

**LAND-ATMOSPHERE INTERACTIONS IN SPRING
WHEAT CROPLANDS OF INDIA: A NUMERICAL
STUDY USING A COUPLED MODEL**

SARITA KUMARI



**CENTRE FOR ATMOSPHERIC SCIENCES
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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STUDY USING A COUPLED MODEL**

by

SARITA KUMARI

CENTRE FOR ATMOSPHERIC SCIENCES

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Certificate

This is to certify that the thesis entitled “**Land-atmosphere interactions in spring wheat croplands of India: A numerical study using a coupled model**” being submitted by **Ms. Sarita Kumari** to the Indian Institute of Technology Delhi for the award of the degree of ‘**Doctor of Philosophy**’ is a record of original bona-fide research carried out by her. She worked under my supervision and has fulfilled the requirements for the submission of this thesis. The results contained in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.

Prof. Somnath Baidya Roy

Professor & Head,

Centre for Atmospheric Sciences

Indian Institute of Technology Delhi

Hauz Khas, New Delhi

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(Sarita Kumari)

Abstract

Vegetation is an integral part of the land surface that strongly contributes to the exchange of moisture, heat, and momentum fluxes between the land surface and the atmosphere. Changes in meteorological variables have significant effects on vegetation growth. Vegetation growth modifies surface properties and fluxes that, in turn, also affect the atmosphere. Such two-way interactions lead to feedbacks that can be positive or negative depending on the behaviour of vegetation and atmosphere. This thesis studied the impact of crop dynamics on the near-surface meteorology over spring wheat croplands in northern India.

A coupled model WRF_NOAHMP_SUCROS was developed to study the land-atmosphere interactions over croplands. First, the well-known Simple and Universal Crop growth (SUCROS) model was calibrated and evaluated for spring wheat using observations collected from an experimental site at the Indian Agricultural Research Institute (ICAR-IARI) campus in New Delhi. The coupled model was developed by incorporating the crop growth module of the calibrated SUCROS model into the Noah-MP land module of the Weather Research and Forecasting (WRF) mesoscale model. In WRF_NOAHMP_SUCROS, meteorological drivers like near-surface temperature, humidity and wind speed affect crop growth. The changes in LAI and root depth due to crop growth directly affects the land-atmosphere fluxes and indirectly affects near-surface temperature and humidity. Thus, the coupled WRF_NOAHMP_SUCROS model is capable of simulating the two-way interactions between the cropland and the atmosphere. When compared with observations, WRF_NOAHMP_SUCROS performs much better than the default dynamic vegetation module in WRF in simulating the observed patterns of Leaf Area Index (LAI) at the ICAR-IARI field site.

The newly developed coupled model was used to quantitatively study the effect of dynamic vegetation on near-surface meteorology. Results show that the impact of dynamic vegetation is evident in the patterns of the meteorological parameters that follow the pattern of LAI growth. The latent heat flux varies directly with LAI, and sensible heat flux varies inversely with LAI. As the crop grows due to increased evapotranspiration, the energy transfer takes place more in latent heat flux than sensible heat flux. Hence the growing crops result in near-surface cooling due to decreased Bowen Ratio. The mixing ratio is also increased due to increased latent heat flux. In comparison, the WRF model driven by climatological LAI also shows similar patterns except in the juvenile crop stage where it overestimates the sensible heating and temperature but underestimates latent heat fluxes and mixing ratio.

The thesis also quantitatively investigated the impact of irrigation on crop growth and cropland-atmosphere interactions using the newly developed WRF_NOAHMP_SUCROS coupled model. Irrigation was mimicked by setting the soil moisture at 90%, 60% of field capacity and without irrigation on the irrigation days. Results show that increased irrigation reduces water stress and increase crop growth leading to a cooling and moistening of the near-surface environment.

Overall, this thesis shows that the coupled WRF_NOAHMP_SUCROS model can be a valuable tool to simulate land-atmosphere interactions over agroecosystems and advance our understanding of the Earth System.

