Intelligent Long Endurance Observing System (ILEOS)

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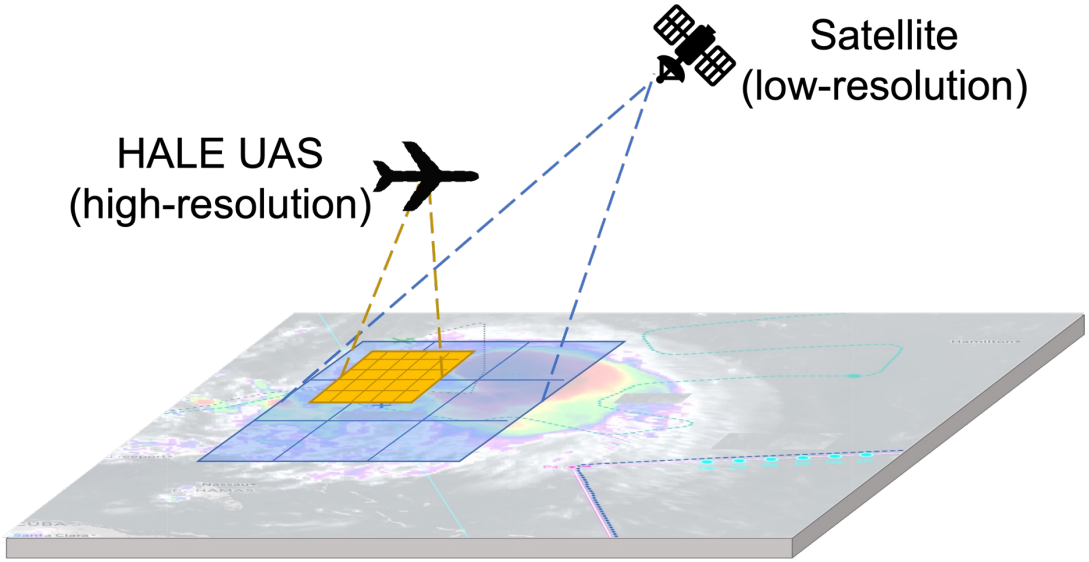
Concept of Operations



- Current satellites and fine-pointing aircraft do not provide sufficient spatio-temporal resolution to observe stochastic, ephemeral events between observations

- HALE UAS provide mechanism for collecting higher spatio-temporal data
  - Operate for months and loiter over targets

ILEOS will provide a science activity planning system to enable NOS
  - Fuse coarse-grained sensor data to target and plan HALE UAS flights

Objectives

- Optimize fine-grained spatio-temporal resolution data collection of Earth observations, such as GHG-relevant gases

Novel automated target generation technology

- Incorporates *coarse-grained satellite data* and near real-time environmental (e.g., wind, weather, airspace constraints) data to generate high-value fine-grained resolution data collection plans.

State-of-the-art automated planning and scheduling algorithms

- Designed for human operators; *plan explanation and data provenance features* will ensure science mission planners understand all key choices made while generating targets and plans.

