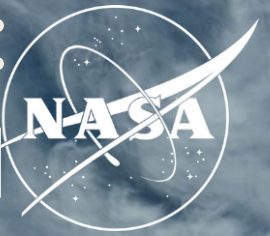




Adaptation and Response in Drylands (ARID): NASA field campaign to advance science and resource management in drylands



White Paper Link

Subset of leadership team:

Andrew F. Feldman (NASA GSFC/UMD), Sasha Reed
(USGS), Shawn Serbin (NASA GSFC)
David J.P. Moore, William K. Smith (U. Arizona)
Marcy Litvak (U. New Mexico)
Niall Hanan (New Mexico State U.)
Konrad Wessels (George Mason)
Joel Biederman, Russ Scott (USDA ARS Tucson)



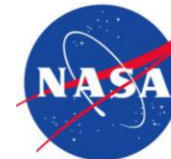
THE UNIVERSITY OF ARIZONA

College of Agriculture,
Life & Environmental
Sciences

Arizona Institute
for Resilience



UNIVERSITY OF
MARYLAND



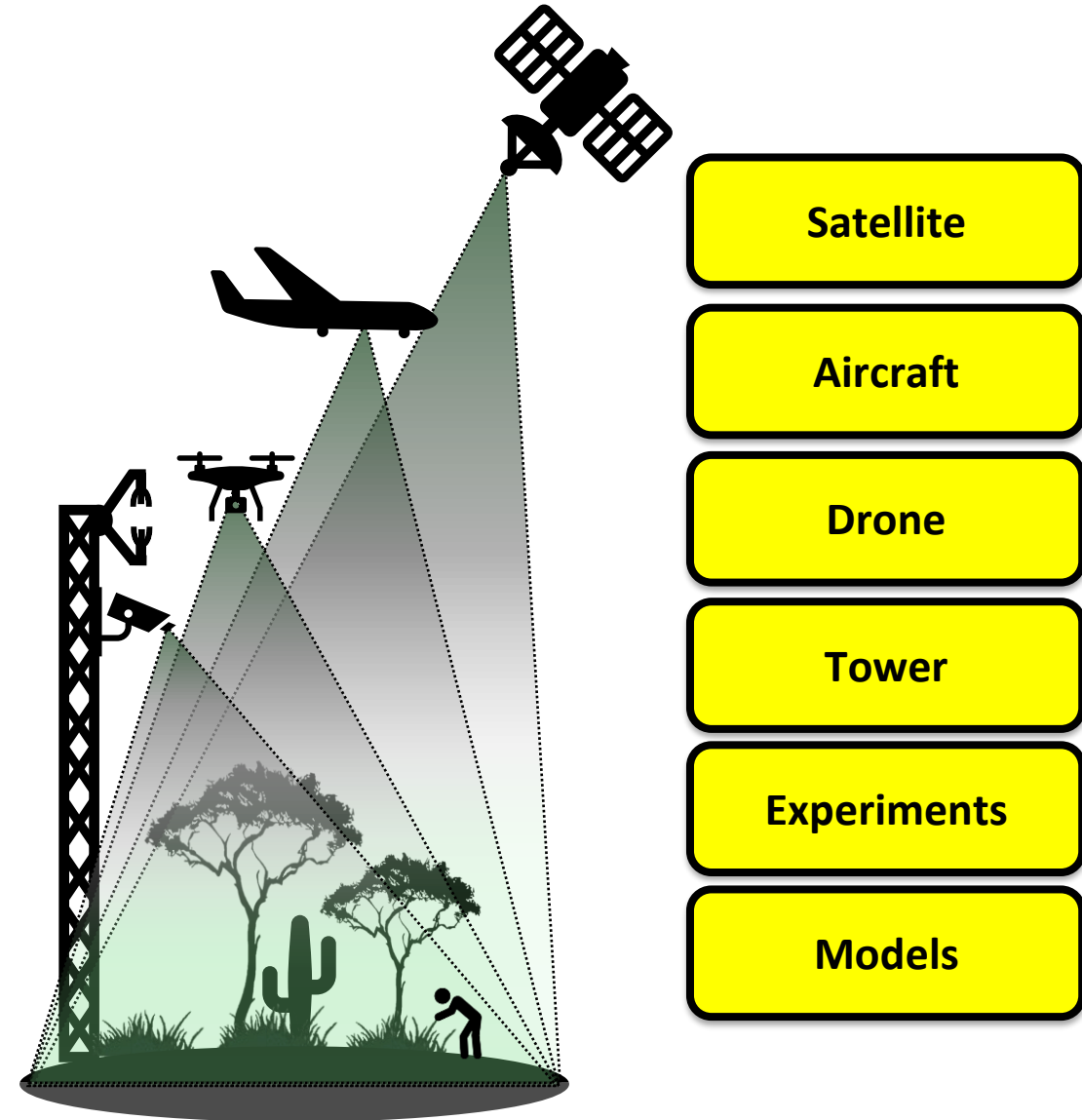
GodDard
SPACE FLIGHT CENTER

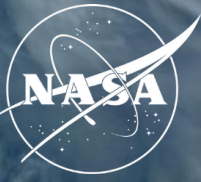
GO DDARD
EARTH SCIENCES

NASA Terrestrial Ecology Field Campaigns are designed to build understanding for complex systems

NASA Terrestrial Ecology field campaigns focus the community's attention on:

- (a) **answering big science questions**
targeted on important regions or biomes
- (b) enabling **more effective interpretation**
and analysis of space-based measurements
- (c) fostering **collaborative interactions** and
building new relationships within the scientific community
- (d) providing valuable opportunities for training and educating the **next generation of scientists**
- (e) leaving a **legacy data** of great value for future research.

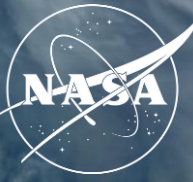




ARID's Main Questions and Themes

- What are drylands' contributions to the Earth System, how are these contributions shifting with change, and what management (e.g., mitigation and adaptation) solutions could help maintain the critical services provided by drylands?
- Major Themes
 - Climate Variability and Drought
 - Ecosystem Structure, Function, and Biodiversity
 - Carbon Cycle Interannual Variability
 - Social-Ecological Systems

Take-aways

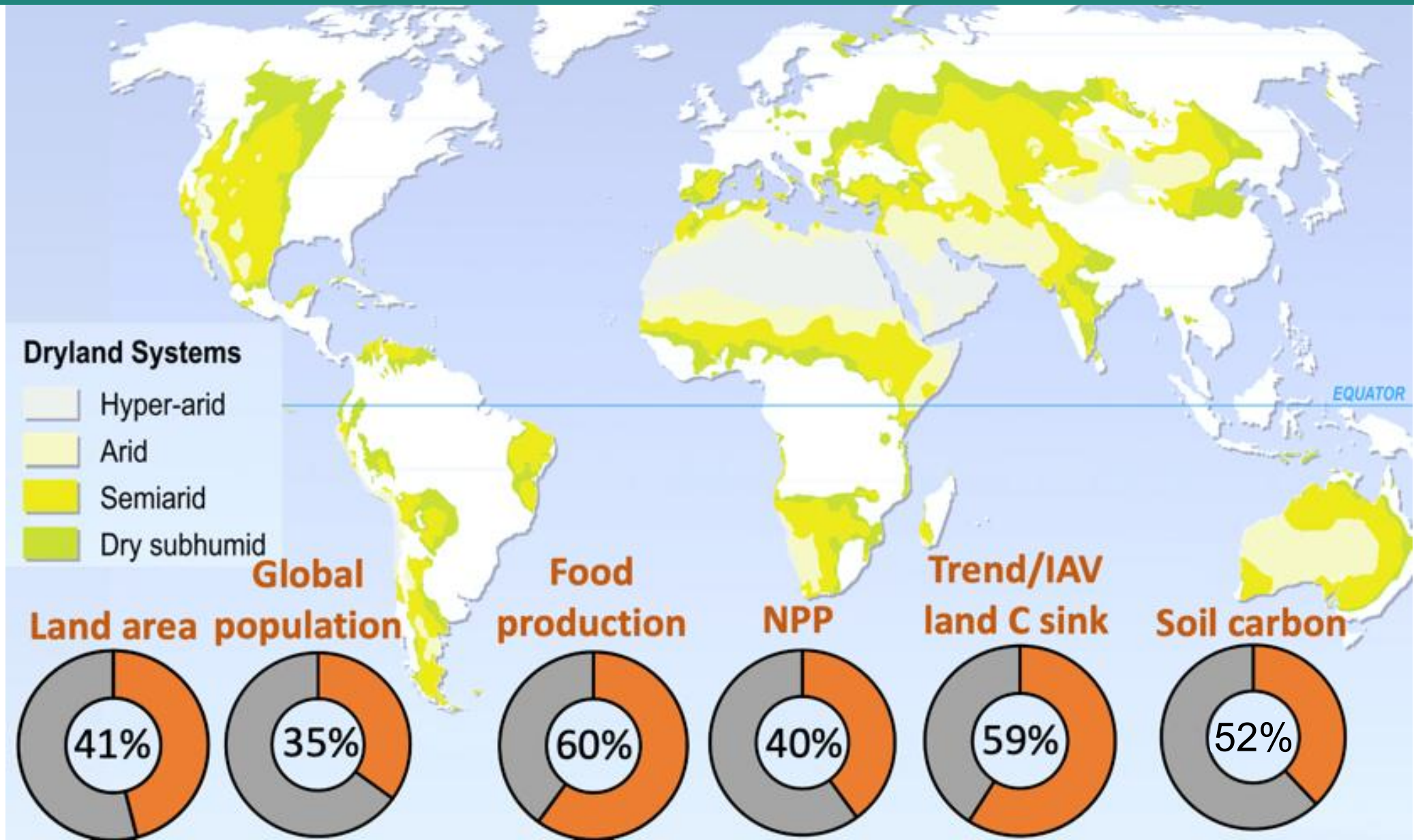


- ARID is selected and activities starting to roll out and occurring at varying scales through early-mid-2030s
 - Potential for funding solicitations
 - Aircraft campaigns ongoing with field collections
 - Request for ongoing field collection metadata
- Pilot demonstrations
 - Field-aircraft-satellite scaling studies and applications
 - Applications with ranchers and military
- Engagement
 - Monthly ARID and Applied Earth Observations Innovation Partnership (USFS & NASA) land management seminars
 - Conferences: New Phytologist Symposium, AGU conference sessions

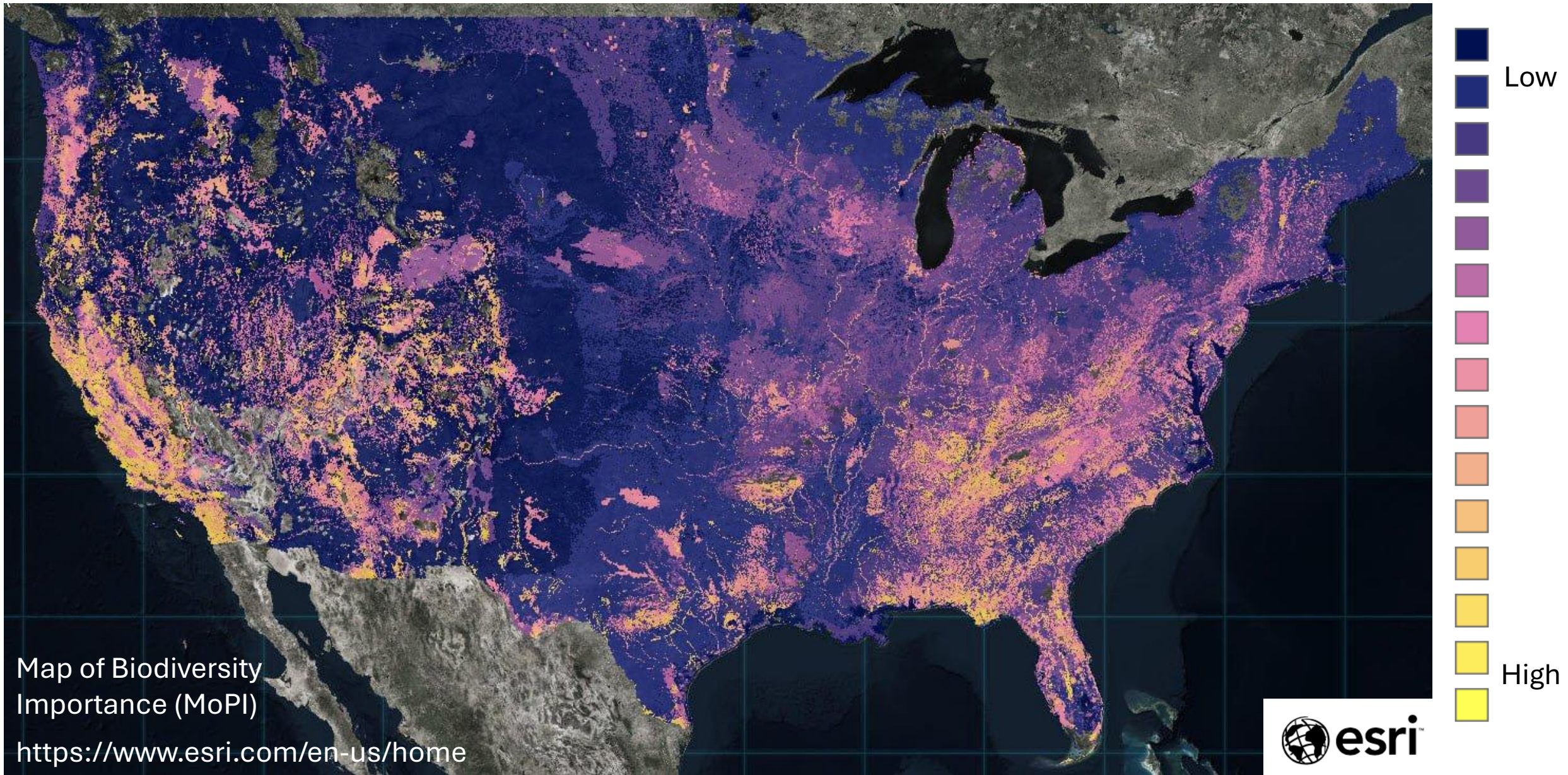


White Paper

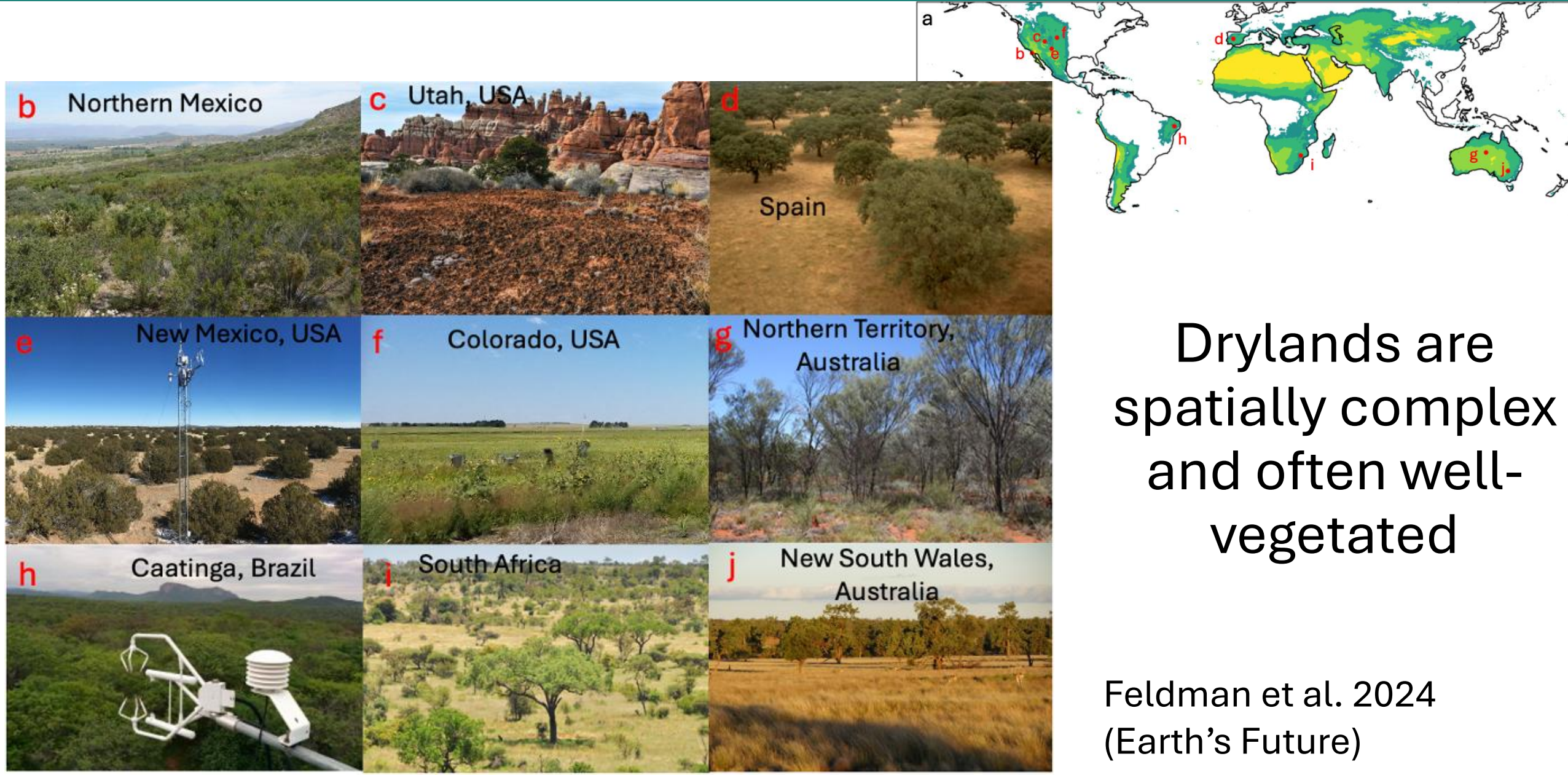
Why focus on drylands?



