As early as 1959, it was suggested by Conney *et al.*[21] that multiple forms of drug-metabolizing enzymes catalysing the same reaction exist in the liver of a given species. The criteria adopted for the presence of multiple forms have been mobility on SDS–PAGE, spectral and catalytic properties, immunological relatedness, peptide mapping and finally the protein sequence. In this study, based on the mobility of the protein on SDS–PAGE, it appears that different forms of cytochrome P-450 are present in drug-sensitive, isoniazid-resistant and isoniazid and rifampicin-resistant *M. tuberculosis* and also the same isoform patterns of the protein are present in the resistant and phenobarbital-induced *M. tuberculosis*. Further studies at the molecular level would confirm these findings and give a better understanding of the significance of this study.

1. Cole, S. T. *et al.*, *Nature*, 1998, **393**, 537–544.
2. Franklin, T. and Snow, G., *Biochemistry of Antimicrobial Action*, Chapman and Hall, London, 1989, 4th edn.
3. Agosin, M., in *Comprehensive Insect Physiology, Biochemistry and Pharmacology* (eds Kerkut, G. A. and Gilbert, L. I.), Pergamon, NY, 1985, vol. 12, pp. 647–712.
4. Ndifor, A. M., Howells, R. E., Bray, P. G., Ngu, J. L. and Ward, S. A., *Antimicrob. Agents Chemother.*, 1993, **37**, 1318–1323.
5. Klopman, G. *et al.*, *ibid*, 1994, **38**, 1794–1802.
6. Osherov, N., Kontoyiannis, D. P., Romans, A. and May, G. S., *J. Antimicrob. Chemother.*, 2001, **48**, 75–81.
7. Ramachandran Geetha, Gurumurthy Prema, Narayanan, P. R. and Mahadevan Usha, *Curr. Sci.*, 1999, **76**, 1231–1234.
8. Edlind, T. D., Henry, K. W., Metera, K. A. and Katiyar, S. K., *Med. Mycol.*, 2001, **39**, 299–302.
9. Kuntzman, R., *Annu. Rev. Pharmacol.*, 1969, **9**, 21–36.
10. Narhi, L. O. and Fulco, A. J., *J. Biol. Chem.*, 1982, **257**, 2147–2150.
11. Rajnarayanan, R. V., Rowley, C. W., Hopkins, N. E. and Alworth, W. L., *J. Agric. Food Chem.*, 2001, **49**, 4930–4936.
12. Schwaneberg, U., Sprauer, A., Schmidt-Dannert, C. and Schmid, R. D., *J. Chromatogr. A*, 1999, **848**, 149–159.
13. Walczak, R. J., Dickens, M. L., Priestley, N. D. and Strohl, W. R., *J. Bacteriol.*, 1999, **181**, 298–304.
14. Kawahara, N., Ikatsu, H., Kawata, H., Miyoshi, S., Tomochika, K. and Sinoda, S., *Can. J. Microbiol.*, 1999, **45**, 833–839.
15. Saribas, A. S., Gruenke, L. and Waskell, L., *Protein Expr. Purif.*, 2001, **21**, 303–309.
16. Green, A. J. *et al.*, *J. Biol. Inorg. Chem.*, 2001, **6**, 523–533.
17. O'Keeffe, D. H., Ebel, R. E. and Peterson, J. A., *Methods Enzymol.*, 1978, **52**, 151–157.
18. Imai, Y., *J. Biochem.*, 1976, **80**, 267–276.
19. Kimura, T., Parcells, J. H. and Wang, H. P., *Methods Enzymol.*, 1978, **52**, 132–142.
20. Guengerich, F. P., *Pharmacol. Ther.*, 1979, **6**, 99–121.
21. Conney, A. H., Gillette, J. E., Inscoe, J. K., Trams, E. R. and Posner, H. S., *Science*, 1959, **130**, 1478–1479.

