**MINISTRY OF MINES AND ENERGY – MME**

**NATIONAL ELECTRIC SYSTEM OPERATOR - ONS**

**META PROJECT**

Technical Assistance Project for the Energy and Mineral Sectors

**WORLD BANK**

INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT – IBRD

Loan: **9074 - BR**

**Term of reference for Subproject 23-2 – Consulting 2**
Diagnosis/assessment of regionalization of a precipitation prediction model and other meteorological variables

July/2023

# SUMMARY

***REFERENCE TERM - TDR***

Diagnosis/assessment of regionalization of a precipitation prediction model and other meteorological variables

## *1. CONTEXT*

The National Electric System Operator (ONS) is the body responsible for coordinating and controlling the operation of electrical energy generation and transmission facilities in the Brazilian National Interconnected System (SIN) and for planning the operation of the country's isolated systems. As part of efforts to promote the development and technical training of the Brazilian energy sector, the ONS is part of the second stage of the project of Technical Assistance for the Energy and Mineral Sectors, also referred to as the META II Project. One of the projects supported by the META II Project is Subproject 23, which seeks to make a study to identify the causality of changes in flow rate regimes and in the major meteorological variables of interest for the SIN operation. The SIN is made up of four subsystems in the South, Southeast/Midwest, Northeast and most of the North regions, which present a diversity of climate regimes.

According to ONS data, around 70% of the average energy produced in the last three years in Brazil comes from hydroelectric plants, even with the growing share of wind generation, which corresponds to around 12.5% of the SIN's capacity. As the SIN operation is linked to the weather conditions, and in particular to the precipitation volume over the river basins, the planning and scheduling of the electroenergy operation, as well as the expansion planning, depend on the forecast/generation of inflow scenarios for all of the SIN's hydroelectric developments, from the first operational week to horizons of five to ten years ahead. Therefore, the understanding of the causes associated with any change in weather conditions is of the utmost importance, since systematic inaccuracies in forecasting flow rates can increase energy costs or jeopardize the proper planning of the SIN.

Within the scope of project META II, the Joint Venture (JV) formed between companies PSR and CLIMATEMPO coordinates Sub-project 23. Table 1 shows the set of products provided for in this sub-project. **Consultancy-1** (JV) is in charge of the execution of Products in Grouping 1 (Products 1, 2, 3, 4 and 12). The Product in Grouping 2 (Product 5), which is the scope of this TDR, will be performed by **Consultancy-2**. Product 5 will be a requirement for Product 8, to be performed by **Consultancy-5**, which will be the purpose of a different, future bidding procedure.

Table 1 – Bidding procedures for Sub-project 23 of the ONS, considering that the bidding procedure for Consultancy-2, which is the scope of this TDR, are the Activities and Products in Grouping 2.

| Grouping | Product | Activity | Bidding Procedure |
|---|---|---|---|
| 1 | **------------** | **COORDINATION** | **Consultancy-1 (Coordinator Joint Venture PSR and CLIMATEMPO)** |
| | **Product-1** | **Literature Review** | |
| | **Product-2** | **Collection and Analysis of meteorological data with long observation periods in the SIN** | |
| | **Product-3** | **Collection and Analysis of Data from Coupled Precipitation Prediction models, Other Meteorological Variables and soil use (considering series obtained per paleoclimate)** | |
| | **Product-4** | **Preliminary assessment of weather variability/change in available meteorological and hydrological series** | |
| 2 | **Product-5** | **Diagnosis/assessment of Regionalization of a Precipitation Prediction model and Other Meteorological Variables** | **Consultancy-2 (Purpose of this TDR)** |
| 3 | **Product-6** | **Studies of Consecutive Years of Extreme Events: major floods and droughts and the associated phenomenology focusing on recent years. Responsible meteorological systems, precursor and successor settings, methods for identifying analogues based on current situations.** | **Consultancy-3 (future bidding procedure)** |
| 4 | **Product-7** | **Paleoclimatology Studies** | **Consultancy-4 (future bidding procedure)** |
| 5 | **Product-8** | **Definition of More Representative Climate Indices for the Oceans/Atmosphere** | **Consultancy-5 (future bidding procedure)** |
| | **Product-9** | **Study of Possible Causes and Possible Predictability of Change/Maintenance of Climate Indices and their Effects on Flow Rates and Meteorological Variables** | **Consultancy-5 (future bidding procedure)** |

| | | | |
|---|---|---|---|
| | **Product-10** | **Analysis of Climate Variables and Correlation structures which can be Incorporated into SIN Operation and Expansion Planning Models.** | **Consultancy-5 (future bidding procedure)** |
| 6 | **Product-11** | **Methodology for Estimating Monthly Hydrological and Meteorological scenarios Using Climate Information** | **Consultancy-6 (future bidding procedure)** |
| 1 | **Product-12** | **Final Report of the Sub-project** | **Consultancy-1 (Coordinator Joint Venture PSR and CLIMATEMPO)** |

The first stage of this sub-project performed by **Consultancy-1** (JV) was the extensive bibliographical review on the latest results of the impacts of natural climate variabilities, climate changes in Brazil and changes in soil use in the SIN river basins (Product 1 on Table 1). Furthermore, the implementation of this sub-project includes the collection and analysis of hydrometeorological databases with long periods of observation in the SIN, which forms Product 2. This product encompasses data from hydrometeorological stations, satellites and reanalysis of several different meteorological variables, such as precipitation, temperature, wind, sea surface temperature, among others, as shown in Annex I. The sub-project also includes the collection and analysis of data from coupled precipitation prediction models, other meteorological variables and soil use (including series obtained per paleoclimate), which forms Product 3 (Annex II). Finally, Product 4 includes the preliminary assessment of climate variability/change in the available meteorological and hydrological series.

