Set-up of CGMS in Ethiopia and first user experiences

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A. Objective

Adaptation of the European CGMS to an African tropical region and improvement of the model with remote sensing integration or assimilation.

Extract a set of comprehensive crop growth parameters at sub-national level for early forecasting/warning purposes and agricultural productions estimates.
Activity included into the GLOBAM project
(GLOBal Agricultural Monitoring systems by integration
of earth observation and modelling techniques – Belgian
Science Policy Funded Project)
B. GLOBAM Model selection

Four criteria were used to select the models:

- Model selection is directed by the number of biophysical variables calculated by these approaches that could be compared with RS derived ones.
- Possibility for the selected models to receive and valorise direct remote sensing information instead of intermediate calculated state or output variables. This requests an accessibility to the source codes.
- The selected models should also have ability to work both at (large) parcel and NUTS3 level. It should also work in the 3 different test sites.
- Finally, the model selection also depends on our own experience with process-oriented crop growth models. Indeed the three scientific teams implied in the selection process have a strong experience with the Mars Crop Yield forecasting System.
B.1. Model selection: WOFOST (CGMS)

CGMS, the Crop Growth Monitoring System,

- used at European level since 1992.
- based on the photosynthesis process
- all the teams implied in the agrometeorological part of GLOBAM have a strong experience with this model.
- the model has got a calibration platform that allows, in principle, a robust calibration of the model for the three different test sites.
B.2. Possibilities for improving Agromet models

- Improving estimates of static parameter values
- Improving estimates of initial conditions in space and time
- Replacing state variables (LAI, ETa, Biomass) by input variable estimated by RS
- Applying sequential assimilation processes to update crop state variables
- Use spatio-temporal dispersion of RS-derived biophysical variables to produce probabilistic model outputs.
B.3. Model validation

- At parcel level, comparison between field biophysical variables observed and model outputs.

- At NUTS 3 level, comparison between official stats figures (if available and reliable) and average values of fields biophysical variables in the same administrative unit.

- Comparison also with operational models running in the study site.
C. Study area

Area: 1,113,380 sq.km
Rural: 85%
Wheat area: 1.3 million ha
C.1. Wheat zone (CSA 2001 census)
<table>
<thead>
<tr>
<th>Agroecological zone</th>
<th>mean temperature (°C)</th>
<th>Annual rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bereha (Less than 500m)</td>
<td>28.4 ± 0.1</td>
<td>327.9 ± 17.9</td>
</tr>
<tr>
<td>Kolla (500 to 1500 m)</td>
<td>25.5 ± 0.2</td>
<td>555.6 ± 26.8</td>
</tr>
<tr>
<td>Woina Dega (1500-2300 m)</td>
<td>21.3 ± 0.3</td>
<td>1310.8 ± 60.8</td>
</tr>
<tr>
<td>Dega (2300 to 3200 m)</td>
<td>19.0 ± 0.4</td>
<td>1655.7 ± 83.0</td>
</tr>
<tr>
<td>Wurch (3200 to 3700)</td>
<td>19.3 ± 1.2</td>
<td>1217.9 ± 214.5</td>
</tr>
</tbody>
</table>
D. METHODOLOGY

D.1 Crop growth model

WOFOST crop simulation model (van Diepen, Rappold, Wolf, and van Keulen, 1989)

CGMS applications: CGMS version 9.2

CGMS has been chosen for:

- the database framework for model inputs and outputs;
- the facility for aggregation at different administrative levels;
- the facility to link with GIS and remote sensing data;
- availability of different complementary tools (CALPLAT, SANPLAT, CGMS-Statool, Pywofost).
D.2. WOFOST Crop Model

- conversion of daily weather data into daily growth of crop biomass
- many crops: Wheat, Barley, Maize, Rice, Sunflower, Rapeseed, Sugar Beet, Potato, Field Beans/Peas, Soy Beans, Pastures (Rye Grass)
- Energy balance, water availability, dry matter partitioning
D.3. Model input

- ECMWF dekadal data
- FAO World Soil map
- WOFOST spring wheat parameters
- Miscellaneous Data
- Ethiopian vector Coverage at sub-national level
D.3.1. Weather data

Source: FOODSEC Climatic database (CID portal)

Parameters:
- average temperature
- maximum temperature
- minimum temperature
- precipitation sum
- evapo-transpiration sum (ES0, bare soil)
- evapo-transpiration sum (E0, over water)
- evapo-transpiration sum (ET0, Penman-Monteith)
- global radiation sum

