Remote sensing of Arctic clouds and aerosol acidification effects

JOUAN C.[1,2], GIRARD E.[1], PELON J.[2], BLANCHET J.P.[1], GULTEPE I.[3], ADAM DE VILLIERS R.[2]

(1) Department of Earth and Atmospheric Sciences, University of Quebec at Montreal, Qc, Canada

(2) Laboratoire Atmosphère, Milieux et Observations Spatiales, Université Pierre et Marie Curie/CNRS UMR 8190, Paris, France

(3) Environment Canada, Toronto, ON, Canada

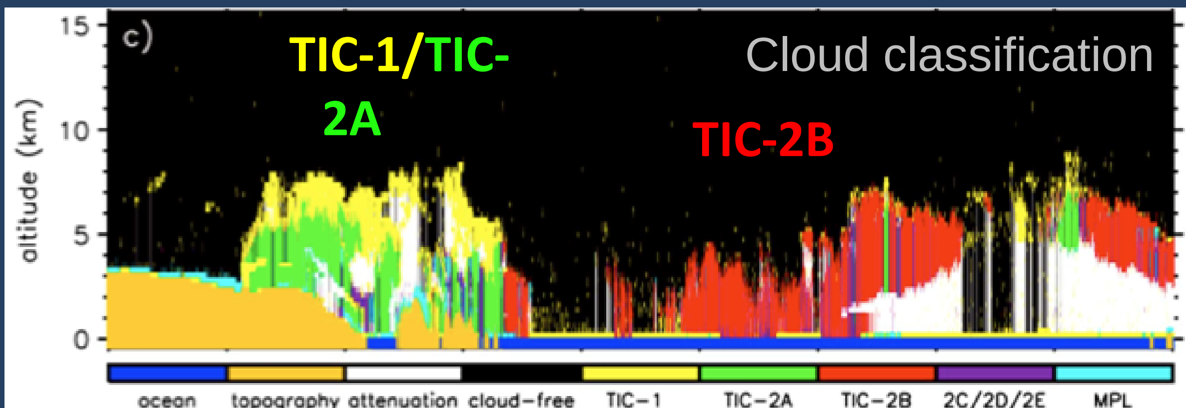
March 28, 2011 - ASR Meeting - San Antonio

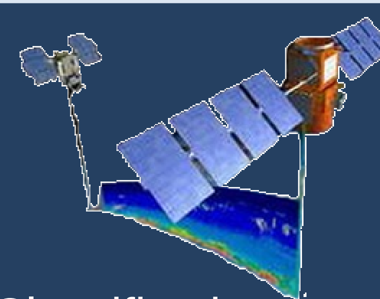
Importance of Arctic clouds for climate change

- o Play an essential role in the Arctic and Global climate system
- o They affect the hydrologic cycle and radiation balance
- o Ice clouds occur at 60-70% of the time per year *(Shupe 2010)*
- o Their representation in models is still not validated
- o Cloud feedbacks are a key source of uncertainty for GCMs' simulations related to climate sensitivity *(Dufresne et Bony 2008)*
- o Aerosol/cloud/radiation interactions are poorly understood

AWAC4 Algorithm

A**rtic **W**inter **A**erosol and **C**loud **C**lassification from **C**loudsat and **CALIPSO



