Space – based Machine Automated Recognition Technique (SMART)

Dr. Torreon Creekmore| Program Manager| 29 May 2019

Proposer's Day

Office of the Director of National Intelligence

IARPA

BE THE FUTURE

Disclaimers

- This presentation is provided solely for information and planning purposes
- The Proposers' Day does not constitute a formal solicitation for proposals or proposal abstracts
- Nothing said at Proposers' Day changes the requirements set forth in a BAA
- A BAA supersedes anything presented or said by IARPA at the Proposers' Day

Goals

Familiarize participants with IARPA's interest in the SMART program.

Please ask questions and provide feedback, as this is your chance to alter the course of events.

Foster discussion of complementary capabilities among potential program participants, AKA teaming.

- Take a chance, someone might have a missing piece of your puzzle.

Questions

- During this session, questions should be recorded on note cards. They will be answered for everyone's benefit at a later point in the presentation.

- If/when a BAA is released, questions can only be submitted to the e-mail address provided in the BAA and will only be answered in writing on the program website.

Agenda

Time	Topic	Speaker
8:30 AM – 9:00 AM	Registration	
9:00 AM – 9:10 AM	Welcome, Logistics, Proposer's Day Goals	Dr. Torreon Creekmore Program Manager, IARPA
9:10 AM – 9:20AM	IARPA Overview	Mrs. Cheri Benedict Deputy Director Operations, IARPA
9:20 AM – 10:20 AM	SMART Program Overview	Dr. Torreon Creekmore
10:20 AM – 10:30 AM	Doing Business with IARPA	Dr. Torreon Creekmore
10:30 AM – 10:40 AM	SMART Question Submissions	
10:40 AM – 11:00 AM	Break	
11:00 AM – 12:00 PM	No-Host Lunch	
12:00 PM – 12:30 PM	SMART Questions & Answers	Dr. Torreon Creekmore
12:30 PM – 3:30 PM	Offerors' Capabilities Briefings	Attendee's (No Government)
3:30 PM – 5:00 PM	Poster Session, Networking and Teaming Discussions	Attendee's (No Government)

IARPA Overview

Cheri Benedict, Deputy Director Operations
Intelligence Advanced Research Projects Activity

Office of the Director of National Intelligence

IARPA

BE THE FUTURE

The United States Intelligence Community

IARPA Mission

IARPA envisions and leads *high-risk, high-payoff research* that delivers innovative technology *for future overwhelming intelligence advantage*

- Our problems are **complex** and **multidisciplinary**
- We emphasize **technical excellence** & **technical truth**

IARPA Method

Bring the best minds to bear on our problems

- Full and open competition to the greatest possible extent
- World-class, rotational Program Managers

Define and execute research programs that:

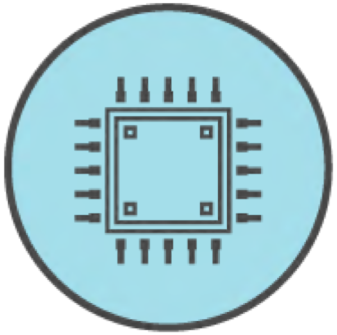
- Have goals that are clear, measureable, ambitious and credible
- Employ independent and rigorous Test & Evaluation
- Involve IC partners from start to finish
- Run from three to five years
- Publish peer-reviewed results and data, to the greatest possible extent
- Transition new capabilities to intelligence community partners

4 Core Research Thrusts

Analysis

Anticipatory Intelligence

Collection



Computing

Analysis R&D

"Maximize insight from the information we collect, in a timely fashion"

LARGE DATA VOLUMES AND VARIETIES

Provide powerful new sources of information from massive, noisy data

SOCIAL, CULTURAL, AND LINGUISTIC FACTORS

Analyze language and speech to produce insights into groups and organizations

IMPROVING ANALYTIC PROCESSES

Enhance analytic process at the individual and group level

Anticipatory Intelligence R&D

"Detect and forecast significant events"

S & T INTELLIGENCE

Detect and forecast the emergence of new technical capabilities

INDICATIONS & WARNINGS

Provide early warning of societal crises, disease outbreaks, insider threats, and cyber attacks

STRATEGIC FORECASTING

Forecast major geopolitical trends and rare events

Collection R&D

"Dramatically improve the value of collected data"

NOVEL ACCESS

Reach hard targets in denied areas

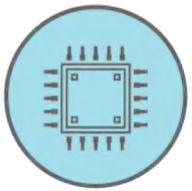
ASSET VALIDATION AND IDENTITY INTELLIGENCE

Assess trustworthiness and advance biometrics in real-world conditions

LOCATING, TRACKING AND DETECTING

Accurately locate and track intelligence interests and detect CBRNE agents

Computing R&D



"Operate effectively in a globally interdependent and networked environment"

COMPUTATIONAL POWER

Revolutionary advances to solve problems intractable with today's computers

TRUSTWORTHY COMPONENTS

Gain the benefits of leading-edge hardware and software without compromising security

SAFE AND SECURE SYSTEMS

Protecting systems against cyber threats

How to Engage with IARPA

iarpa.gov | 301-851-7500

info@iarpa.gov

Reach out to our Program Managers.

Schedule a visit if you are in the DC area or invite us to visit you

Opportunities to Engage:

RFIS AND WORKSHOPS

Opportunities to learn what is coming, and to influence programs.

"SEEDLINGS"

Typically a 9-12 month study; you can submit your research proposal at any time. We strongly encourage informal discussion with a PM before proposal submission.

PRIZE CHALLENGES

No proposals required. Submit solutions to our problems – if your solutions are the best, you receive a cash prize and bragging rights.

RESEARCH PROGRAMS

Multi-year research funding opportunities on specific topics.

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Program BLUF

Hard to automatically find, monitor, and characterize anthropogenic processes/activities, i.e., **heavy construction** over broad areas.

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An ideal solution is capable of mining an archive of satellite imagery to produce **information** to explain past, present, and future anthropogenic activities.

Program BLUF

Hard to automatically find, monitor, and characterize anthropogenic processes/activities, i.e., **heavy construction** over broad areas.

NGA Research Director: "…the volume of data already available cannot be handled by merely adding people" (Curtis 2016, p. 9).

SMART IMPACT

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How can we continue to do what we already do?

Old context, wrong question!

What can we do now that we were not able to do before?

Strength is to exploit data density vs. "perfect scene"

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Strength is to exploit data density vs. "perfect scene"

Optimal use of IC's most valuable resource – TRAINED ANALYSTS!

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- Automate & Augment a portion of the **analyst's awareness** with **AI/ML**

Develop broad-area search (BAS) capabilities to persistently detect, monitor, & characterize heavy construction in the multi-spectral and multi-temporal domains.

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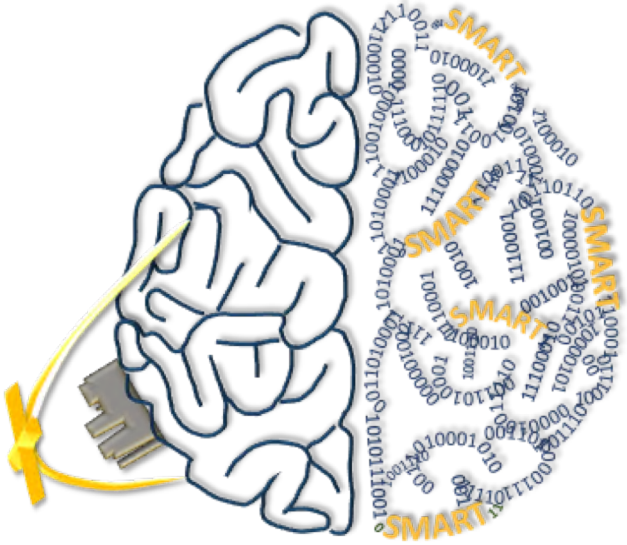

Develop broad-area search (BAS) capabilities to persistently detect, monitor, & characterize heavy construction in the multi-spectral and multi-temporal domains.

SMART GOALS

- ***Automated quantitative analysis of space-based imagery to:***
  - Quantify data quality and cross-sensor inconsistencies found in timeseries of space-based data (automated calibration of data)
    - Variety, Volume, Velocity, Veracity, and Value
  - Quantify relationship b/w surface reflectance and heavy construction
    - Develop indicators & signatures to measure construction with satellites
  - Quantify, inter-compare, and enable transitions to be characterized
    - Describe discrete change events and trends over long periods, i.e., change detection and pattern analysis
  - Develop flexible and adaptable algorithms to provide versatility for a range of future sensors, applications, and scales
    - Rapid and repeatable analysis: Focus analyst on sensemaking

Anthropogenic Activity: Heavy Construction

Anthropogenic Activity: Heavy Construction

Sequences

Site Prep

Anthropogenic Activity: Heavy Construction

Sequences

Site Prep

Excavation

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Sequences

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Excavation

Build Back

Anthropogenic Activity: Heavy Construction

Sequences

Site Prep

Excavation

Build Back

Commissioning

Anthropogenic Activity: Heavy Construction

Sequences

Site Prep

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- **Sequences/Phases (Mob site, Site prep, Excavation, Perm Lining, Build Back, Commissioning)**
  - Site Prep: vegetation, soil piles, moisture, etc.
  - Excavation: geology, surface temperature, etc.
  - Build Back: surface materials, backfill, surface temp, etc.
  - Commissioning: geology, vegetation, surface materials

Heavy Construction

- US Department of Labor:
  - Occupational Safety and Health Administration
  - Description for 1629: Heavy Construction, Not Elsewhere Classified
  - https://www.osha.gov/pls/imis/sic_manual.display?id=413&tab=description

Why this?

- More high-resolution (spatial) and short re-visit satellites are being launched
  - **However, SMART purpose is not to rely on just spatial information, but develop capabilities in the multi-spectral and multi-temporal domains for analysts.**

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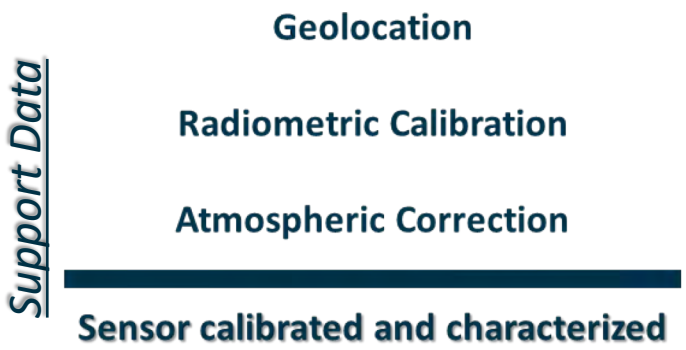

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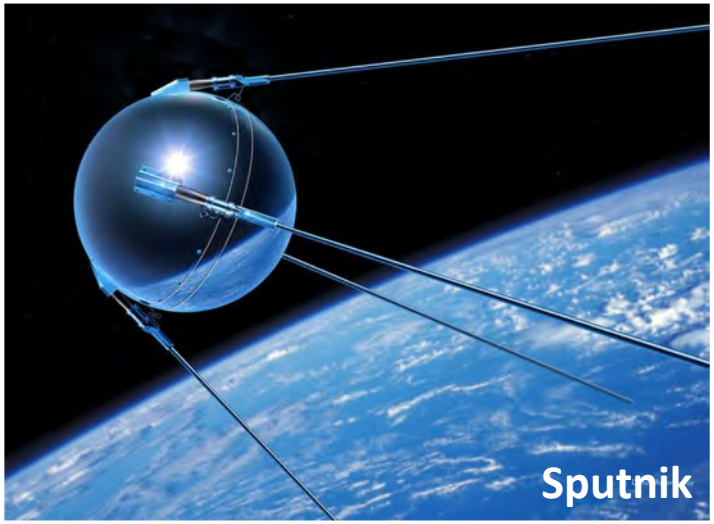
Albert Einstein: "...information, however, is not knowledge. Raw data means nothing without interpretation."

Current State-of-the-Art Limitations

- **Cannot keep up Analytic workflow**
- **Cost of commercial data and priority of tasking**
  - **What should we buy?**
- **Algorithms focused on spatial; spectro-temporal mostly neglected**
  - **Change Activity:** Recorded in multi-temporal data, can contain more information and activity is hard to hide.
  - **Change Detection Challenge:** Match and characterize the temporal scale of phenomena to be observed with the temporal resolution of available data.
- **Most products a year old, likely not intelligence/management relevant**
- **Applications limited to small area due to storage and computing**

