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）

赴加拿大參加國際遙測技術應用研討會
出國報告

服務機關：行政院國家科學委員會精密儀器發展中心
出 國 人：吳宗達　副研究員

出國地點：加拿大
出國日期：九十一年六月二十一日至六月二十八日
報告日期：九十一年七月三十一日

行政院研考會/省（市）研考會
編號欄

系統識別號:C09103121

公 務 出 國 報 告 提 要

頁數: 58 含附件: 否

報告名稱:

赴加拿大參加國際遙測技術應用研討會出國報告

主辦機關:

行政院國家科學委員會精密儀器發展中心

聯絡人／電話:

劉恭霖／03-5779911-522

出國人員:

吳宗達 行政院國家科學委員會精密儀器發展中心 研究發展組 副研究員

出國類別: 考察

出國地區: 加拿大

出國期間: 民國 91 年 06 月 21 日 -民國 91 年 06 月 28 日

報告日期: 民國 91 年 07 月 31 日

分類號/目: I0／綜合（科學類） I0／綜合（科學類）

關鍵詞: 遙測, 感測器, 衛星影像

內容摘要: 在21世紀的科技發展中，世界各國對於遙測技術的建立均投下了大量人力與財力，期待能在區域安全、防災、生態環保、資源規劃及地球科學研究等議題佔有一席之地。而台灣地狹人稠，土地利用畸零，對於防災與資源規劃的需求更是較先進國家爲高。精密儀器發展中心以累積多年之光、機、電及儀器整合技術爲基礎，在幾項大型計畫的成功進行下，已於飛機或衛星之遙測酬載系統領域中獲取相當之技術經驗。爲進一步掌握國際遙測技術研究現況與發展趨勢，特派員赴加拿大參加一年一度之國際遙測技術會議International Geoscience and Remote Sensing Symposium。藉此掌握此領域目前發展的現況並蒐集相關廠商資料，以作爲中心遙測計畫執行基礎及我國未來精密儀器產業技術發展之依據。這次研討會由於是與第二十四屆加拿大遙測技術研討會合併舉辦，故而規模盛大，參加發表的論文與參展的廠商十分眾多。此次行程中除了參與各項遙測新技術議程，蒐集遙測領域最新發表之研究論文，作爲中心未來遙測系統儀器研發計畫的參考。也訪談了一些參加研討會技術展覽之廠商，蒐集遙測儀器與相關零組件的現況，並透過交流相互了解彼此相關之技術與合作空間，爲未來中心遙測系統發展提供國際合作之參考。

本文電子檔已上傳至出國報告資訊網

考察行程表

日期	起	至	工　作　內　容	天次
6/21~22 (五)~(六)	台　北	多倫多 (加拿大)	搭機/資料準備	1~2
6/23~26 (日)~(三)	多倫多 (加拿大)		參加 IGARSS2002 研討會	3~6
6/27~28 (四)~(五)	多倫多 (加拿大)	台　北	回程返國	7~8

摘 要

在21世紀的科技發展中，世界各國對於遙測技術的建立均投下了大量人力與財力，期待能在區域安全、防災、生態環保、資源規劃及地球科學研究等議題佔有一席之地。而台灣地狹人稠，土地利用畸零，對於防災與資源規劃的需求更是較先進國家為高。

精密儀器發展中心以累積多年之光、機、電及儀器整合技術為基礎，在幾項大型計畫的成功進行下，已於飛機或衛星之遙測酬載系統領域中獲取相當之技術經驗。為進一步掌握國際遙測技術研究現況與發展趨勢，特派員赴加拿大參加一年一度之國際遙測技術會議International Geoscience and Remote Sensing Symposium。藉此掌握此領域目前發展的現況並蒐集相關廠商資料，以作為中心遙測計畫執行基礎及我國未來精密儀器產業技術發展之依據。

這次研討會由於是與第二十四屆加拿大遙測技術研討會合併舉辦，故而規模盛大，參加發表的論文與參展的廠商十分眾多。此次行程中除了參與各項遙測新技術議程，蒐集遙測領域最新發表之研究論文，作為中心未來遙測系統儀器研發計畫的參考。也訪談了一些參加研討會技術展覽之廠商，蒐集遙測儀器與相關零組件的現況，並透過交流相互了解彼此相關之技術與合作空間，為未來中心遙測系統發展提供國際合作之參考。

目錄

壹、前言

地球的資源有限，環境保護的意識抬頭，人口的膨脹與快速遷移，使得世界各國無不競相投入遙測的領域中，嘗試著了解與處理人類所處環境的一些問題。一方面從大氣、海洋、土壤、冰層、雪等等自然現象的觀測研究對天氣與氣候的影像，另一方面則由土地開發與農作物生長分佈了解土地資源的變遷與城鄉人口的分佈。這些對於國家安全、土地規劃、生態保育、自然資源管理保護以及災害防治等等議題都十分的重要。而遙測技術正是執行這些任務所不可或缺的利器，透過衛星或飛機在高空對大地做影像擷取，不但可收集到觀測區域內所需要的資訊以供研究分析，亦可傳遞即時訊息予緊急救災系統。

台灣地狹人稠，人口膨脹快速，農地的急速開墾以及都市的擴增，使得土地過度開發的問題擴及到山林地。而台灣處於地震發生頻繁之地域，夏秋之際又有颱風肆虐，往往造成生命財產的重大損失。有鑑於此，政府致力於土地的規劃管理、森林與農地資源應用、災害防治與監控、以及環保監測。國內應用與研究遙測技術單位眾多，主要有中央氣象局、農委會、內政部、水資局、民間顧問公司、中央大學太空及遙測研究中心、工研院能資所、成大航測所、海洋大學海洋研究所等，各單位現已廣泛應用遙測影像於相關領域。由於效果良好，遙測影像需求日漸頻繁，然而所使用之影像資訊均仰賴國外衛星與空載遙測系統，不僅影像取得之時程受限，且費用極高。以遙測影像資訊需求的殷切及國家長遠發展思考，實有必要自行研製高解析度遙測酬載。

有鑑於此,精密儀器發展中心這幾年來在遙測儀器的研發與整合不遺餘力。除了參與中華衛星二號計畫之遙測酬載整測工作，吸收國外發展衛星遙測酬載發展經驗，同時研提長程計畫，開發機載及陸地使用遙測系統。

近期成功研製在六百公里軌道高度時地面解析力為八米之光學遙測模組，並以此光機系統為核心，發展地面遙測應用之全景觀測系統，拍攝淡水、日月潭等地之三百六十度影像，為國內遙測儀器開發奠下基礎。同時成功開發蕃薯號衛星YAMSAT微型光學酬載，交付太空計畫室微微衛星團隊。今年中更成功完成國人第一套自製機載多光譜遙測影像儀之階段性測試，並發表記者會受到各界的肯定與支持。在這些儀器的研製過程中，亦開發了許多光學設計製造之能力，對國內新興之精密光學產業有相當之助益。如今中強光電、普立爾等國內光學及數位相機大廠皆有意願與本中心共同合作，解決關鍵核心技術之問題。植基於這些技術與儀器發展經驗，精密儀器發展中心將逐步達成光電遙測遙載自製目標。

遙測系統技術是未來發展的方向，為進一步掌握國際上遙測技術之發展趨勢，故派員赴加拿大參加國際遙測技術研討會，藉此掌握此領域目前發展的現況並蒐集相關廠商資料，以作為中心遙測計畫執行基礎及我國未來精密儀器產業技術發展之依據。此外也藉由此機會與其他各國先進交流相關技術與經驗。

貳、出國目的

IGARSS 2002 是遙測及地球科學技術發展的國際會議(International Geoscience and Remote Sensing Symposium, 2002)，每年在世界各個國家輪流舉行，而今年是由加拿大主辦，在多倫多一連舉行五天，而且由於是與第二十四屆加拿大遙測技術研討會合併舉辦，故而今年規模盛大，參加發表的論文與參展的廠商十分眾多。會場分有十個大會議廳共討論一百多個主題。所討論的主題層面相當廣泛，大致可分成幾類：

遙測應用：

- 衛星及太空梭遙測資料在全球各地應用的探討，包含 ADEOS2(USA), RADARSAT(Canada), EO-1(USA), EOS(USA), ALOS(Japan), ENVISAT(Europe), NPOESS(USA) 等遙測衛星。
- 地球資源與環境探究(大氣、雲、風、海洋、冰層、土壤地質、植物生長、森林、珊瑚礁)，都市變遷觀察，監測與分類以及災害防治等等。
- 遙測之軍事應用。

感測技術：

- 未來遙測技術走向，2025 年遙測技術的挑戰。
- 聲波、微波、毫微米波、可見光、紅外光到紫外光等等不同波段的遙測技術探索。
- 合成孔徑雷達(SAR)，全偏極化、差分式、干涉式 SAR、全球定位系統與超光譜遙測技術。

<u>儀器系統</u>：

- 遙測儀器系統未來技術發展
- 衛星酬載與飛機酬載系統的探討，儀器硬體與軟體的整合
- 影像儀、合成孔徑雷達、毫微米/次毫微米量測儀、雷射測距儀等等遙測儀器系統的發表。

<u>資料處理</u>：

- 影像資料融合技術，影像資料分類法則。
- 影像處理技術，超光譜資料分析，影像與資料壓縮，影像校正，理論模式與電腦模擬分析，類神經網路的應用以及影像資料的反衍技術探討。
- 整合型資料處理系統，資訊地理系統，影像視覺化技術

參加此一遙測技術與應用研討會的各國研究人員相當踴躍，於會中發表之論文皆為一時之選，在相關的學術研究領域中具有相當重要的參考價值。藉由參加此次的研討會不僅可以了解各國發展的現況，也可以藉此提升本中心與各相關研究機構的技術交流，將有助於本中心相關技術之研發工作的規劃與推動。

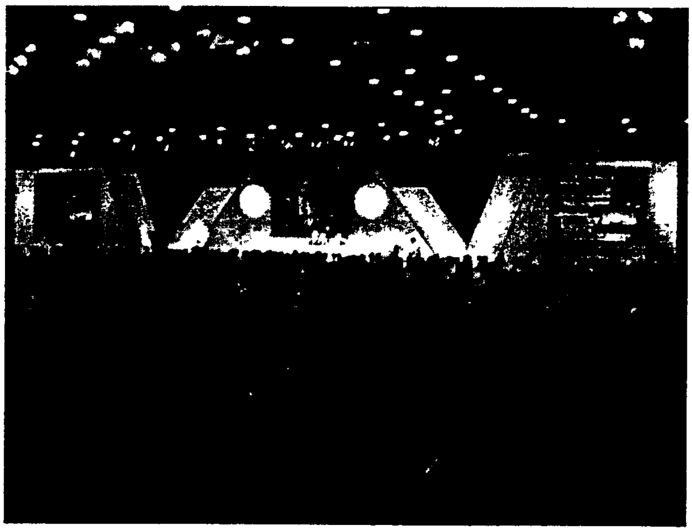
本中心積極參與國家衛星遙測大型計畫，亦進一步將累積之技術經驗應用於微微衛星酬載微光譜儀與飛機酬載光電影像儀之設計與製造整合。在此次研討會中將有許多感測技術、儀器系統與資料處理等技術議題與文章可供本中心相關研究作為參考。對中心遙測技術長遠發展而言，認識遙測應用之領域亦有助於未來研發技術發展之規劃。且同時會中亦可與其他各國與會先進交流相關技術與經驗，預計對中心遙測計畫執行將有極大助益。

大型遙測系統的設計、製造、整合需要光學、機械、電子等多種專門領域的人手相互配合。目前本中心遙測計畫在光學鏡頭上的製造組裝已有累積相當之經驗，而在後端遙測電子電路與相關應用軟體設備仍有賴於外界之支援，因此亟思尋求具經驗者之協助，目前考量對 CCD 與 CMOS 影像感測系統、遙測儀器系統軟硬體整合具經驗之與會廠商與研究機構進行了解，吸取相關經驗。

參、參訪過程

一、研討會專題演講

研討會一開始是由各國國家太空遙測相關研究單位的專題演講，演講貴賓包含加拿大太空總署(CSA)總裁 Dr. Marc Garneau，美國太空總署(NASA)地球科學企業(Earth Science Enterprise)副總監 Dr. Ghassem ASRAR，日本宇宙開發事業(NASDA)衛星部門主任 Dr. Yoji Furuhama, 以及 MOPITT、NPOESS 等衛星計畫主持人。演講主題主要在於各個機構的近況、新計畫的構思以及未來的挑戰。與會人員提到三個目前面臨到的問題以及應有的共識。首先，現今大型遙測計畫均需要跨國性的合作支持，單一組織或國家很難提供整體性的遙測資訊以供研究，故而機構組織之間打破藩籬互相合作與交流就顯得十分重要。NASA 與 CSA 皆暢談未來的計畫希望各個國家能支持，如此才能建立一個完整

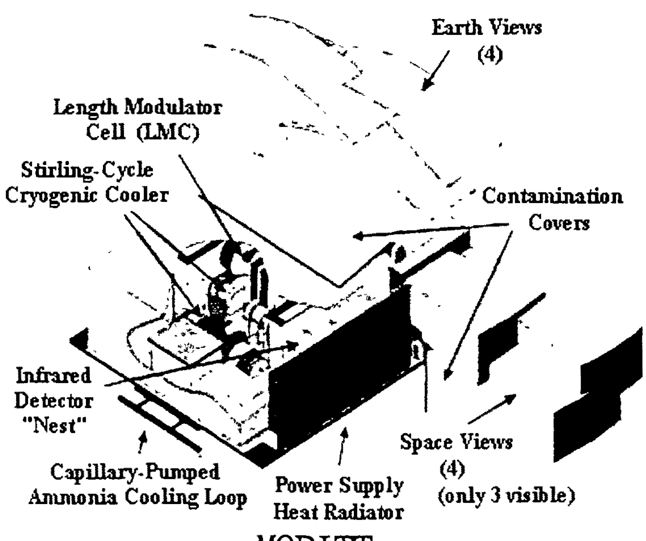


的地球環境資源觀測系統。另一個議題是目前已存在的系統希望做到資訊整合與共享，讓各國的研究者皆有機會使用其他國家與組織的遙測資料。要做到這一點，大型資料處理系統必須建立，使得資訊有效的整理、分類與儲存，並透過網際網路讓各地研究人員使用。最後一個重點是如何提供正確的遙測資訊給政策決定

者，也就是從龐大的遙測資料中整理研究出正確的資訊，以最好的效率即時提供給決策人員處理。

NASA 與會人員 Dr. Ghassem ASRAR 提出 NASA 對這些挑戰的一些想法。在遙測資訊的擷取上，未來的地球觀測系統要由先進的感測儀器組成觀測網絡，不論是在地面遙測系統、機載系統、低軌道衛星、同步軌道衛星、極地軌道衛星，所有的觀測站組成一個強大的資訊網，感測儀器彼此之間資料訊息可以互通，而且擁有處理部份資料與控制感測參數的能力。在資訊的整合上則需要在各地成立強大的資料接收處理站，將各種不同感測儀器的資料合成比對，整合出有效的資訊。在資訊的供給上則提供高效率與親切的使用介面，讓決策者與研究人員能夠即時且快速搜尋到有用的資訊。但 Dr. Ghassem ASRAR 還是再次強調這一切都需要建立在國際合作的基礎上。

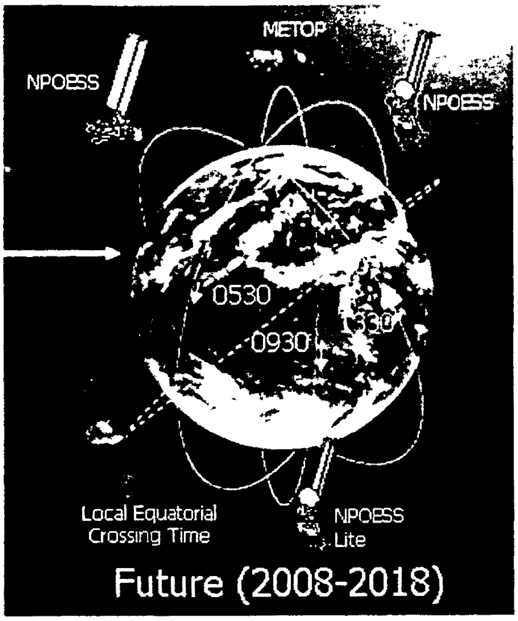
此外加拿大 CSA 與會人員介紹 Terra 衛星上的遙測儀 MOPITT (Measurements Of Pollution In The Troposphere)的使用狀態。此套系統已在 1999 年發射成功，主要用來量測對流層中的一氧化碳及其他化合物污染。



MOPITT

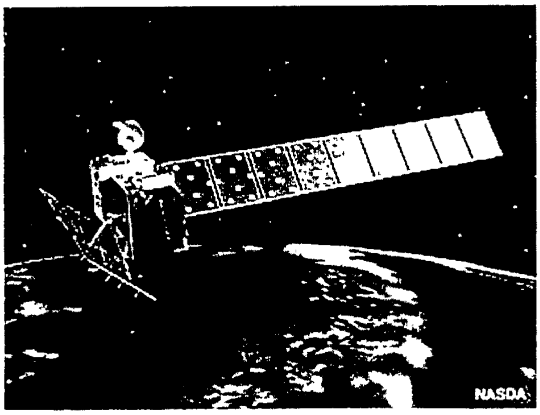
而美國海洋與大氣監測署 NOAA 則發表目前規劃中的繞極軌道衛星系統計畫 NPOESS (National Polar-orbiting Operational Environmental Satellite System)。其中將使用幾個新設計的先進感測儀器，如

VIIRS (Visible / Infrared Imager / Radiometer Suite) 用來監測大



氣、海洋與土壤，CMIS (Conical Microwave Imager/Sounder) 用來監測雲、海風、颶風、降雨，CrIS (Crosstrack Infrared Sounder)量測大氣溼度、溫度、壓力，GPSOS (Global Positioning System Occultation Sensor) 從 GPS 衛星與蘇聯的導航衛星系統接收電波散射，用以量測電離層之特性，OMPS (Ozone Mapping and Profiler Suite)測定臭氧層分布，SESS (Space Environment Sensor Suite)量測磁場、電子、極光與中性或帶電微小顆粒。

日本宇宙開發事業團 NASDA 也介紹了他們在遙測領域上所做的努力。包含了預計在 2003 年發射 ALOS 衛星，上面載有三種遙測儀器。PRISM (Panchromatic Remote-sensing Instrument for Stereo Mapping)是 2.5m 解析度的全波段影像儀，由於有三個鏡頭分別對應三個角度，所以亦可取得地表高度形成立體地圖。AVNIR-2 (Advances Visible and Near Infrared Radiometer type 2)則是含近紅外光的多波段影像儀，用來分



析土地覆蓋物與土地使用分類。PALSAR (Phased Array type

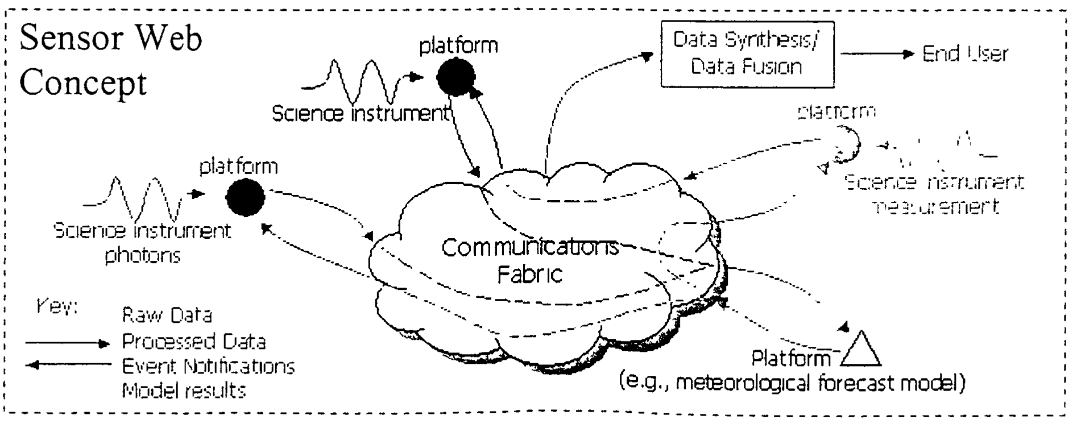
L-band Synthetic Aperture Radar)為合成孔徑雷達，在多雲或夜晚時亦可以使用。

