Climate Data Records from CM SAF
- Error Budget Estimation of HOAPS Evaporation

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CM SAF / Deutscher Wetterdienst, Offenbach

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Overview

- CM SAF
- Radiation / Cloud products
- HOAPS
  - Overview
  - Error budget for evaporation
- Summary / Outlook
EUMETSAT Application Ground Segment

Central processing and generation of products

DATA CENTRE

METEOROLOGICAL PRODUCT EXTRACTION

CLIMATE PRODUCT GENERATION AND CLIMATE SERVICES

De-central processing and generation of products

SATELLITE APPLICATION FACILITIES WITHIN EUMETSAT MEMBER STATES
EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF)
CM SAF exploits satellite based remote sensing data to derive Climate Data Records (CDR) for Essential Climate Variables (ECV) with special emphasis on three target user groups:

- Global and regional climate trends and variability analysis
- Support to global and regional climate modelling
- Climate service and infrastructure planning

CM SAF develops and improves methods to derive CDRs on an operational basis and in a sustained mode.

CM SAF maintains and provides an operational and sustained infrastructure that can e.g. serve the community within the transition of mature CDR products from the research into operational environments.

CM SAF continuously complement and improve its portfolio of CDRs of the global energy and water cycle.
Simple concepts have developed to
Quantitative estimate based on modelling exercises
CM SAFs Climate data set cover almost all of them and support our understanding of the climate.
<table>
<thead>
<tr>
<th>Sensor, Satellite</th>
<th>Parameter</th>
<th>Dataset length</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fundamental Climate Data Record (FCDR)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSM/I, SSMIS</td>
<td>Microwave Radiances</td>
<td>21 years, 1987 – 2008</td>
<td>global</td>
</tr>
<tr>
<td><strong>Climate Data Record (CDR)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEVIRI</td>
<td>Cloud parameters, aerosol optical depth</td>
<td>7 years, 2004 – 2011</td>
<td>Europe &amp; Africa</td>
</tr>
<tr>
<td>GERB/SEVIRI</td>
<td>Top of atmosphere radiative fluxes</td>
<td>7 years, 2004 – 2011</td>
<td>Europe &amp; Africa</td>
</tr>
<tr>
<td>MVIRI/SEVIRI</td>
<td>Cloud parameters, surface radiation parameters, land surface temp., FTH</td>
<td>22 years, 1983 – 2005</td>
<td>Europe &amp; Africa</td>
</tr>
<tr>
<td>AVHRR GAC</td>
<td>Cloud parameters, surface radiation parameters, incl. albedo</td>
<td>27 years, 1982 – 2009</td>
<td>global</td>
</tr>
<tr>
<td>SSM/I, SSMIS</td>
<td>HOAPS 3.2 (precip, evap, hum., wind, ...)</td>
<td>21 years, 1987 – 2008</td>
<td>global ice free ocean</td>
</tr>
<tr>
<td>ATOVS</td>
<td>Water vapour and Temperature profile</td>
<td>10 years, 1998 – 2008</td>
<td>global</td>
</tr>
</tbody>
</table>

All CDR’s are freely accessible via DOI Numbers under www.cmsaf.eu
Radiation and Cloud Data Sets
**CM SAF**

**Surface Solar Radiation Data Set – Heliosat SARAH**

**SARAH**
- 1983 – 2013; 0.05 deg; Meteosat Full Disk, monthly/daily/hourly
CM SAF CLARA

- CM SAF Clouds, Albedo, Radiation (Karlsson et al., 2013)
- 1982 – 2009; 0.25 deg; global coverage, monthly/daily
- 11 different AVHRR satellite instruments used!
Surface Downward Longwave Radiation

The surface downward longwave radiation is derived by correcting the monthly – averaged downward longwave surface radiation from the ERA Interim reanalysis with the CM SAF GAC CFC data set and topographic information.

A cloud correction factor (CCF) to account for the impact of cloud coverage on the surface downwelling longwave radiation is calculated for each month based on ERA - Interim data.

The monthly mean surface downward longwave radiation is calculated from the clear sky surface downward longwave radiation from ERA -Interim considering the cloud effect, which is derived from the CCF and the CM SAF GAC CFC data set.

