WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

The emergence of weather radar as a global resource

Daniel Michelson

Environment and Climate Change Canada

Contributions from

Lars Peter Riishojgaard, WMO Secretariat

Dominik Jacques and Vlado Stojanovic, ECCC

WMO/ASEAN Training Workshop on Weather Radar
Data Quality and Standardization
5-13 February 2018, Bangkok, Thailand

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

Inter-programme Expert Team on Operational Weather Radar : IPET-OWR

Outline

1. Introduction
2. WMO and WIGOS
3. IPET-OWR
4. Calibration
5. Advanced application - NWP

27 years ago


LUNDS UNIVERSITETS NATURGEOGRAFISKA INSTITUTION

SEMINARIEUPPSATSER NR 23

Land Use Mapping of the That Luang - Salakham Wetland, Lao PDR, Using Landsat TM-Data

DANIEL MICHELSON

LUND 1991

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WMO Commissions

Commission for Aeronautical Engineering (CAeM)
Commission for Agricultural Meteorology (CAgM)
Commission for Atmospheric Sciences (CAS)
Commission for Basic Systems (CBS)
Commission for Climatology (CCl)
Commission for Hydrology (CHy)
Commission for Instruments and Methods of Observation (CIMO)
Joint WMO-IOC Commission for Oceanography and Marine Meteorology (JCOMM)

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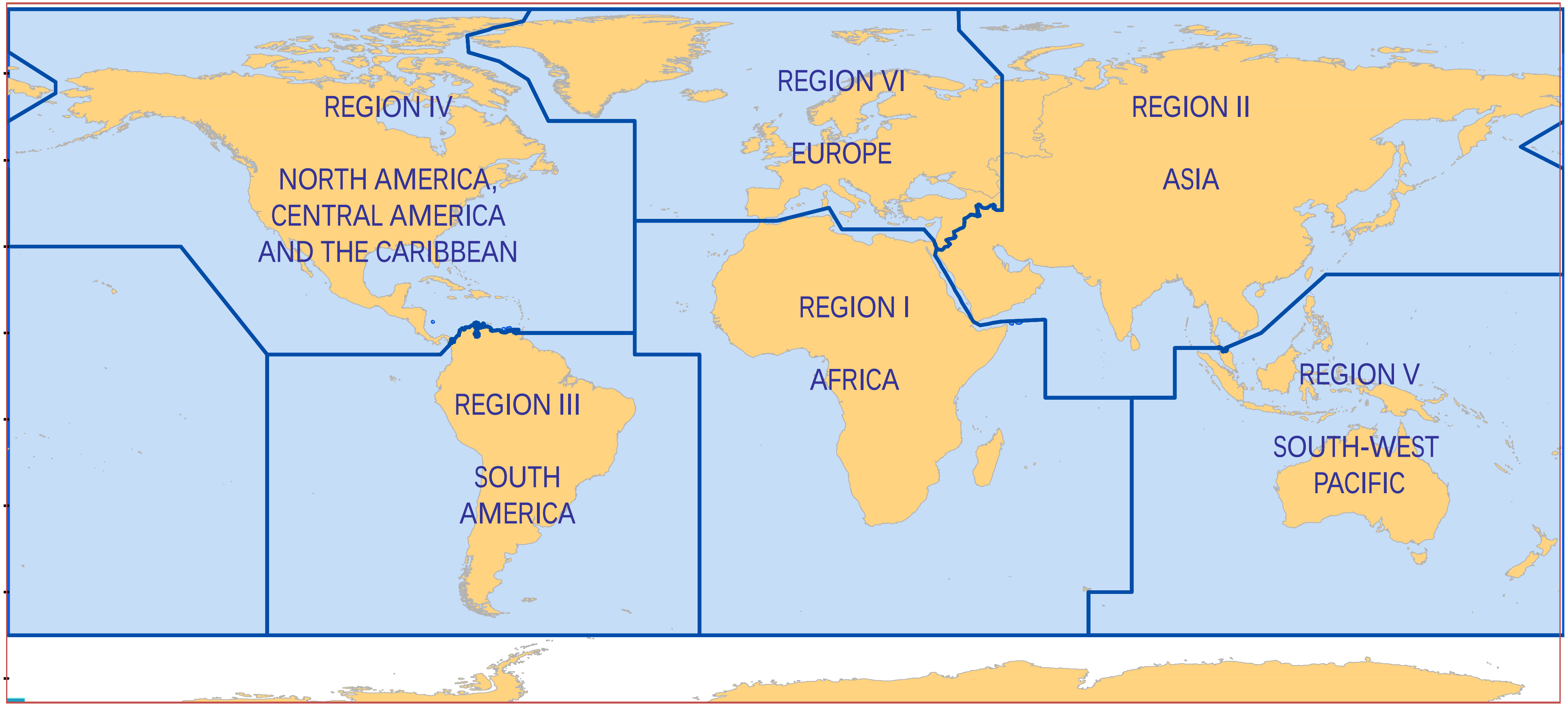
WMO Regional Associations



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What is the WMO Integrated Global Observing System (WIGOS)?

- WMO foundational activity addressing the observing needs of the weather, climate, water and environmental services of its Members
- A framework for integrating all WMO observing systems and WMO contributions to co-sponsored observing systems under a common regulatory and management framework
- WIGOS is not:

Replacing or taking over existing observing systems, which will continue to be owned and operated by a diverse array of organizations and programmes, national as well as international.

http://www.wmo.int/pages/prog/www/wigos/index_en.html

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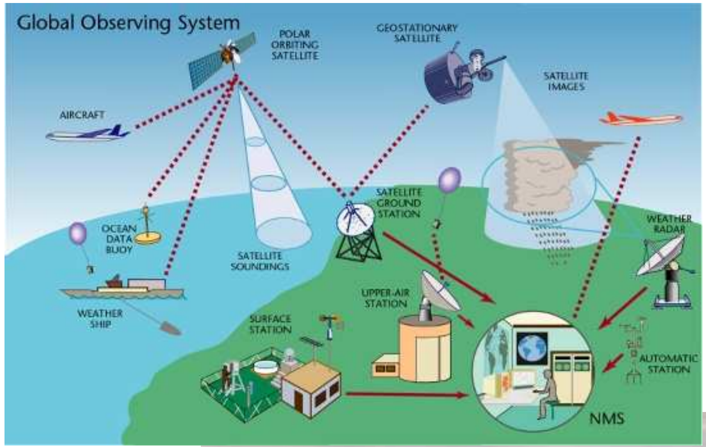
WIGOS Component Systems

- Global Observing System (WWW/**GOS**)
- Observing component of Global Atmospheric Watch (**GAW**)
- WMO Hydrological Observations (including **WHYCOS**)
- Observing component of Global Cryosphere Watch (**GCW**)



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Why do we need WIGOS?

- **I. NMHS mandate typically broader now than when the World Weather Watch and the GOS were created, including e.g.**
  - Climate monitoring, climate change, mitigation
  - Air quality, atmospheric composition from urban to planetary scales
  - Oceans
  - Cryosphere
  - Water resources
- **II. Technical and scientific advances:**
  - Observing technology
  - Telecommunications
  - Numerical modeling and data assimilation
  - Increased user demand to access and use observations in decision making

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Why do we need WIGOS?

- **III. Economic realities**
  - Budgetary pressure on many NMHS, in spite of expanding mandates and increasing demand for services
  - Efficiency by exploiting synergies
    - Integration of observing networks across disciplines (e.g. weather and climate)
    - Integration across organizational boundaries, e.g. between different national ministries/departments operating observing systems
    - Integration across technological boundaries, e.g. between surface- and space-based systems

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WIGOS Network Design Principles (from WMO 1160 « Manual on WIGOS »)

According to the Manual on WIGOS, networks should be designed with a view toward:

1. Serving many application areas
2. Responding to user requirements
3. Meeting national, regional and global requirements
4. Designing appropriately spaced networks
5. Designing cost-effective networks
6. Achieving homogeneity in observational data
7. Designing through a tiered approach
8. Designing reliable and stable networks
9. Making observational data available
10. Providing information so that the observations can be interpreted
11. Achieving sustainable networks
12. Managing change

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OSCAR

- The RRR is supported by three key databases of **OSCAR**, the *Observation Systems Capabilities and Review* tool :
  - **OSCAR/Requirements**, in which "technology free" requirements are provided for each application area, expressed in units of geophysical variables (260 in total currently), not measurands; not just atmosphere, also terrestrial, ocean, cryosphere, …
  - **OSCAR/Space,** listing the capabilities of all satellite sensors, whether historical, operational or planned
  - **OSCAR/Surface,** list surface-based capabilities; developed by MeteoSwiss for WMO, operational since May 2016

http://www.wmo.int/oscar/

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OSCAR/Surface
("What is WIGOS?")

- Implementation layer of the *WIGOS Metadata Standard*: **Modern, electronic, searchable inventory of metadata for all observing stations/platforms under WIGOS**
  - OSCAR/Surface will replace *WMO Pub. 9, Volume A*, but will also include information from similar inventories for other (non-GOS) components of WIGOS
  - Developed jointly by WMO and MeteoSwiss, with the Swiss government providing the major part of the funding
  - <u>Operational since May 2016</u>
  - Education and training Members in populating, editing and using OSCAR/Surface is a major priority for 2016-2019 financial period

Inter-Programme Expert Team on Operational Weather Radar : IPET-OWR

- Jointly managed by CIMO and CBS
  - Data quality and best practices activities from CIMO
  - Data representation and exchange from CBS
  - Liaison with ITU, ISO, others
  - "All things weather radar"
- Work Plan 2016-2019
- The emergence of weather radar as a global resource

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End-to-end weather radar system

WMO OMM

End-to-end weather radar system

User Requirements

Power

Spares

Comms

Vendor

Research & Development

Processing Software

Computational Resources

Data Archive

Network

International Data Exchange

IPET-OWR Work Plan (1)

1. IPET management
2. Survey of Members requirements
3. Regulatory Material, advice and guidance to WMO’s Members
4. Weather radar data exchange
5. Metadata management, WMO radar database (WRD) and contribution to OSCAR

IPET-OWR Work Plan (2)

6. Best practices for weather radar quality control and quantitative precipitation estimation for user applications
7. International and regional collaboration – ISO
8. International and regional collaboration
9. Policy
10. Emerging technologies
11. Capacity development and training

Member requirements

- Survey conducted in early 2017
- 20 questions
- Expected to take around 20 minutes
- Sent to WMO Members
- Analyzed by the Secretariat and reported on at IPET-OWR-1, March 2017
- To guide IPET-OWR work plan

Member requirements summary (1)

- 86 responses from 84 countries
- 79 from NMHS
- 75 from organizations that already operate weather radar
- 10 expected to deploy OWR in future
- 773 radars identified, of which 305 to be replaced or upgraded

Member requirements summary (2)

Most significant issues

1. Obtaining finance to buy and install (2.07 rating)
2. Obtaining finance to maintain (1.85)
3. Lack of experienced or trained technical staff to operate and/or maintain (1.53)
4. Lack of experience or training of radar users (1.37)
5. Lack of data processing applications and tools (1.29)
6. Inadequate radar coverage (1.25)

Member requirements summary (3)

Most common uses of weather radar

1. Weather system monitoring (2.64)
2. Severe weather monitoring (2.56)
3. Weather system evolution and prediction (2.37)
4. Severe weather prediction (2.36)
5. Precipitation estimation for hydrology applications (1.30)

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Member requirements summary (4)

Highest rated issues and aspects of OWR that WMO can assist with

1. Provision of software or applications to support radar data quality monitoring (2.20)
2. Guidance on weather radar data quality (2.15)
3. Provision of software or tools to support radar calibration (2.14)
4. Guidance on weather radar data exchange formats and mechanisms (2.12)
5. Provision of training on radar maintenance (2.04)
6. Guidance on: 1) weather radar calibration, 2) weather radar data use (2.03)
7. Provision of training on radar data processing (2.03)
8. Provision of training on radar data use and application (2.00)

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Member requirements summary (5)

Common or additional themes for assistance and activities that WMO might undertake

- Coordinate regional or technology-common meetings or workshops;
- Guidance on socio-economic benefits of operation of WR to support business case and funding attainment;
- Assistance for obtaining funding in support of OWR;
- Forums are required to support information and best-practice sharing (e.g. workshops, seminars);
- Training, technical support and capacity development are important;
- Promotion and collaboration on data exchange and sharing;
- Standardisation of and guidance on practices, procedures.

Regulatory Material, Advice and Guidance

Existing Material

Manual on the GOS (No. 544)

Guide to the GOS (No. 488)

CIMO Guide (No. 8), Part II, Chapter 7

Manual on WIGOS (No. 1160)

IPET-OWR Goal

WIGOS Weather Radar Best Practices Guide

IPET-OWR Guidance

Weather Radar Network Design

Dual Polarization Radar

Mountainous Terrain

Operation of Weather Radar Systems

Guidance on Interference Issues

Weather radar data exchange

- Single global standard data representation
  - For data in radial coordinates (azimuth, elevation)
  - ODIM_H5 + CfRadial = CfRadial2
  - Documentation outputs ready, to be followed by software implementation
- Weather radar data exchange methods
  - WMO exchange methods should accommodate weather radar
  - Members should use such exchange methods

Summarized user requirements for data exchange

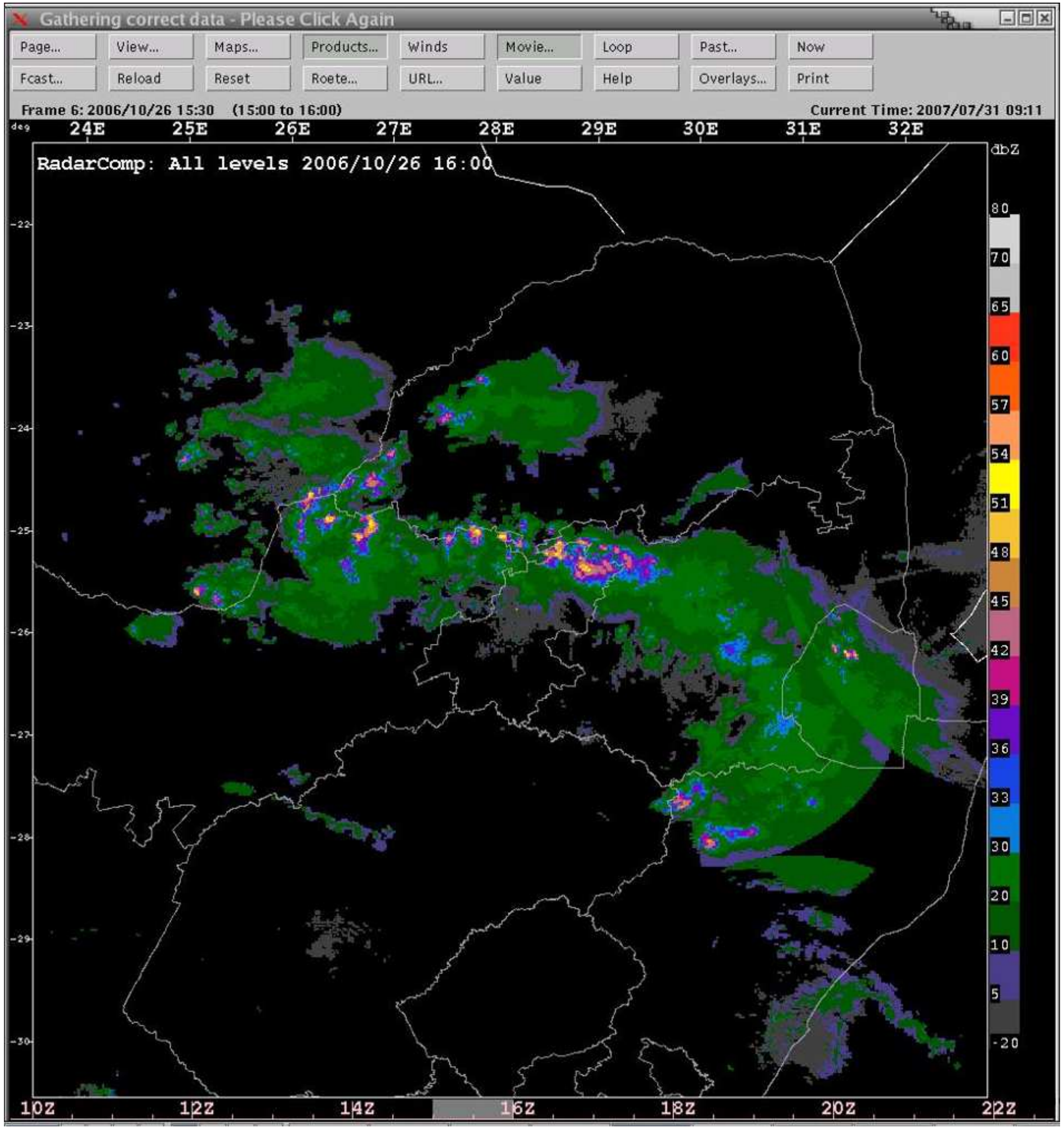
Data User Area	Parameter/Field	Requirement Category	Requirement	Comment
NWP - Global	ECMWF Now: US Stage IV prec. Composites Future: polar data?	Horizontal resolution Cycle Latency	2 km^2 Future: 1 km^2? 15 min 15 - 30 min	Different requirements for different NWP consortia Future standard: polar data?
NWP – High resolution	Polar data (Météo France)	Horizontal resolution Cycle Latency	2 km^2 Future: 1 km^2? 1 hour 15 - 30 min	
Hydrology	Quantitative Precipitation Estimate	Horizontal resolution Cycle Latency		Access to long-term high quality archived precipitation data is critical.
Climate	Quantitative Precipitation Estimate	Horizontal resolution Cycle Latency	1 km^2 possibly later inc. to Future: 0.25 km^2 1 hour Future: 5 min? 48 hrs	Access to long-term high quality archived data is critical.

Status of data exchange: RA I

South Africa

Botswana

Mozambique



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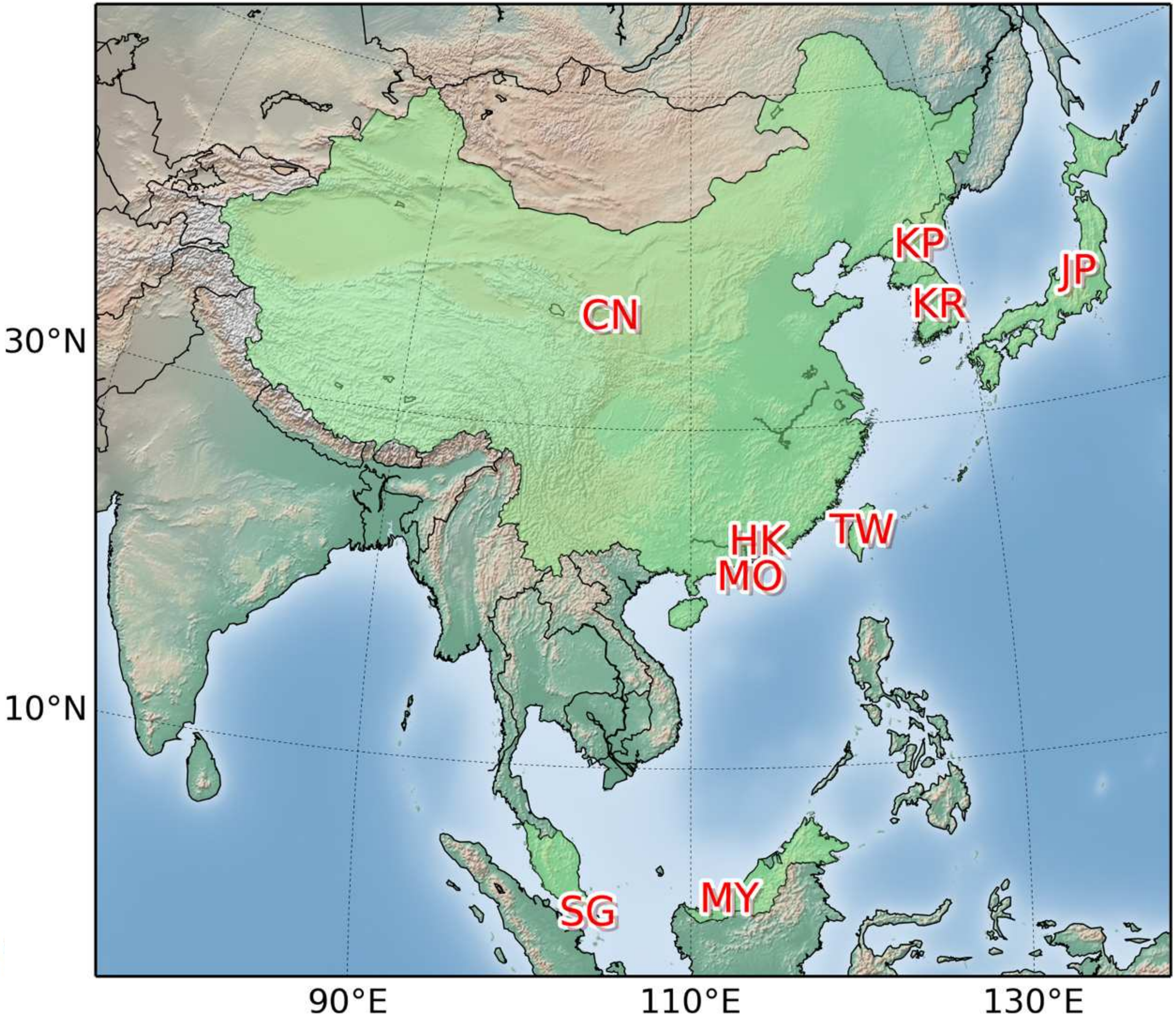
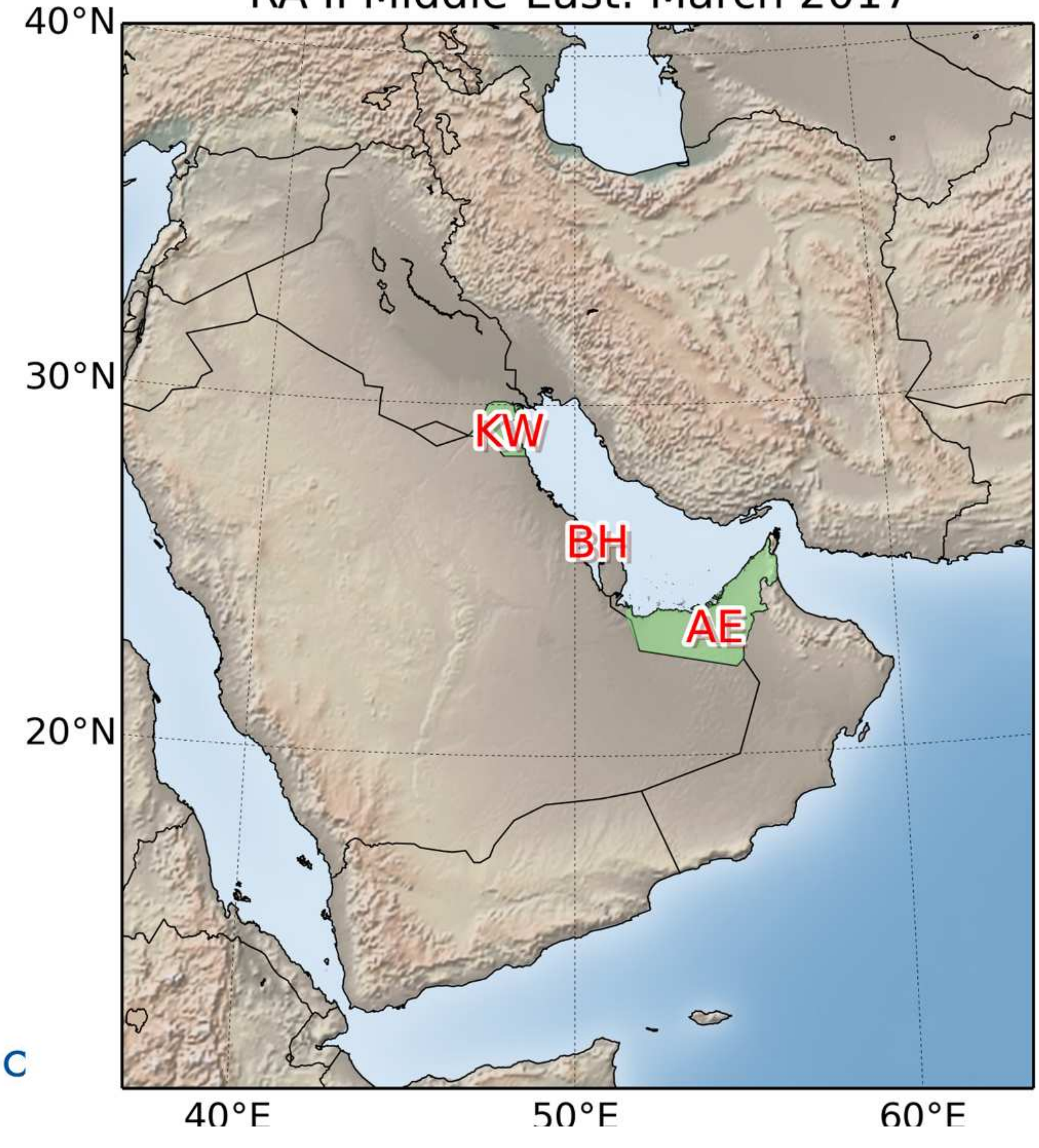
RA II: March 2017

