A Proposed Cloud Microphysics Scheme for the GEM-LAM-2.5

Jason Milbrandt [1]
Bertrand Denis [1]
Amin Erfani [2]
Jocelyn Mailhot [1]
Ron McTaggart-Cowan [1]
André Méthot [2]

[1] **RPN**
[2] **CMC Development**

Acknowledgements:
Bernard Bilodeau
Michel Desgagné
Vivian Lee
Lubos Spacek
Michel Valin

Environment Canada Environnement Canada

9 January 2008

Canada

OUTLINE

1. Background on cloud schemes in NWP models
2. Overview of the proposed scheme
3. Tests/evaluations
   i. QPF – summer 2007
   ii. QPF – winter 2007
   iii. Precipitation types and distribution – winter
      - Examples and evaluation (east)
      - Case study: Vancouver snow forecast bust
4. Future developments

1. Background on Cloud Schemes

Representation* of clouds in GEM:

1. Boundary layer

   e.g. MoisTKE

2. Shallow convection

   e.g. Kuo-Transient

3. Deep convection

   e.g. Kain-Fritsch, Kuo, Manabe

4. Grid-scale condensation

   e.g. Sundqvist, Tremblay (mixed-phase), Kong-Yau, Milbrandt-Yau

* e.g. Bélair et al. (2005) *Mon. Wea. Rev.*

Representation* of clouds in GEM:

1. Boundary layer

    e.g. MoisTKE

2. Shallow convection

    e.g. Kuo-Transient

3. Deep convection

    e.g. Kain-Fritsch, Kuo, Manabe

4. Grid-scale condensation

    e.g. Sundqvist, Tremblay (mixed-phase), **Kong-Yau**, **Milbrandt-Yau**

FUNCTIONS of grid-scale condensation scheme:

1. Latent heat release – feedback to dynamics

2. Cloud coverage – feedback to radiation

3. Prediction of precipitation
   - quantity
   - timing
   - phase (liquid or solid) / type

NOTE ON TERMINOLGY – "explicit" (w.r.t cloud schemes)

Various meanings:

1. Grid-scale saturation → explicitly *<u>resolved clouds</u>*

BUT: schemes for regional scale (Δx =15 km) or larger require possibility for sub-grid-scale clouds (e.g. Sundqvist)

NOTE ON TERMINOLGY – "explicit" (w.r.t cloud schemes)

Various meanings:

1. Grid-scale saturation → explicitly *resolved clouds*

BUT: schemes for regional scale (Δx =15 km) or larger require possibility for sub-grid-scale clouds (e.g. Sundqvist)

2. Explicit prediction of cloud *microphysical processes*

NOTE ON TERMINOLGY – "explicit" (w.r.t cloud schemes)

Various meanings:

1. Grid-scale saturation → explicitly *resolved clouds*

   BUT: schemes for regional scale (Δx =15 km) or larger require possibility for sub-grid-scale clouds (e.g. Sundqvist)

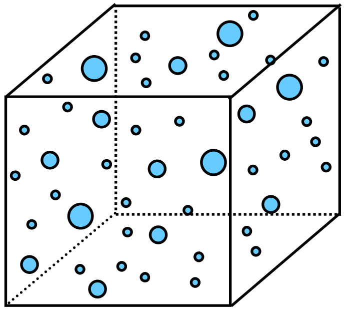
2. Explicit prediction of cloud *microphysical processes*

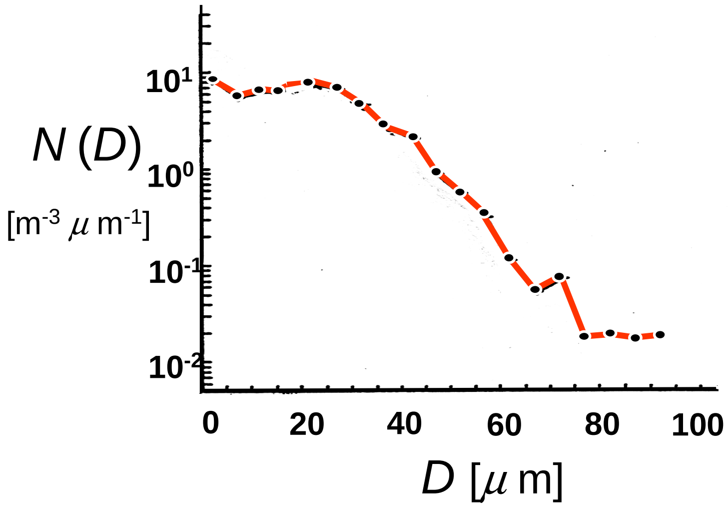
3. Explicit resolution of hydrometeor *size distributions*

   –> i.e. spectral (bin-resolving), rather than bulk

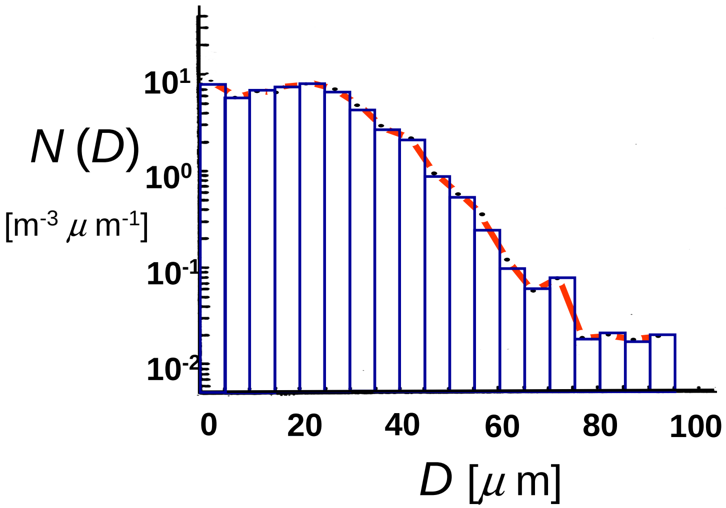
1. Background on Cloud Schemes

Hydrometer SIZE DISTRIBUTION:

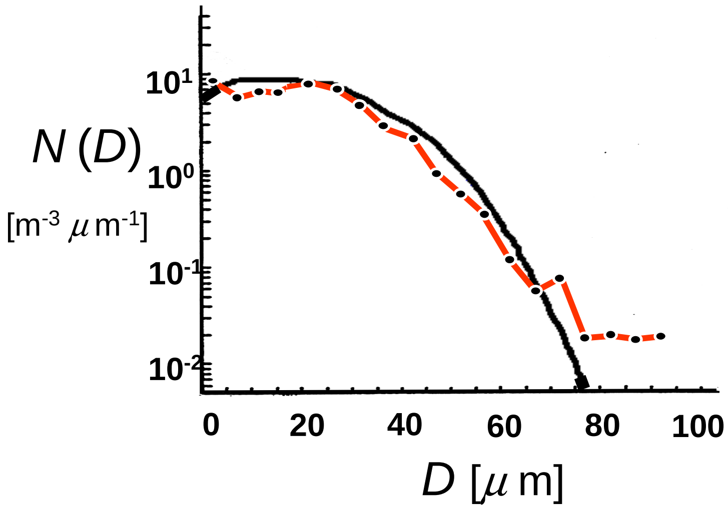




Bin-resolving: $N(D) = \sum_{i=1}^{I} N_i$



Bulk: $N(D) = N_0 D^{\alpha} e^{-\lambda D}$



Explicit or not explicit?

Criterion	Sundquivst	Kong-Yau	Milbrandt-Yau
grid-scale saturation	almost	yes	yes
processes	somewhat	yes	yes
bin-resolving	no	no	no

2. Overview of Proposed Scheme

Milbrandt-Yau* Multi-Moment Bulk Microphysics Scheme

- Originally designed and coded at McGill University (2004)
  - used in MC2 to model hail
- Further developed at RPN (2005-2006)
  - box-Lagrangian sedimentation
  - optimized single-moment and double-moment versions
- Implemented into official RPN-CMC PHY (v4.4) (Jan. 2007)
  - interfaced with GEM v3.2.2
- Further Testing and development (2007)
  - interfaced with GEM v3.3.0 (PHY v4.5)
  - run for 7 months in real-time during MAP D-PHASE (1 June - 31 Dec. 2007)
  - run in user-parallel mode in GEM-LAM (east) during summer (July) 2007
  - run in hind-cast mode for several weeks during winter 2007
  - base on above, modifications were made to reduce winter precipitation

* Milbrandt and Yau (2005a,b) *J. Atmos. Sci.*

Milbrandt-Yau* Multi-Moment Bulk Microphysics Scheme

- Six hydrometeor categories:
  - 2 liquid: ***cloud*** and ***rain***
  - 4 frozen: ***ice***, ***snow***, ***graupel*** and ***hail***

Milbrandt-Yau* Multi-Moment Bulk Microphysics Scheme

- Six hydrometeor categories:
  - 2 liquid: ***cloud*** and ***rain***
  - 4 frozen: ***ice***, ***snow***, ***graupel*** and ***hail***

For each category *x*

gamma size distribution: $$N_x(D) = N_{0x} D^{\alpha_x} e^{-\lambda_x D}$$

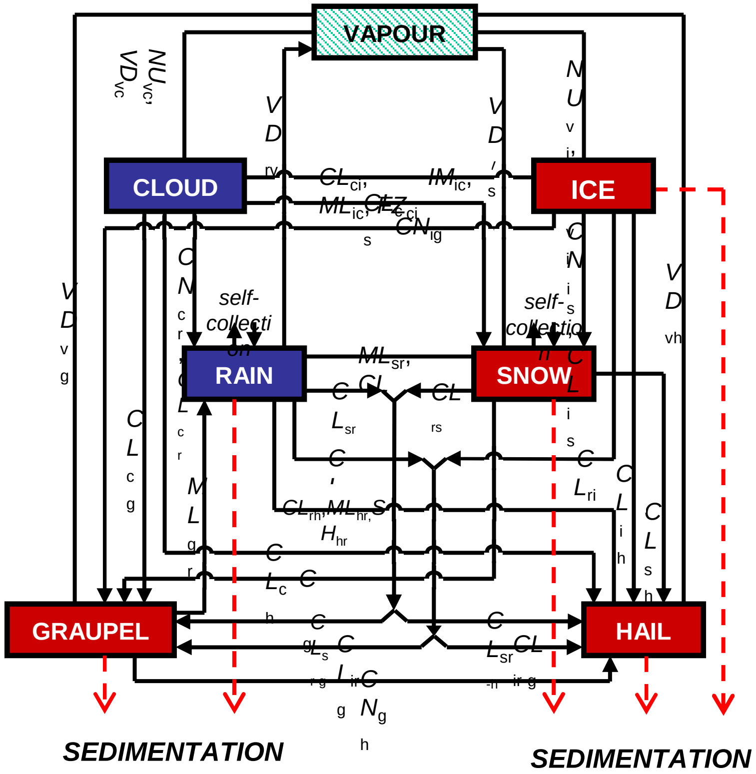
mass-diameter relation: $$m_x(D) = a_x D^{b_x}$$ where* $$a_x = \frac{\pi}{6}\rho_x \qquad b_x = 3$$

fall speed-diameter relation: $$V_x(D) = c_x D^{d_x}$$

(*except for ***ice***, which has parameters for *bullet rosettes*)

Milbrandt-Yau* Multi-Moment Bulk Microphysics Scheme

- Six hydrometeor categories:
  - 2 liquid: ***cloud*** and ***rain***
  - 4 frozen: ***ice***, ***snow***, ***graupel*** and ***hail***
- ~50+ distinct microphysical processes

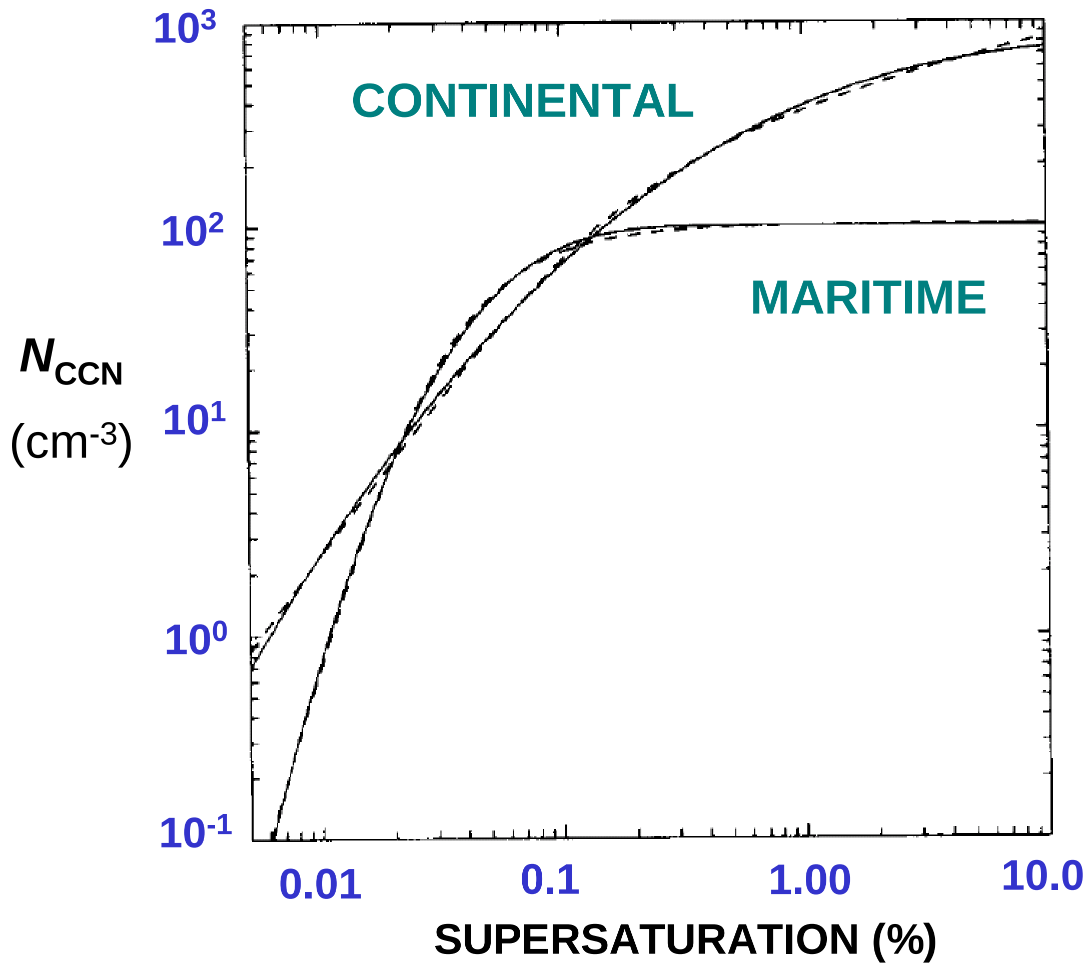


Milbrandt-Yau* Multi-Moment Bulk Microphysics Scheme

- Six hydrometeor categories:
  - – 2 liquid: ***cloud*** and ***rain***
  - – 4 frozen: ***ice***, ***snow***, ***graupel*** and ***hail***
- ~50+ distinct microphysical processes
- Warm-rain scheme based on Cohard and Pinty (2000a,b)
  - – autoconversion (*cloud* to *rain*) dependent on prescribed aerosols
  - – approximation of collection kernel allows solution of stochastic collection eqn.

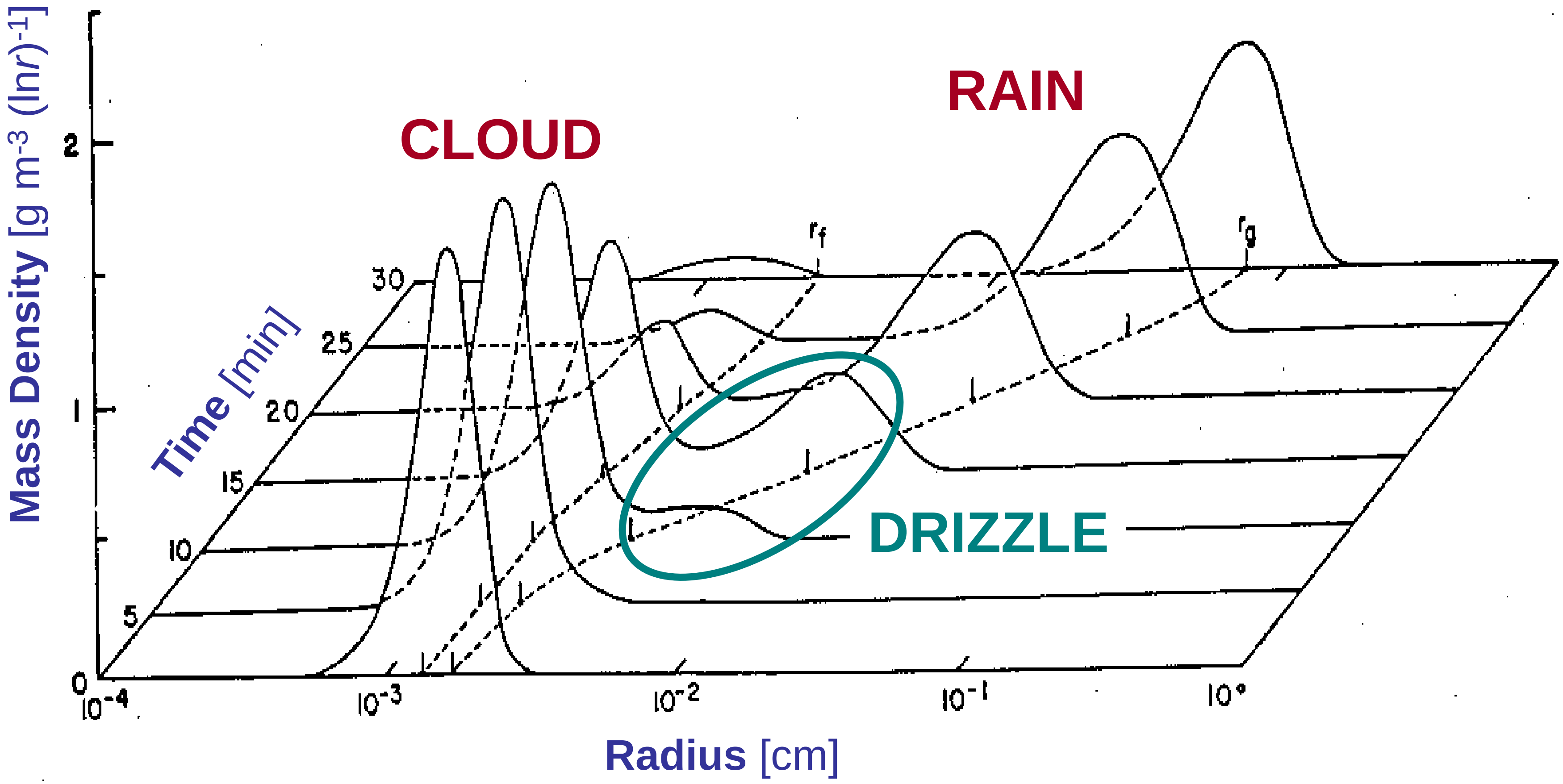
Initiation of Cloud Droplets

***CCN*-dependent N_c nucleation:**



SOURCE: Cohard et al. (1998)

The warm-rain coalescence process



Bin-resolving coalescence model

SOURCE: Berry and Reinhardt (1974)

Milbrandt-Yau* Multi-Moment Bulk Microphysics Scheme

- Six hydrometeor categories:
  - – 2 liquid: ***cloud*** and ***rain***
  - – 4 frozen: ***ice***, ***snow***, ***graupel*** and ***hail***
- ~50+ distinct microphysical processes
- Warm-rain scheme based on Cohard and Pinty (2000a,b)
  - – autoconversion (*cloud* to *rain*) dependent on prescribed aerosols
  - – approximation of collection kernel allows solution of stochastic collection eqn.
- Ice-phase based on various schemes

  e.g. Murakami (1990), Ferrier (1994), Meyers et al. (1997), Reisner et al. (1998)

Milbrandt-Yau* Multi-Moment Bulk Microphysics Scheme

- Six hydrometeor categories:
  - 2 liquid: ***cloud*** and ***rain***
  - 4 frozen: ***ice***, ***snow***, ***graupel*** and ***hail***
- ~50+ distinct microphysical processes
- Warm-rain scheme based on Cohard and Pinty (2000a,b)
  - autoconversion (*cloud* to *rain*) dependent on prescribed aerosols
  - approximation of collection kernel allows solution of stochastic collection eqn.
- Ice-phase based on various schemes

  e.g. Murakami (1990), Ferrier (1994), Meyers et al. (1997), Reisner et al. (1998)
- Full version is triple-moment for all categories (except *cloud*)
  - prognostic *mass* ($\boldsymbol{Q_x}$), *number concentration* ($\boldsymbol{N_x}$), and *reflectivity* ($\boldsymbol{Z_x}$)

Thus, for $N_x(D) = N_{0x} D^{\alpha_x} e^{-\lambda_x D}$,

N_{0x}, α_x, and λ_x are independent variables

Additional features:

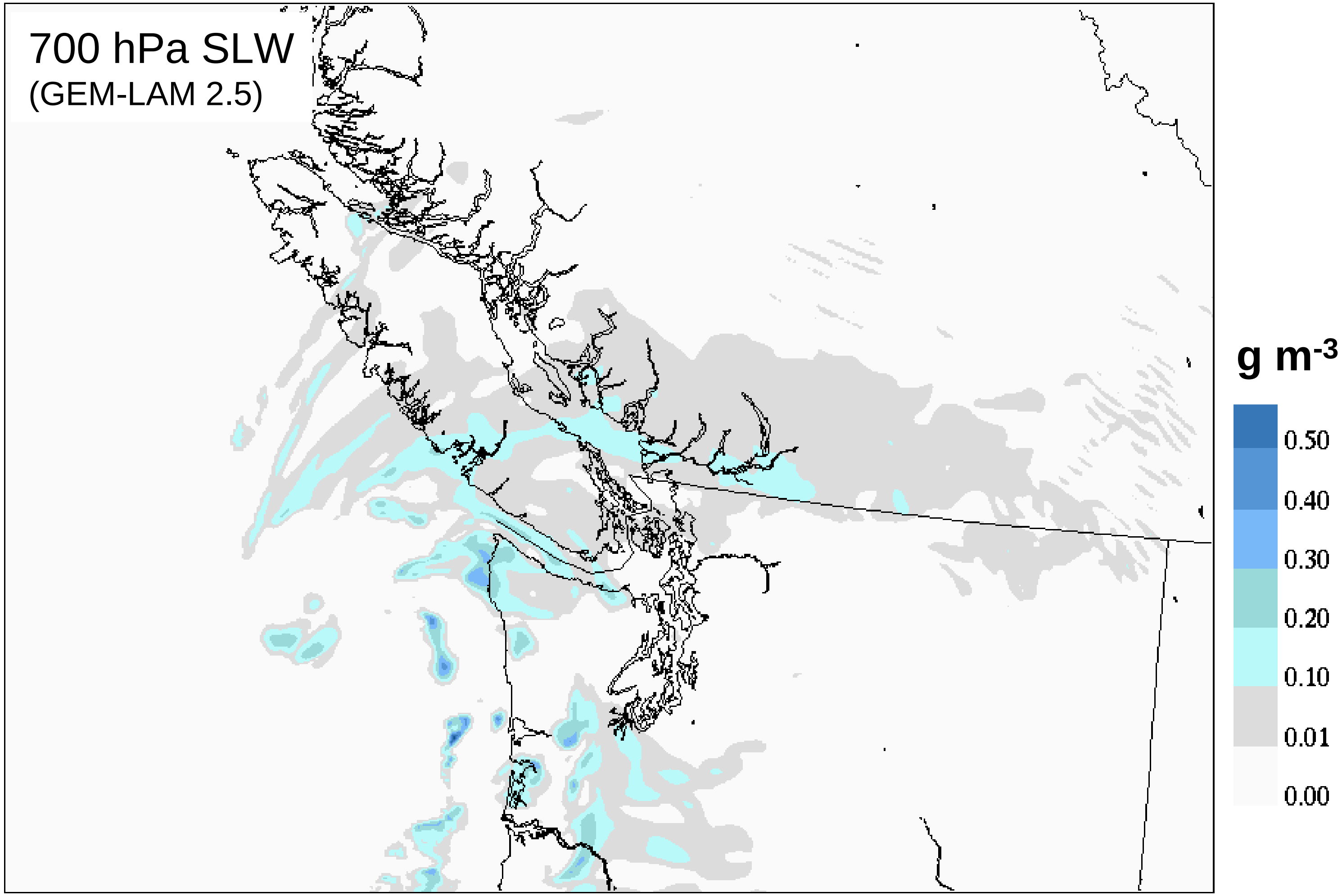
- Prediction of **mean-particle size** (each for hydrometeor category)
  - distinction between *rain* and *drizzle*
  - distinction between *small* and *large hail*
  - potential compatibility with radiation scheme
    (computation of cloud optical properties)

Additional features:

- Prediction of **mean-particle size** (each for hydrometeor category)
  - distinction between *rain* and *drizzle*
  - distinction between *small* and *large hail*
  - potential compatibility with radiation scheme
    (computation of cloud optical properties)
- Prediction of **supercooled liquid water**

SLW – Super-cooled Liquid Water (mass content)

- 3-D output variable [SLW = $\rho_a \cdot (QC+QR)$ where $T < 0°C$]

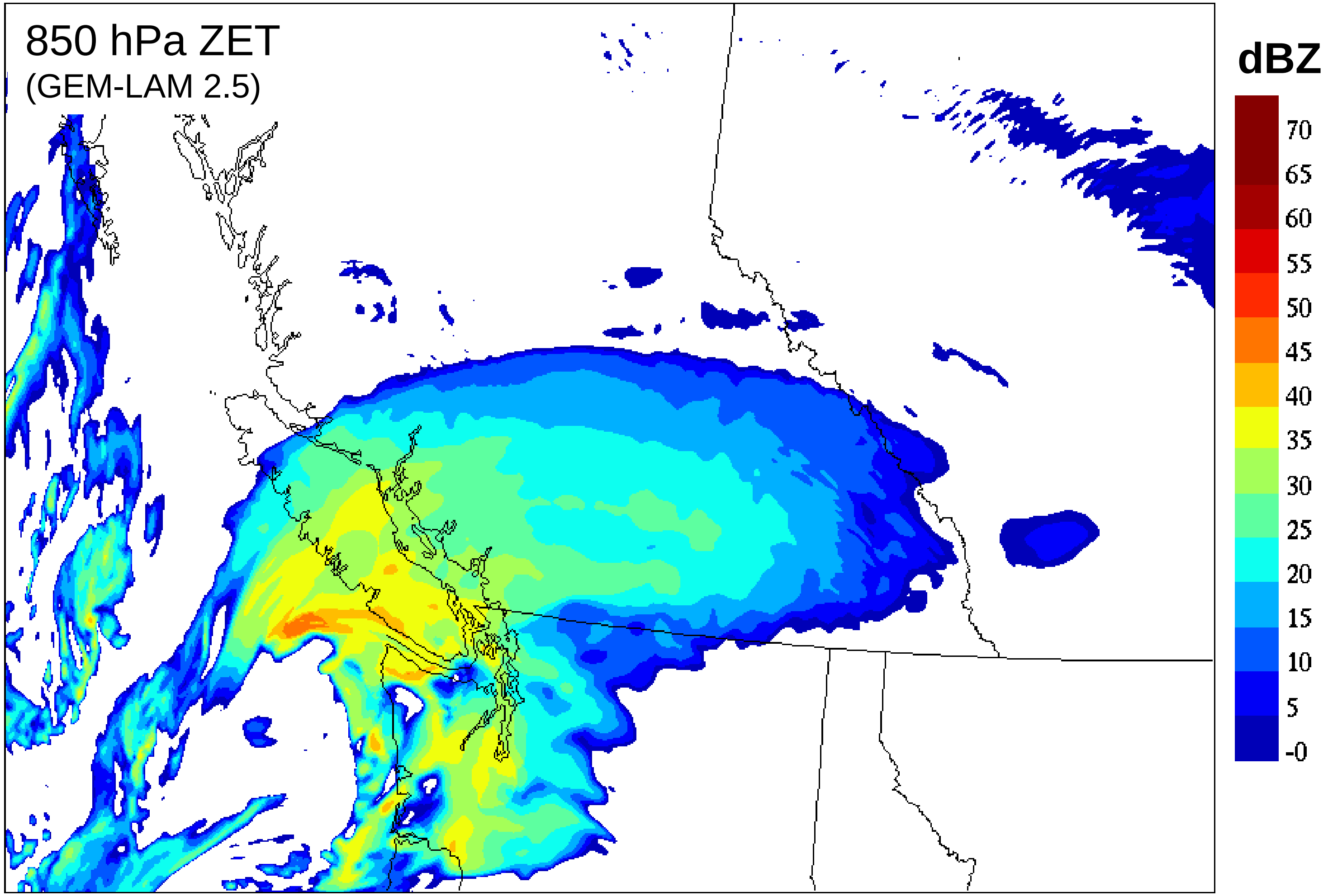


Additional features:

- Prediction of **mean-particle size** (each for hydrometeor category)
  - distinction between *rain* and *drizzle*
  - distinction between *small* and *large hail*
  - potential compatibility with radiation scheme (computation of cloud optical properties)
- Prediction of **supercooled liquid water**
- Synthetic 3D **radar reflectivity**

ZET – Equivalent Radar Reflectivity

- 3-D output variable [ZET = Z_{er} + Z_{ei} + Z_{es} + Z_{eg} + Z_{eh}]



Additional features:

- Prediction of **mean-particle size** (each for hydrometeor category)
  - distinction between *rain* and *drizzle*
  - distinction between *small* and *large hail*
  - potential compatibility with radiation scheme (computation of cloud optical properties)
- Prediction of **supercooled liquid water**
- Synthetic 3D **radar reflectivity**
- Specific **precipitation types**

Current Precipitation Types in GEM:

RN – Liquid Rain
FR – Freezing Rain
SN – Solid Precipitation
PE – Ice Pellets (re-frozen rain)

GEM-15:
- precipitation rates summed (all moist schemes)
- precipitation types diagnosed (Bourgouin, 2000)

GEM-LAM (2.5):
- precipitation rates obtained from Kong-Yau scheme

  $QR \rightarrow$ RN + FR

  $QI + QG \rightarrow$ SN
- RN and FR diagnosed based on surface T (0.995 level)
- PE not produced (explicitly or diagnostically) from Kong-Yau

  (but diagnosed from Kuo-Transient precipitation)

New Precipitation Types from M-Y Scheme:

RN1 – Liquid Drizzle
RN2 – Liquid Rain
FR1 – Freezing Drizzle
FR2 – Freezing Rain
SN1 – Ice Crystals
SN2 – Snow
SN3 – Graupel (snow pellets)
PE1 – Ice Pellets (re-frozen rain)
PE2 – Hail (total)
PE2L – Large Hail

New output variables

New Precipitation Types from M-Y Scheme:

RN
- **RN1 – Liquid Drizzle**
- **RN2 – Liquid Rain**

FR
- **FR1 – Freezing Drizzle**
- **FR2 – Freezing Rain**

SN
- **SN1 – Ice Crystals**
- **SN2 – Snow**
- **SN3 – Graupel** (snow pellets)

PE
- **PE1 – Ice Pellets** (re-frozen rain)
- **PE2 – Hail** (total)
- **PE2L – Large Hail**

New output variables

Existing output variables – now based on new variables (for M-Y)

e.g. SN = SN1 + SN2 + SN3

3. Tests / Evaluations

3. Tests / Evaluations

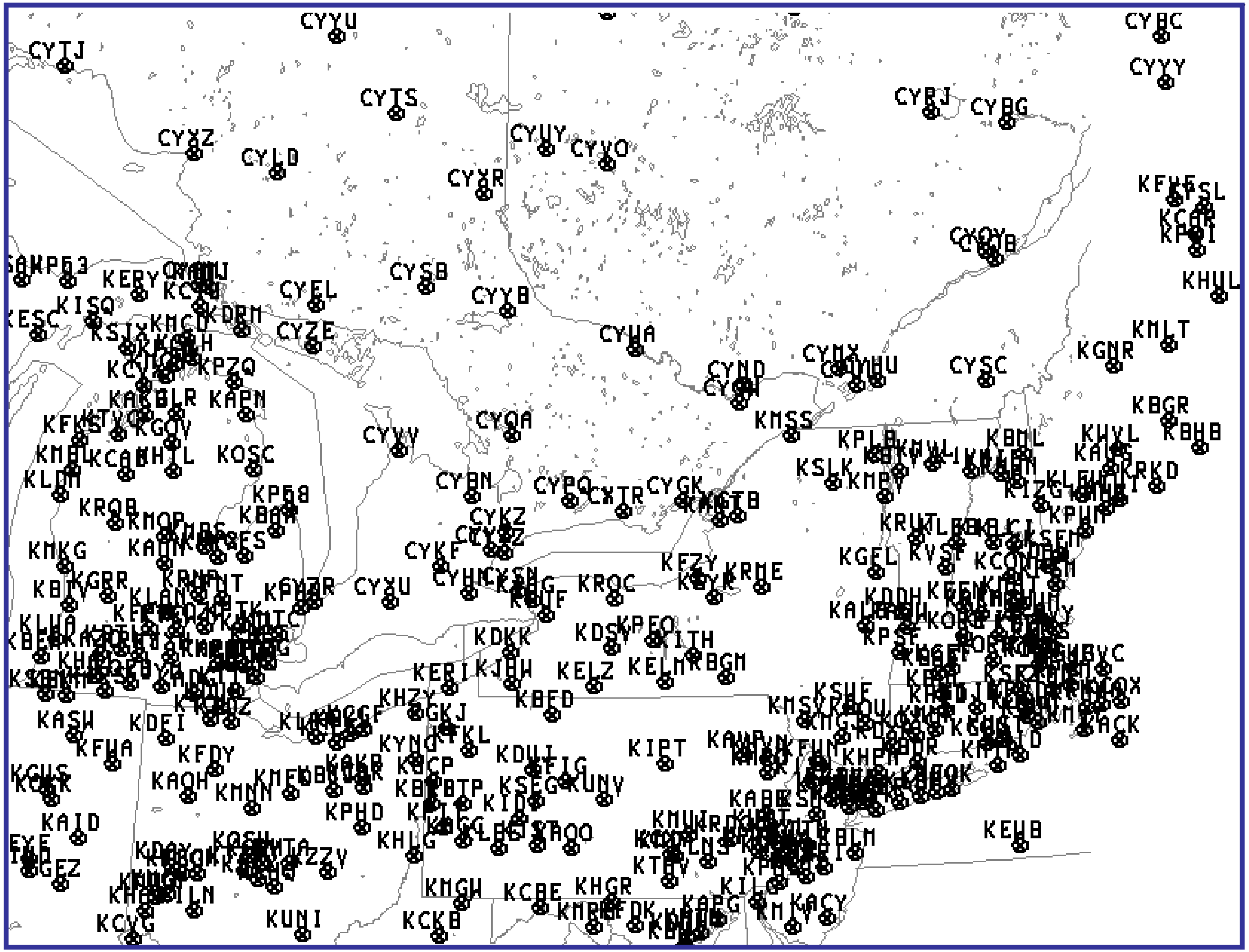
Tests were conducted using GEM-LAM-2.5:

- real-time configuration with **proposed (single-moment) M-Y scheme**
- 8 cases during summer (July) 2007, eastern grid
- 16 cases during winter 2007, eastern grid
- case studies (winter)

Evaluations made for current vs. proposed configuration (scheme):

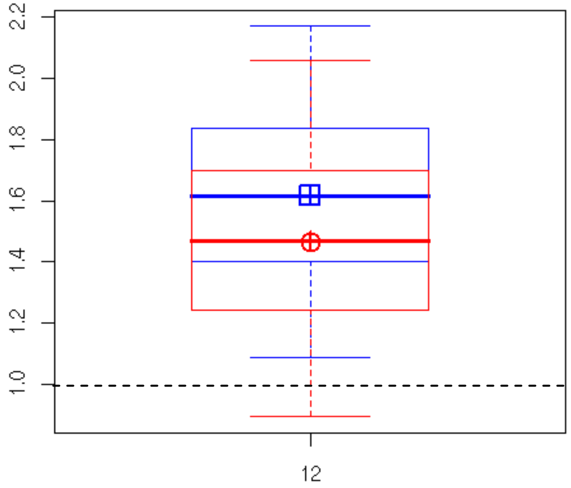
- QPF statistics – model vs. station obs for 6-h PR
- Precipitation type – liquid vs. solid
- Subjective evaluation
- Objective evaluation

EAST 2.5 km Grid – Observations from these stations were used:

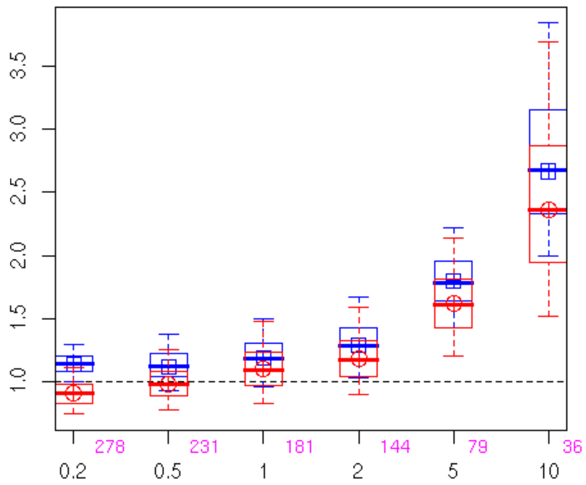


SUMMER 2007 – 8 CASES

MEAN RATIO

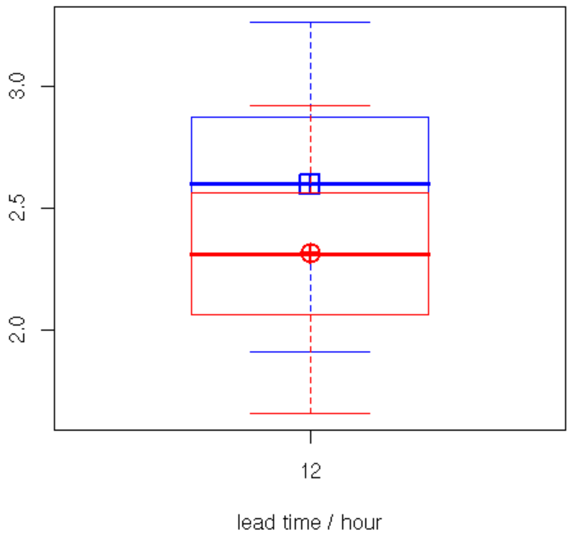


FREQUENCY BIAS

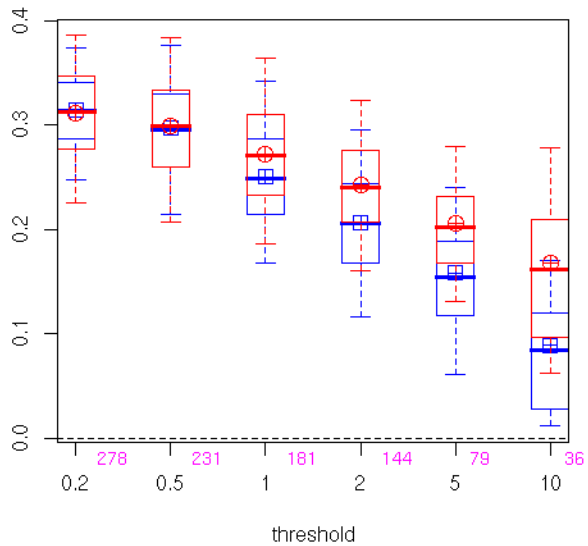


 # events
threshold [mm]

MEAN ABSOLUTE ERROR



EQUITABLE THREAT SCORE



 # events
threshold [mm]

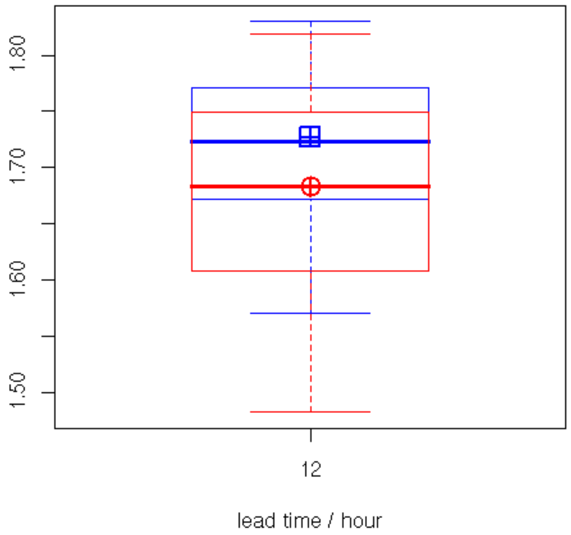
Kong-Yau
Milbrandt-Yau

Period: 18–00 UTC [06–12 h forecast time] (afternoon)

