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Near-Surface Air Temperature from the NOAA-14 AVHRR Data: Validation in the Tropical Environment of Thailand

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ABSTRACT. Recent advances in the satellite remote sensing applications in environmental studies show high promise for estimating near-surface air temperature spatially and temporally using a "contextual analysis" approach. The effectiveness of the approach has previously been successfully tested and validated in the mid-latitude temperate environment. For global and regional applications, knowledge about accuracy of the approach in the contrasting climates and landscapes is important. This study examines the feasibility of the estimation of air temperature by using 1.1 km resolution daily observations from the NOAA-14 Advanced Very High Resolution Radiometer (AVHRR) with the comparison of ground observations made in selected sample sites of Thailand. Further it reveals that the spatial information on air temperature can be generated in the tropical environment of Thailand with an appreciable accuracy.

INTRODUCTION

In the past 150 years, human populations have been growing at an ever-increasing rate, thus the urbanization and industrialization have been taking place beyond the sustainability of the natural resources. These environmental changes influence not only the state of the land surface itself but also the atmosphere, especially the near-surface atmosphere. Temperature observations begun in mid-nineteenth century indicate that globally averaged

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surface temperature increased between 0.3°C and 0.6°C over the past century. The 1980s were the warmest decade on record and 1988 was the warmest single year on record (Hidore, 1996).

Modelling and monitoring of the spatial and temporal variation of air temperature are indispensable for assessing and forecasting climate change. The accuracy of the predictions and forecasting depends on the models and the quality of the data used as an input. Spatial and temporal information on air temperature has been traditionally estimated by methods employing interpolation of ground-based measurements acquired at point locations, but these techniques often introduce considerable uncertainty, particularly in regions where station coverage is sparse. Satellite remote sensing provides a means of estimating the air temperature in a direct and spatial comprehensive manner.

Spatial variations of land surface temperature can be measured and mapped using thermal infrared observations with the "split-window" technique (Price, 1983, 1984). Research in recent years has led to the introduction of a "contextual" analysis method that shows particular promise for estimating and mapping air temperature, atmospheric humidity, vapour pressure, and soil moisture conditions (Goward *et al.*, 1985; Nemani *et al.*, 1993; Goward *et al.*, 1994; Prince and Goward, 1995). The techniques have been successfully tested and validated in mid-latitude temperate environments, but have not yet been successfully evaluated under tropical conditions, which significantly differ in energy, temperature, and precipitation patterns.

The application of contextual analysis approach in tropical environment is greatly influenced by cloud contamination and it requires daily satellite observations for improved accuracy (Saravanapavan and Dye, 1995). Therefore the daily observations from the NOAA-14 AVHRR satellite were employed to examine the success of the technique in seasonally moist environment of Thailand.

BACKGROUND

Spectral vegetation indices (SVI) are commonly employed in studies of biophysical properties of land ecosystems. The most common SVI is use is the normalized difference vegetation index (NDVI), which is a ratio of near inframed (NIR) and visible reflectance (Deering *et al.*, 1975). NDVI is estimated with the NOAA AVHRR observations by the following equation,

$$NDVI = \frac{Ch2-Ch1}{Ch2+Ch1} \qquad (1)$$

where the *Ch1* represents the measured visible red (0.58 - 0.68 μm) reflectance and *Ch2* represents the measured NIR (O.725 - 1.0 μm) reflectance. *NDVI* provides information about the biophysical attributes of the vegetation including its capacity to intercept and absorb solar radiation (Nemani *et al.*, 1993).

Based on the split window technique, there is a stronger attenuation of the thermal Infrared (TIR) longer wavelength channel 5 (11.5 - 12.5 μm) than the shorter wavelength channel 4 (103.3 - 11.3 μm) by atmospheric water vapour. Price (1983, 1984) suggested a simple formula for estimating the land surface temperature:

$$T_s = T_4 + 3.33(T_4 - T_5) \qquad (2)$$

where T_s represents surface temperature in degrees K, T_4 and T_5 represent the brightness of the channels 4 and 5 in degree K. This approach was validated for a grassland region in the midwestern United States by Cooper and Asrar (1989) who found that the Price approach generally produced estimates of surface temperature within ± 3.0°C of ground observations, for a constant emissivity of 0.98.

