Anonymous Referee #5

While I understand the importance of reporting on large analysis projects such as this one and the need for systematic generation of observation products, this paper suffers from unclear goals and an poorly defined target audience: is it supposed to be a "project description" paper or is it supposed to be a report of scientific progress? Assuming the former, then all the details about algorithms and processing can be drastically reduced in favor of outlining (more clearly) the goals, planned or on-going activities, and (possibly) some initial accomplishments. Assuming the latter, then much of the programmatic material could be reduced in favor of more complete discussions of the scientific principles behind the analysis approaches. The text makes this project sound like a mere "data factory" – there is no sense of how the products would actually be used to investigate the problems mentioned. In fact, the evident mismatches of space-time resolution and coverage of the products are simply ignored as if this would not affect actual research using these products, nor is there any consideration of WHAT ELSE would be needed to carry out the research ? as if the four products discussed are sufficient by themselves.

Reply:

We thank the reviewer for the straight and critical comments. After some replies to the general comments, we reply in the following for each theme separately in as much detail as possible.

Indeed there should be some consistency among the products, but actually the project was prepared as four separate thematic priorities identified in close collaboration with the GEWEX scientific community: evapotranspiration, soil moisture, clouds and water vapour among other water cycle components (Scientific Consultation Workshop, Vienna University of Technology, 14th April 2008, ESA, 2008). These four products were selected as it was mainly a trade-off between ESA interest, data availability and budget constraints.

Assuming a programmatic paper, this document is unacceptable because it makes exaggerated and sometimes false claims of what it will do. For a program that claims to be co-sponsored by GEWEX, the text completely ignores all GEWEX activities and data products as if they did not exist. In fact the discussion is completely disconnected from the international research community and its activities ? it is written as if no one else is working on related products or research. These disconnects are illustrated by the opening claim that the data products to be produced are ?novel?. This claim is simply false: not only have many others produced similar products before, some of those products are GEWEX products that are longer-term that are more complete and much more thoroughly evaluated than what is discussed here. Of course, improvements are possible but then the discussion should focus on what deficiencies there are and HOW the WACMOS effort will fix them. There is none of that here. It is completely unacceptable to ignore the other data products that are already available or to simply say that they are deficient in some way (without citations to relevant literature). It is completely unacceptable to simply assert the superiority of some different algorithm or approach without any discussion of how it differs from previous ones ? just because it is different does not make it better.

Reply:

This project was initiated by ESA in consultation with GEWEX but is not a GEWEX activity. The project requirements were prepared in collaboration with the International GEWEX

Project Office with the support of several individual experts contributing to GEWEX activities.

The idea was to create some exploratory initial demonstration products in order to coordinate with other activities and this is organized in a workshop in Vienna on 3 April 2011.

We consider that a product is novel when it has not existed before either because the method is new or because the data used is different from previous/other ones or both, and this is fact for all four themes even though other equivalent observations/products from other sensors do exist.

We did not "simply assert superiority". In the modified text we have tried to justify what has been achieved in this project when compared to independent observations as much as possible, in particular we base our statements on validation using in-situ observations of the different products. It was beyond the scope of this project to assess all previous products, but we have referred to all relevant papers and products in order to put our results in the relevant context. We hope that the reviewer could agree with us that not all the problems related to the water cycle components have been sorted out and the existing products are useful to this respect but there is much room for improvement.

Assuming a paper that is a summary of scientific results, this document is even more unacceptable because it misrepresents what the data products will be like and relies on algorithms that are as yet untested ? the so-called validation plans discussed are far from sufficient as compared with what has already been done for other available products. In fact, the text itself raises some serious issues that are not yet resolved with no indication of how they will resolved in this project, yet the introduction makes it all seem ?wonderful?. As a scholarly work, the text is completely lacking in connection to the relevant literature – what is the context of this project, it makes statements about how such products can be produced that are not true, and it generally does not represent the actual state of knowledge about these measurements. These shortcomings are much more egregious for the more mature quantities, water vapor and clouds, that have be analyzed for the past several decades, but the presentations concerning evapotranspiration and soil moisture also do not represent what is known about such products.

Reply:

We agree with the reviewer that we have not reported all the validation done. In the revised text, we have added more validation results and have modified all the text, tables and figures accordingly.

