EARTHCLIM:
An Integrated Earth System Approach to Explore Natural Variability and Climate Sensitivity

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1. Relevance. EARTHCLIM is a nationally coordinated application addressing Thematic Area 1-4 of the NORKLIMA call "Understanding the Climate System". Central to EARTHCLIM is to improve, implement and verify climate processes in the Norwegian community Earth System Model (ESM) NorESM that are of particular importance at high latitudes, and consequently for polar climate. As the tropics are central for global heat and moisture budgets, as well as for generating major climate variability modes, analysis of climate feedbacks, responses and sensitivities incorporates lower latitudes as well. By including, on average, 6.5 post-doctoral research fellows per year and bundling Norwegian ESM research, EARTHCLIM will substantially strengthen the Earth System modelling and analysis community in Norway.

2. Aspects relating to the research project. ***2.1. Background and status of knowledge (see also Module descriptions in Section 2.3).*** EARTHCLIM builds on the heritage of *RegClim* (1997-2006), the first research project gathering scientists and students from the leading climate research institutions in Norway to address natural variability and human-induced warming, improved representation of atmospheric and oceanic processes, and climate modelling (Iversen 2008; Special Issue of *Tellus*, **60**, Issue 3, 2008). Central to EARTHCLIM is also the development of the *Bergen Climate Model* (BCM; Furevik *et al.* 2003, Otterå *et al.* 2009, 2010), one of four European climate models contributing with global scenario integrations to the Fourth Assessment Report of the *Intergovernmental Panel on Climate Research* (IPCC AR4), and aerosol-cloud-radiation interaction schemes developed in Oslo (CAM-Oslo; Seland *et al.* 2008, Storelvmo *et al.* 2006, Kirkevåg *et al.* 2008, Kristjansson *et al.* 2005, Hoose *et al.* 2009). In *NorClim* (2007-2010), the large-scale and process-oriented climate modelling efforts in Bergen, Oslo and Tromsø have been merged and materialised into NorESM. Analysis of runs and further development of NorESM, together with analysis of other state-of-the-art ESMs, is one of EARTHCLIM'S research pillars.

The level of confidence in the estimates of the radiative forcing (RF) from the long-lived green house gases (GHGs) is high. Huge uncertainties remain, however, when it comes to aerosols, in particular their interaction with clouds (Solomon *et al.* 2007). Biogeochemical feedbacks involving carbon and nitrogen is another major source of uncertainty, possibly adding 0.1-1.5°C degree warming to existing projections (Friedlingstein *et al.* 2006, Tjiputra *et al.* 2010). For the North Atlantic (NA)/Arctic region, key challenges are linked to the dynamics and variability governing the poleward atmosphere/ocean heat transport (Shaffrey & Sutton 2006, Jungclaus & Koening 2010) and the sensitivity of the extreme tail of the precipitation distribution in a warmer world (Bengtsson *et al.* 2009, Zolina *et al.* 2010). Improved representation of the aerosol-cloud interaction, biogeochemical feedbacks, and analysis of poleward heat transport and extreme precipitation, the latter two with focus on polar regions, are EARTHCLIM's additional research pillars.

2.2. Approaches, hypotheses and choice of method. For approaches and hypothesis, see also Module descriptions in Section 2.3. As choice of method, the model development, testing and analysis across the project's research modules is based on (but not limited to) NorESM. NorESM consists of the Community Climate System Model (CCSM4; www.cesm.ucar.edu/models/ccsm4.0/), modified with chemistry-aerosol-cloud-radiation interaction schemes developed for CAM-Oslo, an isopycnic coordinate ocean general circulation model developed in Bergen and used in version 2 of BCM (Otterå *et al.* 2009, 2010), and the carbon cycle model HAMOCC developed at the Max-Plank-Institute for Meteorology, Hamburg (Maier-Reimer 1993, Tjiputra *et al.* 2010). NorESM, with a horizontal resolution of about 2 degrees is currently used for the Tier 1 CMIP5 control and scenario integrations (Moss *et al.* 2010). NorESM is unique notably through the state-of-the-art aerosol-cloud scheme and the isopycnic coordinate ocean component, and it contributes to the much desired climate model diversity in CMIP5 and IPCC Fifth Assessment Report (AR5).

