ATMOSPHERIC CORRECTION FOR MODIS - OVER LAND

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Brent Holben and Eric Vermote

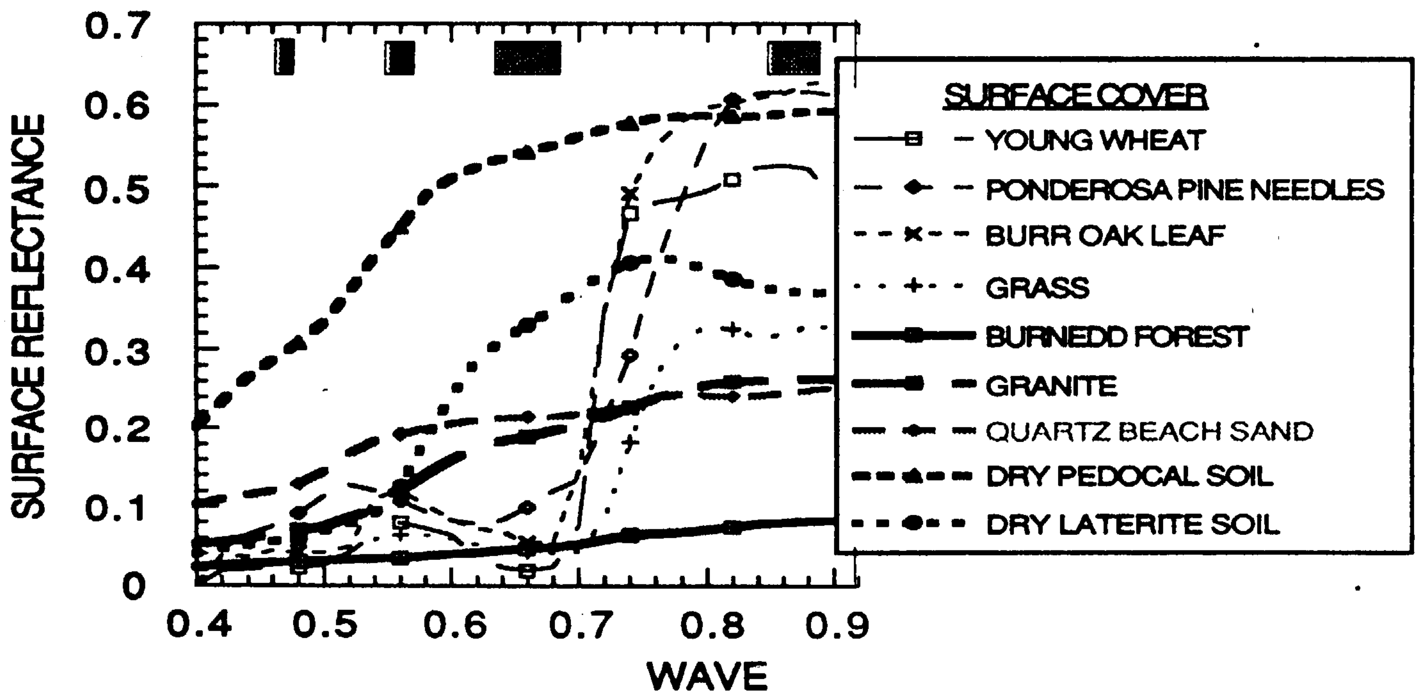
Attachment 1.18

- *WHAT IS THE PROBLEM ?
- *WHY CORRECTION FOR THE LAND IS MORE DIFFICULT THAN ....FOR THE OCEAN ?
- *MINIMUM CORRECTION THAT IS EASY TO PROMISE
- *CORRECTION THAT CAN BE APPLIED FOR PART OF THE 5-D DATA SET $L(\mathbf{X}, t, \lambda)$
- *ALTERNATIVE APPROACHES
- *FIELD EXPERIMENTS, empirical relations and testing.

*** WHAT IS THE PROBLEM ?** (VIOS)

***WHY CORRECTION FOR THE LAND IS MORE DIFFICULT THAN FOR THE OCEAN**

- Surface is brighter and variable $\rho(X,\lambda,t)$ - more difficult to find the atmospheric effect.
- For a bright surface atmospheric effect includes also T, ω_0.
- Higher optical thickness.



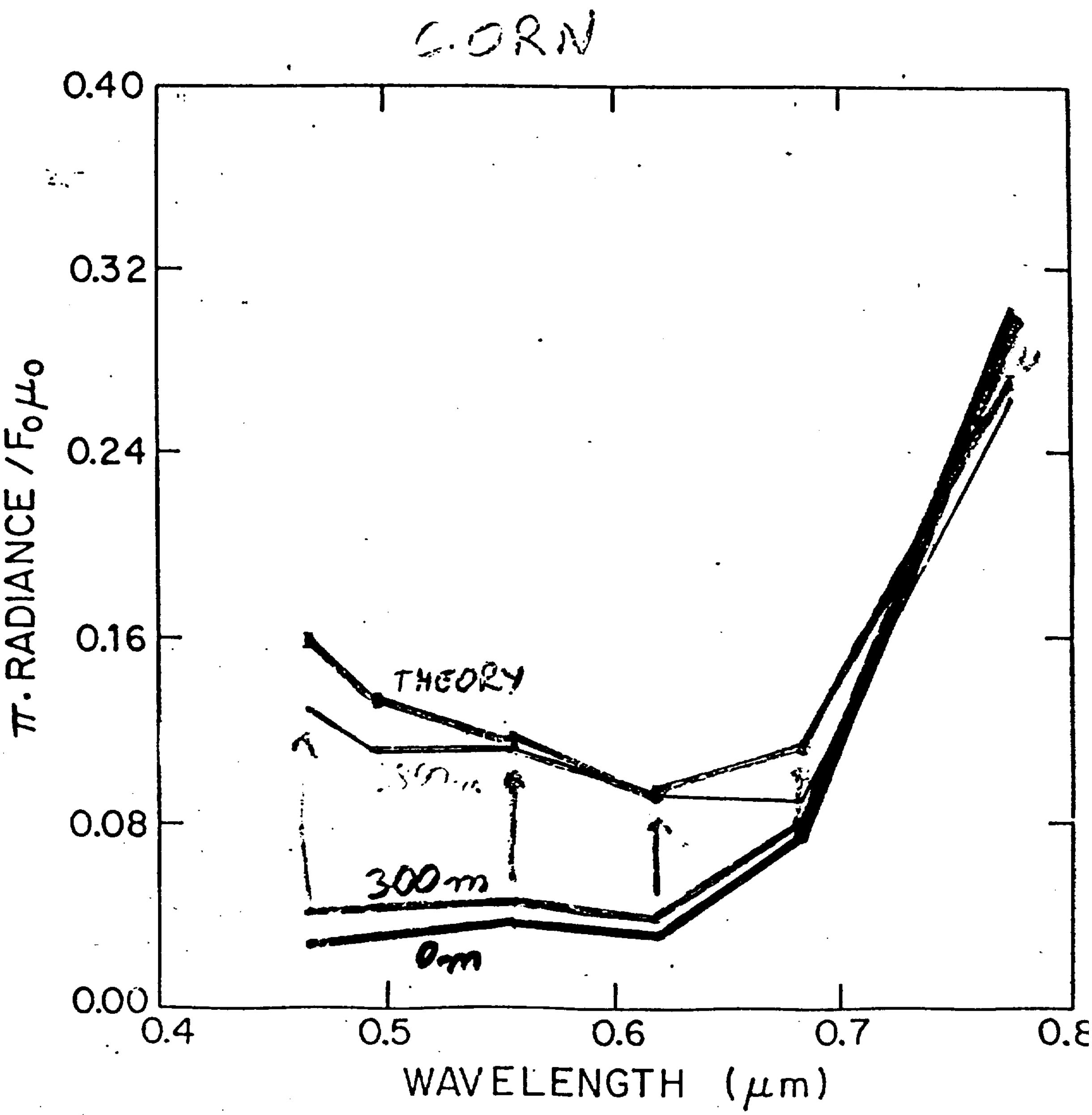


Fig. 3: Same as in Fig.4 but for corn $\theta = 24^0$, $\phi = 120^0$.

