21st Asia-Pacific Advanced Network Meetings

Monitoring for electric power output and fossil CO_2 emissions by means of DMSP/OLS nighttime imagery

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Masanao HARA*1, Hiroshi Yagi*1, Husiletu*2, Fumihiko Nishio *2

*1 VTI Research Institute, VisionTech Inc.(VTI)
*2 Center for Environmental Remote Sensing, Chiba University

Back Ground

- Greenhouse gas is one of big issue in the 21st century.
- In particularly, CO_2 emission is increasing because of human activities.
- Human activities always need energy.
- Typically electric power is one of most important energy for human activities.
- Most electric power is generated by the fossil fuel.

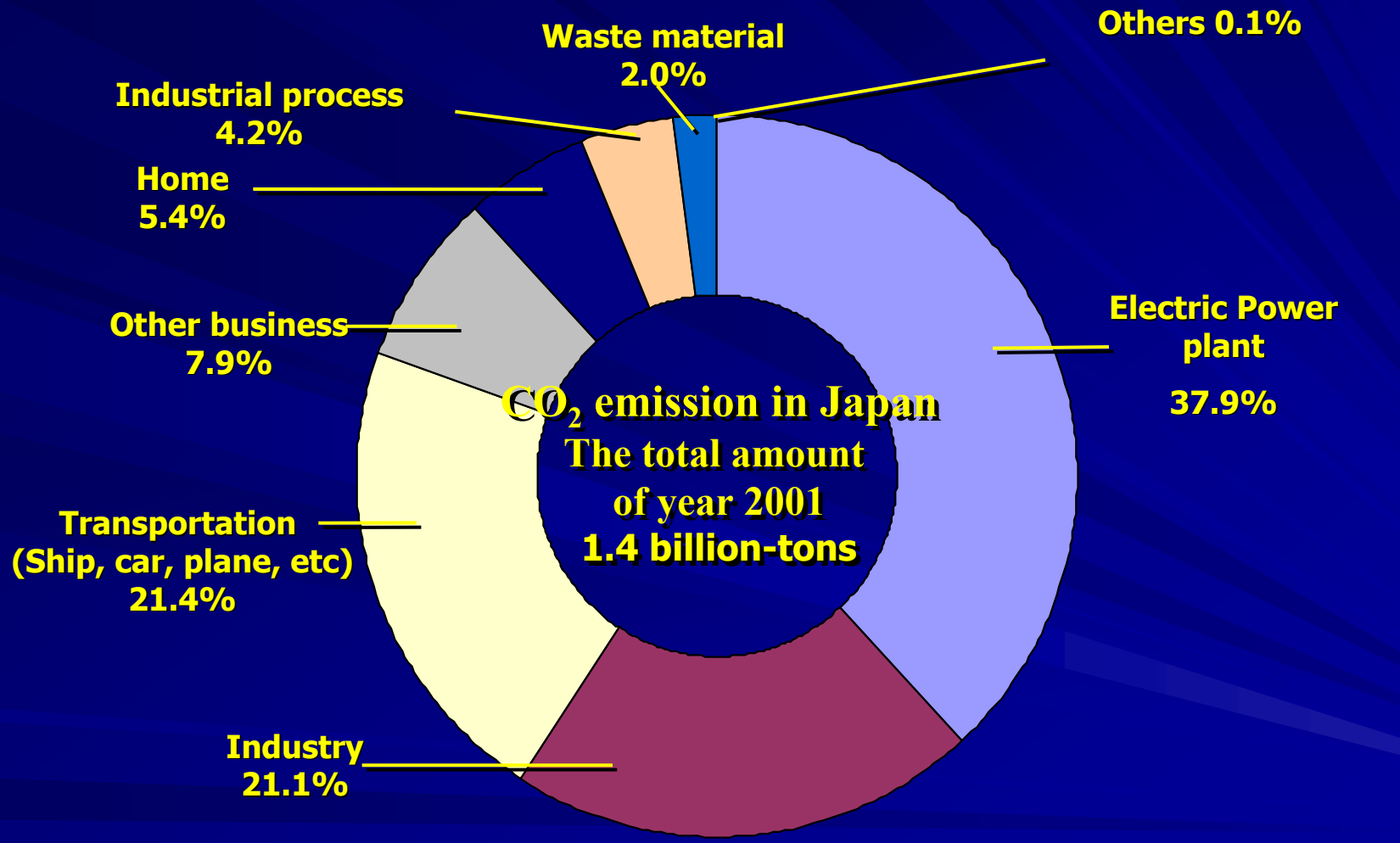
Consumption composition in the top 10 countries of primary energy supply (2000)

units: million tons converted into oil

		USA	China	Russia	Japan	India	Germany	France	Canada	U.K	Korea
Total		2,299.7	1,142.4	614.0	524.7	501.9	339.6	257.1	251.0	232.6	193.6
Energy sources (%)	Coal	23.6	57.4	18.0	17.9	32.9	23.7	5.8	12.1	15.5	21.7
	Oil	38.6	19.4	21.2	50.5	20.4	38.7	33.9	35.1	35.7	53.6
	Natural gas	23.7	2.5	51.9	12.4	4.4	21.1	13.7	29.7	37.6	8.8
	Atomic energy	9.1	0.4	5.6	16.0	0.9	13.0	42.1	7.6	9.5	14.7
	Hydraulic and other energy	5.1	20.4	3.2	3.3	41.5	3.4	4.4	15.5	1.7	1.3

【Source】 IEA, Energy Balance of OECD Countries(2002)
IEA, Energy Balance of NON-OECD Countries(2002)

Structure of CO_2 emission sources in Japan



Source : Ministry of Environment, 2001

Objective

- Estimate electric power consumption and monitoring CO_2 emission from the electric power consumption by using satellite remote sensing.

Data

- DMSP(Defense Meteorological Satellite Program) / OLS(Optical linescan System) data were used.
- A whole year of 1999 data (365 scenes) were used.
- 1 km spatial resolution data generated by NGDC in U.S.A.

Description of the satellite and the sensor

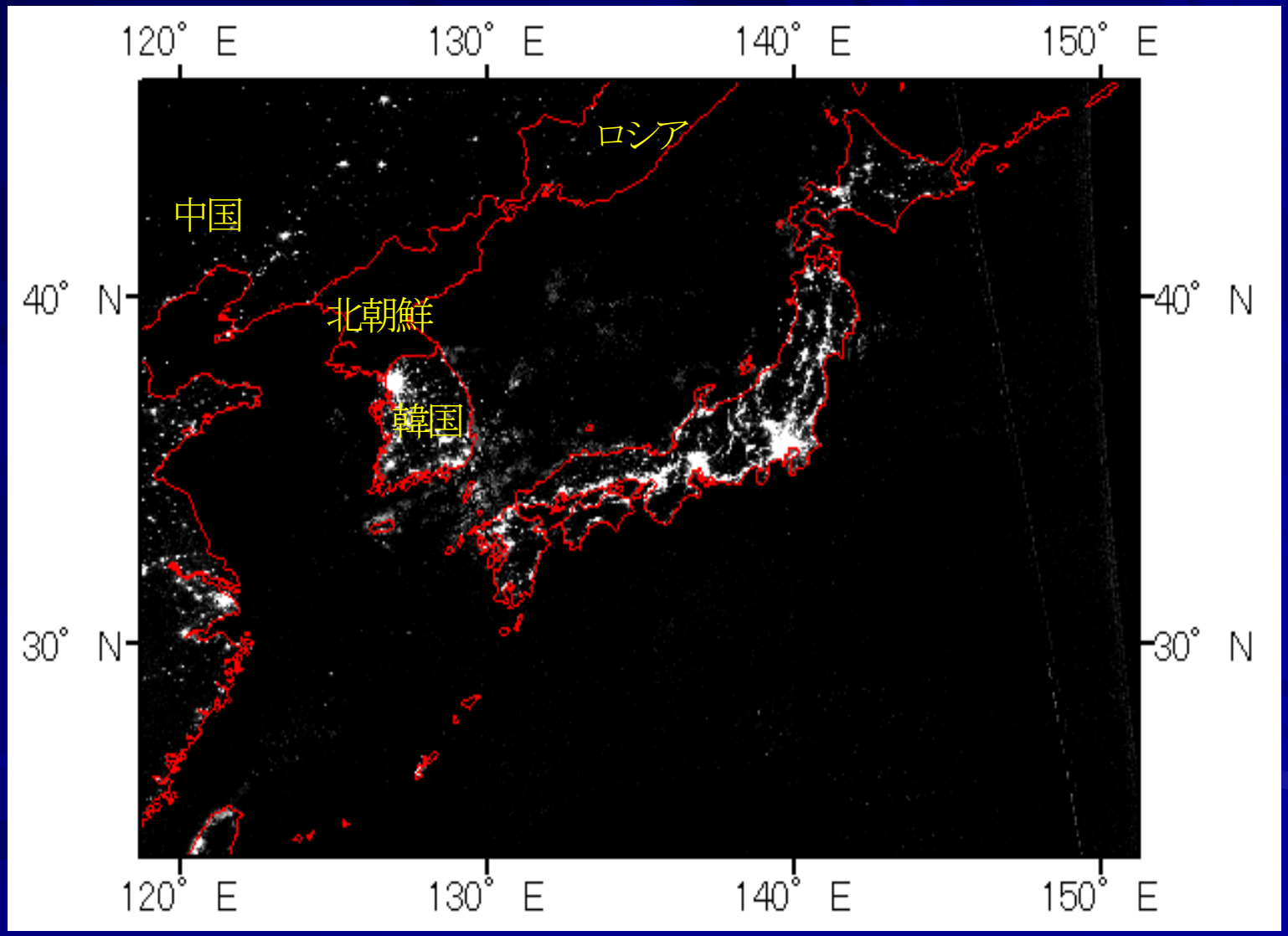
DMSP (Defense Meteorological Satellite Program) specification

