Chapter 7
CONCLUSIONS AND PERSPECTIVES

RESULTS

The goal of this research project has been the design and construction of filter radiometers for the measurement of direct solar irradiance at selected wavelengths from the UV to the near infrared. The instruments were produced and tested in a fruitful cooperative effort, and they have fulfilled their purpose. The instruments were mounted in an existing solar tracker setup at Thule Air Base and used in conjunction with the excellent data acquisition and handling facilities there. The Research and Development Department of the Danish Meteorological Institute in Copenhagen took care of preliminary data preparation and transmission and made it available for further analysis.

Within the limitations in time and resources available for this project, the data for the late spring, summer and early autumn at Thule Air Base has been analyzed. This preliminary data has shown that the resulting aerosol optical depths to be in accord with other observations in Arctic regions during stable summer conditions as described in Chapter 6.

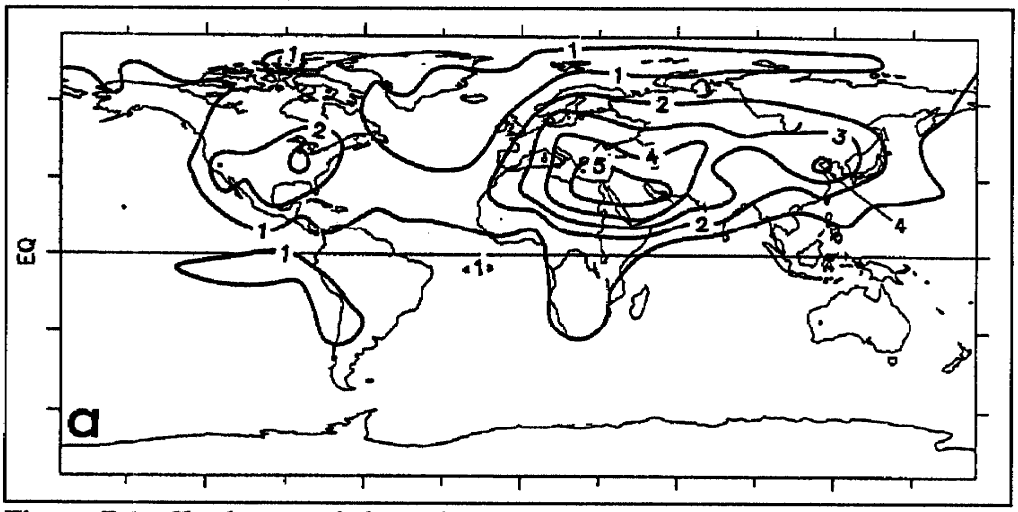

Figure 7.1: *Charlson et al. have demonstrated that the total tropospheric aerosol burden can cause negative radiative forcing* [Charlson, 1991].

GLOBAL IMPLICATIONS

It is worthwhile to place the measurement of atmospheric aerosol in a broader perspective, for the amount and distribution of aerosol has a bearing on the implementation and interpretation of general circulation models. Since C.E. Junge first demonstrated the technique for finding aerosol particle size distributions by optical measurements, there has been an increasing awareness of the importance of aerosol to the global climate [*Hobbs, 1993, p 2*]. As we have seen, the issue of Arctic haze aerosol was pursued in the 1970's and 1980's, and intensive measuring programs such as the AGASP programs in 1983 and 1986 provided valuable information about transport pathways, sources, size distributions, chemical composition, vertical distribution and seasonal variation of Arctic haze aerosol.

Charlson et al. [*Charlson, 1991*] developed a three dimensional global model for describing the concentration of sulfate aerosol and proceeded to estimate the radiative forcing due to anthropogenic and natural sources. Their estimate of the increased reflected flux to space due to the total tropospheric sulfate aerosol burden is shown in Figure 7.1. Their calculations were based upon the best available information on aerosol properties and world-wide distribution. Note that the data in the figure have the units W/m^2 and that the values represent *net flux reductions*, i.e. that the presumed effect upon mean temperatures at the troposphere-surface interface is negative. It is apparent from the figure that the radiative forcing effect due to aerosol is primarily a Northern Hemisphere phenomenon. These authors estimate, with considerable uncertainty, that direct and indirect effects of anthropogenic sulfate aerosol may be responsible for a Northern Hemisphere temperature decrease of 1-2°C.

