ERA-CLIM2

3rd General Assembly

16-18 January 2017 (Univ. of Vienna)

Report

The ERA-CLIM2 3rd General Assembly (GA3), held at the University of Vienna on 16-18 January 2017 and attended by 33 people, provided the ERA-CLIM2 partners and contributors the forum to assess progress. GA3 follows GA1 held in November 2014, and GA2 held in December 2015. During the meeting, open and outstanding scientific and technical issues were discussed, and the work-packages' plans to advance work were presented.

This GA3's report was prepared by the ERA-CLIM2 Coordinator (Roberto Buizza), the Leaders of work-packages 1-4 (Patrick Laloyaux, Matthew Martin, Stefan Brönnimann and Leopold Haimberger) and the external advisor (Sakari Uppala), with input from all the GA3's participants.

The report is organized as follows:

- Section 1 briefly summarizes the main goal and objectives of ERA-CLIM2;
- Section 2 reports the work progress of the past 12 months of the main work-packages (WP1, WP2, WP3 and WP4);
- Section 3 reports the comments of the external adviser who attended the GA3;
- Appendix A lists the GA3 program.

1 ERA-CLIM2 main goal and objectives

The main goal of ERA-CLIM2 is to apply and extend the current global reanalysis capability in Europe, in order to meet the challenging requirements for climate monitoring, climate research, and the development of climate services.

The five main objectives for the ERA-CLIM2 project (see Section B1.1 of Annex I of the Grant Agreement) are:

i. Production of an ensemble of 20th-century reanalyses at moderate spatial resolution, using a coupled atmosphere-ocean model, which will provide a consistent data set for atmosphere, land, ocean, cryosphere, including, for the first time, the carbon cycle across these domains;

ii. Production of a new state-of-the-art global reanalysis of the satellite era at improved spatial resolution, which will provide a climate monitoring capability with near-real time data updates;

iii. Further improvement of earth-system reanalysis capability by implementing a coherent research and development program in coupled data assimilation targeted for climate reanalysis;

iv. Continued improvement of observational data sets needed for reanalysis, in-situ as well as satellite-based, with a focus on temporal consistency and reduction of uncertainties in estimates of essential climate variables;

v. Development of tools and resources for users to help assess uncertainties in reanalysis products.

More information about the ERA-CLIM2 project and a copy of the GA3 talks (see Appendix A for the Agenda and Appendix B for the list of participants) can be accessed from the ECMWF web site, following the links below:

– Project: http://www.ecmwf.int/en/research/projects/era-clim2

– GA3 presentations: http://www.ecmwf.int/en/third-general-assembly-vienna-16-18-january-2017

2 Progress report and plan for 2017

It is worth reminding that, after the 2nd General Assembly held at EUMETSAT in December 2015 and following my request as Project Coordinator, the European Commission agreed to extend the project for 12 months, at no extra cost: thus its end date was moved to 31 December 2017. The main reasons behind this request were:

1. To be able to deliver a prototype coupled analysis system to the Copernicus Climate Change Services (C3S), and thus transfer ERA-CLIM2 R&D outcomes into pre-operational and eventually operational phases of C3S;
2. To be able to complete as many deliverables as possible, including quality-controlled CERA-20C and CERA-20C/Carbon data, and a few years of CERA-SAT and CERA-SAT/Land data.

Results presented at GA3 suggest that the project will achieve these two objectives. Overall, key deliverables are being completed on-time, with only some deliverables linked to data re-processing activities being delayed due to changes in the EUMETSAT computing environment that made the completion of these tasks more complicated and longer than expected. These delays are not having impacts on the deliverables of other work-packages, and on the two objectives stated above. The expectation is that the end of the project, and with the required high-level quality will complete all deliverables by the end of the project.

The past 12 months have seen the CERA-20C reanalysis been completed: this is the first coupled reanalysis of the 20th century, a very impressive and unique achievement. CERA-20C is now being used to generate the CERA-20C/Land and CERA-20C/Carbon reanalyses. The production of a few years of the CERA-SAT reanalysis has started: the aim is to complete 8-to-10 years, say from 2008 to date. Thanks to the extension, more data are being rescued and post-processed, and are delivered to relevant data bases so that they can be used in future reanalysis (e.g. in the forthcoming C3S ERA5 reanalysis, and in the future C3S ERA6 reanalysis). Furthermore, new assimilation methods developed within the project are being integrated in the software repositories, and some of them will be tested to assess their possible impact on future reanalysis.

The progress and plan for 2017 of the ERA-CLIM2 four main work packages, prepared by the ERA-CLIM2 Work-package leaders with input from all participants, are presented below.

2.1 Work-package 1 – Global 20th century reanalysis

WP1 has completed the production of CERA-20C, a new global 20th-century reanalysis which aims to reconstruct the past weather and climate of the Earth system including the atmosphere, ocean, land, waves and sea ice (T1.1). Different diagnostics have been developed to assess the quality of the climate reconstruction and they are discussed below. Associated reanalyses to reconstruct the evolution of the carbon fluxes for the atmosphere and the ocean have been produced (T1.1). New versions will be delivered to correct some flaws and to use the CERA-20C forcings in the ocean carbon reanalysis.

Development and technical works have been finished to implement the coupled assimilation system at higher resolution with the assimilation of satellite observations (T1.2). The production of a second reanalysis (CERA-SAT) over the last decade based on this new assimilation system is ongoing (T1.2) and should be finished by June 2017. The land carbon reanalysis will then be produced based on these CERA-SAT forcings.

2.1.1 Assessment of CERA-20C

First results show that CERA-20C improves on the representation of atmosphere–ocean heat fluxes (Figure 2.1.1) and of mean sea level pressure compared to previous reanalyses. At the same time, there are undesirable discontinuities in ocean heat content and an excessive accumulation of Arctic sea ice.

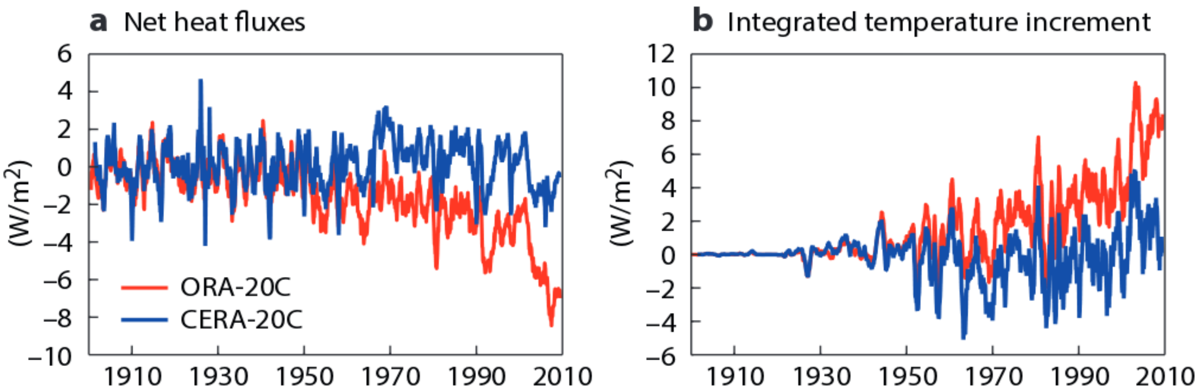

Figure 2.1.1 Time series of CERA-20C and ORA-20C control member values of (a) the global average of net air–sea heat fluxes and (b) the integrated temperature increment over the ocean. The combination of the coupled data assimilation and improvements in the atmospheric data assimilation corrects for the spurious trend in the net heat fluxes received by the ocean seen in ORA-20C. On average, heat flux and ocean temperature increments in CERA-20C oscillate around 0 W/m², suggesting a more balanced system.

2.1.2 Assessment of associated carbon reanalyses

The land carbon reanalysis produced by the ORCHIDEE model with the CERA-20C forcings shows a good agreement when compared to other carbon reanalyses (Figure 2.1.2).

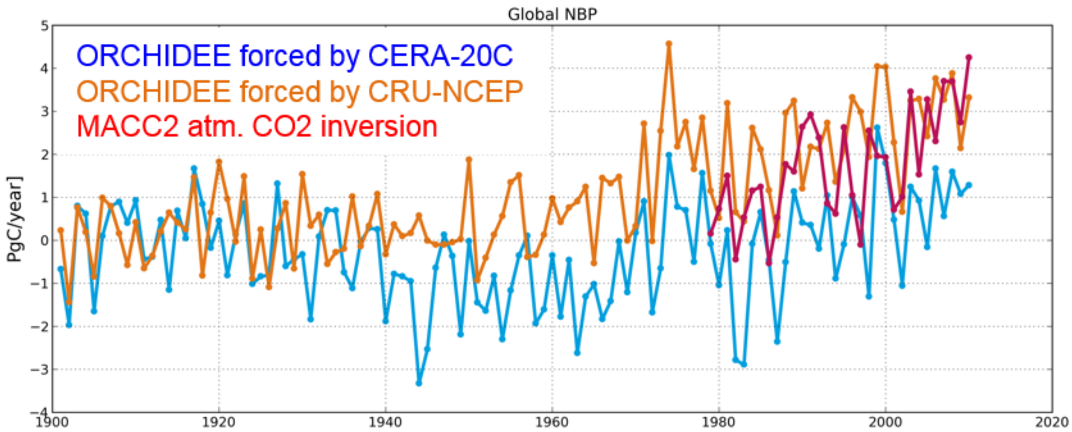

Figure 2.1.2 Global net carbon fluxes from the ORCHIDEE model forced by CERA-20C (blue), from the ORCHIDEE model forced by CRU-NCEP (orange) and from the MACC2 atmospheric CO2 inversion (red).

The sea-air CO2 flux in the ocean carbon reanalysis shows promising results when compared to observations (Figure 2.1.3). Note that forcing from ERA-20C has been used and a new version based on CERA-20C is in preparation.

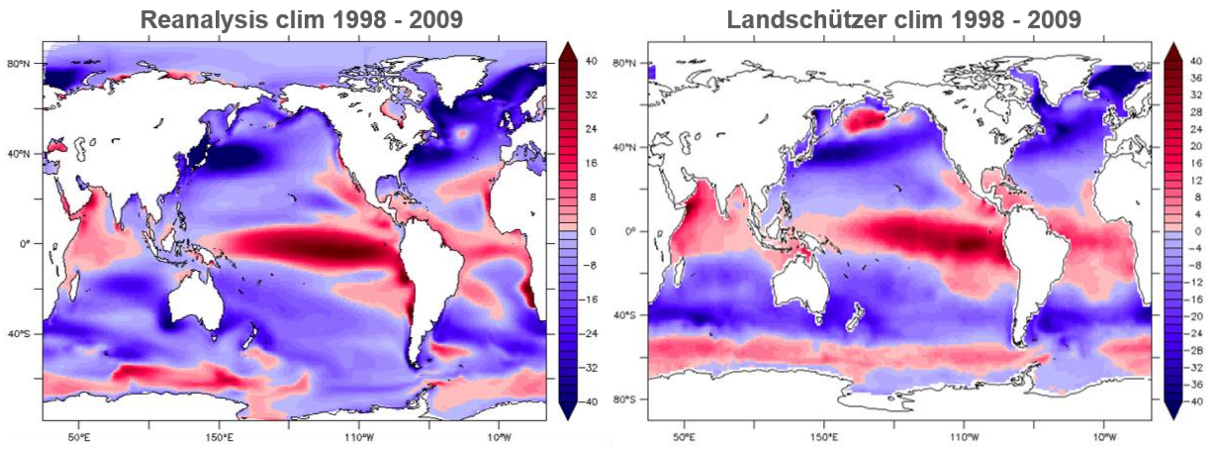

Figure 2.1.3 Climatology of the sea-to-air CO2 flux from the PISCES reanalysis forced by ERA-20C (left) and from observations (right) for the period 1998-2009.