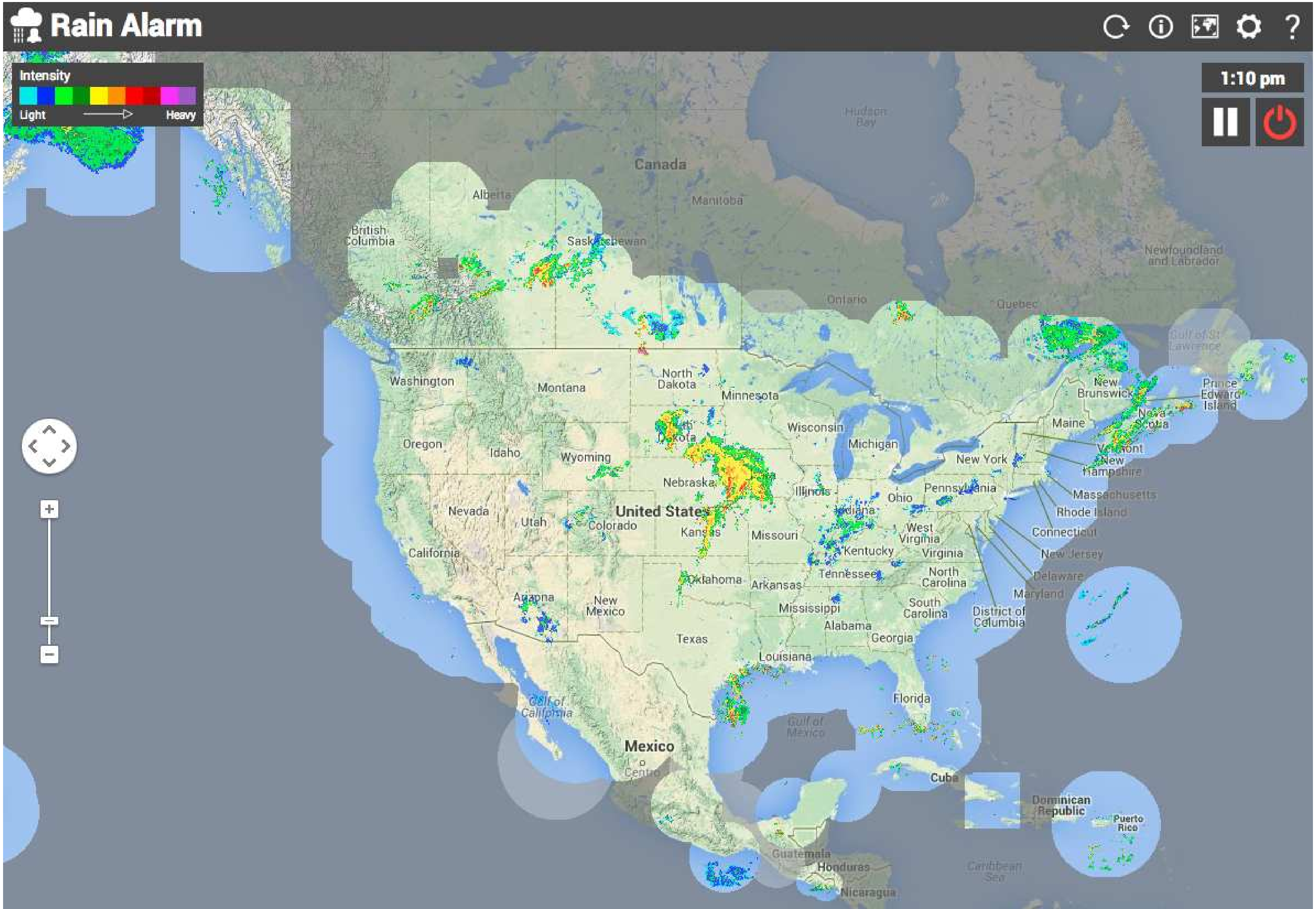


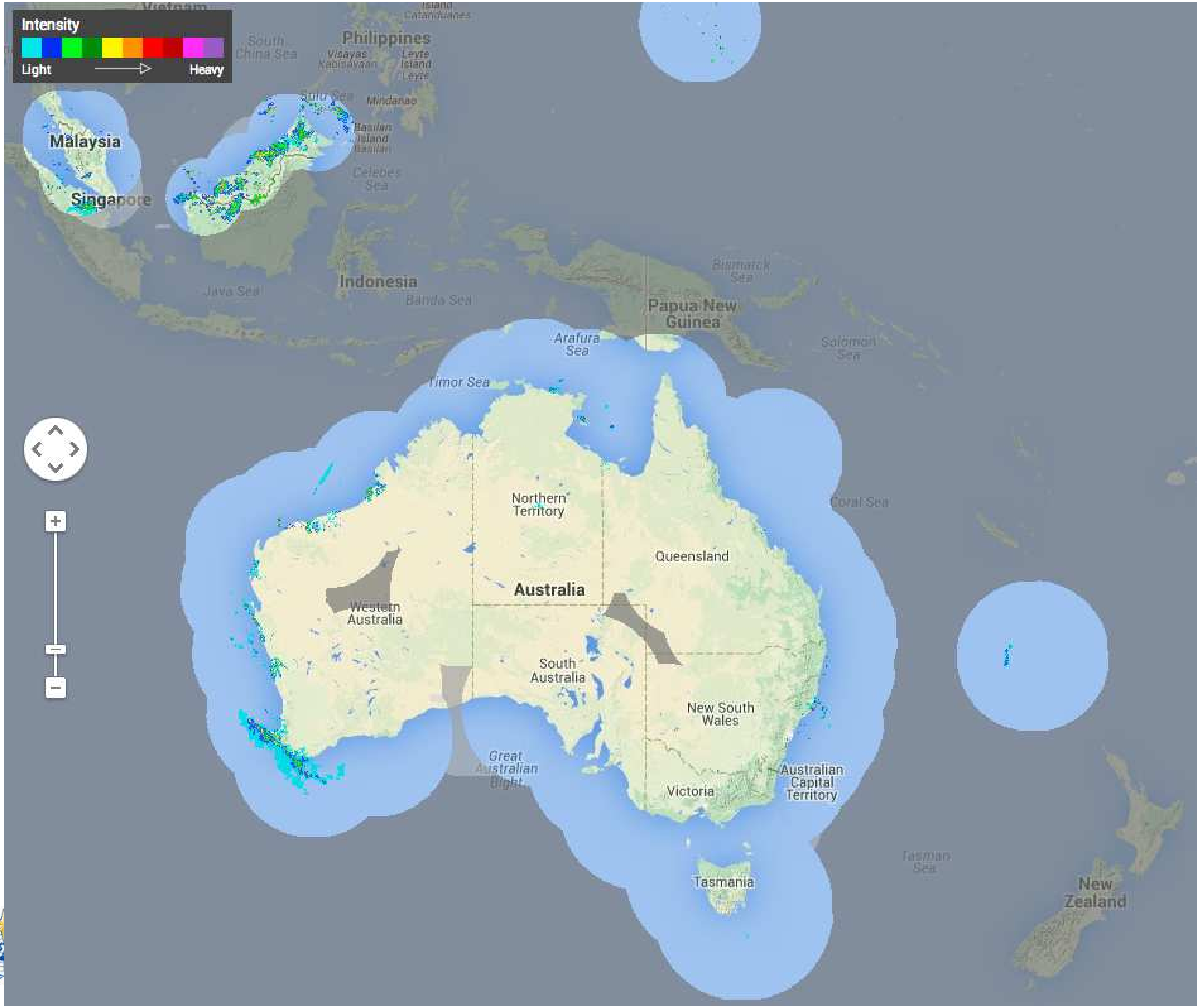
RA II Middle-East: March 2017



WMO C

RADAR Y ADVERTENCIAS
14:50
LLUVIA
VIENTO
TOPES
Pronóstico Extendido
PronosticoExtendido.net
Paraguay
Chile
Argentina
Uruguay
Asuncion
Capiata
Formosa
Presidencia Roque Sáenz Peña
Resistencia
Posadas
Salta
San Miguel de Tucumán
Santiago del Estero
San Fernando del Valle de Catamarca
La Rioja
Copiapó
Vallenar
La Serena, Chile
Ovalle
San Juan
Mendoza
Los Andes
Quilpué
Santiago
Melipilla
Rancagua
Curicó
Córdoba
Río Tercero
Villa María
Bell Ville
Río Cuarto
San Luis
Villa Mercedes
Laboulaye
General Pico
Santa Rosa
Rafaela
San Francisco
Santa Fe
Paraná
Reconquista
Rosario
San Nicolás
Buenos Aires
Lomas de Zamora
Tandil
Mar del Plata
Montevideo
Maldonado
Rocha
Salto
Paysandú
Tacuarembo
Rivera
Artigas
Uruguaiana
Alegrete
São Borja
Ijuí
Santa Maria
Rio Grande do Sul
Caxias do Sul
Novo Hamburgo
Porto Alegre
Pelotas
Rio Grande
Bagé
Santa Catarina
Florianopolis
Blumenau
Itajaí
Joinville
Curitiba
Bairro Novo
Criciúma
Parana
Guarapuava
Cascavel
Toledo
Ciudad del Este
Dois Vizinhos
Francisco Beltrão
Umuarama
Maringá
Londrina
Caballero
Orán


Rain Alarm
Intensity
Light
Heavy
1:10 pm
Canada
Alberta
Manitoba
British Columbia
Saskatchewan
Ontario
Quebec
Hudson Bay
Newfoundland and Labrador
Washington
Montana
North Dakota
Minnesota
Oregon
Idaho
Wyoming
Wisconsin
Michigan
New York
Nebraska
Illinois
Ohio
Pennsylvania
Nevada
Utah
United States
Colorado
Kansas
Missouri
Indiana
West Virginia
Kentucky
Virginia
California
Tennessee
North Carolina
Oklahoma
Arkansas
Arizona
New Mexico
Mississippi
South Carolina
Alabama
Georgia
Texas
Louisiana
Florida
Maine
Vermont
New Hampshire
Massachusetts
Rhode Island
Connecticut
New Jersey
Delaware
Maryland
District of Columbia
New Brunswick
Nova Scotia
Prince Edward Island
Gulf of St Lawrence
Gulf of California
Gulf of Mexico
Mexico
Cuba
Dominican Republic
Puerto Rico
Guatemala
Honduras
Nicaragua
Caribbean Sea

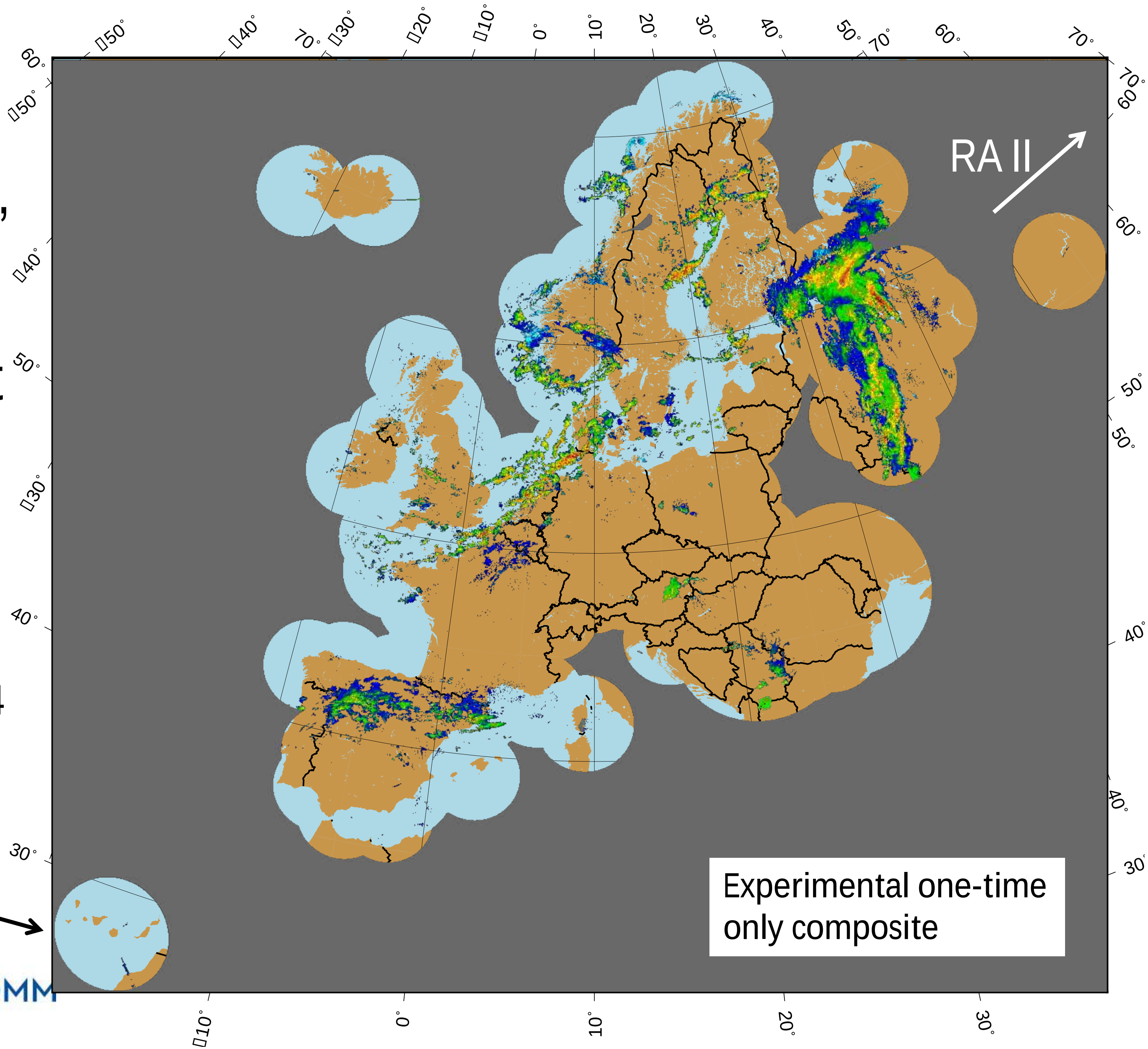


Intensity
Light
Heavy
Philippines
South China Sea
Malaysia
Singapore
Sulu Sea
Mindanao
Celebes Sea
Indonesia
Java Sea
Banda Sea
Bismarck Sea
Papua New Guinea
Solomon Sea
Arafura Sea
Timor Sea
Coral Sea
Northern Territory
Queensland
Australia
Western Australia
South Australia
New South Wales
Australian Capital Territory
Victoria
Great Australian Bight
Tasmania
Tasman Sea
New Zealand

“RA VI composite” in the not-too-distant future?

22 August 2014
06:00 UTC

RA I



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International Standards Organization

Technical Committee: ISO/TC 146/SC 5 Meteorology

ISO/DIS 19926-1

Weather Radar – Part 1: System performance and operation

Drafted jointly by ISO-WMO following the ISO process

Status: under review

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Importance of calibration and monitoring

Assumption when processing data: a well-calibrated radar

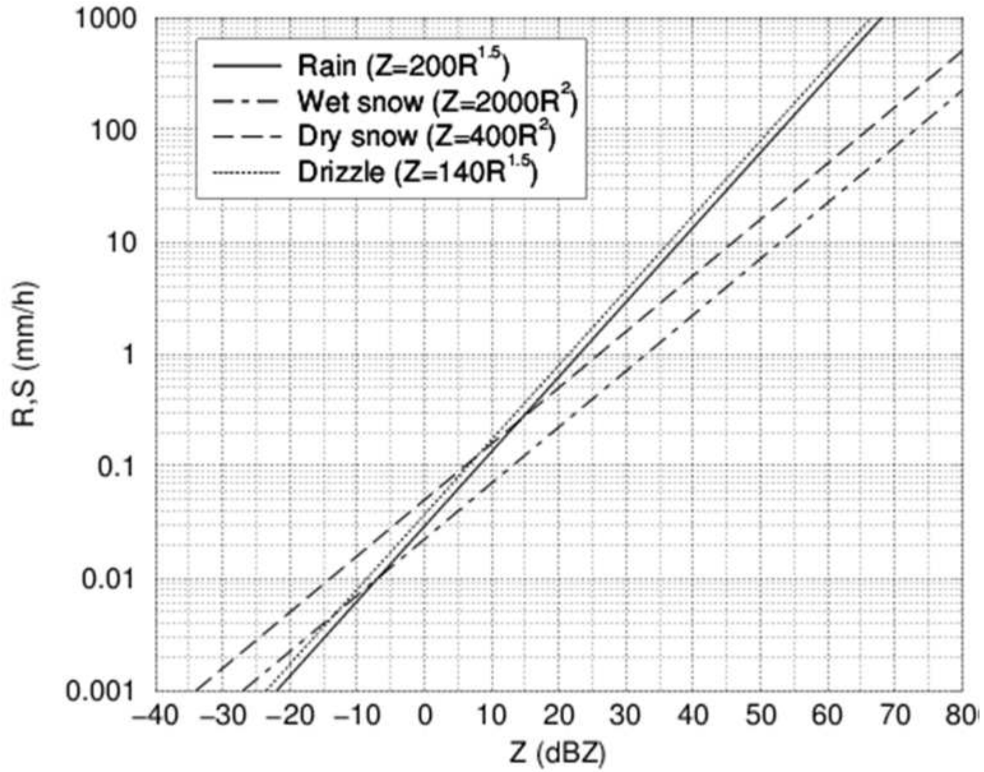
Why calibrate?

- Ensure pointing accuracy
- Ensure consistent performance
  - System availability
  - Calibration levels over time
  - Data quality
  - Network homogeneity

Why monitor?