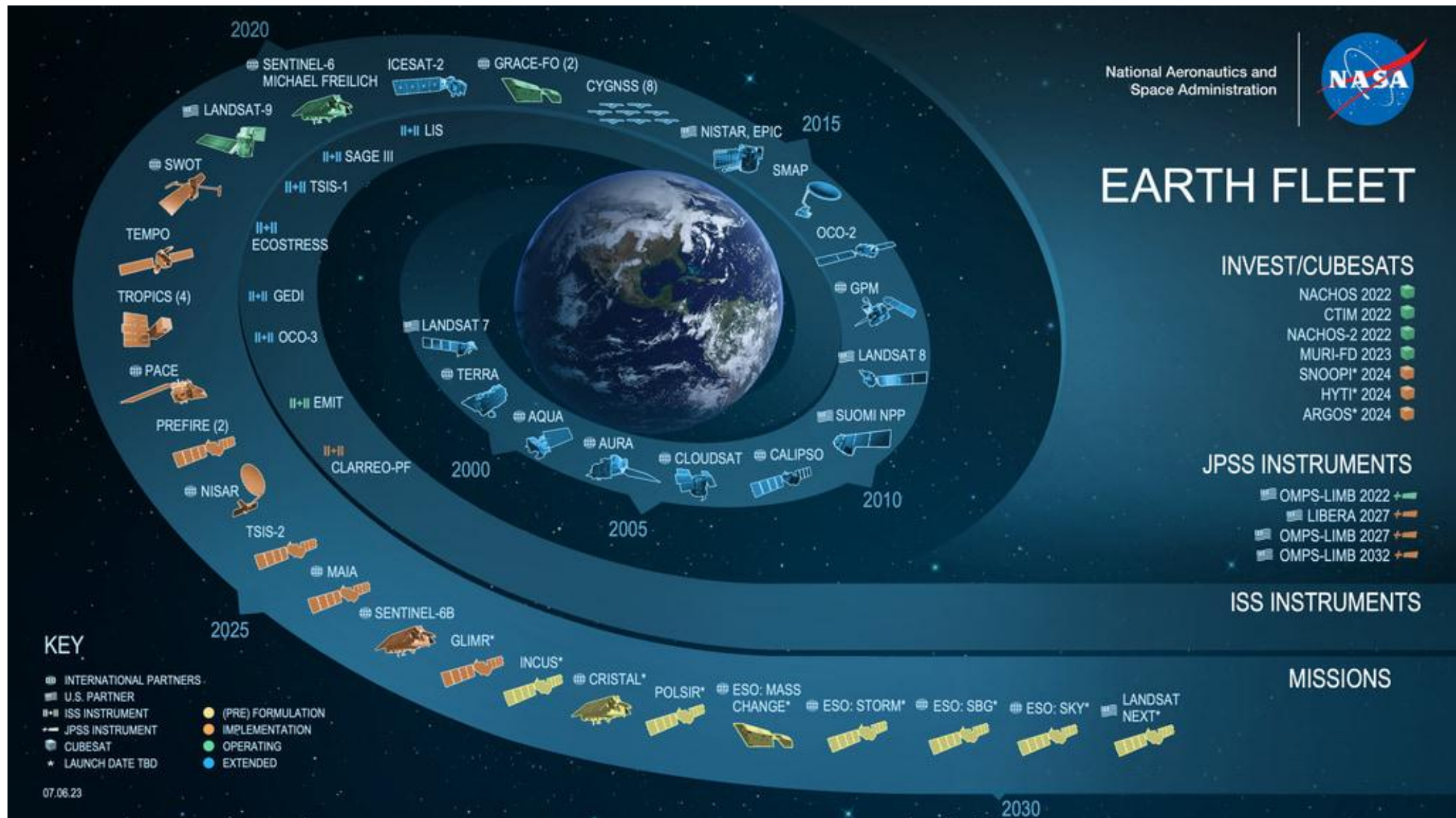
Drylands are hotspots of critical biodiversity



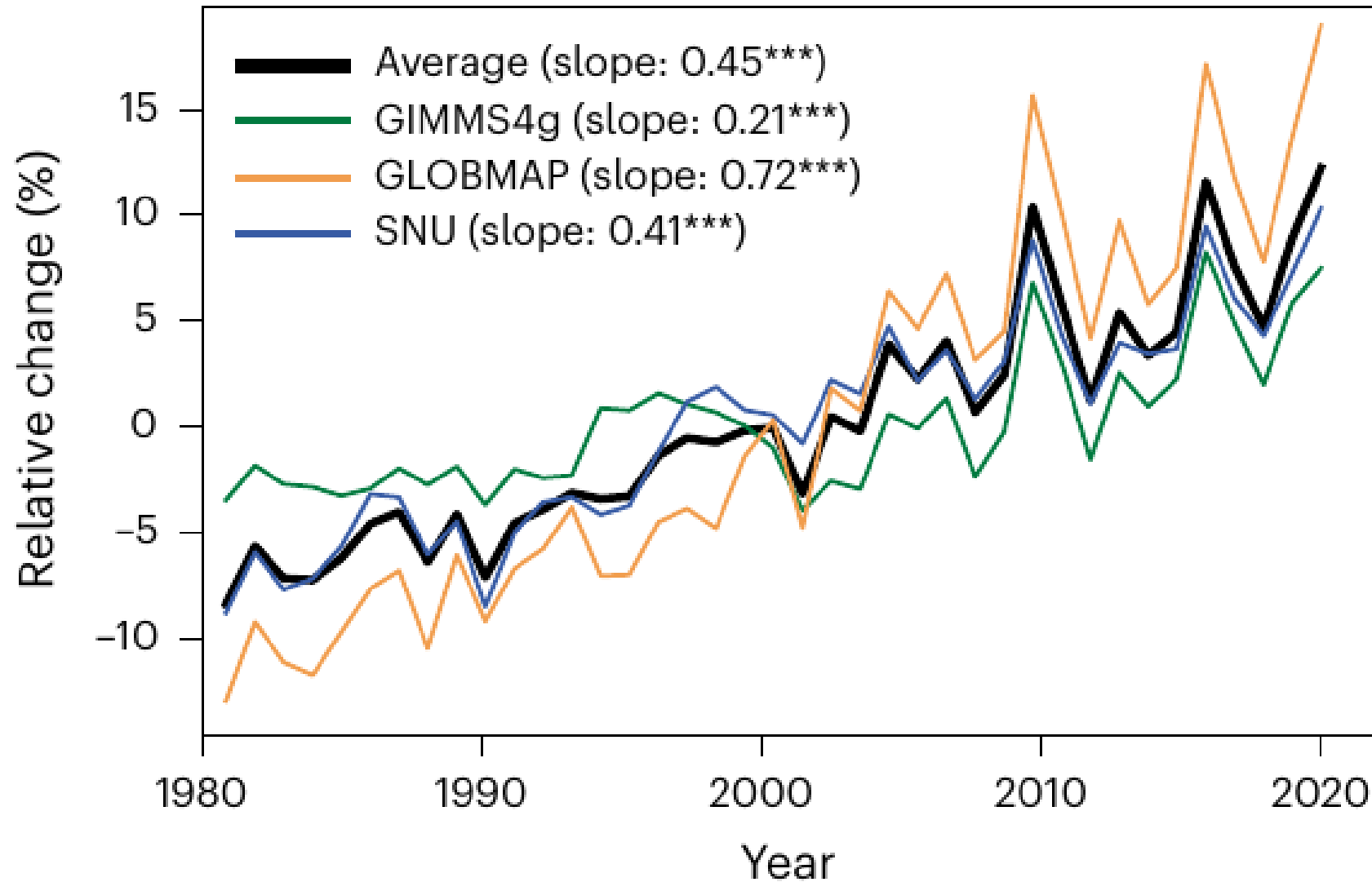
Drylands are often very green!



Unprecedented opportunities in remote sensing



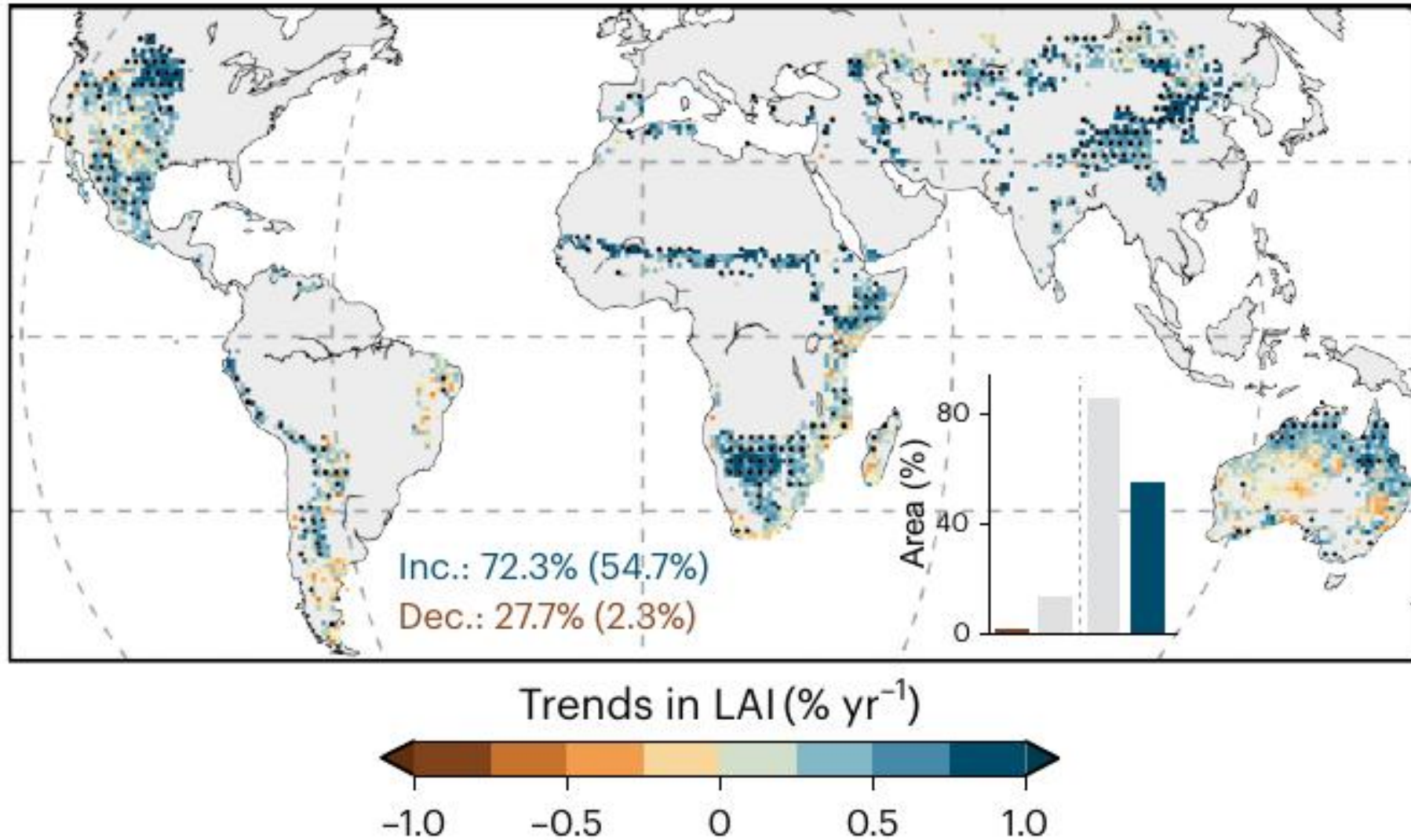
Drylands are greening, but becoming more variable / erratic



- Greening: +0.45% per year since 1982
- Year-to-year swings growing across 82% of drylands



