FCFA IMPALA

Interim progress report

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Contents

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Executive summary

The overarching aim of IMPALA (Improving Model Processes for African cLimAte) is to deliver a step change in global model climate prediction for Africa on the 5-40 year timescale by delivering reductions in model systematic errors, resulting in reduced uncertainty in predictions of African climate and enabling improved assessment of the robustness of multi-model projections for the continent. The project commenced in February 2015 and will make an annual report within the wider FCFA programme in June 2016. This report documents progress as reported at the first IMPALA science meeting 10-11 December 2015.

IMPALA focuses model improvement on a single multi-temporal, multi-spatial resolution model, the Met Office Unified Model (MetUM), to allow rapid pull through of improvements made in the project into improved African climate modelling capability. This focus will facilitate rapid progress which may then be exploited by the wider modelling community – since the methodology developed and understanding obtained will be widely applicable across all contemporary models.

Since project start in February 2015 all project staff and governance mechanisms are in place and good progress has been made across IMPALA's four work packages.

Management and project meetings
The management committee has met twice to review project functioning and a Scientific Steering Committee, with representatives internal and external to FCFA, has been established. IMPALA has engaged with CCKE on a number of activities including: contribution of IMPALA objectives (and CSRP experience) to the development of the FCFA logframe; the FCFA brochure and the Scientific Capacity Development strategy. In addition the CCKE coordinated FCFA pre-event and launch at the fifth Climate Change and Development for Africa conference (October 2015, Victoria Falls, Zimbabwe) was attended by the project manager and four African partners in IMPALA.

An IMPALA science meeting of about 40 researchers and including remote participation by the 4 African partners was held on 10-11 December 2015 at the Met Office to discuss progress to date and to hold an initial discussion on model evaluation metrics for Africa. The CP4-Africa working group has met three times to guide development of the CP4-Africa convection permitting pan-African regional model.

Papers (submitted/published), internal project reports
One peer-reviewed paper addressing large scale (hemispheric albedo) impacts on African rainfall has been published as part of deliverables for WP1: Haywood et al 2016: The impact of equilibrating hemispheric albedos on tropical performance in the HadGEM2-ES coupled climate model.
http://onlinelibrary.wiley.com/doi/10.1002/2015GL066903/pdf

A project report providing a comprehensive assessment of climate changes over Africa predicted by the latest global MetUM version under 4XCO_2 scenarios. This will provide a baseline for assessment of future model versions incorporating IMPALA improvements.
Chadwick et al. 2015: A processed-based summary of African climate change in GC2

Progress highlights
Progress highlights are summarised below by work package.

WP1: Influence of large-scale modes and teleconnections on African climate:
- Idealised corrections of the model imbalance in hemispheric albedo (southern hemisphere too dark) bring striking improvements in cross equatorial energy and

moisture transport, reduce the dry bias in the West African Monsoon and improve the northward "jump" associated with onset in the Sahel. Experiments with more realistic corrections to albedo have so far not reproduced these improvements. Further experimentation is underway to better understand the mechanisms involved and to exploit understanding in model improvement.

- Building on work done in CSRP, a processed-based analysis of SST teleconnections and other modes to Africa rainfall is underway. Model performance for the influences of ENSO, IOD, the Equatorial Atlantic, the Mascarene High, QBO and MJO is being characterised and the role played by model resolution and ocean-atmosphere coupling in representing the local response component of teleconnections is being investigated. Diagnostic techniques to measure performance have been developed and tested with key regions so far studied covering West Africa (Sahel and Guinea coast) and East Africa (both the Short and Long Rains seasons).

WP2: Improved representation of local processes

- A major weakness in climate models – representation of tropical convection – is being addressed with very promising results. Improvements to the MetUM convection scheme have been developed and tested that, using physically-based closure principles, make for a more realistic, slower build-up of convective storms. This successfully delays the modelled peak in the diurnal rainfall cycle – which currently occurs too early in the day in global models. The new scheme also improves the representation of African Easterly Waves which are an important modulator of rainfall in West Africa. These improvements will be included in new releases of the MetUM.

- A haboob parameterisation scheme has been tested and calibrated over West Africa and used to model a full seasonal cycle of haboobs over northern Africa. Results indicate that haboobs contribute one fifth of the annual dust generating winds over northern Africa, one fourth between May and October and one third over the western Sahel during this season. Plans are being developed to integrate the haboob scheme into the MetUM, linking with parallel IMPALA work on representation of cold pool generation from convective downdrafts. Additionally, the MetUM's spatial distribution of Saharan dust emissions are being improved through development of a satellite-preferential source mask. Initial testing of the methodology has been completed and will be extended in future work. Mineral dust is a major cause of respiratory disease in Africa, and improving its representation in climate models will be a major step forward, leading to more reliable projections of health impacts.

- The design of the convection permitting pan-Africa simulation, CP4-Africa, is almost complete and the model has been successfully tested. The simulations will use a ~4.5km horizontal grid length and have been configured to use the latest model physics and revised Africa soil properties. Global model simulations at 25km resolution that will drive the CP4-Africa experiments for both present and future climates are now underway. Initial tests of CP4-Africa indicate, as expected, greater realism in clustering and intensity of convective cells.

WP3: Metrics and Model Evaluation

- Substantial progress has been made in planning the model evaluation work (in consultation with all WP3 researchers, including the 4 IMPALA African partners).
- A first set of data from the baseline MetUM release GA6/GC2 model simulations has been shared with the African partners and model evaluation research has begun. There have also been discussions with other WPs and contacts from all RCs, to plan coordination of model evaluation work outside of WP3.

- Metrics to be developed and shared were discussed at a dedicated session at the IMPALA science meeting. We are arranging for all partners to access JASMIN (for data access and analysis), and the Met Office Twiki (for online collaboration), and waiting to confirm that this is functioning (the back-up plan is to ship additional data on hard drives).
- A prototype spreadsheet for accumulating and sharing information on metrics in use and being developed has been prepared and will soon be circulated.
- A WP3 metrics workshop scheduled for 16-18 March 2016 is in an advanced stage of planning. The aim of the workshop is to share initial model evaluation findings, and begin planning and writing the metrics and model evaluation paper (D3.1), which is due in June 2016.

WP4: Integration and characterisation of model improvements and implication for future climate change

- Work on understanding what processes give rise to specific biases in MetUM simulations has begun, focusing on the role of resolution and model dynamics and, at present, with a regional focus on West Africa, African Easterly Waves (AEWs) and the African Easterly Jet (AEJ).
- A comprehensive study of predicted climate changes over Africa, across a wide range of impact-relevant variables, has been conducted for the MetUM (GC2) using $4XCO_2$ scenarios. These studies will form a baseline against which to measure the impact on climate change signals of Africa-specific model improvements developed in IMPALA. A separate report (Chadwick et al. 2015) has been prepared and will be made available to all RCs.
- Technical work has started to run the GA7 global future climate change experiments that will be used to drive the idealised future CP4-Africa ~4.5km experiments. These will be driven using changes in sea-surface temperature (SST) derived from a HadGEM2-ES simulation for 2080-2100.

Potential delay to CP-4 Africa idealised experiments

The CP4-Africa experiments rely on the speed and availability of High Performance Computing (HPC) at the Met Office that are external to FCFA. Since the original FCFA proposals, the installed new machine operation is slower than was anticipated and this means we are unlikely to complete the full set of 10-year control and future experiments by Spring 2017, although we are still expecting significant amounts of data to be delivered by this milestone. Work is underway to improve the speed of the model including through careful pruning of diagnostic lists and inclusion of optimisation code where possible. We will stage delivery of the model data to the RCs as soon as available and will keep RCs and CCKE updated on delivery timing as the impact of delays becomes clearer.

1. Introduction

The overarching aim of IMPALA (Improving Model Processes for African cLimAte) is to deliver a step change in global model climate prediction for Africa on the 5-40 year timescale by delivering reductions in model systematic errors, resulting in reduced uncertainty in predictions of African climate and enabling improved assessment of the robustness of multi-model projections for the continent. The project commenced in February 2015 and will make an annual report within the wider FCFA programme in June 2016. This report documents progress as reported at the first IMPALA science meeting 10-11 December 2015.

IMPALA focuses model improvement on a single multi-temporal, multi-spatial resolution model, the Met Office Unified Model (MetUM), to allow rapid pull through of improvements made in the project into improved African climate modelling capability. This focus will facilitate rapid progress which may then be exploited by the wider modelling community – since the methodology developed and understanding obtained will be widely applicable across all contemporary models.

Research is structured in four Work Packages (WPs):

WP1: Influence of large-scale modes and teleconnections on African climate
Large-scale modes of variability with centres of action remote from Africa have a major influence on African climate through signals transmitted to the continent along “teleconnection pathways”. WP1 tasks are designed to improve understanding of the mechanisms associated with these modes and pathways, evaluate their representation in the MetUM and develop strategies for their improved representation.

WP2: Improved representation of local processes
Local processes associated with tropical convection, land-atmosphere coupling and aerosol loading play a major role in driving African climate variability both directly and indirectly through influences on the large-scale dynamics. WP2 tasks are focussed on developing better understanding of these processes and designing improved model representations (parameterisations).

WP3: Metrics and Model Evaluation
This activity is coordinating and undertaking model evaluation by identifying, reviewing and prioritising pan-Africa metrics focused on process-based analysis and indices with impacts relevance. Partnerships with African-based experts on model performance are active and being developed – and are focusing on defined regions West, East, Central and southern Africa. The current performance of the MetUM over Africa is being evaluated and compared with that of the current CMIP generation. The improvement in performance following WP1 and WP2 science will also be measured.

