Food and Agriculture Organization of the United Nations

REPORT OF PROCEEDINGS

Enhanced global land and water resources assessment for sustainable agriculture in a high-performing on-demand computing environment

27 June 2023

MISSISSIPPI STATE UNIVERSITY

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Published by

Food and Agriculture Organization of the United Nations

Rome, 2023

Required citation:
FAO and MSU. 2023. *Enhanced global land and water resources assessment for sustainable agriculture in a highperforming on-demand computing environment: Report of proceedings,* 27 June 2023. Rome. https://doi.org/10.4060/cc7514en

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Acknowledgements

The Geospatial Unit of the Land and Water Division (NSL) at Food and Agriculture Organization of United Nations (FAO) in collaboration with the Mississippi State University (MSU) organized a joint event on Enhanced global land and water resources assessment for sustainable agriculture in a high-performing on-demand computing environment on 27 June 2023.

We gratefully acknowledge the unwavering support of Matieu Henry, Federica Chiozza, Gianluca Franceschini, Joyce Ahimbisibwe, Dario Spiller, Vanessa Passafaro and Jippe Hoogeveen at FAO, Gunther Fischer at IIASA, and Mimmo Parisi, John Cartwright, and Kerrie Geil at MSU, without whom this event would not have been possible.

The event was made possible thanks to the support of efforts with the International Institute for Applied Systems Analysis (IIASA), the Asian Institute of Technology (AIT) and all the people that were able to take part in the discussions.

The organizers would like to express their sincere gratitude towards the Honorable speakers who participated in the event: Maria Helena Semedo, Deputy Director General (FAO); Lifeng Li, Director of Land and Water Division (FAO); Mark Keenum, President (MSU) and David Shaw, Executive Vice President and Provost (MSU).

Abbreviations and acronyms

AEZ	Agro-ecological Zones
AIT	Asian Institute of Technology
CMIP5	Coupled Model Inter-comparison Project Phase 5
CRU	Climate Research Unit
ESRI	Environmental System Research Institute
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global Agro-ecological Zones
HWSD	Harmonized World Soil Database
IIASA	International Institute for Applied System Analysis
IPCC	Intergovernmental Panel on Climate Change
ISI-MIP	Inter-Sectoral Impact Model Inter-comparison Project
LUT	land utilization type
MSU	Mississippi State University
PyAEZ	Python Agro-Ecological Zoning
RCPs	Representative Concentration Pathways

Background

As the world population is expected to reach 9.7 billion by 2050 (UNDESA, 2017), the degradation of land and water resources and the potential for sustainable and resilient agriculture is the center of much attention as global demands for food, feed and fuel continue to increase at unprecedented rates. More efforts and innovations are needed to understand the agricultural land risks and opportunities and sustainably increase agricultural production, improve the global supply chain, decrease food losses and waste, and ensure that all who are suffering from hunger and malnutrition have access to nutritious food.

With the increasing in-country and local demand for specific assessment, FAO, in collaboration with the International Institute for Applied Systems Analysis (IIASA) and the Geomatics Unit of the Asian Institute of Technology (AIT) developed a free and open-source tool to run Agro-Ecological Zoning (AEZ) at different levels. This tool, named PyAEZ, running on the high-performing supercomputer of the Mississippi State University (MSU) is able to perform billions of calculations required to generate updated global layers on current and future states of land productivity and suitability for different crops, farming practices, water demand, identification of agricultural constraints and yield gaps among many other potential uses.

Taking the opportunity of the presence of the Mississippi State University (MSU) delegation in FAO Headquarters, a joint hybrid event was organized on 27 June 2023 at FAO Headquarters in Rome and online. The event “Enhanced global land and water resources assessment for sustainable agriculture in a high-performing on-demand computing environment” highlighted this collaboration on land evaluation, crop mapping, suitability and agro-ecological zoning, showing the latest advancements in the generation of updated global layers on current and future states of land productivity and suitability for different crops, farming practices, water demand, identification of agricultural constraints and yield gaps among many other potential uses.

This joint event emphasized the importance of technical collaboration between FAO and MSU and acknowledged the collaborative efforts with the International Institute for Applied Systems Analysis (IIASA), the Asian Institute of Technology (AIT), as well as all the international, regional and national organisations that have contributed to the AEZ and GAEZ process.