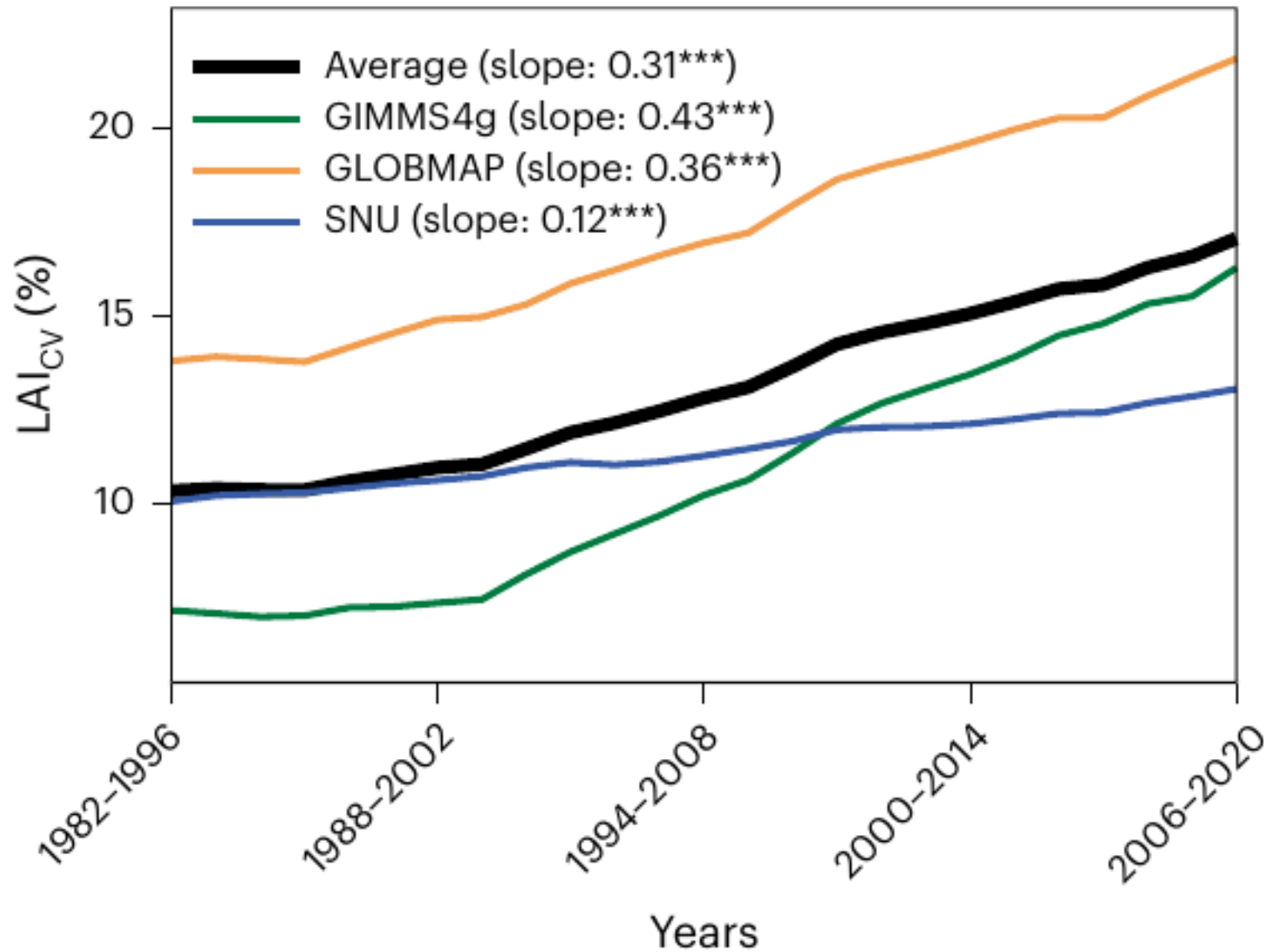
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**Greening
masks
stability
loss?**

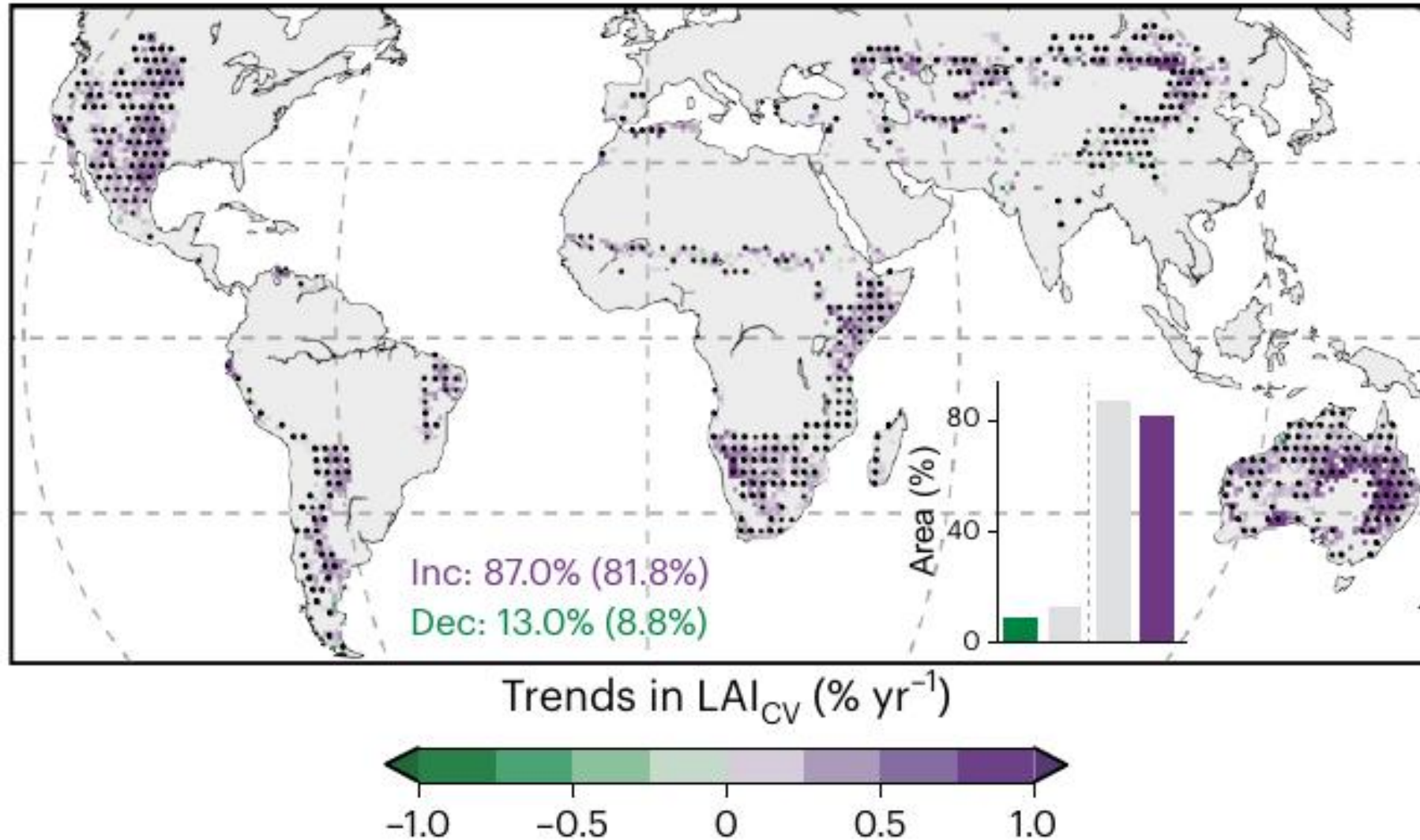
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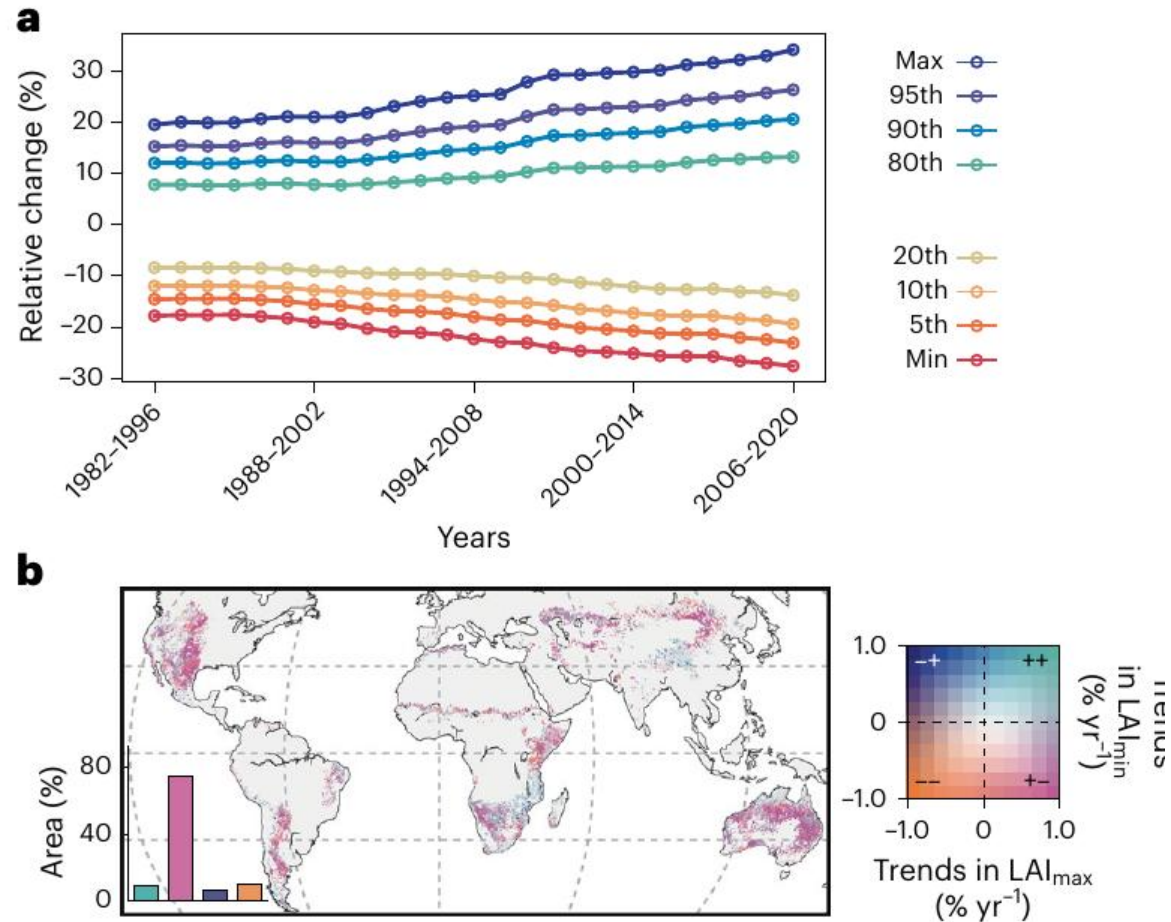
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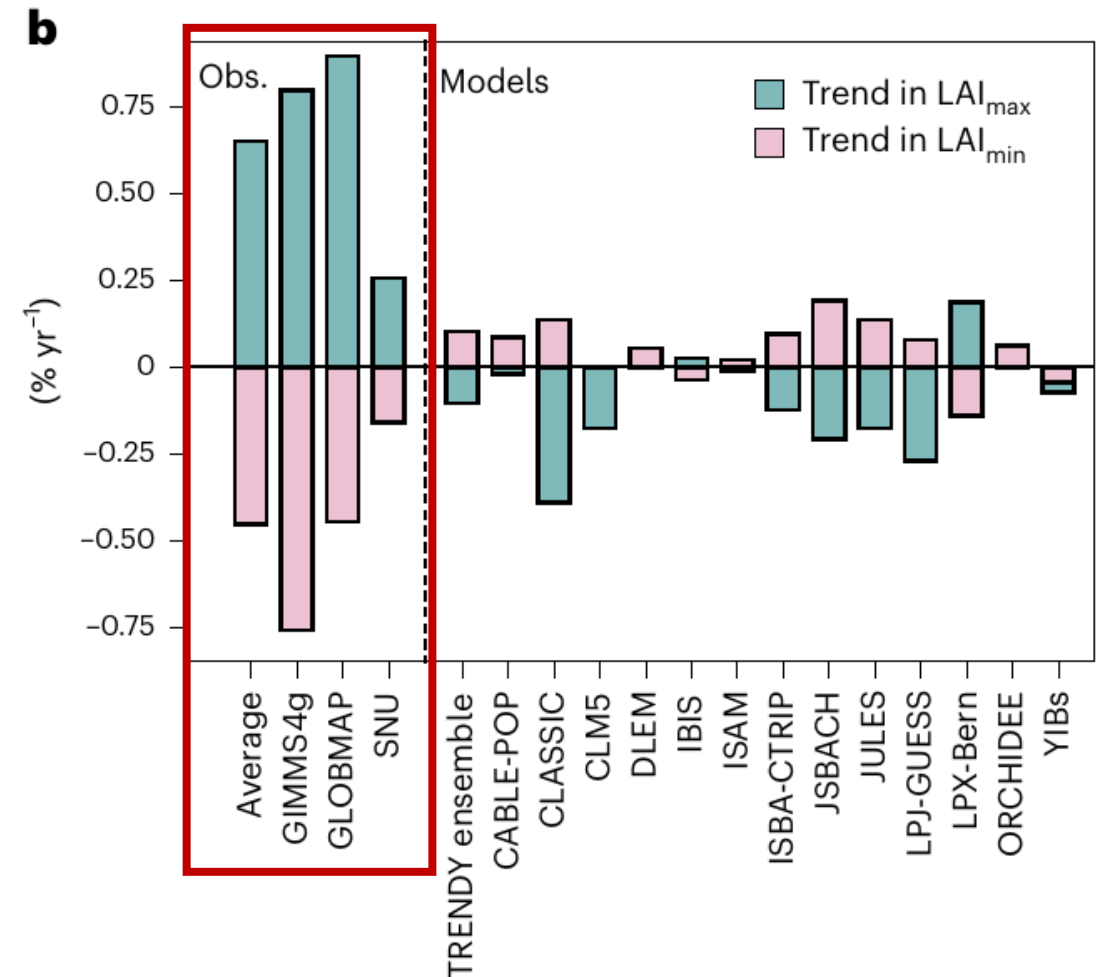
Good years get better, bad years get worse, and models miss it



Leaf area maxima rise, minima fall across 74% of drylands

<https://news.arizona.edu/news/satellite-data-exposes-escalating-boom-and-bust-dynamic-greening-drylands>

Zhang, Moore, Smith et al. (2026) Greening masks stability loss in drylands. *Nature Climate Change*.



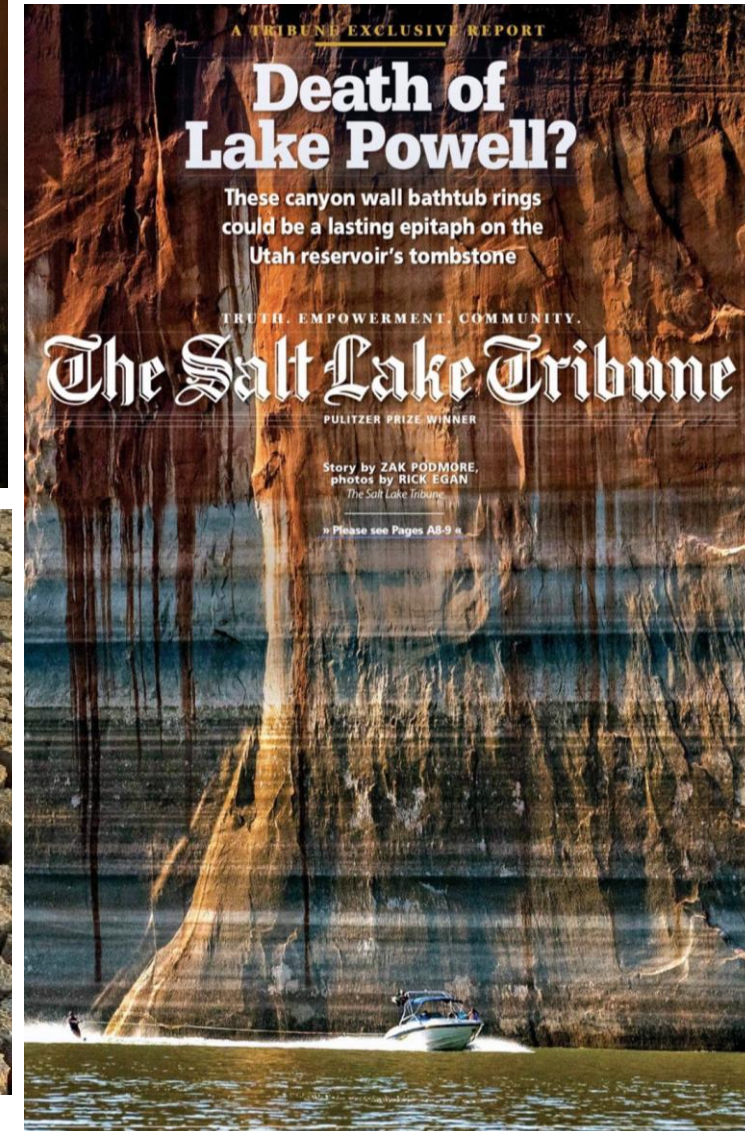
Satellites (boxed) versus 13 global models: flat or opposite

Dryland systems are showing threshold-type responses to change, resulting in new communities



