**Characterization of coastal circulation and pollutant distribution:**

**Benchmark studies using RRFS-CMAQ**

Funding Opportunity Number: NOAA-OAR-WPO-2022-2006969

Targeted Competition: Fire Weather & Atmospheric Composition (FWAC)

Targeted Priority Area: AC-1

Date of Submission: November xx, 2021

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| --- | --- |
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Rajesh Kumar, National Center for Atmospheric Research

**Collaborator:** Jeffery McQueen, Michael Barlage, and Jianping Huang, NOAA/NCEP

Rick Saylor, NOAA/ARL

**Proposed Budget:**

| **Institute** | **Investigator** | **Year 1** | **Year 2** | **Year 3** | **Total** |
| --- | --- | --- | --- | --- | --- |
| UA | Lu, Freedman & Gonzalez-Cruz | $137,268 | $138,616 | $139,707 | $415,591 |
| SBU | Colle | $59,750 | $86,943 | $93,291 | $239,984 |
| NCAR | Alessandrini & Kumar | $60,000 | $60,000 | $60,000 | $180,000 |
| GMU | Baker | $30,000 | $30,000 | $30,000 | $90,000 |
| **Total** |  | $287,018 | $315,559 | $322,999 | $925,576 |

**Characterization of coastal circulation and pollutant distribution:**

**Benchmark studies using RRFS-CMAQ**

PI: Cheng-Hsuan (Sarah) Lu, University at Albany, State University of New York (SUNY)

Co-PI: Brian A. Colle, Stony Brook University, SUNY

Jeffrey M. Freedman and Jorge Gonzalez-Cruz, University at Albany, SUNY

Rajesh Kumar and Stefano Alessandrini, National Center for Atmospheric Research

Barry Baker, George Mason University

Collaborator: Jeffery McQueen, Michael Barlage, and Jianping Huang,NOAA/NCEP

Rick Saylor, NOAA/ARL

**ABSTRACT**

Within coastal regions, accurate air quality and meteorological monitoring is lacking and reliable forecasts can be problematic. Yet both elements are critical for determining exposure abatement and mitigation strategies. We propose a three-year collaborative project to characterize urban air quality and meteorology over two coastal urban environments, New York City, NY and Houston, TX, using the integrated Rapid Refresh Forecast System with CMAQ chemical mechanism (RRFS-CMAQ). The overarching goal of this collaborative project is process-level understanding of coastal air quality and meteorological processes through observation, modeling, and analysis to support the development and improvement of NOAA’s next generation air quality model, RRFS-CMAQ. Anticipated outcomes include: (i) comprehensive observational and modeling AQ-meteorology data set for RRFS-CMAQ evaluation and benchmark dataset for future RRFS-CMAQ science improvements; (ii) benchmark study for RRFS-CMAQ over NYC and Houston metro regions; and (iii) prototype on-demand urban modeling within the RRFS-CMAQ. Our project directly responds to FY2022 Fire Weather & Atmospheric Composition (FWAC) program priority AC-1 to enhance RRFS-CMAQ capabilities in representation of pollutant distribution and local circulation in the coastal urban environment.

1. **PROBLEM STATEMENT**

**Statement of Need**

As of 2017, 94 million people, about 29% of total US population, live in coastal counties, which account for about 10% of land area in the contiguous US (US Census 2018). Within coastal regions, however, accurate air quality (AQ) and meteorological monitoring is lacking and reliable forecasts can be problematic. Yet both elements are critical for determining exposure abatement and mitigation strategies. For instance, the New York City (NYC) metro area, home to more than 20+ million people, is an Environmental Protection Agency (EPA) nonattainment region for ozone (O3). This region is surrounded by large water features including the New York Bight, the Long Island Sound, New York Harbor, and the Hudson River Estuary. Physical processes that affect the coastal environment are unique because of the dominant effect of the thermodynamic gradients at the land-water interface (e.g. sea, bay, lake). Their thermal contrast contributes to the formation of sea breezes, coastal atmospheric fronts, intense convective processes and induced precipitation, and atmospherically induced coastal ocean currents and upwelling [Miller et al. 2003; Hughes and Veron 2018]. The ability to accurately predict air quality in coastal environments depends largely on advanced and adaptable knowledge of coastal atmospheric boundary layer dynamics. Sea breeze circulations and low-level jets (LLJ) frequently occur during the summer season (Colle and Novak, 2010; McCabe 2021; Gamarro et al. 2021) and are modulated by the interaction with the urban heat island (UHI) and coastal topography. This poses a challenge for AQ models in capturing the intricate atmospheric interaction with the complex coastline and estuaries encompassing complex coastal-urban regions such as NYC and Houston.

