VIC5 Routing Model Example with Hybrid Forcing Data

This document provides an update to Section 8.5 of CyberWater's v1.0.0 User Manual, incorporating adjustments to reflect changes made by the data provider to the NCAR ERA5 URLs.

The following example demonstrates the use of the VIC5 coupled with the Routing model within CyberWater for the West Branch Susquehanna (WBS) River Basin. This example is similar to that described in Section 4.6.2 of CyberWater's v1.0.0 User Manual but differs in the forcing data sources used. In Section 4.6.2, the forcing data for VIC5 is retrieved directly from the NASA data center using the NLDAS data agent module (NLDASAgent). In contrast, the forcing data used in this example is obtained from two different data sources.

Four variables (precipitation, longwave radiation, shortwave radiation, and specific humidity) are still retrieved from the NASA data center. The remaining variables, including air temperature, wind, and atmospheric pressure, are obtained from ERA5. ERA5 data are organized using a different structure and format, and each data file is large, as it covers long time periods at globe extent with hourly temporal resolution and 0.25° spatial resolution.

To retrieve ERA5 data efficiently, a generic data agent, the *NetCDF4ToDataset* module, has been developed. This module accesses ERA5 data from the NCAR Research Data Archive (https://gdex.ucar.edu/) and uses the "fsspec" and "xarray" Python libraries to subset the data spatially and temporally, significantly reducing the volume of data retrieved. As a result, users are not required to download entire ERA5 data files. For example, instead of downloading a full 4.31 GB ERA5 data file for 2-meter air temperature, only 435 KB of data retrieved for the WBS study area after subsetting. This functionality, implemented in the *NetCDF4ToDataset* module, greatly optimizes users' resource usage. The subsetted ERA5 data are then resampled to a spatial resolution of 0.125° using the Resample module to match the resolution of the NLDAS data. This unified spatial resolution is subsequently used to run the VIC5 model. In this example, the workflow includes two coupled VIC5-routing model simulations for the period from March 15, 1997, to May 15, 1997. The two simulations differ in the forcing data sources used for VIC5.

Simulation 1 uses a complete set of forcing variables automatically retrieved from the NASA Land Data Assimilation System (NLDAS) through CyberWater's *NLDASAgent* module.

Simulation 2 uses a hybrid forcing dataset, with forcing variables retrieved from both the ERA5 data source via the *NetCDF4ToDataset* module and the NASA NLDAS data source via the *NLDASAgent* module. The variables from the NCAR EAR5 are:

- 2-meter air temperature
- 10-meter U wind component
- 10-meter V wind component
- Surface pressure

The variables from the NASA NLDAS are:

- Precipitation
- Longwave radiation

- Shortwave radiation
- Specific humidity
- Users can construct a workflow capable of accessing both data sources, subsetting ERA5 data before retrieval, preparing and organizing forcing datasets, executing the coupled VIC5-Routing model, comparing simulated streamflow results with observations, and visualizing the outputs. The steps to accomplish these workflow tasks are described as follows: Define the simulation time range using the *TimeRange* module (March 15, 1997 – May 15, 1997).
    - Start date (timeini): 1997/03/15 00:00:00
    - End date (timeend): 1997/05/15 00:00:00
- Specify the spatial extent using the *SpaceRange* module for the WBS River Basin [(x_min, x_max, y_min, y_max): -79.0, -76.125, 40.375, 42.0].
- Access NLDAS data for all required variables in Simulation 1 using the *NLDASAgent* module. Refer to Section 4.5.1 of CyberWater's v1.0.0 User Manual for detailed instructions on configuring the *NLDASAgent* and utilizing the *msmUnitConversion* and *msmDatasetOperation* modules to generate the necessary dataset for executing the VIC5 model.
- Retrieve ERA5 data in Simulation 2 using the *NetCDF4ToDataset* module:
    - Add four *NetCDF4ToDataset* modules to retrieve 2-meter air temperature, 10-meter U wind component, 10-meter V wind component, and Surface pressure.