The large range in climate sensitivity and its long tail (Knutti & Hegerl 2008, Stainforth *et al.* 2005) create a possibility of strong future warming and hinders a quantification of emissions reductions needed to meet future temperature targets (Meinshausen *et al.* 2009). In EARTHCLIM, climate sensitivity and climate feedback mechanisms, based on but not limited to NorESM, will be quantified according to Soden & Held (2006). The carbon cycle feedback will be given particular consideration and quantification following Friedlingstein *et al.* (2006). A fundamentally different method to quantify the climate sensitivity is to use the observed temperature record and estimates of net radiative forcing and fast feedbacks (Knutti & Hegerl 2008). This quantification has been difficult due to the large uncertainties related to short-lived components; in particular aerosols and clouds. To improve this a better quantification of the aerosol effects in NorESM will be sought. To further explore the sensitivity of the climate system, the natural variability and spatial variations in the response will also be investigated.

2.3. The project plan, project management, organisation and cooperation. EARTHCLIM is organised in Modules 1-5 (M1-5) as described below.

Module 1	**NorESM Development and Validation**							
Participant	**UiB**	**CICERO**	**met.no**	**UiO**	**NR**	**NILU**	**NP**	**UNI Res**
Person-yr per participant (in-kind)	0	0	2.5 (1.8)	0	0	0.86 (0.43)	1.5 (0.6)	4.1 (3)
Leader and co-leader	**Trond Iversen (met.no) and Mats Bentsen (Bjerknes UNI Research)**							

Main objective and sub-objectives. *To firmly establish NorESM as a state-of-the-art computer model for the simulation of the global climate and associated Earth System processes through sustained development, validation and analysis.* ***(i)*** To validate NorESM as belonging to the family of state-of-the-art climate and earth system models; ***(ii)*** To further develop the NorESM with a good balance between the need for increased model resolution and code upgrades, and the need for improved parameterizations and more complex on-line processes (cross-cutting: M3); ***(iii)*** To use NorESM experiments to study basic properties of the earth system's natural climate variability and its response to forcing mechanisms (cross-cutting: M2 and M4).

Description of work. ***WP1.1–Validation of NorESM based on CMIP5 runs for IPCC AR5 (Iversen, Heinze).*** Verification will focus on regional flow regimes and storm tracks, blocking, sea-ice extent and thickness, aerosol concentrations and optical depths, cloud and precipitation climatology, the NA ocean circulation, and ocean and land carbon and nitrogen cycles. The modelled 20th century transients and the future RCP scenarios (Moss *et al.* 2010) will be analyzed. ***WP1.2–Further upgrading and developments of NorESM (Bentsen).*** Upgrade of imported model components and own parameterizations (M3). ***WP1.2.1–Upgrading the NCAR-based code.*** Will be made through an agreement with the US *National Center for Atmospheric Research* (NCAR). It will be evaluated if a major upgrade of NorESM fully based on the NCAR CESM1 (released in late

