Jet Propulsion Laboratory
California Institute of Technology

Wind Lidar in the NOAA/NESDIS Future Space Architecture Study

R. T. Menzies, T.S. Pagano, and C. Zuffada
NASA / Jet Propulsion Laboratory
J. Piepmeier
Goddard Space Flight Center
F. W. Gallagher III and K. St. Germain
National Oceanic and Atmospheric Administration
M. W. Maier
The Aerospace Corporation

7 February 2018

Context: NSOSA Instrument Catalog

- ***The Instrument Catalog, along with Instrument Category Reports, are key elements of the NOAA Space Observation System Architecture Study,***
- ***Partners in Development: JPL (lead), with contributions from NASA GSFC, APL, MIT-LL, The Aerospace Corporation, and with Industry input***
- ***Product Development/Description: Generated instrument concepts for the 2030-2050 timeframe, including performance capabilities, instrument SWaP and cost estimates***
  - *Includes concepts for all instrument classes of interest to NOAA that range from projected extensions of legacy instruments to entirely new capabilities,*
  - *Includes concepts that meet three sets of performance guidelines for each instrument class, set by the Space Platform Requirements Working Group*
    - *Study Threshold / Expected / Maximum Effective (increasing order of capability/value)*
  - *Agreement to use NICM for all instrument concept cost estimates*
    - *Major Cost Drivers: (1) Mass (2) Power*

NSOSA

NSOSA Instrument Catalog

RFI

August 2015

NOAA Future Environmental Remote Sensing Capabilities

Environmental Data Records Value Models (EVM)

NOAA Space Platform Req. Working Group (SPRWG)

Measurement parameters for three levels: Study Threshold (ST), Expected (E), Maximum Effective (ME)

Legacy

Inputs from JPL, GSFC, APL, MIT/LL, Aerospace Corp., and industry

JPL-Led Team of Subject Matter Experts

Evolve representative candidates by subsuming characteristics of individual concepts

JPL INSTRUMENT CATALOG PRODUCT

Performance and SWAP-C (Size, Weight, and Power – Cost) estimates for each instrument concept in the catalogs

Instrument Catalog Structure

- ***The Catalog is actually two: (A) "Earth Weather" instruments, (B) "Space Weather" instruments;***
- ***Category A catalog entry classifications shown below***
  - *14 different remote sensor observational capabilities*
- ***NASA GSFC – lead responsibility for Wind Lidar and Ozone Mapper***

Vis/IR GEO Imagers	Vis/IR LEO Imagers	IR GEO Sounders	IR LEO Sounders
Vis/IR Imaging Sounders	MW GEO-MEO Imaging Sounders	MW LEO Imagers	MW LEO Sounders
3D Wind Lidar	AVM	GNSS-RO	Lightning Mapper
Ozone Mapper-Profiler	Precipitation Radar		

Technologies for Infusion and Maturation

- ***Examples of advancing technologies to be infused into instruments in high-scoring constellation payloads:***
  - *Next-gen cryocoolers and heat pipe technologies for Vis/IR imagers and sounders;*
  - *IR Focal plane detector arrays composed of III-V compound semiconductors with LWIR cutoff (e.g. NASA ESTO 2018);*
  - *Multi-frequency feeds, hybrid deployable antennas, and compact radiometers for microwave imagers and sounders (to be demonstrated by e.g., COWVR, TEMPEST launches in 2018, TROPICS in 2020)*
  - *Laser transmitters for 3D wind lidar (ESA ADM Aeolus launch in 2018; NASA ESTO, NASA DAWN airborne lidar technology infusion)*

Close cooperation with NASA would benefit further technology maturation in a timely manner

High Leverage/Impact Instrument Category	Impact of Advancing Technology
3D Wind Lidar	New capability/product
Vis/IR spectrometers	Reduced SWaP
MW imagers/sounders	Reduced SWaP

3D Wind Lidar Concepts Studied Cycle 2a

- ***The Study went through three "cycles" in about 2 years;***
- ***Lidar concepts studied in Cycle 2a were based on GSFC NWOS Study:***
  - *(1) Full Hybrid system – meant to meet most ME-level performance metrics*
  - *(2) UV system only – meant to meet most EXP-level performance metrics*
  - *(3) Concepts include four 70-cm aperture diam. telescopes*
  - *Both concepts with 2 stripes, each stripe with fore/aft looks*
- ***NWOS study resulted in detailed MEL as starting point***
  - *NWOS concepts provided acceptable SWaP proxies*
- ***Cycle 2a Results: (1)Mass in 450-600 kg range, (2) Power in 900-1350 W range***
- ***NICM cost estimates: in $ 1M range***
- ***Not much traction at higher level; shortly the Study moved to Cycle 2b***

