

Misión SMOS de la Agencia Espacial Europea. Estimación del Contenido en Humedad del Suelo desde el Espacio

Ernesto López Baeza
&

Grupo de Climatología desde Satélites

Dept. Física de la Terra i Termodinàmica
Universitat de València



SMOS, la Misión de ESA sobre el Ciclo del Agua

Soil Moisture and Ocean Salinity



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CONFEDERACIÓN
HIDROGRÁFICA
DEL JÚCAR



Facultat de Física

Introducción

El Ciclo del Agua

Motivación

Impactos del Cambio Climático

Incertidumbres de los Modelos Numéricos

Contenido en Humedad del Suelo

Papel en el Ciclo Hidrológico

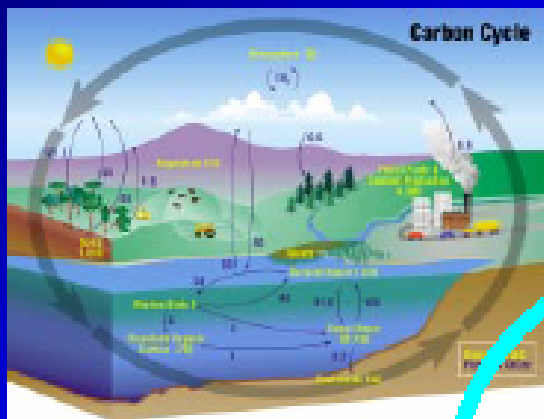
Su Medida con Teledetección . Microondas

Banda L

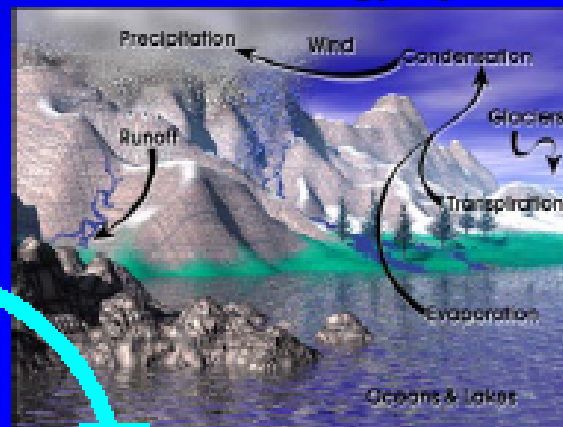
La Misión SMOS de la Agencia Espacial Europea

Major Climate System Elements

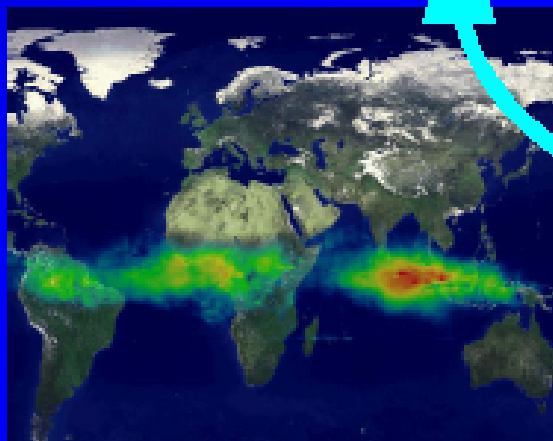
Carbon Cycle



Water & Energy Cycle

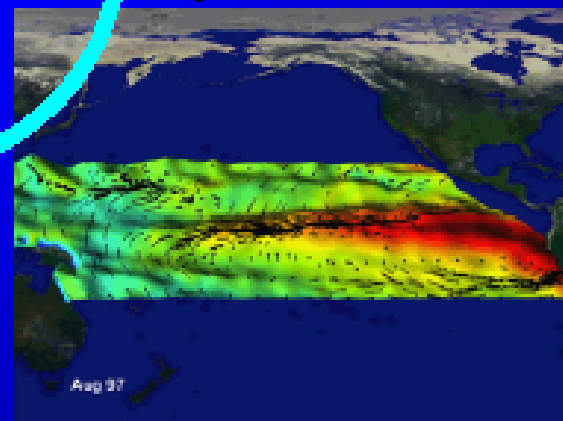


Atmospheric Chemistry



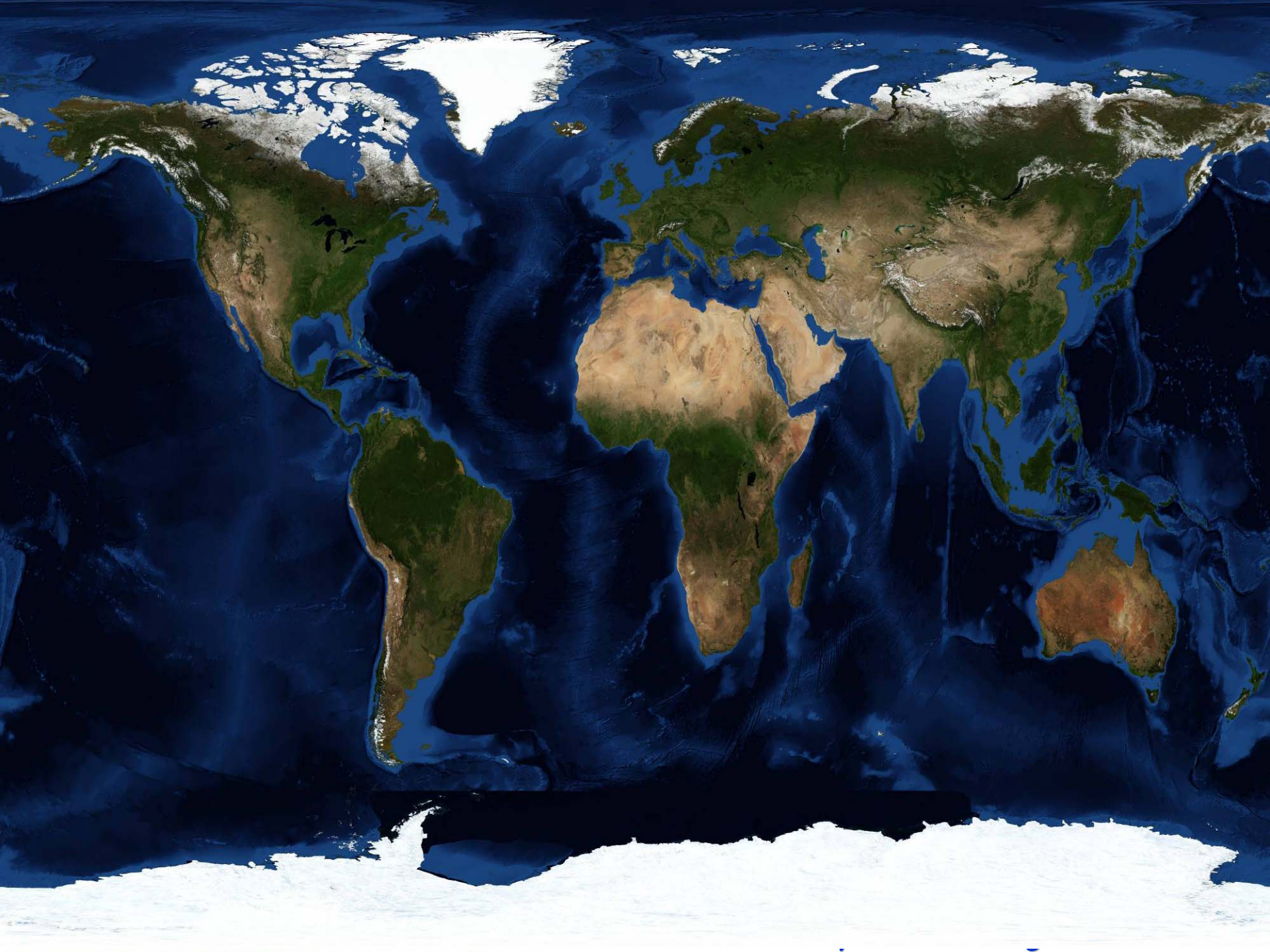
**Coupled
Chaotic
Nonlinear**

Atmosphere and Ocean Dynamics



El Planeta Azul





El agua puede almacenarse en:

- la atmósfera
- los océanos
- lagos
- ríos
- suelos
- glaciares
- campos de nieve
- subsuelo (acuíferos)



Hay evidencia de tendencias significativas en el Ciclo Global del Agua

La mayor parte del agua de la Tierra (**alrededor del 96.5%**) se almacena en los océanos globales,

alrededor del 1.7% se almacena en los casquetes polares de hielo, glaciares y campos permanentes de nieve,

y **otro 1.7%** se almacena en el subsuelo, lagos, ríos, arroyos y en el suelo.

Sólo una pequeñísima cantidad del agua del planeta está presente en la atmósfera, pero al ser el “*gas de efecto invernadero*” más importante, tiene una influencia muy fuerte en nuestro tiempo y nuestro clima.



**El 70% del planeta está cubierto de agua ...
pero sólo 2.5% de esa agua es dulce**

**El 70% del agua dulce está congelada en los
casquetes de hielo de la Antártida y de
Groenlandia**

**La mayor parte del resto está en forma de
humedad del suelo o en los acuíferos
profundos inaccesibles**

o aparece en monzones y riadas

**Menos del 0.08% del agua del mundo queda
por tanto disponible para uso humano directo ...**

**e incluso ésta está distribuida muy poco
equitativamente**

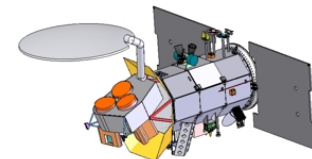




Ciclo Hidrológico

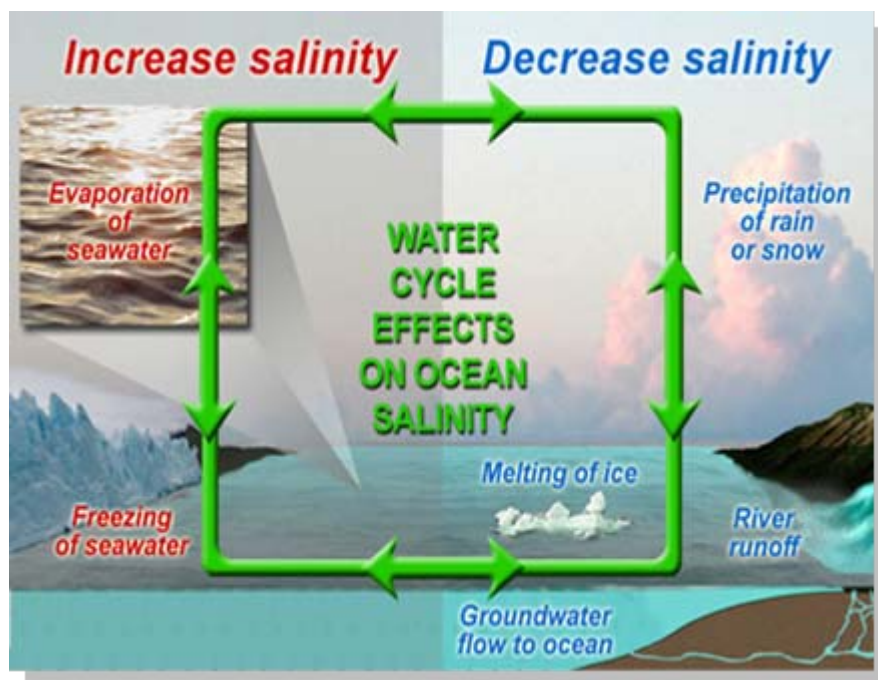
Salinidad del Océano

Contenido en Humedad del Suelo



Salinity links the climatic variations of the global water cycle and ocean circulation

- Salinity is required to determine seawater density, which in turn governs ocean circulation.
- Salinity variations are governed by freshwater fluxes due to precipitation, evaporation, runoff and the freezing and melting of ice.

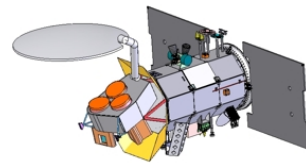


Air-Sea Water Flux accounts for

- 86% of global evaporation
- 78% of global precipitation

Importance

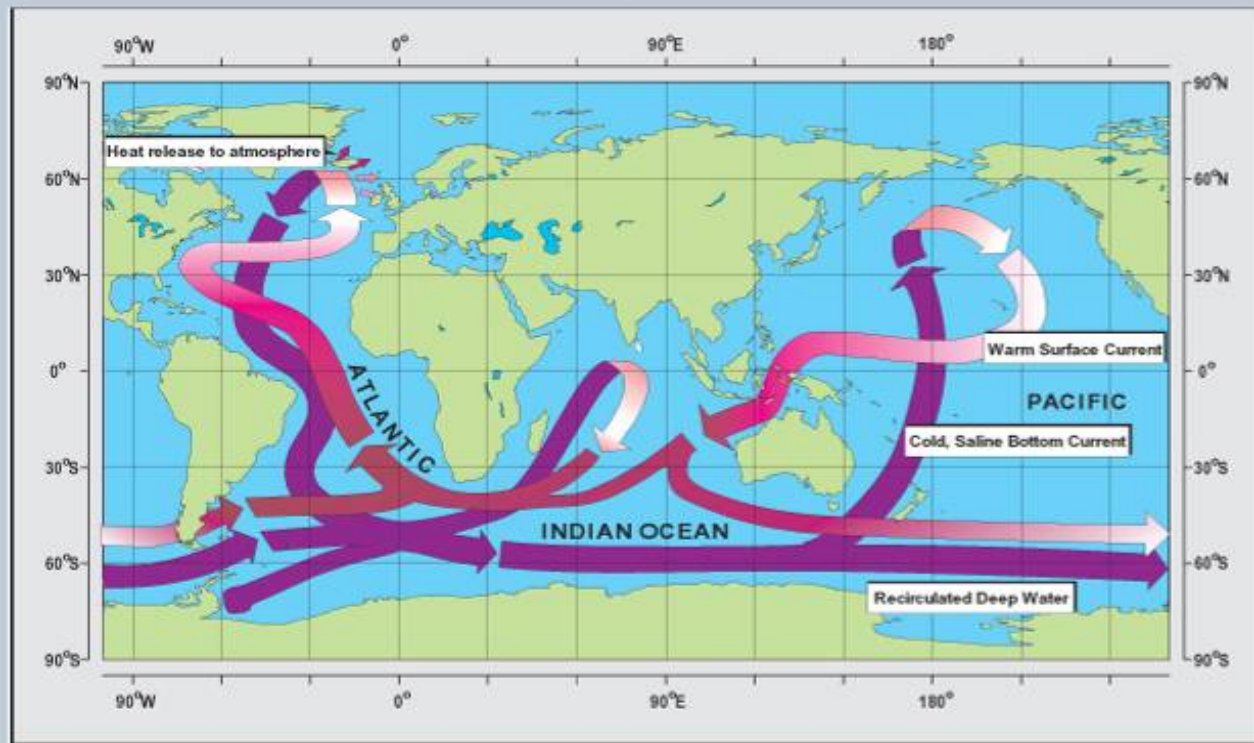
- Climate prediction
- El Niño forecasts
- Global Water budget



The ocean conveyor is sustained by elevated salinity in the Atlantic

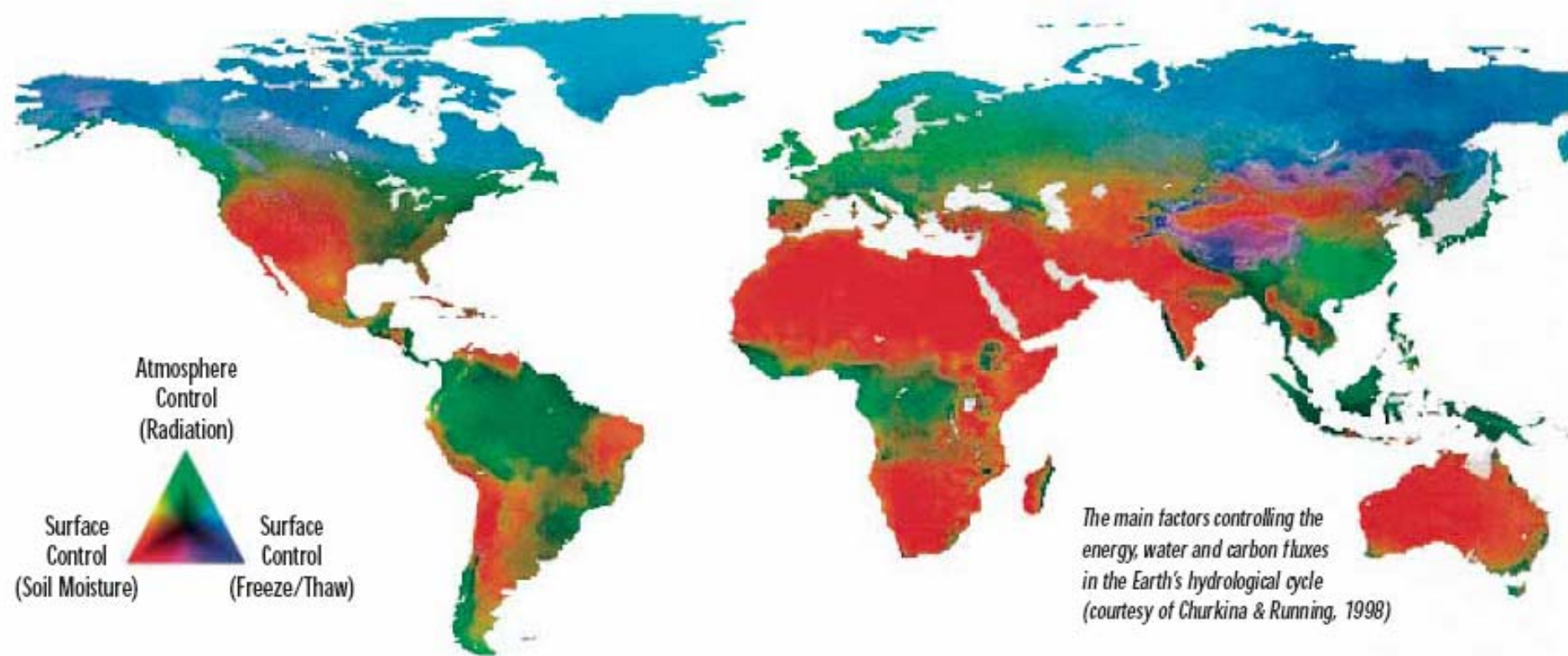
The Atlantic Thermohaline Circulation

- A key Element of the Global Oceanic Circulation -



Schematic diagram of the global ocean circulation pathways, the 'conveyor' belt (after W. Broecker, modified by E. Maier-Reimer).