11

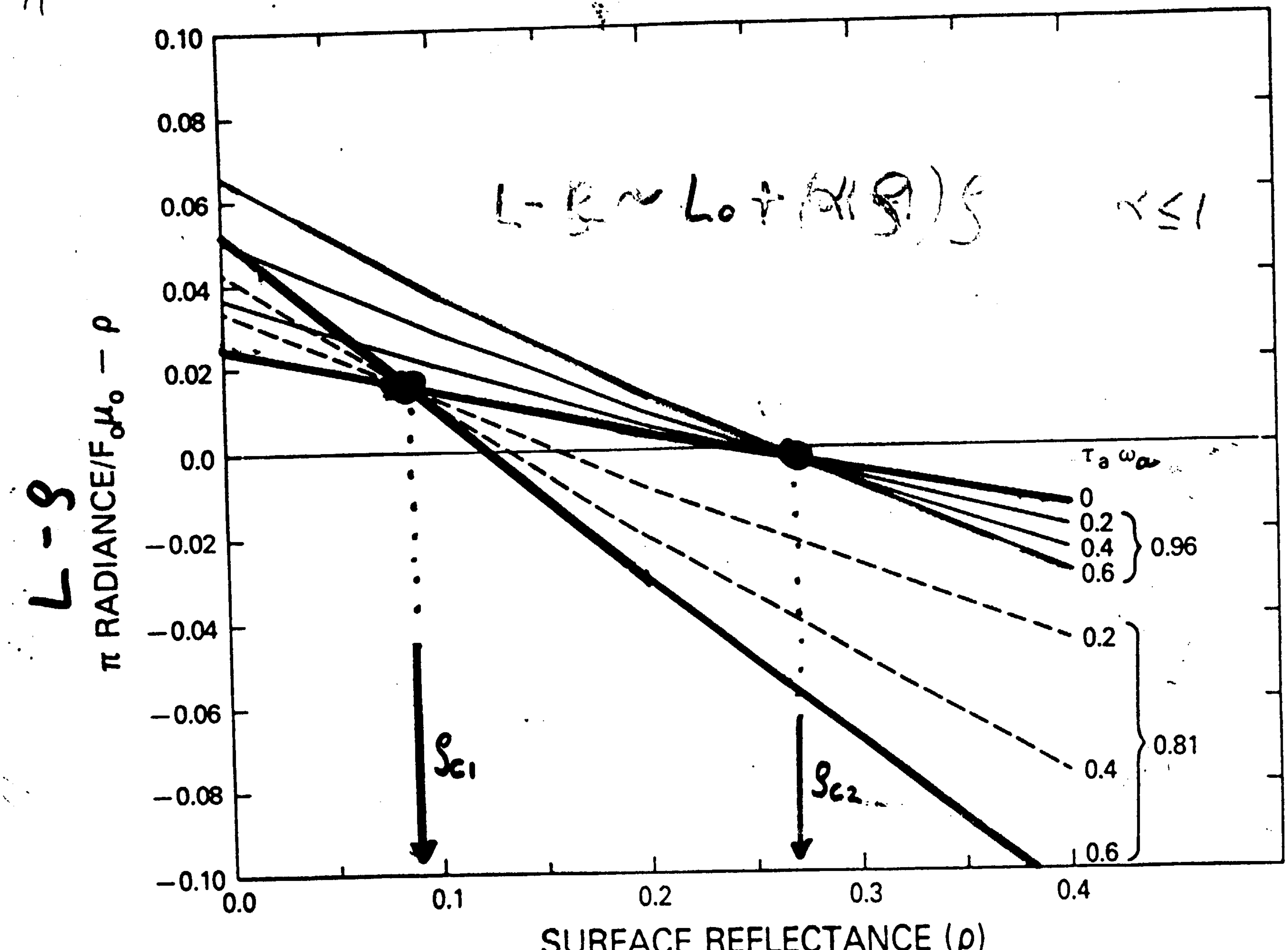


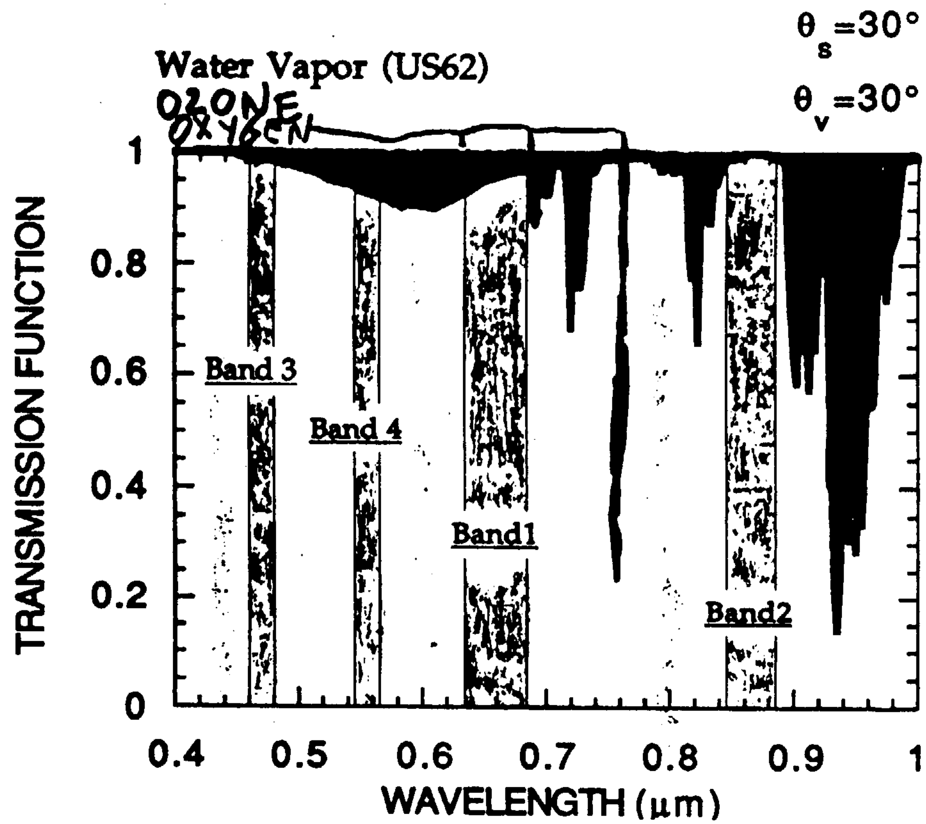
Fig. 11: The radiance of the Earth-atmosphere system (reflectance units) minus the surface reflectance for nadir observations, as a function of the surface reflectance. The aerosol optical thickness τ_a and the single-scattering albedo ω_0 are indicated for each line. $\theta_0=40^0$, $\lambda=$ 610 nm, and $v=$ 3. After Fraser and Kaufman (1985).

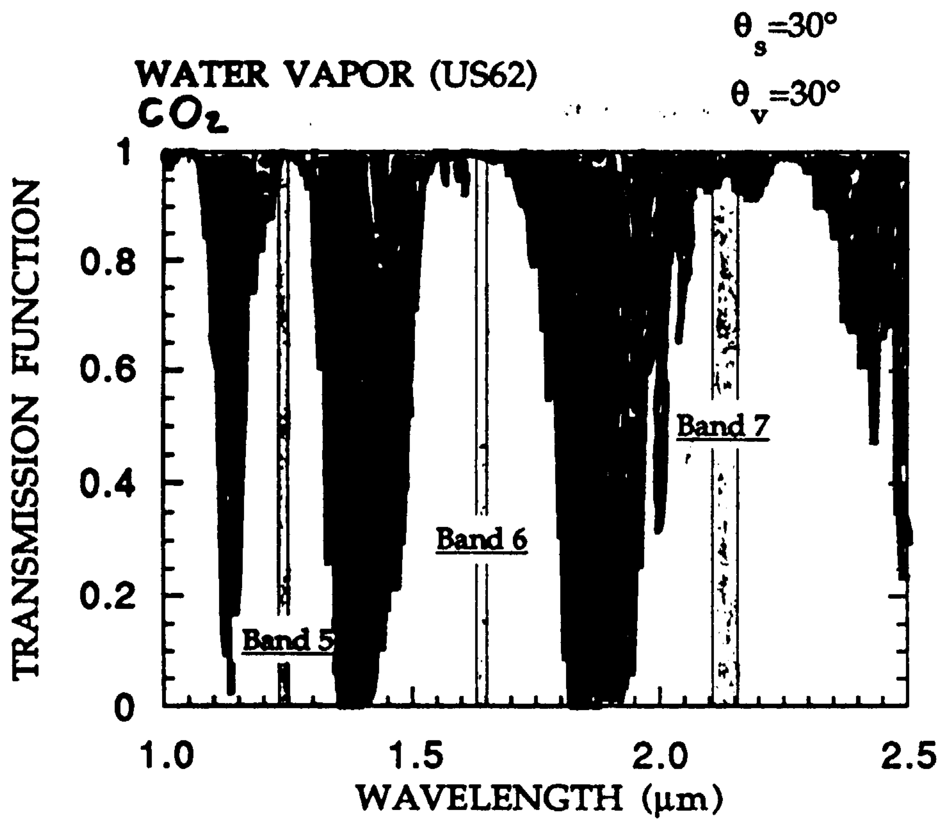
***MINIMUM CORRECTION THAT IS EASY TO PROMISE**

Gaseous absorption

H_2O → reduced to minimum unless there is an anomalous water vapor absorption.

- O_3 is easy to correct for.



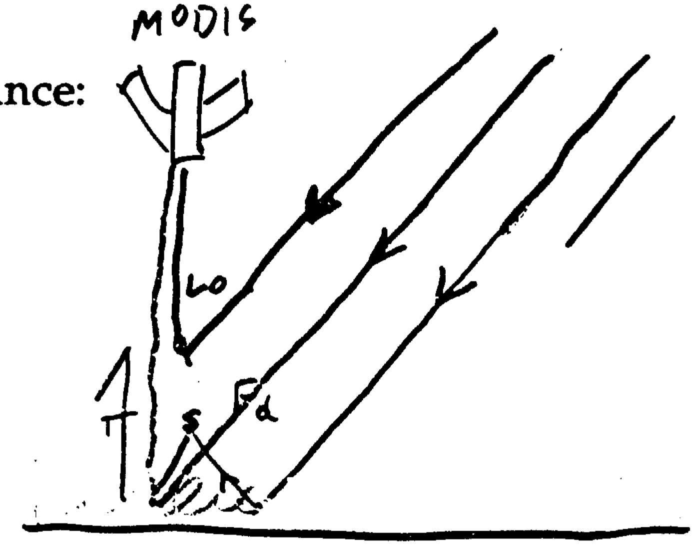

WATER VAPOR (US62)
CO2
θs=30°
θv=30°
TRANSMISSION FUNCTION
1
0.8
0.6
0.4
0.2
0
Band 5
Band 6
Band 7
1.0
1.5
2.0
2.5
WAVELENGTH (μm)

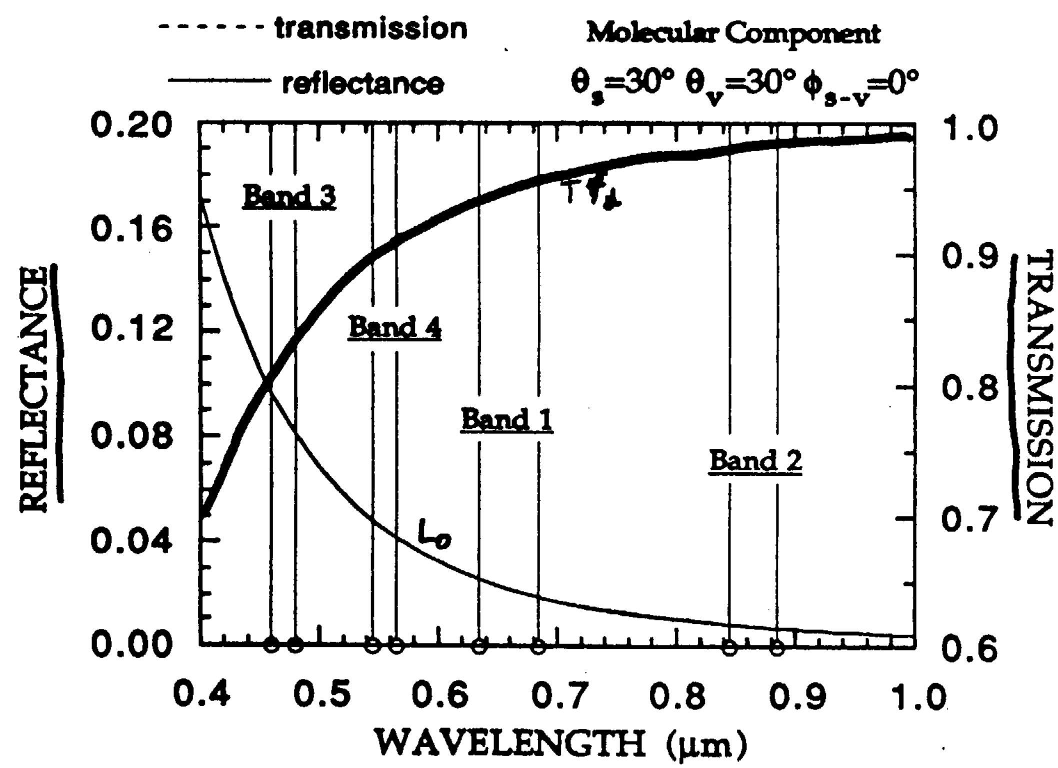
Molecular scattering (can be corrected any time):

- Effect of molecular scattering on the upward radiance:

$$L(\lambda,\theta,\phi) = L_o + (F_d/\pi)\,T\,\rho(\lambda,\theta,\phi)\,/\,(1\text{-}s\rho)$$

