IEEE GEOSCIENCE and REMOTE SENSING Newsletter

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Natural disasters of big magnitude have shaken our world at the end of 2004, reminding us of our fragility vs. the forces of nature. The mass media have largely covered the tsunami that devastated the shores of Indian ocean on December 26th, with an unimaginable death toll. From these lines, we would also like to remember the strong earthquake happened in Chuetsu, Japan, on October 23rd, from which our Associate Editor for Asian Affairs, Yoshio Yamayuchi, and his family are slowly recovering. We wish them, and all the people that have suffered these natural disasters, a quick recovery.

This issue of the Newsletter features three main articles:

- The Feature Article has been written by Tariro Charakupa-Chingono, Associate Editor for African Affairs, and describes the environmental situation of the Kwekwe, Zimbabwe, and how remote can help to remediate the current environmental condition, and plan and manage the current and future development,
- The Industrial Profile presents a review of the activities of Boeing Satellite Systems, and
- and excellent tutorial by Ed R. Westwater, Susanne Crewell and Christian Mätzler on Surface-based Microwave and Millimeter wave Radiometric Remote Sensing of the Troposphere.

Also in this issue, Martti Hallikainen includes a review of the tribute to Kiyo Tomiyasu for his 85 birthday celebration, that took place during the last GRS-S AdCom dinner. In the last pages you will find a number of announcements and conference advertisements that may be of your interest.

President's Message

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On December 26, 2004, the world reeled at a loss of life of staggering proportions. The death toll attributed to the tsunamis originating near Banda Aceh, Sumatra was not the largest of recorded natural disasters, but the impact seems decidedly more global than from others in recent memory. While the direct forces of seawater devastated coastal areas of several nations, the indirect impact was felt by many more as a result of an increasingly interconnected global community. Examples of such connectivity abound. Dozens of ports that contributed to regional and international trade no longer have the infrastructure or labor necessary to function. Hundreds of fishing fleets no longer supply a major source of food to millions who live far inland of the coasts. The world supply of building materials is further strained. Tourism alone accounted for the untimely presence of thousands who normally live far away from the idyllic strands surrounding the Indian Ocean. The more tightly that our global web is woven, the more that such disturbances leave no part untouched.

Just how interconnected are we to this event? One might argue that for each person lost at least a dozen or more lives have been economically and socially destroyed. For each of these ongoing lives, at least a dozen or more are heavily burdened with the task of supporting their uprooted neighbors and kin. Simple calculation suggests that the group of individuals immediately and greatly impacted accounts for roughly a full percent of all living humans. Of all others, it is hard not to be moved by the scale of the event, and in an indirect and at least minimal way, affected economically.

Should we take any solace in the fact this was a natural

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Cover Information: The image shows instrumentation mounted on the "Sky Deck" of the ARM Programs' NSA/AAO field site during the 2004 Water Vapor IOP that was conducted March 9-April 9, 2004. The major goal was to demonstrate that millimeter wavelength radiometers can substantially improve water vapor observations during the Arctic winter. Radiometers that were deployed include the Ground-based Scanning Radiometer of NOAA's Environmental Technology Laboratory (several frequencies from 50 to 380 GHz), the Microwave Radiometer and the Radiometric Profiler of ARM (frequencies from 22.235 to 60 GHz) and the Montana State Infrared Cloud Imager (ICI). Three posters describing results from this experiment have been submitted for the 2005 ARM Science Team Meeting.

Message from the President *continued from page 3*

event and that it was somehow unavoidable? Over the past several years many people have become preoccupied with catastrophes of man-made origin: genocide in Africa; terrorism in the U.S., Spain, and the Middle East; famine in North Korea. Surely the defects in our global social web that give rise to these events are somehow correctable, and indeed, we have a responsibility to find solutions that preclude their recurrence. But the effects of tectonic movement – and for that matter the effects of many other large-scale natural events - seem to be of another class well beyond our control. We have met the enemy, and this time they are not us.

Or are they? When we compare the efforts of world governments to preempt the impacts of natural versus man made events we begin to see disparities. Hundreds of billions of U.S. dollars have been spent in the aftermath of the attacks on September 11, 2001 to curtail the proliferation of weapons of mass destruction that could, if unleashed, indeed claim thousands to millions of lives. As a rough measure only a percent of this amount has been spent to develop and implement new natural hazard detection and warning systems that could protect comparable numbers of people from events of similar likelihood. Indeed, if we consider the cumulative death tolls from natural versus man-made events since 1900 – including two world wars - the numbers are comparable (a few to several tens of millions). In spite of this rough parity the worldwide expenditures to understand and lessen the toll from natural hazards falls short relative to those from some man made events. That governments are currently preoccupied with WMDs might arise from preconceptions about the intentions of other humans, or from fears that the impacts of WMDs would be directed toward our more developed populations. Whatever the reasons, our increasing interconnectedness suggests that we should be more concerned about the safety of the broad global community, and in particular, the impact of large-scale natural events.

Monetary aid in the aftermath of any catastrophe is paramount to recovery, and all of the many donations made to aid the tsunami survivors illustrate the intrinsic generosity of humans. Being familiar with the phenomenology and technology of geophysical sensing and telecommunications I would contend, however, that it is a more effective use of resources to learn to better predict and to warn of impending natural hazards rather than to react to them. Consider the likely consequences of as little as fifteen minutes of warning to the coastal populations ringing the Indian Ocean last December. Many people would have climbed to higher ground in such time, and many would be alive to help rebuild. These same individuals would clearly recognize the importance of geophysical hazard prediction and be inclined to further promote and integrate into their lives new warning systems – much as we now respond to fire alarms without hesitation.

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Although global seismic and buoy networks provided the most reliable means of detecting last December's tsunamis the warnings were neither specific enough nor distributed widely and rapidly enough to help many people. Owing to technological investments over several decades we have significant capability in this area, but clearly more work to do in the collection of relevant data, rapid assimilation of this data into models, and dissemination of products and warnings to officials. I am pleased to hear of several national and international initiatives since last December to extend our current set of in situ measurements and tsunami warning capabilities to most of the world's populated coastlines.

Remote sensing plays an important role in any effective global disaster information network. New geophysical sensing methods, rapid processing and detection techniques that intelligently fuse data from a variety of global sources, reduced data transmission latency, and common data formats for wide and rapid distribution are all areas that offer major potential for reducing the risk from natural hazards. Dissemination of timely, accurate, and relevant remotely-sensed information in the immediate aftermath of an event is also critical to help prevent further downstream calamities such as cholera, famine, and civil strife.

Work in this area needs the support of governments just as if the enemy were "us." Are we doing all we can to improve upon our ability to predict and warn? In my own sphere, for example, I have been privy to concepts for detecting propagating tsunami waves during mid-ocean transit – well prior to their development into deadly coastal anomalies – only to see support for further research into this idea all but vanish amidst tightened budgets, restricted organizational goals, and an emphasis on research that provides a virtual immediate return to a specific constituency. Based on anecdotal evidence my experience is being played out again and again among many of my peers. A funding shift toward activity that increases the security of the taxpayer is justifiably cited as the underlying mission goal. But in an increasingly interconnected global community the true security of even small and affluent segments of population demands that all people are protected, from all types of events, using all available and nascent technological means.

A unique opportunity for equanimity awaits us with the advent of the Global Earth Observation "System of Systems," or GEOSS. A ten-year implementation plan has been negotiated by the international Group on Earth Observations (GEO), with input from the IEEE as one of several participating organizations. In spite of its far-reaching and constructive goals, the plan does not yet provide a concrete means of funding GEOSS. Can we cobble together this all-important global system from ongoing programs and existing infrastructure? The GRS-S and its sister scientific and engineering organizations will play key roles in assembling the prototype GEOSS. They will also be necessary for developing arguments for the resources that most certainly will be required for comprehensive implementation of a global hazard warning and disaster mitigation network within GEOSS.

On a lighter note I am pleased to offer my congratulations to seven individuals in the 2005 class of IEEE Fellows who are members of the GRS-S. They are Professors Qing Huo Liu, Steven I. Franke, Glenn Edward Healey, and Masaharu Fujita, and Drs. Ronald Kwok, Gary G. Gimmestad, and Richard H. Bamler. Once again, we are fortunate to have a disproportionately large number of new IEEE Fellows hail from our Society.

I am also pleased to report a year of outstanding growth for the Society. While most IEEE entities are currently exhibiting flat or negative growth the 2004 statistics show the GRS-S as having increased its overall membership by 10% - by far the strongest growth of any mid- or large-sized IEEE entity. This is no small accomplishment in an era of general stagnation in engineering. I can attribute our growth to a highly professional, dedicated, and active core membership that strives to realize the societal benefits stemming from remote sensing applications.

Many of our most active and dedicated of members choose to serve the Society by contributing to its management through the GRS-S AdCom. Among these members, I would like to welcome new AdCom member Dr. Jay Pearlman and returning AdCom member Dr. Nahid Khazenie. Dr. Khazenie returns to the GRS-S AdCom after serving as IEEE Division IX Director during 2000-2001. Dr. Pearlman currently also serves as Chair of the IEEE Committee on Earth Observations. Other re-elected AdCom members in 2005 include Professor Tony Milne, Dr. Thomas Jackson, and Professor Andrew Blanchard. Of special interest will be Prof. Blanchard's renewed exercise in strategic planning for the GRS-S, the status of which will be featured in an upcoming issue of the Newsletter. Having also been re-elected to the AdCom in 2005 I wish to express my appreciation for your continued vote of confidence.

On a final note, I am looking forward to seeing you all at IGARSS 2005 in Seoul, Korea this July 25-29. Professor Wooil M. Moon and his organizing team are putting together an outstanding agenda of presentations, posters, panel sessions, plenary talks, tutorials, tours, and social events. Our meeting this year marks the 25th anniversary of IGARSS, and promises to be an especially instructive and memorable event.

HAPPY BIRTHDAY, UNCLE KIYO* !

Martti Hallikainen

Mrs. Eiko Tomiyasu (right), Kiyo Tomiyasu, and the artist Airi Hallikainen.

One of the highlights of the GRS-S Administrative Committee Dinner on September 19, 2004 at IGARSS'04 in Anchorage was honoring Kiyo Tomiyasu, who celebrated his 85th birthday on September 25. Artist Airi Hallikainen had painted his portrait and handed it to Kiyo as a personal gift from her and her husband Martti.

Kiyo (S'41-A'42-M'49-SM'52-F'62-LF'85) received the B.S. degree in electrical engineering from the California Institute of Technology, Pasadena in 1940, the M.S. degree in communication engineering from Columbia University, New York, NY in 1941, and the Ph.D. degree in engineering science and applied physics from Harvard University in 1948. His career includes the fields of communication, propagation, remote sensing, radar, and SAR (synthetic aperture radar).

Kiyo is an Honorary Life Member of GRS-S and continues to actively participate in GRS-S matters, often providing guidance to Administrative Committee members on Society Constitution, Bylaws, and Best Practices in IEEE.

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*Uncle Kiyo is how the artist's youngest daughter Paula calls him; they first met in 1997 at the Administrative Committee Dinner in Espoo, Finland when she was 6 years old. Paula now learns to play koto (a Japanese musical instrument) at her school's Music Club, listens to Japanese J-Pop and even knows some Japanese language.

CALL FOR NOMINATIONS FOR THE GRS-S ADMINISTRATIVE COMMITTEE

The Nominations Committee calls upon our membership to nominate members to serve on the GRSS AdCom. A nominating petition carrying a minimum of five names of Society members, excluding students, shall automatically place that nominee on the slate although the Nominations Committee may choose to include a name on the slate regardless of the number of names on the nominating petition. Your nominees should confirm in writing their willingness to stand for election. Candidates must be current members of the IEEE and Society.

A brief biography of the nominee, similar to that used for TGARS authors, will be required and should be submitted with the nominating petition by May 25, 2005 to the GRS-S Nominations Committee, c/o Martti Hallikainen, Nominations Chair, Helsinki University of Technology, Laboratory of Space Technology, P.O. Box 3000, 02015 HUT, Finland; Fax: +358.9.451.2898; E-mail: martti.hallikainen@hut.fi.

The slate derived by the Nominations Committee shall be presented to the Society membership at large via mail ballot, and the three candidates receiving the greatest number of votes shall be elected. The Administrative Committee shall hold an Annual Meeting in November 2005 after the results of this vote are known at which time elections will be held to fill the remaining three regular vacancies in the Administrative Committee to occur on January 1, 2006.

Our AdCom consists of 18 elected persons, each of whom serves for three years. Their terms are overlapping to assure continuity. Additional information on the Society and the AdCom is available at http://ewh.ieee.org/soc/grss/.

GRS-S MEMBERS ELECTED TO THE GRADE OF FELLOW OF THE IEEE, JANUARY 1, 2005:

Prof. Qing Huo Liu
Duke University, Durham, NC, USA
For contributions to computational electromagnetics and to subsurface sensing applications.

Prof. Steven J. Franke
University of Illinois, Urbana, IL, USA
For contributions to wave propagation, atmospheric sensing, and to engineering education.

Prof. Glenn E. Healey
University of California, Irvine, Irvine, CA, USA
For contributions to the modeling and processing of multispectral and hyperspectral images.

Prof. Masaharu Fujita
Tokyo Metropolitan Institute of Technology, Hino, Tokyo, Japan
For contributions to microwave remote sensing.

Dr. Ronald Kwok
Jet Propulsion Laboratory, Pasadena, CA, USA
For contributions to microwave remote sensing for understanding of polar ice processes.

Dr. Gary G. Gimmestad
Georgia Institute of Technology, Atlanta, GA, USA
For contributions to atmospheric remote sensing technology.

Dr. Richard Hans Georg Bamler
Deutsches Zentrum fur Luft- und Raumfahrt e.V., Wessling, Germany
For contributions to synthetic aperture radar interferometry and signal processing.

GRS-S MEMBERS ELEVATED TO THE GRADE OF SENIOR MEMBER FROM APRIL 2004 TO DECEMBER 2004

April 2004: Dara Entekhabi, David J. McLaughlin, Steven C. Reising, Peter W. Gaiser, Charles R. Baker, Ewert Bengtsson, Hans C. Strifors, Lars O. Ulander, Peijun Li, Bosukonda Surya P Rao.
May 2004: Susan Ustin, Vernon Singhroy, Juraj Bartolic, Jocelyn Chanussot, Werner R. Alpers, David J. Daniels.
June 2004: Mark A. Sletten, Siri Jodha S. Khalsa, Joseph A. Shaw.
August 2004: Jian Yang.
September 2004: Anna P. Barros, Olexander Yarovyi, Pascale C. Dubois-Fernandez, Yuriy V. Shkvarko.
November 2004: Charles M. Bachmann, Joseph T. Kujawski, David B. Kunkee, Mary S. Moran, Jon G. Rokne, Antonio Iodice, Mihai Datcu, Hermann Eul.

