DMIP 2: First Results from North Fork American River

Mike Smith[1], Victor Koren[1] Seann Reed[1], Ziya Zhang[1], Fekadu Moreda[1], Zhengtao Cui[1], Yu Zhang[1], Naoki Mizukami[1], Shane Sheldon[1], John Schaake[1],
Pete Fickenscher[2], Eric Strem[2]

NOAA/NWS Office of Hydrologic Development

Distributed Model Intercomparison Project (DMIP) } Phase 2 Scope

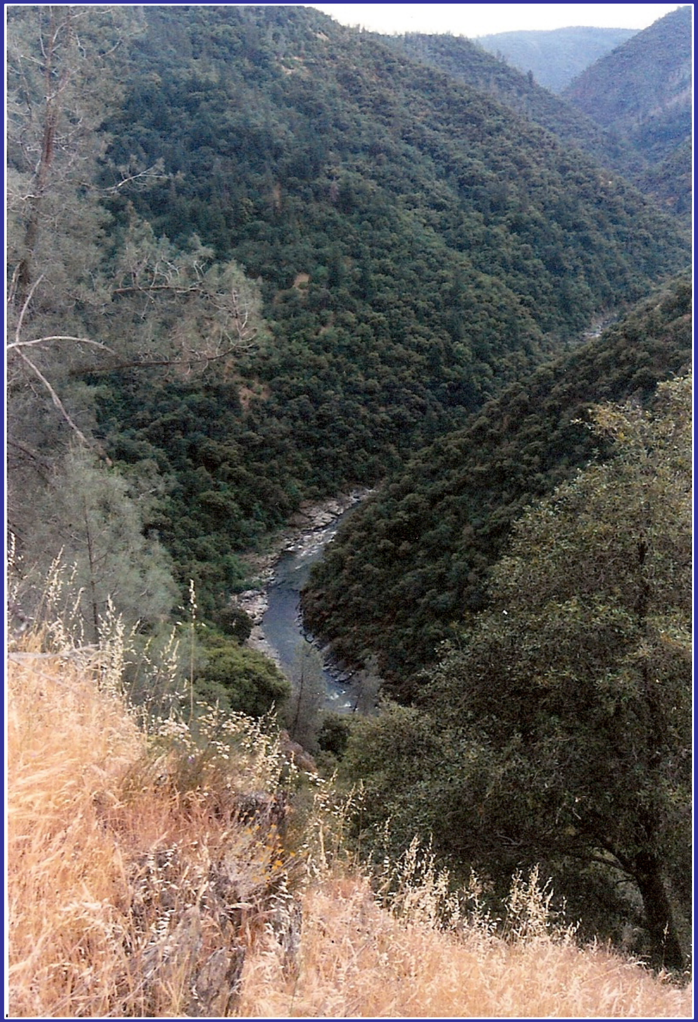
Tests with Complex Hydrology

1. Snow, Rain/snow events
2. Soil Moisture
3. Lumped and Distributed

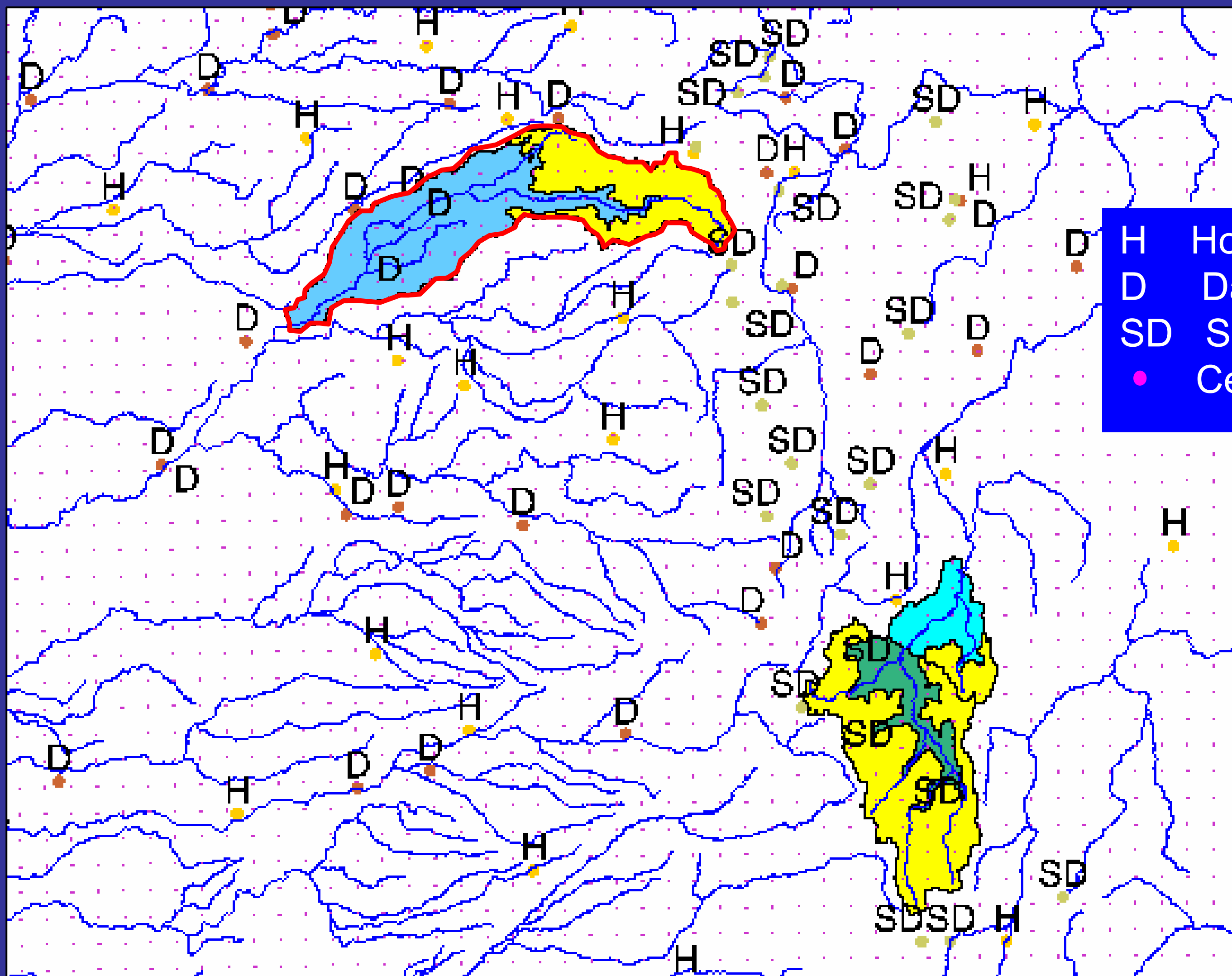
Additional Tests in DMIP 1 Basins

1. Routing
2. Soil Moisture
3. Lumped and Distributed

North Fork American River
Near Iowa Hill Bridge



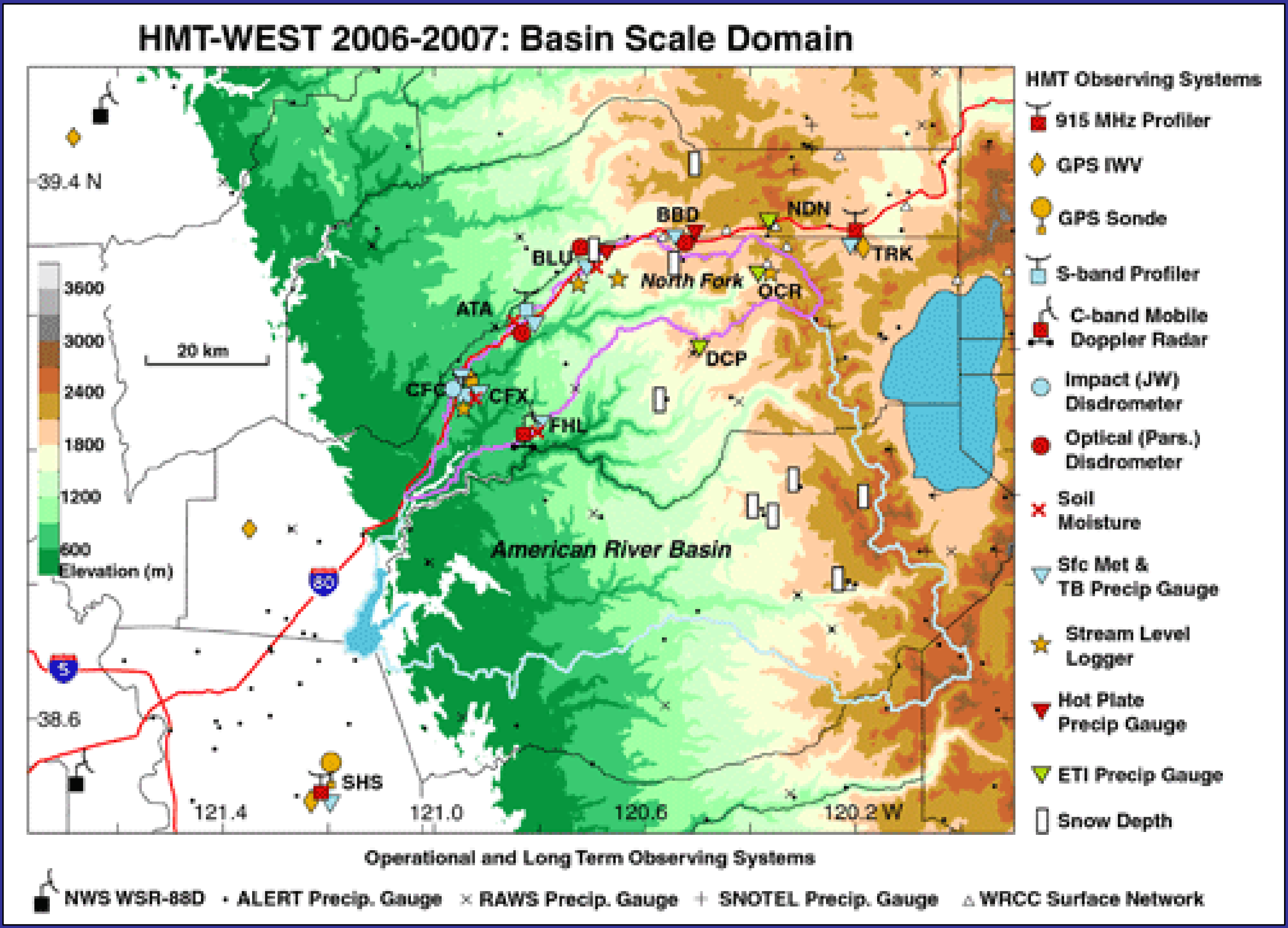
DMIP 2 Western Basins: Gauge Network for ‘Basic’ Data (mimic RFC operations)



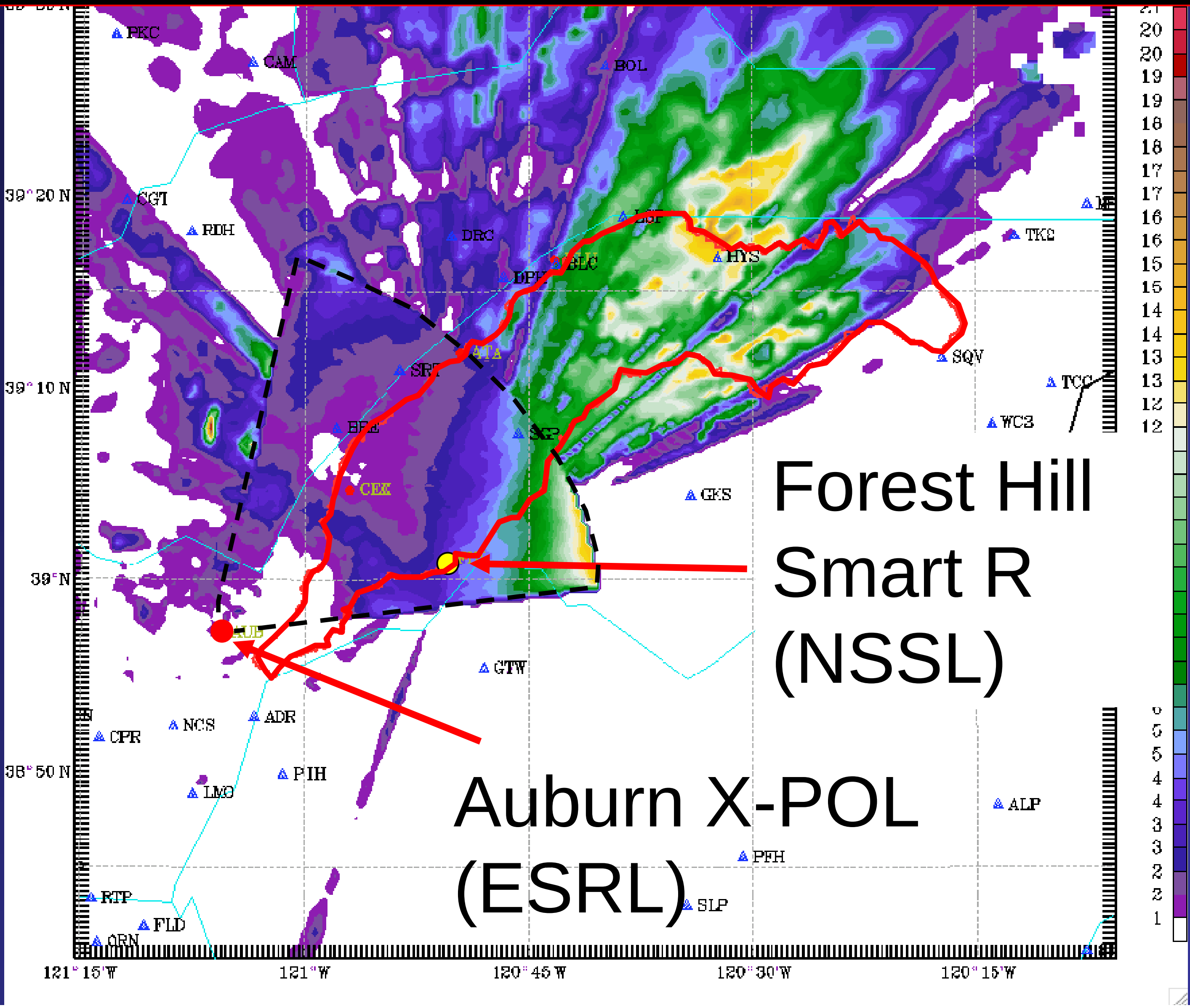
- H Hourly gauges
- D Daily gauges
- SD SNOTEL daily guages
- • Center of HRAP grids

Precipitation
And
Temperature

Additional Data for DMIP 2



DMIP 2 Western Basins: Leverage HydroMet Testbed Radar QPE



Two Radars in 2005-2006

QPE Data Processing for Use in DMIP 2

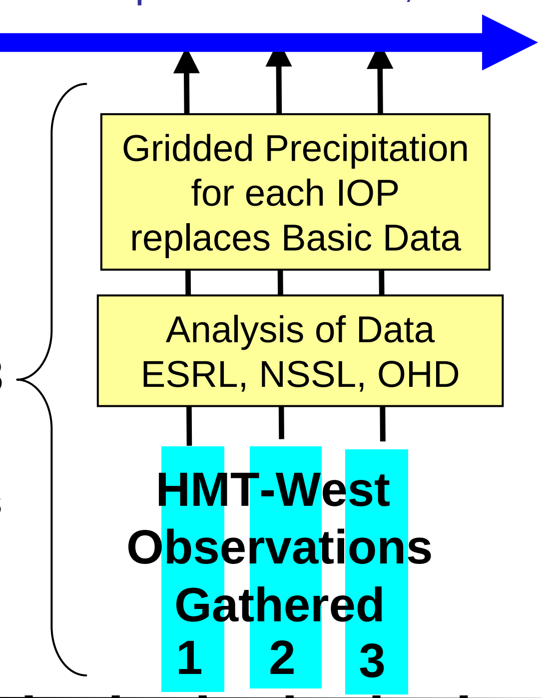
‘Advanced’ DMIP 2 Data: Multi-year time series of gridded data comprised of 1) ‘Basic’ data and 2) Processed and gridded HMT data for each IOP

Step 1:
‘Basic’ DMIP 2 Data: Time series of gridded precipitation and temperature from NCDC, Snotel sites to Dec. 2002;

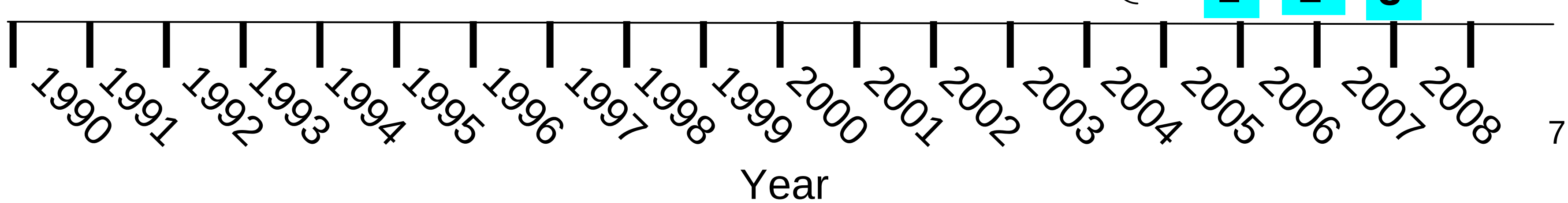
Step 2:
Extend ‘Basic’ Data: gridded precip. and temp. from NCDC, Snotel sites

- -Represent what the RFC uses for current Forecast operations.
- -Used for the initial lumped and distributed DMIP 2 simulations in the western basins.

Step 3



Note: the time scale describes the attributes of the time series, not the schedule for processing the HMT data. The HMT observations will be processed after each campaign and inserted into the Basic Data time series.



STATUS: Use of HMT Data and DMIP 2 Science Questions

	1 Data	2 Type	3 Processing	4 Status	5 DMIP 2 Modeling Experiment	6 DMIP 2 Science Questions
1	NCDC, Snotel precip and temperature	'Basic Data' represents RFC current data	Process into grids	Complete through 2006; being used by DMIP 2 participants through 2002	Run lumped and dist. models with data currently available	Can we run dist. models now with current data in mountains? Is there gain over lumped models? DMIP 2 Science Plan question VIII, pg. 9
2	**HMT** gap filling radar QPE for IOPs	HMT 'value added' QPE; corrected for mean field bias	1. Replace 'basic' grids with HMT value added	Delivered to OHD; tested cases	Run lumped, dist. models with HMT 'value added' QPE	Can we run advanced distributed models using emerging data? Is there gain over lumped models? DMIP 2 Science Plan question IX, pg. 9
3			2. Use MPE, gauge data for correction	Processed all '05/'06 cases	Run lumped, dist. Models with HMT 'value added QPE	Same as above
4	**HMT** estimates of freezing level for IOPs	HMT 'value added' freezing level	Flag grids as rain/snow given freezing level	Data collected; approach identified from 2 journal papers	Run models with new freezing level data; compare to current RFC approach	Art Henkel thinks the greatest improvements may be from better rain/snow level detection. DMIP 2 Science Plan question X, pg. 10
5	**HMT** additional in situ rain, temp gauge data	Denser in situ network	Process into grids using MPE or Schaake's program	Data from CDEC delivered to OHD by Dave Kingsmill;	Lumped, distributed model runs with forcings from networks of various densities.	What is required gauge density in mountainous areas? DMIP 2 Science Plan question IX, pg. 9
6	**HMT** Soil Moisture	HMT value added	QC, process into point time series	Some data collected; new sensors to be installed	Validate distributed models:	Using soil moisture obs., can we understand if we're getting the right answer for right reason? DMIP 2 Science Plan question IX, pg. 9

DMIP 2 Participants for Western Basins with 'Basic' Data

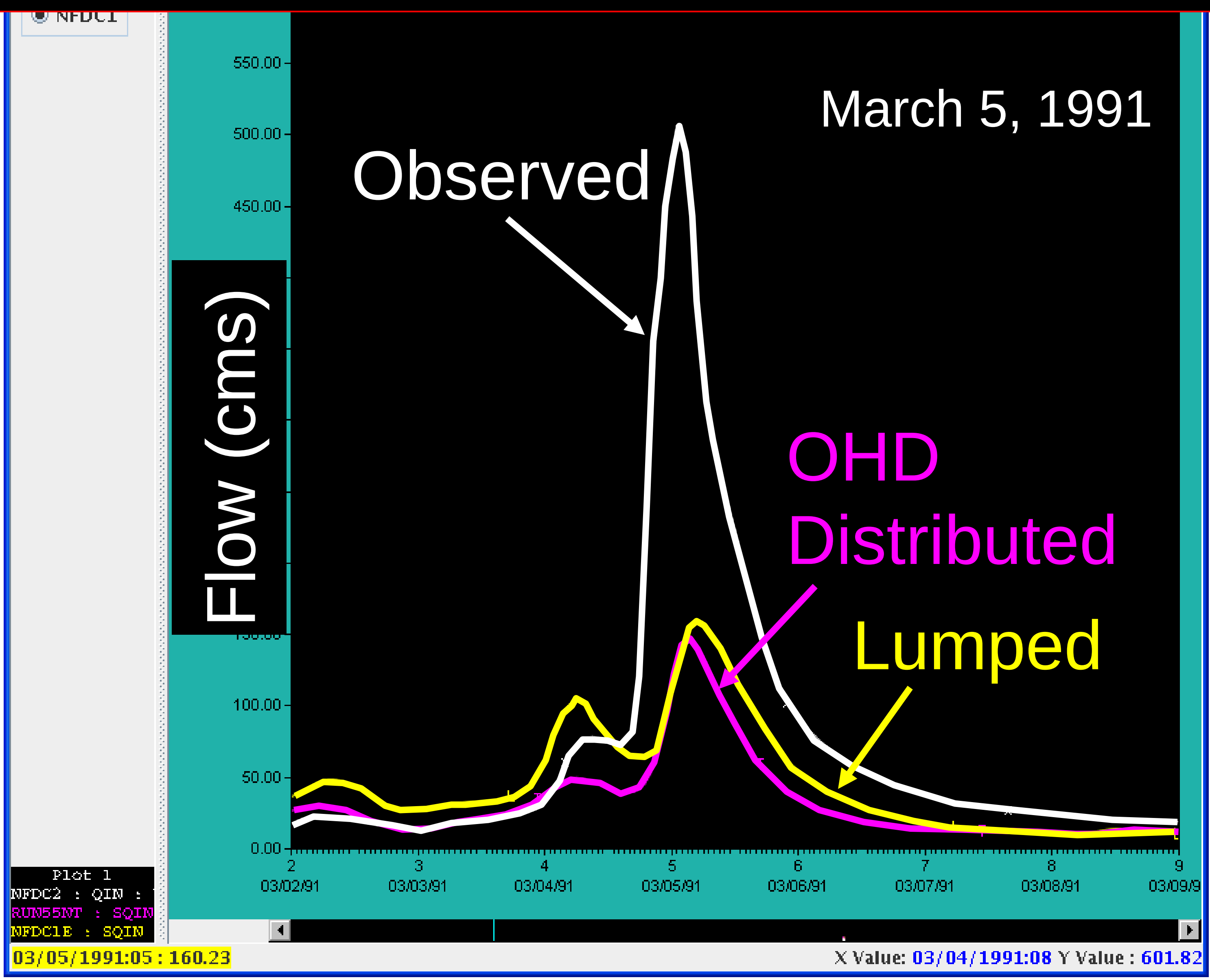
- OHD
- U. Illinois
- Hydrologic Research Center
- U. Bologna
- U. California at Irvine
- U. Nebraska at Lincoln
- U. Arizona

Note: Results not yet analyzed

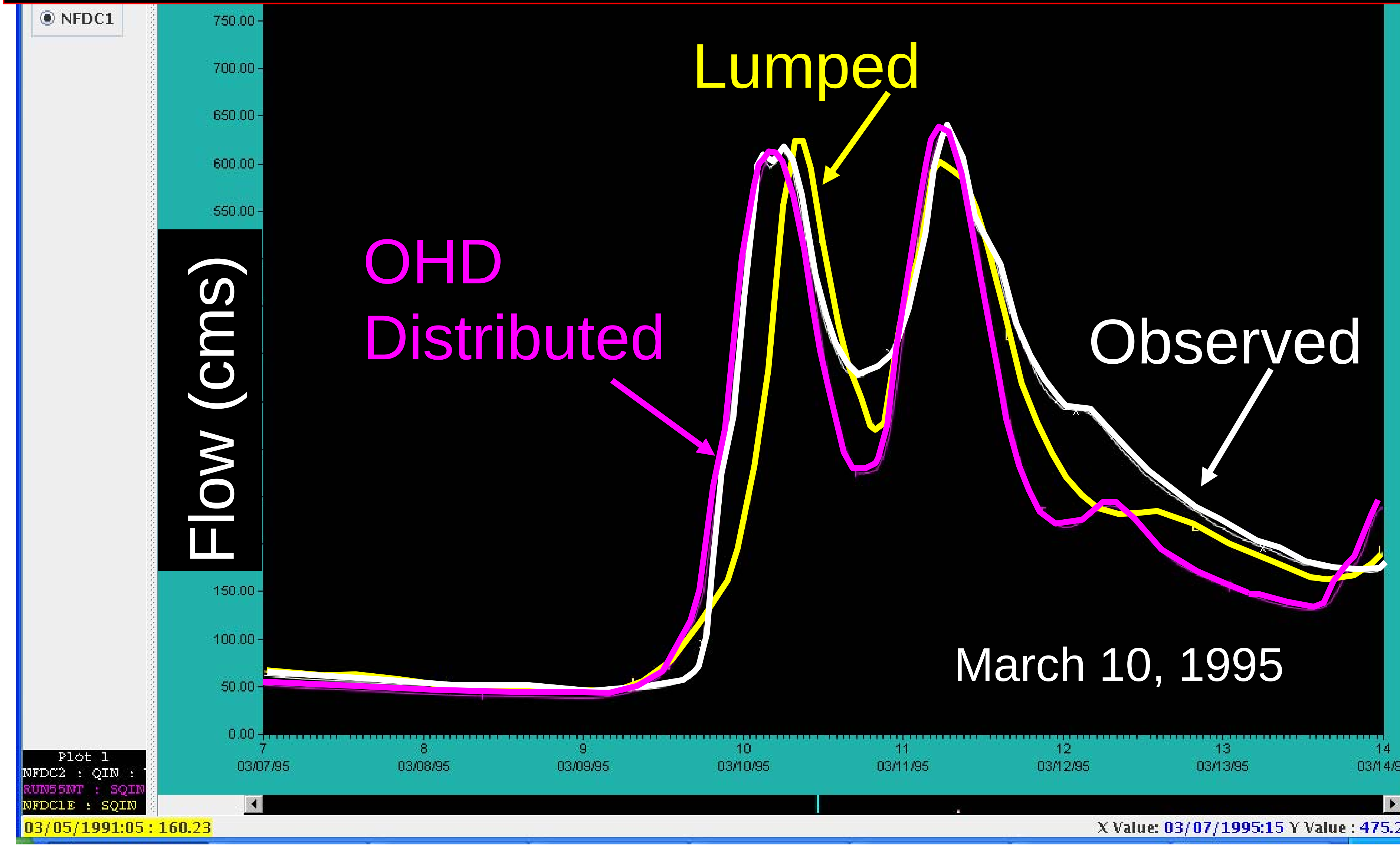
OHD DMIP 2 North Fork Streamflow Simulations Using Basic Data

- OHD Lumped model (standard)
  - Two elevation zones; 5000 ft.
  - Calibrated
- OHD distributed model
  - 48 grid cells, ~4km x 4km
  - Calibrated:
    - Started with calibrated lumped parameters
    - Manual calibration of parameters (scalars)
    - Maintain elevation zone relationships
    - Basic scripts developed to generate zone parameters

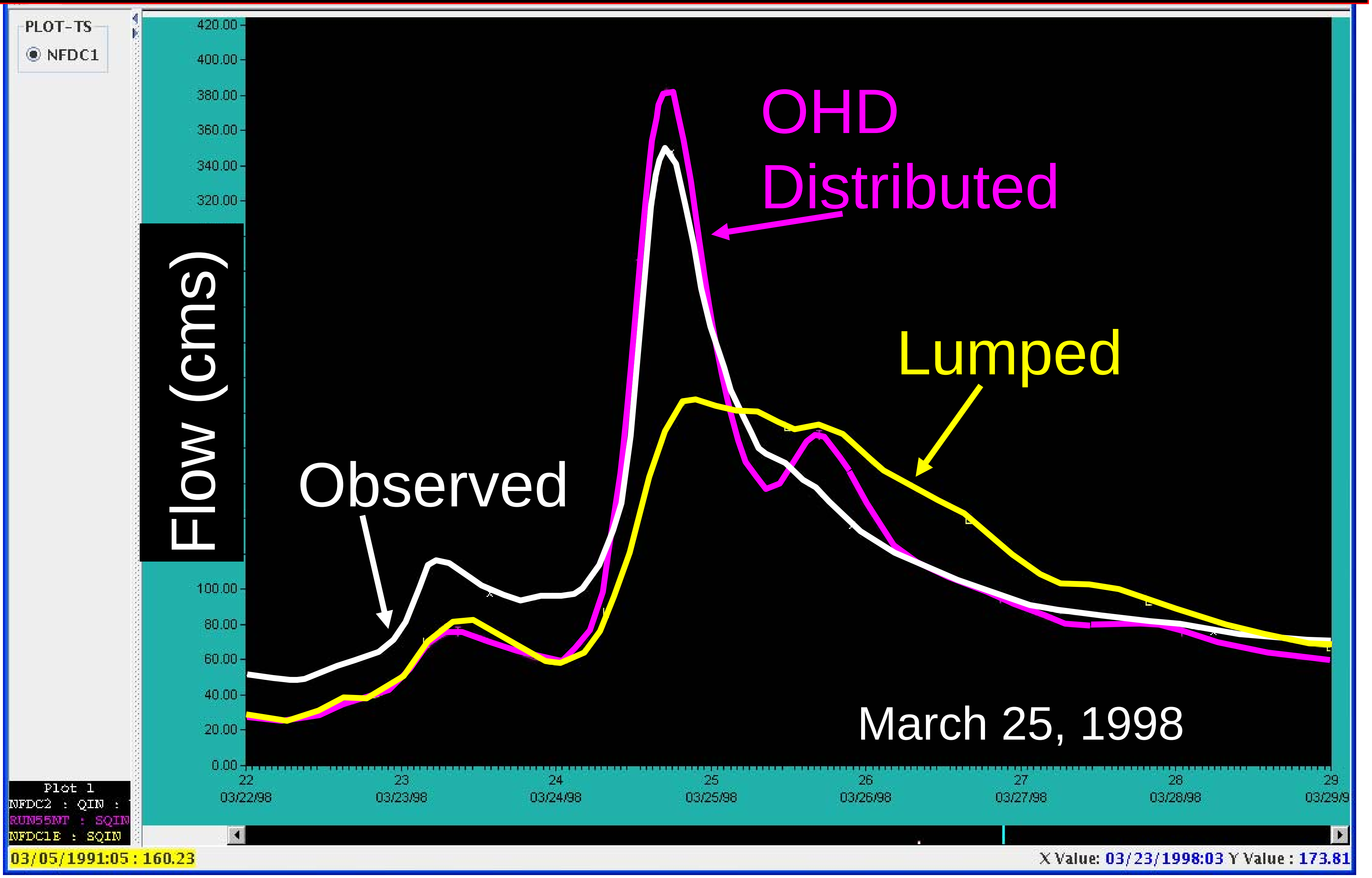
DMIP 2: North Fork American River
OHD Streamflow Simulations with 'Basic Data'



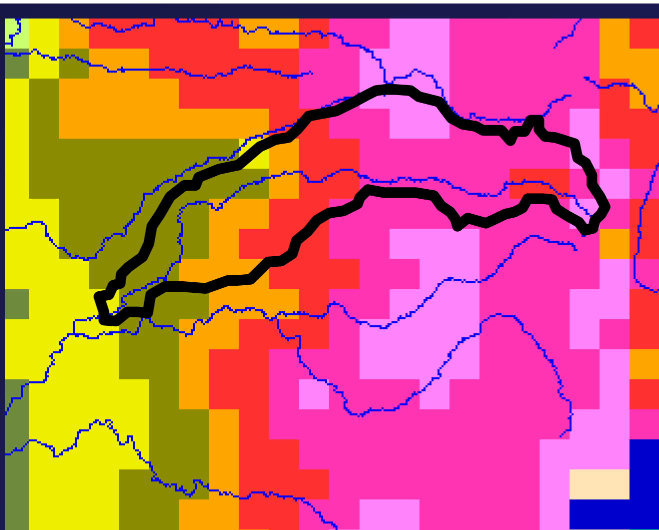
DMIP 2: North Fork American River
OHD Streamflow Simulations with 'Basic Data'



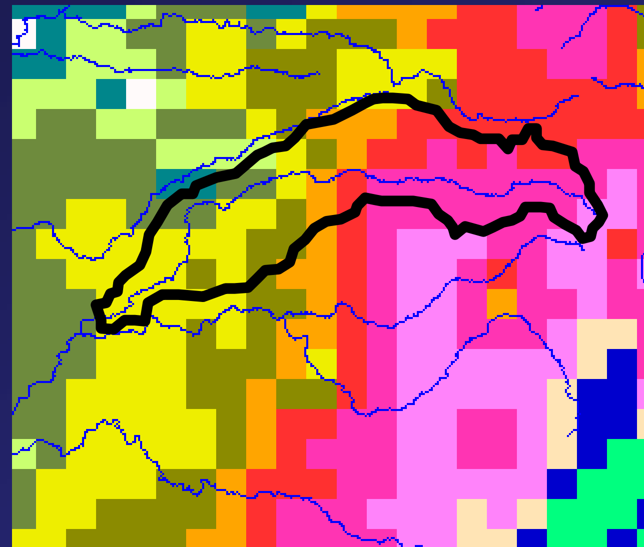
DMIP 2: North Fork American River
OHD Streamflow Simulations with 'Basic Data'



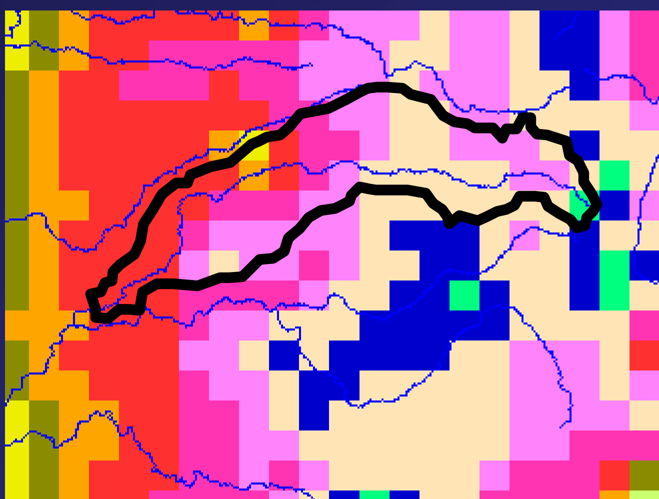
Mar. 23-25, 1998 6hr. precipitation accumulations



