Radiation Laboratory Technical Report 036365-1-T

Annual Report for Year 2
and Budget Submittal for Year 3
under NASA Grant NAGW-5203

Estimating Water Stored in Soil and Vegetation Using LSP/R Models and Assimilated Satellite Radiobrightness

Submitted by: Anthony W. England
Principal Investigator

Department of Atmospheric, Oceanic, and Space Science; and
Department of Electrical Engineering and Computer Science
The University of Michigan
Ann Arbor, Michigan 48109-2122
Tel: (313)-764-8221
FAX: (313)-763-2447
england@umich.edu

Requested Year 3 Period of Performance: July 1, 1998 - June 30, 1999
Reporting date: May 4, 1998

36365-1-T = RL-2509

CONTENTS

Project Objectives

My students and I are developing Land-Surface Process/Radiobrightness (LSP/R) models that use satellite radiobrightness data to improve estimates of stored water in prairie and in arctic tundra. We are also examining the relationship between stored water and soil wetness. We define stored water as the physical measure of moisture available to the atmosphere through evaporation and transpiration, and soil wetness as the parameter that represents stored water in highly parameterized, atmospheric models.

Our strategy is to develop sophisticated, one-dimensional Land-Surface Process (LSP) models for coupled moisture and temperature transport in soil and vegetation. These LSP models are forced by weather or by atmospheric models, and they maintain running estimates of moisture and temperature profiles in the soil and vegetation. We also develop Radiobrightness (R) models that use these profiles to predict the microwave brightness that would be observed by a satellite radiometer. Differences between observed and predicted radiobrightnesses will be used to improve the current estimates of stored water.

Background

The modeling and experimental underpinnings for these investigations were established during our earlier project, "Linking GCM Hydrologic Parameters to the Radiobrightness of Northern Prairie and Arctic Tundra," funded by NASA through Grant NAGW - 3430. The earlier grant enabled us to develop coupled temperature and moisture hydrology models for freezing and thawing snow and soils, and microwave emission models for snow, soil, and prairie grass.

We built a field instrument system for a series of Radiobrightness Energy Balance Experiments (REBEX) to obtain data for development and validation of our LSP/R models. This field system is comprised of a Tower Mounted Radiometer System (TMRS), a Micro-Meteorological Station (MMS), and a Command and Data Management System (CDMS). TMRS consists of 19 and 37 GHz, V- and H-polarized radiometers; an 85 GHz H-polarized radiometer; a thermal infrared radiometer; and a video system. TMRS is mounted on a 10 meter portable tower. The MMS consists of a weather station; up- and down-welling short and long wavelength radiation monitors; net radiation monitor; Bowen ratio instrument; and several soil temperature, moisture, and heat flow probes. The CDMS consists of a multiplexing system; a local computer for autonomous control; a data recording system; and means for slaving the local computer to a computer in our laboratory through a phone link. The CDMS is housed in a trailer pulled by a jeep.

We assisted the National Snow and Ice Data Center (NSIDC) in developing the Equal Area Scalable Earth–Grid (EASE–Grid) for optimal resampling of satellite radiobrightness data to an Earth-based grid. NSIDC now publishes a retrospective EASE-Grid data product based upon Special Sensor Microwave/Imager (SSM/I) brightnesses. We routinely use our version of EASE-Grid to examine the temporal histories of contemporaneous SSM/I data for the REBEX field sites and their surrounding regions.

Highlights of the Current Project

(a) We validated our LSP/R model for prairie grassland in fall. This was the culmination of Mr. Yuei-An Liou's Ph.D. research. This work and the work that led to it have appeared in a series of recently published papers. Examples of the excellent agreement between model and observation are shown in Figure 1(a-c). Note that the model was forced by weather data recorded during REBEX-1.

(b) We have begun to use our models to examine the problems of scaling. For example, we have compared predicted microwave brightnesses of tiled and homogeneous fields. In the tiled case, prairie grasses covered a specified percentage of a field at a vegetation column density of 4 kg/m^2. The rest of the field was bare soil. In the corresponding homogeneous case, that same vegetation was spread uniformly over the field. In all cases, field models were forced by climatic weather for July near Sioux Falls, South Dakota. Our results will appear in Radio Science this spring. Figure 2 from that paper shows that L-band brightness is relatively independent of the distribution of grass while 19 GHz brightness exhibits a strong dependence.