2.2 Work-package 2 – Future coupling methods

WP2 carries out research and development in coupled data assimilation for climate reanalysis, and work on development of the carbon component. Developments will be available for implementation in the CERA framework developed at ECMWF, and the work package will address the special requirements for the pre-satellite data-sparse era and the requirement to maintain a consistent climate signal throughout the entire reanalysis period.

The main tasks within the work package, other than its management and coordination, are:

- T2.2: To include SST and sea-ice assimilation in NEMOVAR
- T2.3: To improve the ocean analysis component including use of ensembles and 4D-VAR
- T2.4: Development of the carbon component of coupled earth system reanalysis
- T2.5: Towards development of fully coupled data assimilation

In terms of the status of deliverables, three of the deliverables (D2.8, D2.9 and D2.12) had been delivered by month 18. In the past 12 months the only deliverable due was D2.4, and this was delivered by CMCC on time. A summary of the progress on that deliverable, and the other deliverables which are due over the next 12 months is provided below.

2.2.1 T2.2: SST and sea-ice assimilation in NEMOVAR

Work at the Met Office has been undertaken to implement two main developments to the NEMOVAR system aimed at improving the capability for SST assimilation within the CERA framework (deliverable D2.1). This should improve the ocean-atmosphere coupling within CERA which currently relaxes to an externally produced SST analysis. The first development is to implement an improved SST bias correction scheme so that changes in the satellite observing system will not introduce spurious trends or jumps in the SST time-series. A scheme was proposed whereby a variational bias correction scheme is combined with a term in the cost function which allows reference observations to be used to give more direct information about observation bias. Theoretical work showed this combined scheme to provide a more robust response to changes in observation bias. The code has been implemented in the NEMOVAR code, and has gone through a review by NEMOVAR partners, and is now available at ECMWF. A demonstration of the code within an ocean-only reanalysis framework is now being undertaken, and a report written to document the code and the tests.

The second development for improved assimilation of SST data at METO aims to use EOF-based error covariances in order to make better use of the sparse pre-satellite in situ data coverage. The scheme was implemented in the NEMOVAR code, and some tests have been run to demonstrate the improvements from EOF-based error covariances compared to the existing scheme in NEMOVAR which models the error covariances as a Gaussian function which does not spread observational information over large scales. Fig 2.2.1 shows the reduction in error from a test run for one month compared to the background, which produces much more reduction in error compared to the current error covariance model in NEMOVAR with the sparse observing network.

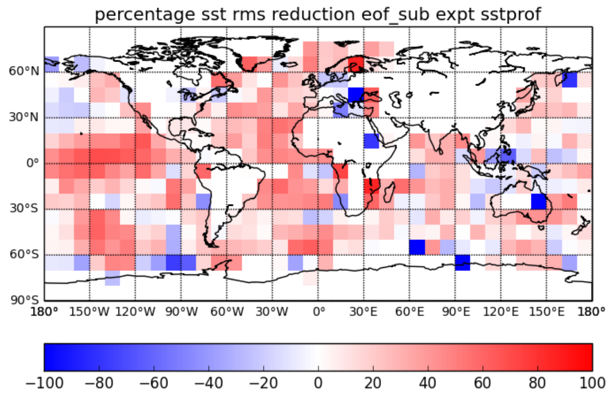

Figure 2.2.1. Percentage reduction in RMS error for SST when compared to independent data for the EOF-based error covariance analysis compared to the background.

Mercator Ocean have been developing assimilation of sea-ice concentration (deliverable D2.2). A system coupling the NEMO3.6/LIM3 model and the Mercator Assimilation System (SAM2) has been developed. An Arctic-Northern Atlantic Configuration at 1/4° (CREG025) has been implemented in SAM2 and is being used to assess improvements to the assimilation of sea-ice concentration. A 7-year free simulation has been produced for the estimation of the uncertainties of the SAM2 analysis where the background error is represented by a prior ensemble of model states. A multivariate sea-ice state vector including sea-ice concentration and volume is used for the sea-ice analysis such that observations of concentration can produce changes to the volume. An anamorphosis transformation is used to move between the sea-ice variable and a Gaussian variable. Multi-year hindcast experiments assimilating EUMETSAT OSI-SAF products have been performed in order to identify an optimal set up for the multivariate sea-ice analysis.

2.2.2 T2.3: to improve the ocean analysis component including use of ensembles and 4D-VAR

CERFACS have been working on implementing the use of ensemble information within a hybrid ensemble/variational scheme in NEMOVAR (deliverable D2.3). The code required to use ensemble perturbations to define the background error covariance matrix (**B**) is complete and has been integrated into the trunk of the NEMOVAR central repository. Two methods have been developed to use ensemble perturbations to define **B**:

1. Estimate parameters (variances and correlation length scales) of the covariance model.
2. Define a low-rank sample estimate of the covariance matrix and localize it using a Schur product.

Hybrid formulations of both (1) and (2) have also been developed in which the ensemble component is linearly combined with a "modelled" (climatological) component. Both formulations include optimally-based algorithms for filtering parameters and estimating hybridization weights and localization scales. Preliminary experiments with hybrid variances have been conducted in collaboration with ECMWF, and Fig 2.2.2 shows an example of filtered background error standard deviation estimates from an ECMWF ensemble ocean reanalysis.

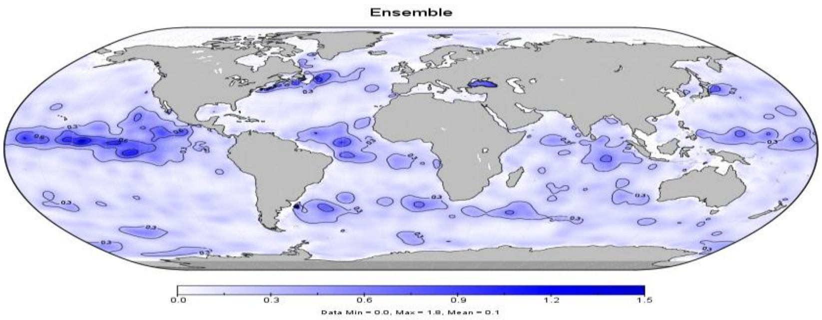

Figure 2.2.2. Example of optimally filtered T error standard deviations at 100m, estimated from the ECMWF 5-member ensemble of ocean reanalyses.

At CMCC, work has been carried out to test ensemble-based error covariances in the context of coupled data assimilation, and have compared that approach to using linearised ocean/atmosphere balance relationships to generate inter-fluid error covariance relationships (deliverable D2.4). An atmospheric boundary layer (ABL) model (CheapAML) has been coupled to NEMO to enable these approaches to be tested. Monthly climatological coupled error covariances have been estimated with different strategies:

1. A linearized balance operator mapping ocean state perturbations to balanced ABL parameter perturbations which is essentially the tangent-linear version of the CORE bulk formulae.
2. Purely statistical covariances between ocean state and ABL parameters are calculated: (a) from ensemble simulations with perturbed wind forcing and (b) from de-trended anomalies with respect to the long-term monthly climatology.

Experiments were performed to investigate the benefits of strongly coupled data assimilation where the ocean observing system is allowed to correct air temperature and humidity at 2 meters through coupled analysis increments. Strongly coupled assimilation appears to produce improved forecasts compared to weakly coupled assimilation, while the impact of ensemble error covariances compared with linearised balance relationships is smaller. The report describing these developments and experiments has been delivered.

INRIA have implemented and tested 4D-VAR in the ocean (deliverable D2.5). With the CERA settings (1° resolution and 1 day assimilation window) it showed only a modest impact compared to 3D-VAR. Because of its importance for biogeochemical models, the impact of 4D-VAR with respect to 3D-VAR on the vertical velocities has been investigated. With the CERA settings, the improvement on vertical velocities is barely noticeable; moreover 4D-VAR shows a strange behaviour on the equatorial band. A digital filter has been added to NEMOVAR, and some further simplification of the TAM dynamics allowed to mitigate this problem. In parallel, experiments have been performed with a higher resolution configuration at ¼°, where 4D-VAR was expected to have a greater impact. Even at this resolution, assimilation windows of length at least several days are necessary to make a significant difference compared with the 3D-VAR. Developments of multi-grid techniques that were primarily designed for making 4D-VAR affordable are now being modified to improve the 3D-VAR performance as well. In particular this requires NEMOVAR to handle several grids at the same time and these developments are being implemented and tested.

2.2.3 T2.4: development of the carbon component coupled earth system reanalysis

LSCE has updated its Carbon Cycle Data Assimilation System (CCDAS) with a new version of the ORCHIDEE land surface model (used in CMIP6). The main areas of work for deliverable D2.6 have been to:

- define a framework/tool to update automatically the Tangent Linear model of ORCHIDEE
- produce a summary of different strategies to minimize the cost function for the CCDAS: gradient-based vs Genetic algorithm (Bastrikov et al., to be submitted).
- compare simultaneous vs stepwise data-stream assimilation
- investigate the potential of new carbon-cycle data streams for the use in the CCDAS: fluorescence data & atmospheric COS concentrations; ice core CO2 data.

An example of the impact of assimilating fluorescence data on the Gross Primary Production analysis is shown in Figure 2.2.3. RMS error reduces from 2.62 to 2.08 globally, with significant improvements in mid-latitude estimates.

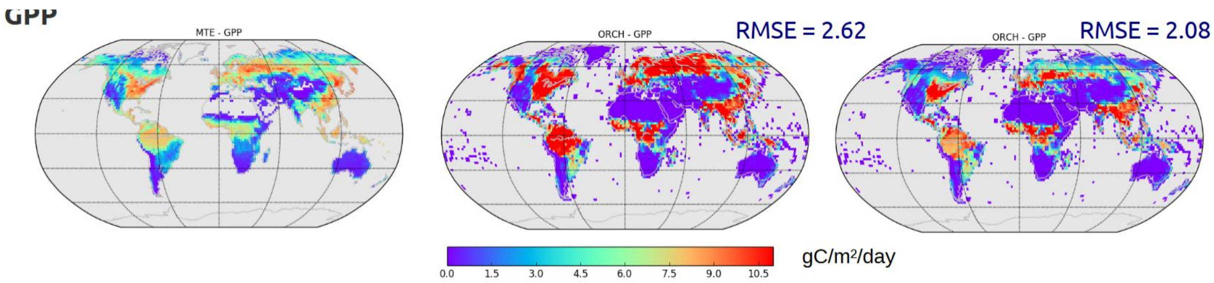

Figure 2.2.3. Impact of the Assimilation of Solar Induce Fluorescence (SIF from GOME-2 data) on the Gross Primary Production (GPP). Left: benchmark GPP (MTE product); middle: ORCHIDEE GPP (prior estimate); right: ORCHIDEE GPP (posterior estimate).

Mercator Ocean are making assessments of alternative methods for coupling ocean biogeochemistry in future Earth system reanalysis for deliverable D2.7. Previous work focused on designing the method for running the ocean biogeochemical reanalysis, and for generating initial conditions. The focus in this area over the past 12 months has been on production work in WP1, so no recent progress in WP2 has taken place on this deliverable.

