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EUropean CLimate and weather Events: Interpretation and Attribution

Deliverable D*6.1*

Description of existing observational datasets and observational needs

Deliverable Title	*Description of existing observational datasets and observational needs*	
Brief Description	*The task will identify existing in situ and remote sensing observations relevant to each type of extreme event (drought, flood, heat wave, cold spell, storm surge) considered and collect them for model evaluation, such as the ESA CCI soil moisture dataset (http://www.esa-soilmoisture-cci.org) or GEOLAND data sets. In addition, ground observations will be used, including soil moisture, runoff, surface fluxes and classical meteorological datasets. Modern reanalysis products will also be considered. The task will then identify observational gaps for event attribution, observation needs for verification and bias correction of attribution models, methodological developments that make synergetic use of in situ and space-borne observations, as well as requirements for observation network density, dataset length, and homogeneity*	
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1. Executive Summary

Observations are critical to detect changes and understand the contribution of the anthropogenic influence in the development of extreme events. Observations allow to better understand underlying processes and to calibrate and validate models. Event detection and attribution can be done in different ways, namely through (i) ensemble model simulations in order to calculate rare event probabilities in a natural or altered climate, (ii) statistical methods using observations only and evaluating the changes of probabilities or return times in exceedance of thresholds or (iii) other type of methods with various assumptions, for instance analog methods. In this report, we outline and discuss the range of useful observations in three different perspectives and the gaps in observations:

- Observations for fast-track attribution (max a few days)
- Observations for slow-track attribution (typically a few months to a year)
- Observations for key processes and model evaluation

We find that observation requirements for attribution are very different depending on the type of event, and on the time scale in which an attribution statement needs to be made. Fast-track attribution can provide rapid analyses, but it has to rely on few datasets (or even forecasts) available in near real-time (NRT), and which are long enough to compute a climatology. In contrast, slow-track attribution takes more time but might be able to make more robust statements as it relies on more (observational and model-based) data. Furthermore we identify existing gaps and shortcomings in available observations. We find that generally atmospheric variables such as pressure or temperature are well observed. Precipitation products are more uncertain as rain or snow may occur very localized. Most gaps are found in observations of land surface hydrology, i.e. soil moisture, or evapotranspiration, therefore hindering a better understanding/attribution of e.g. droughts. Involved measurements through sensors in the soil, or eddy-covariance flux towers, respectively, are complex. Furthermore land surface hydrology depends on soil and vegetation characteristics which can be highly heterogenous.

The most notable observational improvement in recent years is the growing number of satellite-derived products. These can be especially useful thanks to their global coverage. However, as records are still comparatively short or poorly homogeneous along observational time and it may not yet be possible to infer corresponding climatologies which are required for attribution. .

2. Project Objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOW, Section B1.1):

No.	Objective	Yes	No
1	Derive the requirements that targeted user groups (including regional stakeholders, re-insurance Companies, general public/media) have from attribution products and demonstrate the value to these users of the attribution products developed under EUCLEIA.		x
2	Develop experimental designs and clear ways of framing attribution studies in such a way that attribution products provide a fair reflection of current evidence on attributable risk.	x	
3	Develop the methodology for representing the level of confidence in attribution results so that attribution products can be trusted to inform decision making.	x	
4	Demonstrate the utility of the attribution system on a set of test cases of European weather extremes.	x	
5	Produce traceable and consistent attribution assessments on European climate and weather extremes on a range of timescales; on a fast-track basis in the immediate aftermath of extreme events, on a seasonal basis to our stakeholder groups, and annually to the BAMS attribution supplement.	x	

3. Detailed Report

3.1 Observations for fast-track attribution

Fast-track attribution covers attribution statements that could be issued on “media time scale” (a few days). This uses short algorithm using real-time observations and pre-calculated statistics from models and observations. Typical examples are the calculation of return periods for the extreme value that was reached, with non-stationary assumptions, or simple statistics. Making fast-track attribution even faster, the data from real-time observations may be merged with forecasts. That may even allow to attribute an event in line with the forecasts, even before it actually happens. Such a procedure was experimentally set up before the July 2015 European heatwave (see eg. http://www.climatecentral.org/europe-2015-heatwave-climate-change). Fast-track issues are revealed by media based on damages that occur in an area. It is facing two major difficulties: (i) identifying the event, its temporal and spatial extension in order to characterize its exceptionality, and (ii) finding the corresponding observations and their historical records.