Orbit	Sun-synchronous near polar orbit
Altitude	830km
Revisit	101min
Sensor	OLS（Operational Linescan System）
	SSM/I（Microwave Imager ）
	SSM/T（Atmospheric Temperature Profiler）
	SSM/T2（ Atmospheric Water Vapor Profiler ）
	SSJ/4 (Precipitating Electron and Ion Spectrometer)
	SSIES (Ion Scintillation Monitor)

OLS Sensor specification

Band	Spectral range	Spatial resolution		Swath width	Radiometric resolution
		Fine	Smooth		
Visible	0.40－1.10 μm	0.55km	2.7km	3000km	6bit
Visible (Night)	0.47－0.95 μm	0.55km	2.7km	3000km	6bit
Thermal-IR	10.0－13.4 μm	0.55km	2.7km	3000km	8bit

Study area



Methodology

- Remove cloud from a time series of DMSP/OLS imagery by the 10-days Maximum Value Composite method.
- Extract the nighttime stable light(DN) by the NRF (Noise Reduction Filter) algorithm.
- Compensate the saturation of DN by a simple method named Deltaic Model.
- Find correlation between DN and statistical electric power consumption.
- Estimate the electric power consumption from DN by using the correlation.
- Calculate CO_2 emission level from the estimated power consumption.

The Algorithm of Noise Reduction Filter (NRF)

"NRF" is developed to remove a cloud from a time series composite images especially designed for NDVI and SST products.

- Finding a cyclic patterns(seasonal changes) and extract harmonic series from a time series vegetation index(SST).
- Estimating the correct NDVI(SST) of a pixel under the cloud or its shadow by the cyclic patterns and the harmonics series.

$$f_t = c_0 + c_1 t + \sum_{l=1}^{N} \left\{ c_{2l} \sin\left(\frac{2\pi k_l}{M} t \right) + c_{2l+1} \cos\left(\frac{2\pi k_l}{M} t \right) \right\}$$

Where;

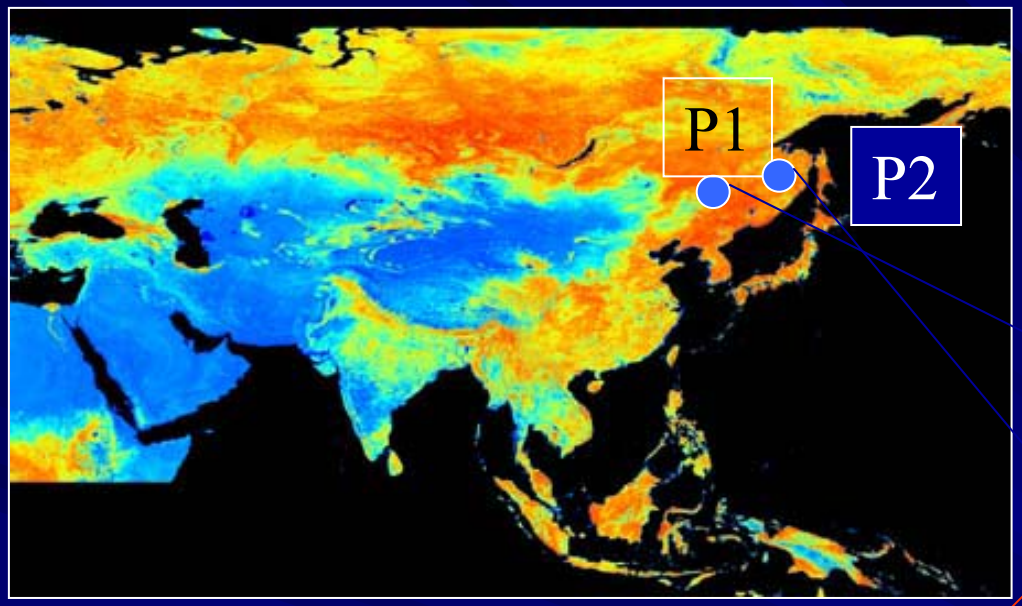
M : Cycle (1 year = 36 for 10-days composite)

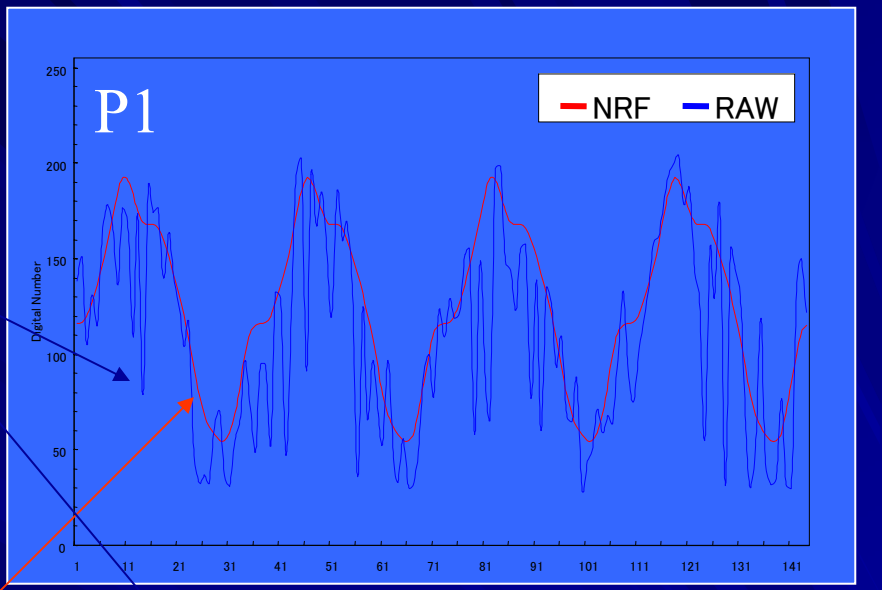
t : Time period (1Year=36, 2Year=72, 3Year=108, 4Year=144)

Kt : Frequency (1, 2, 3, 4, 6, 12 month(s))

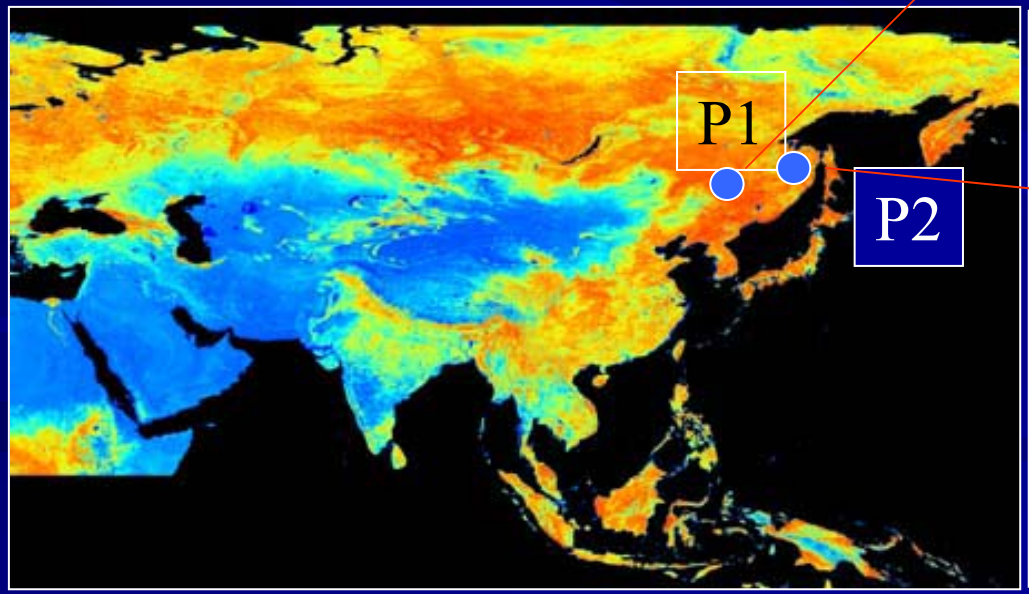
N : Number of pixel

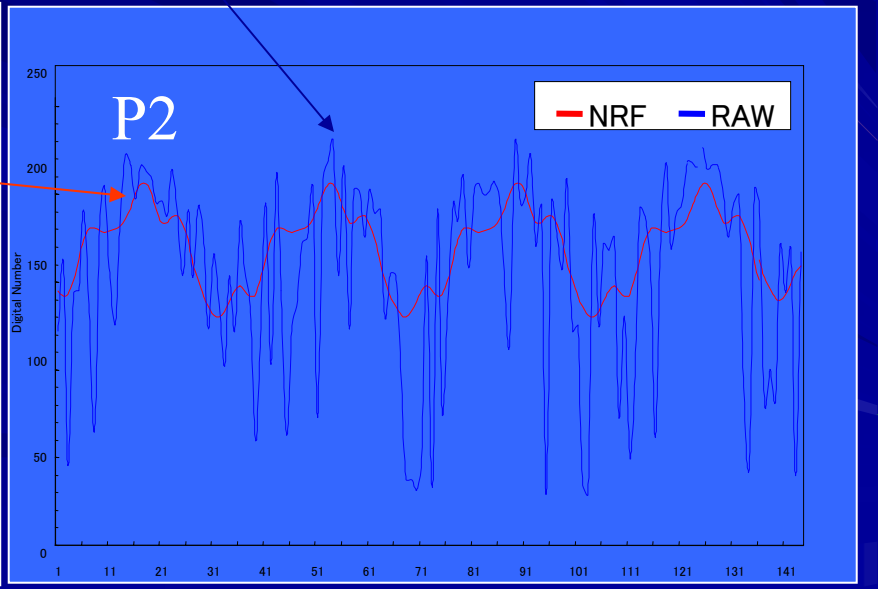
C_0, C_1, C_{2l}, C_{2l+1} : Coefficient of each function