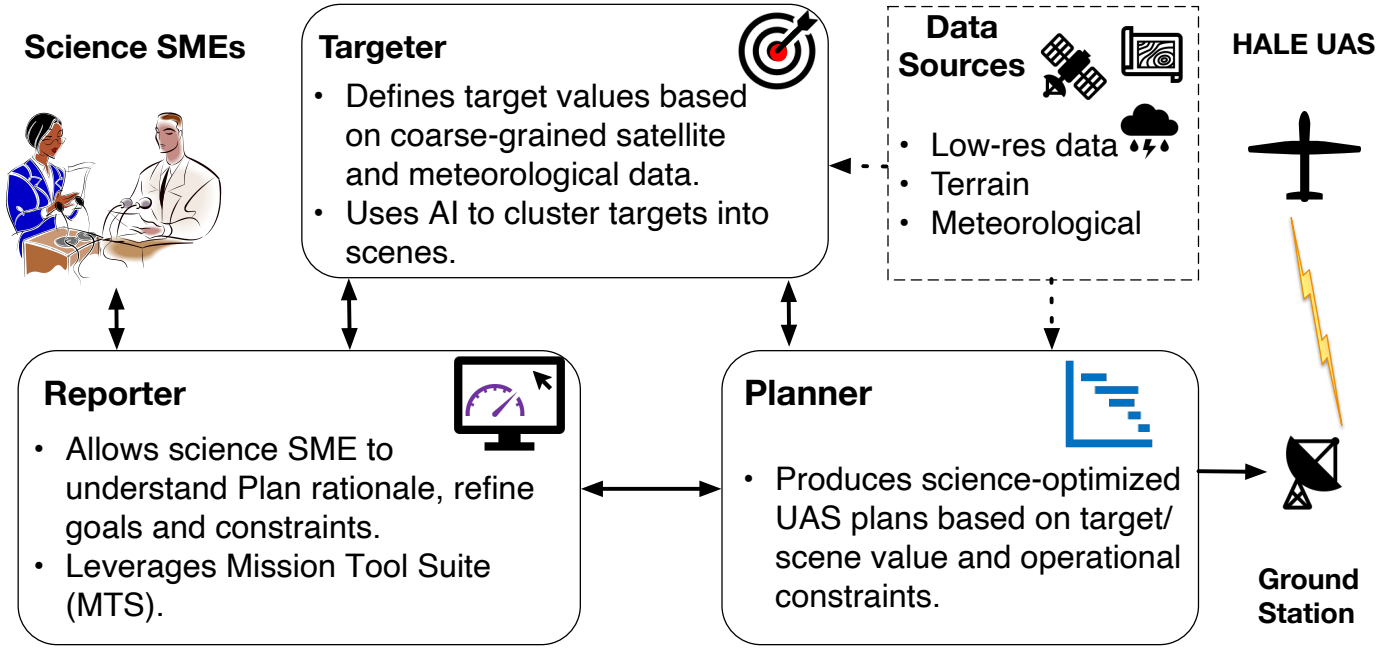
Innovative techniques for user control and review of decision making

IMPACT: Reduced cost for Earth observations in environments ranging from arctic to urban to offshore (some previously inaccessible), continuous observations not possible for current field/in-situ campaigns, improved science outcomes

