Hydros Pathfinder Mission For
Global Mapping of Soil Moisture and Freeze/Thaw

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Yunjin Kim (JPL) – Project Manager
and Hydros Science Team

The 5th SMOS Science Workshop:
November 29th-December 1st, 2004
ESA-ESRIN, Frascati Italy
1. Hydros Project Status/Schedule
2. Priorities Lists
   a. Soil Moisture Working Group
   b. Hydros Project
3. Hydros Requirements/Success Criteria
4. Applications Development
5. Science Impacts Research – Predictability
6. Links to Other Earth Systems Cycles
7. Measurement Approach and Key Technical Trade-Offs
8. Algorithm Plans
9. Role for an International In Situ Soil Moisture Observing System
10. Field Experiments (Recent Past and Future)
Outline

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• Approved to Start Formulation Phase in December 2003
• Profile for September 2010 Launch

**Important Project Dates**

- PMSR: May 2006
- PDR: May 2007
- MCR: July 2007
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1. Enhance Robust Radar Backscatter and Retrieval Models

2. Improve Multiple Resolution Retrieval Algorithms

3. Focus Efforts on Further Demonstrating the Usefulness of Soil Moisture Products in Applications

4. Pursue and Support Science and Data Exchanges With International Colleagues

SMMWG Priorities: Field Campaigns

• Develop a Hydrologic Cycle Experiment (2008) That Engages All Aspects of the NASA Terrestrial Hydrology Program (Carbon, GPM, Cold Lands)

• Coordinate With SMOS and Aquarius Overlapping Needs

• Ensure the Availability of Both Ground and Aircraft Instrumentation

• Work Closely With NASA Sub-Orbital Activities.
2005 Project Priorities

1. Joint Plans and Schedules With Contributing Partners
2. Complete Antenna RFP and Downselect Vendor
3. Develop Algorithm Roadmaps Leading to Algorithm Theoretical Basis Documents (ATBDs) for Baseline Algorithms
4. Develop the Project Requirements Document and Understand the Requirement Flow-Down Concisely
5. Close Trade-Offs on Instruments and Ground Data System Architecture
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Terrestrial Hydrosphere State Variable

Spatial Resolution:
- Soil Moisture: 40 km (Hydroclimatology)
- Soil Moisture: 10 km (Hydrometeorology)
- Freeze-Thaw: 3 km (Heterogeneity)

Temporal Sampling (Global Revisit):
- 2-3 Days Globally (Soil Moisture)
- 1 to 2 Days Above 45°N (Freeze-Thaw)

Integrated Active and Passive L-band Sensors
# Hydros Data Products

<table>
<thead>
<tr>
<th>Data Product</th>
<th>Volume MB/day</th>
<th>Description</th>
<th>Producer</th>
<th>Users</th>
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<tbody>
<tr>
<td>L1B_S0_Lo_Res</td>
<td>970</td>
<td>Low Resolution Radar $\sigma^0$ in Time Order</td>
<td>RdIT (Girard/Spencer)</td>
<td>F/TDAC, DAAC, DU</td>
</tr>
<tr>
<td>L3_3km_S0</td>
<td>4704</td>
<td>High Resolution Time-Ordered Radar $\sigma^0$ in Earth Grid</td>
<td>RdIT (Girard/Spencer)</td>
<td>F/TDAC, SMAC, DU</td>
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<tr>
<td>L2_40km_h</td>
<td>24</td>
<td>Radar-Derived Surface Roughness, and Vegetation Index in Radiometer Footprint</td>
<td>RdIT (Girard/Kim)</td>
<td>SMAC, SMDPC</td>
</tr>
<tr>
<td>L1B_TB</td>
<td>300</td>
<td>Radiometer $T_B$ in Time Order</td>
<td>RmIT (Piepmeier)</td>
<td>SMAC, SMDPC, DAAC, DU</td>
</tr>
<tr>
<td>L3_3km_F/T</td>
<td>500</td>
<td>3 km Earth Grid Freeze/Thaw State</td>
<td>F/TDAC (Kimball)</td>
<td>SMAC, DAAC, DU</td>
</tr>
<tr>
<td>L4_3km_F/T</td>
<td>500</td>
<td>3 km Earth Grid Freeze/Thaw Model Assimilation Product</td>
<td>F/TDAC (Running)</td>
<td>SMAC, DAAC, DU</td>
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<tr>
<td>L3_40km_SM</td>
<td>15</td>
<td>40 km Earth Grid Soil Moisture</td>
<td>SMDPC (O Neill)</td>
<td>DAAC, DU</td>
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<tr>
<td>L3_40km_TB</td>
<td>45</td>
<td>40 km Earth Grid Brightness Temperature</td>
<td>SMDPC (O Neill)</td>
<td>DAAC, DU</td>
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<tr>
<td>L3_10km_SM</td>
<td>300</td>
<td>10 km Earth Grid Soil Moisture</td>
<td>SMAC (Entekhabi)</td>
<td>DAAC, DU</td>
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<tr>
<td>L4_5km_4DDA</td>
<td>1000</td>
<td>5 km Earth Grid Soil Moisture Model Assimilation Product</td>
<td>SMAC (Houser)</td>
<td>DAAC, DU</td>
</tr>
</tbody>
</table>

**Key Points:**
1. High-Res Radar Data for Passive Algorithm Support
2. Combined Active+Passive 10 km Soil Moisture Product
3. Two Level-4 Data Products
4. Team Roles/Responsibilities Structured
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Flash Flood Rain Event Near Fort Collins
July 13, 1996
Chen et al. (2001), JAS, 58, 3204-3223.

