National Aeronautics and Space Administration

Building Climate Risk Assessments from Local Vulnerability and Exposure

Part 2: Developing Climate Adaptation Support for NASA Centers

Alex Ruane (NASA GISS) and Sanketa Kadam (NASA GISS & Columbia University)

September 21, 2023

Building Climate Risk Assessments from Local Vulnerability and Exposure

Overview

Why is Climate Risk Assessment Important?

- Climate change impacts and risks are becoming increasingly complex and more difficult to manage (IPCC AR6, 2022).
- Climate change impacts on infrastructure vary by region.
- Identifying at-risk assets and the types of climate conditions that drive problematic responses, stakeholders and scientists can co-develop risk information to suitably address those risks.

Credit: Scott Pena

Training Learning Objectives

By following the approaches described in this training, participants will be able to:

- Recognize the dramatic contextual nature of climate risk assessments and adaptation planning
- Identify components of their own system that are vulnerable or exposed to climate risks
- Work with stakeholders to construct climate risk information that is useful for their decision-making processes
- Use risk information to identify adaptation strategies for implementation

Prerequisites

- Fundamentals of Remote Sensing
- Introduction to NASA Resources for Climate Change Applications
- Selecting Climate Change Projection Sets for Mitigation, Adaptation and Risk Management Applications

Training Outline

Part 1: Theoretical Framework for Demand-Driven Climate Adaptation Support

Tuesday, September 19, 2023

11:00–12:30pm and 3:00–4:30pm EDT

(UTC-4:00)

Part 2: Developing Climate Adaptation Support for NASA Centers

Thursday, September 21, 2023

11:00–12:30pm and 3:00–4:30pm EDT (UTC-4:00)

Homework

September 21, 2023 – Due October 5, 2023 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Part 2 Objectives

By the end of Part 2, participants will be able to:

- Identify how adaptation decision support theory is applied in practice
- Deepen familiarity with NASA resources and methodologies

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to address all questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Part 2 – Trainers

Alex Ruane

NASA Goddard Institute for Space Studies (GISS)

Sanketa Kadam

NASA GISS & Columbia University

Part 2

Developing Climate Adaptation Support for NASA Centers

The Climate Adaptation Science Investigators Phase 2 Initiative (CASI2)

Mission: Provide the latest scientific research on climate change to help NASA facilities managers adapt to increasing climate risks in timely and effective ways.

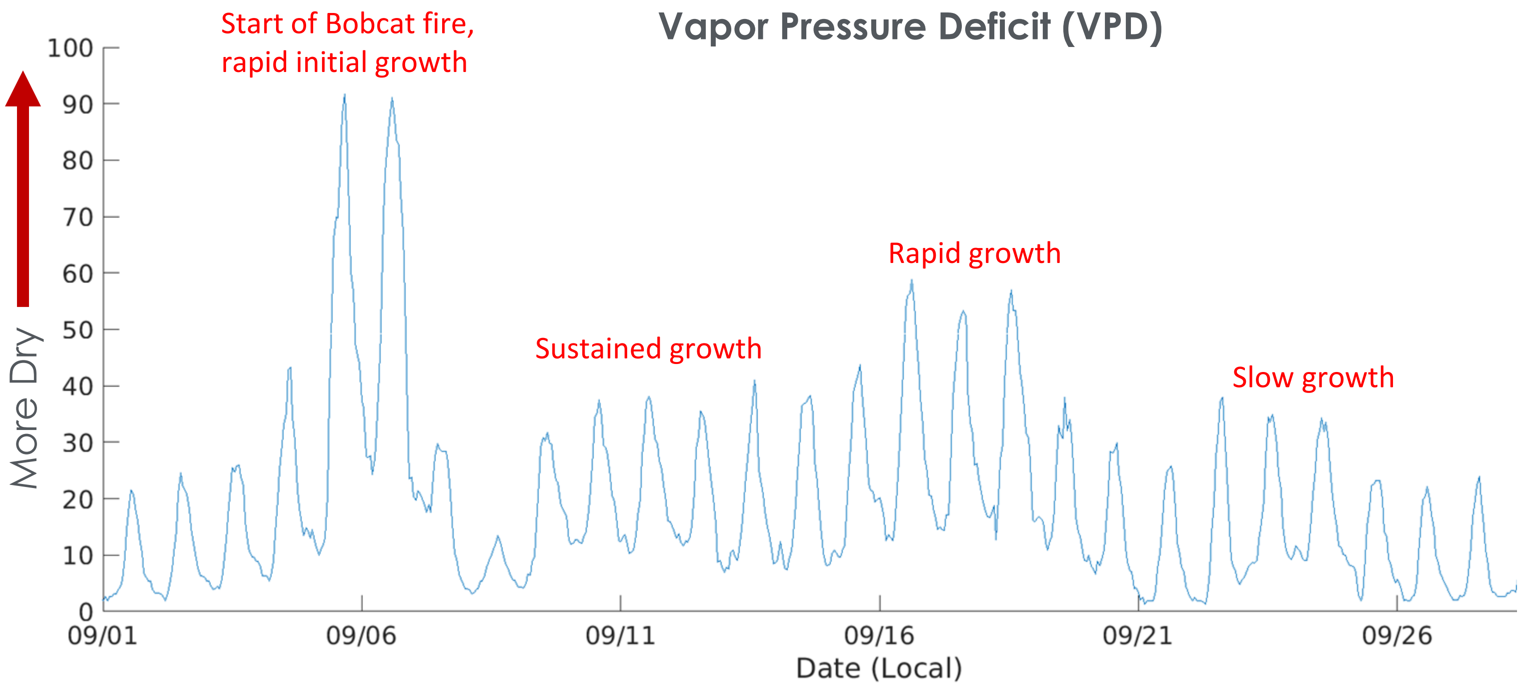
- **CASI provides** a portfolio of key current and future climate risk information for Center managers and their regions.
- These products are co-generated and linked to decisions protecting Center assets, infrastructure and workforce.
- Please note that **CASI-2 is an ongoing initiative**; we will present preliminary results with a more formal report planned for late 2023/early 2024.

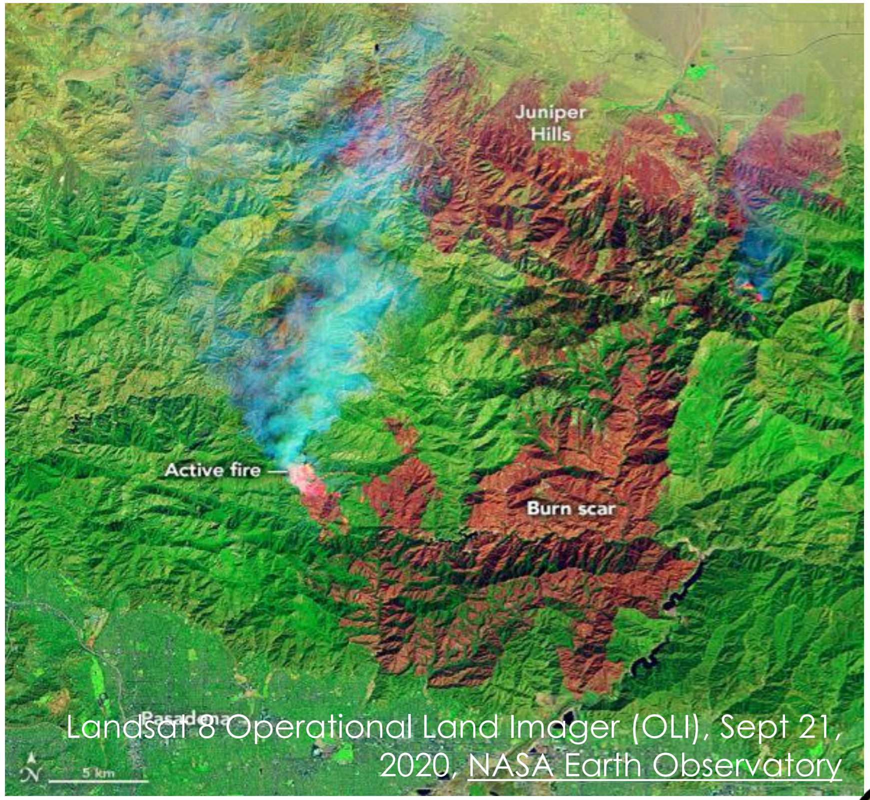
Rosenzweig et al, 2023 (in prep) Climate Adaptation Science Investigators Workgroup (CASI): A Partnership Between Scientists and Facility Managers to Enhance Climate Resilience at NASA

Example of Climate-Driven Impacts on NASA Facilities

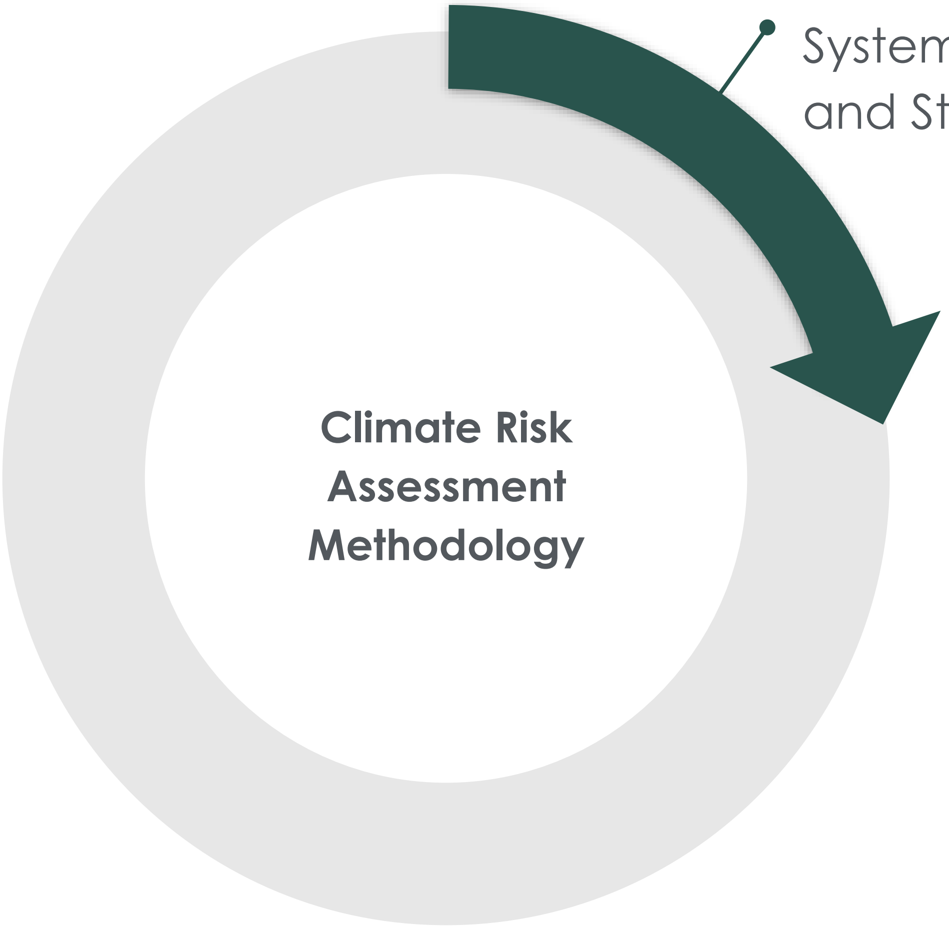
2020 Bobcat Fire (Near JPL in Los Angeles County, California)

- Started Sept 6, 2020, to the northeast of JPL in the San Gabriel Mountains (115,796 acres)
- While the fire was most active, JPL was impacted by the smoke, particularly affecting operations from Sept 15–21.
- Understanding the conditions driving these types of fires helps to interpret projections of future fire weather.
- Two days of high daytime VPD with little nighttime recovery allowed for the fire to grow rapidly on September 6th.





Landsat 8 Operational Land Imager (OLI), Sept 21, 2020, NASA Earth Observatory

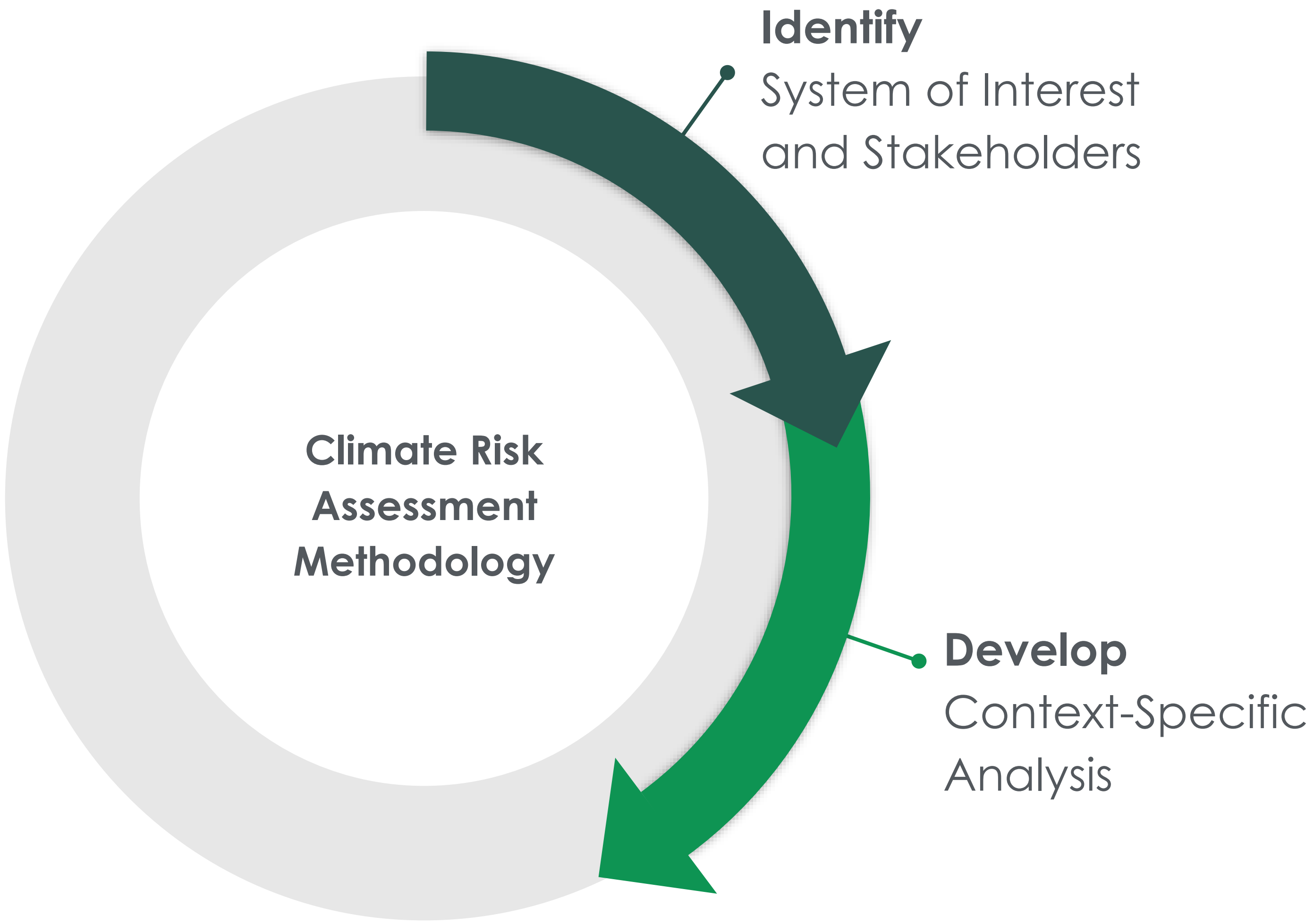


Identify

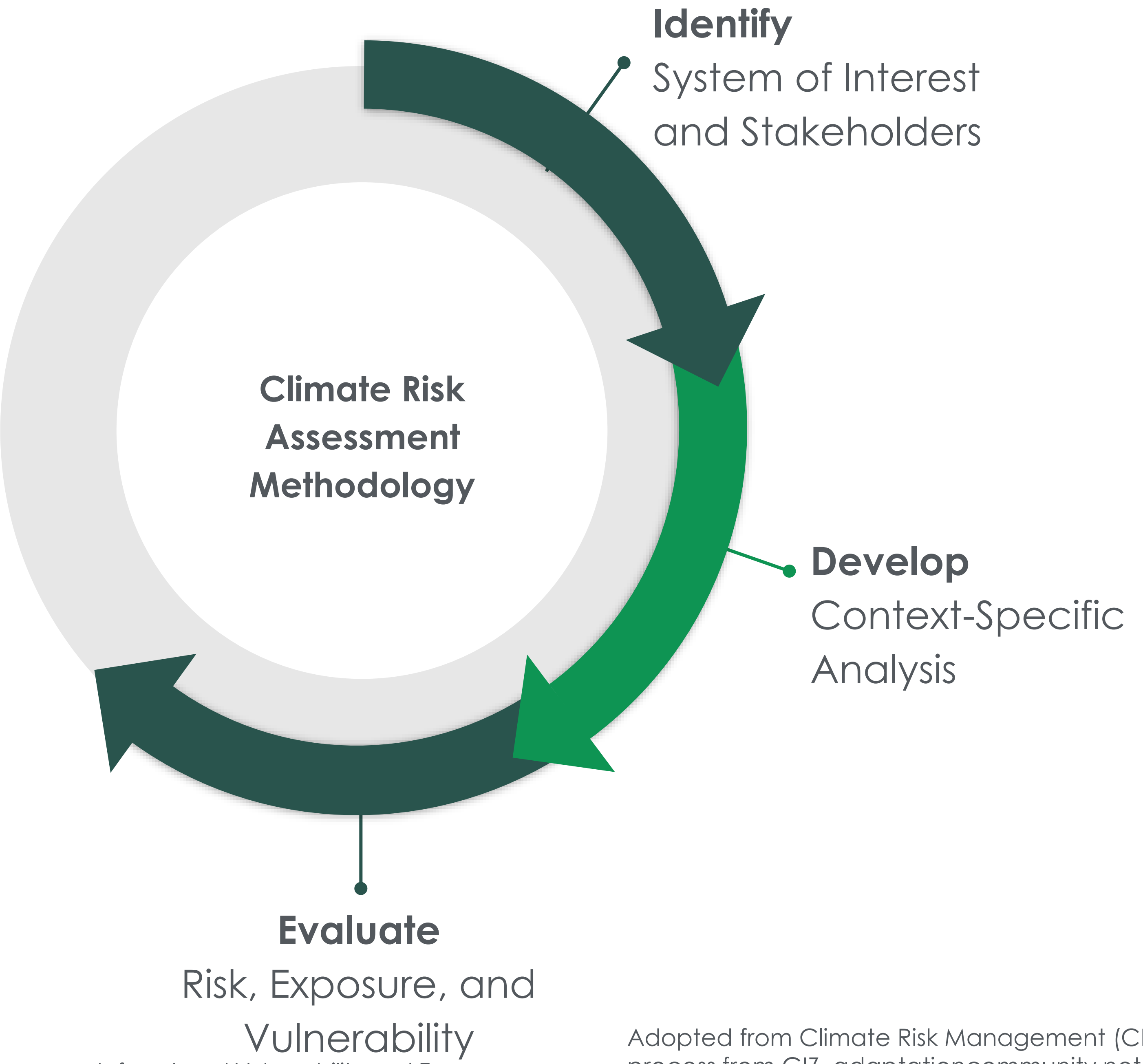
System of Interest and Stakeholders

T (Refresher)

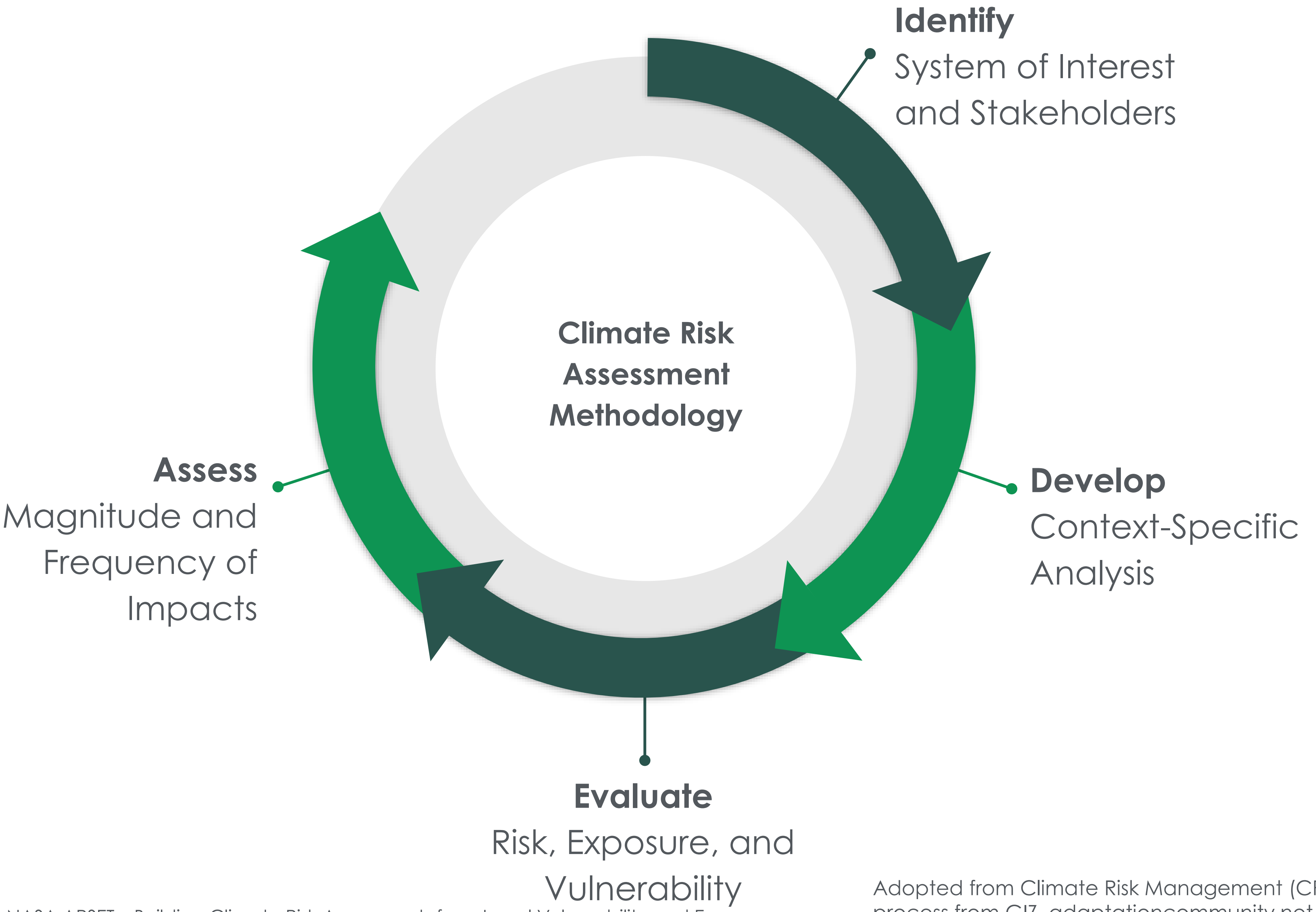
Adopted from Climate Risk Management (CRM) process from GIZ, adaptationcommunity.net



