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|  |  | ERA5 Extension of the Adaptive Hydraulics Software Suite | |
| Coastal and Hydraulics Laboratory |  |  | Samuel Estes, Corey J. Trahan | October 2021 |
|  |  | A close up of a piece of paper  Description automatically generated | |
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| Engineered Resilient Systems | ERDC/CHL TR/SR/CR-20-??  Month 2020 |
| ERA5 Extension of the Adaptive Hydraulics Software Suite | |
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| Final report | |
| Approved for public release; distribution is unlimited. | |
| Prepared for Headquarters, U.S. Army Corps of Engineers Washington, DC 20314-1000  Under Engineered Resilient Systems Program, Data Analytics Work Package, Collaborative Tradespace Analytics Work Unit 92L5D8 | |

Abstract

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In this report we provide instructions for using a new utility to generate input files for AdH from ERA5 wind data. Instructions for downloading the ERA5 data along with an open source program for decoding GRIB files are also provided.

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Preface

This report is a deliverable product under the High-Performance Computing for Rotorcraft Applications (HPC4RA) Program, Physics-Informed Machine Learning Work Unit, PE 0603465 PROJ AL3. Dr. Ian Dettwiller was the Program Manager, and Dr. Robert M. Wallace was the lead Technical Director of the HPC4RA program.

The work was performed by the Computational Analysis Branch (CAB) of the Computational Science and Engineering Division (CSED), U.S. Army Engineer Research and Development Center, Information Technology Laboratory (ERDC-ITL). At the time of publication, Dr. Jeffrey L. Hensley was Chief, CAB, and Dr. Jerrell R. Ballard was Chief, CSED. The Deputy Director of ITL was Ms. Patti S. Duett and the Director was Dr. David R. Horner.

The Commander of ERDC was COL Teresa A. Schlosser, and the Director was Dr. David W. Pittman.

# Introduction

The purpose of this document is to provide instructions for using the ERA5 utility with AdH. The utility is a Python script that interpolates ERA5 wind velocity data to an AdH mesh and outputs these interpolated values to a file which can be used as boundary conditions for AdH. Currently, the utility is only able to take the 10m wind velocity as input but it can be easily extended for other variables in the ECMWF database. We use bilinear interpolation when interpolating from the ERA5 grid to the AdH grid. It should also be noted that the ERA5 grid is a latitude-longitude grid while the AdH grid is flat. In order to perform the interpolation we first project the ERA5 grid to a flat grid using the CPP or equirectangular projection. This requires the user to input a reference latitude and longitude.

In order to use the utility, one must first download the desired data from the ECMWF in GRIB format. Second, wgrib, an open-source program for decoding GRIB files, must be downloaded and compiled into an executable. Third, one must compile the AdH source code. Finally, the user must supply a separate input file which is given as the sole command line argument with the Python script. In the following sections, we will go into more detail about each of these steps.

# Downloading ERA5 Data and Parsing GRIB Format

Here we describe how to download ERA5 data. This data is available through the European Centre for Medium-Range Weather Forecasts (ECMWF). In addition, we provide a link to source code for the wgrib program which can be used to decode the GRIB format in which the ERA5 data is stored.

## Downloading an ERA5 Dataset

Information about the ERA5 dataset provided by the ECMWF can be found [here](https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5). In particular, this page provides links to instructions for downloading a dataset, documentation, and the download page for ERA5 datasets. For convenience, we list this links here:

* [Instructions to download ERA5](https://confluence.ecmwf.int/display/CKB/How+to+download+ERA5)
* [ERA5 Documentation](https://confluence.ecmwf.int/display/CKB/ERA5%3A+data+documentation)
* [Download ERA5 from C3S Climate Data Store](https://cds.climate.copernicus.eu/#!/search?text=ERA5&type=dataset)

In order to download an ERA5 dataset, first review the instructions found in the ‘Instructions to download ERA5’ link in the first bullet point above. The first step is to create a CDS account. There are two ways to download the data, through the CDS web interface, or the CDS API which is Python based. We recommend using the second option. Descriptions for both are provided in the link.

When you are ready to download an ERA5 dataset, follow the link in the third bullet point. This links to various ERA5 datasets. Once you have selected the dataset that you are interested in, you will be taken to the ‘Overview’ page for that dataset. Click on the ‘Download data’ tab and select the subset of the data you are interested in. Once you have made your selections, either select the ‘Show API request’ or ‘Submit form’ option. If you choose to use the API request, simply copy and paste it into a Python script and run the script to pull the data. The ‘Submit form’ option will download the dataset directly.

The ERA5 datasets are available in both GRIB and NetCDF formats. In order to use this utility, select the GRIB format.