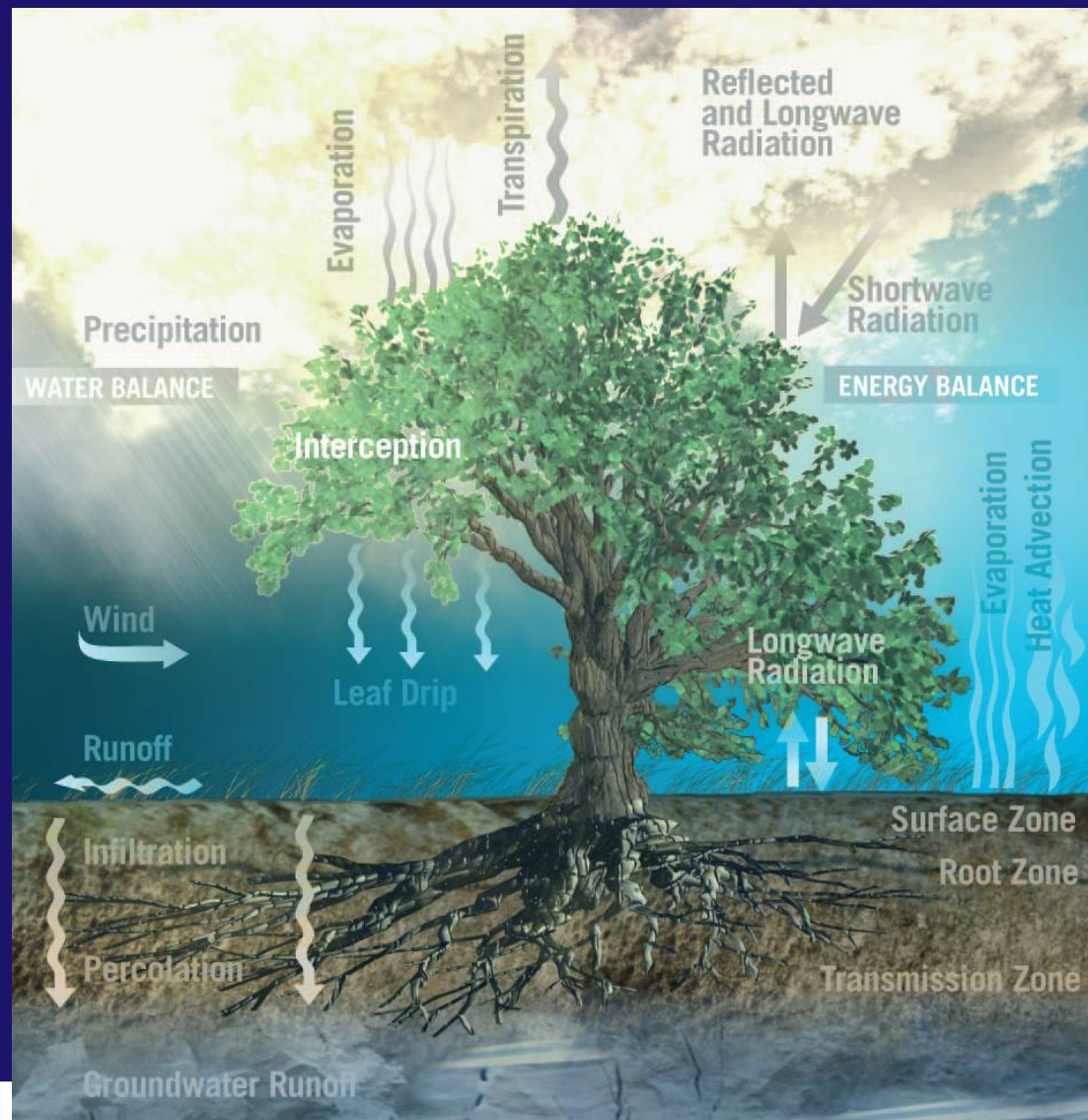
AV/D3/99-2



Energy and water balance of the physical climate system including the terrestrial and atmospheric components of the water cycle



In most parts of the world, the amount of water present in the soil is the dominant factor that affects plant growth. However, the retention of water in the soil is crucial not only to sustain primary production, but is also intrinsically linked to our weather and climate. This is because soil moisture is a key variable controlling the exchange of water and heat energy between the land and the atmosphere through evaporation and plant transpiration. As a result, soil moisture plays an important role in the development of weather patterns.



Motivación

Impactos del Cambio Climático

Incertidumbres de los Modelos Numéricos

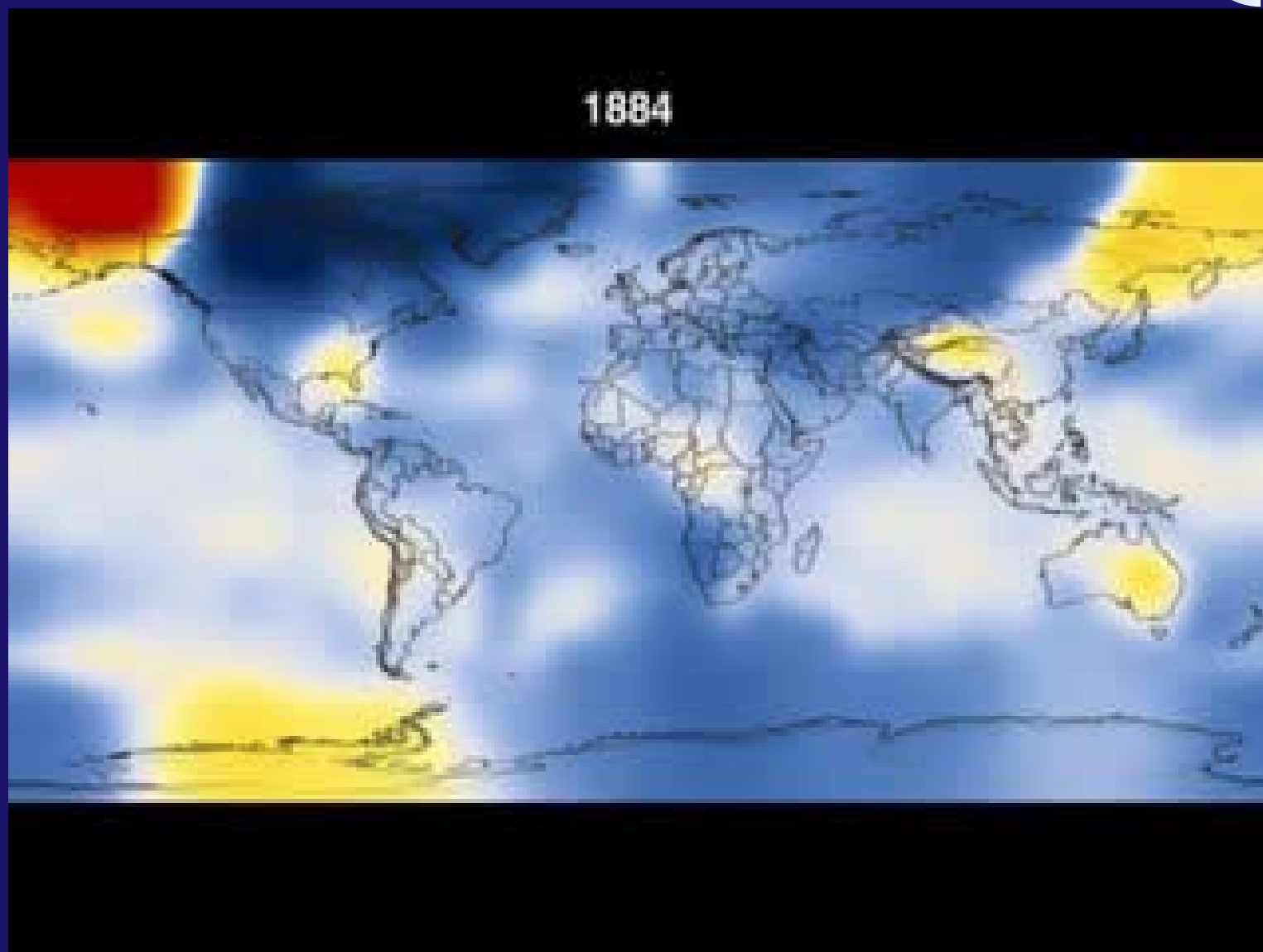


Figure SPM.3. Observed changes in

(a) global average surface temperature

(b) global average sea level from tide gauge (blue) and satellite (red) data and

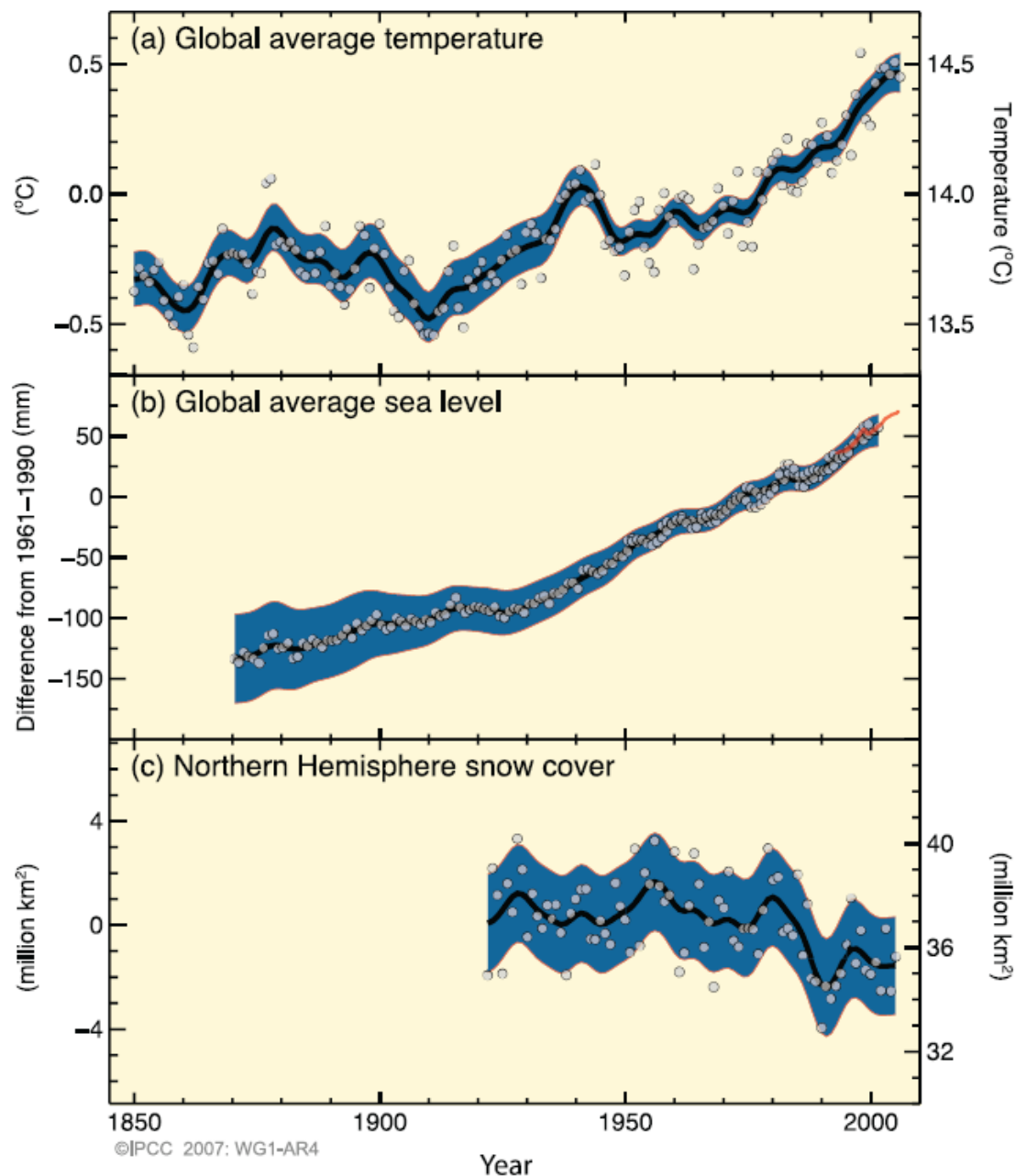
(c) Northern Hemisphere snow cover for March-April

All changes are relative to corresponding averages for the period 1961–1990.

Smoothed curves represent decadal average values while circles show yearly values.

The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c).

