Spatial altimetry to assess hydropower potential of the Congo basin

Windhoek, April 2\textsuperscript{nd}
AGENDA

1. CONTEXT AND PROJECT BACKGROUND
2. INTRODUCTION
3. METHODOLOGY
4. DISCUSSIONS
5. CONCLUSION
• SPATIAL HYDROLOGY WORKING GROUP

− Objective:
  • develop operational applications using satellite data as input, and especially spatial altimetry, in context with few data
  • prepare French-US SWOT program (Surface Water Ocean Topography), a satellite that will be launched in 2021

− The Congo Basin is defined as first pilot basin

− AFD as funding agency

− CNR as member of the 8 French entities involved in the project
PRINCIPLES OF SPATIAL ALTIMETRY

- Altitude measurement of water bodies by satellites
- Intersections between rivers and satellite tracks are called virtual stations
- Accuracy around 10 cm
**CICOS**

| **CICOS**  
| (International Commission for Congo-Oubangui-Sangha basin) |
|----------|--------------------------------------------------|
| **Creation date** | 1999 |
| **Member States** | Rep. of Cameroon (1999)  
| | Rep. of Congo (1999)  
| | Rep. of Angola (2007 as observer, 2015 as member)  
| **Missions** | 1999 : inland navigation promotion  
| | 2007 : integrated water resources management |
INTRODUCTION – COMPANIES’ PROFILES

- CNR, holder of the Rhone River concession in South-East of France with three historical missions:
  - Hydropower
  - Inland navigation
  - Irrigation
  (3000MW)

- CNR offers technical support in the fields of hydropower, navigation and river engineering

- CNR, member of French SWOT working group on space altimetry
INTRODUCTION – CONTEXT AND OBJECTIVE

• CICOS AND HYDROPOWER

– SDAGE: CICOS has adopted a master plan for water development and management (“SDAGE”)

– Program of measures 2016-2020:
  • Identification of projects within the framework of the “SDAGE”
  • Three strategic objectives: economic development of the region, social equity and preservation of environment

– Design and implementation of micro and pico-hydropower plants associated to drinking water supply is part of the main projects identified
OBJECTIVES

- Assess hydropower potential of river sections on the Congo and Ogooué basins
- Use spatial altimetry data and study its added-value
- Subsequently identify sites to be equipped, in cooperation with states Rural Electrification Agencies
## Catchments’ Main Characteristics

<table>
<thead>
<tr>
<th>River</th>
<th>Congo</th>
<th>Ogooue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchm. Size</td>
<td>3.8 M km²</td>
<td>224,000 km²</td>
</tr>
<tr>
<td>Mean annual flow</td>
<td>41,000 m³/s at Kinshasa / Brazzaville¹</td>
<td>4,700 m³/s at Lambarene²</td>
</tr>
</tbody>
</table>

¹ Source: CICOS
² Source: GRDC website
# METHODOLOGY – DATA

## GAUGING STATIONS

<table>
<thead>
<tr>
<th>Type</th>
<th>Hydrological data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source (Congo River)</td>
<td>Runoff data observed and reconstructed¹</td>
</tr>
<tr>
<td>Comments</td>
<td>82 stations</td>
</tr>
<tr>
<td></td>
<td>Period: 1948-2012</td>
</tr>
<tr>
<td></td>
<td>Time step: Daily</td>
</tr>
<tr>
<td>Source (Ogooué River)</td>
<td>GRDC database</td>
</tr>
<tr>
<td>Comments</td>
<td>18 stations</td>
</tr>
<tr>
<td></td>
<td>Period: varying</td>
</tr>
<tr>
<td></td>
<td>Time step: Annual mean</td>
</tr>
</tbody>
</table>

¹ Runoff reconstructed in a previous project (source CICOS / BRLi)
**VIRTUAL STATIONS**

<table>
<thead>
<tr>
<th>Type</th>
<th>Virtual stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source (Congo River)</td>
<td>Data from CICOS / IRD-LEGOS</td>
</tr>
<tr>
<td>Comments</td>
<td>745 stations before selection 253 stations after selection</td>
</tr>
<tr>
<td>Source (Ogooué River)</td>
<td>Hydroweb Theia</td>
</tr>
<tr>
<td>Comments</td>
<td>21 stations before selection 13 stations after selection</td>
</tr>
</tbody>
</table>
# METHODOLOGY – DATA