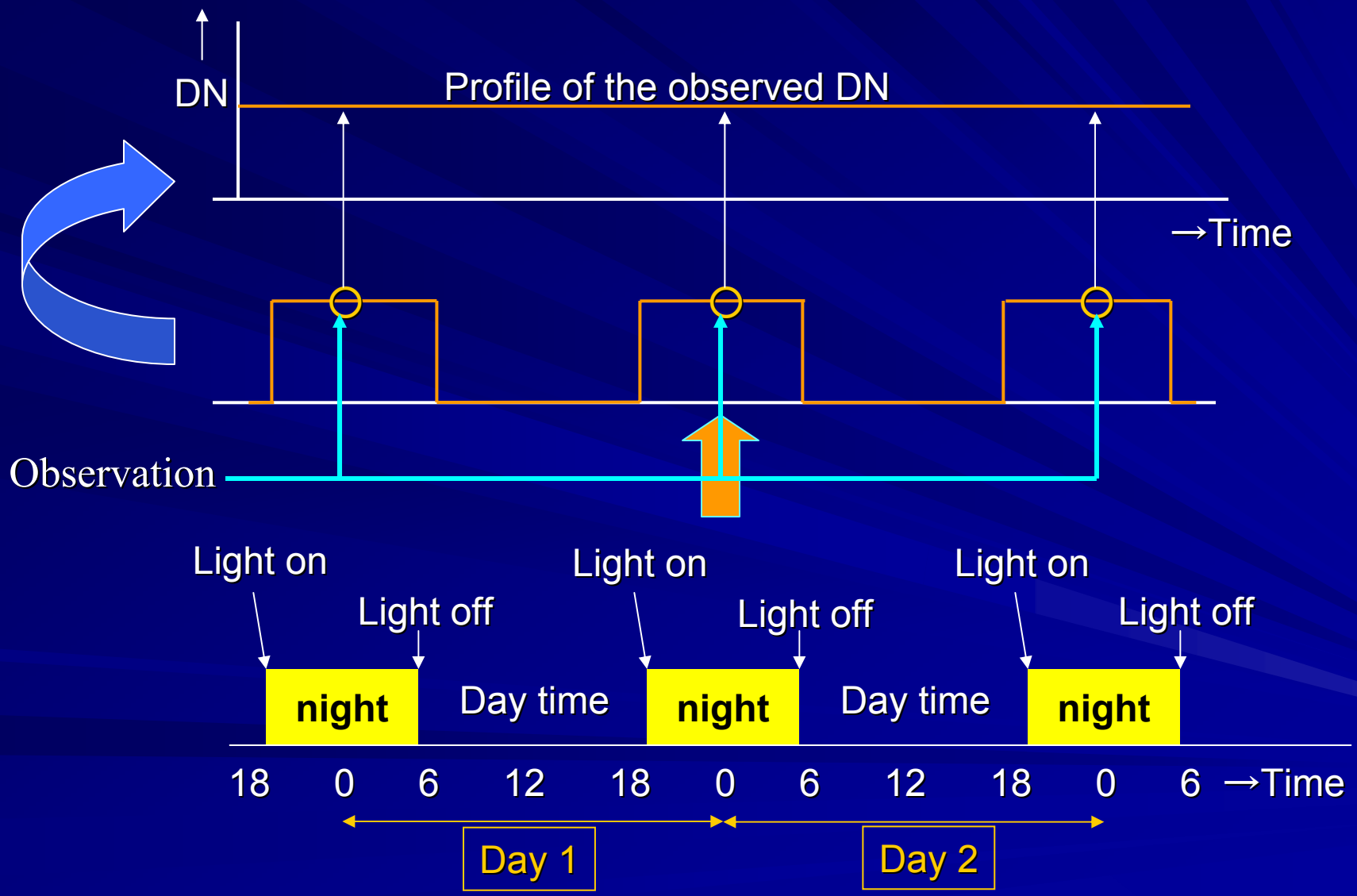
Before NRF processing



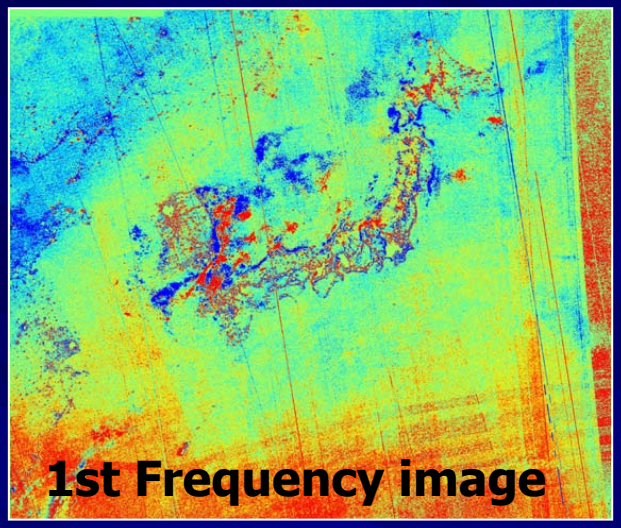


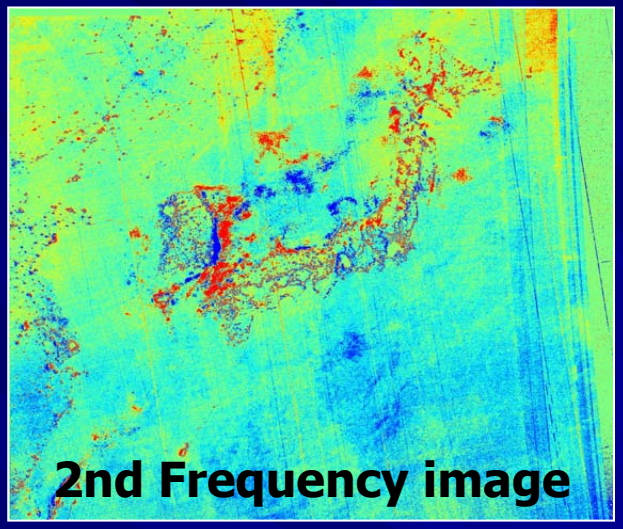
After NRF processing

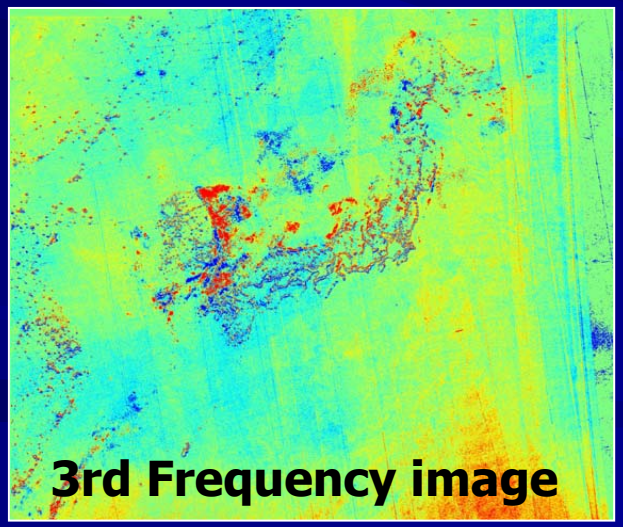
NRF for DMSP/OLS nighttime time series data set