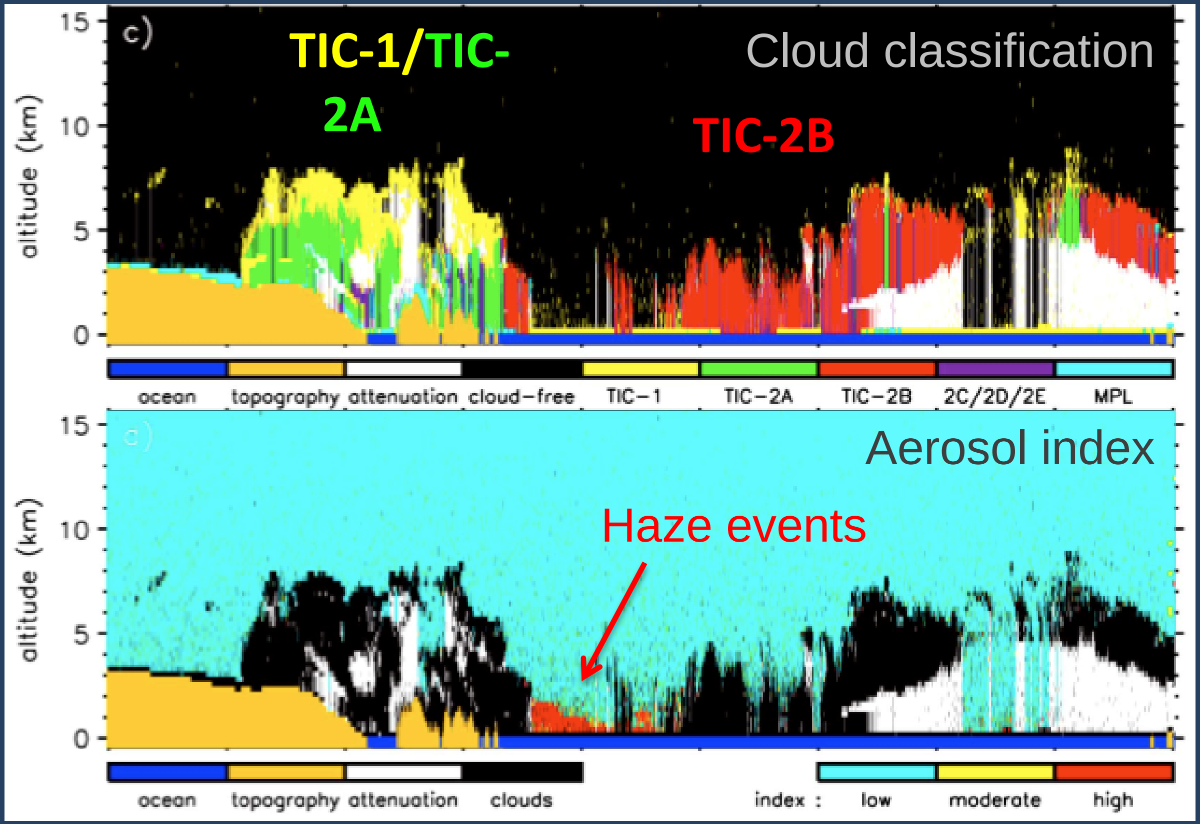


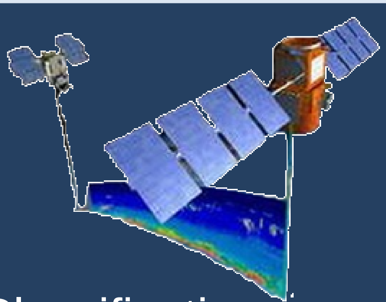
Classification according to **the sensitivity of the CLOUDSAT radar**

<u>Source</u> : Grenier et al., 2009

AWAC4 Algorithm

A**rtic **W**inter **A**erosol and **C**loud **C**lassification from **C**loudsat and **CALIPSO





Classification according to **the sensitivity of the CLOUDSAT radar**

Based on β_{532} and χ

Validated using ground data from Zepplin

➔ Indicator of **sulphate** in non-cloudy aera

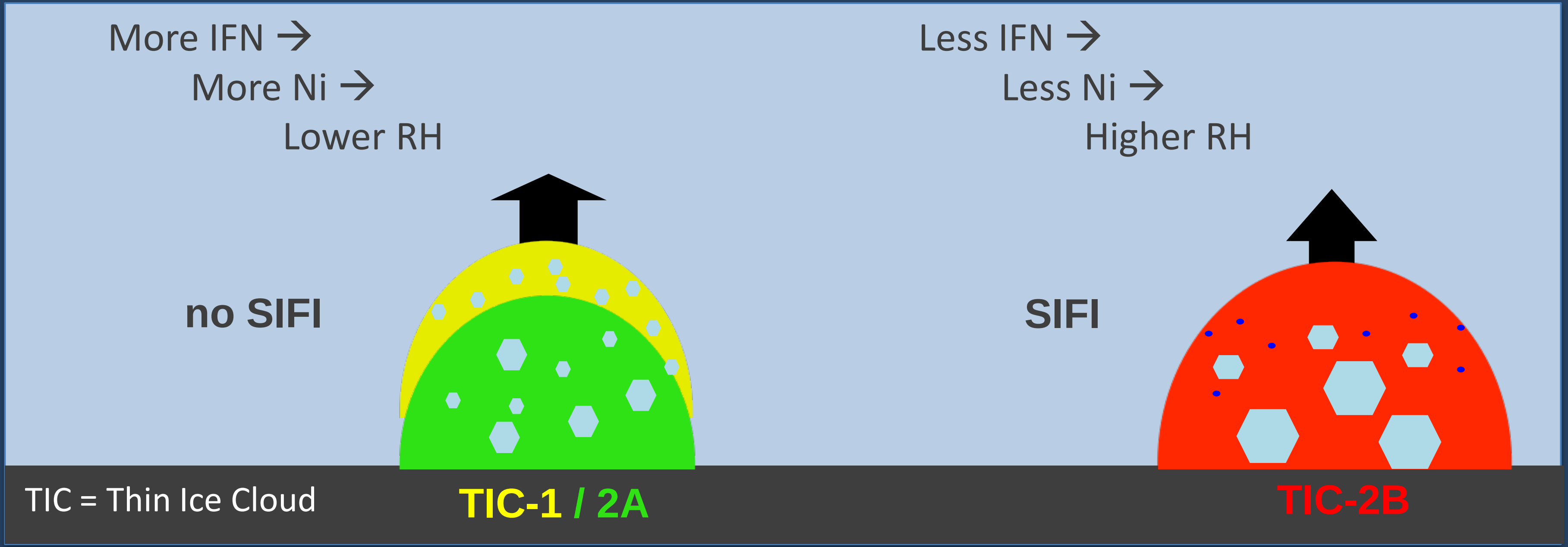
Source : Grenier and Blanchet, 2010

The SIFI effect

***S**ulphate-**I**nduced **F**reezing **I**nhibition*

o Sulphates may inhibit the freezing of coated IFN at cold T C intervals *(Eastwood et al 2009)*

➔ may result in ice clouds with fewer and larger ice crystals with a reduced competition for the water vapor with fewer IFN *(Grenier et al 2009)*



AWAC4 Algorithm

***A**rtic **W**inter **A**erosol and **C**loud **C**lassification from **C**loudsat and **C**ALIPSO*

Distribution Test ➔ **no evidence** of a strong local SIFI effect

Sulphate proxy limitations
(Sensitive to other aerosol mixtures (sea salt …), above-cloud instead of in-cloud proxy …)