Received 11 March 2002; revised accepted 27 July 2002

Estimation of monthly rain rate over Indian Ocean region using MSMR data

D. R. Mishra, A. K. Sahoo, Rahul Kanwar and R. P. Singh*

Department of Civil Engineering, Indian Institute of Technology, Kanpur 208 016, India

India is surrounded by ocean in three directions. The land and ocean interaction controls the climatic conditions over the Indian subcontinent. The study of meteorological parameters over ocean has paramount importance in understanding the interaction between ocean and land. In the present study, efforts have been made to deduce the monthly variations of the rain rate over the oceanic region adjacent to India from July 1999 to June 2000 using brightness temperature data observed by the Multi-channel Scanning Microwave Radiometer (MSMR) sensor on-board IRS-P4 (OCEANSAT). Using brightness temperature measured at 10 and 18 GHz frequencies in horizontal and vertical polarizations, rainfall rate has been compared. The rain rate deduced from MSMR brightness temperature data shows a high value over the ocean during June and July. The rain rate shows moderate to low values during October–November and increases in January, followed by a decrease in March and April, again it increases from May. Variation of rain rate is mainly controlled by summer and winter monsoon. The southwest summer monsoon hits India in May/June; as a result high rain rate, which is responsible for higher rainfall, has been observed over the ocean. Due to the northeast winter monsoon, rain rate increases over the ocean during January–February. The rain rate retrieved from MSMR data is compared with NCEP monthly averaged rain rate.

THE passive microwave remote sensing technique has proved to be a powerful tool in monitoring spatial and temporal behaviour of the earth surface. Numerous studies have been carried out to explore the use of microwave remote sensing technique to retrieve information regarding the physical state of ocean and land surfaces. All-time and all-weather operational advantage of microwave remote sensing allows monitoring of the earth with better temporal resolution compared to the sensors in the visible portion of the electromagnetic spectrum. A number of space-borne sensors have shown sensitivity to rain rate or to other features associated with rain[1]. The retrieval and monitoring of the rain rate over ocean surrounding India has made significant progress after the launching of OCEANSAT-I (IRS-P4). Multi-channel Scanning Microwave Radiometer (MSMR), one of the sensors of IRS-P4, has the ability to penetrate through clouds and is also highly sensitive to rain[2]. IRS-P4 is a polar orbiting satel-

*For correspondence. (e-mail: ramesh@iitk.ac.in)

lite with very high temporal resolution[2] of two days (global coverage). In the present communication, efforts have been made to study the variability of rain rate over ocean surrounding India.

The brightness temperature over a raining ocean is higher than that over a clear ocean. The rain rate is extracted from the difference (excess) between the brightness temperature values of the raining and clear ocean. Passive microwave remote sensing relies on a scattering-based technique to measure rain rate over land, whereas it relies on an emission-based technique to measure rain rate over ocean[3]. The emission signal is related to the total amount of liquid water in the atmospheric column. In order to estimate the surface rain rate, it is necessary to estimate the height of the column. This technique works over the ocean, where a uniform background of microwave emission allows rainfall to be detected by the absorption of low microwave energy by raindrops. The vertical (*V*) and horizontal (*H*) polarizations of brightness temperature are analysed as a function of rain rate over the Indian oceanic conditions. At frequencies 10 and 18 GHz, rain affects predominantly through the emission/absorption process, whereas the scattering contributions are negligible. This lower frequency channel penetrates easily to near the cloud base and the high oceanic reflectivity allows us to take advantage of rainfall detection.

India launched its first ocean remote sensing satellite IRS-P4 (OCEANSAT-1) on 26 May 1999, on-board an MSMR and an ocean colour monitor (OCM) sensor. OCEANSAT-1 is a sun-synchronous satellite with a global coverage period of two days. The MSMR provides global microwave brightness temperature data at 6.6, 10.65, 18 and 21 GHz frequencies, with dual polarizations having spatial resolutions of 150, 75, 50 and 50 km respectively. The operational algorithms for deriving various parameters from MSMR brightness temperature data in different grid schemes have been developed[4].

