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\title{Introduction: Observations and Modeling of the Green Ocean Amazon
(GoAmazon2014/5)}

\runningtitle{Introduction: GoAmazon2014/5}

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\begin{abstract}

The \textit{Observations and Modeling of the Green Ocean Amazon}
(\mbox{GoAmazon2014/5}) \mbox{Experiment} was carried out in the environs
of Manaus,
Brazil, in the central region of the Amazon basin during two years from 1
January~2014 through 31 December~2015. The experiment focused on the
complex
interactions among vegetation, atmospheric chemistry, and aerosol
production
on the one hand and their connections to aerosols, clouds, and
precipitation
on the other. The objective was to understand and quantify these linked
processes, first under natural conditions to obtain a~baseline and second
when altered by the effects of human activities. To this end, the
pollution
plume from the Manaus metropolis, superimposed on the background
conditions
of the central Amazon basin, served as a~natural laboratory. The present
paper, as the Introduction to the \mbox{GoAmazon2014/5} Special Issue,
presents the
context and motivation of the \mbox{GoAmazon2014/5 Experiment}. The nine
research
sites, including the characteristics and instrumentation of each site,
are
presented. The sites range from time point zero (T0) upwind of the
pollution, to T1 in the midst of the pollution, to T2 just downwind of
the
pollution, to T3 furthest downwind of the pollution (70\,\unit{km}). In
addition to
the ground sites, a~low-altitude G-159 Gulfstream I (G-1) observed the
atmospheric boundary layer and low clouds, and a~high-altitude Gulfstream

G550 (HALO) operated in the free troposphere. During the two-year
experiment, two Intensive Operating Periods (IOP1 and IOP2) also took
place
that included additional specialized research instrumentation at the
ground
sites as well as flights of the two aircraft. GoAmazon2014/5 IOP1 was
carried out from 1 February to 31 March~2014 in the wet season.
GoAmazon2014/5 IOP2 was conducted from 15 August to 15 October~2014 in
the
dry season. The G-1 aircraft flew during both IOP1 and IOP2, and the HALO
aircraft flew during IOP2. In the context of the Amazon basin, the two
IOPs
also correspond to the clean and biomass burning seasons, respectively.
The
Manaus plume is present year round, and it is transported by prevailing
northeasterly and easterly winds in the wet and dry seasons,
respectively.
This Introduction also organizes information relevant to many papers in
the
Special Issue. Information is provided on the vehicle fleet, power
plants,
and industrial activities of Manaus. The mesoscale and synoptic
meteorologies
relevant to the two IOPs are presented. Regional and long-range transport
of
emissions during the two IOPs is discussed based on satellite
observations
across South America and Africa. Fire locations throughout the airshed
are
detailed. In conjunction with the context and motivation of
GoAmazon2014/5,
as presented herein in this Introduction, research articles published in
this Special Issue are anticipated in the near future, including thematic
Overview articles, to describe the
detailed results and findings of the \mbox{GoAmazon2014/5} Experiment.

\end{abstract}

\introduction

The Amazon basin functions as a~giant biogeochemical reactor to influence
regional climate, with both exports and imports of climate-relevant
quantities in connection to other regions of Earth (Keller et~al., 2009).
Biogenic emissions of gases and aerosol particles, in combination with
high
absolute humidity and strong solar radiation, maintain chemical and
physical
cycles that sustain the aerosol particle population, the cloud field, and
the
hydrological cycle of the basin (Salati and Vose, 1984; Lelieveld et~al.,
2008; Martin et~al., 2010a). The biology of the forest has a~critical
role in

regulating atmospheric composition and climate over the region
(P\"{o}schl
et~al., 2010; Artaxo et~al., 2013).

Any accurate model of the Earth system must succeed in a~good description
of
tropical regions and in particular the Amazon basin, both in its natural
state as well as when perturbed by regional and global human activities.
The
hydrologic cycle of the basin is one of the primary heat engines of
global
circulation (Nobre et~al., 2009). Models of future climate
accounting for human activities have suggested a~possible drying,
especially
in the eastern regions (Nobre et~al., 1991; Boisier et~al., 2015).
Significant changes in the amounts and patterns of precipitation in the
basin can have far-reaching consequences because of the non-linear,
multiscale interactions that affect clouds, precipitation, and
atmospheric
circulation, leading for example to possible modifications in the annual
migration of the Intertropical Convergence Zone (ITCZ) (Wang and Fu,
2007). The hydrological cycle in the Amazon basin has changed over the
past
two decades, but the causes are not fully
identified and understood (Davidson et~al.,
2012; Gloor et~al., 2013).