二、研討會論文發表

此次研討會中有幾個關於遙測儀器系統發展之議程，對於中心未來遙測計畫之發展提供不少的參考訊息。

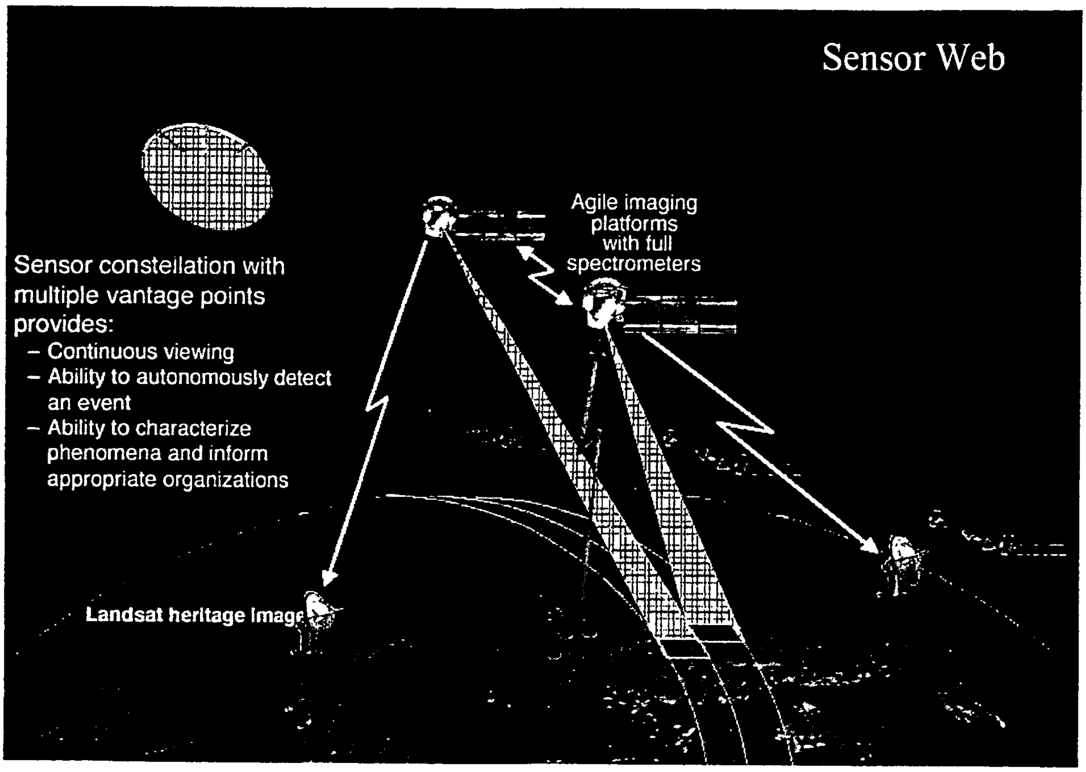
1. An Earth Science Vision — Technology Pathways and Challenges for 2025:

這個議程主要是由 NASA Goddard Space Flight Center (GSFC) 與會人員發表一系列 NASA 對未來地球探勘與監測的計畫與面臨的挑戰。首先發表的主題是感測網絡(Sensor Web)的概念。這是由多個不同種類的感測儀器組成的虛擬巨集儀器 (macro instrument)，每個感測器之間可以互相傳遞訊息與資料判別，互相合作組成一個有智慧的觀測網絡，而且由於具有即時分析與決策的能力，感測網絡中的各級感測器可配合彼此自動彈性調整其觀測方式。這些都是單一獨立的感測器所沒辦法做到的。



感測網絡的成員可以是各種不同型態的先進儀器，例如影像

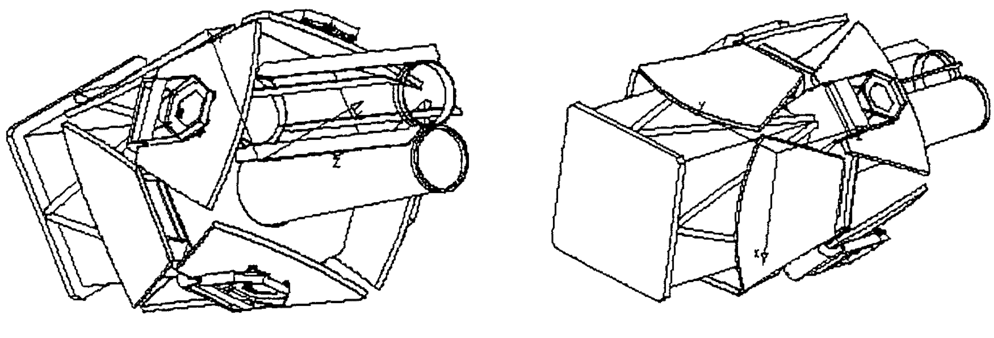
儀、合成孔徑雷達、以及雷射測距儀等等。而且可以是各級軌道衛星、飛機、熱氣球、以及地面儀器所共同組成。而目前感測網絡最佳的遙測應用在兩方面，一是氣象的預報，二是災害的預測、偵測以及監控。



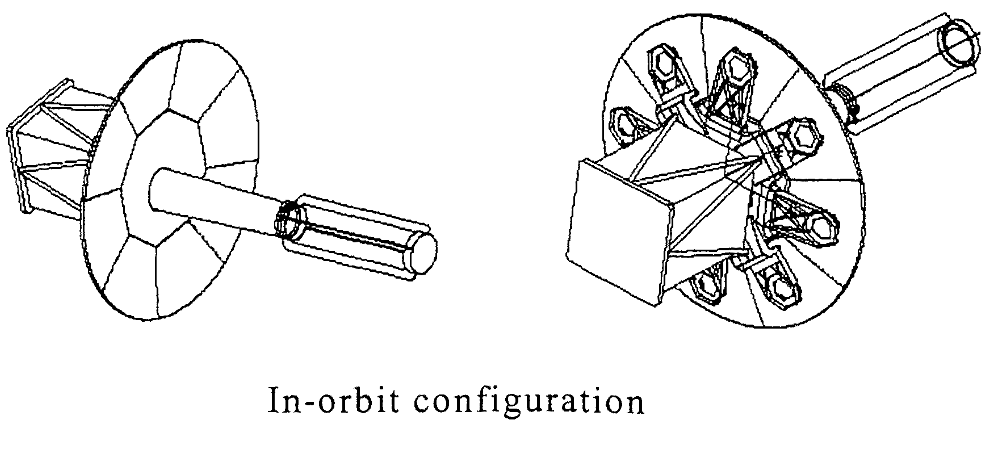
另一個有趣的主題是輕型可展開式的望遠鏡(Lightweight Deployable Telescope)，主要用在紅外光、可見光、以及紫外光波段的科學量測。目前地球觀測衛星主要是低軌道衛星(LEO)與同步軌道衛星(GEO)，前者可提供高解析度影像，然而針對某個特定地點僅能提供週期性的照片，無法連續取得動態影像。而後者提供了連續的地面影像，但由於距離遠故其解析度通常不高，所以目前兩種軌道上的衛星在時間和空間解析度上都無法同時提供足

夠的資訊來監控地球環境的動態發展。科學家們表示若能在同步軌道衛星上使用大孔徑望遠鏡，這樣的問題就可以解決。

據了解在 36 公里高的 GEO 軌道上提供約 4 公尺孔徑的望遠鏡才能獲得在可見光波段 30 公尺地面解析度，紅外光波段 300 公尺地面解析度。然而這樣的尺寸若使用傳統剛性結構的鏡頭，則在發射時體積、重量、製造時程以及風險的考量上都不適合於太空的應用。比較好的做法是使用可展開式、半剛性、主動式控制的望遠鏡。因此輕型鏡片、精密且可展開式結構、波前感測以及適應式控制是發展未來大型遙測望遠鏡所不可或缺技術。



Launch configuration



In-orbit configuration

另一個主題是討論未來龐大的遙測資料面臨到無線傳輸與即

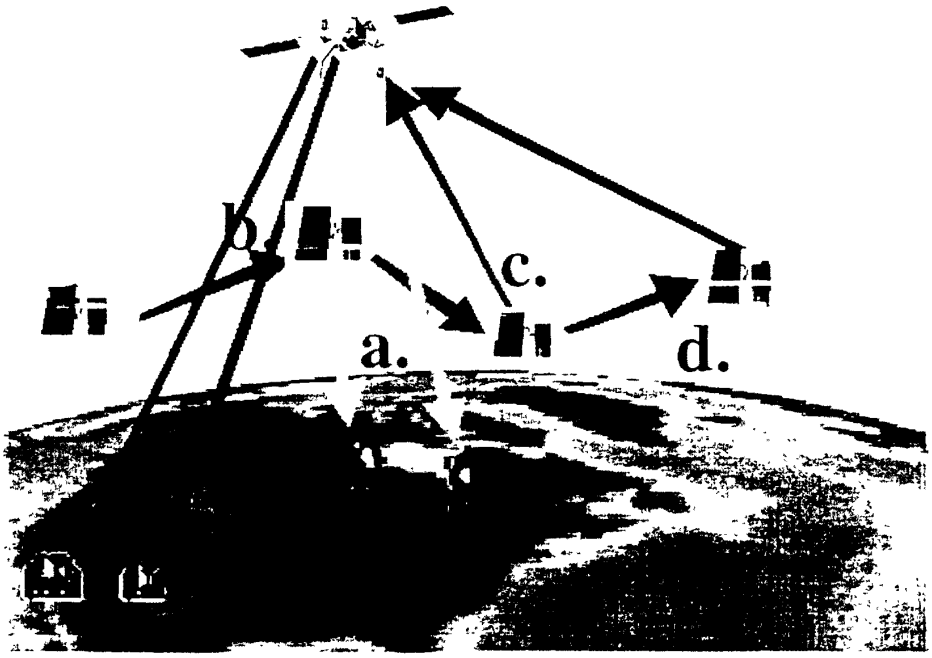
時信號處理的問題。從超光譜影像、合成孔徑雷達、雷射測距儀等等遙測儀器產生的大量資料，除了即時的處理外也需要傳輸至地面站做後級處理。下表是未來預期會面臨的資料速率與傳輸速率。

TABLE I
Instrument Data Rates and downlink rates for each option

Instrument/Year	2010	2020
Hyperspectral	10 Gbps	100 Gbps
SAR	10 Gbps	60 Gbps
LIDAR	150 Mbps	1 Gbps
Downlink Data Rate to Earth	> 1 Gbps	> 10 Gbps

由表中可以看出遙測儀器面臨到龐大的資料處理量與資料處理速度，這對硬體與軟體的技術都是一大挑戰。

NASA 也針對不同傳輸路徑所需要的傳輸速率峰值評估出未來的需求。如下圖所示:



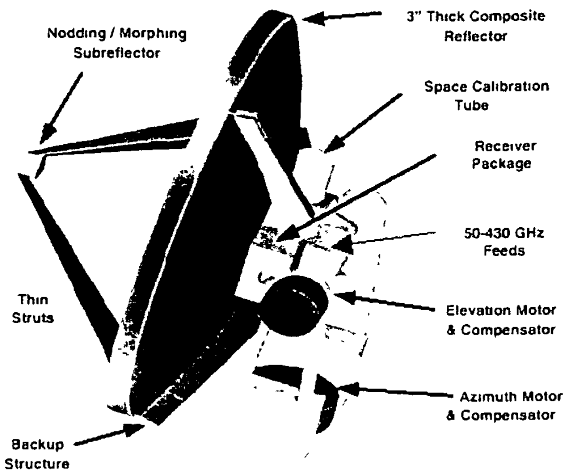
a 是低軌道衛星到地面站資料傳輸，b 是同步軌道衛星到地面站資料傳輸，c 是低軌道衛星到同步軌道衛星資料傳輸，d 是衛星之間通訊連結，e 是感測網絡。下表是資料傳輸速率的預期需求。

TABLE II
Data Rate Peak Needs for each type of link

Type of Link	State-of-the-art	2010	2015	2020
A	X-Band. 150Mbps	10 Gbps	25 Gbps	100 Gbps
B	150 Mbps	10 Gbps	25 Gbps	100 Gbps
C	2 Mbps	150 Mbps to 1 Gbps	-	-
d	4 Mbps	45 Mbps	155 Mbps	-
e	100 bps	a. b. c. d	a. b. c. d	a. b. c. d

2. Instrumentation and Future Technologies

這個議程主要是發表一些先進的遙測儀器系統實驗、開發計畫與關鍵技術。如雷射測距儀用於量測雲層結構的技術。儀器可以由地面、飛機或衛星來觀測雲層。傳統的雷射測距儀是量測 on-beam 的反射，只能測得狹小的視角裡的反射量。而這種儀器使用的技術是可以量測得到 off-beam 的物體散射回波，使得儀器可收集更多待測物的觀測資訊。

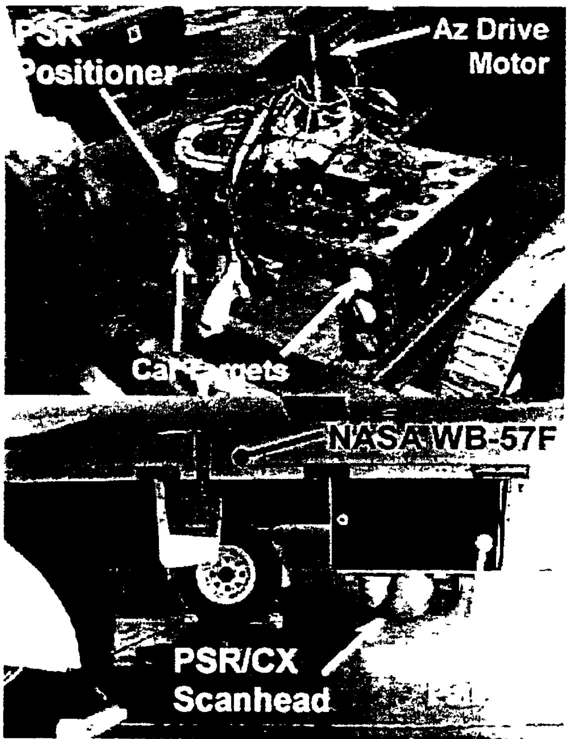


另一個題目是毫微米與次毫微米波雷達用以量測大氣溫度與溼度的分布結構與剖面圖。在同步衛星軌道上使用微波雷達已經有三年多的歷

史。現在更新的技術是希望改用毫微米/次毫微米波的技術。使用 118 GHz 與 425GHz 波段來量測大氣溫度，而以 380 GHz 波段來量測水氣。如此一來在同樣的天線尺寸下可以得到更高的幾何解析度。

另一個成果發表是以衛星全球定位系統量測電離層電子密度剖面結構與閃爍參數。GPSOS 這個全球定位儀是裝置在 NPOESS 衛星上，透過追蹤穿透大氣的 GPS 衛星信號來分析電離層的一些特性。

在機載方面也有發表一個寬頻微波影像系統用於水文研究。使用的儀器是美國海洋與大氣監測部門 NOAA 所發展出來的全極化掃描式輻射儀。這套系統可以提供被動式全極化微波影像，目前有兩種掃描模組可供互換。第一組波段範圍為 X (10.6 - 10.8 GHz), Ku (18.6 - 18.8 and 21.3-21.6 GHz), Ka (36 - 38 GHz), and W (86-92GHz)，第二組波段範圍為 C-band (5.80 - 6.20, 6.30 - 6.70, 6.75 - 7.10,and 7.15 - 7.50 GHz), X-band (10.60 - 10.80, 10.60 - 10.68, 10.68 - 10.70, and 10.70 - 10.80 GHz)。



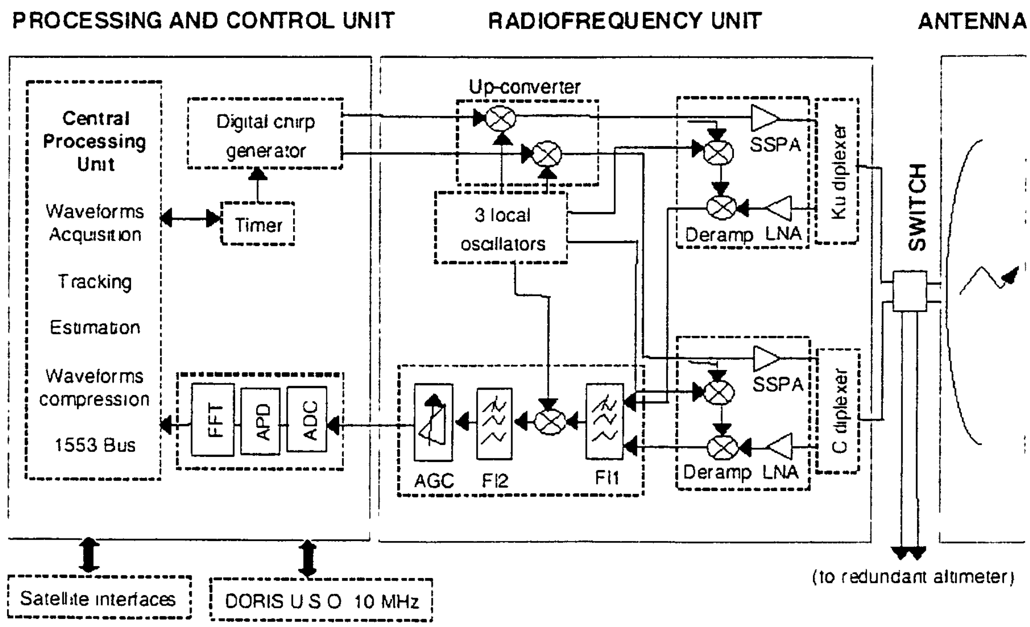
寬頻微波影像系統

從發表的研究論文可以看出，目前遙測儀器的發展漸漸由被動式的感測技術擴展到主動式的感測技術，而所使用的電磁波波

段由可見光、紅外光、微波擴展到毫微米與次毫微米波。故而現在的計畫許多是雷射測距儀、干涉式合成孔徑雷達、毫微米/次毫微米雷達等研究。

3. Advanced and Passive Sensors

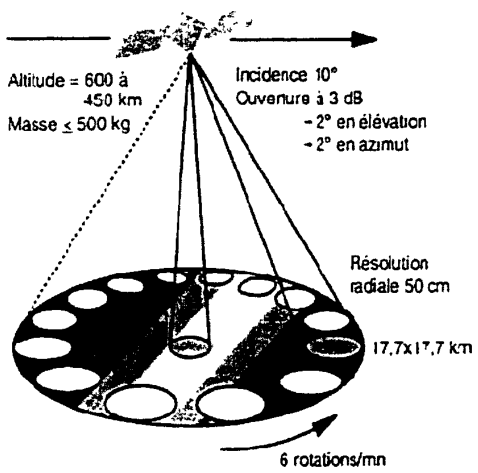
這個議程主要探討先進的感測器與被動感測器技術，如固態雷達測高儀，使用 C-band 與 ku-band 雙頻系統，由於採用固態功率放大器使得重量輕且消耗功率小。設計整合度高，由處理與控制單元、高頻單元以及天線組合而成。設計方塊圖如下:

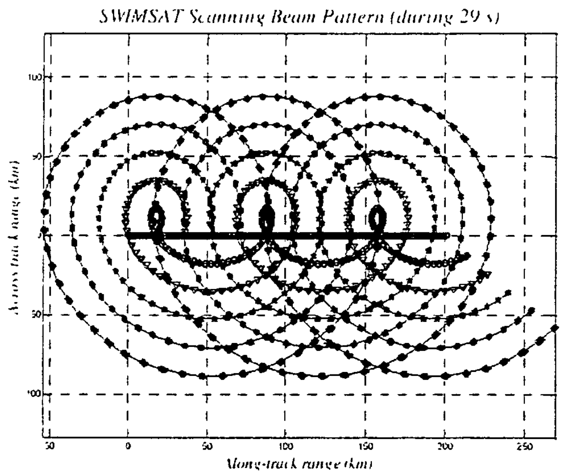


由於具有硬體信號處理機制，演算法則可在硬體電路上即時處理，對於地面站後級信號處理有很大的幫助。

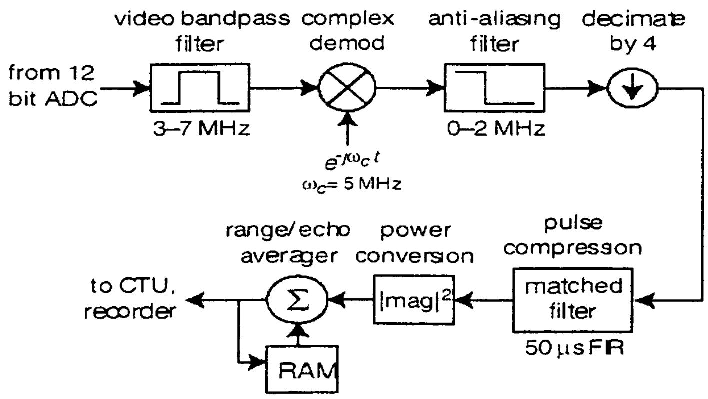
而法國的 Alcatel 太空公司也發表 SWIMSAT 上的微波雷達初步設計，這個儀器是用來量測海洋波浪的空間波譜，同時也監控海洋狀態、風場等等大氣與海洋之間的動態關係。他特殊的地方

在於使用兩個入射波束，而且以旋轉的方式的掃描，其中一個天線保持在入射角 0 度而另一個天線入射角可變化到 10 度。由下圖可以看出波束的相對位置以及在地面所照出的足跡。





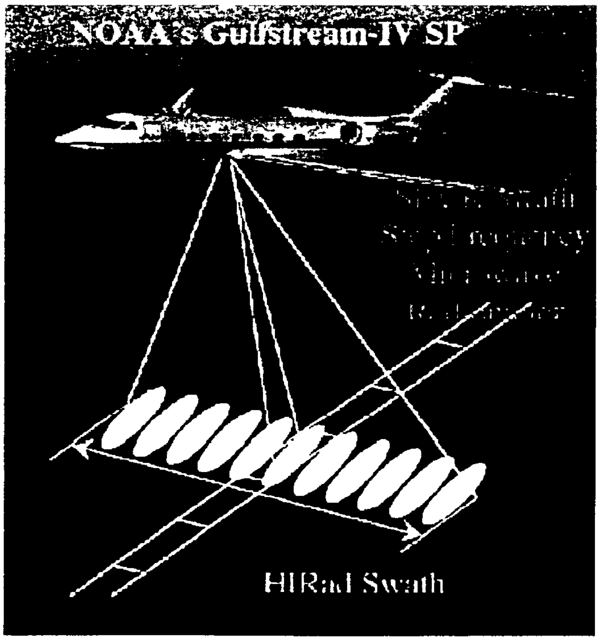
NASA 的 JPL 部門則發表下一代降雨量測雷達 PR-2 所需的數位信號處理器以及控制器。由於儀器需要高效能高速度的即時處理，所以採用現場可程式邏輯陣列晶片(Field programmable Gate Arrays, FPGA)來發展雷達中所需要的脈波壓縮處理以及可調式掃描控制器。方塊圖設計如下:



資料處理器方面的 FPGA 晶片採用的是 Xilinx 公司所生產的

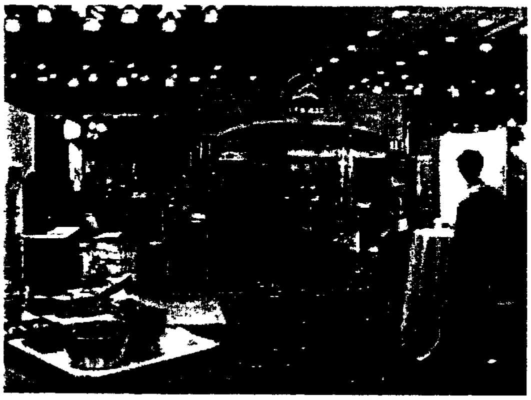
Virtex-1000，設計成四通道 12-bits 數位資料輸入，取樣速率為 20MHz。控制器方面也是使用同一款 FPGA，但是由於速度與時間的嚴格要求，所以並不採用微控制器軟體核心，而是以硬體組成狀態機網路來實現。如此一來可以使的衛星雷達上的即時信號處理能力增高，效率也提高許多。而所設計的處理器可使用在工作於 14GHz 與 36GHz 波段的衛星雷達。

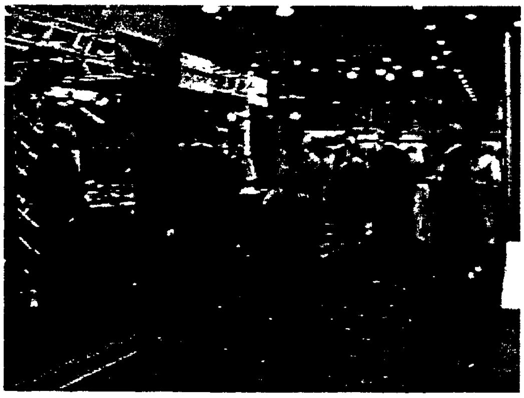
機載遙測儀器方面則有關於微波輻射測量儀(Microwave Radiometer)的概念設計發表，應用於颶風的監視與觀測。所採用的波段是從 4GHz 到 7GHz 的 4 個微波頻道範圍，屬於被動式量測系統。根據對颶風的微波影像資料來分析風速與雨量，進而了解颶風的結構。傳統的輻射量測儀僅針對正下方零度角量測，而此套儀器的設計可使得刈幅(Swath)介於正負 45 度。當飛航在 35000 英呎(11 公里)時，它可以提供 22 公里的刈幅以及介於 1 公里到 3 公里的空間解析度。



三、展覽會場

此次研討會的展覽場約聚集了三十餘個來自世界各國的機構與廠商設立的攤位。光是美國國家太空總署 NASA 的幾個專屬部門 Earth Science Enterprise (ESE)、Goddard Space Flight Center (GSFC) 、Jet Propulsion Laboratory (JPL)等就包辦了五個攤位。其他如美國海洋與大氣監測署 NOAA、加拿大太空總署 CSA、韓國太空研究中心 KARI 等等國家機構也參與這場盛會。展示項目包含各國衛星與機載系統的遙測影像，在場提供海報免費索取以及遙測影像預訂。

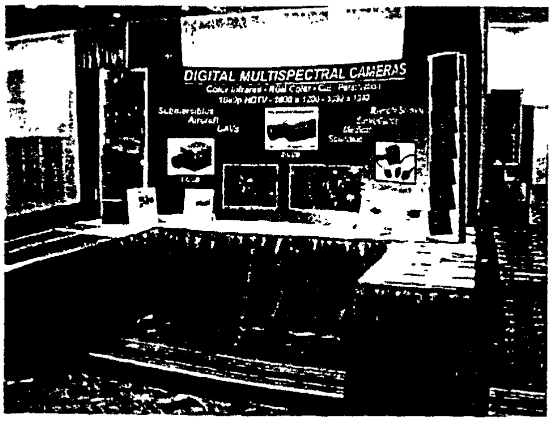




而在廠商方面有來自歐美各國的系統廠商、關鍵零組件廠商、軟體以及資訊服務廠商。此行除了蒐集各家廠商最新資訊外，並與中心遙測儀器開發有關之三家廠商做進一步了解，訪談結果如下：

Duncan Tech

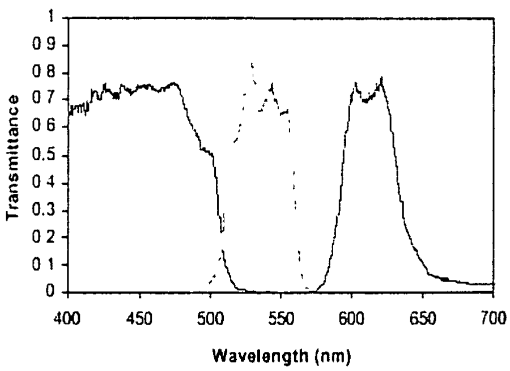
主要產品為高解析度數位多光譜 CCD 照相機(Multispectral CCD Camera)，可應用在機載空照儀器或是地面遙測儀器。該公司多光譜的技術主要是採單一孔徑但以光



學棱鏡分光的方式對應到不同的 CCD 感測晶片上。標準的兩種選項為紅、藍、綠光三色波段或者紅、綠、近紅外光三色波段搭配而成。亦可由客戶自己指定所需波段，範圍在 400nm 到 1100nm 之間。而目前最高解析度的面型 CCD 模組為 1920x1080 pixels，線型 CCD 模組則為 2048 pixel。廠商表示目前希望盡快推出 4 波段 2k x 2k 解析度的 CCD，如果中心有需求的話可以針對所需要的波段開出規格，專門訂做。至於熱門的超光譜照相儀(hyperspectral camera)，廠商認為做為實驗研究用可能是一項很好的工具，可是在實際應用上特定波長的多光譜影像儀就已經足夠，短時間內並不會去開發超光譜方面的儀器。

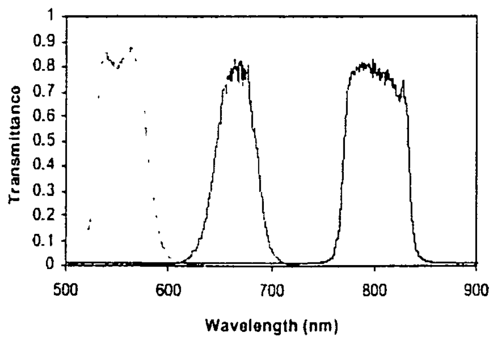
RGB CONFIGURATION

Acquires separate Red, Green, and Blue image planes for outstanding color fidelity.



CIR CONFIGURATION

Color-Infrared imaging acquires Red, Green and Near Infrared bands approximating Landsat satellite bands.



網址: **www.duncantech.com**

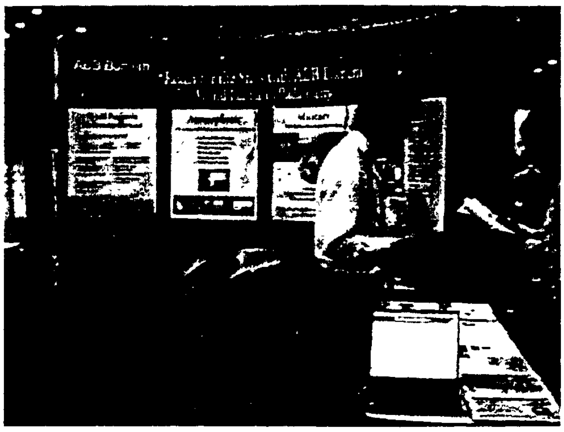
e-mail: **jduncan@duncantech.com**

聯絡人: Judy Duncan, President

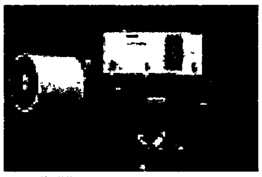
ABB BOMEM

這是一家專門研發紅外線光譜分析儀的公司，目前主推的產品為傅式轉換光譜儀(Fourier Transform Spectrometer) 波譜範圍從 19.5 μm 到 700 nm 而解析度則對應波譜範圍由 38 nm 到 0.05 nm。然而該公司也針對遙測

應用的客戶的需求開發多光譜CCD 照相儀。據技術部門主管Jacques Giroux 博士表示，目前他們正在協助大陸北京某單位開發多光譜 CCD 影像儀，規格是由客戶提供，如果本中心也有相同的需求他們也非常樂意提供服務。同時他們也表示未來希望朝向研製超光譜方面的儀器。



BOMEM 接過許多遙測領域的研發計畫，有紫外/可見光量測儀器用在極光方面的研究，也曾幫NASA GSFC 發展熱氣球上的紅外線光譜儀。近年來更參與太空實驗與遙測衛星應用，例如歐洲太空總署 ESA 的 Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)儀器研製計畫，加拿大太空總署 CSA 的 Measurements of Pollution in the Troposphere (MOPITT) 儀器研製計畫。另外也提供美國 NASA JPL 的 Atmospheric Infrared Sounder (AIRS)衛星酬載的地面校正設備與大尺寸準直儀。



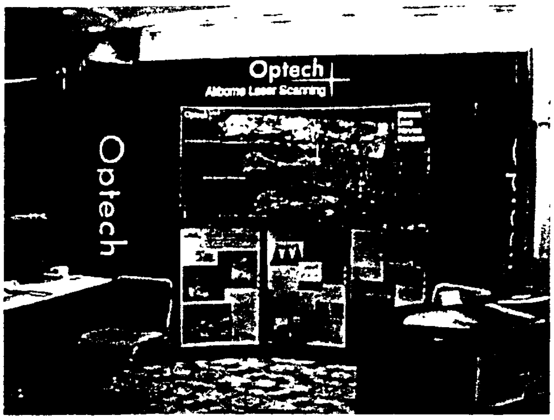
網址: **www.bomem.com**

e-mail: **Jacques.g.giroux@ca.abb.com**

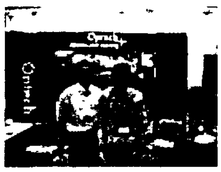
聯絡人:Jacques Gıroux, Ph.D

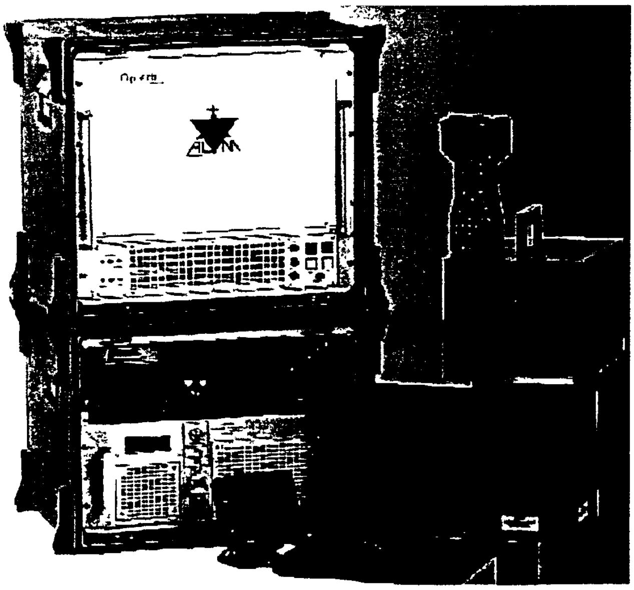
OPTECH

這是一家專門做 LIDAR (LIght Detection And Ranging)儀器的公司。今年四月期間農委會與交大曾經委請該公司提供機載雷射掃描儀 ALTM (Airborne Laser Terrain Mappers)做地震災區形變研究。在會場的應用工程師 Daina Vagners 小姐剛好也來台灣參與這



個研究計畫，談及此行，對台灣工程人員們的熱情招待讚譽有加，大家合作相處愉快。她同時表示 OPTECH 也提供針對客戶需求特殊設計的遙測系統。但是由於他們是以雷射儀器起家，在雷射的領域一路走來深耕多年，累積相當的技術與經驗，所以還是只會提供雷射相關的產品，暫不考慮純 CCD 影像相關產品。另一位與會人員 Eric Floreto 博士表示 OPTECH 剛推出一款更新的 ALTM，雷射重複率(Laser repetition rate)可高達 50 KHz，而之前在台灣使用的是 33 KHz 的。他表示目前在他們的產品中由 Applanix 公司協助整合了日本製的 CCD 照相儀，解析度為 4k x 4k，將來影像資料可以與 LIDAR 的資料做比對。Dr. Eric Floreto 也很熱心的幫忙收集 ALTM 上所整合的 CCD 模組規格，以 e-mail 寄回給筆者，見附錄一。





網址: **www.optech.on.ca**

e-mail: **eric@optech.on.ca**

聯絡人: Eric Floreto, Ph.D

肆、達成之任務

1. 參加在加拿大舉辦之國際遙測技術應用研討會 IGARSS 2002 (International Geoscience and Remote Sensing Symposium, 2002)，瞭解目前遙測領域上最新的資訊與技術發展。由於此次參加研討會的各國研究人員相當踴躍，論文發表主題廣泛而內容深入，許多感測技術、儀器系統與資料處理等技術議題與文章可供本中心相關研究作為參考。特別是對於未來至 2025 年遙測技術的挑戰與期許，與會人士發表了一系列前瞻性的研究與看法，對於中心未來遙測任務的規劃與執行提供了不錯的參考。

2. 訪問參展之廠商，收集相關廠商資料，以了解其產品開發能力及所能提供之服務。目前本中心遙測計畫在光學鏡頭上的製造組裝已有累積相當之經驗，而在後端遙測電子電路與相關應用硬體設備仍有賴於外界之支援。因此透過對 CCD、CMOS 影像感測系統、遙測儀器系統軟硬體整合具經驗之廠商進行了解，吸取相關經驗。除此之外並討論協助開發多光譜影像儀之可能性，透過相互交流認識增進合作機會。

伍、心得與建議

這次出國帶回了許多豐富的資料，經過整理後提出一些心得與建議作為參考：

1. 在研討會會場可以感受到歐、美、日本等國家對遙測發展的重視與耕耘，除了 陣容龐大、資料齊全外，特別還針對未來遙測的發展與挑戰開了一個議程，讓各國與會人員大家一起來討論地球的未來。而展覽會場中更是聲勢浩大。例如美國 NASA 與加拿大 CSA 的攤位免費提供了數十份遙測衛星大型海報、衛星照片海報、遙測計畫簡介手冊、以及遙測資源相關資料光碟片供人索取。並提供了許多另外還提供許多具有教育意義的小禮品讓與會人員帶回去做紀念。此次另人驚訝的是韓國也在遙測領域上急起直追，不但有發表相關遙測衛星的成果，而且也在展覽會場上有個不小的攤位提供遙測衛星照片。相較之下台灣目前的遙測發展起步較晚，緊追在這些國家之後。期望中華衛星二號在發射升空之後台灣也能成為遙測界的一股生力軍，在國際的展覽會場中嶄露頭角。

2. 目前大型遙測計畫都漸漸形成國際合作案，例如美國 NASA 的 Terra 衛星上載了日本與加拿大的遙測儀器當酬載，而 Grace 衛星上也載了美國與法國共同合作開發的酬載 SuperStar。國內機構或國際組織之間合作開發遙測儀器已經漸漸變成一種趨勢，因為高科技遙測儀器的開發已經不是單一組織機構就可以承擔下來的。所以認識更多國內與國際遙測相關之組織與廠商，有助於增廣資源，對儀器的系統整合能力將有很大的助益。對於國內外遙測技術相關的研討會與展覽會可以多派員參與，除了資料的收集之外，也可以增加與外界合作的機會。

3. 遙測的長遠發展是希望了解地球環境與資源，讓人類更懂得珍惜這一片

孕育生命的土地。除此之外也藉由探索地球以外的星球，尋找另一個生命的出處。因此在遙測的領域中除了研究發展更新的技術外，更為重要的一環應該是教育我們的下一代。在 IGARSS 研討會場中，都會有議程是跟遙測與資源環境的教育有關，而且教育的對象是從孩童做起，想盡辦法做出豐富有趣的教材吸引他們。除此之外，展覽會場中 NASA 更是推出許多認識遙測與地球環境的教材與光碟片，而且還細分出小學、中學、大學、研究所與博士後研究的學習教材，甚至提供老師教授一系列的授課教材。在 NASA 的網頁中也可以找到許多遙測教育的資源以及參考材料，可見得他們對推廣教育多麼的重視。本中心在研發遙測相關儀器之餘，除了藉由中心網頁的資源推展遙測技術上的創新與突破，亦可以考慮提供遙測相關的教育資源，讓更多人更認識我們的地球環境。

陸、附件

一、OPTECH 公司 ALTM 雷射掃描儀使用之 CCD 照相模組規格資料

二、IGARSS 2002 議程資料

三、IGARSS 2002 遙測儀器發展相關論文

附件一

Optech Digital Aerial Camera Model 4K02 Specifications

1. Camera

Array Size:	4092 (along flight line) x 4079 (cross flight line)
Pixel Size:	0.009 mm
CCD:	Premium Grade (selected from Class I*) Point Defects <= 2000, Cluster Defects <= 30, Single Column Defects <=10 Dead Columns = none Radiometric and geometric profile for each CCD
Filter Array:	Color or ColorIR
Zeiss Lens:	45.5 mm, 44 deg FOV
Exposure control:	Manual, Aperture priority, or Shutter priority
Light metering:	Center weighted average, or spot
Shutter:	Electronically controlled focal plane
Shutter speed:	125 - 4000 (slower speeds not recommended)
Aspect Ratio	1:1
Fill Factor:	70%
Exposure Compensation:	+- 2 EV in 1/3 EV steps
Max Exposure Rate:	4 sec
Housing:	Proprietary ruggedized CCD array mount, Ruggedized exoskeleton, designed to hold 1 pixel geometric accuracy over RTCA/DO-160D shock and vibe spec.
Calibration:	Terrestrial and airborne calibration with full report

*For definitions of defects refer to page 13 of Kodak KAF-16801CE.V4.pdf

2. Computer System

Ruggedized Data Recorder

- Internal pressurized 80 Gbyte disk
- Removable 80 Gbyte disks (2)
- Optional QC thumbnail image via ethernet or remote display
- Ethernet, TTL, and RS232 interfaces to standard Flight Management System and Applanix POS/AV
- Tested and meets RTCA/DO-106D specs for shock and vibe when mounted in shock isolated rack

3. Performance

Imagery:	GSD	0 15 to 1 m
	Smear	< 15% typical

Radiometry: Repeatability 3% relative

Bands	1	2	3
Color Mode, nm	400-500	500-600	600-680
CIR mode, nm	510-600	600-720	720-800

4. Physical

Size:	Camera	16 x 18 x 41 cm
	Data Recorder	19" rack, 3U height, 51 cm deep
Weight:	Camera	5 kg
	Data Logger	10 kg
Power:	Camera/Data Recorder	28 VDC, 100 W (max), 115V AC, 100 W (max) via Aux power unit (included)
Temp. Range:	Camera	0 deg C to +40 deg C
	Data Logger	-20 deg C to +60 deg C
Humidity:	5 to 90% RH non-condensing	
Altitude:	1 to 20,000 ft	

5. Processing Software

MissionVue

- Data management software
- Downloads images from removable drives

ImageVue

- Image development software
- Lens Fall-off Correction < 3%
- Formats TIFF, JPEG,IMG
- Quantization: 8 bit, 16 bit
- Color balance via calibration inputs

ImageStation Suite from Z/I Imaging

- ISAT Aerial Triangulation Software
- OrthoPro for image orthorectification and mosaicing
- Geomedia support for OrthoPro

6. User Supplied Equipment

PC for Post-processing

- PC with Windows 2000
- Minimum of 300 GB disk space (512 MB of RAM)
- Tower rack with space for removable disk drive frame (provided)

附件二

Monday, June 24 Morning

Plenary Session - Metropolitan Ballroom

Dr. Marc Garneau	President, Canadian Space Agency
Dr. Ghassem Asrar	Associate Administrator, NASA's Earth Science Enterprise
Dr. Yoji Furuhama	Executive Director, Office of Satellite Technology Research and Applications, National Space Development Agency of Japan
Dr. Jim Drummond	Principal Investigator, MOPITT
Mr. John Cunningham	Director, NPOESS

Monday, June 24 Afternoon

Room Name	Room	Afternoon
QUEEN'S QUAY (CC)	1	ADEOS 2
PIER 2	2	THERMAL INFRARED SENSING
PIER 3	3	MONITORING THE ATMOSPHERE
PIER 4	4	DATA FUSION I
PIER 5	5	IMAGE PROCESSING
HARBOUR SALON A	6	AN EARTH SCIENCE VISION: SCIENCE PATHWAYS AND PREDICTIVE CAPABILITY
HARBOUR SALON B	7	RADARSAT 1
HARBOUR SALON C	8	PART 1: SRTM — FIRST RESULTS PART II: INTERFEROMETRIC SAR TECHNIQUES
PIER 9	9	GEOLOGICAL PROCESS MONITORING
PIER 7/8	10	CRYSYS