3D Wind Lidar Concepts Studied Cycles 2b / 3

- ***Cycle 2b EVM provided new/explicit emphasis on number of stripes***
  - *ST-level: single stripe with fore/aft looks*
  - *EXP-level: 4 stripes, each stripe with fore/aft looks*
  - *ME-level: 12 stripes (!), each stripe with fore/aft looks*
  - *Stripe spacing (Bob Atlas): Optimal ~ 10-20 km; Acceptable ~ several hundred km*
- ***Cycle 2b along-track resolution relaxed by ~ factor of 2 (See following slide);***
- ***Motivated a new look at smaller, more agile concepts that could conceivably lead to multiple copies;***
- ***Start with a "near-EXP" performance level concept***
  - *Four 50-cm diameter telescopes, with rotating mechanism visiting each in succession;*
  - *Utilized updated IR Wind Lidar instrument and performance parameters*

3D Wind Lidar Example – (Cycle 3)
400 km altitude assumed

	3D Wind Lidar Performance Metrics from EVM, and Resource Parameters for a 2 stripe version		
	Study Threshold	**Expected**	**Maximum Effective**
Resolution: H – along track V - vertical	H = 400 km V = 4 km	H = 250 km V = 2 km	H = 100 km V = 1 km
# of Stripes (each with fore/aft looks)	single stripe	4 stripes	12 stripes
Accuracy (speed/direction)	10 m/s or 10% 30-deg	3 m/s or 10% 20 deg	2 m/s or 10% 10 deg
Size [m]		0.85x1.3x1.3 (2 stripes)	
Mass [kg]		290 (2 stripes)	
Power [W]		420 (2 stripes)	
Data Rate [Mbps]		1.5	
NICM Cost ($FY16)		292 $M	
Reference Instrument			

Wind Lidar Value Scoring

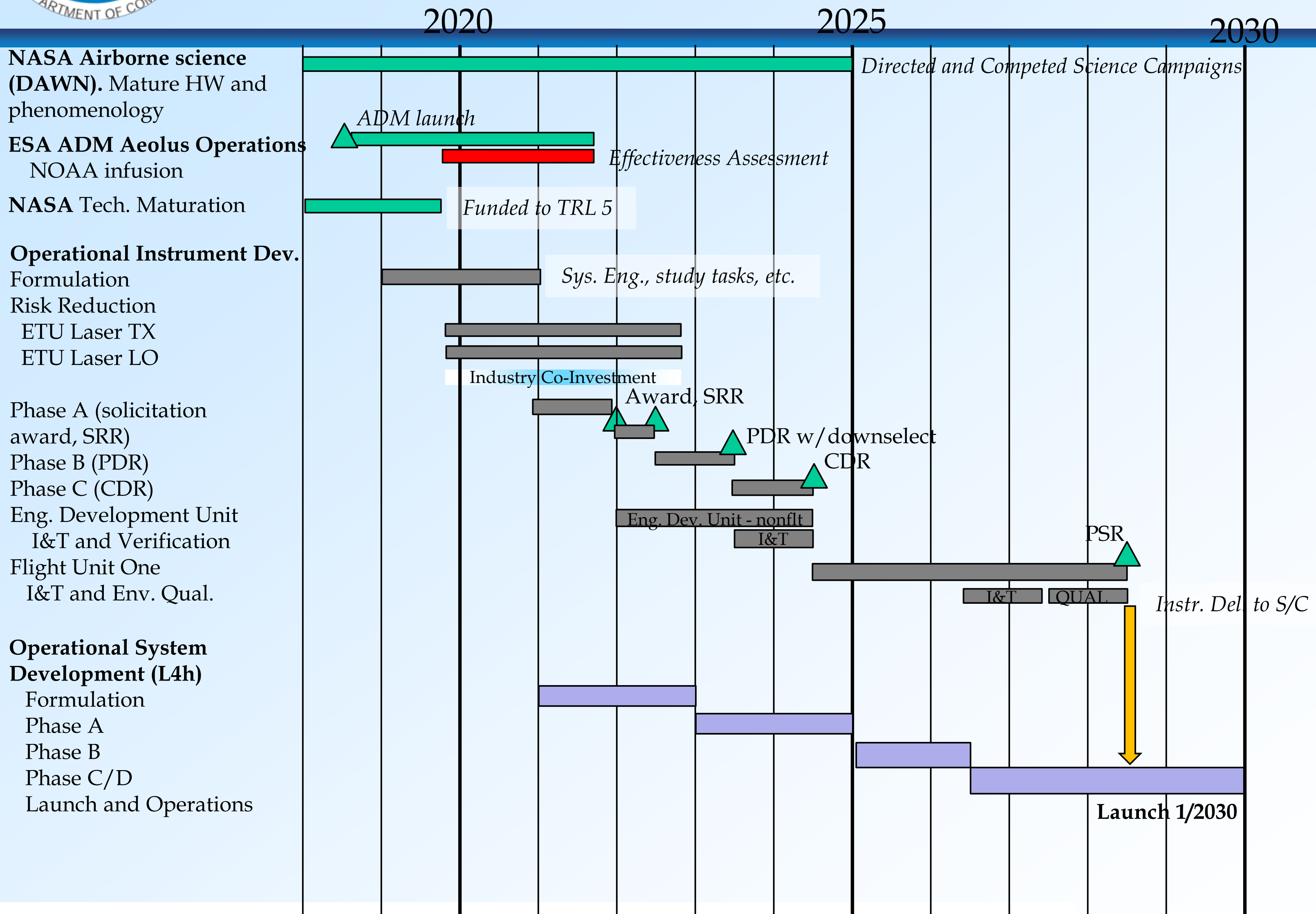
- In the NSOSA analysis, the 3D wind lidar is considered high value, relatively high risk, relatively high cost. (No surprise…)
- The 3D wind lidar concept in the Catalog ranks high in value per unit cost.
- In the process of creating a number of different Constellations consisting of various instruments on platforms in GEO, LEO, L1, etc. orbits, 3D wind lidar is included in the highest scoring Constellations that meet the future NOAA budget criteria.
- Development timeline/roadmap: What is the earliest feasible launch date for the Catalog wind lidar concept?
- Considerable discussion among NSOSA parties at NASA GSFC, JPL, and JHAPL regarding this question…

