Forest-atmosphere interaction in tropical and boreal ecosystems.

Review

Editors HC Hansson and Paulo Artaxo

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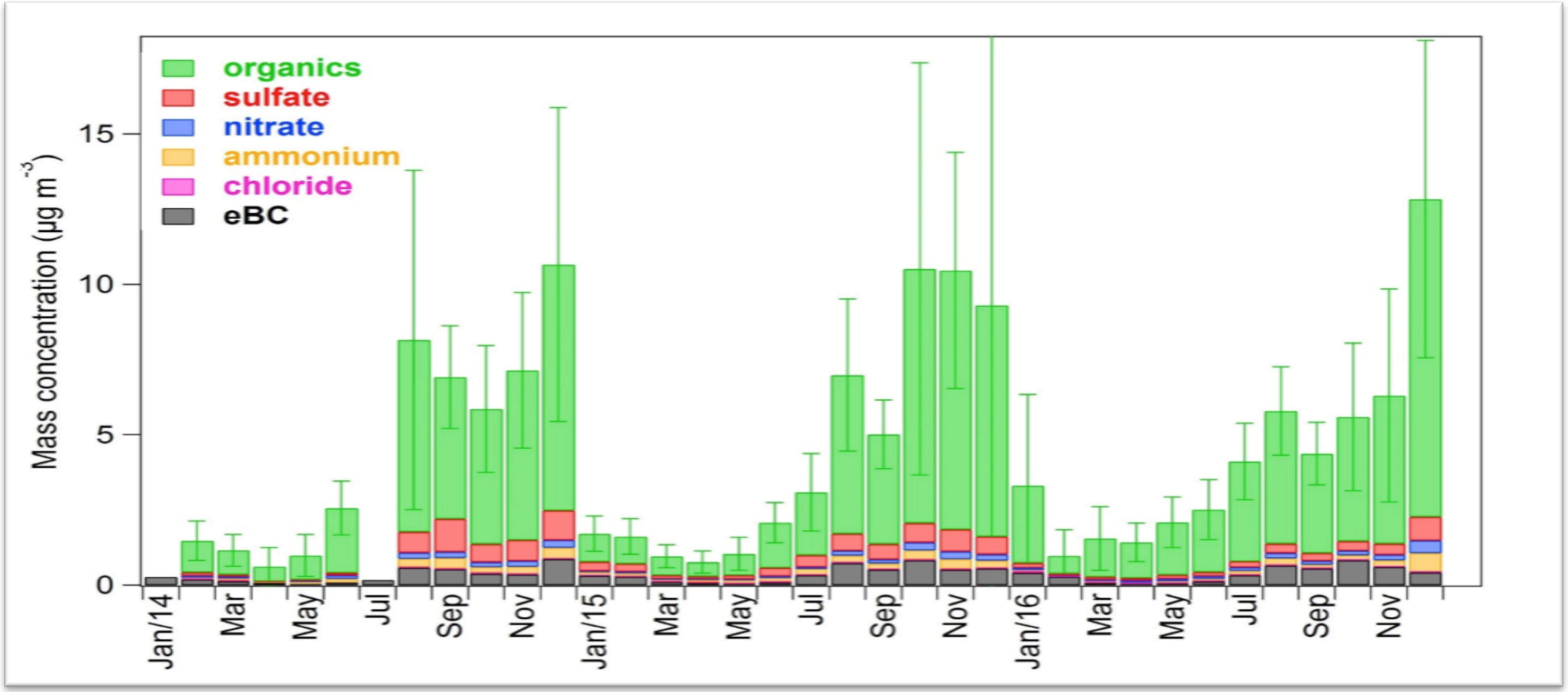
Objective

- *To put forward and compare how two major forest types interacts with the atmosphere and climate.*
- *We aim to explore how these forests ecosystems affect and are affected by atmospheric processes.*
- *It is the ”natural” systems and their interaction that we want to explore*

The boreal forest and important observation sites

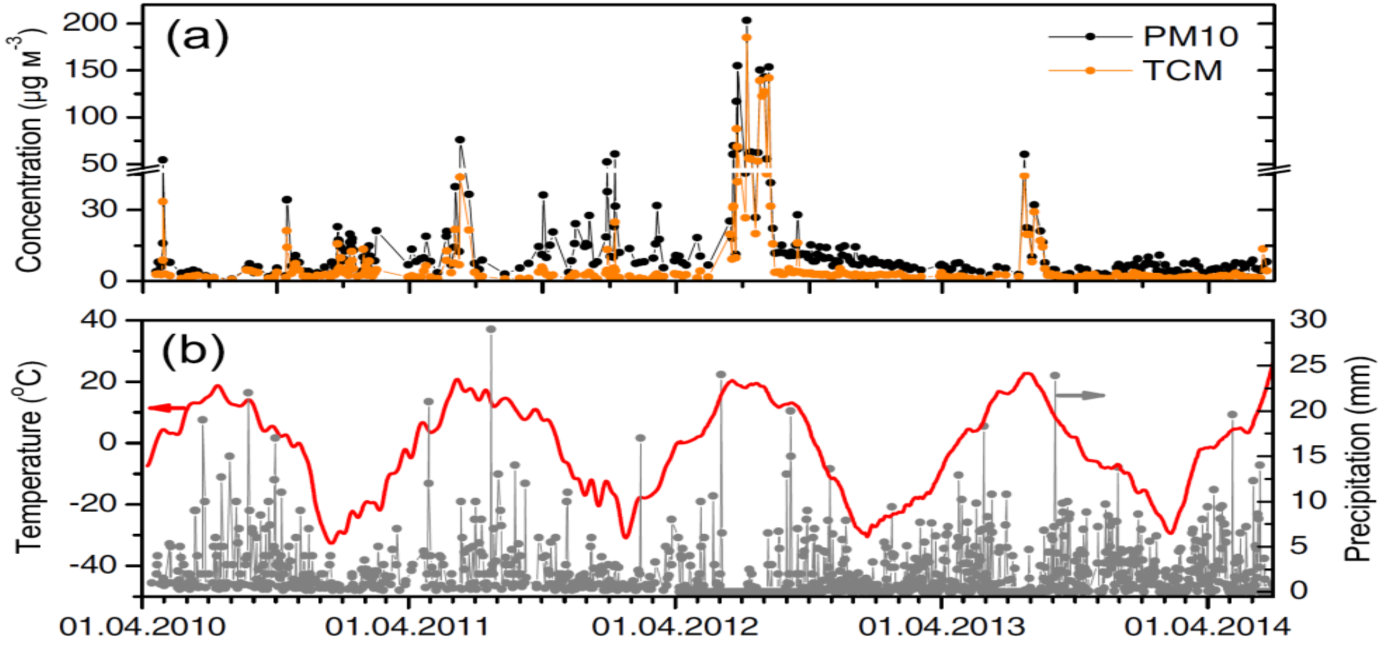
Observations; Atmospheric Chemistry

Organics dominate the aerosol in both the boreal and tropical forest



Time series of PM1 monthly averaged aerosol composition in Central Amazonia (ATTO tower), from January 2014 to Dec 2016.

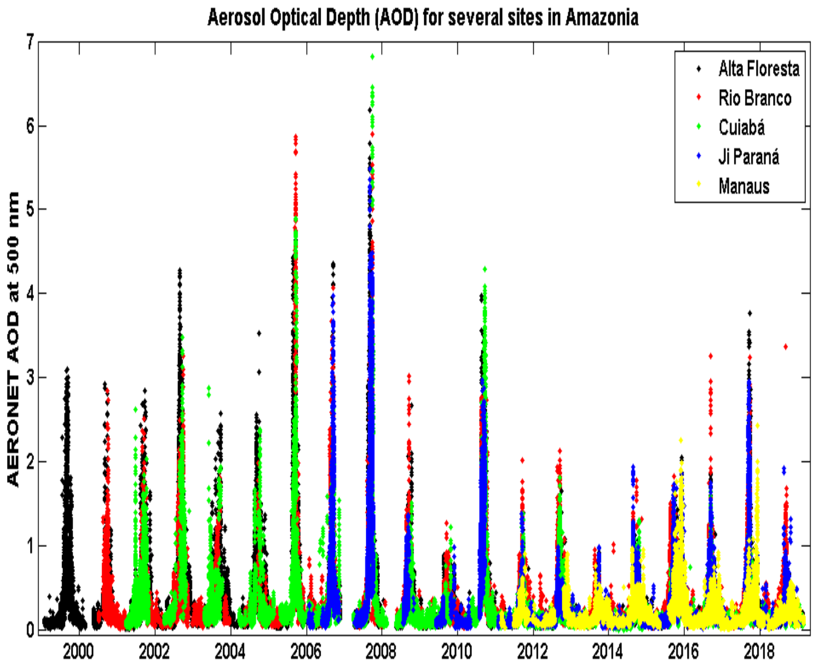
Meteorology in both the boreal and tropical forest strongly affect the aerosol, concentrations and properties.