(c) We are developing LSP/R models for arctic tundra. As part of his Ph.D. research, Mr. Ed Kim successfully completed REBEX-3 – a 1-year, NSF-funded experiment on the Alaskan North Slope during 1994-1995. The NSF grant ended before he completed his modeling studies. I am using NAGW-5203 to support Mr. Kim while he completes development and validation of his LSP/R model for moist acidic tundra. This work will be completed during the summer of 1998. I anticipate using his results to guide our future NSF-funded work in the arctic.

(d) We are developing growing season LSP/R models for grassland and bare soil. As part of her Ph.D. research, Ms. Jasmeet Judge successfully led REBEX-4 – a spring and summer cooperative prairie experiment undertaken by our group and the Climate Research Branch of the Canadian Atmospheric Environmental Service. The experiment occurred during June through August, 1996, on the site of the EROS Data Center, Sioux Falls, South Dakota. Ms. Judge should complete her graduate studies by the end of 1998.

(e) As an opportunity to supplement our growing season experiment, we successfully completed REBEX-5 – our contribution to NASA's Southern Great Plains 1997 (SGP'97) experiment in Oklahoma. TMRS data – V- and H-polarized brightnesses at 19.35 and 37.0 GHz, H-polarized brightnesses at 85.5 GHz, and thermal infrared brightnesses – for winter wheat and wheat stubble during SGP'97 are now available on the Web; we are using EASE-Grid to resample daily SSM/I data for Oklahoma and will make these data available on the Web by the end of April, 1998; and we will extend our prairie grassland model to winter wheat and make the results available on the Web by the end of August, 1998.

(f) We are developing a direct conversion, L-band radiometer for TMRS. Our field data and models have convinced us that the lowest frequency of the SSM/I – 19.35 GHz – is simply too high to reliably estimate near-surface soil moisture to the 4 volume percent desired by hydrologists and atmospheric modelers. While we never questioned the conclusion of many investigations that L-band was optimum for soil moisture, our motive for using SSM/I data was to derive as much as possible about prairie and arctic tundra – relatively homogeneous terrains with modest vegetation densities – from operationally available data. We have identified soil moisture signatures in SSM/I images of the Great Plains and of the arctic, demonstrated that prairie soils can be classified as frozen or thawed using discriminants based upon SSM/I data, but, to achieve sufficiently accurate estimates of near-soil moisture, we must use 1.4 GHz.

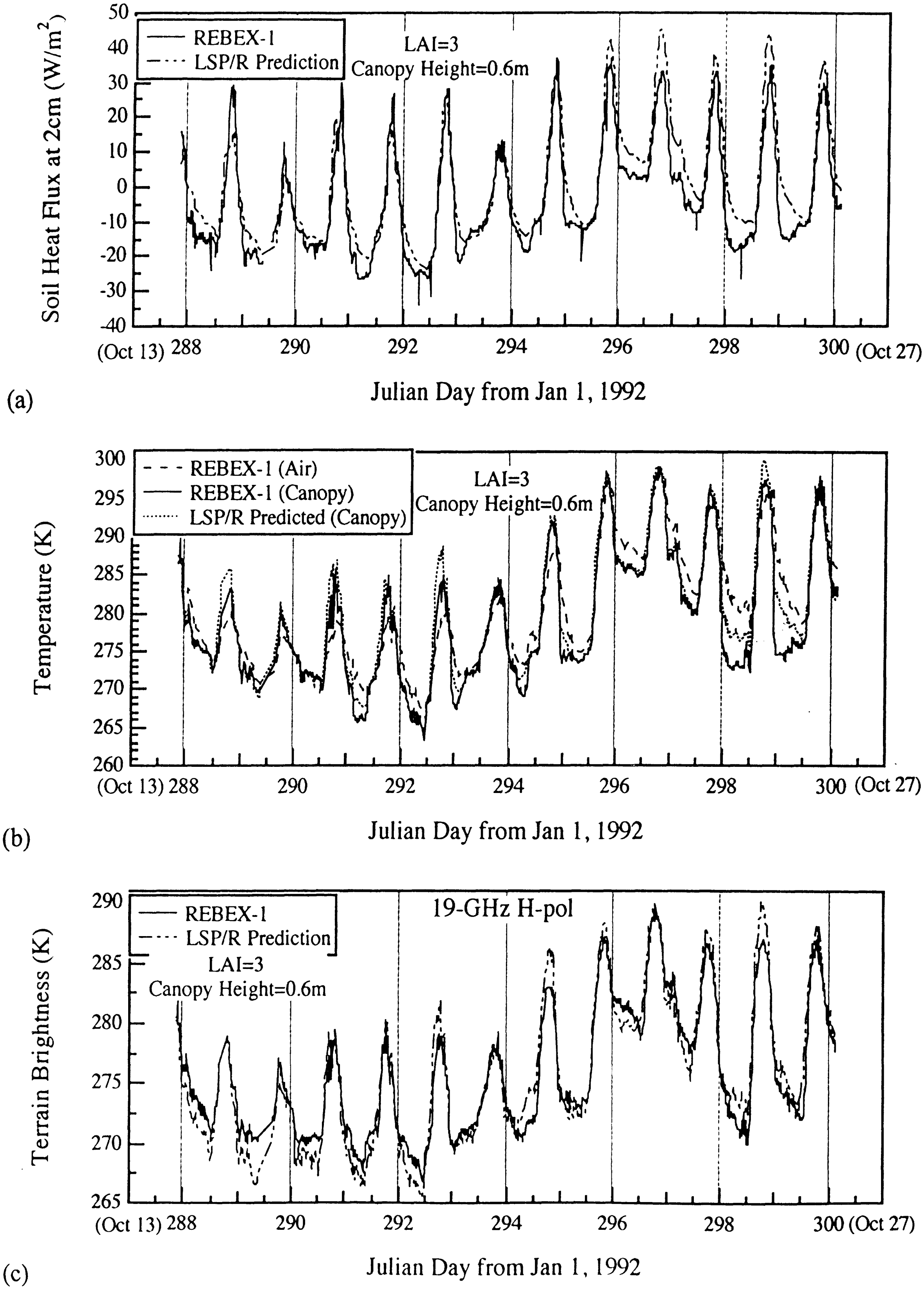
Our new 1.4 GHz field radiometer will be simple and robust. It will have very low noise and employ digital sampling after RF amplification for direct conversion. We emphasize these characteristics because they are essential for future application to Synthetic Thinned Array Radiometry (STAR) technology receivers. As part of his Ph.D. research, Mr. Mark Fischman is developing the new receiver, analyzing its noise characteristics, and building two prototypes to demonstrate stable correlation for a STAR technology receiver.

