Radiative Transfer, Satellite Retrieval Systems and Other Stuff

or

What Have I Been Doing for the Last 35 Years

Thomas J. Kleespies

Acknowledgment

Thanks to Steve English and Alan Huang and the ITWG for travel support.

Education

- BS Atmospheric Sciences, University of Washington, 1974
- MS Atmospheric Science, Colorado State University, 1977
- PhD Meteorology, University of Utah, 1994
  - This gave me pause

Work Experience

- 1977-1978 Systems and Applied Sciences Corporation, Scientific Programmer, Ozone Processing Team GSFC
- 1978-1984 Naval Environmental Prediction Research Facility, Monterey CA, Research Meteorologist
- 1984-1993 Air Force Geophysics Laboratory, Bedford MA, Research Meteorologist
- 1993-2010 NOAA/NESDIS, Physical Scientist

SASC

- Scientific Programmer
- Scribe for Ozone Processing Team
- Discovered the Ozone Hole

Naval Environmental Prediction Research Facility

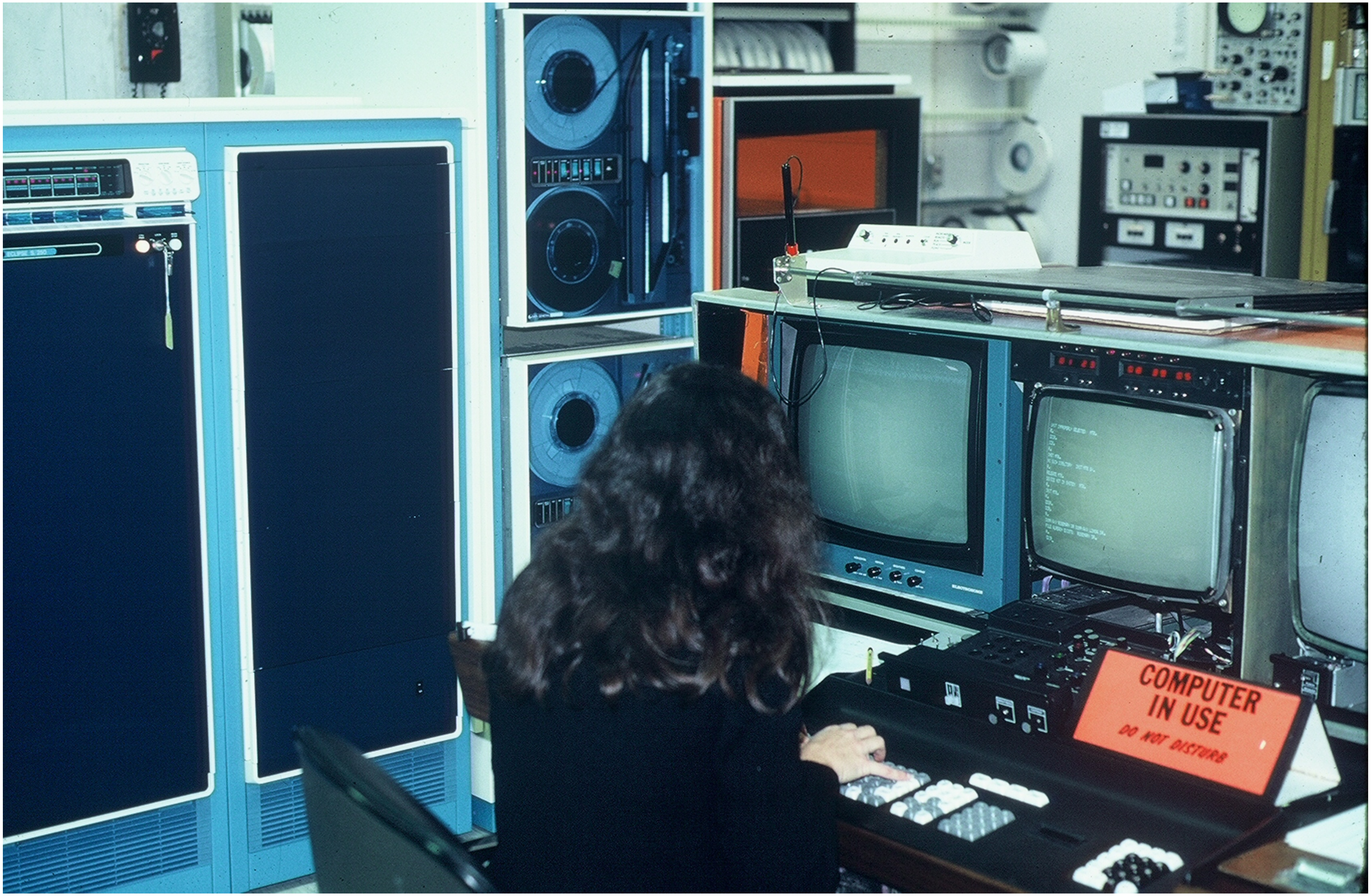
- Now NRL Monterey

First Tasks

- Care and feeding of Chahine retrieval
- DMSP SSH/2 Infrared Sounder
- Six channels (747, 725, 708, 695, 676, 668.5 cm-1) in the 15-micrometer CO2 absorption band, and eight channels (535, 408.5, 441.5, 420, 374, 397.5, 355, 353.5 cm-1) in the 22- to 30-micrometer rotational water vapor absorption band.

Satellite Processing and Display System

- Worked on ingesting GOES Mode AA data
- VAS sounding and multispectral imaging
- Developed Smith Iterative Sounding System


ECLIPSE S/250
COMPUTER
IN USE
DO NOT DISTURB

AVON
59931
$3.95

1982 PULITZER PRIZE-WINNER

THE PHENOMENAL BESTSELLER!

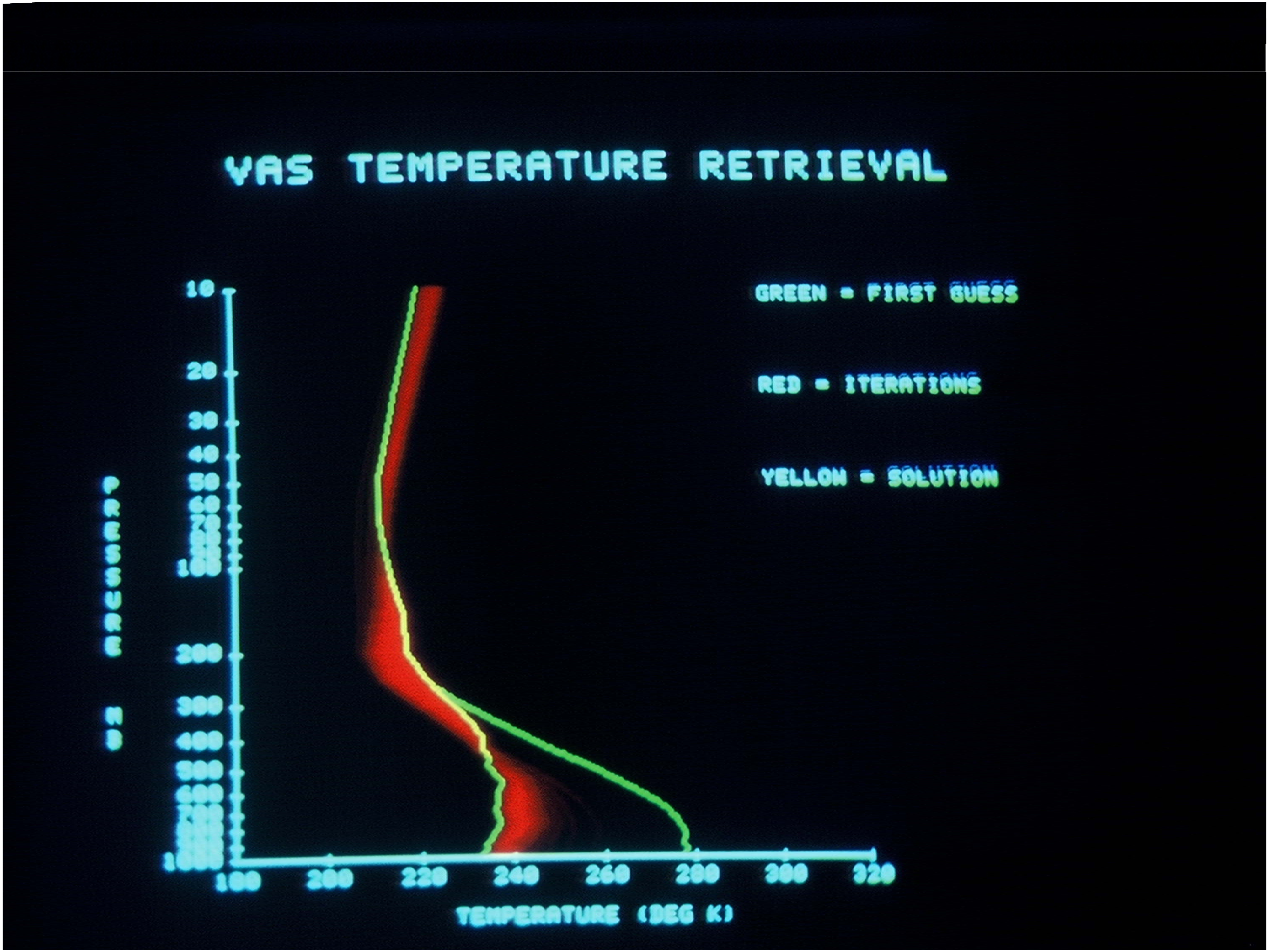
THE SOUL OF A NEW MACHINE

TRACY KIDDER

"BRINGS TO LIFE NOT ONLY HOW COMPUTERS WORK AND THE TECHNOLOGY REQUIRED TO DEVISE ONE...BUT ALSO THE HUMAN DRAMA."
THE NEW YORK TIMES

How did we program back then?

- Punch cards and tape


VAS TEMPERATURE RETRIEVAL
GREEN = FIRST GUESS
RED = ITERATIONS
YELLOW = SOLUTION
PRESSURE MB
10
20
30
40
50
200
300
400
200
220
240
260
280
300
320
TEMPERATURE (DEG K)

Cloud Tracking

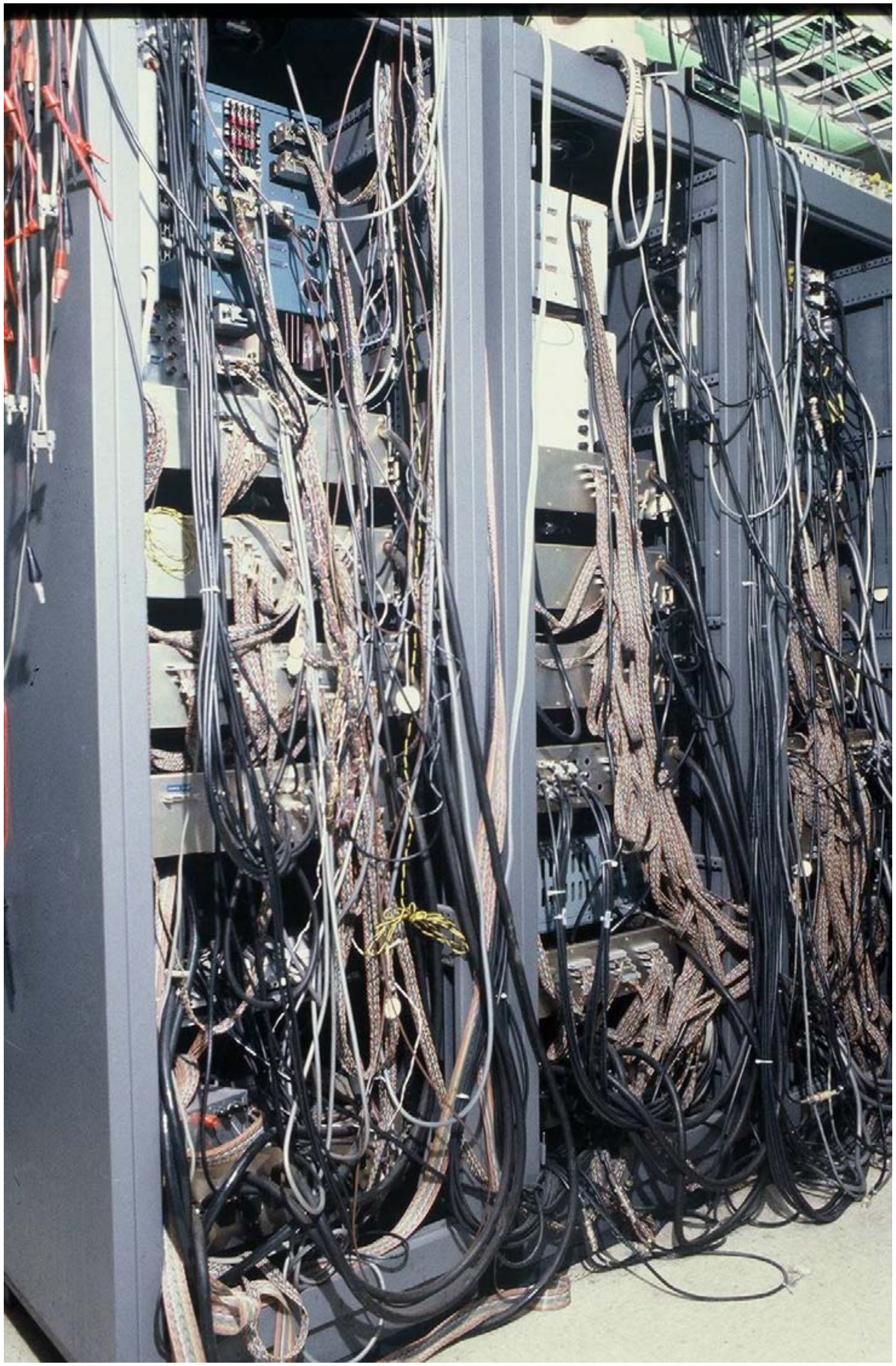
- Cross-covariance algorithm
- Tried it on water vapor imagery
  - basically got the same results as IR imagery
  - algorithm was tracking the clouds imbedded in the wv imagery

Air Force Geophysics Laboratory

- Hanscom AFB, Bedford MA
- Originally Air Force Cambridge Research Laboratory
- Then Geophysics Laboratory
- Then Phillips Laboratory, Geophysics Directorate
- Now Air Force Research Laboratory
- Moving to Wright-Patterson in 2011

McIDAS

- SN 2 McIDAS, SN1 cpu



McIDAS Upgrade Development

- Motto: "Our Name Is MUD"
- After playing acronym soup, I came up with "Air Force Interactive Meteorological System" AIMS
- Motto: "We AIMS to please"

Components

- GOES direct readout ground system
- Gould SEL real time ingest computer
- DEC VAX systems driving Adage image processors

NOAA also using Gould SEL computers for their ingest.

I exercised an option on the NOAA contract with Integral Systems for a frame synch and MIPR'ed the money over to Bill Mazur.
Easiest procurement I ever did.


GOULD
GOULD
32/27

Ground Station

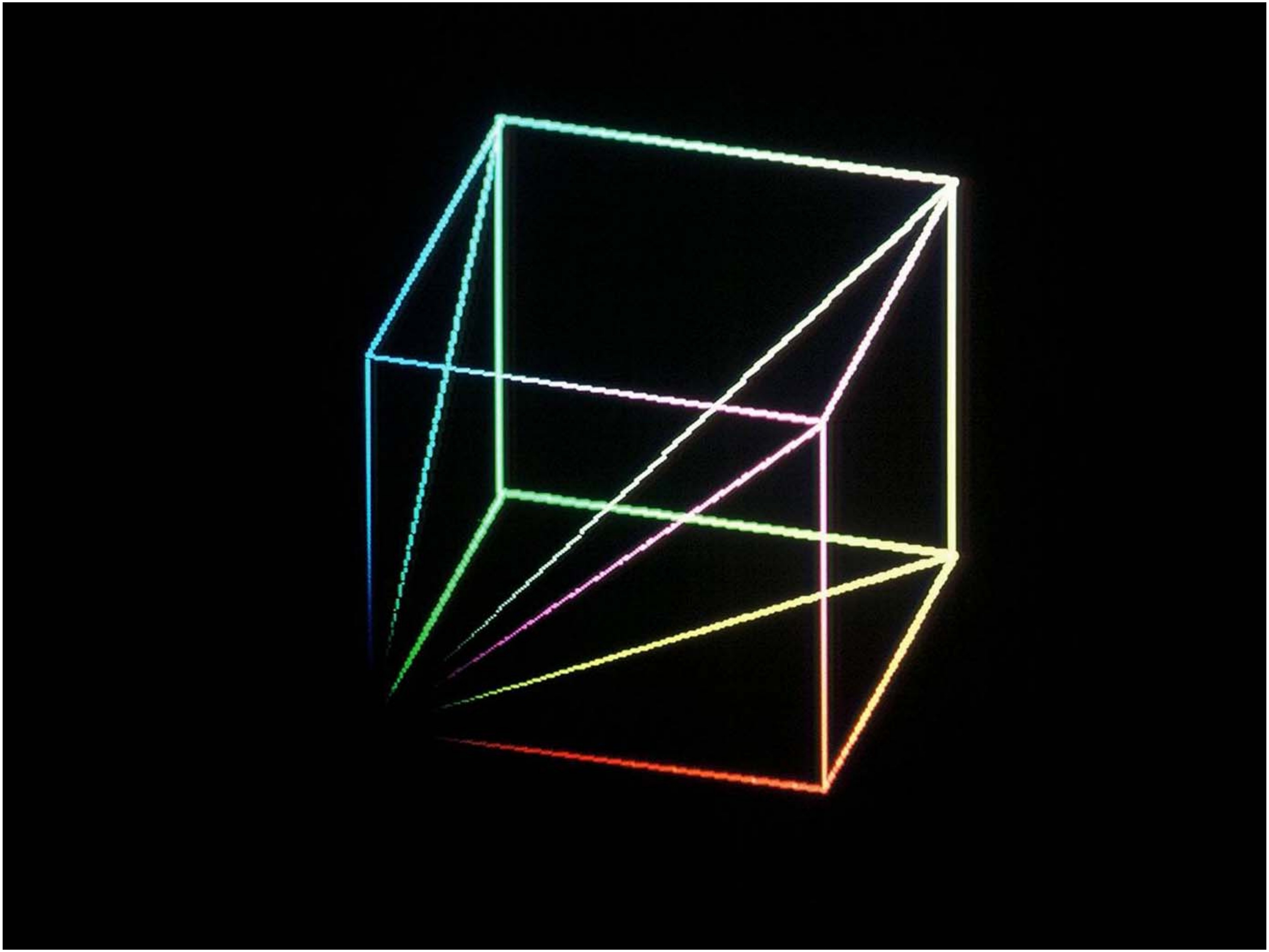
- I wrote the code on the Gould to ingest the Mode AAA data for VAS multispectral imagery
- I wrote code on the VAX to talk with the Gould and have the Gould extract an image sector from the ingest sector and pass it out to the VAX. The map overlay was generated at this time and passed out. Navigation info was inserted into the first line of the image.
- I had one systems programmer to get the Gould to talk with the ground system

Image management

- We could select multiple 512x512 sectors to extract based upon a central lat-lon
- These went into a rotating database where the last 24 hours were kept for all sectors and all channels (typically 4 or 5).
- It was easy for a user to grab any of these for archive purposes.

