Learning from observations
(Info on satellite observations)

Jörg Schulz, EUMETSAT

*Large-scale Deep Learning for the Earth System Workshop, Bonn, Germany, 05/09/2023*
EUMETSAT Mission

Primary objective:
Establish, maintain and exploit European systems of meteorological satellites.

Further objective:
Contribute to the operational monitoring of the climate and the detection of global climatic changes.
COP-21 Paris Agreement: Adaptation (Article 7(c)): Strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making.
EUMETSAT and AI/ML

- AI/ML is part of EUMETSAT’s strategy Destination 2030; roadmap for AI/ML was approved in summer 2022 aiming at:
  - foster inside ML for product development (feature detection (real and artefacts), retrieval, gap filling, etc.), prediction of space craft and instrument anomalies, and ground system health
  - foster ML on top of our data in downstream applications such as NWP, NWC, climate monitoring/modelling, etc.
  - building suitable infrastructure in cloud environment, e.g., GPU in European Weather Cloud
- Currently biggest impact is likely through satellite data contributions for global reanalysis at ECMWF (ERA5 and 6)
- But want to improve knowledge what is needed in terms of observations (scientifically and technically) by the community
Current EUMETSAT satellites

**Meteosat Second Generation**
- Two-satellite system
- Full disc imagery mission (15 mins) (Meteosat-11 (0° E))
- Rapid scan service over Europe (5 mins) (Meteosat-10 (9.5° E))

**METEOSAT-9 (45.5° E)**
- Geostationary orbit
- Meteosat Second Generation providing Indian Ocean data coverage

**METOP-B & -C (98.7° incl.)**
- Low Earth, sun-synchronous orbit
- EUMETSAT Polar System (EPS)/Initial Joint Polar System

**MTG-I1**
- Geostationary orbit
- Meteosat Third Generation imaging mission, currently in commissioning phase

**SENTINEL-3A & -3B (98.7° incl.)**
- Low Earth, sun-synchronous orbit
- Copernicus satellites delivering marine data services from 814 km altitude

**JASON-3 (63° incl.)**
- Low Earth, non-synchronous orbit
- Copernicus ocean surface topography mission (shared with CNES, NOAA, NASA and Copernicus)

**Sentinel-6 Michael Freilich (66° incl.)**
- Low Earth, non-synchronous orbit
- Copernicus ocean surface topography mission (shared with NASA, NOAA, ESA and Copernicus with support from CNES)

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The European Commission has entrusted EUMETSAT with exploiting the four Sentinel missions (Sentinel-3, -4, -5 and -6) dedicated to the monitoring of atmosphere, ocean and climate on its behalf.

EUMETSAT Contributions focus on oceans, atmosphere and climate.

Planned EUMETSAT contribution in Copernicus 2.0:
- **CONTINUITY** of Sentinel operations
- **EXPANDING** the Observation scope

**Synergy with Copernicus**

**Complementarity with EUMETSAT’s METEO missions**
Terminology: Data Levels and NRT versus Climate Data Record

**Near Real Time**

**Level 0**

Measurement of electric signal (voltage, count) = \( \text{count} \)

**Level 1 / level 1a**

Geolocated/calibrated radiance / brightness temperature, backscatter coeff / bending angles

**Level 1.5 / level 1b/1c**

Refinements of geolocation/calibration/rectification radiance + latitude + longitude + time

**Level 2**

Retrieval/algorithm + auxiliary data – model

**Level 3**

Temporal and spatial averaged (e.g., mapped to grid)

**Reprocessing / climate**

**Enhanced Quality Control**

**Fundamental Data Record (FDR)/Fundamental Climate Data Record (FCDR)**

**Thematic Climate Data Record (TCDR)**
Objective for C3S
Improve ERA6/7 w.r.t. ERA5

- Unchanged, as in ERA5
- Planned in phase 2
- New data
- Improved data
- * Option

Improve high-resolution reanalyses (Europe & Arctic)

MFG & MFG Rapid-scan radiances
Metop AVHRR LAC AMV R3

+ Back-ground for, or bridge into future missions (EPS-SG, MTG,…), to create new CDRs for the benefit of C3S
SSM/T FDR R1 (1991 to 2004) for ERA6

- Complements MSU data and adds value to stratospheric temperature prior to AMSU-A
- Calibrated SSM/T data from raw measurements – similar approach to humidity sounders
- Validated against AMSU-A and Radio Occultation measurements and the results show good agreement
- Some inter-satellite biases visible in the time series, might be necessary to employ harmonisation to remove inter-satellite biases
- Data set is in trial test for ERA6
A growing integrated stream of marine products