We anticipate that others will want to build copies of this receiver. We found that, once we began using TMRS in the field, other investigators became interested in acquiring a similar capability. For example, we assisted the Atmospheric Environment Service of Canada with development of their SSM/I frequency field system for snow investigations. There has already been interest in the new radiometer. We are thoroughly documenting its design and construction to aid others in this process.

(g) We have completed most of the very long-duration field experiments that we had planned for this series of projects. There will be many more field projects, but these will focus upon seasonal phenomena, comparing observations among various terrains, and upon scaling from point measurements to satellite measurements. These new investigations require moving from site-to-site at intervals of a few days or even during a single day. This is unworkable with our current tower system because both erecting and stowing the tower require at least one day of intensive labor.

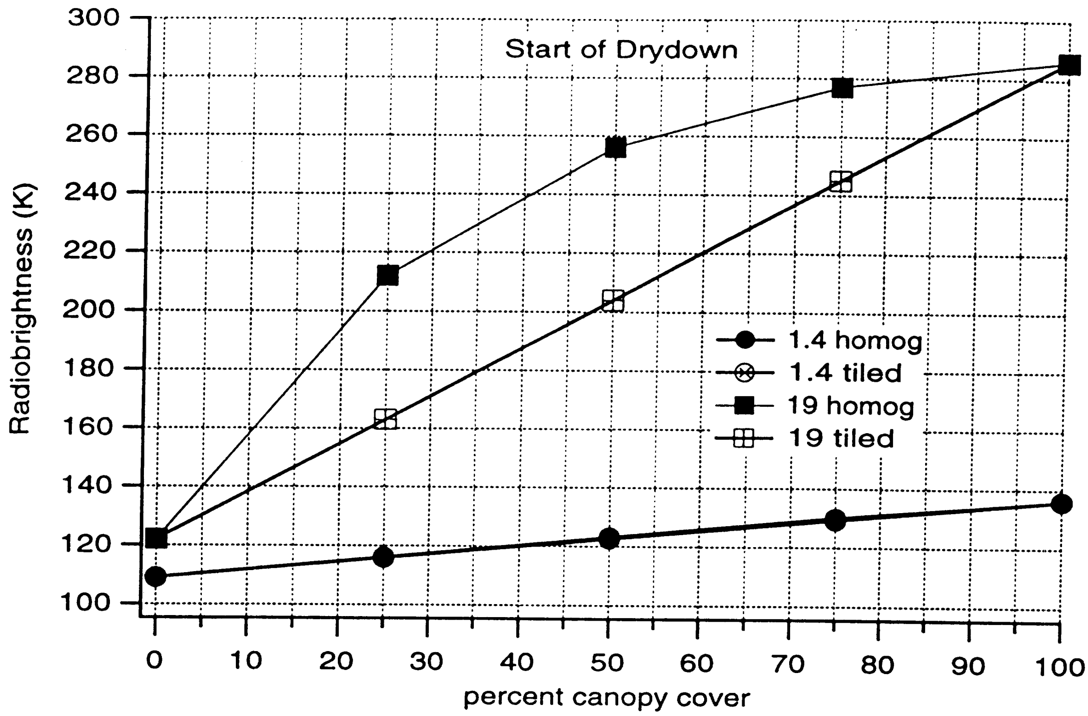
We are replacing our tower with a boom truck. The system that we anticipate acquiring has only a 36 foot reach – two-thirds the reach of the Goddard truck – but is better suited to flexible operations by graduate students. I have acquired funds for purchasing the system (Federal funds will not be used) and we anticipate a request-for-bids this month. Our goal is to have the new Truck Mounted Radiometer System – still called TMRS – ready by late fall, 1998.