Photo by Craig Allen

Drylands face substantial challenges



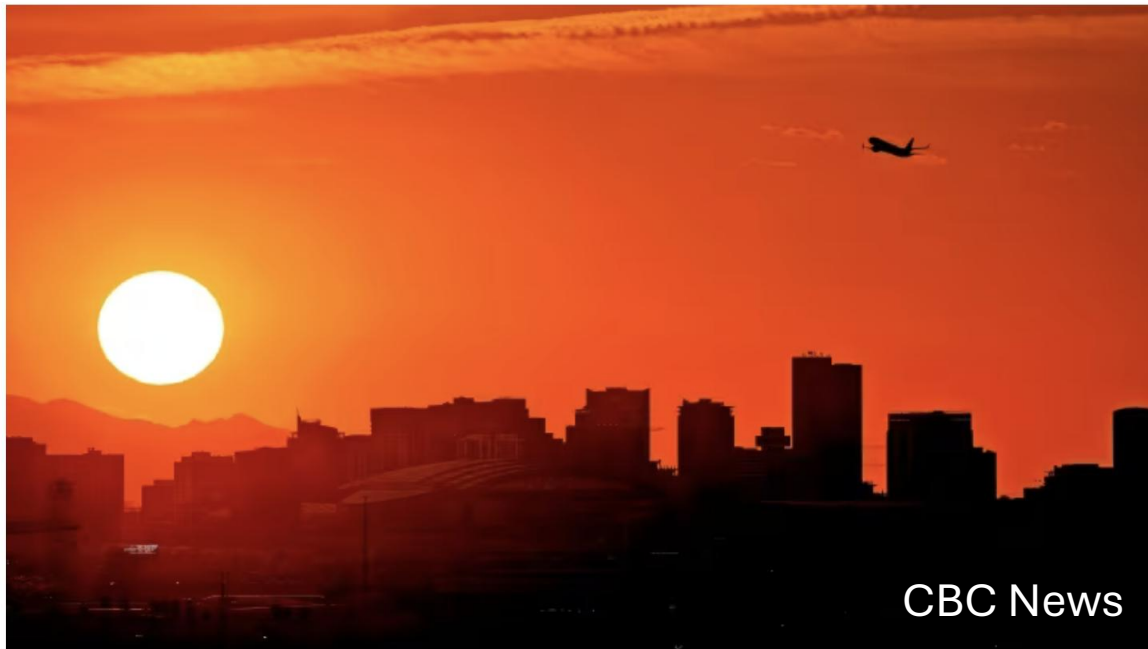
Hotspots for Change: Drought + Heatwaves

Western US drought one of largest seen in over 1200 years

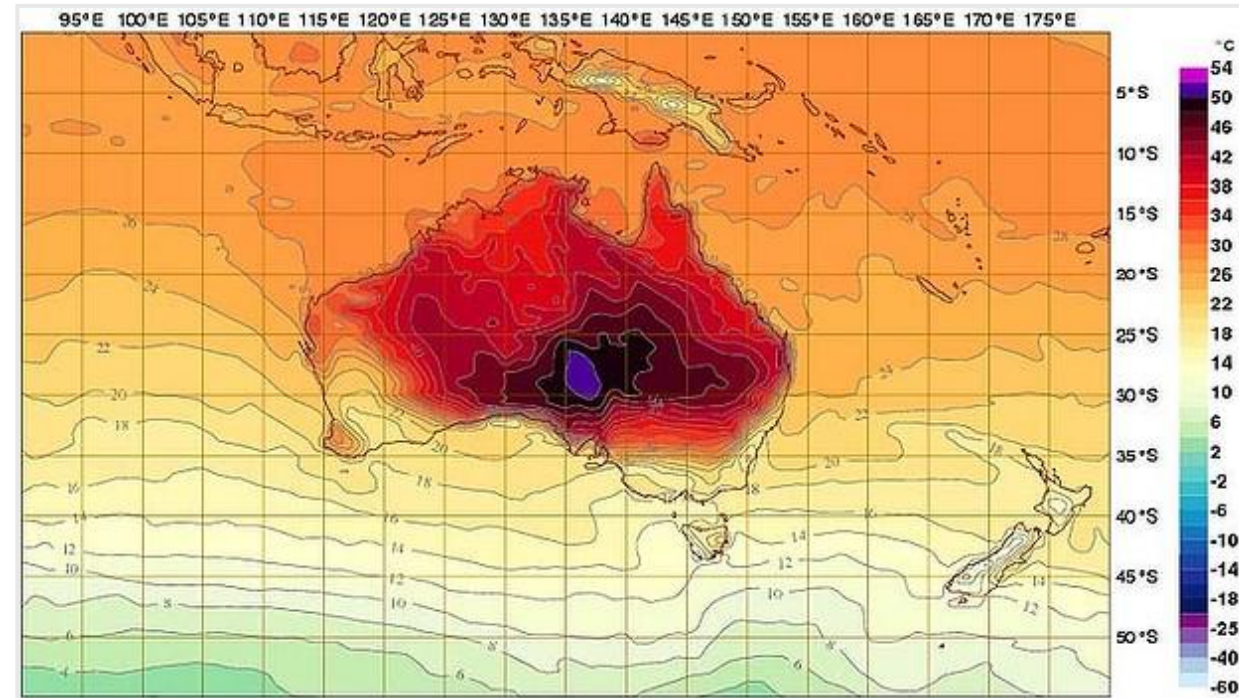
It's so hot in Phoenix, Ariz., that 42 C is considered cooler as record high temperature streak ends

Historic heat began blasting multiple regions across the U.S. in June

The Associated Press · Posted: Jul 31, 2023 9:35 PM EDT | Last Updated: July 31, 2023

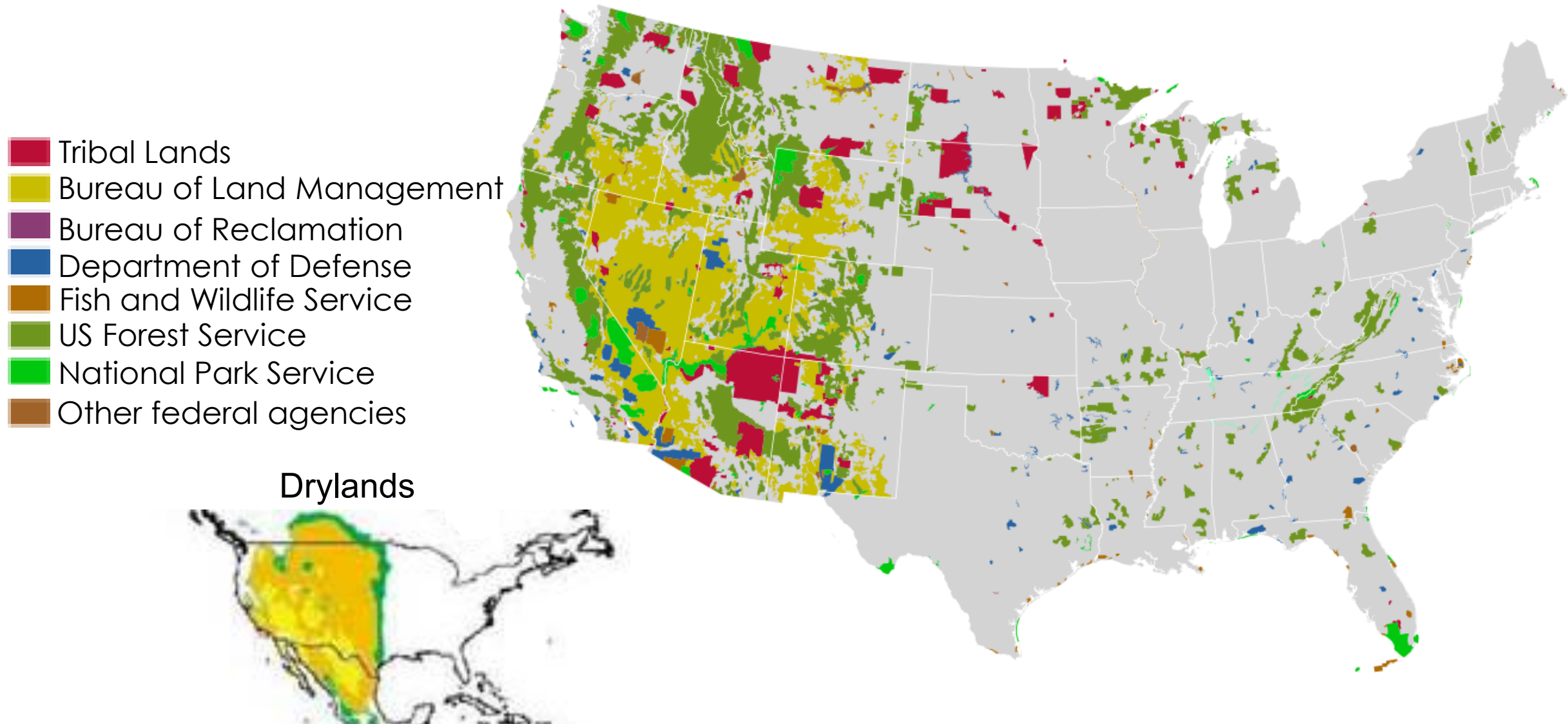


Temperature map of Australia

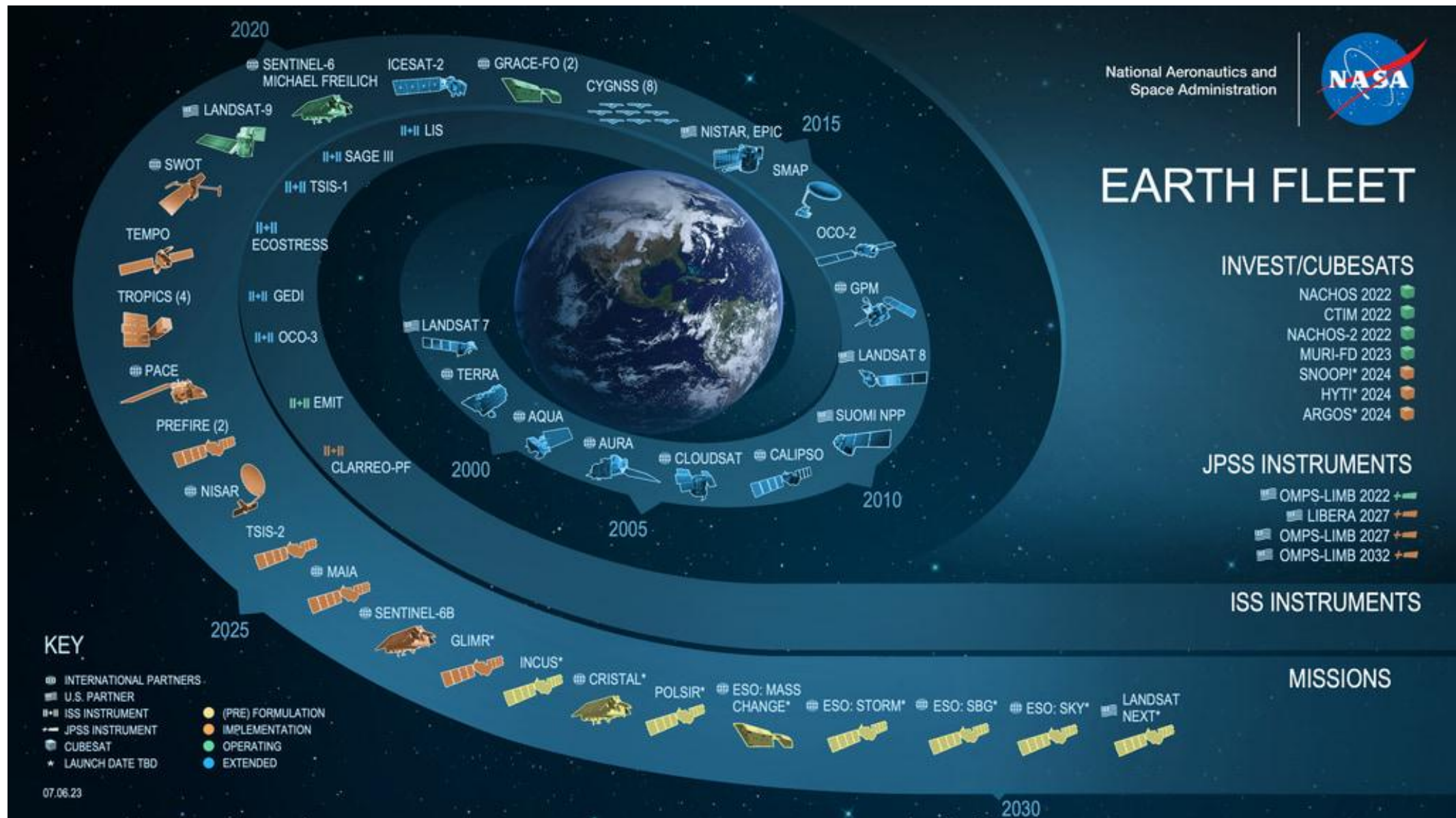


Australia's Bureau of Meteorology

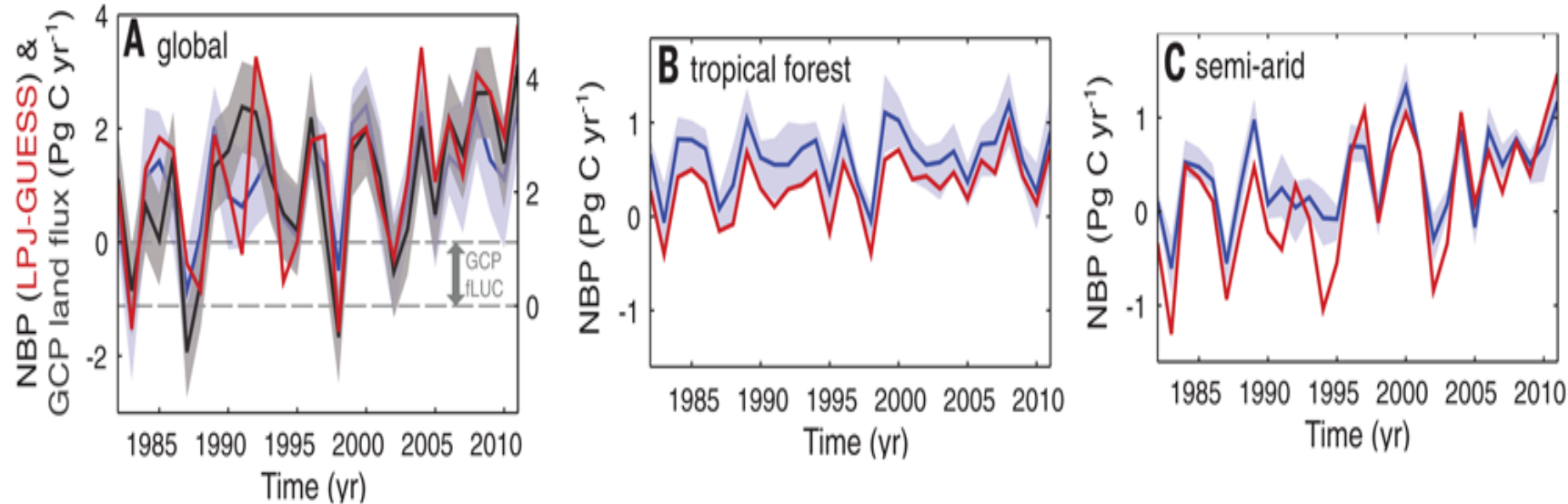
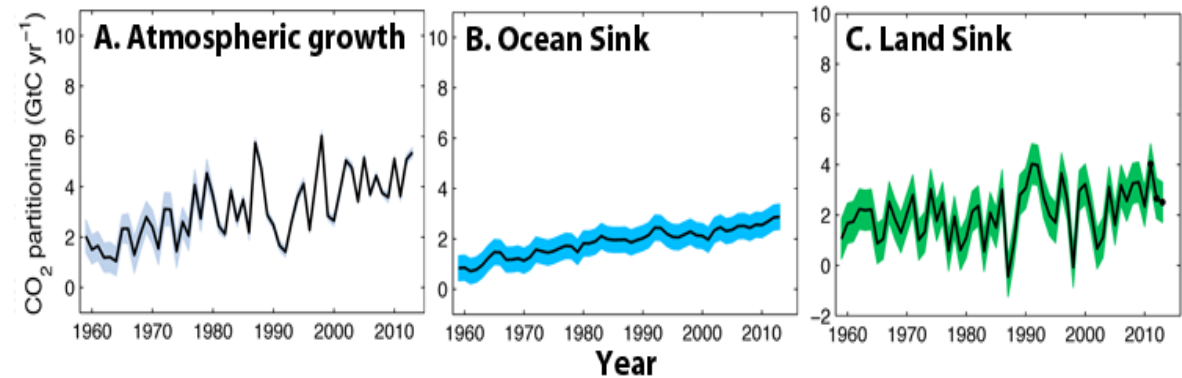
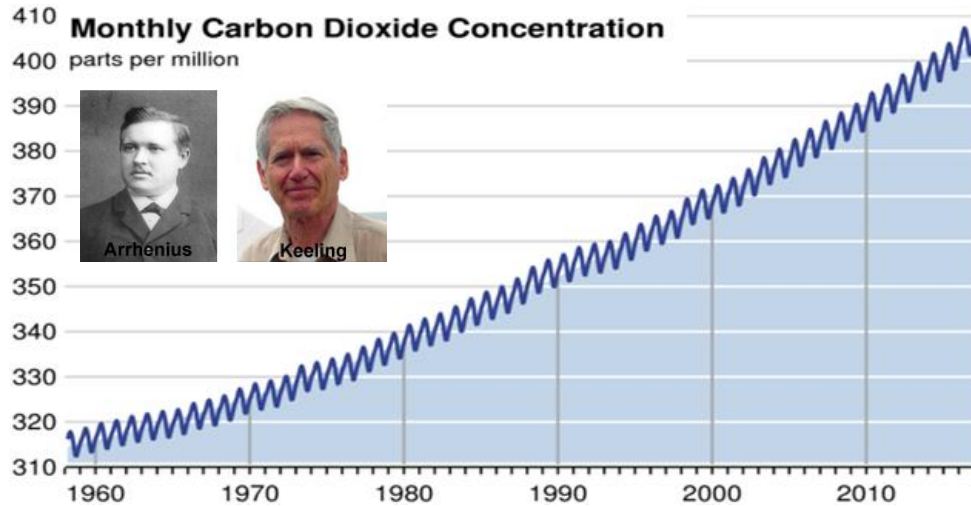
That equals big challenges for decision makers