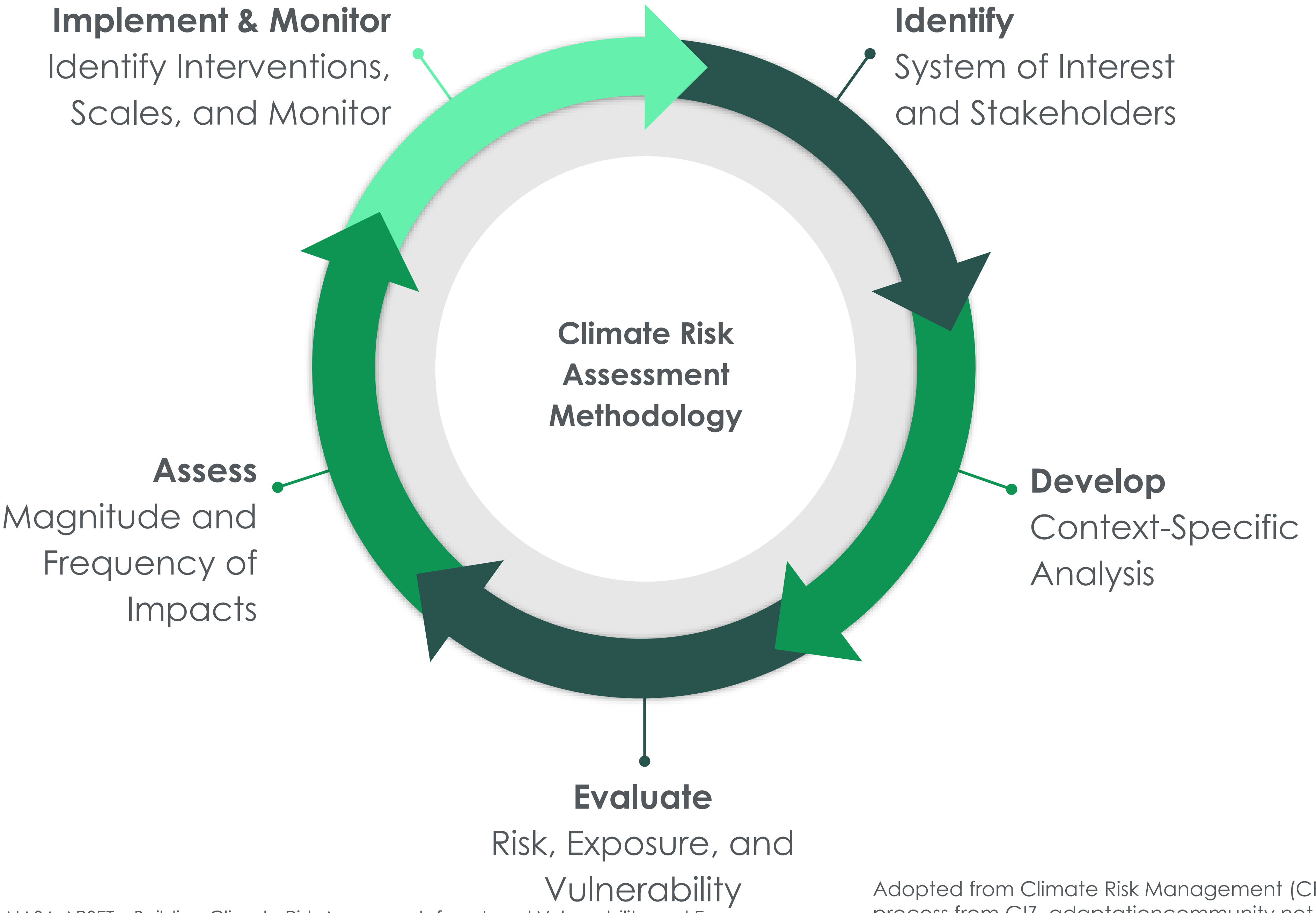
Adopted from Climate Risk Management (CRM) process from GIZ, adaptationcommunity.net



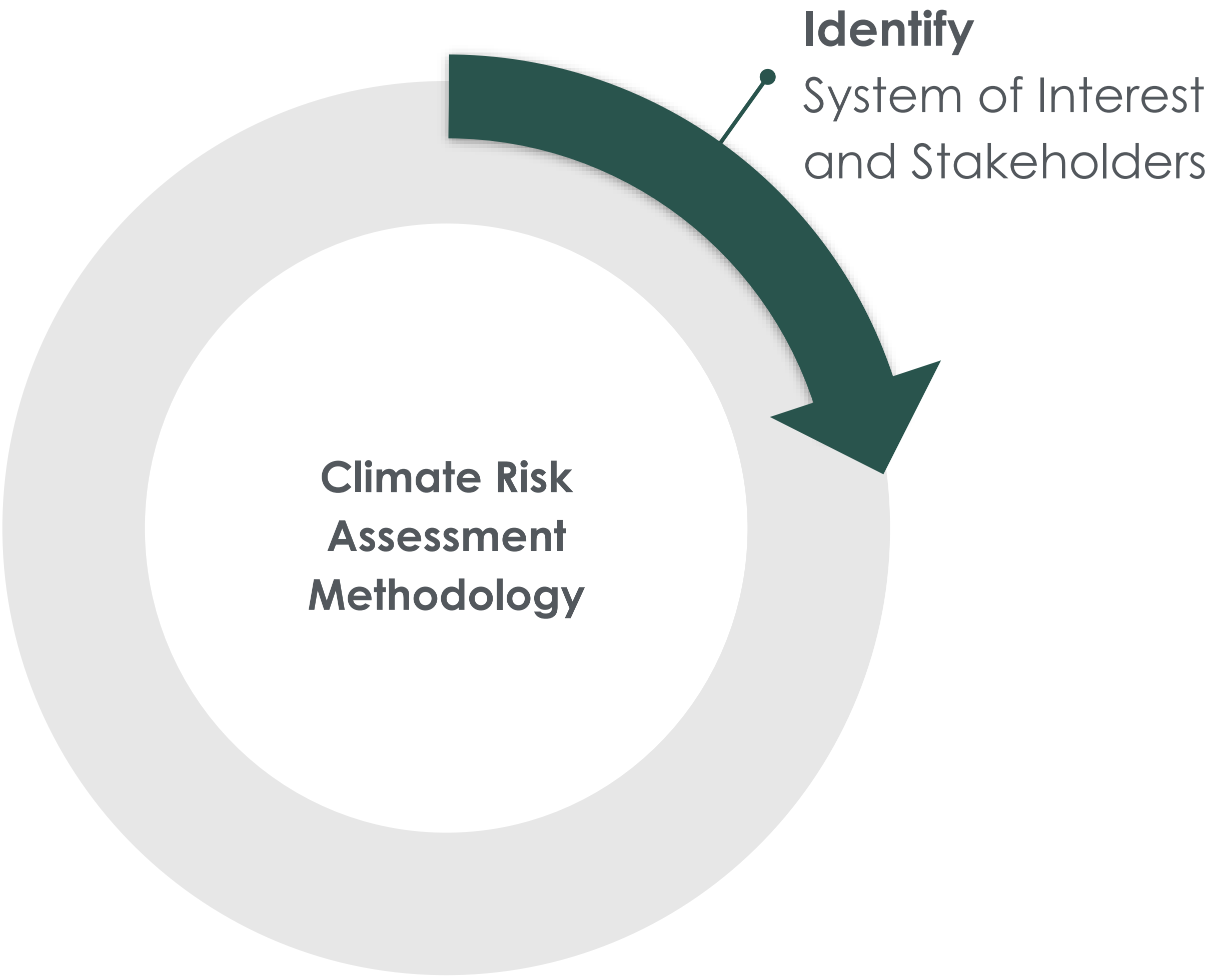
Adopted from Climate Risk Management (CRM) process from GIZ, adaptationcommunity.net



Adopted from Climate Risk Management (CRM) process from GIZ, adaptationcommunity.net



Adopted from Climate Risk Management (CRM) process from GIZ, adaptationcommunity.net



Adopted from Climate Risk Management (CRM) process from GIZ, adaptationcommunity.net

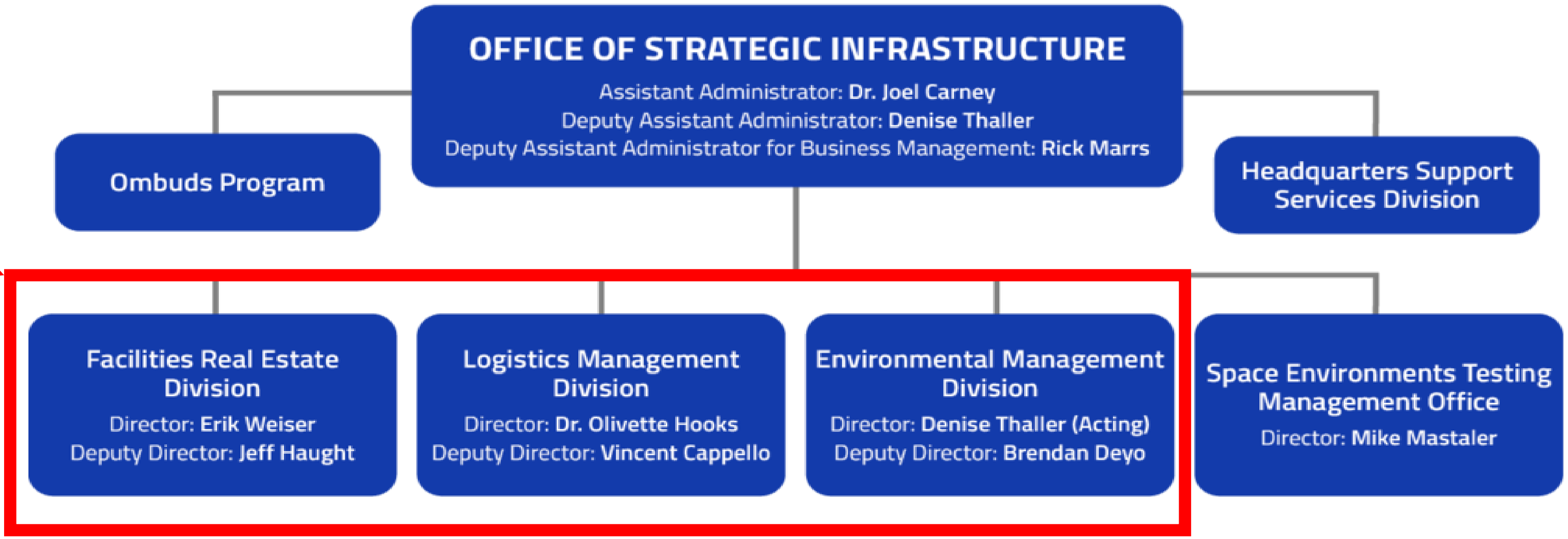
Identify in CASI Initiative

CASI Connects with Infrastructure Planners

Map Out and Identify the Stakeholders and their Mandate:

- Primary Audience/Stakeholder: Office of Strategic Infrastructure (OSI)
- Decisions being made on different time horizons
- CASI responds directly to the U.S. Executive Order 14008 that requires all federal agencies to develop and implement climate adaptation plans.

CASI Interacts with nearly all OSI Divisions



NASA Divisions

Identify in CASI Initiative

Establish Regular Contact with Key People

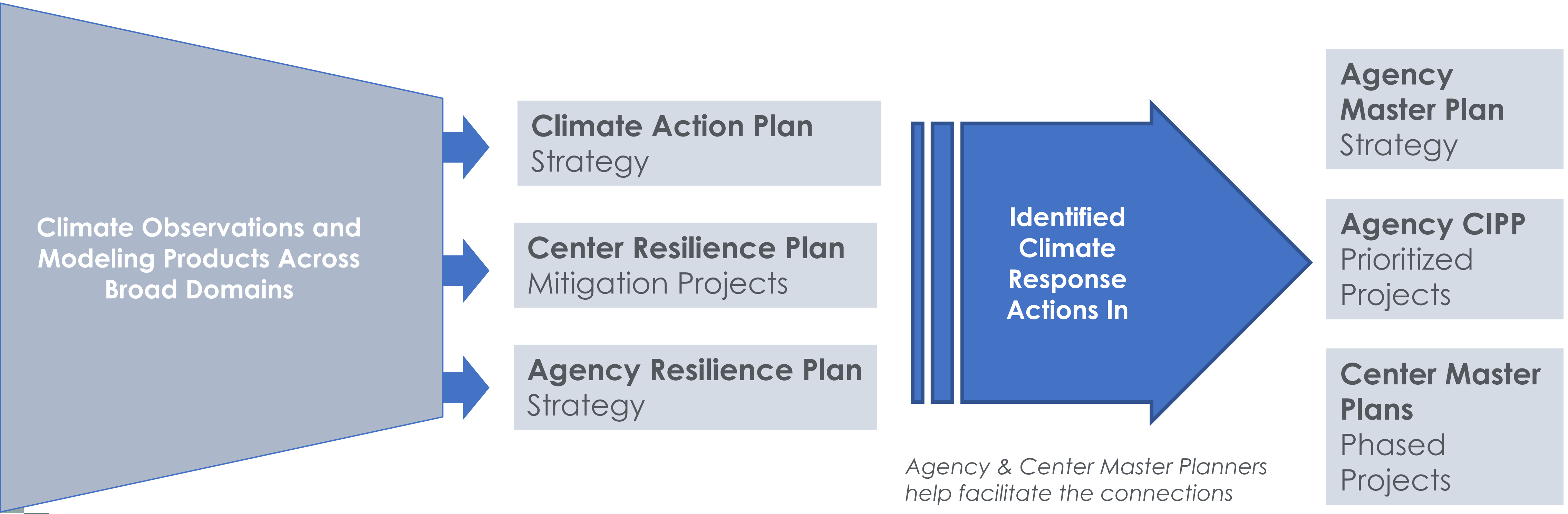
Primary Actors within Office of Strategic Infrastructure:

- Division Directors
- Master Planners, Energy Managers, Environmental Managers
- Center Managers → Points of Contact
    - **Why?** They manage center operations with operational budget connecting to HQ allocations.

Identify in CASI Initiative

CASI connects with ongoing decision processes

- Center operations already deal with weather and climate risks.
- Operations budgets include proactive planning for long-term resilience.
- Each Center has its own master planning process.



NASA HQ works with each Center in this process with findings informing the agency's master planning process.

Identify in CASI Initiative

CASI connects to ongoing agency-wide risk assessments

The Department of Energy's National Renewable Energy Laboratory (NREL) conducts regular assessments of vulnerability and exposure as part of NASA Agency-wide risk assessment.

- Rotates through detailed assessments at ~2 centers each year
- Not just climate (earthquakes, social unrest, tech/IT hazards, natural triggered technological accident risks [NATECH], etc.)
- NREL makes recommendations for risk reduction investments

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Identify in CASI Initiative

Scientific and Extended Partners

- **Center weather and climate scientists form backbone of scientific assessment**
  - Provide unique scientific expertise
  - Have established relationships with local leadership and workforce
  - Understand center culture and day-to-day experience
  - Supported by NASA Earth Science Division (ESD)

- **Many additional engaged partners**
  - Somewhat blurry line between partners and stakeholders because results have multiple uses:
    - NREL is helping develop CASI products, and will use them for own purposes
    - Keep spots for particularly engaged partners
  - CASI engages with these groups via consultations and dissemination of preliminary and final findings

Identify in CASI Initiative

Clarifying the Interest and Influence of Stakeholders

Office of Strategic Infrastructure has Mandate/Interest:

- Prioritizing maintenance and rehabilitation of current infrastructure
- Making investments in future infrastructure that is meant to last

Understanding the decision scopes and processes of stakeholders:

- What is practical flexibility in budget?
- What is command structure on decisions?
- What metrics and time horizons are used to measure success?

Identify in CASI Initiative

Identify Sector Problem to Address and System Scale

Select areas of acute need and determine key characteristics relevant in designing scientific approach

Agency-Wide Master Planning

- Scoping out new properties, new construction
- Recognize that Centers are always changing with diverse priorities

Center Scale

- Challenges are cross-cutting and can overlap/conflict across divisions and departments

NASA Marshall Space Flight Center, Huntsville, Alabama

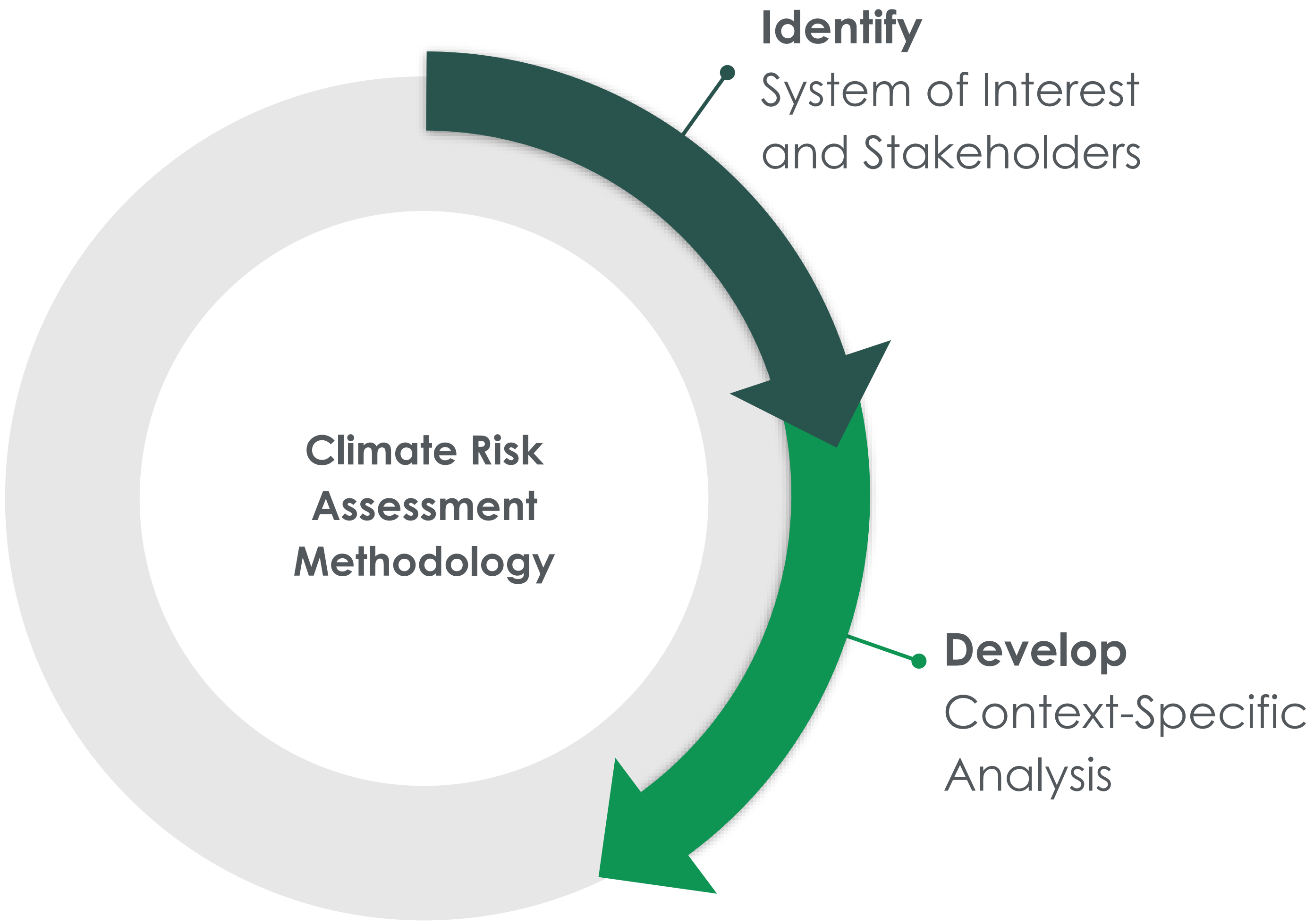
Identify in CASI Initiative

Identify Sector Problem to Address and System Scale

Within the Center, different system challenges have different inherent scales.

- Building infrastructure
- Operations facilities
- Logistics and supply
- Real estate
- Ecosystem directly next to facilities
- Stormwater infrastructure
- HVAC (Heating, Ventilation, and Air Conditioning) or energy load may be location-specific within Center.