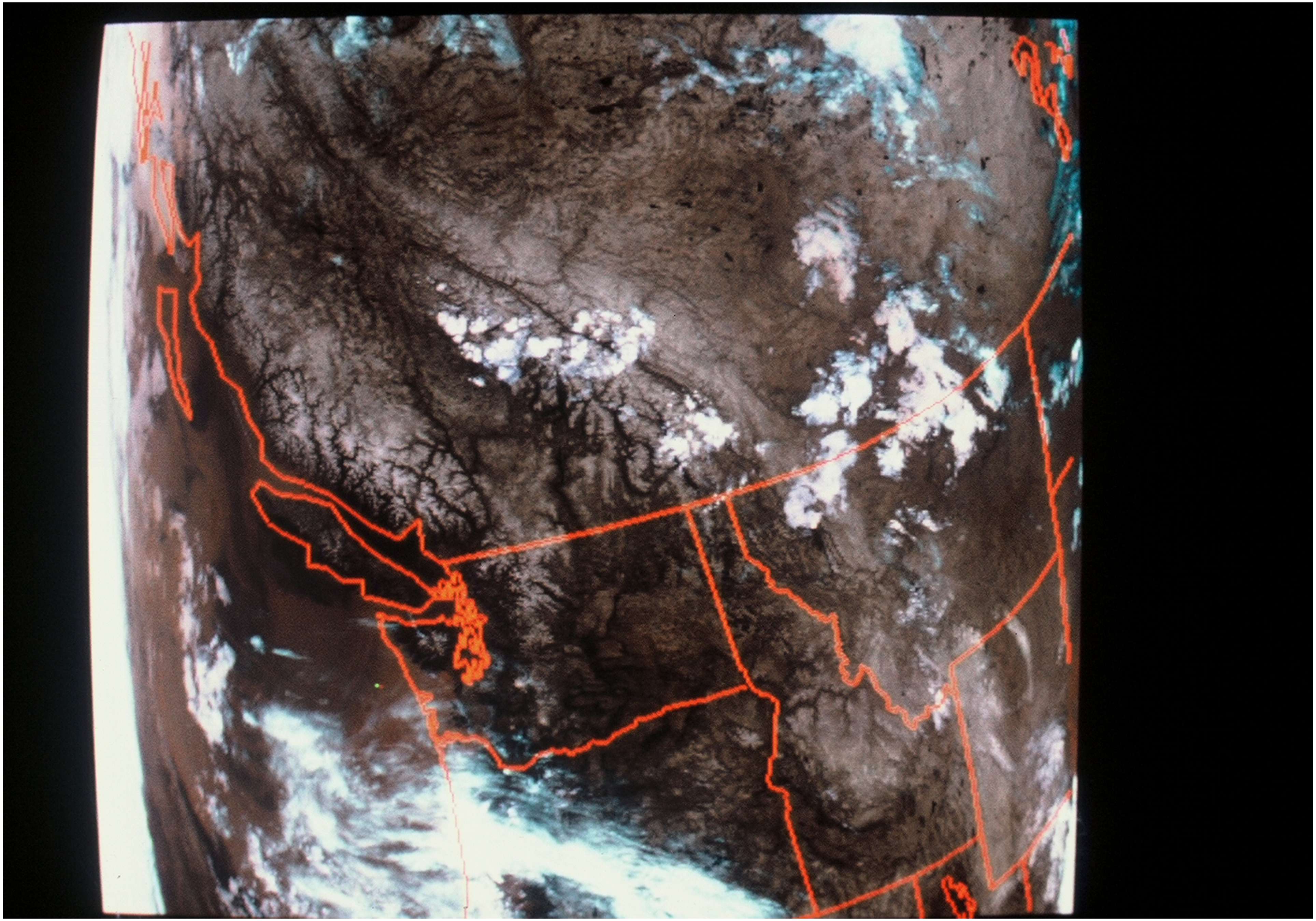
Adage Image Processor

- 1024x1024 full color display
- 32 bits deep
- nominally 8 bits each RGBα
- crossbar switch permitted arbitrary allocation of bits



Multispectral Imagery

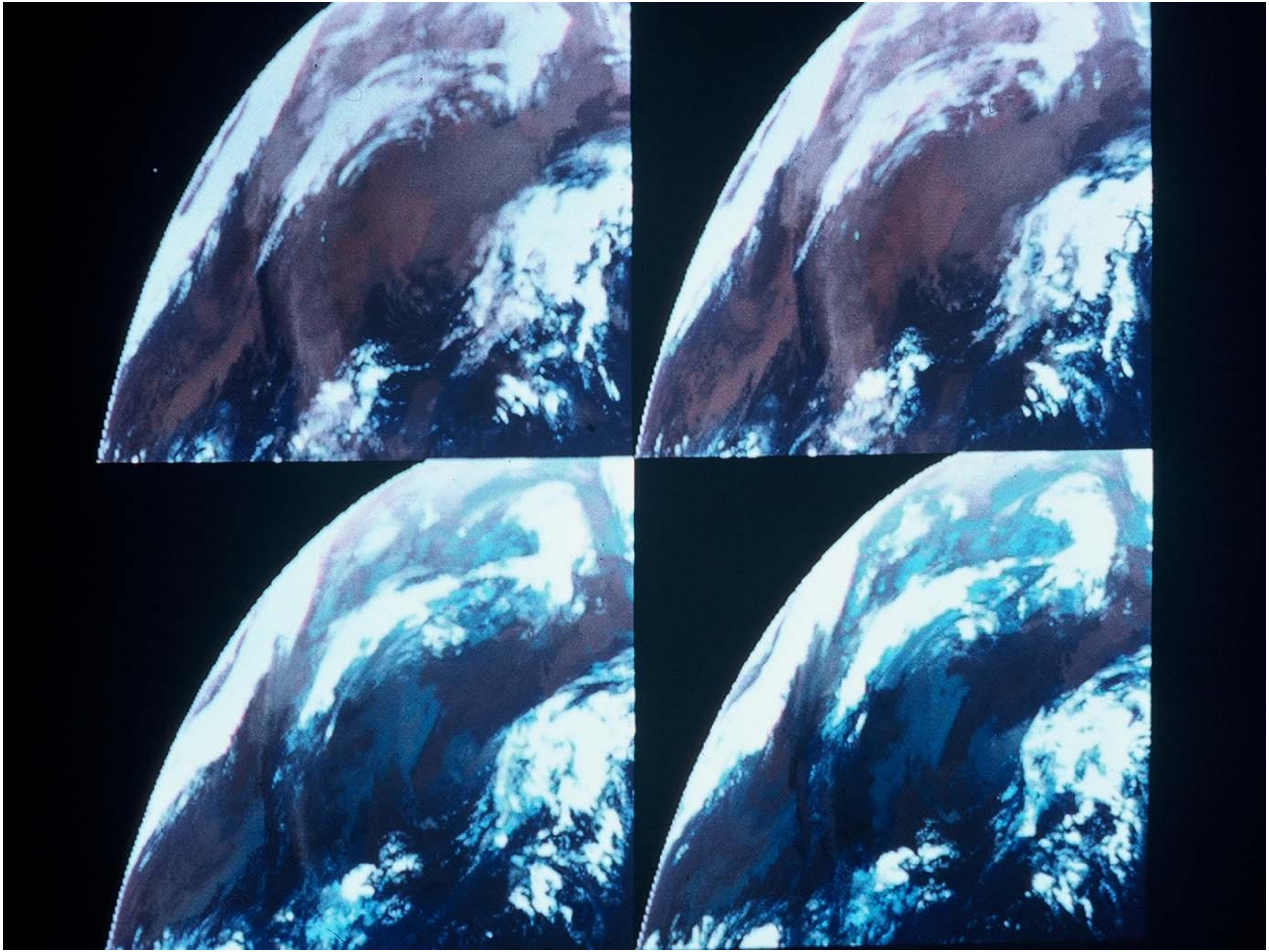
- Use different channels to drive different colors



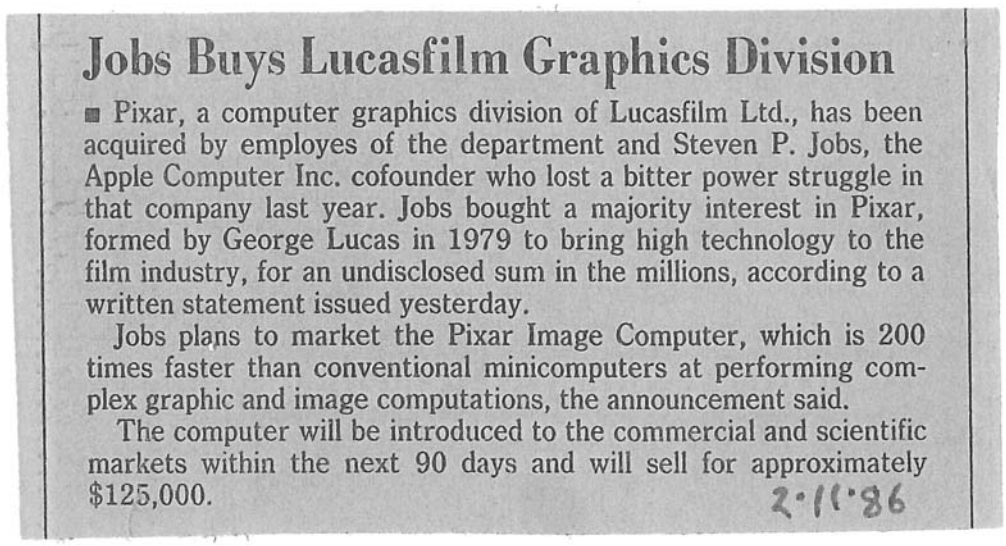
AVHRR 11, 12, 3.7 micrometer

Clouds not black body in near IR

- Following uses 11μm red, 12 μm green, 3.9 μm blue
- sequence ul,ur,ll,lr as sun illuminates the scene
- Dark hot, bright cold
- ul, clear ground relatively bright because cold. Low stratus redish because cold in 3.9 (not as emissive as 11&12)
- lr clear ground dark, hot. Low stratus blue because hotter at 3.9 than 11&12 (more reflective)
- This observation became the basis of my dissertation



Thinking to upgrade from ADAGE, we looked at the Pixar Imaging Computer, but balked at the $125K price tag.



Jobs Buys Lucasfilm Graphics Division

■ Pixar, a computer graphics division of Lucasfilm Ltd., has been acquired by employes of the department and Steven P. Jobs, the Apple Computer Inc. cofounder who lost a bitter power struggle in that company last year. Jobs bought a majority interest in Pixar, formed by George Lucas in 1979 to bring high technology to the film industry, for an undisclosed sum in the millions, according to a written statement issued yesterday.

Jobs plans to market the Pixar Image Computer, which is 200 times faster than conventional minicomputers at performing complex graphic and image computations, the announcement said.

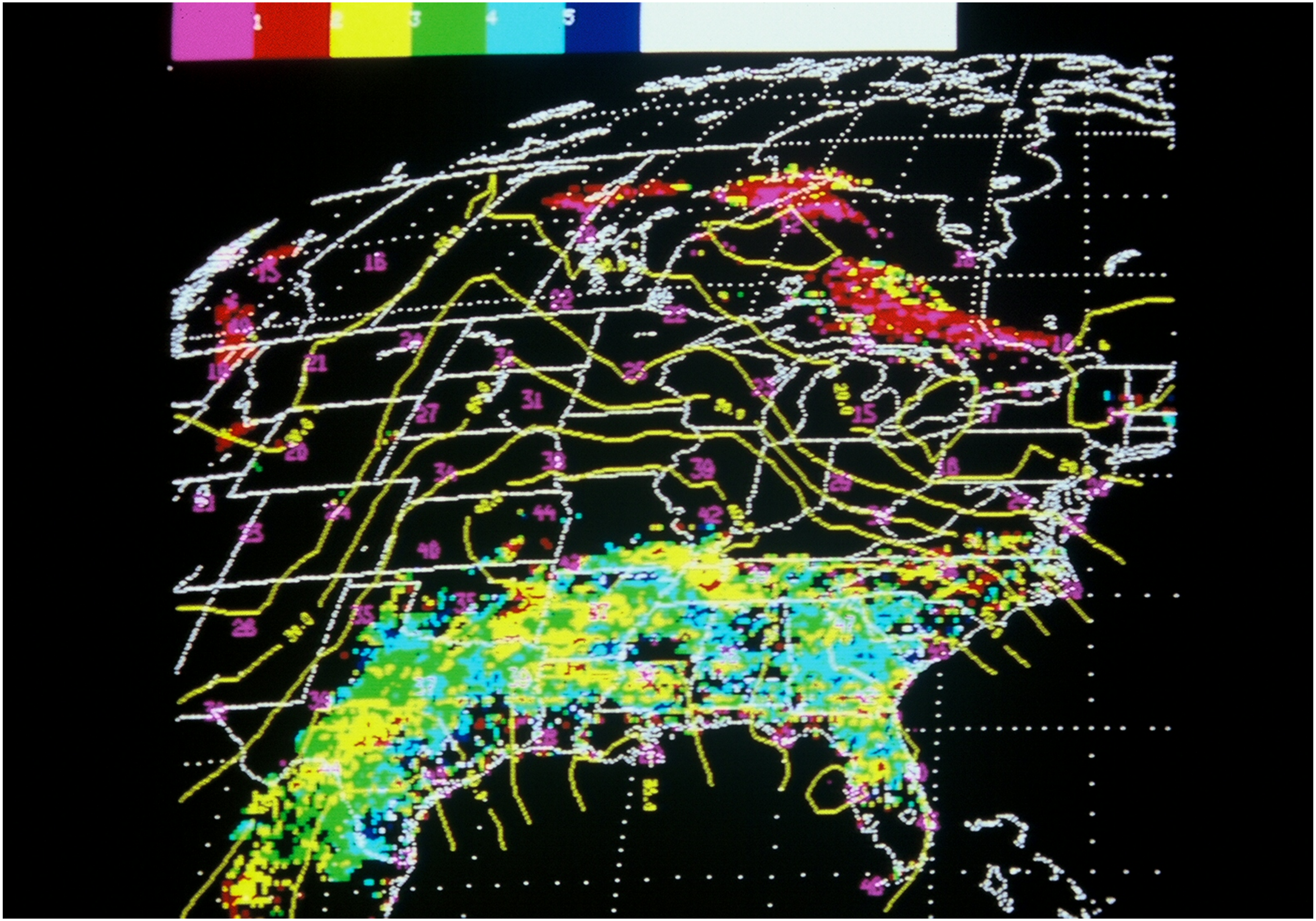
The computer will be introduced to the commercial and scientific markets within the next 90 days and will sell for approximately $125,000.

2·11·86

Pixar started out has a hardware company. With the development of Renderman, they became a software company, then a movie making company.

McMillin Collaboration

- Larry McMillin approached me at ITSC-1
- He knew I had access to direct readout GOES data
- Proposed a collaboration to come up with a new way to get precipitable water from the split window using temporal variation
- Of course this only works in clear air


1
2
3
4
5

Retrieval of Precipitable Water from Observations in the Split Window over Varying Surface Temperatures

THOMAS J. KLEESPIES

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LARRY M. MCMILLIN

National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, Washington D.C.

(Manuscript received 27 August 1989, in final form 4 April 1990)

ABSTRACT

The split window technique makes use of two differentially absorbing channels in the 11 μm region to remove the attenuating effects of atmospheric absorption so as to achieve a better estimate of the underlying skin temperature than could be produced by a single channel measurement. Since the primary absorber in this region is water vapor, it follows that split window measurements should be able to produce bulk water vapor retrievals as well. When observations are made with split window channels under conditions where the surface contribution to measured radiance changes, but the atmospheric contribution does not, it is possible to estimate the ratio of the transmittance of the two split window channels. This transmittance ratio is inversely related to precipitable water. This paper applies this technique to observations from the Advanced Very High Resolution Radiometer, and the VISSR Atmospheric Sounder, and demonstrates the capability of both instruments to determine precipitable water under two different operational scenarios.