Spatial resolution: 0.5 degree grid (≈ 50 * 50 kms)

Temporal resolution: 10-daily

Temporal windows used: 1997 to 2007

Others parameters: wind speed and vapour pressure (FAO new-loclim database at monthly time scale)
D.3.2. Soil database

- Source: FAO-UNESCO soil database and map (Africa soils V.1)
  Scale = 1:5000 000

- Pedotranfer rule: Baruth et al (2006) and Altera Water holding capacity table
  - Soil database elements:
    - 39 soil physical group
    - 288 soils units
    - 26 major soil association

- Other soil database:
  Harmonized World soil database
  [HWSD, (Nachtergaele, 2008)]
D.3.3. CROP Parameters

- **Crop parameters**: Wofost spring wheat parameters provided by ALTERRA

- **Crop data**

  - Phenology (sowing, anthesis, maturity): Ethiopia NMA census

  Sowing date: June
  Harvest date: October

- **TSUM1 and TSUM2 calculation based on climatic data clustering**

<table>
<thead>
<tr>
<th>Variety</th>
<th>TSUM1</th>
<th>TSUM2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1187</td>
<td>1212</td>
</tr>
<tr>
<td>20°&lt;T mean &lt; 22°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1041</td>
<td>13%</td>
<td>1071</td>
</tr>
</tbody>
</table>

TSUM1 and TSUM2 values and coefficient of variation

Wheat area classification
### D.3. Model input

#### D.3.4. Ethiopia NUTS

<table>
<thead>
<tr>
<th>NUTS LEVEL for CGMS</th>
<th>Ethiopia</th>
<th>Administrative Level</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Regions</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>1</td>
<td>Zones</td>
<td>2</td>
<td>68</td>
</tr>
<tr>
<td>2</td>
<td>Woreda</td>
<td>3</td>
<td>≈550</td>
</tr>
</tbody>
</table>
D.3. Model input

D.3.5. Ethiopia NUTS 0 and 1 maps
D.4. Miscellaneous data

- GLOBCOVER image: Check land suitability
- Official statistics yields: 1997 to 2005 for Zone Level
- Official statistics yield, area: 2001 CSA census for Woreda level
D.4. Miscellaneous data

Official statistics: wheat Yield (kg/ha)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Mean</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsi</td>
<td>1690</td>
<td>243</td>
</tr>
<tr>
<td>Hadiya</td>
<td>1644</td>
<td>139</td>
</tr>
<tr>
<td>Bale</td>
<td>1629</td>
<td>203</td>
</tr>
<tr>
<td>East Shewa</td>
<td>1601</td>
<td>117</td>
</tr>
<tr>
<td>West Shewa</td>
<td>1494</td>
<td>221</td>
</tr>
<tr>
<td>South West Shewa</td>
<td>1431</td>
<td>173</td>
</tr>
<tr>
<td>East Gojam</td>
<td>1346</td>
<td>179</td>
</tr>
<tr>
<td>North Shewa</td>
<td>1287</td>
<td>226</td>
</tr>
<tr>
<td>South Wello</td>
<td>1214</td>
<td>184</td>
</tr>
<tr>
<td>North West Shewa</td>
<td>1045</td>
<td>156</td>
</tr>
<tr>
<td>North Gonder</td>
<td>979</td>
<td>218</td>
</tr>
<tr>
<td>South Gonder</td>
<td>773</td>
<td>113</td>
</tr>
<tr>
<td>Mean</td>
<td>1345</td>
<td>142</td>
</tr>
</tbody>
</table>
**E. RESULTS**

**E.1. Region level**

Except Addis Ababa where no real agriculture exists, CGMS water limited grain yield reaches the same level of yield as observed in official statistics and other models (CERES) at regions level.

<table>
<thead>
<tr>
<th>Regions</th>
<th>Potential Biomass</th>
<th>Potential grain yield</th>
<th>Water limited biomass</th>
<th>Water limited grain yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addis Ababa</td>
<td>16594 ± 535</td>
<td>8740 ± 174</td>
<td>9051 ± 1,404</td>
<td>3490 ± 881</td>
</tr>
<tr>
<td>Amhara</td>
<td>14127 ± 315</td>
<td>6895 ± 144</td>
<td>5275 ± 704</td>
<td>1298 ± 342</td>
</tr>
<tr>
<td>Oromia</td>
<td>14382 ± 496</td>
<td>7493 ± 243</td>
<td>5406 ± 343</td>
<td>1517 ± 205</td>
</tr>
<tr>
<td>SNNP</td>
<td>15930 ± 415</td>
<td>8271 ± 196</td>
<td>7885 ± 507</td>
<td>2216 ± 282</td>
</tr>
<tr>
<td>All</td>
<td>15258 ± 272</td>
<td>7850 ± 146</td>
<td>6904 ± 481</td>
<td>2130 ± 278</td>
</tr>
</tbody>
</table>
Weak link with official stats data!
ECMWF rainfall data as a probable main reason of this discrepancy
E.2. Zone level

Regression analyses per region over all years

Simple linear regression between official statistics and CGMS outputs are significant in 4 zones over 12, and water limited grain and biomass, potential grain yield and biomass explain 20 to 58% of the variability of official statistics.