Fast-track methods could also use pre-calculated statistics from model simulations (e.g. CMIP). These simulations may have to be bias-corrected using long sets of observations.

Requirements on observations

- Availability in near real time (NRT) for event identification and production of statistics
- Accessibility for the attribution service

Observations currently used, available, or that could be made available

Table 1: Observation datasets used or with potential for use for fast-track attribution

Dataset	Variables	Type of observation	Spatial chars.	Time chars.	Availability Accessibility	Comments
E-OBS	T, PR	Gridded obs	Europe land	1950 – now Daily	Few days	Useful for fast analysis; limited to T and PR, stations coverage heterogeneous; relatively short length
ECA&D	T, PR, Wind	Station data	Europe land	1900 – now Daily	Few days	Generally longer time series; homogeneity to be checked
GHCN-D	Tmax, Tmin, PR	Station data	Global	Variable	Many stations up to yesterday	Most recent part is from GTS, reliability and availability vary greatly
ISD-LITE	T, Wind	Station data	Global	YYYY – now Hourly or 3Hourly	1 Day	Raw observations, most starting in the 70s (short records), often incomplete from yesterday
Global SOD	T, PR, U, V, …	Station data	Global	YYYY – now Daily	1 Day	Raw observations, most starting in the 70s (short records), often incomplete from yesterday
ERA-Interim	All	Re-analysis	Global	1979 – now 3-hourly	Currently a few months	Could be made available in NRT (few days) ; short record for attribution
ERA-20C		Re-analysis	Global	1900 – now Daily	Available	Could be used to complete ERA-Interim for attribution
Operational analyses	All	Analysis	Global	YYYY – now 3-Hourly		Operational analyses could complete re-analyses for the sake of real-time processing
Other reanalyses	All	Re-analysis	Global	YYYY – now 3-Hourly		
Operational Forecasts	All	Forecasts	Global	YYYY – now 3-Hourly		Operational forecasts could complete re-analyses for the sake of real-time processing

Observational gaps

The clear gap for fast-track attribution is the lack of available and accessible real-time observations that could be compared with long, homogeneous time series for reliable statements for comparing current with past climate. This hampers robustness in the detection as return periods are sensitive to small changes in the extreme values. As listed in Table 1, a few datasets fulfilling these requirements are available, however, more independent products would allow a more robust fast-track attribution. This is important as especially for (localized) extreme events uncertainties can be large, making an accurate attribution statement difficult. The coming availability of ERA5 in NRT will open perspectives for fast attribution for variables and regions where it is reliable, which for convective precipitation (summer in Europe, tropics) is not yet the case. Other possibilities exist such as identifying for Europe reference station series which have been carefully homogenized. Reference long homogenous daily series have currently been produced in several countries. Alternatively, using short-term forecasts and putting them into context of a model climatology could be an option.

3.2 Observations for slow-track attribution

Slow-track attribution has less real-time availability constraints and is usually based on large ensembles of model simulations with and without anthropogenic climate forcing. For uncoupled, atmospheric-only simulations, the climate change signal is currently assumed to be included in the fields of sea surface temperatures, sea ice and radiation, which are generally taken from CMIP climate simulations. In coupled model simulations, the anthropogenic influence is reflected by increased greenhouse gas concentrations. Observations may be used for model bias correction of model outputs. They are also used for new statistical modeling of events, which cannot be done in real-time.

