage rate.
  - For GEO-CAPE FR, the baseline was the smaller, 250m, spatial resolution case. For the coarser 375m & 500m ground pixel sizes, the aperture was reduced while maintaining SNR above 1000 and the scan rate held constant at ~100,000 km^2/min.

- **The results for CEDI and COEDI were generated a second time**
  - There had been two incorrect assumptions during early 2014:
    1. That the optics needed to be scaled for the different spectral resolutions. However, the data is binned into 5nm segments so that wasn't necessary.
    2. That the optics had been scaled sufficiently (aperture size increased) to enable shorter integration times at the 250m ground resolution and maintain the global coverage rate. That additional scaling had not been included.

Instrument Types and Heritage References

A. Filter Radiometer (FR):

- The IDL database of studies did not include any good examples of this instrument type that we could readily adapt for GEO-CAPE
  - A new IDL study was performed in July 2014 to create a well known, scalable design
- We also used the Korean instrument Geostationary Ocean Color Imager (GOCI) which was launched in 2010 and the JPL Coastal Ocean Carbon Observations and Applications (COCOA) design/concept.

B. Wide-Angle Spectrometer (WAS):

- The IDL database of studies did not include any good examples of this instrument type that we could readily adapt for GEO-CAPE
  - A new IDL study was performed in August 2014 to create a well known, scalable design
- Raytheon GLIMR & GOI were also used in the analysis as external instrument references

C. Multi-Slit Spectrometer (MSS):

- Based on the 2012 IDL study for Coastal Ocean Ecosystem Dynamics Imager (COEDI)
- The Ball Multislit Optimized Spectrometer (MOS) used in this analysis was described by the customer as an external instrument reference

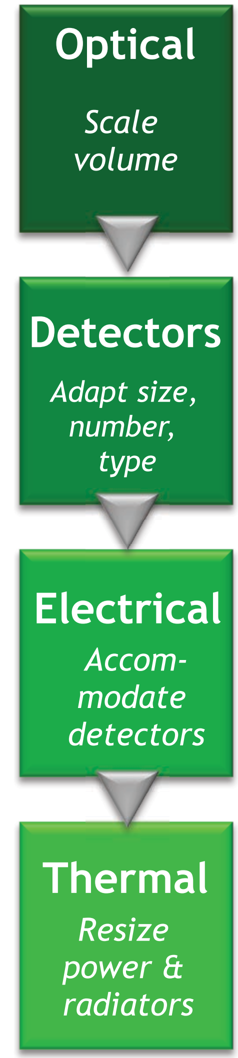
D. Single-Slit Spectrometer (SSS):

- Based on the Coastal Ecosystems Dynamics Imager (CEDI) from the 2010 IDL study for GEO-CAPE
- Also based on the 2011 IDL study for Geostationary Multispectral Atmospheric Composition (GeoMAC)

Scaling the Benchmark Instruments to produce the Derivative Designs

Integrated Design Capability / Instrument Design Laboratory

- **IDL Heritage Design References: CEDI, COEDI, GeoMAC, WAS and FR**
  - We scaled the optical volume for each instrument type to reflect the change in performance
  - Then we adapted the detector choice: size, quantity, type, operating temperature, and readout cadence, if necessary
  - We scaled the electrical readout of the instrument to reflect any changes in the detector scheme, noting additional or fewer circuit boards and boxes, and changes in operating power, if necessary
  - We updated the thermal support subsystem to capture changes in the electrical subsystem power, operating heater power, mass of thermal components, and radiator size(s), if necessary
  - We updated the total estimate of engineering resources (mass, power, volume, and telemetry)



Costing Methods for the Derivative IDL Instrument Cases

- **IDL Heritage Design References: SSS CEDI & GeoMAC, MSS COEDI, GEO-CAPE WAS and GEO-CAPE FR**
  - We manipulated the normalized Price-H parametric cost results to reflect the change in the subsystem-level adaptations
    - We removed all ACS components (to normalize the instrument costs vs. the attitude knowledge suite that has been refined over time)
    - We scaled the mass and associated cost for the optical assembly
    - We adapted the detector cost estimate to reflect the different type and quantity of detectors and associated cost, if necessary
    - We changed the board counts in the electrical assemblies and adjusted the cost estimate
    - We changed the mass of the thermal subsystem and adjusted the cost estimate
    - We recalculated 5% miscellaneous hardware for the scaled instrument
    - We recalculated Integration and Test cost using % of bench mark instrument
  - We produced NICM cost estimates for all of the derivative cases as well

FR Case Study

- We have provided a single case from the most recent IDL study to illustrate the steps taken to scale the resource estimates for a derivative case and to produce the various cost estimates. We applied these same “rules” to all of the instrument types. These charts should enable the user to follow the associated Excel spreadsheets used to make these estimates that were provided with the final report.
- Page 11 shows the scaling rationale used by the various disciplines: the origin of the optical design scaling factors, the applicable detector modifications, followed by the electronics changes to accommodate the detector changes and finally the thermal modifications to accommodate different detector operating temperatures, power dissipations and the changes in the electrical design.
- Page 12 shows which subsystems the optical scale factors were applied to, which were recomputed values (not scaled) and which subsystems remained unchanged to compute the new total mass for NICM input.
- Page 13 lists a summary comparison of the inputs to the NICM cost model and the cost results for the various incarnations.
- Page 14 is a table of the subsystem level mass scaling results which was used in conjunction with the subsystem cost per kilogram calculated on page 15 from the original price-H cost results.
- Page 16 further explains the processes taken in the price-H scaling with the breakout of mass and cost by subsystem listed as well as the final calculated values summarized on page 17.

FR Case Study: Scaling Rational

Capability	Type A. Filter Radiometer	Bench Mark Descope unique representation without SWIR: The two SWIR bands replaced by UV-VIS-NIR Bands	Delta 8B	Delta 8T	Delta 8D unique representation without SWIR
Target Heritage Mission	GeoCape FR BENCHMARK is UV/Vis/ NIR + SWIR - Spatial 250m (B) Spectral 5.0nm	GeoCape FR BENCHMARK Decope spatial 250m (B) Spectral 5.0nm without SWIR channel	GeoCape FR Scaled Spatial 375m (unchanged) Spectral 5.0nm		
Heritage Type	Unaltered IDL FR Baseline Study (2014)	Unaltered IDL FR Descope Study (2014)	scale FR baseline study	will not be represented	scale FR descope study
Optical Scale factors to produce derivative design			reduce focal length by 2/3; reduce the aperture by 2/3; keep the same angular field of view (illuminating 2/3 of the pixels on the array, because we're right at the edge of image quality); integration periods are maintained; overall scan rate is also maintained	N/A	reduce focal length by 2/3; reduce the aperture by 2/3; keep the same angular field of view (illuminating 2/3 of the pixels on the array, because we're right at the edge of image quality); integration periods are maintained; overall scan rate is also maintained
Detector Modifications to reflect changes in optical design: Detector Qty, Detector Type/Material, Format (nxn), Readout Cadence	Benchmark: (1) HAWAII-4RG with substrate removed 1.7um cutoff Mercury Cadmium Telluride for all wavelengths. 4096 x 4096 array of 15um square pixels. Use 32 Output taps.	Benchmark: (1) Silicon split frame, frame transfer CCD, 4096 rows x 4096 columns. 8 output taps per side	No change in HAWAII-4RG Detector Array. 1365 ground pixels in field of view, 2730 x 2730 Detector pixels illuminated. Use only 22 output taps. Still use (1) SIDECAR. Same readout "rate", fewer pixels.	N/A	SMALLER CCD: (1) Silicon split frame, frame transfer CCD, 2730 rows x 2730 columns. (6) output taps per side (12 taps total). Same readout "rate", fewer pixels.
Electrical Modifications to reflect changes in detector readout: change in number of electrical boards, change in power	Use 1 Readout Card with SIDECAR to readout 32 taps total.	Use 4 Readout Cards to readout 16 taps total (ie. 4 taps per card)	Use 1 Readout Card with SIDECAR to readout 32 taps total.	N/A	Use 4 Readout Cards to readout 12 taps total (3 taps per card).
Thermal Modifications to reflect changes in detector readout: change in operating heater power, coarse scale factor for thermal component mass	None	None	A scaling factor of 0.444 is used for baseline telescope surface area and aperture area. A scaling factor of 1 is used for electronics & mechanisms radiator area, sunshade and spreader heat pipes. A scaling factor of 1.0 is used for detector radiator and sunshade. A scaling factor of 0.667 is used for component to radiator heat pipes.	N/A	A scaling factor of 0.444 is used for descope telescope surface area and aperture area. A scaling factor of 1 is used for electronics & mechanisms radiator area, sunshade and spreader heat pipes. A scaling factor of 0.45 is used for detector radiator and sunshade. A scaling factor of 0.667 is used for component to radiator heat pipes.

FR Case Study: Mass Scaling Factors

	FR			Delta 8B&D			
	2014 IDL Study		Source of re-computed numbers	Scaling factor			Scaled mass
				1D	2D		
Total instrument mass	**190.4**	[1]					
Percentage of baseline							
Optical scaling mass adding and substraction SWIR channels show in the previous spreadsheet	**14.5**	[1]	Scaled 2D off Cathy's aperature diameter	0.67	0.44	[2]	6.4
Other mechanical mass	**82.4**	[1]	Scaled 2D off Cathy's aperature diameter	0.67	0.44	[2]	36.6
Optical bench [3]	**10.7**		Scaled 2D: Scaled 1D from focal length, 1D from aperture	0.67	0.44	[3]	7.1
Electrical	**5.2**		All values re-computed by Paul Earle				
Thermal	**18.2**		All values re-computed by Mike Choi				
Contamination	**2.0**	[1]	Same [4]				
Detector	**0.3**						
Harness	**13.2**	[1]	Same [4]				
Mechanism	**34.1**	[1]	Same [4]				
5% misc Hardwaree	**9.9**	[1]	5% of total intrument mass				

FR Case Study: Scaling for NICM Input

- The NICM system tool requires 3 parameters for this type of instrument: Mass, Power, and Telemetry.
- The previous page illustrated how the mass estimate was scaled
- Power was calculated based on the detector format and temperature control requirements. Those estimates were provided by the detector, electrical and thermal engineers.
- The telemetry rate was recalculated as a result of changes to the detector format, compression, and/or aggregation being used. The telemetry estimates were provided by the detector and electrical engineers.