Figure 1



Soil Heat Flux at 2cm (W/m^2)
REBEX-1
LSP/R Prediction
LAI=3
Canopy Height=0.6m
50
40
30
20
10
0
-10
-20
-30
-40
(Oct 13) 288
290
292
294
296
298
300 (Oct 27)
(a)
Julian Day from Jan 1, 1992
Temperature (K)
REBEX-1 (Air)
REBEX-1 (Canopy)
LSP/R Predicted (Canopy)
LAI=3
Canopy Height=0.6m
300
295
290
285
280
275
270
265
260
(Oct 13) 288
290
292
294
296
298
300 (Oct 27)
(b)
Julian Day from Jan 1, 1992
Terrain Brightness (K)
REBEX-1
LSP/R Prediction
LAI=3
Canopy Height=0.6m
19-GHz H-pol
290
285
280
275
270
265
(Oct 13) 288
290
292
294
296
298
300 (Oct 27)
(c)
Julian Day from Jan 1, 1992

Figure 2



Journal articles appearing during period of this grant:

(1) Judge, J., J.F. Galantowicz, A.W. England, and P. Dahl, Freeze/thaw classification for prairie soils using SSM/I radiobrightnesses, IEEE Trans. Geosci. Remote Sensing, 35, pp. 827-832, 1997.

(2) Liou, Y.A., and A.W. England, A Land Surface Process/Radiobrightness model with coupled heat and moisture transport in soil, IEEE Trans. Geosci. Remote Sensing, 36, pp. 273-286, 1998.

(3) Liou, Y.A., and A.W. England, A Land Surface Process/Radiobrightness model with coupled heat and moisture transport for freezing soils, IEEE Trans. Geosci. Remote Sensing, 36, pp. 669-677, 1998.

(4) Liou, Y.A., J.F. Galantowicz, and A.W. England, A Land Surface Process/Radiobrightness model with coupled heat and moisture transport for prairie grassland, accepted by IEEE Trans. Geosci. Remote Sensing, July, 1997.

(5) Liou, Y.A., E.J. Kim, and A.W. England, Radiobrightness of prairie soil and grassland during dry-down simulations, Radio Science, 33, pp. 259-265, 1998.

Refereed Symposia proceedings articles published during period of this grant:

(1) England, A.W., HYDROSTAR: An ESSP Project to provide a 2-year global record of surface soil moisture, International Geoscience and Remote Sensing Symposium (IGARSS'97), Singapore, Malaysia, August 3-8, 1997.

(2) Judge, International Geoscience and Remote Sensing Symposium (IGARSS'97), Singapore, Malaysia, August 3-8, 1997.

(3) Liou, Y.A., Y.C. Tzeng, E. Kim, and A.W. England, Retrieval of soil moisture using a dynamic learning neural network trained with a 1-dimensional hydrology/radiobrightness model, International Geoscience and Remote Sensing Symposium (IGARSS'97), Singapore, Malaysia, August 3-8, 1997.

(4) Kim, E.J., and A.W. England, Land surface process modeling and passive microwave remote sensing of arctic tundra regions, accepted by International Geoscience and Remote Sensing Symposium (IGARSS'98), Seattle, WA, July 6-10, 1998.

(5) Kim, E.J., C. O'Kray, N. Hinds, A.W. England, M.J. Brodzik, K. Knowles, and M. Hardman, A custom EASE-Grid SSM/I Processing System, accepted by International Geoscience and Remote Sensing Symposium (IGARSS'98), Seattle, WA, July 6-10, 1998.

