A dual-frequency SAR Mission for Hydrology and Climate Research in Cold Environment

Claude Duguay & other MAG members of CoRe-H₂O
Outline of Presentation

• Background
• Mission objectives
• Observational requirements
• Preliminary system concept
• Field experiments/science studies
Background
- Science Team of the CoReH$_2$O Proposal -

Proposal submitted in response to the Call for Ideas for the next Earth Explorer Core Missions, 2005

Monique Bernier - CAN
Robert G. Brakenridge - USA
Donald Cline - USA
Robert E. Davis - USA
Jean-Pierre Dedieu - F
Wolfgang Dierking - DE
Matthias Drusch - ECMWF
Richard Essery - UK
Pierre Etchevers - F
Martti Hallikainen - SF
Svein-Erik Hamran - N
Stefan Kern - DE
Ron Kwok - USA
Peter Lemke - DE
Eirik Malnes - N
Kyle McDonald - USA
Heinz Miller - DE
Industrial Partner: EADS Astrium GmbH Friedrichshafen

Keith Morrison - UK
Thomas Nagler - AT
Son Nghiem – USA
Johannes Oerlemans – NL
Paolo Pampaloni - IT
Kim Partington - UK
Shaun Quegan - UK
Walter L. Randeu - AT
Helmut Rott – AT (Chair)
Mathias Schardt - AT
Jiancheng Shi - USA
Detlef Stammer - DE
Rasmus T. Tonboe - DK
Wolfgang Wagner - AT
Anne Walker - CAN
Urs Wegmüller - CH
Simon Yueh - USA
Background
- Mission Assessment Group (MAG) -

- Helmut Rott, Austria
- Claude Duguay, Canada
- Richard Essery, UK
- Christian Haas, Germany
- Giovanni Macelloni, Italy
- Eirik Malnes, Sweden
- Jouni Pulliainen, Finland
- Helge Rebhan, The Netherlands

US-Observers:
- Simon Yueh, JPL
- Don Cline, NOAA

- Technical and scientific studies over a 12-month period.
- “Report for Assessment” to be finalised by spring 2008.
CoReH₂O addresses all main (surface) components of the cryosphere with an emphasis on snow cover.

**LAND SURFACES**
- Land cover
- Water cycle
- Albedo
- Surface temperature
- Wet lands
- Eco-systems
- Carbon cycle

**ATMOSPHERE**
- Temperature
- Pressure
- Motion
- Composition (clouds, precipitation, trace gases, etc.)

**OCEAN**
- Temperature
- Salinity
- Circulation
- Sea level

**Frozen Ground**
- Permafrost
- Heat exchange
- Gas exchange
- Carbon cycle

**Snow Cover**
- Accumulation
- Melt
- Runoff
- Water supply
- Exchange of heat, moisture, momentum

**Glaciers**
- Ice Caps
- Mass balance
- Atmospheric forcing
- Runoff
- Water supply

**Ice Sheets**
- Ice Shelves
- Mass balance
- Accumulation
- Exchange of heat, momentum, and water

**River and Lake Ice**
- Extent
- Thickness
- Energy exchange
- Runoff routing

**Sea Ice**
- Thickness
- Growth
- Snow accumulation
- Melt
- Exchange of heat, momentum

Source: IGOS Cryosphere Theme, 2007
For hydrology CoReH$_2$O aims at closing the gaps in spatially detailed information on snow, glaciers, and surface water, in order to serve the following objectives:

• Improving the modelling and prediction of water balance and stream flow for snow covered and glacierised basins (including ungauged basins).

• Understanding and modelling the water and energy cycles in high latitudes.

• Assessing and forecasting water supply from snow cover and glaciers, including the assessment of effects of climate change.

• Monitoring land surface water extent in high latitudes and studying its relation to climate variability.
CoReH₂O will contribute to weather and climate research by:
• Providing new observation types for advanced data assimilation systems for the initialization of numerical models.
• Improving parameterization of snow and ice processes in NWP and climate models.
• Improving the understanding and modelling of land-cryosphere-atmosphere exchange processes.
• Providing data for the validation of GCMs and meso-scale meteorological models.
• Improving the estimates of glacier and ice sheet mass balances.
Secondary Mission Objectives (2)

CoReH$_2$O will contribute to the characterisation of marine and freshwater ice parameters:

- Monitoring surface melt and melt season length for studies of seasonal sea ice albedo evolution and energy flux partitioning.
- Contributing to understanding of regional ice kinematics and dynamics in marginal ice zones.
- Improving estimates of surface heat fluxes and mass balance and their variability by retrieving properties of snow cover on the ice.
- Mapping thin ice types and polynyas and their temporal evolution for heat flux estimations.
- Improving understanding of coastal ocean wind effects on sea ice extent, polynyas, and leads.
- Observing freezing state and properties of lake (and river) ice covers.
### Key Observational Requirements (1)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Spatial scale [m]</th>
<th>Repeat interval</th>
<th>Accuracy (RMS)</th>
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<td>-Threshold</td>
<td>-Goal</td>
<td>Global</td>
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<td>250</td>
<td>3-15 d</td>
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<tr>
<td>Water equivalent</td>
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<td>15 d</td>
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<td>2.) Secondary Parameters</td>
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<tr>
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<td>250</td>
<td>3 d</td>
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<td></td>
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<td>100</td>
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<tr>
<td>Snow depth</td>
<td>500</td>
<td>250</td>
<td>3-15 d</td>
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<tr>
<td></td>
<td>100</td>
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<td>Facies type</td>
<td>200</td>
<td>100</td>
<td>15 d</td>
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<td>200</td>
<td>15 d</td>
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<td>Terminus position, lakes</td>
<td>N/A</td>
<td>50</td>
<td>15 d</td>
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<tr>
<td>Ice area</td>
<td>N/A</td>
<td>50</td>
<td>3 d</td>
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<tr>
<td>Sea Ice</td>
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<tr>
<td>Snow Depth</td>
<td>N/A</td>
<td>200</td>
<td>3-15d</td>
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<td>100</td>
<td>3 d</td>
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<td>3 d</td>
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<tr>
<td>Surface Water</td>
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<tr>
<td>Extent of open water areas</td>
<td>100</td>
<td>50</td>
<td>3-15 d</td>
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</table>
Key Observational Requirements (2)

http://stratus.ssec.wisc.edu/cryos/documents.html
### General Mission Configuration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
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<tbody>
<tr>
<td>Mission duration</td>
<td>4 years min., target 5 years</td>
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<tr>
<td>Sensors</td>
<td>Ku-band (17GHz) SAR, X-band (9.6GHz) SAR</td>
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<tr>
<td>Polarisation</td>
<td>VV and VH</td>
</tr>
<tr>
<td>Incidence angle</td>
<td>30 ° 40 deg.</td>
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<tr>
<td>Swath</td>
<td>&gt; 100 km (ScanSAR)</td>
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<tr>
<td>Spatial resolution</td>
<td>50 m (multi look with # of looks &gt;5)</td>
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<tr>
<td>Temporal co-registration (X-Ku)</td>
<td>30 ° 60 min</td>
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<tr>
<td>Spatial co-registration (X-Ku)</td>
<td>0.5 pixel</td>
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<tr>
<td>Orbit</td>
<td>Polar dawn/dusk, 98 deg. inclination</td>
</tr>
<tr>
<td></td>
<td>LTAN: 06:00 +- 30 min</td>
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</table>
Potential SAR Satellite Configuration

SAR Instrument:
- 2 frequencies 9.6 and 17.2 GHz
- VV and VH Polarisation
Results from Scatterometer Data

**SWE retrieved from QuikSCAT Ku-band data using a radiative transfer model function compared to observations (Cline, 2004).**

Snow accumulation at NASA-SW station in Greenland and QSCAT retrieval (S. Nghiem)

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**CoReH20**  
*European Space Agency  
*Agence spatiale européenne*

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Preliminary System Concept (3)  

Polar Snowfall Hydrology Mission Workshop (Montréal, Canada)  
26-28 June 2007
## Requirements for Different Mission Phases

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
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<tbody>
<tr>
<td><strong>Repeat cycle</strong></td>
<td>3 days</td>
<td>12-15 days</td>
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<tr>
<td><strong>Orbit</strong></td>
<td>dawn/dusk, sun syncr.</td>
<td>dawn/dusk, sun syncr.</td>
</tr>
<tr>
<td><strong>Spatial coverage</strong></td>
<td>constrained by swath width with emphasis to cover selected test areas</td>
<td>global, permanent gaps (up to 5%) are acceptable</td>
</tr>
<tr>
<td><strong>Coverage to be optimised for latitudes</strong></td>
<td>n.a.</td>
<td>Northern hem.: 40 ° 88 Southern hem. 40 ° 82</td>
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<tr>
<td><strong>Data latency</strong></td>
<td>3-6h for special experiments  1-3 d nominally</td>
<td>7 d</td>
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</table>

Phase 1: Years 1 and 2  Phase 2: Years 3+
Objectives:

• To identify the capabilities and limitations of microwave scattering models.