Address Key Gaps: Labor, Big Data, Cost, & Lack of Data



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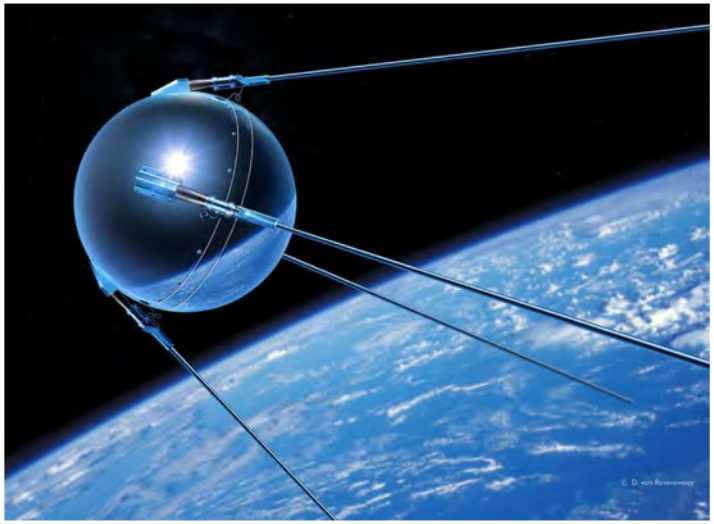
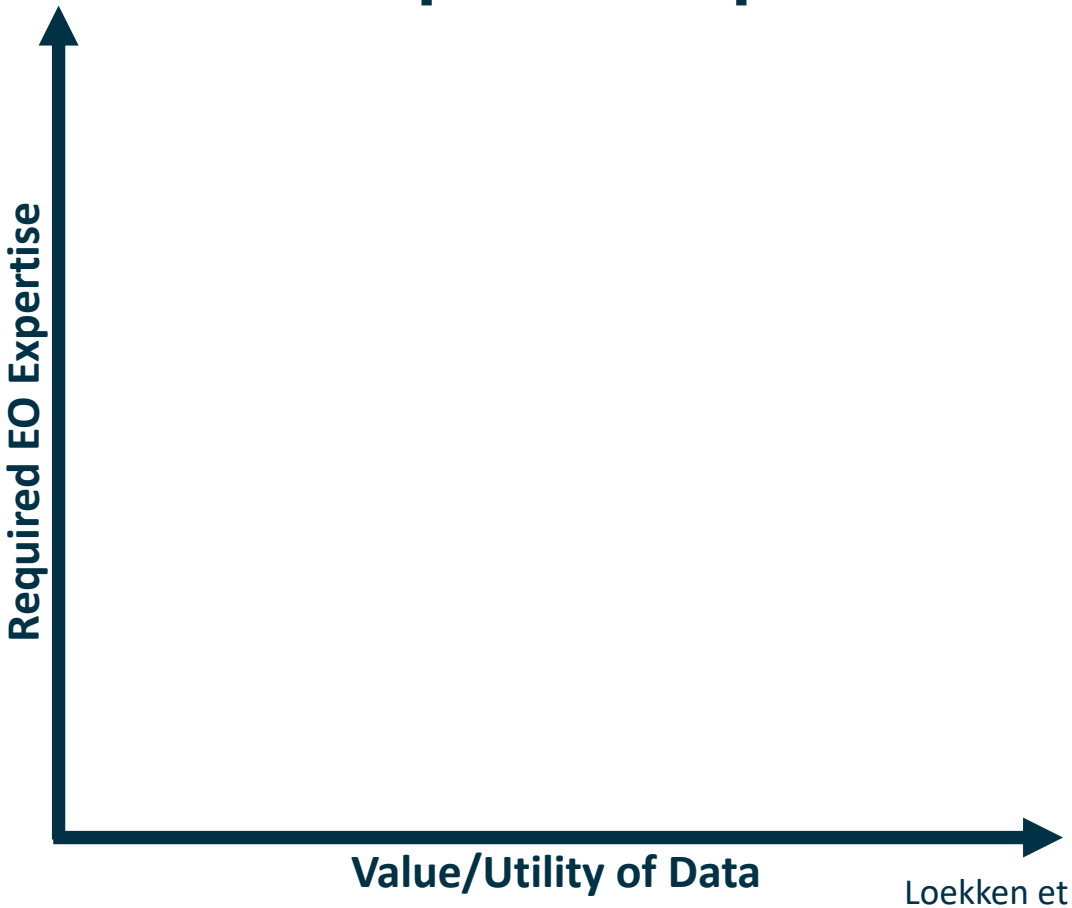


Address Key Gaps: Labor, Big Data, Cost, & Lack of Data

- **Commercial:** ~$633K (~800K) = 30K km^2 Landsat scene at 50 cm (30cm)
- Not optimized for evolving environment

Expensive & difficult to extract intelligence

Reduce Required Expertise



Loekken et al. 2015; Pabian, 2015

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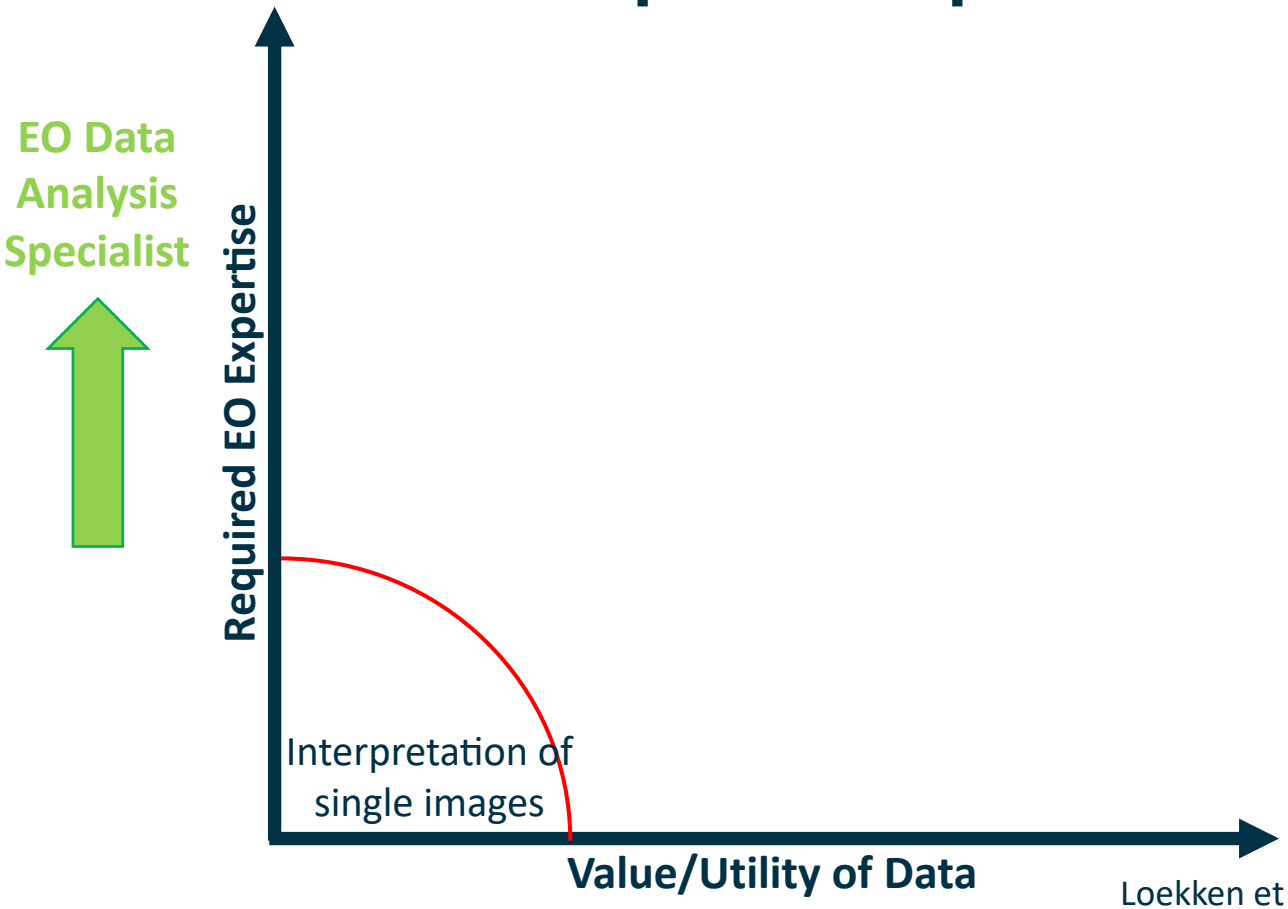

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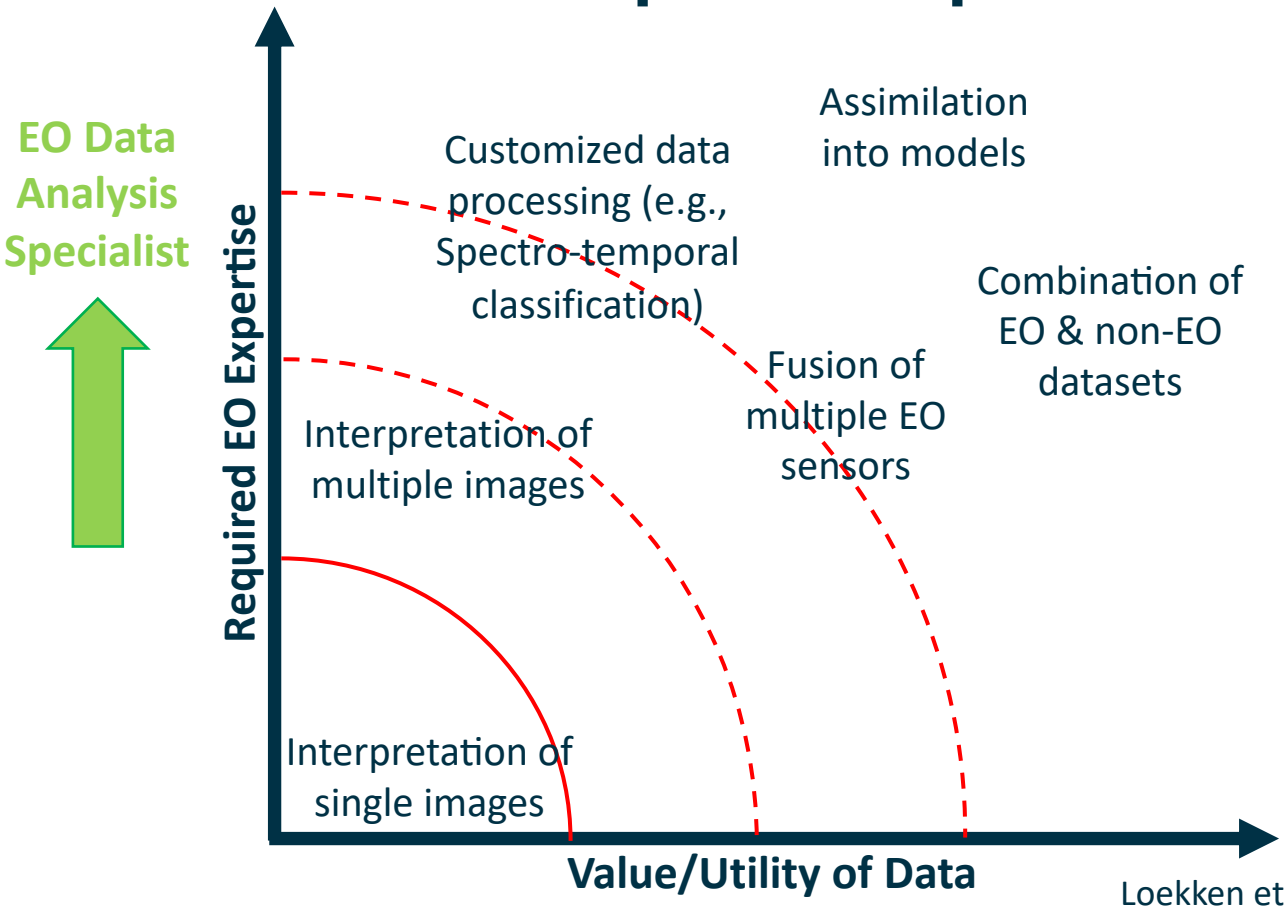

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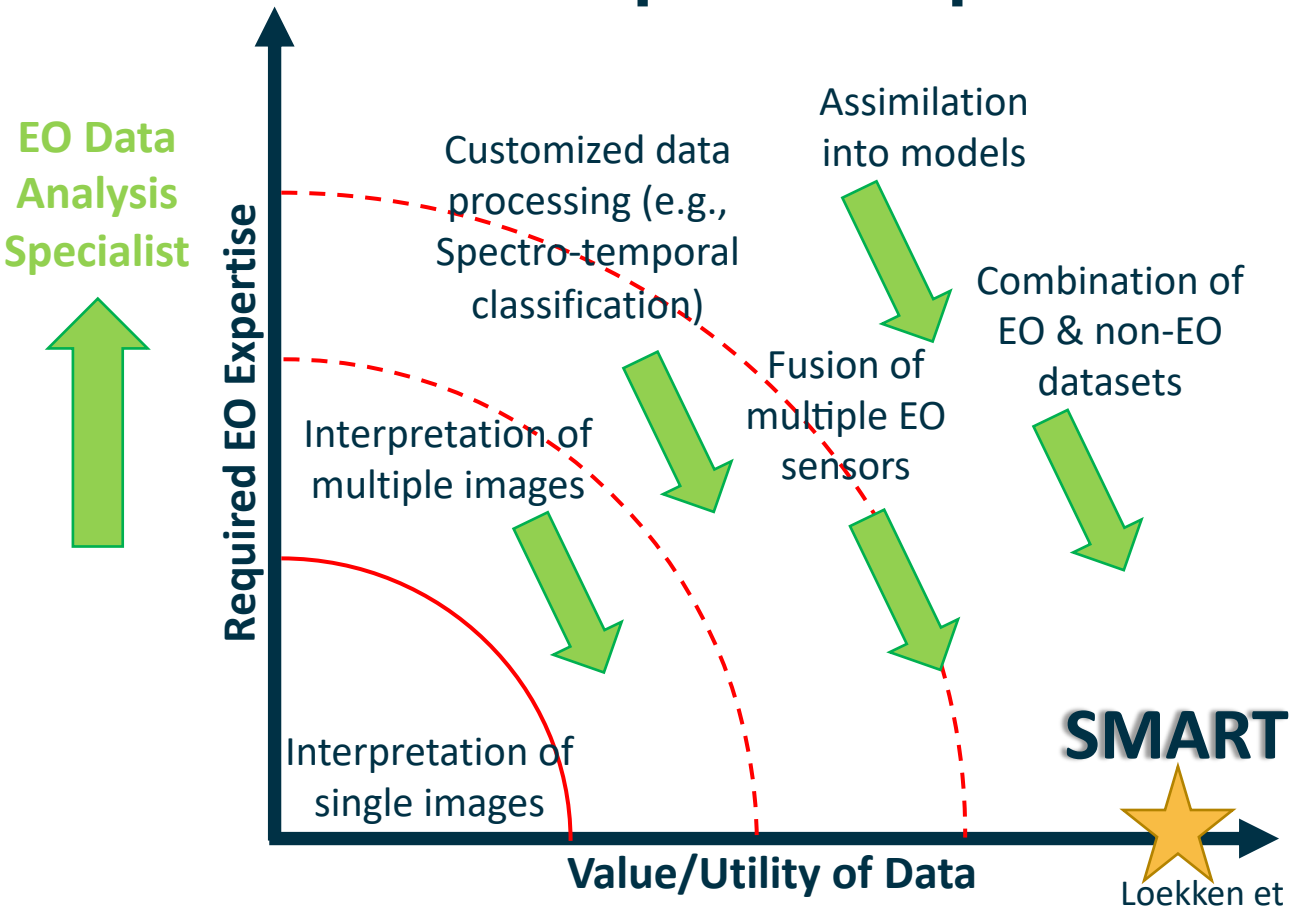

