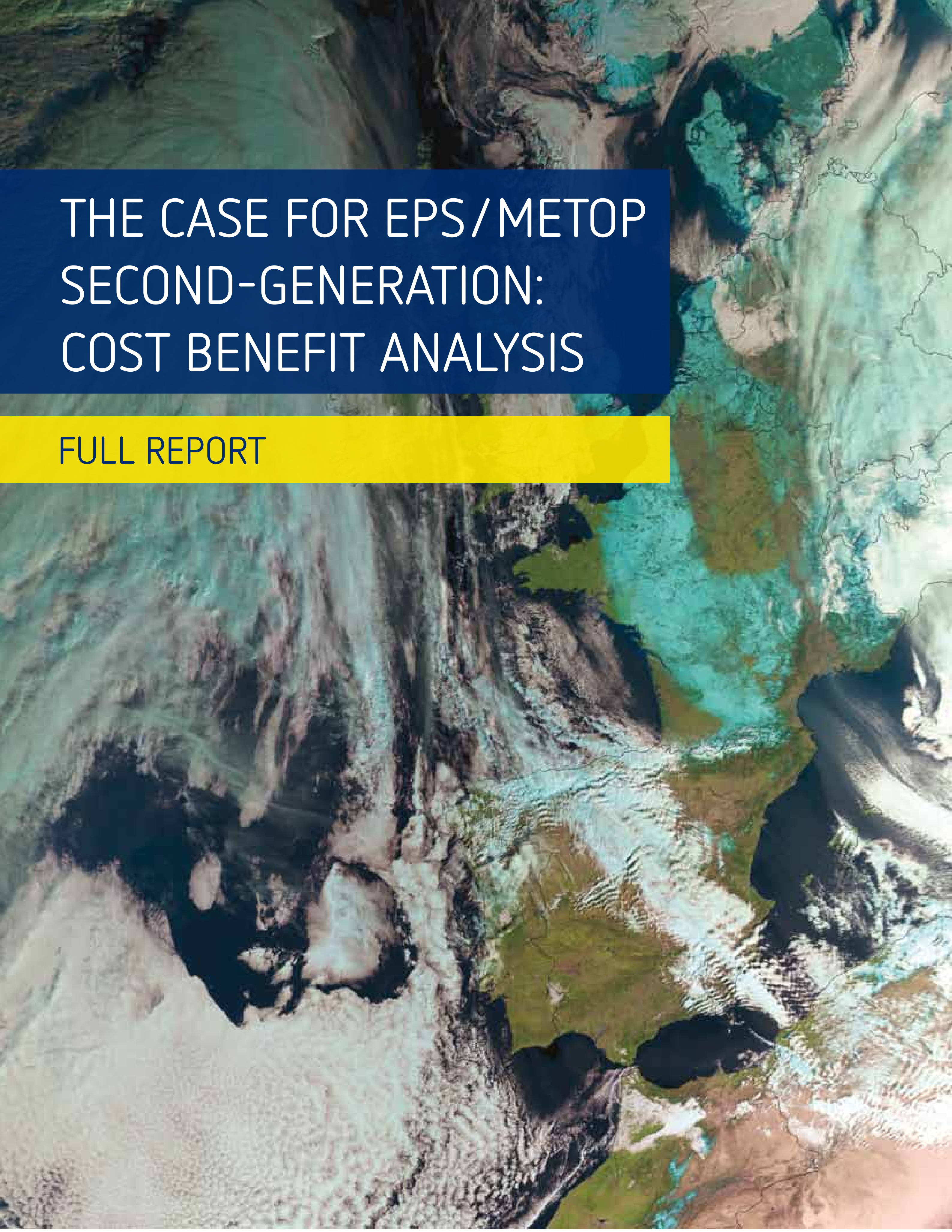

THE CASE FOR EPS/METOP SECOND-GENERATION: COST BENEFIT ANALYSIS

FULL REPORT

MONITORING WEATHER AND CLIMATE FROM SPACE

EUMETSAT

THE CASE FOR EPS/METOP SECOND-GENERATION: COST BENEFIT ANALYSIS

Full Report

EUMETSAT

1 INTRODUCTION

Observations from meteorological satellites are crucial inputs for the generation of weather forecasts by the National Meteorological Services of EUMETSAT Member and Cooperating States, with such forecasts being used to produce warnings and other tailored information in support of public and private decision-making.

The socio-economic benefits of the full information chain result from the impact of the decisions actually made to avoid costs, optimise implementation of public policies or increase gains in private business. The realisation of these benefits depends in the first place on the quality of the input forecasts, but also on the capability to exploit this information in the decision-making processes, and on the ability to respond to the situation through appropriate measures. Weather forecasts also have significant value for individual citizens in their day-to-day lives.

Because of the complexity of the processes involved and the variety of benefit areas, from protection of life and property to weather sensitive sectors, such as transport, energy, agriculture, tourism, or trading of consumer goods, the benefits of weather information are difficult to assess in precise quantitative terms, but a number of studies have met the challenge and demonstrated that they are substantial.

Assessing the benefit of observations from polar orbiting meteorological satellites, like the current generation of EUMETSAT Metop satellites, is even more complex, as it means allocating a fraction of the estimated benefit of weather information to one input of the meteorological information production chain.

However, if it is possible to assess the level of contribution of satellite data to the skill of forecasts, then a relevant fraction of the estimated benefits of forecasts can be attributed on this basis. This has now become possible, because advanced numerical methods are now available to evaluate in an objective and quantitative manner the level of contribution of any type of observations to the performance of Numerical Weather Prediction (NWP) models[1] which provide the basic material for elaborating most forecasts; as long as these observations are actually ingested into models. In particular, the relative contributions of various existing satellite data inputs to forecast skill can be measured and, as a result, estimates of their respective contributions to the socio-economic benefits of forecasts can be extracted.

[1] Joo S, Eyre J R and Marriott R T. “The impact of Metop and other satellite data within the Met Office global NWP system, using an adjoint-based sensitivity method”. Forecasting Research Technical Report 562, Met Office, UK; 2012.

This methodology has been followed to assess the socio-economic benefits of the observations of the current EUMETSAT polar orbiting satellite, Metop, and to estimate by extrapolation the socio-economic benefits, and benefit-to-cost ratios, to be expected from the EPS/Metop-SG programme now proposed by ESA and EUMETSAT to replace this generation of satellites in the 2020-2040 time-frame, i.e.:

- Section 2 assesses the socio-economic benefits of forecasts in the European Union for a set of key benefit areas where a quantitative estimation is, in general, feasible;
- Section 3 provides an analysis of the contribution of observations from polar-orbiting satellites to numerical weather forecast skill;
- Section 4 overlays both analyses to extract the proportion of the benefits of forecasts that can be reasonably attributed to existing satellites such as Metop, and proposes an extrapolation to EPS/Metop-SG in the 2020-2040 timeframe, based on the most conservative assumptions.

As a complement, section 5 proposes a qualitative assessment of the contribution to other benefit areas, which are not amenable to a quantitative analysis.

The main conclusions as regards the benefits, and benefit to cost ratio, of the EPS/Metop-SG programme proposed by EUMETSAT and ESA are presented in section 6.

2 SOCIO-ECOMOMIC BENEFITS OF FORECAST INFORMATION

Forecast information is used by all parts of modern society, and the resultant benefits are diverse and wide-ranging.

In order to provide an insight into some of these benefits, the usage and impact of forecast information is assessed in a number of key areas, including estimation of associated benefits from published scientific literature.

2.1 SAFETY OF LIFE AND PROTECTION OF PROPERTY[2]

A significant part of the benefits of weather forecasts are indirect in the form of lives saved and "costs avoided" in the prevention and management of natural disasters related to extremes of weather; with floods and storms being the most significant examples in the European Union and EUMETSAT Member States.

For example, short-range forecasting (up to 3 days in range) enables preparations to be made for extreme events such as heat waves, cold spells, gales, thunderstorms, floods or forest fires. These forecasts then feed early warning systems which, if embedded within efficient prevention and civil protection policies and used by public and private operators, enable life and property to be protected in many ways.

2.1.1 SAFETY OF LIFE

There are many weather-related threats to safety in Europe, such as floods (e.g. Elbe in Germany in 2002, le Gard in France in 2002 and 2005; Lower Silesia in 2005, Var in France in 2010, Vara river valley in Italy in 2011, Elbe in Germany in June 2013, Danube June 2013), winter storms (e.g. Lothar and Martin in 1999, Klaus in 2009, Xynthia in 2010, Kyrill in 2011), heat waves (e.g. August 2003 and July 2006) and cold spells (e.g. 1984-1985 in France; 2001 in Hungary; 2010 in Poland), avalanches (e.g. in les Orres in France in 1998) and forest fires, e.g. in Greece, Spain and Portugal in recent years.

In Europe, severe winter-storms have a return period of about 10 years and often lead to dozens of casualties. The 2003 heat wave caused about 70,000 deaths in Europe[3] and the 2006 event led to about 2,000 deaths in France alone. Avalanches cause on average 32 deaths per year in France, compared to a total of 4.5 million ski tourists[4]. Forest fires, due to the combination of dry vegetation and wind, have also been devastating, mainly in southern Europe..

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[2] Hallegatte, S., 2012. A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation, Policy Research Working Paper 6058, The World Bank.

[3] Robine, J-M; Siu Lan K. Cheung, Sophie Le Roy, Herman Van Oyen, Clare Griffiths, Jean-Pierre Michel, François Richard Herrmann (2008). Comptes Rendus Biologies 331 (2): 171–178.

[4] Source : Dossier d'information « Avalanche » du Ministère de l'Aménagement du Territoire et de l'Environnement, 2000, available on http://www.prim.net.fr.

It is difficult to assess how many lives prevention and early warning systems save each year, even though civil protection agencies and other policy makers consider these systems to be essential for ensuring the safety of the population. For example, when floods are forecast individuals can avoid travel, implement mitigation actions (e.g. sandbagging), whilst civil protection agencies, organisations and businesses can take tailored safety measures including, in extreme cases, evacuation.

Such warning services have a large audience and probably help avoid hundreds of accidents each year, as demonstrated by studies and analysis of specific examples.

For instance, in the case of heat waves, studies by Inserm and InVS[5] have shown that the forecasts, warning and prevention system implemented in France after the August 2003 heat wave reduced the number of deaths from 6,400 to around 2,000 during the less intense but longer episode of July 2006.