IPCC, 2007



Impacto Humano sobre el Ciclo Hidrológico

Principales procesos humanos que afectan el ciclo del agua sobre tierra:

- R = reserva de agua en los pantanos
- G = sobre-explotación de acuíferos
- I = regadíos
- U = urbanización
- C = combustión
- D = deforestación
- W = tierras húmedas

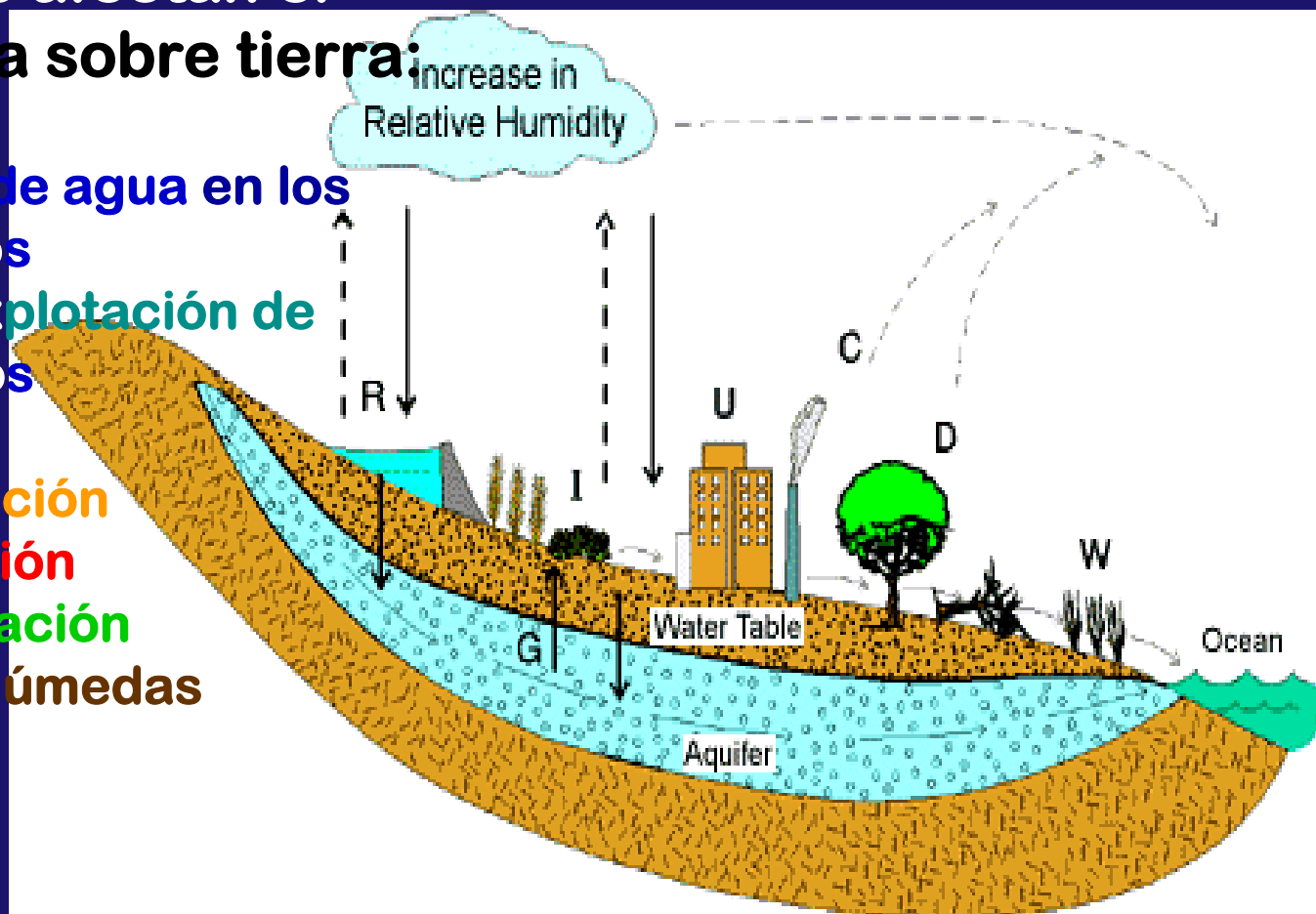


Figure 2: Illustration of the need for soil moisture measurements: Soil moisture fields obtained with three different models (GCM) for the same conditions. The analysis shows the discrepancies, highlighting the need for actual estimates of soil moisture (courtesy E. G. Njoku)

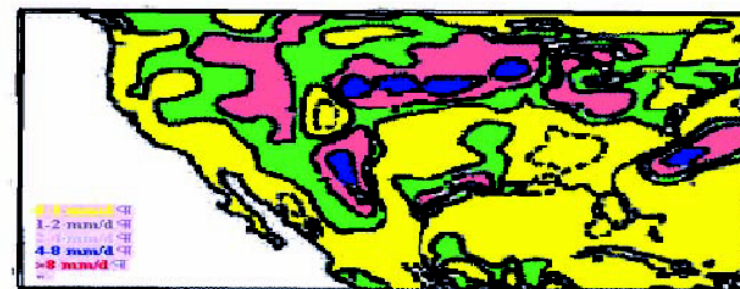
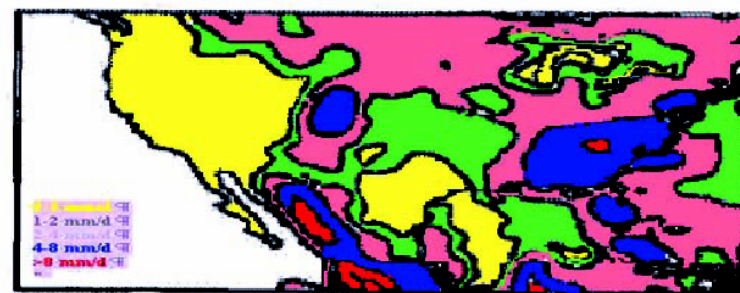
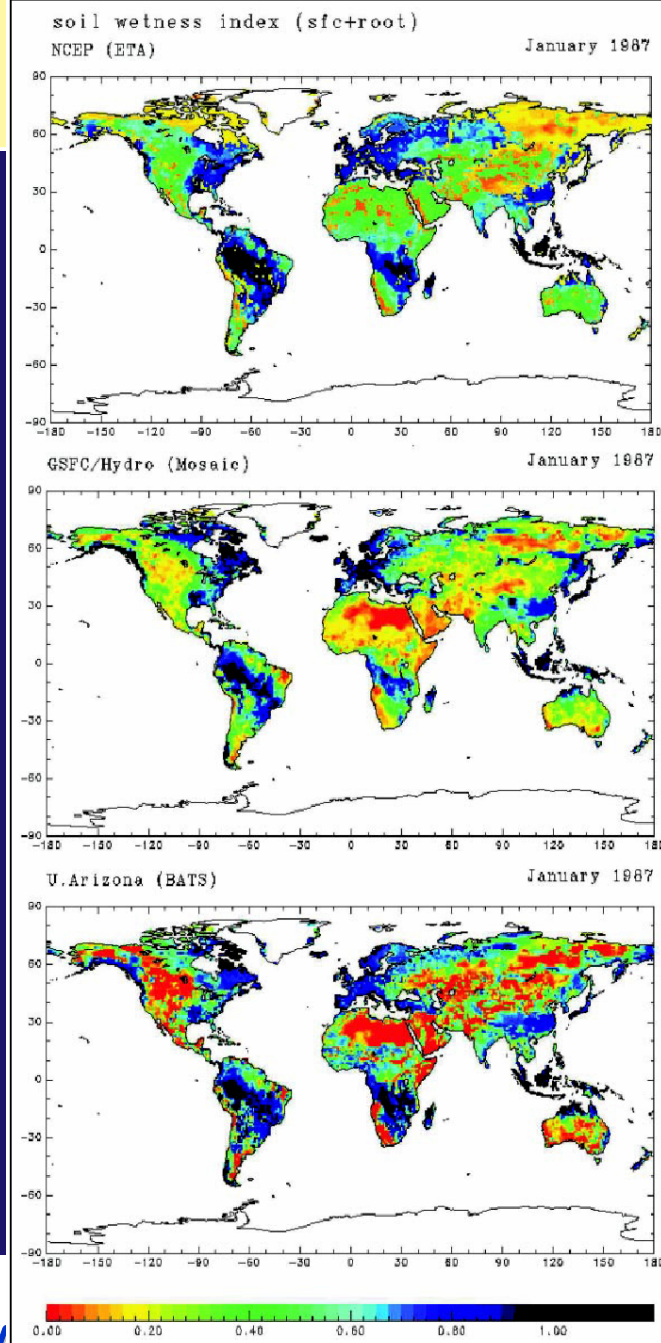


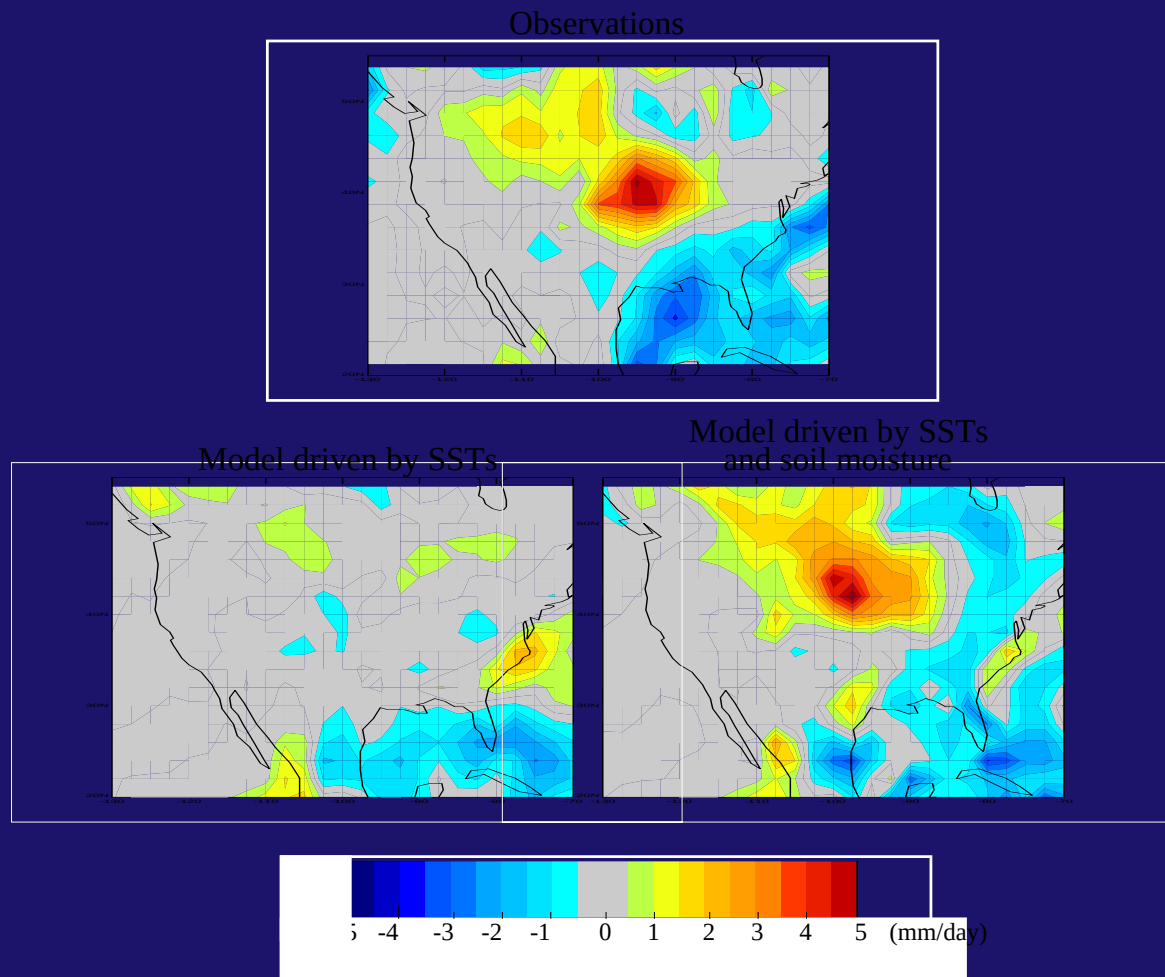
Figure 1: Impact of different soil moisture levels on the precipitation over North America (from [Beljaars et al., 1996]): Rainfall amounts obtained from two simulations with a wet and a dry surface. The difference between the two outputs is shown in the bottom map. This simulation shows the drastic impact of soil wetness on the predicted rainfall pattern.



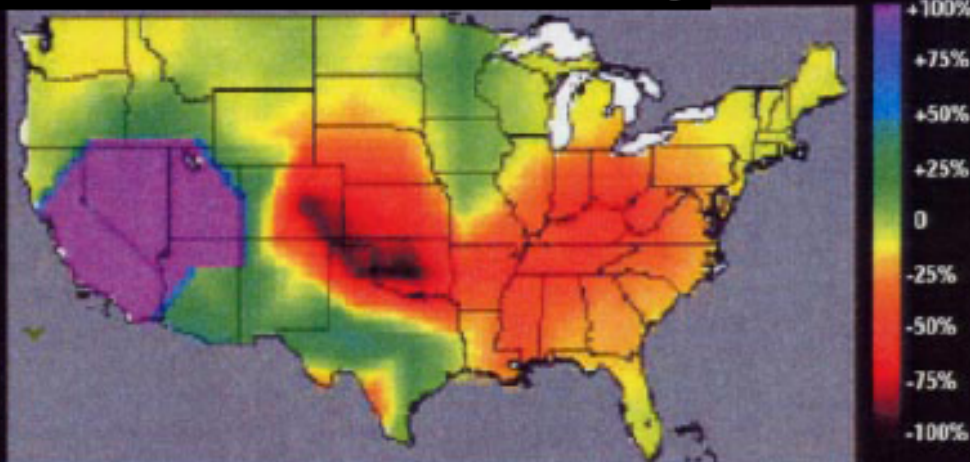
Entekhabi et al, 2001

- La predictibilidad del clima estacional depende de las condiciones en la superficie: temperatura superficial del mar (SST) y humedad del suelo (SM)...
- En este estudio de sensibilidad, se demuestra que la lluvia caída en una región durante verano depende más del contenido de humedad que de la SST en la superficie.

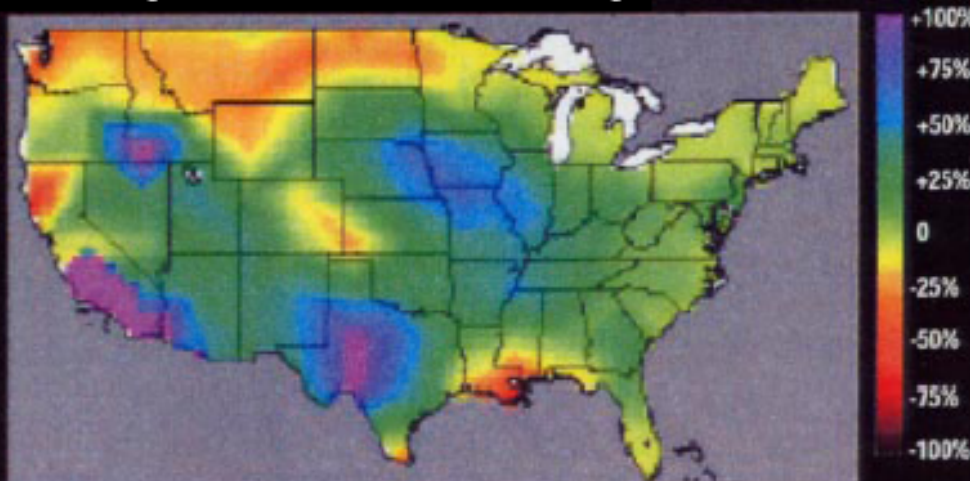
SUMMER 1993 RAINFALL MINUS SUMMER 1988 RAINFALL



Canadian Model 21st Century



Hadley Model 21st Century



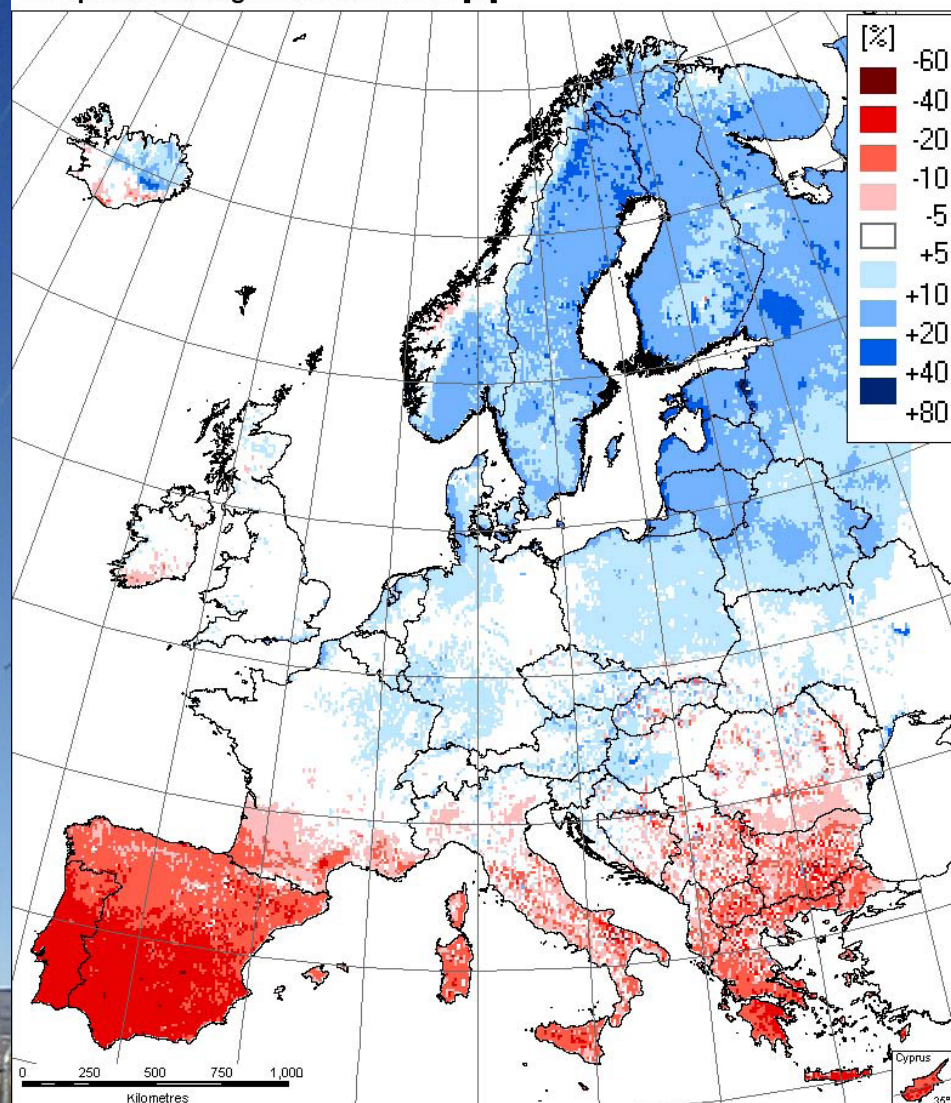
**U.S. summer
soil moisture
predictions:**