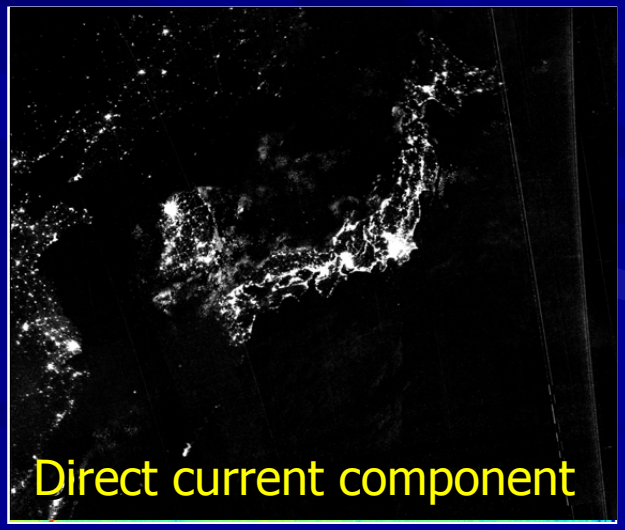


Frequency Component Images



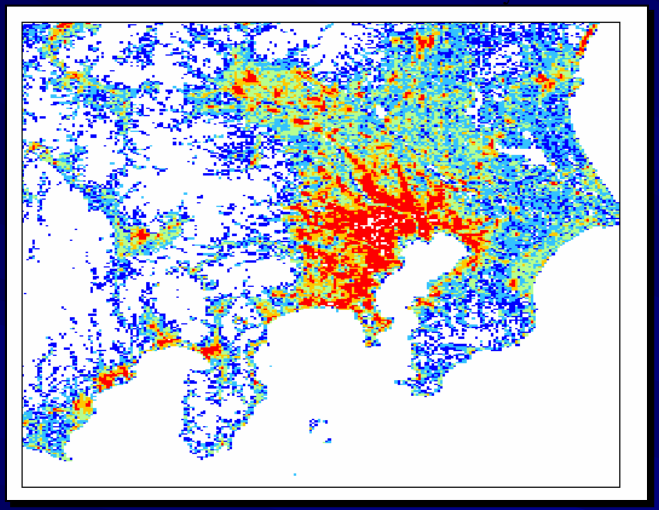




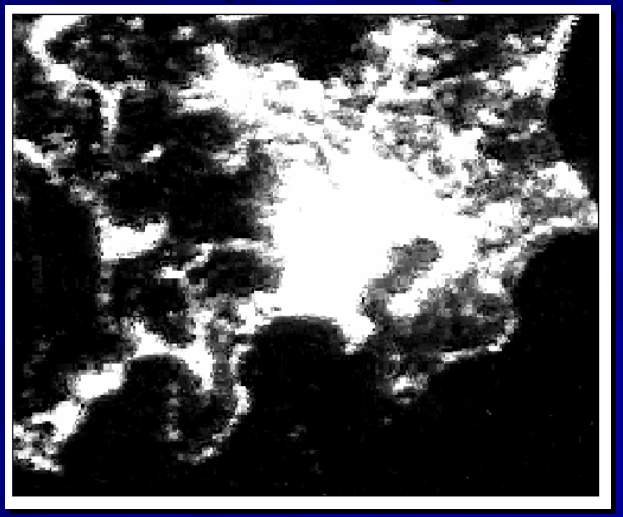


Comparison with a NRF processed data and a Land use map

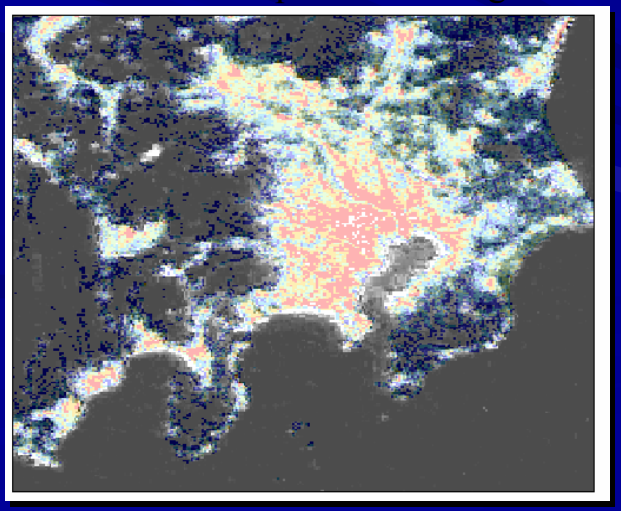
Land use map(1977, GSI)
Urbanization density



A NRF processed image



The composite image of a Land use map
And a NRF processed image

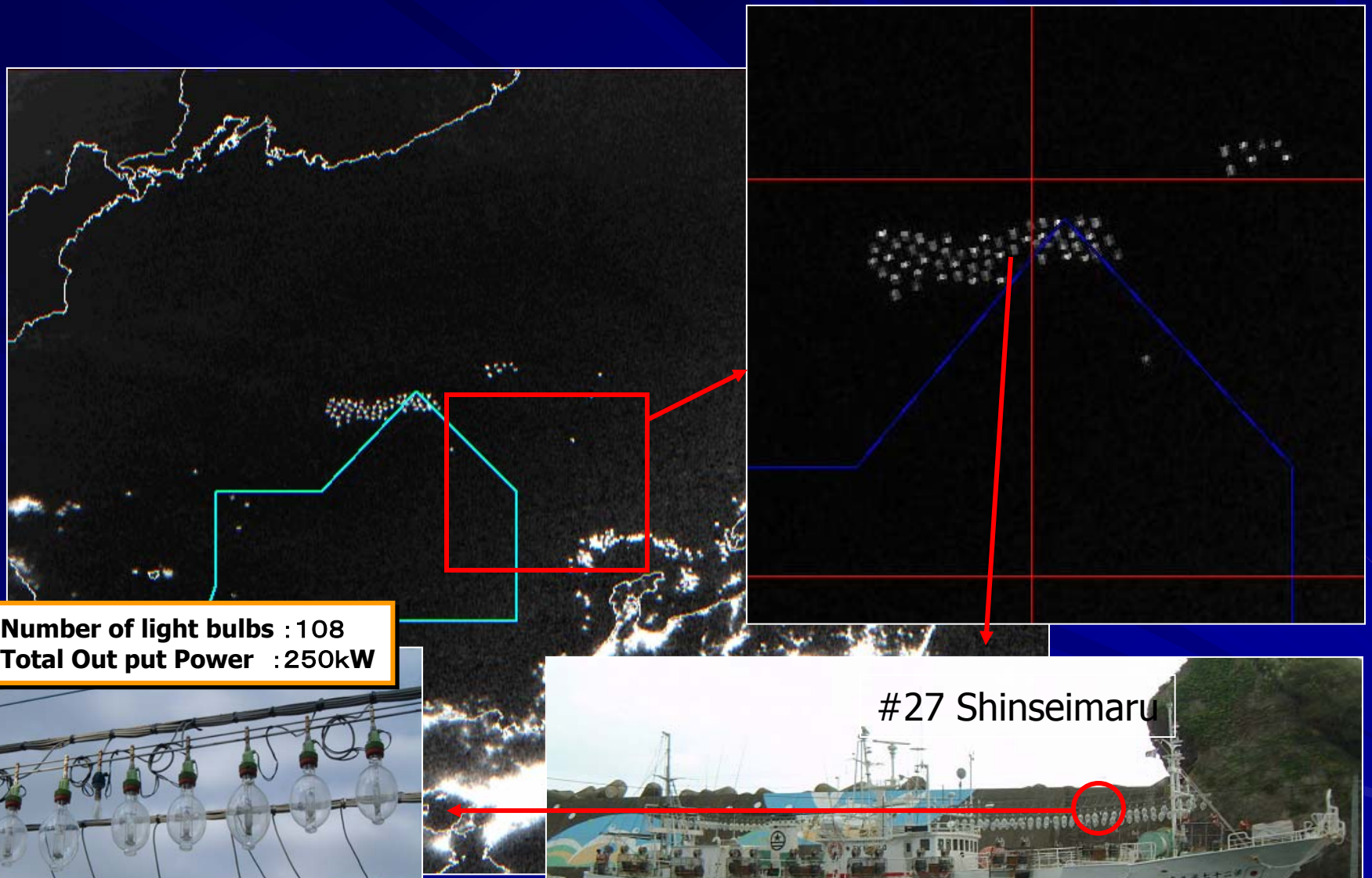


Low density level

		(m^2)
I	0 - 42832	
II	42833 - 160313	
III	160314 - 347184	
IV	347185 - 617576	
V	617577 - 1004871	

High density level

Compensation of light intensity saturation

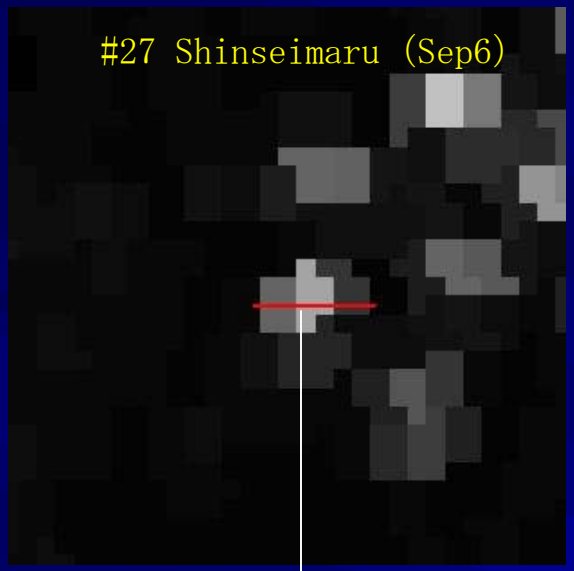


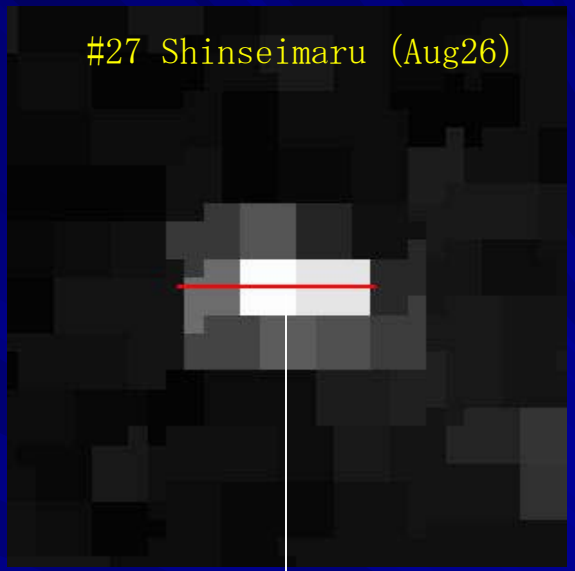
Number of light bulbs : 108
Total Out put Power : 250kW