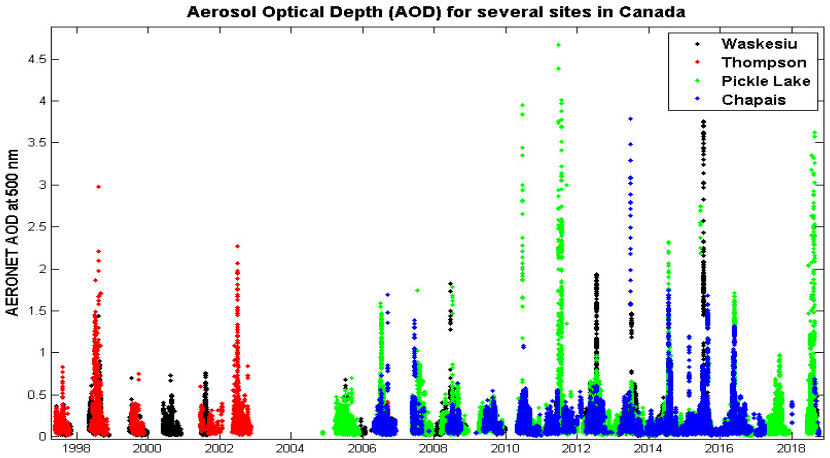
Seasonal and interannual variations in the aerosol particulate matter (PM10) and TCM concentrations (a) and of daily averaged meteorological parameters (b): temperature – red line; precipitations – grey line and symbols.

Biomass burning are dominating a source in both the boreal and tropical forest during the summer and dry periods.