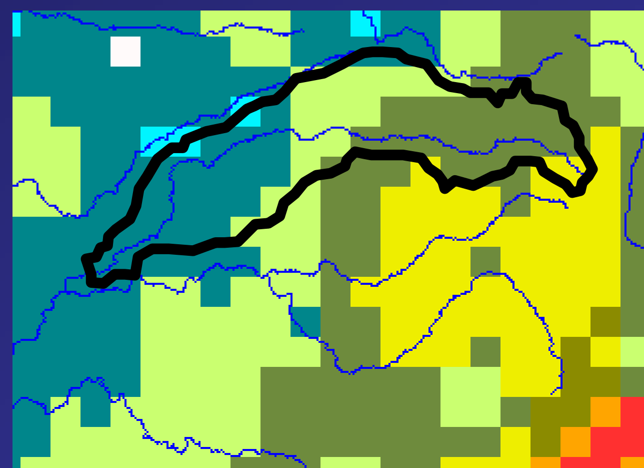
6hr accum. ending Mar. 24, 1998 4Z



6hr accum. ending Mar. 24, 1998 16Z



6hr accum. ending Mar. 24, 1998 10Z

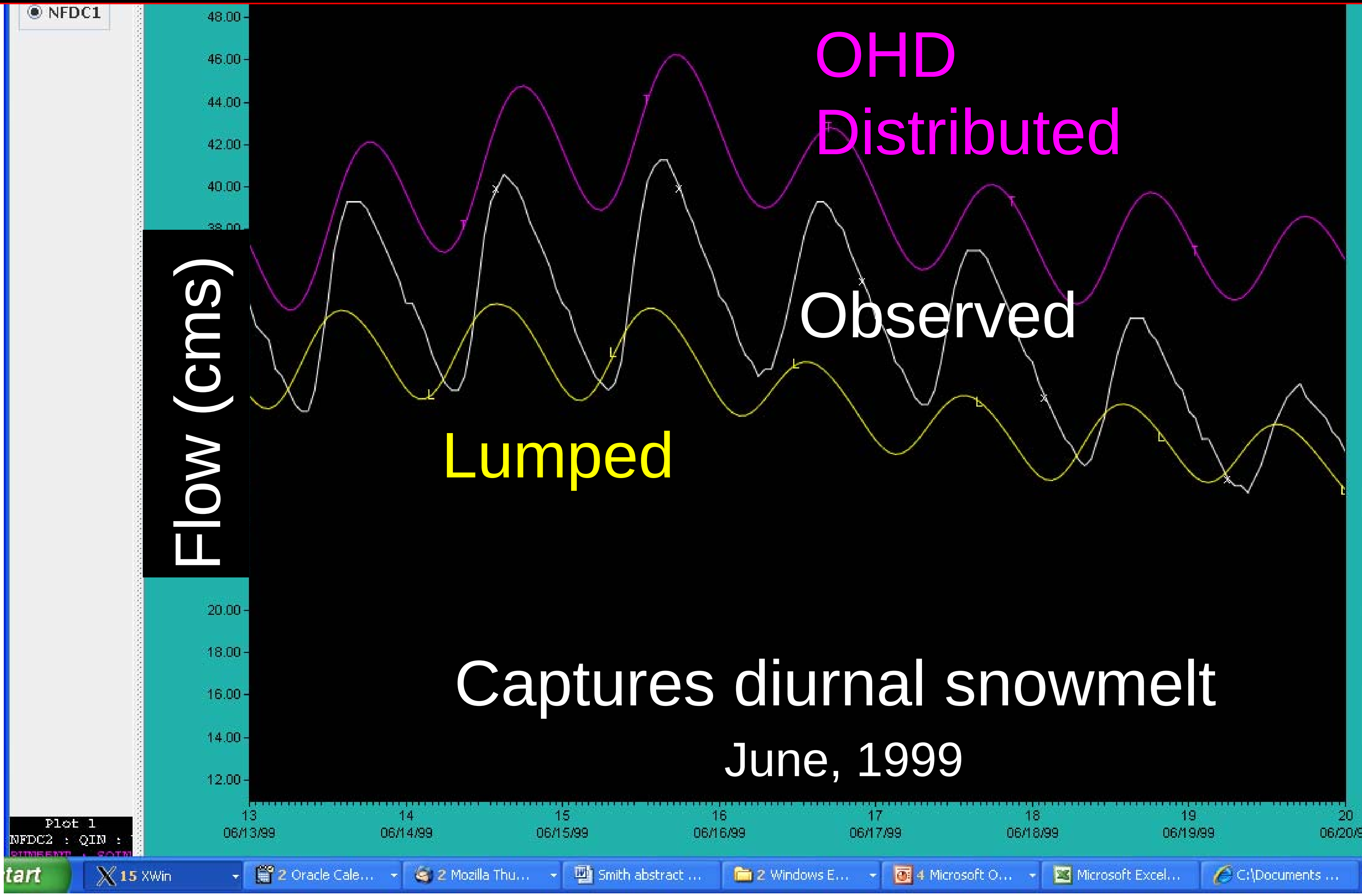


6hr accum. ending Mar. 24, 1998 22Z

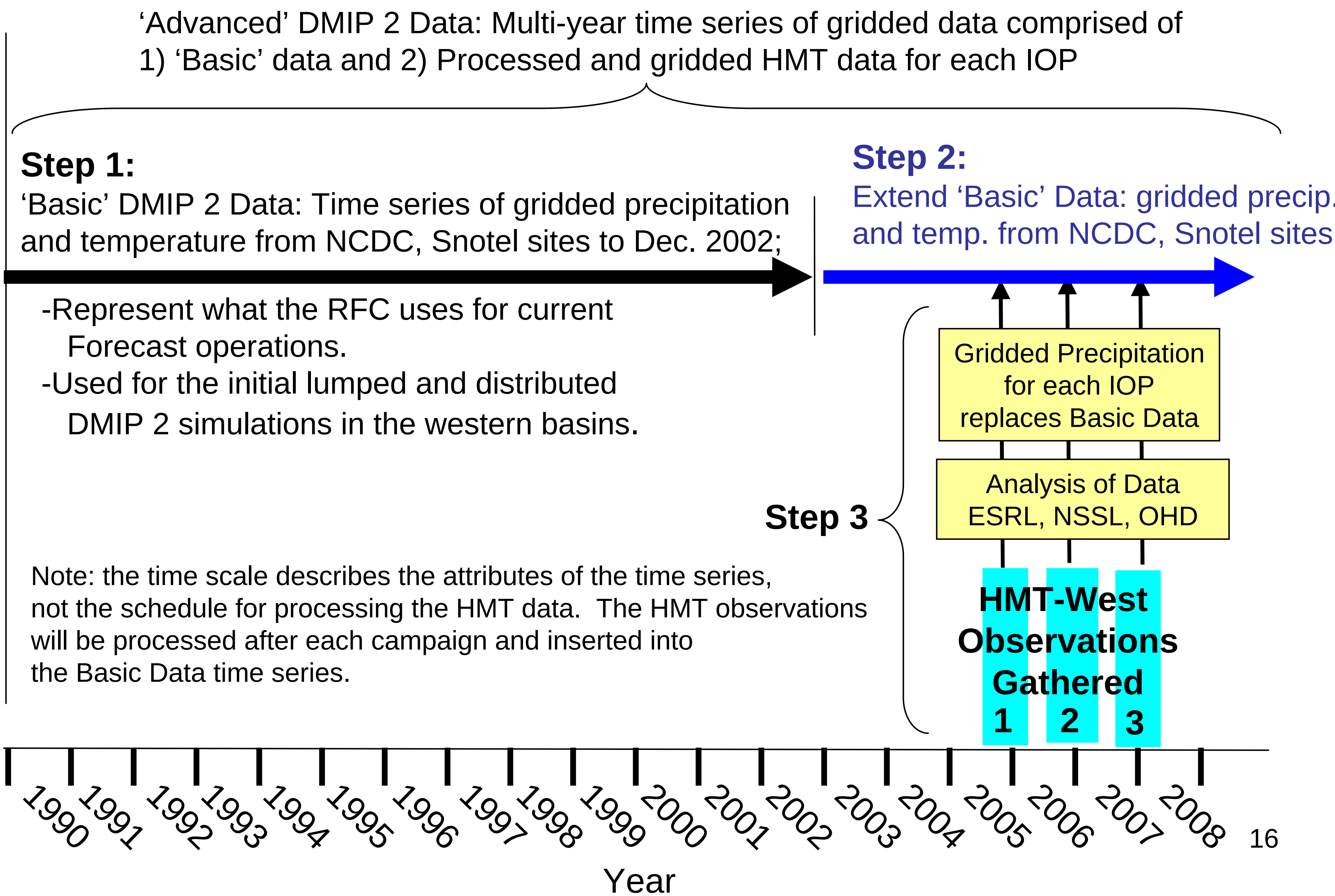
(XDMS Images)

6 hour accumulation in mm

DMIP 2: North Fork American River
OHD Streamflow Simulations with ‘Basic Data’



QPE Data Processing for Use in DMIP 2



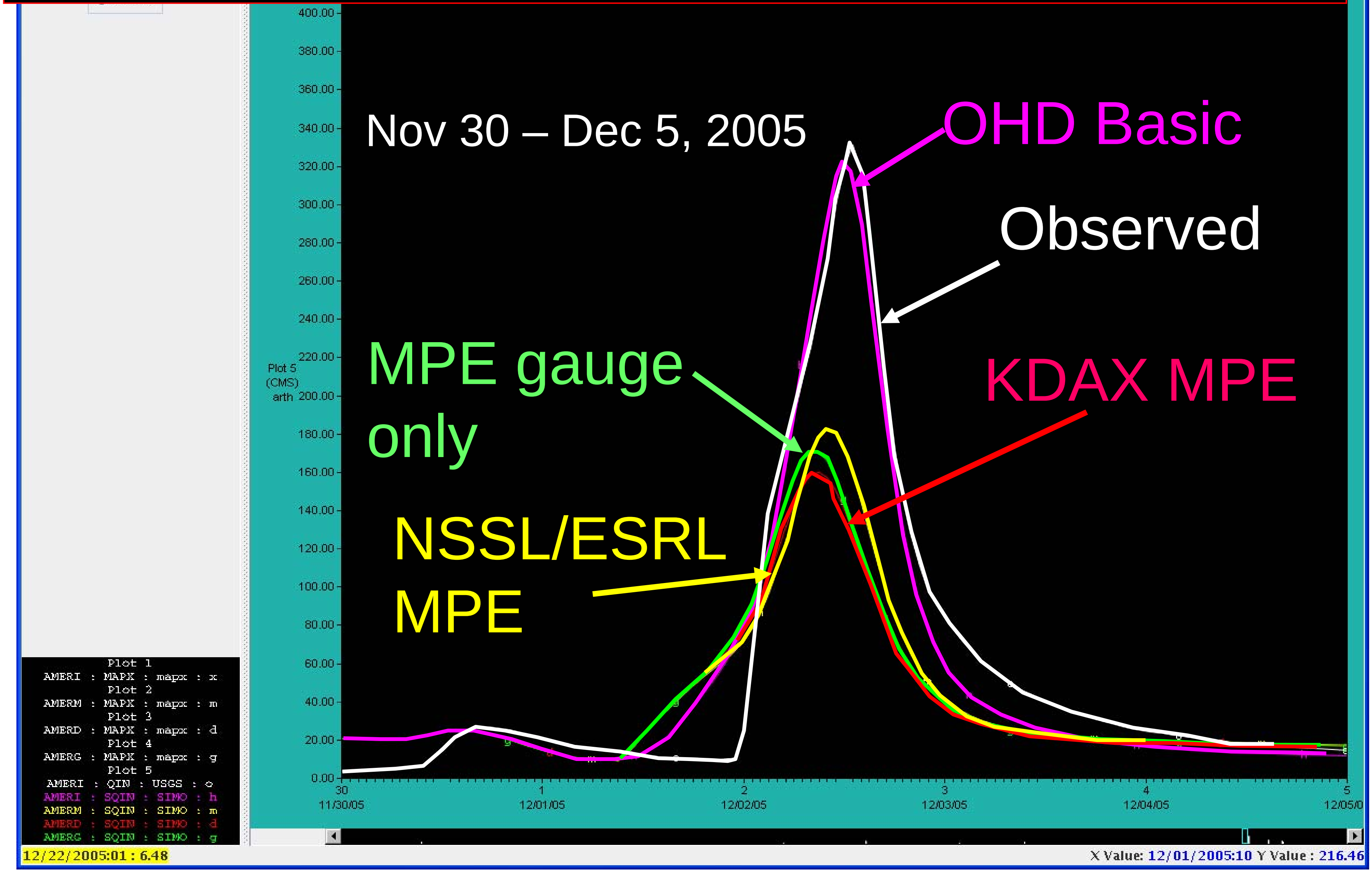
Initial Distributed Model Analysis of Gridded Precipitation Data: 4 QPE Cases for HMT

- OHD gauge only
  - NCDC hourly/daily and SNOTEL
  - PRISM, $1/d^{1/2}$
- MPE gauge only
  - 12 Hourly NCDC gauges
  - No PRISM, $1/d^2$
- KDAX/gauge (MPE)
  - 12 Hourly NCDC gauges
- NSSL/ESRL/gauge (MPE)
  - 12 NCDC hourly gauges
  - Uses KDAX/MPE as ‘fill’ between IOPs

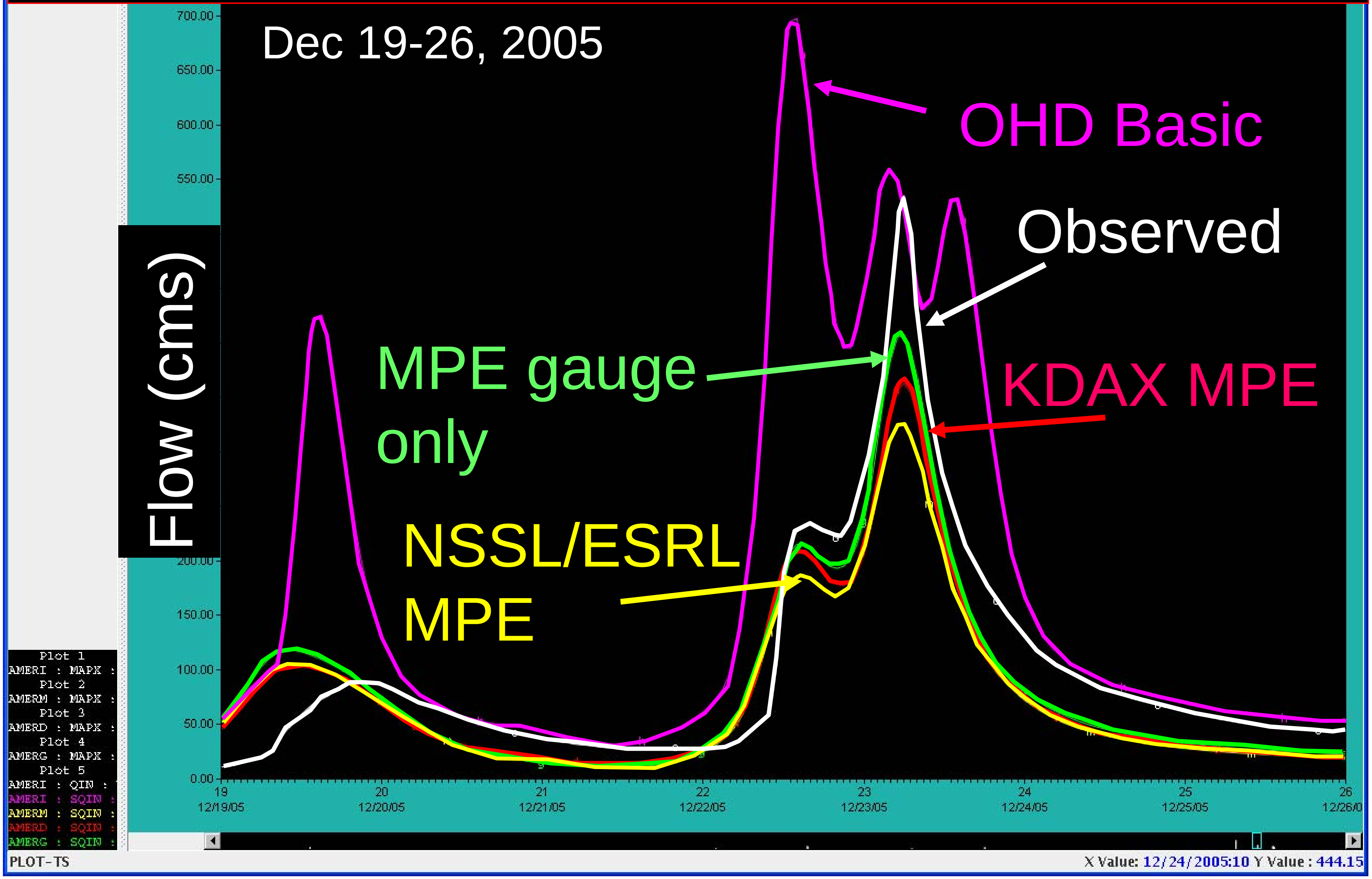
Initial Distributed Model Analysis of Gridded Precipitation Data: 4 QPE Cases for HMT

- Run distributed model to Dec 1, 2005 using OHD Basic data
- Save internal states.
- Use saved states as initial conditions for 4 distributed model simulations

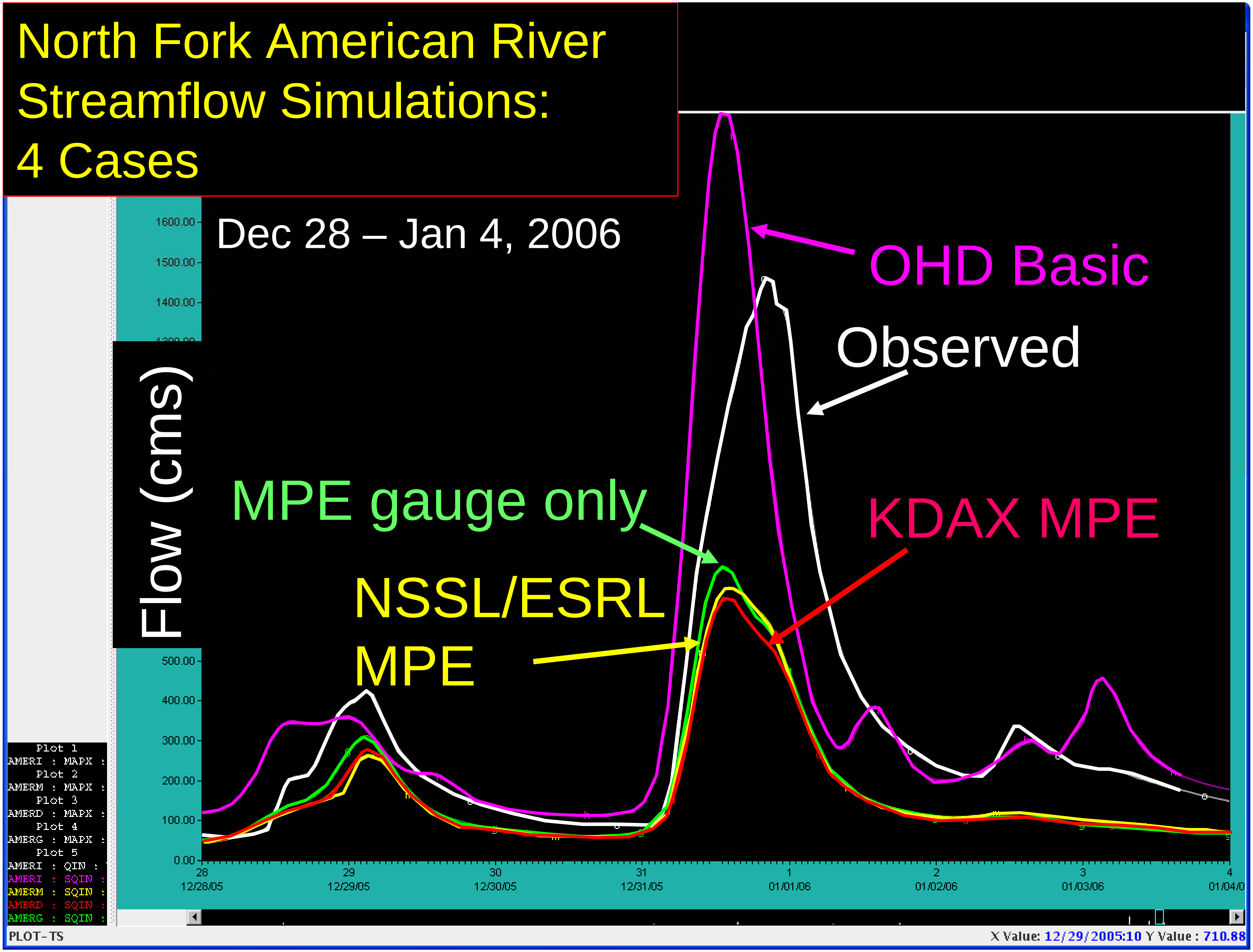
North Fork American River
Streamflow Simulations: 4 Cases



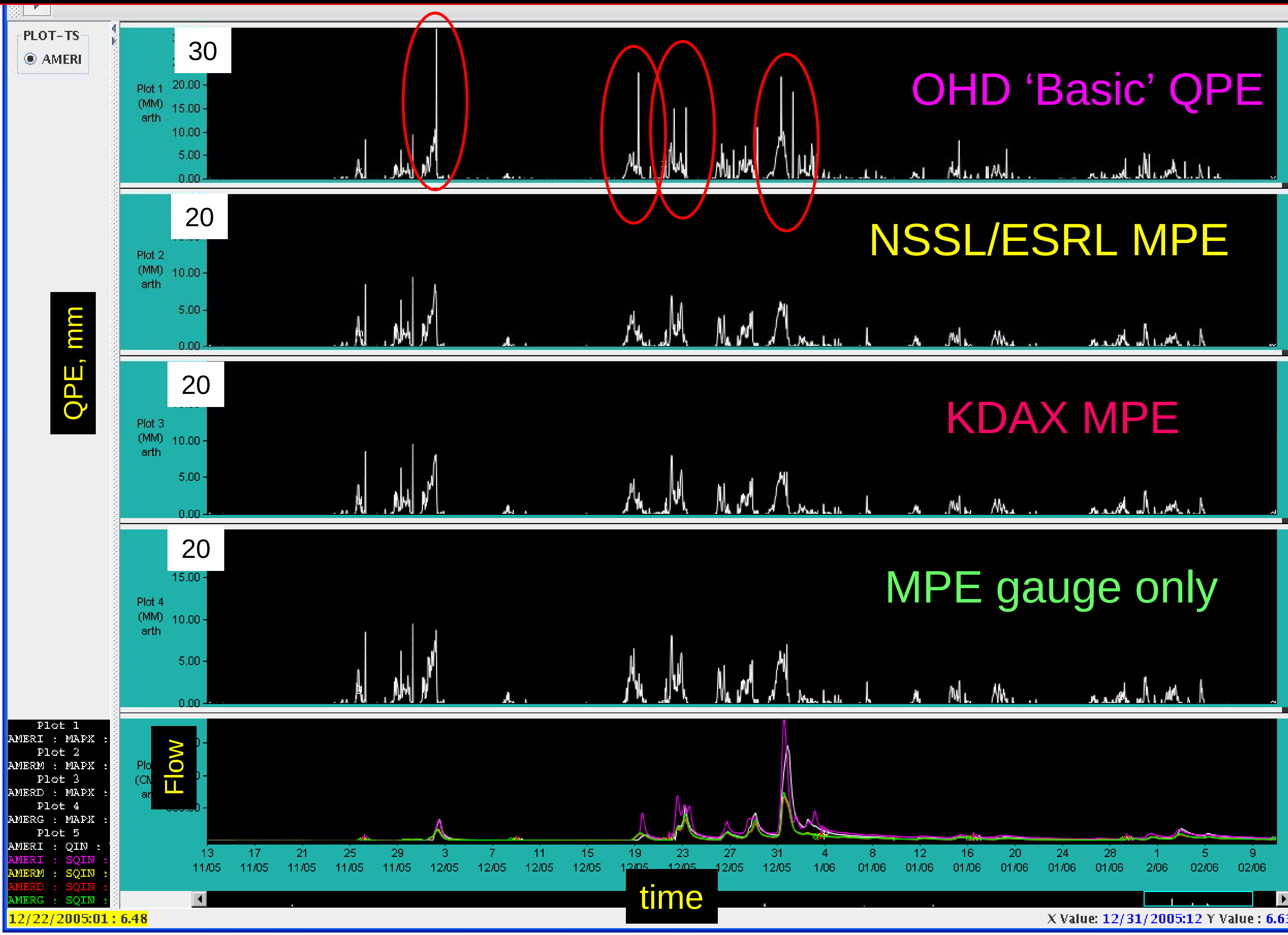
North Fork American River Streamflow Simulations: 4 Cases



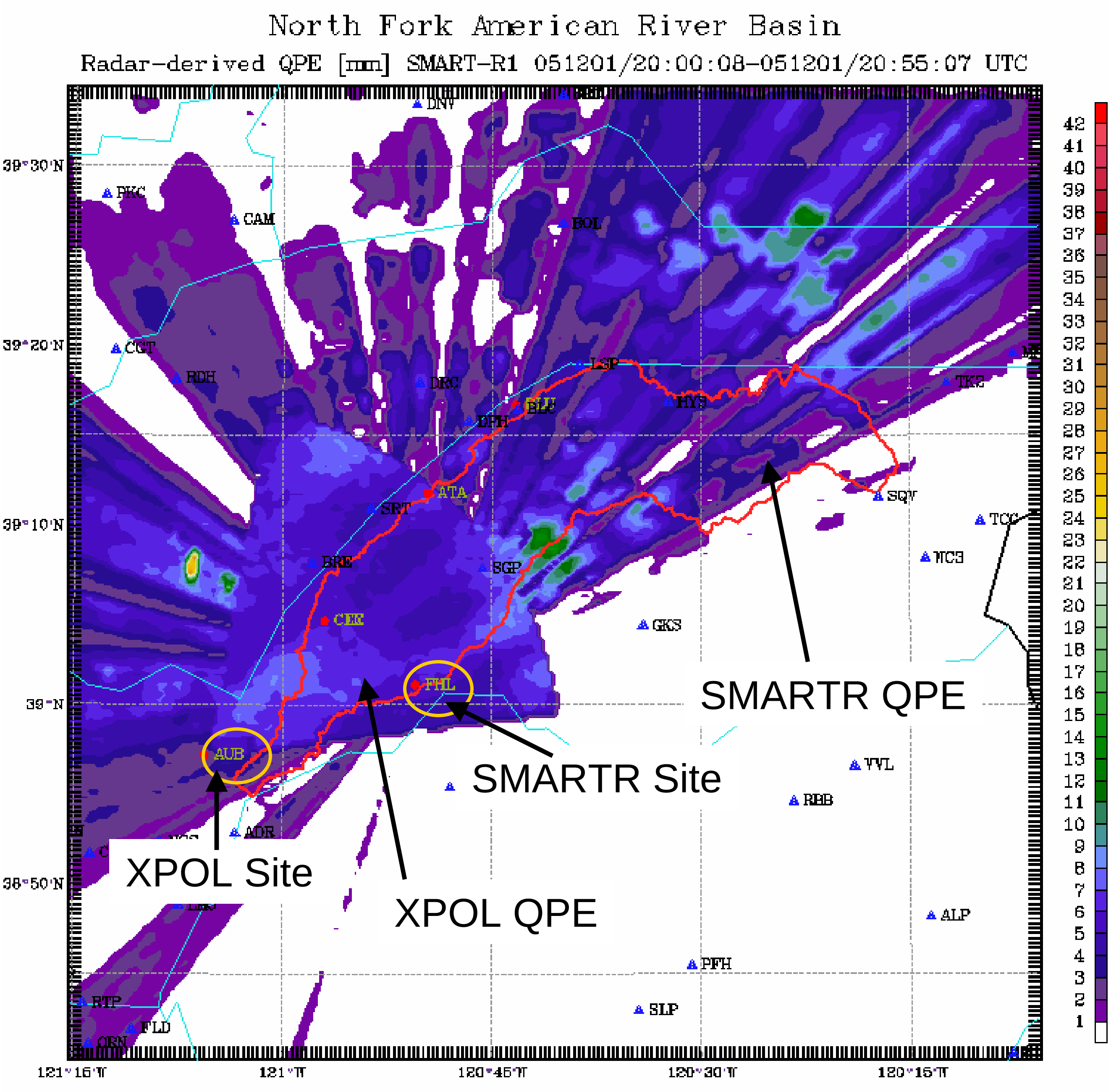
North Fork American River Streamflow Simulations: 4 Cases



North Fork American River Streamflow Simulations: 4 Cases



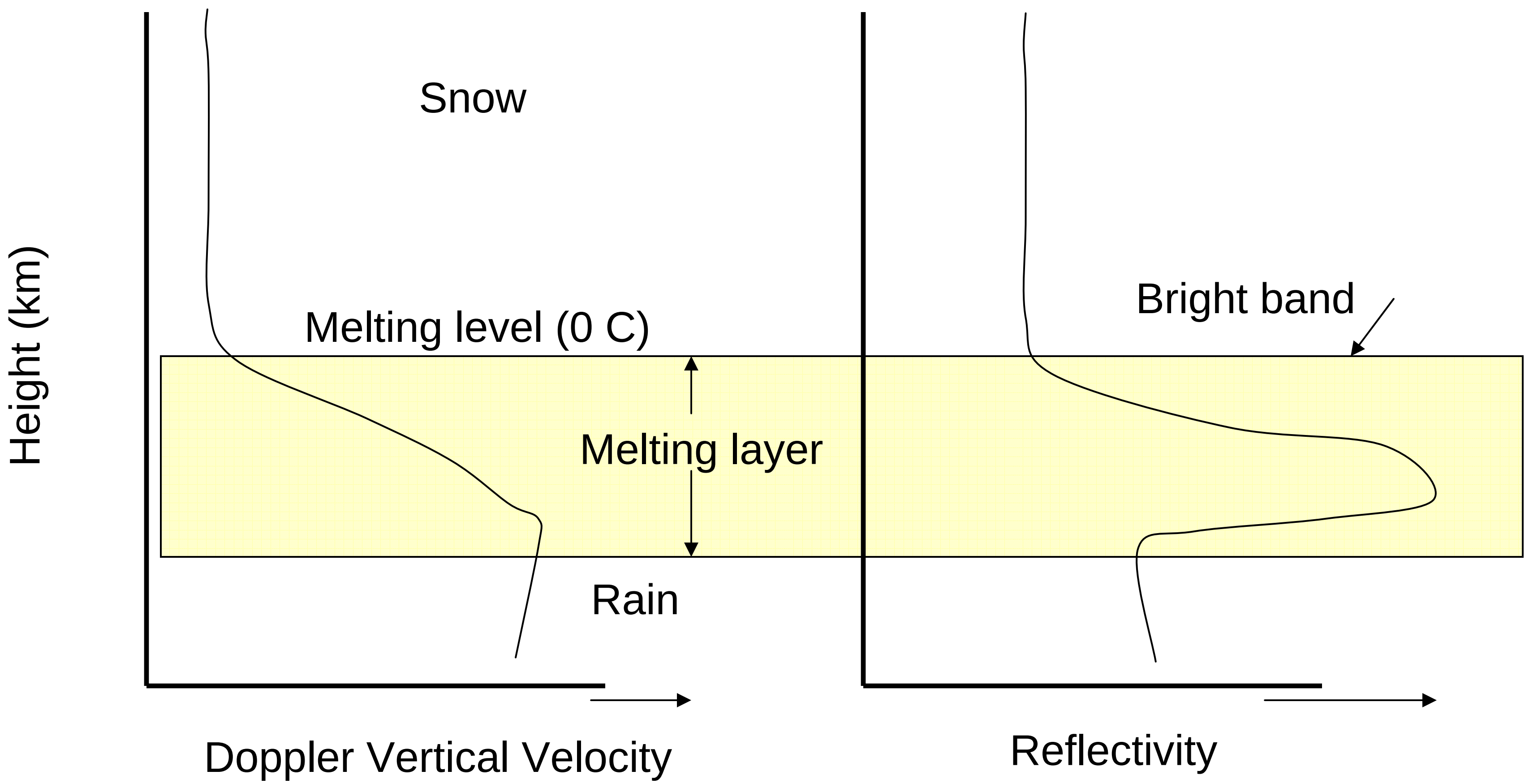
An example of azimuthal artifacts in SMARTR data



Merged QPE for
1 Dec 2005 20-21 UTC

-Note the pattern of QPE that emanates radially from the SMARTR radar site.
-ESRL had artifacts in data too.