WP4: Integration and Characterisation of model improvements and implication for future climate change
This activity integrates advances in model development and improvement from WP1 and WP2 – pulling through the advances into improved model prediction capability. There is strong gearing with ongoing global model development at the Met Office, which follows an annual development cycle and with the Africa Process Evaluation Group (PEG) which monitors the impact of model developments on performance for Africa and prioritises model developments for integration into the model. The activity will also characterise the impact of model improvements on the trustworthiness of model processes driving the future climate change signal for sub-Saharan Africa on the 5-40 year timescale. This will include assessment of the role of convection-permitting resolution on the main processes (from the CP4-Africa and other high resolution simulations).

2. Management, project meetings and interaction with CCKE

All recruitment of personnel is complete with good progress against deliverables across all work packages. The IMPALA project management committee (comprising the WP leaders) has met formally twice (27 July 2015 and 11 December 2015) to review project functioning, plan project events and to review and provide internal steering to science. An external IMPALA Scientific Steering Committee has been set up and comprises: Richard Anyah (HyCRISTAL and affiliated to African Climate Policy Centre), Peter Gleckler (Chair of the metrics panel for the Coupled Model Intercomparison Project (CMIP) and Working Group on Coupled Modelling (WGCM)) as well as the PIs of the Regional Consortia: Declan Conway (UMFULA), Bruce Hewitson (FRACTAL), Chris Taylor (AMMA-2050) and John Marsham (HyCRISTAL). Dates are currently being considered for the first meeting of the Scientific Steering Group. Throughout the period input to CCKE was provided to finalise the FCFA logframe and also the project brochure.

IMPALA has engaged with CCKE on a number of activities including: contribution of IMPALA objectives (and CSRP experience) to the development of the FCFA logframe; the FCFA brochure and the FCFA Scientific Capacity Development strategy. In addition the CCKE coordinated FCFA pre-event and launch at the fifth Climate Change and Development for Africa conference (October 2015, Victoria Falls, Zimbabwe) were attended by Joseph Mutemi, Babatunde Abiodun and Richard Graham (project manager). The latter also gave a presentation on IMPALA and its wider FCFA context in the climate science session of CCDA-5. A preliminary meeting on model evaluation metrics was also held with the 3 aforementioned and Wilfried Pokam Mba and a first tranche of model simulations for evaluation provided by USB (remote access to simulations is being set up through JASMIN (see Section 4.3)).

An IMPALA science meeting was held at the Met Office, 10-11 December 2015. The meeting was attended by around 40 scientists engaged in the project and included representatives from all 4 Regional Consortia. IMPALA scientists, including the four scientists from African institutions (by Skype link), presented their progress and plans. Presentations covered the 4 work packages: local processes (convection, land surface and aerosols); large-scale global modes and their teleconnections to Africa; evaluation of model simulations and integrating model improvement and characterising climate change. Progress on the design and initial testing of a pan-Africa convective permitting model simulation (CP4-Africa) was also reported and this model will be used by all 5 FCFA projects to study the role of currently un-resolved processes on simulations of present and future climate and assessment of the robustness of current climate model simulations of future climate projections. The meeting also included a discussion session on identifying, developing and sharing metrics for evaluation of climate models and a prototype spreadsheet for informing cross-FCFA partners of metrics in use or being developed was introduced. A report of progress presented at the meeting is in preparation. The next IMPALA science meeting is scheduled for December 2016.

The CP4-Africa working group that is driving design of the CP4-Africa convection permitting limited area model has met three times and is the main route for decisions on the detail of the set-up of these experiments.

3. The MetUM development approach

For reference later in this report we here briefly describe the development cycle for the MetUM. The MetUM undergoes continuous development by a large group of scientists working on improvement of model representation of dynamical and physical processes. The development cycle is defined by 1) the release of a new model version; 2) an extensive evaluation of its performance; 3) development, testing and incorporation of a suite of model changes and 4) release of the next version. The evaluation process (step 2) assists in identifying and prioritising the changes incorporated in step 3. Note that while some model changes can be developed, tested and implemented in a single cycle – most take several cycles to complete. A new atmospheric model version is released once each year.

The current "trunk" version of the MetUM is referred to as HadGEM3. Successive releases of HadGEM3 are identified in the global atmospheric (GA) model component as GA1,2,3 etc. More recently, a new series was started to explicitly define global coupled (GC) model releases. For example, GC2 refers to the standard coupled ocean-atmosphere configuration for which GA6 forms the atmospheric component. The baseline model version used in IMPALA is GA6/GC2. The latest model version (GA7/GC3) has just been released (Jan 2016) and evaluation since February 2015 has focussed on these two model versions. The next atmospheric version release (GA8) is expected in around one year's time (early 2017) and we anticipate new physics developed in IMPALA to be included in this release.

Evaluation experiments include models of different horizontal resolution. In this report some studies including evaluation at both N96 (135km) and N216 (60km) are presented – throwing light on the impact of resolution on model realism.

HadGEM3 contains major upgrades on HadGEM2, the previous "trunk" version, including a new dynamical core. HadGEM2, also underwent many development cycles including a branch of development leading to HadGEM2-ES a version which incorporates Earth System features (e.g. atmospheric chemistry). HadGEM2-ES remains a valuable tool for process understanding and is used in some IMPALA studies reported here.

4. Progress

In this section progress to December 2015 is presented for all 4 work packages.

4.1 WP1: Influence of large-scale modes and teleconnections on African climate

WP1 is structured into the following sub-WPs each concerned with evaluating and improving the MetUM for different aspects of the large-scale influences on African climate.

- WP1.1 - dealing with (a) hemispheric-scale drivers of the global energy cycle and (b) large-scale modes of variability (e.g. ENSO) and teleconnections to Africa
- WP1.2 – Reducing uncertainty in the local (Africa) response to the large-scale forcing, focusing on (a) the role of resolution, ocean coupling and convective parameterisation in representing this response and (b) the role of sea-surface temperature (SST) biases in regions bordering Africa and (c) the role of local dynamics and thermodynamics.

WP1.1 Remote and large-scale drivers of African climate variability

WP1.1a: Sensitivity of model rainfall in the ITCZ over Africa to hemispheric albedo

Observations suggest that hemispheric albedos are equivalent (despite the northern hemisphere (NH) containing far more land surface of higher reflectance) owing to the prevalence of more cloud in the southern hemisphere (SH). However, the hemispheres do not have equivalent albedo in HadGEM2-ES: the SH being less bright than the NH. Noting the work of Haywood et al. (2013), where Sahelian precipitation increases if stratospheric aerosol (which has an albedo brightening effect) is applied to the SH, we performed a series of coupled HadGEM2-ES simulations where the hemispheric albedo was equilibrated via brightening of the SH. The results show a dramatic improvement in representation of the African monsoon, with the dry bias being rectified and the monsoon 'jump' (i.e. where the precipitation in the Gulf of Guinea moves rapidly into the interior of the continent) being accurately modelled. The cause of improvement is documented in Haywood et al. (2016), and is briefly summarised below and in Fig. 1.

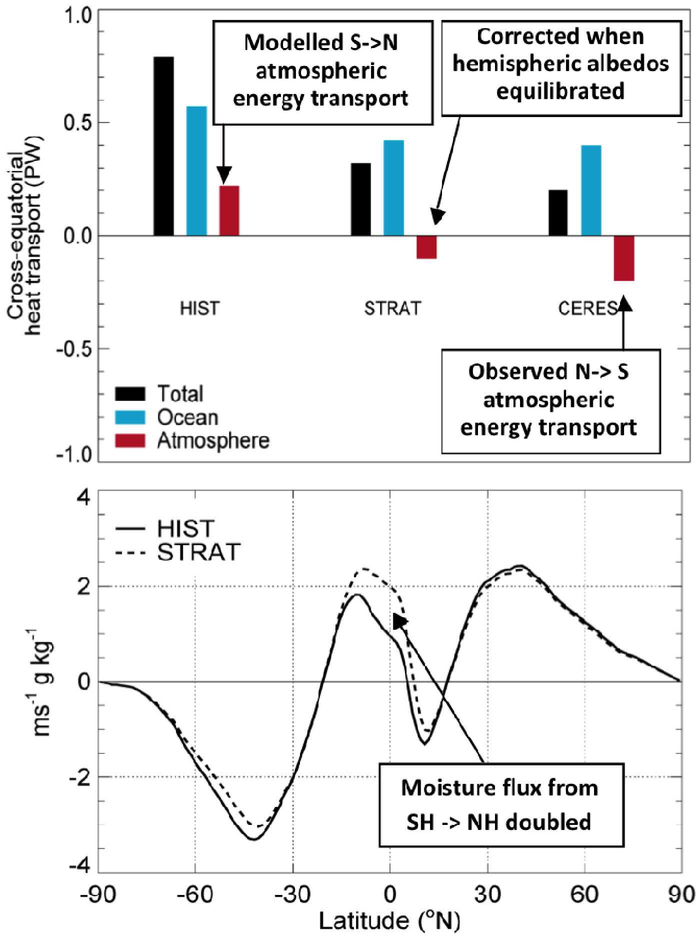

Figure 1: a) Summary of northward cross-equatorial energy transport (PW, Petawatts) from HIST and STRAT coupled-model simulations over 1979-1998. HIST simulations use observed forcings; STRAT simulations have hemispheric albedos equilibrated via SH brightening. Observed energy transport derived from CERES is also shown; b) Annual mean column integrated meridional transport of moisture (MTQ, ms^{-1} g kg^{-1}). Positive values represent northward transport.