Openings

Mr. Lifeng Li, Director of Land and Water Division NSL Food and Agriculture Organization of the United Nations (FAO)

Mr. Lifeng Li started the event by introducing Ms. Maria Helena Semedo, Deputy Director General, Food and Agriculture Organization of the United Nations (FAO) and Dr. Mark Keenum, President, Mississippi State University (MSU) and welcomed all participants, in presence and online, to the event "Enhanced global land and water resources assessment for sustainable agriculture in a high-performing on-demand computing environment".

Mr. Lifeng Li highlighted the fundamental importance of land and water resources in various aspects, such as food production, global food security, poverty alleviation, and environmental sustainability. However, he emphasized that these valuable resources face numerous challenges and risks due to human activities and the impacts of climate change. He further explained that the rapid growth of the world population and the ongoing process of urbanization intensify the pressures on land and water resources, necessitating additional areas for agriculture and water availability. Despite the progress made in data sciences and solutions, he acknowledged that more efforts and innovations are necessary to understand the risks involved and to develop integrated management approaches for land and water resources. In response to these challenges, FAO, together with the Asian Institute of Technology (AIT), and the support of the International Institute for Applied Systems Analysis (IIASA) and Mississippi University have collaborated on the development of a free and open-source tool called PyAEZ. This tool, utilizing high-performing computing systems, provides valuable insights into the status of land resources at both global and national levels.

He concluded with a call for active participation and engagement in the subsequent discussions that would follow the opening remarks. Participants were encouraged to contribute their expertise and insights to further enrich the event and foster the development of practical solutions for sustainable land and water resource management.

Ms. Maria Helena Semedo, Deputy Director General, Food and Agriculture Organization of the United Nations (FAO)

Madame Semedo began with a warm greeting extended to all participants and colleagues from MSU, AIT, IIASA and FAO. In particular she acknowledged the presence of Dr. Mark Keenum, the President of Mississippi State University and Mr Lifeng Li, Director of Land and Water Division at the Food and Agriculture Organization of the United Nations (FAO). She expressed appreciation for the longstanding cooperation between FAO and MSU, emphasizing the importance of their technical collaboration on land and water issues together with the contributions of IIASA and AIT.

With the global population projected to reach 8.6 billion in 2030, 9.8 billion in 2050[1], she emphasized the need for innovative solutions to increase productivity, reduce food loss and waste, improve value chains, address malnutrition, and enhance food security. She highlighted the unfortunate reality that

[1] UNDESA. (2017). World Population Prospects 2017 – Data Booklet (ST/ESA/SER.A/401). United Nations, Department of Economics and Social Affairs, Population Division, 1–24.

over 800 million people already suffer from hunger and malnutrition, despite the availability of sufficient food. The need to access to up-to-date and timely global and national information on natural resources was identified as crucial for making informed decisions. Highlighting the significance of harnessing advancements in geospatial science, Madame Semedo emphasized the crucial role of dynamically characterizing the condition of land and water resources, as well as their potential for crop occurrence. FAO and MSU have formed a robust partnership since 2010, which has facilitated the exchange of expertise, knowledge, and vital information for decision making and planning. Collaboration with IIASA on the development of Global Agro-Ecological Zoning was also highlighted, which has produced critical information on future crop production under climate change scenarios and the significant progress made thanks to the collaboration with AIT in improving access to an innovative free and open-source application for land evaluation, PyAEZ (Python Agro-Ecological Zoning package), to support to countries.

In conclusion, Madame Semedo emphasized the importance of pooling resources, expertise, and knowledge to provide solutions and drive transformative change. Moving beyond pilot initiatives, she stressed the need to scale up efforts and involve all stakeholders to achieve meaningful results in transforming the agri-food system. She expressed gratitude to all partners and participants for their involvement and thanked the technical experts for joining forces to make the collaboration successful.

Dr. Mark Keenum, President, Mississippi State University (MSU)

Dr. Mark Keenum thanked FAO's Deputy Director General Madame Semedo for her appreciation and remarks. The partnership and friendship between the organizations were acknowledged and highly valued. The President introduced the distinguished team from MSU, including the Provost and Executive Vice President, Dr. David Shaw, Dr. Mimmo Parisi, professor in data science, Dr. John Cartwright, a professor at Geosystems Research Institute of MSU, and Dr. Kerrie Geil, professor in Geosciences.