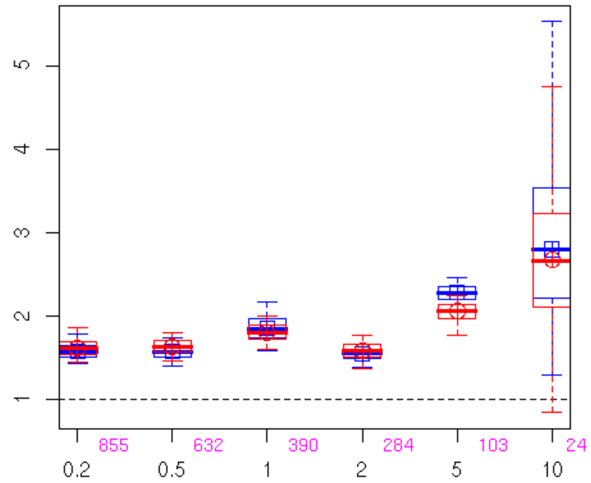
3. Tests / Evaluations – **QPF**

WINTER 2007 – 16 CASES

MEAN RATIO

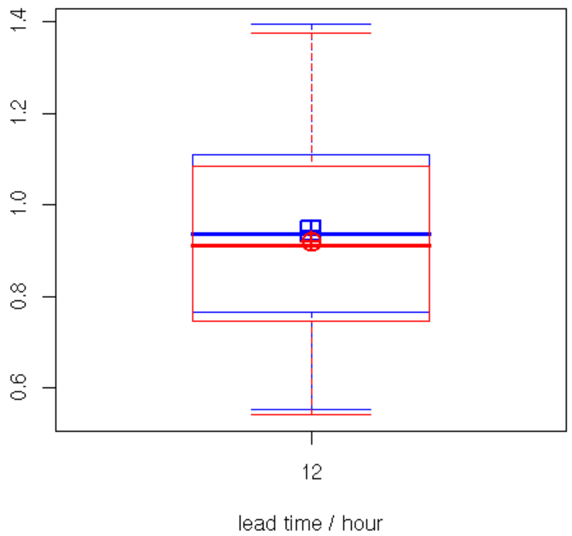


FREQUENCY BIAS

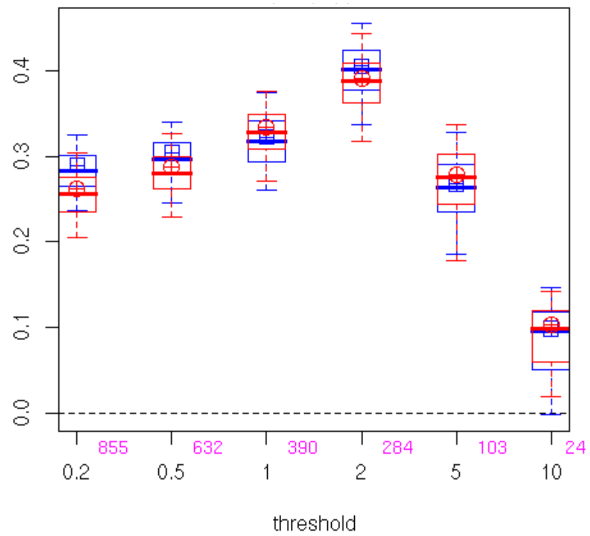


 # events
threshold [mm]

MEAN ABSOLUTE ERROR



EQUITABLE THREAT SCORE

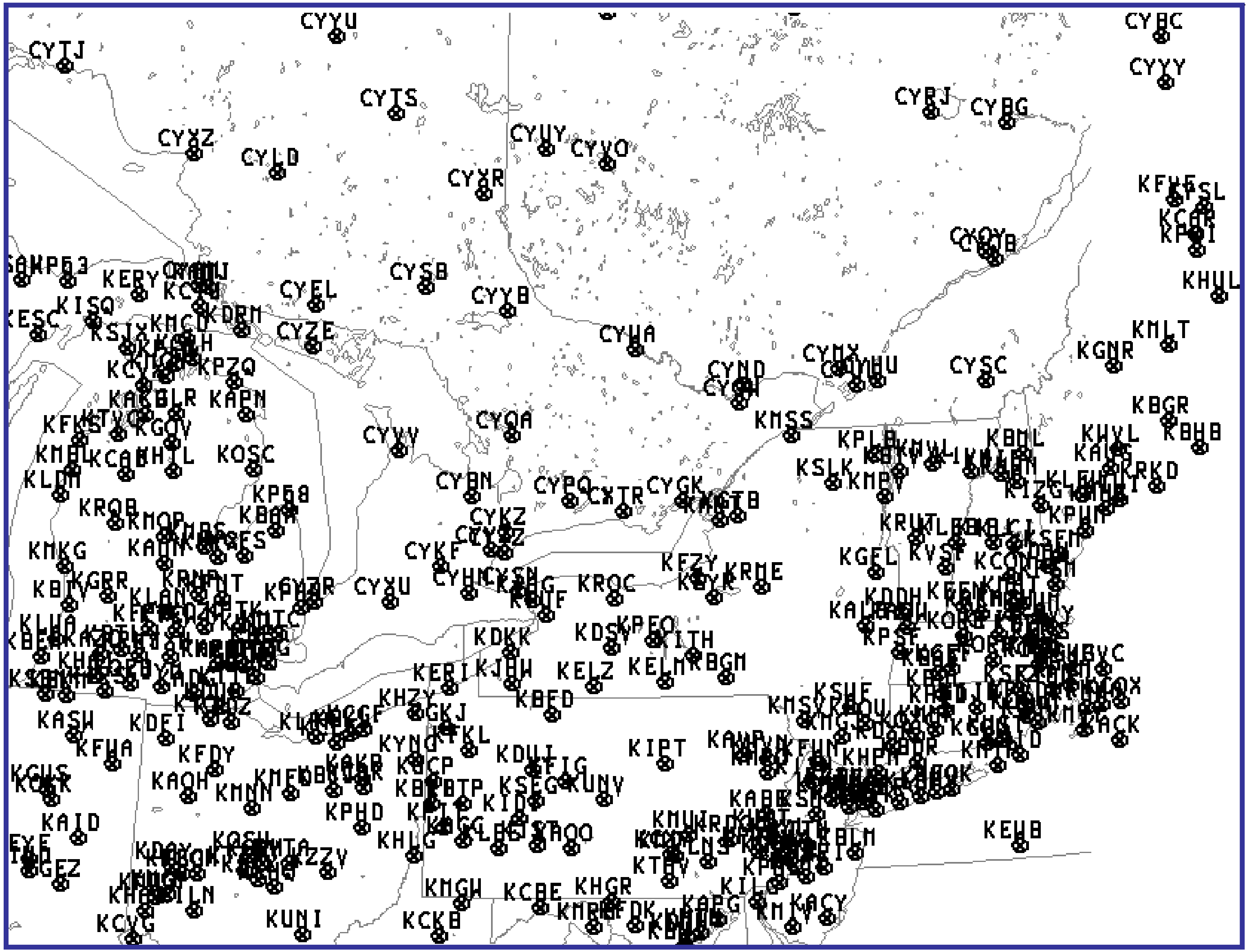


 # events
threshold [mm]

Kong-Yau
Milbrandt-Yau

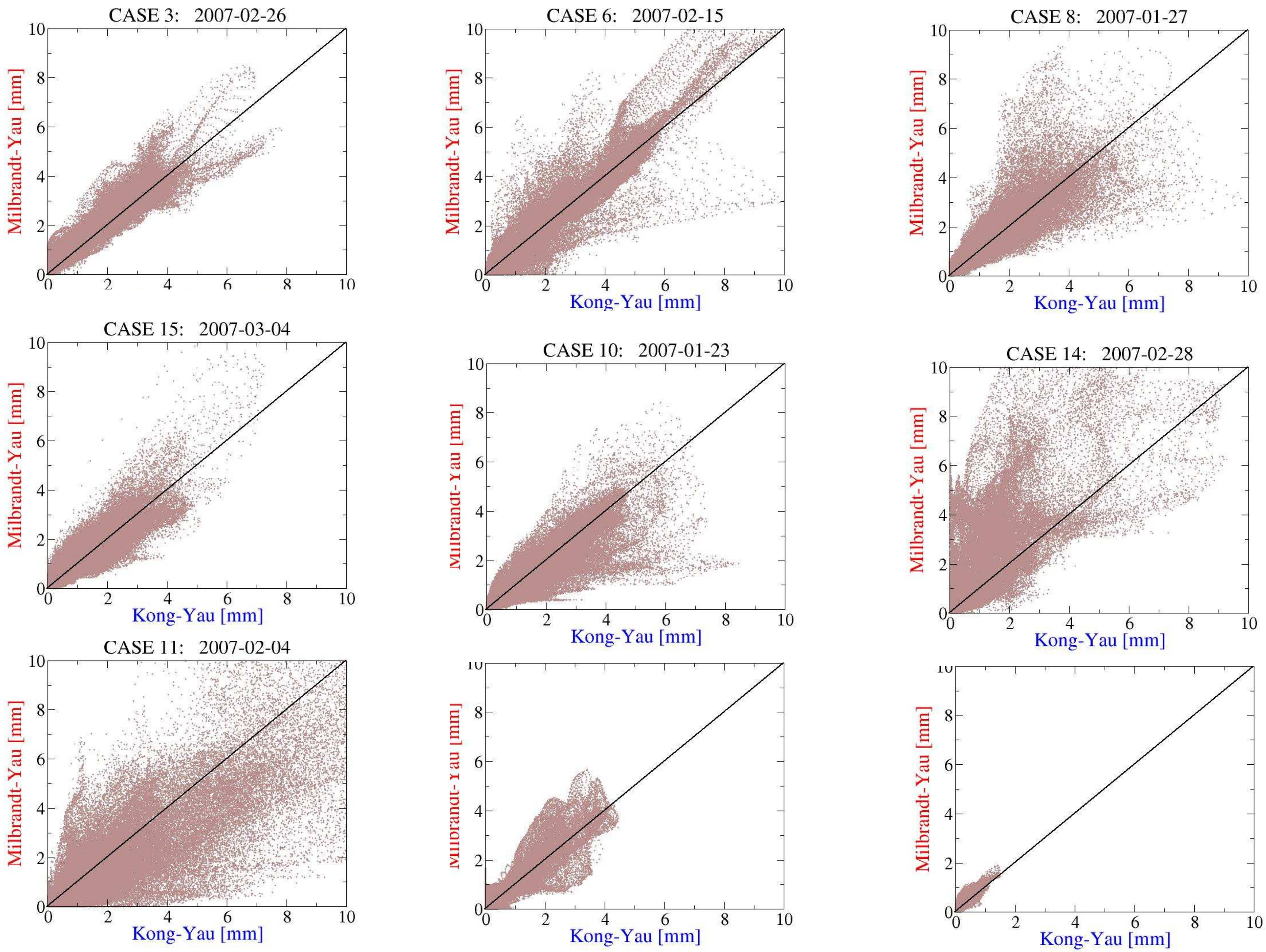
Period: 18–00 UTC [06–12 h forecast time] (afternoon)

EAST 2.5 km Grid – Observations from these stations were used:



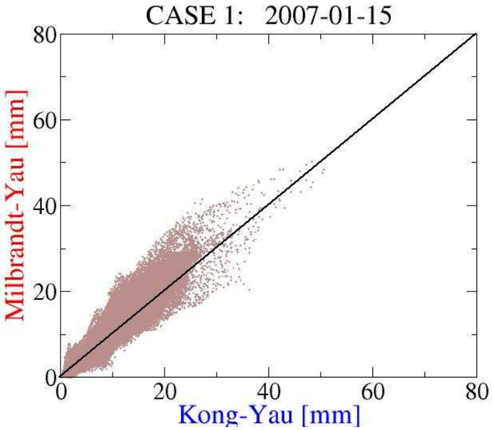
3. Tests / Evaluations – **QPF, winter 2007**

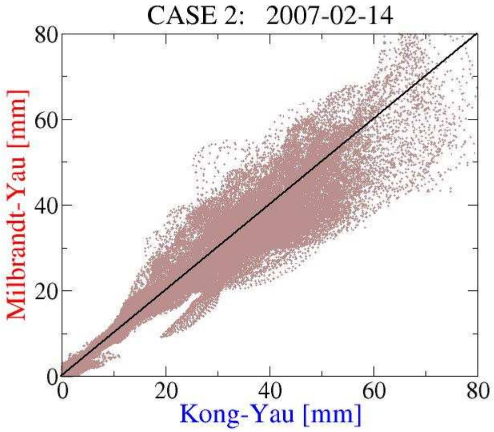
LOW Precipitation Events:

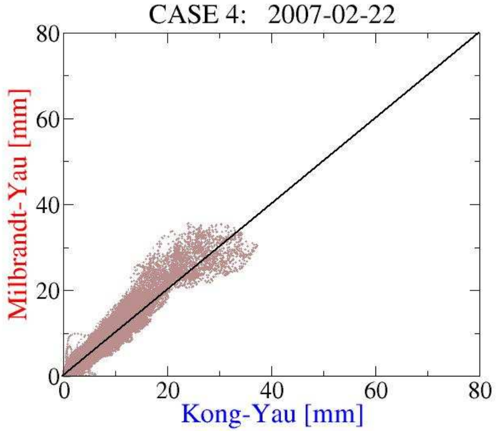


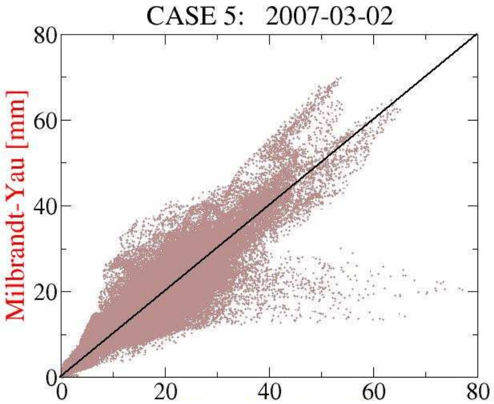
3. Tests / Evaluations – **QPF, winter 2007**

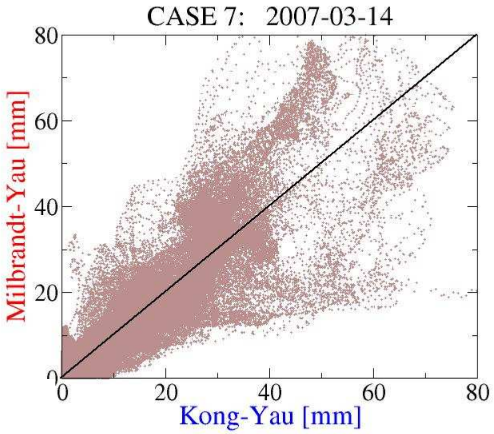
HIGH Precipitation Events:

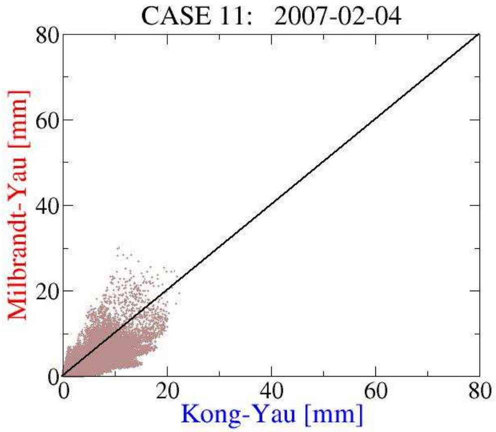


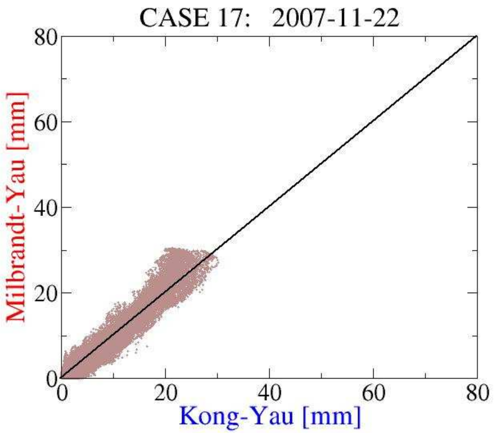




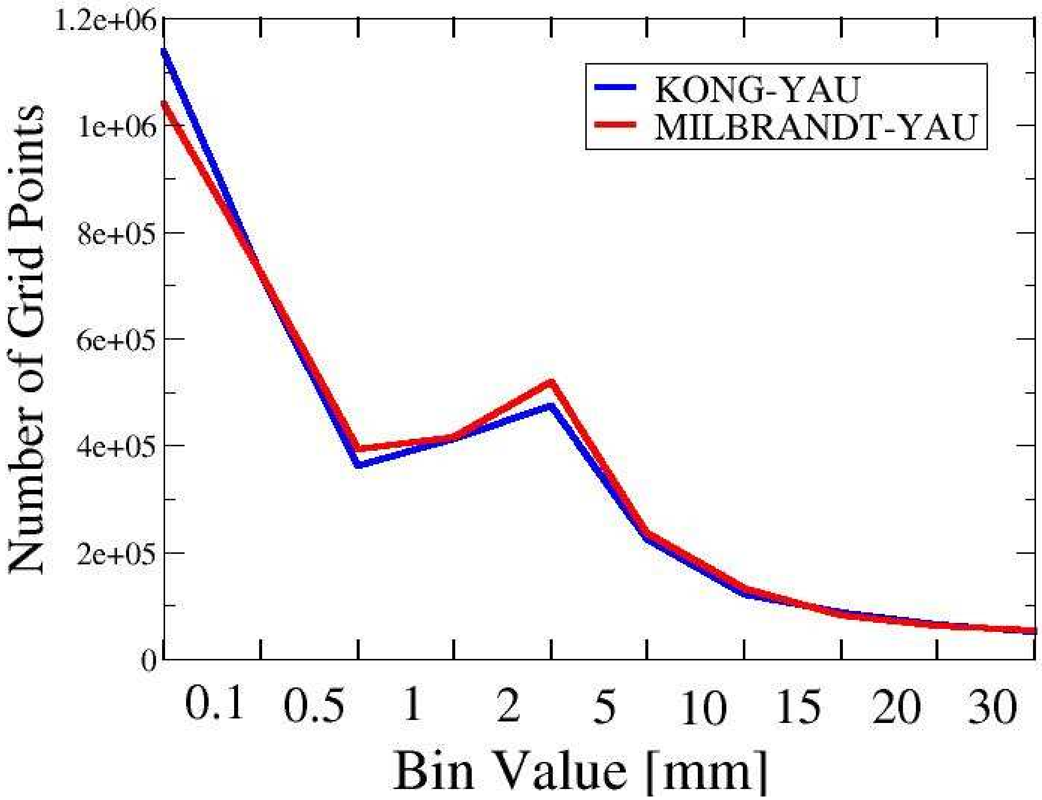








From 16 winter cases:



Conclusions from QPF stats:

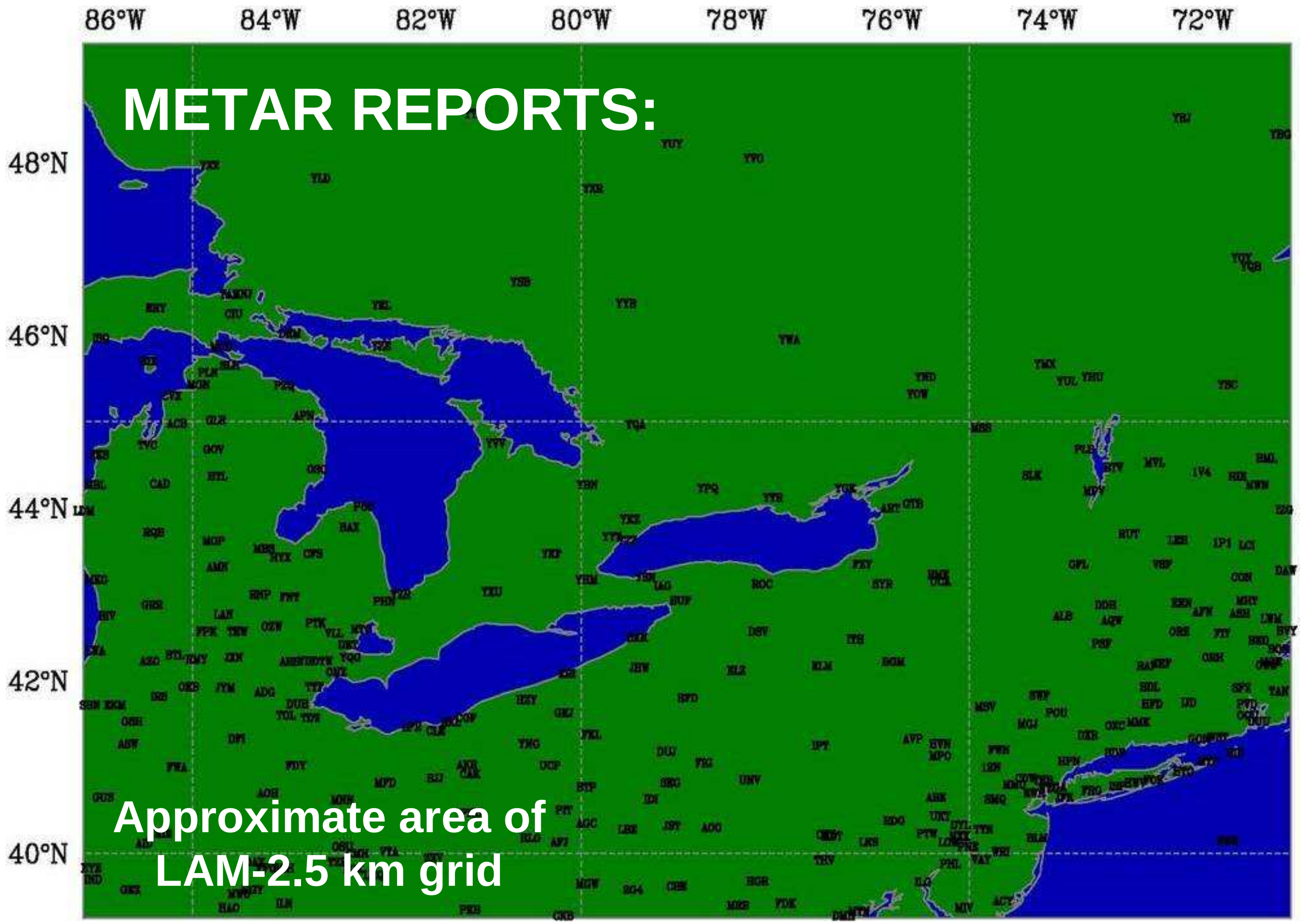
SUMMER

- QPF using M-Y scheme is **notably improved**
- Reduction of overprediction bias while improving ETS

WINTER

- QPF using M-Y scheme **not significantly different**
- Nearly the same general overprediction of precipitation
- M-Y scheme produces:
  - slightly less frequent trace precipitation values (< 0.5 mm)
  - slightly more frequent low values (1-10 mm)
  - similar frequency of high values (> 10 mm)