The overall accuracy of the CM SAF GAC SDL data set has been estimated to be 8 W/m²
Ocean Surface Freshwater Flux Components
HOAPS
HOAPS 3.2

Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data

- Climatology of water cycle parameters over the global ice-free ocean
  - precipitation, evaporation and freshwater flux (+related variables, 14 in total)
- First release through CM SAF in cooperation with MPI-MET and University of Hamburg
  - Sustained development path
  - Algorithm Theoretical Basis Document (ATBD), Product User Manual (PUM), Validation Report available
- Gridded data products (0.5°): Monthly mean, 6-hourly composite
- Instantaneous data available on request

- http://wui.cmsaf.eu
- http://www.hoaps.org
- http://dx.doi.org/10.5676/EUM_SAF_CM/HOAPS/V001
Based exclusively on satellite data: SSSM/I passive microwave, AVHRR IR

- intercalibrated CM SAF SSM/I FDCR
  - Improved data quality control of level 1 data

- Neural network based precipitation retrieval
- Evaporation (+ sensible heat flux) derived through bulk flux algorithm (COARE 3.0)
  \[ E = \left( \frac{\rho_d}{\rho_w} \right) C_E U (q_s - q_a) \]

- AVHRR Pathfinder SST as input for turbulent fluxes
  - New OI-based gap filling and diurnal cycle corrections

- Freshwater Flux: E - P
HOAPS 3.2

- HOAPS-3.2 :: Precipitation [mm/d]
  - Maps showing precipitation patterns around the world.
  - Colors represent different precipitation rates.

- HOAPS-3.2 :: Freshwater Flux [mm/d]
  - Maps showing freshwater flux patterns around the world.
  - Colors represent different flux rates.

- HOAPS-3.2 :: Evaporation [mm/d]
  - Maps showing evaporation patterns around the world.
  - Colors represent different evaporation rates.

Source: www.hoaps.org / CM SAF / MPI-MET / Uni-HH
Validation

Decadal Stability (trend relative to reference)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reference</th>
<th>Decadal stability Threshold</th>
<th>(CDOP2) Target</th>
<th>Decadal stability HOAPS v3.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near surface humidity</td>
<td>NOCS</td>
<td>1%</td>
<td>0.5 %</td>
<td>-0.1 %</td>
</tr>
<tr>
<td>Near surface wind speed</td>
<td>NOCS</td>
<td>0.2 m/s</td>
<td>0.1 m/s</td>
<td>0.09 m/s</td>
</tr>
<tr>
<td>Evaporation</td>
<td>NOCS</td>
<td>0.1 mm/d</td>
<td>0.015 mm/d</td>
<td>0.09 mm/d</td>
</tr>
<tr>
<td>Latent heat flux</td>
<td>NOCS</td>
<td>3 W/m²</td>
<td>0.8 W/m²</td>
<td>2.7 W/m²</td>
</tr>
<tr>
<td>Precipitation</td>
<td>GPCP</td>
<td>0.03 mm/d</td>
<td>0.015 mm/d</td>
<td>-0.01 mm/d</td>
</tr>
<tr>
<td>Freshwater flux</td>
<td>NOCS-GPCP</td>
<td>0.13 mm/d</td>
<td>0.015 mm/d</td>
<td>0.1 mm/d</td>
</tr>
</tbody>
</table>
MPI-ESM, CMIP5 experiments:
➔ amip (prescribed SST)
➔ historical (fully coupled)

Satellite data:
➔ HOAPS-3

Climatological Evaluation:
➔ 1988 – 2005, monthly means
➔ Horizontal resolution: T63 (~1.875° at Equator)

Does the climate model correctly reproduce freshwater flux parameters?
Precipitation MPI-ESM - HOAPS
Evaporation MPI-ESM - HOAPS

MPI ESM historical LR - HOAPS

MPI ESM amip LR - HOAPS
Freshwater Flux MPI-ESM - HOAPS
Freshwater Flux Bias vs. Sea Surface Salinity

MPI ESM historical LR - HOAPS

MPI ESM historical LR - WOA

Sea surface Salinity
[mm/d]

[pwu]
Derivation of Total uncertainty in E

→ DFG research unit FOR1740 – Atlantic Freshwater Cycle

Key questions:
1) How will the fresh water flux (E-P) contribute to the overall salinity change in the upper ocean? (impacts on thermohaline circulation etc.)
2) To what extent does the Atlantic Ocean contribute to the global hydrological cycle?

HOAPS related:
→ Analysis of long-term stability and quality of inter-sensor calibration and impact on derived final products;
→ Implementation of a full error propagation procedure from microwave radiance measurement to final products;
→ Validation of HOAPS precipitation rate accuracy with systematic shipboard disdrometer measurements by point-to-area methods;
→ Improvements of the HOAPS precipitation retrieval including error estimation;
→ Use of HOAPS data for assimilation and testing of long-term stability.
Derivation of total uncertainty in E

Latent heat flux (LHF) essentially contributes to E and thus (E-P)

LHF itself is prone to errors due to input error in the Coare-based bulk parameters (Fairall 1995, 2003), on which HOAPS LHF (E) is based

$$\text{LHF} = \rho_a L_e C_e U(q_s - q_a)$$

Sophisticated approach by combining the systematic and random error contribution to a total uncertainty estimate of LHF (LHF $\propto$ E)!