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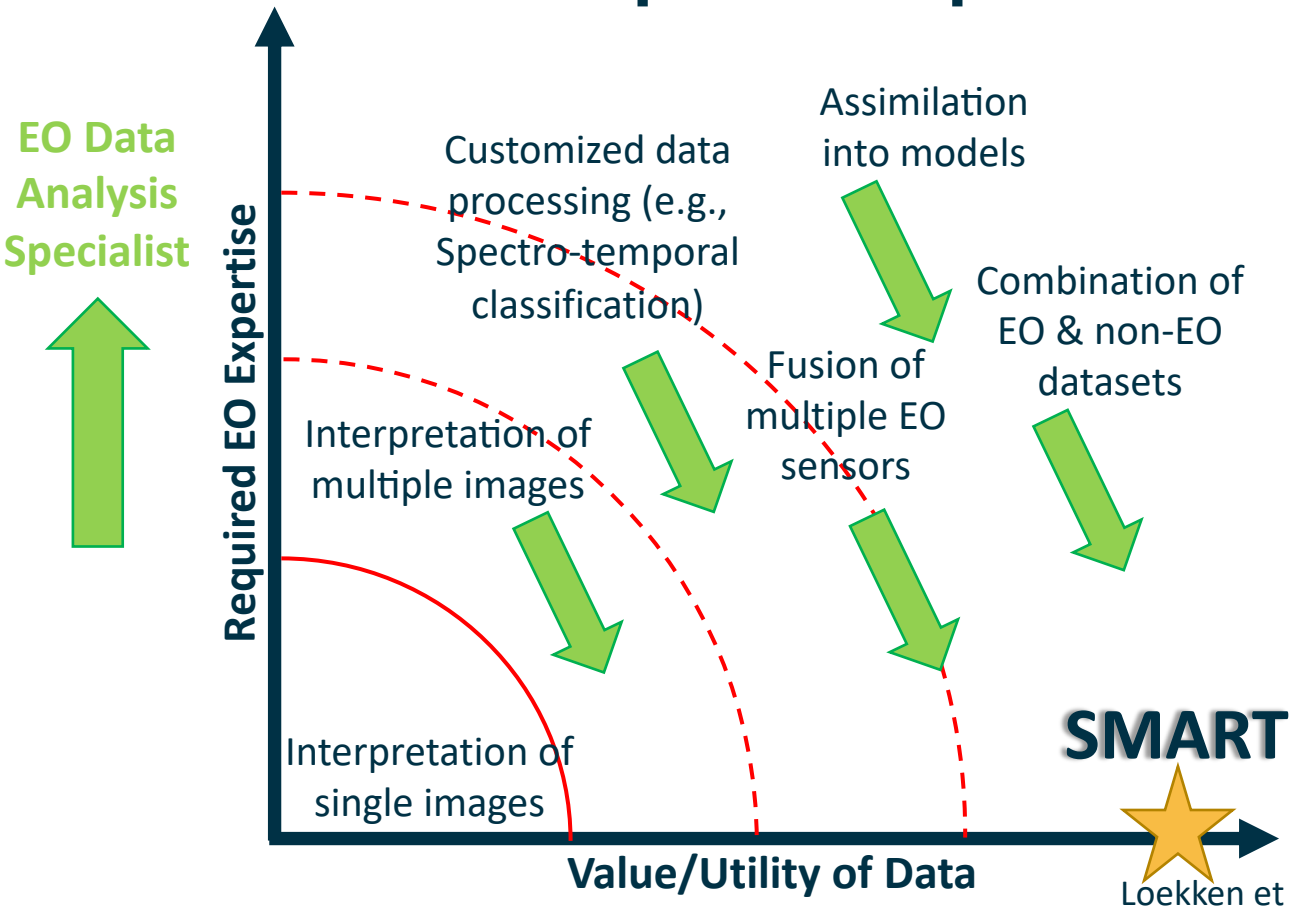

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Bridge the gap between data and information.

Actionable Information is the ends, ***Data*** is the means

Approaches to SMART

- ***Agnostic about proposed approaches***
- Leverage ML to potentially exploit dimensions of:
  - **Time:** multi-temporal analysis
  - **Space:** spatially aligned time-series at pixel level and use of diverse spatial resolutions
  - **Pixel:** exploitation of temporal evolution of target intensities
    - material molecular composition & shape affect reflectance, absorption & emittance of EM radiation
    - Geometric correction, sensor calibration, cloud removal, & advanced aerosol modeling

Enabling Technology (ET)

- New Data Architecture
  - More Input Sources
- Spectral Characterization
  - Relate to absolute
  - Relate sensor-to-senor
- Dynamic Aerosol Modeling
  - Virtual Constellation
- Machine Learning (ML)
  - Normalized Historical Data

20x increase in raw data (15 yrs.)
(ML needs lots of data for training)

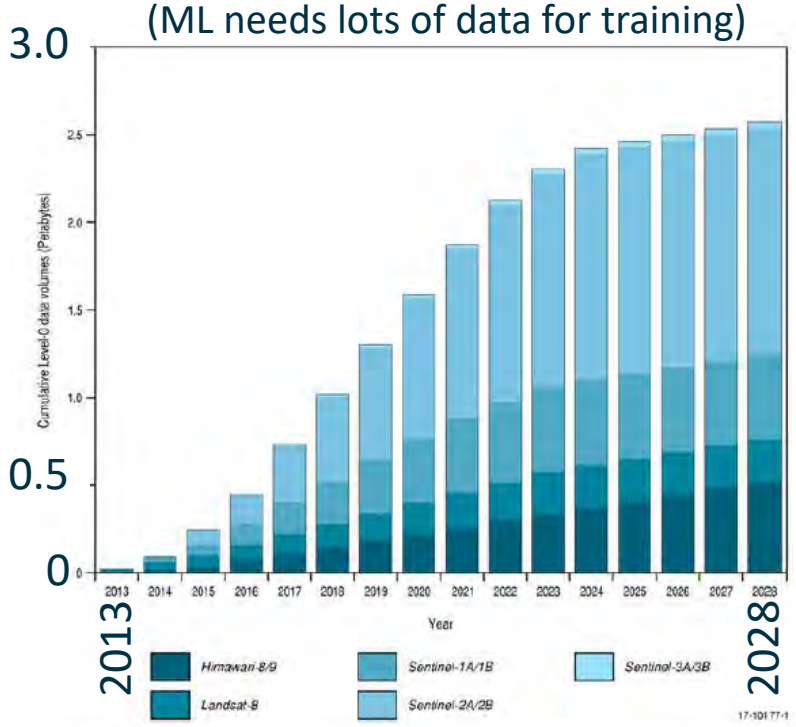

Fig. 1. The estimated volumes EOS data produced by the Landsat-8, Sentinel-1,-2,-3 and Himawari-8/9 missions from 2014 and 2029 for Australia. Only 'raw' data are considered. Data volume estimates are based on CEOS (2014).

Adding processed products: 3 to 5 times greater data volumes (Lewis et al., 2017).

ET: More Input Source + Spectral Characterization = More Frequent Timeseries

Landsat

Sentinel

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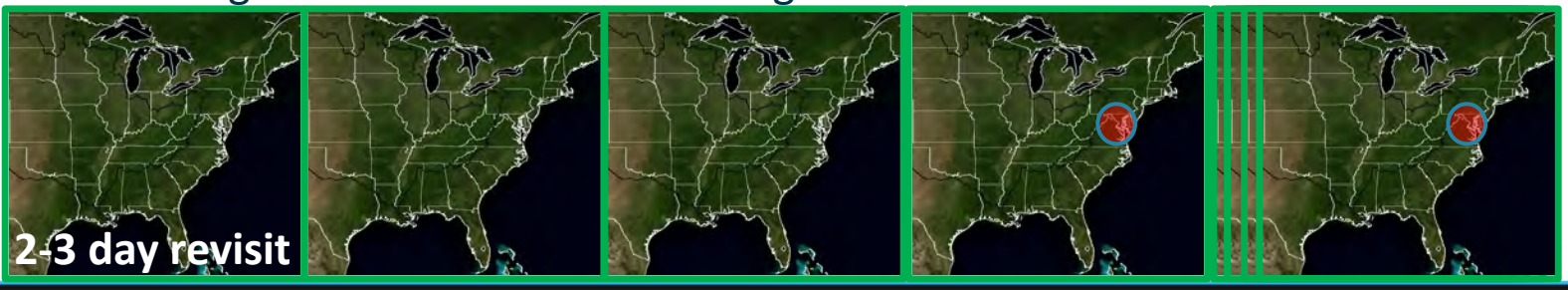
Fused images at Sentinel scale: 14 images



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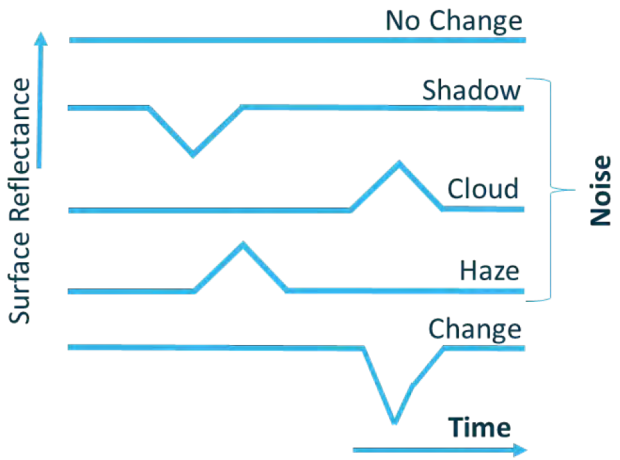


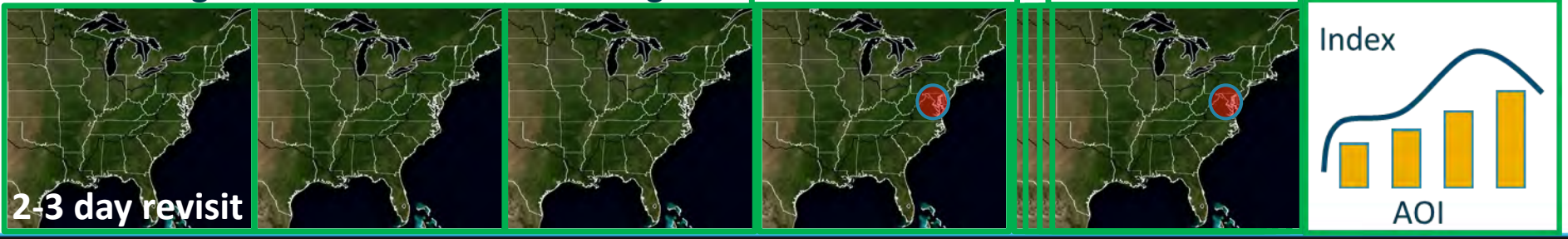
- **Normalized Difference Vegetation Index should not vary more than 5-10%**
- **Atmosphere can have > 50% effect**

Roger et al., 2006; Hilker et al., 2012; Hermosilla et al., 2015

Mob Site

Build Back

Fused images at Sentinel scale: 14 images



ET: Dynamic Aerosol Modeling

Accurate aerosol type & loading estimates is a requirement to sensor fusion and temporal processing (i.e., **Virtual Constellation**).

Today: Only 4 aerosol models

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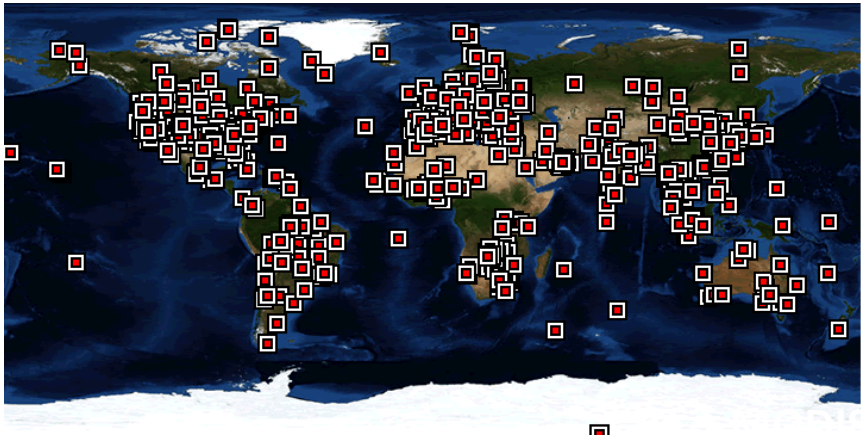