The application of numerical models is justified since the proper planning of the electricity sector depends on hydrometeorological forecasts with the greatest possible reliability. This way, a database of operational prediction models was built on the sub-seasonal and seasonal scales of precipitation and other meteorological variables. On the sub-seasonal scale, project Sub-seasonal to Seasonal (S2S, VITART et al., 2017) gathered 11 research/operational centers to produce meteorological forecasts for up to 60 days in order to improve the accuracy and understanding of the physical processes that dominate this time scale. Using the S2S database, previous studies (e.g. DE ANDRADE; COELHO; CAVALCANTI, 2019; KLINGAMAN et al., 2021) assessed the performance of sub-seasonal prediction models for South America, identifying the models with the best performance. On the seasonal scale, several different centers provide forecasts operationally, such as the European Center for Medium-Range Weather Forecasts (ECMWF) which uses the fifth version of the Seasonal Forecast System (SEAS5), the National Centers for Environmental Prediction (NCEP) with the second version of the Coupled Forecast System (CFSv2) model, in addition to the North American centers that provide the North American Multi-Model Ensemble (NMME) multi-model forecast.

However, the predictability of precipitation and other meteorological variables is dependent on several different factors, including latitudinal location. On the tropical region, the El Niño

Southern Oscillation (ENSO) and Madden-Julian Oscillation (MJO) phenomena influence atmospheric variability (e.g. KOUSKY; KAGANO; CAVALCANTI, 1984; ROPELEWSKI; HALPERT, 1987; LIEBMANN et al., 2004; PAEGLE; BYERLE; MO, 2000; SHIMIZU; AMBRIZZI, 2016), which results in greater predictability. In extra-tropical regions, the models usually perform worse in seasonal forecasting (e.g. GUBLER et al., 2020) due to deficiencies in simulating extra-tropical variability, interactions with the tropics and teleconnection patterns such as the Pacific South American (PSA).

Aiming at improving forecasting, several different studies have used techniques for regionalizing forecasting, both with dynamic methods, using regional models (e.g. CHOU et al., 2012; GOMES et al., 2022), and statistical ones, with techniques such as linear regression, classification and regression trees, grouping and neural networks (e.g. WILBY et al., 1998). Regional climate models are used to translate the large-scale climate evolution of a global model into a physically consistent evolution at a higher resolution (GIORGI et al., 2001; MEARNS et al., 2003). On the other hand, statistical downscaling is based on relationships between regional climate and carefully selected large-scale forecasting variables (WILBY et al., 2004). The choice of the most appropriate forecast regionalization method depends on the meteorological variable and region to be analyzed, and also to the availability of computational resources.

This brief contextualization makes clear the need to assess the performance of the models in a regionalized manner, which is the purpose of this bidding procedure (Product 5), assessing the forecasts of meteorological variables and phenomena that affect each specific region.

## *2. JUSTIFICATION*

The regionalization of precipitation forecasts and other meteorological variables can provide satisfactory results since a series of adaptations can be made, considering the climatological diversity of Brazilian basins. The application of specific methods will contribute to obtaining results which are more appropriate for each sub-system or region of the SIN. With more reliable forecasts, the ONS will be able to improve the operational planning in the Brazilian electricity industry.

## *3. PURPOSE*

The purpose of **Consultancy-2** is to diagnose and assess the regionalization of the forecast of meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.) for the regions of interest to the SIN (Brazilian territory, river basins, South America), based on references, data and results presented by **Consultancy-1** (JV) of Products 1, 2, 3 and 4, and other databases that **Consultancy-2** deems necessary and to which they have access.

The specific purposes are to: i) Identify the limitations of numerical meteorological prediction models; ii) Analyze the impact of the spatial resolution of the model(s) on forecasting meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.) on different time scales; iii) Assess the costs and benefits of different regionalization methods and parameters.

## *4. SCOPE*

In the specific case of this TdR, which addresses the contracting of **Consultancy-2**, they expect to obtain Product 5 in Table 2 below.

## *5. EXPECTED RESULTS & PRODUCTS*

During the contracting period, the product specified in Table 2 must be provided.

**Table 2 – Product to be provided by Consultancy-2.**

| **Products** | **Content description** |
|---|---|
| Product 5 | Report of diagnosis/assessment of the regionalization of the forecast of meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.) for the regions of interest to the SIN (Brazilian territory, river basins, South America), including at least:<br>● A description of the state of the art in the regionalization of forecasting meteorological variables<br>● A description of the regionalized numerical prediction models (of their own or third-party's), to be considered<br>● A description of the diagnosis/assessment methodology to be used.<br>● Diagnosis/assessment of the regionalization of forecasts/scenarios on several different time scales (monthly, quarterly, semi-annually, annually, biannually).<br>● Assessment of regionalization methods/parameters for forecasting meteorological variables. |

Product 5 will be provided through 4 monthly partial reports and a final report, in accordance with Table 3.