	GeoCape FR BENCHMARK - Spatial 250m (T) Spectral 5.0nm		GeoCape FR Scaled Spatial 375m Spectral 5.0nm		
GeoCape FR	Bench Mark		Delta 8		
	Bench Mark B	Bench Mark D	Delta 8B	Delta 8T	Delta 8D
Mass CBE (kg)	190.41	190.36	126.3	N/A	128.5
Power CBE (W)	200.10	230.70	161.2	N/A	190.5
Volume CBE (mxmxm)	1.5 X 1.456 X 1.021	1.5 X 1.456 X 1.021	1.000 X 0.971 X 0.681	N/A	1.000 X 0.971 X 0.681
Telemetry CBE (kbps)	15900	17200	10,600	N/A	11,467
NICM Cost ($M)	213.4	227.6	172.9	N/A	186.3
Parametric Cost ($M)	131.7	118.0	107.7	N/A	$95.8

FR Case Study: Scaling Results Summary for Price-H

- Using the results of the mass scaling shown on a prior chart, the instrument subsystem masses were scaled
- This step is taken so that the parametric cost per subsystem could be scaled

	Unaltered IDL FR Baseline Study (2014)	Unaltered IDL FR Descope Study (2014)	Delta 8B	Delta 8D unique representation without SWIR
Instrument Mass (CBE) Kg (wo/ ACS)	190.41	190.36	126.3	128.5
Contamination	2.00	2.00	2.00	2.00
Detector	0.32	0.51	0.32	0.51
Electrical	5.20	5.95	5.20	5.95
Harness	13.25	13.17	13.25	13.17
Mechanical	93.16	91.04	43.7	43.7
Mechanism	33.92	33.92	33.92	33.92
Optical	14.46	14.34	6.4	6.4
Thermal	18.2	19.5	15.5	16.7
5% misc Hardware	9.92	9.92	6.0	6.1

Case Study

FR Case Study: Parametric Cost for each subsystem, $/Kg Cost and % Cost for I&T

		Unaltered IDL FR Baseline Study (2014)	Unaltered IDL FR Descope Study (2014)
	Instrument Cost (wo/ACS)	$131,695,514.70	$117,990,861.50
	Contamination	$468,904	$468,904
	Detector	$17,542,337	$9,414,948
	Electrical	$15,614,834	$10,756,715
	Harness	$2,668,732	$2,703,442
	I&T	$12,438,668	$14,331,695
	Mechanical	$16,382,095	$17,358,382
	Mechanism	$13,491,678	$13,452,726
	Optical	$9,548,899	$9,920,859
	Thermal	$3,763,541	$3,419,096
	5% misc Hardware	$763,421	$763,478
	Total Hardware Cost	$92,683,109	$82,590,245
	30% Wrap	$27,804,933	$24,777,074
	Total Software + Firmware Cost	$11,207,473	$10,623,543
	Software (incl FSW testbed)	$5,207,703	$5,207,703
	Firmware	$5,415,840	$5,415,840
	ASIC Assembly Code development	$583,930	$0
$/kg	Contamination	$234,452	$234,452
$/kg	Detector	$55,164,583	$18,606,616
$/kg	Electrical	$3,001,121	$2,544,644
$/kg	Harness	$201,490	$202,206
$/kg	Mechanical	$175,851	$175,467
$/kg	Mechanism	$397,773	$397,773
$/kg	Optical	$660,577	$652,755
$/kg	Thermal	$206,962	$198,248
$/kg	5% misc Hardware	$76,941	$76,989
% Cost	I&T	13.4%	15.2%

FR Case Study: Scaling for Parametric Cost

- **The architecture scaling process assumes that each unique subsystem will cost the same $/kg in the scaled result as the original IDL study**
- **We recalculated the 5% misc Hardware for each case study**
- **When we scaled parametric costs of prior studies, we could not recalculate the I&T costs - we had to scale them**
  - I&T is parametrically estimated in Price H based on the number and complexity of components in the assembly
  - To produce the derivative cases, we assumed the I&T costs would be the same % of the total instrument parametric cost as shown in the baseline case
- **We assumed there was no change to the flight software or the FPGA firmware costs.**
- **We added 30% onto the newly calculated hardware cost to account for Flight Spare, ETU, and Instrument environment test and its GSE, as we would do for any normal IDL study**
- **The results of this process to scale the parametric cost is shown on the next page for FR Delta 8B and Delta 8D.**

FR Case Study: Scaling for Parametric Cost

	Delta 8B	Delta 8T
Instrument Mass (CBE) Kg (wo/ ACS)	126.3	128.5
Contamination	2.00	2.00
Detector	0.32	0.51
Electrical	5.20	5.95
Harness	13.25	13.17
Mechanical	43.7	43.7
Mechanism	33.92	33.92
Optical	6.4	6.4
Thermal	15.5	16.7
5% misc Hardware	6.0	6.1
Instrument Cost (wo/ACS)	$107,737,844	$95,823,670
Contamination	$468,904	$468,904
Detector	$17,652,667	$9,489,374
Electrical	$15,605,829	$15,140,632
Harness	$2,669,743	$2,663,053
I&T	$8,774,298	$8,647,449
Mechanical	$7,684,689	$7,667,908
Mechanism	$13,492,460	$13,492,460
Optical	$4,245,308	$4,195,039
Thermal	$3,197,563	$3,302,812
5% misc Hardware	$462,672	$470,929
Total Hardware Cost	$74,254,132	$65,538,559
30% Wrap	22,276,240	19,661,568
Total Software + Firmware Cost	$11,207,473	$10,623,543

GEO CAPE Architecture Scaling

- **The following pages show the outcome of the GEO CAPE architecture scaling effort for external instrument references and IDL study results that was conducted January through September of 2014**
- **These results are intended to show the cost impact to changes in instrument performance for several geostationary instrument types**
- **It should be noted that without detailed mass breakdown of the external instrument references, we had to use a lower fidelity cost estimating tool to compare those cases with the results of more detailed IDL studies**
- **The NICM cost estimating tool has other limitations which have been documented in the backup charts**
  - For example, we are not confident the NICM database includes any instruments at geostationary; all the cases were entered as Earth-orbiting. This may have accounted for a cost sensitivity to the telemetry rates. For larger telemetry rates, NICM appears to account for the impact of a higher bandwidth communication system for a dedicated S/C. While this is not strictly an instrument cost, it appears that some portion of that expense has been borne by the historic instrument cases documented in the NICM database. For a geostationary instrument, we would expect a dedicated transponder to be purchased by the instrument team at a much more modest and constant cost, independent of the exact telemetry rate.

CEDI Type Single Slit Spectrometer
Cases & Results

Instrument Case	Benchmark CEDI	Delta 0	Delta 1	Delta 2	Delta 7	Delta 8	Delta 9
Spatial Resolution (m)	375	375	250	500	250	375	500
Spectral Range (nm)	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135
Spectral Resolution(nm)	0.4	0.4	0.4	0.4	2.0	2.0	2.0
Detector Size (Spatial X Spectral)	2k X 1k	2k x 1k	3k x 1k	1.5k x 1k	3k x 150	2k x 150	1.5k x 150
Aperture	1x	1x	1.5x	0.75x	1.5x	1x	0.75x
iFOV Stare Interval	0.8sec	0.8sec	0.8sec	0.8sec	0.8sec	0.8sec	0.8sec
Mass CBE (kg)	587.5	586.3	1008.9	435.6	1006.2	586.7	432.4
Power CBE (W)	393.2	389.7	654.5	298.3	647.5	389.7	298.3
Volume CBE (m x m x m)	2.8 x .95 x 2.1	2.8 x .95x 2.1	4.2 x 1.4 x 3.2	2.2 x 0.72 x 1.6	4.2 x 1.4x 3.2	2.8 x 0.95 x 2.1	2.2 x .72 x 1.6
Telemetry CBE (kbps)	88,400	10,274	15,410	7,750	8,820	5,880	4,410
NICM Cost ($M)	$460.4*	$385.6*	$555.6*	$304.5*	$554.2*	$351.3*	$298.8*
Parametric Cost ($M)	$262.1	$251.9	$420.5	$197.6	$414.0	$252.0	$196.3

Note: We did not represent the threshold and de-scope cases for the IR bands since the 2D IR array captures all three SWIR channels directly. (If the 1245nm and 2135nm channels are eliminated, the same hardware elements are still necessary to read out the remaining 1640nm channel)

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Baseline Value — Threshold Value — Descope Value

GeoMac Type Single Slit Spectrometer Cases & Results

Instrument Case	Benchmark GeoMac Design	Delta 1B	Delta 2B
Spatial Resolution⌖ (m) (lower resolution than descope)	1333	1333	1333
Spectral Range (nm)	340-590; 550-1050 (No SWIR)	340-590; 550-1050; 1245, 1640, 2135	340-590; 550-1050; 1245, 1640, 2135
Spectral Resolution (nm)	0.6nm for UV-VIS 340-590nm, 1.2nm for VIS-NIR 550-1050nm	0.6nm for UV-VIS 340-590nm, 1.2nm for VIS-NIR 550-1050nm	2.0
Detector Size	4k X 4k	4k X 4k	4k X 4k
Aperture	1X	1X	1X
iFOV Stare Interval	0.8sec	0.8sec	0.8sec
Mass CBE (kg)	147.6	151.5	151.5
Power CBE (W)	157	166.1	166.1
Volume (m x m x m)	1.1 x 1.2x 0.8	1.1 x 1.2x 0.8	1.1x1.2x0.8
Telemetry CBE (kbps)	40,027	41,454	29,232
NICM Cost ($M)	$202.7*	$214.6*	$201.1*
Parametric Cost ($M)	$152.6	$162.5	$153.8

⌖ The Benchmark values for spatial resolution were preserved so that we did not have to change the scan rate

Note: The original GeoMac study included a cloud channel which we used to represent all 3 SWIR channels by replacing the detector with an IR one. As was the case for CEDI, we did not represent the threshold and descope cases for GeoMaC because the 2D array captures all three SWIR channels directly (a single 1640nm channel would still require the same hardware)

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Threshold Value (green cell)

COEDI Multi-Slit Spectrometer
Cases & Results

Instrument Case	Delta 0 Baseline	Delta 1B	Delta 1T	Delta 1D	Delta 2B	Delta 2T	Delta 2D
Spatial Resolution (m)	375	250	250	250	500	500	500
iFOV Stare Interval	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec
Spectral Range (nm)	315-1110 1245, 1640,2135	340-1050; 1245, 1640,2135	340-1050; 1245, 1640	340-1050; 1640	340-1050; 1245, 1640,2135	340-1050; 1245, 1640	340-1050; 1640
Spectral Resolution (nm)	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Detector Size	2k X 1k	3k X 1k	3k X 1k	3k X 1k	1.5k X 1k	1.5k X 1k	1.5k X 1k
Aperture	1X	1.5X	1.5X	1.5X	0.75X	0.75X	0.75X
Mass CBE (kg)	202.8	360.0	358.6	357.4	148.5	147.3	145.9
Power CBE (W)	192.5	264.2	257.7	251.2	180.0	173.5	167.0
Volume (m x m x m)	1.5 x 1.7 x 1.1	2.2 x 2.5 x 1.7	2.2 x 2.5 x 1.7	2.2 x 2.5 x 1.7	1.1 x 1.2 x 0.8	1.1 x 1.2 x 0.8	1.1 x 1.2 x 0.8
Telemetry CBE (kbps)	23,854	35,784	35,765	35,746	17,680	17,674	17,668
NICM Cost ($M)	$238.8	$324.4*	$308.0*	$315.7*	$193.1	$190.2	$180.7
Parametric Cost ($M)	$136.2	$204.7	$200.1	$195.5	$114.4	$109.8	$105.1