The ability to prepare emergency services before an event occurs is also essential. During the few hours before an intense weather event, much can be done to increase the efficiency of the emergency services. For example, in 2002 during the floods in the Gard region and, as a result of the forecast information, 22 out of the 26 helicopters able to conduct rescue airlifts were pre-positioned in the flood area. According to local emergency services, this pre-positioning saved about one hundred lives, compared with a situation in which it would have taken hours to move helicopters to the affected areas, and there are many and frequent similar examples across Europe. From a more general standpoint, the possibility to relay accurate forecasts is critical to the sizing and efficiency of civil protection, rescue and other large-scale safety systems, enabling their optimum deployment and targeting to the most exposed and most vulnerable areas. The benefit is that more lives can be saved, at a lower cost.

It is also important to stress that the benefits from forecasts depend largely, and nonlinearly, on their accuracy, and that threshold effects are important. For instance, the decision to evacuate due to a potential flood cannot be made if the probability of false alarm is too high (or if the warning area is too large) as, after a few unnecessary evacuations, the trust into the warning system is likely to disappear, and the warning system becomes useless. This problem is illustrated by the case of New Orleans, which had been evacuated unnecessarily twice (for hurricanes George in 1998 and Ivan in 2004), making it more difficult to convince inhabitants to leave before hurricane Katrina. If the risk of false alarm becomes low enough to create and maintain trust, and thereby allow significant prevention measures to be taken before disasters, a limited improvement in forecast accuracy can lead to a disproportionately large increase in socio-economic benefit.

Forecast information is critical for the safety of maritime transport and air traffic[6] management. Indeed, to observe appropriate levels of safety, these operations

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[5] Estimation de la surmortalité observée et attendue au cours de la vague de chaleur du mois de juillet 2006 http://www.invs.sante.fr/publications/2007/canicule_2006/canicule_2006.pdf

[6] According to the « Bureau Enquête Accident », 7.5% of plane accident have meteorological causes http://www.bea-fr.org/etudes/stat9798/stats1997-1998.htm

need detailed weather information and, in the absence of such information, it is unlikely that passenger air travel could be safe enough to be commercially viable in its current form.

Other hazards also need to be considered, such as technological catastrophes (accidents in a chemical plant or a nuclear plant) or volcanic eruptions. In these cases, the capacity to forecast winds, and thus the trajectory of the contamination cloud or ash plumes, can save hundreds of lives.

Even in everyday life, forecast information plays a large safety role for people exposed to specific weather-related risks in their outdoor activities linked to the sea (e.g. sailing), in the mountains (e.g., hiking, skiing) or in the air.

So, although no comprehensive quantitative assessment is offered for the benefits associated with safety of life, it can be conservatively assumed based on the figures available, that on a European scale, many hundreds of lives are saved annually by forecast and warning information. Although this cannot be reasonably expressed in monetary terms, this is an invaluable benefit for society and public policy makers.

2.1.2 PROTECTION OF PROPERTY AND INFRASTRUCTURE[7]

Forecasts and warnings also serve to limit as far as possible the economic losses due to severe weather and related hazards. Based on a number of published studies, the benefits in the form of avoided costs can be estimated at least for floods and storms.

For floods, according to Thieken et al.[8], a study on the Elbe and Danube floods in 2002 shows that 31% of the population in flooded areas implemented preventive measures aimed at protecting property. These measures included moving goods to the second floor of buildings (implemented by more than 50% of the inhabitants who carried out prevention measures), moving vehicles outside the flood zone (more than 40%), protecting important documents and valuables (more than 30%), disconnecting electricity and gas supplies and unplugging electric appliances (more than 25%) and installation of water pumps (between 2 and 10%). For the 2002 floods, it has been estimated[9] that the early warning and the subsequent prevention measures reduced flood costs by about 6%.

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[7] Hallegatte, S., 2012. A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation, Policy Research Working Paper 6058, The World Bank

[8] Thieken, A.H., Kreibich, H., Muller, M. & Merz, B. (2007) Coping With Floods: Preparedness, Response And Recovery Of Flood-Affected Residents In Germany In 2002, *Hydrological Sciences*, 52, (5), October, 1016-1037.
Thieken, A. H., Petrow, Th., Kreibich, H. & Merz, B. (2006) Insurability And Mitigation Of Flood Losses In Private Households In Germany. *Risk Analysis* 26(2), 383–395.
Thieken, A.H., Muller, M., Kreibich, H. & Merz, B. (2005) Flood Damage And Influencing Factors: New Insights From The August 2002 Flood In Germany, *Water Resources Research*, Vol. 41, 1-16.
Kreibich, H., Thieken, A.H., Petrow, T.H., Muller, M. & Merz, B. (2005) Flood Loss Reduction Of Private Households Due To Building Precautionary Measures – Lessons Learned From The Elbe Flood In August 2002, *Natural Hazards And Earth Systems Sciences*, Vol. 5, 117-126.

[9] Tapsell et al., 2008, Modelling the damage reducing effects of flood warnings, Final report of the FLOODsite project, available on www.floodsite.net.

Among the inhabitants who did not implement any mitigation measures, 65% said that they had been informed too late, and about 20% said that they were not at home and therefore could not do anything. For this part of the population, it would seem that an earlier warning would have allowed better preparation and lower subsequent damage.

This observation is supported by Day[10], who provides an explicit relationship between the ability to protect property and the warning lead-time.

There is also a large potential for businesses to take mitigation measures. The International Commission for the Protection of the Rhine[11] estimates that 50 to 75% of flood losses could be avoided due to emergency preparation measures. For instance, moving toxic materials and chemicals to safe storage areas prevents local pollution (such as that observed after hurricane Katrina flooded New Orleans). Machines and equipment can also be moved to avoid damage.

According to Carsell[12], a warning emitted 48 hours before a flood enables the overall damage to be reduced by more than 50%. According to Barredo[13], European floods cost on average €4 billion per year (normalised costs calculated over the 1970-2006 period). Assuming that only half of the floods can actually be forecast and the warning reduces losses by only 20%, the benefits from early warnings would be €400 million per year. Using Carsell's estimate, and assuming that 75% of the floods can be forecast, the benefits would reach €1.5 billion per year[14].

For storms, according to Swiss Re[15], the average cost is about €2.6 billion per year in Europe. If weather forecasts help reduce these losses by between 10% and 50%, due to similar preventive actions taken for floods, the corresponding gains lie in the range from €0.26 billion to €1.2 billion per year.

Overall, for floods and storms alone, the total benefit from forecasting could lie between €0.66 billion and €2.7 billion per year. In the same area of safety of protection of property and infrastructure, it is expected that forecasts of other severe phenomena (risks of forest fires, snow, heat waves, cold spells, etc.) bring benefits in the same order, leading to an overall estimate between €1.32 billion and €5.4 billion.

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[10] Day, H.J., 1970. "Flood warning benefit evaluation-Susquehanna River Basin (urban residences)." ESSA technical memorandum WBTM Hydro-10. National Weather Service. Silver Spring, MD.

[11] International Commission For The Protection Of The Rhine (2002). *Non Structural Flood Plain Management – Measures And Their Effectiveness*, ICPR, Koblenz, 2002.

[12] Carsell, K.M., N. D. Pingel, D.T. Ford, 2004: Quantifying the Benefit of a Flood Warning System. *Nat. Hazards Rev*, 5(3), 131–140

[13] Barredo, 2009, Normalised flood losses in Europe: 1970-2006. Nat. Hazards Earth Syst. Sci., 9, 97–104, 2009

[14] It is assumed that false alarms have no cost, which is not the case, especially in case of large scale evacuations.

[15] Swiss Re, 2006. The effect of climate change: storm damage in Europe on the rise. http://www.preventionweb.net/files/20629_publ06klimaveraenderungen1.pdf.

2.2 DIRECT BENEFITS TO THE EUROPEAN ECONOMY IN THE FORM OF ADDED VALUE[16]

Forecast information is widely used by industry and businesses to optimise their activities.

For example, in the transport sector forecast information is used to assist in road network management, route planning, rail network management and air traffic management (considered in more detail in section 2.2.1).

Electricity production industry and grid management authorities use forecast information to anticipate demand as a function of weather conditions as well as to forecast and adjust available production capacity and, if needed, purchase additional capacity at the most affordable price on the market (considered in more detail in section 2.2.2).

Farmers and agro-businesses make use of weather forecast information to make decisions about planting and harvest dates, use of fertilizers and other inputs, and on preventive measures in case of floods or heavy precipitation. The agro-businesses also rely on meteorological information to forecast yield and production, and anticipate the market conditions.

Leisure businesses use weather forecasts to anticipate customer numbers and to adjust their workforce and capacities accordingly.

In all these and other sectors, weather forecasts increase productivity. Their use is growing worldwide, with many new specialised downstream businesses being created to assist in the tailored exploitation of this information.

2.2.1 AVIATION

EUROCONTROL's Central Office for Delay Analysis (CODA) collects operational data from airlines operating within Europe and in the period 2009 – 2012, it was estimated that the total cost of delays from all causes was in average more than €1.4 billion per year in 2009 economic conditions (see Figure 1)[17].

The primary causes of delays during the period 2011 - 2012 are summarised in Figure 2[18] where it can be seen that 6% of the delays were attributed to weather. Assuming that these weather delays linearly affect the delay costs, then the cost of weather-induced delays within Europe was over €84 million in 2009 economic-conditions. Forecast information contributes directly to the minimisation of these delay costs attributed directly to weather, with the capability to minimise such costs being directly correlated to the forecast accuracy.

[16] Hallegatte, S., 2012. A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation, Policy Research Working Paper 6058, The World Bank

[17] PRR 2012: Performance Review Report, An Assessment of Air Traffic Management in Europe during the Calendar Year 2012, Eurocontrol, May 2013

[18] CODA digest: delays to Air Transport in Europe, Report 2012, Eurocontrol

Also due to capacity and safety considerations, as noted in section 2.1.1, it is unlikely that the sector could exist in its current form without reliable forecast information. Hence forecasting has an intrinsic, and very significant, socio-economic benefit as an enabling precondition for the sector, in addition to its role in reducing weather-related delays.