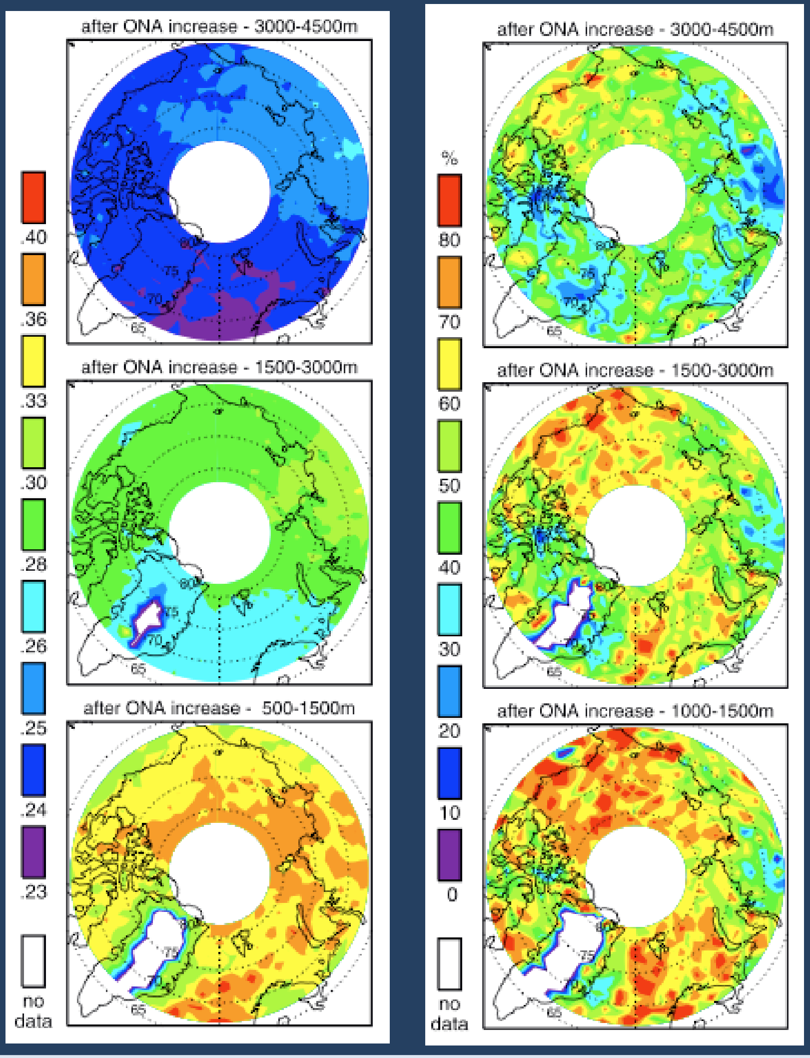
Classification algorithm limitations
(Assumptions in the radar IWC retrieval, attenuation of the lidar beam by liquid droplets, …)

SIFI effect strength
(Increase in CCN caused by sulphates could mask the SIFI effect, …)

Source : Grenier and Blanchet, 2010

Averaged over Winter 08 & 09 (D,J,F)
for different layers in Arctic

Aerosol index **TIC-2B fraction**

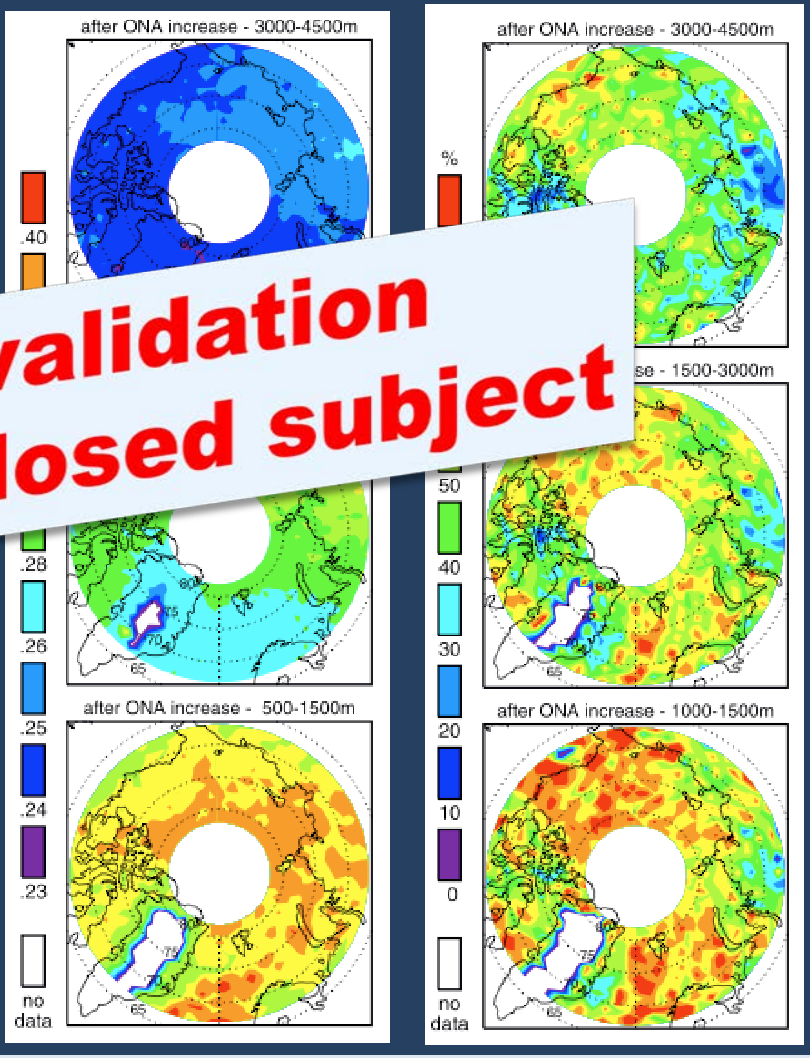


AWAC4 Algorithm

A**rtic **W**inter **A**erosol and **C**loud **C**lassification from **C**loudsat and **CALIPSO