He highlighted the university's excellence in agricultural research, engineering, and high-performance computing, emphasizing their position as a leading agricultural research institution in the United States. MSU is prominent player in high-performance supercomputing, the President shared the university's impressive achievements in the field. Mississippi State University ranks number 5 among all universities in the nation for high-performance supercomputing, and the state itself is ranked number 4 in terms of supercomputing capacity. The President emphasized the importance of leveraging supercomputing capacity to drive meaningful innovations, find solutions, and make informed decisions. He stressed the significance of collaboration and utilizing big data to address global challenges. Addressing the issues of a growing global population and food insecurity requires research, technology, innovation, and partnerships. The President expressed the university's commitment to working closely with FAO to tackle these challenges and make a difference.

In conclusion, the President expressed gratitude for the opportunity to participate in the event and underscored the university's dedication to global problem-solving.

Exploring frontiers in data sciences for innovative land and water resources assessment: big data and computing

Mr. Matieu Henry, a.i. Head Geospatial Unit, Land and Water Division (NSL), Food and Agriculture Organization of the United Nations (FAO)

Mr. Matieu Henry gave a brief presentation on innovative land and water resources assessment highlighting the importance of technological advancement in data analytics and remote sensing in the context of food security, population growth and the increasing challenges related to access to natural resources and food security. The long collaboration with IIASA on developing the Agro- Ecological zoning (AEZ) methodology, a land evaluation approach that has been adopted in several countries to provide technical capacity and information for national investment was emphasized. This year the collaboration has been extended to MSU, considering the increasing demand for information related to future food production especially yield and productivity at a higher resolution. The Global Agro-Ecological Zoning platform, with about 300 000 global layers from 1–10km resolutions spatial resolution, has had over 15 million visitors showing the high potential to increase number of crops as well as spatial resolution and increase open-source access to this data. He concluded by mentioning that FAO may be interested in linking and benefiting from this collaboration in the context of AEZ, land evaluation, land cover, mapping and other natural resource information that integrates land, soil and water.

Dr. Mimmo Parisi, Senior Advisor of European and Data Science Development, Mississippi State University (MSU)

Dr. Mimmo Parisi thanked the president of MSU for his presence and commitment to work and fight for important issues at global level. The scientists are committed to work on technical details of how to make the collaboration work, how to visualize data for decision making and towards addressing hunger and poverty using data, science and artificial intelligence in a realistic way. He emphasized that the collaboration would work towards understanding how to use mass saver metadata and how to use the experience that has been developed and accumulated over the past decade through data science methods and technologies such as AI, high performance computing to solve real world problems. He concluded by pledging that their institution is committed towards achieving the set goals of this collaboration.

Session overview: collaboration on land evaluation, crop mapping, suitability and agro-ecological zoning between FAO-MSU-IIASA-AIT

Mr. Gianluca Franceschini, Senior Geospatial Analyst, Geospatial Unit, Land and Water Division (NSL), Food and Agriculture Organization of the United Nations (FAO)

Mr. Gianluca Franceschini gave a brief presentation (see Annex) on the history of Agro-Ecological Zoning which started in the 1970's with the formulation of the land evaluation framework which provided a technical background for further analysis with the first principle being applied in Bangladesh, China and Kenya. Rapid developments in information technology have produced increasingly detailed and manifold global databases, which made the first global AEZ assessment possible in 2000. With each update of the system, the issues addressed, the size of the database, and the number of results has increased significantly. The current work with IIASA, AIT and MSU on the latest global assessment will give a better understanding of the environment and in particular of future climate scenarios. He emphasized the need to make the code open to countries pushed the development of a Python package for Agro-ecological zoning (PyAEZ). PyAEZ is based on python code while GAEZ is based on the Fortran code. MSU will set up the two Fortran and python together to run together to understand the feasibility of applying PyAEZ at global scale in terms of system requirements and verify that outputs are consistent with the original Fortran code which will give faster outputs.