Senior membership has the following distinct benefits:

- The professional recognition of your peers for technical and professional excellence.
- An attractive fine wood and bronze engraved Señor Member plaque to proudly display.
- Up to $25.00 gift certificate toward one new Society membership.
- A letter of commendation to your employer on the achievement of Senior member grade (upon request of the newly elected Senior Member).
- Announcement of elevation in Section/Society and/or local newsletters, newspapers and notices.
- Eligibility to hold executive IEEE volunteer positions.
- Can serve as Reference for Senior Member applicants.
- Invited to be on the panel to review Senior Member applications.
- Eligible for election to be an IEEE Fellow.

Applications for senior membership can be obtained form IEEE GRS-S website:
http://ewh.ieee.org/soc/grss/ (click Join Us)
or IEEE Senior membership program:
http://www.ieee.org/organizations/rab/md/smprogram.html

FEATURE ARTICLE

KWEKWE A MORIBUND DISTRICT; GEOSCIENCE CAN CONTRIBUTE TOWARDS RESCUING THE SITUATION

Tariro Charakupa-Chingono
Kwekwe, Zimbabwe.

KWEKWE

Kwekwe with a population of 150.000 and about 500.000 within 100 km of the its limits is the fifth largest city of Zimbabwe and is located 213 km south west of the capital city Harare. The district is well endowed with rich gold, iron deposits and other minerals. It is one of the seven districts that comprise the Midlands Province, the mining, manufacturing and agricultural (including cattle ranching, irrigated wheat etc.) power-house of the Zimbabwe.

Production activity in the town is dominated by large smelting plants, namely the Zimbabwe Iron and Steel Company (ZISCO), the Zimbabwe Mining and Smelting Company, a chrome smelting plant, Sable Chemicals, a fertiliser plant producing ammonium nitrate, an explosives manufacturing plant (Nitro Noble), and a gold roasting plant. There also are numerous down stream industries including those that produce rolled products as well as wire and other finished products.

Kwekwe was once a centre of the gold mining industry. The Globe and Phoenix Mine and the Gaika Mine were the largest in Kwekwe the former was once the country's biggest producer. The Government Roasting Plant used for treatment of refractory gold ores was constructed in 1937 and is still operational.

The city of Kwekwe is situated on a watershed; it sits on a catchment of the three major rivers namely, the Kwekwe, Sebakwe and Mbembeswana Rivers. Development activities in and around the city (mining, mineral extraction and industrial production) emit and dump large quantities of harmful gases, solids (as well as heavy metals) and liquids into the air, waterways and soil.

Consequently, production activities in and around the city have and continue to adversely impact the local and regional environment and human health owing to inadequate implementation and policing of environmental management regulations. These impacts should be regarded seriously despite the limited knowledge of their extent.

SOCIO-ECONOMIC SITUATION

The past growth of the towns of Kwekwe and Redcliff can be attributed to the existence of abundant mineral deposits, large hinterland population and good communication with the rest of the nation and the outside world. Accordingly, the cities acquired an important regional and national industrial presence, contributing significantly to the gross national production output.

The Cities of Kwekwe and Redcliff were founded on gold, iron ore and limestone quarry mining respectively. The Globe and Phoenix Gold mine was the largest and richest mine in the Midlands Province and was the basis of growth and development of Kwekwe. Similarly, ZISCO, which was at one time the largest steel works in Sub-Saharan Africa (excluding South Africa) located on rich limestone quarry deposits led to the development of Redcliff.

As a result of the associated developmental activities, the natural environment has come under immense pressure resulting in extensive deforestation, soil erosion and general land degradation especially where informal small-scale gold mining is rampant.

Furthermore, despite contributing significantly to the city's development and growth the large-scale mining and smelting concerns have in last fifteen years fared poorly as a result of:

- The depressed national economic climate:
- Recurrent droughts and their associated effects since 1992
- Low metal prices, in particular gold and ferrochrome, resulting in massive retrenchments
- High input costs, in particular energy and labor costs
- Extremely high interest rates and tight liquidity situation due to runaway inflation.

The 1992 Industrial/Commercial Survey found that approximately 45.2% of the total workforce in Kwekwe was employed in the mining sector. The figure declined to 13% in 1993 and is likely to have declined even further to-date as company downsizing and closures continue at unprecedented rates

Hence, half the adult population of Kwekwe is directly or indirectly involved in the informal small-scale gold mining sector on either part-time or full-time basis as a source of income to sustain their families. The last ten years have seen the proliferation of informal small-scale gold mining activities in both urban and rural Kwekwe particularly in the urban area outskirts. The most affected are the Globe Phoenix; Gaika mines areas (urban) where mine dumps are being reworked and the Silobela and Zhombe areas (rural) where panning is the major activity. Miners are reported to be entering disused dangerous mine shafts, at times going as far as blasting shaft pillars to access the remaining gold in the non-operational shafts. As a result, Kwekwe has seen an increase in mining fatalities, cave-ins, blasting accidents, surface subsidence and undermining of infrastructure foundations.


Kwekwe under sie

. . . As defiant gold panners wreak havoc on school, infrastructure and envi

TAURAYI BANDA (left) and Phillip Simango use sewerage water to separate gold ore from gravel near Globe and Phoenix Primary School.

Figure 1. Zimbabwe Sunday Mail 23/02/03 Article on Gold Panning Wrecking Havoc in Kwekwe

GEOLOGY AND SOILS

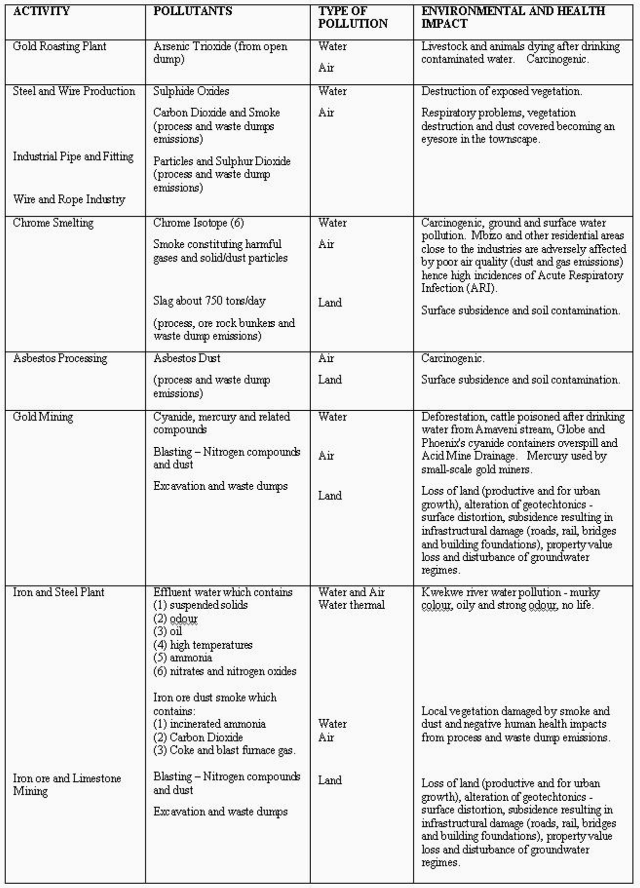
Kwekwe is situated on Zimbabwe's Great Dyke renowned for its mineral deposits. A large portion of Kwekwe area known as the gold belt is underlain by massive volcanic or igneous rocks and lavas with sedimentary rocks deposited on the primarily eroded lavas. Minerals found in the study area include gold, copper, limestone, manganese, barites and banded ironstone.

The local soils are generally granitic and sandy. These soils fall mainly under the fersiacallitic and sodic group. They are well drained, coarse grained, very shallow and of low inherent fertility, with clay fractions mainly kaolinite, together with appreciable amounts of free sesquioxide of iron and aluminium. Generally these well-drained, shallow, sandy and acidic soils are highly susceptible to pollution.

THE ENVIRONMENTAL SITUATION

The highly mineralised natural environment in the study area is continuously under pressure from mining, waste and emission from the manufacturing and mineral processing industry, building materials extraction and energy requirements. Emissions of the development activities especially mining and mineral processing are mobilized accumulating to levels harmful to plant, fish, animal and human health. Ore rock stock piles and waste dumps are eroded by wind and rain-water polluting water, air and soils in the process. Hence, the environmental impacts of these activities and the accompanying health impacts can not be overlooked.

An industrial pollution study carried out in 1992 by the Government of Zimbabwe, Department of Natural Resources (DNR) in the Midlands Province (and covering some of the companies in the study area), concluded that the impact of industrial pollution has long been and still is largely disregarded. It was observed that there is limited objective and monitoring data available on companies' environmental performance. In addition, no one is prepared to financially commit themselves to manage the environmental damage caused.



ACTIVITY	POLLUTANTS	TYPE OF POLLUTION	ENVIRONMENTAL AND HEALTH IMPACT
Gold Roasting Plant	Arsenic Trioxide (from open dump)	Water Air	Livestock and animals dying after drinking contaminated water. Carcinogenic.
Steel and Wire Production Industrial Pipe and Fitting Wire and Rope Industry	Sulphide Oxides Carbon Dioxide and Smoke (process and waste dumps emissions) Particles and Sulphur Dioxide (process and waste dump emissions)	Water Air	Destruction of exposed vegetation. Respiratory problems, vegetation destruction and dust covered becoming an eyesore in the townscape.
Chrome Smelting	Chrome Isotope (6) Smoke constituting harmful gases and solid/dust particles Slag about 750 tons/day (process, ore rock bunkers and waste dump emissions)	Water Air Land	Carcinogenic, ground and surface water pollution. Mbizo and other residential areas close to the industries are adversely affected by poor air quality (dust and gas emissions) hence high incidences of Acute Respiratory Infection (ARI). Surface subsidence and soil contamination.
Asbestos Processing	Asbestos Dust (process and waste dump emissions)	Air Land	Carcinogenic. Surface subsidence and soil contamination.
Gold Mining	Cyanide, mercury and related compounds Blasting – Nitrogen compounds and dust Excavation and waste dumps	Water Air Land	Deforestation, cattle poisoned after drinking water from Amaveni stream, Globe and Phoenix's cyanide containers overspill and Acid Mine Drainage. Mercury used by small-scale gold miners. Loss of land (productive and for urban growth), alteration of geotechtonics - surface distortion, subsidence resulting in infrastructural damage (roads, rail, bridges and building foundations), property value loss and disturbance of groundwater regimes.
Iron and Steel Plant Iron ore and Limestone Mining	Effluent water which contains (1) suspended solids (2) odour (3) oil (4) high temperatures (5) ammonia (6) nitrates and nitrogen oxides Iron ore dust smoke which contains: (1) incinerated ammonia (2) Carbon Dioxide (3) Coke and blast furnace gas. Blasting – Nitrogen compounds and dust Excavation and waste dumps	Water and Air Water thermal Water Air Land	Kwekwe river water pollution - murky colour, oily and strong odour, no life. Local vegetation damaged by smoke and dust and negative human health impacts from process and waste dump emissions. Loss of land (productive and for urban growth), alteration of geotechtonics - surface distortion, subsidence resulting in infrastructural damage (roads, rail, bridges and building foundations), property value loss and disturbance of groundwater regimes.

Table 1. Environmental Polluting Activities in the Kwekwe District

Figure 2. Steel Works not segregated, unlined oil and metal disposal, and slag dump in background.

GEOSCIENCES CAN HELP REMIDIATE THE SITUATION

The district of Kwekwe is under siege from various environmental degradation caused mainly by mining, mineral extraction and industrial processes exacerbated, by the desperate national economic conditions. Hence, there is need for a holistic approach to remediate the situation. If given the chance, geosciences can play a significant role in the remediation process.

Geosciences applications can be of immense benefit, either directly or indirectly, to various segments of the local environment, contributing to day-to-day living significantly, particularly to sustainable management of resources (that support life). Different aspects of geosciences can be built-in into the management plan of local resources in ways that bring local development into harmony with the finite resources of the earth.

Detailed geological, hydro-geological, geochemical, air quality, land use, population information etc. can be used to assess the extent of damage to the geo-environment by developmental activities especially mining and smelting processes. These investigations can result in information vital to the management of adverse environmental and health effects on the local environment and similar settings.

Various geotechnical techniques can be used to:

- Determine the extent of :
  – Surface subsidence, displacement and cave-in
- Evaluate landslip potential of both natural and man-made slopes at mining, ore rock storage, waste dumps and tailings dam sites as well as potential construction sites (to evaluate rock/soil strength and loading capacity)

Remote Sensing and Geographical Information Systems can contribute towards:

- Mapping
  – Time series mapping for landuse, land cover and land condition information
  – Environmental degradation extent data and hazard/sensitivity zoning
  – Rehabilitation planning and remediation action implementation and management
  – Development planning

Together with other environmental and socio-economical information geotechnical data can be used to develop sensitivity and hazard zoning maps vital for planning and managing current and future development. The vital insight into environmental conditions provided by Geosciences applications can go a long way towards helping remediate the current environmental condition in the Kwekwe further supporting informed management of the resources, life and properties that make up the district. In Zimbabwe, geosciences have up to now not been fully recognised as a vital component of a holistic approach towards a possible solution to the degenerating environmental situation of Kwekwe.

INDUSTRIAL PROFILE

Boeing Satellite Systems

Joe Geary
Boeing Satellite Systems Inc.
P.O. Box 92919
Los Angeles, CA 9009-2919

Introduction

Since 1961, Boeing Satellite Systems has developed and produced state-of-the-art space and communications systems for military, commercial and scientific uses. These systems supply communications and meteorological observations for domestic and international customers and meet many of the military and scientific space system requirements of the U.S. government. BSS started as Hughes Aircraft Company's Space and Communications Group; in October 2000 Hughes became Boeing Satellite Systems, Inc.

Capabilities

Communications Satellite Systems

The world's first synchronous communications satellite, Syncom, launched in 1963, was built by Boeing Satellite Systems. Nearly 40 percent of the satellites now in commercial service worldwide were built by Boeing Satellite Systems. Boeing's satellite lines include the spinning Boeing 376, the body-stabilized Boeing 601, and the larger, more powerful Boeing 702. These spacecraft routinely relay digital communications, telephone calls, videoconferences, television news reports, facsimiles, television programming, mobile communications, and direct-to-home entertainment – truly global communications.