We have made every effort in the different themes to make the connection with the previous work. (Please see reply to specific comments). The abstract, introduction and background and objectives parts are revised as following:

"Abstract

Observing and monitoring the different components of the global water cycle and their dynamics are essential steps to understand the climate of the Earth, forecast the weather,

predict natural disasters like floods and droughts, and improve water resources management. Earth observation technology is a unique tool to provide a global understanding of many of the essential variables governing the water cycle and monitor their evolution over time from global to basin scales. In the coming years, an increasing number of Earth observation missions will provide an unprecedented capacity to quantify several of these variables on a routine basis. In this context, the European Space Agency (ESA), in collaboration with the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Program (WCRP), launched the Water Cycle Multi-Mission Observation Strategy (WACMOS) project in 2009. The project aims at developing and validating a novel set of geo-information products relevant to the water cycle covering the following thematic areas: evapotranspiration, soil moisture, cloud characterization and water vapour. The generation of these products is based on a number of innovative techniques and methods aiming at exploiting the synergies of different types of Earth observation data available today to the science community. This paper provides an overview of some preliminary findings of the project with the ultimate goal of demonstrating the potential of multi-mission based strategies to improve current observations by maximizing the synergistic use of the different types of information provided by the currently available observation systems. It describes the rationales and objectives of the WACMOS project and introduces its preliminary products.

1 Introduction

The water cycle is a complex process driven chiefly by solar radiation. The evaporation of water from open water and soil and wet surfaces is controlled by energy and water availability and near-surface atmospheric conditions (air temperature, humidity and wind-speed), while transpiration of water is also controlled by plants. The result of evaporation and transpiration is the presence of water vapour in the atmosphere, a prerequisite for cloud formation. If cloud condensation nuclei are present and if the atmospheric state allows for condensation, clouds are formed which are then globally distributed by winds. In the presence of precipitating clouds, water returns back to the Earth's surface where it accumulates in rivers, lakes and oceans. Surface water may also infiltrate into the soil, moistening the soil layers and accumulating as groundwater replenishing aquifers. Aquifers can store water for several years, provide water for human activities, or discharge it naturally to the surface or to the oceans. The response of the hydrological cycle to global warming is expected as far reaching (Bengtsson, 2010), and because different physical processes control the change in water vapour and evaporation/precipitation, a more extreme distribution of precipitation is expected leading to, in general, wet areas wetter and dry areas dryer and as such the changes in the hydrological cycle as a consequence of climate warming may be more severe that the temperature changes, due primarily to large increases in extreme precipitation rates (Lenderink and van Meijgaard, 2010).

In this context, relying on accurate and continuous observations of the long-term dynamics of the different key variables governing the above processes from global to local scale is essential to further increase not only our understanding of the different components of the water cycle both in its spatial and temporal variability, but also to characterise the processes and interactions between the terrestrial and atmospheric branches of the energy and water cycle, and how this coupling may influence climate variability and predictability. Such global and continuous observations can only be secured by the effective use of Earth Observation (EO) satellites as a major complement to in-situ observation networks.

In recent years, EO technology has proved to be a major source of data to retrieve an increasing number of hydro-climatic variables from space, including radiation and cloud properties (Schulz et al., 2009), precipitation (Kummerow et al., 2001; Huffman et al., 2007; Kidd and Levizzani, 2010), evapotranspiration (Kalma et al., 2008; Jiménez et al., 2011), soil moisture (Aires and Prigent, 2006; De Jeu et al., 2008), water vapour (Schulz et al., 2009), *and many others (see for example, GEO, 2005; ESA, 2006; CEOS, 2009; Su, 2010). Such measurements not only have enhanced our capabilities to predict in a reliable manner the variations in the global energy and water cycle but also have provided a key contribution to the improvement of water governance, the mitigation of water-related natural hazards and the sustainable human development (GEO, 2007; IPCC, 2008).*

This paper introduces the Water Cycle Multi-mission Observation Strategy (WACMOS) project including its background and objectives (section 2), summaries its products (section 3), its methodologies, retrieval results and validations (section 4) and ends with conclusions (section 5).

2 Background and objectives

The past years have seen an increasing earth observation capacity in terms of new missions and sensors. Despite some important improvements in retrieval algorithms and data products, as well as dedicated efforts to better integrate EO-derived products into hydrological models (e.g. McCabe and Wood, 2006; Kalma et al., 2008; Wagner et al., 2009; Ferguson et al., 2010; Gao et al., 2010; Su et al., 2010), the full exploitation of EO technology by the hydrological community is still in its early stages. In order to fully exploit this increasing potential and bring this newly available capacity to practical operational levels, significant scientific efforts are required in order to:

- *Develop validated products for which the range of validity and uncertainties are known and characterised. This will involve the development of robust physically based algorithms supported by a strong validation and inter-comparison exercise;*
- *Consolidate the development of consistent long-term data sets by integrating different EO systems in a synergistic manner. In this context, the development of long-term consistent data records will rely on equivalent and comparable measurements from different systems and to ensure data consistency separating instrument drifts from geophysical drifts.*
- *Develop robust methodologies to integrate and assimilate space observations and in situ measurements into advanced coupled models of biophysical processes and interactions between ocean, land, and atmosphere describing the water cycle and hydrological processes.*

