Question sheet 2 (May 10, 2020)

2020年度の衛星海洋学特論の進め方

・NOAA衛星AVHRRセンサのデータ処理に関する課題を出すので、それに取り組んでください。今年度は、対面での授業は行いません。

・結果のPDFファイルをメール添付で提出してください。

・5つの課題を予定しています。順次、http://caos.sakura.ne.jp/sao/so/とGoogle Classroom にて公開します。

Notification of Advanced Satellite Oceanography 2020

・ Because of preventing the coronavirus infection, this year does not hold a face-to-face lecture. The students try to solve some questions on the AVHRR/NOAA data processing procedure.

・ Please send the answer file to toki [at sign] tohoku.ac.jp. Convert the answer file to PDF and then, the PDF file is attached to E-mail.

・ 5 major questions will be uploaded on http://caos.sakura.ne.jp/sao/so/ and Google Classroom. The exercises are made accessible to you on accordingly.

講義の目的

講義の目的は、 NOAA衛星AVHRRセンサのデータ処理を通して、衛星データ利用の基礎を学ぶことです。

衛星観測に関する技術も進化し、現代では、衛星データがどのような過程を経て処理を経たのかの詳細を知らなくても、そのデータを利用することができます。しかし、データに見られた変化が、本当に自然現象によるものなのかどうかを確かめるには、データの取得と処理に関する知識が必要です。

Purpose of this lecture

Purpose of this lecture is to learn the fundamental things of the satellite data processing procedure. This lecture uses the data of AVHRR/NOAA, which must be a good example for this lecture purpose.

As the technology on the satellite remote-sensing is advanced, we can use the satellite data without the knowledge of the fundamental things. However sometimes the knowledge is needed to confirm some variations in the data whether they are brought by a real natural phenomena or not.

課題 2（Question 2)

・今回の課題は、AVHRRセンサデータの物理量変換（キャリブレーション）に関することです。（課題2-1）は基礎となる放射の法則に関する問題です。（課題2-2）と（課題2-3）はAVHRRの赤外チャンネルの温度変換に関する問題です。

・課題2用のデータは、Google Classroom (j j m h 4 t m)から入手してください。課題1のサンプルデータも使います。

・結果のPDFファイルをメールに添付して境田（toki @ tohoku.ac.jp）まで送ってください。課題2の締切は5月31日とします。

・Question 2 deals with "calibration", or, temperature/radiation conversion from output digital count by the AVHRR infrared channels. (Q2-1) asks the fundamental radiation laws, Planck equation, Wien's displacement Law and Stephan-Boltzman Law. It is important to know the relation between temperature and radiation to understand the calibratin. (Q2-2) and (Q2-3) are the problems on the calibration of the AVHRR infrared channels.

・The data for Question 2 are uploaded on Google Classroom (j j m h 4 t m). Note that the data of Question 1 is also used in Question 2.

・Please send the answer file to toki [at sign] tohoku.ac.jp. Convert the answer file to PDF and then, the PDF file is attached to E-mail. The deadline of Question 2 is May 31.

課題 2-1（Question 2-1）

[Q] 身長170cm、体重70kgの男性（表面積はおおよそ2m²）からの放射に関する次の問いに答えよ。この人物の体温は36℃（～310K）とし、また、放射は黒体放射とする。

(a) この人物からの放射エネルギーのスペクトル分布を（プランク関数を）描け。

(b) ウィーンの変位則を用いて、放射エネルギーがピークとなる波長[μm]を求めよ。

(c) ステファン・ボルツマンの法則を用いて、単位面積当たりの放射エネルギー[W/m²]を求めよ。

(d) この人物は、放射によって1時間当たりどのくらいのカロリーを消費するか。

[Q] Let's consider the radiation from a man, who is 170cm in height, 50kg in weigh, about $2m^2$ in surface area, and 36℃ in body temperature. Supposing that the radiation is from black body, answer the following questions.