Scientific Research and Meteorological Systems

Meteorological and research satellite systems perform a wide variety of tasks and provide an objective view of planet Earth. Boeing Satellite Systems built the first geosynchronous satellite capable of meteorological observations, Applications Technology Satellite (ATS-1), launched in 1966. Today, aboard a polar orbiter, a microwave instrument penetrates clouds to determine wind speeds, soil moisture, ice coverage and age, and, for the first time, the exact location on land where rain is falling. A similar company-built microwave imager is one of several instruments being carried in the joint U.S.-Japanese Tropical Rainfall Measuring Mission, which began in 1997. And in mid-2001, Boeing was awarded a contract for two Conical Microwave Imager Sounder (CMIS) weather instruments for the National Polar-orbiting Operational Environmental Satellite System (NPOESS). In 1998, the company won the competition to build the next-generation weather satellites for NASA/NOAA. The new Geostationary Operational Environmental Satellites, designated "GOES," will provide more accurate location of severe storms and other weather phenomena, resulting in more precise warnings to the general public and industry. Boeing will have built a total of nine satellites in the GOES series.

Scientific Exploration

When the astronauts set foot on the moon, Surveyor lunar landers built by Boeing Satellite Systems were there to greet them. In the mid-1960s, the spacecraft were sent to the moon to scout potential landing sites, leading the way for manned missions. The Galileo spacecraft, with its sophisticated Boeing Satellite Systems built probe, was launched in 1989 to explore the atmosphere of Jupiter. The probe arrived at the planet in December 1995, returning a wealth of scientific data. Meanwhile, incredibly detailed images of Venus' surface have been obtained by a Boeing Satellite Systems built radar on board the Magellan spacecraft, which began orbiting Earth's twin planet in August 1990.

Boeing supports the astronauts and NASA research in space. The company is building NASA's next-generation Tracking and Data Relay Satellites (TDRS), which will relay communications to and from the Space Shuttle and the International Space Station.

National Security

The U.S. Department of Defense is an important customer. In January 2001, a satellite communications industry team led by Boeing was awarded a contract to develop Wideband Gapfiller Satellite (WGS), a high-capacity satellite communications system to support the war fighter with newer and far greater capabilities than provided by current systems. In January 2002, Boeing received an additional contract to begin the manufacture of the first two satellites and to procure long lead items for a third satellite.

Boeing, working under a Navy contract, built and launched 11 UHF Follow-On satellites. These replace existing spacecraft and provide the Defense Department with worldwide communications capabilities. Previously, Boeing Satellite Systems built the Leasat satellites that formed a global military communications network.

Boeing continues as subcontractor providing elements for the satellites' electronic payloads for the Air Force Milstar program. Under a contract awarded by the Air Force Space and Missile Systems Center at Los Angeles Air Force Base, Calif., the best-of-industry team led by Boeing will conduct risk reduction and system definition for the Transformational Communications MILSATCOM Space Segment. The contract, which extends through 2006, supports the government's network-centric operations vision.

Heritage

Overview

Beyond monitoring ordinary weather, satellites have saved countless lives by warning of the approach of severe storms. Such assistance in predicting and mitigating the impact of weather first became possible with the launch of ATS-1 in 1966. ATS-1 had an immediate effect on meteorology. Forecasters could see weather patterns developing thousands of miles off the coast of the United States. Japan joined in geosynchronous weather sensing with the launch of the first Hughes-built Geostationary Meteorological Satellite (GMS) in 1977. In 1978, NASA selected Hughes, now Boeing, to build the second generation of Geostationary Operational Environmental Satellites (GOES). In Jan. 1998, NASA returned with an order for two new GOES satellites, with options for two more. Another product, developed by Hughes, the Special Sensor Microwave/Imager (SSM/I), and helps forecasters quickly identify developing storms. NASA and Goddard Space Flight Center acknowledged Hughes' capability in sensors by choosing them to build the microwave imager for the Tropical Rainfall Measuring Mission.

First Geosynchronous Meteorological Satellites – ATS 1-5

The Applications Technology Satellite (ATS) program was established by the National Aeronautics and Space Administration (NASA) to flight test experimental payloads and investigate the space environment with the aim of developing technology of practical future benefit. Five flight spacecraft of three configurations were built by Hughes from 1966 to 1969. The satellites were designed as basic buses capable of carrying a variety of scientific payloads. A score of experiments were flown to conduct investigations in the fields of space and communications, satellite stabilization, meteorology, and the orbital environment.

Japan's Geostationary Meteorological Satellites - GMS 2, 3, 4, 5

The Geostationary Meteorological Satellites (GMS) for Japan have provided uninterrupted monitoring of weather conditions since 1977. The principal instrument on board all satellites in the GMS series is the visible and infrared spin scan radiometer (VISSR), produced by Hughes' Santa Barbara Research Center. The VISSR obtains a complete 20° by 20°

scan, produces an image of the full Earth disk every 25 minutes, and transmits that image back to Earth as weather facsimile pictures, showing different portions of the hemisphere. This enables meteorologists to identify, monitor, and track cataclysmic weather events such as windstorms, heavy rainfall, and typhoons, and to predict weather dangers long before storms reach densely populated areas.

In addition to providing Earth images, the satellites serve as geostationary repeaters. Weather data is collected from transmitters on the ground, on the high seas, and in aircraft, and is distributed to meteorological centers. GMS also allows remote monitoring of islands, oceans, mountainsides, and other such areas not equipped with weather observation stations.

Geostationary Operational Environmental Satellite-GOES D, E, F, G, H

Provision of timely global weather information, including advance warning of developing storms, is the primary function of the U.S. GOES meteorological program. To provide more complete data, a trio of Geostationary Operational Environmental Satellites known as GOES D, E, and F was launched and operated by the National Oceanic and Atmospheric Administration (NOAA) as part of the Global Weather Watch. Two new satellites of a similar design, GOES G and H, were also built.

GOES was equipped with an improved VISSR incorporating a visible and infrared atmospheric sounder (VAS). The VAS adds a vital third dimension to the imagery. Aboard the GOES, the VAS measured vertical temperature versus altitude cross sections of the atmosphere. From these cross sections the altitudes and temperatures of clouds were determined and a three-dimensional picture of their distribution was drawn for more accurate weather prediction.

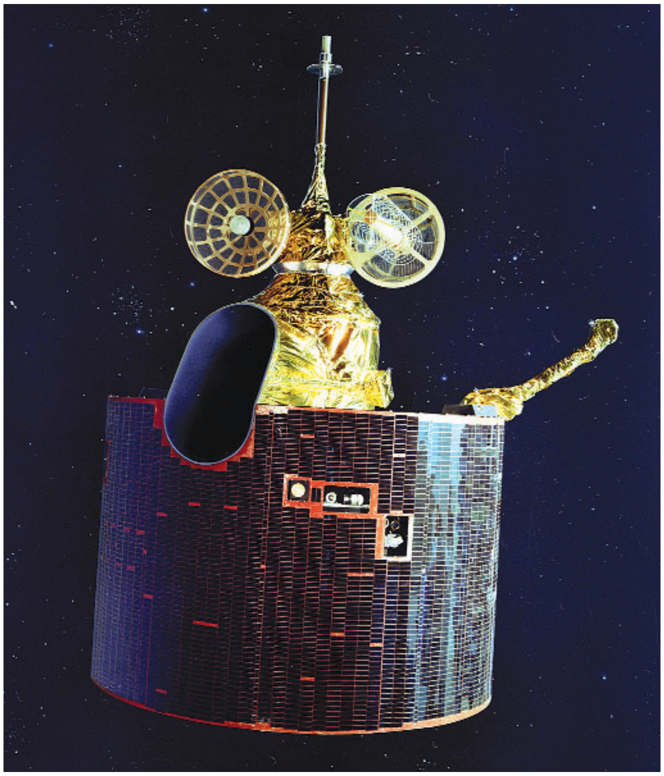


Figure 1. GOES D Series

A data collection system on GOES received and relayed environmental data sensed by widely dispersed surface platforms such as river and rain gauges, seismometers, tide gauges, buoys, ships and automatic weather stations. Platforms transmit sensor data to the satellite at regular intervals, upon interrogation by the satellite, or in an emergency alarm mode whenever a sensor receives information exceeding a preset level.

Next-Generation GOES Weather Satellites – GOES N, O, P, Q

In January 1998 BSS was awarded a contract from NASA's Goddard Space Flight Center in Greenbelt, Md. The contract includes the design, manufacture, integration and launch of two Geostationary Operational Environmental Satellites, GOES N and GOES O, with options for GOES P and GOES Q. Upon completion of N through Q, the company will have built a total of nine spacecraft in the GOES series.

Based on the Boeing 601 spacecraft, the new satellites will provide more accurate location of severe storms and other weath-

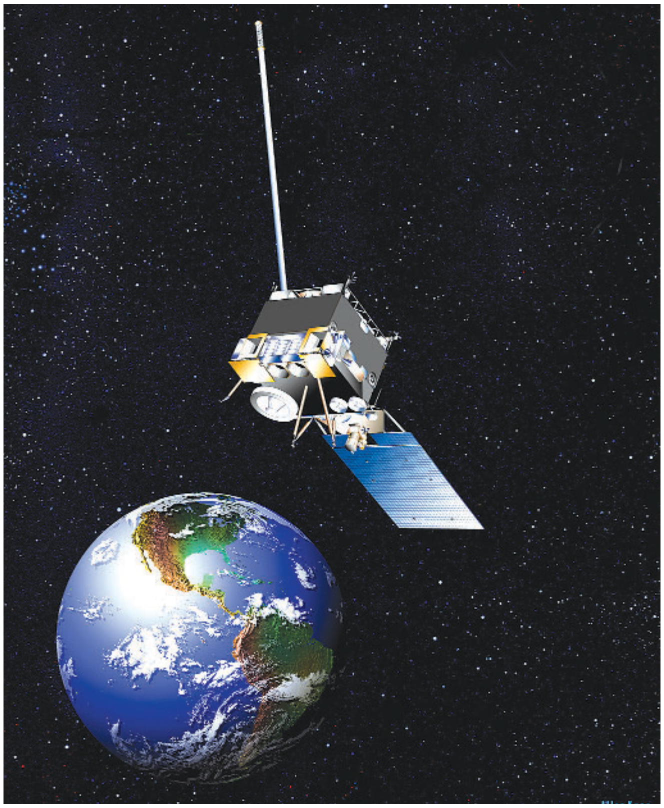


Figure 2. GOES N Series

er phenomena, resulting in more precise warnings to the public. The three-axis Boeing 601 body-stabilized spacecraft design enables the primary sensors to “stare” at Earth and thus frequently image clouds, monitor Earth’s surface temperature, and sound Earth’s atmosphere for its vertical temperature and water vapor distribution. Atmospheric phenomena can be tracked, ensuring real-time coverage of short-lived dynamic events, such as severe local storms and tropical hurricanes and cyclones, two types of meteorological events that directly affect public safety, property, and ultimately, economic health and development.

The imager, built by ITT, is a multispectral five-channel instrument that produces visible and infrared images of Earth’s surface, oceans, cloud cover and severe storm developments. The multispectral sounder provides vertical temperature and moisture profiles of the atmosphere, augmenting data from the imager. Sounder data are also used in computer models which produce mid- and long-range weather forecasts.

SSM/I (Special Sensor Microwave Imager) 1-7

In 1979, the first Special Sensor Microwave Imager (SSM/I) contract was awarded to BSS by the U.S. Air Force. The company’s challenge was to design, develop, and build a space instrument that would complement the capabilities of traditional weather sensing devices. Launched on a Defense Meteorological Satellite Program (DMSP) Block 5D-2 satellite on June 19, 1987, the SSM/I is able to “see” weather images that are out of view for visible and infrared sensors on meteorological spacecraft. By detecting microwave energy emitted from Earth, SSM/I peers “into and through” the clouds. SSM/I data can be used to measure the speed of the wind at the ocean’s surface; the presence, extent, and age (thickness) of ice covering the sea; the approximate amount of water in clouds; areas and intensity of precipitation; and ground moisture.

SSM/I provides data used by the military for tropical storm reconnaissance, ship routing in polar regions, agricultural weather reports, aircraft routing and refueling, and communications management. Seven SSM/I’s were launched, with the last launch in December 1999. Four remain in service providing weather data.

TMI (TRMM [Tropical Rainfall Measuring Mission] Microwave Imager)

Building on the knowledge gained from development of the SSM/I, the National Space Development Agency of Japan (NASDA) and NASA launched the BSS-built Tropical Rainfall Measuring Mission Microwave Imager, or TMI. With capabilities similar to those of SSM/I, the TMI instrument measures tropical rainfall characteristics from space by detecting microwave energy in the form of brightness temperatures from Earth’s surface and atmosphere.

TMI was designed to work in conjunction with a precipitation radar built by NASDA, as well as visible and infrared sensors, and a lightning imaging sensor. The data supplied by the system provides insight into tropical storm formations and their likely paths.

The data provided by TMI gives space and weather agencies valuable insight into meteorological phenomena and their influence over unusual ocean patterns. Additionally, TMI is capable of supplying information useful for tropical storm tracking, cloud and soil moisture levels, land and sea surface temperatures, wave height, and sea surface wind speeds.

CMIS (Conical Scanning Microwave Imager Sounder) 1-2

With the experience derived from the SSM/I and TMI projects, BSS was first awarded a development contract in 1997 and then a production contract in 2001 for two microwave imager/sounders that will be used in a U.S. defense-civilian meteorological satellite program. The new instrument is called the Conical Scanning Microwave Imager/Sounder, or CMIS. The first CMIS instrument is scheduled for delivery by 2008 with the second to be delivered by 2010. CMIS is being built by BSS to participate in the National Polar-orbiting Operational Environmental Satellite System (NPOESS).