**Table 3 – Delivery route for Product 5: requirements and type**

| Product (code) | Requirement | Type |
|---|---|---|
| Partial Report-1 (5.RP1) | - | Technical report |
| Partial Report-2 (5.RP2) | 5.RP1 | |
| Partial Report-3 (5.RP3) | 5.RP2 | |
| Partial Report-4 (5.RP4) | 5.RP3 | |
| Final Report (5.RF) | 5.RP4 | |

## *6. SCOPE OF WORK AND PROJECT BOUNDARIES*

The activities that the contractor must perform for providing Product 5 are listed below. For the listed activities, the database of sub-project 23 (Products 2 and 3) will be provided to **Consultancy-2**. The entire structure of such a database is described in Annex III.

The **Bidder** must consider, in their technical bi, the state of the art of the regionalization of forecasting meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.) for the regions of interest to the SIN (Brazilian territory, river basins, South America).

Consultancy-2 is allowed to propose the use of additional data to that contained in the Product 3 database (Annex-II). The cost relating to the incorporation of such data must be forecast as a non-reimbursable expense. The use and incorporation of the proposed additional data into the Project will be in accordance with the purpose to be contracted.

**Product 5 – Regionalization of precipitation forecast and other variables**

- Based on the knowledge presented in the technical bid, the consultant must deepen the description of the state of the art on the regionalization of precipitation forecasting and other variables in the regions of interest to the SIN.

Inclusion of current relevant studies on the advantages and disadvantages of the different regionalization methods used (e.g. dynamic, statistical, stochastic models and use of artificial intelligence) and for which time scales (e.g. sub-seasonal, seasonal, annual) each method is more suitable.

- A description of the regionalized numerical prediction models (of their own or third-party's), to be considered.
  - Criteria and justifications for selecting regionalized numerical models.
  - A description of the selected regionalized numerical models, detailing their technical characteristics and advantages and disadvantages for the regions of interest to the SIN.

- A description of the diagnosis/assessment methodology to be used.
  - A description of the methods to be used to assess the performance of models in forecasting meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.) for the regions of interest to the SIN (Brazilian territory, river basins, South America).
  - Indication of the performance assessment metrics to be used, in addition to those stated in Annex IV, considering the different space-time scales.

- Diagnosis/assessment of the regionalization of forecasts/scenarios on several different time scales (monthly, quarterly, semi-annually, annually, biannually)

  - Analysis of the performance of models in forecasting meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.) for the regions of interest to the SIN (Brazilian territory, river basins, South America) on different time scales (sub-seasonal, seasonal, annual).
  - Identification of systematic errors in climate models for the regions of the SIN.
  - Assessment of the simulation of meteorological systems that affect each region of the SIN using atmospheric models.

Note:

i) this assessment must at least consider the performance of the ECMWF model and the NCEP CFS model, since they are the operational models used by the ONS.

ii) the computational analysis codes created/used in the diagnosis/assessment of the regionalization of forecasts must be provided to the ONS, in a documented open source. After the completion of the project, the ONS will own the rights to the products provided.

- Assessment of regionalization methods/parameters for forecasting meteorological variables
  - Identification of the most appropriate method for regionalization in the different regions and time scales, aimed at estimating the cost/benefit of regionalizing the forecast of meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.) for the regions of interest to the SIN (Brazilian territory, river basins, South America).
  - Selection of sensitivity tests and/or parameters for the chosen method(s).
  - Assessment of the simulation of meteorological systems, highlighting the improvements obtained with the regionalization of the forecast with the different methods/parameters in relation to the forecast from global models.

- Preparation of the Final Report containing the assessment and the inter-relationship of all information and results obtained, as well as the conclusions and general recommendations associated with them.

## *7. PERFORMANCE PERIOD/SCHEDULE/FIGURES*

The deadline for the consultancy and delivering the product, described in item 5, is within 150 days. Table 1 below shows the products provided for **Consultancy-2**, their durations and estimated percentage of the amount to be paid for each product provided.

**Table 1 – Products provided for Consultancy-2, durations and estimated percentage.**

| **Product** | **Quantity** | **Duration** | **Value of the agreement** |
|---|---|---|---|
| 5.RP1 | 1 | 1 month | 15% |
| 5.RP2 | 1 | 1 month | 15% |
| 5.RP3 | 1 | 1 month | 15% |
| 5.RP4 | 1 | 1 month | 15% |
| 5.RF | 1 | 1 month | 40% |

## *8. TEAM QUALIFICATION AND SPECIFICATION*

### 8.1 Key Team

This qualification and specification (Table 2) addresses the minimum key team to be part of **Consultancy-2** to fulfill the services contracted in Sub-project 23-2, according to the activities provided for in Item-6. Key team professionals will be assessed based on the evidence presented in their CVs. The know-how and experience required for key team positions must be evidenced through professional performance, scientific articles, participation in research and R&D projects, and program patents. It should be emphasized that the evidence presented must be linked to the services/subjects that are the purpose of this sub-project.