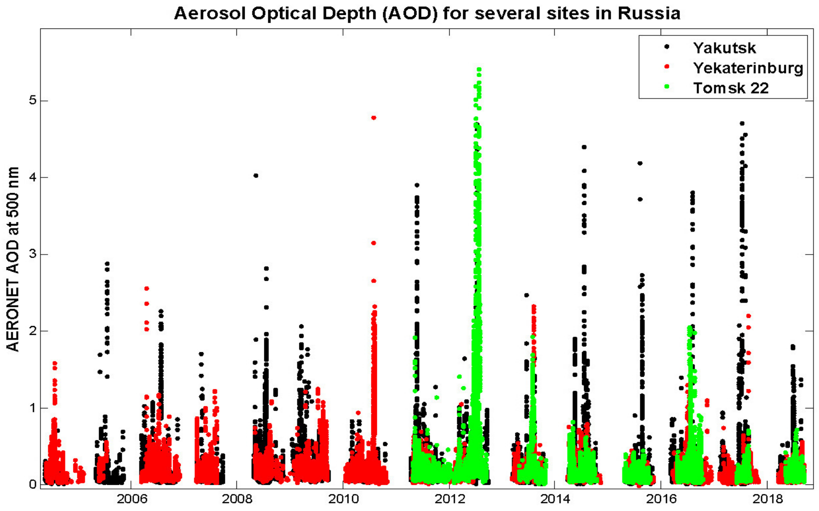
Amazonas



Canada

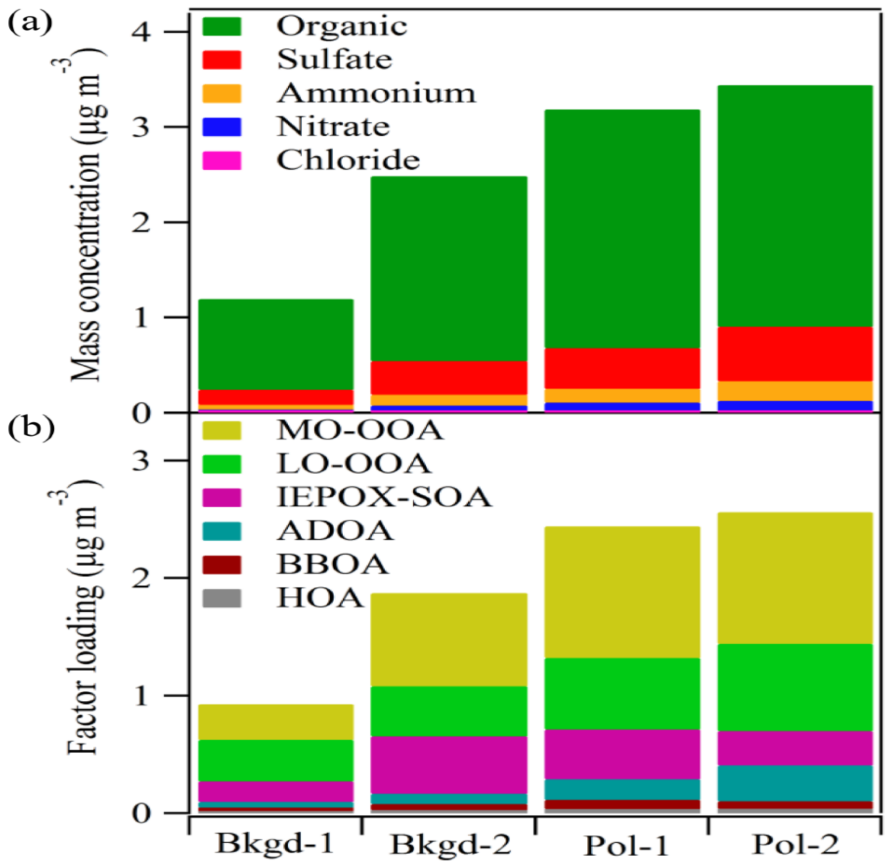


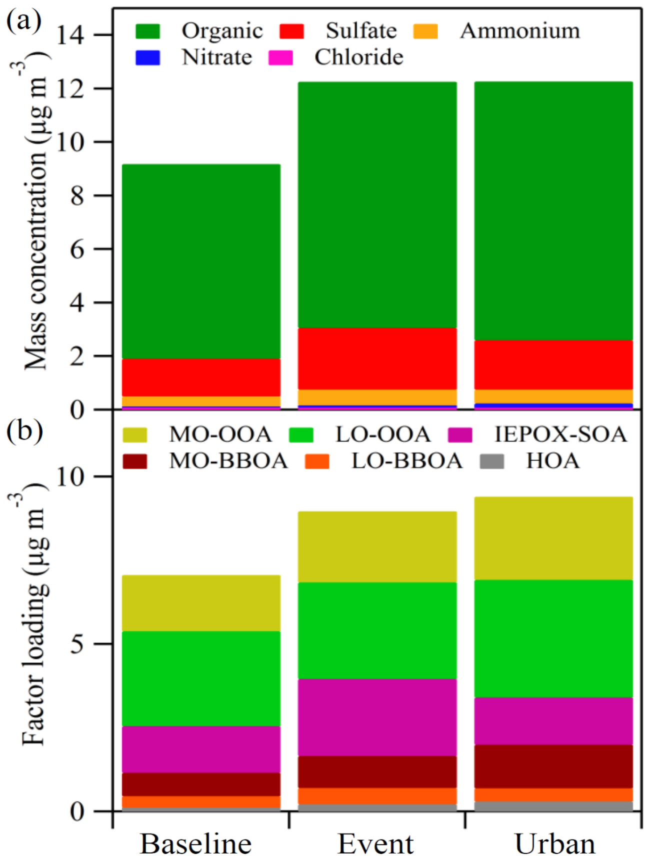
Russia



Groundbased AOD measurements from three major forested areas

Urban emissions boost natural atmospheric chemistry over the Amazonas





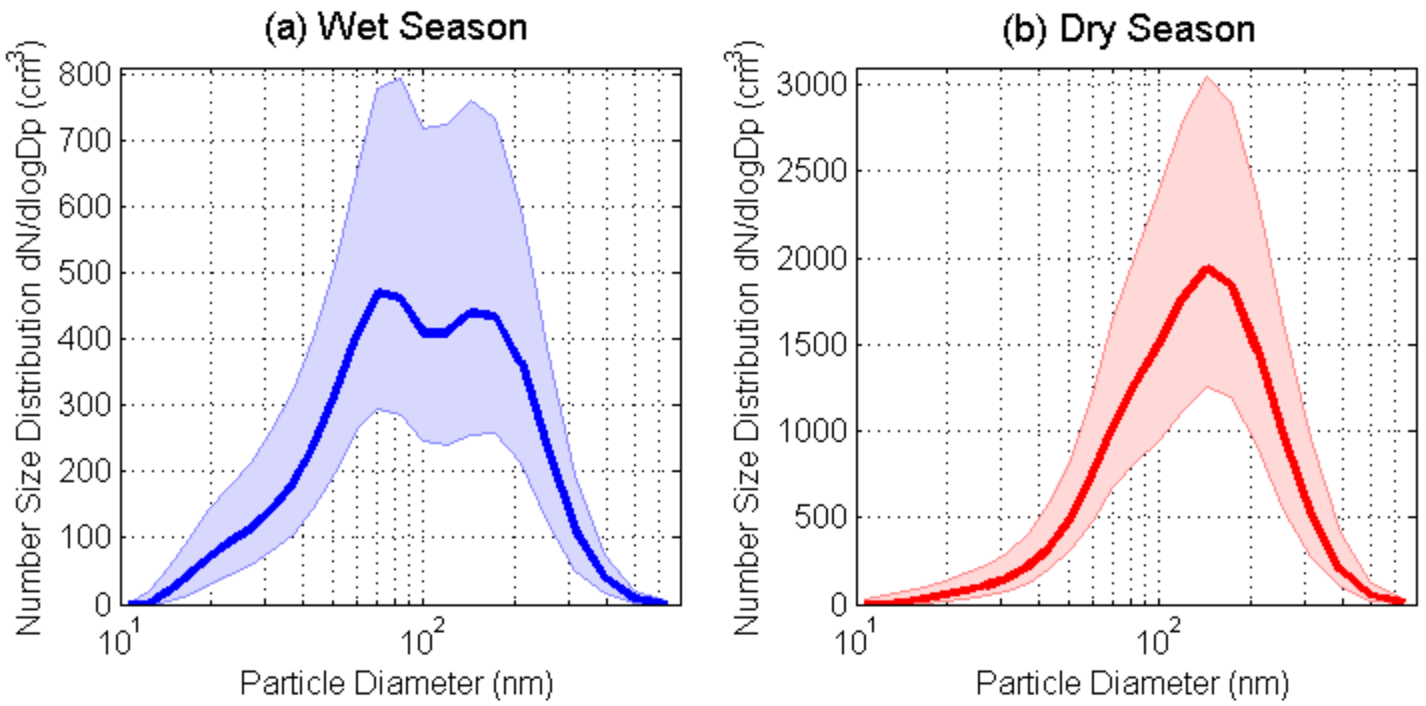
Increase in SOA formation from background to polluted conditions for the wet (left) and dry (right) seasons in Central Amazonia. In the wet season (left) polluted conditions increase aerosol mass from 1.2 to 3.3 ug/m³. IN the dry season, aerosol concentrations increased from 9 to 12 ug/m³.

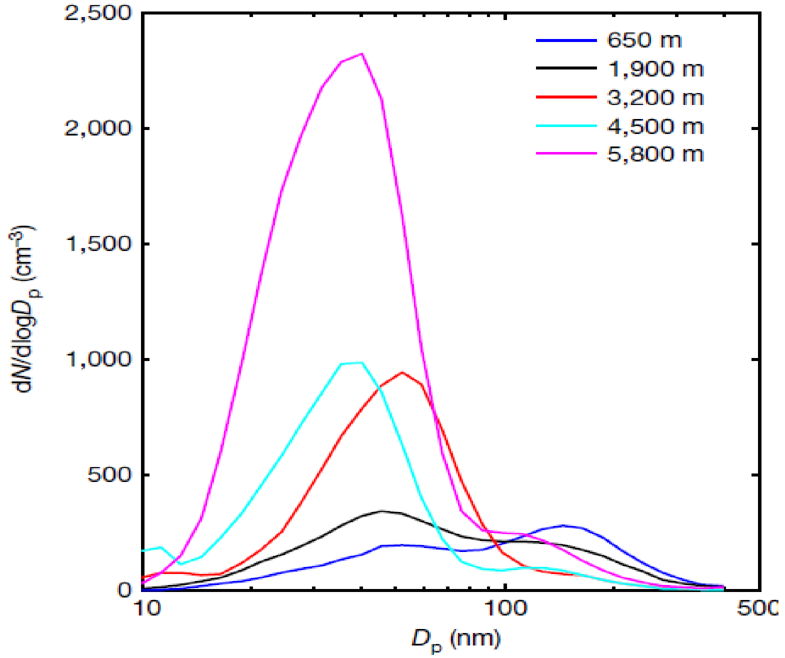
(Sá et al., 2018, 2019)

Observations; Atmospheric Chemistry

- Organic aerosols dominate the natural aerosol in both the boreal and tropical forests, 70-85%
- Forest fires dominating in both systems in the dry and summer periods. The anthropogenic influence larger in boreal during winter.
- Urban emissions speed up the gas phase chemistry and induce formation of new particles
- **However** 2-3 times higher concentrations of SO_2 and BC in the boreal area. Probably due to anthropogenic emissions

Observations: Aerosol Size Distribution, Tropical

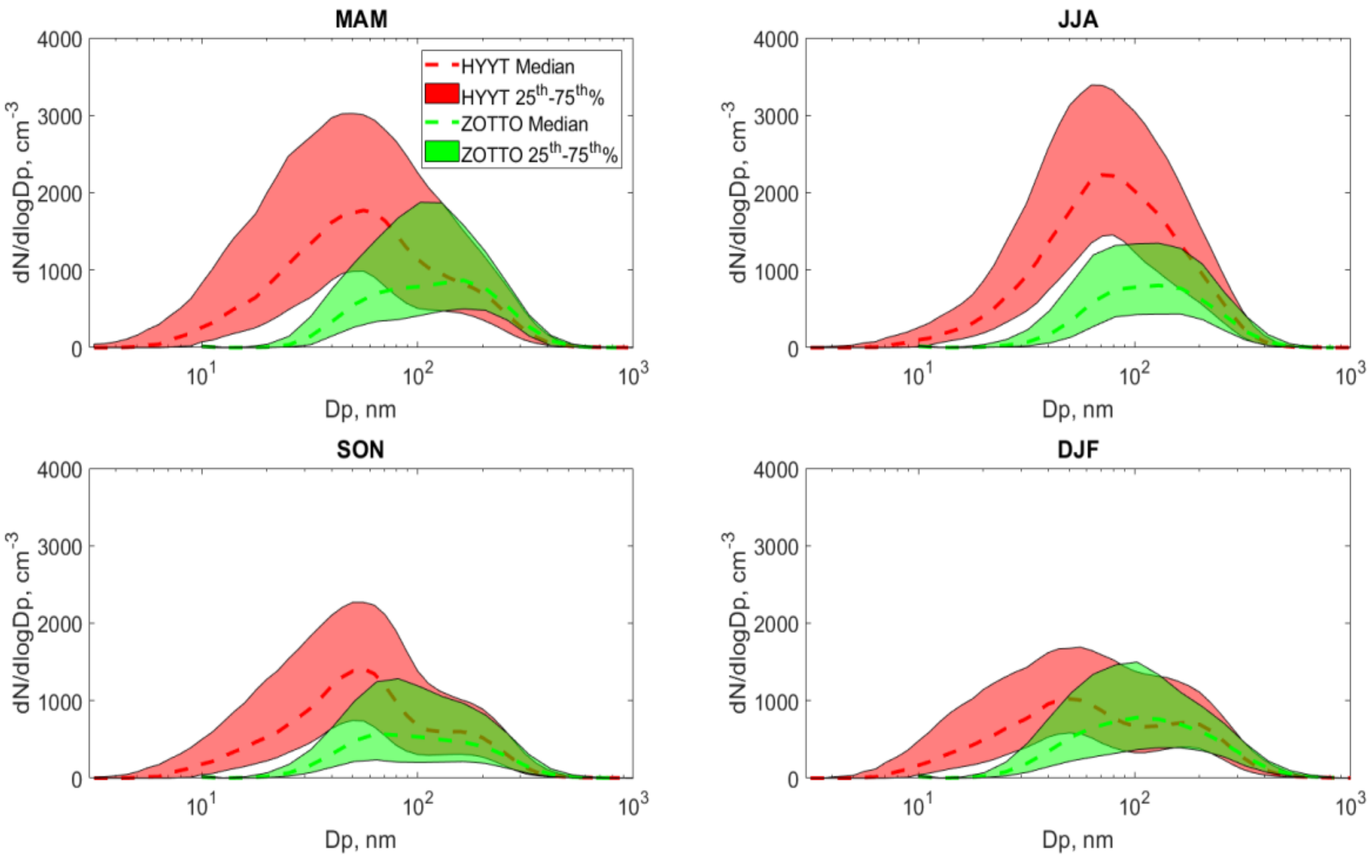




Median particle number size distributions at a forest site in Central Amazonia between 2008 and 2014 during the (a) wet and (b) dry season. Measurements were taken under low RH conditions (30-40%) and about 10 m above the canopy. Shadows represent the 25-75th percentile range. Reproduced from Rizzo et al., 2018.

Airborne observations of submicro-meter particle size distributions at five different altitudes above a forest area in Amazonia on 7 March 2014. Reproduced from Wang et al., 2016.