- Detect system deterioration (instantaneous, gradual)
- Help troubleshoot
- Reduce downtime, data outages
- Determine if acquired data are within quality tolerances

Importance of calibration



Calibration errors can affect Z, thereby also negatively impacting estimates of R

IPET-OWR and calibration

Radar Calibration Reporting – RaCR

- Prototype software
- Validates calibration and harmonizes reporting
- Complements vendor's calibration process, does not replace it
- Single or dual polarization, X, C, S (other) bands
- Different configurations, up to 4 pulse widths
- Follows method developed for GPM mission

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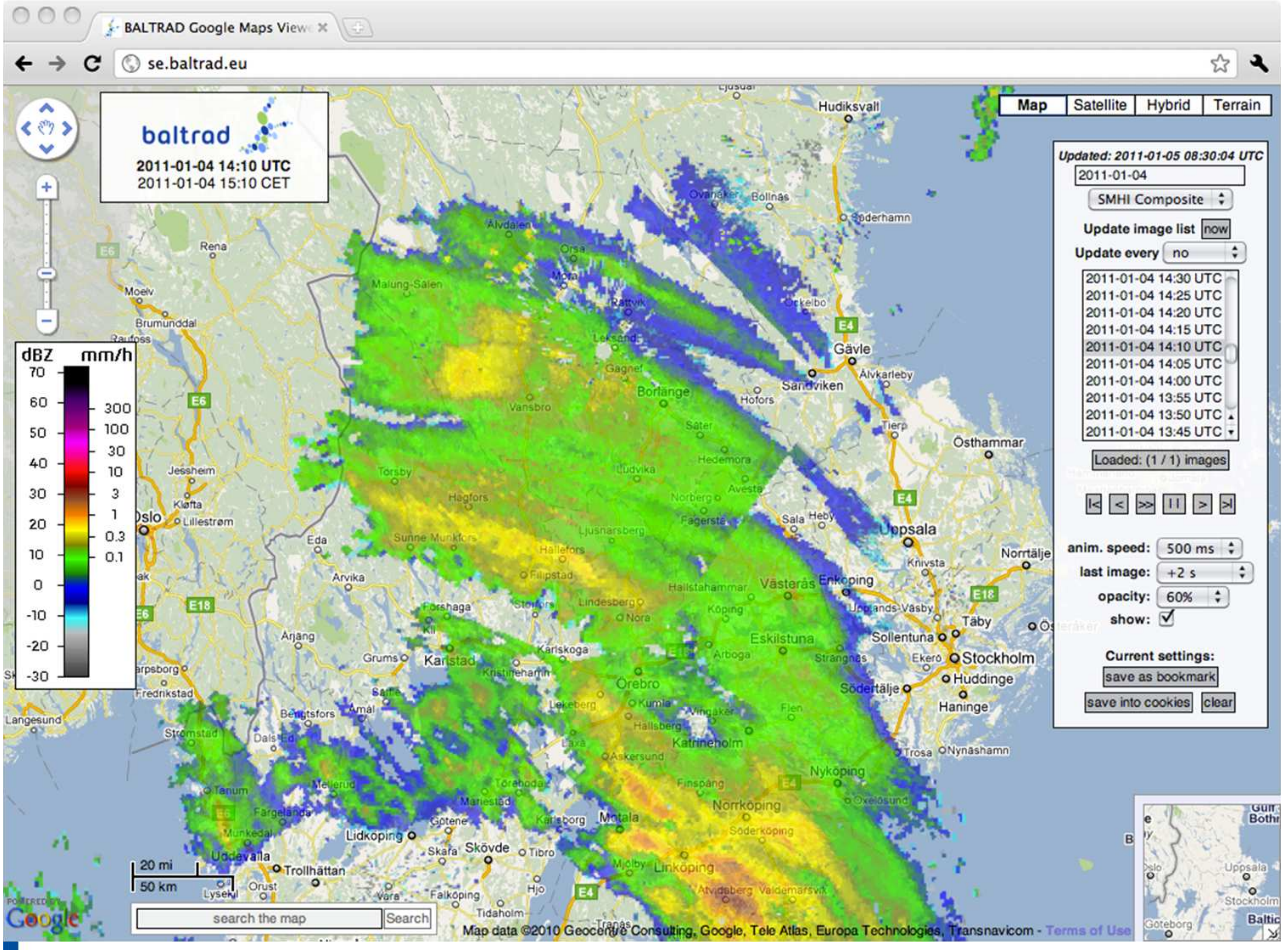
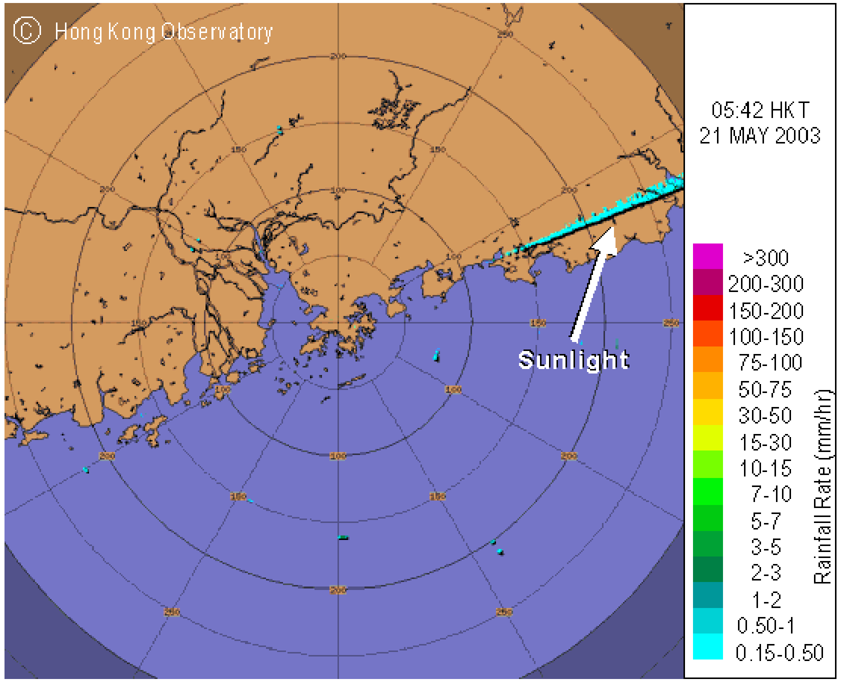


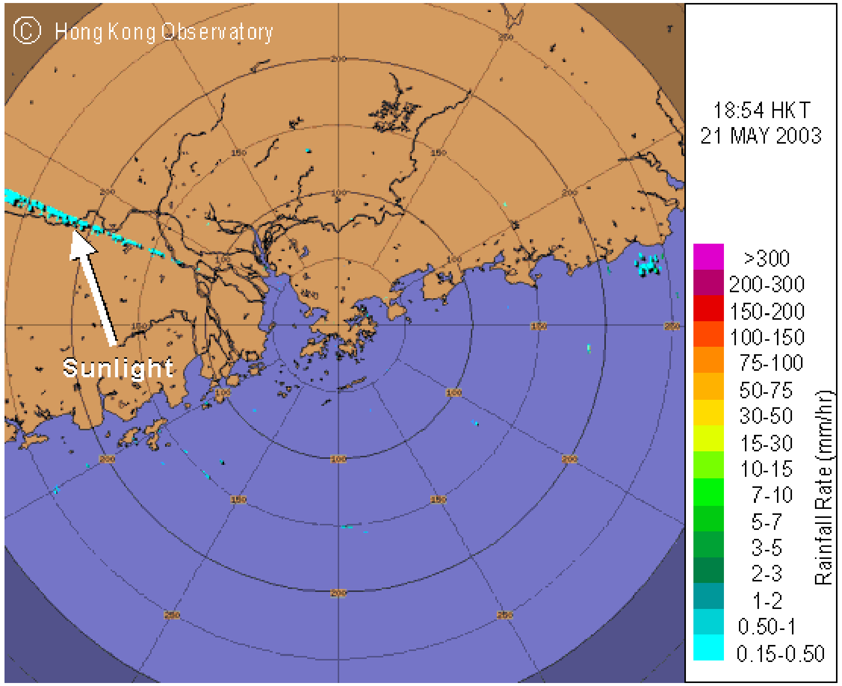
BALTRAD Google Maps View
se.baltrad.eu
baltrad
2011-01-04 14:10 UTC
2011-01-04 15:10 CET
Map
Satellite
Hybrid
Terrain
Updated: 2011-01-05 08:30:04 UTC
2011-01-04
SMHI Composite
Update image list
now
Update every
no
2011-01-04 14:30 UTC
2011-01-04 14:25 UTC
2011-01-04 14:20 UTC
2011-01-04 14:15 UTC
2011-01-04 14:10 UTC
2011-01-04 14:05 UTC
2011-01-04 14:00 UTC
2011-01-04 13:55 UTC
2011-01-04 13:50 UTC
2011-01-04 13:45 UTC
Loaded: (1 / 1) images
anim. speed:
500 ms
last image:
+2 s
opacity:
60%
show:
Current settings:
save as bookmark
save into cookies
clear
dBZ
mm/h
70
60
50
40
30
20
10
0
-10
-20
-30
300
100
30
10
3
1
0.3
0.1
20 mi
50 km
search the map
Search
Map data ©2010 Geocentre Consulting, Google, Tele Atlas, Europa Technologies, Transnavicom - Terms of Use

A reference target that's always there
and it radiates equally in H and V

Sunrise



Sunset



Hong Kong

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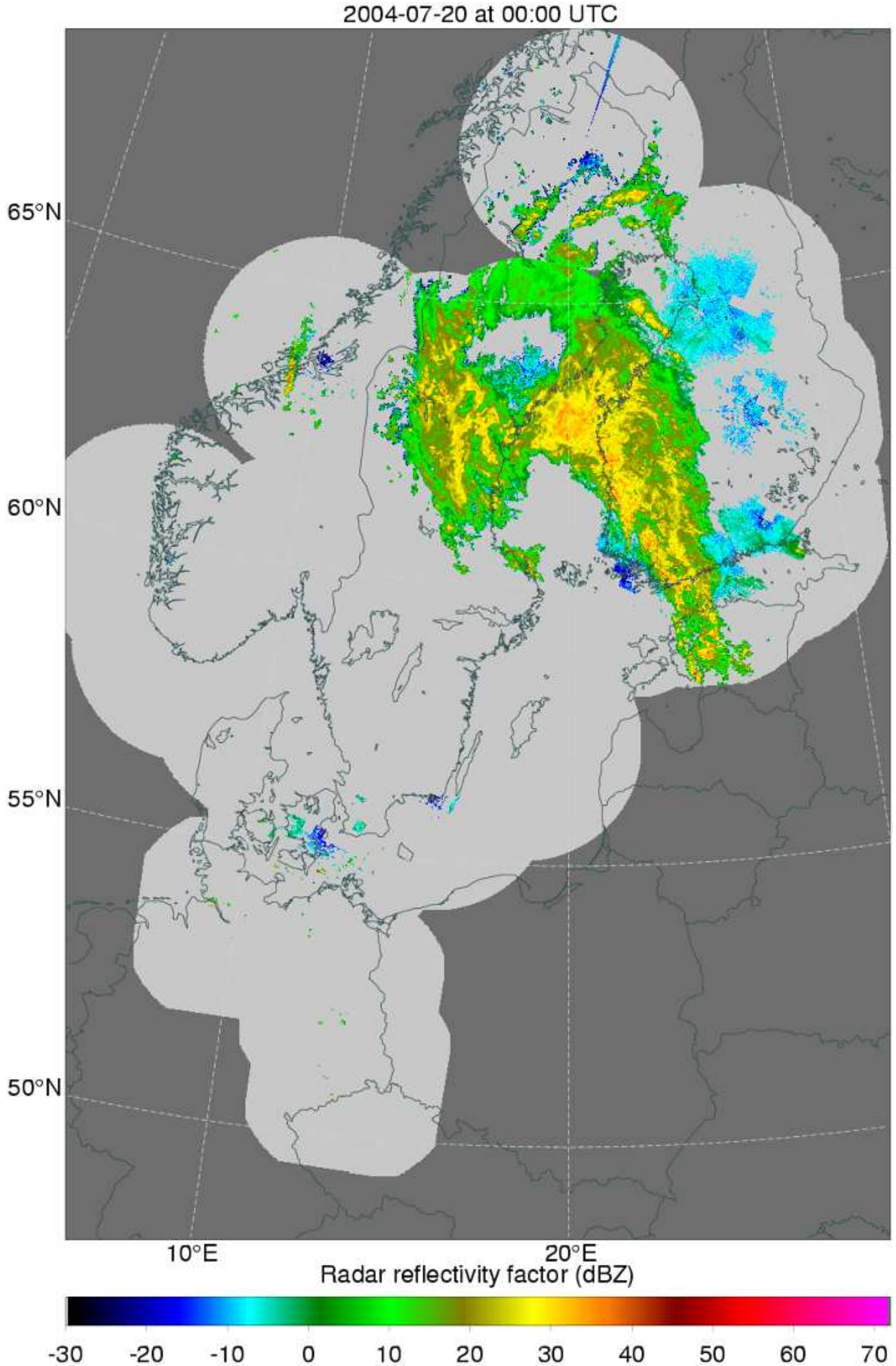

2004-07-20 at 00:00 UTC
65°N
60°N
55°N
50°N
10°E
20°E
Radar reflectivity factor (dBZ)
-30
-20
-10
0
10
20
30
40
50
60
70

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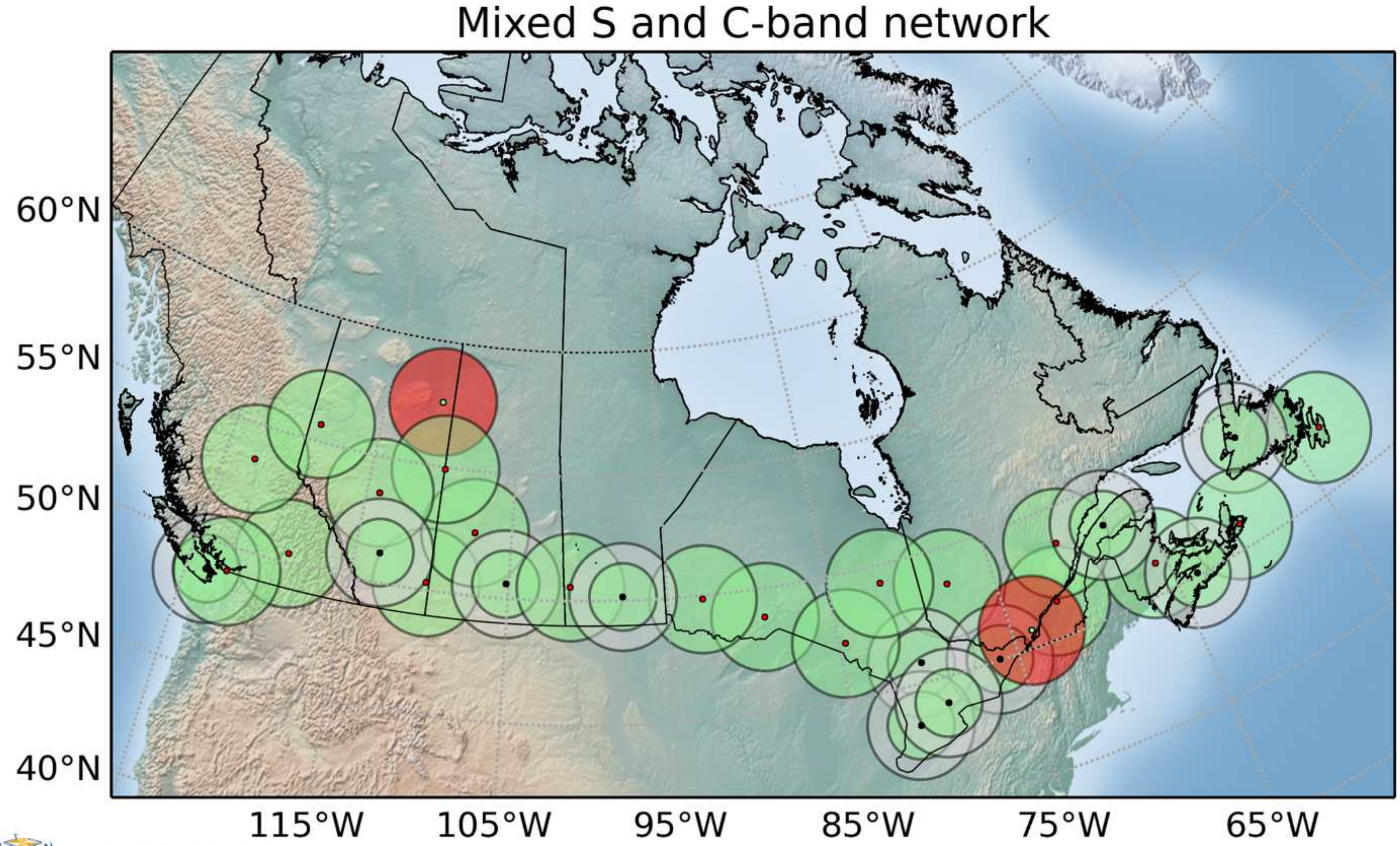
Radar renewal in Canada



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Radisson, Saskatchewan

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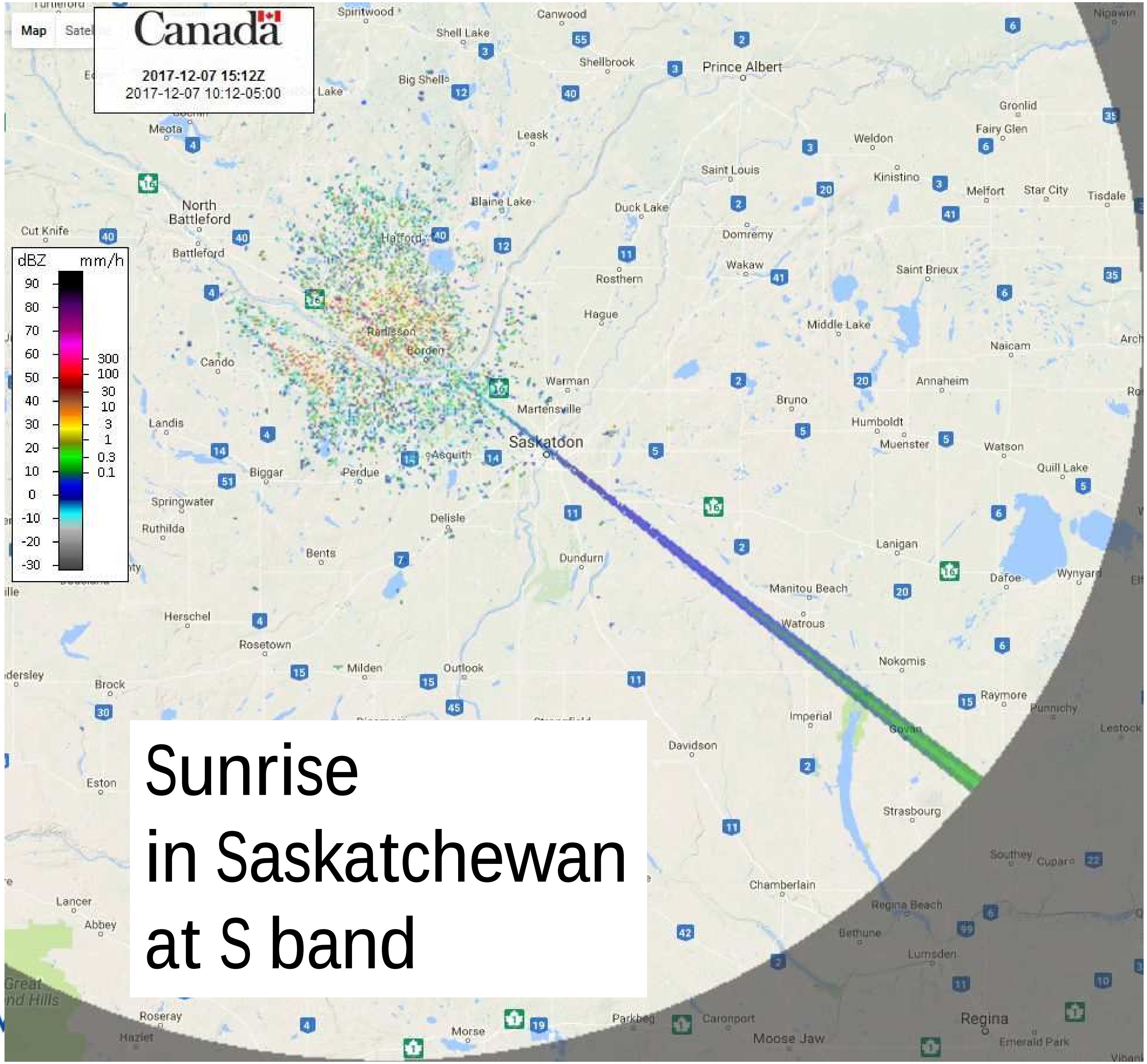
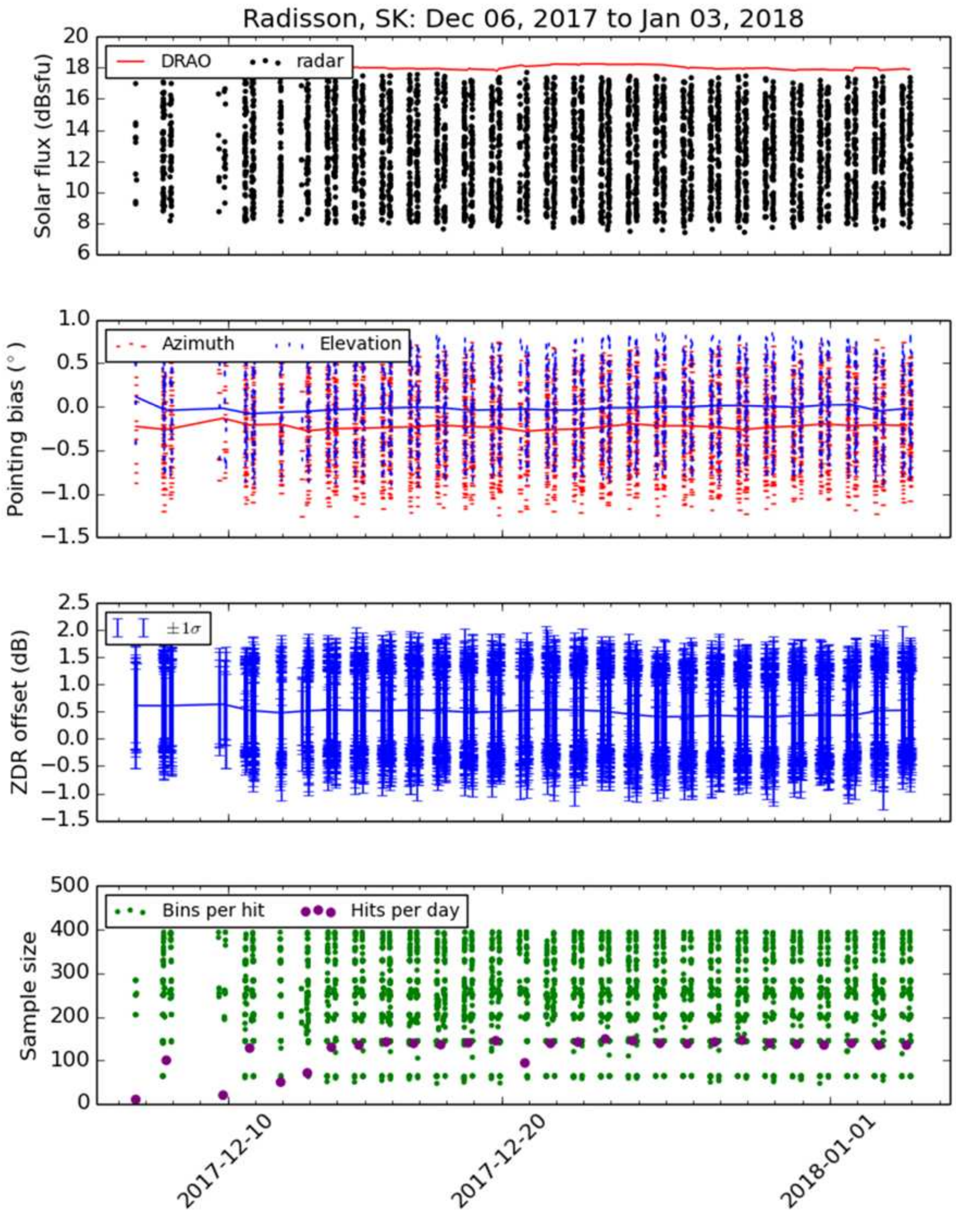
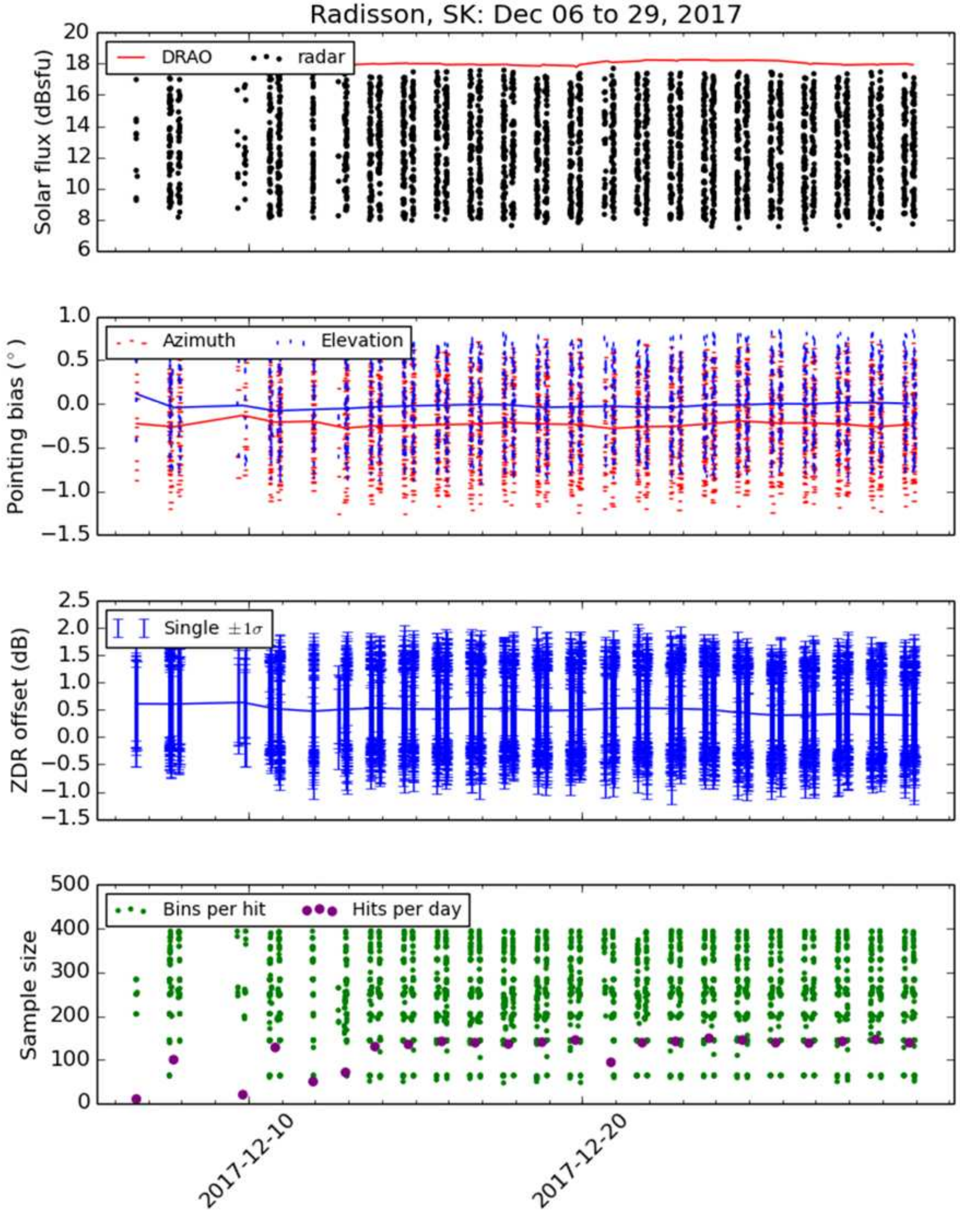