**Table 2 – Key Team Profile of Consultancy-2**

| Qty | Station | Training | Required Experience | Duties |
|---|---|---|---|---|
| 1 | Coordinator | Higher education in Engineering/Mathematics/Physics/Meteorology or areas related to the agreement purpose, with a postgraduate degree also in such areas<br><br>Fluency in English | Minimum of ten (10) years in studies and research in the area; and experience in coordinating and supervising research projects linked to the numerical modeling of the atmosphere | General coordination of the project.<br>Performance of monthly and technical reports for Product 5 |
| 1 | Technical leader | Higher education in Engineering/Mathematics/Physics/statistics/computer science/Meteorology, with a postgraduate degree in areas related to the agreement purpose.<br><br>Fluency in English | Minimum of ten (10) years in studies and research linked to the numerical modeling of the atmosphere and assessment of the performance of numerical prediction on South America. | Definition of technical teams and proposed schedule.<br>Coordinate studies and issue opinions and technical reports, follow up and analyze the planned product.<br>Execution of Product 5 |
| 2 | Executors | Higher education in Engineering/Mathematics/Physics/Meteorology/statistics/computer science | Minimum of five (05) years in studies and research in the area of interest to the study. | Execution of Product 5 |

### 8.2 Support team

**Consultancy-2** may define, at their discretion, the make-up of the support team to support the performance of activities of Product 5. The support team is a team of professionals provided by the consultant to perform part of the services together with the key team, as per this TdR. Therefore, the size of the support team must be described in the technical bid.

### 8.3 Required Consultant Profile

For this sub-project, the contractor must be experienced in the following requirements:

(i) studies and/or projects and/or research in: development and application of numerical models for forecasting meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.);

(ii) studies and/or projects and/or research in: diagnosis/assessment of regionalization of a model for forecasting meteorological variables (precipitation, temperature, wind, shortwave radiation incident on the surface, etc.);

(iii) studies and/or projects and/or research linked to: the numerical modeling of the atmosphere and assessment of performance on South America.

In order to prove the aforementioned requirements, the consultant must present, in their technical bid, only the latest services (last 10 years) which are somewhat associated with the requirements and services requested in this TdR. It should be emphasized that the services presented must only be provided by the consultant as a company, not by their experts, either working privately or for other companies.

## *9. FORM OF PRESENTATION OF PRODUCTS*

The products shall be provided in Portuguese, in the form of a report, electronically, according to the following format:

- Compositions: MS Word® 2013 or later version, with delivery of the file in ".doc"/".docx" format;
- Spreadsheets, Charts and Tables: MS Excel 2013 or later version;
- Pictures in general: JPG, GIF, BMP, TIFF or PNG;
- Presentations: MS PowerPoint 2013 or later version;
- Database: in accordance with the structure and specifications established in Annex-III.
- Products in the form of Reports must display the appropriate logos, to be inserted in the following order: ONS, META Project, World Bank and MME/Federal Government. A template file will be provided to the contractor in ".doc"/".docx" format.

Any electronic spreadsheets developed must be provided unlocked with no editing restrictions.

In addition to said logos, the following information must be informed in the product/report: Research/Product/Work performed with funds from Loan Agreement No. 9074-BR, formalized between the Federative Republic of Brazil and the International Bank for Reconstruction and Development - IBRD, on July 21st, 2021.

### *10. PAYMENT METHODS*

The estimated percentage of the total value of the Agreement, for each product, is provided in item 7 herein. Payment methods, as well as deadlines for delivery and approval of the products, will be linked to the Agreement Draft, an instrument that is part of the Invitation to Bid.

### *11. SUPERVISION*

The Technical Supervisory Committee (TSC) for the activities provided for in this TdR will be formed by at least three full members and three alternates, linked to the ONS and to JV PSR-Climatempo. The JV PSR-Climatempo and the ONS shall be responsible for the following duties for the activities provided for in this TdR:

JV PSR-Climatempo:

- Management of information, basic data and supplies to be provided for Consultancy-2;
- Analysis and assessment of data and products received from Consultancy-2;
- Arrangement for workshops/meetings with preparation of records along with Consultancy-2;
- Issuance of technical opinions relating to studies and products received from Consultancy-2.

ONS:

- General supervision of the terms of the agreement to be established with Consultancy-2;
- Supervision of activities and interaction between JV PSR-Climatempo and Consultancy-2;
- Assessment and final acceptance of products received from Consultancy-2.

The beginning of the works, as well as the presentation of the products provided for herein must be preceded by a meeting with the TSC for general guidance on the process and monitoring by Consultancy-2.

During the performance of Consultancy-2 activities, meetings shall be held for follow-up and direction.

### *12. AVAILABLE SUPPLIES AND ELEMENTS*

In order to prepare this bidding procedure, the ONS shall provide, through JV PSR-Climatempo, the Products 1, 2, 3 and 4 previously detailed in item 1 and in annexes I and II.

### *13. TRAINING NEEDS*

Considering the type of products expected (reports), there is no need for any training.

### *14. WORLD BANK ENVIRONMENTAL AND SOCIAL FRAMEWORK*

All activities supported by the project, including studies to propose policies and regulations, must be analyzed in accordance with the World Bank's Environmental and Social Standards, which establish guidelines for identifying, assessing, mitigating and managing potential risks and impacts associated with projects funded by the Bank.