Despite the availability of a lot of satellite data for the assessment of different components of the water cycle, water budget closure at the scale of even large continental river basins is not possible currently on the basis of satellite data alone (Gao et al., 2010). In the coming years, an increasing number of EO missions will provide unprecedented possibilities to observe the Earth's surface, its interior and the atmosphere, opening a new era in EO and water cycle science and therefore also in hydrology and water resources management. As an example, ESA's Soil Moisture and Ocean Salinity (SMOS) mission (Kerr et al., 2001), launched in November 2009, aims to provide soil moisture and ocean salinity information. These measurements will soon be complemented by NASA's Soil Moisture Active and Passive mission (SMAP) (Enthekabi et al., 2004) planned for launch in 2014-2015 and the Aquarius satellite (http://aquarius.nasa.gov/) for ocean salinity planed for launch in 2011. SMAP will provide global maps of soil moisture and surface freeze/thaw state. Other examples include the Surface Water and Ocean Topography (SWOT) (http://swot.jpl.nasa.gov/), the Global Precipitation Measurement (GPM) mission (http://gpm.gsfc.nasa.gov/), planned to be launched in 2013, and the ESA's EarthCARE mission (ESA, 2004; http://www.esa.int/esaLP/ASESMYNW9SC_LPearthcare_0.html) aiming at improving the representation and understanding of the Earth's radiative balance in climate and numerical weather prediction models. The current requirements for the imager onboard the next third generation of METEOSAT and for the imager onboard Post-EPS foresee water vapour *channels within the ρστ-water vapour absorption band. MERIS-like observations will be continued on the GMES sentinel 3 mission with the Ocean and Land Colour Instrument (OLCI). Depending on the quality of the final products and final instrument designs an operational processing of several water cycle products seems possible within the next few decades.*

In this context, the European Space Agency (ESA) in collaboration with the Global Energy and Water Experiment (GEWEX) of the World Climate Research Program (WCRP) launched the Water Cycle Multi-mission Observation Strategy (WACMOS) project in 2009. The project, funded under the ESA's Support To Science Element, addresses the first two of the above challenges. In particular, the ultimate project objectives are twofold:

- *Developing and validating a novel set of enhanced geo-information products responding to the GEWEX scientific priorities and exploiting the synergistic capabilities between ESA EO data and other non-ESA missions.*
- *Exploring and assessing different methodologies to exploit in a synergistic manner different observations towards the development of long-term consistent datasets of key hydroclimate variables describing the water cycle.*

In this context, WACMOS is focused on four components of the water cycle that are also thematic priorities identified in close collaboration with the GEWEX scientific community: evapotranspiration, soil moisture, clouds and water vapour (Scientific Consultation Workshop, Vienna University of Technology, 14th April 2008, ESA, 2008). The latter three of these components also belong to the Global Climate Observing System (GCOS) Essential Climate Variables (ECVs) for Long-term systematic observation needs of World Climate Research Programme (WCRP) (GCOS, 2006, http://gcos.wmo.int), while the retrieval of the evapotranspiration requires the use of several atmospheric, oceanic and terrestrial ECVs. Since the WACMOS project is an exploratory project rather than a product development project in its current phase, it is important to note that the boundary conditions (a focus on the use of ESA data) and constraints (limited timeframe and budget), hence the outcomes of the project emphasize on the development of algorithms and their validation and preliminary generation of sample data products. A more consistent generation and validation of all WACMOS products and their exploratory applications in water and climate researches and applications need to be addressed in a follow up phase.

In this paper, an overview and short summaries are given for each WACMOS component; the more detailed technical descriptions can be found elsewhere in this special issue (Timmermans et al., 2010; Dorigo et al. 2010; Wolters et al., 2010).

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The conclusions section begins with the statement that "... understanding the role of the global water cycle ... " requires measurement "... from space hydro-climatic variables." So, this project measures four of them but never discusses what will be done with them... they are certainly not sufficient for water cycle studies by themselves. These four products are certainly not "novel" (I can get several examples of each right now) and the analysis approaches described are far from "innovative", so what is going on and why?

I do NOT recommend publication of this paper.

Reply:

The conclusions section is rewritten to reflect the revision in different parts. A comparison text is provided including track changes to previous version.

Some specifics about the "novel" data products: evapotranspiration, soil moisture, clouds and water vapor. None of these products is new and even the analysis approaches are not completely new.