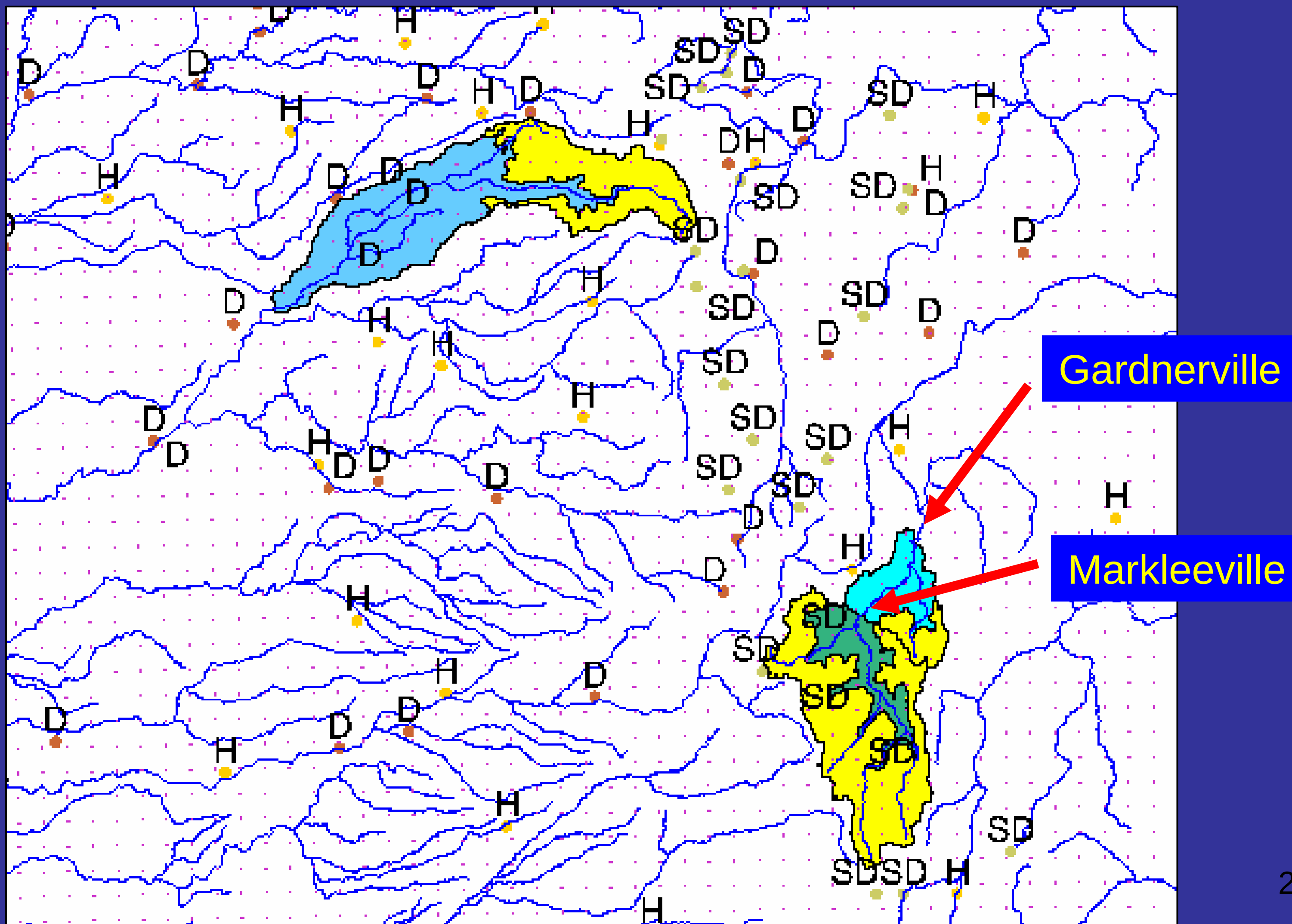
Detection of Rain/Snow Elevation Using Radar Data



Proposed Method for Using HMT Freezing Level Data

- Rain versus Snow in the Sierra Nevada, California: Comparing Doppler Profiling Radar and Surface Observations of Melting Level, Lundquist et al., 2008, Journal of Hydrometeorology
- Using Radar Data to Partition Precipitation into Rain and Snow in a Hydrologic Model, Maurer and Mass, 2006, J. Hydrologic Engineering

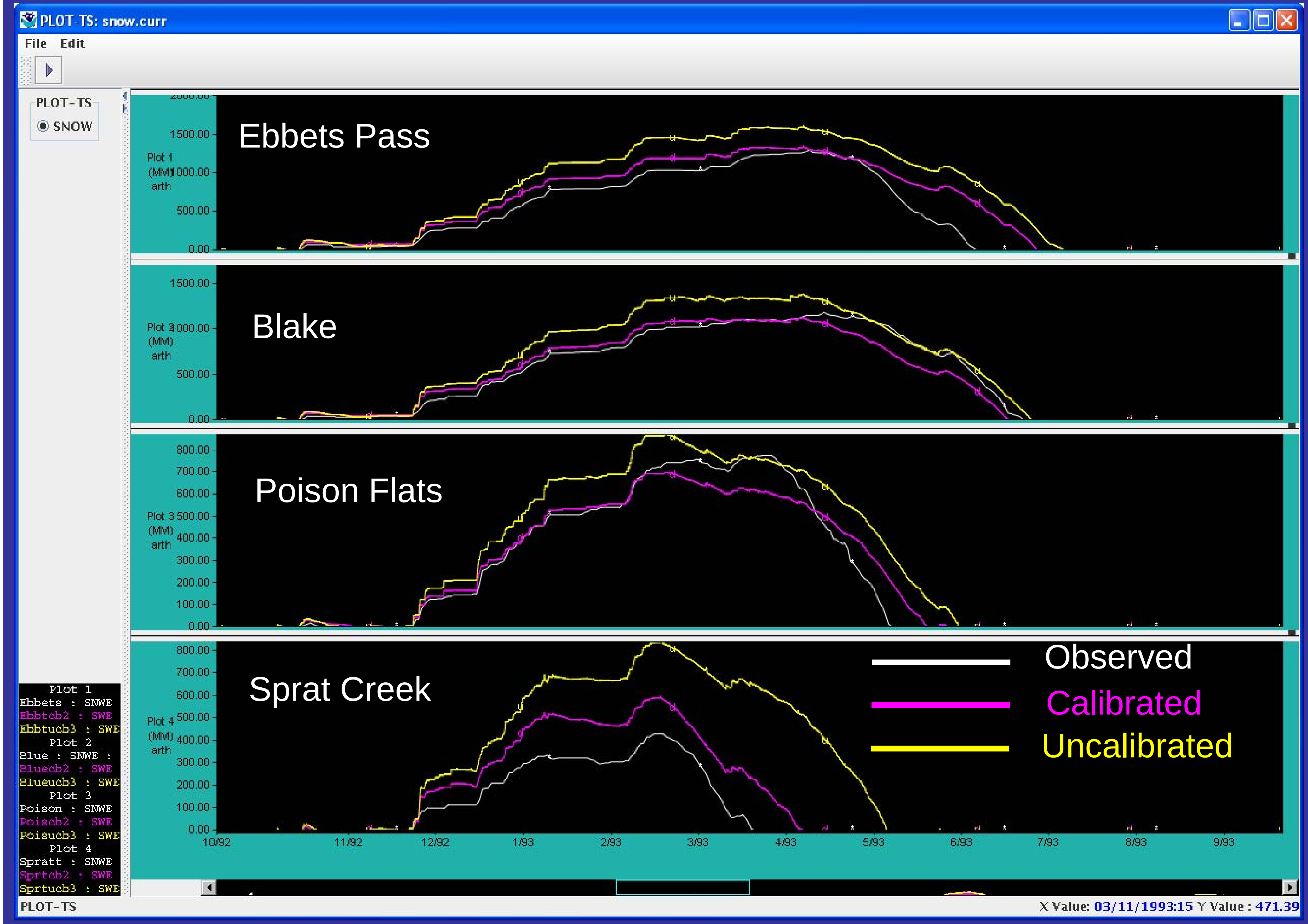
OHD DMIP 2 Results for the East Fork Carson Basin



Outlet Hydrograph Statistics from Lumped and Distributed Simulations: Carson Basin

Statistics	GRDN2 outlet calibration						CEMC1 outlet calibrated	
	GRDN2 outlet			CEMC1 outlet			CEMC1 outlet	
	LMP	OHD	A Priori	LMP	OHD	A Priori	LMP	OHD
Overall statistics								
Bias%	-3.00	-2.40	46.50	-13.40	-13.70	29.60	-3.90	4.50
RMSE%	51.20	47.60	136.00	52.70	57.50	111.00	46.90	46.80
R	0.94	0.94	0.92	0.95	0.95	0.93	0.96	0.96
NS	0.87	0.89	0.09	0.89	0.87	0.51	0.91	0.91
Flood event statistics								
Bias%	19.70	16.70	70.10	20.50	25.70	34.20	8.30	15.30
RMSE%	23.00	21.40	78.90	25.00	25.50	40.10	15.40	17.50
R	0.82	0.83	0.80	0.79	0.88	0.84	0.85	0.87
Rm	0.41	0.54	0.50	0.32	0.44	0.49	0.62	0.57
Peak Error%	22.90	19.30	75.10	25.60	28.90	35.60	12.30	16.00
Peak Time Error, hr	3.32	3.29	3.84	4.58	3.63	3.87	3.63	3.63

Calibrated and Uncalibrated Dist. Model Simulations of SWE



Overall Results for the Carson Basin

- Distributed model calibration at GRDN2 outlet provides slightly better statistics compared to lumped. However, results for nested outlet CEMC1 lead to considerable runoff bias from both models

- Calibration of both models at CEMC1 outlet improves simulations significantly.

- Combination of calibrated distributed CEMC1 and GRDN2 local area parameters leads to slightly better results compared to just GRDN2 based calibrated distributed parameters.

Conclusions

- Density of hourly rain gauges near North Fork basin appears sufficient to support distributed modeling
- Gridded Snow-17 needs areal depletion curve at 4km scale; may need finer scales
- Calibration starting from lumped parameters seems reasonable
- HMT radar QPE data needs to be reprocessed
- Uncertain quality of OHD 'Basic' gridded QPE data after 2003
- In general, may be difficult to identify QPE data impacts given short 3 mo. period

Recommendations

- Re-process radar QPE in HMT
- Develop correction for gridded hourly gauge-only QPE
- Perform data denial experiments:
  - Remove hourly NCDC gauges from MPE analysis to see where radar QPE begins to add value
- Examine events for rain/snow

Discussion?

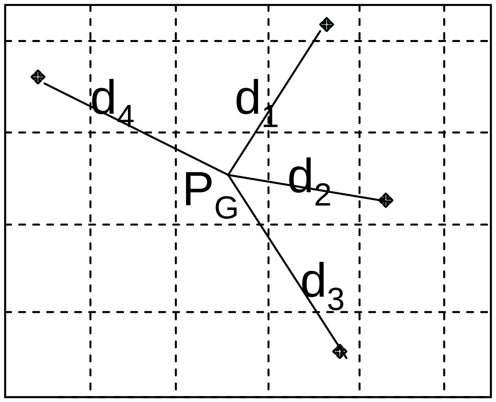
Background Slides:
Analysis of QPE for
North Fork Basin for DMIP 2

Initial DMIP 2 period:	1987 – 2002
Extended DMIP 2 period:	1987 – 2006 (to include HMT QPE)

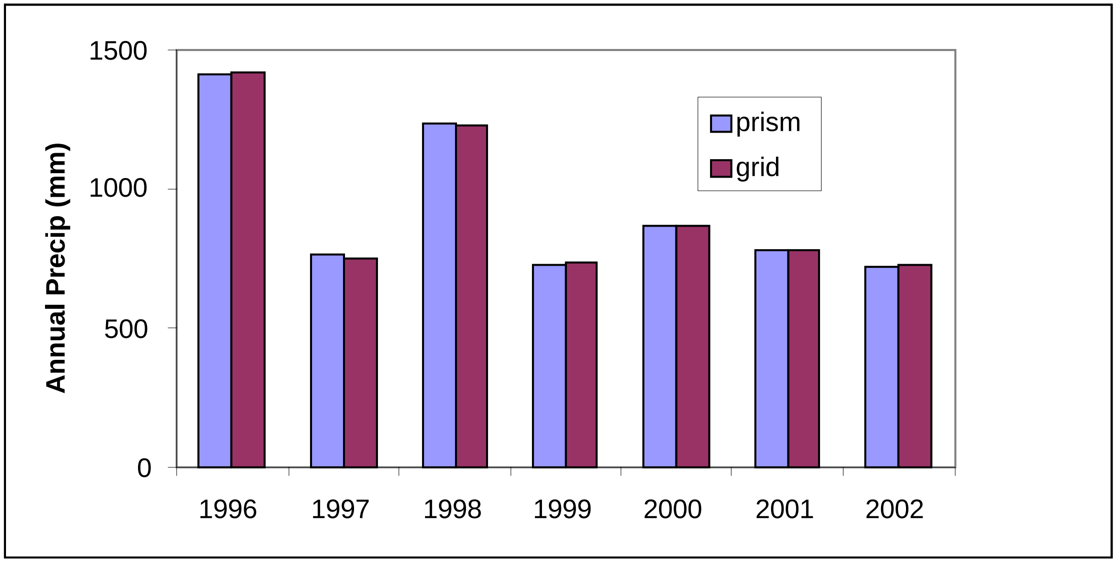
Deriving Hourly Gridded Basic QPE
For Initial DMIP 2 Experiments: 1987-2002

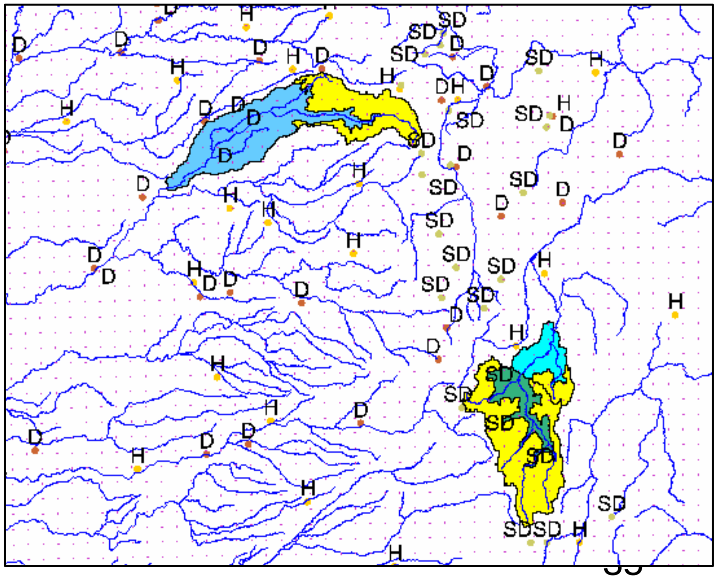
Derive precipitation estimates using three data sources for the period of 1987-2002: 1) NCDC hourly cooperative observer (coop) gauges, 2) NCDC daily total coop gauges, and 3) SNOw pack TELemetry (SNOTEL) daily precipitation gauges. The daily values are disaggregated to hourly using the nearest hourly gauge values. The hourly values, expressed as fraction of normal, are then interpolated to approximately 4km Hydrologic Rainfall Analysis Project (HRAP) (Greene and Hudlow, 1982) grids using an inverse-distance ($1/d^{1/2}$) method. Parameter- elevation Regressions on Independent Slopes Model (PRISM) (http://www.ocs.orst.edu/prism/products/) monthly precipitation climatology grids are used to compute fractions of normal at gage locations prior to the inverse distance interpolation and to convert interpolated fractions of normal to precipitation amounts at each grid point.

Source: Moreda et al., 2006. Gridded Rainfall Estimation for Distributed Modeling in Western Mountainous Areas, Session H23A, AGU 2006 Spring Meeting, May 23 - 27, Baltimore, MD



Checking 1987-2002 OHD Basic QPE



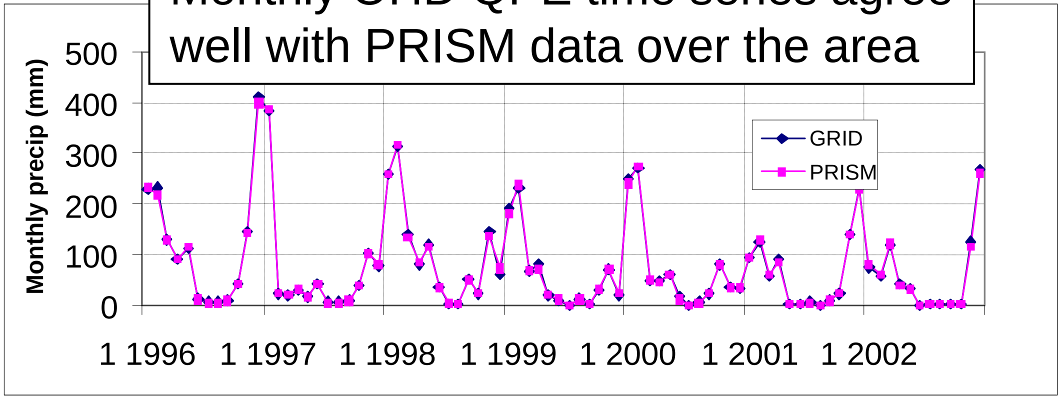


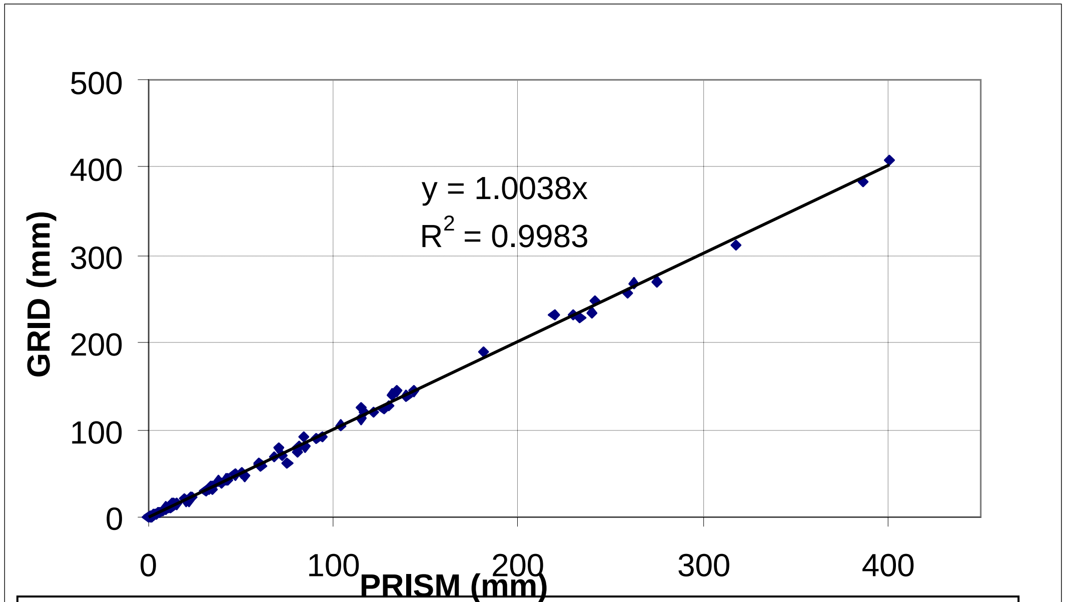
Annual precipitation derived from grids matches annual PRISM for the entire rectangular box

Source: Moreda et al., 2006. Gridded Rainfall Estimation for Distributed Modeling in Western Mountainous Areas, Session H23A, AGU 2006 Spring Meeting, May 23 - 27, Baltimore, MD

Checking 1987-2002 OHD Basic QPE for DMIP 2

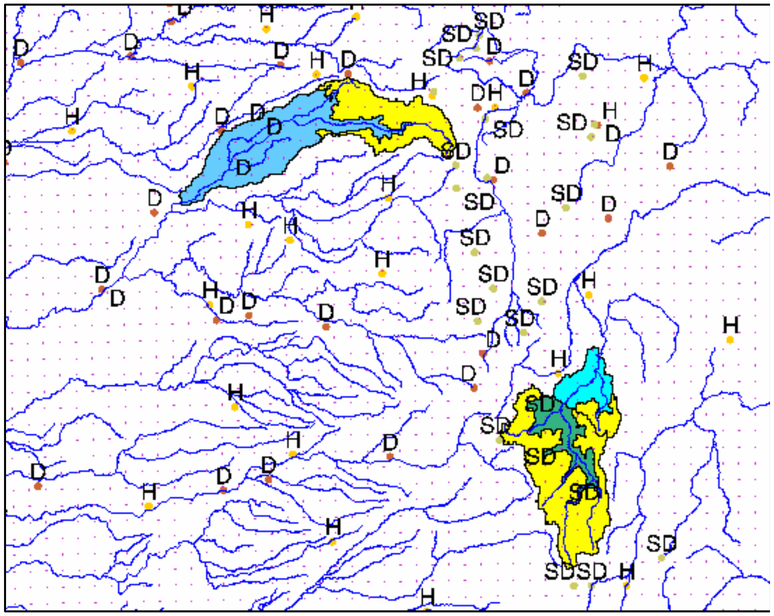
Monthly OHD QPE time series agree well with PRISM data over the area





High correlation between Monthly OHD QPE and PRISM monthly totals

Compare PRISM and OHD QPE Over Analysis Domain



Source: Moreda et al., 2006. Gridded Rainfall Estimation for Distributed Modeling in Western Mountainous Areas, Session H23A, AGU 2006 Spring Meeting, May 23 - 27, Baltimore, MD

Checking 1987-2002 OHD Basic QPE for DMIP 2

Deriving Six-hourly Mean Areal Precipitation

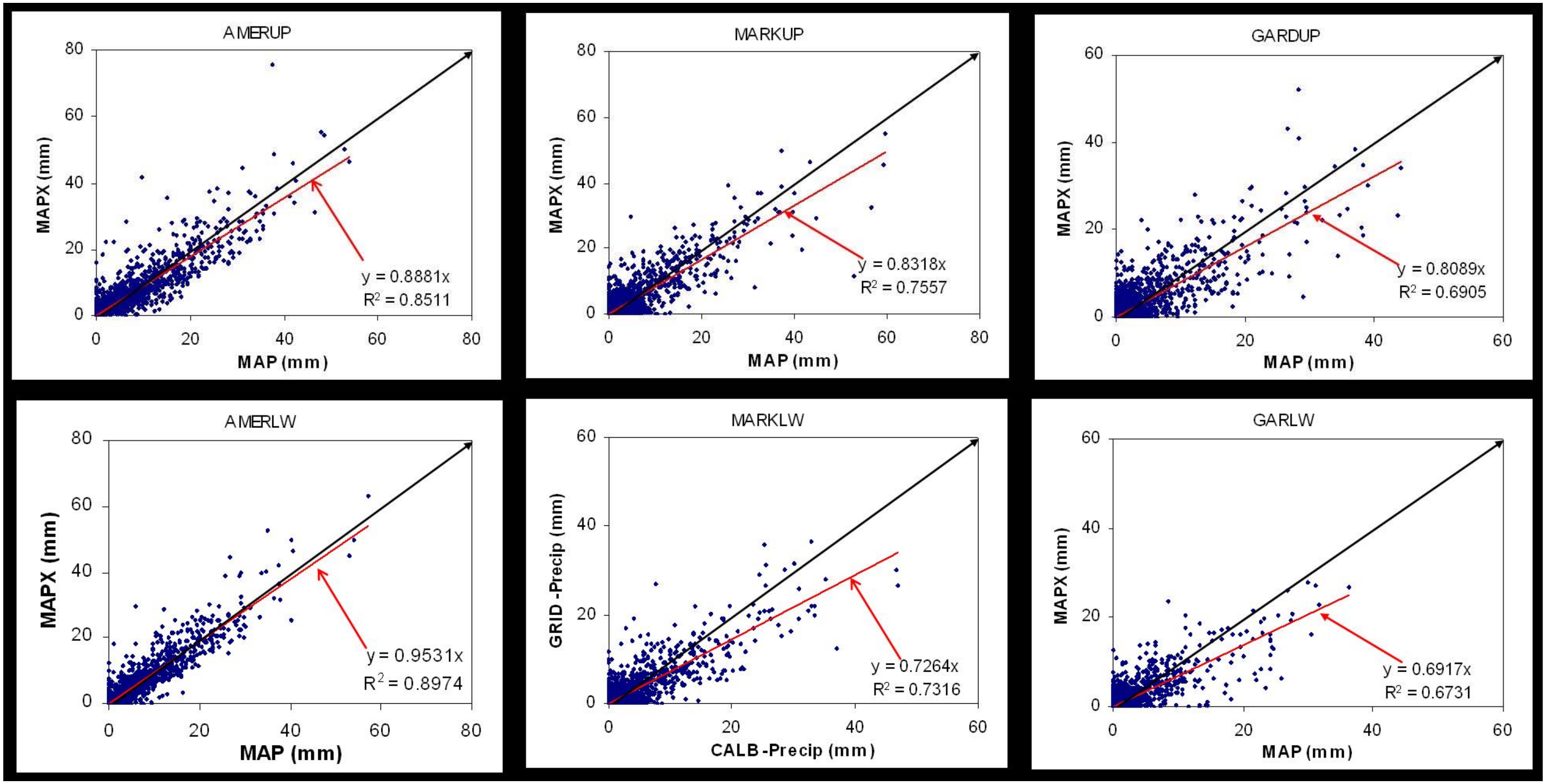
(1) From the CNRFC, we obtained six-hourly MAP time series for each basin. The two basins are decomposed into subbasins based on elevation differences (Table 1). The CNRFC MAP time series were derived using procedures developed by Anderson (2002) employing pre-determined weights.

(2) To derive an MAPX time series based on the gridded precipitation:

- **Clip the subbasin shapefiles of the elevation zones to obtain HRAP points (center) in the subbasins**
- **Create list of HRAP points within a subbasin.**
- **For each of hourly gridded field of precipitation, obtain hourly average precipitation for the subbasins by averaging the value of all pixels in the subbasin**
- **The one hourly time series is then cumulated to obtain six-hourly time series**

Source: Moreda et al., 2006. Gridded Rainfall Estimation for Distributed Modeling in Western Mountainous Areas, Session H23A, AGU 2006 Spring Meeting, May 23 - 27, Baltimore, MD

Comparison of OHD 6 hour QPE MAP values and CNRFC 6 hour values from historical MAP time series 1987 to 2002

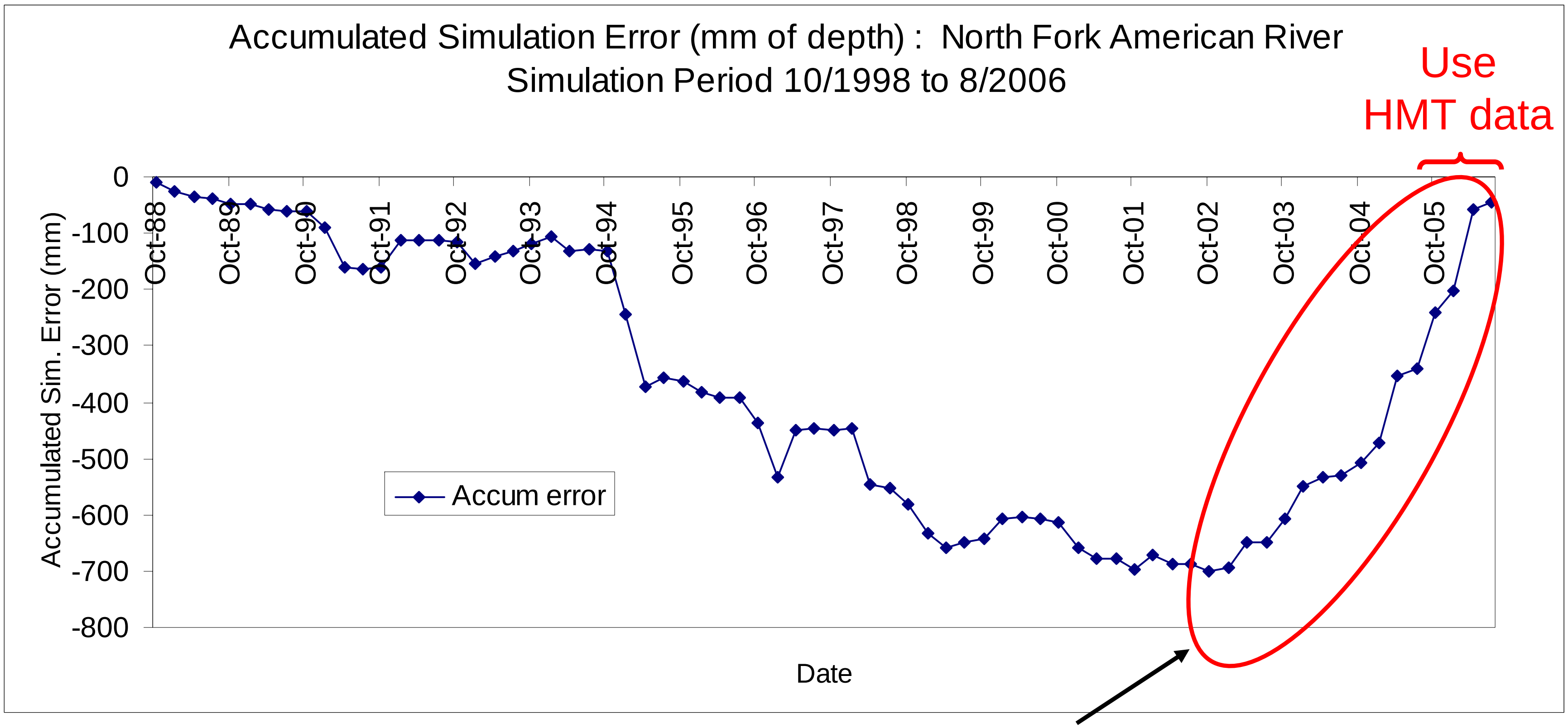


Source: Moreda et al., 2006. Gridded Rainfall Estimation for Distributed Modeling in Western Mountainous Areas, Session H23A, AGU 2006 Spring Meeting, May 23 - 27, Baltimore, MD

Conclusion

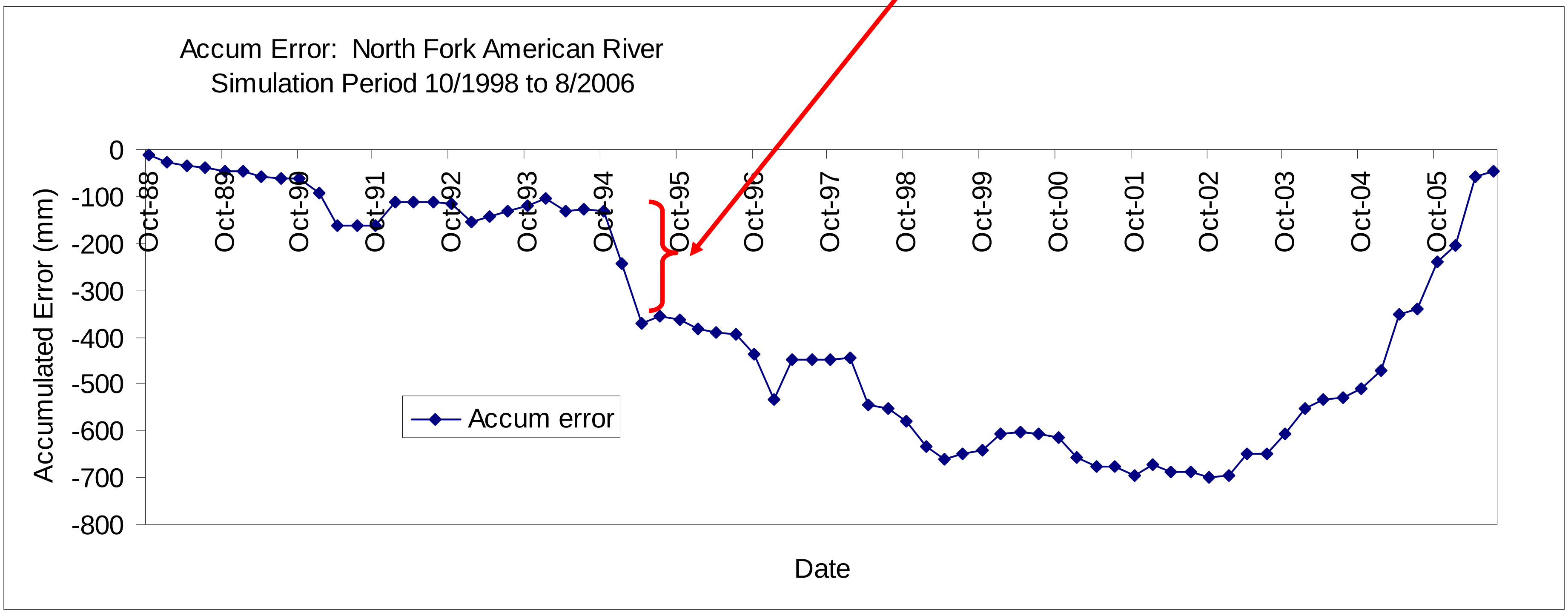
OHD 1987 – 2002 gridded QPE suitable for initial DMIP 2 experiments

Analysis of OHD Basic QPE
1987 - 2006



Inconsistent Precipitation?

Possible cause: bad data for the Blue Canyon station: “a lot of rain in Jan 95” was recorded as zeros in the NCDC data. CNRFC set these values to ‘missing’ in their calibration. See email by Pete Fickenscher April 22, 2008



Analysis of OHD Basic QPE 1987 - 2006

- Problem: time varying bias in precipitation estimates, starting after 2003
- Analyses
  1. Double mass analysis
     - Case 1: OHD QPE values to base of OHD QPE
     - Case 2: OHD QPE values to base of PRISM monthly accumulations
  2. Plot OHD QPE accumulation and PXPP accumulation
  3. Double mass analysis: OHD QPE to Observed North Fork Streamflow

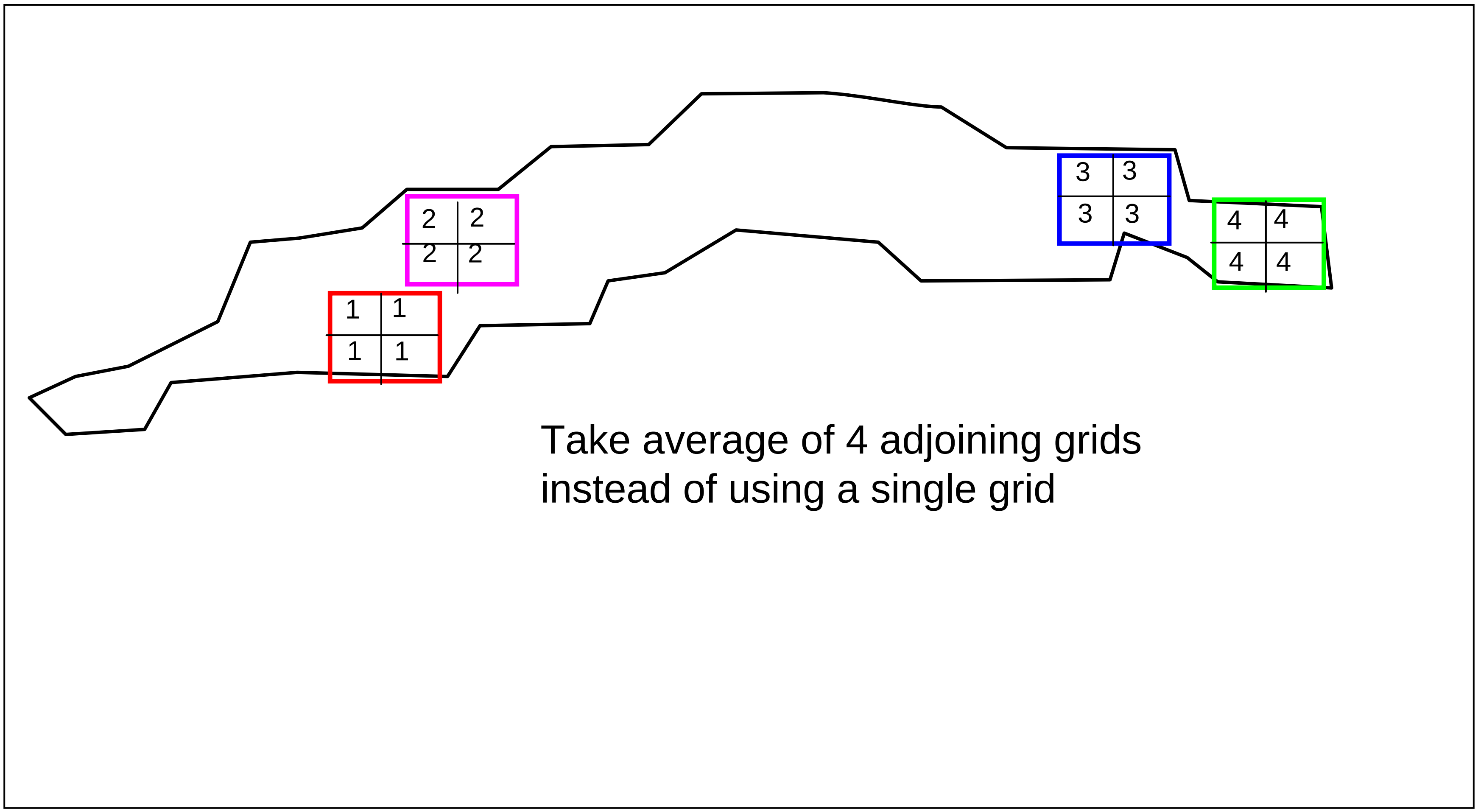
1. Double Mass Analysis of OHD Basic Data

Case 1: Group Base is OHD Basic Gridded QPE

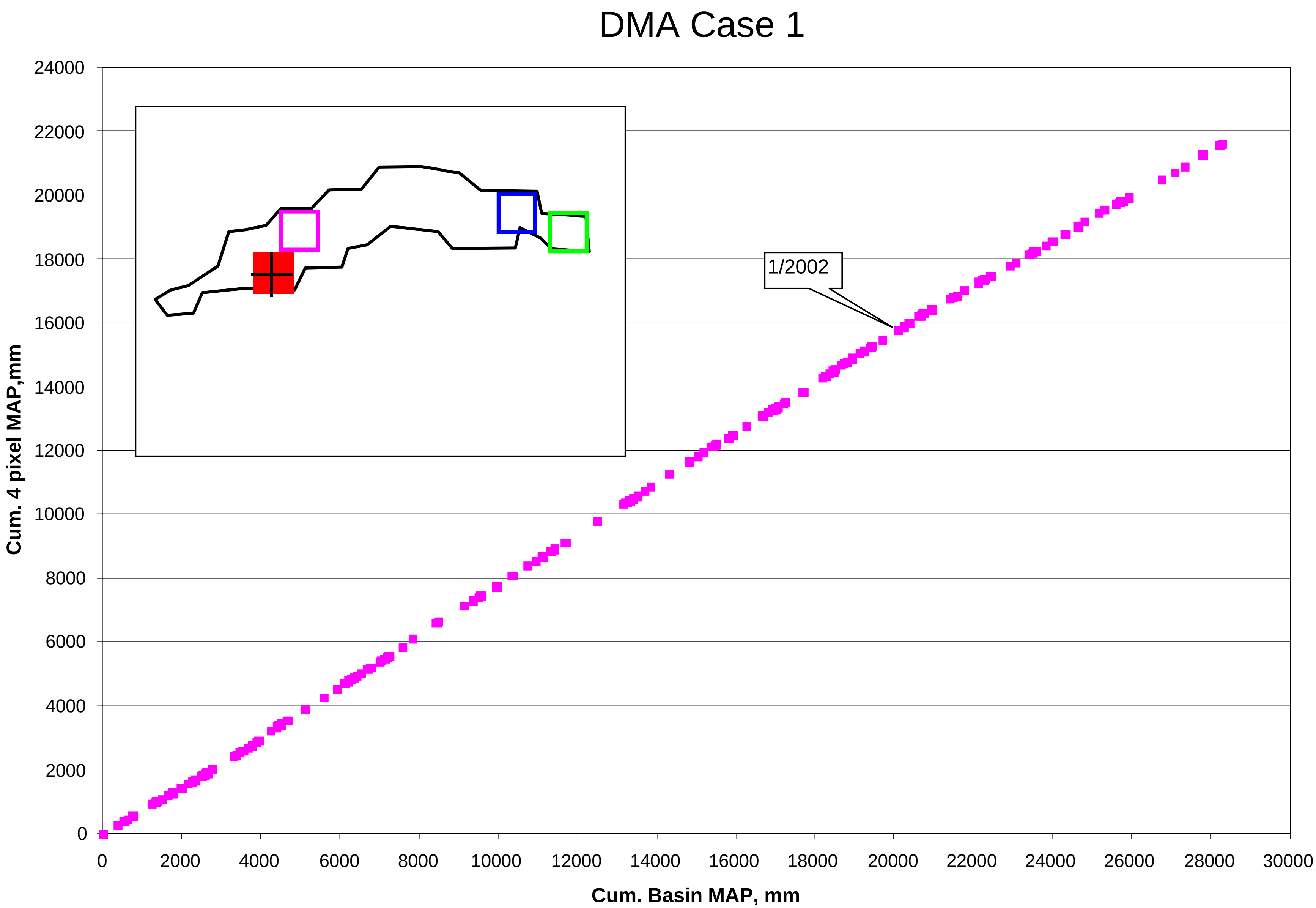
For each set of 4 grids:

- Plot accumulation of grids versus average accumulation of all other OHD grids (group base).
- Use NWS double mass analysis to highlight trends:
  - Compute deviation of grids from group base
  - Plot acc. deviation versus acc. of group base.