(a) Plot the spectrum of the radiation from his body, or, the Planck's radiation equation with 36℃ (about 310K) of temperature on a graph.

(b) Calculate the wavelength [μm] of maximum emission, using Wein's displacement Law.

(c) Calculate the total radiation energy per unit area [W/m^2] from his body, using Stephan-Boltzman Law.

(d) Estimate the calories (energy per hour) that he burns by the radiation emitted from his body.

課題 2-2（Question 2-2）

[Q] AVHRRセンサは、出力カウント値(*C*)と放射量(*N*, mW/m^2 ・sr・cm^{-1})の関係が線形：
N = *G*・*C* + *I* となるように設計されている。赤外チャンネル（チャンネル3(3B),4,5）のキャリブレーションでは、係数(*G*,*I*)を求めるシステムがセンサ内に組み込まれている。

(a) Table 2-1（次ページ）の値を用いて、チャンネル4,5それぞれの(*G*,*I*)の値を求めよ。

(b) 15℃のときのチャンネル4,5のデジタルカウント値を求めよ。ここでは、チャンネル4の中心波数（v_c）を927.8cm^{-1}、チャンネル5の v_c を842.2cm^{-1}とせよ。

[Q] The AVHRR has a linear relation between input radiation (*N*, mW/m^2・sr・cm^{-1}) and output digital count (*C*): *N* = *G*・*C* + *I*. The AVHRR is equipped with on-board calibration system for the infrared channels (channel 3(3B),4,5) to get the coefficients (*G*,*I*).

(a) Calculate (*G*,*I*)s of channels 4 and 5, using Table 1 (next page).

(b) Calculate the digital counts of channels 4 and 5 when the AVHRR observes an object with the temperature of 15℃. Here uses the following central wave number (v_c) : v_c = 927.8cm^{-1} for channel 4; v_c = 842.2cm^{-1} for channel 5.

sr : steradian

Table 2-1 Values for calibration of the NOAA infrared channels in 03:28 (UTC), Nov.9 1988.

	Channel 4		Channel 5	
	Digital Count (*C*)	Radiation (*N*)	Digital Count (*C*)	Radiation (*N*)
IWT	442.00	93.441	381.24	107.729
Space	993.00	0.0	996.34	0.0

IWT : Internal Warm Target （センサ内部の較正用黒体）
Space : This is used as a cold target.（宇宙空間の観測結果で較正に使用）
IWTの温度は白金温度計で計測されており、放射量(*N*)はその温度から求めた。IWTとSpaceのカウント値(*C*)は50個のサンプルの平均値。Spaceの放射量は近似的に0とする。
The temperature of IWT is monitored by platinum thermometers. The radiation (*N*) values in Table 1 are calculated from the IWT temperatures. The digital counts (*C*) of IWT and Space are the averages of 50 samples in the data. The radiation of Space is approximately zero.

The equation for conversion to temperature (*T* [K]) from radiation energy (*N*) observed by AVHRR.

$$T = \frac{C_2 \nu_c}{\ln\left(1 + \frac{C_1 \nu_c^3}{N}\right)}$$

$C_1 = 1.1910659 \times 10^{-5}$ $C_2 = 1.438833$

ν_c : The central wave number of the AVHRR channel filter (cm^{-1})

課題 2-3（Question 2-3）

[Q] AVHRRセンサの赤外チャンネル4,5では、出力カウント値(*C*)と放射量(*N*)の間の線形関係が厳密には成立しない。より正確な温度を求めるために補正(非線形補正)を行う。非線形補正を行った出力カウント値(*C*)と温度(*T*)の対応関係が記録されたファイル : N88110903_H_cv4.txt を用いて、次の問いに答えよ。

