Jet Propulsion Laboratory
California Institute of Technology

The Internet of Animals

5-year incubation study within the NASA Satellite Needs Working Group (SNWG)

BIODIVERSITY AND ECOLOGICAL CONSERVATION MEETING
27 May 2025

Image Credit: NASA/Bill Ingalls

Jet Propulsion Laboratory
California Institute of Technology

Ryan Pavlick
Antonio Ferraz
Darmin Arumugam
Srinivas Prasad
Brook Feyissa
Samuel Chan
Jack Bush







Ames Research Center

USGS
science for a changing world

Ian Brosnan
Susan De La Cruz
Claire Teitelbaum
Morgan Gilmour
Stephanie Pass





MAX PLANCK INSTITUTE
OF ANIMAL BEHAVIOR

Martin Wikelski

Smithsonian
National Zoological Park
Conservation Biology Institute

Lacey Hughey
Autumn-Lynn Harrison
Amy Scarpignato



Yale

Walter Jetz
Scott Yanco
Ben Carlson

Leila Fouda
Alexander Killion
Diego Ellis Soto






Understanding **where, when, how animals interact with and move through/between habitats** is essential to crafting successful management plans to conserve Earth's wildlife, preserve vital ecosystem services, and safeguard human well-being and livelihoods.

↓

Internet of Animals

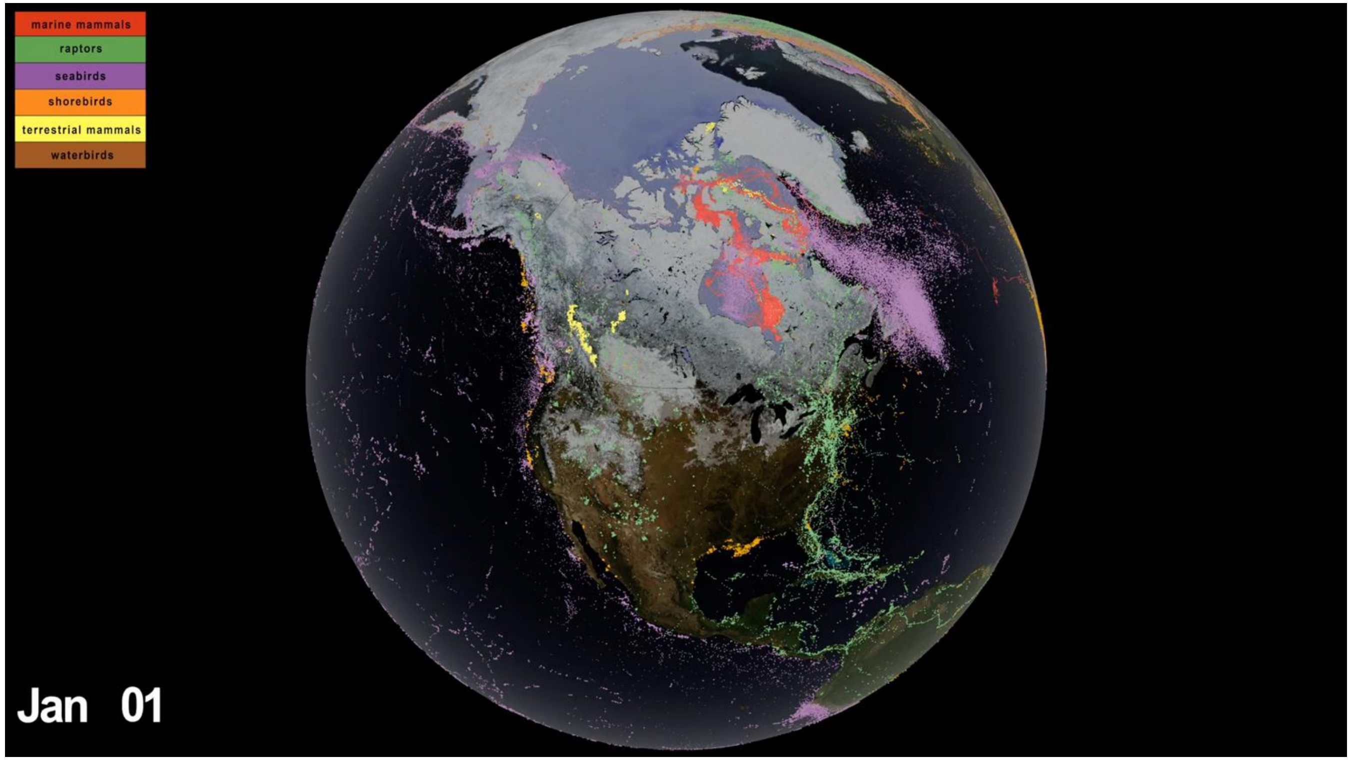
USGS
science for a changing world

U.S. FISH & WILDLIFE SERVICE
DEPARTMENT OF THE INTERIOR

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

The Internet of Animals

1) Understanding User Needs for Spaceborne Animal Telemetry
2) Architecting the next-generation of Spaceborne Animal Telemetry to meet those needs
3) Integrate Animal Movement Data with NASA Remote Sensing and Earth System Modelling
4) Build a Federated Animal Movement Community



https://svs.gsfc.nasa.gov/4877/

1) Understanding User Needs for Spaceborne Animal Telemetry