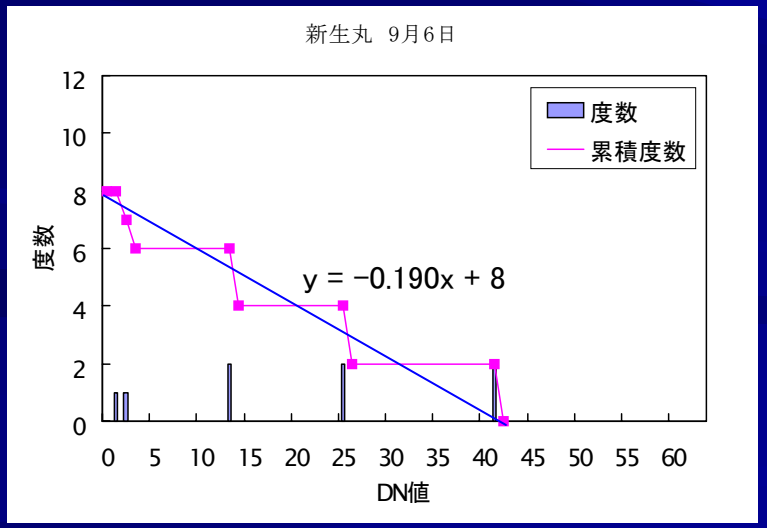
Gross ton : 133 t
Ship length : 42 m
Ship width : 6. 2m

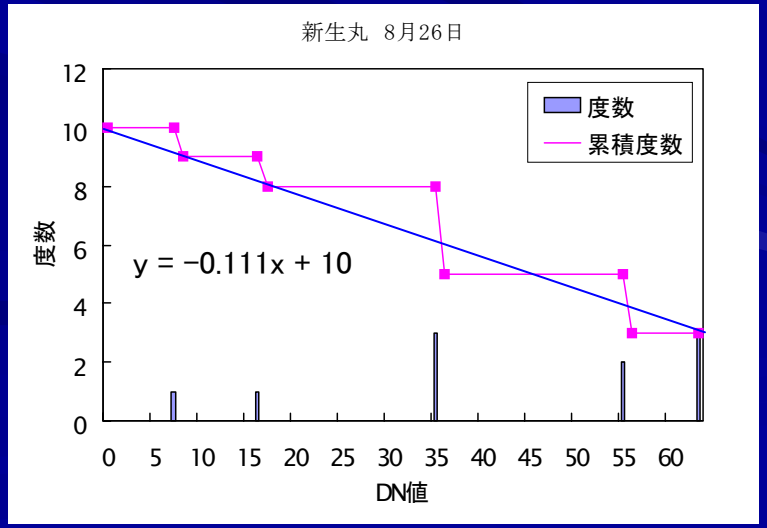
Deltaic Model

The Deltaic model is used for compensation of Saturated DN

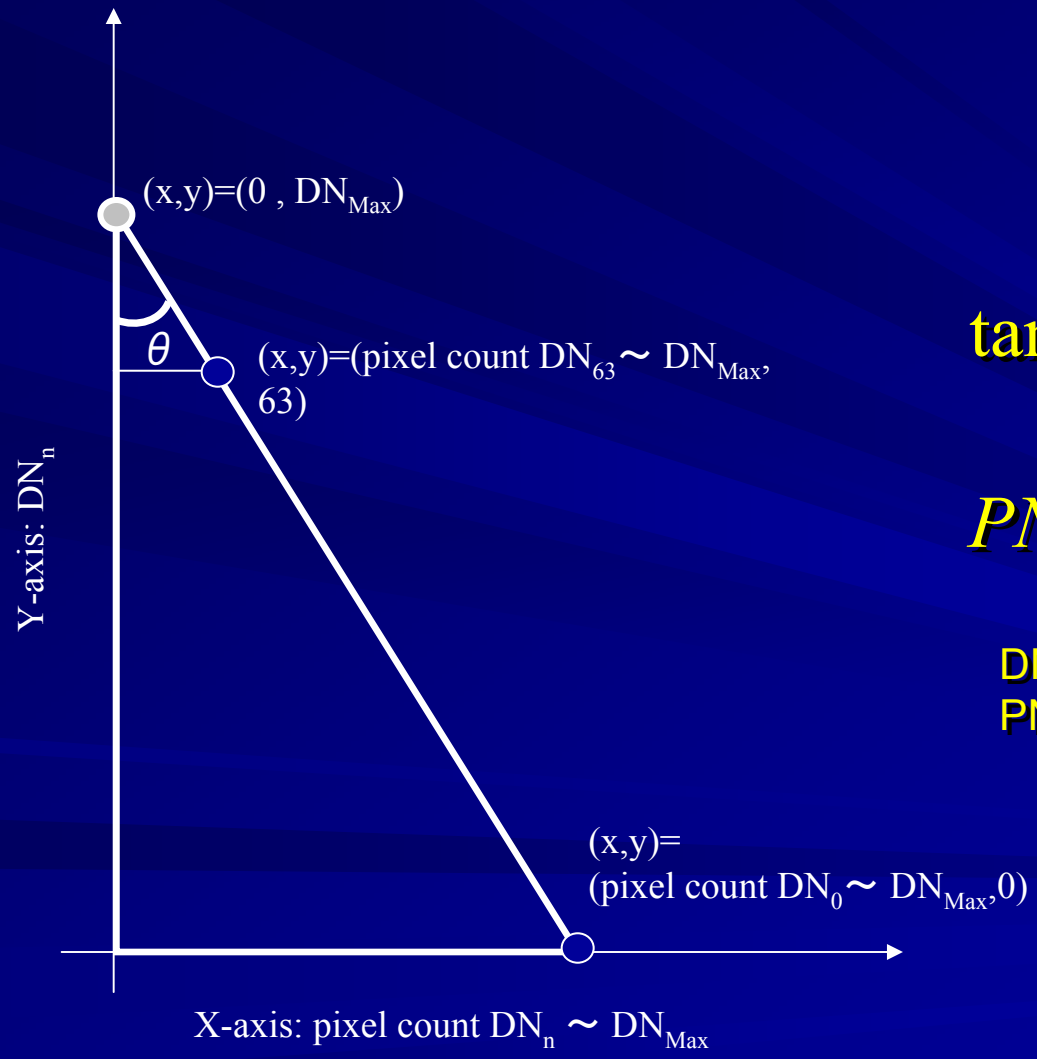








The concept of Deltaic Model



$$\tan\theta = \frac{PN_{total}}{DN_{\max}}$$

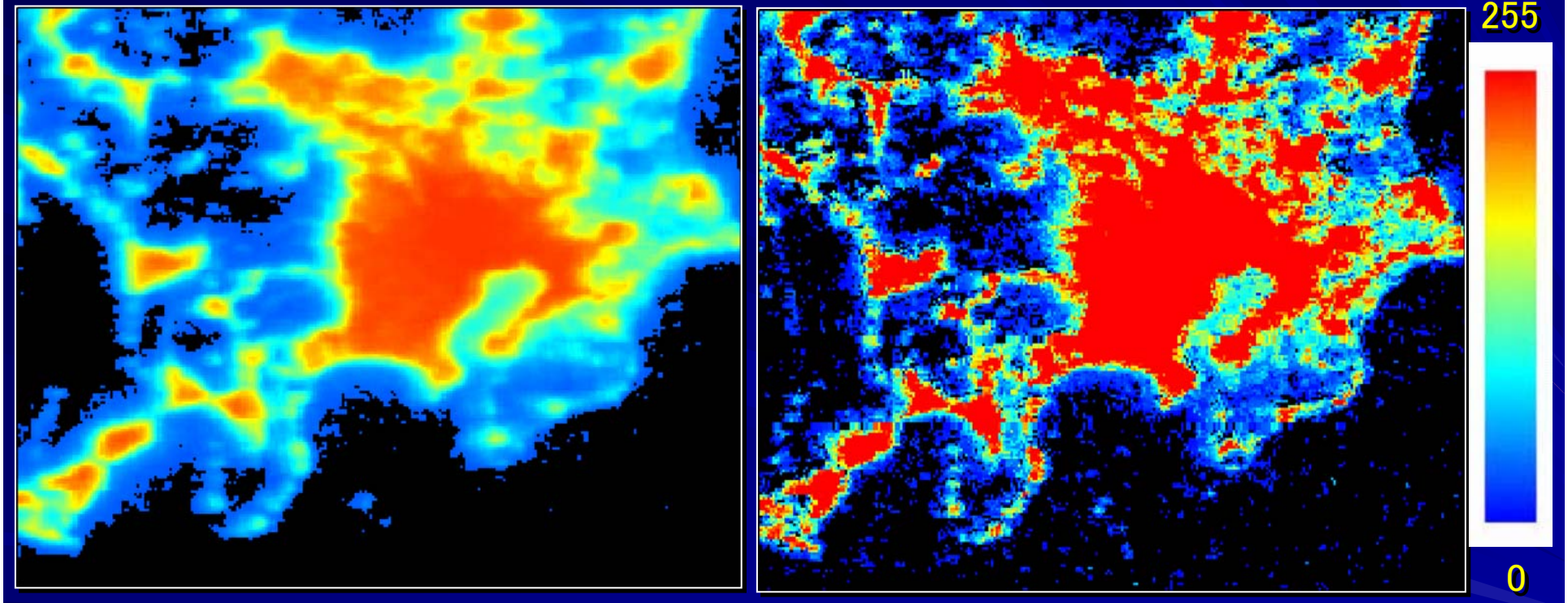
$$PN_n = \tan\theta\left(DN_{\max} - DN_n\right)$$

