行政院所屬各機關因公出國人員出國報告書

（出國類別：　考察　）

考察美國光達雷達及地球觀測衛星遙測應用等懸浮微粒垂直剖面監測技術

服務機關：行政院環境保護署

出國人 職　稱：環境監測及資訊處技正　環境監測及資訊處技士

姓　名：吳權芳　王世奇

出國地點：美國

出國期間：民國九十二年十月十八日至十月二十九日

報告日期：九十三年一月二十九日

行政院研考會/省（市）研考會編號欄

I5/C09203580

行政院及所屬各機關出國報告書提要

公 務 出 國 報 告 提 要

頁數：30 頁(未含附錄)

報告名稱：

考察美國光達雷達及地球觀測衛星遙測應用等懸浮微粒垂直剖面監測技術

主辦機關：

行政院環境保護署

出國人員：

吳權芳 行政院環境保護署 環境監測及資訊處 技正

王世奇 行政院環境保護署 環境監測及資訊處 技士

出國類別：中美環保技術合作計畫出國考察

出國地區：美國

出國期間：民國 92 年 10 月 18 日至 10 月 29 日

報告日期：民國 93 年 1 月 29 日

分類號/目：I5/化學與環境科學

內容摘要：本次出國考察計畫主要觀摩美國地球觀測衛星之中解析度影像分光光譜儀（MODIS）、光達雷達（Lidar）監測及資料分析運用技術，以引進國際監測經驗並蒐集相關最新資訊，作為本署大陸沙塵暴密集觀測實驗計畫與空氣品質監測業務推動參考，並可增強我國與美國環保合作關係。

一、考察美國 SeaSpace 公司地球觀測衛星之中解析度影像分光光譜儀（MODIS）資料格式、分析及運用方式。

二、參訪美國太空總署（NASA）光達雷達監測站運轉操作建置與地球觀測衛星之中解析度影像分光光譜儀（MODIS）資料分析及運用技術。

(一)光達雷達（Lidar）主要是要加強瞭解懸浮微粒垂直剖面監測分析技術，本次考察地點--美國太空總署，其階段性研究目

的為：1.測試、評估新的監測分析方法，並嘗試建立新方法與舊方法間之可比較度（comparability），以及決定這些新方法在空氣品質計畫、暴露評估、健康衝擊影響上之應用性；2.改進光達雷達技術應用，並將軟、硬體技術移轉給業界使用。

（二）美國太空總署針對地球觀測衛星之中解析度影像分光光譜儀（MODIS）資料長期研究，其設計目的涵括：1.驗證不同區域衛星影像資料及演算方程式；2.提出不同影像產品並尋求合適之監測分析方法（具比較性、對照性的方法）；3.為監測工作加值（提升大型監測網和研究之效益）；4.投資共享（美國太空總署與其他部會資源合作已節省國家投資成本）等四大目標，為監測工作加值及投資共享尤其是我們應努力的目標。

目 錄

第一章 緒言

1-1 緣起

由於懸浮微粒一向為國內造成空品質不良之指標污物，為確認本署空氣品質監測網站監測數據品質及加強懸浮微粒組成成分及物化特性之監測等工作，透過本項考察提供本署建立衛星遙測技術參考及監測數據與國際可比較性，確屬迫切需要。

本案係本署九十二年度中美環保技術合作計畫項目，由美國環保署提供參訪單位建議，馬里蘭州之美國太空總署高登太空飛行中心(NASA Goddard Space Flight Center)，協助本署進行光達雷達及地球觀測衛星遙測應用於大氣懸浮微粒垂直剖面監測技術考察。

本署於九十二年十月採購一套 SeaSpace 公司中解析度影像分光光譜儀（MODIS）資料分析處理軟體，並與交通部中央氣象局合作，共用其接收之衛星原始資料，為配合本署設置中解析度影像分光光譜儀(MODIS)資料分析處理之需，安排考察位於美國加州地區 Poway 之 SeaSpace 公司運作管理相關技術。

1-2 目的

1-2-1 地球觀測衛星之中解析度影像分光光譜儀（MODIS）資料分析及運用技術

參訪美國 SeaSpace 公司及太空總署高登太空飛行中心(NASA Goddard Space Flight Center)，瞭解中解析度影像分光光譜儀（MODIS）資料分析、操作及建置等相關技術外，並提供本署建置中解析度影像分光光譜儀（MODIS）資料分析參考，並可藉由中解析度影像分光光譜儀（MODIS）資料分析研判，作為以往本署地面空氣品質監

測站網監測空氣污染物或突發高污染事件案例參考，及提供國內衛星監測影像數據可與國際有比較性。

1-2-2 光達雷達監測站運轉操作建置

觀摩美國太空總署高登太空飛行中心(NASA Goddard Space Flight Center)光達校正實驗室，初步認識全球光達監測站運轉管理現況及光達研究中心計畫執行情形，吸收先進監測經驗並蒐集相關最新資訊，作為本署未來建置光達監測站及操作運轉方式之參考。

1-3 考察行程與出席人員

本次考察期間自 92/10/18 至 92/10/29 日，考察期間分別與受訪單位人員及其專家進行意見交流，及實地觀摩美國太空總署高登太空飛行中心(NASA Goddard Space Flight Center)光達校正實驗室執行標準光源追溯校正程序、加州 Poway 之 SeaSpace 公司現場設備及中解析度影像分光光譜儀（MODIS）資料運作情形；相關行程如表一，行程簡介整理如附錄 1 所示，受訪人員如下：

1. 美國加州 Poway 之 SeaSpace 公司，與負責中解析度影像分光光譜儀（MODIS）受訪人員及其負責業務說明如下：
（1）Kota S. Prasad-負責衛星影像產品研發及其加值應用研究工作，協助解說整個中解析度影像分光光譜儀（MODIS）產品運用領域情形。
（2）David E. Wilensky-SeaSpace 公司操作運轉及技術研發部門主管，此次提供中解析度影像分光光譜儀（MODIS）技術指導。
（3）Kevin B. Davis-負責 SeaSpace 公司商務發展部門主

管，此次提供全球中解析度影像分光光譜儀（MODIS）建置地點分佈說明。

2. 美國太空總署高登太空飛行中心(NASA Goddard Space Flight Center)受訪人員

（1） Dr. ELLSWORTH J. WELTON-負責光達雷達儀器在大氣環境應用之研究人員。

（2） Dr. Si-Chee Tsay-負責光達雷達及地球觀測衛星系統之專案研究人員。

（3） Dr. Allen Chu-負責全球中解析度影像分光光譜儀（MODIS）之觀測研究人員。

表一、出國行程

日期	地點
九十二年十月十八日(星期六)	台灣到洛杉磯
九十二年十月十九日(星期日)	洛杉磯到聖地牙哥
九十二年十月二十至二十二日(星期一至三)	聖地牙哥
九十二年十月二十三日(星期四)	聖地牙哥至華盛頓
九十二年十月二十四至二十五日(星期五至六)	華盛頓
九十二年十月二十六日(星期日)	華盛頓至洛杉磯至聖地牙哥
九十二年十月二十七至二十八日(星期一至二)	聖地牙哥
九十二年十月二十九日(星期三)	聖地牙哥至洛杉磯至台灣

第二章 美國加州 SeaSpace 公司考察紀要

2-1 中解析度影像分光光譜儀（MODIS）

2-1-1 簡介

EOS 衛星軌道高度為距地球 705 公里，目前的第一顆上午軌道衛星過境時間為地方時 11：30am 左右，一天最多可以獲得 4 條過境軌道資料。

EOS 系列衛星上的最主要的儀器是中解析度影像分光光譜儀（MODIS），其最大空間解析度可達 250 米 。MODIS 是當前世界上新一代“圖譜合一”的光學遙感儀器，有 36 個離散光譜波段，光譜範圍寬，從 0.4 微米（可見光）到 14.4 微米（熱紅外）全光譜覆蓋 。

MODIS 的多波段資料可以同時提供反映陸地表面狀況、雲邊界、雲特性、海洋水色、浮游植物、生物地理、化學、大氣中水汽、氣溶膠、地表溫度、雲頂溫度、大氣溫度、臭氧和雲頂高度等特徵的資訊。可用於對陸地表面、生物圈、大氣和海洋進行長期全球觀測。

中解析度影像分光光譜儀（MODIS）最大空間解析度可達 250 米，掃描寬度 2330 公里。MODIS 是 CZCS、AVHRR、HIRS 和 TM 等儀器的繼續。MODIS 是被動式影像分光輻射計。共有 490 個探測器，分佈在 36 個光譜波段，從 0.4 微米（可見光）到 14.4 微米（熱紅外）全光譜覆蓋。

2-1-2 MODIS 儀器的對地觀測

MODIS 儀器的地面解析度為 250m、500m 和 1000m，掃描寬度為 2330km。在對地觀測過程中，每秒可同時獲得 6.1 兆比特的來自大

氣、海洋和陸地表面資訊，每兩日可獲取一次全球觀測資料。

2-1-3 MODIS 儀器特性、波段範圍和主要用途

通道	光譜範嚋 1～19nm 通道 20～36 μm 通道	信噪比 NE ΔT	主要用途	解析度（m）
1	620～670	128	陸地、雲邊界	250
2	841～876	201		250
3	459～479	243	陸地、雲特徵	500
4	545～564	228		500
5	1230～1250	74		500
6	1638～1652	275		500
7	2105～2135	110		500
8	405～420	880	海洋水色浮游植物生物地理化學	1000
9	438～448	8380		1000
10	483～493	802		1000
11	526～536	754		1000
12	545～556	750		1000
13	662～672	910		1000
14	673～683	1087		1000
15	743～753	586		1000
16	862～877	576		1000
17	890～920	167	大氣、水汽	1000
18	931～941	57		1000
19	915～965	250		1000
20	3.660～3.840(μm)	0.05	地球表面和雲頂溫度	1000
21	3.929～3.989(μm)	2.00		1000
22	3.929～3.989(μm)	0.07		1000
23	4.020～4.080(μm)	0.07		1000
24	4.433～4.498(μm)	0.25	大氣溫度	1000

25	4.482～4.948(μm)	0.25		1000
26	1.360～1.390(μm)	1504	卷雲、水汽	1000
27	6.535～6.895(μm)	0.25		1000
28	7.175～7.475(μm)	0.25		1000
29	8.400～8.700(μm)	0.05		1000
30	9.589～9.880(μm)	0.25	臭氧	1000
31	10.780～11.280(μm)	0.05	地球表面和雲頂溫度	1000
32	11.770～12.270(μm)	0.05		1000
33	13.185～13.485(μm)	0.25	雲頂高度	1000
34	13.485～13.785(μm)	0.25		1000
35	13.785～14.085(μm)	0.25		1000
36	14.085～14.385(μm)	0.35		1000

2-1-4 MODIS 與 NOAA 衛星和陸地衛星相比之特點和優勢

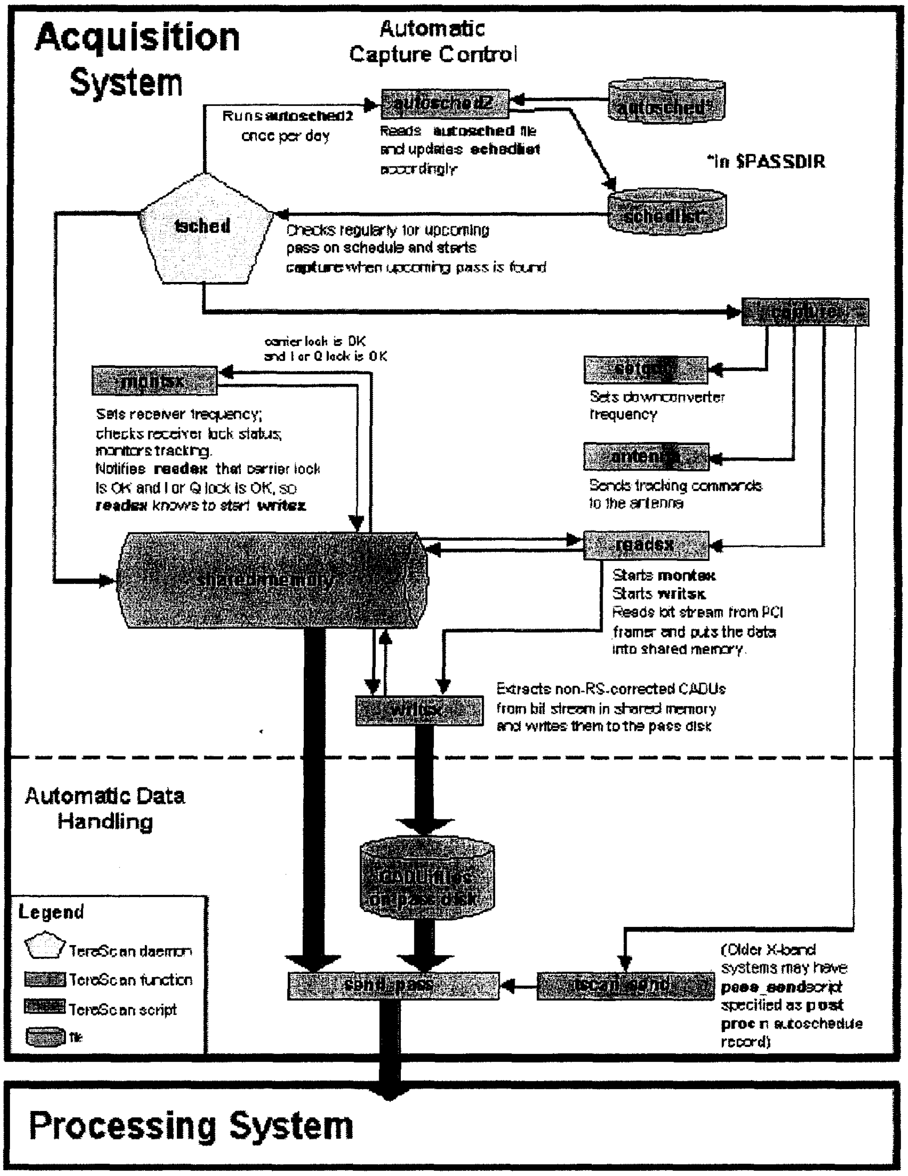
1·空間解析度大幅提高。空間解析度提高了一個量級，由 NOAA 的千米級提高到了 MODIS 的百米級。

2·時間解析度有優勢。一天可過境 4 次 ，對各種突發性、快速變化的自然災害有更強的即時監測能力。

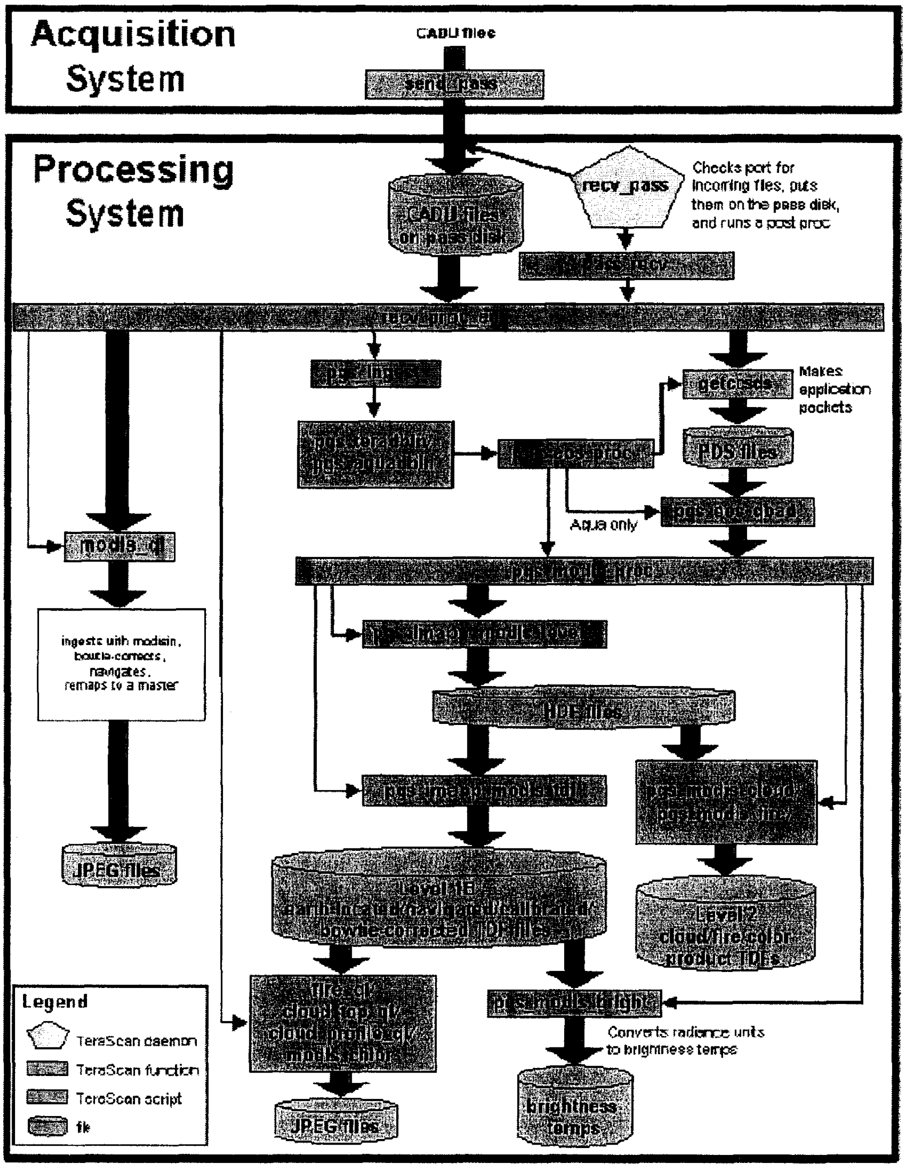
3·光譜解析度大大提高。有 36 個波段，這種多通道觀測大大增強了對地球複雜系統的觀測能力和對地表類型的識別能力。

2-2 MODIS 系統架構

1. 資料接收系統：

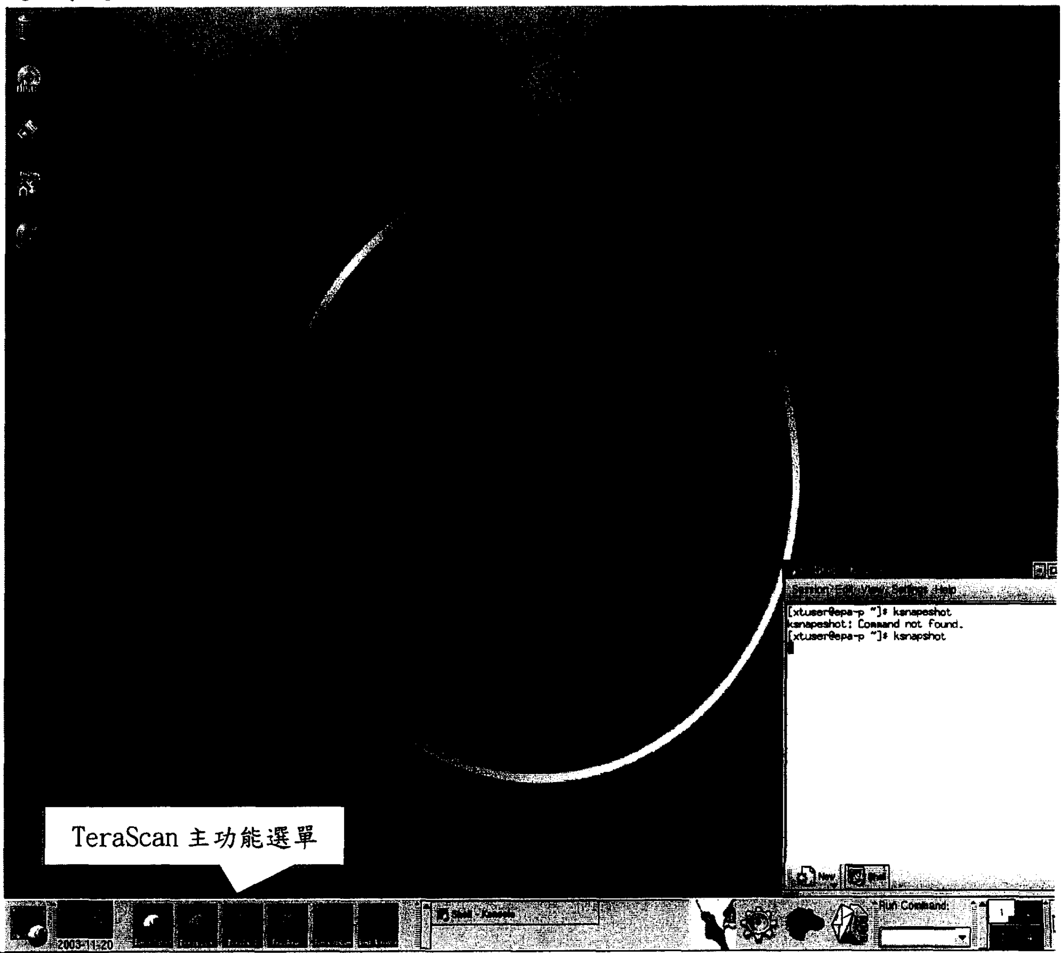


2. 資料後處理系統：


Acquisition System
CADU files
send_pass
Processing System
CADU files on pass disk
recv_pass
Checks port for incoming files, puts them on the pass disk, and runs a post proc
modis_ql
getccsds
Makes application packets
PDS files
Aqua only
ingests with modisin, bowtie-corrects, navigates, remaps to a master
JPEG files
Level 1B
bowtie-corrected TDF files
Level 2
cloud/fire/color
product TDFs
Converts radiance units to brightness temps
brightness temps
JPEG files
Legend
TeraScan daemon
TeraScan function
TeraScan script