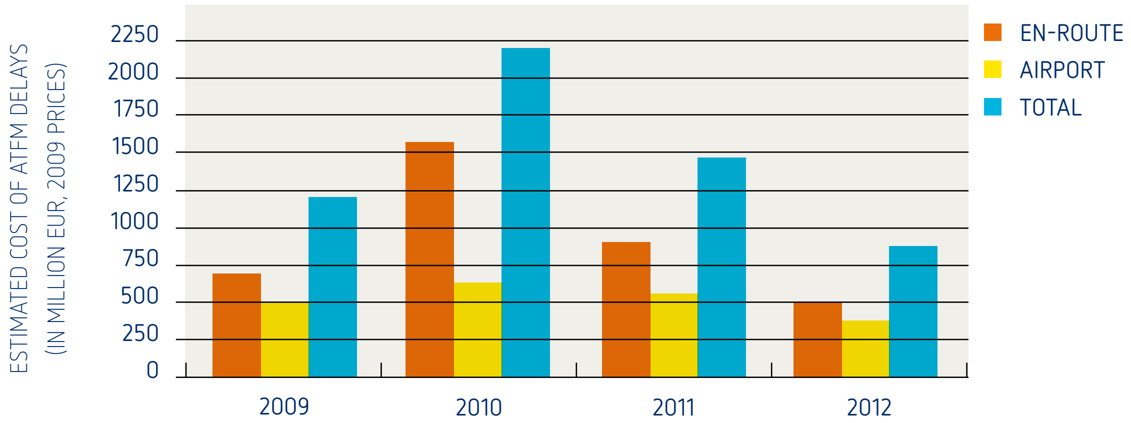

FIGURE 1: ESTIMATED COST OF ATFM DELAYS IN EUROPE (2009 PRICES)

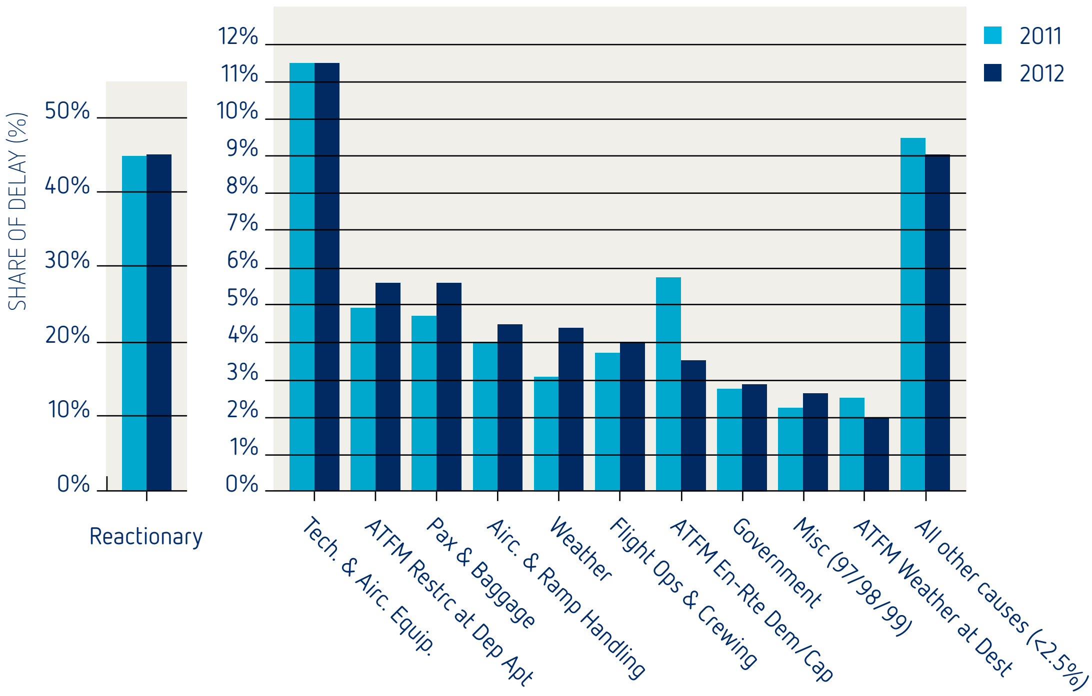

FIGURE 2: PRIMARY AND REACTIONARY DELAY DISTRIBUTION FOR 2011 AND 2012 BY IATA CODE (%)

The benefits of forecasts are expected to further increase in the 2020-2040 time-frame, with the foreseen increase of traffic in the Single European Sky, and the improved use of weather information in the implementation of the trajectory-based air traffic management system under development within the SESAR[19] initiative.

[19] Council Regulation (EC) No 219/2007 of 27 February 2007 on the establishment of a Joint Undertaking to develop the new generation European air traffic management system (SESAR)

2.2.2 ELECTRICAL POWER GRID MANAGEMENT[20]

As human activities become more sophisticated and electrical power-dependent, weather and climate increasingly pose both opportunities and risks for the energy industry. To respond effectively, decision-making processes require accurate and reliable information on weather and climate, at all time-scales.

The power sector includes both renewable and non-renewable resources and, as electricity cannot be stored on a large scale, a strict balance between supply and demand has to be maintained at all times.

Extreme events such as heat waves or cold waves, gales, or floods can, of course, have dramatic consequences on the production capacity of a country or even at continental scale, for the largest scale phenomena.

But normal day-to-day weather variations also have impacts on both supply and demand (as well as on pricing).

On the demand side, air temperature and wind are normally the most important governing factors, as cold conditions imply heating, and warm conditions imply cooling. In France for instance, a cold anomaly of one degree Celsius in winter requires an extra production of around 2100 MW, the equivalent of 1.5 nuclear reactors or around 800 windmills.

On the supply side hydro-electric power is, of course, dependent on precipitation (water and snow), and temperature (which controls snow-melt in spring). Other renewable sources, in particular wind and solar energy, fluctuate in accordance with atmospheric conditions. Indeed, due to such conditions, it is commonplace to experience rapid decreases/increases in production of more than 80% that can last for several minutes/hours. This is particularly notable in northern European countries, where wind energy provides a significant proportion of the total national energy production (Germany being the most obvious example).

Variability in renewable energy power production is a major problem and, as a result, some countries and regions have set limits to the production capacity from such intermittent sources. These limits can only evolve favourably for the further development of wind and solar energy if one can rely on the possibility to accurately forecast the power capability at least one day ahead, and/or to modulate instantaneous power variations through storage mechanisms. In addition, wind forecasts will also be increasingly important to plan production cuts when the wind speed exceeds intensity thresholds, in order to protect the wind turbines.

From a global perspective, according to IEA's World Energy Outlook 2012, world electricity demand is projected to grow at an annual rate of 2.2% to 2030. If coal remains the dominant fuel worldwide, the share of renewables generation (particularly wind and solar energy) almost triples, their share expanding from 20% in 2010 to 31% in 2035.

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[20] Section based on WMO RA VI Conference: Provider-User Collaboration: Planning for the energy sector Laurent Dubus EDF R&D, Chatou, France

In Europe the energy efficiency policy, agreed at EU level, targets an increase of the share of renewable energy to 20% by 2020, as a proportion of overall EU consumption, along with a decrease of CO2 emissions by 20% with respect to 1990 levels[21]. The fluctuating nature of these renewable energy sources will therefore need to be addressed to achieve these ambitious EU policy goals. Technological solutions, like energy storage, may provide some limited contribution, but more accurate forecasts of the expected production capability, and the associated uncertainties, will be crucial for the further development and optimum use of these renewable energy sources.

2.2.3 OVERALL ESTIMATES OF DIRECT BENEFITS TO THE EUROPEAN ECONOMY[22]

Estimations of the value added by weather forecasts to these various "weather sensitive" sectors of the European economy are available within the published literature.

Some of the particularly weather-sensitive sectors, like transport and energy, have dual importance for the European economy. On the one hand aviation contributes over €120 billion[23] to European GDP in its own right and, on the other hand, it provides a vital component of European transport infrastructure on which many other sectors of the European economy depend.

For the Swiss transport sector it has been estimated that the economic benefit of forecast information amounts to at least CHF86 to CHF100 million per year[24].

In the energy sector, Roulston et al.[25] have estimated the value of weather information to optimise wind power production and have found a doubling in profits due to 1 and 2-day forecasts.

In the agriculture sector, some studies have assessed the productivity gains from short to medium term weather forecasts. For instance, Wills et Wolfe[26] look at the use of forecasts to optimize lettuce production in the state of New York, and they find a $900 to $1000 gain per hectare and per year, i.e. a 10% increase in productivity.

In these few examples, a significant impact of weather information on productivity can be observed. Bearing in mind that about one third of the European GDP is sensitive to weather, and if one assumes 0.25% value-added due to forecasts, which is a very conservative estimate in view of all figures published in the literature, the overall economic benefit to Europe of forecast information would be of the order of €10.23 billion per year, based on EU-27 GDP in 2010 of €12.28Tn, which does not include the

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[21] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency

[22] Hallegatte, S., 2012. A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation, Policy Research Working Paper 6058, The World Bank

[23] http://ec.europa.eu/transport/air/internal_market/internal_market_en.htm

[24] Willemse, S (2011): WMO RA VI SEB Conference: Swiss study of economic benefits to the transport sector

[25] Roulston, M.S., Kaplan, D.T., Hardenberg, J. and Smith, L.A. (2003). Using medium-range weather forecasts to improve the value of wind energy production. *Renewable Energy*, **28**, 585-602

[26] Wilks, D.S. and Wolfe, D.W. (1998). Optimal use and economic value of weather forecasts for lettuce irrigation in a humid climate. *Agricultural and Forest Meteorology*, **89**, 115-130.

GDP of Turkey, Croatia, Norway and Switzerland who are EUMETSAT Member States and Bulgaria, Iceland, Serbia will become Member States in the near future. The published literature on the subject, and the high added value to particularly sensitive sectors like aviation, suggests that a 1% added value is more likely, which would lead to a figure of €41 billion per year.

The range of current benefits of forecasts is therefore estimated between a minimum of €10.23 billion per year and a more likely value of €41 billion per year, for the European Union alone.

2.3 PRIVATE USE BY INDIVIDUAL CITIZENS[27]

Measuring the benefit of the private use of forecasts is not straightforward and involves measuring the willingness of users to pay (either directly or through taxation) for the service they get from meteorological information.

Lazo and colleagues conducted a survey of U.S. households to estimate their willingness to pay for the weather information that is currently provided to them, and for potential improvement of this information[28]. The survey focused on normal conditions, and excluded extreme events and safety aspects from the analysis, so there is no double-counting with respect to the previous section. The survey question asked was "Do you feel that the services you receive from the activities of the national Weather Service are worth more than, exactly, or less than $N a year to your household?" - where N consisted of 11 offer prices. As shown in Figure 3, this survey concluded that 50% of US households placed a value of at least US$280 per year on forecast information, with more than 80% of households ready to pay in excess of $30.