(a) 出力カウント値(*C*)と温度(*T*)の対応関係をグラフに描け。横軸を*C*、縦軸を*T*とする。

(b) 出力カウント値に対する温度の変化率（Δ*T*/Δ*C*）をセンサの温度分解能と考える。温度分解能が±0.2℃以内となる温度レンジを求めよ。

(c) Quesiton 1で使用したチャンネル４のデータ(N88110903_ch4.ex)を温度に変換し、それを画像化せよ。

[Q] It is known that the measurement values by the AVHRR infrared channels 4 and 5 have differences from the linear relation between the digital count (*C*) and the radiation (*N*). So, "non-linear correction" is adopted to get more accurate values. The file, N88110903_H_cv4.txt, is a table for the digital count (*C*) - temperature (*T*) conversion. This table is made by use of the non-linear correction. Answer the following questions, using the table in N88110903_H_cv4.txt.

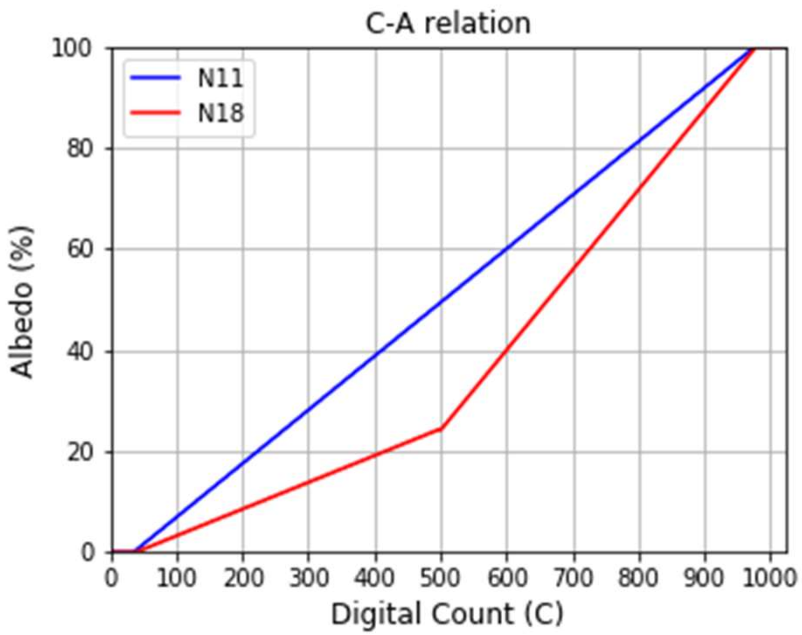
(a) Plot the *C*-*T* relation on a graph with *C* on the horizontal axis and *T* on the vertical axis.

(b) Here defines the rate of the temperature variation to the digital count variation (Δ*T*/Δ*C*) as the temperature resolution. At what temperature range is the temperature resolution within ±0.2℃ ?

(c) Make the image of the AVHRR channel 4 data used in Question 1 (N88110903_ch4.ex) after processing the temperature conversion.

Materials for Question 2

File name	Short description of the file
qs02.pdf	Question 2 sheet (this file)
N88110903_H_cv4.txt	AVHRR channel 4 calibration table for N88110903_H_ch4.ex CSV file (See Fig. 2-1 in Next page)
t_q02.py	Python program to make a graph of N88110903_H_cv4.txt
t_q02ex.py	(Extra) Same as "t_q02.py" but having an additional function
N88110903_H_cv2.txt	(Extra) Channel 2 calibration table for AVHRR/2 on NOAA-11
N06050503_18_cv2.txt	(Extra) Channel 2 calibration table for AVHRR/3 on NOAA-18



← A graph of N88110903_H_cv2.txt and N06050503_18_cv2.txt.

About the calibration table file, N88110903_H_cv4.txt

・N88110903_H_cv4.txt is used to calibrate the data, N88110903_ch4.ex.
・The file is a text file, and a CSV (Comma Separated Values [Variables]) file.
・The values of the first column corresponds to the digital count. The values of the second column are the corresponding temperature. *See* **Figure 2-1**.