Averaged over Winter 08 & 09 (D,J,F) for different layers in Arctic

Aerosol index **TIC-2B fraction**



Distribution Test ➔ **no evidence** of a strong local SIFI effect

Sulphate proxy limitations
(Sensitive to …
…), above …

Classifi… …ations
(Assumpt… … the radar IWC retrieval, attenuation of the lidar beam by liquid droplets, …)

SIFI effect strength
(Increase in CCN caused by sulphates could mask the SIFI effect, …)

SIFI effect validation remains an unclosed subject

Source : Grenier and Blanchet, 2010

Experimental approach

Investigation of the SIFI effect is performed using observations from satellite and airborne instruments as follow :

1. **Compare ice cloud properties before and after an anthropogenic and/or volcanic perturbation event**

2. **Investigate the chemical composition of aerosols for cloud microphysics analysis**

3. **Using the particle dispersion model FLEXPART to study pollution events (detected by CALIPSO or IASI satellites)**

1. Compare ice cloud properties

Arctic circle

ISDAC (April 2008)

- Ice and mixed-phase arctic clouds
- Barrow-Fairbanks (Alaska)
- Aircraft Convair-580 from NRC (Canada)
- **Probes :** 2-DS, 2-DC, 2-DP, Rosemount Icing Detector, PCASP …

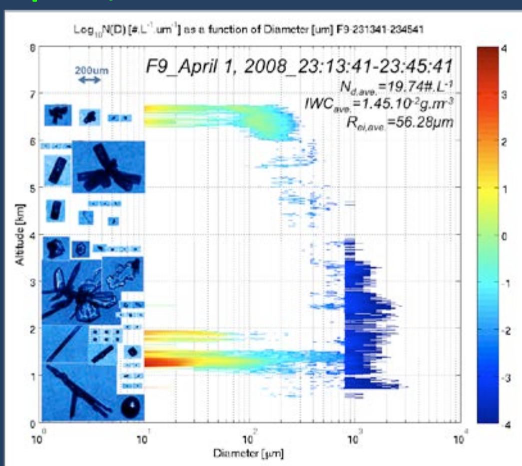
1. Compare ice cloud properties

Arctic circle

ISDAC (April 2008)

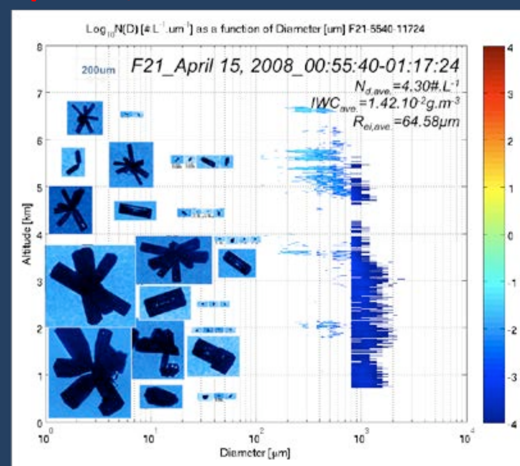
- Ice and mixed-phase arctic clouds
- Barrow-Fairbanks (Alaska)
- Aircraft Convair-580 from NRC (Canada)
- **Probes :** 2-DS, 2-DC, 2-DP, Rosemount Icing Detector, PCASP …

April 1, 2008 23:13:41 – 23:45:41



High [small ice crytsals] looks like a **TIC-1/2A**

April 15, 2008 00:55:40 – 01:17:24



Low [large ice crystals] looks like a **TIC-2B**

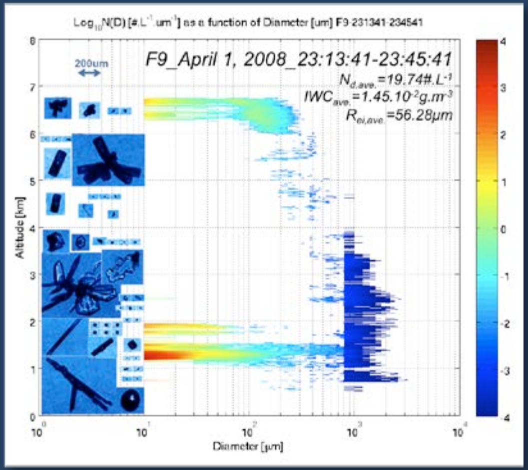
1. Compare ice cloud properties

Arctic circle

ISDAC (April 2008)