June 2010) is needed, or if selected module upgrades are sufficient. In any case, since the upgrade will be substantial, the present NorESM-branch will be maintained in parallel. ***WP1.2.2: Improved atmospheric parameterizations.*** (a) Implementation of the Esau (2008) and Zilitinkevicz *et al.* (2008) scheme for turbulence in the stable atmospheric boundary layer (ABL) is expected to improve NorESM's performance at high latitudes in winter. (b) W.r.t. aerosols and shortlived climate gases, first results from on-line coupling with oxidant chemistry and particulate nitrate are becoming available. Prognostic calculation of aerosol mass disolved in cloud water is planned, and a feasibility study for an experimental version with binned aerosols will be made. ***WP1.2.3: Parameterization of ocean mixing, and interactions with sea-ice, snow, and ice sheets***. *Ice sheet:* The NCAR CESM1 ice sheet model will be coupled to the NorESM ocean component in collaboration with Karen Assmann at *British Antarctic Survey*. *Sea ice:* Differences in optical and thermodynamic quantities between first-year (FY) and multi-year (MY) sea ice, potentially important because of the expected shift from MY to FY ice, will be implemented in NorESM. Additional improvements include the description and changes in melt pond extent, frequency and area (Eicken *et al.* 2004; Light *et al.* 2008; Pedersen et al., 2009), differences in sea ice salinity (Vancoppenolle *et al.* 2005, 2009) between FY and MY ice, and parameterization of snow aging (soot and dust in the snow). ***WP1.2.4–Biogeochemistry.*** *Ocean:* Focus on carbon-nitrogen-oxygen interaction under warming including the combined effect of marine carbon and N_2O sources and sinks; implement improved formulations on the effect of ocean acidification (marine processes as functions of changing seawater *p*H-values, new formulations are now emerging from biological/biogeochemical experiments); *Land:* Focus on test and tuning of carbon-nitrogen interactions (limitation of plant productivity), soil carbon respiration, and land effects of land use change. ***WP1.3 – Further analysis and validation of NorESM based on diagnostics experiments (Iversen).*** Further NorESM experiments are planned to diagnose biases and better understand climate change and variability as manifested by NorESM, including feedbacks. Some of these experiments will likely be made with a further developed NorESM (WP1.2). These studies are closely linked to activities in M2 and 4. ***WP1.3.1:*** **Diagnosis of circulation modes, regional flow regimes, and feedbacks.** Naturally occurring circulation modes (ENSO, AMOC, NAO, PNA, COWL, AO, AAO) as studied in M2 (WP2.4), constitute the basic framework for this analysis. Based on transient simulations, climate response is interpreted in view of changed patterns and relative frequency of occurrence (Palmer 1999; Corti *et al.* 1999). [Aspects of short-lived contaminants are studied in M4 (WP4.2)]. ***WP1.3.2: Diagnosis of transport properties using FLEXPART.*** FLEXPART is a Lagrangian particle dispersion model for diagnosing atmospheric transport and associated properties (Stohl *et al*. 2006). In NorESM it can be used to diagnose transport of short-lived climate forcers (SLCFs), source regions for water vapor contributing to cloudiness and precipitation, biases in regional flow regimes responsible for meridional transport to the Arctic, and strato-tropospheric exchange. The validated *NorESM-FLEXPART* will be a community tool, and it will be used with multi-decadal simulations against re-analysis data (ECMWF ERA-Interim). Relevant diagnostics are described in James *et al.* (2003), Stohl (2006) and Stohl & James (2004). Results will be compared with existing Eulerian tracer calculations in NorESM. **Interaction with other modules**. WP1.2 interacts with WPs in M3, and WP1.1 and WP1.3 with WPs in both M2 and 4. **Relevance for Thematic Area of the call.** In EARTHCLIM, NorESM allows for the implementation of new concepts in an integrated way in order to quantify climate response and feedback. This module's scientific emphasis addresses Thematic Area 1-4. **Deliverables (with time of delivery indicated). D1.1:** CMIP5: NorESM synthesized paper sent for publication, *Dec 2011*. **D1.2:** CMIP5: 1-5 topic papers sent for publication, *Sep2011-Mar2012***.** **D1.3:** Implementation and impact studies of Zilitinkevich/Esau scheme, *Mar 2011-Sept 2012***. D1.4:** Explicit description of aerosols in cloud water implemented and investigated, *Sept 2011-Dec 2012.* **D1.5:** NorESM-version to be (partly or fully) based on CESM1 (i.e. CAM5). *Jun 2011-Mar 2013*. **D1.6:** Ocean cryosphere interactions (sea-ice and ice-sheets). *Aug 2011-Dec 2012***. D1.7:** Biogeochemistry upgrades. *Jan 2011-Dec 2013.* **D1.8:** Flow regimes and feedback analysis. *Mar*

2011-Dec 2013. **D1.9:** Implementation of FLEXPART and transport analysis. *Mar 2011-Dec 2013*. **Personnel and budget (py=person year).** WP1.1-1.3, 2.5 py for researchers at met.no (Kirkevåg, Seland, Debernard, Seierstad, Simondsen); 1.2 py researcher (NN), 2.9 py PostDoc (NN) and 0.3 py resercher (Bentsen) at UNI Research. WP1.3, 1.21 py researcher (Stohl, NN) at NILU; WP1.2, 1.66 py (NN) PostDoc at NP. **In kind:** WP1.1-1.3 1.8 py from met.no (Mauritzen, Iversen, Kristiansen) and 3 py (NN) from UNI Research; WP1.2, 0.5 py (NN) from NP; WP1.3, 0.43 py (NN) from NILU.

