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Attention:

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Mail Stop 424
U. S. Geological Survey
12201 Sunrise Valley Drive
Reston, VA 22092

TITLE:

MAPPING THE BOUNDARY BETWEEN CONTINUOUS AND DISCONTINUOUS PERMAFROST IN ALASKA

by

A. W. England, J. F. Galantowicz, Y. A. Liou, E. J. Kim, and P. A. Dahl

Submitted by: Anthony W. England
Professor
Department of Electrical Engineering
and Computer Science
University of Michigan
Ann Arbor, Michigan 48109-2122

Phone: (313) 936-1340
FAX: (313)747-2106
Internet: england@eecs.umich.edu

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Short Title: **MAPPING PERMAFROST IN ALASKA**

Contents:

1. Summary

September 1, 1991, through August 31, 1992, was the first year of a three year project to develop an operational algorithm for using satellite radiobrightness data to map permafrost in Alaskan tundra. The algorithm will be based upon differences between predicted and observed temporal and spectral characteristics of the radiobrightness. A land-atmosphere boundary layer model for wetland tundra is being developed to provide predicted thermal and radiobrightness signatures. The thermal module of the model will predict whether or not a surface is underlain by permafrost, and the radiobrightness module will predict the consequent radiobrightness signature. Differences between predicted and observed temporal and spectral radiobrightness signatures will be used to continuously refine the boundary model. Operationally, observed radiobrightness will be obtained from the Special Sensor Microwave/Imager (SSM/I) satellite instruments. These sensors fly on a series of Defense Meteorological Satellites and provide at least twice daily coverage of high latitude regions. For the purposes of algorithm development, radiobrightness will be measured with the Tower Mounted Radiometer System (TMRS) -- a field system that we have built. Specific objectives for the project are:

(1) To develop a radiobrightness thermal model for the annual freezing and thawing of soil.

(2) To determine the sensitivity of the model to the existence of underlying permafrost.

(3) To evaluate the consistency of that model with data from the SSM/I.

(4) To test the quality of the model with a limited field experiment.

(5) To produce a three year map of the continuous/discontinuous permafrost boundary in Alaska.

During this first year of the project, we have completed a significant fraction of objective 1, and have reported our results in several publications and seminars.

2. Products of the First Year.

NASA Grant NAGW-1983 has been the primary support for our basic investigation of the radiobrightness signature of land-atmosphere processes. Our USGS grant has been used to extend our diurnal radiobrightness model of northern prairie to an annual model for arctic and subarctic tundra. The following papers and talks include many aspects of this model development along with topics from the basic investigation.

Refereed Proceedings Papers:

England, A.W., J.F. Galantowicz, Y.A. Liou, E.J. Kim, and P.A. Dahl, Diurnal and annual models of the radiobrightness of northern prairie, Proc. of ESA/NASA Workshop on Soil Moisture, Toulouse, France, January 11-15, 1993

England, A.W. and Y.A. Liou, Diurnal and annual radiobrightness thermal inertia of desert soils, Proc. URSI Microwave Signature Conf., Innsbruck, Austria, July 1-3, 1992.

Galantowicz, J. F. and A.W. England, An SSM/I radiometer simulator for studies of microwave emission from soil, Proc. of IGARSS'92, Houston, TX, May 26-29, 1992.

Liou, Y.A. and A.W. England, An annual model of SSM/I radiobrightness for dry soil, Proc. of IGARSS'92, Houston, TX, May 26-29, 1992.

Conference Abstracts:

Dahl, P.A., J.F. Galantowicz, and A.W. England, Frozen soil classification from SSM/I radiobrightness, 1992 Am. Geophysical Union Fall Meeting, San Francisco, December 7-11, 1992.

Liou, Y.A. and A.W. England, Annual model of the energy flux and the radiobrightness of Northern Prairie soil, 1992 Am. Geophysical Union Fall Meeting, San Francisco, December 7-11, 1992.

Seminars:

England, A.W., Radiobrightness signature of land-atmosphere processes, Russian Institute for Control Sciences, Moscow, July 7, 1992.

England, A.W., Radiobrightness signature of land-atmosphere processes, Russian Institute for Space Research, Moscow, July 8, 1992.

Technical Reports:

England, A.W., Status of the remote measure of soil moisture: A report of the SSM/I Products Working Team (SPWT), UM Radiation Laboratory Technical Report 027396-3-T, June, 1992.

3. A Review of Completed Elements

Continental atmospheric circulation models are driven by radiant energy, sensible heat, latent energy, momentum, and moisture flux boundary forcing at the land-atmosphere interface (e.g., Bhumralkar, 1976; Wilson and Henderson-Sellers, 1985; Abramopoulis et al, 1988; Verstraete, 1989; Dickinson et al, 1989; Avissar and Verstraete, 1990; and Giorgi and Mearns, 1991). There is ample evidence that mesoscale and global atmospheric circulation are particularly sensitive to the hydrologic boundary forcing of moisture and latent energy flux (e.g., Namias, 1958 and 1963; Walker and Rowntree, 1977; Rind, 1982; Shukla and Mintz, 1982; Yeh et al, 1984; Oglesby and Erickson, 1989; and Delworth and Manabe, 1988 and 1989). Hydrologic parameters that are interactive with circulation models have evolved from the bucket model of Manabe (1969) and Budyko (1974) to complex parameterizations like the Biosphere-Atmosphere Transfer Scheme (BATS) (Dickinson, 1984; and Dickinson et al, 1986) and the Simple Biosphere Model (SiB) (Sellers et al, 1986). While BATS involves more than 80 parameters and SiB involves 44, many are predictable for large, relatively homogeneous regions like the northern prairie or the arctic tundra. For example, soil thermal conductivity, density, and specific heat are readily estimated for either environment.

However predictable many of the hydrologic parameters are, the dynamic hydrological variables must be obtained through observation. Of these variables, soil moisture is critical because it represents the integrated effects of rainfall, runoff, and evapotranspiration. Because soil moisture tends to be relatively slowly varying with time at mid- and high-latitudes (e.g., Yeh et al, 1984; and Delworth and Manabe, 1988), its estimation is particularly suited to daily, or even to weekly, satellite observation. Given that some satellite observation might yield an estimate of soil moisture, producing such estimates on something like the 25 km spatial grid of a mesoscale atmospheric circulation model is relatively undemanding of sensor spatial resolution or of satellite data management systems.