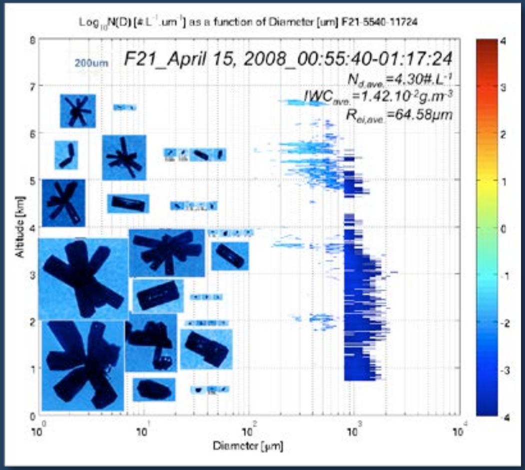
- Ice and mixed-phase arctic clouds
- Barrow-Fairbanks (Alaska)
- Aircraft Convair-580 from NRC (Canada)
- **Probes :** 2-DS, 2-DC, 2-DP, Rosemount Icing Detector, PCASP …

April 1, 2008 23:13:41 – 23:45:41

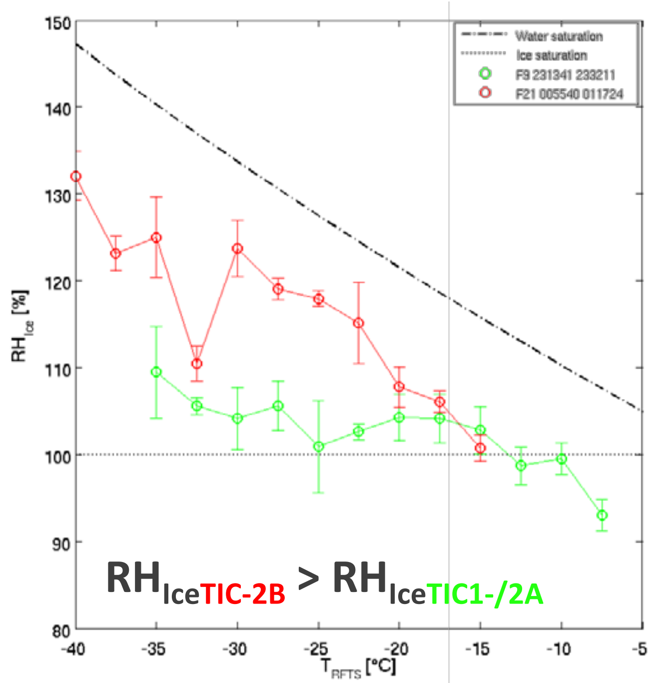


High [small ice crytsals] looks like a **TIC-1/2A**

April 15, 2008 00:55:40 – 01:17:24



Low [large ice crystals] looks like a **TIC-2B**



2. Investigate the chemical composition of aerosols

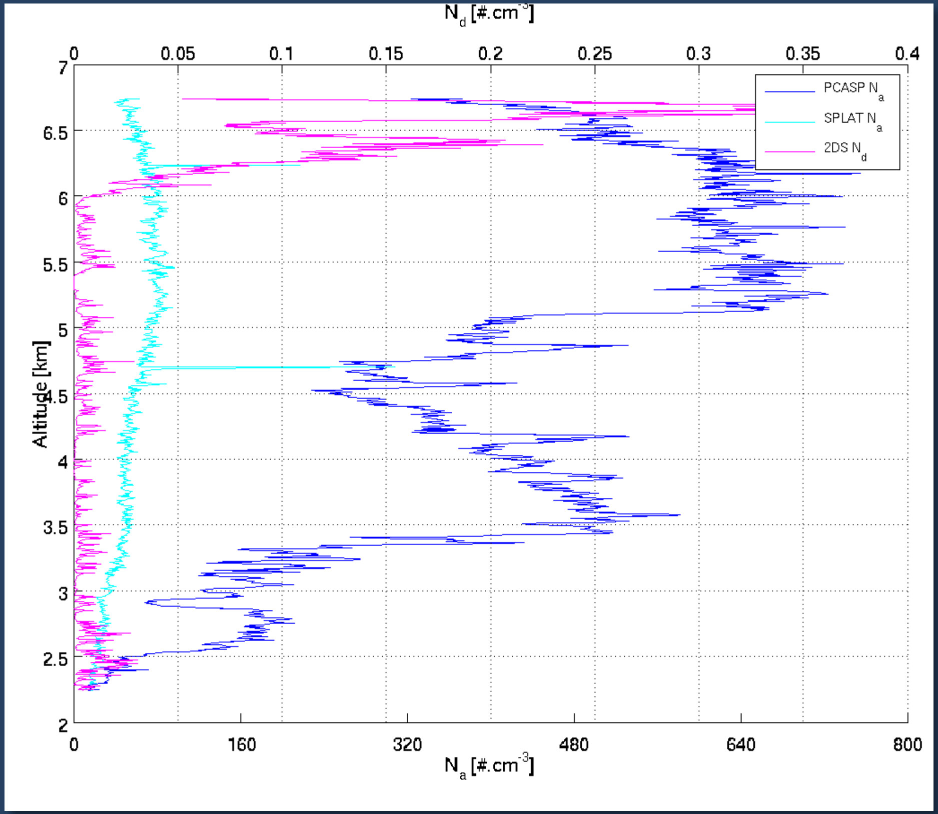
PCASP size range [0.12-3µm]

300cm^{-3} threshold clean vs polluted
(Peng et al. 2002)

Future work :

The IFN and acidic information of aerosols are needed to make a better assessment on IN nucleation capability.

