National Ice Center
Sea Ice Training Lecture Series

AVHRR IMAGERY

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CONTENT

I. TIROS/TIROS-N Platform History

** AVHRR=Advanced Very-High Resolution Radiometer

** TIROS= Television Infrared Observation Satellite

1.1 TIROS History

The TIROS Program was NASA's first experimental step to determine if satellites could be useful in the study of the Earth. At that time, the effectiveness of satellite observations was still unproven. Since satellites were a new technology, the TIROS Program also tested various design issues for spacecraft: instruments, data and operational parameters.

** On April 1, 1960, TIROS-1 was launched, which was the first satellite completely dedicated to satellite meteorology. NASA is the agency responsible for TIROS series. This satellite lasted only 78 days.

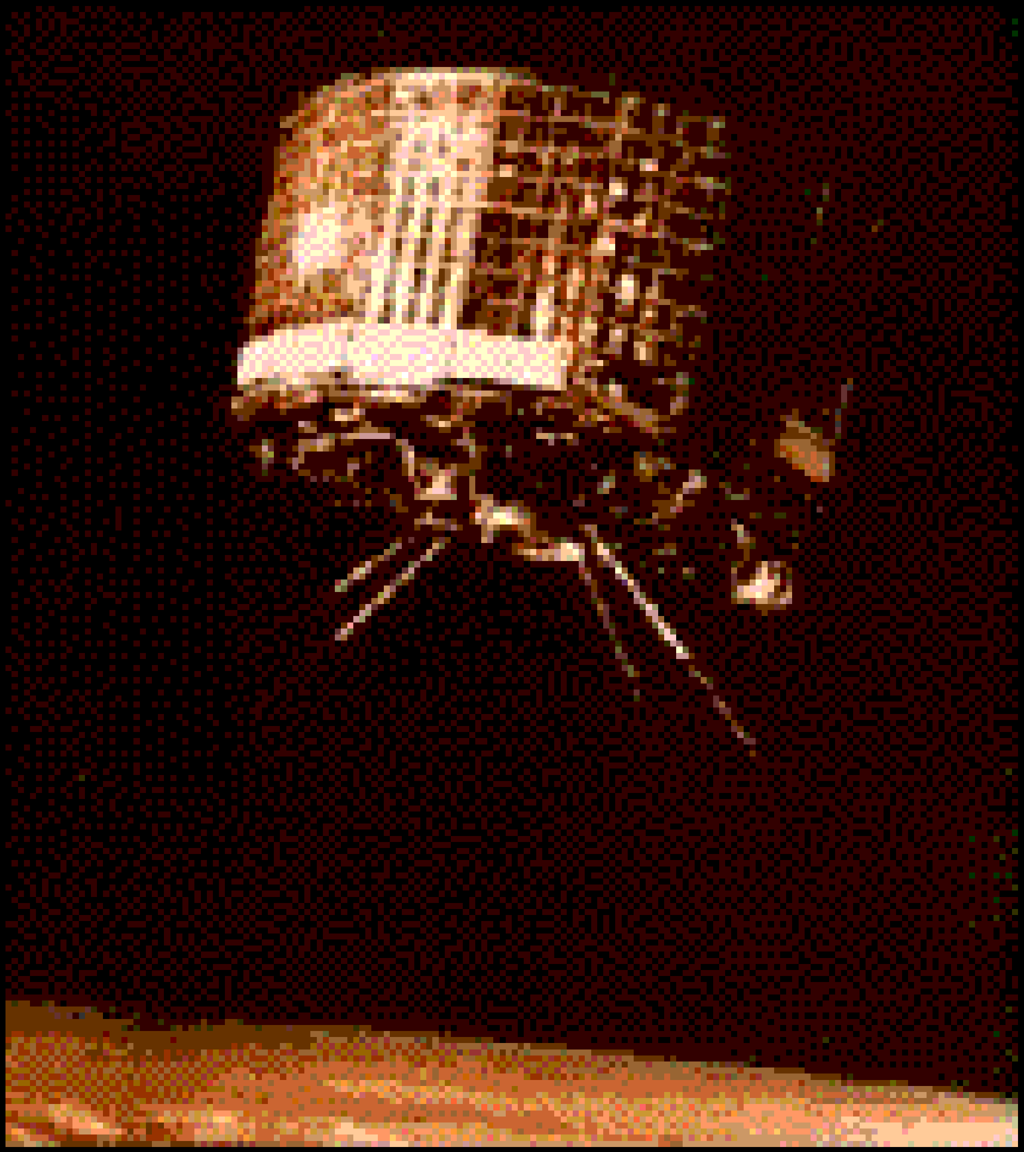


Fig.1 TIROS-1

http://www.earth.nasa.gov/history/tiros/tiros2.html

** The spacecraft was 42 inches in diameter, 19 inches high and weighed 270 pounds. The craft was made of aluminum alloy and stainless steel which was then covered by 9200 solar cells. The solar cells served to charge the on-board batteries. Three pairs of solid-propellant spin rockets were mounted on the base plate.

** Two television cameras were housed in the craft, one low-resolution and one high-resolution

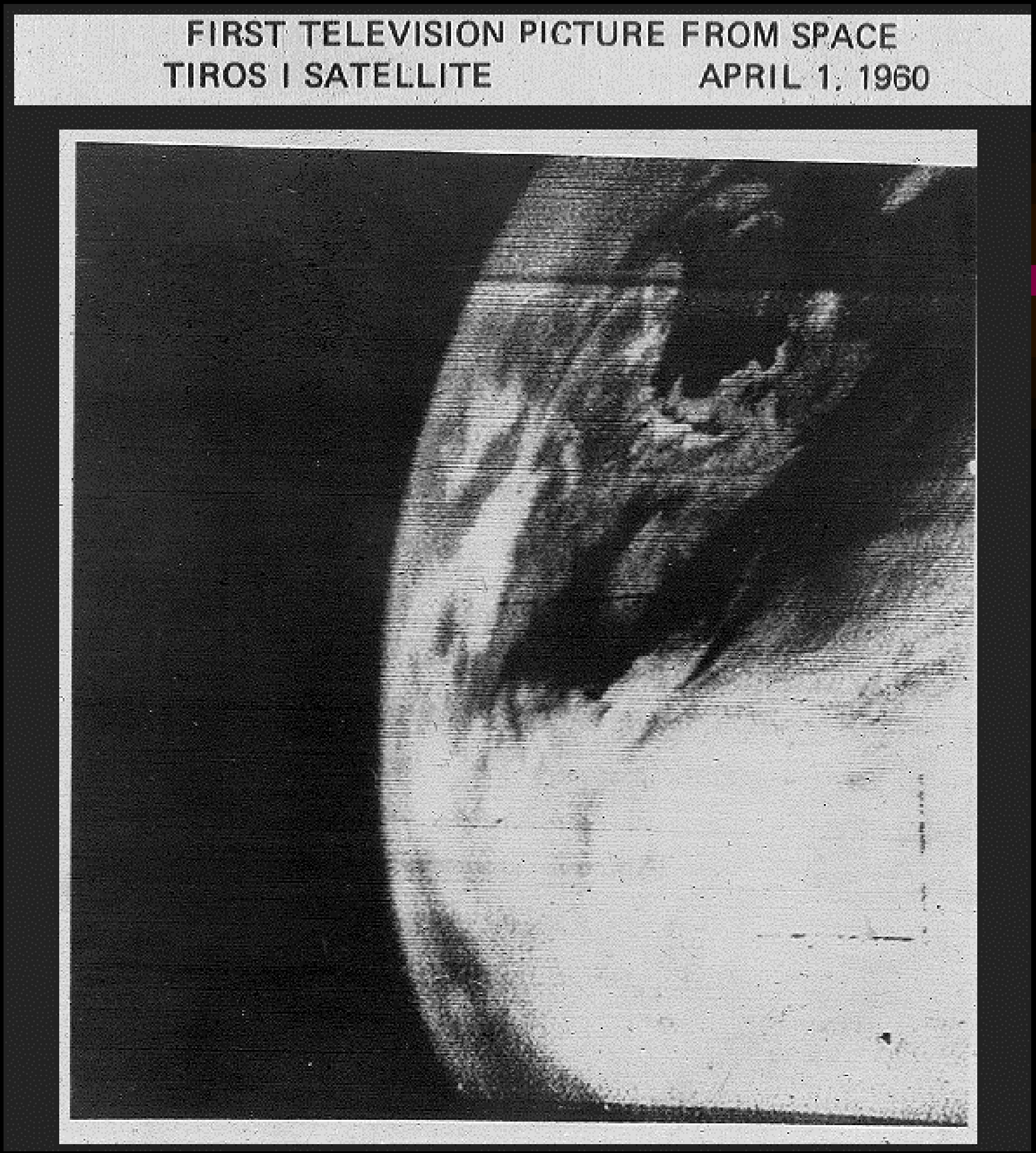


Fig. 2 First television picture from space TIROS-1 satellite on April 1,1960

http://www.earth.nasa.gov/history/tiros/tiros1.html

** From 1960 to 1965, ten TIROS satellites were launched: TIROS-1 to TIROS-10,

** TIROS-10 launch date: July 2, 1965, deactivate date: July 1, 1967

** Last one deactivated in TIROS series is TIROS 9: Launch: Jan 22, 1965, Deactivate: June 12, 1968.

** Major instruments: high-resolution and low-resolution wide-angle television cameras, infrared sensor, etc.

** Tests: APT (Automatic Picture Transmission), infrared horizon scanner, satellite spin-axis, etc.

1.2 ITOS/NOAA Series

ITOS- Improved TIROS Operational System

** Provide improved operational infrared and visual observations of Earth cloud cover, cloud top temperature and surface temperature every twelve hours to APT users for use in weather analysis and forecasting.

**Secondary objectives included providing solar proton and global heat balance data on a regular daily basis.

** NOAA-1 (ITOS-A) was launched in December 11, 1970, and deactivated by NOAA on August 19, 1971

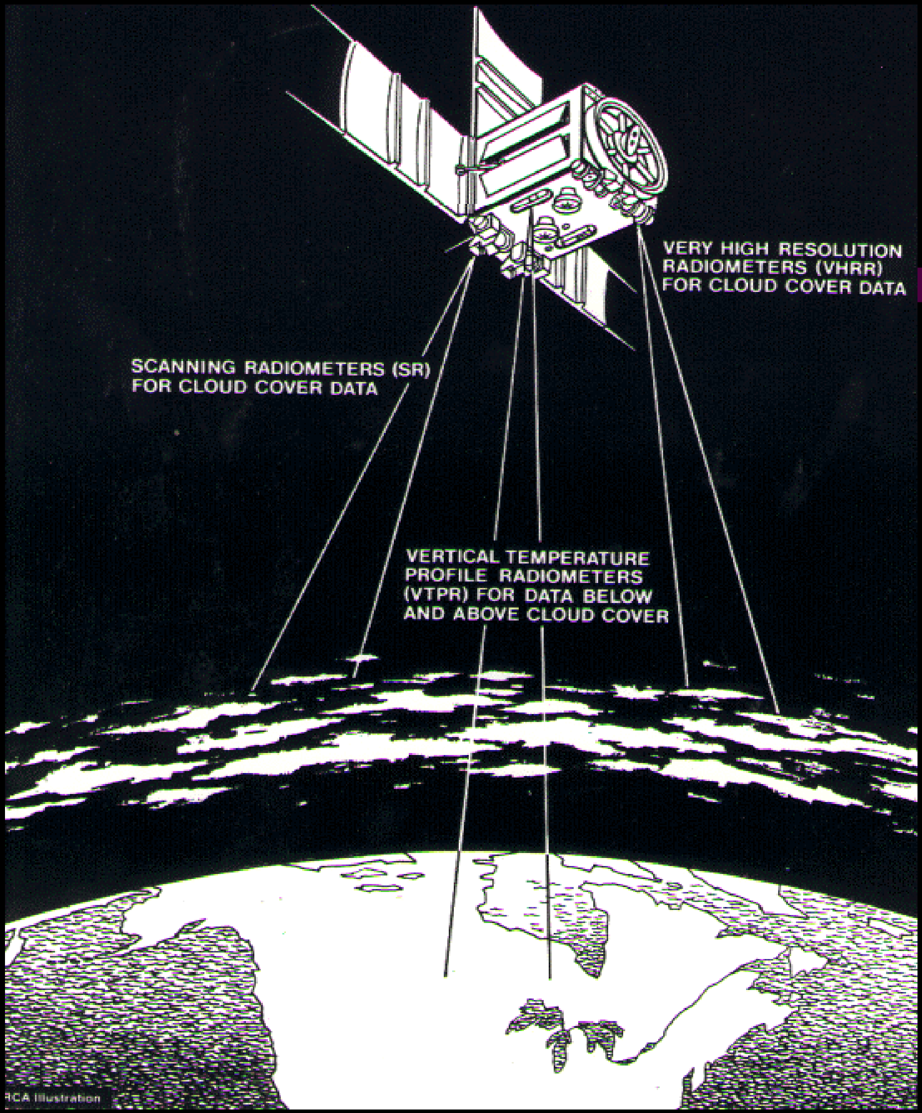


Fig. 3 NOAA-2 schematic show

http://www.earth.nasa.gov/history/noaa/noaa2.html

** The nearly cubical spacecraft measured 1 by 1 by 1.2 m. The TV cameras and infrared sensors were mounted on the satellite base-plate with their optical axes directed vertically earthward.