Estimates of soil moisture and state are always based upon a combination of satellite observations and a model that places the observations in a physical or temporal context. For example, we expect L-band (1.4 GHz) radiobrightness to correlate well with soil moisture in situations where a physical model of emission from a moist soil halfspace is plausible (e.g., Schmugge, 1987). Complications caused by rough surfaces, by vegetation, or by non-uniform distributions of moisture in the soil are viewed as perturbations to the basic halfspace model. Without such physical models, we cannot readily extrapolate to untested situations. As models become more sophisticated, they might include the dynamical effects of diurnal and annual insolation, of vegetation, and of snow. The Michigan Cold Region Radiobrightness (MCRR) models are moist soil radiobrightness models that include the effects of diurnal and annual insolation and the effects of freezing and thawing soils. These models have provided a basis for classifying soils as frozen or thawed and have suggested that soil moisture might be inferred from the diurnal extremes in radiobrightness. Because the MCRR models do not yet include the effects of vegetation or snow, they are not yet suitable links between radiobrightness observations and the land-atmosphere fluxes that drive the continental boundary layer of a General Circulation Model (GCM).

3.1 An annual model of the radiobrightness of dry soils

There are three styles of remotely sensed data: (1) Spatial data, (2) radiometric (or spectral) data, and (3) temporal data. Methods for interpreting temporal data are less mature than are methods for interpreting spatial and spectral data because reliable temporal data tend to require dedicated instruments or operational satellites. Prototype sensors, whether on towers or on aircraft, are generally shared among many investigations so that scheduling observations and assuring data quality often become too difficult for many temporal investigations.

The advent of operational thermal sensing satellite instruments like the Advanced Very High Resolution Radiometer (AVHRR), band 6 of the Thematic Mapper, and the SSM/I offer opportunities to use the temporal history of the land surface temperature to probe below the effective emitting depth. Essentially, the diurnal and annual insolation pulses probe soils to depths of decimeters and meters, respectively, and surface temperatures provide a record of the response. A temporal method that is based upon periodic insolation requires a minimum of two samples per period, and maximum sensitivity is achieved for observations at times near the extremes of the soil's thermal response. Sun synchronous satellites, if their orbits are appropriately phased, are ideal for diurnal methods because they pass over a given region twice each day at intervals of nearly 12 hours.

While any interpretation of remotely sensed thermal radiation involves a static model of emission and scattering, a temporal interpretation also requires a dynamic model of thermal energy storage and exchange. Generally, such models are designed to capture the essence of thermal and emission processes while ignoring second order effects. The difference between diurnal extremes in surface temperatures of sparsely vegetated soils depends upon insolation, thermal exchanges with the atmosphere, and the thermal constitutive properties of the soils (e.g., Watson, 1975; Kahle, 1977; and England, 1990). This dependence is exploited in a satellite thermal infrared technique (Thermal Inertia Mapping) to discriminate among various rock and soil types (e.g., Watson et al, 1983), and to estimate soil moisture (e.g., Price, 1980; Idso et al, 1975b; Reginato et al, 1976; Vleck and King, 1983; and Heilman and Moore, 1980, 1981, and 1982). England et al (1992) have proposed a similar technique which uses the diurnal extremes in radiobrightness to estimate soil moisture. That technique, called Radiobrightness Thermal Inertia (RTI), is based upon the mutually enhancing signatures of increased thermal inertia and decreased emissivity with increasing moisture content. Unfortunately, the SSM/I's orbit is phased poorly for diurnal RTI. Overflight times of 6 a.m. and 6 p.m. correspond to thermal crossovers rather than to thermal extremes.

Though ill-suited for diurnal RTI, current SSM/I data might lend themselves to annual RTI. While our earlier models had shown that diurnal RTI is sensitive to soil moisture, this year we explored the other parameters that might also contribute to diurnal and annual RTI. As a precursor to the MCRR/Annual model, we examined the expected diurnal and annual RTI of dry soils. Through the model, we evaluated the sensitivity of diurnal and annual extremes in radiobrightness to soil thermal inertia -- and, indirectly, to soil density.

Thermal model. The analytical solution for periodic and uniform insolation of a homogeneous halfspace is well known (e.g., Carslaw and Jaeger, 1959), but, because of the dominantly radiative boundary condition, obtaining that solution for a combination of diurnal and annual processes is computationally intensive. The method requires that the radiative boundary condition be linearized and solved either through harmonic analysis or through a Laplace transform. We have examined the two methods for the annual problem, and find that the Laplace method provides greater insight about thermal processes, and greater flexibility with respect to parametric analyses. The Laplace method yields surface temperature and surface temperature gradient through a convolution of past solutions for surface temperature with the thermal response of the system. By introducing a variable time interval modification to the Laplace method, we compress workstation-class computation times from approximately 90 hours per annual model to 10 hours per model. The details of the variable time interval Laplace method were discussed by Liou and England (1992).

Consider a soil that is semi-infinite and homogeneous for $z<0$. If conduction is the dominant heat transfer mechanism,

$$\frac{\partial E(T_g(z,t))}{\partial t} = \frac{\partial}{\partial z}\left\{K(T_g(z,t))\frac{\partial T_g(z,t)}{\partial z}\right\} \tag{1}$$

where $E(T_g)$ is moist soil enthalpy, and $K(T_g)$ is moist soil thermal conductivity. Both are functions of ground temperature, $T_g(z,t)$, at depth z and time t. For dry soils, enthalpy is a linear function of temperature and thermal conductivity is essentially constant so that

$$\frac{\partial T_g(z,t)}{\partial t} = \kappa\frac{\partial^2 T_g(z,t)}{\partial z^2} \tag{2}$$

where κ is thermal diffusivity (m^2/s). The thermal constitutive property, κ, is constant in this formulation which precludes freezing or thawing soil moisture. Either (1) or (2) is solved subject to the energy flux boundary condition that

$$F_{soil}(0,t) = F_g(t) - F_{sun}(t) - F_{sky}(t) - F_{wind}(t) \tag{3}$$

where $F_{soil}(z,t)$ is upward flowing thermal energy flux in the soil, and $F_g(t)$ is Planck emission from the soil ($e\sigma T_g(0,t)^4$ for infrared emissivity, e, and Stefan-Boltzmann constant, σ). The forcing functions are radiant flux from the Sun, $F_{sun}(t)$, radiant flux from the atmosphere, $F_{sky}(t)$, and sensible heat transfer from the atmosphere, $F_{wind}(t)$ (whose form is $A[T_{air}(t) - T_g(0,t)]$ where A is a constant and $T_{air}(t)$ is a model of air temperature). These forcing functions are discussed in the literature (e.g., England, 1990; and Idso et al, 1975a). The thermal energy flux at the soil's surface is related to temperature in the soil through the thermal conductivity, K (W/m-K), i.e.,

$$F_{soil}(0,t) = - K \left(\frac{\partial T_g(z,t)}{\partial z} \right)_{z=0} . \tag{4}$$