Radiance — Path Radiance — Irradiance — Transmission — Reflection — Feedback

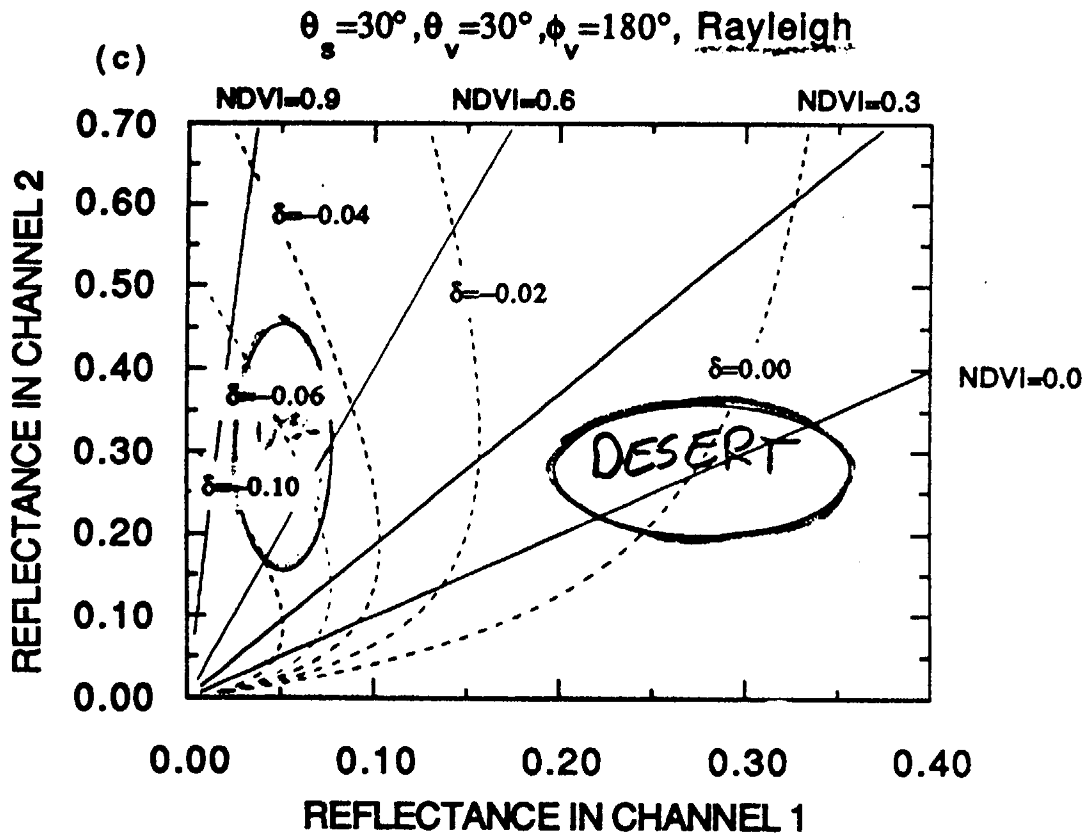




Lo

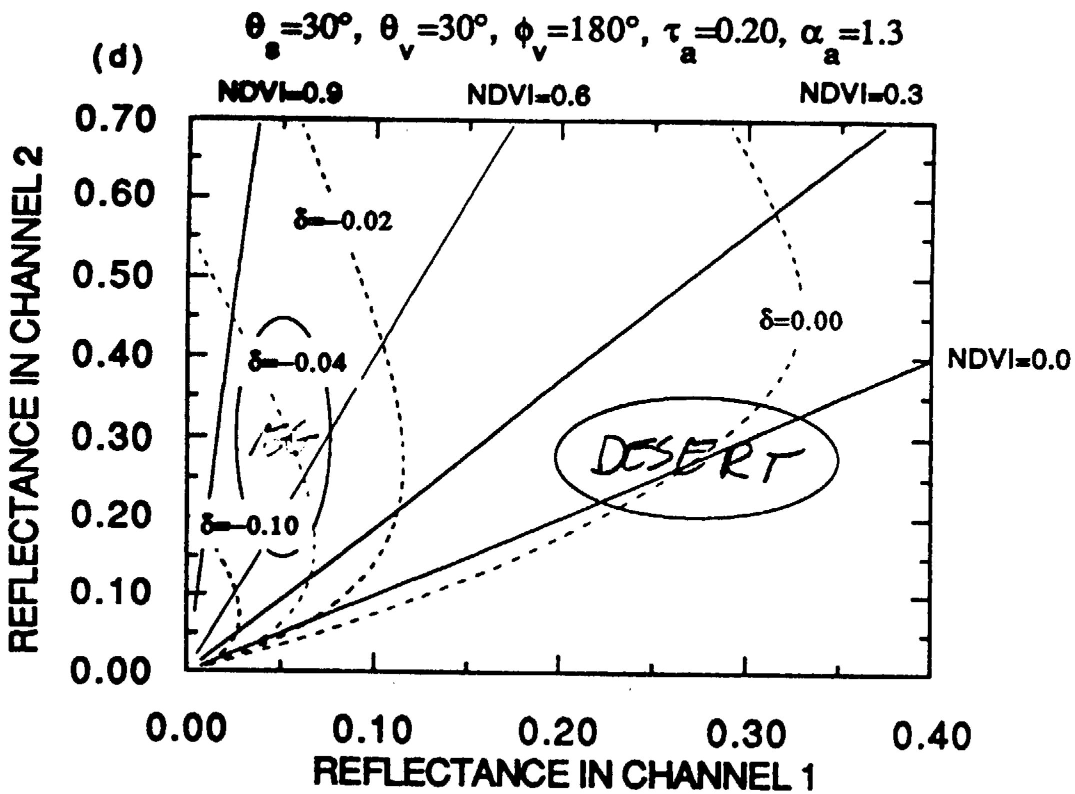
Tfd

Effect on vegetation index $NDVI=(L_2-L_1)/(L_2+L_1)$

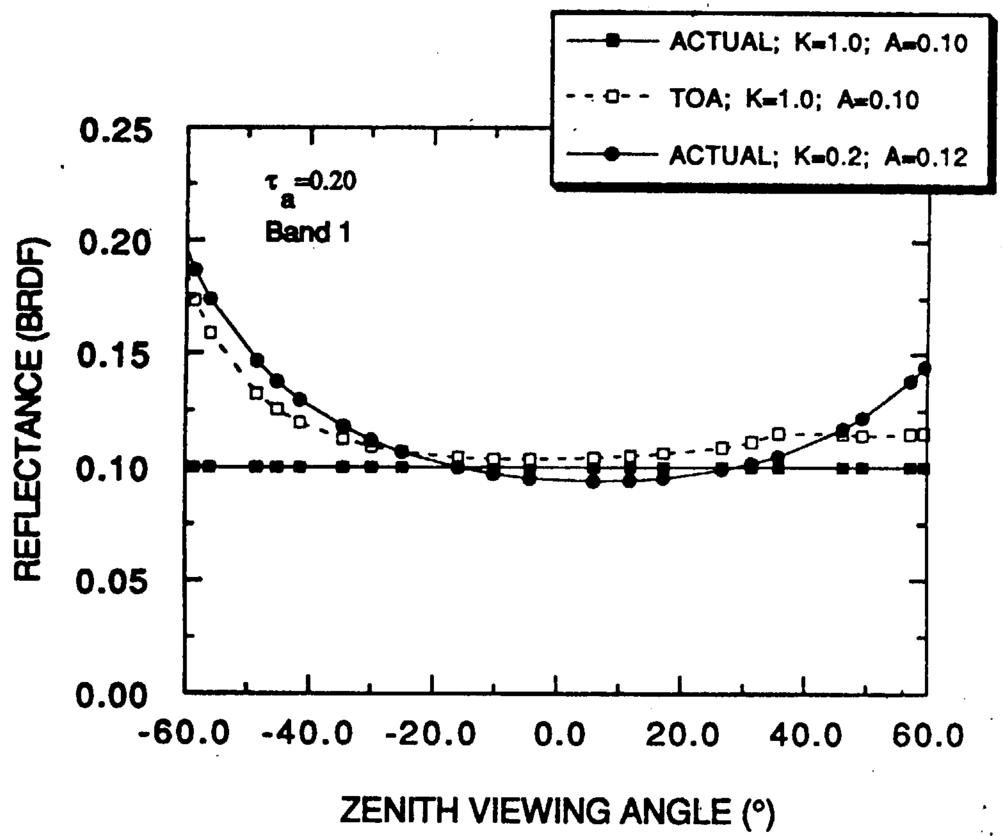


***CORRECTION THAT CAN BE APPLIED FOR PART OF THE 5-D DATA SET (X, t, λ)**

Aerosol effect on vegetation index $NDVI=(L_2-L_1)/(L_2+L_1)$



- Effect on bidirectional reflectance measurements



Reflectance (dashed line) at the top of an aerosol layer for $\theta_o = 35°$ to $55°$ along the scan. The solid line corresponds to a BRDF used for the simulation which corresponds to a Minnaert model with k=1.0 and ρ=0.10. The second solid line corresponds to the actual BRDF with different surface parameters, k=0.2 and ρ=0.12 which displays the same behavior as the simulated reflectance.

Possible correction for the aerosol effect

$$L(\tau) = L_o(\tau) + f_d(\tau)T(\tau)\,\rho$$

$$L_o(\tau) = \frac{P\tau\omega_o}{\mu\mu_o}$$

$$f_d(\tau) = 1-[\tau(1-\omega_o)-\tau\beta]/\mu_o$$

$$T(\tau) = 1-[\tau(1-\omega_o)-\tau\beta]/\mu$$

<u>- Correction for the aerosol properties requires:</u>

*aerosol optical thickness - 50% τ

* Phase function - 35% P

* single scattering albedo - 15% ω_o

Path radiance combines the most out of the three. $L_o \propto \frac{P\tau\omega_o}{\mu\mu_o}$

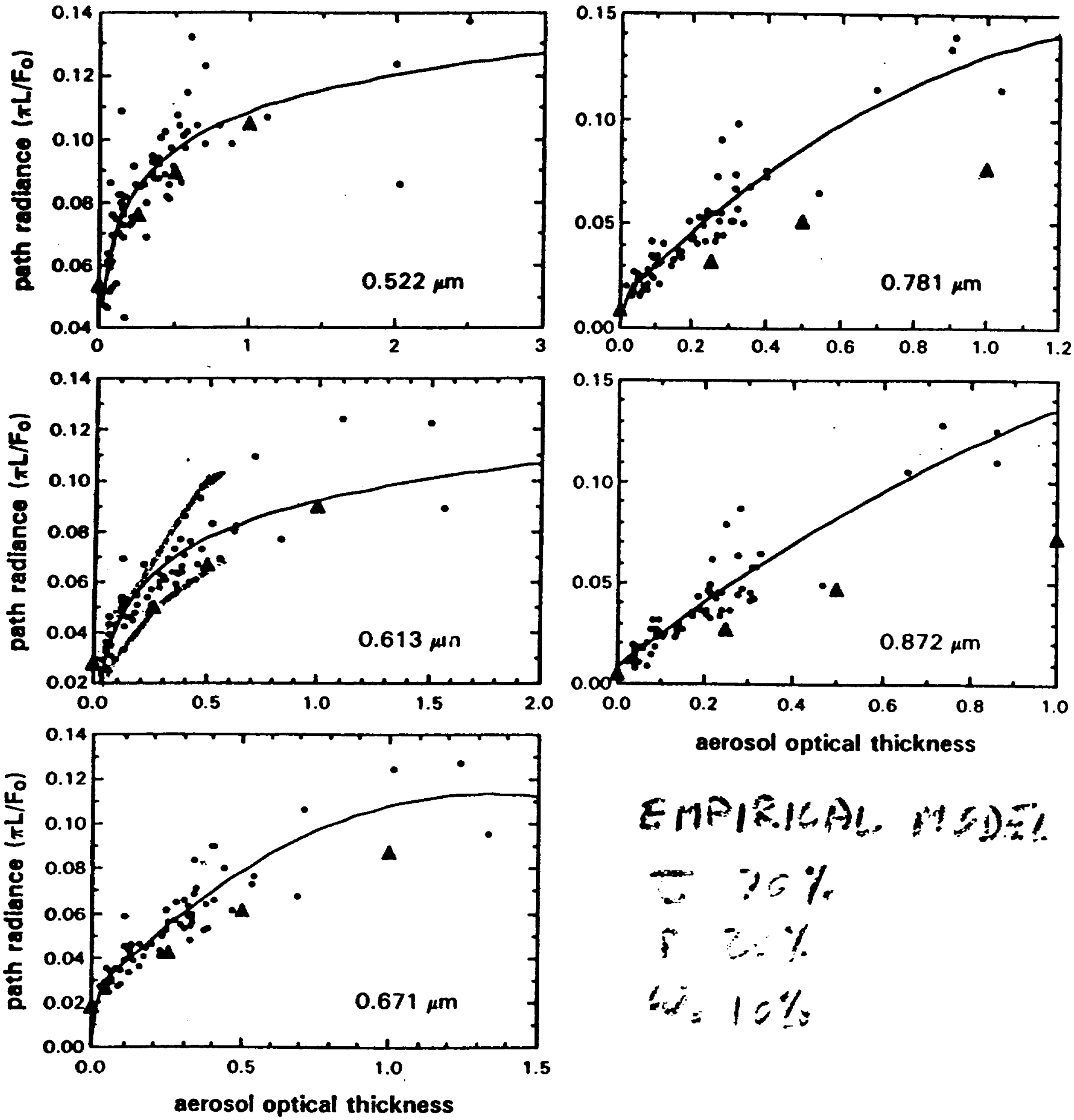
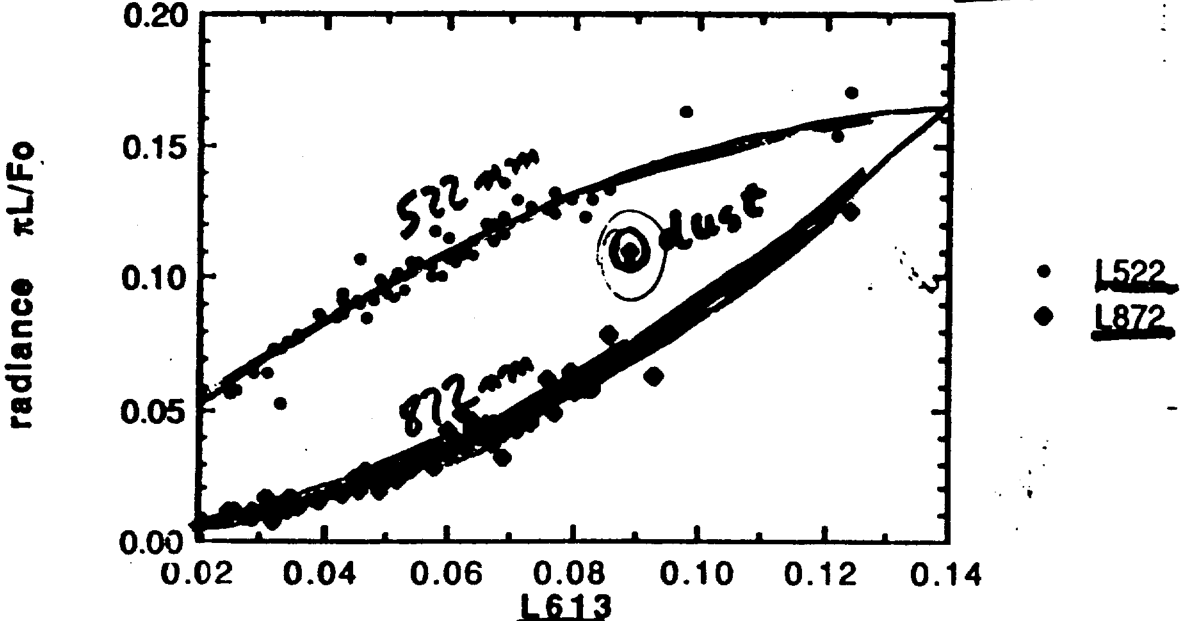


Fig. 3: The relation between the aerosol optical thickness and simultaneously measured atmospheric path radiance L_{pd} (the radiance is normalized to flux of π by $\pi L_{pd}/F_o$). Both the path radiance and the optical thickness data were interpolated for solar zenith angle of 60°. The wavelength is indicated on each graph. A least square fit is given (solid line) for each figure (for equations and correlations see text). Measurements are plotted by (•) and theoretical fit using a rural aerosol model by (Δ).