(1) Recent published work has listed more than a dozen global, daily evapotranspiration products produced by a variety of approaches including the one described here. The claim that "current algorithms are too complex for global implementation" is simply false as demonstrated by the existence of many global products. Exactly what satellite measurement provides 1 km and daily resolution with complete global coverage? A daily "repeat time" – that is, daily sampling interval – completely ignores the whole issue of diurnal variations of evapotranspiration, which are not insignificant. In fact, once we see the details, this product is mostly a modeling construct, not an observational product though some observations are used. The model in question has all the numerous ill-defined, un-measured land surface and vegetation parameters that, in this plan, are not constrained by any observations – there is no explanation of where all the OTHER information will come from. Some of the already-existing products mentioned above use not only more observations than proposed here but more direct approaches to determining the latent heat flux. The authors state explicitly that "no global products of net radiation... exist".... which GEWEX are they co-sponsored by? In the absence of some cloud-penetrating measurement, there is no explanation of how cloudy-day fluxes are determined. Although they say they will evaluate the models use, there is no indication of what data products are needed for this (NOT reanalysis, please) or where they will be obtained from.

Reply related to evapotranspiration:

We are aware of the ongoing different initiatives. We have updated the literature review to incorporate recent and other publications. Some of these publications could only be added now, as the relevant papers became available only after the submission of this manuscript. Other publications deal with approaches that do not conform to the requirements set during the initial phase of this project. These initiatives however should have been cited earlier, this has now been corrected. We have improved the general consistency of the description and referred to Timmermans et al. 2011 for more technical details. We do not agree with the suggestion by the reviewer that the problem is sorted out because "the existence of many global products"; as a matter of fact, once one is interested for a certain application, one is confronted with the lack of products for a certain resolution in both time and space and the availability of data for a certain period.
The claim by the reviewer also contradicts recent studies investigating these aspects. To illustrate this, we have added in the text "Despite the availability of a lot of satellite data for the assessment of different components of the water cycle, water budget closure at the scale of even large continental river basins is not possible currently on the basis of satellite data alone (Gao et al., 2010)." Other relevant works are cited in the text.

Some more specific replies are given below for the more technical aspects.

Diurnal cycle:
The data used is obtained from MERIS/MODIS and AATSR sensors which have a spatial resolution of 1km for thermal spectrum (surface temperature) and higher resolution for the

optical part if one uses level 1B data. However these sensors have a limited revisit time. In essence the product being generated will be level 2 data (including data gaps due to absence of observation or cloud cover). We are currently experimenting with incorporating geostationary data into the methodology which opens the possibility to capture the diurnal cycle. In this aspect we agree with the reviewer that the evaporative fraction can have a diurnal behaviour. The research performed in this project however adapts the hypothesis that the evaporative fraction during the day is stable. This hypothesis of course induces uncertainty in the final product, but is needed to reduce the computational demands of the current methodology. The incorporation of geostationary satellite data will be performed at a later stage. This explanation has been added into the text.

Data:
We agree with the reviewer that evapotranspiration/latent heat cannot be measured directly from space. Instead the fluxes constraining the latent heat are calculated using three sets of variables: land surface variables that are obtained using remote sensing observations and existing retrieval algorithms (Table 2 provides details of variable dependence), atmospheric variables that are obtained from a large scale atmospheric model (ECMWF, Table 3), and radiative variables that are also obtained using the large scale atmospheric model (ECMWF). The remotely sensed albedo is used to derive the outgoing shortwave radiation from the modelled incoming short wave radiation; surface temperature and emissivity are used to derive the outgoing longwave radiation; thus generating a higher resolution net radiation when combined with the model outputs of incoming longwave radiation. ,
We did consult the GEWEX net radiation products, the resolution of 100km is not considered suitable for the requirements given in Table 1. Further cloud contamination remains a problem for optical remote sensing. Although combined use of optical/thermal information with microwave information can improve the situation, the full investigation is beyond the scope of this paper.

Validation:
The validation of the product is performed using data from the CarboEurope/Fluxnet Initiative over land. Over Ocean, although the product is compared against model outputs of the Cummunity Land Model (CLM) and ECMWF, this does not constitute a validation. While this is less optimal (we preferred to do the validation against observations of the SeaFlux initiative, but data have not been opened to us).

Figures 2,3 and 5 are updated.

(2) Soil moisture has been produced UNsuccessfully from SSM/I for a couple of decades and there are at least two products from AMSR-E that look nothing alike. There is no available evidence that the AMSR-E soil moisture products are the "most reliable" – which one is the most reliable? It is true that AMSR-E has two channels with lower frequencies than SSM/I, but they are still no where near as low a frequency as called for in all the textbooks about soil moisture effects on passive microwave measurements. We have known this since SMMR yet people keep on wishing it weren't true. There is no credible evidence presented that the completely different measurements from the passive and active instruments, with a frequency range of about a factor of 4, can be merged – it is well-known that these sensors do NOT see the same surface properties. Apparently, the data will just be "smashed" together. Actually, this product is going to be tuned to agree with an UN-VALIDATED land surface model... it is not a observation product at all! The final merger of all these disparate measurements, despite spot-cross-checks (which appear to assume all differences are random errors), is to be done by

selecting different measurements for different situations – every time this has been tried in the past, it has failed to produce homogeneous products that are useful for climate. Again, there is a lot of attention paid to large spatial variability at small scales and no attention paid to time variability, especially diurnal and weather-related.