The Major Operational Weather Centers are HYDROS Partners:

- NCEP
- Environment Canada
- ECMWF
- NOAA CPC

Hydros Combined Radiometer and Radar Data Will be Used to Develop Global 10 km Soil Moisture Mapping
24-Hour Coverage and NWP Initialization

Meteorological Service of Canada
Environment Canada

h = 670 km
i = 98 deg.
Assimilation of Hydros Simulated Brightness Temperature Using GSWP-II Forcing for 1-Year ISBA Integration
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Impact on The Rates of Earth System Cycles

HYDROS Product Retrieval Error Map (Blue Shades in % Volumetric; Gray >4% Requirement) and Regions Where Soil Moisture Significantly Controls* the Evaporation Rate (Dots Based on Modeling in Koster et al. 2003, J. Hydromet. 4[2])

* 15 Wm² Change in Latent Heat Flux for Every 10% Change in Soil Saturation
Impact on Seasonal Precipitation Predictability

HYDROS Product Retrieval Error Map (Blue Shades in % Volumetric; Gray >4% Requirement) and Regions Where Soil Moisture Has Significant* Impact on Seasonal Precipitation Predictability Through Land-Atmosphere Coupling (Dots Based on Modeling in Koster et al. 2003, *J. Hydromet. 4[2]*)

*At Least 1 in 5 Summers Affected in Model Simulations
Multi-Model Consensus of Regions Where Soil Moisture Impacts Precipitation

The Ratio of Prescribed-Soil Moisture Precipitation Variance to Control Precipitation Variance is a Measure of Influence.

Variance Ratio: Mean of 8 Models at Each Point

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JERS-1 Seasonal Threshold F/T Classification, Bonanza Creek AK

JERS-1 L-band SAR landscape freeze-thaw classification
Knowledge of High-Latitudes Freeze/Thaw Patterns is a Magnifying Lens For Identifying Global Change Processes in Boreal Regions
“Missing Carbon Sink” Problem

SSM/I Spring Thaw Timing Impacts to Annual Vegetation Productivity for the Alaska-Yukon Region

(Kimball, McDonald et al., SPIE, 2004)
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Spacecraft: Same as Coriolis

Light-Weight Mesh Deployable Reflector (6m): Flown Northrop-Grumman & Harris Designs

1.26 GHz Radar at 3 km (VV, HH, HV)
1.41 GHz Radiometer at 40 km (V, H, U) at Constant 40° Incidence

Wide 1000 km Swath for Global Mapping and Good Revisit
1-2 Day Polar;
2-3 Days Equatorial

6 am Nodal Crossing
Design Trades

- Radial-Rib Design:
  - Stationary Boom
  - Rotating Reflector

- Perimeter-Truss Design:
  - Boom and Reflector Spun on S/C Deck
  - Feed and Electronics Fixed

Antenna Selection Criteria:
- Mechanical/Dynamics Risk
- RF Performance
- Testability
- Cost
Scale Model of the Antenna to Test Numerical Models That Will be Used to Optimize Design
Representative Sampling at Equator for Point at Low Latitudes, AM passes only ("Doublets" Not Shown)
Hydros Orbit Selection: 6 am vs. 6 pm LTAN

LTAN = 6 pm

- No Satellite Eclipse in the Northern Hemisphere.
- Data Between 0° N and 40° N on Morning Passes Collected Between 6:00 and 6:30 Local Time.
- All Data Above 40° N Collected Between 6:30 and 17:30 Local Time.
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PALS Airborne L-Band

Radiometer

Brightness Temperature (K)

Radar

Backscatter Coefficient (dB)

Scale: ~10 km
Sensor Responses

Differences from June 25

Difference Images Show Change in Sensor Response ($T_B$ or $\sigma_o$) Primarily Due to Change in Soil Moisture

1600m Gridded Line Scans
Algorithm Roadmaps: By March 2005

• Roadmaps Will Outline
  – Procedures for Downselect of Baseline Algorithm
  – Algorithm Test Procedures and Requirements (Mix of Airborne, Tower-Based, OSSE)
  – Development and Test Schedules
  – Criteria For Evolution of Algorithms Into Baseline
  – Algorithm Interfaces
  – Error Budget (End-to-End)

• Develop Into Algorithm Theoretical Basis Documents (ATBSs) Before PMSR
RFI Mitigation
RFI Approach

- Studies Currently Funded by NASA Spectrum Office
  - Worst Case
  - Typical Case
  - Time Domain
- Constructing Decision Tree
- RFI Flags
  - RFI Free
  - RFI Excised
  - RFI Contaminated (With Probability?)
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a) A coordinated plan for soil moisture networks should be developed first at the national and then at the international levels.