Module 2	**Internal and externaly forced climate variability**							
Participant	**UiB**	**CICERO**	**met.no**	**UiO**	**NR**	**NILU**	**NP**	**UNI Res**
Person-yr per participant (in-kind)	4.0 (0.9)	0	1.3 (0.5)	0	0	0	0	0 (1)
Leader and co-leader	**Asgeir Sorteberg (UiB) and Ivar A. Seierstad (met.no)**							

Main objective and sub-objectives. *To quantify the magnitude of internal climate variability and distinguish internal variability from externally forced variations using long term observations and climate simulations.* ***(i)*** Quantify present day and future atmospheric and oceanic poleward energy transports and the existence of a possible Bjerknes compensation mechanism; ***(ii)*** Quantification of how changes in the hydrological cycle may feed back on extratropical cyclone intensification; ***(iii)*** Quantification of how circulation variability related to internal climate variability will influence mid and high latitude precipitation.

Description of work. ***WP2.1–Quantify change in energy transport (Kvamstø).*** The aim is to estimate simulated response in atmospheric and oceanic energy transport to anthropogenic forcing across the AR5 ensemble. Current methods for calculating energy transport will be reviewed and the most relevant ones will be selected. These will be applied to available AR5 model data and anthropogenically induced changes in transport properties will be estimated based on control vs forced integrations. ***WP2.2–Mechanisms (Czaja, Kvamstø, Furevik).*** For each AR5 model estimate the degree of atmosphere-ocean energy transport compensation in NH and NA (Shaffrey & Sutton 2006, Jungclaus & Koening 2010) and evaluate if the spread can be reconciled by simple considerations of the energetics of the coupled ocean atmosphere system (known as the Bjerknes (1964) compensation hypothesis). This will be done by testing the following hypotheses: 1) Models with low degree of compensation contain the largest sensitivity of dry static energy transport to anthropogenic forcing. 2) In models with significant ocean compensation, the mean mechanism is a weakening of the Atlantic overturning stream function. If results give a basis for it, we will investigate links between compensation statistics and regional (NA) climate change. ***WP2.3 – Analysis of regional flow regimes (Seierstad, Kristiansen, Bentsen, Iversen).*** Biases in regional flow regimes influence energy, momentum, and moisture transport, and thus the nature of climate response and regional feedback mechanisms. To address this, established flow indices and empirical orthogonal functions will be used to diagnose flow regimes in the NorESM control run. These will be compared to similar analyses from re-analysed and hindcast data. This WP links closely to WP1.3.1 and WP4.3. ***WP2.4–Quantification of internal precipitation variability (Sorteberg, Seierstad).*** The new multi-century control runs with constant external forcing performed within CMIP5 will be used to investigate the range of unforced variability in mid and high latitude precipitation. Special emphasis will be placed on relationships to atmospheric circulation variability by calculation of extratropical cyclone tracks and links to moisture and heat transport (calculated in WP2.1). ***WP2.5–Quantification of feedbacks from changes in moisture on cyclone intensification (Sorteberg).*** Use reanalysis and CMIP5 simulations to perform cyclone tracking and diagnoses of the vorticity budget (Azad & Sorteberg 2009) along the cyclone tracks to quantify the contribution from the different forcing terms to cyclone intensification. Analysing the different forcing terms will quantify how the different physical mechanisms that intensify the cyclones may change during climate change scenarios.

Interaction with other modules. Simulations performed in M 1 will be extensively used in the

analysis and we will provide validation of energy transport and cyclone tracks for several of the M1 simulations. Our assessment of the role of internal variability in the observed climate signal will be closely linked to the climate sensitivity and response calculations in M4. **Relevance for Thematic Area of the call.** The module addresses Thematic Area 1 and 4.
Deliverables (with time span/time of delivery indicated). D2.1: Quantify change in energy transport. *Dec 2011*. **D2.2:** Mechanims. *Dec 2013*. **D2.3:** Quantify internal precipitation variability and relationships to atmospheric circulation variability *Dec 2012*. **D2.4:** Quantify the thermodynamic and dynamic contributions to mid latitude precipitation changes *Dec 2013*. **D2.5:** Quantify changes in mid latitude cyclone intensification. *Dec 2011*.
Personnel and budget (py=person year). WP2.1-WP2.2: PostDoc at UiB: 1.83 py for 2011-2013. **WP2.3:** 0.8 py met.no (Seierstad, Kirkevåg, Seland, Debernard). **WP2.4-WP2.5:** PostDoc at UiB: 1.83 py for 2011-2013, researcher at met.no 0.35 py (Seierstad) in 2011-2013. **In-kind:** Sorteberg (UiB) 10%, Kvamstø (UiB) 10%, Eldevik (UiB) 10%, PhD student R. Azad (UNI Research): 100% for 1 year, 0.5 py met.no (Iversen, Kristiansen).