Observations: Aerosol Size Distribution, Boreal



NPF at Hyytiälä is detected in clean air masses from the Arctic Sea or very North Atlantic. The aerosol is sampled in the forest canopy

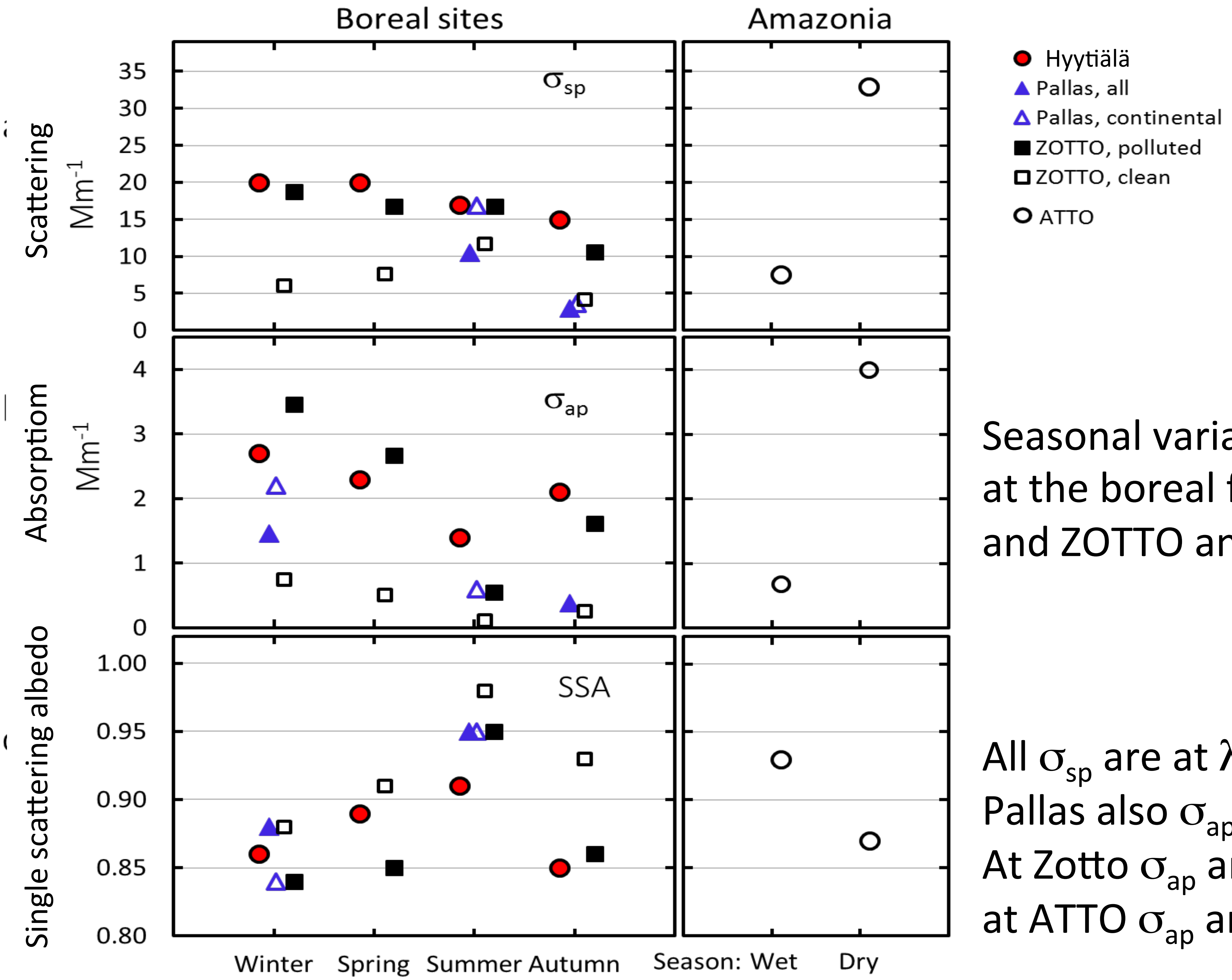
Zotto is located 1500 km from the Siberian Coast in the central Siberia and the sampling at ZOTTO is at 320 meter altitude.

Seasonal median and 25th-75th percentile ranges of particle number size distributions observed at Hyytiälä and ZOTTO 2006-2011. MAM: March-May; JJA: June-August; SON: September-October; DJF: December-February.

Observations: Aerosol Size distribution

- The boreal sites, Hyytiälä and ZOTTO, do not agree in concentration and size distribution.
- ATTO and ZOTTO agree better. Comparing ATTO dry with ZOTTO spring and summer show similar aged size distributions, probably strongly affected by biomass burning. While ATTO wet and ZOTTO fall and winter show signs of cloud processed.
- Lacking NPF at ZOTTO raise questions why so strong NPF over Fennoscandia and not NPF. Possibly influence of air pollution or marine air?

Observations: Aerosol Optical Properties



Seasonal variations of σ_{sp}, σ_{ap} and SSA at the boreal forest sites Hyytiälä, Pallas and ZOTTO and ATTO.

All σ_{sp} are at λ=550 nm, at Hyytiälä and Pallas also σ_{ap} and SSA are at λ= 550 nm. At Zotto σ_{ap} and SSA are at λ=574 nm and at ATTO σ_{ap} and SSA are at λ=637 nm

Observations: Aerosol Optical Properties

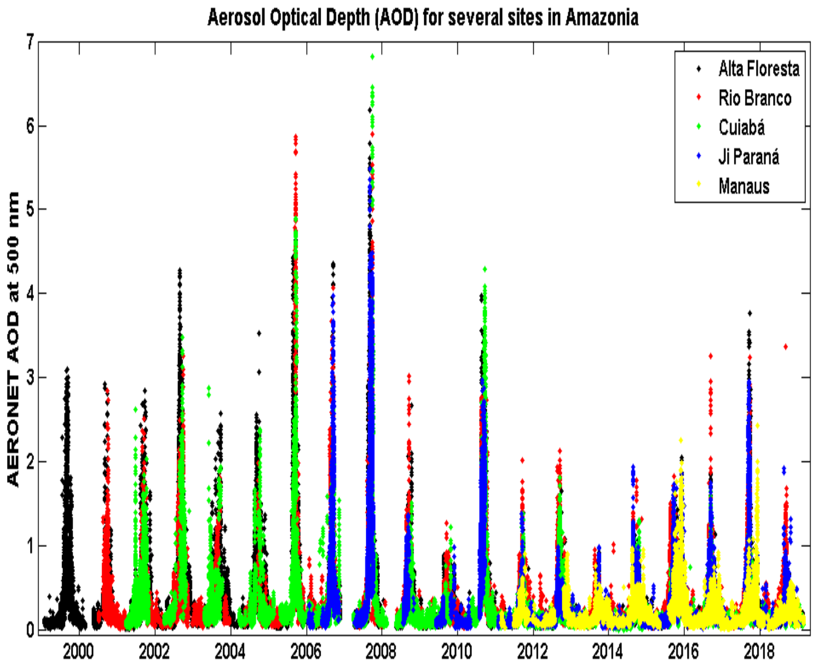
- The Amazonian wet-season averages of both scattering and absorption coefficients are close ZOTTO averages. The Amazonian dry-season averages are higher than winter averages of polluted air masses at the boreal sites.
- The dry-season SSA average at the Amazonian site is at the same level as the winter-season averages at all boreal sites and the wet-season average at the same level as the summer-season averages at the boreal sites.
- Hyytiälä have as high values as polluted ZOTTO. Is the background the same or is Hyytiälä polluted most of the time??

