Copernicus
Emergency Management Service (CEMS)

SMOS Soil Moisture: Potential within CEMS
Flood Forecasting at ECMWF

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Copernicus Emergency Management Service - CEMS

- Provides information for emergency response to different natural, man-made &/or humanitarian disasters

- Composed of
  - on-demand mapping
  - early warning & monitoring systems for floods (EFAS & GloFAS), droughts and forest fires
CEMS-Floods Consortium

- Operational CEMS-Floods is made of 4 centres executed by different consortia, overseen by JRC
European & Global Flood Forecasts

General Modelling Framework

Ensemble NWP

Hydrological + River Modelling

Climate Thresholds

5 km, twice daily

10 km, once daily

EFAS

European Flood Awareness System

ECMWF

EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS
Soil Moisture for Initialisation

- Accurate estimates of antecedent soil moisture conditions are required.
GloFAS Soil Moisture: Data Assimilation via H-TESSEL

Ensemble Data Assimilation (EDA)

Screen level analysis (2D-OI)

Observations

T_2m, RH_2m

& soil moisture

Background

NWP Forecast Coupled Land-Atmosphere (H-TESSEL)

Soil moisture initial conditions

Jacobians

Soil Analysis (SEKF)

SM1, SM2, SM3

σ_0^T_2m = 1K

σ_0^RH_2m = 4%

σ_0^{ASCAT} = 0.05 m^3 m^{-3}

σ^T_2m = 2K

σ^RH_2m = 10%

ASCAT SM

SMOS SM

SMOS TB

Forcings

Observations

T_2m

RH_2m
SMOS Level 2 Soil Moisture Neural Network Product

- SMOS soil moisture Level 2 not available in NRT

- Created a Level 2 NRT soil moisture from Neural Network processor of Level 1 $T_b$ and ECMWF soil temperature against SMOS SM L2

- Pearson Correlation >0.7 in most of world

- Standard deviation of differences <0.05 m$^3$ m$^{-3}$

Rodriguez-Fernandez et al., 2017
Assessing SMOS DA Impact on GloFAS

- SMOS soil moisture L2 NN (ECMWF trained) product assimilated into IFS since 46r1 (12th June 2019)
- What impact has this had upon GloFAS streamflow forecasts?

**Experiment Design:**

- IFS Analysis Data Denial Experiment
  - Cycle 45r1, TCo 399 grid, 0.25° x 0.25° horizontal resolution, climate v015
  - 1st March 2017 – 21st May 2018
  - 1) LDAS without SMOS assimilation, 2) LDAS with SMOS assimilation

- Outputs used to force GloFAS at 24h timestep
- Assess GloFAS streamflow predictions vs:
  - In-situ in USA & Australia
  - GloFAS ERA-5
Impact upon Streamflow: USA

- 283 locations with daily streamflow

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<th></th>
<th>R</th>
<th>Bias</th>
<th>$KGE_{mod}$</th>
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<tbody>
<tr>
<td>Without SMOS DA</td>
<td>0.428</td>
<td>0.840</td>
<td>-0.504</td>
</tr>
<tr>
<td>With SMOS DA</td>
<td>0.420</td>
<td>0.812</td>
<td>-0.472</td>
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- 40 locations where $KGE_{mod}$ Skill Score > 0.05
  - Many such locations have low $KGE_{mod}$ values

- River regulation affects streamflow skill
  - But no correlation with impact of SMOS

$$KGE_{mod} = 1 - \sqrt{(r - 1)^2 + (\beta - 1)^2 + (\gamma - 1)^2}$$

$$r = \frac{\text{cov}_{s_o}}{\sigma_s \cdot \sigma_o}, \quad \beta = \frac{\mu_s}{\mu_o}, \quad \gamma = \frac{\sigma_s / \mu_s}{\sigma_o / \mu_o}$$

$$KGE_{mod \text{Skill Score}} = \frac{KGE_{mod[w \text{ SMOS}]} - KGE_{mod[w \text{ out SMOS}]}}{KGE_{mod \text{Perf}} - KGE_{mod[w \text{ out SMOS}]}}$$
Impact upon Streamflow: Australia

• 32 locations with daily streamflow

• North shows decline in $KGE_{\text{mod}}$ Skill Score with SMOS
  – 9 locations show an improvement

• Neutral results in Murray-Darling

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<tr>
<td>Without SMOS DA</td>
<td>0.410</td>
<td>2.466</td>
<td>-1.248</td>
</tr>
<tr>
<td>With SMOS DA</td>
<td>0.356</td>
<td>2.558</td>
<td>-1.340</td>
</tr>
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</table>

$$KGE_{\text{mod}} = 1 - \sqrt{(r - 1)^2 + (\beta - 1)^2 + (\gamma - 1)^2}$$

$$r = \frac{\text{cov}_{s_o}}{\sigma_s \cdot \sigma_o}, \quad \beta = \frac{\mu_s}{\mu_o}, \quad \gamma = \frac{\sigma_s/\mu_s}{\sigma_o/\mu_o}$$

$KGE_{\text{mod-Skill Score}} = \frac{KGE_{\text{mod[with SMOS]}} - KGE_{\text{mod[without SMOS]}}}{KGE_{\text{mod[perf]}} - KGE_{\text{mod[without SMOS]}}}$
Global Differences: Low Flows

- Small impact upon low flows
  - Greatest differences in upper Amazon and Indonesian archipelago
Global Differences: High Flows

- Impact of SMOS assimilation on high flows more pronounced
- Broader latitude band of difference
- Still no clear spatial trend

GloFAS Specific Discharge 95th Percentile Difference (with SMOS - without SMOS DA)
Impact upon Simulated Hydrographs

- Differences most pronounced at high flows
- Direction of difference has no clear trend

G0640: Wisconsin Dells Wi, Wisconsin, United States

Score w/Out SMOS / w SMOS

- Observed
- GloFAS with SMOS DA
- GloFAS without SMOS DA

KGEmod=0.40 / 0.48
Variability=0.66 / 0.79
Bias=0.79 / 0.78
Correlation=0.58 / 0.58

Lab/Lon=43.61 / -89.76
Ups Area Prov (km2)=20953
Ups Area LDD (km2)=21345
Possible Influence?= N

G1500: Lock 1 Downstream, Murray, Australia

Score w/Out SMOS / w SMOS

- Observed
- GloFAS with SMOS DA
- GloFAS without SMOS DA

KGEmod=-2.08 / -1.91
Variability=1.12 / 1.17
Bias=3.94 / 3.78
Correlation=0.09 / 0.14

Lab/Lon=34.35 / 139.62
Ups Area Prov (km2)=9999
Ups Area LDD (km2)=713793
Possible Influence?= Y
Conclusions

• SMOS already being used automatically in CEMS Floods GloFAS through ECMWF LDAS

• GloFAS experiments show that SMOS data assimilation has a small impact upon streamflow predictions

  • Most pronounced impact at high flows
    – Future analyses to look at high flows / flood event case studies

• Future work looking at impact upon EFAS
  – Fully calibrated hydrological model in Europe
  – Independent from LDAS
  – SMOS soil wetness to possibly inform flood susceptible areas