A combination of brightness temperatures at 10 and 18 GHz frequencies for both *H* and *V* polarizations has been used in the following algorithm for retrieval of rain rate over ocean[5]. This algorithm is validated from some of the observations made from the ship, and it is found that the rain rate estimated using this algorithm is accurate and reliable. Large volume of rain rate data from the ship over the ocean is required for detailed analysis, but at present such observation is very limited.

$$\mathrm{RR\ (mm/h)} = 241.1 - 17.57 \ln [280 - T_{\mathrm{B10V}}] - 40.65 \ln [280 - T_{\mathrm{B10H}}] + 5.478 \ln [280 - T_{\mathrm{B18V}}] + 5.621 \ln 280 - T_{\mathrm{B18H}}], \quad (1)$$

where RR is the rain rate in mm/h, suffix V and H are

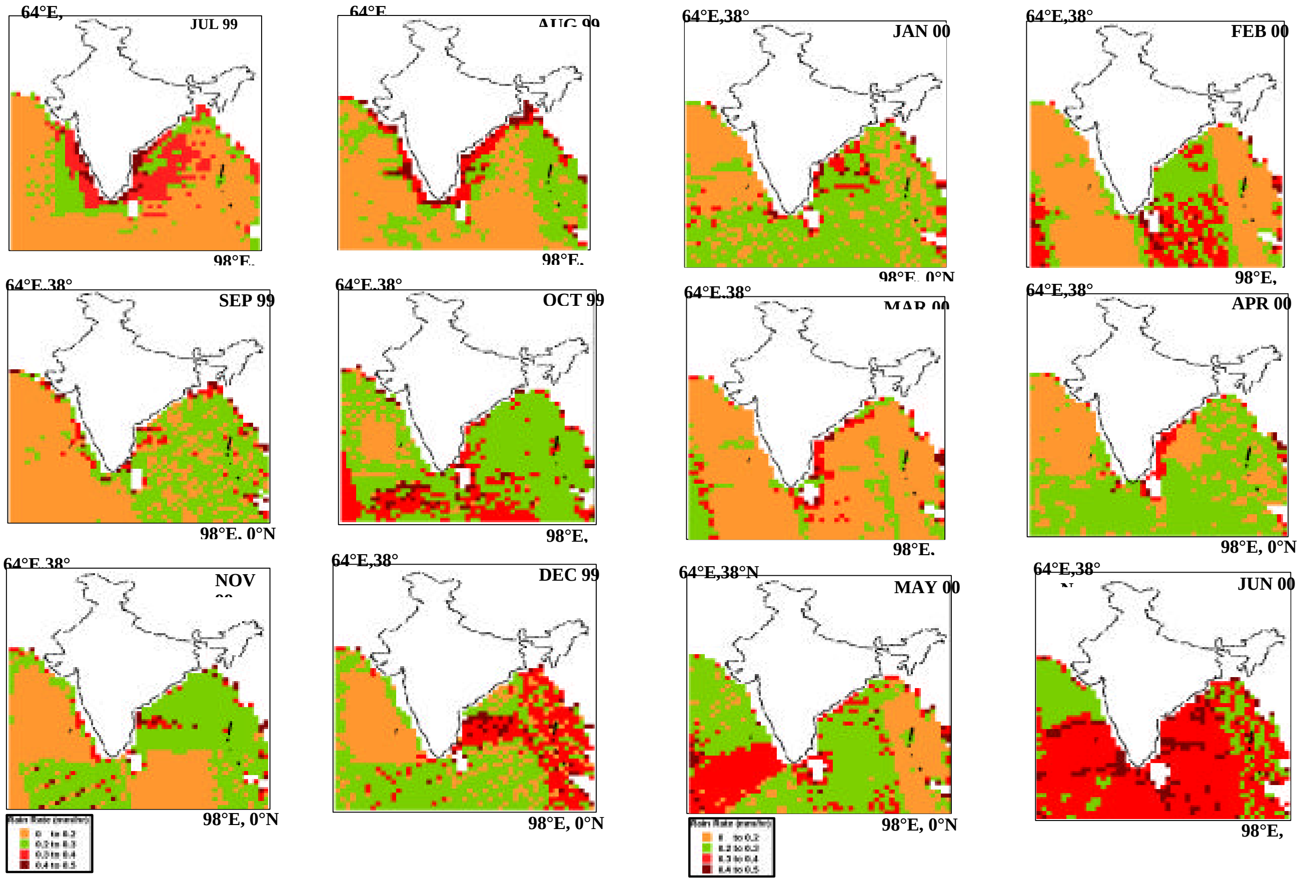

Figure 1. Monthly variations of rain rate over oceanic region around India.

vertical and horizontal polarizations respectively, and 10 and 18 are brightness temperatures at 10 and 18 GHz frequencies respectively.

The averaged monthly variations of rain rate over ocean surrounding India have been computed using eq. (1) for a period of one year, from July 1999 to June 2000. The rain rate measured in mm/h shows highest value over the Bay of Bengal, the Arabian Sea and the Indian Ocean in June in the range 0.4–0.5 mm/h, and shows lowest value in March, in the range 0–0.2 mm/h (Figure 1). It has been observed that the averaged monthly variations of rain rate over the Indian oceanic region are totally controlled by monsoon. The Indian monsoon is an ideal one where differential heating of land and ocean is subjected to the annual latitudinal cycle of the sun, which gives rise to immense seasonal wind regimes[6]. The main reason for the strong development of monsoon is the vast size of the Indian subcontinent and adjacent sea, and the presence of the high and extensive Himalayan mountain system in the extreme north of the subcontinent. The Indian monsoon signifies a marked seasonal reversal of wind direction between summer and winter seasons.