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Baseline Value — Threshold Value — Descope Value

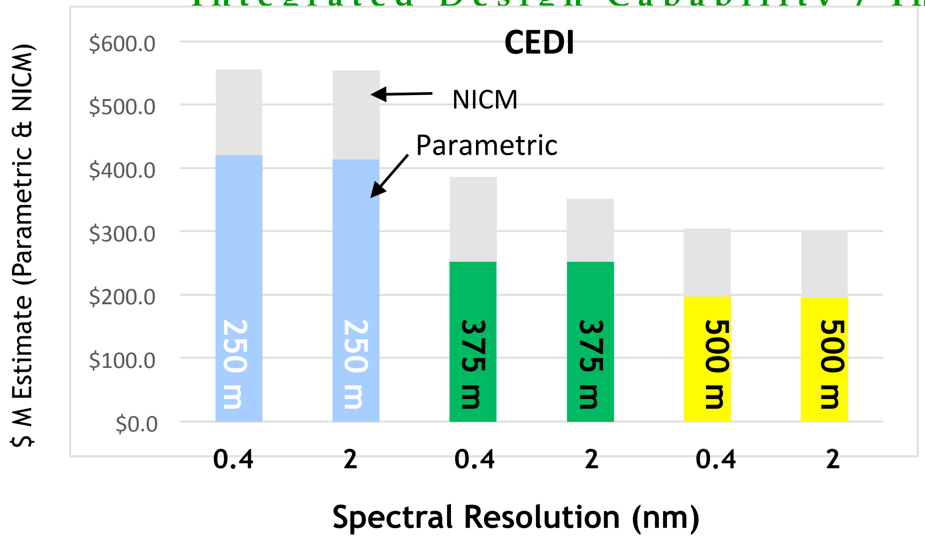
COEDI Multi-Slit Spectrometer
Cases & Results

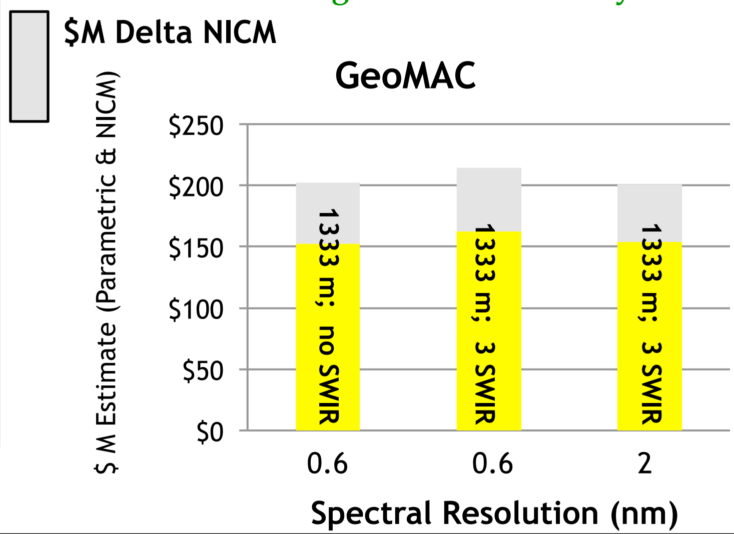
Instrument Case	Delta 7B	Delta 7T	Delta7D	Delta 8B	Delta 8T	Delta 8D	Delta 9B	Delta 9T	Delta 9D
Spatial Resolution (m)	250	250	250	375	375	375	500	500	500
iFOV Stare Interval	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec
Spectral Range (nm)	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640	340-1050; 1640	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640	340-1050; 1640	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640	340-1050; 1640
Spectral Resolution (nm)	2	2	2	2	2	2	2	2	2
Detector Size	3k X 256	3k X 256	3k X 256	2k X 256	2k X 256	2k X 256	1.5k X 256	1.5kX256	1.5kX 256
Aperture	1.5X	1.5X	1.5X	1X	1X	1X	0.75X	0.75X	0.75X
Mass CBE (kg)	345.7	344.7	343.1	198.7	197.5	196.1	145.8	144.5	143.3
Power CBE (W)	198.0	191.5	185.0	173.8	167.3	160.8	169.5	163.0	156.5
Volume (m x m x m)	2.25x2.25 x1.65	2.25x2.25 x 1.65	2.25x2.25 x1.65	1.5x1.7 x1.1	1.5x1.7 x1.1	1.5x1.7 x1.1	1.13x1.28x 0.83	1.13x1.28 x0.83	1.13x1.28 x 0.83
Telemetry CBE (kbps)	16,572	16,553	16,534	11,046	11,034	11,022	8,293	8,281	8,269
NICM Cost ($M)	$261.9*	$259.9*	$254.3*	$199.5	$199.8	$195.3	$173.9	$179.8	$170.7
Parametric Cost ($M)	$199.2	$191.5	$186.9	$133.6	$129.1	$124.5	$111.9	$107.3	$106.1

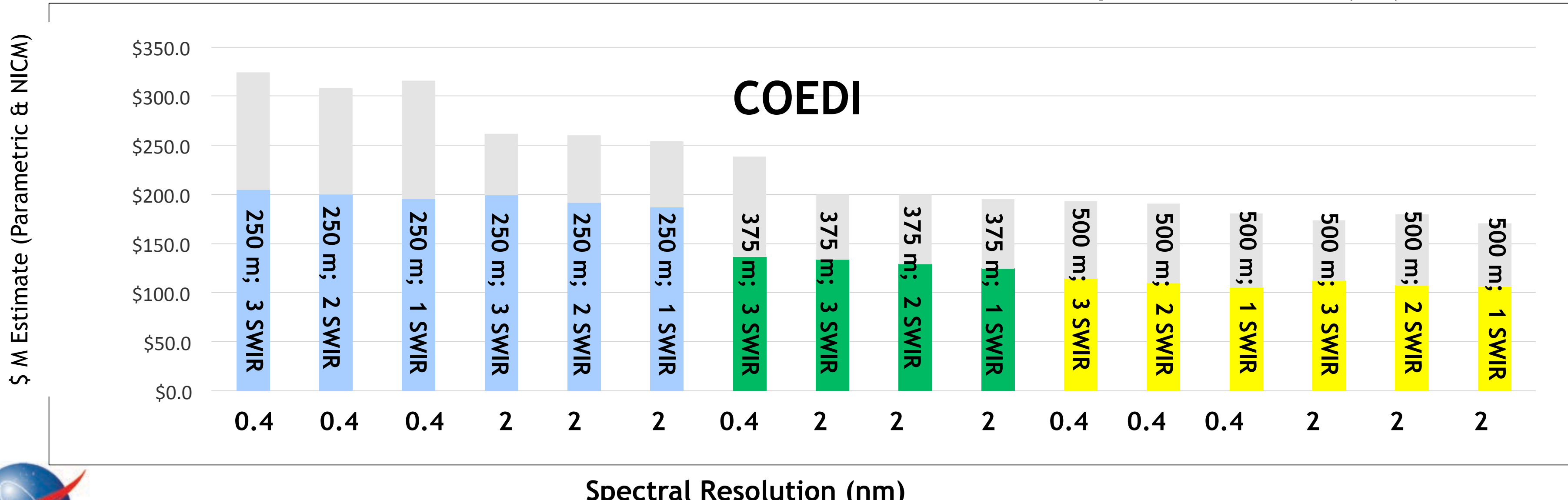
*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Baseline Value   Threshold Value   Descope Value

Cost Sensitivity vs. Spatial and Spectral Changes







Filter Radiometer
Cases & Results

Instrument Case	Benchmark	Benchmark Descope	Delta 8B	Delta 8D	Delta 9B	Delta 9D
Spatial Resolution (m)	250	250	375	375	500	500
iFOV Stare Interval	Variable	Variable	Variable	Variable	Variable	Variable
Spectral Range (nm)	340-1050; 1245, 1640, 2135	340-1050;	340-1050; 1245, 1640, 2135	340-1050;	340-1050; 1245, 1640, 2135	340-1050;
Spectral Resolution(nm)	5	5	5	5	5	5
Detector Size (2pix/ grnd pix)	4k X 4K	4k X 4K	2730 X 2730	2730 X 2730	2k X 2k	2k X 2k
Aperture	250mm	250mm	167mm	167mm	125mm	125mm
Scan Rate km2/sec	100,105	91,404	100,105	91,404	100,105	91,404
Mass CBE (kg)	190.4	190.4	126.3	128.5	103.5	103.1
Power CBE (W)	200.1	230.7	161.2	190.5	147.6	151.6
Volume (m x m x m)	1.5 x 1.46 x 1.02	1.5 x 1.46 x 1.02	1.0 x 0.97 x 0.68	1.0 x 0.97 x 0.68	0.75 X 0.73 X 0.51	0.75 X 0.73 X 0.51
Telemetry CBE (kbps)	15,900	17,200	10,600	11,467	3,975	4,300
NICM Cost ($M)	$213.4	$227.6	$172.9	$186.3	$146.5	$142.9
Parametric Cost ($M)	$131.7	$118.0	$107.7	$95.8	$99.9	$84.7

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Baseline Value — Threshold Value — Descope Value

WAS Wide Angle Spectrometer
Cases & Results

Instrument Case	Delta 0 Baseline (2)	Delta 0 Baseline (3)	Delta 1B	Delta 1D	Delta 2B	Delta 2D
Spatial Resolution (m)	375	375	250	250	500	500
iFOV Stare Interval	1.4 sec	1.4 sec	1.2 sec	1.2 sec	1.7 sec	1.7 sec
Spectral Range (nm)	340-1050 1245, 1640,2135	340-1050;	340-1050; 1245,1640, 2135	340-1050;	340-1050; 1245, 1640,2135	340-1050;
Spectral Resolution (nm)	0.4	0.4	0.4	0.4	0.4	0.4
Detector Size	8k X 1k	8k X 1k	8k X 1k	8k X 1k	6k X 1k	6k X 1k
Aperture (mm)	325	325	525 (1.6X)	525 (1.6X)	225 (0.69X)	225 (0.69X)
Scan Rate km^2/sec	48,200	48,200	25,000	25,000	53,000	53,000
Mass CBE (kg)	309.4	278.6	635.7	559.3	199.4	179.8
Power CBE (W)	341.3	335.3	588.4	582.4	269.0	263.0
Volume (m x m x m)	2.6x1.8x1.5	2.4x1.8x1.5	4.0x2.9x2.4	3.7x2.9x2.4	2.0x1.3x1.1	1.8x1.3x1.1
Telemetry CBE (kbps)	23,832	23,701	27,804	27,651	14,720	14,639
NICM Cost ($M)	$325.2	$311.2	$480.2*	$453.2	$246.4	$237.5
Parametric Cost ($M)	$165.2	$124.1	$281.9	$222.7	$123.3	$87.1