(6) Judge, J., and A.W. England, A growing season LSP/R model for Southern Great Plains, accepted by International Geoscience and Remote Sensing Symposium (IGARSS'98), Seattle, WA, July 6-10, 1998.

(7) Fischman, M.A., and A.W. England, Development of a direct-conversion receiver for Synthetic Thinned-Array Radiometry, accepted by International Geoscience and Remote Sensing Symposium (IGARSS'98), Seattle, WA, July 6-10, 1998.

Papers given at symposia without Proceedings:

(1) Judge, J., A.W. England, and P. Dahl, Freeze/Thaw classification of prairie soils using SSM/I radiobrightnesses, 3rd International Workshop on the Application of Remotes Sensing in Hydrology, Greenbelt, MD, Oct. 16-18, 1996.

(2) Liou, Y.A., and A.W. England, The sensitivity of SSM/I and L-band frequencies to soil moisture in prairie grassland, 3rd International Workshop on the Application of Remotes Sensing in Hydrology, Greenbelt, MD, Oct. 16-18, 1996.

(3) Kim, E.J., and A.W. England, Linking passive microwave observations to a Land-Surface Process model of tundra areas, 3rd International Workshop on the Application of Remotes Sensing in Hydrology, Greenbelt, MD, Oct. 16-18, 1996.

(4) England, A.W., Y.A. Liou, J.F. Galantowicz, and Jasmeet Judge, Radiobrightness of prairie soil and grassland during dry-down simulations, *Special Session: Microwave Radiometer Observations of Soil Moisture and Surface Temperature*, URSI 5th Specialist Meeting, "Microwave Radiometry and Remote Sensing of the Environment", Boston, MA, November 4-6, 1996.

(5) Kim, E.J., and A.W. England, Passive microwave observations and land surface process modeling of arctic tundra regions, *Special Session: Microwave Radiometer Observations of Soil Moisture and Surface Temperature*, URSI 5th Specialist Meeting, "Microwave Radiometry and Remote Sensing of the Environment", Boston, MA, November 4-6, 1996.

(6) Kim, E.J., Y.-A. Liou, and A.W. England, A sensitivity study of a one-dimensional hydrology/radiobrightness model for grassland areas, Annual Meeting of the American Meteorological Soc., Long Beach, CA, February 2-7, 1997

(7) Liou, Y.A., and A.W. England, The sensitivity of a Land-Surface Process/Radiobrightness model to soil and vegetation parameters, accepted for A.G.U. Spring Meeting, Baltimore, MD, 1997.

(8) Liou, Y.A., J.P. Su, Y.C. Tzeng, and A.W. England, Radiometric studies of the land surface: Applications of neural networks, accepted for A.G.U. Spring Meeting, Baltimore, MD, 1997.

(9) England, A.W., Estimating water stored in soil and vegetation using LSP/R models and assimilated satellite radiobrightness, NASA Soil Moisture Workshop, Columbia, MD, March 2, 1998.

(10) Judge, J., D. Boprie, M.A. Fischman, E.J. Kim, C. O'Kray, and A.W. England, SSM/I brightnesses for wheat stubble during SGP'97, SGP'97 Workshop, Columbia, MD, March 3-5, 1998.

NAGW-5203 Budget for Year-3 Performance Period: July 1, 1998 through June 30, 1999		
Salaries and Wages	Number	Cost
PI, Tony England - months @ $11,680/mo	0.25	$2,920
Electronics Technician - months @ 4,025/mo	6	$24,151
Grad Student Research Assistants 10 months @ 1470/mo/stu 2 months @ 1413/mo/stu	2	$35,052
Undergrad Research Assistants (hr/wk) 48 weeks @ $7.50/hr	15	$5,400
TOTAL SALARIES & WAGES		$67,523
Fringe Benefits (28% of PI&ET+$300/mo grad stu)		$14,780
Other Direct Costs		
Grad Student Tuition		
Candidate @3660/term	2	$7,320
Pre-Candidate @ 5264/term	2	$10,528
Lab and Consumable Supplies		$1,022
Communications (Proj-related toll charges, fax, copying, overnight mail)		$500
Present papers at conference		$1,150
Publication charges		$1,420
Equipment		$8,000
TOTAL DIRECT COSTS		$112,243
Total Indirect Costs (52.5% of Direct Costs less tuition & equipment)		$45,357
TOTAL COST TO SPONSOR		$157,600