2.2.4 T2.5 Towards development of fully coupled data assimilation

Deliverables D2.8 [UREAD] and D2.9 [METO] were delivered in month 18. University of Reading have been making assessments of coupled-model drift and approaches for obtaining consistent ocean and atmospheric bias corrections for deliverable D2.10. The impact on seasonal forecasts of the use of equatorial bias correction in the ocean has been analysed and initialisation shocks (period 4-5 days) have been clearly detected in coupled forecasts initialised from the ECMWF ocean reanalysis ORAS4. Initialisation shock can be minimised by slowly removing the bias correction field during the forecast which is found to have a positive impact on forecast SST skill at lead times of a few months (Mullholand et al 2016). SST bias and ocean temperature bias in CERA-20C has also been diagnosed on various time-scales. Approaches are being developed and will be applied in CERA to reduce the bias. Precipitation bias is also being analysed, and appears to be reduced in CERA-20C due to better representation of coupling processes.

INRIA are investigating methods for fully coupled data assimilation in simplified systems with the aim of understanding implications for Earth system reanalysis (deliverable D2.11). The aim is to mimic a Schwarz iterative method to improve coupling convergence within the 4D-VAR framework. To test this idea, a very simple 1D linear coupled system has been implemented and several formulations of the variational scheme have been proposed. They go from strongly coupled to weakly coupled assimilation, with additional terms in the cost function. This work has been accepted as a paper to the CARI2016 conference and presented at the WMO Coupled Data Assimilation Workshop in Toulouse in October 2016. Following the OOPS training school organised at Grenoble in February

2016, this approach has been implemented using OOPS, and the results mentioned above have been reproduced. Additionally, a more realistic toy coupled system mimicking the ocean-atmosphere behaviour has been implemented, is being tested and will soon be interfaced with OOPS.

2.2.5 Outreach

Two important workshops were held recently which were very relevant for WP2. A number of WP2 participants were involved in the GODAE OceanView Data Assimilation Task Team meeting in Santa Cruz, USA, July 2016 (https://www.godae-oceanview.org/outreach/meetings-workshops/task-team-meetings/joint-da-meap-tt-workshop/). ERA-CLIM2 presentations were given by P. Laloyaux on the CERA-20C reanalysis; ensemble ocean data assimilation from A. Weaver; EOF-based error covariances from D. Lea; sea-ice assimilation work from C.-E. Testut; and ocean biogeochemistry from C. Perruche.

There were also many contributions from WP2 participants to the Coupled Data Assimilation Workshop organised by WMO and sponsored by ERA-CLIM2 in Toulouse, October 2016 (http://www.meteo.fr/cic/meetings/2016/CDAW2016/index.html). P. Laloyaux presented the CERA-20C system; D. Lea presented work on coupled DA at METO and WP2 work on EOF error covariances; A. Storto presented work on strongly coupled DA at CMCC; X. Feng presented work on estimating coupled error covariances at University of Reading; J. While presented work on SST bias correction developments at METO; and A. Vidard presented work on strongly coupled DA research at INRIA. A. Weaver and M. Martin chaired a breakout discussion on the challenges and future direction of coupled reanalysis, which aimed to get an international perspective on the future direction for the development work of the type going on within WP2 of ERA-CLIM2. A white paper from the workshop is currently being prepared.

2.2.6 Plans for the rest of the project

The aims for the rest of the project are to continue to make progress against deliverables and to ensure that the reports and code changes are delivered on time. The upcoming WP2 deliverables are due in Mar 2017 [METO, MERCO, INRIA], then Oct 2017 [CERFACS, MERCO, UVSQ, UREAD, INRIA]. The status of the deliverables will be monitored and it was agreed that drafts of reports or code documentation would be provided to the WP2 leader at least one month before due dates to allow for review.

The coordination of code deliverables from METO, CERFACS and INRIA is on-going through the NEMOVAR steering group. These groups are now using the central NEMOVAR git repository hosted by ECMWF so ERA-CLIM2 NEMOVAR code developments will be directly accessible by ECMWF. A discussion on the MERCO code developments for sea-ice assimilation was held, and it was decided that a library of code would be provided to allow the anamorphosis transformation of sea-ice concentration and volume. A template for the reports which describe the code developments has been provided to each of the relevant WP2 partners.

A plan has been prepared between METO and ECMWF to implement and test SST data assimilation capability in the CERA system. This will allow testing of whether the SST assimilation methodology will improve the coupled reanalysis compared to the current approach of relaxing to an external SST product.

2.2.7 WP2 References

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2.3 Work-package 3 – Earth-system observation

WP3 has three main tasks:

- T3.1 - Data rescue for in-situ observations, quality control and metadata
- T3.2 - Satellite data rescue, reprocessing and inter-calibration
- T3.3 - Boundary constraints and external forcing

An overview of the state of the deliverables is given in Table 2.3.1.

Number	Description (Lead beneficiary)	Month
D3.1	Data catalogue (UBERN)	6
D3.2	Priorities for data rescue (UBERN)	6
D3.3	Meta-database update (UBERN)	48
D3.4	In-situ data for reanalysis (UBERN)	36
D3.5	In-situ data (other) (UBERN)	42
D3.6	Quality-controlled version of D3.4 (UBERN)	48
D3.7	Quality-controlled version of D3.5 (UBERN)	48
D3.8	RTTOV updates (METO)	36
D3.9	Early satellite data (METO)	37
D3.10	AVHRR polar winds (EUMST)	**48**
D3.11	SSM/T2 and AMSU-B/MHS radiance data (EUMST)	**42**
D3.12	Geostationary radiance data (EUMST)	**42**
D3.13	AMV from MFG (EUMST)	**48**
D3.14	Radio occultation data (EUMST)	**48**
D3.15	HadISST2 update (METO)	18
D3.16	Ice thickness data (METO)	12
D3.17	Ocean database update (METO)	24
D3.18	Snow data product (FMI)	**42**
D3.19	Quality controlled version of snow data base (in situ) (FMI)	48

D3.20	HadISD update (METO)	12

Table 1: Overview of state of deliverables. Green: Delivered. Red: Delayed – new delivery data is indicated.

2.3.1 T3.1 - Data rescue for in-situ observations, quality control and metadata

With respect to T3.1, D3.4 "In-situ data for reanalysis" was delivered. Note that this deliverable is a continuous one – data have been sent to project partners (UVIE for WP4, ECMWF for WP1) during the entire project and will continue to be sent to ECMWF. This is because, unlike the title of the deliverable implies, most of the data are not used for the production of reanalyses, but mostly for their evaluation. As a consequence, the timing is not critical for the production of further products.

The D3.4 report indicates that in many aspects, the data delivered up to now already exceed the original plan, while the digitisation of some other sources has not yet been fully finished. Furthermore, as new data sources were discovered during ERA-CLIM2, the scope of the data rescue work was expanded. Further sources were inventoried, imaged, digitised and quality-controlled. This work will continue until the end of the project as long as interesting data sources are discovered.

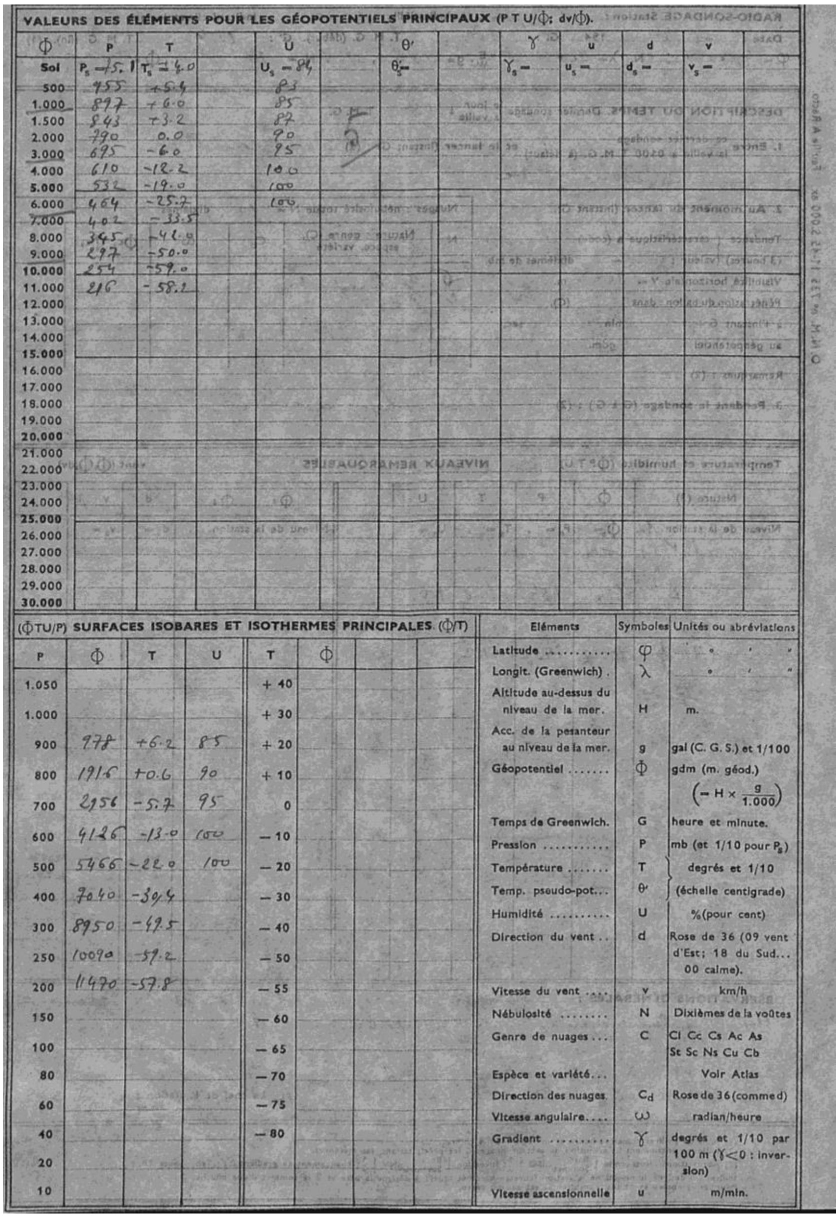
The state of T3.1 can be summarized as follows. In total FFCUL inventoried 40K station days of upper-air and 2.2M station days of surface data (ERA-CLIM and ERA-CLIM2 together). 100% of the upper air data is imaged and digitised, about 97% of the surface data is digitised. The majority of the data has already been quality controlled.

Up to April 2016, METFR inventoried 643K station days of upper-air data (see Fig. 2.3.1 for an example), of which 246K had been defined ‘high priorities’. About 95% of high priorities is imaged, 72% of high priorities is digitised. The inventory is continuously enhanced and updated. The quality control activity of these data is on going.

RIHMI inventoried, imaged and digitized 100% of 390K profiles (9M variables) from 41 upper-air stations. The RIHMI sub-daily (8x) surface station dataset containing 518 stations in Russia from 1966 onwards has been extended backward to the beginning of the stations for 246 selected stations (4x daily). UBERN finished 100% of 754K station days. Note that RIHMI and UBERN finished their tasks for T3.1 already in summer 2015.

The snow data digitised in ERA-CLIM2 have been used in a peer-reviewed publiaction (Wegmann et al., 2016), which compared climatologies, interannual-to-decadal variability as well as day-to-day variability of snow in several reanalysis data sets. As an example, Fig. 2.3.2 shows the difference in snow depth between two 15-yr periods. While the patterns are relatively well captured in most of the reanalyses, there are quite substantial differences in amplitudes (see Wegmann et al. 2016, for more details).