Besides, slow-track attribution may simply provide similar diagnostics as in the fast-track case but taking into account more observations, those that are not available in NRT. The following table includes datasets that can be used in such cases, completing the Table 1.

Requirements on observations

- Available a few months after the event
- Accessible for service
- Homogenous long time series for changes detection

Table 2 : Datasets used for slow-track attribution (completing Table 1)

Dataset	Variables	Type of observation	Spatial chars.	Time chars.	Availability Accessibility	Comments
National station data	T, PR,	Station data	Europe land	YYYY – now Daily	Variable	Generally longer time series (start in/before the middle century); homogeneity to be checked
National gridded data sets (see below)	T, PR, Wind, …	Gridded obs (analysis)	Countries 4-8km resolution	1950 – now Daily	Few months	Useful for a better space-time analysis, and for bias correction of models
CRU / CPC / GPCC	PR	Gridded obs	Global	Monthly/Daily		
GPCP	PR	Gridded obs	Global	1979-now Monthly		
CRU / GISTEMP	T	Gridded obs	Global		Few months	

National gridded data sets for Europe are numerous. They are well described in https://wiki.zmaw.de/euro-cordex/RegionalEvaluationDatasets and the list is repeated below. The main disadvantages of using these data sets for attribution is that they are in general not covering more than a few decades, and can also result in some cases from re-analyses where analysis models have some biases for non-assimilated variables such as, in general, precipitation. As a consequence, a national data set can hardly be used with another one unless methods are similar or a careful check of consistency is done. The advantage of national data sets is the high spatial (and sometimes temporal) resolution provided and the more explicit spatial variability of data. Note that these data sets are not always available a few months after an event, it may take several years.

Table 3: National and high-resolution gridded data sets and their characteristics (see also euro-cordex web site)

Name	**Region**	**Variables**	**Temporal resolution**	**Spatial resolution**	**Period**
REGNIE	Germany	P (corrected, uncorrected)	daily	60'x30' (approx. 1km x 1km)	1951-present
HYRAS	Germany (+neighbouring regions)	P, T, rh	daily	5km x 5km	1951-2006
Spain011, Spain044, Spain02	Spain	P, Tmean	daily	0.11°, 0.44°, 0.2°	1971-2008
RHiresD	Switzerland	P	daily	2 km x 2 km	1961-2011
TabsD, TminD,	Switzerland	Tmean, Tmin, Tmax	daily	2 km x 2 km	1961-2011

TmaxD					
EURO4M-APGD	Alps	P	daily	5km x 5km	1971-2008
SAFRAN	France	Tmean, P, further	hourly, daily	8 km x 8 km	1958-2010
UKCP09 Data	UK	Tmean, Tmin, Tmax, P	daily	5 km x 5 km	1958-2006
NCIC Daily Gridded Datasets	UK	Tmean, P	daily	5km x 5km	1960-present
CARPATCLIM	Carpathian Basin	Tmean, Tmin, Tmax, P	daily	0.1°	1961-2010
seNorge.no (version 1.1)	Norway	Tmean, P	daily	1 km x 1 km	1961-2008 | |met.no
STARTCLIM	Austria	Tmean, P	daily	1 km x 1 km	1950-2007
PTHBV	Sweden	Tmean, P	daily	4 km x 4 km	1961-present
DMI grid	Denmark	Tmean, P	daily	10km x 10km (P), 20km x 20km (T)	1989-2010
FINADAPT	Finland	Tmean, P	daily	10km x 10km	1961-2000
HErZ re-analysis	Complete EURO-CORDEX model domain	T, P (plus additional RCM ouputs)	hourly	about 6.2km x 6.2km (2.0km x 2.0km for timeslices)	2007-2013 (1997-2006 ongoing)
MESAN regional reanalysis	EURO-CORDEX domain	Tmean, Tmin, Tmax, P	daily	0.05° (about 5km)	1989-2010 (1979-1988 ongoing)

Observational gaps

The observational gaps in observations for slow-track attribution are:

- the lack of long homogeneous time series, with sufficient meta-data. Only station data have a long historical coverage. Gridded data sets usually start in the middle of the 20th century;
- Satellite data and remote-sensed data may provide very high resolution (such as products from MODIS), but generally have insufficiently long temporal coverage for attribution use, except for model evaluation;
- No or delayed accessibility as data (or parts thereof) may not be publicly available

3.3 Observations for key processes and model evaluation

There is a large range of extreme events considered in the project. In this section we outline the necessary observations to capture and understand the key processes contributing to each type of event. The identification of these observations is further important to evaluate models in terms of the respective extreme event. We also describe respective gaps or shortcomings in the observations.

Observation requirements

- To allow process studies and model evaluation based on a sufficient number of cases, typically several decades of observations are necessary (and probably sufficient);
- To allow poorly documented processes involved in extreme events or amplifying extreme events, such as soil moisture, surface fluxes for water/energy budget analysis.

Table 4: Observations used for process analysis and model observations

Name	Variable(s) sampled	Type of measurement/obs	Spatial coverage	Temporal coverage	Temporal resolution
Processes involved in droughts and heat waves					
ERA-Interim and ERA-CLIM re-analyses (other re-analyses also available)	All dynamical and physical processes	Reanalysis	Global and continental	1900-2014	3-hourly
GEOLAND products	Vegetation variables, land surface temperature, downwelling short/long-wave surface fluxes, albedo, soil moisture	Remote sensing	Global and continental	Product-dependent	Varying
ESA CCI soil moisture	Surface soil moisture	RS merged active-passive product (SMMR, SSM/I, TMI, AMSR-E, ERS-1/2, ASCAT)	Global	1978-2010	Daily
ESA CCI products (other)	Land cover, clouds, fire	Remote sensing	Global	Varying	Varying
ISMN	Soil moisture	In-situ (global network, coverage mostly in Eurasia, North America, and Australia)	Global network	≤1952-present (varying)	10-min to infrequently
LandFLUX-EVAL	Evapotranspiration	Synthesis of diagnostic data (remote-sensing based, budget products), LSMs, and reanalyses	Global	1989-1995/1989-2005	Monthly
MTE upscaled FLUXNET	GPP, evapotranspiration	Upscaled flux measurements (empirical algorithm, using remote sensing and	Global	1984-2010	Monthly

		meteorological data as forcing)			
GLEAM	Evapotranspiration	Remote sensing driven algorithm	Global	1984-2007	Daily
BSWB	Terrestrial water storage	Basin-scale water balance data (mostly Eurasian and North American river basins)	Global, basin-scale	≤1958-2007 (varying)	Monthly
GRACE	Terrestrial water storage	Remote sensing (from gravity measurement)	Global	2002-present	Monthly
PDSI (Princeton dataset)	PDSI estimate	Drought index computed from observed meteorological forcing	Global	1948–2008	Monthly
SPI	SPI estimate	SPI from several precipitation datasets	Global	Depending on precipitation	Monthly
GRDC	Streamflow	In-situ (river basins)	Global	1970s-present	Monthly
EWA (European Water Archive)	Streamflow	In-situ (including selection of near-natural catchments)	Europe	~1950-2004	Daily
BSRN	Radiation balance	In-situ (global network; mostly Europe, North America, and South America)	Global network	1990s-present	1-minute
GEBA	Radiation balance	In-situ (global network; mostly Eurasia)	Global network	1950s-present	Monthly
Globalbedo	Surface albedo, NDVI and fAPAR	Remote sensing	Global	1998-2011	15-days
GLOBCOVER	Land cover classes	Remote sensing (MERIS/ENVISAT)	Global	2004-2006 / 2009	Time invariant
MCD, MOD and MYD MODIS products	Albedo, NDVI, fPAR, GPP, NPP, LAI, ET, surface temperature, land cover	Remote sensing (MODIS)	Global	1991-present	Monthly
CMORPH	Precipitation	Gridded; combination of microwave and infrared satellite observations	Global	2003-present	3-hourly
HADEX	Temperature and precipitation extremes (based on daily data)	Gridded from in-situ	Global	1951-2003	Seasonal / annual
EU-FP6 CECILIA extremes	Temperature and precipitation extremes indices	In-situ and E-OBS derived (extreme indices)	Eastern Europe	1961-2000	Monthly

datasets					
Re-analyses data	Various variables	Global re-analyses data	Global	Product-dependent	Varying
Princeton global forcing dataset	Precipitation, temperature, radiation, humidity, surface pressure, wind	Blend of NCEP/NCAR reanalysis with observations	Global	1948-2000	3-hourly, daily and monthly
WFDEI meteorological forcing dataset	Precipitation, temperature, radiation, wind, surface pressure	Gridded forcing data based on ERA-interim, CRU and GPCC	Global	1979 – 2009	3-hourly
IGRA – Integrated Global Radiosonde Archive	Wind, Temperature, humidity	Rawinsonde data	World	1980-present	Twice daily
SWBM-Dataset	Soil moisture, Streamflow, Evapotranspiration	Derived with conceptual hydrological model that was calibrated using multiple observation-based datasets	Europe	1984-2013	Daily
Specific processes involved in cold spells					
GlobSnow	Snow water equivalent	Derived from satellite-based and ground measurements	Northern hemisphere	1979-2014	Daily
GlobSnow	Fractional snow cover	Derived from satellite-based and ground measurements	Northern hemisphere	1995-2012	Daily

This section is organized by event type.

3.3.1 Heat Waves

Summer heat waves in Europe are primarily induced by atmospheric circulation patterns favouring warm (and dry) air flowing towards Europe. This happens for instance in persisting anticyclonic summer conditions like blocking (Rex, 1951), but also other types of weather regimes, such an Atlantic Low pressure system off European coasts directing warm air masses in Western/Central Europe (Cassou et al., 2005). These circulation anomalies may be favored by patterns of tropical SSTs (Cassou et al., 2005). The development of continental heat waves is also linked with and supported by the land-atmosphere interactions comprising multiple feedback mechanisms (Seneviratne et al., 2010). Soil moisture conditions can modulate extreme temperatures (Hirschi et al., 2011) through its impact on the partitioning of incoming radiation into sensible (warming) and latent heat flux (evaporation). However, this coupling between soil moisture and temperature requires a dependency of evapotranspiration on soil moisture, which is only is the case if soil moisture is in a transitional regime, i.e. not too wet (no moisture-limitation of evapotranspiration) and not too dry (no available moisture for evapotranspiration). Hence, temperatures under anticyclonic summer weather regimes (producing low precipitation) are especially sensitive to soil moisture (Quesada et al., 2012). Because of the described coupling mechanisms, heat waves and droughts often occur jointly. Therefore, the same type of observations as for droughts are required to qualify models for heat waves.

To allow for simulating (and therefore attributing) such events, models should be able to represent the corresponding persisting dynamical conditions, and to correctly capture land-atmosphere feedback processes. Thus observations on tropical SST anomalies and large-scale midlatitude dynamical variables such as geopotential height and winds or sea-level pressure are important for model testing and verification. Furthermore, measurements of the land surface hydrology such as soil moisture or streamflow, and probably even vegetation activity are required.

Since heat waves are generally large-scale phenomena, atmospheric high-resolution data are not usually required. In contrast, higher resolved data is desired from the land surface since land and vegetation are spatially very heterogeneous.

Observational gaps

While SSTs, land temperatures and dynamical variables are generally available from a number of archives over long periods, high-quality and homogeneous data sets for land surface-related quantities are missing, generally leaving land-atmosphere interactions too weakly constrained in climate models.

The available data sets and their characteristics are described in Table 4, and heat waves and droughts are gathered together. Clear gaps exist in reliable long-term (several decades) soil moisture-related and fluxes data. Furthermore the spatial density of land-related hydrological observations is low in many regions outside Europe and North America. These observations, however, are crucial to understand the contributing processes leading to heat waves and droughts, and to consequently improve forecasts. In addition, land and vegetation are spatially highly heterogeneous, such that the representativeness of existing measurements is low in many areas. However, research has recently identified quantities with larger foot prints such as the soil moisture anomaly (Mittelbach and Seneviratne 2012). In contrast to the absolute soil moisture content which depends on local soil characteristics, the standardized anomaly is usually similar over a broader area. Moreover, an increasing number of satellite-based hydrological observations is available, addressing the problem of limited coverage and resolution in all areas with sparse ground observations. These may be utilized to better constrain models to improve their representation of important vertical hydrological quantities and processes (e.g. root-zone soil moisture, groundwater), which cannot be observed from space.

Addressing these shortcomings, a new dataset has been developed within this deliverable (Orth and Seneviratne 2015). This comprehensive dataset contains long-term data of soil moisture, streamflow, and evapotranspiration, thereby covering the land water balance. A novel methodology has been developed to derive the dataset; A simple water balance model has been calibrated against multiple observation-based datasets. As the model is computationally little demanding, we could test a large number of parameter combinations to finally derive a well-constrained parameterization for the model. Applying this parameterization, we derived the new dataset.

3.3.2 Droughts

Drought is a complex phenomenon which may occur in different forms, impacting different parts of the land hydrology. As for heat waves it involves atmospheric weather patterns, but also has specific processes related to water issues. Investigating the different drought types requires different observational data; (1) soil moisture (or terrestrial water storage) for agricultural drought, (2) streamflow for hydrological drought, and (3) precipitation for meteorological drought. For a comprehensive analysis, all these data are needed as a (severe) drought may be a composite of the different types.

In order to analyze droughts and to attribute human impacts on their occurrence, they need to be accurately captured in climate models. The calibration of these models depends crucially on high-quality observations of the drought-related variables. However, there are shortcomings in the present observational data:

(1) Soil moisture: ISMN: Measurements along the entire soil column. These are scare, existing records are mostly short, and the measurements are done on point scale only. ESA CCI: Satellite-inferred soil moisture. Global coverage, but measurements are representative for the upper centimeters of the soil only and hence do not capture the plant available water storage.

(2) Streamflow: GRDC & EWA: These are measurements from many stream-gauges across the world, covering different spatial scales, depending on the upstream area of the respective catchment. Many time series span over several years/decades. However, only overland flow is measured, sub-surface flow as well as catchment outflows, apart from the main stream, are not captured.

(3) Precipitation: E-OBS/HADEX: Gridded product based on point-scale ground observations. Good spatial and temporal coverage. Underlying rain gauge measurements underestimate precipitation because of wind-induced errors. Gridded product represents spatially larger scales than point-scale measurement and hence misses local extreme events.

Observational gaps

The gaps clearly relate to quality, homogeneity, spatial scale and temporal coverage of existing data sets. See also description of observational gaps in the previous Subsection.

3.3.3 Cold spells

Cold spells in winter, as summer heat waves, generally result from a large scale circulation favorable to the development of cold air masses. The persistence of winter blocking events, with central longitude varying between the middle Atlantic to Europe is key to the development of cold temperatures in Europe. Cold spells have also been shown to follow stratospheric events when the vortex breaks apart, leading to meridional exchanges of air masses. The influence of snow cover is also important (ref), as it enables air masses to further cool along a long travel above snow-covered areas. This typically occurs in blocking situations with air masses arriving over Europe having traveled over Siberian land. Sea ice is also a potentially important variable.

Therefore, for models to correctly capture cold spells, one expects a correct simulation (frequency, persistence) of blocking and atmospheric dynamics in general, including stratospheric dynamics, as well as of snow cover.

Essential observations in this respect are zonal and meridional winds, temperature, and geopotential height as function of longitude, latitude, and pressure levels. These are needed in both the stratosphere and troposphere. From these we can calculate both the stratospheric indicators, e.g. the zonal mean wind at 60N, 10 hPa, and the wave-forcing driving the stratosphere-troposphere coupling. Furthermore, indices related to large scale modes such as the NAO or AO can be calculated from sea-level pressure or 500 hPa heights.

Observational gaps

Dynamics is generally well covered by re-analyses, even though homogeneity of reanalysis over decades may be insufficient to detect trends. Observations of snow such as the GLOBSNOW products (Luojus et al., 2011) are also available but exhibit climatological differences as compared with ERA-Interim (Brun et al., 2013).

3.3.4 Heavy precipitations

The data used for model validation of heavy rains naturally falls into two categories: large-scale precipitation and convective precipitation. Large-scale precipitation extremes occur in the midlatitudes in the winter half year. An example is the large amount of precipitation that was a factor in the floods in England in the winter of 2013/2014. The decorrelation scales for this kind of precipitation are large, so that anomalies can be reconstructed from a small set of stations. The national station data is increasingly available in homogenized form, although it is not clear whether the extremes can be sensibly homogenized using statistical methods.

As weather models represent these events well reanalysis data can also be used instead of observations, possibly resolving orographic effects better than a coarse gauge network. Long-term monthly data are readily available for much of the world, and daily data for shorter-term extremes for selected regions, eg the E-OBS analysis for Europe.

In contrast, convective precipitation extremes that occur in summer in the midlatitudes and in the tropics are much smaller in scale, both in space (often only 10km) and in time a (few hours). Daily station data can be used to characterize these extremes, but will usually miss a large fraction unless the network is very dense (10km) and the data available for research, which depends on the data policy of the country involved. (Many European and developing countries do not yet have open data policies.) Hourly data are even better to evaluate model performance for these types of events. These problems can be partially overcome by the use of sophisticated satellite products such as CMOPRH from NOAA/NCEP, which are readily available. However, comparisons with in-situ data give worryingly large discrepancies, which are not yet understood in the attribution community. Calibrated rain radar fields also show promise, but again often are not publicly available and show deviations from in-situ observations that are larger than the possible model biases. Finally, reanalysis products suffer from the same biases as the attribution models, plus the possibility that there is not enough data to constrain the position of the convective events, leading to correct statistics but an incorrect realization.

National gridded observation data sets exist, but have been constructed in different manners in different countries and cannot be used together without understanding all underlying assumptions. A first European gridded dataset (MESAN) is now available and has been obtained as a reanalysis of available observations using the HIRLAM model. To summarize, this is a field in flux in which rapid progress is expected over the coming years.

Observational gaps

A clear observational gap is in understanding satellite and radar products with station data. Station rain gauge data also suffer from biases such as the well-known under-catchment issue due to winds interacting with the measurement system.

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4. Lessons Learnt

- positive lessons:

The work on this deliverable showed that there is large number of existing observation-based datasets that can be employed in the context of attribution. Moreover, updated or new products appear constantly, slowly addressing some of the observational shortcomings identified in this work. Hence it seems generally possible to conduct well-constrained attribution studies during the further course of the project.

- negative lessons:

Despite the large number of identified datasets, it remains a challenge to select the most appropriate product for a particular attribution exercise, because the products might relate to the same variable but can differ in terms resolution, coverage, or quality.

Furthermore, observing land surface hydrology is most challenging because of the spatiotemporal heterogeneity of the soil and the vegetation. The density of soil moisture and evapotranspiration measurements is too low today to properly account for the involved complexity, and to provide a reliable basis for model evaluation. Some remote sensing products are available but they are generally based on short-term records (e.g. GRACE) or merged products (ESA-CCI), which have some issues for climatological applications.

5. Links Built

The work conducted within this deliverable contributes to WP7. The compiled list of available datasets, and the identification of observational shortcomings will facilitate the test case analyses planned within WP7.