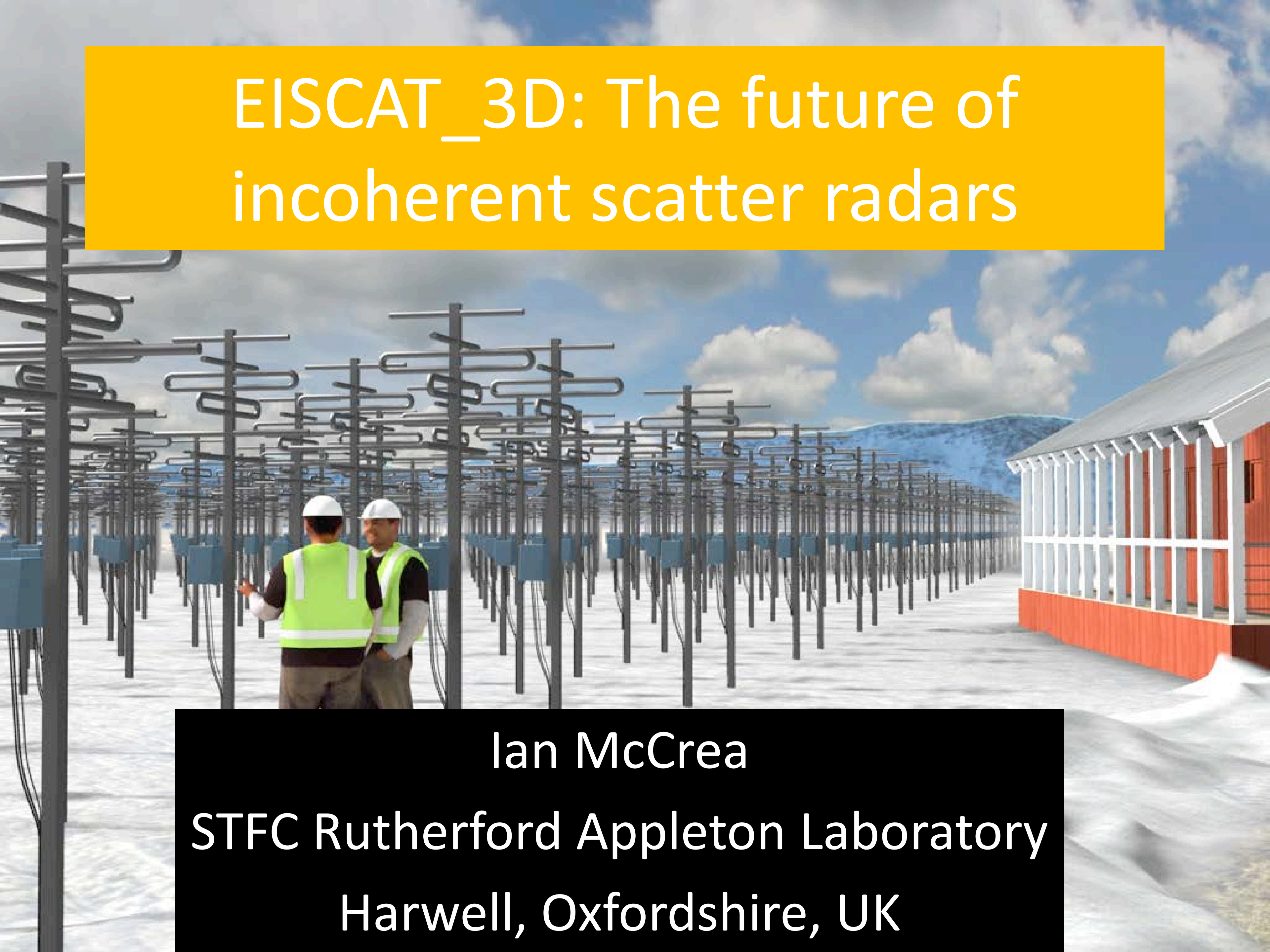
EISCAT_3D: The future of incoherent scatter radars



Ian McCrea
STFC Rutherford Appleton Laboratory
Harwell, Oxfordshire, UK

EISCAT Scientific Association

International research infrastructure

Founded 1975

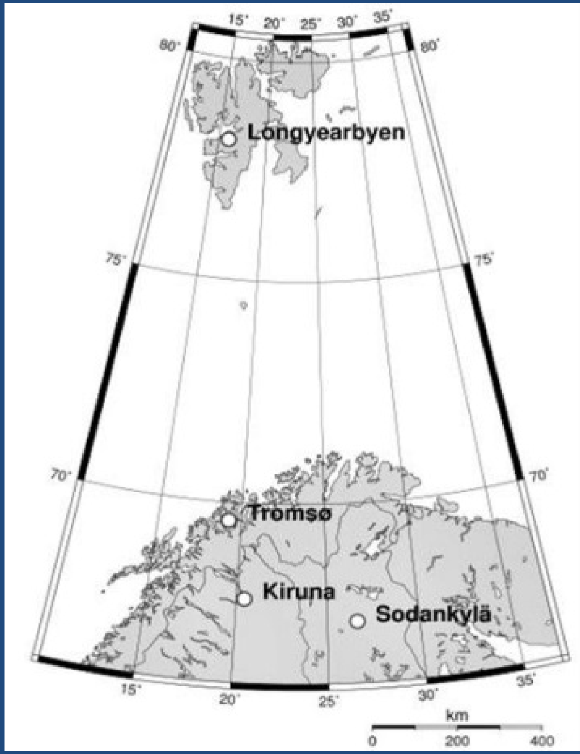
HQ in Kiruna, Sweden

Facilities in Norway, Sweden, Finland and on Svalbard

Six core member countries (Norway, Sweden, Finland, UK, Japan, China)

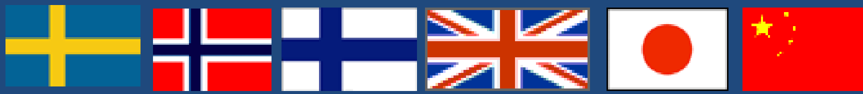
Currently four affiliate members (Russia, France, Ukraine, South Korea)

Discussions with a number of others (including USA and South Africa)