CMIS will be the first conical microwave imager/sounder to be carried on a U.S. civil weather satellite, and will be a “next-generation” instrument, incorporating better calibration and new

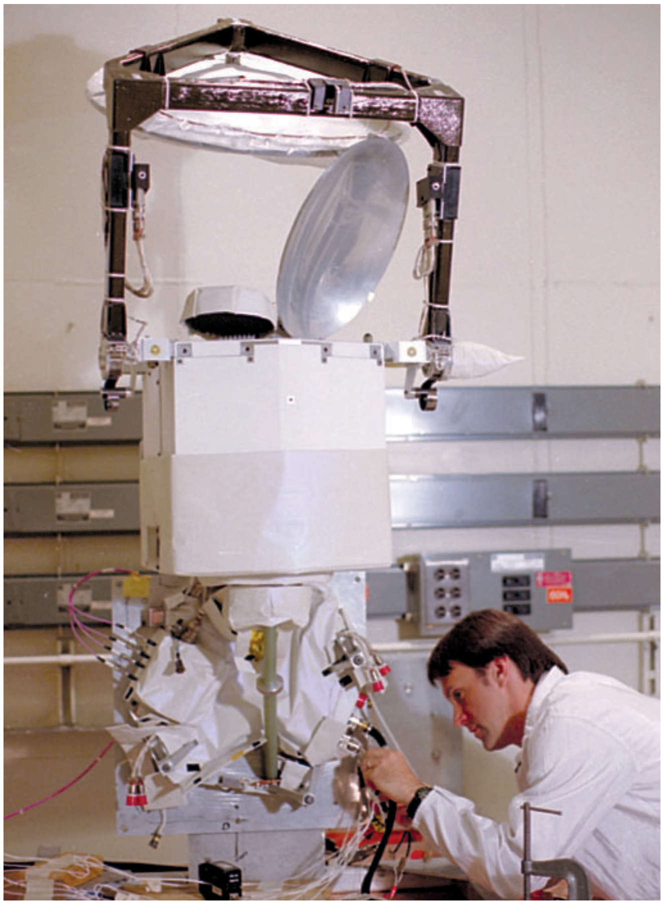


Figure 3. TMI

technologies. CMIS will contain a microwave imager capable of measuring rain rate, wind speed and direction over the ocean, the amount of water in clouds, and soil moisture. It will also feature the addition of a sounder, capable of taking a “vertical picture” through the atmosphere, therefore reading temperature and humidity profiles at various atmospheric levels

Future Directions

Systems That Make a Difference

Boeing Satellite Systems (BSS) is committed to ongoing technological discovery in the field of space/science exploration. Sophisticated instruments play a key role in todays scientific and environmental space missions. The company has played important roles in meeting science objectives by 1) providing reliable space systems, 2) integrating instruments, sensors, and subsystems provided by government agencies and industry (partners) onto a series of selected BSS spacecraft, and 3) integrating BSS-built instruments and subsystems onto customers’ spacecraft.

Boeing Satellite Systems continues to pioneer technologies and to discover new applications for a wide variety of systems that make a difference in our world today and create possibilities for tomorrow. We are committed to expanding knowledge of and appreciation for commercial, civil, and military space activities.

EDUCATIONAL TUTORIAL

Surface-based Microwave and Millimeter wave Radiometric Remote Sensing of the Troposphere: a Tutorial

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Abstract

Surface-based radiometric sensing of tropospheric parameters has a long history of providing useful measurements of temperature, water vapor, and cloud liquid. In this tutorial, a general overview of physical fundamentals, measurement techniques, and retrieval methodology is given. Then several contemporary instruments are discussed and representative results are presented. Recent and promising developments include multi-frequency radiometers, scanning observations of clouds, and combined active-passive remote sensing. The primary applications of these new technologies are weather forecasting and climate, communications, geodesy and long-baseline interferometry, satellite data validation, air-sea interaction, and fundamental molecular physics.

Introduction

A more extensive review is given in [11] and some of the material in this tutorial has been extracted from this document.

2. General Physical Principles

The basic ideas of radiative transfer and thermal emission are given in [12] and their application to microwave radiometric remote sensing is outlined in [13] . From the concept of an ideal black body and Kirchoff's law, it is known that the emission from a black body depends only on its temperature and that the higher the temperature of the body, the more is its emission. The idea is made quantitative by calculating the spectral distribution of a blackbody emission from Planck's law, which expresses the radiance $B_V(T)$ emitted from a blackbody at temperature T and frequency v as

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{(\exp(h\nu/kT) - 1)}\,, \tag{1}$$

where h = Planck's constant, and k = Boltzman's constant. The radiance expresses the emitted power per unit projected area per unit solid angle per unit frequency interval. The second consideration is to relate the emission from a real body, sometimes called a "grey" body, to that of a blackbody at the same temperature. If the fraction of incident energy from a certain direction absorbed by the grey body is A(v), then the amount emitted is A(v) $B_V(T)$. For a perfectly reflecting or transmitting body, A(v) is zero, and incident energy may be redirected or pass through the body without being absorbed. In the situation considered in this tutorial, namely upward-looking radiometers viewing a non-scattering medium, the equation that relates our primary observable, brightness temperature, T_b, to the atmospheric state is the radiative transfer equation (RTE) [13]

$$\begin{aligned} B_\nu(T_b) &= B_\nu(T_c)\exp(-\tau_\nu) + \\ &+ \int_0^\infty B_\nu(T(s))\alpha_\nu(s)\exp\left(-\int_0^s \alpha_\nu(s')\,ds'\right)ds, \end{aligned} \tag{2a}$$

where s = path length in km, $T(s)$ = Temperature (K) at the point s, T_c = Cosmic background brightness temperature of 2.75 K, T_v = opacity = total optical depth along the path s

$$\tau_\nu = \int_0^\infty \alpha_\nu(s)ds, \tag{2b}$$

where $a_v(s)$ = absorption coefficient (nepers/km) at the point s. The use of the blackbody source function in (2a) is justified by the assumption of local thermodynamic equilibrium in which the population of emitting energy states is determined by molecular collisions and is independent of the incident radiation field [12]

Equation (2) and its Rayleigh-Jeans approximation are discussed in [13], and its more general form including scattering is discussed in [14]. Scattering, although neglected here, may arise from liquid, ice, or melting liquid depending on the size distribution of the particles. For our purposes, we note the dependence on the temperature profile $T(s)$ and the implicit dependence on pressure, water vapor, and cloud liquid through $\alpha(s)$. For a plane parallel atmosphere, the path length s and the height h are related by $s\ sin(\theta) = h$, where θ is the elevation angle. Information on meteorological variables is obtained from measurements of T_b as a function of ν and/or θ. Equation (2) is used: (a) in forward model studies in which the relevant meteorological variables are measured by radiosonde in situ soundings, (b) in inverse problems and parameter retrieval applications, in which meteorological information is inferred from measurements of T_b , and (c) in system modeling studies for determining the effects of instrument noise on retrievals and optimum measurement ordinates, such as ν and θ. Calculations of T_b for a warm (surface temperature T_s =293 K) atmosphere are shown in Figure 1. We note the transmission windows near 30-50, 70-100, and 130-150 GHz. Radiometer measurements

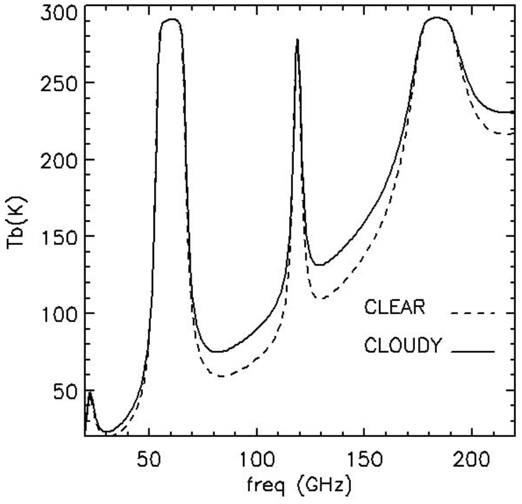

Figure 1. Calculated brightness temperatures (K) from 20 to 220 GHz for clear and cloudy conditions. The clear calculations are based on a standard atmosphere with the surface values (S) of P_S=1013 mb, T_S =293 K, ρ_S = 10 gm^{-3} , and IWV = 2.34 cm. The cloudy atmosphere contains 1 mm of integrated cloud liquid with a cloud layer of liquid density of 0.1 gm^{-3}between 1 and 2 km. The absorption models used are given in Figure 2.

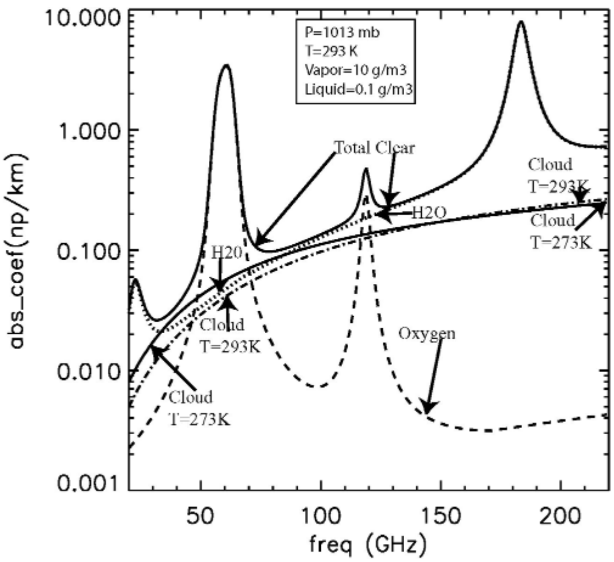

Figure 2. Microwave absorption spectra from 20 to 220 GHz. The absorption models used were Liebe 89 [4] for clear absorption, and Liebe et al. 1991 [6] for cloud liquid. In this figure, P = pressure, T = temperature, ρ_V = absolute humidity, and ρ_L = cloud liquid density.

near these windows are used primarily for remote sensing of clouds and water vapor. The strong absorption features near 60 and 118 GHz are used for temperature sensing. Finally, the strong absorption region near 183 GHz can be used to study very low amounts of water vapor such as are found during Arctic winter conditions.

3. Microwave Absorption and Emission

The principal sources of atmospheric emission and absorption are water vapor, oxygen, and cloud liquid. In the frequency region from 20 to 200 GHz, water-vapor absorption arises from the weak electric dipole rotational transition at 22.235 GHz and the much stronger transition at 183.31 GHz. In addition, the so-called continuum absorption of water vapor arises from the far wing contributions from higher-frequency resonances that extend into the infrared region. Again, in the frequency band from 20 to 200 GHz, oxygen absorbs due to a series of magnetic dipole transitions centered around 60 GHz and the isolated line at 118.75 GHz. Because of pressure broadening, i. e., the effect of molecular collisions on radiative transitions, both water vapor and oxygen absorption extend outside of the immediate frequency region of their resonant lines. There are also resonances by ozone that are important for stratospheric sounding [15]. In addition to gaseous absorption, scattering, absorption, and emission also originate from hydrometeors in the atmosphere. Our focus in this article is on non-precipitating clouds for which emission and absorption are of primary importance.

3.1 Gaseous Absorption Models

Detailed calculations of absorption by water vapor and oxygen were first published by J. H. Van Vleck [16, 17]. The quantum mechanical basis of these calculations, including the Van Vleck-Weisskopf line shape [18], together with laboratory measurements, has led to increasingly accurate calculations of gaseous absorption. Both these historical- and recent- developments are discussed in [19]. Currently, there are several absorption models that are widely used in the propagation and remote-sensing communities. Starting with laboratory measurements that were made in the late 1960s and continuing for several years, H. Liebe developed and distributed the computer code of his Microwave Propagation Model (MPM). One version of the model [20] is still used extensively, and many subsequent models are compared with this one. Liebe later made changes to both water-vapor and oxygen models, especially to parameters describing the 22.235 GHz H2O line and the so-called water vapor continuum [21]. More recently, Rosenkranz [5a, 5b] developed an improved absorption model that also is extensively used in the microwave propagation community. However, there are many issues in the determination of parameters that enter into water-vapor-absorption modeling, and a clear discussion of several of these issues is given in [19]. Relevant to the discussion is the choice of parameters to calculate the pressure-broadened line width, which, in the case of water vapor, arises from the collisions of H2O with other H2O molecules (self broadening), or from collisions of H2O molecules with those of dry air (foreign broadening). In fact, Rosenkranz [5a, 5b] based his model on using Liebe and Layton's [20] values for the foreign-broadened component, and those from Liebe et al. [21] for the self-broadened component. Another model that is used extensively in the US climate research community is the Line by Line Radiative Transfer Model (LBLRTM) by S. Clough and his colleagues [7]. An extension of the model, called MONORTM, is most appropriate for millimeter wave and microwave RTE studies [80]. One feature of the Clough models is that they have been compared extensively with simultaneous radiation and radiosonde observations near 20 and 30 GHz. Recently, two important refinements of absorption models have occurred. This first is the Rosenkranz [22] refinement of his 1998 codes. The second is by Liljegren et al. [23], which incorporates the line width parameters of the 22.235 GHz model from the HITRAN data base [81] with a new continuum formalization. Both of these new models show initial promise in calculating emission from radiosondes [24].

Cloud Absorption Models

For spherical particles, the classical method to calculate scattering and absorption coefficients is through the Lorenz-Mie Equations [25, 26, and 27]; for sufficiently small particles, the Rayleigh approximation can be used. For a given wavelength and single particle, the particle contribution is calculated; the total coefficients are then obtained by integration over the size distribution of particles. An important physical property for the calculations is the complex dielectric constant of the particle. This dielectric constant of liquid water is described by the dielectric relaxation spectra of Debye [28]. The strong temperature dependence of the relaxation frequency is linked to the temperature-dependent viscosity of liquid water; therefore the cloud-absorption coefficient also shows significant temperature sensitivity. Above 0 °C, the dielectric constant can be well measured in the laboratory, and a variety of measurements have been made from 5 to 500 GHz [6]. However for super-cooled water, below 0 °C, the situation is less certain, and, for example, models of [6, 29, 30] differ by 20 to 30% in this region [31]. This is relevant for cloud remote sensing, because measurements of super-cooled liquid are important for detection of aircraft icing [32]. When calculating absorption for nonprecipitating clouds, we assume Rayleigh absorption, for which the liquid absorption depends only on the total liquid amount and does not depend on the drop size distribution, and scattering is negligible. The Rayleigh approximation is valid when the scattering parameter $\beta=|n(2\pi r/\lambda)| << 1$ [26]. Here, r is the particle radius, λ is the free space wavelength, and n is the complex refractive index. For rain and other situations for which the β is greater than roughly 0.1, the full Mie equations, combined with a modeled (or measured) size distribution, must be used.

Due to the nonspherical shape of ice hydrometeors, the situation is more complicated when scattering plays a role. Although this situation is beyond the scope of this article, at millimeter wavelengths, the particle size of cirrus clouds can be of the order of 100 to 200 microns, and scattering may be important near transmission windows. On the other hand, the dielectric properties of ice [33, 34] are very different from those of liquid water. The dielectric losses of ice have a minimum near 1 GHz, and ice is an almost perfectly loss-free medium over a large frequency range. Therefore microwave emission of pure ice particles can be neglected in most cloud situations. Special situations occur when ice particles start to melt. A very thin skin of liquid water can be sufficient to cause significant absorption and thus emission. Usually, these conditions apply to precipitating clouds or in the so-called radar “bright band.”

