Cloud Residue Chemistry during ICE-T

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Key Questions

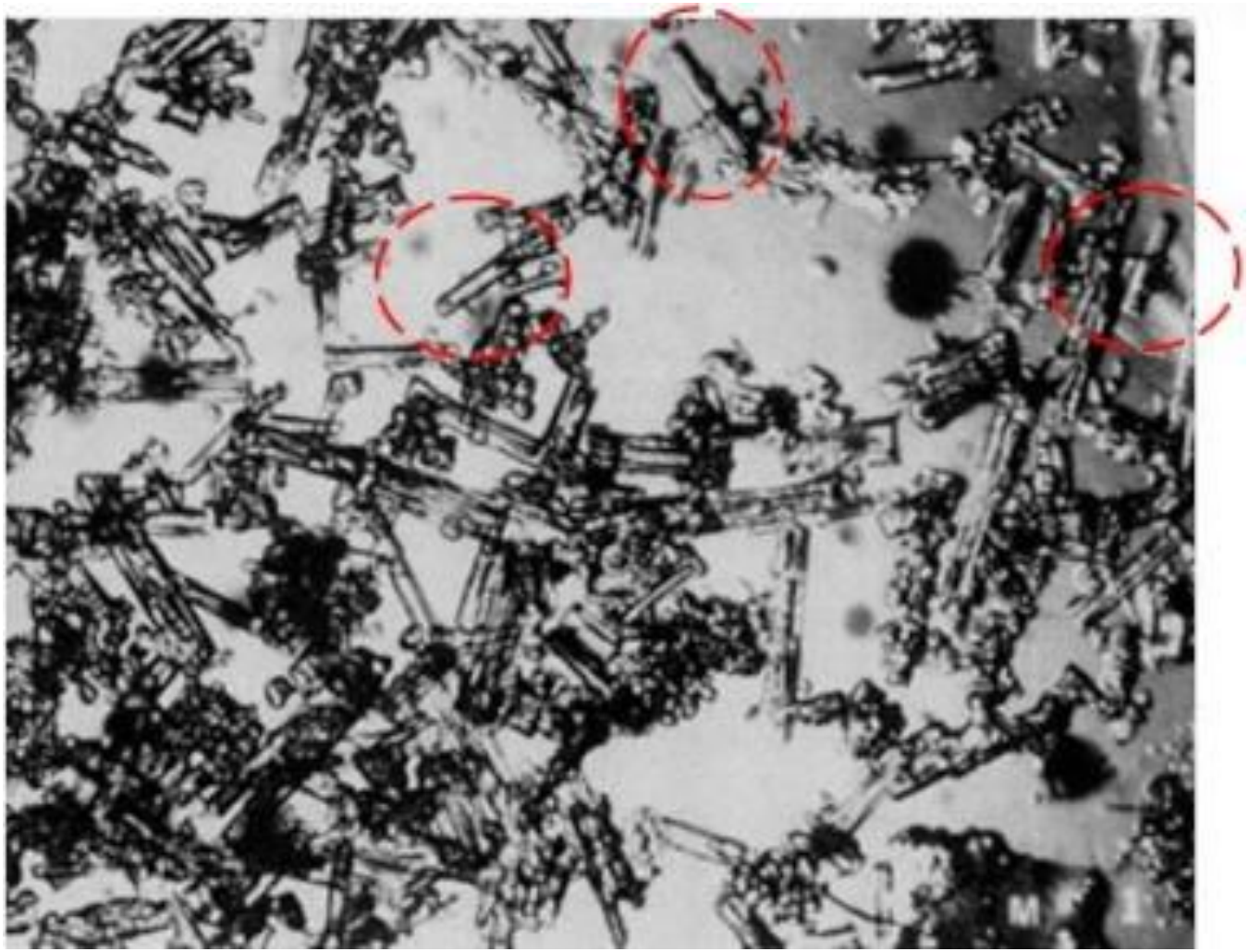
- Which chemical types activate as IN at warmer temperatures?
- How IN active are the biological particles sampled during ICE-T?
- Are there chemical differences between different types of ice (primary vs secondary, rimed vs pristine)?

Analysis Procedure

- Classify 2D-S and 2D-C images
  - Note the amount of liquid present
- Match ice periods to:
  - Temperature
  - Altitude
  - Height above cloud base
  - A-ATOFMS Residual chemistry
- Formed In Situ?