**A tale of
two climate
models...**

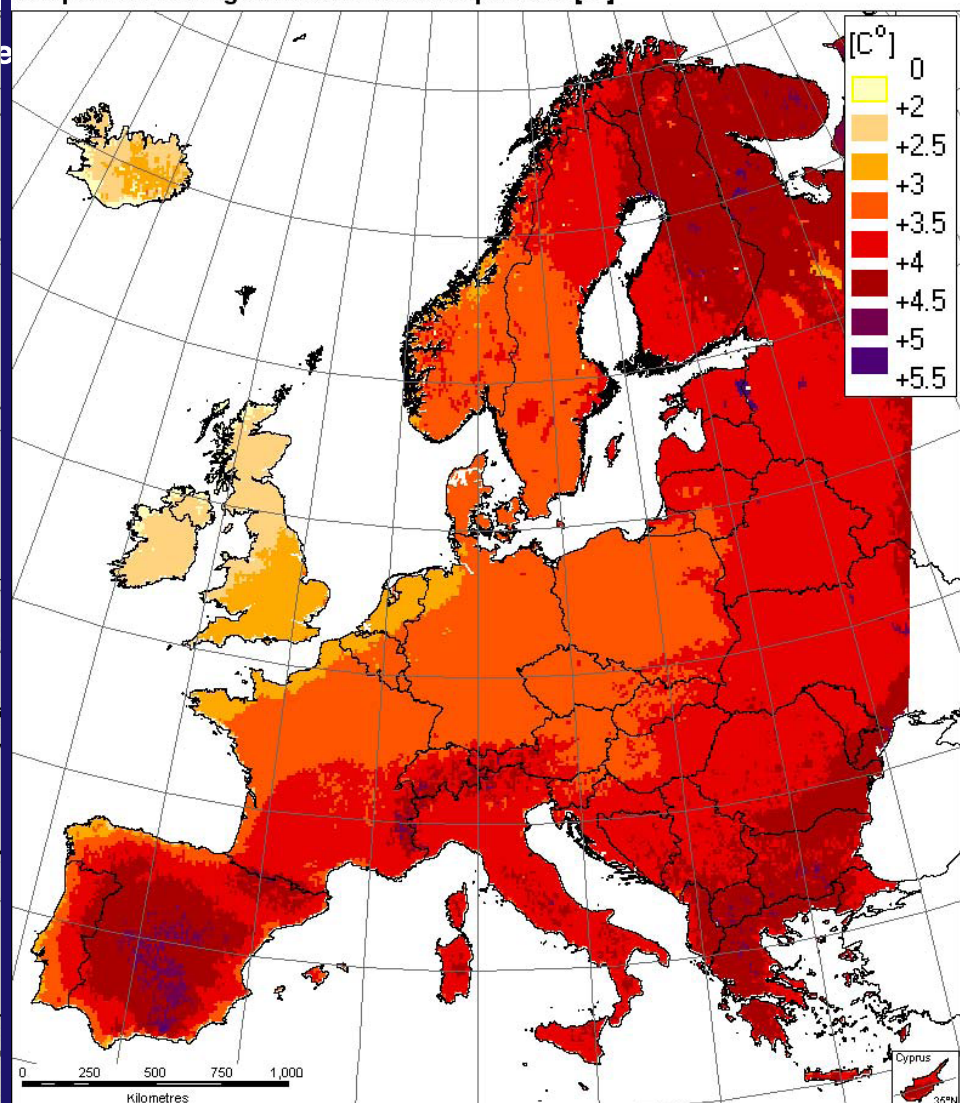
**...and of
large
regional
uncertainties.**

B. Willick's lecture

Precipitation: change in annual amount [%]

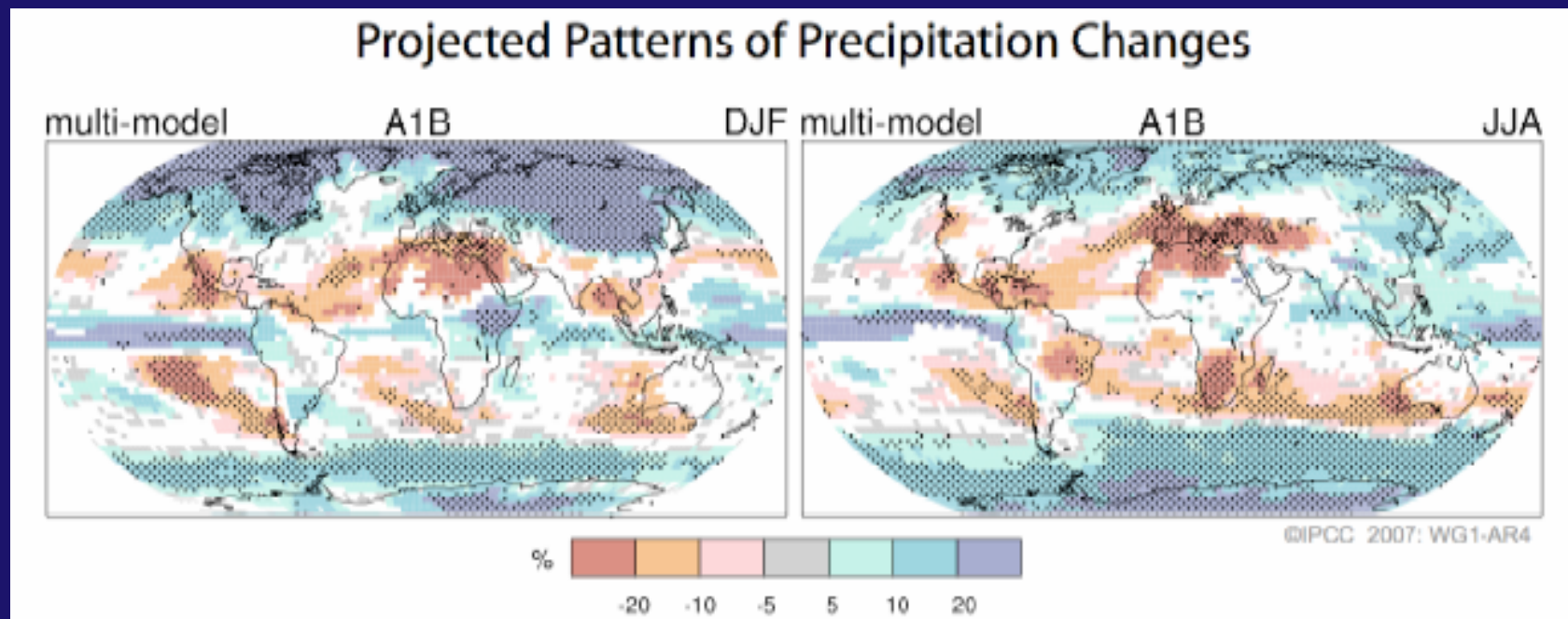


Temperature: change in mean annual temperature [C°]



These maps illustrate what can be expected in Europe by the end of the century, according to the [IPCC scenario \(SRES A2\)](#) whereby no action is taken to reduce greenhouse gas emissions, so that the global mean temperature increases by about 3.4°C by the 2080s compared to 1990 levels. Under this scenario, nearly all European regions are expected to be negatively affected and up to half of Europe's plant species could be vulnerable or threatened by 2080.

Cambios Proyectados en la Precipitación



Cambios relativos en la precipitación (%) para el periodo 2090–2099 con relación al periodo 1980–1999

Los valores corresponden a promedios de varios modelos basados en el escenario SRES A1B para Diciembre a Febrero (izda.) y Junio a Agosto (dcha.)

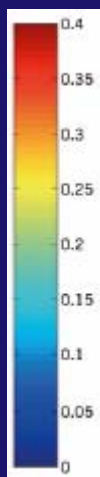
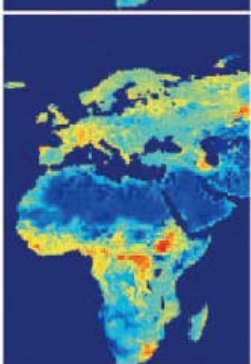
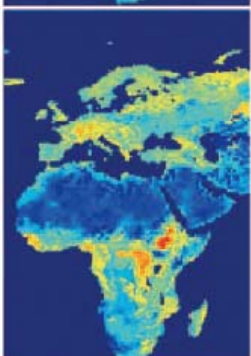
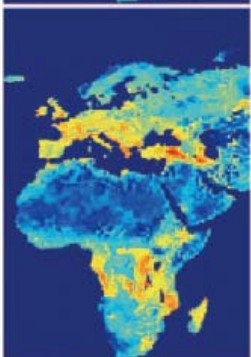
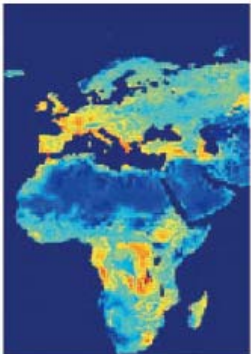
Las zonas en blanco representan un acuerdo entre los modelos inferior al 66% en el signo del cambio. Las zonas punteadas representan un acuerdo entre los modelos superior al 90% en el signo del cambio (IPCC, 2007)



C
S

ciés de la Facultat de Física

tivo Campus de Burjassot, 22 Novembre 2007



Simulated seasonal soil moisture maps (starting with winter at the top) of Europe and Africa. The units are in 'cubic metre of water per cubic metre of soil'. These soil moisture maps were simulated by means of a SVAT scheme using climatological data.

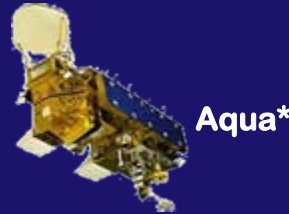


Hoy, los Satélites Proporcionan una Nueva Perspectiva Global del Ciclo del Agua

The Earth Observing System -- systematic measurement of interactions among land, oceans, atmosphere, ice & life

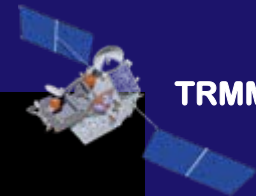


Landsat

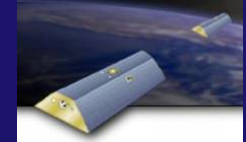


Aqua*

Exploratory missions to probe key Earth system processes globally for the first time



TRMM



GRACE*



Jason*



Terra



SORCE



ICESat^



SeaWiFS



CALIPSO



Cloudsat

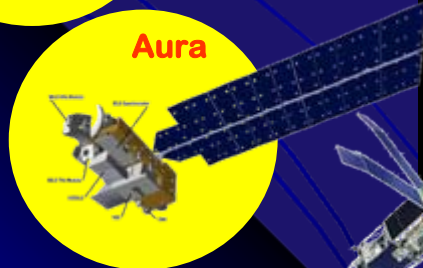


EO-3: GIFTS



EO-1: ALI & Hyperion

Operational precursor / Technology demos



Aura



NOAA/
GOES



NOAA/
POES*

Operational weather services missions for NOAA

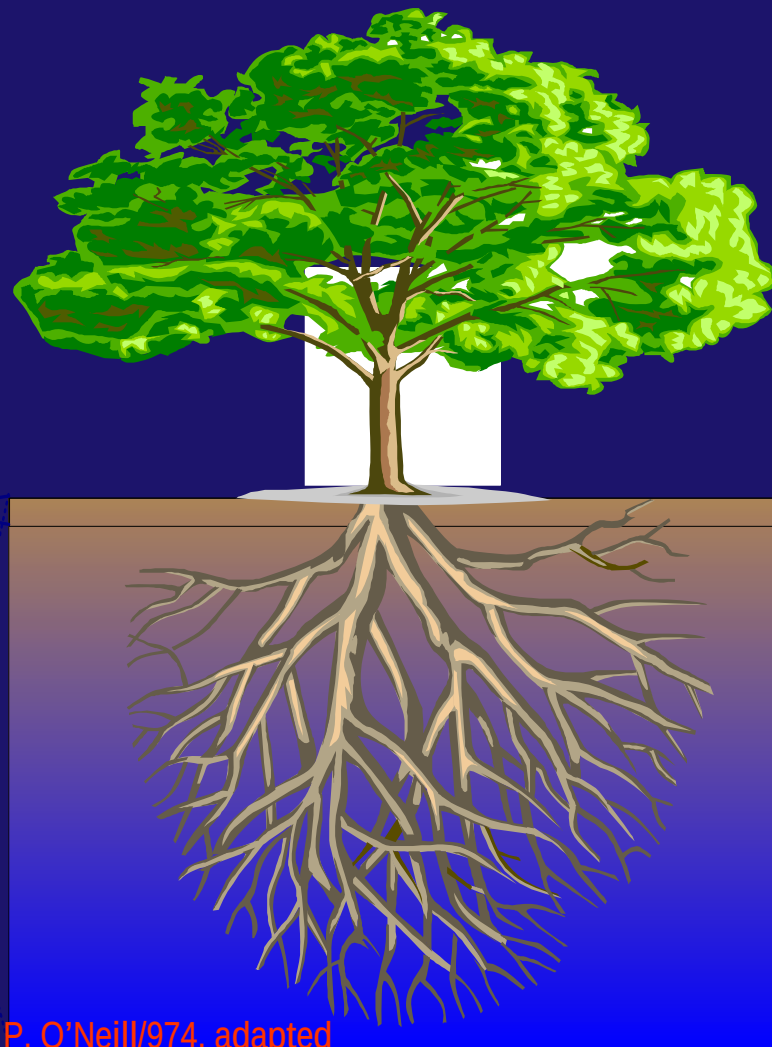
*FY02 launch (+ SAGE III)
^FY03 launch (+SeaWinds)

Contenido en Humedad del Suelo

Papel en el Ciclo Hidrológico
Su Medida con Teledetección
Microondas Banda L

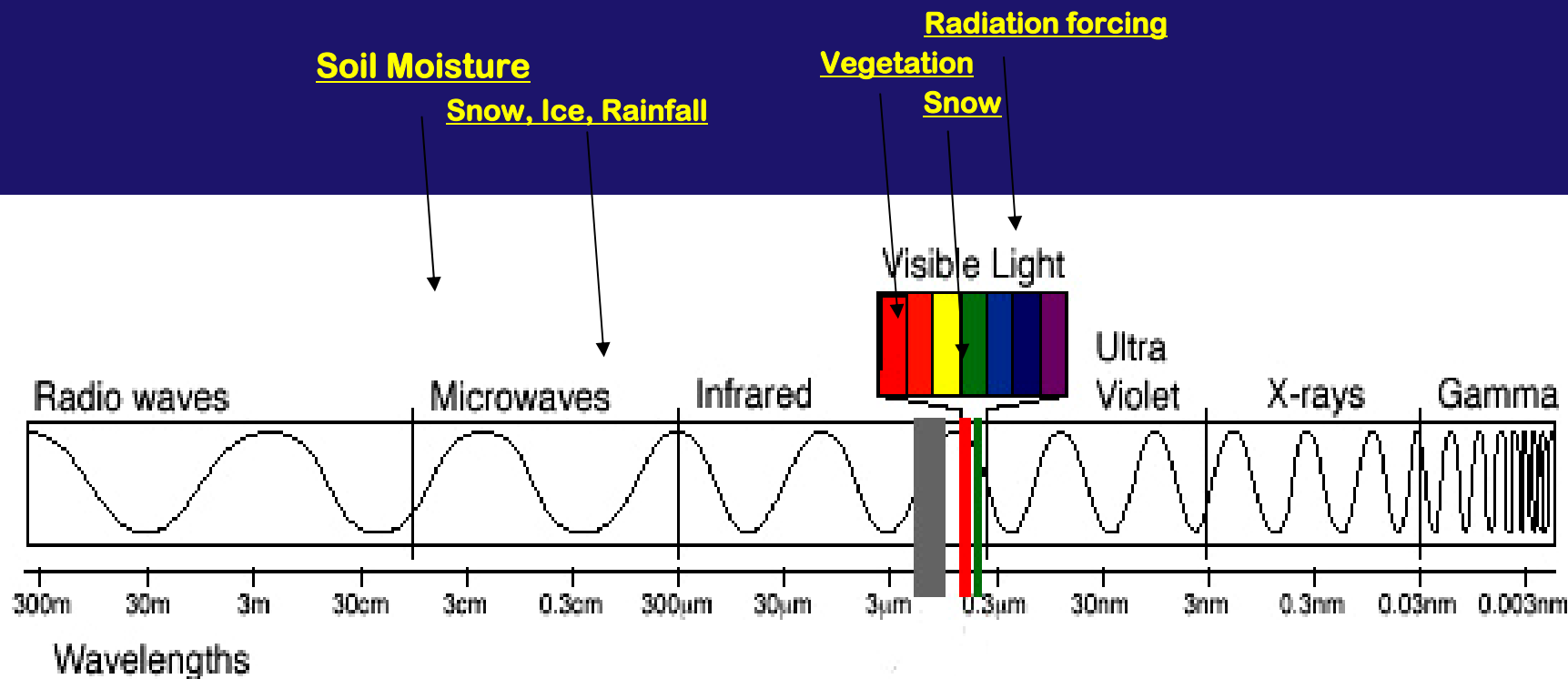
- SM is a **critical state variable in land surface hydrology** which impacts fluxes of water, energy, and carbon.
- **Accurate soil moisture information over a variety of space and time scales** is essential to improved climate prediction, numerical weather forecasting, natural hazards mitigation, and agricultural and water resources management.
- **Microwave remote sensing (primarily at low frequencies such as L-band)** is an important and effective tool for measuring soil moisture over large areas.
- **Over 20 years of modeling and field research in microwave remote sensing of SM** have produced **accurate retrieval algorithms at local and regional scales** which are also applicable to global space missions.
- Current efforts include the technology development activities for large antennas and radiometer instrument design which are necessary for enabling a high-resolution global soil moisture mapping mission in the near future.

