Course Name: An Introduction to Climate Dynamics, Variability and Monitoring

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Lecture- 53

ABSORPTION OF OUTGOING LONGWAVE RADIATION BY ATMOSPHERIC CO2

Good morning class and welcome to our continuing lectures on climate variability, climate dynamics and climate monitoring. In this first lecture, we will quickly conclude our discussion on the CO2 absorption and its effects. So, so far what we have seen is that the change in the outgoing long wave radiation for due to the presence of an absorbing medium say CO2 can be expressed as negative pi with the factor d nu into the blackbody emission from the ground minus the blackbody transmission b nu t. d nu is given by the transmittance, the original transmittance gamma nu minus the nu transmittance due to the change in concentration of the absorbing gas, which is gamma nu not to the power beta. Since transmittance is between 0 and 1, this value is a positive value. And we have seen how d nu is changing in terms of the transmittance gamma for various values of beta.

And what we saw is this d coefficient is 0 both for transmittance values of 0 and 1 and has highest value between transmittance values of 0.2 and 0.8 depending on where the beta value is located. So, for example, for beta equals to 2, The peak value of D is around 0.25 and is at transmittance of around 0.5. In fact, D max with respect to beta can be approximated as e to the power minus 1 log of beta. And this peak occurs between 0.3 to 0.7 transmittance. This we covered in the last class. So now we need to know the transmittance of the absorbing gases in order to evaluate these fractions. Correct. So here on the right side, on the left hand side, we have plotted the transmittance with respect to frequency and wavelength for the CO2 spectrum.

Remember, we discussed the CO2 spectrum in terms of absorptance and transmittance, in terms of frequency and wavelength. So, here we have looked at the frequency, wavelength and wave number. Notice here that the wavelength is increasing on this side and frequency is increasing on this side. And this is just one region. So here wavelength is around 15.

You remember there is a strong CO2 absorption at around 15 micrometers due to the vibrational resonance that is absorbing infrared radiation at those wavelengths. So as expected at around 15 micrometers, transmittance goes to zero. On either side and this is corresponding to frequency of 20 terahertz and wave number of around 675 centimeter inverse. Remember frequency is c by lambda where lambda is the wavelength and wave number is just the inverse of wavelength. On either side, transmittance is seen to increase from 0 back to 1 between 18 THz and 16 THz.

Similarly, transmittance increases back from 0 to 1 from around 22 THz to around 24 THz. If we smoothen out these ranges, take averages, then the smoothed out spectrum kind of looks like this. So, we have transmittance is 0 between around say 18 to 22 and it goes to 1 at around 16 and 24 terahertz frequencies and between 16 and 18 on one side and between 24 and 22 on the other side in terms of frequencies, we will have transmittance values which are between 0 and 1. And it is these values that are very important because the D nu term becomes non-zero only at transmittance values which are neither 0 nor 1. So, what does this mean? Suppose your absorbing media concentration has increased by twice or thrice.

Depending on where the frequency is being measured, the change in the outgoing long wave radiation intensity for that frequency will be quite different. Suppose you are measuring CO2 concentration has increased and you are measuring the outgoing change in the outgoing long wave radiation flux at a frequency of 16 terahertz. Now, at 16 terahertz, the spectral transmittance is 1. So, from this plot where the transmittance is 1, d nu is 0. So, this term is 0.

Hence, there will be no change in the outgoing long wave radiation at 16 terahertz due to increasing CO2 concentrations. Similarly, at 20 terahertz, which is close to 15 micrometers, the transmittance is zero. At zero transmittance as well, the d value is zero. Hence, once again, there will be no change in the net outgoing longwave radiation at 15 micrometers or 20 terahertz. However, now let us look at a frequency of, say, 18.5 somewhere around here or frequency of 23.5 somewhere around here where the spectral transmittance is 0.5 and assume that CO2 concentration is increased twice. So, at say 18.5 terahertz frequency your transmittance is 0.5. So, you put 0.5 here. The expected value of D for beta equals to 2, CO2 concentration is twice, is around 0.25. We can get this expression directly from here, e to the power minus 1 log beta. It will be around 0.25. So, here then d nu at 15 micrometers or 20 terahertz becomes 0.25. Then this expression becomes a negative expression and there will be a significant decrease in the net outgoing long wave radiation at 15 terahertz. So, it is in this window where the transmittance is middle neither 0 nor 1 that you will have a significant alteration or decrease in the outgoing radiation due to increase in the absorbing gases. So, it is very important for any absorbing medium to properly know where this transmittance is in the middle range between 0 and 1.