Module 3	**Radiative forcing of short-lived components**							
Participant	**UiB**	**CICERO**	**met.no**	**UiO**	**NR**	**NILU**	**NP**	**UNI Res**
Person-yr per participant (in-kind)	0	0.85	0	3.1	0	0	0	0
Leader and co-leader	**Jón Egill Kristjánsson (UiO) and Gunnar Myhre (CICERO)**							

Main objective and sub-objectives. *To improve the estimates of RF by increasing the degree of explicit treatment of aerosols, clouds, short-lived gases and their interactions in NorESM.* ***(i)*** To properly account for the contribution of convective clouds to the aerosol indirect effect; ***(ii)*** To improve the understanding of the indirect effect of cold clouds; ***(iii)*** To improve estimates of the aerosol direct effect; ***(iv)*** To improve the representation of the time evolution of SLFCs.

Description of work. *WP3.1–The indirect effect of convective clouds (Kristjánsson).* Most climate model estimates of the aerosol indirect effect only consider it for stratiform clouds. The description of microphysical processes in convective clouds is often so crude that it is hard to formulate corresponding relations between aerosols and cloud properties for this cloud type, which is particularly important in the tropics. In this WP, the current framework for the aerosol indirect effect in CAM-Oslo will be extended to also deal with convective clouds. ***WP3.2–Cloud-droplet activation (Kristjánsson).*** Due to the coarse spatial resolution in current climate models, a subgrid vertical velocity is parameterized to realistically simulate cloud droplet activation. In NorESM, a formulation based on Abdul-Razzak & Ghan (2000) is currently used, assuming a Gaussian distribution of vertical velocity, and linking the minimum standard deviation of vertical velocity to the vertical eddy exchange coefficient. Recently, a new formulation was proposed (Hoose *et al.* 2010b), providing much better agreement with observations. The new formulation will be implemented in NorESM, and the influence on overall model performance will be assessed. ***WP3.3–Anthropogenic ice nuclei and the aerosol indirect effect (Kristjánsson).*** The sensitivity of the estimated aerosol indirect effect to uncertain parameters in the latest version of the parameterization scheme in CAM-Oslo (Hoose *et al.*, 2010a) will be investigated. ***WP3.4–Better understanding of the direct aerosol effect incl. the absorbing aerosols (Myhre).*** Improved understanding and reduced uncertainty associated with the direct aerosol effect will help in further developing the representation of the direct aerosol effect in NorESM. Several experiments are set up in the global aerosol model exercise AeroCom to facilitate investigation the differences between the aerosol models. The models will be evaluated against available observations for key elements of the direct aerosol effect and improvements will be implemented into NorESM. ***WP3.5–Better understanding of time evolution of RF of SLCFs (Myhre).*** The time evolution of the radiative forcing of all SLCF will be simulated in the NorESM based on the best available emissions scenarios and processes included in NorESM with improvements from WP3.1-3.4. In addition, sensitivity simulations will be performed using other modelling tools and emission scenarios to

explore the uncertainty. Comparison with observations will be sought where available.
Interaction with other modules. New parameterizations developed in M3 will be provided to M1, for implementation and use in the NorESM, thereby benefiting both M2 and 4. Collaboration with M4 on the time evolution of RF. **Relevance for Thematic Area of the call.** The module mainly addresses Thematic Areas 1 and 2. It also addresses important aspects of Arctic climate concerning aerosol-cloud interactions and the direct effect of soot aerosols in the Arctic.
Deliverables (with time span/time of delivery indicated). D3.1: A new parameterization of aerosol-cloud interactions for convective clouds. *Mar 2012-Apr 2013.* **D3.2:** An improved parameterization of cloud droplet activation. *Aug 2011-Feb 2012.* **D3.3:** Better estimates of the direct aerosol effect. *Jan 2011-Mar 2012.* **D3.4:** Submitted manuscript on the time evolution of radiative forcing. *Jul 2011-Apr 2013*.
Personnel and budget (py=person year). WP3.1: PostDoc at UiO: 0.8 py in 2012, 0.3 in 2013. **WP3.2:** PostDoc at UiO: 0.4 py in 2011, 0.2 py in 2012. **WP3.3:** PostDoc at UiO: 0.7 py in 2013. **WP3.4:** Researcher at CICERO: 0.35 py in 2011, 0.10 in 2012. **WP3.5:** Researcher at CICERO: 0.20 py in 2012, 0.20 in 2013. PostDoc at UiO: 0.3 py in 2011, 0.3 in 2012, 0.1 in 2013. **In-kind:** Kristjánsson (UiO) 8%.