Satellite observed surface temperature measurements are the additive compositions of TIR emissions from background soils and overlying vegetation canopy while the NDVI measurement is an estimate of the vegetation cover. Therefore the contextual analysis method takes the advantage of the relations between the coincidental measurements of NDVI and surface temperature. The observed surface temperature varies with the heterogeneity of the vegetation in landscape. When the coincidental measurements of NDVI are plotted against corresponding surface temperature measurements, the spread of points generally exhibits a negative slope. The slope tends to be negative because, as the vegetation cover in an observed landscape increases, the surface temperature decreases as a result of different heat capacity between bare soil and vegetation canopy. The air temperature is estimated by extrapolating the best fit line through the NDVI corresponding to a full vegetation canopy. The air temperature is estimated as the surface temperature at that point, because a fully vegetated landscape generally exhibits temperatures close (within ± 2°C) to air temperature (Goward *et al.*, 1994).

DATA AND METHODOLOGY

Satellite data and pre-processing

Daily level 1-b Local Area Coverage (LAC) data from NOAA-14 Advanced Very High Resolution Radiometer (AVHRR) for November 1, 11 and 15, 1995, were obtained from Japan's National Institute of Environmental Studies (NIES) and the United State's National Climate Data Center (NCDC). Level 1b data is raw 1.1 km resolution data that have been quality controlled, assembled into discrete data sets, and to which Earth location and calibration information have been appended, but not applied (Kidwell, 1995).

Initially, the basic data processing, including radiometric calibration and geometric registration of the satellite observations (navigation) to a common Miller Cylindrical projection were carried out. The region of analysis was limited to the Southeast Asia Region, centred on Thailand, between latitudes of 10^0 and 20^0 N and longitudes of 95^0 and 110^0 E. This area was covered by an image window consisting of 1501 pixels and 1001 lines with a registration precision of approximately equal to 1 km. The mapping process included the use of the NOAA supplied satellite ephemeris data by which each individual pixel can be geometrically registered and use of control points to eliminate the residual registration errors. The radiometric calibration was performed with pre-flight calibration for all five channels and on-board calibration information for the thermal infrared channels (channels 3, 4 and 5). The new radiance correction procedure, recommended in the NOAA Polar Orbiter Data User Guide (Kidwell, 1995), was adopted which corrects both the non-linearity of AVHRR Channels 4 and 5 and the observed offset of the space point from the calibration curve for channel 3. The AVHRR visible data values (Channels 1 and 2) were converted to albedos and the AVHRR thermal data values (Channels 3, 4 and 5) were converted to brightness temperatures with 16 bit precision.

Typically fifty percent of the Earth's surface is covered by cloud at any one time (Paltridge and Platt, 1976). The moist tropical conditions are particularly prone to daytime convective cloud formation, consequently persistent cloud coverage is common. To minimize potential cloud contamination of satellite data, the gross cloud test, bi-directional reflectance test and thin cirrus cloud test proposed by Saunders and Krieble (1988) were employed to detect and screen suspected cloud-contaminated pixels from analysis.

Table 1. **Geographic information of the selected sample sites.**

Site No.	Name	Latitude/(dd.mm)	Longitude/(dd.mm)	Elevation/(m)
1	Chiang Rai	19 55 N	099 50 E	395
2	Chiang Mai	18 47 N	098 59 E	314
3	Nong Khai	17 52 N	102 43 E	175
4	Mae Sot	16 40 N	098 33 E	197
5	Mukdahan	16 32 N	104 43 E	139
6	Chiyaphum	15 48 N	102 02 E	183
7	Ubon Ratchathani	15 15 N	104 52 E	127
8	Supan Buri	14 28 N	100 08 E	8
9	Korat	14 58 N	102 05 E	188
10	Surin	14 53 N	103 30 E	147
11	Bangkok	13 44 N	100 34 E	20
12	Rayong	13 38 N	101 21 E	5
13	Chanthaburi	12 36 N	102 07 E	4

Surface data and sample site selection

Ground measured air temperature data were compiled for validating the satellite estimation of the air temperature. The surface data measured at 1.00 p.m. were employed because which were the nearest in time to the 1.30 p.m., overpass time of the NOAA-14 satellite. Ideally the comparison of the satellite estimation should be made with the ground observation at the time of passing of the satellite, 1.30 p.m. of Local Standard Time (LST) for the validation (Kidwell, 1995).

