Measuring and Analyzing of Thermal Infrared Emission Directionality over crop canopies with an airborne wide-angle thermal IR camera.

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Abstract
During several clear days from January to October 1997 in the Alpilles test site, multi-angular thermal infrared data were acquired by using an airborne thermal video camera (INFRAMETRICS) equipped with an 80 degree FOV lens to study on the angular variances of longwave radiation for different kinds of agricultural fields under several growing periods. The research presents the methodology developed to extract the directional distribution of ground-level brightness temperature of several agriculture fields including the data pre-processing, the generation of polar diagram for directional brightness temperature distribution. The key difficulty was the temporal variation of temperature of observed targets (about 1 °C) during the time period of multidirectional observations (about 20 minutes). A method basing on the cross observations of the same target from the same direction but by different time was developed for normalising this temporal effect. Results have shown (a) that significant angular effects of the agricultural surfaces could be extracted by using this airborne observation protocol and the developed processing method, (b) and that the observed directional variation in the solar incidence plan can reach 4 °C but within 1°C in the plan perpendicular to it. These angular effects vary as function of both target type and its stat or growing period.

1 Introduction
Thermal infrared remote sensing has been widely used in various environmental applications including the heat flux evaluation of vegetation canopies these several years. The scientific community has reported that the acceptable error on surface temperature estimation is about 1K for energy balance purpose. For the recent two decades, considerable efforts have been devoted for corrections of the atmospheric and emissivity effects on the remote sensed images, but in most of cases, thermal infrared emission of a surface is considered as isotopic. Several scientists (Prévot et al. 1995, Lagouarde et al. 1995; François et al. 1997, Snyder and Wan 1998) pointed out that the existence of some stronger directional effects on the various vegetation canopies and the quantification of directional effects of different surfaces in different conditions were very important both for improving surface temperature estimation and for deriving surface aerodynamic parameters as KB³.

During the experiment period, several selected days flights had been realised over a flat 5x5x km² agriculture test site in the framework of an European remote sensing research project ReSeDA (Baret 1999). By taking successive thermal infrared video images along the solar principal plane and perpendicular plane over the site, most of fields in the site were viewed in multi-directions. The objectives of this study is to presents the methodology development for extracting the directional variation of ground-level brightness temperature of agriculture fields, including the radiometric and atmospheric corrections, the geometric matching and especially the temporal normalisation of images. Some examples of the extracted directionality of different fields were also presented at the end.

2 Data acquisition and pre-processing
There were nineteen effective days flights were performed with the thermal infrared camera INFRAMATRICS 760 mounted on the small aircraft (PIPER PA28 ARROW4) from March to October 1997 over the Alpilles test site (Gu et al. 2000) in the ReSeDA experiment. The camera allowed an multidirectional observation (Fig.1) instantaneously. Fives fights lines at 3000 m flights altitude were performed as an unit in order both to cover the whole region of the 5kmx5km test site and to realise multidirectional observation facility. Four of them were parallel to solar principal plan and one was perpendicular to it. The standard image size is 250 lines x 256 columns. The spatial resolution was about 20 meters in foot print.

In order to extract the directional variance information of different vegetation’s surface brightness temperature, the acquired images have been processed successively in following 3 steps:
1 radiometric corrections including absolute radiometric calibration and corrections on instrumental angular effects;
2 atmospheric corrections;
3 geometric matching of individual images to a geographical map;

The more details about the data acquisition and processing can be found in the specific paper in the same issue (Gu et al., 2000).

3 Mapping of Directional distribution of brightness temperature of agricultural fields

3.1 Viewing angles determination

Determination of viewing zenith angles of image pixels depends principally on two kinds of parameters: (1) the internal optical geometric parameters of sensor as focal length, detector size and its sampling or scanning mode; and (2) the external geometric parameters as airplane’s position, flight altitude and orientation of the sensor’s optical axis. If the observed surface is not flat, topographic effects have to be also considered.

In this experiment, the test region was selected to be very flat and all images were matched to map with a Lambert II projection system. On the map matched images, the viewing zenith angle $\theta_v$ and azimuth angle $\phi_v$ can be determined easily by the following equations:

$$\hat{\theta}_v = \arctan \left( \frac{\sqrt{(X-X_c)^2+(Y-Y_c)^2}}{H} \right)$$

and

$$\hat{\phi}_v = \arctan \left( \frac{Y-Y_c}{X-X_c} \right)$$

where, $X_c$, $Y_c$ are Lambert coordinates of the optical centre of the camera, $X$, $Y$ are the pixel's Lambert coordinates. $H$ is the flight altitude. The azimuth angle is clockwise direction with zero value to north direction.