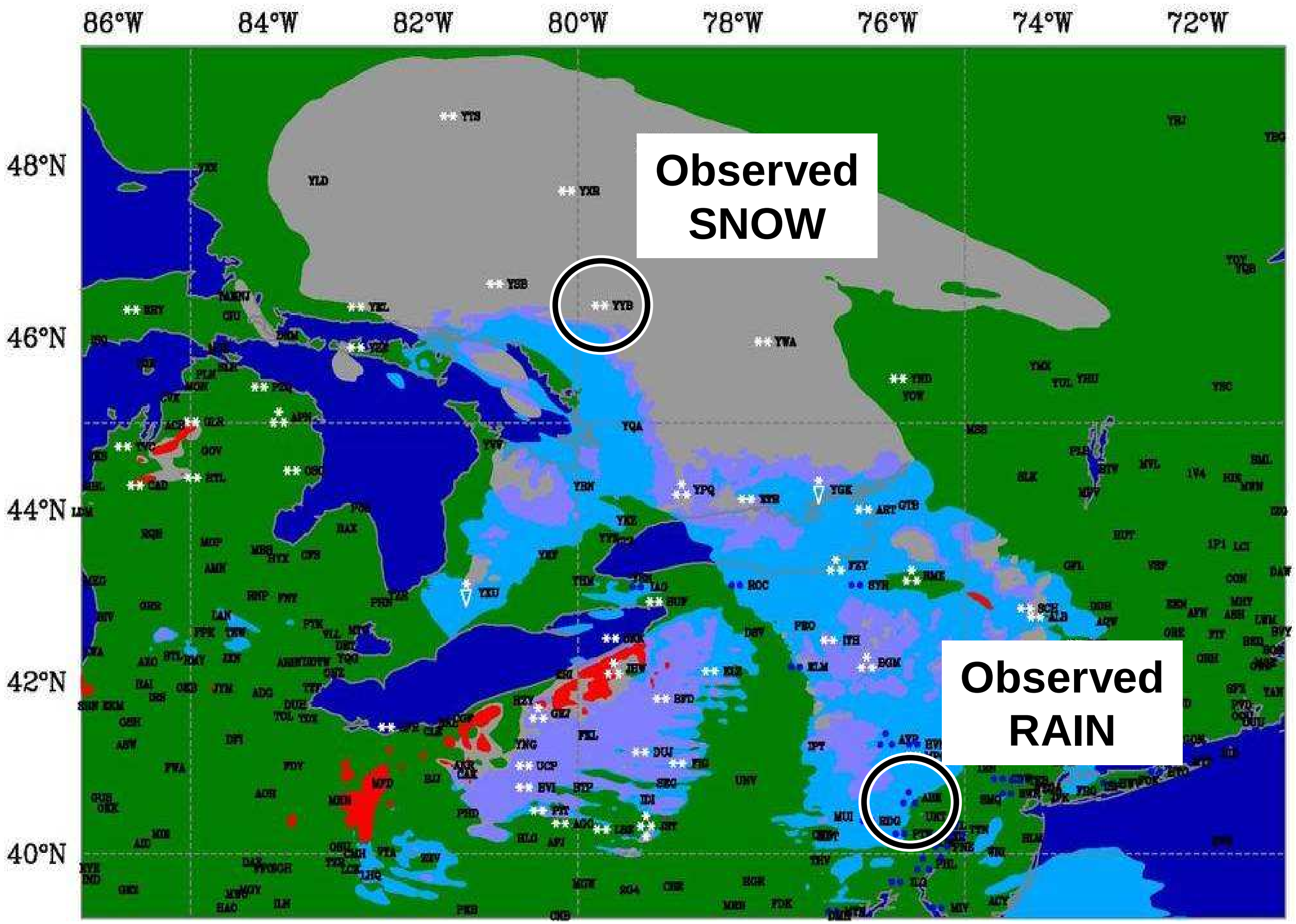
From 16 winter 2007 cases, model **precipitation TYPES** from the **current** and the **proposed** schemes were compared



3. Tests / Evaluations – **Precipitation Types and Distribution**

EXAMPLE:

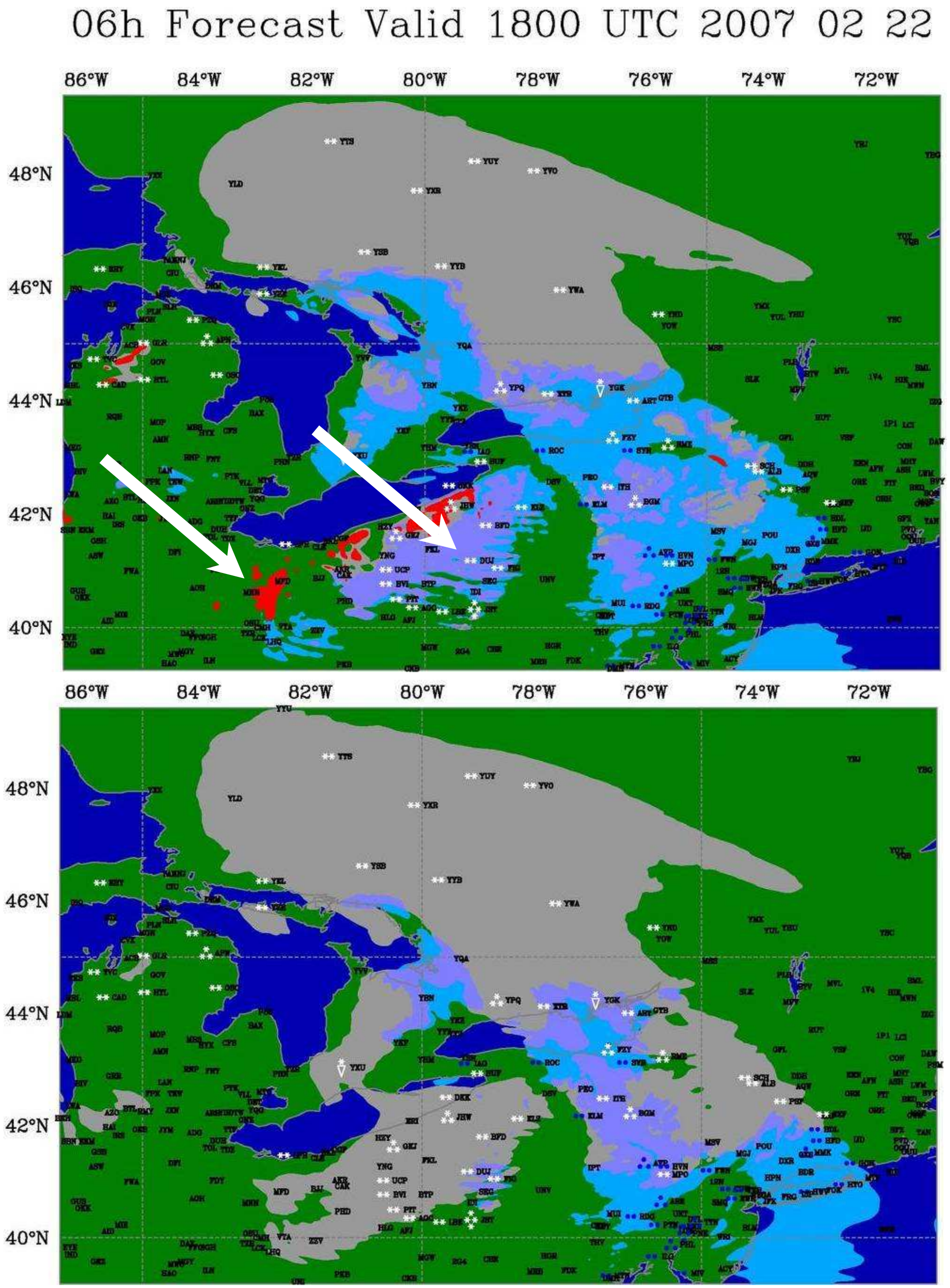
1-h accumulated SNOW (SN), RAIN (RN), MIXED (SN+RN), FREEZING RAIN, and ICE PELLETS from model:



3. Tests / Evaluations – **Precipitation Types and Distribution**

Current
Kong-Yau

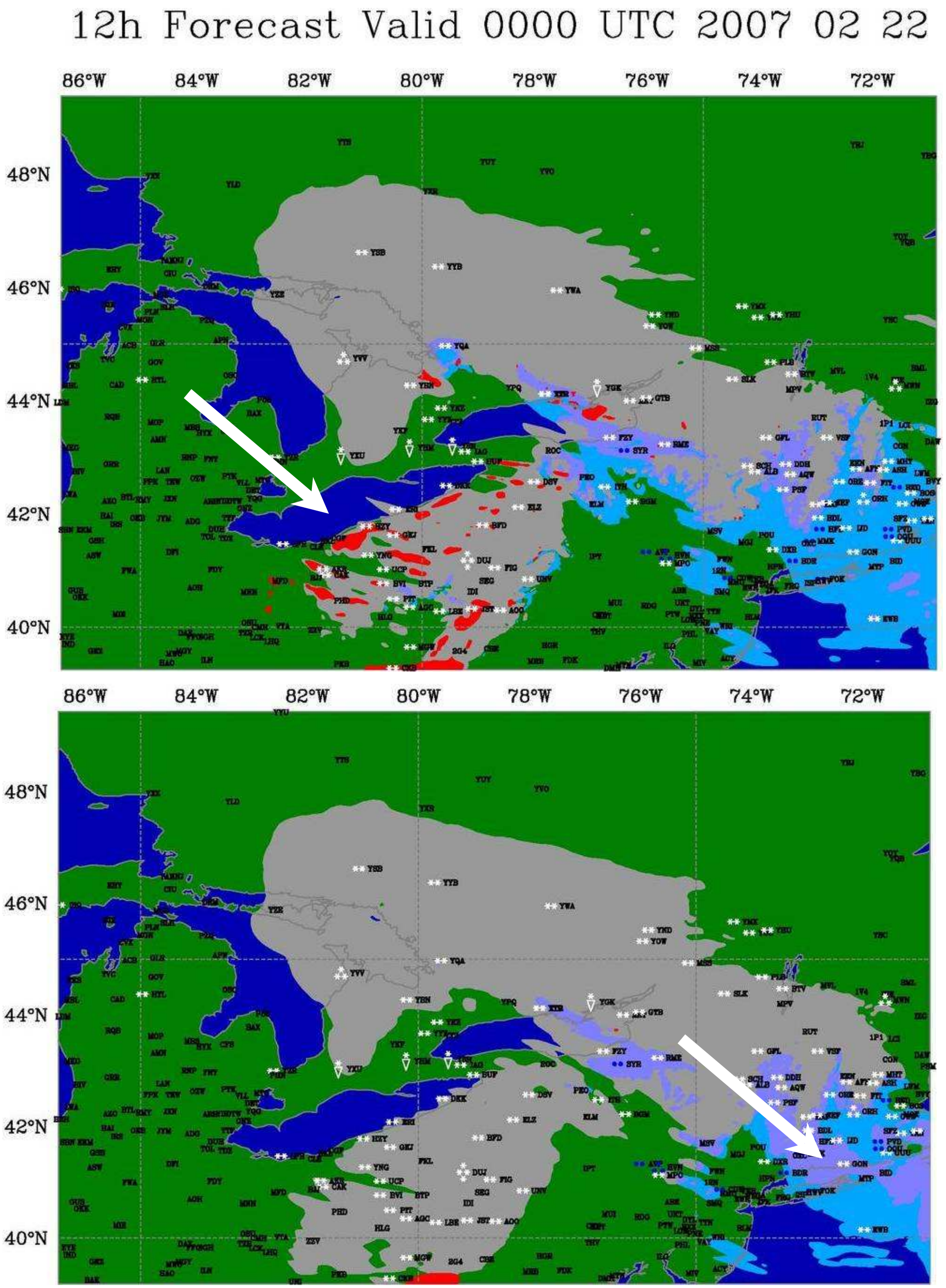
Proposed
Milbrandt-Yau



3. Tests / Evaluations – **Precipitation Types and Distribution**

Current
Kong-Yau

Proposed
Milbrandt-Yau



3. Tests / Evaluations – **Precipitation Types and Distribution**

2007-07-22
(24-h)