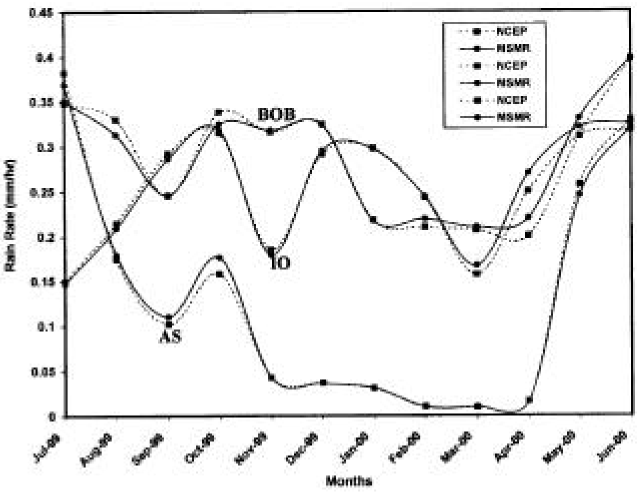

Figure 2. Relationship between MSMR-derived and NCEP-generated rain rate data for the Bay of Bengal (BOB), Arabian Sea (AS) and Indian Ocean (IO) respectively.

During May and June, the monsoon hits the south-western part of India full of moisture and chances of heavy precipitation, which is called the southwest (SW) monsoon. This monsoon splits into two branches called the Arabian Sea branch and the Bay of Bengal branch, by the shape of peninsular India. These two branches result in maximum rainfall over the ocean because of high moisture content[6]. During July–September, monsoon is prevalent over the Indian land region producing heavy rain, whereas low rain rate is observed over the Indian ocean region. During October–December, monsoon retreats after hitting the Himalayan region producing medium to heavy rainfall over the Bay of Bengal, the Arabian Sea and the Indian Ocean. During January and February, at the time of the northeast monsoon, high rain rate is seen over the Bay of Bengal. During the summer season (March and April), almost no or little rainfall is seen over the ocean. The rain rate retrieved from MSMR has been compared with NCEP/NCAR-derived rain rate of same location, which shows almost similar variations (Figure 2). The NCEP/NCAR data are validated by limited observation from the ocean using ship and buoy. In general, the rain rate is found to be low in the Arabian Sea compared to those of the Bay of Bengal and the Indian Ocean. Along the coastal region, large rain rate at few places is seen due to mixing of the land and ocean pixels, which was not possible to separate in the present study. Figure 3 shows the scatter plot of rain rate data estimated from MSMR and NCEP for the Bay of Bengal (Figure 3 *a*) and the Arabian Sea (Figure 3 *b*). These plots show high correlation between these two data sets, with correlation coefficients 0.97 (Bay of Bengal) and 0.99 (Arabian Sea).