The UK Met Office supports ACRE (established by Rob Allan) via ERA-CLIM2. In that context, historical data rescue is started for specific regions (e.g., East Russian/Alaskan region, Iran). Furthermore, the link with ACRE also ensures the important link with WMO/GFCS and other initiatives at the global level. Furthermore, the UK Met Office supports the imaging of historical Southern Ocean observations (Clive Wilkinson). The sources turned out to be much richer than expected. Up to no 80K images could be taken, ca. 40K more could be done, and many new sources were discovered.



VALEURS DES ÉLÉMENTS POUR LES GÉOPOTENTIELS PRINCIPAUX (P T U/Φ; dv/Φ).

Φ	P	T	U	θ'	γ	u	d	v
Sol	P_s –15.1	T_s – 4.0	U_s – 84	θ'_s –	γ_s –	u_s –	d_s –	v_s –
500	955	+5.4	83					
1.000	897	+6.0	85					
1.500	843	+3.2	87					
2.000	790	0.0	90					
3.000	695	–6.0	95					
4.000	610	–12.2	100					
5.000	532	–19.0	100					
6.000	464	–25.7	100					
7.000	402	–33.5						
8.000	345	–42.0						
9.000	297	–50.0						
10.000	254	–59.0						
11.000	216	–58.2						
12.000								
13.000								
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(ΦTU/P) SURFACES ISOBARES ET ISOTHERMES PRINCIPALES (Φ/T)

P	Φ	T	U	T	Φ
1.050				+ 40	
1.000				+ 30	
900	978	+6.2	85	+ 20	
800	1916	+0.6	90	+ 10	
700	2956	–5.7	95	0	
600	4126	–13.0	100	– 10	
500	5466	–22.0	100	– 20	
400	7040	–30.4		– 30	
300	8950	–49.5		– 40	
250	10090	–57.2		– 50	
200	11470	–57.8		– 55	
150				– 60	
100				– 65	
80				– 70	
60				– 75	
40				– 80	
20					
10					

Eléments	Symboles	Unités ou abréviations
Latitude	φ	° ′ ″
Longit. (Greenwich) .	λ	° ′ ″
Altitude au-dessus du niveau de la mer.	H	m.
Acc. de la pesanteur au niveau de la mer.	g	gal (C. G. S.) et 1/100
Géopotentiel	Φ	gdm (m. géod.) $\left(= H \times \frac{g}{1.000}\right)$
Temps de Greenwich.	G	heure et minute.
Pression	P	mb (et 1/10 pour P_s)
Température	T	degrés et 1/10 (échelle centigrade)
Temp. pseudo-pot...	θ'	degrés et 1/10 (échelle centigrade)
Humidité	U	%(pour cent)
Direction du vent ..	d	Rose de 36 (09 vent d'Est; 18 du Sud... 00 calme).
Vitesse du vent	v	km/h
Nébulosité	N	Dixièmes de la voûtes
Genre de nuages ...	C	Ci Cc Cs Ac As St Sc Ns Cu Cb
Espèce et variété...		Voir Atlas
Direction des nuages	C_d	Rose de 36 (comme d)
Vitesse angulaire....	ω	radian/heure
Gradient	γ	degrés et 1/10 par 100 m (γ<0 : inversion)
Vitesse ascensionnelle	u	m/min.

Figure 2.3.1. Radio-sound from Trappes, taken on 21 December 1945.

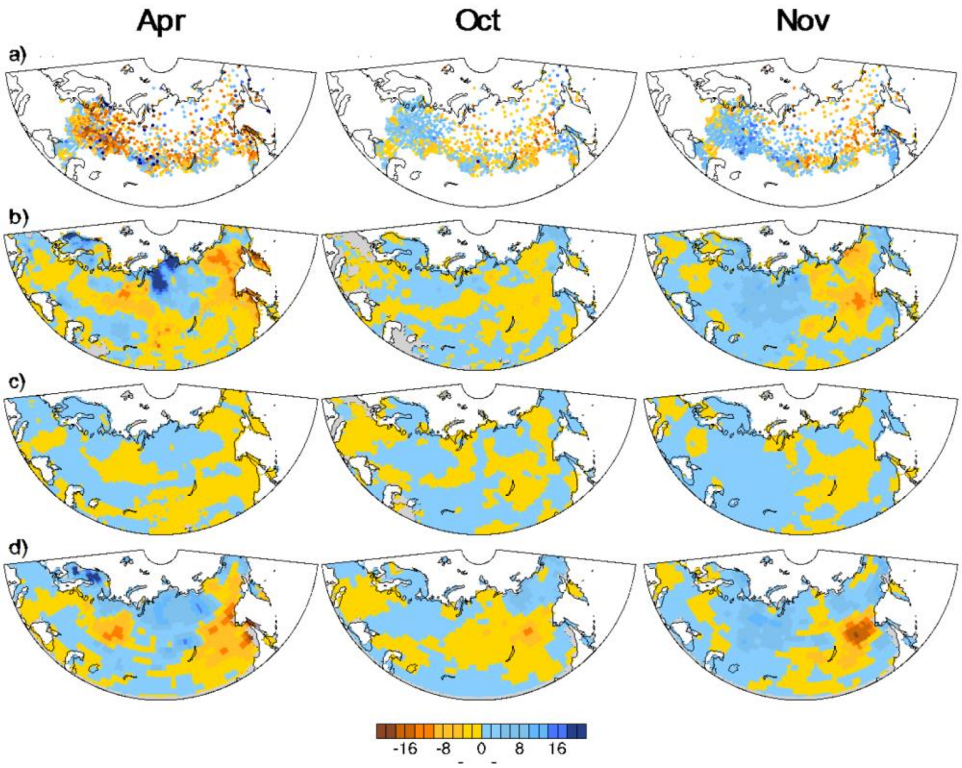

Figure 2.3.2. 1996-2010 minus 1981-1995 snow depth anomalies (in cm) of (from left to right) April, October and November in a) observations, b) ERA-INTERIM land, c) ERA20C and d) 20CRv2c. ERA20CL, ERA-INTERIM land-e and 20CRv2 are not displayed due to insubstantial differences to ERA20C, ERA-INTERIM land and 20CRv2c.

In addition to the planned data rescue for reanalyses, further data rescue work was performed for two demonstration projects, showing the potential value of reanalyses for studying past extreme events. One case concerned the period 1815-1817, with which the "Year Without a Summer" of 1816 was studied (Brugnara et al. 2015). Pressure data from around 50 stations could be compiled and rescued (and submitted to ISPD), which allowed studying atmospheric circulation variability (e.g., band-passed filtered pressure variability to focus on synoptic variability) directly in the data.

The second case concerned the extreme snowfall event and subsequent avalanches in December 1916 (Brugnara et al. 2016). For that case, precipitation and snow data were digitized and the ERC-CLIM reanalysis ERA-20C was dynamically downscaled using the WRF model (see Brugnara et al., 2016, for details). Figure 2.3.3 shows the comparison between the downscaled daily precipitation sum (left) and snow accumulation over the previous week (right) in the downscaled reanalysis as well as the digitised data. The agreement is excellent, showing the potential of historical reanalyses.

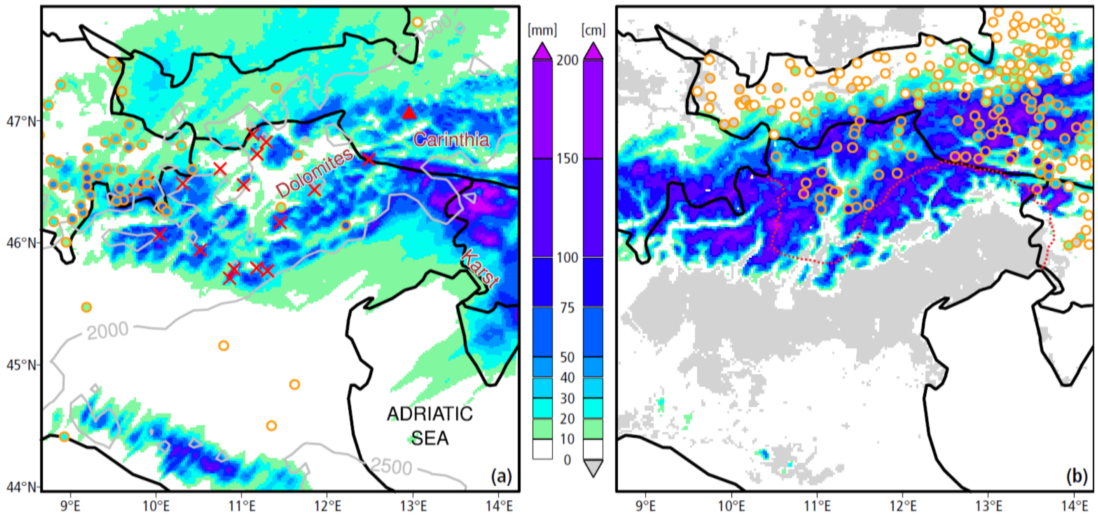

Figure 2.3.3. Results from the dynamical downscaling of ERA-20C. (a) Total precipitation on 13 Dec 1916 (defined as the 24 hours until 0700 UTC 14 Dec 1916) with mean freezing level (m) indicated by the grey lines. Circles represent observations obtained from public datasets or digitized within ERA-CLIM2. Red crosses locate documented major avalanches on 13 Dec 1916. (b) Change in snow depth between 5 and 13 Dec 1916 (at 0700 UTC) with circles representing observations from the network of the Austro-Hungarian hydro-graphic office, part of which was digitised within ERA-CLIM2. The military front line in 1916 is also shown (red dotted line) (from Brugnara et al. 2016).

2.3.2 T3.2 - Satellite data rescue, reprocessing and inter-calibration

With respect to T3.2, the MetOffice has delivered D3.8 (RTTOV) and D3.9 (Early satellite data).

There are several motivations to update the RTTOV coefficients for radiance assimilation:

- Benefit from updated radiative transfer models from which RTTOV is referenced to (i.e. LBLRTM v12.2 together with the MT_CKD continuum version 2.5.2);
- Use improved instrument spectral response functions (e.g. HIRS, AMSU-A, allow for SSU cell pressure changes, …);
- Better atmospheric state (i.e. Allow for changes in GHG concentrations over period analysed) and more vertical levels 43□54;
- Addition of Zeeman effect for SSMIS and AMSU-A upper peaking channels;
- Use latest version of RTTOV (i.e. Version 11) which requires newer file formats and coefficients.

Tables 2.3.2 and 2.3.3 give an overview of the work on deliverable D3.8.

Sensor	Platforms	Period	Measured primary variables	Status
SMMR	Nimbus-7	1975-1983	Sea-ice, total col water vapour, ocean surface wind, cloud LWP	Available with RTTOV-11/12
SSM/T-2	DMSP-F8◊F14	1992-2008	Upper tropospheric humidity	Available with RTTOV-11/12
PMR	Nimbus-6	1975-1976	Stratospheric temperature	To be made available on RTTOV web site by end of Feb 2017.
THIR	Nimbus-4◊7	1970-1980	Surface/cloud top temperature and upper tropospheric humidity	Available with RTTOV-11/12
HIRS-1	Nimbus-6	1975-1976	Temperature and humidity profiles	Available with RTTOV-11/12
MVIRI	Meteosat-1◊4	1978-1995	Surface/cloud top temperature and upper tropospheric humidity	Available with RTTOV-11/12
GOES-Imager	GOES-4◊7	1980-1996	Surface/cloud top temperature and upper tropospheric humidity	Available with RTTOV-11/12
SCAMS	Nimbus-6	1975-1976	Temperature profiles and total column water vapour	To be made available on RTTOV web site by end of Feb 2017.