Sunrise in Saskatchewan at S band

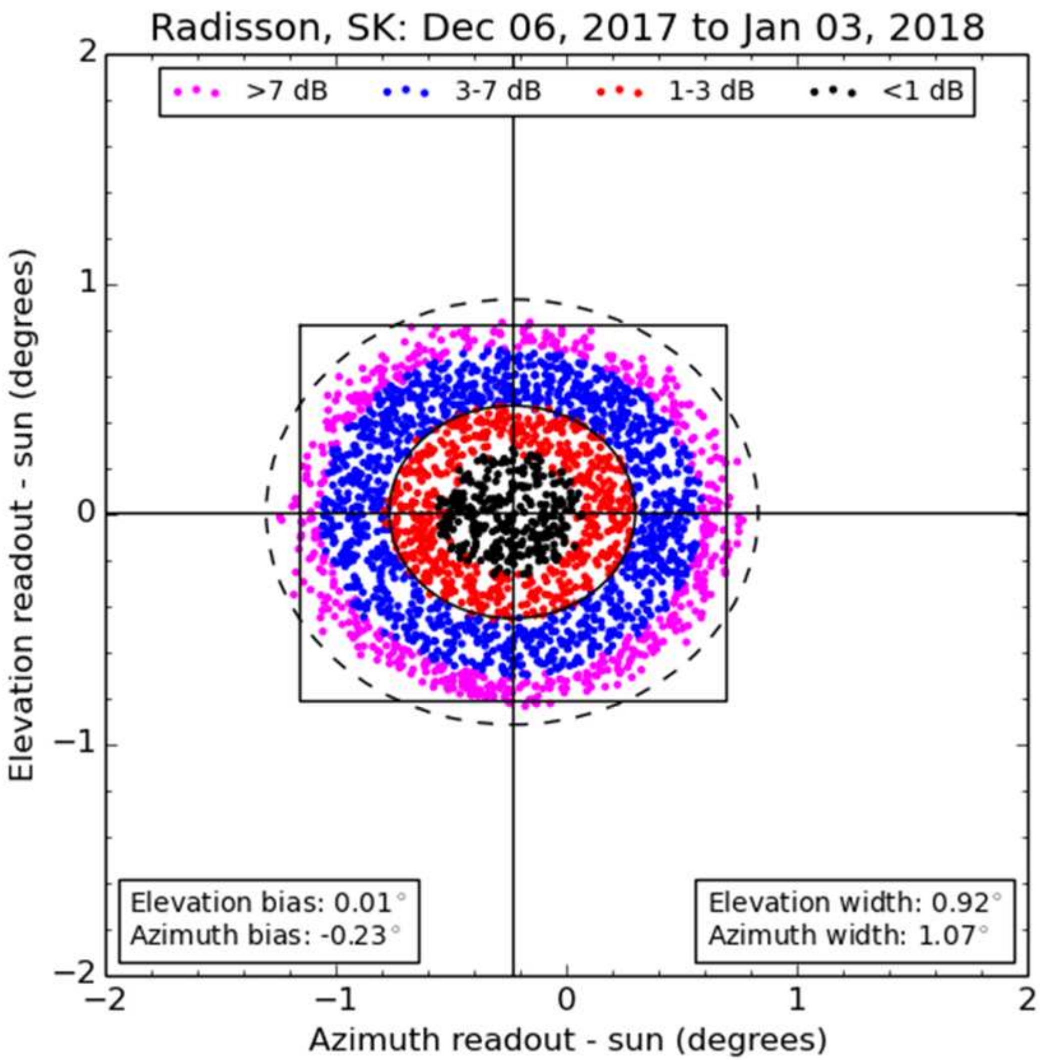

Radisson, SK: Dec 06, 2017 to Jan 03, 2018
Solar flux (dBsfu)
DRAO
radar
Pointing bias (°)
Azimuth
Elevation
ZDR offset (dB)
±1σ
Sample size
Bins per hit
Hits per day
2017-12-10
2017-12-20
2018-01-01

WMO OI


Radisson, SK: Dec 06 to 29, 2017
DRAO
radar
Solar flux (dBsfu)
Azimuth
Elevation
Pointing bias (°)
Single ±1σ
ZDR offset (dB)
Bins per hit
Hits per day
Sample size
2017-12-10
2017-12-20

WMO OI

Pointing accuracy and power distribution



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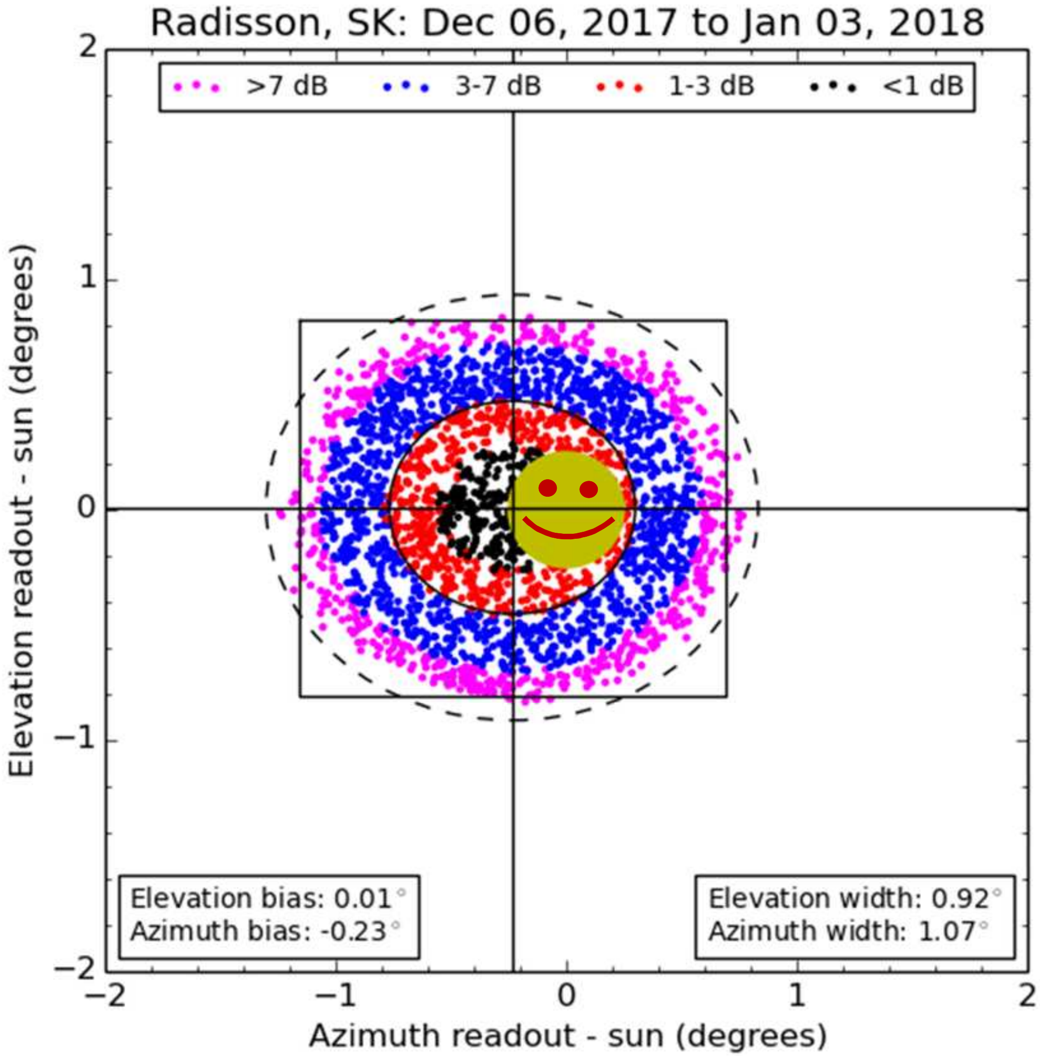
Pointing accuracy and power distribution



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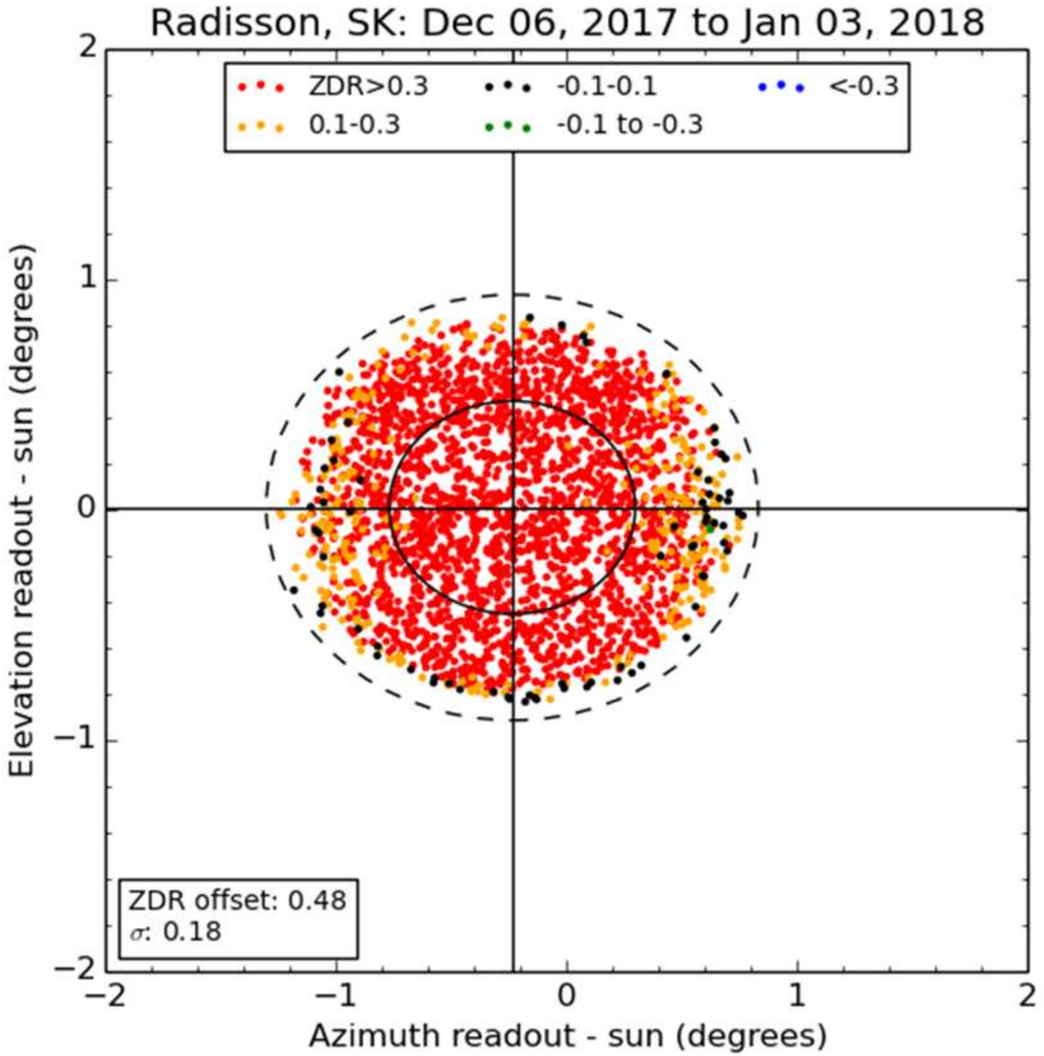
Pointing accuracy and ZDR distribution



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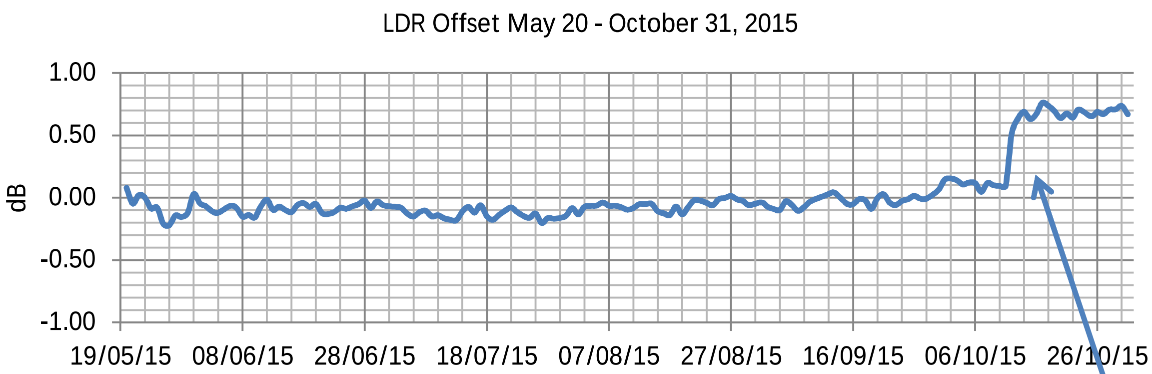
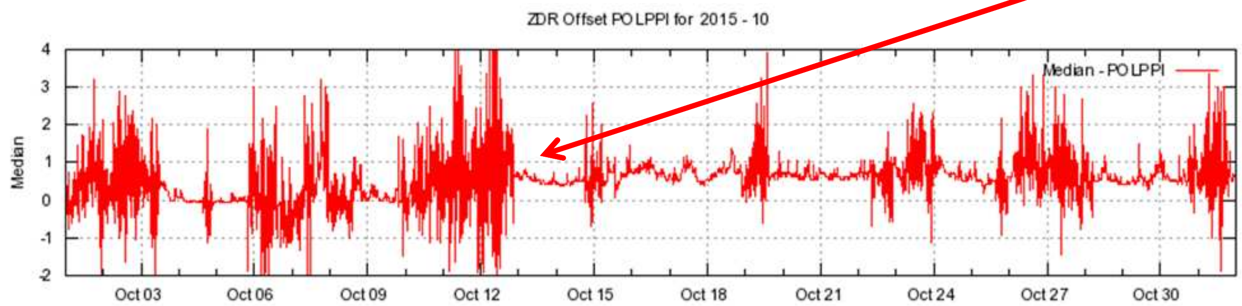
Other monitoring of ZDR
King City, Ontario. C-band

IRIS Suncal utility



Degraded TR cell

Median values derived from PPI data



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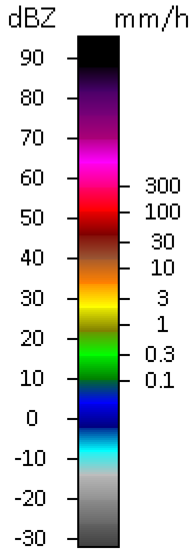
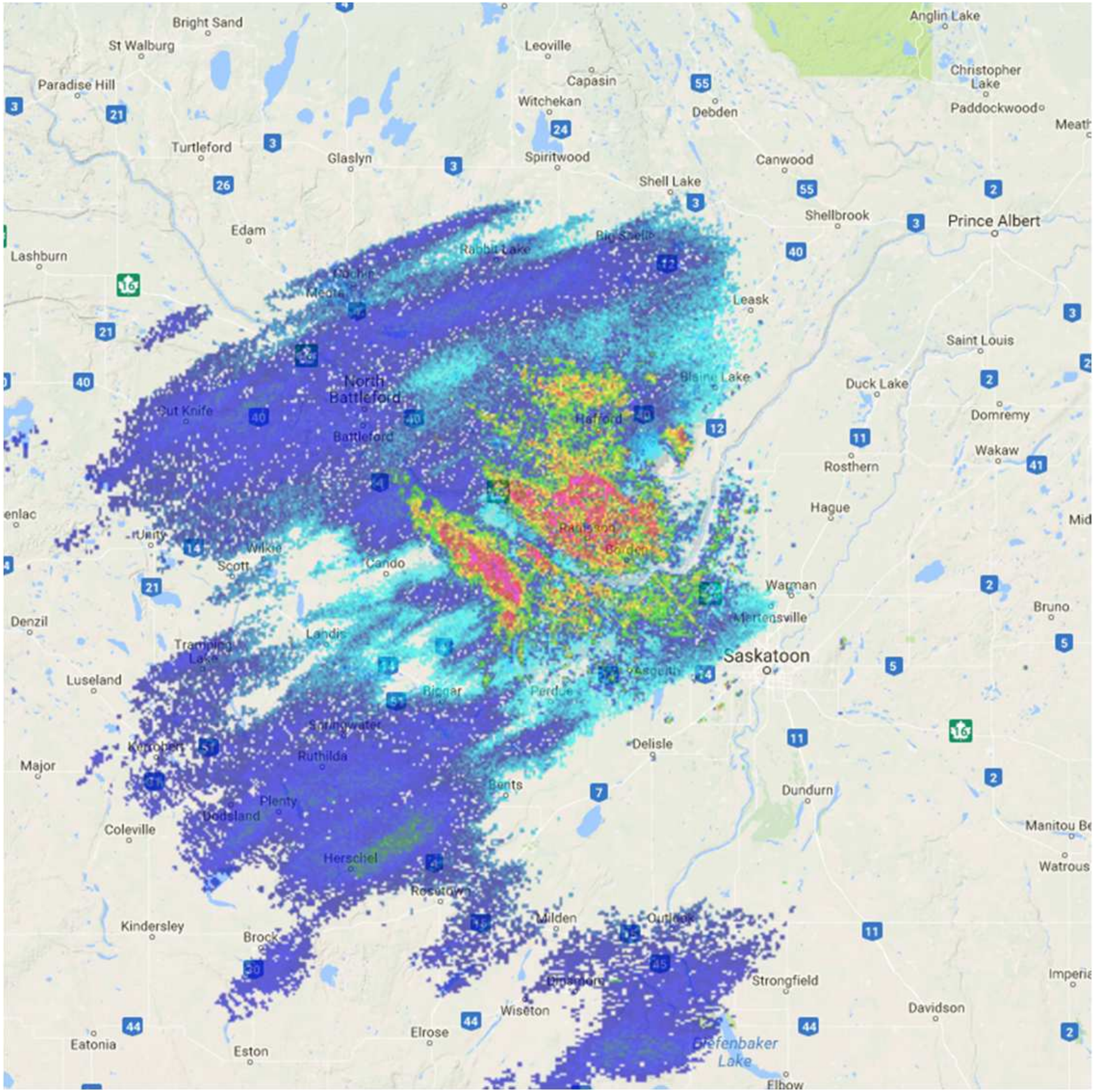
Uncorrected vs
Corrected Z