Figure 1a shows that, in HadGEM2-ES (HIST) atmospheric cross-equatorial energy transport is from the SH to NH, i.e., the wrong way round. An imposed correction to the hemispheric albedo asymmetry (STRAT) forces the inter-hemispheric flow of atmospheric energy to be of correct sign (observed, CERES) and of commensurate magnitude. This in

turn doubles the moisture flow into the interior of Africa (Fig. 1b). The increased flow of moisture therefore increases monsoon precipitation, reducing the Sahel dry bias by ~70%.

The improvements to model Sahel precipitation totals and the representation of the "monsoon jump" are striking. However the modifications to hemispheric albedo above are simplified since we assume a spatially uniform forcing in the SH. This does not target the source regions of the bias, such as the Southern Ocean, and the framework of the experiments is such that the top-of-atmosphere radiation balance is perturbed, cooling the model climate. To investigate the impact of more realistic corrections to albedo, we performed further experiments where albedo is corrected via zonally varying adjustments, in order to correct biases at source (though not, at this stage, correcting the associated physical origins of the bias). These experiments (SWex) were designed to keep the top-of-atmosphere radiation budget balanced whilst simultaneously perturbing the hemispheric albedo bias, by adjusting the shortwave (SW) radiation budget via alterations to ocean albedo. A spectrum of forcings was applied to investigate the impact of a steady reduction of the hemispheric albedo bias on cross-equatorial energy transport and the ITCZ/monsoon. In contrast to the Haywood et al. (2016) experiments, described above, no material improvement in the representation of the ITCZ and the monsoon is achieved in these new experiments. Figure 2 shows the meridional energy transport in the model and the change from the historical experiment, demonstrating the partitioning in energy transport adjustment. It can be seen that the model's adjustments in meridional energy transport in the tropics are mostly achieved via the ocean, such that the tropical atmospheric circulation largely remains the same (note in contrast to STRAT (Fig. 1a) the cross-equatorial atmospheric energy transport remains in the wrong direction in all the SWex experiments, see inset Fig. 2a) . In the extratropics, the dynamical response of the atmosphere is much greater than in the tropics as the changes in meridional energy transport are dominated by the atmospheric response (Fig. 2b). Previous studies of inter-hemispheric energy transport have frequently used atmosphere-only or slab-ocean models, where the dynamical response is confined to the atmosphere. A recent study by Kay et al. (*in revision* with *Journal of Climate*) using the CAM5 coupled model shows a similar response to our work.

This work demonstrates the importance of using a coupled model to understand dynamical responses to perturbations to the radiation and energy budget and highlights sensitivities to experimental design. Further experiments where both SW and long-wave (LW) biases are corrected were undertaken though do not materially improve cross-equatorial energy transport and the ITCZ/monsoon. Underlying biases in representation of physical processes, such as convective-dynamical coupling, are not corrected via these experiments and continue to control tropical biases. A peer-reviewed paper is in preparation (Hawcroft et al.) and near submission at the time of writing (likely submission date in February 2016).

Next steps are to evaluate the relationship between the TOA energy budget, meridional heat transport and the ITCZ/Monsoon in several versions of the Hadley Centre Model. Use of different model versions can assist identification of sensitivities in these factors to model physics.

Progress against deliverables:
Deliverable D1.1a, January 2017: Submitted peer-reviewed paper on the role of large-scale hemispheric processes and model biases on the simulation of the West African Monsoon, including the specification of process-based diagnostics for evaluating models.

The work described will contribute to this deliverable, which is ahead of schedule and will have generated two peer-reviewed papers by early 2016 (Haywood et al. (2016) and Hawcroft et al. (*in prep*), as described above).

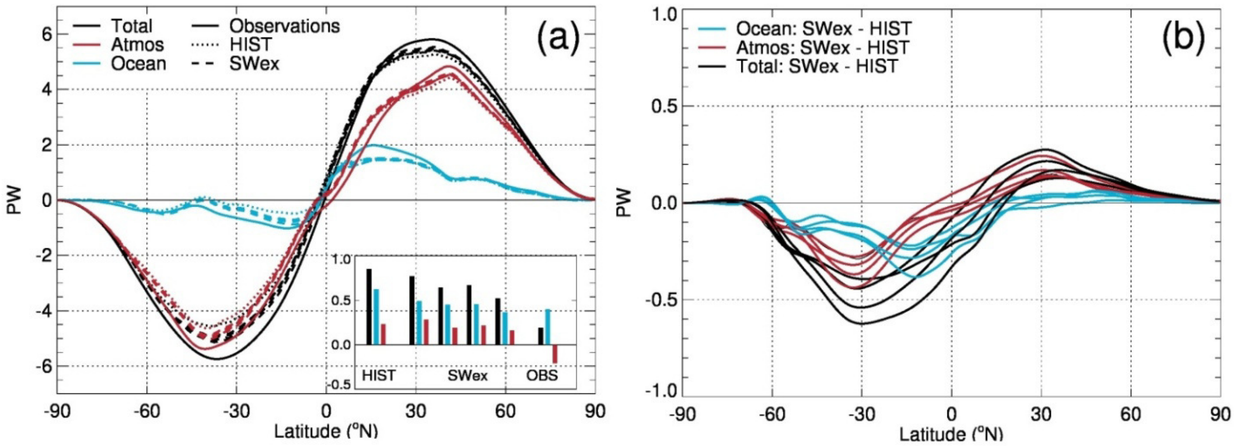

Figure 2: a) Meridional energy transport (PW) with cross-equatorial energy transport (inset) from the historical (HIST) and perturbed (SWex) simulations against CERES observations; b) changes in meridional energy transport from the historical to SWex simulations (PW).

WP1.1b Errors in remote drivers and their pathways controlling African climate

Initial work has focused on the representation of remote and large-scale drivers of African climate variability in the Met Office Unified Model (MetUM) Global Coupled 2 with a horizontal atmospheric resolution of N216 (GC2-N216). Rowell (2013) developed a framework for assessment of model representation of remote influences (teleconnections) on Africa rainfall, based on the influence of 6 SST regions to 6 African rainfall regions. This framework has been applied to the GC2-N216 model using a simulation of 100 years' duration. Comparisons are made with the observational period 1979-2014. It was found that although many of these teleconnections are weaker in GC2-N216 than in observations, they are generally well captured. We are now focusing on teleconnections to selected regions, taking a more detailed mechanistic approach, to better understand the processes involved and how their representation can be improved in the MetUM. The regions selected are: (a) the Guinea coast in West Africa for July-September (JAS), and (b) Great Horn of Africa for both the October-December (OND) Short Rains (SR) season and the March-May (MAM) Long Rains (LR) season.

(a) West Africa – Guinea Coast: JAS

The teleconnection of enhanced JAS rainfall when equatorial Atlantic SSTs are warm is captured in GC2-N216, although weaker than in observations. Potential (not exhaustive) reasons for this are warm SST biases in the southern Atlantic, the ITCZ being too far south and an African Easterly Jet (AEJ) that is too broad and extends too far south. Investigation of the vertical structure of the West African Monsoon in GC2-N216 shows that the modeled region of vertical ascent in the main rainbelt (near 10°N) is weaker than observed, with a spurious secondary peak in ascent deep into the troposphere occurring over the coast. These model biases will be further investigated in future work.

(b) Great Horn of Africa (GHA)

OND Short Rains (SR) season

Enhanced (depressed) east African short rains in OND are associated with El Niño (La Niña) events in the Pacific and the positive (negative) phase of the Indian Ocean Dipole (IOD). These teleconnections are well captured in GC2-N216. The zonal displacement of the eastern ridge of the Mascarene High (MH; Manatsa *et al.* 2014) has been investigated as a further driver of variability in the GHA SR season. When the eastern ridge of the MH is displaced east, there is a positive IOD pattern with enhanced rainfall over the GHA (Fig. 3, left). This suggests the variability in the MH displacement and the IOD are connected.

Although the MetUM reproduces similar SST anomalies in association with an eastward extended MH, the amplitude is too weak (Fig. 3, right). The anomalous easterly flow is also too weak, suggesting a possible lack of moisture advection towards the GHA. The rainfall dipole in the MetUM does not have the separation observed (dry in eastern Indian Ocean; wet in western Indian Ocean). Analysis of these and other aspects of the model's behavior will form the basis of further research to understand and reduce the MetUM biases.

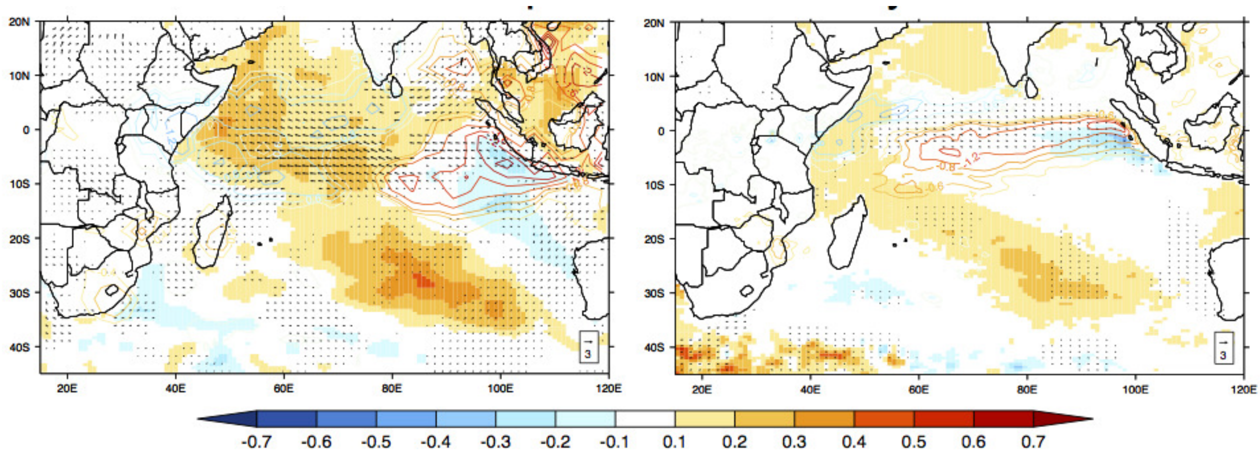

Figure 3: Composite of years when the eastern ridge of the Mascarene High is anomalously displaced to the east for observations (left) and GC2-N216 (right). Figure shows anomalous SSTs (colours), rainfall (contours) and low-level wind at 925 hPa (vectors).