    2-meter air temperature

    - Connect the Case Study input port to the *SpaceRange* module output port.
    - Configure the NC4 Link(s) port by adding the following links:
        - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199703/e5.oper.an.sfc.128_167_2t.ll025sc.1997030100_1997033123.nc?var=VAR_2T&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-03-01T00:00:00Z&time_end=1997-03-31T23:00:00Z&&&accept=netcdf3
        - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199704/e5.oper.an.sfc.128_167_2t.ll025sc.1997040100_1997043023.nc?var=VAR_2T&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-04-01T00:00:00Z&time_end=1997-04-30T23:00:00Z&&&accept=netcdf3
        - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199705/e5.oper.an.sfc.128_167_2t.ll025sc.1997050100_1997053123.nc?var=VAR_2T&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-05-01T00:00:00Z&time_end=1997-05-31T23:00:00Z&&&accept=netcdf3
    - Set the Directory port to any folder path where the subsetted .nc4 files will be saved. In this example, all NetCDF files will be stored in C:\Temp\CyberWater\GT\VIC5Routing\WBSusquehanna\NCFiles, so make sure to create this folder accordingly.

- Set the variable name to “VAR_2T”.

10-meter U wind component

- Connect the Case Study input port to the *SpaceRange* module output port.
- Configure the NC4 Link(s) port by adding the following links:
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199703/e5.oper.an.sfc.128_165_10u.ll025sc.1997030100_1997033123.nc?var=VAR_10U&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-03-01T00:00:00Z&time_end=1997-03-31T23:00:00Z&&&accept=netcdf3
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199704/e5.oper.an.sfc.128_165_10u.ll025sc.1997040100_1997043023.nc?var=VAR_10U&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-04-01T00:00:00Z&time_end=1997-04-30T23:00:00Z&&&accept=netcdf3
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199705/e5.oper.an.sfc.128_165_10u.ll025sc.1997050100_1997053123.nc?var=VAR_10U&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-05-01T00:00:00Z&time_end=1997-05-31T23:00:00Z&&&accept=netcdf3
- Set the Directory port to any folder path where the subsetted .nc4 files should be saved.
- Set the variable name to “VAR_10U”.

10-meter V wind component

- Connect the Case Study input port to the *SpaceRange* module output port.
- Configure the NC4 Link(s) port by adding the following links:
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199703/e5.oper.an.sfc.128_166_10v.ll025sc.1997030100_1997033123.nc?var=VAR_10V&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-03-01T00:00:00Z&time_end=1997-03-31T23:00:00Z&&&accept=netcdf3
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199704/e5.oper.an.sfc.128_166_10v.ll025sc.1997040100_1997043023.nc?var=VAR_10V&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-04-01T00:00:00Z&time_end=1997-04-30T23:00:00Z&&&accept=netcdf3
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199705/e5.oper.an.sfc.128_166_10v.ll025sc.1997050100_1997053123.nc?var=VAR_10V&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-05-01T00:00:00Z&time_end=1997-05-31T23:00:00Z&&&accept=netcdf3

- Set the Directory port to any folder path where the subsetted .nc4 files should be saved.
- Set the variable name to “VAR_10V”.

Surface pressure

- Connect the Case Study input port to the *SpaceRange* module output port.
- Configure the NC4 Link(s) port by adding the following links:
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199703/e5.oper.an.sfc.128_134_sp.ll025sc.1997030100_1997033123.nc?var=SP&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-03-01T00:00:00Z&time_end=1997-03-31T23:00:00Z&&&accept=netcdf3
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199704/e5.oper.an.sfc.128_134_sp.ll025sc.1997040100_1997043023.nc?var=SP&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-04-01T00:00:00Z&time_end=1997-04-30T23:00:00Z&&&accept=netcdf3
  - https://tds.gdex.ucar.edu/thredds/ncss/grid/files/g/d633000/e5.oper.an.sfc/199705/e5.oper.an.sfc.128_134_sp.ll025sc.1997050100_1997053123.nc?var=SP&north=42.0&west=-79.0&east=-76.125&south=40.375&horizStride=1&time_start=1997-05-01T00:00:00Z&time_end=1997-05-31T23:00:00Z&&&accept=netcdf3
- Set the Directory port to any folder path where the subsetted .nc4 files should be saved.
- Set the variable name to “SP”.

Figure 1 illustrates the workflow for retrieving ERA5 datasets, including 2-meter air temperature, 10-meter U-wind component, 10-meter V-wind component, and surface pressure, using the *NetCDF4ToDataset* module.

