Early warning of forest fire and evaluation of Asian dust using remote sensing technique

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Last lecture PPI, 23 September 2005

Introduction

- Remote sensing by satellite is one of the more recent advances in telecommunications and has important applications for the environmental sciences.
- The forest fire in Kalimantan, Indonesia and the Asian dust events in East Asia provide important case studies of environmental remote sensing.

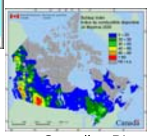
- Both have caused serious damages and affected the human health and environment

Reviews (cont'd)

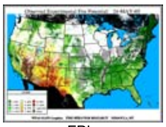
- Fire danger is described by means of constant and variable factors, which determine the inception and controllability of wildland fires. Several fire index developed in the US and Canada:
  - Chandler Burning Index
  - Keetch-Byram Drought Index
  - Canadian Buildup Index
  - Fire Potential Index


CBI


KBDI


Canadian BI

- We develop an algorithm to assess the FPI using NDVI, weather data and fuel model map modified from NFDRS for Kalimantan Island in Indonesia.
- First attempt to test the efficacy of the FPI in a tropical setting.

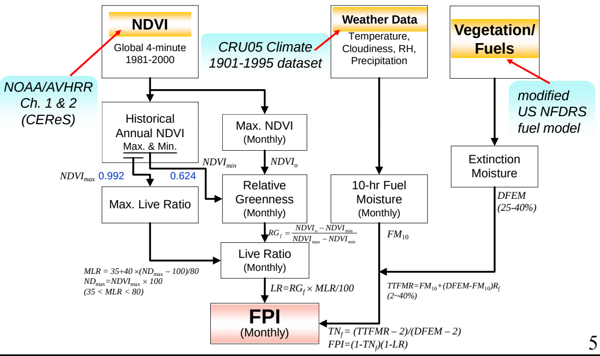

FPI

Reviews (cont'd)

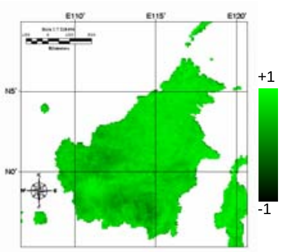
- Aerosols: fine particles (radius < 10 μm) within the atmosphere.
- Key parameter to quantify the aerosols in the atmospheres: Aerosol Optical Thickness (AOT)
- Under cloud-free conditions, some retrieval methods have been established to derive AOT over the ocean using NOAA/AVHRR data (Rao et al., 1999, Nakajima and Higurashi, 1997).

- We propose a simple-straightforward algorithm to retrieve the aerosol optical thickness (AOT) over the ocean during the Asian dust event.
- A direct relationship between NOAA/AVHRR digital number vs. AOT is derived.

Methodology: the FPI calculation



Normalized Difference Vegetation Index (NDVI)



Example of NDVI on Aug. 1997

- Source: global 10-day composite 8 km AVHRR NDVI data

$$NDVI = (Ch_2 - Ch_1)/(Ch_2 + Ch_1)$$

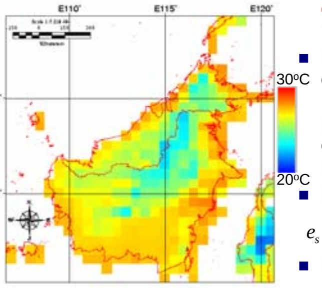
- Temporal coverage: Jul.1981~Dec. 2000
- AOI: Kalimantan Island 9.33°N,106.67°E~4.76°S,120.67°E
- Derived parameters:

$$RG = \left(\frac{NDVI_o - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right) \times 100$$

$NDVI_0$: highest NDVI in 10-day composite period;
$NDVI_{max}$: historical (1983-2000) maximum NDVI;
$NDVI_{min}$: historical (1983-2000) minimum NDVI;

$MLR = 35+40 \times (ND_{max} - 100)/80$
ND_0: $NDVI_{max} \times 100$

Weather data



Example of Mean Temperature on Apr. 1995

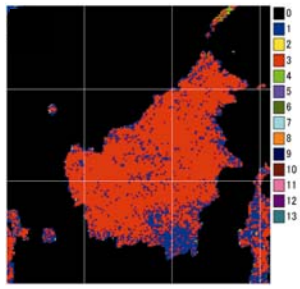
cloud cover, and ground-frost frequency (7 data).

