Frequently Asked Questions

FAQ 7.1 | How Do Clouds Affect Climate and Climate Change?

Clouds strongly affect the current climate, but observations alone cannot yet tell us how they will affect a future, warmer climate. Comprehensive prediction of changes in cloudiness requires a global climate model. Such models simulate cloud fields that roughly resemble those observed, but important errors and uncertainties remain. Different climate models produce different projections of how clouds will change in a warmer climate. Based on all available evidence, it seems likely that the net cloud–climate feedback amplifies global warming. If so, the strength of this amplification remains uncertain.

Since the 1970s, scientists have recognized the critical importance of clouds for the climate system, and for climate change. Clouds affect the climate system in a variety of ways. They produce precipitation (rain and snow) that is necessary for most life on land. They warm the atmosphere as water vapour condenses. Although some of the condensed water re-evaporates, the precipitation that reaches the surface represents a net warming of the air. Clouds strongly affect the flows of both sunlight (warming the planet) and infrared light (cooling the planet as it is radiated to space) through the atmosphere. Finally, clouds contain powerful updraughts that can rapidly carry air from near the surface to great heights. The updraughts carry energy, moisture, momentum, trace gases, and aerosol particles. For decades, climate scientists have been using both observations and models to study how clouds change with the daily weather, with the seasonal cycle, and with year-to-year changes such as those associated with El Niño.

All cloud processes have the potential to change as the climate state changes. Cloud feedbacks are of intense interest in the context of climate change. Any change in a cloud process that is caused by climate change—and in turn influences climate—represents a cloud–climate feedback. Because clouds interact so strongly with both sunlight and infrared light, small changes in cloudiness can have a potent effect on the climate system.

Many possible types of cloud–climate feedbacks have been suggested, involving changes in cloud amount, cloud-top height and/or cloud reflectivity (see FAQ7.1, Figure 1). The literature shows consistently that high clouds amplify global warming as they interact with infrared light emitted by the atmosphere and surface. There is more uncertainty, however, about the feedbacks associated with low-altitude clouds, and about cloud feedbacks associated with amount and reflectivity in general.

Thick high clouds efficiently reflect sunlight, and both thick and thin high clouds strongly reduce the amount of infrared light that the atmosphere and surface emit to space. The compensation between these two effects makes

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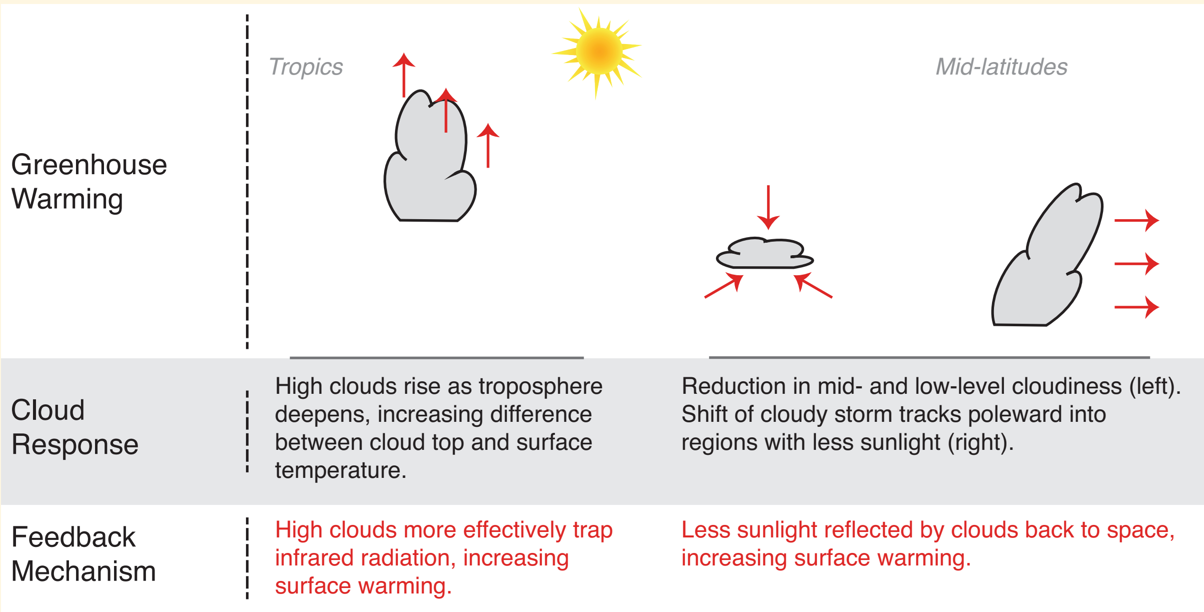

FAQ 7.1, Figure 1 | Schematic of important cloud feedback mechanisms.

