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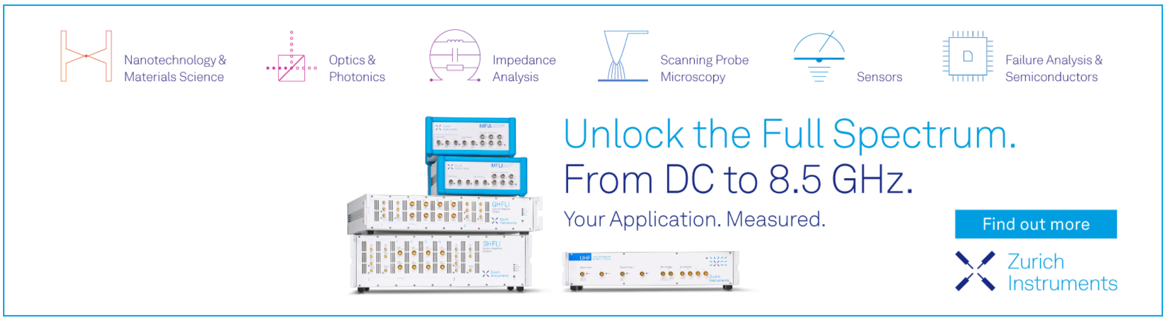

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Simulated variability in visible and near-IR irradiances in preparation for the upcoming Libera mission

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Abstract. NASA's upcoming Libera mission is predominantly a continuity mission, aiming at the seamless continuation of the Earth Radiation Budget record maintained by CERES. It therefore provides CERES-characteristic measurements, but also innovative and added capability that allows to discern the visible (VIS) and near-IR (NIR) contributions to the deposition of shortwave radiation in the climate system. Main scientific areas and applications for Libera's "split-shortwave" measurement are the improved understanding of processes that contribute to changes in shortwave absorption, a main contributor to sustained global climate change, and to study Earth's albedo and hemispheric symmetry observed therein. Here, we use Earth System Model (ESM) output to characterize the variability in VIS and NIR irradiances and absorption under pre-industrial conditions and under abrupt 4xCO_2 forcing. Similar to the NDVI, NIR/VIS ratios are indicative of the surface's "greenness" and allow to track changes in surface cover and cloud effects. Global mean NIR and VIS irradiances elucidate on the role of surface albedo, water vapor and cloud feedbacks for curiously maintaining a NIR/VIS ratio near 0.8 for both the forced and unforced simulation. With multiple spectral shortwave missions on the way, approaches to exploit these novel datasets and to reduce uncertainty in observed and modeled radiative effects and feedbacks, is quintessential, especially because enhanced shortwave absorption will continue to play a major role in contributing to Earth's energy gain currently observed and expected to increase under ongoing CO_2 forcing.

INTRODUCTION

With a few exceptions, spaceborne measurements of Earth's top-of-atmosphere (TOA) outgoing reflected shortwave and emitted longwave radiation have been made over broad spectral bands covering the entirety of the solar spectral region, terrestrial infrared spectral region or the combination of both. Evidence suggests that separating the solar band into just two sub-bands, roughly equal in incoming solar irradiance levels but coincidently, where the atmosphere is nearly transparent to solar radiation in the visible (λ<700nm; VIS) and partially absorbing in the near-infrared sub-band (λ >700nm; NIR) primarily due to water vapor and clouds, provides great insight into the deposition of radiative energy in the atmosphere. Moreover, the two sub-bands also demarcate reflectance differences at the ground from different surface types such as vegetation, desert, ice and snow. Therefore, TOA reflected shortwave

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radiation in the two sub-bands support the characterization of processes relevant for shortwave absorption by the climate system, climate feedbacks, and Earth's albedo variability with added insight into hemispheric albedo symmetry given the hemispheric differences in ocean, continent and cloud distributions. A new NASA Earth Radiation Budget mission, Libera, will directly measure the two sub-bands. Here, we use spectral output of the Earth system model UKESM1 [1] to investigate the variability in VIS and NIR irradiances, spatially and into the future under idealized CO_2 forcing. The goal is to gain insight into the applicability of this quasi-spectral knowledge to the attribution and understanding of shortwave radiative effects and feedbacks.