Using the Laplace method (Jaeger, 1953), we find that the thermal flux at the surface appears as a convolution of past surface temperatures with the thermal response of the soil, i.e., if thermal inertia, $p = Kk^{-1/2}$ in units of $J/kg\text{-}K\text{-}s^{1/2}$, then

$$F_{soil}(0,t) = -p \left\{ \frac{\partial}{\partial z} \left(\frac{z}{2\sqrt{\pi}} \int_0^\infty T_g(0,t-t') \, \frac{e^{-z^2/4\kappa t'}}{t'^{3/2}} \, dt' \right) \right\}_{z=0} . \tag{5}$$

Equation (5) is solved by replacing the integral by a summation over time intervals of length $\tau = \tau_o/N$ where τ_o is the number of seconds in one year, and N is large enough that the surface temperature, $T_g(0,t)$, changes little in any time interval. For τ = 600 s (10 minutes) which corresponds to N = 52,560, the numerical form of (5) is

$$F_n = \frac{p}{\sqrt{\pi\tau_o}} \sum_{s=0}^{N-1} Tg_{n-s} \, \phi_s \tag{6}$$

where $F_n = F_{soil}(0,nt)$, $Tg_{n-s} = T_g(0,(n-s)t)$, and weighting coefficients, ϕ_s, are independent of the thermal properties. In terms of Tg, the boundary condition becomes

$$\frac{p}{\sqrt{\pi\tau_o}} \sum_{s=0}^{N-1} Tg_{n-s} \, \phi_s = e\sigma Tg_n^4 - Fsun_n - Fsky_n - A(Tair_n - Tg_n) . \tag{7}$$

For iteration, r, a linear approximation for ground emission, and the approximation, $Tg^r_{n-s} \approx Tg^{r-1}_{n-s}$ for s>0, yields

$$Tg_n^r = \frac{\frac{p}{\sqrt{\pi\tau_o}} \sum_{s=1}^{N-1} Tg_{n-s}^{r-1} \phi_s + 3e\sigma\left(Tg_n^{r-1}\right)^4 + Fsun_n + Fsky_n + A\ Tair_n}{\frac{-p\phi_0}{\sqrt{\pi\tau_o}} + 4e\sigma\left(Tg_n^{r-1}\right)^3 + A} \tag{8}$$

For an initial $Tg_n^1 = Tair_n$ for all n, (8) converges in 5 iterations to $|Tg_n^5 - Tg_n^4| < 0.001$ K for all n.

Table 1 represents a realistic range of thermal constitutive properties for dry sandy to loamy soils [16]. Higher densities like those of very rocky soils were not included because they are rarely the target of SSM/I investigations. Latitude was 47^o, cloud cover was 20%, F_{sky} was based upon a typical Great Plains atmosphere, and winds were a constant 5 m/s.

Table 1. Thermal Constitutive Properties

Case	Density (kg/m^3)	Specific Heat (J/kg-K)	Thermal Cond. (W/m-K)	Thermal Inertia ($J/kg\text{-}K\text{-}s^{1/2}$)
1	1,000	1,000	0.17	412
2	1,400	1,000	0.17	490
3	1,800	1,000	0.17	550

Radiobrightness Model. To first order, the radiobrightness of a dry soil whose interface is quasi-specular to is

$$T_b(t) = e_m \left\{ T_g(0,t) + \frac{\cos\theta_g}{\kappa_m} \left(\frac{\partial T_b(t)}{\partial z} \right)_{z=0} \right\} \tag{9}$$

where $e_m = 1 - R(\theta)$ and $R(\theta)$ is the Fresnel reflectivity at $\theta = 53^o$ -- the SSM/I incidence angle, θ_g is direction with respect to vertical of a ray within the soil (θ_g is related to θ by Snell's law), and κ_m is microwave absorptivity in the soil. In terms of the thermal model and (3), this becomes

$$Tb_n = e_m \left(Tg_n - \frac{\cos\theta_g F_n}{\kappa_m K} \right). \tag{10}$$

The intrinsic dielectric properties for dry soil are not functions frequency. However, frequency appears in absorptivity, so we choose 19 GHz -- the lowest of the SSM/I frequencies (Table 2).

Table 2. Dielectric Properties at 19 GHz and $\theta = 53^{\circ}$

Case	Relative Permittivity	Loss Tangent	Microwave Absorptivity	V-Pol. Emissivity	H-Pol. Emissivity
1	3.3	0.23	166 m^{-1}	0.99	0.78
2	4.6	0.32	273 m^{-1}	0.96	0.70
3	5.9	0.41	396 m^{-1}	0.94	0.63

Conclusions. Figure 1 shows predicted soil surface temperatures and V- and H-polarization radiobrightness temperatures for the three soil models. The uppermost three plots are the diurnal temperatures for December 25 (the choice of date was arbitrary), and the lower four sets of plots are the annual temperatures for 2:00 am/pm and 6:00 am/pm local solar time. The 6:00 am/pm times are the current SSM/I overflight times, while the 2:00 am/pm times correspond very nearly to diurnal minima and maxima, respectively.

For this limited range of thermal inertia, there is very little difference among the surface temperature predictions, but there is considerable difference among the radiobrightness predictions. That is, the effect of density upon emissivity dominates the effect of density upon thermal response. While this might be read as a negative result, it means that the quantity and state of moisture, and processes associated with vegetation and evapotranspiration dominates the thermal response. Soil composition plays its role primarily through characteristic differences in stored moisture.