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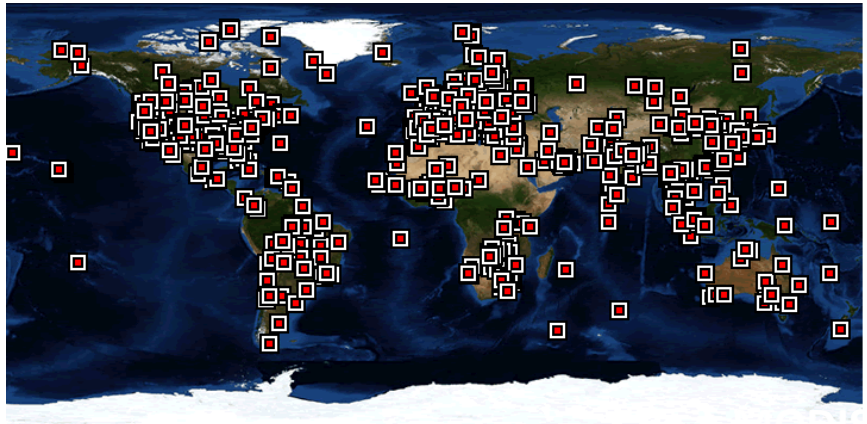
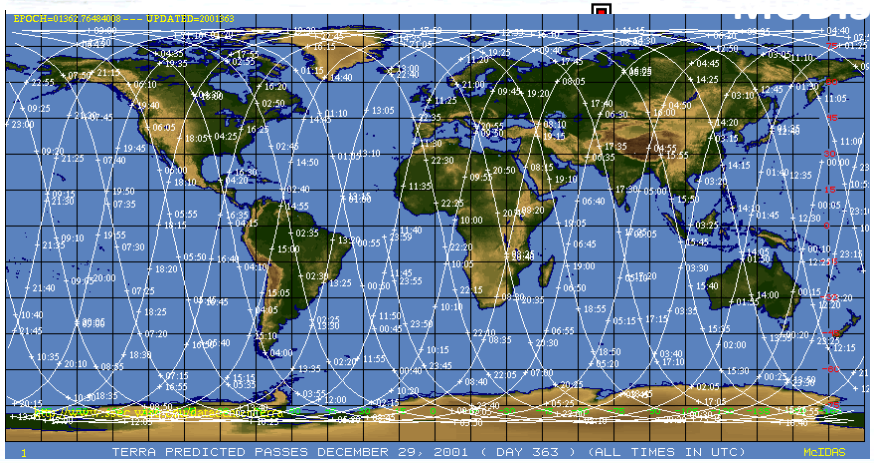


space



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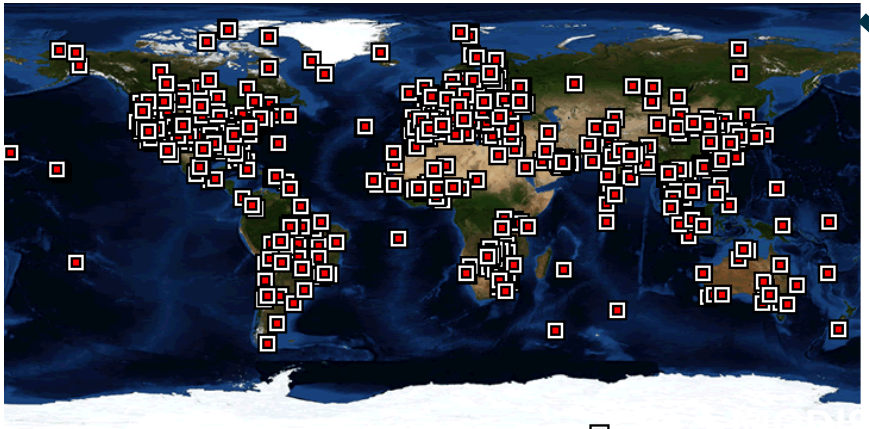
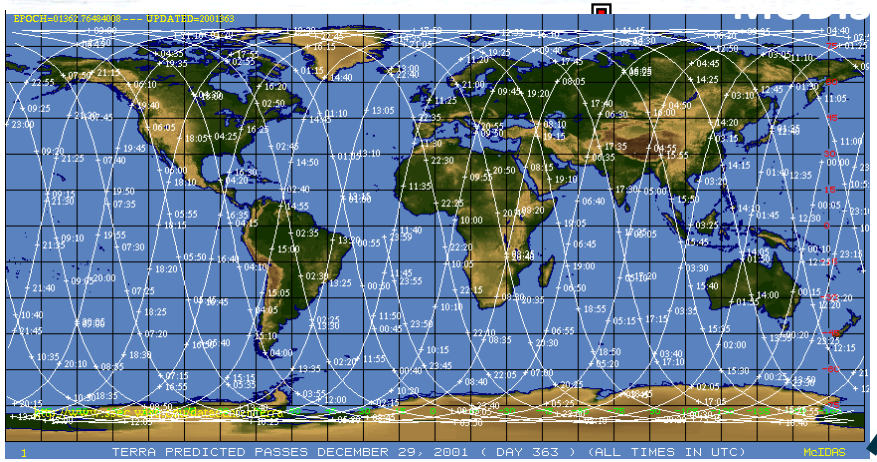
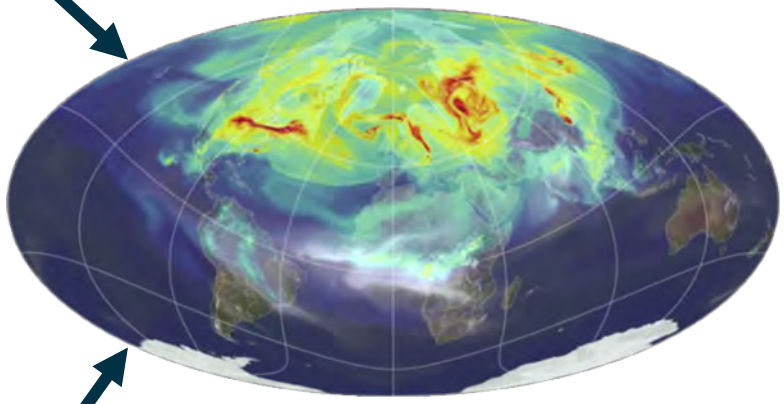




surface

space

Dynamic Aerosol Models



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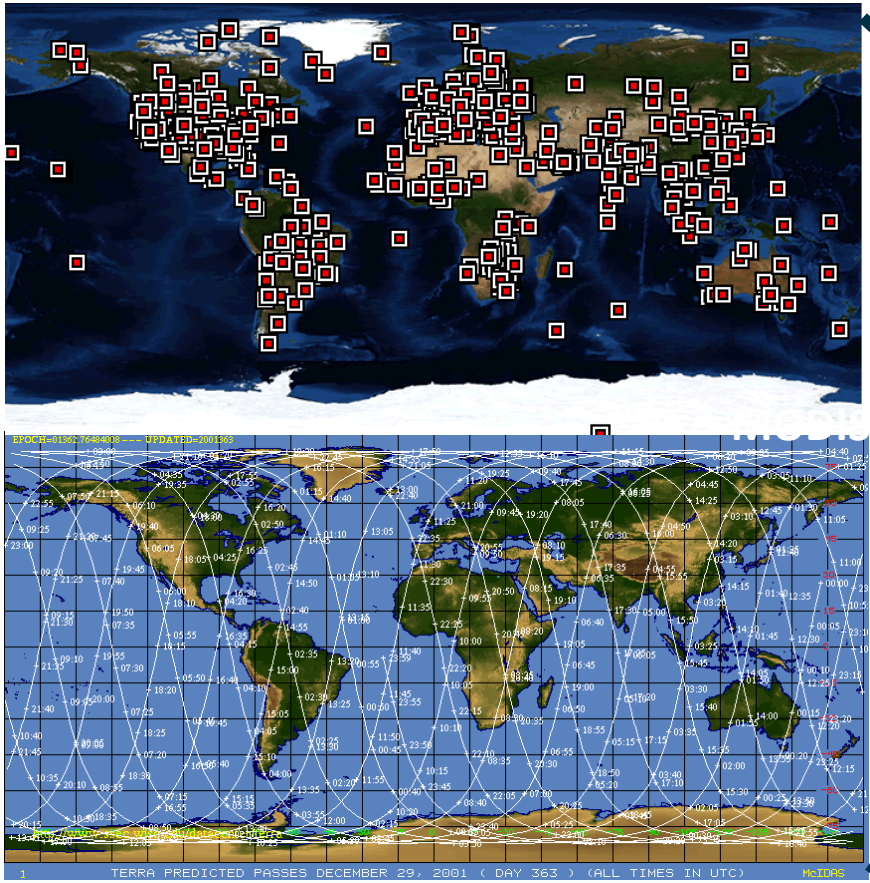

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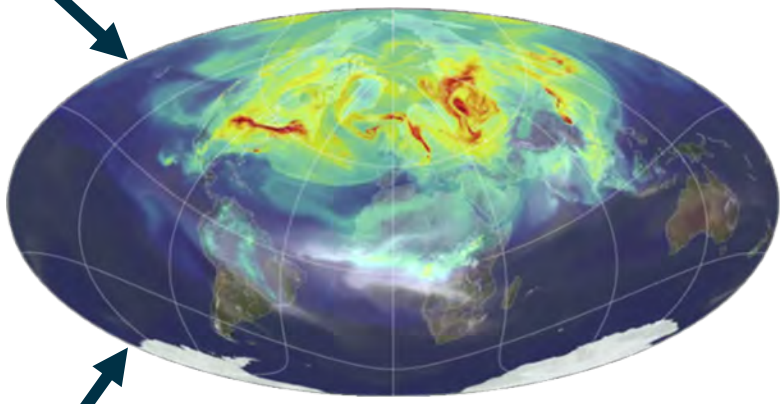
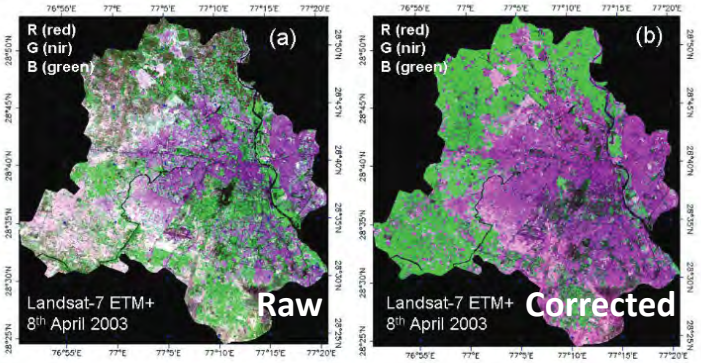
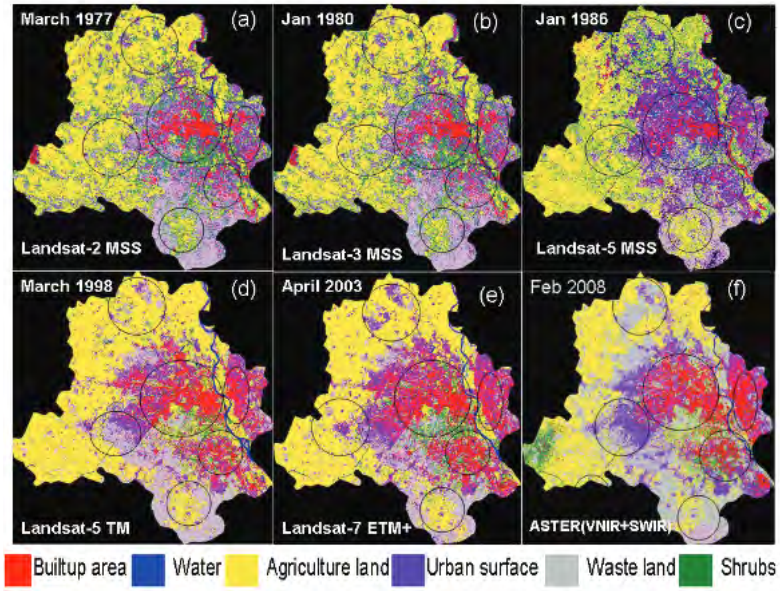


Atmospheric Correction permits operation in the same spectral space in which AOI/target is known (**understand true change**)

ET: Virtual Constellation





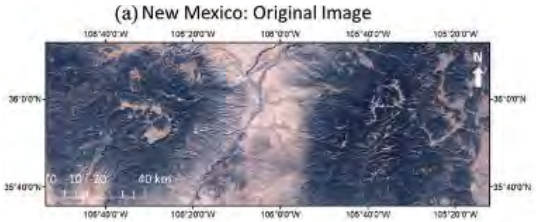
The Use of Multi-temporal and Multi-spectral Satellite Data to Detect Land Use and Land Cover Changes in the Urban City Delhi

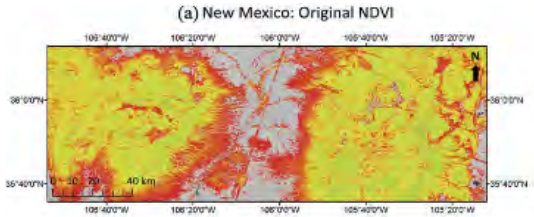
Dr.Devendra Singh[1*]

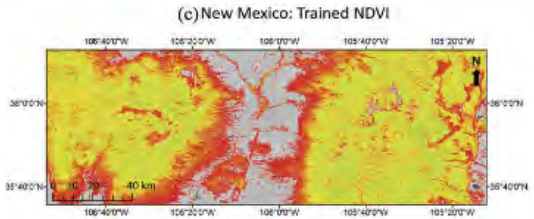
[1]*Department of Science and Technology, Technology Bhavan, New Mehrauli Road, New Delhi-110016, INDIA.*

- Variety of sensors available for high resolution imagery
- Landsat monitored urbanization to 81-93% overall accuracy (Li & Yeh, 1998)
- Landsat & ASTER highlighted large scale construction from 1977-2008