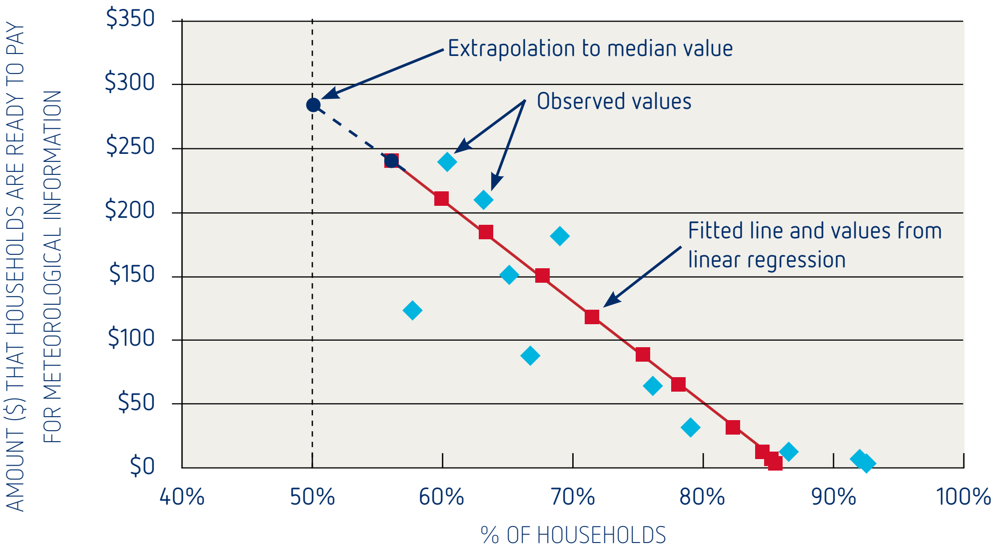


FIGURE 3: ASSESSMENT OF VALUE OF ALL WEATHER FORECASTING AND INFORMATION SERVICES TO HOUSEHOLDS

[27] A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation, Policy Research Working Paper 6058, The World Bank

[28] Lazo, J.K., R.E. Morss, and J.L. Demuth. 2009. "300 billion Served: Sources, Perceptions, Uses, and Values of Weather Forecasts." Bulletin of the American Meteorological Society. 90(6):785-798

Assuming that each European household is ready to pay at least €20 per year, again a conservative estimate, the societal benefit from weather information would be around €4 billion per year. With a more likely value of €80 per household per year, the estimate would reach €15 billion.

Therefore, the current benefits of private use of forecasts by European citizens are estimated to be a minimum of €4.0 billion per year, with a more likely value being €15 billion per year.

2.4 SUMMARY OF SOCIO-ECONOMIC BENEFITS

Assessing the socio-economic benefit of forecast information is not an exact science but, by using simple and approximate techniques, an estimate of the resultant minimum and likely socio-economic benefits[29] for these three benefit areas is provided in the following table (excluding any provision for safety of life)

BENEFIT AREA	MINIMUM	LIKELY
Protection of Property and Infrastructure	€1.3 billion/year	€5.5 billion/year
Added Value to the European Economy	€10 billion/year	€41 billion/year
Private Use by European Citizens	€4 billion/year	€15 billion/year
TOTAL (rounded)	**€15 billion/year**	**€61 billion/year**

TABLE 1: SUMMARY OF ESTIMATED ANNUAL BENEFITS OF FORECAST INFORMATION IN THE EU27

So, with a focus on three benefit areas, excluding any provision for safety of life, and with a conservative estimation approach, approximate calculations suggest that, for the EU27 economy alone (i.e. excluding benefits in EUMETSAT Member States that are not EU Members), the socio-economic benefits of forecast information exceed €15 billion per year, with a more likely benefit being €61 billion per year. Benefits to non EU Member States have also been estimated, assuming proportionality of benefits to GNP.

[29] The benefits are independent and therefore additive

3 CONTRIBUTION OF POLAR-ORBITING METEOROLOGICAL SATELLITE OBSERVATIONS TO FORECAST SKILL

3.1 BACKGROUND

Forecast models, which are the basis of modern forecasting, depend on having an accurate estimate of the initial state to function correctly.

This initial state is constructed from observations and, in the persistent absence of such observations, the model capability rapidly degenerates and the resultant forecast loses all its skill.

So the availability, quality and coverage of observations, via their impact on the initial state, is a pre-requisite for forecasting using models. Observations also have an important role to play in the design and improvement of forecast models, as these models are validated and improved via a systematic comparison with observations.

The importance of satellite observations for short-range forecasting, at centres across Europe, is reflected in the significant expansion in their use within NWP models, with the number of satellite observations ingested in such models typically increasing by more than one order of magnitude over the last decade.

Meteorological satellite observations mostly stem from the complementary combination of geostationary and polar-orbiting systems.

In comparison to geostationary meteorological satellites, polar-orbiting meteorological satellites deliver less frequent but global observations and, flying at a much lower altitude (850km instead of 36,000km) above the Earth, give access to a wealth of ocean, land and atmospheric parameters measured by instruments (e.g. microwave) that cannot be flown in geostationary orbit. This makes a much bigger impact on the accuracy of short to medium-range forecasting, and this impact is now assessed from various perspectives (see Annex I for further information on the distinct, and complementary, contributions of the two types of system).

3.2 IMPACT OF POLAR OBSERVATIONS ON SHORT RANGE FORECAST ACCURACY

The process of generating a short-range forecast starts with the running of a global model to produce a global forecast, and four centres within Europe maintain and run such global models:

- European Centre for Medium range Weather Forecasts (ECMWF, intergovernmental);
- Deutscher Wetterdienst (DWD, Germany);
- Météo-France (France);
- Met Office (UK).

For some applications, the resulting global forecast can be an end-product in itself[30], but in all cases the global forecast output will be used at national level, by all National Meteorological services of the EUMETSAT Member States, to constrain the limited area models that they then run, with higher resolution, to generate short-range forecasts at a regional scale.

Hence for short-range forecasts, the overall quality of the forecast depends on the performance of both the global and limited area models. The limited area models can only add value if the forecasts from global models, used as boundary conditions, are good enough.

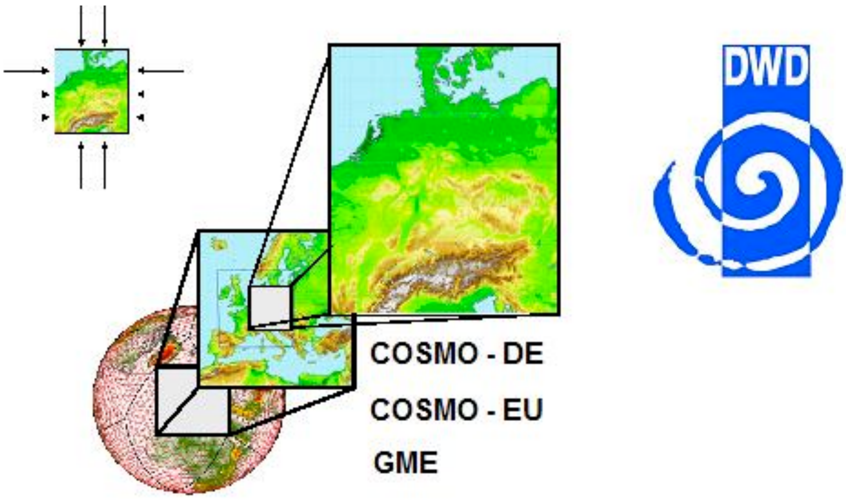


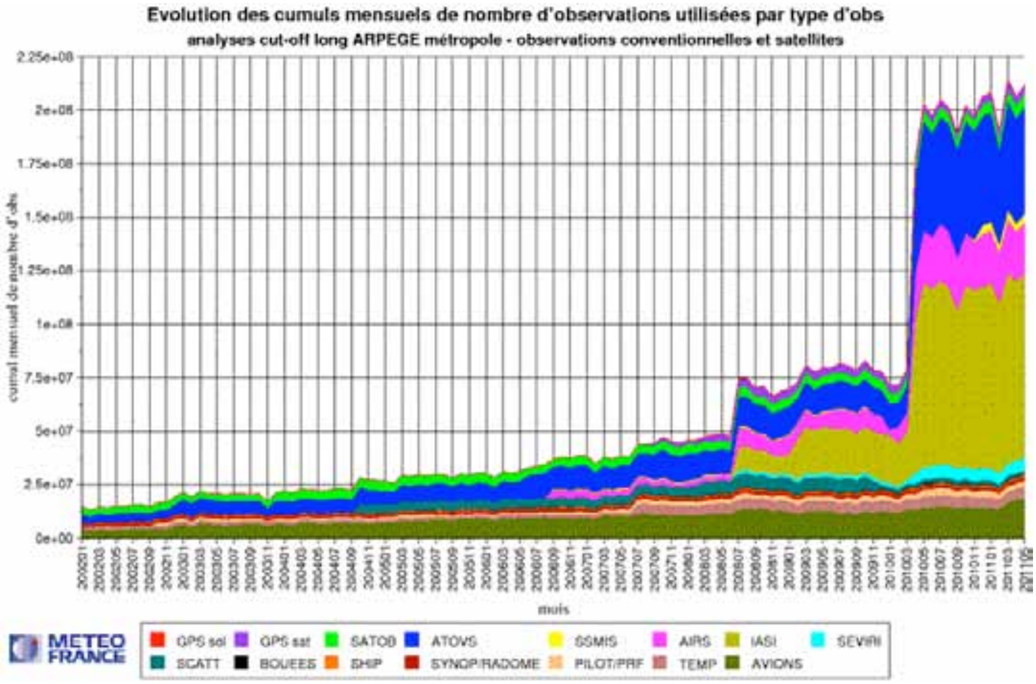
FIGURE 4: RELATIONSHIP BETWEEN GLOBAL AND REGIONAL LIMITED AREA NWP MODELS FOR SHORT RANGE FORECASTS - EXAMPLE OF THE OPERATIONAL NWP SUITE OF DWD (GERMANY)

Global satellite data, such as that from EUMETSAT's Metop-A, is always assimilated in global models and, in a still limited but increasing number of cases, is also assimilated in limited area models as well, in this latter case resulting in an additional impact.

[30] e.g. in fulfillment of responsibilities to civil aviation as a World Area Forecast Centre (WAFC)

3.2.1 INCREASING USAGE OF POLAR-ORBITING OBSERVATIONS

A first element to note is the importance of satellite observations for short-range forecasting, at centres across Europe, which is reflected in the significant increase in their use within NWP models over the last decade (see figures below).