In the angular calculations, the coordinates of optical centre of the camera images need to be measured accurately. For the used camera system, some of the additional acquisition information have been added to the camera output images, the image centre would be different from the optical one. In the experiment for determining the real optical centre position on the image, we used images of a regular spaced grill target to help the evaluation. The optical centre was determined by identifying the least deformed position of grill images. Result showed that the identified optical centre had a shift of 10 pixels to right and 7 to up compared to the image centre. This was confirmed by the neglected difference between the ground positions corresponding to the corrected optical centre of image and that derived from simultaneous Polder image acquisition and GPS – Inertia system.

The regular grill images analyses allowed us also to determine accurately the scanning angles of selected part of image, which are from $+37^\circ$ to $-32.8^\circ$ along the track and $+27.4^\circ$ to $-23^\circ$ across the track. The induced maximum view angle (for diagonal direction) was $42^\circ$, as shown in Figur1.

3.2 The generation of polar diagram for directional brightness temperature distribution

From the radiometric and geometric corrected images, directional brightness temperature distribution polar diagrams have been generated by the following steps:

a. **Zenith and azimuth angle images generation**

Corresponding to each geometric corrected image, a zenith map and an azimuth map were created respectively.

b. **Extraction of each agricultural field’s brightness temperature value, zenith and azimuth angles**

The centre of the field was determined by the weighted centre of the field's coordinates and the median value of a 5x5 pixels square of the objective field’s centre was considered as the field’s brightness temperature. The choice of 5x5 region is to minimise geometric correction errors and reducing radiometric noise.

c. **Viewing angles plot and temperature plot**

A polar coordinate system was used to represent the multidirectional observations (Fig. 2). The concentric circles represent iso-viewing angles and the graduations, on the external circle, correspond to azimuths of observation.

d. **Interpolation of temperature image**

For interpolation convenience, a mirror temperature image on orthogonal coordinate system was created. From this mirror image, the matlab soft function "mesh" was used for the interpolation and the interpolated image
was then re-transformed to the polar coordinate system.

Fig. 2: An example of real directional sampling of airborne thermal infrared camera measurements over a wheat field.

Fig. 2 is an example of viewing angles plot of a wheat field obtained by 5 flights at 12:20 on March 12, 1997, every cross represents an observation. The format is the typical one of directional sampling distribution for our data set. It’s found that the field was observed within ±30° zenith angles and had observation lines in and perpendicular to the solar incidence plane. The two stars correspond to sun positions at beginning and the end of the flight.

3.3 Normalisation of temporal effects for different flight lines

As reported by many scientists, the observation of surface brightness temperature is affected by many factors change with time such as solar radiation, air temperature, wind speed etc. In this experiment, about 30 minutes were needed for five flights as an observation unit performed to collect enough multi viewing angles of the objects. For two images with 20 minutes difference, it’s found that there are up to 1K variance for the same object with the same viewing angle. In order to extract the directional characteristics of thermal emission, it’s necessary to eliminate the bias caused by time varying to obtain a time-normalized brightness temperature.

Fig. 3 presents contour display of the brightness temperature distribution of that winter wheat field. The 5 flights cost 30 minutes from 12:20 local time, with each line needed less than 1 minutes and 5 minutes for the moves from line to line, when the solar azimuth had a 10 degree movement with an average value of 200°, and the solar zenith is about 50° at the time. From the map, it’s found the temperature values of each flight line varies smoothly compare with the obvious deviations of different fight lines, caused by temporal effects. The shape of the temperature distribution is dominated by this kind of deviation. The temperature differences at the cross points are presented in Fig. 4. The values change from –0.3K to 0.5K.

Two methods were considered in eliminating the temporal effects: normalizing the brightness temperature by comparing the air temperature changes with time as reference, and comparing the brightness temperature at the cross point of two flight lines. Air temperature has a very strong relation with ground temperature, it’s temporal changes can be used to estimate the difference of brightness temperature of different time. However, very possibly, the air temperature’s change is not same as that of interesting field’s brightness temperature within a short period, especially in this experiment carried out in noon when the turbid heat flows over the surface had a great change rapidly. To be refrained from the problems, another method was taken into practice to eliminate the difference of brightness temperature obtained from different flights by using the cross points of different flights. Generally, there are five flights form an observation unit that builds a directional distribution map: 4 flights parallel to the
solar principal plane with one flight is perpendicular to. The perpendicular flight line intersects the other four lines. At the cross point, the viewing angle is same, but the viewing time is different. Suppose the differences of brightness temperature of different lines at the point are from the temporal effects, these difference could be used to normalize the values of different lines.

Fig.5 shows the brightness temperature angular distributions after the elimination of temperature differences for different flight lines. To avoid occasional errors of different flight’s temperature at cross point and decrease the shake of profiles, every flight line’s temperature is assimilated by a 2 order series to form a more smooth contour map and profile. The 5 curves that simulate the 5 fights value are present by Fig 6, the smoothed contour map is showed by Fig 7.