Secondary Ice Multiplication

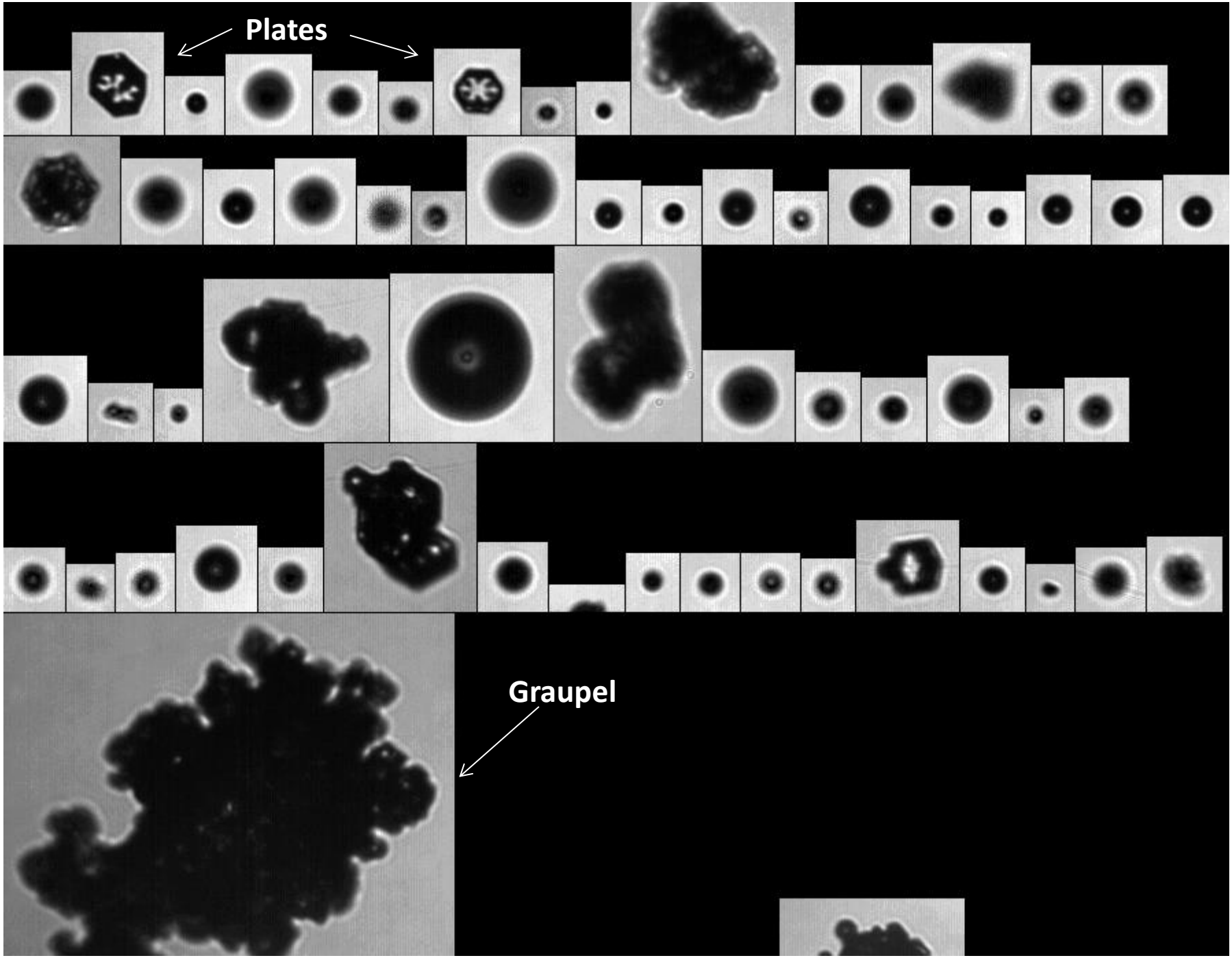
-3 to -8 ˚C



Harris-Hobbs and Cooper, 1987. Field evidence supporting quantitative predictions of secondary ice production rates. J. Atmos. Sci., 44, 1071-1082.

Analysis Complications

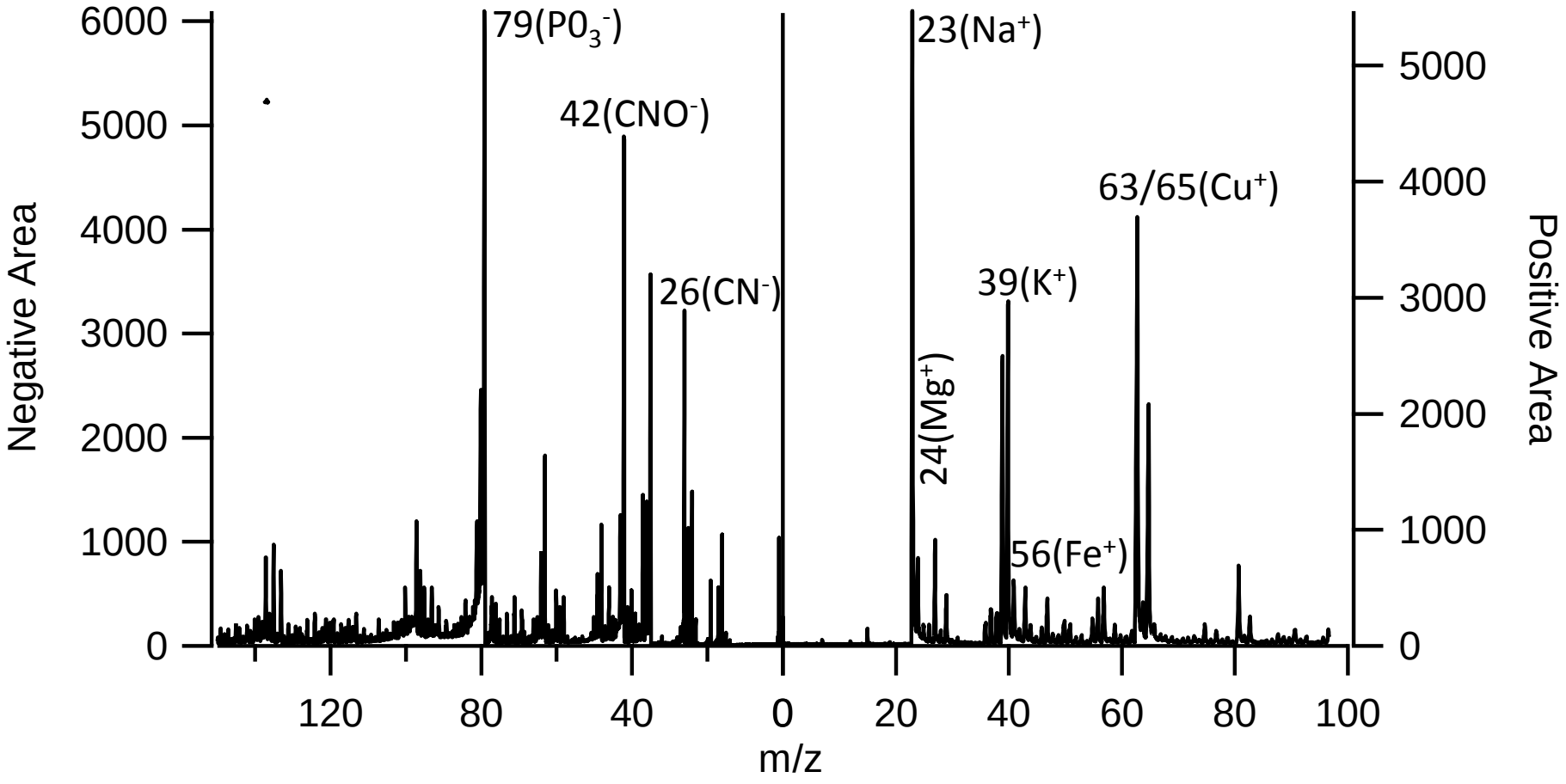
- Sampled residues may not represent the IN
- Look for primary ice
  - Unrimed
  - Not secondary
  - Very limited amount of pristine ice
- Compare to coldest supercooled liquid
  - No supercooled liquid below -3 °C.
- Possible inlet artifacts