DN = Digital Number of each pixel
PN = Number of pixels

Comparison between Deltaic compensation and non-compensation data

Before

After

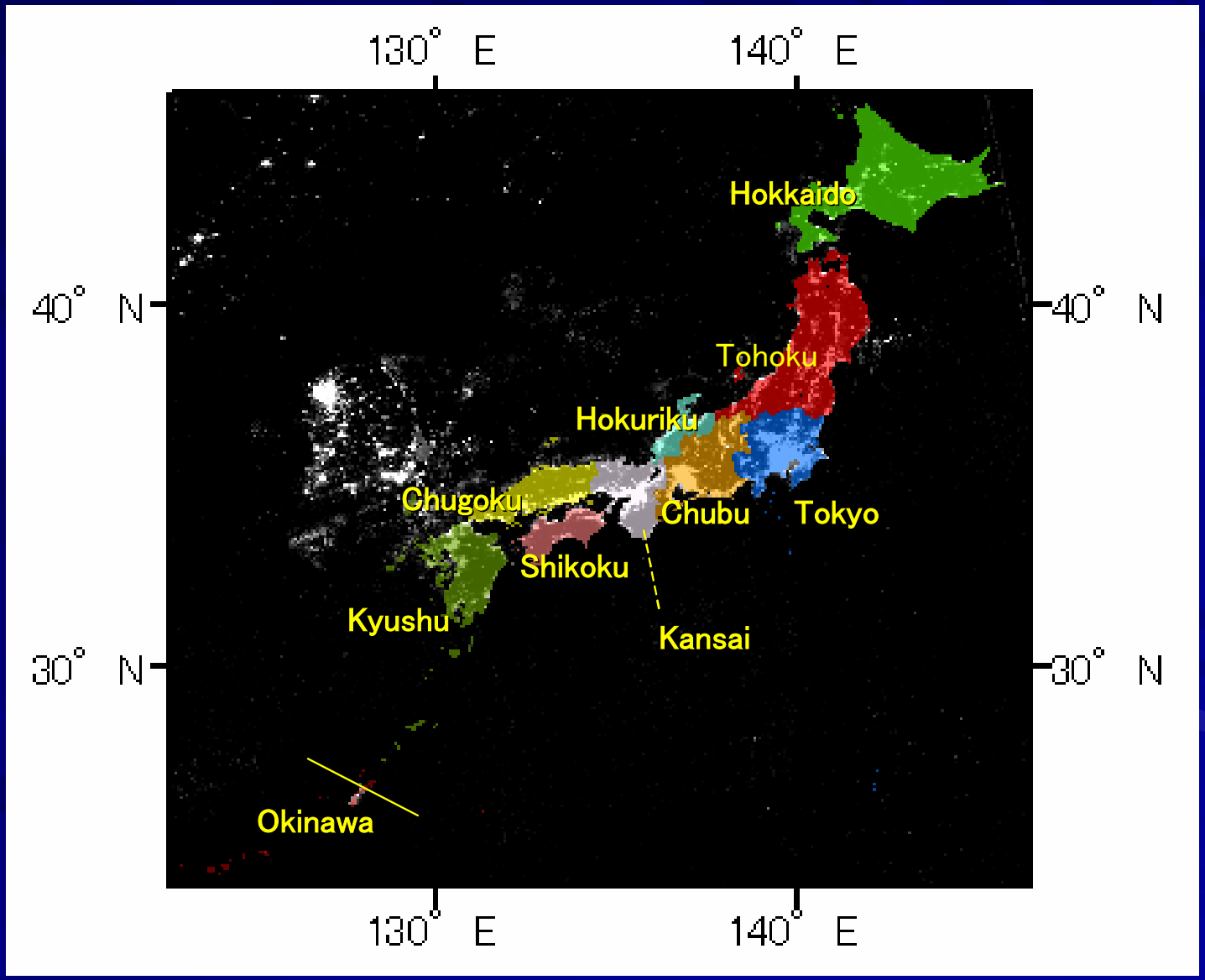


Estimation of electric power consumption from Stable nighttime lights

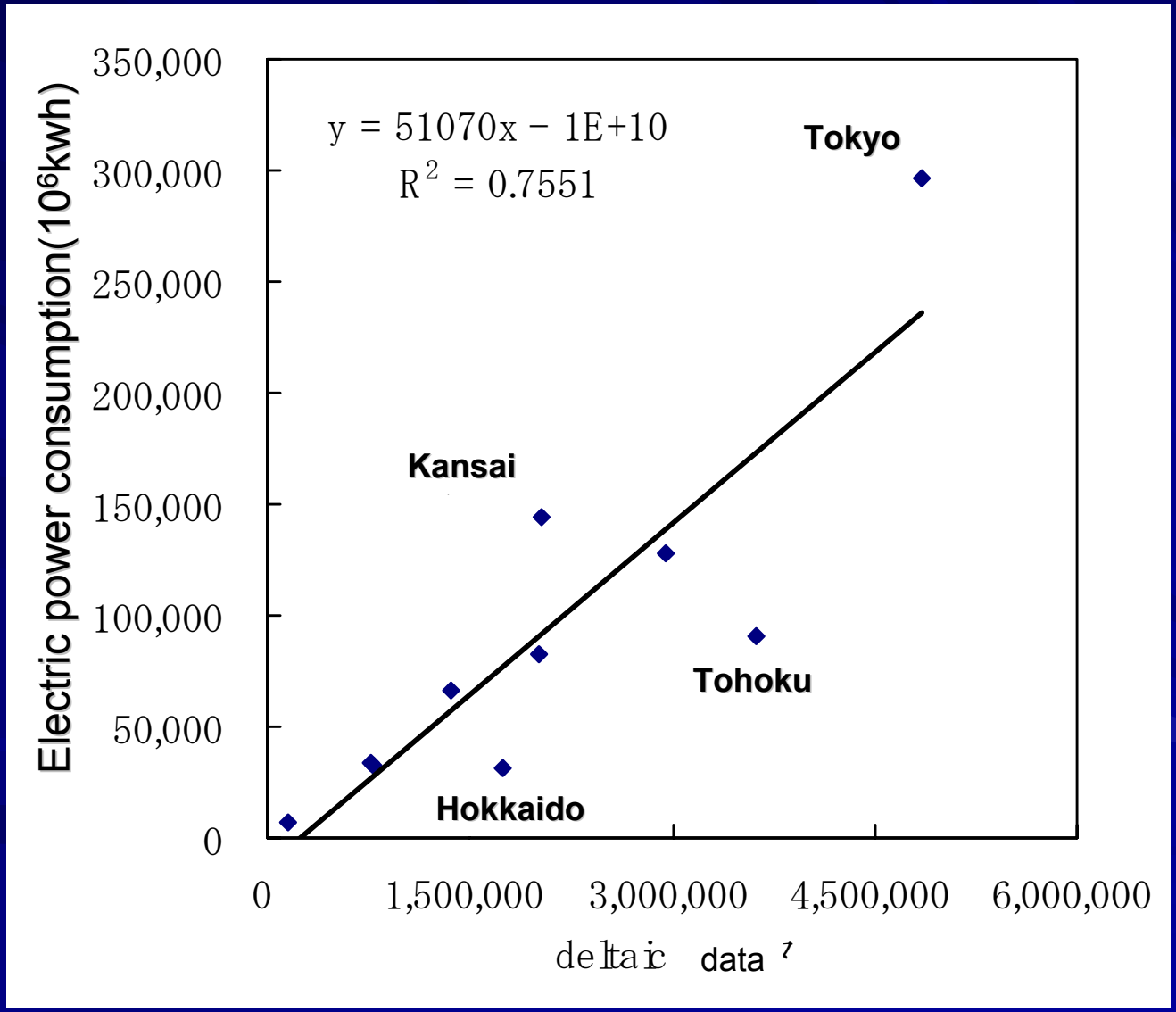
Regression analysis are used to find correlation between stable nighttime lights and electric power consumption of each prefecture in Japan.