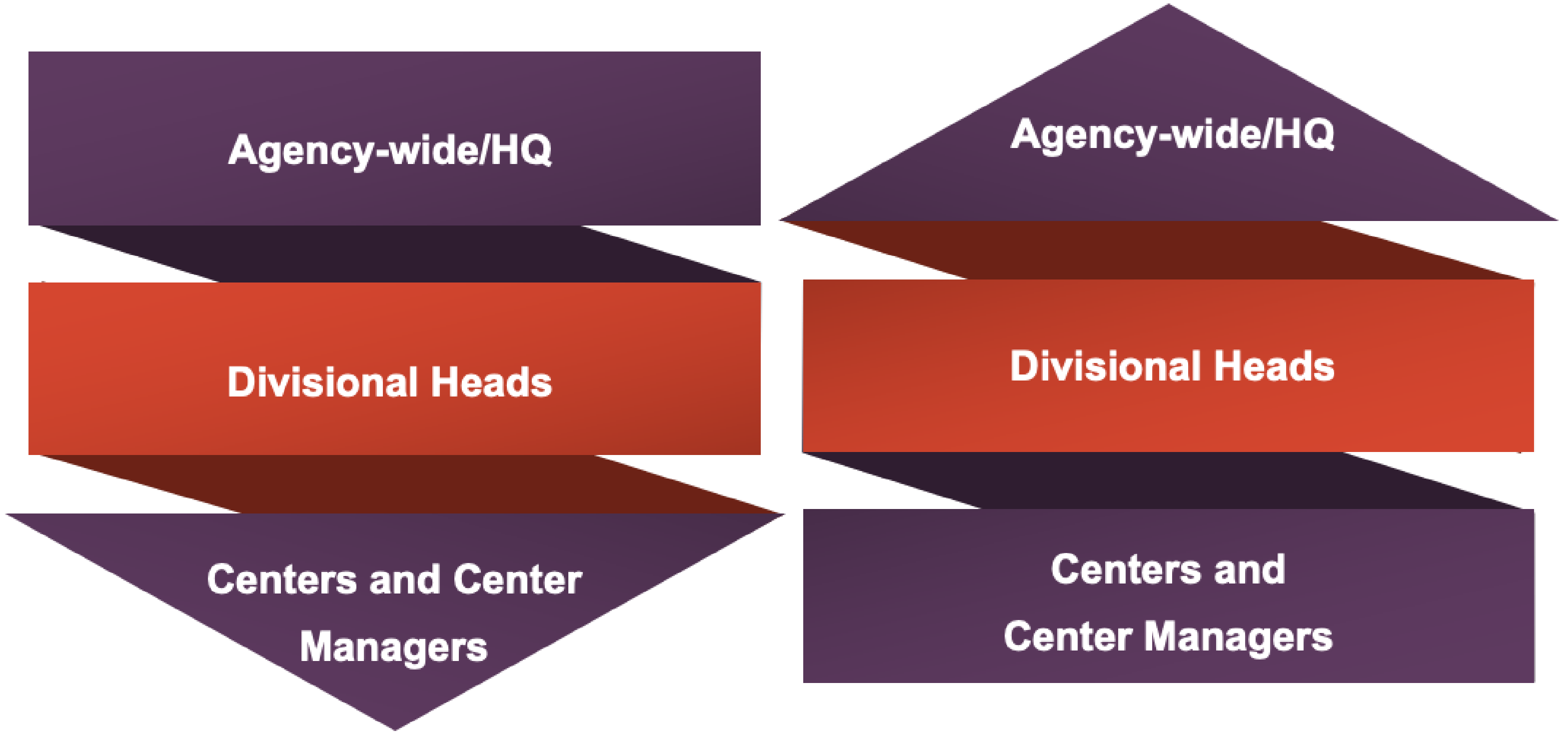
NASA Marshall Space Flight Center, Huntsville, Alabama


Identify
System of Interest and Stakeholders
Climate Risk Assessment Methodology
Develop
Context-Specific Analysis

Develop in CASI Initiative

Ensuring that Scientific Products are Targeted and Relevant for Decision Support

- **Bottom-up approach** of engagement with Center Points of Contact (POCs) through monthly meetings (agency-wide and center-to-center)
- **Top-down approach** organized with NASA headquarters folks building agency-wide plans
- Identify challenges together



Develop in CASI Initiative

Agreeing on the Process of Engagement Between Partners

Create inclusive and focused process to create targeted products

- **Align Roles and Responsibilities**
  - Local scientists provide local trust and context
  - Division heads help provide space for these discussions
  - Master planners ensure project objectives align with overall organizational goals
  - GISS CASI-2 Leadership
    - Refines overall scientific protocols
    - Connects findings across Centers
    - Manages relationship with stakeholders
  - OSI leadership works with GISS leadership to ensure overall agency objectives are met

CASI-1 Meeting at Ames Research Center

Develop in CASI Initiative

Agreeing on the Process of Engagement Between Partners

Create inclusive and focused process to create targeted products

- **Develop Communications Plan**
  - Communications among project science team
  - Center-by-center communications meetings to manage relationship with stakeholders
  - important that these groups have frequent engagement

- Agree on co-development and sustained engagement process
- Develop data sharing plan
- Develop communications and dissemination plan

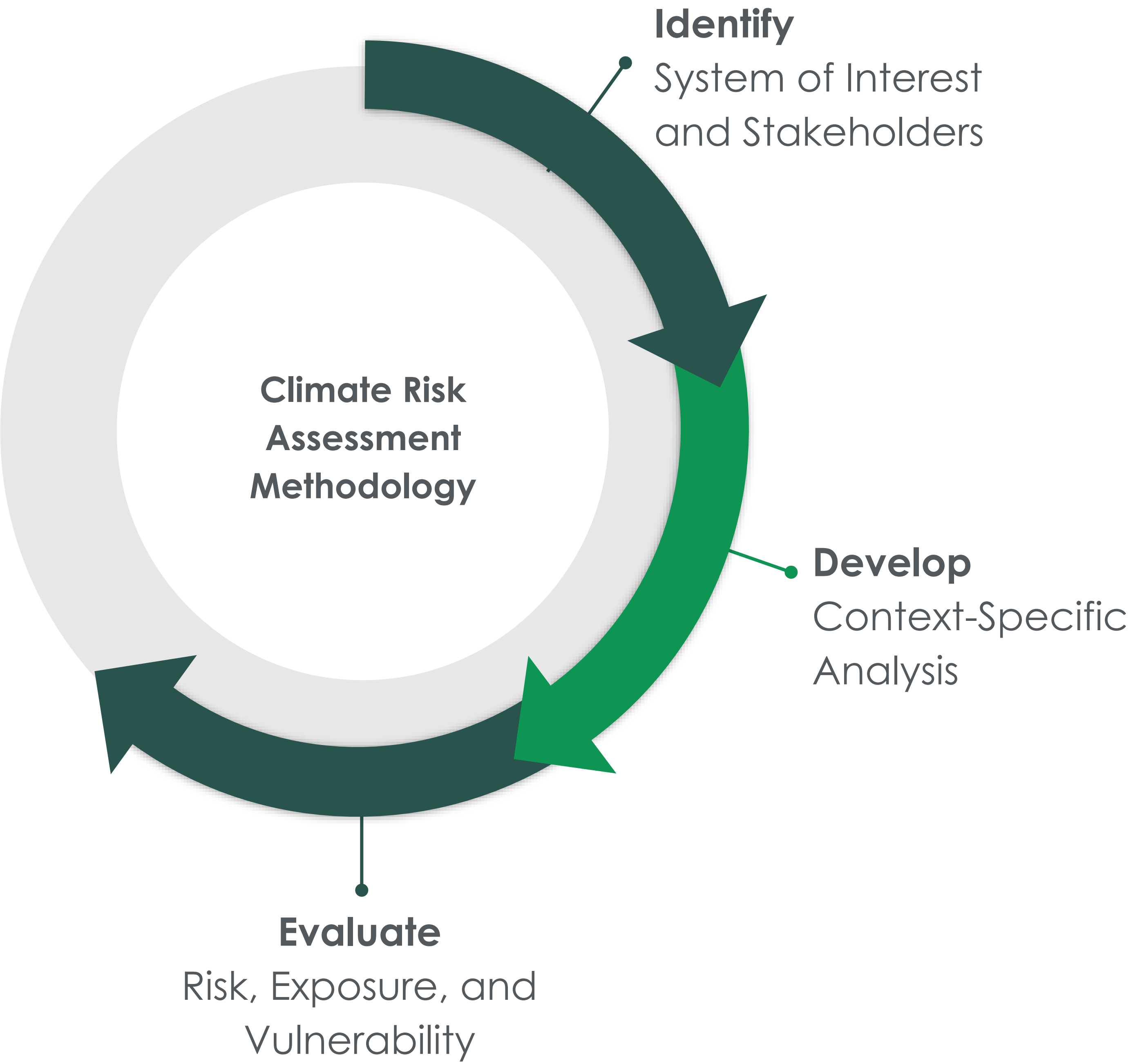
CASI-1 Meeting at Ames Research Center

Develop in CASI Initiative

Working with Partners to Develop Decision-Relevant Products

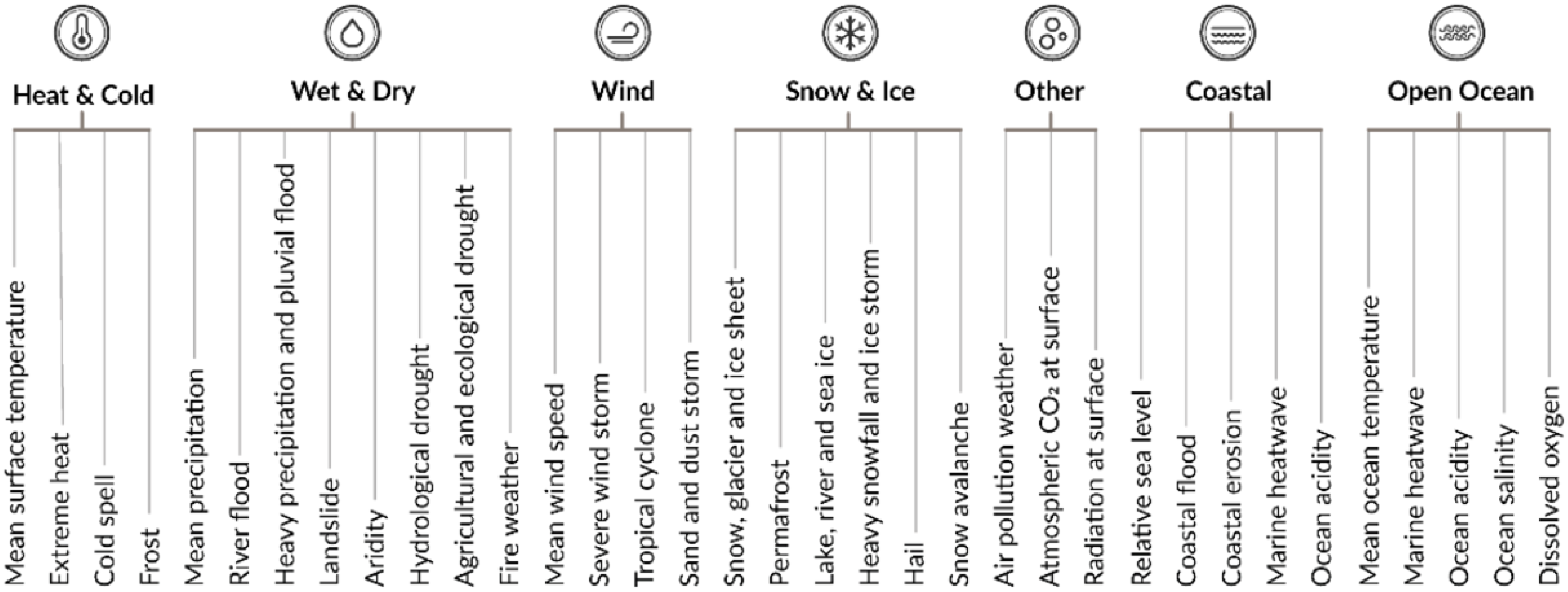
Co-Generation/Co-Production *is a form of knowledge production based on the dynamic interaction between scientists and stakeholders to develop useful, usable, and used information products.*

- What decisions should the products focus on aiding?
- Are these products useful and usable? How can they be made more useful?
- How would you like to see the data presented? (Maps, graphs, tables)
- Are there other CASI products you would suggest?
- Are there other Subject Matter Experts you suggest be included in this workgroup?


Identify
System of Interest and Stakeholders
Climate Risk Assessment Methodology
Develop
Context-Specific Analysis
Evaluate
Risk, Exposure, and Vulnerability

Climatic Impact-Drivers

Capturing Diversity of Climate Change Factors



Adopted from IPCC WGI (2021)
Figure SPM.9; see also WGI Chapter 12
Ranasinghe et al. (2021); Ruane et al., 2022

Evaluate in CASI Initiative

Center-Specific Climate Information Needs (In Particular)

- **Western Centers** need information on drought and wildfires
- **Coastal Centers** need information on sea level rise and coastal flooding
- **Launch Facilities** need information on severe wind speed
- **Broad Interest** in heavy precipitation/flooding and extreme heat

Wildfires reached within a mile of JPL (2009). Rosenzweig et al., 2014

Climatic Impact-Drivers

Capturing Diversity of Climate Change Factors

CASI Work Groups:

Sea Level Rise and Coastal Flooding
- Sea level rise projections
- High tide flood levels
- Extreme water levels
- Coastal inundation maps

Extreme Weather Events
- Droughts & high temperatures
- Heat-humidity extremes
- Inland floods

Fires and Air Quality
- Wildfire risk
- Smoke risk

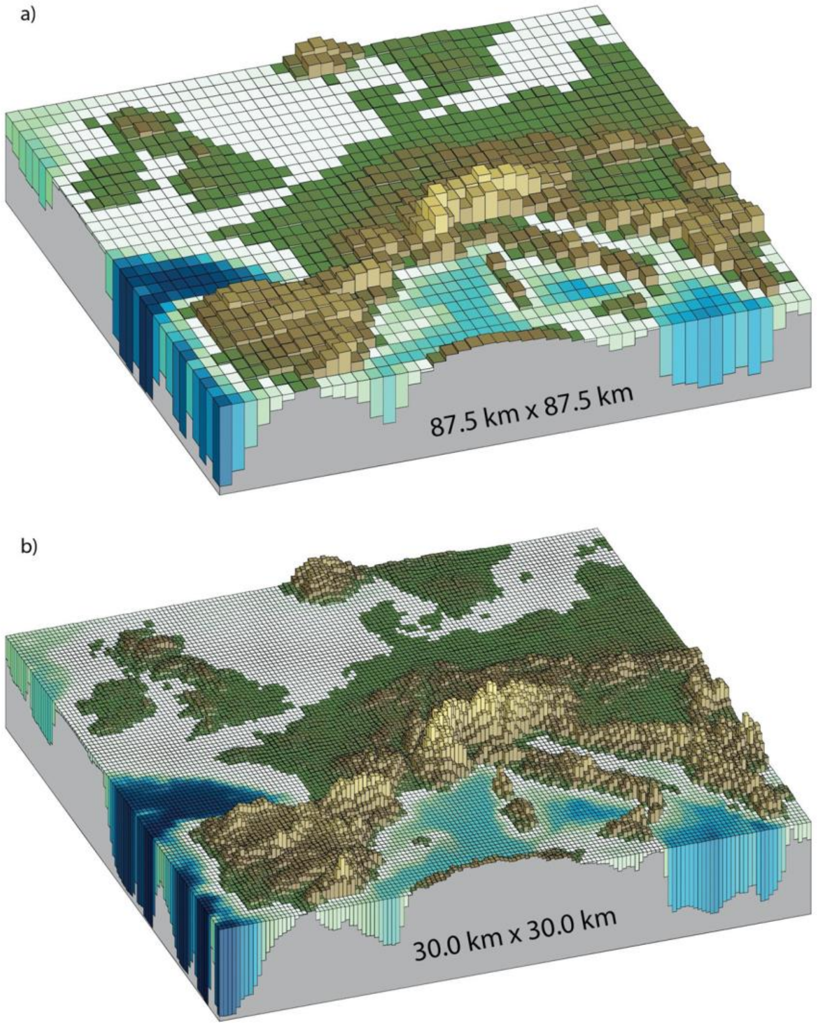
Energy
- Energy management tools

Water Budgets
- Water management tools

Evaluate in CASI Initiative

Summary of Climate Projection Needs

- **Fine-Resolution** to see finer features given that Centers are small compared to climate model grid cells
- **Bias-Adjusted** to ensure observed features are well-represented below grid-scale
- **Latest Climate Model Outputs** from CMIP6 to ensure we are using the best data
- **Multiple Emissions Scenarios** to give stakeholders a range of plausible futures to prepare for
- **Multiple Climate Models** are used to find the multi-model mean
- **Distinguished Ensemble** to exclude 'hot' models so our projections don't have a hot bias
- **Lots of Variables** to provide climate projection data for all climate change risks



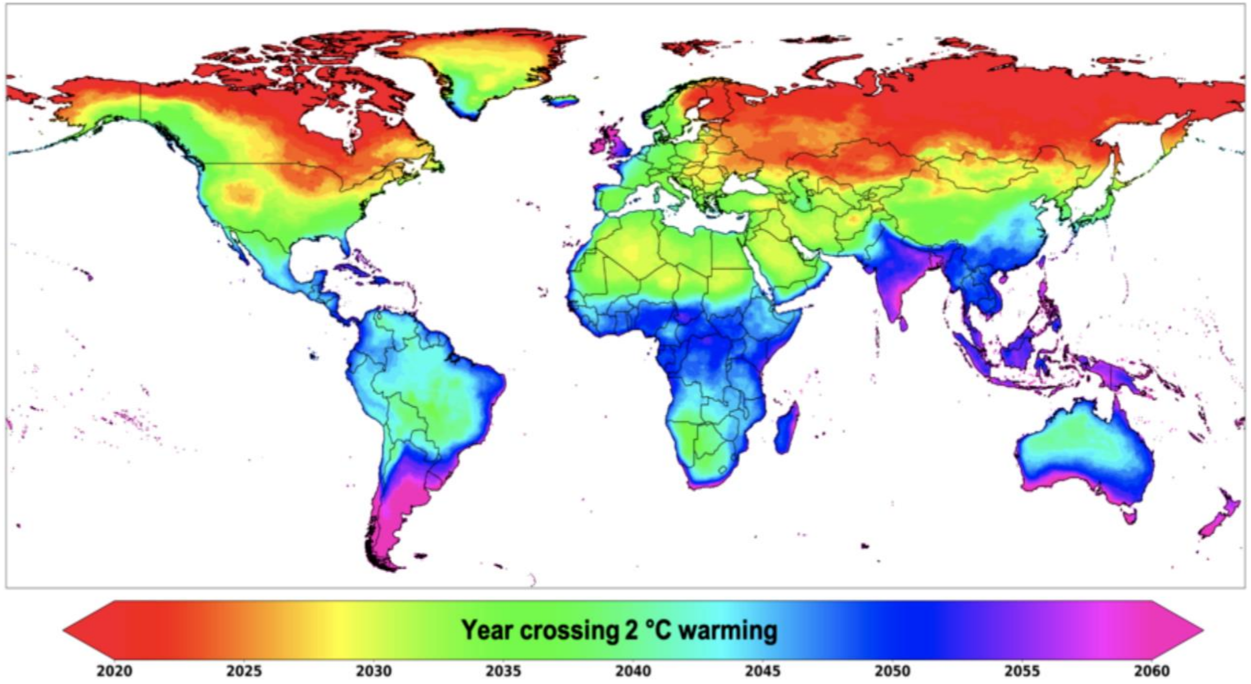
Example comparing different model resolutions
IPCC 2013 WG1 figure 1-14

Evaluate in CASI Initiative

Selection of Climate Projection Sets - NEX GDDP

NASA Earth Exchange (NEX) GDDP

CMIP6 Bias-Adjusted Projections



Year of Crossing 2C Warming Relative to 1950-1979 under SSP5-8.5 Scenario

Source: NASA NEX-GDDP; https://www.nasa.gov/nex/gddp

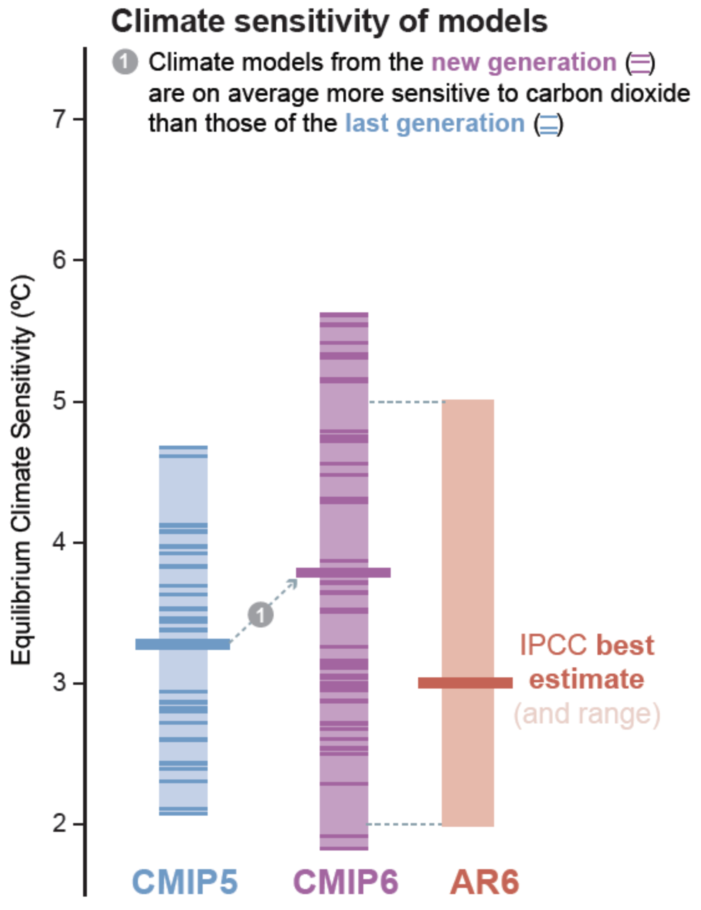
NASA NEX Global Daily Downscaled Projections (GDDP) includes 35 General Circulation Models (GCM) from the Coupled Model Intercomparison Project Phase 6 (CMIP6), which is the latest iteration of climate models. (Thrasher et al., 2021, 2022)

Variables in the NEX dataset include: *minimum, maximum, and average temperatures, precipitation, relative humidity, specific humidity, downwelling longwave and shortwave radiation, surface windspeed*

Evaluate in CASI Initiative

Avoid 'Hot' Models

- **"Hot Models"** (see IPCC AR6 Glossary plus WGI CH7: Forster et al., 2021; Hausfather et al., 2022)
  - Equilibrium Climate Sensitivity (**ECS**) = The equilibrium (steady state) change in the surface temperature following a doubling of the atmospheric carbon dioxide (CO_2) concentration from pre-industrial conditions.
    - IPCC Assessed very likely range for ECS: 2.0-5.0°C
  - Transient Climate Response (**TCR**) = The surface temperature response for the hypothetical scenario in which atmospheric carbon dioxide (CO_2) increases at 1% yr^{-1} from pre-industrial to the time of a doubling of atmospheric CO_2 concentration (year 70).
    - IPCC Assessed very likely range for TCR: 1.2-2.4°C
  - Beware of models with ECS or TCR beyond assessed range. 'Hot Models' may be overly sensitive to greenhouse gas emissions and aerosol changes.