ET: ML-Normalized Historical Data







Predicting the spectral information of future land cover using machine learning

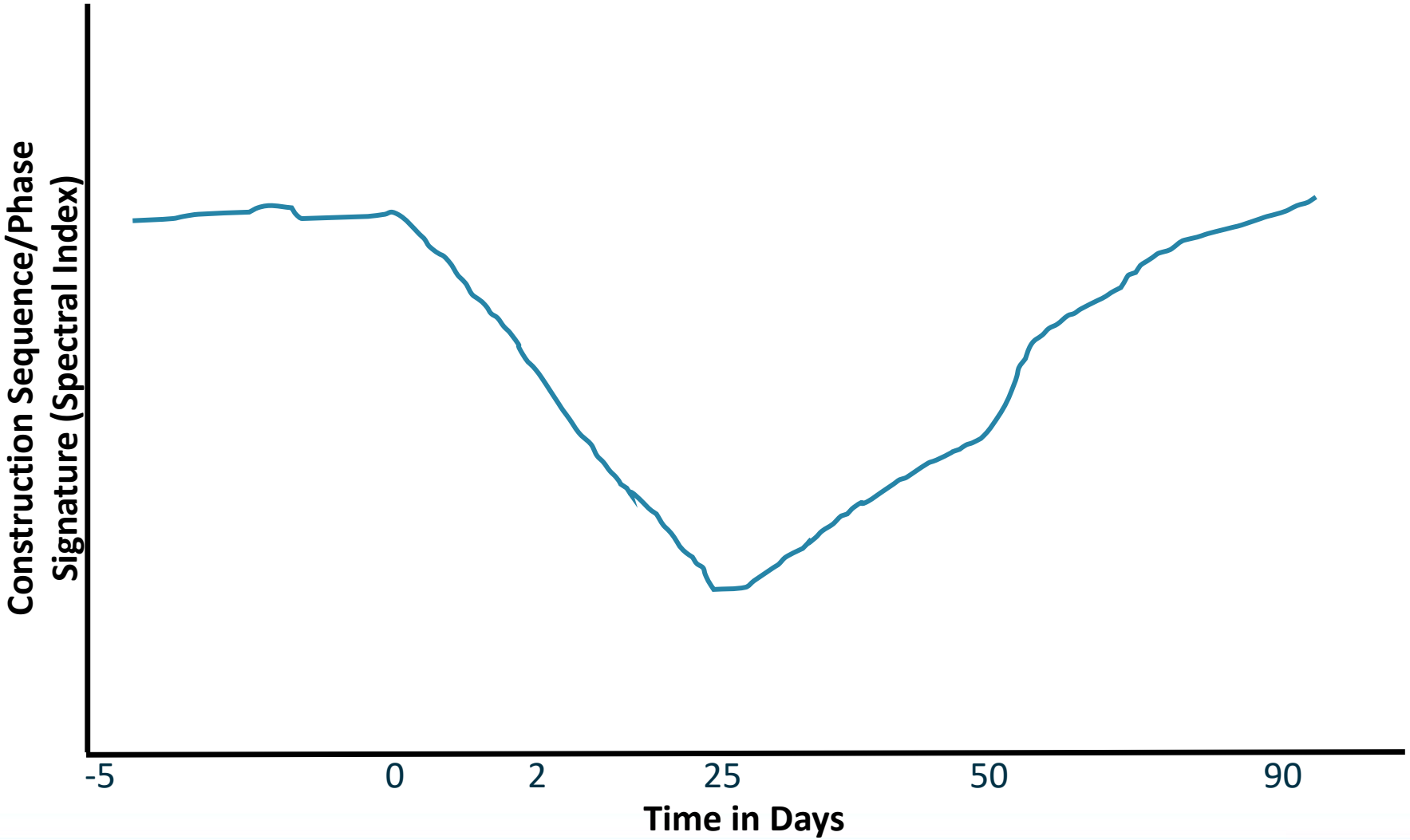
Sopan D. Patil [a], Yuting Gu[b], Felipe S. A Dias[c], Marc Stieglitz[c] and Greg Turk[b]

[a]School of Environment, Natural Resources and Geography, Bangor University, Bangor, UK; [b]School of Interactive Computing, Georgia Institute of Technology, Atlanta, GA, USA; [c]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, USA

- Random Forests ML model trained on historical imagery
- Predicted photo – realistic image and NDVI image for a 2026-2080 climate change scenario
- Demonstrated that the direct prediction of spectral band information could derive ecological products
- **Future opportunities:** improved sensors, data quality, regional –to – continental, and short – time scale change detection

SMART
Approach & Program Plan

SMART Approach



SMART Approach

Landsat
Sentinel-2

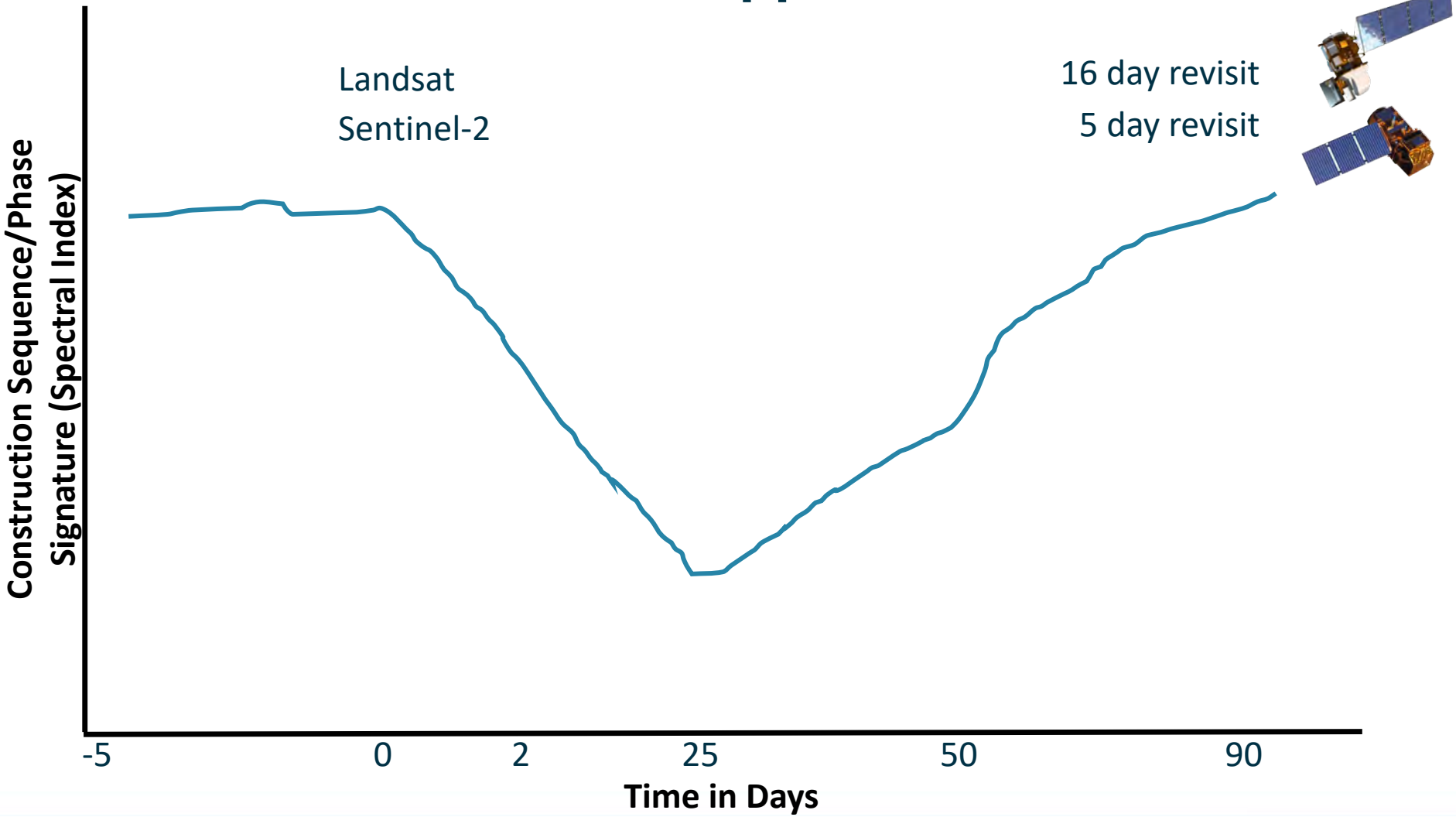
16 day revisit
5 day revisit

Construction Sequence/Phase
Signature (Spectral Index)