Remember, transmittance value is given by this expression here, exponential of minus mod of 1.66, 0 to the top of the atmosphere, the mass absorption coefficient of CO2, the partial density of CO2 into diesel. This will give you the transmittance value and based on this, these expressions have been plotted. So, what do we get out of this? We see then that the change in transmittance change in CO2 concentration has minimal effect when transmittance is either close to 1 or 0, complete absorption. So, based on them, then we can evaluate this delta F outgoing long wave radiation value in terms of watt per meter square per terahertz, so per unit frequency. Spectral, the change in the spectral outgoing long wave radiation has been plotted for CO2 for a density of beta equal to 2. So, CO2 concentration has increased twice and we have used this smooth function to evaluate this expression for this frequency range from say 15 terahertz to 25 terahertz. And we see that the main change and this is assumed that the tropospheric temperature at the top of the troposphere is 225 kelvins and Tg is 290 kelvins. So, based on that we can find the B nu T and B nu G.

$$\underbrace{\Gamma_\nu^0}_{\text{old Transmittance}} = \exp\left[-\left|1.66\int_0^H k^i_{\nu_{abs}}\,\rho_i^0(z)\,dz\right|\right]$$

So, this is the tropospheric temperature, this is the ground temperature. we have kind of make the simplification assumption that we have an isothermal atmosphere at a certain mean temperature. A more complicated model will of course have a far more complicated value of this black body radiation intensity due to the troposphere. But based on that, we can evaluate these expressions, and we will see that the maximum change in SOLR is happening exactly at around 18.5 or 23.5 where the transmittance is 0.5. So, let us set ground temperature to be 290 Kelvin and mean troposphere temperature to be 225 Kelvin. Let us set beta equals to 2, doubling of CO2. So, the max decrease in spectral outgoing longwave radiation is given by this expression here. What is this max value? That is what we want to find, d nu g d nu t. Now, this expression is basically d max, where d max is e to the power minus 1 log beta as we have evaluated here. So, this is the expression which will give you the maximum values here. Now, you can see that given a constant ground temperature and constant tropospheric temperature, the maximum change in the outgoing long wave radiation depends only on beta, everything else is constant.

So, delta Sol at a max by log beta will be very nearly identical and this is kind of plot that can be plotted regardless of the values of beta or the values of beta. So, this has been plotted for two values of beta, beta equals to 2 and beta equals to 4 and we can see they are almost on top of beta. So, if you have this plot for various absorbing gases, then you can use that and integrate that and evaluate. So, this was spectral. So, the net outgoing long-wave radiation change due to the change in the absorbing gas concentration can be evaluated by integrating this over the entire frequency.

$$|\Delta SOLR_{max}| = \pi\left(B_{\nu_g} - B_{\nu_t}\right)\left(\Gamma_\nu - \Gamma_\nu^\beta\right)^{max} = \pi\left(B_{\nu_g} - B_{\nu_t}\right)e^{-1}ln(\beta)$$

Thus $\frac{|\Delta SOLR_{max}|}{ln(\beta)}$ vs v gives nearly identical plots for various values of β as seen in the 2nd figure.

So, the radiative forcing for CO2, because remember we are trying to find the radiative forcing for CO2. What was it? It is the change in the net outgoing long wave radiation, F downward minus F up. What are the net down going, whichever way you are thinking of that, due to change in the density of CO2, this gradient into the change in density of CO2. So, the gradient, so it is the negative of the outgoing long wave radiation by due to change in density of CO2 for a specific change in density. And this expression basically becomes the change in the net outgoing longwave radiation delta Solr that we have derived here from and integrating this over all frequency 0 to infinity from all frequencies. So, this will be the actual value of the radiative forcing caused by change in concentration of CO2. The integration of the spectral outgoing long wave radiation with frequency for all the frequency band in the infrared spectrum. Since delta Solr has logarithmic dependence on beta, the final form will look like Rf CO2 equals to A log beta. Remember, delta Solr has this expression. So, it is a log beta kind of an expression.

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\begin{aligned}
RF_{CO2} &= \frac{\partial}{\partial \rho_{CO_2}}\left[F^{\downarrow} - F^{\uparrow}\right]\Delta\rho_{CO_2} \\
&= -\frac{\partial F^{\uparrow}}{\partial \rho_{CO_2}}\Delta\rho_{CO_2} \\
&= -\int_0^{\infty} \Delta SOLR \, dv
\end{aligned}
$$

The max has this expression. The actual frequency will also have a log beta expression. And integration of that will also give you a log beta type of term. So, the final functional form will look like A into log of beta where beta is the ratio of the final concentration of CO2 to the initial concentration of CO2. So, the proper modeling shows that RfCO2 is 5.3 log beta watt per meter square. Hence, a doubling of CO2 creates a radiative forcing of 3.67 watt per meter square. So, if you put 2 here, you will have a positive radiative forcing because there is a radiative forcing of 3.67 watt per meter square. The outgoing long wave radiation will decrease.

A proper modelling shows that $RF_{CO2} = 5.3 ln(\beta)$ W/m². Hence a doubling of CO_2 creates a radiative forcing of 3.67 W/m².

So, del F, del rho CO2 will be negative. Negative of negative is positive. So, this will be the final value. Alright? So, what this means is If you double the CO2 concentration, an extra 3.67 watt per meter square of solar energy will be trapped within the troposphere due to this doubling effect.

So, this kind of concludes our session on. climate sensitivity, radiative forcing and other parameters. We have exhaustively discussed the analytical basis based on which we are defining the various global warming effects. The next set of lectures over the next few weeks will be on a different track. We will be discussing how to measure the various important climatological and meteorological parameters which helps us to develop and test and validate this theory and the associated models. We will look at both land-based, upper atmospheric and satellite-based measurement systems and see how we can use them to properly measure the various climatological factors, how they are changing as well as help to validate model predictions based on them.

Thank you for listening. We will come back with the next lecture shortly.