RN

Kong-Yau

OBS \ FCST	Y	N
Y	15	26
N	116	1010

Milbrandt-Yau

OBS \ FCST	Y	N
Y	14	27
N	68	1070

SN

Kong-Yau

OBS \ FCST	Y	N
Y	97	165
N	38	867

Milbrandt-Yau

OBS \ FCST	Y	N
Y	140	122
N	73	844

FR

Kong-Yau

OBS \ FCST	Y	N
Y	0	1
N	9	1157

Milbrandt-Yau

OBS \ FCST	Y	N
Y	0	1
N	1	1177

PE

Kong-Yau

OBS \ FCST	Y	N
Y	0	0
N	0	1167

Milbrandt-Yau

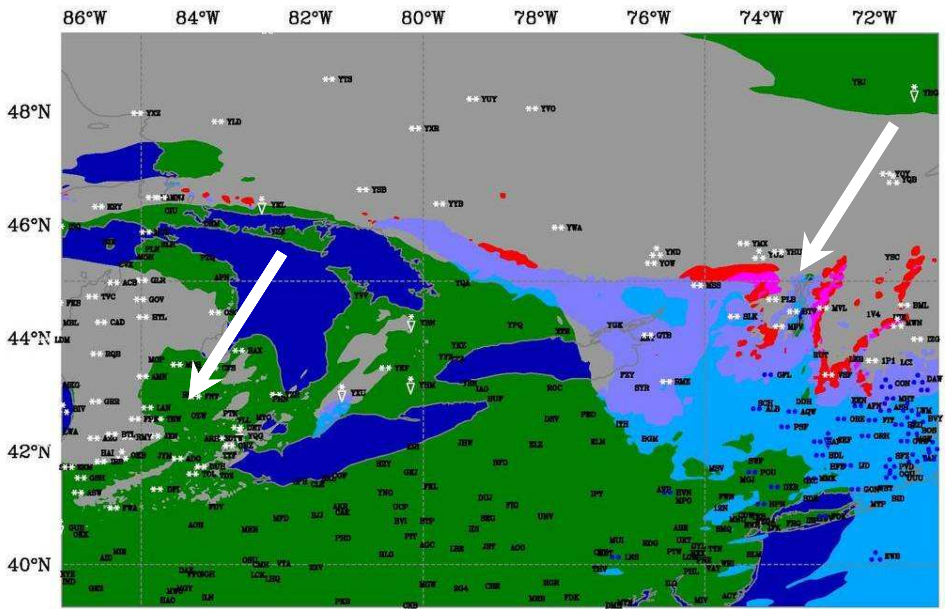
OBS \ FCST	Y	N
Y	0	0
N	0	1179

3. Tests / Evaluations – **Precipitation Types and Distribution**

06h Forecast Valid 1800 UTC 2007 03 02

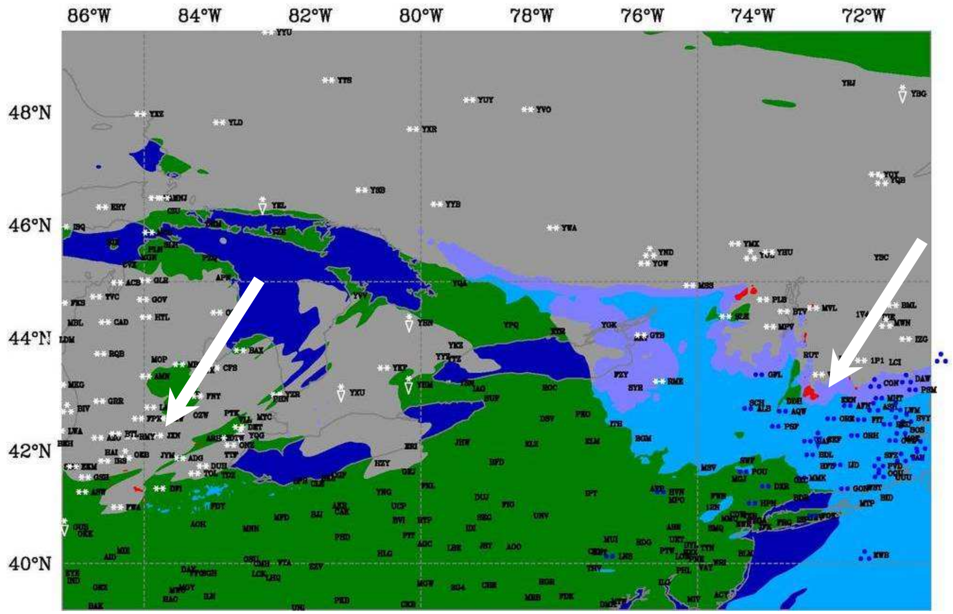
Current

Kong-Yau



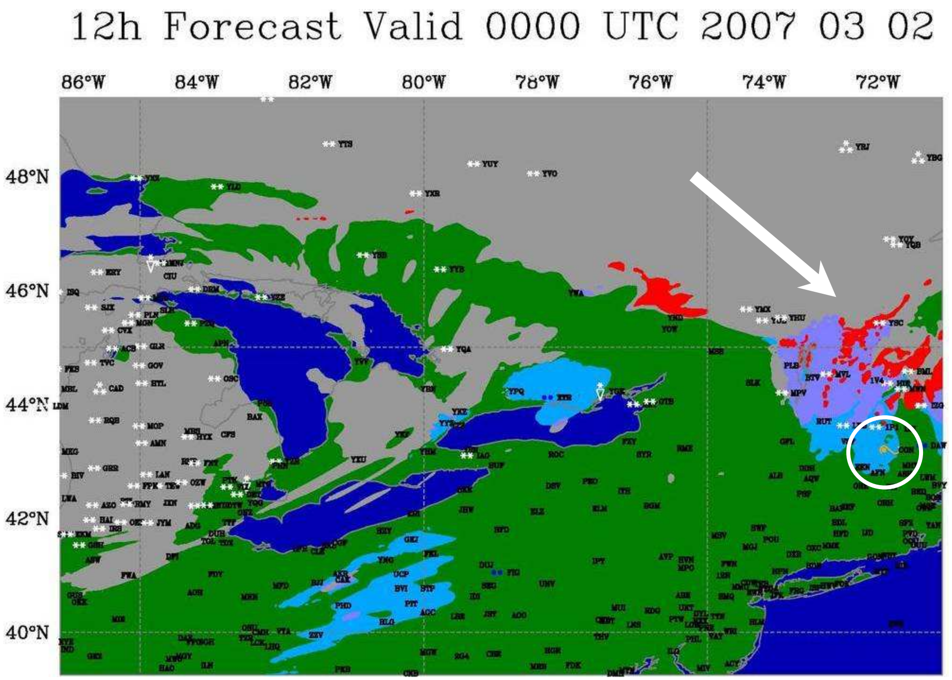
Proposed

Milbrandt-Yau

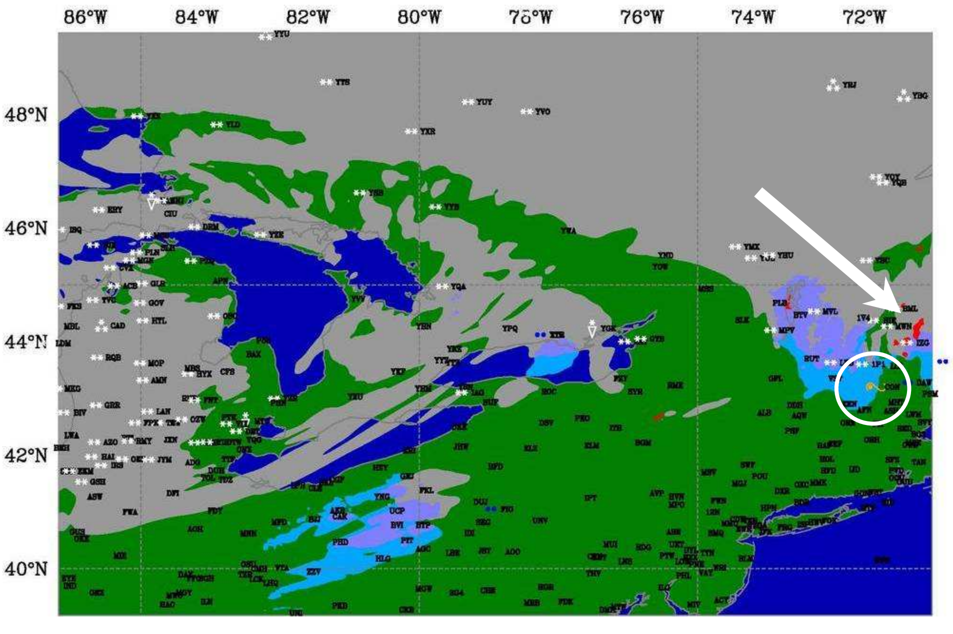


3. Tests / Evaluations – **Precipitation Types and Distribution**

Current
Kong-Yau



Proposed
Milbrandt-Yau

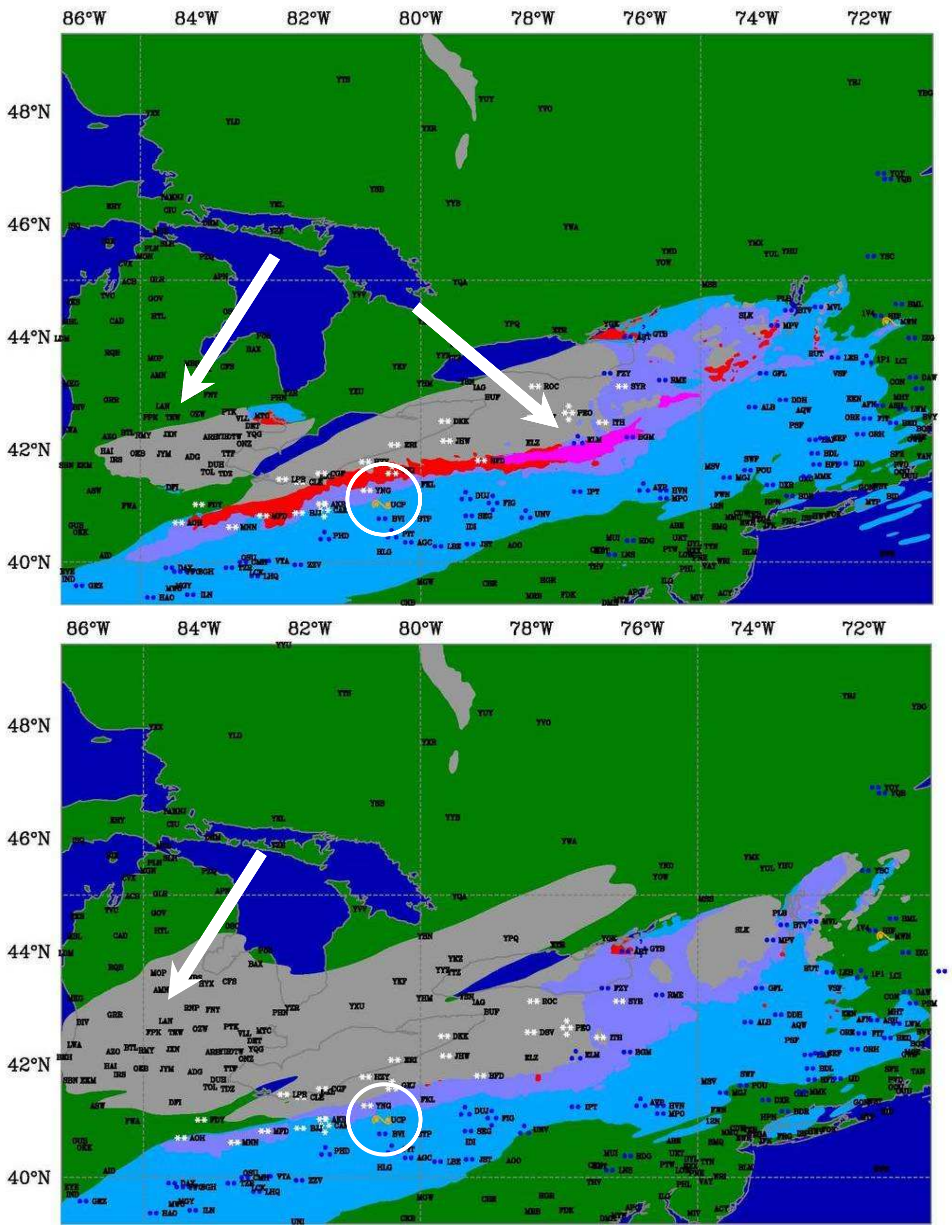


3. Tests / Evaluations – **Precipitation Types and Distribution**

24h Forecast Valid 1200 UTC 2007 03 14

Current
Kong-Yau

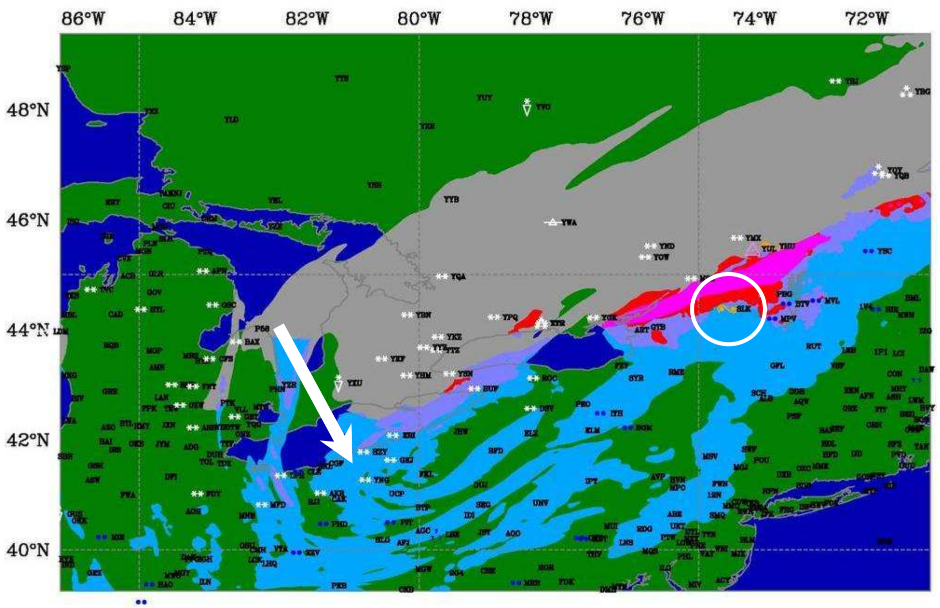
Proposed
Milbrandt-Yau



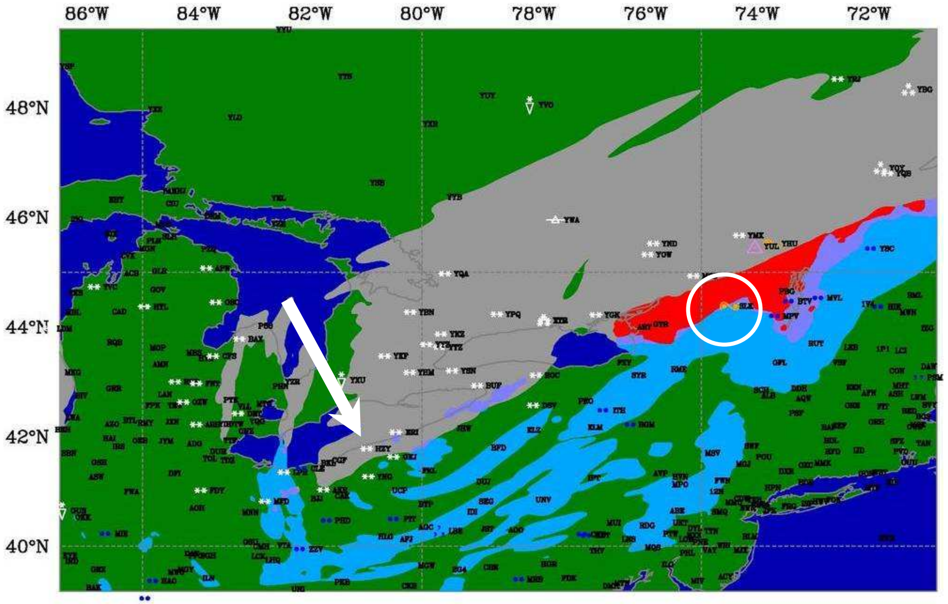
3. Tests / Evaluations – **Precipitation Types and Distribution**

06h Forecast Valid 1800 UTC 2007 11 22

Current
Kong-Yau



Proposed
Milbrandt-Yau



Summary of 16 winter cases: (~19 000 observations)

		K-Y	M-Y
BIAS:	Liquid Rain	199.4	149.8
	Solid	59.3	74.6
	Freezing Rain	174.1	98.3
POD:	Liquid Rain	55.8	52.7
	Solid	34.8	38.6
	Freezing Rain	25.9	16.9
FAR:	Liquid Rain	72.0	64.8
	Solid	41.3	48.8
	Freezing Rain	85.1	82.2

IMPROVEMENT

RN – Liquid Rain
SN – Solid
FR – Freezing Rain

3. Tests / Evaluations – **Precipitation Types and Distribution**

Case Study: Vancouver snow, forecast bust, 2006-11-26

10 cm of SNOW in 12 h

32 cm of SNOW in 12 h

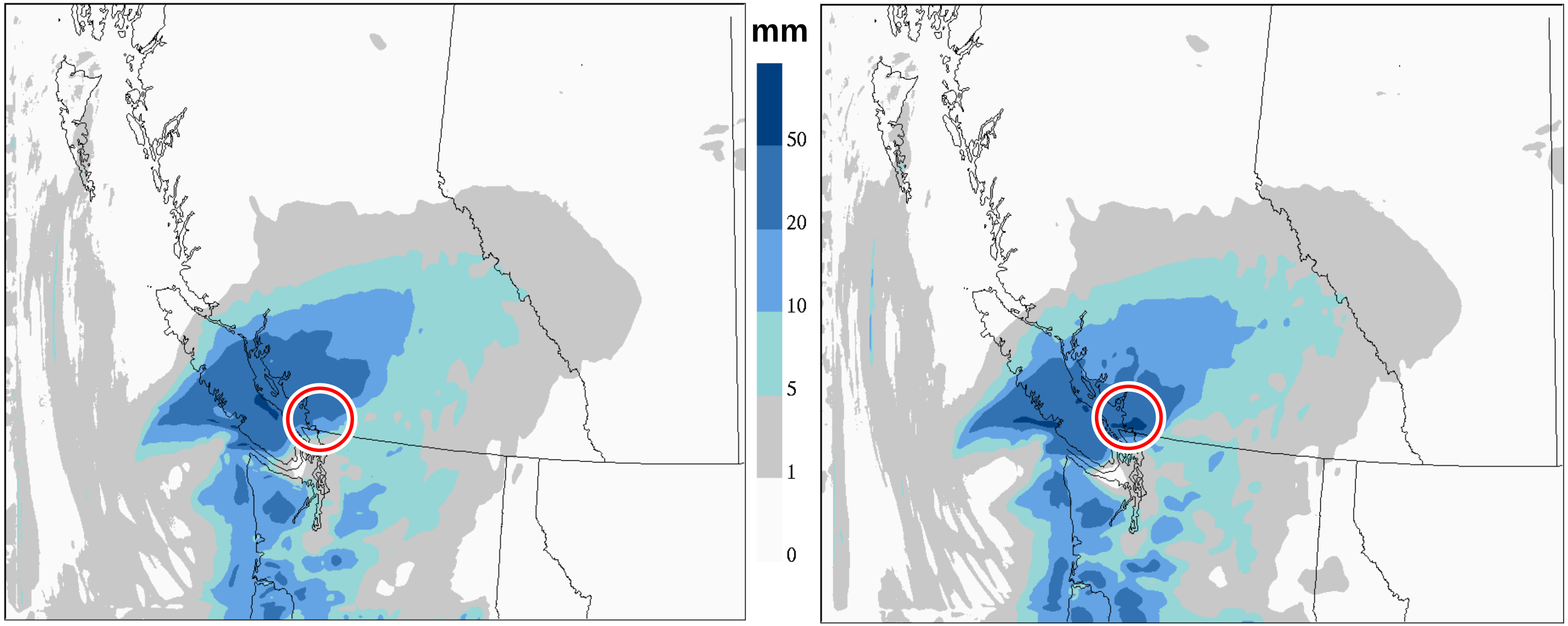
11 mm liq. eqv. of SNOW in 12 h

Name	Station ID	26 Nov [illegible]		26 Nov [illegible]		26 Nov 2100 UTC		27 Nov 0000 UTC	
		[illegible]	Water Equiv. [illegible]	[illegible]	Water Equiv. [illegible] ain [illegible] unt [illegible] n)	Snow (cm)	Water Equiv. or Rain Amount (mm)	Snow (cm)	Water Equiv. or Rain Amount (mm)
Vancouver Inter. Airport	CYVR / YVR	**1**	-	**3**	4	**4**	-	**1**	8
Abbotsford Airport	CYXX / YXX	**3**	-	**1**	4	**11**	-	**17**	24
Victoria International Airport	CYYJ / YYJ	0	-	0	9	0	-	2	8
Comox	YQQ / CYQQ	4	-	1	7	2	-	0	2
Powell River Airport	CYPW / YPW	11	5.2	1	-	0	-	0	8.8
Campbell River Airport	CYBL / YBL	19	22	6	-	0	-	1	-
Nanaimo Airport	CYCD / YCD	8	20	0	-	3	-	3	-
Hope Slide	W[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-
Whistler	CW[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	1	-
E.C. Auto Station									
West Vancouver	**WWA**	**-**	**3**		**4.5**	**-**	**3.7**	**-**	**2.7**
Vancouver Harbour	WHC	-	2.4	-	3.4	-	4	-	3
Pitt Meadows	WMM	-	0.8	-	1	-	2.8	-	1.2
White Rock	WWK	-	0	-	0	-	0.8	-	0.8

Courtesy of Neil McLennan, MSC (PYR)

12-h QPF – Accumulated TOTAL Precipitation

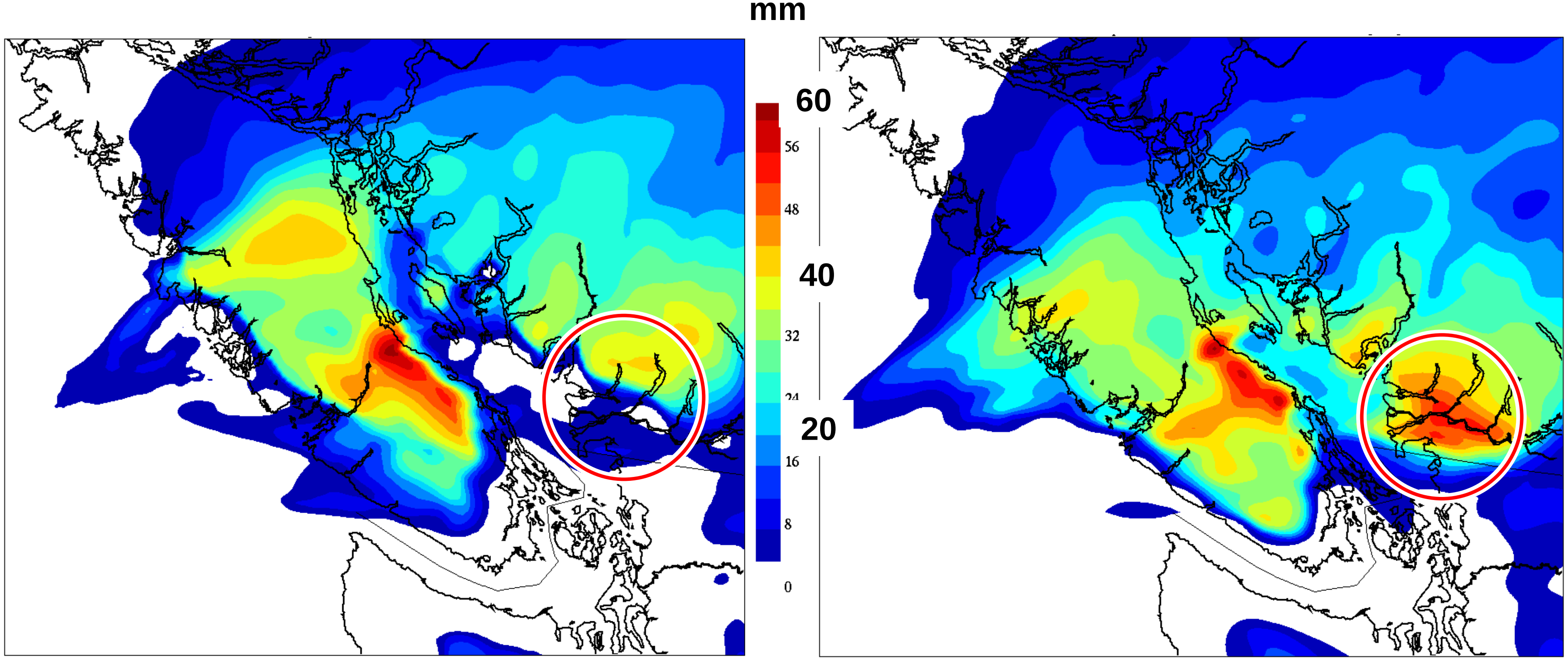
Kong-Yau **Milbrandt-Yau**



Valid: 2007-11-12 00z

12-h QPF – Accumulated <u>SOLID</u> Precipitation

Kong-Yau | **Milbrandt-Yau**



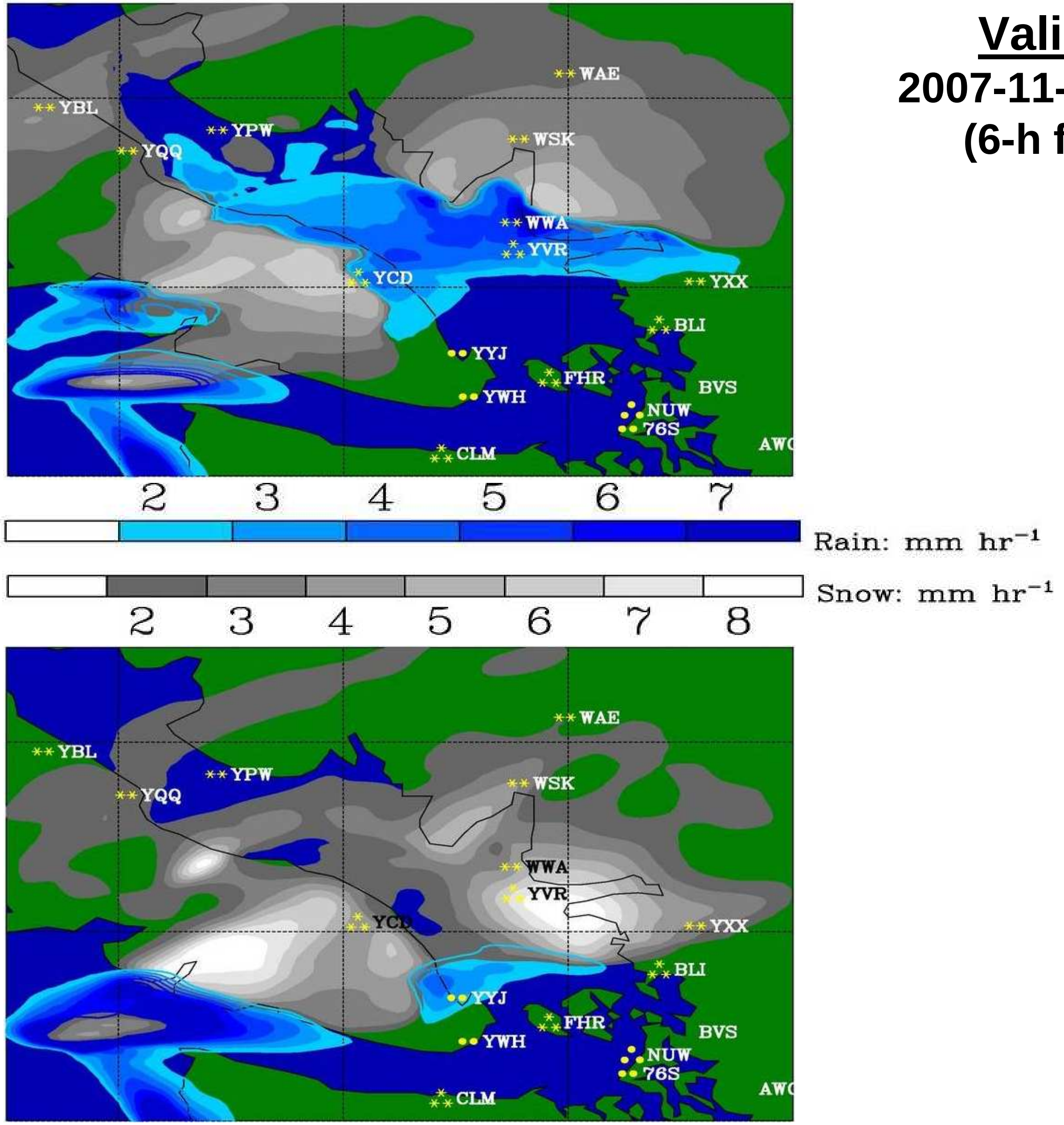
Valid: 2007-11-12 00z

3. Tests / Evaluations – **Precipitation Types and Distribution**

Valid:
2007-11-26 18z
(6-h fcst)

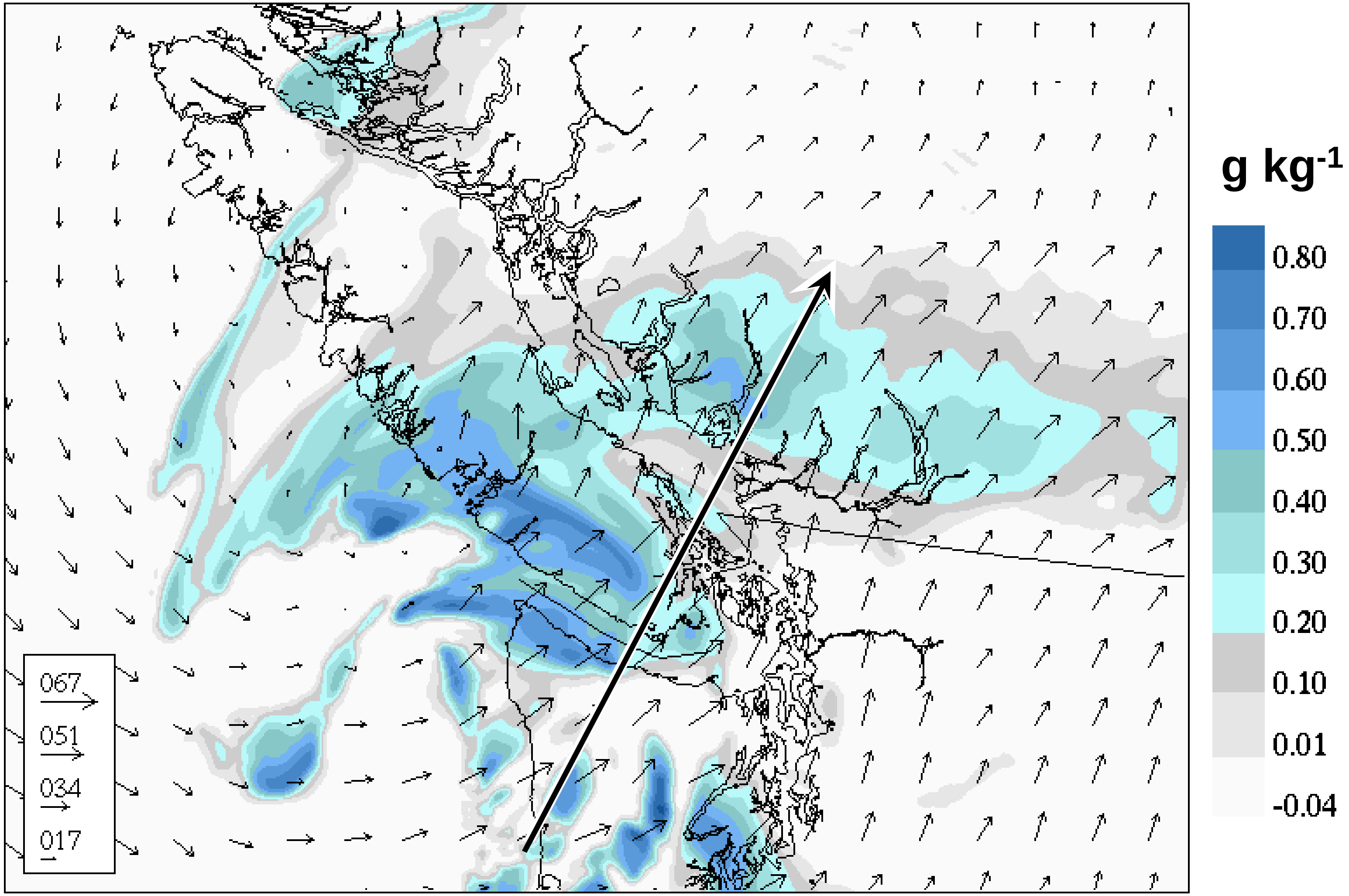
CURRENT
Kong-Yau:

PROPOSED
Milbrandt-Yau:



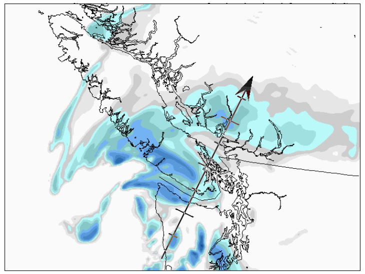
(based on 1-h accumulation)

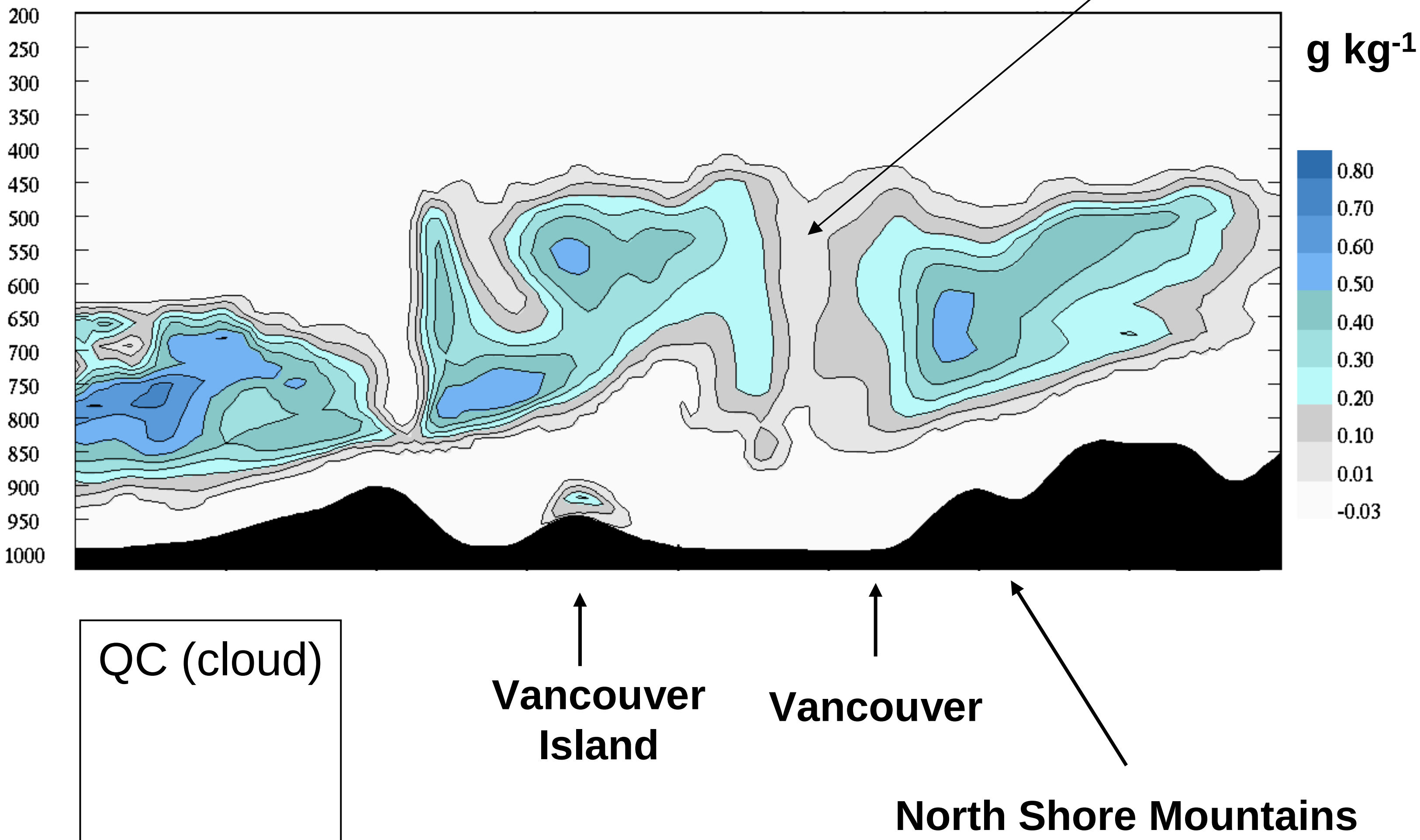
700 hPa QC + winds (Kong-Yau, 2006-11-26 16 z)



3. Tests / Evaluations – **Precipitation Types and Distribution**

Kong-Yau

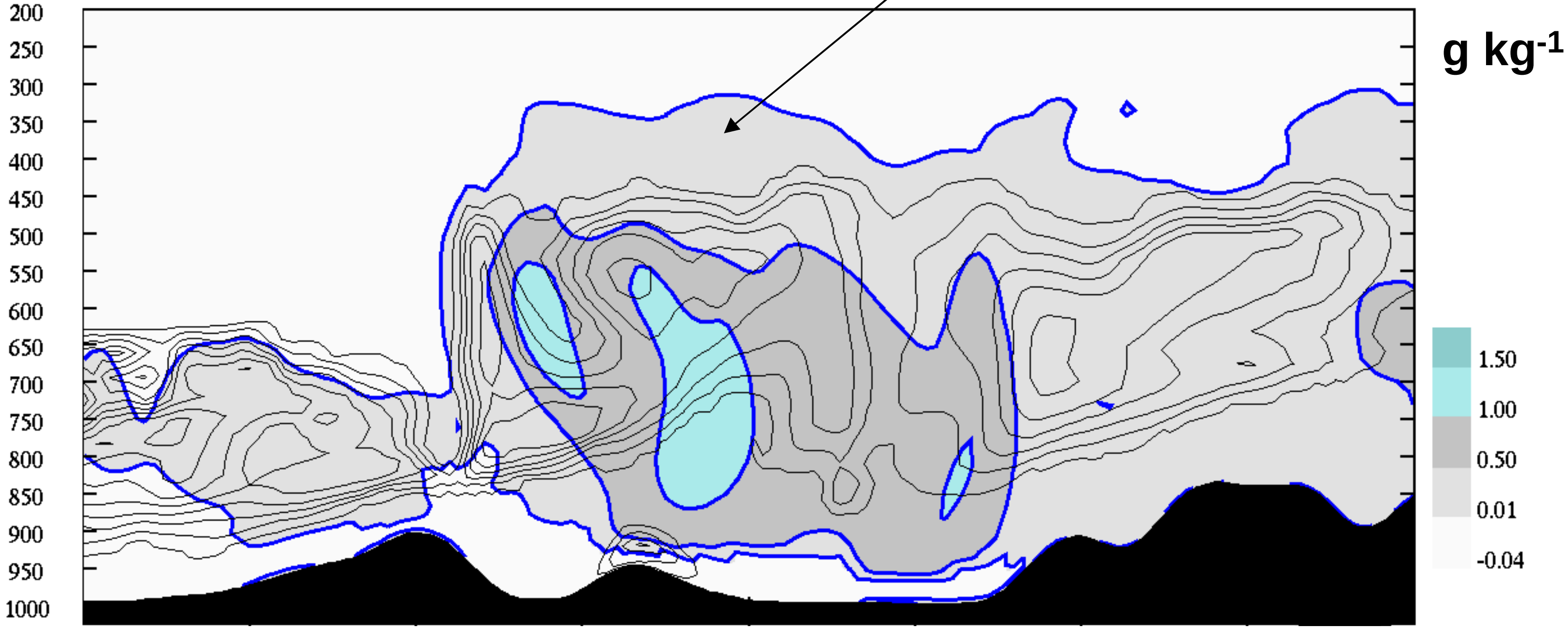




QC (cloud)

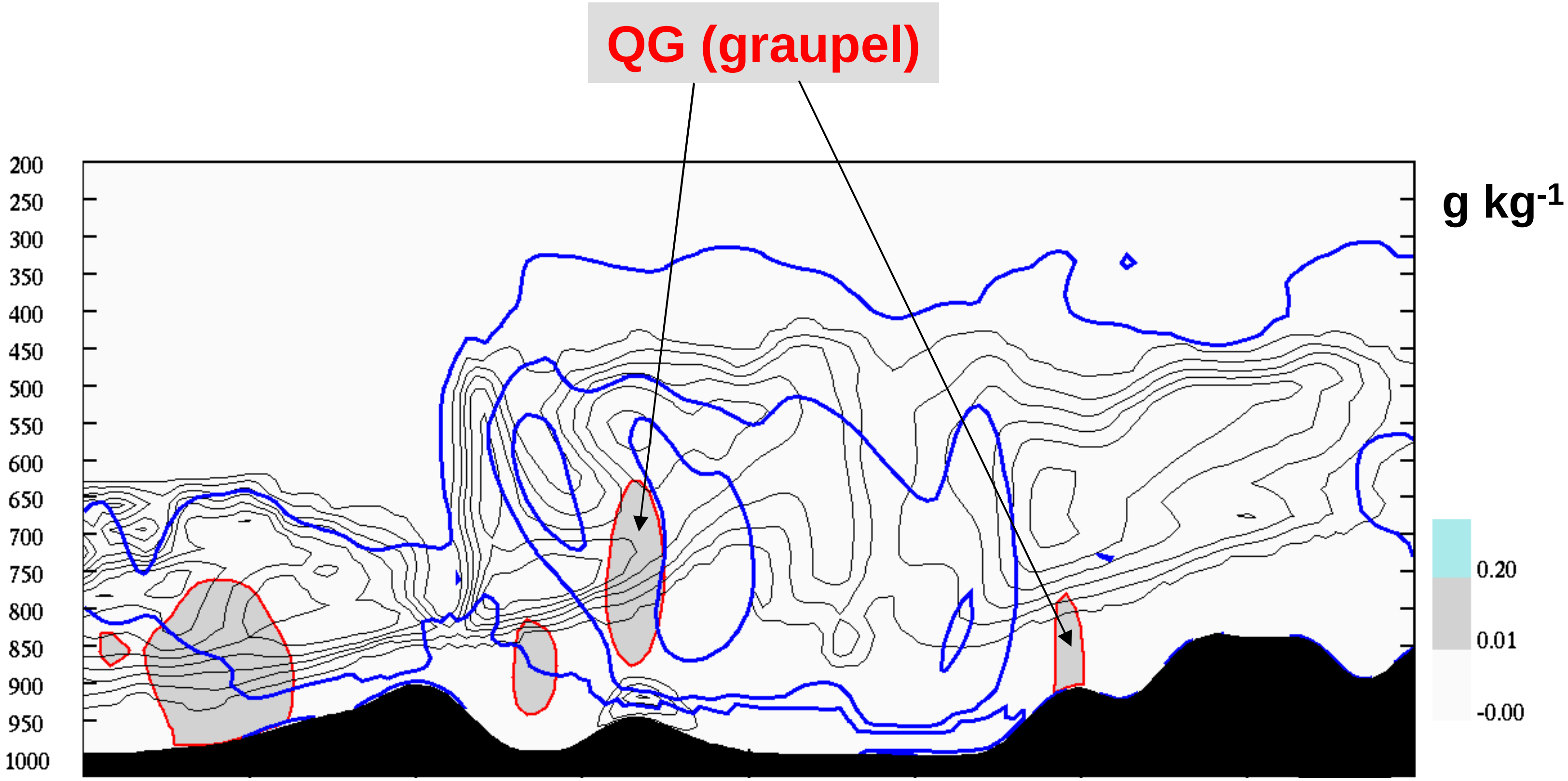
Kong-Yau

QI (ice/snow)



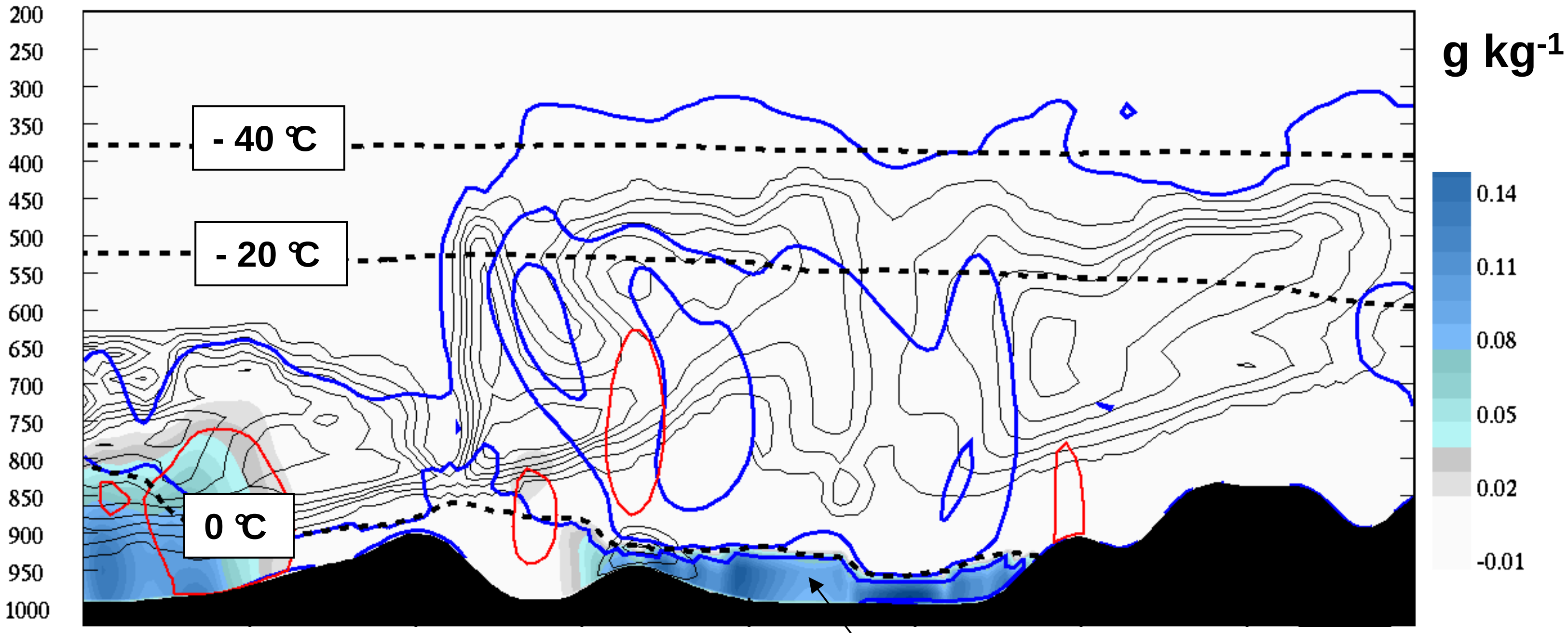
QC (cloud)
QI (ice/snow)

Kong-Yau



QC (cloud)
QI (ice/snow)
QG (graupel)

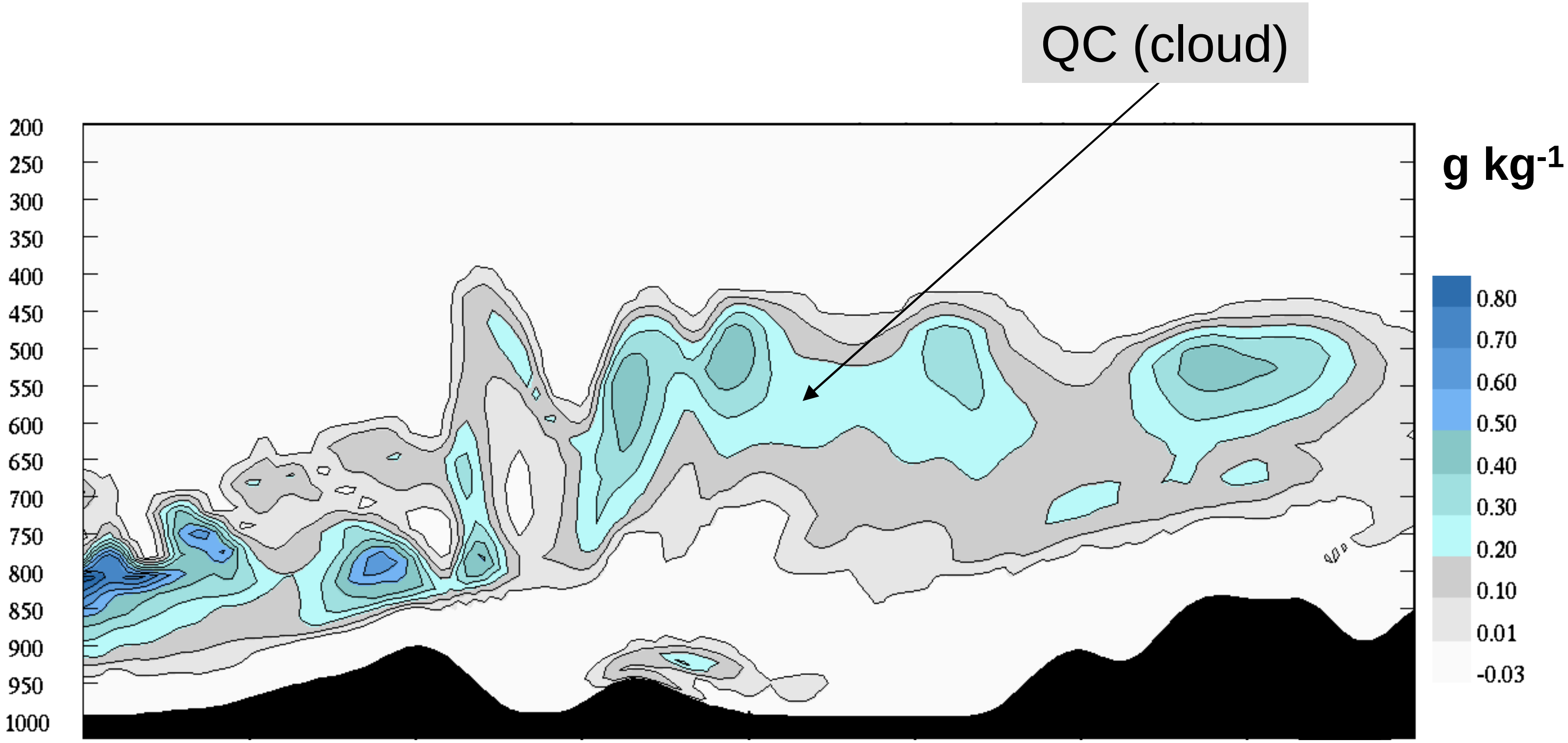
Kong-Yau



QC (cloud)
QI (ice/snow)
QG (graupel)
QR (rain)

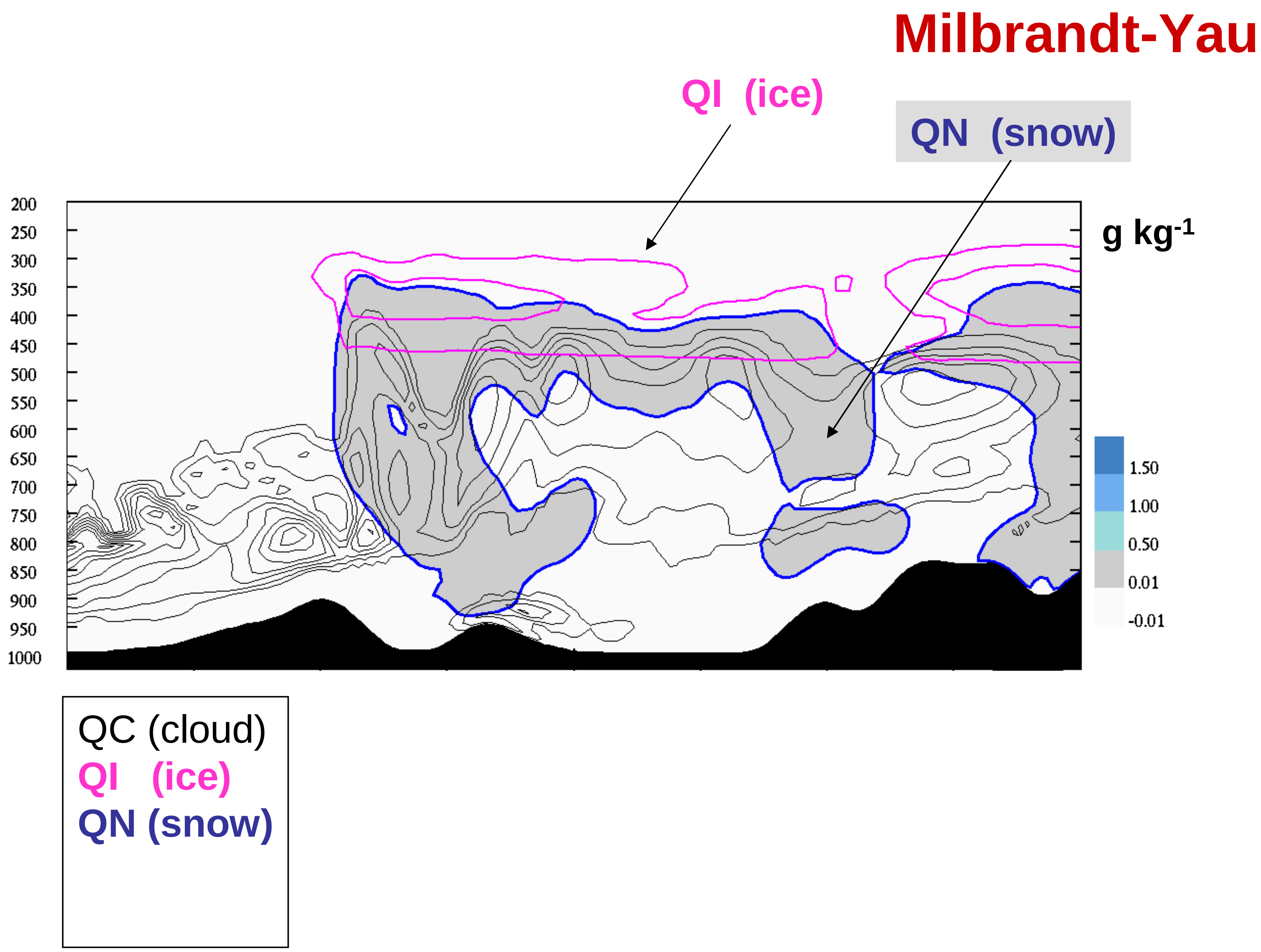
QR (rain)