**The spacecraft was equipped with three curved solar panels. Each panel measured over 4.2 m in length when unfolded and was covered with 3420 solar cells. The attitude control system maintained desired spacecraft orientation through gyroscopic principles incorporated into the satellite design.

**** Major Instruments in ITOS\NOAA:**

--TV cameras for APT on NOAA-1
--Advanced Vidicon Camera System (AVCS)
--Very High Resolution Radiometer (VHRR) since NOAA-2
--Vertical Temperature Profile Radiometer (VTPR)
--Scanning Radiometer (SR)

**** Operation date:** 1970-1979:

NOAA-1: 12-11-70 to 08-19-71
NOAA-2: 10-15-72 to 01-30-75 -- first satellite to have VHRR instrument
NOAA-3 : 11-06-73 to 08-31-76
NOAA-4: 11-15-74 to 11-18-78
NOAA-5 07-29-76 to 07-16-79

1.3 TIROS-N/NOAA Series

** TIROS-N: TIROS-Next Generation

** TIROS-N: 10-13-78 to 02-27-81-- first satellite to have AVHHR

** The TIROS-N/NOAA Program was NASA's next step in improving the operational capability of the TIROS system first tried in the 1960's and the ITOS/NOAA system of the 1970's. Technological improvements integrated into the satellite system provided higher resolution image, and more day and night quantitative environmental data on local and global scales than seen with the two earlier generations of TIROS. Like earlier TIROS systems, NASA took responsibility for the satellite only until proven operational. Once operational the satellite's name was changed to 'NOAA' with day to day use under the direction of NOAA.

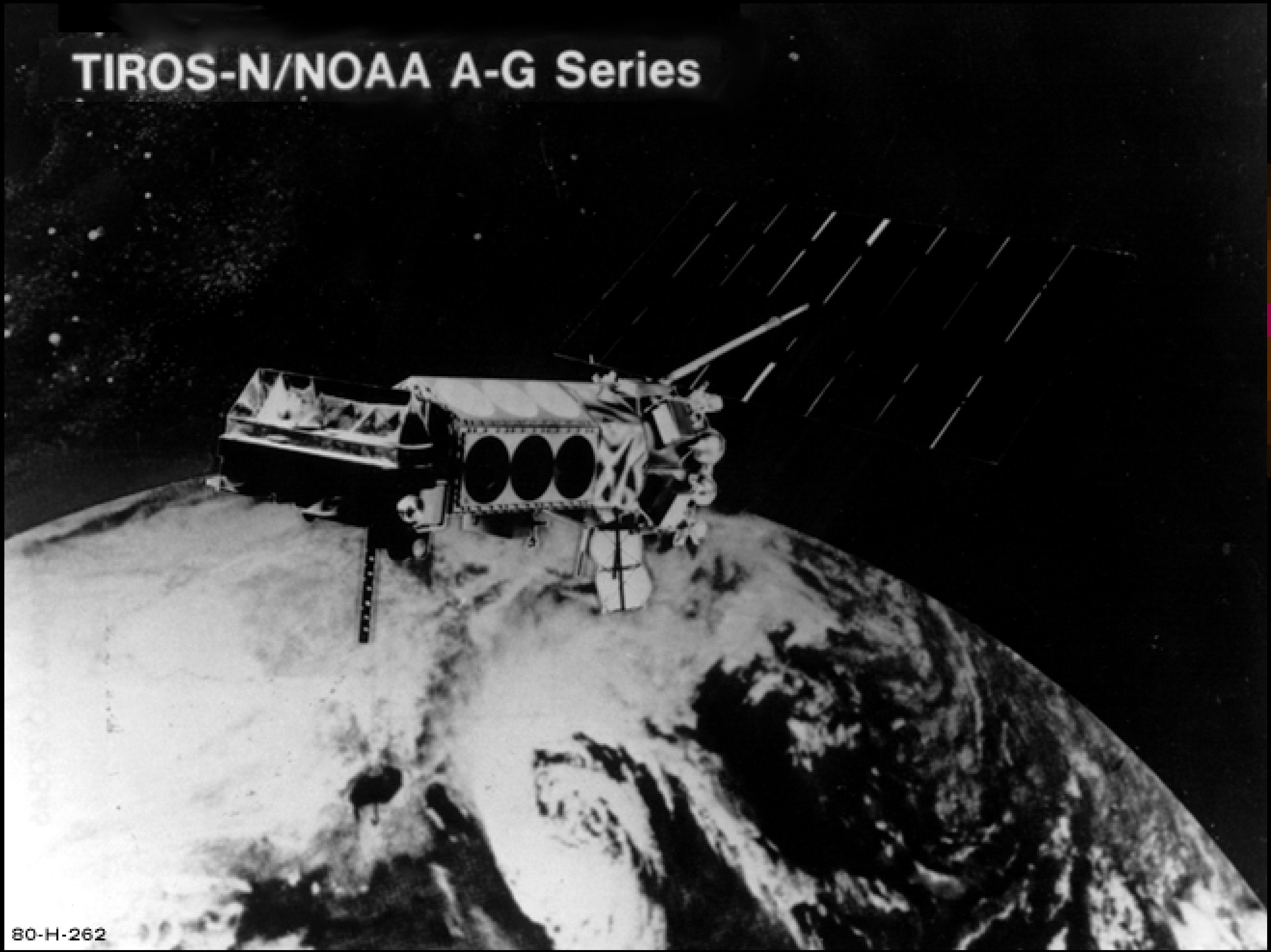


Fig. 4 TIROS-N schematic show.

The spacecraft was rectangularly shaped (146" long by 74" high) with one large solar panel attached. The satellite was Earth oriented, three-axis stabilized and weighed 1594 pounds.

http://www.earth.nasa.gov/history/tiros/tirosn.html

Major instruments:

**Advanced Very High Resolution Radiometer (AVHRR) -- provided day and night cloud-top and sea surface temperatures, as well as ice and snow conditions.

** TOVS - (TIROS Operational Vertical Sounder) -- provided vertical profiles of temperature and water vapor from the Earth's surface to the top of the atmosphere.

** A solar proton monitor -- detect the arrival of energetic particles for use in solar storm prediction.

** A data collection platform -- to receive, process and store information from free floating balloons and buoys worldwide for transmission to one central processing facility (first time).

TIROS-N/NOAA Program Satellites:

** TIROS-N: 10-13-78 to 02-27-81 --first to have AVHRR

** NOAA-6: 06-27-79 to 03-31-87

** NOAA-B 05-29-80-- Failed

** NOAA-7 : 06-23-81 to 06-07-86

** NOAA-8 : 03-28-83 to 12-29-85

** NOAA-9 : 12-12-84 to 08-01-93, 08-23-93 to 02-13-98

** NOAA-10 09-17-86 to 09-17-91

** NOAA-11 09-24-88 to Present

** NOAA-12 05-14-91 to Present

** NOAA-13 08-09-93, circuit failure, still in orbit, no data

** NOAA-14 12-30-94 to Present

** NOAA-15 05-13-98 to Present -- first to have AMSU

** NOAA-16 09-20-00 to Present

II. AVHRR Characteristics

2.1 Brief history

** AVHRR's ancestors were the Scanning Radiometers (SRs), first orbited on ITOS-1 in 1970. These early SRs had a relatively low spatial resolution (8 km) and fairly low radiometric fidelity.

** The VHRR (since NOAA-2) was the first improvement over the SR and for a while flew simultaneously with the SR.

**Later, the VHRR was replaced by the AVHRR which combined the high resolution and monitoring functions.

Three versions of AVHRR instruments:

** AVHRR/1: a four-channel, filter-wheel spectrometer/radiometer;

** AVHRR/2: built in the early 1980s, identical to AVHRR/3 except for the addition of Channel 5.

** AVHRR/3: six channels on board NOAA-15, 16, 17 (-KLM).

2.2 Sensor Description

Optics: 20.3-cm diameter focal Cassegrain telescope.

Scan mirror: Ribbed beryllium; 29.46-cm major axis, 20.96-cm minor axis.

Scanner: 360 rpm 80-pole hysteresis synchronous motor with ribbed beryllium scan mirror.

Power consumption 4.5 Watts maximum.

Cooler: Two-stage radiant cooler, Infrared detectors operate at 105k.

Data Output: 10-bit binary, channels simultaneously sampled at a 40 kHz rate.

Power: 28 Watts Maxim (total instrument).

Size: 79 cm by 28 cm by 41 cm maximum.

Mass: 30 kg maximum.

Detector Type: Silicon (Ch 1 & 2); InSB (Ch 3); HgCdTe (Ch 4 & 5).

2.3 Spatial/Temporal Resolutions

Basic Parameters:

** IFOV(instantaneous field of View, C):

1.3 to 1.5 milliradians

** Satellite Nominal Altitude: 833 km

-> 1.1 km resolution at nadir

6.0 km near edge (D) of scan

** Scan Angle: ±55.4 Degrees

-> Angular FOV (E): 110.8 Degree

-> Swath Width (F): 2800 km

** 6 scans per second

** 2048 samples per scan

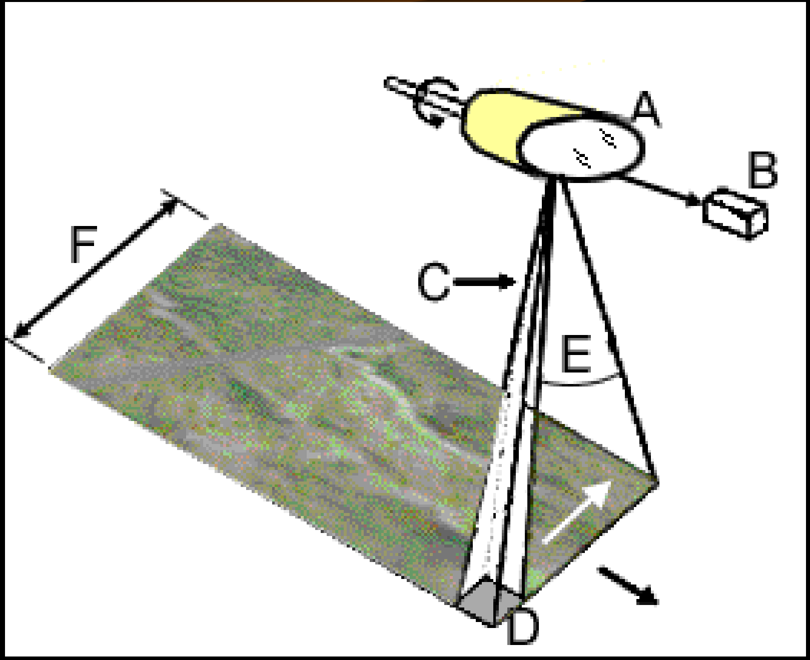


Fig. 5 Schematic show of a sensor's parameters

http://www.ccrs.nrcan.gc.ca/ccrs/eduref/tutorial/indexe.html

2.3 Sensor Frequencies

Spectral Band Widths (μm) of the AVHRR

Channel #	Position	TIROS-N	NOAA-6,-8,-10	NOAA-7,-9,-11,-12,-13,-14	NOAA-15 -16	IFOV(mr)
1	VIS	0.55-0.90	0.58-0.68	0.58-0.68	0.58-0.68	1.39
2	NIR	0.725-1.10	0.725-1.10	0.725-1.10	0.725-1.0	1.41
3a	MID-IR				1.58-1.64	1.30
3b	MID-IR	3.55-3.93	3.55-3.93	3.55-3.93	3.55-3.93	1.51
4	TIR	10.5-11.5	10.5-11.5	10.3-11.3	10.3-11.3	1.41
5	TIR			11.5-12.5	11.5-12.5	1.30

