Dual Cloud Seeding Operations in Texas: an update

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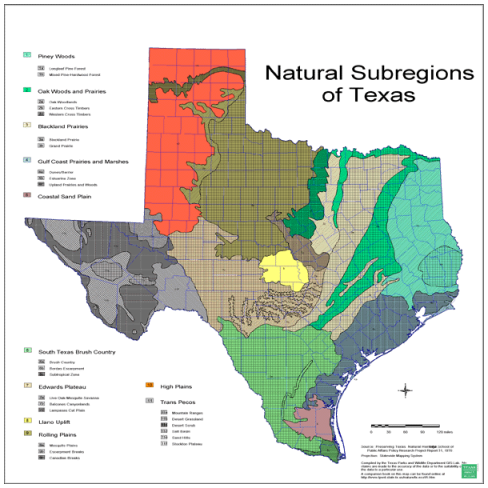
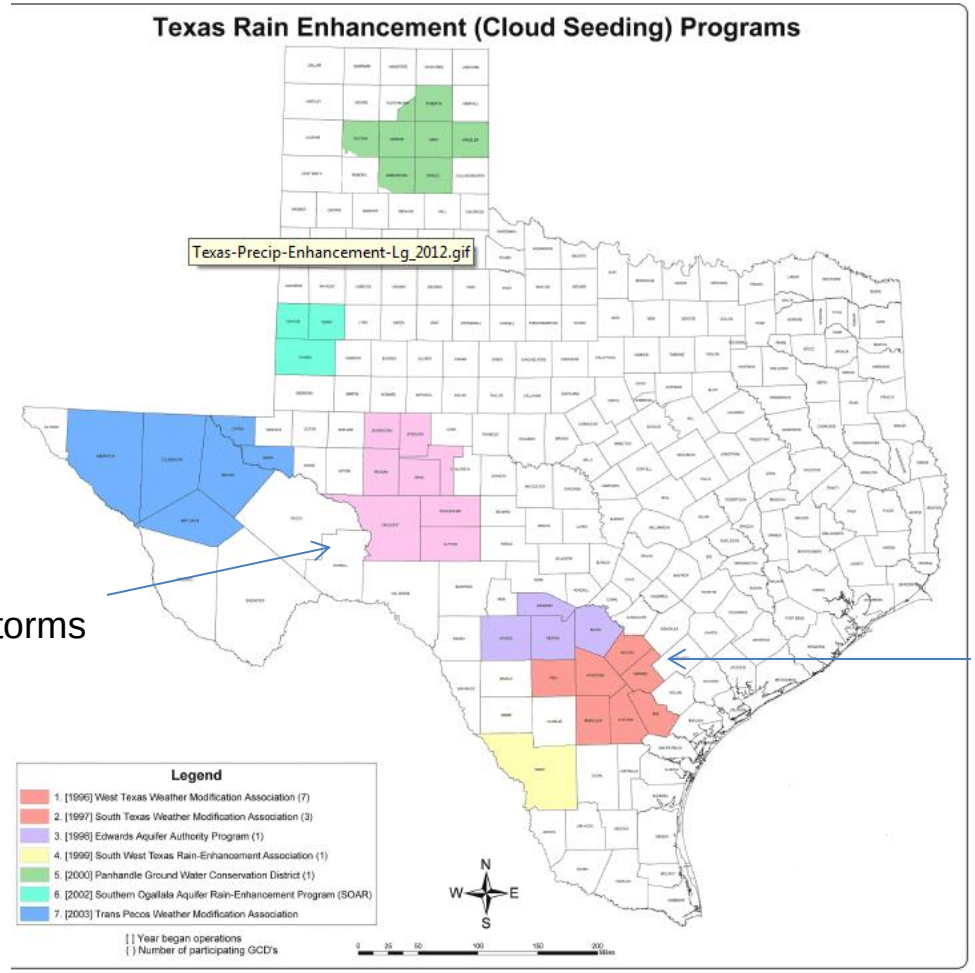


After a timid beginning (2009-2011) at an exploratory level, dual seeding operations in Texas (the use of both hygroscopic and glaciogenic flares) have become an important component of the operational design. The systematic evaluation of those operations using TITAN has led to a noticeable body of evidence on the suspected synergy between hygroscopic and glaciogenic materials in convective clouds for precipitation enhancement purposes. This presentation offers an update of those evidences.

The WTWMA (san Angelo) and the STWMA (Pleasanton) Projects used dual seeding within the years 2011-2013:



2011-2013
Dual seeding:55 small storms
Only glaciogenic: 166

221 small storms

2011-2013
Dual seeding: 65 small storms
Only glaciogenic: 127

192 small storms

A1. Results for WTWMA (San Angelo): AgI seeding: 166 cases

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	45 min	1.33	33 (**20**)
Area	63.4 km^2	44.6 km^2	1.42	42 (**34**)
Volume	234.4 km^3	156.5 km^3	1.50	50 (**37**)
Top Height	9.0 km	8.6 km	1.05	5 (**2**)
Max dBz	51.5	49.7	1.04	4 (**3**)
Top Height of max dBz	3.93 km	3.93 km	1.00	0 (**1**)
Volume Above 6 km	73.5 km^3	46.1 km^3	1.59	59 (**36**)
Prec.Flux	414.3 m^3/s	257.6 m^3/s	1.61	61 (**35**)
Prec.Mass	1796.3 kton	828.3 kton	2.17	117 (**92**)
CloudMass	155.5 kton	97.5 kton	1.59	59 (**36**)
η	11.6	8.5	1.36	36 (**41**)