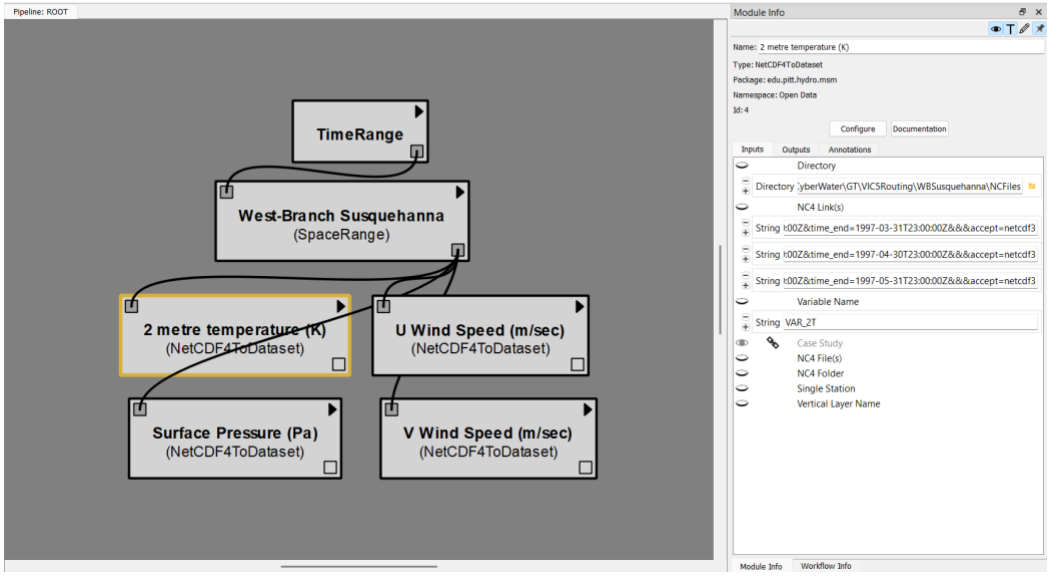

Figure 1. Workflow for retrieving ERA5 datasets – 2-meter air temperature, 10-meter U-wind component, 10-meter V-wind component, and surface pressure -- using the NetCDF4ToDataset module. Please note: Access to the links is valid as of November 2025. If any of the URLs are changed or updated, the workflow will produce an error. Users should verify that the links remain valid by checking: https://gdex.ucar.edu/datasets/d633000/

- Add two *msmUnitConversion* modules (to convert pressure from Pa to kPa and temperature from K to °C) and one *msmDatasetOperation* module to compute wind speed magnitude from the U and V components, as shown in Figure 2.

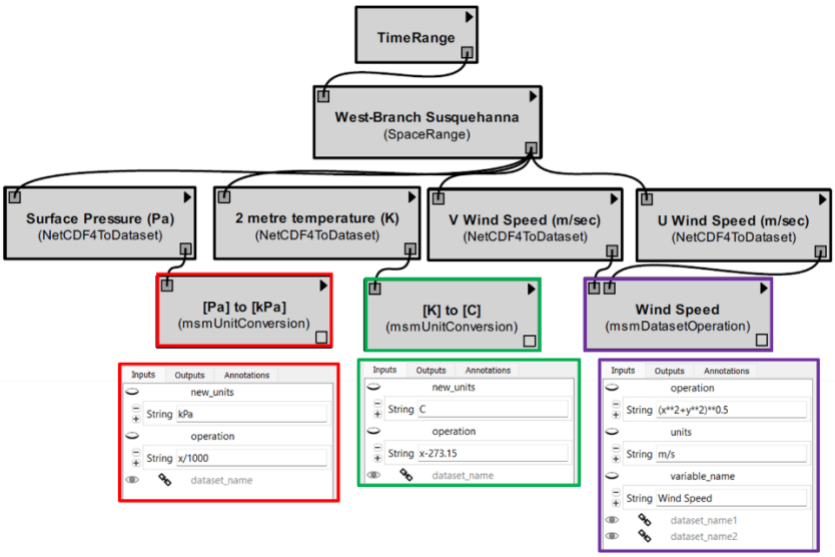

Figure 2. Using msmUnitConversion and msmDatasetOperation modules to convert units and calculate wind speed magnitude.

- Use the *Resample* module to convert ERA5 data to the spatial resolution of 0.125°.
  - Adjust both the base resolution and side resolution to 0.125 in the *Resample* module as shown in Figure 3.