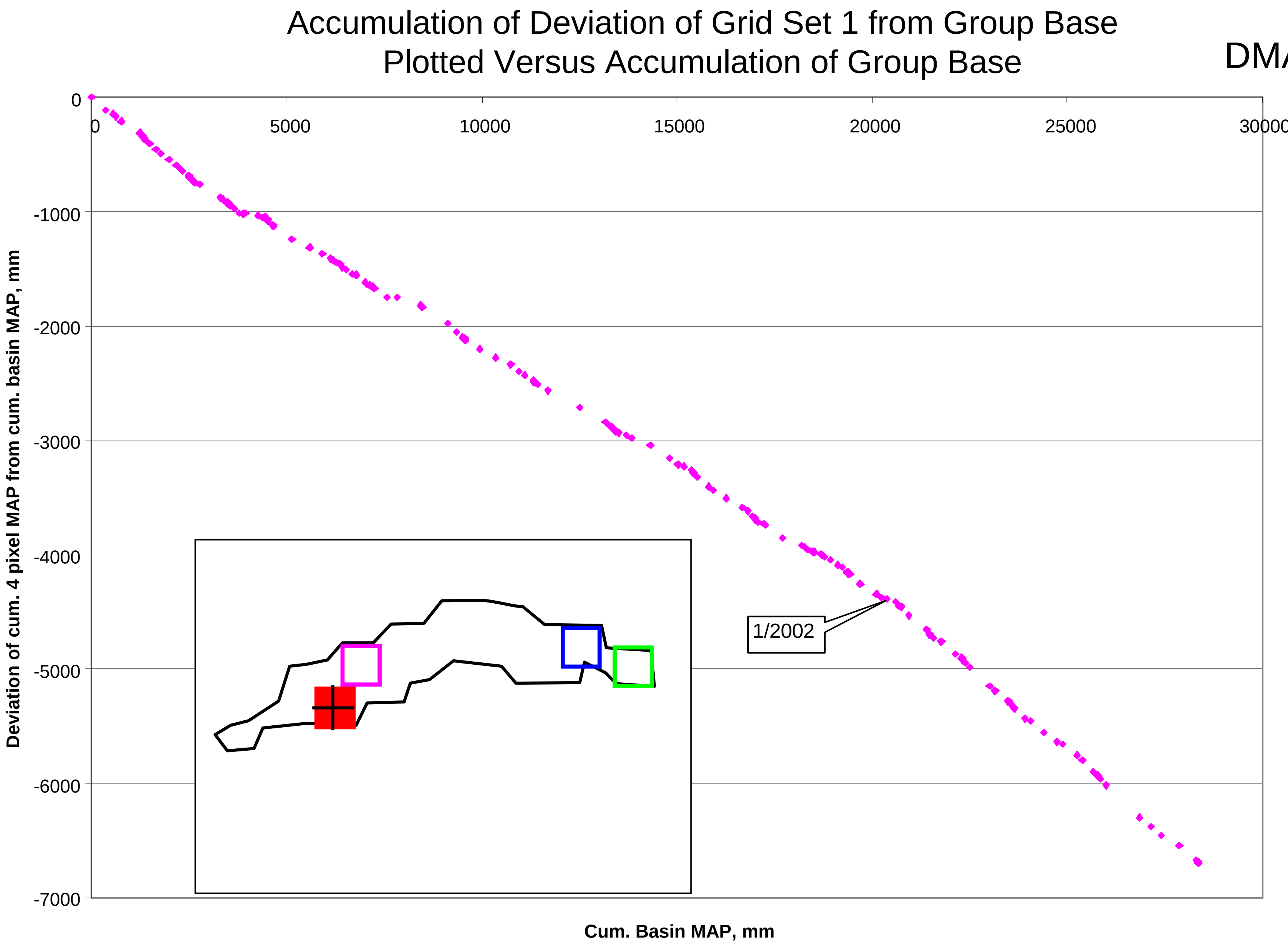
Grid Sets Used in Analysis of OHD Gridded QPE 1987 - 2006



Accumulation of Grid Set 1 versus Average Accumulation of Group Base

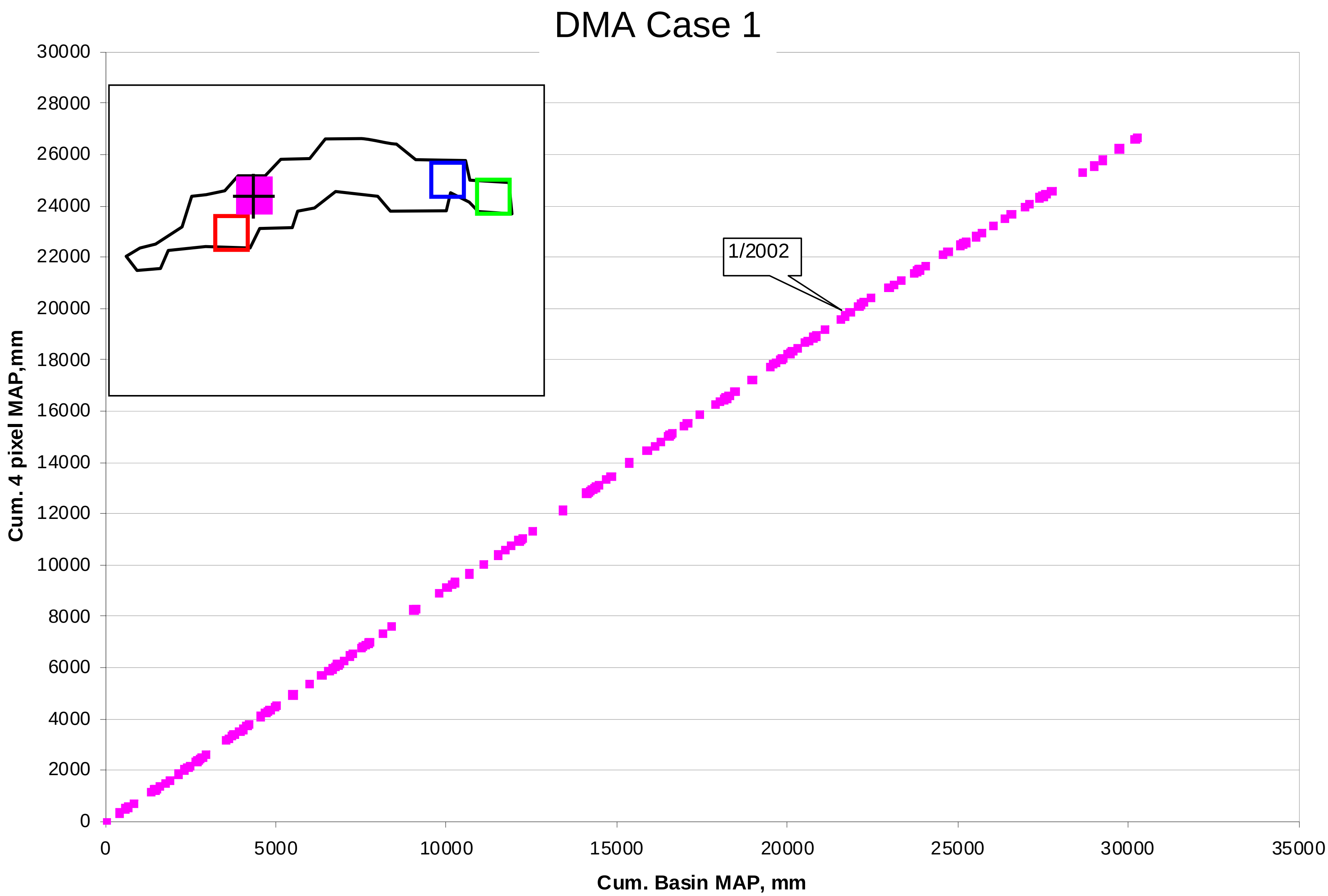


DMA Case 1



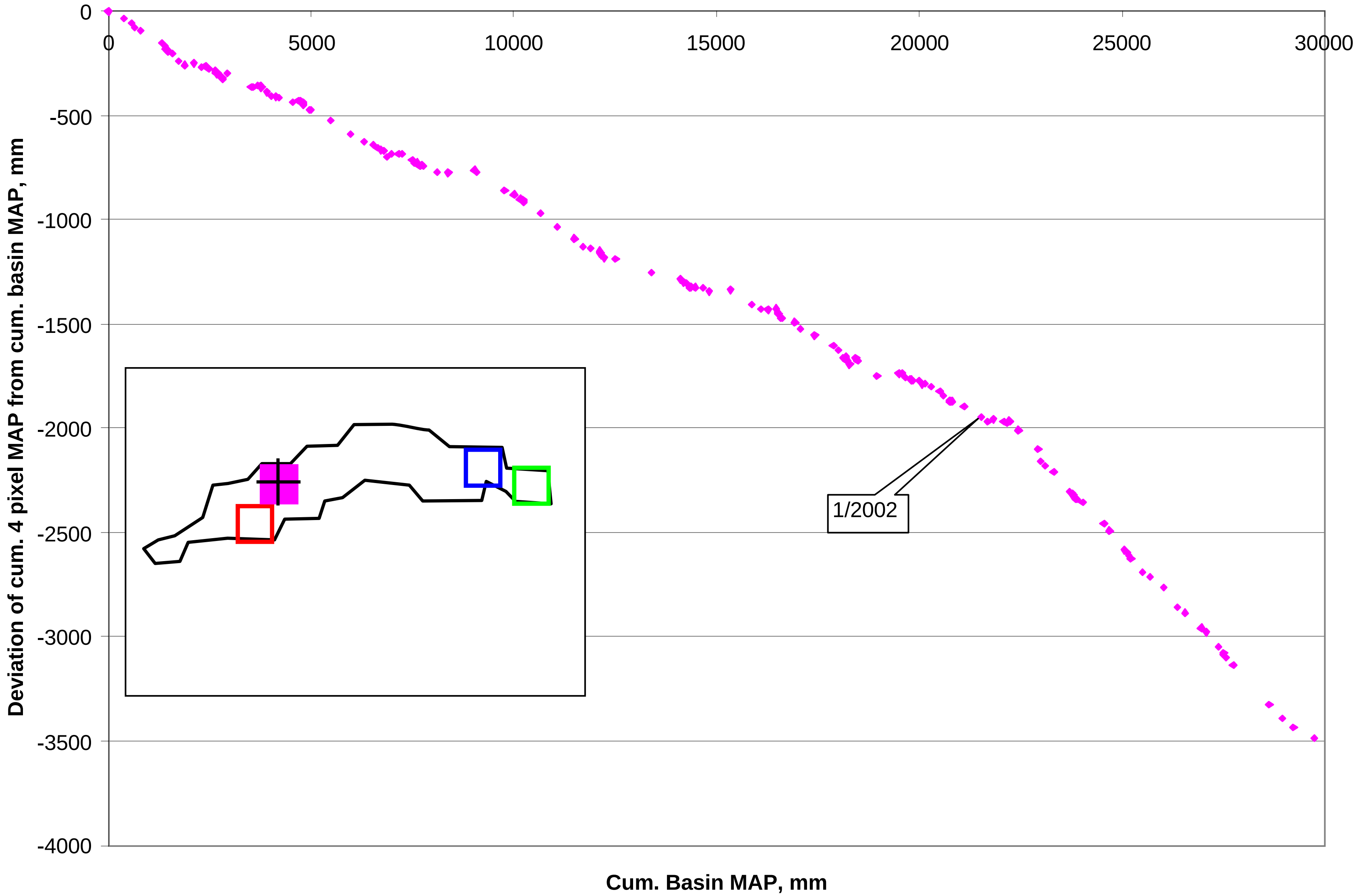
Accumulation of Deviation of Grid Set 1 from Group Base
Plotted Versus Accumulation of Group Base
0
5000
10000
15000
20000
25000
30000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
1/2002
Deviation of cum. 4 pixel MAP from cum. basin MAP, mm
Cum. Basin MAP, mm

Accumulation of Grid Set 2 versus Average Accumulation of Group Base



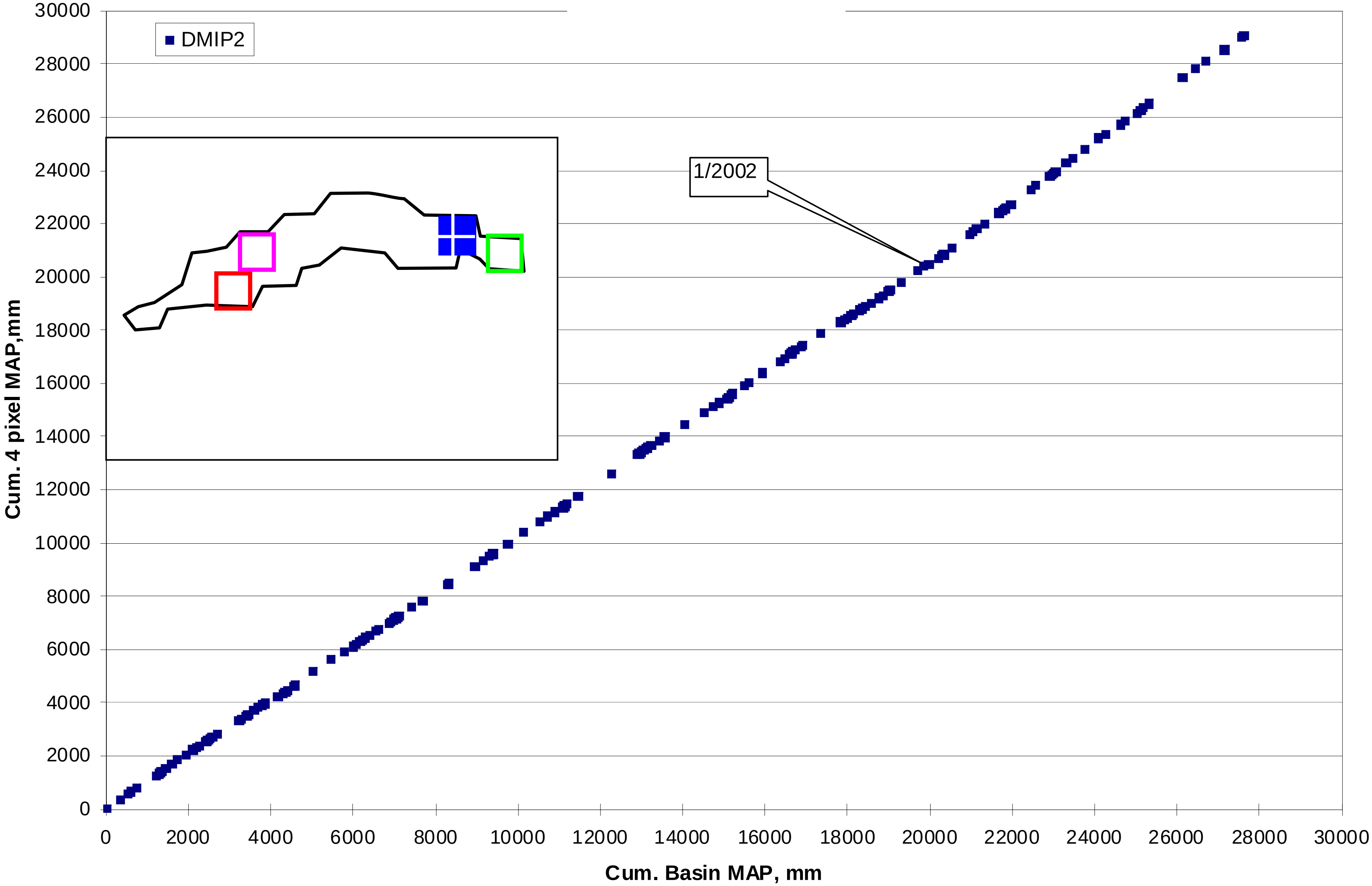
Accumulation of Deviation of Grid Set 2 from Group Base Plotted Versus Accumulation of Group Base

DMA Case 1



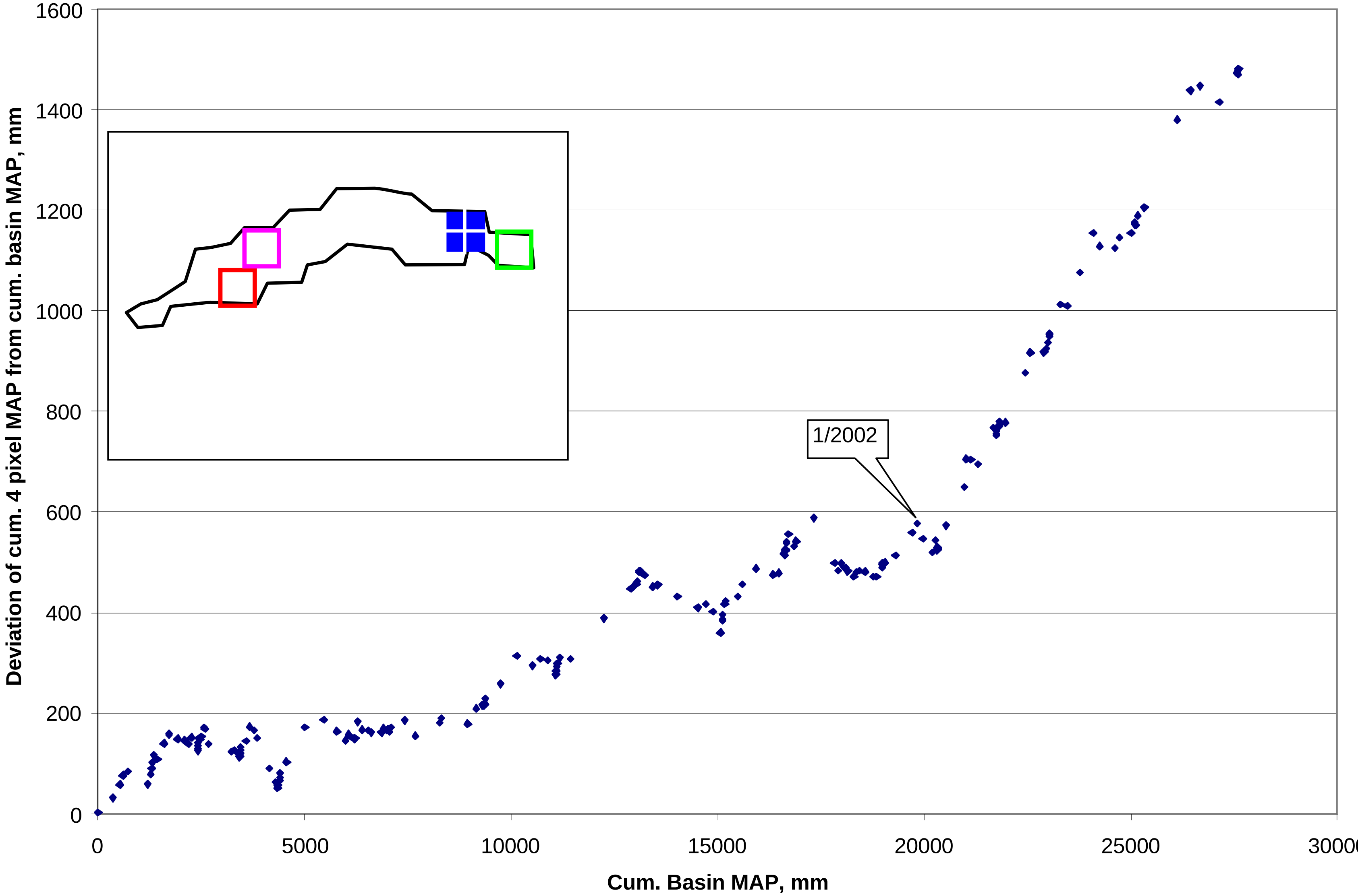
Accumulation of Grid Set 3 versus Average Accumulation of Group Base

DMA Case 1

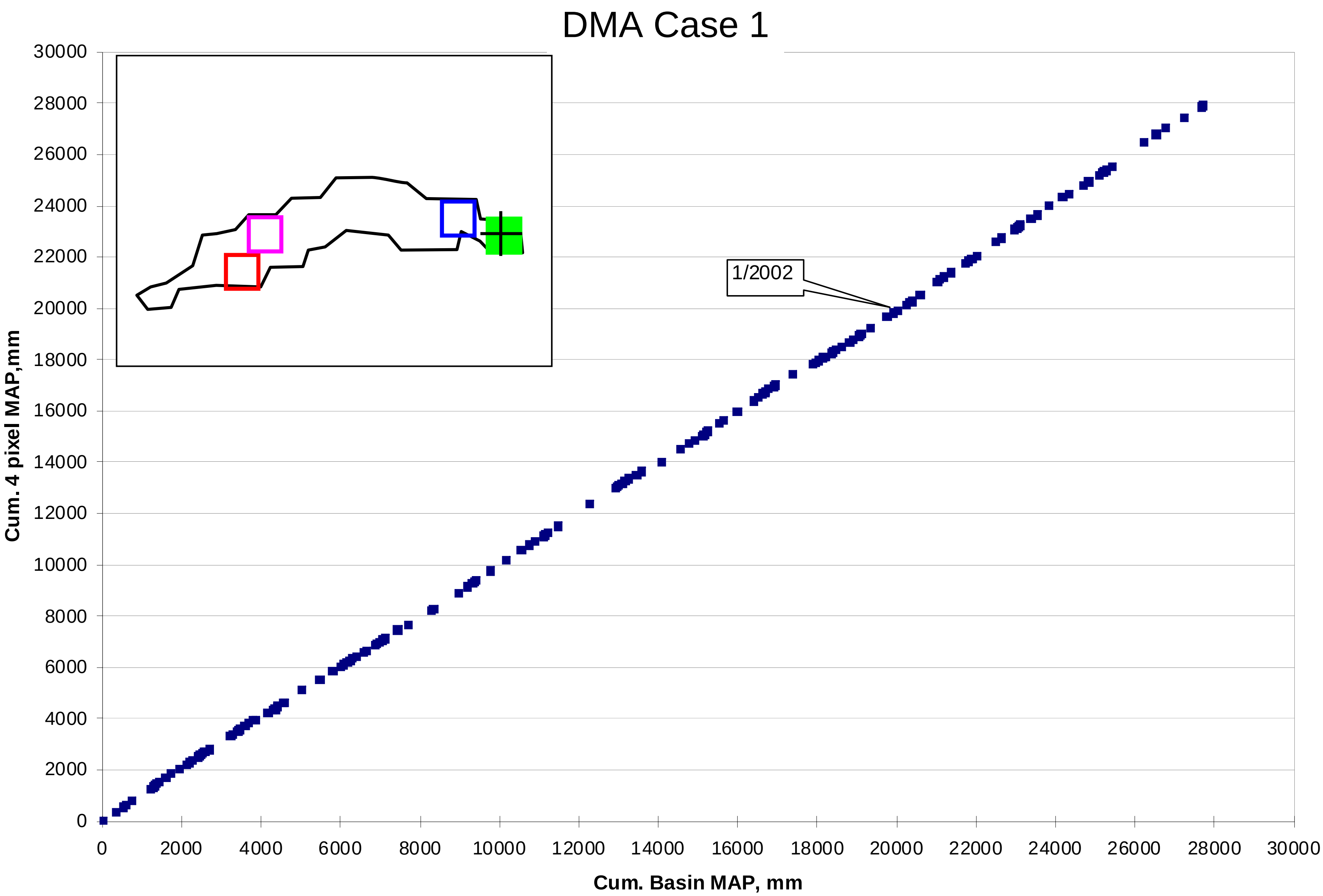


Accumulation of Deviation of Grid Set 3 from Group Base Plotted Versus Accumulation of Group Base

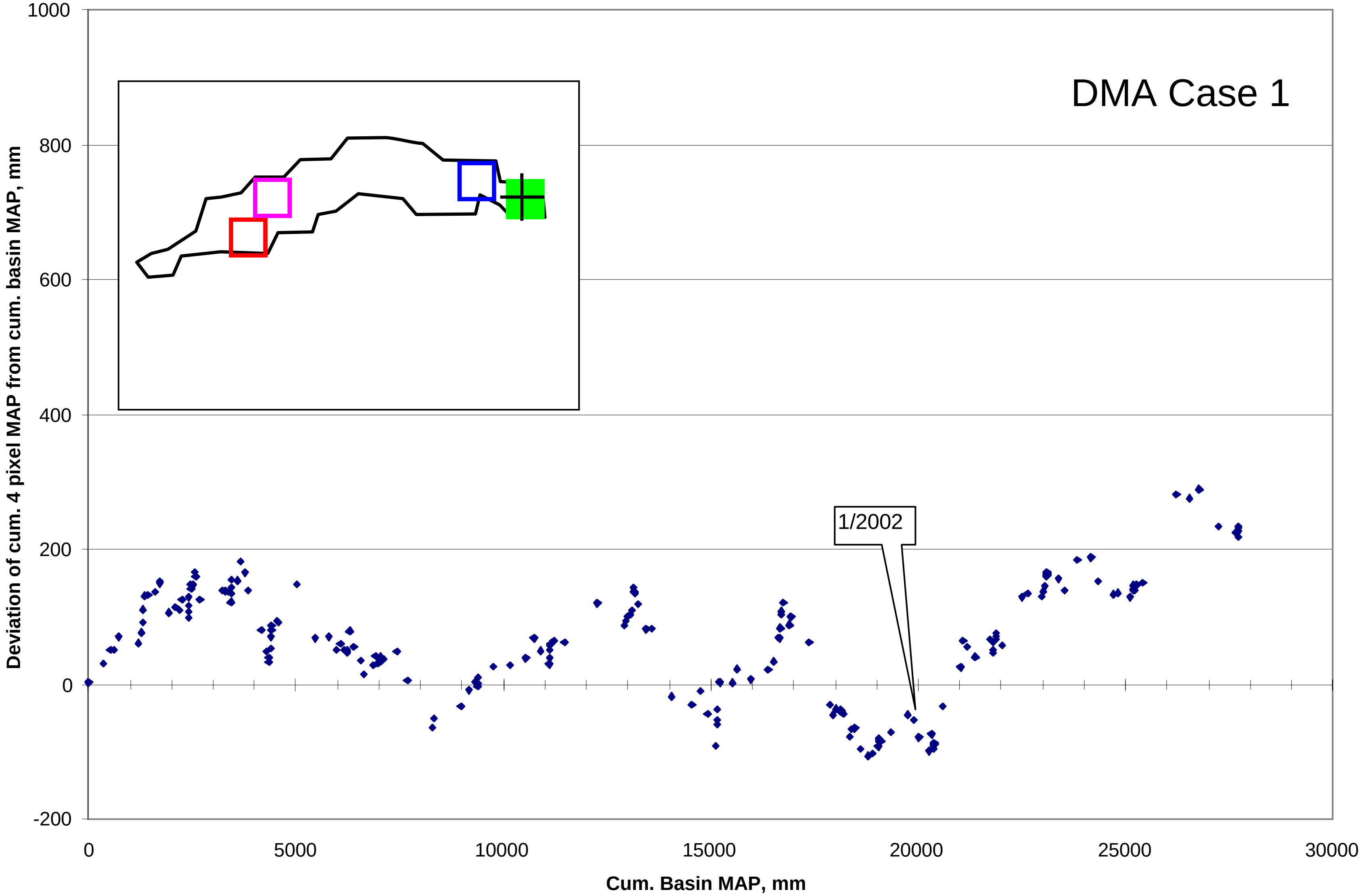
DMA Case 1



Accumulation of Grid Set 4 versus Average Accumulation of Group Base



Accumulation of Deviation of Grid Set 4 from Group Base Plotted Versus Accumulation of Group Base



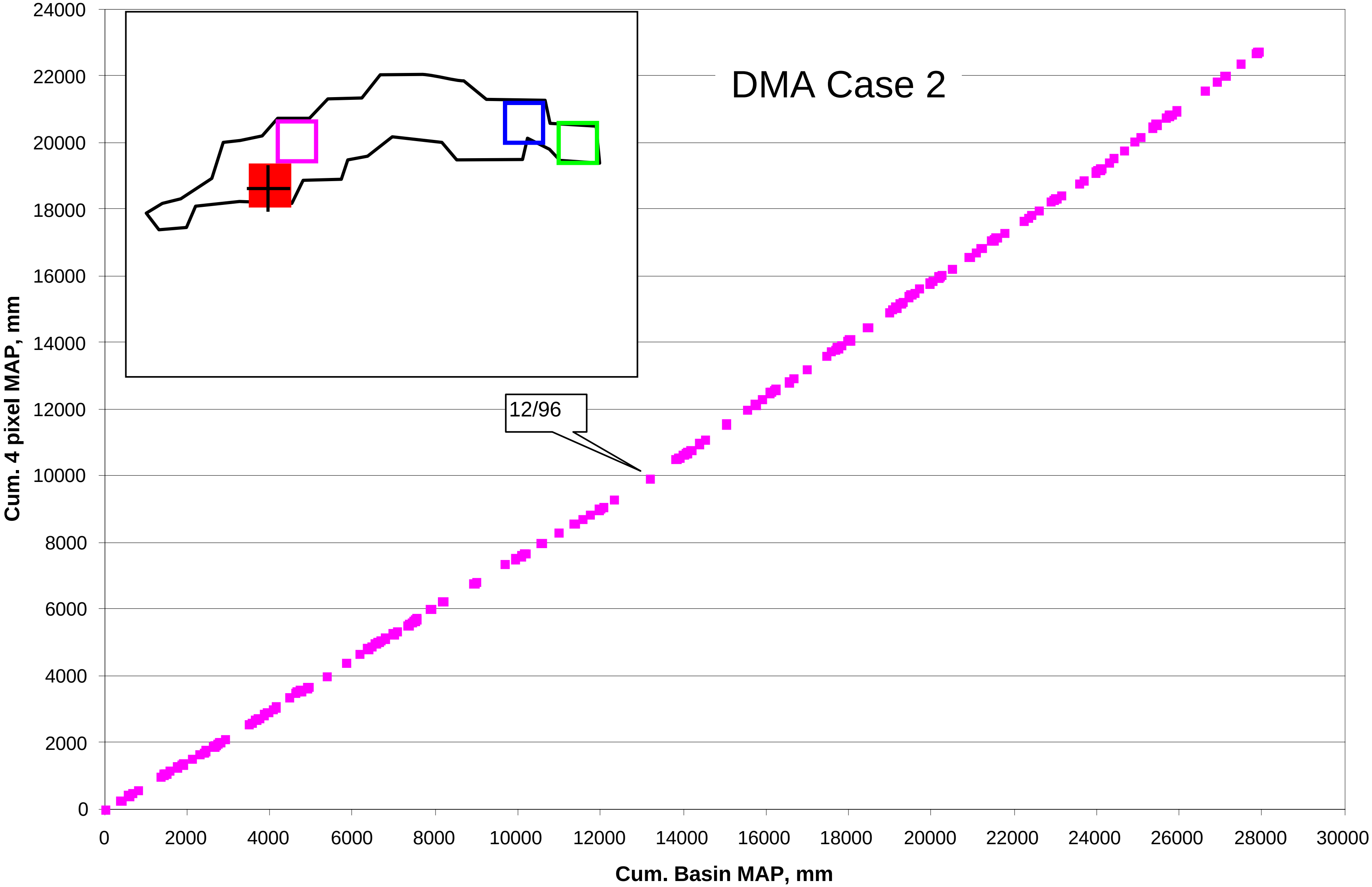
1. Double Mass Analysis of OHD Basic Data

Case 2: Group Base is PRISM Monthly Gridded QPE

For each set of 4 grids:

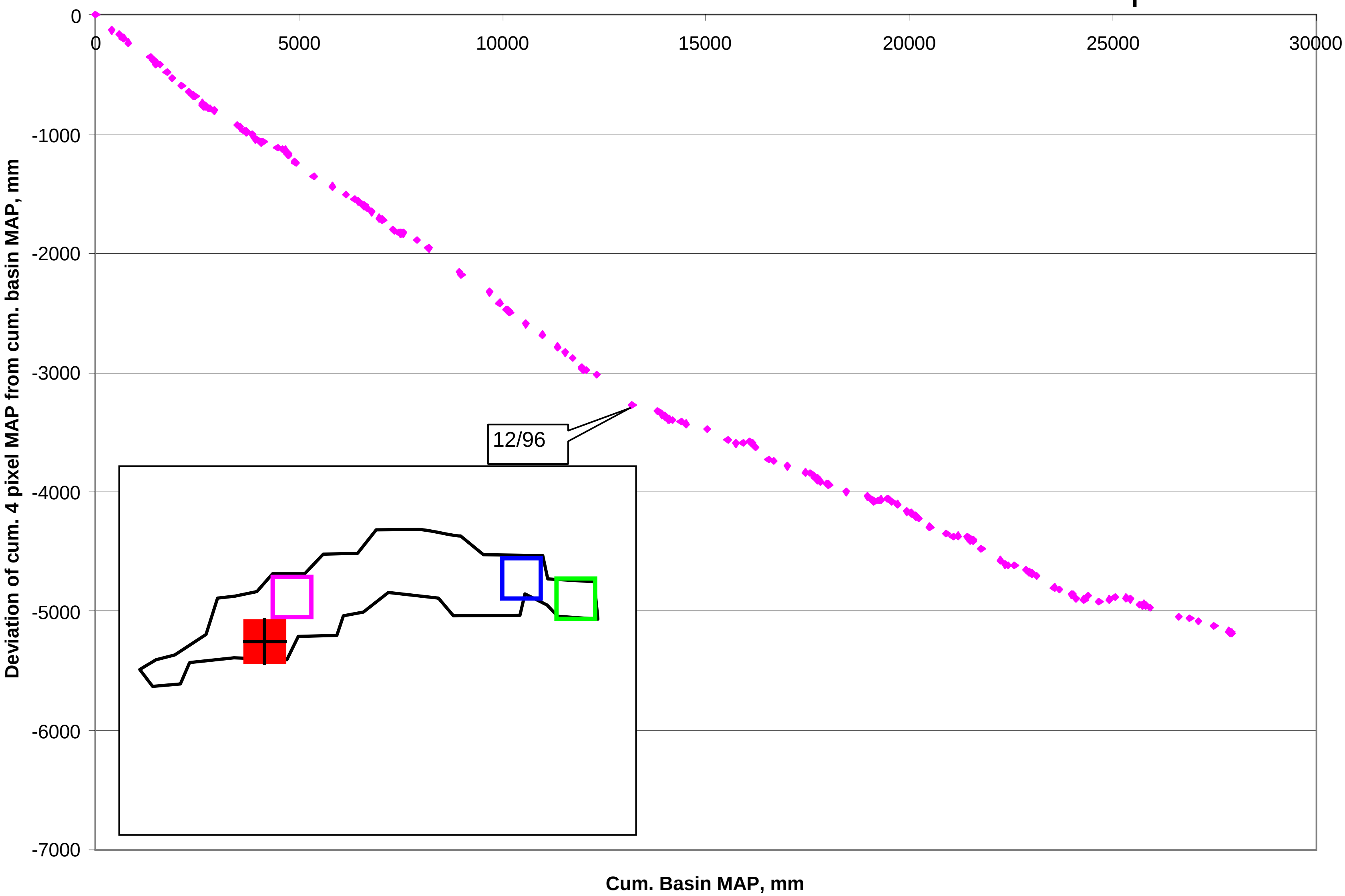
- Plot average accumulation of grids versus average accumulation of PRISM grids (group base).
- Use NWS double mass analysis to highlight trends:
  - Compute deviation of grids from group base
  - Plot acc. deviation versus acc. of group base.