Plates
Graupel

Primary Ice Residuals

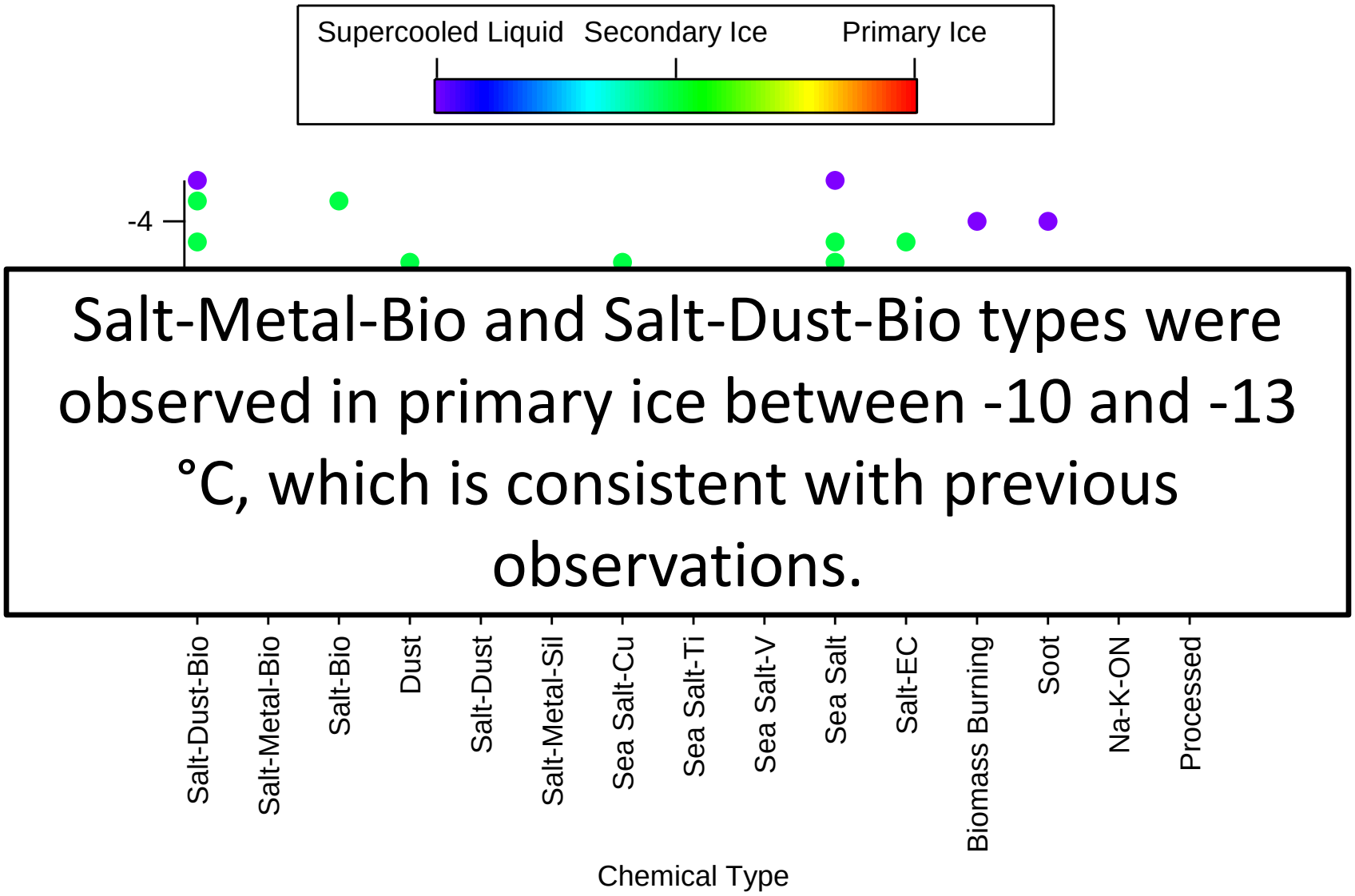
- Sea salt, Salt-Metal-Bio, and Salt-Dust-Bio were the dominant particle types present in primary ice.
  - Present between -10 and -13 °C.
- The ice residuals look like 2 distinct types of particles: one type resembles marine biological particles and the other looks like marine biological particles mixed with dust in the same residual.