Unprecedented opportunities in remote sensing

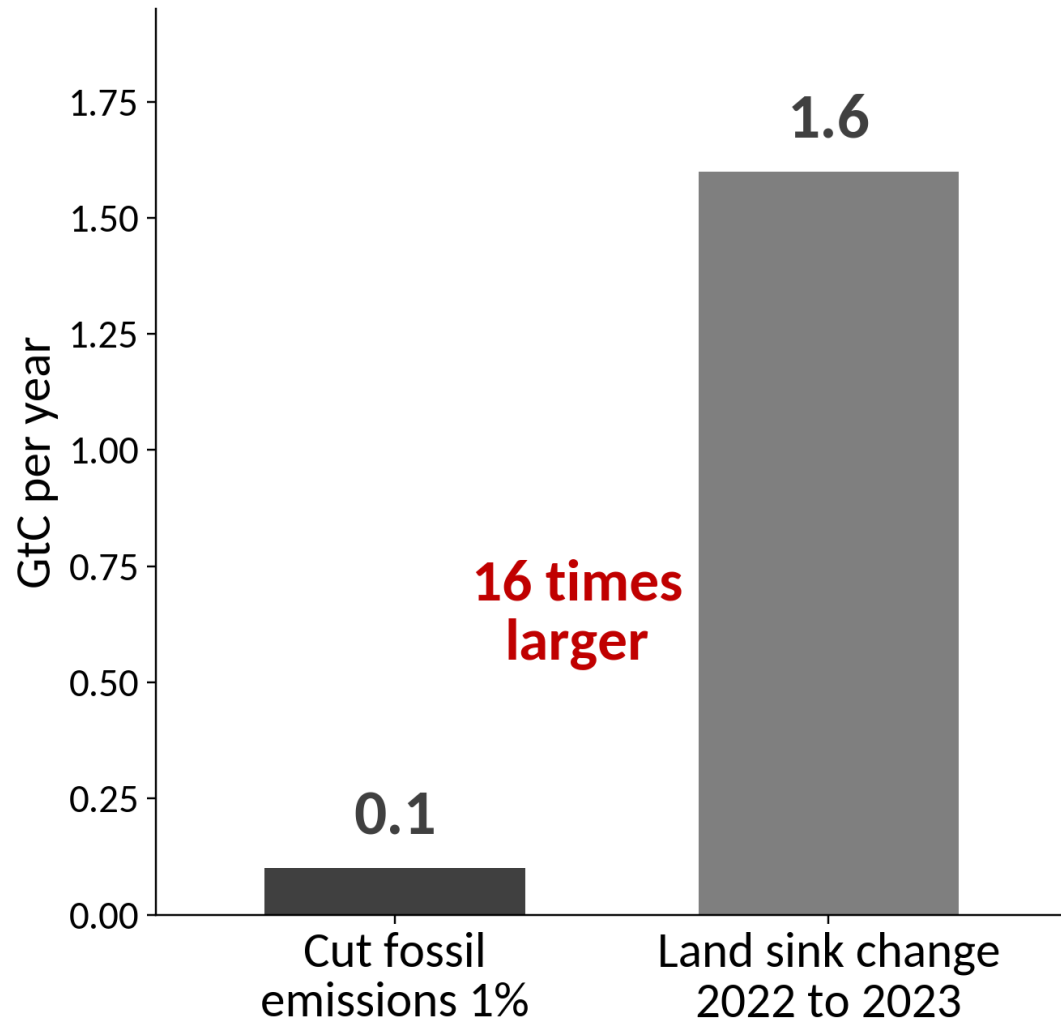


Carbon Emissions & the Land Carbon Sink



- Strong contribution of drylands to carbon interannual variability
- Challenges our ability to measure carbon emission reductions

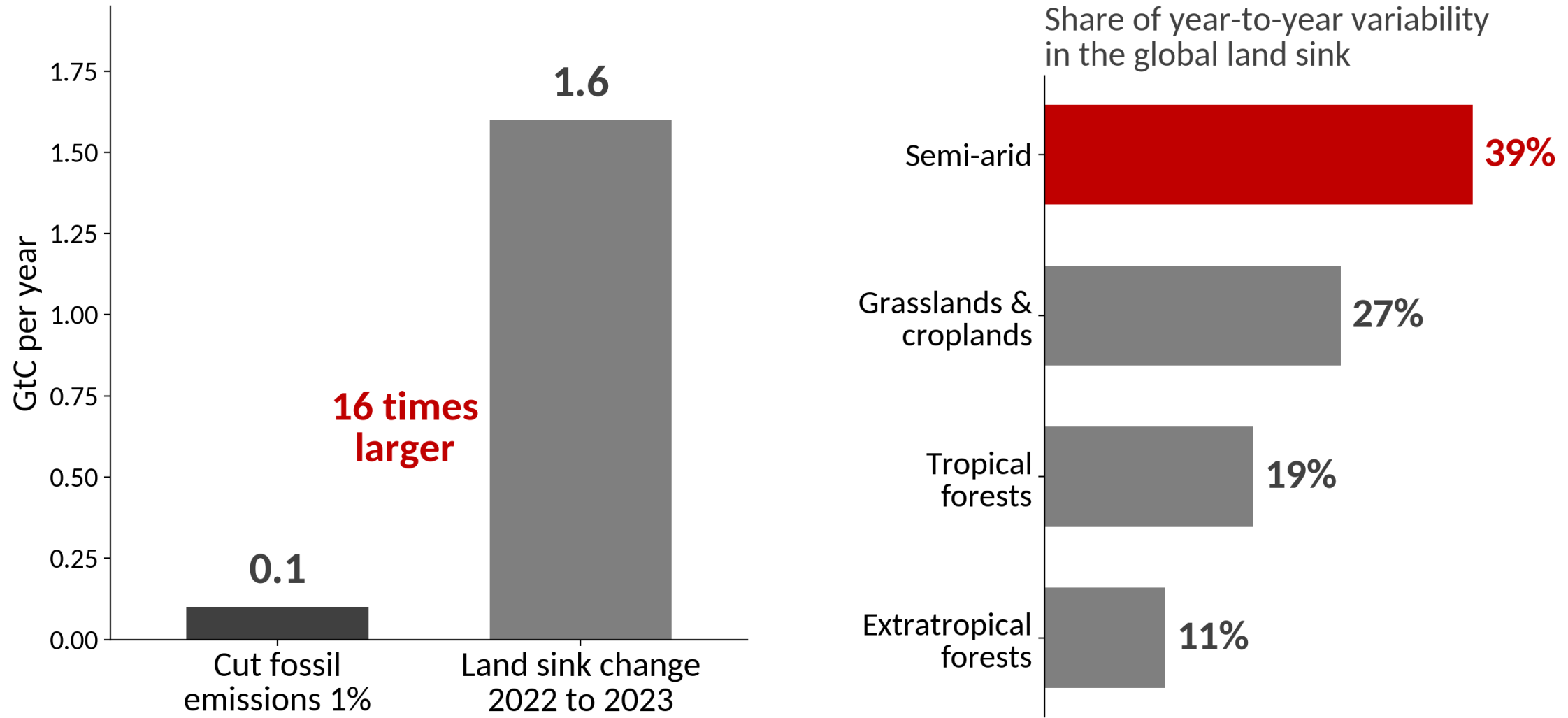
A 1% emissions cut is lost in the land sink's wobble



Year-to-year swings in the land sink can hide the effect of emission cuts.

So where does the noise come from?

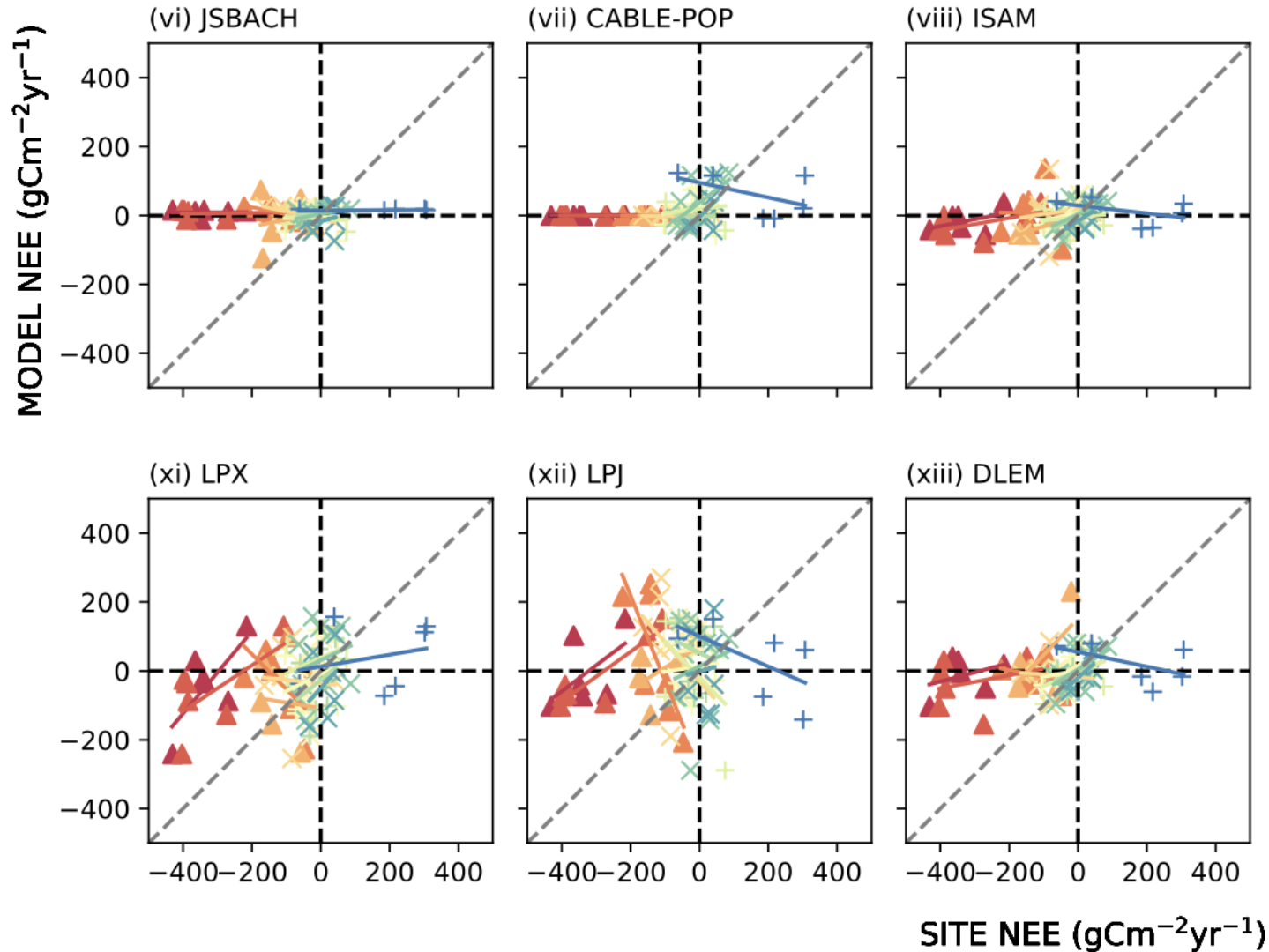
A 1% emissions cut is lost in the land sink's wobble



The biggest share of that noise comes from semi-arid lands.

Friedlingstein et al., Global Carbon Budget 2024 and 2025, ESSD. Ahlström et al. 2015, Science (LPJ-GUESS).