Accumulation of Grid Set 1 versus Ave. Accumulation of PRISM Group Base

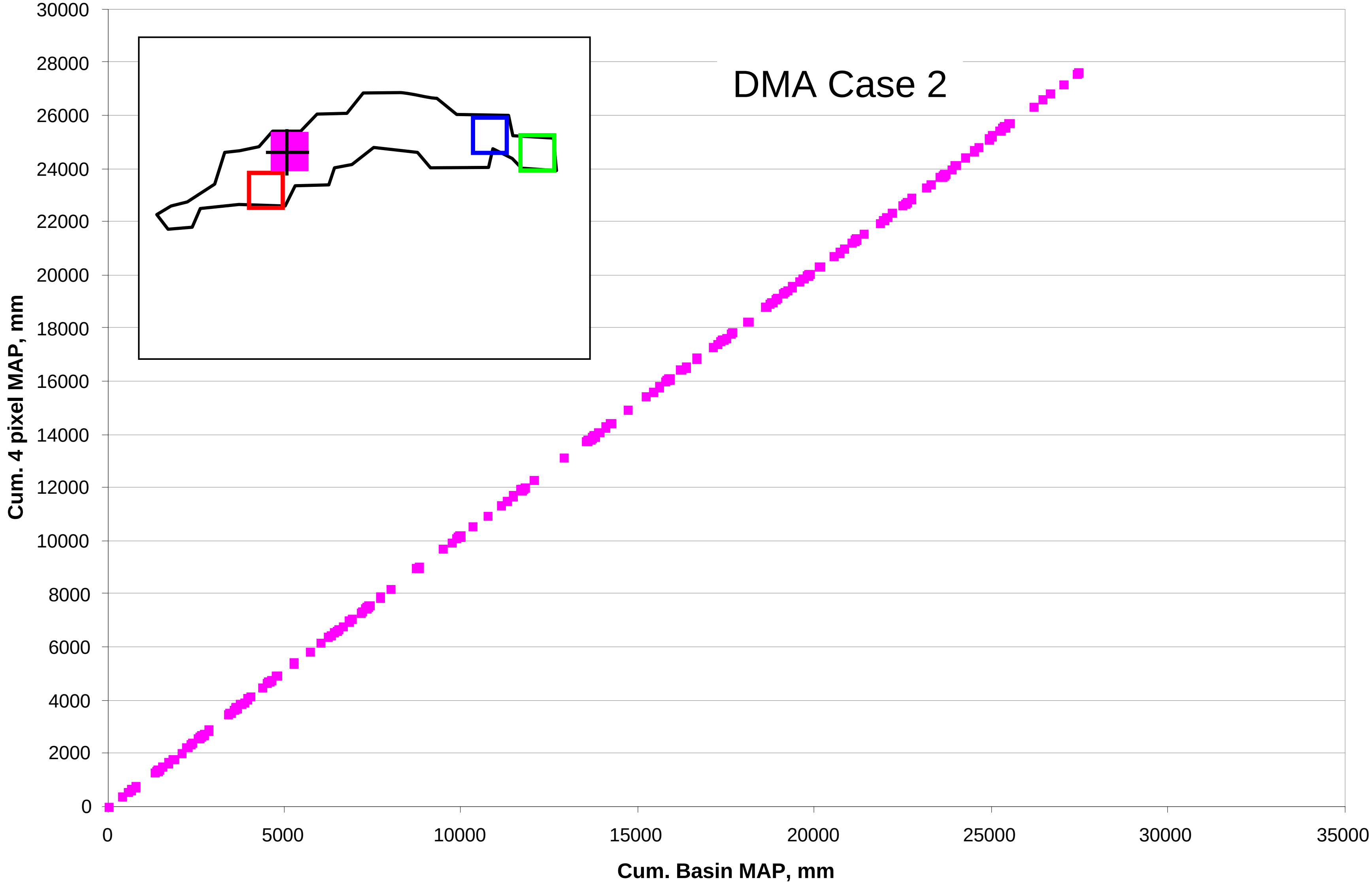


DMA Case 2

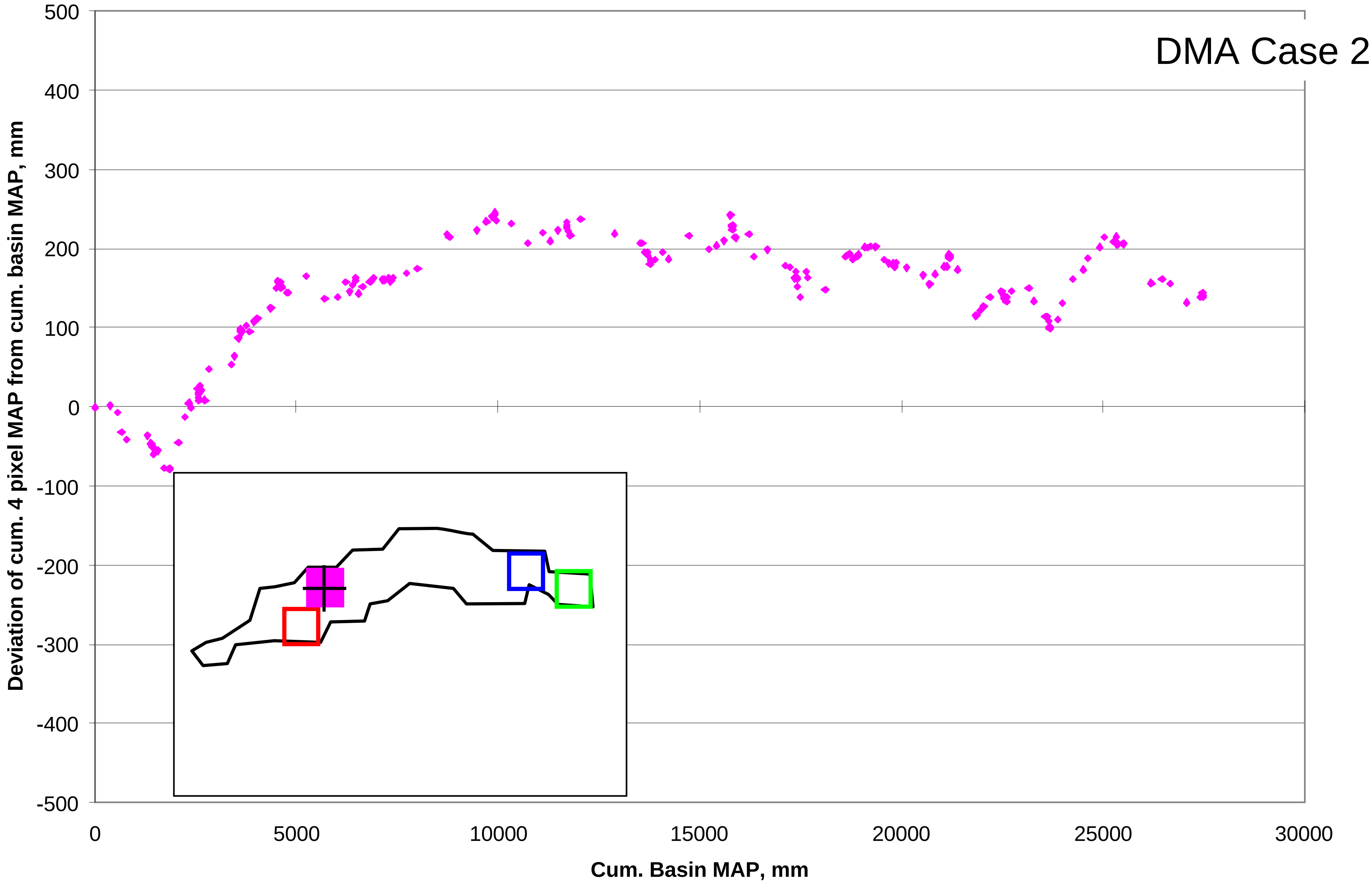
Accumulation of Deviation of Grid Set 1 from Group Base Plotted Versus Ave. Accumulation of PRISM Group Base



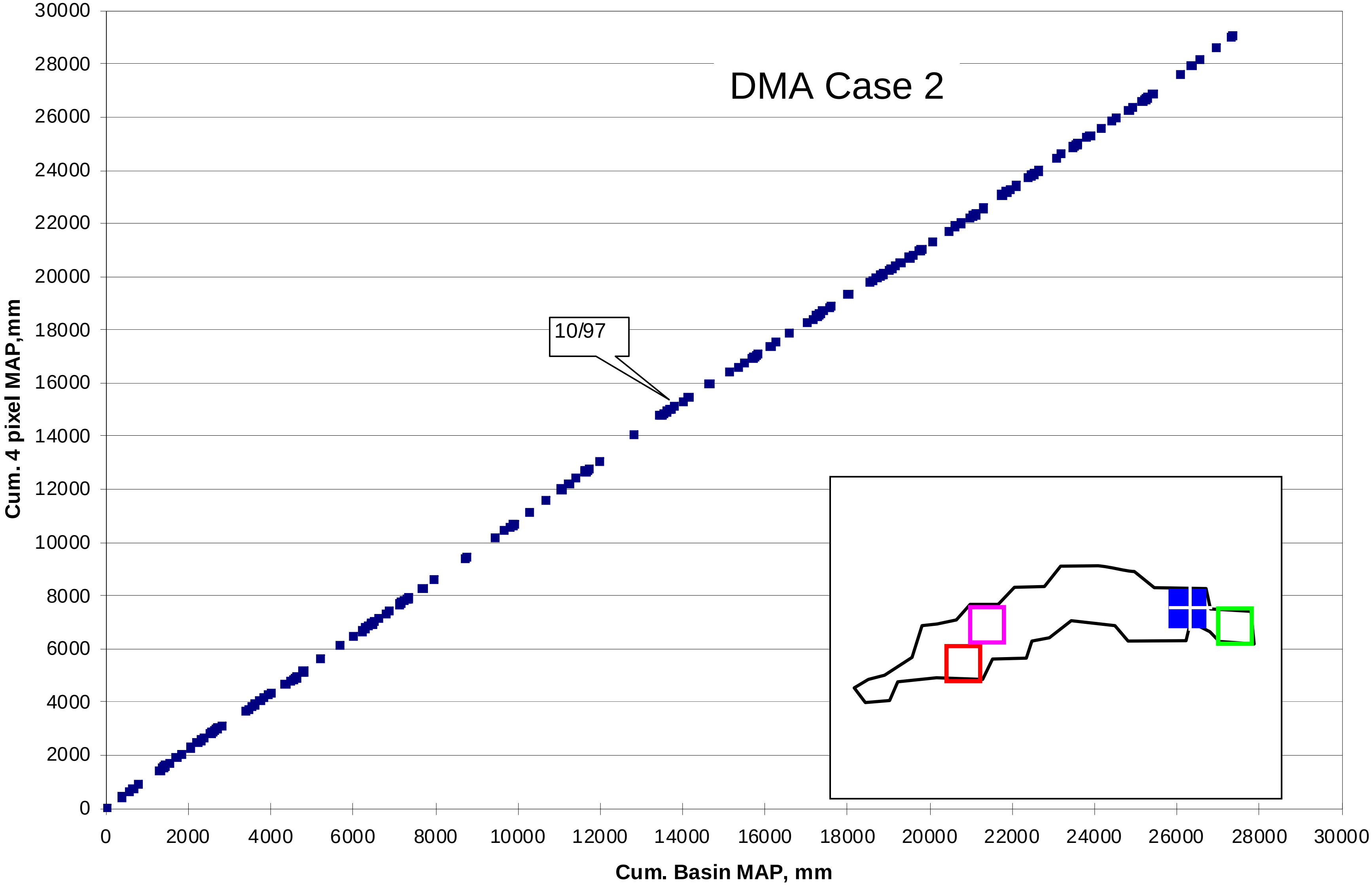
Accumulation of Grid Set 2 versus Ave. Accumulation of PRISM Group Base



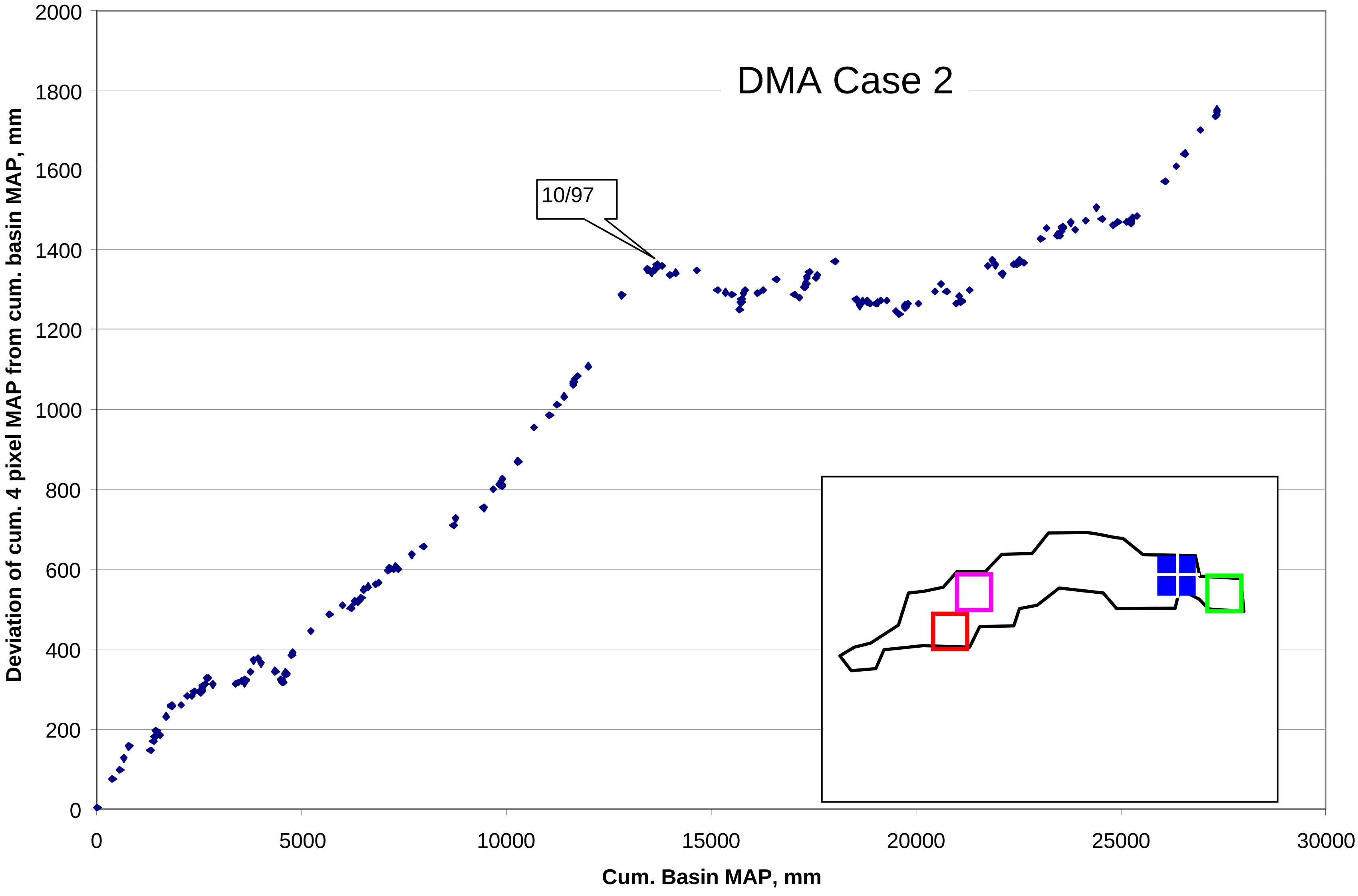
Accumulation of Deviation of Grid Set 2 from Group Base
Plotted Versus Ave. Accumulation of PRISM Group Base



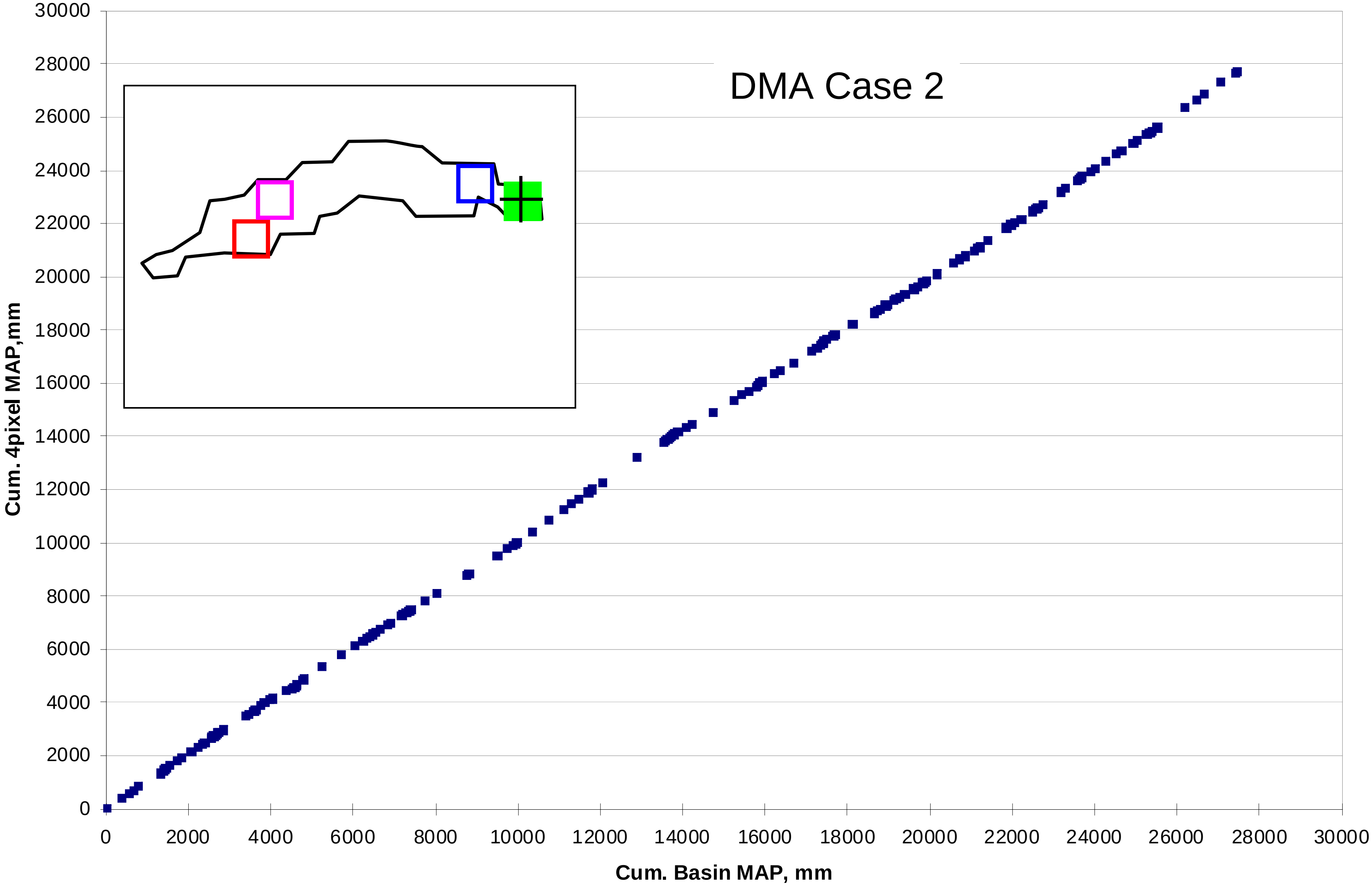
Accumulation of Grid Set 3 versus Ave. Accumulation of PRISM Group Base



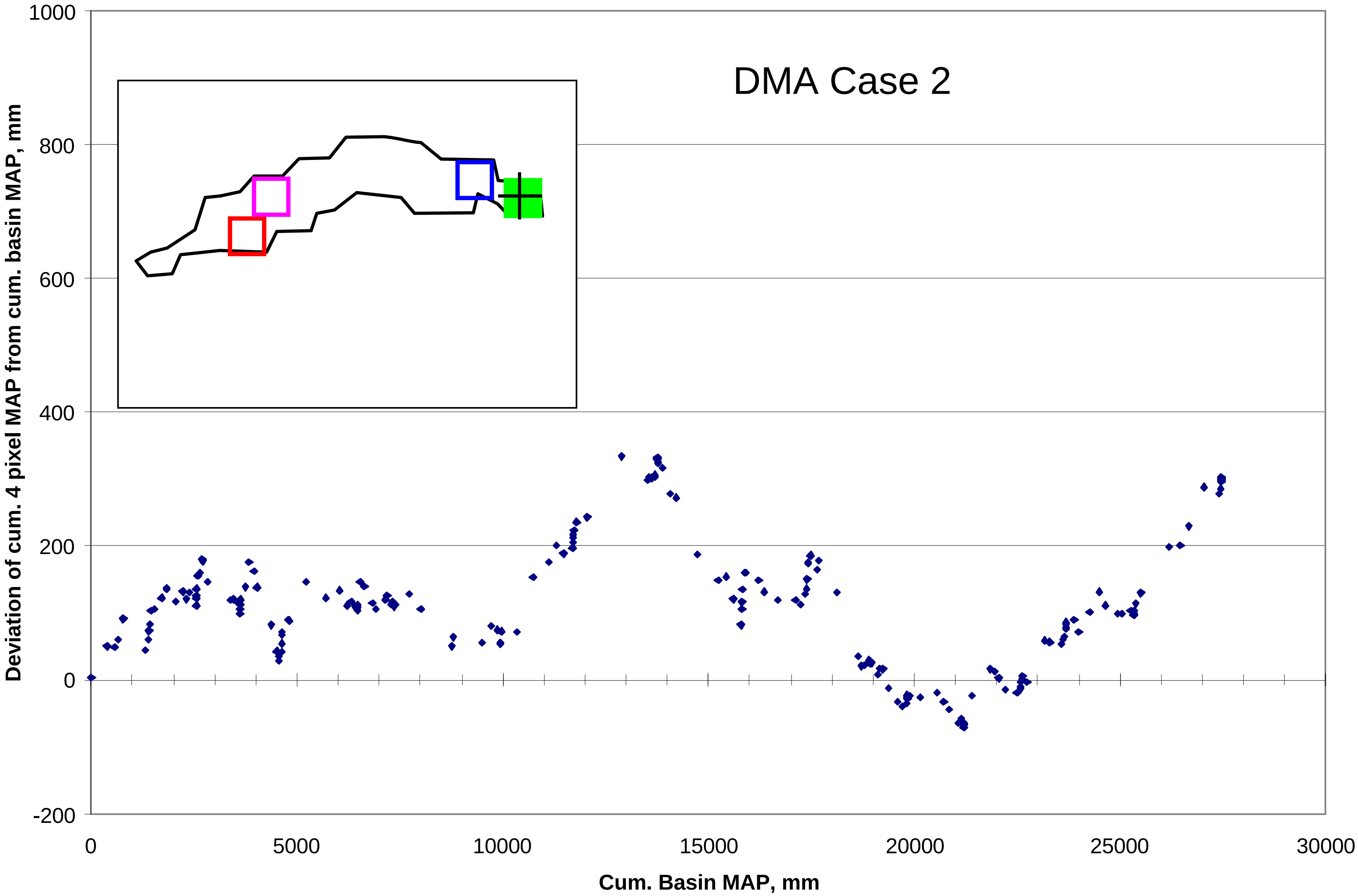
Accumulation of Deviation of Grid Set 3 from Group Base Plotted Versus Ave. Accumulation of PRISM Group Base



Accumulation of Grid Set 4 versus Ave. Accumulation of PRISM Group Base



Accumulation of Deviation of Grid Set 4 from Group Base
Plotted Versus Ave. Accumulation of PRISM Group Base

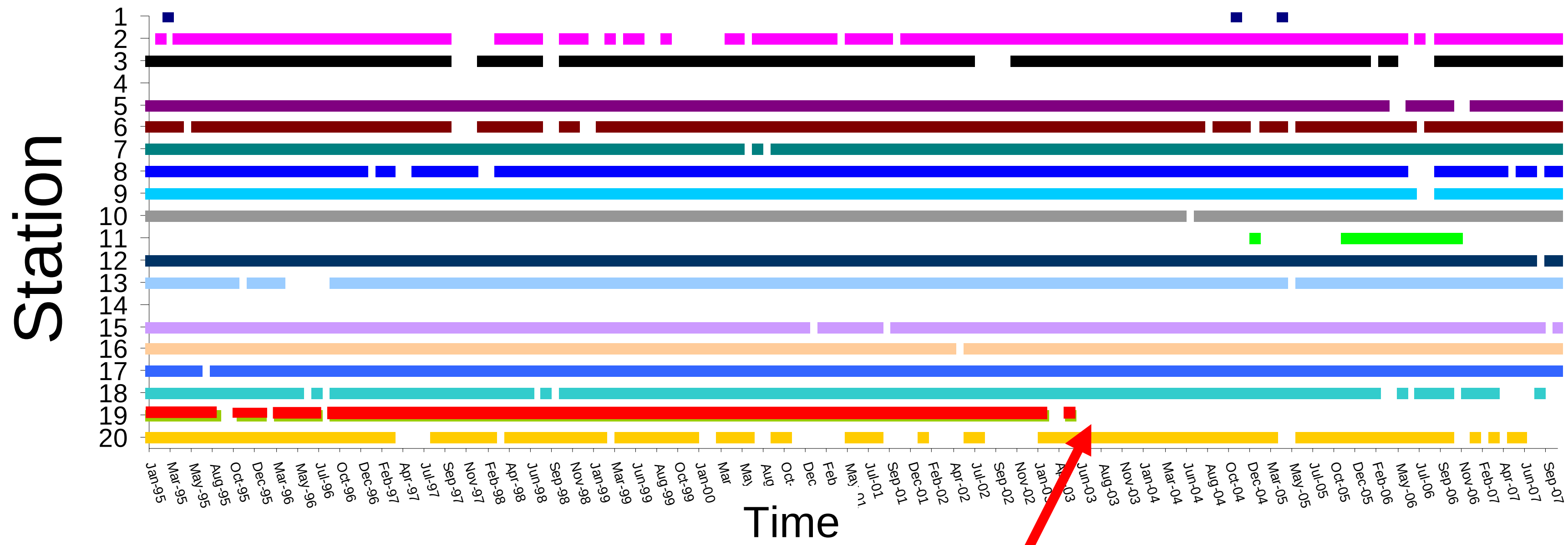


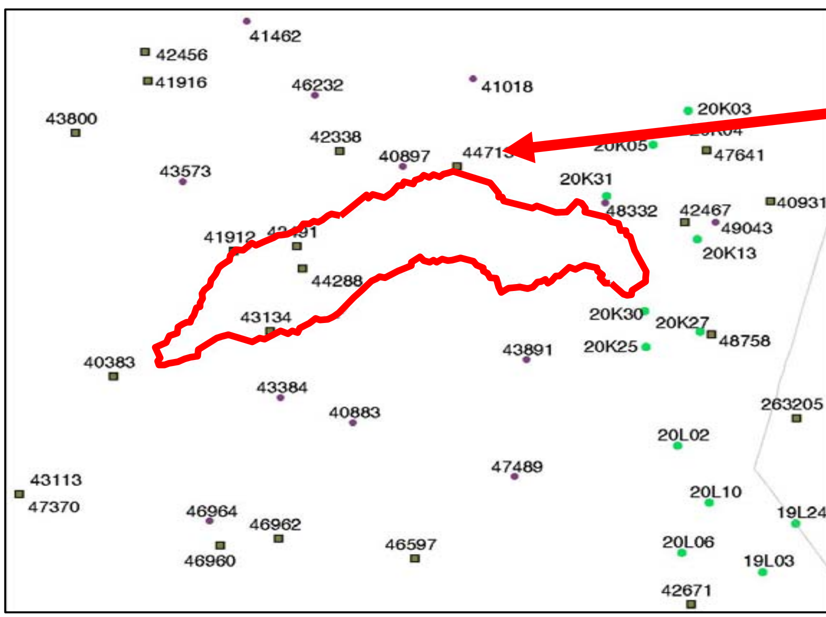
2. Plot OHD QPE accumulation and PXPP accumulation

Method

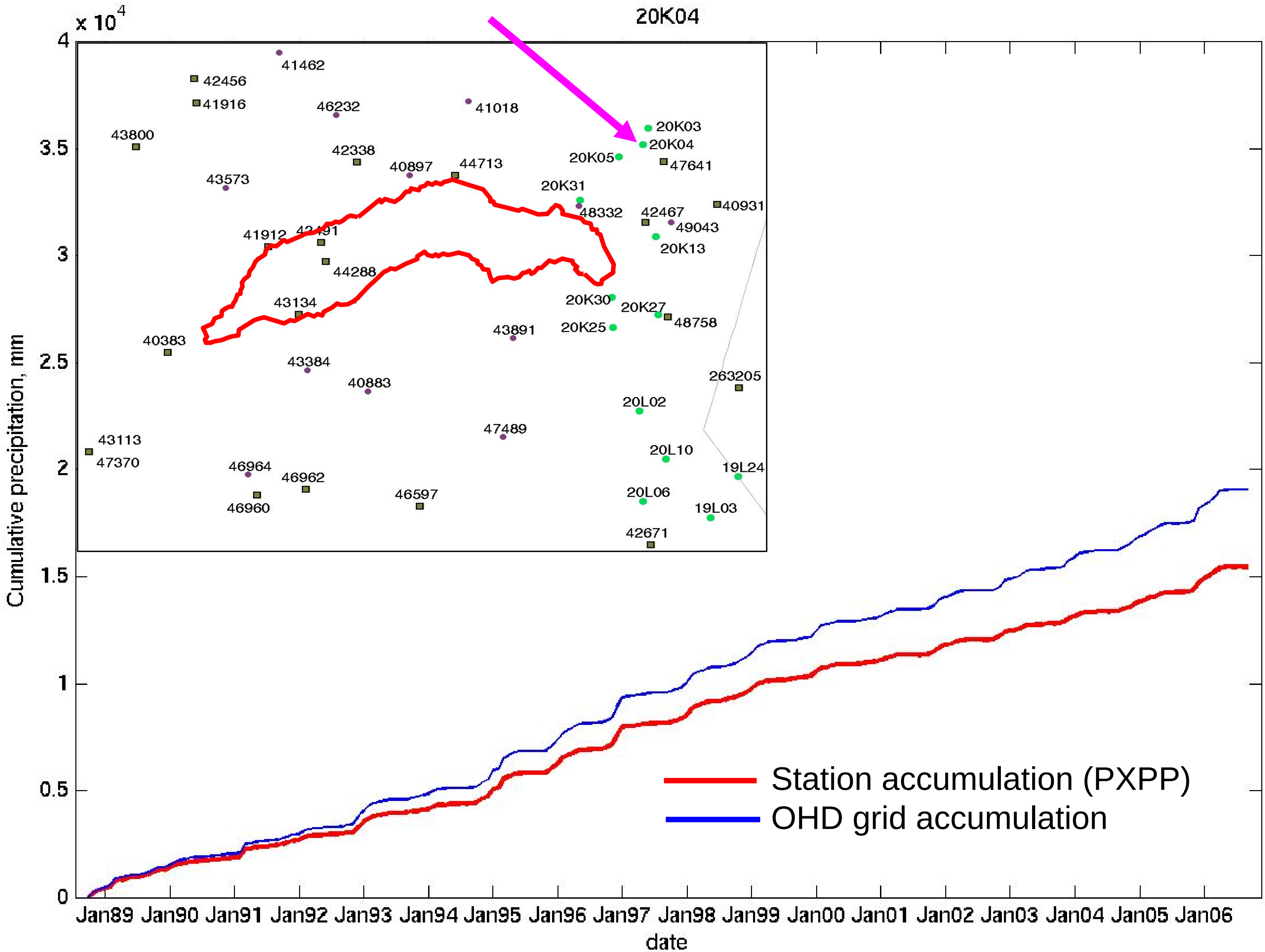
- Download NCDC hourly/daily and SNOTEL data for 1980-2007 for stations around North Fork basin
- Use PXPP program to generate monthly time series at each station for entire period.
- Plot accumulation of PXPP time series and the accumulation of the ‘co-located’ OHD QPE grid