Tuesday, June 25

Room Name	Room	Morning	Afternoon
QUEEN'S QUAY (CC)	1	CORAL REEFS	AGRICULTURAL MONITORING AND CLASSIFICATION
PIER 2	2	DATA SERVICES AND TOOLS	NEURAL NETWORKS
PIER 3	3	CLOUDS AND PRECIPITATION	HF OCEAN RADAR
PIER 4	4	IMAGE PROCESSING TECHNIQUES	INNOVATIONS IN REMOTE SENSING EDUCATION
PIER 5	5	ANTIPERSONNEL MINES AND SUBSURFACE SENSING	INSTRUMENTATION AND FUTURE TECHNOLOGIES
HARBOUR SALON A	6	AN EARTH SCIENCE VISION: TECHNOLOGY PATHWAYS AND CHALLENGES FOR 2025	EO-1 PART I
HARBOUR SALON B	7	ADVANCED LAND OBSERVING SATELLITE (ALOS)	ENVISAT
HARBOUR SALON C	8	RADAR POLARIMETRY AND APPLICATIONS	POLARIMETRIC SAR INFORMATION PROCESSING
PIER 9	9	BISTATIC REMOTE SENSING	PART I: BISTATIC MEASUREMENTS PART II: RECONFIGURABLE FUTURE SAR SYSTEMS
PIER 7/8	10	STUDENT PRIZE PAPER COMPETITION	SNOW

Wednesday, June 26

Room Name	Room	Morning	Afternoon
QUEEN'S QUAY (CC)	1	MILITARY APPLICATIONS OF REMOTE SENSING	FOREST MONITORING AND CLASSIFICATION
PIER 2	2	INFORMATION SYSTEMS, GIS AND VISUALIZATION	DATA FUSION II
PIER 3	3	REMOTE SENSING OF OCEAN WINDS	RADAR OCEAN WAVE MEASUREMENTS
PIER 4	4	DISASTER MANAGEMENT SUPPORT	PART I: SCISAT PART II: EARTH SCIENCE VISION AND FUTURE CAPABILITIES
PIER 5	5	ADVANCED AND PASSIVE SENSORS	HYPERSPECTRAL REMOTE SENSING INSTRUMENTATION
HARBOUR SALON A	6	EO-1 PART II	NASA EARTH OBSERVING SYSTEM (EOS) TERRA MISSION RESULTS
HARBOUR SALON B	7	NATIONAL POLAR-ORBITER OPERATIONAL SATELLITE SYSTEM (NPOESS)	INTERAGENCY COLLABORATIONS
HARBOUR SALON C	8	POLARIMETRIC SAR INTERFEROMETRY AND APPLICATIONS	POL-IN-SAR APPLICATIONS
PIER 9	9	SYNTHETIC APERTURE TECHNIQUES	DATA MINING IN REMOTE SENSING
PIER 7/8	10	ACOUSTICAL REMOTE SENSING OF THE ENVIRONMENT	GLACIERS AND ICE SHEETS

Thursday, June 27

Room Name	Room	Morning	Afternoon
QUEEN'S QUAY (CC)	1	VEGETATION AND ENVIRONMENTAL MONITORING	EOSD
PIER 2	2	POLLUTION MEASUREMENTS IN THE TROPOSPHERE WITH MOPITT	REGISTRATION AND COMBINATION OF IMAGERY
PIER 3	3	OCEAN SURFACE AND SUBSURFACE PROCESSES	PART I: ALTIMETERS AND SMALL SATELLITES PART II: SMOS, TRMM AND SALINITY
PIER 4	4	PART I: DATA COMPRESSION TECHNIQUES PART II: DATA ASSIMILATION	LIDAR REMOTE SENSING
PIER 5	5	SOIL MOISTURE AND FLOODING	SOIL MOISTURE AND HYDROLOGICAL MODELING
HARBOUR SALON A	6	NASA/EOS MODIS STATUS AND RESULTS	HYPERSPECTRAL PROCESSING AND ANALYSIS I
HARBOUR SALON B	7	LAND COVER CHANGE	IMAGE ANALYSIS
HARBOUR SALON C	8	DIFFERENTIAL INTERFEROMETRIC SAR TECHNIQUES AND APPLICATIONS	RADARSAT 2
PIER 9	9	SURFACE/VOLUME SCATTERING TECHNIQUES	DISASTER AND HAZARD ASSESSMENT AND MANAGEMENT
PIER 7/8	10	REMOTE SENSING USING GPS	REMOTE SENSING OF SEA ICE

Friday, June 28

Room Name	Room	Morning	Afternoon
QUEEN'S QUAY (CC)	1	SOIL AND VEGETATION BIOPHYSICAL PROPERTIES	FOREST MONITORING AND CLASSIFICATION
PIER 2	2	UWB SUBSURFACE DISCRIMINATION FROM MAGNETOSTATICS TO GPR	PART I: IMAGE FILTERING / PART II: DATA MINING
PIER 3	3	REMOTE SENSING OF THE COASTAL ZONE	ACTIVE AND PASSIVE MICROWAVE OCEAN SENSING
PIER 4	4	SEGMENTATION AND CLASSIFICATION	PART I: CLIMATE CHANGE / PART II: CHANGE DETECTION
PIER 5	5	INVERSE PROBLEMS	CLOUDS AND PRECIPITATION
HARBOUR SALON A	6	HYPERSPECTRAL PROCESSING AND ANALYSIS II	SAR WIND AND WAVES
HARBOUR SALON B	7	PART I: RFI AND SPECTRUM MANAGEMENT PART II: REMOTE SENSING IN ENVIRONMENTAL POLICY	NPOESS PANEL
HARBOUR SALON C	8	AIRBORNE POLARIMETRIC SYSTEMS	PART I: POLARIMETRIC SAR CLASSIFICATION PART II: HF-OCEAN POLARIMETRIC RADAR
PIER 9	9	INTERFEROMETRIC SAR PHASE UNWRAPPING AND INFORMATION	MONITORING URBAN GROWTH
PIER 7/8	10	CRYOSAT	SEA ICE

附件三

IGARSS 2002 遙測儀器發展相關論文

Lightweight Deployable UV/Visible/IR Telescopes

Frank Peri, Jr.
Earth Science Technology Office
NASA Goddard Space Flight Center
Code 711
Greenbelt, MD 20771

Michael Hagopian
Earth Sciences Directorate
NASA Goddard Space Flight Center
Code 900
Greenbelt, MD 20771

Mark Lake
Composite Technology
Development, Inc
1505 Coal Creek Drive
Lafayette, CO 80026

Abstract-**The vision of the Earth Science Enterprise (ESE) of the National Aeronautics and Space Administration (NASA) established a variety of science challenges for the next 20 years, relating to predictions of weather, climate, and foreseeable changes in the Earth's environment. In this paper, we discuss the attendant needs for space-based, lightweight deployable telescopes for a variety of science challenges. In addition, we suggest some strategies for deploying the necessary assets.**

I INTRODUCTION

The ESE vision encompasses a wide variety of instrument, data information and platform technologies that enable an even broader set of science and application needs. In order to determine how to achieve this vision, the Enterprise commissioned several workshops to capture the needs of the science and application communities and to derive the requisite technology requirements In addition, the workshop participants devised strategies for maturing those technologies that included laboratory demonstration as well as on-orbit validation necessary for the technology to become available for a science mission. The workshops were comprised of scientists and technologists in each of several disciplines The specific workshop topics were determined by examining the broad set of science and application needs and finding common technology drivers

One resultant technology area for which a workshop was conducted is lightweight, deployable telescopes for science measurements in the infrared (IR), visible (VIS) and ultraviolet (UV) region of the electromagnetic (EM) spectrum. The foci of science measurements discussed in that workshop, and summarized in this paper are those for which deployable telescopes are enabling technologies:

- lidar observations for high vertical resolution mapping of tropospheric ozone, CO_2, water vapor, NO_2, aerosols, and for imaging, and
- high resolution imaging and spectroscopic observations from high orbits (GEO, LI, and L2)

The first step towards realizing NASA's Earth Science vision is to devise a strategy that carries the enabling technologies through the lifecycle of conceptual study, risk reduction and finally validation. The science requirements, enabling technologies and a notional strategy to achieve validation of these technologies are described in the following sections

II SCIENCE REQUIREMENTS

The process for enabling science measurements for the ESE is that of a systematic flow-down from science needs to implementation options that ultimately lead to specific, enabling technology requirements. In most cases, science measurement needs can be accommodated with several instrumentation alternatives, typically leading to diverse technology requirements. Generally, the ESE will narrow the resultant measurement capability down to one implementation via a competitive process. As part of the maturation of a given implementation, though, is a process of balancing options within the implementation to, in a fashion, optimize the requirements of the component technologies that comprise the implementation.

Most current remote sensing systems monitoring the Earth's atmosphere, land surfaces and oceans, provide global data sets to study seasonal and long-term changes of the Earth's environment These systems, typically part of polar-orbiting, i.e. low Earth orbit (LEO) satellite missions, provide only periodic high-resolution snapshots of the Earth's environment at any given location Some weather satellites (e g. GOES) do observe clouds and water vapor from a geostationary orbit (GEO); but these offer continuous coverage at only moderate resolution None of these current systems is sufficient, in temporal and spatial resolution, to monitor the development of dynamic environmental processes While a single GEO observatory cannot provide global coverage, a high resolution sensing capability from such a vantage point can reveal short term forcing processes on complex Earth ecosystems The time-resolved small-scale observational capability of such a system would allow detailed studies of diurnal effects, and provide instantaneous access to special events anywhere in the large coverage area

In order to allow high spatial resolutions from GEO (36 Km altitude) in the visible and infrared wavelengths (VIS/IR) which are equivalent to those currently available at LEO (850 Km), aperture diameters on the order of 4 meters are required This assumes a desire for 30m resolution in the visible and near-infrared, and 300m in the far-infrared

Another vantage point that could enable new Earth observations on global scales with good temporal and spatial resolutions is that of the L1 and L2 Lagrange points (about 1 5 million Km altitude) One such system under study is the "L2 View" solar occultation mission which could produce the first high resolution 3D mapping of greenhouse gases of the whole Earth Because of the extreme distance from the Earth, this mission would require an interferometer with a 10-meter baseline to achieve a 2 Km resolution Other imaging applications with higher resolutions would require next generation "gossamer" active/adaptive apertures made of membrane-type structures

The measurement of chemical constituents in the Troposphere can be achieved with a differential absorption lidar (DIAL) or with a radiometer sensitive in the UV region of the EM spectrum The DIAL approach can permit the measurement of vertical profiles of atmospheric ozone and trace constituents by collecting photons from transmitted laser pulses that are backscattered from the atmospheric constituents In order for the science retrieval algorithms to extract the concentration of chemical species, a minimum signal to noise ratio must be achieved. The DIAL equation relates the power of the individual laser pulses to the backscattered return signal received at the detectors Recent studies have indicated that a laser transmitter power of approximately 500 mJoules combined with a telescope aperture of 3 meters would yield sufficient signal for the science algorithms to be effective. Of course, there are other factors are involved in this relationship, including, for example, detector sensitivity. In this instrument, the detector is counting photons and therefore has a minimal requirement for surface figure of $\lambda/2$.

Table 1 summarizes these measurement requirements.

TABLE I
SUMMARY OF SCIENCE NEEDS

Science Need	Resolution	Telescope Diameter, m	Figure	Orbit km/orbit
Imaging spectro-radiometers	30-100	>2.5	$\lambda/20$	GEO, L1, L2
Lidar observations	100-500	>3 0	$\lambda/2$	500/polar
Lidar imagers	30-300	>3 0	$\lambda/20$	500/polar

III TECHNOLOGY NEEDS

Apertures of the size and precision required for a VIS/IR imaging application must be affordable in terms of both aperture development cost and aperture-driven cost to GEO Traditionally, meter class precision apertures for space applications have been designed as rigid structures, but the required mass, launch volume, time to manufacture, and risk of such an approach is not feasible for apertures on the order of 4 meters. To illustrate this point one only needs to look at the most ambitious aperture ever flown, that of the Hubble Space Telescope, which at a diameter of 2.4 meters, weighed 1820 lbs (not including support structure), and took 5 years to polish. While manufacturing techniques have improved, it is generally accepted that the only cost effective route to larger space based imaging applications is that of deployed, semi-rigid (possibly replicated segments), actively controlled mirrors The principal goal in developing a deployable telescope is thus to provide an increase in collecting or imaging area compared to a non-deployable telescope while maintaining a minimal payload envelope, comparable to a non-deployable telescope Three primary technologies will be considered for meeting these needs: lightweight mirrors, deployable structures and adaptive figure control

Future imaging missions that move current LEO measurements to, or create new measurements from non-traditional vantage points (GEO and L1, L2) will require large, deployed, and actively controlled apertures. This will in turn require technology advances in low areal density mirrors, lightweight precision deployable structures, and wavefront sensing and control actuators and algorithms Wavefront control systems will have to maintain diffraction limited performance without point sources to effect control; this will require the advancement of different approaches, like phase diversity, which can operate on the non-ideal-for-phasing real Earth scenes being measured

Likewise, future DIAL and lidar systems for atmospheric chemistry will require telescope apertures greater than 3 meters This will also require advances in low areal density mirrors and lightweight deployable structures. However, because the surface figure requirements for this science need are not very strict, actively controlled deployment may not be required; passive techniques may be sufficient. To achieve this, though, will require latches with high deployment accuracy and stability.

For the purposes of discussing the relevant technologies for a deployable telescope, a notional design of six deployable mirror panels hinged to a central mirror panel will be used [1]. In addition, the central mirror may be segmented and actively controlled to provide wavefront correction. Extensions to this strategy may include actively controlled deployed panels.

Extensive on-going work in deployable telescopes has uncovered unique problems associated with Earth observing measurements including:

- Thermal cycling effects due to variable solar loading, day/night transitions, thermal shock from going into and out of eclipse and pointing close to Sun line.
- Pointing non inertial reference frame or scene reference complicates attitude control
- Doppler shifts (wavelength calibration)
- Orbit maintenance, thruster issues, contamination, control law issues
- Minimize structural mass with uniform and low CTE across structure with good optical surface
- Active/adaptive control on Earth scenes
- Image registration (mapping, landmarking)

These problems affect the deployment, calibration image (quality and radiometric), maintenance or correction and stability of the instrument. Solar shields used to mitigate thermal effects for astronomical observations can interfere with or limit the field of view of Earth observing instruments

Recent advancements in mirror research have considered the following materials·

- composite mirrors
- glass/composite
- beryllium
- membranes (powered and flat)
- carbon silicon carbide
- thin meniscus glass
- light weighted glass
- fresnel lens

The fundamental issues associated with these materials are their manufacturability and their subsequent integration into associated control actuators, reaction structures, and deployment systems Other factors include filter coatings to reduce the heat load on the mirror and the ability to control the mirror in the dynamic thermal environments

Structures and mechanisms are also a significant challenge for deployable telescopes The state of the art is currently·

- Mid-modulus CFRP, open truss design
- USAF/RL MISTI (solid hexagonal frame)
- Multifunctional structures
- Isogrid vs solid tubular frame

These technologies have not yet been validated on-orbit and under the conditions relevant for an Earth observing instrument.

IV NOTIONAL VALIDATION FLIGHT

Past spaceflight validation experiments of deployable structures have taught us to expect that critical structural response might change from 1-g to 0-g Specifically, many tests of macrodynamic behavior (e.g., damping and vibration frequencies) have shown gravity dependency, and recent test of microdynamic behavior indicate the possibility of gravity dependency (in fact, IPEX-II data seems to indicate that 1-g-loading might stabilize some of the thermal pops seen on-orbit).

Unfortunately, at this time it is unclear whether the 0-g environment is better, worse, or nearly the same from a microdynamic performance standpoint It is possible that some structures will exhibit gravity-independent microdynamic behavior while others might exhibit gravity-dependent behavior In any event, it is clear that more on-orbit data is necessary to answer these questions.

In developing a validation test plan to determine what characteristics will be tested, the following elements must be considered.

- characterization of disturbance sources (e g , sunshields, reaction wheels, fine-pointing and alignment systems)
- microdynamic response of mechanically deployable support structures and active control of microdynamics
- dimensional stability of thin-membrane mirrors and active wavefront correction

Other effects like environmental durability and reliability of on-orbit construction must also be validated, but are long-term effects that are better suited for independent validation

Significant to the validation test is the environment from which the tests will be conducted. Of concern are both the long- and short-term vibration environments For example, the design requirements for the International Space Station (ISS) are to maintain quiet periods of less than 1 mg peak and 10 μg short duration These can be effectively managed via a combination of an isolation bench and a fast steering mirror for line-of-sight jitter management

V CONCLUSIONS

The science needs established by the vision of NASA's Earth Science Enterprise challenge the state of the art for instrument technologies. A process by which technology requirements are developed begins by translating the science needs into notional measurement implementations and then defining the critical drivers for achieving the science needs These drivers result in a set of technology requirements from which development plans can be established. Depending upon the technologies, the plan may require on-orbit validation in addition to the laboratory development and field experiments In this paper we define the needs for a particular class of technology, a deployable telescope. The resultant technologies necessary to achieve the science needs stated herein are summarized as follows·

- light-weight mirrors
  - glass/composite
  - thin film (stretch membrane/replicated shells)
- structures and latches
  - deploy/redeploy capability
  - elastic memory composite materials
- optical alignment techniques
  - active vs. passive
  - deformable/correction optics
  - wavefront sensing/control

A nominal space validation experiment would include fabrication of a test article of a deployable telescope structure and mating it to a microgravity test platform on the ISS. Tests of micro and macrodynamic characteristics of the structure would be conducted in order to understand and characterize the dynamic responses and deployment of the structure in zero-g

VI REFERENCES

[1] Lake, Mark S , et al , "A deployable primary mirror for space telescopes," presented at the 1999 SPIE International Symposium on Optical Science, Engineering, and Instrumentation, Denver, Colorado, July, 1999.

Needs for Communications and Onboard Processing in the Vision Era

Faiza Lansing, Loren Lemmerman, Amy Walton, and Graham Bothwell
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

Kul Bhasin
Glenn Research Center
21000 Brookpark Road
Cleveland, OH 44135

Glenn Prescott
HQ NASA
Office of Earth Science/Code YF
300 E. Streets, SW
Washington D.C. 20546

Abstract-- **The NASA New Millennium Program (NMP), in conjunction with the Earth Science Enterprise Technology Office, has examined the capability needs of future NASA Earth Science missions and defined a set of high priority technologies that offer broad benefits to future missions, which would benefit from validation in space before their use in a science mission. In the area of spacecraft communications, the need for high and ultra-high data rates is driving development of communications technologies. This paper describes the current vision and roadmaps of the NMP for the technology needed to support ultra-high data rates downlink to Earth. Hyperspectral land imaging, radar imaging and multi-instrument platforms represent the most demanding classes of instruments in which large data flows place limitations upon the performance of the instrument and systems. The existing and prospective Data Distribution (DD) modes employ various types of links, such as DD from low-earth-orbit (LEO) spacecraft direct to the ground, DD from geosynchronous (GEO) spacecraft, LEO to GEO relays, multi-spacecraft links, and sensor webs. Depending on the type of link, the current data rate requirements vary from 2 Mbps (LEO to GEO relay) to 150 Mbps (DD from LEO spacecraft). It is expected that in the 20-year timeframe, the link data rates may increase to 100 Gbps. To ensure such capabilities, the aggressive development of communication technologies in the optical frequency region is necessary. Current Technology Readiness Levels (TRL) of the technology components for space segment of communications hardware varies from 3 (proof of concept) to 5 (validation in relevant environment).**

Development of onboard processing represents another area driven by increasing data rates of spaceborne experiments. The technologies that need further development include data compression, event recognition and response, as well as specific hyperspectral and radar data processing. Aspects of onboard processing technologies requiring flight validation include: fault-tolerant computing and processor stability, autonomous event detection and response, situation-based data compression and processing. The required technology validation missions can be divided in two categories: hardware-related missions and software-related missions. Objectives of the first kind of missions include radiation-tolerant processors and radiation-tolerant package switching communications node/network interface. Objectives of the second kind of missions include autonomous spacecraft operations and payload (instrument-specific) system operations.

I INTRODUCTION

NASA's imaging strategy for the 21st century calls for supporting the needs of the Earth Observation System (EOS) missions with a suite of smaller and more capable satellites. These satellites will carry advanced hyperspectral imaging instruments and synthetic aperture radar that will generate terabits of data to meets the scientists' demand for higher spectral and spatial resolutions. Transmitting these data to Earth and distributing them to the science investigators will require substantial advancement of many currently existing technologies

In this paper, the future science requirements are discussed in Section II, where instrument data rates for future high spectral and spatial resolution imaging instruments data rates are projected for both the years of 2010 and 2020 Section III describes future communications technology capabilities required to accommodate the science requirements These communications technologies include X-Band, Ka-Band, and optical frequencies and assessment of the current state-of-the-art, and future communication capabilities in the years 2010, 2015 and 2020. In Section IV, on-board processing technology capabilities are discussed where the need for autonomy, fault tolerant and radiation-tolerant software and hardware are required Section V presents conclusions and recommendations for future communications and on-board processing technologies

0-7803-7537-8/02/$17 00 (C) 2002 IEEE

II. SCIENCE REQUIREMENTS

Improved monitoring and management of Earth's resources and environment requires the deployment of high spatial and spectral resolution instruments on board of the spacecraft The spatial and spectral resolution obtained with the advanced spaceborne hyperspectral imagers, Synthetic Aperture Radars (SAR) provides information on Earth's dynamic processes SARs provide valuable information on ocean dynamics, wave and surface wind speed and direction, desertification, deforestation, volcanism, and tectonic activities Also, hyperspectral imagers generate high spectral resolution images of surface features, such as soil and vegetation that enables geologists, agriculturalists and others to identify mineral deposits and to monitor crop health Both Instruments generate Gbps and the challenge is be able to deliver this information as soon as possible to the principal investigators. Table 1 shows the future trends of the high data rate for the missions around the Earth The table clearly shows that the near future is going to demand an ultra high rate transmission from the satellite to the ground station. This need must be addressed in the very near future

TABLE I
Instrument Data Rates and downlink rates for each option

Instrument/Year	2010	2020
Hyperspectral	10 Gbps	100 Gbps
SAR	10 Gbps	60 Gbps
LIDAR	150 Mbps	1 Gbps
Downlink Data Rate to Earth	> 1 Gbps	> 10 Gbps

In addition to the predicted data rates above the scientific community has defined the peak data rates needs for several types of links. These peak rates are shown in Table II The types of links are classified as a) DD from LEO Earth Orbiting spacecraft to ground, b) DD from GEO to ground, c) Leo to Geo, d) Multi-spacecraft links, e) sensor web. These types of links are shown in Fig 1

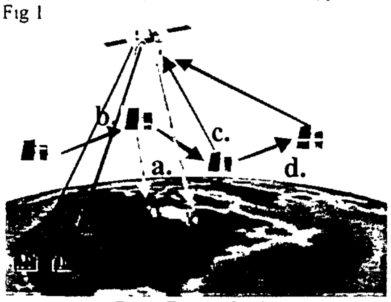


Fig 1 Types of links

III FUTURE COMMUNICATIONS TECHNOLOGY CAPABILITIES

In order to accommodate science needs and be able to deliver the desired data rate several communications technologies and their associated components have to be developed in the near future Using the several types of links defined above, these technologies and their technology readiness levels (TRL) are listed below in Table III.