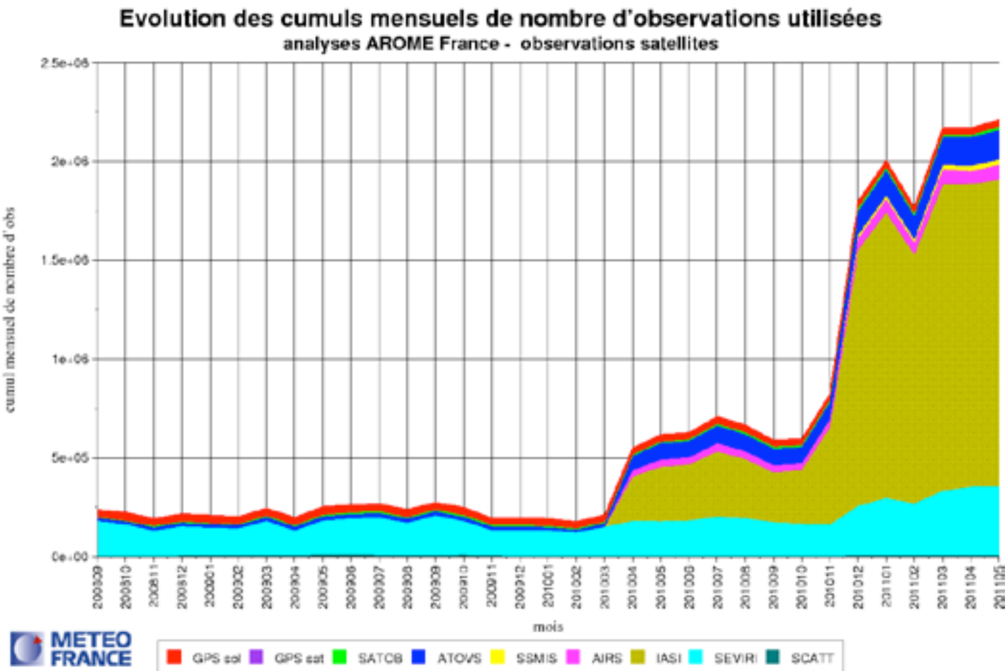


FIGURE 5: INCREASING VOLUME OF SATELLITE DATA INGESTED BY A GLOBAL (TOP) AND A REGIONAL (BOTTOM) NWP MODEL - EXAMPLE OF THE ARPEGE AND AROME MODELS OF MÉTÉO-FRANCE (FRANCE)

3.2.2 POSITIVE IMPACT OF POLAR-ORBITING OBSERVATIONS

Three different perspectives on the impact of polar-orbiting observations on short range forecasting accuracy are presented in this section:

- relative contributions of the various observation sources to forecast accuracy (Met Office - UK);
- statistical impact on forecast accuracy estimated through data denial experiments (ECMWF);
- a case study on the impact of polar data on the forecasting of winter storms over Europe in February 2011 (DWD).

3.2.2.1 RELATIVE CONTRIBUTIONS OF OBSERVATIONS TO FORECAST ACCURACY

The Met Office (UK) has generated Forecast-Sensitivity-to-Observations (FSO) statistics[31] which illustrate, how much each observation type, contributes to the reduction in Day 1 numerical forecast error, relative to other observations. The forecast error is measured by a single figure of merit, a global moist energy norm from the surface to 150 hPa which takes into account a comprehensive set of forecast variables.

The NWP system used is the Met Office global Unified Model (UM) with 4D-Var, version PS26 – operational from 16 March 2011, with resolution N320 for the UM and N216 for 4D-Var assimilation.

Figure 6 illustrates the relative contributions of all observations to the reduction in the error of the Day 1 forecast from the global NWP system of the Met Office (UK), estimated using the adjoint-based forecast sensitivity to observation method. The observation sources comprise different satellites, including operational polar orbiting meteorological satellites, i.e. EUMETSAT's Metop-A and all NOAA satellites (bundled together).

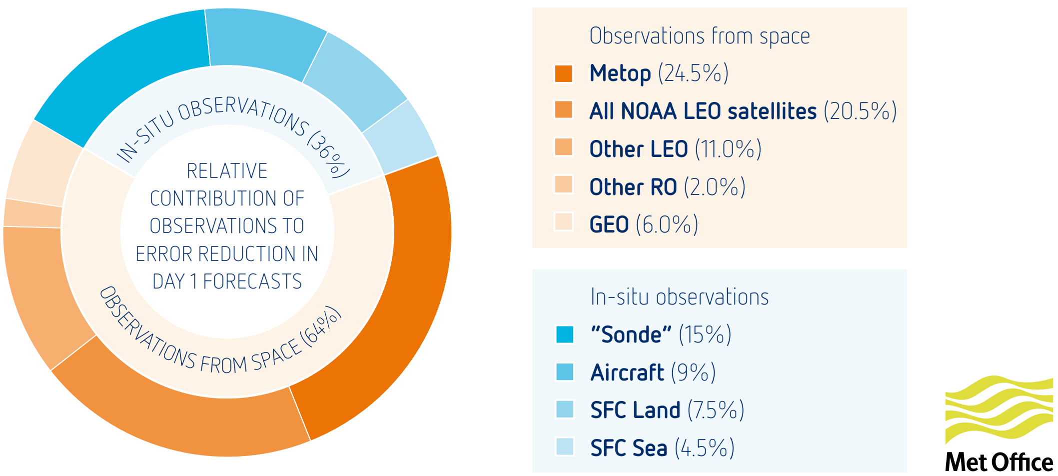
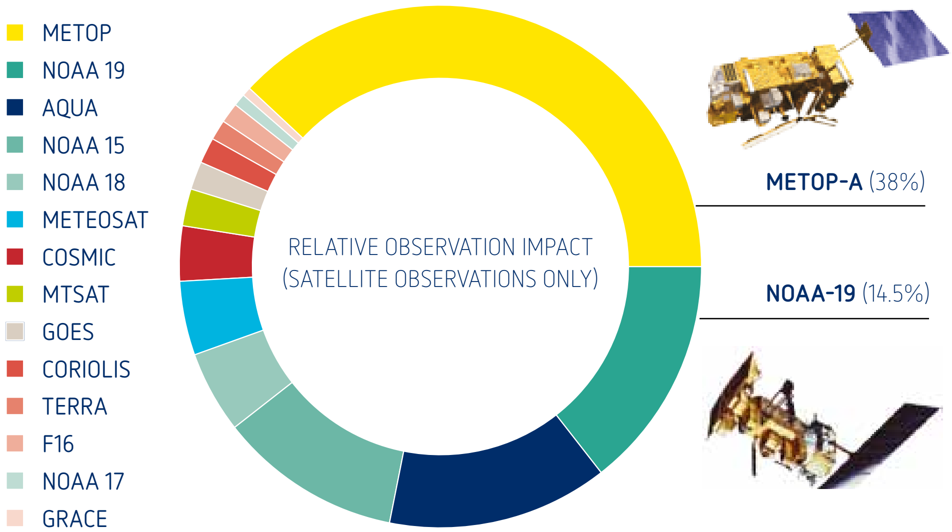


FIGURE 6: RELATIVE CONTRIBUTIONS OF ALL OBSERVATIONS TO THE REDUCTION IN THE ERROR OF THE DAY 1 FORECAST FROM THE GLOBAL NWP SYSTEM OF THE MET OFFICE (UK), ESTIMATED USING THE ADJOINT-BASED FORECAST SENSITIVITY TO OBSERVATION METHOD

[31] Joo S, Eyre J R and Marriott R T. "The impact of Metop and other satellite data within the Met Office global NWP system, using an adjoint-based sensitivity method". Forecasting Research Technical Report 562, Met Office, UK; 2012.

From figure 6, it is evident that the overall impact of satellite data dominates that of surface-based observations, and that the impact of polar orbiting satellites dominates contributions from geostationary satellites and accounts for more than 58% of the total. More specifically, it can be concluded that one polar-orbiting satellite of the current generation, i.e. Metop-A, accounts for around 25% of the impact of all observations on NWP forecasts for Day 1.

Figure 7, from the same source, is restricted to satellite data only, i.e. the non-space data sources have been ignored. From this viewpoint the varying contributions of each individual satellite platform are evident. NOAA 15, NOAA 17, NOAA 18 and NOAA 19 are first generation polar orbiting satellites with NOAA 19, the most recently launched satellite in this NOAA series, forming with Metop-A, the Initial Joint Polar System shared between Europe and the USA. A fully functional spacecraft of this first generation, e.g. NOAA 19, has a relative impact of 14.5% and this can be contrasted with the contribution of the next generation spacecraft, i.e. EUMETSAT's Metop-A, which has a relative impact of 38%. This illustrates the increase in benefits (a factor of 2.5) resulting from the European investment in a new generation of more capable spacecraft, decided in the mid-nineties by ESA and EUMETSAT Member States when approving the Metop/EPS programme.



Met Office

FIGURE 7: RELATIVE CONTRIBUTIONS OF SATELLITE OBSERVATIONS TO THE REDUCTION IN THE ERROR OF THE DAY 1 FORECAST FROM THE GLOBAL NWP SYSTEM OF THE MET OFFICE (UK), ESTIMATED USING THE ADJOINT-BASED FORECAST SENSITIVITY TO OBSERVATION METHOD

From these Met Office statistics one can conclude that one polar-orbiting satellite of the current generation, i.e. Metop-A, accounts for around 25% of the impact of all observations on NWP forecasts for Day 1, and has about 2.5 times more positive impact than a single satellite from the previous generation, i.e. NOAA 19. This emphasises the benefits to be expected from investing in more capable satellite systems.

3.2.2.2 DATA DENIAL EXPERIMENTS BY ECMWF

A number of Observing System Experiments (OSEs) have been carried out by ECMWF to assess the impact of the loss of polar-orbiting observations on the skill of forecasts[32].

For this series of experiments the ECMWF analysis and forecasting system was run over a test period covering the winter of 2009/2010, with a number of sources of satellite data deliberately withheld to simulate a variety of potential observation network scenarios. In all experiments, a minimum set of core observations was used, consisting of conventional data (in situ measurements from the surface, balloons, ships and aircraft) and products from Meteosat and GOES geostationary spacecraft (clear-sky radiances and atmospheric motion vectors).

In order to be as realistic as possible, the baseline operational observing system was assumed to consist of one polar satellite from the United States (termed "US Polar") and Metop. The instrument complement of the US polar satellite was selected so as to be as representative as possible, albeit with the limitation that the instrument sources have to come from the operationally assimilated data set.

Forecasts were run from 00z and 12z each day during the period of the experiment and these were verified using the ECMWF operational analysis. This analysis is arguably the best available estimate of the true atmospheric state and is considered a more reliable verification than using each systems own analysis for verification.

In these data denial experiences, the skill of the forecasts is quantified in terms of root mean square error (RMSE) of 500hPa geopotential height, with an assessment of statistical significance provided (based on the spread of population). The percentage loss of forecast skill for the degraded scenarios, with respect to that of the baseline, is shown in Figure 8 for the European Region (green: loss of Metop observations, blue: loss of US Polar observations, and red: loss of both Metop and US Polar observations).