Dissertation

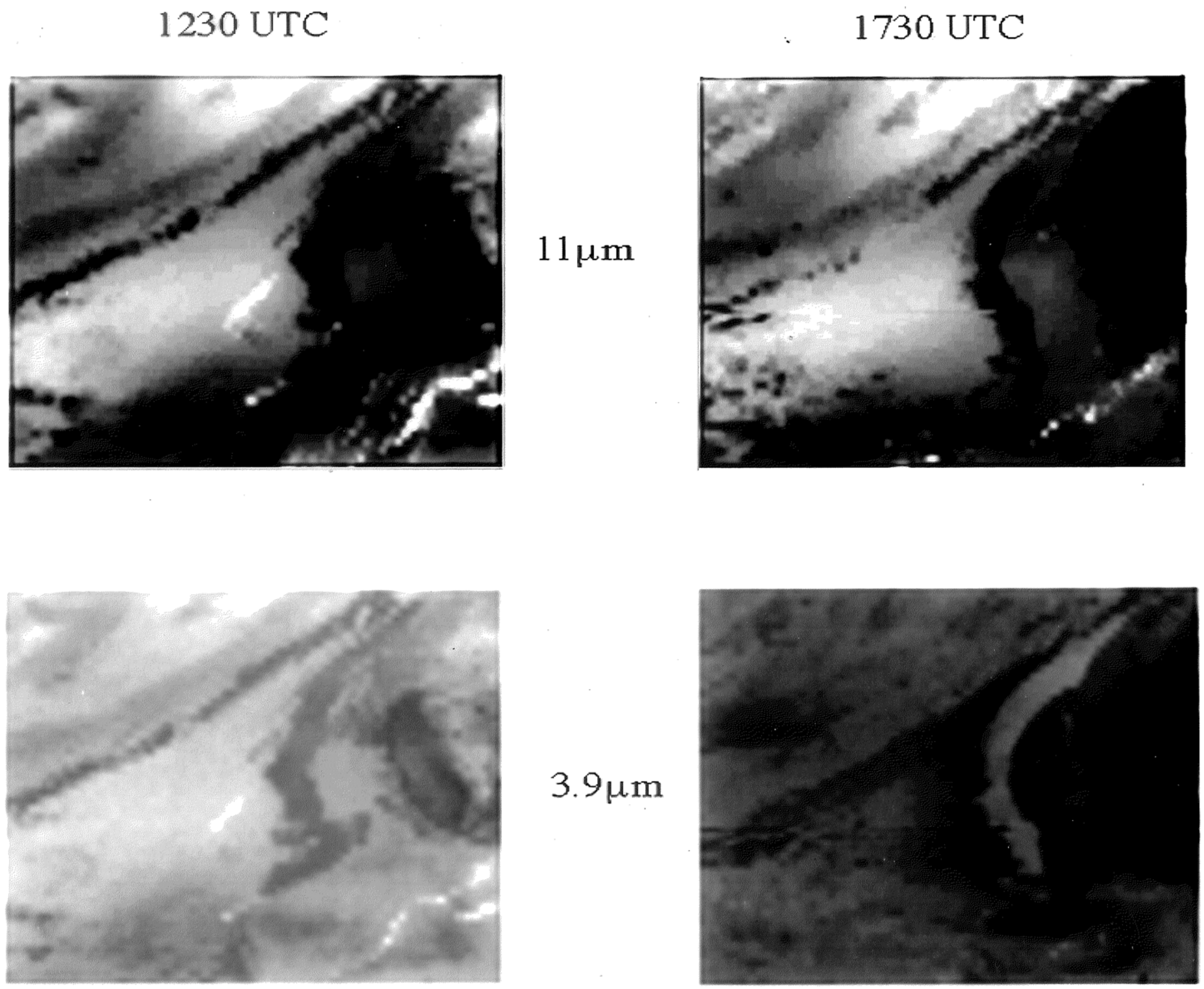
- Air Force Long Term Full Time Training
- Up to a year of study at your favorite institution
- Took some convincing to show that I could go out of town
- Studied under K-N Liou at U Utah
- Recommend this highly: Get your employer to send you to school and go on salary

Retrieval of Marine Stratiform Cloud Parameters by Multiple Observations in the 3.9 μm Window Under Conditions of Varying Solar Illumination

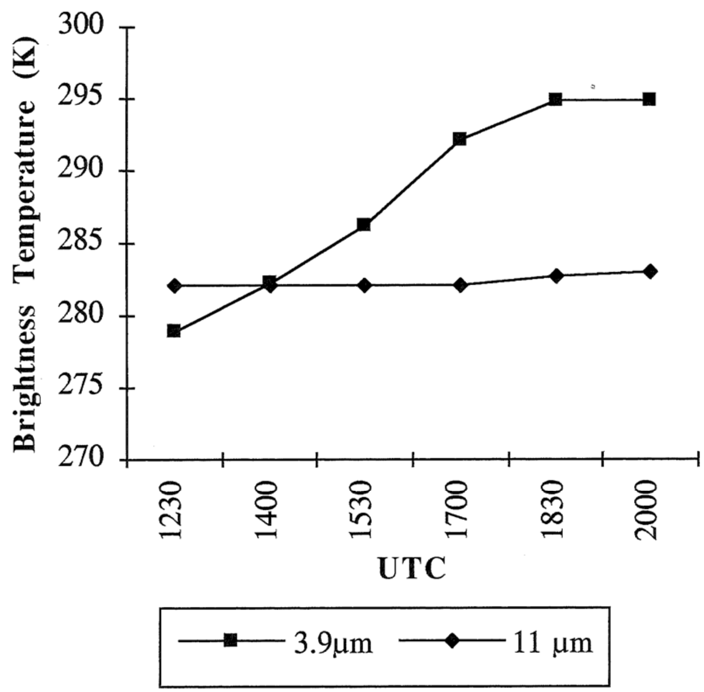
Thomas J. Kleespies

Satellite Research Laboratory
National Environmental Satellite, Data and Information Service
National Oceanic and Atmospheric Administration

Spring AGU 23 May 1994


1230 UTC
1730 UTC
11μm
3.9μm

VAS 3.9 and 11 μm Brightness Temperature for Coastal Stratus



Spring AGU 23 May 1994

$$I(0,+\mu,\phi) = \varepsilon(\mu)B(T_s)e^{-\tau_s/\mu}$$
$$+\int_0^{\tau_s}(1-\tilde{\omega}(\tau))B(T(\tau'))e^{-\tau'/\mu}\frac{d\tau'}{\mu}$$
$$+\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu_0}P(\tau',\mu,\phi;-\mu_0,\phi_0)e^{-\tau'/\mu}\frac{d\tau'}{\mu}$$
$$+\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}I(\tau',\mu',\phi')P(\tau',\mu,\phi;\mu',\phi')e^{-\tau'/\mu'}d\mu'd\phi'\frac{d\tau'}{\mu}$$
$$+\frac{\mu_0}{\pi}I_0e^{-\tau_s/\mu_0}\rho(\mu,\phi;-\mu_0,\phi_0)e^{-\tau_s/\mu}$$
$$+e^{-\tau_s/\mu}\int_0^{2\pi}\int_0^{1}\rho(\mu,\phi;-\mu',\phi')I\downarrow(\tau_s,-\mu',\phi')\mu'd\mu'd\phi'$$

$$I\downarrow(\tau_s,-\mu,\phi) = \int_0^{\tau_s}(1-\tilde{\omega}(\tau))B(T(\tau'))e^{-(\tau_s-\tau')/\mu}\frac{d\tau'}{\mu}$$
$$+\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu_0}P(\tau',-\mu,\phi;-\mu_0,\phi_0)e^{-(\tau_s-\tau')/\mu}\frac{d\tau'}{\mu}$$
$$+\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}I(\tau',\mu',\phi')P(\tau',-\mu,\phi;\mu',\phi')e^{-(\tau_s-\tau')/\mu}d\mu'd\phi'\frac{d\tau'}{\mu}$$

$$I_1 = T_{sfc_1}+T_{atm_1}+S_{U_1}+M_{U_1}+D_{R_1}+F_{R_1}$$
$$I_2 = T_{sfc_2}+T_{atm_2}+S_{U_2}+M_{U_2}+D_{R_2}+F_{R_2}$$

$$I_1-I_2 = (T_{sfc_1}-T_{sfc_2})+(T_{atm_1}-T_{atm_2})+(S_{U_1}-S_{U_2})+(M_{U_1}-M_{U_2})+(D_{R_1}-D_{R_2})+(F_{R_1}-F_{R_2})$$

$$T_{sfc_1}-T_{sfc_2} = \varepsilon(\mu)B(T_s)e^{-\tau_s/\mu}-\varepsilon(\mu)B(T_s)e^{-\tau_s/\mu} = 0$$

$$T_{atm_1}-T_{atm_2} = \int_0^{\tau_s}(1-\tilde{\omega}(\tau'))B(T(\tau'))e^{-\tau'/\mu}\frac{d\tau'}{\mu} - \int_0^{\tau_s}(1-\tilde{\omega}(\tau'))B(T(\tau'))e^{-\tau'/\mu}\frac{d\tau'}{\mu} = 0$$

$$S_{U_1}-S_{U_2} = \int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu_{01}}P(\tau',\mu,\phi;-\mu_{01},\phi_{01})e^{-\tau'/\mu}\frac{d\tau'}{\mu}$$
$$-\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu_{02}}P(\tau',\mu,\phi;-\mu_{02},\phi_{02})e^{-\tau'/\mu}\frac{d\tau'}{\mu}$$

$$= \int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu}\left\{e^{-\tau'/\mu_{01}}P(\tau',\mu,\phi;-\mu_{01},\phi_{01})-e^{-\tau'/\mu_{02}}P(\tau',\mu,\phi;-\mu_{02},\phi_{02})\right\}\frac{d\tau'}{\mu}$$

$$M_{U_1}-M_{U_2} = \int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}I_1(\tau',\mu',\phi')P(\tau',\mu,\phi;\mu',\phi')e^{-\tau'/\mu}d\mu'd\phi'\frac{d\tau'}{\mu}$$
$$-\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}I_2(\tau',\mu',\phi')P(\tau',\mu,\phi;\mu',\phi')e^{-\tau'/\mu'}d\mu'd\phi'\frac{d\tau'}{\mu}$$

$$= \int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}\left\{I_1(\tau',\mu',\phi')-I_2(\tau',\mu',\phi')\right\}P(\tau',\mu,\phi;\mu',\phi')e^{-\tau'/\mu}d\mu'd\phi'\frac{d\tau'}{\mu}$$

$$I_n(\tau,\mu,\phi) = I_{T_n}(\mu)+I_{S_n}(\tau,\mu,\phi)$$

$$M_{U_1}-M_{U_2} = \int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\{$$
$$\int_0^{2\pi}\int_{-1}^{1}\left\{I_{T_1}(\mu)-I_{T_2}(\mu)+I_{S_1}(\tau',\mu',\phi')-I_{S_2}(\tau',\mu',\phi')\right\}P(\tau',\mu,\phi;\mu',\phi')e^{-\tau'/\mu}d\mu'd\phi' \}\frac{d\tau'}{\mu}$$

$$= \int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\left\{ \int_0^{2\pi}\int_{-1}^{1}\left\{I_{S_1}(\tau',\mu',\phi')-I_{S_2}(\tau',\mu',\phi')\right\}P(\tau',\mu,\phi;\mu',\phi')e^{-\tau'/\mu}d\mu'd\phi' \right\}\frac{d\tau'}{\mu}$$

$$D_{R_1}-D_{R_2} = \frac{\mu_{01}}{\pi}I_0e^{-\tau_s/\mu_{01}}\rho(\mu,\phi;-\mu_{01},\phi_{01})e^{-\tau_s/\mu}-\frac{\mu_{02}}{\pi}I_0e^{-\tau_s/\mu_{02}}\rho(\mu,\phi;-\mu_{02},\phi_{02})e^{-\tau_s/\mu}$$

$$= \frac{I_0}{\pi}\left\{\mu_{01}e^{-\tau_s/\mu_{01}}\rho(\mu,\phi;-\mu_{01},\phi_{01})-\mu_{02}e^{-\tau_s/\mu_{02}}\rho(\mu,\phi;-\mu_{02},\phi_{02})\right\}e^{-\tau_s/\mu}$$

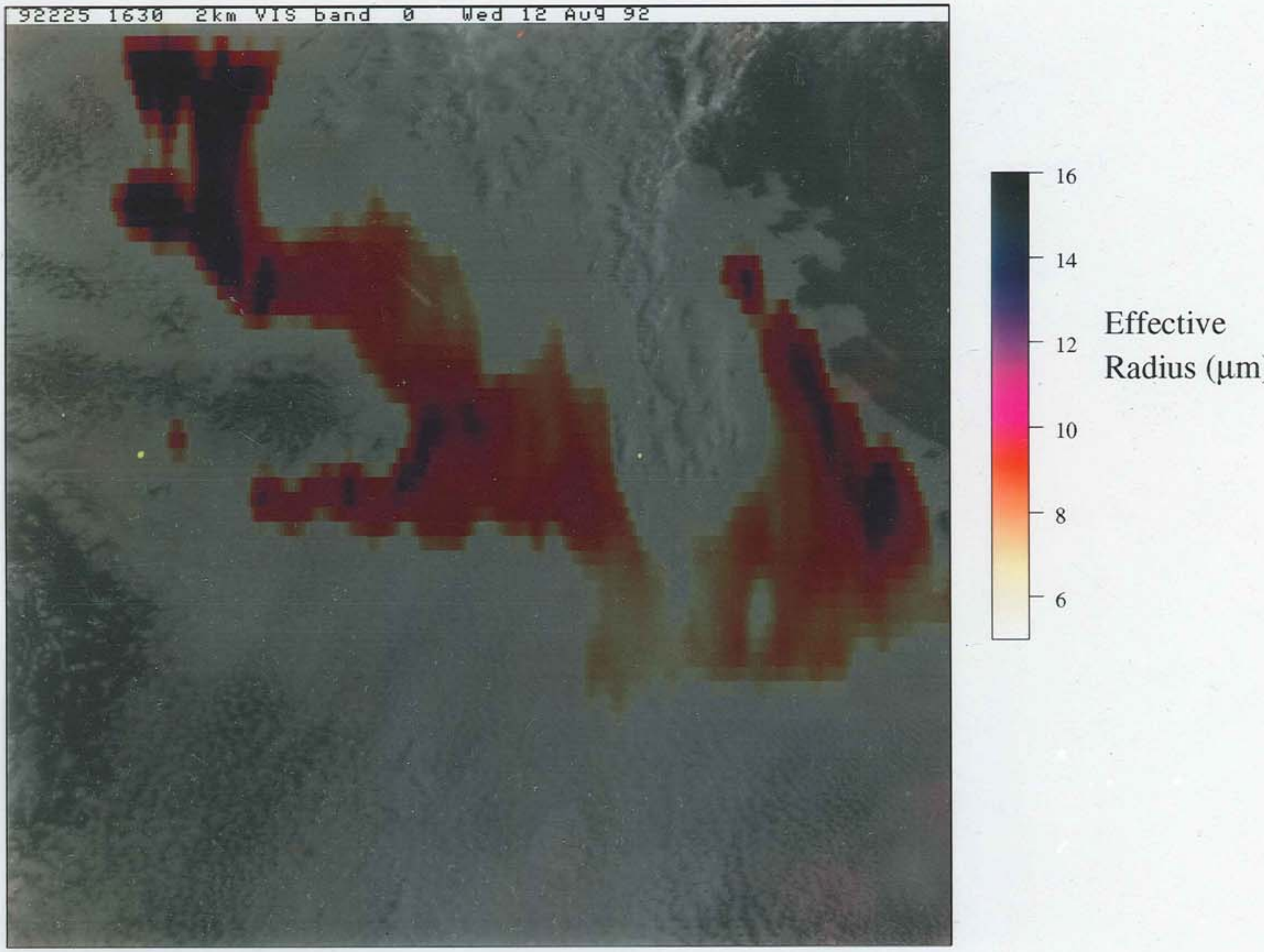
$$F_{R_1}-F_{R_2} = \frac{e^{-\tau_s/\mu}}{\pi}\int_0^{2\pi}\int_0^{1}\rho(\mu,\phi;-\mu',\phi')\{$$
$$\int_0^{\tau_s}(1-\tilde{\omega}(\tau'))B(T(\tau'))e^{-(\tau_s-\tau')/\mu'}\frac{d\tau'}{\mu'}$$
$$+\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu_{01}}P(\tau',-\mu',\phi';-\mu_{01},\phi_{01})e^{-(\tau_s-\tau')/\mu'}\frac{d\tau'}{\mu'}$$
$$+\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}I_1(\tau',\mu'',\phi'')P(\tau',-\mu',\phi';\mu'',\phi'')e^{-(\tau_s-\tau')/\mu'}d\mu''d\phi''\frac{d\tau'}{\mu'} \}\mu'd\mu'd\phi'$$
$$-\frac{e^{-\tau_s/\mu}}{\pi}\int_0^{2\pi}\int_0^{1}\rho(\mu,\phi;-\mu',\phi')\{$$
$$\int_0^{\tau_s}(1-\tilde{\omega}(\tau))B(T(\tau'))e^{-(\tau_s-\tau')/\mu'}\frac{d\tau'}{\mu'}$$
$$+\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu_{02}}P(\tau',-\mu',\phi';-\mu_{02},\phi_{02})e^{-(\tau_s-\tau')/\mu'}\frac{d\tau'}{\mu'}$$
$$+\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}I_2(\tau',\mu'',\phi'')P(\tau',-\mu',\phi';\mu'',\phi'')e^{-(\tau_s-\tau')/\mu'}d\mu''d\phi''\frac{d\tau'}{\mu'} \}\mu'd\mu'd\phi'$$

$$= \frac{e^{-\tau_s/\mu}}{\pi}\{ \int_0^{2\pi}\int_0^{1}\rho(\mu,\phi;-\mu',\phi')$$
$$\{ \int_0^{\tau_s}(1-\tilde{\omega}(\tau))B(T(\tau'))e^{-(\tau_s-\tau')/\mu'}\frac{d\tau'}{\mu'}$$
$$-\int_0^{\tau_s}(1-\tilde{\omega}(\tau))B(T(\tau'))e^{-(\tau_s-\tau')/\mu'}\frac{d\tau'}{\mu'} \}\mu'd\mu'd\phi'$$
$$+ \int_0^{2\pi}\int_0^{1}\rho(\mu,\phi;-\mu',\phi')\{$$
$$\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu_{01}}P(\tau',-\mu',\phi';-\mu_{01},\phi_{01})e^{-(\tau_s-\tau')/\mu'}\frac{d\tau'}{\mu'}$$
$$-\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-\tau'/\mu_{02}}P(\tau',-\mu',\phi';-\mu_{02},\phi_{02})e^{-(\tau_s-\tau')/\mu'}\frac{d\tau'}{\mu'} \}\mu'd\mu'd\phi'$$

$$+ \int_0^{2\pi}\int_0^{1}\rho(\mu,\phi;-\mu',\phi')\{$$
$$\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}I_1(\tau',\mu'',\phi'')P(\tau',-\mu',\phi';\mu'',\phi'')e^{-(\tau_s-\tau')/\mu'}d\mu''d\phi''\frac{d\tau'}{\mu'}$$
$$-\int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}I_2(\tau',\mu'',\phi'')P(\tau',-\mu',\phi';\mu'',\phi'')e^{-(\tau_s-\tau')/\mu'}d\mu''d\phi''\frac{d\tau'}{\mu'} \}\mu'd\mu'd\phi'$$

$$= \frac{e^{-\tau_s/\mu}}{\pi}\{ \int_0^{2\pi}\int_0^{1}\rho(\mu,\phi;-\mu',\phi')\{ \int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{2\pi}I_0e^{-(\tau_s-\tau')/\mu'}\{$$
$$e^{-\tau'/\mu_{01}}P(\tau',-\mu',\phi';-\mu_{01},\phi_{01})-e^{-\tau'/\mu_{02}}P(\tau',-\mu',\phi';-\mu_{02},\phi_{02}) \}\frac{d\tau'}{\mu'}$$
$$+ \int_0^{\tau_s}\frac{\tilde{\omega}(\tau')}{4\pi}\int_0^{2\pi}\int_{-1}^{1}\{ I_{S_1}(\tau',\mu'',\phi'')-I_{S_2}(\tau',\mu'',\phi'') \}$$
$$e^{-(\tau_s-\tau')/\mu'}P(\tau',-\mu',\phi';\mu'',\phi'')d\mu''d\phi''\frac{d\tau'}{\mu'} \}\mu'd\mu'd\phi' \}$$

Effective Radius Retrieval
12 Aug 92 1530-1630



SPIE 15 April 1993

The Retrieval of Marine Stratiform Cloud Properties from Multiple Observations in the 3.9-μm Window under Conditions of Varying Solar Illumination

THOMAS J. KLEESPIES

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(Manuscript received 28 March 1994, in final form 12 December 1994)

ABSTRACT

Radiometric observations in the 3.9-μm region have been used by a number of investigators for the determination of cloud parameters or sea surface temperature at night. Only a few attempts have been made to perform quantitative assessments of cloud and surface properties during the daytime because of the inability to distinguish between the thermal and solar components of the satellite-sensed radiances. This paper presents a new method of separating the thermal and solar components of upwelling 3.9-μm radiances.