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Baseline Value | Threshold Value | Descope Value

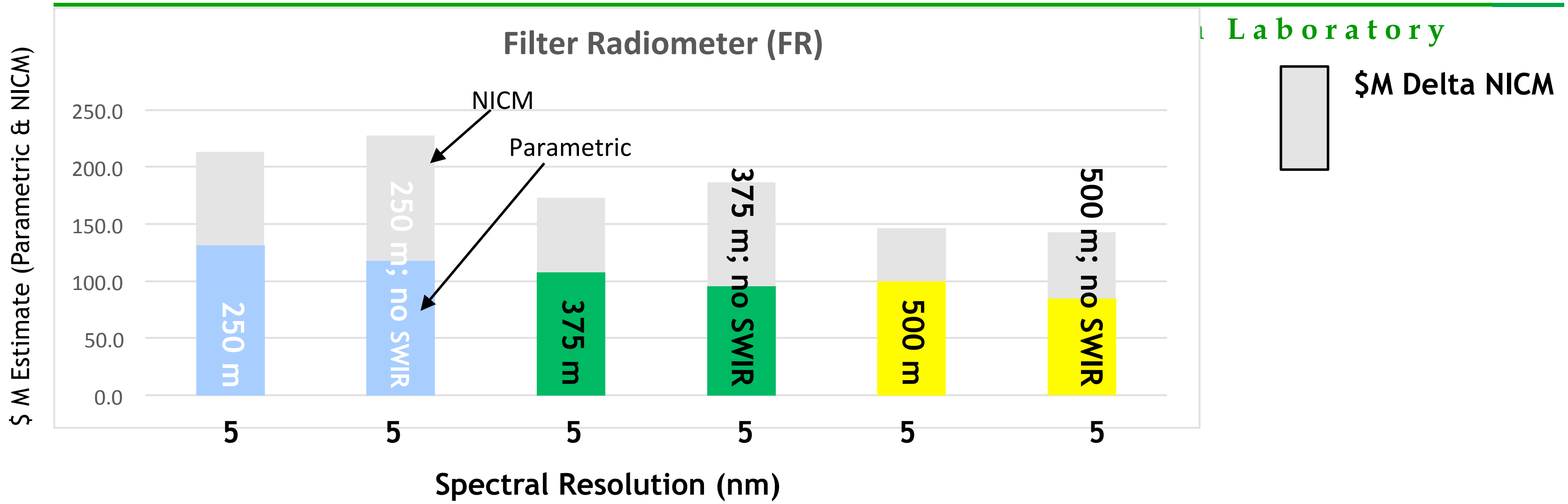
WAS Wide Angle Spectrometer
Cases & Results

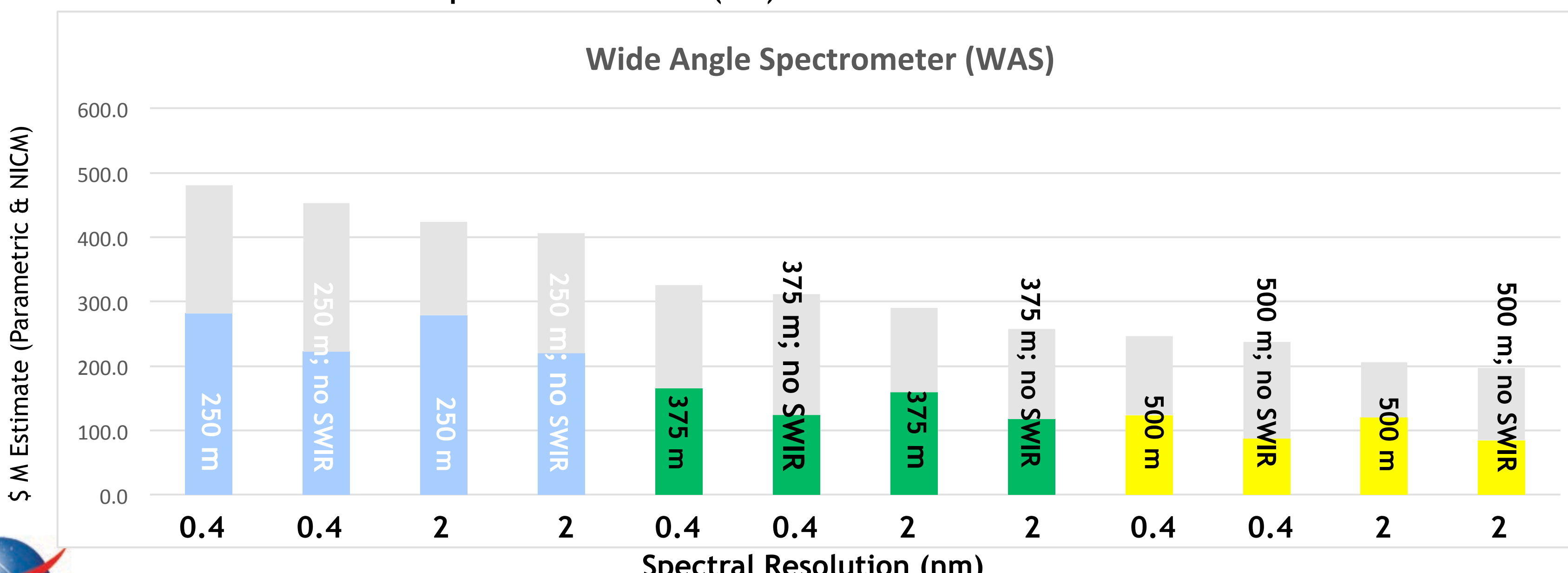
Instrument Case	Delta 7B	Delta7D	Delta 8B	Delta 8D	Delta 9B	Delta 9D
Spatial Resolution (m)	250	250	375	375	500	500
iFOV Stare Interval	1.2 sec	1.2 sec	1.4 sec	1.4 sec	1.7 sec	1.7 sec
Spectral Range (nm)	340-1050 1245, 1640,2135	340-1050;	340-1050 1245, 1640,2135	340-1050;	340-1050 1245, 1640,2135	340-1050;
Spectral Resolution (nm)	2	2	2	2	2	2
Detector Size	8k X 512	8k X 512	8k X 512	8k X 512	6k X 512	6k X 512
Aperture	525 (1.6X)	525 (1.6X)	325	325	225 (0.69X)	225 (0.69X)
Scan rate km2/sec	25,000	25,000	48,200	48,200	53,000	53,000
Mass CBE (kg)	633.1	557.8	306.1	273.4	196.9	178.5
Power CBE (W)	562.6	557.6	315.6	310.6	243.4	238.4
Volume (m x m x m)	4.0x2.9x2.4	3.7x2.9x2.4	2.6x1.8x1.5	2.4x1.8x1.5	2.0x1.3x1.1	1.8x1.3x1.1
Telemetry CBE (kbps)	6951	6913	5958	5925	3680	3660
NICM Cost ($M)	$424.6*	$406.5*	$290.1	$257.0	$205.7	$197.2
Parametric Cost ($M)	$278.6	$219.8	$159.5	$118.0	$120.0	$84.3

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Baseline Value | Threshold Value | Descope Value

Cost Sensitivity vs. Spatial and Spectral Changes





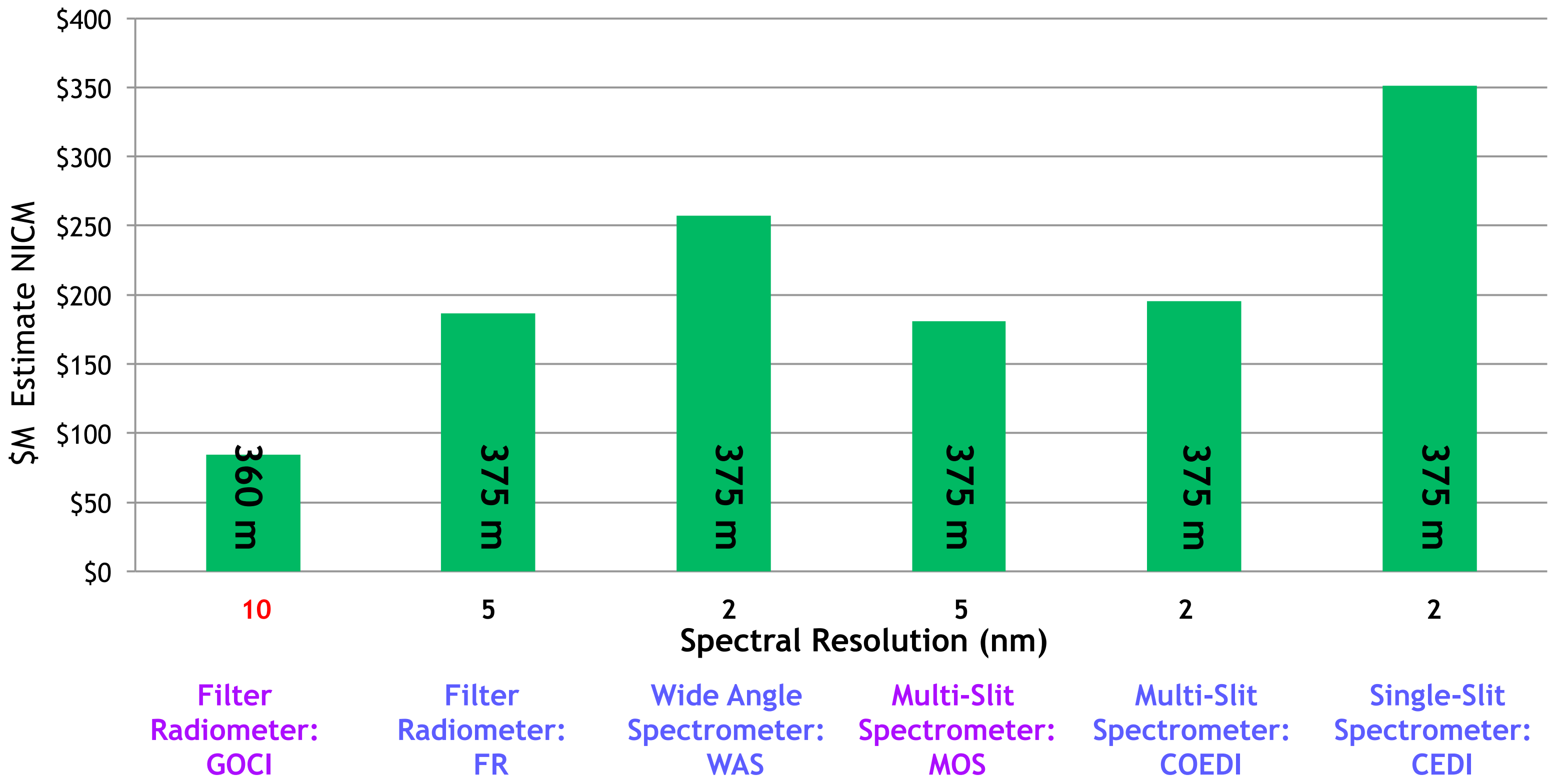
Resources Estimates for Matching Science Performance: GOCI & MOS