Module 4	**Climate Sensitivity and Response**							
Participant	**UiB**	**CICERO**	**met.no**	**UiO**	**NR**	**NILU**	**NP**	**UNI Res**
Person-yr per participant (in-kind)	1 (0.3)	0.8	1.26 (0.5)	0.8 (0.3)	0.6	0	0	2.5 (2)
Leader and co-leader	**Christoph Heinze (UiB) and Terje Berntsen (UiO)**							

Main objective and sub-objectives. *To quantify and analyse responses and long-term feedbacks in the climate system, and in particular to assess relationships between regional forcing patterns and responses, including non-linear responses, and the climate sensitivity.* ***(i)*** Quantification and analysis of short term responses (decadal) as well as long-term feedbacks (centennial) in the climate system; ***(ii)*** Assessment of regional forcing-response relationships, including non-linear responses; ***(iii)*** Assessment of the overall climate sensitivity comparing basic and improved models versions; ***(iv)*** Determine the possibility for changes in the climate sensitity under future climate conditions.

Description of work. ***WP4.1–Feedback quantifications and separation of feedbacks (Heinze & Sorteberg).*** We will implement and apply the "partial radiative perturbation method" (Soden & Held 2006) for ESMs, to quantify the different radiative feedbacks (water vapour, lapse rate, surface albedo, clouds). The carbon cycle feedback will be assessed through full ESM simulations (full coupled simulations for pre-industrial CO_2 and anthropogenic CO_2 emissions and simulations where the carbon cycle does not see climate change but only increasing CO_2) in order to separate the feedback of climate change to the carbon fluxes (γ factors for land and ocean) and the feedback of atmospheric CO_2 itself on the carbon fluxes (ß factors for land and ocean) following Friedlingstein *et al.* (2003, 2006). ***WP4.2–Regional response and non-linearity (Berntsen).*** Based on the chemistry-aerosol-cloud module in NorESM, we will carry out detailed studies on the role of SLCF, focusing on regional temperature responses, and if time allows also other key climate parameters such as precipitation (e.g. Andrews *et al.* 2010). A series of experiments based on the CMIP5 experiment design will be performed: Ensembles of 30 yr hindcasts starting in 1960 and 1980 with and without the inclusion of the SLCFs. The responses will be analysed in terms of fast responses (i.e., not coupled to ΔT_s) and slow responses (Bala *et al.* 2009, Andrews *et al.* 2010), with specific attention to the Arctic (e.g. changes in snow cover and sea ice). The results will guide policymakers in designing mitigation measures to avoid rapid changes (e.g., Quinn *et al.* 2008, Jacobson 2010). This links to M1, WP1.3.1. ***WP4.3–Synthesis on climate sensitivity and its uncertainty range (all module leaders/co-leaders).*** The project results will be summarised for policy makers and stakeholders. The climate sensitivity will be analysed using two independent methods. (i) The overall transient climate sensitivity of NorESM will be quantified using NorESM; the standard version and, if resources permits, also an upgraded version. (ii) The improved history of RF and the fast feedbacks (WP3.6) as well as observed climate change (atmospheric and oceanic temperatures) will be used as input to a Bayesian statistical approach using a simple climate model (e.g. Tomassini *et al.* 2007). An important factor in this analysis is the role of natural climate variability in the observational records.

Interaction with other modules. M4 will work very closely together with M1 in particular on the accomplishment of the CMIP5 (phase I) and post-CMIP5 (phase II) scenarios with NorESM. The impact of the new model components as developed under M1 and 3 on climate feedbacks and climate sensitivity will be analysed. The complementary approach to estimating the climate sensitivity using the Bayesian statistical approach in WP4.3 will collaborate very closely with M3 (RF and fast feedbacks), as well as with M2 (role of natural unforced variability).

Relevance for Thematic Area of the call. The module addresses directly Thematic Area 1-3.

Deliverables (with time span/time of delivery indicated). D4.1: Manuscript on radiative forcing/ feedback quantifications for CMIP5 simulations (*Dec 2012*). **D4.2:** Manuscript on carbon cycle feedback analysis in CMIP5 simulations (*Dec 2012*). **D4.3:** Manuscript on radiative forcing/feedback quantifications for phase II simulations and comparison to CMIP5 results (*Dec 2013*). **D4.4:** Manuscript on regional climate responses and non-lineratities (*Dec 2013*). **D4.5:** Synthesis report on new overall climate sensitivity assessment with NorESM (*Dec 2013*).