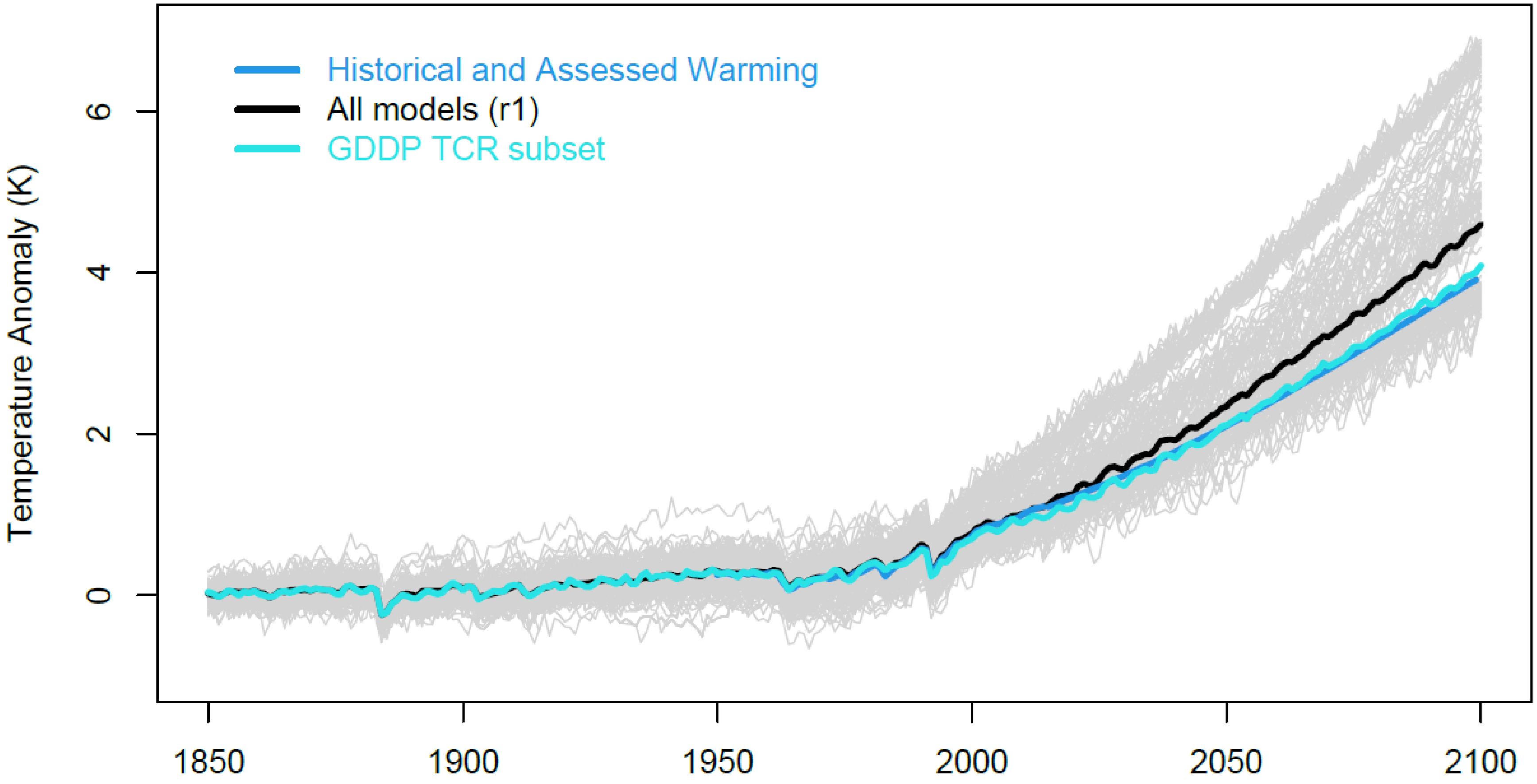


Evaluate in CASI Initiative

Avoid 'Hot' Models

By selecting models that fall within IPCC Assessed "Likely" range of Transient Climate Response (TCR) we stay more in line with assessed future projections.

Global Temperature Projections Across Models and Ensemble Subsets (High Emissions Scenario)



Credit: Gavin Schmidt, NASA GISS

Evaluate in CASI Initiative

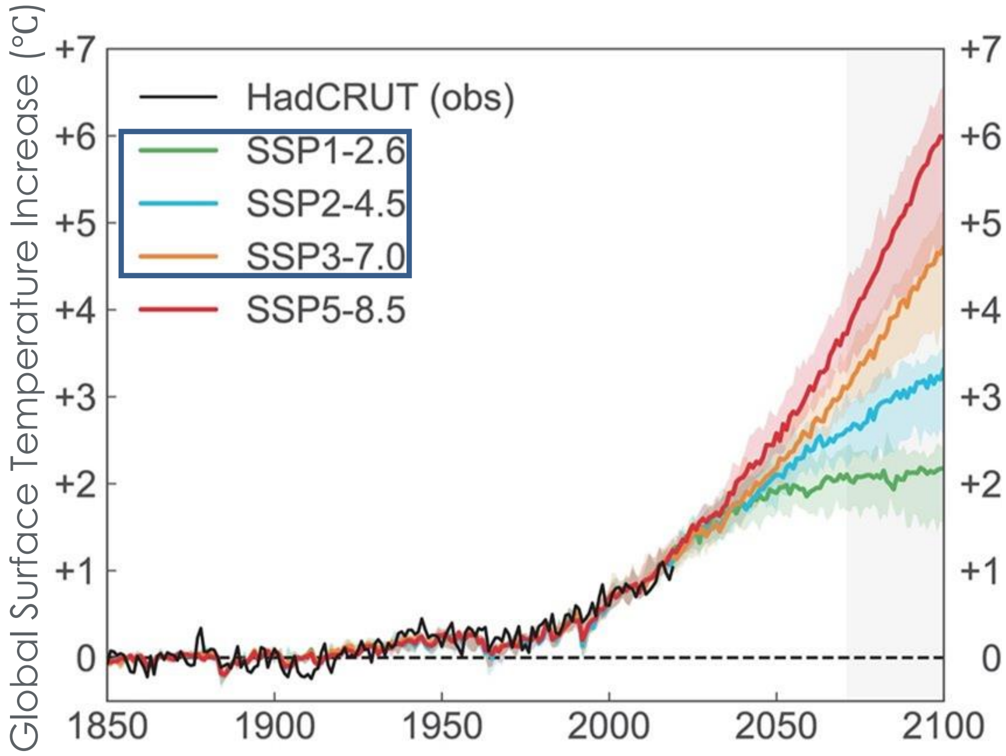
Selection of Climate Projection Sets

Low, intermediate, and high projections based on IPCC AR6 SSP1-2.6, SSP2-4.5, SSP3-7.0 scenarios

Timescale 2020s to 2100; Spatial Scale ~27km (higher resolution later via NEX LOCA at 5-6km); LIS 10km

Outputs – Projections calculated as averages and distributions across 22 models (avoiding 'hot models')

Delivery – Maps, Tables and Data tailored for NASA Centers resilience decisions



Also evaluating newly released LOCA-2 (Localized Constructed Analogs) dataset produced by UCSD.

Evaluate in CASI Initiative

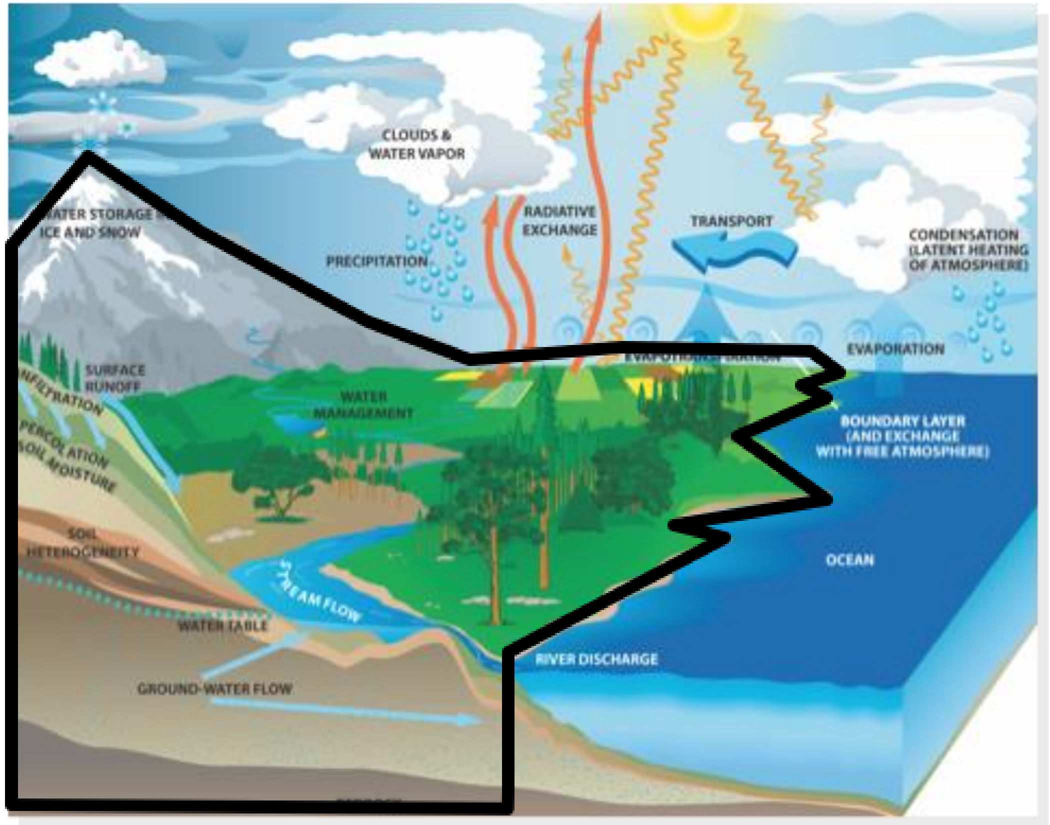
Elaborate land surface information

Linkages with the NASA Land Information System

CASI linked with the NASA Land Information System (LIS) to provide higher resolution and elaborated hydrological variables beyond what NASA NEX-GDDP natively provides.

LIS is:

- A system for uncoupled and coupled land modeling and data assimilation
- Runs a variety of land surface models (Noah, Noah-MP, CLM, VIC, CABLE, JULES, etc.)
- Integrates satellite, ground, and reanalysis data with a comprehensive data assimilation infrastructure
- Includes high performance support for fine resolution and ensemble modeling



Kumar et al., 2006

Evaluate in CASI Initiative

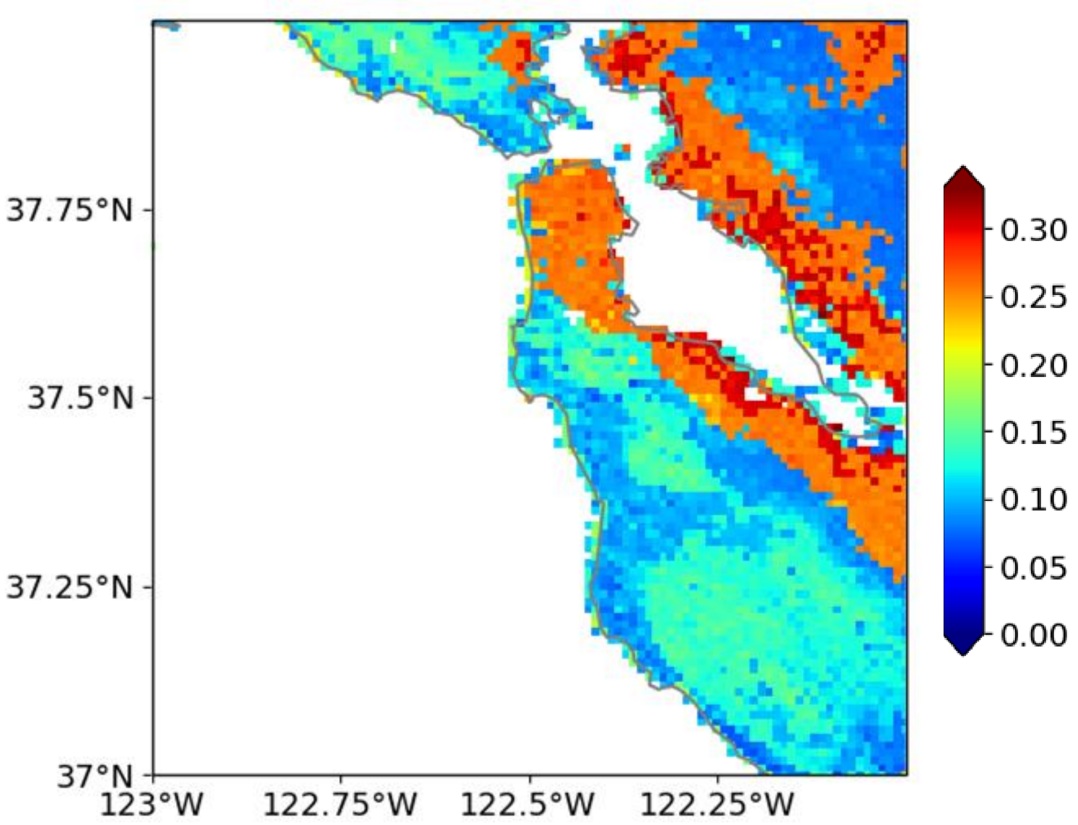
Elaborate land surface information

LIS Elaborations of NEX-GDDP Outputs

An LIS-based configuration has been setup to develop hydrological projections for the NASA Climate Adaptation Science Investigators (CASI) Initiative.

- Further downscaling (to ~1 km)
- 22 GCMs, 3 Emissions Scenarios
- Augmentation of extreme events at land surface
- More hydrological variables

LIS Soil Moisture on August 1st, 2015



Soil moisture data from LIS simulation for Aug 1, 2015, at Ames Research Center at 1km resolution (units are volumetric m3/m3)

Evaluate in CASI Initiative

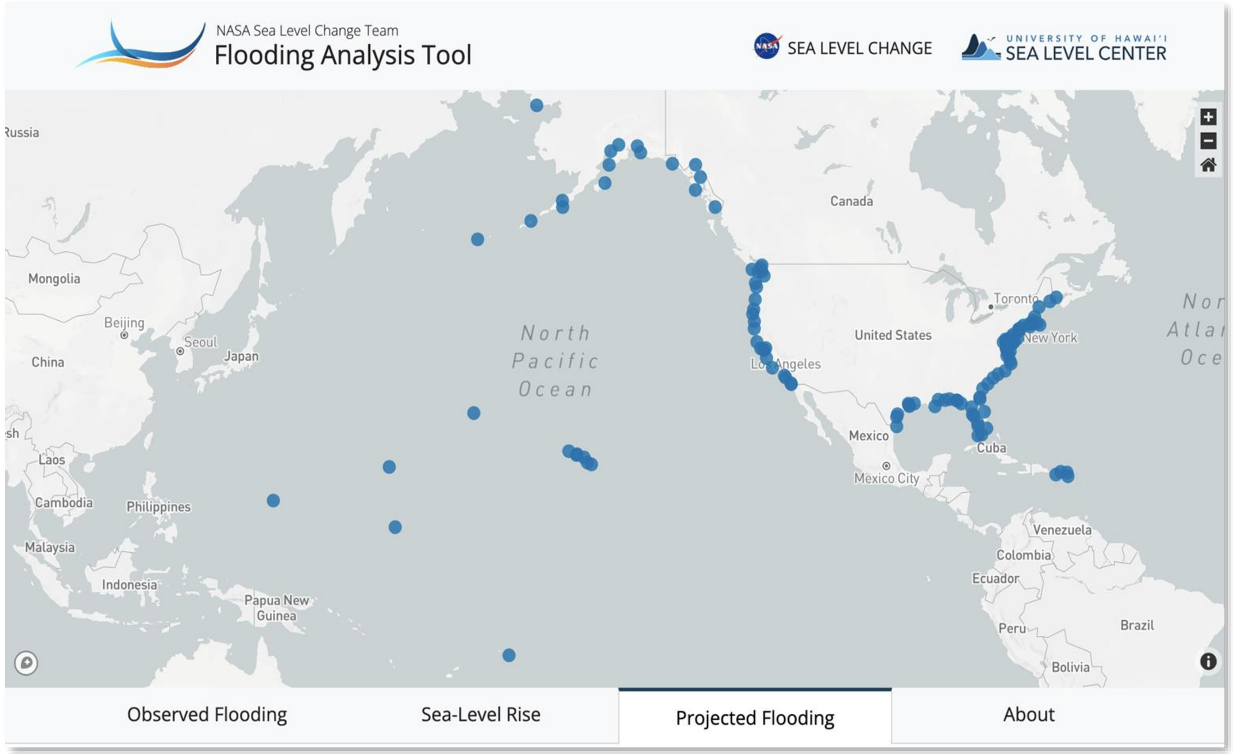
Selection of Climate Projection Sets

NASA Sea Level Rise Projections

https://sealevel.nasa.gov/data_tools/15

Has the following features:

- Many GCMs and scenarios
- Connections to tide gauge observations
- Distinguishes different contributions to sea level increase
- Captures local land movement influences



Evaluate in CASI Initiative

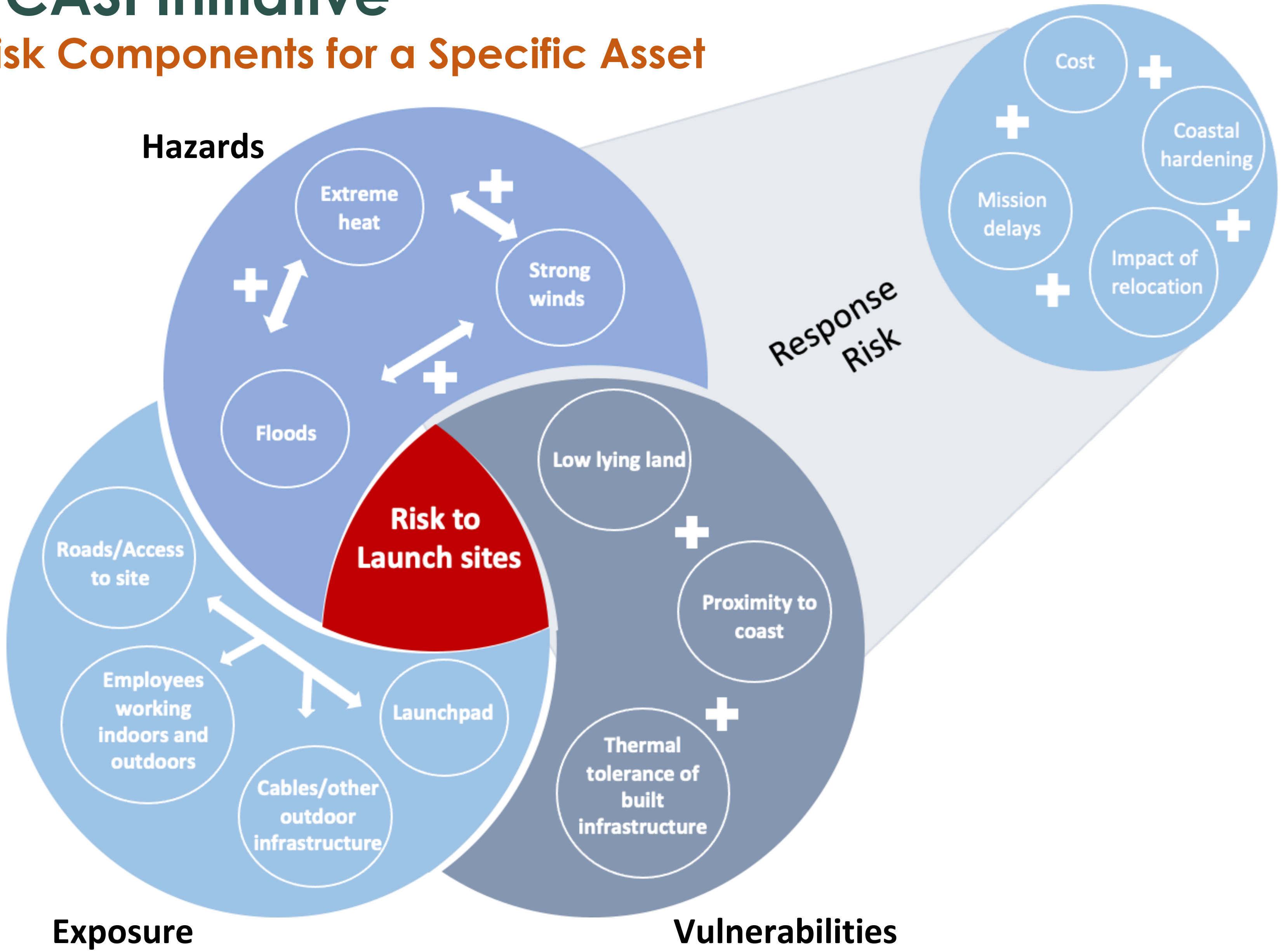
Vulnerability and Exposure Assessment

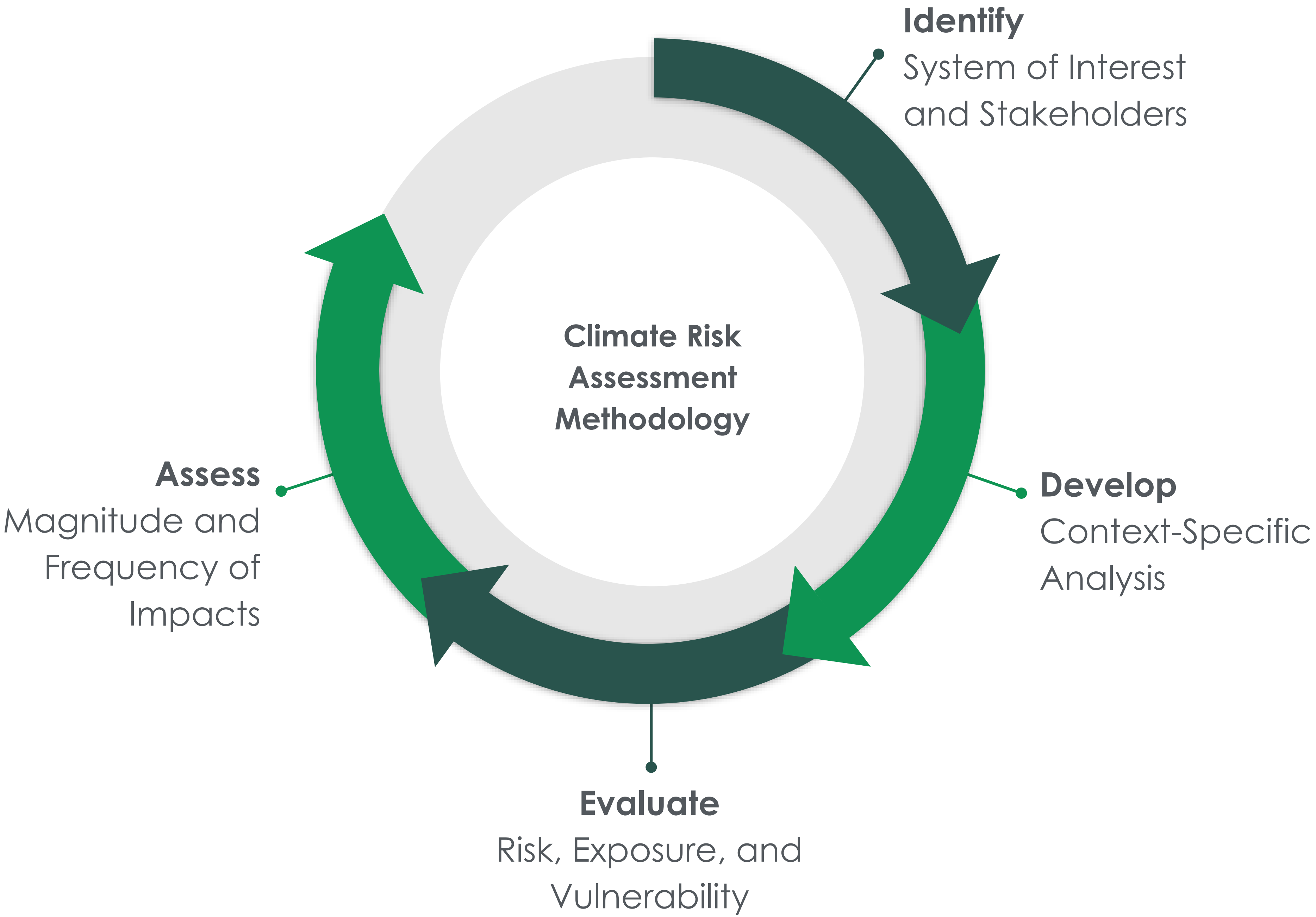
Evaluate climate risks for primary assets and costs on NASA Centers