Addressing these challenges requires the use of comprehensive observational datasets and AQ models representing processes across a range of scales. Key questions we seek to address include: how are 3-D near surface coastal atmospheric turbulence processes at multiple scales influenced by the unique topographic and energetic surface heterogeneity characteristic of coastal cities and natural environments? How do these processes affect the distribution of pollutants in major coastal metropolitan regions? The proposed work intends to address these questions, and therefore the current observational and modeling gaps extant in NOAA’s AQ forecasting capabilities.

**Motivation and Project Objectives**

Over the coastal urban region, precursor emissions and hence pollutant production and transport are strongly influenced by meso- and micro-scale meteorological processes. For instance, observational and modeling studies indicate that sea breeze circulation, with its associated phenomena of reduced mixing depths, fumigation, and recirculation, can exert control on mesoscale air pollution patterns in urbanized coastal areas (Schultz and Warner, 1982; Gaza, 1998; Banta et al. 2005). During the Long Island Sound Tropospheric Ozone Study (LISTOS) field campaign, spatial heterogeneity in surface ozone observed by a mobile laboratory (Zhang et al., 2020) and complex ozone vertical structures sampled by ozonesondes (Couillard et al., 2021) were attributed to sea breeze circulation. Modeling experiments by Ma et al. (2021) highlighted the importance of spatially resolved emission and meteorology for improving predictability of high ozone episodes during LISTOS.

The overarching goal of this collaborative project is process-level understanding of coastal air quality and meteorology through observation, modeling, and analysis to support the development and improvement of NOAA’s next generation air quality model, RRFS-CMAQ. The scientific objectives of this 3-year project are to:

# Characterize the influence of meteorological fields (land-sea breeze, LLJ, and UHI) on pollutant distributions over two coastal metro areas (NYC, NY and Houston, TX);

1. Assess how well RRFS-CMAQ can capture meteorological processes and their impact on air quality over coastal urban environments; and
2. Enhance RRFS-CMAQ by improving characterization of coastal-related processes and introducing an urban modeling component.

**Relevance to FWAC Program Priorities**

Our project directly responds to FY2022 Fire Weather & Atmospheric Composition (FWAC) program priority AC-1 to enhance RRFS-CMAQ capabilities in representation of pollutant distribution and local circulation in the coastal urban environment.

**Prior Relevant Research**

***Lu (UAlbany PI).***  *New York State Energy Research and Development Authority (NYSERDA): IDEA-NYS air quality forecast and analysis system: Real-time aerosol detection, monitoring, and trajectories in NYS (PI: Lu; $537,316; 02/2017-02/2023).* This project develops a real-time aerosol forecast and analysis system for NY, resulting from the adoption of air quality forecasting system and the utilization of aerosol measurements from satellite sensors and NYS Mesonet (NYSM) network. The air quality model was used to study re-noxification in NYS (Ninneman et al, 2020). The NYSM profiler observations were used to investigate long-range transported smoke plumes and its impact on NYS air quality (Hung et al., 2020).

***Colle (SUB PI).*** *NOAA-CSTAR: An evaluation and application of multi-model ensembles in operations* *for high impact weather over the Eastern U.S (PI: Colle; $337,722; 10/2013-09/2017)* and *Better use of ensembles in the forecast process: Scenario-cased tools for predictability studies and hazardous weather communication (PI: Colle; $421,543; 07//2017-06/2021).* These projects have helped to increase the use of ensembles in operations by (1) demonstratingmulti-model ensemble performance for high impact weather during the cool season alongthe U.S. East coast, (2) developing tools to synthesize multiple global ensemble systems*,* and (3) development and training of these tools operationally. Some references include: Layer and Colle (2015); Zhenget al. (2017); Zheng et al., (2018); Zhenget al., (2020). *NOAA-NGGPS:**Validation of significant weather features and processes in operational model using a cyclone relative approach (PI: Colle; $415,219; 05/2015-04/2018) and Using process-orientated diagnostics with feature-based verification software to improve models (PI: Colle; $366,769; 09/2018-08/2021).* Both extratropical and tropical cyclones have been verified for the past several years (Korfe and Colle 2018; Leonardo and Colle 2017; 2019). More recently, diagnostics have been developed to validate and improve the new NWS FV3 model.