Instrument Type	Filter Radiometer GOCI	Filter Radiometer FR (Delta 8D case)	Wide Angle Spectrometer WAS (Delta 8D case)	Multi-Slit Spectrometer MOS	Multi-Slit Spectrometer COEDI (Delta 8D Case)	Single-Slit Spectrometer CEDI (Delta 8 Case)
Spatial Resolution (m)	~360 m (375=T)	375	375	375	375	375
Spectral Resolution (nm) (2nm=T)	20, 10 (680 band) or 40nm (865 band) (10nm=D)	5nm	2 nm	~ 5 nm	2 nm	2 nm
Spectral Range (nm)	412,443,490,555, 660, 680, 745,865 (no SWIR)	340-1050	340-1050	340-900; SWIR bands	350 -1050; 1640	350 -1050; 1640 (includes 1235,2145)
Mass CBE (kg)	78	128.4	273.4	147	196.1	586.7
Power CBE (W)	100	190.5	310.6	139	160.8	389.7
Volume (m x m x m)	1.4 x 0.8 x 0.8	1.0 x 0.97 x 0.68	2.4 x 1.8 x 1.5	1.5 x 1.5 x 1.7	1.5 x 1.7 x 1.1	2.8 x 0.95 x2.1
Telemetry CBE (kbps)	2,867	11,467	5,925	24,000	11,022	5,880
NICM Cost ($M)	$84.7	$186.3	$119.6	$180.9	$195.3	$351.3*

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Resources Estimates for Matching Science Performance: GOCI & MOS

Threshold Science Performance

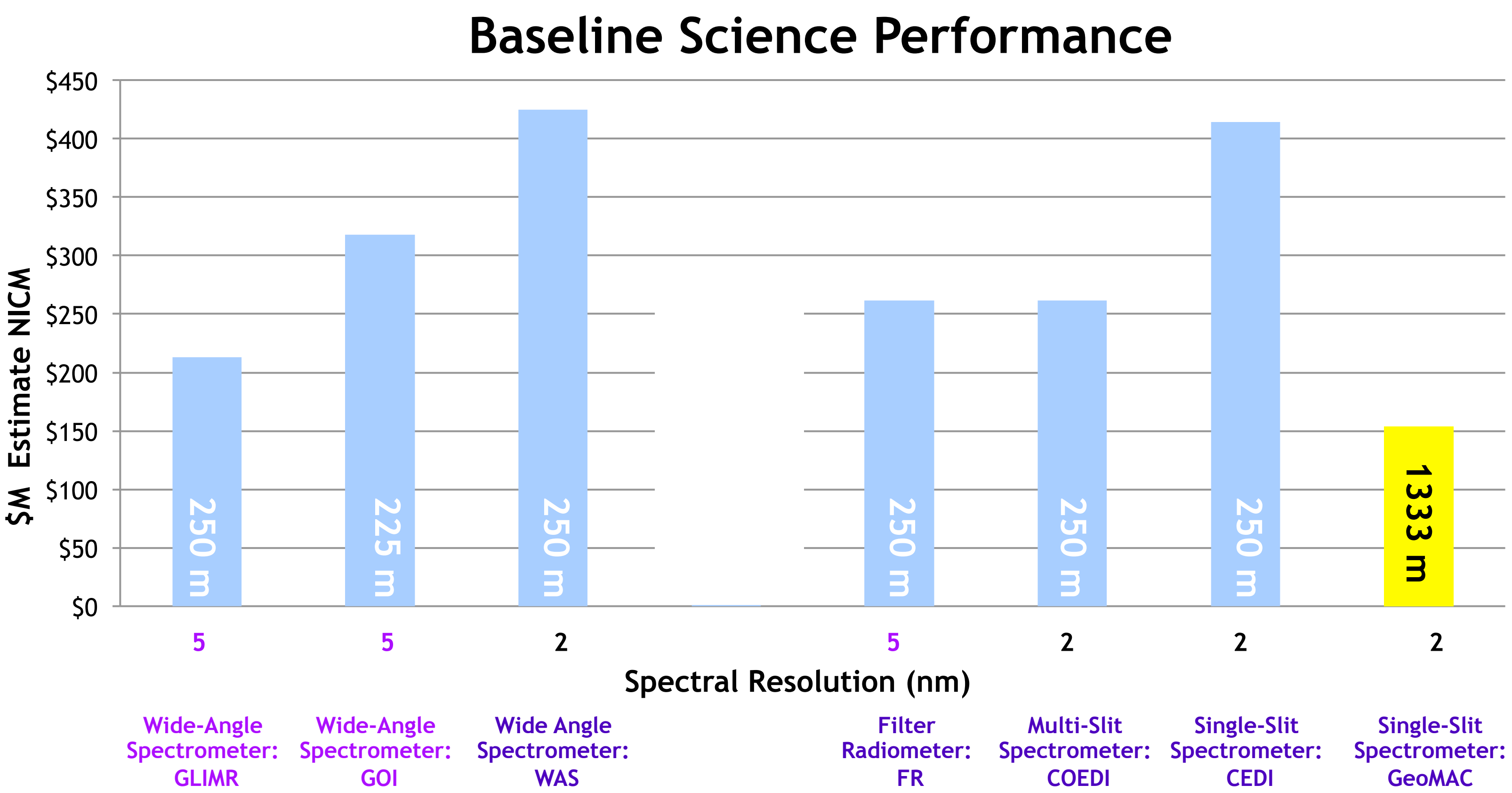


Resources Estimates for Matching Science Performance for GLIMR, GOI, COCOA

Instrument Type	Wide-Angle Spect: GLIMR	Wide-Angle Spect: GOI	Wide Angle Spect: WAS (Delta 7B CASE)	Filter Radiometr: COCOA Requires S/C for pointing	Filter Radiometr: FR (Benchmrk Case)	Multi-Slit Spect: COEDI (Delta 7B Case)	Single-Slit Spect: CEDI (Delta 7 Case)	Single-Slit Spect: GeoMAC (Delta 2B Case)
Spatial Resolution (m)	250	225	250	200	250	250	250	1333
Spectral Resolution (nm)	~5nm (2nm=T)	5nm (2nm=T)	**2nm**	**<5** (2nm=T)	5nm	2nm	2nm	2nm
Spectral Range (nm)	340-885; 980-2200	340-885, 980-2200	340-1050; 1245,1640, 2145	350-1050 (no SWIR)	340-1050; 1245,1640, 2145	340-1050; 1245,1640, 2145	340-1050; 1245,1640, 2145	340-1050; 1245,1640, 2145
Mass CBE (kg)	132	283	633.1	71	190.4	345.7	1006.2	151.5
Power CBE (W)	360	390	562.6	50	200.1	198	647.5	166.1
Volume (m x m x m)	0.7 x 0.6 x 0.8	1.7 x 1.5 x 2	4.0x2.9x2.4	Cylinder 0.9m dia. X1.3m	1.5 X 1.46 X 1.02	2.25x2.25x 1.65	4.2x1.4x3.2	1.1x1.2x0.8
Telemetry CBE (kbps)	3,200	14,400	6,951	20,000	15,900	16,572	8,820	29,232
NICM Cost ($M)	$212.8	$317.6	$424.6*	$96.7	$213.4	$261.9	$414.0*	$153.8

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Resources Estimates for Matching Science Performance for GLIMR, GOI, COCOA



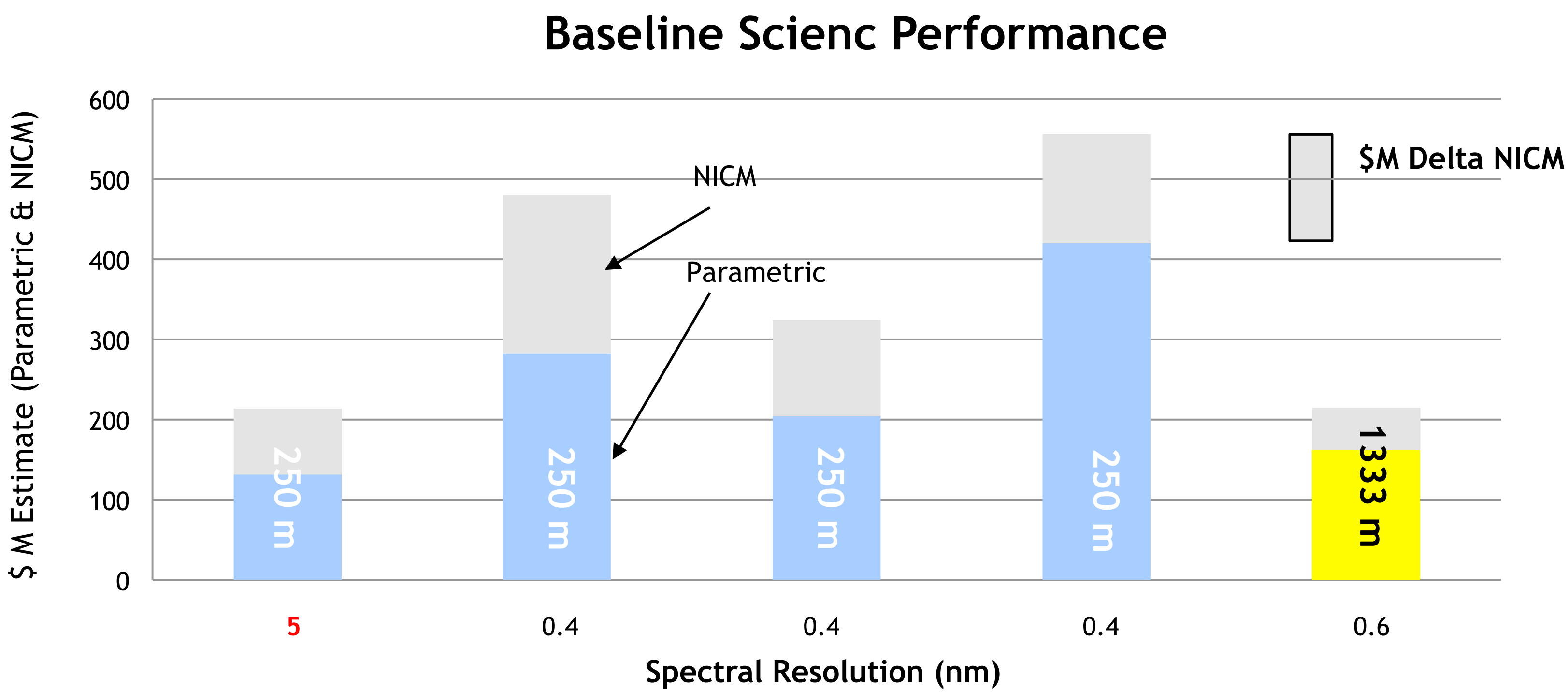
Only NICM cost estimates were possible for external instrument references