SM reply:

SSM/I

In 1977 Njoku and Kong wrote an important pioneer paper on the theory for passive microwave remote sensing of near surface soil moisture. In their study they demonstrated that the most reliable soil moisture retrievals could be obtained from low microwave frequencies (< 4 GHz). But they also showed that higher frequencies (~19 GHz) also contain soil moisture information. These findings were also confirmed by the microwave handbook series of Ulaby et al. (1986).

Now more than 30 years later several researchers did demonstrate the limited capability of SSM/I to derive soil moisture values from deserts and semi arid regions (i.e. Owe et al., 2008, Liu et al., 2009). In addition Dorigo et al. 2010 actually quantified the error of SSM/I soil moisture retrieval at a global scale. Within the WACMOS long term soil moisture dataset SSM/I soil moisture only plays a minor role. Because the soil moisture errors of this dataset are large and it has a limited spatial extent (only useful over deserts and sparse vegetated region i.e. see Owe et al., 2008). In practice this means we only use the SSM/I data in the WACMOS soil moisture dataset for the period between August 1987 and 1991when ERS data became available.

AMSR-E

From the used passive microwave satellites within the WACMOS soil moisture dataset only AMSR-E, Windsat and SMMR carried a C-band radiometer. From these three satellite sensors, AMSR-E has the best coverage and the highest temporal, instrumental and spatial resolution.

Soil moisture retrievals from all these different satellites have been validated extensively using ground observations, models and other additional datasets (e.g. already more than 20 papers on the validation of LPRM alone using SMMR (e.g. Owe et al., 2001, De Jeu 2003, De Jeu and Owe 2003, Liu et al., 2009), AMSR-E (e.g. Champagne et al. 2010, Draper et al., 2009, Wagner et al., 2007, De Jeu et al., 2008, Rudiger et al. 2009, Loew et al., 2009, Schuman et al., 2009), TRMM (e.g. Gruhier et al., 2010, Scipal et al., 2008, Jung et al., 2010) and Windsat (e.g. Parinussa et al., 2011b). Based on all these studies, we think it is fair to say that we are aware of the quality of all our soil moisture products. In addition we applied different statistical methods to quantify the quality of the different products (i.e. triple collocation (see Dorigo et al., 2010) and error propagation (see Parinussa et al., 2011a)

Smashing

We think smashing is not the right word for our approach. We use statistics to rank and merge these different products. Both the method we used to rank the different product (triple collocation method) and the merging strategy have been used by other research groups and have been published in several peer reviewed journals (e.g. Miralles et al., 2011, Drusch et al 2005, Reichle et al., 2008). In addition our complete merging approach has been evaluated by other different research group and has recently been published in HESS (Liu et al., 2011).

Tuning

The WACMOS soil moisture dataset uses GLDAS Noah data to scale the set. This is something different than tuning because you don't change the temporal behaviour of the dataset. The impacts of scaling are well described in Liu et al., 2011 including validation with ground observations.

Passive vs Active

Both passive and active systems respond directly to changes in the dielectric properties of the soil and both are used to retrieve surface soil moisture. The differences and similarities between active and passive are well studied over the past 30 years (e.g. Ulaby et al., 1986) and recently very intensively with the upcoming launch of SMAP.

Section 3.2 has been updated and added with most relevant additional literature.

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(3) About a dozen cloud products are being compared by GEWEX now, not to mention the ISCCP product which does more than is discussed here. By the way, the group producing the cloud product here is NOT participating in this GEWEX effort, but has been conducting its own separate activity – nothing wrong with that but then should not be claimed to be GEWEX co-sponsored. The proposed retrieval approach does not even account for variations of other surface and atmospheric quantities that are "routinely" accounted for by a number of other

cloud products that are already available. Many of the sub-products appear to be monthly mean products – what is the value of that? Again, diurnal variations are completely ignored, which is especially problematic for precipitation. Especially alarming are the cavalier claims about inferring precipitation from the cloud properties. How can day-time-only cloud property measurements be used to characterize the convective rainfall events in the evening, which are known to constitute an important, if not dominant, contribution even over land? If precipitation intensity could really be trivially calculated from current-day determinations of cloud water path (what about ice?) and particle size (known to be biased to cloud top), then there would be no problem with precipitation in GCMs – this is very simple physics – and this approach could be verified against measurements that have been available for the whole MODIS epoch at least. While SEVIRI can obtain the cloud parameters for the "Meteosat view" with high time resolution, what is going to be done with SCIAMACHY, which takes many days to provide ONE sample with complete spatial coverage – this is never explained. Why develop a new surface radiation product when WACMOS is (supposedly) co-sponsored by GEWEX – even so, why not compare to the GEWEX product?