SPATIAL NEAR-IR/VISIBLE PATTERNS IN PRE-INDUSTRIAL CONTROL SIMULATIONS AND THEIR CHANGE UNDER ABRUPT CO_2 FORCING

Figure 1 (top) shows the 20-year mean all-sky and clear-sky NIR/VIS ratios of the pre-industrial control (piControl) simulation at TOA. Qualitatively, the spatial pattern is very similar to the normalized difference vegetation index (NDVI) as for example derived by MODIS [2] in that vegetated land surfaces are more reflective in the NIR than in the VIS, while the ocean scenes and most scenes containing other surface types are more reflective in the VIS. In the atmosphere, molecular and aerosol scattering contribute to larger VIS reflection. This pattern holds for both, all- and clear-sky conditions, but is more pronounced for clear-sky conditions. Through the addition of clouds, the global mean clear-sky ratio of NIR/VIS= 0.59 is enhanced to 0.79 under all-sky conditions and the land-sea contrast is significantly muted. While there is a hemispheric difference in clear-sky NIR/VIS ratio (NH=0.63; SH=0.55), the all-sky case exhibits a nearly balanced NIR/VIS ratio across hemispheres [3] which appears to be in contrast with SCIAMACHY analysis [4] and requires further investigation.

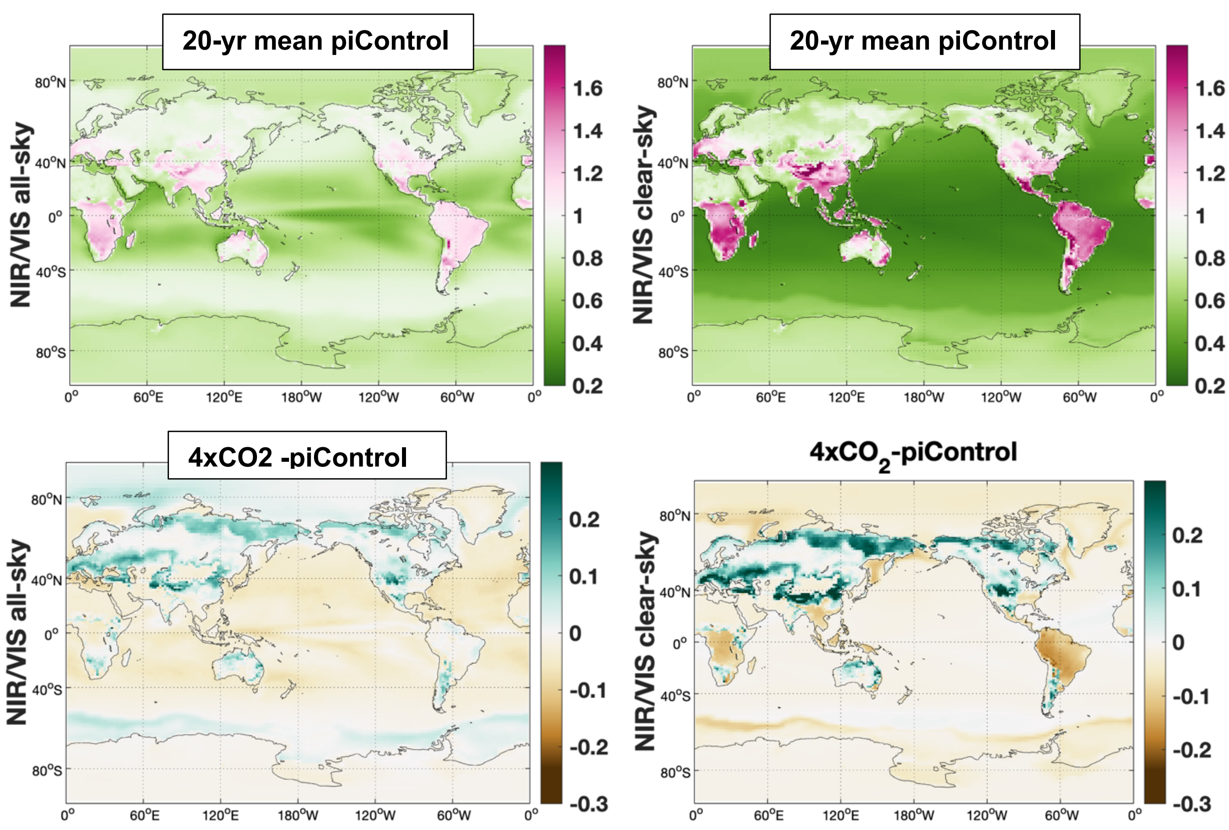

FIGURE 1. (top left) The piControl 20-year mean ratio of near-IR over visible irradiance (NIR/VIS) at TOA under all-sky conditions. (top right) Same as top left but for clear-sky conditions. (bottom left) The difference in NIR/VIS between the 20-year mean abrupt $4xCO_2$ and 20-year mean piControl simulation under all-sky conditions. (bottom right) Same as bottom left but for clear-sky conditions.

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The 20-year simulation with abrupt $4xCO_2$ forcing is on average 4K warmer than the piControl run and, under clear-sky conditions, exhibits features of "greening" over land predominantly north of 30° N (Figure 1, bottom), while many regions with NIR/VIS >1 in the piControl run, experience a reduction in NIR/VIS under the forcing scenario. This "browning" is nearly canceled under all-sky conditions, indicating that cloud effects buffer the NIR/VIS decrease induced by land cover