Fig 8 presents the profiles in the sun’s principal and perpendicular planes of that wheat field named as ‘in-SPP’ and ‘V-SPP’ respectively, the solar’s position is –48° in zenith, 195° in azimuth. It’s can be found that the directional brightness temperatures are reach the highest value when the viewing direction is near the sun’s position. This phenomenon, generally referred to as the ‘hotspot’ in visible band, was also described by J.P. Lagouarde et al. 1995. In the viewing range of 30° to –30°, the temperature difference is about 1K. For the profiles vertical to the solar principal plane, The differences are around 1K and the curves have an asymmetry shape.

4 Preliminary analyses of Directional distribution of brightness temperature of agricultural fields

4.1 Directional temperature variations of different type fields obtained on 12 March 1997

Fig.9 shows the brightness temperature varying with viewing angle over another winter wheat field in the same experiment site obtained also on March 12, 1997. In the sun’s principal plane, a increasing trend is visible along the solar incident direction, that means, at larger zenith viewing angle in sun’s direction, the larger temperature difference to vertical viewing appears. The lowest temperature appears within the range from 0° to 20° view opposite to sun’s position, which can also be found in Fig. 8.
In the perpendicular plane configurations, the curve is also symmetrical as that in Fig. 8. The vertical viewing is always obtaining a lower temperature compare with that of oblique viewing. Obviously, the curves’ shape is strongly linked with the fraction of the soil and vegetation temperature in the field of view, it appear the soil temperature is lower than the temperature of the canopy at the time.

4.2 Temporal Variation of Directional temperature of corn field

The profiles in and perpendicular to the solar principal plane of June 9, July 29, September 4 are presented on Figure 11-13. It’s can be found that the temperature along the solar principal plane reached

Under the same environmental and monitoring conditions, the two winter wheat field show the similar shape for the temperature angular distribution and a similar range of temperature for different viewing angle. However, the absolute value has about 1K deviation.

Fig. 10 shows the profiles in the sun’s principal and perpendicular planes of a bare soil field in the experiment site. The shape of V-SPP curve has a slight of asymmetry, the vertical viewing measured a lower temperature value. For the curve in the solar principal plane, there is a different trend compared with that observed by Lagouarde et al. 1995 and that of wheat field, the temperature always increase from the viewing facing the Sun to viewing along sun’s incident direction. Compare with wheat field, the bare soil filed had a higher temperatures in all directions.
to it’s maximum between the vertical and solar zenith position for the different period. On the other side of inclination, the temperature profile had a minimum value.

Fig.11 shows the profiles along and vertical to the solar principal plane on June 9. At the time, the corn is at an average height of 1m, the field was in partial covered conditions. The soil had a higher temperature than the corn, so around the sun’s location appeared the maximum temperature and the nadir part of the perpendicular profiles has a higher value compare with that of high zenith area.

With the crow growing, the corn covered the most part of the field, the temperature obtained from nadir view turned lower compared with that with a high zenith viewing, which are shown in Fig.12 and 13 of July 29 and September 4 respectively. In Fig 12, the profile vertical to the solar principal plane doesn’t show the symmetry around nadir view. The corn field’s geo-structure and sampling process effects may be used to interpret the phenomena which need more further research.

Observations of June, July and September showed that the brightness temperature profiles along and vertical to the solar principal plane were varied with the growing period, the canopy density is a key factor influencing the temperature distribution, it decides the soil and leaves temperature changes in different time of the day .

5 Conclusion

During 19 clear days from January to October 1997 in the Alpilles test site, agricultural vegetation such as corn, winter wheat, alfalfa, sunflower, tomato, grass were monitored by using an airborne thermal video camera (INFRAMETRICS) equipped with an 80 degree FOV lens under several growing period. The angular variation of brightness temperature is studied. Several primarily conclusions are drawn as follows:

Besides the influence of atmospheric contributions, the land surface longwave radiation’s directional variances much depend on the objective geo structure and emissivity characteristics, and temporal effects. For example, the curves of one winter wheat field is much similar with that of another wheat field at the same measuring time, while much different from that of bare field, for the corn field, angular distributions of different growing period have different shapes.

Another conclusion can be reached by the measurement is that the temporal effects and environment have a great influence on the shape of the variations. Within 30 minutes difference, the brightness temperature value deviate up to 1K at the time, that means the measuring time is very important to the final results and the environment conditions must be considered in the monitoring.

The curves in the solar principal plane and in the vertical plane appear different shapes. It seems shape of the perpendicular one is affected more by the homogeneity of the objective, the fields of bare soil, winter wheat and whole covered corn field show any strong asymmetry, while the partially covered corn field hasn’t that trend. For the curve along the principal plane, the sun’s position has a great effects on it’s shape, when viewing the objectives along the solar incident direction, the brightness temperature value increases with the viewing angle increase; when the viewing faces the sun, the curves are variant with different objectives.

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Reference