The averaged monthly rain rate variations over ocean surrounding the Indian sub-continent give a clear picture of the monsoon circulation pattern. Generally the rain

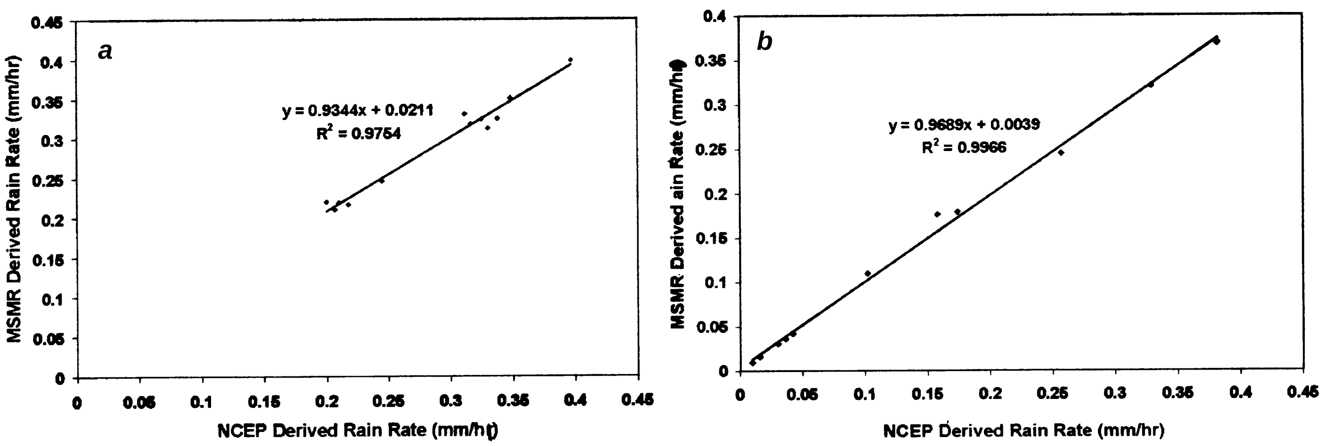

Figure 3. Scatter plot between MSMR-derived and NCEP-generated rain rate data for the Bay of Bengal (***a***) and the Arabian Sea (***b***).

rate over the Bay of Bengal, Arabian Sea and Indian Ocean is found to be higher during May and June due to the onset of SW monsoon compared to other months. It gradually decreases in the succeeding months, again followed by increase during winter due to winter (NE) monsoon. Low rainfall is found over ocean during March and April due to hot and dry weather. Satellite-derived rain rate is found to be similar to the NCEP/NCAR-derived climate reanalysis data. The MSMR data show the potential in deducing rain rate over the ocean, which will be useful in understanding the complex climatological phenomena over the Indian subcontinent and in the numerical forecast modelling.

1. Quartly, G. D., Srokosz, M. A. and Goymer, T. H., *J. Geophys. Res.*, 1999, **104**, 31489–31516.
2. Gohil, B. S., *First Science Workshop Proceedings of Megha–Tropiques*, ISRO, Bangalore, 19–22 May 1999, pp. 20.1–20.15.
3. Ferraro, R. R., *J. Geophys. Res.*, 1997, **102**, 16715–16735.
4. Mishra, D. R., M Tech thesis, IIT Kanpur (unpublished), 2002, pp. 13–33.
5. Varma, A. K., Gairola, R. M., Mathur, A. K., Gohil, B. S. and Agrawal, K., Proceedings of PORSEC-2000, Goa, 2000, pp. 240–243.
6. Hartmann, D. L. and Michelsen, M. L., *J. Atmos. Sci.*, 1989, **46**, 2838–2862.