Reply:
The reviewer perceives that many of the cloud products that are delivered within WACMOS are monthly mean products. We want to emphasize that the examples shown in this overview paper certainly do not capture the entire range of possibilities to present our cloud products. Especially for the SEVIRI products, instantaneous SSI and PRP retrievals will be available at the nominal temporal and spatial resolution of 15 minutes and 3×3 km^2, respectively.
We realize that the SCIAMACHY SSI product should be evaluated in the context of GEWEX. Within the WACMOS project we found that the major strength of the SCIAMACHY product is in its temporal stability The SSI retrieval from SCIAMACHY is based on radiative transfer theory, and therefore can be applied to different satellite measurements. From the time-series of GOME and SCIAMACHY measurements, which covers 15 years a consistent SSI time series can be constructed. Such a time series might be a good alternative or complement to global SSI data sets retrieved from ISCCP. Due to the calibration units on-board of GOME(-2), SCIAMACHY and OMI a high potential for the construction of a climate data record with high stability and homogeneity is present. To emphasis this point we added the following lines in the conclusions section:

"Due to the calibration units on-board SCIAMACHY, and its predecessors GOME and GOME-2, the SSI retrievals from these instruments are high potentials for the construction of Thematic Climate Data Records with high stability and homogeneity, and complement the SSI datasets that have been assessed within GEWEX."

Another concern of the reviewer is the ignorance of diurnal variations in the precipitation retrievals. We acknowledge that through using visible/near-infrared reflectances our algorithm is limited to daytime only observations and that as a result a considerable part of night-time precipitation is missed. We will investigate incorporating a night-time precipitation retrieval scheme using the SEVIRI WV and IR channels (see for example Behrangi et al., 2009) in the near future. However, we also want to stress that despite lacking night-time precipitation retrievals, the high temporal and spatial resolution of SEVIRI enables detailed studies on the daytime variation of precipitation, for example over West Africa during the monsoon season (Wolters et al., 2011). In addition, the state-of-the-art TRMM satellite does cover the entire diurnal cycle, but this takes ~45 days, which in turn implies that several years of observations are needed to obtain a dataset with a sufficient sample size for a single location.

Third, the reviewer expresses his/her concern on the usage of retrieved cloud top properties to estimate rain rate. We acknowledge that it has to be realized that any cloud property dataset obtained from passively observed reflectances attempts at providing information on a column-integrated quantity, while for most clouds this is derived from the upper few hundreds of meters of the cloud. However, the precipitation retrieval algorithm contains some physically based thresholds, in particular those for the effective radius and condensed water path, which are close to values of Rosenfeld and Gutman (1994) and Wentz and Spencer (1998).

Finally, the reviewer states that it would have given no problems in current GCMs precipitation schemes if precipitation were simply based on the amount of condensed water path and effective radius. However, we think that any deficiency in the GCM precipitation scheme might not be attributed to a more complex precipitation formation process, but that this likely is connected to unresolved turbulence scales and cloud microphysics.
In addition, with respect to convective precipitation processes, due to the rather coarse resolution of climate models the non-hydrostatic nature of convection cannot be properly parameterized. Reference is made to the work of Greuell et al. (2011) and Roebeling and van Meijgaard (2009), which provide an extensive comparison on the difference between model-predicted and SEVIRI-observed cloud-top parameters and which give further clues on what causes these differences.

References:
*Greuell, W., E. van Meijgaard, J.F. Meirink, and N. Clerbaux, 2011: Evaluation of model predicted top-of-atmosphere radiation and cloud parameters over Africa with observations from GERB and SEVIRI, J. Climate, **24**, in press.*

*Roebeling, R. A. and E. van Meijgaard, 2009: Evaluation of the Daylight Cycle of Model-Predicted Cloud Amount and Condensed Water Path over Europe with Observations from MSG SEVIRI. J. Climate, **22**, 1749–1766.*

(4) Again, there are many already-available water vapor products, including numerous “analyses” and “reanalyses”, some of which have been around for decades. Although there are some new types of measurements available (like GPS-based methods), the proposed exploration of “novel methodologies” – which are never defined – seems focused on infrared measurements for clear sky conditions only. In other words, the novel part of a possible project is not really discussed. That also means that this water vapor product will be spatially and temporally anti-correlated with the cloud-precipitation product, which is very curious – how will water studies be done with these two?