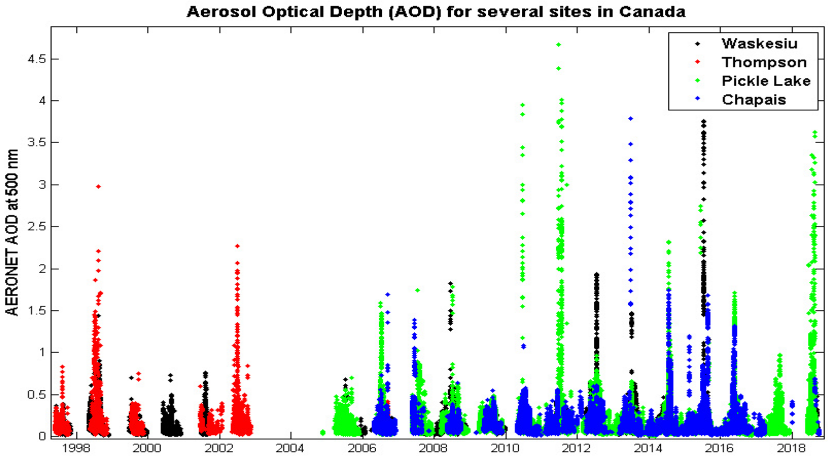
Observations: AOD and radiative effects

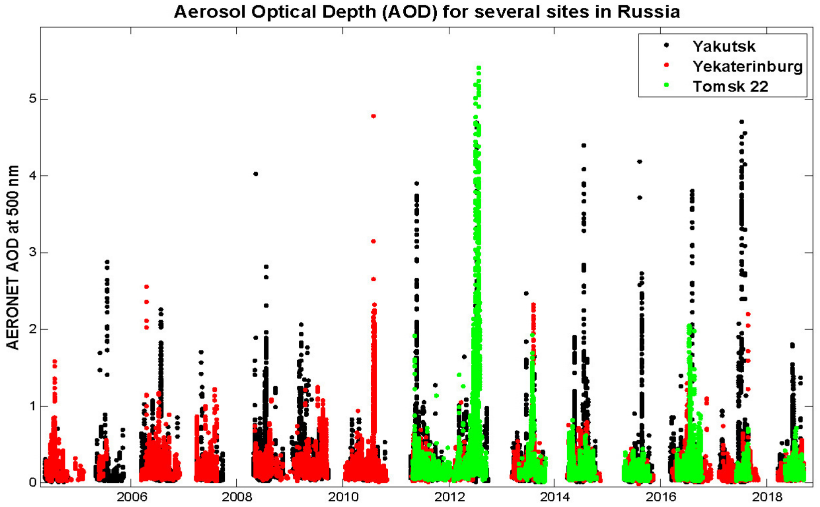
Amazonas

Canada

Russia

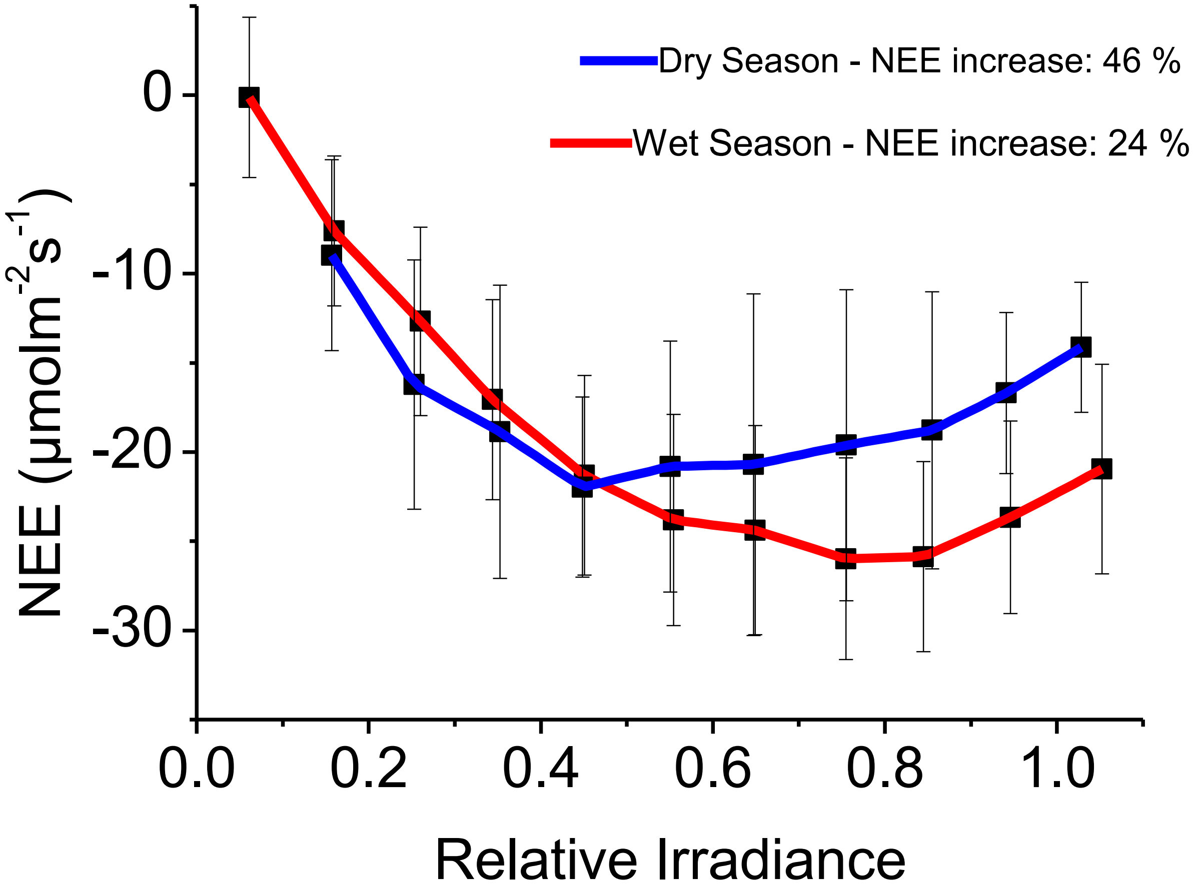






Groundbased AOD measurements from three major forested areas

Observations: AOD and radiative effects



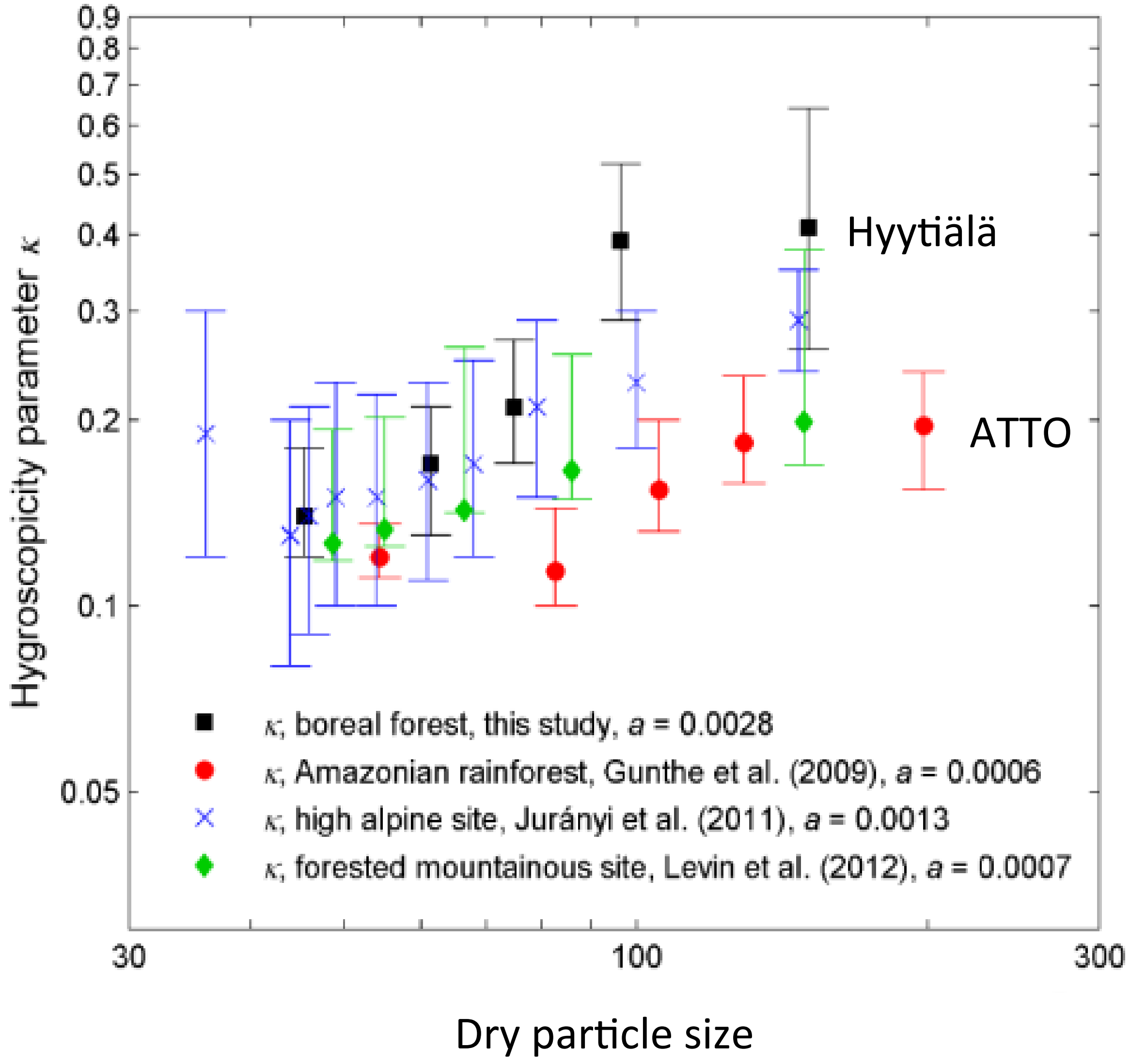
Effects of aerosols on carbon uptake expressed as NEE for dry and wet seasons in a LBA tower in Rondonia (Rebio Jaru), Amazonas.