***Freedman (Co-PI).*** *NYSERDA: Development of a wind extremes forecast system (PI: Freedman; $569K*; *03/2018-12/2020)*.This project involves development of a Wind Extreme Forecast System (WEFS) to produce forecasts of threshold wind speeds and wind gusts that may result in power outages at county to sub-county scales (transmission down to distribution lines). WEFS is based upon state-of-the-art numerical weather prediction modeling combined with observations from the NYSM and Machine Learning techniques that will produce high spatial (1 km) and temporal (15 minutes to 48 hours) resolution wind forecasts. *NYSERDA: Effects of Climate Change on Renewable Energy Production in New York State (PI: Freedman; $629K; 05/2017-12/2020).* In collaboration with academic and private sector partners this project’s primary focus is on developing a quantified, probability-based study of the potential redistribution of New York’s renewable energy resources (wind, solar, and hydro). This project uses the Weather Research and Forecasting model system to dynamically downscale climate projections from three models in the Climate Model Inter-comparison Project version 5 (CMIP5) ensemble for two different climate change scenarios: Representative Concentration Pathways (RCP) 4.5 and RCP 8.5, for near-future (2018 - 2037) and mid-future (2038 - 2057) periods.

# PROJECT OUTPUTS/PRODUCTS

# Identify the planned outputs/products (e.g., model code, software, or algorithms; published data sets; outreach, education, training events; publication, conference paper, and presentation)

# Provide the current/starting and target/project-completion RL with an explanation of how each level was determined

# Planned Output and Products

# The proposed observational and modeling study will be used to assess the RRFS-CMAQ model performance, identify physics-related systematic errors, provide insight into physical parameterizations, and ultimately foster parameterization improvement. The planned output and products include:

* Comprehensive observational and modeling AQ-meteorology data set for RRFS-CMAQ evaluation;
* Software (or algorithms)???? ; and

# Conference presentation and peer-reviewed publication to report the project results

**Readiness Level (RL)**:

The current/starting and target/project-completion readiness level for proposed modeling study is RL 4-5 (Development) and RL 7 (Demonstration).

1. **OUTCOMES AND IMPACT**

Identify the planned impacts / outcomes/benefits for this project (e.g. improvements in detection, accuracy, lead time, skill, processing speed, efficiency, cost, knowledge). Identify which specific weather enterprise group or organization is expected to be the ultimate recipient(s) and beneficiaries (end-users) of these project outcomes (e.g., local weather forecast offices, a national operational forecast center, a state mesonet, .etc). Include a statement describing the ultimate societal benefits of the proposed project. Briefly describe, qualitatively or quantitatively, how the project’s outcomes contribute to the well-being of society and/or ecosystems. Provide any metrics or performance indicators as appropriate.

**Anticipated Project Outcomes**

* Benchmark observational and modeling dataset for RRFS-CMAQ science improvements;
* Benchmark study for RRFS-CMAQ over NYC and Houston metro regions; and
* Prototype on-demand urban modeling within the RRFS-CMAQ.

**Operational Recipients**

The core team for developing the NOAA air quality forecast capability (i.e., ARL and NCEP) is expected to be the recipients of the project outcomes.

**Societal Benefits**

Output from National Air Quality Forecast Capability (NAQFC) provides a vast source of information to NOAA managers, decision makers (e.g., air quality forecasters), stakeholders (e.g., the environment agency and health authorities), and the scientific community. The project will focus on the RRFS-CMAQ model, which is being developed as the next generation version of the NAQFC. Modeling advancement in RRFS-CMAQ, resulting from improving physical processes over coastal urban environments and prototyping the urban modeling capability, is anticipated to have broad societal benefits.