- **IoA-Yale Community Workshop** [November 2022]
  - Pre-workshop webinar
  - 3-day in-person event with **36 participants**
  - Participants from US Agencies (28), Academia (6), and conservation NGOs (2)

- **Community of Practice** [August 2024 - January 2025]
  - 10 online interviews with **22 participants/users**
  - Interviewed 10 agencies

Science and Applications themes identified

1: Migratory routes of small animals

2: Sensing mortality

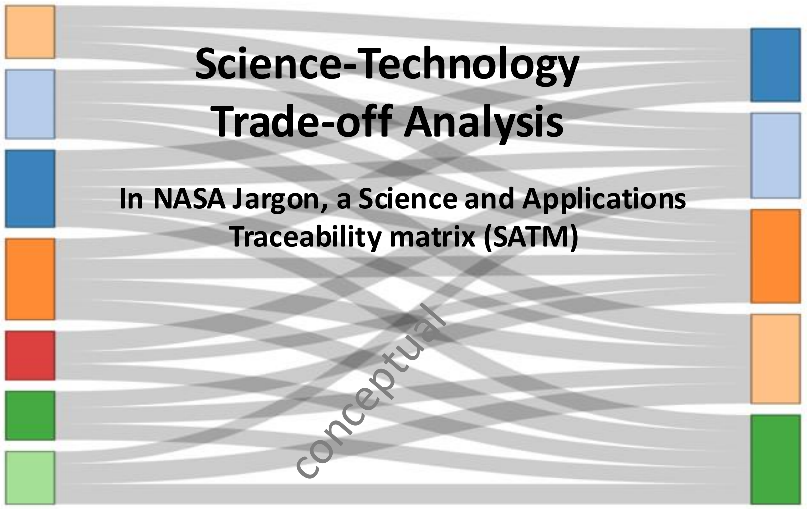
3: Diseases transmission

4: Animal-borne sensors

5: Responses of animals to human activity

6: Managing human-animal conflict

7: Responses of animals to human development



Spaceborne Observing System requirements

1: Tag Mass (< 1gr)

2: Tag Duration (> 10 years)

3: Measurements Rate (1 x/min)

4: Data Latency (1 min)

5: Spatial Accuracy (3 meters)

Journal Paper submission by September 2025

2) Architecting the next-generation of Spaceborne Animal Telemetry

Misson Concept study (pre-phase A):

defining potential mission architectures, identifying the necessary technologies, and evaluating the cost-benefit trade-offs.
Present a few viable concepts associated with feasibility scores to stakeholders for further consideration and funding.

- **Tag trade-space analyses**
- **Prototype Miniaturized Tags**
- **New Satellite Architectures**

2) Architecting the next-generation of Spaceborne Animal Telemetry

Misson Concept study (pre-phase A):

defining potential mission architectures, identifying the necessary technologies, and evaluating the cost-benefit trade-offs.
Present a few viable concepts to stakeholders for further consideration and funding.