Soil
Moisture
Stored
Water



P. Houser & P. O'Neill/974, adapted

¿Cómo se Hace Teledetección?



In order to measure changes on Earth, we “remotely sense” the radiant energy that is reflected and emitted from Earth at various “wavelengths” of the Electromagnetic Spectrum. Everything — from plants, to water, to clouds, to burning objects — reflects, emits, and absorbs radiant energy in unique and distinct ways. But our eyes are only sensitive to the “visible light” portion of the EM spectrum.

¿Cómo se puede medir la humedad del suelo?

- **Laboratorio**
 - Secado en el horno de muestras de suelo
 - Métodos químicos
- ***In situ***
 - Sondas de neutrones
 - Resistividad, capacidad
 - TDR
- **Teledetección**

Óptico/Infrarrojo (IR)

Solamente durante el día

Atenuado por nubes

No penetra la vegetación

Radar

Poco atenuado por nubes

Poca precisión

Alta resolución

Radiometría

Poco atenuado por nubes

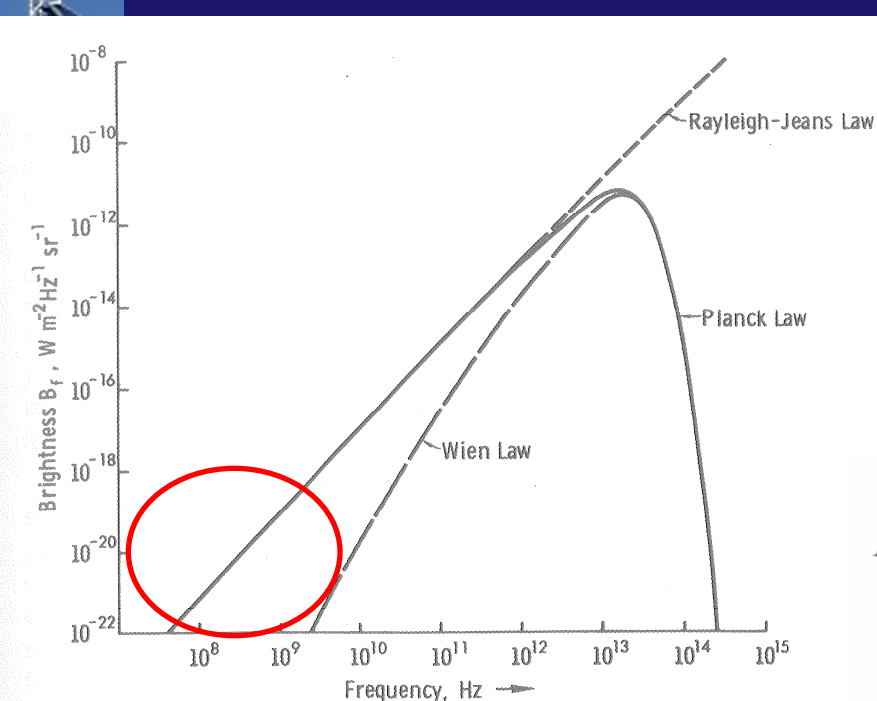
Alta precisión

Poca resolución

→ La teledetección por microondas abre un camino hacia el mapeado de la humedad superficial del suelo.

Concepto Básico de Radiometría

Emisión de un cuerpo negro ideal: ley de Planck.



En equilibrio térmico:

- Absorbe toda la energía recibida.
- Emite toda la energía absorbida.
- A frecuencias de microondas la potencia radiada es proporcional a la temperatura física.

$$B_{bb}(f) = \frac{2hf^3}{c^2} \frac{1}{e^{\frac{hf}{k_B T}} - 1} \left[\text{W} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{Hz}^{-1} \right]$$

$$\lim_{f \rightarrow 0} \frac{2k_B}{\lambda^2} T \quad \text{Ley Rayleigh-Jeans}$$



μwaves

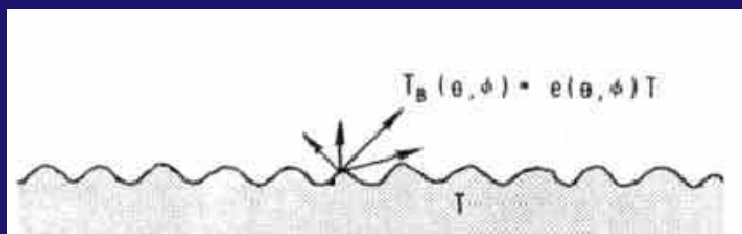
IR VIS

(Ullaby)

Concepto de Emisividad

- El brillo de los cuerpos reales: **Cuerpos Grises**
 - No absorben toda la energía incidente
 - Una parte la reflejan
 - La fracción absorbida la reemiten después direccionalmente

• Temperatura de Brillo y Emisividad



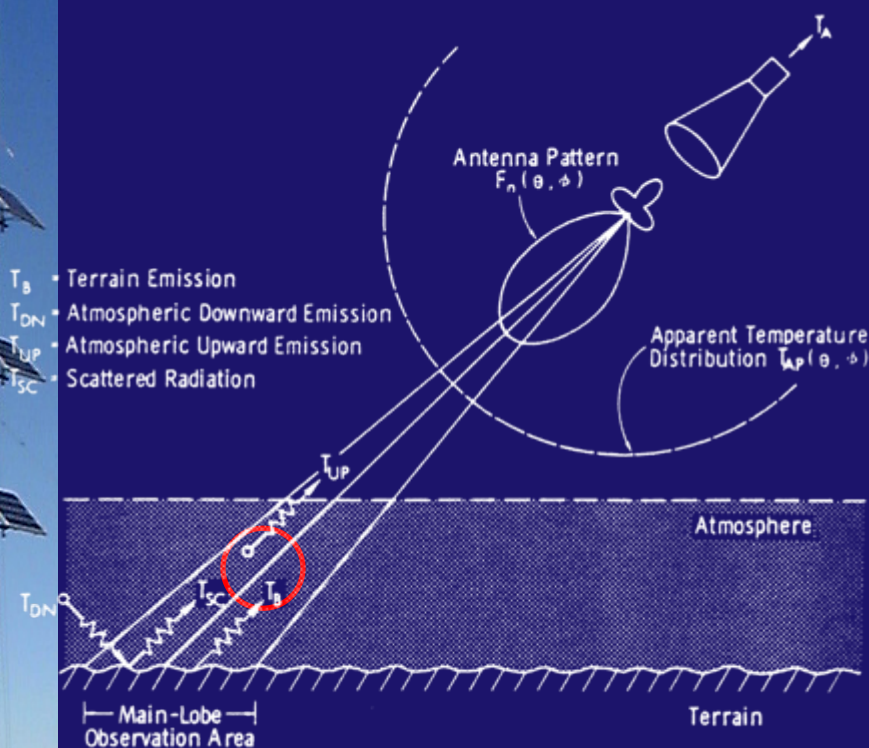
$$B(\theta, \varphi) = \frac{2 k_B}{\lambda^2} T_B(\theta, \varphi) \triangleq \frac{2 k_B}{\lambda^2} e(\theta, \varphi) T$$

$$0 \leq e(\theta, \varphi) \leq 1$$

- Cuerpos “Grises”: $T_B = e T_{ph} \longrightarrow$ Temperatura de brillo

Emisividad : $e(\theta, \varphi, f, \text{mat. \& props. surf.})$

Potencia de ruido captada por una antena



T_A suma ponderada de:

- Potencia emitida por el objeto (T_B) atenuada por la atmósfera (L_a)
- Potencia de la atmósfera (T_{up})

Reflexiones de otras fuentes (T_{DN}), Sol, luna, ruido galáctico, ruido cósmico, atmósfera...

⇒ **TEMPERATURA APARENTE DE BRILLO**

$$T_{AP}^p(\theta, \varphi) = \frac{1}{L_a(h, \theta, \varphi)} (T_B^p(\theta, \varphi) + T_{SC}^p(\theta, \varphi)) + T_{UP}(\theta, \varphi)$$

Sensibilidad de la temperatura de brillo a los parámetros atmosféricos en función de la frecuencia

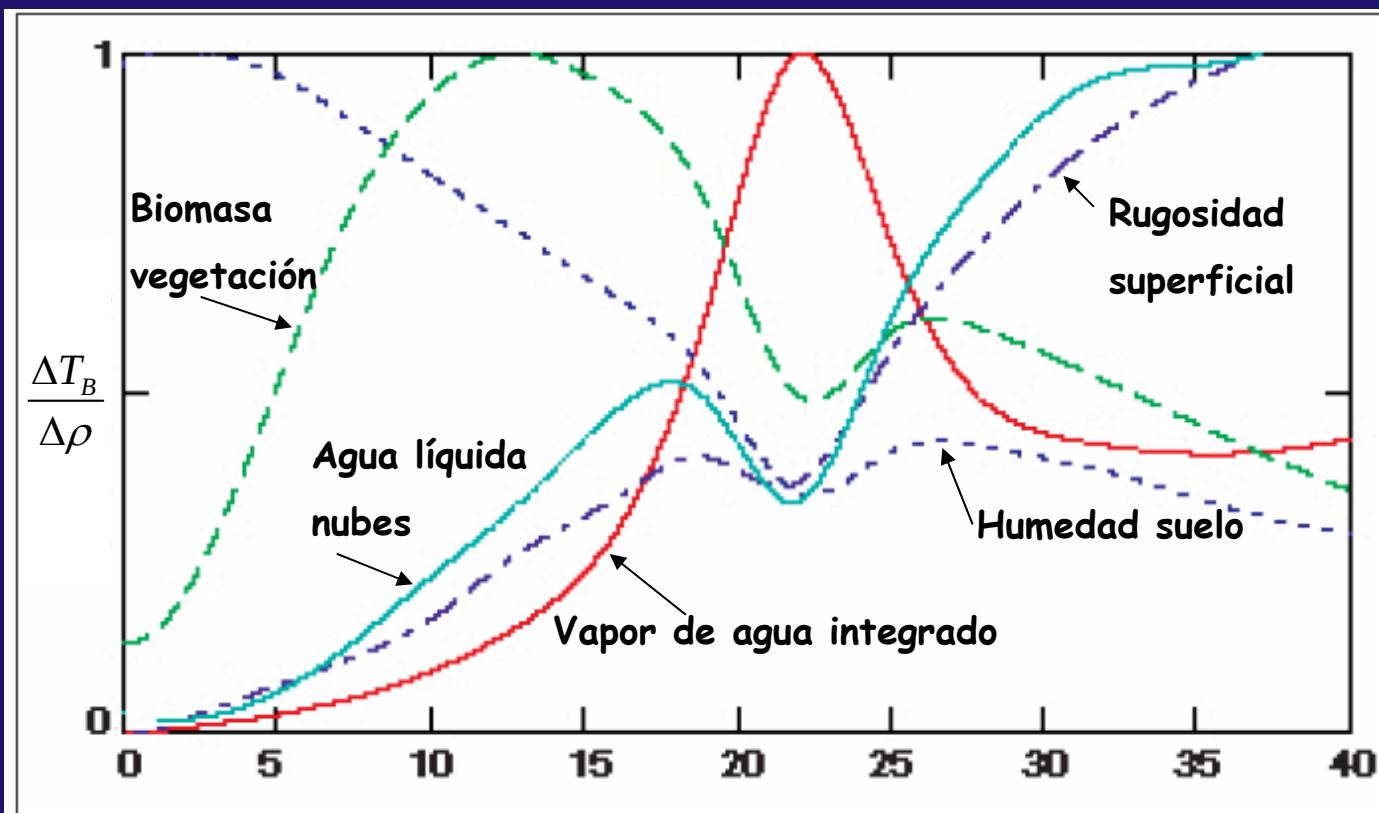
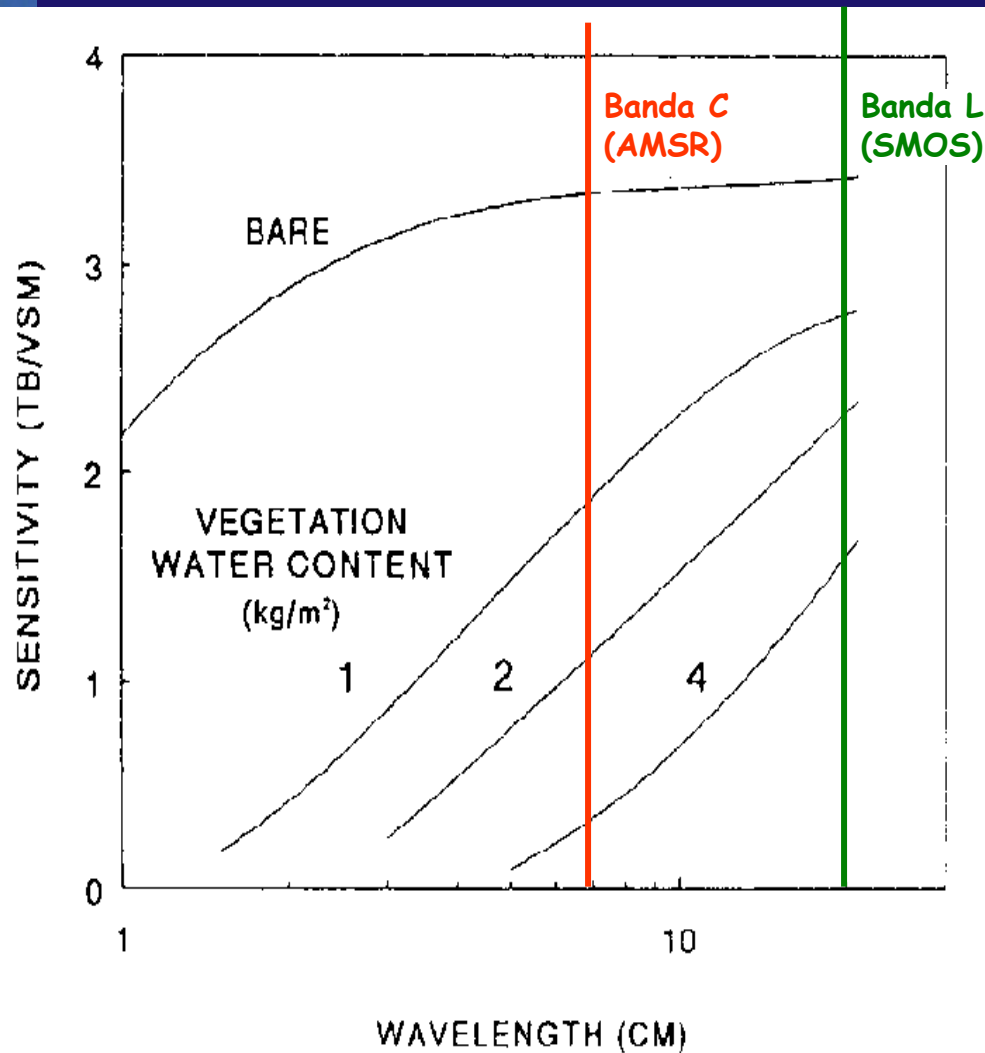


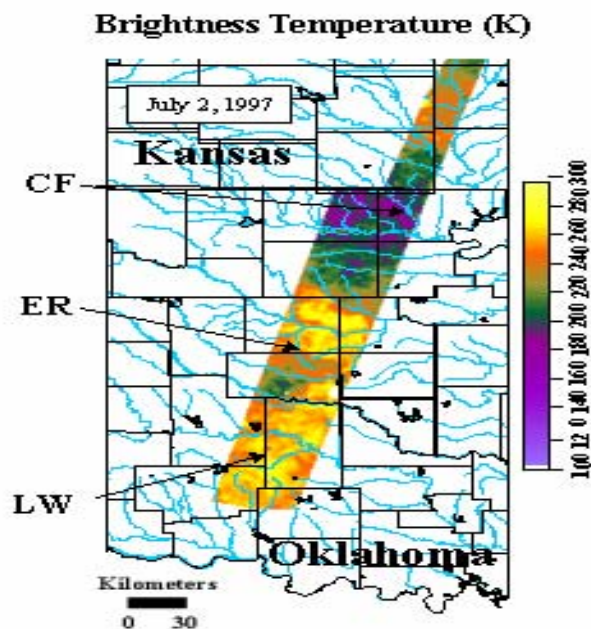
Figure 7: Sensitivity to surface and atmospheric parameters as a function of frequency [Kerr, 1996].