b) The capabilities to measure soil moisture from space have been demonstrated, but committed missions are needed to perfect these measurements and to determine the utility of soil moisture measurements derived from space.

c) Space measurements provide estimates of the water in the upper 5-10 cm of soil, frequently referred to as soil wetness measurements. While these meet the needs for some applications, many applications require moisture measurements through the soil profile. The relationships between surface soil wetness and deep soil moisture profiles needs to be quantified or at least understood.

d) Vegetation cover can obscure the radiation arising from warm wet soils. Research is needed to find better ways of removing the vegetation effect from the signal that is being used to derive soil moisture.

e) A supersite program is needed to provide the comprehensive data sets needed for sensor evaluation and calibration, and to provide a basis for developing soil wetness algorithms for satellite measurements and the evaluation of climate model outputs.
The Global Climate Observing System (GCOS)

The Latest Version of the GCOS IP:

- Recognizes Soil Moisture as an Emerging Climate Variable
- Commits to a Global Network of in situ Soil Moisture Measurements
- Commits to Developing a Quasi-Operational Soil Moisture Data Product
Role For *In Situ* Sensor Networks
Time Variations Can Be Captured With Automatic Sensors

Volumetric Soil Moisture, m$^3$/m$^3$

Walnut Gulch, AZ

Day, 2004
Benefits of a World-Wide Soil Moisture in situ Sensors:

1. Valuable Data for Evaluating the Time-Response of Environmental Data Record
2. Spawn New Scientific and Operational Developments
3. Link Soil Moisture to Fluxes (co-Location with Flux Towers) at Diverse Sites
4. Evaluate Models and Prepare for Assimilation of Space-Borne Measurements
5. Collect Below-Surface or Profile Measurements
Regional study areas
50 by 75 km linked to Ease-grid 25 km cells

Landsat 5
June 8, 1997

Shrub Dominated

Grass Dominated
<table>
<thead>
<tr>
<th>Sunday</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
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<td>Day 207</td>
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<td>Day 210</td>
<td>Day 211</td>
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<tr>
<td>8/1 Aqua</td>
<td>8/2 Aqua</td>
<td>8/3 Aqua/Coriolis</td>
<td>8/4 Coriolis</td>
<td>8/5 Aqua/Coriolis</td>
<td>8/6 Aqua</td>
<td>8/7 Aqua</td>
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<td>Day 214</td>
<td>Day 215</td>
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<td>Day 217</td>
<td>Day 218 ASAR(3D)</td>
<td>Day 219 ASTER</td>
<td>Day 220</td>
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<td>8/8 Aqua/Coriolis</td>
<td>8/9 Aqua/Coriolis</td>
<td>8/10 Coriolis</td>
<td>8/11 Coriolis</td>
<td>8/12 Aqua</td>
<td>8/13 Aqua/Coriolis L5</td>
<td>8/14 Aqua/Coriolis</td>
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<tr>
<td>Day 221 ASAR(2A)</td>
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<td>Day 226</td>
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<td>8/15 Coriolis</td>
<td>8/16 Coriolis</td>
<td>8/17 Coriolis</td>
<td>8/18 Aqua</td>
<td>8/19 Aqua</td>
<td>8/20 Coriolis</td>
<td>8/21 Aqua/Coriolis</td>
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<td>Day 228</td>
<td>Day 229</td>
<td>Day 230</td>
<td>Day 231 ASAR(6D)</td>
<td>Day 232</td>
<td>Day 233</td>
<td>Day 234</td>
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<td>8/23 Aqua ASAR(2A, 2D)</td>
<td>Day 236</td>
<td>Day 237</td>
<td>Day 238</td>
<td>Day 239</td>
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<td>Day 238</td>
<td>Day 239</td>
<td>Day 240</td>
<td>Day 241</td>
</tr>
</tbody>
</table>

**SMEX04 Calendar**

Soil Moisture Sampling

P-3 Flight (and SM)
SMEX04 Raw PSR/CX C Band H Arizona

SMEX04 08/13/2004 7.32 GHz \( T_h \)
• Soil Moisture Experiment in Summer 2005.
• Snow/Sea Ice Experiments in Spring 2006.
• NRL P-3 platform
• Satellite Sensors: WindSat, SSMIS, AMSR-E
• Aircraft Sensors: APMIR and PALS
Walnut Creek Watershed Area
Landsat Images Summer 2002

Return to SMEX02 Study Region
Potential Forest Site

Map Showing the SMEX02 Region and Landsat TM Frame Coverages.
Summary

1. Follow-Up on Splinter Session Recommendations of April 2004 Joint Workshop - Here Build on Those Recommendation Sets

2. Support Global in situ Measuring Network (Define How it Will be Used Jointly With Space-Borne Measurements)

3. Develop a Structured Record of Science and Operational Applications (Multi-Model)

4. Work on Mitigation Strategies for Common Risk Elements

5. Joint Algorithm Tests, Auxiliary Data Preparation, Field Experiments