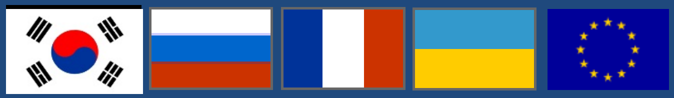


EISCAT Scientific Association

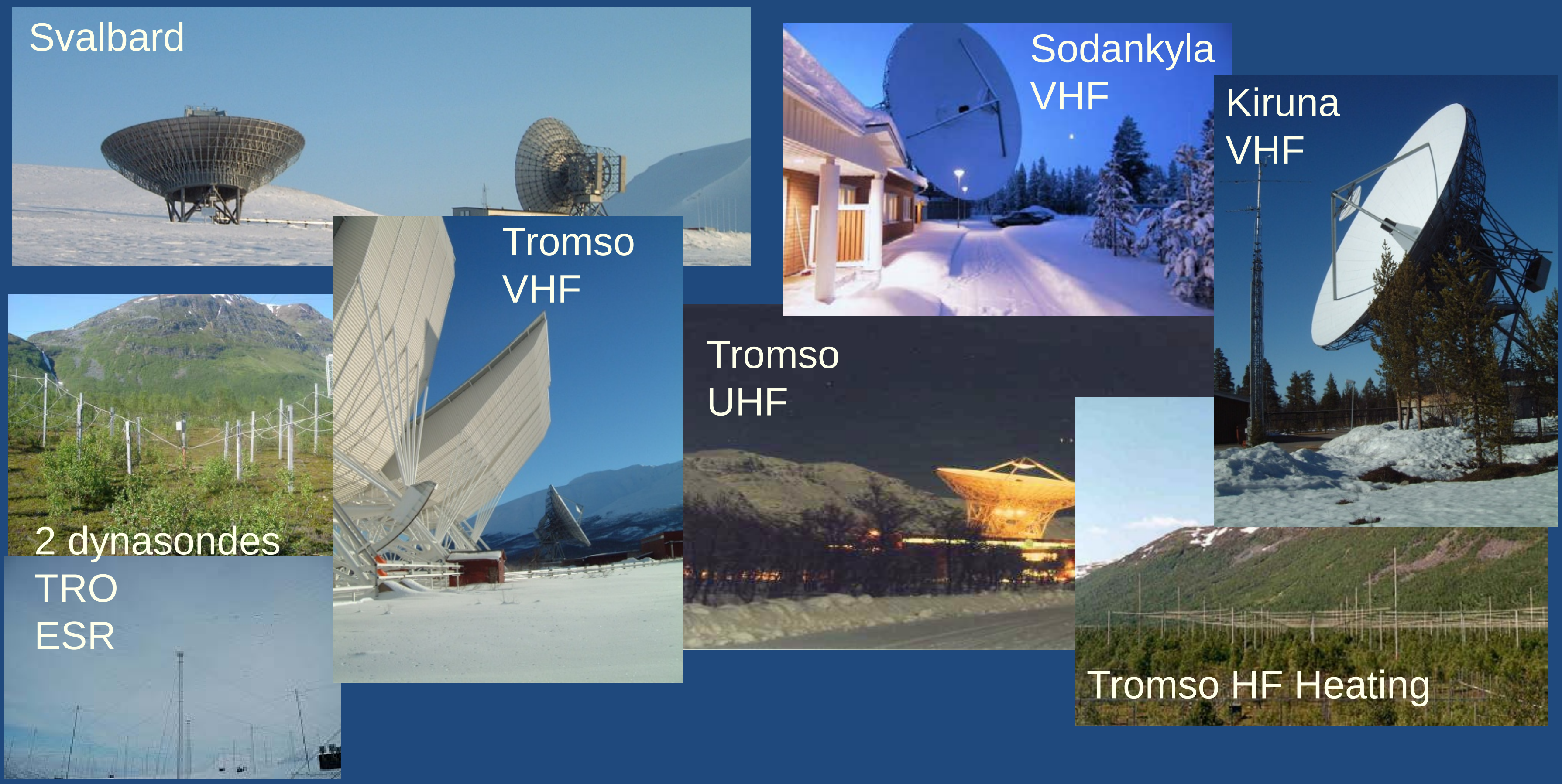
Associate countries and institutes



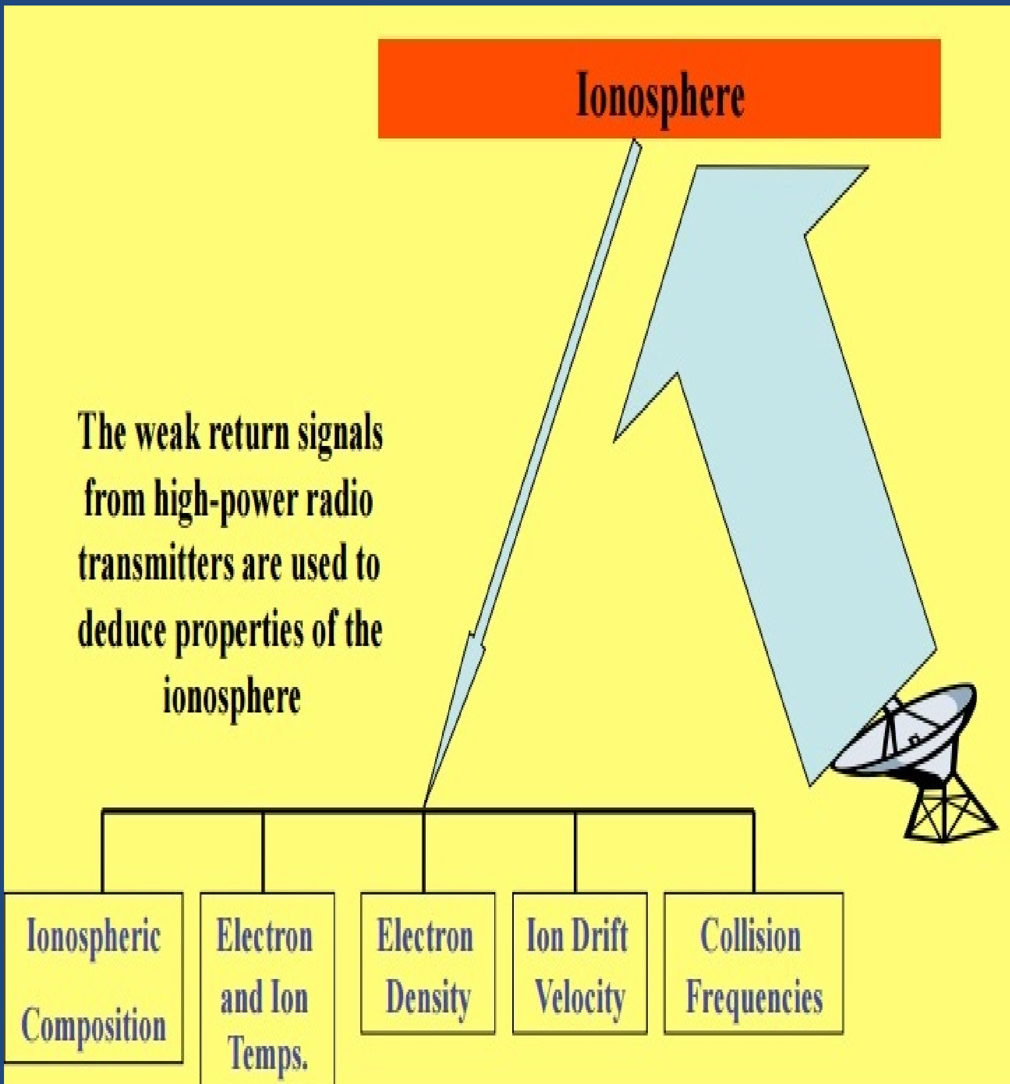
Contributing:

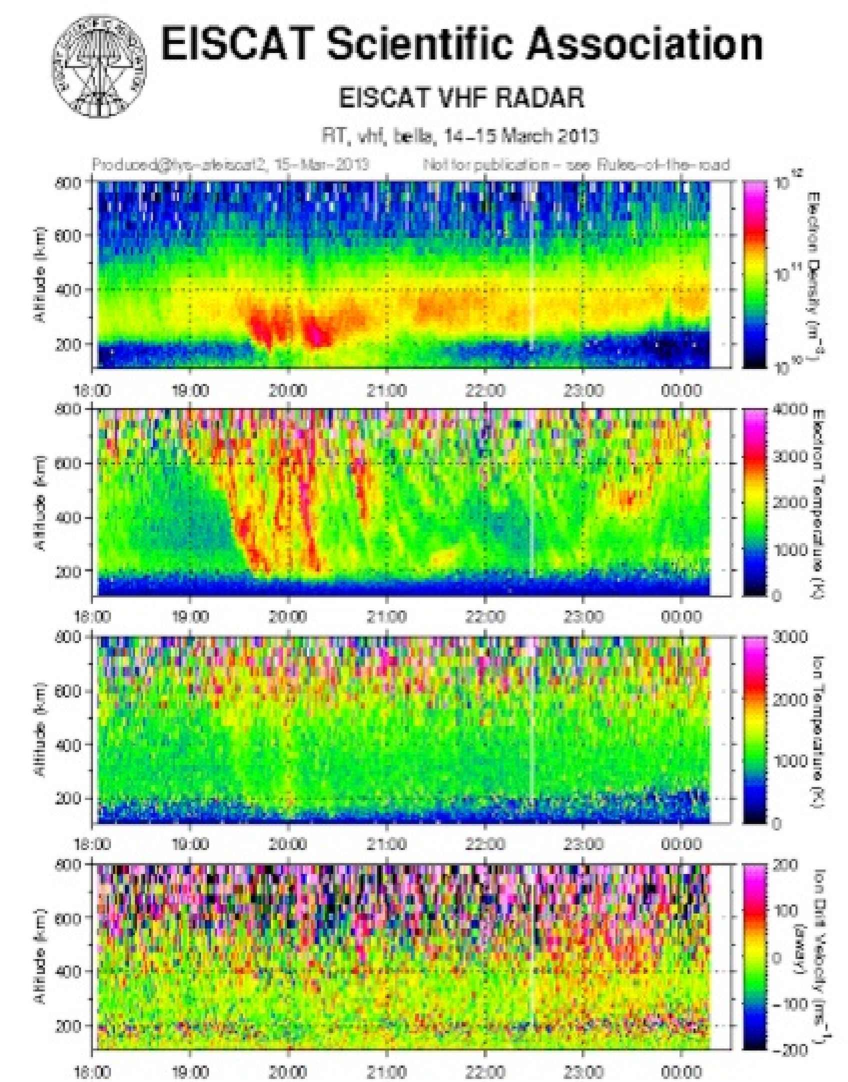


EISCAT Incoherent Scatter Radars

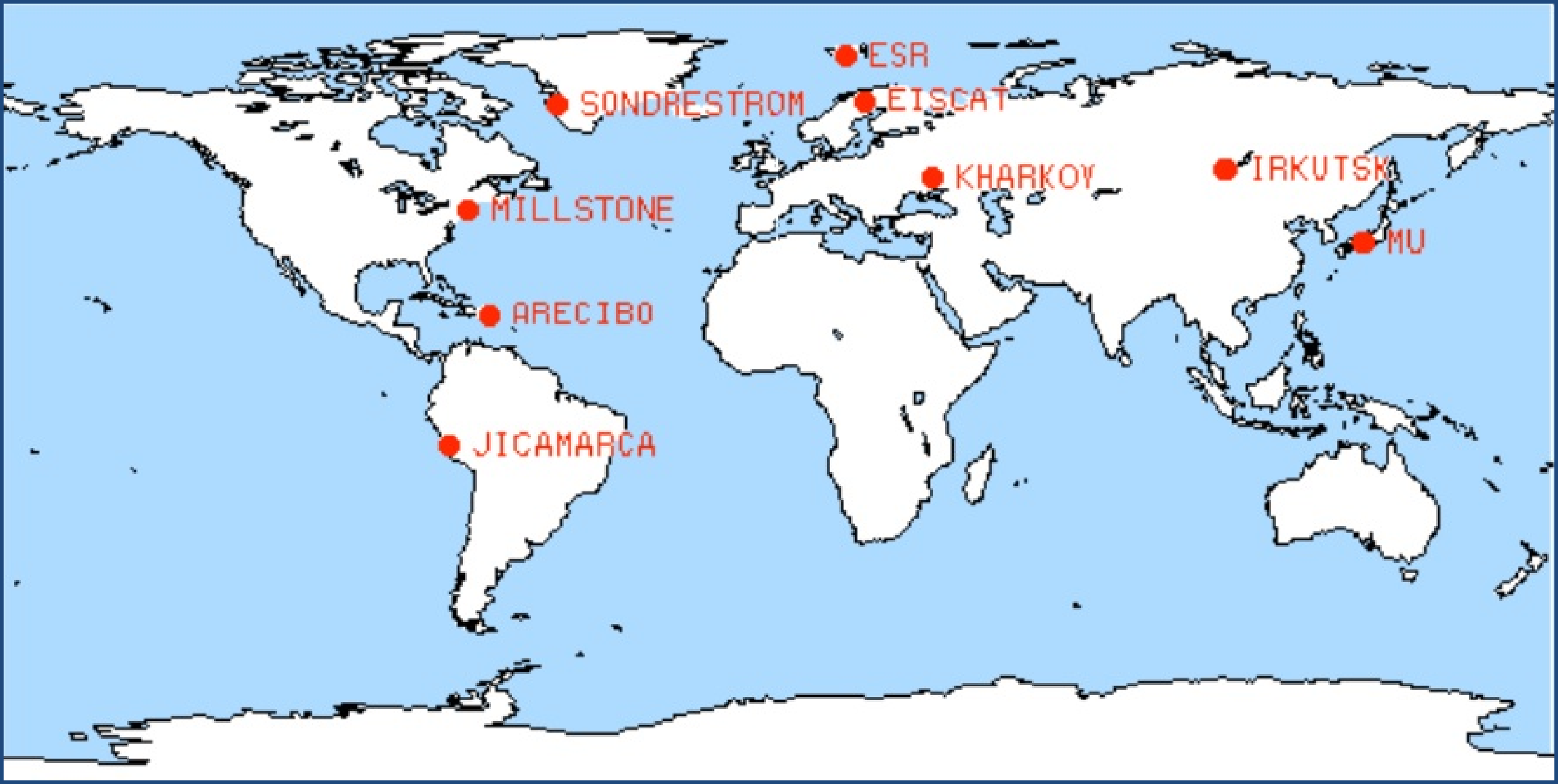


ISR Technique and Data

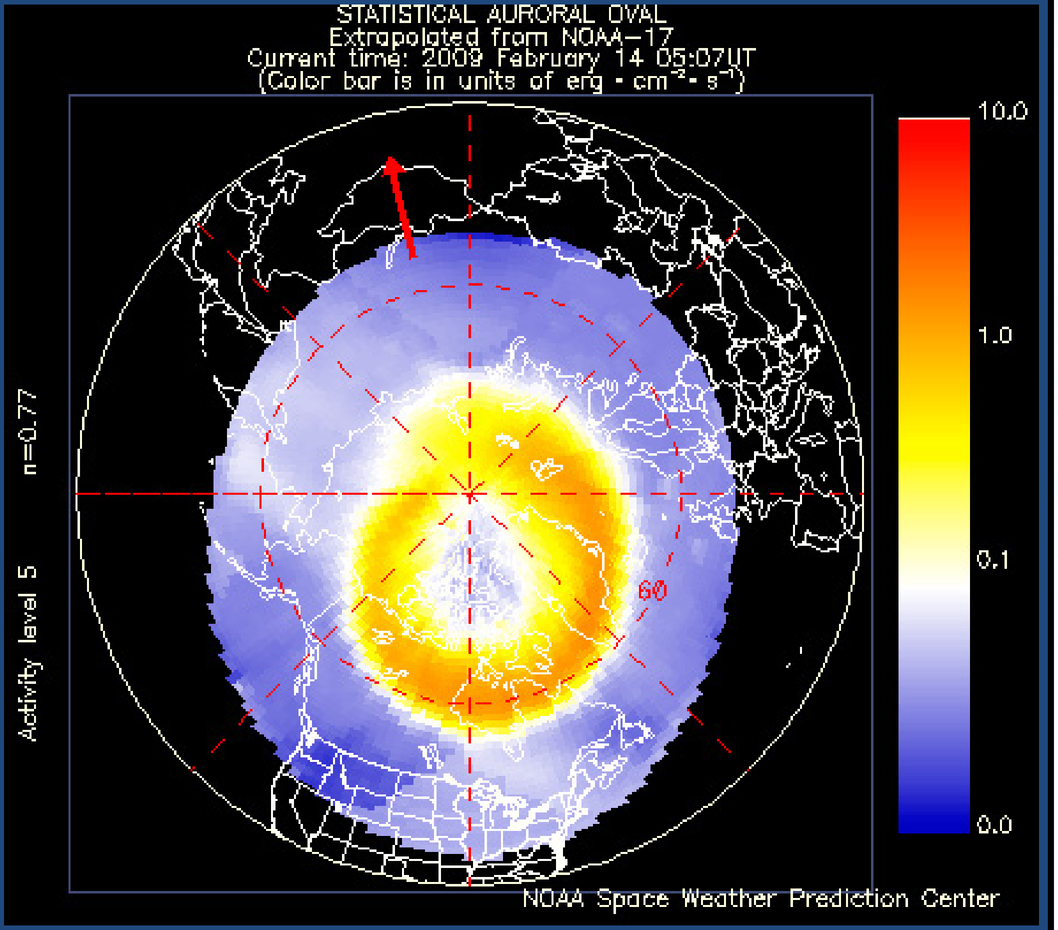


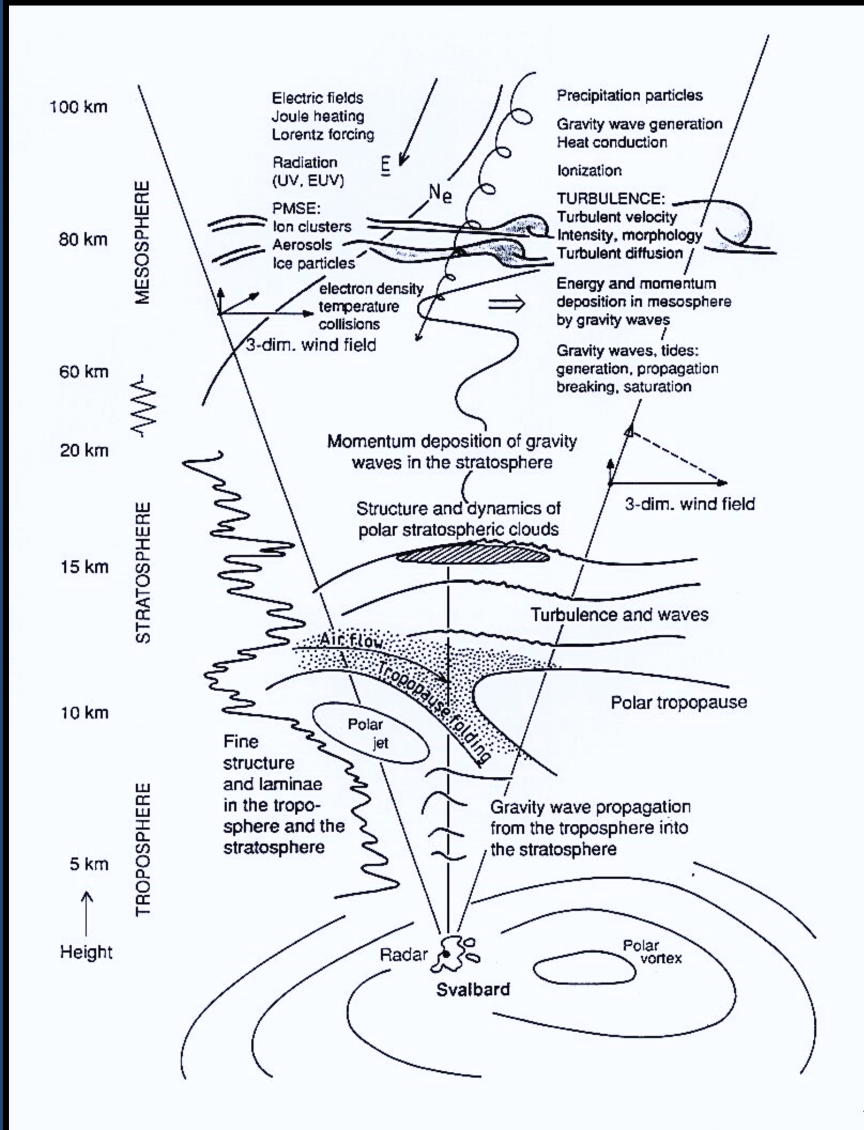


The Global ISR Network



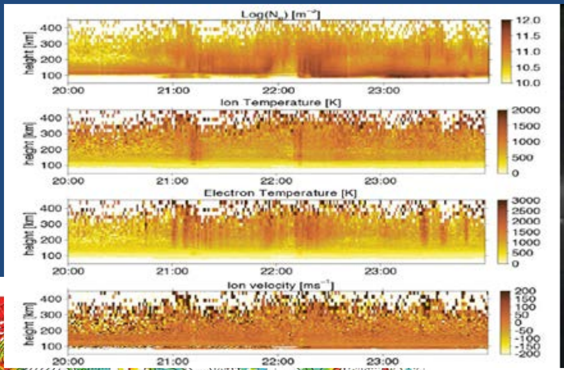
Why our location is special

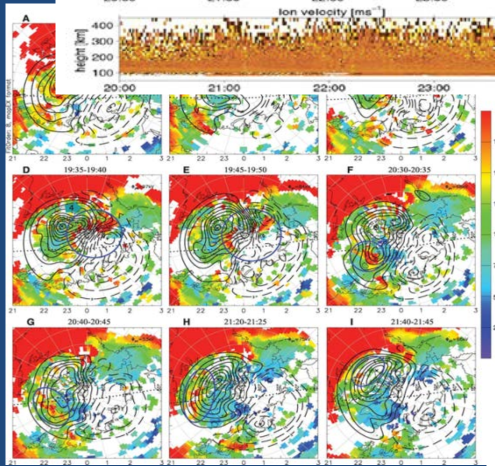


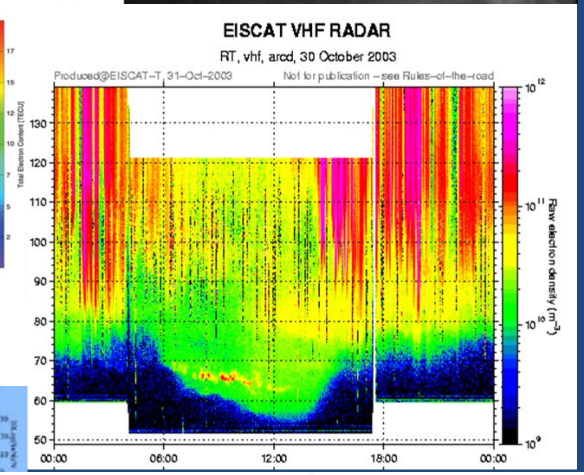


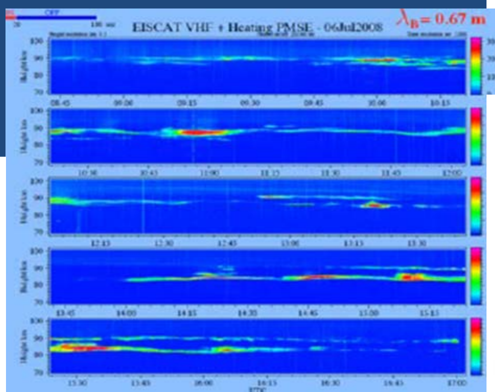
EISCAT Science

