Radiative Forcing of Climate and Chemistry-Climate Interactions

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Main findings of ongoing research:

Estimates of traditional (i.e. stratosphere-adjusted) radiative forcing (RF) have recently been improved, which narrow the uncertainty for trace gases to around 10%, with somewhat larger shortwave (SW) forcing uncertainty. A number of alternative definitions of RF have recently been proposed, which are easier to evaluate and which incorporate different components of the climate feedback, so the concept of RF now needs to be linked to atmospheric processes.

In CMIP5, as in CMIP3, climate models appear to be getting similar responses to historical forcings for very different reasons, like different RF and feedbacks to cancel each other. This reflects the tuning to fit the historical record, but obscures the uncertainty in our understanding of the atmosphere response to climate forcings.

At present, decadal variations of observed radiative fluxes can be assessed with uncertainties of order of +/-10 W/m2 at the surface and +/-3 W/m2 at top of the atmosphere (TOA). Models show very large differences compared with observations in both SW and LW fluxes, both at the surface and the TOA. Various future aerosol emission scenarios, such as those of RCP, give a significant positive aerosol RF trend in the 21st century both at TOA and surface relative to 2000 owing to expected decreases in the aerosol emission, with large scenario-dependent results in the Asian region.

Rapid mobilization of Arctic carbon store manifesting as methane admissions is not confirmed in observations, but tropical methane emissions are found to increase. Changes in stratospheric ozone are reasonably well simulated by models. The ozone hole has been related with the recent observed changes in summertime SH high-latitude circulation, and ozone recovery is expected to approximately offset future GHG-induced changes in summertime SH high-latitude circulation over the next half century. There is progress in developing new emission databases for tropospheric ozone of relevance to the atmospheric chemistry-climate interactions.

Research needed to address future/emerging challenges;

There is a need to continue to determine RF and "fast" climate feedback and the individual roles of clouds, snowpack, sea-ice and other factors in it. Cloud resolving models and superparameterized simulations of climate system response to CO_2 can be used to identify the forcing associated with and feedback of the cloud system. We need to grapple with the fact that models are getting the same response to historical forcings for very different reasons, and work towards eliminating this situation. The very large discrepancies between modeled and observed radiative fluxes need to be reduced.

More studies are needed to find link between RF, especially including that of black carbon (BC) and brown aerosols, and observed changes of the surface energy budget and hydrological cycle. Sulfate emissions and their linkage to aerosol-cloud interactions also play significant roles. Continued efforts of monitoring aerosols and RF, especially in Asia and Africa, are needed to monitor the RF trend and validate the model projections. Models are able to simulate the continental scale sulfate, BC, OC and other aerosol species burden changes over time, as well as the RF change due to the BC and short-term gas mitigation efforts, such as changing cooking stoves. Nations should expand their monitoring system, such as the UNEP/ABC climate observatories, to observe these changes. Biomass burning aerosols are difficult to reduce, so that it is needed to study mitigation scenario and its future impact on RF.

Non-linear feedback mechanisms among trace gas burdens, such as NO_x burden change versus tropospheric O_3 production, should be studied. Different radiation codes result in ambiguities in the sign of the stratospheric ozone RF.

Model-simulated ozone holes tend to be weaker than observed. Dynamical mechanisms on how stratospheric ozone interacts with tropospheric circulation are still not clear. More work is needed to quantify the expected effect of ozone recovery on SH circulation and precipitation, in light of existing model biases, as well as links to ocean circulation and sea ice. Recent records of some PFCs differ significantly from the standard emission models such as EDGAR.

The nature of solar variability (specifically, how much is in the UV part of the spectrum) is highly uncertain, with recent measurements suggesting very large discrepancies with previous estimates. If the recent measurements are correct, then the impact of solar variability on climate via stratospheric ozone changes could be very substantial.

Identification of major gaps in the WCRP research agenda

There is still a large uncertainty of cloud forcing estimates by model and observation, especially that of cloud indirect effects. Models still overestimate shortwave (SW) downward flux and underestimate longwave (LW) downward flux. GCM values are consistent with the observed LW downward flux increase since 1870, but have problems in simulating brightening since 1990. Major rainfall shifts during the last 50 years were detected over the Indian Peninsula that are likely associated with large burden of aerosols. However, the processes, mechanisms and eventually the attribution is not clear because of complex mechanisms involved in the precipitation changes. The accounting of all aerosol species with regards to their effects on the hydrologic cycle, especially in the context of precipitation in Asia over the latter half of the 20th century is essential to understand the roles aerosols will have in the 21st century as well.

Persistent tails of stratospheric aerosol and non-zero aerosol optical thickness (AOT) lead to uncertainty of determining stratospheric aerosol RF, which is equivalent to that of stratospheric water vapor over the last decade. The reasons for the recent increase (since about 2000) in the stratospheric AOT need to be clarified, in particular the relative role of small volcanic eruptions and possible anthropogenic sources.

Carbon tracker observation is limited to monitor the trend in the trace gases change.

Major Recommendations:

* More effort to be dedicated to improving our understanding of the RF of various climate change agents, including the climate feedbacks and responses in the surface and precipitation evolution, and reduce the extent to which models get the same response to historical forcings for very different reasons.

* There is a need to enhance the monitoring capability for radiative fluxes, short-lived trace gases, and aerosols globally; individual regions like Asia, South America and Africa may be providing discernible spatial patterns in both changes in emissions and also in socially-relevant climate responses..