## Parsing the GRIB Format with wgrib

This utility relies on the program wgrib to manipulate and decode GRIB files. Information on wgrib along with the source code can be found [here](https://www.cpc.ncep.noaa.gov/products/wesley/wgrib.html). The source code for wgrib is in C and consists of a single file. In order to use the utility, one must download the wgrib source code and compile it into an executable.

# Running the ERA5 Utility

Here we describe how to use the ERA5 utility to interpolate wind velocity records to an AdH mesh. The utility is a Python script which converts a GRIB file into a text file containing the interpolated wind velocities which can then be read into AdH as boundary conditions. The Python script is called ‘ERA5\_utility’ and calls both the wgrib executable and another executable called ‘grid\_interpolator’.

## Input and Output of the Utility

Here we describe the input and output of the utility along with some intermediate files which are produced. The utility takes an input file as a command-line argument. This will be further discussed in the following section. The input file should specifiy the GRIB file of ERA5 data and the file containing the AdH mesh. The GRIB file must have a .grib extension in order for the utility to read it. The naming convention for the AdH grid is <adh\_root>.2dm or <adh\_root>.3dm, where adh\_root is the project name. The output of the utility is a text file containing the interpolated wind velocities with the naming convention <adh\_root>\_wind.txt. There is an option to output the wind velocities in binary format, however the AdH codebase is not currently set up to handle this format.

The ERA5 grid is initially given as a latitude-longitude grid. In order to perform interpolation, the utility projects this grid to a plane using an equirectangular projection or CPP. This requires the user to give a reference latitude and longitude. This reference latitude and longitude specifies where the origin of the flat AdH mesh is located on the globe. The interpolation from the (flattened) ERA5 grids to the AdH mesh is bilinear and assumes that the AdH grid is contained within the bounds of the ERA5 grids.

There are three intermediate files generated by the utility. The first two are created by the wgrib program which is used to decode the original GRIB file. It produces an inventory file which contains a description of each of the grids along with a binary file which contains the actual parameter values of each grid. Note that the utility will automatically only select for the two components of wind velocity. If the user accidentally downloads additional variables the utility will ignore them. More information on the files generated by wgrib can be found on the website linked in the previous section. The third intermediate file generated by the utility is a text file containing the time of each record. These times are given in hours from some user-provided reference time. The naming convention for each of these three intermediate files are to use the same name as the GRIB file but with extensions “inventory”, “bin”, and “time” respectively. These files are used to feed information to the grid\_interpolator executable and can be deleted after the utility has generated the output file of interpolated wind velocities. It may be useful to keep the inventory file as it summarizes the information about each of the records of wind velocity used by the interpolator. The user does not need to concern themselves with these files if they are only interested in generating the interpolated wind velocity output file to use as input for AdH.

## The Input File and Running the Utility

In order to use the utility, one must download and compile wgrib and compile the grid\_interpolator executable. The wgrib source code can be downloaded by following the link in section 2.2. The grid\_interpolator is compiled with AdH.

There are a set of parameters which need to be set in the input file to perform the interpolation. We list them here, along with a description of how to properly set them:

* **wgrib\_exe**: absolute path to the wgrib executable
* **interpolator**: absolute path to the grid\_interpolator executable
* **grib\_file**: name of the GRIB file minus the .grib extension
* **adh\_root**: the project name. This should be the name of the AdH mesh file minus the file extension, e.g. <adh\_root>.2dm
* **lat1, lat2, lon1, lon2, ni, nj:** these parameters determine the latitude and longited bounds of the ERA5 grid along with the number of points in the grid. The lat1 and lat2 variables should be set to the northern and southern boundaries of the domain respectively. Similary, the lon1 and lon2 variables are the eastern and western bounds of the domain respectively. The ni and nj parameters are the number of points in the east-west and north-south directions respectively so that the total number of grid points is ni \* nj. If not already known, these parameters can be obtained using wgrib, see link in previous section
* **reference\_lat and reference\_lon:** these values are for projecting the ERA5 grid onto a plane. The AdH gridpoints are given in meters with an arbitrary origin. These reference values determine where that origin is on the globe
* **reference\_time**: sets the reference time. The date of all GRIB records will be converted into the number of hours between the date and this reference time. The format is YYYY-MM-DD-HH
* **binary\_format**: determines whether to output the interpolated wind file in binary or ASCII format. The AdH codebase is only set up to handle ASCII format at this time so this parameter should always be set to 0 (which corresponds to ASCII format) until AdH can be modified to handle binary wind files
* **variables\_string**: string which selects the variables to be interpolated. Currently, the utility only works when this variable is set to ‘:10U:|:10V:’. Note that the single quotes should be included in the parameter. We use the grep command to select the 10 meter wind velocity components. Having the parameter names as a variable in the utility will allow us to extend the utility to other meteorological data such as pressure in the future

Once these parameters have all been set correctly, simply use the command ‘python ERA5\_utility <input\_file>’ to run the utility and generate the interpolated wind file.

References

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