The purpose of the adoption of the Environmental and Social Standards is to support borrowers in adopting the international best practices related to environmental and social sustainability by fulfilling their domestic and international environmental and social obligations, and also by increasing non-discrimination, transparency, participation, accountability, governance and improvement of projects' sustainable development outcomes through ongoing stakeholder engagement. In addition to the World Bank Environmental and Social Framework, the World Bank Group's Environmental Health and Safety Guidelines (IFC-EHSGs) shall be complied with, including specific guidelines for the mineral, power, and oil and gas industries.

The preparation of the work should consider the World Bank's Environmental and Social Framework, which became effective on October 1st, 2018, assessing potential social and environmental impacts of sub-projects, whenever necessary. The most relevant standard for the concerned Sub-project 23 is Environmental and Social Standard 2 - Working Conditions and Workforce of the team that will perform the studies.

### *15. INSTITUTIONAL AND ORGANIZATIONAL ARRANGEMENTS*

Sub-project 23 shall be managed by organizational structures linked to the Brazilian Ministry of Mines and Energy (MME) and to the Brazilian National Electric System Operator (ONS), as determined by the Operational Manual for the Project – MOP, available online at the MME website (www.mme.gov.br).

At the MME, the project will be managed by the Project Management Committee (CGP) and the Central Project Management Unit (UGP/C).

At the ONS, it will be managed by the Sectorial Project Management Unit (UGP/S), as per Figure 1~~Figure 1~~.

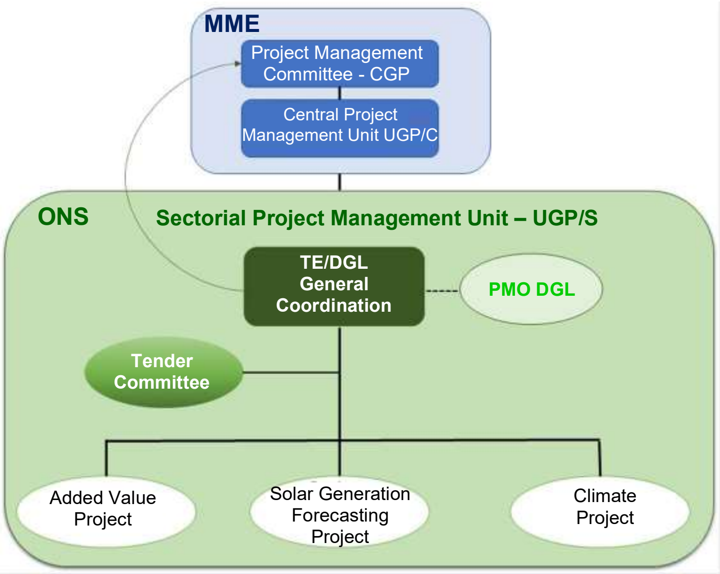


**Figure 1 Functional structure of ONS' Sectorial Project Management Unit – UGP/S**

**Table 1 UGP/S Formation in ONS**

| UGP/S | Managements |
|---|---|
| **General Coordination** | Strategic Transformation Executive Management |
| **DGL Projects Office** | Strategic Transformation Executive Management |
| **Tender Committee** | Financial Executive Management |
| | Legal Executive Management |
| | Water Resources and Meteorology Management |
| | Methodology and Energy Model Management |
| | Calculation, Analysis and Operation Costs Executive Management |
| | Supply Executive Management |
| **Climate Project(*)** | Water Resources and Meteorology Management |

(*) Climate Project is the short name for Sub-project 23 within the ONS

## *16. LIST OF REIMBURSABLE EXPENSES*

Reimbursable activities will not be necessary with regard to the contracting of Consultancy-2 in Sub-project 23.

### *17. LEGAL PROHIBITION*

The contractor may not directly or indirectly hire, in any capacity, active servants of the Federal, State, Federal District or Municipal Government or employees of its subsidiaries and controlled companies, within the scope of international technical cooperation projects. Art. 7 of Decree 5,151 from 07.22.2004.

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| **18. Technicians in Charge Name:**<br>**Paulo Diniz de Oliveira**<br>**Agency: Water Resources and Meteorology Management – Operating Board**<br>**Signature:** |

| |
|---|
| **19. Approval:**<br>**Name: Maria Cândida Abib Lima**<br>**Position: Executive Operation Schedule Manager Signature:** |

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*ANNEX I - Product 2 hydrometeorological databases*

Tables I.1 and I.2 show the hydrometeorological data that make up Product 2. (Note: The availability of the data listed shall depend on an internal assessment and finalization of Product 2).