Two collocated satellite observations are made under conditions where the solar illumination angle changes but the thermal structure of the cloud and atmosphere, as well as the cloud microphysics change very little. These conditions can easily be met by observing the same cloud from geosynchronous orbit over a short time interval during the morning hours. When the radiances are differenced under these constraints, the thermal components cancel, and the difference in the radiances is simply the difference in the solar component. With a few simplifying assumptions, a cloud microphysical property, specifically effective radius, can be inferred. This parameter is of particular importance to both climate modeling and global change studies. The methodology developed in this paper is applied to data from the Visible–Infrared Spin Scan Radiometer Atmospheric Sounder onboard the *GOES-7* spacecraft for a period in August 1992.

1. Introduction

in greenhouse gases is expected to cause a correspond.

The Road to NESDIS

Henry Fleming 1921-1992

COURSE NOTES FOR:

MR 4417, Topics in Remote Sensing and Satellite Observations (3-3)

by

HENRY E. FLEMING

SUBTITLE:

PRINCIPLES OF PASSIVE REMOTE SENSING OF THE ATMOSPHERE AND OCEAN SURFACE FROM SATELLITES

Department of Meteorology
Naval Postgraduate School
Monterey, California 93940

October 1978

Transmittance Work

- Start with McMillin-Fleming works for heritage

Atmospheric transmittance of an absorbing gas: a computationally fast and accurate transmittance model for absorbing gases with constant mixing ratios in inhomogeneous atmospheres

Larry M. McMillin and Henry E. Fleming

At a given pressure level the atmospheric transmittance for an absorbing gas with a constant mixing ratio varies only with the temperature profile of the atmosphere. A simple transmittance model based on temperature differences is derived for monochromatic radiation. This model then is extended to the more important case of polychromatic radiation through the use of scaling approximations. The resulting algorithm for calculating transmittances for an arbitrary temperature profile is simple to use, accurate, and computationally fast because only arithmetic operations are required. In fact, resulting transmittances agreed with line-by-line calculations to within 0.0031 for the cases tried. Details for calculating the expansion coefficients are provided.

I. Introduction

Retrieval of atmospheric temperature profiles from satellite radiation measurements is now commonplace. In all known inversion procedures used to calculate the temperature profiles,[1] except the regression technique, it is necessary to know the nature of the atmospheric transmittances for all the absorbing gases in the spectral intervals used.

The most accurate method of obtaining these transmittances is by summing the absorption coefficients in very narrow spectral intervals over each contributing line followed by an integration over the atmospheric path. This is known as the line-by-line method of calculation. Transmittances for these narrow spectral intervals are calculated from the program developed by Drayson,[2] then convoluted with the spectral response function of the instrument. However, the line-by-line procedure is much too laborious and time consuming for use in the real-time processing of satellite data. A much faster process, which satisfies the accuracy requirements, must be used.

Fast and accurate methods, such as the one described by Weinreb and Neuendorffer,[3] exist; these should be used for calculating atmospheric transmittances for gases such as H_2O, which have variable mixing ratios. On the other hand, for the gases with essentially constant mixing ratios such as CO_2 and O_2, the method developed by the authors is several times faster and is sufficiently accurate for temperature retrievals.

Essentially, the method is a recurrence procedure in which the transmittance for an arbitrary temperature profile, evaluated at n pressure levels, is given at the ith pressure level by

$$\tau_i = \tau_{i-1} f_i(T,\hat{T}), \qquad i = 1, \ldots, n, \qquad (1)$$

where $\tau_0 = 1$ at the top of the atmosphere, $f_i(T,\hat{T})$ is a linear combination of temperature-dependent terms that depend upon the index i, T is the given temperature profile, and $\hat{T}$ is a reference temperature profile.

II. Theoretical Discussion

For monochromatic radiation and a constant mixing ratio, the fractional transmittance of the atmosphere between the effective top of the atmosphere and pressure level p at zenith angle θ is given by

$$\tau(\nu,T,\theta,p) = \exp\left[-(q \sec\theta/g) \int_0^p k(\nu,T,p')dp'\right], \qquad (2)$$

where q is the constant mass mixing ratio of the absorbing gas, g is the gravitational acceleration, and $k(\nu,T,p)$ is the absorption coefficient at wavenumber ν, pressure p, and temperature $T = T(p)$.

In practice, temperature retrievals are not obtained as continuous functions of pressure, but rather

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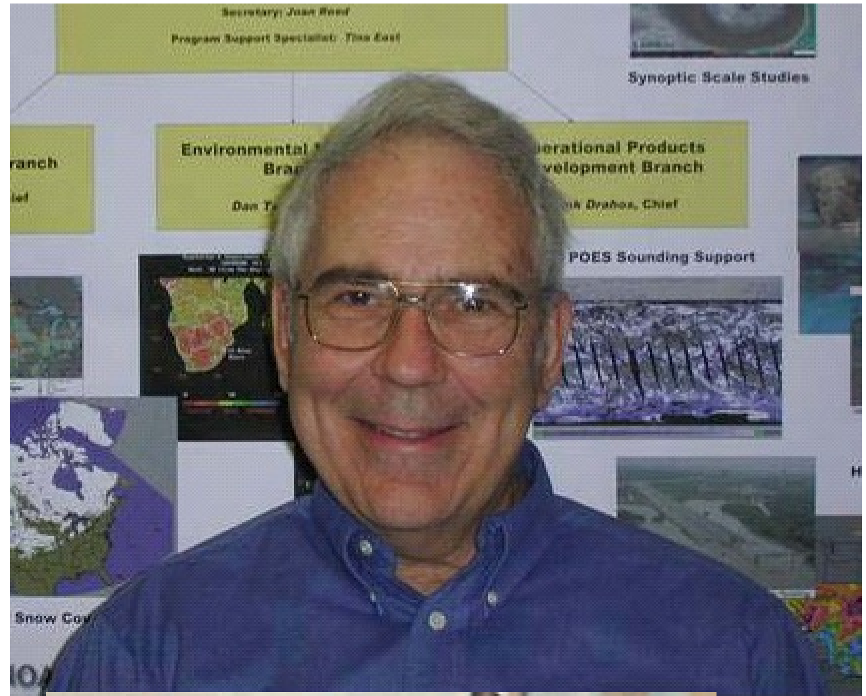
The authors are with NOAA, National Environmental Satellite Service, Washington, D.C. 20233.
Received 1 August 1975.



McMillin & Fleming (1976)

- Fixed Angle, Constant Mixing Ratio
- Regression on fixed pressure levels

$$\frac{\tau_i}{\tau_{i-1}} - \frac{\hat{\tau}_i}{\hat{\tau}_{i-1}} = \beta_i \Delta T_i + \gamma_i \Delta T_i + \zeta_i \Delta T_i^* + \eta_i \Delta T_i^{**} \quad i = 1, \ldots, n$$

$\Delta T^{n(*)}$ is a pressure weighted temperature deviation from a reference profile

Atmospheric transmittance of an absorbing gas. 2: A computationally fast and accurate transmittance model for slant paths at different zenith angles

Henry E. Fleming and Larry M. McMillin

Models exist which allow the calculation of atmospheric transmittance at a given zenith angle for an absorbing gas with a constant mixing ratio. However, many applications require transmittances at several zenith angles. A simple, fast, and accurate model for calculating the angular dependence is given. This model is computationally fast because only the four arithmetic operations are used. Details for calculating the expansion coefficients are provided. When this technique is combined with a procedure for calculating transmittances at a fixed angle, it is possible to calculate transmittances for slant paths at arbitrary zenith angles and temperature profiles, provided the mixing ratio is constant. This technique was evaluated with a method capable of calculating transmittances at zero zenith angle with an accuracy of 0.0031. For zenith angles ranging from 0° to 40°, transmittances agree with line-by-line calculations to within 0.0038.

I. Introduction

In a previous paper[1] published in this journal we presented an iterative model, using only arithmetic operations, to calculate atmospheric transmittances for polychromatic radiation for an arbitrary temperature profile. This model was based on temperature differences and scaling approximations. However, it has the limitation of providing transmittances for only a single zenith angle. Since satellite instruments scan from side to side and thus view areas at different zenith angles, there is a need for a rapid method of calculating transmittances at various angles. This paper, in combination with the method described in our previous paper, provides a computationally fast and accurate transmittance model for slant paths having arbitrary zenith angles and arbitrary temperature profiles. The approach closely parallels that of the previous paper; consequently, extensive use is made of those results. To simplify referencing the earlier paper,[1] henceforth it will be identified by the abbreviation Trans. I.

In Trans. I we developed a recurrence procedure in which the transmittance for an arbitrary temperature profile, evaluated at n pressure levels, was given at the ith pressure level by

$$\tau_i = \tau_{i-1} f_i(T,\hat{T}) \quad i = 1,\ldots,n, \tag{1}$$

where $\tau_o = 1$ at the top of the atmosphere, $f_i(T,\hat{T})$ is a linear combination of temperature-dependent terms that depend on the index i, T is the given temperature profile, and $\hat{T}$ is a reference temperature profile. However, Eq. (1) holds only for a single, fixed zenith angle θ_0.

In this paper we relate the transmittance for an arbitrary zenith angle θ to the transmittance of a fixed zenith angle θ_0 at the ith pressure level by the equation

$$\tau_i(\theta) = \tau_i(\theta_0) + F_i(\sec\theta - \sec\theta_0, \Delta T_i^{**}) \quad i = 1,\ldots,n, \tag{2}$$

where $\tau_i(\theta_0)$ is the transmittance for the fixed zenith angle θ_0, calculated using Eq. (1) and temperature profiles T and $\hat{T}$; F_i is a bilinear combination of terms, depending on the index i, and involving $\sec\theta - \sec\theta_0$ and the scaling approximation ΔT_i^{**} described in Trans. I.

II. Theoretical Discussion

For monochromatic radiation passing through a gas with a constant mixing ratio, the fractional transmittance of the atmosphere between the effective top of the atmosphere and pressure level p at zenith angle θ is given by

$$\tau(\nu,T,\theta,p) = \exp\left[-(q/g\sec\theta)\int_0^p k(\nu,T,p')dp'\right], \tag{3}$$

where q is the constant mass mixing ratio of the absorbing gas, g is the gravitational acceleration, and $k(\nu,T,p)$ is the absorption coefficient at wavenumber ν, pressure p, and temperature $T = T(p)$.

Now consider Eq. (3) for a fixed zenith angle θ_0 and divide the resulting equation into the original form of Eq. (3) to obtain

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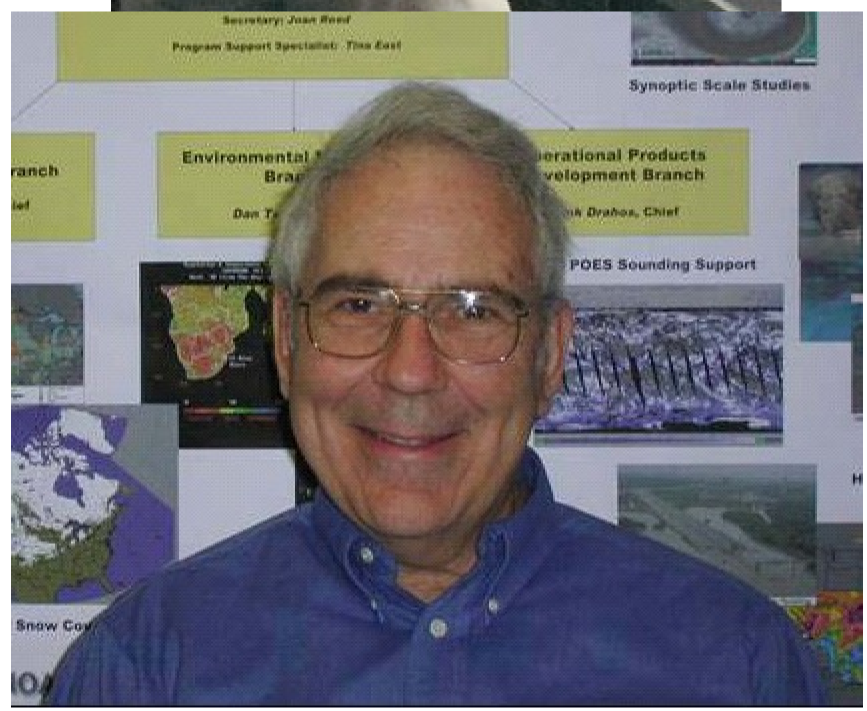

Fleming & McMillin (1978)

- Slant path, constant mixing ratio
- Regression on fixed pressure levels
- Essentially a correction to transmittances from (1)

$$\tau_i(\theta) = \tau(\theta_0) + \alpha_i(\Delta \sec\theta) + \beta_i(\Delta \sec\theta)\Delta T_i^{**} + \gamma_i(\Delta \sec\theta) \qquad i = 1,\ldots,n$$

Reprinted from APPLIED OPTICS, Vol. 18, page 1600, May 15, 1979

Atmospheric transmittance of an absorbing gas. 3: A computationally fast and accurate transmittance model for absorbing gases with variable mixing ratios

Larry M. McMillin, Hernry E. Fleming, and Michael L. Hill

Atmospheric transmittance models for absorbing gases with constant mixing ratios were described in the two preceding papers of this series. In this paper a method for calculating atmospheric transmittances for absorbing gases with variable mixing ratios is described. Because the model uses only arithmetic operations, it is computationally fast as well as accurate. Details of the computational algorithm are given, including the calculation of the expansion coefficients. In a test of eleven independent profiles, the resulting transmittances agreed with line-by-line calculations in an rms sense to within 0.0090 in the worst case and to within 0.0018 in all other cases. This paper also includes a discussion for computing transmittances when several gases absorb in the same spectral interval. These three papers provide a complete treatment for modeling transmittances in inhomogeneous atmospheres.

I. Introduction

This is the third in a series of papers devoted to developing mathematical models for the rapid and accurate computation of atmospheric transmittances of absorbing gases. The transmittances are used in retrieving temperature and composition profiles from satellite radiation measurements; however, they are applicable to other situations as well, such as flux calculations.

In each of the two preceding papers[1,2] we presented computational models satisfying the conditions of (1) polychromatic radiation, (2) arbitrary temperature profiles, and (3) gases with constant mixing ratios. The first model was applicable to a single slant path in an inhomogeneous atmosphere at a fixed zenith angle, while the second model extended the first one to include slant paths over an arbitrary range of zenith angles. This third paper generalizes and extends the earlier models to include absorption by gases having variable mixing ratios, such as ozone and water vapor. Note that our use of the word model does not mean band model but, rather, a general mathematical approximation of the transmittance function. The computational approach in this, our latest, model is similar to the other two in that we again are using an iterative scheme that requires only arithmetic operations to calculate the atmospheric transmittances. In both of the previous models the predictors included temperature differences and scaling approximations. Analogous, but generalized, predictors are used in the present approach.

Because the techniques of this paper in several respects are similar to those of the preceding two papers, extensive use is made of those results. Therefore, to simplify referencing those papers, we will refer to the first paper[1] as Trans. I and to the second paper[2] as Trans. II. Also, a gas with a constant mixing ratio will be called simply a constant gas, and a gas with a variable mixing ratio will be called a variable gas.

The essentials of the method of this paper are as follows. The method is a recurrence procedure in which the transmittance for an arbitrary temperature profile and an arbitrary mixing ratio profile, evaluated for n absorber amounts (i.e., optical paths), is given for the ith amount by

$$\tau_i = \tau_{i-1} f_i(T,\hat{T},p,\hat{p}), \qquad (1)$$

where $\tau_0 = 1$ at the top of the atmosphere, $f_i(T,\hat{T},p,\hat{p})$ is a linear combination of temperature and pressure-dependent terms that depend upon the index i, T and p are the given temperature and pressure profiles, respectively, and $\hat{T}$ and $\hat{p}$ are the respective reference profiles.

The authors are with NOAA National Environmental Satellite Service, Washington, D.C. 20233.
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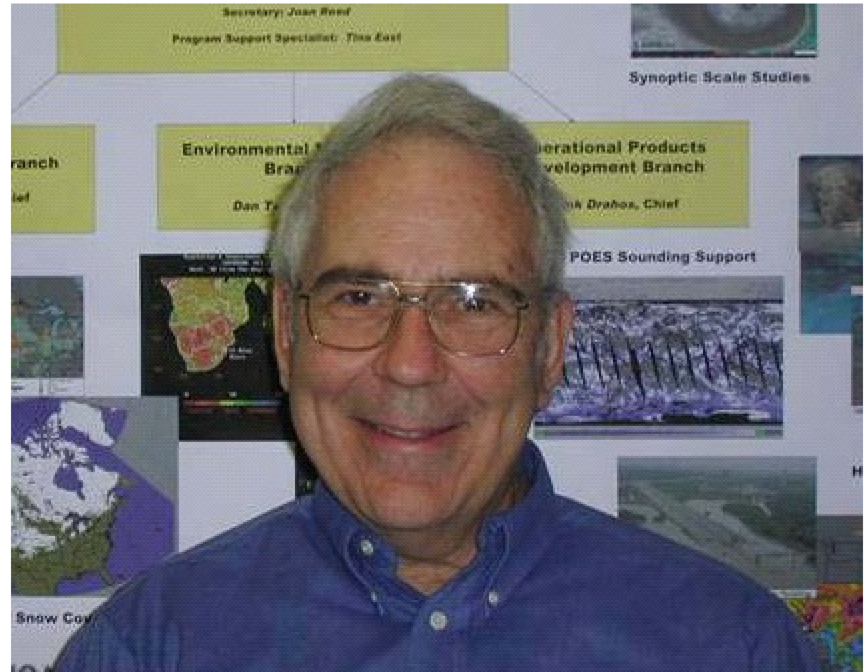
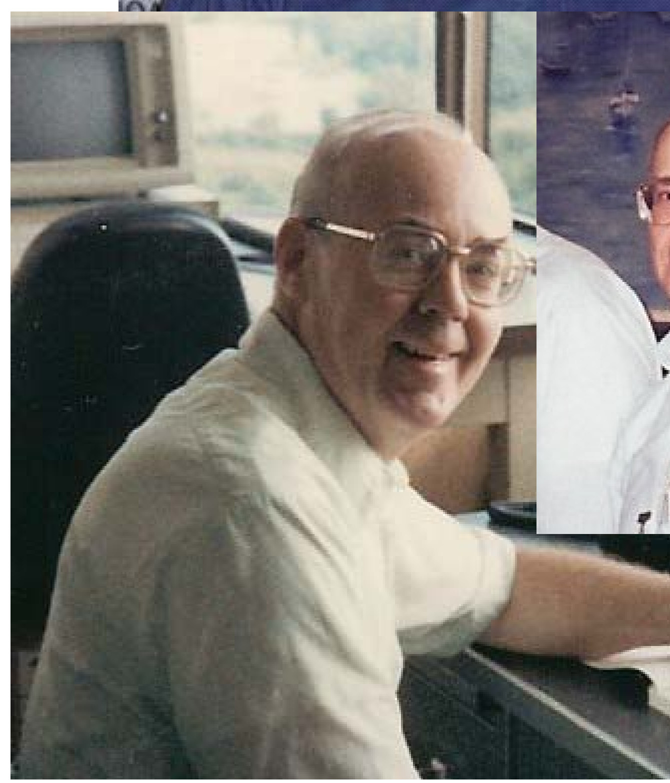
0003-6935/79/101600-07$00.50/0.