Relevance to Earth Science

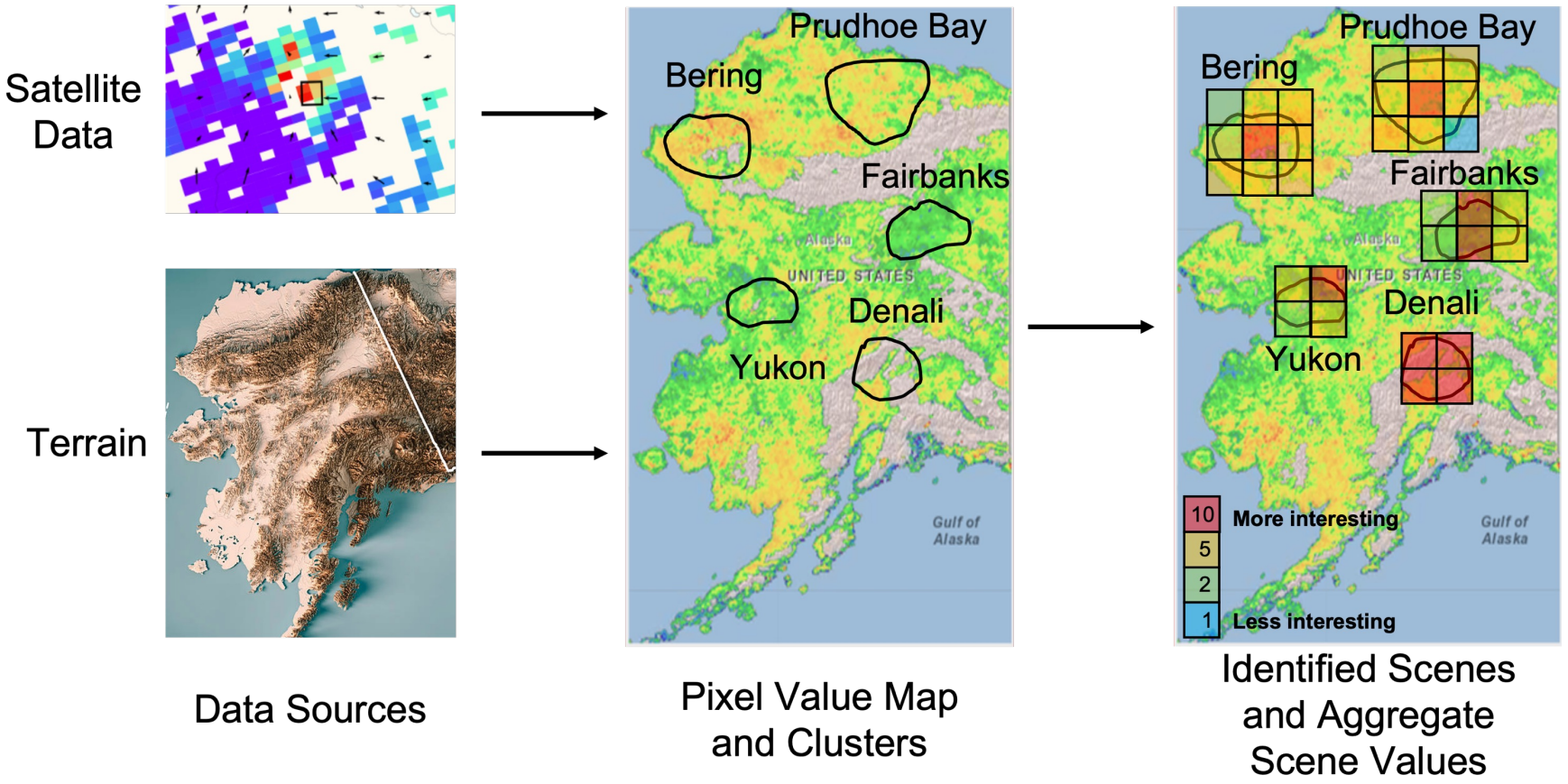
- ILEOS will focus on use cases related to NO_2 and CH_4, which both high relevance to the science and application priorities presented in the 2019 Decadal Survey:
  - NO_2, here a proxy for combustion emissions (e.g., CO_2), and CH_4 over oil and natural gas extraction areas of the Gulf of Mexico.
    - Estimation of these emission sources(e.g., point - large rigs, line - shipping lanes, and area - small wells and support ships).
  - NO_2 down to the city block level in urban environments
    - Human health (unhealthy to breathe) and environmental justice
  - NO_2 generated from lightening (collected from above storm clouds)
    - Important ingredient in formation of upper tropospheric ozone, expensive to collect with crewed aircraft
  - CH_4 over Artic-Boreal zone
    - Characterize how the water table and air temperature affect the rate of emission
  - CH_4 from various anthropogenic sources such as industrial processes and leaky natural gas distribution pipelines, in complex urban environments
    - Pinpoint sources needing migration for safety reasons or to reduce the GHG footprint of urban areas

ILEOS Architecture



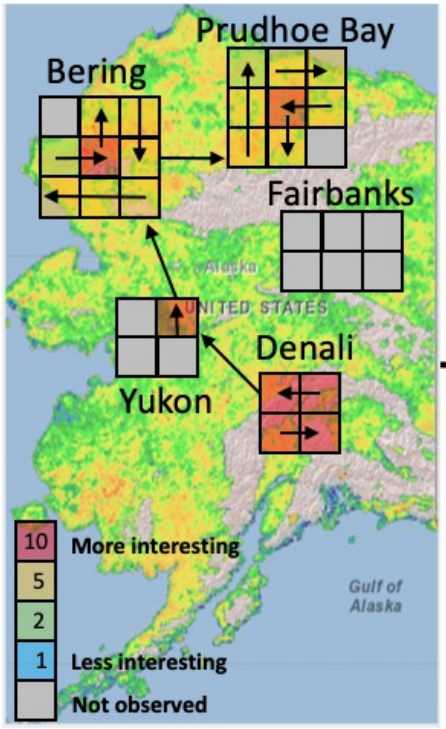
- Targeter – leverages Science SME domain knowledge to fuse available coarse-grained data into pixel value maps to generate target scenes
- Planner – generate flight plan to observe best identified target scenes while enforcing HALE UAS operating constraints
- Reporter – allow users to configure Targeter and Planner, visualize all data and outputs, and request explanations