MAM Long Rains (LR) season

It is well-known that variations of tropical SST are not very important for year-to-year variations in the Greater Horn of Africa 'Long Rains' season (March-April-May; 'LR'). In that respect the LR season is very different from rainfall in other tropical regions where teleconnections to tropical SST are typically important and underpin the skill in seasonal forecasting. Lack of understanding of controls on year-to-year variability of the LR complicates solving the East African Paradox (the name given to the inconsistency between observed drying of the LR season since 1979 and its projected wetting in 21st century projections from CMIP5).

In the work we have started here we aim to improve understanding of processes controlling year-to-year variability of the LR season. We have started by identifying teleconnections to the LR season of global modes of variability other than tropical SST, using longer observational records, spanning the satellite era, than used in previous published studies. Our initial results with a number of observed rainfall datasets confirm that the MJO and QBO have moderately strong links to the LR, strongly exceeding the (near absent) constraints by tropical SST. Our next step is to clarify through what mechanisms these modes influence the LR in the observations as the literature is not very clear on this point. This understanding will then be used to analyse to what extent similar processes act in the UM, including in convection permitting configurations.

Next steps: For the coming year the above analysis will be continued and also extended through conducting idealised diabatic heating experiments.

WP1.2 Reducing uncertainty in the final local response to remote drivers

WP1.2a The role of model resolution and coupled processes; and WP1.2b Process-based evaluation of biases in the mean and teleconnection pathways

Initial work feeding into both these sub-workpackages aims to understand the sensitivity in the final response to remote drivers to (a) air-sea coupling and (b) horizontal resolution. This is done by applying metrics developed in WP1.1 above to MetUM coupled (GC2, 100 years) and atmosphere-only (GA6, 27years) simulations forced with observed SST at high (N216, ~60km) and low (N96 ~135km) atmospheric resolution. Observational comparisons are made with ERA-Interim reanalysis over 1979-2014.

West Africa – Guinea Coast JAS

A striking result is that the teleconnection of warm SSTs in the equatorial Atlantic being associated with wet JAS rainfall over the Guinea coast is captured in all simulations except the low-resolution coupled model (GC2-N96). Potential reasons are the ITCZ being furthest south in GC2-N96, and a lack of interannual variability in the southern flank of the AEJ. Further, in GC2-N96 the maximum ascent occurs at the coast rather than near 10ºN.

WP1.2c Regional circulation, thermodynamic and internal dynamics responses to teleconnections

Observed rainfall in Africa (and other regions) is subject to variations on a range of timescales and diagnostic methods to measure this variability and compare it with that simulated by the MetUM are required. In this sub-WP work has focused on developing a methodology for diagnosing how such local rainfall processes and variability respond to external forcing and quantifying the relative role of these local processes. Spectral analysis of time series of rainfall, local diagnostics and metrics for remote forcings, after transformation into a frequency domain, shows promise. This approach has been tested on data from a relatively coarse GCM with parameterised convection (HadGEM2 1.875° longitude x 1.25° latitude). Rainfall and local or more remote diagnostics show coherent relationships with physically plausible phase differences (leads/lags). An example is included for the lead/lag relationship between rainfall and low-level moisture convergence over West Africa during July-November (Fig. 5). The figure shows, in HadGEM2, a widespread lag (blue shading) for rainfall of 1-2 days behind the moisture convergence. Figure 4 also indicates that rainfall leads moisture convergence (red shading, particularly between 15°N and 19°N) in the Sahel region for variations with a frequency of around 0.05 (period 20 days); this will be investigated further and its statistical significance established.

Next steps will involve:

- Testing the spectral analysis method for a wider range of diagnostic terms, both local and more remote
- Application of the method to data at finer spatial and temporal resolutions (e.g., data from CASCADE and SWAMMA projects)
- Investigating improvements gained from wavelet cross-spectrum analysis
- Application to data and model output from IMPALA

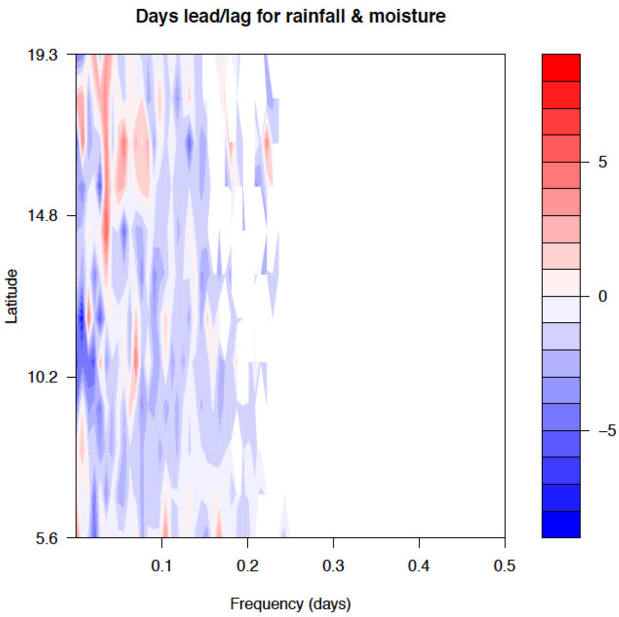

Figure 4: Lead/lag relationship between rainfall and low-level moisture convergence in HadGEM2 over West Africa during July-November.

Progress against deliverables to 2017:

Deliverable D1.1b, June 2017: 1) Submitted paper detailing the MetUM performance for Africa teleconnections in the CMIP5 context with a focus on the relative roles of overturning-type circulations and wave activity from remote tropical biases on teleconnections to Africa; 2) demonstration of the impact of diabatic heating bias correction from idealised and nudged experiments in key regions on African climate variability.

The work referred to under WP1.1b above contributes to the first part of this deliverable.

4.2 WP2: Improved representation of local processes

W2.1 Convection parameterisation development

Improving the diurnal cycle of convection over Africa

The Unified Model (UM) convection parameterisation scheme has been modified to make convective clouds grow more slowly with time, allowing the gradual build-up of storms over many hours, with the aim of addressing a long-standing model bias in the timing of rainfall over continental land. This has been achieved by retaining information about convective storm activity at previous model time steps, introducing for the first time a form of memory into the scheme. In this new approach the model remembers where and when there has been rainfall, and uses this to influence the amount of mixing (entrainment) the clouds experience with their local environment. Where there has been little precipitation, it is assumed the clouds are small and so experience high levels of entrainment, limiting their growth. As the rainfall from the clouds increases, larger patches of moisture form in the boundary layer, and these enable bigger clouds to form. These clouds experience lower entrainment rates because the ratio of cloud perimeter to horizontal cloud area decreases.

By introducing an entrainment rate that depends on past precipitation, the timing of the peak in convective precipitation is delayed by 2-3 hours. Figure 5 shows the time of day (local time) of the daily peak in precipitation, comparing observations, a control version of the model (GA7), and the new 'memory' version. While observations show the peak over Africa occurs between 6pm and midnight, in the control model precipitation peaks between noon and 3pm local time. The introduction of memory moves the peak to between 4pm and 9pm, in closer agreement with the observations. Work will now focus on the detail of this change, ensuring that the best agreement with observations is obtained.

The inclusion of a memory term has also been found to have a beneficial impact on model representation of African Easterly Waves (Fig. 6). While in the control version the number of waves per season was lower than those found in observations, inclusion of memory has increased the number of waves to a much more realistic level. This may in part be due to an improved ability of convective systems to propagate over Africa, but further analysis of the nature of the AEW and their coupling to convective systems will be a key focus in the coming months.

In summary, this initial implementation of convective memory is providing very promising results which will lead to more realistic model rainfall patterns, both on short (daily) and longer (seasonal) timescales. This work is addressing a key error in climate models.

Understanding convective cold pools

Intense convective rainfall has the ability to create local regions of colder air near the surface (cold pools). These spread out under gravity, and may de-stabilise the boundary layer in remote regions, potentially triggering further convection. It is believed that this is an important component of convective memory and parameterisation of this effect will improve the modelled diurnal cycle of precipitation.

Using the Met Office Large-Eddy Model (LEM), an initial study (Rooney 2015) of the fluid dynamics of single-phase cold downdraughts has yielded estimates of the size and intensity of the cold pools they produce (Fig. 7). It has been shown that these flows obey self-similar scaling to a good approximation. Future work will involve using this understanding to introduce a representation of cold pools into the UM convective memory scheme (see above), improving its physical basis. This will include a representation of the horizontal spreading of cold pools, which will then be linked to the haboob dust parameterisation (see WP 2.3).