Weak snow

Radisson, SK
Jan 10, 2018
15:59-17:00 UTC

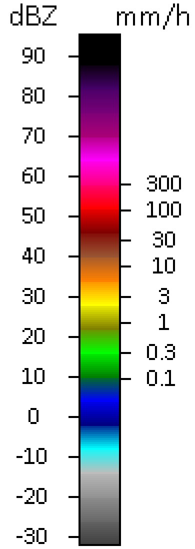


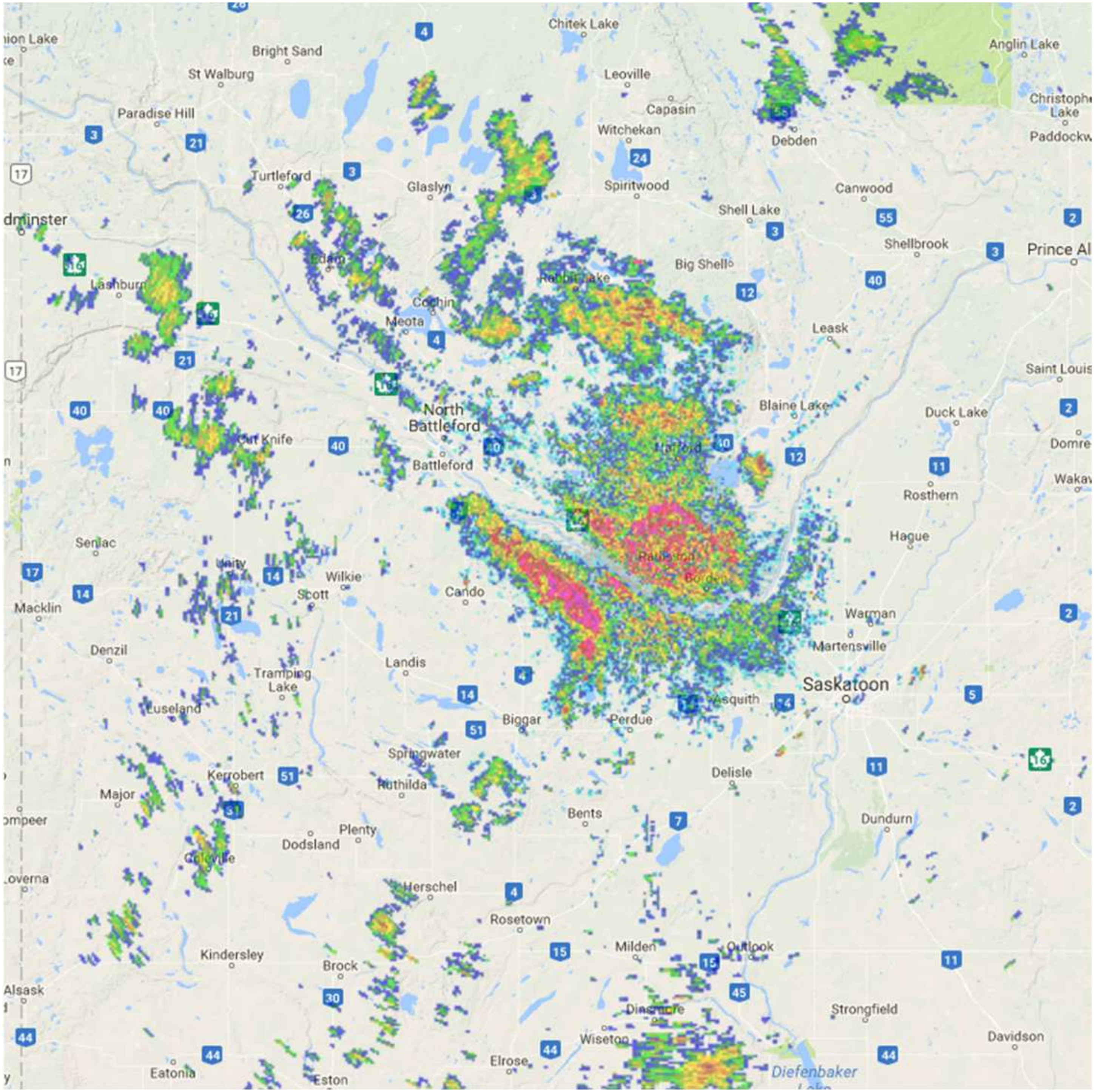


Uncorrected vs Corrected Z

Anomalous propagation

Radisson, SK
Jan 16, 2018
17:41-18:42 UTC





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Radar Data Assimilation: Input weather radar data

Canadian network

- 30 C-band Doppler radars
- 10 minute acquisition cycle
- 24-sweep non-Doppler volume, no QC, 256 km range
- 4 Doppler sweeps, reflectivity and radial winds, 125 km

McGill University S-band

- Reflectivity only, 480 km
- 5 min acquisition cycle

NEXRAD Level II

- Continental United States + Alaska, ~6 min data

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Quality control of weather radar data

ECCC

NEXRAD

McGill

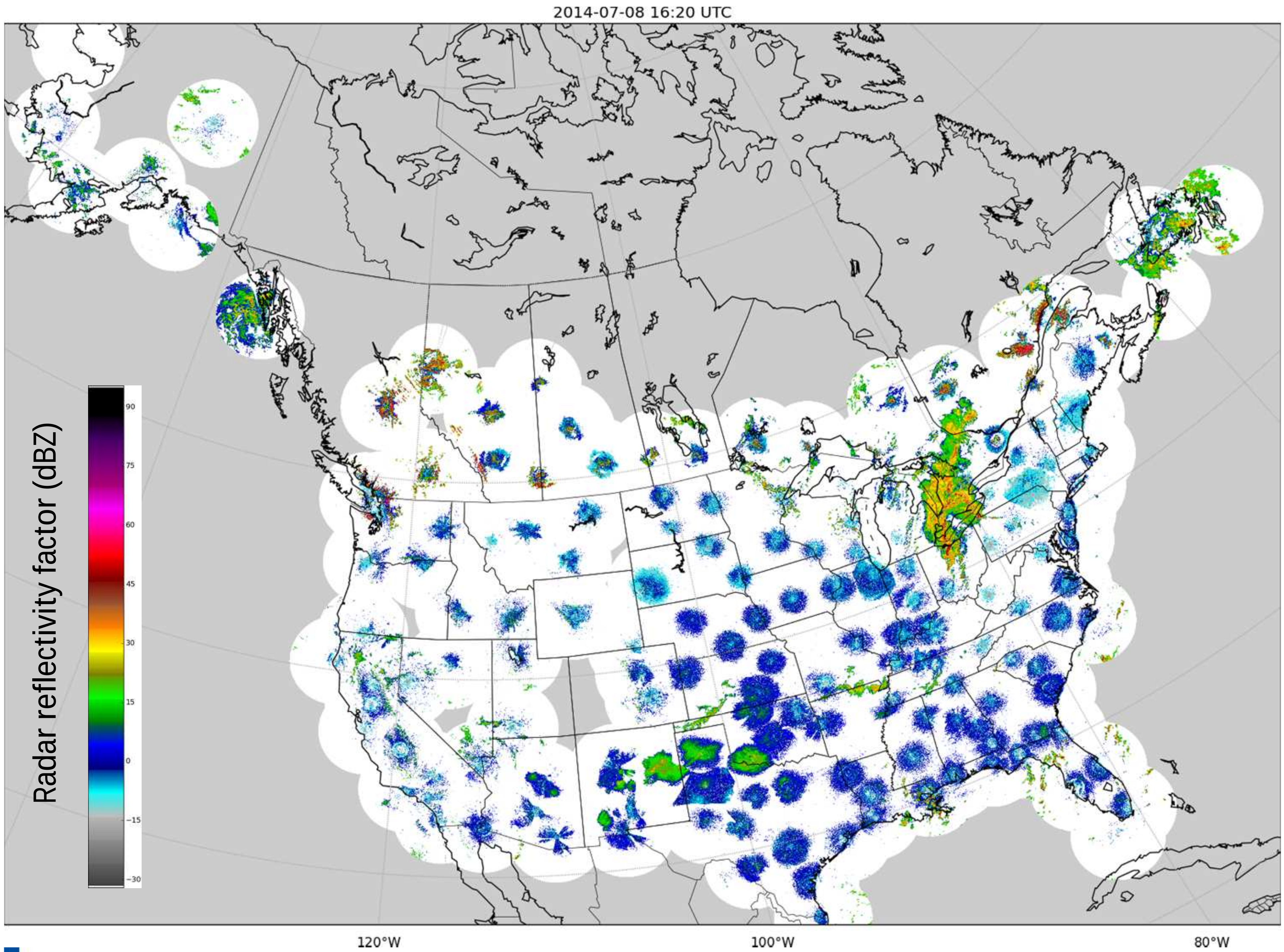
1. Hit-accumulation clutter filter
2. Non-precipitation identification and removal:
   - Biometeors: birds, insects
   - Speckle
   - External emitters, ie. RFI
3. Beam blockage identification and correction <60%
4. Attenuation correction (conventional)
5. Beam broadening – descriptive
6. “Total quality” – descriptive, minimum of 3-5

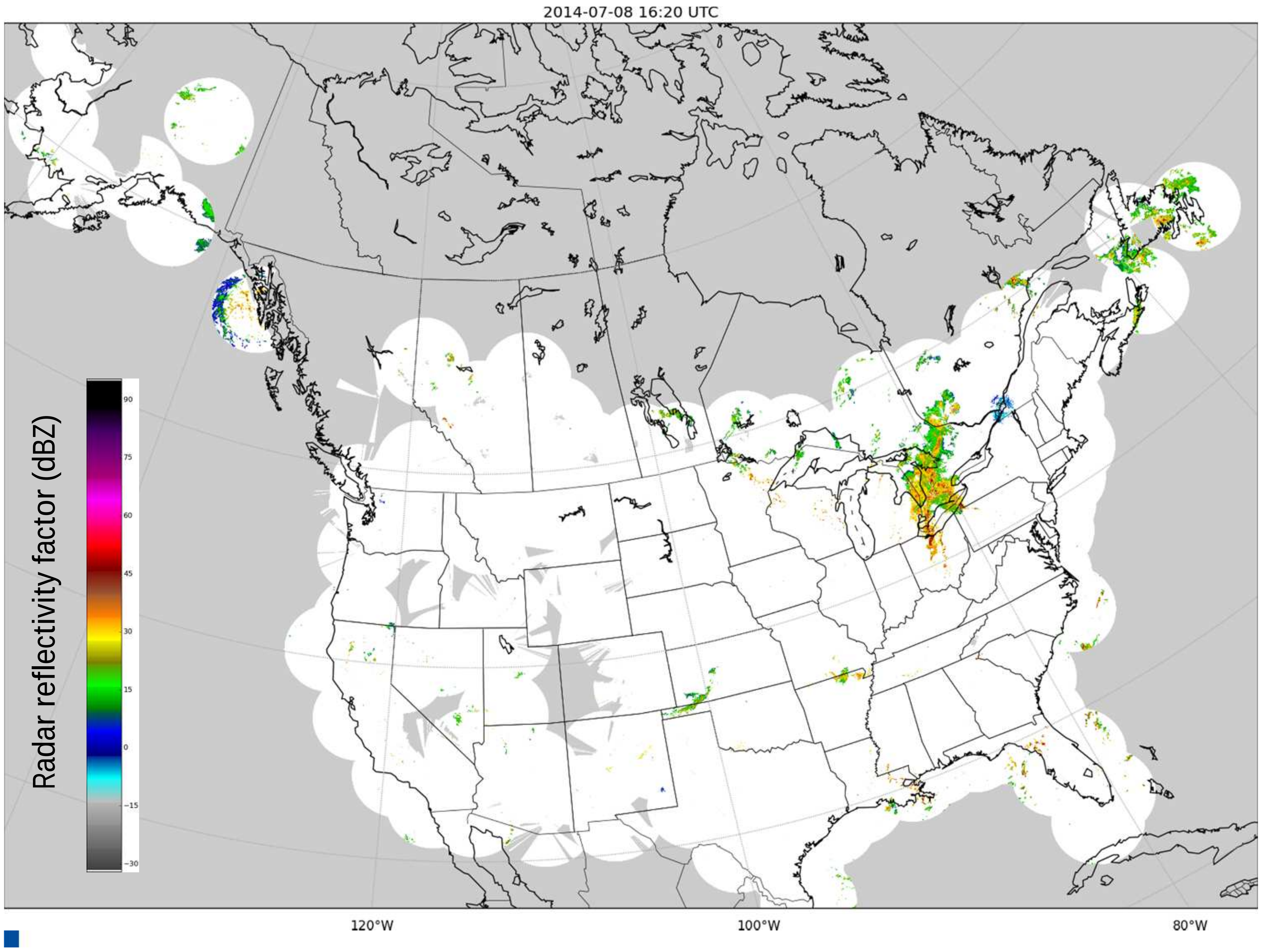
Data processing / compositing

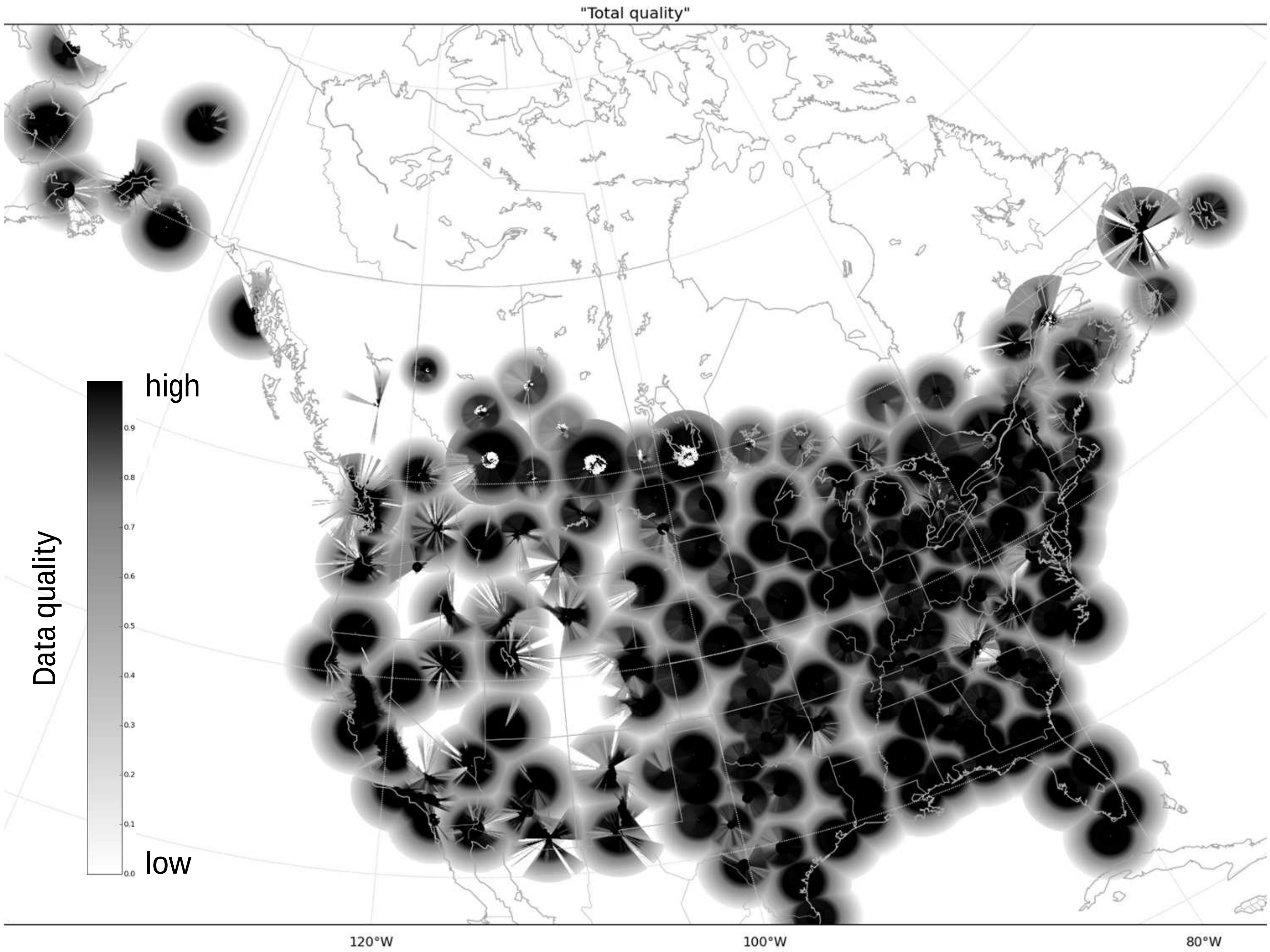
- BALTRAD Toolbox deployed at ECCC
  - ✓ Decodes for IRIS and McGill formats developed
  - ✓ NEXRAD Level II decode from Py-ART
  - ✓ BALTRAD data quality framework exploited
- 2.5 km reflectivity composites generated
  - ✓ Containing **both** corrected and uncorrected reflectivities
  - ✓ All data quality metrics carried over from polar to Cartesian space
  - ✓ 10 minute
  - ✓ 1 km pseudo-CAPPI
  - ✓ Selection criterion: maximum "total" data quality
- All data and composites represented in ODIM_H5

WMO OMM

built by baltrad


2014-07-08 16:20 UTC
Radar reflectivity factor (dBZ)
90
75
60
45
30
15
0
−15
−30
120°W
100°W
80°W

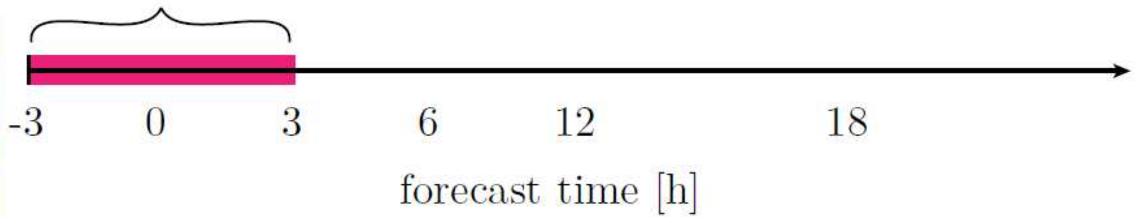

2014-07-08 16:20 UTC
Radar reflectivity factor (dBZ)
90
75
60
45
30
15
0
−15
−30
120°W
100°W
80°W

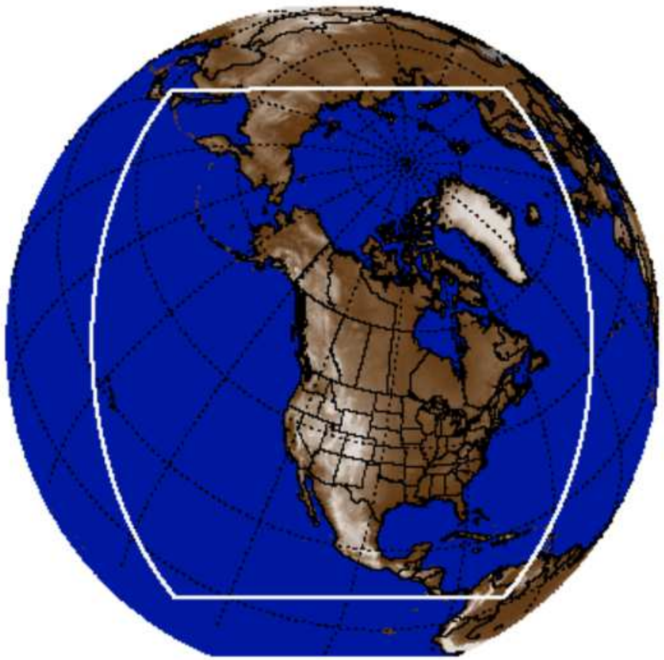

"Total quality"
high
low
Data quality
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
120°W
100°W
80°W

NWP model & Latent Heat Nudging

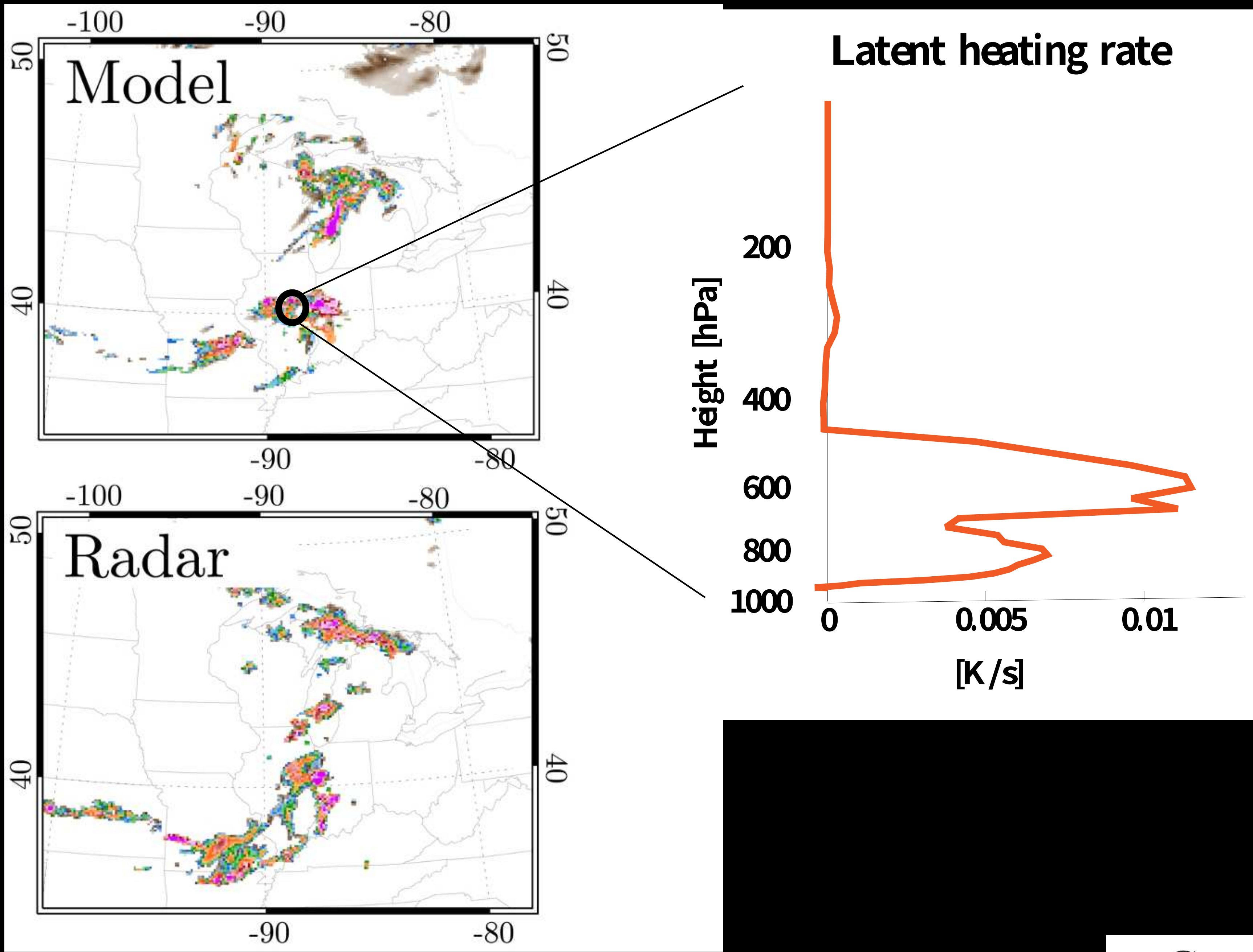
- Regional Deterministic Prediction System
- EnVAR assimilation using Incremental Analysis Updating
- 10 km horizontal resolution
- 48h forecasts at 00Z and 12Z
- July 2014