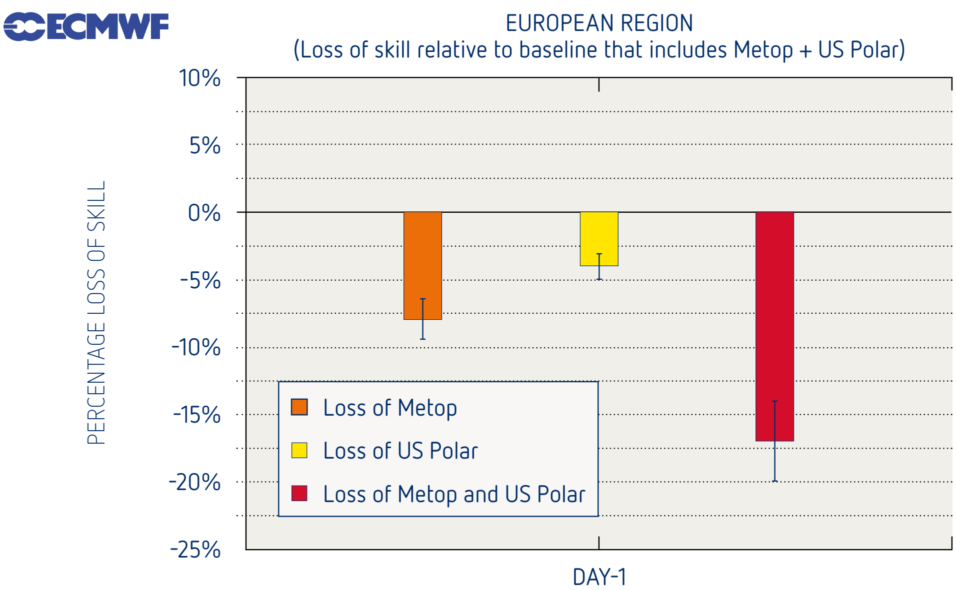


FIGURE 8: IMPACT OF POLAR OBSERVATIONS ON DAY-1 FORECAST ACCURACY

[32] Observing System Experiments to Assess the Impact of Possible Future Degradation of the Global Satellite Observing Network, Tony McNally, ECMWF Technical Memo 672, November 2011, Final Report in preparation

From these experiments it can be seen that the presence of the polar satellites has a clear and unambiguous positive impact on forecast accuracy. The simultaneous loss of both European and US polar satellites could be expected to degrade the 24-hour forecast skill by 15-20% over Europe.

Losing just one source of polar satellite observations produces a smaller, but still very significant, degradation of the short-range forecast accuracy; with around 8% degradation for the loss of Metop observations, and just under 5% degradation for the loss of US Polar observations.

Furthermore, and not explicitly shown in Figure 8, if Metop were to be the only potential source of polar observations, its loss would have an even more pronounced impact at around 13% (i.e. the 17% degradation resulting from no polar observations - red bar, is reduced to a 4% degradation - blue bar, leading to a net impact of around 13%).

From these ECMWF experiments, one can conclude that the loss of Metop-A leads to a loss of 8% in forecast skill over Europe (if the other components of the observing system remain in place to partially compensate for this loss) and a 13% loss of forecast skill if the missing Metop data source had previously been the only polar-orbiting satellite available. Finally a 15-20% loss of forecast skill would result from the simultaneous unavailability of both Metop and the US satellite forming the Initial Joint Polar System shared with the U.S.

3.2.2.3 CASE STUDY: WINTER STORMS OVER EUROPE IN FEBRUARY 2011

It is acknowledged that beyond statistics, forecasting high impact weather accurately has more important socio-economic stakes and benefits than forecasting “normal” weather. Therefore, the German meteorological service (DWD) has investigated the impact of the assimilation of observational data from polar orbiting satellites on short-range forecasts of major storms using their operational global forecast model (GME)[33].

The evaluation period was selected so as to embrace winter storms over Northern Germany at the beginning of February 2011.

For an estimation of the impact of satellite data on forecasts, data denial experiments were performed, i.e. simulations where less data was used compared to normal operations, i.e. assimilation of all observations available in real-time.

Two experiments were run, i.e. one where no data from polar satellites were assimilated and one where only Metop-A data (AMSU-A, ASCAT and GRAS instrument) were denied.

[33] The Impact of Satellite Data on GME Short-Range Forecasts - A Case Study, DWD Internal Report, January 20, 2012.

A verification of forecasts against surface observations showed that the assimilation of satellite data leads to better forecast scores at days 2 and 3 for surface pressure and wind gusts in the selected winter storm period, with the differences between the various forecasts and the verifying analysis (the best approximation of the ground truth) being particularly large for the winter storm "Nicolas", which hit northern Germany and Denmark during the night of 7 February 2011 - see Figure 9.

In this high impact weather event, without observations from Metop, the 45-hour forecast would have totally missed the storm, both in terms of its intensity (minimum pressure over-estimated by 10hPa) and position (missed by several hundred kilometres), leading to no significant warnings to the exposed populations.

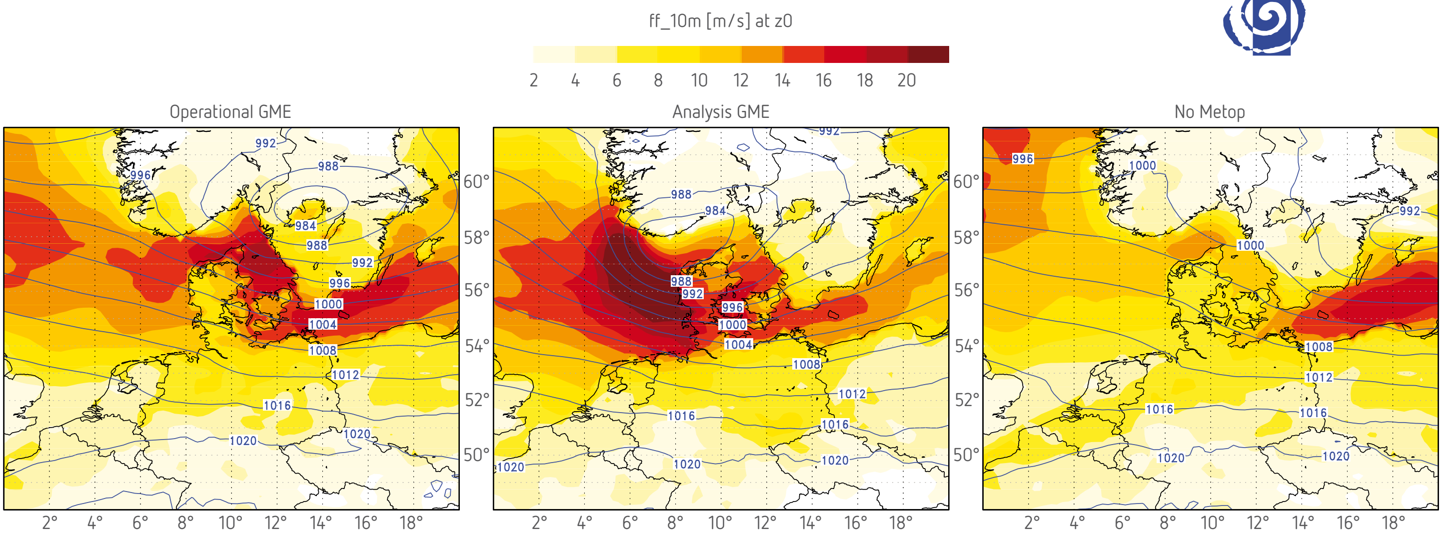


FIGURE 9: WINTER STORM "NICOLAS": 45 HOUR FORECASTS WITH (LEFT) AND WITHOUT (RIGHT) METOP OBSERVATIONS COMPARED TO OPERATIONAL ANALYSIS (BEST APPROXIMATION OF GROUND TRUTH, CENTRE) OF SURFACE PRESSURE (CONTOUR LINES) AND 10M WIND SPEED (SHADED AREAS - UNITS M/S) FOR 7 FEBRUARY 2011, 21:00 UTC

With forecast lead times of 36 to 48 hours, the experiments run with no, or less, satellite data ingestion show consistently larger errors in the severity (lower pressure gradients and wind speed), location and displacement and fast evolution of the trough, than the operational system using all satellite data. In summary, the assimilation of satellite data in general, and of Metop-A data in particular, has been found to increase the lead time of weather warnings for this severe weather event. As DWD's global data assimilation did not operationally use data from the IASI and the MHS instruments on-board Metop at that time, the potential benefit is expected to be even higher.

4 SOCIO-ECONOMIC BENEFITS OF EPS/METOP-SG SATELLITES RELATED TO FORECASTING

4.1 APPORTIONMENT FACTORS

The three approaches (Met Office, ECMWF and DWD) provide a complementary, and consistent, picture of the positive impact of EPS/Metop observations on short-range forecast accuracy.

Whilst the Met Office and ECMWF provide statistics that can be used to estimate, from two different perspectives, the contribution of polar-orbiting satellite data to forecasts skill, the case study demonstrates that the impact can be massive in the case of a high impact weather event, with potentially severe consequences. This illustrates that a poor forecast can, in such a case, lead to a dramatic loss of benefits to society.

From the Met Office statistics, one could conclude that, because one polar-orbiting satellite of the current generation, i.e. Metop-A, accounts for around 25% of the impact of all observations on NWP forecasts for Day 1, 25% of the estimated current benefits of forecasts could be attributed to this satellite.

However, for the purpose of assessing socio-economic benefits the most conservative, worst-case estimate of 8% from the ECMWF statistics was adopted as the proportion of forecasting benefits attributable to Metop. On this basis, the resultant estimated annual benefits of the current Metop/EPS satellites range from a minimum of €1.2 billion to a more likely figure of € 5 billion (obtained by applying the 8% factor to the benefits given in Table 1).

The same assumption is also retained for EPS/Metop-SG in the 2020-2040 timeframe.

4.2 ESTIMATED SOCIO-ECONOMIC BENEFITS OF THE EPS/METOP-SG PROGRAMME IN THE AREA OF FORECASTING

A rather conservative approach has been adopted to estimate the benefits to be expected from 20 years of EPS/Metop-SG observations in the 2020-2040 timeframe, based on the extrapolation of the current annual socio-economic benefit figures of forecast information given in Table 1 of section 2.4, together with the following assumptions:

- an apportionment factor of 8%, reflecting the worst case contribution to forecast skills of the current Metop satellite, with no improvement with EPS/Metop-SG;
- no allowance for progress in numerical weather prediction with respect to the current 'state-of-the-art' (against all expectations);

- an assumed 2% annual increase in EU GDP for the benefit areas sensitive to GDP ("Protection of Property and Infrastructure[34]" and "Added Value to the European Economy");
- a 4% annual discount rate.

The resultant estimated cumulative socio-economic benefits are given in Table 2 for the 20-year operational lifetime of EPS/Metop-SG from 2020 to 2040.