TABLE II
Data Rate Peak Needs for each type of link

Type of Link	State-of-the-art	2010	2015	2020
A	X-Band, 150Mbps	10 Gbps	25 Gbps	100 Gbps
B	150 Mbps	10 Gbps	25 Gbps	100 Gbps
C	2 Mbps	150 Mbps to 1 Gbps	-	-
d	4 Mbps	45 Mbps	155 Mbps	-
e	100 bps	a, b, c, d	a, b, c, d	a, b, c, d

TABLE III
Major Communications Technology Components and their Current TRL

Type of Link	State-of-the-art	Future Technology Capability	Technology for Space	TRL
a	X-Band	Ka-Band and Optical	•Phased Array Antennas •Acq/Trk for Optical •High power/BW Lasers	3-5
b	Ku- and X-Band	Ka-Band and Optical	•Large Deployable Antennas •Acq/Trk for Optical •High power/BW Lasers	3-5
c	S- and Ku-Band	Ka-Band and Optical	•Agile Reconfig Antennas •Low Noise Receivers •High Energy Transmitter •Acq/Trk for Optical •High power/BW Lasers	3-5
d	UHF	UHF to W-Band and Optical	•Multi-Beam Antennas •Acq/Trk for Optical •High power/BW Lasers •Miniature Circuit Component	3-5
e	None	All of the above	All of the above	

IV FUTURE ON-BOARD PROCESSING TECHNOLOGY CAPABILITIES

Recent advances in science instruments technology continue to widen the gap between the volume of data collected by the instruments and the capacity of the data link to Earth Moreover, the rate at which scientists analyze data is significantly less than the rate of data acquisition. To close or reduce these gaps, scientifically important information content of the downlink data should be maximized. Thus the development of new technologies to intelligently extract and process science data represents another challenge driven by increasing data volumes and rates of spaceborne experiments These technologies that need further development can be classified in two classes, those requiring validation in space and those that don't. Here in this paper we will consider these technologies whether or not they require validation in space, such as data compression, data reduction, reconfigurable-processors, high-speed data bus etc Several aspects of onboard processing technologies especially those requiring flight validation include several major topics, such as Autonomy, Which include: Setting mission priorities, science event handling, on-board resource management, Autonomous formation keeping, on-board data management, feature detection, recognition and response, and science decision making processes. In addition fault-tolerant computing and processor stability, situation-based data compression and processing The required on-board technology validation missions include software-related and hardware-related missions Software-related missions face several challenges such as mission planning, and science data extraction for interesting targets. Objectives of the software-related mission include on-board planning, synchronization, hazard checking, resource management and event handling. Science objectives include target handoff, region classification, template matching, and model-based identification On the other hand most of hardware-related missions focus on radiation-tolerant processors and communications node (package switching) / radiation tolerant network interface. Reliability and stability of radiation-tolerant processors and its ability to withstand >100Krad is the current challenge for this technology. For the communication node in the sky, technology challenges such as. radiation-tolerant network interfaces, common data exchange architecture, and distributed systems have to be resolved.

V CONCLUSIONS AND SUMMARY

The demand to improve monitoring of the Earth's resources and its dynamic processes drives scientists to require high spatial and spectral resolution from Earth-orbiting satellites. The instruments needed to support this demand are hyperspectral imagers, synthetic aperture radars, and lidars. In viewing the projected demands in 2010 and 2020, we find that the hyperspectral and SAR imagers' demand for higher resolution drives the instrument data rates from 10 Gbps in 2010 to 100 Gbps in 2020 Future communications technology capabilities must include Ka-Band and Optical, besides the current X-Band communications. The need for autonomy and radiation-tolerant processors are identified as key components for the future on-board processing technology capabilities.

ACKNOWLEDGMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

The authors wish to thank both New Millennium Program Office, and the Earth Science Technology Office for the help and support provided to the authors while writing the manuscript for this paper Also, the authors are grateful to Dr Anil Kantak for reviewing the paper on a very short notice.

REFRENCES

[1] W Schober, F Lansing, K Wilson, and E Webb, "High Data Rate Instruments Study," Jet Propulsion Laboratory publication 99-4

[2] F Lansing, K. Bhasin, and G. Prescott, "Ultra-High Data Rate Communications," Earth Science Enterprise Technology Workshop, January 24, 2001

[3] G Bothwell, L Lemmerman, A. Walton, "On-Board Processing," Earth Science Enterprise Technology Workshop, January 24, 2001

Preliminary Design of the SWIMSAT Radar for the Measurement of Ocean Wave Spectra

P. Calvary, L. Phalippou
Alcatel Space Industries, 26 Avenue J F Champollion, 31037 Toulouse Cedex, France
Tel/Fax +33 (0) 5 34 35 44 92 / 61 63, Email philippe calvary@space alcatel fr
E. Thouvenot
Centre National d'Etudes Spatiales, 18 Av E Belin, 31401 Toulouse Cedex 4, France
Tel/Fax +33 (0) 5 61 28 25 68 / 18 15, Email Eric Thouvenot@cnes fr
D. Hauser
CETP/CNRS, 10-12 Avenue de l'Europe, 78140 Vélizy, France
Tel/Fax · +33 (0) 1 39 25 48 52 / 48 72, Email· hauser@cetp ipsl fr

Abstract – **The main objective of SWIMSAT is to measure the directional spectra of waves thanks to a space-borne radar. The instrumental concept involves a real-aperture radar using a multi-beam conical scanning, in order to provide measurements of the spectral properties of the wave field, and to estimate the profile of radar cross-section depending on incidence (0° to 10°) and azimuth (0° to 360°).**
The paper provides an overview of the mission and of the measurement principle, and the status on instrument design.

I INTRODUCTION

Studies about SWIMSAT (formerly known as VAGSAT) have begun about 8 years ago. Several papers have been published since then, among them [1] gives a detailed description of the measurement principle, and [2] presents preliminary results about data assimilation. SWIMSAT has been submitted this year in response to the second ESA call on "Earth Explorer Opportunity Missions"
The present paper focuses on the instrument preliminary design. It is organized as follows :
Part II is a short description of SWIMSAT science objectives. Part III gives an overview of the measurement principle. Part IV presents the general mission characteristics. The instrument preliminary design is addressed in part V

II SCIENCES OBJECTIVES

A. Main Objective

The main objective of SWIMSAT is the improvement of knowledge and modeling of sea-surface processes related to the presence of surface ocean waves. The first objective is to improve wave prediction and sea-state monitoring by providing spectral information of ocean surface waves and wind estimates. The second objective is to provide information on sea-state to better account for surface ocean wave effects in atmospheric and oceanic circulation models.

B Secondary Objectives

Additionally, SWIMSAT will allow to :

- Complement the observations of ocean ice-covered regions.
- Provide spectral information on waves to improve the estimate of other parameters measured by altimeters or radiometers (e.g. topography, salinity, wind estimates, ..).
- Improve knowledge of the statistics of waves, in particular the wave slope probability distribution function.

III. MEASUREMENT PRINCIPLE

The validity of the principle to derive the spectra of ocean waves from a real-aperture radar has been demonstrated several times, using airborne systems developed at NASA (ROWS system) and in France at CETP/CNRS (RESSAC Radar). Recent studies supported by French Space Agency CNES and performed at Alcatel Space Industries and CETP/CNRS have proved the feasibility of the proposed space-borne system.
The measurement principle is based on measuring modulations of the radar back-scatter coefficient (its spectrum can be related to the wave spectrum) inside the swath. The technical requirement is to get a minimum detectable wavelength of about 70 m, a resolution in wave propagation direction of about 15°, and a resolution in wavelength of 10 to 20%
The need to acquire measurements in all directions of wave propagation, at scales up to 90 km, led to the design of a real aperture radar using a multi-beam conical scanning. The antenna beam scans both in azimuth (over 360°, thanks to a mechanical rotation of the antenna source), and in incidence (between 0° and 10° in 2° step). The nadir beam allows to measure the significant wave height and wind speed as done by current space-borne altimeters. The five off-nadir beams allow the measurement of the wave spectrum, and of the mean radar cross-section.

IV GENERAL MISSION CHARACTERISTICS

The mission is based on a mini-satellite on a sun synchronous orbit at about 500-km altitude, allowing a 3 years lifetime mission, and an global ocean coverage. A cycle of 8 days has been chosen, in order to optimize coverage of ocean over latitudes above 35° (N or S) The ground segment consists in X-band receiving stations (data rate up to 8 Mb/s) The payload is a Ku-band radar (mass 75 kg, consumption . 190 Watt).
A scheme of the geometry of observation is shown in Fig. 1, for two incidences (0° and 10°). For an orbit altitude of 500 km, the footprint will be about 18 km x 18 km. This footprint will sweep a pseudo-circle with a diameter ranging from 18 km to 90 km for incidence angles ranging from 2° to 10° The corresponding surface pattern is illustrated in Fig. 2

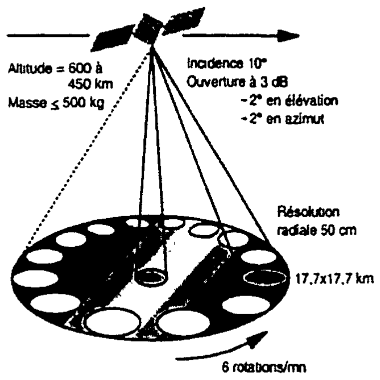


Fig. 1 Geometry of observation for 2 incidence beams (0° and 10°)

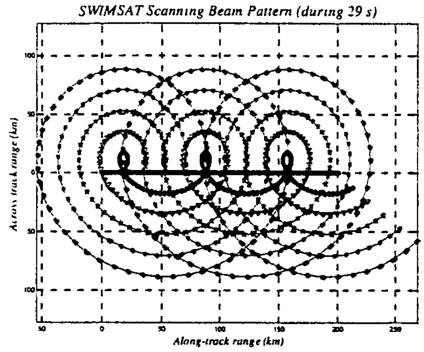


Fig. 2. Surface pattern

V INSTRUMENT PRELIMINARY DESIGN

A General Description

The payload is a radar system at 13 6 GHz Its main characteristics are given in Table 1.

TABLE 1

INSTRUMENT MAIN CHARACTERISTICS

Radio-Frequency Part	
Frequency	13 575 GHz
Peak power	120 W
Bandwidth	200 to 320 MHz depending on incidence
Pulse duration	50 µs
PRF	2 to 6 5 kHz depending on incidence
Antenna (nadir antenna)	
Design	40 cm passive parabole
3 dB Beamwidth	4 °
Antenna (offset beams)	
Design	80 cm passive offset parabole, with 5 rotating feeding horns
Incidence	2, 4, 6, 8, and 10°
3 dB Beamwidth	2 °
Rotation	6 rotations/minute

B Instrument Architecture

The transmission chain is based on a chirp, with bandwidth varying from 200 MHz to 320 MHz, depending on incidence. The frequency up-converted chirp is then amplified through a 120 W TWTA.

The receiving chain integrates the following functions

- Low noise amplification
- Pulse compression using full deramp principle
- Variable gain amplifier
- Analog amplitude/phase demodulation
- Analog to digital conversion (at about 100 MHz)

C Transmission Cycle

The transmitted bandwidth, the number of incoherently integrated pulses, and the pulse repetition frequency depend on incidence, in order to optimize a trade-off between signal to noise ratio, range resolution, and decorrelation of successive pulses.

Transmission cycle parameters are provided in Table 2, whereas Table 3 contains for each incidence angle the bandwidth of the received signal. This table shows that the received signal duration (subtracting pulse duration) is always smaller than the pulse duration, so that the choice of full deramp for range compression is an attractive solution

TABLE 2

RADAR PARAMETERS DEPENDING ON INCIDENCE

Incidence (°)	PRF (kHz)	Bandwidth (MHz)	Pulse number	sub-cycle duration (ms)
0	2	320	90	48 3
2	2	320	90	48 3
4	6 5	320	90	17.2
6	6 4	320	135	24 4
8	5	250	135	30 3
10	4	200	135	37 1
combined				205 7

TABLE 3

SWIMSAT BEAMS BANDWIDTH

Incidence (°)	Echo duration (µs)	Analysis duration (µs)	Transmitted pulse bandwidth (MHz)	Reference pulse Bandwidth (MHz)	Pulse bandwidth after deramp (MHz)
0	<0 5	<52	320	<323	<2.56
2	<4 1	<56	320	<358	<38
4	8 2	60	320	384	64
6	12 3	64	320	410	90
8	16 5	68	250	340	90
10	20 8	72	200	288	88

C. Antenna

The antenna configuration is illustrated by Fig. 3. The system actually consists in two antennas. The 40-cm diameter parabolic antenna is pointing towards nadir. The second one is an offset parabolic antenna (diameter about 80 cm), with 5 rotating feeding horns. This configuration was selected as it ensures good electrical performances, it is compatible with small satellite class, and it minimizes development costs. Including the nadir beam into the main antenna feed subsystem might be envisioned as well, but would require further optimization.

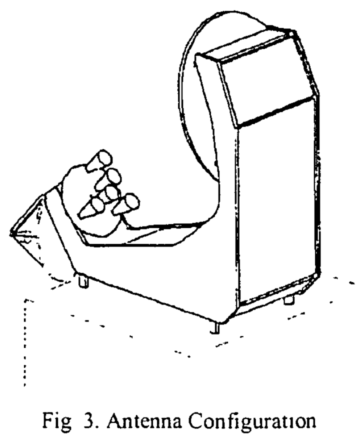


Fig 3. Antenna Configuration

D On-Board Processing

The functions to be computed on board are the following·

- For the nadir beam, it is a classical altimeter processing, consisting in altitude estimation and echo tracking (in range and in gain).
- For the offset beams, the objective of on-board processing is to reduce the data-rate The chosen principle is to realize on board the estimation of the modulation spectrum and the speckle reduction

Nadir Processing

The processing architecture of the nadir beam is illustrated by Fig 4

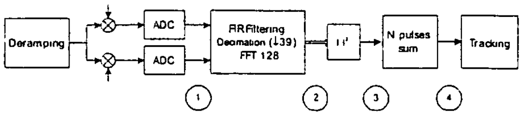


Fig 4 On board processing architecture (nadir beam)

After sampling, the signal is filtered and under-sampled, in order to adapt sampling period to useful bandwidth (indeed, the signal is sampled at 100 MHz, and the useful bandwidth is about 2 6 MHz, leading to an under-sampling factor of 39) After filtering and under-sampling, an FFT is applied on the 128 remaining samples, and the resulting echoes are incoherently integrated over the 90 transmitted pulses. The resulting integrated signal constitutes the input of the tracking algorithm. Note that the tracking algorithm uses only data coming from nadir, but its output is used to control in range the receiver chain for the signals coming from all the offset beams

Offset Beams Processing

The processing architecture for offset beams is illustrated by Fig. 5 (for beams 4, 6, 8, and 10°) Note that the 2° beam processing is similar to the nadir beam processing, but with different parameters (FFT 2048 instead of FFT 128, no tracking).

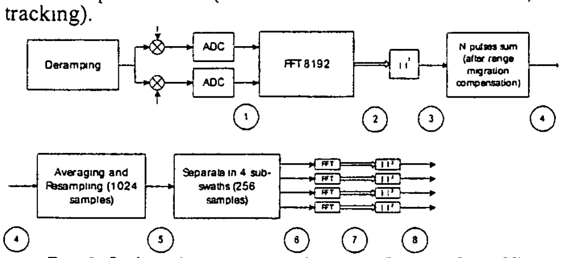


Fig. 5 On board processing architecture (beams 4° to 10°)

The signal bandwidth for beams 4°, 6°, 8°, and 10° is respectively equal to 64, 90, 90, and 88 MHz, so that it does not appear necessary to filter and under-sample the received signal. After sampling, a 8192 points FFT is applied.
The resulting echoes are integrated (after range migration compensation). An averaging is then applied over adjacent range gates (in order to reduce speckle noise), and the signal is resampled on 1024 points
The resulting signal is splitted in 4 sub-swaths, and an FFT is applied on each sub-swath in order to estimate the modulation spectrum. The signal before FFT being real, each power spectrum is characterized by 128 useful samples
Two options are possible for the last step :

- ➢ Transmission of the 4 spectra to the ground
- ➢ Averaging over the 4 spectra, and transmission of the mean spectrum to the ground

The hypothesis considered in the scope of this paper is the first option, which leads to better science performances (at the price of higher data-rate)

E Down-linked Data

The scientific transmitted data are the following

- ➢ For incidence angles from 4 to 10° 4 modulation spectra (128 samples per spectrum), and backscatter coefficient (every 0 5° in incidence).
- ➢ For incidence angles 2° and 0° . return waveform (step 4 of Fig. 4), and backscatter coefficient (every 0.5° in incidence).

VI. Conclusion

The feasibility of the Swimsat radar has been assessed. The key points concerning the instrument design are the following·

- ➢ Design of a new antenna configuration, allowing multi-beam conical scanning,
- ➢ 120 Watt TWTA, currently under development for the JPL WSOA (Wide-Swath Ocean Altimeter) instrument,
- ➢ Powerful processing architecture, due to the high processing demands on board (about 200 Mips). The proposed solution combines an ASIC for FFT operations and time integration, and a combination of two 100 MHz LEON processors for the remaining parts of the processing.

Acknowledgement

This work is based on a CNES R&D funding

References

[1] Hauser D , E. Soussi, E Thouvenot, L. Rey, SWIMSAT . A Real-Aperture Radar to Measure Directional Spectra of Ocean Waves from Space – Main Characteristics and Performance Simulation, J. Atm. And Oceanic Tech, vol 18 N°3, 421-437, 2001.

[2] Hauser D , L Aouf, J-M Lefèvre, Prospect of new ocean waves spectral observations from the SWIMSAT satellite . measurements and assimilation, Proceedings of the ECMWF Workshop on Ocean Wave Forecasting, Readings, 2 to 4 July 2001

A Feasibility Study for a Wide-Swath, Airborne, Hurricane Imaging Microwave Radiometer for Operational Hurricane Measurements

W Linwood Jones, Jun-Dung Park and Josko Zec
University of Central Florida, Orlando, FL
Christopher S. Ruf
University of Michigan, Ann Arbor, MI
Marion C. Bailey
Research Triangle Institute; Hampton, VA
James W. Johnson
NASA Langley Research Center; Hampton, VA

ABSTRACT

This paper presents a conceptual design of an airborne Hurricane Imaging (microwave) Radiometer (HIRad) instrument for use in operational hurricane surveillance. The basis of the HIRad design is the Stepped Frequency Microwave Radiometer (SFMR) that has successfully measured surface wind speed and rain rate in hurricanes from the NOAA Hurricane Research Division's P-3 aircraft. Unlike the SFMR that views only at nadir, the HIRad provides wide-swath measurements between ± 45 degrees in incidence angle with a spot-beam spatial resolution of approximately 1-3 km. The system operates at four equally spaced frequency channels that cover a range between 4 GHz and 7 GHz.

I INTRODUCTION

Contemporary hurricane numerical models such as MM-5 (Penn State/NCAR Mesoscale Model) have the ability to predict precipitation as well as to forecast storm evolution (intensity, size and track). To aid forecasting, the most important contribution that could be made from remote sensing platforms would be daily mapping of the surface wind field from the center of the storm to a distance just outside the ring of maximum winds located in or near the eyewall cloud. In the Atlantic basin such measurements are operationally available at limited times from sensors mounted on research aircraft, but none of the world's other hurricane basins have aircraft reconnaissance capabilities. Even in the Atlantic hurricanes are out of range of the aircraft for most of their lifetimes. Timely measurements of the surface wind fields in tropical cyclones, with wide swath (10's of km) and high resolution (1 km), would dramatically improve model initialization and resulting forecasts.

II HURRICANE IMAGING RADIOMETER

A Instrument Heritage

Retrievals of hurricane ocean surface wind speed and rain rate have been performed operationally by the Stepped Frequency Microwave Radiometer (SFMR) from aircraft by NOAA Hurricane Research Division (HRD) for more than a decade. SFMR was originally developed by the NASA Langley Research Center in the 1970s [Jones *et al.*, 1981] and it has continued to be an integral part of NOAA operations since Wind speed and rain rate are retrieved simultaneously from measurements of microwave brightness temperature (T_B) made by the nadir-viewing SFMR on board a NOAA P-3 flying at ~25,000 ft (7 6 km). Winds in excess of 180 mph (150 m/s) and rain rates of greater than 100 mm/h have been successfully estimated by the SFMR and validated against weather radars, dropsondes released from aircraft, and extrapolations of flight-level winds. Even at these extreme levels, the T_B responses to both wind speed and rain rate have not reached saturation.