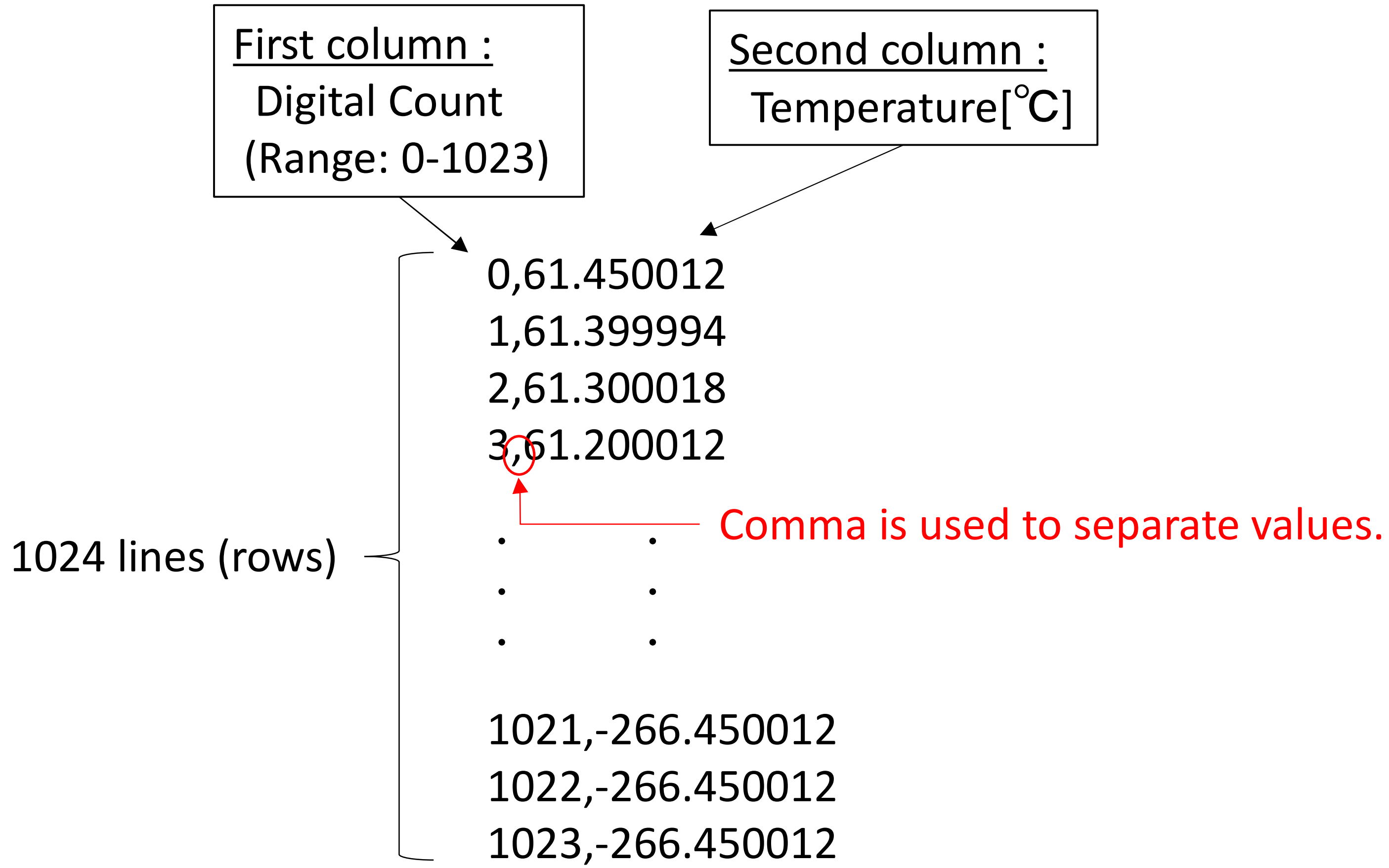


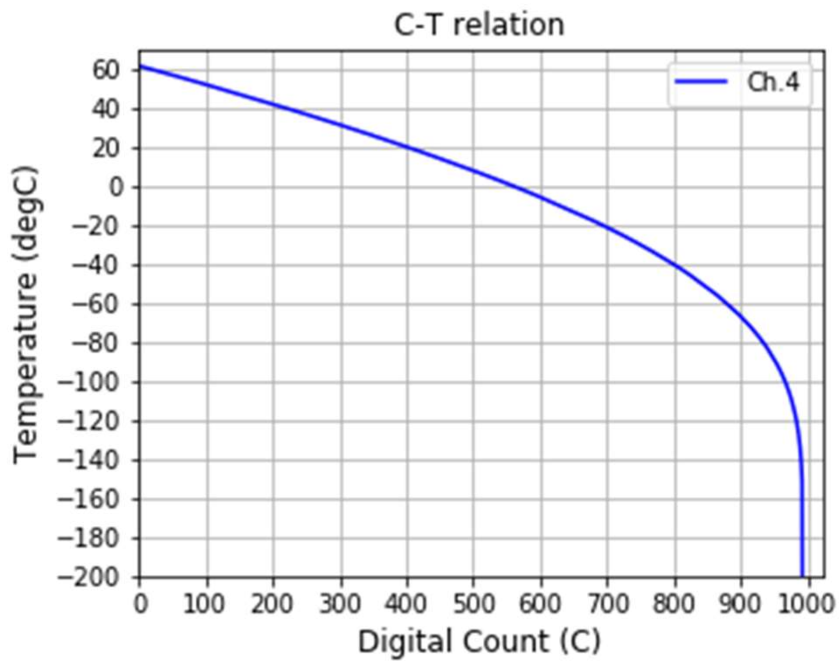
Figure 2-1 The values in N88110903_H_cv4.txt

Program example by Python to read the calibration table

```
import matplotlib.pyplot as plt
import numpy as np

tbl = np.loadtxt('./N88110903_H_cv4.txt', delimiter=',')

print(tbl[442,0],tbl[442,1])

plt.figure(figsize=(5,4))
plt.plot(tbl[0:,0],tbl[0:,1],color='blue', label ='Ch.4')
plt.xlabel('Digital Count (C)', fontsize=12)
plt.ylabel('Temperature (degC)', fontsize=12)
plt.xlim(0,1023)
plt.ylim(-200,70)
plt.xticks(np.arange(0,1100,step=100))
plt.yticks(np.arange(-200,80,step=20))
plt.grid(b=None,axis='both')
plt.title('C-T relation')
plt.legend(loc='best')
plt.tight_layout()
plt.savefig('c4tbl.png')
plt.show()
```

The data are stored to the array, "tbl". (Only 1 line !)

This part to make the graph below ↓



補足（Supplement）