Reply:

The existence of many already available water vapour products has been mentioned in Section 3.4 and as a reference Hollweg (2005) was given in the paper. Despite the large number of already available data sets, e.g. a recent study by Ferguson et al. (2010) has shown that research is still needed. In addition, GEWEX is currently initiating a GEWEX water vapour assessment where the existing data sets for total column water vapour and water vapour profiles will be reviewed and their appropriateness for long-term climate applications will be analysed (GEWEX Newsletter, Feb 2011).

To provide more information to the reader and to point out the possible advantages of the WACMOS water vapour products, some text was added in Section 3.4 (see below) in order to:

- *mention also existing reanalysis products*
- *list the main global single and combined sensor water vapour products*
- *highlight that up to now, the ATOVS water vapour products are the only ones for which a merging of different instruments in horizontal space is done over a long time period.*
- *mention the work by Lindenbergh et al. (2008) who present a Kriging method for combining Global Positioning System (GPS) and MERIS total column water vapour estimates in space and time for a single day in August 2003*

Concerning the novel methodologies that "are never mentioned", the paragraph on already existing data added provides some additional information. As mentioned in the manuscript now, the ATOVS water vapour products provided by CM SAF are – to our knowledge – the only ones for which a merging of different instruments in horizontal space is done over a long time period. Aside, there is the work by Lindenbergh et al. (2008), but they use different types of measurements and perform the Kriging for a single day only.
Although the merging algorithm developed in the framework of WACMOS is based on the work of CM SAF and Lindenbergh et al. (2008), the proposed method is something new from our point of view. Nevertheless we agree to tone down the 'novelty' by using adjectives like 'improved' or 'enhanced'.

Regarding the focus of IR measurements:
It is true that both water vapour products are based on clear-sky measurements only. Nothing is wrong about that, if this is clearly stated. It is a matter of fact that the focus on IR measurements and the resulting restriction to clear-sky cases results in the well known clear-sky bias compared to all-sky measurements. This could only be avoided by using additional (e.g. passive microwave radiometers) measurements which allow the determination of water vapour within clouds. This is outside the scope of our work, but could be a next step – given that the benefit of the merged products (i.e. SEVIRI+IASI and SEVIRI+MERIS) has been shown.
In the manuscript a sentence on the clear-sky bias is added (see below) including the references *Lanzante and Gahrs, 2000; Sohn and Bennartz, 2008.*

In terms of the 'anticorrelation with cloud/precipitation products' we refer to the reply at the beginning of the review where we mention that the project was prepared as four separate thematic priorities. Since the water vapour products are provided for clear-sky only, they are complementary in space to the cloud products. They are not anti-correlated, because the water vapour content is certainly increased in the vicinity of clouds.

References:

Ferguson, C. R., E. F. Wood: An Evaluation of Satellite Remote Sensing Data Products for Land Surface Hydrology: Atmospheric Infrared Sounder. J. Hydrometeor, 11, 1234–1262. doi: 10.1175/2010JHM1217.1, 2010.

Text added in Section 3.4:

"In addition, satellite observations are used within assimilation methods to generate model-based reanalysis products like ECMWF's ERA-40 (Uppala et al., 2005) and ERA-INTERIM, the Japanese ReAnalysis (JRA-25, Onogi et al., 2007) and the Modern-Era Retrospective analysis for Research and Applications (MERRA) produced by NASA's Global Modeling and Assimilation Office (GMAO) (Rienecker et al., 2011). Exemplary sensors are the Special Sensor Microwave/Imager (SSM/I) carried aboard Defense Meteorological Satellite Program (DMSP) satellites, the Meteorological Operational satellite (MetOp) Infrared Atmospheric Sounding Interferometer (IASI), the METEOSAT Second Generation (MSG) Spinning Enhanced Visible and Infrared Imager (SEVIRI), the Environmental Satellite (ENVISAT) Medium Resolution Imaging Spectrometer (MERIS) and the MetOp Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS). Global single and combined sensor products are publicly available: The daily and monthly mean total column water vapour over ice free ocean with a spatial resolution of (0.5)² from SSM/I data (Anderson et al., 2010) is available for the time period July 1987 to August 2006 from the Satellite Application Facility on Climate Monitoring (CM SAF) and from the University of Hamburg/Max-Planck-Institute for Meteorology. A similar data set is available from Remote Sensing Systems (Wentz, 1997). Atmospheric water vapour profiles (daily, 5-day and monthly means) gridded on a 1° x 1° latitude-longitude grid for the time period 1985-1999 are part of the TIROS (Television Infrared Observation Satellite) Operational Vertical Sounder (TOVS) Pathfinder Path A dataset (Susskind et al., 1997). Within the GEWEX GlobalWater Vapour Project (GVaP), the NVAP total column water vapour product was derived from a combination of SSM/I, TOVS and radiosonde data covering the time period 1988-2001 (Randal et al., 1996). Total column water vapour and integrated water vapour for five thick layers based on the Advanced TIROS Operational Vertical Sounder (ATOVS) suite of instruments is provided by CM SAF (Schulz et al., 2009). Available are global daily and monthly means at a horizontal resolution of (90 km)² for the time period from 2004 onwards. Up to now, the ATOVS water vapour products are the only ones for which a merging of different instruments in horizontal space is done over a long time period. Lindenbergh et al. (2008) present a Kriging method for combining Global Positioning System (GPS) and MERIS total column water vapour estimates in space and time for a single day in August 2003.