- **Altimeters**
  - For Surface Temperature and Fluxes
  - For Sea Surface Height, Waves and Wind Speed
  - For Wind Vectors
  - And Sea Ice Parameters

- **IR radiometers**

- **VIS radiometers**

- **Scatterometers**

For Ocean Colour
Climate data records

Images from 2 consecutive orbits
about 1500 AMVs

Arctic Sea Ice Extent

Sunshine Duration Anomaly March 2022
Reference 1981-2010

Temperature (10Vor), 90S–90N
monthly mean anomalies

Arctic

Pressure (hPa)

Speed (m/s)

EUMETSAT

EUM/OPS/VWG/23/1375350, v1 Draft, 28 August 2023
Data Access - Services portfolio

Push data services
24/7 support

Pull data services and software
Normal office hours support

EUMETSAT opens call for research projects every year closing end of June.
https://www.eumetsat.int/european-weather-cloud-research-development-call

Provides access to data services in controlled computing environment for member states

https://navigator.eumetsat.int/start
https://www.eumetsat.int/access-our-data
• Space agencies maintain an **Inventory** (v4.1, 2022) that describes ~1000 CDRs of **GCOS Essential Climate Variables (ECVs)**

• The Inventory improves CDR discoverability and interoperability, e.g., in support of assessments of weather and climate extremes and disaster impacts and losses, and it informs space agency planning (missions and data set production)
New joint project with NOAA to realise georing radiance record

- ~1980-2023 and beyond, 30 minutes, 2-4 km resolution
- will amend with polar orbiting data towards the poles
How far back can we go?

ATS-1 visible image (11 December 1966)  
Visible images of ATS-1 18 November 1967
Objective: Elaboration of a 30min/full resolution global tropical and homogeneous Database of MCS for as many as possible geostationary satellites starting late 1970s.
EUMETSAT:
- A space-based climate observation from the 39 year long-term serie of METEOSAT.

<table>
<thead>
<tr>
<th>Period</th>
<th>Platform</th>
<th>Nadir location</th>
<th>Instrument</th>
<th>Central wavelength</th>
<th>Spectral interval</th>
<th>Spatial resolution at nadir</th>
<th>Temporal resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981/08-1999/08</td>
<td>METEOSAT-2</td>
<td>0°</td>
<td>MVIRI</td>
<td>11.5 μm</td>
<td>10.5 μm - 12.5 μm</td>
<td>5km</td>
<td>30min</td>
</tr>
<tr>
<td>1988/08-1999/11</td>
<td>METEOSAT-3</td>
<td>0°</td>
<td>MVIRI</td>
<td>11.5 μm</td>
<td>10.5 μm - 12.5 μm</td>
<td>5km</td>
<td>30min</td>
</tr>
<tr>
<td>1989/06-1994/02</td>
<td>METEOSAT-4</td>
<td>0°</td>
<td>MVIRI</td>
<td>11.5 μm</td>
<td>10.5 μm - 12.5 μm</td>
<td>5km</td>
<td>30min</td>
</tr>
<tr>
<td>1991/11-1997/02</td>
<td>METEOSAT-5</td>
<td>0°</td>
<td>MVIRI</td>
<td>11.5 μm</td>
<td>10.5 μm - 12.5 μm</td>
<td>5km</td>
<td>30min</td>
</tr>
<tr>
<td>1997/02-1998/06</td>
<td>METEOSAT-6</td>
<td>0°</td>
<td>MVIRI</td>
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<td>10.5 μm - 12.5 μm</td>
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<td>30min</td>
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<tr>
<td>1998/06-2004/10</td>
<td>METEOSAT-7</td>
<td>0°</td>
<td>MVIRI</td>
<td>11.5 μm</td>
<td>10.5 μm - 12.5 μm</td>
<td>5km</td>
<td>30min</td>
</tr>
<tr>
<td>2004/10-2007/05</td>
<td>METEOSAT-8</td>
<td>0°</td>
<td>SEVIRI</td>
<td>10.8 μm</td>
<td>9.8 μm - 11.8 μm</td>
<td>3km</td>
<td>15min</td>
</tr>
<tr>
<td>2007/05-2013/02</td>
<td>METEOSAT-9</td>
<td>0°</td>
<td>SEVIRI</td>
<td>10.8 μm</td>
<td>9.8 μm - 11.8 μm</td>
<td>3km</td>
<td>15min</td>
</tr>
<tr>
<td>2013/02-2017/12</td>
<td>METEOSAT-10</td>
<td>0°</td>
<td>SEVIRI</td>
<td>10.8 μm</td>
<td>9.8 μm - 11.8 μm</td>
<td>3km</td>
<td>15min</td>
</tr>
<tr>
<td>2018/01-2020/12</td>
<td>METEOSAT-11</td>
<td>0°</td>
<td>SEVIRI</td>
<td>10.8 μm</td>
<td>9.8 μm - 11.8 μm</td>
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Homogenisation of the long-term dataset
IASI, AIRS and HIRS/2 as reference instruments for recalibration