• To give first guidance on observational strategies and algorithms.

• To assess the maturity of algorithms.
Ku-band measurement campaign in Austria Jan-Mar 07:
- First experimental field measurements with existing radar system
  - time series for a specific test site
  - Intensive in-situ sampling of snow parameters

Cold Land Processes Field Experiments (CLPX-II)
Merci / Thank you
Backup Slides
### Work Plan and Schedule (1)

<table>
<thead>
<tr>
<th>WP No.</th>
<th>WP Title</th>
<th>Institution</th>
<th>WP Manager</th>
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<td>Project Management</td>
<td>ENVEO</td>
<td>H. Rott</td>
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<td>Review of Models, Methods, and Experimental data</td>
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<td>210</td>
<td>Review of Backscatter Models and Retrieval Algorithms</td>
<td>FMI</td>
<td>J. Pulliainen</td>
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<td>220</td>
<td>Review of Experimental Work and Compilation of Data Sets</td>
<td>NORUT</td>
<td>E. Malnes</td>
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<tr>
<td>300</td>
<td>Assessment of Critical Issues</td>
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<td>Atmospheric Propagation Effects</td>
<td>FMI</td>
<td>J. Pulliainen</td>
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<td>320</td>
<td>Effects of Snow Physical Properties</td>
<td>FMI or NORUT or ENVEO</td>
<td>J. Pulliainen</td>
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<td>Effects of Vegetation and Topography</td>
<td>IFAC</td>
<td>G. Macelloni</td>
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<td>Physical Properties of Sea Ice, Lake Ice, and Glaciers</td>
<td>AWI</td>
<td>C. Haas</td>
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<td>Retrieval Algorithms</td>
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<td>Specifications for Level-1 Satellite Products</td>
<td>NORUT</td>
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<td>Snow Retrieval Algorithms over Land Surfaces and Glacier Ice</td>
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<td>Retrieval Algorithms for Sea and Lake Ice</td>
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<td>Impact of Satellite Snow Products for Process Models</td>
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<td>Use of CoReH2O Products for Snow Process Models</td>
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<td>Conclusions and Recommendations</td>
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# Work Plan and Schedule (2)

## Time Schedule
(started 1 May 2007)

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Innsbruck
16-20 July 2007
Models for Snow Scattering and SWE Retrieval

1.) Discrete dipole approximation (DDA)
   • computing scattering of radiation by particles of arbitrary shape. (Purcell, Pennyacker, 1973)
   • adopted for snow scattering models (Pulliainen, Hallikainen)

2.) Dense Medium Radiative Transfer (DMRT)
   • Applied for numerical simulation of $\sigma^\circ$ for a wide range of snow conditions.
   • Algorithm developed for SWE estimation with dual-frequency (9.6 & 17 GHz) & polarization (VV and HV) SAR by scattering decomposition (J.C. Shi, UCSB)
   • Depolarization factor for dry snow proportional to the scattering contribution in co-polarization signals; used to decompose surface and volume scattering

With the estimations of scattering albedo and optical thickness at two frequencies, SWE can be retrieved.
Scattering at different frequencies and polarisation

Each Scattering Contribution in % for 3 Components
Scientific Issues

CoRe-H2O very ambitious in claimed accuracies

-> Dedicated scientific studies together with in-situ campaigns

Particular issues to assess:

• Feasibility of required observation accuracy using X- and Ku-band (17.2 GHz) SAR data (e.g. ambiguity between snow depth and water equivalent)
• Decomposition of grain size effects and snow mass (SWE) in backscattering signatures.
• Layover in mountain terrain, snow in presence of vegetation and in forested areas
• Atmospheric effects
Technical Studies

Technical Design Phase-0 study with industry to assess implementation concepts

• Status: start foreseen May/June 2007

Ku-band Scatterometer development

• Objectives:
  To develop a scatterometer at Ku-band for ground-based campaigns;
  To perform an initial proof-of-concept campaign for demonstrating its functionality and performance.

• Status: start foreseen mid 2007