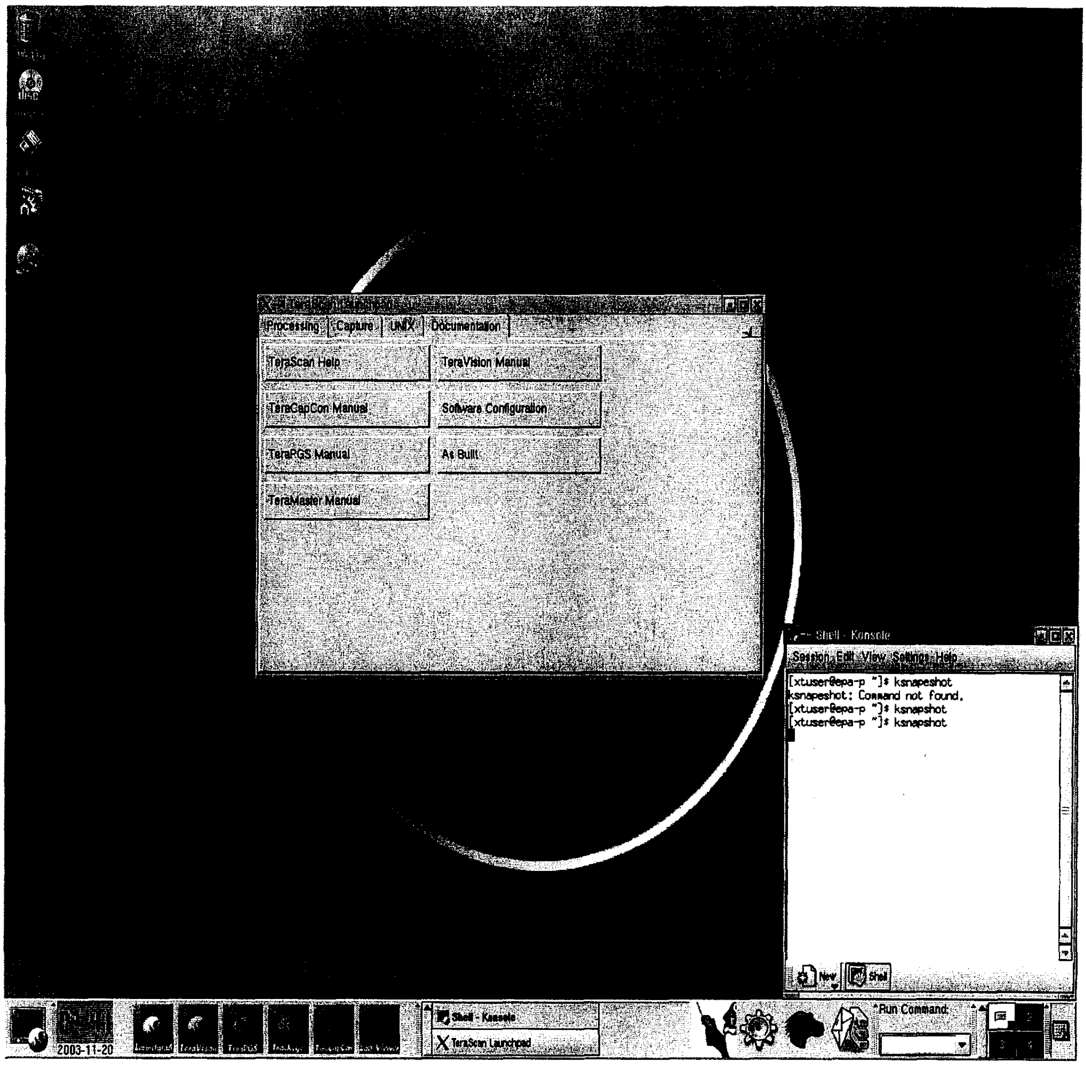
2-3 MODIS 系統作業功能

1. 進入系統



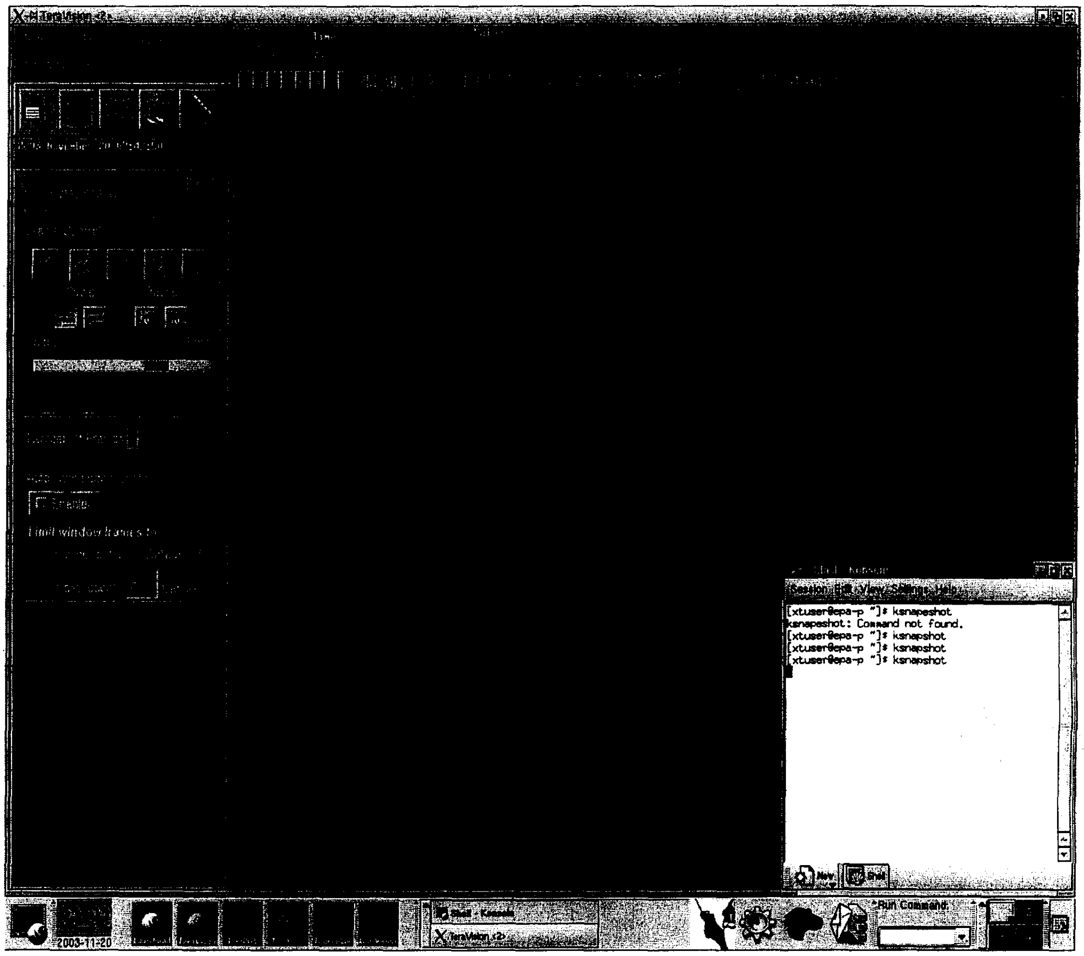
Launchpad	軟體啟動工作台模組
TeraVision	衛星影像處理模組
TeraPGS	產品自動程序管理模組
Trackeye	衛星資料接收監控模組
TeraCapcom	衛星排程管理模組
Log View	系統訊息資料模組

2. 軟體啟動工作台模組



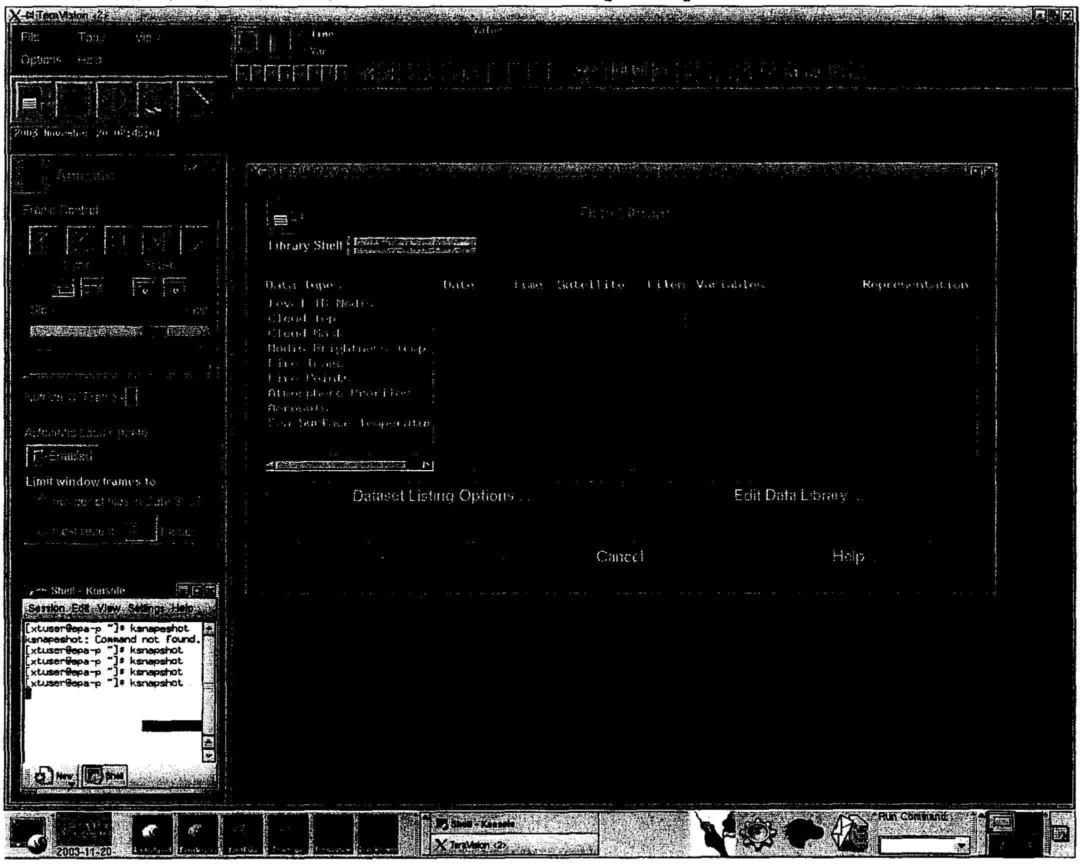
Processing
Capture
UNIX
Documentation
TeraScan Help
TeraVision Manual
TeraCapCon Manual
Software Configuration
TeraRGS Manual
As Built
TeraMaster Manual
Shell - Konsole
Session Edit View Settings Help
[xtuser@epa-p ~]$ ksnapeshot
ksnapeshot: Command not found.
[xtuser@epa-p ~]$ ksnapshot
[xtuser@epa-p ~]$ ksnapshot
New
Shell
2003-11-20
Shell - Konsole
TeraScan Launchpad
Run Command:

3. 衛星影像處理模組


[xtuser@epa-p ~]$ ksnapeshot
ksnapeshot: Command not found.
[xtuser@epa-p ~]$ ksnapshot
[xtuser@epa-p ~]$ ksnapshot
[xtuser@epa-p ~]$ ksnapshot
2003-11-20
Run Command:

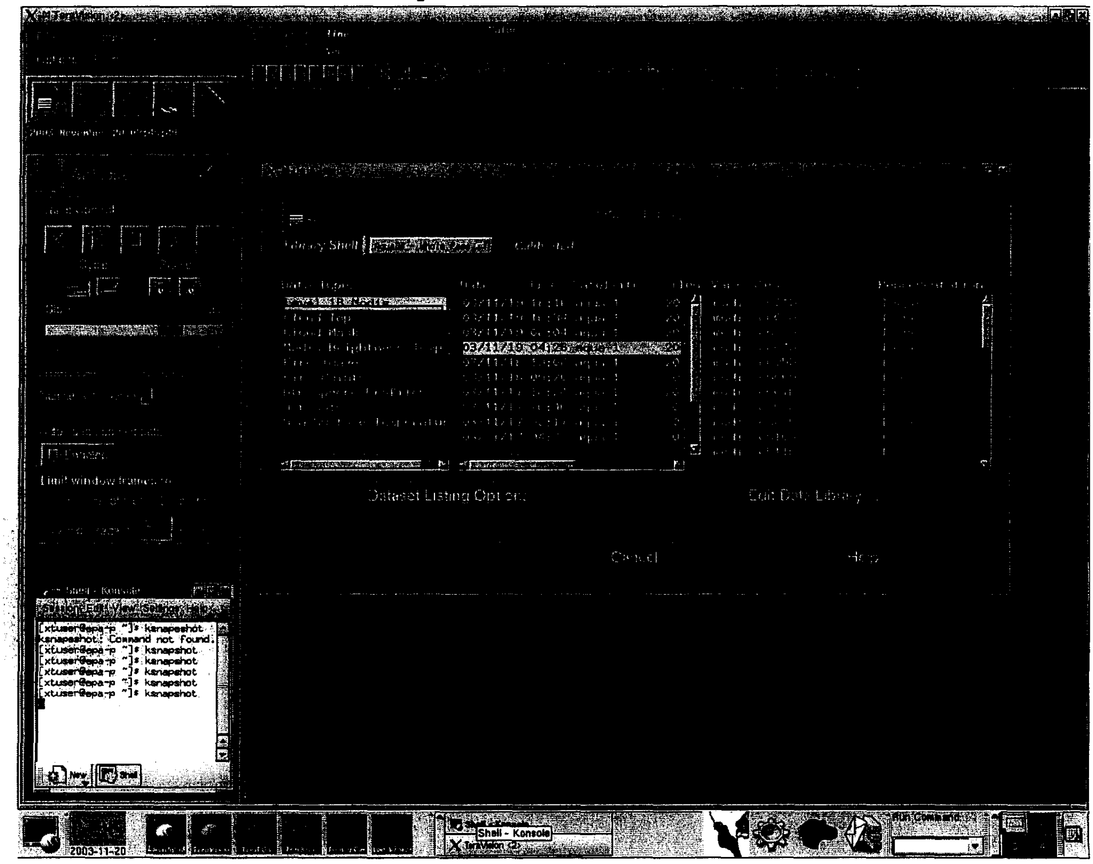
3-1. 衛星影像處理模組

產品影像選取(Tera, Tera WholePass, Aqua, Aqua WholePass)



3-2. 衛星影像處理模組

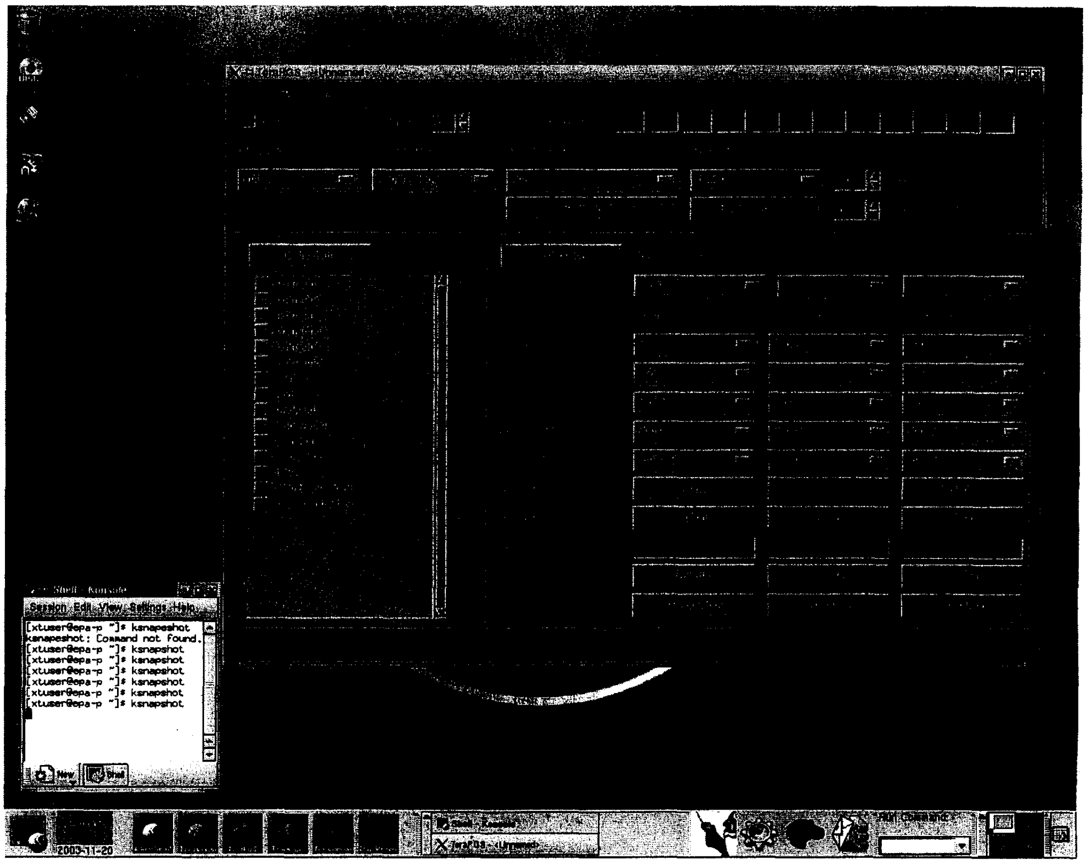
產品影像選取(Level 1B Modis, Cloud Top, Cloud Mask, Modis Brightness Temp, Fire Image,Fire Point, Atmosphere Profiler, Aerosols, Sea Surface Temperature)