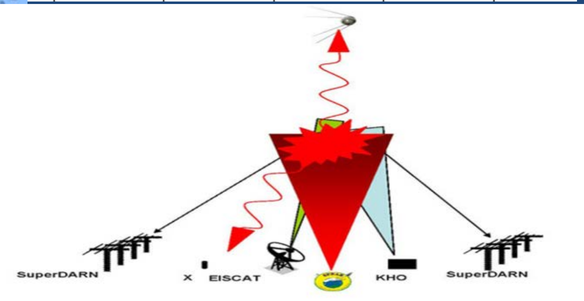
- Ionospheric structure
- Magnetosphere coupling
- The aurora
- Energetic particles
- Plasma processes
- Atmospheric coupling
- Mesospheric echoes
- Solar wind studies
- Meteors and NEOs
- Long-term trends

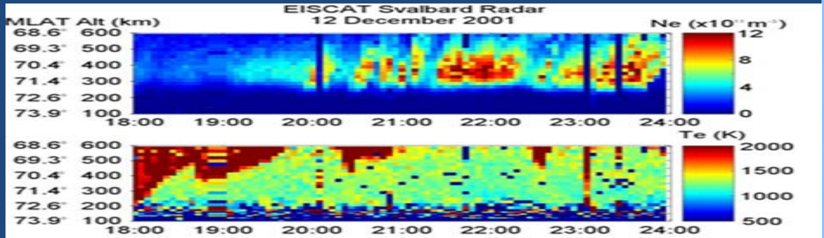




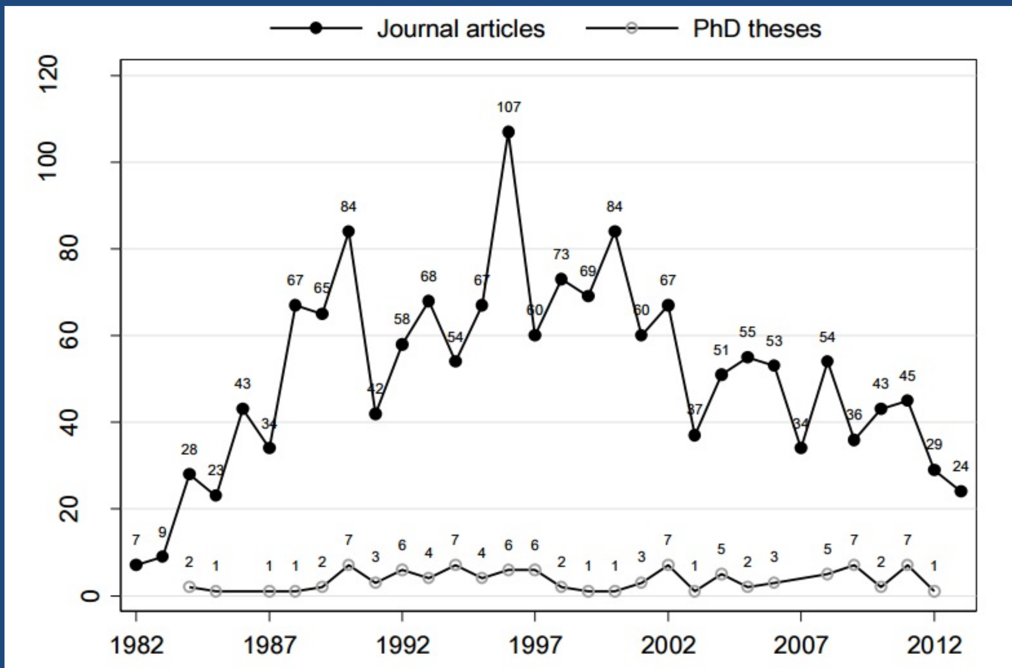




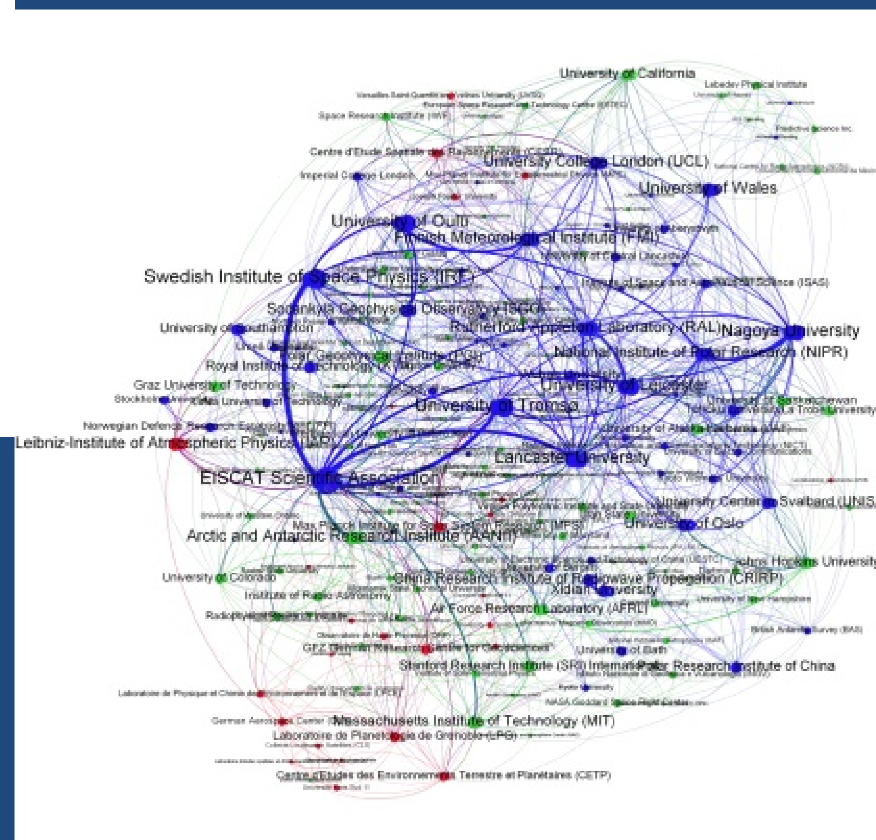




EISCAT Publications and Collaborations



Excellent international collaboration!