AgI flares: 788, ~4.75 per storm

Timing: 86 %

<d>= 20 icn/liter

mar= -3.95

A2. Results for WTWMA (San Angelo): dual seeding: 55 cases

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	70 min	50 min	1.40	40 (**27**)
Area	77.1 km^2	53.4 km^2	1.44	44 (**41**)
Volume	300.6 km^3	217.5 km^3	1.38	38 (**33**)
Top Height	9.7 km	9.2 km	1.05	5 (**1**)
Max dBz	51.6	49.7	1.04	4 (**3**)
Top Height of max dBz	4.05 km	4.11 km	0.99	-1 (**- 6**)
Volume Above 6 km	109.7 km^3	87.4 km^3	1.26	26 (**17**)
Prec.Flux	515.3 m^3/s	301.6 m^3/s	1.71	71 (**35**)
Prec.Mass	2340.3 kton	1057.9 kton	2.21	121 (**104**)
CloudMass	199.8 kton	134.2 kton	1.49	49 (**33**)
η	11.7	7.9	1.48	48 (**52**)

AgI flares: 367, ~6.67 per storm

Hygro flares: 69

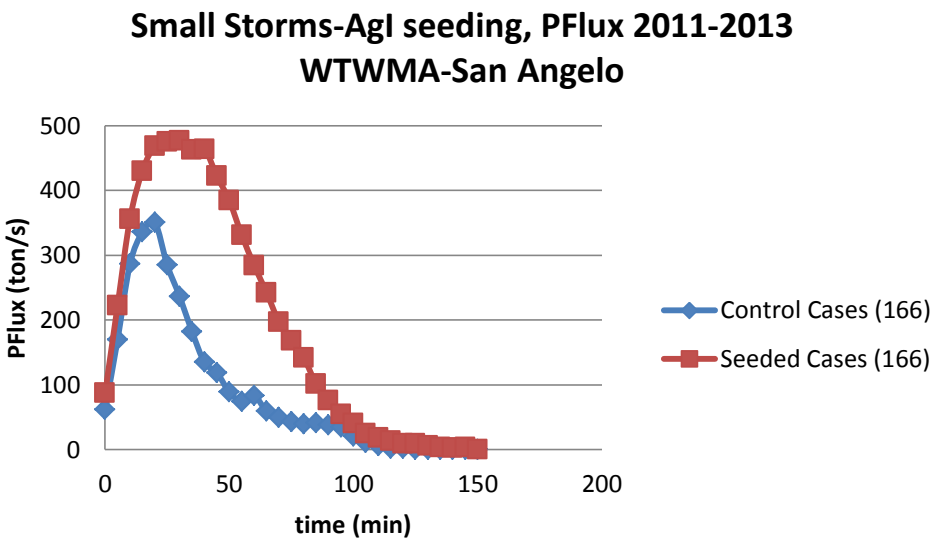
Timing: 91 %

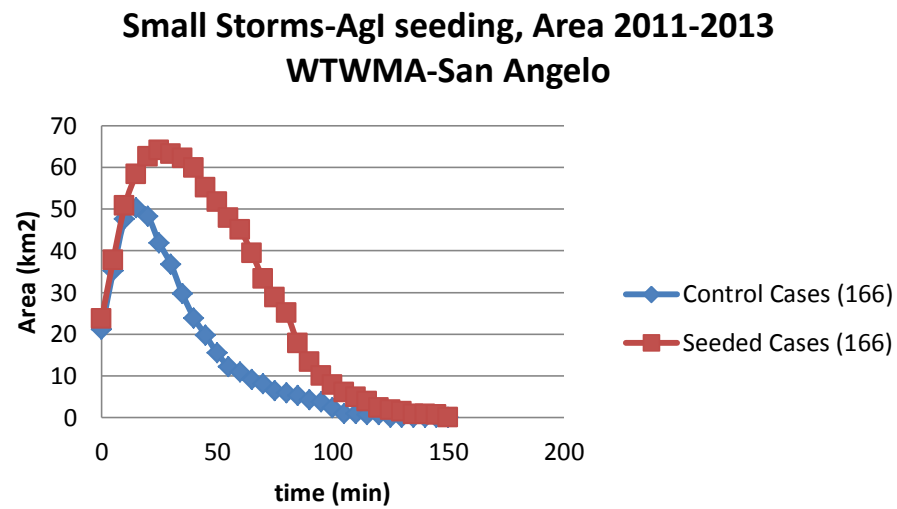
<d>= 20 icn/liter

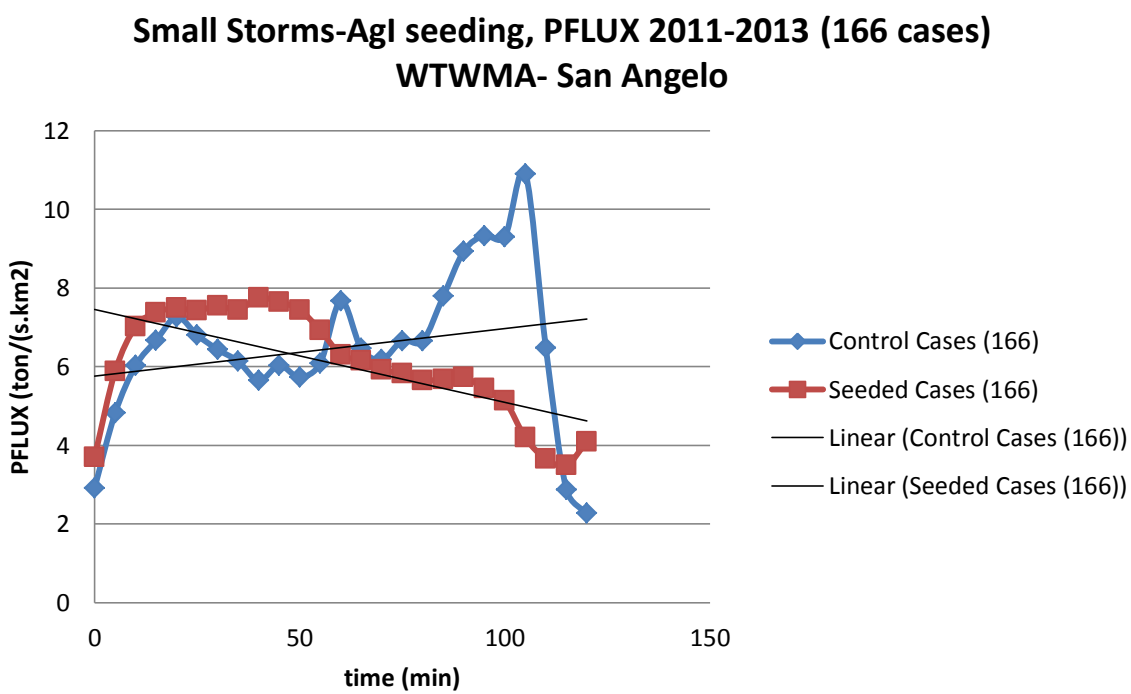
mar= -3.78

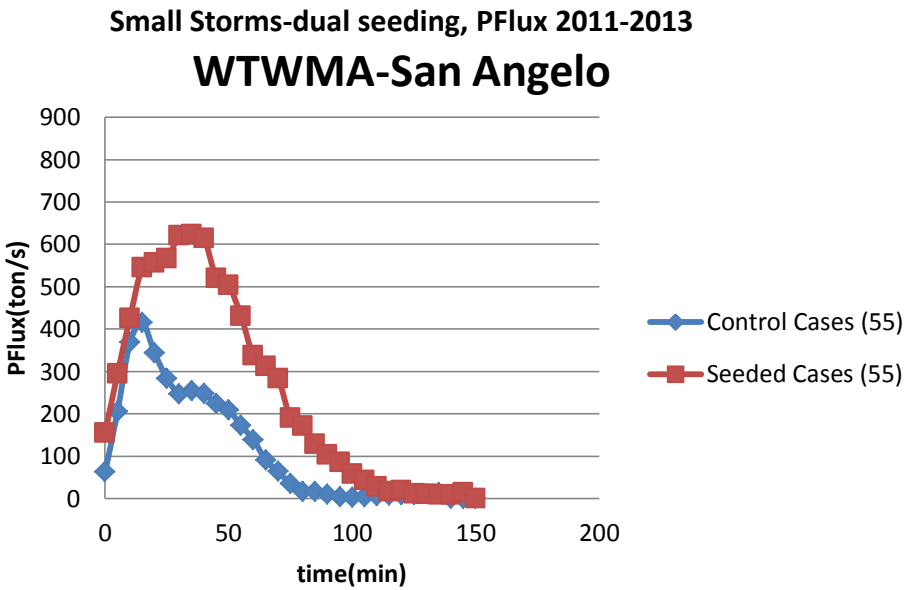
A3.Double Ratios: dual/AgI

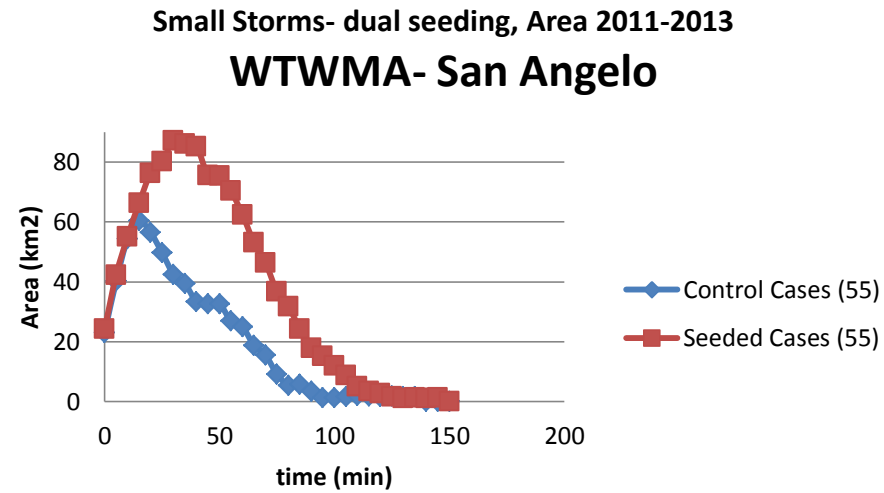
Lifetime:	1.27/1.20 ≈ 1.06
Area	1.41/1.05 ≈ 1.05
Volume	1.33/1.37 ≈ 0.97
Volume ab. 6km	1.17/1.36 ≈ 0.86
Pflux	1.35/1.35 = 1.00
Pmass	2.04/1.92 ≈ 1.06