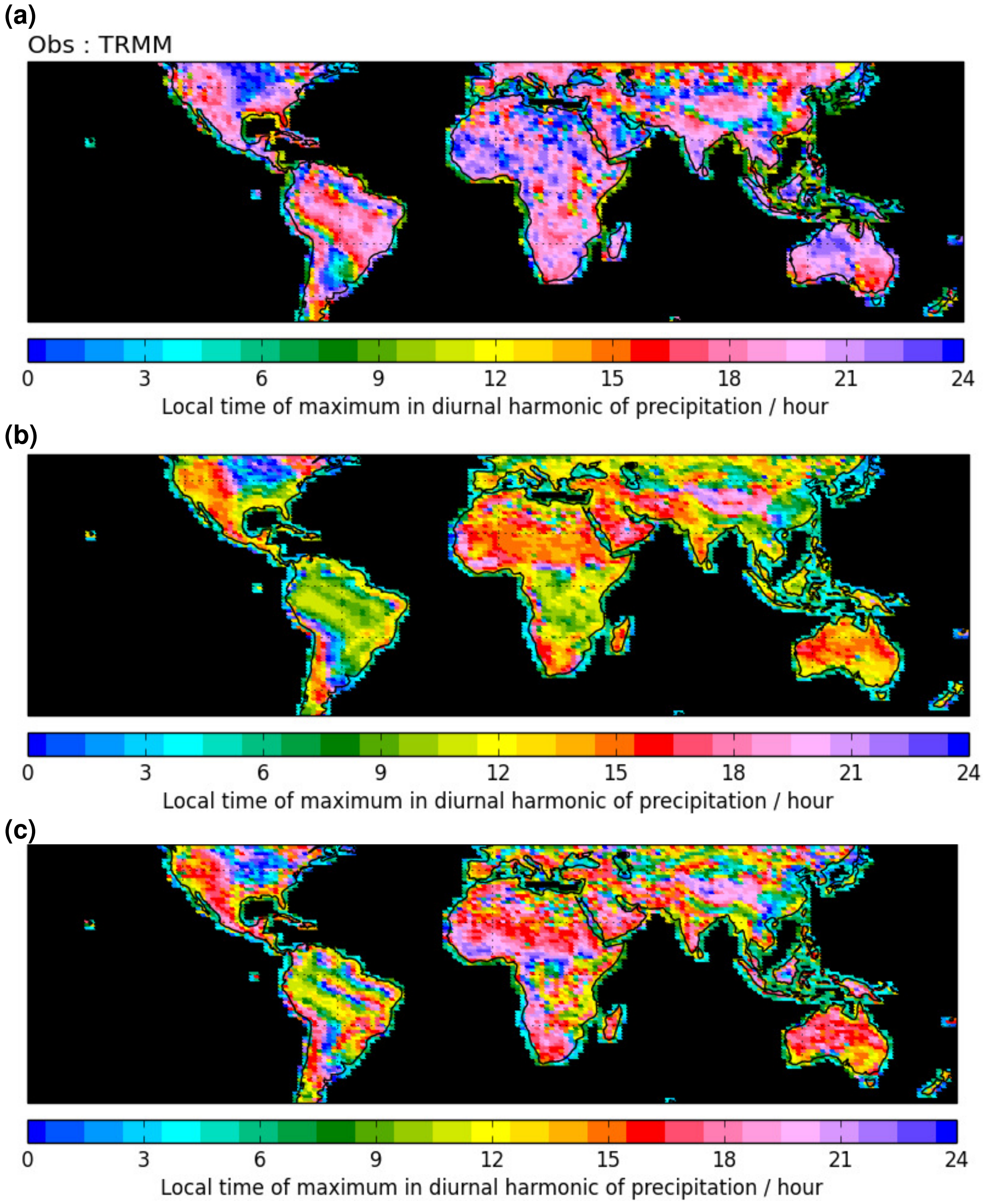

Figure 5: The timing of the maximum daily precipitation (local time): (a) observations from the TRMM satellite; (b) control model (GA7); (c) impact of introducing convective memory.

(a) (b)

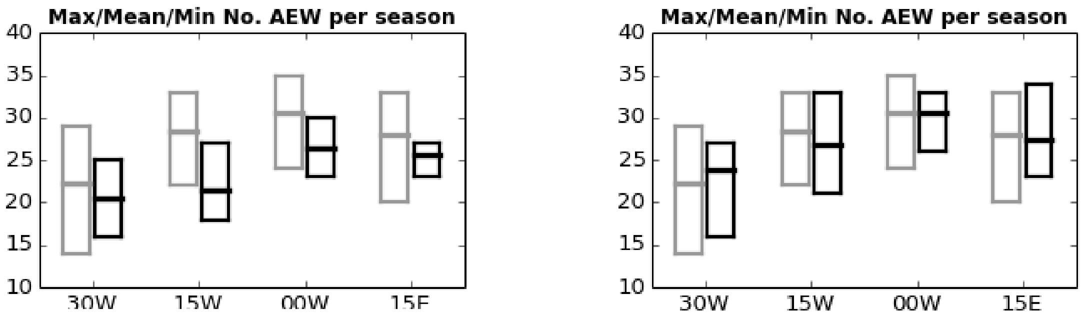

Figure 6: The number of African Easterly Waves per season at different longitudes. Grey boxes show estimates of the number of waves from the observations, and black boxes show the model results. The left panel shows the control model (GA7), and the right panel shows the model with convective memory included.

Figure 7: Vertical sections through LEM simulations showing successive stages of a downdraught spreading to form a cold pool. Colours show negative potential-temperature perturbations, ΔΘ (K). Lines show the horizontal velocity component in the x-direction (black: positive, white: negative; interval 0.5 ms^{-1}).

CP4-Africa

The design of the convection permitting pan-Africa simulation, CP4-Africa, is almost completed and the model has been successfully tested. Figure 8 compares OLR from test output of CP4-Africa (~4.5 km) with that from a 25km run with parameterised convection forced with the same boundary data: the greater realism of the CP4-Africa simulation in terms of grouping, organisation and intensity of convective clusters is evident. Production runs will use the ~4.5km horizontal grid length and have been configured to use the latest model physics from the Met Office operational UK NWP model (UKV), with a small number of modifications deemed suitable for a tropical environment. These include an increase in vertical resolution (providing more model levels in the tropical troposphere), increased sub-grid turbulent mixing and changes to the microphysical parameterisations to improve the representation of graupel. The soil properties for CP4-Africa have also been altered such that they are homogeneous across the continent (representing sandy soil), removing spurious unreliable small-scale detail in the data which in previous studies (e.g. Cascade) has been shown to contaminate the simulation, for example by unrealistically influencing the rainfall patterns. The present day CP4-Africa runs will be driven by a N512 GA7 climate simulation. The simulation will be for a 10 year period starting on 01 January 1997 with soil moisture fields obtained from a spun-up off-line land-surface simulation (itself driven by observations). The CP4-Africa production runs will begin in early 2016.

These CP4-Africa simulations will be used to understand the behaviour of convection across Africa and how it interacts with the land surface and the large-scale flow. This understanding will be used to develop the convection parameterisation scheme. A future climate CP4-Africa run (currently being designed) will provide high-resolution information on extremes in a changing climate. Both the present-day and future CP4-Africa data will be made available to the FCFA regional consortia.

See WP4 for upcoming deliverables for CP4-Africa.

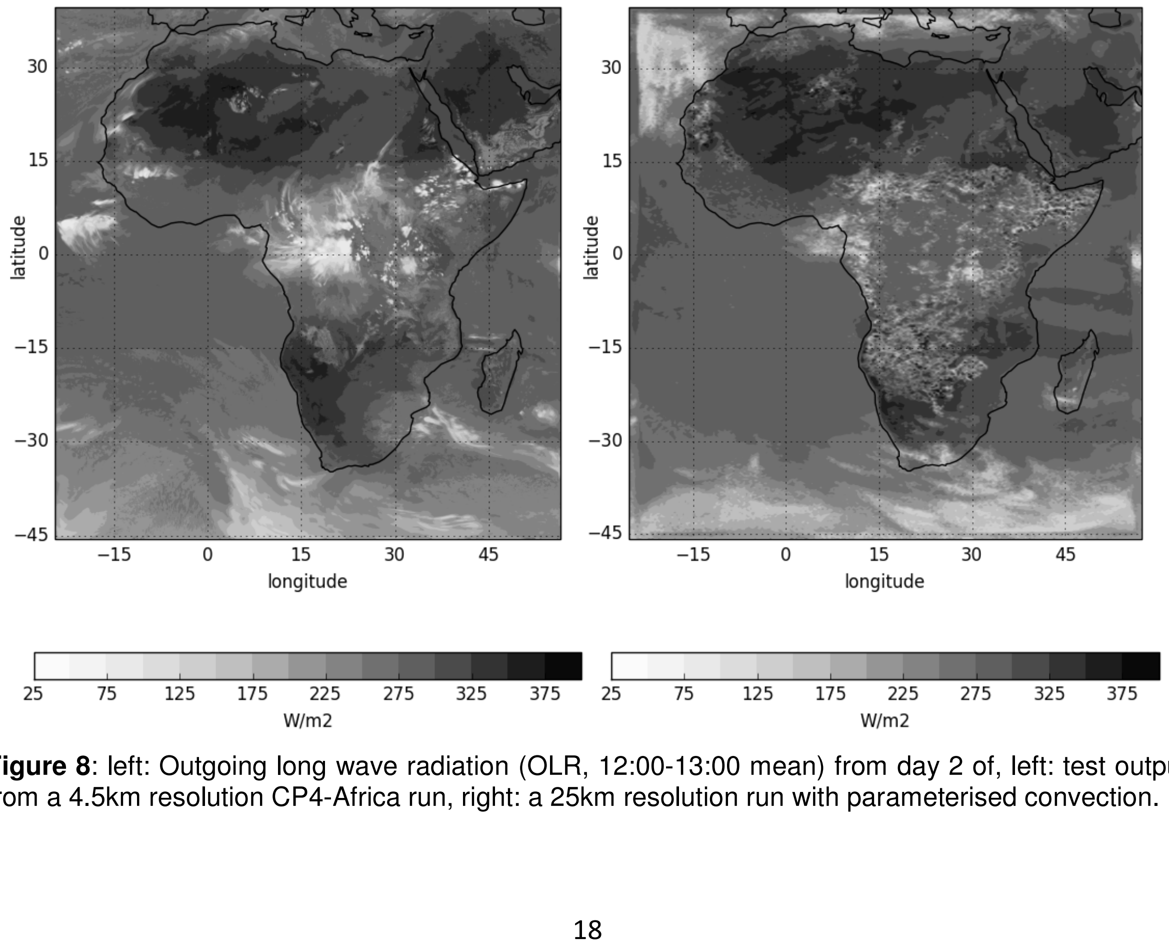

Figure 8: left: Outgoing long wave radiation (OLR, 12:00-13:00 mean) from day 2 of, left: test output from a 4.5km resolution CP4-Africa run, right: a 25km resolution run with parameterised convection.