The statistical data of electrical consumption are picked up from the data book of "Summary of electrical supply and demand" issued by Ministry of Economic, Trade and Industry(METI), 2001.

Electric power distribution map of each power supply companies in Japan



Regression analysis between DN and electric power consumption of each prefecture in Japan



Computation of CO_2 emission from estimated electrical power consumption

The CO_2 emission level Computation from electric power consumption is guided by METI.

$$G_p = C_e \bullet \beta$$

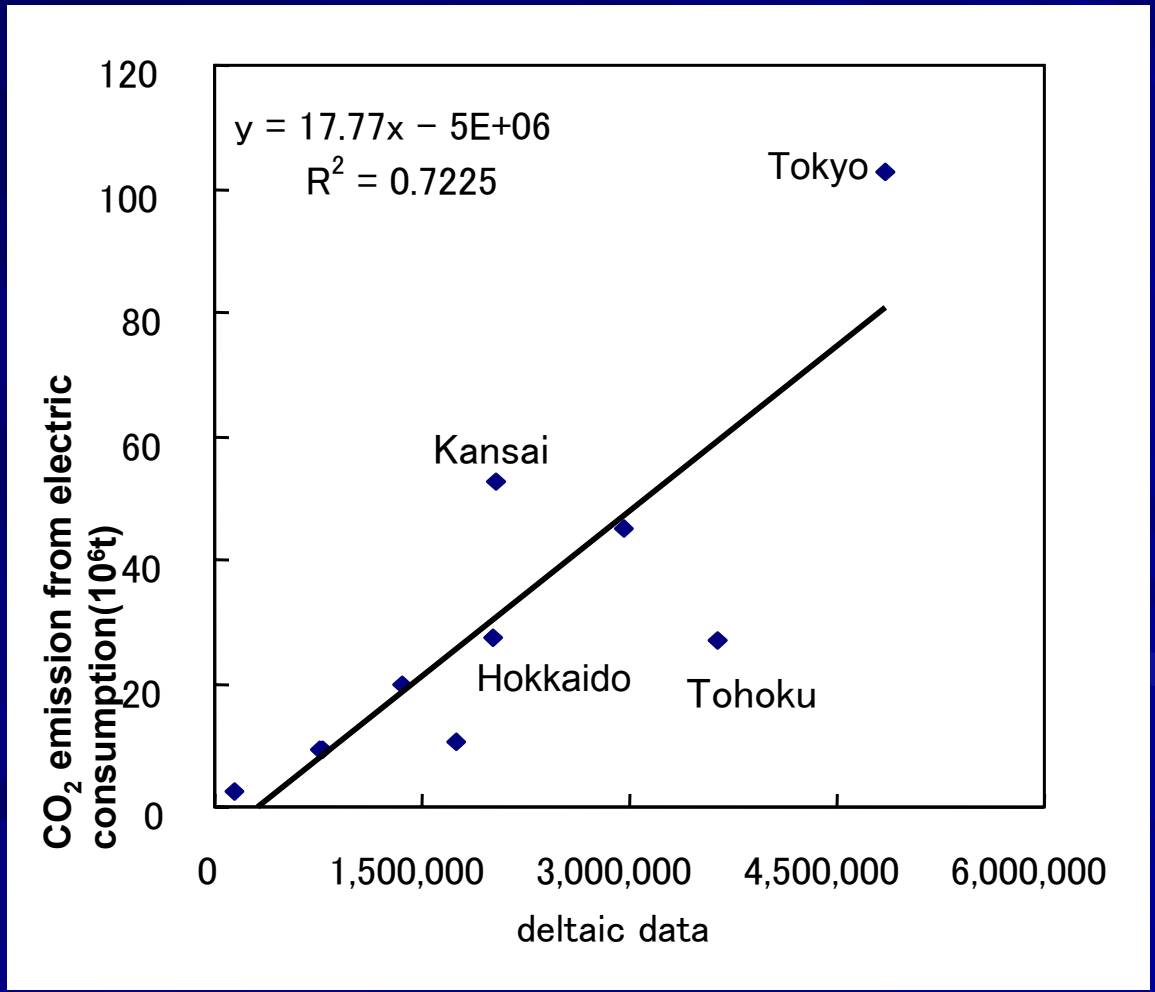
Where;

G_p: CO^2 emission volume (kg)

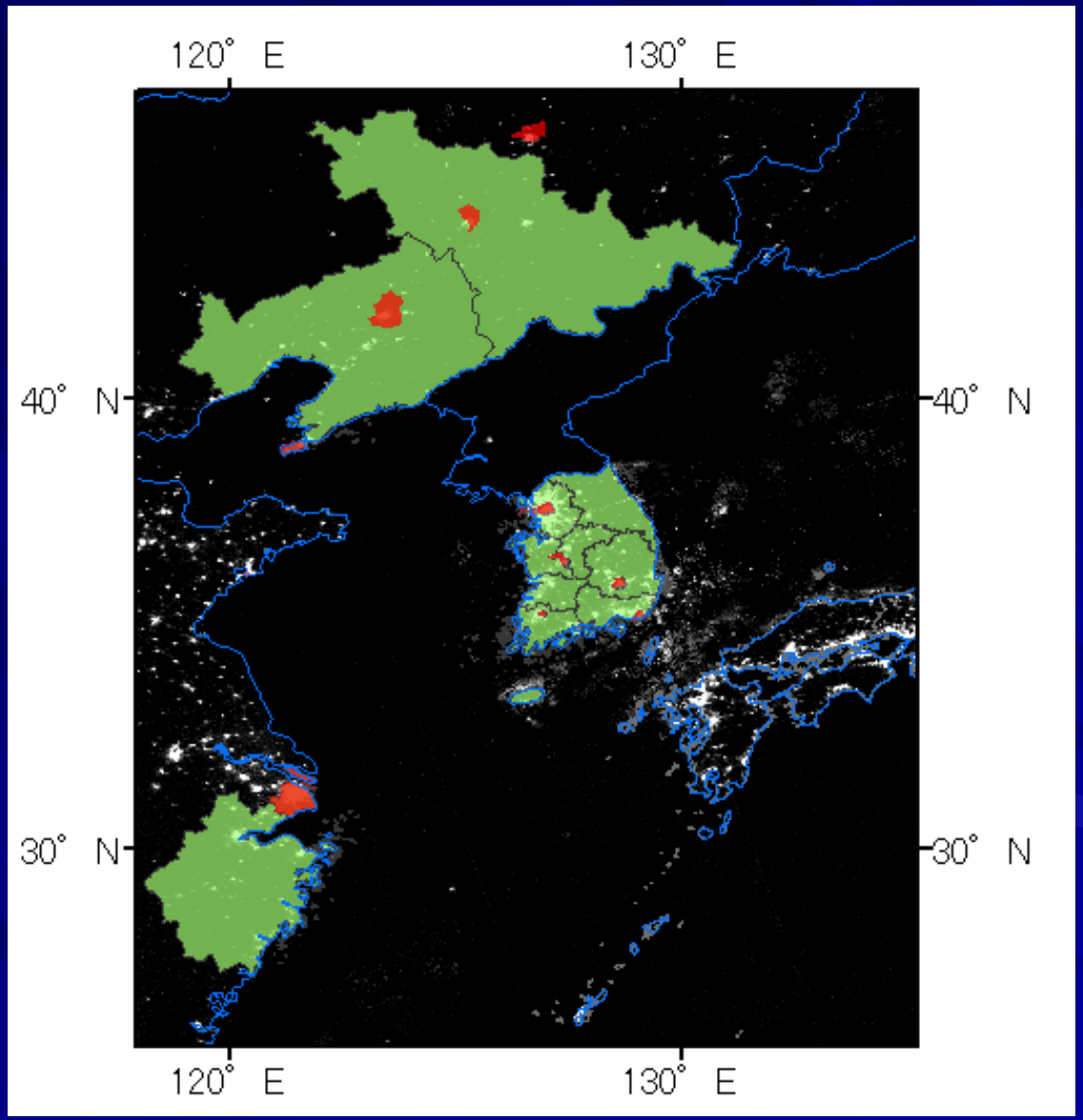
C_e: Electric power consumption

β : CO^2 emission coefficient(0.375 at Japan)

Regression analysis of CO_2 emission between DN and statistical electric power consumption of each prefecture in Japan

