Towards a Global High-Resolution Inundation Map: African continent application

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Presentation Outline

- **Intro:** Global wetland inventories
- **Objective**
- **Methods:** Downscaling with topographic inundation probabilities
- **Results:** Downscaled inundation maps
- **Follow-up:** Global mapping progress & customization
- **Application:** Mekong basin ecosystem connectivity
- **Conclusion**
# Intro: Global wetland area

Adapted from MEA – Inland Water Systems Chapter (Finlayson et al. 2005)

<table>
<thead>
<tr>
<th>Geopolitical Region</th>
<th>Bottom-up compilation of inventories</th>
<th>Aggregation of existing global maps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GRoWI: Global Review of Wetland Resources (Finlayson et al. 1999)</td>
<td>GLWD: Global Lakes and Wetlands Database (Lehner and Döll, 2004)</td>
</tr>
<tr>
<td>Africa</td>
<td>1,247 (thousand km²)</td>
<td>1,314 (thousand km²)</td>
</tr>
<tr>
<td>Asia</td>
<td>2,043 (thousand km²)</td>
<td>2,856 (thousand km²)</td>
</tr>
<tr>
<td>Europe</td>
<td>2,580 (thousand km²)</td>
<td>260 (thousand km²)</td>
</tr>
<tr>
<td>Neotropics</td>
<td>4,149 (thousand km²)</td>
<td>1,594 (thousand km²)</td>
</tr>
<tr>
<td>North America</td>
<td>2,416 (thousand km²)</td>
<td>2,866 (thousand km²)</td>
</tr>
<tr>
<td>Oceania</td>
<td>358 (thousand km²)</td>
<td>275 (thousand km²)</td>
</tr>
<tr>
<td>Total Area</td>
<td>~ 12,792 (thousand km²)</td>
<td>~ 9,167 (thousand km²)</td>
</tr>
</tbody>
</table>

+ Lakes and Rivers     + 0                                   + 2670
+ Max. Fractional classes + 0                                   + 952
Reviewed Area          12792                                               12798
**Intro: Global Spatial Inventories**

Global Lake & Wetland Database (GLWD)  
Global Surface Water Extent Dataset (GSWED)

Maximum wetland extent.  
Monthly cell inundated fraction.

Aggregation of global datasets creates inconsistencies.  
Generated from multi-satellite method.

Compounds errors from source data.  
Coarse res. doesn’t distinguish distinct waterbodies nor detects low inundation fractions.

*(Lehner & Döll. 2004)*  
*(Papa et al. 2010)*
Intro: Inventorying Challenges

Conventional approaches struggle to produce a complete global wetland inventory:

- Aggregation of regional map:
  Definition inconsistencies and untraceable errors.

- Remote sensing imagery:
  Spatial VS Temporal resolution trade-off.

A novel approach is required to circumvent these methodological hurdles.
Produce a global inundation extent map:

- High spatial resolution for conservation applications
- Based on actual observations for continued monitoring
- Globally consistent for comparison across regions
Methods: Available Global Datasets

GSWED - Global Surface Water Extent Dataset
(Papa et al. 2010)

HydroSHEDS
(Lehner et al. 2008)
**Methods:** Available Global Datasets

**GSWED - Global Surface Water Extent Dataset**  
(Lehner et al. 2008)

- *HydroSHEDS*  
  (Papa et al. 2010)

**Inundated fraction of cell (%)**

- ~27 km at equator
- 1993 to 2004

**Topographic & Hydrographic**

- ~500 m at equator
- Static snapshot of 2000

**Mean Annual Maximum GSWED Inundation Fraction**

- 0%
- 1 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 40%
- 41 - 50%
- 51 - 60%
- 61 - 70%
- 71 - 80%
- 81 - 90%
- 91 - 100%

River network and basin outlines derived from SRTM elevation data at 300m resolution.
**Method: Topographic Downscaling**

Downscale GSWED inundated area to finer resolution of HydroSHEDS.