$L_{872} \times L_{613}$ $\quad$ $L_{522} \times L_{613}$

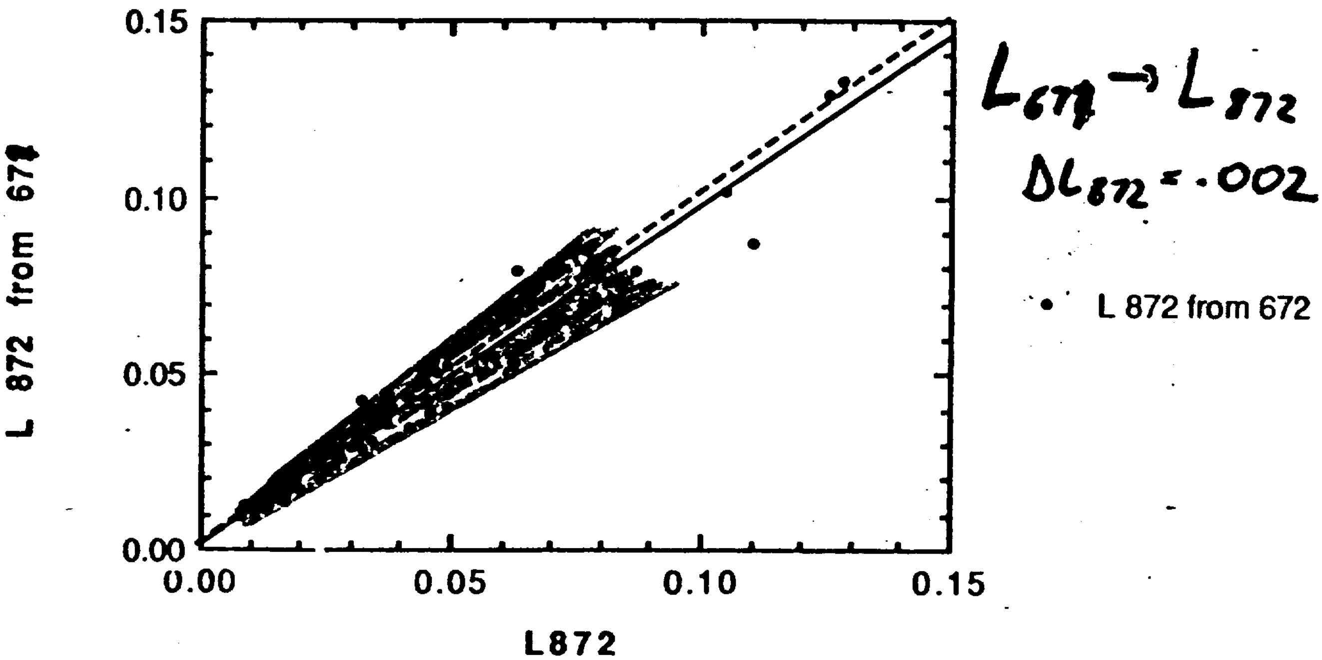
522 $\quad y = 1.4518e\text{-}2 + 1.9496x - 6.2741x^2 \quad R^2 = \underline{0.923}$



872 $\quad y = -1.6213e\text{-}3 + 0.19800x + 7.0881x^2 \quad R^2 = \underline{0.939}$

How well can we predict L_{872} from L_{671}

$y = 1.4237e\text{-}3 + 0.96162x \quad R^2 = 0.962$



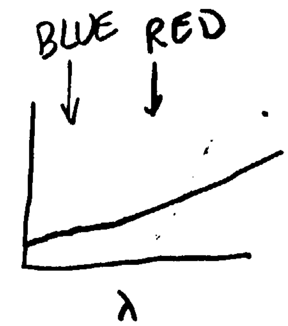
$L_{672} \rightarrow L_{872}$

$\Delta L_{872} = .002$

6

Methods of correction: STRATEGY

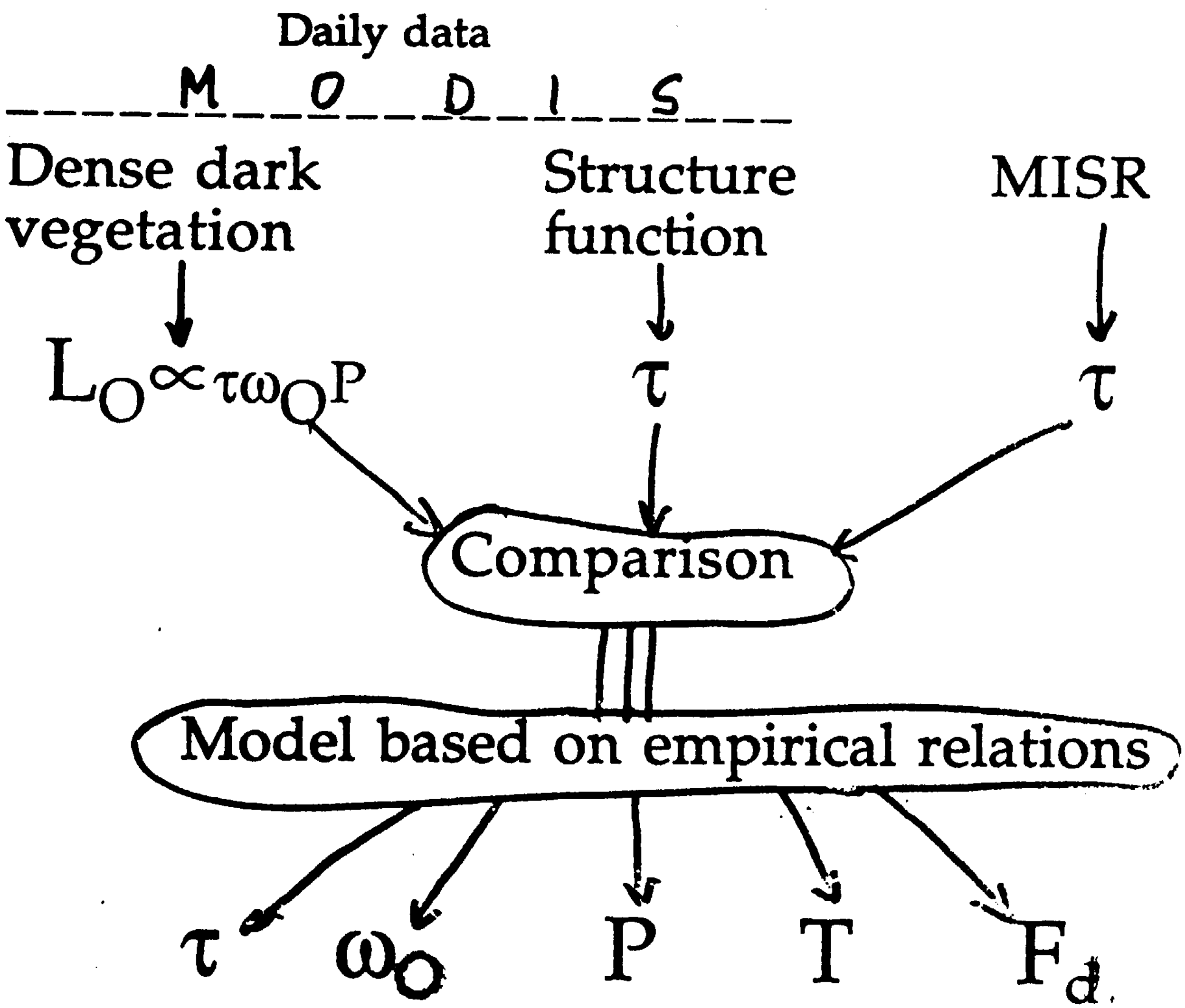
- Correction methods are based on derivation of one aerosol parameter from space (τ or L_o) and computing the others using a model that is heavily based on empirical relations.



1 - Dense dark vegetation method is for single image correction assuming $\rho_{DDV}(\lambda,\theta,\theta_o)$. Test possibility to apply also for non dense vegetation targets that are dark in the blue.

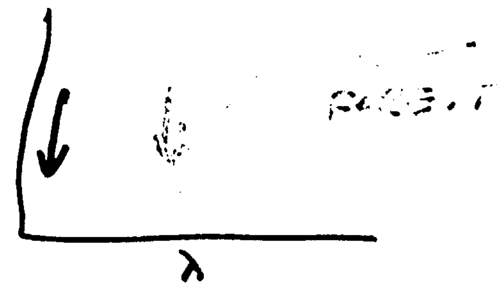
2 - Structure function approach to find τ relative to a single day from a sequences of images with same view direction.

3 - Optical thickness derived every several days from MISR to be used directly to verify DDV, and to give τ of the reference day for the structure function method.


Daily data
M O D I S
Dense dark vegetation
Structure function
MISR
$L_O \propto \tau \omega_O P$
τ
τ
Comparison
Model based on empirical relations
τ
ω_O
P
T
F_d

- DENSE DARK VEGETATION (over regions that include forests)

- On a box of 1°x1° find pixels with dense dark vegetation using NDVI or 3.7 μm reflectance
(vio 3.7 vs. ch1, NDVI vs. ch1)
- Assume $\rho_O(\theta_O, \theta)$ for blue and red
- Find τ and L_O vio
- Interpolate on X and λ vio
- Correct all the box
(vio corrections)



Structure function (over regions with high contrasts)

$F_S(d)=\Sigma[(L(x)-L(x+d)]^2$

$L=L_O + Tf\rho$

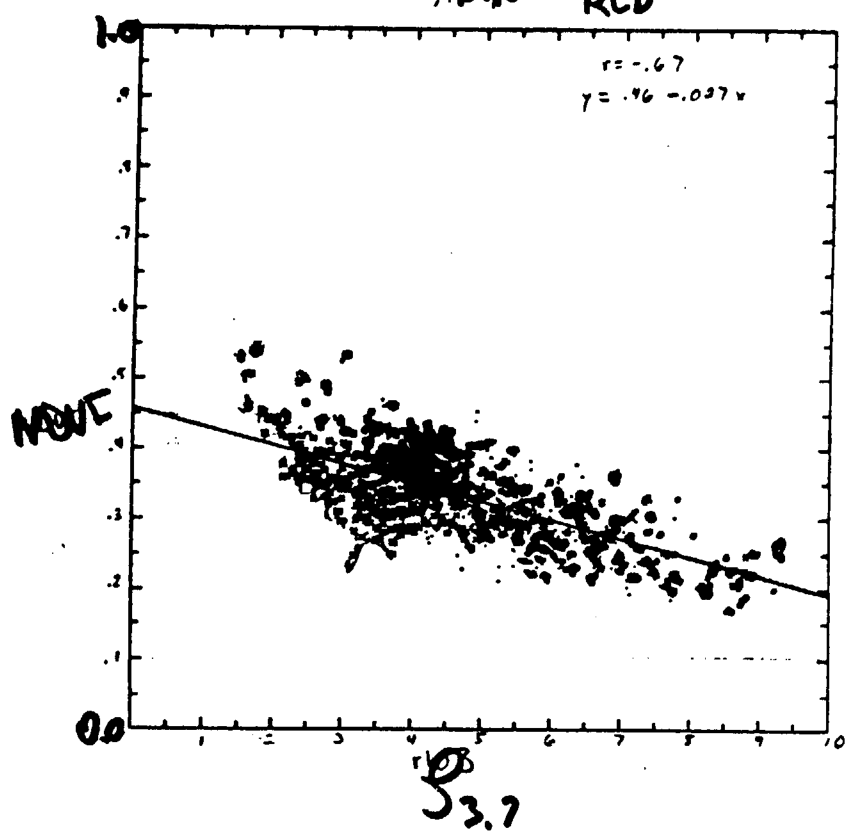
$$\sqrt{\frac{F_{s1}(d)}{F_{s2}(d)}} \propto \frac{T_1 f_1}{T_2 f_2} \propto \tau^* g(\omega_o,\beta)$$

This ratio should be independent of d which is a test if the region is appropriate for the technique.