3.2 An annual model of the radiobrightness of wet soils

The thermal module of the MCRR/Annual model follows the approach of England (1990) for a periodically heated, moist soil halfspace that is subject to freezing and thawing. Permitting the moisture in soil to freeze and thaw means that the heat flow equation (1) cannot be linearized. The problem is particularly difficult because phase boundaries propagate in time, and because soils, particularly clay-rich soils, freeze over a range of temperatures rather than at 0° C. That is, their phase boundaries are diffuse (Hoekstra and Delaney, 1974). We employ a modified Chernous'ko method—a finite element method that tracks isotherms within the soil—to achieve an annual solution to equation (1). The MCRR/Annual model typically converges to within 0.01 K after 5 iterations for all 10 minute intervals of an annual cycle. Model predictions are tested by their reasonableness and, for non-freezing soils, by comparison with numerical solutions to the variable time interval form of the Laplace analytical method that was developed for dry soils.

Figures 2 and 3 show examples of solutions for prairie soils near Bismarck, North Dakota. The 7% moist soil is atypically dry while the 25% moist soil is atypically wet. We note that diurnal extremes in soil temperature are relatively

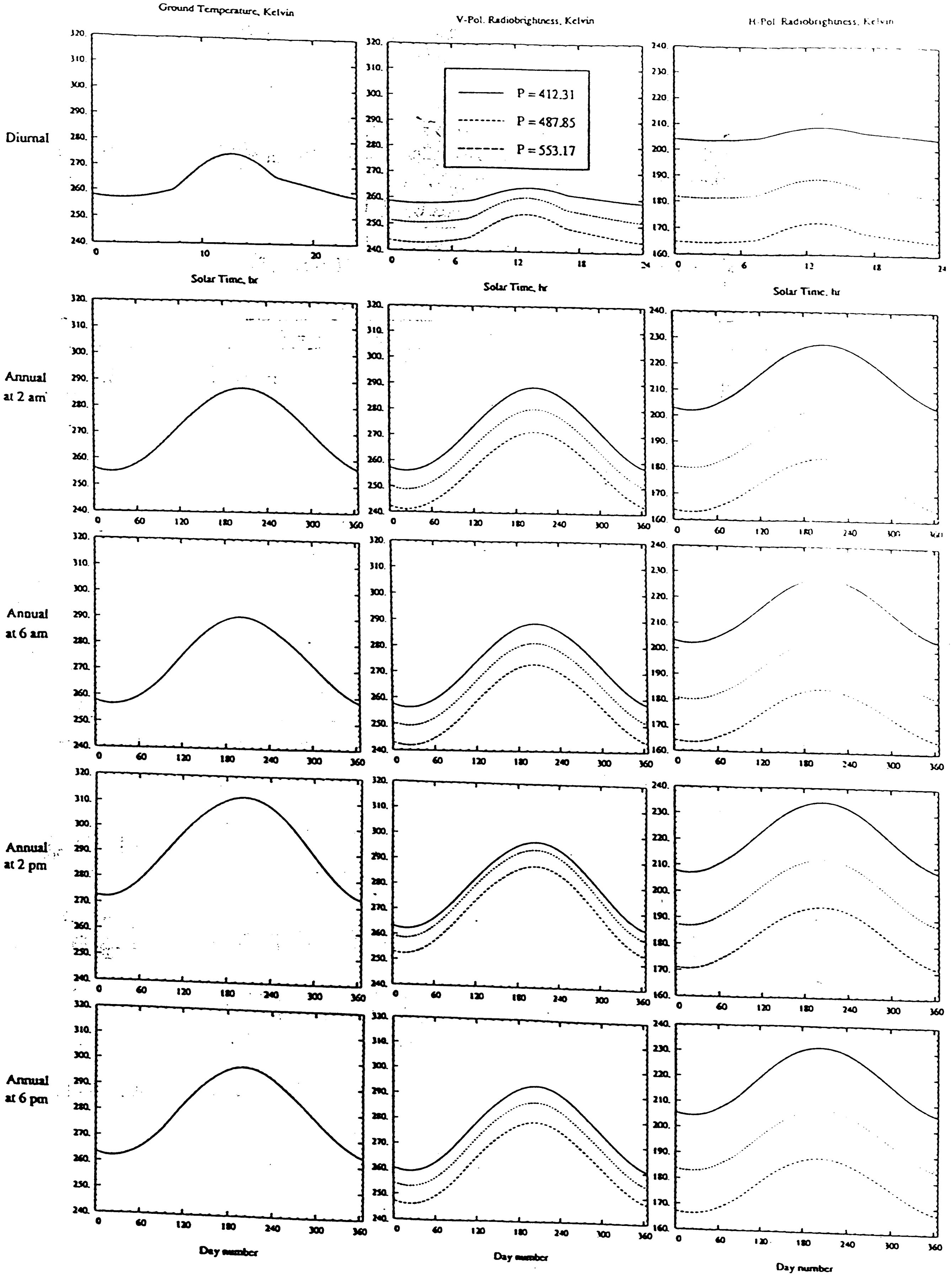


Fig. 1. Diurnal and annual surface temperature and radiobrightness of dry soil.