सार

वनस्पति भूमि की सतह का एक अभिन्न अंग है जो भूमि की सतह और वातावरण के बीच नमी, गर्मी और गति प्रवाह के आदान-प्रदान में दृढ़ता से योगदान देता है। मौसम संबंधी चरों में परिवर्तन का वनस्पति विकास पर महत्वपूर्ण प्रभाव पड़ता है। वनस्पति विकास सतह के गुणों और प्रवाह को संशोधित करता है, जो बदले में, वातावरण को भी प्रभावित करता है। इस तरह की दो-तरफा बातचीत प्रतिक्रिया प्रदान करती है जो वनस्पति और पर्यावरण के व्यवहार के आधार पर सकारात्मक या नकारात्मक हो सकती है। इस थीसिस ने उत्तर भारत में वसंत गेहूं की फसल पर निकट-सतह के मौसम विज्ञान पर फसल की गतिशीलता के प्रभाव का अध्ययन किया।

एक युग्मित मॉडल डब्ल्यूआरएफ_नोआहएमपी_सुक्रोस को कृषि भूमि पर भूमि-वायुमंडल की बातचीत का अध्ययन करने के लिए विकसित किया गया था। सबसे पहले, प्रसिद्ध सरल और सार्वभौमिक फसल वृद्धि (सुक्रोस) मॉडल को नई दिल्ली में भारतीय कृषि अनुसंधान संस्थान (आईकार-आईएआरआई) परिसर में एक प्रयोगात्मक साइट से एकत्र किए गए अवलोकनों का उपयोग करके वसंत गेहूं के लिए अंशांकित और मूल्यांकन किया गया था। मौसम अनुसंधान और पूर्वानुमान (डब्ल्यूआरएफ) मेसोस्केल मॉडल के नोआह-एमपी भूमि मॉड्यूल में कैलिब्रेटेड सुक्रोस मॉडल के फसल विकास मॉड्यूल को शामिल करके युग्मित मॉडल विकसित किया गया था। डब्ल्यूआरएफ_नोआहएमपी_सुक्रोस में, सतह के निकट तापमान, आर्द्रता और हवा की गति जैसे मौसम संबंधी कारक फसल की वृद्धि को प्रभावित करते हैं। फसल वृद्धि के कारण एलएआई और जड़ की गहराई में परिवर्तन सीधे भूमि-वायुमंडल प्रवाह को प्रभावित करता है और अप्रत्यक्ष रूप से सतह के तापमान और आर्द्रता को प्रभावित करता है। इस प्रकार, युग्मित डब्ल्यूआरएफ_नोआहएमपी_सुक्रोस मॉडल कृषि भूमि और वातावरण के बीच दो-तरफा बातचीत का

अनुकरण करने में सक्षम है। अवलोकनों के साथ तुलना करने पर, डब्ल्यूआरएफ_नोआहएमपी_सुक्रोस, आईकार-आईएआरआई फील्ड साइट पर लीफ एरिया इंडेक्स (एलएआई) के देखे गए पैटर्न को अनुकरण करने में वरफ में डिफ़ॉल्ट गतिशील वनस्पति मॉड्यूल की तुलना में बहुत बेहतर प्रदर्शन करता है।

नव विकसित युग्मित मॉडल का उपयोग निकट-सतह मौसम विज्ञान पर गतिशील वनस्पति के प्रभाव का मात्रात्मक अध्ययन करने के लिए किया गया था। परिणाम बताते हैं कि गतिशील वनस्पति का प्रभाव मौसम संबंधी मापदंडों के पैटर्न में स्पष्ट है जो एलएआई वृद्धि के पैटर्न का पालन करते हैं। गुप्त गर्मी प्रवाह सीधे एलएआई के साथ बदलता रहता है, और समझदार गर्मी प्रवाह एलएआई के विपरीत भिन्न होता है। जैसे-जैसे वाष्प-वाष्पोत्सर्जन में वृद्धि के कारण फसल बढ़ती है, ऊर्जा हस्तांतरण संवेदनशील ऊष्मा प्रवाह की तुलना में अव्यक्त ऊष्मा प्रवाह में अधिक होता है। इसलिए झुके हुए अनुपात में कमी के कारण बढ़ती फसलों के परिणामस्वरूप सतह के करीब ठंडा हो जाता है। अव्यक्त ताप प्रवाह में वृद्धि के कारण मिश्रण अनुपात भी बढ़ जाता है। इसकी तुलना में, जलवायु विज्ञान एलएआई द्वारा संचालित डब्ल्यूआरएफ मॉडल भी किशोर फसल चरण को छोड़कर समान पैटर्न दिखाता है जहां यह समझदार ताप और तापमान को अधिक अनुमानित करके आंकता है लेकिन गुप्त गर्मी प्रवाह और मिश्रण अनुपात को कम करके आंकता है।