According to the availability of cloud free observations, the satellite estimations were compared with ground observations in 13 selected sample sites (Table 1) of Thailand, which represents the seasonally moist tropical environment.

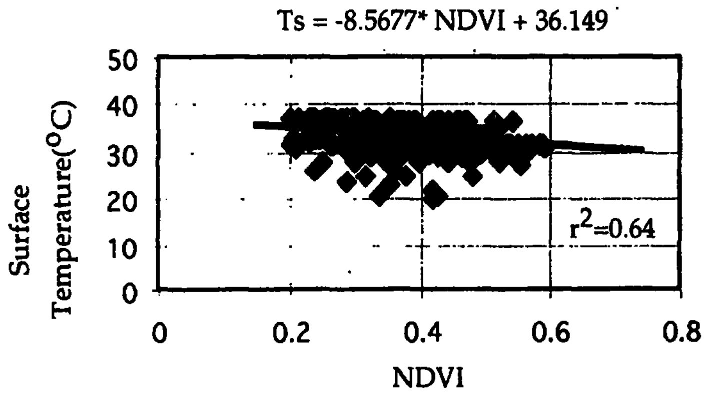

Figure 1. **A sample observation of Ts/NDVI relations at Rayong of Thailand on November 15, 1995. The scattering of points exhibit a negative slope as the vegetation canopy increases the surface temperature decreases as a result of different heat capacity of vegetation canopy and bare soil and the transpiration effect.**

Estimation of air temperature

The determination of the appropriate window size for this analysis depends on the landscape pattern of observation. It was observed that some fully or partially cloud-contaminated observations were always within the target window. Considerable number of cloud free observations and having reliable range of NDVI for determining accurate contextual relation of NDVI and T_s are major factors influencing the selection of appropriate window size. The estimations were carried out with 9x9 pixels (same as Goward *et al.*, 1994), 24x24 pixels, and 36x36 pixels of observations for all clear sample sites. The approach of Goward *et al.* (1994) was followed by recognizing an NDVI of 0.7 as representing fully vegetation canopy. Air temperatures, estimated with three window sizes centered over the meteorological station, were compared with the observed temperature at 1.00 p.m. at the respective stations.

RESULTS AND DISCUSSION

The best fit line of the T_s/NDVI plot (Figure 1) was extrapolated to the full vegetation canopy, where the NDVI is equal to 0.7, to determine the air temperature. When the estimations were compared with the observations, application of 9x9, 24x24 and 36x36 windows in estimating the air temperature, showed that the 24x24 provides more accurate estimation than the others with a coefficient of determination (r^2) of 0.69 and the RMS error of 2.2°C. Further, the comparison showed that the accuracy of estimation of the windows of 24x24 and 36x36 comparatively same and better than that of 9x9 (Figure 2). However, the increase in window size decreases the accuracy in representing the 1.1 km coverage for estimating air temperature and the slope of the Ts/NDVI relation. Therefore, the 24x24 window was identified as the best among the three, compared in this study, and used in the rest of the analysis.