Personnel and budget (py=person year). WP4.1: PostDoc at UNI Research: 1.21 py for C cycle analysis, PostDoc at UiB: 0.9 py for partial radiative perturbation analysis, researcher at CICERO: 0.25 py. **WP4.2:** PostDoc at UiO: 1.2 py (0.3 in 2011, 0.5 i 2012, 0.4 i 2013). met.no 0.2 py (Seland, Kirkevåg). **WP4.3:** Researcher at NR (0.29 py in both 2012 and 2013). Researcher at CICERO 0.1 py. Researchers at met.no 1.06 py (Seierstad, Debernard, Seland, Kirkevåg, Simondsen) in 2013. **In kind:** WP4.3, contributions from UiB, met.no 0.5 py (Iversen, Seland, Kirkevåg. Mauritzen), UiO and UNI Research.

Module 5	**Management**							
Participant	**UiB**	**CICERO**	**met.no**	**UiO**	**NR**	**NILU**	**NP**	**UNI Res**
Person-yr per participant (in-kind)	0	0	0.25	0	0	0	0	0.7 (0.3)
Leader and co-leader	**Helge Drange (Bjerknes UNI Research) and Øystein Hov (met.no)**							

Main objective. *To provide project management and co-ordination, and to organise project meetings and dissemination measures like www-site, leaflet, newsletters, and workshop.*

Approach. To ensure visibility and efficient transfer of knowledge and results including to engage with important stakeholders, the following dissemination measures will be conducted: Set-up and maintain an EARTHCLIM www-site; produce and distribute a leaflet describing the EARTHCLIM research and information about plenary EARTHCLIM meetings; produce and distribute half-yearly electronic newsletters; oversee publication plan; contribute to public outreach in general and providing articles to the popular science magazine *KLIMA* in particular; organise plenary EARTHCLIM project meetings; apply for access to national high performance computer (HPC) facilities; daily management of the project. Organise Project Steering Group meetings (consisting of module leaders, coordinator and his deputy) every 4 months. Inform and interact with the Scientific Advisory Board consisting of representatives from NCAR; the Nordic climate modelling community; the EC-Earth (ecearth.knmi.nl/) consortium; and ENES, the European Network for Earth System Modelling consortium (www.enes.org/).

Description of work. ***WP5.1***–Set-up and maintain EARTHCLIM www-site. ***WP5.2***–Produce a leaflet describing the research in EARTHCLIM and information about project meetings. ***WP5.3***–Produce half-yearly electronic newsletters describing the scientific findings in EARTHCLIM. ***WP5.4***–Organise plenary and Project Steering Group meetings. ***WP5.5***–Apply for access to national HPC facilities. ***WP5.6***–Enroll the Scientific Advisory Board into the project activities. ***WP5.7***–Identify and oversee Mentors for female Master and PhD students in climate research in Norway (see Section 3.5). ***WP5.7***–Oversee and contribute to outreach activities (including articles in *KLIMA*).

Interaction with other modules. The coordinator and his deputy will interact with the module leaders, and together be the Project Steering Group with the responsibility to ensure that individual researchers blend into teams appropriate for the tasks at hand. The management will depend on regular physical meetings for important discussions, and phone meetings or electronic meetings for the daily operations and quaterly status meetings. This is analogous to the practise in most international projects and shows good results. **Relevance for call.** The proposal is directed to the call for a national, coordinated project with a budget of at least 24 mill NOK, and the management module is set up to ensure a proper implementation of the work.
Deliverables (with time of delivery indicated). D5.1: EARTHCLIM www-site operational. *Mar 2011.* **D5.2:** EARTHCLIM kick-off meeting. *June 2011.* **D5.3:** EARTHCLIM electronic newsletter. *Every 6 months.* **D5.4:** EARTHCLIM project meeting. *Every 12 months.* **D5.5:** EARTHCLIM Project Steering Group meetings. *Every 4 months.* **D5.6:** Access to national HPC facilities. *Every 12 months.* **D5.7:** Mentor organisation. *Jul 2011*. **D5.8:** Oversee outreach activities. *Throughout project period*. **Personnel and budget (py=person year).** Co-ordinator Bjerknes UNI Research 0.7 py (plus 0.3 py in kind) and his deputy (met.no) 0.25 py.