Period of Record for NCDC Data

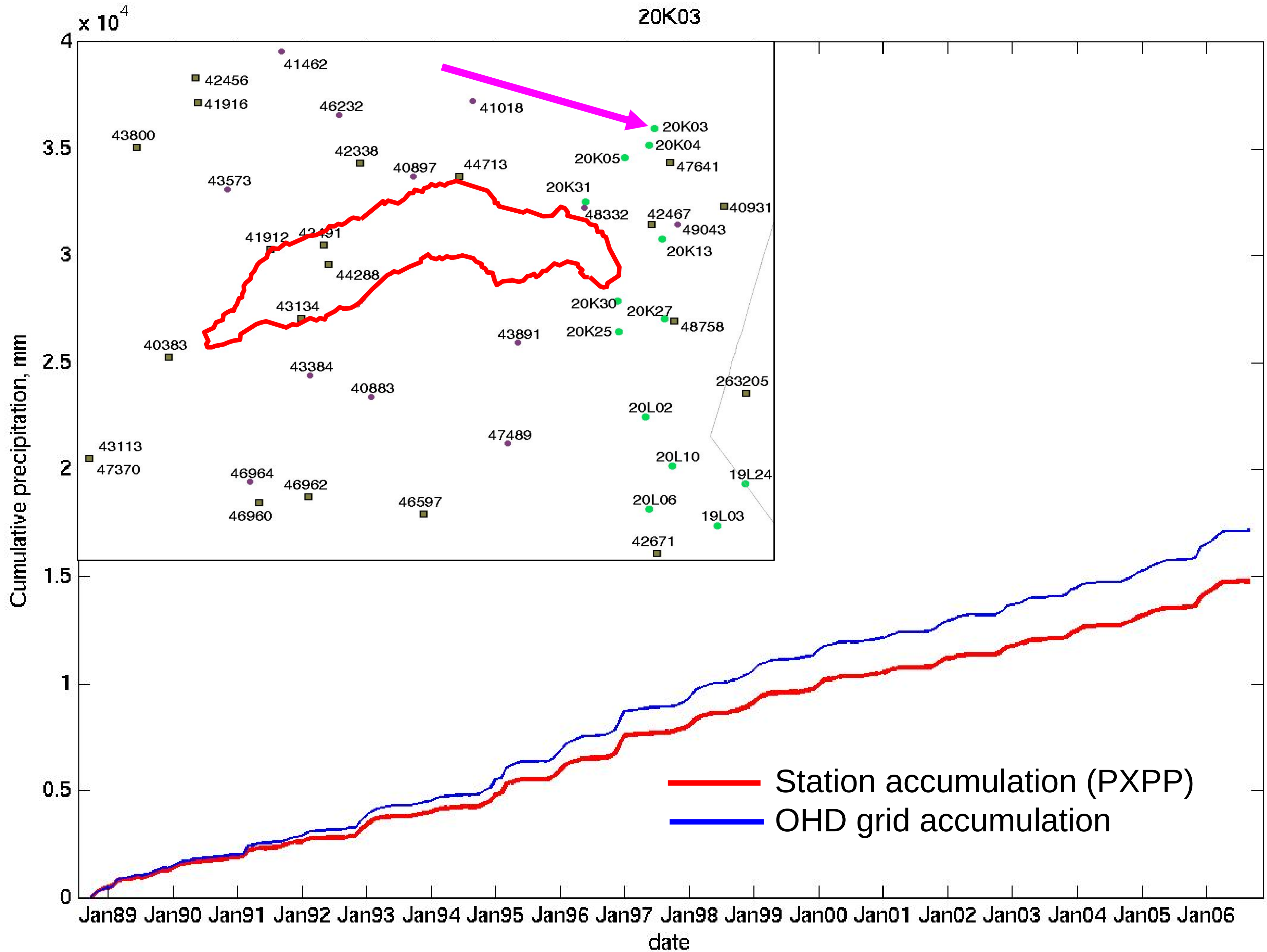




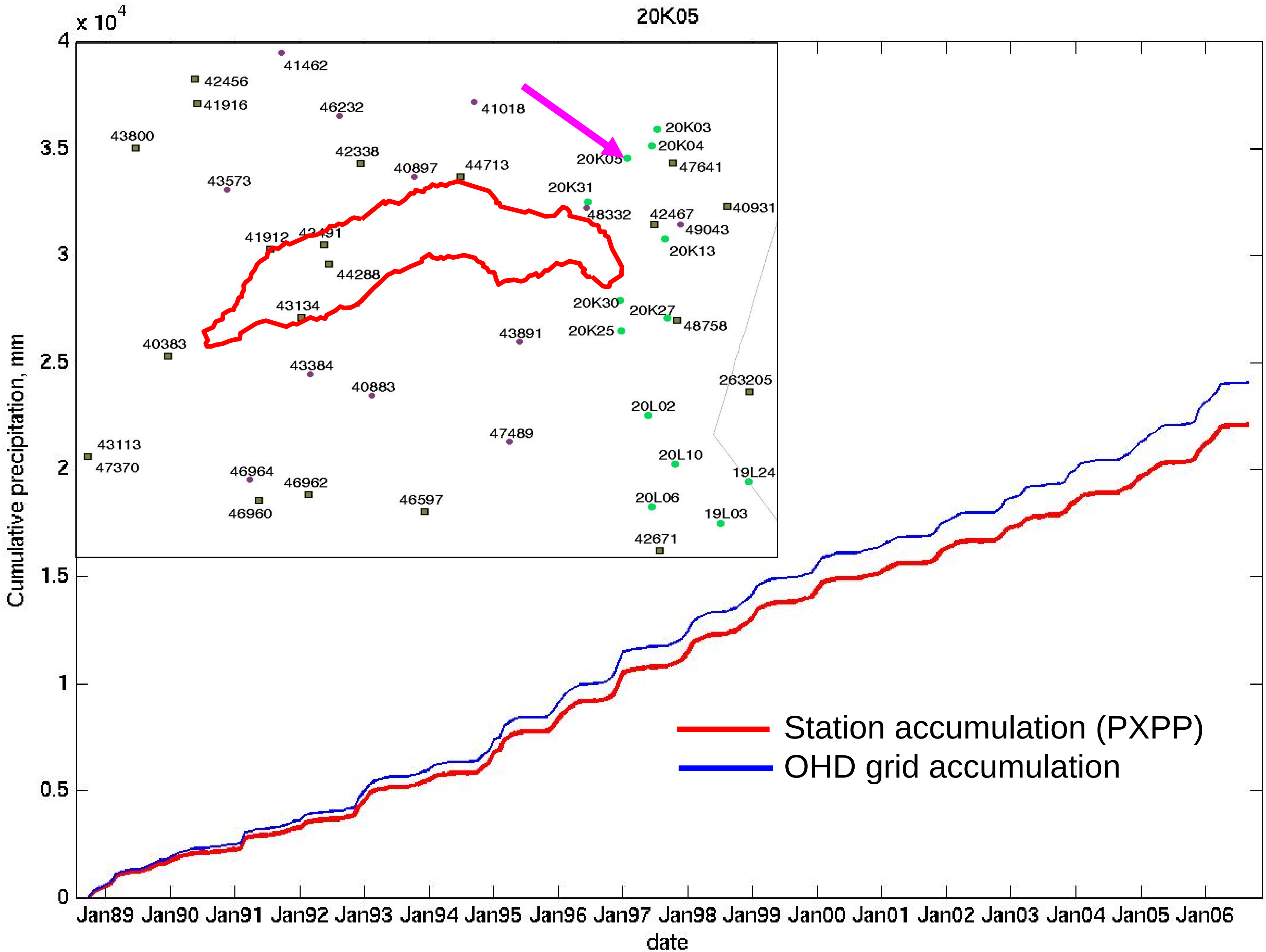
Lake Spaulding NCDC daily gauge discontinued

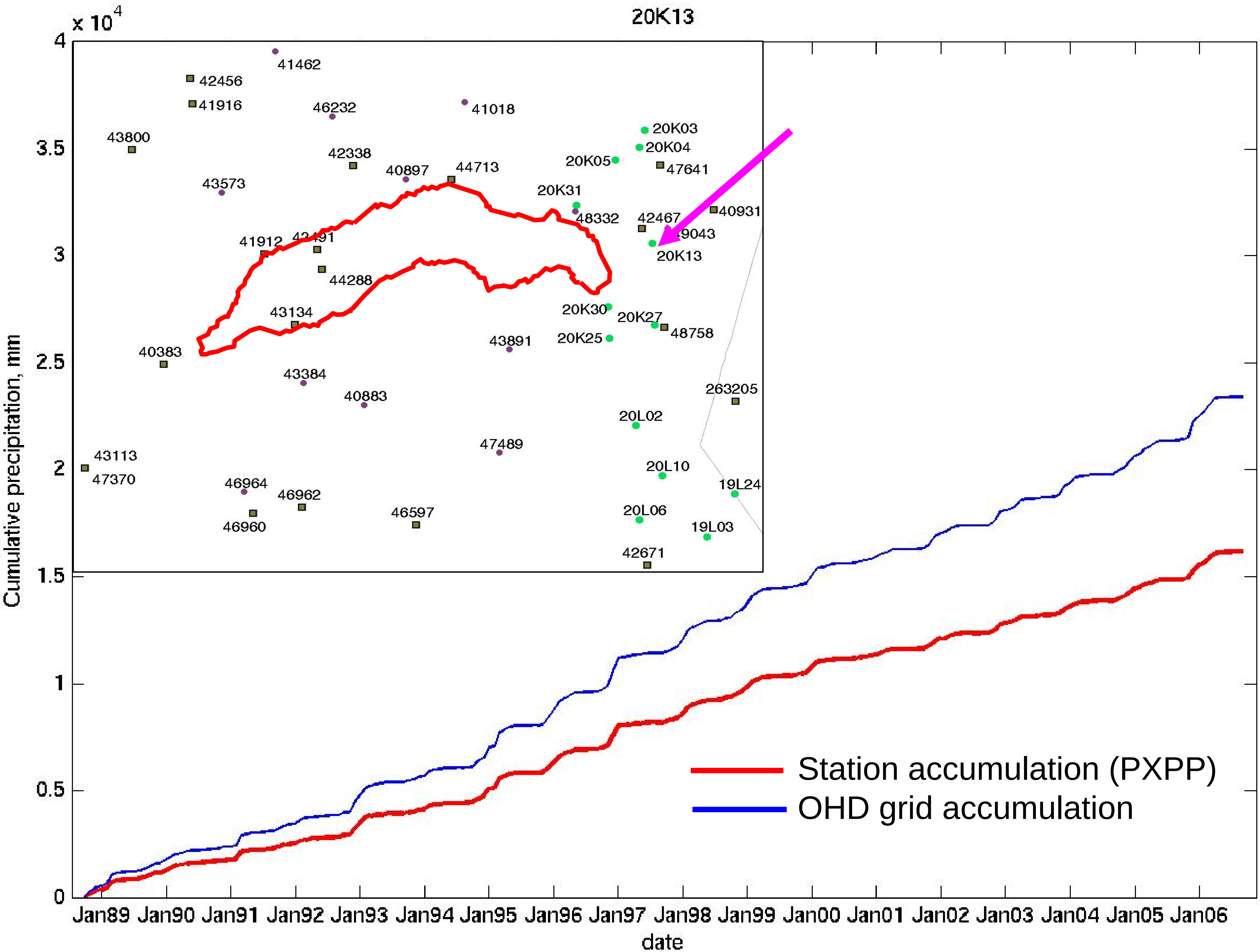


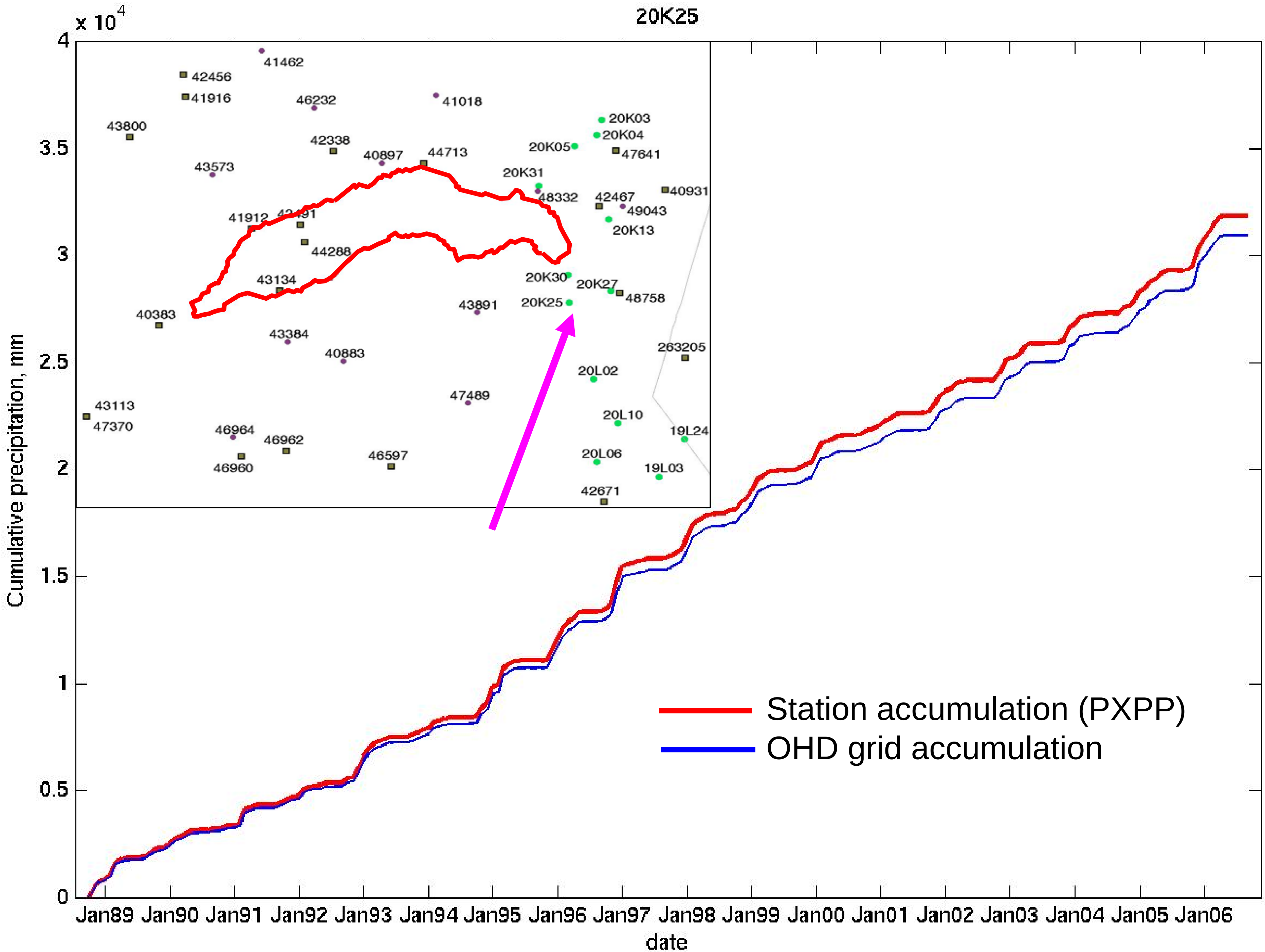
20K04
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
43573
20K03
20K04
20K05
47641
20K31
48332
42467
40931
49043
20K13
41912
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
19L24
46964
46962
46960
46597
20L06
19L03
42671



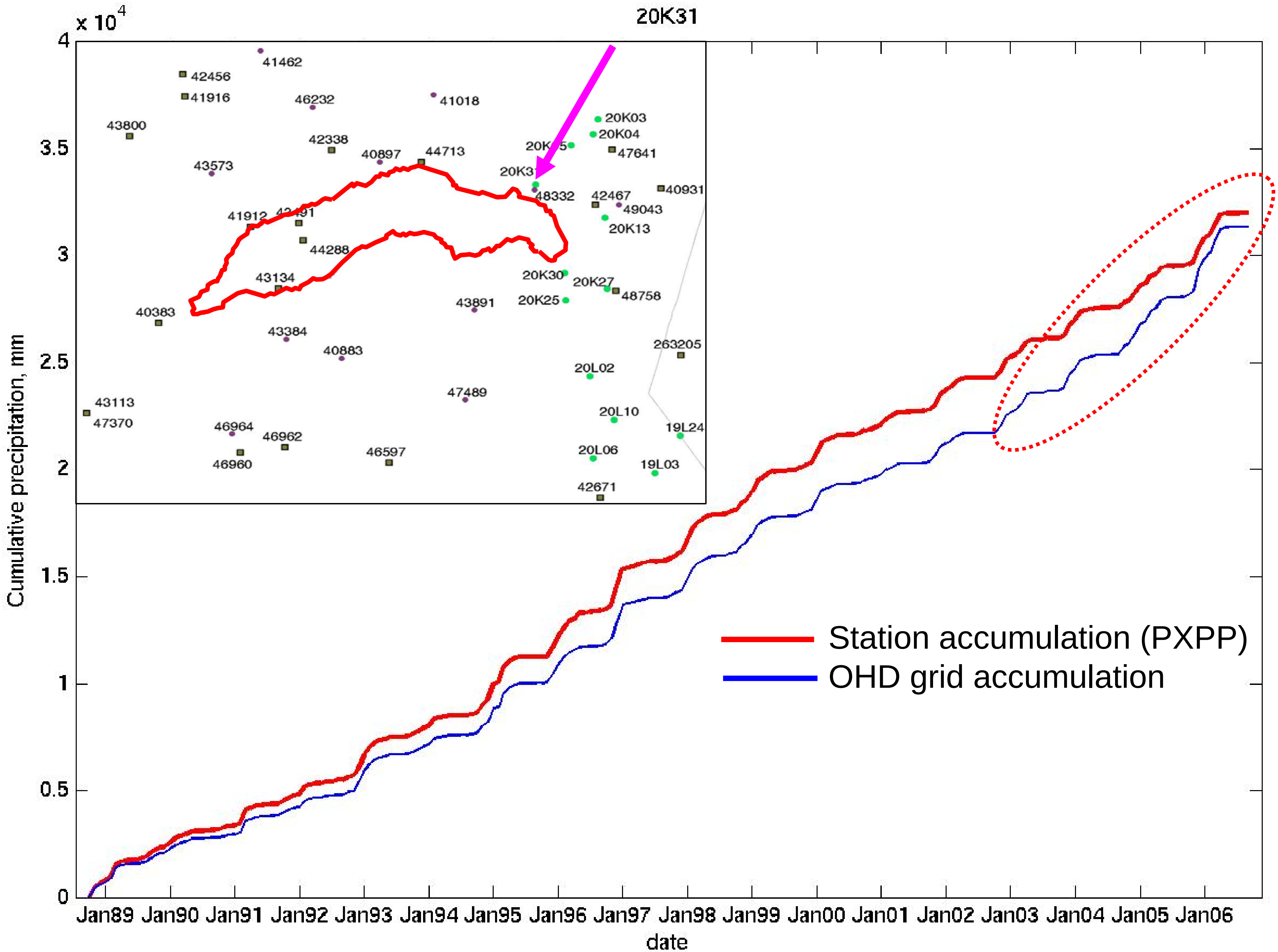
20K03
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
20K03
20K04
43800
42338
20K05
47641
40897
44713
43573
20K31
40931
48332
42467
49043
41912
42491
20K13
44288
43134
20K30
20K27
48758
43891
20K25
40383
43384
263205
40883
20L02
47489
43113
20L10
47370
46964
19L24
46962
20L06
46960
46597
19L03
42671

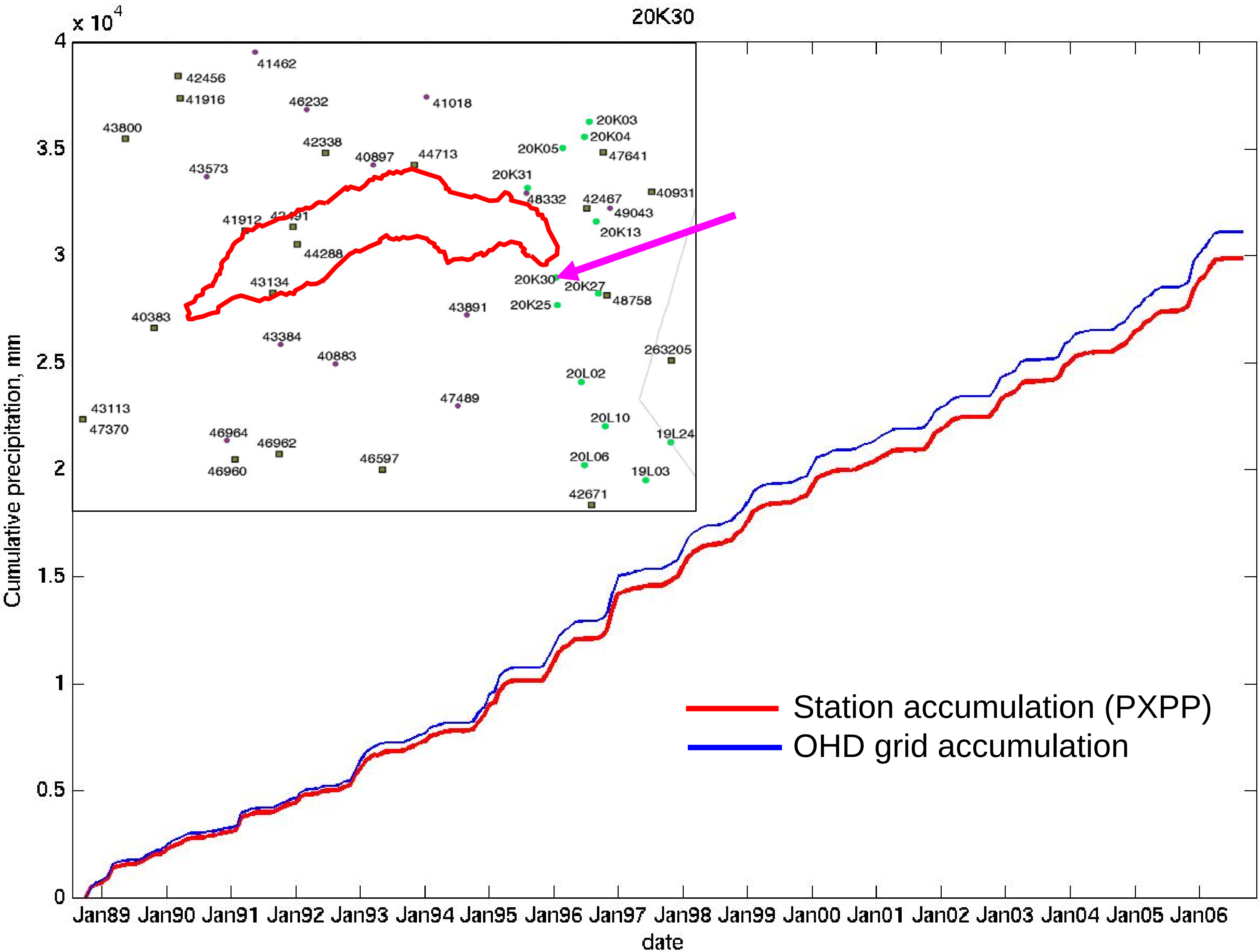

20K05
x 10^4
Cumulative precipitation, mm
0
0.5
1
1.5
2
2.5
3
3.5
4
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
date
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
20K03
20K04
20K05
47641
43800
42338
40897
44713
43573
20K31
48332
42467
40931
49043
20K13
41912
44288
20K30
20K27
48758
43134
43891
20K25
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
19L24
46964
46962
20L06
46960
46597
19L03
42671

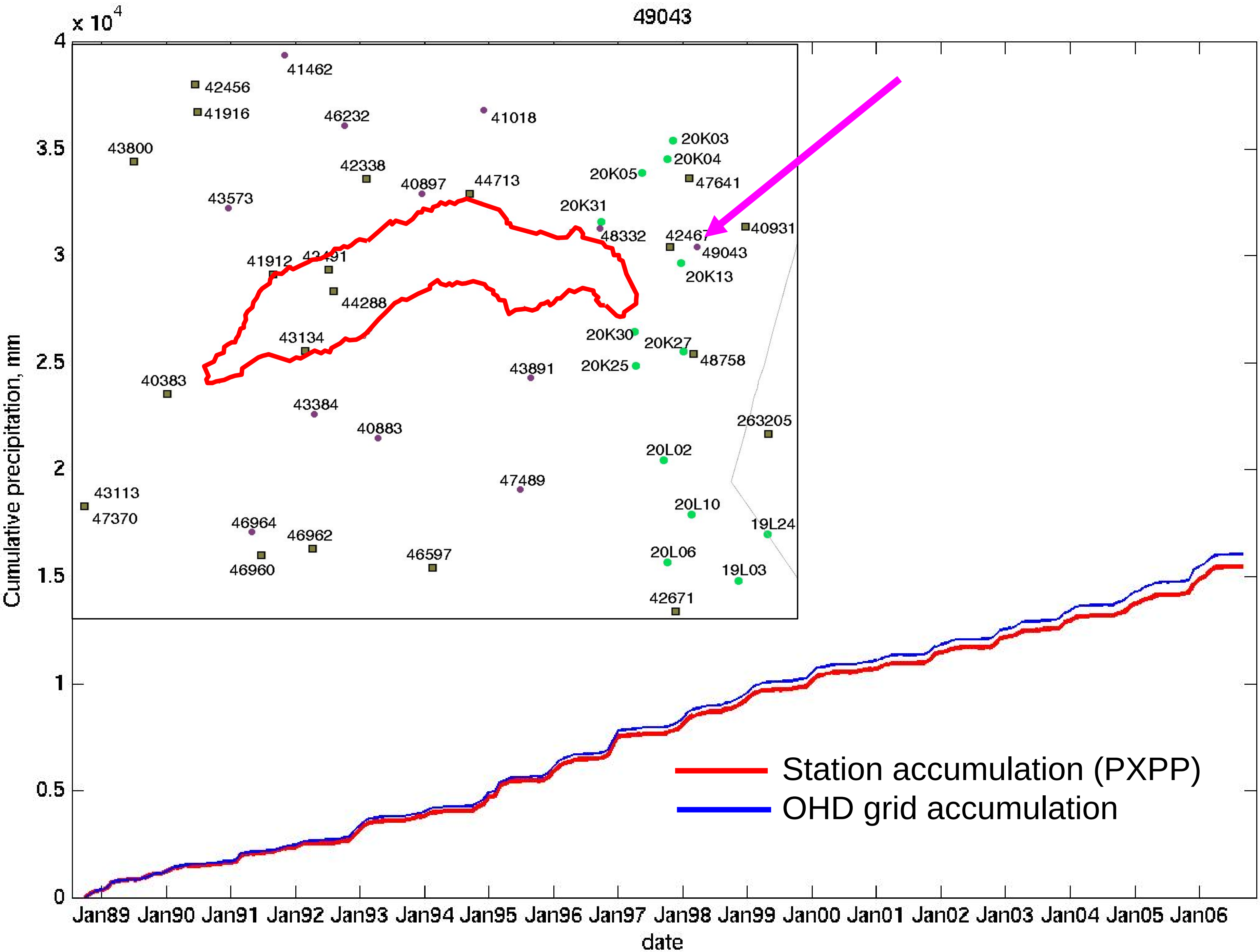

20K13
x 10^4
4
3.5
3
2.5
2
1.5
1
0.5
0
Cumulative precipitation, mm
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
date
41462
42456
41916
46232
41018
20K03
20K04
43800
42338
40897
44713
20K05
47641
43573
20K31
48332
42467
40931
41912
44288
20K13
20K30
43134
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46597
20L06
46960
19L03
42671
Station accumulation (PXPP)
OHD grid accumulation

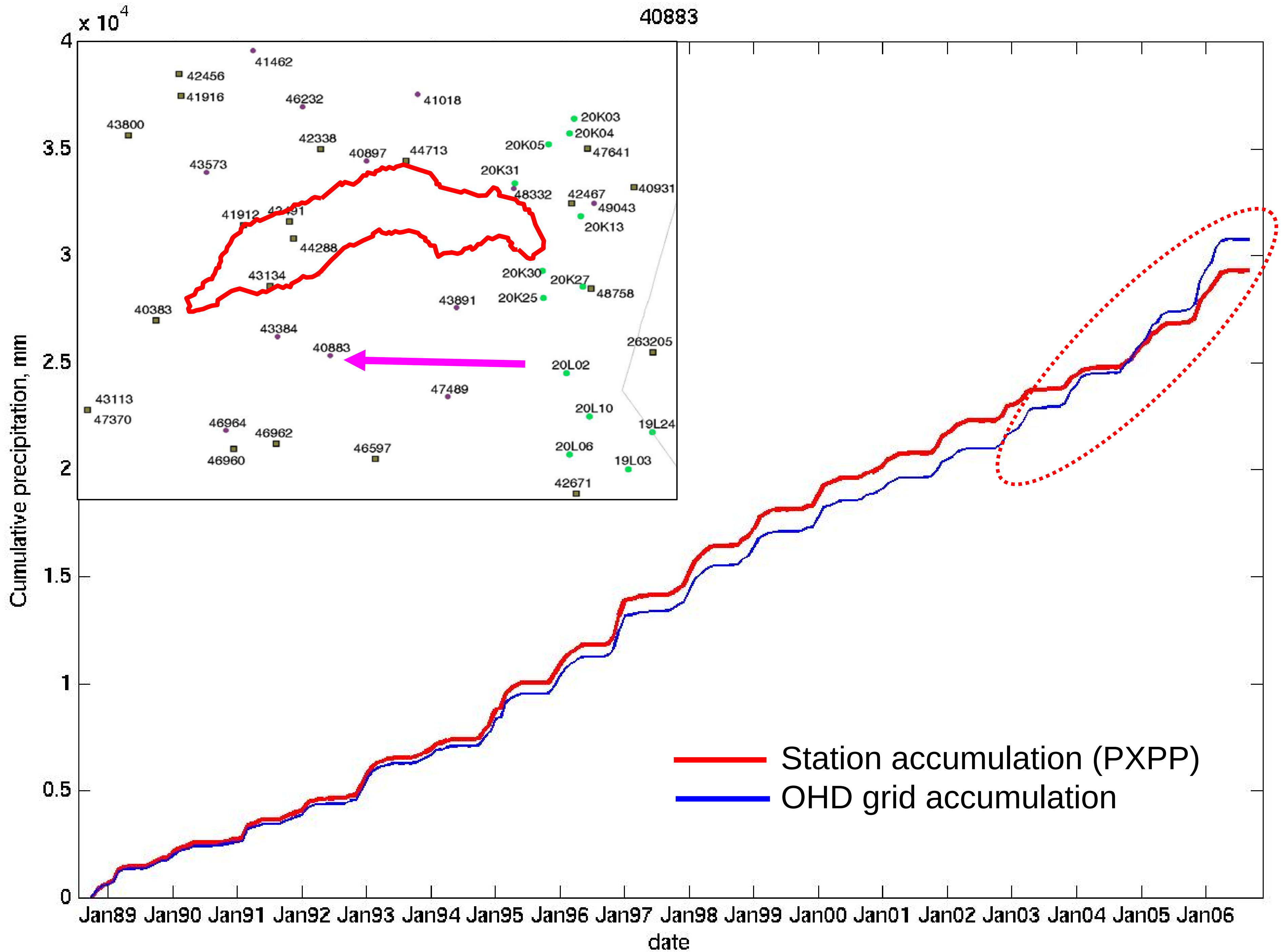


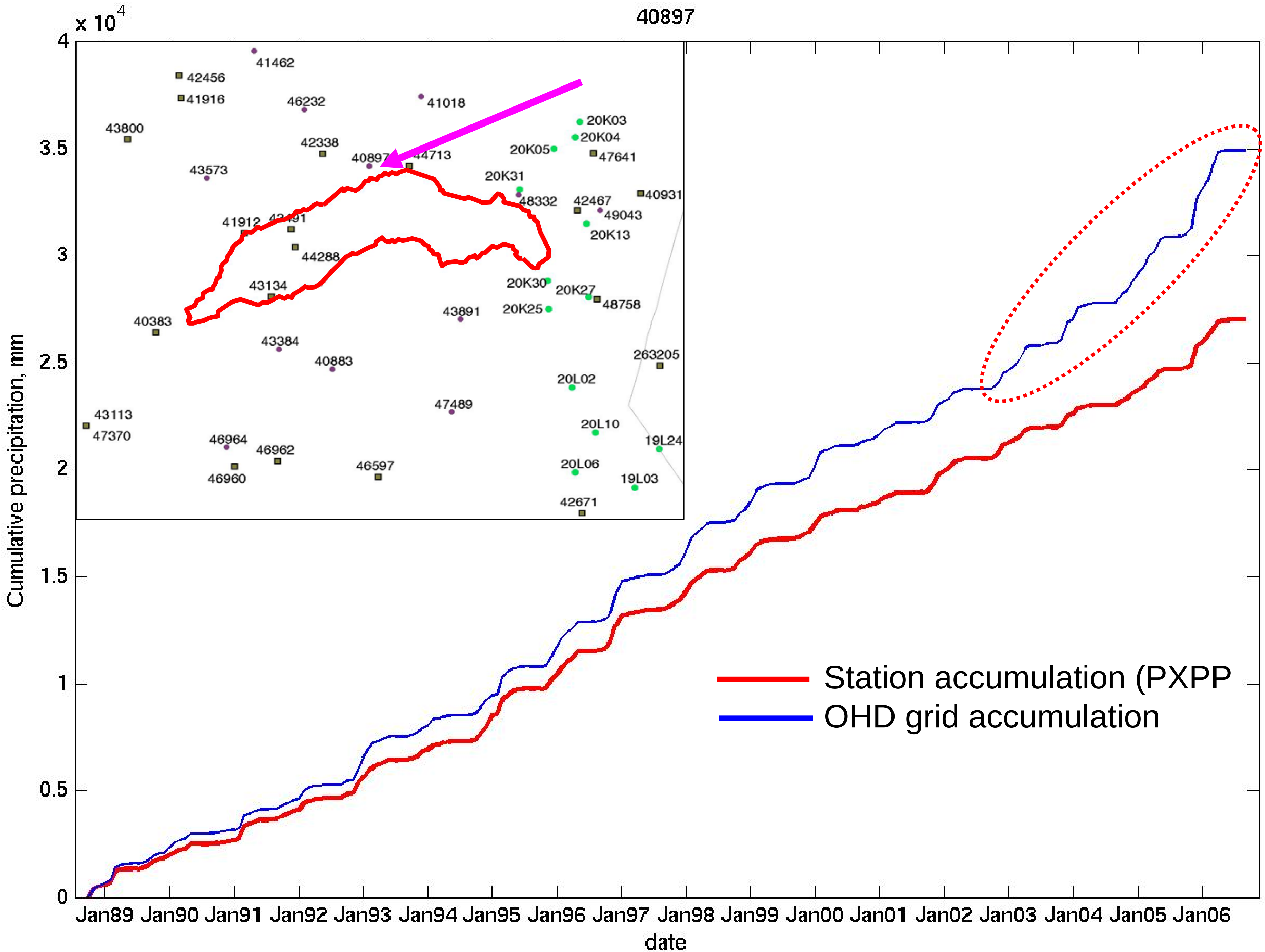
20K25
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
20K03
20K04
42338
20K05
47641
40897
44713
43573
20K31
40931
48332
42467
49043
41912
42491
20K13
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
263205
40883
20L02
47489
43113
47370
20L10
46964
19L24
46962
46597
20L06
46960
19L03
42671