Mr. John Cartwright, Assistant Extension Professor, Mississippi State University (MSU)

Dr. John Cartwright presented briefly the MSU High Performance Computing (HPC) Environment highlighting that it's composed of many computer processors linked together with a centralized communication system that a user can interact with from their personal computer. A collaborative high performance compute environment was established through the collaboration, training and support is provided on the use of MSU HPC resources for both PyAEZ and GAEZ to facilitate the use and feasibility of applying PyAEZ at global scale. The goals of the optimization process are: i) to improve the run time required for PyAEZ/GAEZ and, II) to enable PyAEZ to run with bigger data (higher resolution and/or global domain) even on machines where the size of the data inputs may be bigger than the available computer memory. He gave an example of China at a scale of approximately 300 000 pixels), the speed of PyAEZ v2.0.0 Module I by a factor of 11 has been increased. Previously, the v2.0.0 module 1 took about 10.5 minutes to run at this scale and it's now been brought down to about 55 seconds. The speed is expected to be further optimized to approximately scale for global data inputs and outputs (approx. 7.7 million pixels). PyAEZ will be able to run with global or high-resolution inputs and outputs in a reasonable amount of time on a laptop.

Mr. Günther Fischer, Senior Researcher, International Institute for Applied Systems Analysis (IIASA)

Mr. Günther Fischer started his presentation on the GAEZ version 5 developments by highlighting what will be different in this version which include Input data update to base year 2020, additional crops (now > 350 LUTs) parameterized, methodological changes and downscaling of 2019-2021 crop area and production statistics. Some of the outputs are already available such as module one on climatic indicators with historical data and future trajectories. He presented an example on rain-fed conditions the simulated length of growing period for historical climate and conditions projected by the Earth System Model GFDL-ESM4 and for rain-fed and irrigated conditions under simulated multi-cropping zones for historical climate and conditions projected by the Earth System Model GFDL-ESM4. The collaboration with MSU will contribute to completing GAEZ v5 that will require a large computational effort for historical trajectory of 1980 to 2022, 15 future CMIP6 climate trajectories for 2021 to 2100 and >350 LUTs at 2 (possibly more) input/management levels. In conclusion, he emphasized that through collaboration with MSU there will be an opportunity to simulate GAEZ v5 production runs with access to HPC resources which will allow higher resolution for regional products and full time-series analysis for all major crops.

Future perspectives and closing remarks

Mr. Lifeng Li, Director of Land and Water Division (NSL), Food and Agriculture Organization of the United Nations (FAO)

Mr. Lifeng Li appreciated all the participants for their participation and attention during the event and appreciated the recent assessments, projections and scenarios from the international community have shown the continued and increasing depletion of land and water resources, loss of biodiversity, associated degradation and pollution, and scarcity in the primary natural resources.

He commended the distinguished panelists and discussants for the substantial progress made so far in data sciences and innovations in understanding the agricultural land risks and opportunities, towards sustainable land management, conservation of natural resources, ecosystem and climate change benefits. This event was very informative and will hopefully contribute to exploration of different options available to support generating useful data and information at different spatial levels and for different time horizons, benefiting Ministries, agricultural extension office, practitioners and farmers. He mentioned that the Land and Water Division (NSL) is taking the lead on the Soil-Land- Water Digital Information System (SoLaWISe) Initiative, aimed at supporting sustainable Land, Soil and Water management through integrated approaches, increased technical capacities, better information and targeted decision-making.

He concluded by emphasizing the importance of partnerships, collaborations and the essential contribution of appropriate policies, institutions and investments towards build awareness of the status of land and water resources, highlighting the risks, and informing on related opportunities and challenges for a better tomorrow.

Dr. David Shaw, Executive Vice President and Provost, Mississippi State University (MSU)

Dr. David Shaw commenced with expressing his delight at the opportunity to engage in a technical discussion in the field of precision agriculture and remote sensing, taking them on a nostalgic trip down memory lane. He shared that MSU has had experience of working in this arena 25 years ago and highlighted the significance of high-resolution data and its transformation from massive amounts of information to actionable decision making.

He gave a recap of the combination of the 3 major points of discussion i.e. Data, more data and better data as well as what to do with it. An agreement of partnership has been signed between FAO and MSU towards achieving this. He mentioned that MSU pledged to identify the niche areas of need at FAO and bring their expertise and that they are looking forward to contribute to achieving the Sustainable Development Goals which are a priority at FAO. Dr. Shaw acknowledged the recent partnership agreements and announcements, underscoring the importance of collaboration and also emphasized the value of partnerships in research, teaching, and service, citing examples of collaborations with universities, federal and international agencies, and various partnership agreements.