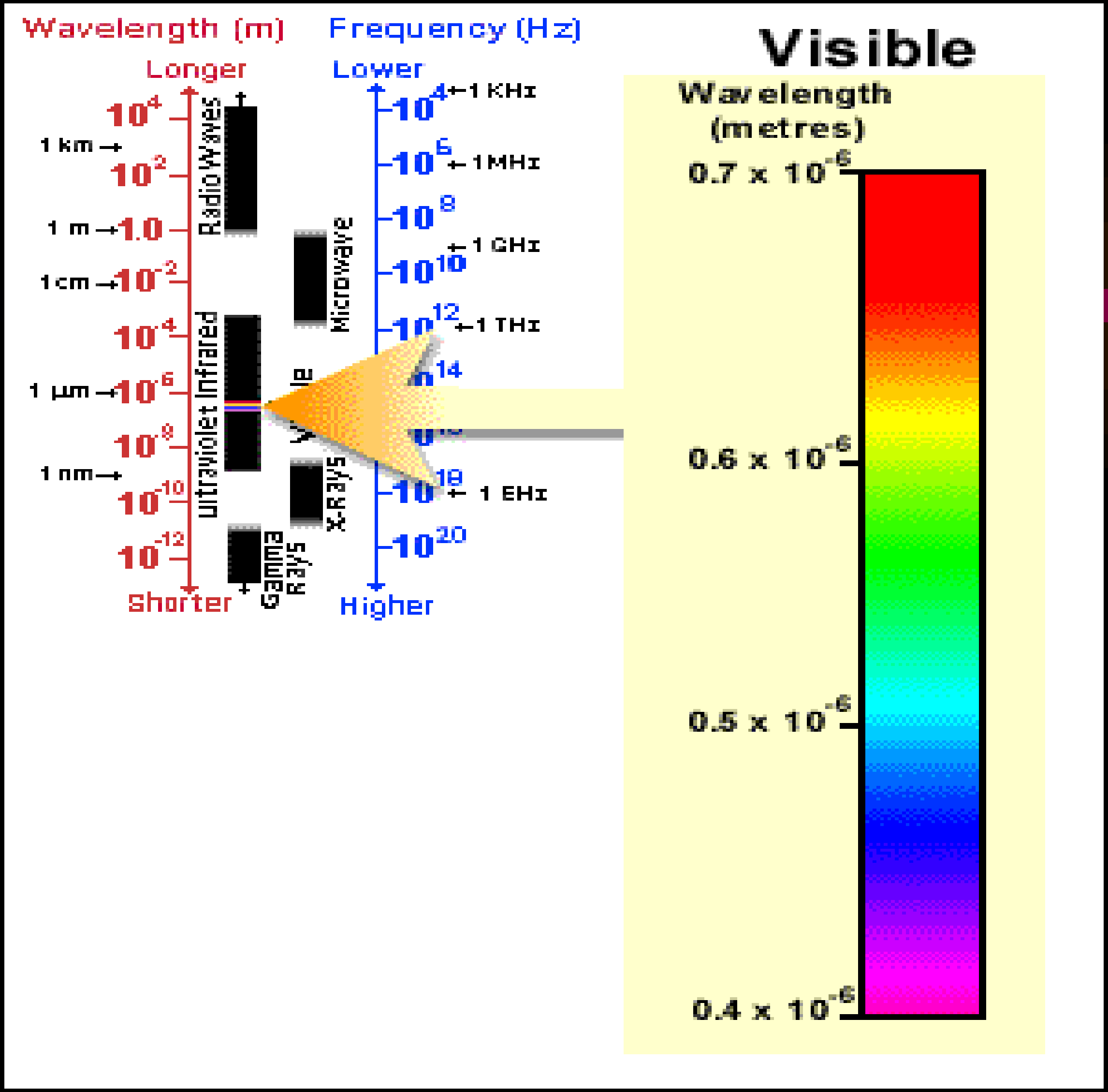


Fig. 6 Schematic show of visible spectrum

http://www.ccrs.nrcan.gc.ca/ccrs/eduref/tutorial/indexe.html

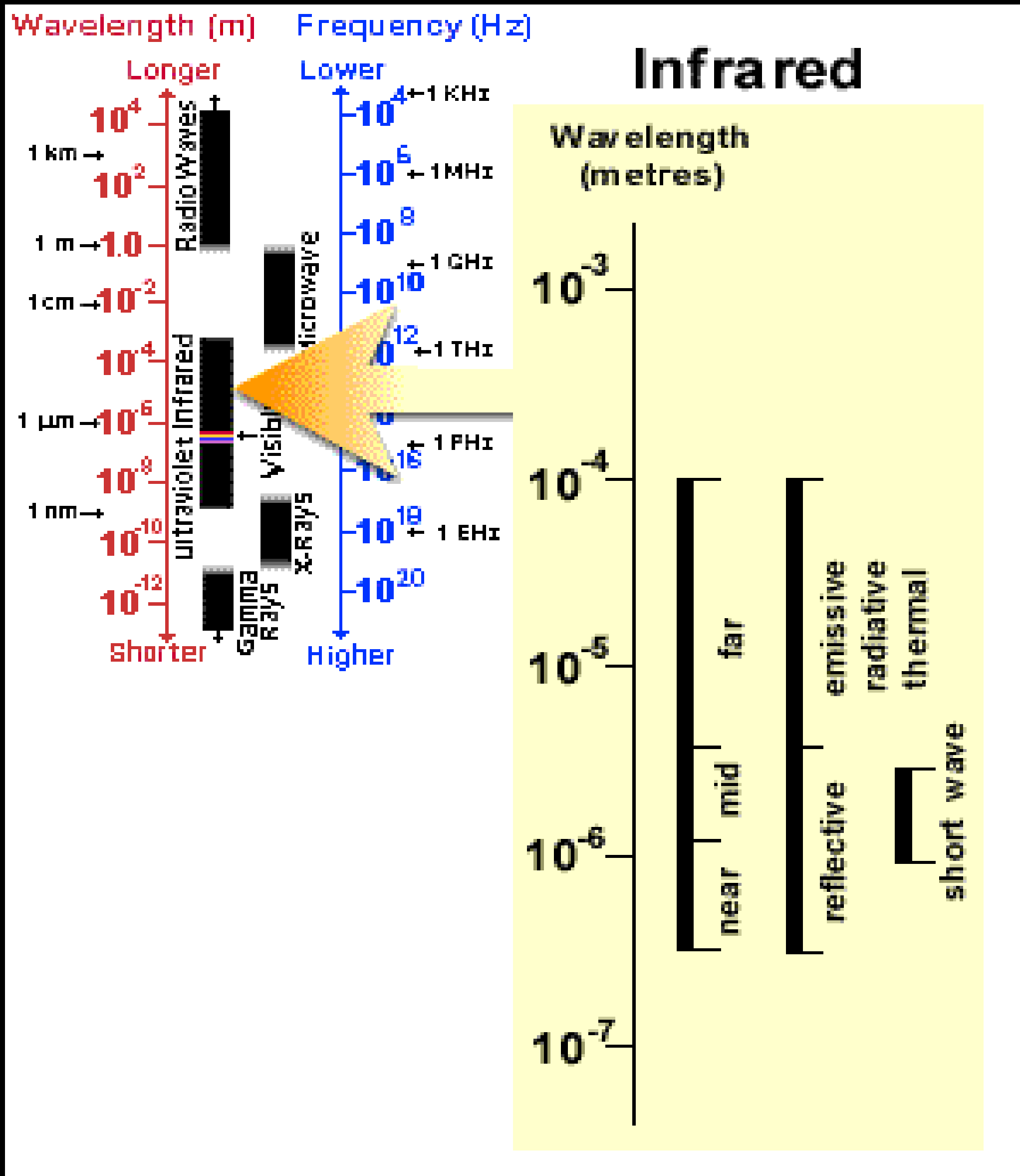


Fig.7 Schematic show of IR spectrum

http://www.ccrs.nrcan.gc.ca/ccrs/eduref/tutorial/indexe.html

2.4 DMSP Series

** DSMP-- Defense Meteorological Satellite Program

** DSMP f8,f9,f10,f11,f12,f13,f14 have a sensor similar to AVHRR, called Operational Line Scanner (OLS), with higher resolution (0.5 km) but only two channels (visible between 0.4 and 1.1 μm and infrared between 10.5 and 12.6 μm)

III. AVHRR Data Transmission

AVHRR has three types of datasets: HRPT, LAC, GAC

1. HRPT : High Resolution Picture Transmission

** Full 1.1 resolution, Digitized to 10-bit precision.

** directly, continuously transmitted to the Command and Data Acquisition (CDA) stations.

** The two NOAA/NESDIS operated stations are

(i) Wallops Island, Virginia

(ii) Fairbanks, Alaska

2. LAC: Local Area Coverage

** 11 minutes of high-resolution data per orbit recorded on board the satellite over any portion of the world as Selected by NOAA/NESDIS .

** Received also through Wallops and Fairbanks, then transmitted via satellite relay to the processing facility at Suitland, Maryland.

** Not real-time, dumped to the CDA stations at later time.

3. GAC : Global Area Coverage

** GAC data contains only one out of three original AVHRR lines and the data volume and resolution are further reduced by averaging every four adjacent samples and skipping the fifth sample along the scan line.

** GAC data has 1.1 km X 4 km resolution with 3 km gap between pixels across the scan line, generally treated as 4 km resolution.

** Recorded only for readout by NOAA’s CDA stations.

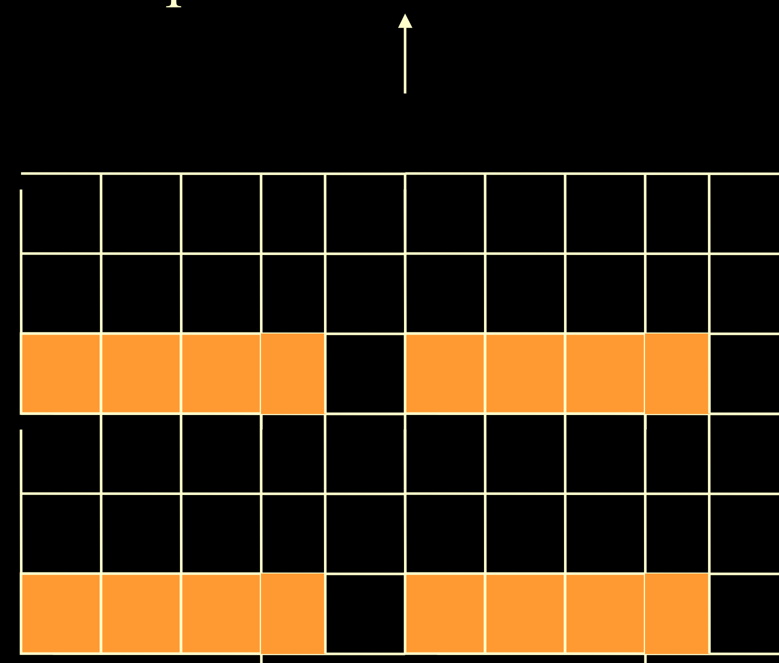
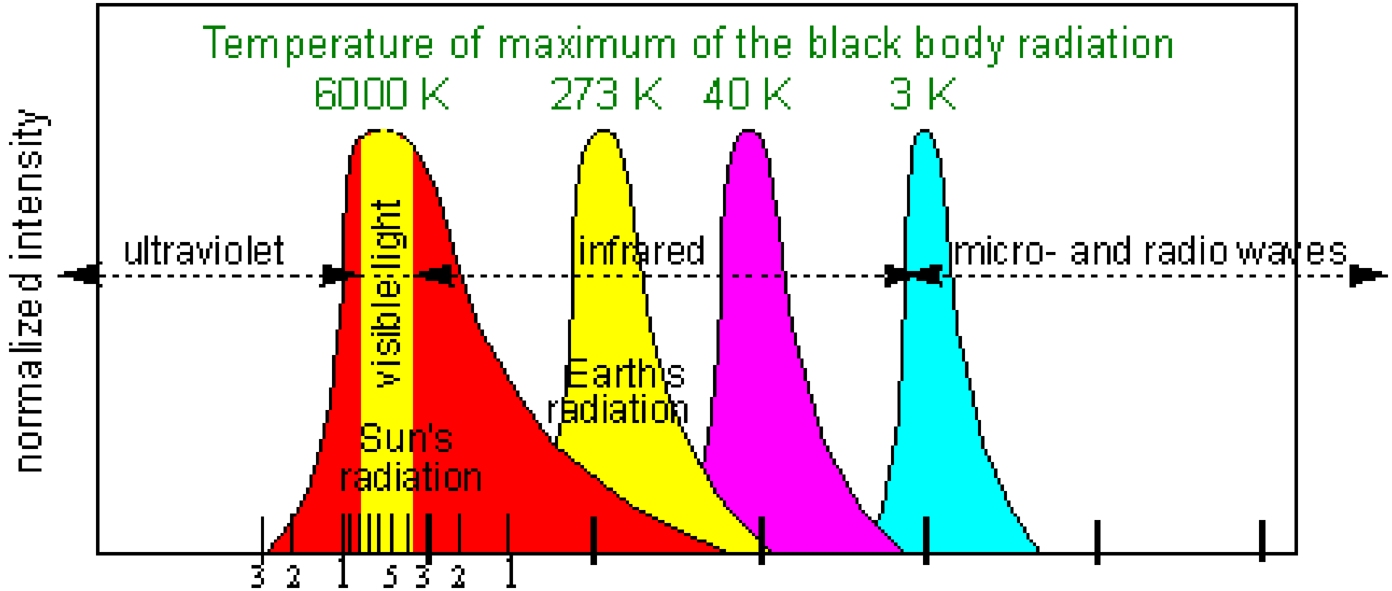


Fig. 8 schematic show the averaging of GAC

** NIC uses HRPT and LAC data taken from the NESDIS main frame and analyze channel 1 and 4 data as needed.

III. Theoretical Basis of AVHRR Sea Ice Detection



r_{vacuum}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	[m]
$f_{quantum}$	$3*10^{15}$	$3*10^{14}$	$3*10^{13}$	$3*10^{12}$	$3*10^{11}$	$3*10^{10}$	$3*10^{9}$	[Hz]
$T_{Boltzmann}$	144000	14400	1440	144	14.4	1.44	0.144	[K]

Traditional "vacuum"-wavelength, $r = c/f$, of the electromagnetic radiation
Traditional quantum frequency, f, of the electromagnetic radiation
Traditional Boltzmann temperature, $T = hf/k_B$, of the electromagnetic radiation

Fig. 9 Energy spectrum of solar and terrestrial radiation.