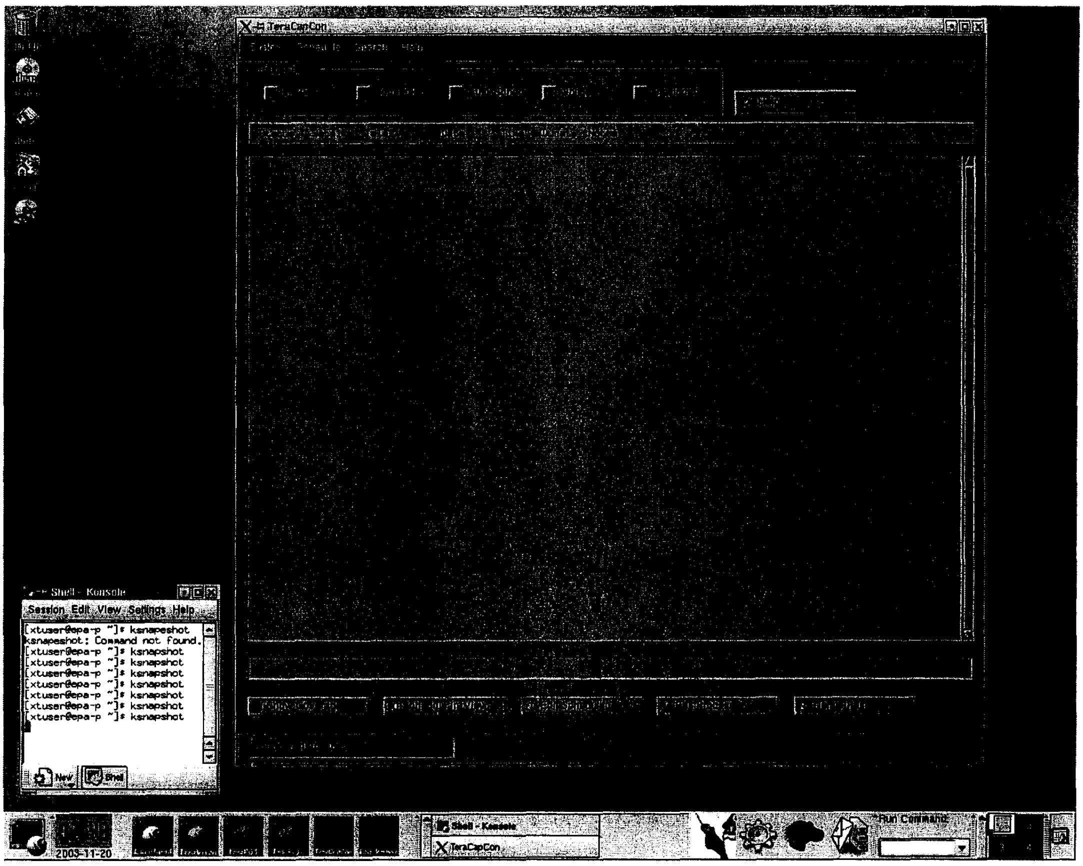
3-3. 衛星影像處理模組

選取衛星經過(PASS)時間，衛星頻道

4. 產品自動程序管理模組

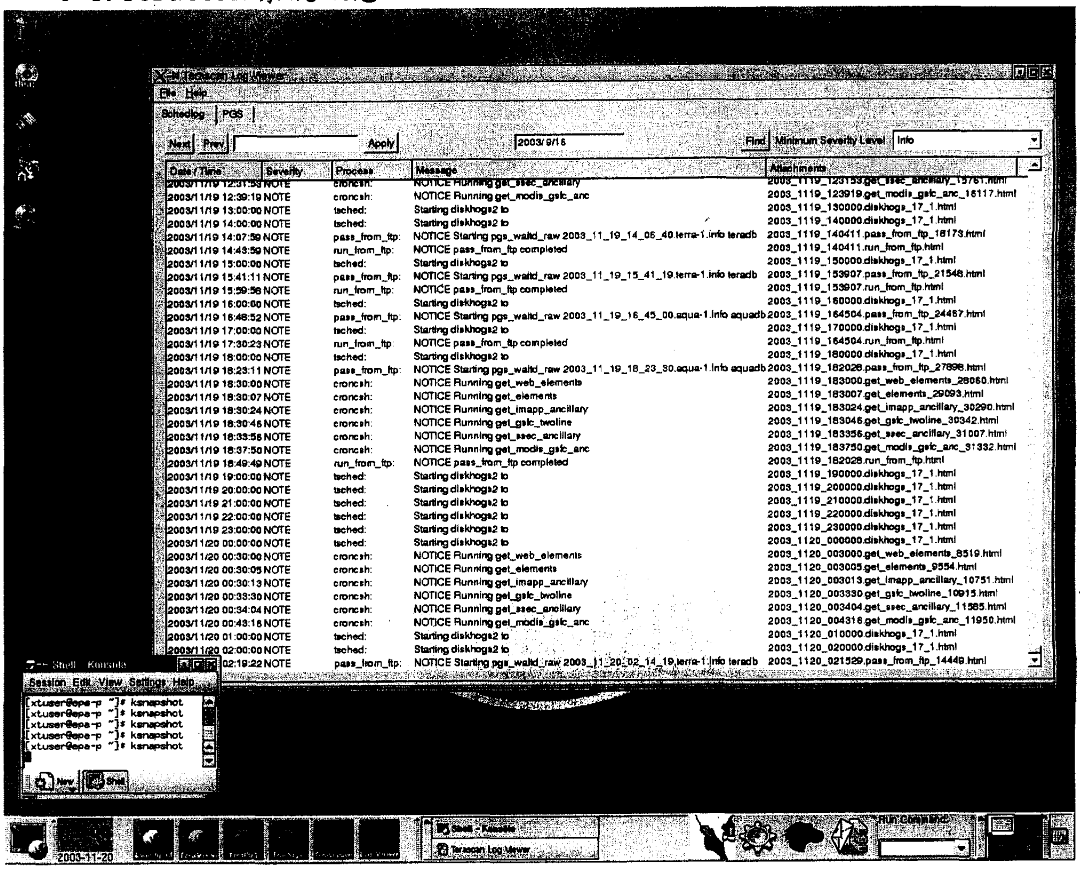


5. 衛星資料接收監控模組

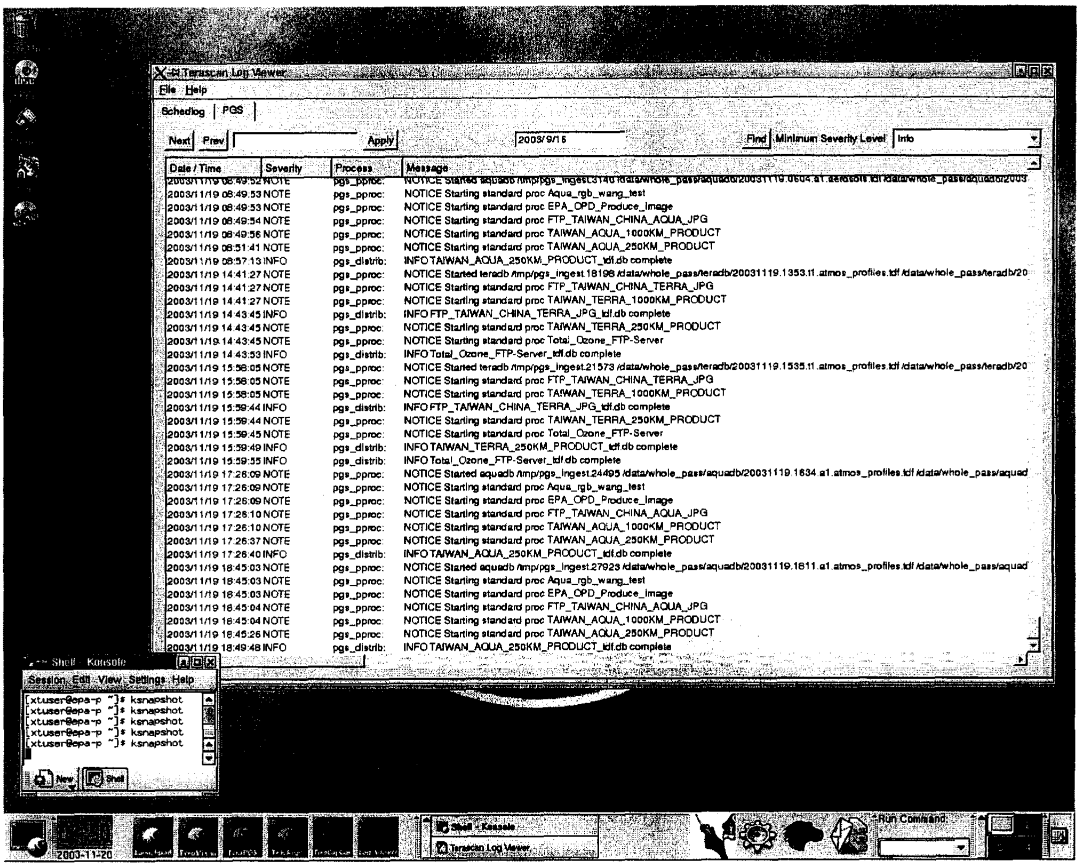


6. 系統訊息資料模組

6-1. TeraScan 系統訊息



6-2. TeraPGS 排程子系統訊息



2-4 MODIS 標準作業檢查表

MODIS 作業系統檢查表			
#	檢查項目	指令	備考
1	檢查衛星作業軌道資料元件更新	lastoes	
2	檢查衛星通過即時資料	lspass	
3	檢查衛星作業大氣參數元件更新	/data/ancillary/	
4	檢查衛星產品產生情況	/data/whole_pass/	
5	檢查衛星作業磁碟空間容量	du and df	
6	檢查衛星作業系統訊息	logviewer	
7	檢查衛星產品影像自動產生情況	ftp xxx.xxx.xxx.xxx	
8	檢查衛星作業系統時間精確度	trakeye	
9	檢查衛星資料自動備份及磁帶抽換	Archive list	
10	檢查衛星導航資料精確度	Teravision	
11	檢查中央氣象局 FTP 伺服器作業狀況	ftp xxx.xxx.xxx.xxx	
12	檢查磁碟陣列作業狀況	/data1/data 下磁碟空間	
13	檢查作業主機磁碟作業狀況	/data /home/xtuser	
14	檢查衛星作業大氣參數元件備份情形		
15	檢查衛星作業資料集產生情形		
16	MODIS 網頁資料更新情形		
17	Level 3 氣溶膠厚度產品執行情形		

第三章 美國太空總署高登太空飛行中心
(NASA Goddard Space Flight Center)
光達校正實驗室考察紀要

3-1 微脈衝光達系統（Micro-pulse Lidar）簡介

微脈衝光達(MPL)是一種慣性時間間隔偵測之雷射光達系統，可獲得非常接近大氣中雲層和氣溶膠結構的剖面圖，亦是一種對眼睛安全之儀器，能長期性全時、獨立操作運轉，最主要微脈衝光達系統傳送使用低功率脈衝光束(10micro-joules ,0.2m exit-aperture width, 1.2E10^{-6}beam divergence)，且脈衝重複頻率較標準雷射光達系統高。訊號獲得經由光子計數器偵測，相較於類比式偵測器有更多的方法及具高準確度處理所擷取到的低階訊號。

微脈衝光達原型設備係由美國國家航空暨太空總署下高登太空飛行研究中心(GSFS)所發展，最初的系統於 1993 年初期在太平洋西南區域進行探測研究，於該年 10 月美國奧克拉荷馬州一套微脈衝光達系統開始全時進行大氣中雲層輻射試驗，而第一個微脈衝光達網站位址於 1999 年 12 月座落在南極。

最初的微脈衝光達系統有高達 300 公尺垂直解析度，自從 1994 年起微脈衝光達系統藉由 SESI 公司商業化應用需求,發展出 30 公尺垂直剖面高解析度產品，至今全球近乎有 20 套系統在運轉，也構成了全球微脈衝光達系統監測站網。

3-2 微脈衝光達系統標準規格

1. 波長：0.523 μm
2. 雷射功率：1.0w

3. 輸出能量：～10μj

4. 重複脈衝頻率：2500Hz

5. Transceiver 孔：0.2m

6. Beam Divergence：～50μrad

7. 垂直解析度：30～300 公尺

8. Transceiver Field-of-View：～100μrad

系統軟體設定：

1. 雷射脈衝頻率：2500Hz

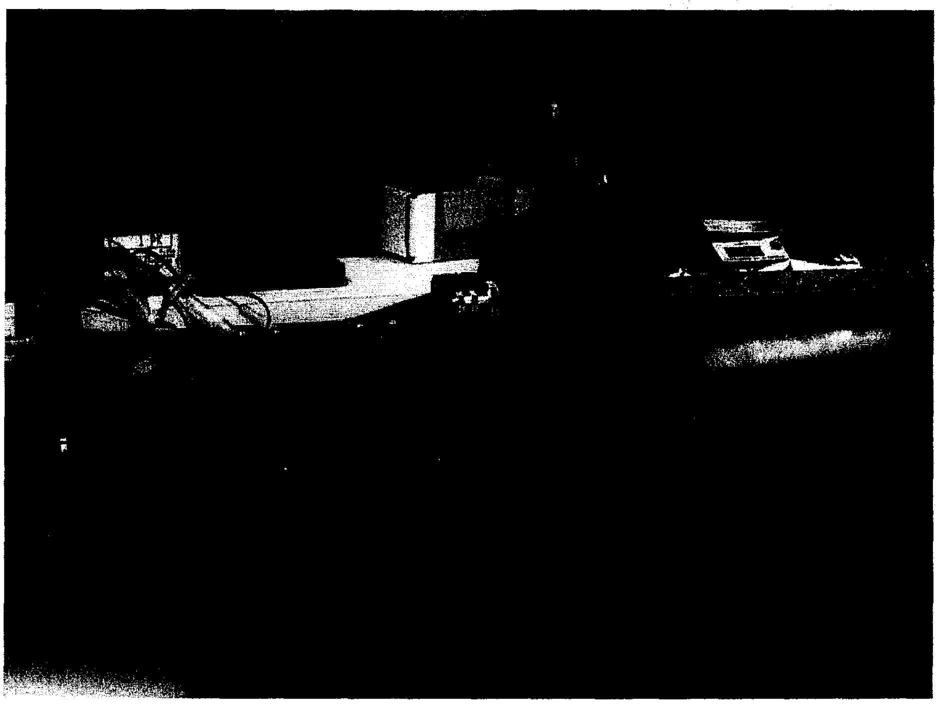
2. 最大採樣高度：60km

3. 數據檔案格式：依美國國家航空暨太空總署

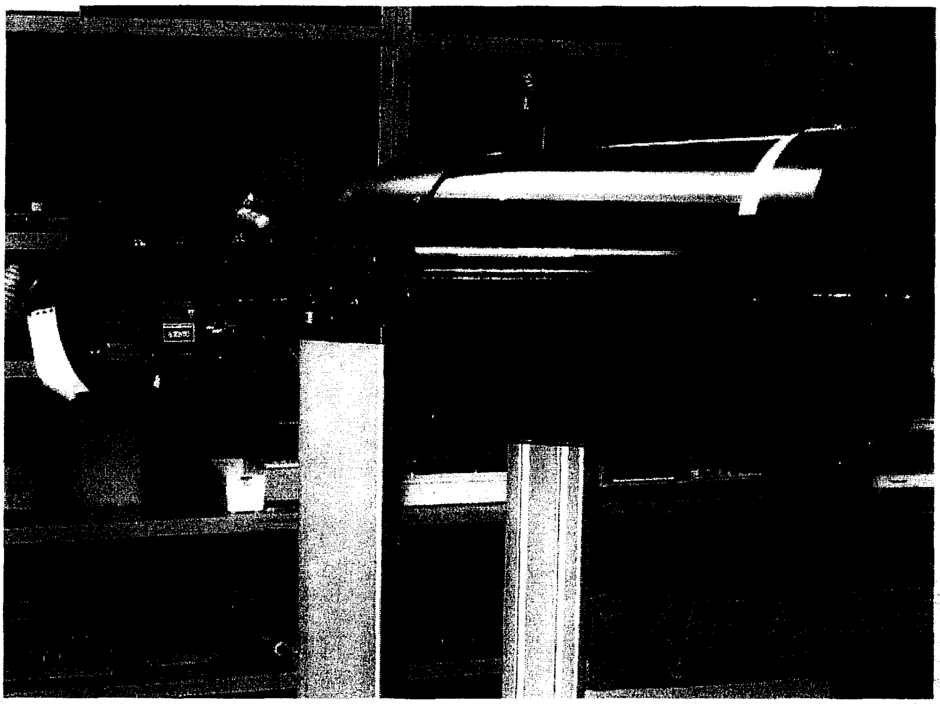
4. 平均時間：60sec

5. 偵測頻率：12MHz

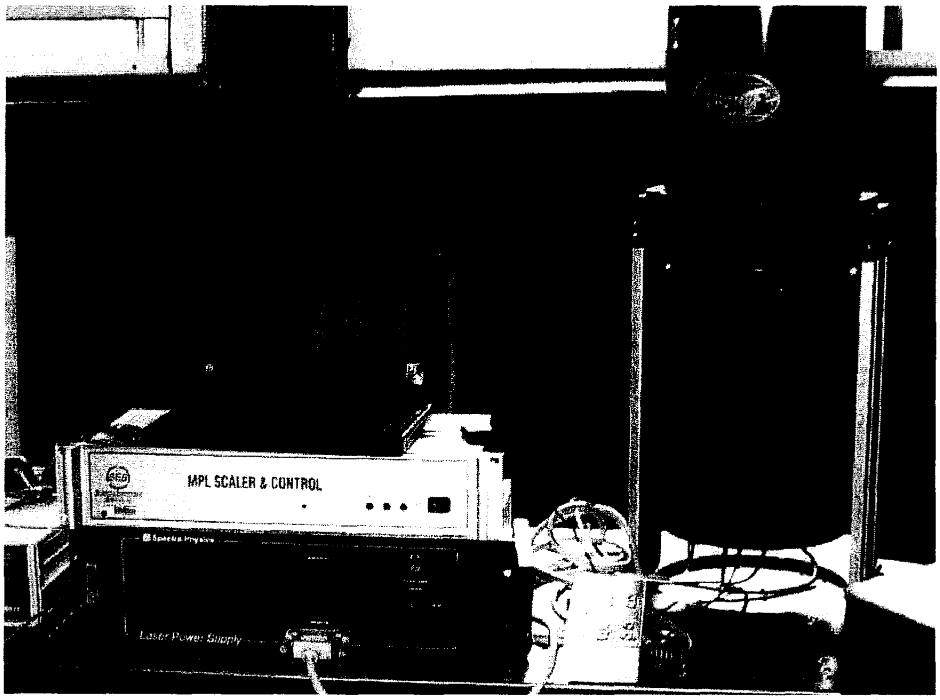
圖一、第一代微脈衝光達照片



圖二、第二代微脈衝光達照片



圖三、第三代微脈衝光達系統



3-3 微脈衝光達監測網（Micro-pulse Lidar Network,MPLNET）

微脈衝光達監測網（Micro-pulse Lidar Network,MPLNET）是遍及全球之微脈衝光達網路系統，其運作成員包括雲層及氣溶膠光達研究團隊，係屬美國國家航空暨太空總署下高登太空飛行研究中心(GSFS)，資金來源為美國國家航空暨太空總署環境觀測系統(NASA/EOS)，昔日額外的資金來自 NASA SIMBIOS 計畫以研究海洋相關資訊為主。

微脈衝光達屬於單一光譜（523nm）、自主、對眼睛無害的系統，起初發展在太空光達系統而延伸至商業上之應用，微脈衝光達主要是偵測雲和氣溶膠在大氣垂直剖面結構且其觀測數據可進一步分析產生雲和氣溶膠光學厚度剖面圖。

微脈衝光達監測網（Micro-pulse Lidar Network,MPLNET）首要目的是提供全球監測站長期雲層和氣溶膠垂直剖面數據，這些長期監測數據將被使用確認和幫助改進全球、區域性氣候模式，也可藉由地面觀測站實際觀測數據與 NASA/EOS 衛星遙測影像資料相互比對確認。

微脈衝光達監測網（MPLNET）由美國國家航空暨太空總署選定運轉站址、反雷達飛彈合作站址及其他學術研究單位站址所組成，成員遍及全球，微脈衝光達監測網（MPLNET）的發展已逾七年，在數據處理和儀器校正技術上有一定準則，除了長期使用的地點，每年微脈衝光達監測網（MPLNET）使用微脈衝光達系統提供區域性研究支援，也儘量部署於陸地或船上，這些站址除了有影像和監測數據外，數據處理的訊息、使用儀器規格及軟體程式版本等也一併會上載於網站上。

3-4 數據資料描述

微脈衝光達監測網（MPLNET）監測數據產品區分為下列：

- Level 0
- Level 1
- Level 1.5a
- Level 1.5b
- Level 2a
- Level 3a

3-4-1 Level0(原始數據)

Level 0 數據包含來自微脈衝光達原始訊號計算數值及不同的監測參數（例如：溫度、雷射能量和環境背景資料等），Level 0 數據可即時由微脈衝光達系統電腦產出並由高登太空飛行研究中心收集、歸檔，目前 Level 0 數據檔案無法藉微脈衝光達監測網被廣泛使用。

3-4-2 Level 1(Normalized Relative Backscatter)

Level 1 數據係將 Level0(原始數據)移除儀器相關干擾參數後之處理數據且保留校正參數值，Level 1 數據亦被稱為 Normalized Relative Backscatter（NRB）訊號。