>2100 papers
~60 UK PhD theses
~50 MSc theses

Where is our science heading?

To higher altitudes

- Role of ionosphere in magnetosphere structure/dynamics
- Ion outflow and acceleration processes

To lower altitudes

- Plasma-Atmosphere interactions
- Energetic particles, chemistry and heat balance
- Wave breaking and effects on dynamics

To smaller scales

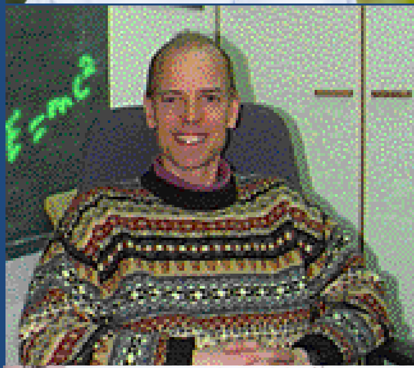
- Small-scale non-thermal structures
- Effect of small scale processes and large-scale dissipation

To larger scales

- Ionosphere as a “screen” for magnetospheric physics
- Cross-scale energy coupling
- Contextual support for a new generation of space missions

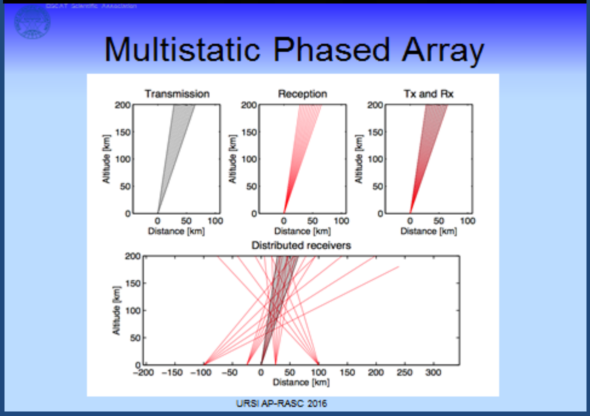
To continuous operations

- Monitoring role (synergy with models and services)
- Capturing rare events
- Operational roles for observing systems

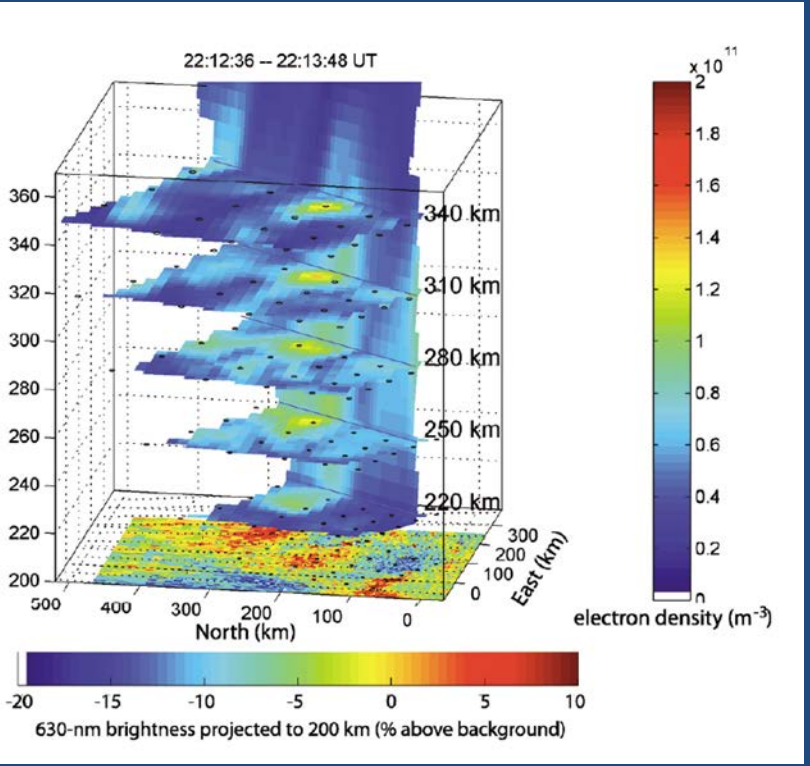


Why we need a new radar

- **More sensitivity**
  - For high and low altitudes
  - Good data even at low average power (duty cycle)
- **Multiple beams or fast scanning**
  - For broad spatial coverage (volumetric imaging)
- **Multistatic, multibeam data**
  - For vector fields
  - For multistatic parameter determinations
- **Imaging capabilities and narrow beams**
  - For small-scale structure
- **Continuous operations, adaptive experiments**
  - For capturing rare events
  - Responding to changing conditions



The first phased array ISRs



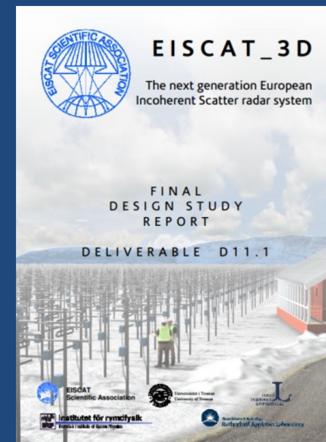
Dahlgren et al, 2012

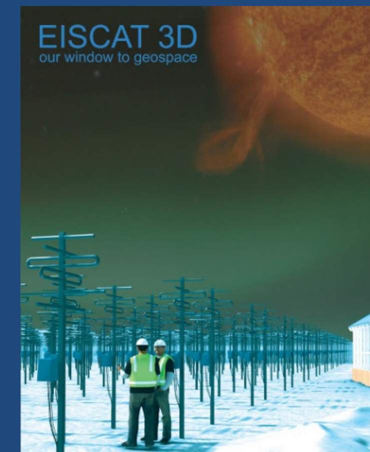
EISCAT_3D System Concept

- **Multistatic (five site) volumetric vector-imaging radar**
- **Good geometry for vector determinations**
  - North-South and East-West baselines
- **Fully digital beam-forming at all sites**
- **Figure-of-merit an order of magnitude better than existing radars**
  - 10 MW peak transmitter at central site
  - 16,000 antennas at each site
- **Distributed solid-state transmitters**
  - Continuous unattended operations (mostly low duty cycle)

EISCAT_3D Timeline

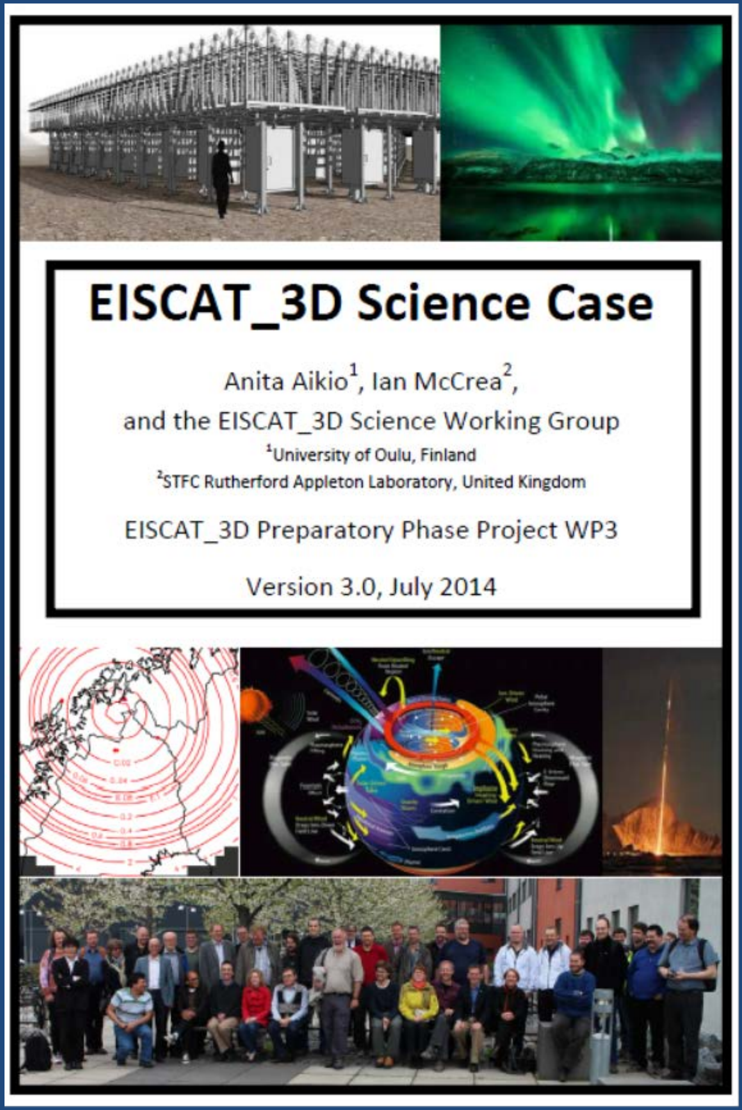
- 2002: First discussions of phased array replacements for EISCAT mainland
  - Discussions at EGU in Nice
  - First brochure for “E-Prime” (2003)
- 2004: Application for EU-funded design study under Framework 6 programme
  - Intended to gain experience, but succeeded at first attempt!
- 2005-2009: EU FP6 Design Study
  - Total cost 2.6M Euro, 368 staff months
  - Basic system design and first discussion of logistics
- 2006: EISCAT_3D added to ESFRI Roadmap
  - As part of the Environmental Chapter
  - Opened many doors for the project
- 2010-2014: EU FP7 Preparatory Phase
  - Further iteration of the design
  - Development of the science case
  - First prototypes and field tests
  - Discussions with national authorities
  - Outreach to local community
- 2014-present: EISCAT_3D Funding Round Table Meetings
- 2015-2016: EU H2020 “Preparation for Production”