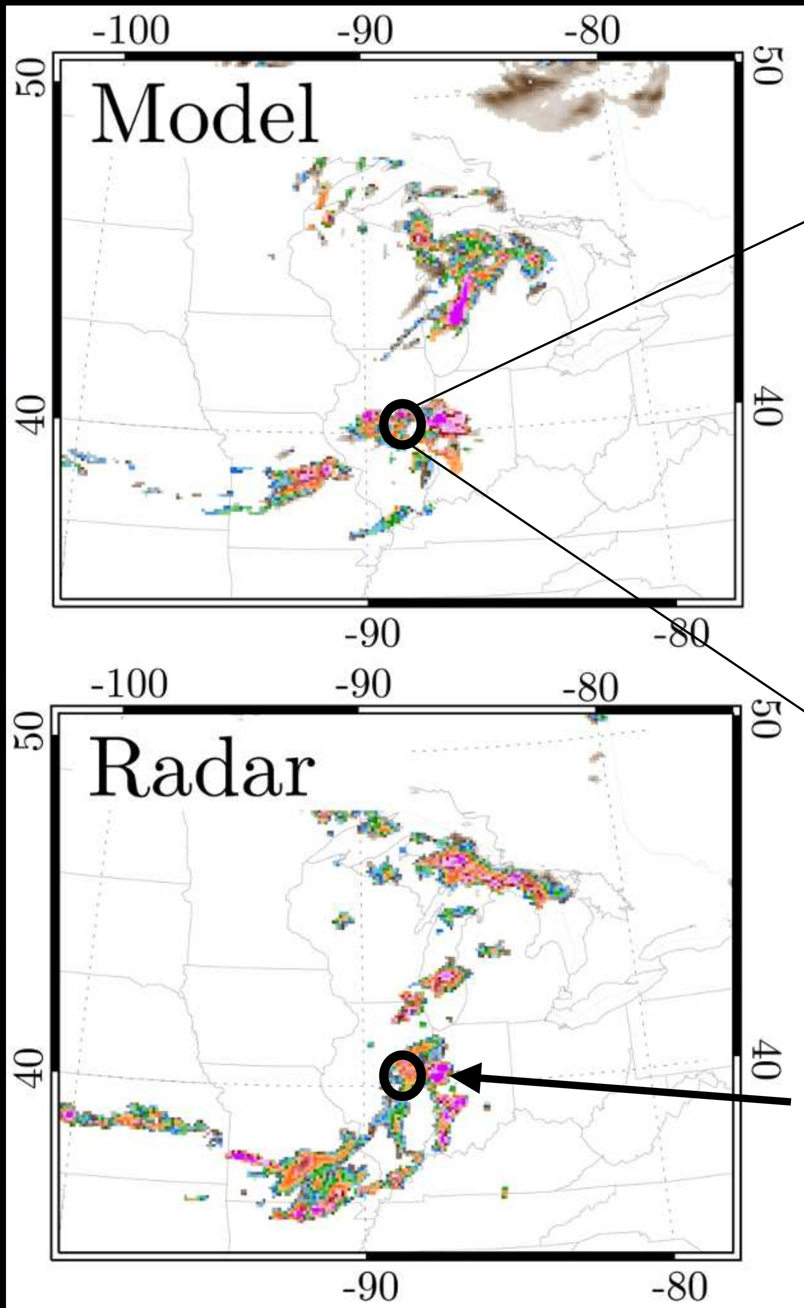
LHN is applied every 10 minutes between
-3 and +3h forecasts

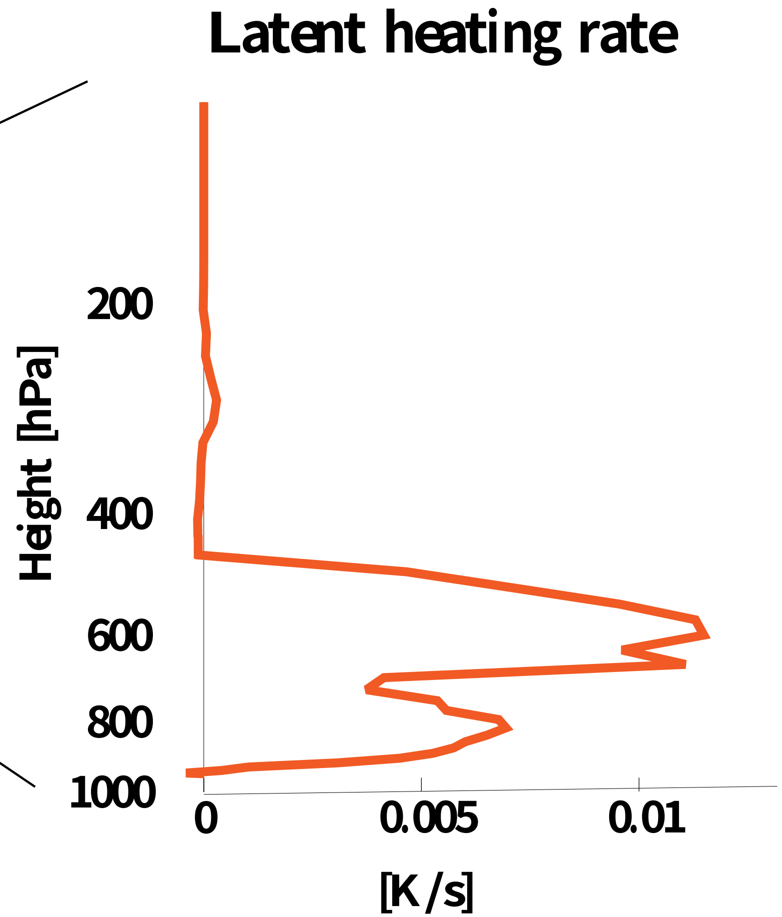




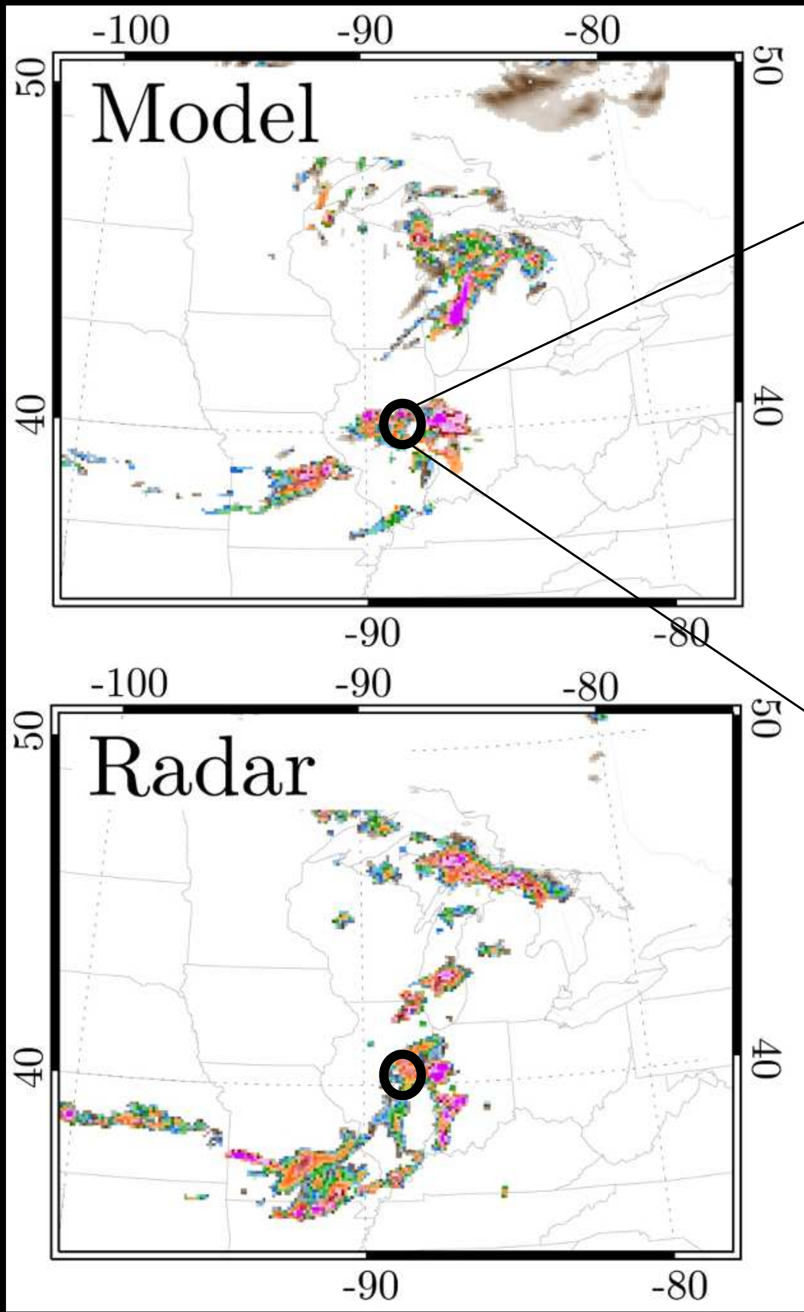
WMO OMM

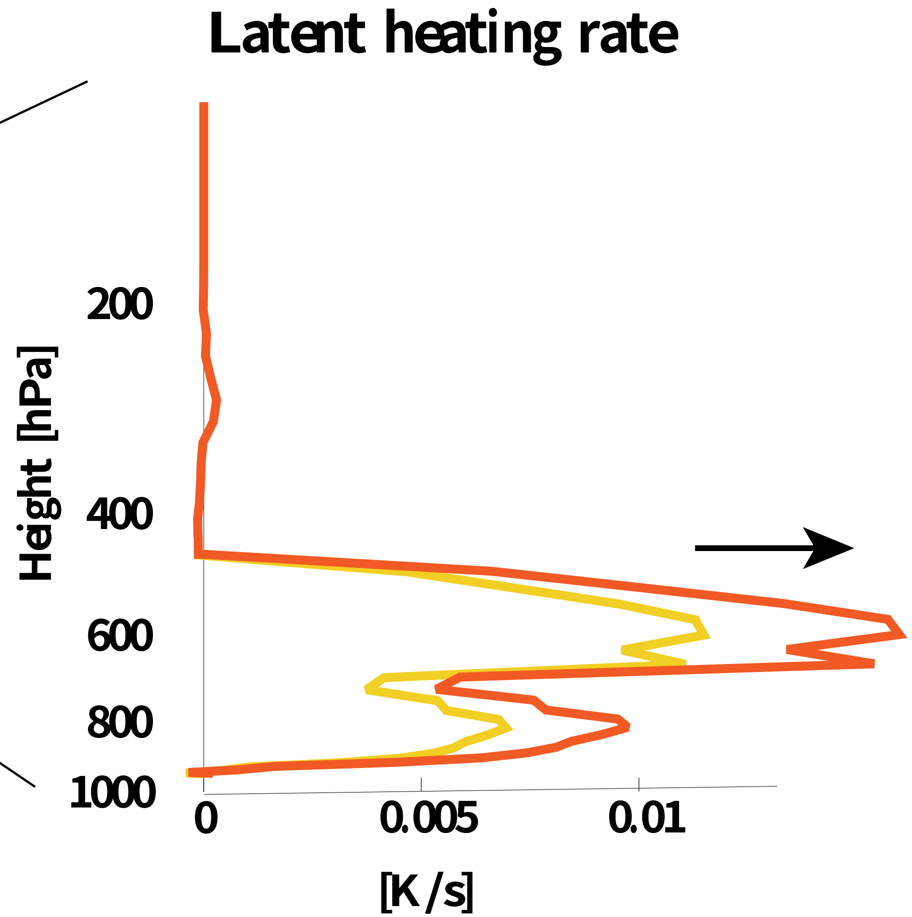

Latent heating rate
Model
Radar
-100
-90
-80
50
40
Height [hPa]
200
400
600
800
1000
0
0.005
0.01
[K/s]





Comp[redacted]
again[redacted]

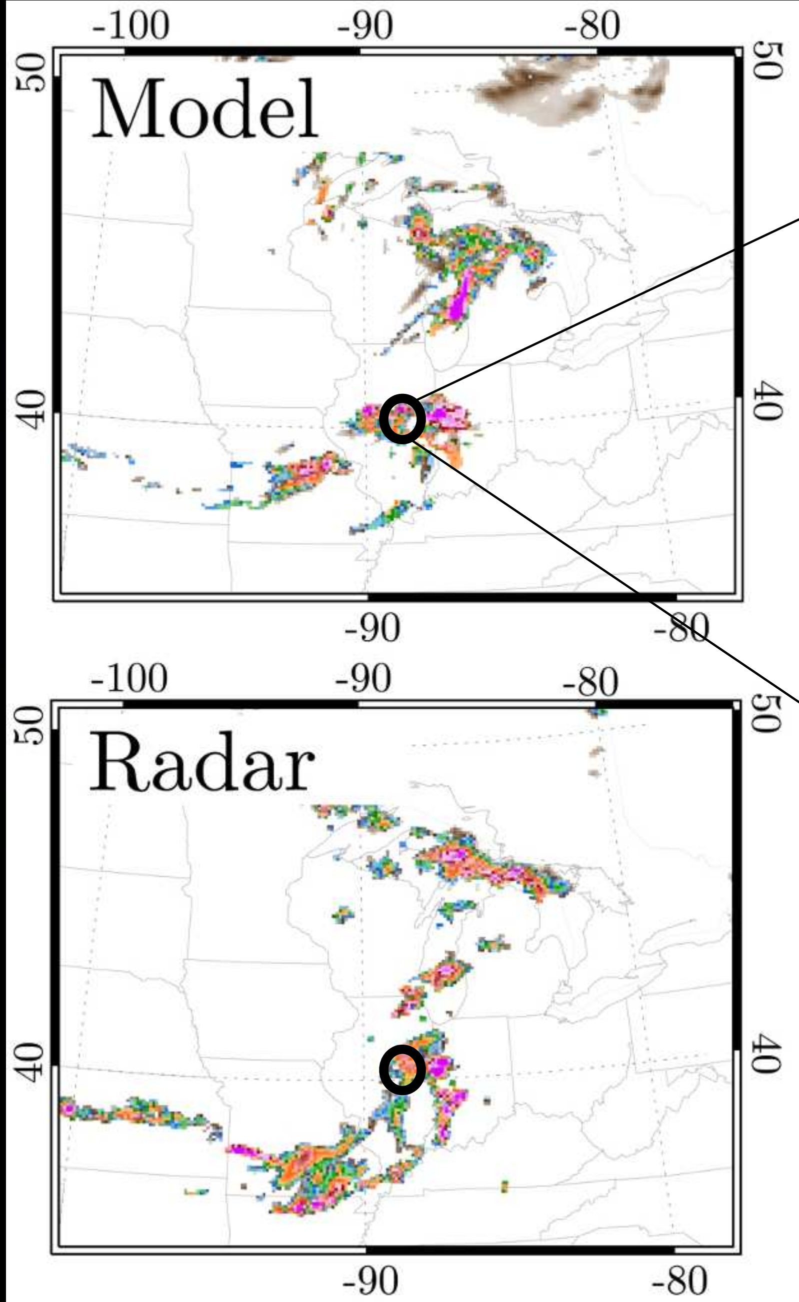


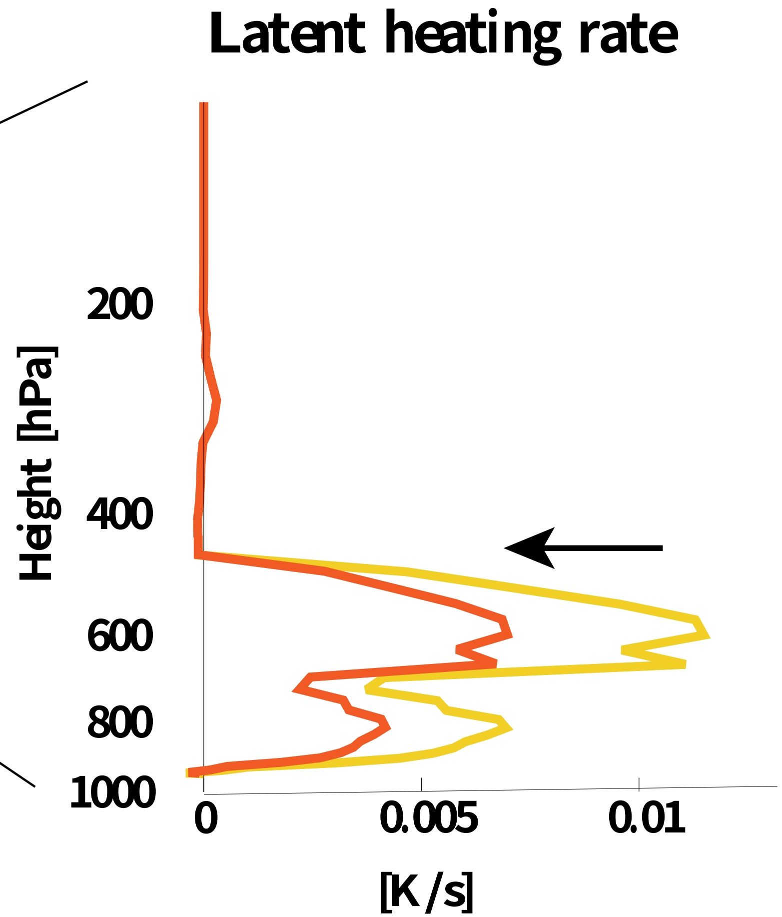


Increa[redacted]
if mo[redacted]

Canada

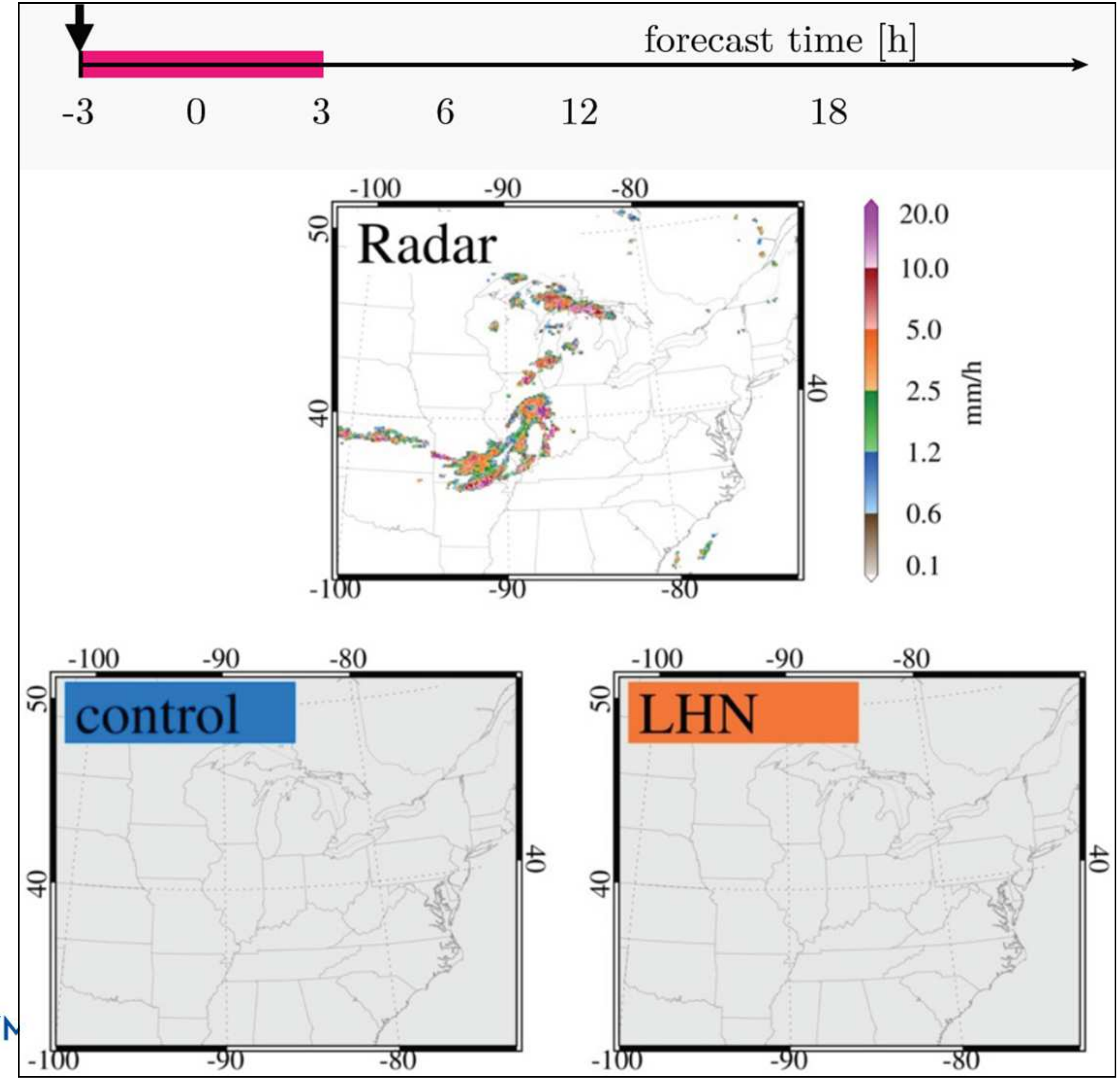
[redacted]