- Workforce
- Operations
- Built Infrastructure
- Mission Facilities (e.g., launchpads, test facilities)
- Energy and Cooling Systems
- Transportation Infrastructure
- Ecosystems on Center Grounds
- Water Resources

Evaluate in CASI Initiative

Breakdown of Risk Components for a Specific Asset



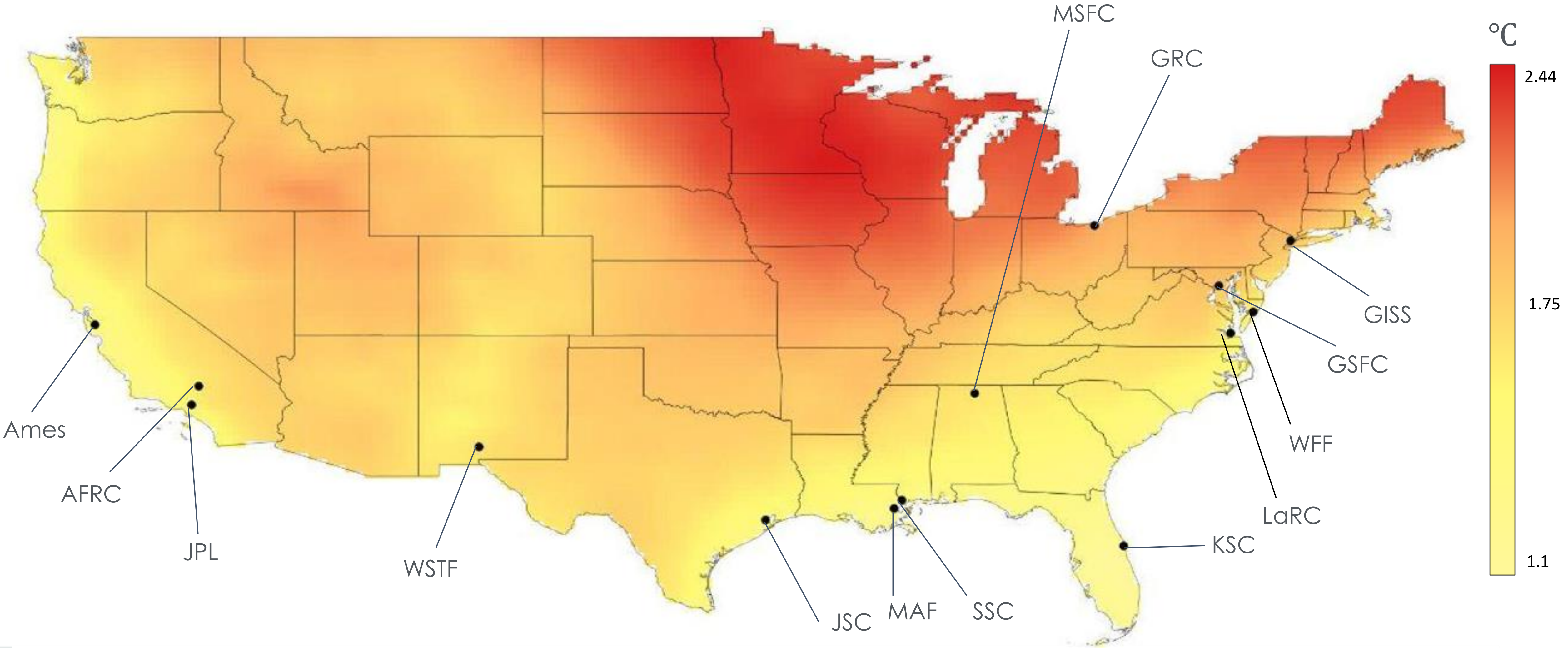

Climate Risk Assessment Methodology
Identify
System of Interest and Stakeholders
Develop
Context-Specific Analysis
Evaluate
Risk, Exposure, and Vulnerability
Assess
Magnitude and Frequency of Impacts

Assess in CASI Initiative

- Multiple acute and chronic risks challenging each Center

- Different threat levels given unique contexts

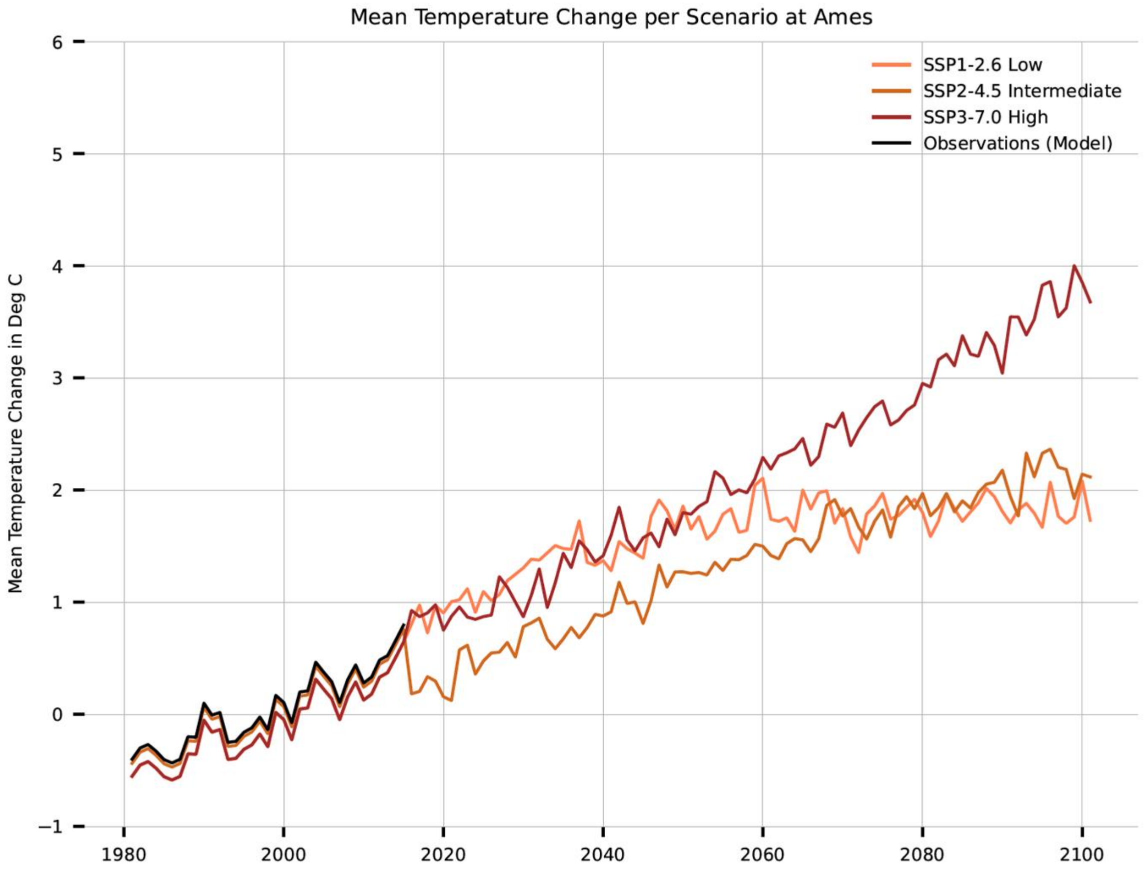
Background Large-Scale Patterns of Warming

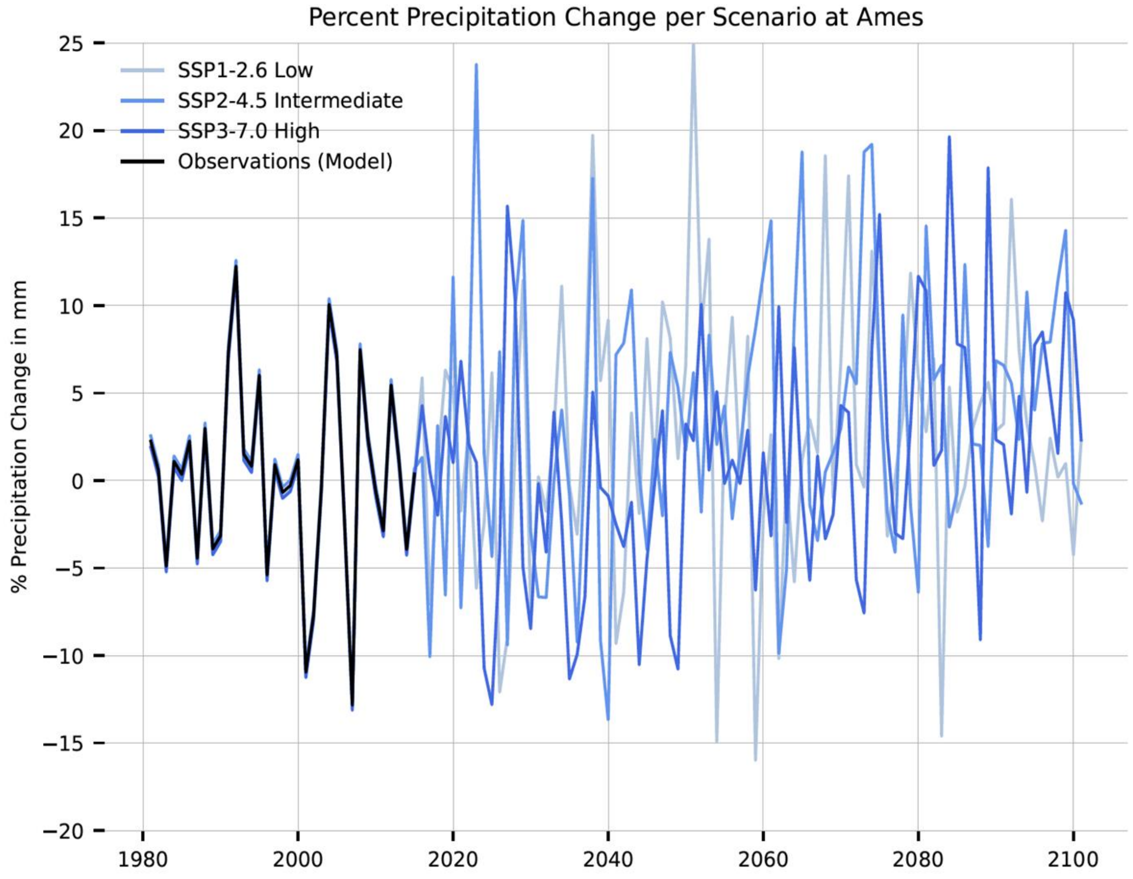


2050s Ensemble mean change in Annual temperature (compared to 1981-2020)
SSP2-4.5, 22 NEX GCMs

Patterns of Mean Change

Different Levels of Certainty at NASA Ames





Mean Trend > Internal Variability for Temperature

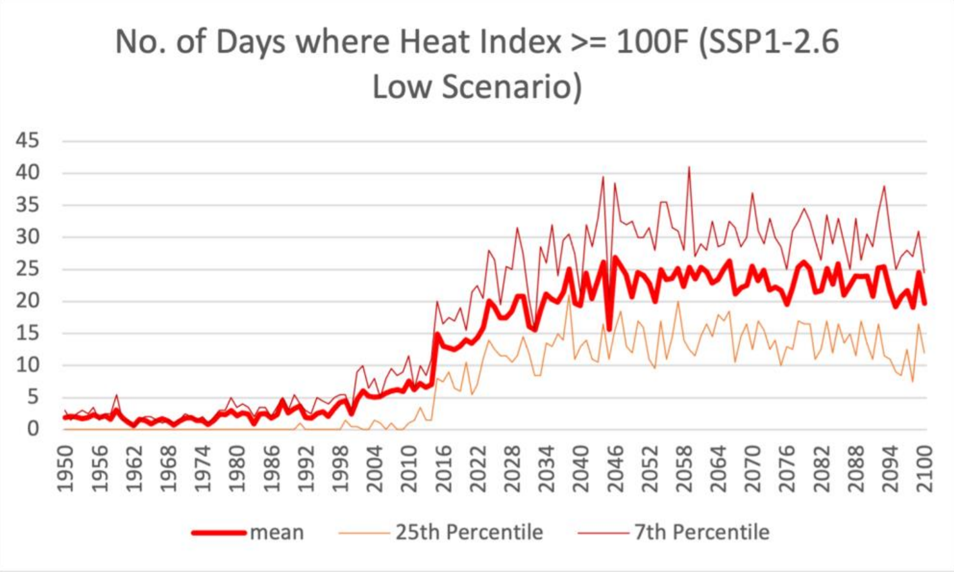
Mean Trend < Internal Variability for Precipitation

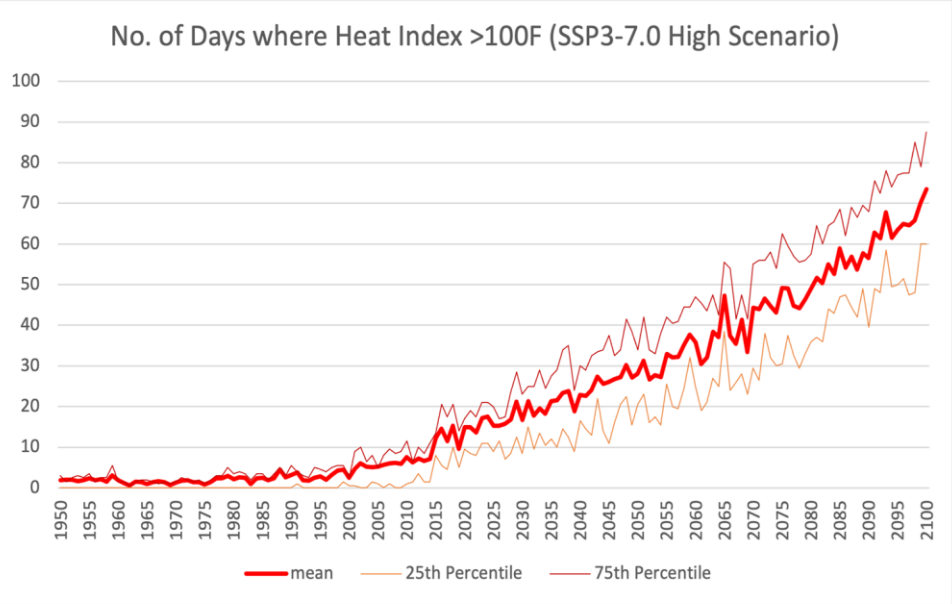
Assess in CASI Initiative

Extreme Weather - Heat Index at Langley (LaRC)

Heat Index is a combination of extreme heat and humidity, which compound to have substantial effects on outdoor workers

- Ensemble mean projections indicate more than 70 days per year will have dangerously high Heat Index (>100°F) at Langley by the end of the century under the High Emission Scenario.
- Even under the low emissions scenario, the threat is substantially higher (>20 days per year).





CASI Extremes Working Group

Ben Cook

Assess in CASI Initiative

Energy – Building Zones for Jet Propulsion Laboratory (JPL)

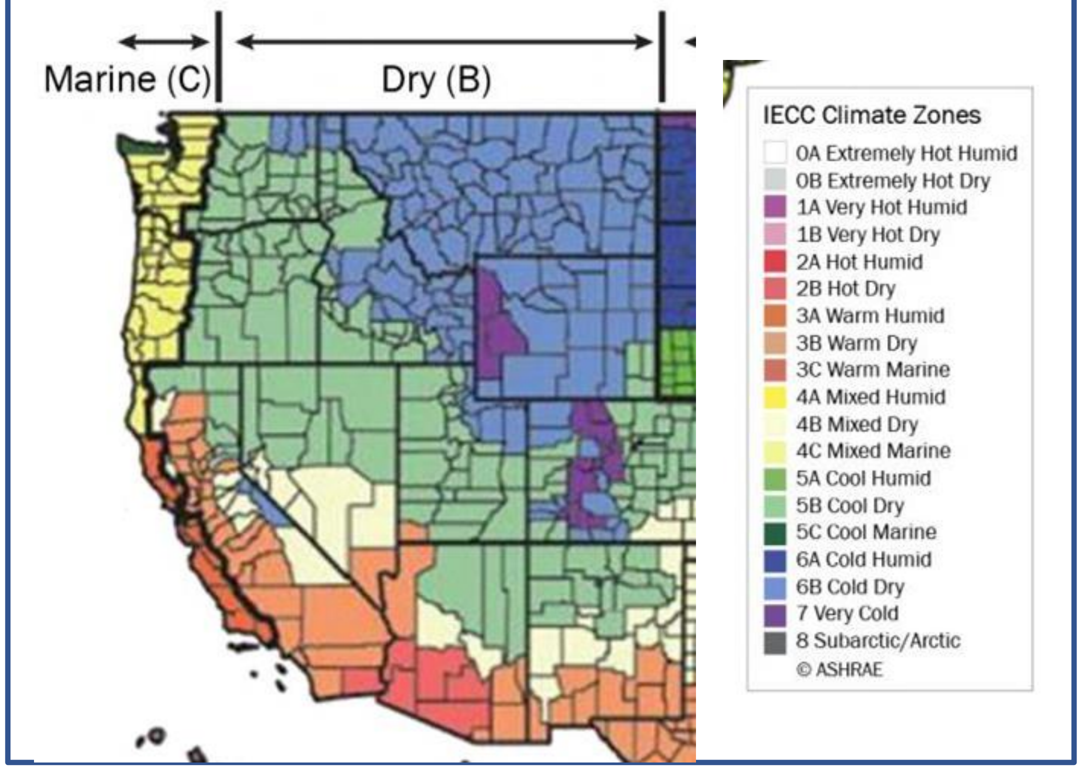
Climate designations created by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) to describe the climate conditions for buildings

- Based on the integration of daily surface temperature to create annual Cooling Degreee Days (CDD) / Heating Degree Days (HDD), annual precipitation
  (Lower Number -> Warmer)

- By our calculations, the current ASHRAE climate zone of JPL is 3 and is projected to change to 2 after 2090 in the highest emission scenario. The climate zone does not change in the other emissions scenarios.

- **Why is this important?** The ASHRAE zone designation determines building codes required for any new/modernized building (e.g., HVAC, lighting, insulation, etc.)

Current US ASHRAE Climate Zones



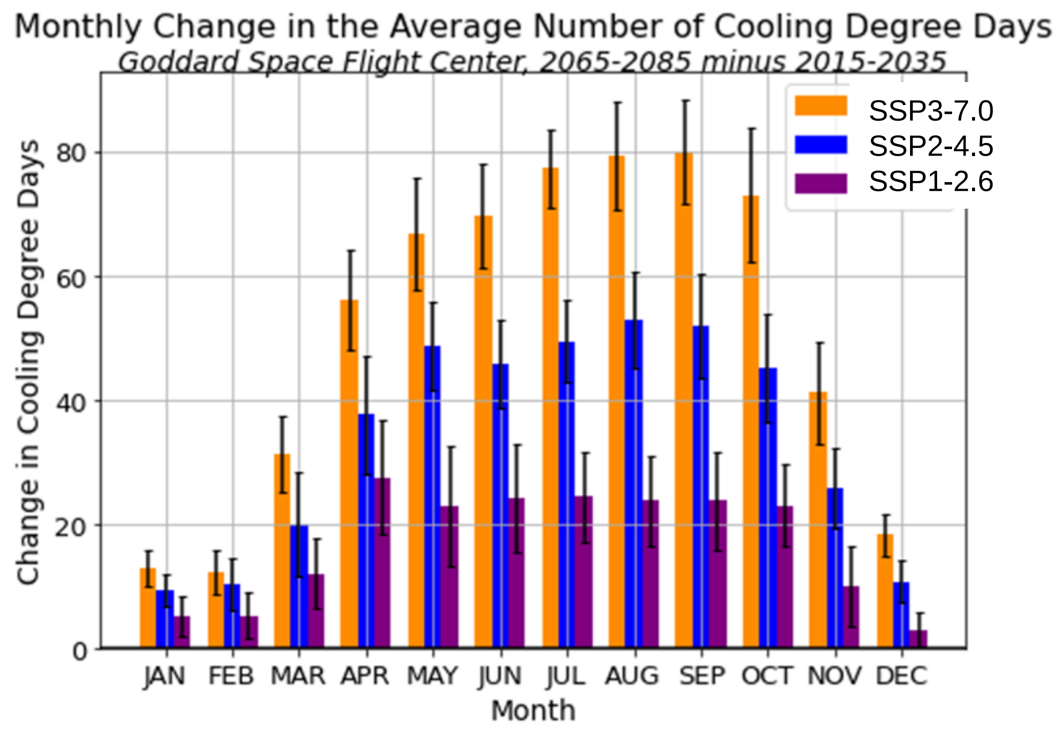
CASI Energy Working Group

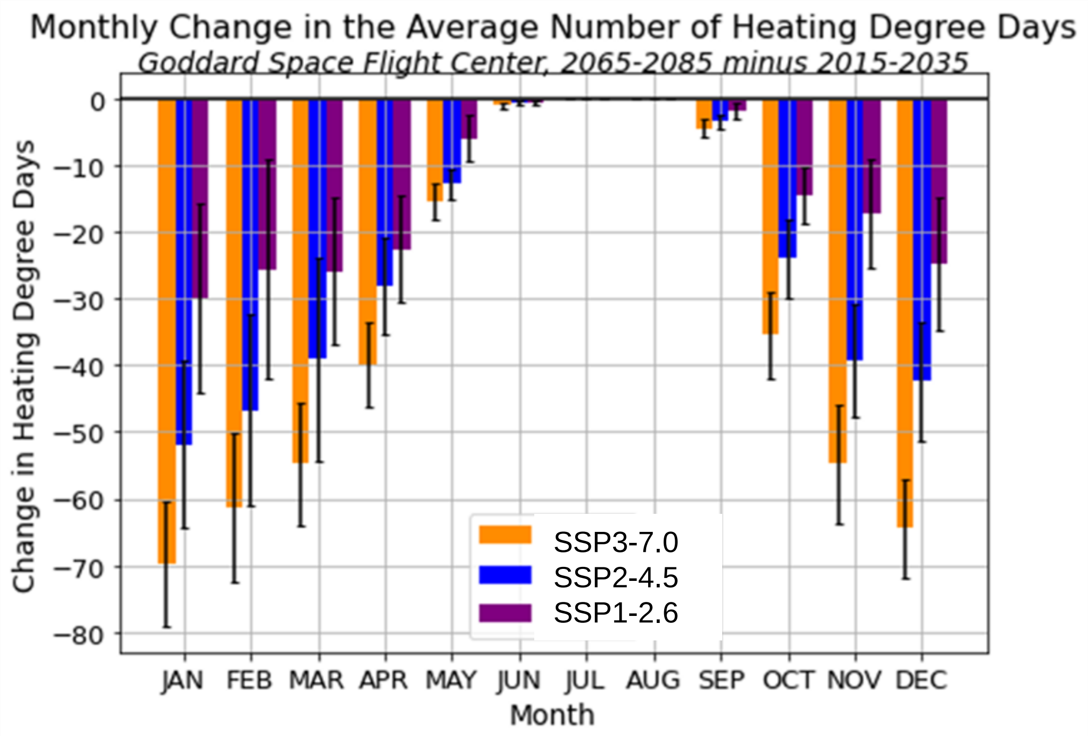
Assess in CASI Initiative

Energy – Building HVAC Needs at Goddard Space Flight Center (GSFC)