Targeter



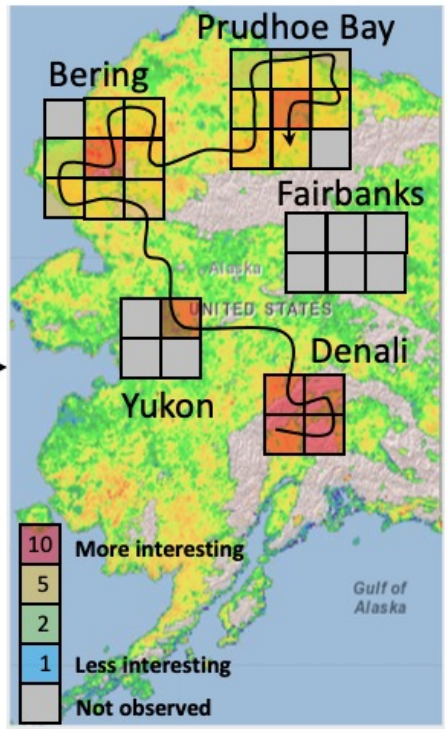
The Targeter leverages a pixel value module to assign pixel values from varying inputs (left). It then groups similar pixels (middle), and then breaks these groups into scenes with values aggregated from the pixels within them (right).

Planner



Scene Selection and Sequencing

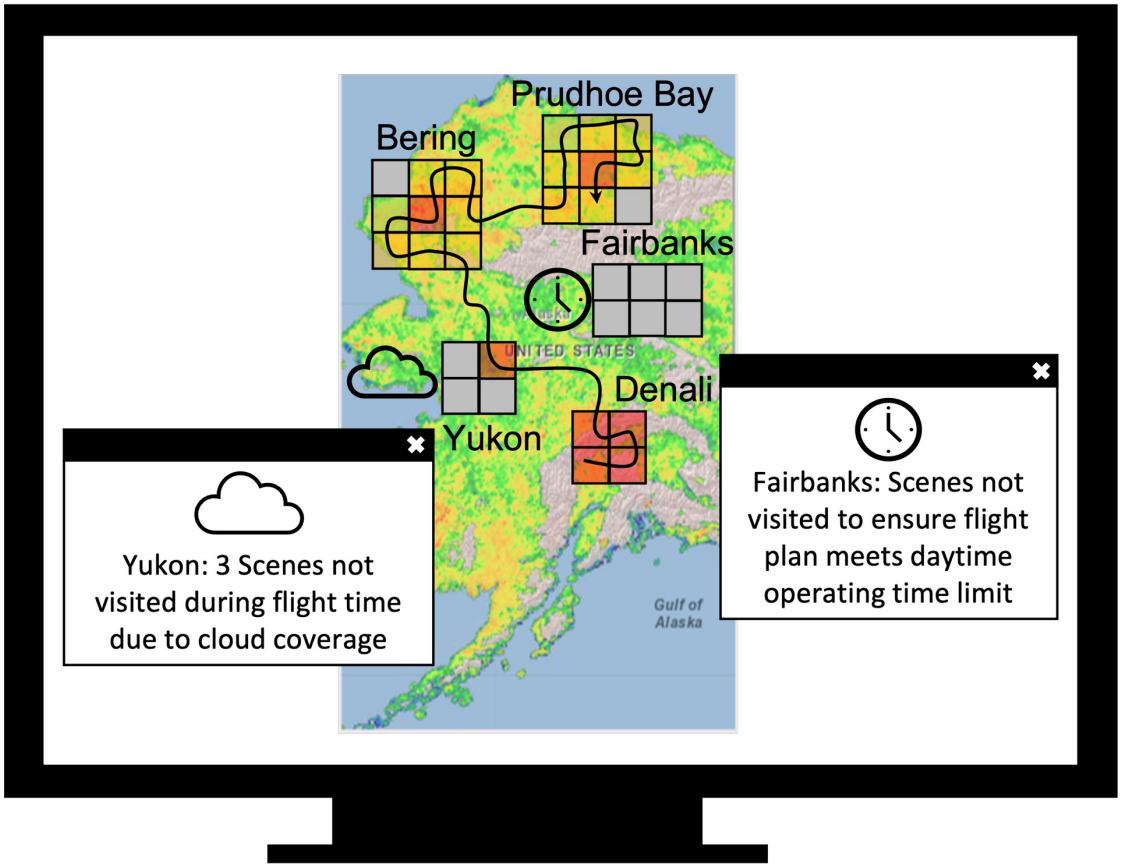
Route + Motion Planning Output (UAS plan)		
Plan Step	**Action**	**Duration**
1	Observe Denali 3	30 mins
2	Observe Denali 4	30 mins
3	Observe Denali 2	30 mins
4	Observe Denali 1	30 mins
5	Traverse Denali to Yukon (Avoid T-Storm)	120 mins
6	Scan Yukon 2	30 mins
5	Traverse Yukon to Bering (Strong Headwind)	180 mins
6	Scan Bering 9	30 mins
…	…	…