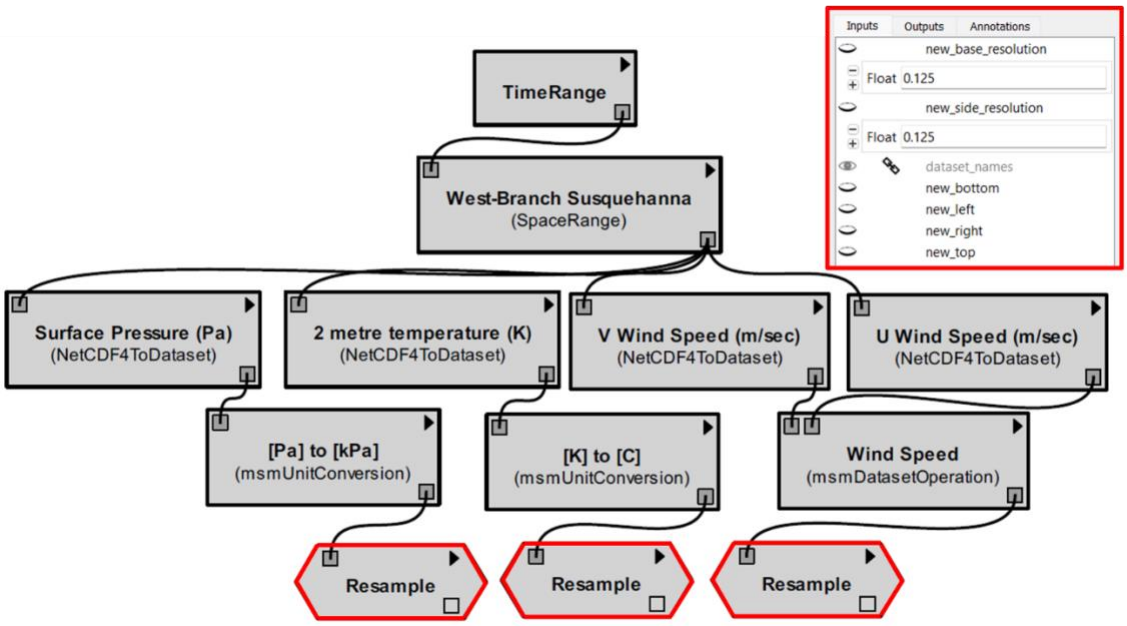

Figure 3. Using the Resample module to convert ERA5 data to the spatial resolution of 0.125° by setting both base and side resolutions to 0.125.

- Group all modules shown in Figure 4 by selecting them and choosing Workflow → Group. Note that the same grouping process is applied to the NLDAS data. Additionally, the group should not include the *TimeRange* and *SpaceRange* modules.
- Configure and run the VIC5 model using the prepared forcing datasets with the *VIC5Agent_g* module.
    - Add two *VIC5Agent_g* modules. For the first module, use the retrieved NLDAS datasets for all VIC5 forcing variables. For the second module, use the same configuration, but replace the pressure, temperature, and wind speed inputs with the datasets retrieved from ERA5.
    - Use the VIC5 parameter files and the initial state file for both modules, available from the HydroShare link. Note that you need to create two folders for the WD_Path option to store the output files. Create these folders at any desired location and select them in the WD_Path option for each module. In this example, the VIC5 results are stored in C:\Temp\CyberWater\GT\VIC5Routing\WBSusquehanna\VIC NLDAS MainAgent and C:\Temp\CyberWater\GT\VIC5Routing\WBSusquehanna\VIC NLDAS ERA5 MainAgent, corresponding to each simulation.
    - For more information on configuring the remaining ports, refer to Section 4.6.2 of CyberWater's v1.0.0 User Manual.
- Configure and run the Routing model using the VIC5 output with the *RoutingAgent_g* module.
    - Add two *RoutingAgent_g* modules for each *VIC5Agent_g* module.
    - Use the Routing parameter file and initial state file for both modules, available from the HydroShare link. Note that you need to create two folders for the WD_Path option to store the output files. Create these folders at any desired location and select them in

the WD_Path option for each module. In this example, the Routing results are stored in C:\Temp\CyberWater\GT\VIC5Routing\WBSusquehanna\RoutingNLDAS MainAgent and C:\Temp\CyberWater\GT\VIC5Routing\WBSusquehanna\RoutingNLDAS ERA5 MainAgent, corresponding to each simulation.