Changing Seasonal Profile of Heating and Cooling

CASI Energy Working Group





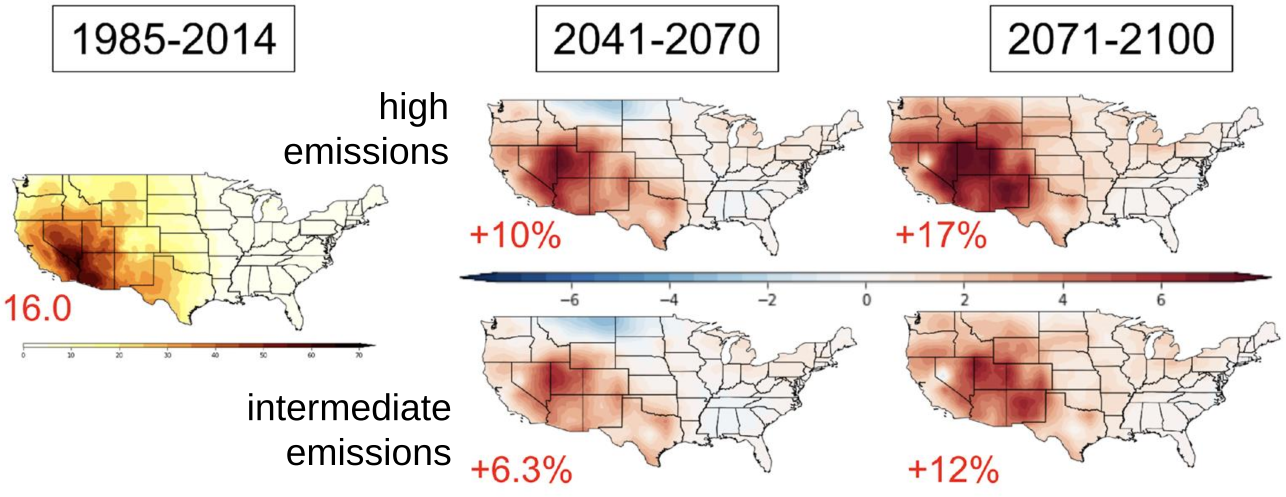
Paul Stackhouse, Bradley Hegyi

Assess in CASI Initiative

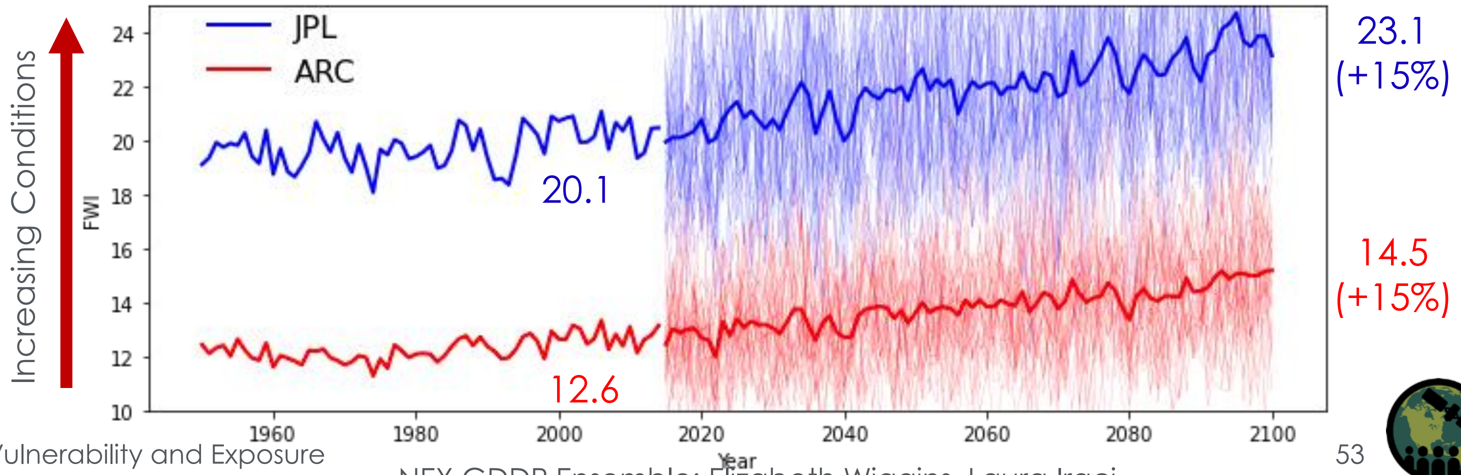
Fire Weather – Growing Risks at Jet Propulsion Laboratory (JPL) and Ames Research Center (ARC)

- Fire Weather Index (FWI) was calculated using meteorological variables from climate projections.
- Conditions around JPL are significantly more conducive to fire than at Ames Research Center.
- Under the high emission scenario (SSP5-8.5), both ARC and JPL are expected to experience approx. 15% increase in fire weather index.

FWI climatology difference (future – present)



Annual Mean FWI around ARC and JPL (Historical + SSP5-85)



NEX GDDP Ensemble; Elizabeth Wiggins ,Laura Iraci

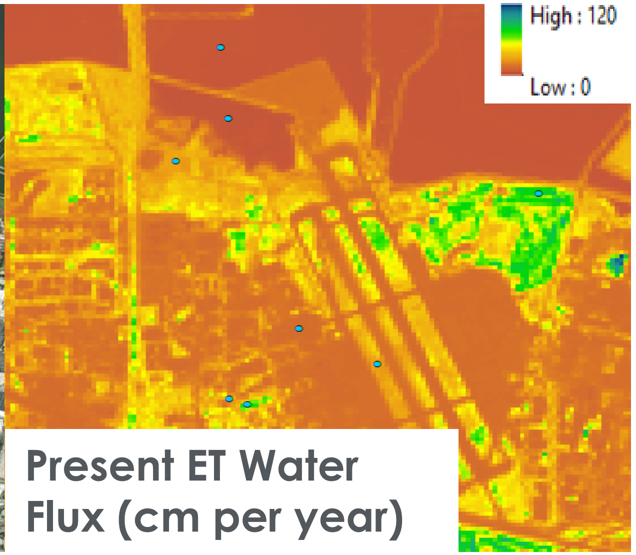
CASI Fire and Air Quality Working Group

Assess in CASI Initiative

Multiple Perspectives on Hydrology of Ames Research Center

CASI Water Budgets Working Group

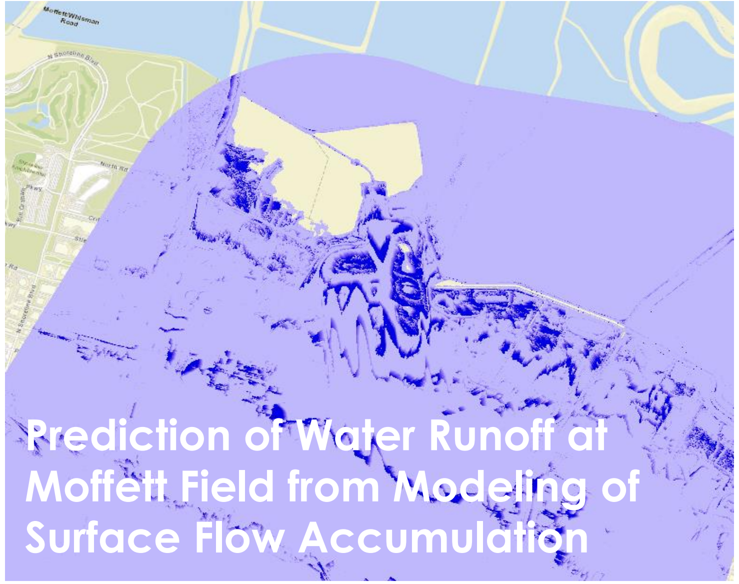

Land Cover



Present ET Water Flux (cm per year)

Surface Inundation (blue shades) after Heavy Rainfall Event of 2.7 inches/24-hours (October 24, 2021):
(Based on Sentinel-1 SAR)

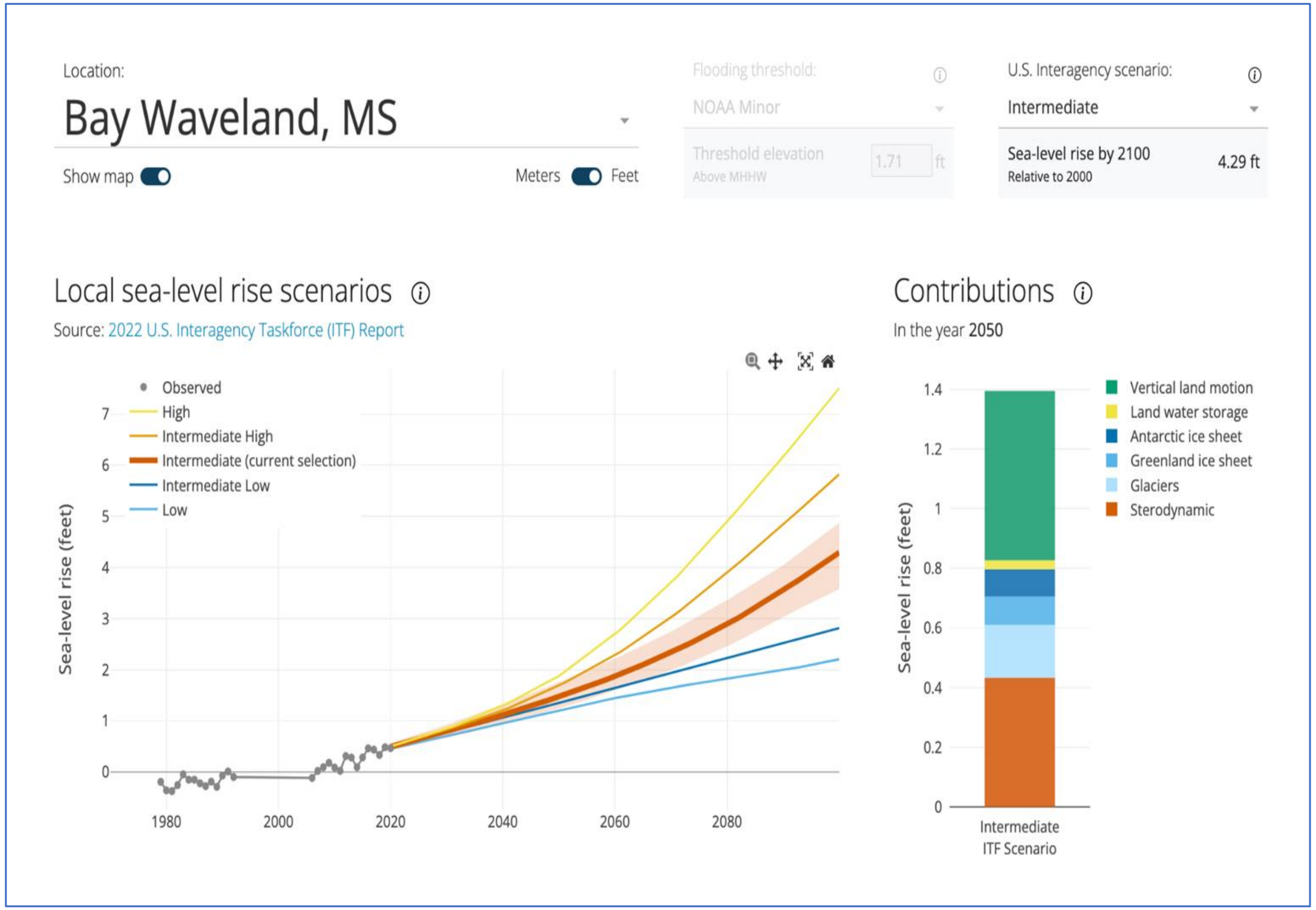

1-Meter Resolution Impervious Cover Classes

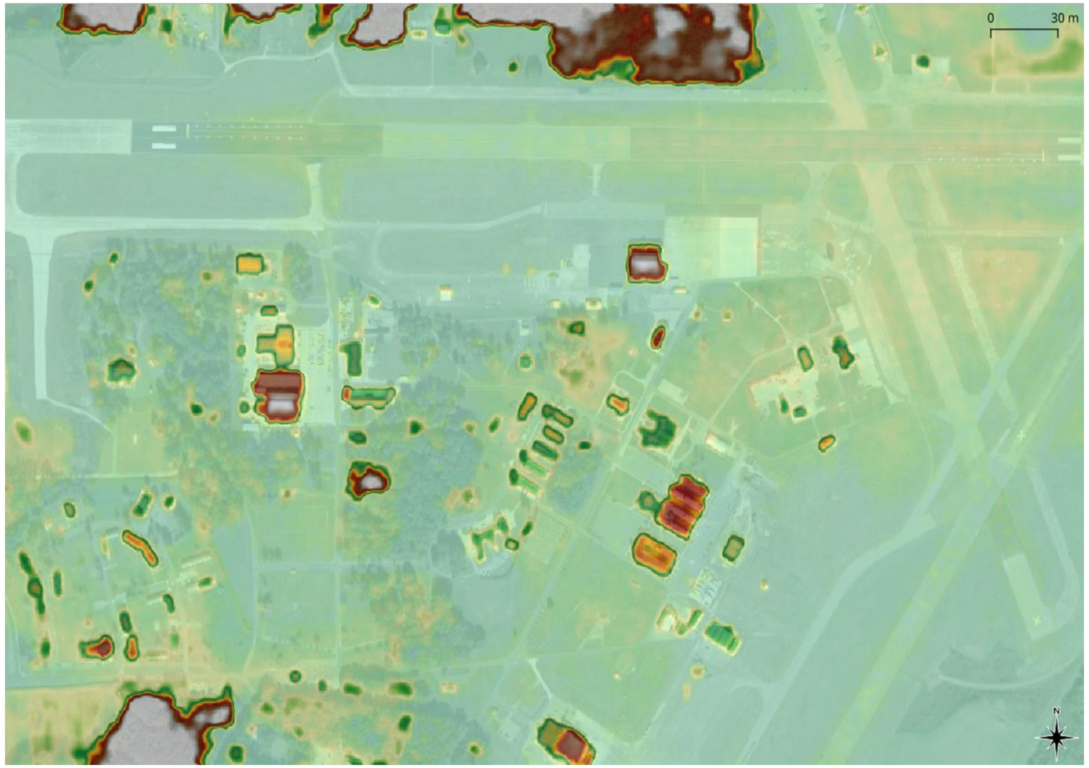

Prediction of Water Runoff at Moffett Field from Modeling of Surface Flow Accumulation

Chris Potter

Assess in CASI Initiative

Coastal Risks at Stennis and Wallops



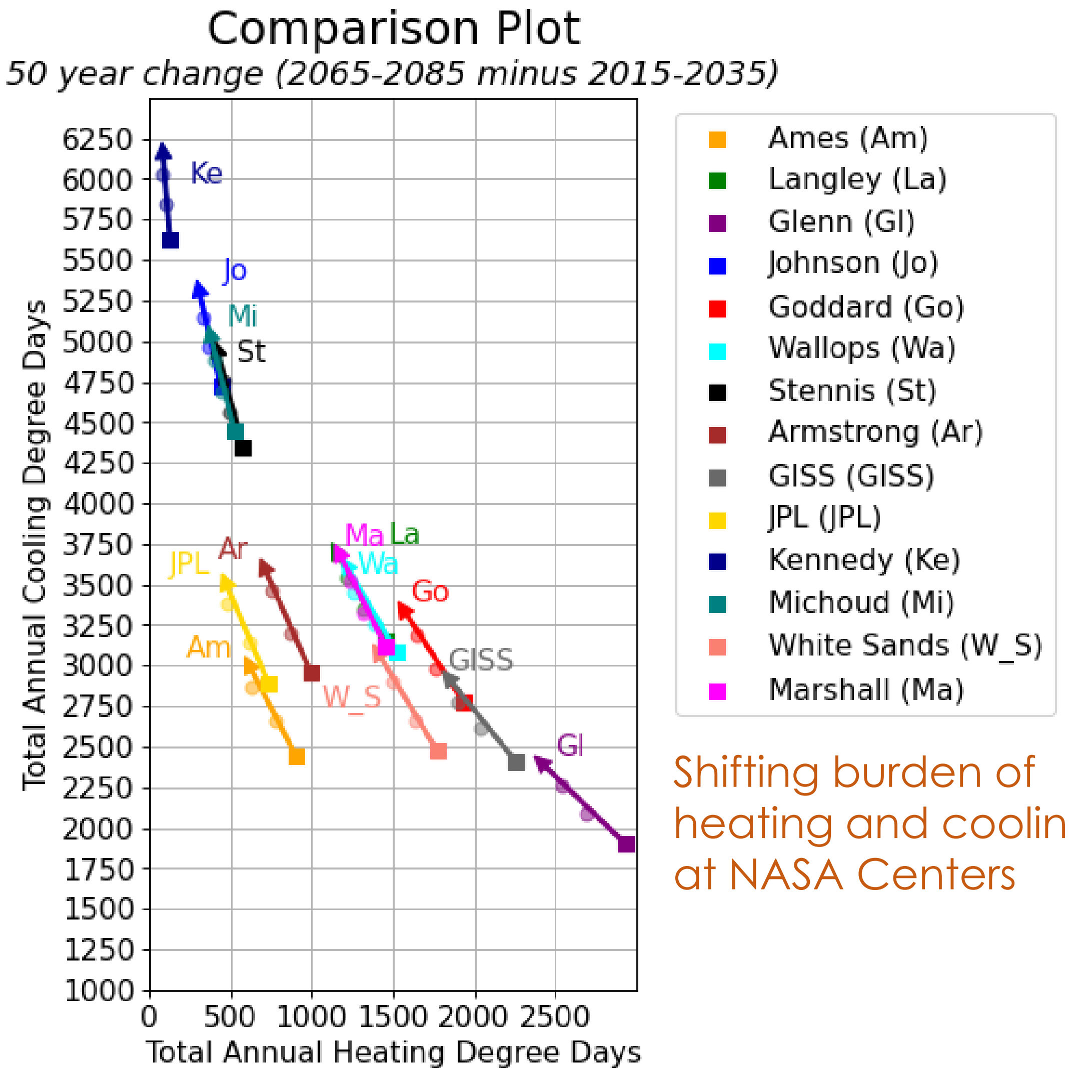


Wallops Island Example DSM (2 m horizontal resolution, +/- 10 cm vertical accuracy)

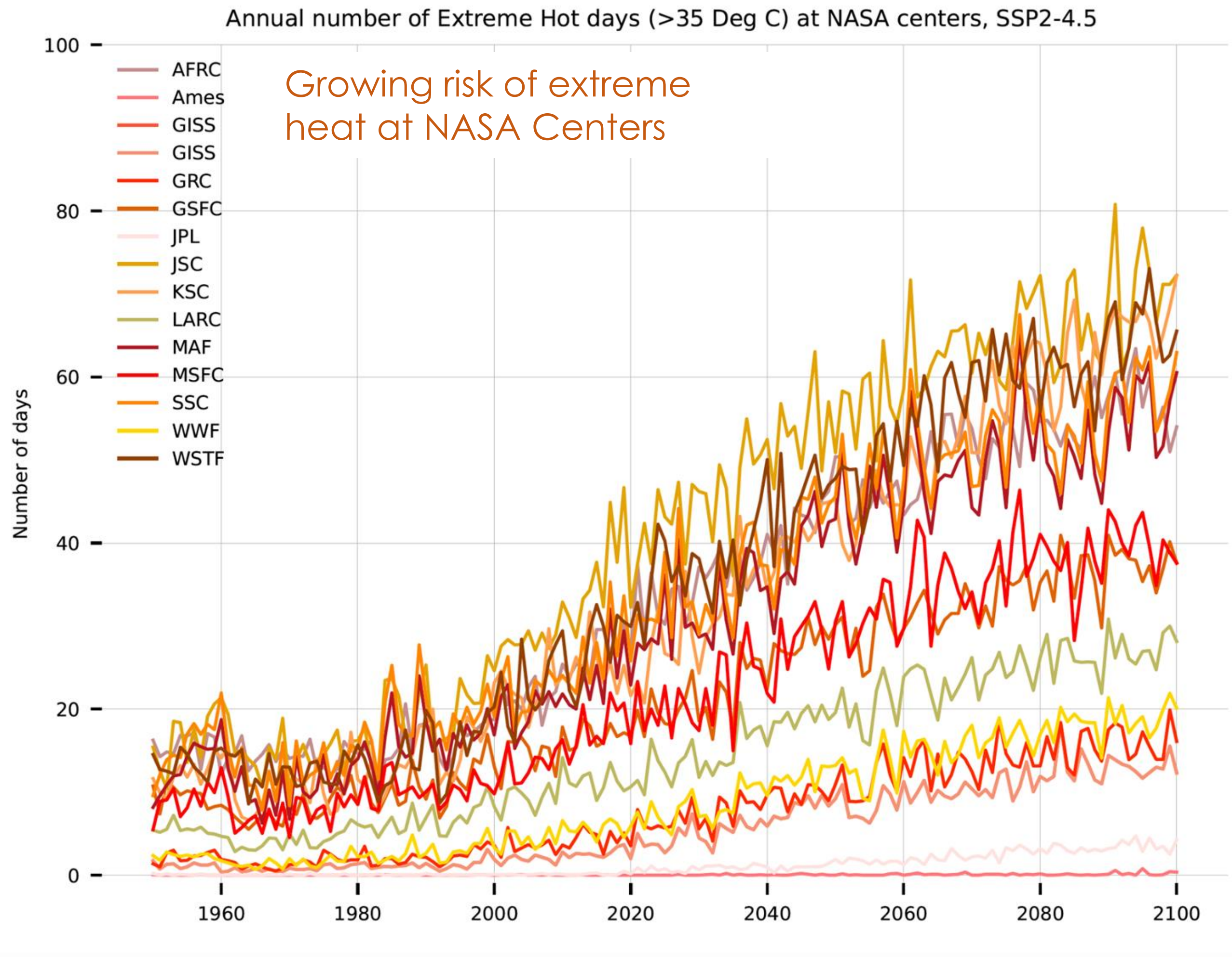
Sea Level Rise and Coastal Risks Working Group