BENEFIT AREAS	SOCIO-ECONOMIC BENEFIT[35] (over 20 years of EPS/Metop-SG)	
	MINIMUM	LIKELY
Protection of Property and Infrastructure	€1.5 billion	€6.0 billion
Added Value to the European Economy	€11.3 billion	€45.2 billion
Private Use by European citizens[36]	€3.0 billion	€11.5 billion
TOTAL (rounded)	**€16 billion**	**€63 billion**

TABLE 2: ESTIMATED SOCIO-ECONOMIC BENEFITS OF EPS/METOP-SG OBSERVATIONS DUE TO THEIR POSITIVE IMPACT ON FORECASTING

It is emphasised that the figures in Table 2 are the result of applying conservative apportionment assumptions and equally conservative estimates of the socio-economic benefits of forecasting, and is for EU-27 only, excluding benefits to other EUMETSAT Member States not EU Members, such as Turkey, Switzerland or Norway.

In the case of the benefits of private use by individuals, the very conservative nature of the assumptions is particularly noteworthy, as the probability is high that European households would be ready to spend more, directly or through taxation, than 40€ per year to get access to weather forecasts. A median estimate of US$280 per year/per household was the result of a US study on the benefits in this area - if this median estimate was applied to Europe the annual benefit would be over €40 billion - compared to the minimum of €4 billion that has been assumed in this analysis.

A further aspect not reflected in these figures is the "leverage" accruing from the availability of high-quality EPS/Metop-SG observations to the worldwide user community which will, under the auspices of the World Meteorological Organisation (WMO), stimulate the development of comparable and complementary satellite systems by other space-faring nations, delivering additional observations that will be available for ingestion into European NWP models; thereby achieving additional positive impacts on forecast accuracy within Europe and,

[34] In the last 50 years flood and storm losses have generally increased, as fast or faster, than GDP.

[35] Present Value (2010) with a discount rate of 4%

[36] These benefits are extremely conservative, at an order of magnitude less than the benefits found in the US

consequently, further socio-economic benefits. The high quality observations of the current Metop satellites are already a particularly attractive proposition for data exchange with other satellite operators.

Even with such conservative assumptions, when the estimated costs of the EPS/Metop-SG programme in the order of €3 billion are contrasted with the discounted benefits, the minimum benefit/cost ratio is over 5 and the likely benefit/cost ratio is over 20, with the understanding that these ratios would increase by a factor of 3, if a 25% apportionment was assumed instead of the worst case 8%.

Also, at the time of the operational programme, it is expected that the actual benefits will be further increased for reasons highlighted hereafter.

4.3 FURTHER EVOLUTION OF BENEFITS IN THE EPS/METOP-SG TIMEFRAME (2020-2040)

In the timeframe of EPS-SG (2020-2040) the actual benefits of forecasts, and thereby the benefit attributable to EPS/Metop-SG observations, are expected to be much higher than the worst-case figures used for the socio-economic benefit calculation, for a number of reasons:

a. The fraction of benefits attributable to Metop-SG satellites may increase if its capabilities are significantly enhanced, compared to the current Metop, enabling Europe to keep its leadership in the provision of satellite observations for numerical weather prediction;

b. Improvements in the absolute accuracy of forecasts due to advances in science, numerical weather prediction and better observations, are likely to disproportionately increase the benefit of the forecast information as its higher accuracy renders it suitable for new decision-making areas (e.g. flood evacuation decisions and the "threshold effect");

c. Improvements in the response of decision-makers to forecasts and warnings;

d. Increasing vulnerability of our society and economy to weather and related hazards;

e. Changing climate and the expectation of more frequent high-impact weather events.

5 OTHER BENEFIT AREAS

Polar meteorological satellites contribute to other important benefit areas or applications, not currently amenable to a quantitative assessment, and for which a qualitative description of the benefits is now provided, including defence and security, nowcasting at high latitudes, contribution to Copernicus services, seasonal forecasting, climate monitoring and benefits to the European space industry.

5.1 DEFENCE AND SECURITY

Most of meteorological satellite systems are civilian, but weather information is also important to support military and security operations such as peace-keeping, humanitarian or other operations undertaken under UN auspices. In such operations, and in particular where no in situ observations are available, meteorological satellites are an invaluable source of input information to produce the weather information required for safe operations. The related benefits cannot be assessed but are certainly significant.

5.2 NOWCASTING AT HIGH LATITUDES

In contrast to geostationary satellites, the frequency of observations (i.e. revisit frequency) from polar orbiting satellites generally increases with increasing latitude. This revisit frequency also increases as the number of polar orbiting satellites increases, assuming appropriate orbit phasing (see figure below). The mean coverage in a 24-hour period ranges from 2 at 50 degrees latitude to 6-7 between 70 and 90 degrees latitude. This coverage frequency is doubled for a dual satellite configuration with 180 degrees orbit phasing.

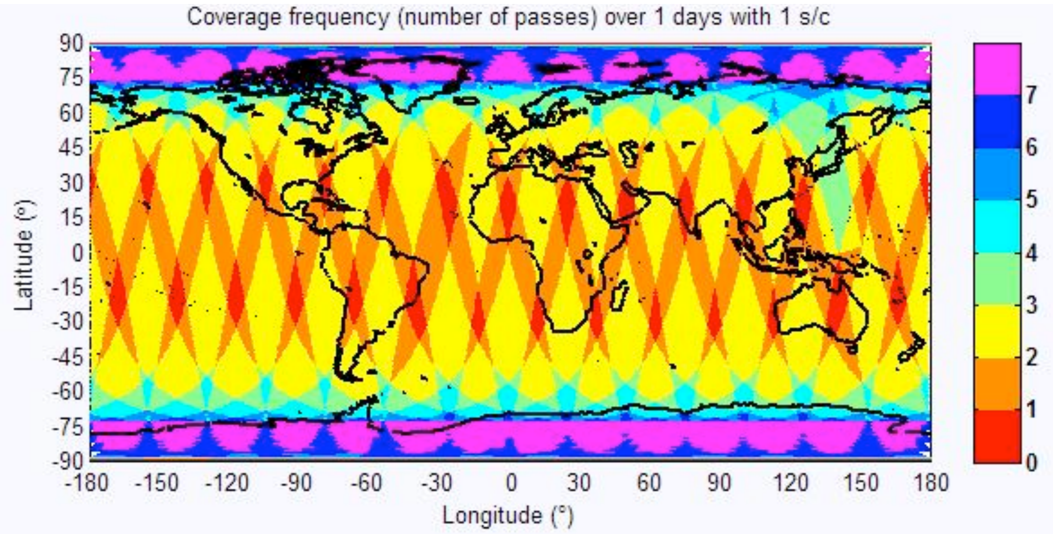


FIGURE 10: REVISIT FREQUENCY AS A FUNCTION OF LATITUDE: NUMBER OF PASSES PER DAY FOR ONE SINGLE POLAR ORBITING SATELLITE.

This frequent coverage provides an opportunity to develop nowcasting services at high latitudes using polar satellite observations. This could be particularly useful for observing extreme phenoma such as “polar lows” which are hurricane-like features found over open ocean in the Arctic region where, due to its remoteness, no conventional observations are available. In this respect studies have shown the potential of IASI data in forecasting such polar lows[37], and large benefits are expected from the combination of visible, infrared and microwave wide swath imagery delivered by the selected Metop-SG instruments (METImage, 3MI, MWI and ASCAT).

5.3 ADDITIONAL BENEFITS THROUGH COPERNICUS SERVICES

Additional benefits are expected from specialised forecast services already developed within the context of the European Earth Observation programme Copernicus , which require weather forecasts as inputs. In the future, such services may be delivered by numerical models coupled to, or integrated with, numerical weather prediction systems.

This is the case for air quality forecasts generated by global, continental, regional and local scale prediction systems, which are used by public and private decision makers to maintain atmospheric pollution levels below harmful thresholds for health through emission regulation measures. It should be further noted that the EPS/Metop-SG satellites are expected to embark infrared and ultraviolet sounding instruments, including the Copernicus Sentinel 5 instrument, which, in combination, will provide a unique set of trace gases and aerosols observations for ingestion in air quality prediction models.

Some ocean and marine forecasts, in the open sea and in the coastal zone, are also highly dependent on accurate forecasts of surface pressure and winds. This is the case for the prediction of storm surges and the transport and dispersion of marine surface pollution, e.g. the likelihood of an oil spill affecting a vulnerable coastline.

It can therefore be assumed that a fraction of the benefits of relevant Copernicus services[38] can be attributed to the performance of weather forecasts and hence, to polar-orbiting meteorological satellites such as EPS/Metop-SG.

5.4 SEASONAL FORECASTING

Potential benefits exist from the use of seasonal forecasts which may, on the one hand, require the production of new information by meteorological services and, on the other hand, depend on the development of new decision-making process by the users of the information. It is however recognised that, in the state of the art, the skill of such forecasts remain less favourable over the European continent than at lower latitudes or in North America.

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[37] Assimilation of Satellite Data for Arctic Weather Prediction, Harald Schyberg (Met. No.), EUMETSAT Meteorological Satellite Conference, Oslo, September 2011

[38] Socio-economic benefits analysis of GMES, PWC et al. 2006, Cost benefit analysis for GMES, Booz& co 2011

5.5 CLIMATE MONITORING

In addition to their central role in forecasting, observations make a key contribution to climate variability; provided such observations span the long time periods associated with the slow dynamics of climate.

As observational continuity is equally essential for weather forecasting and climate monitoring, the instrument complement of EPS/Metop-SG has been designed to provide consistency and continuity with respect to the current EPS/Metop observations, together with some specific capability enhancements.
As many of the EPS/Metop and EPS/Metop-SG observations combine global coverage with long-term continuity and are directly linked to Essential Climate Variables, they will provide a unique contribution to the generation of long series of consistent observations called Climate Data Records that are used in the context of the IPCC for assessing climate variability and change over several decades, and for validating the Earth system models used to deliver climate projections into the next decades. The necessary long-term consistency and coherence of such Climate Data Records is secured through a combination of cross-calibration of observations from overlapping missions (e.g. Metop and Metop-SG in the transition period) and reprocessing.

The financial impact of climate change is likely to be large, with many decisions having to be revisited based on climate change projections[39]. This is particularly true for sectors that are climate-sensitive and where decisions have consequences over many decades.

As an illustration, the infrastructure capital stock within Europe (including housing) is worth at least 200% of GDP. If inappropriate climate information leads to the need to retrofit between 0.1 and 1% of this stock per year over the next century, the total cost would be a 0.2 to 2% consumption decrease, i.e. a consumption loss of €20 billion to €200 billion per year at the current consumption level. Even if this retrofit need appears only in 2050, and with a 4% discount rate and a 2% economic growth, this sum represents a net present value of €500 billion to €5000 billion, equivalent to an annual cost of €10 billion to €100 billion per year henceforth.