1. **METHODS AND ACTIVITIES [4 pages]**

List the key activities and methods that will be conducted to successfully complete the project. This includes information on data collection, analysis, collaborations needed (including needed operational collaborations for transition), and necessary travel (associated with data collection, project meetings, testbed planning meetings, testbed experiment and the presentation of results at scientific conferences)

The proposed scientific objectives will be accomplished by: (1) characterize sea breeze circulation and associated coastal LLJ and UHI over NYC and Houston regions; (2) evaluate RRFS-CMAQ simulations using observational dataset compiled in this project; (3) incorporate compiled meteorology-air quality dataset into RRFS-CMAQ verification suite, Model and ObservatioN Evaluation Toolkit (MONET, discussed in section 4A), and (4) xxx

The proposed study will exploit observation capabilities and modeling expertise of the team (discussed in section 4-B and 4-C, respectively) and leverage observations taken from recent or planned field study (section 4-D).

**4-A Atmospheric composition data analysis**

Model and ObservatioN Evaluation Toolkit (MONET) is an open source project and Python package created at NOAA ARL that aims to create a common platform for atmospheric composition data analysis for weather and air quality models. MONET, originally developed to evaluate NAQFC, is designed to be a modularized Python package. Common statistical metrics (e.g., skill scores) and plotting routines (e.g., scatter plots) are included in the package. It is well modularized and can add further observational datasets and models. Currently, MONET is being integrated into the enhanced Model Evaluation Tools (METplus) framework. METplus, in turn, is being integrated into the NOAA community Unified Forecast System (UFS) workflow to evaluate, diagnose, and verify UFS model suites. The proposed work to incorporate compiled dataset into MONET thus has a clear pathway for the research-to-operation transition.

**4-B Observational Assets**

The proposed efforts will exploit unique observational assets. These include:

***(i) NYS Mesonet (NYSM) network.*** The NYSM includes 126 automated surface weather stations across the state (22 within the NYC metro area) to measure standard meteorological variables, 17 “profiler” sites (6 within the NYC metro area) with measurements of boundary layer wind, temperature, and humidity, and 18 “flux” sites (6 within the NYC metro area) with measurements of radiation and surface-atmosphere fluxes of momentum, heat, moisture;

***(ii) Offshore Lidars.*** The New York State Energy Research and Development Authority (NYSERDA) operates two offshore buoy-based lidar systems 60 and 90 km south of NYC which are well-positioned to sample wind profiles upstream of NYC during southerly wind events;

***(iii) NYC Micronet***. The NYSM is currently establishing a sub-network, the New York City Micronet (NYCM), under the sponsorship of the Consolidated Energy Company of New York. Low-cost AQ sensor packages (including measurements of O3, PM, CO, NO2) will be added to 17 NYCM sites and 22 NYSM surface sites within the NYC metro area.

**4-C Modeling Assets**

To represent the urban impacts on coastal urban convective processes, sea breeze front, and air quality, it is required to properly represent the urban boundary layer processes. The UAlbany team (in collaboration with City College of New York) has been developing urban physics parameterizations to improve the urban meteorology and incorporated these developments into the Weather Research Forecast Model (WRF). These parameterizations consider the building effects using the Building Effects Parameterization (BEP), a multilayer scheme that takes into account turbulent canyon effects. A Building Energy Model (BEM) considers the energy and mass balance between buildings and the local environment resulting in an improved representation of anthropogenic heat (AH) effects. Recent collaboration with NOAA/ESRL/GSL is leading to further improvements of the planetary boundary layer (PBL) represented in uWRF. The Mellor-Yamada-Nakanishi-Niino (MYNN) PBL scheme currently used in HRRR has been imported into uWRF to better represent super-adiabatic conditions, typical under extreme heat conditions, and local surface cooling due to the presence of clouds. The uWRF modeling is further expanded into WRF-Chem through the collaboration with ESRL/CSL. uWRF-Chem incorporates an improved Urban Canopy Parameters data set at 1km of resolution that includes buildings topologies and updated urban emission sources.

**4-D Field Study over coastal urban regions**

The Long Island Sound Tropospheric Ozone Study (LISTOS, 2018) is a multi-agency collaborative study investigating precursor emissions and ground-level ozone formation and transport in the NYC metropolitan region and downwind locations (https://www.nescaum.org/documents/listos#about). The Atmospheric Emissions and Reactions Observed from Megacities to Marine Area (AEROMMA, 2023) is a comprehensive field study focusing on anthropogenic and marine emissions that alter tropospheric composition and impact air quality and climate (https://csl.noaa.gov/projects/aeromma). xxxxx

**Proposed Tasks**

The proposed tasks are presented here. The quarterly schedule is presented in “TIMELINE”.