He concluded by expressing MSU’s enthusiasm for translating the insights and discussions from the session into future opportunities that would help address FAO's priority Sustainable Development Goals. He extended his gratitude for the chance to be part of the event and concluded by thanking all the participants and FAO for hosting them.

Annex

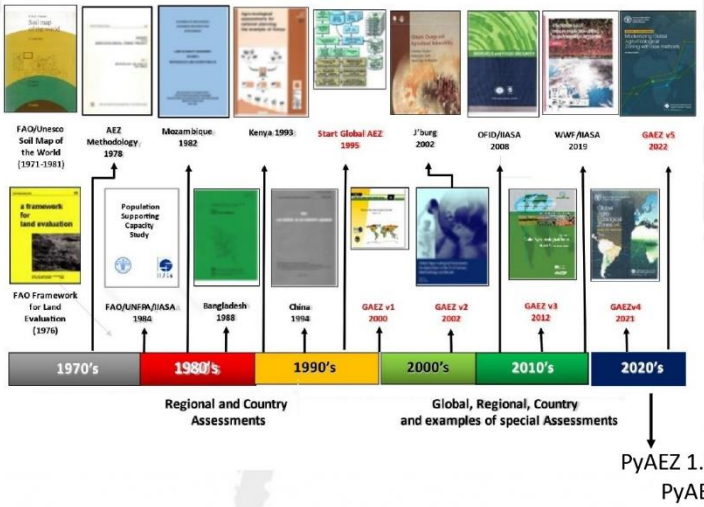
Collaboration on land evaluation, crop mapping, suitability and agro-ecological zoning

FAO-MSU-IIASA-AIT

Gianluca Franceschini, Geospatial Unit, Land and Water Division (NSL), FAO
John Cartwright, Geosystems Research Institute, Mississippi State Univeristy
Günther Fischer, International Institute for Applied Systems Analysis (IIASA)

WWW.FAO.ORG/GAEZ

History AEZ



Rapid developments in information technology have produced increasingly detailed and manifold global databases, which made the first global AEZ assessment possible in 2000. Since then, Global AEZ assessments have been performed every few years.
With each update of the system, the issues addressed, the size of the database, and the number of results have increased significantly.
The need to make the code open to countries pushed the development of a Python package for Agro-ecological zoning (PyAEZ).

PyAEZ & GAEZ on MSU

PyAEZ

- Based on Python
- Code open, documented and available at GitHub
- National and Regional assessments
- Initially developed for Lao PDR, with limitations on scaling-up to non-tropical contexts
- Easy set-up also on cloud-computing
- Only subset of GAEZ v4 functions available

GAEZ / NAEZ

- Based on Fortran
- Code not distributed for external users / code shared in projects
- Global, National and Regional assessments
- Repository of various ancillary modules and algorithms developed during the history of GAEZ
- Computationally efficient
- Complete suite of all GAEZ v4 assessment modules available