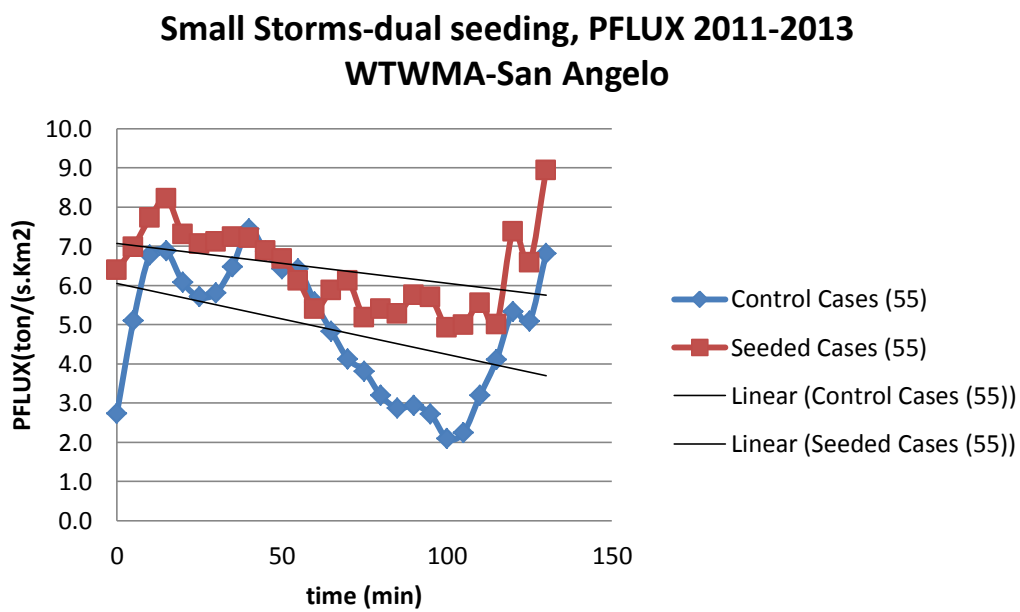

Small Storms-AgI seeding, PFlux 2011-2013
WTWMA-San Angelo
PFlux (ton/s)
500
400
300
200
100
0
0
50
100
150
200
time (min)
Control Cases (166)
Seeded Cases (166)


Small Storms-AgI seeding, Area 2011-2013
WTWMA-San Angelo
Area (km2)
70
60
50
40
30
20
10
0
0
50
100
150
200
time (min)
Control Cases (166)
Seeded Cases (166)


Small Storms-AgI seeding, PFLUX 2011-2013 (166 cases)
WTWMA- San Angelo
PFLUX (ton/(s.km2)
12
10
8
6
4
2
0
0
50
100
150
time (min)
Control Cases (166)
Seeded Cases (166)
Linear (Control Cases (166))
Linear (Seeded Cases (166))


Small Storms-dual seeding, PFlux 2011-2013
WTWMA-San Angelo
PFlux(ton/s)
900
800
700
600
500
400
300
200
100
0
0
50
100
150
200
time(min)
Control Cases (55)
Seeded Cases (55)


Small Storms- dual seeding, Area 2011-2013
WTWMA- San Angelo
Area (km2)
80
60
40
20
0
0
50
100
150
200
time (min)
Control Cases (55)
Seeded Cases (55)


Small Storms-dual seeding, PFLUX 2011-2013
WTWMA-San Angelo
PFLUX(ton/(s.Km2)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
50
100
150
time (min)
Control Cases (55)
Seeded Cases (55)
Linear (Control Cases (55))
Linear (Seeded Cases (55))

Synergy between IRG and CRG mechanisms

- IRG: ice crystal growth followed by
  riming (and aggregation) into graupel;

- CRG: coalescence-grown drizzle drops followed by
  freezing and subsequent riming
  (and aggregation) into graupel.

B1. Results for STWMA (Pleasanton): AgI seeding: 127 cases

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	40 min	1.50	50 (**33**)
Area	64.0 km^2	42.5 km^2	1.51	51 (**24**)
Volume	175.3 km^3	115.3 km^3	1.52	52 (**27**)
Top Height	7.4 km	7.1 km	1.04	4 (**2**)
Max dBz	51.9	50.5	1.03	3 (**1**)
Top Height of max dBz	3.50 km	3.55 km	0.99	-1 (**0**)
Volume Above 6 km	23.8 km^3	14.2 km^3	1.68	68 (**36**)
Prec.Flux	503.1 m^3/s	279.9 m^3/s	1.80	80 (**32**)
Prec.Mass	2207.1 kton	805.4 kton	2.74	174 (**120**)
CloudMass	161.0 kton	95.4 kton	1.69	69 (**29**)
η	13.7	8.4	1.63	63 (**69**)

AgI flares: 558, ~4.4 per storm

Timing: 86 %

<d>= 65 icn/liter

mar= -4.10

B2. Results for STWMA (Pleasanton): dual seeding: 65 cases

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 (**44**)
Area	71.7 km^2	45.4 km^2	1.58	58 (**42**)
Volume	227.6 km^3	137.5 km^3	1.66	66 (**43**)
Top Height	8.2 km	7.5 km	1.09	9 (**3**)
Max dBz	53.1	51.6	1.03	3 (**1**)
Top Height of max dBz	3.64 km	3.53 km	1.03	3 (**- 5**)
Volume Above 6 km	48.9 km^3	27.7 km^3	1.77	77 (**36**)
Prec.Flux	636.0 m^3/s	359.7 m^3/s	1.77	77 (**42**)
Prec.Mass	2872.3 kton	1059.9 kton	2.71	171 (**146**)
CloudMass	219.6 kton	125.6 kton	1.75	75 (**43**)
η	13.1	8.4	1.56	56 (**72**)