ACKNOWLEDGEMENTS. We thank the Space Application Centre, ISRO, Ahmedabad for providing MSMR data under OCEANSAT AO project to R.P.S. We are grateful to the anonymous referee for comments and suggestions.

Received 4 April 2002; revised accepted 27 July 2002

Laser-induced chlorophyll fluorescence spectra of mung plants growing under nickel stress

R. Gopal[‡,#], K. B. Mishra*, M. Zeeshan[+], S. M. Prasad[+] and M. M. Joshi[‡]

[‡]Saha Laser and Spectroscopy Laboratory, Department of Physics, University of Allahabad, Allahabad 211 002, India
*M.N. Saha Centre of Space Studies, Institute of Inter-Disciplinary Studies, Nehru Science Centre, University of Allahabad, Allahabad 211 002, India
[+]Ranjan Physiology and Biochemistry Laboratory, Department of Botany, University of Allahabad, Allahabad 211 002, India

The *in vivo* laser-induced chlorophyll fluorescence (LICF) spectra of mung (*Vigna radiata* Linn.) for the control, and nickel (a heavy metal)-treated plants were recorded in the region 600–800 nm with two characteristic bands lying at 680 nm and 730 nm using 488 nm argon ion laser line for excitation. The chlorophyll fluorescence intensity ratio (FIR) F680/F730, and peak positions were calculated by evaluating curve-fitted parameters using Gaussian spectral function. It was found that the FIR decreases with increasing chlorophyll content in case of 0.1 mM nickel-treated plants. When the nickel concentration was raised to 1.0 mM, the FIR showed increasing trends, although it was much less than the control, with decreasing chlorophyll content. Our study demonstrates the use of LICF spectra in the early detection of heavy metal stress impact on crops, particularly mung.

LASER-induced fluorescence (LIF) for remote detection of vegetation stress had been initially proposed by Chappelle *et al.*[1]. Later, LIF studies of vegetation were used to explore the possibility of using laser as a remote means of measuring vegetation characteristics such as plant vigour, as affected by various stress factors such as drought, natural nutrient deficiency, etc. plant type identification and forest biomass estimation. LIF signal can be used to make an inference regarding health and identity of the plants[2,3]. Saito *et al.*[4] have reported fluorescence lidar as a potential new technique for remote terrestrial vegetation monitoring.

The chlorophyll fluorescence spectrum of a green leaf has the maxima near 690 nm and 730 nm. The fluorescence intensity ratio (FIR) of the two maxima red/far-red (F690/F730) is strongly influenced by variation in photosynthetic activity. The intensity of the red and far-red chlorophyll fluorescence is inversely related to the photosynthetic activity. When photosynthesis decreases owing to various stress conditions, the FIR increases. The increase in chlorophyll content in plants results in a decrease in the value of the FIR. The FIR has also been established as an indicator of the *in vivo* chlorophyll content in plants[3]. This stress indicator has been utilized in active remote sensing of the plant in fluorescence lidar system by Valentini *et al.*[5]. Subhash and his associates have studied the effect of different stresses on various plants[6–11], collecting LIF radiation using optical fibre. Buschmann *et al.*[12] have recorded fluorescence imaging of leaf, which provides ample information about as many as ten thousand pixels over the whole leaf area. This allows detection of local disturbances and the gradients in the fluorescence emission. Single-point or spot-data fluorescence measurements, which are still widely used, usually have the advantage of low cost and possibility of relatively high spectral resolution, but a disadvantage that fluorescence information of one leaf spot seldom represents the whole leaf.

[#]For correspondence. (e-mail: dr_ramgopal@hotmail.com)