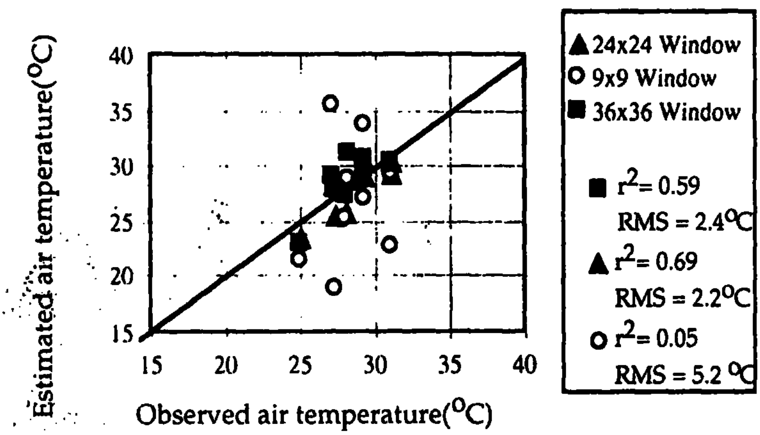

Figure 2. **The satellite estimated air temperatures of different sizes of contextual windows are compared with the ground observed air temperature at different sites of Thailand on November 15, 1995. The 9x9 window shows less reliability in the estimation as it includes small range of NDVI in getting the Ts/NDVI relationship.**

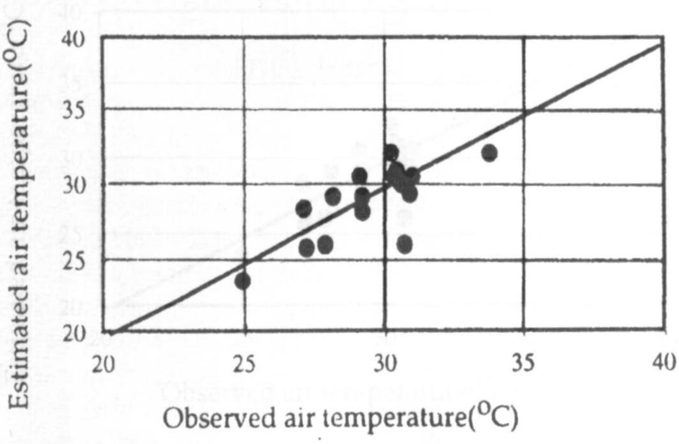

Figure 3. Comparison of the air temperature estimated from the Ts/NDVI relation versus the air temperature observed at the selected sample sites. Outlier is associated with the observation contains active pixels, excluded cloud contaminated observations and the defects if the projection, less than 30% of total available pixels (24x24) for the contextual analysis, and the off-nadir observations.

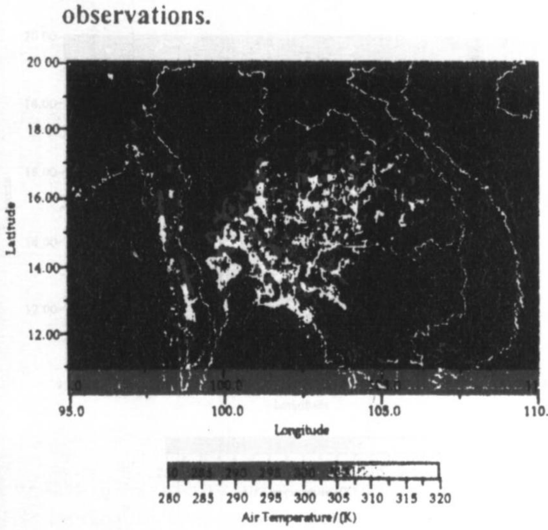

Figure 4. Generated air temperature image on November 15, 1995 based on the contextual relations between satellite surface temperature and NDVI of 24x24 contextual window size.

The comparison between the estimated air temperature and observed air temperature (Figure 3) for all sites and days produced a coefficient of determination of 0.77 and the RMS error of 2.4°C, which suggests high promise for estimating air temperature from NOAA AVHRR satellite observations. The generation of spatial information on air temperature for this study region (Figure 4) revealed the capability of acquiring spatial information without depending on ground observations. Therefore, the contextual analysis method is highly recommended for generating spatial information on air temperature in the seasonally moist tropical environment, which has large cover of land surface and high temperature fluctuation. It was observed throughout this study that the cloud contamination had been the major drawback of this technique However cloud free observations provide useful information. The additional accuracy in estimating the temperature may be obtained by including a characterization of the emissivity pattern of the landscape in the surface temperature estimation.

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