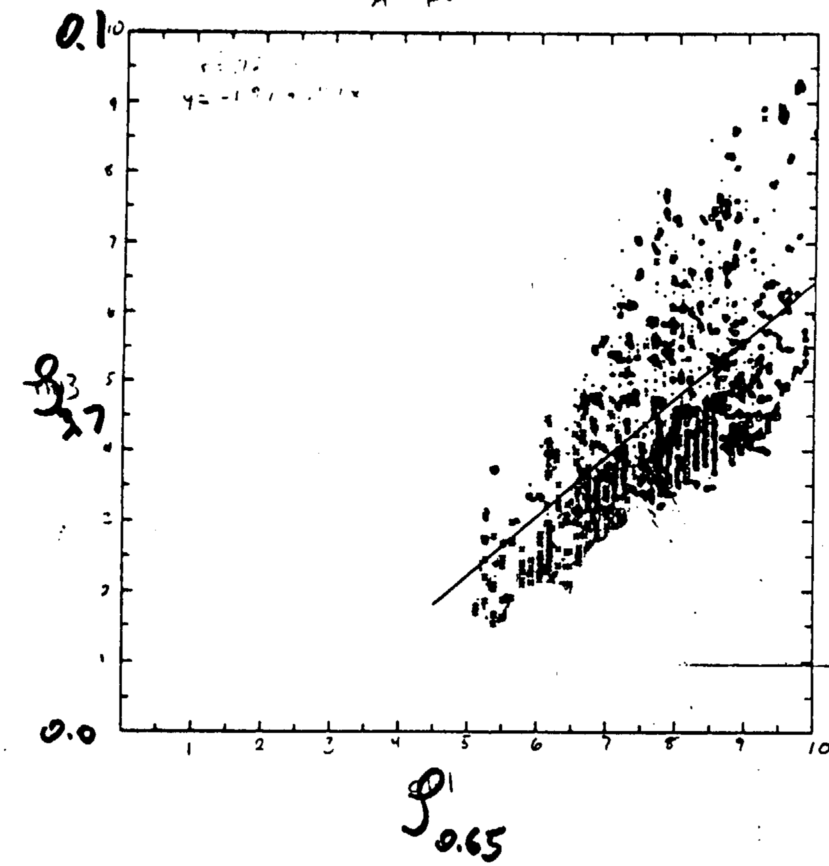
(vios)

view ~ 35°
very clear

$$NDVI = \frac{L_{NIR} - L_{RED}}{L_{NIR} + L_{RED}}$$

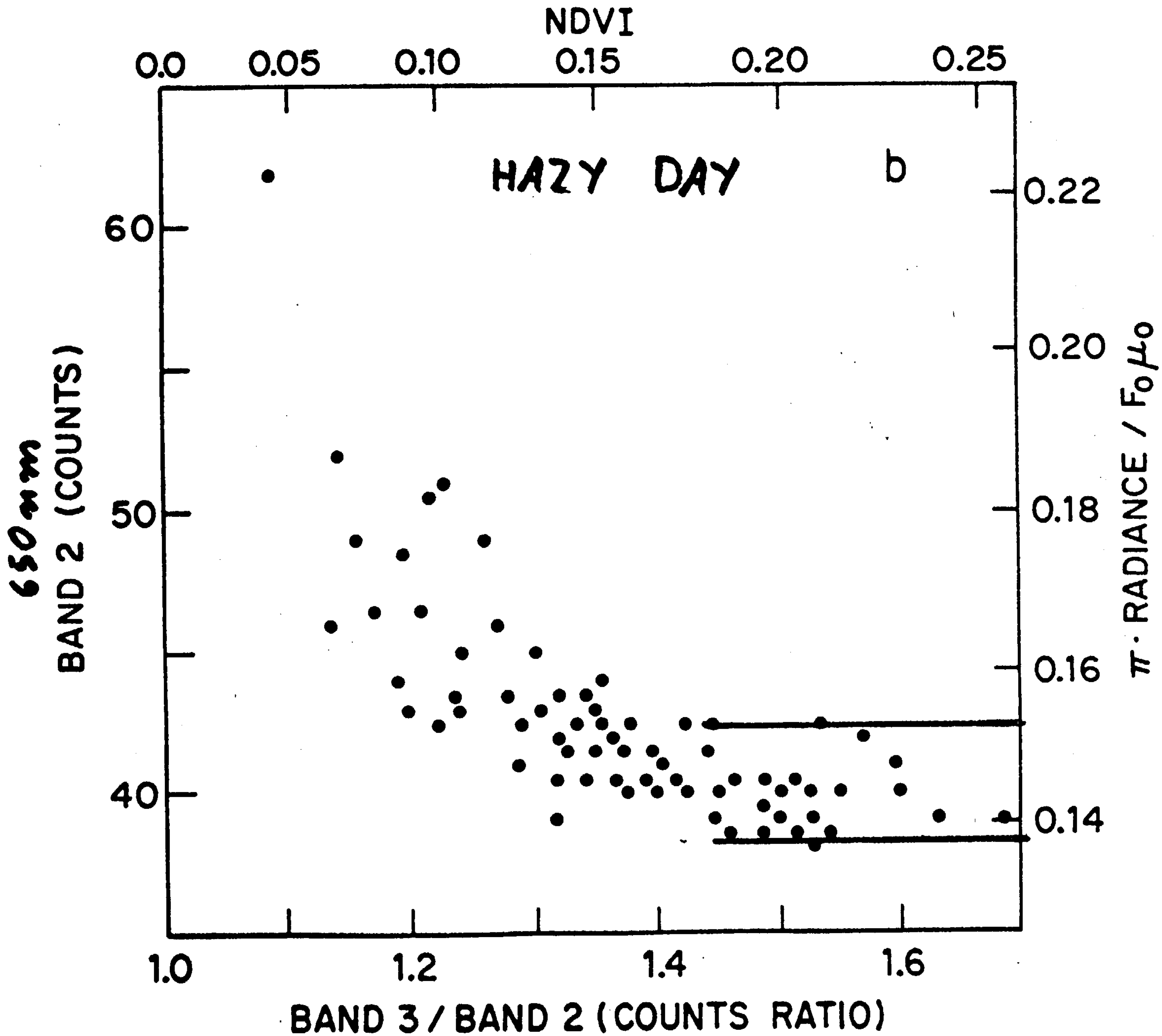


X FOREST



Remer & Kaufman 92

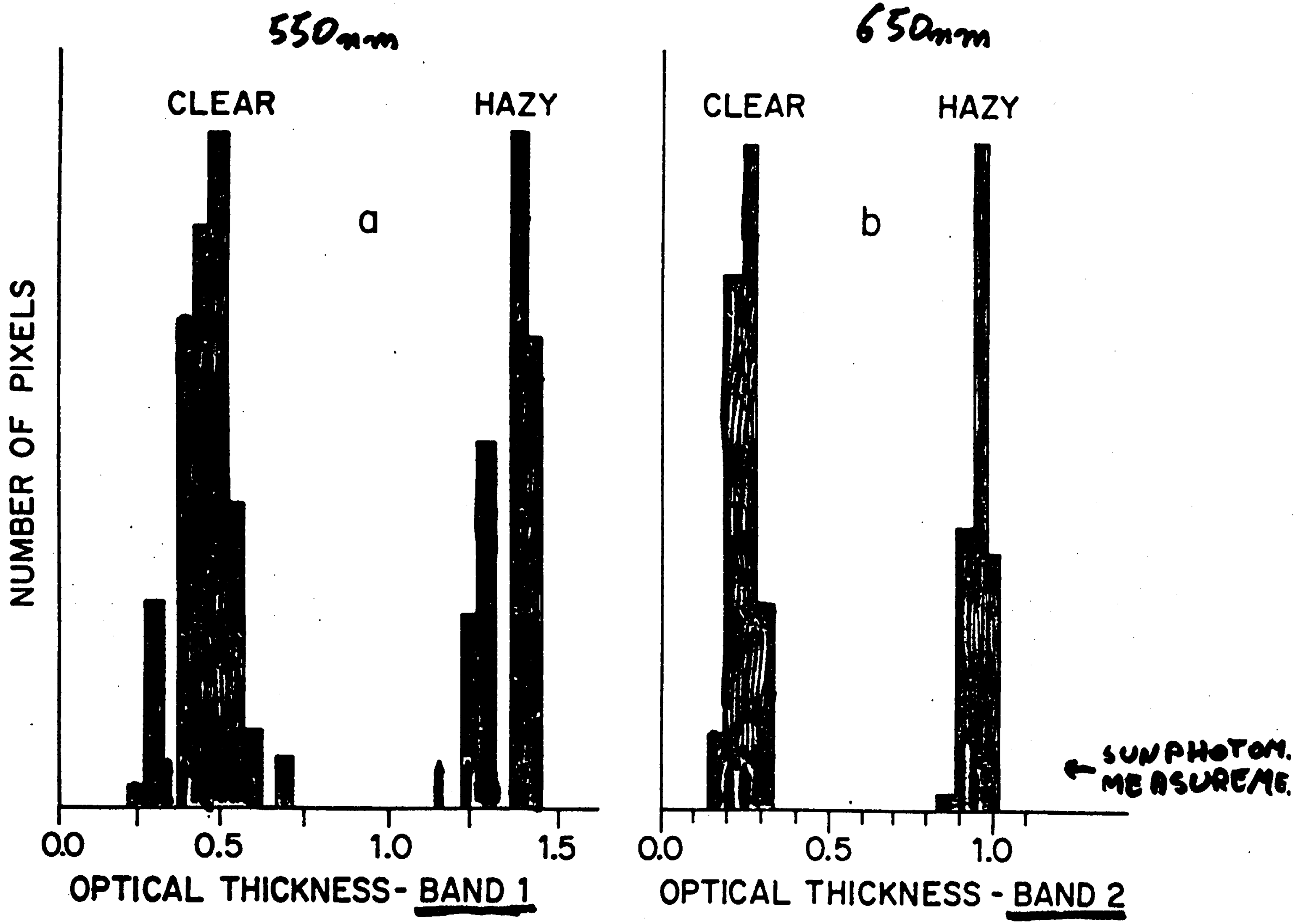
LANDSAT MSS



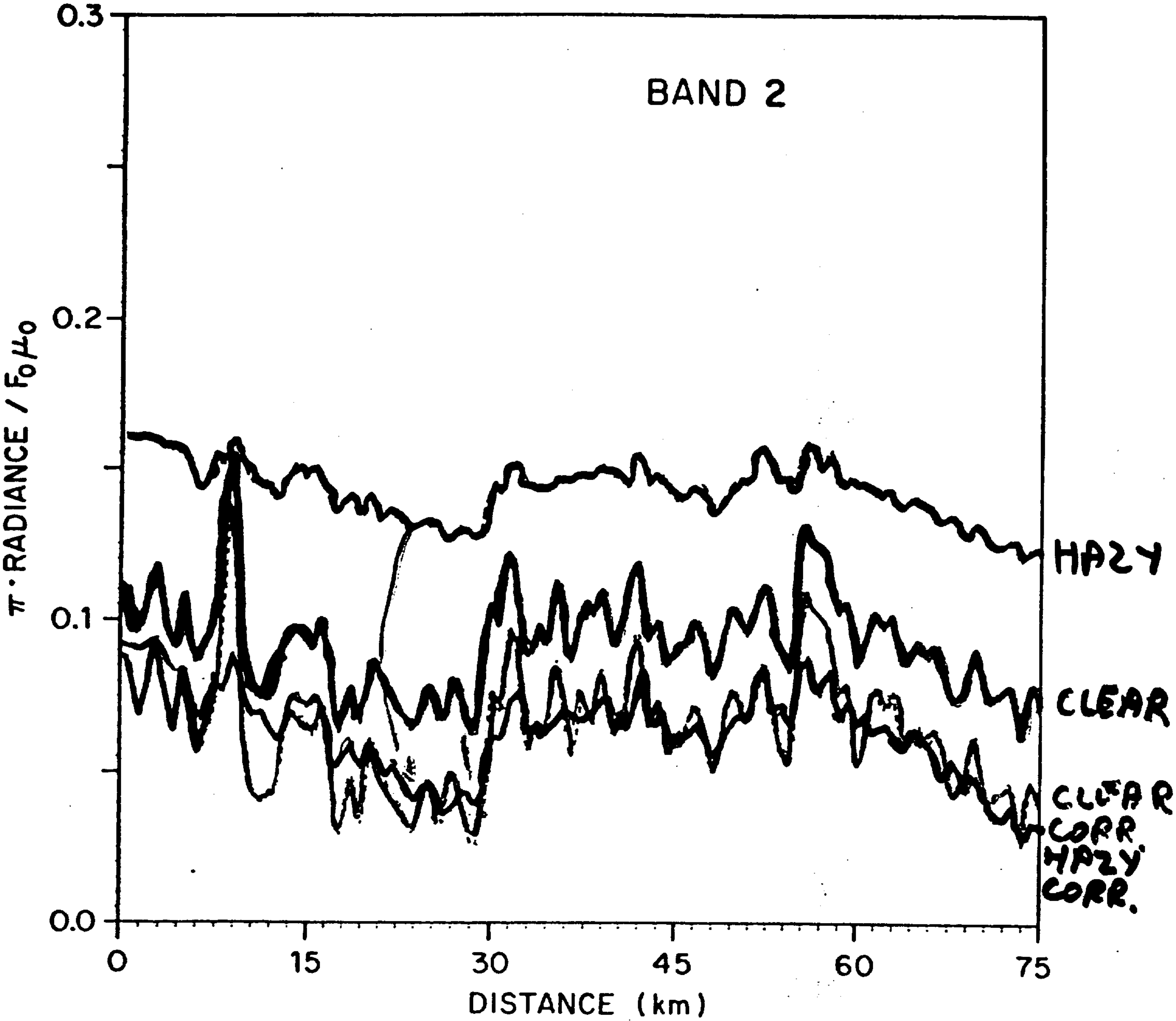
NDVI
0.0
0.05
0.10
0.15
0.20
0.25
HAZY DAY
b
60
50
40
650 nm
BAND 2 (COUNTS)
0.22
0.20
0.18
0.16
0.14
π · RADIANCE / $F_o \mu_o$
1.0
1.2
1.4
1.6
BAND 3 / BAND 2 (COUNTS RATIO)