**Table I.1 - Hydrometeorological data obtained from stations.**

| **Source** | **Variable** | **Time scale** |
|---|---|---|
| ONS | Flow rate | daily and monthly |
| INMET | Precipitation, temperature, wind direction and speed, solar radiation, relative humidity | daily and monthly |
| ANA | Precipitation and flow rate | daily and monthly |
| CEMADEN | Precipitation | daily and monthly |

**Table I.2 - Data obtained from satellites, analyzes and reanalyzes.**

| **Name** | **Type** | **Area and starting year** | **Variable** |
|---|---|---|---|
| CHIRPS | Satellite estimation | Latitude: 50°S - 50°N<br>Longitude: 0° - 360°<br>1981 | Precipitation |
| CMORPH | Satellite estimation | Global, 1998 | Precipitation |
| MERGE | Satellite estimation | Latitude: 85°W-27°W<br>Longitude: 57°S-13°N<br>2000 | Precipitation |
| MSWEP | Satellite estimation | Global, 1979 | Precipitation |
| ERA-5 | Reanalysis | Global, 1940 | Temperature (2m and pressure levels), wind (10m, 100m and pressure levels), pressure (surface and sea level), solar and longwave radiation, sea surface temperature, precipitation, precipitable water, geopotential at pressure levels, relative and specific humidity at pressure levels, vertical speed at pressure levels |

| | | | |
|---|---|---|---|
| GPCC | Reanalysis | Global, 1951 | Precipitation |
| ERSSTv5 | Reanalysis | Global, 1854 | Sea surface temperature |
| HadISST2 | Reanalysis | Global, 1850 | Sea surface temperature |
| DOISST2.1 | Reanalysis | Global, 1981 | Sea surface temperature |

ANNEX II - Databases of coupled sub-seasonal and seasonal prediction models of Product 3

Tables II.1 and II.2 show forecast data on the sub-seasonal and seasonal scales that make up Product 3, respectively. (Note: The availability of the data listed shall depend on an internal assessment and finalization of Product 3).

**Table II.1 - Sub-seasonal prediction models.**

| Model | Time range (days) | Resolution | Hindcast Period | Forecast Period | Coupled Ocean | Coupled Sea Ice |
|---|---|---|---|---|---|---|
| ECMWF - version CY48R1 | 0-46 | Tco639/ 319L91 | 1995-2021 | 2015-2022 | Yes | No |
| NCEP - CFSv2 | 0-44 | T126L64 | 1999-2010 | 2015-2022 | Yes | Yes |

**Table II.2 - Seasonal prediction models.**

| Model | Time range (months) | Resolution | Hindcast Period | Forecast Period | Coupled Ocean | Coupled Ice |
|---|---|---|---|---|---|---|
| ECMWF - version SEAS5 | 7 months (13 months) | T319 | 1981-2016 | 2017-2022 | Yes | Yes |
| GFS - CFSv2 | 9 months | T126 | 1982-2010 | 2011-2022 | Yes | Yes |

ANNEX III - Data engineering pipeline

This document is the definition of the data storage infrastructure to be provided for developing the activities. For this purpose, a Desktop as a Service shall be contracted. The chosen technology was designed to meet some requirements, namely:

- Flexible;
- Storage of different file types;
- Availability of data refinement;
- Viewing not restricted to any technology.

The technological platform of the products shall follow the layered architecture pattern, especially separated into data and integration. The data layer is responsible for collecting data from different sources (stations, weather models, satellite data, environmental data) and sharing it in a standard format for the platform's internal processing. The integration of data and its proper storage to meet product demands takes place in the integration layer. This component of the platform also acts in a centralized manner to allow access to data, seeking to ensure traceability, resilience and access scalability. This layered architecture also ensures a separation of responsibilities, which supports not only the traceability of access to information, but also the handling of errors, delivery (deployment) of new features or refinement of existing ones.

It should be emphasized that all of these technologies have been widely adopted and used in the market in general, which ensures the long-term continuity and maintenance of the platform.

This structure shall remain under the responsibility of Climatempo for 34 months. It should be emphasized that, from the second half of 2023, new companies (referred to herein as consultants) shall be contracted to keep performing the works. At this stage, Climatempo shall only act as a supervisor of the works, as well as being responsible for the maintenance/supervision of the cloud service. New consultants must bear the costs of:

- Downloading data for performing studies in their own environment;
- The inclusion of new data in the database or data lake following the previously described standards.
- The creation of new EC2 for development.
- At the end of the service, the closure of the EC2 and the transfer of the database by Deployment in the Contracting Party's environment will be requested.
- A brief description of the assembled infrastructure can be seen below.

## <u>Cloud Environment</u>

AWS (Amazon Web Service) was chosen to be the cloud service for this project.

**Managing access permissions**

Amazon Virtual Private Cloud (Amazon VPC) lets you launch AWS's features in a virtual network.

Servers will be accessed via SSH on private or Public IP with default port 22. The console will be accessed by creating users in IAM with the necessary permissions.

The database must be accessed via CLI (Command Line Interface) or via PGadmin (if the database is Postgres or Aurora) with IP/DNS and standard port, in the case of data in S3, access can be via console or using AWS CLI (AWS Command Line Interface).

**Data Layer**

AWS S3 or Amazon Simple Storage Service is a site where we can store objects. S3 Standard Storage with a capacity of 32 Tb per month shall be contracted for this project. It should be emphasized that AWS Aurora will be used as the data source.