How EARTHCLIM extends beyond state-of-the-art. The proposed activities in M1, 3 and 4 address weaknesses in state-of-the-art climate and ESMs. The planned improvements will extend beyond state-of-the-art in the defined work packages. M1, 3 and 4 provide a systematic analysis of the effects of present and advanced ESM configurations and separate the influence of single processes on the overall climate sensitivity. The NorESM results will be directly comparable with the other key European (and other) ESM groups. Therefore, NorESM with its unique combination of different modules will contribute also to a better uncertainty assessment on European and international level, contributing to, e.g., CMIP5 and IPCC AR5. In addition, M2 provides an in depth analysis of heat and moisture transport related to synoptic scale mid and high latitude circulation (also addressed in WP1.3.2). By using simplified physical-based diagnostic in analysis of state-of-the-art climate simulations, an attempt will be made to identify the physical processes governing climate variability and change in the NA/Arctic region. This requires data with high temporal resolution and the CMIP5 simulation archive will be the first opportunity to perform such analysis on a wide range of models. **International collaboration.** The institutions and researchers in EARTHCLIM have an extensive international network, securing international collaboration. The Scientific Advisory Board will also secure Intenational collaboration. ***Access to national HPC facilities.*** *EARTHCLIM is heavily dependent on access to state-of-the-art computational and storage resources, appropriate compiler, system and analysis software, and technical assistance, for instance through the national NOTUR (www.notur.no/) and NorStore (www.norstore.no/) projects.*

2.4. Budget. See Module descriptions in Section 2.3 and the *Grant Application Form*.

3. Perspectives and compliance with strategic documents. ***3.1. Compliance with strategic documents.*** As a national CoE, Bjerknes Centre has leading expertise within climate dynamics, climate modelling and scenario projections. From 2010 the Norwegian Government has awarded the centre a long-term contribution to secure the competence of the centre for studies of the climate system. EARTHCLIM fits well into the strategic plans of the centre as outlined in the mission statement provided to the Government. At met.no climate research including scenarios and adaptation is one of five strategic foci. For CICERO climate research is a main focus. For NP EARTHCLIM provides the platform to couple its ICE centre activities to the NorESM research. UiB, UiO, NR and NILU all have climate research high on their strategic agendas. All institutions are also well positioned with respect to the scientific foci of the national climate research strategy document (*Klima 21*). ***3.2. Relevance to society.*** Physically based and thoroughly evaluated ESMs and climate analysis, derived from state-of-art-knowledge in the field, are needed for policy makers and governmental bodies to ensure proper, scientifically based, knowledge for assessing the human induced global and regional climate change problem, and for conducting optimal timing and scaling of mitigation and adaptation strategies. EARTHCLIM is the Norwegian climate modeling community contribution to this grand challenge. Furthermore, all of the activities in EARTHCLIM will contribute to the climate impact research community's need for best possible climate projections through improved and verified model systems and better quantification of model uncertainty. EARTHCLIM will provide advanced training of young Earth System researchers, and thus contribute to the first generation of Earth System scientists in Norway. ***3.3. Environmental perspectives.*** Not directly applicable. But project meetings will take place on environmentally certified (www.miljofyrtarn.no/) hotels and, to the extent possible, along the Norwegian railway tracks to accommodate low-emission travelling. ***3.4. Ethical aspects.*** The project management will, to the extent practically possible, respond to any requests from scientists and the public regarding the project, availability of data and analysis tools, and general questions regarding climate in a transparent, rigorous and comprehensive way. ***3.5. Gender equality and gender perspectives.*** Female candidates will be encouraged to apply for the open positions. Female Master and PhD students in climate research in Norway, with the support of Mentors appointed by the project, will be invited to the project meetings for presenting their research and getting introduced to the Norwegian climate analysis and modeling community.

4. Communication with users and utilisation of results. 4.1 and 4.2. Communication with users, dissemination plan. All research in EARTHCLIM will be published in international peer reviewed journals or publically available reports. To the extent practically feasible, all results will be made openly available for the scientific community and the public. Information about the project and data availability will be made through the project's web page. The project will contribute to the IPCC AR5 through authorship (J. Fuglestvedt and G. Myhre) and review authorship (C. Heinze), and through publications in peer reviewed journals. Two-way engagement with stakeholders will provide state-of-the-art research results of relevance for further refinement in climate impact and adaptation research.

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