- For more information on configuring the remaining ports, refer to Section 4.6.2 of CyberWater's v1.0.0 User Manual.

- Retrieve observed streamflow data using the *UsgsAgent* module for comparison (Site code:01553500) and adjust the conversion factor to be 0.0283168466.
- Visualize and analyze the results using the *msmShowChart* module. Connect the outputs from the two *RoutingAgent_g* modules and the *UsgsAgent* module to display the streamflow.

Figure 4(a) illustrates the workflow for retrieving forcing data from the NLDAS data source using the NLDASAgent module, while Figure 4(b) illustrates the extraction of forcing data from ERA5 using the *NetCDF4ToDataset* module. The right panel of Figure 4 shows the complete workflow successfully executed. The workflow in Figure 4 can be downloaded from the CyberWater website <Running VIC5-Routing Using Online Data Sources>. Figure 5 shows the streamflow comparison results from executing the workflow in Figure 4.

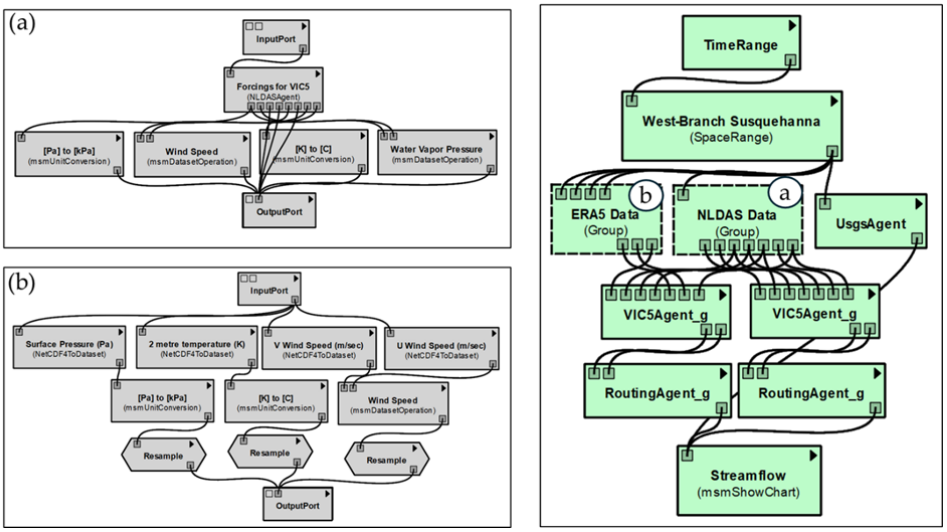

Figure 4. Workflow for retrieving forcing datasets and executing VIC5-Routing coupled model simulations using the NLDAS and hybrid NLDAS–ERA5 data sources. (a) Extracting NLDAS data using the NLDASAgent module; and (b) Retrieving ERA5 data using the NetCDF4ToDataset module.

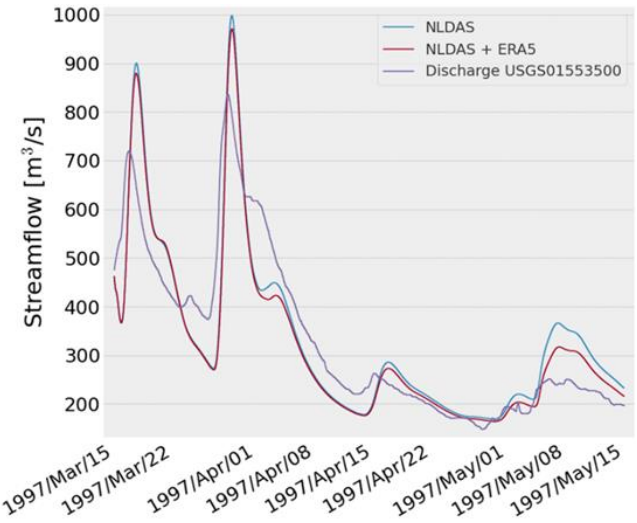

Figure 5. Comparison of model simulated streamflow with two different forcing datasets to the USGS observations at Site ID 01553500 for the West Branch Susquehanna River Basin.