change. Likewise, the "greening" is muted by clouds. In contrast to the clear-sky case, the change in the polar oceans' NIR/VIS ratio under all-sky conditions is slightly positive, suggesting that clouds compensate for the negative NIR/VIS effect due to sea-ice loss. In the global mean, the forced NIR/VIS ratio is with 0.77 (all-sky; 0.57 in Clear-sky) only slighted reduced compared to the piControl run.

GLOBAL MEAN CHANGES IN NIR AND VIS ABSORPTION UNDER CO_2 FORCING

According to the UKESM1 model, the global mean surface temperature changes by 4K over the course of the first 20 years of the abruptly forced $4xCO_2$ simulation. The total absorption of, both, NIR and VIS radiation by the climate system tracks the quadratic increase in surface temperature (not shown), and increases by about 3 Wm^{-2} each. These almost equivalent contributions to the change in total SW absorption are curious and originate from largely distinct processes. The NIR absorption is clearly a result of enhanced atmospheric absorption, attributable to a positive water vapor feedback, while the increase in VIS absorption is largely driven by surface processes and attributable to the melt of snow and ice over land and sea. The decrease in NIR surface absorption under clear-sky conditions, is attributable to both enhanced atmospheric absorption and a surface "browning", but compensated by a positive NIR cloud feedback. In the VIS, atmospheric absorption is negligible, and the positive change in clear-sky VIS absorption at the surface is more than doubled under all sky conditions, likewise indicative of a positive cloud feedback. The increase in clear-sky shortwave absorption of about 2.5 Wm^{-2} over these 20 years is in line with results by Donohoe et al., (2014) and to nearly equal parts attributed to albedo and water vapor feedbacks. In UKESM1, we find that positive cloud feedback more than doubles the positive SW clear-sky absorption through balancing NIR and increasing VIS surface absorption, indicative of a decrease in cloud cover. These curiously balanced NIR and VIS changes under CO_2 forcing explain why the global mean NIR/VIS ratio under pre-industrial conditions is overall maintained.