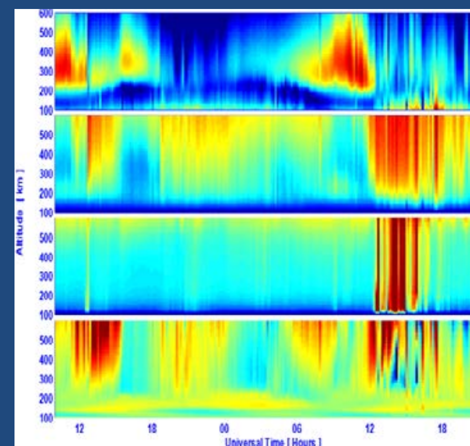
Building the Science Case

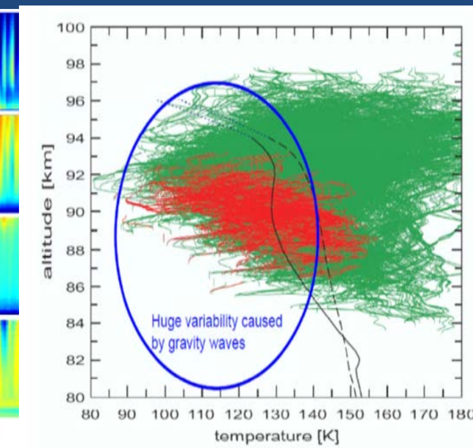
- EISCAT_3D Preparatory Phase project included a dedicated work package on building the science case
- Succession of working groups drawn from the EISCAT user community
- Different “focus area” in each of the first three years (atmospheric science, plasma physics, space weather – also solar system science and new techniques as background tasks)
- Annual updates of the science case and table of capabilities
- Appendices covering observing modes and supporting instruments. Feed into data requirements.
- Final version July 2014. Reduced version published in the open literature
- McCrea, I., A. Aikio, L. Alfonsi, E. Belova, S. Buchert, M. Clilverd, N. Engler, B. Gustavsson, C. Heinselman, Johan Kero, M. Kosch, H. Lamy, T. Leyser, Y. Ogawa, K. Oksavik, A. Pellinen-Wannberg, F. Pitout, M. Rapp, I. Stanislawska and J. Vierinen, The science case for the EISCAT_3D radar, Progress in Earth and Planetary Science, 2:21, DOI 10.1186/s40645-015-0051-8, 2015

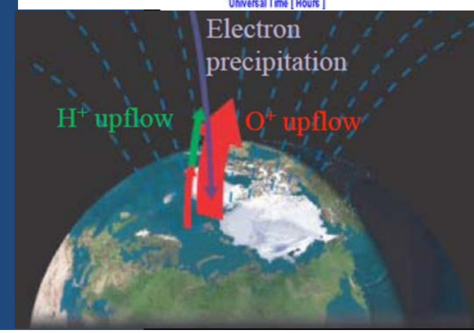


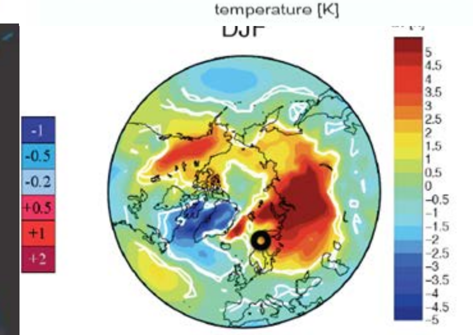
Science Targets for EISCAT_3D

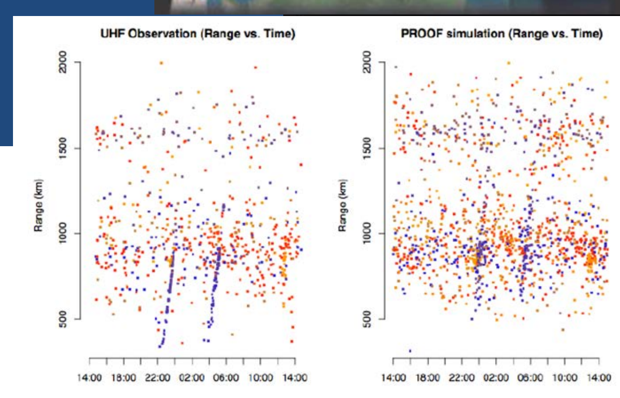
- Space weather monitoring
- Model verification
- Space debris
- Small-scale structure
- Composition
- Lower atmosphere coupling
- Winds and waves
- Ion outflow
- Meteor Tracking
- Solar wind studies
- Novel techniques