Table 2.3.2. Description of updates of RTTOV coefficient for radiance assimilation.

Sensor	Platforms	Measured primary variables	Reason for update
HIRS	TIROS-N ◊ NOAA-14, METOP-A/B	Temperature and humidity profiles	Shifted spectral response functions. More levels, better CO2.
SSMI(S)	DMSP-F15 ◊ F19	Temperature profiles, upper tropospheric humidity, total column water vapour, surface wind, cloud LWP	Revised treatment of Zeeman effect for mesospheric channels. Improved pressure levels.
AMSU-A1	NOAA-15-19 METOP-A/B	Temperature profile	Shifted pass-bands, better treatment of AMSU-A ch 14 for Zeeman more levels
SSU	TIROS-N ◊ NOAA-14	Stratospheric temperature profile	Allowance for cell pressure variations which affect spectral response.
MODIS	Terra, Aqua	Surface and temperature and humidity profiles	Shifted spectral response functions. More levels, better CO2.

Table 2.3.3. Description of updates.

Deliverables D3.10-3.14 (EUMETSAT) are delayed. The main reason was the unexpected, late availability of the new EUMETSAT compute environment (mid October 2016 instead of June 2016) that basically prevented most of the production-scale processing tasks. The good news is that, since the new system is much faster than the old one, the processing tasks will be completed within the remaining project time despite the delay. None of the delayed deliverables impacts any other deliverable of the ERA-CLIM2 project. The delays do not have any impact on the usage of the delivered data outside of the framework of ERA-CLIM2 since, as in large reanalysis projects, development of methods as well as data products are often one cycle ahead of the production schedule. In fact, data rescued/quality-controlled/re-processed within the ERA-CLIM2 will feed the next climate reanalysis, since the climate reanalyses produced within ERA-CLIM2 could not wait for these data and had to start production earlier during the project.

Table 2.3.4 gives an overview of the expected delivery dates for D3.10-3.14:

Deliverable	Deliverable Title	Delivery date *(months after kick off)**	
		Current	New
D3.10	AVHRR: polar winds (30+ years)	36	48
D3.11	SSM/T2 and AMSU-B/MHS: radiance data	24	42
D3.12	MFG* and MSG**: inter-calibrated radiances	36	42
D3.13	MFG* and MSG**: Atmospheric Motion Vectors (AMVs) *including All Sky Radiances (ASRs) and Clear Sky Radiances (CSRs)*	42	48
D3.14	Metop, CHAMP, COSMIC (GRACE): consolidated Radio Occultation (RO) data	36	48

Table 2.3.4. Overview of old and new deliverable plans for EUMETSAT deliverables.

The next paragraphs describe in more details what has been achieved for each deliverable during the reporting period and what was causing the delays.

2.3.2.1 D3.10: AVHRR Polar Winds

The collection of all AVHRR Level-1c input data, the ERA-Interim and the ERA-20C reanalysis data from ECMWF for the years 1982-2014 has been finalised. All developments concerning the use of the CIMSS AMV algorithm with AVHRR Global Area Coverage (GAC) data (generation of consistent brightness temperature maps for target tracking and adaptation of the tracking algorithm to the coarser resolution) have been finalised. The algorithm package has been tested on all NOAA satellites back to NOAA-7 with a limited amount of data and is now implemented in the operational processing environment.

Developments for the use of the EUMETSAT AMV algorithm with AVHRR GAC data have been progressed as well and the implementation in the operational processing environment is on going. This includes a required reformatting of the AVHRR-GAC data into a EUMETSAT Metop equivalent format which is still under development for the historic AVHRR instruments prior to NOAA-18.

The deviations in the work plan was caused by the fact that the earlier reported change in consultancy at the beginning of 2015 had long term effects on this deliverable because the new person needed to be trained in programming languages and the use of the computer system. In addition, the complexity of adapting the EUMETSAT AMV algorithm for the use of AVHRR-GAC data was underestimated but finally solved. In addition the EUMETSAT algorithm scheduled for the new compute environment could not be implemented because of the above mentioned delay in the availability of the environment. A delay of the AMV data record deliverable is nonetheless unavoidable and is now scheduled for Q4/2017 instead of Q4/2016.

2.3.2.2 D3.11: SSM/T2 and AMSU-B/MHS radiance data

The deliverable was due in Q4/2015, but was dependent on the delivery of the inter-satellite calibration method by the EUMETSAT CM SAF that was delayed into 2016. EUMETSAT has reviewed the Algorithm Theoretical Baseline Document describing the inter-satellite calibration for the microwave sounder instruments SSM/T2 / AMSU-B / MHS provided by EUMETSAT CM SAF. A first version of the data records was produced but the evaluation of the obtained result led to a need for improvements in the inter-satellite calibration algorithm. Such improvements will be implemented in Q1/2017 and the data record delivered in Q2/2017. EUMETSAT has collected all necessary data and also put all needed pre-processing software (ATOVS and AVHRR Processing Package (AAPP)) to convert AMSU-B/MHS data from level-1b to level-1c into place to allow for a rapid processing of the data.

2.3.2.3 D3.12: MFG and MSG inter-satellite calibrated radiances

The preparation of a Fundamental Climate Data Record (FCDR) of sensor equivalent calibrated radiances and reference sensor normalised calibrations for the Meteosat First Generation (MFG) infra-red and water vapour channels has been finalised. Based on a database of matchups between the reference instruments (IASI/AIRS/HIRS) and the monitored instruments (METEOSAT-2 to METEOSAT-7) the re-calibration coefficients for all Meteosat First Generation satellites have been generated. The method has been extended to the Meteosat Second Generation satellites and the generation of re-calibration coefficients is on going.

The quality of the MFG re-calibration has been validated by a set of beta-testers including the EUMETSAT CM SAF that used the re-calibrated data to derive a land surface temperature time series that fulfils GCOS stability requirements.

The FCDR will be provided in two ways: (1) NetCDF files with re-calibration coefficients and uncertainty statistics that can be used by anybody who already has the Meteosat image data and (2) the image data in NetCDF that contain the re-calibration coefficients. The software for integrating the re-calibration coefficients into the satellite images has been finalised and the processing will start in Q1/2017.

The development and generation of the recalibration coefficients for the Meteosat First Generation were finalised in time but the generation of the re-calibration coefficients for the Meteosat Second Generation could not be done before the availability of the new compute environment as the needed storage for about 8 years of the IASI reference measurements was not available. This has also delayed the generation of the satellite images that needs the calibration coefficients. As a consequence the data record will be delivered in Q2/2017 instead of Q4/2016.

2.3.2.4 D3.13: MFG and MSG Atmospheric Motion Vectors (AMV) and All Sky Radiances

Based on an inventory of methods and algorithms to generate Atmospheric Motion Vectors (AMVs) using Meteosat First Generation (MFG) and Second Generation (MSG) the selection for the use of a new cloud detection and analysis scheme has been made that allows the retrieval of AMVs from MFG and MSG with a similar algorithm (Cross-Correlation Contribution CCC).

The new cloud detection algorithm for MFG and MSG data has been implemented and tested in the new EUMETSAT compute environment but due to the late availability of the new EUMETSAT compute environment and the dependence on D3.12 the processing could not be started in 2016. Implementation work for the AMV algorithm is still on going and will not be finished before Q2/2017. It is expected that the data record will be delivered at the end of the project in Q4/2017.

2.3.2.5 D3.14: Metop-A, CHAMP and COSMIC radio Occultation Data

Metop-A/B GRAS data were processed using the new Wave Optics algorithm for data covering the time period from the start of the Metop satellites in 2007 to the end of 2015 as planned and would have been available by mid 2016. Unfortunately, during the validation of the wave optics products a systematic error in the bending angle profiles was found due to a non inclusion of the 26,000 year Earth precession cycle. If not taken into account it causes an error in the altitude referencing of the profiles, consistent with the biases found during the validation of the data product. This error was corrected and a full second unplanned reprocessing of the GRAS data has been performed until the end of 2016. The data is currently technically evaluated (completeness, etc.) and then distributed to ECMWF and the ROM SAF for further quality evaluation.

For the COSMIC data the Precise Orbit Determination processing has been finalised for all space craft and will be followed by the generation of Level 1a and 1b products using the corrected wave optics algorithm in 2017. The CHAMP data record is still under development due to the work needed to correct the GRAS data. The detection and correction of this error in the radio occultation data processing that in particular effects long time series has prevented us from delivering defected data. As a consequence the full deliverable will be delayed to the end of the project in Q4/2017.

2.3.3 T3.3 - Boundary constraints and external forcing

With respect to T3.3, the MetOffice has delivered D3.17 (Development of HadIOD, surface and sub-surface ocean data).

The FMI has two deliverables, D3.18 (Prototype snow data product) and 3.19 (Quality controlled version of snow data base (in situ) and snow data product). Delivery of D3.18 would have been due on month 36. Here, a change of the sequence of the two deliverables has taken place in that a first version of the in-situ snow data base (D3.19 due month 48) was already released in April 2016 and revised in September 2016. This is due to the fact that D3.19 will be used further in the project by other tasks, whereas D3.18 will not be further used within ERA-CLIM2, and the delay thus has no effect on the outcome of the project.

Deliverable D3.18 is about complementing the GlobSnow product that is based on passive microwave data of snow water equivalent, supplemented with optical data on snow extent in order to obtain a better estimation. Figure 2.3.4 shows, for the example of a specific date, the value if incorporating such data. Specifically at mid-latitude (over the USA and Russia), the unrealistic snow extent could be corrected.

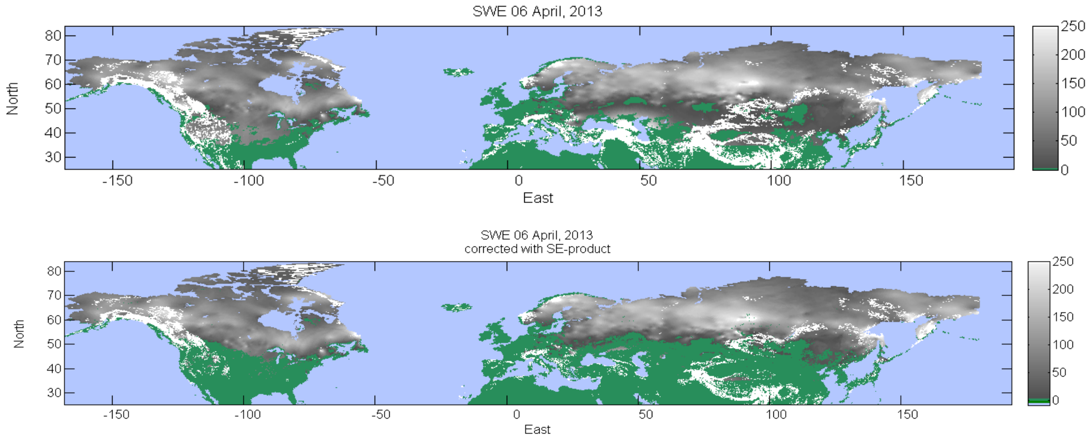

Figure 2.3.4. Snow-water equivalent on 6 April 2013 from passive microwave data (top) and supplemented with snow extent data (bottom).

This deliverable was delayed because the product chosen for the optical snow extent, the NOAA-CDR data, turned out to be unrealistic when compared against other snow data products. Careful evaluation showed that the Japanese JaXa product should be used. This will now be implemented and the product is expected to be delivered on month 42.

