IceCube: Spaceflight Validation of an 874-GHz Submillimeter Wave Radiometer for Cloud Ice Remote Sensing


NASA Goddard Space Flight Center, Greenbelt, Maryland
Outline

• Importance of ice clouds in Earth climate and weather systems

• Limitations and gaps of current remote sensing from space

• IceCube to enable future global cloud ice measurements at submm-wave

• IceCube project development and challenges
Importance of Ice Clouds and Their Processes

• Climate models
  – Cloud as the leading uncertain factor in predicting climate change on this water planet.
  – Too many degrees of freedom
  – Tunable parameters: cloud cover, water content, microphysics
  – Differences by 2x - 10x

• Cloud-precipitation processes
  – Interactions with dynamics
  – Water vapor
  – Microphysics
  – Vertical development
  – Lifecycle and distribution

Li et al., (JGR, 2012)

Gong and Wu (2014)
Submillimeter-Wave Radiometry for Cloud Ice Remote Sensing in the Upper Troposphere
Ice Cloud Scattering at Submm-Wave

- Higher sensitivity to cloud scattering at submm-wave
- Cloud-induce radiance, $T_{cir}$, proportional to cloud ice water path (CIWP)
- Cloud microphysical properties (i.e., particle size) from different frequencies
- Simultaneous retrievals with $T$, $H_2O$
NASA/GSFC Airborne Sensor:
Compact Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)

Evans et al. (2005)

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<th>Tsys (K)</th>
<th>NEDT (K)</th>
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- CRYSTAL-FACE campaign near Florida in July 2002
- Co-flight of CoSSIR and 94-GHz Cloud Radar System (CRS)
- Simultaneous retrievals of ice water path (IWP) and particle size ($D_{me}$) from CoSSIR
- Simultaneous retrievals of ice water content (IWC) and $D_{me}$ from CoSSIR and CRS
CoSSIR in Tropical Composition, Cloud and Climate Coupling (TC4)

Evans et al. (2012)

- Flights on ER-2 near Costa Rica in Aug 2007
- First time to fly 874-GHz cloud radiometer (11 channels)
- Tsys=\approx 5000 \text{ K}, \text{ BW}=5 \text{ GHz}, \text{ NEdT}=0.84 \text{ K}, \text{ H-Pol}
- WB-57 and DC-8 underflights of ER-2 (CoSSIR) to study cirrus anvils
- Dual-axes gimbals for programmable scan patterns.
IceCube Objectives

Climate Research Needs
• Accurate cloud ice measurements.
• Cost-effective, sensitive instruments for diurnal and global coverage.
• Mature technology

IceCube Objectives
• Raise overall TRL (5->7) of 874-GHz receiver technology
• Reduce instrument cost and risk by developing path-to-space for COTS submm-wave receiver systems
• Enable remote sensing of global cloud ice with advanced technologies and techniques

Pros
• Good sensitivity to small cloud ice
• Compact and mature receiver technology
• Day-night measurements

Cons
• Large attenuation from water vapor
• High power consumption
874-GHz measurement requirements:
- Accuracy < 2 K
- Precision (NEdT) < 0.25 K
- Spatial resolution < 15 km

Mission requirements:
- In-flight operation 28 days
- Periodical views of Earth (science) and space (calibration) within an orbit
- Science data 30+% (8+ h/day)
- Pointing knowledge < 25 km

Validation plan:
- Lab measurement and verification
- Modeled vs observed clear-sky radiances for accuracy verification
- Space-view radiances for precision verification
IceCube Challenge #1: 
874-GHz Radiometric Calibration

Calibration Challenges:
1. Stable $C_1$ from space view
   Spinning S/C (~2.25 min/rev)
2. Receiver gain variations
   $G = G_1 G_2$
   $G_1 = G_1(T)$ to be measured in lab
   $G_2 = G_2(t)$ from noise diode

$TB = TB_1 + G(C - C_1)$
Spinning CubeSat: In-Flight Calibration

$$TB = TB_1 + G_1(T)G_2(t)(C - C_1)$$

Key assumptions:
1. Linear TB-count relationship
2. $C_1$ constant during Earth view
3. $G_1(T)$ same as measured in lab

Note: #2 needs to be valid only within a spin cycle (2.25 minutes)

Adv. with spinning S/C:
1. Accurate gain monitoring
2. Attitude control stability
3. No moving parts needed for instrument
IceCube Challenge #2: Large Orbital Thermal Variations

Constraints:

- Preferred instrument operation temperatures: 20C-30C
- Low CubeSat/instrument mass, or thermal inertia, for thermal stability
- Wide range of beta angles: -75° to 75°
- Day-on and night-off operation
- Spin around the Sun-pointing axis

Colorado Student Space Weather Experiment (CSSWE)
[Gerhardt et al., 2013]
IceCube Flight Configuration