•Tag Features • Prototype Miniaturized Tags • New Satellite Architectures

1) Catalog animal tags, detailing their technical specifications and capabilities (includes 100+ tags)

ID	Tag Name (System)	Satellite Infrastructure	Status	Manufacturer	Tag Mass	Battery Life	Measurement Frequency (Rate)	Data Latency	Position Accuracy (Horizontal & Vertical)	Cost	Auxiliary Sensors	Communication Approach	Communication Protocol	References
1	**SOLAR PTT**	Argos	Commercial	Microwave Telemetry	2 g, 5 g, 9.5 g, 12 g, 18 g, 35 g, 50 g	≤2 years (solar-powered rechargeable)	Programmable duty cycle; transmits ~every 60 s when active	Near real-time (Argos uplink on each sat pass)	~250 m (Argos Doppler, best-case); up to ~1500 m error in poor conditions	~$5,000 (5 g) – ~$6,800 (2 g) per tag	Temp and battery voltage sensors; optional activity sensor	UHF Argos uplink (~401 MHz) one-way to NOAA polar satellites	Argos DDS protocol	Solar PTT
2	**SOLAR Argos GPS PTT**	Argos	Commercial	Microwave Telemetry	17 g, 22 g, 30 g, 45 g, 50 g, 70 g	up to 3 years	Programmable duty cycle; transmits ~every 60 s when active	Transmit to argos every 3 days	GPS location within +/- 18m	$3650 - $4200	GPS, temperature, battery voltage, activity	Argos network uplink	Argos DDS protocol	Solar Argos GPS PTT
3	**ETA-2920**	Argos	Commercial	Telonics	26 g	75–200 days (battery, duty-cycle dependent)	Transmits 4–12 h/day (user-scheduled duty cycle)	Near real-time (data with each satellite pass)	~150–500 m (Argos Doppler location)	N/A	Mortality, activity, temp, low-voltage sensors	UHF Argos uplink (401.65 MHz) to NOAA satellites (Doppler tracking)	Argos DDS protocol	ETA-2920
								Near real-time				UHF Argos uplink		

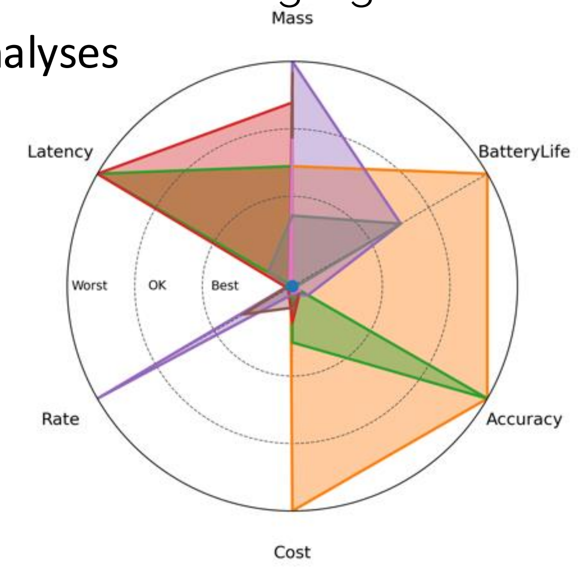
The catalog is a living document intended for consultation, feedback, and practical use by the community

2) Identify gaps in tag performance to highlight areas for technological development

Trade-space analyses

Ideal Tag is a dot in the center of radar plot.

Attribute	Min	Max
Mass	0.0 gram	30.0 gram
BatteryLife	>2.0 years	>20.0 years
Accuracy	0.0 meter	250.0 meter
Cost	0.0 USD	6800.0 USD
Rate	0.0 Minutes	120.0 Minutes
Latency	0.0 Hours	8.0 Hours



2) Architecting the next-generation of Spaceborne Animal Telemetry

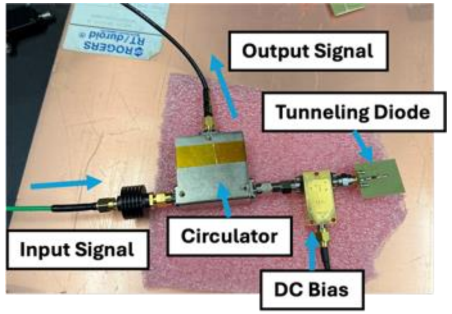
Misson Concept study (pre-phase A):
defining potential mission architectures, identifying the necessary technologies, and evaluating the cost-benefit trade-offs.
Present a few viable concepts to stakeholders for further consideration and funding.