3.3 Calculations of Absorption Spectra

For standard conditions at sea level, we calculated the water vapor (H_2O), oxygen (O_2), and total clear ($H_2O + O_2$) contributions to the absorption coefficient. In addition, we calculated the liquid absorption coefficient for $\rho_L = 0.1$ gm^{-3} at T= 293 and 273 K. From the results shown in Figure 2, we note the strong oxygen absorption regions near 60 and 118 GHz due to oxygen and the large absorption near 183 GHz. For a given location and altitude, the oxygen absorption is relatively constant, with variations of 10 to 20%, while both the 22.235 and the 183.31 GHz absorptions can vary by a factor of 10 to 20. Note also the strong temperature dependence of cloud absorption, and the reversal of this dependence at around 150 GHz.

4. Observation techniques

Measuring downwelling thermal emission by microwave and millimeter wavelength radiometers from a surface-based platform is now routinely performed on an operational basis [2, 3]. In addition, surface-based radiometers are frequently deployed in campaigns specifically designed to study water vapor [35, 36], clouds [37], and temperature [38, 39, 40]. In some deployments, specifically designed to measure water vapor and clouds in combination with other zenith-looking sensors, zenith observations are of primary interest. In others, particularly those used to measure boundary-layer temperature profiles, elevation scanning radiometers are frequently used. More recently, radiometers scanning in both azimuth and elevation are also used to observe clouds [41].

The fundamentals of microwave radiometers are clearly discussed in [13, 42, 43]. Radiometers used to observe the atmosphere are comprised of a highly directional antenna, a sensitive receiver, followed by a detector unit and a data-acquisition system, a total system that requires calibration.

Figure 3. ASMUWARA in operation the IAP in Bern, Switzerland. The openings of the 4 horns appear as grey disks at the left of the rotatable mirror, while the IR radiometer looks through the white cylinder below the largest horn.

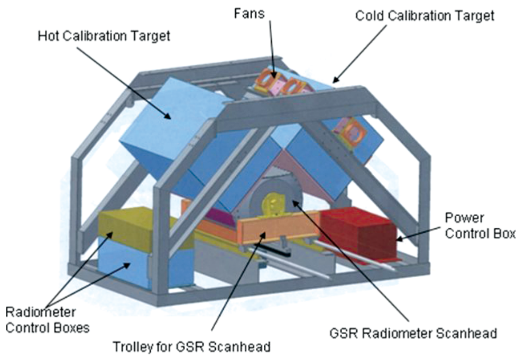

Figure 4. Schematic diagram of the GSR calibration and scanning system. The GSR scanhead periodically moves out of the framework for atmospheric viewing on a trolley system, and shares time observing the atmosphere and the two thermally controlled blackbody reference targets.

In this section, we briefly discuss general techniques common to ground-based systems, and then give examples of contemporary radiometers.

4.1 Antennas

An antenna measures the antenna temperature, T_A, which is the integration over 4π steradians of the product of the angular distribution of brightness temperature and the power pattern of the antenna. Usually, the antennas have symmetric beam patterns with typical widths from 1 to 6°. Because most remote-sensing systems perform scanning in a vertical plane, low side lobes are required to minimize contamination from ground emission. In addition, because surface-based antennas are deployed in rain and snow, protection from and reduction or elimination of environmental effects is of primary concern.

Perhaps the simplest antenna used to observe the atmosphere is a horn, either scalar or corrugated, that has a suitable beam pattern. If a multi-frequency and equal-beamwidth system is desired, the dimensions of the horns can be scaled appropriately. For some systems, the entire electronics package is rotated with the antenna. A more common system is to direct the antenna beam from the primary antenna onto a flat reflecting mirror that is scanned. In this configuration, only the flat reflector is moved. An example of this type of system is shown in Figure 3 [44]. Another common method is to use a lens antenna, which may view a flat reflector. More sophisticated scanning designs are also possible, such as the use of subreflectors, reflectors, and mirrors. Frequently, to protect the system from the environment, the electronics package and the antenna are enclosed within a radome.

It is important to consider the loss from dielectric lens antennas. Lenses for remote sensing are usually constructed from low-loss material (loss tangent less than ~ 10^{-3}). A lossy antenna attenuates an incoming signal and adds noise due to its own physical temperature. If the loss factor and the lens temperature are known, the unwanted signal can be corrected from the measured brightness temperature. The effect can be calibrated out by external targets or tipping curves (see Section 4.3.2), and a limitation is imposed by the time spent between valid calibration observations.

4.2 Receivers

A variety of receiver designs are also common in surface-based radiometry and several involve Dicke modulation-type radiometers in which the input to the receiver is alternatively switched between the scene (sky) and an internal calibration load [43]. In the original ETL design [1], the receiver was based on the Hach [45] design in which the signal was sequentially switched between the scene and two internal blackbody targets (hot = 145 °C and reference = 45 °C). These targets were simply waveguide terminations kept at strictly controlled and measured temperatures. In the Radiometrics Corporation design (http://www.radiometrics.com), a signal generated by a noise diode is alternatively turned off and on and added to the signal from the scene at each angle, including the target [2]. The Russian-designed scanning radiometers for boundary-layer temperature measurement [38, 39, 40] are total-power radiometers but have been modified to include the signal from a noise generator. Both the NOAA/ETL Dual Channel radiometer (see Section 5.1) and the NOAA/ETL Ground-based Scanning Radiometer (see Section 5.9) receivers use either conventional Dicke or Hach switches that alternate between an internal reference load(s) and the scene. Finally, all of the above receivers are of double-side-band design in which the signal from a stable local oscillator is mixed with the incoming radio-frequency signal emanating from the scene; the intermediate-frequency (IF) signal is then amplified and detected. With IF bandwidths usually around 500 MHz to 1 GHz, 1-sec radiometric sensitivities of 0.1 K are common. Also noteworthy is a specially constructed high-stability radiometer [46]. Based on tipcal analysis (see Section 4.3.3), this unit gave rms errors of less than 0.05 K over time periods of a month. and stabilities of better than 0.01 K over time scales of 1000 to 10000 s. Another possibility is to use direct detection at the radio frequency of interest, thus eliminating the mixer and local oscillator. As improvements are made in radio frequency amplifiers, increasing use of direct detection is expected. The use of Dicke or Hach switching overcomes the effect of receiver-gain variations, but can reduce the sensitivity of the receiver. As improvements are made in temperature and other environmental controls, total-power radiometers may become more common. Both MICCY (see Section 5.6) and RPG-HATPRO (see Section 5.7) illustrate some of these more recent developments.

4.3 Calibration

To derive quantitative information from radiometric measurements, accurate calibration with accuracies of 0.5 to 1.0 K is required. Most radiometric receivers have one or two internal noise sources that provide some measure of calibration. However, waveguide losses, lack of complete knowledge of radiometric parameters, and a host of other causes usually dictate that some external calibration method also be employed. We assume that the radiometer uses a square law detector, in which the output voltage is proportional to the input power; i. e., voltage is proportional to the antenna temperature. We will briefly describe three commonly used calibration techniques.

4.3.1 External Blackbody Reference Targets

A seemingly straightforward calibration method is to view two external blackbody targets that are kept at two widely separated temperatures [43]. If T_2 and T_1 are the two target temperatures with respective output voltages of v_2 and v_1, then

$$(T_A)_s = T_1 + \frac{T_2 - T_1}{v_2 - v_1}(v_S - v_1) \tag{3}$$

where $(T_A)_S$ is the antenna temperature of the scene and v_s is its corresponding voltage. Preferably, the target temperatures bracket the range of antenna temperatures emitted from the scene. Also, it is important to construct targets with high emissivity such that reflections from external sources are negligible, and to have the targets sufficiently large that at least 1 1/2 to 2 projected antenna diameters are captured by the target system. Targets are frequently constructed with a surface having high thermal conductivity covered with a thin layer of very absorbing material. Many times, a corrugated pyramidal surface with wavelength-dependent spacing and depth ratios, is constructed to reduce reflections and hence to increase emissivity. The target is frequently embedded in a thermal insulator that is transparent to incoming radiation. Finally, when a target is placed in a thermal environment in which the environmental temperature differs greatly from desired target temperature, measurements of target temperatures at several locations within the target are essential. The target calibration methods are most useful when the atmospheric brightness temperatures are within the range of easily achieved target temperatures; e.g., near the center of the 60 GHz O_2 absorption or near the 183.31 GHz water vapor line.

4.3.2 The Tipping Curve Calibration Method

In the transmission windows from 20 to 45 GHz or from 70 to 150 GHz, clear-sky T_b's can be in the 10 to 50 K range and, hence, operational deployment of targets whose temperatures are in this range is difficult. In this low transmission case, the so-called tipping-curve calibration method (tipcal) can give a high degree of accuracy [2, 47] and has been commonly used throughout the microwave community. In this method, brightness temperatures are measured as a function of elevation angle θ, and are then converted to opacity $\tau(\theta)$ using the mean radiating temperature approximation [48].

For each angle θ, an angular-dependent mean radiating temperature $T_{mr}(\theta)$ is used to derive the optical depth $\tau(\theta)$ by

$$\tau(\theta) = \ln\left(\frac{B_\nu(T_{mr}(\theta)) - B_\nu(T_c)}{B_\nu(T_{mr}(\theta)) - B_\nu(T_b(\theta))}\right). \tag{4}$$

If the system is in calibration, then the plot of $\tau(\theta)$ as a function of (normalized) air mass m (= csc (θ)), will pass through the origin; conversely, if $\tau(m) = \tau(1)m + b$ does not pass through the origin, then a single parameter in the radiometer equation is adjusted until it does. Note that when the calibration is achieved, then the slope of the line is equal to the zenith opacity. Several of the factors affecting the accuracy of tipcals were analyzed in [47]. The most serious of these errors are those caused by non-stratified

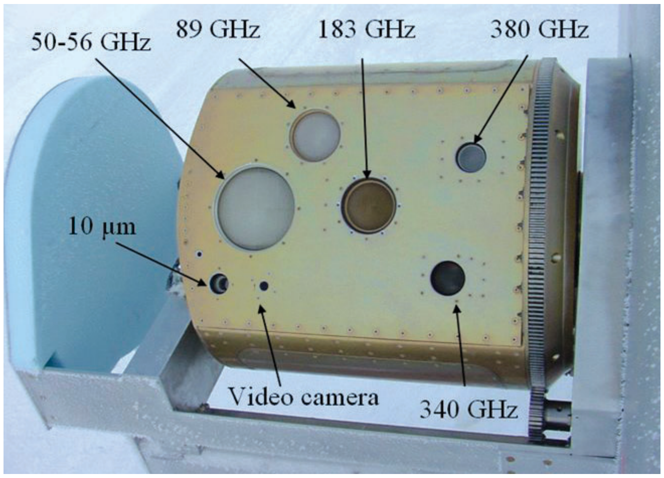

Figure 5. Photograph of the scanhead of the GSR.

atmospheric conditions and can occur due to clouds and horizontal variations in the water vapor field. Various criteria, based on symmetric scans, are available to determine the quality of a tipcal [2, 47]. In summary, the tipcal method, when applicable, can give absolute accuracies of 0.3 to 0.5 K rms over 20 to 200 GHz frequency range.

4.3.3 Brightness Temperature Calculations to Calibrate

For a highly stable radiometer such at the NOAA/ETL prototype [1] that was operated at a radiosonde launch facility, radiosonde data that are taken during clear-sky conditions can be used with a forward radiative transfer model (1) to calculate T_bs. If the T_bs are taken over a variety of elevation angles, or over a range of meteorological conditions, the measured data can be used as calibration points. This method assumes implicitly the correctness of the forward model and also of the radiosondes. The technique is most applicable near highly absorbing spectral regions, such as in the 60 GHz oxygen region, for which the calculated T_bs are insensitive to choice of forward model. When applied to all channels of a multi-frequency radiometer that derives meteorological information, it also ensures internal consistency between radiometric data and the forward model used in retrievals.

4.3.4 Cryogenic Loads to Calibrate

The use of blackbody targets immersed in cyrogenic fluids, such as liquid nitrogen (LN2), is another commonly used method of establishing a single calibration point [42, 82, 83]. In this method, a blackbody target is immersed in the cryogen and the antenna looks directly at the target. Allowance for the reflection of the ambient scene must be made, and the reflection coefficient of the cryogen must also be known. For example, the apparent brightness temperature of LN2 at 290 K at a wavelength of 2.2 mm is 79.05 [82]. In [83], a series of LN2 calibrations were done, and the Tb differences between the Radiometrics Corporation Microwave Radiometer (see Section 5.2) and the predicted value of Tb emitted from LN2 was within 0.7 K. Frequently a transparent enclosure, such as polystyrene, surrounds the LN2-imersed blackbody, and care must be taken to avoid condensation on the polystyrene.

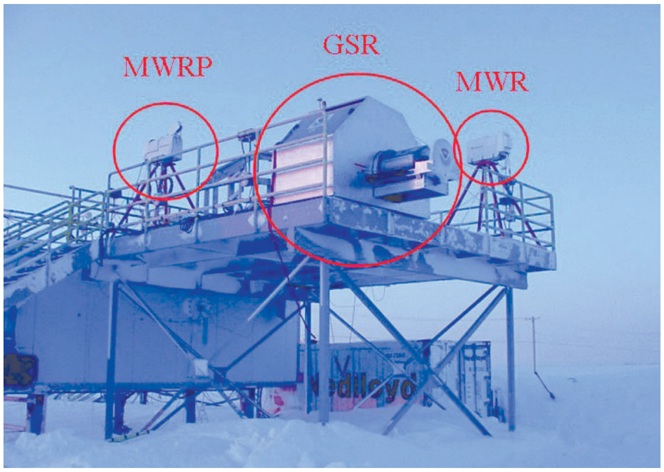

Figure 6. Photograph of the deployment of the GSR, MWRP, and MWR at the NSA/AAO Arctic Winter Radiometric Experiment that was conducted in Barrow, Alaska, USA, during March-April 2004.

5. Examples of Radiometric Systems

In this section, we discuss several types of contemporary ground-based radiometers. Since some of these are commercially available, we, of course, do not endorse any particular instrument.