At present, many aspects of continental tropical deep convection, such as
the
daily cycle, are poorly understood and inaccurately modeled (Betts, 2002;
Dai, 2006). Cloud properties simulated in climate models have high
sensitivity to changes in droplet concentration, droplet size
distribution,
and liquid water content (Dandin et~al., 1997; Liu and Daum, 2002;
Rotstayn
and Liu, 2003). Cloud microphysical properties, cloud cover,
precipitation,
lightning, and regional climate over the Amazon basin can be
significantly
affected by aerosol particles (Andreae et~al., 2004; Lin et~al., 2006;
Rosenfeld et~al., 2008; Martins and Silva Dias, 2009; Altaratz et~al.,
2010;
Koren et~al., 2012; Gon\c{c}alves et~al., 2015; Rosenfeld et~al., 2014).
For
background conditions in the basin, aerosol particle concentrations at
Earth's surface number several hundred per \unit{cm^{3}} (Andreae, 2007;
Martin et~al., 2010a). By comparison, background concentrations increase
by
an order of magnitude in the dry season because of widespread biomass
burning
(Martin et~al., 2010a; Artaxo et~al., 2013). Shifts in the concentrations
of cloud condensation nuclei
(CCN) from a~few hundred up to one thousand per cm^3 can strongly
affect

cloud microphysics (McFiggans et~al., 2006; Reutter et~al., 2009; Koren et~al., 2014). Future expansion of cities and population throughout the basin
can be expected to alter particle concentrations, and changes in cloud properties can be expected.

The \textit{Observations and Modeling of the Green Ocean Amazon} (GoAmazon2014/5) Experiment was motivated by the need to gain a~better understanding of aerosol-cloud-precipitation interactions and processes over
the largest tropical rain forest on Earth. GoAmazon2014/5 sought to advance
the goal of understanding how the chemical, hydrological, energy, and ecosystem cycles of the basin function today and how they might evolve under
scenarios of future stress and pollution. The experiment assembled a~network
of observation sites to intercept both background air of the Amazon basin and pollution from the Manaus metropolis in the central region of Brazil (Fig.~1). Manaus, situated at the confluence of the Black River (``Rio Negro'') with the Solim\~{o}es River, which together form the Amazon River,
is an isolated urban region of over two million people (IBGE, 2015). The city has been a~free trade zone since 1967 to encourage economic development, leading to the presence today of hundreds of local and global manufacturing companies. Most of the manufactured products are shipped
thousands of kilometers by boat to the consumers in the southern states of
Brazil. Outside of the city there is natural forest for over 1000\,\unit{km} in
every direction. In this context, the airshed intersecting the GoAmazon2014/5 research sites downwind of Manaus oscillated between (i) one of the most natural continental sites on Earth and (ii)
one characterized by the interactions of the pollution emissions of a~tropical metropolis with the natural emissions of the rain forest. \mbox{GoAmazon2014/5} was designed to explore
cloud-aerosol-precipitation interactions over a~tropical rain forest for which contrasting conditions of clean compared to polluted conditions were
clearly and regularly delineated. The most heavily instrumented research site (``T3'') of GoAmazon2014/5 was 70\,\unit{km} downwind of Manaus, and it intersected
clean compared to polluted air with day-to-day variability in the position
of the Manaus plume. The pollution plume from Manaus thus served as a laboratory for investigating perturbations to natural processes.

The regular synoptic changes between the wet and dry seasons offered an additional important scientific contrast. In the wet season, the Manaus plume aside, the Amazon basin is one of the cleanest continental regions on
Earth (Andreae, 2007; Martin et~al., 2010a). The particle population is in dynamic balance with the ecosystem (which produces them directly and

indirectly) and the hydrologic cycle (which removes them). In the dry
season, biomass burning is prevalent throughout the basin. The most
intense
burning and atmospheric perturbations take place at the southern and
eastern
edges of the vast forest. Local fire emissions as well as basin-wide
background
pollution also affect the Manaus region during this time period. Wet
deposition
also decreases during the dry season. As result of these spatial and
temporal differences, cloud-aerosol-precipitation
interactions are significantly different between the two seasons (Andreae
et~al., 2004; Feingold et~al., 2005; Artaxo et~al., 2013).