AVHRRの可視チャンネル（チャンネル1,2,3A）のキャリブレーションには触れることが出来なかったのでここで補足しておきます。可視チャンネルのキャリブレーションも赤外チャンネルと同様、*A* = *G*・*C* + *I*という線形関係を使います。赤外チャンネルとの違いは以下の通りです。

- 得られる値(*A*)はalbedo(%albedo, 0-100%)。
- 係数(*G*,*I*)は衛星の打ち上げ前に決められた値を使う（センサには可視チャンネル用のキャリブレーションシステムはない）。

可視チャンネルのキャリブレーションの詳細は、次ページ以降のNOAA衛星データのUSERS GUIDEからの抜粋を読んでください。余力のある方は、AVHRR/2とAVHRR/3の可視チャンネルのキャリブレーションの違いについても調べてみてください。

Here gives extra information about the AVHRR visible channel (channel 1, 2,3A) calibration, which is cut out from Question 2. In the calibration for the visible channel, a linear relation between digital count (*C*) and %albedo (*A*), *A* = *G*・*C* + *I*, is also used. The visible channel calibration differs from the infrared channel calibration in the following points,

- The digital counts are converted into albedo (%albedo, 0-100%) values.
- The calibration coefficients (*G*,*I*) are determined by the pre-launch calibration procedure, no on-board calibration system for the visible channels.