Use topographic information to allocate inundated area to high-resolution pixels.
Methods: Inundation Probabilities

The predictive information of inundation occurrence from topography summarized into topographic inundation probabilities.

13 Topo. Variables

- Slope
- Dist. to river (x6)
- Elev. above river (x6)

Validated regional inundation/wetland extent map

Training Data

Inund. Probability Map

Decision Tree Learner

Method inspired by work from Bwangoy et al. (2010)
**Methods:** Inundation Probabilities
Methods: Inundation Probabilities
Methods: Probability Thresholding

- Inund. Probability Map
- GSWED Inund. Fraction
  - Time #1: 25% Inundated
- Frequency (Nb. of pixels) vs. Inundation Probability
  - Threshold: Inundated 25% of pixels
- Inund. Extent Map
Methods: Probability Thresholding

- **GSWED Inund. Fraction**
  - **Time #1**: 25% Inundated
    - Frequency (Nb. of pixels) vs. Inundation Probability
    - Threshold: Inundated 25% of pixels
  - **Time #2**: 10% Inundated
    - Frequency (Nb. of pixels) vs. Inundation Probability
    - Threshold: Inundated 10% of pixels

- **Inund. Extent Map**
Evaluates spatial distribution of downscaled inundation from probability map over validation areas.

Accuracy metrics:
- Producer Accuracy: 84.3%
- Overall Accuracy: 92.3%
- Kappa Index: 80.1%
Methods: Recap.

Topographic Downscaling
(Spatial Distribution error)

- Topo. Variables
- Decision Tree
- Inundation Probability
- Moving Window Thresholding

Inundation estimates
(Inundation area error)

- GSWED
- GLWD

Fusion of estimates

Validation Data

Downscaled Inundation Map
**Methods:** Fusion of GLWD & GSWED

Inundated area from GLWD & GSWED merged, based on their values in each cell.
Inundated area from GLWD & GSWED merged, based on their values in each cell.

Methods: Fusion of GLWD & GSWED
Methods: Africa Total Wetland Area

Note: artificial inundation from irrigated rice paddies account for 8.7 thousand km² over the continent.
Results: Downscaled Inundation Maps

Mean Annual Maximum

Fusion Maximum

MAMax Moving Window Thresholding (MWT)

Moving Window Thresholding (MWT)
Results: Downscaled Inundation Maps

Mean Annual Maximum

Fusion Maximum

- Nile River Floodplain
- Sudd Marshes
- Congo River Cuvette Centrale
- Okavango Delta
- Zambezi Delta
Results: Study Sites

---|---|---|---|---|---
Okavango
Sudd Marshes
Congo
Nile
Zambezi Delta
## Results: Study Sites Metrics

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Okavango</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>8,528 km²</td>
<td></td>
<td>14,969 km²</td>
<td></td>
<td>12,573 km²</td>
<td>3,596 km²</td>
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<tr>
<td>Kappa Index</td>
<td>-</td>
<td>41.6%</td>
<td>51.2%</td>
<td>40.1%</td>
<td>37.2%</td>
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<tr>
<td>Inundated Area</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>Sudd Marshes</strong></td>
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</tr>
<tr>
<td>Area</td>
<td>31,331 km²</td>
<td></td>
<td>32,961 km²</td>
<td></td>
<td>57,589 km²</td>
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<tr>
<td>Kappa Index</td>
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<td>63.7%</td>
<td>58.3%</td>
<td>50.5%</td>
<td>34.9%</td>
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<tr>
<td>Inundated Area</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td><strong>Congo</strong></td>
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</tr>
<tr>
<td>Area</td>
<td>143,256 km²</td>
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<td>198,179 km²</td>
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<td>134,061 km²</td>
<td>44,796 km²</td>
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<td>Kappa Index</td>
<td>-</td>
<td>61.6%</td>
<td>51.4%</td>
<td>52.8%</td>
<td>41.6%</td>
<td>-</td>
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<tr>
<td>Inundated Area</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td><strong>Nile</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Area</td>
<td>12,475 km²</td>
<td></td>
<td>2,877 km²</td>
<td></td>
<td>20,812 km²</td>
<td>18,772 km²</td>
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<tr>
<td>Kappa Index</td>
<td>-</td>
<td>69.6%</td>
<td>3.9%</td>
<td>14.4%</td>
<td>47.6%</td>
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<td>Inundated Area</td>
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<tr>
<td><strong>Zambezi Delta</strong></td>
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<tr>
<td>Area</td>
<td>16,660 km²</td>
<td></td>
<td>8,055 km²</td>
<td></td>
<td>18,309 km²</td>
<td>7,396 km²</td>
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<tr>
<td>Kappa Index</td>
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<td>59.7%</td>
<td>25.0%</td>
<td>28.9%</td>
<td>52.8%</td>
<td>-</td>
</tr>
<tr>
<td>Inundated Area</td>
<td>-</td>
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<td></td>
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</tr>
</tbody>
</table>
Follow-up: Global Mapping Progress