5.1 NOAA/ETL Dual Channel Radiometer

NOAA/ETL designed, constructed, and currently operates several dual-frequency radiometers at (20.6 or 23.87 GHz, 31.65 GHz) that are used for measuring integrated water vapor (IWV) and liquid water path (LWP) [1]. For each of the radiometers, the electronics, and the antenna and feed, are all housed in a benign environment, such as a seatainer. In this environment, the radiometer is free from precipitation and the internal temperature of the seatainer is controlled to about 5 degrees. The antenna is an offset paraboloid with a hybrid-mode feed, which results in high-quality radiation patterns that minimize the effect of extraneous sources of noise; the antenna aperture is devoid of blockage and the beam is steerable in a vertical plane. The antenna has the same beamwidths at both frequencies (the full width at half power –FWHP- is either 2.5 or 4.0 º), thus minimizing differential beam-filling during nonhomogeneous cloud conditions. Some ETL systems have rapidly rotating reflectors to reduce the effects of rain [49]. The radiometer is triple switched in the Hach [45] mode; this results in continuous internal calibration and high stability. External calibration is accomplished on approximately a weekly basis using the tipcal method.

5.2 Radiometrics Corporation Microwave Radiometer (MWR)

Radiometrics Corporation has designed, constructed, and sold several dual-frequency (23.8 and 31.4 GHz) MWRs for measuring IWV and LWP [2]. Each radiometer is easily portable and all electronics, antenna, and calibration targets are enclosed in a radome. The antenna is a corrugated horn with a dielectric lens that views a stepping mirror for scanning the atmosphere and a blackbody target. The FWHP beamwidths of the system are 5.9 ° at 23.8 GHz and 4.5 ° at 31.4 GHz. The gain of the system is determined by viewing the target with and without noise injected by a noise diode. Calibration of the system consists in determining the effective noise diode temperature T_{ND} and is done by the tipcal method. When tipcals can't be done, T_{ND} is estimated by a procedure described in [2]. The MWR is equipped with a heated blower and a moisture detector to minimize the effects of rain and dew. Data from several MWR's have been used extensively by the U. S. climate community [84, 85]

5.3 Tropospheric Water Vapor Radiometer (TROWARA)

At the Institute of Applied Physics (IAP) at the University of Bern, a first generation radiometer system for continuous measurements of IWV and of LWP has been operated since 1994. The instrument, called TROWARA, was designed and built at the IAP, operating at 21 and 31 GHz [50] with internal calibration, and supplemented by hourly tipping curves [51]. The limitation to two channels requires an estimate of the effective tropospheric temperature [52]. Over the years TROWARA has provided a large data set, which has been used for validating other remote sensing methods [89] and for climate monitoring. The positive IWV bias of 2 mm observed by Ingold and Mätzler [90] over the1995 to 1998 period was eliminated by radiometer improvements. Since December 2002 the instrument has been working with improved stability and with complete protection against raindrops, thus allowing measurements during all-weather conditions [91].

5.4 Meteorological Temperature Profiler MTP5

Kipp & Zonen BV is now marketing a radiometer that was originally designed and deployed by the Russian firm ATTEX [38, 40]. This radiometer is designed to measure temperature profiles in the boundary layer from 0 to 600 m above ground level (AGL). The radiometer is a single-channel (61 GHz) solid-state Dicke-type super-heterodyne receiver that is electronically chopped at 1 KHz between the sky and a reference noise source. The antenna is a scalar horn with a FWHP beam width of 6 º and scans by viewing a flat reflector at each of 11 scanning angles. Because of the 2 GHz bandwidth and a low receiver noise temperature of 600 K, a high sensitivity of 0.04 K is achieved. Calibration of the receiver is achieved by 0.1 °C temperature control and a switched internal noise generator. A one-point absolute calibration is achieved either by viewing an external target or by knowing the emission temperature in the horizontal direction. A variation of this radiometer, developed at NOAA/ETL, scans continuously in a 360 º vertical plane, and, in addition to temperature profiles, can also be used to measure air-sea temperature difference [53].

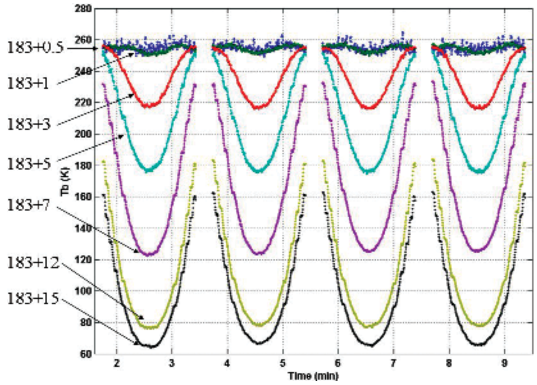

Figure 7. Time series of GSR data near 183.31 GHz at the NSA/AAO Arctic Winter Radiometric Experiment that was conducted in Barrow, Alaska, USA, during March-April 2004.

5.5 Radiometrics Corporation Microwave Profiler (MWRP)

Radiometrics Corporation has developed a multi-frequency microwave radiometer that is based on a highly stable, tunable, and synthesized, local oscillator in the receiver. This design overcomes errors caused by receiver frequency drift, while allowing observation of a large number of frequencies across wide tuning ranges. The total power receiver has a highly stable noise diode that is used as a gain reference. The radiometer observes atmospheric brightness temperatures in five frequency bands from 22 to 30 GHz, and in seven bands from 51 to 59 GHz [3, 54, 55]. It also measures zenith infrared temperature, surface temperature, humidity and pressure. The radiometer has automated elevation- and azimuth-scanning capability, and the observation interval can be as short as several seconds. The instrument is relatively portable, with 0.12 m^3 volume and 32 kg weight.

5.6 Microwave Radiometer for Cloud Cartography (MICCY)

MICCY is an 11 frequency 22-channel radiometer operated by the University of Bonn [41] which is capable of high temporal (0.1 s) and spatial (< 1°) resolution. The radiometer has 10 channels on the high-frequency side of the 22.235 GHz water vapor line, 10 channels on the low-frequency side of the 60 GHz O_2 absorption ban, and two channels at 90 GHz; at each of the 11 frequencies of operation, both H and V polarization are measured. MICCY is a single sideband total power radiometer that is based on a heterodyne receiver filter-bank design (parallel detection of all frequency channels). The thermal stability of the receivers is less than 20 mK, which implies that the instrument is capable of maintaining its radiometric accuracy for several minutes without recalibration. Both targets and inserted noise from highly stable diodes are used in cali-

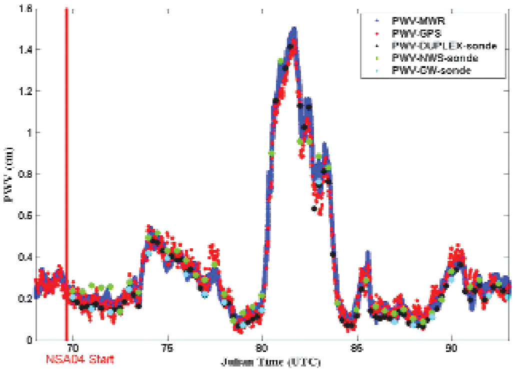

Figure 8. Time series of comparisons of IWV from radiosondes, the Global Positioning System, and the MWR. Data were taken at the NSA/AAO Arctic Winter Radiometric Experiment that was conducted in Barrow, Alaska, USA, during March-April 2004.

bration. With FWHP beam widths of about 0.9 ° the radiometer is capable of full 360 ° scanning in azimuth and a zenith scan of 0 to 90 °. For mapping of clouds, the entire system can be scanned in azimuth and elevation. The latter is performed by a planar mirror that reflects the incoming radiation into a fixed 1 m Cassegrain system. The system comprises a quasi-optical multiplexer for three frequency bands. Internal ambient and cold blackbodies are used for absolute calibration, while internal noise calibration standards are used in between absolute calibrations. The entire system is mounted on a transportable trailer, and all parts are enclosed in a radome.

5.7 Radiometer Physics GmbH-Humidity and Temperature Profiler (RPG-HATPRO)

Because the implementation of an operational network of microwave radiometers is presently hampered by the cost and complexity of the available instruments, it was a major objective of the European CLIWA-NET project [37] to develop a network-suitable low-cost microwave radiometer. This radiometer – RPG-HATPRO – has been built by German company Radiometer Physics GmbH (http://www.radiometer-physics.de/html/RPG_home.html). The RPG-HATPRO comprises total-power radiometers utilizing direct detection receivers at all frequencies (14 channels up to 60 GHz). This approach avoids any problems that might arise from mixers or local oscillators (standing waves, frequency drifts, insufficient isolation, sideband suppression, higher system complexity and cost). Thus, the stability and accuracy of the system are drastically improved. Furthermore, possible IF interferences caused, for example, by communication systems that frequently operate near the IF frequencies, are eliminated. The receivers of each frequency band are designed as filterbanks in order to acquire each frequency channel in parallel. In addition, the flexibility to adjust each channel bandwidth individually allows for optimizing temperature profiling for both boundary layer and full troposphere.

5.8 All-Sky Multi-Wavelength Radiometer (ASMUWARA)

The ASMUWARA is a radiometer system designed for remote sensing of tropospheric water vapor, cloud liquid water, and temperature profiles [44]. It was designed and built at the IAP. The instrument consists of nine microwave channels in the frequency range from 18 to 151 GHz, a broad-band thermal infrared radiometer (wavelength band: 8 to 14 μm), meteorological sensors, including a rain detector, and an optional camera. The radiometers are housed in a temperature-controlled cylinder with all beams aligned in a horizontal direction pointing to a rotating mirror that scans the sky and two calibration loads. The entire instrument can be rotated around its vertical axis. The beams perform a rosetta-like pattern to map the sky hemisphere within 20 minutes. All channels have the same view and a common full beam width of 9°, formed by corrugated horns. The beam width is a compromise between angular resolution and sky coverage within the time scale of atmospheric variations. All horns are vertically polarized. The mirror reflection rotates the polarization during the scan from vertical (at the horizon) to horizontal (at nadir and zenith). A special challenge was the broad bandwidth required for the common instrument optics, ranging from 18 GHz to the thermal infrared. The solution was to construct a sufficiently large flat aluminum mirror that allowed parallel beams for each spectral range, and to avoid any sort of radome. In this way the instrument works well in periods without precipitation. A planned extension to all weather operability will include a movable roof with a limited sky view during periods of rain. Figure 3 shows the weather-exposed parts of ASMURARA in operation on the roof at IAP. In principle, ASMUWARA is similar to other recently developed radiometer systems for the troposphere [3, 54, 55]. The main difference is the availability of and the concentration on the hemispheric imaging mode for all channels, including the infrared.

5.9 NOAA/ETL Ground-Based Scanning Radiometer (GSR)

For purposes of Arctic deployments, NOAA/ETL designed and constructed a multi-frequency scanning radiometer operating from 50 to 380 GHz. The radiometers are installed into a scanning drum or scanhead (see Figures 4 and 5). The GSR uses a sub-millimeter scanhead with 11-channels in the 50-56 GHz region, a dual-polarized measurement at 89 GHz, 7-channels around the 183.31 GHz water vapor absorption line, a dual-polarized channel at 340 GHz, and three channels near 380.2 GHz. It also has a 10.6 micrometer infrared radiometer within the same scanhead. All of the radiometers use lens antennas and view two external reference targets during the calibration cycle. In addition, each of the radiometers' design includes two internal reference points for more frequent calibration. The GSR instrument is a modification of a similar instrument that operated at the North Slope of Alaska/Adjacent Arctic Ocean site in 1999 [36]. A substantial improvement in radiometer calibration for ground observation in the Arctic environment has been achieved. Based on experience from the 1999 experiment, a new set of thermally stable calibration targets with high emission coefficients were also designed, constructed, and deployed. The primary use of the instrument is to measure temperature, water vapor, and clouds, at cold (-20 to -55 °C) and dry (PWV < 5 mm) conditions. A schematic of the GSR is shown below in Figure 4. The GSR, along with the MWR and the MWRP was deployed in the NSA/AAO Arctic Winter Radiometric Experiment that was conducted in Barrow, Alaska, USA, during March-April 2004 [56] (See Figure 6). The beam widths of the GSR channels are 1.8 ° and can be averaged to given beam-widths that are consistent with the MWR (4.5° to 5.5 °). An example of data from the GSR is shown in Figure 7. Here we see time series of consecutive scans at each of the 7-channels of the 183 GHz system. Each scan begins and ends with the radiometer viewing the hot and cold calibration targets. The scanhead then moves out of the calibration housing where it views the atmosphere with a series of continuous and dwell movements. Each scan takes about 2-min to complete. Data from the 26 channels of the GSR should lead to unprecedented information on the evolution of temperature, water vapor, and clouds in the Arctic.

6.0 Retrieval techniques

Techniques to derive meteorological information from radiation measurements are generally based on Equation (2). Because only a finite number of imperfect radiation measurements are available, and a continuum of parameters is needed to describe profiles of temperature, water vapor, and cloud liquid, a rigorous mathematical solution does not exist and the inverse problem is said to be ill-posed [57, 58]. Therefore, it is better to regard the measurements as constraints and to blend them with supplementary sources of information or to drastically reduce the dimensionality of the inverse problem by projecting the profiles onto their linear functionals. Useful supplementary information can be provided by numerical meteorological forecasts, or by a priori information obtained from past data. Examples of profile linear functionals are IWV and LWP for moisture variables and geopotential height for temperature profiles [48]. An excellent review of algorithms that are commonly used in meteorological remote sensing is given by Rodgers [9]. Other frequently used methods: neural network inversion [59, 60]; and Kalman filtering [61, 62, 63] and regression [64]; Kalman Filtering is also a general technique and is described in excellent books [65, 66]. Another technique of great promise is to combine radiometer data with a numerical forecast model, as has been done successfully in satellite meteorology [67, 68].

7. Radiometric Sensing of Tropospheric Meteorological Variables

Remote sensing of meteorological variables by radiometry is now a mature field, with a history of applications at least since the mid 1960's. The strengths of the techniques are accurate calibration, temporal resolutions of the order of seconds, and the ability to measure spatially integrated quantities. In this section, we review a few of the techniques that are now well-established internationally. We then present newer applications that have considerable potential for both research and operational meteorological applications.