2.3.4 Discussion

The discussion of WP3 in the General Assembly can be summarised in 3 points:

- There was some uncertainty in the data stream of the rescued data. It was now agreed that all digitised upper-air data will be delivered to RIHMI for QC, from where they will be sent to UVIE as well as ECMWF. The surface data will be QC'ed at FFCUL and sent directly to ECMWF.
- The update cycle of the inventory was not clear. It was agreed to produce an updated inventory in January 2017, June 2017, and December 2017.
- Several publications have been produced that use data rescued within ERA-CLIM2 (see list below). Similar as for ERA-CLIM, which ended with a common publication on the ERA-CLIM data rescue efforts (Stickler et al., 2014), it was decided also to write a publication on data work in ERA-CLIM2. However, in contrast to the ERA-CLIM article, the ERA-CLIM2 article should be more comprehensive and also encompass the satellite data work.

2.3.5 Outreach and communication activities

As part of this work-package, several communication/outreach/coordination activities with other projects were performed, e.g.:

- *WMO SCOPE-CM IOGEO project* - Within this coordinated activity space agencies collaborate on generating an inter-calibrated fundamental climate data record of the infrared, water vapour, and visible channels on board of the heritage of all geostationary satellites. The ERA-CLIM2 work greatly contributes to this international activity (relates to D3.12).

- *WMO GSICS* - Within this coordinated CGMS activity space agencies collaborate on establishing common procedures to re-calibrate past/present/future satellite instruments, with the focus on passive images and microwave sounders. The ERA-CLIM2 activities are reported in this framework by which visibility of European activities is strongly enhanced (relates to D3.12).

- *EU H2020 FIDUCEO* - This project is addressing the recalibration of the reference data set HIRS used in ERA-CLIM2 at fundamental level. This leads to further improvements of reference data used for the calibration of Meteosat data at a later stage. The experiences gained in ERA-CLIM2 helped to identify relevant issues in the HIRS data and to inform FIDUCEO. It also further completes the Meteosat re-calibration by addressing the visible channel of Meteosat First Generation (relates to D3.12).

- *EUMETSAT CM SAF* - The CM SAF is a primary user of the recalibrated Meteosat radiances outside the ERA-CLIM2 project and enhances the use of the project results. Their work was fundamental to establish confidence into the Meteosat First Generation re-calibration coefficients. In addition, a work relation with the CM SAF exists on the re-calibration of SSM/T2 and AMSU-B/MHS radiances that are being used within ERA-CLIM2 (relates to D3.11).

- *Copernicus Climate Change Service (C3S)* - The developments performed and experiences gained during the ERA-CLIM2 and also the prior ERA-CLIM project were substantial and without them EUMETSAT would have not been in position to support the C3S as it will do now. To a great extent this applies to generate the technical environment that allows for a correct and efficient mass processing of satellite data. The developments and needs of the ERA-CLIM2 project were driving the requirements for a new compute environment at EUMETSAT which finally came to its existence in late 2016 and is now heavily being used for the remaining ERA-CLIM2 data processing and the upcoming C3S data processing. In addition, many data records first developed for the ERA-CLIM projects will have improved new releases in C3S benefitting from further developments in particular in the FIDUCEO project.

2.3.6 WP3 References and ERA-CLIM2 publications

- Brönnimann, S. (2015) *Climatic Changes Since 1700.* Springer, Adv Global Change Res **55,** 375 pp.
- Bližňák, V., M. A. Valente, and J. Bethke (2015), Homogenization of time series from Portugal and its former colonies for the period from the late 19th to the early 21st century. *Int. J. Climatol.,* **35,** 2400–2418. doi:10.1002/joc.4151
- Brugnara, Y., R. Auchmann, S. Brönnimann, R. J. Allan, I. Auer, M. Barriendos, H. Bergström, J. Bhend, R. Brázdil, G. P. Compo, R. C. Cornes, F. Dominguez-Castro, A. F. V. van Engelen, J. Filipiak, J. Holopainen, S. Jourdain, M. Kunz, J. Luterbacher, M. Maugeri, L. Mercalli, A. Moberg, C. J. Mock, G. Pichard, L. Reznícková, G. van der Schrier, V. Slonosky, Z. Ustrnul, M. A. Valente, A. Wypych, and X. Yin (2015) A collection of sub-daily pressure and temperature observations for the early instrumental period with a focus on the "year without a summer" 1816. *Clim Past,* **11,** 1027-1047.
- Brugnara, Y., S. Brönnimann, M. Zamuriano, J. Schild, C. Rohr, D. Segesser (2016) December 1916: Deadly Wartime Weather. *Geographica Bernensia* **G91**. 8 pp. ISBN 978-3-905835-47-2, doi:10.4480/GB2016.G91.01 (also appeared in German and Italian)
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- Wegmann, M., Y. Orsolini, E. Dutra, O. Bulygina, A. Sterin, and S. Brönnimann (2016) Eurasian snow depth in long-term climate reanalyses, *The Cryosphere Discuss.,* doi:10.5194/tc-2016-253.

2.4 Work-package 4 – Quantifying and reducing uncertainties

The main objective of work package 4 is making optimal use of observations in reanalysis, and providing end users with meaningful information about uncertainties in reanalysis products. The first part of the work focuses on assessment of input data uncertainties as well as on providing improved input data. Development of quality control (QC) and bias adjustment algorithms for data assimilation is an equally important task.

The work package involves seven ERA-CLIM2 partners: European Centre for Medium-Range Weather Forecasts (ECMWF), University of Vienna (UNIVIE), University of Bern (UNIBE), University of Versailles Saint-Quentin-en-Yvelines (UVSQ), Deutscher Wetterdienst (DWD), Fundacao da Faculdade de Ciencias da Universidade de Lisboa (FFCUL) and All-Russian Research Institute of Hydrometeorological Information-World Data Centre (RIHMI).

2.4.1 Summary of technical achievements

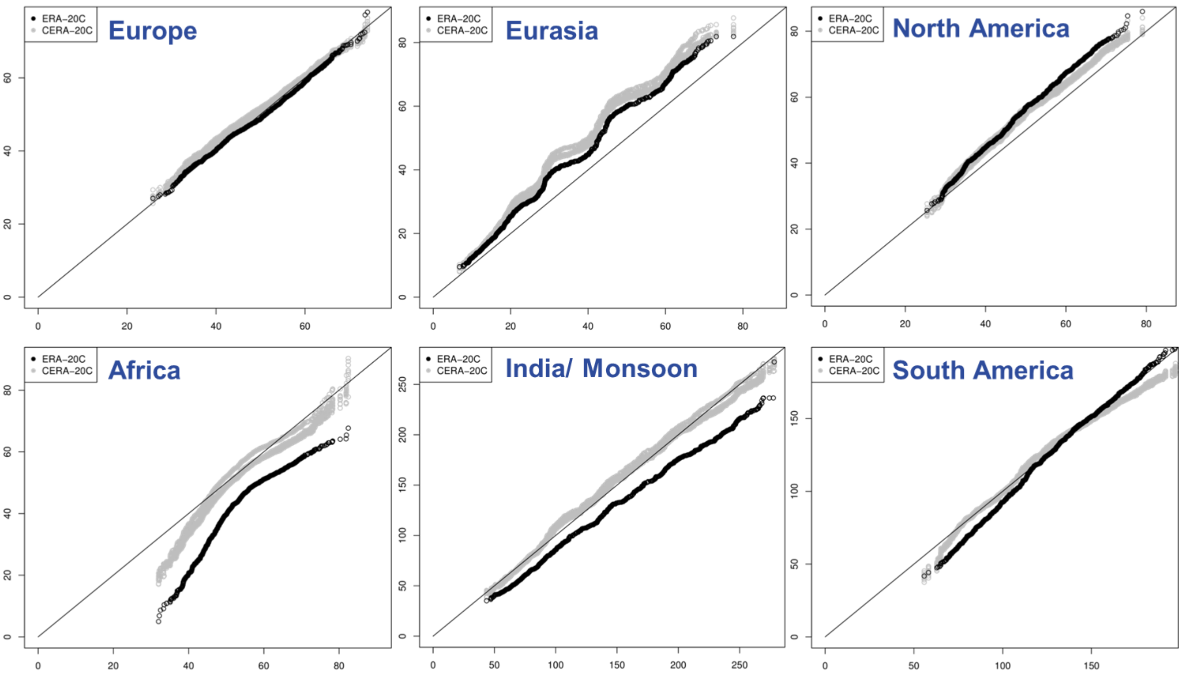

Fig. 2.4.1: QQ-plots of monthly mean ERA20C (black) and CERA20C (grey, 10 member ensemble) surface precipitation against GPCC precipitation over period 1901-2010 over selected regions.

With the availability of the CERA20C ensemble it has become possible to validate it against surface precipitation and against upper air observations. First results find it quite competitive compared to earlier surface data only reanalyses, in particular ERA20C and NOAA 20CRv2c. Fig. 2.4.1 shows quantile-quantile (QQ) plots of regional monthly mean surface precipitation from reanalyses against GPCC precipitation. In general the agreement is much better than for ERA20C, except over Eurasia.

Surface precipitation from CERA20C has been used together with other meteorological input for driving the "Orchidee" carbon land surface model. Up to now ERA20C has been used as a substitute.

Diagnostic evaluations of regional energy budgets could be extended to ocean reanalyses. Using the native NEMO discretization it has become possible to obtain accurate mass-consistent horizontal flux and flux divergence estimates from oceanic reanalyses CGLORS025V5 (Storto et al. 2016) and ORAS5 (Balmaseda et al. 2017, in preparation). Also the method to calculate the net surface energy flux from horizontal atmospheric energy flux divergence plus TOA radiation could be substantially improved.

Radiosonde temperature bias corrections developed in ERA-CLIM2 are now being used in the generation of the first Copernicus reanalysis ERA5. Long time series of upper air observation minus CERA20C background departures have been created to allow for detailed quality control of observations as well as reanalyses. A web portal (see section outreach below) has been made public to allow external users a close look into the data available.

FFCUL has been applying QC tools, testing the homogeneity and homogenizing land surface pressure, temperature and precipitation series recovered in the project. Some of these surface pressure series have already been included in ISPD V3 used to force the different reanalyses produced in the project. Lists of statistically significant breakpoints are being compiled to be compared with the reanalyses feedback on the land surface observations. Some unknown metadata information has been retrieved through relative and absolute mode homogeneity tests that detect simultaneous non-documented breakpoints in different series, contributing thus to a better knowledge of the data forcing the reanalyses or being used for comparison purposes.

RIHMI has delivered its quality control report for upper air and snow data (D4.5) over the Former Soviet Union, which have been digitized in ERA-CLIM and ERA-CLIM2. This work will continue until the end of ERA-CLIM2. Deliverable D4.6 documents the methodology used for quantifying observation errors for surface and upper air data. It includes detailed examples of statistics and available metadata at selected stations as well as more global statistics.

