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Physical basis for climate change models

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Objectives

The objectives for this research were two-fold:

- To identify means of using measurements of the outgoing radiation stream from earth to identify mechanisms of climate change.
- To develop a flexible radiation code based upon the *correlated-k* method to enable rapid and accurate calculations of the outgoing radiation.

Product

The intended products are three papers and a radiation code. The three papers are to be on *Entropy fluxes and the dissipation of the climate system*, *Radiation fingerprints of climate change*, and *A rapid correlated-k code*.

Approach

The radiation code is based on the work of Goody, West, Chen and Crisp (1989). The problems are those of efficient data handling and the incorporation of a code for combining the absorptions of two bands. The heating rates for specific atmospheres were calculated with increasing precision until the results for any one spectral range had errors less than 1%. Since many spectral ranges are combined in a heating rate calculation, and since there is no reason to expect correlations between ranges, the final result should be accurate to a few tenths of a percent following these techniques.

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The method is based on a primary archive, the AFGL HITRAN tape. The correlated-k method allows data from such an archive to be incorporated directly into a calculation, but in summarized form. The result is that whenever the archive is updated, with new data or new gases, these data can immediately be incorporated into radiative heating calculations.

The second criterion in this work, in addition to accuracy, is speed. The objective was to complete a full radiation calculation in the same time as that used to calculate one dynamical time step in a GCM. This would mean that the radiation calculation takes at the most 50% of the computing time of a GCM; in fact, since radiation calculations need not be made at each time step, they should take less.

The radiation fingerprint approach is self-explanatory. A number of investigators are currently working on the "detection" problem for CO₂ warming. At present they use the output of GCM's to test statistically against surface temperature observations. The methodology can be extended to any signal. The more refined the signal, the more sensitive is the detection. Our approach is to use a simple climate model, together with the radiation code discussed above, to test the sensitivity of the outgoing radiation stream as a fingerprint of climate change.

The third topic concerns the use of the outgoing entropy stream (which may be calculated directly from the radiance) as an additional datum to test the output of a GCM. If the prediction is correct it should indicate that the dynamical dissipation of the model is correct, a control of major importance. A number of investigators have been calculating outgoing entropy streams from satellite observations (*eg* Stephens and O'Brien, 1993). Our approach is to ask whether calculations from low spectral resolution data are accurate enough to obtain the entropy flux, and what proportion is the result of unwanted irreversible processes in radiative transfer.

Results-to-date

Funding for this work was discontinued in 1991 and the full-time investigator, Ms Gerstell, left to pursue graduate studies at Caltech. Without continuing funding it was not possible to complete the work in the time available. Nevertheless, the work performed has not been wasted and all three objectives have been pursued under different auspices; all are moving towards completion. There follows a review of the state of this work.

The correlated-k task has been taken up by Tony Clough of Atmospheric

and Environmental Research, with the PI (Richard Goody) acting as an adviser. The work is progressing well. It is a testimony to the importance of this technique that it has been adopted as the method of choice for a "modern" approach to GCM radiation calculations.

The radiation fingerprint approach has been continued by the PI and Dr. Wedad Abdou under a NASA grant at the Jet Propulsion laboratory. The radiation fingerprint is calculated at 1 cm^{-1} resolution with the MODTRAN code, or the high resolution of the LBL code using HITRAN. These calculations are made on the results from a tropical cumulus one-dimensional model developed by Dr. Arthur Hou of Goddard Space Flight Center. We have compared the radiation fingerprint for climate changes that lead to the same change in ground temperature, but with different physical causes. The four different causes are :doubling CO_2 ; changing the water-vapor feed-back; changing the solar irradiation; changing the cloud amount. The spectral signatures of these four changes are completely different and provide a finely-tuned test for the statistical "detection" methods. A paper is being prepared for the *Journal of Remote Sensing*

The entropy investigation is also being investigated by the PI and Dr. Abdou. We have made detailed tests of the effect of spectral resolution on the calculation of entropy, and have reached the conclusion that, with empirical correction, $1\text{-}3\text{ cm}^{-1}$ resolution may be sufficient. Work published to date in the literature does not use such a high resolution, but it is achievable with a simple fourier transform spectrometer.

Discussion of the irreversible contribution to the entropy stream has advanced with theoretical "grey" models, and we understand the general principles involved. Both reversible and irreversible contributions can be calculated numerically, and we are starting to do this with MODTRAN and realistic climate data. We expect to publish a Shorter Contribution in the *QJRMS* in the next few months.

References

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- Stephens, G.L., and O'Brien, D.M., 1993, "Entropy and climate. I: ERBE observations of the entropy production of the earth", *Q. J. Roy. Met. Soc* **119**, 121-152.

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