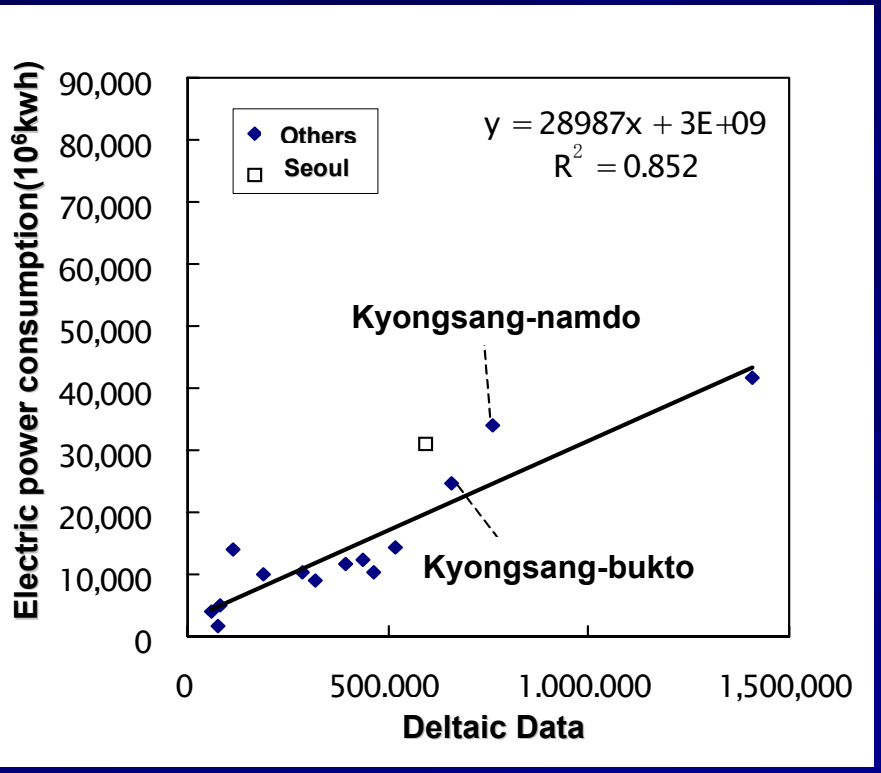


Electric power distribution map of Korea and China

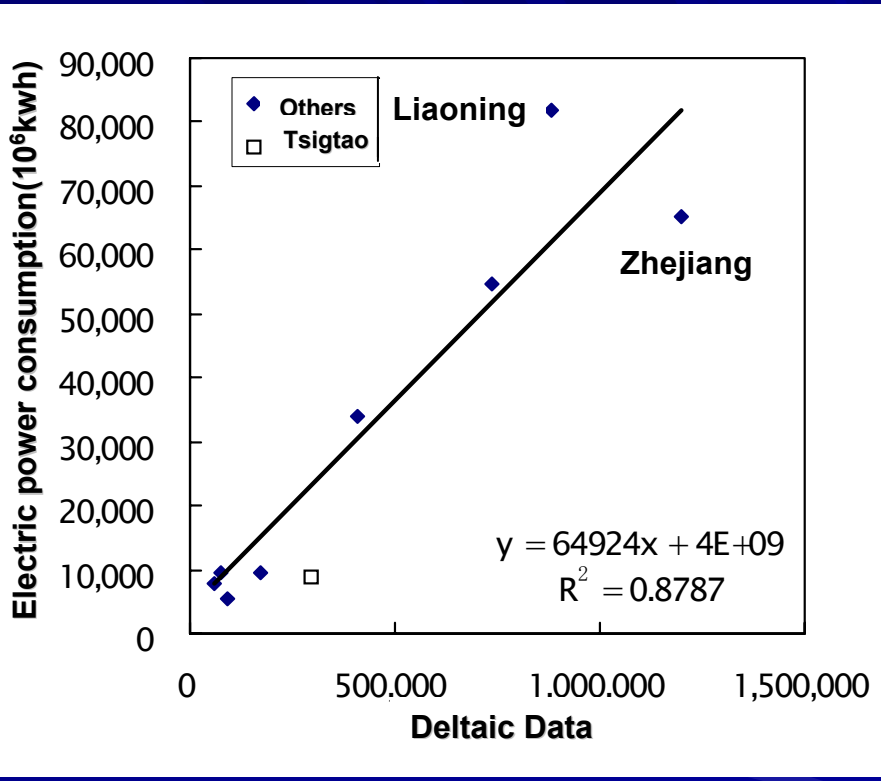


Regression analysis between DN value and electric power consumption of each prefecture in Korea and China

Korea

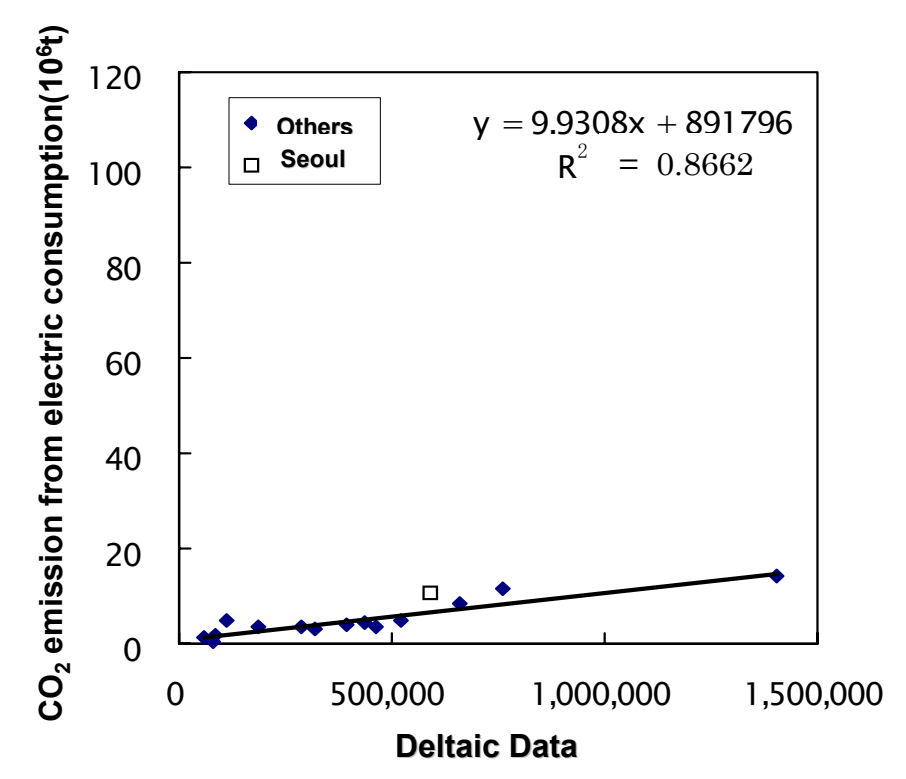


China

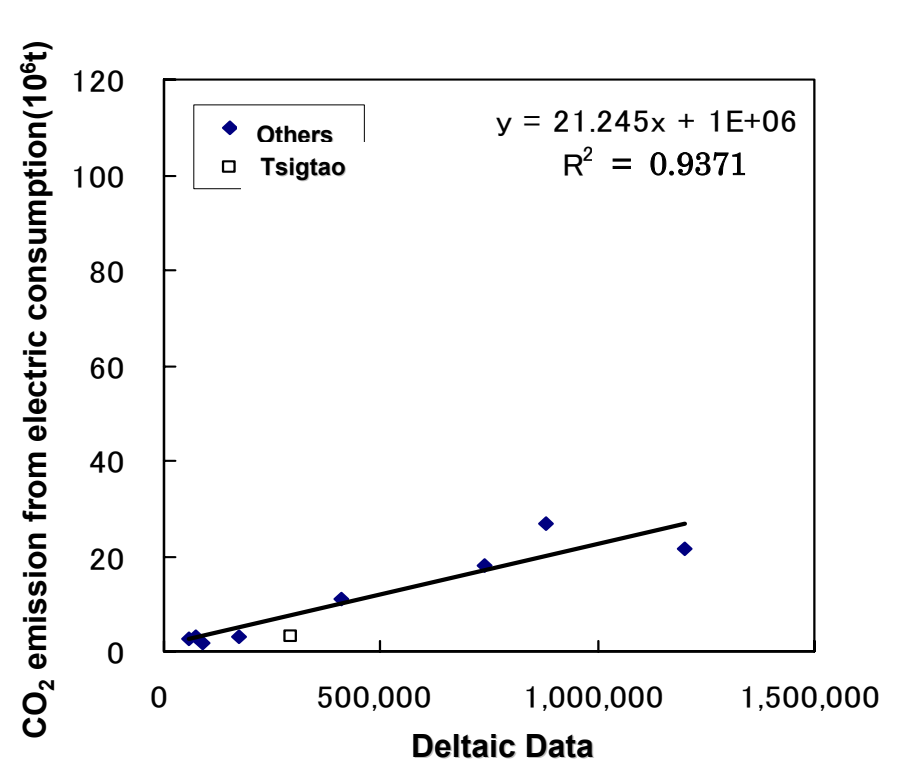


Regression analysis of CO_2 emission between DN and statistical electric power consumption of each prefecture in Korea and China

Korea



China



Summary

- The average intensity of artificial stable light can be extracted from the DMSP/OLS nighttime imagery by using NRF method.
- A method to estimate electric power consumption from DMSP/OLS data is developed and the coefficient of determination R^2=0.7551 was achieved.
- CO_2 emission volume is calculated by using electric power consumption which extracted from DMSP/OLS satellite imagery and the coefficient of determination R^2=0.7225 was achieved.

Further Study

- Improve the Deltaic model to get more accurate compensation of DN.

- Additional evaluation of this method will be done to adapt for other countries, especially the country used deferent type of energy such as atomic energy.


Thank You