Assess in CASI Initiative

Different Risks at Different NASA Centers



Shifting burden of heating and cooling at NASA Centers

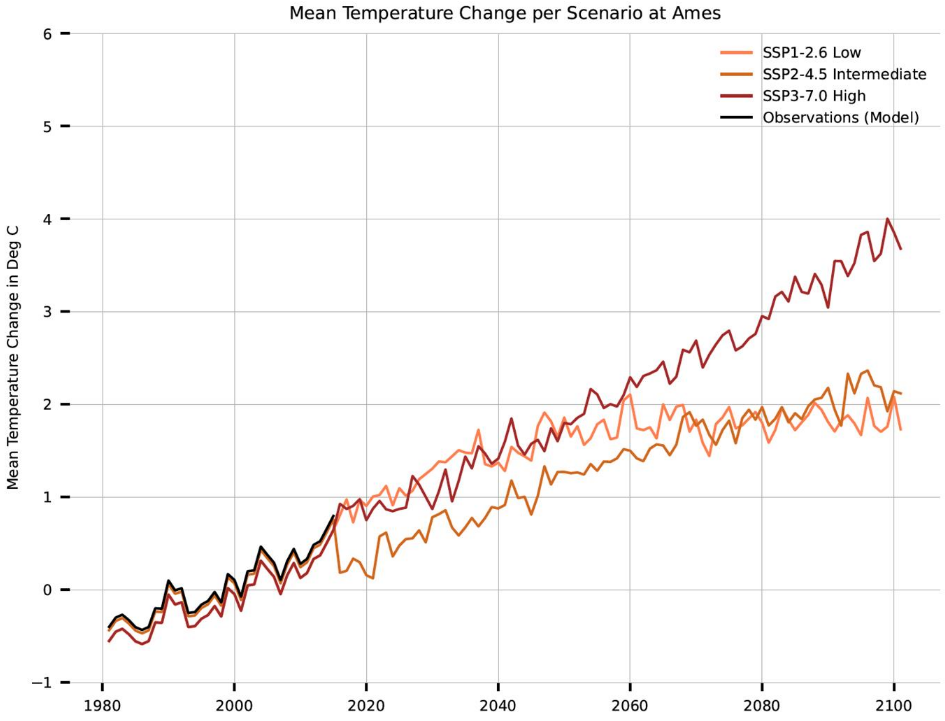


NEX GDDP Ensemble; Paul Stackhouse, Bradley Hegyi, Ben Cook

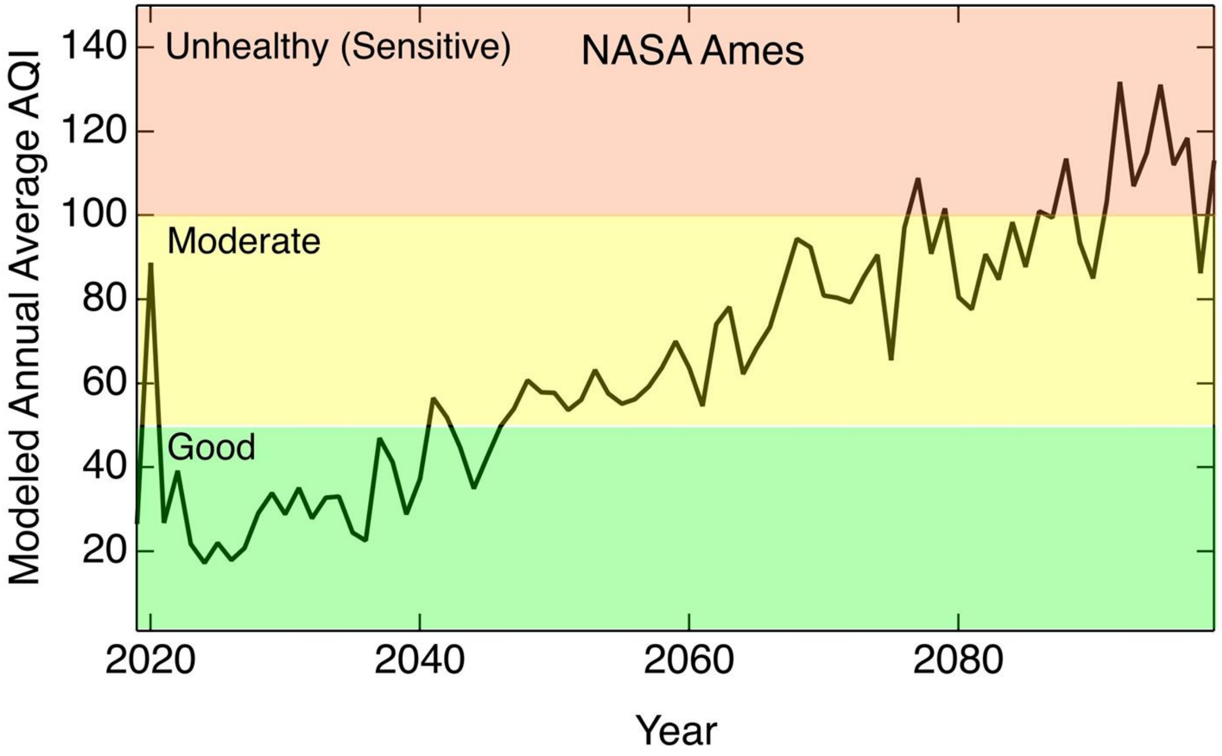
Assess in CASI Initiative

Multiple Risks at Same NASA Center (Ames) (1/4)

Mean Temperature Change



Annual Average Air Quality Index

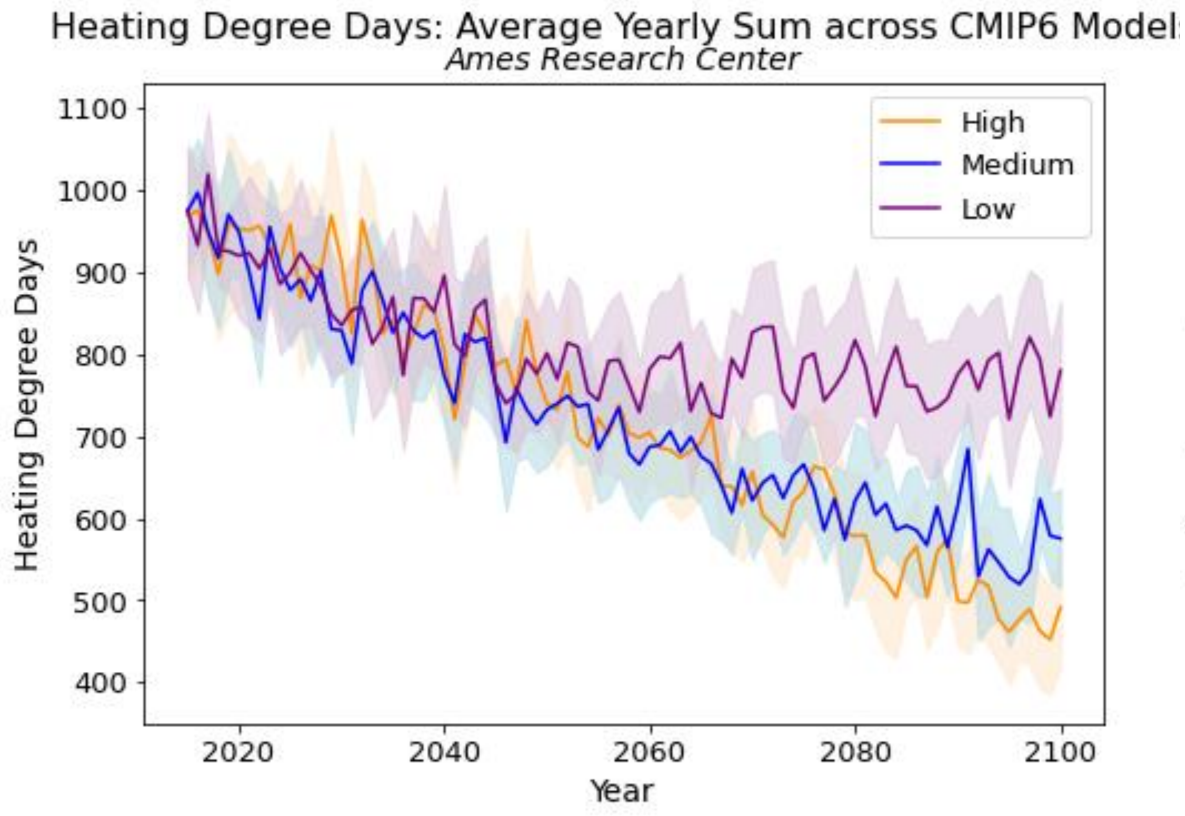


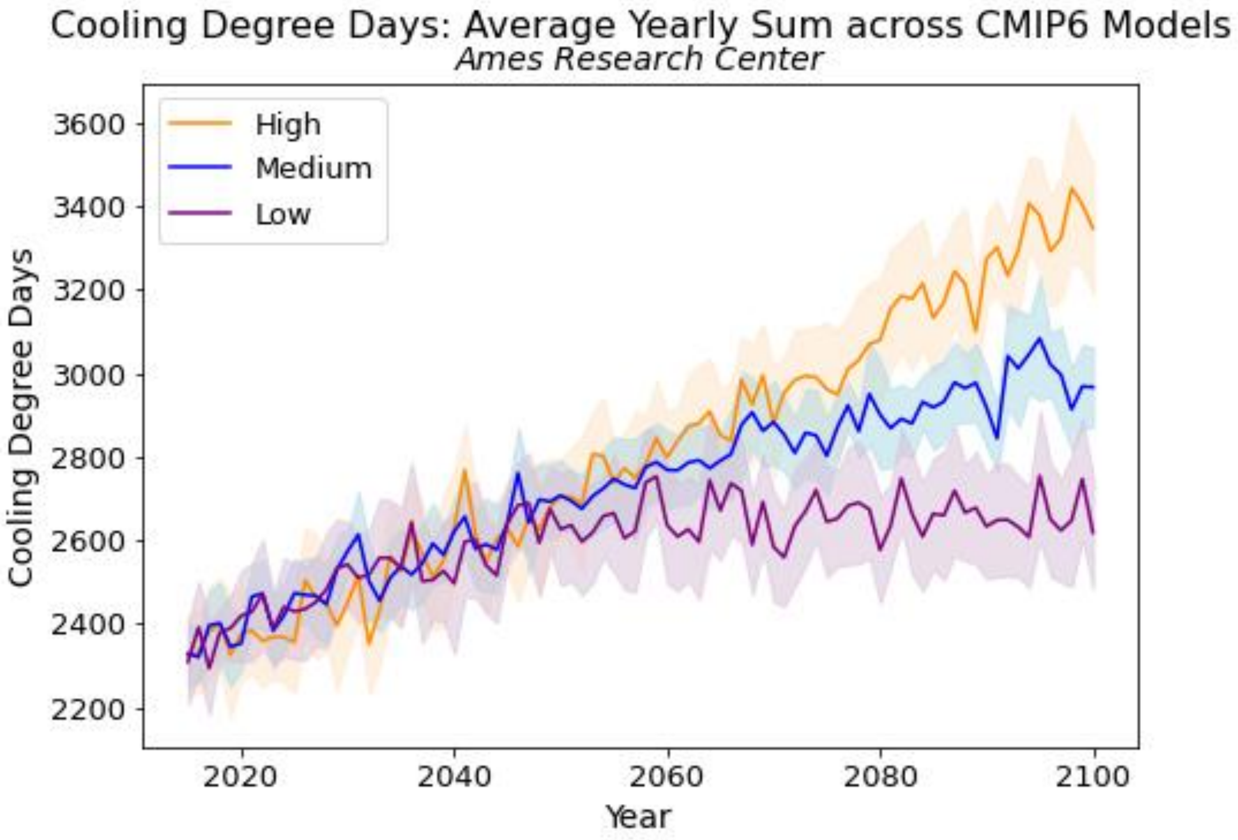
NEX GDDP Ensemble; Sanketa Kadam, Cynthia Rosenzweig, Laura Iraci, Elizabeth Wiggins

Assess in CASI Initiative

Multiple Risks at Same NASA Center (Ames) (2/4)

Shifting cold and warm season energy demands at NASA Ames



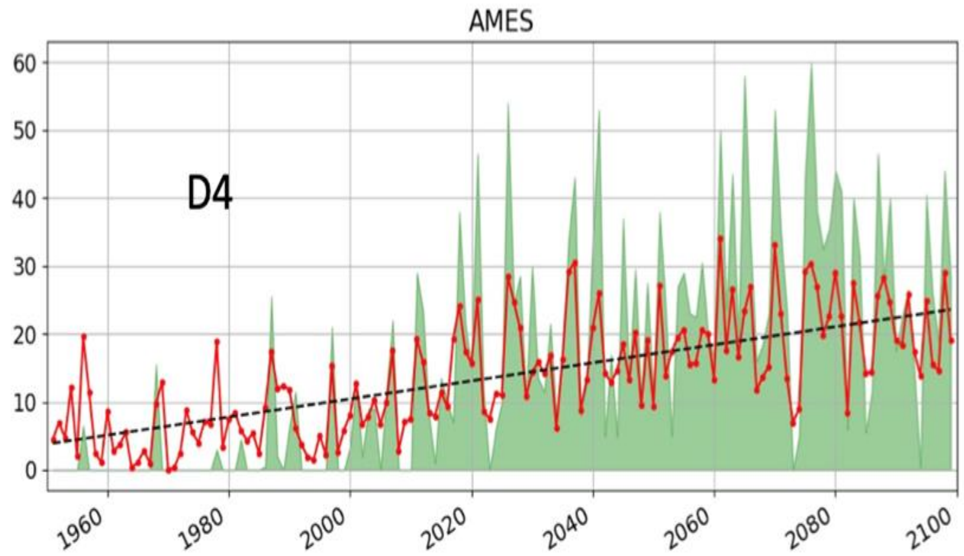


NEX GDDP Ensemble; Paul Stackhouse, Bradley Hegyi

Assess in CASI Initiative

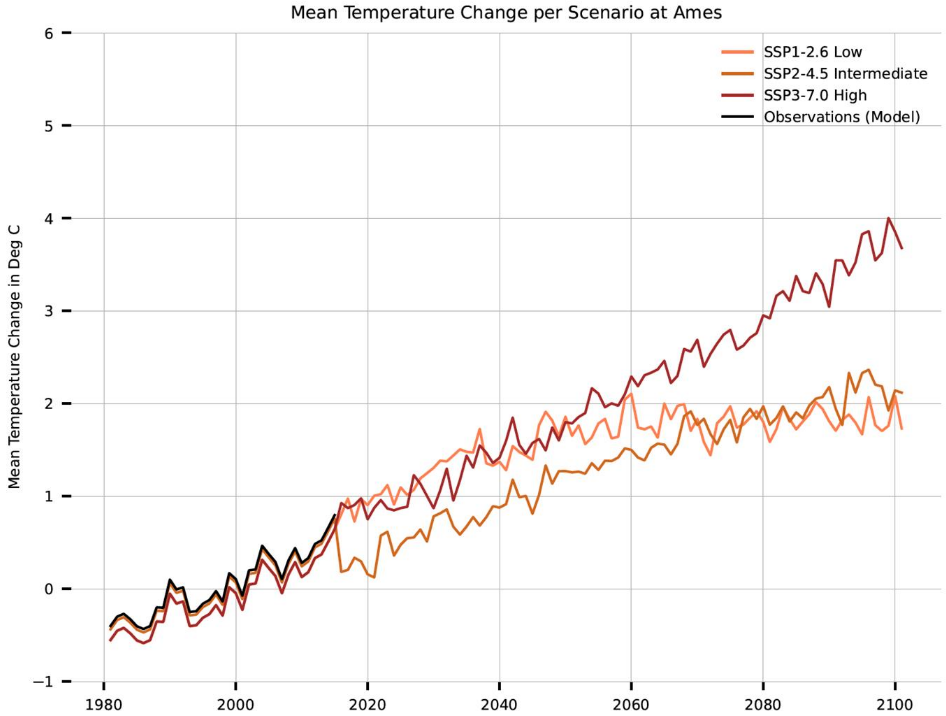
Multiple Risks at Same NASA Center (Ames) (3/4)

Heat also compounding with increasing drought conditions



D4, Extreme Drought Category per US Drought Monitor Definition (<2 % root zone soil moisture) (SSP2-4.5)

Mean Temperature Change



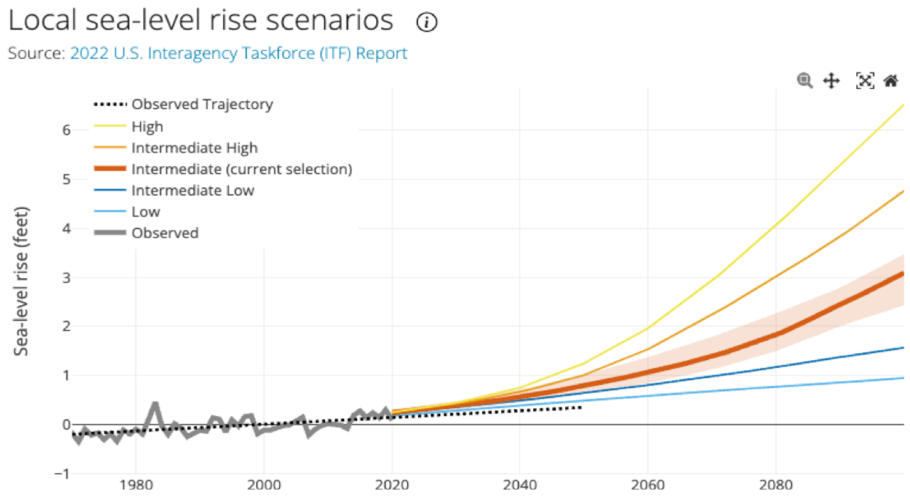
Ben Cook, Sujay Kumar

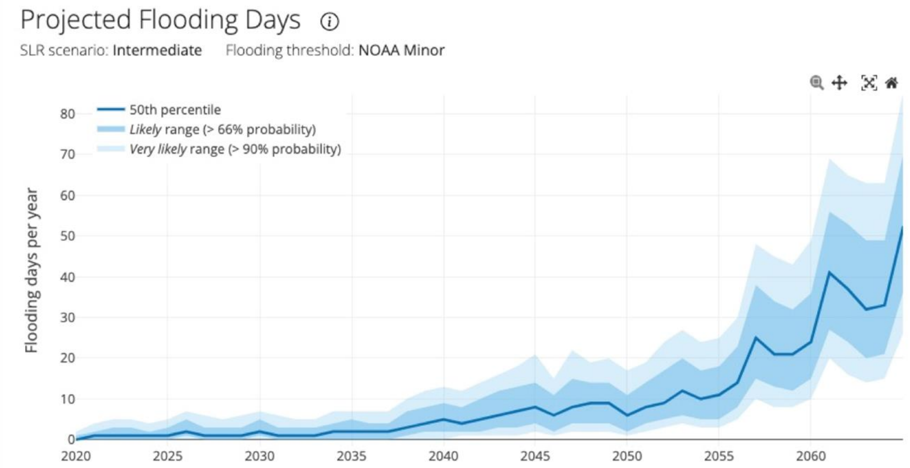
Assess in CASI Initiative

Multiple Risks at Same NASA Center (Ames) (4/4)

Coastal and Inland Flooding: Chronic and Episodic Hazards

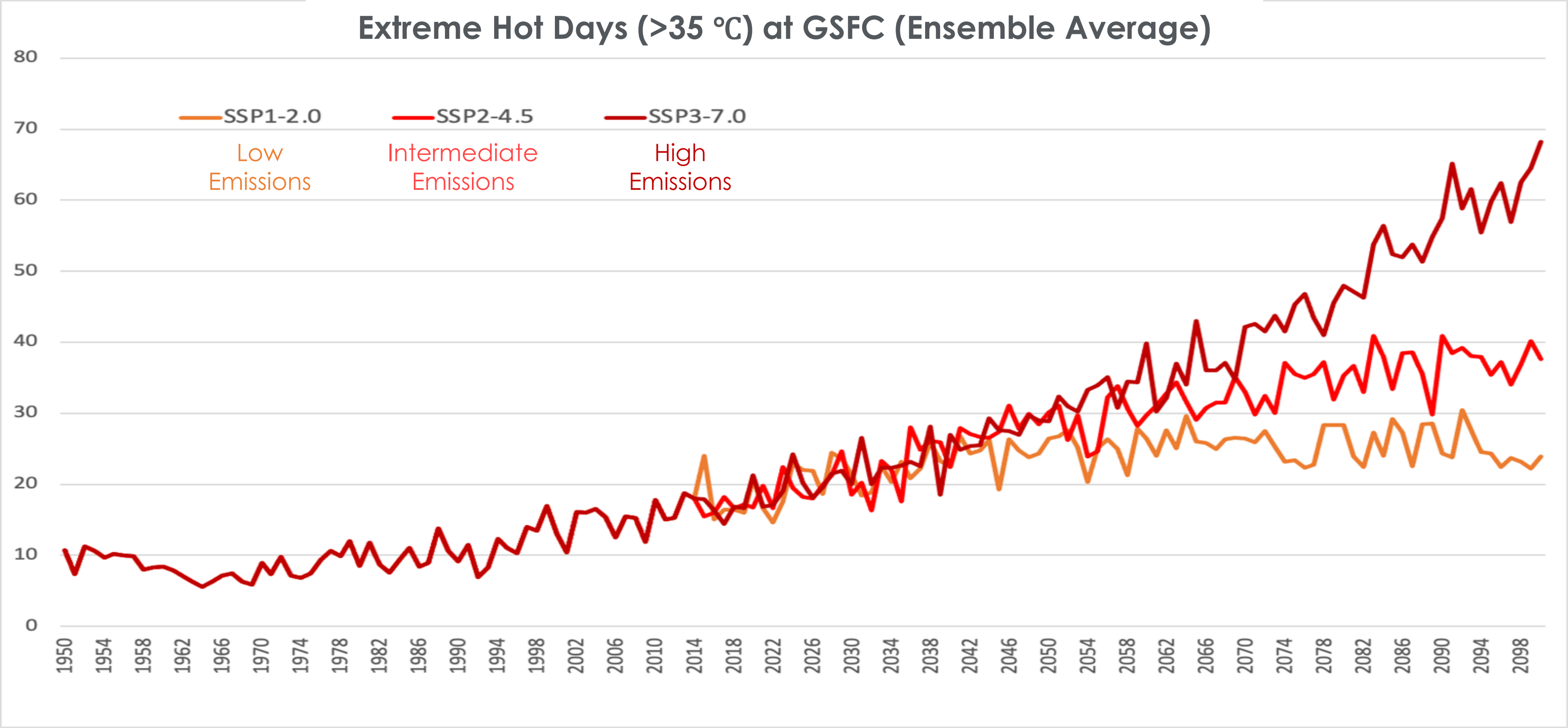
ARC Surface Inundation (blue shades) after Heavy Rainfall Events [based on Synthetic Aperture Radar (SAR) images from the Sentinel-1 satellite]