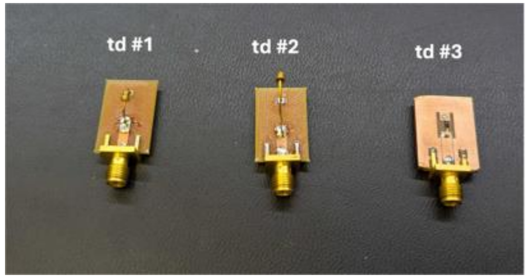
•Review of Tag Features • **Prototype Miniaturized Tags** • New Satellite Architectures

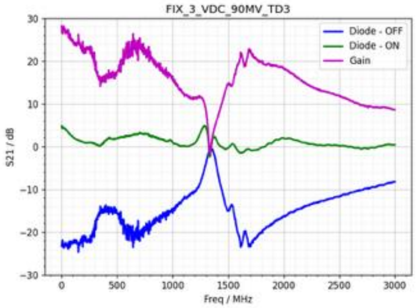
- Exploring <u>signals of opportunity</u> to develop **< 1 gram** tags

- Prototyping passive or semi-passive RFID tags reflecting existing RADAR signals to a constellation of CubeSats receivers

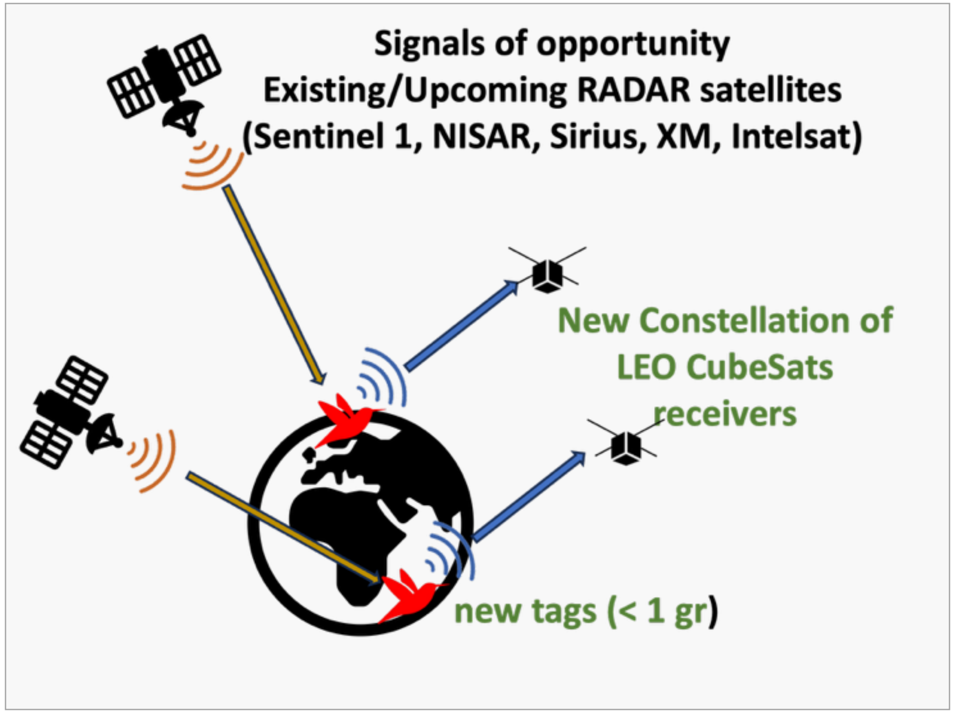
Status: Proof-of-concept in controlled setting (lab) finalized, with promising results







Upcoming this summer, System-level feasibility: testing tag reflectivity from real-world sources (Sirius, XM, Sentinel-1, NISAR) towards outdoors antennas scattered around JPL.