- Datasets used in the FPI calculation: mean temperature, precipitations, cloud coverage, relative humidity (RH)
- RH: $RH = e/e_s \times 100\%$

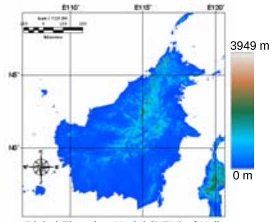
$$e_s = 6.39\exp(19.65 \times (T - 273)/T)$$

- Derived parameter: FM_{10} (10-hr fuel moisture)

Modified NFDR fuel model



Vegetation class derived from AARS classification system



Digital Elevation Model (DEM) of Kalimantan
Source: GTOPO30 Project

- Fuel models are a set of numbers that describe vegetation.
- Models adopted from US NFDR: water, hardwoods, agricultural land, heavy, intermediate and light logging slash
- Derived parameter: extinction moisture (DFEM)

Extinction moisture [%]

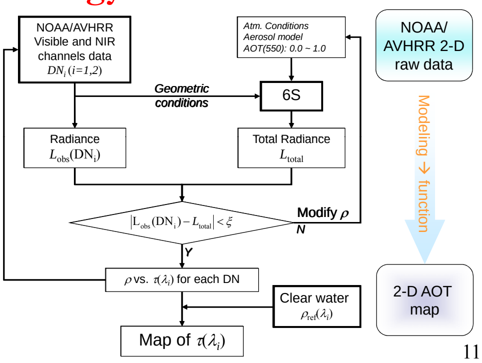
Class	AARS Category	DFEM NFDRS(%)	DFEM (%)	Vegetation Represented	Number of Pixels
0	0	-	-	Waters, including Ocean & Inland waters[1]	34164
1	10	25	40	Vegetation	3194
2	12	25	40	Forest or shrubland	13
3	14	25	40	Evergreen forest or shrubland	12986
4	18	25	40	Evergreen broadleaf forest	36
5	120	25	40	Mixed forest or shrubland	7
6	130	15	30	Grassland	55
7	132	15	30	Natural grassland/pastures	16
8	140	15	30	Grass crops	80
9	146	15	30	Wheat and rice	18
10	184	15	25	Dwarf vegetation	21
11	191	-	-	Bare ground[1]	29
12	222	-	-	Inland water[1]	6

[1] Fire Potential Index not calculated for this case

FPI computation

- Set FPI to "no data" (FPI = 105)
- Convert RG to fractional values: $RG_f = RG/100$ (range: $0 \sim 1$)
- Calculate current live fuel ratio: $LR = RG_f \times LR_{max}/100$ (range: $0 \sim 0.8$)
- Find normalized 10-h fuel moisture from 10-h moisture and extinction moisture:
  $TN_f = (TTFMR - 2)/(DFEM - 2)$ (range: $0 \sim 1$)
  where TN_f: fractional 10-h fuel moisture
  $TTFMR$: 10-h moisture[%]
  $DFEM$: dead fuel extinction moisture[%]
- Calculate $FPI = (1 - TN_f) \times (1 - LR) \times 100$ (range: $0 \sim 80$)

Methodology: AOT retrieval

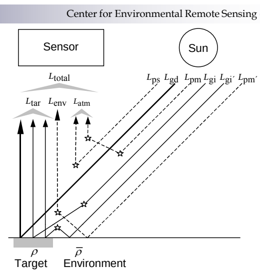


Satellite data and 6S

Radiance calculated by 6S:

$$L_{total} = L_{atm}(\tau, M_{R+M}) + L_{tar}(\rho, \bar{\rho}, \tau, M_{R+M}) + L_{env}(\rho, \tau, M_{R+M})$$

M_{R+M}: atmospheric model of molecules and aerosols
ρ: target albedo
$\bar{\rho}$: environment albedo
τ: aerosol optical thickness of the atmosphere



The albedo (reflectance factor) A_i of each channel: $A_i = S_i \times DN + I_i$

$$A_1 = \begin{cases} 0.0523 \times DN - 2.016, \text{ for } DN < 497.5 \\ 0.1528 \times DN - 51.91, \text{ for } DN > 497.5 \end{cases}$$

$$A_2 = \begin{cases} 0.0513 \times DN - 1.943, \text{ for } DN < 500.3 \\ 0.1510 \times DN - 51.77, \text{ for } DN > 500.3 \end{cases}$$