PyAEZ & GAEZ on MSU

PyAEZ

MSU HPC

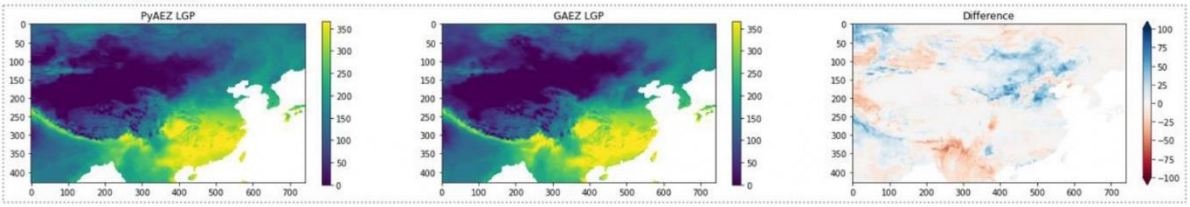
GAEZ

MSU HPC

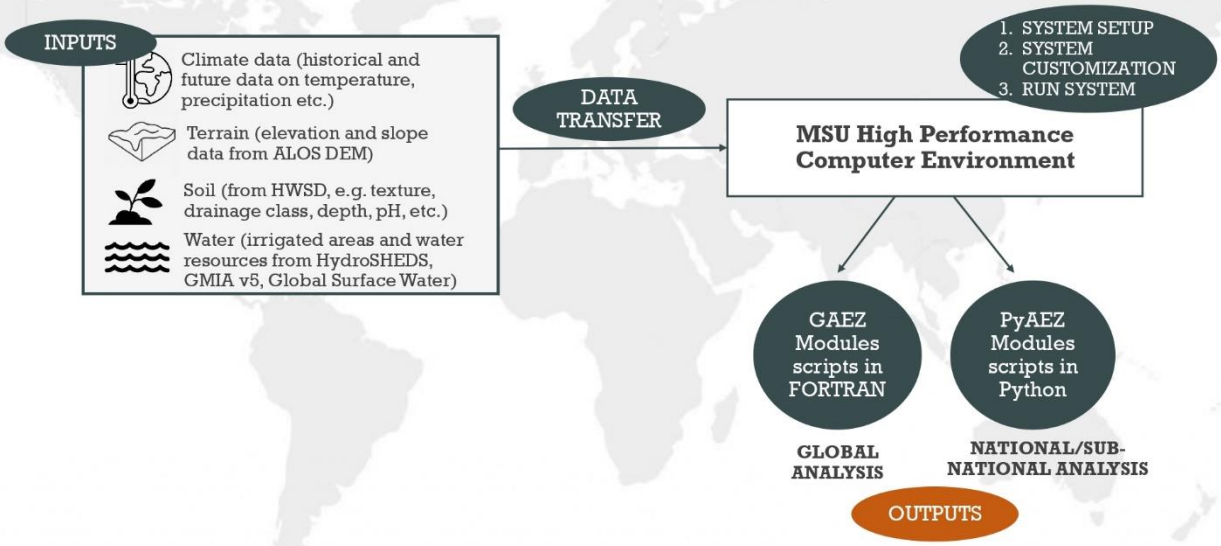
The objective of running both the systems is to understand the feasibility of applying PyAEZ at global scale in terms of system requirements and verify that outputs are consistent with the original Fortran code.

Output comparison – using the same input data

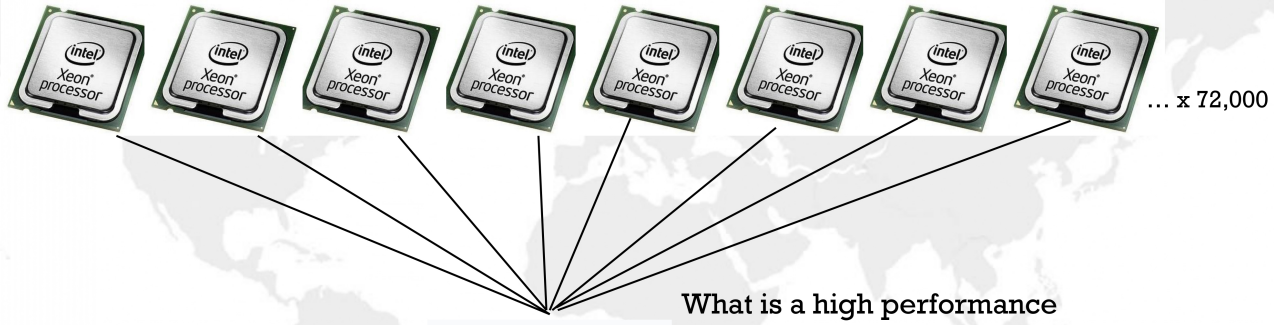
Current modification



Process workflow



MSU High Performance Compute Environment



What is a high performance computer?

Many computer processors linked together with a centralized communication system that a user can interact with from their personal computer (or a from a web interface).

MSU High Performance Compute Environment

To facilitate the use and feasibility of applying PyAEZ at global scale a collaborative high performance compute environment was established.

Through the collaboration training and support is provided on the use of MSU HPC resources for both PyAEZ and GAEZ.