थीसिस ने नए विकसित डब्ल्यूआरएफ_नोआहएमपी_सुक्रोस युग्मित मॉडल का उपयोग करके फसल की वृद्धि और फसल-वायुमंडल की बातचीत पर सिंचाई के प्रभाव की मात्रात्मक रूप से जांच की। सिंचाई के दिनों में मिट्टी की नमी को 90% और 60% खेत की क्षमता पर और बिना सिंचाई के निर्धारित करके सिंचाई की नकल की गई थी। परिणाम बताते हैं कि सिंचाई में वृद्धि से पानी का दबाव कम होता है और फसल की वृद्धि में वृद्धि होती है जिससे सतह के पास के वातावरण में ठंडक और नमी आती है।

कुल मिलाकर, इस थीसिस से पता चलता है कि युग्मित डब्ल्यूआरएफ_नोआहएमपी_सुक्रोस मॉडल कृषि-पारिस्थितिकी तंत्र पर भूमि-वायुमंडलीय अंतःक्रियाओं का अनुकरण करने और पृथ्वी प्रणाली की समझ को आगे बढ़ाने के लिए एक मूल्यवान उपकरण हो सकता है।

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List of Acronyms

ACHAB	Analysis Code for High-Altitude Balloons
AGBM	Above Ground Biomass
APSIM	Agricultural Production Systems Simulator
AVIM	Atmosphere Vegetation Interaction Model
BATS	Biosphere-Atmosphere Transfer Scheme
CERES	Crop Environment REsource Synthesis
CLM	Community Land Model
CM	Momentum drag coefficient
CMB	Momentum drag coefficient due to bare ground
CMV	Momentum drag coefficient due to vegetated ground
COAPS	Centre for Oceanic and Atmospheric Prediction Studies
CSM	Cropping System Model
DSSAT	Decision Support System for Agrotechnology Transfer
ENSO	El Niño-Southern Oscillation
FACE	Free-Air Carbon dioxide Enrichment
FCEV	Evaporation heat over canopy
FCTR	Transpiration heat
FGEV	Evaporation heat over vegetated ground
FSH	Sensible heat flux
FSU	Florida State University
FVEG	Vegetation greenness fraction
GCM	General Circulation Model

GLAM	General Large-Area Model
GPP	Gross Primary Productivity
HadAM3	Hadley Centre climate model
IBIS	Integrated Biosphere Simulator
ICAR-IARI	Indian Council of Agricultural Research-Indian Agricultural Research Institute
ISAM	Integrated Science Assessment Model
JULES	Joint UK Land Environment Simulator
LAI	Leaf Area Index
LCLU	Land Use Land Cover
LH	Latent heat flux
LHF	Latent Heat Flux
Li-COR	Lambda Instruments Corporation
LSM	Land Surface Model
MCWLA	Model to capture the Crop–Weather relationship over a Large Area
MODIS	Moderate Resolution Imaging Spectroradiometer
NCAR	National Centre for Atmospheric Research
NCEP-FNL	National Centres for Environmental Prediction - Final analysis data
NDVI	Normalized Difference Vegetation Index
NEE	Net Ecosystem Exchange
Noah-MP	Noah land surface model with multi-Physics options
OTC	Open-Top Chamber
PAR	Photosynthetically Active Radiation
RAMS	Regional Atmospheric Modeling System
RCM	Regional Climate Model

SHB	Sensible heat flux over bare ground
SHC	Sensible heat flux over canopy
SHF	Sensible Heat Flux
SHG	Sensible heat flux over vegetated ground
SiBcrop	Simple Biosphere model
SO	Storage Organ
STICS	Simulateur multIdisciplinaire pour les Cultures Standard
SUCROS	Simple and Universal CROp growth Simulator
U.S.	Unites states
WOFOST	WOorld FOod STudies
WRF	Weather Research and Forecasting Model
WUE	Water Use Efficiency