Salts-Metal-Bio Type



Secondary Ice, Supercooled Liquid

- Supercooled liquid residues:
  - Between -4 and -6 °C contained Salt-Metal-Bio, Salt-Dust-Bio, Salt-Dust, sea salt, biomass burning particles, processed particle, and soot.
- The supercooled liquid residues show that the Salt-Metal-Bio and Salt-Dust-Bio types are not IN active at or above -6 °C.
- Secondary ice:
  - Between 0 and -8 °C contained Salt-Bio, Salt-Dust-Bio, Salt-EC, sea salt, Salt-Dust, sea salt-Vanadium, Salt-Metal-Bio, dust, salt-Cu.



Salt-Metal-Bio and Salt-Dust-Bio types were observed in primary ice between -10 and -13 °C, which is consistent with previous observations.

Binary Logistic Regression

- Treats the presence of ice as binary: there is ice or there isn't
- Ice is a function of:
  - Temperature + Size + Iron + CN + CNO + Phosphate + Aluminum + Sodium + Potassium + Magnesium + Copper + Zinc + Calcium + Titanium + Titanium Oxide + Silicates + Soot + Sulfate + Nitrate + Ammonium

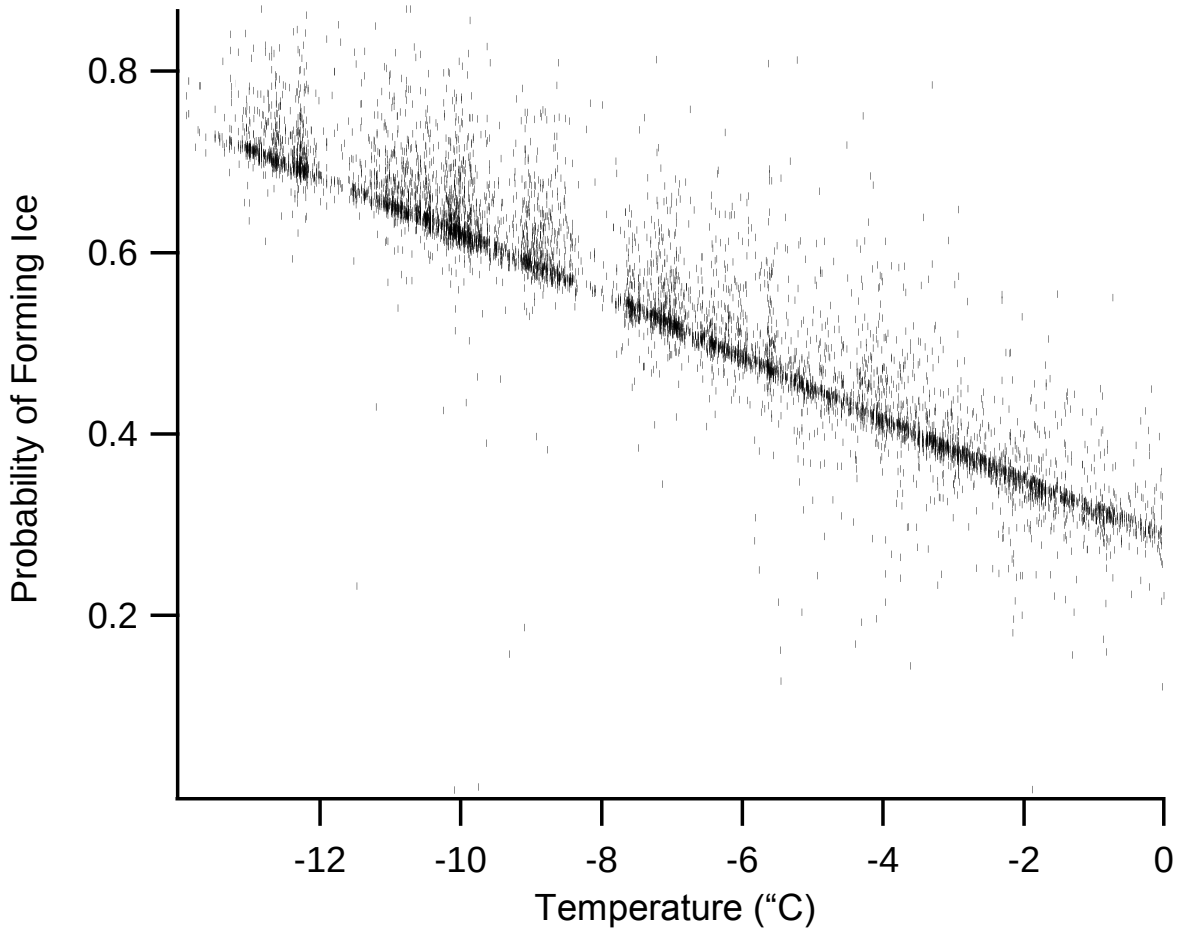
Binary Logistic Regression Results

Coefficients:

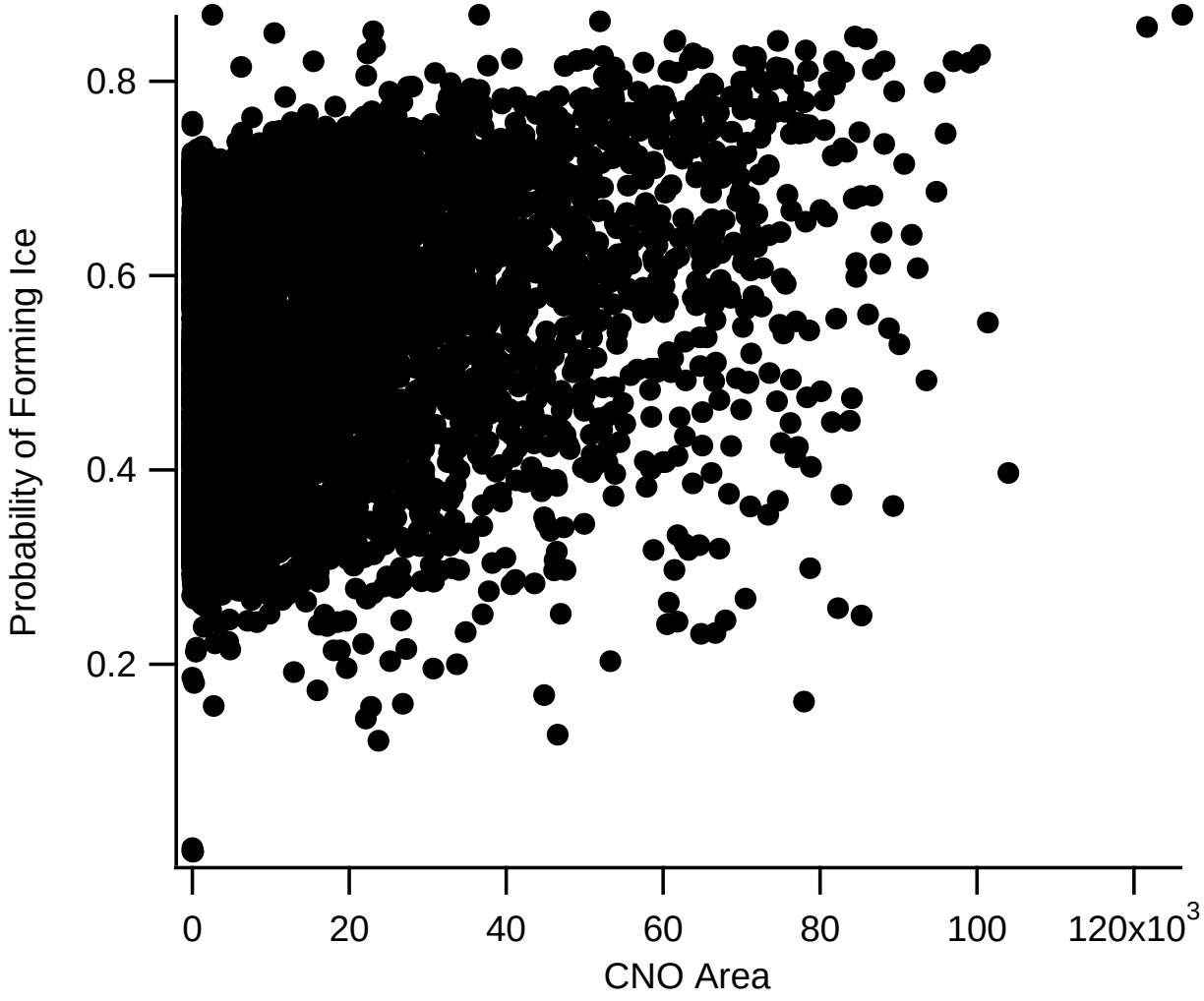
	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-6.139e-01	4.903e-02	-12.521	< 2e-16	***
Temp	-1.054e-01	3.651e-03	-28.883	< 2e-16	***
Size	-3.798e-05	1.031e-04	-0.368	0.712686	
Fe	-4.761e-06	4.202e-06	-1.133	0.257233	
CN	3.990e-06	2.757e-06	1.447	0.147863	
CNO	9.473e-06	3.506e-06	2.702	0.006901	**
PO3	8.540e-07	3.902e-06	0.219	0.826736	
Al	3.884e-06	2.392e-06	1.624	0.104426	
Na	6.712e-08	1.192e-06	0.056	0.955084	
Mg	-2.127e-07	1.755e-06	-0.121	0.903577	
Cu	2.679e-06	1.937e-06	1.383	0.166635	
Zn	-6.107e-06	1.290e-05	-0.473	0.635948	
Ca	-1.039e-06	1.235e-06	-0.841	0.400305	
Ti	-4.416e-07	3.732e-06	-0.118	0.905801	
TiO	4.138e-06	5.342e-06	0.775	0.438621	
K	-5.211e-07	1.361e-06	-0.383	0.701840	
Sil	-8.389e-06	6.155e-06	-1.363	0.172884	
Sil2	1.223e-05	7.353e-06	1.663	0.096298	.
Sil3	-7.463e-06	6.386e-06	-1.169	0.242541	
Soot	-8.852e-04	4.410e-04	-2.007	0.044723	*
Sulf	2.191e-06	3.277e-06	0.669	0.503726	
Nit	-4.427e-06	4.369e-06	-1.013	0.311028	
Nit2	-9.482e-06	9.714e-06	-0.976	0.328991	
NH4	-7.308e-03	1.896e-03	-3.855	0.000116	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