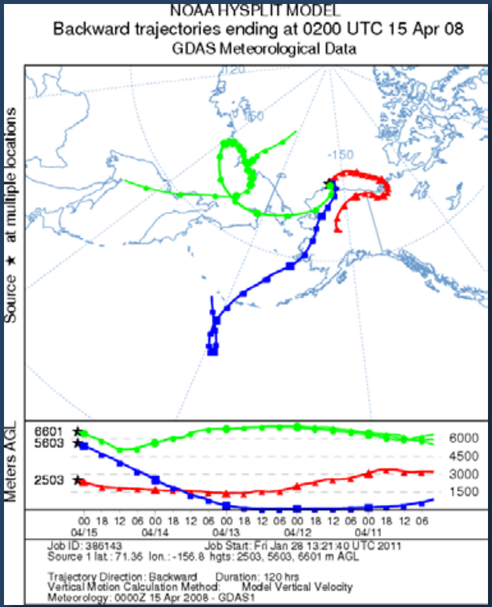
April 1, 2008 23:13:41 – 23:32:11

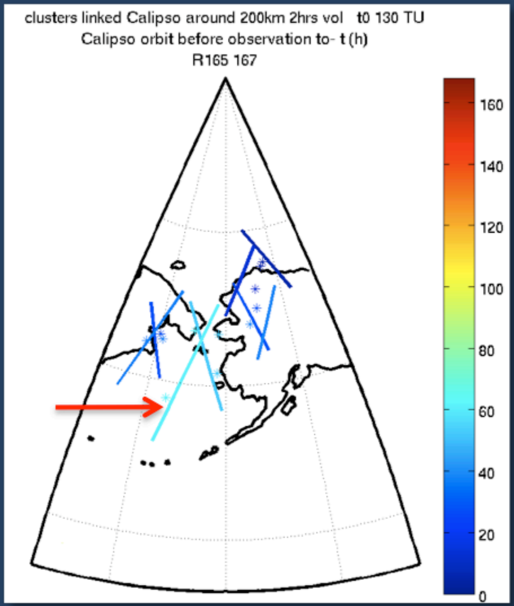


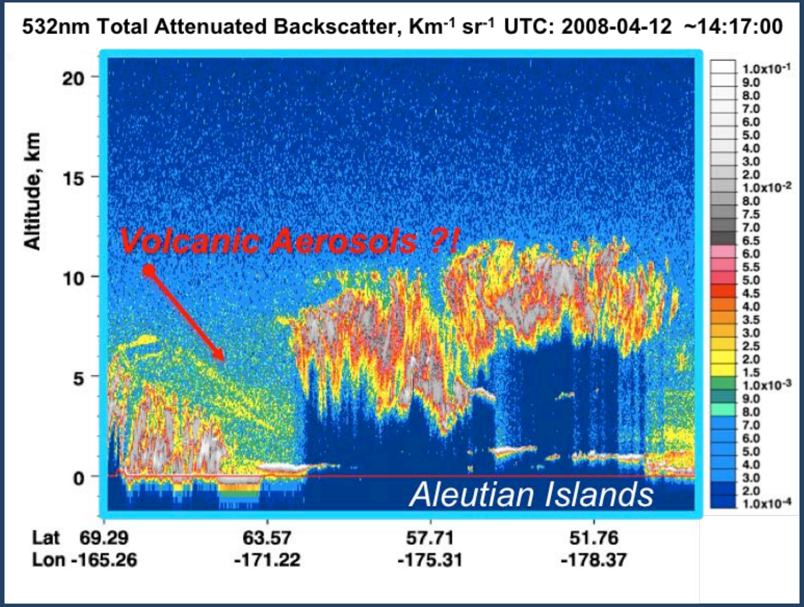
3. Using the particle dispersion model (Hysplit, Flexpart)

To study origin of observed air masses to be linked with pollution (SO_2) sources

April 15, 2008 00:55:40 – 01:17:24







Examination of the CALIPSO satellite tracks, which intersects the back trajectories in the region away from the airborne measurements

In april 2008, sustained eruptive activity was recorded at Cleveland and Veniaminof in the Aleutian Islands.

Conclusion

ISDAC measurements are considered as:

- Ice clouds in clean conditions
- Ice clouds occurred within the polluted conditions

These clouds occurred in various environmental conditions (e.g. changing RH_{Ice} and T_a C)

Results appear to be consistent with the SIFI effect's hypothesis (e.g. increasing acidic coating results in decreasing IN but increasing snow)

<u>Further work is needed and will include:</u>

→ Additional data set related to the chemical composition of aerosols.

→ Examination of the CALIPSO satellite observations, which intersect the airmass back trajectories and will provide additional information on aerosol type/acidifications.

→ New observations from PIC3 project will be used for further validations of SIFI effect.

References

Dufresne J.-L.,and S. Bony (2008), An assessment of the primary sources of spread of global warming estimates from coupled atmosphere-ocean models, *J. Climate, 21, 19, 5135-5144, doi: 10.1175/2008JCLI2239.1.*

Eastwood, M. L., S. Cremel, M. Wheeler, B. J. Murray, E. Girard, and A. K. Bertram (2009), Effects of sulfuric acid and ammonium sulfate coatings on the ice nucleation properties of kaolinite particles, *Geophys. Res. Lett., 36, L02811, doi:10.1029/2008GL035997.*

Grenier, P., and J.-P. Blanchet (2010), Investigation of the sulphate-induced freezing inhibition effect from CloudSat and CALIPSO measurements*, J. Geophys. Res., 115, D22205, doi:10.1029/2010JD013905.*

Grenier, P., J.-P. Blanchet, and R. Munoz-Alpizar (2009), Study of polar thin ice clouds and aerosols seen by CloudSat and CALIPSO during mid- winter 2007, *J. Geophys. Res., 114, D09201, doi:10.1029/2008JD010927.*