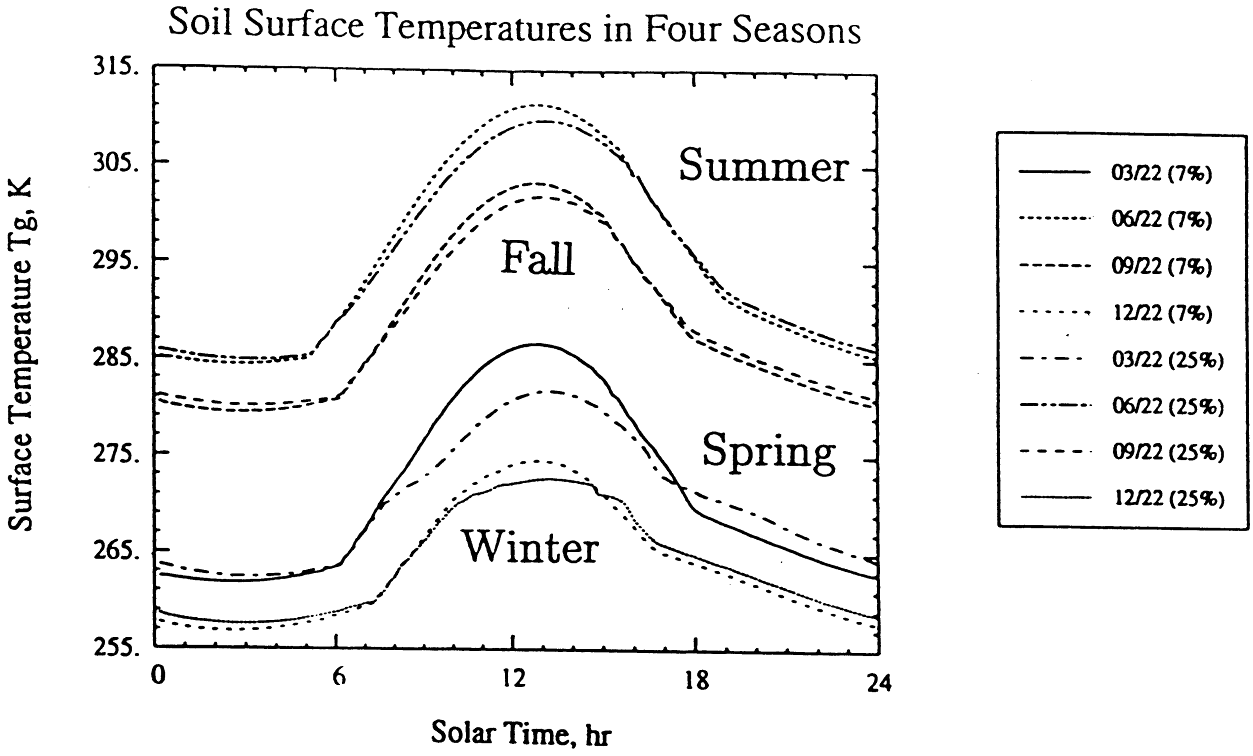


Fig 2. Predicted diurnal surface temperature for prairie near Bismarck, North Dakota.

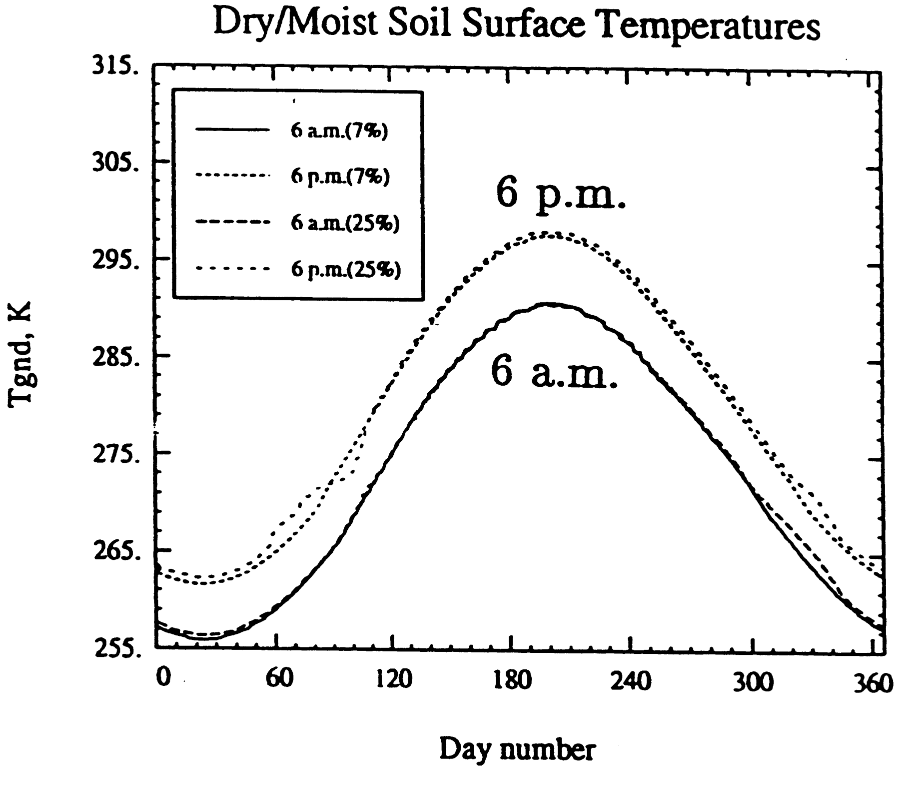


Fig 3. Predicted annual surface temperature for prairie near Bismarck, North Dakota.