Radiance observed by satellite:

$$L_{obs} = (S \times DN + I)\, E_s / 100\pi$$

S, I: calibration factors of AVHRR visible channel
DN: digital number
E_s: solar spectral irradiance [W/m^2/sr/mic]

6S input parameters

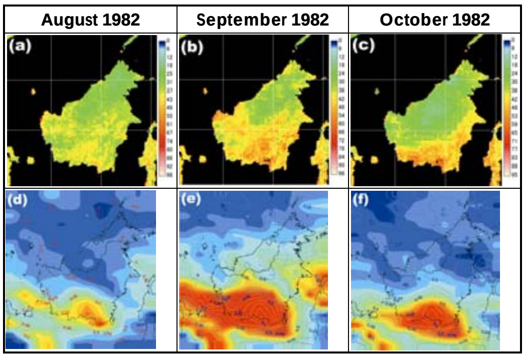
- Atmospheric condition: midlatitude winter
- Study cases:
  - Clean (no-dust/no-cloud by visual inspection): maritime aerosol model (pre-defined)
  - Turbid (on Kosa events):
    - Aerosol model: user-defined lognormal size distribution

$$\frac{dV}{d\log_{10} r} = \sum_{n=1}^{2} C_n \exp\left[-\frac{1}{2}\left(\frac{\log_{10} r - \log_{10} r_{vn}}{\log_{10} \sigma_n}\right)^2\right],$$

    - Volume mean radius r_{v1} = 0.18 μm, r_{v2} = 1.74 μm
    - Standard deviation σ_1 = 2.16, σ_2 = 1.78 (Wang et al., 2003)
    - Refractive index: 1.53 – 0.002i (Patterson et al., 1977)

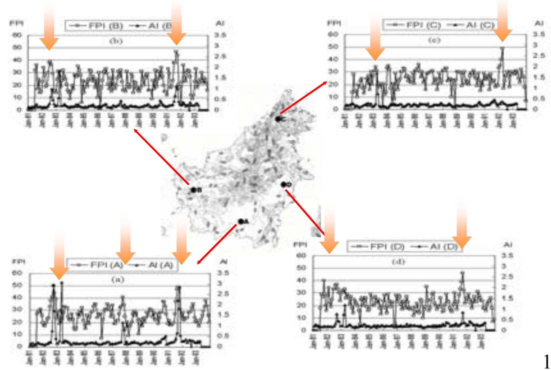
Center for Environmental Remote Sensing (CEReS)

FPI and TOMS-AI map (1982 case)



Center for Environmental Remote Sensing (CEReS)

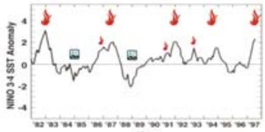
FPI assessment (1981-1993)



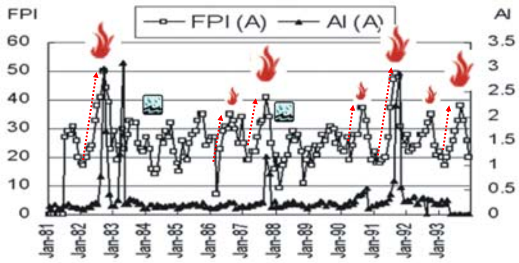
Center for Environmental Remote Sensing (CEReS)

South Kalimantan

(Point A: 2°S, 113.75°E)

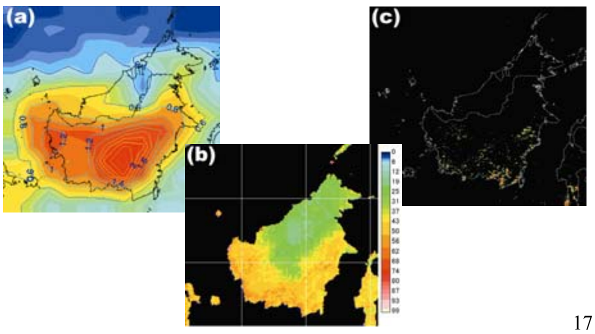


: El-Niño
: La-Niña



Center for Environmental Remote Sensing (CEReS)

FPI, TOMS AI and Hotspot Map (September 1991)