Shupe, M.D. (2011), Clouds at Arctic Atmospheric Observatories, Part II: Thermodynamic phase characteristics. *J. Appl. Meteor. Clim., accepted.*

Aknowledgements

Thanks to Ismail Gultepe, Greg McFarquhar, Nicole Shantz, Alla Zelenyuk and DOE ARM for the airborne measurements

Thanks to Raphael Adam de Villiers (FLEXPART)

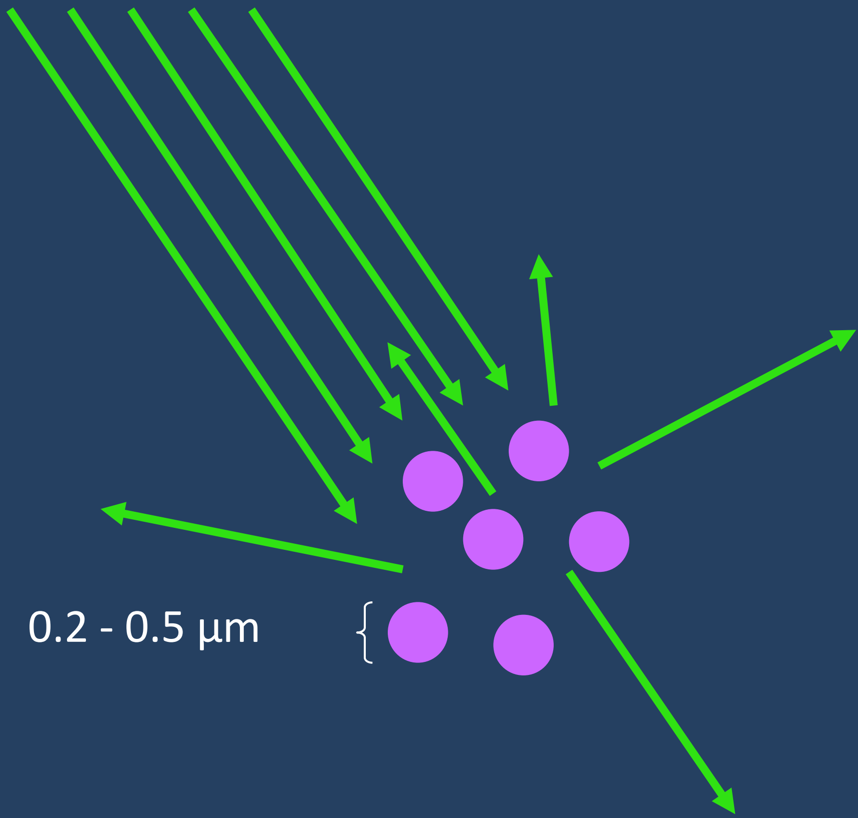
Financial contribution

- Global Environmental and Climate Change Centre (GEC3EG)
- Natural Sciences and Engineering Research Council of Canada (NSERC)
- International Polar Year (IPY)
- Fonds Québécois de Recherche sur la Nature et les Technologies (FQRNT)
- Centre National d'Etudes Spatiales (CNES)
- Fonds à l'Accessibilité et à la Réussite des Etudes (FARE)

Thank you for your attention

ED Expédition en arctique août 2007
www.ac-nancy-metz.fr/enseign/svt

Sulphates form and properties

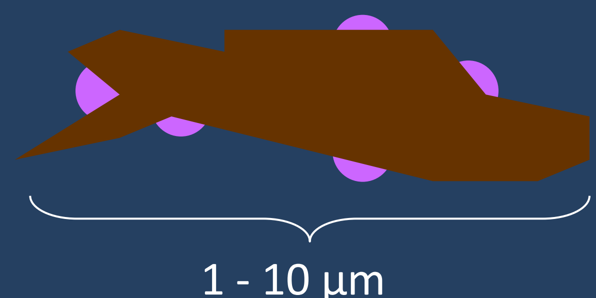


Represent the High Arctic dominant species in terms of abundance and mass.

Are hydrophilic : attract water molecules to form **solution droplets**, hence are good cloud condensation nuclei (CCN).

Are scatterers : reflect solar light and **laser beams**.

Internally mix : covers 80 % of other aerosols.