3-4-3 Level 1.5(未經品質保證之即時雲層和氣溶膠數據產品)

Level 1.5a 未經品質保證之即時單層氣溶膠產品，數據包括：

- 微脈衝光達校正數值
- 氣溶膠垂直剖面結構

- Layer Averaged Aerosol Extinction-to-Backscatter Ratio
- Aerosol Backscatter, Extinction,and 光學厚度

Level 1.5b 未經品質保證之複合雲層產品，此產品目前尚未被操作使用。

3-4-4 Level 2（經品質保證之雲層及氣溶膠數據產品）

Level 2a 數據產品包括：

- 微脈衝光達校正數值
- 氣溶膠垂直剖面結構
- Layer Averaged Aerosol Extinction-to-Backscatter Ratio
- Aerosol Backscatter, Extinction,and 光學厚度
- Cloud Presence Flag

此項數據產品尚未操作使用。

3-4-5 Level 3（加值數據產品）

Level 3a（連續性複合雲層和氣溶膠數據產品），產品包括：

- 經校正後之 Level 1 訊號
- 邊界層高度、最大至 20km 之懸浮微粒層高度
- 偵測雲層、氣溶膠或未知物
- 每個被偵測到懸浮微粒層之光學厚度
- Layer Averaged Aerosol Extinction-to-Backscatter Ratio
- Backscatter and Extinction Profiles

第四章 結論與建議

一、本署九十二年九月與交通部中央氣象局衛星中心達成合作協議，並將於年底建置完成一套中解析度影像分光光譜儀（MODIS）衛星資料處理分析系統，除了與本署於台灣地區架設之空氣品質監測站網監測數據相互驗證，並提供國內針對東南亞地區、大陸沿海地區工業污染及內蒙古大陸沙塵暴等境外傳輸污染物路徑資料，使本署在環境監測領域上與國際接軌。

二、經考察了解美國太空總署高登太空飛行中心(NASA Goddard Space Flight Center)之管理運作狀況，將可提供未來本署完成中解析度影像分光光譜儀(MODIS)衛星資料處理分析系統建置後，製定一套國內營運管理制度，提供國內衛星監測資料統一標準及確保監測影像之正確性參考。

三、此次協助單位美國太空總署高登太空飛行中心(NASA Goddard Space Flight Center)，除負責全美中解析度影像分光光譜儀（MODIS）衛星資料處理分析標準程式業務外，尚有負責其他統一標準項目，如光達雷達（Lidar）標準校正實驗室、全球衛星觀測雲水實驗室…等等，均可作為本署推動空氣品質監測業務參考，並加強我國與美國環保合作關係。

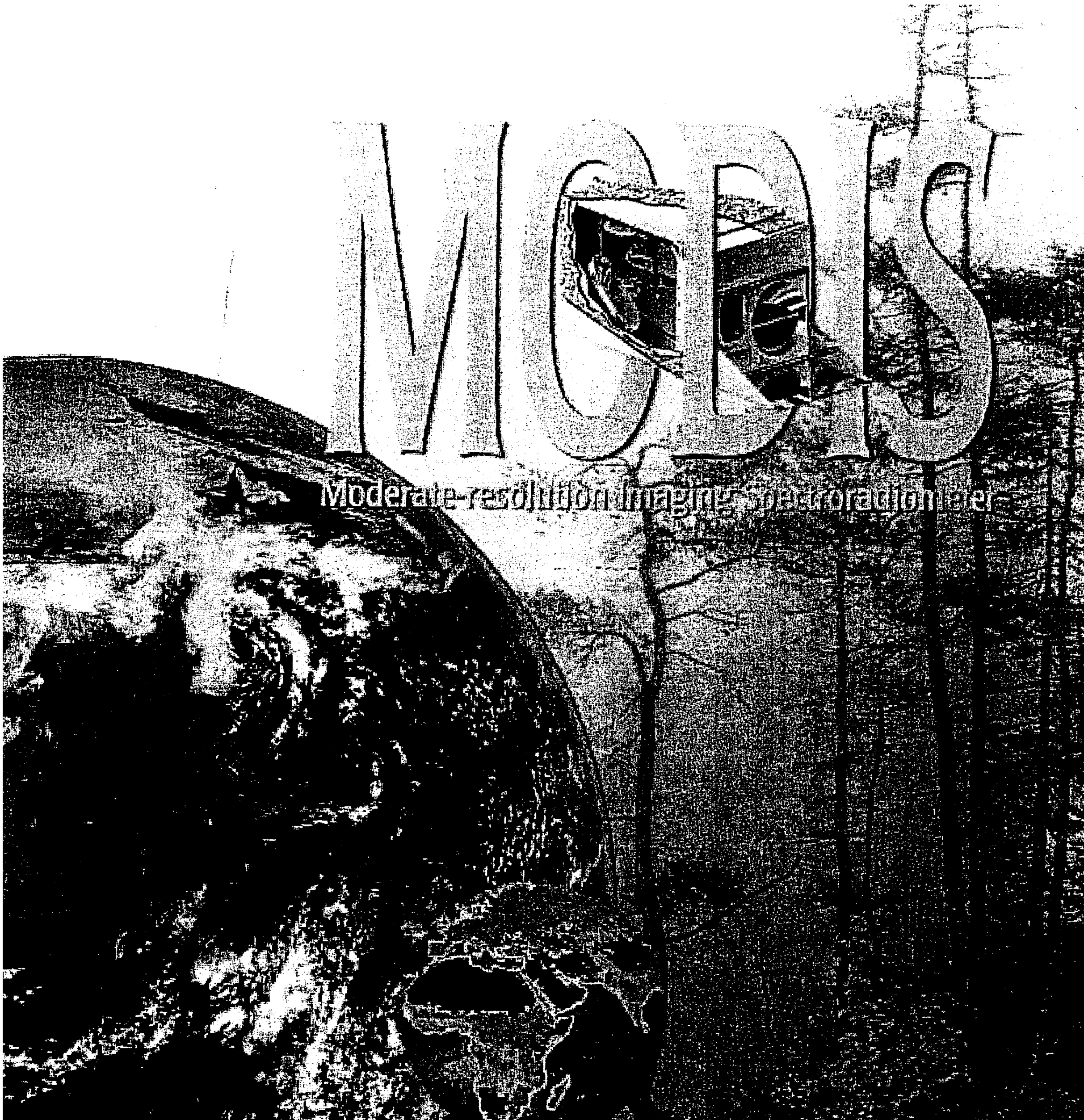
四、本署目前正在汰舊換新空氣品質監測站網設備，已建置完成有逆溫儀、光化學監測站等，並擬於九十三、九十四年陸續引進之國際間先進儀器設備，未來可參考美國環保署模式，因應空氣污染防制目標需求，分別進行短期、中期之大型研究計畫，以研擬有效污染管制對策，並使本署空氣品質監測站網工作發揮最大效益。

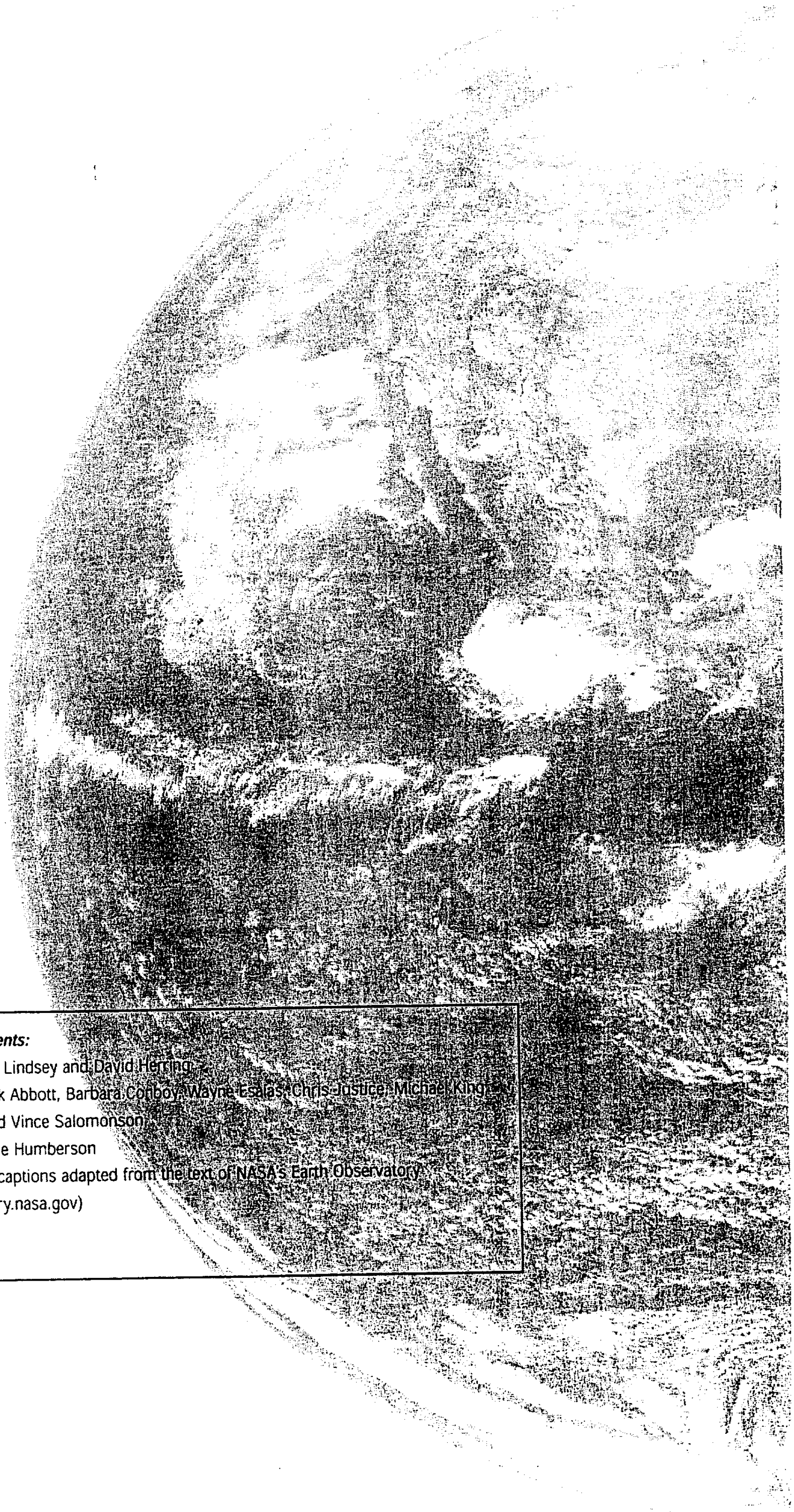
五、為確保監測數據品質，提供正確污染管制及研究資訊，監測作業之操作維護及品保程序相當重要，故亟需建立本署測站之操

作維護運轉及品保品管制度並將所有相關監測設備整合，使其操作查詢界面簡易明瞭，讓對環境監測資料有需求的對象得以順利獲得。

附錄一

Moderate-resolution Imaging Spectroradiometer/NASA`s Earth Observing System


MODIS
Moderate-resolution Imaging Spectroradiometer
NASA's Earth Observing System



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Design by Winnie Humberson
Selected image captions adapted from the text of NASA's Earth Observatory
(earthobservatory.nasa.gov)

Global Change and Life on Earth

For decades scientists have been piecing together clues about Earth's climate from ancient rocks, ice cores, patterns in the growth rings of trees, historical weather records, and satellite data. They know that Earth's climate has changed many times throughout its history. Changes in the tilt of the Earth's rotation on its axis, ocean currents, and volcanic eruptions have all impacted Earth's climate and life. Now scientists are accumulating evidence that human industrial and agricultural activities may be accelerating naturally occurring changes in our climate, and that we are contributing to such hazards as global warming, rising sea level, ozone depletion, acid rain, and loss of biodiversity. People all over the world—not just scientists, but also farmers, fishermen, and policymakers—are asking questions about global change and the consequences for life on Earth.

To answer these questions, scientists must study the Earth as an interacting system because the relationships among life, land, oceans, and atmosphere are tightly interwoven. Clouds, gases, and aerosol particles in the atmosphere affect both land and oceans. For example, air pollution can reduce crop yields. Marine plant life depends on iron-rich dust that winds pick up over arid regions and deposit into the oceans. Changes occurring on the land can affect the atmosphere as well. Studies from around the world have shown that the asphalt and concrete of urban development can absorb and re-radiate enough heat energy back into the atmosphere to trigger thunderstorms. And because trees and other vegetation participate in the rainfall cycle by releasing water vapor into the atmosphere, scientists predict that massive tropical deforestation could result in significant decreases in tropical rainfall. Clearly, the Earth is a complex, changing system. The cycles of change in Earth's atmospheric, oceanic, and terrestrial processes are called global dynamics. Scientists are

Earth's land, oceans, and atmosphere interact and undergo constant change. (Top) A natural fertilizer, dust from arid regions is rich in iron on which marine ecosystems depend. (Middle) Volcanic eruptions inject sulfur gases high into the atmosphere. (Bottom) Land use patterns in Southern Africa include massive prescribed burns that transform ecosystem vegetation and release soot and aerosols into the atmosphere.

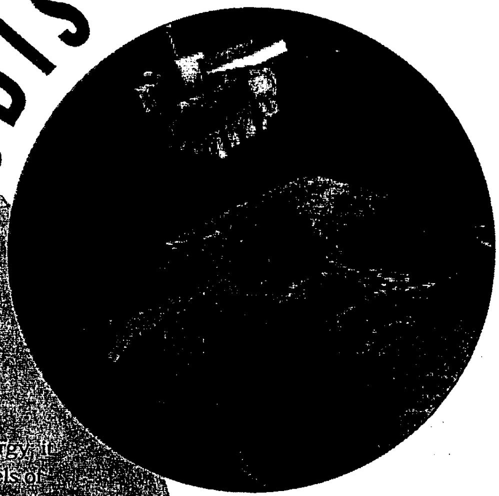
modeling global dynamics to better understand natural climate changes and human impact on those changes. To improve global models, scientists need information, or data, for every region of the Earth every day for many years. The most powerful way to collect such comprehensive data is through the use of satellite sensors that measure different types of energy coming from the Earth. The way the Earth reflects or emits electromagnetic energy into space gives scientists valuable information about its ecological, hydrological, and meteorological conditions.

Understanding the importance of studying global dynamics, the United States Congress instituted the U.S. Global Change Research Program in 1990. NASA's Earth Science Enterprise is making substantial contributions to the program through its Earth Observing System (EOS). Through EOS, NASA is working with the national and international scientific community to design, develop, and launch advanced satellite sensors that collect data across a wide spectrum of energy—ultraviolet, visible, infrared, and microwave. With these sensors, NASA will collect multi-year data sets that will help to answer questions about global change.

The first EOS satellite, called Terra, was launched on December 18, 1999, carrying five remote sensors. The most comprehensive EOS sensor is MODIS, the

The eastern United States seen by MODIS on March 6, 2000. MODIS captured the green sweep of spring vegetation creeping northward, as well as geologic features such as the Appalachian Mountains, seen prominently in [illegible] Pennsylvania as alternating dark and light patterns. Image credit: MODIS Land Team/Jacques Descloitres, SSAI

MODIS



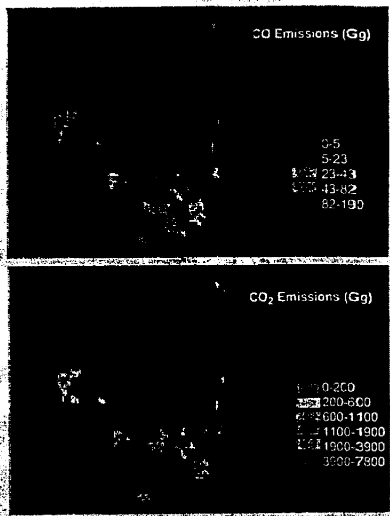
MODIS's continuously rotating scan mirror can make an image of nearly half the continental United States in a single orbital pass. Image credit: NASA-GSFC TV/Susan Byrne, HTSI.

Moderate-resolution Imaging Spectroradiometer MODIS offers a unique combination of features: it detects a wide spectral range of electromagnetic energy; it takes measurements at three spatial resolutions (levels of detail); it takes measurements all day, every day; and it has a wide field of view. This continual, comprehensive coverage allows MODIS to complete an electromagnetic picture of the globe every two days. MODIS's frequent coverage complements other imaging systems such as Landsat's Enhanced Thematic Mapper Plus, which reveals the Earth in finer spatial detail, but can only image a given area once every 16 days—too infrequently to capture many of the rapid biological and meteorological changes that MODIS observes.

Terra is the first large, multi-instrument EOS satellite, and its orbit around the Earth is timed so that it passes from north to south across the equator in the morning. A second EOS satellite, Aqua, will also carry a MODIS instrument. Aqua will pass south to north over the equator in the afternoon. Working in tandem to see the same area of the Earth in the morning and the afternoon, the two satellites will help scientists ensure MODIS's and other instruments' measurement accuracy by optimizing cloud-free remote sensing of the surface and minimizing any optical effects—like shadows or glare—that are unique to morning or afternoon sunlight. Having morning and afternoon sensors also permits investigation of changes that occur over the course of the day, such as the build-up or dissipation of clouds and changes in sea or land surface temperature.

These MODIS instruments are designed to take measurements in spectral regions that have been used in previous satellite sensors. MODIS is adding to existing knowledge by extending data sets collected by heritage sensors such as the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR), used for meteorology and monitoring sea surface temperature, sea ice, and vegetation; the Coastal Zone Color Scanner (CZCS) and the Sea-viewing Wide Field of View Sensor (SeaWiFS), used to monitor ocean biological activity; Landsat, used to monitor terrestrial conditions; and NOAA's High Resolution Infrared Radiation Sounder (HIRS), used to observe atmospheric conditions. By extending these data sets, MODIS promotes the continuity of data collection essential for understanding both long- and short-term change in the global environment.

Our Changing Land



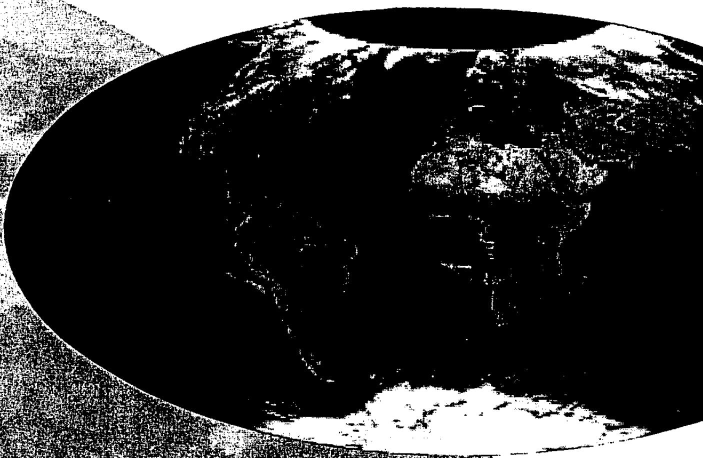
Severe forest fires scorched Montana and Idaho in August 2000. This false-color, 250-m resolution MODIS image from September 26, 2000, shows the scars (dark purple) left by the Wilderness Complex, Valley Complex, and various smaller wildfires along the Idaho/Montana border. The burned areas in this image totaled about 1,250,595 acres, which accounts for about 14% of all burned area in the United States in 2000. The pictographs at right correspond to the burn scars, and are color-coded to show different amounts of gases released by individual fires. These fires released about 31,026 gigagrams of carbon dioxide and 760 gigarams of carbon monoxide.

With its 2,330-km viewing swath width, MODIS can monitor far more land surface than can be covered by ground crews or airplanes, and it can detect thermal energy from fires even through a thick cloud of smoke. MODIS imagery is being used for rapid response by the USDA Forest Service to plan burned area rehabilitation and watershed protection efforts. Image credits: False-color composite, MODIS Land Team/Mark Carroll, University of Maryland, College Park. Pictographs, MODIS Land Team/Chris Justice, Principal Investigator, and Stefania Korontzi, University of Maryland, College Park.