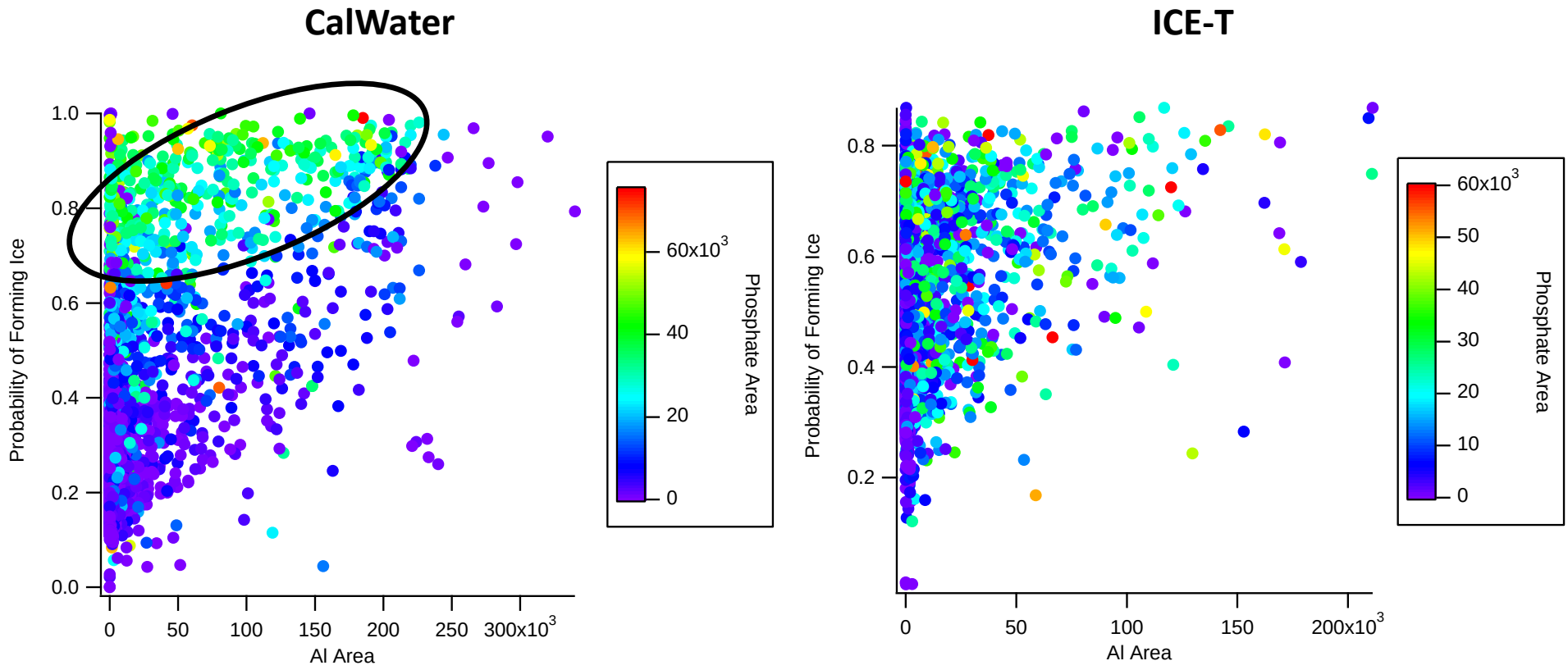
Binary Logistic Regression Results



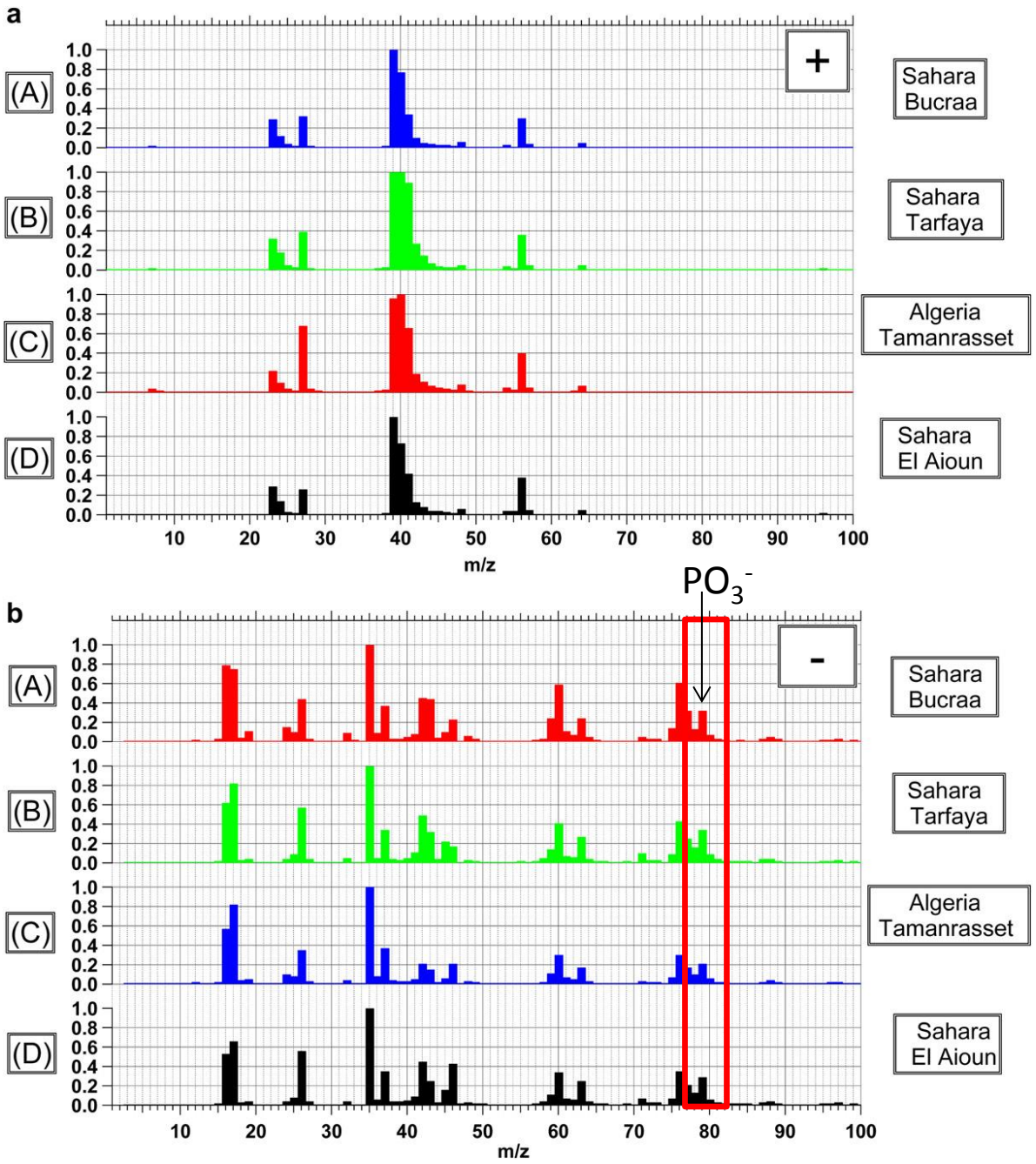
Binary Logistic Regression Results



Comparison to CalWater