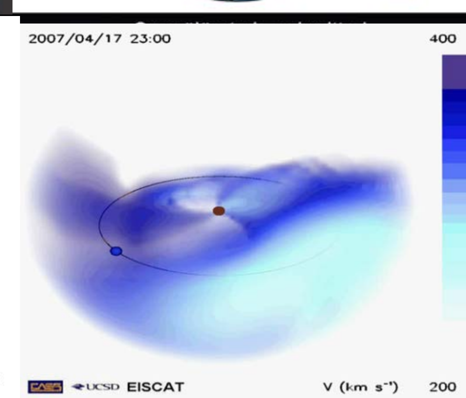


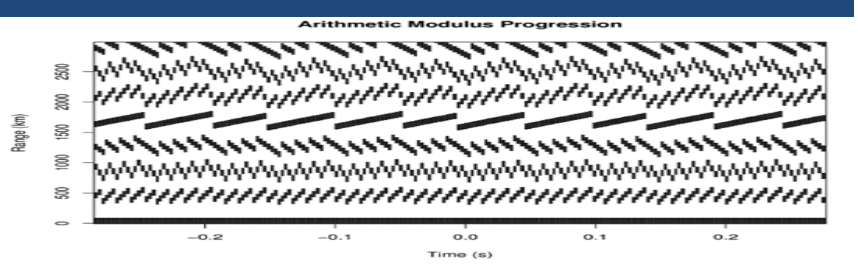


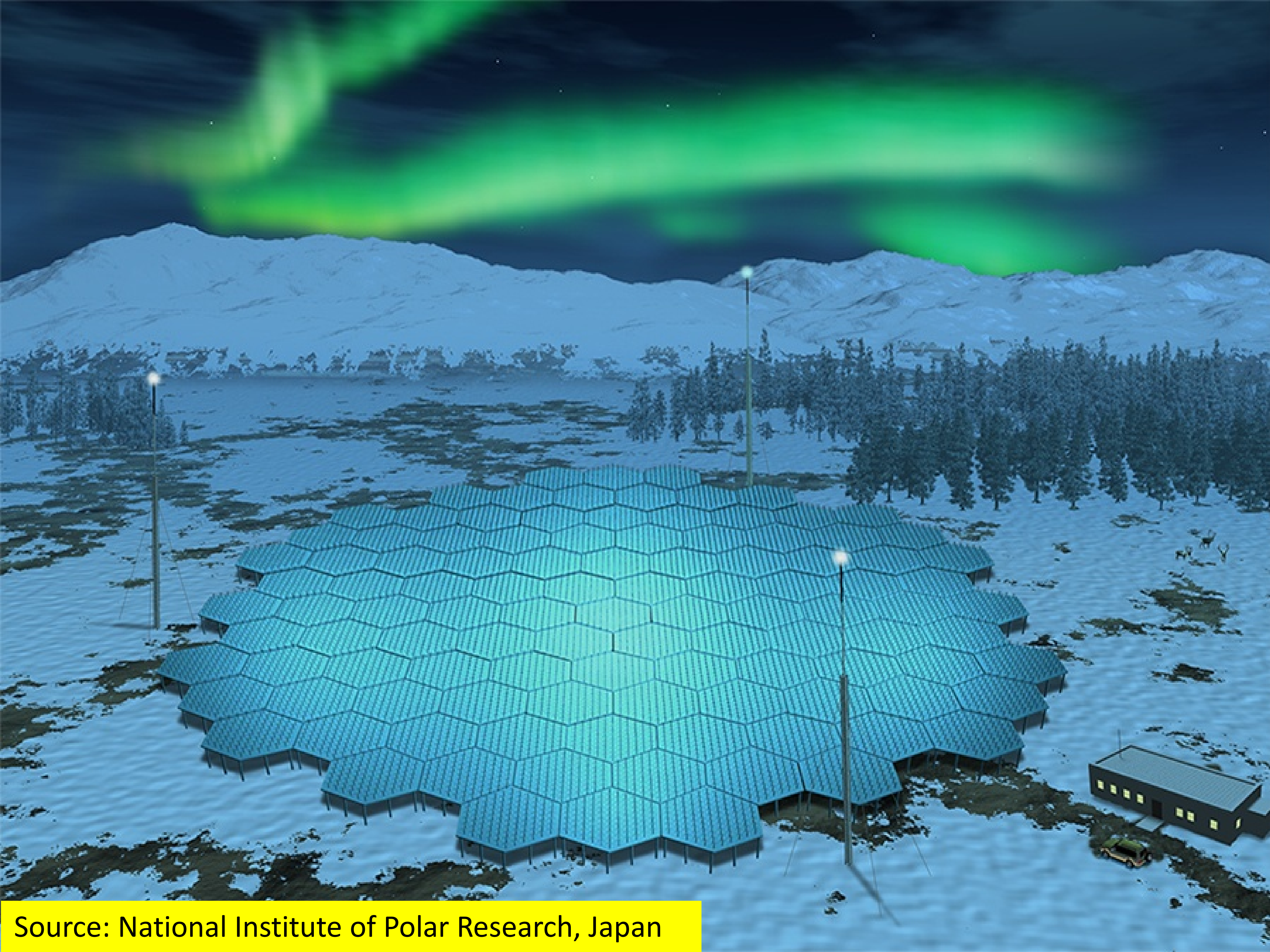












Source: National Institute of Polar Research, Japan

Staged Construction: Phase 1

- Three full-size arrays
- Half-power transmitter (5 MW)
- Good for scalar parameters and E-region vectors
- Support for rocket flights from ESRANGE

Staged Construction: Phase 2

- Upgrade transmitter to full 10MW power
- Wider coverage area, particularly for E-region
- Better temporal resolution
- Improved scalar parameters in F-region

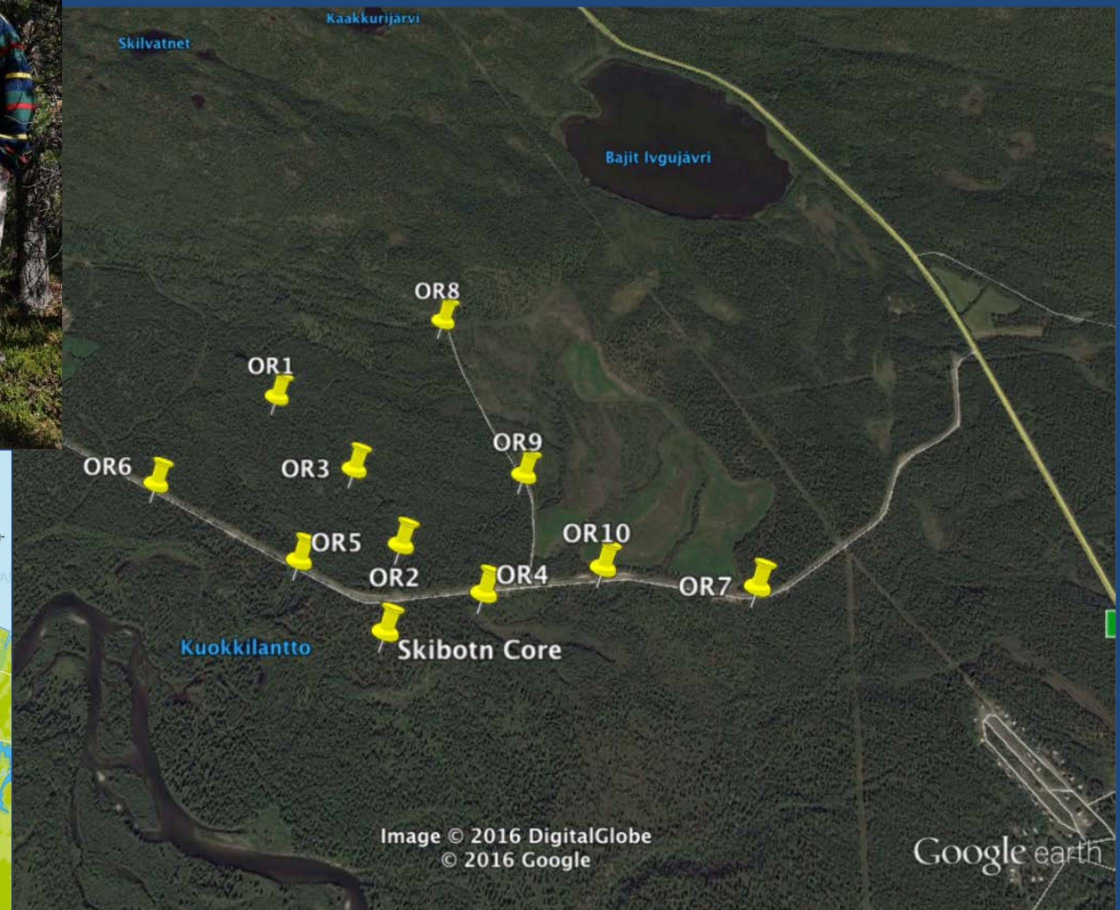
Staged Construction: Phase 3

- Add receiver array on Andøya
- Extend coverage area westward
- Better geometry for EISCAT heater
- Support for rocket flights from Andenes