Resources Estimates for Matching Baseline Science Performance

Instrument Type	Filter Radiometer: FR (Benchmark case)	Wide Angle Spectrometer: WAS (Delta 1B case)	Multi-Slit Spectrometer: COEDI (Delta 1B Case)	Single-Slit Spectrometer: CEDI (Delta 1 Case)	Single-Slit Spectrometer: GeoMAC (Delta 1B Case)
Spatial Resolution (m)	250 m	250 m	250 m	250 m	1333 m
Spectral Resolution (nm)	5.0 nm (B=0.4 nm)	0.4 nm	0.4 nm	0.4 nm	0.6nm for UV-VIS 340-590nm, 1.2nm for VIS-NIR 550-1050nm
Spectral Range (nm)	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135
Mass CBE (kg)	190.4	635.7	360.0	1008.9	151.5
Power CBE (W)	200.1	588.4	264.2	654.5	166.1
Volume (m x m x m)	1.5 X 1.46 X 1.02	4.0x2.9x2.4	2.2 x 2.5 x 1.7	4.2 x 1.4 x 3.2	1.1x 1.2x 0.8
Telemetry CBE (kbps)	15,900	27,804	35,784	15,410	41,454
NICM Cost ($M)	$213.4	$480.2*	$324.4*	$555.6*	$214.6*
Parametric Cost ($M)	$131.7	$281.9	$204.7	$420.5	$162.5

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Costs Estimate for Different Type of Instruments



Filter Radiometer: FR (Benchmark case)

Wide Angle Spectrometer: WAS (Delta 1B case)

Multi-Slit Spectrometer: COEDI (Delta 1B Case)

Single-Slit Spectrometer: CEDI (Delta 1 Case)

Single-Slit Spectrometer: GeoMAC (Delta 1B Case)

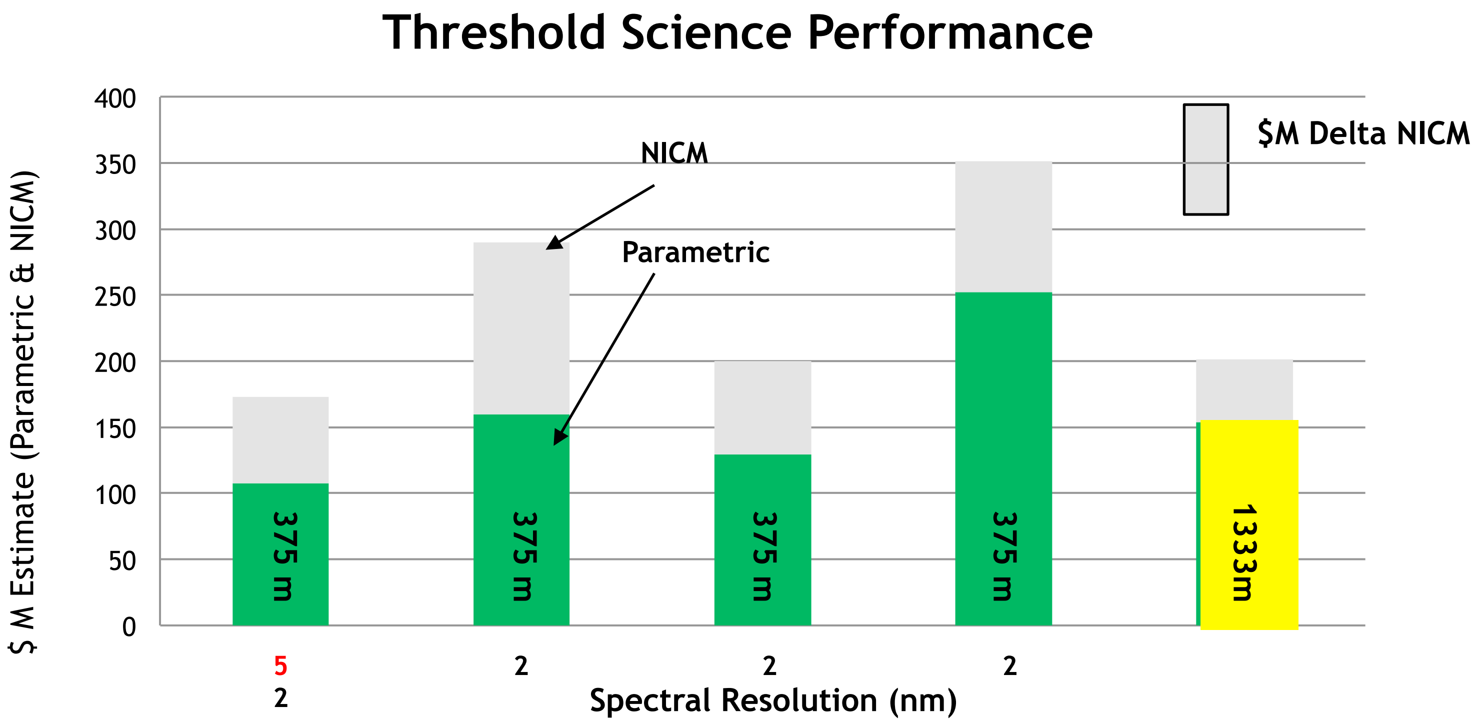
Resources Estimates for Matching Threshold Science Performance

Instrument Type	Filter Radiometer: FR (Delta 8B case)	Wide Angle Spectrometer: WAS (Delta 8B case)	Multi-Slit Spectrometer: COEDI (Delta 8T Case)	Single-Slit Spectrometer: CEDI (Delta 8 Case)	Single-Slit Spectrometer: GeoMAC (Delta 2B)
Spatial Resolution (m) Threshold	375	375	375	375	1333
Spectral Resolution (nm) Threshold	5 nm	2 nm	2nm	2nm	2nm
Spectral Range (nm) Threshold (2135 nm was not req as a threshold)	340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135	340-1050 1245,1640	340-1050 1245,1640, 2135	340-540/490-890; 1245,1640, 2135
Mass CBE (kg)	126.3	306.1	197.5	586.7	151.5
Power CBE (W)	161.2	315.6	167.3	389.7	166.1
Volume (m x m x m)	1.0 X 0.97 X 0.68	2.6 x 1.8 x 1.5	1.5 x 1.7 x 1.1	2.8 x .0.95 x 2.1	1.1 x 1.2 x 0.8
Telemetry CBE (kbps)	10,600	5,958	11,034	5,880	29,232
NICM Cost ($M)	$172.9	$290.1	$199.8	$351.3*	$201.1*
Parametric Cost ($M)	$107.7	$159.5	$129.1	$252.0	$153.8

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Purple text – this channel was already available in the design so no add'l charge required

Costs Estimate for Different Type of Instruments



Filter Radiometer: FR (Case 8B)

Wide Angle Spectrometer: WAS (Case 8B)