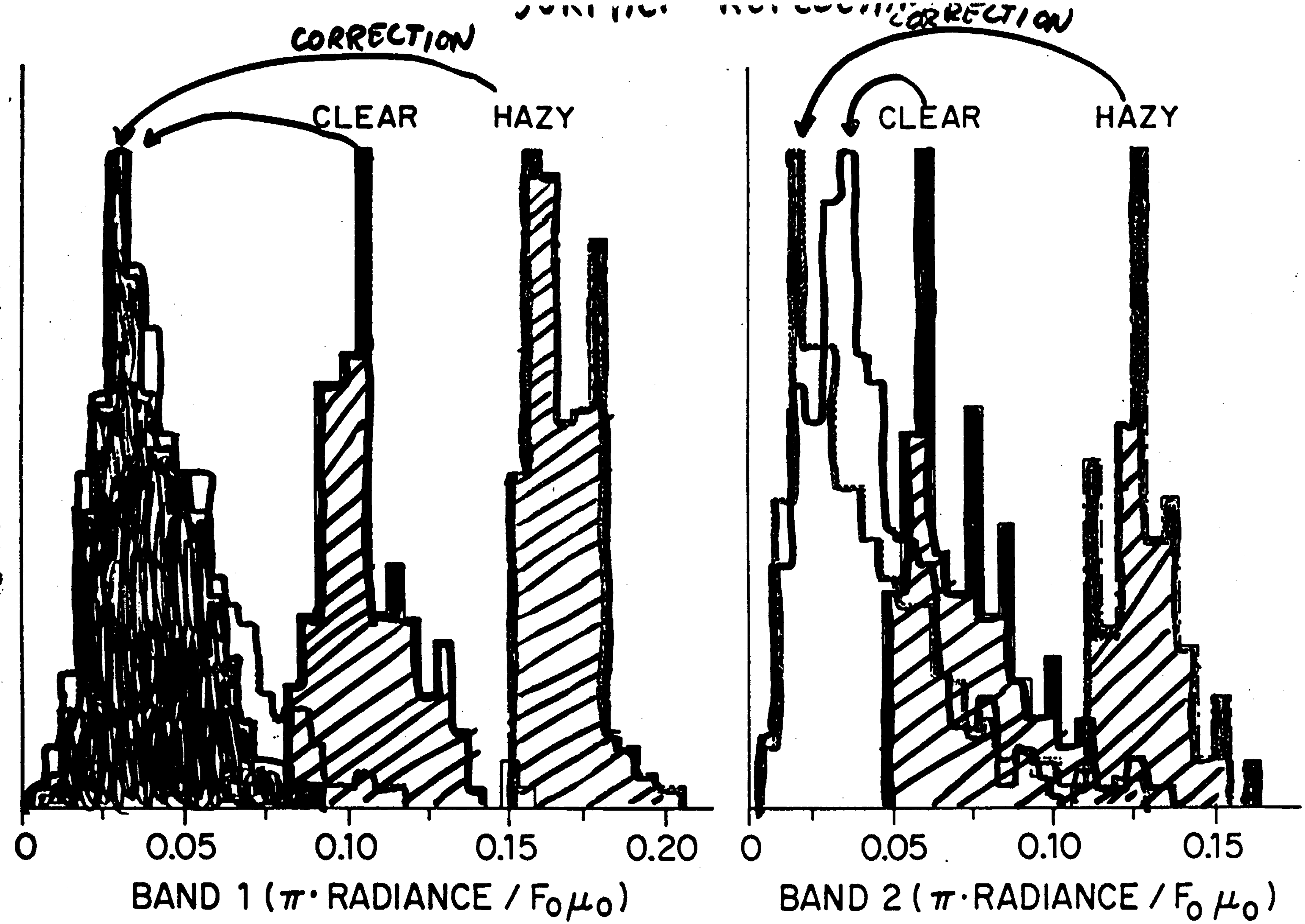
5. RESULTS

OPTICAL THICKNESS



CORRECTION OF THE RADIANCE





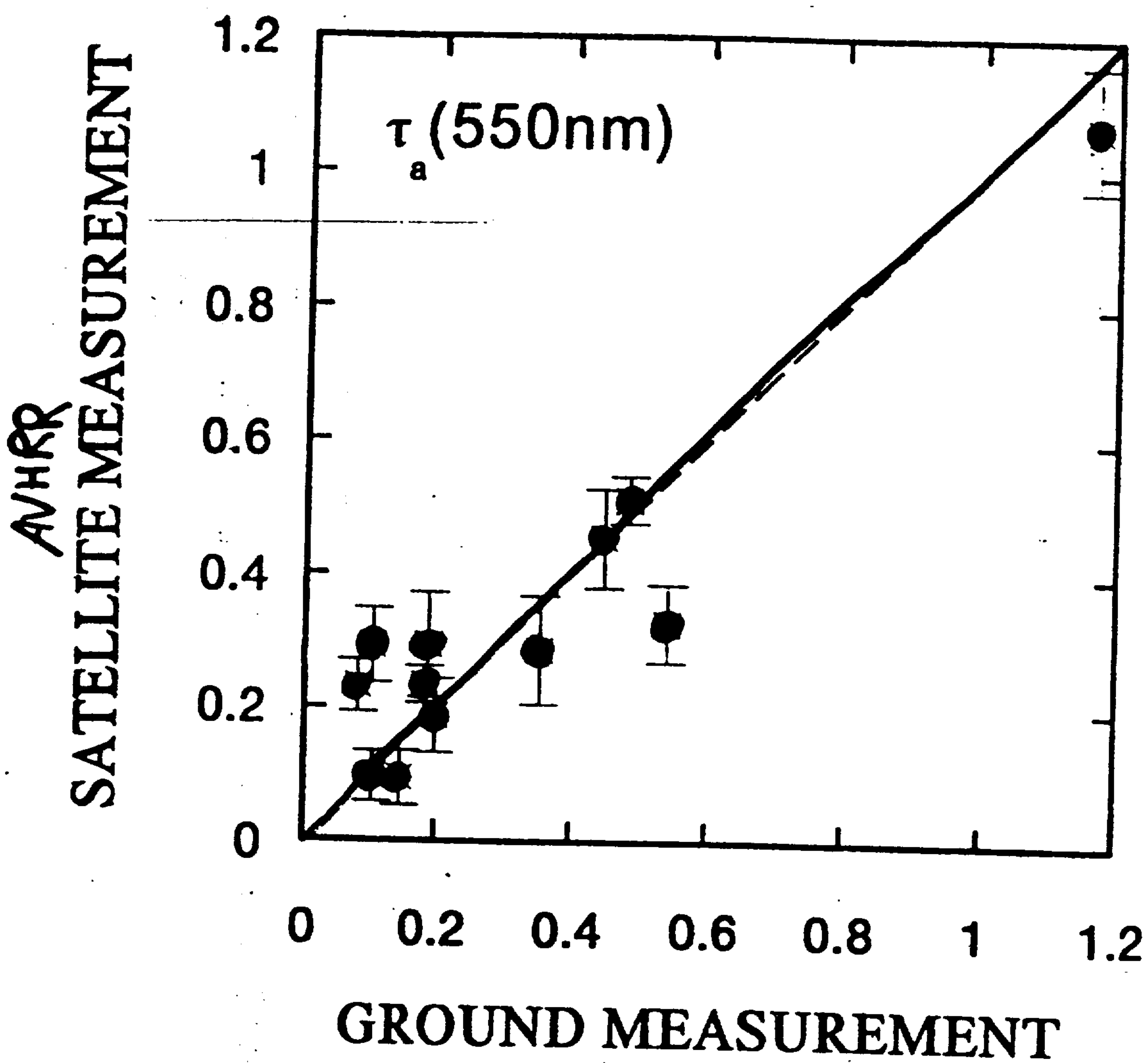
$$L = L_0 + F_0 T \rho / (1 - s\rho) \Rightarrow \rho = \left[s + \frac{T F_D}{L - L_0} \right]^{-1} \sim \frac{L - L_0}{T F_D}$$

F. 12

SOUFFLET & TANRÉ, 1992

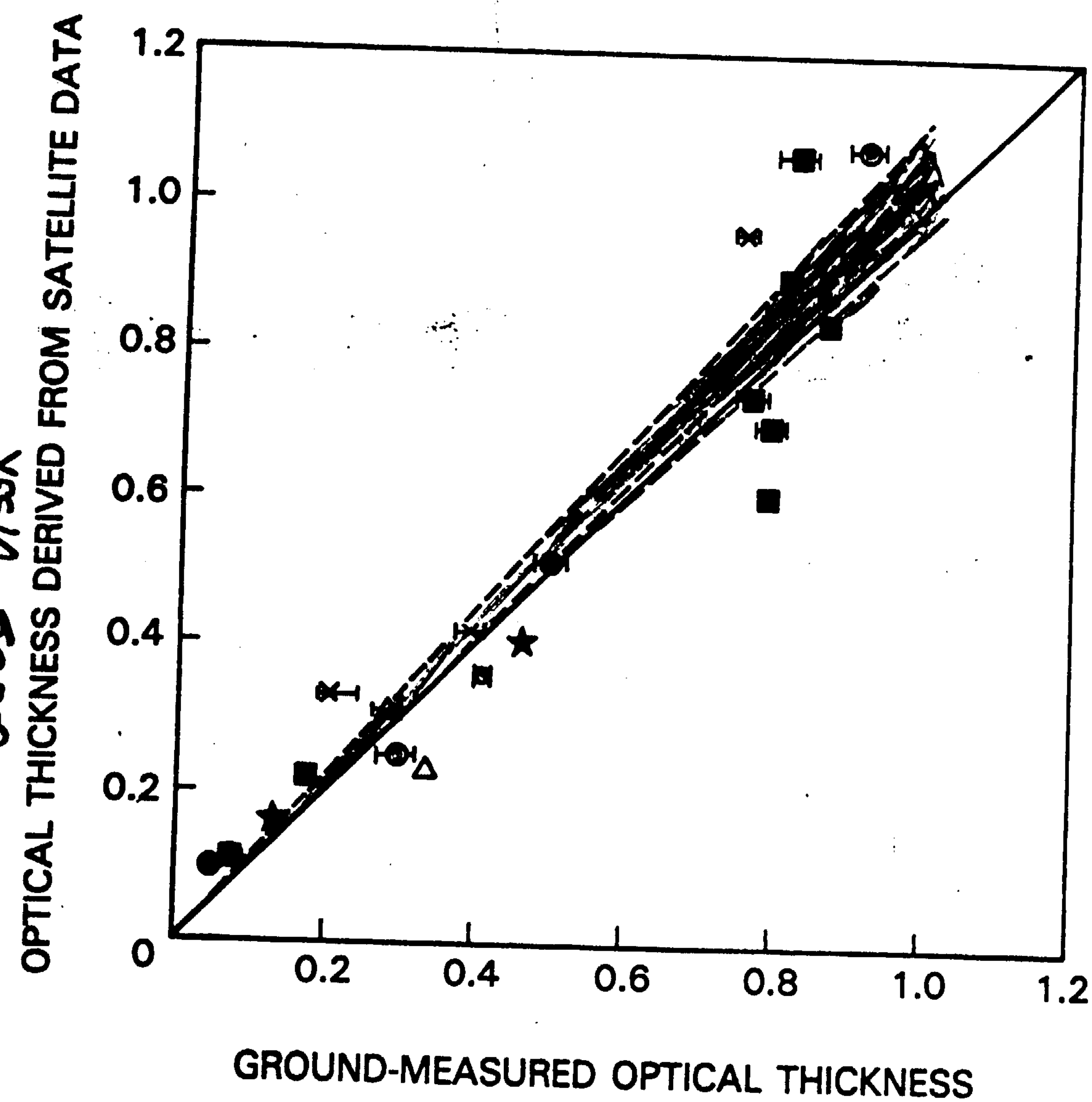
MANIWAKI ---> RESULTS OVER VEGETATION

MEAN VALUE AND STANDARD DEVIATION
OVER ALL THE SCENE (120x120 PIXELS)