Some of the most easily recognizable changes are occurring on land. Human-induced changes such as deforestation, urbanization, and hydroelectric and irrigation projects combine with the Earth's existing cycles of fire, erosion, and floods to change our landscape. While we can often see these changes happening on a local scale, it is impossible to assess global effects through fieldwork alone. With its near-daily coverage of the Earth's surface, MODIS provides comprehensive measurements that scientists and land managers need to make informed decisions about managing Earth's natural resources from season to season, year to year, and decade to decade.

Monitoring and assessing conditions on the Earth's surface is critical to understanding the impacts of weather and climate change and human activities. MODIS provides global maps of several land surface characteristics, including surface reflectance, albedo (the percent of total solar energy that is reflected back from the surface), land surface temperature, and vegetation indices. Vegetation indices tell scientists how densely or sparsely vegetated a region is and help them to determine how much of the sunlight that could be

Surface reflectance is an estimate of the reflectance at specific wavelengths as it would have been measured at the Earth's surface if the atmosphere did not scatter or absorb radiation. To produce such images, scientists must take into consideration the effects of gases, aerosols, and thin cirrus clouds. This image was made from data collected by MODIS during November of 2000, during polar night in the Northern Hemisphere. The surface reflectance product is the foundation of most land products, including vegetation indices. Image credit: MODIS Land Team/Surface Reflectance Product, Eric Vermote, Principal Investigator, University of Maryland, College Park, and Nazmi El Saleous, Raytheon, ITSS.

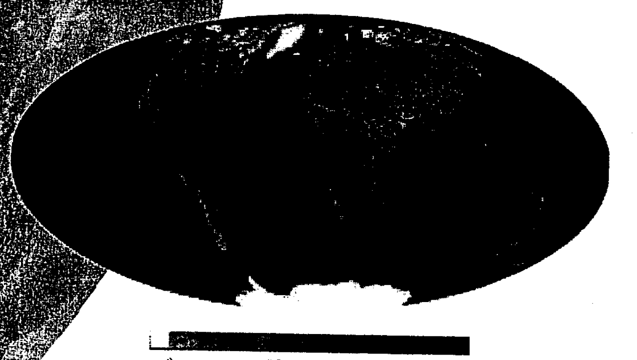


used for photosynthesis is being absorbed by the vegetation. The maps will provide the basis for MODIS's real-time global monitoring of subtle changes in vegetation that may signal biospheric stress, such as pollution, drought, or temperature extremes, which in turn could be used to predict and prevent wildfire danger or crop failure.

MODIS provides data for land cover maps that tell scientists not only whether an area is vegetated, but also what kind of vegetation is growing there, separating coniferous forests from deciduous forests, or cropland from grassland. In addition to 11 categories of vegetation, the maps recognize various non-vegetated surfaces, including bare soil, water, and urban areas—17 land cover types in all. MODIS's high-quality, daily measurements allow scientists to track changes in land cover types and land use, to determine where forested land is becoming deforested, where grassland is becoming cropland, or where burned land is returning to natural vegetation.

NDVI

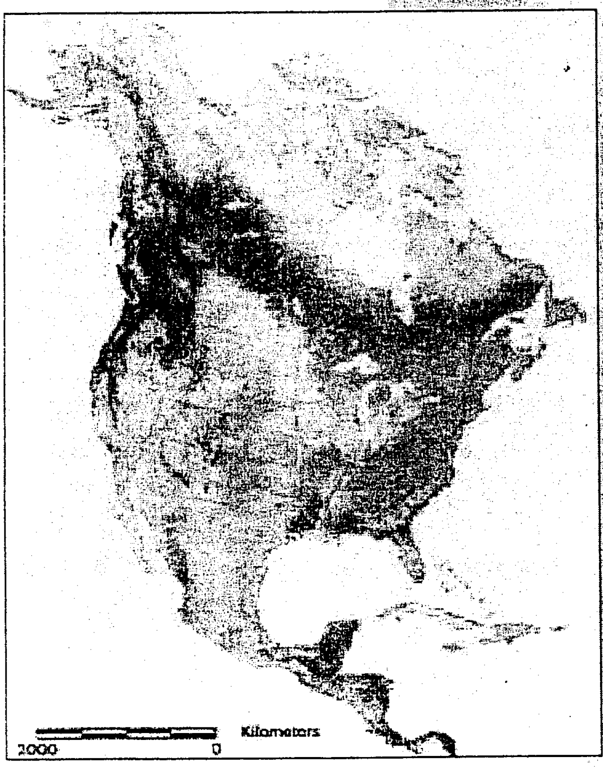
EVI



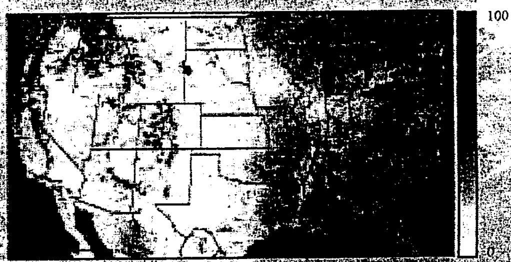
...is pair of Vegetation Indices highlights some of the refinements of the MODIS Enhanced Vegetation Index (EVI, right) over the traditional Normalized Difference Vegetation Index (NDVI, left) that has been used with previous satellite instruments. NDVI tends to "saturate" over dense vegetation such as the rainforests of South America, failing to distinguish variability. The MODIS EVI provides a more detailed look at variability within such highly vegetated regions. Production of MODIS NDVI provides continuity with data sets from heritage instruments, while EVI provides added detail about global vegetation variability. Data for the images were collected between September 30 and October 15, 2000. Values range from 0, indicating no vegetation, to nearly 1, indicating the densest vegetation. Image credit: MODIS Land Team/Vegetation Indices, Alfredo Huete, Principal Investigator, and Kamel Didan, University of Arizona.

MODIS collects data on land surface characteristics that are crucial for modeling the Earth's carbon cycle, or the exchange of carbon between the Earth's life, land, oceans, and atmosphere. Modeling the carbon cycle is especially important given increases in atmospheric carbon dioxide, a known greenhouse gas. Land surface variables such as amount and type of vegetation, soil composition, and temperature play a significant role in calculating mass and energy exchange between the Earth's surface and the atmosphere.

Since plants remove carbon dioxide from the atmosphere as they make food, scientists call them a carbon sink; when vegetation is burned, it becomes a carbon source. Estimates of carbon storage in plants vary widely, but MODIS data will help reduce that uncertainty by allowing scientists to make more accurate estimates of global photosynthesis and productivity. However, other questions remain. Will plants increase their uptake of carbon dioxide in response to atmospheric



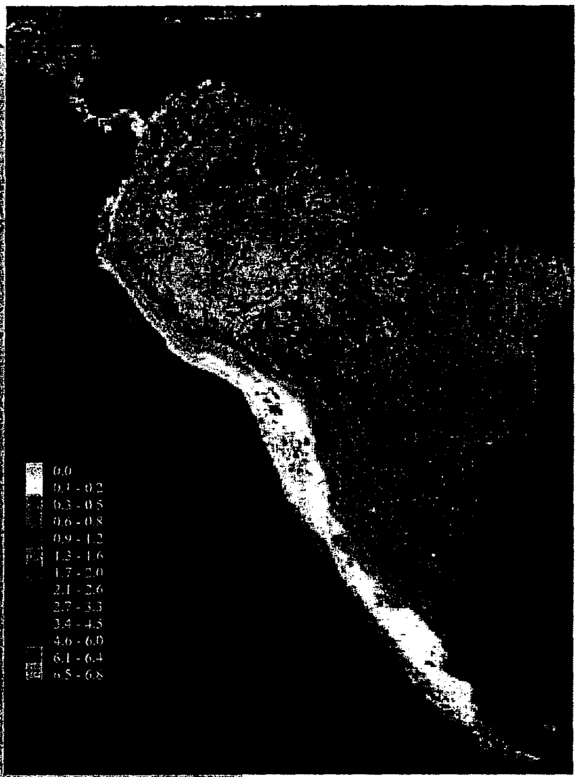
North American Land Cover Classification map using MODIS data collected from July 2000 through January 2001. Image credit: MODIS Land Team/Land Cover Classification Product, Alan Strahler, Principal Investigator, and John Hodges, Boston University.

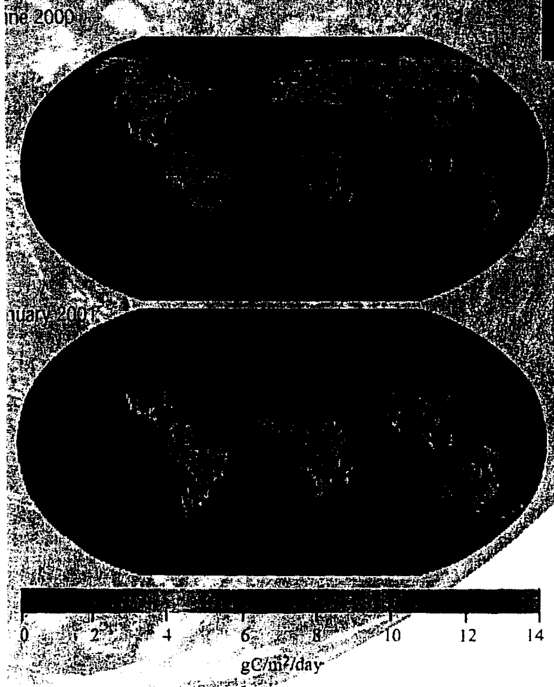


Percent tree cover map of the United States using MODIS data from the summer and fall of 2000. The color bar represents 0% tree cover (white) to 100% cover (dark green). Image credit: MODIS Land Team/Vegetation Continuous Fields Product, Ruth DeFries, Associate Team Member, and Matt Hansen, University of Maryland, College Park.

increases? What are the effects of diminishing carbon sinks through land use changes such as deforestation and urbanization? Will increasing land surface temperatures melt frozen arctic soils, transforming them into a carbon source rather than a sink? MODIS land data will help scientists to model these biogeochemical processes and find answers to these increasingly more urgent questions.

This South American Leaf Area Index (LAI) map provides an estimate of one-sided green leaf area per unit land area (m^2/m^2). Before MODIS, LAI was produced by individual researchers for selected regions, using different, unvalidated techniques. The MODIS LAI is the first global scale operational production of this important vegetation parameter, which is used as an input to large scale climate and carbon models. Image credit: MODIS Land Team/Leaf Area Index, Ranga Myneni, Principal Investigator, and Seth Hoffman, Boston University.





This pair of images shows MODIS measurements of gross primary production (GPP) in Northern Hemisphere summer (top) and winter (bottom). Measured in grams of carbon taken up by vegetation per square meter each day, GPP shows how actively the Earth's vegetation was photosynthesizing during a week in June 2000 and January 2001. Black areas are regions where vegetation activity is virtually nonexistent, such as Africa's Sahara Desert and polar regions. These images generally represent the maximum and minimum annual photosynthetic activity of vegetation, and illustrate the ranges of variability found at different latitudes. Image credit: MODIS Land Team/Gross Primary Production, Steve Running, Principal Investigator, and Petr Votava, University of Montana; Rob Simmon, SSAI.

In their development of global dynamical models, scientists are confronted with another unknown: the role of snow cover and sea ice in climate change. Snow cover greatly influences the Earth's albedo, which is how much incoming solar energy various parts of the Earth's surface reflect back into the atmosphere. Snow and ice cool the Earth's surface by reflecting radiation from the Sun away from the Earth. In the short term, many scientists suspect that climate warming will mean more evaporation from the oceans and thus more moisture in the air. Increases in moisture and subsequent increases in precipitation could actually increase snow cover for a time, as temperatures in arctic regions increase, but remain below freezing. Until long term data like those collected by MODIS are available, however, the effects of global temperature increases on snow and sea ice's thermal regulation of the planet will remain uncertain.

March 5-12, 2000

March 6-13, 2001

Winter snow cover and the resulting spring thaw play an important role in recharging underground aquifers and refilling lakes that supply plants, humans and other animals with water. Changes in extent and duration of regional snow packs are associated with both short- and long-term climate change. For these reasons, monitoring snow cover is an important part of understanding hydrological, ecological, and climatological cycles.

These two MODIS maps of North America show the maximum extent of snow cover from March 5-12, 2000 (left) and March 6-13, 2001 (right). In March of 2000, snow cover during this eight-day period was well below the average for that time of year (red line), and this "snow drought" contributed to a devastating summer fire season in the American West. In March of 2001, the snow cover was considerably closer to average conditions. In both images, light gray areas indicate persistent cloud cover. Image Credit: MODIS Land Team/Snow Cover, Dorothy Hall, Associate Team Member, NASA-GSFC; Janet Chien, SAIC/GSC; Nick DiGirolamo, SSAI; James Foster, NASA-GSFC; and George Riggs, SSAI.

Our Changing Ocean

Given the enormous expanse of Earth's oceans, their crucial role in climate change is not surprising. Oceans absorb solar radiation and modulate the Earth's temperature, they exchange gases with the atmosphere, and they harbor an astounding diversity of plants and animals, many of which human cultures all over the world depend on for food. The oceans act as the "memory" of the Earth system. They store enormous amounts of carbon and heat, reflecting the integrated result of many centuries of climatic variation. In general, the upper layers of the ocean reflect recent weather and short-term climate change, and deeper layers reflect progressively older climatic records. Because oceans are slower to change than the atmosphere, long-term data collection is especially important. Scientists are using MODIS data to understand the complexities of how oceans both react to and bring about global change.

One way MODIS helps scientists studying oceans is through collection of data that they can use to make global maps of *ocean color*. Variations in ocean color are related to the concentration of organisms in the surface waters of the world's oceans. Sunlight strikes the ocean and is reflected by these organisms. Among the most abundant organisms are microscopic marine plants called phytoplankton. Like other plants, phytoplankton use chlorophyll pigments to capture energy for photosynthesis. The pigment-containing organisms make the detectable color patterns across the ocean surface.

Despite their microscopic size, phytoplankton have a great impact on global change. Like other plants, phytoplankton transform carbon dioxide into organic molecules during photosynthesis; they do so at about the same rate as land plants. This process is called carbon fixation, and it's the beginning of a biological pump that draws carbon from the atmosphere and stores it in the ocean, Earth's largest carbon sink. Some of the carbon that is taken up by phytoplankton sinks to the ocean floor, where it can remain for millions of years. Indeed, 99.5% of all carbon on Earth is found within sediments of marine origin.

附錄二

TeraScan Data Products List

Processing using TeraScan software and NASA EOS_HDF Toolkits

BOTH HDF and Earth-located TeraScan Data Format (TDF) end products will be available for the listed products below. Processing begins with a MODIS level-0 PDS file.

Product list

MOD01 (level1a), MOD02 (calibration), MOD03 (Geolocation)

The MODIS Level 1 Processing Software for Direct Broadcast is a set of science processing algorithms for producing geolocated, calibrated radiance from raw Level 0 production data sets for the MODIS instrument. It includes: the Level1a algorithm, which reorganizes the raw data; the geolocation algorithm which geolocates each MODIS field of view; and the calibrated radiance (aka Level 1B) algorithm, which outputs calibrated radiance at 1 KM, 0.5 KM and 0.25 KM resolutions. This release is nearly identical to the algorithms run at the Goddard Earth Sciences Distributed Active Archive Center.

MOD_PR35 (Cloud Mask), MOD_PR07 (Atmos. Profiles), MOD_PRVOLC (Volcanic Alert)

Cloud Mask (MOD_PR35), Atmospheric Products (MOD_PR07), and Volcano Alert (MOD_PRVOLC) algorithms. The Cloud Mask product is generally required by all other level 2 products.

Level 2 Cloud Mask (MOD35) file in HDF format, which indicates the presence/absence of cloud shadow effects, cirrus clouds, ice/snow, and sun-glint contamination for each pixel. 2. Level 2 Atmosphere Profile (MOD07) file in HDF format, containing atmospheric temperature and moisture profiles, atmospheric stability, and total ozone burden (MOD07) 3. Volcano alert file (ASCII)

MOD04 (Aerosol product) & MOD05 (Precipitable Water)

Level 2 Aerosol Product (MOD04) file in HDF format, which contains information about atmospheric aerosols, including ambient aerosol optical thickness (over oceans globally and a portion of the continents) and aerosol size distribution (over ocean) or type (over land). 2. Level 2 Precipitable Water (MOD05) file in HDF format, which contains water vapor columns as estimated using infrared (day and night) and near-infrared (day only) algorithms.

MOD10 (Snow Cover product)

Level 2 Snow Cover Product (MOD10) file in HDF format. It contains results of the snow mapping algorithm for each 500 m pixel. The results are stored as coded integers corresponding to various classes: snow (200), snow-covered lake ice (100), cloud obscured (50), ocean (39), inland water (37), non-detections (25), and other.

MOD29 (Sea Ice Extent product)

Level 2 Sea Ice Extent Product (MOD29) file in HDF format. It contains results of the sea ice mapping algorithm and ice surface temperature (IST) for each 500 m pixel. All files contain the results of the "Sea Ice by IST" test, which classes pixels with temperatures below 271.5 K as sea ice and pixels with temperatures above 271.5 K as open ocean. Files generated for swaths acquired during daylight also contain the results of the "Sea Ice by Reflective Characteristics" test, which classifies pixels as sea ice, cloud, open ocean, inland water, or land.

MOD18 (Ocean Color product)

Level 2 Ocean Color files (MODOCL2, MODOCL2A, MODOCL2B) in HDF format. These contain measurements of normalized water leaving radiances, aerosol optical thickness, aerosol correction epsilon, diffuse attenuation; bio-optical properties for Case 1 waters (including chlorophyll-a, chlorophyll-a + pheopigment, total pigment, and total suspended matter concentrations);

Case 2 chlorophyll-a concentrations, Gelbstoff, phytoplankton and total absorption coefficients; clear water epsilons; instantaneous photosynthetically available radiation (IPAR) and radiation absorbed by phytoplankton; chlorophyll fluorescence line height, baseline, and efficiency; detached coccolith concentration, pigment concentration in coccolithophore blooms, calcite concentration; phycoerythrin (PEB) and phycourobilin (PUB) concentrations

MOD28 (Sea Surface Temperature product)

Level 2 Sea Surface Temperature (SST; MOD_PR28) algorithm.

MOD09 (Surface Reflectance product)

It runs the Level 2 Surface Reflectance (MOD_PR09) algorithm. The Surface Reflectance product is required by several higher level land processes:

Vegetation Indices (VIs),
Bi-directional Reflectance Distribution Function (BRDF),
thermal anomaly,
snow/ice, and
Fraction of Photosynthetically Active Radiation/ Leaf Area Index (FPAR/LAI).

The output of this PGE is as follows:1. Level 2 Surface Reflectance (MOD09) file in HDF format, which contains estimates of the true land surface reflectances in 7 bands, corrected for atmospheric scattering and absorption.