Influencia del Contenido de agua de la vegetación (W_v) en la sensibilidad radiométrica a la humedad del suelo (SM)

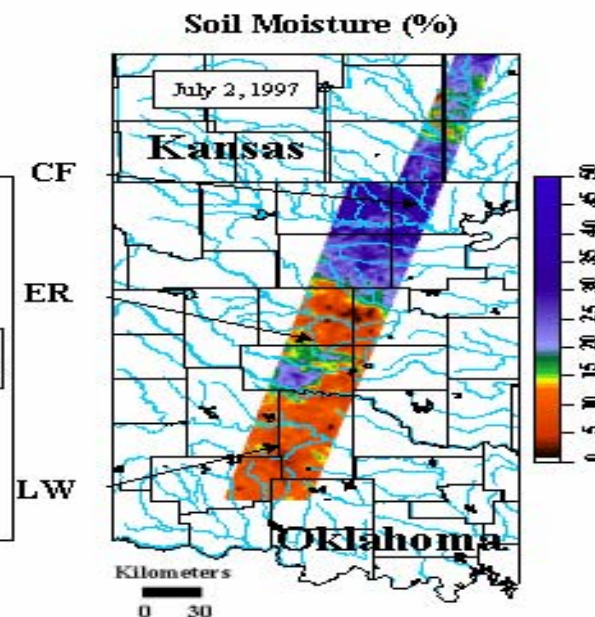
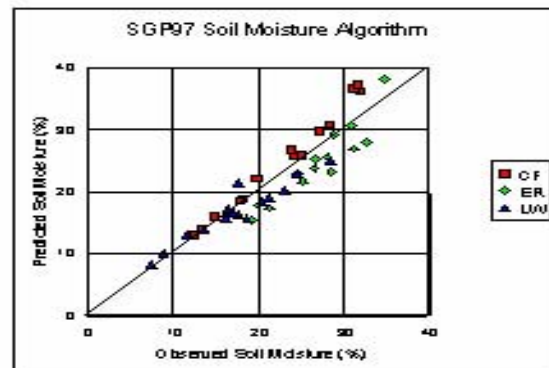


- Para penetrar en la capa de vegetación se deben elegir frecuencias bajas.
- Banda de frecuencias protegida: 1.41 GHz

Soil Moisture Mapping and Validation Using ESTAR

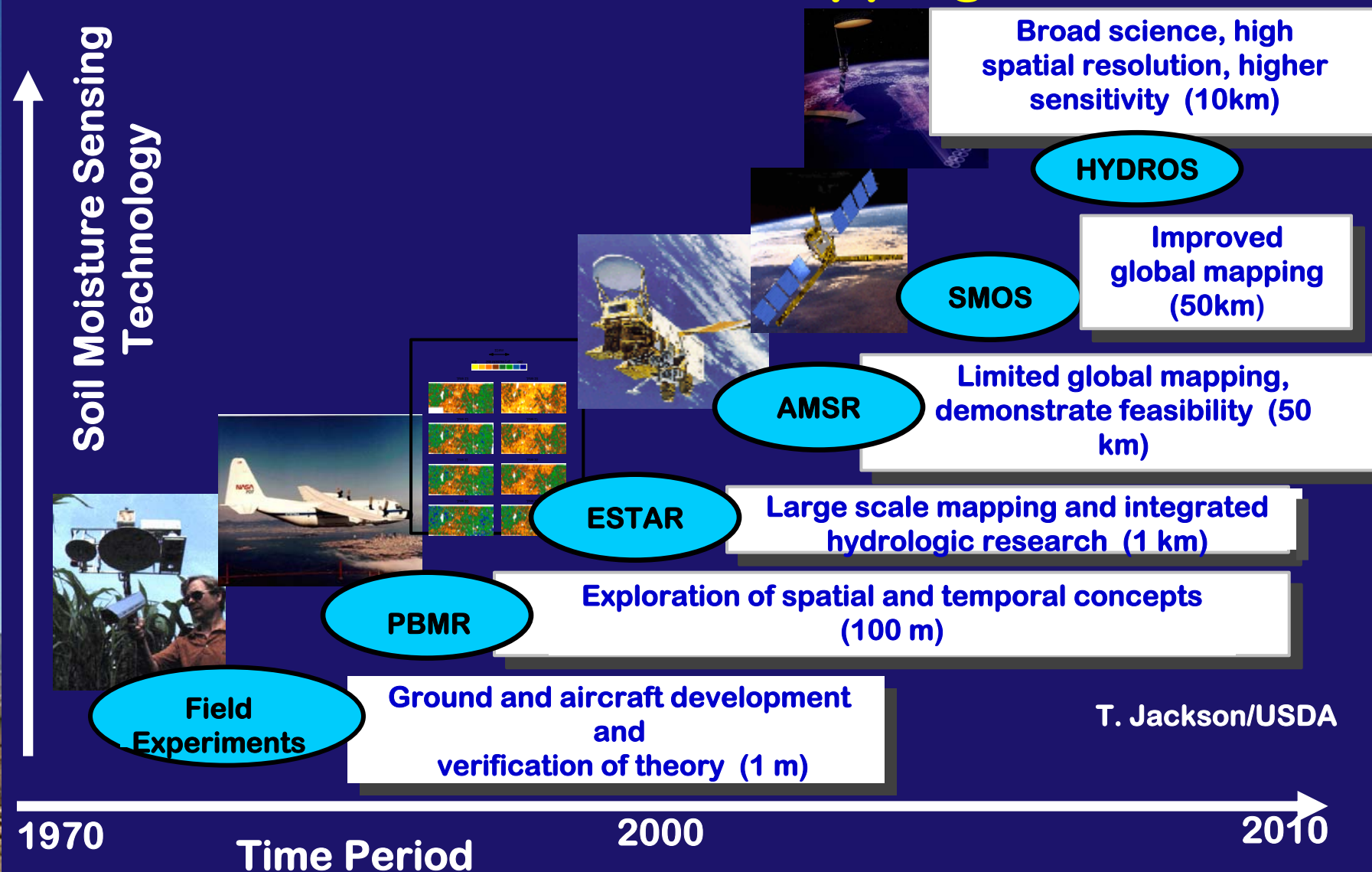


Validation: Standard Error ~3%



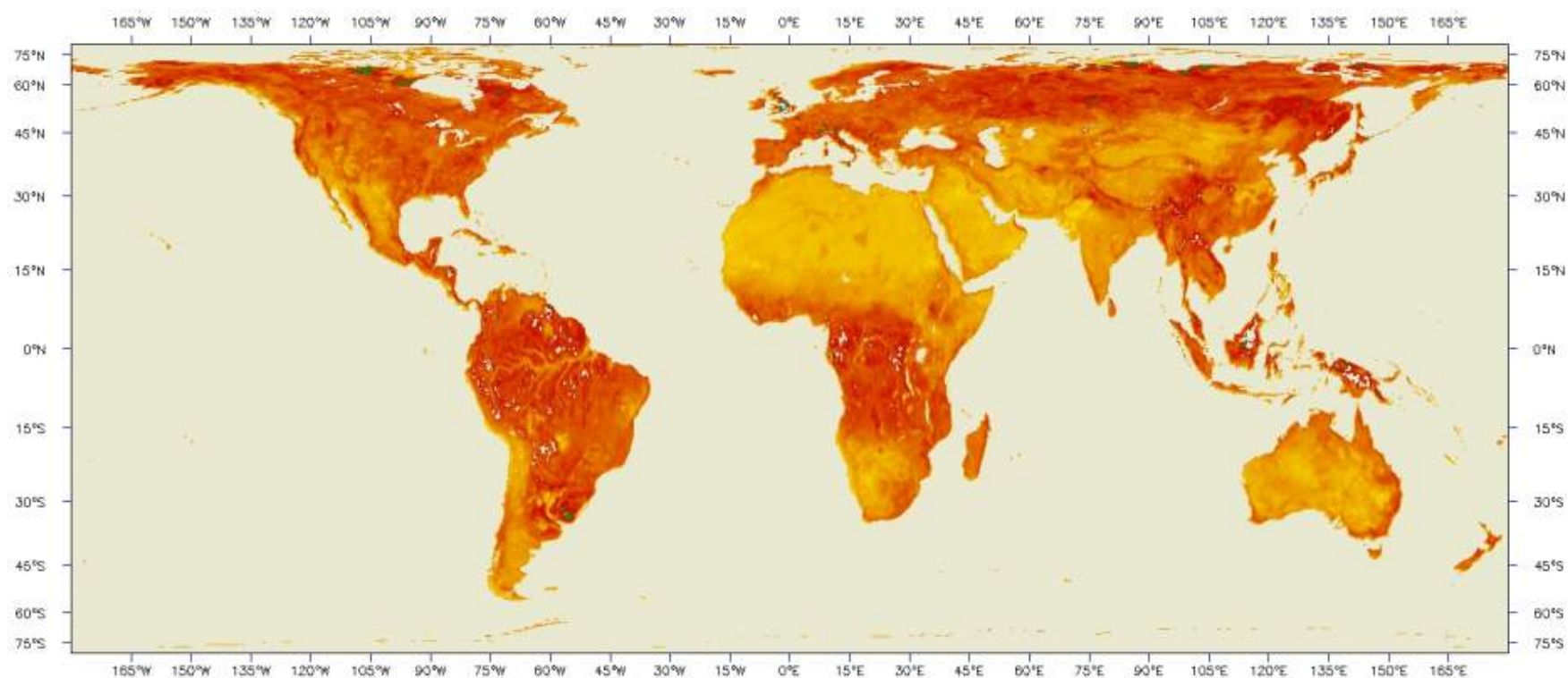
T. Jackson/USDA

Evolution of Soil Moisture Mapping





Mean Soil Moisture (% volume): April 2003-2005 A



Projection: EASE Grid Global; Datum: WGS-84



Teodosio Lacava – IMAA-CNR

YHK-PHW

AMSR-E data





La Misión SMOS de la ESA

Scientific Requirements for Soil-Moisture Measurements

The scientific requirements for the SMOS mission have been formulated to gain maximum information on the surface-emitted 'brightness temperature' to allow the retrieval of surface soil moisture with an accuracy in the range of its natural variability. These requirements are:

- Soil-moisture Accuracy: $0.04 \text{ m}^3 \text{ m}^{-3}$ (i.e. 4% volumetric soil moisture) or better

For bare soils, for which the influence of near-surface soil moisture on surface water fluxes is strong, it has been shown that a random error of $0.04 \text{ m}^3 \text{ m}^{-3}$ allows a good estimation of the evaporation and soil transfer parameters.

- Spatial Resolution: $< 50 \text{ km}$

For providing soil-moisture maps to global atmospheric models, a 50 km resolution is adequate, and will allow hydrological modelling with sufficient detail for the world's largest hydrological basins.

- Global Coverage: $\pm 80^\circ$ latitude or higher

- Revisit Time: 2.5 to 3 days

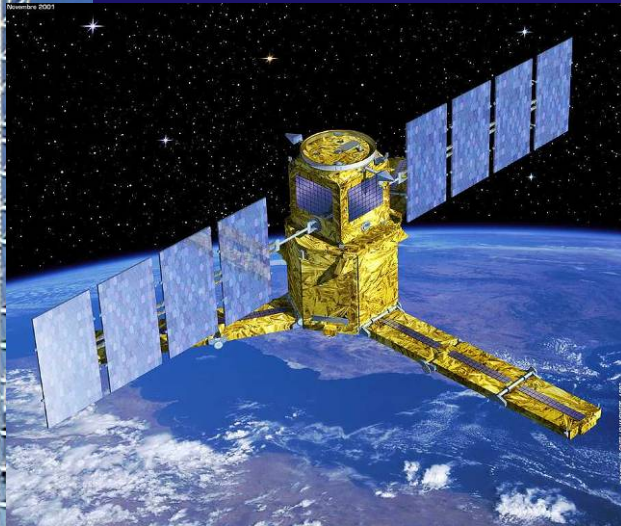
A 3 to 5 day revisit cycle is sufficient to retrieve vadose-zone soil-moisture content and evapo-transpiration, provided ancillary rainfall information is available. To track the quick-drying period after rain has fallen, which is very informative about the soil's hydraulic properties, a one- or two-day revisit interval is optimal. The stipulated 2.5 to 3 day bracket will satisfy the first objective always, and the second one most of the time.

- Observation Time:

The precise time of the day is not critical for data acquisition, but the early morning (about 06:00 h) is preferable, when ionospheric effects can be expected to be minimal and conditions are as close as possible to thermal equilibrium. The retrievals will then be more accurate, but dew and morning frost can sometimes affect the measurements.

MIRAS: *Microwave Radiometer by Aperture Synthesis*

- Radiómetro de potencia total inviable (tamaño de la antena)
- Tecnología: Radiometría por Síntesis de Apertura: MIRAS .



- Concepto heredado de radioastronomía.
- Agrupación en Y (brazo: ~ 4.5 m)
- 21 antenas Banda L/brazo.
- Doble polarización (H y V)
- Espaciado 0.875λ
- No se utilizan mecanismos de escaneado
- Imágenes 2D por síntesis Fourier

• Masa instrumento 175kg

VLA (Socorro, New Mexico)