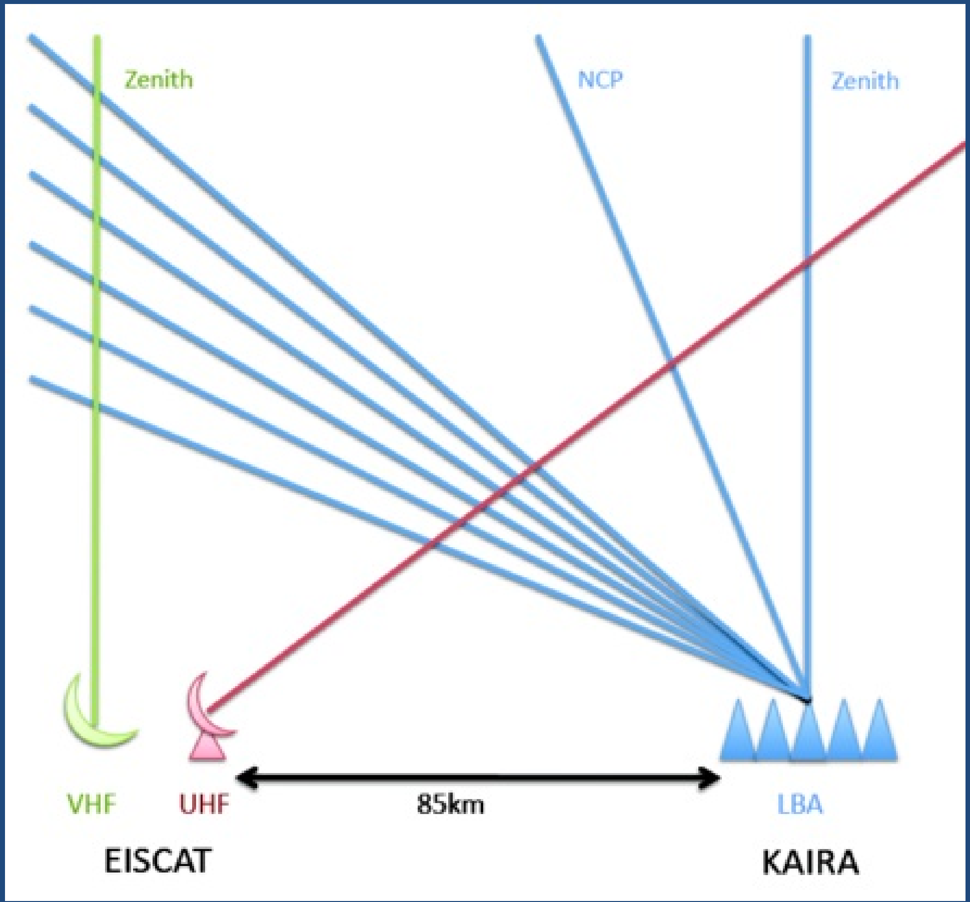
Staged Construction: Phase 4

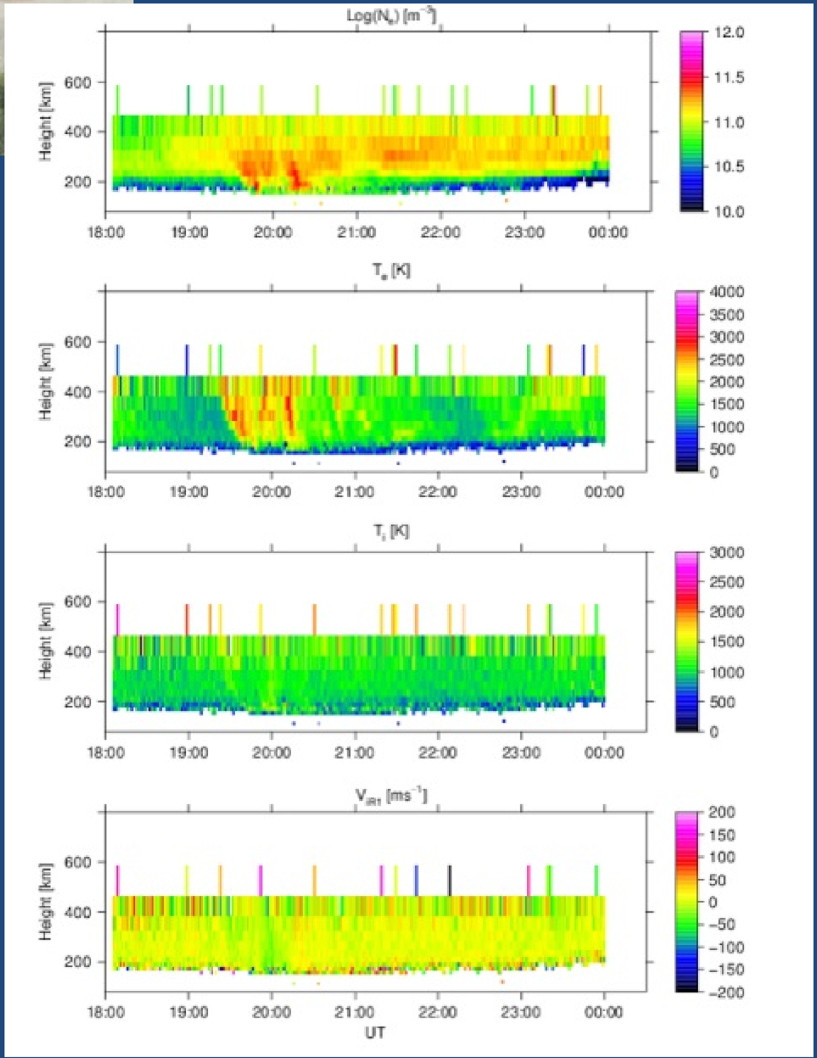
- Add Jokmokk array
- Final EISCAT_3D configuration
- Extend latitude coverage southward
- Improve F-region vector determinations

Skibotn Site



KAIRA Data

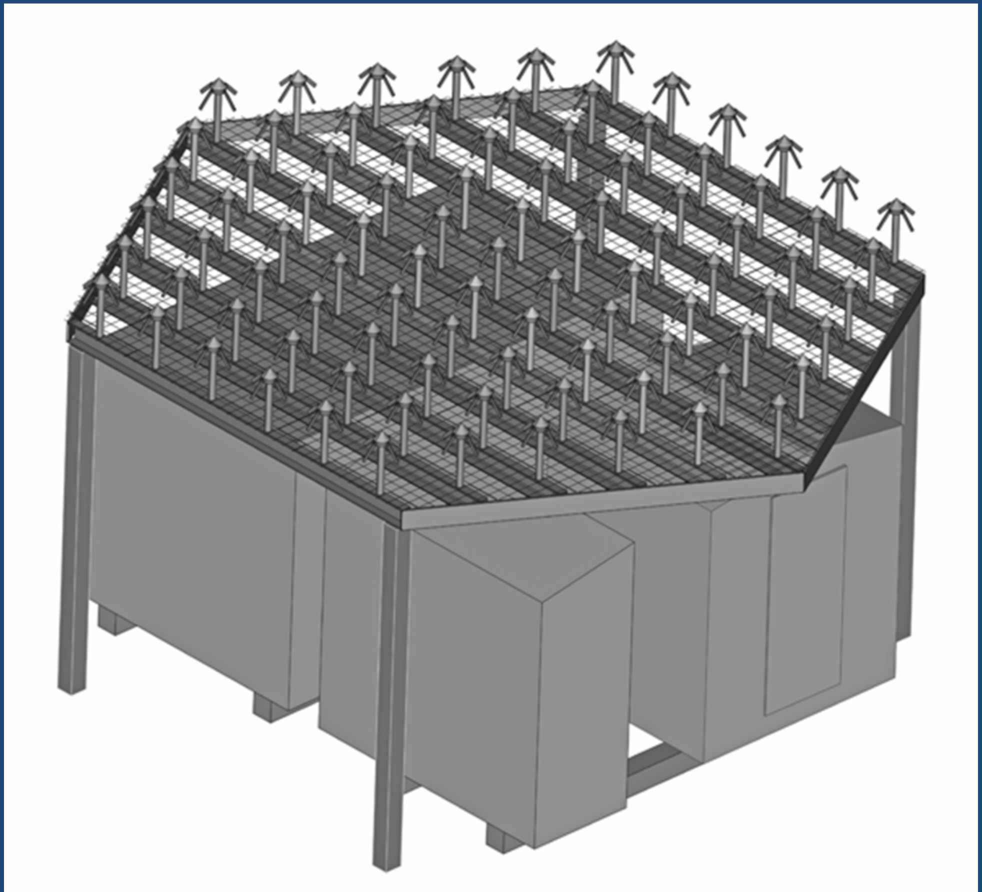

Zenith
NCP
Zenith
VHF
UHF
85km
LBA
EISCAT
KAIRA


Log(N_e) [m^-3]
T_e [K]
T_i [K]
V_iR1 [ms^-1]
Height [km]
UT

Test Subarray Location

EISCAT_3D "Preparation for Production"

- Funded by EU from H2020
- Started October 2015
- EISCAT is the single beneficiary.
- Four staff at HQ working on the project
- Aim is to bridge the gap from prototypes to construction-ready systems
- Will produce a demonstrator array at Tromso, based on E3D technology
- Tenders already issued for receiver unit, antenna unit, pulse generation and steering control
- Tenders currently under evaluation



Funding: Where are we now?

Nation	Capital*	Resource*	Comments
China	0	£0.3M† *(3,002,280 CNY)*	Depends on next 5-year plan to start in 2017.
Finland	£10.7M *(12.8 MEUR)*	£0.6 M *(0.749 MEUR)*	20% in kind (= 2,568,212 EUR)
Japan	£0.5M *(0.66 MEUR)*	£0.2 M† *(22,468,950 JPY)*	Small setup fund for tx module development by end Mar 2017
Norway	£20.2M *(228 MNOK)*	≤ £1.1M *(12 MNOK)*	Subject to phase 1 total being committed by end 2016 60 MNOK resource for 2020-2024?
Sweden	£10.5M	£1.0 M	20% in kind (= 24 MSEK))
UK	0	£0.2M† *(£214k)*	
USA	0	0	
Affiliates	0	£0.1M†	AARI (Russia), IRA-NASU (Ukraine), CNRS-IRAP (France), KASI (S. Korea), KOPRI (S. Korea)
INFRADEV-3	£2.5M	0	EU funding for Preparation for Production project EISCAT3D_PfP
Total	**£44.5M (73.5%)**	**£3.5M (78.6%)**	
Phase 1 Target	**£60.5M**	**£4.5 M**	

Current commitments as of July 2016

*Currency conversions using xe.com on 27 July 2016

† Assumes national subscription continues at 2016 rate

Funding: Where do we plan to be?

Nation	Capital*	Resource*	Comments
China	0	£0.3M † *(3,002,280 CNY)*	Depends on next 5-year plan to start in 2017.
Finland	£10.7M *(12.8 MEUR)*	£0.6M *(0.749 MEUR)*	20% in kind (= 2,568,212 EUR)
Japan	£14.2M *(17 MEUR)*	£0.2M † *(22,468,950 JPY)*	EISCAT cost book valuation of 28 MEUR in-kind contribution
Norway	£20.2M *(228 MNOK)*	≤ £1.1M *(12 MNOK)*	Subject to phase 1 total being committed by end 2016 60 MNOK resource for 2020-2024?
Sweden	£10.5M (120 MSEK)	£1.0M (11.4 MSEK)	20% in kind (= 24 MSEK))
UK	£16.0M	£0.2M	Could reduce capital contribution to 14.7 MGBP to meet phase 1+3 target or increase to 17.3 MGBP to meet phase 1+2 target
USA	0	£0.8M ‡ *(1 MUSD)*	
Affiliates	0	£0.1M †	AARI (Russia), IRA-NASU (Ukraine), CNRS-IRAP (France), KASI (S. Korea), KOPRI (S. Korea)
INFRADEV-3	£2.5M	0	EU funding for Preparation for Production project EISCAT3D_PfP
Total	**£74.2M**	**£4.3M (96%)**	
Target (phase 1 + 2)	**£75.5M (98%)**	**£4.5 M**	
Target (phase 1 + 3)	**£72.9M (102%)**	**£4.5 M**	

* Currency conversions using xe.com on 27 July 2016
† Assumes national subscription continues at 2016 rate
‡ Assumes national subscription recommended by the 2016 NSF Portfolio Review "Investments in Critical Capabilities for Geospace Science 2016 to 2025"

Summary

- EISCAT_3D will be the best radar of its kind in the world.
- System is well-established as an ESFRI infrastructure and on several national capital roadmaps.
- Two EU-supported phases of the project (FP6 Design Phase and FP7 Preparatory Phase).
- Developing the science case has established what questions can be answered and allowed each country to pick the things it can do best
- Now in "Preparation for Production" phase, funded by EU-H2020.
- Our major goal is to secure the capital funding for the new radar, from multiple national sources. We already have > 70% pledged (85M Euro)
- Next few months will be critical in determining funding for Phase 1.