7.1 Integrated Amounts of Water Vapor and Cloud Liquid

Both water vapor and cloud liquid are important variables in meteorology and climate. Due to thermodynamic processes of evaporation and condensation, as well as transport by winds, these quantities vary greatly in space and time. Water vapor is characterized by water-vapor density as a function of spatial coordinates and time. To characterize liquid in clouds requires knowledge of particle size as well. Water clouds consist of a large number of

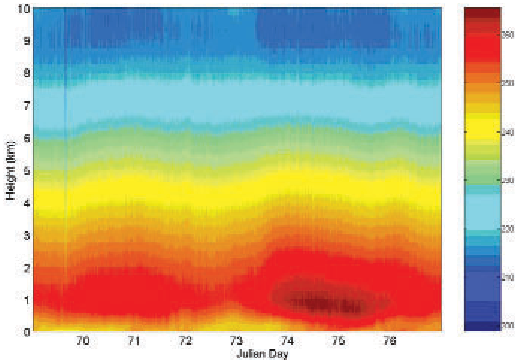

Figure 9. Time-height cross-sections derived from MWRP data during the NSA/AAO Arctic Winter Radiometric Experiment that was conducted in Barrow, Alaska, USA, during March-April 2004.

droplets of varying sizes. The number of all droplets within a unit volume is the total number density [m^{-3}]. The drop size distribution (DSD) describes the number density as a function of droplet radius; i. e., the number of drops per unit volume within a given radius interval. Due to the complex microphysical processes within clouds, DSDs are highly variable in time and space. In contrast to raindrops, cloud droplets are perfect spheres. Thus, all cloud microphysical parameters can be calculated from the DSD. For example, the cloud liquid-water content (LWC) [kg m^{-3}] is given by the product of the total volume of water and the density of water. Because the volume of a sphere is proportional to the radius cubed, LWC is also called the third moment of the DSD. It comprises one of the most interesting properties of clouds and is the prognostic variable in most numerical weather prediction and climate models to describe clouds, but few observations are available for the validation of the model results. By far, the most accurate method to determine the LWP, the vertical integral of LWC, is ground-based passive microwave radiometry. However, for many applications, it is also crucial to know at which altitudes the water is located. To determine the cloud-base height several instruments can be used (e.g. cloud radars, cloud lidar ceilometers, and infrared (IR) radiometers); for cloud thickness, cloud radars are used. Finally, to determine profiles of LWC, the combination of passive microwave and cloud radar measurements is promising [69, 70].

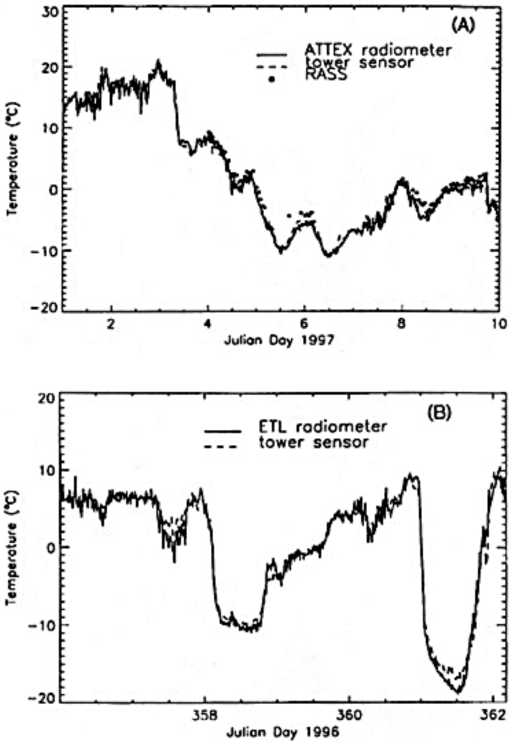

Figure 10. (A) A 10-day time series of temperature at 200 m as measured by the ATTEX radiometer, by the in situ measurement on the tower, and by a Radio Acoustic Sounding System (RASS). January 1–10, 1997.(B) A 6-day time series of temperature at 200 m as measured by the ETL radiometer and by the in situ measurement on the tower. December 21–27, 1996. After [40].

Dual-frequency measurements of brightness temperature at an optimum frequency near the 22.235 GHz water vapor line and in a transmission window have been used to measure IWV and LWP for about 25 years [1, 48, 63]. The general accuracy of dual-frequency radiometric measurement of IWV has been shown to be better than 1 mm rms [35]. However, because of the lack of in situ measurements of cloud liquid, an adequate experimental evaluation of LWP over a range of cloud conditions is not available.

An example of IWV retrievals is shown in Figure 8. Here, we show the comparisons from data taken during the 2004 NSA/AAO Arctic Winter Radiometric Experiment [56]. Data shown include soundings from radiosondes, the Global Positioning System, and the MWR.

Improvements on the dual-channel method can be made with multi-frequency observations. The liquid-water path can be estimated from atmospheric emission measurements in the microwave region because in this spectral region, the cloud contribution strongly increases with frequency (Figures 1 and 2). The standard dual-channel principle has been described above for the determination of IWV. For the retrieval of LWP, the channel close to the water-vapor absorption line corrects for the changing water-vapor concentration of the atmosphere. Such observations are, with the exception of expensive and rather limited aircraft measurements, the most accurate method to observe LWP with an estimated accuracy of better than 25 gm^{-2}. A rough estimation shows that about 10 gm^{-2} are caused by the measurement error while the rest can be attributed to the under-determined retrieval problem. The additional use of the 90 GHz channel can further constrain the problem and improve accuracy to less than 15 gm^{-2} [69, 70].

7.2 Temperature Profiling by Multi-frequency Radiometers

Radiometric temperature profiling can be accomplished by measuring the spectrum of radiation intensity at points along the side of the oxygen feature at 60 GHz [71]. By scanning outward from band center, where the opacity is so great that all signal originates from just above the antenna, onto the wing of the line, where the radiometer "sees" deeper (higher) into the atmosphere, altitude information is obtained. Emission at any altitude is proportional to local temperature; thus, the temperature profile can be retrieved. Either shoulder of the band center is suitable for retrieval of temperature profile information.

As discussed in Section 4.5, Radiometrics Corporation has developed the MWRP. Historical radiosonde and neural network or regression methods are used for profile retrieval [3] and comparsions between radiosondes and derived profiles are shown in [77]. Retrievals include temperature and humidity soundings up to 10 km height, and one-layer cloud liquid soundings. Radiometric retrievals from this instrument are similar in accuracy to radiosonde soundings when used for numerical weather prediction [3]. Retrieval error is smaller than radiosonde sounding error for boundary-layer temperatures, and slightly higher above the boundary layer. The dominant radiosonde error is the representativeness error that results from the characterization of a model cell volume by a point measurement. This type of error is especially important when there are strong temporal or spatial gradients in the meteorological profiles. Radiometric retrievals are based on temporal averages and are less susceptible to representativeness error than radiosonde soundings. One of the potential advantages of high-temporal-resolution radiometric data (10 to 15 min) is that the data could be directly assimilated into weather forecast models and improve short term forecasts. A useful technique for displaying radiometric retrievals is that of time-height crossections in which the horizontal axis is time, the vertical axis is height, and the radiometric data are color coded. An example is shown in Figure 9 using MWRP data taken during the 2004 NSA/AAO experiment [56]. Note that the retrievals capture the intense thermal inversion (temperature increases with altitude) near the ground, and how the diurnal changes in the profiles are evident. Temperature profiles have also been derived from the ASMUWARA [44].

7.3 Boundary layer Temperature Profiling from Scanning Radiometers

Angular techniques for measuring emission were developed by ETL in the early 1970s [72], but due to mechanical simplicity, the zenith-viewing multi-spectral radiometers were chosen by them [1] as a component of a prototype remote-sensing system. However, in 1992, Russian scientists developed a scanning single-channel radiometer that showed promise for routine monitoring of the boundary layer [38, 73]. Development of this kind of radiometer has been continued by the Russian firm (ATTEX) and numerous applications to boundary-layer studies have been published. The technique consists of measuring atmospheric emission at different angles in a wavelength band that exhibits relatively high atmospheric attenuation. The radiometer operates at 60 GHz (wavelength 5 mm), near the peak of the strong oxygen band, has a 6 ° beam width, and can yield data on a 1 sec basis. In this frequency region, the radiation in the horizontal direction can be used as a reference level since T_b is essentially equal to the air temperature at the measurement height. Thus, an accurate air-temperature measurement provides a calibration of the radiometer offset. An independent measurement, such as a laboratory blackbody reference load, or calculations of T_b from radiosondes, is necessary to determine the radiometer's gain. From the downwelling radiation at different elevation angles, atmospheric air temperature profiles can be obtained. The vertical resolution of the retrieved profiles is a function of altitude, and ranges from about 10 m near the surface to about 300 m at the 500 m altitude. Several experiments were conducted in Russia, Germany, the United Kingdom, and Japan by E. Kadygrov and his coworkers at ATTEX; a similar instrument has been operated by ETL near Boulder, Colorado, at a meteorological tower [40], at three experiments in Oklahoma, one in the tropics [53], and one at Barrow, Alaska [36]. In all cases, the rms errors were less than 0.5 K below 500 m. An example of temperature measured at 200 m above ground level (AGL) by the radiometer and by in situ measurements on a tower is shown in Figure 10. Because of the simplicity and portability of the instrument and its extremely flexible characteristics, it has been used from airborne, ship-, and ground-based platforms [40, 53, 86].

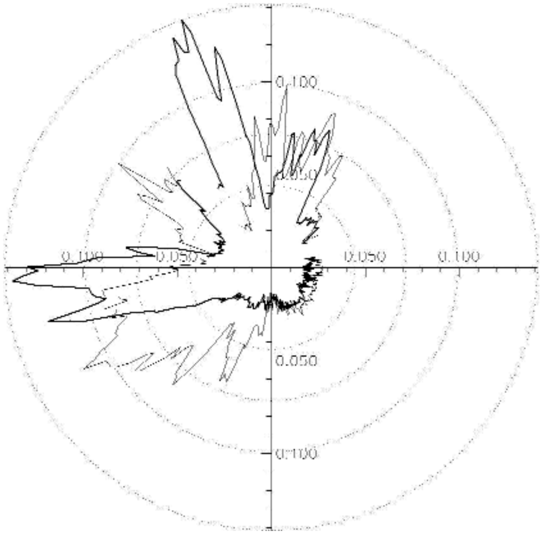

Figure 11 Series of 14 successive azimuth scans at 30 deg elevation with the multi-channel microwave radiometer MICCY having a beam width of less than 1 deg in all channels. Liquid water path was derived using a regression algorithm employing four frequency channels. After [69].

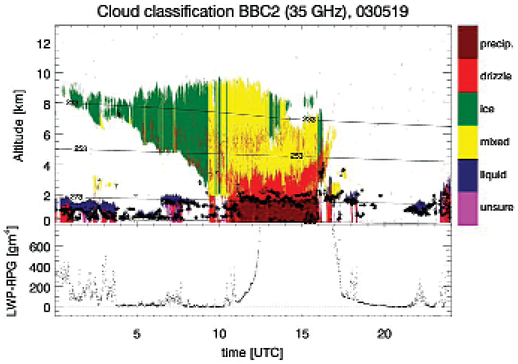

Figure 12. Cloud classification and LWP for May 19, 2003 at Cabauw. Temperature is derived from interpolated radiosondes. The classification is performed for each individual cloud radar range gate. Black dots indicate the cloud base height as observed by lidar ceilometer.

There also was a substantial amount of research into temperature profiling, in particular, and microwave radiometry, in general, in the former Soviet Union. A comprehensive review of this work that contains numerous references to the original work is contained in the book by Stepanenko et al. [74].

7.4 Angular Scanning Observations of Cloud Liquid

Small scale information on the cloud structure is measured by the microwave radiometer for cloud cartography (MICCY-see Section 4.6) [41]. This radiometer makes scanning measurements with high temporal (0.1 s) and angular (less than 1 °) resolution. Figure 11 shows several azimuth scans observed by MICCY, made at an elevation angle of 30°. Such information can be used for studies concerning three-dimensional radiative transfer of solar radiation through clouds by improving our estimate of the cloud water distribution and cloud structure. Scanning is also important to study the anisotropy of cloud structure. The autocorrelation function can be calculated for bins with a certain range of distances and angles to get a two-dimensional autocorrelation function. Case studies have shown strong anisotropies in the *LWP* field oriented in the direction of the wind. Thus, zenith measurements of the clouds that drift by on the wind would show a correlation length that is not representative of the field.

7.5 Integrated Profiling by Sensor Synergy

While the cloud water column can be derived accurately from microwave radiometer measurements alone, the information about its vertical distribution is rather limited. Therefore, microwave radiometer measurements are often combined with simultaneous cloud radar observations which provide the radar reflectivity factor *Z* with a vertical resolution of approx. 50-100 m. Since *Z* is proportional to the sixth moment of the drop size distribution and the cloud liquid water content *LWC* is proportional to the third, a direct conversion of *Z* to *LWC* results in large errors. Thus, a common approach used by Frisch et al. [75] scales the radar reflectivity profile to the *LWP* as measured by a radiometer. A more sophisticated, physically based technique [76] combines the microwave brightness temperatures, the attenuation-corrected radar reflectivity profile, the lidar-ceilometer cloud base, ground temperature and humidity, and the nearest operational radiosonde profile within an optimal estimation retrieval. This Integrated Profiling Technique (IPT) can simultaneously derive profiles of temperature, humidity, and *LWC*. The retrieved IPT profiles are characterized by their physical consistency with respect to the microwave radiometer and cloud radar measurements. Additional constraints guarantee a match with the ground-level measurements, saturation within the cloud boundaries, and statistical consistency with the radiosonde temperature and humidity profiles. Error covariances of all measurements are required, such that all constraints can be met within an iterative optimal estimation procedure. The solution is interpreted as a probability density so that a retrieval error estimate is inherently given. A further advantage of the IPT is that, in contrast to the *LWP* scaling methods, the *LWC* profiles are independent of errors of an *LWP* algorithm.

Presently, the IPT has been developed only for cases when the radar reflectivity is solely caused by liquid-water drops. This means that the occurrence of mixed phase clouds within the vertical column above the instruments will make IPT application impossible. However, the presence of pure ice clouds above one or more liquid cloud layers will not influence the IPT because ice clouds do not contribute to the microwave signal in the frequency range below 90 GHz. Furthermore, insect- and precipitation-dominated radar pixels need to be removed. Thus, to be able to apply the IPT automatically, a cloud classification was developed that distinguishes between six phases/regimes (pure ice, mixed-phase, pure liquid water, drizzle, significant precipitation and unclassified). The classification makes use of cloud radar, lidar-ceilometer, the nearest operational radiosonde temperature profiles, and microwave-radiometer-derived LWP. An example of the cloud classification for one day is shown in Figure 12. Obviously, the ice- and mixed-phase- clouds dominate the radar signal. Although the classification suggests that water clouds play a minor role, their strong influence on the solar radiation makes them of utmost importance for climate research.

The advantage of microwave remote sensing is that even in the presence of thick clouds, temperature and humidity can be determined with good accuracy. However, because the vertical resolution is relatively coarse (about 1-2 km [77]) sharp inversions can't be resolved completely.