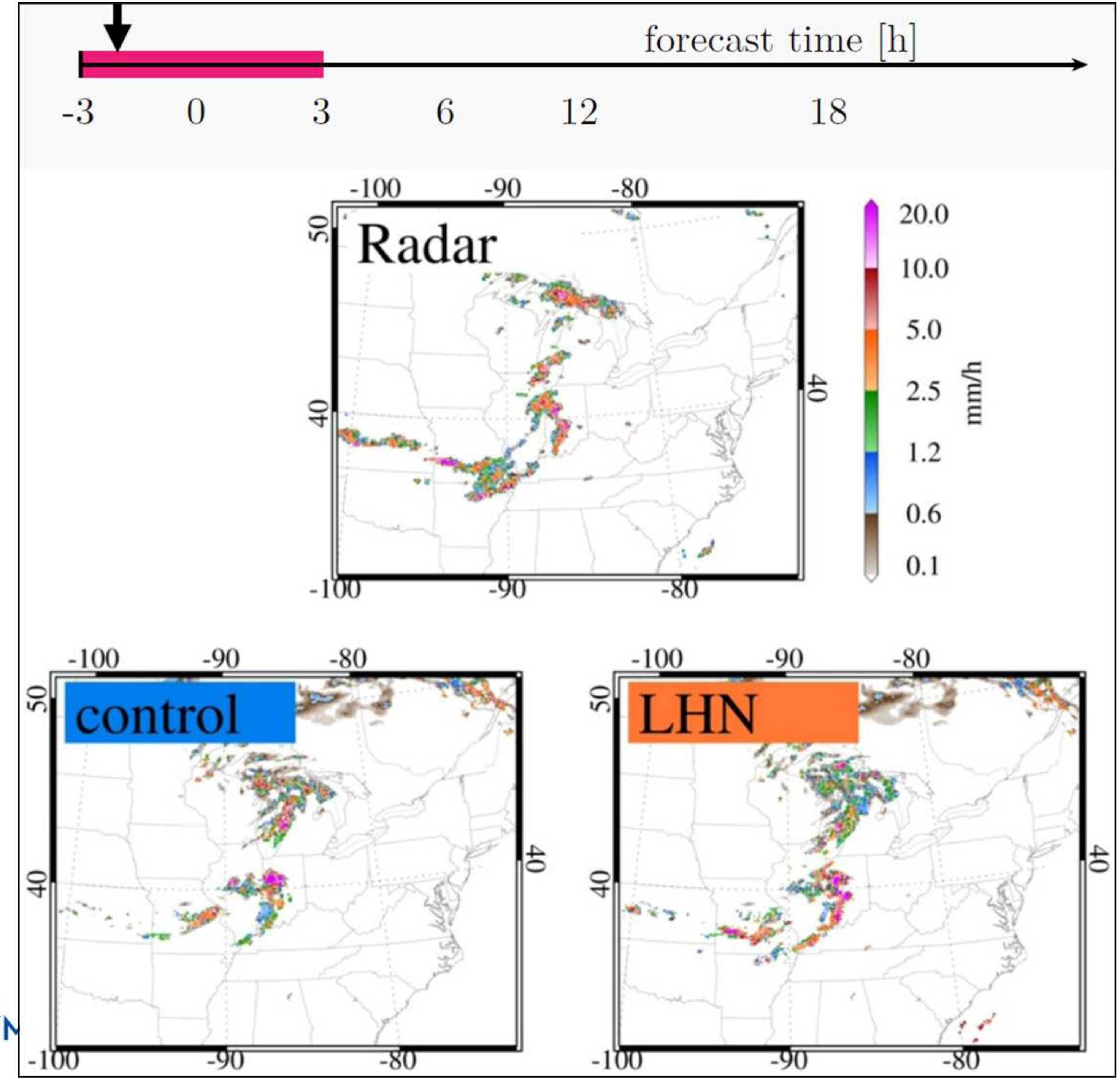




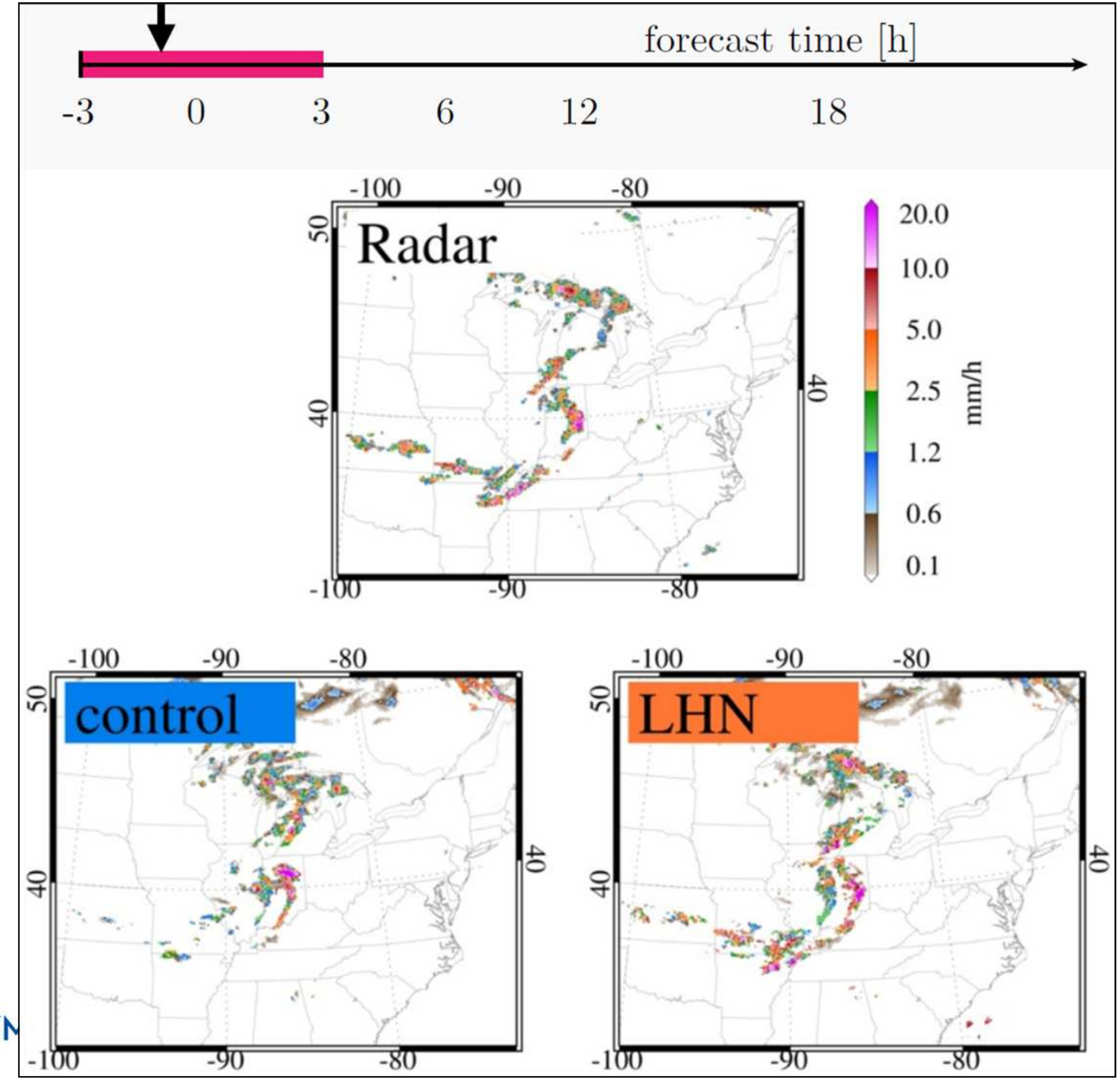
Decre[redacted]

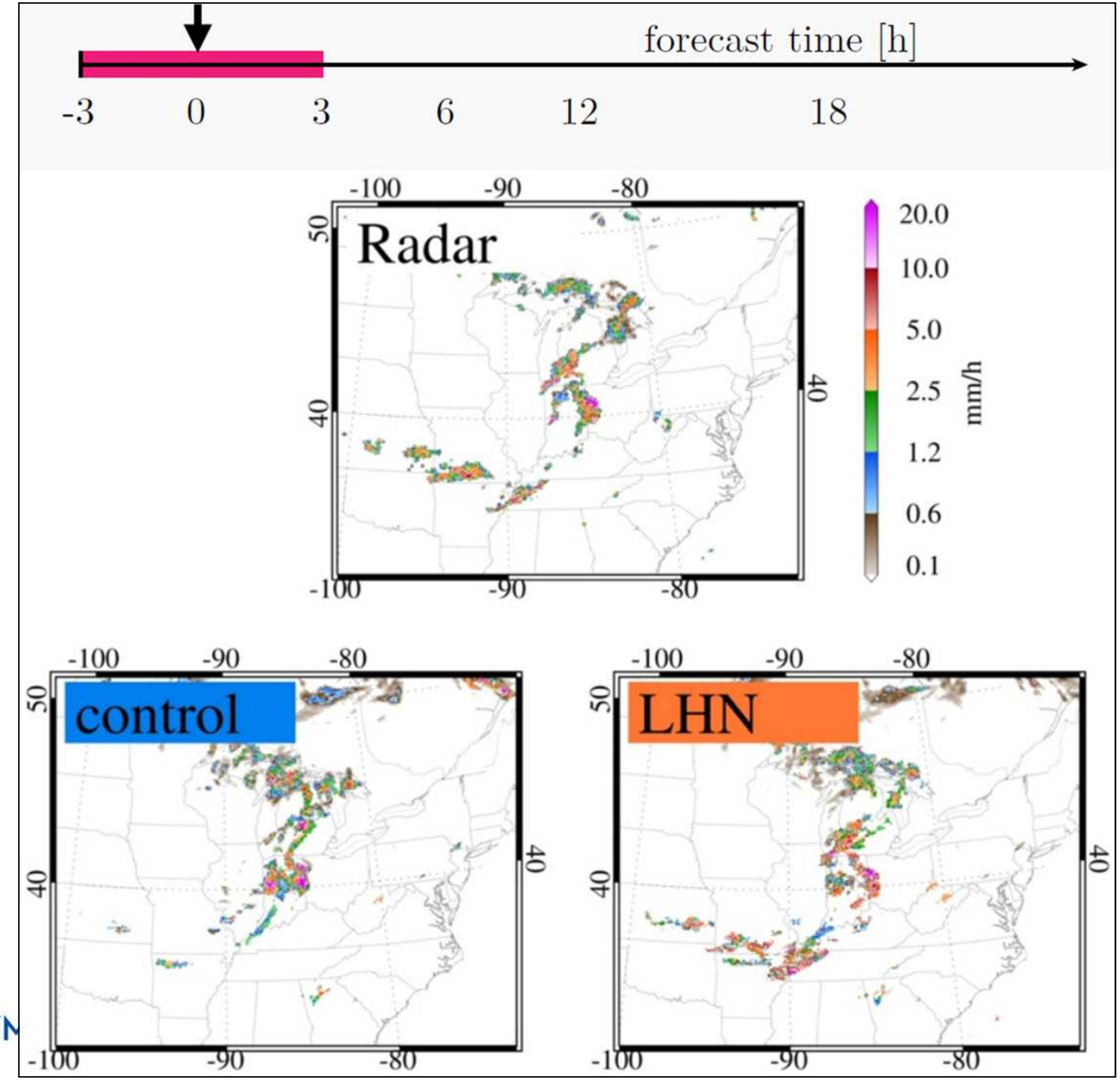
if less[redacted]

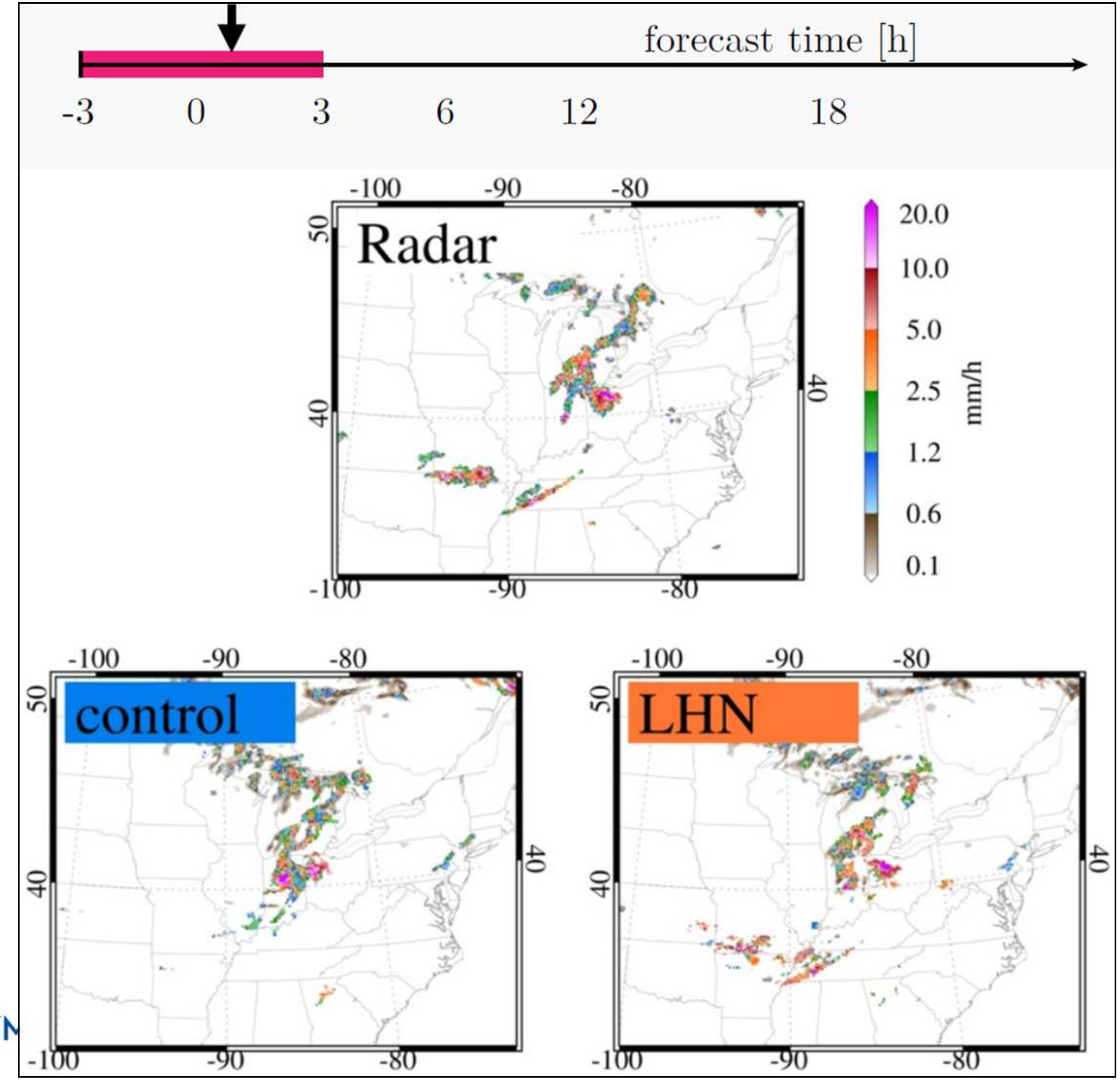

forecast time [h]
-3
0
3
6
12
18
Radar
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h
-100
-90
-80
50
40
control
LHN



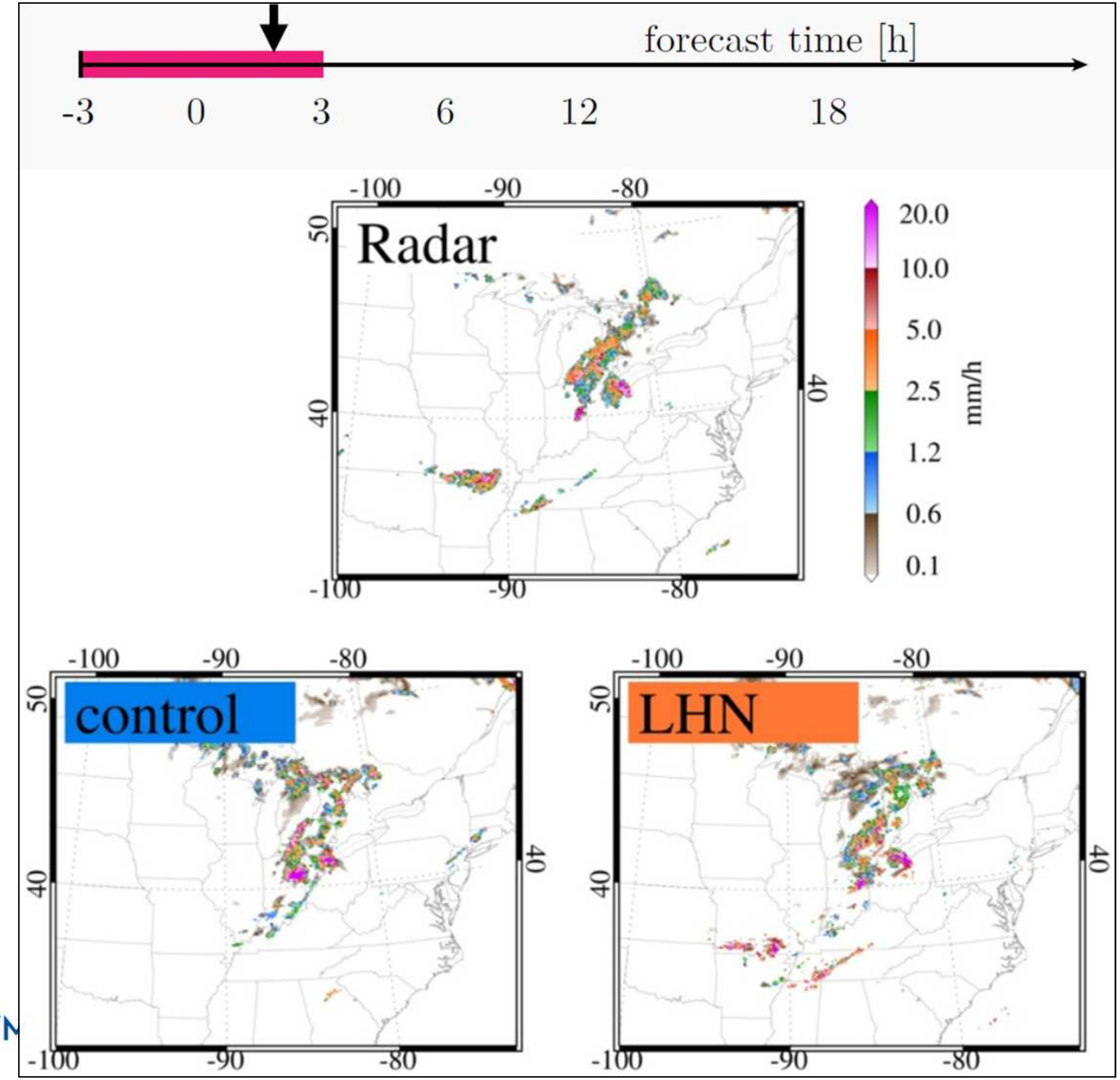
forecast time [h]
-3
0
3
6
12
18
Radar
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h
control
LHN
-100
-90
-80
50
40


forecast time [h]
-3
0
3
6
12
18
Radar
control
LHN
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h
-100
-90
-80
50
40

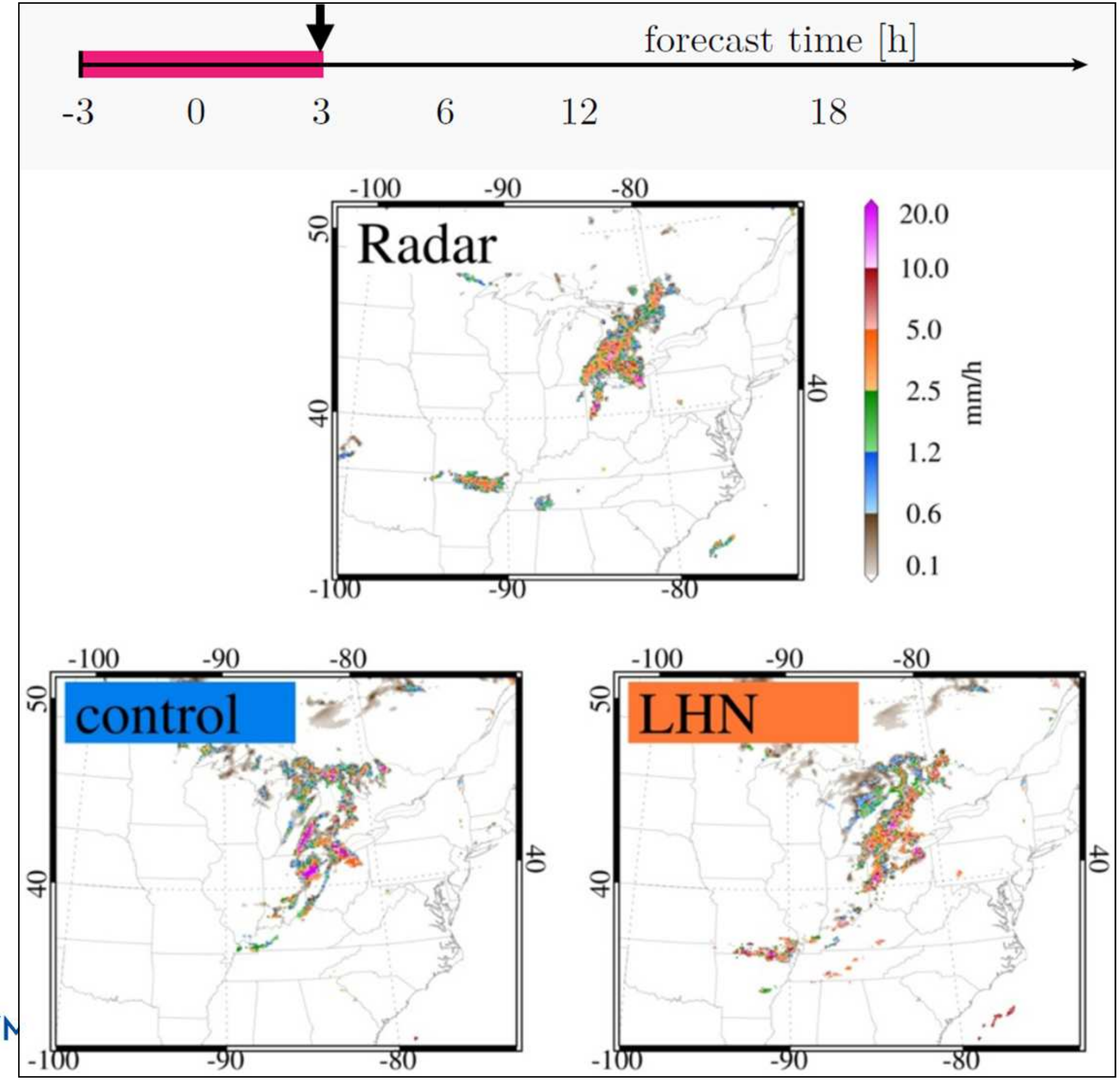

forecast time [h]
-3
0
3
6
12
18
Radar
control
LHN
-100
-90
-80
50
40
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h