- Inundation Extent Map
- Inundation Probabilities
- Not Mapped
Follow-up: Product Customization

Method designed for different resolutions.

Temporal Resolution

Current: Mean Annual Maximum
Historical Maximum (from Fusion)

Minimum: Monthly

Spatial Resolution

Current: 500m
Reproducible at: 90m or 1000m
Application: Mekong Basin Inundation
Application: Mekong Basin Connectivity

River habitat classification

Ecological Regions

River Habitat Types

- Karstic River
- Small River without Floodplains
- Medium River without Floodplains
- Large River without Floodplains
- Small River with Floodplains
- Medium River with Floodplains
- Large River with Floodplains

Ecosystem Connectivity

Current situation (2011)

- Number of ecosystems connected
  - 1 - 4
  - 5 - 8
  - 9 - 12
  - 13 - 16
  - 17 - 20
  - 21 - 24

Dendritic Connectivity Index (DCI): 44.4%

River Ecosystem Connectivity Index (RECI): 73.4%

Existing Dams
Planned Dams

Ecosystem Connectivity

Current and future dams (2022)

- Number of ecosystems connected
  - 1 - 4
  - 5 - 8
  - 9 - 12
  - 13 - 16
  - 17 - 20
  - 21 - 24

Dendritic Connectivity Index (DCI): 9.7%

River Ecosystem Connectivity Index (RECI): 5.1%

Existing Dams
Planned Dams

(Lehner et al., in prep)
Conclusion

Provides improved wetland baseline inventory
- Superior spatial res. than other global inventories
- Globally consistent, quantified accuracy.

Much room for improvement in future
- Cannot distinguish natural from artificial inundation
- Monthly temporal variations depends on GSWED
- Possibility to improve map accuracy with:
  Additional reference data
  Downscaling method optimization
  Improved inundation GSWED estimates.
Thank You!

Questions?
Literature Cited


Lehner, B., Grill G., Ouellet-Dallaire C., Fluet-Chouinard, E., in prep., Ecosystem fragmentation and flow regulation in the Mekong River Basin due to past and future dam development:


Extra Slides

Reference Data (for train/valid.)

Moving Window Thresholding
## Reference Data

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Region</th>
<th>Wetland/Inundation Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Africa Regional Program for the Environment (CARPE) – Congo Wetland Map (Bwangoy et al. 2010)</td>
<td>Central Congo Basin</td>
<td>General wetland definition, to distinguish from non-wetland upland forests. Map produced from thresholding of wetland probabilities from remote sensing and topographic indices.</td>
</tr>
</tbody>
</table>

### Sampled Reference Data

- **UMD** (n = 502) (Carroll et al. 2009)
- **CARPE** (n = 288) (Bwangoy et al. 2010)

### Training / Validation Subsets

- **Training** (80%) (n = 633)
- **Validation** (20%) (n = 157)
Methods: Moving Window Thresholding

Thresholding on single tiles creates linear features at the borders.

MWT eliminates linear features by reallocating inundated area.

Reallocating inundated area among adjacent cells based on probabilities of each cell.

Reallocating does not significantly alter total inundated area.