20K31
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
20K03
20K04
42338
20K05
47641
40897
44713
43573
20K31
40931
48332
42467
41912
49043
20K13
44288
20K30
43134
20K27
48758
20K25
43891
40383
43384
263205
40883
20L02
47489
43113
47370
20L10
46964
19L24
46962
46597
20L06
46960
19L03
42671

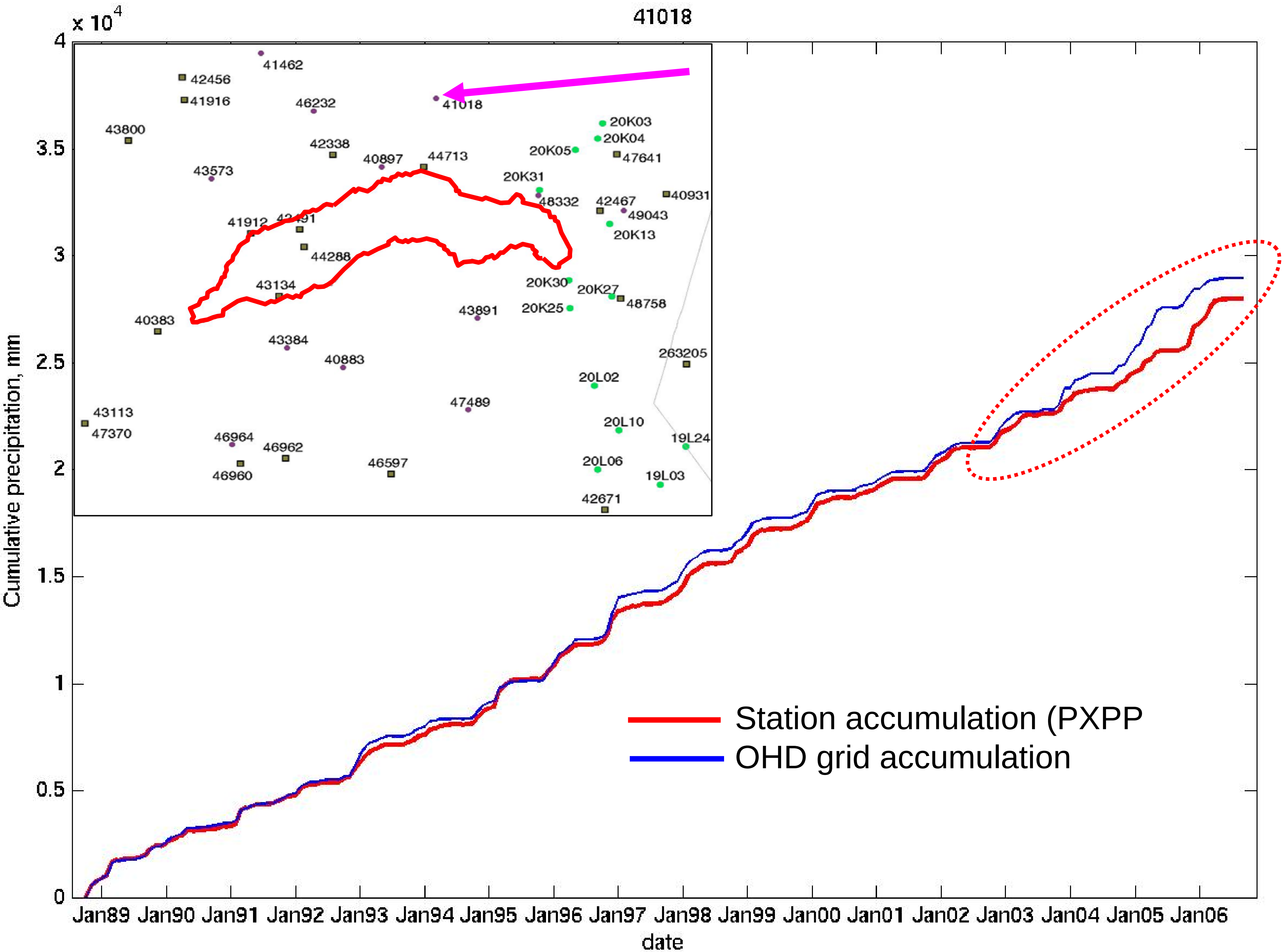

20K30
x 10^4
Cumulative precipitation, mm
0
0.5
1
1.5
2
2.5
3
3.5
4
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
date
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
20K03
20K04
42338
44713
20K05
47641
40897
43573
20K31
40931
48332
42467
49043
41912
42491
20K13
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
263205
40883
20L02
47489
43113
47370
20L10
46964
19L24
46962
46597
20L06
46960
19L03
42671


49043
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
20K03
20K04
20K05
47641
42338
40897
44713
43573
20K31
40931
48332
42467
49043
41912
42491
20K13
44288
20K30
43134
20K27
48758
20K25
43891
40383
43384
263205
40883
20L02
47489
43113
47370
20L10
19L24
46964
46962
20L06
46597
46960
19L03
42671

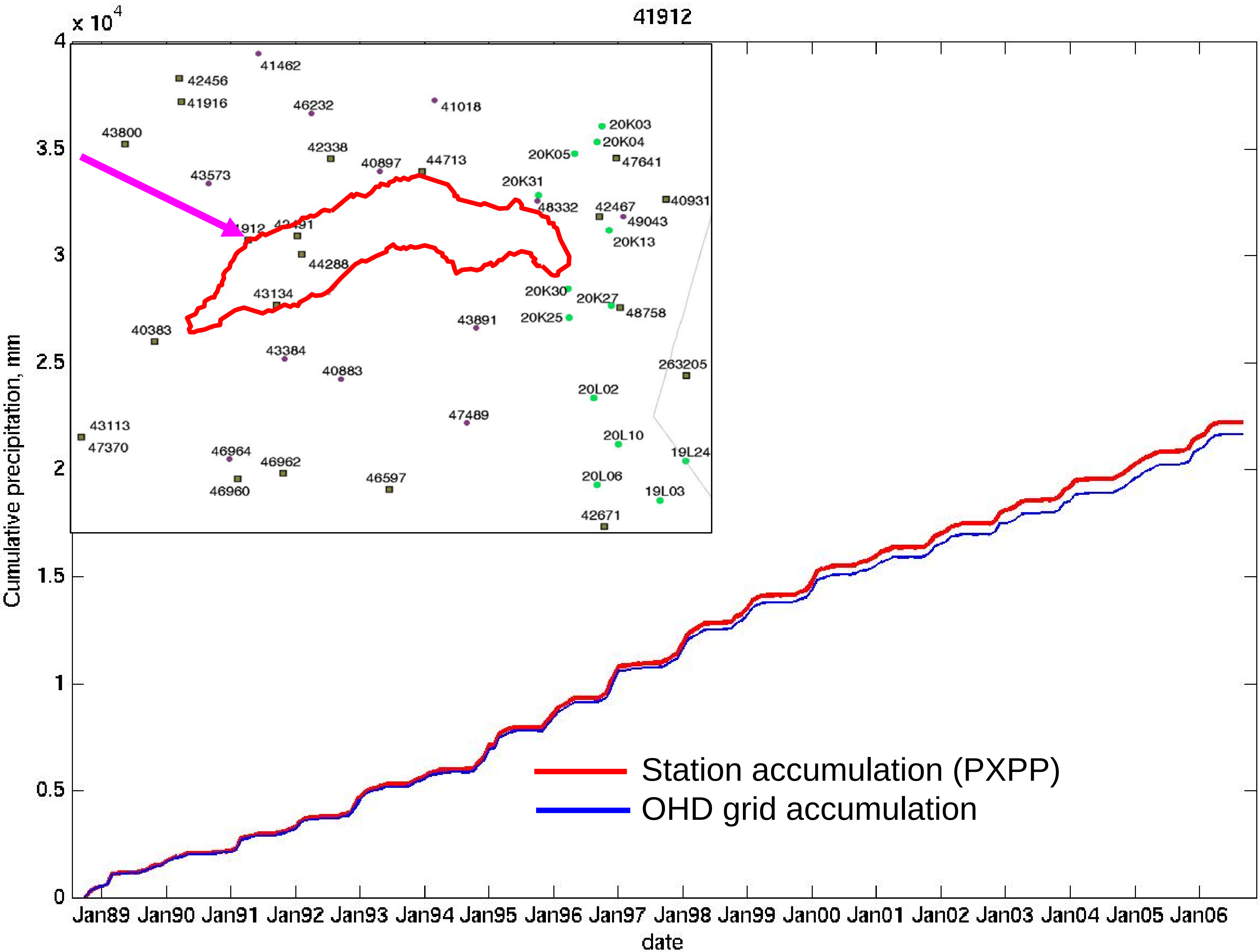

40883
x 10^4
Cumulative precipitation, mm
date
0
0.5
1
1.5
2
2.5
3
3.5
4
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
20K03
20K04
43800
42338
40897
44713
20K05
47641
43573
20K31
48332
42467
40931
41912
42491
49043
20K13
44288
43134
20K30
20K27
48758
43891
20K25
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46597
20L06
46960
19L03
42671

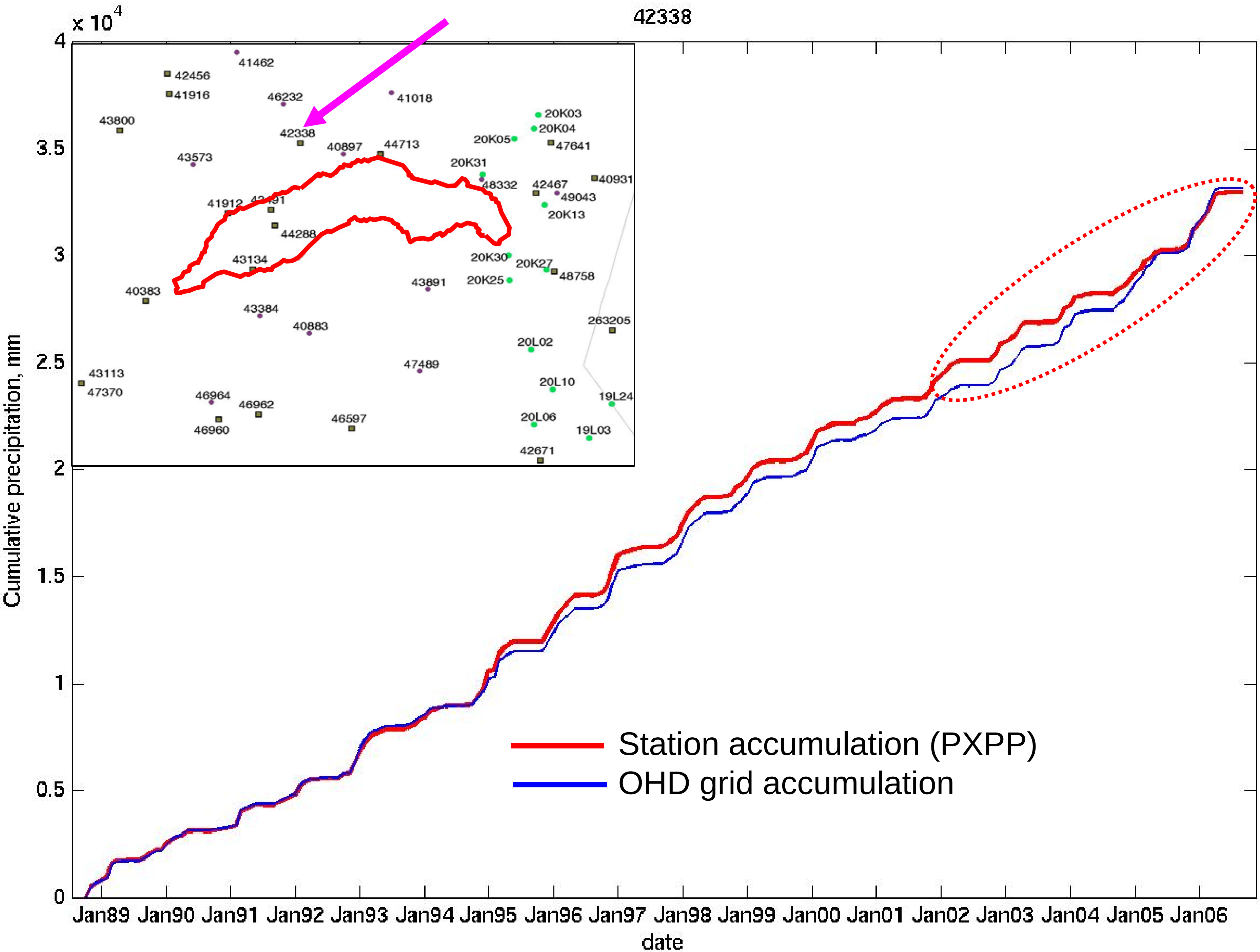


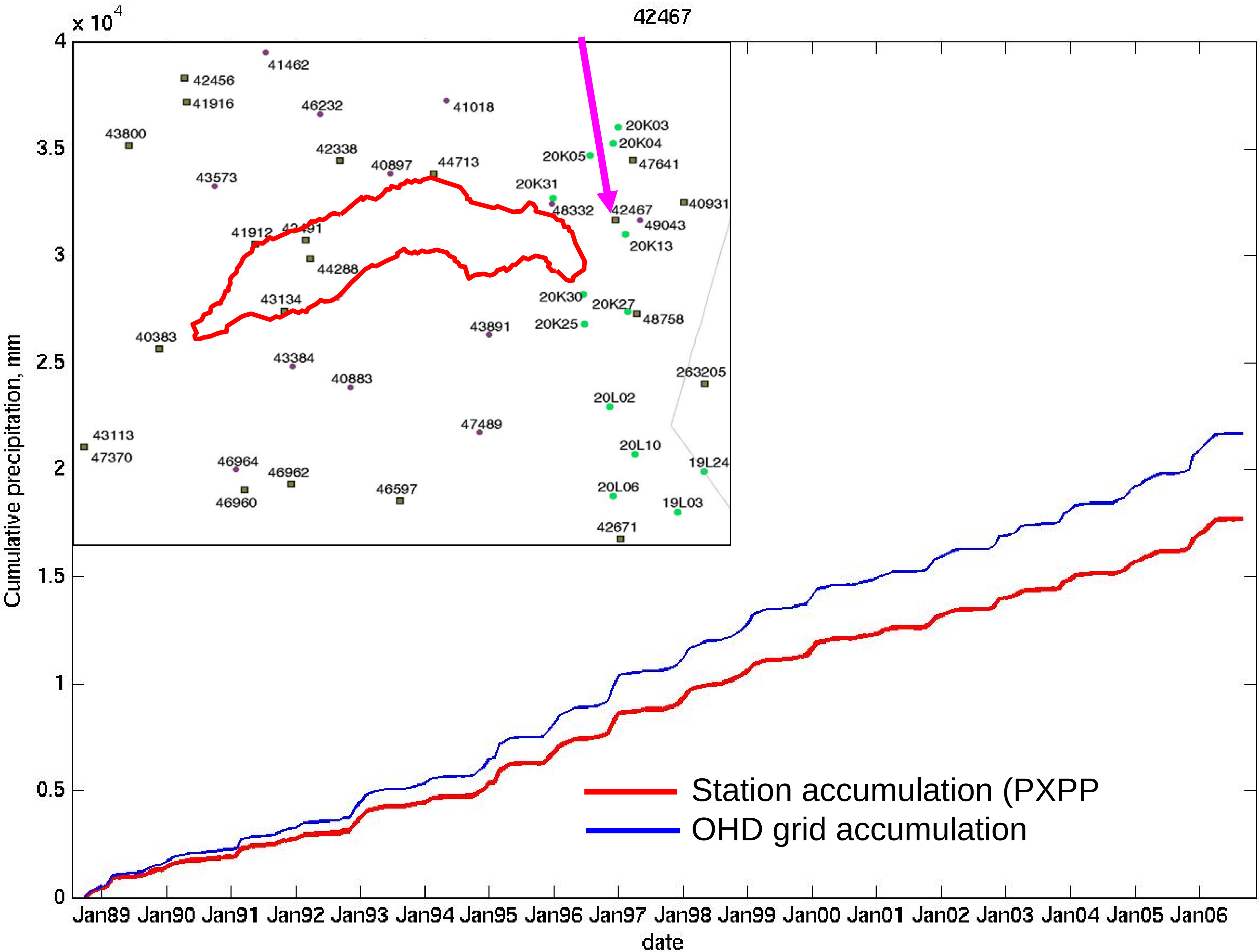
40897
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
43573
20K03
20K04
20K05
47641
20K31
48332
42467
40931
49043
20K13
41912
44288
43134
20K30
20K27
48758
43891
20K25
40383
43384
40883
263205
20L02
47489
43113
47370
46964
46962
20L10
19L24
46960
46597
20L06
19L03
42671

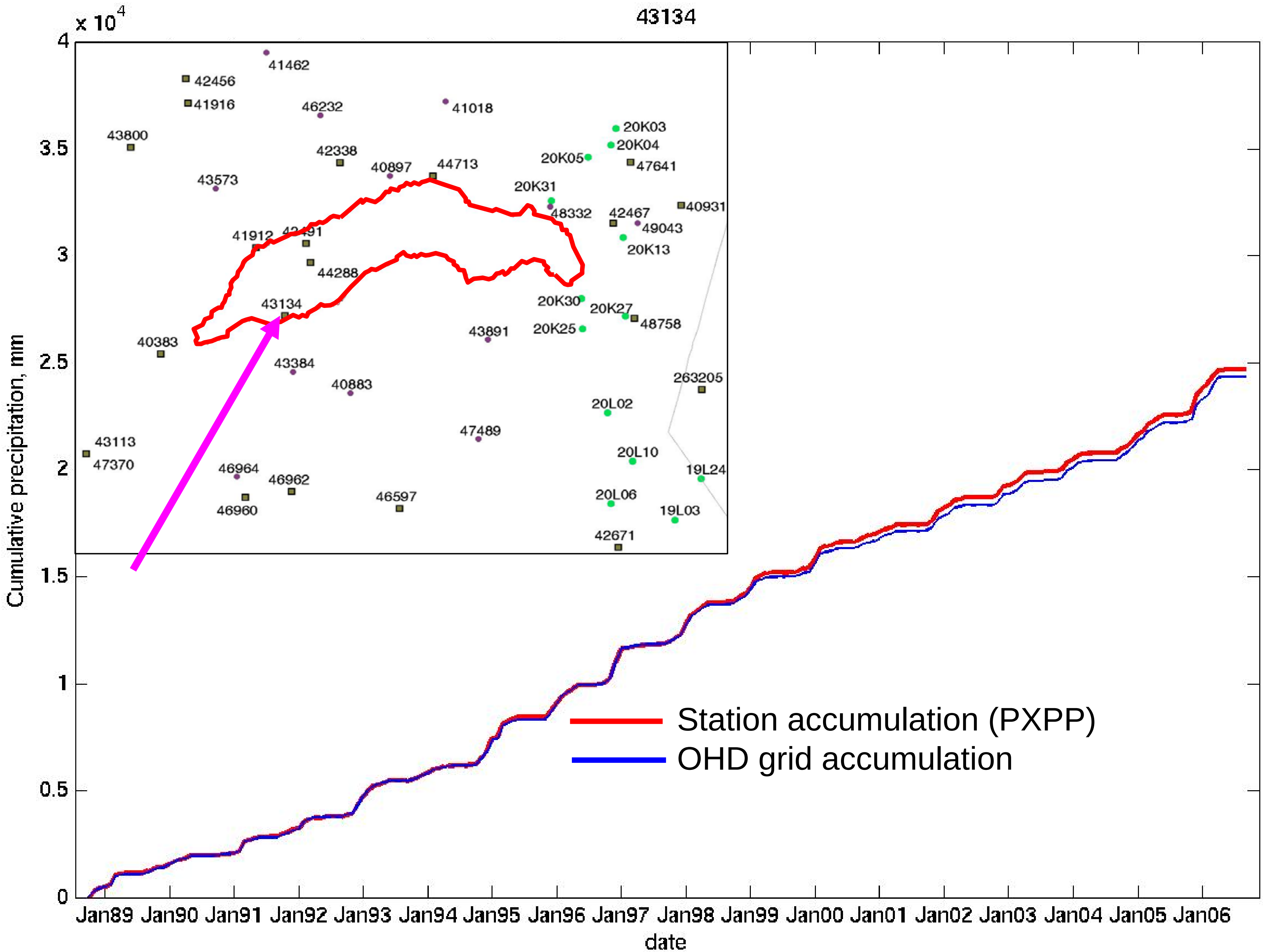


41018
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
Station accumulation (PXPP
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
20K03
20K04
20K05
47641
43573
20K31
48332
42467
40931
49043
20K13
41912
44288
43134
20K30
20K27
48758
43891
20K25
40383
43384
40883
263205
20L02
47489
43113
47370
46964
46962
46960
46597
20L10
19L24
20L06
19L03
42671

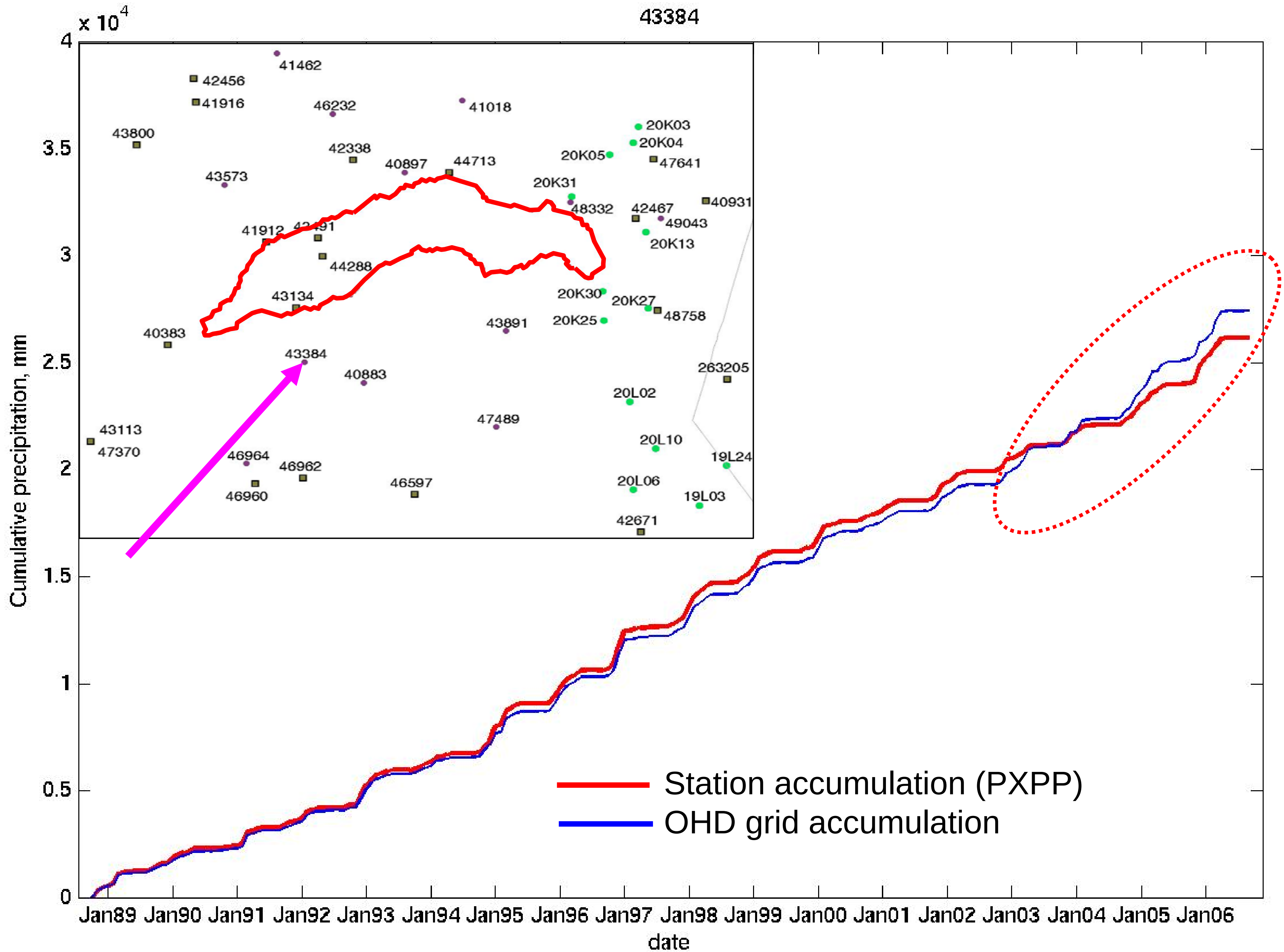

41912
x 10^4
Cumulative precipitation, mm
4
3.5
3
2.5
2
1.5
1
0.5
0
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
date
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
20K03
20K04
20K05
47641
43573
20K31
40931
48332
42467
49043
20K13
44288
43134
20K30
20K27
48758
20K25
40383
43891
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46597
20L06
46960
19L03
42671

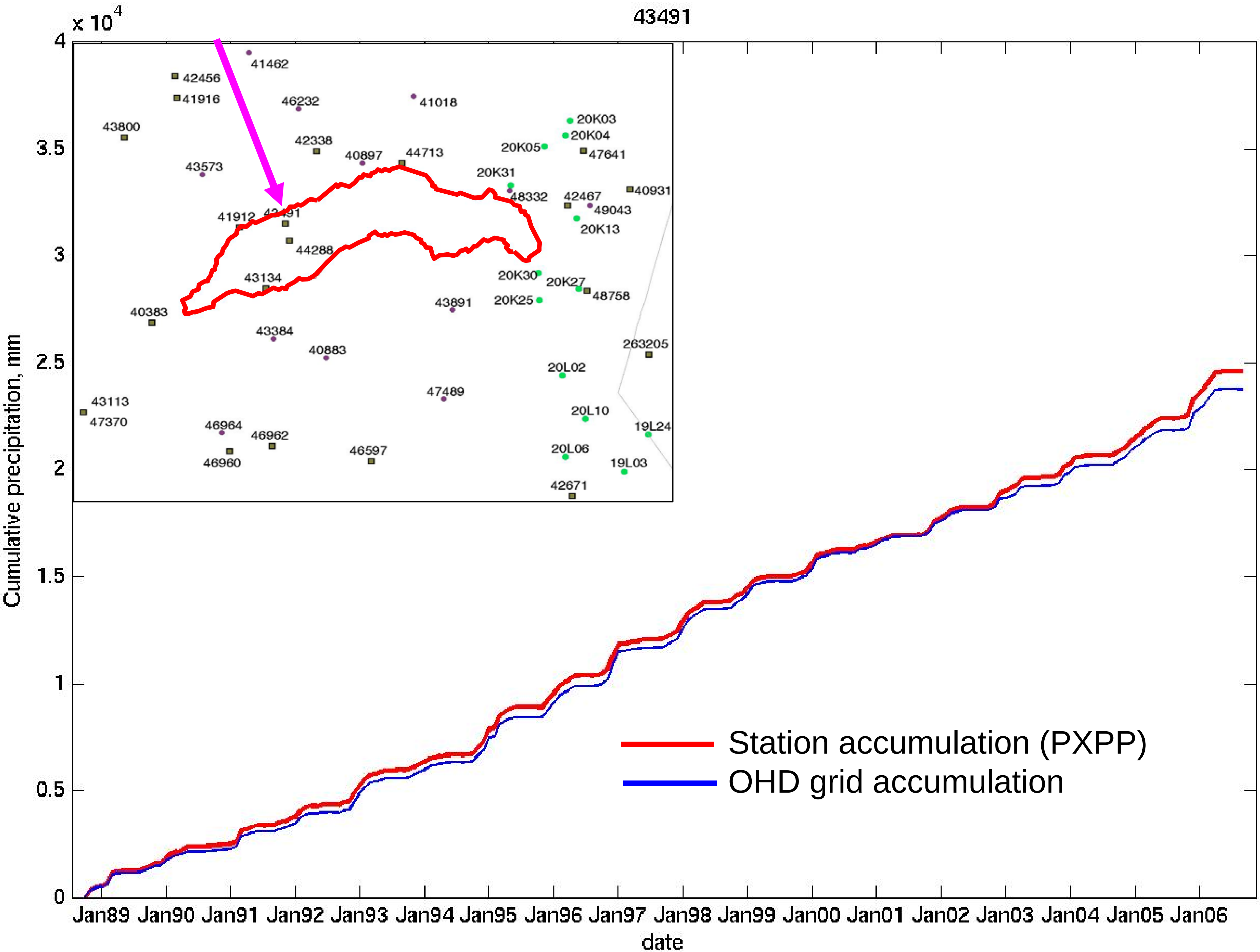

42338
x 10^4
Cumulative precipitation, mm
date
0
0.5
1
1.5
2
2.5
3
3.5
4
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
20K03
20K04
20K05
47641
43573
20K31
48332
42467
40931
49043
20K13
41912
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46597
20L06
46960
19L03
42671


42467
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
43573
20K03
20K04
20K05
47641
20K31
48332
42467
40931
49043
20K13
41912
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
46964
46962
20L10
19L24
46960
46597
20L06
19L03
42671

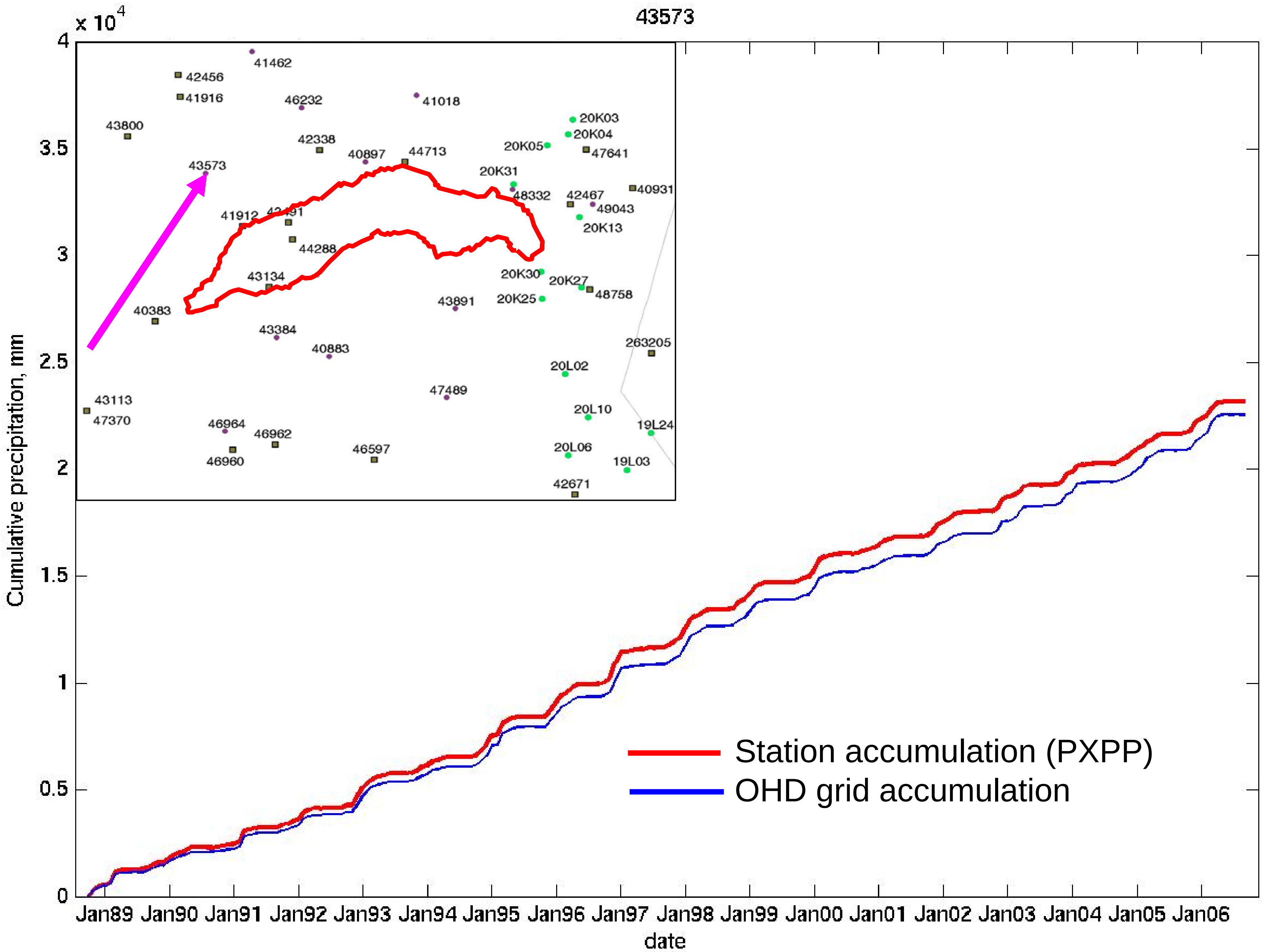


43134
x 10^4
Cumulative precipitation, mm
date
Station accumulation (PXPP)
OHD grid accumulation
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
41462
42456
41916
46232
41018
43800
42338
40897
44713
43573
20K03
20K04
20K05
47641
20K31
48332
42467
49043
40931
20K13
41912
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
19L24
46964
46962
46597
46960
20L06
19L03
42671

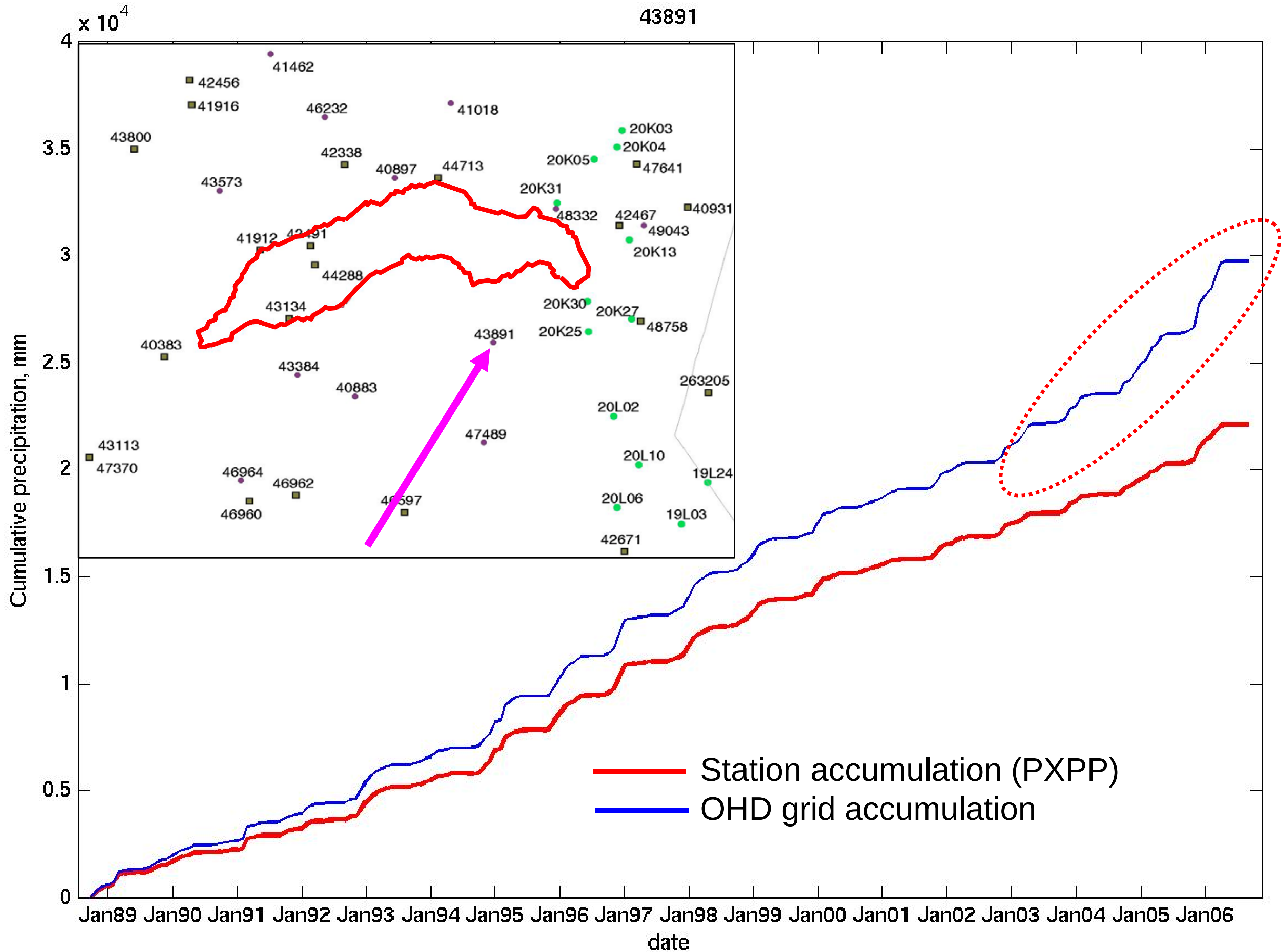

43384
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
20K03
20K04
20K05
47641
43573
20K31
48332
42467
40931
49043
20K13
41912
44288
43134
20K30
20K27
20K25
48758
40383
43891
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46960
46597
20L06
19L03
42671