2) Architecting the next-generation of Spaceborne Animal Telemetry

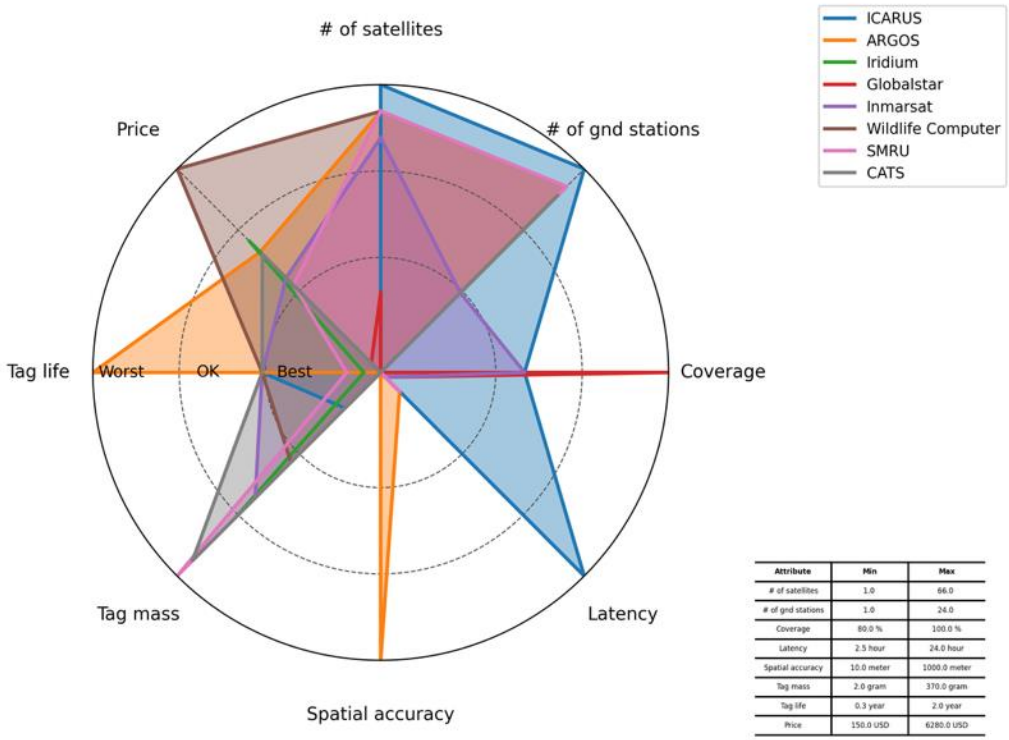
Misson Concept study (pre-phase A):

defining potential mission architectures, identifying the necessary technologies, and evaluating the cost-benefit trade-offs.
Present a few viable concepts to stakeholders for further consideration and funding.

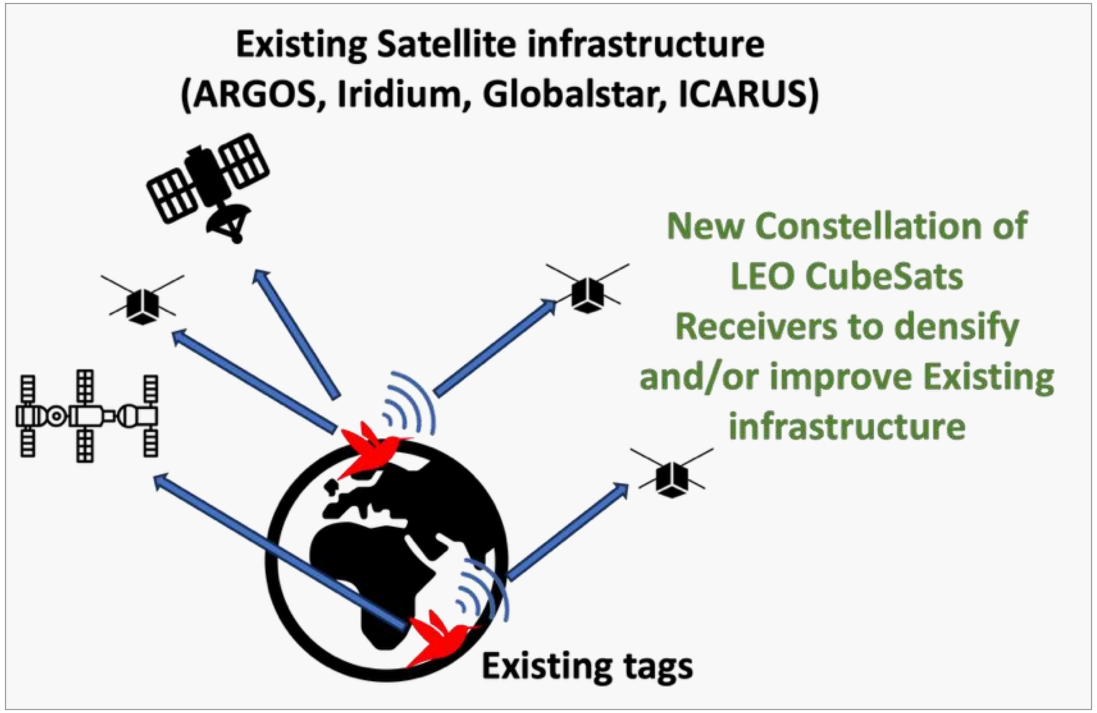
- Review of Tag Features
- Prototype Miniaturized Tags
- **New Satellite Architectures**

- Compare options for different Observing Systems architectures based on factors like cost, performance and risk.