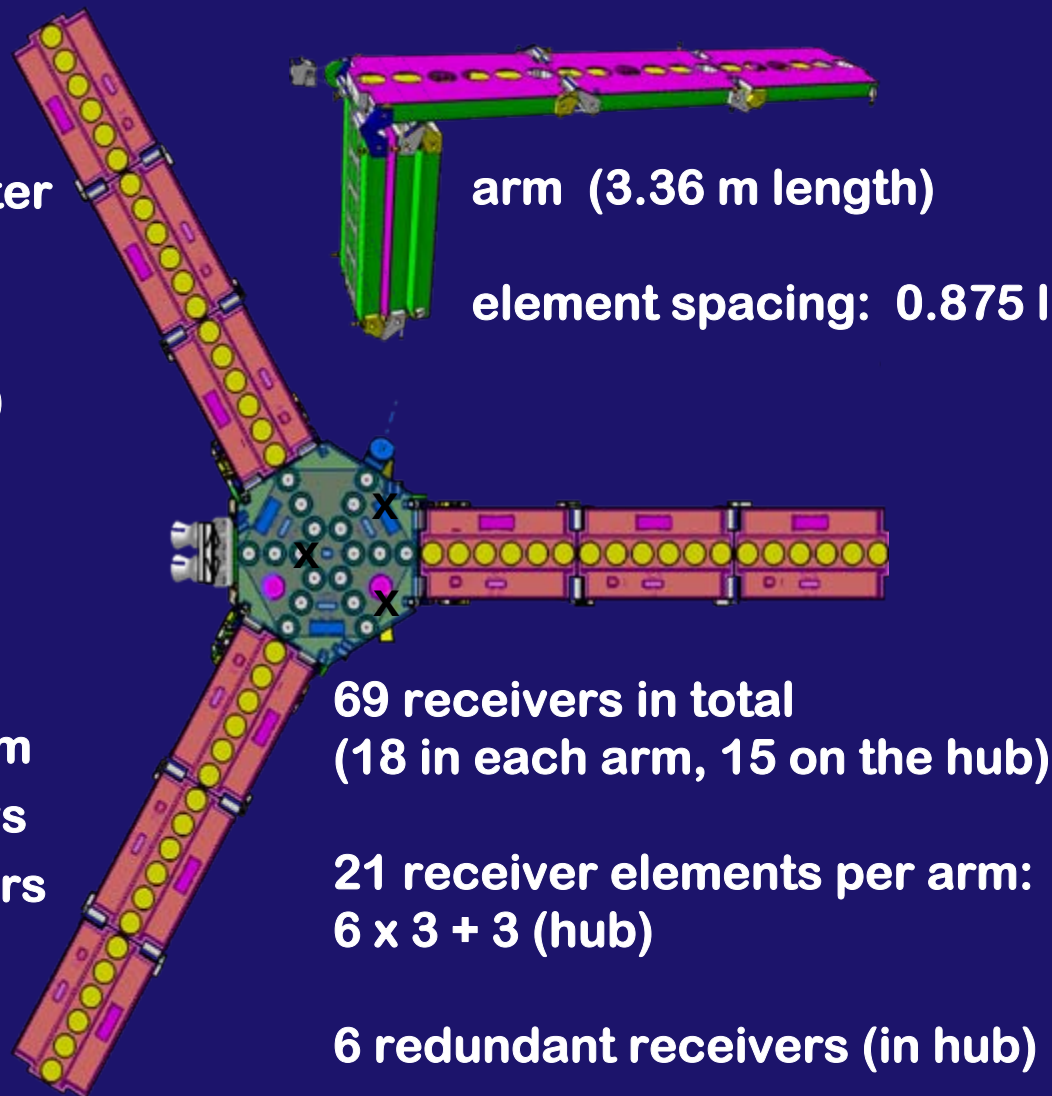


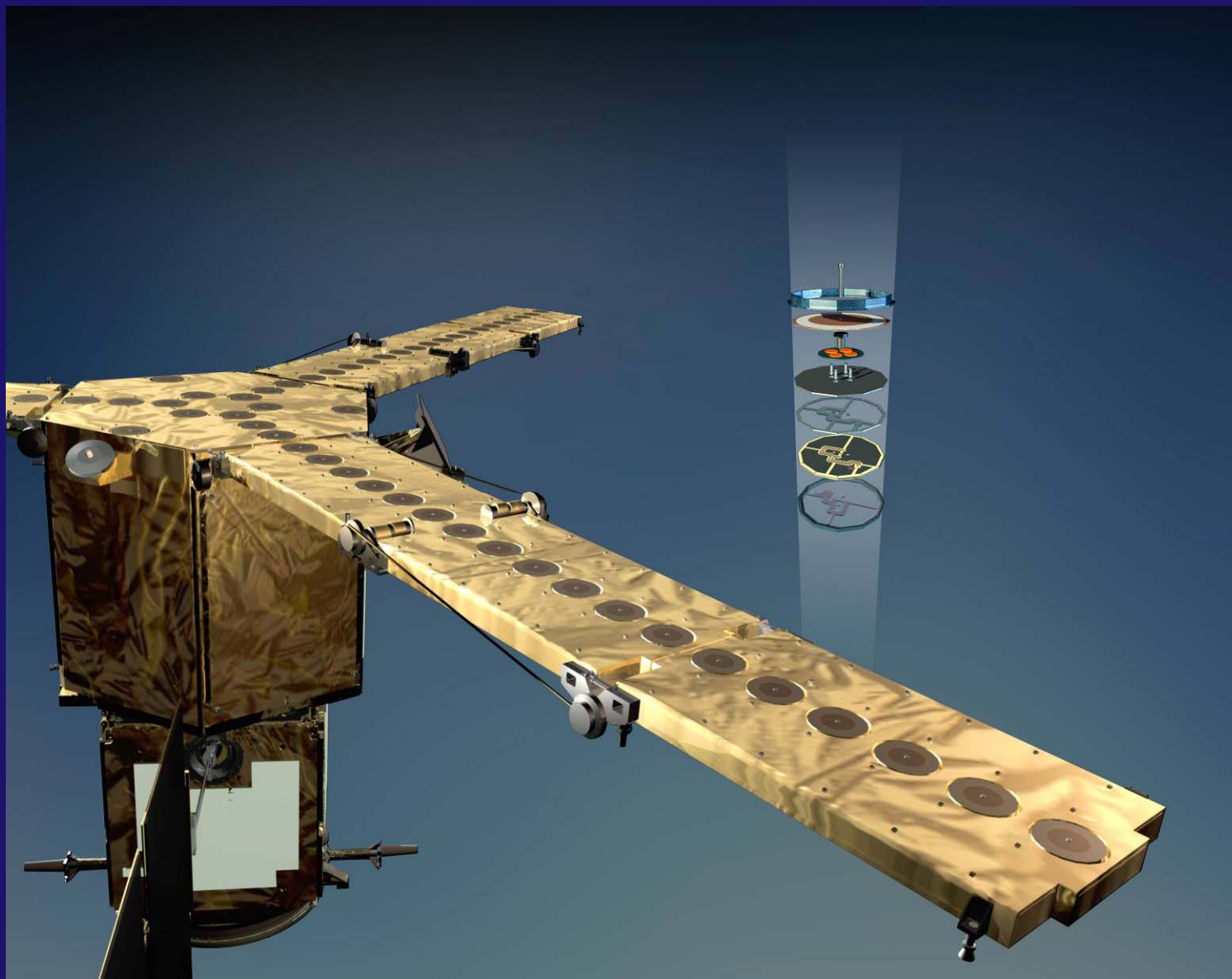
Technical Concept

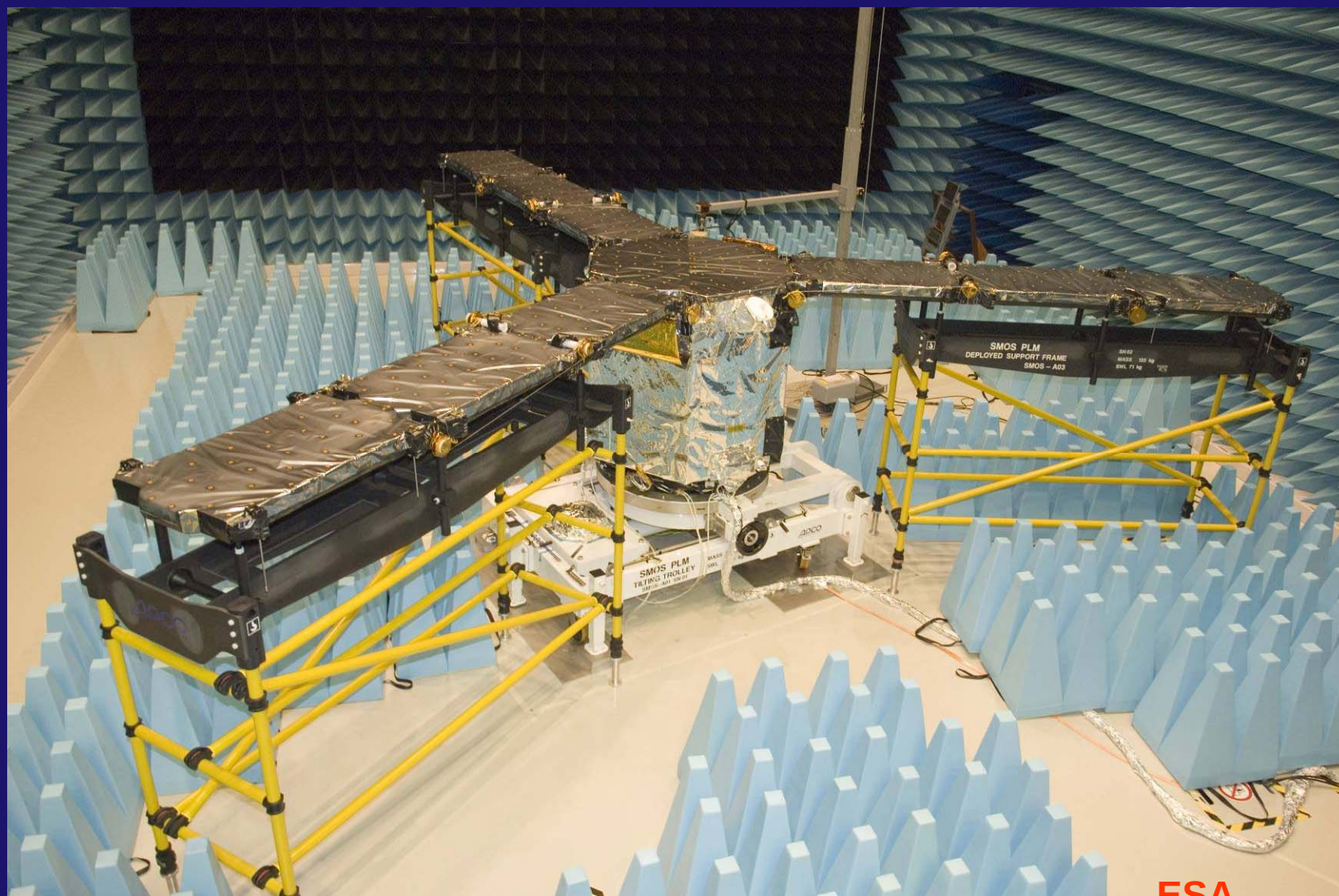
MIRAS: Microwave Radiometer with Aperture Synthesis

- Passive microwave radiometer (L-band - 1.4GHz)
- 2D interferometry
- multi-incident angles (0° - 55°)
- 755.5 km altitude
- ~ 1000 km swath
- polarimetric observations

- spatial resolution: 20-50km
- revisit time: 1-3 days
- mission duration: 3-5 years
- 30° steer angle
- 32.5° tilt angle







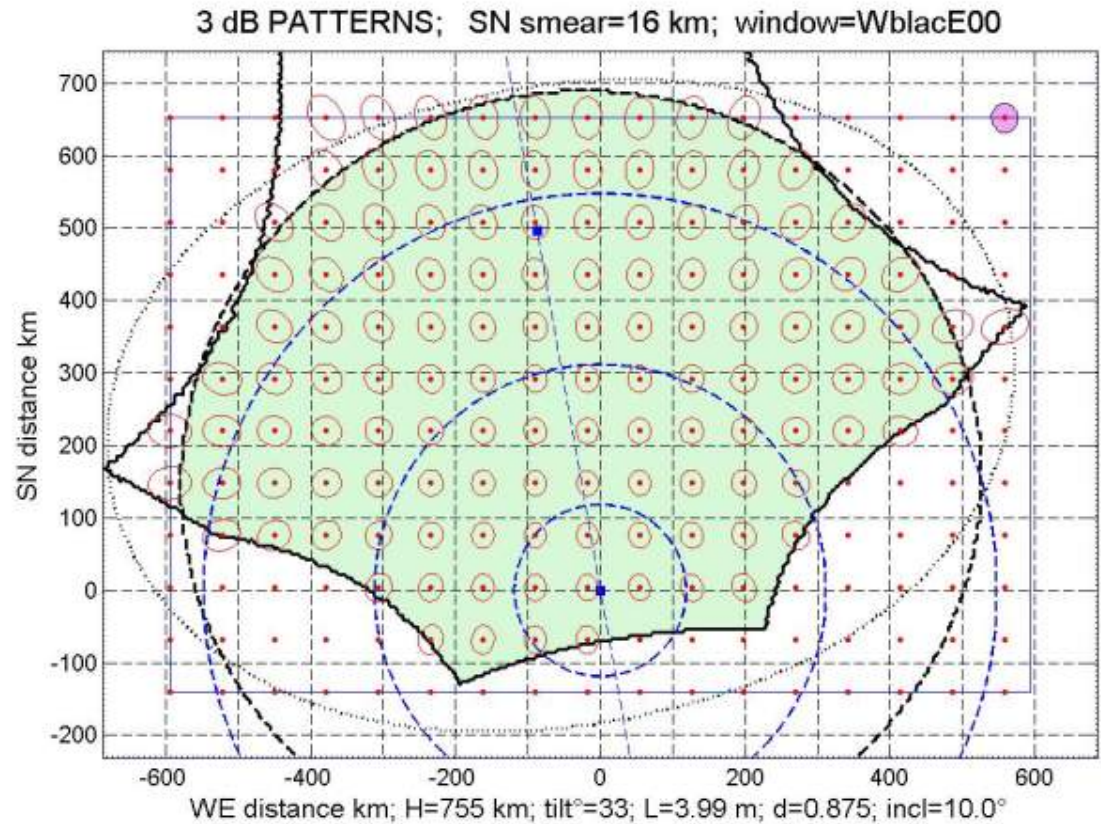
ESA



Principle of operations

SMOS FOV; 755 km, 3x6, 33°, 0.875λ,

- Each integration time, (2.4 s) a full scene is acquired (dual or full pol)
- Average resolution 43 km, global coverage
- A given point of the surface is thus seen with several angles
- Maximum time (equator) between two acquisitions 3 days



P. Waldteufel, 2003



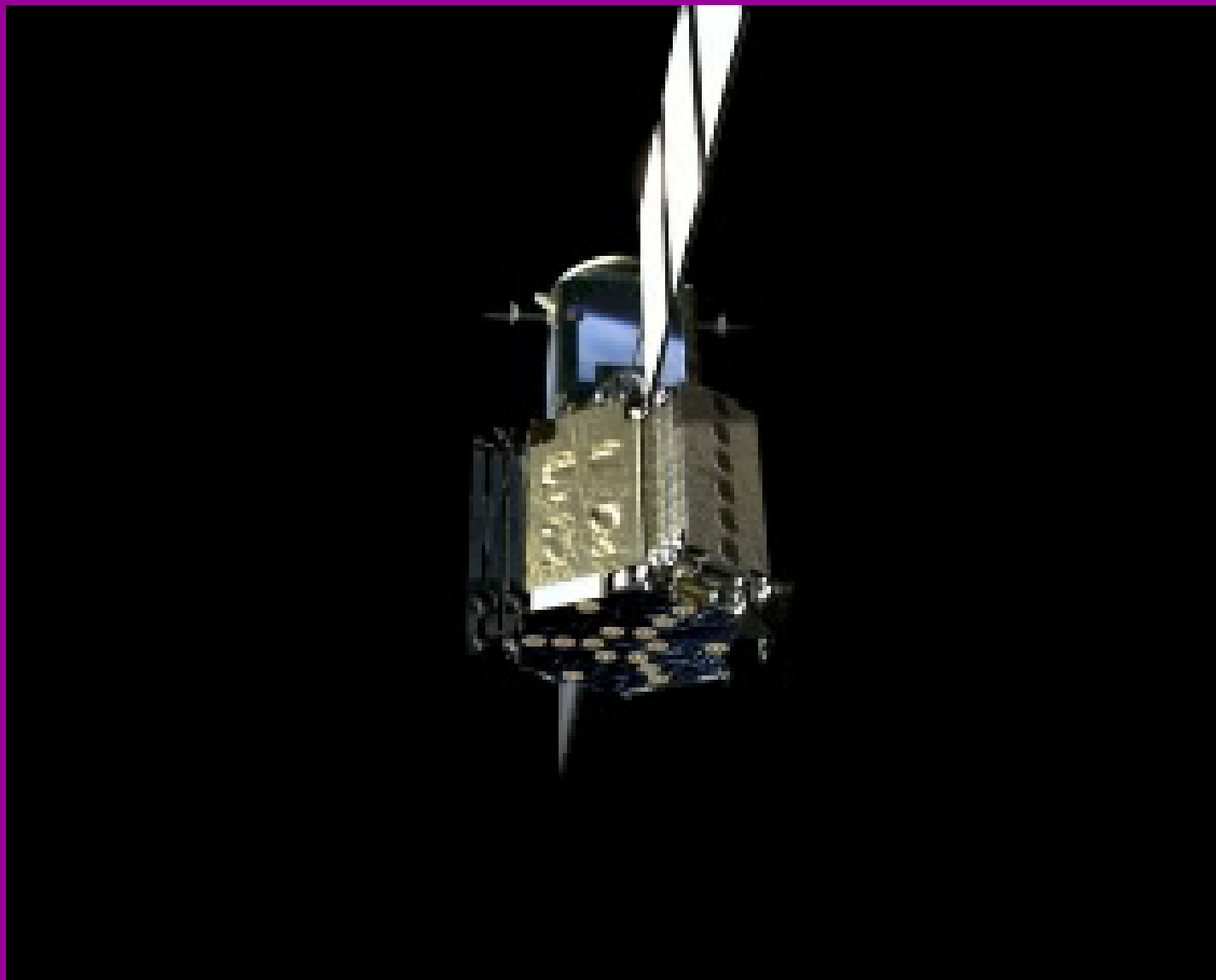
Soil Moisture and Ocean Salinity (SMOS)