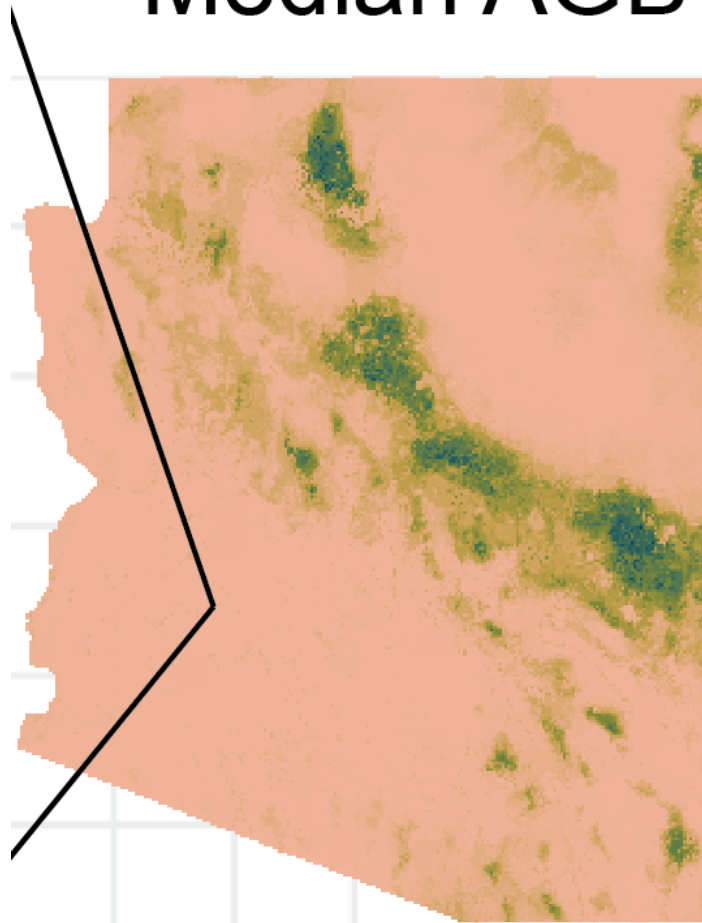
Models do not capture dryland variability



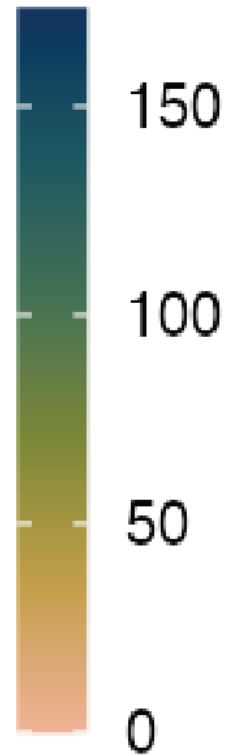
MacBean et al. 2021 (ERL)

*“We find that **all the models underestimate both mean annual carbon uptake/release as well as the magnitude of net ecosystem exchange (NEE) interannual variability (IAV)**, suggesting that improvements in representing dryland regions will improve global C cycle projections...Our analysis suggests that improvements in modeling C cycle processes across more than a quarter of the Earth’s land surface could be achieved by addressing the moisture sensitivity of dryland C uptake”.*

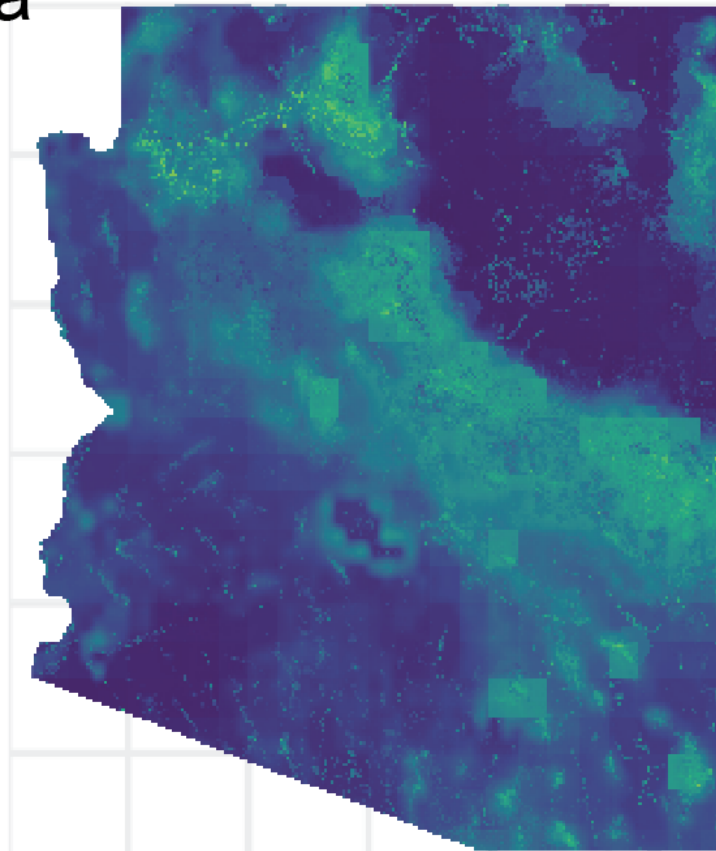
Median AGB



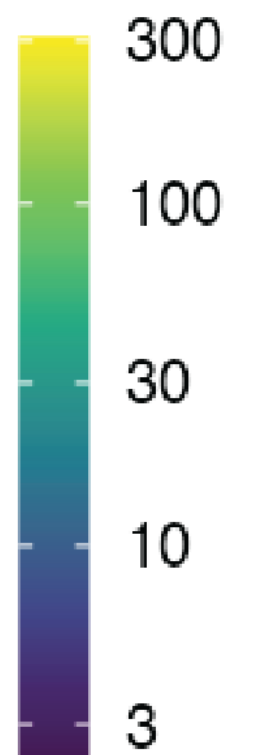
Mg C/ha



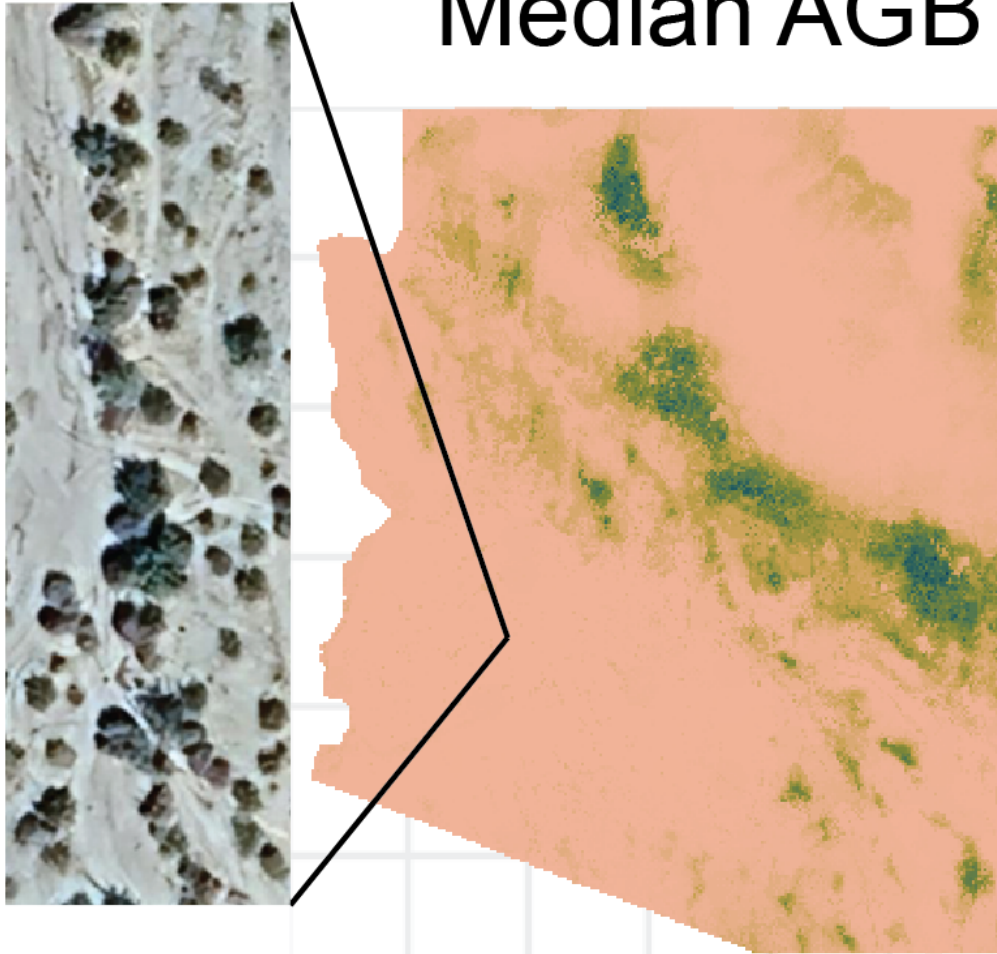
STDev AGB



Mg C/ha

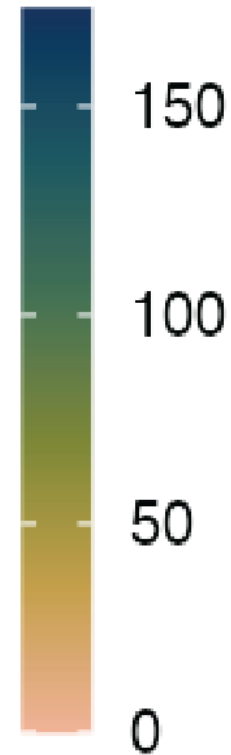


Median AGB

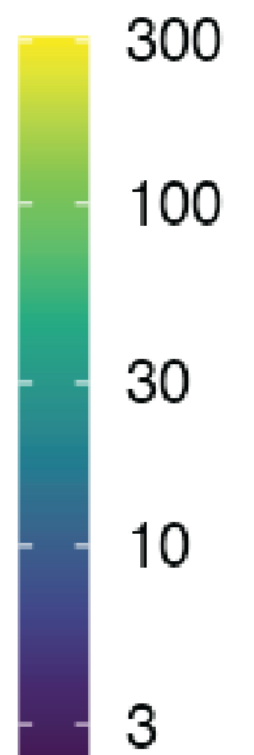


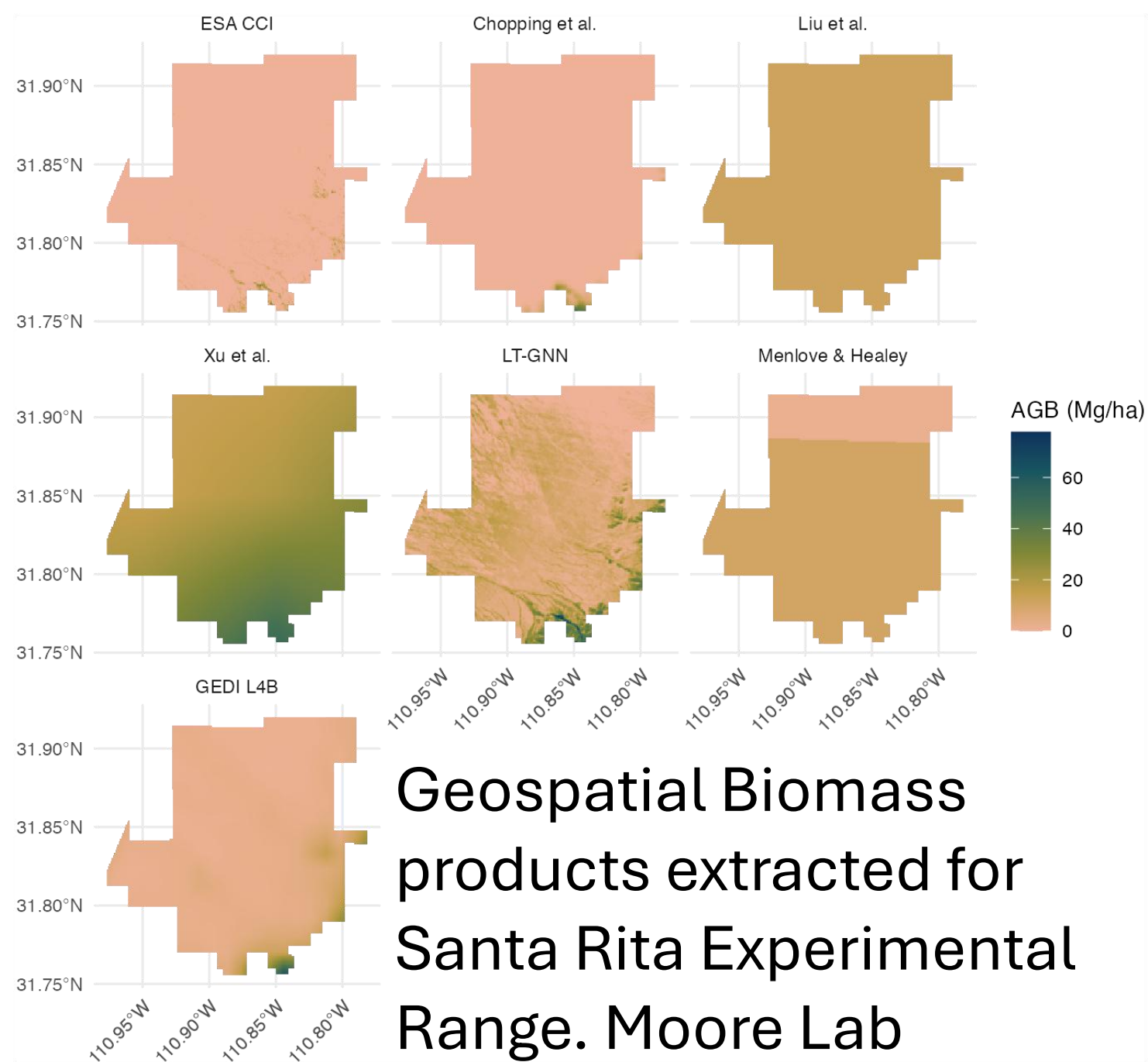
STDev AGB

Mg C/ha



Mg C/ha



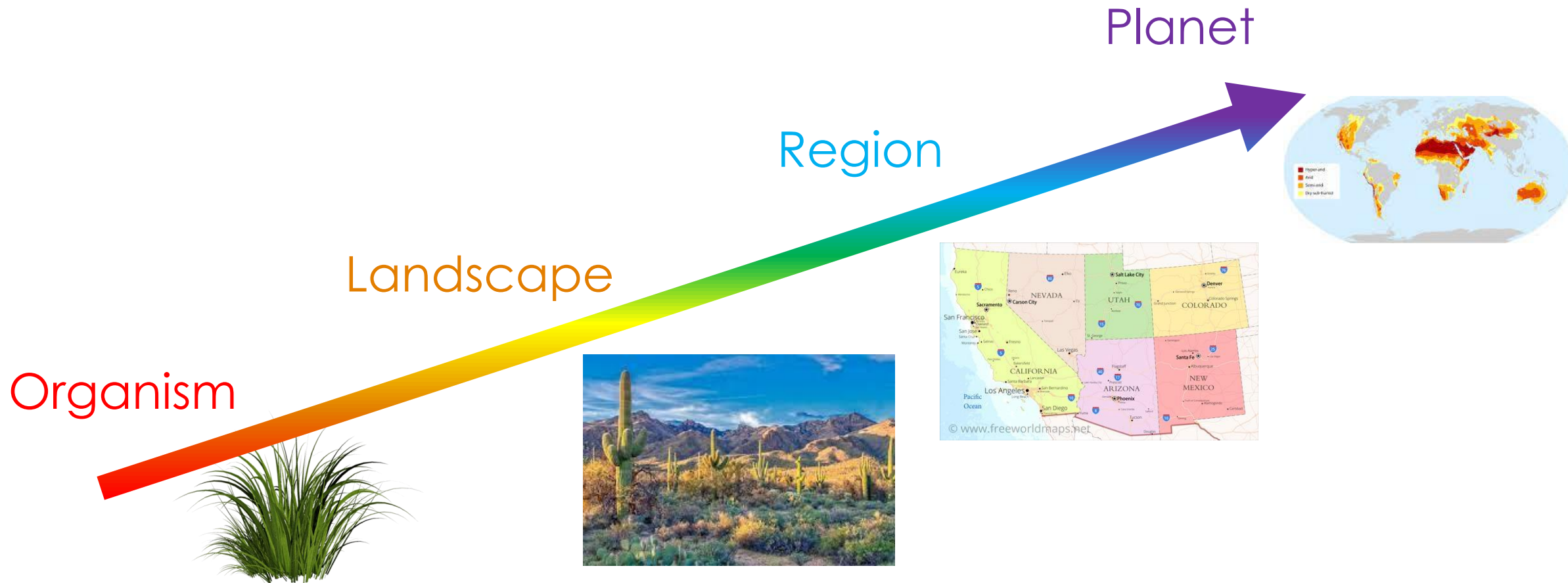


Many satellite resources and geospatial reanalysis are too coarse for county or local decision support.

Too coarse for many scientific questions

Some problems are too complicated to be solved with only one approach

From Point to Leaf to Orbit – building actionable science together





Marcy Litvak
(U. New Mexico)



Ben Poulter
(Spark Climate)



Dennis Ojima
(Colorado State U.)