Initial efforts are focused on:

- Scaling and running PyAEZ module 1 for global high-resolution inputs and outputs
- Performance optimization/testing of PyAEZ (speed improvements)
- Plans for scaling, optimizing, and running additional PyAEZ modules at global high resolution

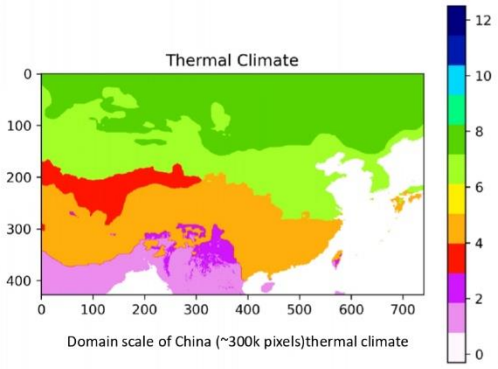
PyAEZ Optimization

Optimization Goals

- Improve the run time of PyAEZ/GAEZ
- Enable PyAEZ to run higher resolution and/or global domain data

Current Progress

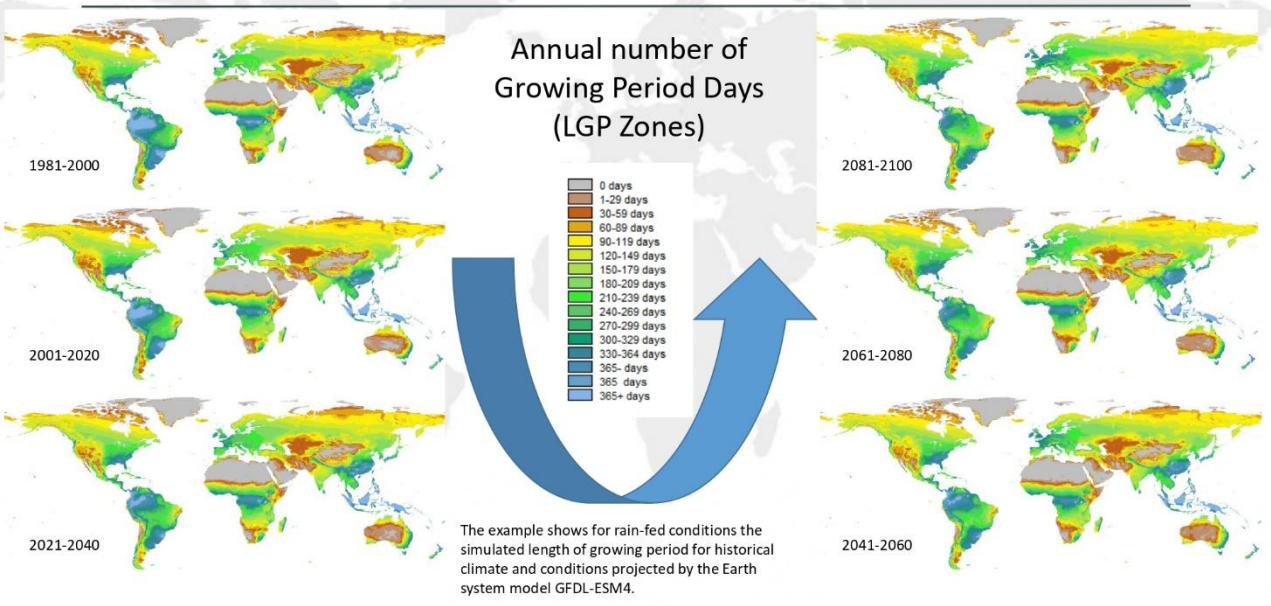
- Domain scale PyAEZ Module 1 speed improvements by a factor of 11
- Speed optimization is expected to scale for global data inputs and outputs
- Optimization will enable the ability to run global or high-resolution inputs and outputs without needing HPC enviroment