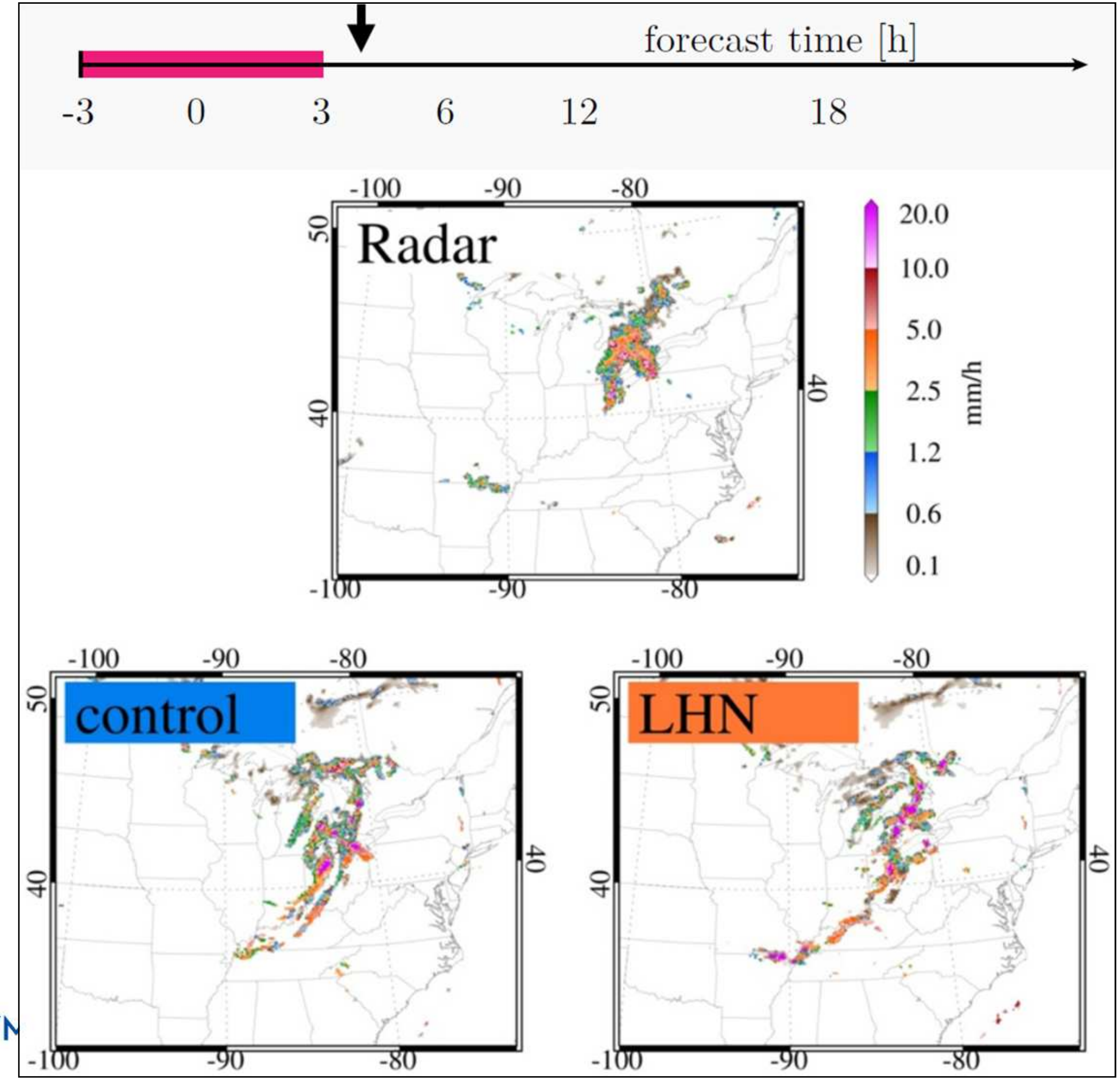


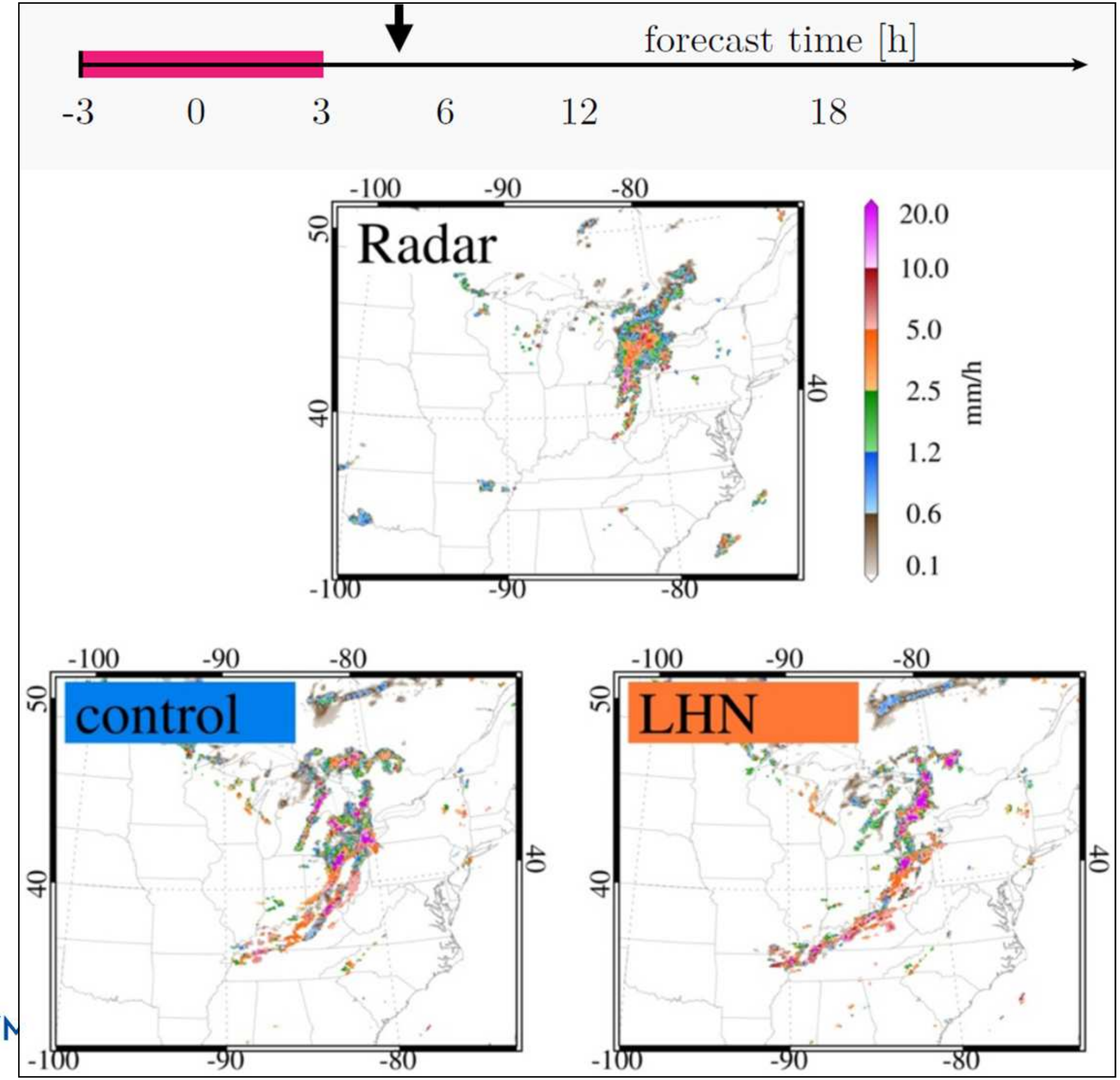
forecast time [h]
-3
0
3
6
12
18
Radar
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h
control
LHN
-100
-90
-80
50
40



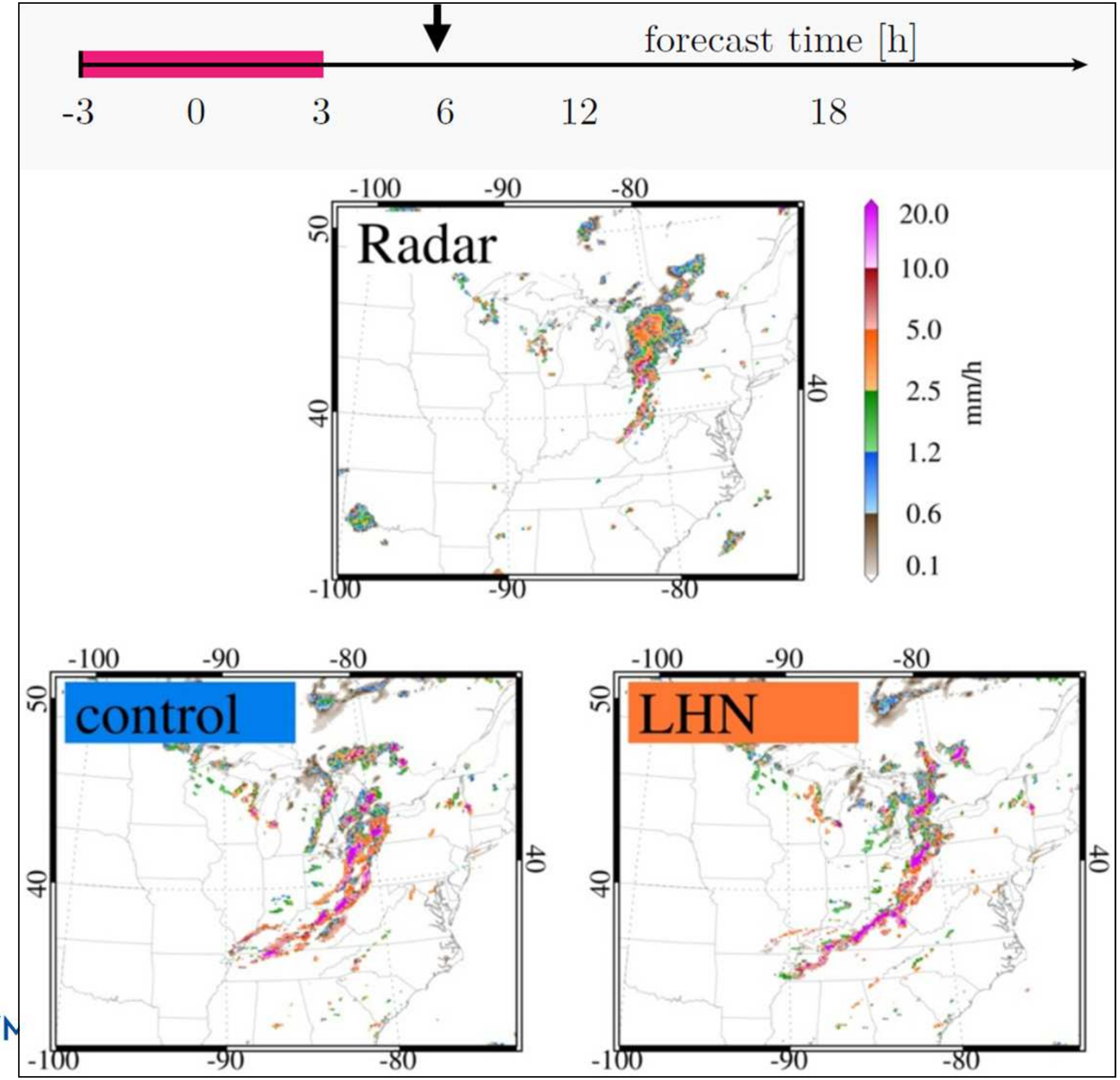
forecast time [h]
-3
0
3
6
12
18
Radar
control
LHN
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h
-100
-90
-80
50
40


forecast time [h]
-3
0
3
6
12
18
Radar
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h
-100
-90
-80
50
40
control
LHN

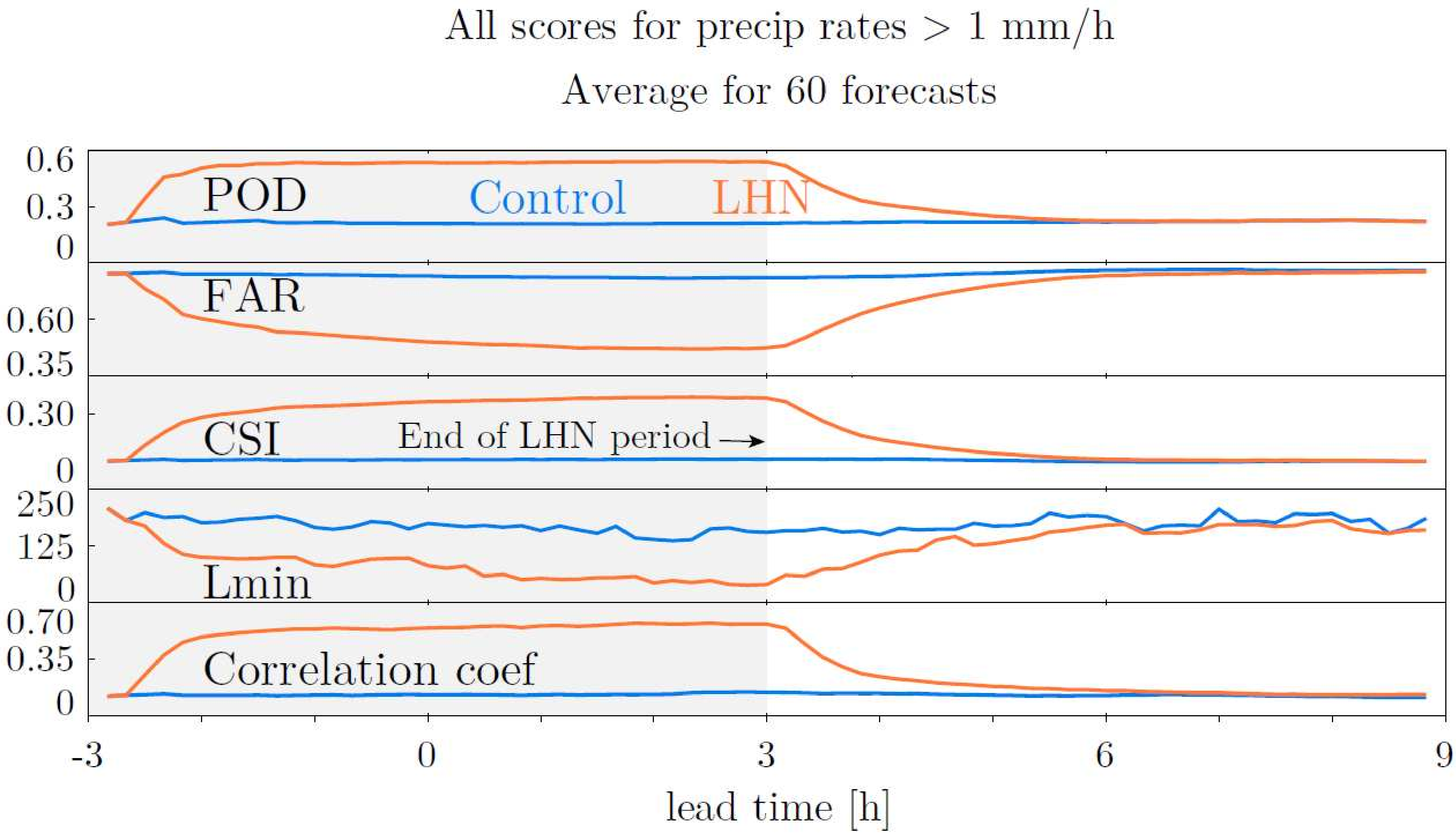

forecast time [h]
-3
0
3
6
12
18
Radar
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h
-100
-90
-80
50
40
control
LHN



forecast time [h]
-3
0
3
6
12
18
Radar
control
LHN
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h
-100
-90
-80
50
40


forecast time [h]
-3
0
3
6
12
18
Radar
control
LHN
-100
-90
-80
50
40
20.0
10.0
5.0
2.5
1.2
0.6
0.1
mm/h

Verification 1

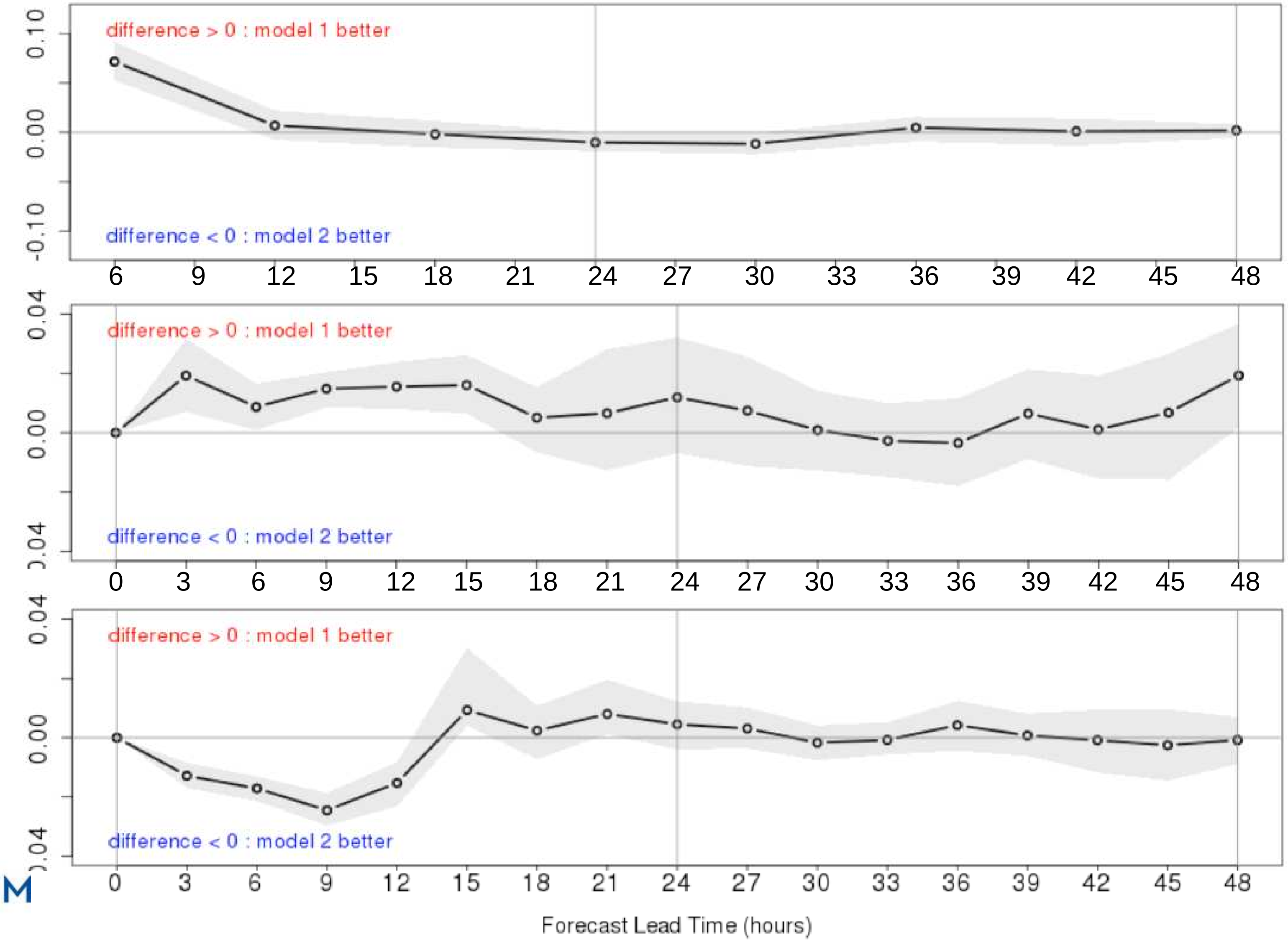


Verification 2

ETS score
6hr accum
Precip > 1 mm

RMSE of wind
module error
(m/s)

Cloud cover
frequency bias

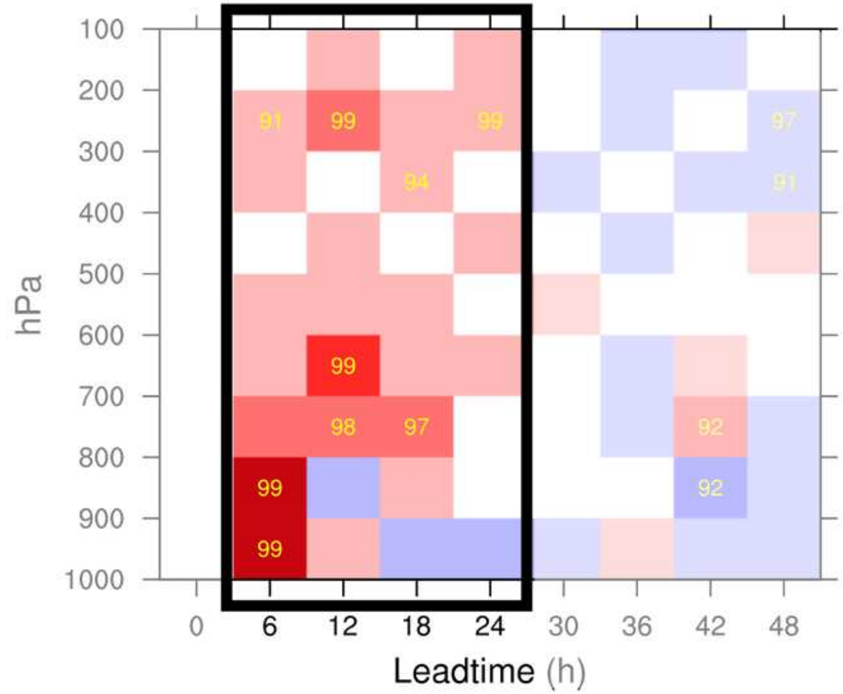


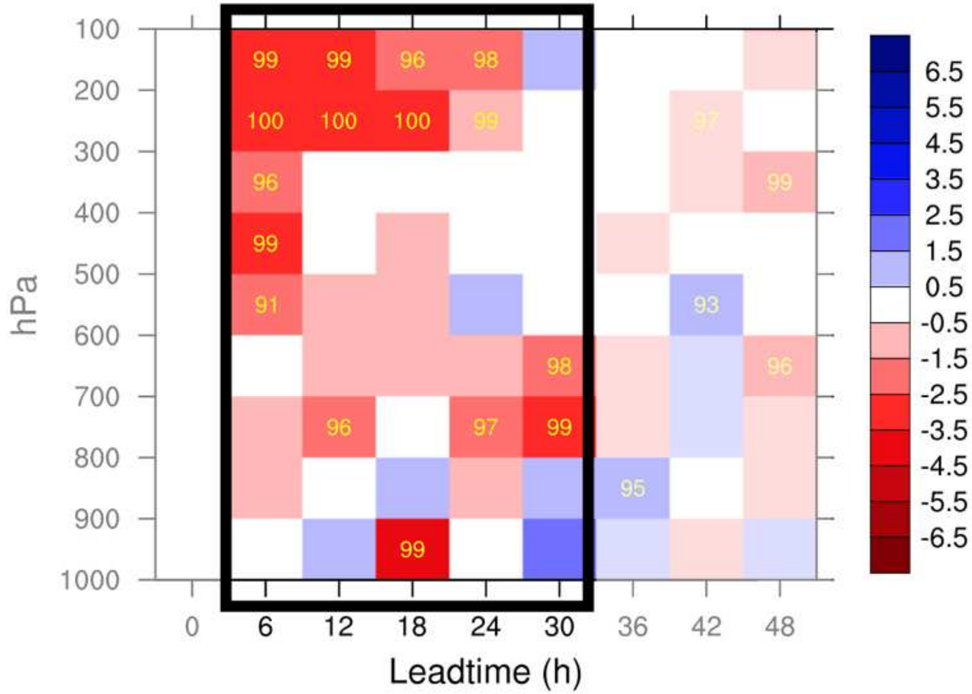
WMO OMM

Other variables are also positively impacted

~2% improvement RMSE
of **Temperature**
for ~**12-18h**

~2-3% improvement RMSE
of **U wind**
for ~**18-24h**





Status of RDA at ECCC

- Radar data quality-control framework in place
- QC is critical to RDA (end-to-end radar system)
- First impact study has been performed
  - ✓Positive impact 2-3 hours
  - ✓Neutral-to-positive impact ~24 hours
  - ✓Replicates well-known LHN behaviour
- Baseline RDA established
- Operational implementation expected to follow
- But first: more impact studies

Weather radar best practices guide

Preliminary Table of Contents

Open Source Software can offer reference implementations potentially for deployment and/or training.

WMO OMM

Thank you
Merci