AgI flares: 206, ~3.13 per storm

Hygro flares: 65

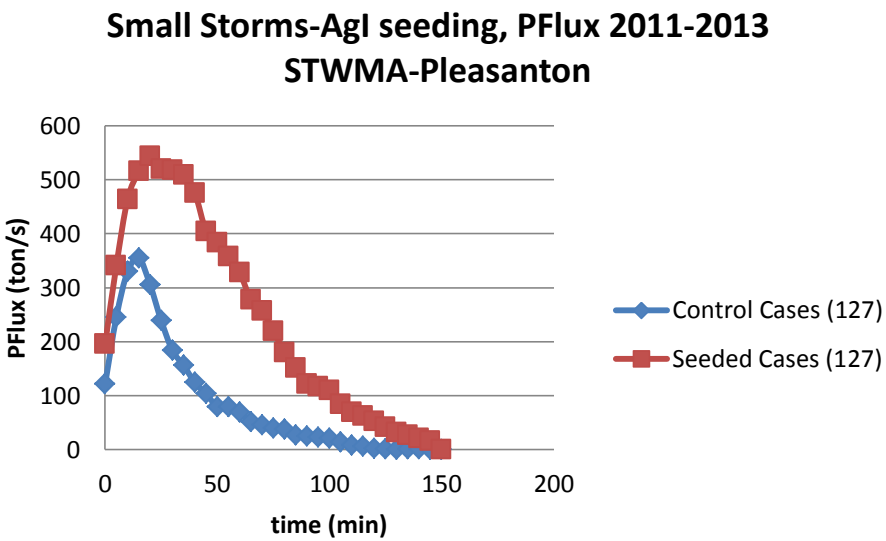
Timing: 85 %

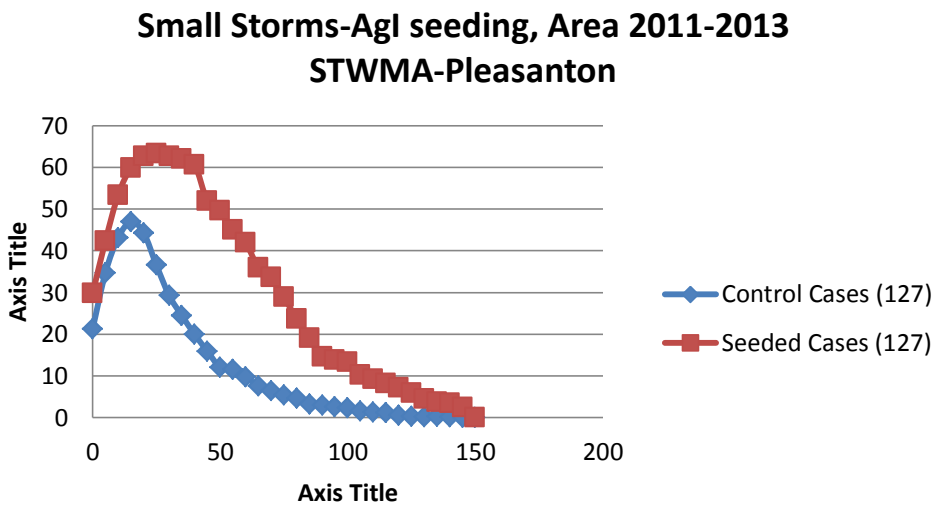
<d>= 20 icn/liter

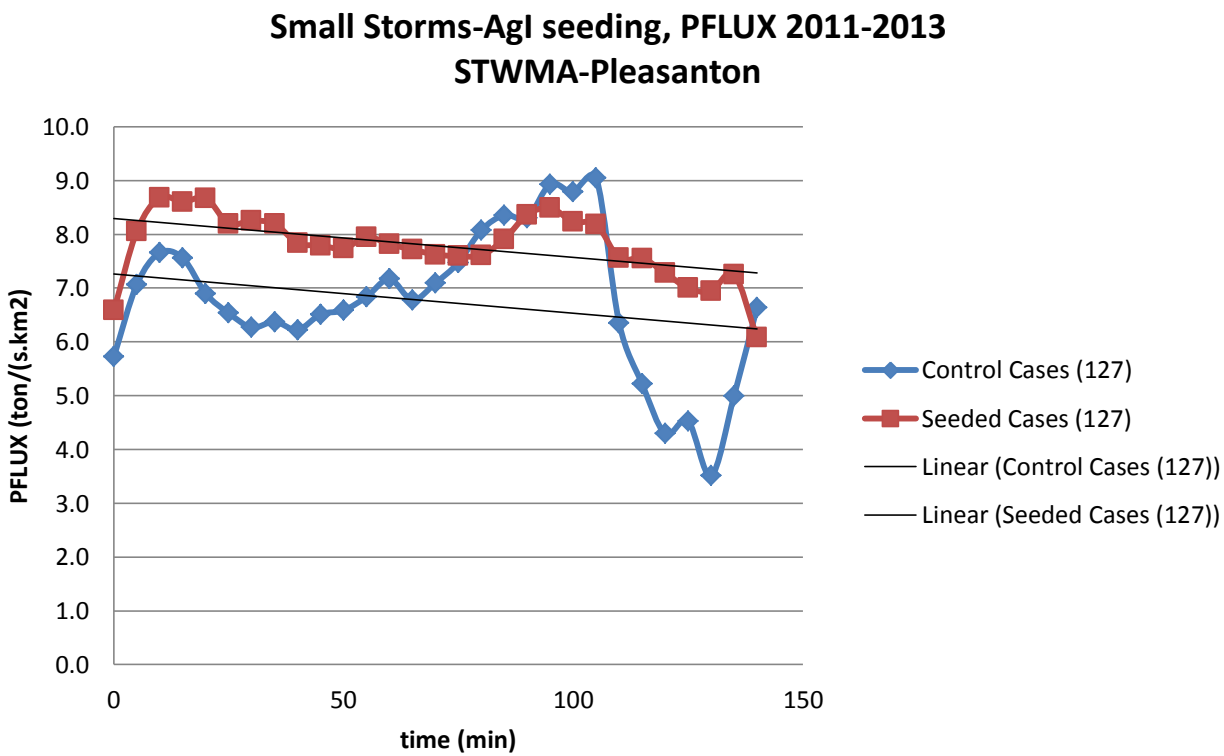
mar= -4.4

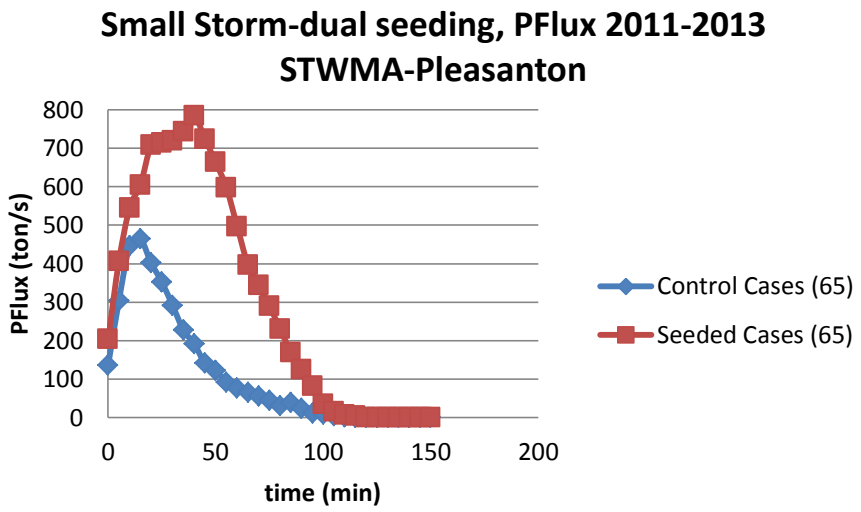
B3. Double Ratios: dual/AgI

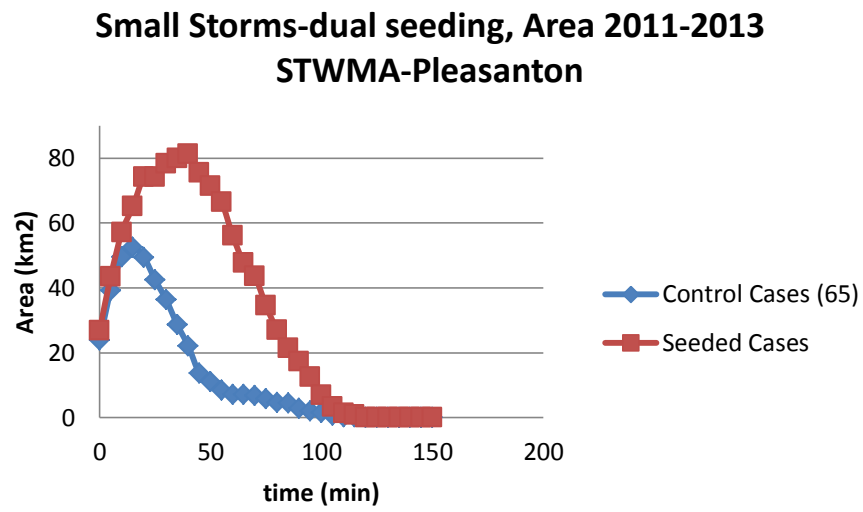