3.1 Visible and NIR:

** Visible and NIR bands can measure the albedo of surface.

Albedo= reflection/insolation

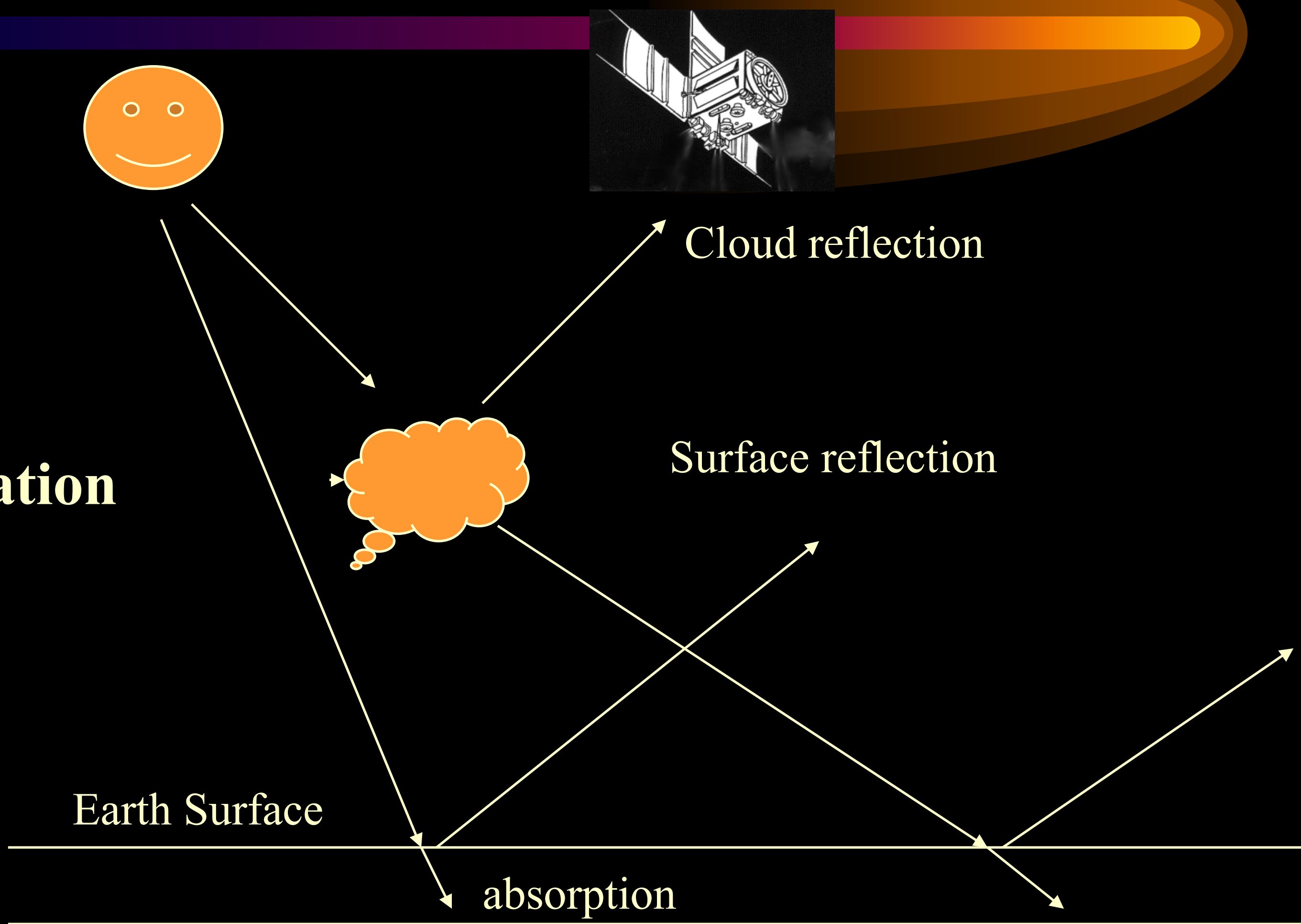


Fig. 9 schematic show earth/cloud reflection process

** Ice has a higher albedo than the other materials

snow type	albedo
new snow	0.8
old snow/dry old ice	0.6
wet ice/wet snow	0.2
pure water	0.02

Problem: cloud albedo is close to the ice/snow albedo so it is difficult to discriminate ice from clouds

Solution: At NIR from 1.0 to 1.3 um, snow reflectance is very sensitive to grain size of the snow, and decreases rapidly compared to the visible range.
Clouds have smaller crystals and droplets so they have less absorption and higher albedo.
This characteristics can be used to distinguish snow/ice from clouds.

3.2 Thermal IR:

** **TIR measures the brightness temperature from the surface or cloud.**

COLD=CLOUD
WARM=WATER or ICE

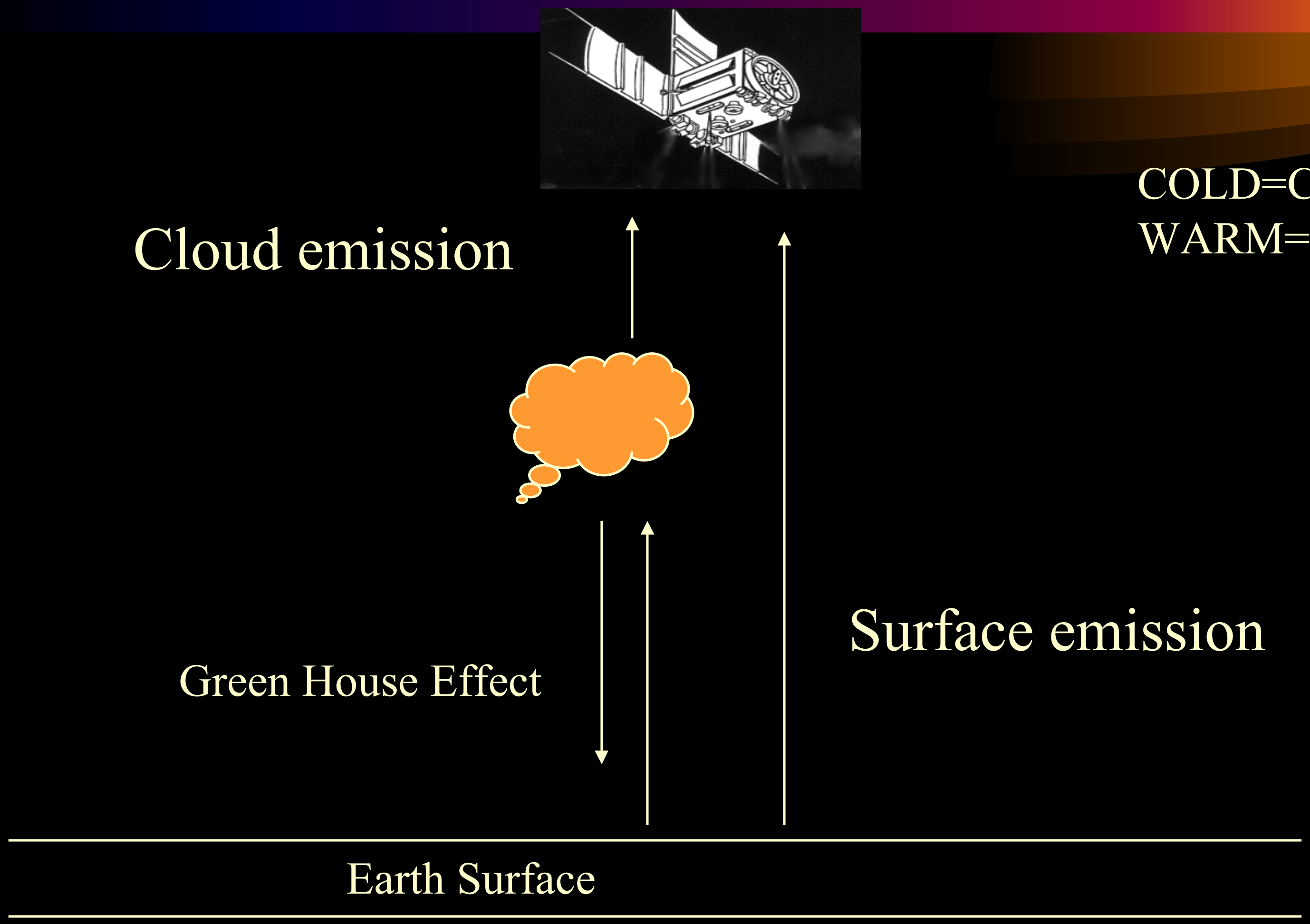


Fig.10 Schematic show earth/cloud emission process.

An Example of Classification Criterion taken form Simpson and Keller (1995)

Number	Criterion	*Threshold*	*Classification*
1	a_1	> 11%	Sea ice or cloud
		< 11%	Cloud-free ocean
2	a_2	> 10%	Sea ice or cloud
		< 10%	Cloud-free ocean
3	a_2/a_1	> 0.82	Cloud
		< 0.82	Sea ice or cloud-free ocean
4	T_3-T_4	> 3.5^0C	Cloud
		< 3.5^0C	Sea ice or cloud-free ocean
5	L_3 - $L_3(T_5)$	> 0.0022W/sr	Cloud
		< 0.0022W/sr	Sea ice or cloud-free ocean
6	T_4-T_5	> 1^0 C	Cloud
7	T_5	< -6^0C	Cloud
		> -6^0C	Sea ice or cloud-free ocean

V. AVHRR Sea Ice Mapping-Examples

5.1 Arctic case (Simpson and Keller, 1995)

Fuzzy logic concept: Fuzzy logic is an extension to Boolean logic, in which it allows partial 'true' or 'false' instead of only 'true' or 'false' in Boolean logic.

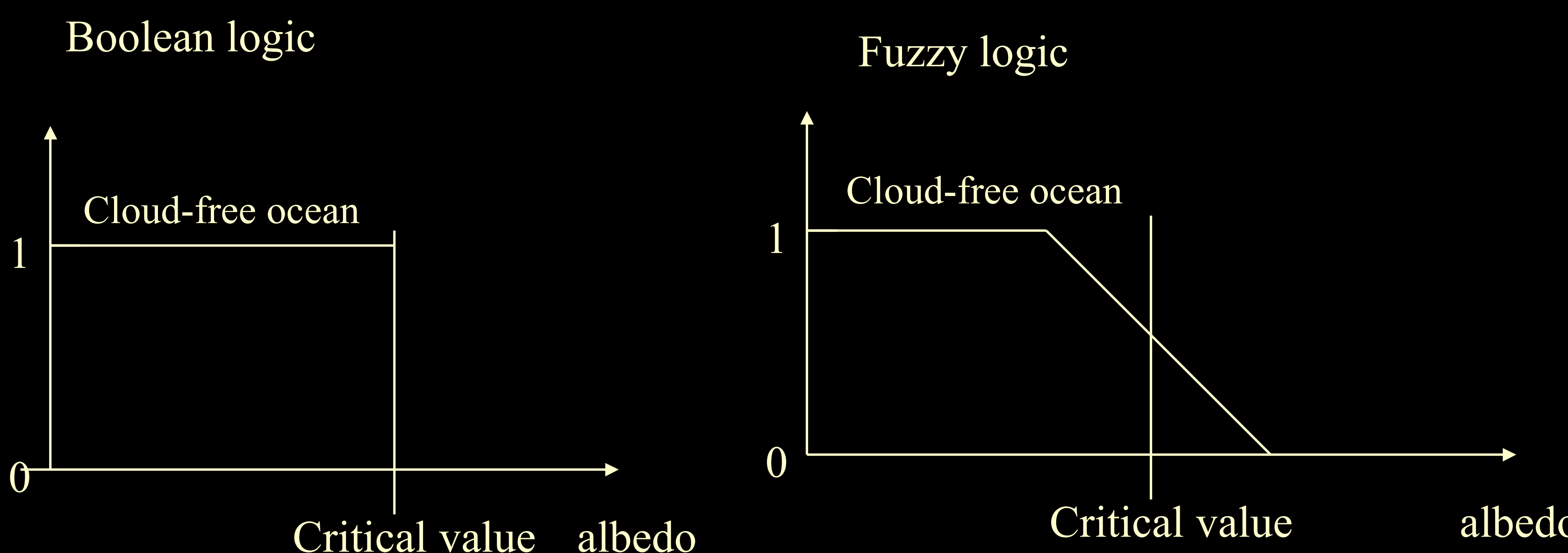
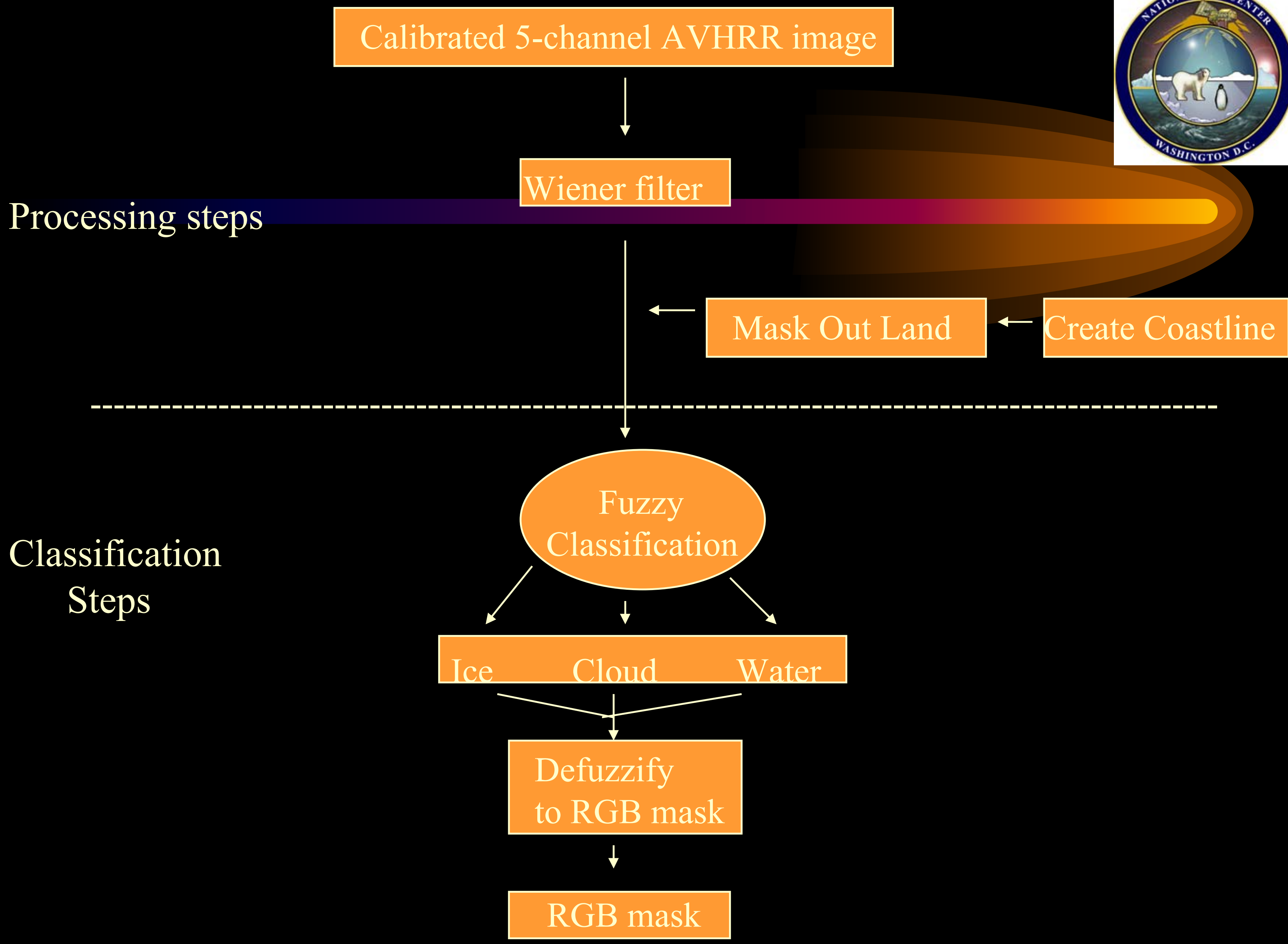