2. Coarse resolution Surface Reflectance (MOD09CRS) file in HDF format, containing above information at 5 km resolution.

Aerosol_product

Contents from TDF

Variable	Type	Units
Longitude	float	Degrees_east
Latitude	float	Degrees_north
Scan_Start_Time	double	Seconds since 1993-1-1 00:00:00.
Solar_Zenith	short	Degrees
Solar_Azimuth	short	Degrees
Sensor_Zenith	short	Degrees
Sensor_Azimuth	short	Degrees
Cloud_Mask_QA	byte	None
Scattering_Angle	short	Degrees
Optical_Depth_Land_And_Ocean	short	None
Optical_Depth_Ratio_Small_Land_	short	None
Reflected_Flux_Land_And_Ocean	short	None
Mean_Reflectance_Land_All	short	None
Standard_Deviation_Reflectance_	short	None
Path_Radiance_Land	short	None
Error_Path_Radiance_Land	short	None
Critical_Reflectance_Land	short	None
Error_Critical_Reflectance_Land	short	None
QualityWeight_Path_Radiance_Lan	short	None
QualityWeight_Critical_Reflecta	short	None
Aerosol_Type_Land	short	None
Continental_Optical_Depth_Land	short	None
Corrected_Optical_Depth_Land	short	None
Estimated_Uncertainty_Land	short	None
Mass_Concentration_Land	float	1.0e-6g/cm^2
Angstrom_Exponent_Land	short	None
Reflected_Flux_Land	short	None
Transmitted_Flux_Land	short	None
Cloud_Fraction_Land	short	None
Optical_Depth_Ratio_Small_Land	short	None
Number_Pixels_Percentile_Land	short	None
Mean_Reflectance_Land	short	None
STD_Reflectance_Land	short	None
Quality_Assurance_Land	byte	None
Quality_Assurance_Crit_Ref_Land	byte	None
Solution_Index_Ocean_Small	short	None
Solution_Index_Ocean_Large	short	None
Effective_Optical_Depth_Best_Oc	short	None
Effective_Optical_Depth_Average	short	None
Optical_Depth_Small_Best_Ocean	short	None
Optical_Depth_Small_Average_Oce	short	None
Optical_Depth_Large_Best_Ocean	short	None
Optical_Depth_Large_Average_Oce	short	None
Mass_Concentration_Ocean	float	1.0e-6g/cm^2
Effective_Radius_Ocean	short	micron
Cloud_Condensation_Nuclei_Ocean	float	CCN/cm^2
Asymmetry_Factor_Best_Ocean	short	None
Asymmetry_Factor_Average_Ocean	short	None
Backscattering_Ratio_Best_Ocean	short	None
Backscattering_Ratio_Average_Oc	short	None
Angstrom_Exponent_1_Ocean	short	None
Angstrom_Exponent_2_Ocean	short	None
Reflected_Flux_Best_Ocean	short	None
Reflected_Flux_Average_Ocean	short	None
Transmitted_Flux_Best_Ocean	short	None
Transmitted_Flux_Average_Ocean	short	None
Least_Squares_Error_Ocean	short	None
Optical_Depth_Ratio_Small_Ocean	short	None
Optical_Depth_by_models_ocean	short	None

		Aerosol_product
Cloud_Fraction_Ocean	short	None
Number_Pixels_Used_Ocean	short	None
Mean_Reflectance_Ocean	short	None
STD_Reflectance_Ocean	short	None
Quality_Assurance_Ocean	byte	None

附錄三

SeaSpace TeraScan System

SeaSpace TeraScan® Systems

Reliable Proven Solutions

Lowest Cost of Ownership

PROVEN LEADERSHIP AND EXPERIENCE

Over the past 20 years, SeaSpace Corporation has designed, built, installed and supported over 220 groundstations worldwide. SeaSpace is proud of its successful track record for on-time delivery of systems, meeting needs for research, military and civilian organizations. TeraScan® products, both hardware and software, are built to meet the mission critical requirements of our operational and research customers, utilizing best engineering principles and by leveraging innovations in collaboration with other industry leaders.

RGB composite of Terra MODIS data showing a dust storm from China over Korea, reaching Japan. Courtesy of: Korea Meteorological Administration.

SeaSpace provides advanced products and services

X- BAND	L/S-BAND	OTHER
Terra & Aqua	SeaWiFS, AVHRR, FY-1C (HRPT)	TeraScan® Software
IRS-P4 (Oceansat)	DMSP	Annual Users Conference
ERS-2	GOES, GMS, Meteosat	Quality Customer Support
RADARSAT	Over 220 land-based, portable and shipboard systems installed	Custom Engineering and development
The most installations worldwide		

Timely upgrades to next generation satellites
Active User Community

ERS-2 SAR (synthetic aperture radar) image of Salton Sea in the desert region of southern California. Note the pattern of slicks indicating circulation in this shallow, highly saline body of water. The ERS-2 data was acquired by a SeaSpace SX-EOS system at the University of Wisconsin - Madison when the spacecraft was just a few degrees above the horizon. Courtesy of: SeaSpace Corporation.

All SeaSpace systems include the <u>industry standard</u> TeraScan® software:

- Over 400 licenses worldwide
- Customizable, end-to-end solution
- Automatic product generation and delivery
- Built and supported by SeaSpace based on our customers' requirements
- Seamless interfaces to other applications
- Export to HDF, NetCDF, GeoTIFF
- Developer's Toolkit Included

RGB composite of Terra MODIS data over Western Australia. Courtesy of: Western Australian Satellite Technology and Applications consortium.

Highest quality antennas and components

- Every system completely built and tested at SeaSpace prior to shipping
- Full support throughout life cycle of each system
- Longest service life and easiest to maintain
- Fastest and most thorough installation and commissioning in the industry

Image of northern California fires on 29 August, 2001 from India's Oceansat-1 OCM, acquired and processed at SeaSpace Corporation, San Diego, CA. Courtesy of: SeaSpace Corporation.

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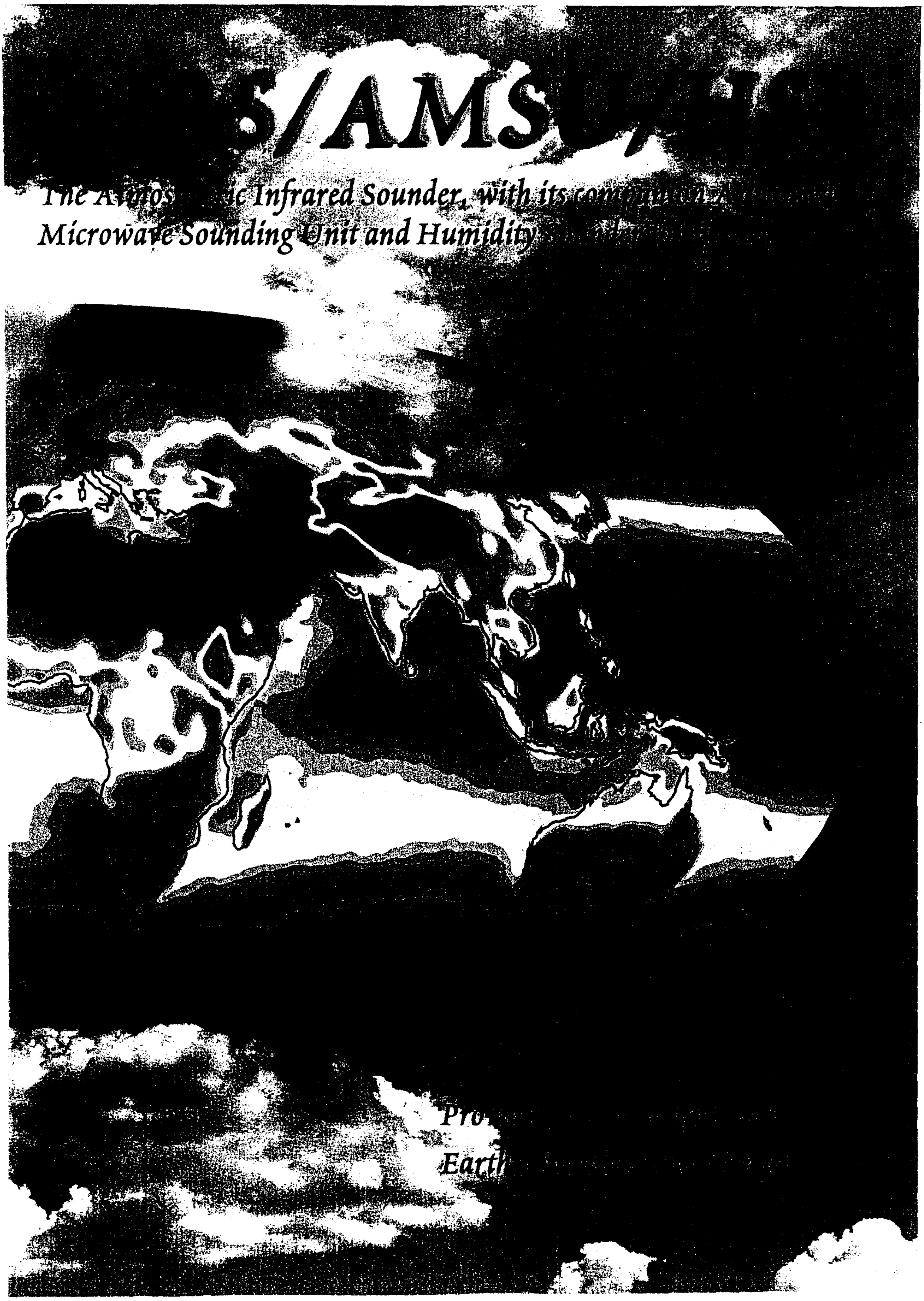
REV. 1-12-02

附錄四

The Atmospheric Infrared Sounder,with its companion Advanced Microwave Sounding Unit and Humidity Sounder for Brazil


S/AMS
Infrared Sounder, with its
Microwave Sounding Unit and Humidity

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Designed by: Scott Hulme, Winnie Humberson

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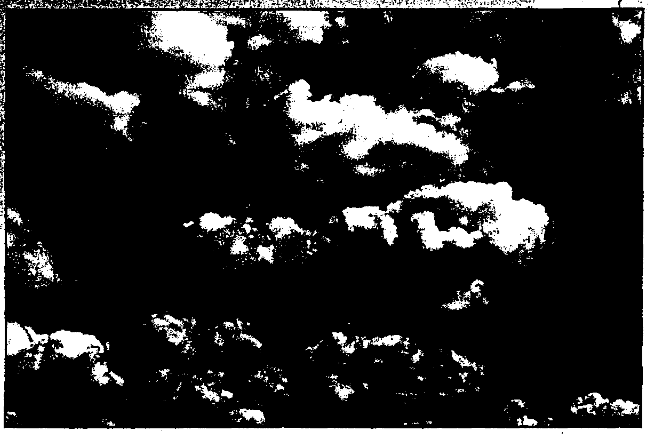
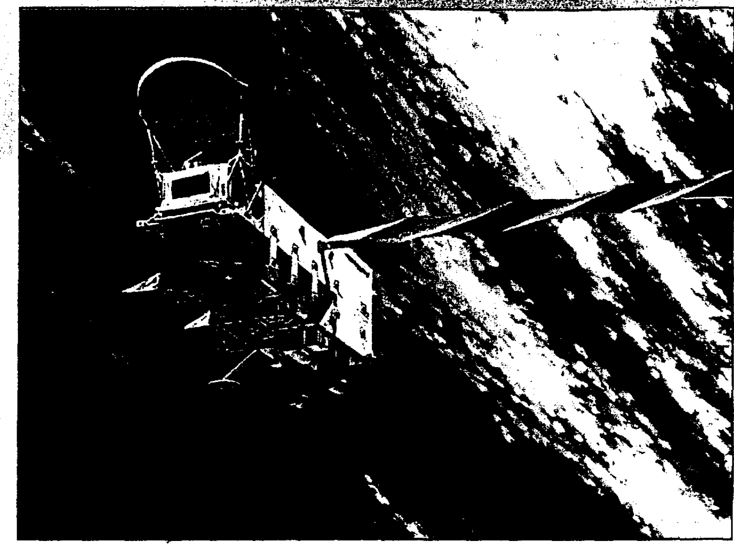


The Atmospheric Infrared Sounder

Enhancing the quality of global meteorological observations can yield considerable economic benefits through more reliable climate prediction, improved weather forecasts, better understanding of the factors influencing air quality, and mitigation of the economic and human costs of natural hazards.

Terra, launched in December 1999, and Aqua, planned for launch in 2001, are two main Earth Observing System (EOS) observatories that will use multiple instruments to acquire the necessary data with the required high precision and accuracy.

The Atmospheric Infrared Sounder, set for launch aboard Aqua, will make global measurements of our atmosphere, providing new insights into Earth's weather and climate.



The Atmospheric Infrared Sounder (AIRS), together with the Advanced Microwave Sounding Unit (AMSU) and the Humidity Sounder for Brazil (HSB) on the Aqua mission, represents the most advanced sounding system ever deployed in space. The system is capable of measuring the atmospheric temperature in the troposphere with radiosonde accuracies of 1 K over 1 km-thick layers under both clear and cloudy conditions, while the accuracy of the derived moisture profiles will exceed that obtained by radiosondes. Furthermore, the system will provide additional data on land and ocean surface temperature and surface emissivity, cloud fraction (see centerfold example from an earlier instrument) and cloud top height, and ozone burden of the atmosphere. This makes AIRS / AMSU / HSB the primary observing system to study the global water and energy cycles, climate variation and trends, and the response of the climate system to increased greenhouse gases.

Weather or Climate?

When we talk about the weather, we are talking about conditions at one specific place and time. If someone says "Yesterday we had an inch of rain in Los Angeles, but today is clear and dry," he is talking about weather. The weather is constantly changing.

When we talk about climate, we are describing the long-term average of weather. If someone says "Los Angeles usually gets two inches of rain in the month of November," he is talking about climate. You have to make measurements for many years to get an idea of what the true climate is.

The difference between weather and climate is like the difference between a sports team winning one game and having a winning year. Some games you win, some games you lose (which is like the weather changing day-to-day), but if at the end of the year you've won a lot more than you've lost, you'd say you've had a winning year (or a winning climate)!

Measuring the Atmosphere with Radiosondes

Currently, weather balloons are the most important source of information about Earth's atmosphere. They are usually called 'radiosondes,' sonde meaning 'sounding' in French, a reference to the ancient maritime practice of measuring the deep ocean from ships. 'Radio' refers to their method of data return. Hundreds of balloons are launched around the globe twice daily to sample the atmosphere to heights of about 15 km (10 mi). Each balloon, about the diameter of a child's wading pool, lifts temperature, humidity and pressure sensors in a milk carton-sized box. The sensors transmit information to a receiver on the ground, where it is processed and distributed to weather forecasting centers. The result is a snapshot of the atmosphere every twelve hours at a limited number of sites around the world.

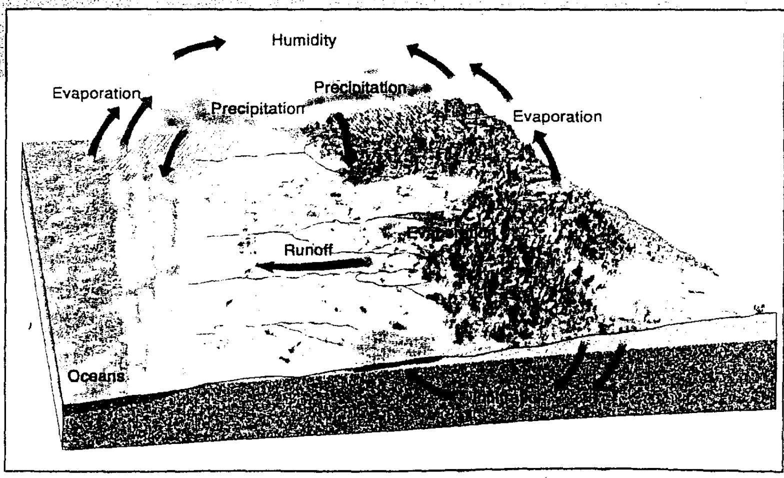
This picture is not complete. Most radiosondes are launched over land, so that the 75% of the world covered by ocean is not sampled. Furthermore, economic differences between countries further influence coverage. Europe and North America have excellent coverage, while much of Africa, Asia and South America are sparsely sampled.

Improving the world weather observing system is also an essential objective of Earth system science and applications, because the phenomena that govern long term climate are the same as those that manifest themselves in transient weather perturbations. The AIRS/AMSU/HSB observations are therefore equally applicable to both climate and weather studies and will be provided to the US National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF) for assimilation into the operational forecast General Circulation Models. Through such assimilation, the AIRS/AMSU/HSB observations will lead to substantial increases in the mid- and long-range weather forecast skill.

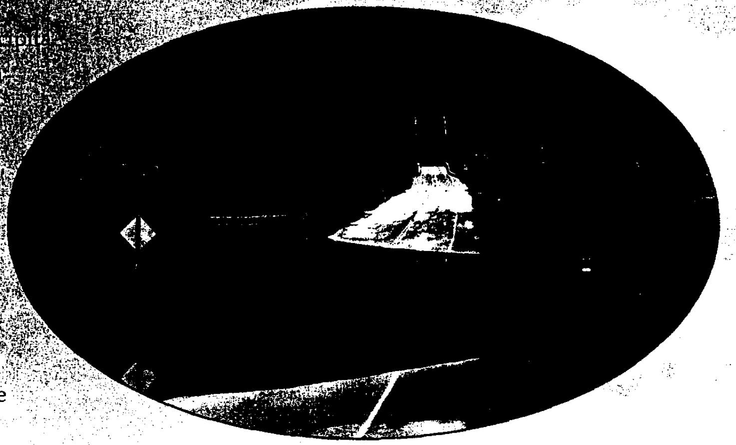
Is the Global Water Cycle Accelerating?

Water is indispensable to all living species, and fresh water is an essential ingredient of life on land. Water also plays a unique and almost irreplaceable role for innumerable industrial processes and domestic applications. For these reasons, fresh water is an immensely valuable resource on which our existence depends. Evaporation, precipitation, and the long-range transport of water vapor by winds are the processes that constantly recycle water and renew fresh water resources - a feature unique to our planet, at least as far as we know. As civilization has evolved, we have been making ever-increasing demands on water resources and by now, any substantial change in the global water cycle would entail serious consequences in many regions of the world where water resources are already strained.

The amount of water vapor carried by the atmosphere increases dramatically with temperature, because warm air has a much larger water holding capacity than cold air. As our global climate becomes warmer, models predict an acceleration of the global water cycle, increased evaporation and increased global precipitation. Increased evaporation entails faster depletion of ground water resources, although more abundant rainfall means more frequent and generally larger flooding events. The report from the Intergovernmental Panel on Climate Change (1996) states that "Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places .... Several models



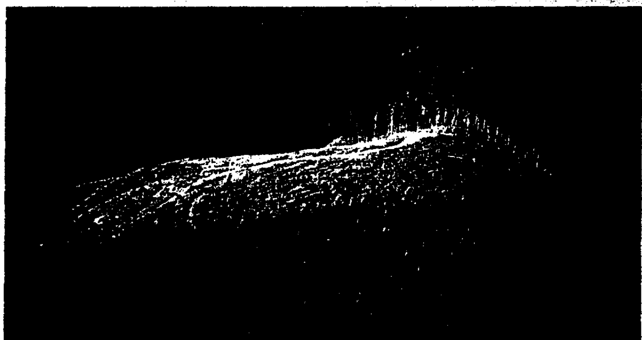
indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events. Thus, accurate characterization of the rate of recycling of water in the atmosphere may be a sensitive index of the multiple roles of hydrology in the climate system.



One general indicator of the strength of the global water cycle is the mean residence time of water in the atmosphere. The equivalent of the entire water content of the atmosphere is recycled 33 times each year. (This is obtained by dividing the average global yearly precipitation of 95 cm/year by the total atmospheric content of precipitable water vapor of 2.9 cm). This gives water a mean global residence time in the atmosphere of about 11 days (Chahine, *Nature* 1992). Variations in the residence time, or its equivalent the recycling rate, can be obtained from space observations with an accuracy that permits determination of how it is changing on a monthly basis.

The results from current space data are not very accurate but nevertheless show a small trend toward acceleration of the recycling rate of 0.4 ± 0.5% per year. If this trend persists, it may lead to an intensification of the global hydrological cycle, having major impacts on regional water resources and the possibility of changes in the magnitude and timing of runoff and the intensity of floods and droughts.

Thus we have a direct and compelling interest in learning about any significant change in the global water cycle. The most precise way to identify such a trend is by measurement of changes in the precipitable water load carried by the atmosphere. The AIRS/AMSU/HSB suite of instruments will provide the most accurate information ever obtained about the total atmospheric water content. From this we can deduce whether, and at what rate, the Earth's water cycle may be accelerating.



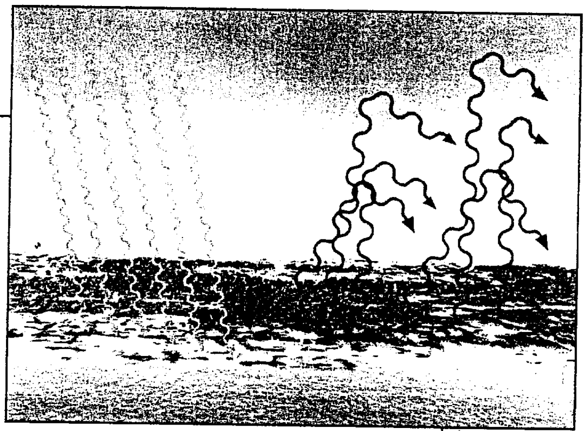
Water Vapor: Earth's Primary Greenhouse Gas

Water vapor is the dominant greenhouse gas in the Earth's atmosphere. It accounts for about 60% of the greenhouse effect of the global atmosphere, and most of its sensitivity to temperature, far exceeding the total combined effects of carbon dioxide, methane, ozone and other greenhouse gases.