The IPT is a first step toward an "all-encompassing" profiling algorithm which combines measurements from all available instruments to derive the atmospheric state as accurately as possible. Since this task should ideally be accomplished in a physically consistent way, knowledge of all involved forward models is required. Future extensions will include infrared and ceilometer forward models to further constrain cloud microphysical parameters, especially in the lower part of the cloud.

8.0 Concluding Remarks

For the past 35 years, surface-based microwave radiometers operating below 60 GHz have provided useful data on temperature, water vapor, and clouds. Steady progress has been made in the development of robust, sensitive, and accurate radiometers. This has been accompanied by continued development of forward models for the accurate calculation of brightness temperature, although there is still some concern about cloud liquid characterization below freezing temperatures. The development of suitable inverse models has also occurred, but, it now seems likely that assimilation of data with forecast models is the most promising technique for exploiting radiometer data [67, 68]. Of equal promise, is the synergism of active and passive sensors, as has been achieved in cloud sensing [69, 87, 75], in moisture profiling [78], and in the use of wind profiler estimates of significant moisture gradients to improve humidity profile retrieval [79].

Another promising area of research is the development of scanning radiometers that can measure horizontal gradients in water vapor and cloud liquid. For example, moisture gradients are frequently seen in tipcal measurements by MWRs [47].

The ASMUWARA has the potential to be an important tool for ground-based remote sensing of the troposphere. Advancements are expected to be made from the participation at the COST-720 intercomparison campaign for temperature, humidity and cloud profiling that was made in Payerne (Switzerland) from November 2003 to January 2004. Improvements will include the synergy of all channels in a coherent retrieval. With respect to instrumentation of ASMUWARA, an advancement will be the addition of the 151 GHz channel which will allow higher sensitivity to clouds. Also to be exploited is the potential to measure precipitation [88]; for this purpose use will be made of the lower frequency channels in case of rain and the 151 GHz channel for dry snow. If the methods are successful, ASMUWARA will become a valuable tool in the ground validation of the international Global Precipitation Mission to be created by the space agencies of Europe, Japan and the USA. On the practical side, main improvements are expected from the protection of the instrument against wetting by raindrops.

Finally, the sensitivity of radiometers to both water vapor and cloud liquid increases with frequency, and arctic regions, with typical small amounts of both liquid and vapor, seem especially amenable to millimeter wave radiometry. As satellite sensors increasingly use millimeter wavelength radiometers, accurate forward models for satellite retrievals can be developed by using data from upward-looking sensors coupled with radiosondes. Such forward models are important in surface-, airborne-, and satellite-based remote sensing, as well as for communication.

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NASA is an Equal Opportunity Employer.

The Alfred T. C. Chang Memorial Symposium

In memory of Dr. Alfred T.C. Chang's contribution to Earth Science, there was a memorial symposium held at the Visitor Center at NASA's Goddard Space Flight Center in Greenbelt, Maryland, on October 12, 2004. The symposium, entitled The Alfred T. C. Chang Memorial Symposium, and sponsored by NASA, the U.S. Department of Agriculture and the IEEE GRS, consisted of invited and contributed presentations dealing primarily with microwave remote sensing.

Dr. Alfred T. C. Chang, IEEE Fellow, was employed by NASA at Goddard Space Flight Center from 1974 until his death on May 26, 2004. Dr. Chang's main area of research was the use of microwave instruments for remotely sensing properties of the atmosphere and land. Most of his illustrious career was spent on analysis of microwave data of snow cover and rainfall, and he produced several seminal papers on these subjects. Dr. Chang published more than 100 journal articles, and among his many honors and awards is the NASA Medal for Exceptional Scientific Achievement.

Al Chang (right) with Jim Foster taking spectrometer measurements on the Black Rapids Glacier, Alaska, July 1987. Photo taken by Dorothy Hall.

The symposium program was full, with 13 oral and 8 poster presentations. 78 people registered for the symposium and many also attended a dinner following the symposium. Dr. Chang's widow, Flora, and daughter, Mary, attended both events and his son, Michael, attended the dinner. Many people traveled from out of town and two from outside the country (A. J. Chen/Taiwan and Anne Walker/Canada) to participate in the event. An extensive web site http://neptune.gsfc.nasa.gov/chang/index.php was developed in conjunction with the symposium in which the agenda is shown along with the list of speakers and a multitude of pictures of Dr. Chang with colleagues.

The technical program was divided into two basic sessions, beginning with the microwave remote sensing of snow cover, chaired by Jim Foster with Dorothy Hall, Anne Walker, Richard Kelly, Ed Kim, Bob Bindschadler, Per Gloersen and Marco Tedesco as speakers. The second session dealt with rainfall and was chaired by Tom Wilheit who was also a speaker along with A. J. Chen, Long Chiu, Bob Adler and Ana Burros.

In the 1970s, Dr. Chang and colleagues figured out how to integrate the radiative-transfer equation in the presence of scattering, and this breakthrough became the basis for the Tropical Rainfall Measurement Mission (TRMM), an outstanding success that is still churning out data. Dr. Chang was also able to modify the theory to understand the passive-microwave remote sensing of snow cover, and this provided the basis for many subsequent microwave-derived snow-cover products including the snow-cover extent and snow-water equivalent product from the AMSR-E on the Aqua satellite.

The speakers successfully demonstrated how collaboration with Dr. Chang enhanced their own personal research, and many said that Dr. Chang's work had inspired them to continue in either snow or rainfall research. They also told many stories indicating close collegial relationships and friendships with Dr. Chang. Nearly all of the speakers spoke of Dr. Chang's unselfish counsel in discussions relating to both snow and rainfall research.

IMA INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

Annual Program 2005-2006

IMAGING

The Institute for Mathematics and its Applications (IMA) will run a year-long program on Imaging from September 2005 to June 2006. Imaging science is highly interdisciplinary, connecting mathematical sciences with a variety of application areas. This program will bring together researchers from a broad range of disciplines, emphasizing the underlying mathematical structures and algorithms. Typically, half of the participants in IMA programs come from the mathematical sciences, and the other half comes from other areas such as engineering and biological or medical sciences. The main focus areas of the program are Sensors to Images in Fall 2005 and Images to Understanding in Spring 2006. Detailed information about the Imaging program can be found at: http://www.ima.umn.edu/imaging/

At this time, the IMA invites participation in its program for scientists from academia or industry with expertise or interest in imaging.

WORKSHOPS: As part of the Annual Program, the IMA will host 8 workshops and a tutorial. In addition, the SIAM Meeting on Imaging Sciences will be held next door at the Radisson Metrodome.

Participation in IMA workshops is free and limited travel support is available; to register, please fill out an online registration form at: http://www.ima.umn.edu/docs/reg_form1.html

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10/17-21/05 Workshop: Imaging from Wave Propagation
11/7-11/05 Workshop: Frontiers in Imaging
12/5-9/05 Workshop: Integration of Sensing and Processing
1/9-12/06 Workshop: New Mathematics and Algorithms for 3-D Image Analysis
2/6-10/06 Workshop: The Mathematics and Art of Film Editing and Restoration
3/6-10/06 Workshop: Natural Images
4/3-7/06 Workshop: Shape Spaces
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GENERAL MEMBERSHIPS provide an opportunity for mathematicians and scientists employed elsewhere to spend a period of one month to one year in residence at the IMA, and to participate in the 2005-2006 thematic program. The residency should fall in the period September 2005 through June 2006 (in special cases, extending into the summer months). Logistic support such as office space, computer facilities, and secretarial support will be provided, and local expenses may be provided. Preference will be given to supplementary support for persons with sabbatical leaves, fellowships, or other stipends. Applications may be submitted at any time until the end of the thematic program, and will be considered as long as funds remain available: http://www.ima.umn.edu/docs/genmemapp.html

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For details or to submit a short abstract of a talk or software demonstration please contact Dr. Mohammed Shokr of Environment Canada: Tel: +1 416 739 4906, email: mohammed.shokr@ec.gc.ca

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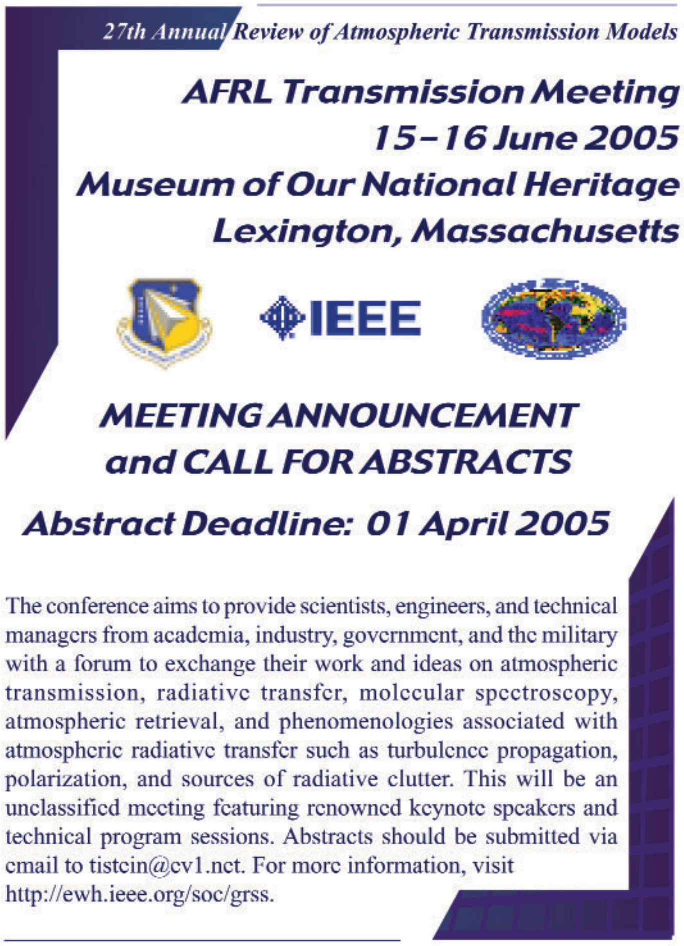

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A.J. Gasiewski, NOAA (al.gasiewski@noaa.gov), and
V. Chandrasekar, Colorado State University
(chandra@engr.colostate.edu), General Co-Chairmen

IGARSS 2007 • Barcelona Spain

23-27 July 2007 • Centre de Convencions Internacional
Ignasi Corbella, Universitat Politecnica de Catalunya,
Barcelona (corbella@tsc.upc.es), General Chairman

IGARSS 2008 • Boston Massachusetts

7-11 July 2008 • Hynes Veterans Memorial Convention Center
John Kerekes, Rochester Institute of Technology
(kerekes@cis.rit.edu), and Eric Miller, Northeastern University
(elmiller@ece.neu.edu) General Co-Chairmen

IGARSS 2009 • Cape Town South Africa

Harold Annegarn, Rand Afrikaans University
(annegarnh@geosciences.wits.ac.za) General Chairman

Proposals to host IGARSS 2010 (North American sites only) will be accepted through 01 October 2005. To obtain proposal preparation instructions, contact IEEE GRSS at ieeegrss@adelphia.net. For general conference and Society information, visit ...

http://ewh.ieee.org/soc/grss/

UPCOMING CONFERENCES

See also **http://www.techexpo.com/events** or **http://www.papersinvited.com** for more conference listings

Name: **URBAN 2005 / URS 2005**
Dates: March 14-16, 2005
Location: Tempe, Arizona, USA
Fax: +1+480- 965-8087
E-mail: ursconference@asu.edu
URL: http://ces.asu.edu/urs/

Name: **XXX General Assembly of the European Geophysical Society (EGS), American Geophysical Union (AGU)**
Dates: April 24-29, 2005
Location: Viena, Austria
Contact: EGS Office
Fax: +49-5556-4709
E-mail: egs@copernicus.org
URL: http://www.copernicus.org/EGU/ga/egu05/index.htm

Name: **IEEE Radar Conference**
Dates: May 9-12, 2005
Location: Arlington, VA, USA
Contact: Tom Fagan
Fax: +1+856/338-2555
E-mail: thomas.fagan@drexel.edu
URL: http://www.radar05.org/

Name: **IEEE Workshop on Remote Sensing of Atmospheric Aerosols. A Workshop Honoring Professor John A. Reagan**
Dates: April 5-6, 2005
Location: Tucson, Arizona, USA
Contact: Tammy Stein
Fax: 281-251-5841
E-mail: tistein@ev1.net
URL: http://ewh.ieee.org/soc/grss/

Name: **URSI Commission F Symposium on Microwave Remote Sensing of the Earth, Oceans, Ice, and Atmosphere**
Dates: April 20-21, 2005
Location: Ispra, VA, Italy
Contact: Joaquim Fortuny
Fax: +39 0332 785469
E-mail: Joaquim.Fortuny@jrc.it
URL: http://ursi-f-2005.jrc.it/

Name: **2005 AVIRIS Workshop - General Information**
Dates: May 24-27, 2005
Location: Pasadena, CA, USA
URL: http://aviris.jpl.nasa.gov/html/workshopinfo2005.html

Name: **Multiptemp 2005. Third International Workshop on the Analysis of Multitemporal Remote Sensing Images**
Dates: May 16-18, 2005
Location: Biloxi, Mississippi, USA
Contact: Prof. Roger L. King
E-mail: multitemp05@gri.msstate.edu
URL: www.multitemp05.org

Name: **The 25th EARSeL Symposium and Workshops**
Dates: June 6-11, 2005
Location: Porto, Portugal
Contact: Mrs. M. Godefroy
FAX: +33-1-45 56 73 61
E-mail: earsel@meteo.fr
URL: http://www.fc.up.pt/earsel2005/

Name: **RAST 05. 2nd International Conference on Recent Advances in Space Technologies**
Dates: June 9-11, 2005
Location: Istanbul, Turkey
Contact: Dr. Col. Sefer Kurnaz
Fax: +90-212-6628551
E-mail: rast2005@hho.edu.tr
URL: http://www.hho.edu.tr/RAST2005

Name: **OCEANS 05 Europe**
Dates: June 20-23, 2005
Location: Brest, France
Contact: Réné Garello
URL: www.oceans05europe.org

Name: **IEEE INTERNATIONAL GEOSCIENCE AND REMOTE SENSING SYMPOSIUM, IGARSS 2005**
Dates: July 25-29, 2005
Location: Seoul, Korea
Contact: Wooil Moon
E-mail: wmoon@eos1.snu.ac.kr
URL: www.igarss05.org

Name: **PIERS'05 - Progress in Electromagnetics Research Symposium**
Dates: August 22-26, 2005
Location: Hangzhou, Zhejiang, China
Contact: Prof. Kong
Fax: 1-617-258-8766
E-mail: jpier@ewt.mit.edu
URL: http://emacademy.org/piers2k5zj/

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