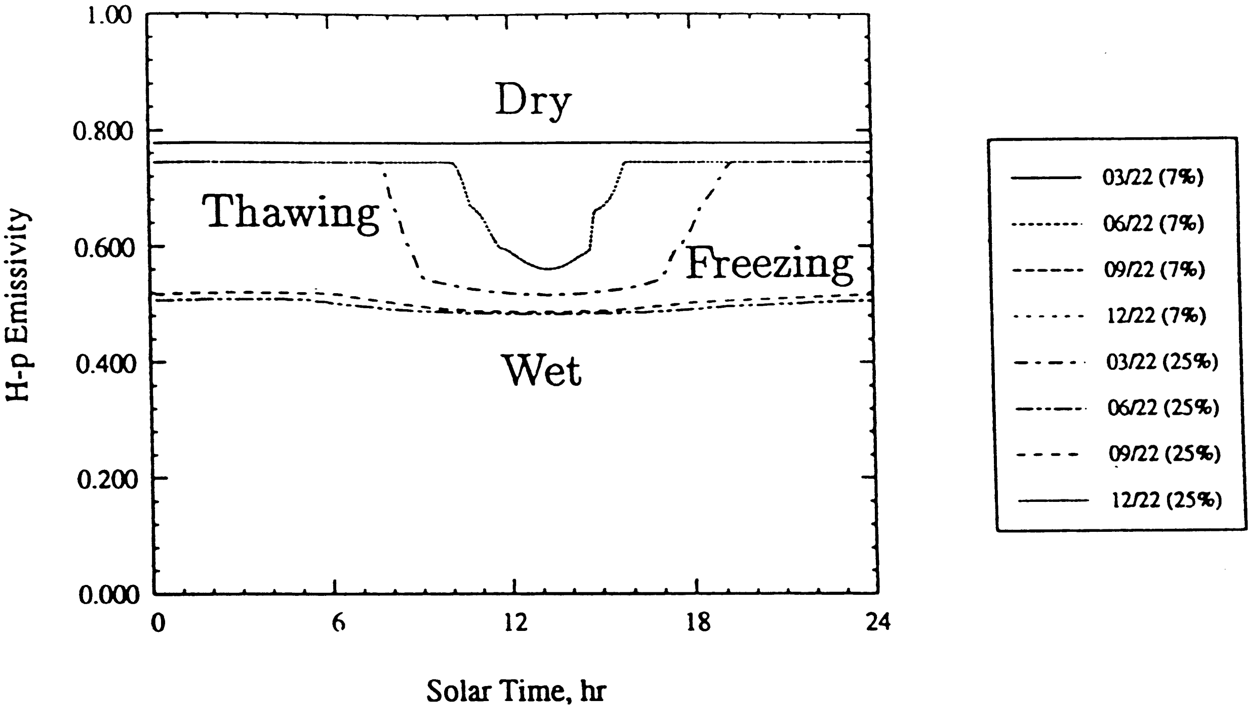


Fig 4a. 19 GHz, H-polarized diurnal emissivity.

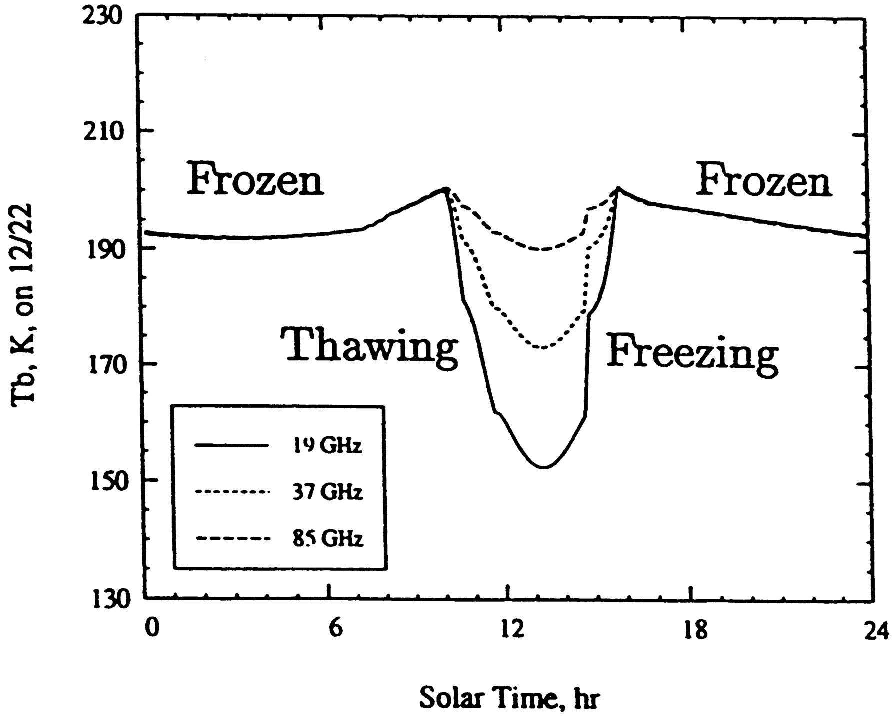


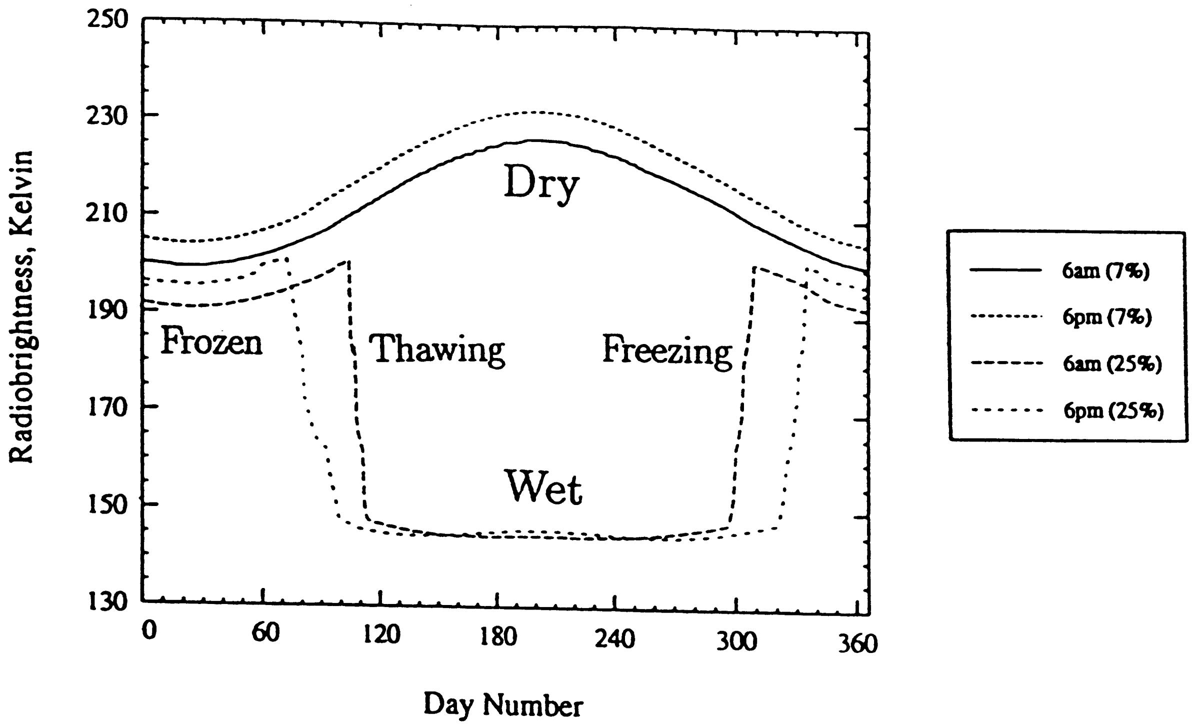
Fig 4b. 19.35, 37.0, and 85.5 GHz, H-polarized diurnal radiobrightness.

sensitive to moisture content but annual extremes are not. Moisture dependent anomalies in the annual cycle occur during fall freezing and spring thawing.