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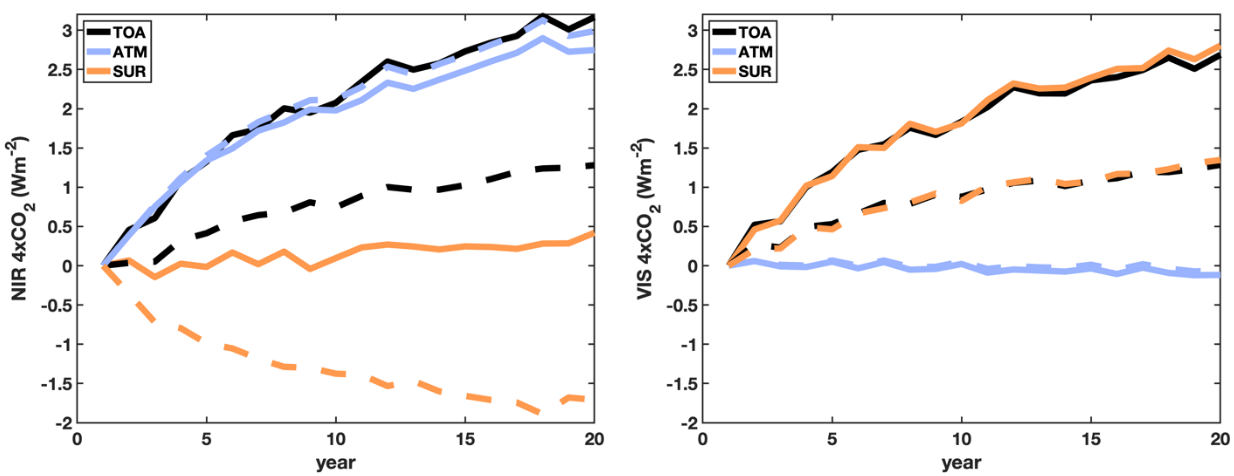

FIGURE 2. (left) Year-to-year change in NIR absorption by the Earth system (TOA, black); by the atmosphere (blue) and by the surface (orange) based on 20 years of a forced (abrupt $4xCO_2$) UKESM1 simulation. Dashed lines indicate clear-sky conditions; continuous lines are for all-sky. (right) Same as left but for VIS absorption.

CONCLUSIONS AND OUTLOOK

The UKESM1 simulations described and analyzed here, provide evidence for discernable visible and near-IR radiative effects and feedbacks that shape the current Earth radiation budget and its future under global warming. Changes in land cover, water vapor, and clouds shape the spectral characteristics of absorbed and reflected shortwave radiation distinctly (e.g., [5]) and are largely captured by the visible and near-IR split at 700 nm. A quasi-spectral product of visible and near-IR irradiances at TOA and the surface is planned for Libera, the upcoming NASA EVC-1 mission to be launched in 2027. In the presented simulation, the NIR and VIS irradiances allow to separately track the evolution of surface cover and atmospheric changes due to global warming. We find that NIR/VIS ratios give insight into the spatial variability of land cover and cloud effects, similar to the use of NDVI, and indicate processes relevant for maintaining and potentially changing the observed albedo symmetry across hemispheres (e.g., [6], [7]).

Since shortwave absorption is a major component of the observed (e.g., [8]) and modeled [9] net energy gain by Earth, a particular focus on spectral or “split-shortwave” observation and analysis appears logical and is already an important component of the current and upcoming landscape of Earth observations (e.g., TRUTHS, CLARREO-PF, DSCOVR/NISTAR, Libera). Discerning the impact of climate effects and feedbacks spectrally, allows for more probing evaluation of climate models, should they provide their spectral irradiances for intercomparison. In parallel, OSSEs such as developed for CLARREO [10] and in development for Libera, can bridge the gap between GCM/ESM broadband irradiances and spectrally resolved irradiances and radiances. Such tools and model output will furthermore allow additional analysis pre-Libera and to include uncertainty estimates to presented results. Further, in preparation for Libera science, a better understanding of processes that are detectable by the NIR-VIS split and of metrics to complement the NIR/VIS ratios and NDVI discussed here, will facilitate the best possible means to exploit the upcoming Libera datasets.

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