Deliverable number	Deliverable title	Delivery date
D4.1	RS bias adjustments (UNIVIE)	20
D4.2	Updated RS bias adjustments (UNIVIE)	48
D4.3	Visualization tool for QC (FFCUL)	12
D4.4	QC for obs from FFCUL (FFCUL)	48
D4.5	QC for upper-air, surface and snow obs (RIHMI)	37
D4.6	Methodology for quantifying obs error (UBERN)	37
D4.7	Verification of precipitation against GPCC (DWD)	48
D4.8	Global energy, water, carbon cycles (ECMWF,UNIVIE, UVSQ)	48
D4.9	Upper air data qc (UBERN, RIHMI)	24
D4.10	Comparison with other reanalyses (UNIVIE; ECMWF)	48
D4.11	Low frequency variability and trends (ALL)	48
D4.12	Uncertainty of input parameters for carbon budget (UVSQ)	20

D4.13	Confidence intervals on carbon fluxes (UVSQ)	48
D4.14	Comparison of CTESSEL, ORCHIDEE flux estimates (ECMWF, UVSQ, UNIVIE)	48

Table 2.4.1: Status of all the deliverables in WP4. Green highlights deliverables provided on time, while orange highlights deliverables with a delay.

2.4.2 Status of all deliverables and deviations from the work plan

Table 2.4.1 lists the status of this work-package deliverables. D4.5 and D4.6 have been completed almost on time. The remaining deliverables D4.2, D4.4, D4.7, D4.10, D4.11, D4.13 and D4.14 are due by the end of 2017, in accord with the cost neutral amendment of the project. Responsibilities for contributing to these deliverables have been clarified during the general assembly and no delays are expected.

2.4.3 Preliminary results

Validation activity on ERA-20C as described in the GA2 Summary has been wrapped up, and a paper describing the preliminary full assimilation of early upper data from 1939-1967 (ERA-preSAT) currently is under review (Hersbach et al. 2017).

DWD has now included CERA20C in its comparison of the GPCC Full Data Monthly (Version 7, doi: 10.5676/DWD_GPCC/FD_M_V7_100) data set with monthly aggregated precipitation reanalyses. Fig. 2.4.1 shows QQ plots for ERA20C as well as the CERA20C ensemble vs. GPCC precipitation. CERA20C performs clearly better over most regions except Eurasia. CERA20C precipitation exhibits significant minima over Amazonia during some but not all El Nino episodes, which seem exaggerated compared to GPCC precipitation.

UVSQ continued its investigation of uncertainties in estimating the effect of Land Use Change (LUC) on the global carbon cycle. Six LUC scenarios have been defined over the past century using different possible assumptions for these transitions and simulations with the land carbon model Orchidee have been performed accordingly. In the meantime also uncertainties arising from using forcing from different reanalyses, including CERA20C are investigated. When forced with CERA20C the tropical land areas show simulated net emission of carbon, whereas the tropical land is a carbon sink if forced with CRU/NCEP forcing or when run in coupled mode within a climate model (Fig. 2.4.2). One reason may be water deficit, since CERA20C precipitation tends to be smaller over many tropical areas such as Amazonia or central Africa. In the remaining months also a comparison with carbon fluxes simulated by the ECWMF land surface model CHTESSEL (Boussetta et al. 2013), which is used in CERA-SAT assimilation runs, will be prepared (D4.14).

Comparison of CERA20C temperatures in the lower troposphere with independent radiosonde observations revealed smaller sub-daily standard deviations than the 20th century reanalysis over most of the Northern Hemisphere (Fig. 2.4.3) for periods with good surface observation coverage (after the IGY). This result highlights the generally very high quality of CERA20C analyses compared to other surface data only reanalyses. Detailed inter-comparison of reanalyses has just started, however, and many aspects have yet to be investigated. For example further back in time and over the Southern Ocean the 20CR tends to perform better. The reasons for this have to be thoroughly investigated but the background error estimates for data sparse regions likely play an important role. A major novelty in this respect is the availability of ensembles of reanalyses (10 members in CERA20C), which allows to investigate spread-skill relationships for state and flux quantities.

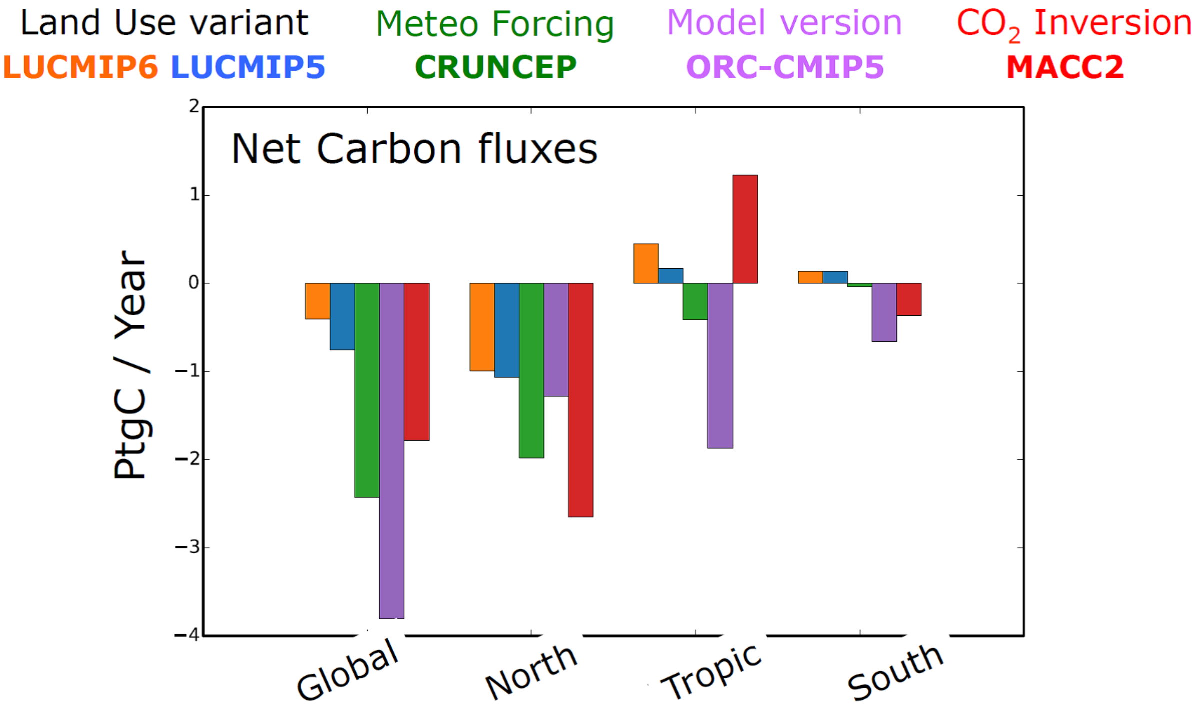

Fig. 2.4.2: Net CO_2 fluxes in PgC/year for period 2001-2004 calculated by Orchidee land surface model using CERA20C input and CMIP6 land use (orange), CERA20C input and CMIP5 land use (blue), CRUNCEP input and CMIP6 land use (green). For comparison the Orchidee fluxes gained in a coupled climate model run (violet) and fluxes from MACC2 inversion(red) calculations are included.

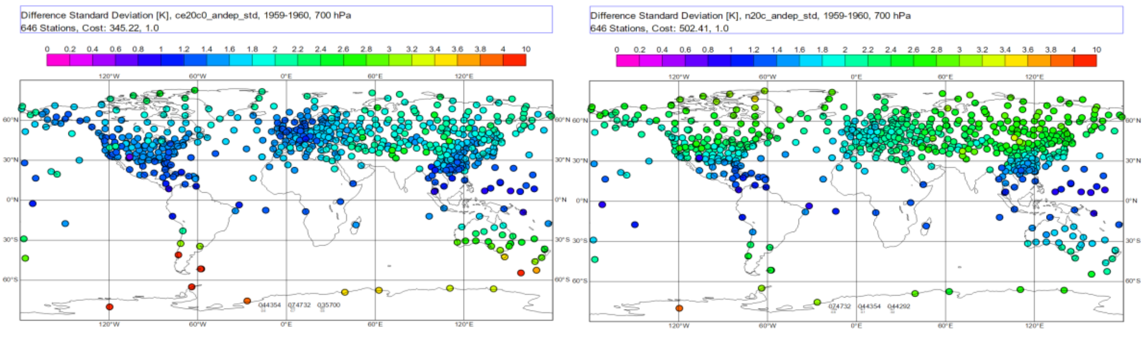

Fig. 2.4.3: CERA20C-obs(left) and NOAA 20CR-obs (right) standard deviations for temperature at 700hPa for period 1959-1960. Obs are unadjusted radiosonde temperatures.

Several atmospheric reanalyses and ocean reanalyses such as CGLORS025V5, ORAS4 (Balmaseda et al. 2012) and ORAS5 have been compared with climate model simulations (Mayer et al. 2016a) and have been used in conjunction with satellite data to get nearly independent estimates of surface energy fluxes and oceanic heat accumulations (Mayer et al. 2016b). Recently fluxes from ocean reanalyses have also been compared to in situ horizontal oceanic flux measurements at Arctic gateways, (Pietschnig et al 2017, in preparation), as envisaged in CMIP6 design documents (Griffies et al. 2016).

UBERN performed several case studies using ERA20C and NOAA 20CR reanalyses showing the potential of reanalyses to catch tropical cyclones and to reproduce cyclone indices. In a spectacular case study the ability of reproducing the weather conditions which led to the catastrophic snowfall event in December 1916 was demonstrated also to the public, see Brugnara et al. (2016). Wegmann et al (2016) compared snow depth from reanalyses with station snow depths and found very large differences in both ERA20C and NOAA 20CR compared to station data.

2.4.4 Collaboration between partners

The general assembly demonstrated close collaboration between WP1 and WP4 as well as between WP3 and WP4. There was also collaboration between WP2 and WP4 on Ocean energy flux diagnostics, which has not been anticipated when the project was proposed (Mayer et al. 2016b). With the availability of CERA20C the diagnostics developed for comparison with ERA-20C and ERA-preSAT are now quickly being extended to CERA20C. Validation of CERA-SAT will start as soon as a few years of assimilated data are available.

2.4.5 Risks and expectations

The ERA-CLIM and ERA-CLIM2 projects were launched with the intention of capacity building for the recently established Copernicus Climate Change Service (C3S). This has indeed been achieved in many respects. Millions of new data records have been digitized and inventoried. The inventories will be incorporated into the C3S in the near future; an ITT for this is currently under way. A standardized portal to these inventories will speed up the incorporation of new data as well as the correction of observations and their metadata. Bias corrections for radiosonde temperatures developed in ERA-CLIM2 now go back to 1939 and are used in the first Copernicus reanalysis ERA-5. Adjustments for radiosonde humidity have been developed for the period 1979-present as well (Blaschek and Haimberger, 2017, in preparation).

However, the collected data and bias corrections could not be assimilated within ERA-CLIM2 in a satisfactory manner. This would require a full reanalysis, including upper air data, at least for the period 1939-1978. Ideally there would be a reanalysis with conventional data only, covering the period 1918-2017, which could be termed “ERA100”. Both options are expected to realize at least the following enhancements compared to ERA-preSAT:

1) Close the gap between 1967 and 1978 that has never been assimilated at ECMWF since ERA-40. This would be straightforward if only conventional data were assimilated but may be a somewhat larger effort if also the early satellite data were assimilated. Radiative transfer

coefficients for the most promising satellite data of this period have, however, been developed in the meantime (see WP3 report);

2) Whitelist tropical cyclone track data and assimilate them, if possible, with realistic background errors;
3) Assimilate all digitized upper air data collected so far and avoid ingestion of inconsistent duplicates as it happened with CHUAN data in ERA-preSAT (Hersbach et al. 2017);
4) Fix the issue of spurious interhemispheric gradients caused by the uneven distribution of upper air data before the IGY and by the inconsistency between model climate and those observations. This may require some experimentation since it is possible that either the early upper air observations are biased high or the model climate is biased low or both. Also the error covariance specification may have some impact;
5) Improved carbon flux assessments using offline or online land surface models that include the carbon cycle.

