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Inverse radiation problem to retrieve hydrometeors from satellite microwave radiances

V. Swaminathan [a,b], R.M. Gairola [a,c], C. Balaji [a,*], V.K. Agarwal [a,c], S.P. Venkateshan [a]

[a] Heat Transfer and Thermal Power Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India
[b] Thermal Specialist, Flomerics India Pvt. Ltd., 581/2, 8th Block, Koramangala, Bangalore 560 034, India
[c] Scientist, Oceanic Sciences Division, Remote Sensing Applications Area, Space Applications Centre (ISRO), Ahmedabad 380 015, India

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Abstract

This study presents a new hybrid method that combines regression analysis with genetic algorithms for the retrieval of hydrometeors (cloud liquid water, ice and rain) in the atmosphere, from satellite microwave radiances. A three layered atmosphere model (divided into 30 sub-layers) is used to generate simulated profiles of hydrometeors. The equation governing the transfer of radiation is solved using the finite volume method to obtain radiances (brightness temperatures) in the microwave region. This is known as the forward problem and is solved repeatedly to create a database with which regression equations are developed for the monochromatic microwave radiances, for six typical frequencies ranging from 6.6 to 85 GHz. The regression is done using nonlinear parameter estimation techniques. The inverse problem of retrieving the hydrometeors characteristics from microwave radiances is accomplished by posing the parameter estimation problem as an optimization problem, wherein, minimization of the sum of squares of residuals between the estimated and known radiances, for the above mentioned six typical frequencies, is done. In this study, genetic algorithms have been used for solving the minimization problem.
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1. Introduction

Precipitation (any form of water that falls on to the earth's surface) is an important part of the global energy cycle, since moisture is an important channel of atmospheric heat transport. The uneven heating of the earth creates areas of warm air that tend to rise. When the warm air rises, it leaves behind a gap that's filled by air from surrounding regions moving in. As the warm air rises it expands and cools. Since cool air cannot hold as much moisture, this often results in precipitation (called convective precipitation). Quantitative assessment of precipitation is needed to improve the understanding of the behaviour of global energy and circulation patterns. Since 70% of the earth is covered with water, land-based techniques of rainfall estimation (for example, raingauges) are not sufficient for global rainfall estimation. Hence, one uses satellite remote sensing of clouds and precipitation for global estimation of rainfall. In the remote sensing scenario, an orbiting satellite records radiant energy at wavelengths that range from the visible, infrared to the microwave regime. Various algorithms can then be used to estimate rates of rainfall from the emergent radiant energies.

Compared to visible and infrared observations, satellite remote sensing using microwave data is a new development and provides more accurate, instantaneous retrievals, due to the direct physical relationship between microwave radiation and column cloud, rain water and ice. Many microwave rainfall retrieval algorithms have been developed in

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[*] Corresponding author. Tel.: +91 44 22574689.
E-mail address: balaji@iitm.ac.in (C. Balaji).

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Nomenclature

Avg_CLW	average of cumulative cloud liquid water content, g m^{-3}
Avg_Ice	average of cumulative ice content, mm/h
Avg_Rain	average of cumulative rain content, mm/h
BT	brightness temperature, K
C_{lw}	normalized average of cumulative cloud liquid water content (refer Table 3)
C_1	first Rayleigh–Jeans constant, 0.59552197×10^8 Wμm^4 m^{-2} s r^{-1}
C_2	second Rayleigh–Jeans constant, 14387.69 μm K
F,f	objective function
g	asymmetry factor or function defined in Eq. (4)
I	radiation intensity, W m^{-2} s r^{-1}
$\bar{I}$	in-scattering term, W m^{-2} s r^{-1}
I_{ce}	normalized average of cumulative ice content (refer Table 3)
J	Jacobian
p	parameter vector defined in Eq. (7)
q	correction to the parameter vector defined in Eq. (10)
Rain1	rainfall rate in 1st layer, mm/h
Rain2	rainfall rate in 2nd layer, mm/h
R_C	normalized average of cumulative rainfall rate (refer Table 3)
R_1, R_2	normalized rainfall rate in 1st and 2nd layer, respectively (refer Table 3)
s	coordinate along ray path, m
S	residual defined in Eq. (5)
T	absolute temperature, K
T_B	normalized brightness temperature (refer Table 3)
T_B^*	normalized, known brightness temperature (refer Table 3)
$X_1 \ldots X_4$	dummy variables used in GA (refer Appendix A)
z	coordinate along vertical direction, m

Greek symbols

ε	emissivity of surface or damping factor defined in Eq. (11)
ϕ	azimuthal angle, rad
Φ	scattering phase function
γ	polar angle, rad
κ	absorption coefficient, m^{-1}
λ	wavelength, μm
v	frequency, GHz
σ_s	scattering coefficient, m^{-1}
ω	solid angle, sr
ρ	correlation coefficient

Subscripts

actual	already available data
b	black body
correlation	data obtained using correlation
retrieved	retrieved using genetic algorithm
z	z direction
λ, v	spectral quantity

Superscripts

L	lower limit
T	transpose of the matrix
U	upper limit
$'$	incoming direction

the last two decades [1–3]. From the reviews, one can see that, retrieval of precipitation using passive microwave sensors is developing at a rapid pace, with a lot of effort going towards improving cloud models [4–7] and also retrieval algorithms [8–10]. Independently, considerable work is also going on in developing new methods to solve the equation of transfer with added complexities like polarization and anisotropic scattering.

The present work is concerned with retrieval of column rainfall rate, ice content and cloud liquid water simultaneously by using the signal (radiance/brightness temperature) emerging from the top of the atmosphere in the microwave regime. This signal is frequently referred to as the TOA (top of the atmosphere) radiance and is recorded by the passive remote sensing device. The signal results from the radiant energy which is emitted and scattered by the surface (either land or ocean), by the clouds, raindrops, ice and atmospheric gases (such as H_2O and O_2).

In this numerical study, the forward calculations are carried out with known atmospheric constituents to obtain the brightness temperatures. These will be treated as the satellite measured brightness temperature values for the inverse problem, in the place of real satellite measured brightness temperatures. The frequencies used for the forward calculations are $v_1 = 6.600$, $v_2 = 10.700$, $v_3 = 19.350$, $v_4 = 22.235$, $v_5 = 37.500$ and $v_6 = 85.000$ GHz, respectively. These are selected by noting that these frequencies are used in passive microwave radiometers such as the Electrically Scanning Microwave Radiometer (ESMR) aboard the Nimbus-5 satellite [11], the Scanning Multichannel Microwave Radiometer (SMMR) aboard the Nimbus-7 satellite [12], the Special Sensor Microwave/Imager (SSM/I) [13], the TRMM Microwave Imager (TMI) [14], the Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) [8]. AMSR-E is the instrument with a set of frequencies that most closely resembles that used in this paper.

From the review of the literature, one can see that, often, the procedure that has been used in the literature for the retrieval of parameters is to solve the direct problem

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