> *....*
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> *<old text>*
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> *...*
>
> *Provided the successful development and validation, the expected improvements of the WACMOS water vapour products compared to existing datasets are the combination of benefits from two different sensors and the availability of the water vapour files plus corresponding error maps. In case of the SEVIRI+MERIS product the spatial resolution is better than the grid size of state-of-the-art regional climate models. Furthermore, the continuation of measurements with similar sensors is very likely. On the other hand, it has to be mentioned that both WACMOS products are generated under clear-sky conditions only, because at infrared and near-infrared wavelengths clouds are opaque and do not allow water vapour retrieval. Hence, the clear-sky bias (Lanzante and Gahrs, 2000; Sohn and Bennartz, 2008) compared to all-sky products has to be taken into account when a comparison is done."*

Other problems.

(1) The second sentence of the Introduction starts off with an erroneous statement that means that the whole concept is flawed: incident solar radiation at the surface is not the whole story for evapotranspiration – the net longwave and sensible heat fluxes also play a role, albeit

smaller – but this program completely ignores longwave radiation exchanges. Oceanographers used to do this all the time (although surface temperature is less variable, air temperature is not, which is why it was a poor idea even over oceans), but this approach doesn't even begin to work for land surfaces.

Reply: The model does not rely solely on the incident solar radiation. Instead it characterises the net shortwave and net long wave radiation, through the incorporation of the albedo, emissivity and land/ocean surface temperature. A complete energy balance including sensible heat, latent heat and soil/water heat fluxes is considered (See Su, 2002 as given in the references). This has been updated in the text.

(2) In the Introduction, if these data products are to be used for studying the atmosphere-land coupling processes, then they need to resolve variations – aka meteorological – consistently. Yet, there is no consideration of the different scales of the products to be produced.

Reply: Indeed consistency among the products is important and critical, but because the project was prepared as four separate thematic priorities based on a trade-off between ESA interest, data availability and budget constraints for the current phase of the project. These concerns are addressed as far as the current state of the data processing permits, i.e. to collocate all data products for the same period so as intercomparison and consistency checks can be carried out. A full consideration of the different scales should be considered for different applications and needs to be pursued in a follow up phase.

(3) At the end of the Introduction it is claimed that Earth Observations have already provided a "key contribution to the improvement of water governance" – this claim is not only contradicted by much of the rest of the paper, but is well-known to be false. It may be that these data products can be valuable but they have not been used for this purpose yet.

Reply*: it is arguable to which extent Earth Observations have contributed to water governance; nevertheless EO data have become a major information source for data poor regions. In terms of water budget closure, major progresses have been reported in the literature as cited elsewhere in the text, albeit the fact that the currently available data, including those labelled as GEWEX, do not permit water budget closure at even large river basins. In several other projects we are involved; EO data are used for irrigation water management, water disaster assessment and monitoring, drought and food security early warning and environmental monitoring. These are all parts of water governance in a broader sense. The higher resolution products of evapotranspiration and precipitation are of most relevance to such purposes.*

(4) The words "robust", "integrating" and "synergetic" [sic] (should be "synergistic") are used throughout in the most annoying way... what is actually meant by these words is never explained.

Reply*: We have improved the text to make our description more precise and factual, including some typos. Relevant literatures are included and the tables and figures updated.*

In general, we appreciate that the reviewer has taken time to provide a lengthy critique to our manuscript. We do feel that many assertions are misplaced by suggesting that the efforts in our work are not worthwhile. Such is also in contradiction with the initial use of the available and the interests of the science and user community for access to the available data and algorithms that suggest quite the opposite that the our efforts need to be further pursued in *order to generate consistent data for model verification and parameterization improvements, for water budget closure studies at river basins and regional/continental scales, for feedback studies (evapotranspiration, precipitation, soil moisture), for detection of long term climate variability and trends as well as for data assimilation to improve analysis and forecast skills of key weather parameters.*