The IPCC has in recent years recognized the importance of atmospheric aerosol in the assessment of possible changes in the global climate while pointing out that anthropogenic aerosol has a very short residence time compared with e.g. greenhouse gasses such as CO_2. Thus effective reductions in aerosol emissions would have a nearly instantaneous effect (on the order of weeks or months) on the atmospheric concentration of anthropogenic aerosol [*Jørgensen, 1996*].

Up to date aerosol optical depth information is essential to the ongoing evaluation of direct and indirect climatological effects of all atmospheric components. In particular it is important to be able to distinguish between signals of human origin and the natural background noise which is characteristic of Earth's climate fluctuations. Therefore data series extending over years or decades, such at the data available from CMDL for Mauna Loa, Samoa, the South Pole and Barrow [*Hofmann, 1998, p 55*], would be very desirable to have for Thule Air Base. Only with access to such extensive data series will it be possible to draw qualified conclusions about seasonal and long term variations in aerosol properties and amounts.

One interesting observation available from the CMDL data is the correlation between changes in the Ångström exponent p in the power law relationship describing the variation in the optical depth with wavelength $(\tau = k \cdot \lambda^{-p})$ and the particle size distribution. CMDL data suggests that larger values of the Ångström exponent are characteristic when scattering is predominantly due to small particles (e.g. Figure 6.18 showing our TAB data from 19 Sep 1999). They found that smaller values of the exponent are associated with particle distributions with many large particles, as can be seen in our data for 25 May 1999 (Figure 6.20). The data available so far from Thule Air Base is inadequate to draw any general conclusions.

Another important parameter having a direct bearing on radiative forcing calculations for tropospheric aerosol is the *single scattering albedo* ω_0. This quantity is defined as follows:

$$\omega_0 = \frac{\sigma_{sp}}{\sigma_{ap} + \sigma_{sp}} \tag{7.1}$$

where σ_{sp} is the particle *scattering cross section*, and σ_{ap} is the *absorption cross section*. Sulfate aerosol, which is an effective scattering agent with minimal absorption, has a single scattering albedo close to unity, while carbon black (e.g. from biomass burning) has a value around 0.3 [*Hofmann, 1998, p 55*]. Finally the CMDL data make it possible to address the problem of finding the mass scattering efficiency for various aerosol species, a quantity which is also needed in order to evaluate aerosol radiative effects.

Continuation of the aerosol optical depth measurements at Thule Air Base could supply important additional information related directly to the study of aerosol radiative transfer and thus to our ability to make realistic estimates of long term climate changes.

PRACTICAL MATTERS

As with any complex endeavor, problems can arise, and it is the goal of this brief section to comment on possible improvements in procedures and equipment which can perhaps ease the task of those who may follow to continue the aerosol optical depth measurement program. This is particularly relevant for a project undertaken in an Arctic environment where supply lines are subject to delay and extra expense.

Here are a few critical comments on SolData filter pyrheliometer design which was described in Chapter 3. The basic mechanical design was sound, and the instruments were easy to assemble and to disassemble for maintenance. The Minco heater solution appeared to serve its purpose well, as there was no sign of fogging of the radiometer window or drift due to temperature variations. With ambient temperatures down to about –15°C the heating element packed within the 4 mm foam insulation protected by the climate shield held the printed circuit and detector environment at 20±½°C with no difficulty. The heater pulse current of 1 ampere ran in the same 10-lead cable as the signal and power supply leads with no evidence of electrical interference with the data signal due to heater current on/off pulses.

The detector and electronics were as simple as possible to achieve the task at hand. Here is room for improvement and optimization of the circuit design to achieve a noise level comparable to the Kipp-Zonen instrument and to assure that no overshoot occurs during periods with very high direct solar irradiance. This did occur for a few weeks in mid-summer on the 500 nm channel, fortunately without any serious consequences for the analysis of data on these days. Instead of freely accessible screw terminals the instrument junction box inside the laboratory should be a shielded metal construction with appropriate shielded connectors, e.g. BNC connectors, for connection to the data acquisition system.

Although there was no evidence of faulty collimator-detector alignment, one would be more comfortable with an improved method for fixing the position of the photodiode and insuring that the interference filters are perfectly normal to the incident beam. The field of view using the 10 mm collimators was satisfactory, and we have found no evidence in the literature suggesting that the field of view should be limited further.