The SFMR scans between 5 and 8 GHz with a variable number of channels. Retrievals have been demonstrated with as few as two and as many as eight channels. A minimum of two T_B channels is required to uniquely separate the contrasting spectral signatures of surface emission and rain Additional channels serve to over-constrain the system of equations that relate the T_B measurements to the state parameters of wind speed and rain rate. This effectively reduces the sensitivity of the retrieval algorithm to instrument noise and common-mode calibration biases. The current operational NOAA sensor uses eight channels.

B HIRad Instrument Description

The Hurricane Imaging (microwave) Radiometer (HIRad) is a candidate airborne sensor for future operational surface wind speed and rain rate measurements in hurricanes and typhoons. This sensor is an interferometric microwave radiometer that uses a one-dimensional thinned synthetic aperture array antenna to synthesize multiple simultaneous beams in a push-broom configuration. When used on an operational hurricane surveillance aircraft such the NOAA HRD's Gulfstream-IV (Fig. 1), the hurricane may be imaged with high resolution as shown in Fig. 2 & 3.

Unlike the SFMR, that views only at nadir, the HIRad provides wide-swath measurements with simultaneous multiple "pushbroom" fan-beams between ± 45° in incidence angle. When flying at an altitude of 35,000 ft

0-7803-7537-8/02/$17 00 (C) 2002 IEEE

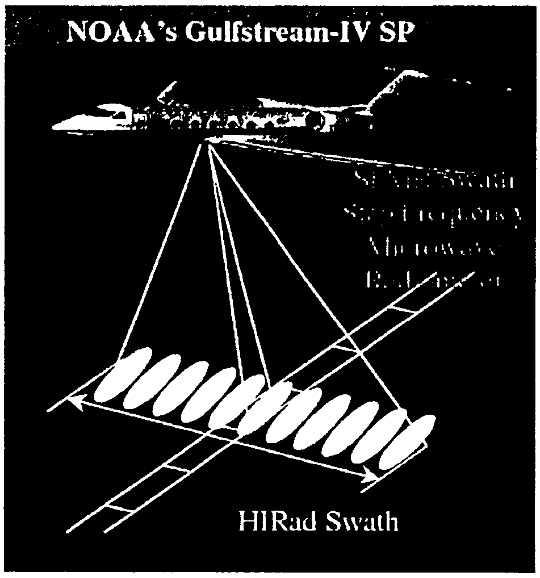


Fig 1 HIRad measurements from NOAA's hurricane surveillance aircraft

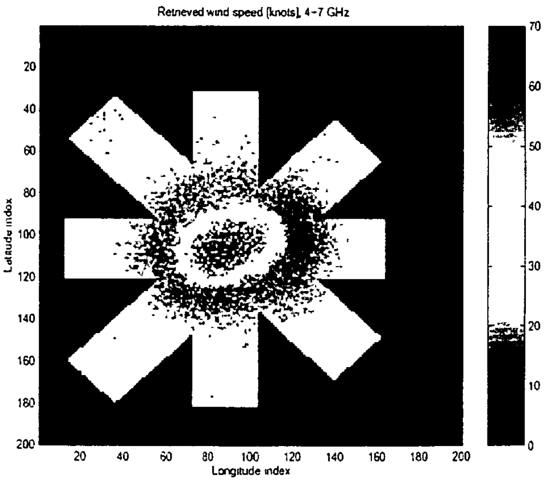


Fig 2 Simulated HIRad measurements of surface winds from Hurricane Floyd (1999) Ordinate is latitude index (0 125° steps) and the abscissa is longitude index (0 125°) Color scale is 0-70 knts (36 m/s)

(11 km), HIRad provides a measurement swath of 22 km and a spatial resolution of 1-3 km depending upon the operating frequency and cross-track position in the swath This geometry provides excellent opportunity to image the high wind gradients and spiral rain bands surrounding the hurricane eye while flying the typical "butterfly" transects. The image produced in Fig. 2 and 3 results from four transects of the eye The advantage of HIRad over a profiling sensor such as SFMR is obvious. The equivalent SFMR coverage would be a single strip (one pixel wide) centered along each the aircraft track.

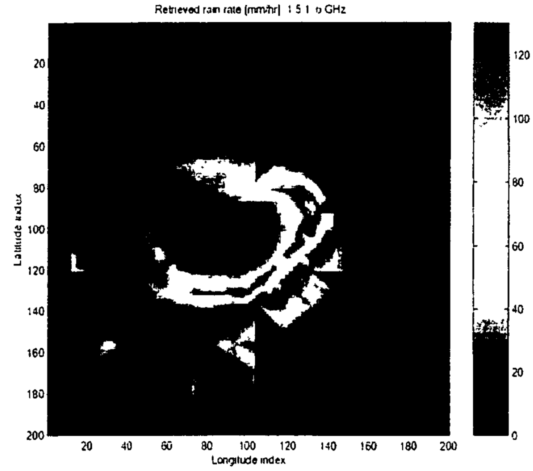


Fig. 3 Simulated HIRad measurements of rain rate from Hurricane Floyd (1999) Color scale is 0-130 mm/hr

C Synthetic Thinned Array Radiometer (STAR) System

The STAR instrument design presented here has a frequency plan similar to SFMR but provides a cross track swath at each frequency of 65 independent pixels covering $\pm 45^{\circ}$ about nadir. The pixels are generated using interferometric aperture synthesis [Ruf *et al.*, 1988]. The thinned aperture antenna array consists of 10 active fan beam antennas, each of which is a linear broadside phased array of 36 multi-resonant dipoles (see antenna design section). The linear arrays are oriented in the direction of flight of the aircraft so that their fan beam patterns define the cross track instantaneous field of view of the imager. Full two-dimensional images are then formed by push broom aircraft motion.

The flat panel antenna array (1 1x1.1 m aperture x 25 cm thick) consists of a rectangular grid of 38x38 multi-resonant dipoles with ten receiver front-ends. The small element size (0.4 $\lambda_{free\ space}$ at 4 GHz and 0 7 $\lambda_{free\ space}$ at 7 GHz) allows the design of the array without introduction of grating lobes into the scanning field of view A multi-slot antenna array element (Fig. 4) is being developed for the 4-7 GHz frequency range Four resonant frequencies (4, 5, 6 & 7 GHz) were selected for the design. The multi-resonant element is realized by multiple narrow slots in the wall of a specially configured thin cavity Excitation of the slots is via a stripline inside the cavity and passing directly underneath the slots. Because of the very close proximity of all the slots, there is significant slot-to-slot field interaction. Therefore, the fundamental design was developed and optimized through electromagnetic computational simulations, which model the entire configuration as a single device. Test results on the initial laboratory constructed element demonstrates the four resonant frequencies as predicted. More attention to details in fabrication will be addressed in the next test article in order to improve the impedance match at all frequencies.

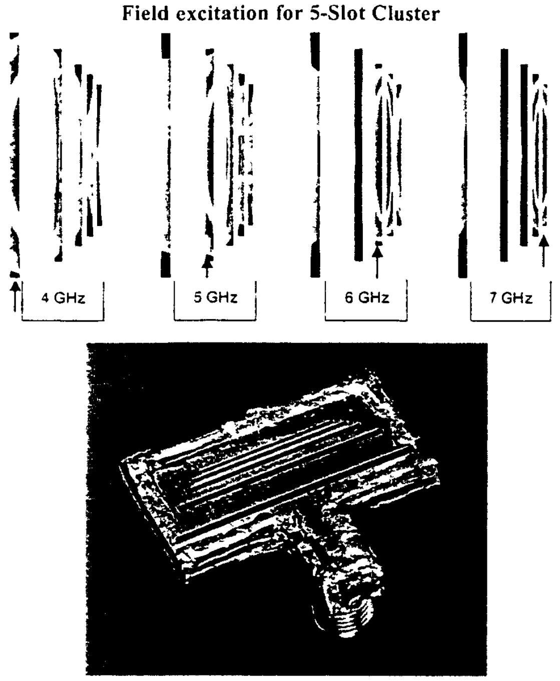


Fig 4 Antenna element for HIRad array Top panel illustrates the field excitation and the bottom panel shows a brass-board test article.

The outermost ring of dipoles are passively terminated to ensure consistent mutual coupling between active elements, leaving a 36x36 central grid. The 26 rows of dipoles that do not comprise the 10 active fan beams are also passively terminated. Which 10 of the 36 possible rows are active is determined using an interferometric sampling algorithm [Ruf, 1993].

Each active fan beam antenna is connected to a frequency agile correlating radiometer receiver The input stage of each receiver features a reference load and injected noise diode for absolute system calibration followed by a wideband low noise amplifier covering the 4-7 GHz input frequency range. The frequency selection is achieved by single sideband downconversion to a fixed narrowband (20 MHz) intermediate frequency (IF) range using a variable local oscillator, in a manner adapted from the SFMR design. The IF signal is digitized (prior to detection) with a coarse 2-bit digitizer and then digitally quadrature demodulated to baseband and complex cross-correlated between receivers using technology and signal processing algorithms developed under a NASA Global Precipitation Measurement Mission technology development incubator [Ruf *et al.*, 2000].

D. *HIRad Simulated Performance Results*

HIRad hurricane measurements are simulated using a statistical Monte Carlo technique. The wide-swath coverage provided from typical aircraft altitudes is capable of mapping the entire hurricane eye wall during a few flight tracks across the storm. These simulated retrievals show good accuracy for surface wind speed and rain rate under realistic hurricane conditions An example of the spatial distribution of retrieval errors is presented in Fig 5. The top panel is the modeled wind field with the error in the retrieved wind speed directly below The maximum errors ~ 5 m/s occur at light winds inside of the eye, and at stronger winds where the system is optimized, the error is less. Also note that the wind speed errors are not correlated with the location of strong rain (panel 3rd from top). Directly below the model rain intensity is the rain rate retrieval error. Again the largest errors are for light rains inside of the eye, and for stronger rains, where the system is optimized, the errors are less. Also note that rain rate errors are independent of wind speed. Scatter diagrams of the wind speed and rain rate retrieval errors are presented in Fig. 6 for the entire hurricane. As discussed above, the errors reduce as the wind speed and rain rate increase. At light winds and rain there is a sensitivity issue because of selecting the low frequency microwave channels (4 GHz - 7 GHz). However, at the strong wind speeds and rain intensity associated with tropical cyclones there is an exponential increase in T_b with these increasing parameters, and the retrievals improve.

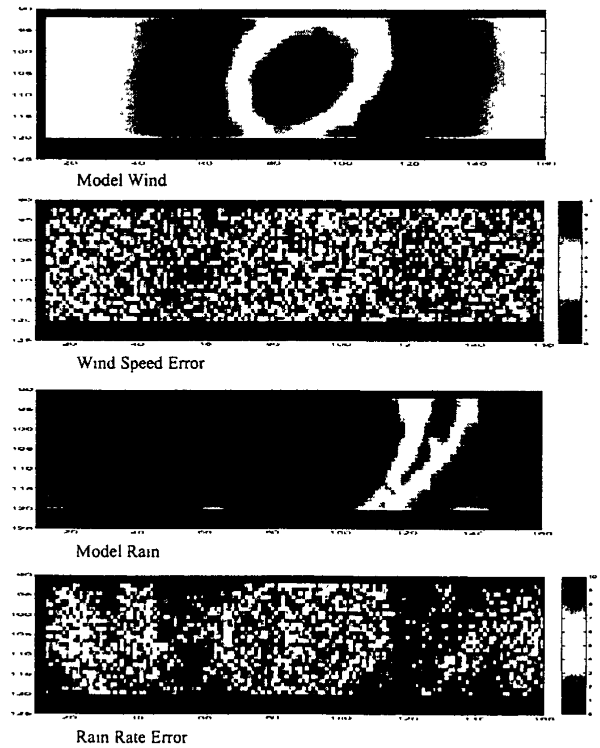
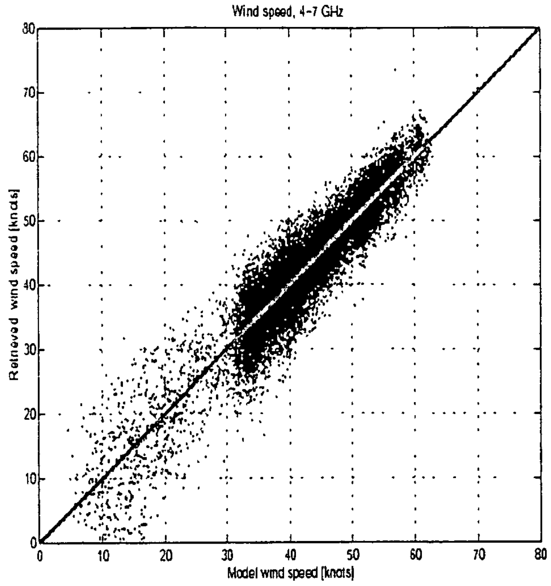


Fig. 5 HIRAD simulated east-West flight leg Top panel is the modeled wind speed, next is the retrieved wind speed error - color bar is 0-10 knts (5 2 m/s), next is the modeled rain intensity and the bottom panel is the corresponding rain rate retrieval error - color bar is 0-10 mm/hr



(a) - HIRad wind speed error - entire hurricane image

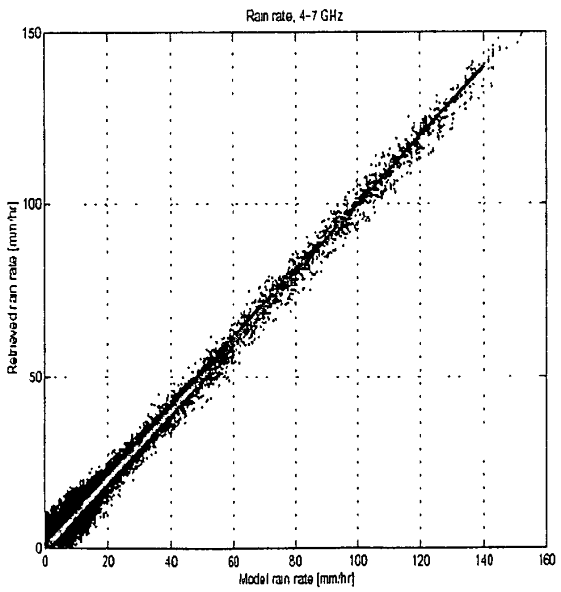


Fig 6 HIRAD simulated hurricane retrieval error Top panel is the wind speed error and the bottom panel is the corresponding rain rate error

III Conclusions

This design study has demonstrated the feasibility of developing a new Hurricane Imagine Radiometer using currently available technologies for Synthetic Thinned Array Radiometers There is significant potential for this candidate airborne sensor for future operational surface wind speed and rain rate measurements in hurricanes and typhoons.

ACKNOWLEDGMENT

This work was performed under a Research triangle institute contract with NASA Langley Research Center.

REFERENCES

Jones, W L, P G Black, V E Delnore, and C T Swift (1981), "Airborne Microwave Remote Sensing Measurements of Hurricane Allen," Science, 214, 274-280.

Ruf, C S, C T Swift, A B Tanner and D M Le Vine, "Interferometric synthetic aperture microwave radiometry for the remote sensing of the earth," IEEE Trans Geosci Remote Sens, **26**(5), 597-611, 1988

Ruf, C S, "Numerical annealing of low redundancy linear arrays," IEEE Trans Antennas and Propag, **41**(1), 85-90, 1993

Ruf, C S, C M Principe and S P Neeck, "Enabling Technologies to Map Precipitation with Near-Global Coverage and Hour-Scale Revisit Times," Proceedings of the 2000 International Geoscience and Remote Sensing Symposium, Honolulu, HI, IEEE Cat #99CH37120, Vol VII, 2988-2990, 2000

Initiatives for Millimetre/Submillimetre-Wave Sounding from Geostationary Orbit

Bizzarro Bizzarri (1), Albin Gasiewski (2) and David Staelin (3)

(1) CNR Istituto Scienze dell'Atmosfera e del Clima (ISAC), Roma, Italy
(2) NOAA Environmental Technology Laboratory, Boulder CO , USA
(3) MIT Research Laboratory of Electronics, Cambridge MA., USA

Abstract - **The concept of microwave sounding from geostationary orbit is over three decades old, but can now be facilitated using submillimetre-wave sounding technology. A "GEM" concept has been pursued in the U.S. in the past few years, and now a "GOMAS" proposal has been submitted to ESA for implementation. The principle is to extend the number of bands usually exploited for sounding (54 GHz for temperature and 183 GHz for humidity) to higher frequencies (118 and 425 GHz for temperature, 380 GHz for humidity), so as to obtain higher geometric resolution for a given antenna size. Measurements in absorption bands at frequencies differently affected by liquid and ice water, enable simultaneous retrieval of temperature and humidity profiles, cloud ice and liquid columnar amounts and gross profile and, most important, precipitation, appropriately sampled at time intervals of some 15 minutes. The paper will highlight the basic concepts and technical features of the GEM/GOMAS project and comment about feasibility and sizing elements.**

I. INTRODUCTION

The idea of MW sounding from geostationary orbit dates from 1978, with the NASA "Applications Review Panel Report, High Resolution Passive Microwave Satellites", edited by Staelin and Rosenkranz [1]. In Europe, MW sounding was placed in 1984 as a requirement for Meteosat Second Generation, and led to an industrial study presented in 1988 after a definition study by Chedin, Pick and Rizzi [2]. Those early initiatives were premature because of the technological state-of-the-art at the time. Recently, the idea of MW sounding from geostationary orbit has received renewed interest because of two developments.

- On the technological side, it has become possible to extend radiometry to the submillimetre-wavelength range, which enables corresponding reductions in the antenna size or, alternatively, improvements in resolution for a given antenna size [3],
- On the application side, strong requirements have appeared to frequently observe precipitation. These requirements have been driven by the growing capability of NWP models to assimilate precipitation data at the appropriate scale.

In the U S , a "Geosynchronous Microwave Sounder Working Group" reported to the NOAA-NESDIS GOES Program Office in 1997 [4] and gave rise in 1998 to the proposal for GEM (<u>Ge</u>ostationary <u>M</u>icrowave Observatory) [5] In Europe, an analysis of scenario was prepared by Bizzarri for EUMETSAT in 2000 [6] and finally, in January 2002, a proposal has been submitted to ESA in the framework of the Earth Explorer Opportunity Missions, for GOMAS (Geostationary Observatory for Microwave Atmospheric Sounding). The GOMAS proposal includes all GEM heritages and was submitted by Bizzarri on behalf of 40 European and U.S. proponents.

The GEM/GOMAS objectives are to explore the capabilities of very-high-frequency microwaves and sub-millimetre waves to provide frequent sounding as allowed from the geostationary orbit of:

- <u>Precipitation rate</u> from convective clouds (and non-convective ones to an extent to be determined),
- <u>Cloud liquid and ice water</u> (mainly total column, with inference of gross profile to an extent to be determined);
- Atmospheric <u>temperature and humidity profiles</u> in nearly all weather conditions.

The observation principle is based on the use of absorption bands of oxygen (54, 118 and 425 GHz) and of water vapour (183 and 380 GHz). Narrow-bandwidth channels are implemented (for a total of about 40 in the five bands) so as to observe the full profiles of temperature and water vapour. Profiles from different bands are differently affected by liquid and ice water of different drop size and shape, and finally by precipitation. Simultaneous retrieval of all these ingredients is in principle possible, and partially demonstrated by several airborne MW/Sub-mm instruments.

The GEM concept defined an instrument using a 2-m antenna suitable to be flown on the next upgraded series of operational GOES (e.g., GOES-R+, starting in 2011). GOMAS, however, is intended as a stand-alone mission mostly for demonstration, and can be implemented as a relatively small satellite. Launch is proposed for 2007-2009 and operations co-ordinated with the NMP-EO3 GIFTS for a full assessment of the benefit of combined high-vertical-resolution IR sounding and MW/Sub-mm nearly-all-weather sounding and precipitation imagery.

The 3-m GOMAS antenna will provide geometric resolutions ranging from 10 km (for precipitation) to 20 km (for water vapour and cloud liquid/ice water) and 30 km (for temperature). Each 15 min a sector of 1/12 of the Earth's disk will be imaged, the sector being movable within the disk and the satellite able to be shifted for experiments between the American continents and the Indian ocean.

II Observing Principle

In order to use an antenna of practical size (∅ = 3 m), GOMAS adds frequency bands in the sub-millimetre range to those currently used on polar orbiters Fig 1 shows the distribution of available bands in the MW/Sub-mm range.

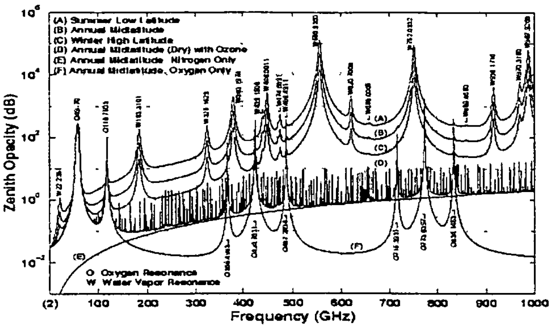


Fig 1 Atmospheric spectrum in the MW/Sub-mm ranges (from [7])

The figure shows that.