EASTERN US $D\tau$

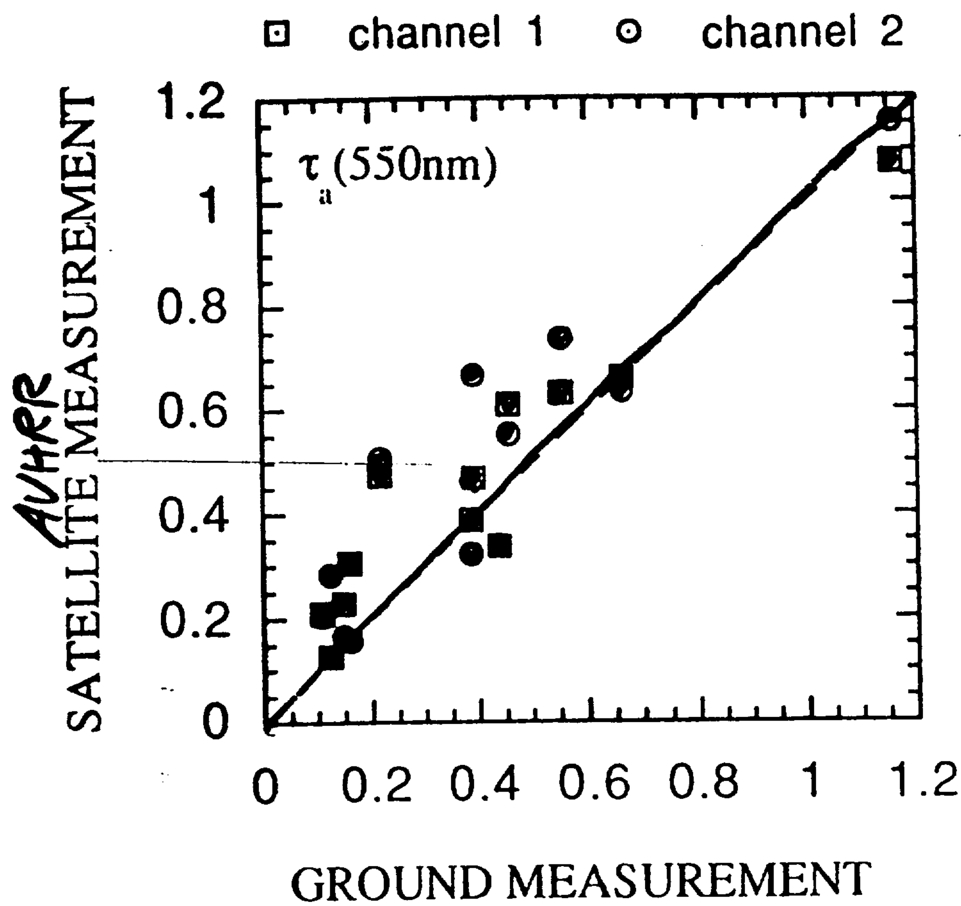
$\Delta L_{VIS} \propto \tau_a \cdot P_a \cdot \omega_0 \qquad \tau_a \xrightarrow[\text{DIST.}]{\text{SIZE}} M_a$



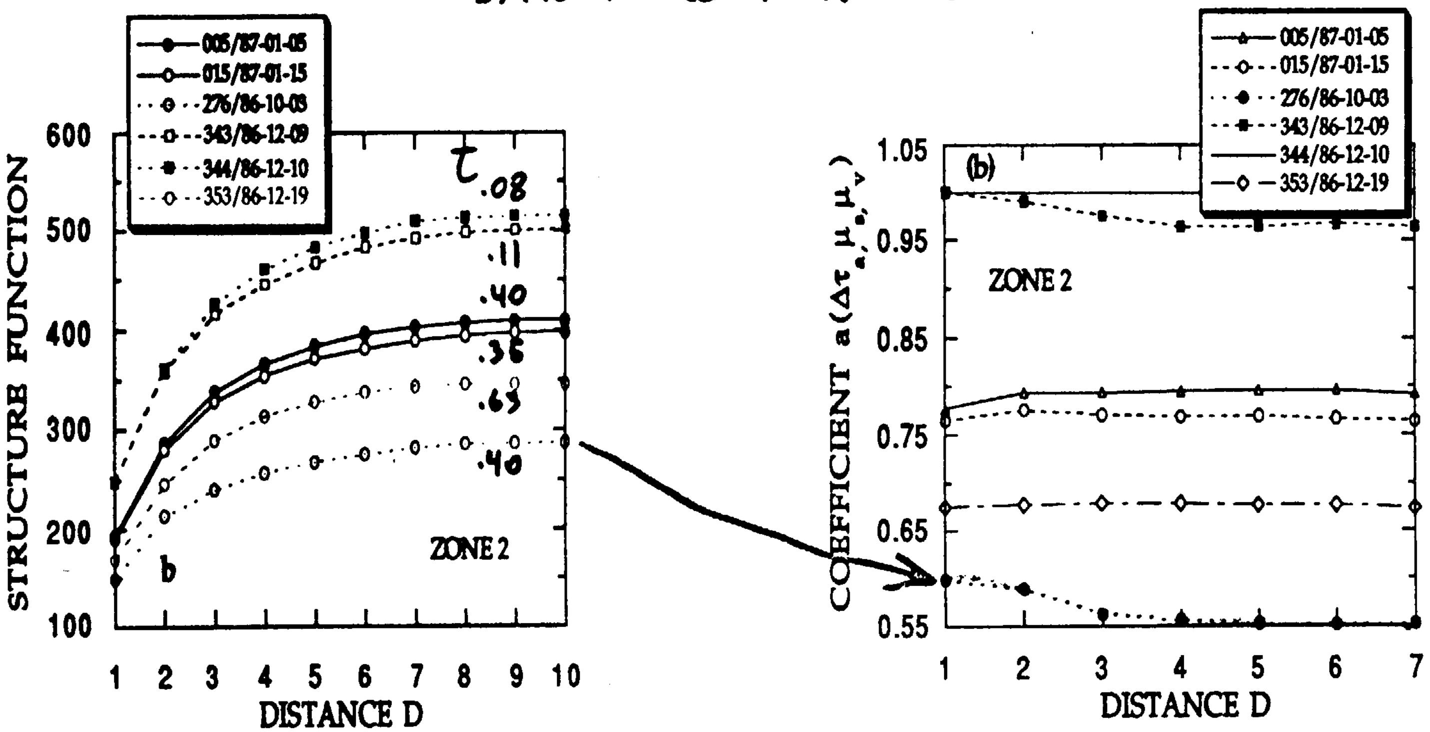
FRASER, KAUFMAN & MAHONEY, 1984

Fig. 16

PETERBOROUGH ---> RESULTS OVER WATER



STRUCTURE FUNCTION

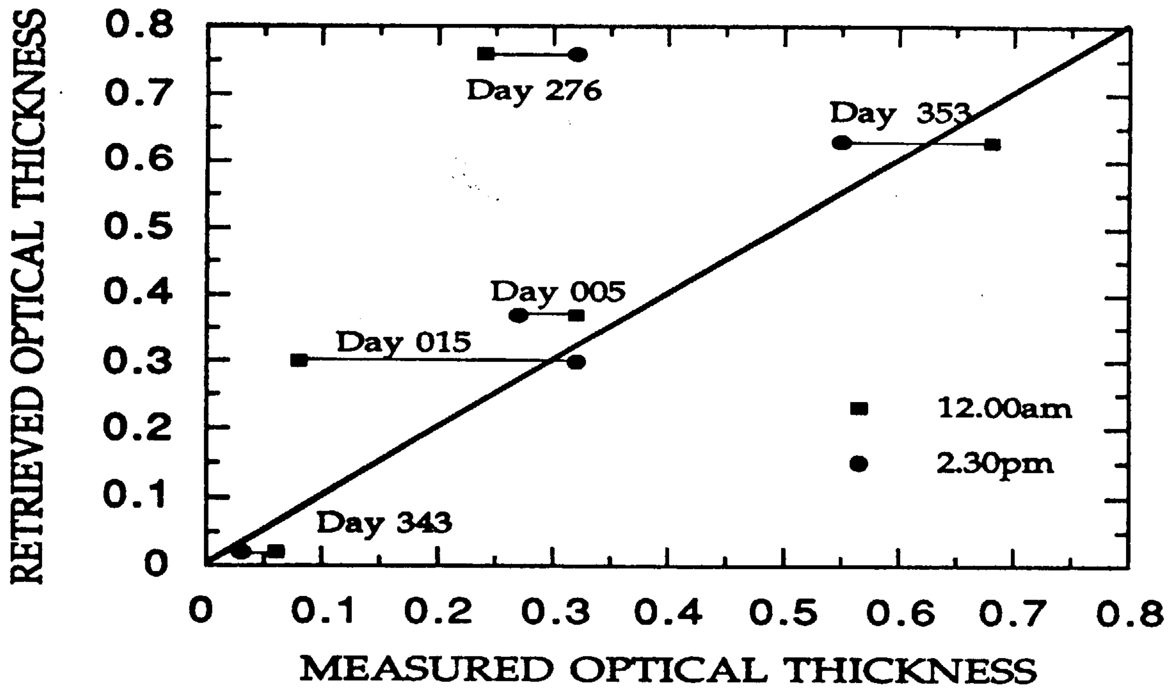


$$F_s = \sum \left[L(x) - L(x+d) \right]^2$$

$$\frac{F_s(t_1)}{F_s(t_2)} \sim \frac{f_1 T_1}{f_2 T_2}$$

GAO, MALI

GAO, MALI


RETRIEVED OPTICAL THICKNESS
MEASURED OPTICAL THICKNESS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Day 276
Day 353
Day 005
Day 015
Day 343
12.00am
2.30pm

ATMOSPHERICALLY RESISTANT VEGETATION INDEX - ARVI FOR EOS-MODIS

Yoram J. Kaufman and Didier Tanré

Modis Team Meeting Oct. 1991

Principle of the self correction for the atmospheric effect:

- The path radiance in the blue is used to correct the path radiance in the red (Fig 1)

$$NDVI = (\rho^*_{NIR} - \rho^*_r)/(\rho^*_{NIR} + \rho^*_r)$$

$$ARVI = (\rho^*_{NIR} - \rho^*_{rb})/(\rho^*_{NIR} + \rho^*_{rb})$$

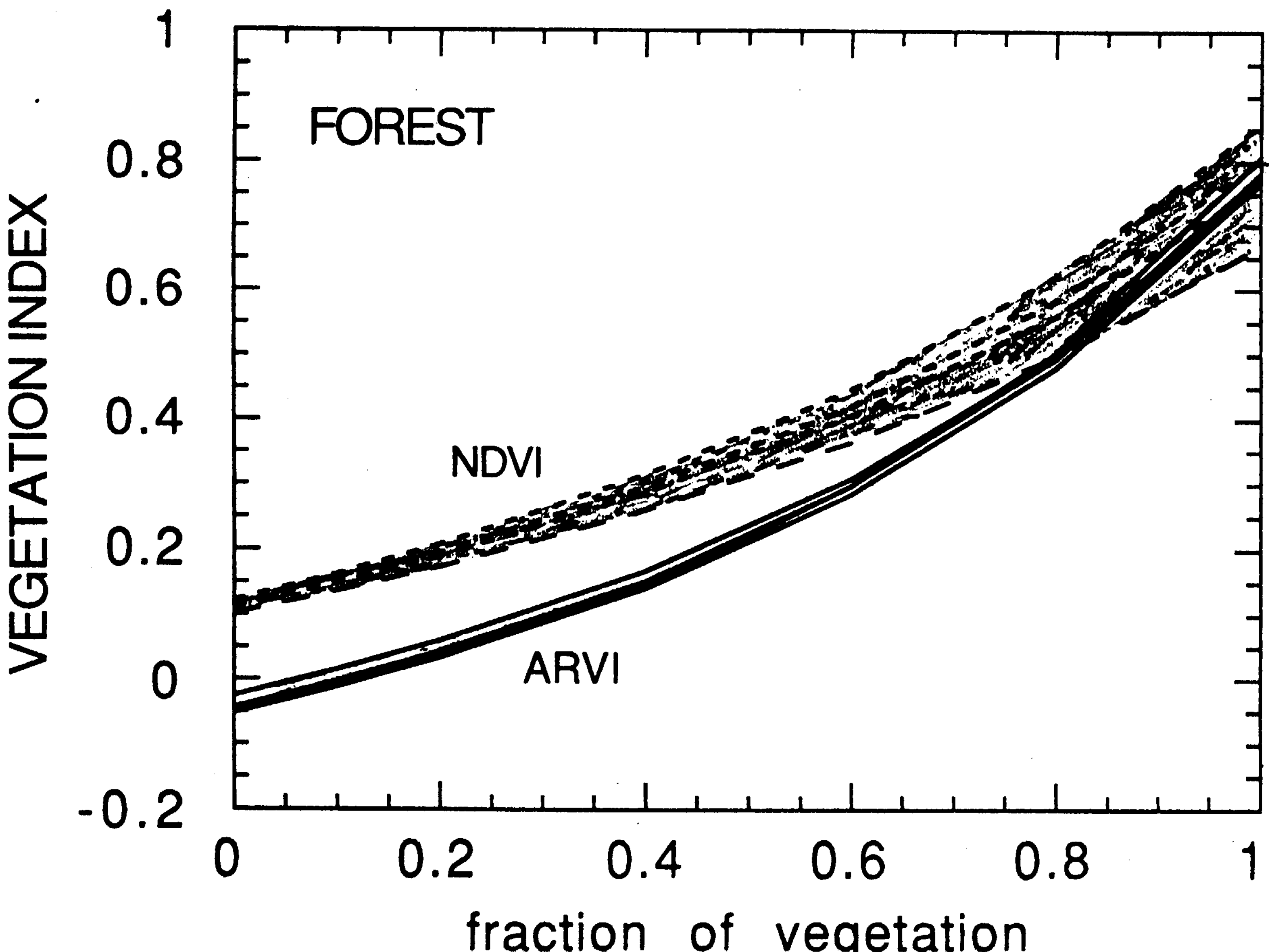
where $\rho^*_{rb} = \rho^*_r - \gamma(\rho^*_b - \rho^*_r)$