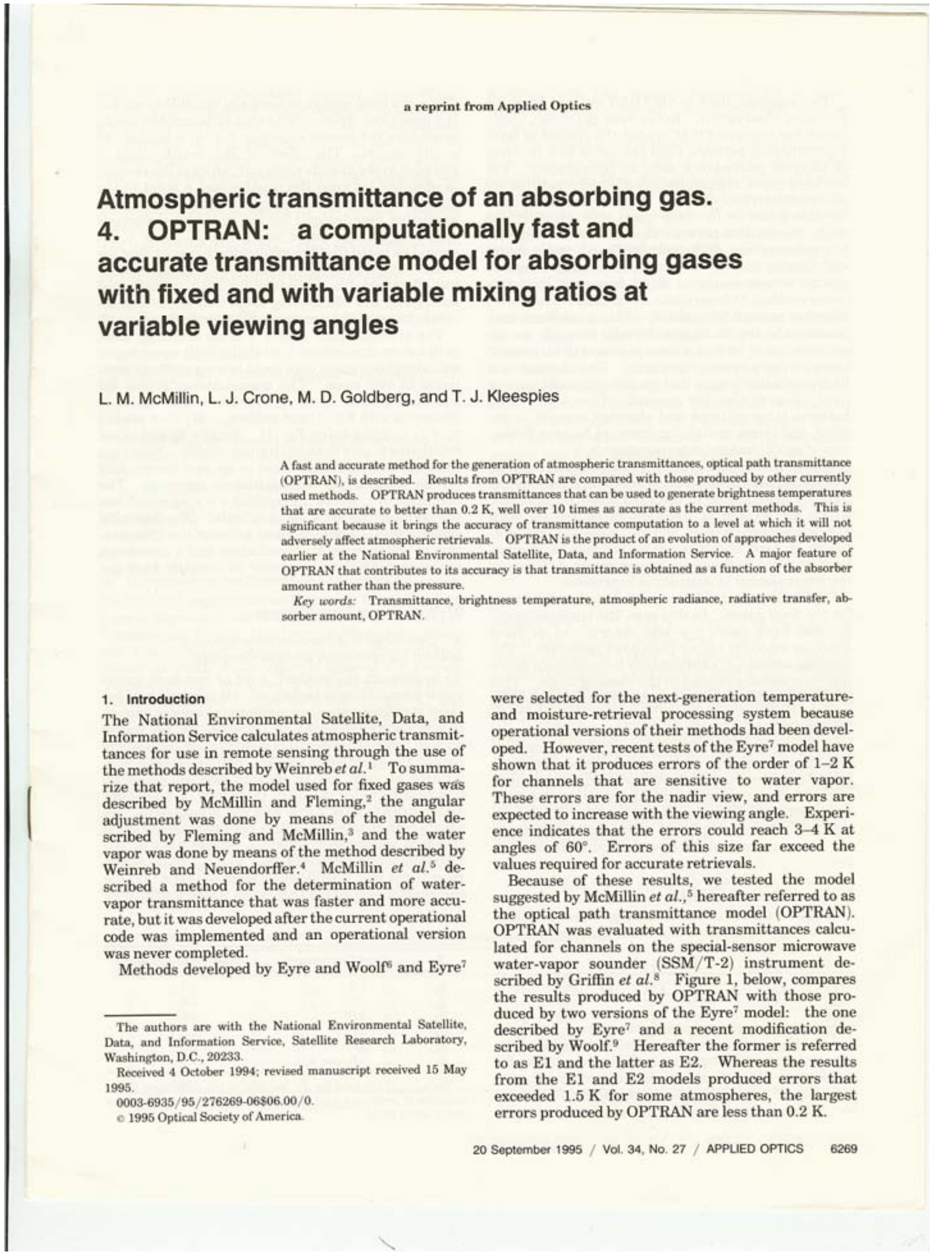
McMillin, Fleming and Hill (1979)

- Slant path, variable mixing ratio
- Regression performed on absorber levels

$$\frac{\tau_i}{\tau_{i-1}} - \frac{\hat{\tau}_i}{\hat{\tau}_{i-1}} = \sum_{j=1}^{12} c_{ij} x_{ij} \qquad i = 1, \ldots, n$$

Predictors x a function of temperature and pressure

Temperature and pressure interpolated to absorber levels, transmittance
Interpolated back to pressure levels.



a reprint from Applied Optics

Atmospheric transmittance of an absorbing gas. 4. OPTRAN: a computationally fast and accurate transmittance model for absorbing gases with fixed and with variable mixing ratios at variable viewing angles

L. M. McMillin, L. J. Crone, M. D. Goldberg, and T. J. Kleespies

A fast and accurate method for the generation of atmospheric transmittances, optical path transmittance (OPTRAN), is described. Results from OPTRAN are compared with those produced by other currently used methods. OPTRAN produces transmittances that can be used to generate brightness temperatures that are accurate to better than 0.2 K, well over 10 times as accurate as the current methods. This is significant because it brings the accuracy of transmittance computation to a level at which it will not adversely affect atmospheric retrievals. OPTRAN is the product of an evolution of approaches developed earlier at the National Environmental Satellite, Data, and Information Service. A major feature of OPTRAN that contributes to its accuracy is that transmittance is obtained as a function of the absorber amount rather than the pressure.

Key words: Transmittance, brightness temperature, atmospheric radiance, radiative transfer, absorber amount, OPTRAN.

1. Introduction

The National Environmental Satellite, Data, and Information Service calculates atmospheric transmittances for use in remote sensing through the use of the methods described by Weinreb *et al.*[1] To summarize that report, the model used for fixed gases was described by McMillin and Fleming,[2] the angular adjustment was done by means of the model described by Fleming and McMillin,[3] and the water vapor was done by means of the method described by Weinreb and Neuendorffer.[4] McMillin *et al.*[5] described a method for the determination of water-vapor transmittance that was faster and more accurate, but it was developed after the current operational code was implemented and an operational version was never completed.

Methods developed by Eyre and Woolf[6] and Eyre[7] were selected for the next-generation temperature- and moisture-retrieval processing system because operational versions of their methods had been developed. However, recent tests of the Eyre[7] model have shown that it produces errors of the order of 1–2 K for channels that are sensitive to water vapor. These errors are for the nadir view, and errors are expected to increase with the viewing angle. Experience indicates that the errors could reach 3–4 K at angles of 60°. Errors of this size far exceed the values required for accurate retrievals.

Because of these results, we tested the model suggested by McMillin *et al.*,[5] hereafter referred to as the optical path transmittance model (OPTRAN). OPTRAN was evaluated with transmittances calculated for channels on the special-sensor microwave water-vapor sounder (SSM/T-2) instrument described by Griffin *et al.*[8] Figure 1, below, compares the results produced by OPTRAN with those produced by two versions of the Eyre[7] model: the one described by Eyre[7] and a recent modification described by Woolf.[9] Hereafter the former is referred to as E1 and the latter as E2. Whereas the results from the E1 and E2 models produced errors that exceeded 1.5 K for some atmospheres, the largest errors produced by OPTRAN are less than 0.2 K.

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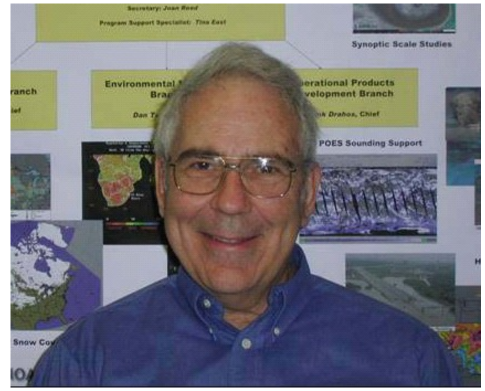

McMillin, Crone, Goldberg & Kleespies (1995)

- Slant path, variable mixing ratio
- Regression performed on absorber levels
- Introduction to OPTRAN

$$\frac{\tau_i}{\tau_{i-1}} - \frac{\hat{\tau}_i}{\hat{\tau}_{i-1}} = \sum_{j=0}^{N} c_{ij} x_{ij} \qquad i = 1, \ldots, n$$

Predictors x a function of temperature and pressure

Temperature and pressure interpolated to absorber levels, transmittance Interpolated back to pressure levels.

This is the same as paper 3 applied to the microwave except different predictors a reprint from Applied Optics

Atmospheric transmittance of an absorbing gas. 5. Improvements to the OPTRAN approach

L. M. McMillin, L. J. Crone, and T. J. Kleespies

Improvements to a fast and accurate transmittance-calculation procedure, Optical Path TRANsmittance (OPTRAN), are described. The previous version computed a transmittance ratio for an absorbing layer. It required special attention to the interpolation methodology. The new approach reported here computes the absorption coefficient for an absorbing layer. This modified approach is not only simpler but also runs in one twentieth the time of the original OPTRAN approach with the same accuracy.

Key words: Transmittance, brightness temperature, atmospheric radiance, radiative transfer, absorber amount, OPTRAN.

1. Introduction

A series of three papers in the 1970's described techniques for the rapid computation of atmospheric transmittances for constant-mixing-ratio gases at nadir,[1] at different zenith angles,[2] and for gases with variable mixing ratios.[3] In 1995 McMillin *et al.*[4] published such a method called Optical Path TRANsmittance (OPTRAN), which unifies the treatments of the constant- and variable-mixing-ratio gases reported in Refs. 2 and 3, respectively. The key to obtaining accuracy in OPTRAN was a reversal of the usual roles of the pressure and the absorber amount. In OPTRAN the expansion of the transmittance was done at fixed values of the optical path rather than of the pressure. This meant that coefficients were generated at fixed optical-path values, which provided estimates of the transmittance at these same values of an optical path, and pressure became a predictor. This approach differed from past approaches in which the coefficients and transmittances were defined at fixed pressure values. The difficulty with this approach was that atmospheric profiles are available in terms of pressure, but estimated transmittances are needed as a function of pressure. As a result, the atmospheric variables had to be interpolated from the pressure to the absorber amount, and the resulting transmittances had to be interpolated back to pressure. The irregular spacing of the standard pressure levels and the choice of predictand combined to make the original OPTRAN program very sensitive to the details of the interpolation.

In OPTRAN, the ratio of the transmittance at fixed absorber amounts was estimated by an expression of the form

$$\frac{\tau(\nu, A_i)}{\tau(\nu, A_{i-1})} = \frac{\tau_{\text{ref}}(\nu, A_i)}{\tau_{\text{ref}}(\nu, A_{i-1})} + \sum_{j=0}^{N} C_{ij} Z_{ji}, \qquad (1)$$

where $\tau(\nu, A_i)$ denotes the transmittance at wave number ν and absorber path A_i from the satellite to level i at the appropriate zenith angle, τ_{ref} is the transmittance for a reference atmosphere, N denotes the total number of predictors, C_{ij} denotes the regression coefficient for predictor j at level i, and Z_{ji} denotes the jth predictor at level i. The same form applied to fixed and variable gases, but the predictors differed.

The ratio of transmittances was used as the predictand because it depended primarily on conditions local to that layer in the atmosphere. To ensure that these ratios were smooth functions of the absorber amount, it was necessary to take special precautions in the interpolation of transmittances from standard pressures to standard absorber amounts. In particular, a cubic interpolation of the log of the transmittance was used.

In this paper, instead of a ratio of transmittances, we estimate an effective absorption coefficient $\hat{k}$:

$$\hat{k}(A_i) = C_{i0} + \sum_{j=1}^{N} C_{ij} Z_{ji}, \qquad (2)$$

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0003-6935/95/368396-04$06.00/0.

McMillin, Crone & Kleespies (1995)

- Predictand is absorption coefficient
- Predictors function of temperature and pressure
- Regression on absorber levels

$$\hat{k}(A_i) = C_{i0} + \sum_{j=0}^{N} C_{ij} Z_{ij} \qquad i = 1, \ldots, n$$

$$\tau_{\mathrm{Pi}} = \tau_{\mathrm{P,i-1}} e^{-\hat{k}^*_{\mathrm{Pi}}(A_{\mathrm{Pi}} - A_{\mathrm{P,i-1}})}$$

Temperature and pressure interpolated to absorber levels, absorption coefficient Interpolated back to pressure levels.

Factor of 20 speed improvement in spite of the exponentiation.

Tangent Linear/Adjoint Models

- Taught myself how to write TL/Adjoint code
- Wrote the TL/Adjoint/Jacobian versions of OPTRAN
- NCEP/EMC went operational with this code for NOAA-15 HIRS/AMSU-A/B, saw huge improvements in forecast skill
- (hence the medal, shared with John Derber)
- This is one of the reasons we now have the JCSDA

Atmospheric transmittance of an absorbing gas. 6. OPTRAN status report and introduction to the NESDIS/NCEP community radiative transfer model

Thomas J. Kleespies, Paul van Delst, Larry M. McMillin, and John Derber

Since the publication of the Optical Path Transmittance (OPTRAN) algorithm [Appl. Opt. **34,** 8396 (1995)], much of the code and implementation has been refined and improved. The predictor set has been expanded, an objective method to select optimal predictors has been established, and the two-interpolation method has been discarded for a single-interpolation method. The OPTRAN coefficients have been generated for a wide range of satellites and instruments. The most significant new development is the Jacobian–*K*-matrix version of OPTRAN, which is currently used for operational direct radiance assimilation in both the Global Data Analysis System and the ETA Data Analysis System at the National Oceanographic and Atmospheric Administration, National Weather Service, National Centers for Environmental Prediction Environmental Modeling Center. This paper documents these improvements and serves as a record of the current status of the operational OPTRAN code.

OCIS codes: 010.1300, 010.1320.

1. Introduction

The Optical Path Transmittance (OPTRAN) model[1,2] computes atmospheric transmittances by predicting, by means of regression, the absorption coefficient for each absorbing species on the absorber path for that species. This methodology distinguishes OPTRAN from other fast transmittance algorithms such as that used in the Radiative Transfer Television-Infrared Observation Satellite (TIROS) Operational Vertical Sounder[3–5] (RTTOV), which predicts optical depth at fixed pressure levels (see Ref. 6 for a description of some of the other transmittance models in use). This approach was chosen because the increments of absorber amount can be selected such that the variation in transmittance is less than that of pressure increments. The advantages of performing regression on absorber levels rather than on pressure levels are threefold: (1) pressure is available for use as a predictor, (2) zenith angle is implicitly included in the absorber profile and no longer needs to be treated explicitly, and (3) an arbitrary input pressure profile is permitted, so interpolation to specific pressure levels is not required.

Since the most recent publication to summarize OPTRAN,[1] a number of improvements and refinements have been made to its formulation and implementation within a radiative transfer model (RTM). The purpose of this paper is to document these modifications and to provide a reference point for a companion paper.[7] In Section 2 the refinements and improvements to OPTRAN are presented. Section 3 provides an overview of the updates made to the forward RTM, and Section 4 describes the development and testing of the *K*-matrix RTM for use in direct radiance assimilation at the National Oceanographic and Atmospheric Administration, National Weather Service, National Centers for Environmental Prediction Environmental Modeling Center (NOAA/NWS/NCEP/EMC). Section 5 provides a summary of this work. Because a large number of instruments and organizations are discussed in this paper, a list of their acronyms is provided as Appendix A. We have also listed in the appendix acronyms and abbreviations used often in the paper. In all cases, the complete word or name is given in text at the first mention.

T. J. Kleespies and L. M. McMillin are with the National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite, Data and Information Service (NESDIS). J. Derber is with NOAA, National Weather Service, National Centers for Environmental Prediction, Environmental Modeling Center (NWS/NCEP/EMC). P. van Delst is with the Cooperative Institute for Meteorological Satellite Studies at NCEP/EMC. The mailing address for all authors is 5200 Auth Road, Camp Springs, Maryland 20746-4304.

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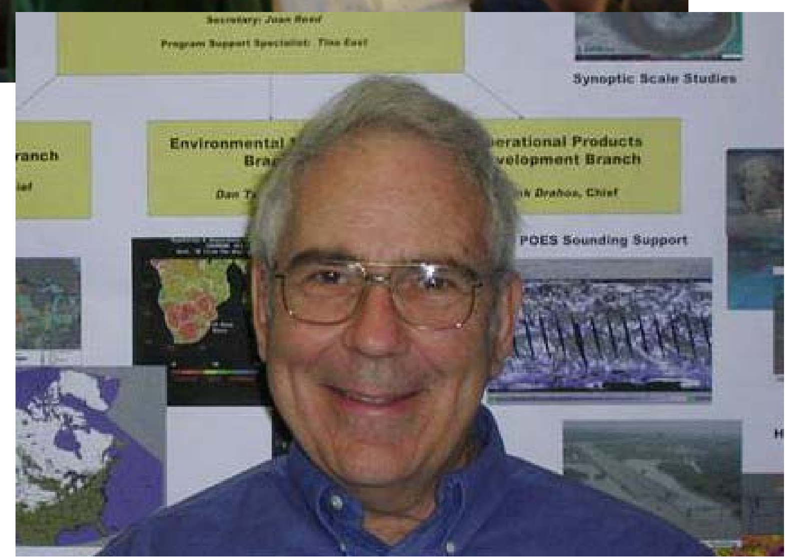

Kleespies, vanDelst McMillin & Derber (2004)

- Predictors optimized for each channel and absorber
- 11 instruments on 26 satellites supported
- Adjoint model
- CRTM introduced
  - Surface emission and reflection
  - CBR
  - Direct solar influence

Atmospheric transmittance of an absorbing gas. 7. Further improvements to the OPTRAN 6 approach

Larry M. McMillin, Xiaozhen Xiong, Yong Han, Thomas J. Kleespies, and Paul Van Delst

We present recent improvements in accuracy to the fast transmittance-calculation procedure, Optica Path Transmittance (OPTRAN), which is used for satellite data assimilation at the National Oceanic an Atmospheric Administration. These improvements are (1) to change the absorber space used for ozon (2) to add new predictors for each gas, and (3) to treat the water vapor line absorption and wate continuum absorption as separate terms. Significant improvements in the accuracy of the OPTRA algorithm for High-Resolution Infrared Radiation Sounders (HIRS) and the Atmospheric Infrare Sounder (AIRS) are demonstrated. The results that we show here extend a recent paper of Xiong an McMillin (2004) that describes the use of a polychromatic correction term to replace the effectiv transmittance concept to include additional changes that improve accuracy. © 2006 Optical Society o America

OCIS codes: 010.1300, 010.1320, 010.3920.

1. Introduction

The assimilation of satellite radiance observations into numerical weather and climate prediction models has been demonstrated to be an important element for improving weather forecasts. Development of, and improvements to, transmittance models are essential for data assimilation as new data and instruments are added to the system. The Optical Path Transmittance[1,2] (OPTRAN) algorithm is one of several regression-based fast transmittance models that have been derived from the work of McMillin and Fleming[3] and has been used in the Global Data Assimilation System[4] of the National Oceanic and Atmospheric Administration (NOAA) National Weather Service, National Centers for Environmental Prediction, Environmental Modeling Center. Another widely used regression-based model is the

Radiative Transfer for Television and Infrare
Observation Satellite Operational Vertical Sounde
(RTTOV), originally developed at the European Cen
tre for Medium range Weather Forecasts (ECMWF
and used in their data assimilation system[5–7] an
elsewhere.