From time immemorial, humans have been engaged in activities that alter the environment, first by clearing forests and using the land for their own purposes, and now by burning fossil fuels at a rate that results in a major increase in the amount of carbon dioxide and other absorbing greenhouse gases present in the atmosphere. As a result, the atmospheric concentration of carbon dioxide has already reached a level 30% higher than at any time during the past 300,000 years, despite drastic changes in the Earth's climate and successive ice ages. Methane concentration has more than doubled, while unknown amounts of "aerosol" haze have been introduced in the atmosphere. In these examples, the primary impact of human activities is well understood, yet the long-term consequences cannot be readily predicted. The reason is that the primary impacts or "forcing" of the Earth's climate may be enormously amplified by further re-adjustments in the Earth's atmosphere, land and oceans.

Water vapor in the atmosphere strongly absorbs infrared radiation emitted by the Earth's surface and therefore acts as a blanket that insulates us from the cold radiation sink of deep space. This atmospheric blanket is thickest in the tropics, where nighttime air temperature remains close to daytime values. It is thin over deserts, high mountains, and plateaus, where, partly as a consequence, temperatures drop precipitously at night. Because of the presence of variable amounts of water vapor in the air above us, the surface warming associated with an increase of energy absorbed by the planet is twice as much as it would be with a totally dry atmosphere. This is a major effect and also a source of considerable uncertainty about future climate change.

While relatively thin, water vapor in the upper troposphere is particularly effective at absorbing infrared radiation emitted by the Earth's surface. Water is brought to this level by tall storm clouds that rise high in the troposphere. However, we are not sure how clouds interact with water vapor in this critical region and whether more active convection, as anticipated with warmer conditions at the Earth's surface, would add moisture to the upper troposphere or, to the contrary, dry the air. Accurate measurements of atmospheric humidity profiles will resolve this uncertainty.

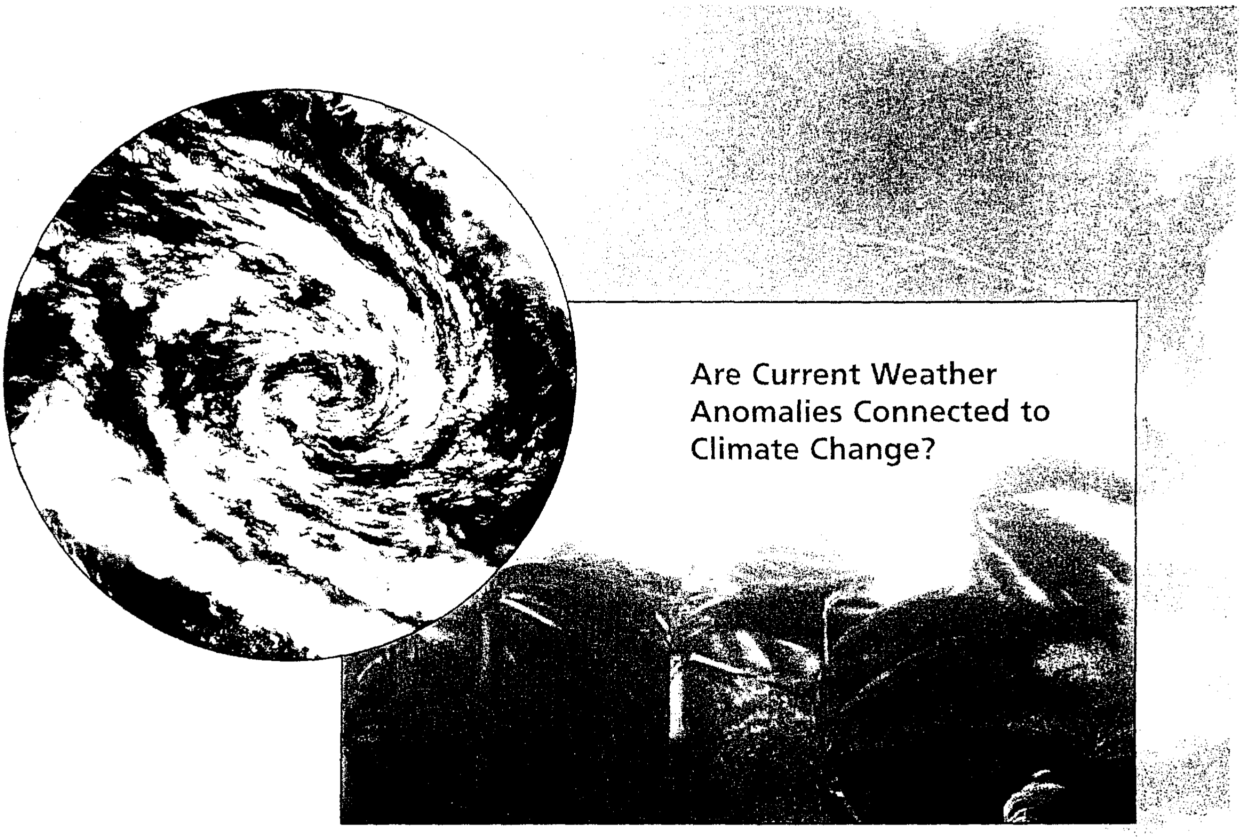


The Greenhouse Effect

The Earth without its atmosphere would be, on average, a much colder place. Warming to the familiar temperatures of sun-heated surfaces during the day, our planet would cool to far below freezing at night. The atmosphere retains much of the daytime heat by absorbing infrared radiation (this is the familiar warmth felt a few feet from a west-facing wall on a summer evening). A similar phenomenon occurs when sun shines through a window into a closed room, hence the term "greenhouse effect."

All gases absorb infrared radiation, but some are particularly effective. Water vapor is the most important greenhouse gas, mostly because it is so abundant. Next in importance are carbon dioxide and methane. Water vapor varies naturally, but human activities have produced significant amounts of additional atmospheric carbon dioxide and methane, particularly since the start of the industrial revolution in the late eighteenth century. (Current United States per capita production of carbon dioxide is about six tons per year.) As early as a century ago scientists speculated that increasing carbon dioxide from burning coal and oil might warm the Earth. And as Earth warms, evaporation increases, sending more water vapor into our atmosphere.

Our planet has experienced a rapid temperature increase since the 1970s, and six of the ten warmest years of the past century were in the 1990s. Significant changes in climate have accompanied this warming. Are these changes caused by increasing greenhouse gases, notably carbon dioxide? While many climate researchers believe so, the causes of climate change are not well understood. A goal of the AIRS/AMSU/HSB science team is long-term, stable observation of the atmosphere for monitoring global warming and other types of climate change.



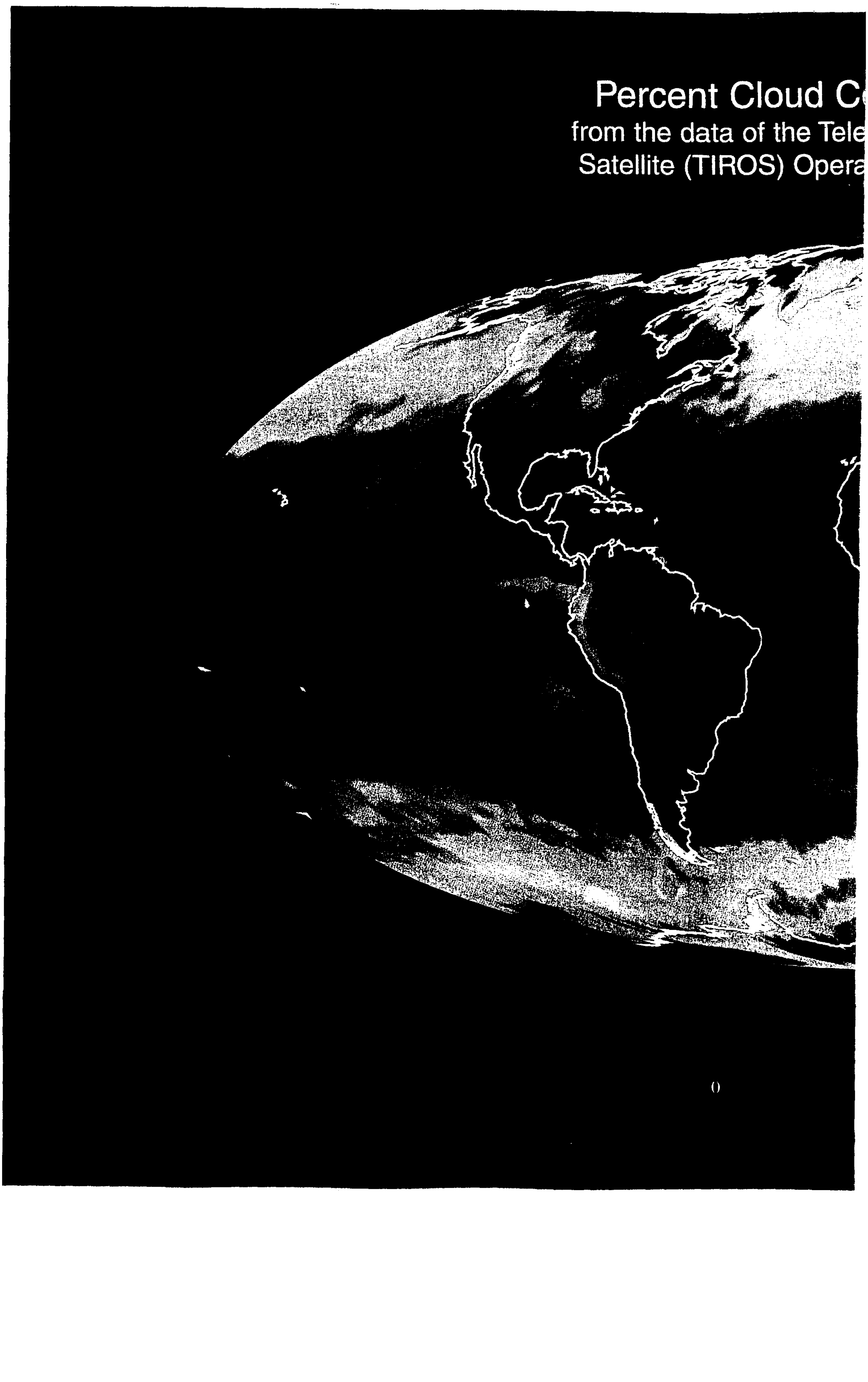
Are Current Weather Anomalies Connected to Climate Change?

Change in global-mean temperature would not draw much attention if we did not foresee that relatively small variations in the global environment can entail changes of much greater significance in regional weather, water resources and agricultural productivity. The striking manifestations of "El Niño weather" are but one example of such climate-weather connections.

Much remains to be learned, however, about the relationship between observed year-to-year changes or long-term trends in planetary climate, and corresponding changes in storm tracks and intensity. We already know that the frequency and distribution of tropical cyclones, hurricanes or typhoons, between the Atlantic and Pacific oceans changes from year to year, governed in part by El Niño events or their counterparts, but they are also sensitive to other, longer term changes in global winds, the water content of the lower atmosphere, the temperature of the ocean and probably more. Likewise, the intensity and path of mid-latitude storms respond to planetary-scale patterns or "oscillations" of the global atmosphere, of yet unknown origin. We surmise that these phenomena hold the key to effective predictions of the anticipated regional effects of climate variations. We want to know the extent to which variations in local weather, precipitation and water resources are related to global climate change.

Furthermore, weather disturbances govern the distribution of clouds, their water content, and resulting rainfall, as well as solar radiation that reaches the surface. In order to understand and predict climate change, it is not sufficient to consider atmospheric, oceanic or land processes in isolation from the atmospheric circulation that controls the fluxes of radiant energy, heat, and water among the atmosphere, ocean and land surface. Such connections are transient and can only be understood by comparing meteorological and hydrological forecasts with observations at the same place and time.

To learn more, we need to capture both the large-scale patterns of the global atmosphere and the details of individual storms or dry spells. Satellite observation is the ideal tool for this purpose; only space-based sensors can provide at the same time detailed information on current weather events and a global view of the atmosphere. The most directly applicable information is delivered by atmospheric sounders like AIRS/AMSU/HSB, which can resolve the vertical structure of weather systems.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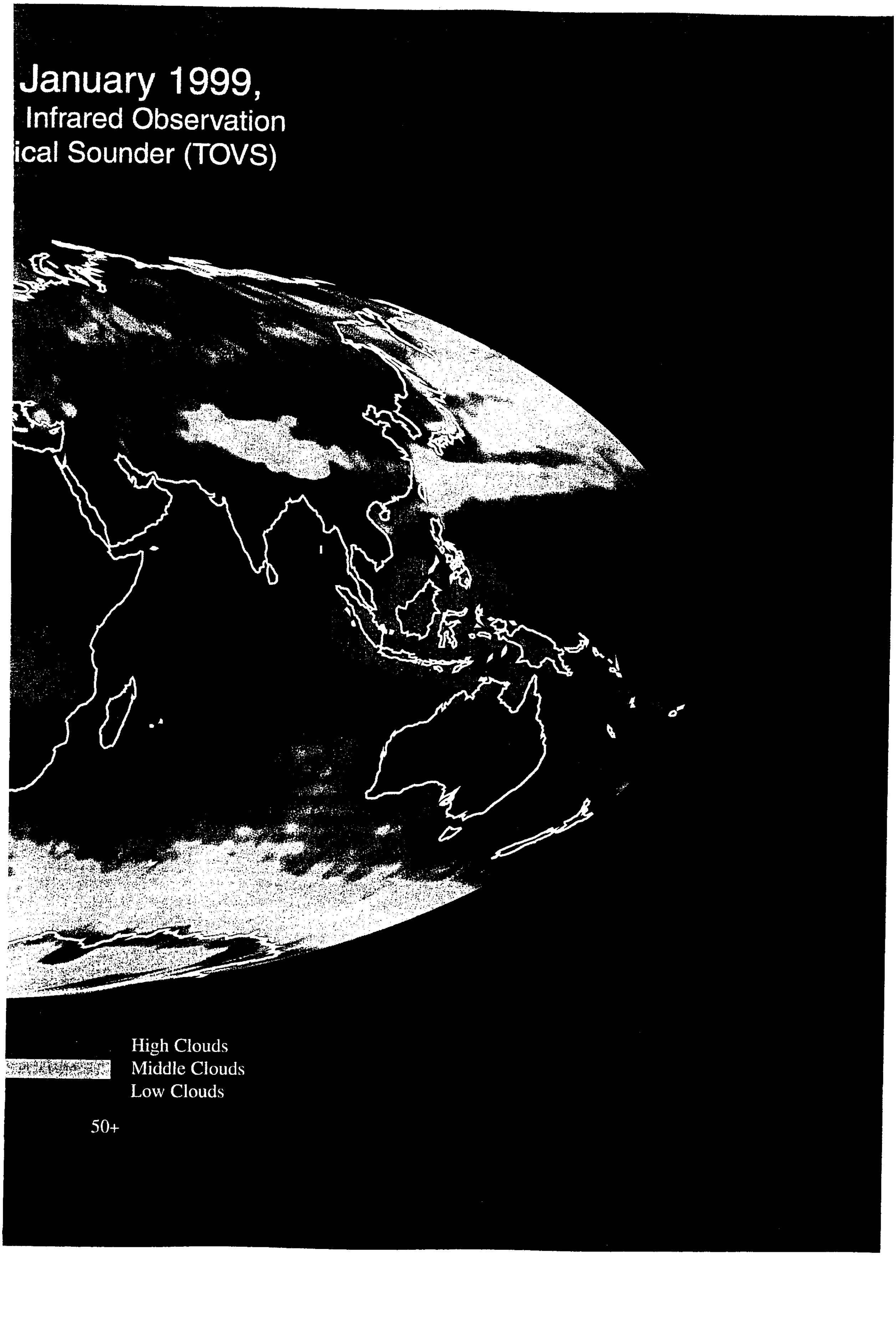
January 1999,
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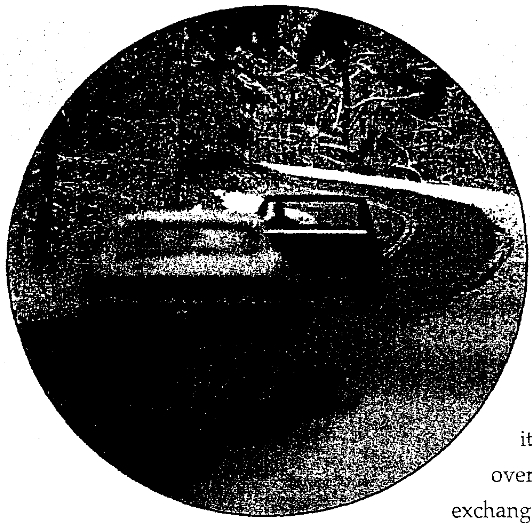
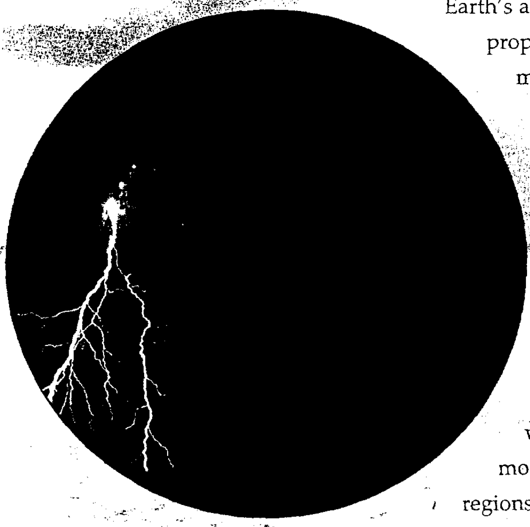
50+



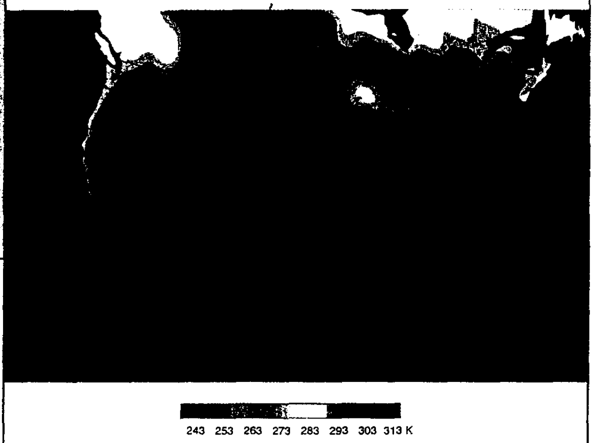
Improving Weather Forecasts

Only 50 years ago, weather forecasting was an art, based on the inspired interpretation of scarce data from a loose array of ground-based observing stations, balloons, and aircraft. The ability to conduct appropriate weather reconnaissance over the ocean was a decisive advantage. The timely exchange of terse meteorological messages was the essence of a successful "synoptic" (instantaneous) analysis of the weather situation over the region. Thirty years ago, meteorologists had their first opportunity to use global observations collected for the scientific purpose of demonstrating the feasibility of one-to-two-week weather prediction using computer models of the atmosphere. We are now finally on the verge of achieving this objective, thanks to successive breakthroughs in global weather observation from the Earth's surface and from space, a sweeping acceleration in worldwide communications, and the ever increasing computer capabilities.



Satellite-based sensors can only detect radiation emerging from the Earth's atmosphere, not measure directly the meteorological properties of interest. The interpretation of satellite measurements requires a complicated mathematical procedure that consists of recreating as best we can the radiation signature of the partially absorbing, partially transparent atmospheric medium below. This procedure was hitherto limited by the accuracy and resolution of the basic radiation measurements and incapable of matching the accuracy of measurements made directly in the atmosphere. For this reason, satellite observations added to the available information only where local measurements were scarce, such as most of the southern hemisphere and large oceanic regions in the northern hemisphere. These technical limitations have been overcome. We expect that satellite sounding data will finally match the accuracy of balloon-borne sensors and deliver the same precision worldwide as was possible so far only over the developed regions of the northern hemisphere, with corresponding improvement in the quality and range of extended weather forecasts.