W2.2 Land surface development

Work this period has largely fed into development of the CP4-Africa model (see above) through a focus on developing the land surface ancillary datasets, including the homogenised soil properties, associated soil moisture fields for initialising the UM referred to above. A series of offline runs using the GL6 science configuration and forced with a reanalysis derived dataset (WFDEI) have been conducted to examine changes to surface parameters i.e. the change to uniform sandy soils, changing land cover fractions and the use of a seasonally varying leaf area index (LAI). Offline runs were used to generate the soil moisture climatology required to initialise the CP4-Africa model. Updated land cover fractions centred on the year 2000 were derived in conjunction with the remote sensing community to provide mapping to the five standard plant functional types (PFTs) and four non-vegetated functional types (Poulter et al. 2015). This data set provides a more realistic distribution of forests than IGBP derived fractions. The overall pattern is of a reduction in broad leaf forest south of the Congo basin and a reduction in C3 grasses across east and southern Africa with a corresponding increase in C4 and shrub. The new land cover fractions, and changes, are shown in Fig. 9.

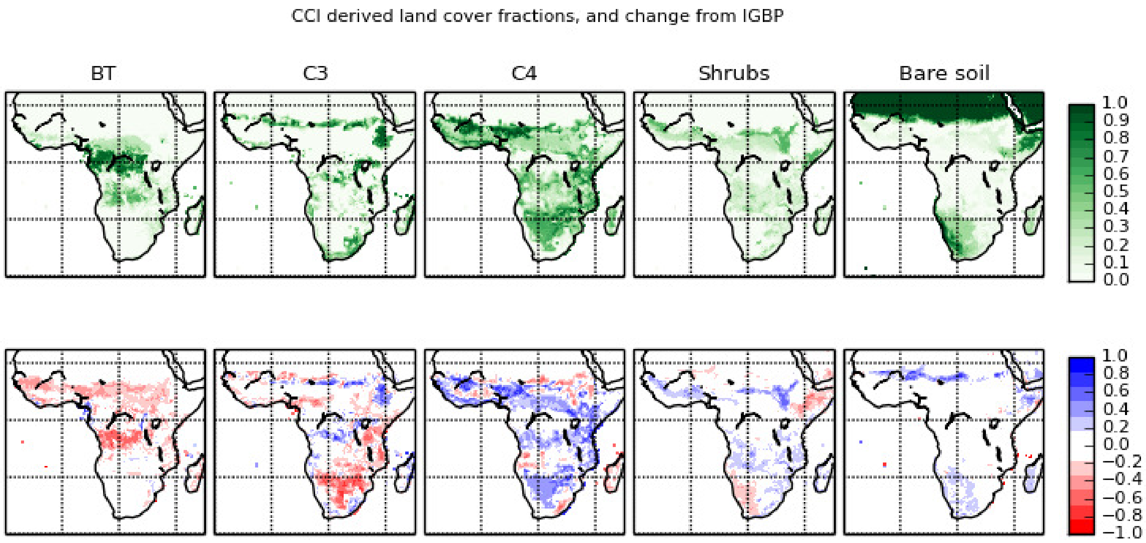

Figure 9: New land cover fractions for use in the CP4-Africa simulations (top row) and differences between the new fractions and control (bottom row).

The changes imposed have been compared to observations at flux sites in West Africa with respect to the evaporation regime and against a climatology of MODIS Terra land surface temperature (Fig. 10) to understand the impact on surface fluxes more widely across Africa. The clear-sky land surface temperature is sensitive to local meteorology but also surface physical characteristics such as albedo and surface roughness, and as a diagnostic of sensible heat flux it is also sensitive to variations on soil moisture particularly during the hours before and after midday. The relative amplitudes in the annual cycle reflect different vegetation roughness lengths. Whilst large biases persist in the Sahara in absolute terms (see Fig. 10b) due to the thermal response over the thickness of the level 1 soil layer, the changes in land cover fraction have yielded reductions in absolute bias particularly in the Congo basin. The combined effect of the changes introduced (i.e. to soil properties, land cover and varying LAI) are within the overall model bias. Comparing incremental changes (not shown here), the degraded response along 5 to 15º S in July to September is largely due to the introduction of varying LAI.

Modis Terra Climatology LST GL6_new minus Modis LST GL6_new minus control

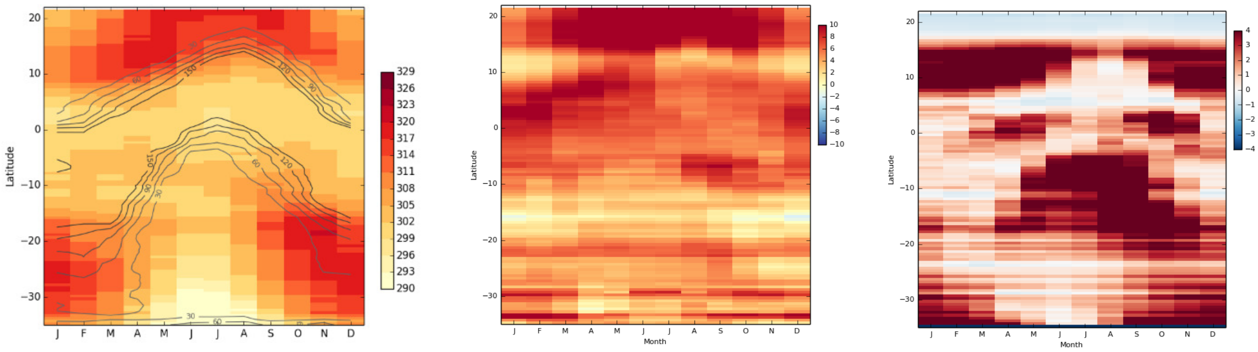

Figure 10: (a) zonal means of MODIS Land Surface Temperature (LST) between 20E to 25W, (b) model biases and (c) the impact of combined changes made to the model.

W2.3 Aerosols

Haboobs

The development of a haboob parameterisation has now been completed within the Desert Storms project. The parameterization is based on a simple conceptual model, in which the downdraft mass flux from the convection scheme spreads out radially in a cylindrical cold pool. The parameterization has been tested with a set UM simulations for June and July 2006 over West Africa, and calibrated with a convection-permitting simulation. Additionally a one-year convection permitting simulation has been used to model a full seasonal cycle of haboobs over northern Africa. The study suggests that haboobs contribute one fifth of the annual dust-generating winds over northern Africa, one fourth between May and October, and one third over the western Sahel during this season. Off-line calculations based on simulations with a range of resolutions demonstrate that the haboob parameterisation successfully captures the geographical distribution and seasonal cycle of haboobs and will correct a major and long-standing limitation in global dust models.

Two papers have been written based on the above research. Plans are now being developed to integrate the haboob scheme into the UM and link it to a cold pool scheme (see WP2.1). Mineral dust is a major cause of respiratory disease in Africa, and improving its representation in climate models will be a major step forward, leading to more reliable projections of health impacts.

Dust emissions

Improvements to the UM's spatial distribution of Sahara dust emissions are being made by incorporating a satellite-derived preferential source mask into the dust emission scheme. The simulated emissions can be tuned according to whether or not a given model grid box is observed as being a dust source area. Different approaches are currently being evaluated. These include tuning the vertical dust flux in each model grid box over the Sahara according to the frequency with which that grid box is observed to be a dust source, combined with modifying the soil property data to improve the dust emission. Some initial short-duration model experiments have been conducted at low (N96) resolution to test the methodology. The experiments will next be extended to higher resolution and model runs will be conducted for periods of several years and results compared to available aerosol observations. Together with the implementation of the haboob scheme, this work will lead to improved representation of dust loading and its radiative impact in the UM over Africa, allowing more reliable projections of climate change and its impact of human health.

Next Steps: Continue a global model N512 AMIP timeslice experiment to force the future CP4-Africa experiment, as well as the CP4-Africa future experiment. We will also run present day and future ~25 km resolution regional experiments with parameterised convection for comparison with the CP4-Africa simulations. We will conduct an analysis of spatio-temporal characteristics of rainfall in CP4-Africa output as data becomes available and make CP4-Africa data available to FCFA regional consortia via JASMIN.

Progress against deliverables to 2017:
D2.3a, January 2017: Submitted paper detailing the performance of the dust model developments against observations and the implications for climate prediction.
The work on dust emissions referred to above contributes to this deliverable.

D2.3b, December 2017: Project report detailing the performance of the optimal biomass burning aerosol model against AERONET and satellite observations.
The work on dust emissions referred to above contributes to this deliverable.

4.3 WP3: Metrics and Model Evaluation

Summary
During this period substantial progress has been made in planning the model evaluation work (in consultation with all WP3 researchers) and model evaluation research has begun. There have also been discussions with other WPs and contacts from all RCs, to plan coordination of model evaluation work outside of WP3.