In the OPTRAN, RTTOV, and many other fas
transmittance models, the absorption of radiation b
the gases in the atmosphere is commonly treated a
the sum of three components. These three compo
nents are water vapor, ozone, and the remainin
gases (CO_2, N_2O, CO, CH_4, N_2, O_2 and other trac
gases) that we refer to collectively as dry gases.[2] A
the concentrations for these dry gases are generall
held constant, they are also referred to in the litera
ture as fixed gases. In the OPTRAN algorithm a set o
regression equations is developed to parameteriz
the absorption coefficient of each of these three com
ponents separately. Because the absorption coeffi
cient for each gas is a function of the absorbe
amount, the atmosphere is discretized in terms of th
integrated path absorber amounts [which are simpli
fied to a fixed pressure level times the secant of th
local zenith angle discretization for the fixed (dr
gases]. By predicting the channel absorption coeffi
cients for dry gases, water vapor, and ozon
OPTRAN can be used to calculate the transmittanc
under clear sky conditions.

Line-by-line (LBL) transmittance calculations fo
previous versions of OPTRAN were performed b

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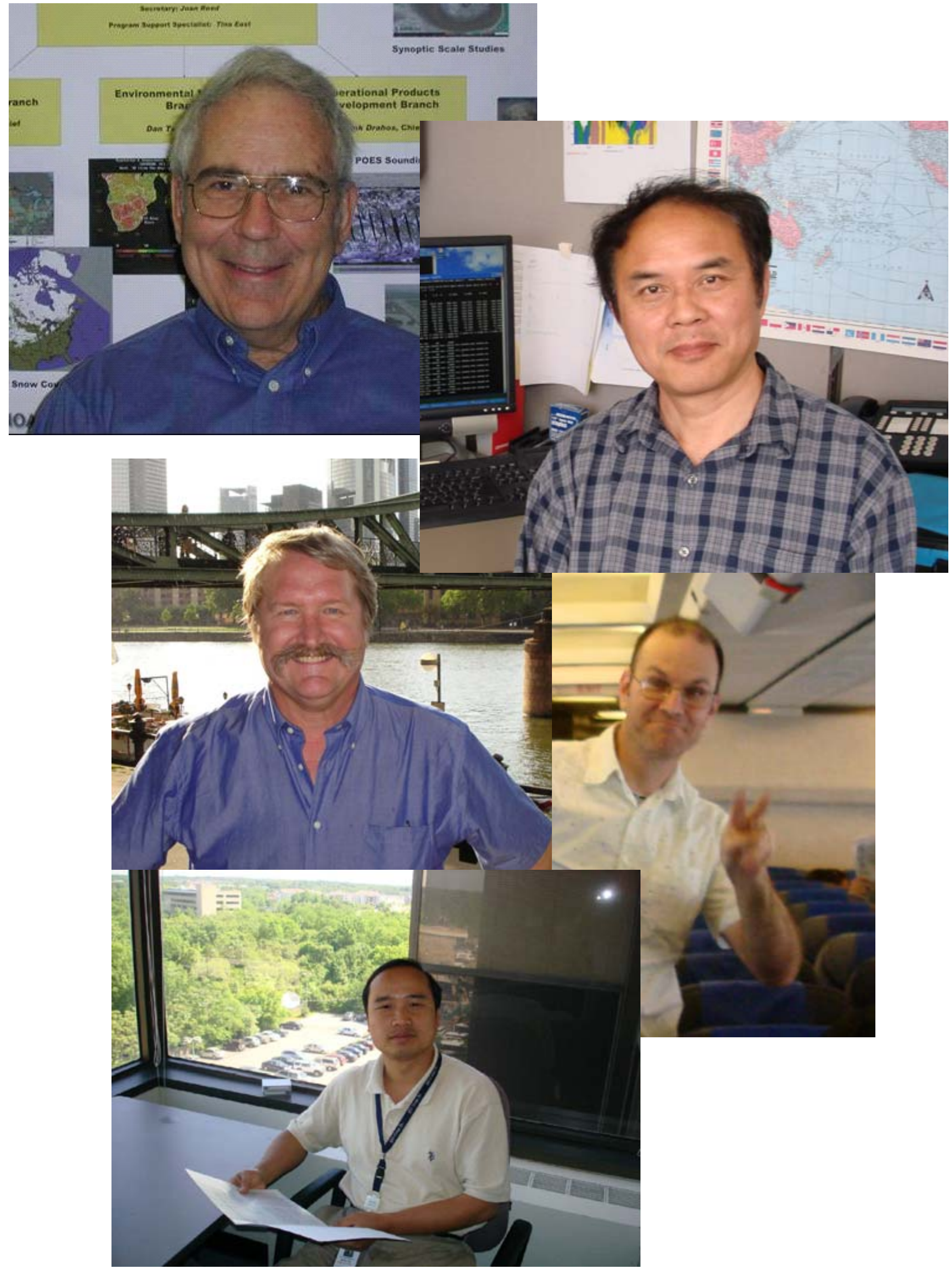


McMillin, Xiong, Han, Kleespies & vanDelst (2006)

- Improved ozone absorber space
- New predictor set
- H_2O continuum treated as separate absorber
- Correction term improves errors in departure of polychromatic transmittances from monochromatic

TL/Adjoint coding class

- Gave class to JCSDA members in 2003
- Gave class to data assimilation workshop at University of Maryland in 2007
- Posted at http://cimss.ssec.wisc.edu/itwg/groups/rtwg/tl_ad_lectures/
- Numerous people have taken the class in person or online, including some of you

Tangent Linear and Adjoint Coding Short Course
Day 1
Overview and Tangent Linear Coding

Thomas J. Kleespies

Instrument Characterization

- NOAA-L,M,N,N’,METOP-B
- HIRS, AMSU-A/B, MHS, AVHRR

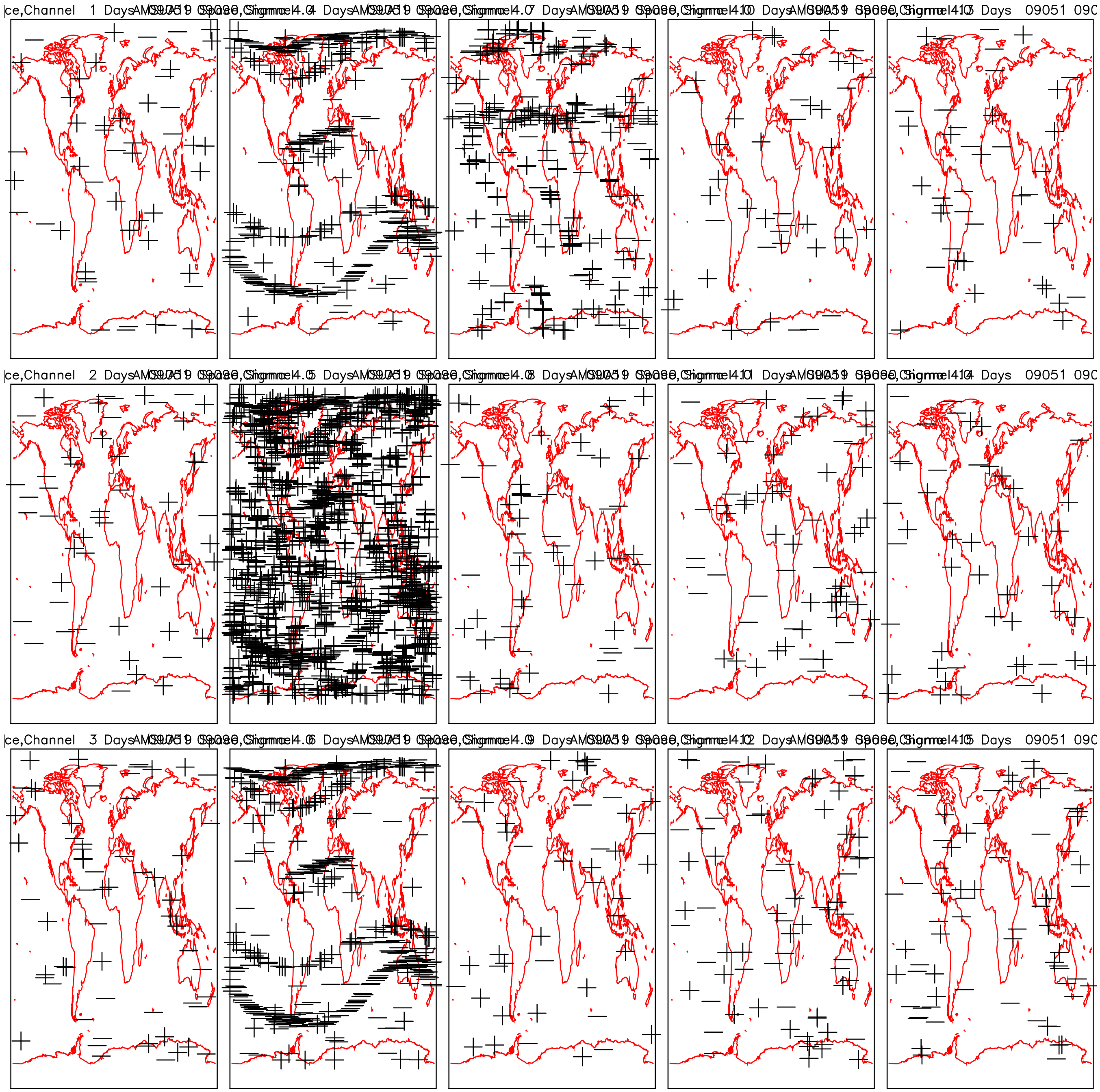
NOAA 19 AMSU-A RFI?

Thomas J. Kleespies

Methodology

- Space look antenna temperatures

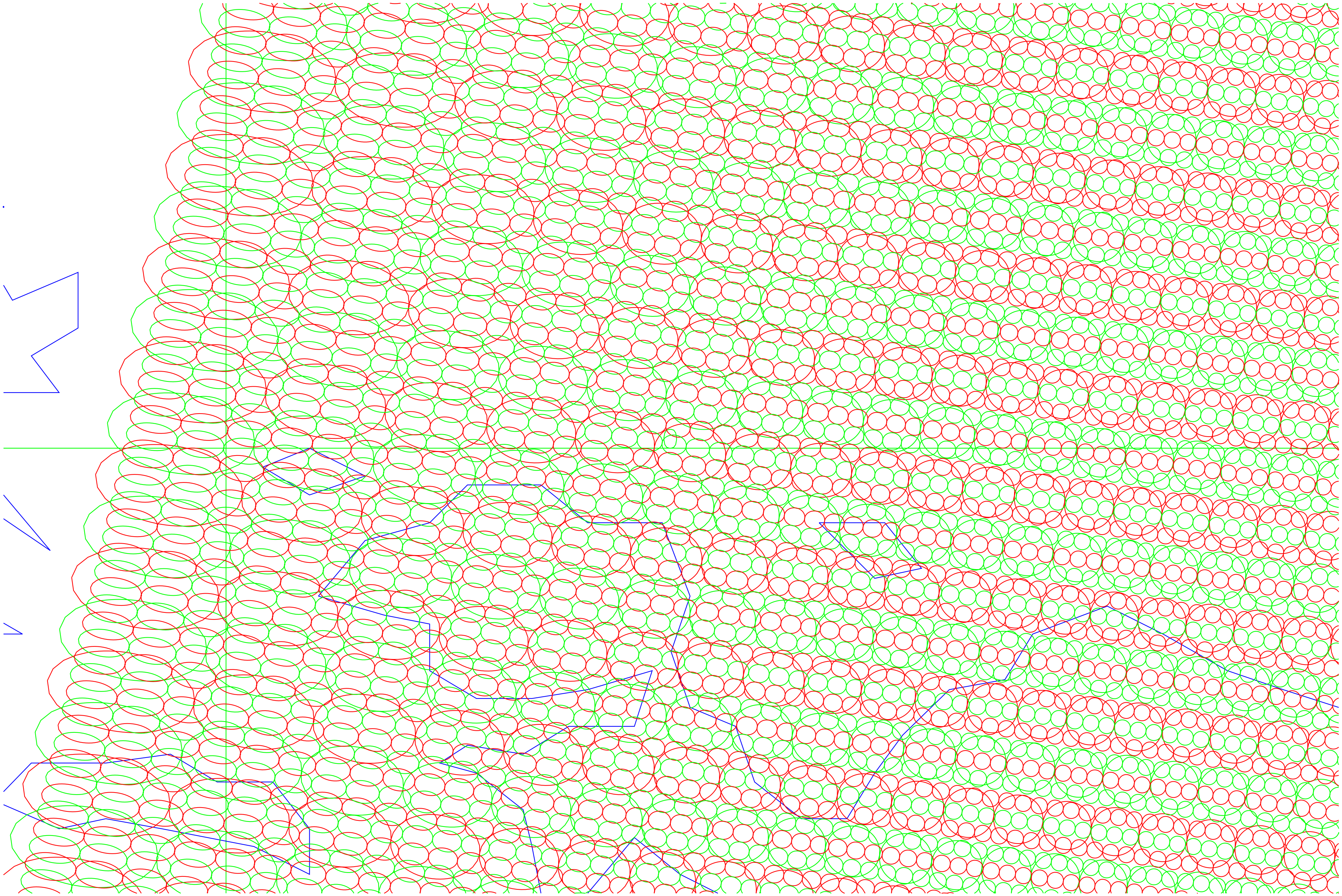
  30 days 09051-09090
- Flagged when space look Ta > 4 sigma from orbital mean
- + = gt +4 sigma from mean: - = lt -4 sigma
- ^ ascending v descending
- Plotted at the spacecraft subpoint when event happened


ce,Channel 1 Days
ce,Channel 2 Days
ce,Channel 3 Days
09051

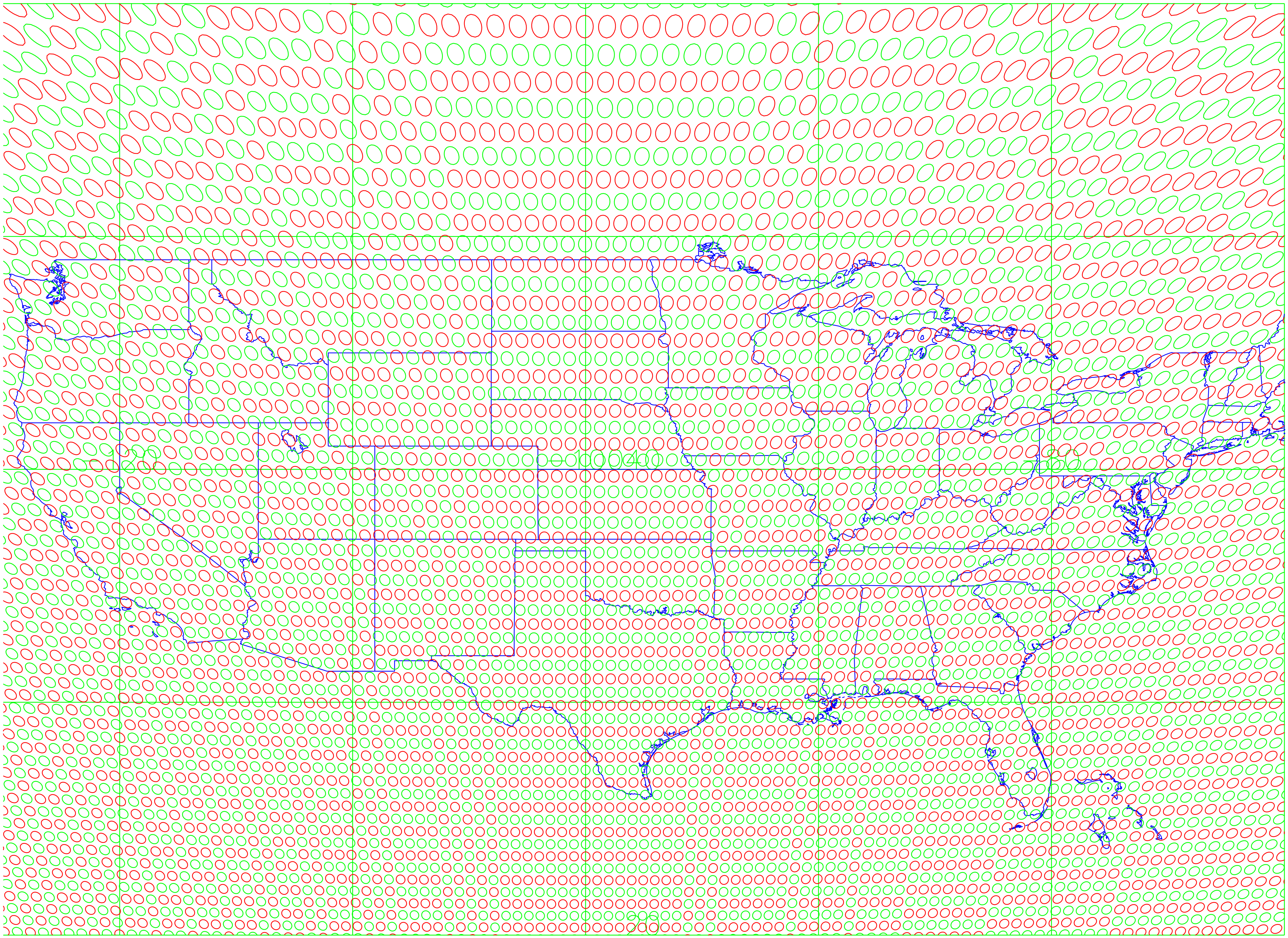
Instrument FOV Depiction

- Uses plane and spherical trigonometry with instrument characteristics and scan characteristics to give a realistic depiction of the scan patterns
- AVHRR,HIRS,SSU,MSU,AMSU-A, AMSUB,MHS,ATMS,AIRS,IASI,SSMIS, GOES
- This lead to a host of applications

NOAA-17 AMSU-A and AMSU-B scan pattern computed analytically.
Coastline is North New Guinea.