**S
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S**



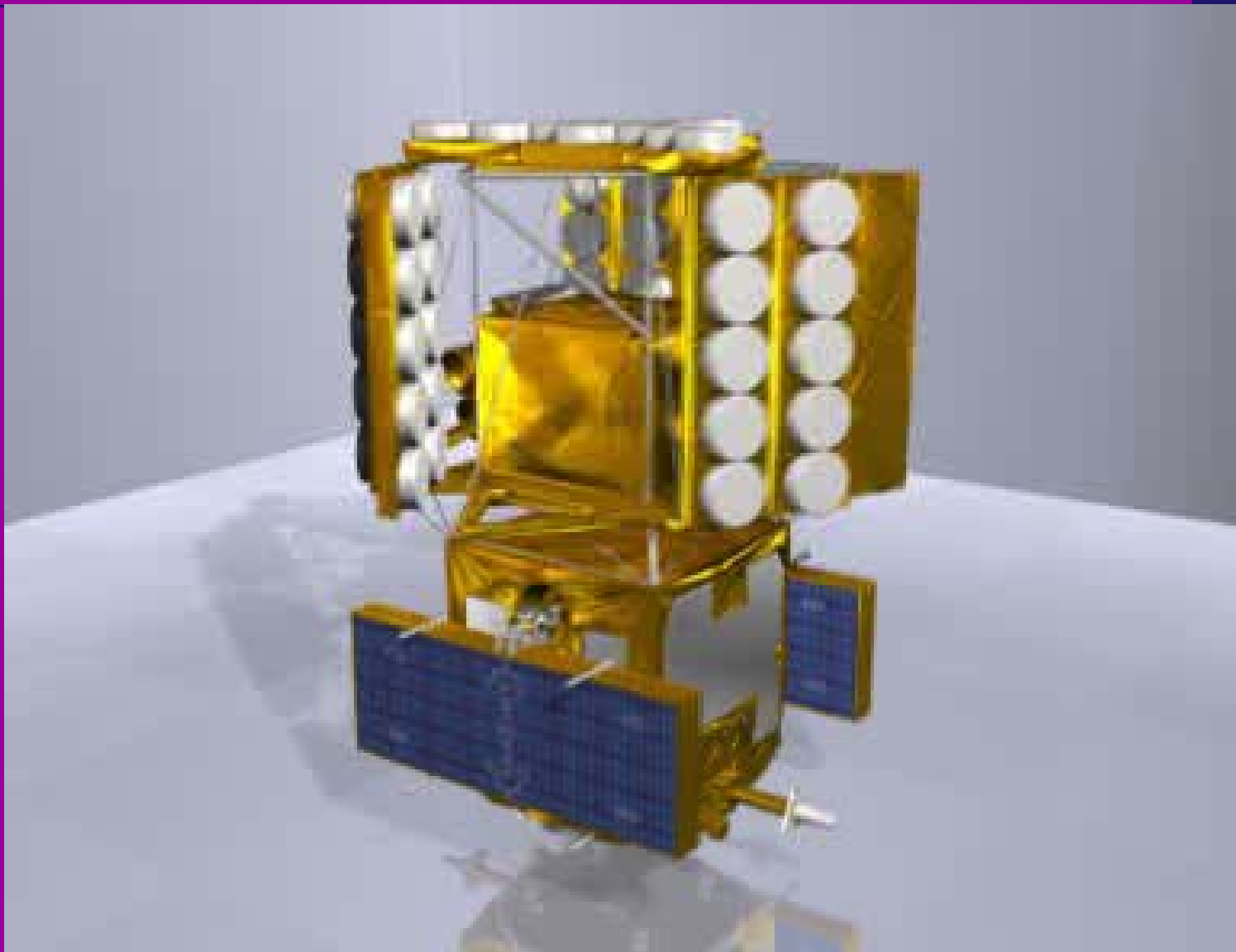
Soil Moisture and Ocean Salinity (SMOS)

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Soil Moisture and Ocean Salinity (SMOS)

S
M
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S



<http://www.esa.int/esaLP/LPsmos.html>

<http://www.cesbio.uprs-tlse.fr/us/indexsmos.html>

<http://www.icm.csic.es/oce/projects/smos/>

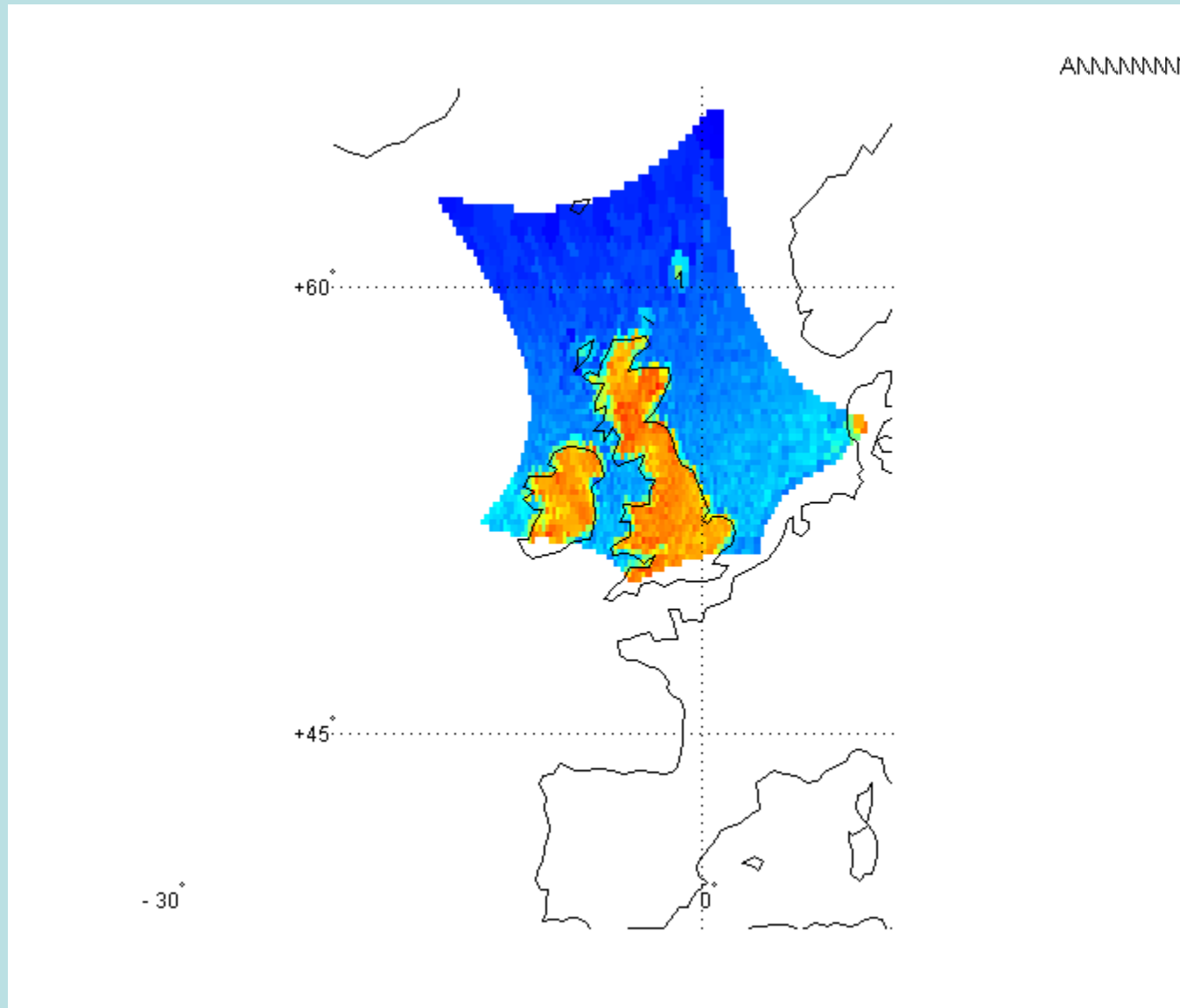
<http://www.uv.es/elopez/?19>

Demostrar el uso de la interferometría 2-D de microondas en Banda L para observar operativamente:

- ***Salinidad de los océanos,***
- ***Contenido en humedad del suelo, y***
- ***Caracterización del hielo de la Criosfera***

y mejorar los modelos meteorológicos, climáticos e hidrológicos

SMOS 2-D Field of view (1 FOV / 10) (F. Petitcolin, ACRI-st)



AAAAAAAA

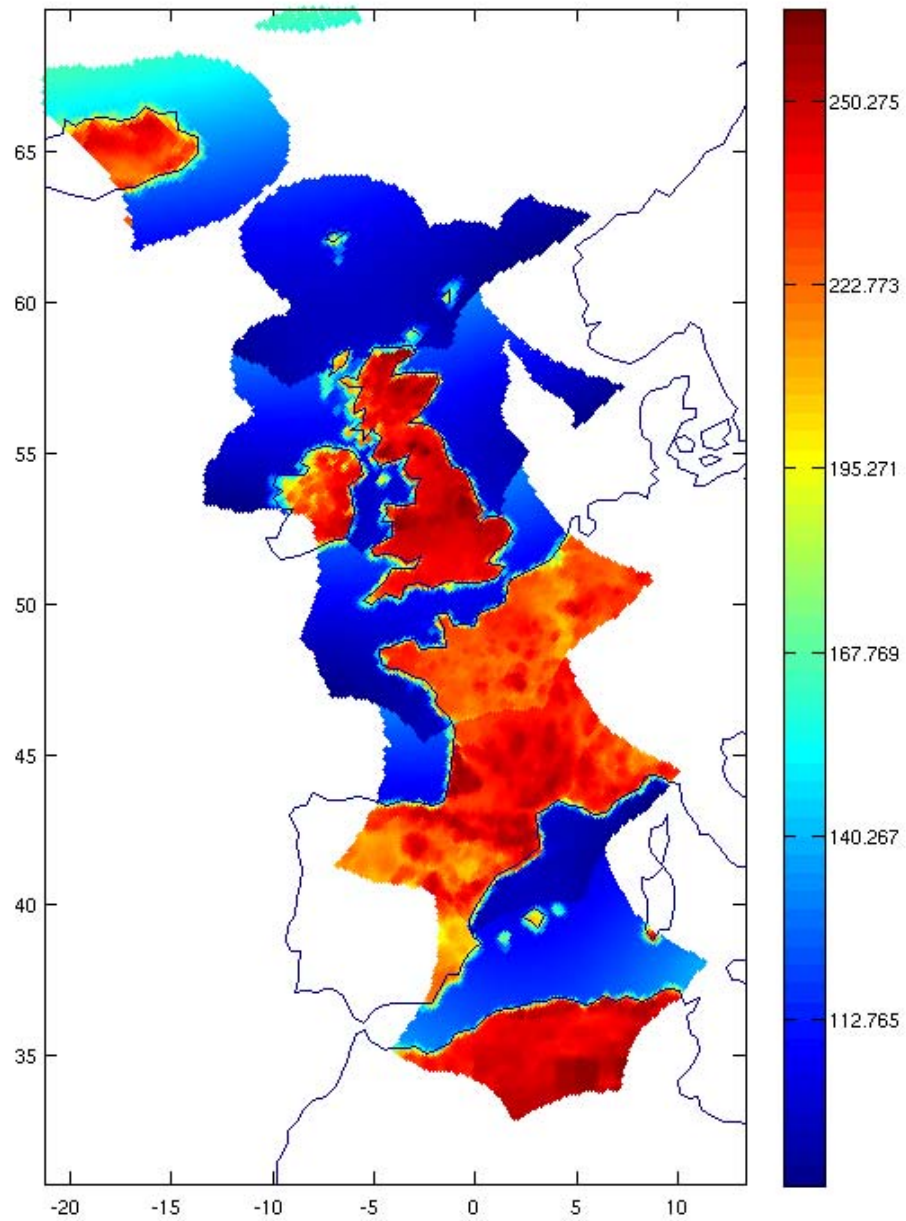
SEPSv3 simulations

S90	216s
S80	192s
S70	168s
S60	144s
S50	120s
S40	96s
S30	72s
S20	48s
S10	24s
S1	T0

Satellite pass: 06 & 18 h local time (Equator)

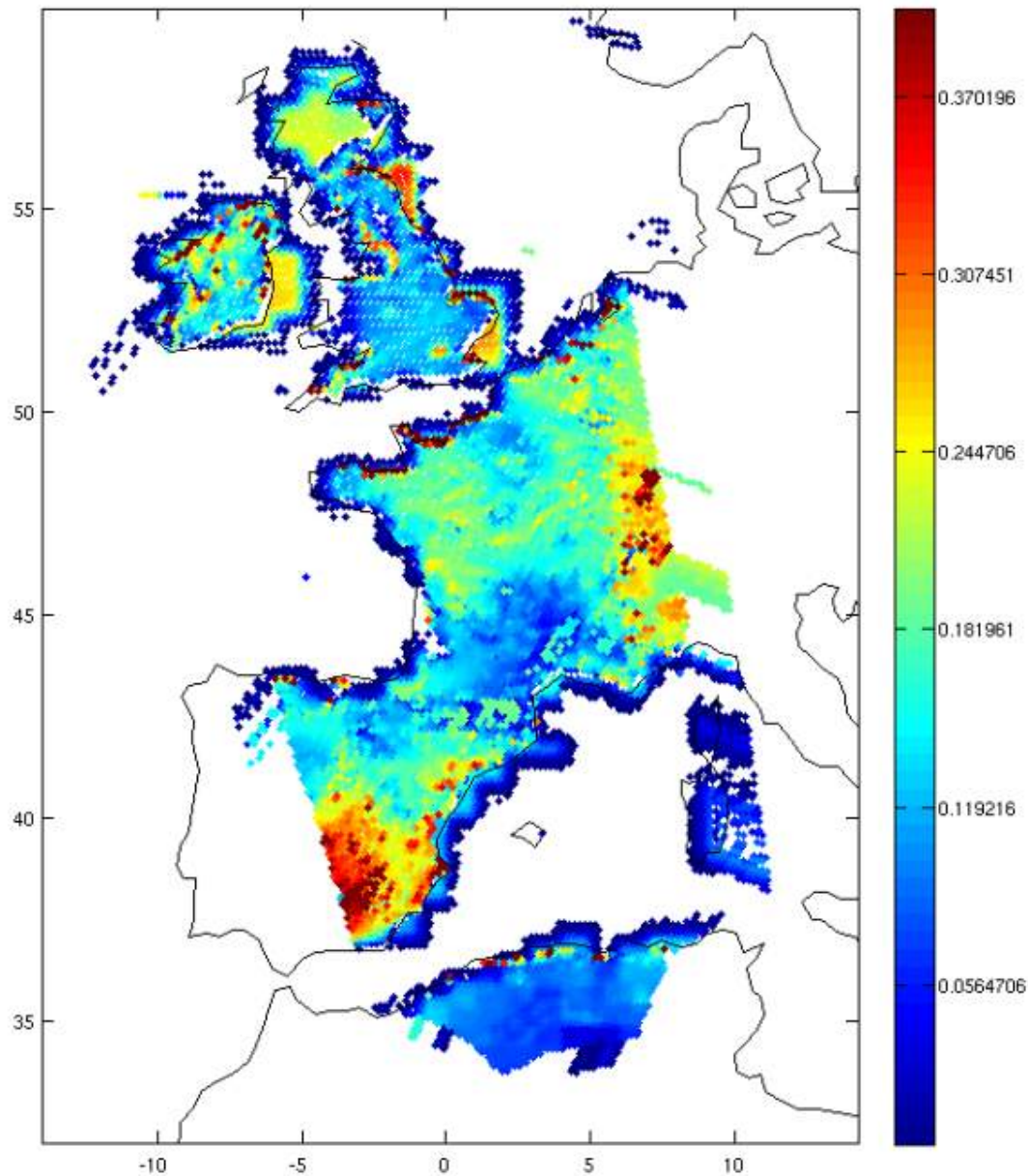


Snapshots



YHK-PHW





Retrieved SM

YHK-PHW



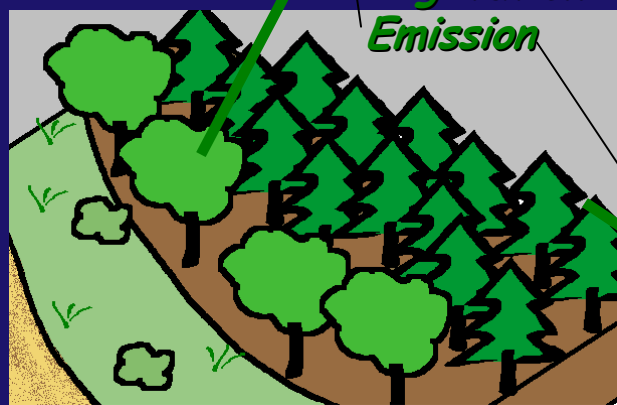
T_B

SMOS



ATMOSPHERE

VEGETATION



Extinction γ

Extinction γ

Soil Emission

Soil Reflectivity
 Γ_s

SOIL

(Wigneron,
adapted)

Agradecimientos

- Spanish Programme on Space Research (MIDAS Projects)
- Regional Government of Valencia, Dept. for Environment, Directorate General for Climate Change
- ESA
- SMOS Science Group