Please read next 2 pages, which are extracted from "NOAA POLAR ORBITER DATA USERS GUIDE", to get the more information about the AVHRR visible channel calibration. if you have time, check the difference in the visible channel calibration between AVHRR/2 and AVHRR/3.

3.3.2 Visible Channel Calibration

The scaled visible channel slope values are in units of percent albedo/count for slope and in percent albedo for intercept.

The percent albedo measured by the sensor channel *i* is computed as a linear function of the input data value as follows :

$$Ai = Si\ C + Ii \qquad (3.3.2\text{-}1)$$

Where *Ai* is the percent albedo measured by channel *i*, *C* is the input data value, and *Si* and *Ii* are respectively, the scaled slope and intercept values. The visible channels (1 and 2) are calibrated using Equation 3.3.2-1 to obtain the percent albedo. The calibration procedure is very similar to that described above for the thermal channels. The pre-launch slopes and intercepts for AVHRR Channels 1 and 2 are shown in Table 3.3.2-1.

Table 3.3.2-1 Pre-launch slopes and intercepts for AVHRR Channels 1 and 2.

NOAA-11	$S_1 = 0.0950$	$I_1 = -3.8$	$S_2 = 0.1061$	$I_2 = -3.6$

The two visible channels on the AVHRR instrument are calibrated prior to launch using the following procedure. The calibration source is a large aperture integrating sphere equipped with 12 calibrated quartz-halogen lamps. These lamps were carefully selected to match each other as closely as possible in spectral output and operating current. The sphere is then calibrated with all 12 lamps on, against a National Institute of Standards and Technology secondary standard of spectral irradiance. The ratio of the output of *n* lamps to that of 12 lamps is also determined. This yields the spectral output of the sphere when any number of lamps, *n*, is on. By varying the number of bulbs which are turned on, a calibration curve from dark level to a maximum of 12 lamps output can be obtained.

The following computations must be made in order to present the calibration in terms of percent albedo vs. radiometer output. First, the spectral output of the sphere is integrated with the spectral response function of the AVHRR channel to yield an effective radiance for the spectral band for 12 lamps operating. This is then multiplied by the appropriate *Kn* factor to convert to *n* lamps. This is described by equation 3.3.2-2:

$$N_L = K_n \int_{\lambda 1}^{\lambda 2} C(\lambda)\phi(\lambda)\, d\lambda \qquad (3.3.2\text{-}2)$$

where, N_L = effective radiance as seen by the channel in the appropriate spectral band.

K_n = the factor to convert to radiance for *n* lamps.

$C(\lambda)$ = calibrated spectral radiance of the sphere with 12 lamps on.

λ = wavelength, in the spectral region $\lambda 1$ to $\lambda 2$.

$\Phi(\lambda)$ = the measured spectral response of the channel being calibrated.

Similarly, if one takes the solar irradiance at the top of the atmosphere and performs a similar calculation, the results are shown in Equation 3.3.2-3.

$$N_S = \frac{1}{\pi} \int_{\lambda 1}^{\lambda 2} S(\lambda)\phi(\lambda)\, d\lambda \qquad (3.3.2\text{-}3)$$

where, N_L = effective radiance of the radiometer viewing reflected sunlight.

$S(\lambda)$ = spectral irradiance viewed at the top of the atmosphere.

$\Phi(\lambda)$ = spectral response function of the channel.

The resultant *Ns* represents what would be "seen" from space with 100% reflecting, diffuse surface when the solar zenith angle is zero.

Thus, the percent albedo *A* is calculated using Equation 3.3.2-4:

$$A = \frac{N_L}{N_S} \times 100 \qquad (3.3.2\text{-}4)$$