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Let's now try to summarize the various agents that have contributed to climate forcing over the last 250 years or so. This graph shows the contributions of various natural and anthropogenic forcings to the total forcing since about 1750. The contribution of these agents to the net forcing in the year 2011 is given by the bars together with the error bars, over here on the far right side of the diagram.

Let's begin on the positive side of the ledger, and check out the effect of carbon dioxide by itself. The estimated greenhouse forcing-- effective radiative forcing-- watts per meter squared read off the left-hand axis. You can see a slow increase toward the end of the 19th century, and a more rapid increase into the end of the 20th century.

On top of that, we have the contributions from other well-mixed greenhouse gases. That brings us up to this green curve here. Tropospheric ozone is the dark green here. Stratospheric water vapor is the light blue. And on top of that, solar variability is in orange.

So adding up all these gives the net positive contribution. Again, some of these agents are natural. Some of them are man made.

Let's now look at the negative side of the ledger. Let's begin with atmospheric aerosols. Most of these are man made. The direct interaction with radiation is given by this red curve here, so a cooling effect.

If we add in the estimated indirect effect of aerosol through clouds, that adds in the orange curve here. Changes in land use produce further cooling here. Stratospheric ozone depletion is the blue curve you can barely see here. And then these downward green spikes-- that you see here, here, and here-- are the contribution from volcanic aerosols.

Now, the total forcing, natural and anthropogenic, is given by the black curve here. It is dominated in the short time scale by the negative influence of volcanic eruptions. But the total forcing, aside from these downward spikes, has grown more positive, particularly in the last few decades.

The red curve that you see here is the total anthropogenic contribution to radiative forcing, which has getting ever more increasingly positive, particularly in the last few decades. One can see a summary of the net effects of these various forcing agents on climate, over on the right-hand side of the graph.

Let's look at the same kind of forcing statistics in a slightly different way. This graph shows estimates, together with uncertainties, of contributions to the net radiative forcing of the climate over the period 1750 to 2011. So this is changes to the radiative forcing, read off the bottom axis here in watts per meter squared.

We'll begin at the top of this graph and work down. So the first contribution we look at is carbon dioxide, which has contributed something shy of two watts per meter squared to the change in radiative forcing over this time, and with an uncertainty of on the order of 1/2 to 3/4 of a watt per meter squared.

But other well-mixed greenhouse gases, shown here, make substantial contributions. Methane in particular, nitrous oxide, and the halocarbons all add another watt per meter squared or so to the radiative forcing.

Ozone has been increasing in the troposphere, but decreasing in the stratosphere from anthropogenic causes. In the troposphere, that contributes a little bit shy of half a watt per meter squared, with a little bit of a negative contribution coming from depletion in the stratosphere.

There's also a small positive contribution from methane injected into the stratosphere, oxidizing into water vapor, which contributes to a greenhouse effect. The surface albedo change has some uncertainty, of course, associated with it as well. Black carbon on snow giving a slight positive contribution. Changes in land use giving a negative contribution.

Contrails from jet aircraft have a direct and indirect effect. The direct effect is a small positive warming. And there's a somewhat larger-- but somewhat more uncertain-- indirect effect from the increase of cirrus clouds at high altitudes. These operate principally in the infrared to trap and re-radiate infrared radiation back down to the surface, therefore contributing positively to a greenhouse effect.

Now, the direct effect of aerosol radiation interactions-- these are anthropogenic aerosols-- is negative, but with quite a large uncertainty, averaging about half a watt per meter squared, with another roughly half a watt meter squared-- but with terrific uncertainty-- coming from the cloud aerosol indirect effect.

Now, when we add all of these together, including the uncertainties, we get the net anthropogenic contribution to radiative forcing change over this period of somewhat over two watts per meter squared, but with uncertainty ranging from just over a watt per meter squared to somewhat over three watts per meter squared.

By contrast, changes in solar irradiance over this period, as we mentioned before, are fractions of a watt per meter squared. Now, the uncertainty in the forcings can also be looked at with this graph. And this is showing basically the same kinds of statistics, but illustrating the uncertainty in bell curves.

So the net effect of greenhouse gases is shown by the red curve over on the right, centered at just over three watts per meter squared, but with uncertainty varying from two to somewhat over four watts per meter squared. The net negative contribution of aerosol-- shown by the blue curve over here on the right-- extending from somewhat more than two watts per meter squared of negative forcing to a little bit of positive forcing.

And then when one sums those up, those two bell curves, one gets a total anthropogenic forcing effect, again centered just over two watts per meter squared, but with a half-width of about a watt per meter squared. So there's still a certain amount of uncertainty in forcings by aerosols.

This concludes our discussion of climate forcing. We'll next turn to a discussion of feedbacks in the climate system.