Production of a new 1981-2020 MCS database over Africa and the Atlantic Ocean
MCS Climatology Analysis

- 1983-2020 ➞ Significant trend of the cold cloud fraction (~0.02%/y)
- 1990-2020 ➞ No significant trend

2D Distribution of the MCS annual occurrence function of Smax and lifetime duration

Characterization of MCS properties from the TOOCAN database

How do convective cloud, precipitation, and radiative characteristics evolve over the full lifecycle?

Fusion of MCS morphological properties with LEO data

Elsaesser et al. 2022
The TOOCAN algorithm was developed to track and characterise Mesoscale Convective Systems from geostationary images. It was executed on 40 years of Meteosat data on the EWC and 10 years of geostationary ring. Here it is applied to the new style km-scale climate models (SAM Stony Brook University, USA). Applying this to both satellite and model data allows for object oriented validation over several decades.

DYAMOND = DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains
Steps to Uncertainty budget

1. **MEASURAND 01**
   - Define the measurand and measurement function

2. **TRACEABILITY 02**
   - Establish the traceability with a diagram

3. **UNCERTAINTY 03**
   - Evaluate each source of uncertainty and fill out effects tables

4. **CALCULATE 04**
   - Calculate the product and its uncertainty

5. **STORE 05**
   - Store relevant information for future users

(Slide from Emma Woolliams)
Estimation of uncertainties

Effects  Sources of Uncertainty  Uncertainty propagation  Combined uncertainty

Uncertainty characterised Microwave Humidity Sounder data

- Data set releases contains data from SSM/T-2, AMSU-B, MHS, ATMS, MWHS, and MWHS/2 – brightness temperatures and fully traceable uncertainties – Independent, structured, and common using a common processing software for all instruments.

3 components of uncertainty: independent, structured, common

SSM/T-2 channel 183 ± 7 GHz (lower tropospheric humidity)
Sensor harmonisation

- The method for harmonisation based on metrological principles optimises calibration parameters in the measurement equation.

- Harmonisation:
  - uses fundamental measurements, i.e. raw measurements (counts);
  - considers uncertainties;
  - does not minimise differences caused by different spectral characteristics;
  - uses a reference within the set of satellites, here MHS on Metop-A, multi-instrument collocations transfer the reference forward/backward in time
  - uses cold match-ups from simultaneous satellite overpasses
  - uses warm match-ups at lower latitudes over temporally homogeneous scenes identified in geostationary images;
Harmonisation of MW Sounder Data

- Harmonisation has greatly reduced biases between instruments; upper tropospheric humidity retrieval and assimilation bias correction should benefit.
- AMSU-B and SSM/T2 are currently being incorporated and a harmonised FCDR for all the instruments will be released by EUMETSAT in Q3/2023 and is available in time for ERA6.
- Will also work for EPS-SG MWS.
Summary

- Measurements from satellites exist since about the late 1960s but only since ~2000 large parts of the Earth system are covered.
- EUMETSAT operates a big fleet and portfolio of measurands is expanding, also serves third party data particularly for NWP and reanalysis.
- Strengths are:
  - can measure surface features (vegetation, fires, ice) and atmospheric constituents, thermodynamical, hydro variables
  - space and time resolution often higher compared to global models
  - global coverage for most individual systems within 2 days, combination can result in 30 minutes sampling if measurement from geostationary is used
  - can deliver consistent data over long times (spectral continuity, orbit stability, etc.) and not needed in real time (enhanced QC)
  - feature detection enables data volume reduction and eases combination with other products
  - methods to assess observational uncertainty are developed and applied
- Weaknesses are:
  - are not able to measure in atmosphere close to the surface except wind vector, cannot measure subsurface, have issues in measuring dynamics (wind)
  - are sometimes difficult to use, e.g., provided in many different formats, do not have regular mapping, etc.
- Satellite measurements are underexploited, e.g., DA still uses limited spectral information, clear sky, ocean only — is also because of industry push for new technology.
Questions for discussion

• How arrive at ML community user needs that EUMETSAT may address?
  Could contain:
  • prioritisation of data sets, e.g., radiances (may use same as for DA), surface data sets, hydrological variables, etc.
  • combination of ERA with satellite derived quantities
  • combination of satellite data for features, e.g., MCS enhanced with precipitation, or tropical cyclones with ocean wave height and surface wind vector
  • What's the best data service to support ML?
• Explore observational uncertainty estimates not used in DA?