<table>
<thead>
<tr>
<th>NUTS NAME</th>
<th>Model</th>
<th>RMSE</th>
<th>$R^2$</th>
<th>Intercept</th>
<th>slope</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsi</td>
<td>WB</td>
<td>246</td>
<td>0.58</td>
<td>543</td>
<td>0.26</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>WG</td>
<td>272</td>
<td>0.48</td>
<td>814</td>
<td>0.9</td>
<td>0.056</td>
</tr>
<tr>
<td>North Gonder</td>
<td>WB</td>
<td>234</td>
<td>0.53</td>
<td>581</td>
<td>0.08</td>
<td>0.042</td>
</tr>
<tr>
<td>South Gonder</td>
<td>WG</td>
<td>114</td>
<td>0.58</td>
<td>924</td>
<td>-0.1</td>
<td>0.029</td>
</tr>
<tr>
<td>West Shewa</td>
<td>PB</td>
<td>259</td>
<td>0.2</td>
<td>-943</td>
<td>0.15</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td>PG</td>
<td>250</td>
<td>0.25</td>
<td>-2662</td>
<td>0.48</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>WB</td>
<td>215</td>
<td>0.45</td>
<td>2062</td>
<td>-0.06</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>WG</td>
<td>188</td>
<td>0.58</td>
<td>1852</td>
<td>-0.11</td>
<td>0.001</td>
</tr>
</tbody>
</table>
E.2. Zone level

Regression analyses for one year over all regions

High R-square has been obtained with spatial trend analysis in 2002.
**E.3. Woreda level**

At woreda level, only one year (2001) figures has been compared and the variability observed in water limited grain and biomass are greater than what is observed in official statistics and the spatial concordance rank percentage is only 40%.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean±s</th>
<th>CV</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>W.L. Biomass</td>
<td>209</td>
<td>6885 ± 263</td>
<td>55%</td>
<td>8146</td>
</tr>
<tr>
<td>WL grain yield</td>
<td>209</td>
<td>2068 ± 113</td>
<td>79%</td>
<td>2081</td>
</tr>
<tr>
<td>P. Biomass</td>
<td>209</td>
<td>12932 ± 291</td>
<td>32%</td>
<td>13887</td>
</tr>
<tr>
<td>P. Grain yield</td>
<td>209</td>
<td>6579 ± 159</td>
<td>35%</td>
<td>6973</td>
</tr>
<tr>
<td>Statistics yield</td>
<td>209</td>
<td>1245 ± 28</td>
<td>32%</td>
<td>1206</td>
</tr>
</tbody>
</table>
F. Preliminary analysis

1. Trend observed in CGMS outputs times series is different from official statistics trend at national and zone levels.
2. CGMS outputs trends are very similar to ECMWF rainfall trend
3. Spatial ranks show a high correspondence between CGMS outputs and Official statistics in 2002, which is the year with lower total rainfall, statistics yield and CGMS outputs
4. A comprehensive database has been built for wheat in Ethiopia
G. Next step

Model improvements by:

- Checking rainfall data by using an interpolated source from raingauge data

- Sensitivity analysis to refine phenology spatial distribution and TSUM1, TSUM2 calculation

- Replace the soil data with the existing 1:1,000,000 scale data from SOTER database

- Combine R.S. data with CGMS outputs

- Compare CGMS outputs with other well-established models (AMS)
H. Conclusions and perspectives

First trial of CGMS in Ethiopia: possible but data accessibility remains a key problem.

CGMS framework offers for the African region an interesting tool to build historical databases for crop growth indicators and yield database. This database can improve identification of vulnerable zone to enhance early warning systems assessments.

Model can be improved by updating parameters with actual field data and remote sensing data.

Wheat, millet, sorghum and maize, the most important crops in food insecure African regions, have been tested in Wofost and this experience should be used through CGMS tools to serve as crop monitoring tools also for food security and early warning purposes.