Fig. 11 schematic show fuzzy logic concept


Calibrated 5-channel AVHRR image
Wiener filter
Processing steps
Mask Out Land
Create Coastline
Fuzzy Classification
Classification Steps
Ice
Cloud
Water
Defuzzify to RGB mask
RGB mask

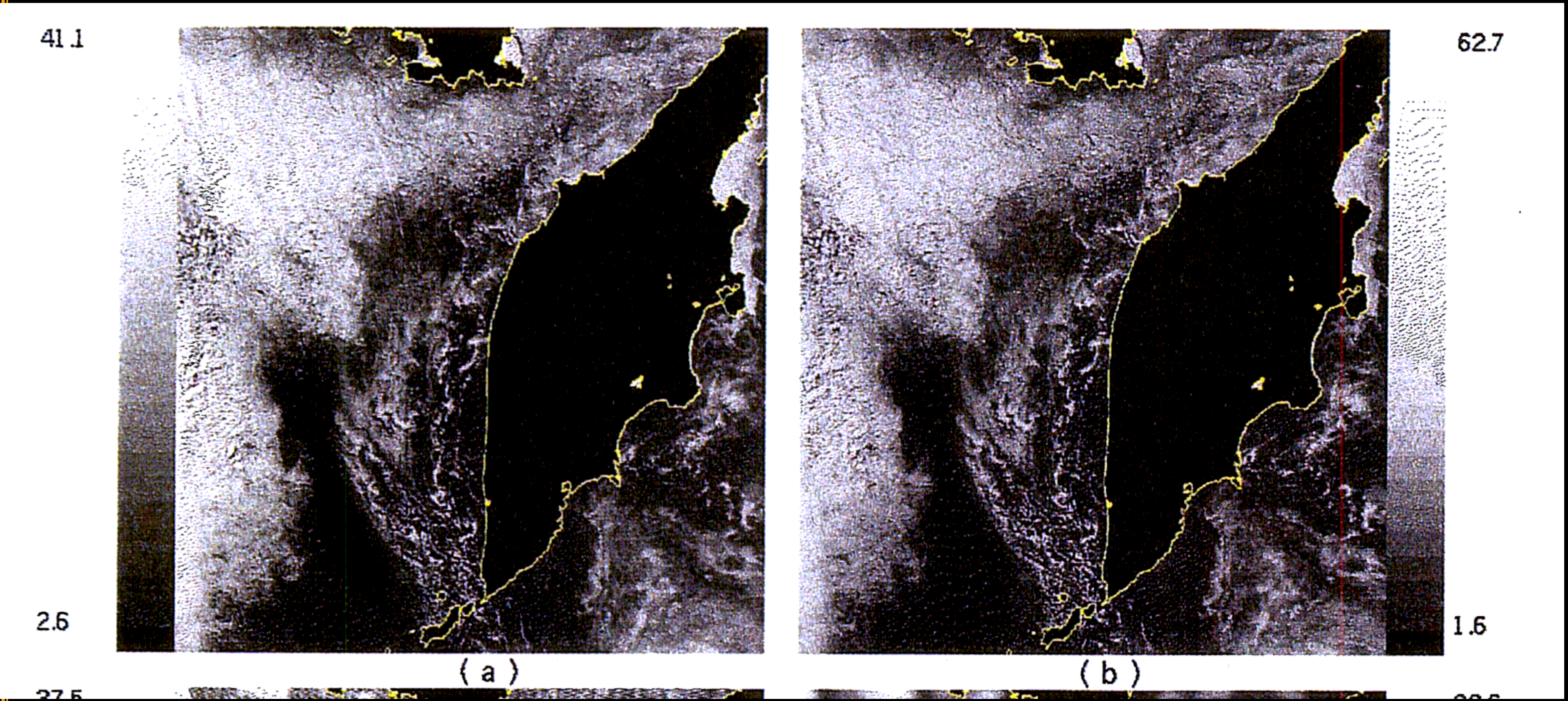


Figure 12. AVHRR image taken on March 31, 1983 by NOAA-7 at local time 14:07:45. Geographic location is Sea of Okhotsk with center latitude/longitude (55^0N, 155^0E) . (a) Channel 1 albedo (%); (b) Channel 2 albedo (%)

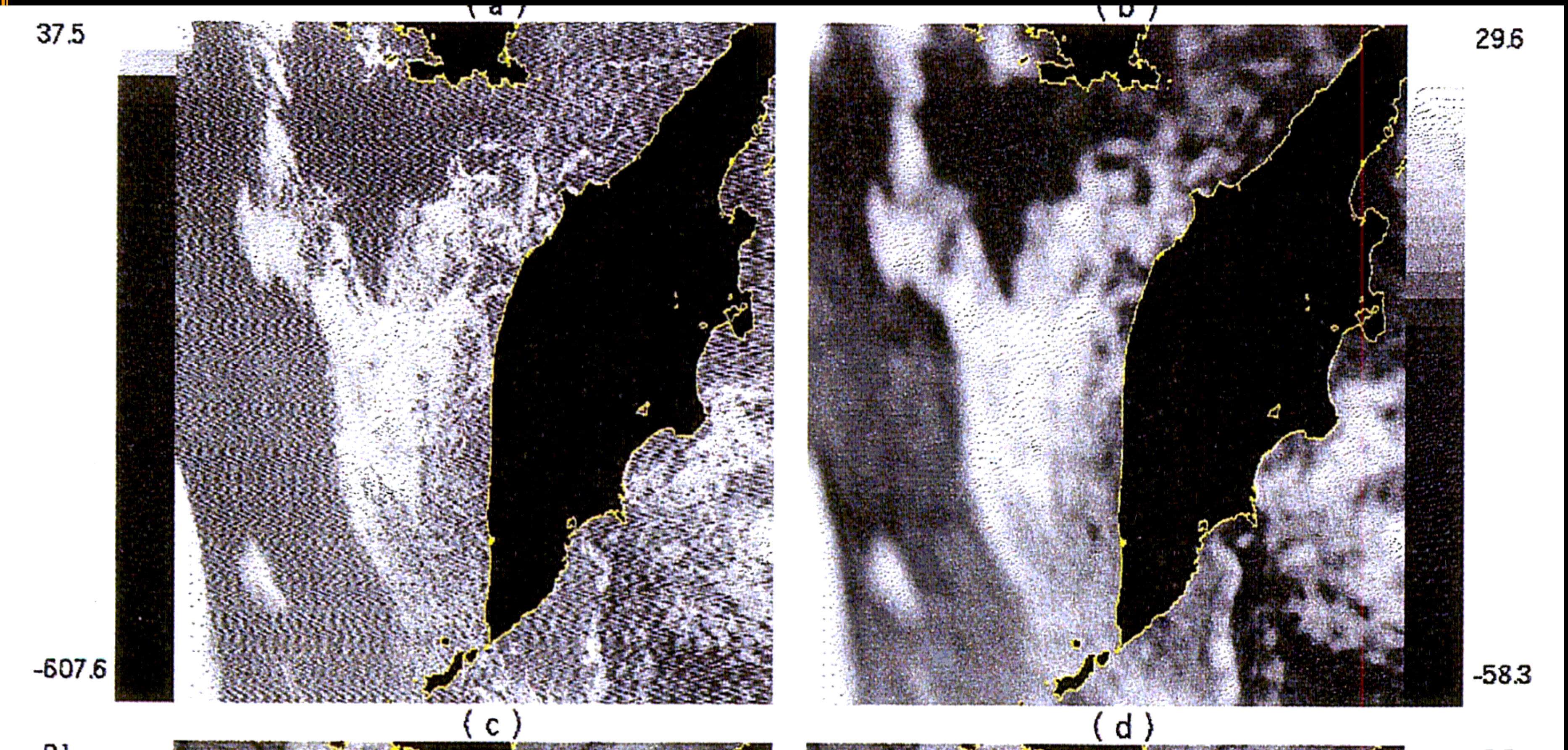


Figure 12-continue: (c) Raw channel 3 brightness temperature (^{0}C); (d) Wiener filtered channel 3 brightness temperature (^{0}C);

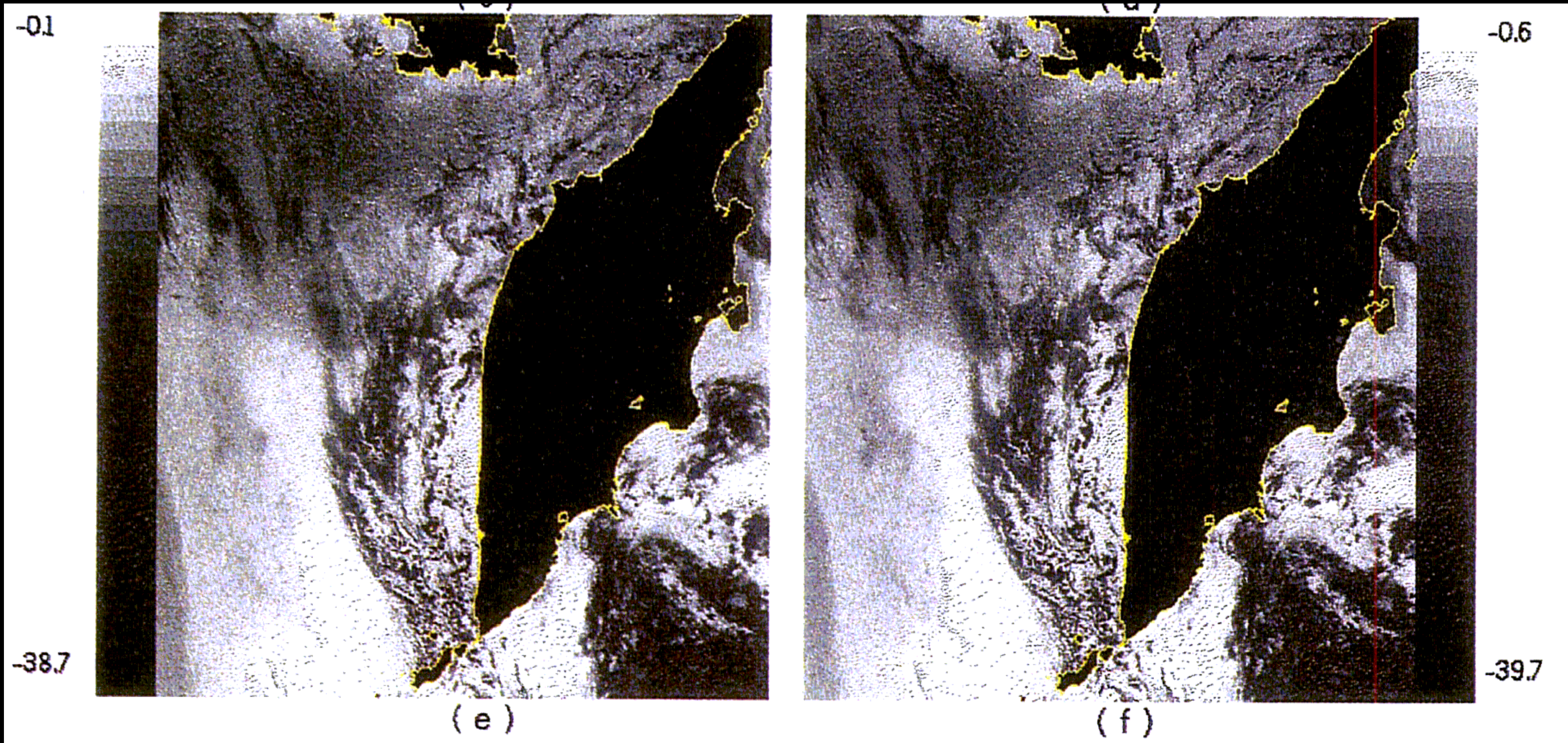


Figure 12-continue: (2) Channel 4 brightness temperature (^{0}C); (f) channel 5 brightness temperature (^{0}C).