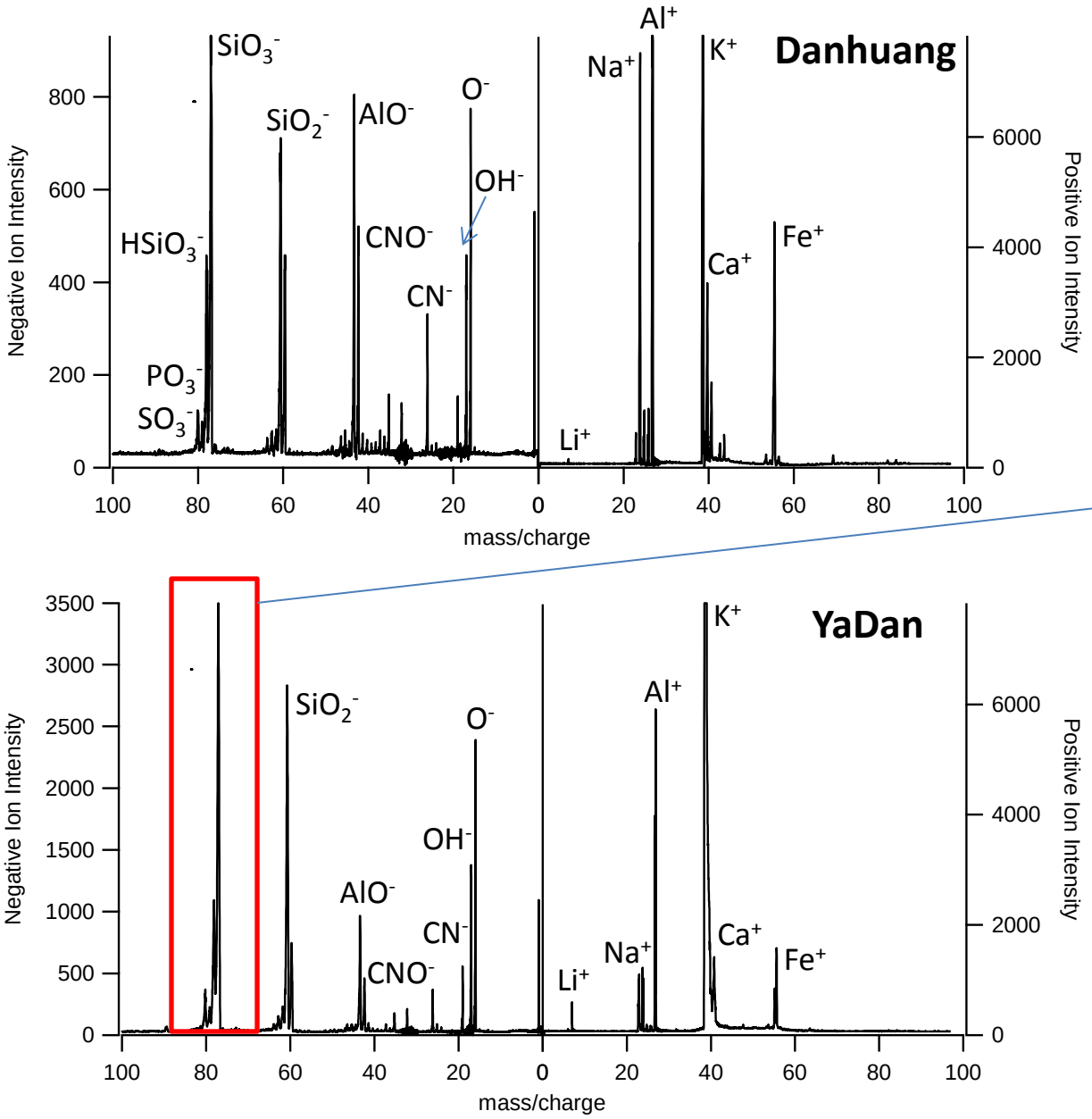


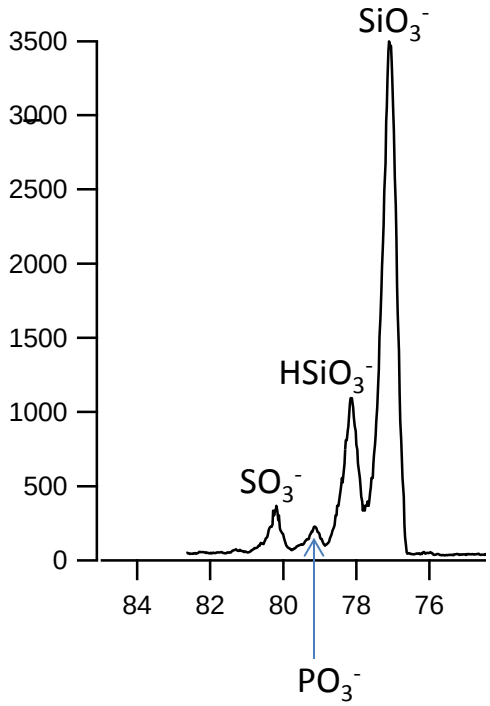
ATOFMS mass spectra of Saharan dust show a significant amount of PO_3^-.