The plexiglas rings supporting the climate shield may prove to be a weak point in the mechanical construction. Rings could be machined from aluminum to provide a more robust solution. The application and removal of the insulation layer during servicing could be facilitated by using strips of insulating fiber cloth with velcro strips to secure it.

The Sci-Tec solar tracker worked well but gave problems occasionally due to stripping of segments of the belt drive. If possible the quality of the belts should be improved, or, failing that, there should be a supply of extra belts on hand for periodic replacement.

The weather station data available for the 1999 season was not always reliable and should perhaps be replaced or updated. Redundancy of the weather data sensors would be wise so that dependable weather data would always be available, e.g. for pressure and temperature corrections.

SUGGESTIONS FOR FURTHER RESEARCH

It is remarkable that the study of microscopic particles suspended in the air should be the subject of so many books and articles in the literature of atmospheric physics. Indeed the subject has also attracted attention in many other scientific disciplines ranging from chemistry, geology and meteorology to paleontology, as described in Chapter 2. Here are a few informal suggestions for further research, some of which might be undertaken within the framework of existing Danish initiatives in the field of geophysics.

- Continue the systematic observation of optical depths at selected WMO wavelengths at the Thule Air Base laboratory. This effort could be pursued by using updated versions of the SolData pyrheliometers described in Chapter 3 of this thesis.
- The optical depth observations could be supplemented by installing the CCD spectrometer and fiber optic detector head described in Chapter 3. The instrument is available for use, and the physical dimensions of the detector assembly are identical to the existing radiometers so that mounting on the Sci-Tec solar tracker would be easy to implement. The use of this instrument could complement the filter instrument measurements as a wider of selection of WMO wavelengths (in the visible range) could be selected for study.
- A coordinated effort analogous to the AGASP programs of 1983 and 1986 to study Arctic haze could be mounted with Thule Air Base as the focal point for activities in Northern Greenland. The initiative could include continuing optical depth observations, airborne data collection (particularly during the season where Arctic haze is expected) and ground-based aerosol particulate studies to learn more about the chemical composition of Arctic aerosol. Such programs have previously been carried out in the Norwegian Arctic and in

Greenland with the participation of scientists from the Risø Research Laboratory in Denmark.

- Transport pathways of haze aerosol to Arctic regions could be studied by the application of actual weather data or by the application of a General Circulation Model to the problem.
- The winter Arctic haze phenomenon at Thule Air Base has not been examined in this work, for the measurement technique we have used requires direct solar illumination. A star photometer could be mounted at the Thule Air Base laboratory to study the phenomenon during a winter season. This would be an exceptionally challenging task due to the severity of winter weather in Northern Greenland.
- The performance of photovoltaic systems for generation of electricity under difficult climatic conditions is affected by temperature, ground albedo and by sky radiance. Sky radiance is dependent on the size distribution and concentration of atmospheric aerosol. Some of the results of this thesis are currently being applied to this engineering problem.
- We have briefly touched upon the historical evolution of solar radiation measuring instruments. The historian of science and technology could perhaps find a fruitful and interesting area of research by pursuing the evolution of these instruments in greater detail.
- Certain locations in Denmark and abroad are well known by artists for the unique quality of the illumination available. Provincetown, at the tip of the Cape Cod peninsula in Massachusetts, and the Danish town of Skagen at the northern tip of Jutland are examples of locations where this phenomenon can be experienced. The quality of the daytime illumination there is probably due to the properties of maritime haze aerosol particles which cause light from the sky to have a more "whitish" appearance than the blue of the clear sky with little aerosol at an inland location. Here is an opportunity for an interdisciplinary study between science and the humanities.

A FINAL WORD

The student of atmospheric aerosol will encounter a wide range of scientific and engineering disciplines, and with sufficient time and resources aerosol studies could prove to be a fruitful and interesting endeavor. This fact is apparent when studying the literature of atmospheric aerosol where names such as Twomey, Junge, Kasten, Young, McCartney and many others are represented over a period of decades. Many aesthetically appealing natural phenomena such as dramatic sunsets, rainbows, haloes, coronas and other effects are due to atmospheric aerosol. Highly practical matters such as visibility restrictions due to aerosol dynamics in the formation of haze and fog can be of a matter of life and death. It would not be unfair to conclude by claiming that the student of this subject will frequently have occasion to use and appreciate this knowledge.