Task 1. Coastal urban meteorological analysis

Task 2. RRFS-CMAQ analysis and evaluation

Task 3. Urban Modeling

**Coordination Plan**

The project will be completed by the multi-institution team under the overall coordination of the lead PI (C-H. Lu, UAlbany). The lead PI will organize monthly tele-conference meetings to communicate progress and coordinate activities. Upon completion of each task, the team will communicate the results and status, identify issues and make adjustments, if necessary, prior to initiating subsequent stages.

All team members will participate broadly in the project, but each team member will have certain key responsibilities as summarized in the list below.

* ***UAlbany***. C-H. Lu, UAlbany (lead P.I.) will take on overall responsibility for this project. She will coordinate project-related research activities, conduct/analyze RRFS-CMAQ experiments, and prepare/submit the project status report. J. Freedman will xxx. J. Gonzalez-Cruz will lead the efforts to prototype uWRF modeling??
* ***SUB.*** B. Colle will lead xxxx.
* ***NCAR***. R. Kumar and S. Alessandrini will xxx
* ***GMU.*** B. Baker will be responsible for overall management of MONET-related tasks.
* ***NCEP and ARL.*** R. Saylor (ARL) and J. McQueen and J. Huang (NCEP)will provide scientific input and technical guidance on conducting and evaluating RRFS-CMAQ experiments. M. Barlage will guide the strategy to urbanize RRFS-CMAQ.

**Project Reporting**

The team will report project status and research results in semi-annual and final project progress reports. The team members will also participate in WPO-FWAC PI meetings and/or NOAA Testbed workshops. In addition, the team members will present research results at scientific conferences and peer-review journals.

1. **TIMELINE**

Timetable to accomplish the proposed tasks during the funding period is presented here. Also shown are key milestones, planned products and expected progression of RLs.

------------- reserved for the time table --------------

1. **ADDITIONAL INFORMATION**

**High-performance Computing Request**

This project will not request additional NOAA high-performance computing resources.

**Federal Collaborators**

Collaborator Acknowledgement Forms from NOAA federal collaborators, Jeffery McQueen, NCEP and Rick Saylor, ARL, are included in the full proposal.

**Use of NOAA Testbeds**

Theproposed work will not directly involve testing in one of NOAA Testbeds or Proving Grounds.

1. **OUTREACH AND EDUCATION**

This project will provide the education experiences and professional development for graduate students from UAlbany and SBU. The project progress and results will be disseminated in peer-review open-access publications and conference presentations as well as shared with the general public through posting the research highlights at ASRC-hosted website. The project team will develop training materials to ensure the community can replicate the RRFS-CMAQ evaluation using the project compiled dataset as well as invoke the urban modeling component using the project compiled sample dataset.

1. **DIVERSITY AND INCLUSION (D&I)**

We support NOAA’s commitment to diversity, inclusion and accessibility although the proposed work does not directly address issues of diversity, inclusion, or equality. This project, led by a diverse team (e.g., female and Hispanic faculty), will embrace diversity and inclusion, including hiring graduate students representing a diverse cultural, ethnic, and economic backgrounds. Research groups led by Drs. Lu, Gonzalez-Cruz, and Freedman include members of underrepresented groups (e.g., gender and geographic) in science, technology, engineering, and mathematics (STEM). Dr. Lu is a member of the D&I Committee at Atmospheric Sciences Research Center (ASRC), UAbany.

UAlbany is one of the 2019 Higher Education in Diversity (HEED) Award recipients. ASRC along with UAlbany’s Department of Atmospheric and Environmental Sciences (DAES), recently issued a statement that includes: “We have taken important first steps to improve diversity and inclusion in our department. In 2019, we became an [AGU Bridge Program](https://www.agu.org/bridge-program) member to improve our recruitment and support of students from underrepresented racial groups in our graduate program. We are partnering with the [Significant Opportunities in Atmospheric Research and Science](https://soars.ucar.edu/) bridge program to augment mentorship and provide research opportunities for undergraduates from underrepresented groups. We will continue to reach out to high school students from underprivileged areas within the Capital District (e.g., [Weather and Climate Camp](http://www.atmos.albany.edu/facstaff/jminder/UAWCcamp/activities.html) and [Rise High](http://rise-high.org/)) to cultivate interest in the geosciences and encourage greater participation of underrepresented groups in STEM fields. We will develop a roadmap of recommendations and actions and be held accountable, not only in this moment, but in our actions going forward.”