The original use of the expression ``green ocean'' was related to the
similarities in aerosol particle concentrations and cloud microphysics
between the Amazon basin and remote oceanic regions during clean periods
of
the wet season (Williams et~al., 2002). The expression, in reference to
Green Ocean Amazon (``GoAmazon'' in short form) or ``Observations and
Modeling
of the Green Ocean Amazon'' (in long form), has grown into a~more general
meaning to refer to the energy, water, and chemical cycles over the vast,
mostly green Amazon rain forest.

The anticipated publications for this Special Issue of GoAmazon2014/5 can
be broadly
categorized as related to (1) the aerosol life cycle, (2) the cloud life
cycle
, (3) cloud-aerosol-precipitation interactions, and (4) terrestrial
ecosystems (TES). The publications can be largely grouped into focusing
on
one or more of the following topics:

\begin{itemize}
\item 1: (a) Perturbations of atmospheric composition and atmospheric
oxidant cycle due to human activities in tropical continental regions,
including interactions with biogenically
produced volatile organic compounds. (b) Associated influences on the
number
concentration, the mass concentration, the size distribution, and the
optical, cloud-forming, and ice-nucleating properties of aerosol
particles.
\item 2: (a) The evolution of storms over tropical rain forests in the
dry season (i.e., intense and relatively isolated storms) compared to the
wet season
(i.e., less intense but more widespread storms). (b) The daily transition
in cloud development from shallow to deep convection, with comparison and
understanding between tropical and other environments.
\item 3: (a) Effects of aerosol particles on clouds, precipitation, and
lightning across a~range of clean and polluted conditions. (b) The
connections to aerosol direct, semi-direct, and indirect radiative
effects.

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\item 4: (a) Identities, amounts, and seasonal patterns of emissions of
biogenic volatile organic compounds (BVOCs). (b) The controls on the
fraction of assimilated carbon that is allocated to the production and
emission of BVOCs.
\end{itemize}
This Introduction to the Special Issue presents the objectives and
motivation
of the GoAmazon2014/5 experiment. It also provides a~description of the
field
sites, the environmental conditions during the two Intensive Operating
Periods (IOPs), and the context of the Manaus metropolis in the center of
the
largest rain forest on Earth.

\section{Experimental design}

The GoAmazon2014/5 Experiment took place in the environs of Manaus in the
central region of the Amazon basin. Manaus, a~city presently of over two
million people and expanding rapidly, is an isolated urban region within
the
surrounding rain forest (Fig.~1). It is large enough to have an urban
island heat effect of up to 3\,{\degree}C relative to the surrounding
forest (de Souza and dos Santos Alval\'{a}, 2014). Several important
geographic features include the confluence of two large rivers, an urban
landscape, and undulating land relief (50 to 200\,\unit{m}) that affects
its daily
meteorological cycles (dos Santos et~al., 2014; Tanaka et~al., 2014).
GoAmazon2014/5 measurements were made from 1 January~2014 through 31
December~2015. Two Intensive Operating Periods, including aircraft and
additional personnel and instrumentationat the ground sites, took place
in the wet and
dry seasons of 2014. GoAmazon2014/5 IOP1 took place from 1 February to 31
March~2014, and GoAmazon2014/5 IOP2 was active from 15 August to
15~October~2014. There were nine ground stations in and around Manaus as
well as
coordinated flights by research aircraft. The rationale for the use of
the multiple platforms was to characterize the Amazonian atmosphere under
varying degrees of urban influence and photochemical processing

\subsection{Site and aircraft descriptions}

The locations of Manaus and the nine research sites are shown in Fig.~1.
The latitude--longitude coordinates of each site are listed in Table~1.
The
sites range from time points zero (T0) upwind of the pollution, through
time
points one (T1) and two (T2) closer to the pollution sources, to time
points
three (T3) furthest downwind of the pollution. Instrumentation at each
site,
including the aircraft, is catalogued in Tables~S1 to S13 in the
Supplement. The scope and
duration of the datasets that were collected by this combined set of

instrumentation represents a~new milestone for the study of climate and air
quality in the Amazon basin.