Milbrandt-Yau

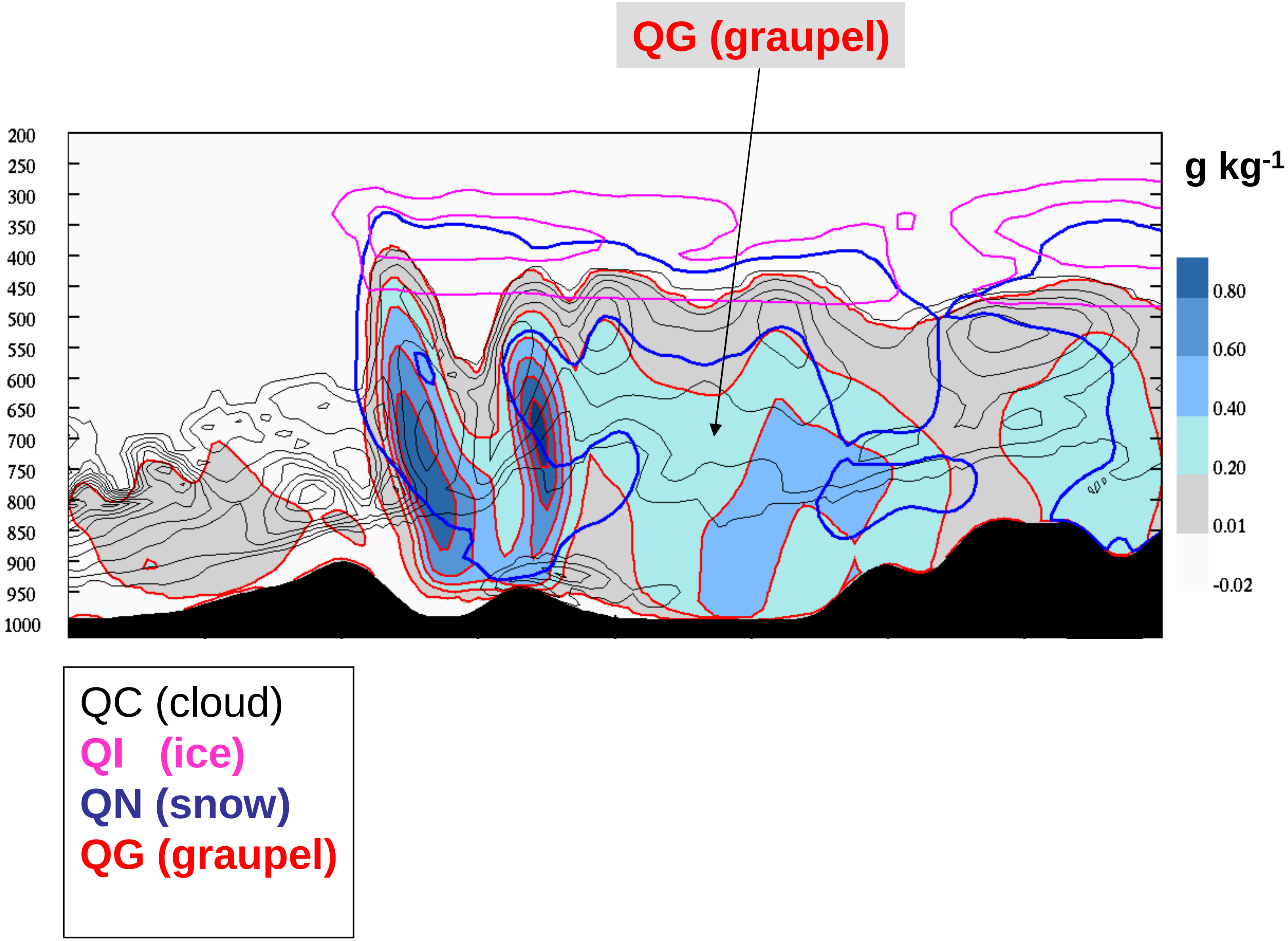


QC (cloud)

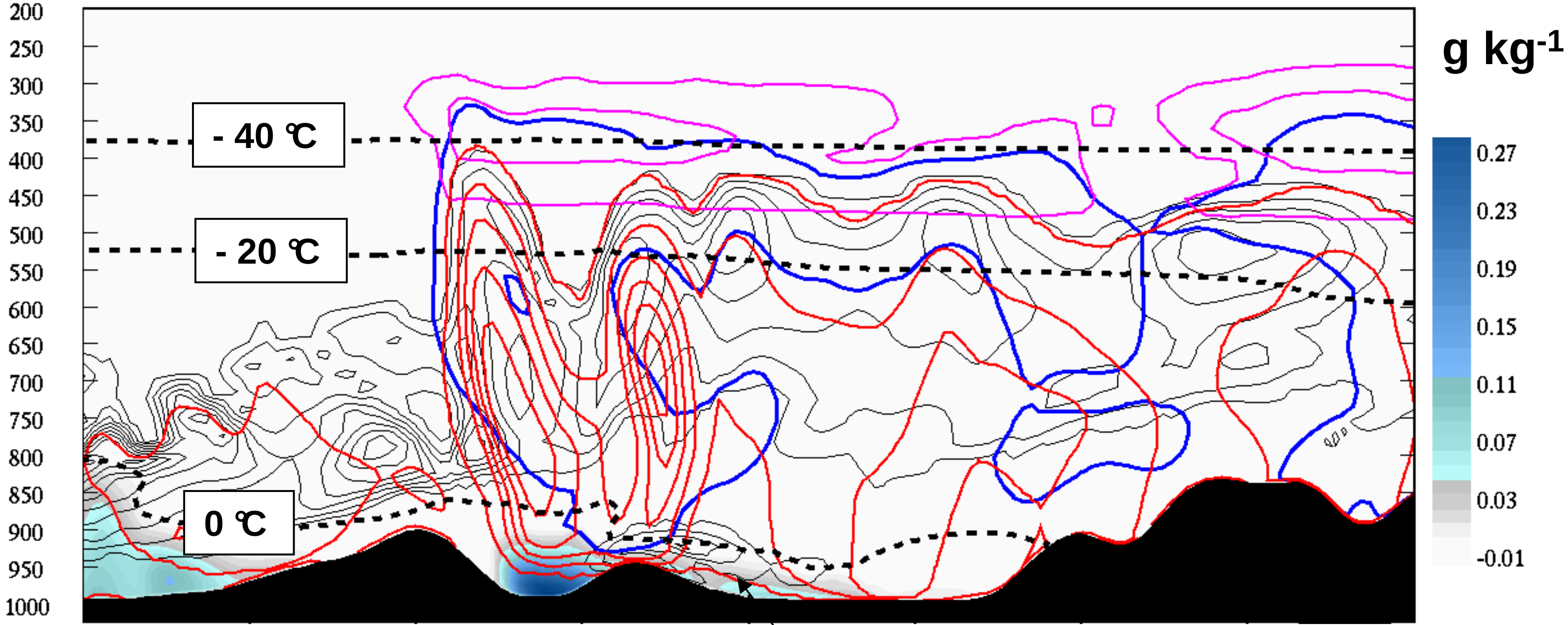
3. Tests / Evaluations – **Precipitation Types and Distribution**



Milbrandt-Yau



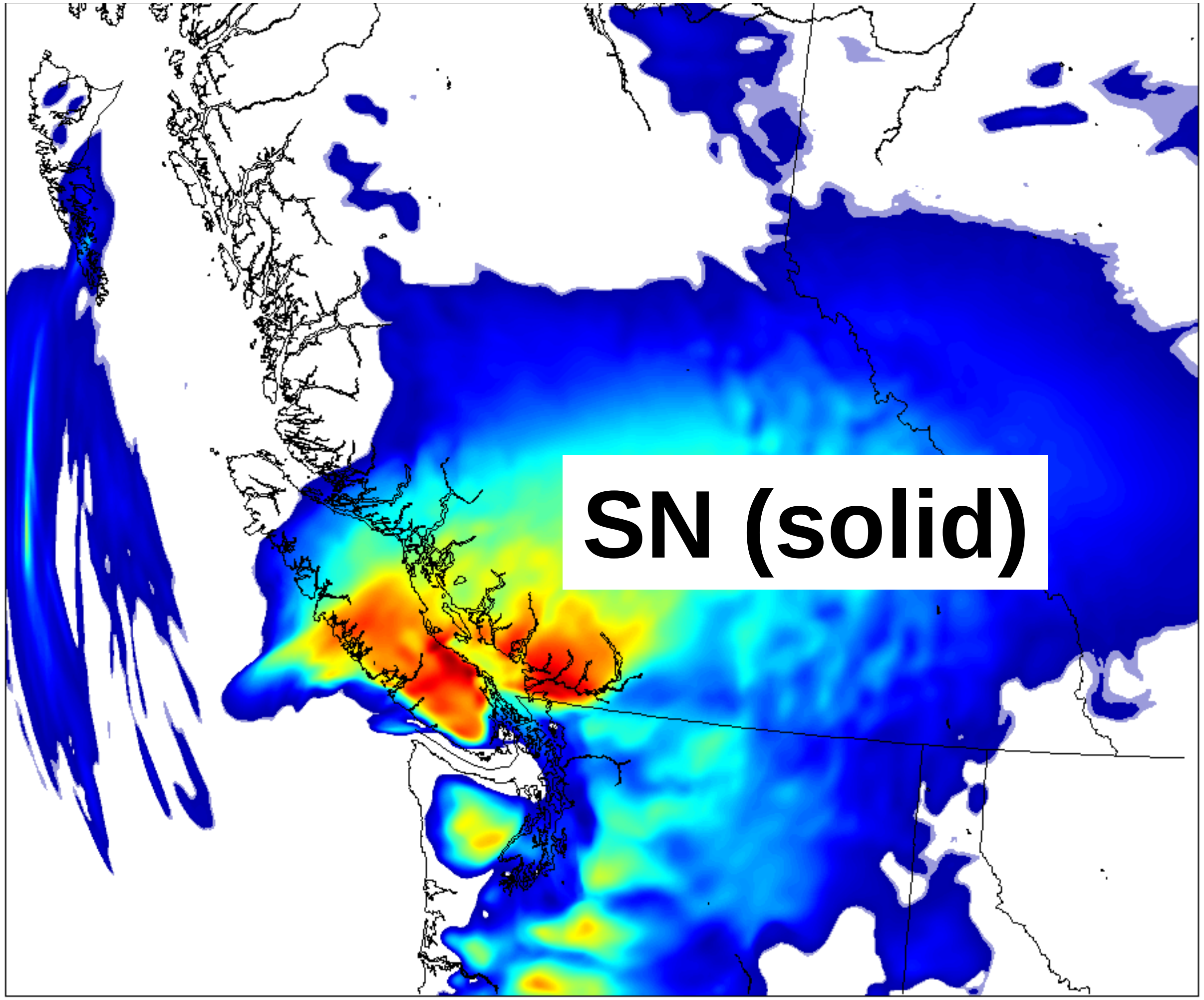
Milbrandt-Yau



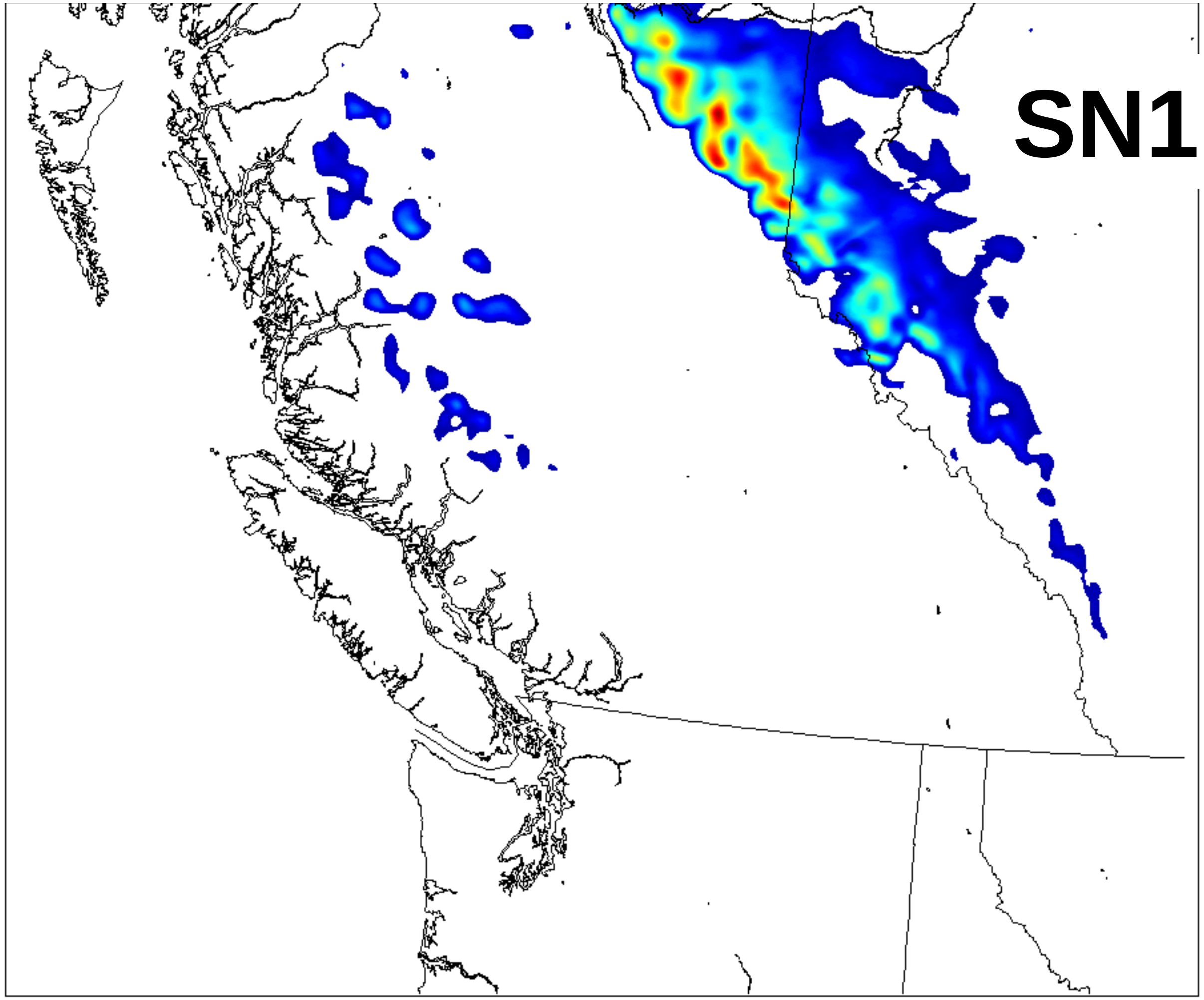
QC (cloud)
QI (ice)
QN (snow)
QG (graupel)
QR (rain)

QR (rain)

Milbrandt-Yau



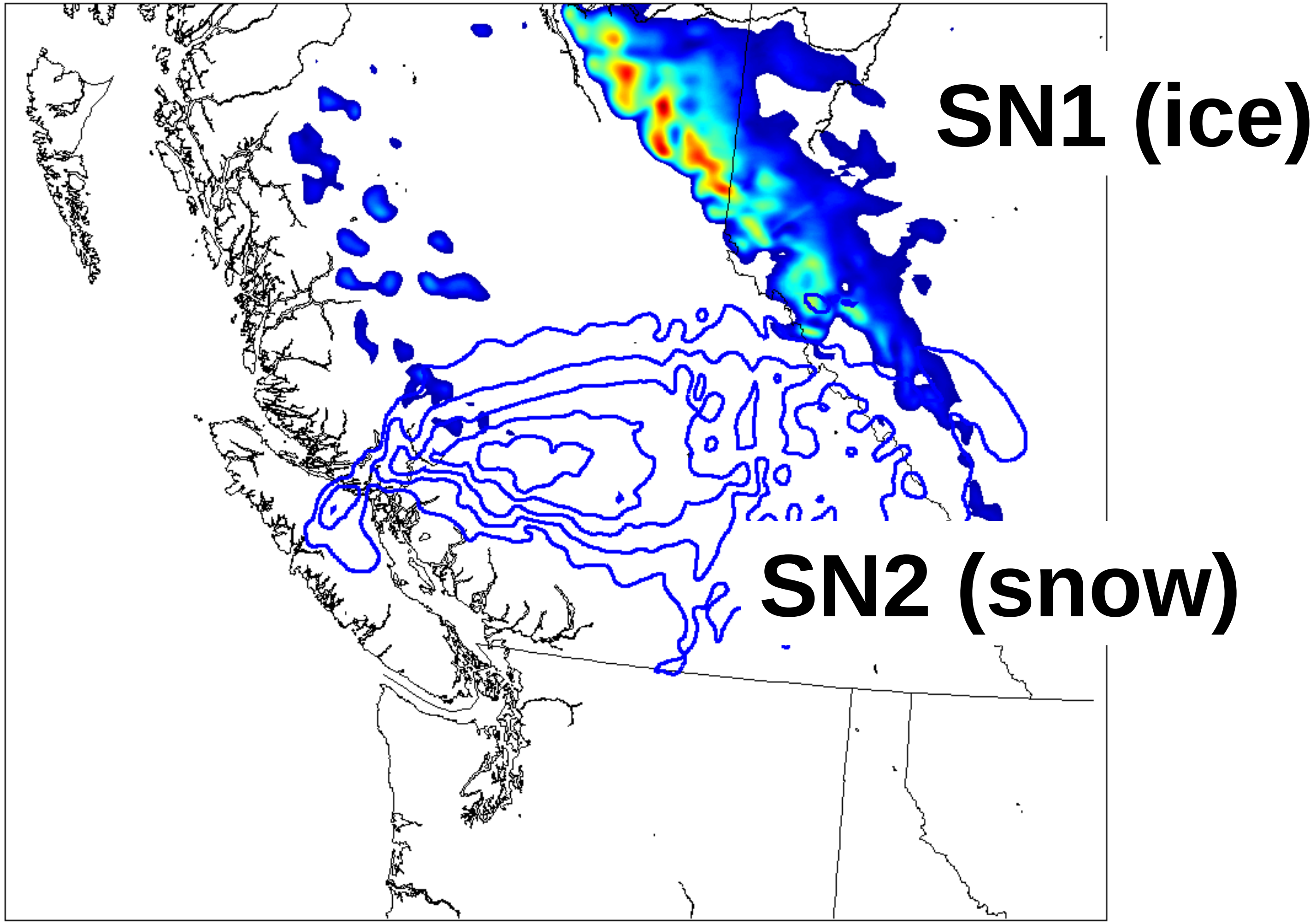
Milbrandt-Yau



SN1 (ice)

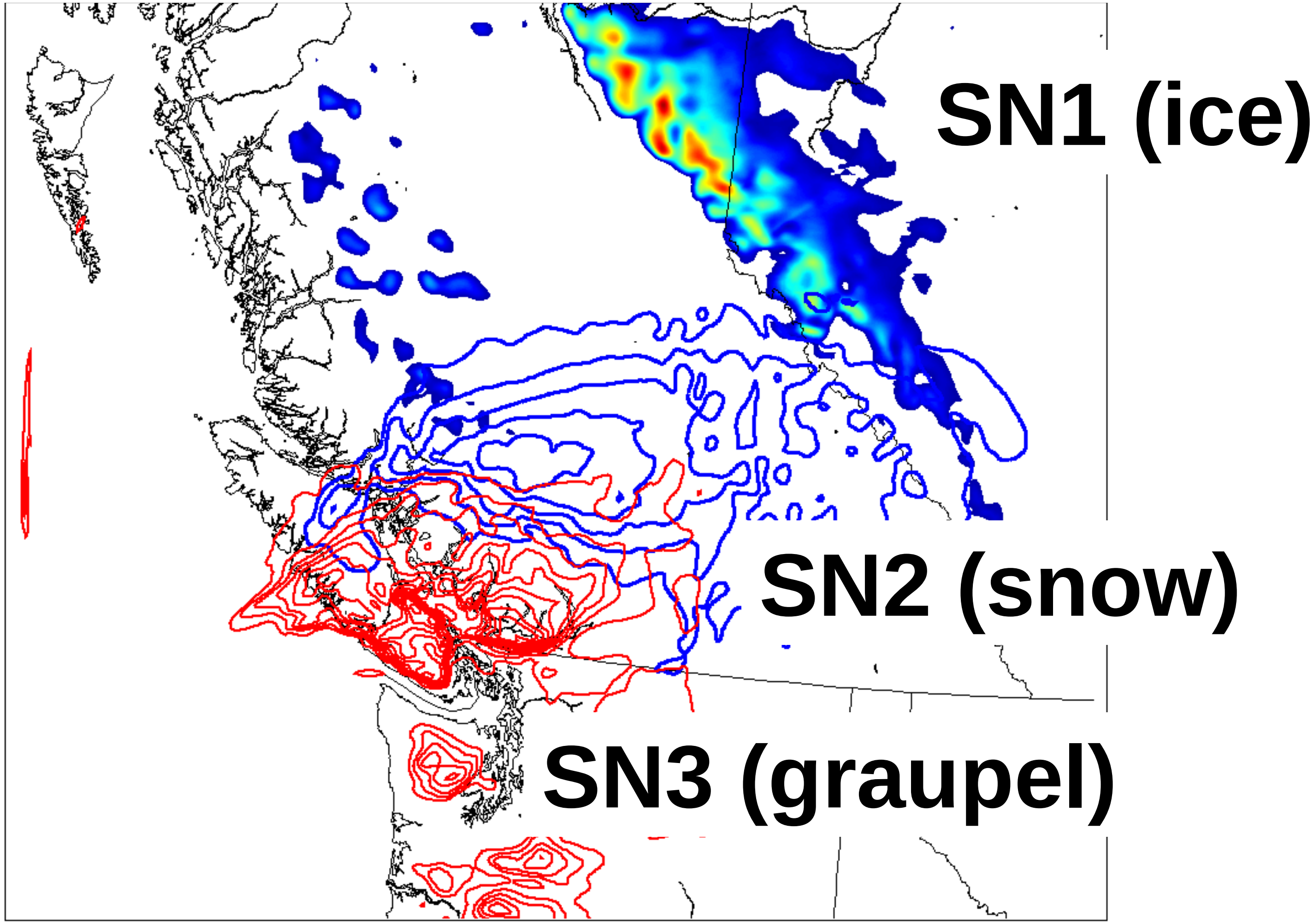
3. Tests / Evaluations – **Precipitation Types and Distribution**