Daytime Atmospheric Surface Temperature
TOVS data, July 1999



Predicting the Weather

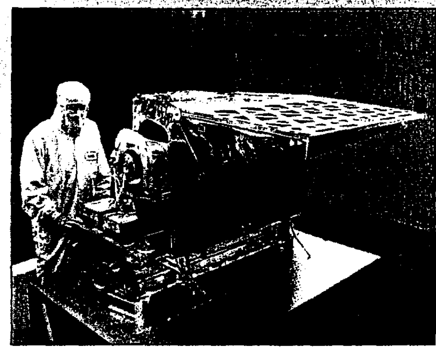
The simplicity of tomorrow's weather forecast masks a remarkably complex and difficult activity. The forecast process begins with the timely gathering of atmospheric observations. These data sets are very large, but also surprisingly incomplete: current satellites take limited numbers of observations, and radiosondes are confined to the continents twice daily. Large areas of our planet, especially over the oceans, are poorly observed. (Oceans may seem inconsequential to those of us living on land, but many weather disasters have featured poorly forecast oceanic storms moving ashore.)

Observations are combined mathematically with computer models of the atmosphere. These models embody the equations describing the physical properties of the atmosphere. Despite their sophistication, they only partially describe the atmosphere's true behavior. For example, even a high resolution global model has gridpoints spaced every 100 km, so a single profile represents a volume of roughly 200,000 cubic km. The best possible observations entered into the most sophisticated forecast models sometimes yield questionable predictions.

This leads to the final step in the forecast process. Weather forecasters analyze weather observations and predictions from computer models. Forecasters use judgment and experience to sort through complex and sometimes contradictory information. The result is tomorrow's forecast.

A major goal of the AIRS/AMSU/HSB science team is improving weather forecasts. This will be achieved through more complete observations, especially over the oceans.

Science Objectives

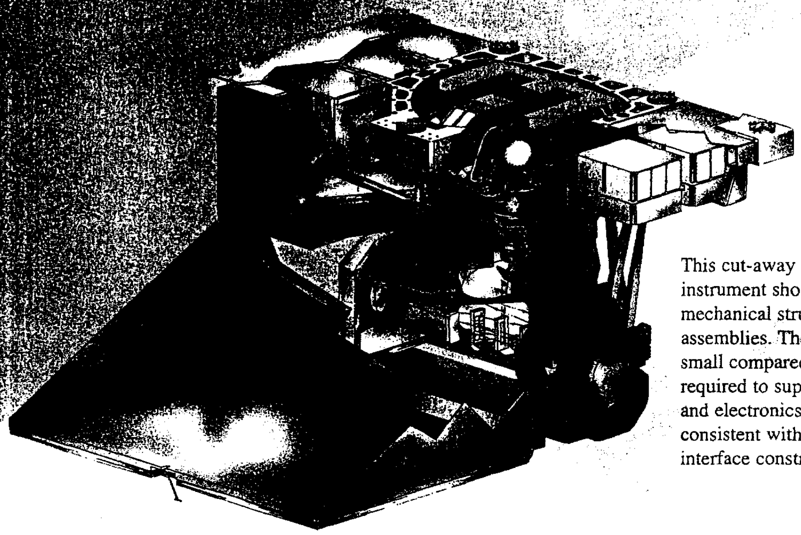


Understanding the dynamics of climate, the transport of chemical agents in the atmosphere and their distribution over the surface of the Earth, and the rainfall and evaporation that control the growth of vegetation requires a precise knowledge of the global atmospheric circulation, temperature profiles, and water vapor content.

AIRS / AMSU / HSB will observe and characterize the entire atmospheric column from the surface to the top of the atmosphere in terms of surface emissivity and temperature, atmospheric temperature and humidity profiles, cloud amount and height, and the spectral outgoing infrared radiation. These data and scientific investigations will answer long-standing questions about the exchange and transformation of energy and radiation in the atmosphere and at the Earth's surface.

1. **Determination of the factors that control the global energy and water cycles:** The study of the global hydrologic cycle and its coupling to the energy cycle is a key to understanding the major driving forces of the Earth's climate system. AIRS / AMSU / HSB will measure the major components of these driving forces including the thermal structure of the surface and the atmosphere, the outgoing longwave infrared radiation, and the atmospheric water vapor content.

2. **Investigation of atmosphere-surface interactions:** The high spectral resolution of AIRS will provide several spectrally transparent window channels that will observe the surface with minimal contamination by the atmosphere and will allow the determination of accurate surface temperature and infrared spectral emissivity. In addition, the narrow spectral channels in the short-wavelength infrared region will observe the atmospheric layers near the Earth's surface with the highest vertical resolution possible by passive remote sensing. The observations will enable investigations of the fluxes of energy and water vapor between the atmosphere and the surface, along with their effect on climate.



This cut-away view of the AIRS instrument shows the key mechanical structures and assemblies. The spectrometer is small compared to the volume required to support space radiators and electronics in a configuration consistent with the spacecraft interface constraints.

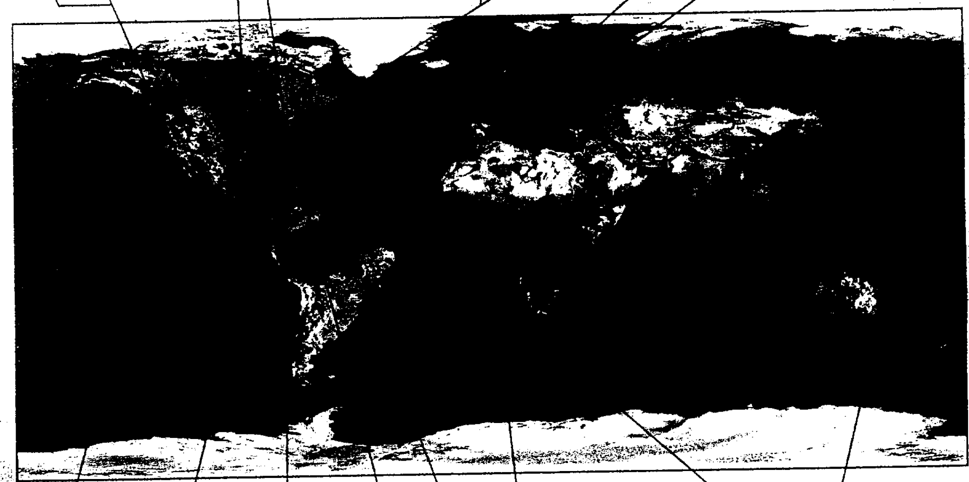
3. **Improving numerical weather prediction:** Numerical weather prediction models have now progressed to the point where they can predict atmospheric temperature profiles to an accuracy of 2 K, which is equivalent to the accuracy of current satellite data. Further improvement in our knowledge of temperature profiles is essential in order to improve forecasting accuracy. AIRS/AMSU/HSB temperature profiles with radiosonde accuracy of 1 K in 1 km-thick layers are key to improving the accuracy and extending the range of weather forecasts.

4. **Detection of the effects of increased greenhouse gases:** AIRS will map the concentration of carbon dioxide and methane globally. In addition, the ability to provide simultaneous observations of the Earth's atmospheric temperature, ocean surface temperature, and land surface temperature and infrared spectral emissivity as well as humidity, clouds and the distribution of greenhouse gases makes AIRS/AMSU/HSB a primary space instrument to observe and study the response of the atmosphere to increased greenhouse gases.

5. **Assessing climate variations and feedbacks:** The accuracy and high spectral resolution of AIRS provide a powerful new tool for climate studies. AIRS' high resolution infrared coverage from 3.74 to 15 μm will give researchers the ability to validate numerical models and to study different climate processes as needed. For example, emission to space by strong and weak water vapor lines is a critical climate feedback mechanism in the middle and lower troposphere. Numerical models must reproduce such lines as an indication of their ability to describe the climate system.

Science Team

The international science team for the AIRS instrument includes experts from the United States, France, Italy and Australia. Under the leadership of Dr. Moustafa Chahine at the Jet Propulsion Laboratory, the team guides the definition of the AIRS instrument and its scientific goals.



ABM	Australian Bureau of Meteorology
AEB	Agencia Espacial Brasileira (Brazilian Space Agency)
EP	Ecole Polytechnique, France
GSFC	Goddard Space Flight Center (NASA)
JPL	Jet Propulsion Laboratory (NASA)
LaRC	Langley Research Center (NASA)
MIT	Massachusetts Institute of Technology
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
UB	University of Bologna, Italy
UCSB	University of California, Santa Barbara
UMBC	University of Maryland, Baltimore County
UMCP	University of Maryland, College Park
UW	University of Wisconsin

Atmospheric Sounding

Atmospheric sounding for information about temperature and abundance of gases is based on the fact that thermal radiation received by a radiometer originates at wavelength-dependent depths in the atmosphere. This is caused by a non-uniform absorption spectrum, particularly by molecular absorption lines. (Note that in an atmosphere in thermal and radiative equilibrium, emission equals absorption. If that were not the case, the atmosphere would either cool down or heat up until balance is reached.) At wavelengths near the peak of such a line, absorption may be so strong that most of the underlying atmosphere is opaque, and only the top of the atmosphere is "seen." Conversely, at wavelengths away from the lines, often called a "window" region, the atmosphere may be nearly transparent, and the surface or the bottom of the atmosphere is seen. Through spectral sampling, i.e., by measuring narrow spectral bands or "channels," it is then possible to probe into different depths of the atmosphere.

It is possible to separate the effects of different atmospheric gases by using channels in different spectral regions where one gas has absorption features while the others do not. To measure temperature profiles, AIRS uses a large number of CO_2 absorption lines in the infrared spectral region, while AMSU-A uses a few O_2 absorption lines at microwave wavelengths. To measure water vapor profiles, AIRS uses many H_2O absorption lines throughout its spectral range, and HSB uses a single H_2O absorption line in the microwave region. Since the vertical distribution of CO_2 and O_2 are both stable and well known, the CO_2 and O_2 channels allow the temperature distribution to be determined. With that known, the H_2O channels allow the vertical distribution of water vapor density to be determined.

The infrared spectral range covered by AIRS also features absorption lines of other molecular species, such as O_3 and CH_4. This makes it possible to deduce ozone and methane profiles. Finally, while liquid water makes most clouds completely opaque in the infrared region, in the microwave region they are partially transparent. The microwave spectral absorption features of liquid water therefore make it possible to determine the vertical distribution of liquid water in clouds from AMSU-A and HSB measurements. This information is used to make the derived AIRS temperature and water vapor profiles more accurate.

The Instruments

AIRS measures upwelling radiances in 2378 spectral channels in the infrared (IR) from 3.74 μm to 15.4 μm. A set of 4 channels in the visible/near-infrared (Vis/NIR) observes wavelengths from 0.4 to 1.0 μm to provide cloud cover and spatial variability information. The microwave sounders provide sea ice concentration, snow cover, and additional temperature profile information, as well as precipitable water and cloud liquid water content. If cloud cover is too great for IR retrievals, the microwave measurements alone will provide a coarse, low precision atmospheric temperature profile and surface characterization.

AMSU-A is actually two completely separate sensor units, AMSU-A1 and AMSU-A2, but during data processing on the ground the observations from the two instruments are combined and treated as if they came from a single instrument. (This is possible because the two units are very similar and are operated in a synchronized way.) Together they provide measurements in 15 spectral channels. Most of them are used to derive temperature profiles, from the surface upward to about 40 km. Some are used to provide cloud information. The AMSU-A "footprint" is three times as wide as the AIRS footprint, and an AMSU-A spot therefore covers a cluster of nine AIRS spots. Data from a single AMSU-A spot are used to "cloud clear" a cluster of nine AIRS observations.

HSB provides measurements in four spectral channels, which are used to derive water vapor profiles, from the surface to about 10 km, and some supplemental cloud information. They are also used, together with AMSU-A data, to derive liquid water (i.e., cloud) profiles to help make the AIRS-derived profiles more accurate. Rain intensity can also be deduced from the HSB measurements.

The instruments are all cross-track scanners. They view their respective scan mirrors, which rotate around an axis along the flight direction. As a mirror is rotated, the "viewing beam" sweeps across the ground track below the satellite and is reflected into its instrument. As the spacecraft moves along this results in a scan "swath" that extends a little more than 800 km on either side of the ground track. The AMSU-A reflectors make a complete revolution in 8 seconds. The AIRS reflector and HSB reflector each make three revolutions in the same time (i.e., each makes one revolution in 2.67 seconds). About 99° of each 360° revolution is used to sample the atmosphere and surface below. This takes about 6 seconds for AMSU-A and 2 seconds for AIRS and HSB. AMSU-A takes 30 Earth-view samples in the 6-second period, and AIRS and HSB each take 90 Earth-view samples in the 2-second period. The sampling density of AIRS and HSB is therefore triple that of the AMSU-A instruments, both along and across the swath. Hence for each AMSU-A sample (or spot) there are nine HSB and nine AIRS spots.

The remainder of the rotation cycle is spent looking at empty space or internal calibration targets. Calibrating every scan cycle results in a very stable measurement system.

FACTS ABOUT AIRS

Size:	stowed: 116.5 x 80 x 95.3 cm
	deployed: 116.5 x 158.7 x 95.3 cm
Mass:	177 kg
Power:	220 W
Data Rate:	1.27 Mbps
Spectral Range:	IR: 3.74 - 15.4 μm
	Vis/NIR: 0.4 - 1.0 μm
Channels:	IR: 2378
	Vis/NIR: 4
Aperture:	10 cm
Instrument Field of View:	IR: 1.1° (= 13.5 km @ nadir)
	Vis/NIR: 0.2° (= 2.3 km @ nadir)
Swath Width:	99° (= 1650 km)
Scan Sampling:	IR: 90 x 1.1°
Pointing Accuracy:	IR: 0.1°
Thermal Control:	IR detectors: active cooler @ 60 K
	Passive radiator @ 150 K
	Electronics @ ambient
Prime Contractor:	British Aerospace Systems
	(formerly Lockheed-Martin)
Responsible Organization:	Jet Propulsion Laboratory

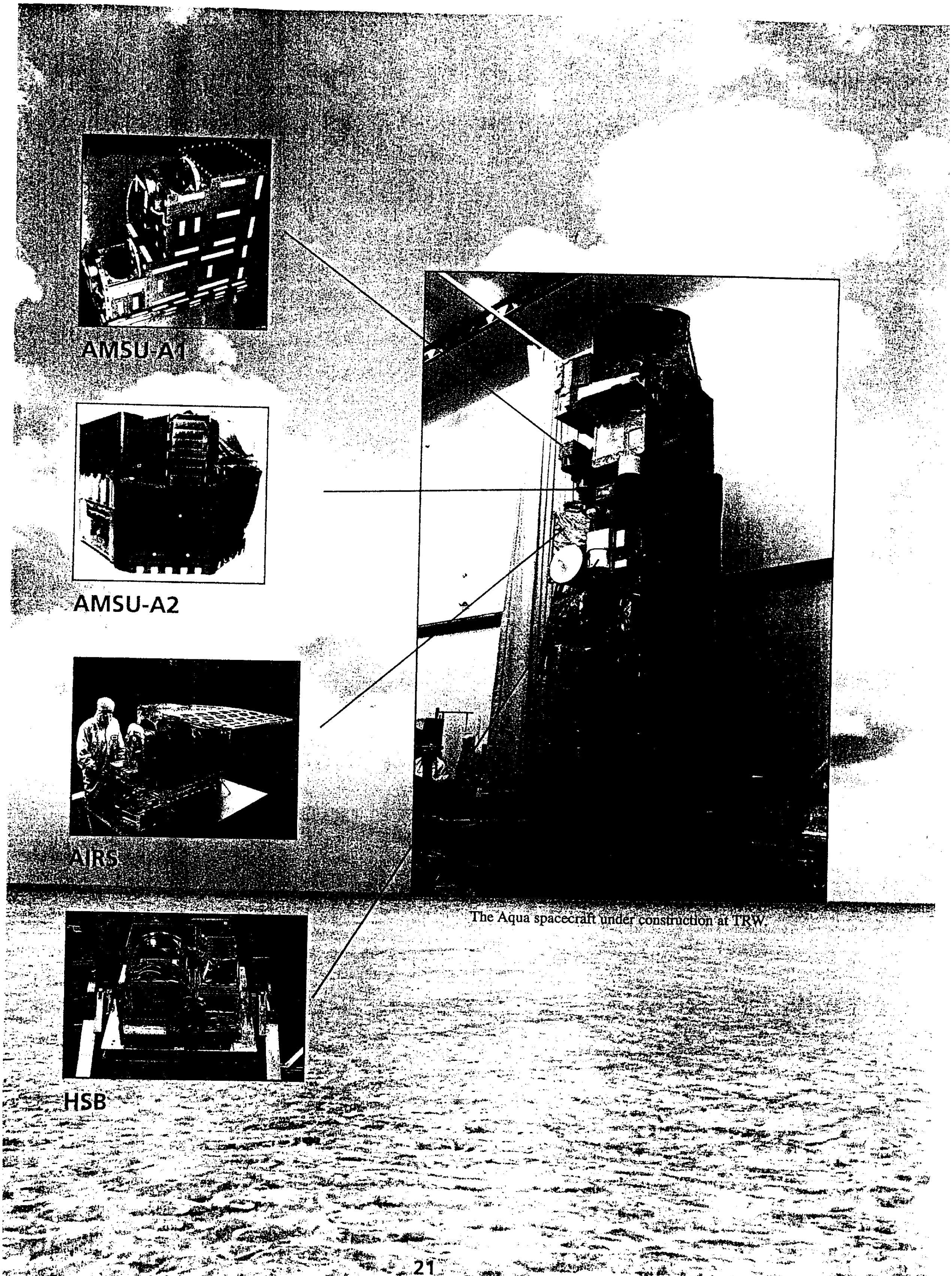
FACTS ABOUT AMSU

Instrument:	AMSU-A1	AMSU-A2
Size:	72 x 34 x 59 cm	73 x 61 x 86 cm
Mass:	49 kg	42 kg
Power:	77 W	24 W
Data Rate:	1.5 kbps	0.5 kbps
Spectral Range:	50 - 90 GHz	23 - 32 GHz
Channels:	13	2
Aperture:	15 cm (two)	30 cm (one)
Instrument Field of View:	3.3° (= 40.5 km @ nadir)	3.3° (= 40.5 km @ nadir)
Swath Width:	100° (= 1690 km)	100° (= 1690 km)
Scan Sampling:	30 x 3.33°	30 x 3.33 °
Pointing Accuracy:	0.2°	0.2°
Thermal Control:	None (ambient)	None (ambient)
Prime Contractor:	Aerojet	Aerojet
Responsible Organization:	NASA/GSFC	NASA/GSFC

FACTS ABOUT HSB

Size:	70 x 65 x 46 cm
Mass:	51 kg
Power:	56 W
Data Rate:	4.2 kbps
Spectral Range:	150 - 190 GHz
Channels:	4
Aperture:	18.75 cm (one)
Instrument Field of View:	1.1° (= 13.5 km @ nadir)
Swath Width:	99° (= 1650 km)
Scan Sampling:	90 x 1.1°
Pointing Accuracy:	0.1°
Thermal Control:	None (ambient)
Prime Contractor:	Matra Marconi Space (UK)
Responsible Organization:	INPE (Brazil)

Data Products to be Derived from the AIRS/AMSU/HSB Data by the AIRS Science Team	
Each of these products is described in the *EOS Data Products Handbook, volume 2*, published in 2000 and available from the EOS Project Science Office web site at http://eospso.gsfc.nasa.gov.	
Level 2 Cloud-Cleared Radiances	
Flux Product	Clear-column radiance Outgoing longwave radiation at the top of the atmosphere Outgoing shortwave radiation at the top of the atmosphere Net longwave flux at the surface Net shortwave flux at the surface
Atmospheric Temperature Product	Temperature profile through the atmosphere (30 levels) Troposphere height Stratosphere height
Humidity Product	Water vapor profile through the atmosphere Total precipitable water Cloud liquid-water content Precipitation indication Cloud-ice indication
Cloud Product	Cloud-top pressure Cloud-top temperature Fractional cloud cover Cloud spectral properties Cloud type
Ozone Product	Ozone profile through the atmosphere Total ozone
Trace Constituent Product	Methane Carbon monoxide
Surface Analysis Product	Sea surface skin temperature Land surface skin temperature Infrared surface emissivity Microwave surface emissivity



The Aqua spacecraft under construction at TRW.


NASA