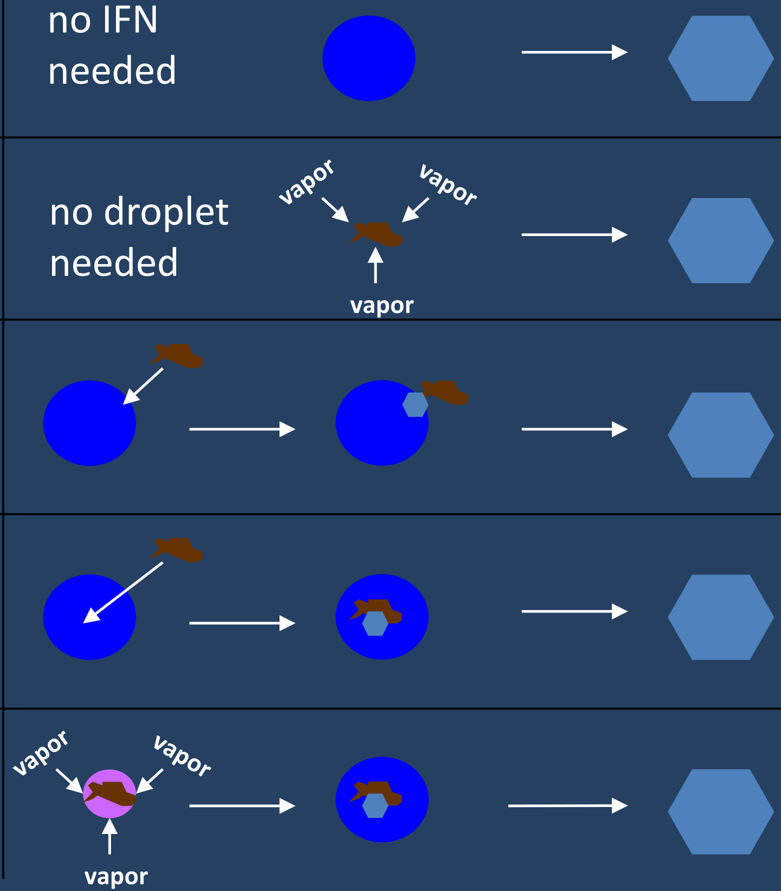


Prevents **ice-forming nuclei (IFN)** from initiating ice formation. This is termed the sulphate-induced freezing inhibition or **SIFI effect**.

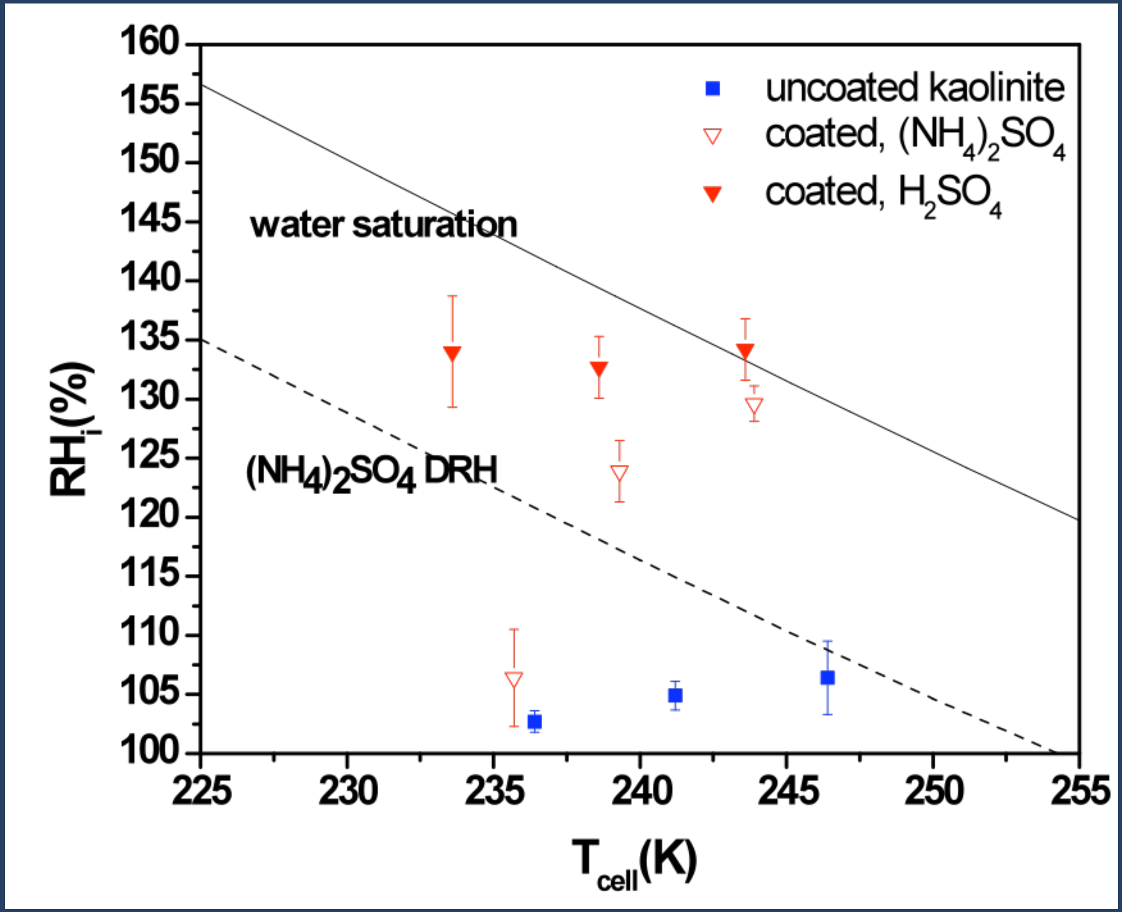
SIFI from laboratory experiments

(ice nucleation modes)

	Mode	Condition	SIFI ?
	Homogeneous	no IFN needed	YES
Heterogenous	Deposition	no droplet needed	YES
Heterogenous	Contact		?
Heterogenous	Immersion / freezing		MAYBE
Heterogenous	Condensation / freezing		?



Onset of Ice Nucleation on Kaolinite Particles Coated with $(NH_4)_2SO_4$



- All experiments obtained with a surface area of 10^{-4} to 10^{-3} cm^2.
- At 245 K and 240 K, $(NH_4)_2SO_4$ coated kaolinite particles are poor ice nuclei.
- At 236 K, the coated particles are just as efficient at nucleating ice as uncoated kaolinite particles.
- Why the big difference between H_2SO_4 and $(NH_4)_2SO_4$ coatings ?
- May be related to the phase of the coatings.