December 2021, V. Venus

Bangladesh TMT+

#### Exercise

**Estimating crop stress from remotely sensed Land-surface temperature (LST)**



# Exercise outline

## Time

2,5 days.

**Objectives**

To provided practice in procedures to infer crop canopy temperature from polar-orbiter and geo-stationary satellite imagery.

**Software**

ILWIS 3.8

## Data – located on Blackboard “Exercise data”

1. NOAA-14/AVHRR and GMS-5/S-VISSR (1999) imager data, bands 1,2,3,4 of Eastern Asia.
2. Global Land Cover Map (2001) for Asia, consisting of 14 land cover types.
3. LST coefficients for GMS-5 (2002), for 14 land cover types.
4. A digital version of this document (lst.doc)\*.
5. A spreadsheet to calculate the local pixel size (Object 1).
6. A spreadsheet to calculate resample the local pixel size (Object 2).

\* Optional.

# Introduction

This exercise falls within the “Inferring Land Surface and Climate Parameters from Remotely Sensed Imagery for Food Security Monitoring” group of image application techniques, and focuses on estimation of crop canopy temperature from satellite imagery. In the next sections we will describe the dataset, which is available for this exercise, explain the relevance of certain pre-processing steps and follow these for each input. Although some principles also apply to data from polar-orbiting satellites, this exercise deals with data from geo-stationary satellites. The general workflow for the estimation of land surface temperature on a diurnal cycle (LSTD) is outlined in figure 1. The dashed box indicates the focus of this exercise, and in it, the bold text indicates what we will practice today (optional).

# 

Land Cover Dataset

**Satellite imager data**

# A\_01, A2, …, A\_04

**Satellite viewing angle**

Coefficients from global forward simulations

# {LA}..C\_{ID}

# Clear

<87.5 °(day)

Solar zenith angle

Advanced split window algorithm

>87.5 °(night)

Three-channel LST algorithm

Land Cover Dataset

Spectral Library

Clear LST or LSTD

Sensor specific

emissivity

Satellite viewing angle and imager data

Coefficients from global forward simulations

# Dataset

**Figure 1** Flow diagram showing major steps to derive land surface temperature (LST) from GMS-5.

A subset of the Gobal Land Cover Map (2001) for Asia prepared by the University of Maryland is also available, depicting 14 land cover types. One scene is available from the imager aboard the GMS-5 (Geostationary Meteorological Satellite) for the 20th of July 1999. For this date and hour the imager data is almost cloud-free. GMS-5’s repeat cycle is hourly (24 times/day) at 36669 km high). Some properties of the original data are listed in table 1 below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **File name(s)** | **Date** | **Pixel size (nadir)** | **Bands** |
| IGBP land cover | Categorial | multitemporal | 1 km | (1) |
| Imager data | {SAT}yymmddhh\_{BAND} | 20 Jul 1999 | 5 km | 4 |
|  |  |  |  |  |
|  |  |  |  |  |

**Table 1.** Dataset description

The imager sensor aboard the GMS-5 is called the Stretched-Visible Infrared Spin Scan Radiometer (S-VISSR). The Visible and Multi-Infrared imager has four channels centred at 0.67, and 6.7, 11 and 12 µm, respectively.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Channel ID** | **Channel Name** | **Wavelength** | **Spatial Resolution\*** | **Brightness Level** |
| VIS | Visible (VIS) | 0.55 - 0.90 µm | 1.25km | 64 |
| IR1 | Infrared 1 (IR1) | 10.5 - 11.5 µm | 5km | 256 |
| IR2 | Infrared 2 (IR2) | 11.5 - 12.5 µm | 5km | 256 |
| IR3 | Water Vapor (WV) | 6.5 - 7.0 µm | 5km | 256 |

**Table 2.** GMS/FY-2/HW-8 description

The 11 and 12 µm channels are infrared windows with little water vapour absorption, while the 6.7 µm band is a water vapour band that can be used to detect atmospheric water vapour in the upper troposphere. The 0.67-µm is a visible band that can be used during daytime to detect clouds. The visible, infrared ch1, infrared ch2, and infrared ch3 data (called VIS, IR3, IR2, IR2 hereafter) with a spatial resolution of 0.05 degree are rectified on rectangular projection. During the data acquisition process, the digital counts of the imagery are converted into TBB (Temperature Equivalent Black Body) using the calibration tables stored in the documentation part of the GMS S-VISSR data. It was found that the calibration tables for IR1 and IR2 have errors of ±0.2 K due to quantization (8-bit) by Shuichi Tanahashi *et al.* (2000). It is expected that use of these tables may be a possible source of error in the LST estimate, and requires further investigation.