The radiobrightness module (based upon (10)) of the MCRR/Annual model is the first-order approximation to emission from a semi-transparent halfspace whose temperature varies with depth. The MCRR models predict V- and H-polarized radiobrightnesses for a choice of incident angle and frequencies appropriate to either the Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR), (50^{o} and 10.7, 18.0, and 37.0 GHz [Gloerson and Hardis, 1978]), or the Defense Meteorological Satellite's Special Sensor Microwave/Imager (SSM/I), (53.1^{o} and 19.35, 37.0, and 85.5 GHz [Hollinger et al, 1987]). Microwave emissivity, e_m, ray angle within the soil, θ_g, and microwave absorbtivity, κ_m, are each a function of the complex permittivity of the moist soil. Because of the moisture, this complex permittivity varies with temperature and, thus, with time so that emissivity, ray direction, and optical depth become time dependent.

Figures 4a and 4b show examples of the 19 GHz, H-polarized emissivity during a diurnal cycle and the corresponding radiobrightness, respectively. Note that moisture causes an extreme variation in emissivity for winter and spring days when freezing and surficial thawing occur. Figure 5 shows the annual radiobrightness at 6:00 am and 6:00 pm—times of SSM/I overflight. The precipitous drop in radiobrightness during the spring thaw or rise during the fall freeze should be evident among the SSM/I data.

Fig 5. 19.35 GHz, H-polarized annual radiobrightness.



We have examined SSM/I data for August through December of 1988. Figure 6a is a plot of atmospherically corrected, temporally filtered, 19 GHz, H-polarized, 6:00 am radiobrightness averages for a 100 km square region centered on Fargo, North Dakota. Radiobrightness was estimated by correcting the SSM/I antenna temperatures for a standard atmosphere based upon observed differences between 19.35 and 22 GHz data, and upon an assumed water vapor scale height of 3 km. The temporal filter was a 7-day running boxcar. Relevant meteorological data of precipitation, snowpack thickness, and minimum and maximum air temperatures are shown in Figure 6b. Meteorological data are not temporally filtered. Qualitatively, the rainfall in mid-September correlates with the dip in radiobrightness during the second half of September; the snowpack during the second half of November correlates with the anomalously low radiobrightness during the same period; the low air temperatures beginning in mid-November and extending through December correlate with the rise in radiobrightness during December; and the new snowpack in late December correlates with the precipitous drop in radiobrightness in late December. We note that the period of cold temperatures and freezing soil does correspond to an increase in radiobrightness as predicted by the model. We also observe the dominant volume scatter darkening caused by dry snow.

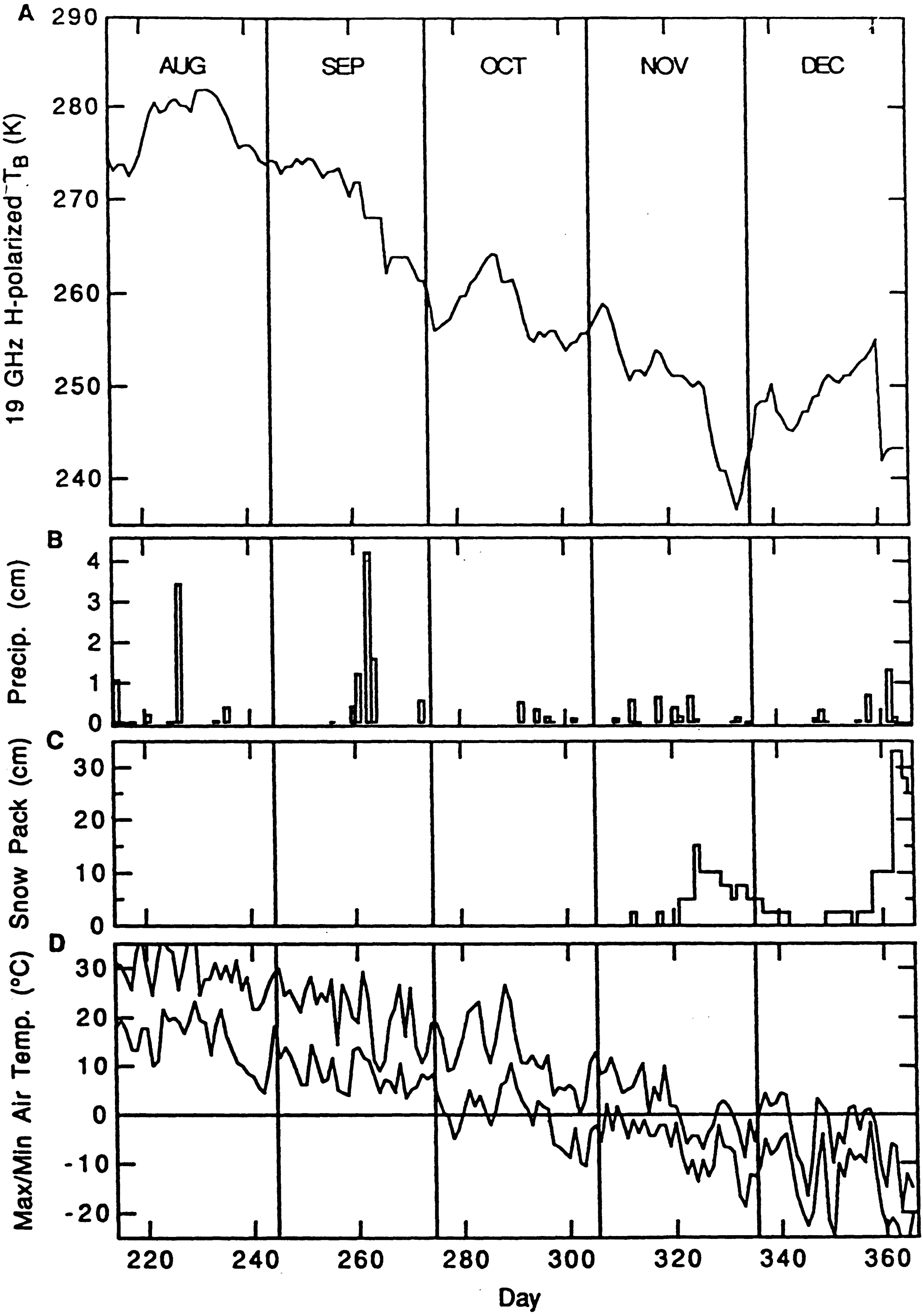


Fig 6. (a) 19 GHz, H-polarized, 6:00 am, SSM/I radiobrightness near Fargo, North Dakota (b) daily precipitation, (c) snow pack depth, and (d) high and low air temperatures, August through December, 1988.