Table 1: Reflectances of typical surfaces in the three bands .

surface cover	ρ_{blue}	ρ_{red}	ρ_{NIR}
Soil [37]	0.110	0.190	0.243
Grass [4]	0.012	0.052	0.660
Forest [36]	0.010	0.016	0.210

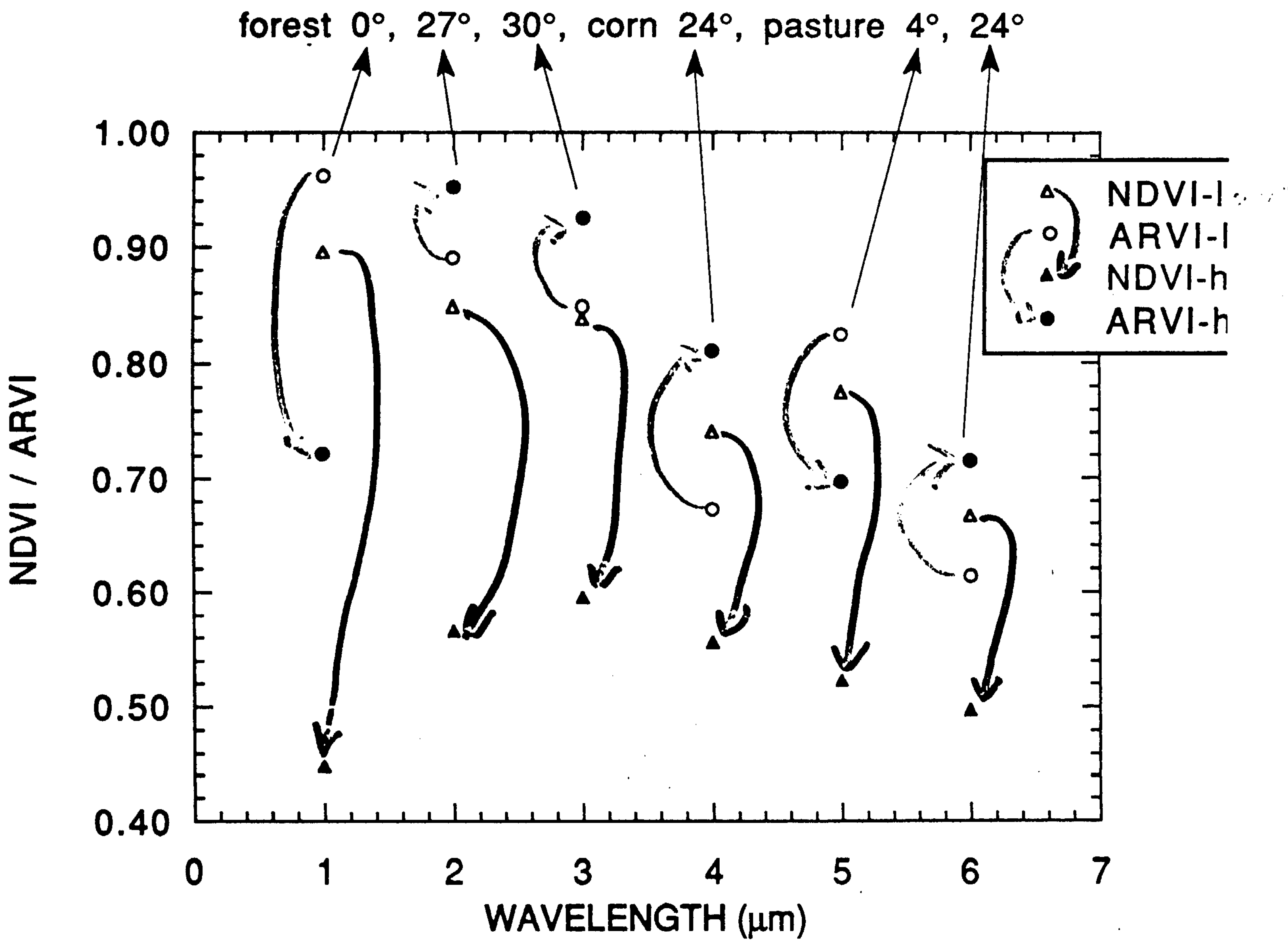
Table 2: Relation between the reflectance in the red channel (0.66±0.025 μm) and in the blue channel (0.47±0.01 μm).

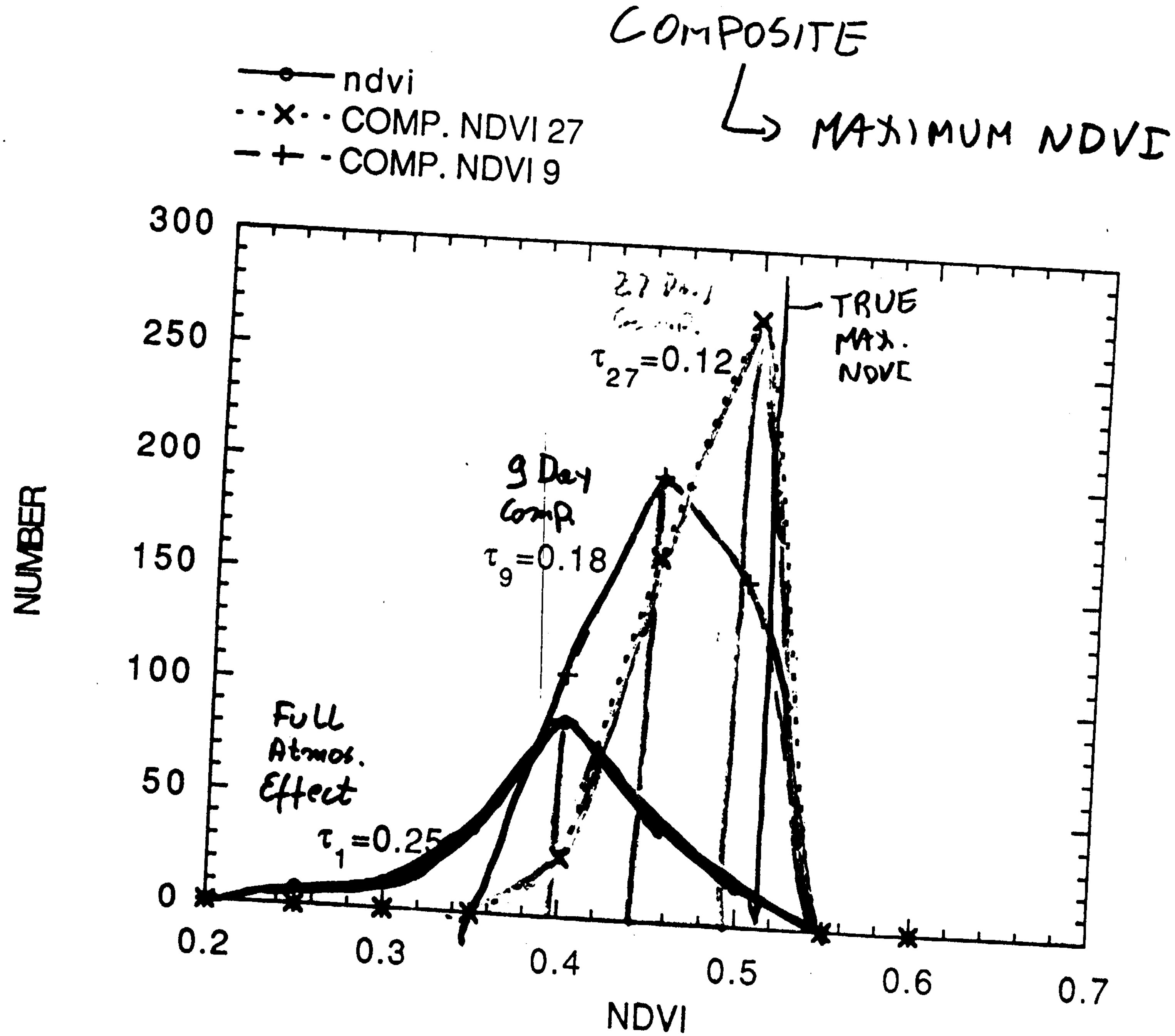
surface /property	reflectances BLUE 0.47 μm	RED 0.66 μm	NIR 0.86 μm	RATIO blue/red	difference	NDVI	ARVI
all surfaces	0.11±0.11	0.19±0.17	0.41±0.19	0.64±0.24	0.08±0.08	0.38±0.33	0.26±0.40
vegetation	0.06±0.04	0.10±0.07	0.45±0.18	0.71±0.25	0.04±0.05	0.63±0.25	0.55±0.32
soils	0.18±0.14	0.31±0.18	0.35±0.18	0.56±0.19	0.13±0.09	0.09±0.06	-0.08±0.08



FOREST
NDVI
ARVI
VEGETATION INDEX
fraction of vegetation
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.2
0.4
0.6
0.8
1

1982 AIRCRAFT DATA




COMPOSITE
MAXIMUM NDVI
ndvi
COMP. NDVI 27
COMP. NDVI 9
TRUE MAX. NDVI
τ27=0.12
9 Day Comp
τ9=0.18
Full Atmos. Effect
τ1=0.25
NUMBER
NDVI
300
250
200
150
100
50
0
0.2
0.3
0.4
0.5
0.6
0.7

* ALTERNATIVE APPROACHES

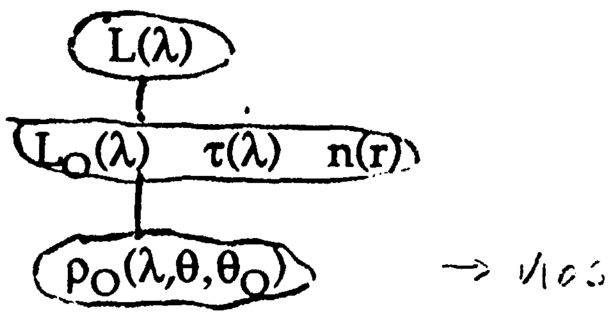
ARVI,

TOOLS

- 6S code, RT codes (Eric)
- bidirectional scheme (updated from data)

FIELD EXPERIMENTS empirical relations and testing.

- Pre- and post MODIS measurements from the ground of aerosol physical and optical properties as a data set for relation between L_O and τ and for ground truth (Brent).
- Field experiments with surface properties, aerosol properties and radiance transfer.
- To generate a data set of the parameters to test and update radiative transfer models and to validate remote sensing procedures and atmospheric correction schemes.



1. $L_O(\lambda)$, $\tau(\lambda)$ - network of instruments

Brent - 7 instruments in Brazil from 1992
Didier - 5 instruments in West Africa from 1992
Yoram - 4 instruments for targets of opportunity (desert transition area, Puerto Rico, East Europe, GSFC). from 1992
Yoram and Didier - additional instruments from 1993 on depending on the budget.

2. Didier: 1992 HAPEX-SAHEL tau, Lo, fluxes, atmospheric samplers, surface bidirectional reflectance, PAR, METEOSAT,AVHRR,TM,POLDER,ATSP,TIMS

3. Yoram, Brent: 1992 Wallops, Desert transition area in Israel: tau, Lo, L(l) from digitized camera. - Need of a not expensive visible to near IR radiometer-imager.

4. MODIS team: 1993 Brazil, in collaboration with Ames and Hobbs aerosol, clouds and gases characterization simultaneously with radiation measurements, MAS, vegetation characterization and ground based measurements.

CONCLUSIONS

- Strategy that adds and sophisticates the corrections in stages
  - molecular scattering and gaseous absorption
  - alternative approaches
  - aerosol correction
- Simulations of the performance and error analysis
- Data sets of surface properties of aerosol properties and of simultaneous surface, aerosol and radiance measurements :

MAS, TM, DIGITIZED PHOTOGRAPHY

X

SUN PHOTOMETER