* Before you start, it is a good idea to copy the data to your local hard disk, e.g. to a folder like D:\LST.
* Before using data from satellite observations, it is a good practise to understand the local pixel size (off-nadir), which is determined by the geometry of the satellite field of view and the location on earth you are interested in (So, see figure 1).
* Take a look at the pixel size calculator below (Object 1). Please estimate the pixel size at your area of interest. To do this fill the grey cells for our satellite of interest, GMS-5 using values you find on the Internet for example. To be able to do this you will have to open the object in Excel first (right mouse-click, Worksheet Object, choose Open).



**Object 1.** Pixel size calculator.



**Figure 1.** Geometry of satellite and earth.

* What is the difference between the satellite zenith angle and satellite-viewing angle (draw a picture to explain)?
* Calculate the local pixel for Quzhou (4867 km away from at-nadir). Is this acceptable given the heterogeneity of the maize land-use systems of this area?
* Annotate Figure 1 by adding the corresponding filenames (A\_01, etc.) at the appropriate locations of the EO-processing diagram (see the Blue textbox example).

For this study satellite data from *NOAA-14* and *GMS-5* were used primarily because of the similar specifications of the far-thermal instruments and their complementary viewing frequency. The *NOAA-14* spacecraft passes at approx. 14.00 h local time (range: 13.00 – 15.00 h), whereas *GMS-5* scans the whole of South East Asia every hour.

**Note that** currently we have two datasets that may or may not differ by roughly one (1) hour in observation time:

Product ID: LST1, Satellite ID: NOAA-14 AVHRR, Observation Time (UTC): 09/20/1999 07:00, Algorithm: split-window (Col and Caselles, 1997).

Product ID: LST0, Satellite ID: GMS-5 VISSR, Observation Time (UTC): 09/20/1999 06:00, Algorithm: adv. split-window (Donglian Sun and Rachel T. Pinker, 2002)

We could retrieve land-surface temperate *aka* canopy temperature for more observation hours for our agricultural monitoring and research sites as follows:

1. Obtain new satellite VISible and far-thermal InfraRed observations in the split-window portion of the spectrum using the GetGMS script (see equivalent folder name) for the 07:00 UTC hour
2. Copy the exsting example sub-folder, 99092006, and rename the copy to reflect the new date of interest, i.e. 99092007.
3. As-per the following ILWIS Raster import expression, add the adjacent GMS-5 observation also (example import statement for VIS-channel given below, repeat for IR channels):

A\_01.mpr=map('GMS599092007\_VIS.bin',genras,UseAs,1800,0,Real,4,NoSwap)

1. Register the projection system for the new imports, see properties and select A\_00 for the Map projection:

Graphical user interface, application

Description automatically generated

1. Then, calculate LST for the new observations (UTC 06, 07, and 08) as-per this ILWIS MapCalc expression example (Map “C\_01 = ”):

B\_06.a0\_gms\_adsplit\_allday\_coef + B\_06.a1\_gms\_adsplit\_allday\_coef\*B\_02 + B\_06.a2\_gms\_adsplit\_allday\_coef\*(B\_02-B\_03) + B\_06.a3\_gms\_adsplit\_allday\_coef\*SQ(B\_02-B\_03) + B\_06.a4\_gms\_adsplit\_allday\_coef\*(1/COS(B\_07)-1)

* Calculate the LST from GMS-5 for 09/20/1999 **07:00 and 08:00** also, meaning you should download and import e.g. GMS599092007\_{BAND}.bin. Is the temperature at the Quzhou research stations warmer or colder compared to 06:00 UTC? Is it more commensurate with the NOAA/AVHRR 07:00 observation? Are some previously cloud-contaminated pixels now cloud free to yield reliable LST information?

Next, a background on the radiative transfer theory is provided to understand the retrieval of land-surface temperature using split-window channels in the far-thermal infrared portion of the electromagnetic spectrum.

# Radiative Transfer for LST Determination

In clear sky conditions, for far-IR bands, solar contributions are negligible and the outgoing infrared spectral radiance at the top of atmosphere can be represented by:

 (1)

Where ε0 is the surface spectral emissivity, B is the Plank function, τ0 is the transmittance at the Earth’s surface, La the thermal path radiance, Ts is the skin temperature, λ is the wavelength, μ=cos(θ), where θ is the satellite-viewing angle, also known as satellite nadir angle.