GAEZ v5 Development

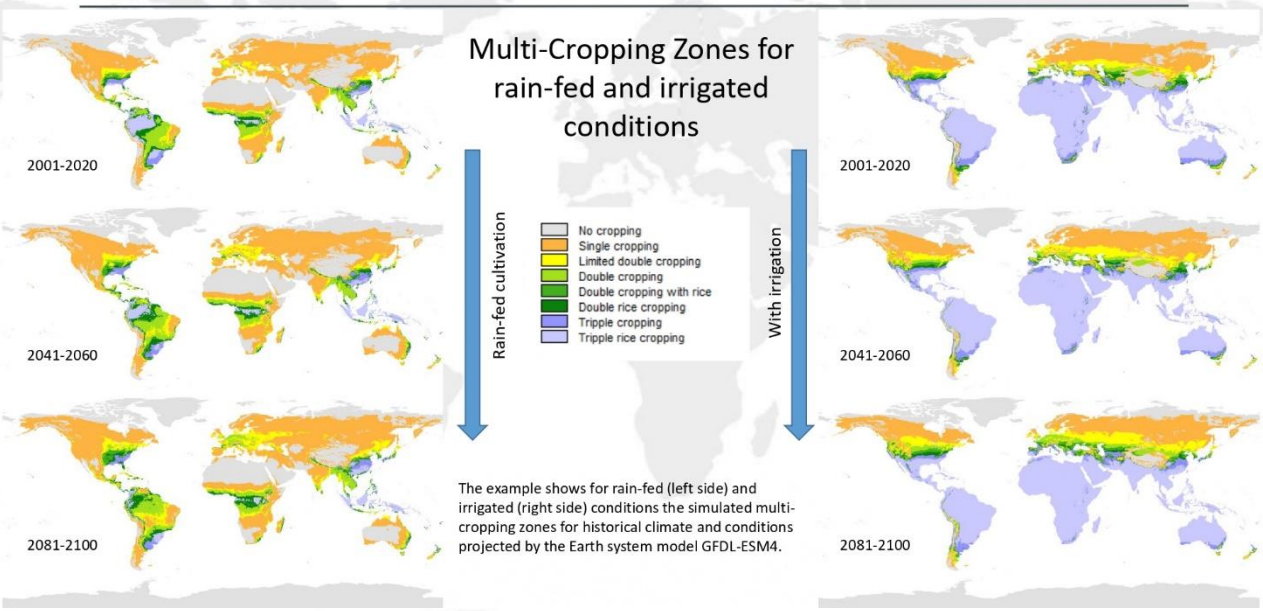
1. Input data update to base year 2020
   - Climate database for 1980-2022 based on AgERA5
   - Future climate projections based on CMIP6 (5 ESMs and 3 Pathways)
   - Harmonized land cover based on recent high-resolution LC products; calibration of cropland and forest areas to available FAO statistics
   - Harmonized global soil database HWSD v2
   - Updated 'exclusion' layer: Protected areas, Key biodiversity areas, Forest areas, Wetlands
2. Additional crops (now >350 LUTs) parameterized
3. Methodological changes
   - Daily ET0 and water balance using daily data for all climate attributes
   - Enhanced edaphic evaluation procedures (7 soil depth levels; use of specific plant rooting depths)
4. Downscaling of 2019-2021 crop area and production statistics

GAEZ v5 Outputs are becoming available …



The example shows for rain-fed conditions the simulated length of growing period for historical climate and conditions projected by the Earth system model GFDL-ESM4.

GAEZ v5 Outputs are becoming available …



Completing GAEZ v5 requires a large computational effort

- Historical trajectory of 1980 to 2022
  - Yearly results and summaries for two 20-year periods (1981-2000, 2001-2020)
- 15 future CMIP6 climate trajectories for 2021 to 2100
  - Portrays transitions of crop suitability and attainable yields for 80 years and four 20-year periods (2021-2040, 2041-2060, 2061-2080, 2081-2100)
  - By individual ESMs and for ensemble means
- >350 LUTs at 2 (possibly more) input/management levels
  - Simulations require daily crop water balances
  - Automatic crop calendars

➢ Through collaboration with MSU there is an opportunity to simulate GAEZ v5 production runs with access to HPC resources.

➢ This will allow higher resolution for regional products and full time-series analysis for all major crops (was not possible with computer resources available for GAEZ v4).

FAO, in collaboration with the International Institute for Applied Systems Analysis (IIASA) and the Geomatics Unit of the Asian Institute of Technology (AIT) developed a free and open-source tool to run Agro-Ecological Zoning (AEZ) at different levels. Powered by Mississippi State University's high-performing supercomputer, PyAEZ generates global layers on land productivity, crop suitability, and water demand, facilitating identification of constraints and yield gaps.
FAO and MSU jointly hosted an event on 27 June 2023, showcasing advancements in land evaluation, crop mapping, and agro-ecological zoning for sustainable agriculture.

Land and Water Division - Geospatial Unit
Food and Agriculture Organization of the United Nations
Rome, Italy

CC7514EN/1/09.23