Sasha Reed
(USGS)



Andrew Feldman
(NASA/UMD)



Bill Smith
(U. Arizona)



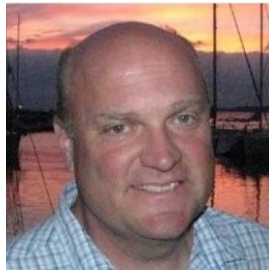
Konrad Wessels
(George Mason U.)



Shawn Serbin
(NASA)



Niall Hanan
(New Mexico
S.U.)



Bob Swap
(NASA)



Russell Scott
(USDA)



Jennifer Watts
(Woodwell Climate)



Natasha MacBean
(Western U.)



Flurin Babst
(U. Arizona)



Dave Moore
(U. Arizona)



Ray Kokaly
(USGS)



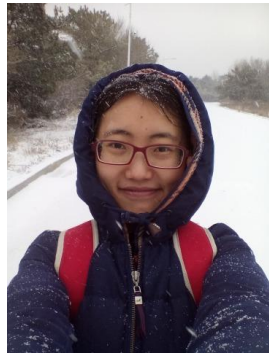
Joel Biederman
(USDA)



Cibeles Amaral
(U. Colorado)



Julia Green
(U. Arizona)



Fangyue Zhang
(U. Arizona)



Jessica Guo
(U. Arizona)



Charlie Devine
(U. Arizona)



Compton Tucker
(NASA)



Lixin Wang
(IUPUI)



Alicja Babst-Kostecka
(U. Arizona)



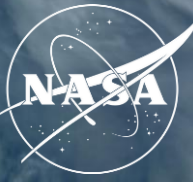
Wen Zhang
(U. Arizona)



Zheng Fu
(U. Arizona)

ARID Steering Committee

ARID Engagement by the Numbers



Broad Feedback

2 Community Updates

Tucson, AZ
October 2023

Albuquerque, NM
May 2024

301 Participants 196 Participants

3 Conference Townhalls

AGU 2023
San Francisco, CA

ESA 2023
Portland, OR

160 Participants 60 Participants

ESA 2024
Long Beach, CA

70 Participants

3 Listening Webinars

49,54,67 Participants
Per Event

13 Working Group Townhalls

9-38 Participants
Per Event

169 Registered Working
Group Members

6 NASA Science Team
Meeting Briefings

20-40 Participants
Per Event

163
ARID
Engagement
Events

Intensive Discussion

2 End-User/Rights Holder
Workshops

Tucson, AZ
October 2023

Albuquerque, NM
May 2024

34 End-Users 8 Tribal Members

24 Scientists 20 Scientists

18 End-User
Meetings

6 Focus
Roundtables

Lincoln, NE

2 Fort Collins, CO

South America Webinar

Great Plains Webinar

Phoenix, AZ

50

5, 8 Participants

59 Per Event

31

14

2 End-User
Roundtables

14,20 Participants
Per Event

18 Tribal Member,
Liaison, +Educator
Meetings

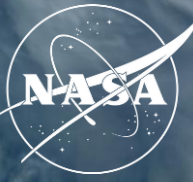
28 International
Partner
Meetings

30 Research
Partner
Meetings

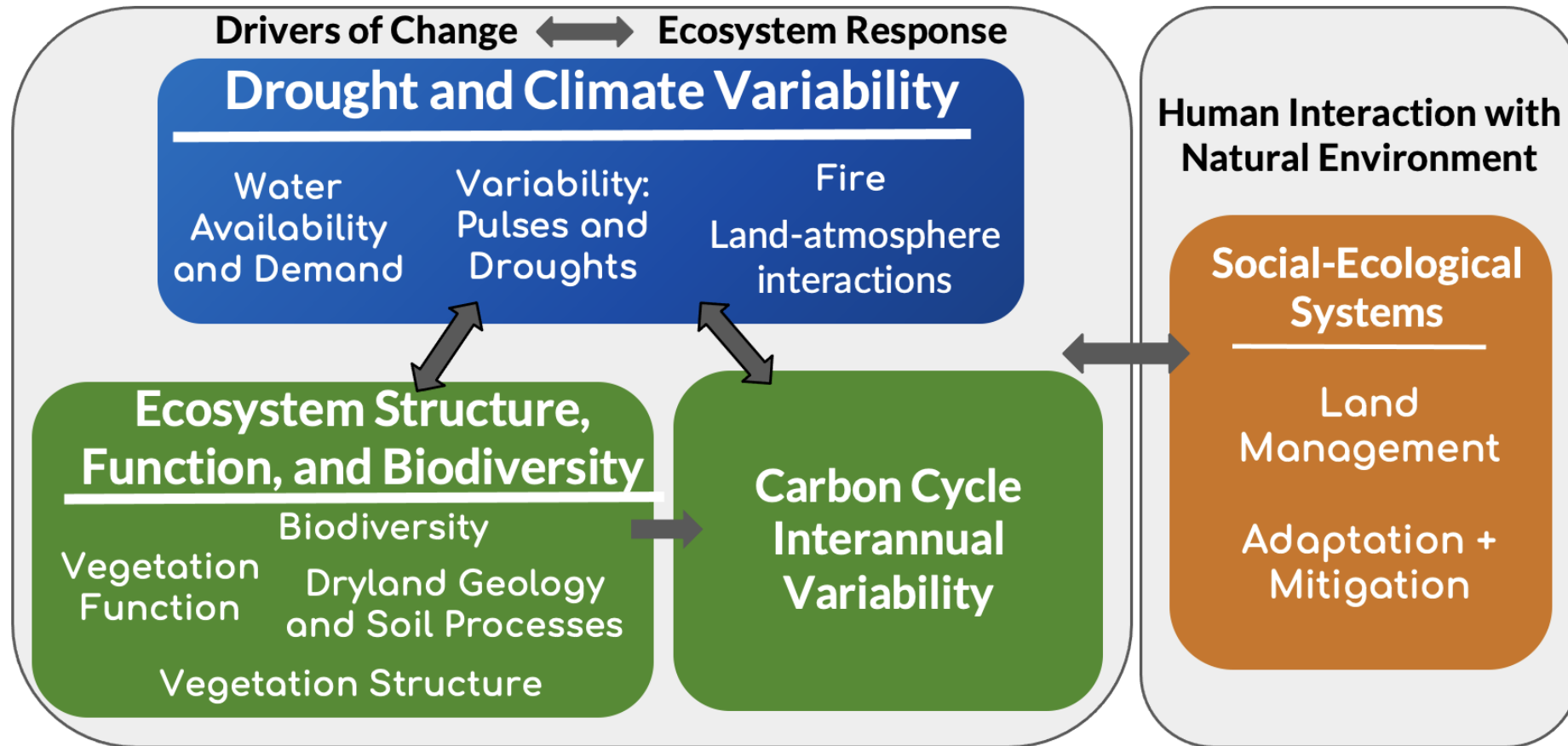
27 Federal
Government
Synergy Meetings

5 Cyberinfrastructure
Working Group
Meetings

ARID Primary Goals

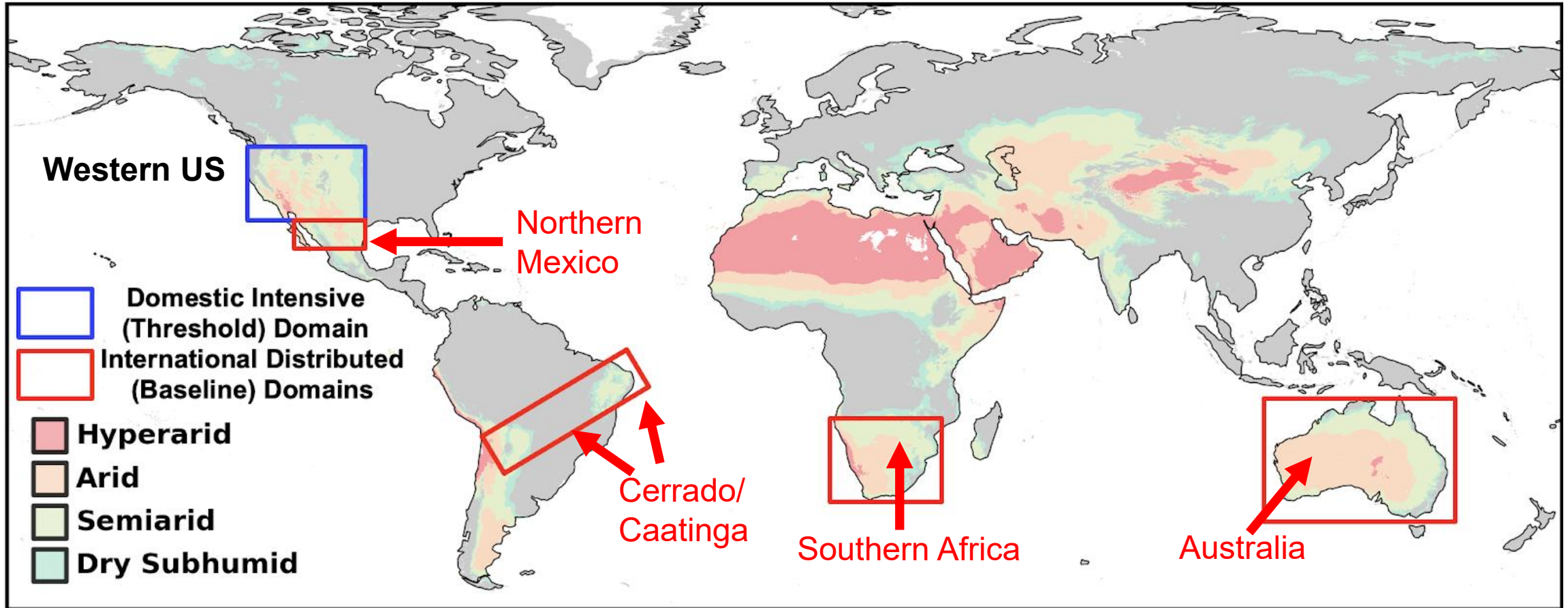
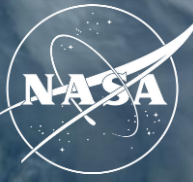


ARID Science Themes



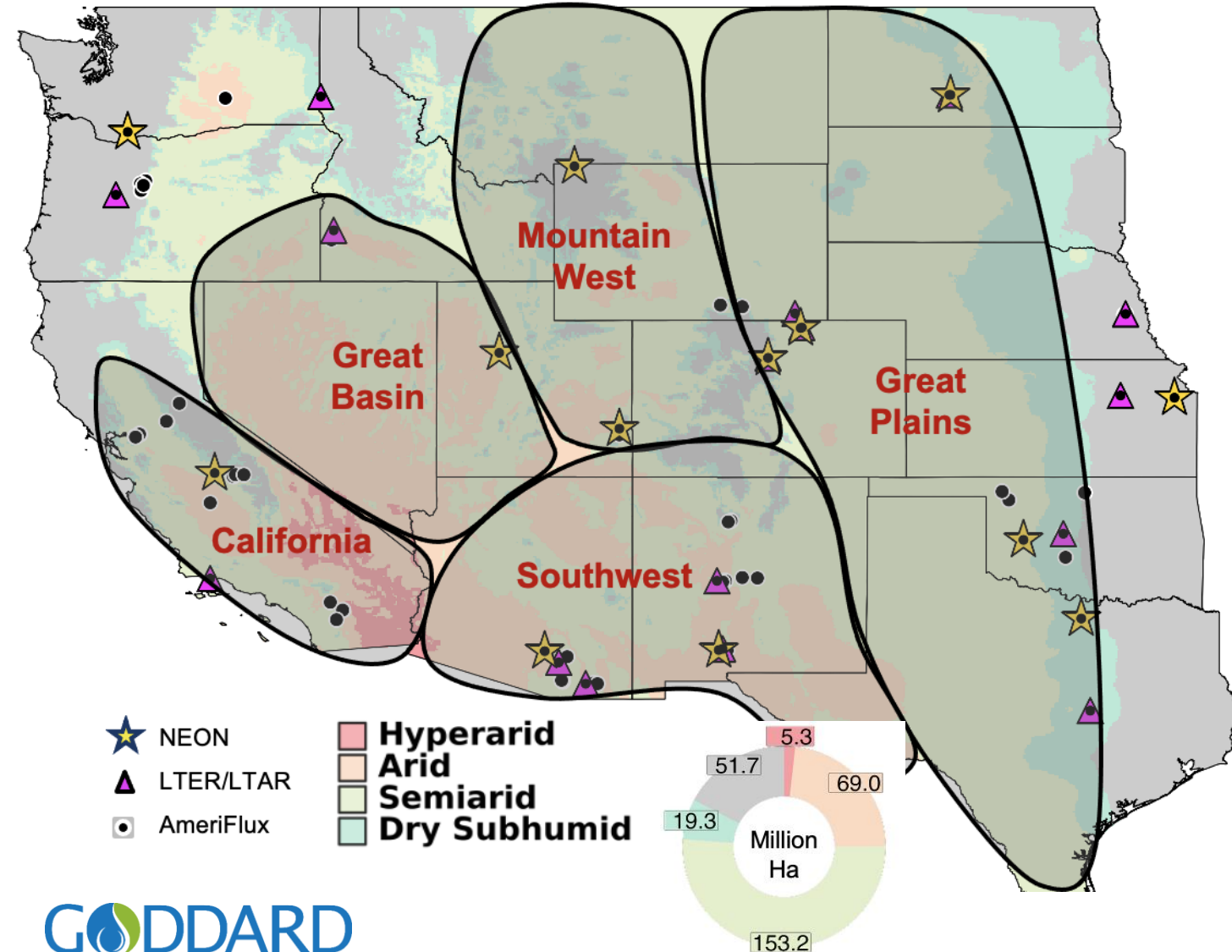
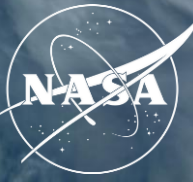
- **Advance Science:** ARID will leverage new measurements coupled with existing networks to advance dryland science themes (left)
- **Natural Resource Management:** ARID will enable development of remote sensing techniques urgently needed to manage resources (food, water, infrastructure) on water limited military, private, and public lands

Global approach but West US focus



- International engagement started in **Red locations**
 - Interest in flights and experiments

Global approach but West US focus



- Existing instrumentation throughout western US that can be complemented with NASA campaign
- Opportunity to capitalize on gradients:
 - Hot to cold (South to North)
 - Dry to wet (West to East)
 - Land cover gradients (natural, rangeland, and cropland)
- Western US aridity is near average of all global drylands
 - Western US representative of global drylands

Increasing Spatial Scale and Coverage

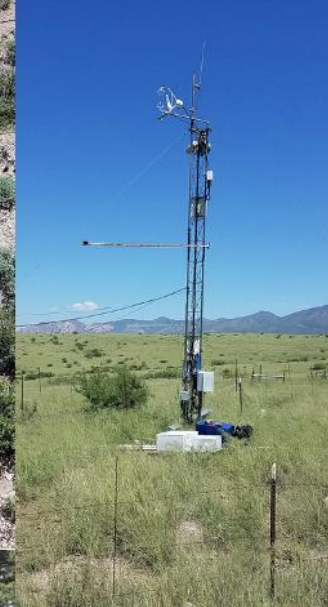
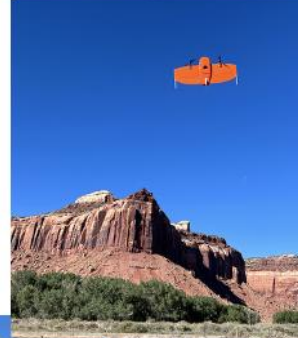
Satellite Remote Sensing