The first term represents the surface contribution term; it is the gray-body radiance emitted by the earth’s surface. The second term is the atmospheric contribution term, referred to as path thermal radiance in equation (1), and is the vertically integrated effect of emission from every atmospheric layer modulated by the transmittance of the air above that emitting layer, namely:

 (2)

Where Tp is the air temperature at vertical layer p, and p is the pressure of the vertical emitting layer.

## Advanced split window algorithm

For a specific land surface type with surface emissivity close to unity, the radiance error introduced by the atmosphere, ΔL, can be represented as:

(3)

From the Planck function we find:



(4)

Where Tλ is brightness temperature at wavelength λ.

For an optically thin gas the following approximations can be made:

 (5)

Where kλ is the absorption coefficient and l is the optical path-length, dl =ρdz ≈ ρ0exp(-z/H)dz, ρ is the density of the absorption gas, ρ0 is the densityat 0 km, H is the atmospheric scale height, z is the height. If we assume that the Planck function is adequately represented by a first order Taylor series expansion in each window channel, then:



(6)

Substituting Equations 4, 5, 6 into equation 3, we obtain:



(7a)



(7b)

l0 is the optical depth from the surface to the top of the atmosphere.

If two close spectral channels are selected to give equal values of Tp, such as the GOES split window channels 11 and 12 μm, we will have two equations with different absorption coefficient kλ to solve simultaneously:

 (8a)

or:



(8b)

Here T11 and T12 are the brightness temperature of the 11 and the 12 μm channel, k11 and k12 are the absorption coefficients of the 11 and 12 μm channels. This equation is frequently used as a basis for split window SST algorithms (McClain et al., 1985). In our case, equation (8b) can be used for any surface type, land or water, as long as the surface emissivities in the split window channels are close to unity.

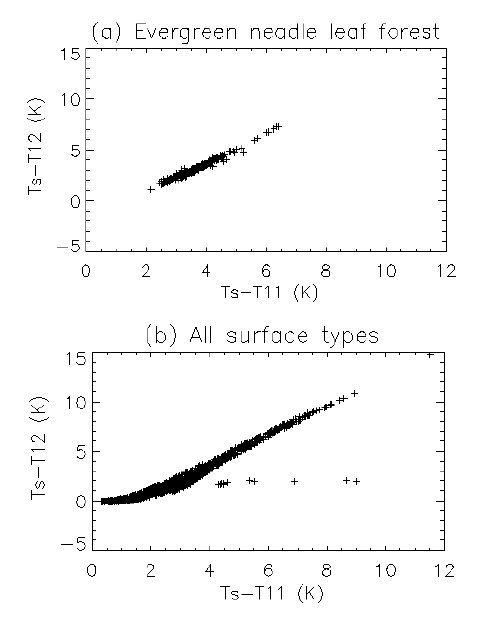


Figure 3. Temperature deficits (Ts-T11) vs (Ts-T12): (a) forest only (b) all surface types. Ts is skin temperature; T11 and T12 are the GOES brightness temperatures in channel 4 and 5.

Figure 3 (a) shows simulation results for the relationship between band temperature deficits Ts-T11 and Ts-T12 for one surface type (evergreen needleleaf forest) compared with all surface-types mixed together (b). If all surface types are mixed together, there is much more variability and the relationship between (Ts-T11) and (Ts-T12) is non-linear. For a specific surface type the relationship is rather linear, which confirms that for a particular land type, the linear split window algorithm used for SST retrieval can be adopted for LST retrieval. Since most land surface emissivity can depart significantly from unity, we can see in Figure 4 that a parabolic relationship exists between (T11-T12) and Ts.

The developed split window LST algorithm, referred to as advanced split window, is one where a separate equation is established for each surface type by using 11 and 12 μm split window. When the satellite viewing angle increases, the optical path increases, and the atmospheric attenuation increases. Therefore, McClain et al. [1985] added a zenith angle correction term (secθ-1) to the SST split window algorithm equation. It has been found that by adding the second term of the brightness temperature difference (T11-T12)2, the atmospheric effect can further be removed. If we add this term to the LST retrieval, the equation will have the following form:



(9)

B\_06.a0\_gms\_adsplit\_allday\_coef + B\_06.a1\_gms\_adsplit\_allday\_coef\*B\_02 + B\_06.a2\_gms\_adsplit\_allday\_coef\*(B\_02-B\_03) + B\_06.a3\_gms\_adsplit\_allday\_coef\*SQ(B\_02-B\_03) + B\_06.a4\_gms\_adsplit\_allday\_coef\*(1/COS(B\_07)-1)

-11.97796 +

1.04018\*B\_02 +

2.025938\*(B\_02-B\_03) +

0.2767631\*SQ(B\_02-B\_03) +

2.04314\*((1/COS(B\_07))-1)

Where i is the index of the surface types, and θ is the satellite viewing angle.