Milbrandt-Yau



3. Tests / Evaluations – **Precipitation Types and Distribution**

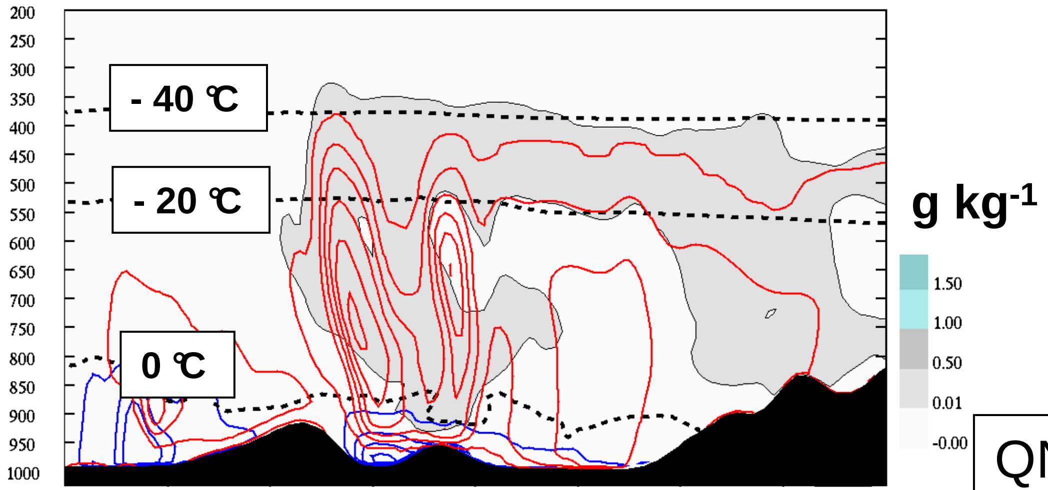
Milbrandt-Yau



2007-11-26 18z:
(4-h)

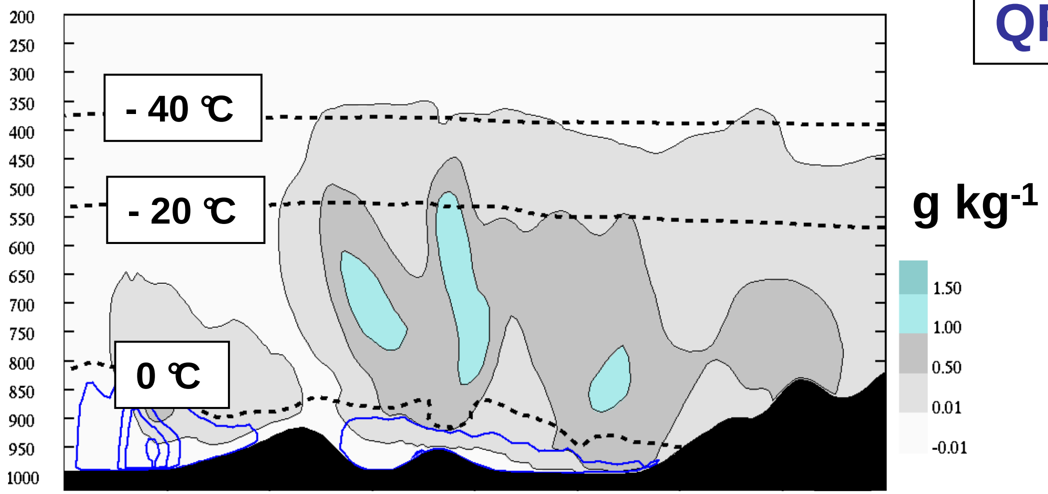
Milbrandt-Yau

CONTROL



QN (snow)
QG (graupel)
QR (rain)

NO GRAUPEL
(sensitivity run)



Kong-Yau run

- lots of cloud liquid water (*QC*)
- lots of ice/snow (*QI*), little conversion to graupel (*QG*)
- instantaneous melting to rain (*QR*) when $T > 0°C$

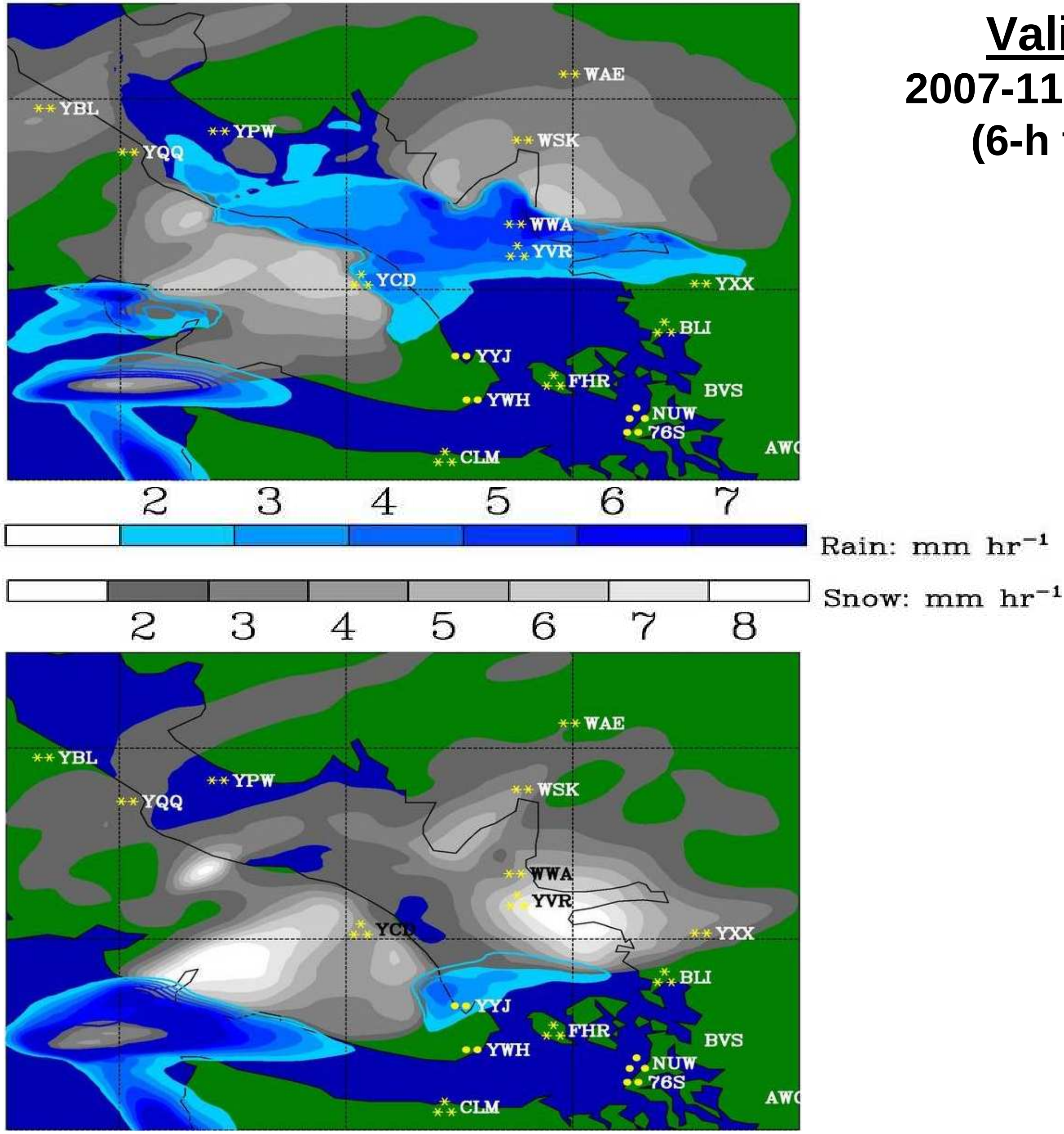
Milbrandt-Yau run

- lots of cloud liquid water (*QC*)
- lots of riming conversion of snow (*QN*) graupel (*QG*)
- gradual melting to rain (*QR*) when $T > 0°C$

3. Tests / Evaluations – **Precipitation Types and Distribution**

<u>Valid</u>:
2007-11-26 18z
(6-h fcst)

<u>CURRENT</u>
Kong-Yau:



(based on 1-h accumulation)

<u>PROPOSED</u>
Milbrandt-Yau:

SUMMARY OF EVALUATIONS

of effects of Milbrandt-Yau vs. Kong-Yau schemes
in the GEM-LAM-2.5:

- notable improvement in QPF statistics for SUMMER
- (improvement in storm structure for deep convection)*
- little change in QPF statistics for WINTER
- significant improvement in precipitation type for WINTER

** TBA*

<u>Increase in computational resources</u>:

Based on several direct comparisons of running the GEM-LAM-2.5, the **<u>total wall clock time</u>** using the proposed (single-moment) scheme is **<u>2% higher</u>** than with the current scheme

4. Future Developments

FUTURE WORK with M-Y scheme:

- Propose implementation of single-moment version
    - Jan. 15, 2008 (CPOP)
- Optimized (further) double-moment version
    - expected by Spring 2008
- Incorporation of cloud fraction
    - applicable for larger-scale (non-cloud resolving) configurations (i.e. *regional* and *meso-global*)
- Consistency between microphysics and radiation schemes
- Exploit information about aerosols for cloud nucleation

MERCI

THANK YOU

EXTRA

Milbrandt-Yau Cloud Scheme

UPCOMING VERSION AVAILABLE FOR GEM:

Prototype cloud scheme for the 2010 Winter Olympics

Operational version *

CLOUD	double-moment	(Q_c, N_c)	
RAIN	double-moment	(Q_r, N_r)	[diagnostic-α_r]
ICE/SNOW	double-moment	(Q_i, N_i)	[hybrid category]
GRAUPEL	single-moment	(Q_g)	
HAIL	double-moment	(Q_h, N_h)	[diagnostic-α_h]

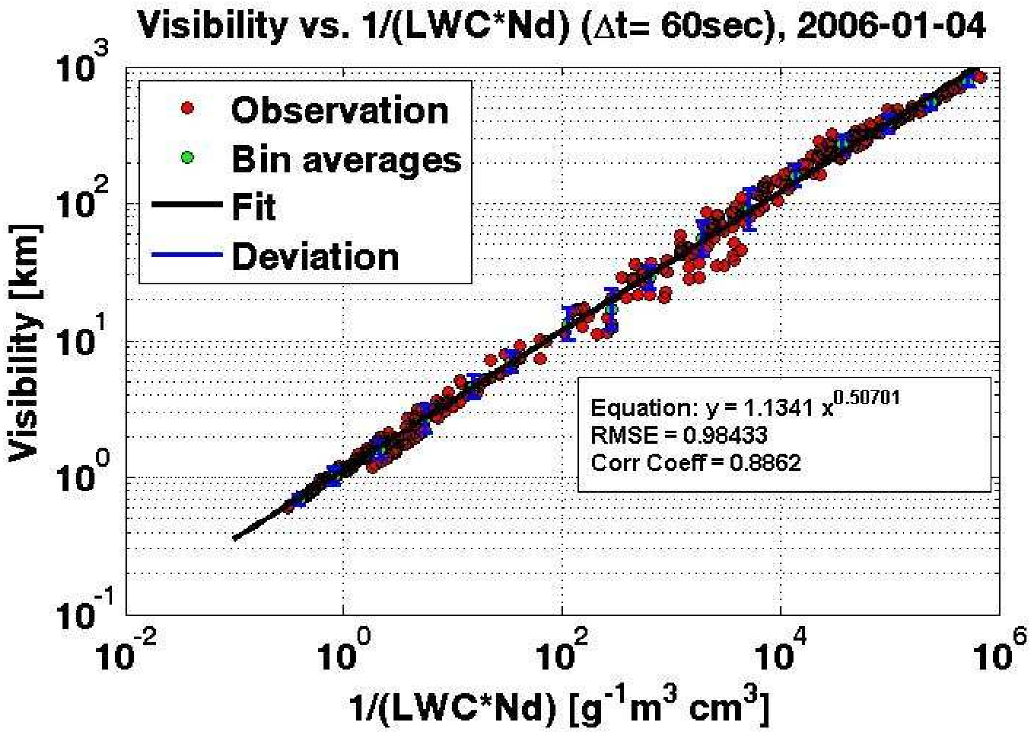
Expected Cost: < 15% additional total CPU time (vs. Kong-Yau)

* To be developed and proposed for implementation in GEM-LAM 2.5 km by **SPRING 2007**

Parameterization of VISIBILITY:

$$VIS = f\,(Q_c, N_c)$$

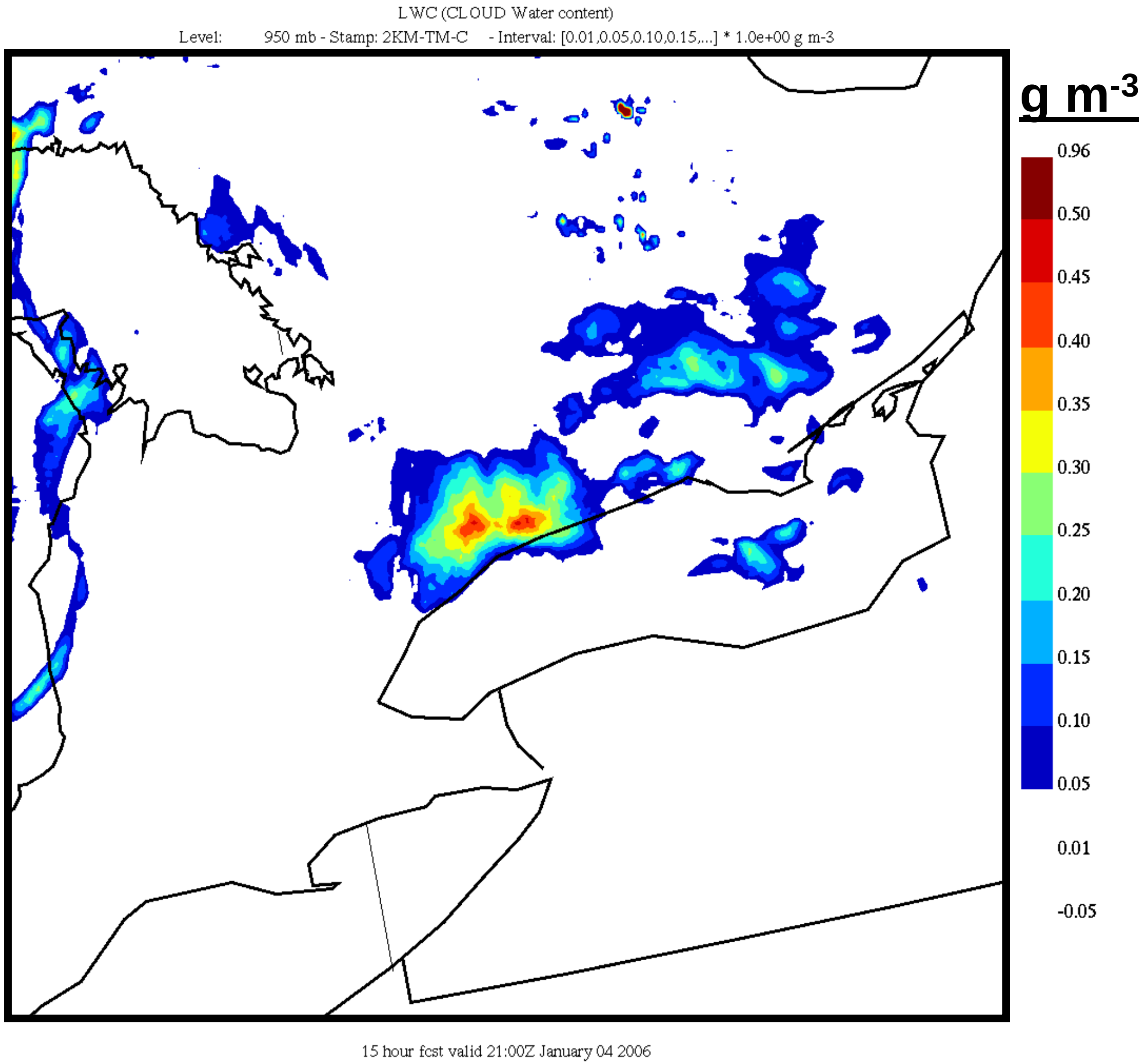
i.e. $VIS = f\,(LWC, N_d)$



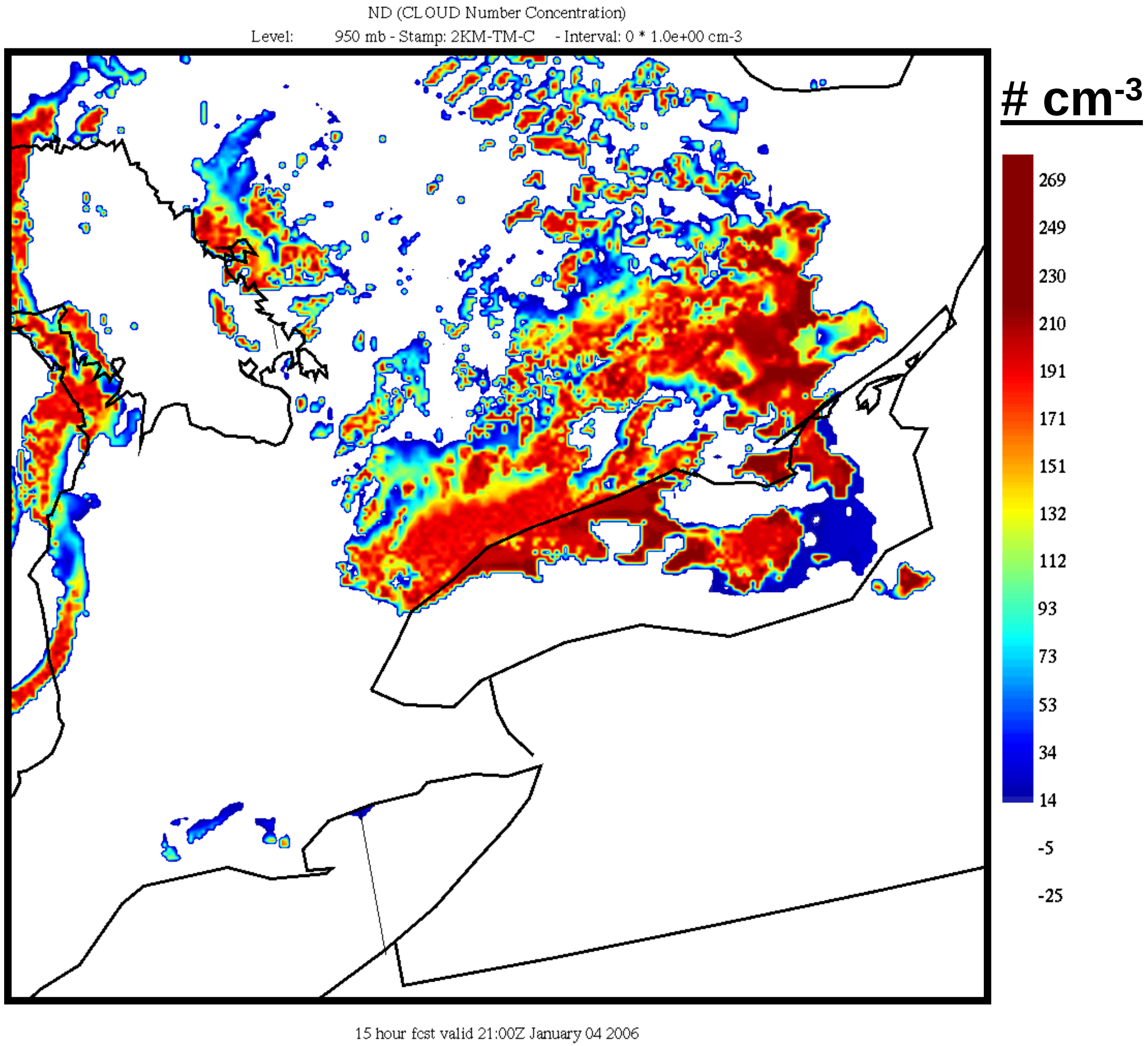
SOURCE: Gultepe and Milbrandt (2007)

Advantages of M-Y: **Prognostic N_c**

Q_c (Cloud Water Content)



N_c (Cloud Number Concentration)



Advantages of M-Y: **Prognostic N_c**

VIS (Visibility)