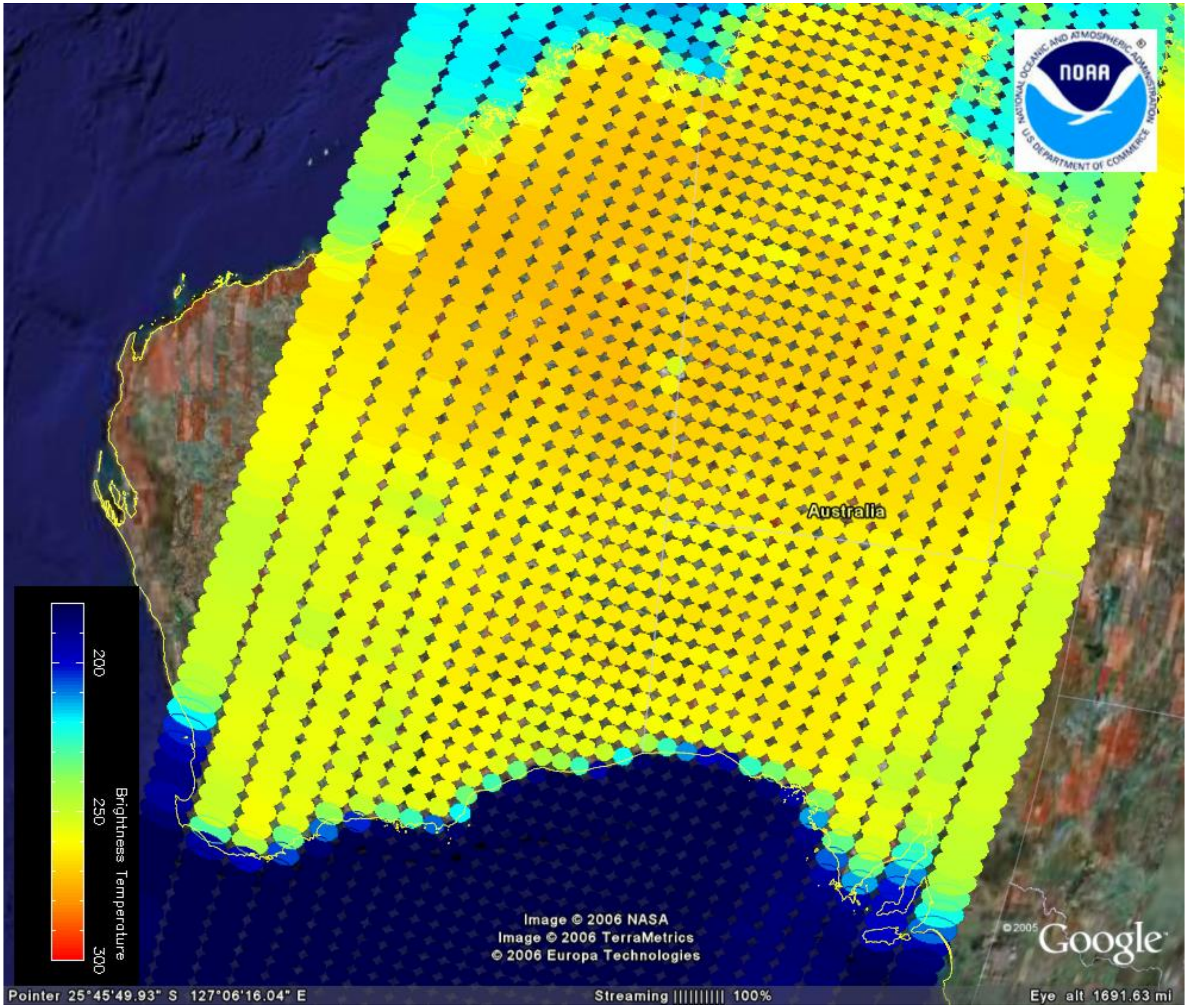


Have also worked out the math for Geo and conical (not shown)

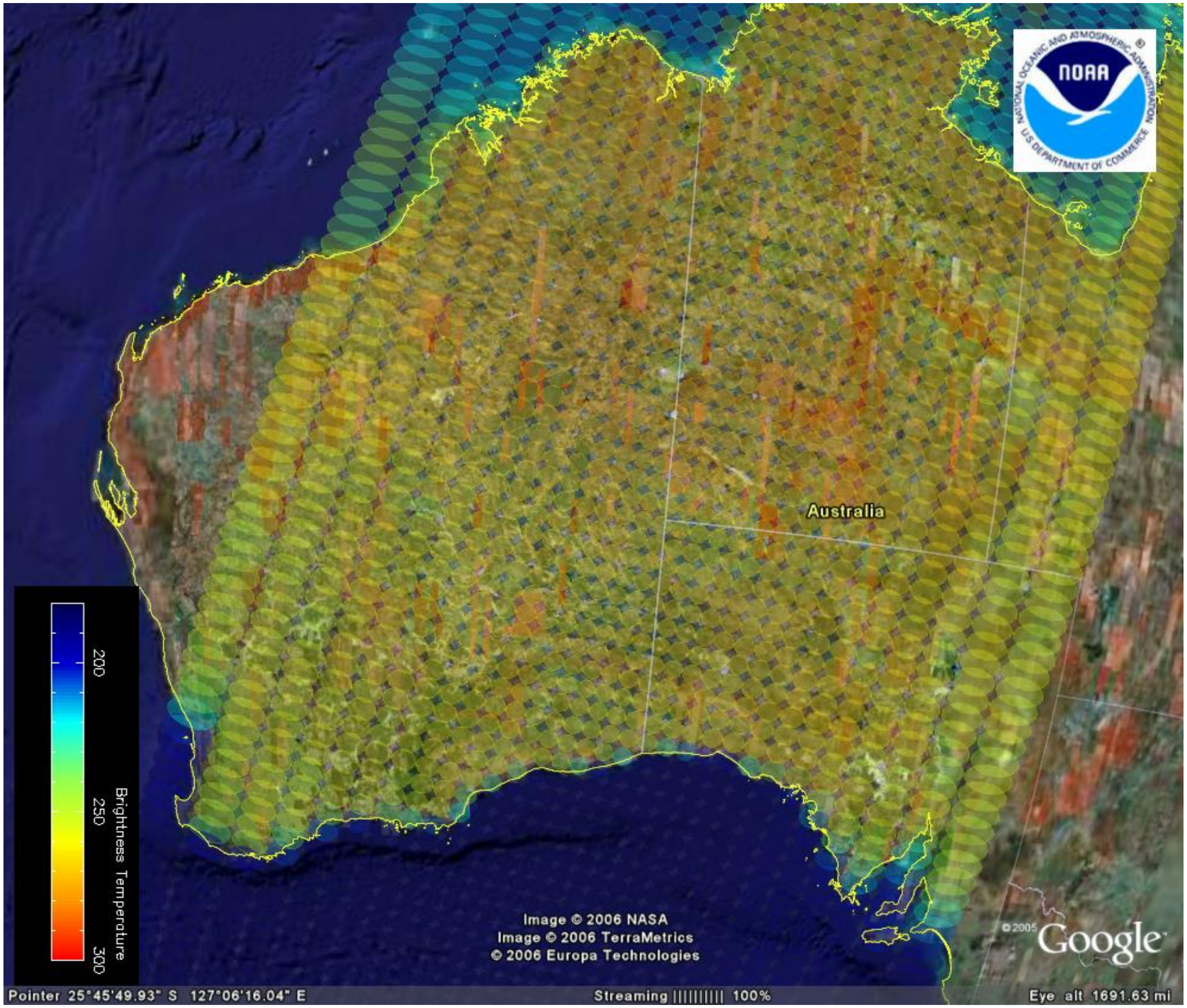


Google Earth Depiction of AMSU

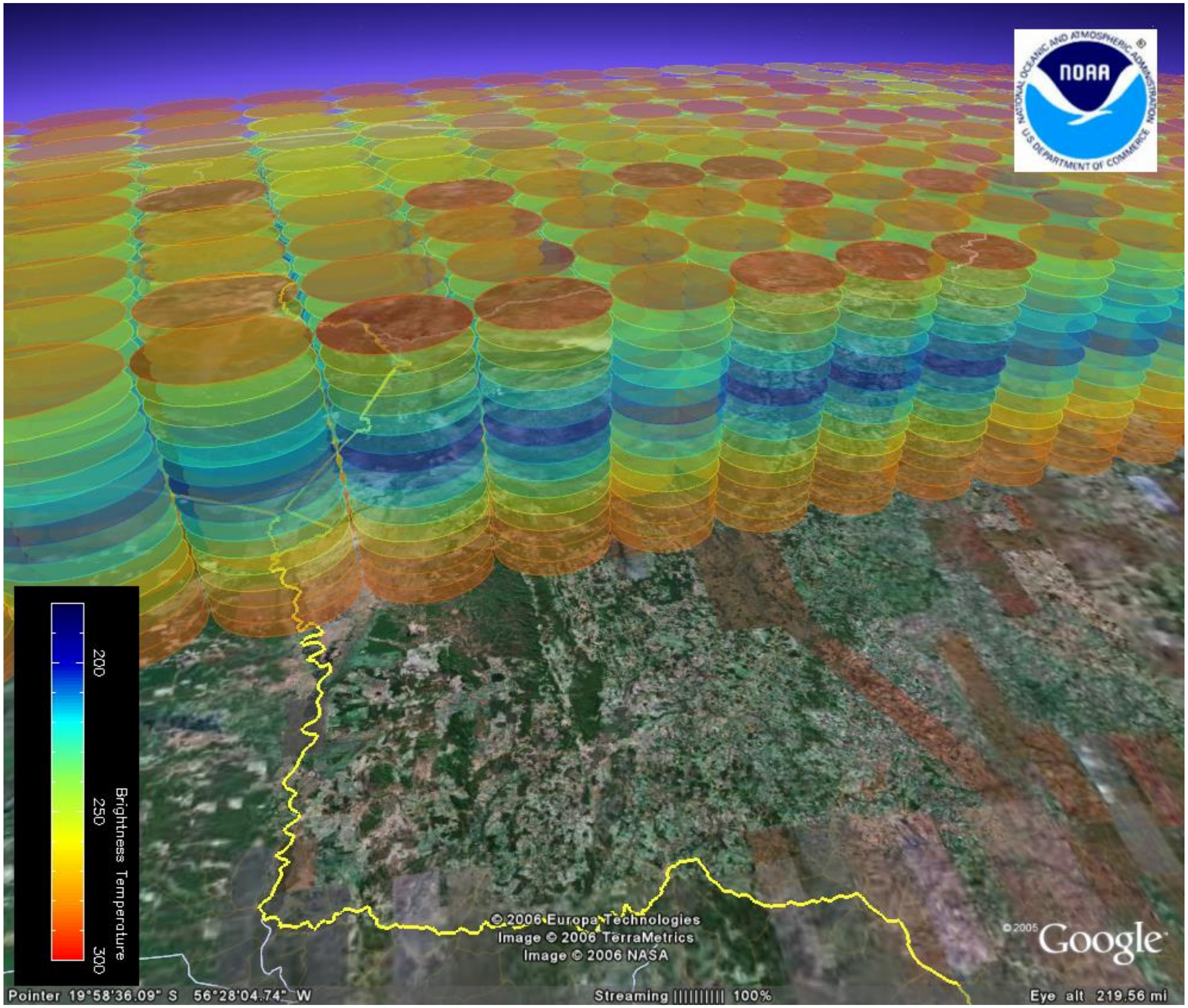
- Most GE applications paste an image on the earth.
- This application draws realistic AMSU fields-of-view as polygons color coded for antenna temperature on the surface or at specified altitude



AMSU-A Channel 1 imagery over Australia at full opacity.



AMSU-A Channel 1 imagery over Australia at half opacity.



AMSU-A-data over Brazil. Channels are stacked in order: Channel 1 at surface, Channel 15 at top. Separation is an arbitrary 10km. This clearly shows the cooling of the atmosphere with height through the troposphere, and warming in the stratosphere. Channel 15 on top indicates surface values.

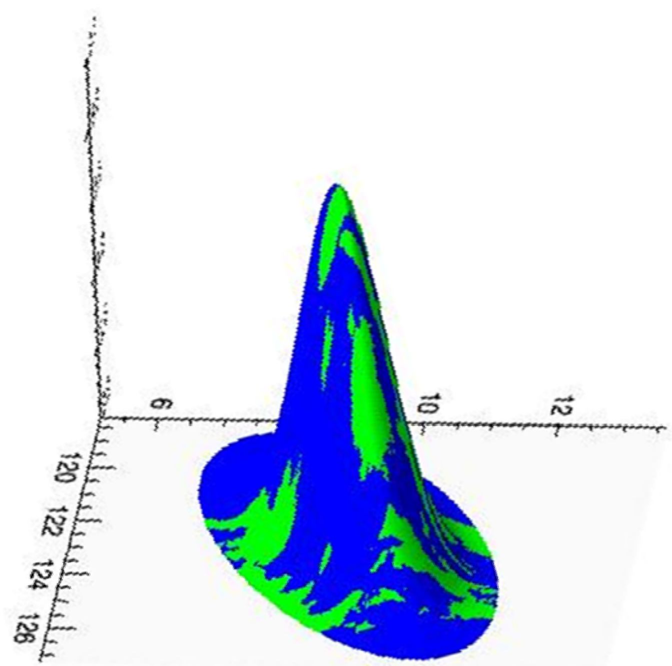
Detection of earth location within specific field of view

- Used fov drawing mathematics to solve inverse problem.
- Given a specific instrument fov and a location on earth, code determines whether that location is within the fov
- Useful for NWP where multiple grid points within fov
- AVHRR,HIRS,SSU,MSU,AMSU-A,AMSU-B,MHS,ATMS,AIRS,IASI

Microwave Antenna Power

- Enhanced fov earth location detection to return relative antenna power for microwave instruments
- Permits radiative transfer over inhomogeneous terrain if surface conditions well known
- AMSU-A,MHS, SSMIS,ATMS,AMSR-E (sort of)
- Code used in EMC SSI analysis

ATMS 5.2° FOV with land-sea warped over relative antenna power



International (A)TOVS Study Conference

- Started by Bill Smith and Rolando Rizzi as an ad hoc meeting to try to get the best use out of the TOVS instruments

- Is now convened as a sub-group of the Radiation Commission of the International Association of Meteorology and Atmospheric Sciences (IAMAS). ITWG continues to organize International TOVS Study Conferences (ITSCs) which have met every 18-24 months since 1983. Through this forum, operational and research users of TIROS Operational Vertical Sounder (TOVS) data from the NOAA series of polar orbiting satellites and other atmospheric sounding data have exchanged information on methods for extracting information from these data on atmospheric temperature and moisture fields and on the impact of these data in numerical weather prediction and in climate studies. They have also prepared recommendations to guide the directions of future research and to influence relevant programs of WMO and other agencies (NASA, NESDIS, EUMETSAT).

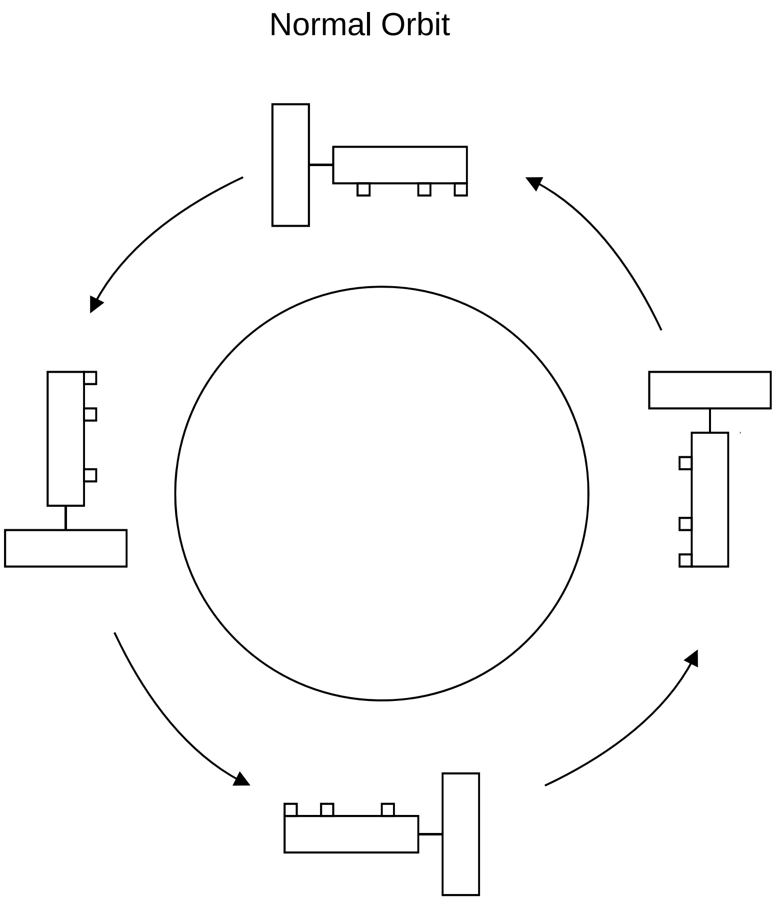
International (A)TOVS Study Conference (*attended)

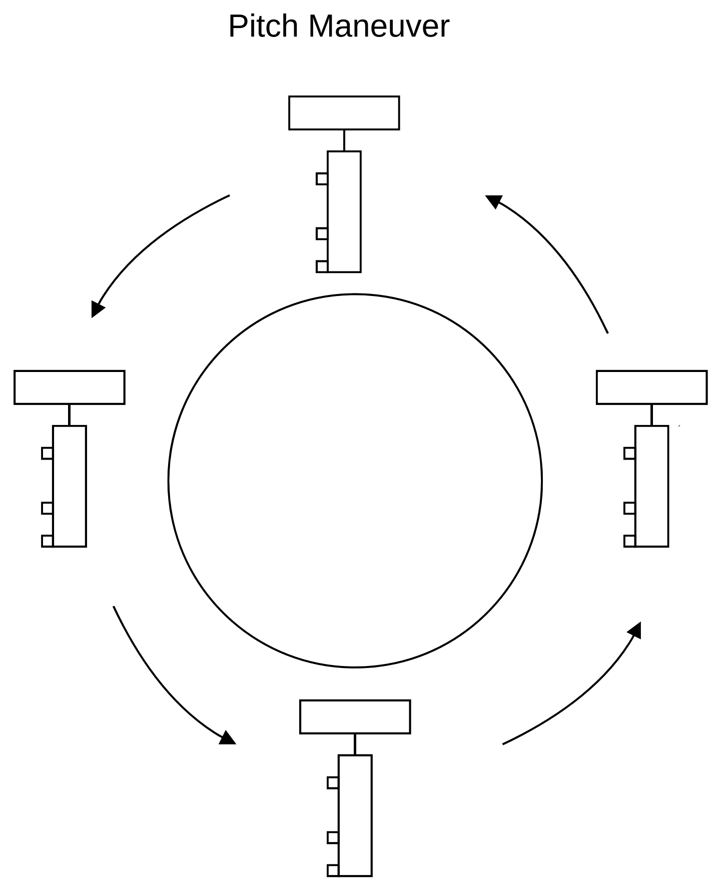
ITSC-I	Igls, Austria	Aug-83	* **
ITSC-II	Igls, Austria	Feb-85	* **
ITSC-III	Madison, Wisconsin, USA	Aug-86	*
ITSC-IV	Igls, Austria	Mar-88	* **
ITSC-V	Toulouse, France	Jul-89	
ITSC-VI	Airlie, Virginia, USA	May-91	*
ITSC-VII	Igls, Austria	Feb-93	
ITSC-VIII	Queenstown, New Zealand	Apr-95	*
ITSC-IX	Igls, Austria	Feb-97	*
ITSC-X	Boulder Colorado, USA	Jan-99	*
ITSC-XI	Budapest, Hungary	Sep-00	*
ITSC-XII	Lorne, Australia	Feb-02	*
ITSC-XIII	Sainte Adele, Canada	Oct-03	*
ITSC-XIV	Beijing, China	May-05	*
ITSC-XV	Maratea, Italy	Oct-06	* **
ITSC-XVI	Angra dos Reis, Brazil	May-08	*
ITSC-XVII	Monterey, California, USA	Apr-10	* **