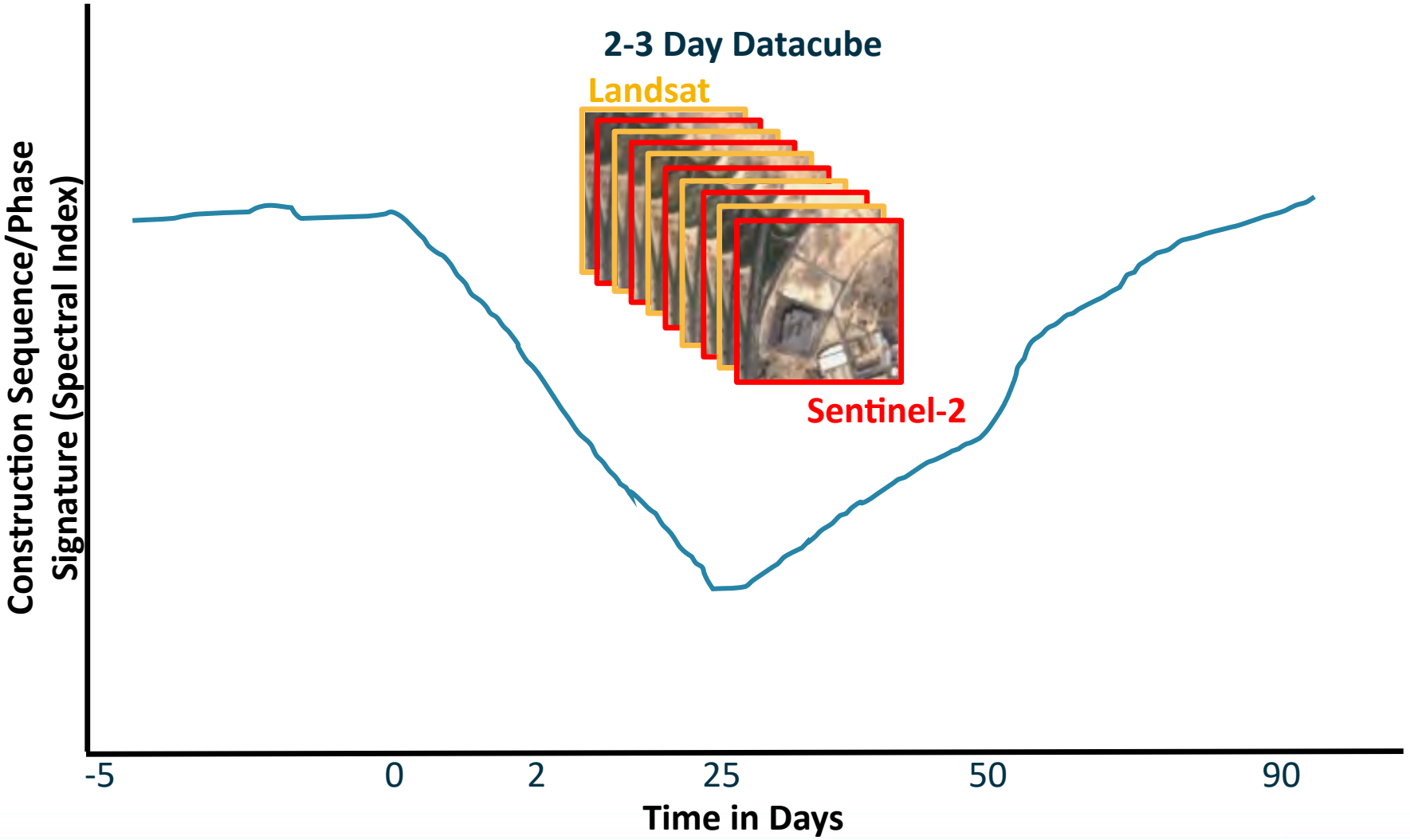
-5 0 2 25 50 90

Time in Days

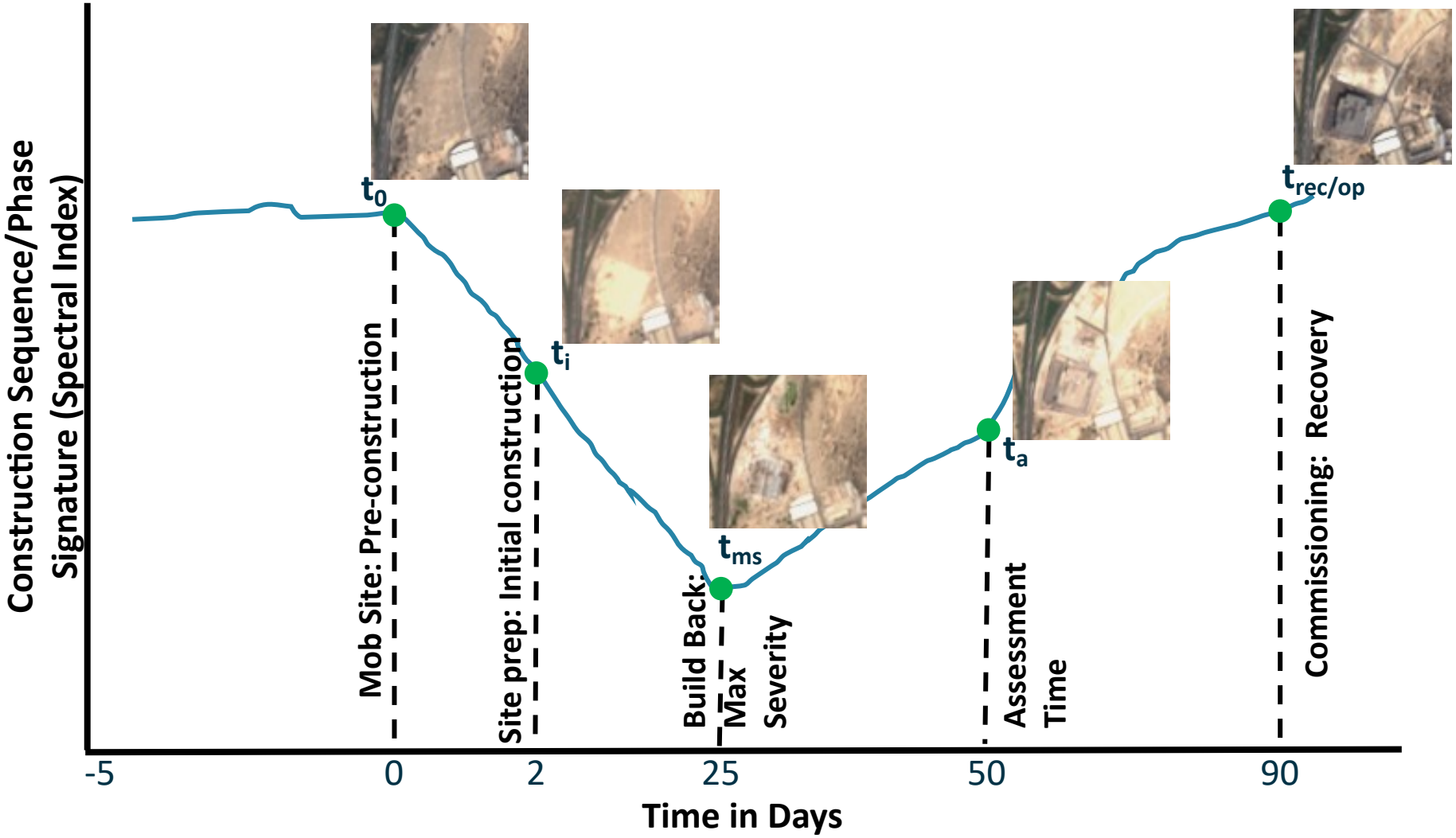
SMART Approach



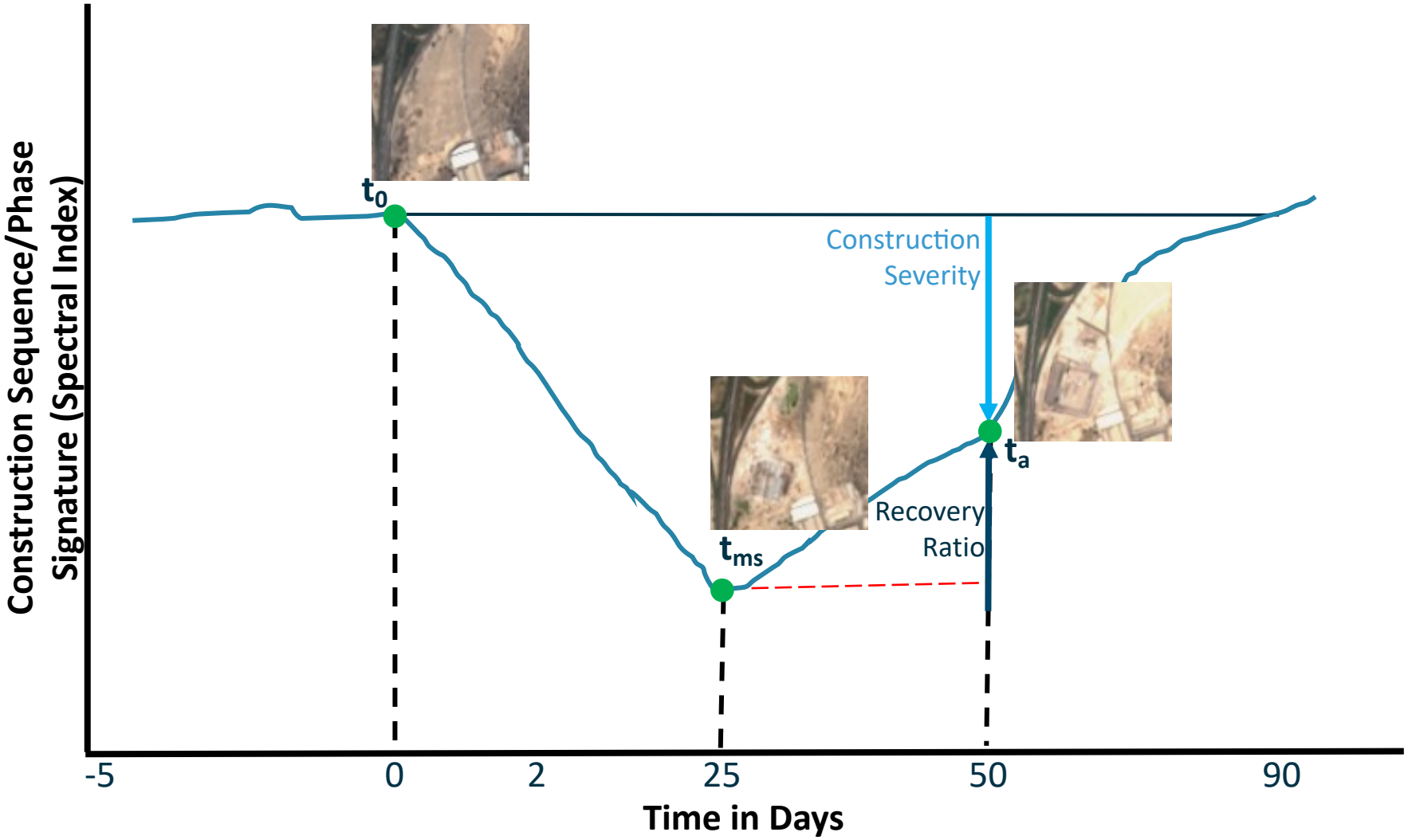
SMART Approach



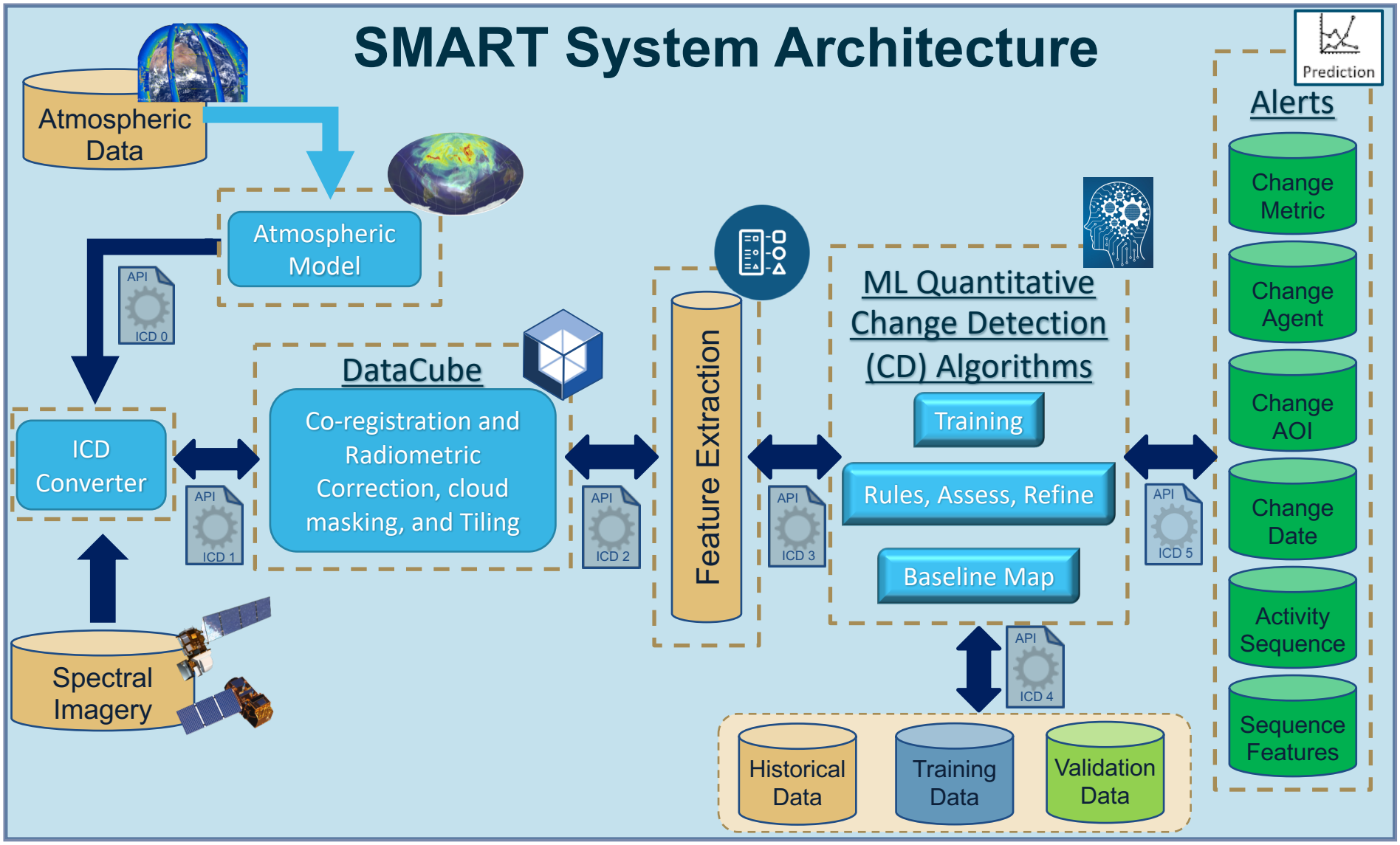
SMART Approach



SMART Approach



SMART System Architecture



SMART Program Plan

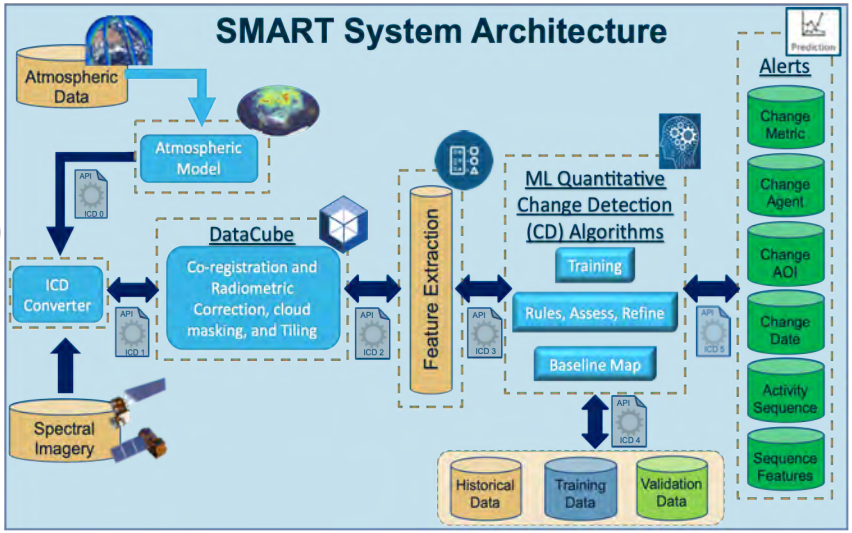
- **Phase 1**
  - Develop technology to co-register and tile imagery spatially and temporally.
  - Develop dynamic radiometric correction by assimilating ground- and space-base data sources.
  - Leverage ML technology for detecting heavy construction at regional scales (e.g. 150 km X 150 km).
- **Phase 2**
  - Integrate additional data sources to Phase 1, .e.g., datacube
  - Develop ML change detection to investigate and provide:
    - Information on heavy construction (detect and monitor)
    - Inform on heavy construction transition (characterization both temporally and categorially)
  - Semi-automated integrated prototype demonstration at 10X regional scale
- **Phase 3**
  - Real-time (data collected at certain rate, detect continuously) at global scales
  - Fully automated end-to-end solution

SMART Program Plan: Data

SMART T&E Teams will provide the following pre-processed (surface reflectance) & raw data (Digital Number):

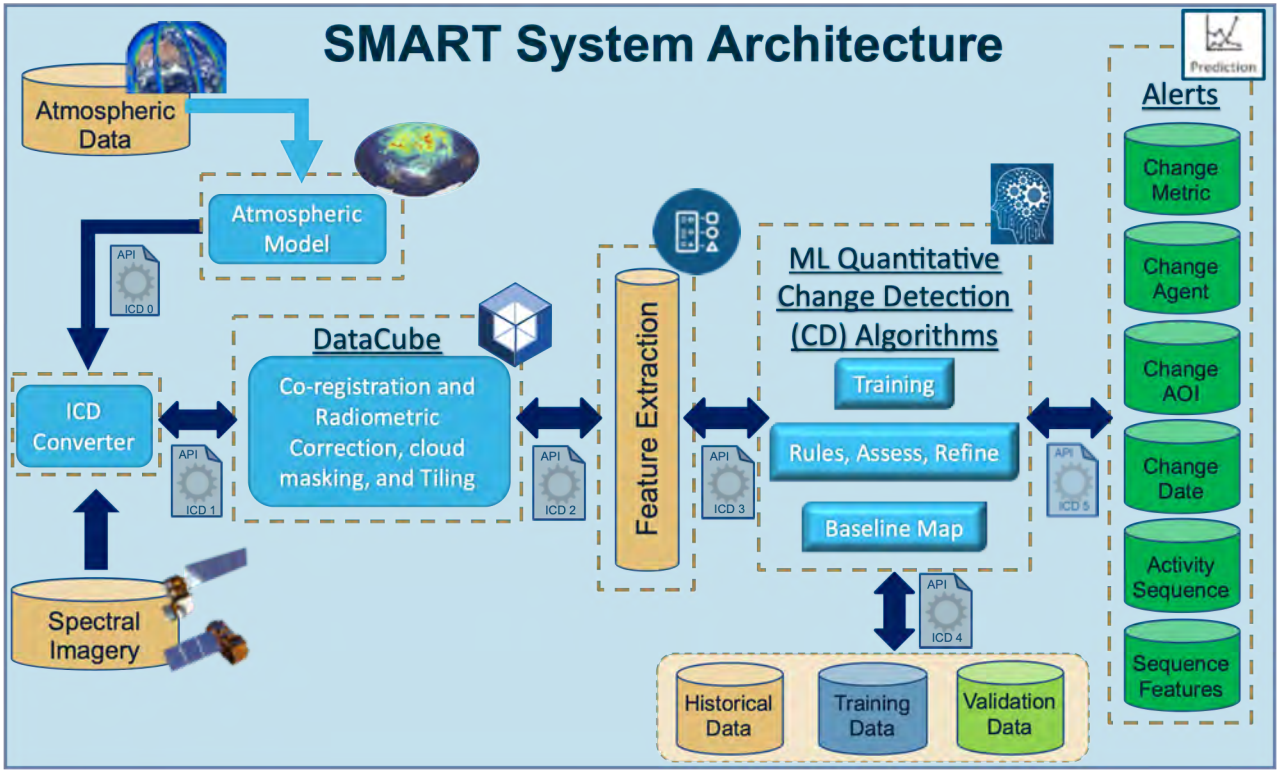
Landsat:	**2003 - Current**
Sentinel:	**2015 - Current**
Worldview:	**2015 – Current**

- **Additional data and tools:**
  - Land Surface Reflectance Code (LaSRC)
    - Baseline atmospheric model
  - Committee on Earth Observation Sats (CEOS) Visualization Environment (COVE)
    - Visualize satellite orbit swaths and overpass times
  - The NASA & USGS Geometric & Radiometry Sites
    - Atmospheric characterization



SMART Program Plan: Performer Activities

- **Performer systems**
  - Data ingest, fusion, & automated alerts (no human in the loop; Off-Line)
  - Train with historical data
  - Alerts updated for new data and as system improves its estimates (On-line)



- **Performers submit their code to T&E (Integration and Delivery)**
- **Test against blind construction & non-construction projects**
  - For each test, run for data in bounding box before project start

SMART Integration and Delivery

Git Server

Docker Registry

REDMINE
flexible project management

Program Office (PMO)

JIRA

Development Environments

Building a code workflow to allow processes to be iterated and improved.