- For O_2 above the 54 GHz band, the desirable temperature sounding bands are at 118 GHz and 425 GHz. Other bands exist, but are either too weak or obscured by the water vapour continuum.
- For H_2O above the band at 183 GHz, several other bands exist starting at 325 GHz, then at 380 GHz and higher These bands become progressively less useful because of the increasing continuum absorption contribution.

Accordingly, the optimal choice of bands for GEM/GOMAS is. 54 GHz, 118 GHz, 183 GHz, 380 GHz and 425 GHz. The resolutions at the sub-satellite-point (s s p) achievable using several different antenna diameters at these frequencies are in Table I. While these resolutions degrade toward the poles, image oversampling facilitates a reasonable degree of deconvolution and effectively restores the s.s p. resolution for most mid-latitude regions.

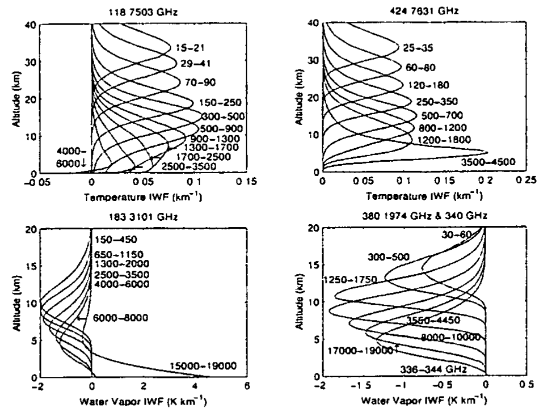
TABLE I

Resolution at s s p v/s Frequency at Reference Antenna Diameters

Antenna ∅	54 GHz	118 GHz	183 GHz	380 GHz	425 GHz
1 m	242 km	112 km	73 km	35 km	31 km
2 m	121 km	56 km	36 km	18 km	16 km
3 m	81 km	37 km	24 km	12 km	10 km
4 m	60 km	28 km	18 km	8 8 km	7 8 km

The selected GOMAS antenna diameter of 3 metres will provide good spatial resolution at the high European latitudes.

The incremental weighting functions (IWFs) of the ~40 channels selected in these bands are reported in Fig. 2. The figure shows that the higher-frequency bands (380 and 425 GHz) are useful down to the top of the lower troposphere, whereas both the 118 and 183 GHz bands reach the surface and are thus indispensable for a geostationary satellite mission. The 54 GHz band is somewhat redundant and of limited resolution but nonetheless very useful due to both a minimum sensitivity to liquid water and ice and for cross-calibration purposes using AMSU (the 183 GHz band also serves this purpose)



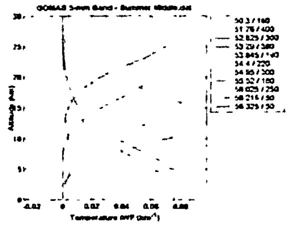


Fig. 2 Incremental weighting functions (IWF) for temperature and humidity in the bands 118, 183, 380 and 425 GHz (above) The numbers attached to the curves indicate the distance (in MHz) from the frequency of the peak (from [7]) The more familiar IWF's relative to the 54 GHz band are also plotted (aside)

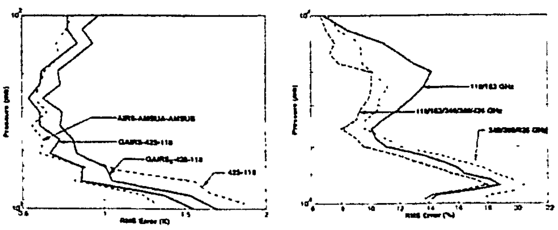


Fig 3 Expected retrieval errors (RMS) for bands 118, 183, 340/380 and 425 GHz, as stand-alone or in association with an IR sounder of the AIRS class (GAIRS) (Left) temperature, (right) humidity In the left, the case of GAIRS-425-118 is compared with GAIRS alone and 425-118 alone The EOS-Aqua AIRS-AMSU/A-AMSU/B is shown as reference (from [8]

The capability of these spectral bands to retrieve temperature and humidity profiles is shown in Fig 3. We note that the bands 425+118 GHz have the same performance as GAIRS for altitudes above 600 hPa, and that the association GAIRS+425+118 closely approaches the performance of AIRS+AMSU/A+AMSU/B, except for lower troposphere. For GEM/GOMAS the addition of the 54 GHz band would reduce this gap In the right-hand figure, it is interesting to note the strong impact of the 380+425 GHz bands in the high troposphere. These simulations show that GEM/GOMAS retrievals will be accurate enough to initialise NWP models, and their use in combination with an IR spectrometer of the AIRS class (GAIRS), or of the IASI class (GIASI) would approach polar satellite sounding performance A GOMAS launch during the window of operation of the NMP-EO3 GIFTS would provide excellent cross-validation and cloud-clearing capabilities, and would extend GIFTS' capabilities into cloudy regions.

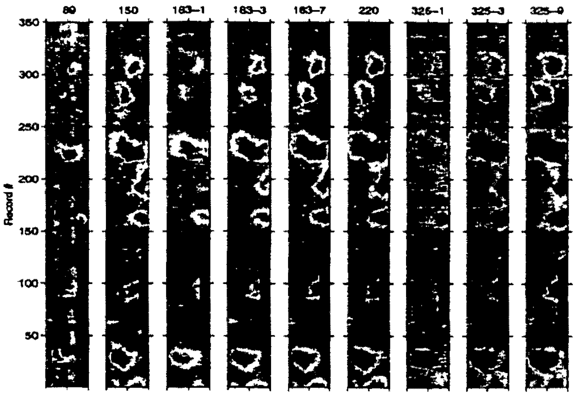


Fig 4 Image strips of convective precipitation cells over ocean obtained by a multi-channel airborne radiometer Scenes of 40 km (width) x 200 km (length) (from [9])

The effects of clouds on bands comparable to those to be used on GEM/GOMAS are shown in Fig. 4 The strip maps of Fig. 4 show the impact of clouds as a function of frequency and absorption for a set of channels comparable to those of GOMAS. Cloud impact is as follows:

- An increasing impact with increasing frequency as detectable in "window" or "nearly-transparent" channels (89 GHz, 150 GHz, 183 ± 7 GHz, 220 GHz, 325 ± 9 GHz); cloud and raincell brightness signatures become monotonic at the submillimetre-wave channels, thus eliminating detection ambiguities that occur within the window channel at 89 over oceanic backgrounds.
- Cloud "altitude slicing" from the lower to upper troposphere occurs when moving towards the band absorption peaks (from 183 ± 7 GHz to 183 ± 3 GHz and 183 ± 1 GHz; and from 325 ± 9 GHz to 325 ± 3 GHz and 325 ± 1 GHz).
- The 380 GHz band is anticipated to behave similarly to the 325 GHz band.

Temperature and humidity profiles retrieved from the various GEM/GOMAS sounding bands are affected to differing degrees by cloud liquid and ice content, mixing ratio, vertical distribution, and drop size and shape. Since these cloud properties closely correlated with precipitation rate, the differential observations (i.e., 54/118/424 and 183/380/340 GHz) enable simultaneous retrieval of temperature/humidity profiles, cloud liquid/ice water columnar amounts and gross profiles, and precipitation rate. Some examples using actual data from NOAA AMSU and airborne instruments are shown in Figures 5 and 6.

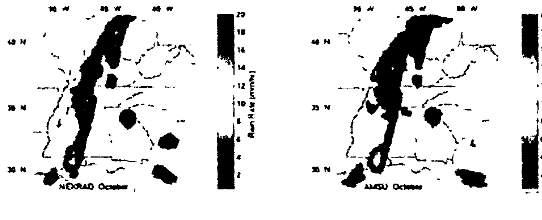


Fig 5 Precipitation images from a cold front on October 7, 1998 NEXRAD precipitation map smoothed to 15 km resolution (left image), and NOAA/AMSU precipitation map obtained using a neural net retrieval technique (right image) (from [10])

Fig. 5 shows a preliminary investigation to infer precipitation rate using AMSU sounding channels The comparison with radar imagery is surprisingly good, over both land and ocean. Observing precipitation using absorption bands instead of windows, as generally practised in MW radiometry, is particularly advantageous over land since surface emissivity is of little or no consequence.

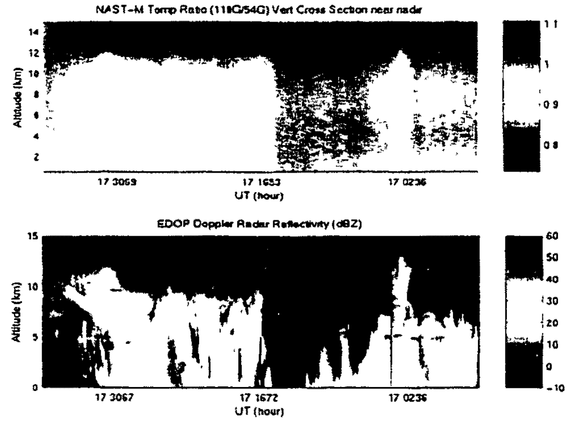


Fig 6. Comparison between the 118/54 GHz profile ratio from the NAST-M microwave radiometer on the NASA ER-2 aircraft and simultaneous EDOP Doppler radar reflectivity observation Hurricane Bonnie at 17 GMT on August 26, 1998 (from [11]).

Fig. 6 shows what can be inferred by exploiting differential information from the 54 and 118 GHz bands. In the top figure the ratio between temperature profiles obtained independently from the 118 and the 54 GHz bands is reported, as the aircraft travels. If there is no precipitation the ratio of the two temperature profiles is unity throughout the entire vertical range. When precipitation is present the ratio becomes less than unity below the altitude of the precipitation cell due to the higher attenuation at 118 GHz than at 54 GHz. The effect is the result of the use of "similar clear-air weighting functions" along with the difference in ice scattering characteristics for the two wavelength regions [3,12] A similar effect will be observed using 118 and 425 GHz, and 183 and 380 GHz, albeit these ratio signatures will be more closely related to cloud top particle size and less to low-level precipitation The bottom figure reports the precipitation profile simultaneously recorded by the Doppler radar onboard ER-2 (EDOP) The agreement is striking, and it can be inferred that GEM/GOMAS would give information similar to what is currently obtained by ground-based radar Pending confirmation by GEM/GOMAS multi-band sounding at 15 min intervals, meteorologists will have available ***a proxy rain radar operating over continental field of view, and particularly over oceans and mountainous terrain.***

III GOMAS Instrument and System Concepts

The GOMAS concept is based on a 3-m antenna and 5-band/40-channel spectrometer, depicted in Fig. 7

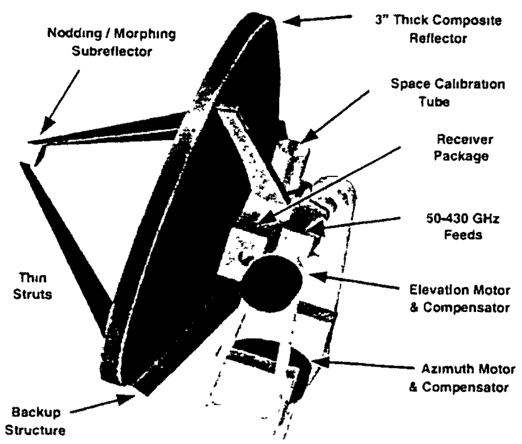


Fig 7 GOMAS antenna system (as from the GEM concept, i e before adaptation for accommodation on a dedicated platform - see Fig 9)

The antenna surface has a quiescent accuracy of ~10 µm. Thermal and inertial deformations are monitored by a series of sensors on the antenna border and actively compensated using a nodding/morphing subreflector, which also provides for limited image scanning Gross movements (e.g., to change the observation sector) are performed by the elevation and azimuth motors, although the possibility of using the satellite attitude control system in combination or as alternative is being studied. A single feedhorn path is baselined so as to provide hardware co-alignment of all feeds for the five bands. An option of a feed cluster to simplify the receiver design is still being studied. The baseline receiver uses a quasi-optical multiplexer and includes five individual spectrometers for the five bands. State-of-the-art HEMT technology for high performance, reduced volumes, and low electrical consumption is exploited. Critical parameters are.

- antenna. Ø = 3 m, 40 kg, 40 W
- radiometer: 30 cm x 50 cm x 50 cm, 67 kg, 95 W
- total payload 107 kg, 135 W, data rate 115 kbps.

The problem of sensitivity that exists with the current state of receiver technology is solved by limiting the scanned area of the Earth's disk, as suggested in Fig 8.

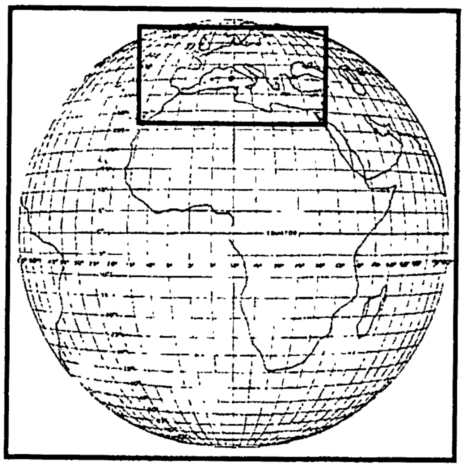


Fig. 8 Earth's disk observed by Meteosat and reference GOMAS coverage.

Within the current technological state-of-art it is not possible to scan the full Earth disk in the required short time at the required resolution. Assuming a 10-km sampling interval in 15 min (required for precipitation), the full disk includes 1250 x 1250 pixels Using an integration time of 0 5 ms one cannot achieve the radiometric accuracy necessary for sounding (SNR ≥ 100) A compromise is achieved by scanning a sector of about 1/12 of the disk (250 x 500 pixels) with an integration time of ~6 ms per pixel. Averaging over a convenient number of 10-km pixels provides the required radiometric sounding accuracy The number of pixels to be averaged (during ground-processing) is consistent with the required resolution (~30 km equatorial for temperature profiles, ~20 km for water vapour profiles and cloud liquid/ice water, and ~10 km for precipitation)

The above figures represent a reference for radiometric computation. In practice it will be possible to drive the scanning mechanism with different speeds and over areas of different size, and the reference sector of 1/12 of the disk can be selected anywhere within the disk so as to track interesting events as they evolve In addition, during the satellite lifetime the longitude of stationarity can be shifted so as to allow observation over the American continents to the Indian ocean following seasonal events.

A dedicated satellite is baselined for GOMAS The study so far performed is based on the adaptation of a current-generation bus in a basic configuration designed to support medium-size sensors. Fig 9 shows that this bus is somewhat oversized, although will be made more compact pending further study. For example, the elevation and azimuth motors of the antenna shown in Fig 7 could be combined with the satellite attitude control system.

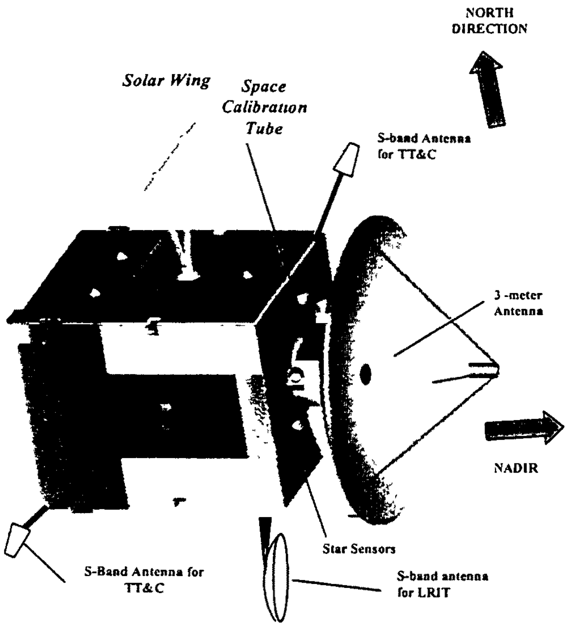


Fig 9 Artist's view of GOMAS deployed in orbit

The GOMAS satellite is proposed to be launched as a co-passenger of MSG-3 (2007), MSG-4 (2009), or perhaps GOES-P (2007). It is designed for a 5-year lifetime of which the first three would be a scientific demonstration phase and the last two would be for pre-operational exploitation. Critical parameters are:

- Mass: 860 kg (430 kg dry),
- Electrical power· 600 W (peak), 440 W (average);
- Volume (stowed): 3 0 x 3.0 x 3.0 m^3;
- Data rate: 128 kbps (S-band), compatible with the MSG Low-Rate Information Transmission (LRIT) standard, to be received at Low-Rate User Stations (LRUS).

IV CONCLUSION

Based on the U.S GEM concept, GOMAS is proposed as a ***demonstration mission*** in the framework of the ESA Earth Explorer Opportunity Missions. If accepted, GOMAS would be a ***precursor*** for future operational applications since frequent observations of temperature/humidity, cloud liquid/ice water, and precipitation rate are of primary importance for both nowcasting and regional/global NWP, as well as for hydrological climate characterisation and improved descriptions of the water cycle in General Circulation Models. Direct use in hydro-agro-meteorology would also be important.

From the technical standpoint, and building on the studies conducted on GEM, it is believed that no enabling technology is currently missing and that the GOMAS satellite could be developed in time for a launch in the 2007-2009 timeframe. This window would permit co-flight with the NMP-EO3 GIFTS and use as an important temporal precipitation interpolator within the Global Precipitation Mission (GPM) constellation.

REFERENCES

[1] Staelin D H and P W Rosenkranz, editors, 1978 "Applications Review Panel High resolution passive microwave satellites" *Report for NASA Contract NAS5-23677*, MIT Research Laboratory of Electronics.

[2] Chedin A, D Pick and R Rizzi, 1985. "Definition study and impact analysis of a microwave radiometer on a geostationary spacecraft" *ESA Report* dated March 1985, pp 58.

[3] Gasiewski, A J, 1992 "Numerical Sensitivity Analysis of Passive EHF and SMMW Channels to Tropospheric Water Vapor, Clouds and Precipitation" *IEEE Trans Geosci Remote Sensing*, vol 30, no 5, p 859-870

[4] Staelin D H., J P Kerekes and F J Solman III, 1997 "Final Report of the Geosynchronous Microwave Sounder Working Group" *Prepared for the NOAA/NESDIS GOES Program Office*, MIT, Lexington Mass, pp 51

[5] Staelin D H., A.J Gasiewski, J P Kerekes, M.W. Shields and F J Solman III, 1998. "Concept proposal for a Geostationary Microwave (GEM) Observatory" *Prepared for the NASA/NOAA Advanced Geostationary Sensor (AGS) Program*, MIT, Lexington Mass, pp 23

[6] Bizzarri B, 2000 "MW/Sub-mm sounding from geostationary orbit" Report to EUMETSAT Science W G, EUM/STG/SWG/9/00/DOC/11, pp 11

[7] Klein M. and A.J Gasiewski, 2000 "The Sensitivity of Millimeter and Sub-millimeter Frequencies to Atmospheric Temperature and Water Vapor Variations" *J Geophys. Res, Atmospheres*, vol. 13, p 17481-17511

[8] Blackwell W J. and D H Staelin, 1996. "Comparative performance analyses of passive microwave systems for tropospheric sounding of temperature and water vapor profiles" *Goes-8 and Beyond, Denver Co, August 7-9 1996 - SPIE Proceedings Series*, vol 2812, p 472-478

[9] Gasiewski A J, D M. Jackson, J R Wang, P E. Racette and D S. Zacharias. 1994 "Airborne imaging of tropospheric emission at millimeter and submillimeter wavelengths" *Proc of the International Geoscience and Remote Sensing Symposium*. Pasadena, Ca, August 8-12, 1994, p 663-665

[10] Staelin, D H and F W Chen, 2000 "Precipitation Observation near 54 and 183 GHz using the NOAA 15 Satellite" *IEEE Trans Geoscience Remote Sensing*, vol 38, no 5, p 2322-2332

[11] Tsou J J, W L Smith, P W Rosenkranz, G M Heymsfiels, W J Blackwell and M J Schwartz, 2001 "Precipitation Study Using Millimeter-wave Temperature Sounding channels" *Specialist Meeting on Microwave Remote Sensing*, Boulder, CO, November 2001

[12] Gasiewski, A J and D H Staelin, 1990 "Numerical Analysis of Passive Microwave O_2 Observations Over Precipitation," *Radio Science*, vol 25, no 3, pp 217-235

A Wideband Microwave Airborne Imaging System for Hydrological Studies

M. Klein[1], A.J. Gasiewski[2], V. Irisov[3], V. Leuskiy[1], A.Yevgrafov[1]

[1] CIRES, University of Colorado/NOAA Environmental Technology Laboratory, R/E/ET1, 325 Broadway, Boulder, CO 80305, e-mail. Marian.Klein@noaa.gov, tel: +1 303 497-6418, fax· +1 303 497-3577, e-mail. Aleksandr.Yevgrafov@noaa.gov, tel +1 303 497-7075, e-mail Vladimir.Leuskiy@noaa.gov, tel +1 303 497-6937

[2] NOAA Environmental Technology Laboratory, R/E/ET1, 325 Broadway, Boulder, CO 80305, e-mail: Al.Gasiewski@noaa.gov, tel· + 303 497-7275, fax· + 303 497-3577

[3] Zel Technologies, Boulder, CO USA, e-mail Vladimir.Irisov@noaa.gov, tel. +1 303 497-6549, fax +1 303 497-3577

Abstract - The development of the NOAA Polarimetric Scanning Radiometer (PSR) system commenced in the fall of 1995, with the first-generation system operated on the NASA P-3B aircraft to study passive microwave ocean surface wind signatures in March, 1997 [1]. The PSR system consist of sets of polarimetric radiometers housed within standardized gimbal-mounted scanhead drums. Each scanhead is rotatable by a gimbaled positioner so that the radiometers can view any angle within 70° elevation of nadir and at any azimuthal angle (1.32π sr solid angle), as well as external hot and ambient calibration targets. The configuration supports conical, cross-track, along-track, fixed-angle stare, and spotlight scan modes. Scanheads are designed for in-flight operation without the need for a radome (i.e., in contact with the aircraft slipstream), thus allowing precise calibration and imaging without superimposed radome signatures. The conical scan mode allows the full Stokes' vector to be imaged without polarization mixing.