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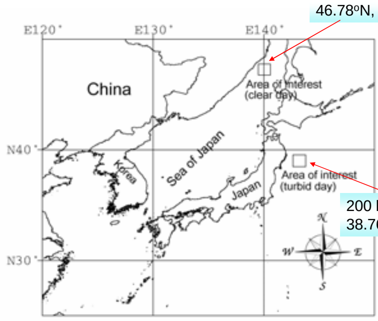
AOT retrieval: area of interests

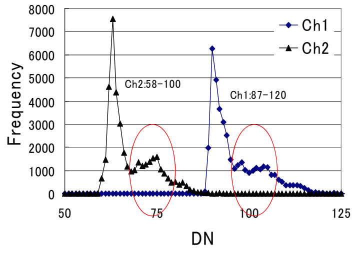
(both cases)

200 km x 200 km
46.78°N, 140.27°E

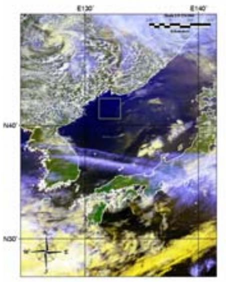


200 km x 200 km
38.76°N, 143.45°E

Clear case

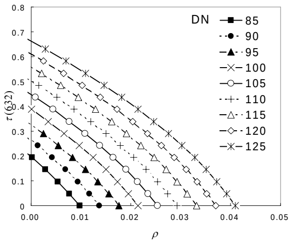


NOAA-16, 10 April 2002
04:40:23 UTC

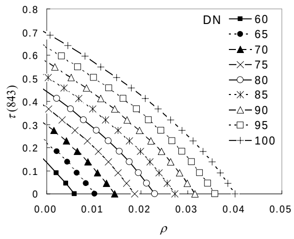


Original image (RGB: ch. 124)

Simulation results

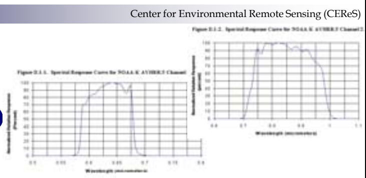


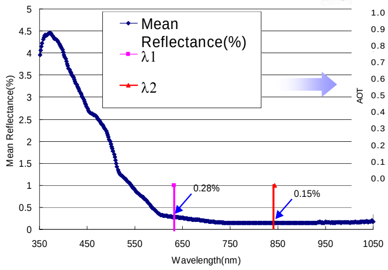
Channel 1

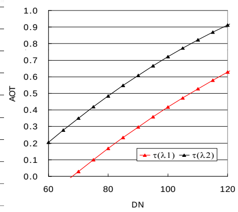


Channel 2

Sea surface reflectance (Kozai et al., 2000)

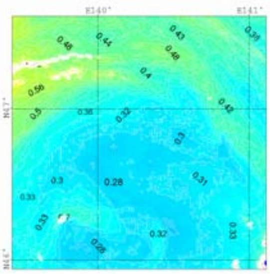






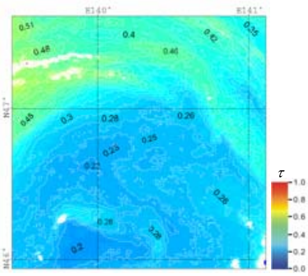
DN vs. AOT

AOT maps



Channel 1

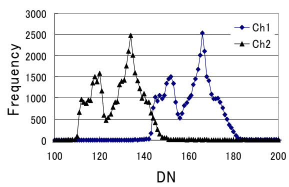
Actual AOT(λ_1): 0.35 to 1.12



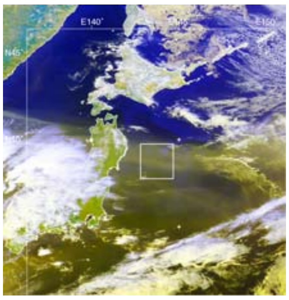
Channel 2

Actual AOT(λ_2): 0 to 1.118

Turbid case



NOAA-16, 18 March 2002
03:49:27 UTC



Original image (RGB: ch. 124)