Build Server

Production Environment

Performer 1 Build

Performer 2 Build

Performer 3 Build

Non-Production Environment
Continuous Integration
Collaboration

Operations
Configuration Management

AWS

Version Control

T&E and Performers

T&E and Performers

SMART Integration and Delivery

New Code

Git Server

Docker Registry

REDMINE
flexible project management

Program Office (PMO)

JIRA

Development Environments

Performer 1 Build

Performer 2 Build

Performer 3 Build

Version Control

Build Server

Non-Production Environment
Continuous Integration
Collaboration

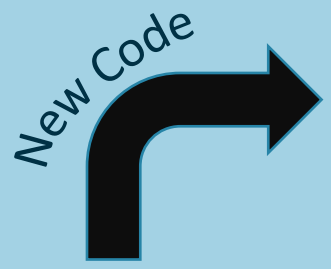
T&E and Performers

Production Environment

Operations
Configuration Management

T&E and Performers

SMART Integration and Delivery



Git Server

Docker Registry

Program Office (PMO)

Development Environments

Performer 1 Build

Performer 2 Build

Performer 3 Build

Version Control

Build Server

Non-Production Environment
Continuous Integration
Collaboration

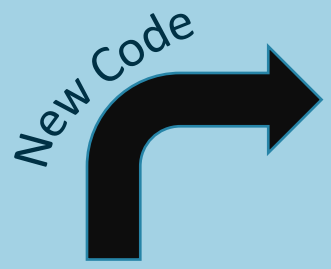
T&E and Performers

Production Environment

Operations
Configuration Management

T&E and Performers

SMART Integration and Delivery



Git Server

Docker Registry

Program Office (PMO)

Development Environments

Performer 1 Build

Performer 2 Build

Performer 3 Build

Version Control

Build Pass
Test Suite

Docker Image

Build Server

Non-Production Environment
Continuous Integration
Collaboration

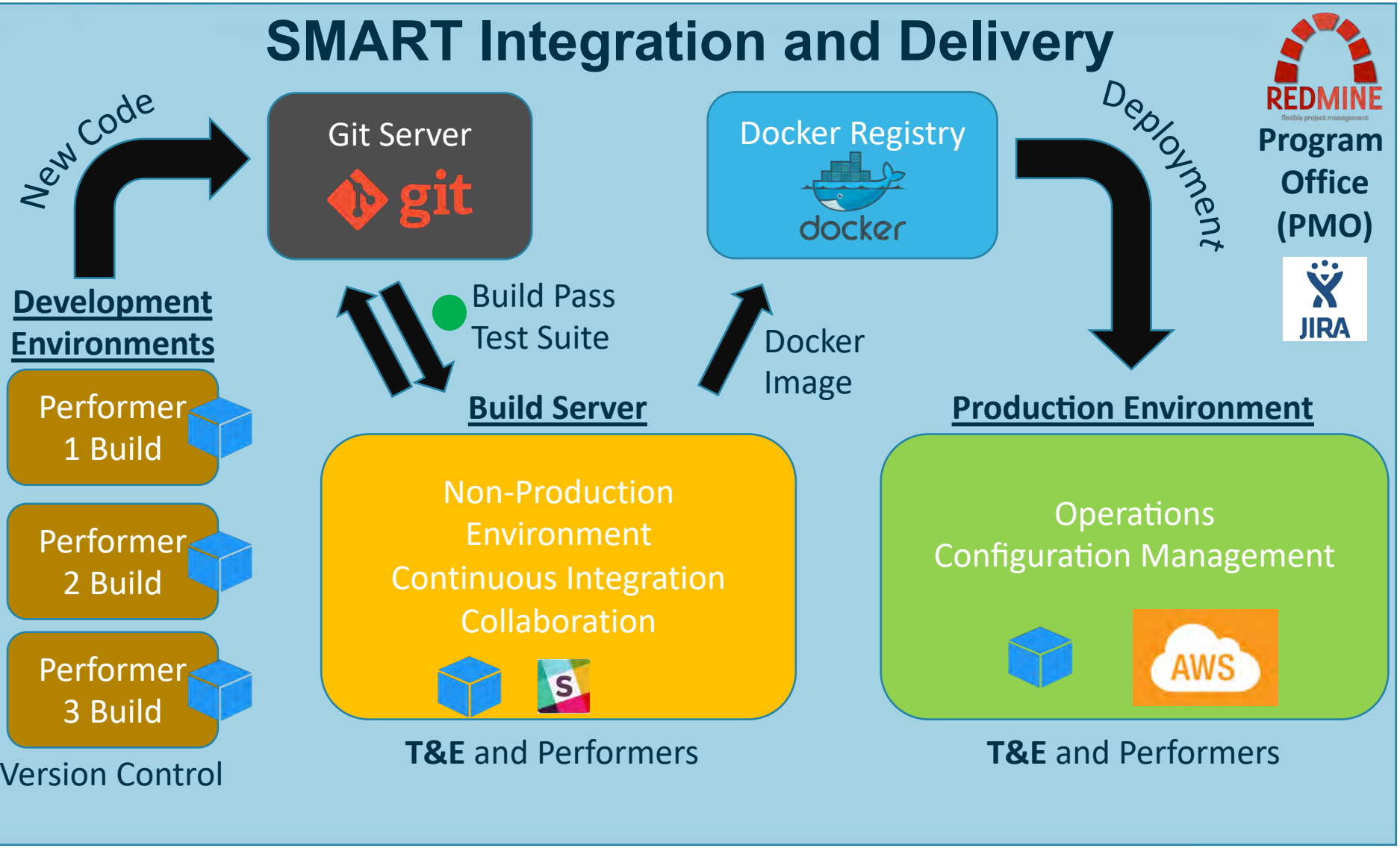
T&E and Performers

Production Environment

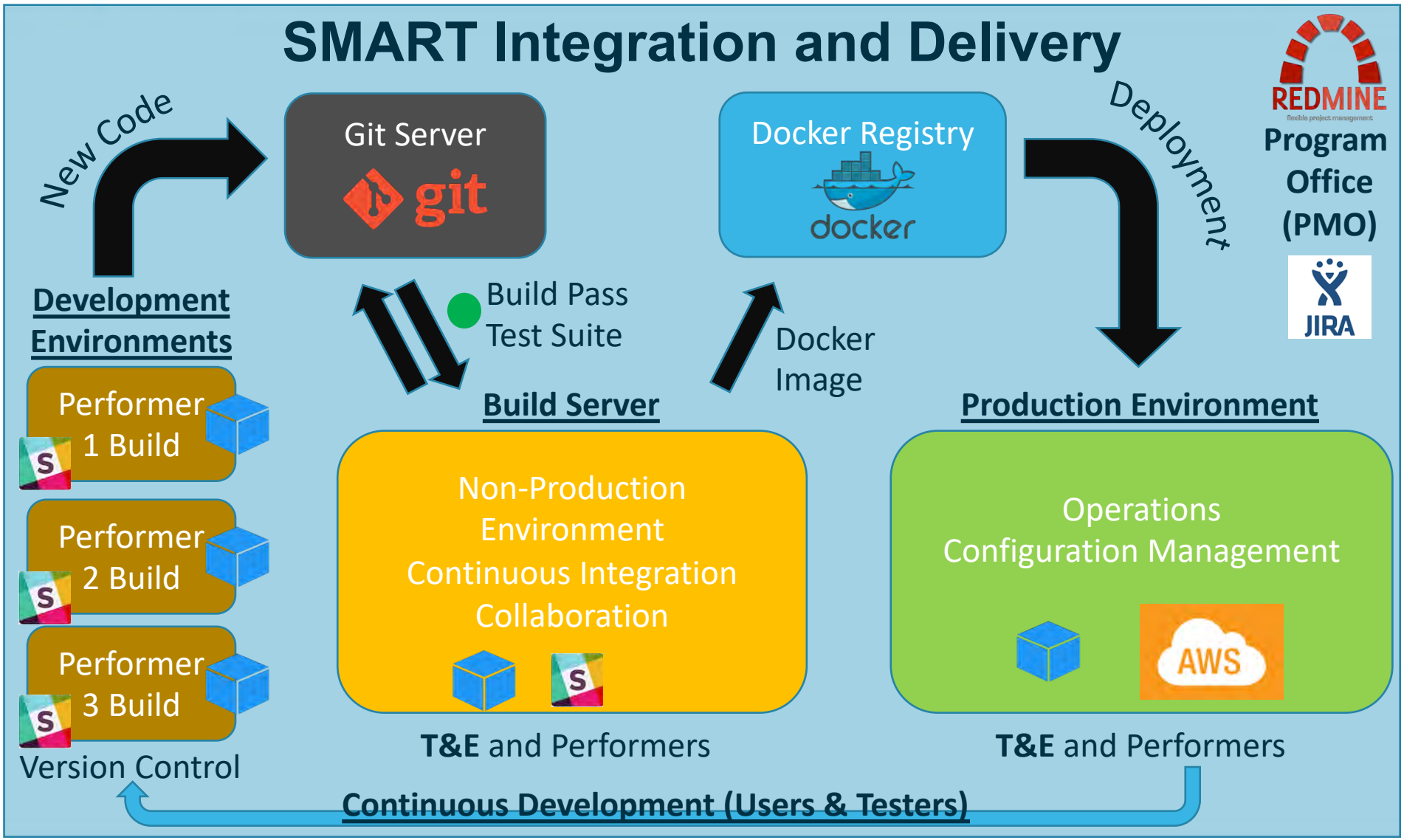
Operations
Configuration Management

T&E and Performers

SMART Integration and Delivery



SMART Integration and Delivery



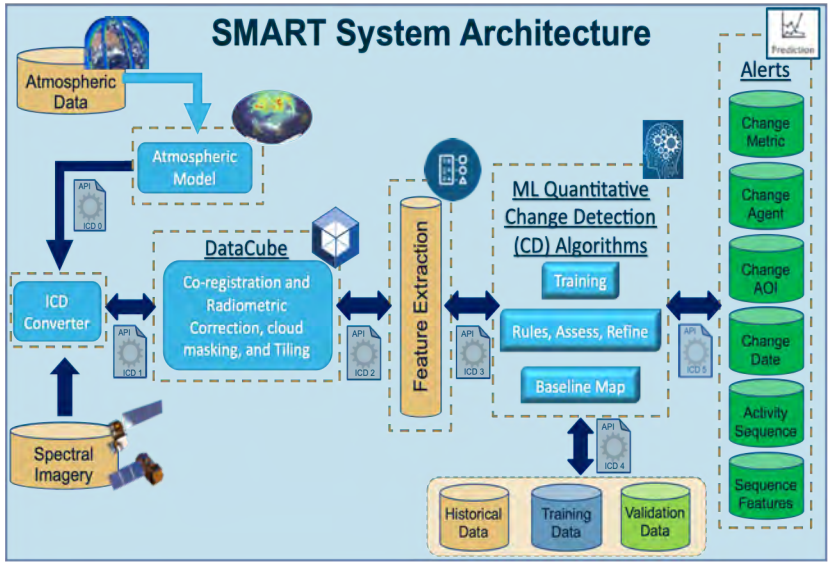
SMART
Test & Evaluation

SMART Program Plan: Test & Evaluation (T&E)

The primary objective of SMART is: *Automated BAS with* multi-sensor (timeseries), -spectral imagery.

Performers must demonstrate approaches that:

1. ***classify/determine the specific geo-location(s) of heavy construction of interest***
2. ***develop techniques/algorithms to detect & characterize significant changes in the construction sequence/phase***
3. ***deliver automated alerts on nature of these changes with minimum error & latency***



Performers must fuse EO imagery from multiple sensors/collection systems;

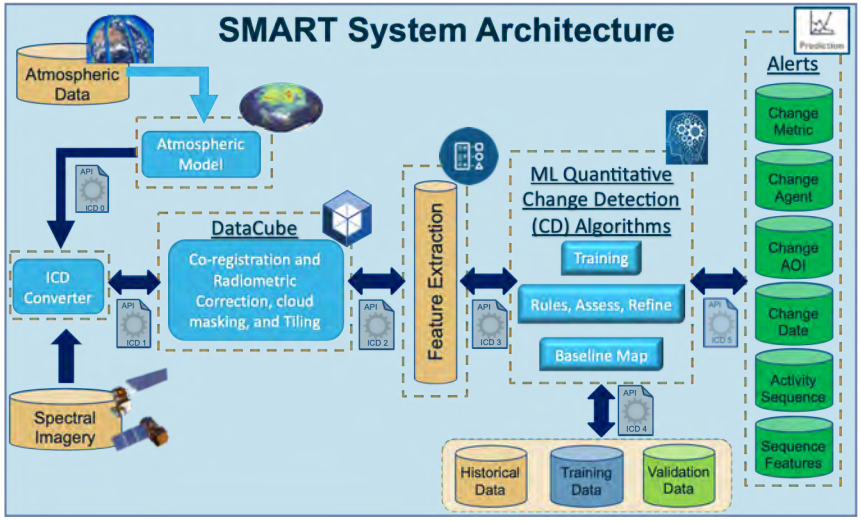
Develop methods for accurate physically-based feature extraction;

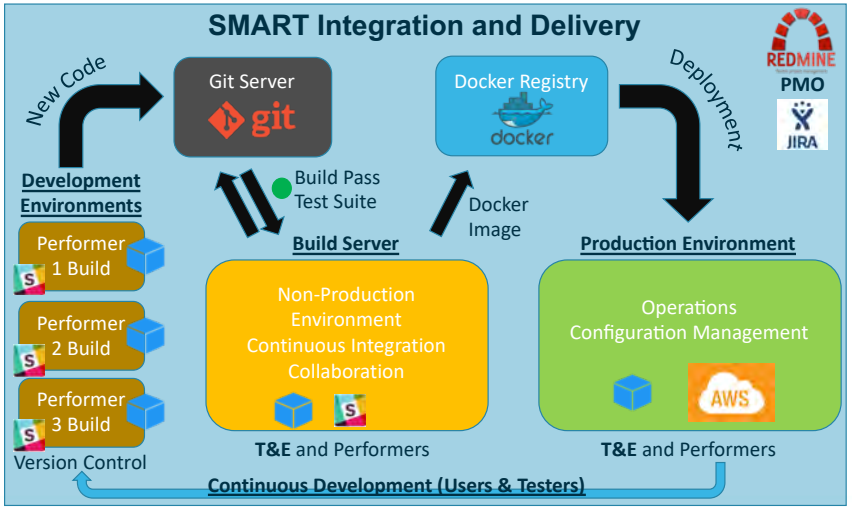
Develop methods for spectral-temporal change detection of these features;