(Cirino et al., 2014)

Observations: AOD and direct radiative forcing

- AOD time series for Canadian and Siberia boreal forests as well as Amazonia, show biomass burning is a major driving force on aerosol concentrations, and radiative forcing modification over these forest ecosystems.
- Biomass burning season varies with meteorological conditions.
- Radiation scattering has important effects on the radiation balance in tropical forests, but play a minor role in boreal, due to different light intensity, diffuse to direct radiation and leaf area index causing enhancements in NEE of 30% in tropical forests and 10% over boreal.

Observations: Hygroscopic properties



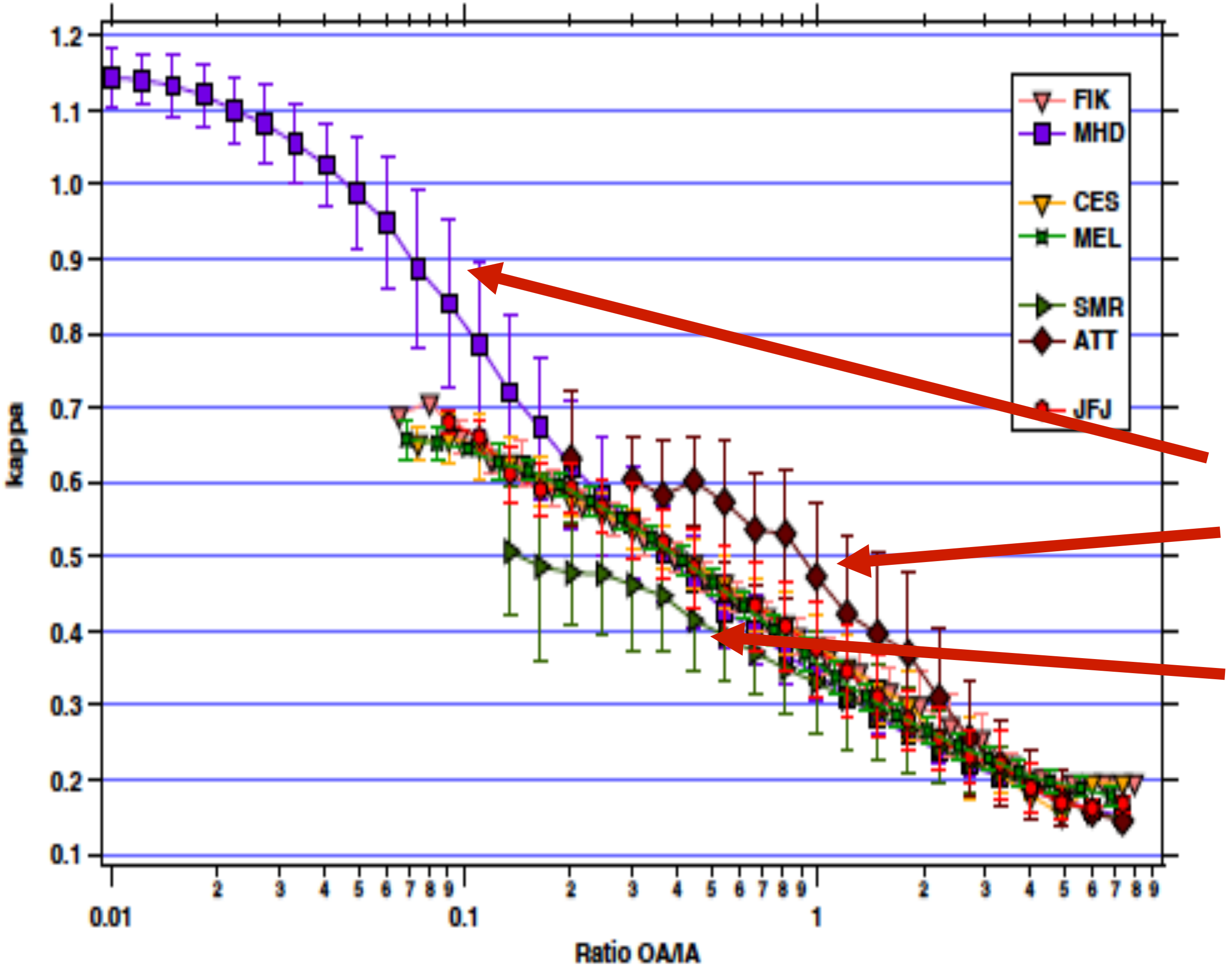
Relationship between particle dry diameter and κ for boreal and tropical forests.

Panel shows the comparison among sites.

The median values are shown with error bars being 25th and 75th percentiles. Legend entries also indicate the slope of the linear regression y = ax +b fit.

Figure from Paramonov et al., 2013.

Observations: Hygroscopic properties



Relationship of the composition-derived hygroscopicity parameter κ to the binned and averaged ratio of organic (OA) to inorganic (IA) aerosol components (Schmale et al., 2018) for:

FIK = Finokalia, Crete;
MHD = Mace Head, Ireland;
ATT = ATTO tower, Amazon;
MEL = Melpitz, Germany;
SMR = Hyytiälä, Finland;
JFJ = Jungfraujoch, Switzerland.

Note that the asymptotic-like approach of the curves towards 0.1 is due to the assumption of $\kappa_{OA} = 0.1$.

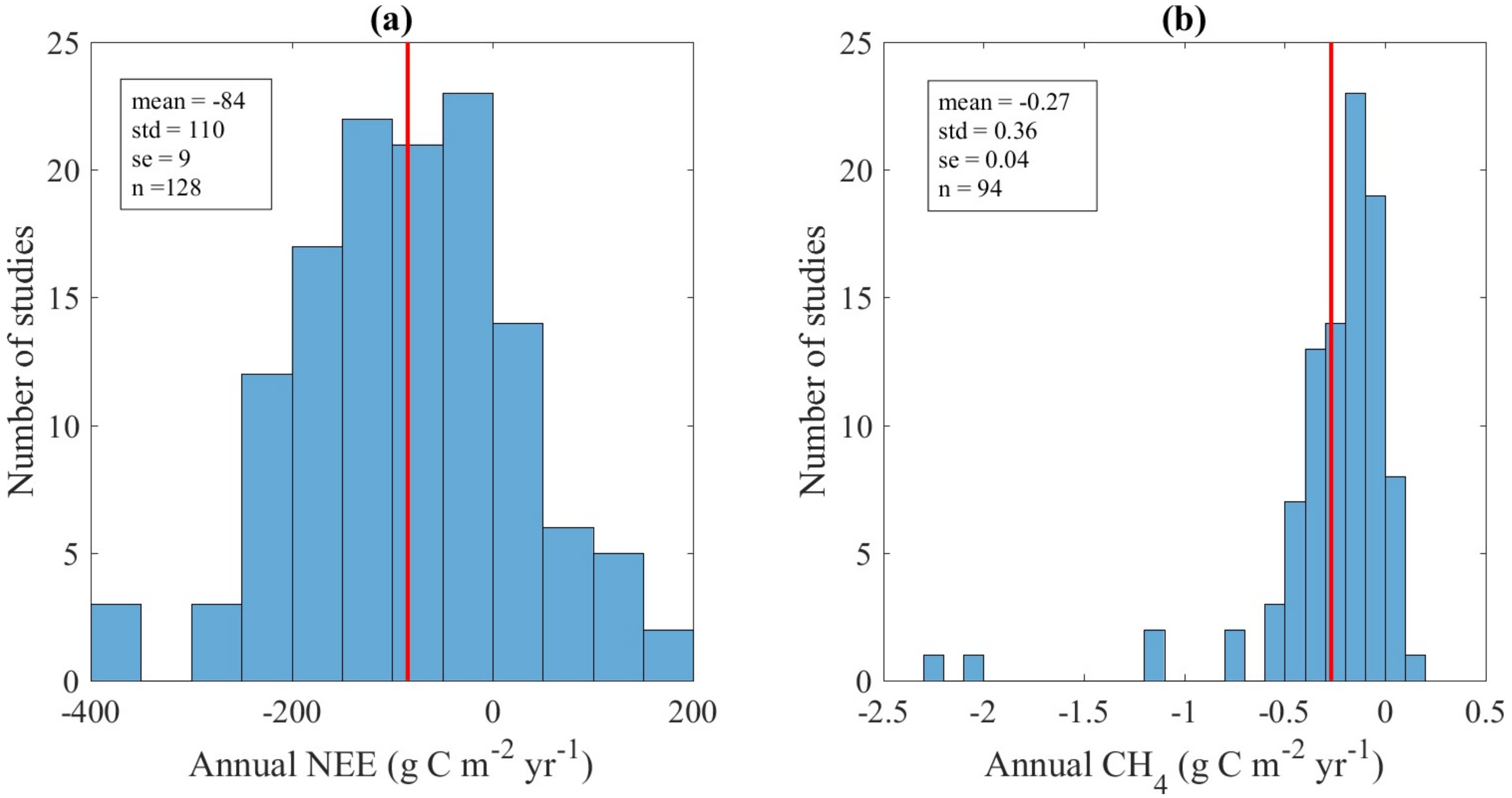
Observations: Hygroscopic properties

- Hygroscopic properties are strongly dependant on the chemical composition but are also influenced by size. Typically, inorganic compounds are strongly hygroscopic while organics are much less hygroscopic.
- The organics in Amazon is mainly isoprene driven giving SOA that in laboratory studies is found to be slightly more hygroscopic than the boreal monoterpene driven SOA. However observations show boreal aerosol to be more hygroscopic.
- Even though such small differences can have a significant effect on the radiation balance. At least in present models.
- EFFECT on CCN?????? Mainly the degree of inorganics.