Notional Wind Lidar Development Timeline: Assumptions

- ***Multiple near-term flights of airborne prototypes (DAWN, OAWL);***
  - *Improve understanding of the phenomenology / mature data analysis algorithms / validate performance predictions / contribute to science;*
  - *Imperative that airborne lidars meet performance metrics and teams publish*
- ***ADM Aeolus wind lidar (ALADIN): early 2018 launch, 3-yr mission lifetime;***
- ***NOAA personnel have access to Aeolus lidar (ALADIN) datasets / will lead U.S. cal/val effort;***
- ***NASA ~ $2.5M/yr commitments to laser transmitter tech dev/maturation through 2020 to achieve TRL 5***
- ***Start Project Office with Formulation and Risk Reduction Activities***
  - *Develop TX and LO lasers through continued Tech Mat. Investment*
  - *Invest to mitigate other identified subsystem technical risks*
  - *Expect Industry Investment*
- ***Solicitation and Award: consider two Phase A/B awards with downselect at PDR – perhaps mitigates risk of parallel tech mat.***
- ***Form-fit-function EDU (but non-flight to save cost)***
- ***Roadmap itself is currently "colorblind" – applicable to UV/IR***

R^2+ETU+EDU+FM

Wind LIDAR Integrated Roadmap



Multi-Stripe Future: A Challenge

- ***There is a revolution in SmallSat capabilities/offerings***
- ***Why not take advantage with a Distributed 3D Wind Lidar Architecture?***

- ***Rideshare capabilities exist (or will soon exist) for a 200-300 kg bus carrying a 100 kg, 100 W class instrument in a carrier/payload adapter (ESPA, SSPS/SHERPA, Moog CSA Propulsive ESPA, etc);***
- ***Example: COWVR, a MW imager with 75-cm rotating reflector, in MSV bus that is ESPA-compatible, will launch summer, 2018 (ORS-6 mission).***

- ***Optimize the capabilities of a 100 kg, 100 W class wind lidar;***
- ***Launch multiple copies, with 400-km drop-off, and use thrusters to separate orbital planes by several 10's of km.***

Compact Ocean Wind Vector Radiometer

Conclusions

- ***The Instrument Catalog provides the performance, SWaP, and Cost estimates for the range of instrument observational capabilities of value to NOAA in the upcoming decades;***

- ***The NSOSA activity includes the result of a joint NOAA-NASA effort producing a roadmap leading to launch of an operational wind lidar with unique 3D winds measurement capabilities in the 2030 timeframe.***
  - *Industry would work together with national labs (e.g. NASA-related resources) to accelerate tech infusion and maturation.*

- ***Looking ahead at the revolution in "SmallSat" capabilities, a serious effort to investigate a distributed wind lidar architecture should be undertaken.***

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov