Summary Report of the
SAF Hydrology Framework Working Group

1 Executive Summary

Flooding is the most widespread and most damaging natural hazard in Europe. In recent years, Europe has experienced severe and catastrophic flood events, both localised flash floods and basin-wide flooding in large river systems. The floods caused a toll of several hundred fatalities, while nearly one million people were evacuated and damages were estimated to more than 25 billion EUR. These events have demonstrated the need for continuing improvement of flood forecasting and flood warning systems, as a European priority.

Progress can be accelerated by a multi-disciplinary approach involving the concerted efforts of research and operational teams in hydrology and meteorology whose expertise in hydro-meteorology,operational flood forecasting systems, flood warning dissemination and emergency planning can be focussed to improve flood forecasting and warning systems

Droughts in recent years, have also caused extensive damage to crops and posed a severe problem to freshwater supply. Although less dramatic in public perception than floods, droughts carry significant economic and environmental costs. Drought frequencies react sensitively both on climate and water use changes. Most climate scenarios imply a change in drought frequencies for almost all regions of Europe with a decreasing trend in future drought frequencies in Northern and Central Europe and an increasing frequency in Southern Europe,

Recent developments in satellite remote sensing technologies open new possibilities to provide detailed spatially distributed information about precipitation, snow cover and soil humidity. Substantial increase in forecast accuracy can be obtained by integrating diverse sources of information in hydro-meteorological forecasting, such as radar and satellite imagery, as well hydrological and meteorological ground observations using advanced data assimilation techniques.

In response to those needs and opportunities, Council decided in principle to create a Satellite Applications Facility on Hydrology (EUM/C/02/Min) and charged this working group to formulate the Framework for a Satellite Applications Facility on Hydrology, with the following Terms of Reference:

"The Working Group on the SAF Hydrology Framework (SHFWG) is expected to:

- *Establish a vision on how operational catchment hydrological applications and their relationship to numerical weather prediction models will evolve in the next 5 to 10 years;*
- *Assess how the relevance and use of ground-based and satellite observations could evolve accordingly in the same timeframe;*
- *Derive priorities on the services (satellite or combined products, software packages..) that could be expected from a potential SAF on Operational Hydrology and Water Management in the next 5 to 10 years;*
- *Identify relevant satellite observations expected to be available in real time and continuously over at least the next decade, and rank them according to their expected value to SAF services;*
- *Define/map the added value of the potential new SAF with explicit reference to services and products to be expected from other SAFs and operational European initiatives;*
- *Determine the expertise that should be combined in a potential SAF Consortium to develop and deliver the most relevant services, with emphasis on a first operational phase of 5 years, starting around 2008."*

The Working Group met three times between mid-2003 and early-2004, and benefited from the advice of distinguished experts (Appendix 4).

The working group first reviewed the expected lines of development of operational hydrometeorology over the period 2005-2015 (section 2), including the expected needs of hydro-meteorological forecast models over that period. As expressed in Section 3 on Needs, fast provision of the best possible information on precipitation and reliable information on soil moisture and snow are critical requirements to improve the products of hydrological services. The observational resources and technical possibilities to address these needs are reviewed in Section 4 (precipitation), section 5 (soil moisture) and section 6 (snow).

There are large variations across Europe in the availability of facilities to address those needs. Undoubtedly, with the passage of time, the availability of critical resources for flood forecasting (such as state-of-the-art radar networks and high-end computers) will improve and become more even across Europe. In the meantime, the hydrological and hydro-meteorological services of Europe must confront substantial flood risks on a routine basis and with the resources to hand.

Section 7 considers likely developments in global and regional Numerical Weather Prediction in the period 2005-2015, and concludes that the products of the proposed SAF are likely to be complementary to related NWP products, and will also provide an independent and valuable resource for validation of the NWP products.

A review of the products related to hydrology from other SAFs (Section 8) indicates that the work proposed for the Hydrology SAF will be a valuable addition to existing capabilities.

The partner skills and experience required for the Hydrology SAF are summarised in Section 9.

The working group's recommendations are presented in Section 10. The WG concludes that current and planned satellite systems (both research and operational) can support a step-wise fulfilment of the user needs, and that some of the steps are already in the development phase. The working group identifies the products/ deliverables for a potential SAF on Operational Hydrology and Water Management in Appendix 2, and also identifies the relevant satellite systems. With the expected evolution of satellite systems in the timeframe 2005-2015, these needs will be supported more and more effectively towards their breakthrough levels in the operational phase.

The WG recommends the STG to

- Consider the outcomes and conclusions of the H-SAF framework WG,
- Recommend Council to approve the defined scientific framework, within which a proposal on an H-SAF should be developed.

2 Lines of Development of Hydro-meteorological Forecasting 2005-2015 - a Long-term Vision

Floods are the most costly natural hazards for Europe. There is a powerful case for mobilising all available resources of talent, institutional capability and technology to improve the European capability to assess, forecast and manage risks of heavy rains and floods on a range of time scales from flash floods (1-6 hours), through floods lasting a few days through extensive floods lasting a week or more in the large European basins. Droughts, which typically have time scales of several months, also have significant potential for damage to life and property in Europe.

Predicting floods and droughts are classical hydrological tasks. Over the past years there has been a shift in both the societal expectation and the predictive capabilities and it is likely that this trend will continue over the next decade. The main societal changes in the context of floods have been an increase in the risk awareness and an increase in the targets for protection levels. Now floods need to be predicted more accurately, over longer lead times and in smaller catchments than in the past years. The predictive capabilities have also changed tremendously. Accurate weather forecasts are playing an increasingly important role in hydrologic predictions and the hydrologic models are becoming more complex and data intensive. One of the cornerstones of the data needed for accurate hydrologic predictions are satellite data from various platforms. The working group's long-term vision (2005-2015) for the development of operational hydrological applications, and their relationship to numerical weather prediction models, is illustrated in Figure 1.

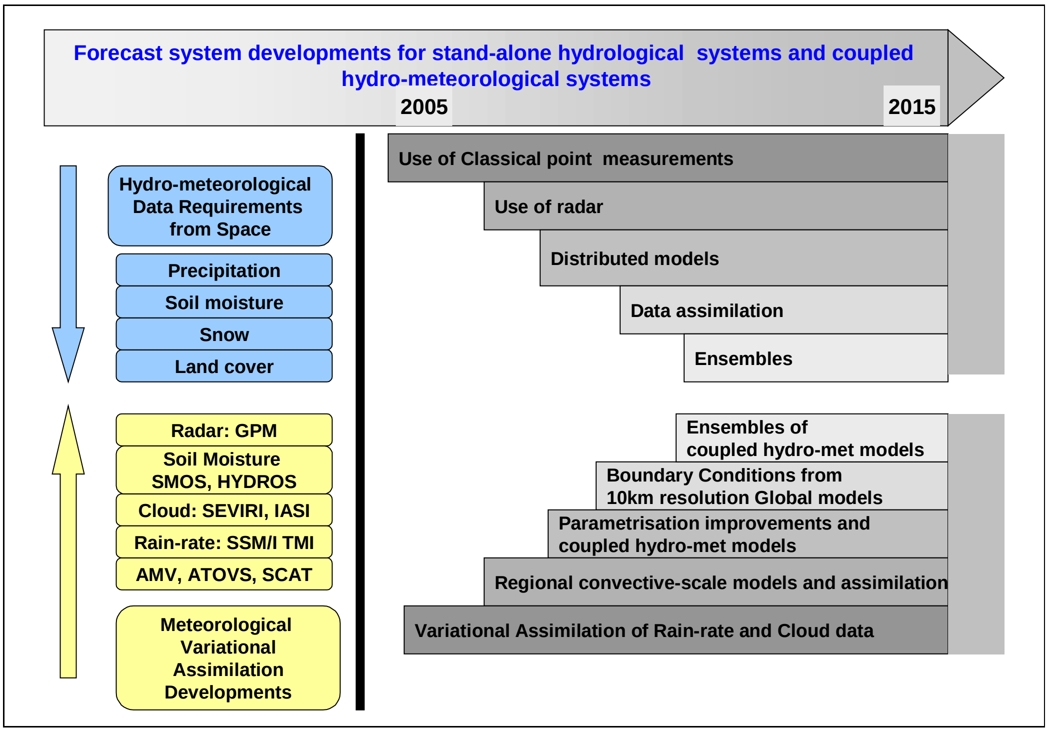


Figure 1. A sketch of the likely evolution 2005-2015 of the observational, modelling and assimilation capabilities for stand-alone and coupled operational hydrological forecast systems.

The long-term vision was derived from an analysis of expected developments in satellite capabilities, in hydrological modelling, in global and regional meteorological modelling, in hydrological and meteorological data assimilation, in coupled hydrological/meteorological (hydro-meteorological) models, and in the provision through ensemble techniques of useful estimates of the uncertainty of hydrological and meteorological forecasts.

The left-hand part of the figure considers the development of observational and assimilation capabilities, while the right-hand side of the plot considers developments in both operational stand-alone hydrological forecast systems and in coupled hydro-meteorological forecast systems.

The upper left-hand part of the figure (in blue) summarises hydro-meteorological data needs which can be met from space, and which will be addressed by the proposed SAF in the first five years of its development (Precipitation, Soil moisture, Snow) or in a later phase, possibly in cooperation with other SAFs (e.g., Land cover).

The lower left-hand part (in yellow) outlines the expected developments in satellite availability and in meteorological variational data assimilation targeted on the hydrological cycle. The space agencies will provide many satellite instruments (AMSR, AMV, ATOVS, ASCAT, SSMI SSMI/S, TMI, SEVIRI, IASI, CrIS, the instruments on SMOS, HYDROS and on the GPM constellation satellites, and the continuation of heritage instruments from this group on NPOESS), with the general aim of providing, as far as possible, an all-weather capability for measurement of key aspects of the hydrological cycle (humidity, ice-, water- and mixed-phase clouds, rain-rate, soil moisture, and snow parameters). The aim of the NWP assimilation and hydrological laboratories will be to assimilate all that information in a manner which is consistent with our knowledge of hydro-meteorological processes and atmospheric and soil water dynamics.

The upper right-hand part of the figure outlines projected developments in operational stand-alone hydrological modelling, whether driven by hydrological data (for hydrological forecasts to a few days ahead) or driven by the radar data, or driven by precipitation forecasts from meteorological models of appropriate scale. The foreseen developments include further developments of distributed hydrological models, of data assimilation methods, and of the application of ensemble methods to quantify the uncertainty of hydrological forecasts.

The lower right-hand part of the figure outlines foreseen developments in meteorological models and in coupled hydro-meteorological models. Essential in the latter type of models is to suitably address the up/down-scaling issue in coupling the models. It is expected that regional convective-scale models with resolutions ~ 1 km, which approach feasible scales for distributed hydrological modells will become operational by 2010, and will be driven by global forecast models with resolution of 10 – 15 km. Depending on the progress of research, it is likely that in the ensuing five years coupled hydro-meteorological models with resolution of ~1km for the meteorological part and 100 m for the hydrological part will become operational. Preliminary research on this topic has been encouraging. It is likely that such research will be pursued vigorously in the coming years.

The long-term vision foreshadows a convergence between stand-alone hydrological and coupled hydro-meteorological forecast systems in terms of data usage, particularly of data from the proposed SAF. An active research programme will be needed to assess the strengths and weaknesses of the two approaches, through inter-comparisons of different systems. Scaling problems related to the variability of water and water-related processes in the atmosphere, biosphere, and on and in the ground will be a major issue. Research access to the necessary hydrological data will be an essential pre-requisite for such inter-comparisons. It is currently impossible to predict whether the stand-alone or the coupled approach will ultimately be the approach of choice for operational hydrology.

Whatever the outcome of such system inter-comparisons, a number of recent studies of coupled hydro-meteorological models suggest, that intensified collaboration between the hydrological community and the meteorological community through the activity of the proposed SAF and elsewhere, will substantially benefit the work of both communities. Equally important will be a more intense collaboration between the hydrologic services involved in operational hydrologic forecasts both at national and European scales.

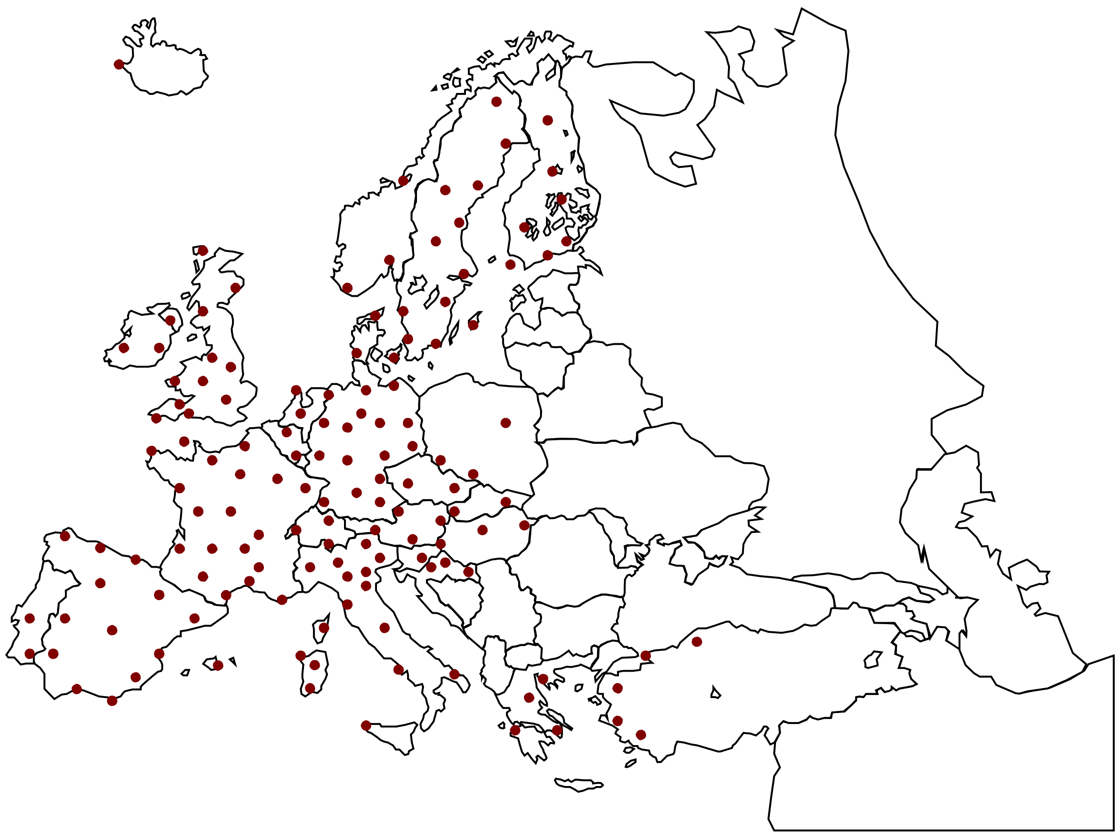


Figure 2. Weather radar coverage in Europe.

There are uncertainties in the proposed long-term vision. It will be some time before we know if convective-scale data-assimilation systems can cope with a situation where the assimilating model correctly initiates intense convection over an Alpine valley (say), but initiates it over the wrong valley 30 km away. Solutions to such problems may take some time to emerge. Since rainfall verification on such small scales is a very difficult problem (section 7), it is necessary, as foreseen by Council, that the proposed SAF develops the most accurate possible forecast-model-independent estimates of rain-fall.

The resources available to address the hazards posed by floods and drought are unevenly spread across the European continent. Central and Western Europe is well covered by rain-radars, and there is effective cross-border exchange of radar data, which was initially organised under the COST banner. The situation in the Accession countries and elsewhere in Eastern Europe is quite different. Coverage by rain radars is effectively limited to the vicinity of very large conurbations (Figure 2). Moreover the availability of powerful computers for state-of-the-art national/regional short-range forecasting (including variational assimilation of satellite and radar data) is also uneven across Europe.

The products of the proposed SAF will continue to be extremely useful in the long-term future when a weather radar network is fully developed, as the SAF products are complementary to radar because of different errors structures. Collaboration in the proposed SAF across institutional boundaries, national boundaries, and discipline boundaries will be necessary to provide the best possible services on a steadily improving technical infrastructure.

The proposed SAF will develop the most accurate possible forecast-model-independent estimates of rain-fall to support existing hydrological services. Such data sets will also be valuable tools for validating the advanced convective-scale forecast models, including models that are directly coupled to hydrological models, and the 10 km global models, which will come on-stream in the coming decade. The two further main elements of the proposed SAF activity on soil moisture and snow were also foreshadowed by Council. Soil moisture in hydro-meteorological models will ultimately evolve from a tuning parameter used for adjusting model deficiencies to a physical quantity. The availability of spatial soil moisture data foreseen by the proposed SAF will accelerate this process, and will allow assimilation of soil moisture into forecast systems. Snow cover and snow water equivalent products from this SAF will be extremely useful for a number of purposes in operational hydrology including long term snow melt forecasts as needed by numerous water management agencies throughout Europe, in assimilating snow cover into forecast models, and in providing independent validation for the land assimilation activities going forward in the Numerical Weather Prediction laboratories.

3 Needs for satellite data for hydrologic applications

3.1 Current status and trends in operational hydrology

3.1.1 Observations and models used

For the determination of user needs, the working group has focussed on the meteorological input required for hydrological models and flood forecasting systems. In consideration of the fact that any operational activities of an H-SAF will take place in a time frame of 4-5 years from now, the needs of both operational and research systems have been assessed. By the time that an H-SAF would enter its operational phase, new ground- and space-based observing systems will have become available, and hydrological models will have become both more demanding in terms of meteorological input and more capable of ingesting and using this information successfully. The working group has attempted to take these trends into account.

Precipitation observations in operational hydrology still are largely obtained from rain gauge networks. These provide relatively accurate in-situ information, but the spatial coverage of gauge data and their representativeness for their environment is limited. Near-real-time data exchange between individual gauge networks is not common, so data availability can be a problem for users, particularly for larger catchment areas cutting across national borders. It is to be expected that neither the technical capabilities nor the extent of present gauge networks will change drastically in the coming years.

The use of precipitation radar in operational hydrology is growing fast. Radars offer a spatially dense observational coverage for precipitation; however, the interpretation of radar reflectivities in terms of quantitative rain rate or accumulated precipitation can be quite problematic. Within Europe, radar precipitation is routinely exchanged in near-real-time. Increasingly, radar data are combined with gauge observations to provide accumulated precipitation information of both high spatial density and accuracy.

In Western Europe, radar coverage over land is nearly complete. In Eastern Europe, the situation is not so good at present, gauge networks often being the only source of precipitation observations available. There still exist ungauged catchments or catchments with only one raingauge. This situation is rapidly changing, however; for example, in the past two years no less than 7 new radars have been installed in Poland. It is to be expected that by 2015, radar coverage over land in Europe will be nearly complete. Gaps in the precipitation network will then exist primarily over sea, and in mountainous areas. In regions with steep topography, radars have a limited range due to beam blocking, and full radar coverage may not be economically feasible. Gauge networks in mountainous regions also have their problems, due to the limited representativeness of in-situ data under these conditions.

Satellite precipitation observations are presently practically not used in operational hydrology (with some exceptions), and this is not expected to change until products become available on an operational basis which either are comparable in accuracy and resolution to ground-based observations, or which clearly fill gaps in the existing networks.

For soil moisture, the availability of operational ground-based observations in Europe is very poor. This is largely due to the very high spatial variability of soil moisture, which severely limits the usefulness of monitoring with in-situ data. Snow monitoring networks are more extensive, particularly in Northern Europe and in mountainous regions, but their spatial coverage is still limited. Processes of snow accumulation, melting and soil moisture are modelled using few ground observations.

Hydrological models vary greatly in characteristics, scale and level of complexity. Research systems tend to be of far greater sophistication than operational models. At present, operational hydrological models mainly use rain gauge data and deterministic NWP precipitation forecasts as meteorlogical input. Soil moisture and snow observations are rarely used; instead, soil moisture and snow characteristics are inferred and calculated by the model itself. These model calculations often are not validated directly against observations.

Hydrological models can ingest meteorological observations either in the form of gridded data, or of spatially averaged observations, providing mean values for Hydrological Response Units (HRU's) or subcatchment areas.

The trends to be expected in operational hydrological modelling can be inferred from research models. They tend to use grid-based input, and to include far greater amounts of spatially dense information from radar and satellite-based observations. They sometimes have been adapted already to accept soil moisture , snow, radiation and evapotranspiration information directly from available observations, and contain more complex physical descriptions of snow, soil and evapotranspiration processes. Data assimilation methods for hydrological purposes are increasingly being developed, as well as probabilistic forecasting techniques. Rapid changes and adaptations in operational hydrological models along these lines can be expected for the coming years.

3.1.2 Present use of satellite observations in hydrology

While the use of satellite data in operational hydrological models is still quite rare, they are being successfully applied in research models. The scope of their application is quite broad. They are used as input data, or for the determination and actualisation of model parameters. The following types of satellite measurements have been in use so far:

- Precipitation – estimates of precipitation intensity and accumulated values by VIS/IR imagery from geostationary satellites and, more recently, microwave imagery from low-orbiting satellites, often combined with ground radar;

- Evapotranspiration – inferred from surface temperatures, radiation fluxes (and their diurnal variations) and vegetation indexes, as systematically observed in VIS/IR imagery from geostationary and low-orbiting meteorological satellites.

- Snow cover and water equivalent – direct observation (cover) or model-aided estimates (water equivalent) from VIS/IR and MW imagery from low-orbiting meteorological satellites (coarse resolution) or R&D or commercially-oriented satellites equipped with high-resolution imagers in the optical range or by active MW (SAR).

- Soil moisture – inferred from thermal inertia by VIS/IR imagery from geostationary and low-orbiting meteorological satellites, or more directly observed in the MW range in passive (coarse resolution) or active way (coarse resolution by scatterometer, high resolution with SAR).

- Digital elevation modelling – possible by stereoscopy in the optical range from high-resolution R&D or commercially-oriented satellites, or by interferometry between SAR images.

- Land use classification – current application of commercially-oriented high-resolution optical satellites.

- Determination of flooded area – possible with active MW imagers (SAR).

It may be observed that a large amount of information is based on data available from the backbone satellite-based Global Observing System (GOS) for operational meteorology (METEOSAT, NOAA, etc.) and from other meteorological systems not part of GOS but anyway operationally available (e.g., DMSP). However, a number of applications, generally those at small-catchment scale, are based on data from satellites of either R&D nature (e.g., carrying SAR) or organised on commercial basis (e.g., LandSat, SPOT, etc.).

A few examples of successful implementation of satellite data in hydrological modelling are presented in the supporting document.

3.2 User needs and priorities

3.2.1 Key parameters

The key meteorological quantities for operational hydrology are the following:

- **Precipitation**. The main parameters of interest are precipitation rate, accumulated precipitation and precipitation type, for a wide range of temporal and spatial scales.

- **Snow conditions**. The main parameters of importance are snow covered area (SCA), snow water equivalent (SWE), wet/dry snow conditions, and thawing/freezing conditions. Of these, the parameters of highest priority are SCA and SWE.

- **Soil moisture**. Both the soil moisture at the surface and that of the root zone are of interest.

Operational hydrology is largely concerned with water quantity. Since water quantity is the basis also for proper water quality modelling, improvements induced by H-SAF products will also directly be beneficial for operational water quality assessment.

3.2.2 Accuracy, resolution and time aspects

Existing compilations of hydrological needs at global and European level will constitute the basis to establish detailed User Requirements for H-SAF. WMO has already collected user requirements from the meteorological and hydrological community, and owns a Database of user requirements from the different WMO programmes (including the Hydrology programme) and from other organisations/programmes such as WCRP, GCOS, GOOS, GTOS, IGBP, ICSU and UNEP. The Database has been established in cooperation with the Committee for Earth Observation Satellites (CEOS) and it is updated at intervals according to a "Rolling Requirements Review" mechanism (users start with technology-free requirements, space agencies react by specifying realistic capabilities, users review the situation, and so on). Table 1 of Appendix 1 collects the requirements for precipitation, soil moisture and snow parameters observation as available from the WMO/CEOS Database at end-2003. Unfortunately, it is noted that requirements from hydrology are poorly represented and very generic. The reason is that the information from the WMO hydrological units has not been updated since 1999, when the use of satellites in Hydrology was probably not yet well addressed.

The EUMETSAT Convention has determined that WMO requirements have to be taken into account as much as possible. EUMETSAT itself has produced a set of requirements for defining the satellite series to replace MSG in the 2015 timeframe. Table 2 of Appendix 1 collects the requirements for precipitation, soil moisture and snow parameters observation as prepared after a one-year activity for the 1st Post-MSG User Consultation Workshop, Darmstadt 13-15 November 2001. It is noted that requirements have been set up for Global and Regional NWP and for a number of applications of Nowcasting, including some hydrological item. Also to be noted that, whereas WMO requirements reflect current or near-future state-of-business, the EUMETSAT requirements refer to the perspective state-of-business in the decade 2015-2025.

In both the WMO and EUMETSAT cases, the requirements are intended as technology-free, specifically not necessarily to be met by satellite systems only. Therefore, when planning for H-SAF, that is responsible of satellite-derived products, attention should be paid not to directly confront the expected performances with the theoretical requirements, but rather to ensure that the H-SAF products represent a significant contribution to the overall system (satellites + ground systems + GIS + assimilation model + ...).

The information on WMO and EUMETSAT requirements recorded in Appendix 1 are provided for information only. In effect, none of the two sets can simply be adopted for H-SAF (WMO currently too generic, EUMETSAT too biased towards applications lying under the responsibility of Meteorological Services). A critical analysis of these (and possibly other) compilations (e.g., from the EC framework), undoubtedly will constitute a good starting point for building the User Requirements Document (URD) for H-SAF during the planning phase.

Nevertheless, a very preliminary brainstorming was attempted at this early stage within the Working Group. The results, limited to the key hydrological parameters, are summarised in the following Table where two requirement figures are provided: the "optimum" in the sense that better performance would not bring noticeable additional benefit, and "threshold" in the sense that a system unable to provide at least that performance would not be worth to be developed since the measurement would bring irrelevant contribution in respect of what is already known or can be modelled with no need for observing.

Table 1. Preliminary user requirements for operational hydrology.

Parameter	Resolution		Accuracy		Cycle	
	Optimum	Threshold	Optimum	Threshold	Optimum	Threshold
Precipitation rate (heavy rain)	1 km	10 km	10 %	30 %	15 min	3 hours
Precipitation rate (light rain / snowfall)			20 %	100 %		
Precipitation (accumulated)	1 km	50 km	10 %	30 %	3 hours	24 hours
Soil moisture	100 m	50 km	3 %	30 %	4 hour	2 weeks
Fractional snow covered area	250 m	10 km	10 %	25 %	1 hour	24 hours
Snow water equivalent	250 m	10 km	1 mm	50 mm	1 hour	2 weeks

3.2.3 Additional requirements

Operational hydrologists have a strong need for obtaining a quantitatively accurate impression of the precipitation in and around their catchment area of interest, at all times and length scales. For flood forecasting, the near-real-time access to precipitation data is of paramount importance; availability is preferred over accuracy.

In-situ networks are generally preferred operationally, because the accuracy of gauge observations is still considered to be the best and most reliable. Radar data, preferably in combination with gauge information, are considered important for obtaining a better idea of the spatial distribution of precipitation. The value of satellite data will be highest for areas for which no radar data are available, and where the network of rain gauges is sparse or not representative. For Eastern Europe, radar data coverage is still limited, and there satellite precipitation observations will be useful in the coming years to "fill the gaps" in the coverage of in-situ ground-based networks.

Radar coverage is swiftly improving, and it can be expected that with 10 years or so, radar coverage over the whole of Europe will be largely complete. However, some important gaps will still exist even then. Most importantly, ground-based networks do not cover precipitation occurring over sea. Hydrologists in the Mediterranean countries in particular have emphasized the need for precipitation information overseas, for the purposes of nowcasting. Secondly, ground-based networks have problems in observing precipitation in mountainous areas. Satellite observations can help fill these two types of gaps, provided that they are of sufficient and reliable accuracy.

Also, hydrologists have stressed the need for some redundancy in precipitation observations. They cannot afford gaps in operational networks at critical moments due to e.g. instrument failure. In severe weather conditions and during floods, frequently ground measurements are not available due to damage of equipment or data links. Sometimes ground-based observations are suspect, and independent information from satellites is considered to be very useful as a means to assess their quality. For example, at large distances from a radar, the radar beam may be at too high elevation to detect precipitating low clouds, or the beam may be attenuated by nearby precipitation; likewise, rain gauges may be faulty for a variety of reasons. Satellite precipitation in such cases can be used to aid quality control of ground-based data.

Hydrologists need high quality estimates of both absolute values of precipitation and of its variability in time and space. They are well aware that satellite precipitation data have different sampling characteristics than in-situ or radar observations, and that care should be taken in comparing and combining data from these three sources. Still, they would like to use satellite data effectively to complement existing ground-based networks. All sources above a certain quality threshold can contribute to the overall result. Consequently, they have expressed a need for tools which may assist them in combining satellite measurements with ground-based observations, and in weighing the various data types according to coverage, resolution and expected accuracy. The development of methods and algorithms for this purpose would be a very useful activity for an H-SAF.

Operational ground-based monitoring networks for snow and particularly for soil moisture conditions are very limited in Europe. Also, the accuracy of snowfall measurements is generally very poor, of much worse quality than precipitation measurements. Here, satellite observations are not merely complementary to other sources, as was the case for precipitation, but offer truly new information, which could contribute significantly to hydrological models. At present, soil moisture in particular is normally not determined from observations, but calculated internally in the hydrological model, with very limited opportunities to validate it independently. Satellite observations offer us the first real opportunity to validate soil surface processes in hydrological models, either directly or through soil moisture analyses by NWP models. They can thereby also significantly contribute to the improvement of operational hydrological models through better calibration and an improved description of soil moisture processes. The same is true for snow parameters such as snow water equivalent. In order to benefit from the inclusion of satellite data of snow and soil moisture, hydrological models need to be adjusted to capture this information, something which at present they are usually not designed to do. An increased use of satellite information hence is likely to trigger significant changes and adaptations in the operational hydrological models themselves. An important activity for an H-SAF would be to strengthen the dialogue between the hydrological and remote sensing communities, so that the development of satellite products and of hydrological models can be harmonized.

The demands of operational models for satellite data are expected to increase in the future. Both NWP and hydrological models will increasingly assimilate precipitation, snow and soil moisture parameters, preferably from as many independent sources (of sufficient quality) as possible. It is to be expected that a significant number of hydrological modellers will not content themselves with using NWP analyses of precipitation, snow and soil moisture, but that they will insist on the possibility of assimilating these meteorological quantities in their own models directly. They will therefore desire direct access to satellite observations of these parameters. In that respect, it is important to note that one of the barriers mentioned by users preventing the use of satellite data in operational hydrological models at the moment, is the limited availability of operational satellite products to users from operational hydrology.

A set of parameters required by operational hydrology is already being covered by existing SAFs e.g.: convective precipitation rate, soil moisture, snow cover, evapotranspiration, radiation, land use, vegetation parameters. Of these, the precipitation, soil moisture and snow products,based mainly on geostationary satellite data, are probably inadequate to meet the needs of hydrological users. A further improvement and extension of those products, including other satellite data sources is highly required.

3.3 Conclusions

The following conclusions can be drawn regarding the needs for operational space-borne hydrologic information:

- At present, the needs in operational hydrology are highly varied and changing. They are expected to evolve further as hydrological models are being adapted and enabled to use new types of input data, such as precipitation radar observations, NWP products and satellite data. An H-SAF should therefore cater to a broad and evolving spectrum of needs.

- Precipitation is the most essential and sensitive source of meteorological input in hydrological models, and therefore should be the quantity of highest importance to an H-SAF. An improved coverage in time and space of precipitation measurements is highly desirable. Satellite observations have the potential to complement precipitation observations of ground-based gauge and radar networks, particularly over sea and possibly in mountainous areas. Hydrologists have expressed a strong desire for the possibility to combine satellite precipitation observations with, and weigh them against, available ground-based data.

- Snow and soil moisture information is also of high importance to operational hydrology. Key parameters requested are: snow covered area, snow water equivalent, and soil moisture at both the surface and the root zone.

- In order to benefit from the inclusion of satellite data of snow and soil moisture, hydrological models need to be adjusted to capture and exploit this information. An important activity for an H-SAF would be to strengthen the dialogue between the hydrological and remote sensing communities, so that the development of satellite products and of hydrological models can be harmonized.

- The potential usefulness of satellite products for operational hydrology is not limited to their applicability as input in hydrological models. They can also be used for the quality assessment and quality control of ground-based observations, and in model validation and calibration exercises.

- Clear benefits of the use of satellite data have been shown in hydrological research models. However, the present use of satellite data in operational models is limited. This is partly due to the limited availability of relevant satellite products for operational purposes. An H-SAF could improve this situation.

4 Means for providing data for hydrologic applications - Case PRECIPITATION

4.1 Sampling Problems in Precipitation Measurement

4.1.1 Spatial Sampling

Rainfall is characterised by a high degree of variability at all scales in both time and space. This can be formalised in the power-law expressions typical of a fractal quantity. A consequence is that there is no minimum scale below which the rainfall intensity distribution becomes smooth, and point measurements can be taken as representative of larger areas. For accumulations, the effect of time averaging introduces a corresponding smoothing of the spatial variability, so that the distribution of monthly accumulations may, for instance, be adequately represented in much of the UK by the current network of about 5000 daily gauges. Such a density is not adequate in the coastal and mountainous areas, where the influence of topography introduces small scale variability even at the monthly time scale. Perversely, these are also the areas for which the rain gauge density is, in general, poorer.

In order to optimise the use of available data, it is possible to define climatically homogeneous regions within which the monthly rainfall is well correlated. However, this breaks down for shorter accumulation periods, such as those required for flood design. Here, the variability arising from the meteorological origin of the rainfall, is such that an acceptable rain gauge density is not achievable, except for special experimental campaigns. For instance, a typical convective storm has a diameter of about 10km, and a complex space and time evolution at smaller scales, depending on the atmospheric structure in which it is embedded.

The only available in situ space-integrated precipitation information may be inferred from the water level of natural basins (river, lakes) and/or from very expensive fine mesh raingauge wide networks. However remotely sensed precipitation, especially weather radar, is well suited to this problem, as it provides area-average intensities

4.1.2 Temporal Sampling

Time structure analysis of ground precipitation shows the typical behaviour of a noise signal: not random noise, but noise with a memory. Such structure means that the phenomenon (system) moves between events (rainfalls) in a complex way according to a Self-Organised Criticality (Bak et al., 1987). In addition to this, spectral analysis and computation of the Hurst index show typical fractal characteristics, i.e. infinite repetition at both small and large scales. This means that for both rainfall and drought events there is no ultimate time scale; in other words, there is no Nyquist frequency that satisfies the Shannon theorem for a correct time sampling which allows reconstruction of the “true” continuous series.

This characteristic is not critical for time continuous integrated observations like those made by classical direct instruments (rain gauges), but it leads to serious limits for instantaneous time sampling observations like those which can be retrieved by remote sensing systems using electromagnetic radiation. In this case we have the problem of the error (underestimation) in reconstructing the total amount of precipitation at ground. If we consider rainfall events, simulation of instantaneous observations using high frequency rain gauge series (15 minutes integration time) shows that in the cases of 30’, 60’ and 180’ time sampling the quantitative error referring to original rain gauges series leads to an underestimation of cumulated precipitation since about 35%, 50% and 63% events respectively are missing.

For these reasons the preferred sampling interval for operational radars is 5 minutes or less. Alternatively, the evolution of the precipitation distribution between observations can be estimated using a Lagrangian extrapolation, and the results as the basis for estimating rainfall accumulations.

4.1.3 Validation

These different characteristics of radar and rain gauge sampling make comparison extremely difficult. As the time and space scales of the integrated data increase, the ergodic nature of precipitation means that small scales are progressively removed in both space and time. Thus comparison may usefully be made of monthly rainfall accumulations on scales of 50km or more, but not of data at the hourly or 5km scale.

4.2 Ground based Data Sources: Rain gauges and radar

4.2.1 Rain gauges

The traditional basis for estimating actual rainfall accumulation has been to collect it at an orifice into a suitable container and to measure the collected water at regular intervals, typically daily for manually operated gauges and hourly for automated gauges.

A well designed, properly shielded and maintained rain gauge can minimize losses due to e.g. evaporation, splashing and under-collection of rain due to distortion of the airflow around and over the gauge. A particular problem with automatic tipping bucket gauges arises from the finite tip volume, which results in errors in the estimates of the onset and end of precipitation periods. In cases of light rainfall, this may result in significant errors in hourly rainfall totals. In heavy rain, the rainfall amount may also be underestimated due to the "dead time" while the bucket is emptying. The major source of error, however, is the very limited representativeness of a rain gauge for the area surrounding it: the small size of the orifice, together with the limited number of rain gauges, results in very poor spatial sampling of the spatial distribution.

4.2.2 Radar

The discovery that radar reflections from rainfall were related to its intensity, offered an alternative approach to estimation that provides continuous, but area-averaged estimates of precipitation, with dense spatial coverage. Radar emits microwave radiation and observes the back scattered radiation from precipitation particles. Reflectivity is converted to rain rate using an estimate of the droplet spectrum.

Errors in radar-derived precipitation rates arise from several sources, including the radar hardware and its siting, the conversion of observed reflectivity to rain intensity and the location of the observed volume of the atmosphere. As the range from the radar increases, the quality of rainfall estimate falls off due to the increase in beam width, and hence the variety of conditions that are being aggregated to form a single observation. In addition, attenuation of the beam by nearby precipitation may significantly decrease the available power for reflection from more distant precipitation. The curvature of the earth generally introduces an increase in beam height with range. Having located the height of the radar beam, and correctly deduced the rain intensity at that height, an estimate must be made of how the precipitation at the height observed will alter (due to e.g. wind drift and sub-cloud evaporation) as it falls to the ground. Where there are strong moisture gradients in the atmosphere, the radar beam may be anomalously bent, leading to intersection with the ground (anaprop) and resulting spurious echoes. None of the approaches which are used to remove this contamination is fully satisfactory.

Making allowances for these problems, high-quality precipitation information can be obtained from radars. Hourly accumulated rainfall measured by UK radars, for example, has an RMS fractional difference of about a factor of 2 with gauge measurements. This is close to what can be expected given the different time and space sampling of the two observing approaches, indicating that the quality of measurement is similar.

4.2.3 Gaps in the present gauge and radar networks

The quality and coverage of rain gauge and radar networks is uneven across Europe. In Eastern Europe, both gauge and radar spatial coverage is relatively poor, although this situation is rapidly improving. Both gauge and radar networks suffer from serious deficiencies in mountainous areas. In regions of steep topography, the representativeness of individual gauges for the catchment area can be highly questionable. For radars, obstruction of the radar view of the horizon by intervening mountains is a major difficulty; a large number of radars would be required to achieve full coverage of precipitation in valleys, which is unlikely to be economically feasible. Operational hydrological forecasting in coastal regions requires knowledge of precipitation coming inland from the sea; this obviously cannot be obtained from gauge networks, and only to a very limited extent from radars.

4.3 Satellite based data sources and satellite capabilities

4.3.1 Satellite data considered for H-SAF and main potential products

The key precipitation products required by hydrologists are assumed to be:

- instantaneous rain rate reaching the ground
- rain water phase at the ground
- cumulated precipitation over one day and over as few hours as possible

It is essential that any product is conveniently appended with information on its error structure, necessary for its correct use in the application.

Precipitation rate estimate from satellite is a long-standing application, initially based on visible/infrared imagery (particularly from geostationary satellites) associated to conceptual models. That is a rather indirect technique, since VIS and IR radiation only provides information on the cloud top reflectance and temperature, in addition to the pattern. Because of this, plenty of external information has to be used when processing the data, and results are applicable only under circumstances limited to specific observing conditions, related to the model concept adopted for retrieval and the nature of the external information entered in the processing scheme.

More direct information is provided using microwave radiation, where the cloud interior is penetrated and the signal is controlled by emission and scattering (from ice), and by polarisation and depolarisation effects (over the sea). In addition, if the MW radiation is actively generated by the instrument (radar), measurement of ranging and intensity of the back scattered radiation provides the precipitation vertical profile and an estimate of drop size. However, since radar cannot have a large swath and, if used in an imaging configuration, is a huge instrument, its best use is as a means to calibrate passive microwave observations, which must form the basis for global, regular and frequent coverage.

Another useful principle is to use absorption bands instead of atmospheric windows. In atmospheric windows the observation is more direct, but it is invariably connected to total-columns (of liquid or ice water). In absorption bands (of O2 for temperature, or H2O for humidity) water drops only represent a "disturbance" for the primary sounding mission, but the observation in channels of different absorption strength is sensitive to the height where the disturb occurs. This information on the vertical structure, and also on the different effect of liquid and ice water at different frequencies, may be exploited to infer precipitation, as it has been shown using AMSU-A (O2 band around 54 GHz) and AMSU-B (H2O band around 183 GHz), available in orbit since 1998 (NOAA-15). It is important to note that precipitation measurements in absorption bands are equally possible over land and sea, whereas sea is privileged in atmospheric windows. In addition, it should be noted that absorption bands are also present at higher frequencies, in the sub-millimetre range, where good spatial resolution can be achieved by relatively small antennas, so that the perspective exists to use geostationary satellite, the only possibility to measure precipitation at few minutes intervals, as required for accurate cumulative precipitation computation.

Waiting for the advent of MW/Sub-mm sounding from geostationary orbit, the technique for implementing frequent observation relies on using many satellites in coordinated orbits, equipped with MW radiometers. The Global Precipitation Measurement mission (GPM) aims at a constellation of eight satellites to provide global observation at 3-hourly rate. Fusion with frequent IR imagery from geostationary satellite enables to generate a product at GEO-type frequency (15 min with MSG/SEVIRI) that, at times of overpasses of LEO satellites, is "calibrated" by the MW-derived product, and carries forward the calibration at intermediate times with a degradation linked to the type of precipitation and the temporal distance from the calibration session. This technique is already demonstrated, even in Europe, by using 30-min IR images from Meteosat/MVIRI and 8-hour MW images from DMSP-SSM/I.

The use of absorption bands also is current practise, even in Europe, by exploiting AMSU-A and AMSU-B on the operational NOAA satellites. Future MW radiometers will combine "window" channels and absorption bands to synergistically exploit the two principles. The first radiometer of this sort, SSMIS, is now (2004) replacing SSM/I on DMSP satellites. A similar concept, CMIS, associated to a much larger antenna for much improved resolution, is being developed to be flown on NPOESS satellites starting from 2009. Meanwhile, MW "window channels" radiometers with large antennas are already in use (AMSR on ADEOS-II, now failed, and AMSR-E on EOS-Aqua).

Satellite data available to feed the H-SAF activity will, in the operational phase (2010-2014), consist of the three CMIS instruments flown on NPOESS, complemented by further five (smaller) radiometers on the GPM constellation, possibly including the European contribution EGPM. For the development phase, SSM/I, SSMIS, AMSR and AMSU will provide sufficient databases (SSMIS and AMSU also in the operational phase). The basic imager in GEO will be SEVIRI for both the development and the operational phases.

In Appendix 2 the instruments potentially available for the H-SAF development and operational phases are listed, and their main characteristics (resolution and observing cycle over Europe) noted. Moving from these characteristics, the Appendix attempts to estimate the potential performances (resolution, accuracy, observing cycle and timeliness) of the products that are considered feasible. It is explained which product will be sufficiently consolidated during the development phase to the extent of being operational at Day 1 and which one will be consolidated later, or his quality will improve in the course of the operational phase. In addition to the deliverable geophysical products, the Appendix lists further deliverables and activities (Software packages, Workshops and courses, Studies and Collaborations).

4.3.2 Assessing the accuracy of precipitation measurement from space

The accuracy figures for precipitation measurements reported in Appendix 2 only represent a rough guess, averaged over a multitude of situations where the individual accuracy may be extremely different. In fact, it is impossible to summarise in a single figure the complexity of the error structure associated to precipitation measurement from space.

The accuracy figure represents, in the statistical sense, the difference from the measured value and the "ground truth". In the case of precipitation, even for ground measuring systems it is rather problematic to state an accuracy figure. As discussed in Section 4.1, raingauge suffer of several sources of instrumental errors and of siting errors, and perform very poorly for snowfall; radar is an indirect measurement through reflectivity, with implied retrieval errors, and suffers of siting problems and of the conversion of volume measurement to surface precipitation, also affected by the Earth's curvature. In Section 4.1.1 and 4.1.2 we also have learnt that the sampling errors (in time and space) may have dominant role. To sum up, in the case of precipitation the ground truth does not exist.

More dramatic, in the case of remote sensing from space, is the problem of the dependence of the accuracy (in terms of sensitivity) from the different type of precipitation and the underlying surface. Convective precipitation over the sea may be measured to an accuracy of < 1 mm/h by frequencies as low as 10 GHz, whereas over land one has to use higher frequencies where the relationship between brightness temperature and precipitation rate is progressively more indirect. For light rain and snowfall the relationship is rather complex, especially when cloud ice becomes the vehicle to infer precipitation. There, the retrieval algorithm must be supported by appropriate cloud modelling, so that the accuracy is conditioned by the appropriateness of the selected cloud model to the actual meteorological situation. When using IR imagery to interpolate between MW (more accurate) measurements to improve temporal sampling, the accuracy of the product depends on the time distance from the MW "calibrating" image, and on the nature of the precipitating system (IR practically contains information on precipitation only in the case of convective clouds).

Therefore, a direct reply to the question "what is the accuracy of precipitation measurements from space ?" would be difficult and misleading because it is not a matter of an average error estimate, but rather of an error structure. So far, the single well-equipped mission to measure precipitation was TRMM, that provided a very optimistic view because was placed in a low-inclination orbit (thus was mostly observing convective precipitation over the sea), and also was in-line exploiting the synergy of passive MW radiometry with rain radar. In the case of precipitation of European interest (frontal rain, light rain, snowfall) so excellent performances cannot be expected. However, in the ESA EGPM project, a number of features have been envisaged to improve the potential observing capability to meet European requirements.

So far, the effort in EGPM has been to assess whether the addition of high frequency channels (e.g., 150 GHz) and channels in absorption bands (54 and 118 GHz) increases the amount of information related to precipitation. This has been assessed by means of techniques such as weighting functions, Jacobians and differential Jacobians. However, the possibility to actually retrieve the potential information and estimate the error structure requires much more effort. A simulator is being developed, based on:

- a database of well-described meteorological situations generally based on actual events but essentially simulated, representative of all hydrometeors of interest, for both initialising the simulator and to serve as "ground truth" for the results of the retrieval;

- radiative transfer models (some at large-scale, some at cloud-resolving scale) to simulate the radiances at the antenna input under the various observing conditions;

- the instrument model, to convert input radiances into expected brightness temperatures at instrument output, providing information on instrument-induced error structure (covariance matrix from channels cross-talk, cross-polarisation effect, etc.);

- retrieval algorithms, to recover precipitation measurements to be compared with the initial data.

The simulator will provide the replay to the question on accuracy in a rather complex way, articulating the figures by type of precipitation, type of synoptic meteorological situation, observing condition, etcetera. This will be important for using data in NWP, where the knowledge of the error structure is basic for data assimilation. It will also help the general user, e.g., hydrologists, to interpret in which areas of the precipitation image the rain rate figures are reliable and where they require more caution in use.

4.3.3 Status of modelling and retrieval

As mentioned, the TRMM mission has been instrumental for fostering the development of cloud-precipitation radiative transfer models and precipitation retrieval algorithms. The results of these development have been spread over the exploitation of other MW instruments of more operational status such as SMM/I and AMSU. In addition, the availability of good-quality precipitation data from MW instruments has been exploited to "calibrate" VIR/IR frequent precipitation estimates from geostationary satellites.

The precipitation algorithms are the subject of international study and review in the context of the International Precipitation Working Group (IPWG) sponsored by WMO and CGMS. There is no need here to review the details of current operational, pre-operational and research algorithms. The interested reader will find an inventory of algorithms on the IPWG web-site:

`http://www.isac.cnr.it/~ipwg/algorithms-nocss.html`

The algorithms studied in IPWG vary in terms of the type of satellite data used, the type of *a priori* information used, and whether they are applicable over land or sea or land & sea.

4.4 Data Merging

4.4.1 Data sources appropriate for merging

Characteristics of the data sources (normal printing) and the requirements (boldface printing) for precipitation information are depicted in the following table. The requirements can only be met through synergetic merging of several individual data sources. Only geostationary satellite data provide continuous global (land & sea) coverage at the required time sampling (15min). Data merging relies on space/time down-scaling and up-scaling techniques (averaging and interpolation).

Table 2. Data sources appropriate for merging.

PRECIPITATION **X = hydrological requirements** X = single data source product characteristics						
Single data source characteristic		Data sources				
		passive MW (satellite)	IR,WV,VIS (satellite)	active MW (ground radar)	rain gauges	GIS
Space	50 km grid	X				
	5 km grid		X			
	1 km grid			**X**		
	0,5 km grid					**X**
	single point				X	
Time	4 hr sampling	X				
	15 min sampling		**X**			
	10 min sampling			X		
	10 min integral				X	
Accuracy	off line	X	X	X		
	on line				**X**	
	exact error				X	
Estimation	atmospheric rainfall rate	X	X	X		
	surface rainfall rate			X		
	surface cumulated rainfall				**X**	
Detection	atmospheric rainfall rate		X			
Area coverage	local land				X	X
	regional land and sea	**X**	**X**			
Product generation technique	direct observation				X	
	retrieval	X		X		
	statistical regression		X			

4.4.2 Existing techniques for merging conventional and satellite-derived data

It has been mentioned earlier that two different rainfall quantities are measured: its intensity and accumulation. Of course the two are related through integration in time. Most sources of indirect observations (radar, satellite, lightning data) are related to rainfall intensity, whereas rain gauges measure accumulation. Therefore, methods are first described for merging intensity data, and then, briefly, for accumulations. The techniques described here are largely those used in the Met Office Nimrod system (Golding, 1998).

The quality of current satellite rainfall intensities, based on geostationary visible and infra-red imagery, is significantly lower than that of ground-based radar. It is therefore appropriate to use satellite data only where radar data is not available. Other sources of rainfall data that are appropriate to use outside the radar observed area are surface rain rates observed either by human observer or by a present weather sensor; inferences from lightning location data, and also very short range forecasts of the rainfall distribution advected out of the radar area.

A key issue is to determine the area over which the radar will be used. In general it is assumed that if the radar can see rain, and this is supported by other data, the corrected radar estimate should be used. However, this is not true for non-raining areas, where the radar beam may simply be observing above cloud top. With this in mind, Nimrod computes an "Area of Radar Coverage" map which estimates the area over which the radar derived rainfall should be believed. All other areas are estimated using other data sources.

An advection nowcast is a useful input for areas close to radar cover, and especially for small gaps, or for temporary outages. However, the main source of areal information outside the radar area is satellite derived data. In order to optimise the fit between the two data sources, Nimrod uses real-time calibration against radar to estimate satellite rain rate. This results in very good continuity between the two data sources, at least for major frontal rain belts, and for deep convection.

In Nimrod, the final analysis of the rain distribution is enhanced by fitting point observations from surface reports and from lightning locations obtained with the Met Office long range ATD system. A simple distance weighted correction is made using these data.

In order to merge the result with accumulation data from rain gauges, it is necessary first to integrate the intensity data in time. This should use analyses carried out at the highest possible frequency. However, since most data sources are only available every 15 minutes, an alternative is to use an advection nowcast to estimate the evolution over each 15 minutes, and to sum these nowcast accumulations.

Despite removal of many of the differences between rain gauge and radar measurements, their combination to generate a merged distribution of hourly accumulations remains difficult due to the sparse and uneven distribution of rain gauge measurements, and to residual radar errors, such as anaprop. In Nimrod an approach based on Kriging is being developed, and has shown some success.

5 Means for Providing Data for Hydrologic Applications - Case SOIL MOISTURE

5.1 Introduction

Soil moisture controls the partitioning of rainfall into runoff and infiltration and therefore has an important effect on the runoff behaviour of catchments (Aubert et al., 2003). When the soils are close to saturation runoff will be much higher compared to the situation when soils are dry. The effect of saturated soil condition played for example a role during the record floods of 2002 in Austria. In August 2002 intense rainfall hit the northern parts of Austria from August 7 to 9, and again from August 11 to 13 (Godina et al., 2002). These two distinct rainfall periods resulted in two consecutive flood events with elevated runoff during the second period, possibly to a large extent due to the already saturated soil conditions .

Satellite based observations of soil moisture may not only be useful for improving the predictive capability of runoff models, they may also be of high value for improving and validating hydrologic process representation at catchment scale. Hydrologists increasingly use physically-based hydrologic models that aim to achieve a realistic representation of the hydrology of a catchment. Based on such distributed hydrological models, the influence of land-use conditions or climate change on the catchment's hydrology can be simulated (Niehoff et al., 2002; Menzel and Bürger, 2002).

Soil moisture can be measured in the field or by means of remote sensing. Field measurements are much more accurate than remotely sensed data, but represent only small areas (point measurements). Also they are expensive to collect. This has motivated much research in the field of remote sensing to retrieve soil moisture (Engman and Chauhan, 1995). Despite significant progress has been made no operational use of remotely sensed soil moisture information is as of yet made by the hydrologic community. The operational provision of remotely sensed soil moisture products within the framework of the proposed Hydrology SAF could be an important step forward to overcoming this situation.

5.2 Scaling Properties of Soil Moisture

Soil moisture is spatially and temporally variable across a wide range of scales, from centimetres to hundreds of kilometres and from minutes to years. Studies, which have investigated the scaling properties of the soil moisture field based upon dense field observations, have revealed the strong influence of vegetation, soil type and topographic patterns (Nielsen et al., 1973; Vieira et al., 1981; Vachaud et al., 1985). Due to these factors, soil moisture varies over distances in the order of 1 m or even smaller. These findings may suggest that beyond this distance there is too much variability of soil, vegetation and topographic properties to maintain a correlation of soil moisture. However, it was shown by Kontorschikov (1979), Meshcherskaya et al. (1982) and more recently by Canyon and Georgakakos (1995) that a second factor, which is related to atmospheric forcing effects, influences soil moisture variability on a scale of hundreds of kilometres. Recent studies by Vinnikov et al. (1996) and Entin et al. (2000) support a two scale concept with a small scale component influenced by vegetation, soil type, topography acting on the range of centimetres to hundreds of meters and a large scale component influenced by climatic conditions and atmospheric events such as precipitation and radiation acting on a scale of kilometres. It was further argued by Vinnikov et al. (1999) that small scale variability does not effect soil moisture above 1 km, and that above this scale the variability in soil moisture for the scale of typical coarse resolution satellite sensors (ranging from 1km to 100 km resolution) is relatively constant.

5.3 Ground Measurement Networks

Various methods exist to measure the soil water content in-situ. They can be divided into direct and indirect methods. With a direct method, the water content of the soil is directly determined, thus avoiding any calibration procedure. The most important direct method for the determination of the soil water content is the gravimetric method. A soil sample taken is weighted before and after drying it at 105 ºC for at least 24 hours; the difference in weight gives directly the mass of the removed water. Hence no further calibration procedure is necessary. Taking soil samples is inexpensive and relatively easy to handle, and samples from different soil depths can be drawn. The gravimetric method is usually considered as the reference method for the measurement of the soil moisture content, and is used for the calibration of most indirect methods (Kutilek and Nielsen, 1994). Monitoring relies on taking new soil samples every time and taking several samples in close vicinity may permanently change the soil's structure by creating artificial macropores. Indirect methods to measure the soil water content generally make use of a physical parameter that is closely related to the soil moisture, and comprise the determination of the electric resistance, thermal dissipation, scattering and attenuation of gamma radiation, scattering of neutrons and the determination of the dielectric constant by so-called capacitance methods. The latter two groups of methods, which comprise the time domain reflectory (TDR) and frequency domain reflectory (FDR) methods, produce the most reliable and accurate results (Western et al., 2002, Ley et al., 1994).

In general, in-situ techniques provide very accurate measurements of the soil moisture when properly calibrated (Kutilek and Nielsen, 1994). They are applicable to any depth in the soil. Continuous or periodic registration over time is possible so that a monitoring of the soil water status can be performed. Disadvantages, however, are the low spatial validity of the measurements due to the high spatial variability of soil properties and consequently the soil moisture distribution. Even with numerous local measurements in an area the spatial interpretation will remain always difficult. Additionally, there is a high demand for man power, sometimes even for a laboratory, and sensors can create high costs, especially if large areas have to be monitored. Therefore in-situ measurements are usually limited to points measurements or to areas less than one km² or a few km² and to a limited period of time like in intensive field campaigns (Western et al., 2002).

Nevertheless, there are several operational soil moisture monitoring networks worldwide. The first soil moisture observation networks operating on a regular basis with a long-term perspective have been started in the 1930s in the former Soviet Union (Robock et al. 2000). Similar measurement networks have been established mainly in countries under communist administration such as Mongolia and China. Although not being standardized the observation design for these networks is very similar. Soil moisture is measured for several layers at least for the surface layer (top 20 cm) and for the first meter, either weekly or every tenth day. Samples are more or less exclusive to agricultural fields and to the growing season taken using the gravimetric method. The measurements stations are normally separated by large distances (10 - 100 km) which is why these networks, similar to coarse resolution satellites, provide only information about the large-scale atmosphere-driven soil moisture field. Also in the United States a number of operational soil moisture monitoring networks have been started in the last decade, albeit the number of stations is comparatively small. Unfortunately, the data coverage is even less good over Europe and practically no operational data sources are known for Africa or Southern America.

5.4 Overview of current and forthcoming capabilities for remote sensing of soil moisture

Remote sensing of soil moisture has been conducted in the thermal and in the microwave domain of the electromagnetic spectrum. The thermal approach rests on the coupling of the energy and water fluxes at the Earth's surface and normally uses remotely sensed surface skin temperature to estimate soil moisture in a data assimilation approach. This method has for example been adopted by the Land SAF which will produce evapotranspiration and soil moisture products at a spatial resolution of 5 km tailored to the needs of Numerical Weather Prediction (NWP). For operational hydrology, the thermal approach is not well suited since cloud cover will often impede the observation of the land surface in the infrared domain during flood events. Also, hydrologists would like to obtain direct measurements of soil moisture, a condition which is much better fulfilled for microwave techniques.

Microwaves offer a relatively direct means of assessing soil moisture since they exploit, like many in-situ observation techniques, the strong relationship between the moisture content and dielectric constant of soil. Active microwave techniques (SAR, scatterometer) measure the backscattering coefficient which generally increases with increasing water content. Passive microwave instruments (radiometers) measure the brightness temperature. When the physical temperature of the Earth's surface is known the emissivity can be calculated which generally decreases with increasing soil moisture content. For both active and passive techniques the confounding influence of vegetation and surface roughness needs to be accounted for. Low microwave frequencies are beneficial for soil moisture retrieval because longer wavelengths are better able to penetrate vegetation. This is why **SMOS** and **HYDROS**, two experimental satellite missions dedicated to measure soil moisture over land, are operated in L-band. The choice of L-band is due to the fact that longer wavelengths are better able to penetrate vegetation. SMOS is ESA's second Earth Explorer Opportunity Mission and will make passive measurements at a spatial resolution of about 50 km. HYDROS is a NASA Earth System Science Pathfinder mission and will combine a radiometer (40 km) and a radar (3 and 10 km). Foreseen launch dates are 2007 and 2010 respectively. These two missions will perform first-of-a-kind exploratory measurements and aim to measure soil moisture with an accuracy of 0.04 m3m-3. The H-SAF should seek a close link with these programmes to fully benefit from their research experience.

Besides these two dedicated soil moisture missions there are other microwave systems which have been found capable of soil moisture retrieval. **Synthetic Aperture Radar** (SAR) represent the only possibility to map small-scale soil moisture patterns due to their high spatial resolution. However, the spatial variability of surface roughness and vegetation cover poses a problem for soil moisture retrieval. With currently available C- and L-band SAR systems (ERS-1/2, Radarsat-1, ENVISAT, JERS-1) it has not yet been demonstrated that soil moisture can be retrieved from single images accurately enough for hydrologic applications. Still it appears feasible to implement change detection algorithms for monitoring changes in soil moisture conditions at regional scale with reasonable accuracy. Such an approach requires significant efforts to build up long SAR time series and in-situ soil moisture observations for region-dependent model calibration. Factors that impair the possibility to use change detection approaches are the limited recording time of high-resolution SAR modes per orbit and changes in the sensor configurations from satellite to satellite (e.g. changing imaging modes, frequencies). In the case of flood events dedicated efforts are needed to acquire and process SAR images over the flood affected areas within an acceptable time frame. Future SAR systems such as ALOS, TerraSAR-L, or SAOCOM willbe operated in L-band which penetrate vegetation well (with the exception of forests). Most interesting would be to collect data at multiple frequencies, incidence angles, and polarizations, that would possibly allow the determination of soil moisture from single images. Nevertheless, critical research problems like how to characterize surface roughness in backscatter models need to be resolved before this will become a feasible option for operational applications.

Research has also investigated the potential of **operational radiometer systems** for soil moisture retrieval. Numerous studies that have use passive microwave observations in C-band (~6.6 GHz) or even X-band (10 GHz) for soil moisture retrieval have reported very encouraging results. Since these frequency channels are now commonly available on R&D satellites (e.g. AMSR on ADEOS-II, now failed, and AMSR-E on EOS-Aqua) and operational successors are being developed (CMIS on NPOESS), they represent an attractive option for the H-SAF. One advantage of radiometers compared to radars is that the retrieval from passive data appears to be less confounded by surface roughness effects than from active data. However, no globally consistent soil moisture data set has yet been derived from spaceborne radiometers; not even for SMMR which has acquired global 6.6 and 10.7 GHz brightness data in the period from 1978 to 1987. Therefore, the achievable accuracy and potential problems are not well known at present. One concern for the future is that C-band brightness temperature data may increasingly be spoiled by Radio Frequency Interference (RFI) over densely populated areas.

Finally, also **operational scatterometers** operated in C-band have been demonstrated to be capable of soil moisture retrieval. Despite scatterometry has so far received comparably little attention by the scientific community, it has resulted in the first multi-year, global remotely sensed soil moisture data set. This data set was derived from ERS-1/2 scatterometer data (1992-2000) and has been found to be of comparable quality with state-of-the-art modelled soil moisture products. The accuracy of the scatterometer based soil moisture product was assessed based on over 48 000 measurements worldwide (Ukraine, Russia, China, Illinois, India, Spain) and is around 0.05 m3m-3 for the 0-1 m layer for temperate and tropical climatic regions (a red-noise filtering approach was used to estimate the water content in the soil profile from the remotely sensed surface soil moisture series). More research is needed over cold and dry climatic regions. The successor of the ERS scatterometer is the Advanced Scatterometer (ASCAT). It will be part of EUMETSAT Polar System (EPS) which is designated as an operational system with the intention to ensure data continuity over an initial period of at least 14 years, staring in 2005. Thus it would be possible to deliver operational 25 km soil moisture products in quasi-real time (2-3 hours after reception) with an accuracy of about 0.05 m3m-3 from 2006 onwards.

Independent of the considered remote sensing technique, substantial research efforts are still needed to develop methods for ingesting remotely sensed soil moisture data into hydrologic models. The questions of spatial resolution, irregular sampling intervals, and low penetration depth into the soil surface need to be addressed. Fortunately, the technique of data assimilation has recently gained significant attention and will provide important impetus for the Hydrology SAF. The operational provision of remotely sensed soil moisture products within the framework of the proposed Hydrology SAF could lay the basis for a successful adaptation of remote sensing technology by the hydrologic community.

Satellite data available to feed the H-SAF activity will, in the operational phase (2010-2014), consist of the MetOp ASCAT and the three CMIS instruments flown on NPOESS. For the development phase, in addition to ASCAT, archived data from ERS-1/2are considered useful. The case for including SAR is currently controversial. On one side, SAR is the only tool for providing sub-kilometre resolution, and also L-band SAR's are being developed for demonstration in the near future. However, demonstration has still to occur and, most important, there is no plan at present to have operational L-band SAR during the H-SAF operational phase (not to mention access modalities and data cost). Therefore, at present, SAR is not envisaged for use in H-SAF. The situation may be revised at a later stage.

In **Appendix 2** the instruments potentially available for the H-SAF development and operational phases are listed, and their main characteristics (resolution and observing cycle over Europe) noted. The scenario, for completeness, also records the use of VIS/IR imagery for soil moisture indexes inference, though occasional and qualitative. Moving from the characteristics of the various data sources, the Appendix attempts to estimate the potential performances (resolution, accuracy, observing cycle and timeliness) of the products that are considered feasible. It is explained what can be delivered at Day 1 and how data quality will improve in the course of the operational phase. The question of inferring the soil moisture content in the roots region is considered, and the possibility (at Day 2) is recorded, though it is understood that the product will be model-dependent. In addition to the deliverable geophysical products, the Appendix lists further deliverables and activities (Software packages, Workshops and courses, Studies and Collaborations).

6 Means for Providing Data for Hydrologic Applications - Case SNOW

6.1 Introduction

Snow is an important factor in the interactive processes between earth's surface and the atmosphere. The seasonal snow covers 30-40 million km2 in the northern hemisphere, where it has a high impact on hydrological, climatological and meteorological issues. Due to its high albedo, snow plays an important role in the earth's energy balance, affecting weather and climate. From the hydrological point of view, snow acts as a high-volume water storage controlling water reservoirs, affecting the evaporation process, and is a source of sometimes uncontrolled discharge when starting to melt. Snow melting constitutes a potential risk of flooding in certain areas, but it is also an excellent source of energy for power plants. Hydrological models are commonly used for simulating and forecasting snow melt and flooding. They typically suffer from the lack of reliable information on the extent and volume of snow, as the accuracy of ground-based observations of seasonal snow cover is restricted by the sparseness of gauging networks. However, the information provided by ground-based networks is very important for the best possible performance of hydrological models.

Remote sensing constitutes a unique technique to obtain spatially and temporally well-distributed information on snow parameters to complement ground-based observation networks. Optical and microwave sensors can distinguish between snow and snow-free ground, each system being affected by its own limitations (cloudiness for optical sensors, dependence of sensitivity on the frequency for microwave sensors). They are used for monitoring the areal extent of snow, to measure its surface temperature (in infrared) and to discriminate wet from dry snow (better in microwave). The snow water equivalent can be estimated in microwave, with coarse resolution if passive and low sensitivity to dry snow if active (since current radars operate at relatively low frequencies).

Measuring snow has it's own characteristics not only the snow covered area can be fragmented but also the vegetation and mountainous areas cause problems. Thus the resolution, which can be achieved by measurements is also depending on those characteristics. It is not feasible (technically and economically), to set up a ground based network, which would take into account all these limiting factors. Combination of ground based and space spaced observations seems to be the key issue in snow monitoring.

6.2 Ground Measurement Networks

Basically ground based snow measurements are made with very simple means just measuring the snow depth both on synoptic and precipitation stations. Synoptic stations also give twice a day description of snow covered area (wet/dry snow, ice, fully covered/partly covered). On more modern observation sites snow depth is measured using a sonic ranging (SR) sensor, which can be connected to automatic weather station, thus enabling frequent measurements. The number of synoptical and precipitation stations in one country is considerably high, but still the areal coverage of snow detection remains poor.

A snow course is a several kilometer long trail through various land cover types typical for the local landscape. Measurements on fractional snow cover and snow depth and snow water equivalent are taken along the track. Of course snow courses can be used only, when measuring on considerably flat terrain.

The snow depth field can be analyzed with the ground observations for instance by using Kriging interpolation. The drawback in such a snow map is that it is not very detailed (woodlands vs open areas, mountainous areas vs flat land).

6.3 Overview of current and forthcoming capabilities for remote sensing in snow monitoring

Snow observation from satellite is a relatively easy task for meteorological purposes (i.e., for the purpose of describing air-surface interaction). The cover is already a most valuable parameter, as well as the surface temperature, enabling to capture the transition between thawing and freezing conditions. Imagers such as AVHRR can provide good observation of edges, albedo and temperature, the only problem consisting of the regularity, affected by clouds. However, since snow properties change slowly relative to cloudiness, multi-day analysis (e.g., “minimum brightness” and “maximum temperature” maps in a given number of days) can provide satisfactory results. Use of MSG/SEVIRI, though at reduced spatial resolution, would help with reducing the number of days necessary to achieve a map with acceptable gap areas. Comparison between VIS and SWIR, possible with both AVHRR and SEVIRI (and MODIS), would help reducing the ambiguity between snow and cloud.

For hydrological purposes snow cover and snow surface temperature are not the only important parameters. What is also needed for hydrology is the evaluation of the amount of water stored in the snow mantle, i.e. the snow water equivalent, and the status (wet or dry). In fact, whereas for meteorology the interest for snow focuses on the air-surface radiative interactions, for hydrology the interest is for forecasting catchment basin outflows (and floods) and water reservoirs. Interesting operational systems have been developed making use of satellite-derived snow cover and surface temperature for basin outflow prediction. They heavily rely on the assimilation of satellite observations in GIS (specifically, Digital Terrain Models) contextually with in situ measurement networks, specifically for snow thickness and temperature/density profile across depth. In several cases, results are surprisingly good, but obviously they are more controlled by the available a priori knowledge of the basin and in situ facilities than by satellite information. Obviously, the regularity of the basin morphology and its dimensions are crucial.

In the VIS/IR range, some information related to snow depth and surface conditions is present. The surface temperature (or, better, the difference between snow surface and air temperatures) is significant of the depth. The depression of reflectance in SWIR is significant of thawing conditions. Some improvement may be expected with the introduction of NPOESS VIIRS, that includes more channels in the NIR/SWIR and for atmospheric correction, and more channels for surface temperature and emissivity (in the 3.7-4.0 m range); and better spatial resolution, a very important feature.

Much higher sensitivity to snow is in the MW range. The signal in MW responds very strongly to electrical conductivity, which is closely linked to the wetness of snow and to density (i.e. the mixture of crystals and air). The wavelengths are such that penetration extends to several centimeters or decimeters. The spatial resolution is a problem but, unlike with soil moisture, for snow even high frequencies are sensitive enough (see AMSR, with less than 4 km at 90 GHz). Of course, the all-weather capability, which enables several measurements regularly be taken across the day, is a great advantage, particularly for snow melting condition monitoring. At large scale, the radar scatterometer such as ASCAT could be useful, though the C-band frequency (5.3 GHz) is not ideal. American scatterometers such as SeaWinds on QuikSCAT working at 13.4 GHz would be more useful, but they are going to be no longer used after the advent of CMIS.

When very high resolution is needed, as well as all-weather capability, the Synthetic Aperture Radar (SAR) represents the unique solution. Unfortunately, in the frequency range so far used in most SAR’s (C-band), dry snow is rather transparent so that the impact of scattering from the underlying surface is disruptive. C-band SAR, however, may still be useful in the melting season and to capture thawing/freezing conditions in early winter. SAR systems exploiting the X-band (about 10 GHz) are being developed (the COSMO-SkyMed constellation and Severjanin on the operational METEOR-3M N2 series), or studied (TerraSAR-X). Also, thoughts to Ku-band SAR (up to 18 GHz) have been given, that would better serve snow water equivalent. However, in the absence of consolidated plans for operational SAR systems to be active during the H-SAF operational phase (not to mention access modalities and data cost), at present SAR is not envisaged for use in H-SAF. The situation may well be revised at a later stage.

Satellite data available to feed the H-SAF activity will, in the operational phase (2010-2014), consist of the three CMIS instruments flown on NPOESS, complemented by further five (smaller) radiometers on the GPM constellation, possibly including the European contribution EGPM. For the development phase, SSM/I, SSMIS, AMSR and AMSU will provide sufficient databases (SSMIS and AMSU also in the operational phase). The optical imagers will be SEVIRI and AVHRR for both the development and the operational phases, VIIRS on NPOESS for the operational phase and MODIS on EOS-Terra/Aqua for the development phase.

In **Appendix 2** the instruments potentially available for the H-SAF development and operational phases are listed, and their main characteristics (resolution and observing cycle over Europe) noted. Moving from these characteristics, the Appendix attempts to estimate the potential performances (resolution, accuracy, observing cycle and timeliness) of the products that are considered feasible. It is explained which product will be sufficiently consolidated during the development phase to the extent of being operational at Day 1 and which one will be consolidated later, or his quality will improve in the course of the operational phase. In addition to the deliverable geophysical products, the Appendix lists further deliverables and activities (Software packages, Workshops and courses, Studies and Collaborations).

7 Numerical Weather Prediction and Hydrology

7.1 Introduction

The meteorological observational resources available to assess and forecast current and future risks of heavy rains in Europe on short and medium-range timescales include in-situ rain-gauges, radars of varying levels of sophistication, geostationary visible and near infrared imagers and sounders, polar orbiting infra-red and microwave sounders and imagers, and radars. There are US plans for an active rain-radar in orbit and covering mid-latitudes, and there are also plans for more refined radar altimeters to measure the stage of large inland water bodies such as large lakes and wide rivers.

The hydrological forecast problem also requires information on soils, vegetation cover, land use, soil moisture, snow cover, snow depth, snow density profiles, as well as geographical information such as the profiles and connectivity of river basins. Satellites can provide some, but by no means all, of this data.

Besides the need for observations, scientific and institutional resources are also needed to provide improved hydrometeorological services, in the form of current status assessment and forecasts. The scientific and institutional resources include now-casting capabilities, meteorological short-range and medium range data assimilation and modelling capabilities as well as hydrological data assimilation and modelling capabilities.

In a long term vision major developments in meteorological models and in coupled hydro-meteorological models are foreseen. It is expected that regional convective-scale models (resolution ~1 km) will become operational by 2010, and will be driven by global forecast models with resolution of 10-15km. Depending on the progress of research, it is likely that in the ensuing five years, coupled hydro-meteorological models with resolution of ~1 km will become operational. Preliminary research on this topic, under the auspices of the Mesoscale Alpine Programme (MAP), has been encouraging and such research will be pursued vigorously in the coming years.

The general aim of these coupled models will be to provide as far as possible an all-weather capability for measurement of key aspects of the hydrological cycle, such as humidity, ice-, water- and mixed-phase clouds, rain-rate and similar, and to assimilate all that information in a manner which is consistent with our knowledge of hydrological processes and our knowledge of atmospheric dynamics.

7.2 Assessments of skill in Quantitative Precipitation Forecasts from global forecast models

Today global NWP models provide Quantitative Precipitation Forecasts (QPF) with a computational grid length of 40-50 km. With the expected upgrades in computer power this will certainly increase during the next 5-10 years. For example ECMWF plans to provide global forecasts with increased vertical resolution and a horizontal grid spacing of 25 km in 2005.

In a review by Ebert et al. (2003), inter-comparisons of operational rainfall forecasts from global models at major forecast centres (ABOM, CMC, DWD, ECMWF, JMA, UKMO, NCEP) for periods since the early 1990s show that operational NWP models are still a long way from producing perfect QPFs. Among other things they notice that upgrades in operational models during the last five years have not led to significantly improved precipitation forecasts. However, further verification must be done to check the dependence of this conclusion on the scales included in the verification.

They also find that precipitation forecasts strongly depends on the model’s predictions of atmospheric and surface conditions, i.e. a good precipitation forecast gives a strong indication of a good forecast in all other atmospheric variables. In other words, focusing on the precipitation forecasts will ensure improvements in several different parts of the model, e.g. surface parameterisation, convection etc.

The assessment by Ebert et al. (2003), does not give a too positive picture of precipitation forecasting capability, which perhaps was justified at the time of writing some years ago. Since then there have been substantial improvements in many aspects of forecast skill in recent years, coming from

- the availability of improved observations, especially ground- and space based remote sensing observations,

- the availability of more powerful computers, permitting improved model resolution,

- improved meteorological process understanding, implemented in more advanced model parameterisations allowing the assimilation of parameters, such as satellite observations, which are complex functions of model variables,

- improved data assimilation methods, particularly from the application of variational methods to the assimilation of satellite data, which is normally a complex function of model variables.

A critical issue which still is in need of much further study is the verification of QPFs. Many problems and issues of scaling and representativeness arise, both in the choice of methodology and in the interpretation of precipitation verification data. A number of important general observations on this point are made in a review by Bougeault (2003). For example, the difference in resolution between the model and observations is a problem, which may have to be solved by either improving the spatial density of observation networks or by adopting verification techniques that account for this. Some problems in verification may be resolved by posing the verification in probabilistic terms, either by use of ensembles, or by grouping adjacent grid-points and time-steps. The difficulty of verifying QPF increases with high resolution models which are able to produce more intense cores of precipitation than those of the large scale operational models. For instance, small timing and spatial errors in high resolution models may significantly degrade objective verification scores. This problem, also called the 'double penalty' problem has been clearly illustrated by Balwin et al. (2001).

Work is thus needed to design new approaches for the verification of high resolution NWP. Verification scores should, for example, always be accompanied by information on the uncertainty and/or statistical significance. Extreme cases are limited in number, so verification without proper accounting for uncertainty may result in wrong conclusions.

These difficulties in model verification are a considerable motivation for the requirement that the proposed SAF should use all available resources to provide the best possible estimates of precipitation, independent of forecast models.

7.3 Current and future developments in regional NWP modelling

As computer power is increasing and models and assimilation schemes become more and more sophisticated and efficient regarding use of computer power, the resolution, especially the spatial resolution, of NWP models is increasing steadily. It is therefore expected that, within the next 10 years, medium and long range forecasts, and to some extent short range forecasts, will be produced by global models with grid spacing of the order of 10 km.

There will at the same time be higher demands on forecasting small scale events such as convective precipitation, winds (sea breeze, gust front, …), fog and low level ozone and other air pollutants on a smaller scale. This will lead to a need for regional models to change their focus to very short range forecasts, up to 24 hours, of the small scales that a global model is not able to resolve, which, in turn, will lead to a new model generation of non hydrostatic models, able to resolve explicitly the convective scale motions using horizontal grid spacing of 1-2 km..

Most of the National Weather Services (NWS) are planning to replace or complement their current operational systems with non-hydrostatic models (if they have not already done so) with very high resolution

(1-2 km). Examples of institutes and limited area modelling groups with such plans are the UK Met Office and the HIRLAM, COSMO and AROME/ALADIN consortia.

These high resolution NWP systems will have a better representation of the water cycle with new model variables such as rainwater, ice crystals, cloud water, graupel or snow and advanced parameterization of the microphysical processes. A more realistic forecast of clouds and precipitation is expected.

The increase in resolution will also accompanied by an increase in resolution both in the data assimilation system and in the assimilated observations. Indeed, it is planned to assimilate more mesoscale observations, including in–situ observations, such as mesonet surface observations, but also all remote sensing observations, such as MSG or radar data. Various assimilation schemes are considered in the plans of the NWS (3D-VAR, 4D-VAR, Nudging, ensemble Kalman filter,…)

Assimilation of surface variables will also be developed further and possibly included in, or directly coupled to the atmospheric data assimilation.

As deterministic high resolution forecasts are aimed for the end of the decade, probabilistic high resolution forecasts are ‘envisaged’ beyond, when computer power as well as research in new methological methods will enable ensemble forecast at this resolution. Such a probabilistic approach is necessary given the low predictability at the convective scale. Nevertheless, orographic or synoptic forcing may increase the predictability of convection and deterministic high resolution forecasts of organized moist convection may be relevant up to 12-24 hours (Ducrocq et al. 2001)

Another expected scenario, following the increase in computer power and model resolution, is that nowcasting (NWC) and very short range forecasting (VSRF) will gradually be replaced by the output of short range forecasts (less than 6 hours) from NWP models. NWC and VSRF have, up till now, very often been tailored for each specific forecasting problem using a wide range of techniques. By using NWP models with high resolution and assimilation techniques suitable for the mesoscale this can be made more general.

7.4 Observational Requirements of Convective (meso-γ) scale models

The basic atmospheric variables of present NWP models will remain the most important to observe and model. Therefore surface pressure and profiles of l wind, temperature and water vapour inside, outside and below clouds will continue to be given highest priority. The importance of the humidity distribution has been demonstrated in many regional models and observations derived from satellite cloud imagery are widely used. Initialisation of the precipitation distribution using either convective “physical initialisation” or “latent heat nudging” has also been shown to improved forecasts by several models through indirect modification of the thermal and divergence fields. Both ground-based radar and satellite derived precipitation estimates have been successfully used as data sources for these techniques.

For very high resolution modelling, surface parameters like soil moisture, snow cover, sea and lake temperatures and ice cover will become more important since many mesoscale/stormscale phenomena are strongly forced from inhomogeneities and sharp gradients in the lower boundary conditions.

Radar data will be (or is) very important for regional high resolution models to get a good initialisation of the hydrometeors and motions within the clouds (Albertoni et al. 2003). Satellite data also offer products (or radiances) at high horizontal resolution. Water vapour channels are particularly interesting for initializing the model moisture, which is of key importance for the forecast of precipitation. Cloud top height as well as information on cloud liquid water and cloud ice can already be obtained by satellite measurements. Other techniques, e.g. ground based GPS, measuring water vapour with high spatial resolution are already available today and will be more ‘numerous’ in the future. As these techniques mature and sufficient data become operationally available, the necessary improvements in data assimilation techniques will be developed to enable them to be used.

Appropriate observations of these quantities to be used in data assimilation systems are thus needed and will help to improve weather forecasts also to be used in hydrology. The observations are used as initial information but they are also useful for verification purposes. The data requirements depend on the application either verification or data assimilation.

<u>Data requirements for verification</u>

Accuracy	comparable to in situ observing systems (precipitation 0.1 mm/day)
Resolution in space	size of catchments (can be smaller than the resolution of the model)
Resolution in time	at least 1 h for mesoscale NWP models
Delay	no specific requirements (1 day)
Observation area	model domain

<u>Data requirements for data assimilation</u>

Accuracy	comparable to existing ground based remote sensing systems (Radar)
Resolution in space	comparable to the resolution of the forecast model (2-5 km)
Resolution in time	10 minutes (2π/N)
Delay	less than 15 minutes (for very short range forecasts)
Observation area	model domain

7.4.1 Data Output Issues

Today non hydrostatic forecast models are typically applied with grid sizes of 10 km (7 km at DWD). It can be expected that grid sizes will decrease down to 1 km to be able to simulate deep convection explicitly during the next few years. The time scale of processes with length scales corresponding to these grid sizes is about a few hours or less. The deterministic predictability is of the same order of magnitude. The interpretation of the output of these models on these small scales as a deterministic forecast is therefore only allowed for very short range forecasts. For larger forecast time intervals, additional interpretation procedures are required to provide probabilistic forecasts or to reduce the resolution to predictable scales, for example by averaging in space and time (accumulation of precipitation). Even when such a degradation on resolution is applied to the end product, a high resolution helps to achieve better forecast skills also on larger scales because of the more direct and realistic simulation of small scale processes (effect of small and steep topographic structures on larger scales or effect of deep convection on larger scales and of non linear interactions on small scales).

Considering these limitations, non-hydrostatic models together with appropriate data assimilation techniques are suitable tools to provide precipitation analysis and forecasts on the meso- scale. Products of satellite data will help to improve the quality of analyses and forecasts of non hydrostatic models, provided that they are suitable for the data assimilation process.

7.5 Current and Future Developments in Hydro-meteorological Forecasting.

For over a century, the sciences of hydrology and meteorology have largely progressed for along their own lines of development, with little interaction on issues other than the measurement of rainfall. The dialogue between the two sciences has intensified substantially in the last twenty years. One driver of the dialogue is the need to mitigate the damage inflicted by major floods across populated continents. The other has been the need to understand the role of land-atmosphere interactions in climate fluctuations on short (seasonal) to long time scales.

The recently concluded FP_5 project ‘The European Flood Forecast System’ has demonstrated the ability of ensemble medium-range hydrological forecasts, made by a distributed hydrological model driven by an ensemble of meteorological medium-range forecasts, to provide valuable medium-range alerts of serious flooding. That work is being followed up through continuing collaboration of the EFFS partners.

More recently, preliminary investigations in the MAP project of the value of coupled regional hydrological-meteorological have given very encouraging results (Ranzi et al. 2003, Jasper and Pirmin 2003). These results will be followed up vigorously by the MAP partnership in the coming years.

7.6 NWP benefits from and contributions to a hydrology SAF

Diagnosis of the performance of NWP models has repeatedly demonstrated the necessity for high-quality observations, models and assimilation systems. Most NWP centres are currently developing dedicated assimilation systems for the surface in interaction with the atmosphere and hydrology at the regional scale. These are based on advanced parameterizations of land surface processes including detailed representation of vegetation, soil physics, hydrology (snow, runoff, water budget) and advanced methods to handle sub-grid processes (ex. of such schemes are the Tessel (ECMWF), the Isba (Météo-France and HIRLAM), the Moses (UKMO) or the Terra (DWD) schemes). Recently, Boone et al. (2001) analyzed the regional hydrological capacities of advanced land surface schemes used in the meteorological community (both for the NWP and climate models). The products from the proposed hydrology SAF can contribute significantly as input /validation in these land data assimilation systems with the aim of improving the initial conditions for land surface variables which are of paramount importance for subsequent short to medium range atmospheric forecasts

7.6.1 Precipitation information

As precipitation will be an important focus of NWP models, the products from the proposed hydrology SAF are expected to be very useful. The precipitation fields can be used for validation of short range precipitation forecast, but also enter as input in the land data assimilation system (in combination of real-time observed radiation fluxes) for a better control of the hydrology model included in the NWP models.

The NWP models can provide initial fields of soil moisture, snow and forecasted precipitation for hydrology models in data sparse areas as well as short range forecasts, provided that the model accuracy and resolution is good enough.

Satellite precipitation data stored and distributed as radiances can be a product useful in the assimilation schemes of NWP models. The general outlook is that products with the lowest possible level of processing will be assimilated.

7.6.2 Soil moisture information

With the increase in resolution of NWP models, surface parameters like soil moisture will become very important. Since many precipitation events, especially convective precipitation, are triggered by in-homogeneities in the boundary layer parameters such as soil moisture, will need to be described and initialized correctly in the NWP models.

The development of advanced surface schemes in the NWP models is a research area where a lot of effort is placed presently and in the coming years. Assimilation of soil moisture in surface schemes is already carried out in many NWP centres (retrieval of the root zone soil moisture) and will be improved in the future based on real-time products delivered by the Land-SAF (albedo, short and long wave incoming radiation fluxes, surface temperature,…) and the H-SAF (precipitation, shallow soil moisture, snow cover fraction and snow water equivalent).

In the same way as precipitation, the soil moisture products from the proposed H-SAF will also be able to provide valuable independent validation data, initial conditions for both NWP and hydrology models, and hopefully eventual input data for the assimilation schemes.

7.6.3 Snow information

Very similar to soil moisture, snow information (snow water equivalent, snow cover fraction, albedo) is very important for the surface schemes in NWP models providing forecasts in areas with potential snow cover. In addition, snow cover also changes the albedo of the surface, which has a strong influence on the radiation budget of the model. Analysis of snow is presently limited because of the lack of enough real-time information on the amount of water retained by the snow mantle and the H-SAF could provide valuable information in this respect.

7.7 Conclusions on NWP and the Hydrology SAF

As indicated in the long term vision, the coming decade will see considerable convergence of the interests of the hydrological and meteorological communities in Europe, a convergence likely to benefit both communities. The H-SAF will provide important new data products and other resources to improve hydrological forecasting and hydro-meteorological forecasting in Europe. Both the use of these products for improving the initial conditions of NWP and hydrological models, and their application for validation and verification of both types of models will be of great importance. To optimize impact of H-SAF products in NWP models, care should be taken to provide the data in the form most suitable for the data assimilation schemes used. This will require an ongoing dialogue between H-SAF developers and the NWP modelling community.

8 Products Related to Hydrology from Other SAFs

8.1 SAF on Support to Nowcasting and Very Short-Range Forecasting

8.1.1 PRECIPITATION: NWCSAF/MSG CRR (Convective Rainfall Rate) product

The objective of the SEVIRI CRR product is to estimate the precipitation rate associated with convective clouds and its final output is a calibrated numerical product (mm/hr) divided into classes in an image format as can be seen in CRR Figure 3. The algorithm developed for the NWCSAF CRR product assumes that clouds being both high and with large vertical extent are more likely to be rainy clouds, and that the difference IR-WV brightness temperatures is a useful parameter for extracting deep convective clouds with heavy rainfall.

The basic CRR value for each pixel is obtained from calibration matrices different for day and night. For day pixels CRR calibration data are a 3-D matrix and their bands are: IR10.8, WV6.2 brightness temperatures and VIS0.6 normalised visible reflectances. For night pixels the calibration values are stored in a 2-D matrix using only two bands: IR10.8 and WV6.2.

The calibration method establishes a statistical relationship between normalised VIS reflectances, IR&WV brightness temperatures and radar derived rainfall rates. In summary, composite radar data were compared pixel by pixel with geographically matched same resolution Meteosat data, and total rain rates were calculated as a function of two (IR, IR-WV) or three variables (VIS, IR, IR-WV). The radar data are used only for training the system and are not used directly as part of the output product. A smoothing process is later performed in order to eliminate stratiform rain data which is not associated with convective clouds.

Several corrections can be applied to basic CRR data to take into account the temporal and spatial variability of the cloud tops (Cloud Growth Rate correction factor and Cloud-top Temperature Gradient correction) , the amount of moisture available to produce rain (Moisture correction) and the influence of orographic effects on the distribution of precipitation (Orographic correction).

8.1.2 PRECIPITATION: NWCSAF/MSG and PPS PC (Precipitating Clouds) product

The objective of the PC product is to support detailed precipitation analysis for Nowcasting purposes. The focus will be on the delineation of non-precipitating and precipitating clouds for light and heavy precipitation, rather than quantifying the precipitation rate. Particular attention will be given to the identification of areas of light frontal precipitation.

The product will be (PC Figure 3) an image providing probabilities of precipitation intensities in pre-defined intensity intervals. From the probabilities, a categorical estimate of precipitation intensity may be derived. It is not intended to provide information on the type of precipitation.

The precipitating clouds product gives the likelihood of precipitation in intensity classes. A linear combination of those spectral features, which have the highest correlation with precipitation, is used to construct a Precipitation index PI. For each value of the PI, the probability of precipitation in the respective classes is then determined from a comprehensive data set of collocated satellite data, precipitation rates from surface radar and surface temperatures from NWP. Special attention has been given to spectral features in the visible, which implicitly contain information on cloud microphysical properties at the cloud top, such as effective radius and cloud phase. The algorithm to retrieve information on the presence (including rough intensity estimations) of precipitation will be based on the Cloud Type output. The algorithm will rely much on the microphysical information available in both the 1.6 micron and 3.8 micron channels. For each algorithm a day and a night version exists.

8.1.3 SNOW: NWCSAF/MSG CT (Cloud Type)

The cloud type (CT) developed within the SAF NWC context mainly aims to support Nowcasting applications. The main objective of this product is to provide a detailed cloud analysis. CT product therefore contains information on the major cloud classes: fractional clouds, semitransparent clouds, high, medium and low clouds (including fog) for all the pixels identified as cloudy in a scene and land snow cover and sea snow/ice on clear air pixels. The CT algorithm is a threshold algorithm applied at the pixel scale, based on the use of a Cloud Mask and spectral & textural features computed from the multispectral satellite images and compared with a set of thresholds. This set of thresholds to be applied depends mainly on the illumination conditions, whereas the values of the thresholds themselves may depend on the illumination, the viewing geometry, the geographical location and NWP data describing the water vapour content and a coarse vertical structure of the atmosphere.

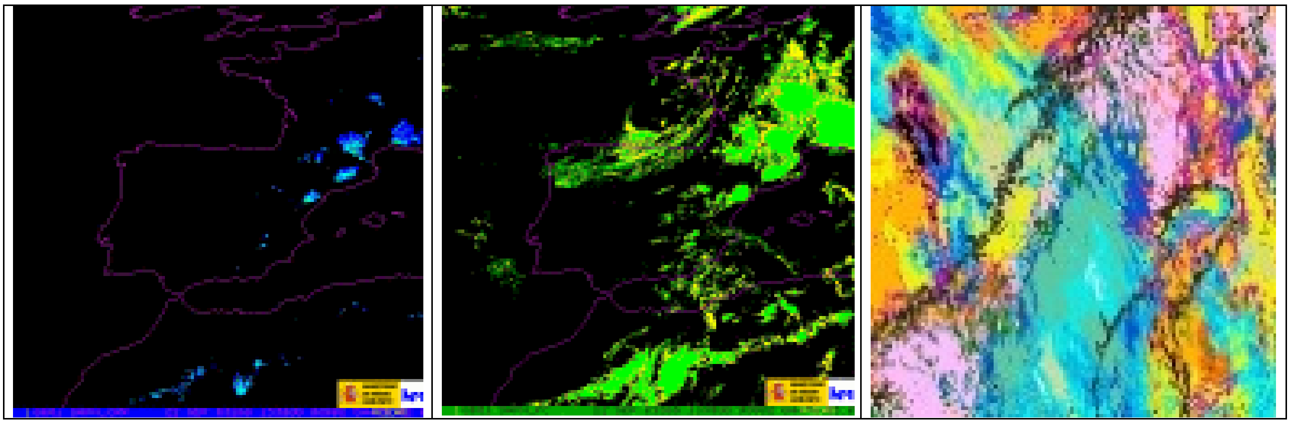
The ice and snow appear rather cold and bright, and may therefore be confused with clouds (especially with low clouds) during the cloud detection process. Ice and snow must therefore be identified first, prior to the application of any cloud detection test. This tests, restricted to daytime conditions, aims to detects pixels contaminated by snow or ice: if this test is satisfied, the pixel is classified as snow or ice and no further cloud detection is attempted.

The MSG Cloud Type output consists on a 21-category image in which classes 3 and 4 corresponds to land snow and sea snow/ice respectively.

8.1.4 SNOW: NWCSAF/PPS CT (Cloud Type)

The highest priority of the Cloud Type product is given a the reliable identification of the major cloud categories: low, medium, high, and semi-transparent cirrus. The Cloud Type algorithm takes as input the Cloud Mask output and utilises all 5/6 spectral channels of the AVHRR/2 or AVHRR/3 sensor, NWP short range forecast data, and 1 km GIS (digital elevation model and land use) data. The algorithm distinguishes different cloud types as well as land snow cover and sea snow/ice using thresholds defined by off-line radiative transfer calculations and a database of interactively collected training targets. The coverage and resolution of this product is north of the 50ºN parallel - depending on local radio horizon. (The product quality cannot be guaranteed below 50ºN, but the algorithm will work anywhere). Full AVHRR (1 km) resolution.

The AVHRR Cloud Type output (CT SNOW Figure 3) consists of a 21-category image in which snow and ice are the same as for the MSG-based CT product described above.



CRR (Convective Rainfall Rate)	*PC (Precipitating Clouds)*	*CT (Cloud Type) including snow*

Figure 3. Examples of SAFNWC products.

8.1.5 SAFNWC/MSG Software Package

The SAFNWC aims to develop a set of Nowcasting and Very Short Range Forecasting tools to obtain the optimum benefit from the big amount of satellite data coming mainly, but not only, from the MSG satellite. The final objective of the SAF NWC/MSG is the development and distribution of an integrated Software Package to enable the Operational Extraction of a list of products, among them the products described above.

The SAFNWC/MSG SW requirements are as follows:

- All SEVIRI modules shall be integrated in a single SW application
- The application shall be fully configurable by products to be generated, Geographical Area / Full Frame and execution priorities (PGE / regions).
- The SAFNWC/MSG package shall be robust, execution will not need human assistance, schedule of tasks automatically fixed by the Task Manager and information will be logged to monitor the processing and to extract statistics.
- The application shall allow the processing of real-time and archived data

Meteorological Product and Engineering SW development shall be as de-coupled as possible being composed by:

Task Manager: Interface between the user and the SAFNWC/MSG product generation, provides the initialisation and set-up of the system according the configuration, drives and optimise the execution of the PGEs, execute pre-processing tasks required by the PGEs, schedule the execution of the PGEs according their dependencies and priorities, monitor the processing and logs information and statistics and execute other programmable activities defined by the user.

NWCLIB : General purpose library, provides common functionalities for the product generation such as the management of the SEVIRI 1.5 input files, the GRIB input files and the SAFNWC/MSG output files, processing of specific functions (region, navigation, sun and satellite angles, time conversion, …) and Radiative Transfer Model (RTTOV).

PGEs: (Product Generator Elements) Implement the scientific algorithms in charge of extracting the Meteorological Products, are coded as stand-alone applications, supported by the NWCLIB functions and region and algorithm parameters are fully configurable.

SAFNWC/MSG v0.1 has been preliminary tested and successfully compiled under the next platforms

Sun/Solaris 5,6, 5,7, 5,8; Workshop 6 & Forte 7

SGI IRIX6.5, gnu 3.0.4

Linux Red Hat 7.3, gnu 2.96

Component Tests for the NWCLIB have successfully passed in all 3 platforms. Only minor differences appear in Linux as consequence of precision in mathematical calculations.

SAFNWC/MSG v1.0 only tested in SUN/Solaris will be delivered to users early summer 2004 and SAFNWC/MSG v1.1 fully portable version will be delivered early autumn 2004.

The SAFNWC/MSG software has proved to be robust and friendly for the Nowcasting purposes and it is flexible enough to adapt to any new products or requirements. New input or output files from an hypothetical H-SAF requirements can be adapted to the NWCLIB as well as new products can be performed as new PGEs.

8.2 SAF on Land Surface Analysis

8.2.1 Soil Moisture product

The 2nd Mid Term Review of the SAF on Land Surface Analysis was held in January 2004 (MTR 2). As one of the results of the review, the review board proposed to keep the soil moisture product as an Experimental Product, and to carry on research and comparative studies. An experimental product means that it requires scientific justification, validation and comparison with similar products from other sources to argue its added value.

This proposition was justified for Soil Moisture by the following rationale:

- While recognizing Soil Moisture as an important product, the Review Board had doubts on its competitiveness and maturity, especially at spatial and time scales that could take full advantage of SEVIRI characteristics, as well as on its operational readiness for start of Initial Operations Phase (IOP). It was therefore proposed to keep it as an experimental product.

- The Review Board noted also that the Soil Moisture algorithm has an important limitation in not using information from precipitation.

The Review Board also recommended to the Soil Moisture Team to:

(a) Demonstrate the added value of the Soil Moisture product over the soil moisture obtained with a standard off-line application of the TESSEL model;

(b) Explore the use of other sources of data to constrain Soil Moisture;

(c) Assess the dependence of the Soil Moisture product and associated errors on the wind speed, in particular with regards to a possible need of downscaling of the NWP wind speed values to the MSG grid;

(d) Explore the value of the Soil Moisture product to disaggregate coarser information on soil moisture (e,g., from global NWP models or SMOS retrievals);

(e) Link their research with SMOS activities;

(f) Follow closely activities from the Hydrology SAF Working Group;

(g) Coordinate their work with the research and validation of LST and TSP parameters.

9 Breakdown of partner skills and experiences required for H-SAF

Roles	Essential Skills	Essential Experience
Host institute / core team	• Operational services • Interaction with users • Engineering of product generation chains (EUMETSAT standards) • Management of large projects	• Knowledge of SAFs • (N)RT or offline operations (including dissemination) • Archiving • Processing of large data sets (in real and non-real time) • End-to-end system validation
Pilot users (user requirements)	• Operational hydrology • Related science behind the products • Links with international user and scientific communities • User requirements analysis and validation	• Hydrological modelling experience • Downscaling
Product line teams	• Development of algorithms • Microwaves • VIS/IR data • Modelling and science behind (theoretical algorithms, …) • Interaction with users • Coordination of product teams (one per line)	• Processing of large data sets (in real and non-real time) • Product validation • CAL/VAL (knowledge of satellite instrument) • Knowledge of other SAFs' products
(independent) validation	• Hydrology (user perspective) • Data assimilation	• Validation (scaling, sampling, ground-based observing systems)
Development of algorithms	• Development of algorithms • Microwaves • VIS/IR data • Modelling and science behind (theoretical algorithms, …) • Interaction with users	• Processing of large data sets (in real and non-real time) • Validation • Error analysis and characterisation
Engineering support (SW etc)	• Engineering of product generation chains (EUMETSAT standards)	• (N)RT or offline Operations (including dissemination) • Archiving • Processing of large data sets (in real and non-real time) • SW engineering in remote sensing projects
Beta-users (external to the consortium and from the user community)	• Hydrology (user perspective) • Data assimilation	• Operational hydrology and water management (and related organisations) • Decision support entities • Distributed modelling experience (hydrology)

10 Conclusions and Recommendations

The SHFWG objectives as laid out in the related Terms of References have been met. Specifically:

- A long-term vision has been established (see section 2);
- The expected evolution of ground-based and a satellite observation in the identified application areas (precipitation, soil moisture, and snow) has been assessed (see sections 4-6);
- A list of products/deliverables for a potential SAF on Operational Hydrology and Water Management has been identified, and listed in Appendix 2 of the Summary Report (see sections 4-6 and Appendix 2);
- Relevant satellite systems have been identified and assessed as described above (see sections 4-6 and Appendix 2);
- The relationship and potential added value of the potential new SAF with the other SAFs have been investigated (see section 8);
- The experiences and partners skills necessary in a potential SAF consortium to deliver the most relevant products services have been identified (see section 9).

In particular:

- The WG has established a vision of the evolution of operational catchment hydrological models and their relationship to NWP models and their expected evolution in a timeframe 2005-2015.
- The WG has identified specific needs in the field of operational hydrology, which can be supported by satellite data. Three applications areas which would mostly benefit from the use of such data were identified, i.e. the retrieval of precipitation, soil moisture and snow.
- The WG has concluded that the current satellite systems (both research and operational) can support an incremental fulfilment of the user needs, as drafted by the SHFWG, already in the development phase. With the evolution of satellite systems in the investigated timeframe, these needs would be supported more and more closely to their breakthrough levels in the operational phase.

Recommendations:

The WG recommends the STG to

- Consider the outcomes and conclusions of the H-SAF framework WG,
- Recommend Council to approve the defined scientific framework, within which it is expected that a proposal on an H-SAF should be developed.

APPENDIX 1 - COLLECTION OF OFFICIAL USER REQUIREMENTS FOR PRECIPITATION, SOIL MOISTURE AND SNOW PARAMETERS

This Appendix collects User Requirements for precipitation, soil moisture and snow parameters as published by official sources. One set refers to world-scale international organisations as represented by WMO and connected agencies; the second one to European interests as represented in EUMETSAT. It is noted that the EUMETSAT Convention establishes that EUMETSAT activities should take into account WMO requirements as much as possible.

User requirements use to be specified in terms of several quality indexes:

- horizontal resolution (Δx)
- accuracy (RMS)
- observing cycle (Δt)
- delivery time (δ) from observation taking to availability of the product for distribution to the user.

For each figure, three values could be quoted:

- the *optimum* value: to do better would provide insignificant incremental benefit;
- the *threshold* value: if not met, the impact of the data would be insignificant;
- the *breakthrough* value: if met, it would provide a sharp improvement of the forecast.

WMO requirements

WMO requirements have been established since several decades: to establish user requirements is a primary task for WMO, particularly for the Commission of Instruments and Methods of Observation (CIMO) and the Commission for Basic Systems (CBS). In recent years, in the framework of CEOS (Committee for Earth Observation Satellites), WMO has reviewed the requirements from its various programmes, and also has coordinated the collection of requirements from other international programmes (WCRP, GCOS, GOOS, GTOS, IGBP, ICSU, UNEP). A "CEOS/WMO Online Database" is available on the web [1] . Table 1 is derived by extracting the relevant information and assembling in a compact fashion. It is noted that, at present, WMO does not include "breakthrough" requirements.

EUMETSAT requirements

EUMETSAT requirements have been established during the User Consultation Process that led to the 1st Post-MSG User Consultation Workshop, Darmstadt, 13-15 November 2001. The requirements can be found on the web [2] . From there, Table 2 (that incorporates some update introduced soon after the Workshop) is derived. It is noted that, whereas WMO requirements refer to near-term future, the EUMETSAT requirements refer to the decade 2015-2025, i.e. the timeframe for Meteosat Third Generation (MTG).

Important note

It is noted that the requirements of Tables 1 and 2 refer to processed products. The fact that certain large-scale applications accept values integrated over hundreds of kilometres or several hours and days does not imply that the basic measurement can have that sort of resolution: in fact, there are sampling constraints associated to the nature of the field to be observed (e.g., the fractal nature of precipitation) or to the fact that the addressed observation may be disturbed by an overlapping field (e.g., surface observation in VIS/IR disturbed by cloudiness); therefore the instrument resolution must generally be much better than that one of the final product.

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[1] http://www.wmo.int ; search by alphabetic topics: "Satellites in WMO programmes"; "Online database information"; "Satellite systems and user requirements information (CEOS/WMO database)"; "Observational requirements (WMO, WCRP, GCOS, GOOS, GTOS, IGBP, ICSU, UNEP)".

[2] http://www.eumetsat.de ; "Preparation of future programmes"; "Meteosat Third generation (MTG)"; Quick links: "User consultation process"; "High level user needs and priorities".

Table 1. Requirements for precipitation, soil moisture and snow from the WMO/CEOS database.

Precipitation rate at ground (liquid or solid)		Δx (km)		RMS (mm/h)		Δt (hours)		δ (hours)	
Source	**Application**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**
WMO	Global NWP	50	100	0.1	1	1	12	1	4
	Regional NWP	10	50	0.1	1	0.5	6	0.5	2
	Synoptic meteorology	20	100	0.1	1	1	6	0.25	6
	Nowcasting	5	50	0.1	1	0.083	1	0.083	0.5
GCOS	Atmosphere and surface interface	100	500	0.6	2	3	6	3	12
GCOS and GTOS	Terrestrial climate	1	10	0.05	0.1	3	6	24	120
IGBP	Global Analysis, Interpretation and Modelling	100	500	0.5	3	168	720	168	720

Daily cumulative precipitation		Δx (km)		RMS (mm/d)		Δt (hours)		δ (days)	
Source	**Application**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**
WMO	Global NWP	50	250	0.5	5	1	12	1	30
	Regional NWP	10	250	0.5	5	0.5	12	1	30
	Agricultural meteorology	10	50	2	10	24	72	1	2
WCRP	Global Energy and Water Cycle Experiment	50	500	0.5	5	1	12	30	60

Soil moisture		Δx (km)		RMS (g/kg)		Δt (days)		δ (days)	
Source	**Application**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**
WMO	Seasonal to Inter-annual Forecasts	50	500	10	50	1	7	1	7
	Global NWP	15	250	10	50	1	7	0.25	1
	Regional NWP	5	250	10	50	1	7	7	7
	Nowcasting	5	50	10	50	0.5	2	0.25	1
	Agricultural meteorology	0.1	1	10	50	1	7	1	5
	Hydrology	0.01	250	10	50	1	3	0.04	6
WCRP	Global Energy and Water Cycle Experiment	15	250	10	50	1	10	10	30
GCOS and GTOS	Terrestrial climate	25	100	missing	missing	1	5	3	5
IGBP	Biospheric Aspects of Hydro. Cycle, Global	50	200	missing	missing	10	30	30	90
	Biospheric Aspects of Hydro. Cycle, Regional	0.03	1	missing	missing	1	10	0.125	1

Snow cover		Δx (km)		RMS (%)		Δt (days)		δ (days)	
Source	**Application**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**
WMO	Global NWP	15	250	10	50	0.5	7	0.5	1
	Regional NWP	5	250	10	50	0.5	7	0.25	1
	Nowcasting	5	50	10	20	0.04	6	0.04	0.25
	Agricultural meteorology	1	10	2	10	5	7	1	6
	Hydrology	0.1	100	5	20	1	7	1	6
WCRP	Arctic Climate System Study	1	25	10	20	1	5	7	30
	Global Energy and Water Cycle Experiment	15	250	10	50	1	7	30	90
GCOS	Atmosphere and surface interface	100	500	10	20	1	7	0.25	1
GCOS and GTOS	Terrestrial climate	1	5	5	10	1	3	2	3

Snow melting conditions		Δx (km)		RMS (classes)		Δt (days)		δ (days)	
Source	**Application**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**
WMO	Hydrology	0.1	10	5	2	0.02	12	0.04	6
GCOS and GTOS	Terrestrial climate	10	25	6	2	1	3	2	3

Snow water equivalent		Δx (km)		RMS (mm)		Δt (days)		δ (days)	
Source	**Application**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**	**Opt.**	**Thres.**
WMO	Seasonal to Inter-annual Forecasts	50	500	5	20	1	7	1	7
	Global NWP	15	250	5	20	0.5	7	0.25	1
	Regional NWP	5	250	5	20	0.25	12	0.25	1
	Agricultural meteorology	1	10	5	500	7	30	1	7
	Hydrology	0.1	10	5	20	1	7	1	6
WCRP	Arctic Climate System Study	10	25	5	20	1	5	7	30
	Global Energy and Water Cycle Experiment	15	250	5	20	0.5	7	30	90
GCOS	Atmosphere and surface interface	100	500	5	10	1	7	0.25	1
GCOS and GTOS	Terrestrial climate	10	25	5	10	1	3	2	3

Appendix 1

Table 2. EUMETSAT requirements for precipitation, soil moisture and snow for > 2015.

Precipitation rate		Δx (km)			Accuracy (mm/h)			Δt (min)			δ (min)	
Field	**Application**	Opt	Break	Thres	Opt	Break	Thres	Opt	Break	Thres	Opt	Thres
Numerical Weather Prediction	Global	5	15	100	0.1	0.5	1	60	180	720	60	240
	Regional	3	10	50	0.1		1	30	60	180		
Observation/Extrapolation	Public information	1	10	50	(*)	(*)	(*)	15	60	60	5	15
	Transport	1	2	50	0.1	10	10	5	15	60	5	15
	Information	1	5	50	0.1	0.2	1	15	60	60	15	60
	Telecommunications	1	1	50	0.5	1	1	10	10	60	10	30
	Coastal zones	1	10	50	0.1	5	5	15	60	60	15	60
Convection forecasting techniques	Monitoring	1	5	5	1	10	10	5	30	30	5	10
Non-convective forecasting techniques	Melting layer lowering	5	5	10	1	2	5	15	15	60	15	30
Land surface and hydrological models	Flood run-off	1	5	10	(**)	(**)	(**)	15	15	180	5	15
	Snow accumulation	0.1	0.5	1	0.1	1	1	30	60	180	15	60
	Mud slices	0.1		10	0.5		1	60		120	15	30
	Fires	0.1		10	0.1		1	1		60	1	30
Dispersion, chemistry, biology models	Atmosphere washing	0.1		1	0.1		0.5	1		60	1	15
	Wet deposition	1		10	0.1		1	15		60	5	15

Daily cumulative precipitation		Δx (km)			Accuracy (mm/d)			Δt (hours)			δ (hours)	
Field	**Application**	Opt	Break	Thres	Opt	Break	Thres	Opt	Break	Thres	Opt	Thres
Numerical Weather Prediction	Global	5	50	250	0.5	1	5	24	24	180	24	180

Soil moisture		Δx (km)			Accuracy ($m^3 m^{-3}$)			Δt (hours)			δ (hours)	
Field	**Application**	Opt	Break	Thres	Opt	Break	Thres	Opt	Break	Thres	Opt.	Thres
Numerical Weather Prediction	Global	5	100	250	0.04	0.06	0.10	3	24	120	3	120
	Regional	1	10	50	0.04	0.06	0.10	1	6	24		
Land surface and hydrological models	Flood run-off	1	50	50	0.02	0.05	0.10	1	24	24	0.25	24
	Mud slide models	0.1		10	0.02	0.05	0.10	1		24	1	3
	Fire initiation	0.1	1	1	0.02	0.05	0.10	0.17	1	6	0.5	1
	Fire risk	1	3	3	0.02	0.05	0.10	6	24	24	1	3

Snow cover		Δx (km)			Accuracy (%)			Δt (hours)			δ (hours)	
Field	**Application**	Opt	Break	Thres	Opt	Break	Thres	Opt	Break	Thres	Opt	Thres
Numerical Weather Prediction	Global	5	15	250	10	20	50	3	12	120	3	120
	Regional	3	10	50	5		20	3	6	24		
Observation/Extrapolation	Transport	1	10	50	10	30	50	0.25	6	6	0.25	1
Non-convective forecasting techniques	Changes of stability	1		10	20		50	0.17		0.5	0.17	0.5
Land surface and hydrological models	Snow melt	1		50	10		25	1	24	24	0.25	3

Snow water equivalent		Δx (km)			Accuracy (mm)			Δt (hours)			δ (hours)	
Field	**Application**	Opt	Break	Thres	Opt	Brea.	Thres	Opt	Break	Thres	Opt	Break
Numerical Weather Prediction	Global	5	15	250	5	10	20	1	6	120	1	24
	Regional	3	10	50	5		20	3	6	24		
Observation/Extrapolation	Transport	1	1	50	1	10	100	0.25	0.25	6	0.25	1
Land surface and hydrological models	Snow melt	1	5	10	1	5	5	1	24	24	0.25	3
	Avalanches	0.1	0.5	0.5	40	200	200	0.5	2	3	0.25	1

(*) Probability of detection, defined in terms of Hit Rate (HR) and False Alarm Rate (FAR):

Optimum: 99 % HR, 2 % FAR	Breakthrough: 95 % HR, 10 % FAR	Threshold: 50 % HR, 50 % FAR

(**) Defined in terms of percent of actual amount:

Optimum: 10 %	Breakthrough: 50 %	Threshold: 50 %

APPENDIX 2 - POTENTIAL H-SAF PRODUCTS AND AVAILABLE DATA SOURCES

This Appendix summarises the candidate products to be generated by H-SAF and reviews the situation of satellite data availability to support the development and the operational phases. The selection criteria for the products are based on feasibility and readiness, those for data sources on availability and access. Only satellites data sources are considered in this Appendix, but a substantial amount of ground-based data will be necessary to support product generation in both the development and the operational phases.

The **satellite data sources** have been selected according to the following principles:

- for the operational phase:
  - Meteosat Second Generation
  - MetOp/EPS and the Joint Polar System (three NPOESS progressively replacing NOAA and DMSP)
  - further five components of the GPM mission (possibly including EGPM);
- for the development phase:
  - satellites selected to support the operational phase or their current series undertaking replacement
  - specific instruments being flown on R&D missions, mainly from ESA and NASA;
- precipitation radar (on TRMM, on the “core” GPM satellite, on EGPM in a nadir-only version) are considered part of the calibration mechanism of GPM and not addressed specifically (their limited swath is not considered sufficient for stand-alone operational application);
- Synthetic Aperture Radar (SAR), though the only system capable of providing sub-kilometre resolution in all-weather conditions, are currently not considered in H-SAF because of lack of plans for long-term operational continuity and lack of demonstrated capability. The situation might be revisited in future.

The **products readiness** analysis is summarised as follows:

- Precipitation:
  - there is enough experience on merging Meteosat IR images with the DMSP SSM/I to prepare for operational retrieval of frequent precipitation rain at Day 1, ultimately based on MSG SEVIRI, NPOESS CMIS and the other five satellites of the GPM constellation. However, since the launch schedule of NPOESS 1/2/3 is spread in years 2009, 2011 and 2013 respectively, the data quality will need time, i.e. Day 2, to reach full performance, particularly as regards cumulative precipitation;
  - the use of AMSU to retrieve frontal and light rain, though with coarse resolution, also is well developed and can be brought to operations at Day 1. Another product mature for Day 1 is the rain rate estimate from SEVIRI by convective phenomena automatic detection based on objects analysis;
  - to discriminate liquid from solid precipitation (snowfall) is an objective of CMIS and of the ESA EGPM. Current data to feed the development phase are not fully representative, thus actual operations are likely to need waiting for Day 2.
- Soil moisture:
  - the product based on MetOp/EPS ASCAT could be operationally available at Day 1;
  - the product based on NPOESS CMIS could potentially be ready at Day 1 (because of the availability of precursor instruments for the development), but the repeat cycle will actually improve progressively, in phase with the deployment of the NPOESS 1/2/3 system.
- Snow parameters:
  - the products based on optical instruments (AVHRR and VIIRS), in spite of their dependence on cloudiness, are well consolidated and proven useful in several European areas; they could be operationally available at Day 1 also thanks to the availability of MODIS in the development phase;
  - use of MW imagery, ultimately from NPOESS CMIS, is necessary for the utmost important snow water equivalent, though applicable to relatively large basins due to the limited resolution (several kilometres); they could be operationally available at Day 1 with improved frequency on Day 2.

It is noted that the listed products only represent what will be considered during the H-SAF planning phase and thereafter development phase. Which product to actually develop will depend on the existence of a partner willing to take over the effort and on the available level of resources (from EUMETSAT and from the interested partner). The readiness of a product to enter the operational phase will additionally depend on the success of the development phase and on the confirmation of the satellite system programmatic aspects.

Potential data sources for H-SAF development and operations

Visible / Infrared imaging radiometers

Precipitation - Frequent observation from GEO to interpolate between MW-derived accurate measurements from LEO, waiting for the availability of MW measurements from GEO. If used as stand-alone, only qualitative inference, mostly limited to convective rain.

Soil moisture - Indexes by measuring differential reflectivity between short-wave IR and VIS or by monitoring the diurnal variation of the phase between incoming solar radiation and soil heating. Qualitative information only, not available in the presence of clouds.

Snow - Snow recognition and surface temperature by multi-day analysis (required because of cloudiness impact on instantaneous measurements). Qualitative discrimination of wet/dry conditions. Inference of snow water equivalent by association to ground measurements and models (applicable over suitable areas only).

Instrument	Satellite series	Resolution	Cycle	Availability
MVIRI	Meteosat up to -7	10 km (Europe)	30 min	Development phase
SEVIRI	MSG	8 km (Europe)	15 min	Development and operational phases
AVHRR	NOAA + MetOp	1 km at s.s.p.	6 times/day (3 satellites)	Development and operational phases
VIIRS	NPOESS	0.8 km at s.s.p.		Operational phase
MODIS	EOS Terra & Aqua	1 km at s.s.p.	2 times/day	Development phase

Microwave imaging radiometers and/or sounders

Precipitation – In <u>atmospheric windows</u>: direct observation of liquid precipitation over the sea in the lower frequencies, thus with coarse resolution. With increasing frequency (that improves resolution), sensitivity to cloud ice increases, that enables extending the observation over land by exploiting scattering. More polarisations required, to filter surface roughness and exploit scattering. In <u>absorptions bands</u> (of O_2 and H_2O): temperature and/or humidity profiling at relatively high frequencies are affected by liquid water and ice. Coarse resolution but applicable over land and sensitive to frontal rain, light rain and snowfall. SSMIS, CMIS and EGPM include both atmospheric windows and sounding channels. Some radiometer is associated to rain radar for system calibration.

Soil moisture - Observed through its effect on the soil dielectric constant. All weather capability. Best observed at low frequencies, e.g. L-band (higher sensitivity and less dependence on vegetation). C-band still useful. Higher frequencies and polarisation supportive to enable accounting for vegetation and surface roughness. Coarse resolution associated to low frequencies.

Snow - Recognition in all-weather conditions. Discrimination of wet/dry conditions. Good sensitivity at high frequencies, thus good spatial resolution. Snow water equivalent requires multi-frequency analysis to work with several snow depths, thus resolution degrades with increasing snow depth requiring lower frequencies. More polarisations needed, to account for roughness.

Instrument	Satellite series	Resolution at most suitable frequency for:			Cycle	Availability
		precipitation	soil moisture	snow		
SSM/I	DMSP	30 km at 37 GHz	N/A	15 km at 90 GHz	3 times/day (3 satellites)	Development phase
SSMIS						Development and operational phases
CMIS	NPOESS	8 km at 37 GHz	40 km at 6.9 GHz	4 km at 90 GHz		Operational phase
AMSR-E	EOS/Aqua				Once/day	Development phase
AMSR	ADEOS-II				Once/day	Development phase (archived data)
MW radiometer	EGPM	13 km at 37 GHz	N/A	6 km at 90 GHz	5 times/day (5 satellites)	Operational phase
MW radiometer	Further 4 GPM					Operational phase
TMI (with PR)	TRMM				Low inclin.	Development phase
L-band	SMOS	N/A	50 km at 1.4 GHz	N/A	3 days	R&D missions for cal/val at end of development and early operations
L-band (+SAR)	HYDROS	N/A		N/A	3 days	
AMSU-A	NOAA+MetOp	48 km ssp	N/A	48 km ssp	6 times/day (3 satellites)	Development and operational phases
AMSU-B / MHS	NOAA+MetOp	16 km ssp		16 km ssp		Development and operational phases
ATMS	NPOESS	32 km ssp		16 km ssp		Operational phase

Radar scatterometer

Soil moisture - Same principle than with passive MW radiometry, but less dependent on electromagnetic interferences (C-band). Only European C-band scatterometers are considered (American scatterometers use Ku-band, not sufficiently sensitive to soil moisture). Multiple-viewing capabilities useful for accounting of vegetation and surface roughness. SAR, including L-band SAR, not considered at this stage due to lack of long-term plans.

Snow - Same principle than with passive MW radiometry. Only European C-band scatterometers are considered (American scatterometers using the Ku-band would be better suited for snow, but no follow-on is expected to support the operational phase). SAR, including X- and Ku-band, not considered at this stage due to lack of long-term plans.

Instrument	Satellite series	Resolution	Cycle	Availability
SCAT (C-band)	ERS 1 and 2	50 km (25 km)	4 days	Development phase (archived data)
ASCAT (C-band)	MetOp	25 km	1.5 days	Development and operational phases

Appendix 2

Potential data delivery from H-SAF during the operational phase (2010-2014)

Product	Resolution (Europe)	Accuracy	Cycle (Europe)	Timeliness
Precipitation rate from MW imagery	10 km (with CMIS) 15 km (with other GPM)	10-20 % (rate > 10 mm/h), 20-40 % (rate 1 to 10 mm/h), 40-80 % (rate < 1 mm/h)	6 h (with CMIS only) 3 h (with full GPM)	15 min
Precipitation rate merging MW & IR	10 km	Ranging from MW performance to degraded one to an amount to be assessed	15 min	5 min
Water phase (based on MW)	10 km (with CMIS) 15 km (with other GPM)	80 % probability of correct classification	6 h (with CMIS only) 3 h (with full GPM)	15 min
3, 6, 12 and 24 h cumulated rain	10 km (from merged MW + IR)	Depending on integration interval. Tentative: 10 % over 24 h, 30 % over 3 h	3 hour	15 min
Soil moisture in the surface layer	25 km (from ASCAT) 40 km (from CMIS)	0.05 m3 m-3 (depending on vegetation)	36 h (from ASCAT) 6 h (from CMIS)	2 h
Soil moisture in the roots region	25 km (from ASCAT) 40 km (from CMIS)	To be assessed (model-dependent). Tentative: 0.05 m3 m-3	36 h (from ASCAT) 6 h (from CMIS)	2 h
Snow recognition	5 km (in MW) 2 km (in VIS/SWIR/TIR)	95 % probability of correct classification	6 h	2 h
Snow effective coverage	10 km (in MW) 5 km (in VIS/SWIR/TIR)	15 % (depending on basin size and complexity)	6 h	2 h
Snow thawing-freezing conditions	5 km (in MW) 2 km (in TIR)	80 % probability of correct classification	3 h (under cloud-free conditions)	30 min
Snow status (wet or dry)	5 km	80 % probability of correct classification	6 h	2 h
Snow water equivalent	10 km	To be assessed. Tentative: 20 mm	6 h	2 h

Format / representation	Precipitation, soil moisture and snow parameters derived from polar satellites are generated on a satellite pass basis as image strips in a projection corrected for panoramic distortion and earth's rotation.
	Precipitation rate and cumulative precipitation maps from merged SEVIRI and MW images are delivered in the Meteosat projection (rectified) ready for animation. Integrated values over specific basins might be considered.
Scene size	Precipitation: Europe (including Turkey) and North Africa. Soil moisture and snow: Europe (including Turkey). Actual scene in maps from polar satellites consistent with acquisition range and EPS NRT/EARS dissemination.

Other potential deliverables and activities	
Software packages	Processing modules to handle image-like precipitation, soil moisture and snow parameters maps, specifically to overlay contours of hydrological basins and compute average, integrated and fractional quantities within the basin.
	Interface modules to support down-scaling / up-scaling and assimilation procedures for the utilisation of H-SAF products in NWP, hydrological models and runoff forecasting.
	Software procedures for the fusion of H-SAF products of different characteristics derived from different sources: e.g., soil moisture from ASCAT and CMIS, snow parameters from optical and MW instruments.
Workshops and courses	Specialist workshops supporting the development phase (e.g., for radiative transfer models selection, retrieval algorithms consolidation, organisation of calibration/validation activities).
	Training courses on the operational use of products from H-SAF.
Studies	Long-term continuing assessment of calibration and validation performances (the initial basic calibration/validation activity is an integral part of the development phase).
	Pilot studies on the impact of H-SAF products on NWP, hydrological models and runoff forecasting; and on the use of H-SAF products for water reservoir evaluation.
	Research on possible improvements of the quality of H-SAF products by combining the information from the envisaged data sources with that one from other satellites and from ground systems (specifically, radar).
Collaboration	With Nowcasting-SAF: exchange of codes and databases for clouds/precipitation characterisation.
	With Land-SAF: appropriate sharing of responsibility on soil moisture and snow products (e.g., characterisation of products by Land-SAF for use in NWP, by H-SAF for use in Hydrology and water resources).
	With NWP-SAF: promotion of improved assimilation models for precipitation, soil moisture and snow parameters.
	With Clim-SAF: promotion of climatological surveys on precipitation, soil moisture and snow parameters.
	With GMES (Global Monitoring for Environment and Security): connections with the activities of *Priority Theme "G", Systems for Risk Management*, specifically as concerns floods, landslides and avalanches.

Appendix 3 - List of Acronyms and Abbreviations

ADEOS	Advanced Earth Observation Satellite (I and II)
ALOS	Advanced Land Observing Satellite
AMSR	Advanced Microwave Scanning Radiometer (on ADEOS-II)
AMSR-E	Advanced Microwave Scanning Radiometer - E (on EOS-Aqua)
AMSU-A	Advanced Microwave Sounding Unit - A (on NOAA satellites and EOS-Aqua)
AMSU-B	Advanced Microwave Sounding Unit - B (on NOAA satellites up to NOAA-17)
AMV	Atmospheric Motion Vectors
ASCAT	Advanced Scatterometer (on MetOp)
ATMS	Advanced Technology Microwave Sounder (on NPP and NPOESS)
ATOVS	Advances TIROS Operational Vertical Sounder
AVHRR	Advanced Very High Resolution Radiometer (on NOAA and MetOp)
CBS	Commission for Basic Systems (of WMO)
CEOS	Committee for Earth Observation Satellites
CIMO	Commission of Instruments and Methods of Observation (of WMO)
CMIS	Conical-scanning Microwave Imager/Sounder (on NPOESS)
CrIS	Cross-track Infrared Sounder
DMSP	Defense Meteorological Satellite Program
EGPM	European contribution to the GPM mission
EOS	Earth Observing System
EPS	EUMETSAT Polar System
ERS	European Remote-sensing Satellite (1 and 2)
FDR	Frequency Domain Reflectory
GCOS	Global Climate Observing System
GIS	Geographical Information System
GMES	Global Monitoring for Environment and Security
GOOS	Global Ocean Observing System
GOS	Global Observing System
GPM	Global Precipitation Measurement mission
GPS	Global Positioning System
GTOS	Global Terrestrial Observing System
HRU	Hydrological Response Unit
HYDROS	Hydrosphere State Mission
IASI	Infrared Atmospheric Sounding Interferometer
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Programme
JERS	Japanese Earth Resources Satellite
JPS	Joint Polar System (MetOp + NOAA/NPOESS)
MAP	Meso-scale Alpine Programme
MetOp	Meteorological Operational satellite
MHS	Microwave Humidity Sounder (on NOAA N/N’ and MetOp)
MODIS	Moderate-resolution Imaging Spectro-radiometer (on EOS Terra and Aqua)
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
MVIRI	Meteosat Visible Infra-Red Imager (on Meteosat 1 to 7)
NOAA	National Oceanic and Atmospheric Organisation (intended as a satellite series)
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Programme
NWC	Nowcasting
NWP	Numerical Weather Prediction
NWS	National Weather Service
PR	Precipitation Radar (on TRMM)
QPF	Quantitative Precipitation Forecasting
R&D	Research and Development

RFI	Radio Frequency Interference
SAOCOM	Argentinean Satellite for Observation and Communication
SAR	Synthetic Aperture Radar
SCAT	Scatterometer (on ERS 1 and 2)
SEVIRI	Spinning Enhanced Visible Infra-Red Imager (on MSG)
SMMR	Scanning Multichannel Microwave Radiometer (on SeaSat and Nimbus VII)
SMOS	Soil Moisture and Ocean Salinity
SR	Sonic Ranging sensor (for snow)
SSM/I	Special Sensor Microwave / Imager (on DMSP up to F-15)
SSMIS	Special Sensor Microwave Imager/Sounder (on DMSP starting with F-16)
TDR	Time Domain Reflectory
TMI	TRMM Microwave Imager (on TRMM)
TRMM	Tropical Rainfall Measuring Mission
UNEP	United Nations Environmental Programme
VIIRS	Visible/Infrared Imager Radiometer Suite (on NPP and NPOESS)
VSRF	Very-Short Range Forecasting
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

Some useful definitions

Bands of the electromagnetic spectrum exploited for Remote Sensing

UV	Ultra-Violet	0.01 - 0.38 µm
VIS	Visible	0.38 - 0.78 µm
NIR	Near Infra-Red	0.78 - 1.30 µm
SWIR	Short-Wave Infra-Red	1.30 – 3.00 µm
MWIR	Medium-Wave Infra-Red	3.00 – 6.00 µm
TIR	Thermal Infra-Red	6.00 – 15.0 µm
FIR	Far Infra-Red	15 µm - 1 mm (= 300 GHz)
Sub-mm	Submillimetre wave (part of FIR)	3000 - 300 GHz (or 100 µm - 1 mm)
MW	Microwave	300 - 1 GHz (or 1 mm - 30 cm)
SW	Short Wave	0.2 - 4.0 µm
LW	Long Wave	4 - 100 µm
IR	Infra-Red (MWIR + TIR)	3 - 15 µm
VNIR	Visible and Near Infra-Red (VIS + NIR)	0.38 - 1.3 µm

Bands used in radar technology (according to ASPRS, American Society for Photogrammetry and Remote Sensing)

Band	Frequency range	Wavelength range
P	220 - 390 MHz	77 -136 cm
UHF	300 - 1000 MHz	30 -100 cm
L	1 - 2 GHz	15 - 30 cm
S	2 - 4 GHz	7.5 - 15 cm
C	4 - 8 GHz	3.75 - 7.5 cm
X	8 – 12.5 GHz	2.4 - 3.75 cm
Ku	12.5 - 18 GHz	1.67 - 2.4 cm
K	18 - 26.5 GHz	1.18 - 1.67 cm
Ka	26.5 - 40 GHz	0.75 - 1.18 cm
V	40 - 75 GHz	4.0 - 7.5 mm
W	75 - 110 GHz	2.75 - 4.0 mm

Appendix 4 - List of SHFWG members, observers and invited experts.

Country / Affiliation	**WG Member or Replacement**
Austria	**Günter BLÖSCHL**, Vienna University of Technology
Belgium	**Emmanuel ROULIN**, IRM
France	**Joel NOILHAN**, Météo France
Germany	**Gerhard ADRIAN**, Deutcher Wetterdienst **Clemens SIMMER**, University of Bonn
Italy	**Giuseppina MONACELLI**, APAT / National Hydrological Service **Stefano DIETRICH / Alberto MUGNAI**, CNR-ISAC
The Netherlands	**Jeannette ONVLEE**, KNMI
Poland	**Piotr STRUZIK**, Institute of Meteorology and Water Management
Portugal	**Carlos DA CAMARA**, IM
Sweden	**Martin RIDAL**, Swedish Meteorological and Hydrological Institute
Switzerland	**Urs GERMANN**, MeteoSvizzera
United Kingdom	**Brian GOLDING**, MetOffice
EC/JRC	**Ad DE ROO**
ECMWF	**Anthony HOLLINGSWORTH, Chairman** **Peter BAUER**
Country	**WG Observer or Invited Expert**
Austria	**Wolfgang WAGNER**, Technical University of Vienna **Veronika ZWATZ-MEISE / Alexander JANN, ZAMG**
Finland	**Pirkko PYLKKÖ**, Finnish Meteorological Institute **Sari METSÄMÄKI**, Finnish Environment Institute **Jouni PULLIAINEN**, Helsinki University of Technology
Italy	**Luigi DE LEONIBUS**, Servizio Meteorologico dell'Aeronautica **Bizzarro BIZZARRI,** Scientific Advisor to the EUMETSAT Director **Roberto SORANI**, Servizio Meteorologico dell'Aeronautica **Luca ROSSI**, Dipartimento Protezione Civile
Slovakia	**Jan KANAK**, Slovak Hydrometeorological Institute, Bratislava
Spain	**Pilar FERNANDEZ**, INM
EUMETNET	**Lotta ANDERSSON**, SMHI
EC	**Panagiotis BALABANIS**, EC
ESA	**Einar-Arne HERLAND**, ESA/ESTEC
WMO	**Avinash TYAGI**, WMO