Detailed Flight Planning

The Planner determines which scenes should be visited and in which order (left), detailed behaviors within each scene (middle), and refines routes for traveling between and within scenes with wind speed and velocity and HALE UAS operating constraints (right).

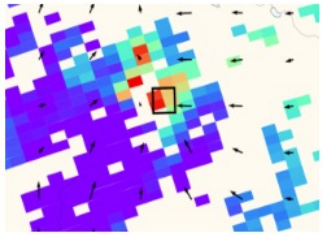
Reporter

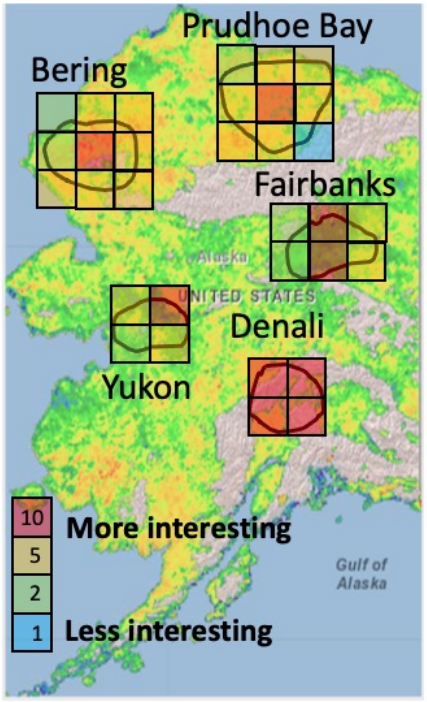


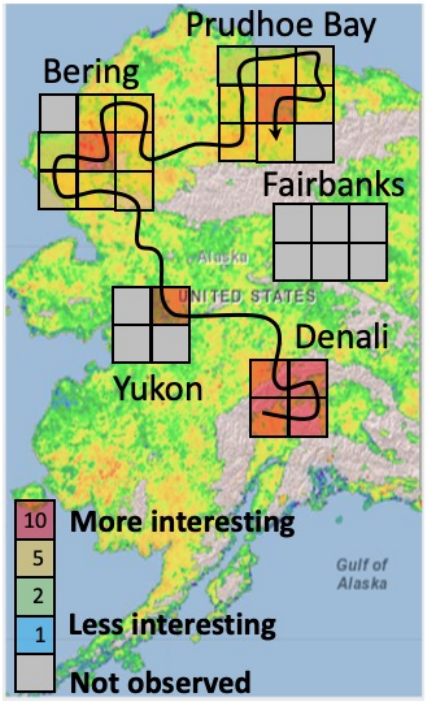
The Reporter provides explanations for Targeter and Planner outputs to the user. For example, explanations include icon and popout descriptions of why scenes were not included in a flight.