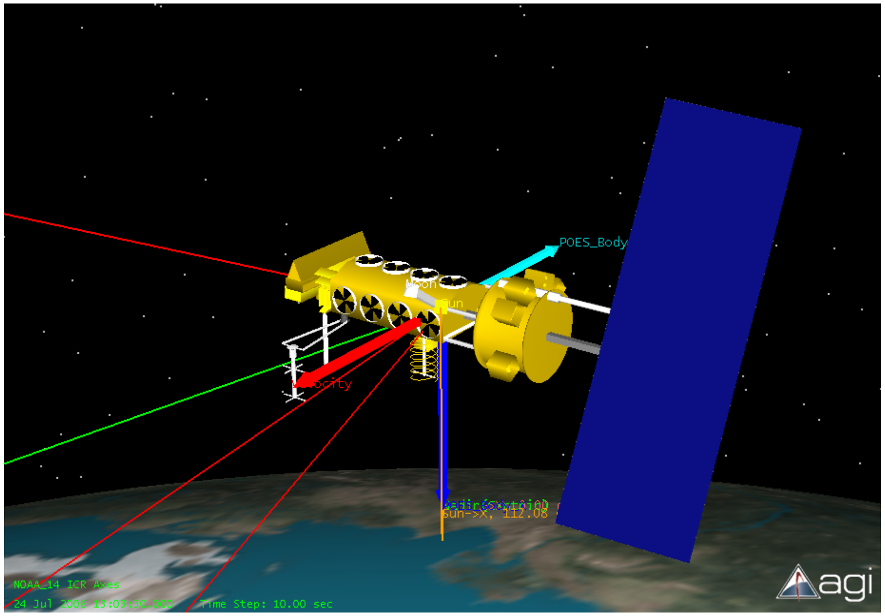
NOAA-14 Pitch Maneuver

- Requested a pitch maneuver to evaluate asymmetry on the MSU
- NOAA-14 almost 12 years old at that point
- Permission given to use as training for SOCC engineers
- Maneuver successfully executed 10 Aug 2006
- Seven weeks later a hydrazine thruster cut loose, sending N14 into a tumble. SOCC engineers brought the SC back using techniques perfected for the maneuver
- Additional data were collected from the tumble

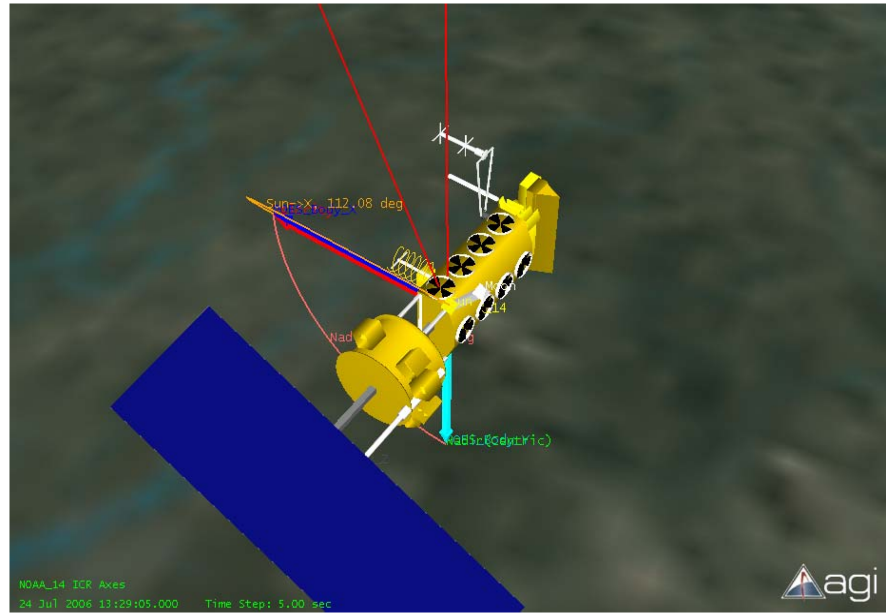
Pitch Over Maneuver



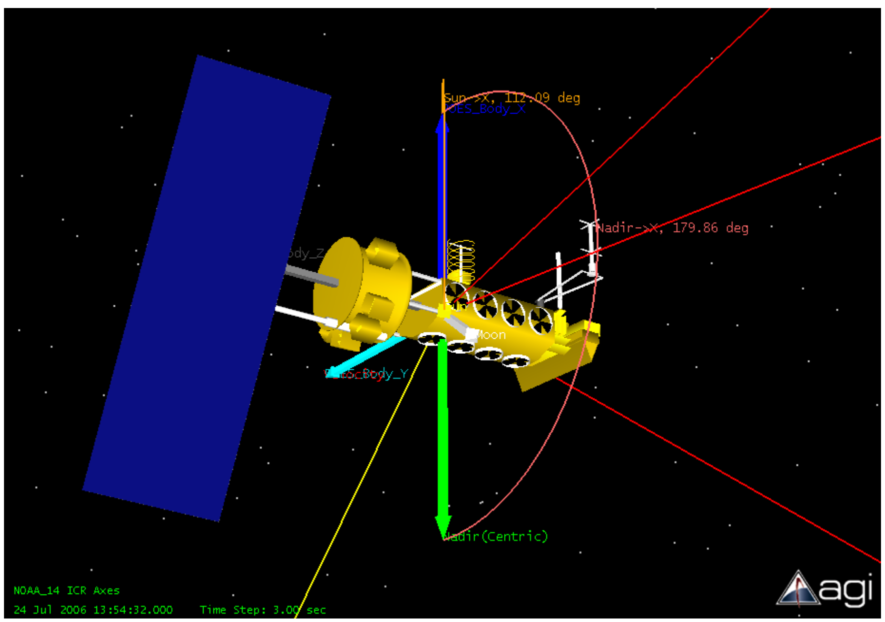




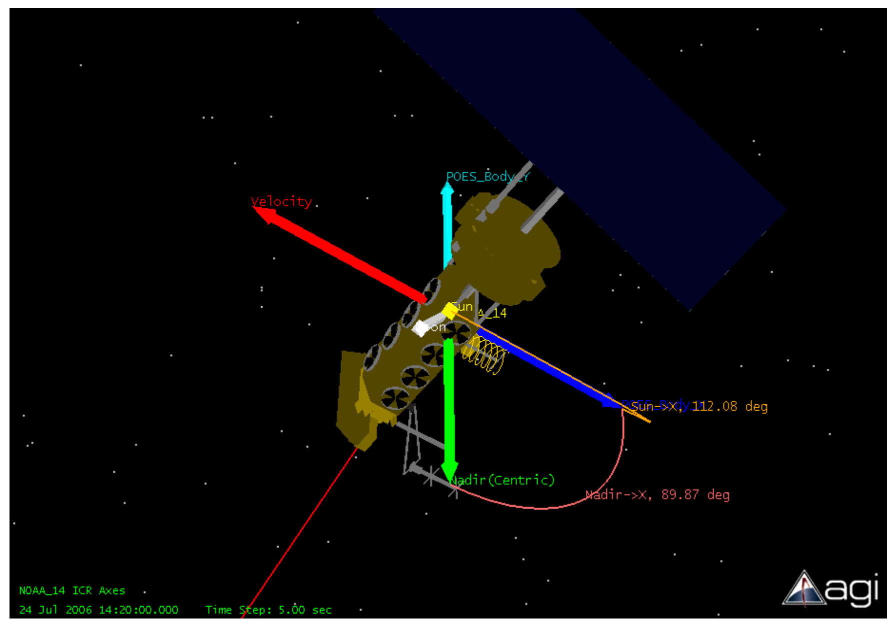
0 Deg into POM at 80 Deg north Lat ascending over Russia



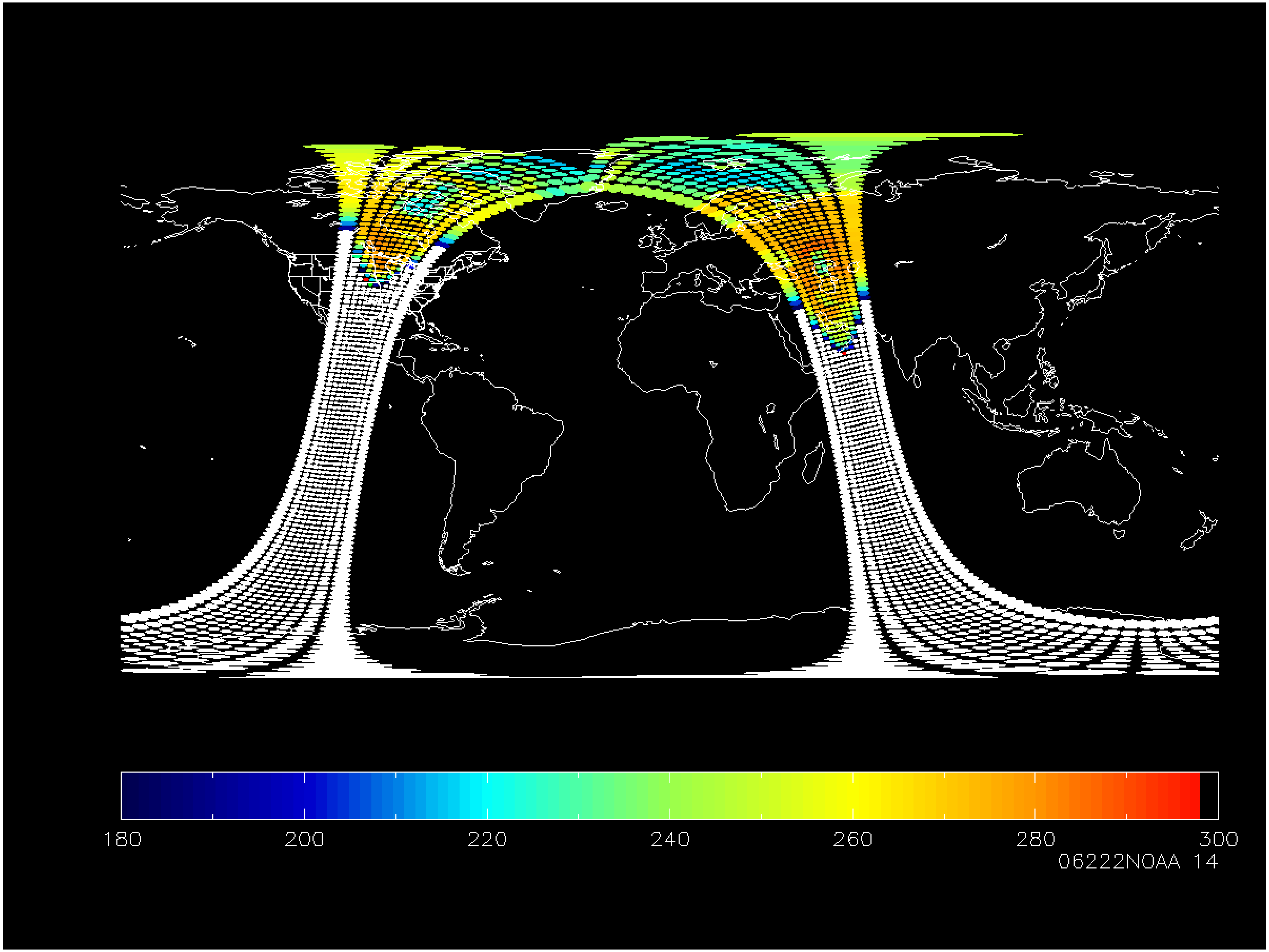
90 Deg into POM at 10 Deg north Lat descending from Wallops



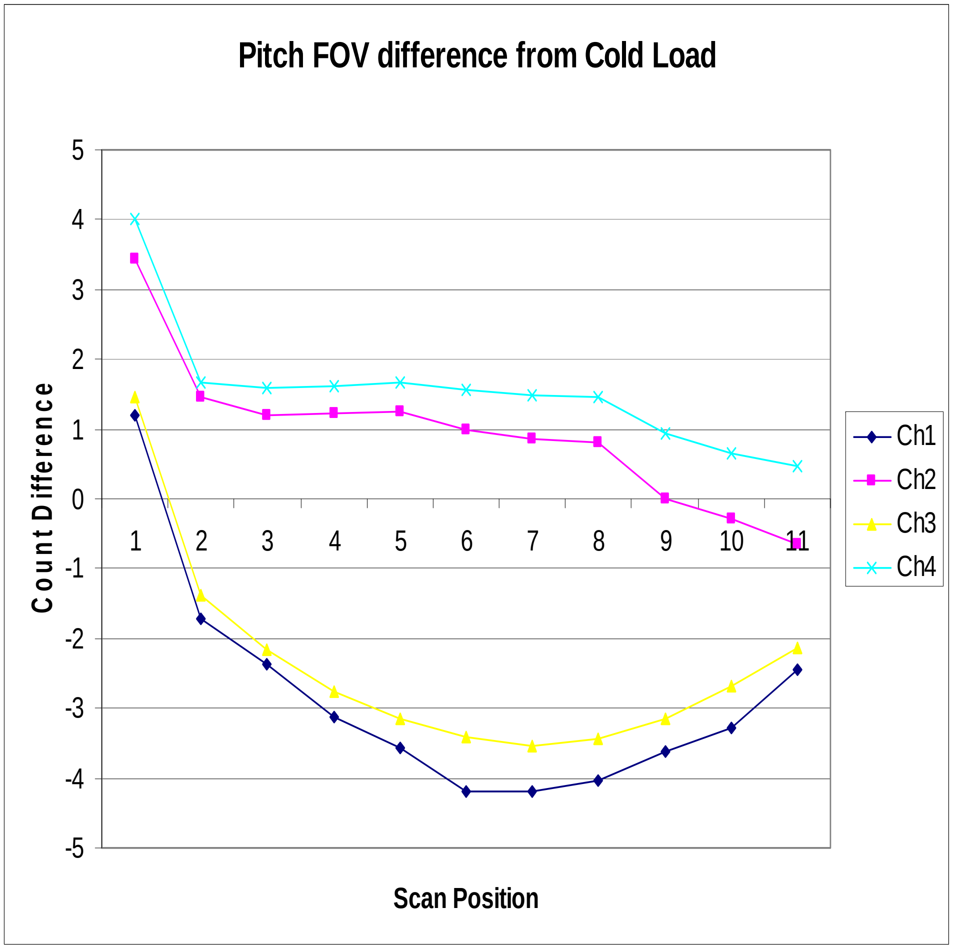
180 Deg into POM at 80 Deg south Lat descending towards McMurdo

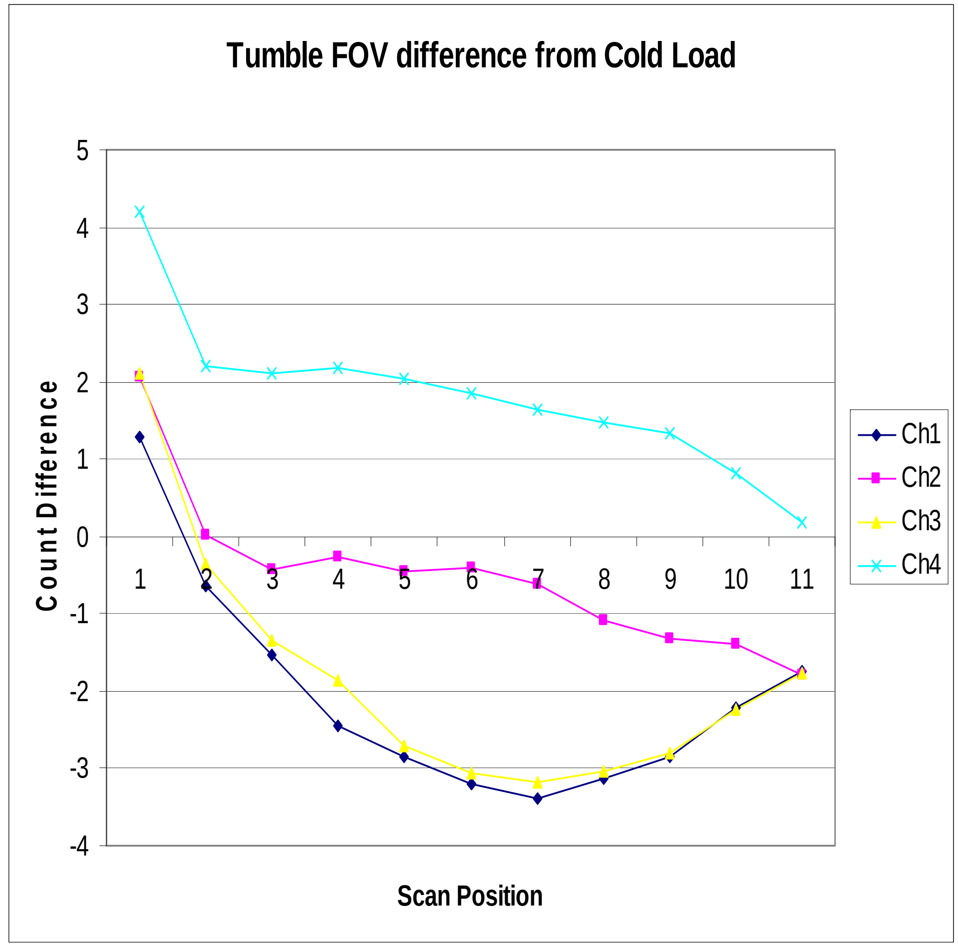


270 Deg into POM at 10 Deg south Lat ascending away from McMurdo


180
200
220
240
260
280
300
06222NOAA 14

Real Time


Pitch FOV difference from Cold Load
5
4
3
2
1
0
-1
-2
-3
-4
-5
Count Difference
1
2
3
4
5
6
7
8
9
10
11
Scan Position
Ch1
Ch2
Ch3
Ch4


Tumble FOV difference from Cold Load
5
4
3
2
1
0
-1
-2
-3
-4
Count Difference
1
2
3
4
5
6
7
8
9
10
11
Scan Position
Ch1
Ch2
Ch3
Ch4

Integrated Program Office

- Involved with IPO since inception in 1995
- Member Microwave Operational Algorithm Team
- Participated in CMIS source selection
- Participated in prime contractor source selection
- Glad that the President ordered a divorce
- Keeping open option for part time work on JPSS

That's All Folks!

- I think you will agree with my assessment that I am a Jack of All Trades, and Master of None

- Thanks for listening

So Long

And thanks for all the fish.

Douglas Adams 1952-2001