Lifetime:	1.44/1.33 ≈ 1.08
Area	1.42/1.24 ≈ 1.15
Volume	1.43/1.27 ≈ 1.13
Volume ab. 6km	1.36/1.36 = 1.00
Pflux	1.42/1.32 = 1.08
Pmass	2.46/2.20 ≈ 1.12

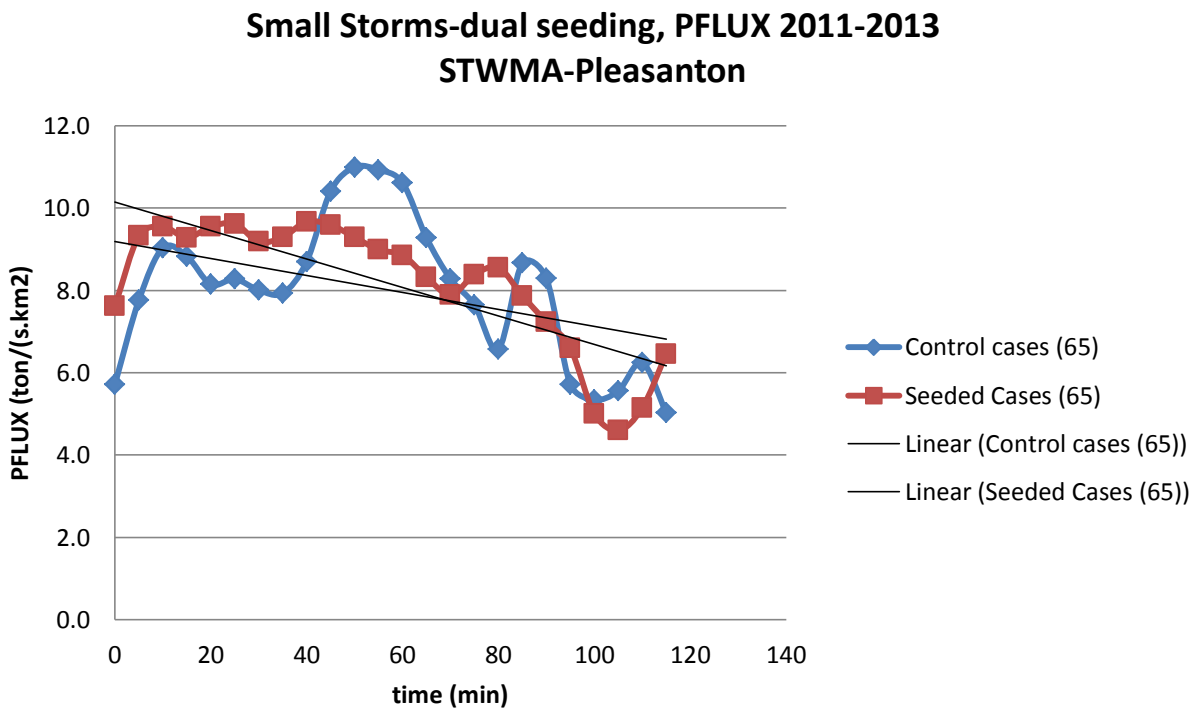

Small Storms-AgI seeding, PFlux 2011-2013
STWMA-Pleasanton
PFlux (ton/s)
time (min)
Control Cases (127)
Seeded Cases (127)