Aircraft
Remote Sensing



Drone Remote Sensing



Flux
Towers



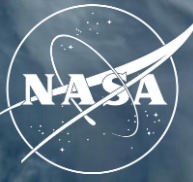
Proximal
Remote
Sensing



Field
Measurements/
Experiments

Feldman et
al. (2026)
*Cambridge
Prisms
(Drylands)*

ARID Pre-Campaign Ramping-Up Strategy

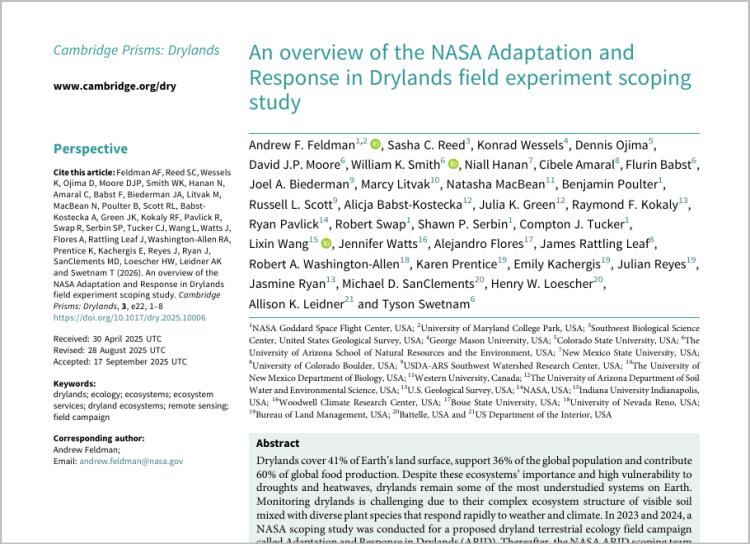


- Pre-Campaign Pilot Analyses, Demonstrations, and Workshops
 - Formulating teams to pursue multi-scale research
 - Successful ARID team proposals in NASA ROSES, DoD SERDP, USGS, etc.
 - Land Management Applications
 - Utilization ongoing/planned aircraft flights
- Solidifying Partnerships
 - Targeting U.S. Agencies (DoD/DoW, USGS) and philanthropies
 - Tiger Teams formed to coordinate partnerships, funding sources, and field collections
- Targeted Engagement
 - Field and aircraft field meta data collection
 - ARID Seminar Series (monthly)
 - Conferences: New Phytologist Symposium

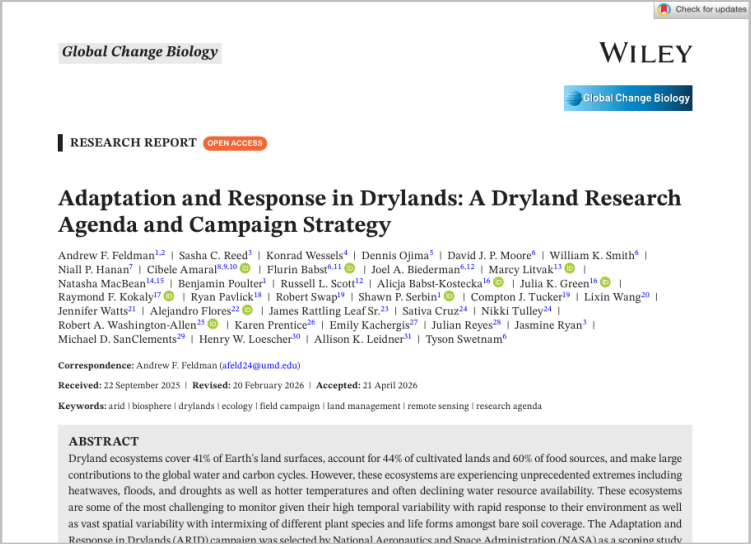
Three papers since 2024



Feldman et al. 2024
Earth's Future
How the community shaped ARID



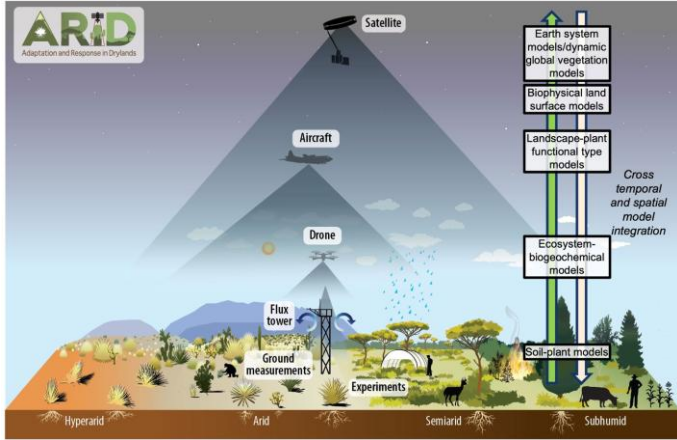
Feldman et al. 2026
Cambridge Prisms: Drylands
Overview of the final plan



Feldman et al. 2026
Global Change Biology
Research agenda and campaign strategy

Plus the full final report, openly archived: Reed et al. 2025, ORNL DAAC.

Two white papers to the next Decadal Survey



1

Observing Dryland Function Across Scales

- The gap: satellites miss fast, rain-driven dryland processes
- Proposal: ARID aircraft and ground data, dryland-tailored satellite products, new space investments
- Focus on resilience in the western U.S.

Atmosphere · Biosphere · Geosphere · Hydrosphere



2

Dryland Social-Ecological Systems

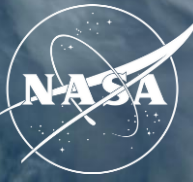
- Starts from land managers' needs, gathered through ARID
- Proposal: a NASA initiative using spectral, radar, lidar and fluorescence data
- Forecasting tools for climate-resilient land use

Biosphere · Hydrosphere

Led by Andrew Feldman with co-authors. Submitted 24 August 2026 to the National Academies' Earth Science Decadal Survey (ESAS 2028).

Aim: put drylands on NASA's list for the next decade.

Several ARID Key Partnerships



• Department of War

- U.S. Navy and USMC agreements with NASA GSFC team to improve installation management and resilience (2025-2028)
- NRO supporting 606/618 wildland fire risk mitigation efforts (starting March 2026)
- NAVFAC and Innovative Landscape Network Partnership (Jesse Ross)
- DoW/FireSense campaign in July/August, synergistic with ARID, focused on pre-fire vegetation risk to installations, with a focus on dryland installations in the western U.S. Planning to fly G-LiHT, AVIRIS-3, PICARD, c-FIRST
- Potential larger multi-million investment in ARID more broadly from SERDP (Kevin Hiers)



• U.S. Geological Survey

- Powell Center and Core System Science areas funding and planning to co-fund pre-campaign analyses with NASA, NEON, and USGS aircraft data
- GEMx hyperspectral and thermal remote sensing flights between 2023-2027 (\$15M) across Western U.S. in ARID domain with input from ARID team on flight paths
- GEMx lead a member of the ARID team



• Wyoming Rancher / NASA BDEC

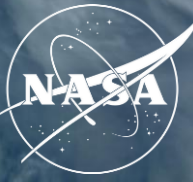
- Collaborating with NASA GSFC-based team via NASA Earth Action directed funds
- Wyoming rancher family partnering for ground validation of satellite-based tools
- Broader opportunities within NASA BDEC Virtual Center & GSFC participation to lead targeted efforts focused on improving rangeland monitoring and management w/ NASA data

• NEON (Batelle)

- Potential to align ongoing NEON AOP flights with ARID-based flights
- Leadership on ARID team (Hank Loescher and Mike SanClements)



Pre-ARID campaign opportunistic measurements



FireSense* (NASA/DoD)

July/Aug 2026

AZ/CA, MT (INSPYRE)
AVIRIS-3, G-LiHT, PICARD,
PIRS, c-FIRST
Goals: Pre-fire conditions,
fuels, meas. plumes



**Also synergistic NRO fuels project
(GSFC 606/618)*

ASCENT (NASA)

(June 2026)

California
UAVSAR/LVIS
Vegetation



GEMx (USGS)

Western U.S.
(2023-2026)

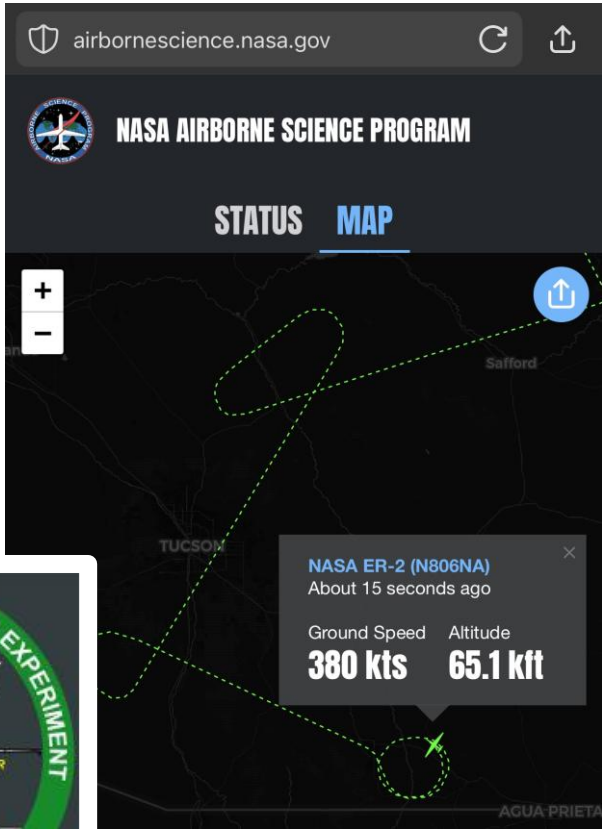


AVIRIS (NASA)

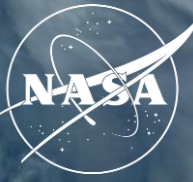
Australia (Spring
2027)

AVIRIS
Airborne Visible / Infrared Imaging Spectrometer

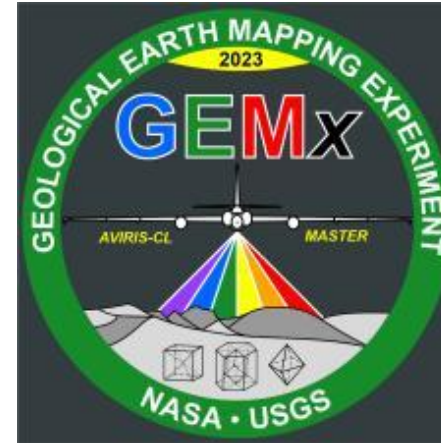




Remote Sensing Aircraft Flights



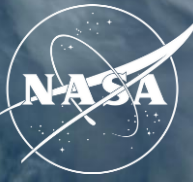
- USGS-NASA GEMx (2023-2027)
 - Location: Western U.S.
 - Instrument: AVIRIS hyperspectral
- NASA ASCENT (June 2026)
 - Location: Southwest, West Coast
 - Instrument: UAVSAR radar, LVIS lidar, Others
- Australia-NASA AVIRIS (Spring 2027)
 - Location: Australia (substantial portion)
 - Instrument: AVIRIS hyperspectral
- NASA G-LiHT (Varies)
 - Location: Varies
 - Instrument: hyperspectral, lidar, thermal
- NASA SARP (June 2026, 2027)
 - Location: Texas, Varies
 - Instrument: hyperspectral, lidar, thermal, radar



GEMx Spring 2024 Collections



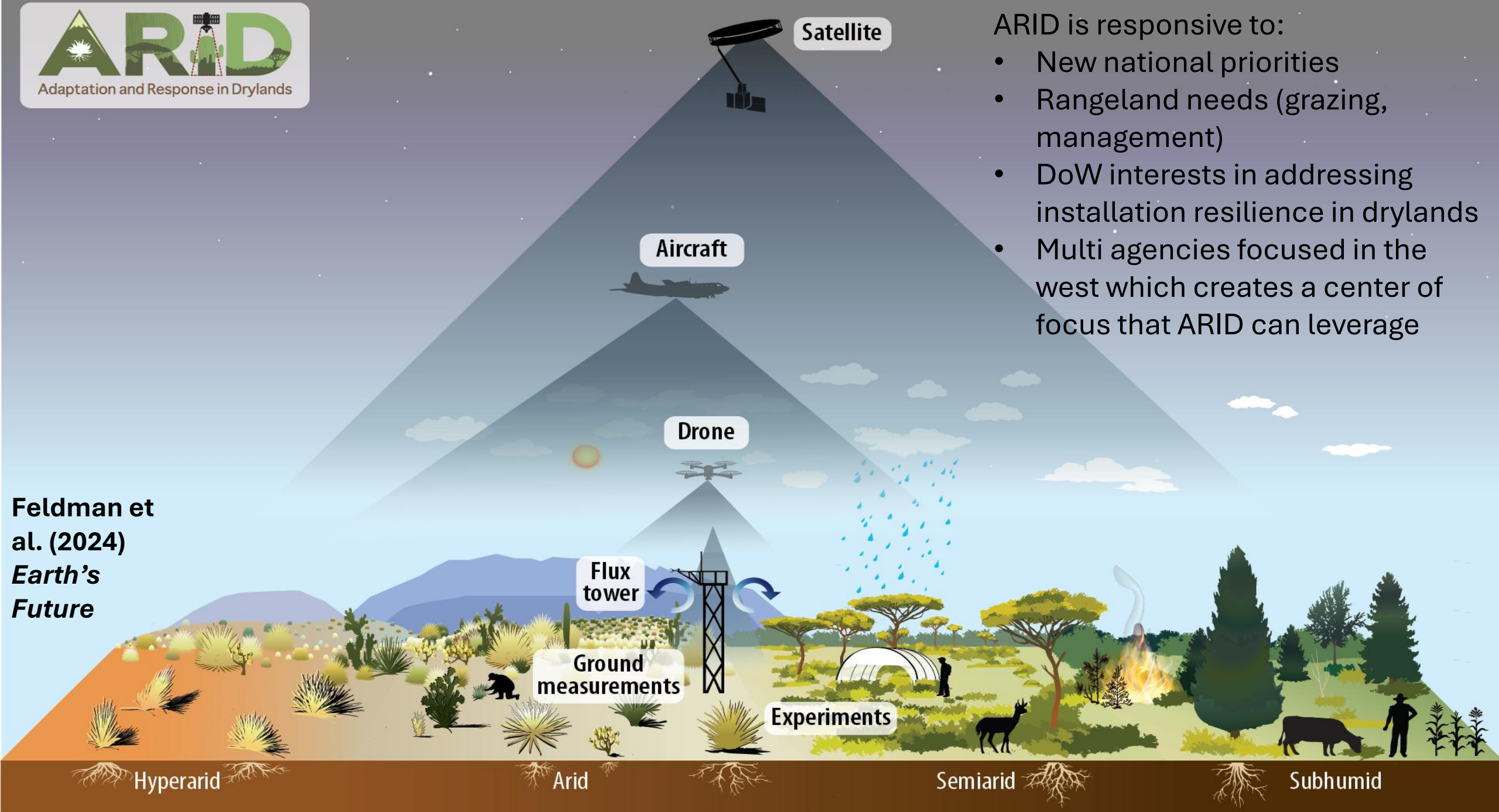
Take-aways



- ARID is selected and activities starting to roll out and occurring at varying scales through early-mid-2030s
 - Potential for funding solicitations
 - Aircraft campaigns ongoing with field collections
 - Request for ongoing field collection metadata
- Pilot demonstrations
 - Field-aircraft-satellite scaling studies and applications
 - Applications with ranchers and military
- Engagement
 - Monthly ARID and Applied Earth Observations Innovation Partnership (USFS & NASA) land management seminars
 - Conferences: New Phytologist Symposium, AGU conference sessions



White Paper



ARID is responsive to:

- New national priorities
- Rangeland needs (grazing, management)
- DoW interests in addressing installation resilience in drylands
- Multi agencies focused in the west which creates a center of focus that ARID can leverage

Feldman et al. (2024)
Earth's Future