- Instrument Section (w/ antenna aperture)
- Top Plate w/ aux solar panel
- Solar Arrays (Deployable) cells face sun vector
- +Y Shear Panel
- GPS Antenna
- Umbilicals
- UHF Antenna
- Solar Array mount panel
- Main Panels (w/ rails)
- S/C Bottom Plate
- 340 mm [13.4”]

Courtesy of John Hudeck
Launch Opportunity and Orbit

• NASA CubeSat Launch Initiative (CSLI)
  – Coordination of upcoming launches
  – 1U, 2U, 3U, or 6U

• International Space Station (ISS)
  – Secondary cargo payload on ISS resupply missions
  – Mid 2016
  – 350-450 km, 51.6° inclination near-circular orbit
  – β angle variation: 0-75°

• 3U CubeSat Launchers
  – NanoRacks CubeSat Deployer from ISS
  – Small-Sat Orbital Deployer (J-SSOD) from ISS/JEM
  – NASA NEXT
IceCube Communication System
at NASA/GSFC Wallops Flight Facility (WFF)

WFF 18 M Ant.

50ohm load

TX

449.98MHz

20db LNA

468MHz

IceCube Power Amp (27dBm)
TE Sys. Power Amp 1647185

Position Propagator

NORAD (TLE)

Point Dish

IceCube Spacecraft

UHF Ant.

380 TO 480MHz

Interface TBD

Downlink (RX)
USRP N210
Ettus USRP2 w/WBX Daughtercard

Coax SMA

Interface TBD

L3 Cadet UHF Radio

Flight CPU

RS-422 or TTL

8 TO 13VDC

Coax SMA

IceCube Spacecraft

SDL Computer

Mission Operations Computer

Interface TBD

IceCube Development Kit

Uplink (TX)

SDS

Coax SMA

RS-422 or TTL

8 TO 13VDC

50ohm load

RX

IceCube Communication System

Downlink

Wallops Supplied
Filters & Amplifiers

IceCube
Communcation System

at NASA/GSFC Wallops Flight Facility (WFF)

Courtesy of Brian Corbin (WFF)
WFF UHF Ground-station Contacts

IceCube Contact to WFF UHF Ground Station

Time - GMT (Hrs/Min)


MM/DD in 2016

6/26 10/30
Project Schedule

Mission Formulation (Phase A/B)
- ATP
- System Analysis and Trades
- Programmatic Assessments
- Requirements and Interface Definition
  - SRR/MDR (End Phase A)

System Preliminary Design
- Table Top Design Review (End Phase B)
- System Preliminary Design
- SRR/MDR (End Phase A)
- Requirements and Interface Definition
- Programmatic Assessments
- System Analysis and Trades
  - ATP
- Mission Formulation (Phase A/B)

Mission Implementation (Phase C/D)
- System Detail Design
- CDR (End Phase C)
- System Integration & Test
- Instrument Test
- Instrument Fabrication & Assembly
- CubeSat Fabrication & Assembly
- Flight Simulation
- System Integration & Test

Launch, Operations, Data Analysis (Phase E/F)
- Data Analysis
- Flight Operations
- FRR (End Phase D)
- PPOD Integration
- PSR

Launch, Operations, Data Analysis (Phase E/F)
- Flight Simulation
- System Integration & Test
- CubeSat Fabrication & Assembly
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Project Challenges and Pathways

• Not traditional kind of NASA missions
  – Limited resources and tight schedule
  – Short, quick path to space for science exploration

• Risk management
  – Take risks and spread them evenly
  – Mitigate risks associated with CubeSat and instrument thermal environments
Acknowledgments

• NASA ESTO, SMD and CSLI supports
• IceCube Team

PI
Deputy-PI
Tech Lead
Mission Sys Engr.
Mgt. Support

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Esper, Jaime (GSFC)
Mast, William (WFF)
Johnson, Tom (WFF)

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Inst. Lead
Antenna Engr.
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Power
Power
Mechanical Engr.
Parts Support
DSP Engr.
Inst Video Amp/RIC
RF Engr.

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Solly, Michael
Fetter, Lula (Lu)
Wong, Mark (Englin)
Lu, Daniel
Hersey, Ken

CubeSat, Ground System, Op (WFF, VA)
Power Systems
Power Systems
Software/Avionics
Software/Avionics
Mechanical/Thermal
Mechanical/Thermal
GN&C

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Daisey, Ted
Lewis, Christopher
Huideck, John
Smith, Sally
Heatwole, Scott

874-GHz Receiver (Virginia Diode, Inc)
Tech POC
LO Drive Module Design
Integration and Testing
CAD and Mechanical

Hesler, Jeff
Bryerton, Eric
Retzloff, Steven
Neff, Chuck
Examples CoSSIR in TC4

Evans et al. (TC4 Sci Meeting, 2008)
IceCube Operations

Spacecraft attitude is not controlled during eclipse. Instrument is OFF, heater ON.