Small Storms-AgI seeding, Area 2011-2013
STWMA-Pleasanton
Axis Title
Axis Title
Control Cases (127)
Seeded Cases (127)


Small Storms-AgI seeding, PFLUX 2011-2013
STWMA-Pleasanton
PFLUX (ton/(s.km2)
time (min)
Control Cases (127)
Seeded Cases (127)
Linear (Control Cases (127))
Linear (Seeded Cases (127))


Small Storm-dual seeding, PFlux 2011-2013
STWMA-Pleasanton
PFlux (ton/s)
800
700
600
500
400
300
200
100
0
0
50
100
150
200
time (min)
Control Cases (65)
Seeded Cases (65)

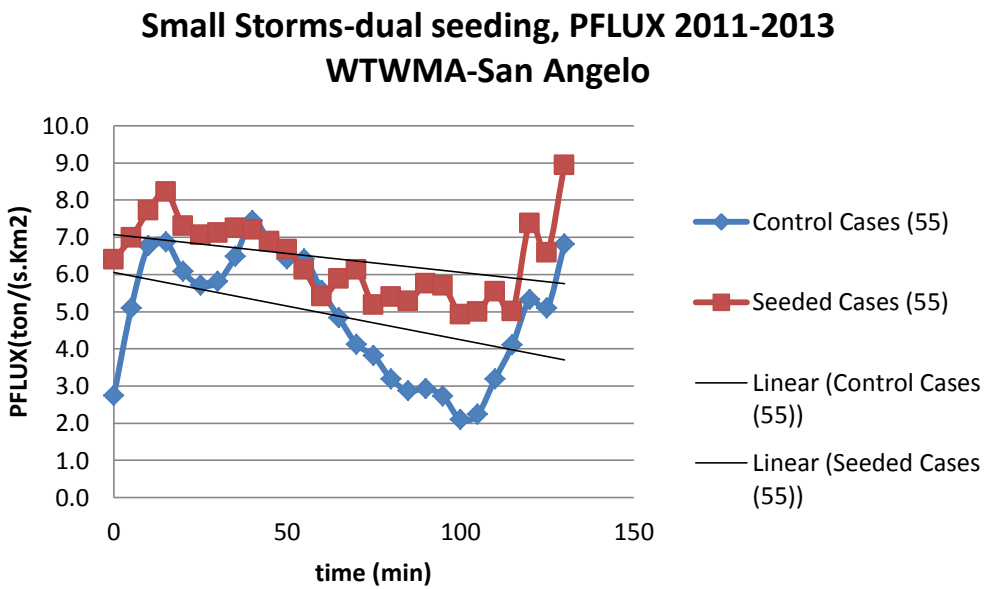

Small Storms-dual seeding, Area 2011-2013
STWMA-Pleasanton
Area (km2)
80
60
40
20
0
0
50
100
150
200
time (min)
Control Cases (65)
Seeded Cases


Small Storms-dual seeding, PFLUX 2011-2013
STWMA-Pleasanton
PFLUX (ton/(s.km2)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
20
40
60
80
100
120
140
time (min)
Control cases (65)
Seeded Cases (65)
Linear (Control cases (65))
Linear (Seeded Cases (65))

Synergy between IRG and CRG mechanisms

- IRG: ice crystal growth followed by
  riming (and aggregation) into graupel;

- CRG: coalescence-grown drizzle drops followed by
  freezing and subsequent riming
  (and aggregation) into graupel.