Employ an architecture that automates the exploitation process for analysts

SMART Program Plan: T&E Activities

- **Clearinghouse for Imagery, Data, & Tools:**
  - Obtain all designated data & tools
  - Nominate AOIs; distribute labeled data
- **Validate Performer Data & Results**
  - Detection rates of construction, feature extraction, & ID Construction Sequence
  - Evaluate geometric accuracy, ability to discriminate features & sequences
- **Validate Advanced Approaches to Reflectance Normalization:**
  - For performers going beyond baseline
- **Perform/Obtain Ground Truth (GT)**
  - Provide appropriate GT measurements as necessary to facilitate validations
- **System Integration & DevOps Implementation**





Metrics: Primary Evaluation Criteria

- **Area of Interest (AOI) Detection/Location:**
  - Nominated AOIs (construction project), true/false detect rate
  - Geometric accuracy (distance between alert geolocation & true location)
  - **Evaluate over baseline** capabilities (e.g., human, Refined Persistent Change Modeling; RPM, LaSRC, etc.)
- **Feature Extraction:**
  - Closed set: e.g., concrete type, excavation/method, geology (rock type or tailing piles), thermal anomalies, soil permeability, roads, surface restoration, equipment etc.
  - Feature identification, true/false detection rate
- **Construction Sequence/Phase Characterization:**
  - Closed set: e.g., Mob Site, Site Prep, Excavation, Perm Lining, Build Back, Commissioning, Long-term Recovery, etc.
  - Sequence identification, true/false detection rate
- **Minimization of Sequence/Phase timestamp:**
  - Elapsed time between alert timestamp & true date of construction Sequence

Accuracy Metrics

- **Overall Accuracy:** out of all of the area mapped what proportion were mapped correctly

$$\hat{O} = \sum_{j=1}^{q} \widehat{p_{jj}}.$$

$$q = category;\ p_{ij} = estimated\ area\ proportions$$

- **User's Accuracy:** how often the category on the map will actually be present on the ground as that category

$$\widehat{U_i} = \frac{\widehat{p_{ii}}}{p_{i.}}$$

- **Producer's Accuracy:** how often are real features on the ground correctly mapped as that category map

$$\widehat{P_i} = \frac{\widehat{p_{jj}}}{p_{.j}}$$

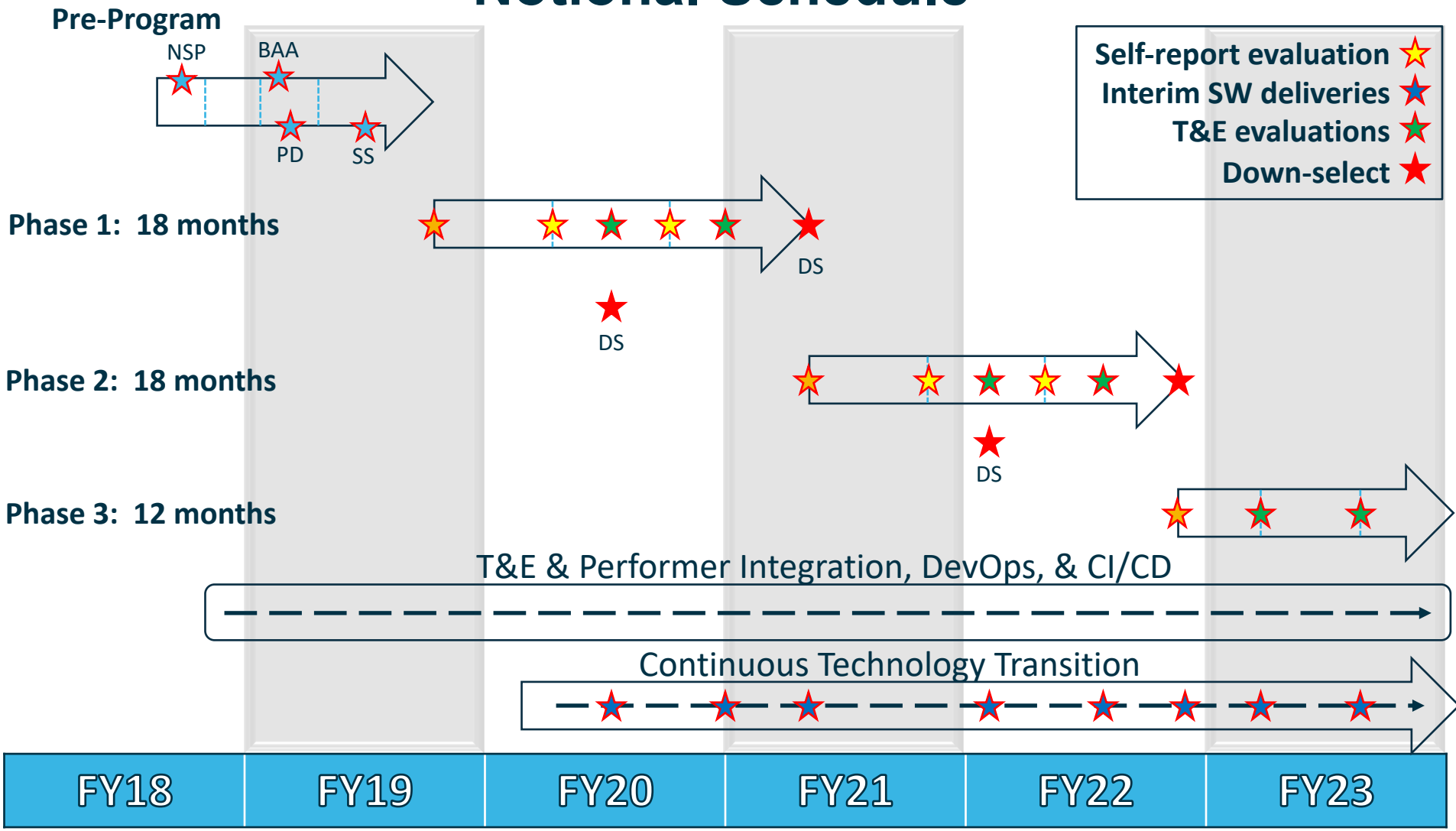
Reference: Olofsson et al. 2014

Secondary Evaluation Criteria

Pixel-based Reflectance Normalization Across All Regimes

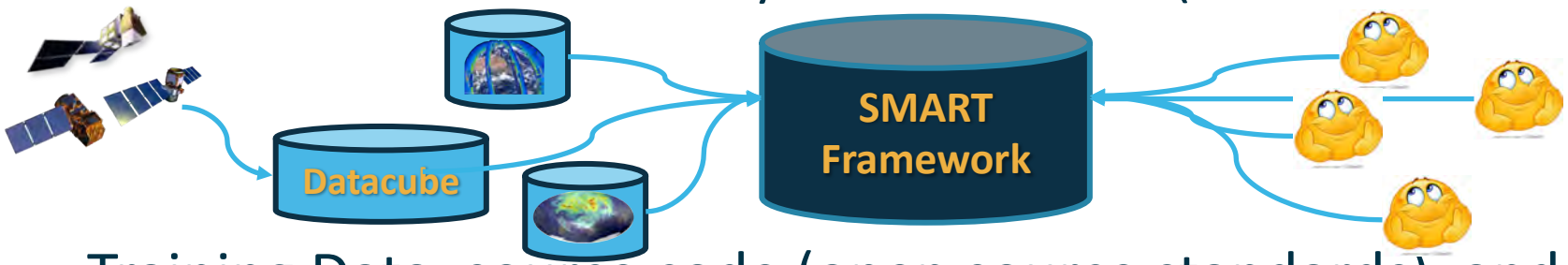
- **Performance relative to baseline models & inputs:**
  - Atmospheric model
  - Aerosol model
  - Aerosol Optical Depth (AOD)
  - Adjacency and topographic effects, and water vapor content
- **Absolute evaluation against Performer model:**
  - Field measurements
  - AERONET two valid observations bracket imagery within 15 min.
    - Spectral calibration AOIs
    - Pseudo Invariant AOIs
  - Inter-comparison with a validated product (MODIS)
- **Root-Mean-Square Error (RMSE)**: quantify estimated differences
- **Mean Bias:** Over/under estimates vs. Ground-truth

Notional Schedule



Deliverables

- Tools & models for rapid data access, pre-and post processing:
  - **Change AOI:** Know what is changing
  - **Change Agent:** Understand the cause of the change
  - **Attribute** observation times to key phases in heavy construction
  - **Dynamic data collection:** handle modifications (old/current data) and insertions (future/new data).
- Tools & models delivered in SW containers
  - Work in a common analytical framework (data structures & tools)



- Training Data, source code (open source standards), and manuals/reports

Point of Contact

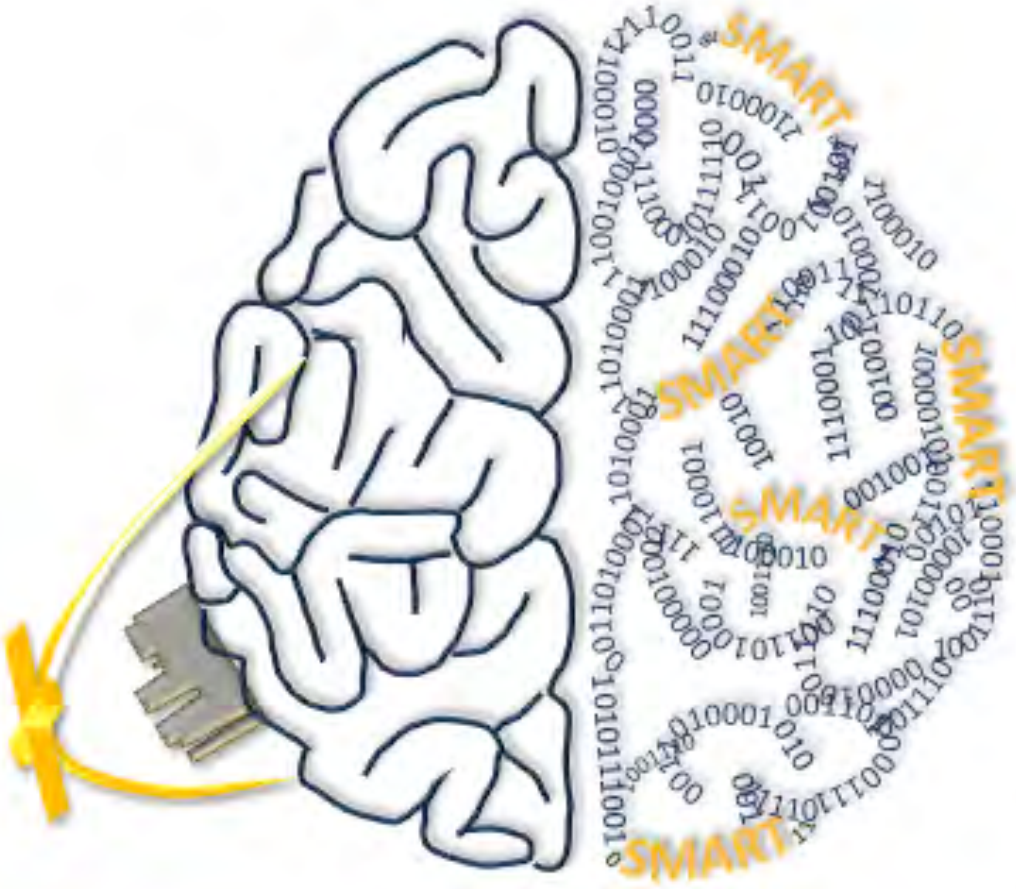
- **Dr. Torreon "Torrie" Creekmore**
  - Program Manager
  - Office of the Director of National Intelligence
  - Intelligence Advanced Research Projects Activity (IARPA)
  - Washington, DC 20511
  - Phone: (301) 851-7546
  - Fax: (301) 851-7673
  - Electronic mail: dni-iarpa-BAA-19-04@iarpa.gov

include IARPA-BAA-19-04 in the Subject Line

- Website: https://www.iarpa.gov/index.php/research-programs/smart

Questions? Please fill out index cards.

THANK YOU & TEAM UP!



Agenda

Time	Topic	Speaker
8:30 AM – 9:00 AM	Registration	
9:00 AM – 9:10 AM	Welcome, Logistics, Proposer's Day Goals	Dr. Torreon Creekmore Program Manager, IARPA
9:10 AM – 9:20AM	IARPA Overview	Mrs. Cheri Benedict Deputy Director Operations, IARPA
9:20 AM – 10:20 AM	SMART Program Overview	Dr. Torreon Creekmore
10:20 AM – 10:30 AM	Doing Business with IARPA	Dr. Torreon Creekmore
10:30 AM – 10:40 AM	SMART Question Submissions	
10:40 AM – 11:00 AM	Break	
11:00 AM – 12:00 PM	No-Host Lunch	
12:00 PM – 12:30 PM	SMART Questions & Answers	Dr. Torreon Creekmore
12:30 PM – 3:30 PM	Offerors' Capabilities Briefings	Attendee's (No Government)
3:30 PM – 5:00 PM	Poster Session, Networking and Teaming Discussions	Attendee's (No Government)

Doing Business with IARPA

Acquisition Team

Office of the Director of National Intelligence

IARPA

BE THE FUTURE

BAA, Questions, & Answers

The BAA will be posted to Federal Business Opportunities (fbo.gov)

- There will be a specified period for questions stated in the BAA. All questions and answers will be posted. (**Note:** Questions may be submitted not only regarding technical requirements but all other sections of the BAA).
- Responses will be posted to fbo.gov.

Send your questions as soon as possible

- SMART BAA: **dni-iarpa-baa-19-04@iarpa.gov**
- Write questions as clearly as possible
- Do NOT include proprietary information *or mark as proprietary or otherwise confidential.*

Pay attention to Section 4 (Proposal & Submission Information)

Frequently Asked Questions can be found on the IARPA website: **http://www.iarpa.gov/index.php/faqs**

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