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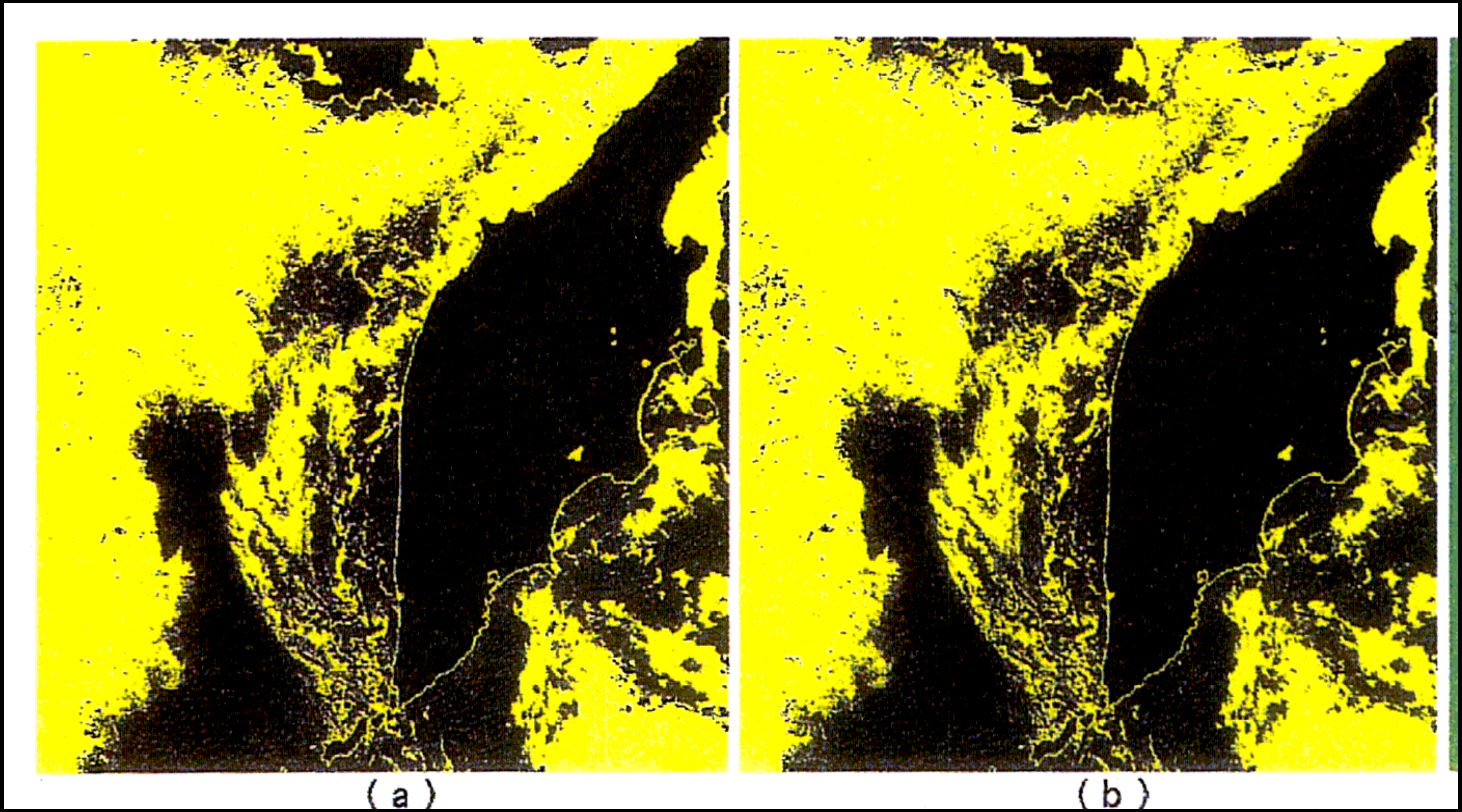


Figure 13. Performance of the criterion in the rule base if used as single static threshold classifier. Red-sea ice; Green-cloud; Blue-cloud-free ocean. (a) Criteria 1, yellow pixels are greater than 11% and would be classified as sea ice or cloud. (b) Criteria 2, yellow pixels greater than 10% albedo for channel 2 would be classified as sea ice or cloud.

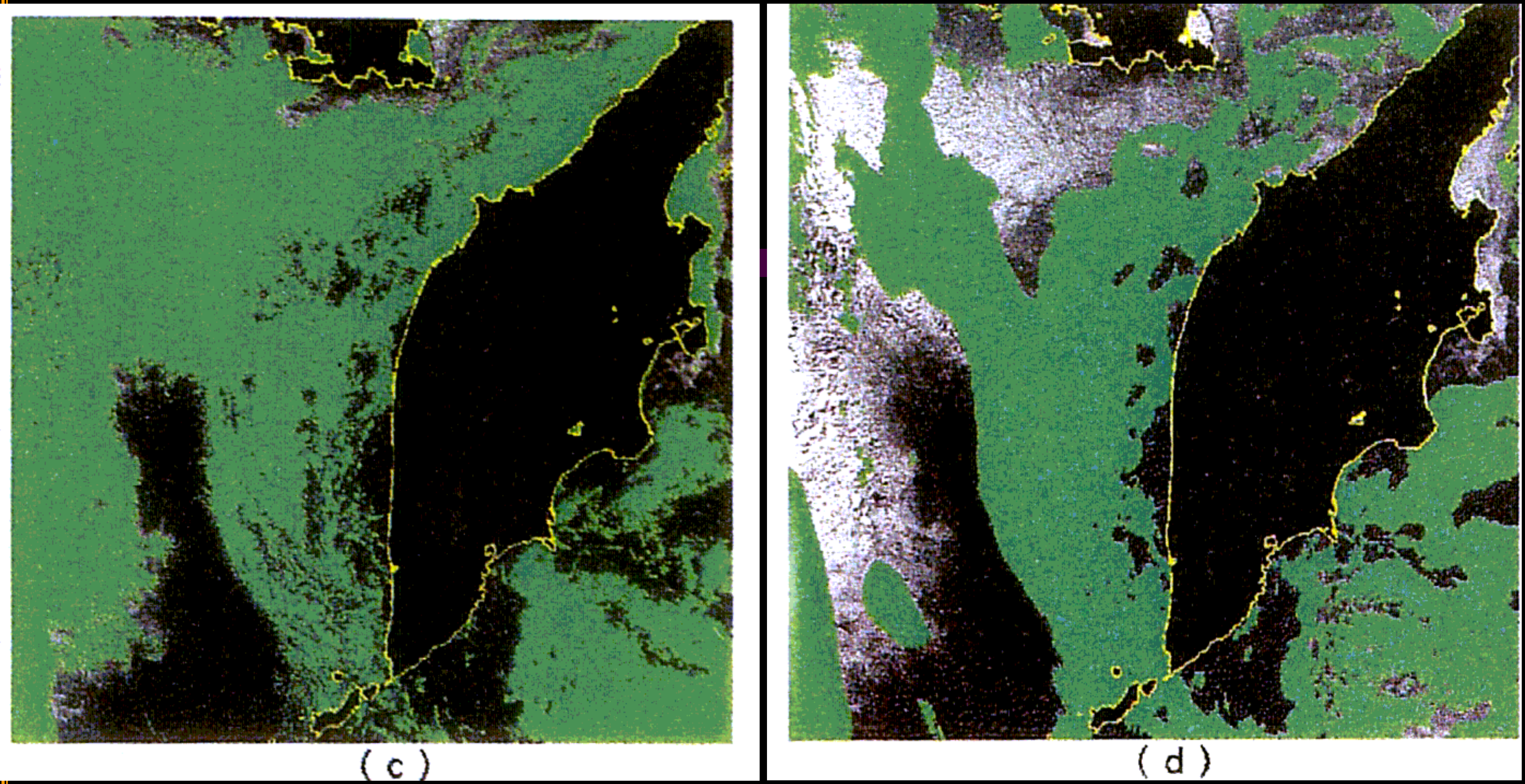


Figure 13-continue: (c) Criteria 3, green pixels have a_2/a_1 albedo ratio greater than 0.82 would be classified as cloud. (d) Criteria 4, green pixels have a T_3-T_4 difference greater than 3.5 ^{0}C would be classified as cloud.

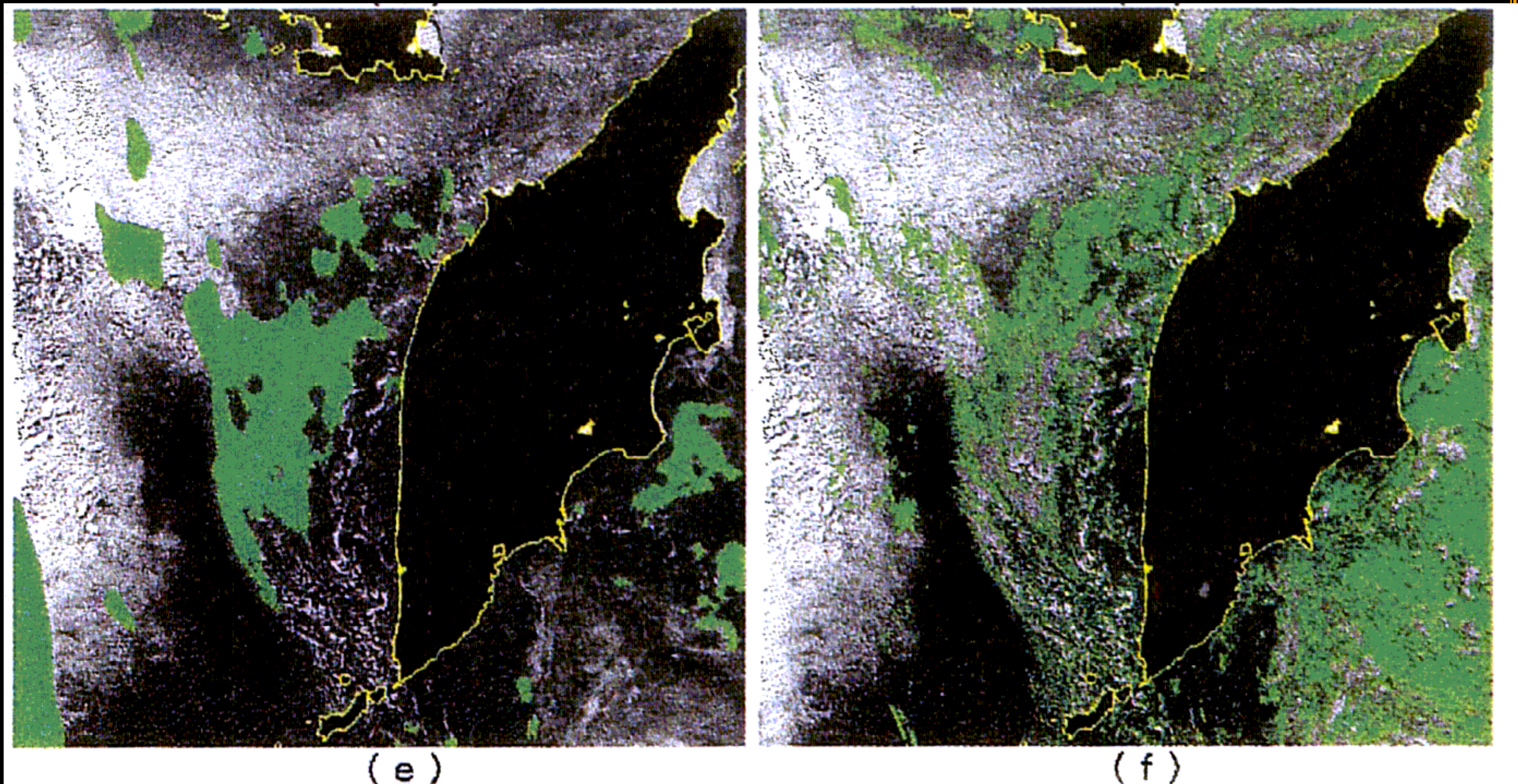


Figure 13-continue:(e) Criteria 5, Green pixels have a solar reflectance greater than 0.0022 W/sr and would be classified as cloud. The solar reflectance was computed using Planck function with a wavenumber argument; (f) Criteria 6, green pixels have a T_4-T_5 temperature difference greater than 1 ^{0}C would be classified as cloud.