Multi-Slit Spectrometer: COEDI

Single-Slit Spectrometer: CEDI

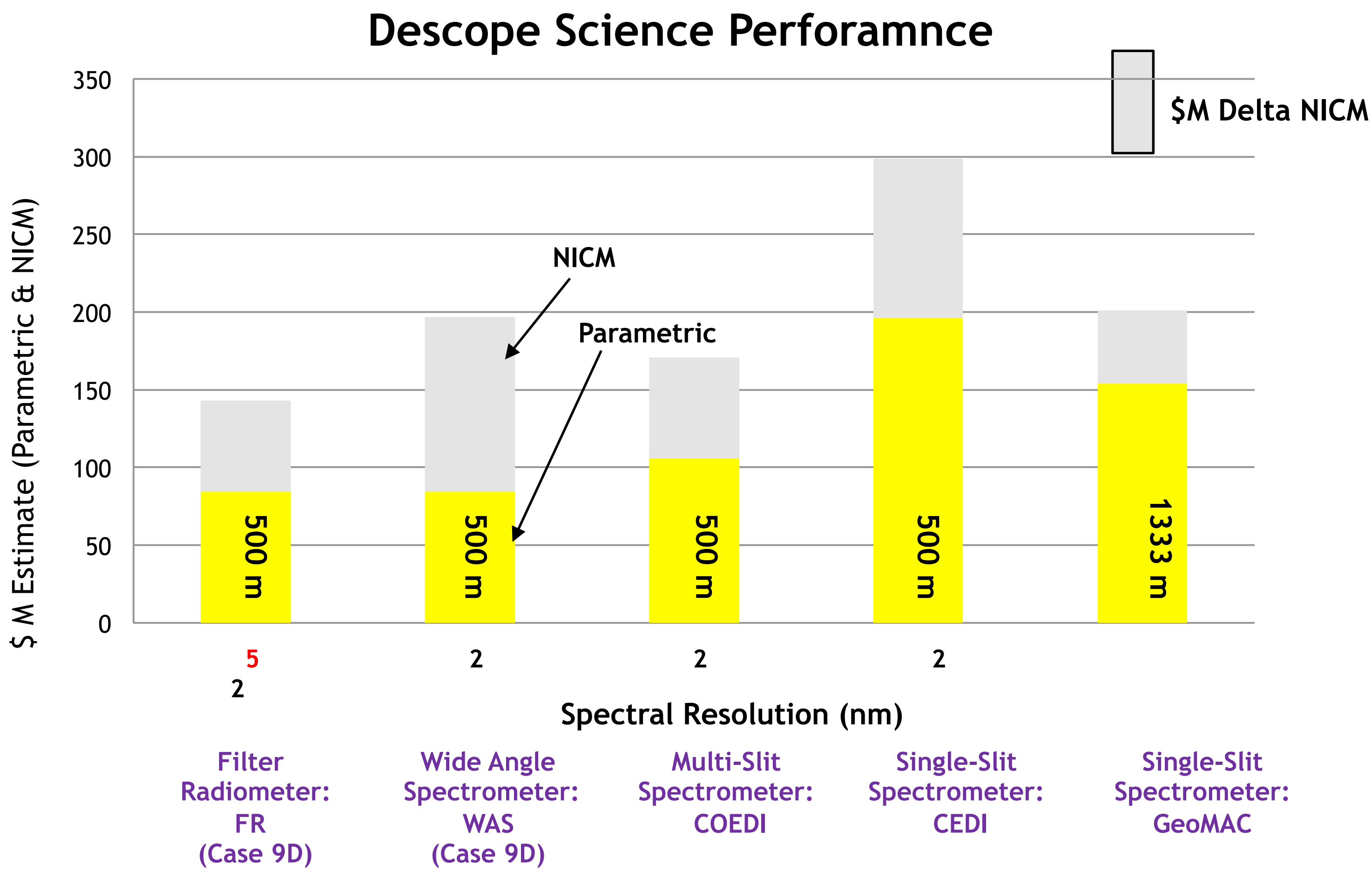
Single-Slit Spectrometer: GeoMAC

Resources Estimates for Matching Descope Science Performance

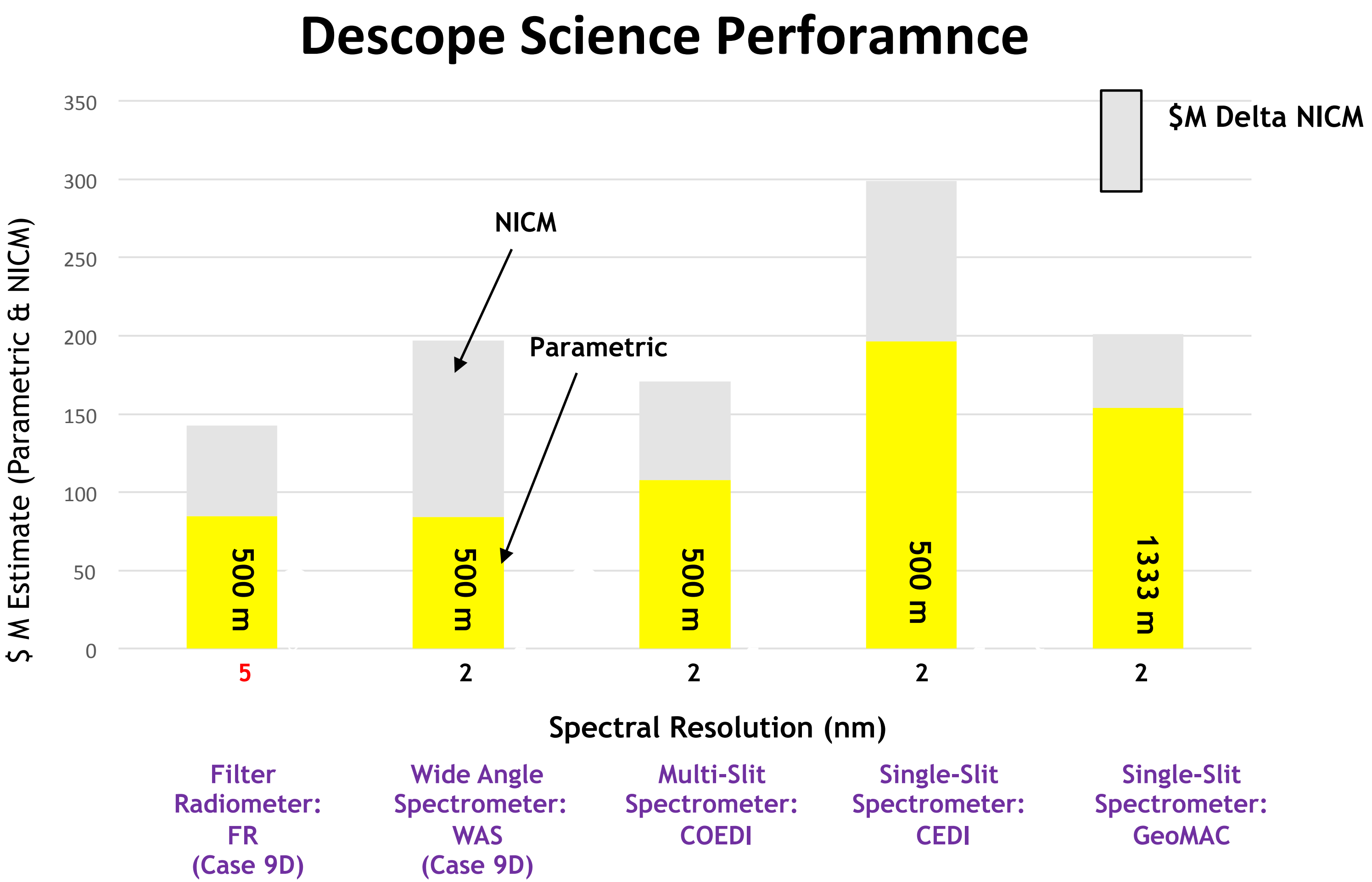
Instrument Type	Filter Radiometer: FR (Delta 9D case)	Wide Angle Spectrometer: WAS (Delta 9D case)	Multi-Slit Spectrometer: COEDI (Delta 9D Case)	Single-Slit Spectrometer: CEDI (Delta 9 Case)	Single-Slit Spectrometer: GeoMAC (Delta 2B)
Spatial Resolution (m) Descope	500	500	500	500	1333
Spectral Resolution (nm) Threshold	5 nm	2 nm	2 nm	2 nm	2 nm
Spectral Range (nm) Descope	350 -1050 (no 1640)	350 -1050 (no 1640)	350 -1050; 1640	350 -1050; 1640 (includes 1235, 2135);	350 -1050; 1640 (includes 1235, 2135)
Mass CBE (kg)	102.6	178.5	143.3	432.4	151.5
Power CBE (W)	151.6	238.4	156.5	298.3	166.1
Volume (m x m x m)	0.75 X 0.73 X 0.51	1.8 x 1.3 x 1.1	1.13 x 1.28 x 0.83	2.2 x 0.72 x 1.6	1.1 x 1.2 x 0.8
Telemetry CBE (kbps)	4,300	3,660	8,269	4,410	29,232
NICM Cost ($M)	$142.9	$197.0	$170.7	$298.8*	$201.1*
Parametric Cost ($M)	$84.6	$84.3	$106.1	$196.3	$153.8

*Instrument resources exceeded at least one of the NICM input ranges; see backup charts

Costs Estimate for Different Type of Instruments



Costs Estimate for Different Type of Instruments



WAS Comparison Using Different Cost Models

Instrument Case	Delta 0 Baseline (2)	Delta 0 Baseline (3)
Spatial Resolution (m)	375	375
iFOV Stare Interval	1.4 sec	1.4 sec
Spectral Range (nm)	340-1050 1245, 1640,2135	340-1050;
Spectral Resolution (nm)	0.4	0.4
Detector Size	8k X 1k	8k X 1k
Aperture (mm)	325	325
Scan Rate km^2/sec	48,200	48,200
Mass CBE (kg)	309.4	278.6
Power CBE (W)	341.3	335.3
Volume (m x m x m)	2.6x1.8x1.5	2.4x1.8x1.5
Telemetry CBE (kbps)	23,832	23,701
NICM System Cost ($M) (50%-tile)	**$325.2**	**$311.2**
Parametric Cost ($M) CBE	**$165.2**	**$124.1**
NICM Subsystem Cost ($M) (50%-tile)	**$179.3**	**$162.8**

FR Comparison Using Different Cost Models

Instrument Case	Bench Mark	Bench Mark D
Spatial Resolution (m)	250	250
iFOV Stare Interval	Variable	Variable
Spectral Range (nm)	340-1050; 1245, 1640, 2135	340-1050;
Spectral Resolution(nm)	5	5
Detector Size (2pix/grnd pix)	4k X 4K	4k X 4K
Aperture	250mm	250mm
Scan Rate km2/sec	100,105	91,404
Mass CBE (kg)	190.4	190.4
Power CBE (W)	200.1	230.7
Volume (m x m x m)	1.5 x 1.46 x 1.02	1.5 x 1.46 x 1.02
Telemetry CBE (kbps)	15,900	17,200
NICM System Cost ($M) (50%-tile)	**$213.4**	**$227.6**
Parametric Cost ($M) CBE	**$131.7**	**$118.0**
NICM Subsystem Cost ($M) (50%-tile)	**$128.7**	**$138.3**

Backup Charts

- **IDL Team for GEO CAPE Precost/Architecture Scaling**
- **Summary of Internal & External References**
- **PRICE H Cost Assumptions**
  - Global setting used to recost IDL benchmark cases
- **NICM Considerations**
  - Nominal input ranges

2014 IDL Team for GEO CAPE Precost/Architecture Scaling and WAS & FR Studies

Integrated Design Capability / Instrument Design Laboratory

- Aron Brall/Reliability/Code 322
- Bobby Nanan/Mechanical Design/Code 547
- Bryan Monosmith/Radiometry/ Code 553
- Cabin Samuels/Costing/GSFC 158
- Cathy Marx/Optics/Code 551
- Carl Kotecki/Detectors & Systems/Code 553
- Cheryl Salerno/Systems/Code 592
- Dick McBirney/Mechanisms/GSFC Code 540
- Elizabeth Matson/Structural Analysis/ Code 542
- Eric Stoneking/Attitude Determination/ Code 591
- Greg Bowers/Mechanical Design/Code 547
- Jay Smith/Radiometry/Code 540
- Jeff Bolognese/Structural Analysis/Code 542
- Jennifer Bracken/IDC Manager/Code 500
- John Panek/IDL Deputy Team Lead/Code 599
- Jonathan Verville/Systems/Code 585
- JP Swinski/Flight Software/Code 582
- Kequan Luu/Flight Software/Code 582
- Mark Wilson/Optical Design/Code 551
- Mike Choi/Thermal/Code 545
- Mike Clark/Mechanical Systems/Code 543
- Mark Secunda/Contamination/Code 546
- Martha Chu/Systems/Code 592
- Paul Earle/Electrical/Code 300
- Sanjay Verma/Costing/Code 158
- Sharon Seipel/Costing/Code 158
- Tammy Brown/IDL Team Lead/Code 550