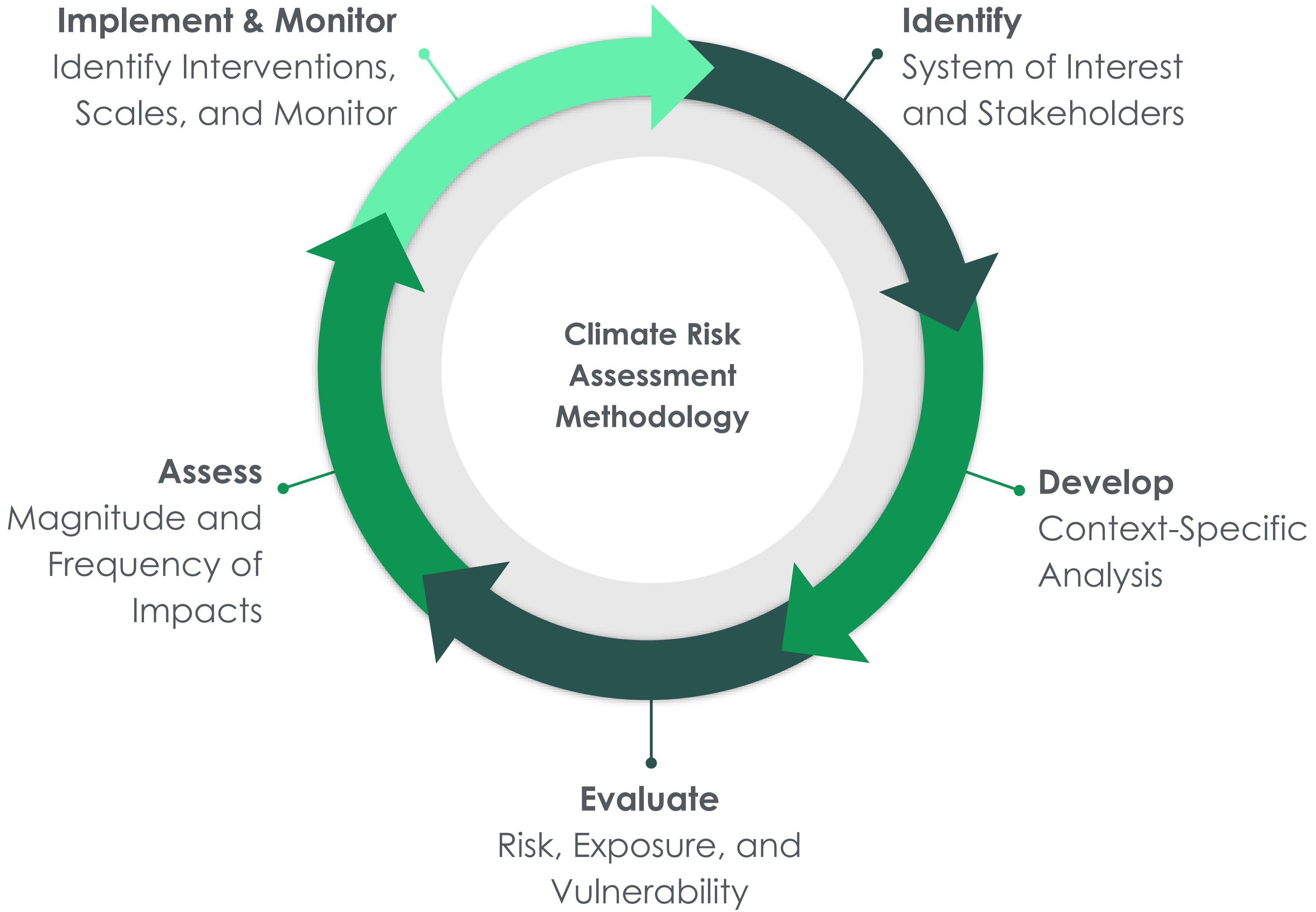


Assess in CASI Initiative

Emissions Scenario Matters



- Risks are generally lower for SSP1-2.6 (low emissions) than SSP2-4.5 (intermediate emissions), and both are less than SSP3-7.0 (high emissions).
- Mitigation beyond Center gate is still critical to addressing adaptation challenge.


Implement & Monitor
Identify Interventions, Scales, and Monitor
Identify
System of Interest and Stakeholders
Climate Risk Assessment Methodology
Assess
Magnitude and Frequency of Impacts
Develop
Context-Specific Analysis
Evaluate
Risk, Exposure, and Vulnerability

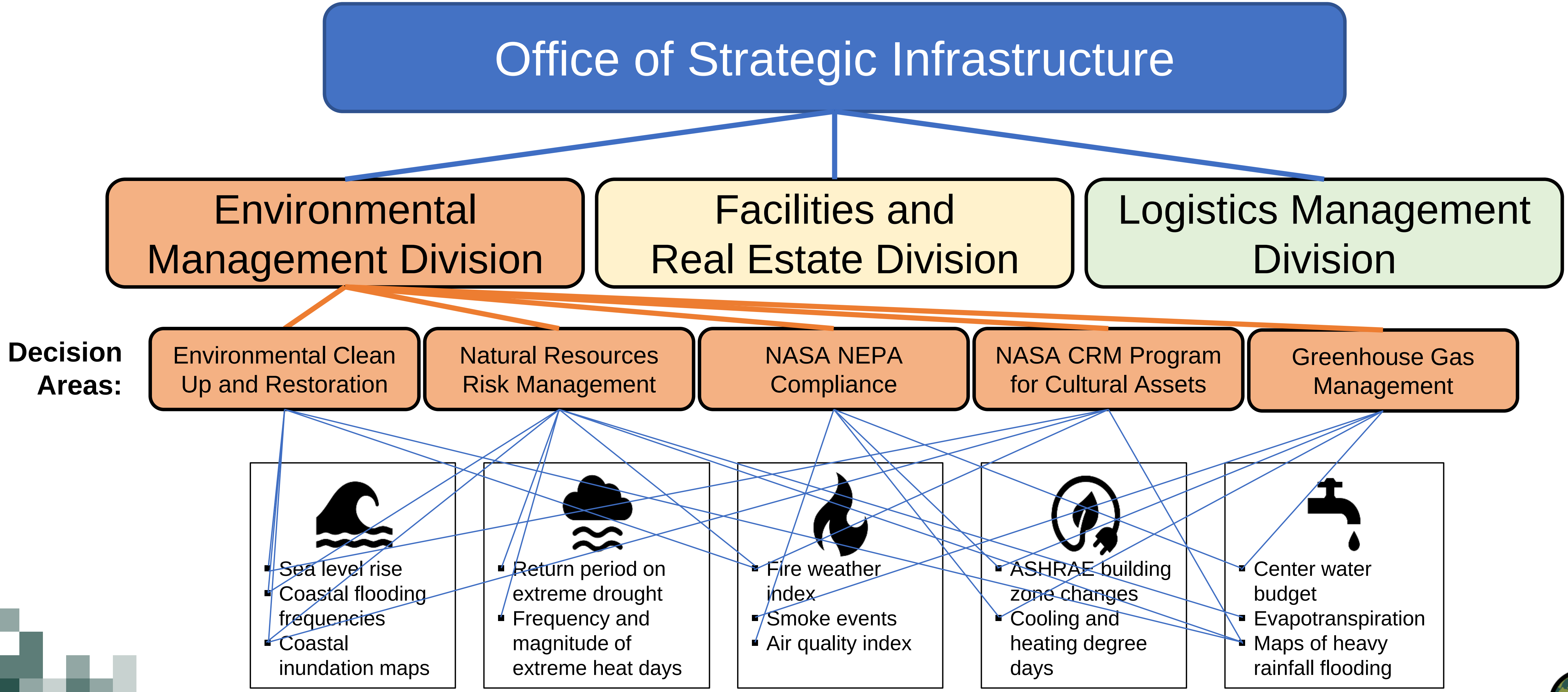
Implement and Monitor in CASI Initiative

CASI2 is an ongoing initiative

- We will present preliminary results with a more formal report planned for late 2023/early 2024.
- Adaptation and mitigation planning still underway across NASA *(timeline for implementation not dictated by CASI)*
- Plan is to deliver CASI2 report and maintain collaboration through consideration of interventions and their implementation

Implement and Monitor in CASI initiative

Mapping decision processes and CASI products to decisions in each OSI Division



Implement and Monitor in CASI Initiative

Informing Ongoing Decision Processes

- Identify reactive and proactive interventions that target acute climate risks
- Recognize multiple time horizons and metrics for success
- Scope out feasibility according to costs, technical capabilities, increase in resilience (effectiveness), intervention lifespan, personnel requirements, economies of scale, existing rehabilitation cycles, and leadership support
- Align interventions with existing rehabilitation cycles
- Deliver findings in existing or new communication products
  - E.g., included in facilities' annual reports, NASA Design Standards document, etc.

NASA White Sands Test Facility, Las Cruces, New Mexico

Implement and Monitor in CASI initiative

Creating Targeted and Synergistic Adaptations

- Working now to create synergies and co-benefits between adaptation, mitigation, and other Center priorities.


NASA Michoud Assembly Facility

Fundamental CASI Findings

Fundamental CASI Findings

Growing Climate Risks Identified by Each CASI Working Group

- **Sea Level Rise and Coastal Flooding**
  - Sea level rise strongly dependent on scenario, with currently rare coastal flooding risks becoming increasingly normal.
- **Extreme Climate Events**
  - Increased heat-humidity events, heavy rainfall, drought, and extreme storms.
- **Fires and Air Quality**
  - Rising risk for wildfire and smoke impacts, particularly for Western centers.
- **Energy**
  - Decreased seasonal heating and increased seasonal cooling loads.
  - Climate zones and associated building energy standard (ASHRAE) changes.
- **Water Budgets**
  - Increased evaporative demand at all centers, even in some regions with increased rainfall.
  - Increased drought in many Western centers.

Fundamental CASI Findings

Examples of Growing Climate Risks Across Centers

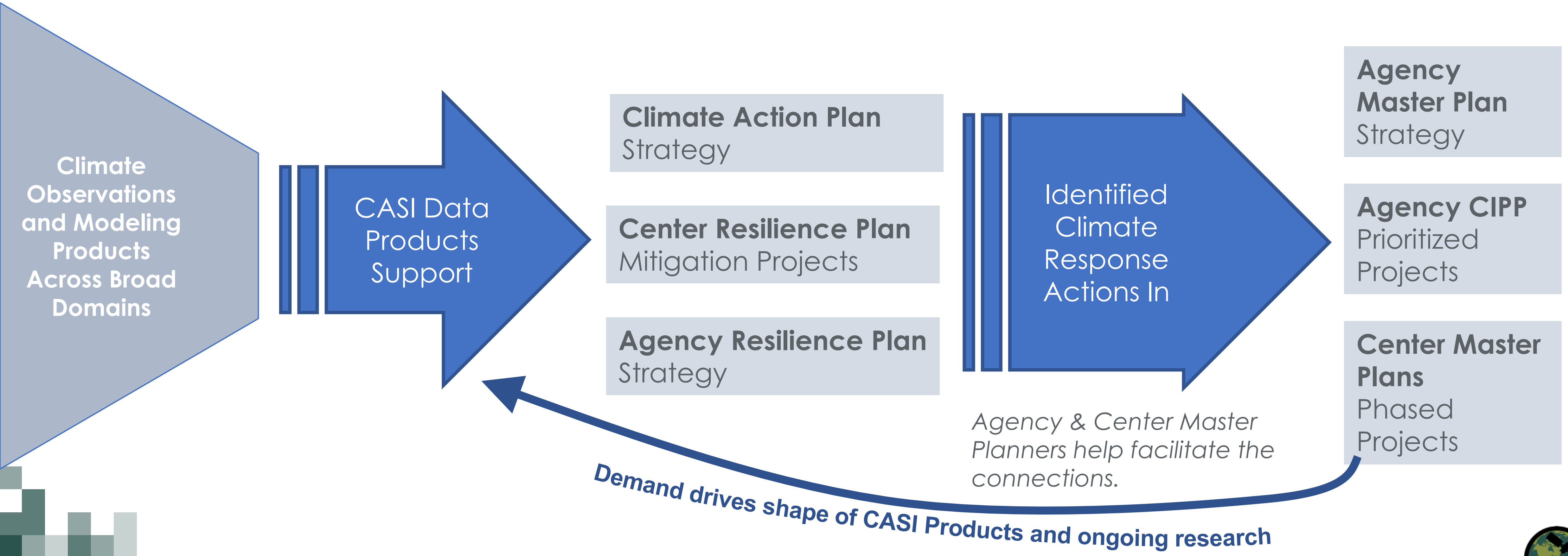
- **All Centers** are projected to experience increase in extreme heat, with shift from heating toward air conditioning expenses.

- **Langley** is projected to shift from ASHRAE climate zone 3 to 2 in the 2060s under the high emissions scenario.
- **Ames** is projected to experience large increase in frequency of moderate to unhealthy air quality conditions from fires after the late 2070s under the high emissions scenario.
- **Goddard** is projected to experience a 38% increase in extreme inland flood days per year by 2100 under the intermediate scenario
- **Wallops** projections indicate that chronic flooding (at least 50 days per year) becomes likely on an annual basis beginning in 2038 under NOAA's intermediate sea level rise scenario.
- **Kennedy** projections indicate that it is likely to see an increase in chronic coastal flooding beginning in the 2040s and has a 98% chance of at least 20 flooding days in a year by 2030.
- **Johnson** is projected to experience an increase in cooling degree days by at least 5% under the low emissions scenario, 9% under the intermediate, and 14% under the high emissions scenario.

Fundamental CASI Findings

Providing Targeted Information to Support Climate Decisions

CASI data and products help Agency and Center Master Planners incorporate climate risk information into ongoing planning processes.



Theoretical Approach Helps CASI Achieve Decision Support Goals

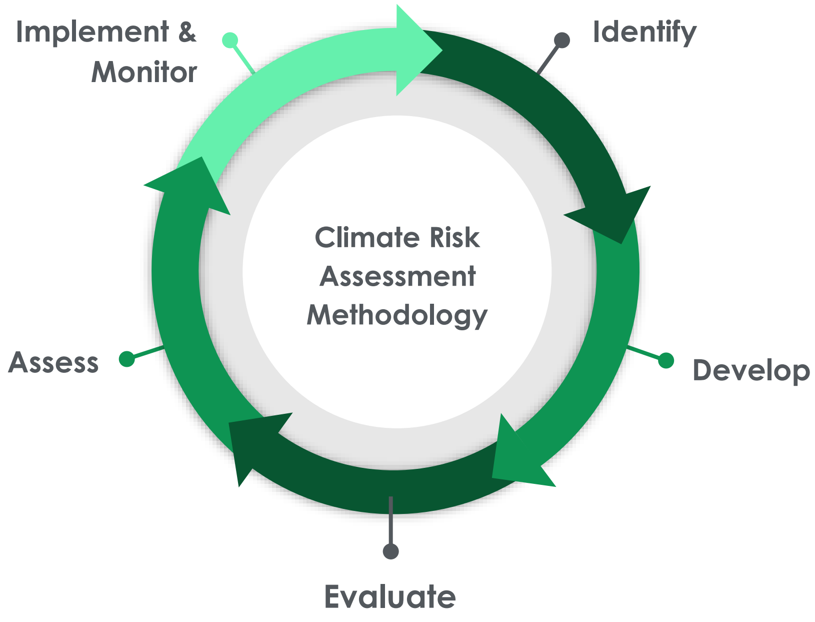
Based Upon Inclusive and Comprehensive Climate Risk Assessment

- **Identify** partners, stakeholders, and vulnerable assets
  - CASI approach allows climate information to be tailored to decision processes
- **Develop** scientific plan to assess shifts in climate conditions
  - CASI approach allows for contextual analysis in close collaboration with partners
- **Evaluate** vulnerable assets and conditions driving climate risk
  - CASI approach selects climate products to match hazards that drive risk for key assets
- **Assess** changing climate risks across centers, hazards, and scenarios
  - CASI approach is producing risk assessments and characterizing uncertainty across models and scenarios
- **Implement** findings into decision processes, then **monitor** and re-assess
  - CASI approach connects information with decisions in support of sustained scientific engagement and flexible adaptation pathways tailored for each Center

Summary

Summary

- **CASI provides** a portfolio of key current and future climate risk information for Center managers and their regions.
- These products are co-generated and linked to decisions protecting Center assets, infrastructure and workforce.
- Centers can use risk information to identify adaptation strategies for implementation



Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 9/21/2023
  - Access from the training webpage
  - Answers must be submitted via Google Form
  - **Due by 10/5/2023**

- **Certificate of Completion:**
  - Attend all live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

Trainers:
- Alex Ruane
  - alexander.c.ruane@nasa.gov
- Sanketa Kadam
  - ssk2241@columbia.edu

CASI Point of Contact:
- Nick Pelaccio
  - nick.pelaccio@nasa.gov

- ARSET Website
- Follow us on Twitter!
  - @NASAARSET
- ARSET YouTube

Visit our Sister Programs:
- DEVELOP
- SERVIR

Acknowledgements

- Cynthia Rosenzweig (NASA GISS)
- Nick Pelaccio (NASA GISS / Columbia University)
- Daniel Bader (NASA GISS / Columbia University)
- Jack Kaye (NASA HQ)
- Joel Carney (NASA HQ)
- Denise Thaller (NASA HQ)
- Rhonda Pepper (NASA HQ)
- Brenden Deyo (NASA HQ)
- Juan Tiscereno (NASA HQ)
- Rena Schlachter (NASA HQ Master Planner)
- Gavin Schmidt (NASA GISS)
- Paul Stackhouse (NASA LARC)
- Bradley Hegyi (NASA LARC)
- Sujay Kumar (NASA GSFC)
- Benjamin Cook (NASA GISS)
- Benjamin Hamlington (NASA JPL)
- Christopher Potter (NASA ARC)
- Gary Jedlovec (NASA MSFC)
- Laura Iraci (NASA ARC)
- Elizabeth Wiggins (NASA LARC)

…and the rest of the CASI Team!

Thanks also to the ARSET Team!

References

Ara Begum, R., R. Lempert, E. Ali, T.A. Benjaminsen, T. Bernauer, W. Cramer, X. Cui, K. Mach, G. Nagy, N.C. Stenseth, R. Sukumar, and P. Wester, 2022: Point of Departure and Key Concepts. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 121–196, doi:10.1017/9781009325844.003.

Bader, D. A., Blake, R., Grimm, A., Hamdi, R., Kim, Y., Horton, R., and Rosenzweig, C. (2018). Urban climate science. In Rosenzweig, C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. New York. 27–60

Forster, P., T. Storelvmo, K. Armour, W. Collins, J.-L. Dufresne, D. Frame, D.J. Lunt, T. Mauritsen, M.D. Palmer, M. Watanabe, M. Wild, and H. Zhang, 2021: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054, doi: 10.1017/9781009157896.009.

Hausfather, Z., Marvel, K., Schmidt, G. A., Nielsen-Gammon, J. W., & Zelinka, M. (2022). Climate simulations: Recognize the 'hot model' problem. Nature, 605(7908), 26–29. https://doi.org/10.1038/d41586-022-01192-2

Horton, R., De Mel, M., Peters, D., Lesk, C., Bartlett, R., Helsingen, H., Bader, D., Capizzi, P., Martin, S. and Rosenzweig, C. 2017. Assessing Climate Risk in Myanmar: Technical Report. New York, NY, USA: Center for Climate Systems Research at Columbia University, WWF-US and WWF-Myanmar.

Kumar, S., Peters-Lidard, C., Tian, Y., Houser, P., Geiger, J., Olden, S., Lighty, L., Eastman, J., Doty, B., & Dirmeyer, P. (2006). Land information system: An interoperable framework for high resolution land surface modeling. Environmental Modelling & Software, 21(10), 1402–1415. https://doi.org/10.1016/j.envsoft.2005.07.004

New York City Panel on Climate Change 2015 Report Executive Summary. (2015). Annals of the New York Academy of Sciences, 1336(1), 9–17. https://doi.org/10.1111/nyas.12591

Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz Carrascal, J. Sillmann, M.B. Sylla, C. Tebaldi, W. Wang, and R. Zaaboul, 2021: Climate Change Information for Regional Impact and for Risk Assessment. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1767–1926, doi: 10.1017/9781009157896.014.

References (continued)

Ruane, A.C., R. Vautard, R. Ranasinghe, J. Sillmann, E. Coppola, N. Arnell, F.A. Cruz, S. Dessai, C.E. Iles, A.K.M.S. Islam, R.G. Jones, M. Rahimi, D. Ruiz Carrascal, S.I. Seneviratne, J. Servonnat, A.A. Sörensson, M.B. Sylla, C. Tebaldi, W. Wang, and R. Zaaboul, 2022: The Climatic Impact-Driver framework for assessment of risk-relevant climate information. Earth's Future, 10, no. 11, e2022EF002803, doi:10.1029/2022EF002803.

Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.). 2011. Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York. www.nyserda.ny.gov

Rosenzweig, C., Horton, R. M., Bader, D. A., Brown, M. E., DeYoung, R., Dominguez, O., Fellows, M., Friedl, L., Graham, W., Hall, C., Higuchi, S., Iraci, L., Jedlovec, G., Kaye, J., Loewenstein, M., Mace, T., Milesi, C., Patzert, W., Stackhouse, P. W., & Toufectis, K. (2014). Enhancing Climate Resilience at NASA Centers: A Collaboration between Science and Stewardship. Bulletin of the American Meteorological Society, 95(9), 1351–1363. https://doi.org/10.1175/BAMS-D-12-00169.1

Simpson, N. P., Mach, K. J., Constable, A., Hess, J., Hogarth, R., Howden, M., Lawrence, J., Lempert, R. J., Muccione, V., Mackey, B., New, M. G., O'Neill, B., Otto, F., Pörtner, H.-O., Reisinger, A., Roberts, D., Schmidt, D. N., Seneviratne, S., Strongin, S., … Trisos, C. H. (2021). A framework for complex climate change risk assessment. One Earth, 4(4), 489–501. https://doi.org/10.1016/j.oneear.2021.03.005

Stuart, L. et al: Enhancing Global Food Security: Opportunities for the American Meteorological Society (submitted)

Thrasher, B., Wang, W., Michaelis, A. et al. NASA Global Daily Downscaled Projections, CMIP6. Sci Data 9, 262 (2022). https://doi.org/10.1038/s41597-022-01393-4

Thrasher, B., Wang, W., Michaelis, A. Nemani, R. (2021). NEX-GDDP-CMIP6. NASA Center for Climate Simulation. https://doi.org/10.7917/OFSG3345

Zimmerman, R., & Faris, C. (2010). Chapter 4: Infrastructure impacts and adaptation challenges. Annals of the New York Academy of Sciences, 1196(1), 63–86. https://doi.org/10.1111/j.1749-6632.2009.05318.x

Thank You!