Observations: BVOC emission

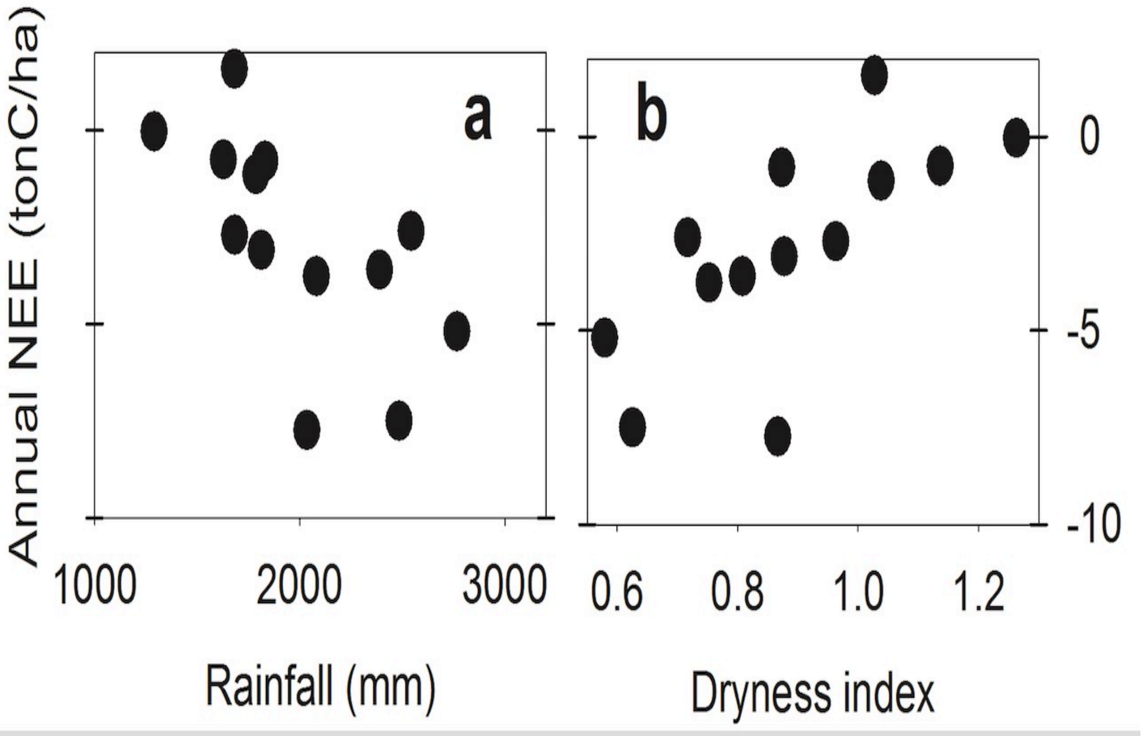
- The BVOC emissions are highly sensitive to landuse change, climate change, and other disturbances but our limited understanding of the processes controlling the specific responses makes it difficult to quantitatively compare and contrast tropical and boreal ecosystems.
- Major and clear difference is isoprene in the Amazonas and monoterpenes in the boreal forest.
- The role of these disturbances in determining emission variations should be a priority for future research efforts.

Observations: Land atmosphere exchange of CO2, CH4 and H2O in the boreal forests



Histograms of published annual net ecosystem exchanges of CO_2 and CH_4 in boreal forests from 1990 to 2015.

Observations: Land atmosphere exchange of CO2, CH4 and H2O in the Amazon



Annual Net Ecosystem Exchange of carbon measured in Amazon flux towers at pristine forests, in the period 1999-2006, compared to measured rainfall and dryness index ($D = R_n / \lambda P$). Adapted from Von Randow et al., 2013.

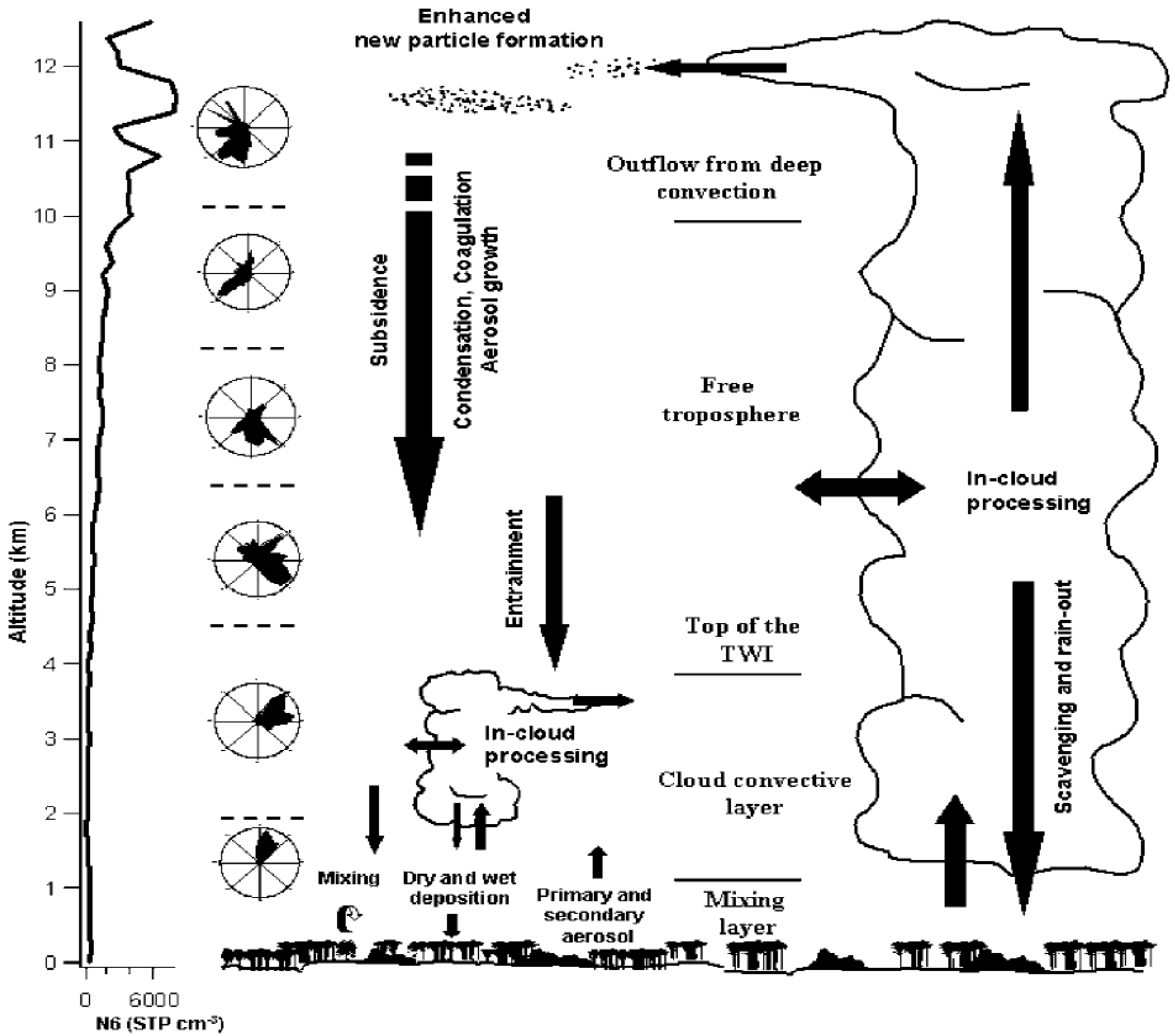
Observations: Land atmosphere exchange of CO2, CH4 and H2O

- Natural undisturbed forests are sink for CO_2 due in part to the CO_2 fertilization effect.
- Forest NEE is regulated by rainfall, and any changes in the hydrological cycle affects CO_2 exchange. Recent increase in extreme events are reducing the net flux of CO_2 in Amazonia.
- Tropical forests are the major source of N_2O, due to high nitrogen turnover. N_2O and CH_4 are emitted by tropical soils, and increase in global temperature can change these fluxes.