Internal & External Instrument References

Reference Source	Filter Radiometer (FR)	Wide-Angle Spectrometer (WAS)	Multi-Slit Spectrometer (MMS)	Single-Slit Spectrometer (SSS)
IDL Study Reference	• 2014 study for GEO CAPE Filter Radiometer (FR)	• 2014 study for GEO CAPE Wide Angle Spectrometer (WAS)	• 2012 study for Coastal Ocean Ecosystem Dynamics Imager (COEDI)	• 2010 study for Coastal Ecosystems Dynamics (CEDI) • 2011 study for Geostationary Multispectral Atmospheric Composition (GeoMAC)
Industry Reference	• 2010 launch of Geostationary Ocean Color Imager (GOCI) • JPL instrument concept for Coastal Ocean Carbon Observations and Applications (COCOA)	• Raytheon instrument concept for GLIMR • Raytheon instrument concept for Geosynchronous Ocean-color Hyperspectral Imager (GOI)	• Ball Aerospace instrument concept for Multi-slit Optimized Spectrometer (MOS)	

PRICE H: Cost Assumptions

- **The customer provided the global costing parameters on the subsequent charts for the IDL to recost historic IDL cost models to normalize the results**
  - These normalized results were the ‘benchmark’ instrument configuration we scaled to represent the delta instrument cases

PRICE H: Cost Assumptions

- **Build Assumptions:**
  - Out of house
  - GSFC CM&O charges in the original estimate have been removed
- **Cost Assumptions**
  - Constant year dollars FY2016
- **Class of Electronics Parts:**
  - This was not changed, as would require editing at a line item level that was beyond the level of detail we wanted to achieve in an architecture study
  - If we noted that an electronics assembly has inconsistent settings, we have adjusted this so that the parts class is consistent and noted this discrepancy in our results (so that if this case is later developed in a week-long IDL study, we can make those corrections)
- **Throughput or Purchased Item(s) from Customer**
  - No additions were made in this recosting effort
  - Prior estimates from the original study were escalated to 2016

PRICE H: Cost Assumptions

- **Instrument Life Cycle**
  - Project Start Date — Dec, 2017
    - Authorization to Proceed (ATP)
  - CDR Date — Dec, 2018
  - Start of Instrument-Level Environmental Testing — May, 2021

- **Mission Duration** — 3 years

PRICE H: Test Units

These inputs are intended to be consistent with the way that COEDI was costed

Build Quantity - Fully Integrated Instrument-Level Units	Quantity for GEO CAPE 2014	
Flight Unit	1	
Flight Spare Unit	0	
Build Quantity	**Costing Approach for GEO CAPE 2014**	
	Fully-Integrated Instrument-Level	**Not Fully-Integrated at the Instrument-Level**
Engineering Test Unit (ETU)* or protoflight	0	10% Wrap for Subsystem-Level ETUs
Engineering Development Unit (EDU) or prototype	1	Accounted for mechanisms and electronic box assemblies

* A fully-integrated instrument-level (FIIL) ETU would be modeled as a flight spare unit (or a second flight spare unit if a spare is already included in the build approach). If the FIIL is intended to be environmentally tested separately from the flight unit, additional considerations for the instrument development schedule are necessary, and facility and labor costs for the separate testing need to be accounted for. We recommend keeping the 10% wrap for subsystem-level ETUs as a way to cover those costs.

PRICE H: Instrument-Level Wraps

Integrated Design Capability / Instrument Design Laboratory

These inputs are intended to be consistent with the way that COEDI was costed

Additional Instrument-Level Costs *These are estimated as a % of the total instrument hardware costs*	**Typical IDL Wrap**	**GEO CAPE 2014 Wrap**
Ground Support Equipment (GSE) that is instrument-specific (that is, cannot be readily adapted from general purpose GSE)	5%	5%
Environmental testing at the Instrument-Level	5%	5%
Component-Level flight spare components	10%	10%
Engineering Test Unit (ETU) at the Subassembly-Level	10%	10%
If FSW GSE was not accounted for in a grassroots estimate, it was instead estimated using a wrap *on the FSW costs*	5%	5%
Center Management & Overhead (CM&O) does not apply to out-of-house builds		N/A
Instrument to S/C Integration and Test (typically included in WBS 10.0 and not shown in the instrument totals for WBS 5.0)	5%	5%

PRICE H Cost Assumptions

PRICE H Cost Results: FSW Considerations

- **FSW parametric cost estimates were recosted and normalized to the current mission duration of 3 years (to adjust the sustaining engineering cost estimate)**
  - We have documented in the following chart how FSW was costed in the original estimate
  - If the FSW was originally estimated parametrically, the estimate includes FSW sustaining engineering and those costs will reflect the duration of the mission (as it's been entered in the model)
  - If FSW was not originally estimated parametrically, as was the case for older IDL studies where it was instead estimated using a grassroots approach, the sustaining engineering costs are not accounted for

- **FSW GSE costs were escalated to FY16**
  - We have indicated in the following chart how FSW GSE was costed in the original estimate
  - Typically we estimate FSW GSE costs with a grassroots scheme, in which case inflation was added to escalate that estimate to FY16
  - In older studies, FSW GSE is estimated as 5% of the FSW costs; in this case the 5% will be recomputed after the FSW estimate is recalculated

- **We did not change the build approach for the FSW effort to out-of-house labor**
  - The rates were updated for FY16, but we did not change the rates to out-of-house because it would have been labor intensive to do that for the grassroots estimates
  - The FSW estimates for the newer 2014 studies for WAS & FR were costed using in-house rates in order to be consistent with the other study references

PRICE H Cost Results: FSW Considerations

Study	FSW	FSW GSE	Sustaining Engineering
All FSW labor was encoded as in-house for both grassroots and parametric estimates			
2010 CEDI	Grassroots estimate escalated to FY16	Accounted for with 5% wrap	Not accounted for
2011 GEO MAC	Parametric SEER-SEM estimate normalized to same global GEO CAPE settings & scaled to FY16	Grassroots estimate escalated to FY16	Parametric SEER-SEM estimate normalized to same global GEO CAPE settings & Escalated to FY16
2012 COEDI	Parametric SEER-SEM estimate normalized to same global GEO CAPE settings & scaled to FY16	Grassroots estimate escalated to FY16	Parametric SEER-SEM estimate normalized to same global GEO CAPE settings & Escalated to FY16
2014 WAS	Parametric SEER-SEM estimate	Grassroots estimate at FY16	Parametrically estimated with SEER-SEM
2014 FR	Parametric SEER-SEM estimate at FY16	Grassroots estimate at FY16	Parametrically estimated with SEER-SEM

We have provided NICM Cost Estimates to Compare Internal & External References

- **For external instrument references, we did not have the design details to produce a PRICE H cost result, so we used the NASA Instrument Cost Model (NICM) tool**
  - NICM is a parametric costing tool developed by JPL for NASA HQ based on historic aerospace cost data, including missions from Goddard and other NASA centers
- **We used the parametric costing tool NASA Instrument Cost Model (NICM) in order to cost the external instrument cases, because it only requires a few instrument-level details**
- **We also used this tool to cost the heritage IDL instrument cases to provide a comparison to the external instrument cases**
- **NICM outputs are considered a more conservative, higher confidence cost estimate (the actual cost to produce the instrument is less likely to exceed the estimate) than the PRICE H estimates based on Current Best Estimates (CBE) of mass**
  - NICM cost estimates are generally considered to have 50-70% cost confidence; all NICM system level estimates shown in this report were the 50% confidence estimates. Both 50% & 70% estimates are shown in the NICM report spreadsheets.
  - PRICE H estimates based on CBE mass are generally considered to have 20-30% cost confidence

NICM Input Ranges

- **NICM is an analogy-based cost tool that uses historic aerospace cost data, much of which has been normalized**
- **That historic data is used to establish the nominal input range of inputs, outside of which NICM will extrapolate the cost estimating relationship (CER)**
  - In those cases where the CER was extrapolated to produce an estimate outside of the nominal input range, we expect that the cost confidence may decrease with extreme extrapolation
- **All the GEO CAPE instrument types fall into the NICM category of Remote Sensing, Optical, Earth Orbiting**
- **The acceptable input ranges for that NICM instrument category are as follows:**
  - Mass < 350 kg
  - Power < 400 W
  - Data Rate <30,000 kbps
- **We have indicated where the GEO CAPE instrument case was outside of the NICM input ranges**
  - In some cases it may only have been outside of one NICM input parameter
- **The IDL only used the systems NICM tool, because we were limited to instrument-level details for the external references**
  - The subsystem level NICM tool requires a breakdown of mass by instrument subsystem
  - The subsystem level NICM estimate is available for an IDL study product that includes a MEL, and can achieve a higher NICM cost confidence

NICM Description

- **NASA Instrument Cost Model (NICM), latest version: NICM V, Rev 2 (as of May 2012)**
- **Inputs for NICM System Tool: the IDL only used the system tool, because we were limited to instrument-level**
  - Cost Base Year for Output
  - Flagship Mission (needed for schedule estimate)
  - Instrument Type (Remote Sensing, In-situ)
  - Remote Sensing Type (Optical, Active, Passive, Particle, Fields) or In-situ Type (Body, Arm/Mast or Probe)
  - Environment (Earth Orbiting or Planetary)
  - Other items vary depending on selection of above categories. Include items such as Mass (Min, Most Likely, Max); Power (Min, Most Likely, Max); Data Rate (Min, Most Likely, Max)
    - Min=CBE
    - Most Likely=Current Best Estimate (CBE) + Contingency
    - Max=Max. Instrument Allocation (if not defined use Most Likely+30%)
- **Output from NICM System Tool:**
  - Cost for 50% and 70% confidence levels
  - S-curves for Sensor Cost (Hardware + Software) and Total Instrument Cost (includes wraps for Management, Systems Engineering, S&MA, I&T)
  - Schedule and Phase Estimates based on rules of thumb developed from JPL missions
  - Joint Confidence Level
  - Represents Phase B through D (launch +30 days) for a single Protoflight unit

NICM Considerations

- NICM does:
  - *NOT* include charges from alternate funding sources (partner contributions, etc)
  - *NOT* account for technology development costs (TRL 1, 2, 3)
  - *NOT* include science teams, ground data development and mission operations costs
  - *NOT* include a non-recurring engineering (NRE) breakdown
  - *NOT* apply to airborne instruments
  - *NOT* apply to instrument suites
  - *NOT* apply to special instrument subsystems (such as Electra)
  - *NOT* allow for multiple build copies (includes 1st unit build only-Protoflight)
  - *NOT* include a breakdown of resource estimates (labor, material, etc)
  - *NOT* address the portion of Phase E software costs that usually start in Phases B/C/D

  - Provide the capability for a more refined estimate using the NICM Subsystem Tool, when enough input data is available
  - Provide schedule and phase estimates based upon rules of thumb developed from JPL missions
  - Provide Joint Confidence Level (JCL: the probability that cost will be $\leq$ the targeted cost and the schedule will be $\leq$ the targeted schedule date)
  - Provide a solver to trade cost cap/schedule cap/JCL for interrogating options