The University Corporation for Atmospheric Research (UCAR) and NCAR community is a diverse and vibrant group, composed of individuals with a wide array of backgrounds, identities, and perspectives. We acknowledge that in order to create an inclusive and welcoming environment that maximizes scientific, engineering, business, and education excellence, we must understand and value the myriad voices and perspectives of those in our community, and develop a culture of respect, inclusivity, and belonging that enables all of us to reach our full potential. As a result, we recognize that diversity, equity, and inclusion cannot be separated from the core mission of our organization. In 2019, UCAR published a DEI Strategic Plan that lays out UCAR’s commitment to increasing excellence through hiring and promoting a talented and diverse workforce, establishing an environment of equity and inclusion, and to integrating these principles into our research, management, administrative, and educational practices at UCAR and NCAR.

As outlined online (https://www.stonybrook.edu/commcms/cdo/plan/plan.php), SBU is committed to having a diverse community and workforce. This serves as a foundation of Stony Brook’s mission to educate and provide broader impacts to society.

GMU strives to build and sustain an inclusive campus community and to foster a welcoming climate that values and respects all members of the community (as outlined online, https://diversity.gmu.edu/diversity).

1. **Data/Information Sharing Plan**

This project will fully embrace an open source and open access data management plan. The environmental data expected to be created during the project period includes:

* Xxxxx

Environmental datasets being produced under this NOAA grant will be made discoverable by and accessible to the general public, within 18 months, without restrictions as permitted by applicable law and NOAA regulations. Environmental data along with metadata (machine-readable documentation) will be created in machine-readable open-standard format (e.g., Netcdf or CSV) at an open access domain (UAlbany data server).

Code development made in RRFS-CMAQ will be pushed into a feature branch in RRFS-CMAQ code repository, coordinated by ARL/NCEP collaborators. Additionally, we will archive product and workflow descriptions, specific configuration files and other necessary metadata within the relevant data and code repositories and use case documentation.

Final pre-publication manuscripts of journal articles produced entirely or primarily with this NOAA fund will be submitted to NOAA Institutional Repository after acceptance. The manuscripts will be made publicly available by NOAA one year after the publication by the journal.

**------------------- NOTE: 14 page limit -------------------------**

**References**

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United States Census (2018). Coastline county population continues to grow, retrieved from <https://www.census.gov/library/stories/2018/08/coastal-county-population-rises.html>

Zhang, J., M. Ninneman, E. Joseph, M. J. Schwab, B. Shrestha, and J. J. Schwab (2020). Mobile laboratory measurements of high surface ozone levels and spatial heterogeneity during LISTOS 2018: Evidence for sea breeze influence. J. Geophys. Res., 24, doi:10.1029/ 2019JD031961.

Documents (not in 14-page count)

CV: < 3 pages, including publications and conference presentations relevant to the proposed work with at least three years) from all PIs, co-PIs, and co-Is

C&P: A list including project title, supporting agency, funding start/end months, investigator month, total dollar value/duration.

Status

1. Collaborator Acknowledgement Form from Jeff M
2. Collaborator Acknowledgement Form from Rick
3. Collaborator Acknowledgement Form from Mike
4. CV from Sarah
5. CV from Jeff F
6. CV from Jorge
7. CV from Brian
8. CV from Barry X
9. CV from Rajesh
10. CV from Stefano
11. CV from Jeff M
12. ~~CV from Rick~~ not needed
13. CV from Jianping
14. C&P for Sarah
15. C&P for Jeff F.
16. C&P for Jorge
17. C&P for Brian
18. C&P for Barry
19. C&P for Rajesh
20. C&P for Stefano
21. BUDGET from UAlbany (including SBU subaward)
22. Budget for NCAR
23. Budget for GMU