The data to be stored are:

i. Daily and monthly flow rate data from the hydroelectric plants of the SIN: noticed database from natural flow rates at daily and monthly time frequencies of all hydroelectric plants belonging to the SIN. Such data will be acquired from the public database provided by the Brazilian National Operator for the Electricity System (ONS) and the Energy Research Company (EPE).

ii. Observational data from conventional and automatic stations: Observational data from conventional and automatic stations will be collected from the primary official public sources in Brazil that comprise the territorial domain of the SIN. Data of variables for precipitation, wind direction and speed, air temperature at 2 meters, relative humidity and solar radiation on the surface will be collected by the meteorological stations of the Brazilian National Institute of Meteorology (INMET), both conventional and automatic, daily and monthly. For the precipitation variable, other official observation sources will be used to make up the observational set that will serve as the supply for the studies resulting from this one. Such sources refer to the rainfall stations of the Brazilian National Water Agency (ANA), the National Center for Natural Disaster Monitoring and Warnings (CEMADEN) and the ONS itself.

iii. Grid point data, analyses, reanalyzes, data estimated per satellites, proxies and synthetic series: Climate Hazards Group Infra-Red Precipitation with Station – CHIRPS; Climate Prediction Center (CPC Morphing Technique (MORPH), database referred to as CMORPH; MERGE from the Center for Weather Forecasting and Climate Studies (CPTEC) of the Brazilian National Institute for Space Research (INPE); Multi Source Weighted-Ensemble Precipitation – MSWEP; ERA5 from the European Centre for Medium-Range Weather Forecasts (ECMWF); CFSv2 from the National Centers for Environmental Prediction (NCEP); and Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA2), from the National Aeronautics and Space Administration (NASA) of the Global Modeling and Assimilation Office (GMAO).

iv. Data from operational models for forecasting precipitation, air temperature at 2 meters, wind strength and solar radiation incident on the surface:

- Sub-seasonal prediction models: ECMWF 0–46 Tco639/ 319L91 3–4 Days 1995–2021 2015-2022; and NCEP 0–44 T126L64 Daily 1999–2010 2015–2022.
- Seasonal prediction models: ECMWF (version SEA5); and CFSv2.
- Series of climate indicators.

v. Paleoclimate model data:

- Paleoclimate models: PMIP4.

vi. Georeferenced data:

- Land coverage;
- Digital elevation model;
- Pedology; and
- Others.

Hydrometeorological station data is stored in Aurora (pre-described items i and ii). It will provide information on source, id, latitude, longitude, altitude, variable and figures. All information will be stored in UTC time. It should be emphasized that two structures will be created in it: one for raw data and another one for processed data. A database drawing can be seen in Figure III.1.

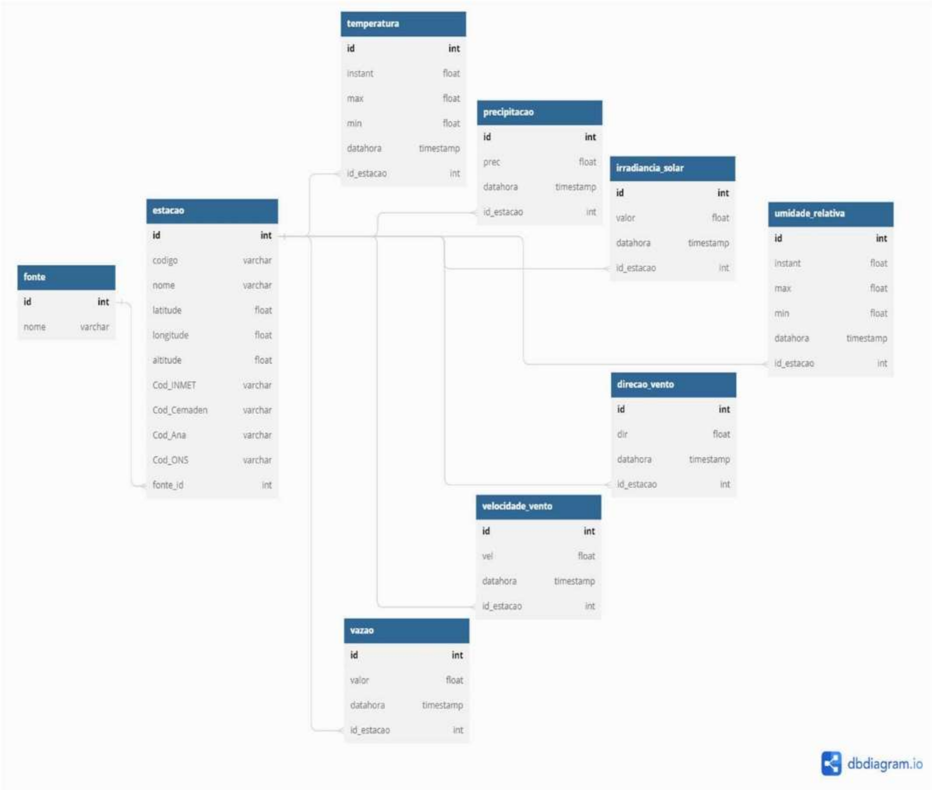


**Figure III.1 - Relationship of entities - ONS Climate Project.**

All of the other project data (models, reanalysis, satellite, environmental and others) are stored in S3. The files will be separated by type (satellite, reanalysis, environmental, models), source (ECMWF, NCEP, INPE and others), period (historical, time, sub-seasonal, seasonal and paleoclimate), time scale (year, month, day, hour, minute).