Dall'Osto, M., R. M. Harrison, E. J. Highwood, C. O'Dowd, D. Ceburnis, X. Querol, and E. P. Achterberg (2010), Variation of the mixing state of Saharan dust particles with atmospheric transport, *Atmos Environ*, *44*(26), 3135-3146.

ATOFMS Mass spectra from 2 Asian dust samples





Small PO_3^- peak

Conclusions

- Salt-Metal-Bio and Salt-Dust-Bio types were the most prominent types seen during ice periods
  - Present in primary ice between -10 and -13 °C
- CNO correlated the best to ice formation
- Phosphate from Saharan dust may overwhelm the biological phosphate signal
- These results suggest biological residues were important to ice formation during ICE-T

CalWater Recap

- Salts-Fe-bio type is the most prominent type seen during ice periods
- Salts-Fe-bio type appears to nucleate as ice between -10 and -13.6 °C
- Differences in chemical types by altitude are associated with changes in phase
- The rimed ice has more pollution associated with it

CalWater Binary Logistic Regression

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-1.182e+00	2.249e-01	-5.256	1.47e-07	***
Temp	-1.528e-01	1.553e-02	-9.841	< 2e-16	***
Size	4.469e-04	2.240e-04	1.995	0.046059	*
bio	1.101e+00	2.831e-01	3.889	0.000101	***
sil	7.370e-02	3.674e-01	0.201	0.841041	
fe	-1.100e+00	3.596e-01	-3.059	0.002224	**
al	3.507e+00	1.083e+00	3.238	0.001205	**
dust	1.519e+01	5.992e+02	0.025	0.979782	
BB	-2.841e-01	4.447e-01	-0.639	0.522878	
salt	3.975e-01	3.056e-01	1.301	0.193341	
soot	7.505e-02	4.736e-01	0.158	0.874071	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 797.60 on 627 degrees of freedom

Residual deviance: 600.06 on 617 degrees of freedom

AIC: 622.06

Number of Fisher Scoring iterations: 15

> qchisq(0.95,617) = 675.8955

Temperature and the presence of biological components were highly significant, with aluminum less significant, iron was anti correlated and size was moderately significant.

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-1.797e+00	5.999e-02	-29.957	< 2e-16	***
Size	1.757e-05	7.663e-05	0.229	0.818687	
Temp	-4.162e-02	3.298e-03	-12.619	< 2e-16	***
Fe	-6.215e-06	3.994e-06	-1.556	0.119726	
CN	1.547e-05	3.719e-06	4.160	3.19e-05	***
CNO	-3.051e-05	7.058e-06	-4.322	1.54e-05	***
PO3	3.382e-05	6.570e-06	5.148	2.63e-07	***
Al	9.711e-06	1.114e-06	8.721	< 2e-16	***
Na	8.749e-06	2.530e-06	3.457	0.000545	***
Mg	-2.428e-05	4.246e-06	-5.718	1.08e-08	***
Cu	-2.035e-05	4.721e-05	-0.431	0.666431	
Zn	1.160e-04	1.792e-04	0.647	0.517326	
Ca	5.851e-06	2.277e-06	2.570	0.010175	*
Ti	8.734e-07	2.426e-05	0.036	0.971280	
TiO	-3.995e-06	4.261e-05	-0.094	0.925312	
K	2.652e-05	3.645e-06	7.275	3.46e-13	***
Sil	-9.703e-06	1.223e-05	-0.793	0.427622	
Sil2	-3.526e-05	1.252e-05	-2.817	0.004848	**
Sil3	3.319e-06	6.443e-06	0.515	0.606405	
Soot	1.559e-04	5.340e-05	2.920	0.003503	**
Sulf	1.927e-04	5.625e-05	3.426	0.000612	***
Nit	-4.684e-06	3.561e-06	-1.315	0.188427	
Nit2	-6.888e-06	4.788e-06	-1.438	0.150323	
NH4	-1.045e-05	8.733e-05	-0.120	0.904773	
Cr	1.107e-05	4.976e-06	2.226	0.026038	*

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 8054.7 on 6737 degrees of freedom
Residual deviance: 6886.1 on 6713 degrees of freedom
AIC: 6936.1
Number of Fisher Scoring iterations: 6

Call:

glm(formula = Ice ~ Size + Temp + Fe + CN + CNO + PO3 + Al + Na + Mg + Cu + Zn + Ca + Ti + TiO + K + Sil + Sil2 + Sil3 + Soot + Sulf + Nit + Nit2 + NH4 + Cr, family = binomial)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-3.3387	-0.7180	-0.5883	0.6802	2.7697

Research Flight 7

- Primary ice:
  - At -11 °C contained Salt-Dust-Bio, salts-Cu, and Salt-Dust
  - At -13 °C contained Salt-Dust-Bio
- Secondary ice:
  - At -3.5 °C contained salts-bio, Salt-Dust-Bio
  - At -4.5 °C contained Salt-Dust-Bio, salts-EC, and sea salt
  - At -8.7 °C contained Salt-Dust, sea salt-Vanadium, Salt-Metal-Bio

Research Flight 10

- Primary ice:
  - At -11 °C contained Salt-Metal-Bio, dust
  - At -13 °C contained dust and salts-Ti
- Supercooled liquid residues at -6 °C contained sea salt, NoPos, salts-Cu-bio, and biomass burning particles.