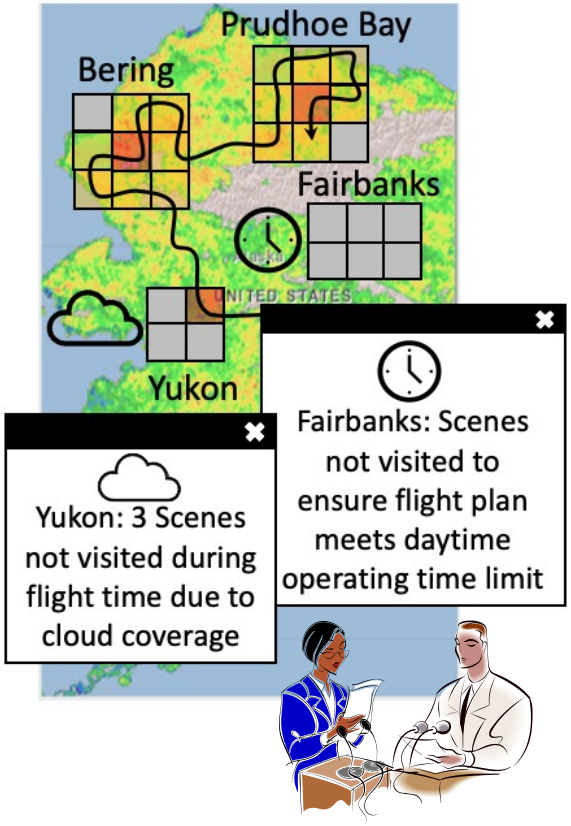
Full ILEOS Pipeline

Data Sources → Targeter → Planner → Reporter









System Evaluation

- ILEOS' first 2 years will culminate with a capstone demo featuring simulated observing campaigns overseen by SMEs
  - Evaluated on at least 2, ideally 4 climate-relevant gas sensing science use cases

Sensing Domain	Use Case Type	
	Nominal	Stressing
Methane	Urban emissions	Artic permafrost thaw
Nitrogen Dioxide	Urban emissions	Upper atmospheric lightening

- Assess users' ability to generate desired plans and understand relationship between scenes, priority, constraints, and their impact on plan
  - Human-in-the-loop evaluation

Tentative 3rd Year

- Technology infusion into NASA Airborne Sciences Program (ASP) via integration with:
  - Heritage Mission Tool Suite (MTS) application
  - Upper-E Traffic Management (ETM) Project

- Demonstrate management of 2 (or more) HALE UAS simultaneously conducting missions in close geometric proximity.
  - Within simulation environment

Key Performance Parameters

Key Performance Parameter	Minimum Performance	Desired Performance
Targeter Pixel Value Modules	2 pixel value modules (1 each for CH_4 and NO_2) are developed.	Pixel value modules for all 4 identified science use cases are developed.
Plan Quality	Plans produced by SMEs using the Planner have a higher total value and are more efficient than SMEs alone for 2 use cases.	Plans produced by SMEs using the Planner have a higher total value and are more efficient than SMEs alone for 4 identified use cases.
External Data Source Integration	Planner can integrate cloud forecast and wind speed/velocity data as constraints to generate plans.	Planner can integrate cloud forecasts, wind speed/velocity, and poor weather proximity as constraints.
Explainability	Users are satisfied with 70% of explanations. Can provide explanations about why scenes are/aren't included.	Users are satisfied with 85% of explanations. Can provide explanations about why scenes are/aren't included and why the scene order was chosen.
Usability	Overall System Usability Scale score of 70 or more. Overall Bedford Workload rating of 6 or less.	Overall System Usability Scale score of 85 or more. Overall Bedford Workload rating of 4 or less.

TRL Assessment

Component	Entry TRL	Justification	Exit TRL
Targeter: Pixels Values	3	While pixel/scene values are use case dependent, computing merit metrics from science inputs is well-established. Management and swapping of science modules is well advanced, since the Ziggy pipeline infrastructure under development uses/leverages heritage in use on flight missions. We will develop science use cases, rely on SMEs to describe properties of interest, and implement algorithms to determine pixel/scene values.	5
Targeter: Scene Generation	4	Computer science principles for clustering algorithms and geometric algorithms are well established. Characteristics for generation of scenes are similar to existing algorithms. Prioritization schemes will vary based on science use case. Infrastructure will enable rapid prototyping and swapping of science algorithm modules. We will survey and select the most appropriate technology	5
Planner	4	Computer science principles for task and motion planning, and plan diversity / top-k planning are well established. Characteristics for adaptations to flight planning many different UAS are established. We will survey and select the most appropriate technology.	5
Reporter: Explaining Plans	3	Computer science principles for task plan explanation are an active area of research. We will survey and select the most appropriate technology for HITL testing.	5
Reporter: Provenance	2	Provenance has not been developed as part of user explanation capability. HITL studies will be used to identify best practices for displaying provenance data from Targeter on Reporter.	4
System Integration	2	No existing system has integrated all of these components. MTS provides standard interfaces for display. Integration of Targeter and Planner components will be undertaken by project. Standard software design practices will ensure seamless integration of all components.	5

Intelligent Long Endurance Observing System

PI: Meghan Chandarana (NASA Ames Research Center)

Objective

Intelligent Long Endurance Observing System (ILEOS):

A *Science activity planning* system to enable NOS consisting of satellites and *HALE UAS-mounted instruments.*

Optimize *fine-grained spatio-temporal resolution data collection of Earth observations, such as GHG-relevant gases,* using HALE UAS.