Trade-space analyses



Attribute	Min	Max
# of satellites	1.0	66.0
# of gnd stations	1.0	24.0
Coverage	80.0 %	100.0 %
Latency	2.5 hour	24.0 hour
Spatial accuracy	10.0 meter	1000.0 meter
Tag mass	2.0 gram	370.0 gram
Tag life	0.3 year	2.0 year
Price	150.0 USD	6280.0 USD



Example: Design improved constellations of CubeSats with multi-system antennas (e.g., ARGOS, ICARUS, Iridium) to enhance current tag-satellite connectivity, coverage, latency, and cost-efficiency.

3) Integrate Animal Movement Data with NASA Remote Sensing and Earth System Modelling

- **ARSET Training**
- RSAM: Remote Sensing for Animal Movement
- Animal-borne sensors

Registrants: ~2000 in 1st week

live participants 900+

Part 1, May 20th
Part 2, May 22th

Main Goals / Learning Objectives:

- Identify types of animal tracking tags and sensors.
- Recognize types of remote sensing data and products.
- Integrate animal movement data with remote sensing for analysis

3) Integrate Animal Movement Data with NASA Remote Sensing and Earth System Modelling

•ARSET Training

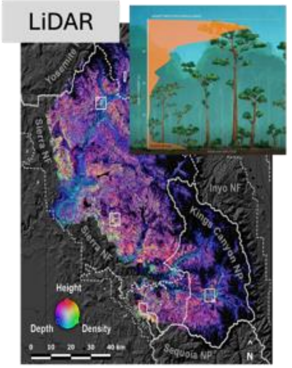
• RSAM: Remote Sensing for Animal Movement

• Animal-borne sensors

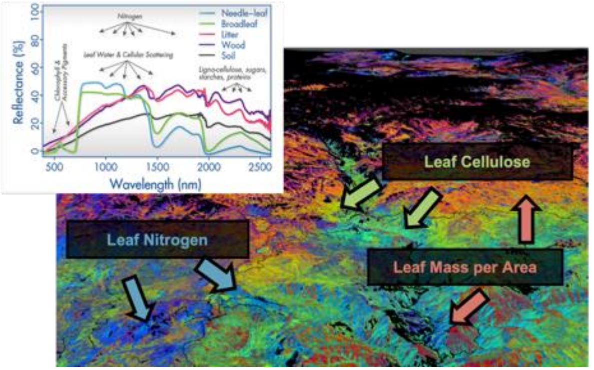
Problem: Animal movement data has been predominantly integrated with NDVI and Land Cover Maps

Goal: Stimulate the integrating of advanced remote sensing of habitat **structure**, **physiology** and **function**

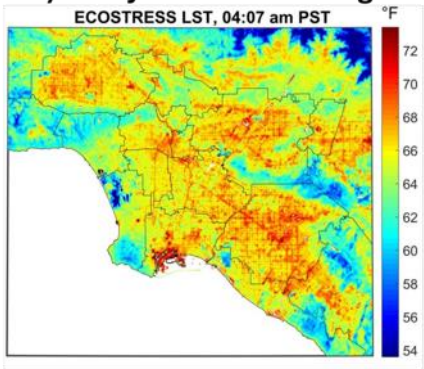
1) Ecosystem Structure



2) Ecosystem Physiology



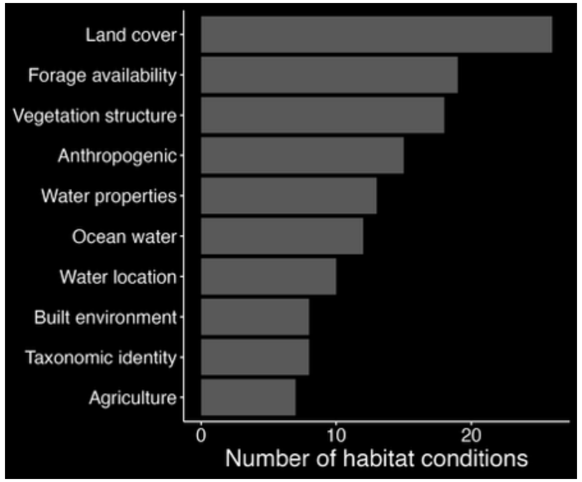
3) Ecosystem Functioning



(LIDAR, RADAR, Thermal, Spectroscopy, SIF)