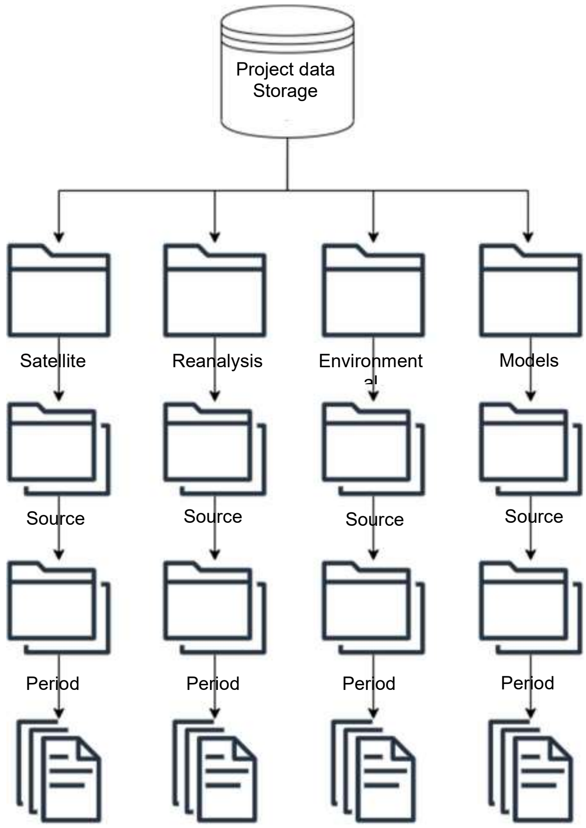


**Figure III.2 - Data storage.**

## Integration layer

Amazon Elastic Compute Cloud (Amazon EC2) is a Web-based service that provides safe, scalable cloud-based computing power. EC2 offers many options that allow the creation and execution of virtually any application. A machine will be created in it for project development, where:

- Leasing: shared instances;
- Operating System: Linux;
- Workload consistent with the number of instances: 1;
- Advanced EC2 instance: m7g.4xlarge (Family: m7g | 16vCPU | 64 GiB Memory);
- Pricing strategy: use on demand – 214 hours/month;
- Storage capacity: 1 TB.

In this environment, researchers will perform all of the activities required to deliver Product 2 - Analysis of meteorological data with long periods of observation in the SIN, Product 3 - Analysis of Data from Coupled Precipitation Forecasting Models, Other Meteorological Variables and soil use (considering series obtained by Paleoclimate) and 4 - Preliminary assessment of climate variability/change in available meteorological and hydrological series.

All scripts created will be developed in Python language. The justification for its adoption, compared to all other valid alternatives, such as R, is the expectation of wide application of different machine learning architectures, and that Python has consolidated itself as the main development language with greater support for this type of application. Among the most important frameworks to be applied in development, PyTorch will be adopted. Still in relation to the main frameworks applied in development, given the expectation that the models will have to continually process large volumes of input data, the Polars framework will be adopted for IO activities, data processing and DataFrame handling in general, as it has considerable performance gains and better memory management compared to more classic Python alternatives, such as Pandas.

**<u>Tools</u>**

In order to view the data, the following will be used: Climate Data Operators (CDO), which represents a set of statistical and arithmetic commands which are useful for processing meteorological data in GRIB and NetCDF formats; Quantum GIS (QGIS), which is a free, open-source program used to process geospatial data; and an picture (charts and tables) viewer; Python 3 to run scripts; Python’s own frameworks (E.g.: PyQT5 and Tkinter).

ANNEX IV - Statistical metrics for assessing coupled models for forecasting precipitation and other meteorological variables

Figure IV.1 shows the main metrics used to assess the performance of precipitation prediction models and other meteorological variables.

| Metric | Definition | Equation |
|---|---|---|
| **Bias** | Threshold: - ∞ - ∞ Perfect Score = 0. Simple interpretation. It does not measure the magnitude of errors or the correspondence between prediction and observation. In other words, it is possible to obtain a perfect score for a bad forecast if there are errors that are offsetting. | $Viés = \frac{1}{N}\sum_{i=1}^{N}(Previsão_i - Observação_i)$ |
| **Mean Absolute Percentage Error** | Threshold: 0 - ∞. Perfect Score = 0. Simple interpretation, intuitive in terms of relative error. It does not indicate the direction of the deviations. | $MAPE = \sum_{i=1}^{N}\left\lvert\frac{Observação_i - Previsão_i}{Observação_i}\right\rvert$ |
| **Root of the Mean Square Error** | Threshold: 0 -∞ Perfect Score = 0, Simple interpretation. Measures the mean error weighting according to the root of the error. It does not indicate the direction (sign) of the deviations. The RMSE is greatly influenced for high errors than for low error values, which can be interesting when especially high errors are not desired. | $RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Previsão_i - Observação_i)^2}$ |
| **Pearson Correlation** | Threshold: -1 -1. Perfect Score = 1. Good measure of linear association or phase error. Visually, the correlation measures how close the points of a scatter plot are to a straight line. It does not consider the forecast bias. It is possible for a forecast with high errors to have a high correlation with the observations. It is sensitive to outliers. | $R = \frac{\sum_{i=1}^{N}(Previsão_i - Previsão_{média})(Observação_i - Observação_{média})}{\sqrt{\sum_{i=1}^{N}(Previsão_i - Previsão_{média})^2}\sqrt{\sum_{i=1}^{N}(Observação_i - Observação_{média})^2}}$ |

**Figure IV.1 – Main statistical metrics used to assess the performance of prediction models.**