## RAINFALL AND DEM

<table>
<thead>
<tr>
<th>Type</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>CRU observed rainfall</td>
</tr>
</tbody>
</table>
| Comments| Resolution: 0.5° grid  
Period: 1901-2016 
Time step: Monthly |

<table>
<thead>
<tr>
<th>Type</th>
<th>DEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>HydroSHEDS</td>
</tr>
</tbody>
</table>
| Comments| Resolution: 30”  
(926m at the Equator) |
METHODOLOGY – IN A NUTSHELL

• 3 MAJOR STEPS

1. Calculate water head between two consecutive virtual stations
   \[ h = H_{US} - H_{DS} \]

2. Extrapolate discharge at virtual stations \((Q_{US})\)

3. Calculate linear power potential for each river section (MW/km)

Representation of a catchment with two virtual stations (US: upstream, DS: downstream).
METHODOLOGY – STEP BY STEP

• STEP 1: CALCULATE WATER HEAD BETWEEN TWO CONSECUTIVE VIRTUAL STATIONS

  – Preprocessing of virtual stations datasets to:
    • Identify and delete outliers
    • Select relevant subset of stations (number of data, distance to other stations...)
    • Accurately locate virtual stations on the DEM

  – Calculation of average water levels for each virtual station

  – Calculate catchment area at each virtual station
• **STEP 2: EXTRAPOLATE DISCHARGE AT VIRTUAL STATIONS**

  - Calculation of mean annual discharge using observed or reconstructed daily flow for 82 gauging stations
  - Identification of a reference in-situ station for each virtual station
  - Extrapolation of virtual stations mean discharge (Q) using:
    - Rainfall mean annual data (P)
    - Catchment sizes (S)

\[
Q_{VS} = Q_{hydro} \times \frac{S_{VS}}{S_{hydro}} \times \frac{P_{VS}}{P_{hydro}}
\]
METHODOLOGY – STEP BY STEP

• STEP 3: CALCULATE LINEAR POWER POTENTIAL FOR EACH RIVER SECTION (MW/KM)

  – Assessment of power potential: \( P \approx 8 \cdot h \cdot Q \)
    • \( h \) average head between two consecutive virtual stations
    • \( Q \) mean annual discharge at the upstream station

  – Transformation into linear power potential (LPP) by dividing \( P \) by the length \( L \) of the river section between the two corresponding consecutive virtual stations
    • \( LPP = \frac{P}{L} \)
METHODOLOGY – RESULTS

- IDENTIFICATION OF RIVER SECTIONS WITH HIGH POTENTIAL (LPP)
  - Sections with high potential
    - Sections with high flow (Congo, Ubangui, Kasai)
    - Sections with steep slopes (Congo upstream Kisangani)
  - Sections with low potential
    - Central basin
    - Smallest rivers

LPP scale

[Scale with colors and intensity levels]
DISCUSSIONS – ABOUT THE METHOD

• ADVANTAGES
  – Method identifying river sections with the most interesting densities of hydropower potential
  – Method based on innovative data
  – Method replicable for other catchments with similar characteristics in terms of river width and catchment size

• DRAWBACKS
  – The technically and economically feasible potential has to be derived from the linear power potential
  – The identification of a site requires additional information: proximity of energy consumption points, affordable electricity price, technical information, etc.
DISCUSSIONS – ABOUT SPATIAL ALTIMETRY

**SPATIAL ALTIMETRY: CURRENT LIMITATIONS**

- The density of virtual stations varies on the basins:
  
  • Over-representation in some areas (largest rivers, Central basin)
  
  • Under-representation in other areas (mountainous areas and northern end of the basin)

- Spatial altimetry is not spatialized
  
  • The use of a DEM is a good alternative for a full coverage of the basin and the choice of relevant river sections
DISCUSSIONS – ABOUT SPATIAL ALTIMETRY

**SPATIAL ALTIMETRY: SWOT PERSPECTIVES**

- SWOT will provide continuous information of altitude and slope, with added-value for:
  - The global methodology presented
  - The local knowledge of the river while studying a specific site

CONCLUSION

- SWOT: a new technology with interesting perspectives available in 2021
- Innovative data benefiting to the knowledge of water resources in scarce data areas
- Partnership between organizations and companies operating in complementary fields:
Merci de votre attention!
Thank you for your attention!