Incorporates *coarse-grained satellite data* and near real-time environmental (e.g., wind, weather, airspace constraints) data to generate high-value fine-grained resolution data collection plans.

Designed for human operators; *plan explanation and data provenance features* will ensure science mission planners understand all key choices made while generating targets and plans.

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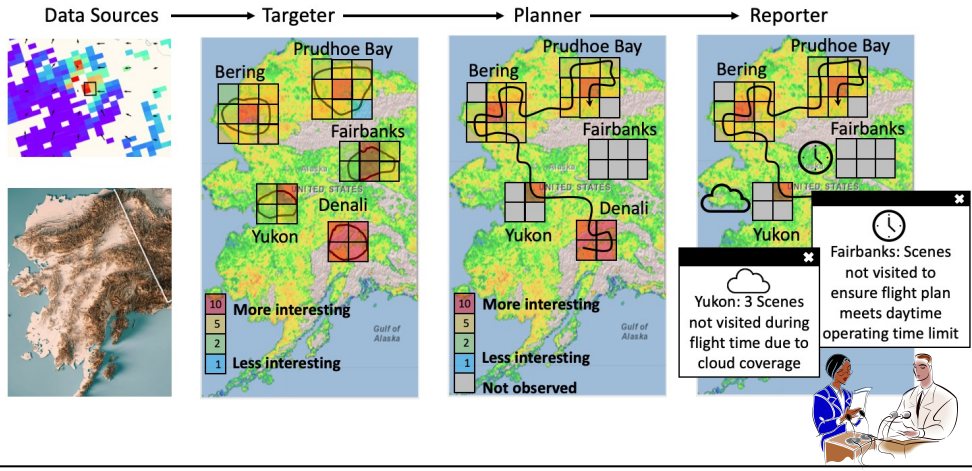
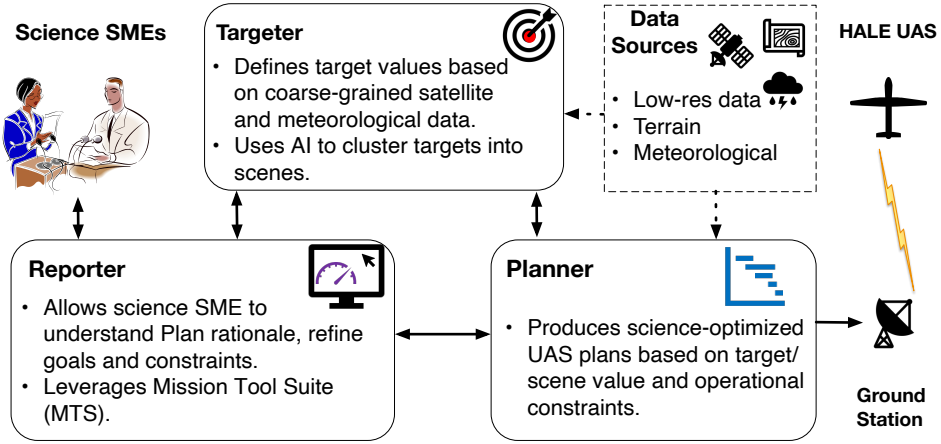
ILEOS Functional Flow



Approach



Key Milestones

• Complete ILEOS requirements / design	Q4/22
• Prototype ILEOS for NO2 science use case	Q3/23
• Prototype ILEOS for CH4 science use case	Q4/23
• 3rd year proposal to AIST program	Q4/23
• User testing and evaluation of ILEOS	Q2/24
• Airborne Science Program integration reqts/design	Q3/24
• Infusion into Airborne Sciences Program	Q2/25
• Final Report / Project Closeout	Q2/25

$TRL_{in} = 3$
$TRL_{out} = 5$

Co-Is/Partners: NASA GSFC, USGS, JHU/APL

Thank You

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Backup Slides

Project Schedule