**PROCEDURE**

⇒ Investigate errors in specific humidity $q_a$, wind speed $u$, and $q_s$ and subsequently perform error propagation to derive total error in LHF (E)

⇒ **HOW?** Determine the individual error contributions of $q_a$, $u$, and $q_s$ based on four-dimensional look-up tables ("how large is the error, given a specific atmospheric state?“)
Why 4d tables? → Parameters characterising the atmospheric state

1. mean $q_a$ [g/kg] (1995-2008)
2. mean wind speed [m/s] (1995-2008)
3. mean $H_2O$ vapor path [kg/m²] (1995-2008)
Exemplarily: pixel-level systematic / random error in $q_a$, based on a 3d look-up table

1) Derive extensive match-up database of HOAPS $q_a$ (pixel-level) and quality controlled SWA / ICOADS *in-situ* data (1995-2008)

2) “Given a specific atmospheric state (i.e. unique combination of HOAPS wind speed, $H_2O$ vapor path, and $q_a$), what is the concurrent systematic bias, $\Delta q$ (HOAPS minus *in-situ*)?”

3) The assignment of $\Delta q$ into the correct bin within the 3d cube is based on preliminary 1d look-up tables:

Assignment of $\Delta q$ based on 20 bins, exemplarily for $q_a$
Exemplarily for $q_a$: Hotspots of (std) $\Delta q_a$ [1995-2008]

Local maxima within tropical oceans

Broad maxima within subtropical belt

**NOTE:** std ($\Delta q_a$) includes uncertainty due to *in-situ* sources and collocation procedure

-> remove their contribution!
Error-decomposition of HOAPS $q_a$ Using Multiple Triple Collocation (O’Carroll et al. (2008))

**Concept:**

- Make advantage of having multiple satellites and in-situ records available!
- Set up a system of 6 equations, including the data source’s error variances
- Successively derive each single error source underlying the experimental setup!

Remove the contributing fraction of in-situ source and collocation. Desired: Total (retrieval) error!
**Total uncertainty in LHF (E) via error propagation**

\[
\sigma_F = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial F}{\partial y}\right)^2 \sigma_y^2 + 2r_{xy} \left(\frac{\partial F}{\partial x} \frac{\partial F}{\partial y}\right) \sigma_x \sigma_y}
\]

Recall:

\[LHF = \rho_a L_e C_e U(q_s - q_a)\]

- Overall pixel-level error in LHF ($\Delta F$)
- Partial derivatives with respect to either $C_E$, wind speed, $q_a$, and $q_s$
- Correlation coeff. Between two of either $C_E$, wind speed, $q_a$, and $q_s$
- Total RMSE (systematic, corrected random) due to either $C_E$, wind speed, $q_a$, and $q_s$

**Total HOAPS LHF uncertainty, 1995-2008**

Random component set to 0!

24 % rel. uncertainty

0 - 70 W/m²

**Total HOAPS E uncertainty, 1995-2008**

Random component set to 0!

24 % rel. uncertainty

0 - 1.5 mm/day
Summary

CM SAF exploits and provides satellite based remote sensing data to derive CDR for ECVs with special emphasis on three target user groups

Global and regional climate trends and variability analysis
Support to global and regional climate modelling
Climate service and infrastructure planning

- Radiation, Clouds (-properties) from Meteosat, AVHRR
- HOAPS 3.2 ocean surface freshwater flux parameters
  - Improved level-1 SSM/I data preprocessing
  - Improved SST background fields (for turbulent fluxes)
  - Error model being implemented in FOR1740 + interim extension to 2013

Data is freely available from www.cmsaf.eu
Outlook

- Next HOAPS Release Scheduled Q2 2016
- 1D-Var retrieval scheme (including uncertainty estimates)
- New SSM/I / SSMIS FCDR (1987-2013)
- New SST data set (ESA CCI)

- ESA TIE-OHF project
- Other satellite derived (turbulent) surface flux data sets:
  - IFREMER, Seaflux, J-Ofuro, GSSTF
  - OAFLUX (merge of satellite & reanalysis)

- NCDC's CDR Program (http://www.ncdc.noaa.gov/cdr/index.html)