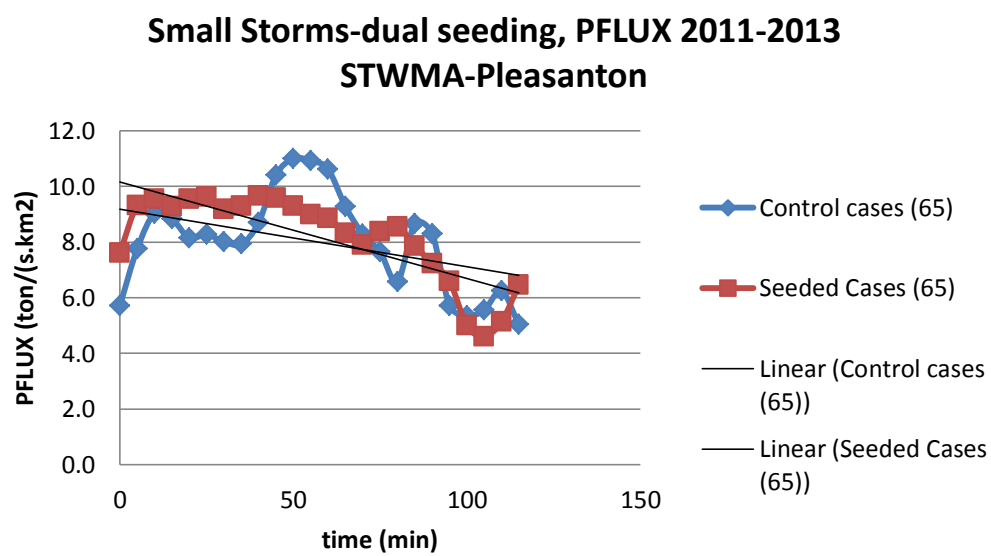


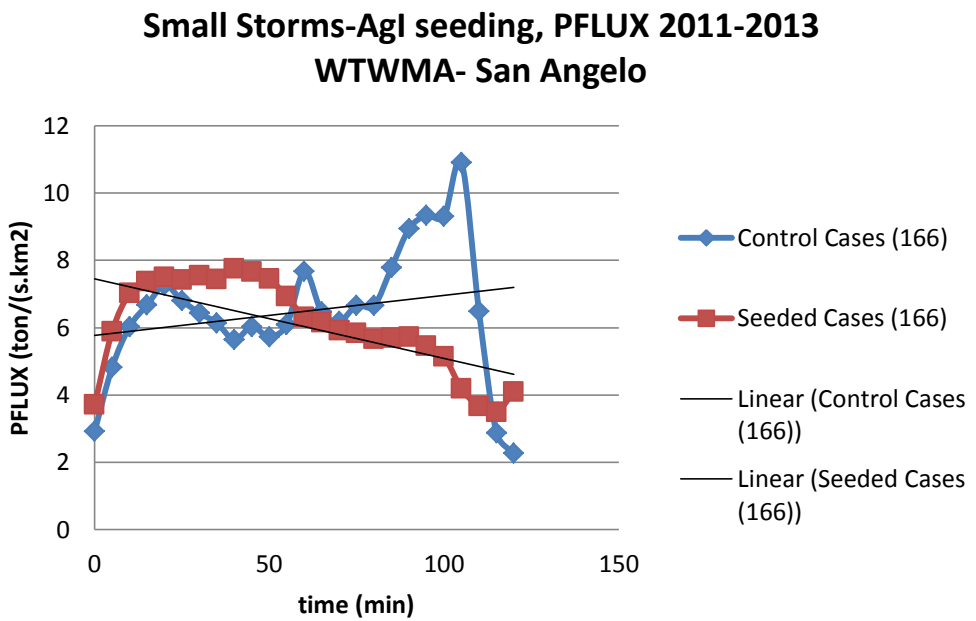
N=55

|| pattern

N=65

X pattern



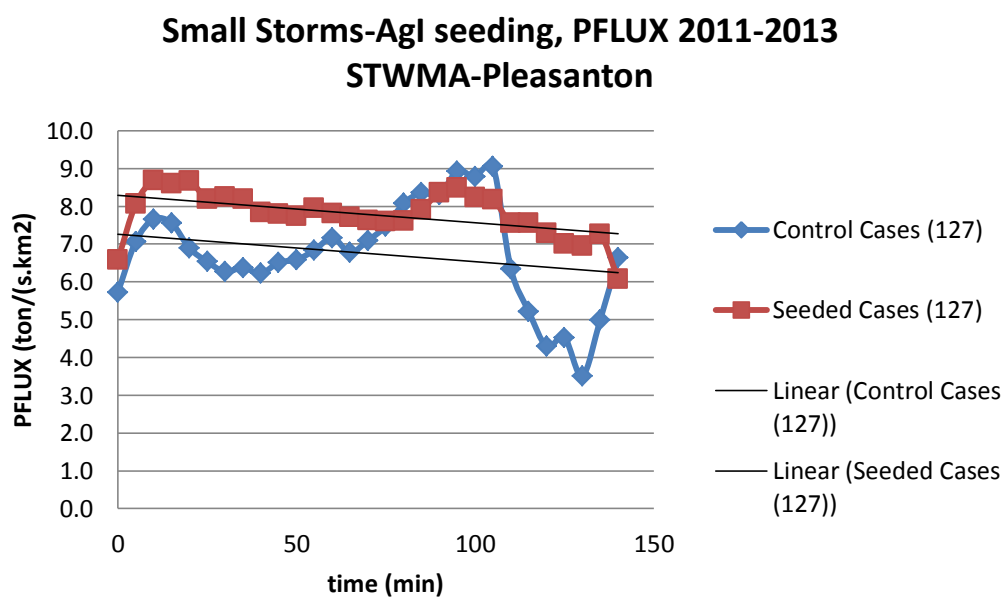


N=168

X pattern

N= 127

|| pattern



Extra mathematical considerations

$$y = Ce^{-\alpha t}(t+1)^{\beta}$$

$$\frac{dy}{dt} = C(-\alpha)e^{-\alpha t}(t+1)^{\beta} + Ce^{-\alpha t}\beta(t+1)^{\beta-1}$$

$$\frac{dy}{dt} = -\alpha y + \frac{\beta}{t+1}y$$

$$\frac{dy}{dt} = (-\alpha + \frac{\beta}{t+1})y$$

$$\frac{dy}{y} = -\alpha dt + \frac{\beta}{t+1}dt$$

	WTWMA	STWMA
AgI:	$PFlux_{Control}^{AgI} = 47.0e^{-0.065t}(t+1)^{1.061}$	$PFlux_{Control}^{AgI} = 95.6e^{-0.059t}(t+1)^{0.780}$
	$PFlux_{Seeded}^{AgI} = 43.4e^{-0.065t}(t+1)^{1.338}$	$PFlux_{Seeded}^{AgI} = 149.9e^{-0.037t}(t+1)^{0.699}$
Dual:	$PFlux_{Control}^{dual} = 80.6e^{-0.053t}(t+1)^{0.782}$	$PFlux_{Control}^{dual} = 96.5e^{-0.074t}(t+1)^{1.008}$
	$PFlux_{Seeded}^{dual} = 85.6e^{-0.055t}(t+1)^{1.061}$	$PFlux_{Seeded}^{dual} = 90.9e^{-0.068t}(t+1)^{1.290}$

Fittings are all significant! ($r^2 > 0.81$; $F < 10^{-10}$

WTWMA: exponents in the exponential do not seem to change with seeding;

STWMA: exponents in the exponential do seem to change with seeding.

By way of conclusion

1) For the small storms over the two target areas, there seems to exist a synergy between glaciogenic and hygroscopic seeding:

   dual seeding is advice;

2) However, the synergy patterns appear to be different between the two target areas. More detailed studies are needed.

Questions and Comments