FAQ 7.1 (continued)

the surface temperature somewhat less sensitive to changes in high cloud amount than to changes in low cloud amount. This compensation could be disturbed if there were a systematic shift from thick high cloud to thin cirrus cloud or vice versa; while this possibility cannot be ruled out, it is not currently supported by any evidence. On the other hand, changes in the altitude of high clouds (for a given high-cloud amount) can strongly affect surface temperature. An upward shift in high clouds reduces the infrared light that the surface and atmosphere emit to space, but has little effect on the reflected sunlight. There is strong evidence of such a shift in a warmer climate. This amplifies global warming by preventing some of the additional infrared light emitted by the atmosphere and surface from leaving the climate system.

Low clouds reflect a lot of sunlight back to space but, for a given state of the atmosphere and surface, they have only a weak effect on the infrared light that is emitted to space by the Earth. As a result, they have a net cooling effect on the present climate; to a lesser extent, the same holds for mid-level clouds. In a future climate warmed by increasing greenhouse gases, most IPCC-assessed climate models simulate a decrease in low and mid-level cloud amount, which would increase the absorption of sunlight and so tend to increase the warming. The extent of this decrease is quite model-dependent, however.

There are also other ways that clouds may change in a warmer climate. Changes in wind patterns and storm tracks could affect the regional and seasonal patterns of cloudiness and precipitation. Some studies suggest that the signal of one such trend seen in climate models—a poleward migration of the clouds associated with mid-latitude storm tracks—is already detectable in the observational record. By shifting clouds into regions receiving less sunlight, this could also amplify global warming. More clouds may be made of liquid drops, which are small but numerous and reflect more sunlight back to space than a cloud composed of the same mass of larger ice crystals. Thin cirrus cloud, which exerts a net warming effect and is very hard for climate models to simulate, could change in ways not simulated by models although there is no evidence for this. Other processes may be regionally important, for example, interactions between clouds and the surface can change over the ocean where sea ice melts, and over land where plant transpiration is reduced.

There is as yet no broadly accepted way to infer global cloud feedbacks from observations of long-term cloud trends or shorter-time scale variability. Nevertheless, all the models used for the current assessment (and the preceding two IPCC assessments) produce net cloud feedbacks that either enhance anthropogenic greenhouse warming or have little overall effect. Feedbacks are not 'put into' the models, but emerge from the functioning of the clouds in the simulated atmosphere and their effects on the flows and transformations of energy in the climate system. The differences in the strengths of the cloud feedbacks produced by the various models largely account for the different sensitivities of the models to changes in greenhouse gas concentrations.

Aerosol emitted within the aircraft exhaust may also affect high-level cloudiness. This last effect is classified as an aerosol–cloud interaction and is deemed too uncertain to be further assessed here (see also Section 7.4.4). Climate model experiments (Rap et al., 2010a) confirm earlier results (Kalkstein and Balling Jr, 2004; Ponater et al., 2005) that aviation contrails do not have, at current levels of coverage, an observable effect on the mean or diurnal range of surface temperature (*medium confidence*).

Estimates of the RF from persistent (linear) contrails often correspond to different years and need to be corrected for the continuous increase in air traffic. More recent estimates tend to indicate somewhat smaller RF than assessed in the AR4 (see Table 7.SM.1 and text in Supplementary Material). We adopt an RF estimate of +0.01 (+0.005 to +0.03) W m^{-2} for persistent (linear) contrails for 2011, with a *medium confidence* attached to this estimate. An additional RF of +0.003 W m^{-2} is due to emissions of water vapour in the stratosphere by aviation as estimated by Lee et al. (2009).

Forster et al. (2007) quoted Sausen et al. (2005) to update the 2000 forcing for aviation-induced cirrus (including linear contrails) to +0.03 (+0.01 to +0.08) W m^{-2} but did not consider this to be a best estimate because of large uncertainties. Schumann and Graf (2013) constrained their model with observations of the diurnal cycle of contrails and cirrus in a region with high air traffic relative to a region with little air traffic, and estimated a RF of +0.05 (+0.04 to +0.08) W m^{-2} for contrails and contrail-induced cirrus in 2006, but their model has a large shortwave contribution, and larger estimates are possible. An alternative approach was taken by Burkhardt and Kärcher (2011), who estimated a global RF for 2002 of +0.03 W m^{-2} from contrails and contrail cirrus within a climate model (Burkhardt and Kärcher, 2009), after compensating for reduced background cirrus cloudiness in the main traffic areas. Based on these two studies we assess the combined contrail and contrail-induced cirrus ERF for the year 2011 to be +0.05 (+0.02 to +0.15) W m^{-2} to take into uncertainties on spreading rate, optical depth, ice particle shape and radiative transfer and the ongoing increase in air traffic (see also Supplementary Material). A *low confidence* is attached to this estimate.