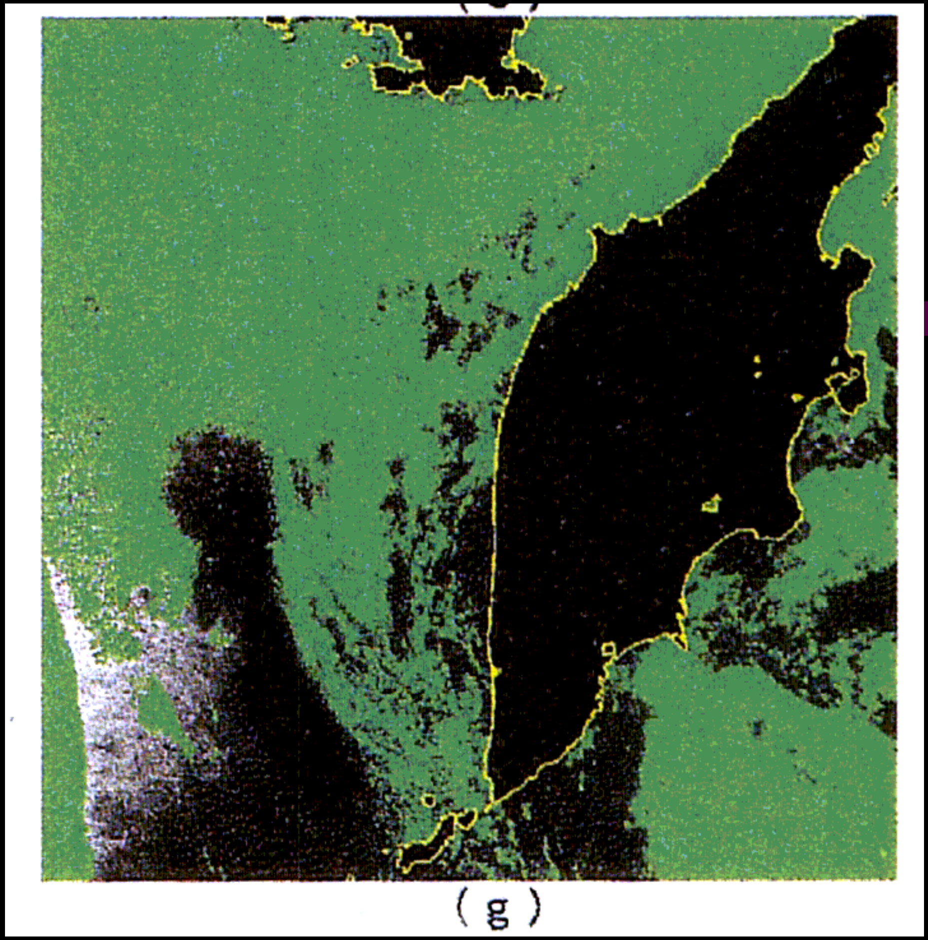


Figure 13-continue: (g) Criteria 7, pixels with T_5<-6 ^{0}C (i.e., colder) would be classified as cloud.

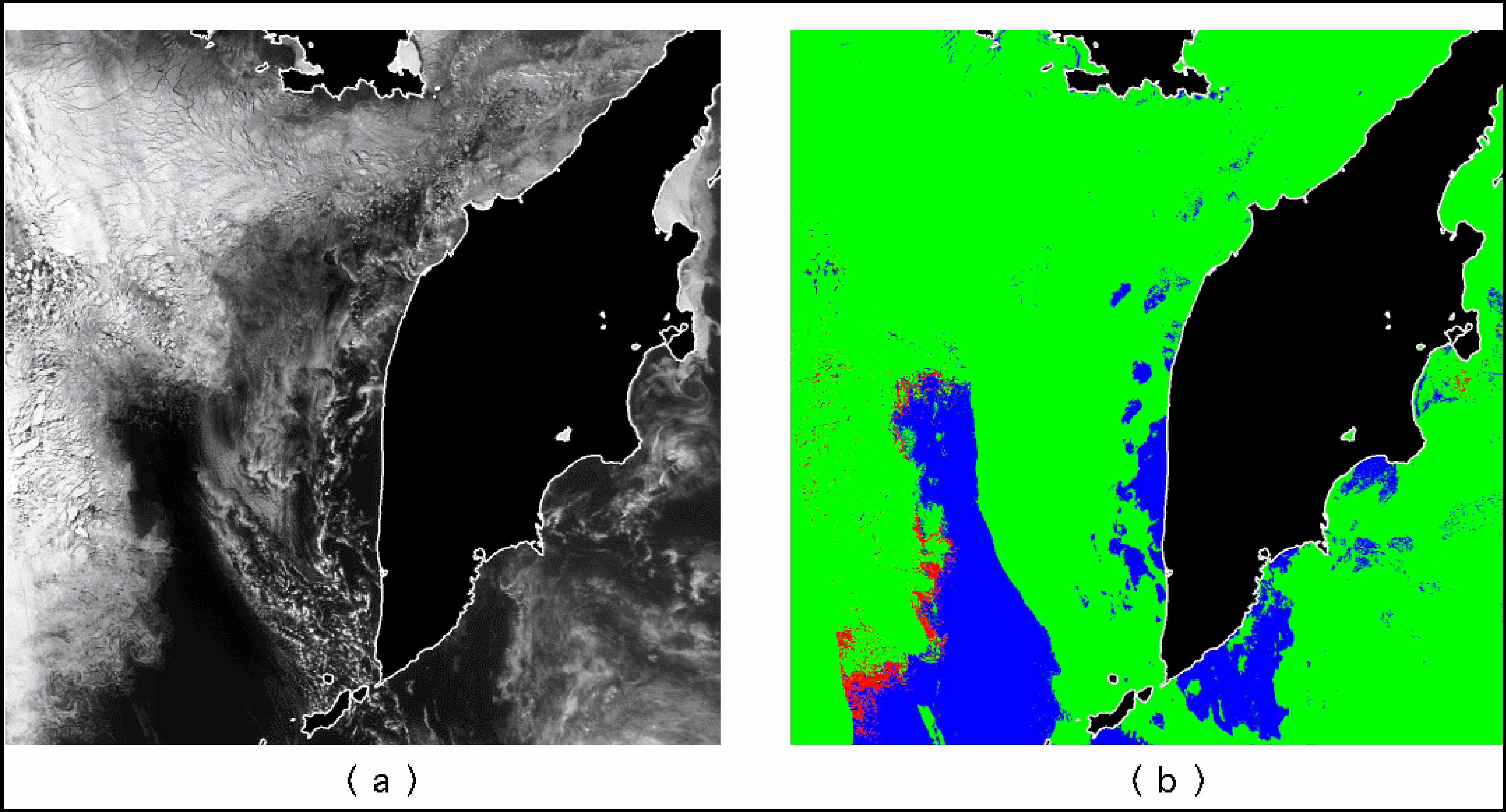


Fig. 14 Performance of the fuzzy logic algorithm as compared with traditional static threshold classification. (a) AVHRR channel 2 data for reference; (b) Traditional static threshold method where if any of criteria 3-7 are true, then the pixel is labeled as cloud, otherwise, if either criteria 1 or 2 is true, then the pixel is labeled as sea-ice. If none of the criteria are met, the pixel is labeled as cloud-free ocean.

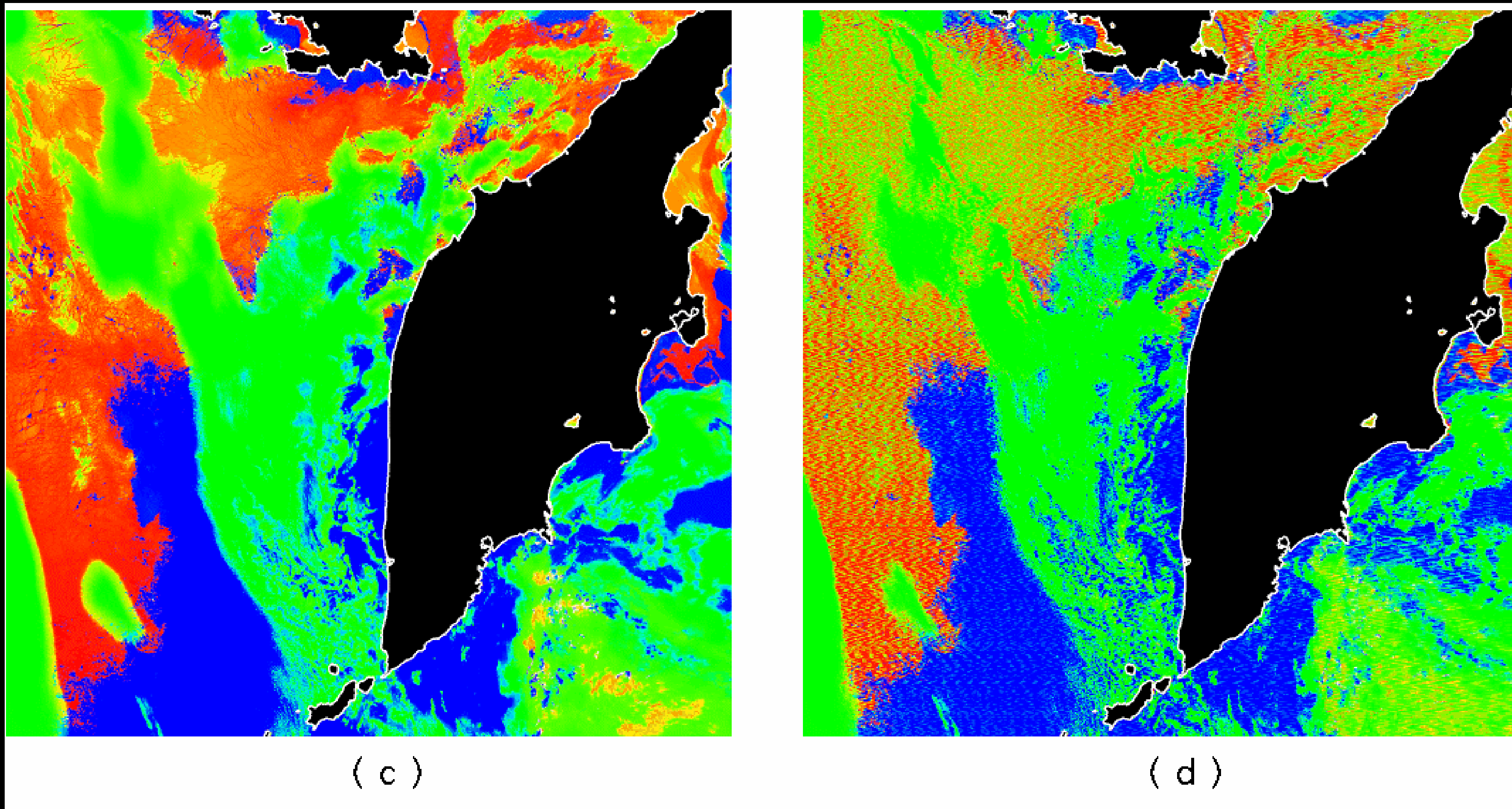


Fig.14-continue: (c) The fuzzy logic red-green-blue (RGB) classification. Red-sea ice; Green-cloud; Blue-cloud-free ocean. Mixture of the three colors represent mixed classes. The result has used Wiener filtered Channel 3 image data; (d) Same as (c) except using raw channel 3 data.