The four IMPALA African colleagues: Benjamin Lamptey (BL, ACMAD), Babatunde Abiodun (BA, UCT), Joseph Mutemi (JM, ICPAC/Nairobi University), and Wilfried Pokam (WP, University of Yaoundé) have participated in planning work and regional evaluation of the MetUM has started. The required due diligence procedures are complete, and contracts have been drafted. We have been in communication via Skype and email, and Richard Graham (RG) also met with the partners at the FCFA meeting in Victoria Falls in October. BL, JM, BA and JM each presented their research plans at the IMPALA science meeting (10-11 December 2015) via Skype link. The focus of each partners work has been agreed, metrics have been discussed, and UM data has been distributed using USB drives. We are arranging for all partners to access JASMIN (for data access and analysis) and the Met Office Twiki (for online collaboration), and the performance of these links is being tested by the African partners (the back-up plan is to ship additional data on hard drives). Several of the African partners are recruiting PhD students or other researchers to assist with the work.

We have planned a WP3 workshop for 16-18 March 2016. The aim of the workshop is to share initial model evaluation findings, and begin planning and writing the metrics and model evaluation paper (D3.1), which is due in June 2016. The workshop will take place in Oxford, with the first two days allocated for intensive collaboration amongst WP3 researchers, and the third day comprising a larger Africa Process Evaluation Group (PEG) style meeting which UK researchers working on African model evaluation have been invited to (PEGs are key instruments in coordinating integration of model improvements into the MetUM development cycle). Each of the four African researchers will present to the group, followed by a selection of presentations from UK researchers. We are currently in the process of booking flights and accommodation.

WP3.1 Review of suitable metrics

University of Oxford continued to review suitable metrics. Alongside the existing list of metrics from the science plan, we developed a set of “regionally-focused priority metrics”

targeting circulation systems in each of West, Central, East, and southern Africa. These were shared with the African partners for comment and they have been adding their own ideas.

At the December science meeting metrics were reviewed by all IMPALA researchers at a focused metrics discussion. The existing lists of metrics (including from the science plan, the regionally-focused priority metrics, and the metrics already in the Met Office facilities Auto-Assess/Maverick) were provided for comment. The majority of the discussion focused on possible synergies in model evaluation work between WPs (and to some extent with the other FCFA RCs) – a summary of the discussion is provided in Appendix 1. All IMPALA researchers were encouraged to provide additional input as to which metrics they perceived to be important.

A WP3 Twiki page has been developed to encourage researchers from IMPALA and beyond to share ideas, plots, and code for priority metrics. This will hopefully be an ongoing resource for reviewing metrics, and also for sharing analysis tools. We hope it will form a starting point for a hub of metrics on African climate.

The review of metrics will be an ongoing activity throughout IMPALA: it has been a useful activity in planning the evaluation work, but will also be an output from the model evaluation work, as we identify strengths and weaknesses of the UM, areas which need monitoring and development, and particularly useful plots.

WP3.2 Preparation of assessment tools

Assessment tools will partly be an output of the model evaluation work. The primary goal in this period was to plan the model evaluation work: after achieving the primary objective of evaluating the UM's ability over Africa we plan to identify which metrics are the priority to feasibly share and/or include in Auto-Assess/Maverick. We will then work to improve the code to a level that is suitable for assessment tools which can be shared via the Twiki, and integrated into Auto-Assess/Maverick. In the meantime we have been exploring options for developing easily sharable and usable analysis tools, including JASMIN CIS. All researchers have been encouraged to use Python where possible, but their primary motivation should be to deliver model evaluation results rather than perfect code.

WP3.3 Model evaluation

As noted above, model evaluation plans for each WP3 researcher have been agreed. Note that in the first phase of the project we will be evaluating GC2/GA6 (including coupled, atmospheric only, at N96 and N216; but focusing on GC2 N216). All researchers now have access to some UM data and are beginning evaluation research, in preparation to share initial findings at the March workshop, and to contribute to the paper ahead of submission in June 2016.

A Google drive spreadsheet has been developed to encourage researchers from WP3, other IMPALA WPs, FCFA RCs, and other affiliated researchers, to share their model evaluation plans. This should identify synergies, potential overlaps, and gaps.

Next steps: Finalise and run the WP3 metrics workshop and Africa-PEG (Oxford, 16-18 March 2016). Complete and compile evaluation results for the metrics and model evaluation paper (D3.1), which is due in June 2016.

Progress against deliverables to 2017:
Deliverable D3.1 June 2016: Submitted paper on metrics and model evaluation in Africa.

The planning and commencement of evaluation research and planned March workshop contribute to this deliverable.

4.4 WP4: Integration and Characterisation of model improvements and implication for future climate change

WP4.1 Model Integration and Improvement

Work on understanding what processes give rise to specific biases in MetUM simulations has continued, focusing on the role of resolution and model dynamics and, at present, with a regional focus on West Africa, African Easterly Waves (AEWs) and the African Easterly Jet (AEJ).

Representation of the African Easterly Jet and African Easterly Waves in Met Office Unified Model Global Atmosphere configurations

Recent model configurations have been assessed across a range of resolutions. The consideration of different resolutions allows for discriminating between model errors that are due to coarse resolution and deficient dynamics, and model errors that are likely due to model physics and parameterisation errors. The focus was dedicated to West Africa and in particular to the ability of the model to represent African Easterly Waves (AEWs). Since the simulation of AEWs depends on the basic state, and in particular on a faithful reproduction of characteristics of the African Easterly Jet (AEJ) from which the waves originate, the AEJ and related large-scale patterns of pressure and temperature fields were examined as well. The ultimate goal is to better understand the two-way interaction between large-scale dynamics and convection in the region, and to shed light on the question of why the most recent UM configuration (GA7) shows a significant improvement in the representation of AEWs and related mesoscale convective systems. Such understanding is important to help maintain this improvement across future release cycles of the MetUM. Next work will be an analysis and report on simulation of African climate (including rainfall) in the next MetUM version (GA7/GC3).

WP4.2 Characterising model improvement in key processes for future climate 5-40 years ahead

A processed-based summary of African climate change in GC2

A comprehensive study of predicted climate changes over Africa, across a wide range of impact-relevant variables, has been conducted for the MetUM (GC2) using $4XCO_2$ scenarios. These studies will form a baseline against which to measure the impact of Africa-specific model improvements developed in IMPALA. The study (available as a separate report: Chadwick et al. 2015) finds that large changes occur in many regions and variables, including temperature, the hydrological cycle, clouds and seasonality, and would be likely to lead to substantial climate change impacts. The type of changes in GC2 are consistent with models in the CMIP5 archive, but the pattern and regional detail of change for many variables varies widely across different GCMs, and reducing inter-model uncertainty in future climate projections over Africa remains a major challenge. One key focus of FCFA will be on developing a much greater range of metrics at the regional scale, and it would be useful if many of these were appropriate for examining both biases in present-day climate, and simulated changes in future climate. A more detailed knowledge of the processes that drive climate change over Africa could allow any dependence of future projections on present-day model biases to be better understood.

Figure 11 shows an example of the process-based approach used in this baseline study. The rainfall response to CO_2 forcing is separated into different components, each associated

with a different physical mechanism of rainfall change (see Chadwick et al., 2013). As with most areas of the tropics, and in common with the CMIP5 ensemble, the pattern of annual rainfall change in GC2 over Africa is dominated by spatial shifts in convective regions (ΔP shift), with moisture increases playing a smaller role by modulating the size of the changes (this is evident from the similarity in the pattern of total change with the pattern of the ΔP shift component: compare first and second columns in Fig. 11). These dynamical changes in rainfall are largely consistent with the pattern of vertical wind and low-level convergence changes – showing increased ascent in regions with increased rainfall and increased descent in regions of rainfall decreases (Fig. 11 third column). There are some discrepancies between the rainfall and vertical wind changes on the southern tip of Africa, where mid-latitude systems (rather than convection dominated systems) may contribute significantly to total rainfall, and so the assumptions underlying the rainfall decomposition may be less valid.

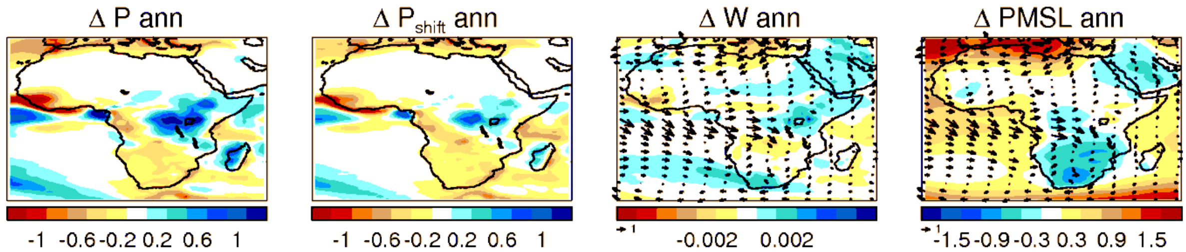

Figure 11: Annual mean change of selected variables in GC2 under $4xCO_2$ forcing over Africa. From left: Precipitation (mm day^{-1}), Component of precipitation associated with shifts in convection (mm day^{-1}), Vertical winds (Colours, Pa s^{-1}) and 925hPa horizontal winds (arrows, m s^{-1}), Pressure at Mean Sea Level (hPa) and 925hPa horizontal winds (arrows, m s^{-1}).

The IPCC AR5 assessment of projected future changes in African climate indicates very low confidence and a wide range of possible outcomes. For regional monsoons such as that over West Africa, local processes and errors in models limit our ability to make robust assessments. By further developing the processed-based methodology introduced above we aim to improve this situation by (i) understanding the physical processes which translate model errors and biases into differences in future responses in models and (ii) searching for constraints on projections which allow us to reject or down-weight possible outcomes.