Research efforts needed to realize ERA100 require funding by a dedicated research project and substantial computer resources. Such a research project has so far not been formally proposed and also no EU call addressing that need has been issued. Waiting too long with such an effort would likely mean that European assimilations of the pre-1958 period or even the pre-1978 period fall behind other centres such as JMA, who have published a modern reanalysis that assimilated upper air data back to 1958 and are planning a reanalysis back to at least 1939.

UVSQ has been impacted by the delay on the provision of this reanalysis to estimate the uncertainties on the land carbon fluxes due to the meteorological forcing, however carbon fluxes forced by CERA-20C have become available. Further runs using CERA-SAT forcing will likely be made towards the end of the project to be able to compare with fluxes from CHTESSEL.

GPCC has progressed far in validating CERA20C monthly precipitation and now focuses on validation on daily time scales. The development of ensembles of the gridded precipitation product, as requested by some ERA-CLIM project partners, would be an excellent research topic for a follow-on project. For the time being the comprehensive uncertainty estimations for the daily analyses have been developed and published by Schamm et al. (2014) and are available for validation. In addition, GPCC could contribute an estimation of the monthly analyses' uncertainty through adaptation of the interpolation techniques it already applies for its daily analyses.

The validation and uncertainty assessments for CERA-SAT will be started within ERA-CLIM2 but will be only preliminary since the assimilation will likely continue until the end of the project.

2.4.6 Outreach and dissemination

As part of this work-package, several communication/outreach/coordination activities with other projects were performed, e.g.:

- CERA-20C (at least the monthly means) is now available via http://apps.ecmwf.int/datasets/, which greatly facilitates external validation efforts.
- The results of quality control and inventory efforts are available via eraclim-global-registry.fc.ul.pt/era/index.html and are expected to be soon promoted to C3S.

- A visualization tool for upper air data is being developed at University of Vienna http://srvx1.img.univie.ac.at/raobvis/ which allows for quick look validation of radiosonde time series and their departures from several reanalyses.

- UVSQ has an advanced visualization tool on many aspects of the global carbon cycle, http://transcom.globalcarbonatlas.org/, which also allows for tailor-made comparison between different products.

Besides regular contributions to the Bulletin of the American Meteorological Society's "State of the Climate" supplement, a large number of papers has been submitted or published covering research topics of WP4. Only a selection of those has been referenced below. Results have been presented at many occasions at conferences, workshops etc.

2.4.7 WP4 References

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- Storto, A., S. Masina, and A. Navarra (2016), Evaluation of the CMCC eddy-permitting global ocean physical reanalysis system (C-GLORS, 1982–2012) and its assimilation components, Q. J. R. Meteorol. Soc., 142, 738–758, doi:10.1002/qj.2673.
- Wegmann, M., Y. Orsolini, E. Dutra, O. Bulygina, A. Sterin, and S. Brönnimann, 2016: Eurasian snow depth in long-term climate reanalyses. Cryosphere Disc., doi:10.5194/tc-2016-253, in review

3 Advisers' comments

GA3 was attended by Mr Sakari Uppala, one of the three ERA-CLIM2 external advisors (the other two advisors could not attend the meeting). This is a brief summary, in bullet format, of his assessment of the project status and progress.

In general progress is very good and even exceeds the expectations made by the EU Expert Group on Climate Change in 2011, especially in the following areas:

- ERA-20C and CERA-20C
- Access to data
- ERA5 in progress
- CERA-SAT implemented
- Biogeochemical reanalysis
- Carbon reanalysis
- Future coupling methods progressing well including SST, Sea-ice assimilations

Observation rescue and reprocessing activities have also been progressing well. To obtain maximum amount of historical observations and learning of their characteristics (both satellite and conventional observations) will remain as core functions in reanalysis activities. The further back in time reanalyses are extended the importance of even single observations grow. It is therefore important to maintain these activities and the special expertise developed in Europe. These include:

- Rescue of conventional data including snow cover
- Radiative transfer model (RTTOV) developments
- Satellite data reprocessing and rescue by EUMETSAT
- Preparation of early satellite records
- Quantifying/ reducing uncertainties

Future aspects that will require attention for the future of reanalysis production:

- Preparation of the ERA6 reanalysis system, and in particular:
    - Integration of all new data-assimilation components;
    - Extensive test program during selected modern and pre-satellite periods
    - Evaluation of hydrological cycle, river runoff, major historical storms, stratospheric warmings, El-Ninos, tropical cyclones, fluxes over Arctic areas, QBO (+stratosphere in general) and the performance of the new observations;
    - Perform impact studies;
    - Document the strengths and weaknesses;
- Sharing responsibilities for quality assessments between ECMWF, data producers, expert groups and Copernicus team during the experimentation and the production with occasional end-to-end tests;
- Monitoring of bias corrections systematically for all data types, in particular for radiosondes and satellite radiances;
- Comparison of products with other reanalysis centres;
- Observation feedback data for wider use

- System maintenance;
- There are several reanalyses available for users, therefore recommendations are needed which reanalysis dataset qualify for climate change studies;
- Application utilities for the users;
- Readymade high quality map products through reanalysis period including e.g. cross-sections of Ocean+atmosphere;
- Time series of observations and products?
- **Enough resources. The Copernicus Services have resources, but the essential reanalysis system (observation-data assimilation development/ maintenance) to provide information for Copernicus services should have a long-term strategy including human, technology and funding requirements to the future**.
    - Operational system designed to perform and use the latest observing systems for medium-range forecasts is probably not optimal to assimilate long historical records for climate change purposes.

Reanalysis will always be a huge effort: work should start to define the strategy for the preparation of ERA6 and for the future beyond ERA6.

4 Forthcoming meetings

It is worth listing the following meetings were ERA-CLIM2 work is expected to be presented:

- 97th AMS Annual Meeting (22-26 Jan 2017; Seattle, US)
- EGU Meeting (23-28 Apr 2017; Vienna, Austria)
- ECMWF Annual Seminar on 'Ensemble prediction: past, present and future' (11-15 Sep 2017; Reading, UK) - Roberto Buizza, coordinator of the ERA-CLIM2 project, is chair of the Scientific Organizing Committee of this Seminar;
- 5th International Conference on reanalysis, Rome (ICR5, 13-19 Nov 2017; Rome) - Roberto Buizza, coordinator of the ERA-CLIM2 project, is co-chair of the Scientific Organizing Committee of this conference;

Furthermore, as part of the project's activities, the following two meetings are planned:

- 12-14 Dec 2017 - The final General Assembly of the project (GA4) is planned for this period at the University of Bern (Prof. Stefan Brönnimann will take care of the organization).
- 15 Dec 2017 – The M48 Project Review Meeting will be held at the Univ. of Bern

5 Appendix A – Agenda of the ERA-CLIM2 3rd General Assembly

Monday 16 January (1300-1800), Kleiner Festsaal der Universität Wien		
1230-	Registration (Foyer kleiner Festsaal)	
1300-1315	Welcome	Vice Rector Prof. Regina Hitzenberger
1315–1340	1. Introduction	Roberto Buizza
1340-1520 ***WP1*** *(Global 20th century reanalysis)*		
1340-1405	2. Overview WP1	P. Laloyaux
1405-1430	3. CERA-20C: climate indices, ocean and flux	E. de Boisseson
1430-1455	4. CERA-20C: uncertainty estimation	P. Dahlgren
1455-1520	5. CERA-20C: observation feedback	Y. Kosaka
1520-1540 Coffee break		
1540-1800 ***WP1*** *(Global 20th century reanalysis) and* ***WP5*** *(Service developments)*		
1540-1605	6. CERA-SAT implementation	D. Schepers
1605-1630	7. PISCES biogeochemical reanalysis	C. Perruche
1630-1655	8. Land carbon reanalysis	P. Peylin/P. Masina
1655-1720	9. Upper-air observations	P. Dahlgren
1720-1745	10.Overview WP5	P. Laloyaux
1745-1800	Questions	
1800-2000	Reception (Erika Weinzierl Saal)	
2000	End of first day	

Tuesday 17 January (0900-1800) Elise Richter Saal		
0900-1250 ***WP2*** *(Future coupling methods)*		
0900-0910	11. Overview of WP2	M. Martin
0910-0935	12. WP2.2 – SST assimilation developments	J. While/D. Lea/M. Martin
0935-1000	13. WP2.2 – Sea-ice assimilation developments	C.-E.Testut
1000-1025	14. WP2.3 – Ocean assimilation algorithm developments	A. Weaver
1025-1050	15. WP2.3 – Coupled ensemble information	A. Storto
1050-1110 Coffee break		
1110-1135	16. WP2.4 – Land carbon component developments	P. Peylin
1135-1200	17. WP2.5 – Coupled error covariances and bias correction	X. Feng/K. Haines
1200-1225	18. WP2.5 – Coupled DA in idealised studies	A. Vidard
1225-1250		
1250-1430 Lunch break		
1430-1800 ***WP3*** (Earth System Observations)		
1430-1455	19. WP3 Overview and accomplishments	S. Brönnimann
1455-1520	20. Historical snow in situ data set and snow cover satellite products	J. Pulliainen
1520-1555	21. Upper air deliverables contributed by Météo-France to WP3	S. Jourdain
1555-1620	22. Updating FFCUL contribution to WP3 (Data Rescue and Global Registry)	M. A. Valente
1620-1640 Coffee break		
1640-1705	23. RIHMI contribution to WP3	A. Sterin
1705-1730	24. Data rescue, use of satellites and integrating surface and sub-surface ocean temperature and salinity	N. Rayner
1730-1755	25. EUMETSAT contribution to WP3	J. Schulz
1900 Dinner at Heurigen “Mayer am Pfarrplatz”, Pfarrplatz 2, 1190 Wien		
End of second day		

Wednesday 18 January 2017 Elise Richter Saal		
*900-1200 **WP4** (Quantifying and reducing uncertainties)*		
900-920	26. Radiosonde temperature homogenization	L. Haimberger
920-940	27. Towards homogenizing land surface data: QC and breakpoint detection	M. A. Valente
940-1000	28. Hurricanes in ERA-20C and CERA-20C	S. Brönnimann
1000-1020	29. Reproducing upper air temperature, humidity and wind characteristics in late 1930s-1960s by reanalyses	A. Sterin
1020-1040	30. Validating daily precipitation totals by means of ETCCDI	E. Rustemeier
1040-1100 Coffee break		
1100-1120	31. Homogenization of global radiosonde humidity data	M. Blaschek
1120-1140	32. Coupled energy budget diagnostics of the Arctic	M. Mayer
1140-1200	33. Uncertainties on the land carbon cycle re-analysis	N. Vuichard/P. Peylin
1200-1220	Instructions to Working Groups (break out sessions)	
1220-1400 Lunch break		
*1400-1600 **Working Groups** (break-out sessions, WP1/WP2/WP3/WP4)*		
	WG1/5 Marietta Blau Saal	
	WG2 Sitzungszimmer VAM2	
	WG3/4 Erika Weinzierl Saal	
1600-1630 Coffee break		
1630-1830 Report of WG discussions, back in Elise Richter Saal		
1630-1645	34. Report from WP1/2 breakout session	M Martin/P Laloyaux
1645-1700	35. Report from WP3/4 breakout session	L Haimberger/S Broennimann
1700-1730	36. Comments from Ext. Advisors	Sakari Uppala
1730-1830	Discussion	
	End of General Assembly	

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(Roberto Buizza - 22 February 2017)