Observations: Trace gas concentrations and emissions

- Forest interacts strongly with the atmosphere. In terms of CO_2 forests are key to sequester atmospheric CO_2. Meteorology affects CO_2 sequestration!
- Tropical flooded areas are a major source of CH_4, as well as boreal regions with permafrost.
- CO and O_3 precursors from biomass burning are key to regulate oxidative processes in the atmosphere.
- Ozone damage to plants can reduce significantly the CO2 uptake for tropical forests. OH reactivity is controlled by VOC emissions and reactions, and is key to atmospheric lifetime of key gases.
- NO_X regulates the pathway of VOCs oxidation. SO_2 emissions are important to NPF even at very low concentrations.

New Particle formation



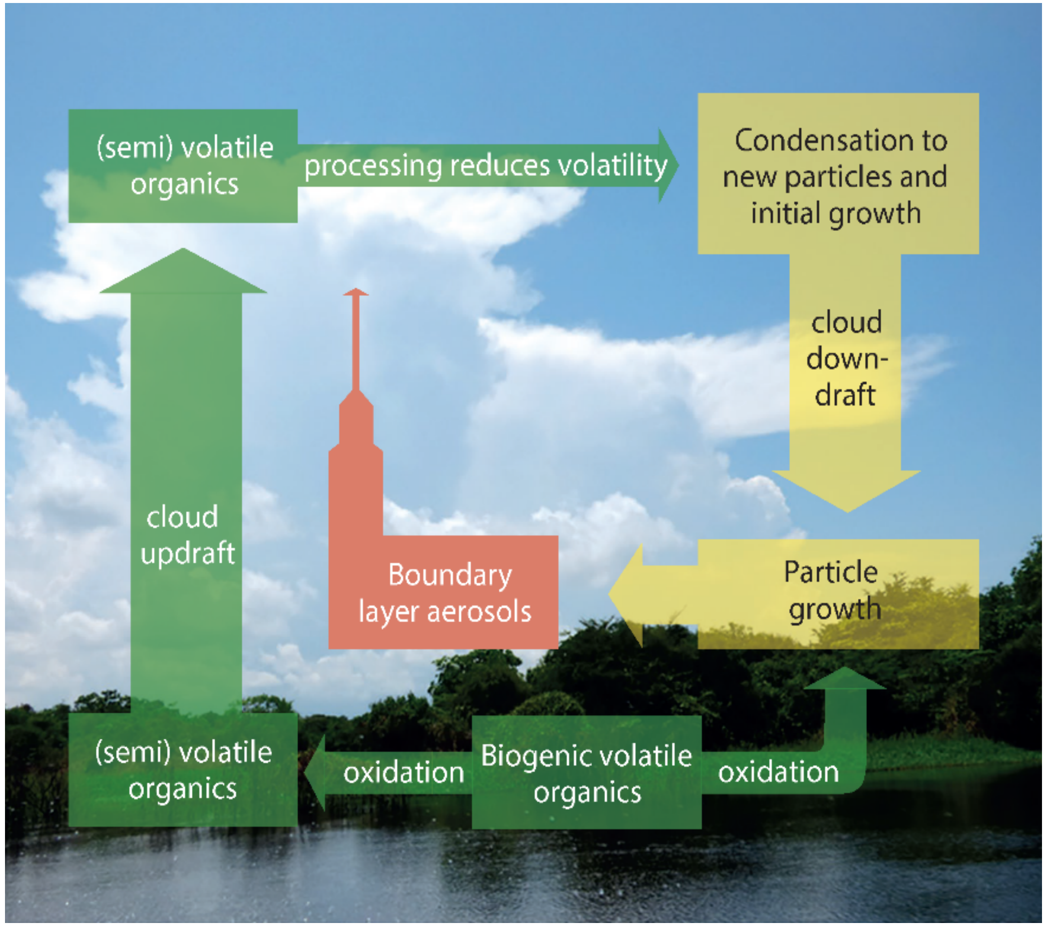
Schematic diagram showing processes producing fine particles as a result of convective cloud outflow above Suriname in Northern Amazonia, with enhanced ultrafine number concentrations at regions of cloud outflow, suggesting nucleation (Krejci et al., 2003).

Martin et al, 2010, Reviews of Geophysics copies and says “The original intent was to describe observations over Suriname, but the processes depicted are applicable to the wider Amazon Basin.

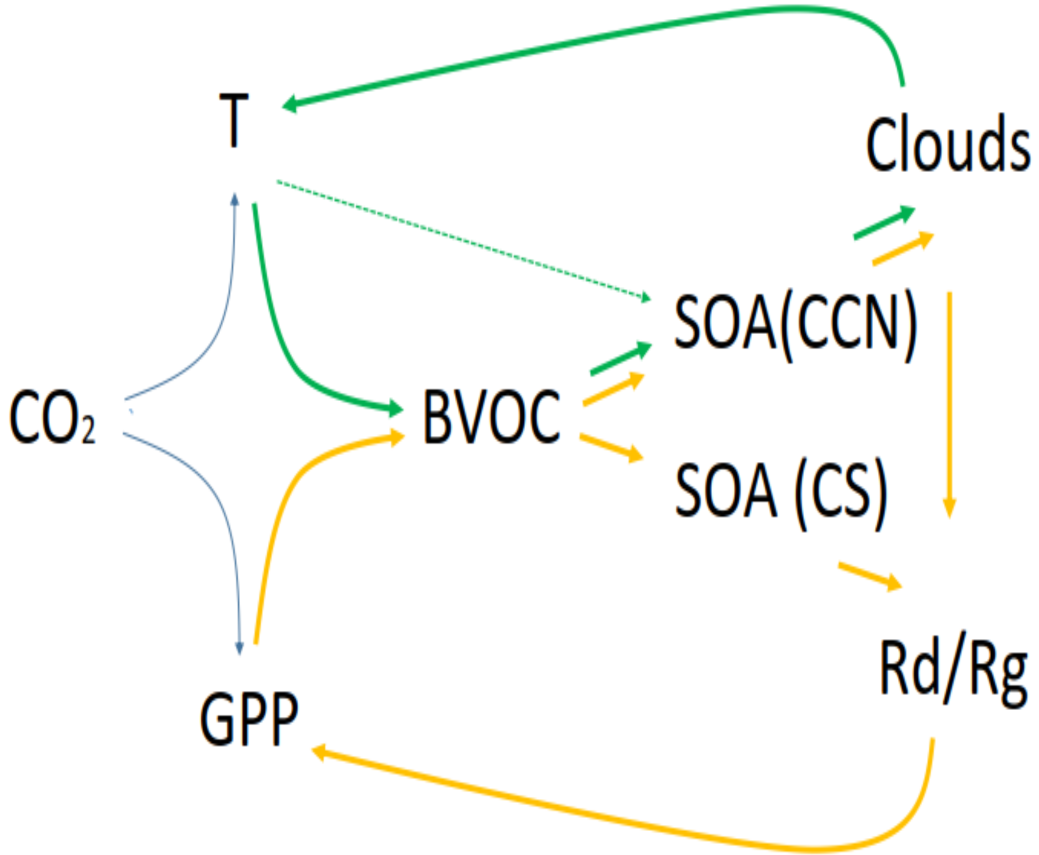
New particle formation

- **Outside the winter period, formation of new aerosol particles in the forest boundary layer is a frequent phenomenon throughout the western European part of the boreal forest zone, less frequent in the northern and Siberian parts of this region, and apparently almost non-existent in the Amazon Basin and central Siberia.**
- Over the Amazon, free-troposphere NPF associated with convective cloud systems and subsequent entrainment into the boundary layer appears to be an important source of aerosol particles during non-polluted periods.
- The most plausible reason for the rare occurrence of NPF in the Amazonian and central Siberian boundary layer is the lack nearby sulfur sources, even though the available mixture of biogenic organic vapors might also play a role.
- Once NPF is taking place, there appears to be enough organic vapors over both boreal forest zone and Amazonia to make the newly-formed particles to grow into sizes at which they can effectively interact with the climate system.

Ecosystem feedback processes



Aerosol life cycle, close interaction ecosystem - clouds



Ecosystem emission affect clouds and radiation affecting the ecosystem

AT LAST final conclusions

- The **understanding of land-ecosystem-atmosphere has increased considerably lately, but still** on a global scale the knowledge is only in many parts **rudimentary** concerning emissions, atmospheric chemistry, particle formation and effect on cloud and climate. The feedback processes are mostly hypothetical where many interfering processes are not well known.
- The **continental and most remote boreal forest seems at the moment least studied** and where major ecosystem changes are expected to be large due to climate change.
- **Climate change, temperature and precipitation will induce major changes** in the ecosystem and with that in the interaction with the atmosphere. Knowledge needed!!!
- I wish for a CaTTO, The Canadian Tall Tower Observatory, placed as remote as ever possible in the Canadian Boreal Forest.


Thank you for your attention!
CSAT3