The PSR has been used in several successful airborne missions, demonstrating the first 2-dimensional ocean surface wind vector mapping, high-resolution hurricane rainband imaging and satellite rainfall rate validation, C-band soil moisture imaging, high-resolution sea-ice mapping, and ocean internal wave imaging. Since its inaugural mission there have been several new hardware developments that have extended the capability of the PSR system in terms of the observable spectrum, polarizations, and compatibility with various aircraft. Currently in progress are developments which will provide the capability to perform wideband airborne hydrological studies with a single suite of synchronized, compatible sensor heads. This suite will include the PSR/CX, PSR/S, and PSR/L scanheads, which collectively extend the capabilities of the original PSR/A scanhead. Four positioners are anticipated to be available for operation in 2003. Each assembly (scanhead and positioner) was designed for integration into several aircraft, including the NASA DC-8, Orion P-3B, and WB-57F, Scaled Composites' Proteus, Airplatforms, Inc. Canberra B-6, U.S. Navy P-3A, and NASA ER-2. Upon completion, the PSR system will provide passive polarimetric microwave imagery at most of the channels in the range of 1.4 to ~800 GHz that are useful for spaceborne or airborne hydrological remote sensing. Studies planned using the system include vapor-to-runoff phase monitoring of precipitation, estuarian runoff and mixing, targeted forecasting, and cirrus generation by convection.

I SYSTEM DESCRIPTION

The PSR system consists of three major components a scanhead, positioner, and equipment rack. Figure 1 illustrates the positioner and PSR/CX scanhead as integrated into the NASA WB-57F high-altitude aircraft. The scanhead houses all radiometer hardware and supporting electronics, including the data acquistion computer The positioner serves to move and point the scanhead. The scanning drum can be positioned to view any angle with 0 1° precision using a two-axis high-torque stepper motor positioner system The positioner also houses external blackbody calibration targets, one at ambient temperature and one heated to a higher preset temperature The equipment rack contains data acquisition, archival, and motion control systems and is typically located within the aircraft cabin. Three new positioners being built at NOAA

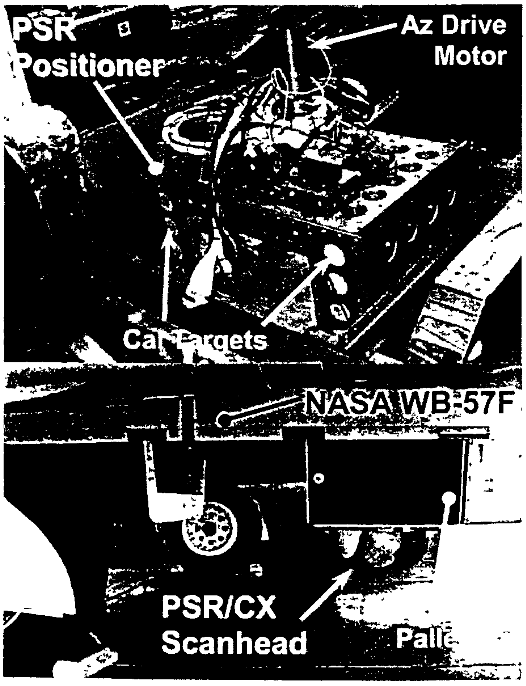


Figure 1. PSR positioner and scanhead as installed on the NASA WB-57F

ETL will have the supporting electronics installed on the top of each positioner. In this scheme the interface to the operator is implemented using an ethernet connection to a notebook PC running a web-based control program.

The typical weight of a PSR scanhead is ~70 kg (~150 lbs). The weight of a scanhead/positioner unit depends on the positioner version and the specific design of the calibration targets, but typically does not exceed ~340 kg (750 lbs)

A PSR Radiometers Two interchangeable scanheads, PSR/A and PSR/CX, are currently operational. The precise radiometric bands for PSR/A are X (10.6-10 8 GHz), Ku (18.6-18.8 and 21.3-21.6 GHz), Ka (36-38 GHz), and W (86-92 GHz). These bands were selected to provide sensitivity to clouds, precipitation, and surface features over almost one decade of microwave bandwidth at octave intervals. The current PSR/A scanhead uses analog correlators, although digital correlators were demonstrated in the first version of this scanhead (PSR/D, see [1]). In addition, a color CCD video camera and 9.6-11.5 μm wavelength infrared sensor are installed. The camera is used to observe the scene for purposes of cloud clearing, ocean foam coverage estimation, surface feature detection, and scanhead operation. PSR/A is currently maintained by ETL as a complete and operational scanhead.

The second PSR scanhead (denoted "PSR/CX," for its implementation of C and X-band channels) consists of polarimetric sub-band radiometers at C- and X-bands. The C-band radiometer provides polarimetric measurements within four adjacent subbands at 5.80-6.20, 6.30-6.70, 6.75-7.10, and 7 15-7 50 GHz, with full Stokes' vector measurements at 6.75-7 10 GHz. The X-band radiometer uses the same antenna as the C-band unit and has subbands at 10.60-10.80, 10.60-10 68, 10.68-10.70, and 10.70-10 80 GHz. Applications of PSR/CX include ocean surface emissivity studies, soil moisture mapping, and imaging of heavy precipitation. The multiband capability of PSR/CX is also used to study the feasibility of frequency agile radiometry for use over interference prone regions. A color CCD video camera and IR sensor are included.

All PSR antennas are of the lens/corrugated feedhorn type and are dual orthogonal-linear polarized with grooved rexolite lenses. All main beam efficiencies are in the 95-97% range and all on-axis cross-polarization isolation ratios exceed -27 dB.

Each PSR scanhead contains an embedded data acquisition computer, all radiometers and detectors, power conditioning modules, and antennas inside a 51 cm (20") diameter and 51 cm (20") long rotating drum. Radiometric data are sampled and formatted by the embedded computer, then transmitted to an archival computer outside of the scanhead via a 10-base 2 LAN link through the sliprings. Thus, all radiometric detection is accomplished inside the scanhead drum

Currently under development are two additional PSR scanheads: the PSR/S "Sounding/Sub-millimeter wavelength" scanhead and the PSR/L L-band imaging scanhead Descriptions of each of these new scanheads are available at http://www1.etl.noaa.gov/radiom/psr.html

B Calibration. In-flight calibration of all PSR radiometer is accomplished using a three-stage process employing radiometric views of i) noise diodes or internal thermal standards at ~100 msec intervals, ii) external (unpolarized) hot and ambient blackbody targets at intervals of approximately several minutes, and iii) upward-looking views of cold space performed approximately once per sortie

Internal noise diodes are available for all PSR channels up to 89 GHz (above which - for PSR/S - stable free-space thermal standards are being developed). Frequent views of these stable internal references permit identification of time-varying radiometer gains and offsets. These references, however, are not considered good absolute standards, and are further referenced to the external standards to determine their radiometric temperatures.

The unpolarized external targets consist of identical arrays of iron-epoxy absorbing pyramids installed in a two-bounce L-shaped corner configuration. The absorbing pyramids are canted at an angle of 45° so as to provide maximum absorption in the direction of PSR antennas. The pyramidal arrays are encased in transparent insulating foam and overlie a thermally-conducting substrate of aluminum pyramids so that the physical temperature of the entire structure remains homogeneous to within ~1 K. The microwave emission temperature of the structure is precisely calculable through 8-fold redundant physical temperature measurements and target emissivity estimates obtained using cold space views.

The cold space views permit a comprehensive empirical estimation of the external target temperature, and include the effects of residual scattering, thermal gradients, and beam spillover. The cold space views are obtained using a steep roll of the aircraft. The procedure consists of pointing the PSR scanhead 65° above nadir to starboard, then rolling the aircraft up to 60° port for ~3-5 seconds. The procedure provides the radiometers an unobstructed view of cold space for which the brightness temperature is typically very cold (~3-40K, depending on altitude, humidity, and channel) and calculable to better than ~0 5-1 K uncertainty.

An additional ground-based pre- and post-flight calibration procedure using a fully polarized target is being developed to provide accurate 3rd and 4th Stokes parameter calibration of all PSR polarimetric radiometers

II PSR MISSIONS

To date, the PSR has flown for over 430 flight hours on three different aircraft (NASA P-3B, DC-8, and NAWC P-3A). A list of missions is provided in Table 1. A versatile bomb bay fairing and support structure for the P-3 integration has been developed and successfully flown for the two P-3 integrations. Hardware for integration of the PSR on the NASA WB-57F has recently been completed, and similar hardware for integration on Proteus, the ER-2, and a Canberra B-6 is under design. An aerodynamic fence has been fabricated for the DC-8 integration Fabrication of hardware to permit two PSRs to operate synchronously on the P-3Bs and WB-57F is underway. During the entire series of flights the PSR exhibited excellent aerodynamic, mechanical, and electrical performance in ambient conditions as cold as -51° C and at true air speeds up to 400 knots.

The precise configuration of the PSR system for a given mission depends on the specific scientific goals These goals impact the selection of scanheads, platform, accompanying instruments, and aircraft altitude and airspeed.

TABLE I - PSR MISSIONS

Mission	Dates	Approximate Airtime (hrs)	Aircraft & Scanhead
Ocean Winds Imaging Experiment (OWI '97)	March 1997	40	NASA/WFF P-3B PSR/D
Hurricane Winds Experiment (HOWEX)	August 1997	25	NASA/WFF P-3B PSR/D
Over-the-Horizon Experiment (OTH '97)	November 1997	20	NASA/WFF P-3B PSR/D
Third Convection and Moisture Experiment (CAMEX-3)	August-September 1998	80	NASA/DC-8 PSR/A
North American Polar Scanning Radiometer Experiment (NAPSCAR98)	October-November 1998	40	NASA/DC-8 PSR/A
Southern Great Plains Experiment (SGP99)	July 1999	40	NASA/WFF P-3B PSR/C
North American Polar Scanning Radiometer Experiment (NAPSCAR00)	May 2000	50	NAWC P-3A PSR/A
Meltpond 2000	June-July 2000	40	NAWC P-3A PSR/A & PSR/C
North American Polar Scanning Radiometer Experiment (NAPSCAR01)	July-August 2001	35	NAWC P-3A PSR/A
Cold Land Processes Experiment (CLPX02)	February 2002	60	NASA/DC-8 PSR/A
Total		**430**	

For example, to study the potential for retrieving ocean surface wind fields by passive microwave radiometry the PSR was flown at medium-to-low altitude on the NASA P-3 over the Labrador Sea as part of the 1997 Ocean Winds Imaging Experiment. This study demonstrated that one and two-dimensional ocean surface wind fields could be retrieved using passive polarimetric microwave imagery of the ocean surface, and illustrated the robustness of polarimetric measurements of the surface state in the presence of clouds (Figure 2) [1]. The use of digital correlators along with appropriate calibration techniques for polarimetric measurements was also demonstrated [2], and a wideband surface emission harmonic model was developed. The PSR model both corroborated and extended one proposed earlier by Wentz (see [1]) that was obtained earlier using SSM/I data The results of this study have been used to support the further development of passive microwave wind vector retrieval for the U.S. NPOESS.

Validation of TRMM rain rate retrievals was performed using PSR/A data obtained from the NASA DC-8 during the Third Convection and Moisture Experiment (CAMEX-3). High-resolution PSR/A rain rate retrievals based on a 10.7-GHz emission algorithm compared favorably to coincident data from the JPL ARMAR Ku-band rain radar and the TRMM Microwave Imager (TMI) level 2A12 rain rate product [3] The intercomparison revealed the greatest discrepancies at rain cell edges where the relatively large footprint of the TMI could be expected to produce beam-filling errors in the retrieved rain rate. The study illustrates the potential use of PSR to validate rain rate maps from the DMSP SSMIS and NPOESS CMIS instruments

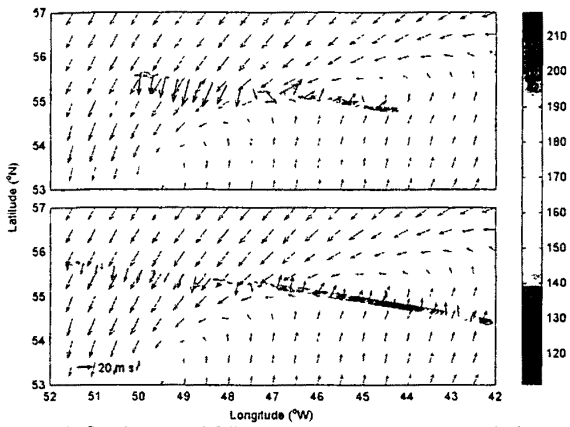


Figure 2. One-dimensional full-scan oceanic wind vector retrievals during two crossings of a cold cyclone centered in the Labrador Sea. Retrieved wind vectors are overlaid onto PSR and SSM/I 37H GHz brightness imagery (color scale) Blue arrows are wind data from the NOAA/NCEP ETA analysis, and the two orange arrows are dropsonde surface winds Tight cyclonic rotation of retrieved and model wind fields is revealed.

The PSR/C scanhead was initially developed to determine the impact of vegetation on C-band mapping of soil moisture (SM), for example, using AMSR-E or CMIS. Although SM is more directly measurable using L-band, the high cost of implementing a viable L-band aperture in space warrants the use of smaller C-band apertures. The PSR/C was first operated during the 1999 Southern Great Plains Experiment (SGP99), providing the first high-resolution (~2.3 km) C-band SM maps under conditions of low vegetation biomass. (Figure 3). The SM algorithm developed from the PSR aircraft data suggested that C-band will be useful for SM retrievals under such conditions. The relatively small footprint size provided watershed-scale spatial resolution that revealed a range of drydown rates within the SGP99 region of interest (central Oklahoma). The experiment also offered the first opportunity to demonstrate anthropogenic RFI interference mitigation using a radiometric a sub-band technique [5].

Snowpack emissivity in cold land regions can vary considerably depending on the initial properties and melt history of the snow crystals. The wide variation in emissivity compromises the interpretation of satellite microwave imagery for snowpack estimation The NASA Cold Lands Processes Experiment in 2002 (CLPX02) was designed to study remote measurement of snowpack within three intensive study areas in the Rocky Mountains of Colorado The PSR/A instrument was used on the NASA DC-8 during CLPX02 to image snowpack emission with ~180 meters spatial resolution at 89 GHz and ~600 meters resolution at 10.7 GHz. Large brightness temperature drops (of up to ~100K at 89 GHz and horizontal polarization) were observed after fresh snowfalls (Figure 4) over kilometer scale regions. The high resolution of the PSR was required to provide unambiguous registration of observed snowfield emission with snow parameters obtained through surface sampling. The results of CLPX02 will be used to support satellite-based snow cover depth retrieval algorithm development.

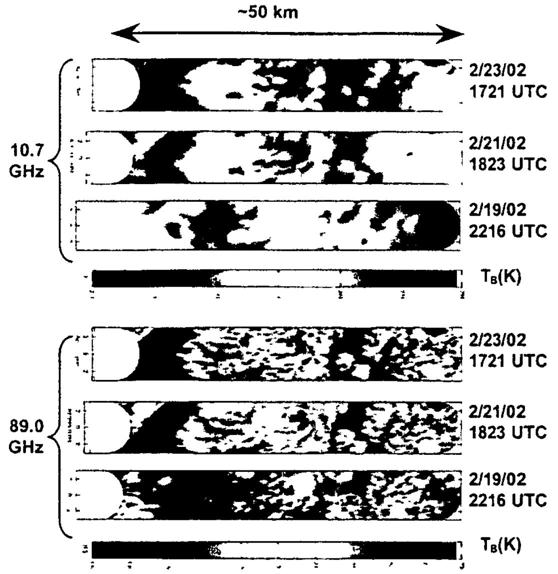


Figure 4. PSR/A 10 7 and 89 GHz images of surface emission from snowpack in the Rocky Mountains on three days during the CLPX02 The spatial resolution is ~600 m and ~180 m, respectively Strong surface scattering - as revealed by cold brightness temperatures - was observed after fresh snowfall, as occurred between 2/19/02 and 2/21/02

Further information on PSR data sets from the above missions can be found at http://www1 etl noaa.gov .

IV CONCLUSION

The PSR system provides a means of high-resolution imaging of several hydrological and related meteorological variables, including ocean surface winds, soil moisture, and cryospheric parameters This parameter list will be extended to include water vapor and temperature profiles, cloud water and ice content, and ocean/estuarian salinity upon completion of PSR/L and PSR/S The high spatial and temporal resolution available using this system is anticipated to facilitate detailed hydrological studies, targeted weather forecasting, and NPOESS and NASA satellite calibration and validation.

ACKNOWLEDGEMENTS

The authors acknowledge the invaluable assistance of many colleagues on the design, development, and operation of the PSR, including J. Baloun, J. Piepmeier, I. Corbella, A Francavilla, T. Jackson, J. Lahtinen, B. Patten, and L. Fedor. Support for the PSR development has been provided by the U.S. Office of Naval Research, NASA, NPOESS Integrated Program Office, USDA, NOAA/NESDIS, U S. DoD, and NOAA/OAR.

REFERENCES

[1] Piepmeier, J R, and A J Gasiewski, "High-Resolution Passive Microwave Polarimetric Mapping of Ocean Surface Wind Vector Fields," IEEE Trans Geosci Remote Sensing, vol 39, No 3, pp 606-622, March 2001

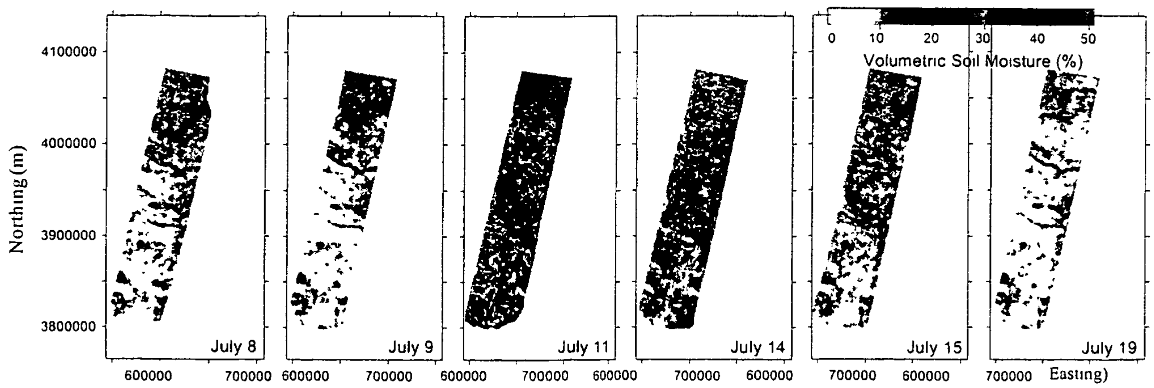
[2] Piepmeier, J R, and A.J Gasiewski, "Digital Correlation Microwave Polarimetry Analysis and Demonstration", IEEE Trans. Geosci. Remote Sensing, vol 39, No 11, pp 2392-2410, November 2001

[3] M. Klein, A J Gasiewski, I Corbella, A Evgrafov, V Leuskiy, "Rain Rate Retrieval Using Airborne Imaging Radiometry During CAMEX-3/TEFLUN-B", Proc of the IGARSS, Piscataway, NJ, IEEE, 2002

[4] Jackson, T J, A.J Gasiewski, A. Oldak, M Klein, E G Njoku, A Yevgrafov, S Christiani, and R Bindlish, "Soil Moisture Retrieval using the C-band Polarimetric Scanning Radiometer During the Southern Great Plains 1999 Experiment," accepted for publication in IEEE Trans Geosci Remote Sensing, February, 2002

[5] Gasiewski, A.J , M. Klein, A.Yevgrafov, and V Leuskiy, "Interference Mitigation in Passive Microwave Radiometry," *Proc of the IGARSS*, Piscataway, NJ, IEEE, 2002

Figure 3. PSR/C 7 3 GHz soil moisture maps retrieved during the 1999 Southern Great Plain Experiment (SGP99) [4]. The raw T_B maps show a ~60 K decrease in brightness for horizontal polarization after 1-2" rainfall The spatial resolution of ~2 km reveals watershed scale moisture features



授 權 書

（出 國 報 告 書）

本授權書所授權之出國報告書名稱：

赴加拿大參加國際遙測技術應用研討會出國報告

茲授予行政院國家科學委員會（含附屬機關）、行政院研究發展考核委員會及前述兩機關所指定之寄存圖書館，有權將上述出國報告書之摘要及全文資料，收錄於該單位之網路或光碟或紙本或微縮不限地域與時間予以發行，供相關學術研發目的之公開利用。

本授權內容無須訂立讓與及授權契約書。依本授權之發行權為非專屬性之發行權利。依本授權所為之收錄、重製、發行及學術研發利用均為無償。

共同授權人均請親筆簽名：

日期：民國九十一年七月三十一日

....

簽署人須知：

1. 依著作權法的規定，該單位以網路、光碟、紙本與微縮等方式整合國內學術資料，均須先得到您的書面授權。
2. 如果您已簽署專屬性的授權言於其他法人或自然人，請勿簽署本授權書。
3. 請將本授權書裝訂在每份出國報告書末頁。
4. 本案聯絡電話：02-7377746 科資中心 江守田、王淑貞。