So the financial amounts at stake for climate change mitigation and adaptation measures are large and could reach hundreds of billions of Euros per year in Europe during this century. It is likely that accurate information on future climate change, associated with efficient detection and attribution techniques, could result in large savings for the cost of adaptation.

However, as the development of climate services is at an early stage, under the Global Framework for Climate Services (GFCS) recently approved by the WMO Congress, the estimation of the associated benefits of long-term climate information is accordingly embryonic. So, at this stage, it is not possible to make a quantitative assessment of the benefits associated with availability of EPS and EPS/Metop-SG Climate Data Records

[39] Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change, Global Environmental Change, 19, 240-247.

5.6 BENEFITS TO THE EUROPEAN SPACE INDUSTRY

The EPS/Metop-SG programme will be a major development and will directly benefit European space industry and its contribution to GDP. As such it will be a driving force for innovation, competitiveness, growth and the preservation and creation of highly-qualified jobs; thereby contributing to the objectives of the "Europe 2020 Strategy for smart, sustainable and inclusive growth". It will thus represent a major component of the implementation of the European Space Policy, being user-driven and delivering direct benefits to European citizens and, as a result, contributing to the objectives of competitiveness and innovation.

6 CONCLUSION: THE CASE FOR EPS/METOP-SG

The socio-economic benefits of forecasts to Europe are very large, with their contribution affecting many sectors of society.

The accuracy of these forecasts, which ultimately determines their benefit, depends on the availability of relevant and high quality observations, as these observations are used to constrain the forecast models that are the backbone of modern forecasting and provide critical information on the initial state. Without such observations the forecasts would have no skill.

Since the 1980s satellite observations have been increasingly used within forecast models. In this period forecasting accuracy has improved dramatically, typically with an increase of one day's predictability per decade in the medium range. The increased availability of high quality satellite observations during this period has been one decisive factor in this improvement.

By assessing the benefit of forecasts to the European economy in a number of key areas, and then combining this information with impact assessments and highly conservative apportionment techniques, it is possible to derive a socio-economic benefit range for the current EPS/Metop satellite system. The resultant estimated annual benefit range from a minimum of €1.2 billion to a more likely value of €5 billion.

When applied to the EPS/Metop-SG programme, over a period of 20 years ranging between 2020 – 2040 and taking a 2% assumption on annual increase of EU GDP together with a 4% discount rate, the 2010 Net Value of the benefits range from a "minimum" of €16 billion to a more "likely" value of €63 billion.

The conservative nature of these benefit estimates is underscored by the absence of provisions in these figures for the anticipated enhancements to the EPS/Metop-SG instruments the increasing value of forecasts due both to better observations and expected advancements in numerical modelling in the 2020-2040 timeframe, the increasing vulnerability of society and the economy to weather, and the expectation of more frequent high-impact weather events. This estimation also ignores a number of benefit areas, including contributions to protection of life, defence and security, climate monitoring, and direct benefits to space industry. The benefit estimates also take no account of the leverage accruing from the availability of high-quality EPS/Metop-SG observations to the worldwide user community, which stimulates the development of comparable and complementary satellite systems by other space-faring nations. As a result of these developments, additional observations will become available for ingestion into European NWP models; thereby achieving additional positive impacts on forecast accuracy within Europe and, consequently, further socio-economic benefits.

Furthermore, these figures do not include the benefits for those EUMETSAT Member and Cooperating States that are not EU Members (Croatia, Iceland, Norway, Serbia, Switzerland and Turkey).

When these highly conservative annual benefit estimates are contrasted with the estimated cost of the EPS-SG Programme in the order of €3.4 billion (e.c. 2012), **the minimum benefit to cost ratio is over 5 and the likely ratio exceeds 20,** with the understanding that these ratios would increase by a factor of 3, if a 25% apportionment was assumed instead of the worst case 8%.

In conclusion, there is a clear and compelling socio-economic benefit case for ESA and EUMETSAT embarking upon an ambitious EPS/Metop-SG programme that will deliver more capable satellites, secure the continuity of polar observations in the 2020-2040 timeframe and preserve Europe's leadership in the provision of satellite observations for numerical weather prediction.

Therefore deciding on an ambitious EPS-Second Generation programme to continue and enhance the observations from European polar orbiting satellites in the 2020-2040 timeframe, is a strategic investment for the EUMETSAT Member States and their economy. Aware of this, the ESA Ministerial Council, meeting in Naples in November 2012, has already agreed to fund the development of the first Metop-SG satellites, and EUMETSAT Member States are now expected to approve the mandatory EPS-SG Programme by the end of 2014. This will keep Europe's leadership in satellite meteorology, weather forecasting and climate monitoring from space.

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ANNEX I: COMPLEMENTARY CONTRIBUTIONS OF POLAR-ORBITING AND GEOSTATIONARY METEOROLOGICAL SATELLITES

From their very different orbital sensing positions, geostationary and polar-orbiting meteorological satellites provide two contrasting, and complementary, views of the atmosphere.

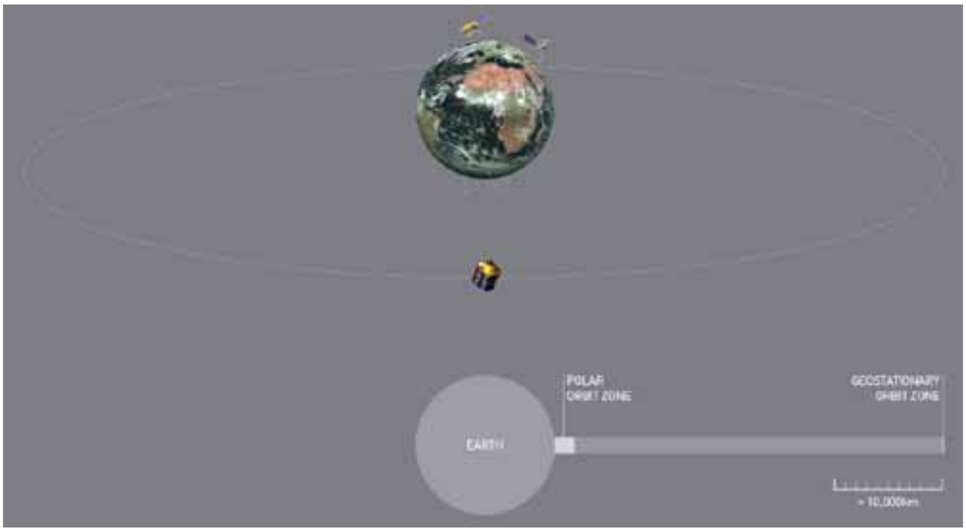

FIGURE I.1: COMPARISON BETWEEN GEOSTATIONARY AND POLAR ORBITS USED BY METEOROLOGICAL SATELLITES

I.1 GEOSTATIONARY METEOROLOGICAL SATELLITES

Geostationary satellites, at an altitude of over 36,000 km, benefit from having a fixed viewpoint relative to the Earth's surface. From this vantage point they can provide frequent observations (e.g. every 10 minutes in the case of MTG) of a fixed region of the globe, typically using a combination of imaging and sounding techniques.

This sensing perspective is very suitable for observing rapid processes associated with the atmospheric water cycle, and is of particular benefit to both nowcasting and regional numerical weather prediction; leading to a positive impact on severe weather forecasting and early warnings. Atmospheric motion vectors, derived from image observations, are also used extensively in numerical weather prediction models.

Sounding observations, which are a relatively new introduction on geostationary meteorological satellites, are used to provide 3-dimensional atmospheric temperature and humidity profiles. In addition to its own intrinsic benefit for numerical weather forecasting, this 3-dimensional sounding information complements, and adds benefit to, the imaging information (e.g. with the more accurate height assignment of the atmospheric motion vectors).

The orbital geometry of geostationary satellites, with a fixed position relative to the Earth, also has some drawbacks. Firstly, the coverage is always regional, which is a major limitation for numerical weather prediction as the sequential process of weather forecasting relies on first having accurate global forecasts, derived from global models, to provide the boundary conditions for limited area models that produce national and regional forecasts. In addition, because of the equatorial sensing position coupled with the curvature of the Earth, the benefit of the observations at high latitudes and the polar regions is correspondingly limited.

Secondly, the spatial resolution from sensors located at an altitude of 36,000km is relatively coarse over European latitudes. For example, at the sub-satellite point on the equator, the spatial resolution of an advanced imaging instrument is typically around 1km. This degrades with increasing latitude (and longitude separation) with the result that over Europe the same instrument would typically have a spatial resolution of between 3 and 4 km (depending on the actual location).

This limitation on spatial resolution has a corresponding impact on the level of detail to which the structure of the atmosphere can be determined from the geostationary orbit (particularly at higher latitudes).

In addition to the limitations on coverage and spatial resolution, the geometry of the geostationary orbit means that some sensing techniques cannot be meaningfully used (e.g. radio occultation, scatterometry,…).

I.2 POLAR-ORBITING METEOROLOGICAL SATELLITES

Polar-orbiting meteorological satellites are positioned much closer to the Earth than a geostationary satellite and have an orbital plane that is almost polar, rather than equatorial.

For example, the altitude of the Metop (EPS) orbit is 837km, which means that its sensing position is 42 times closer to the Earth's surface compared to a geostationary satellite.

The orbital parameters are also usually selected so that the orbit is sun-synchronous (i.e. the satellite crosses the equator at the same local solar time every orbit – keeping the angle of sunlight on the Earth as constant as possible and thereby providing consistent sensing conditions).

In addition, such orbits provide full global coverage and, in the case of Metop, this is achieved approximately every 5 days. Also, in direct contrast to the coverage from geostationary orbit, the polar and high latitude regions enjoy excellent coverage due to the near polar orbital plane.

From this much lower altitude it is also possible to observe the atmosphere in finer detail (compared to what is possible from a geostationary orbit) using a combination of imaging and sounding techniques. In addition, from this altitude it is possible to accurately sense the amount of water vapour at the top of the atmosphere using radio occultation sensing, and to measure the near surface wind vectors over the ocean using scatterometry techniques.

The information from polar-orbiting meteorological satellites, with their global coverage and wide range of sensing techniques, provides the core set of satellite observations for ingestion in global forecast models, and is an important determinant of their forecast accuracy.

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EUMETSAT also has established cooperation agreements with organisations involved in meteorological satellite activities, including the National Meteorological Services of Canada, China, India, Japan, Korea, Russia and USA.

MEMBER STATES

COOPERATING STATES

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* Pending ratification