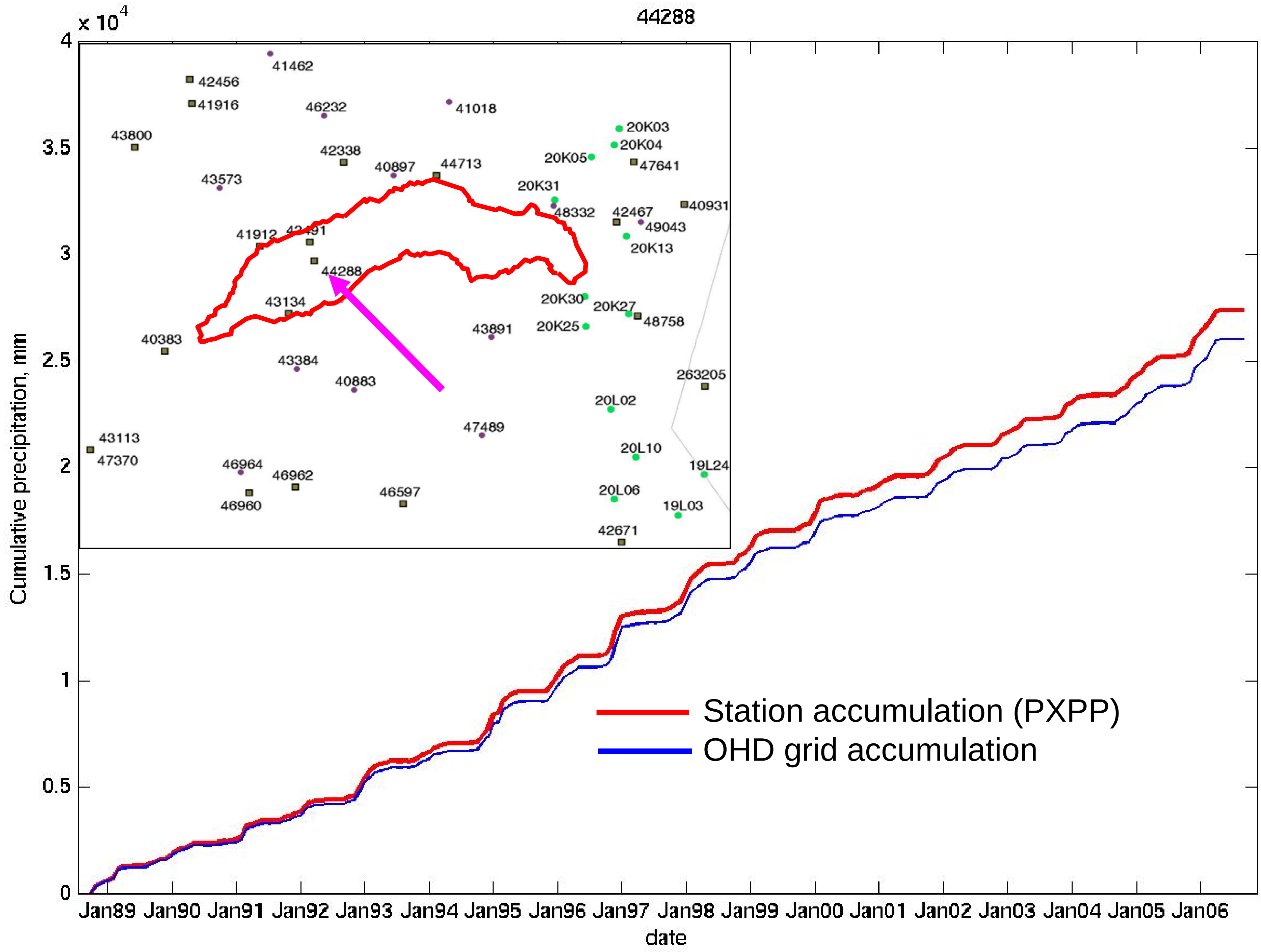


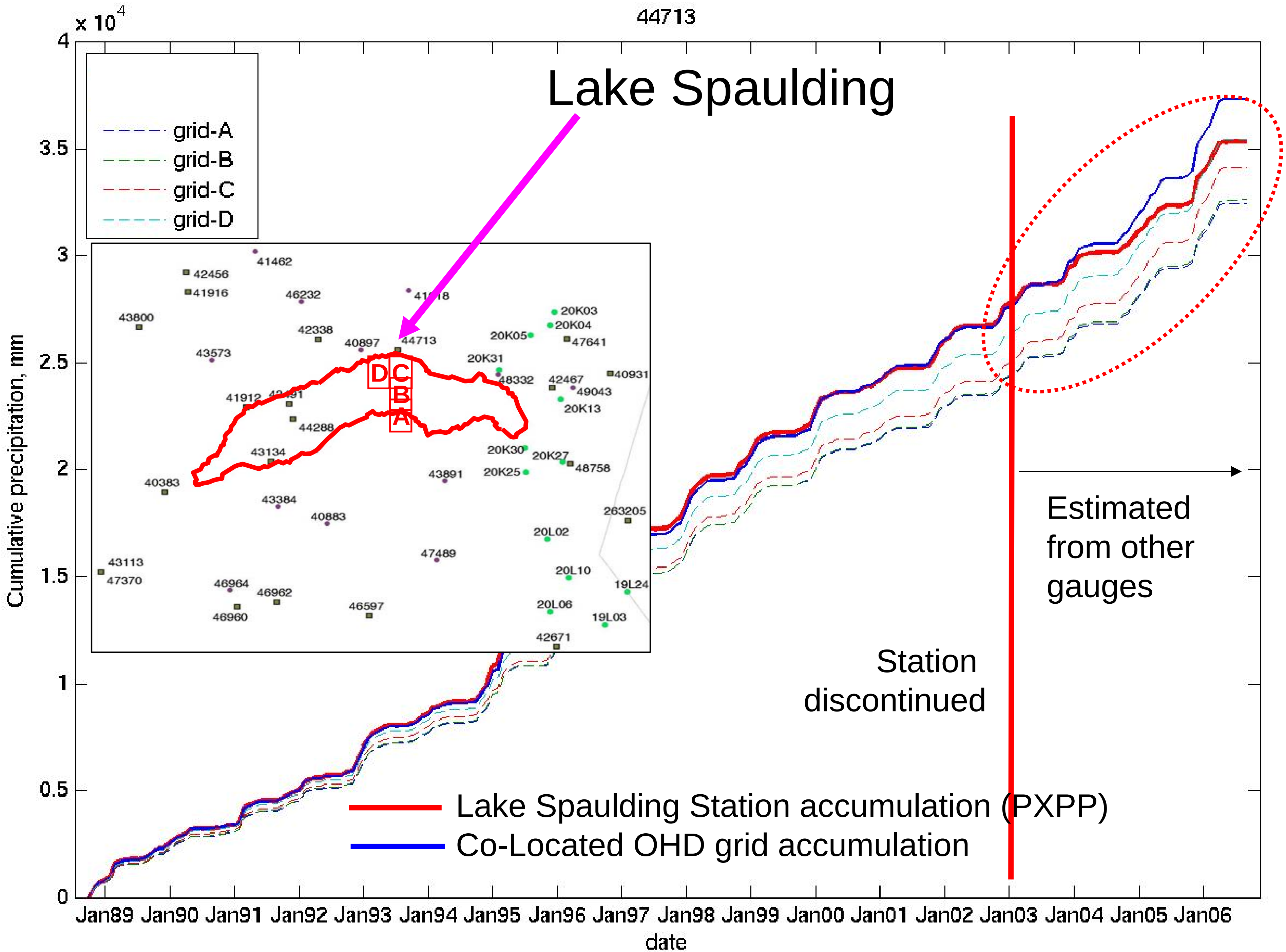
43491
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
43573
20K03
20K04
20K05
47641
20K31
48332
42467
49043
40931
20K13
41912
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46597
20L06
46960
19L03
42671



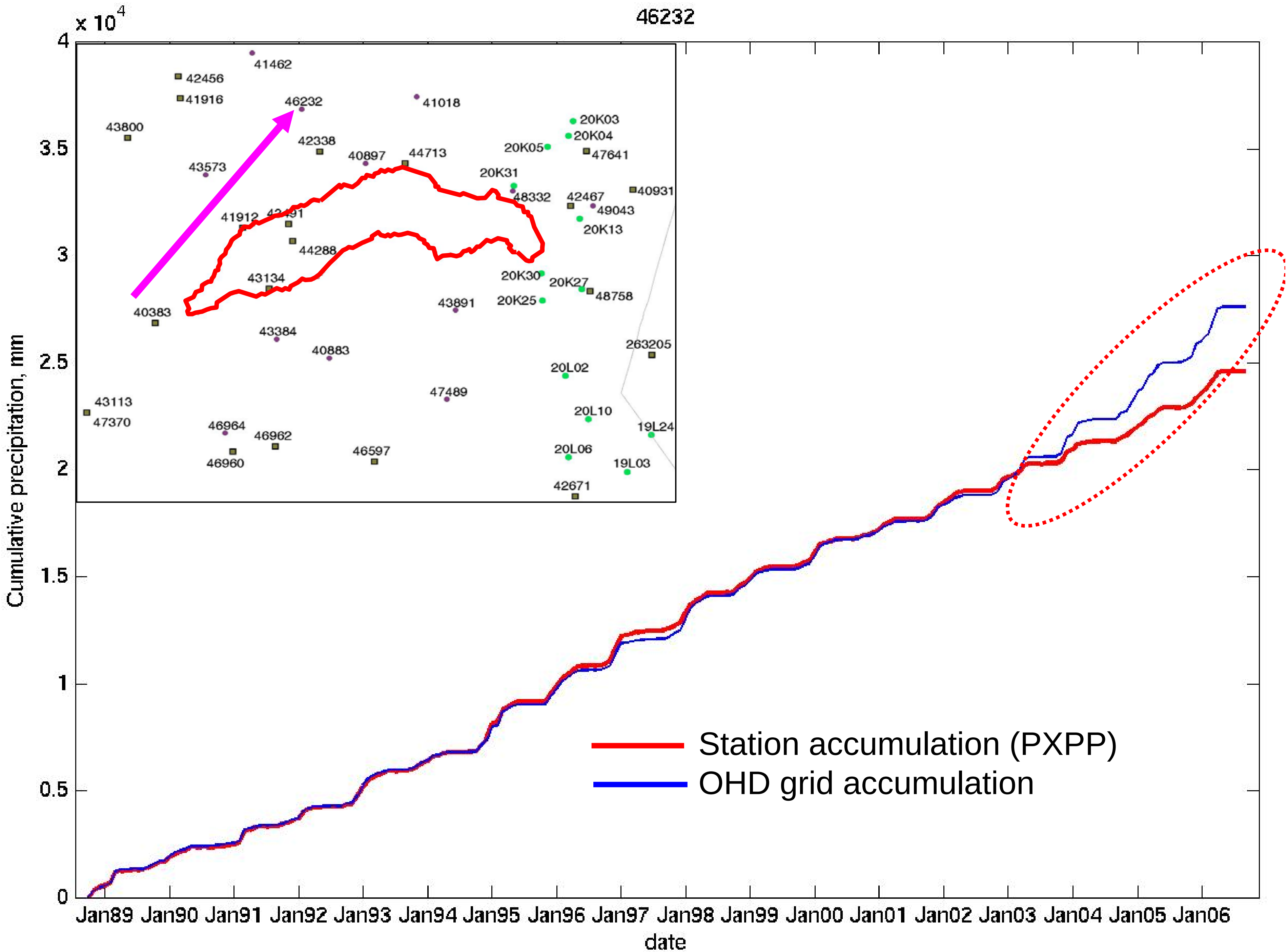
43573
x 10^4
Cumulative precipitation, mm
date
0
0.5
1
1.5
2
2.5
3
3.5
4
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
20K03
20K04
42338
20K05
47641
40897
44713
43573
20K31
40931
48332
42467
49043
41912
20K13
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46597
20L06
46960
19L03
42671


43891
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
43573
20K03
20K04
20K05
47641
20K31
48332
42467
40931
49043
20K13
41912
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46960
20L06
19L03
42671

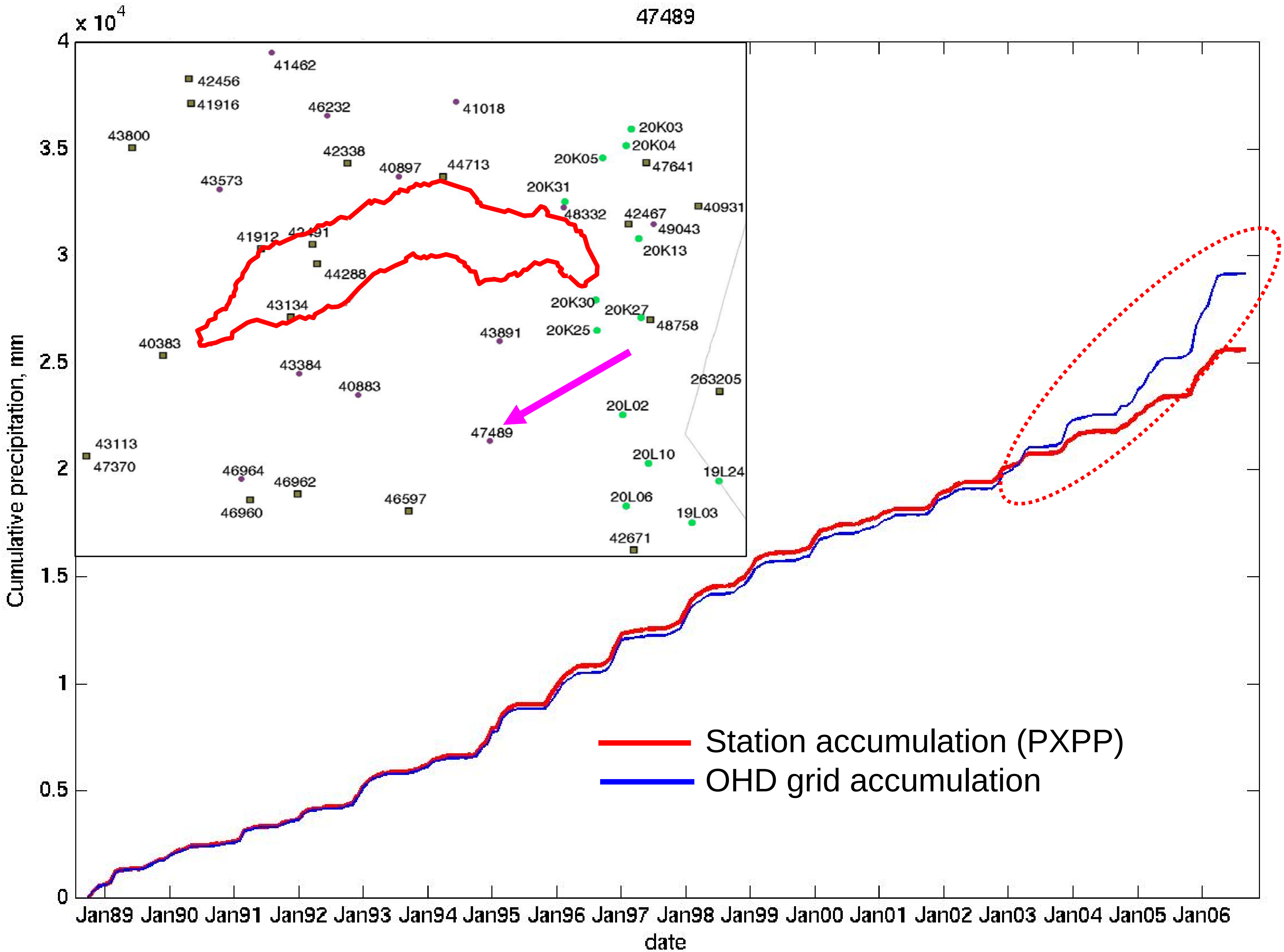

44288
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
20K03
20K04
43800
42338
40897
44713
20K05
47641
43573
20K31
40931
48332
42467
49043
41912
20K13
44288
43134
20K30
20K27
48758
43891
20K25
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46597
20L06
46960
19L03
42671



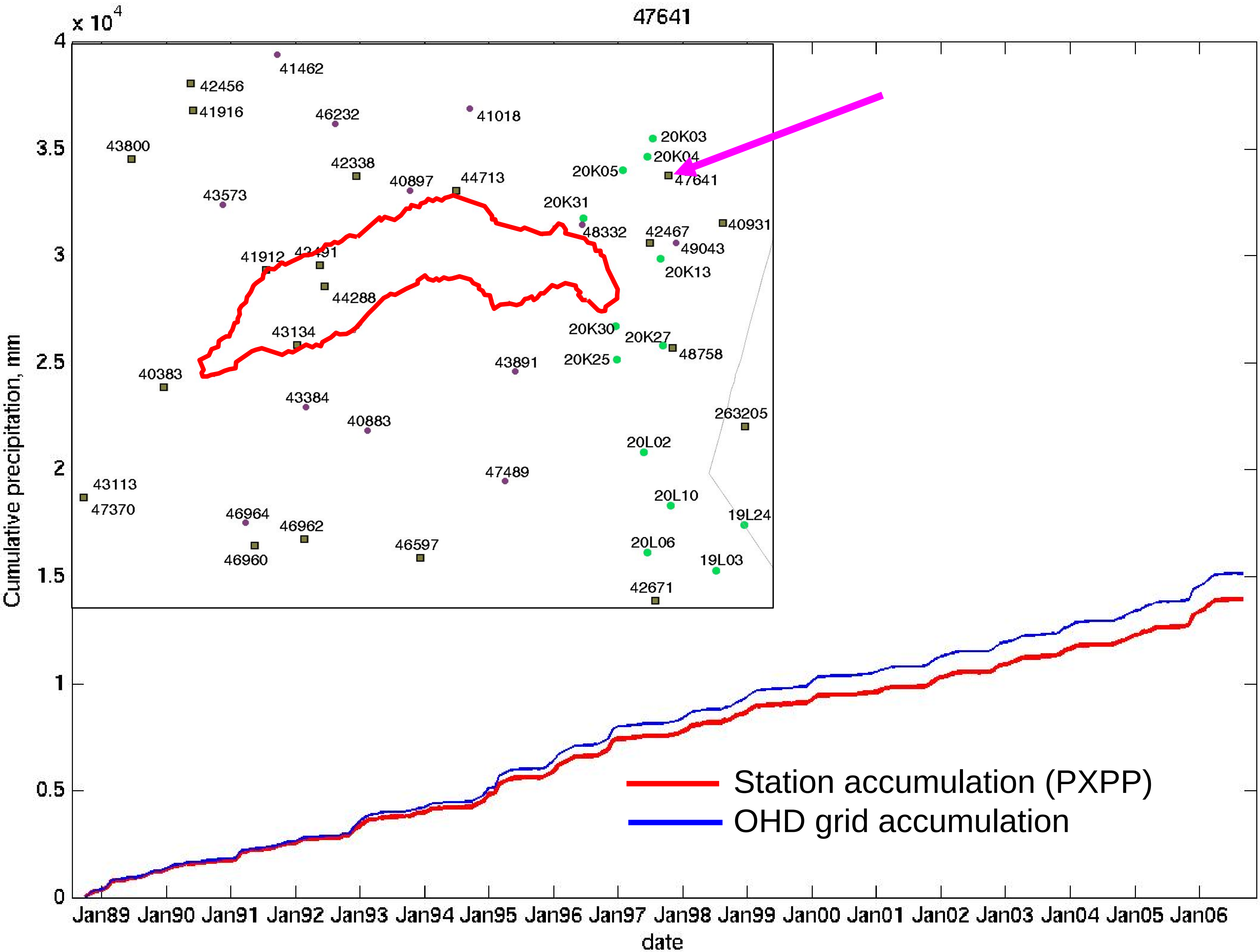
44713
Lake Spaulding
x 10^4
grid-A
grid-B
grid-C
grid-D
Cumulative precipitation, mm
date
Estimated from other gauges
Station discontinued
Lake Spaulding Station accumulation (PXPP)
Co-Located OHD grid accumulation
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06

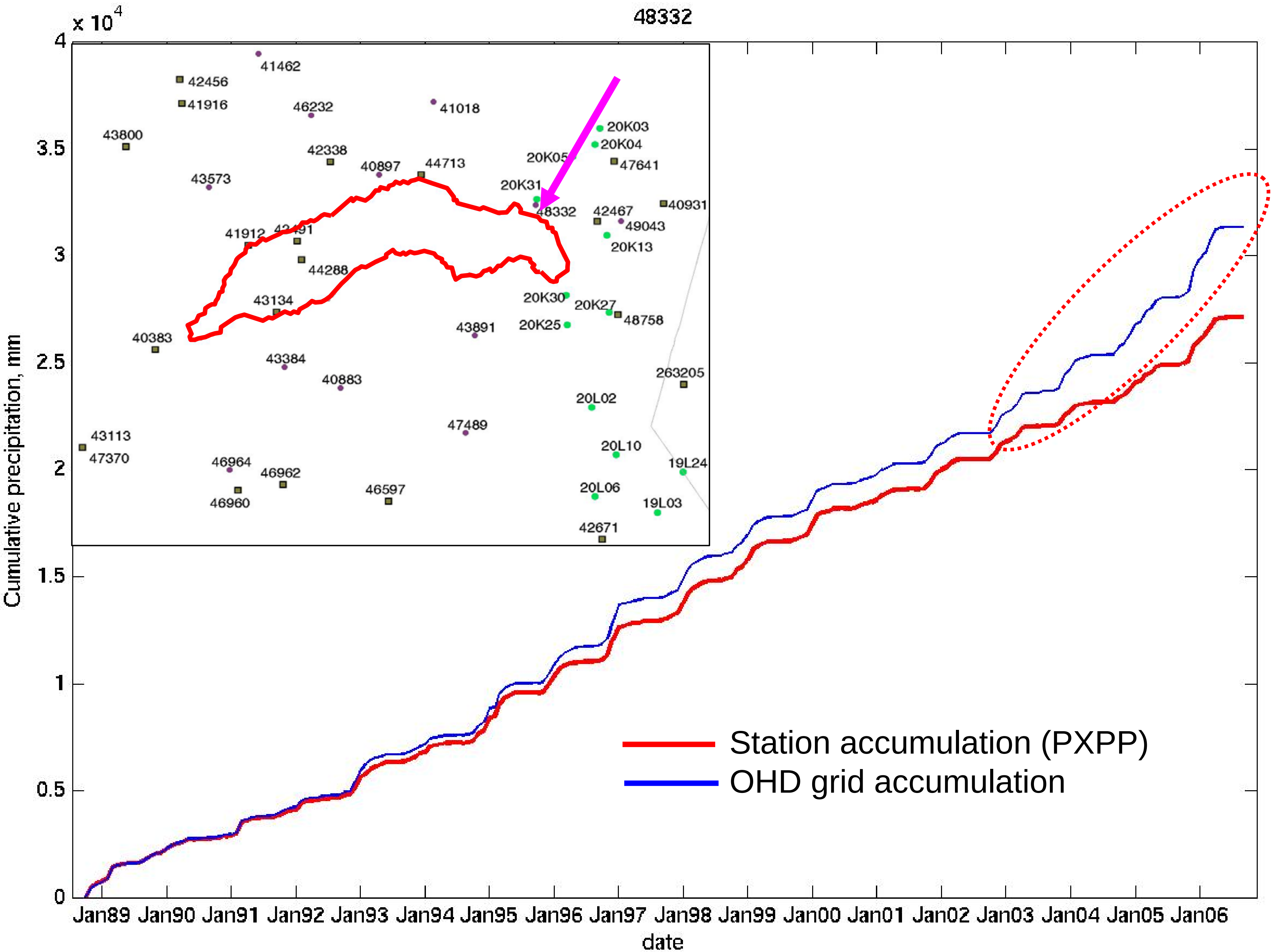


46232
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
43573
20K03
20K04
20K05
47641
20K31
48332
42467
40931
49043
20K13
41912
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
19L24
46964
46962
46597
20L06
46960
19L03
42671



47489
x 10^4
Cumulative precipitation, mm
date
Station accumulation (PXPP)
OHD grid accumulation
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
41462
42456
41916
46232
41018
43800
42338
40897
44713
20K03
20K04
20K05
47641
43573
20K31
48332
42467
40931
49043
20K13
41912
42491
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
46964
46962
46960
46597
20L10
19L24
20L06
19L03
42671

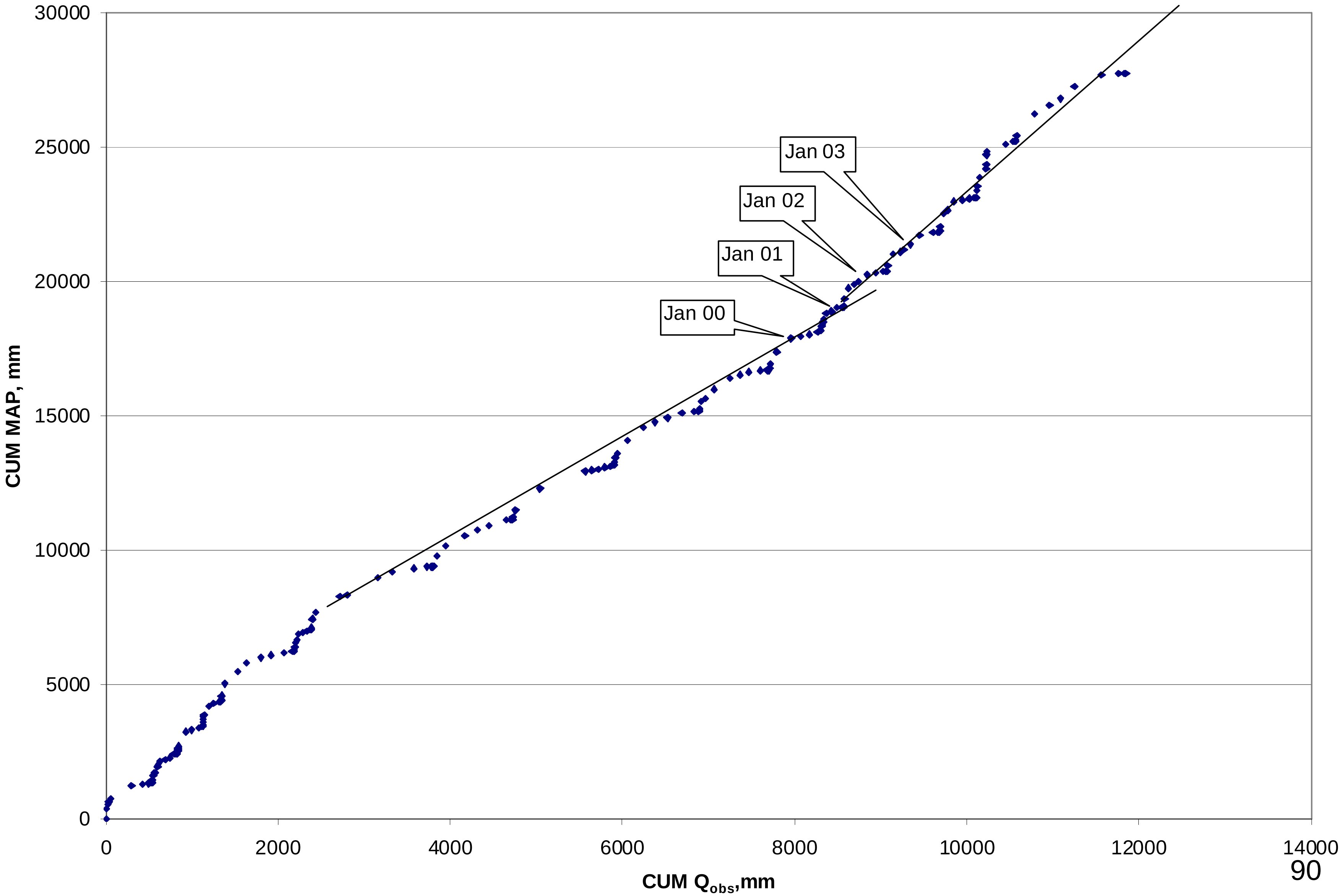

47641
x 10^4
Cumulative precipitation, mm
date
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
0 0.5 1 1.5 2 2.5 3 3.5 4
Station accumulation (PXPP)
OHD grid accumulation
41462
42456
41916
46232
41018
43800
42338
40897
44713
43573
20K03
20K04
20K05
47641
20K31
48332
42467
49043
40931
41912
20K13
44288
43134
20K30
20K27
48758
20K25
43891
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
19L24
46962
46597
20L06
46960
19L03
42671


48332
x 10^4
Cumulative precipitation, mm
date
Station accumulation (PXPP)
OHD grid accumulation
0
0.5
1
1.5
2
2.5
3
3.5
4
Jan89 Jan90 Jan91 Jan92 Jan93 Jan94 Jan95 Jan96 Jan97 Jan98 Jan99 Jan00 Jan01 Jan02 Jan03 Jan04 Jan05 Jan06
41462
42456
41916
46232
41018
43800
20K03
20K04
42338
40897
44713
20K05
47641
43573
20K31
48332
42467
40931
49043
41912
20K13
44288
20K30
20K27
43134
48758
43891
20K25
40383
43384
40883
263205
20L02
47489
43113
47370
20L10
46964
46962
19L24
46597
20L06
46960
19L03
42671

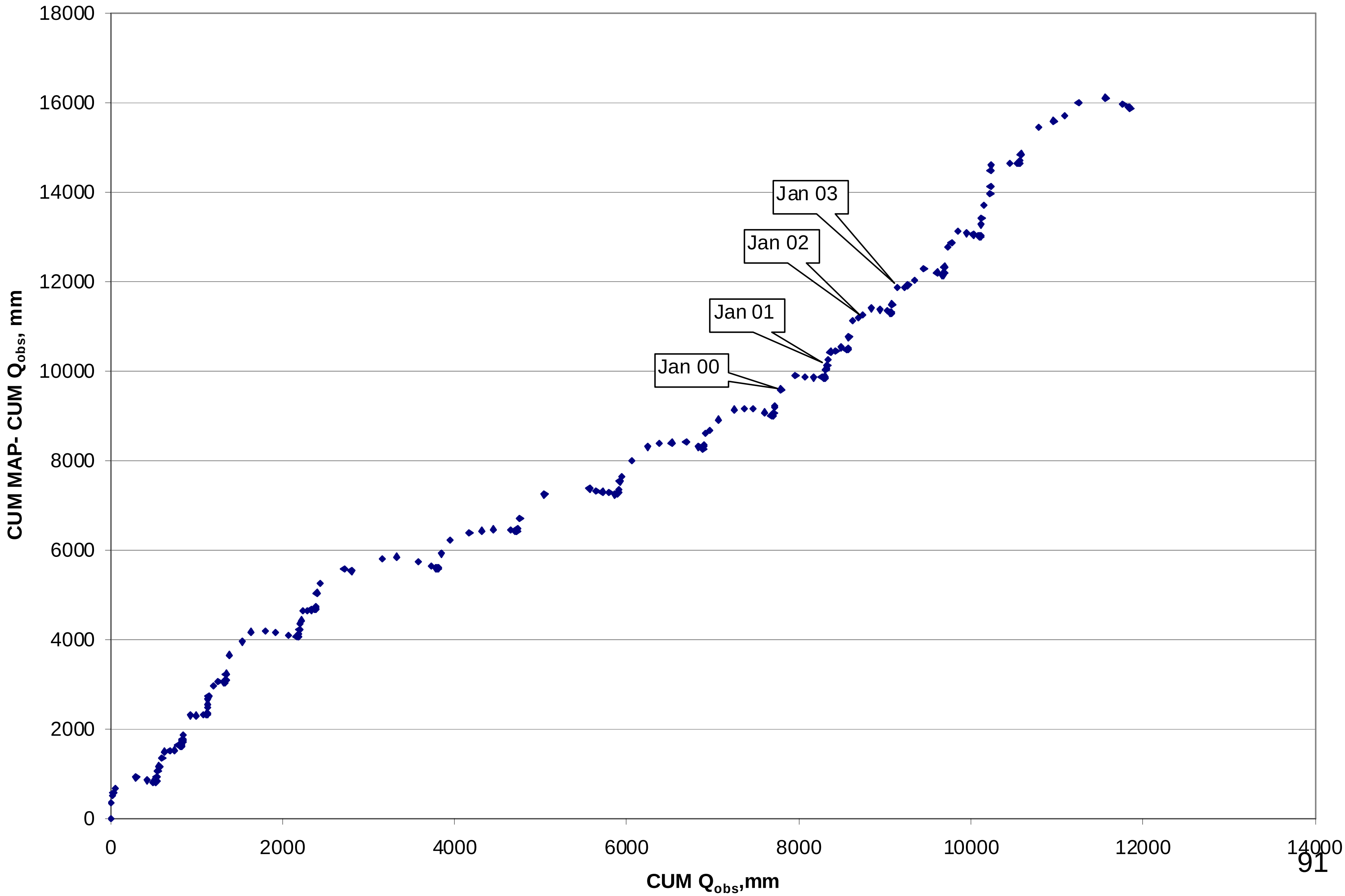
3. Double Mass Analysis: OHD QPE to Observed North Fork Streamflow

- Assumption: real changes in precipitation 'catch' should be reflected in the streamflow record
- Convert observed streamflow to mm depth over basin per time
  - 1. Plot accumulated OHD basin-ave QPE versus accumulated observed flow
  - 2. Use NWS approach: plot deviation of OHD basin-ave QPE from obs. flow versus accumulated observed flow to highlight trends

1. Accumulated OHD Basin-ave. QPE versus Accumulated Observed Flow



2. Deviation of OHD QPE from Observed Flow versus Accumulated Observed Flow



Conclusions

- OHD gridded QPE is inconsistent over time after 2003
- Potential causes:
  - Problems interpolating gridded data after Lake Spaulding gage stopped reporting
  - $1/d^{1/2}$ weighting used to interpolate grids