To make the LST simulation results applicable on global scale, input information on surface emissivity and corresponding atmospheric profiles is needed on similar scale for the forward radiative transfer simulations. The Department of Geography at the University of Maryland generated a 1-km resolution global land cover product [Hansen et al., 1998] (http://gaia.umiacs.umd.edu: 8811/landcover/index.html). These products include the following 14 International Geosphere-Biosphere Programme (IGBP) classes [IGBP, 1993]:

1) water;

2) evergreen needle leaf forest;

3) evergreen broadleaf forest;

4) evergreen broadleaf forest;

5) deciduous broadleaf forest;

6) mixed forest;

7) woodland;

8) wooded grassland;

9) closed shrub land;

10) open shrub land;

11) grassland;

12) cropland;

13) bare ground;

14) urban and built-up.

This product was first aggregated to the resolution of the global simulations of 2.5˚ and to the analyzed data resolution of 0.5˚. In the aggregation process, the land cover type in each grid box was assigned on the basis of the dominant surface type, while the surface emissivity was calculated according to a linear mixing with weighted sum of the land cover percentage times the emissivity of this surface type. See Map “B\_06” for a subset of Asia.

* Now that we have retrieved the LST from GMS-5/VISSR and NOAA/AVHRR, see “C\_01” and “C\_02” respectively, calculate the maize production levels (water limited) for Quzhou, 1999 (using alternative water balance, *cfH2O*). Is the error in your estimate acceptable? How different are the drought stress periods between NOAA/AVHRR alone (“N14-99Tc.dat”) and the two far-thermal satellite platforms combined (“N14+GMS5-99Tc.dat”)?

Seeding rate: 25 kg/ha

Seed mortality: 0.1 (10% is lost)

Planting time: 166

Year: 1999

And select the PS-n input files from:

Exercise Data - ILWIS/99092006/CROP GROWTH/

As-per:

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You should get similar results as what is presented in [[1]](#footnote-1)Venus et al. 1999, see snapshot below:

Diagram

Description automatically generated

For PS-n, the following procedure was adopted to obtain equivalent canopy temperature values for whole days from instantaneous satellite observations ([[2]](#footnote-2)Venus and Rugege, 2004):

* Calculate the equivalent satellite-derived instantaneous canopy temperature for days in-between measurements as a function of the daily rate of change over the interval between two successive cloud-free satellite observations in a linear interpolation procedure.
* Convert obtained instantaneous canopy temperatures to equivalent daily values by accounting for actual conditions during the day. To this end, the instantaneous canopy temperature values are multiplied by the fraction of sunshine hours for the day of year plus 20% of the clouded fraction. (It is assumed that there is still 20% radiation under an overcast sky.)
* Watch the thermodynamics movie “Wheat\_thermodynamics.mov” captured over a (water limited) wheat-field, located Barrax, Spain. Is a satellite pixel representative, and is a [[3]](#footnote-3)daily snapshot sufficient to capture the thermodynamics of a field crop do you think?

1. ISPRS\_fullpaper\_VenusRugege.pdf, see also [online here](https://research.utwente.nl/en/publications/combined-use-of-polar-orbiting-and-geo--stationary-satellites-to-improve-time-interpolation-in-dynamic-crop-models-for-food-security-assessment(c4439dcd-6023-4fdf-98b0-d8b7eea37cf3).html). [↑](#footnote-ref-1)
2. See pp. 3 of ISPRS\_fullpaper\_VenusRugege.pdf, see also [online here](https://research.utwente.nl/en/publications/combined-use-of-polar-orbiting-and-geo--stationary-satellites-to-improve-time-interpolation-in-dynamic-crop-models-for-food-security-assessment(c4439dcd-6023-4fdf-98b0-d8b7eea37cf3).html) (also contained in the zip-file). [↑](#footnote-ref-2)
3. See also “Analysis of a resistance-energy balance method for estimating daily evaporation from wheat plots using one-time-of-day infrared temperature observations.pdf” (contained in the zip-file). [↑](#footnote-ref-3)