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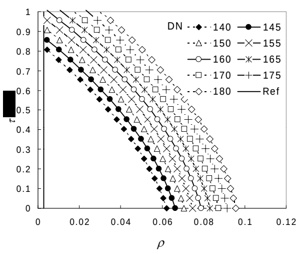
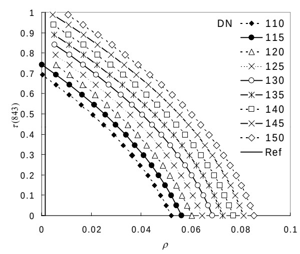
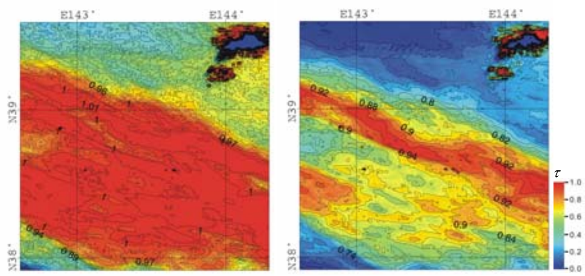


Channel 1



Channel 2

AOT maps

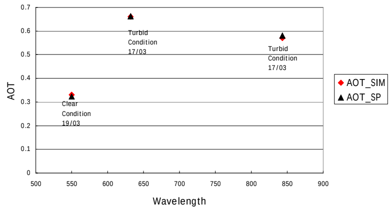


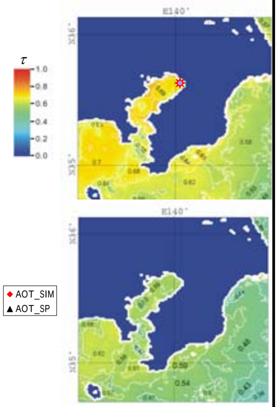
Channel 1 — Actual AOT(λ_1): 0.01 to 1.02

Channel 2 — Actual AOT(λ_2): 0.65 to 1.02

Validation

- Kosa event on March 17, 2002 using Sunphotometer at Chiba University:
  - AOT(632) = 0.660; AOTSP632 = 0.662 (ξ = 0.4%)
  - AOT(843) = 0.57; AOTSP843 = 0.58 (ξ = 3.1%)
- Clear condition on March 19, 2002:
  - AOT(550) = 0.331; AOTsp550 = 0.324 (ξ = 2.2%).





Conclusions and future works

- Applications of satellite remote sensing to develop the early warning of forest fire and evaluation of Asian dust were presented.
- Two cases of large forest fires (1982/83, 1991) have been treated in this work on the basis of the monthly potential fire index calculated between 1981 and 1993.
- It has been shown that both spatial and temporal distributions of the FPI exhibit good correlation with those of the TOMS Aerosol Index in the southern-eastern provinces of Kalimantan.

Conclusions

- It has also been shown that high FPI values were associated with actual fire occurrence in 1991 and KBDI values in 1997.
- Thus, this work indicates that the FPI algorithm can be successfully applied to tropical fire warning systems, even though the relevant parameters such as dead fuel extinction moisture, temperature, precipitation, relative humidity and cloud coverage are different from the case of US-NFDRS.

Conclusions (cont'd)

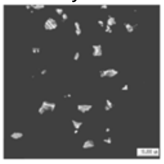
- The radiance from the NOAA/AVHRR data is simulated using the 6S radiative transfer code to retrieve the aerosol optical thickness over the ocean during clear (non-dust) and Asian dust events is presented.
- The aerosol models are based on maritime and bi-lognormal size distribution for both clear and turbid cases, respectively.
- The results show that a $\rho_{ref}(\lambda_1)$ value of 0.28%, a $\rho_{ref}(\lambda_2)$ value of 0.15% and the aerosol model (maritime, bi-lognormal) utilized in the 6S code calculation are indeed appropriate for accurately estimating the AOT in the present study.

Future works

- Since this study was limited to monthly FPI from historical data, the FPI calculations could be more operatively useful for fire management if they were computed weekly or daily.
- The fuel map will be based on higher class resolution.
- The forest fire in Indonesia is also affected by human activities and other social factors. We plan to consider these factors, as well as other geographical and weather parameters.

Future works (cont'd)

- The accuracy of the AOT retrieval is dependent on the sea-surface reflectance on clear condition. Therefore, the retrieval is only limited to sea surface.
- Improve this algorithm to analyze the AOT over the land using different land-surface references.
- Cloud removal algorithm will be applied
- Dust particles have non-spherical shapes. The Mie theory assumes the particles are spherical. The non-spherical analysis is needed to improve the accuracy of these results.



(Source: Krotkov, et al., 1999)

GLC2000 Vegetation Map