WP4.3 Impact of resolved convection on future projections

Technical work has started to run the GA7 global future climate change experiments that will be used to drive the idealised future CP4-Africa ~4.5km experiments. These will be driven using changes in sea-surface temperature (SST) derived from a HadGEM2-ES simulation for 2080-2100. Thought is also being given to the method needed to define the lake SST in both global and 4.5km regional experiments, where lakes that have been previously un-resolved (because of the coarser standard resolutions used) will need lake surface temperatures sensibly derived (e.g. by using differentials in surface temperature from averages of the nearest land-SST adjacent points). The CP4-Africa working group that has now met three times continues to be the main route for decisions on the detail of the set-up of these experiments. Other highlights and next steps for CP4-Africa work are reported under WP2 (Section 4.2).

Next steps: These will include analysis and report on simulation of African climate (including rainfall) in the next MetUM version (GA7/GC3) and further development and application of the processed-based analysis to understand model biases.

Progress against milestones to 2017:
Deliverable D4.3a, Spring 2017: Datasets from the present day and future climate runs of CP4-Africa model made available through JASMIN for use by RPCs.

Work reported under WP2 to set up and test the CP4-Africa model and global model driving experiments is contributing to this deliverable.

Note: the CP4-Africa experiments rely on the speed and availability of High Performance Computing (HPC) at the Met Office that are external to FCFA. Since the original FCFA proposals, the installed new machine operation is slower than was anticipated and this means we are unlikely to complete the full set of 10-year control and future experiments by Spring 2017, although we are still expecting significant amounts of data to be delivered by this milestone. Work is underway to improve the speed of the model including through careful pruning of diagnostic lists and inclusion of optimisation code where possible. We will stage delivery of the model data to the RCs as soon as available and will keep RCs and CCKE updated on delivery timing as the impact of delays becomes clearer.

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Appendix 1: IMPALA Science Meeting 2015: WP3 Report

The primary aim of IMPALA WP3 is to evaluate the ability of the UM at a variety of spatial resolutions, to represent key processes for African climate: at the beginning of the project, and at the end, after developments from WP1 and 2. Since all of the WPs will involve some form of evaluation, coordination of evaluation work between WPs is also a key role for WP3. The IMPALA science meeting in December 2015 was an important opportunity to learn about initial research and future plans of each WP, including WP3 which also plans process-based evaluation, and to discuss the interaction between WPs and other FCFA Regional Consortia (RCs), to prevent any overlap or gaps. On the second day of the meeting there was a dedicated metrics session to address these issues.

Summary of metrics discussion

Questions to be considered

- Does the evaluation in WP1, 2, and 4 replicate what is planned/in process in WP3? How is it different? How should it be different?
- How can insights from WP1, 2, 4 and WP3 best be exchanged?
- How should the CP4-Africa evaluation be staged?
- Is there potential for work to overlap with FCFA RCs? How should this be managed?

Format for discussion

After a brief introduction of the key issues by Rachel James (RJa), the room was divided into two groups: WP1 (remote influences) and WP2 (local processes). Both WP3 and 4 are integrative, so researchers from these WPs were able to join either group. Discussion was led by WP1 and WP2 leads respectively in order to ensure that these WPs had control over contributions to the discussion. The two breakouts then came back together for a plenary discussion.

Notes from WP1 breakout

- There was some discussion of methods for communication, and enthusiasm for a Google drive spreadsheet (or similar). Someone should check what is being entered. This should also indicate the stage of development of any metrics: are they experimental, or ready to be applied by other scientists? The benefits of a code repository, on JASMIN or GitHub, were also highlighted.
- The discussion highlights the importance of evaluating key metrics such as temperature: there is a danger of overlooking the simple stuff.
- The importance of communication with the RCs was discussed. The metrics or diagnostics should be linked to specific science questions, and then those people across FCFA working on similar science areas joined up, perhaps through regular teleconferences.
- WP4 could use metrics from other WPs to track progress.

Notes from WP2 breakout

- The role of WP2 relative to other WPs was discussed. Scale is a key distinction: generally, small-scale processes are being modelled and developed in WP2, in contrast to the large-scale in WP1. Evaluation in WP2 is of individual schemes, sometimes in a particular location, and testing the effects of modifying these schemes. The overlap with

other WPs is in how these local modifications scale up to larger processes/phenomena. Here it is important to communicate with WP1 and also WP3 which can assist by facilitating evaluation of a comprehensive suite of metrics for important large scale phenomena. WP2 researchers should therefore highlight which phenomena they perceive to be important.

- New initiatives are not necessary to promote communication between WP1 and WP2 because they already work together, some members of staff work on both of these WPs, and because they are following the usual procedure for MO model development.
- WP4 also has some shared staff with WP2 – model integration work in close contact with convective development.
- There may be value in developing a common set of code to evaluate things which are important across WP2 and other WPs, e.g. the diurnal cycle of precipitation and/or OLR.
- CP4Africa
    - It is important that the large scale and mean climate are not ignored (WP2 focusing on local processes but first want to check what is happening with the large scale – a basic "sanity check"). This should be included in some of the first papers.
    - There is a need for a publication strategy and strategy to divide work between all 4 WPs.
    - Important to include FCFA RCs and WP3 African Partners in evaluation because they may have access to superior datasets at the relevant resolution, and there are many important processes to evaluate on a regional level (IMPALA will not have time to evaluate all of these)

Summary of lessons for WP3

The role of each WP in evaluation

WP1

- Evaluation of teleconnections

WP2

- Evaluation of local processes, parameterisation schemes

WP3

- Main task to evaluate UM at the beginning and end of project
- Emphasis on process-based evaluation, meaning interest in why the model acts in a particular way
- Focus on regional evaluation, and pan-African perspective
- Coordination of evaluation work streams from WP1-4

WP4

- Ongoing evaluation throughout the project: audit trail of model improvements
- Evaluation of future response including in CP4Africa

Evaluation of CP4-Africa

3/4 papers will be written within short period of release of CP4-Africa:

- 1 or 2 papers on the technical design: ancillary fields, resolution etc., and design for future scenarios.
- 1 paper giving overview of results of present day simulations
- 1 paper giving overview of results of idealised future scenarios

Beyond these papers, there is a need for coordination including a publication strategy and strategy for release and licensing of the data. Given the quantity of data/number of potential

processes to evaluate, there is a role for all WPs and the RCs in the evaluation. There is also a need for assistance at an early stage to ensure quality assurance of set up and initial output.

Communication between WPs

- Spreadsheet: all IMPALA researchers will populate a spreadsheet with their evaluation plans
- Africa PEG (Process Evaluation Group): an important mechanism for sharing results. Next meeting will be 18 March 2016 in Oxford.
- IMPALA science meetings: next meetings will be WP1&2 in mid 2016, and all WPs in late 2016
- Twiki: not discussed much during the conference, but still an important tool for sharing ideas
- Code repository: may be a better way to share metrics code than the Twiki due to version control etc.
- JASMIN: important for sharing data, but perhaps could also serve as a code repository. May be useful to encourage CEDA to archive reference datasets which can be then centrally stored and accessed by all researchers.

Communication with RCs

- Spreadsheet: can also be shared with specific people in RCs
- Africa PEG: UK researchers from RCs are already included in Africa PEG network, which should be extended to include new PDRAs (this will provide a link to the RCs)
- Ambassadors: in each RC are important for communication. Key people are Richard Jones (RJo) (FRACTAL), Richard Washington (RW) (UMFULA), John Marsham (JM) (HyCRISTAL), Chris Taylor (CT) (AMMA-2050)
- Teleconferences: It may be useful to set up teleconferences between those researchers working on shared/similar research questions

Benefits of evaluation work beyond FCFA

- Cath Senior (CS) presented the plans for a CMIP initiative for routine evaluation. IMPALA has the ambition to become a hub of metrics on African climate, and should aim to contribute to this routine evaluation of CMIP6.
- Duncan Watson-Parris (DWP) presented progress on the JASMIN Group Workspace (GWS) JASMIN Community Intercomparison Suite (CIS) and there was a discussion about how this might be most useful within IMPALA. A user interface will be developed: the most useful application was considered to be some basic evaluation visualisations aimed at expert stakeholders/RC researchers with limited programming ability or difficulty with storing/analysing large datasets on their own computer systems.

Actions

Note that many of these actions were decided and documented in the management committee meeting

- All researchers to highlight to WP3 any phenomena/processes they perceive to be important to include in the WP3 evaluation, including which are priorities for Auto-Assess
- All researchers continue to consider what visualisations/diagnostics might be most useful as part of the CIS user interface
- RJa/RW to proceed with development and circulation of the diagnostics spreadsheet. When available all WP leaders to coordinate population of the spreadsheet.

- RW/RJa to review evaluation plans following meeting to ensure that basics are covered, and if there are any particular common metrics which would benefit from coordination (e.g. diurnal cycle)
- RJa/Duncan Watson-Parris (DWP) to initiate discussion of code repository
- RJa to add new RC postdocs to Africa PEG list
- RJa/RW to proceed with planning Africa PEG on 18 March, aiming to send invitation before Christmas
- Philip Stier (PS)/DWP to ask CEDA if we can put reference datasets on JASMIN
- Simon Vosper (SV)/Doug Parker (DP)/CS to refine the publications strategy for CP4-Africa papers
- SV/DP/CS to develop a strategy for release and licensing of the CP4-Africa output
- SV/DP/CS: to identify persons who can assist with quality assurance of the CP4-Africa set up and output
- RJ/RW to report back on these actions to the management committee

Break out group during the session on Model Evaluation Metrics at the IMPALA Science Meeting