Two step approach:

a) Requirements. Wish list of habitat characteristics from Movement Ecologists (50+ expert interviews)



b) Gap Analysis. What habitat requirements can be met by

a) current remote sensing sensors
b) upcoming remote sensing sensors
c) require the design of new remote-sensing sensors

Deliverable: Journal paper submitted by October 2025

3) Integrate Animal Movement Data with NASA Remote Sensing and Earth System Modelling

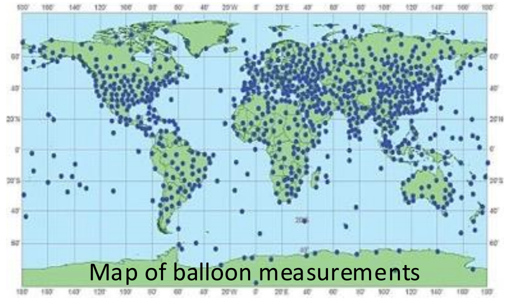
•ARSET Training

• RSAM: Remote Sensing for Animal Movement

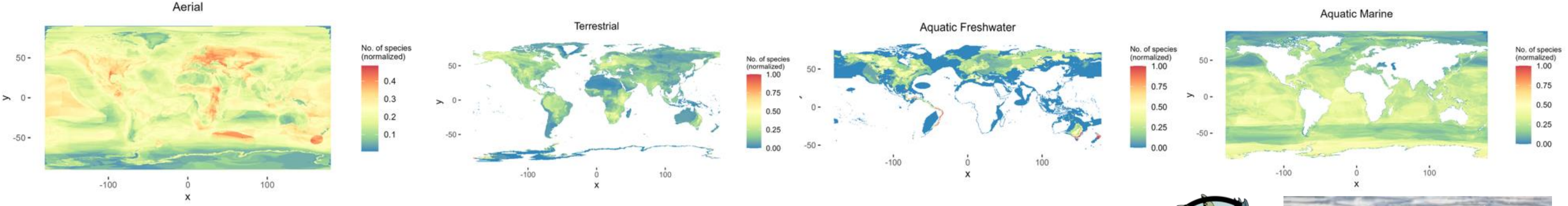
• **Animal-borne sensors**

Problem: Significant Observational Gaps (e.g., temperature, salinity, CO_2, air pressure) hinder our understanding of the Earth System

Existing infrastructure (weather stations, balloons, buoys) is sparse and biased toward populated areas.



Potential: Tracked animals have global coverage and inhabit hard-to-reach areas: deep oceans, polar regions, high altitudes, and ice-covered



Real world Applications: : Marine animals: feed salinity and temperature profiles into the Global Ocean Observing System (GOOS).

We want to expand these concepts to a broader terrestrial–aerial-water framework to inform NASA Earth System Understanding & Modelling

4) Build a Federated Animal Movement Community

- **MoveBON:** Movement Biodiversity Observation Network

•3-day in-person event with **110 participants**
•Participants from Agencies (43), Academia (27), conservation NGOs (25)
•Participants from N. America (65), S. America (1), Europe (13), Africa (3) and Asia (1)

Advance science-policy impact of movement data
- develop biodiversity indicator
- support national use cases demonstrating the value of integrating animal movement into policy.

Establish a thematic BON on animal movement
- formalize a dedicated BON focused on tracking and interpreting animal movement.

Being prepared

- MoveBon Concept Journal Paper
- Proposal to become an official BON

Smithsonian National Zoological Park Conservation Biology Institute

Jet Propulsion Laboratory California Institute of Technology

GEO BON Group on Earth Observations Biodiversity Observation Network

WILDLABS.NET [The conservation technology network]

THANK YOU

Antonio Ferraz

Antonio.A.Ferraz@jpl.nasa.gov

NASA Jet Propulsion Laboratory, California Institute of Technology