3.3 The Tower Mounted Radiometer System

Our Tower Mounted Radiometer System (TMRS) was built in-house over the two year period from June, 1990, to June, 1992. It has 19.35, 37.0, and 85.5 GHz radiometers, a thermal IR radiometer, solar and net flux radiometers, a met station, and heat flow, moisture, and temperature probes that go in the soil. The radiometers are single polarization and mechanically switchable (but we are adding dual polarization prior to the Alaskan work). The radiometers are on a 10 m portable tower and the electronics are in a 9 foot enclosed trailer pulled by a Jeep Cherokee. The system is completely computer controlled through a Macintosh interface. If we can get a telephone line in the field, as we have in our prairie experiment near Sioux Falls, South Dakota, we call once per day and takeover local control of TMRS with a computer in our Lab. With TMRS slaved to the Lab computer, we get data dumps for the previous 24 hours and perform any housekeeping that TMRS requires. Data takes are programmed -- currently at 15 minute intervals. A data take consists of recording all sensor and housekeeping data, opening the radiometer door to the sky measurement position, recording sky radiance at all frequencies, opening the door to the ground viewing position (53 degree incidence angle), recording ground radiance at all frequencies, and closing the door. The details of TMRS have been described by Galantowicz and England, 1992.

4. A Discussion of Future Work

4.1 Model enhancements

The additions of snow and of vegetation are necessary refinements to the MCRR models. With vegetation comes evapotranspiration and scattering, and with snow comes scattering. We will borrow from the GCM land-atmosphere parameterizations to incorporate evapotranspiration. There are many volume scattering models which might be applied to microwave emission from snow (e.g., Gurvich et al, 1973; England, 1975; Tsang and Kong, 1976; Fung and Chen, 1981; and Tsang and Ishimaru, 1987), and to grass and sedge vegetation (e.g., Lang and Sidhu, 1983; Ulaby et al, 1990a; and Sarabandi et al, 1990). The simplest would be to treat the snow or the canopy as a Rayleigh scattering layer. The most complex for vegetation would be to develop scattering matrices for leaves and stems based upon their dielectric properties, size, orientation, and distribution, and incorporate these scattering matrices in a multi-layer, radiative transfer model, e.g., the Michigan Microwave Canopy Scattering Model (MIMICS) (McDonald et al, 1989, and Ulaby et al, 1990b). The Rayleigh scattering layer would be unrealistically simple, but the MIMICS models are likely to be unnecessarily complex. MIMICS models are designed to predict radar backscatter where scattering is the dominant process. Emission, absorption, and scattering are equally important to a radiobrightness model of a canopy so that second order scattering might safely be ignored. That is, first order scattering models based upon leaf and stem statistics should reliably predict scatter-induced darkening without the complexity of solving the radiative transfer equation. Dry snow is not absorbing so that one of the many radiative transfer models must be used.

4.2 TMRS enhancements

Currently, the TMRS microwave radiometers are single polarization (but mechanically switchable). Our recent theoretical models suggest that frozen soil classification is improved if both V- and H-polarization data at 19.35 and 37.0 GHz are used along with 85.5 GHz data of either polarization. Therefore, we are building new, dual polarization radiometer modules for the 19.35 and 37.0 GHz frequencies. The old radiometers will act as backup systems for the Alaska work.

The original TMRS radiometer configuration was that IF amplification occurred within the radiometers on the tower. The IF signal was routed over coaxial cable to the instrument trailer where detection were occurred. We are concerned that the extreme temperature fluctuations in the Alaska experiment may result in cable losses that vary with time. Because this would appear as a radiometer gain variation, we have decided to move the detectors and the analog-to-digital sampling to the radiometer box on the tower where temperature must be precisely controlled anyway. The digital signals from the radiometers and the housekeeping instructions to the radiometers will be carried over optical fibers (optical fibers are known to be tolerant of temperature fluctuations). These modifications will be complete by July, 1993.

4.3 The Alaskan field work

Our plan had been to conduct our field experiment at the University of Alaska's Toolik Field Station. It lay in wetlands permafrost along the Alaskan Pipeline in the northern foothills of the Brooks Range. However, after much discussion, it appeared that the cost of keeping the Toolik Station open beyond their normal end of August closing time could be prohibitive. Furthermore, because the Toolik site had been used as a dump during pipeline construction, we became concerned that its thermal regime might have been seriously altered. For these reasons the Toolik site was discarded.

Only a few miles north on the pipeline road, a Department of Transportation refueling (DOT) depot is open continuously and has power and telephone service. DOT has been very helpful during the discussions of our possible use of their facilities. We have acquired most of the necessary permits and are hopeful that this will become our field site.

4.4 Safety

Working on the North Slope of Alaska during fall can be hazardous. The PI has had two seasons of field experience in Antarctica and has worked on the North Slope in mid-spring. The primary graduate student recently completed a two-day, snow survival course offered by EMI in New England as part of his preparations for the Alaskan work. Our practice will be to always work in pairs; to stay on the pipeline road or within an specified distance of the DOT depot; and to carry a CB radio and survival gear in the jeep.

5.0 Tasks for Year Two

Our specific tasks for the period of September 1, 1992, through August 31, 1993, follow:

(a) Include vegetation in the annual MCRR model.

(b) Develop an algorithm for correcting the SSM/I antenna temperatures for emission and absorption in the atmosphere.

(c) Modify TMRS for the Alaska field experiment.

(d) Establish the Alaska field experiment by the end of August, 1993.

6.0 References

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