5.2 Antarctic Case-- (Zibordi and Van Woert, 1993)

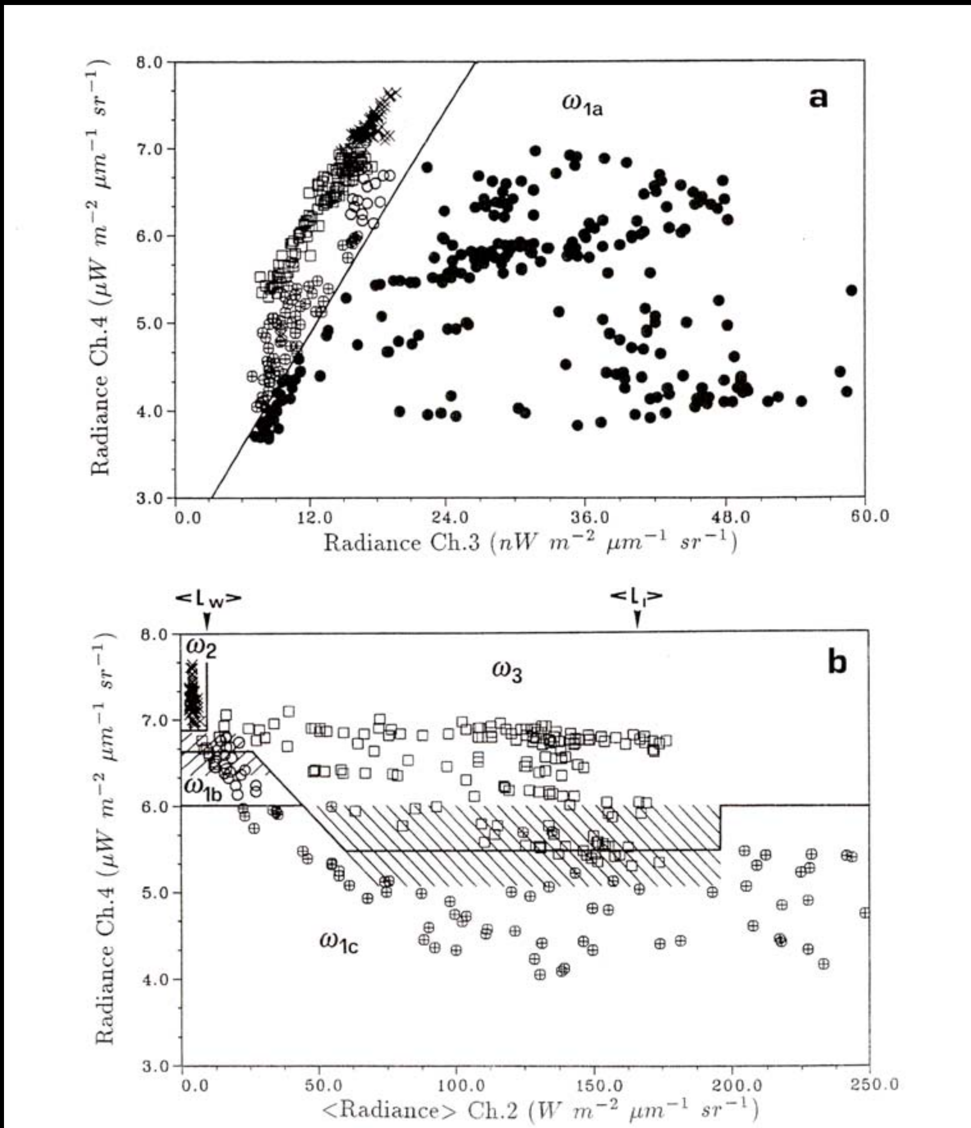
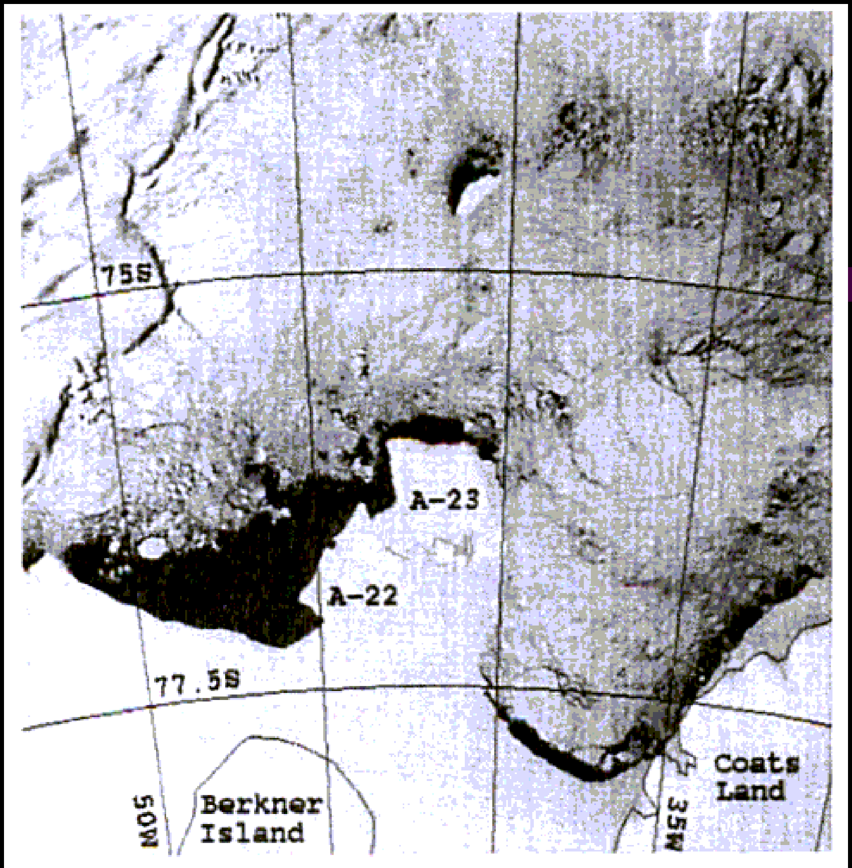


Fig. 15 Scatter plots of: (a) radiance in Channel 4 vs. radiance in Channel 3 and b) radiance in Channel 4 vs normalized radiance in Channel 2 [(•) moist cloud; (o) thin clouds; (⊕) cold clouds; (×) open sea; (□) sea ice]. Straight lines specify the decision regions used in the classification scheme for the different categories (ω_{1a}: moist clouds, ω_{1b}: thin clouds, ω_{1c} cold clouds, ω_2 : open sea, ω_3 : sea ice). Slashed and back-slashed regions indicates the ranges for the thresholds.

(a) AVHHR channel 2 image



(b) Sea ice mapping

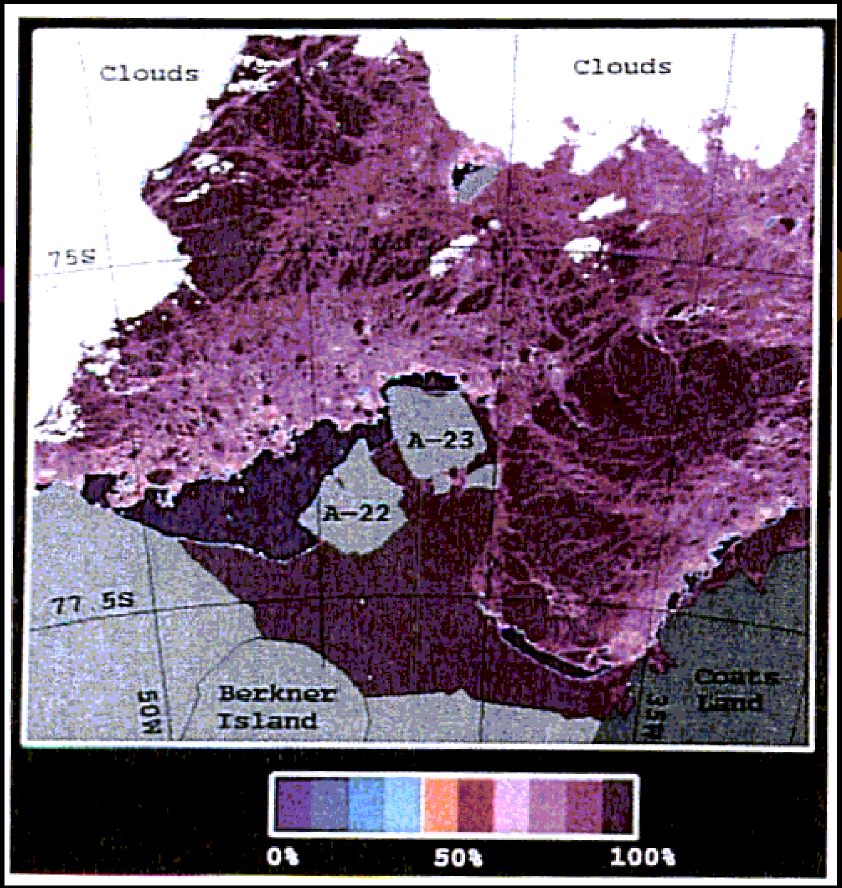


Fig. 15 December 21, 1990 , NOAA-11 AVHRR Channel 2 image (a) and sea ice map (b) for the southern Weddell Sea re-gridded onto a polar stereographic projection. Clouds are masked in white, and land regions are masked in dark gray. The Ronne Ice Shelf, Filchner Ice Shelf, and Icebergs A22 and A23 (names designed by the Navy/NOAA Joint Ice Center) are masked in light gray. Sea Ice concentration is color coded in 10% increments from 0% to 100%. Open sea is shown in navy blue.

(a) AVHRR channel 2 image

(b) Sea ice mapping

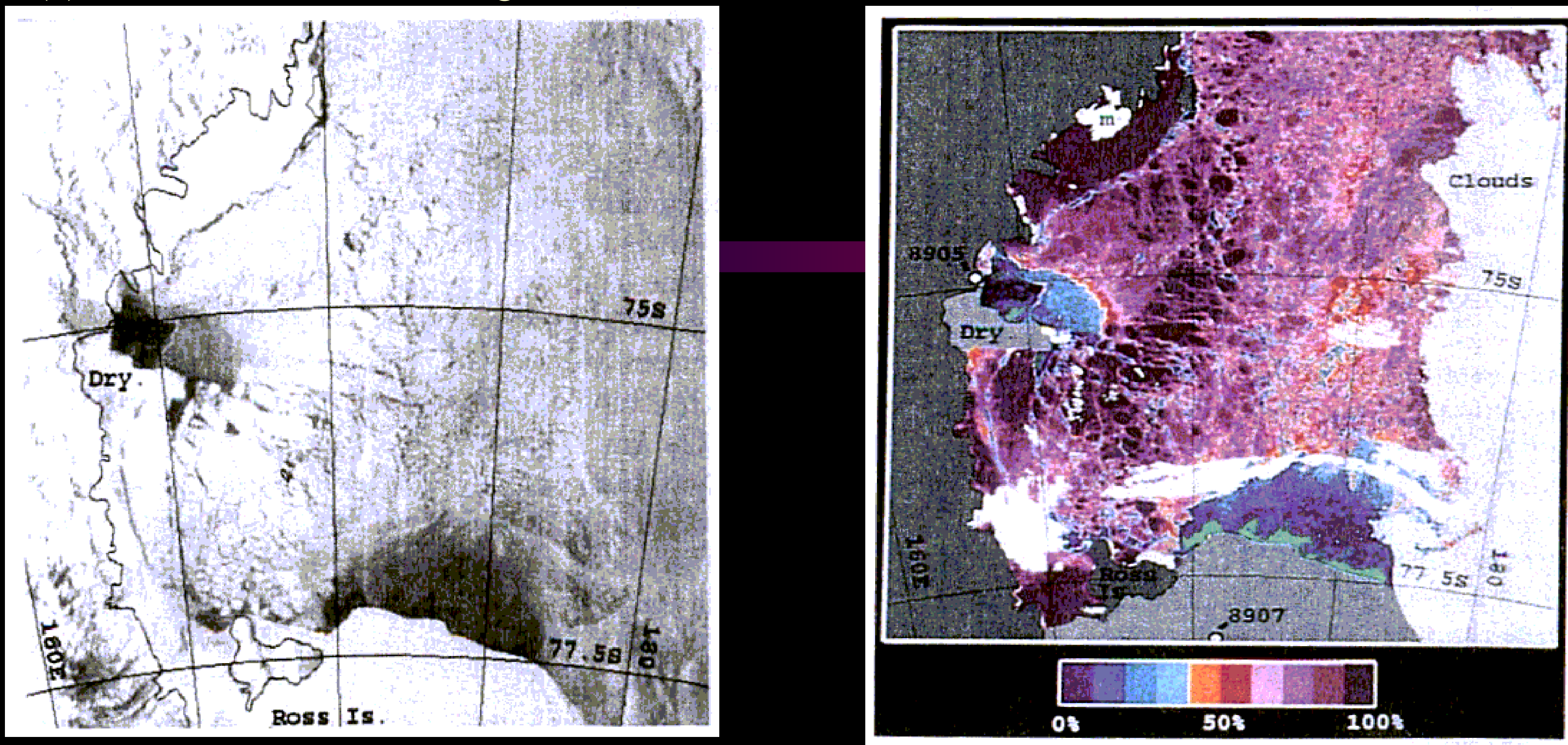


Fig. 16 November 10, 1990, NOAA-11 AVHRR Channel 2 image (a) and sea ice map (b) for the western Ross Sea re-gridded onto a polar stereographic projection. Clouds are masked in white, land is masked in dark gray, and the Ross Ice Shelf and the Drygalsky Ice Tongue are masked in light gray. Sea ice concentration is color coded in 10% increments for 0% to 100 %. Open sea, which occurs mainly in Terra Nova Bay, is shown in Navy blue and green. indicates mixed area.

Refrences:

1. 40 years of NASAEarth Science, @ http://www.earth.nasa.gov/history/tiros/tiros.html
2. *Lecture and Presentation* for the CEO Training Course Sea Ice Monitoring by Satellites, Contract no. 14048-1998-06 F1PC ISP NO, @http://www.nrsc.no/CEO_Training/
3. Simpson, J.J., and R.H. Keller, 1995: An improved Fuzzy logic segmentation of sea ice, clouds, and ocean in remotely sensed Arctic imagery, *Remote Sens. Environ*., 54, 290-312.
4. Burns, B.A.,M.Schmidt-Grottrup, and T. Viehoff, 1992: Methods for digital analysis of AVHRR sea ice images, IEEE Trans. Geosci.Remote Sens.,30,589-602.
5. Zibordi, G., and M.L. Van Woert, 1993: Antarctic sea ice mapping using the AVHRR, *Remote Sens. Environ*., 45, 155-163.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