Site T0a was the Amazonian Tall Tower Observatory (ATTO) (Andreae et~al.,
2015). Although the site has been active since 2012, the 325-m tall tower
(inaugurated in August~2015) had not yet been completed during the IOPs of
GoAmazon2014/5. Measurements were instead made from two 80-m towers at the
site. Site T0e was located at a~branch of the Brazilian Agricultural Research
Corporation (EMBRAPA) about 10\,\unit{km} beyond the northern limits of the
Manaus metropolitan area (Barbosa et~al., 2014). Sites T0k and T0t were
situated in the Cuieiras Biological Reserve (``ZF2'') that has been a~central
part of Amazonian ecology and climate studies for over 20\,\unit{years}. In
particular, T0k was the tower ``K34'' that has been the centerpiece of the
Large-Scale Biosphere--Atmosphere (LBA) experiment since its construction in
1999 (Ara\'{u}jo et~al., 2002). Site T0t was tower ``TT34'' established for
the Amazonian Aerosol Characterization Experiment (AMAZE-08) in 2008 (Martin
et~al., 2010b). The T0 sites were all nominally upwind of Manaus so that the
pollution plume was not present most of the time. In all cases, however,
except possibly for T0a, the local winds did occasionally transport some
pollution to these sites (Chen et~al., 2015).

Within Manaus, site T1 was a~tower in a~forested section of the campus of the
National Institute of Amazonian Research. Site T1p was located at the
military airport at Ponta Pelada in Manaus. Site T2 consisted of a~research
container placed at a~hotel on the western edge of the Black River and just
across the river from Manaus (J.~Brito, personal communication, 2015). It
sampled the fresh Manaus pollution plume across approximately 8 to
11\,\unit{km} of river width depending on the prevailing wind direction. Site
T3u was located on the regional campus of Amazonas State University in
Manacapuru.

The most comprehensively instrumented site of GoAmazon2014/5 was T3. For
twenty-four months, a~suite of containers representing the Atmospheric
Radiation Measurement (ARM) Climate Research Facility of the United States
Department of Energy operated at T3. This facility included the Mobile
Facility One (AMF-1) and the Mobile Aerosol Observing System (MAOS)
(Mather and Voyles, 2013). There were four

additional containers of instrumentation deployed by university investigators and other scientists during the two
IOPs. The T3 site was located 70\,\unit{km} downwind of Manaus, representing several
hours of air travel time depending on the daily wind speeds. It was
a~pasture site of 2.5\,\unit{km} by 2\,\unit{km} situated 2\,\unit{km} to the north of a~lightly
traveled two-lane road (AM-070) that connects Manaus to Manacapuru. Manacapuru was 10\,\unit{km} downwind of T3 to the southwest.

Two aircraft, a~low-flying G-159 Gulfstream I (``G-1'')
(Schmid et~al., 2014) that mostly sampled the
atmospheric boundary layer and low clouds and a~high-flying Gulfstream G550
(``HALO'') (Wendisch et~al., 2015) that mostly observed the free
troposphere, collected data during the two IOPs. The flight tracks of HALO
appear in Wendisch et~al.~(2015), constituting 14 research flights, mostly in the
mid- and upper troposphere, during IOP2. The domain of flights was across
a~large part of the Amazon basin. There were two dedicated flights coordinated
with the G-1 aircraft, including for instrument comparison. The G-1 carried
out 16 flights in IOP1 and 19 flights in IOP2, mostly in the late morning
and early afternoon (local time). Figure~2 shows all flight tracks of the
G-1. Figures~S2 and S3 in the Supplement segregate the tracks by altitude. Other than a~few
flight missions set up to sample background conditions, the flight tracks
shown in Fig.~2 represent a~synopsis of the actual location of the Manaus
pollution plume on specific days. The flight tracks show that easterly winds
carried the plume westward over the rain forest. On a~given day, flight
plans were filed in early morning based on boundary layer winds sampled by
radiosondes as well as on the forecasted location of the pollution plume.
The plume was forecast by the CATT-BRAMS model (Coupled Aerosol and
Tracer Transport model to the Brazilian developments on the Regional
Atmospheric Modelling System) (Freitas et al. 2009). In
some cases, adjustments to the flight plans were made during flight once
instrumentation had identified the actual location of the daily plume.

\subsection{Climatology}

In the middle of the Amazon basin, Manaus is situated in an attractive
scientific location because the full range of basin meteorology can be
encountered. Cold fronts, which typically occur in the southwest part of the
basin (Rondonia), can reach further north and affect the meteorology of the
central part of the basin, most often in June and July. Squall lines, which
are frequent in the eastern portion of the basin, also penetrate and

propagate from the South Atlantic to middle of the basin (Greco et~al., 1990;
Cohen et~al., 1995; Alc\^{a}ntara et~al., 2011), often leading to late night
or early morning precipitation in Manaus (Machado et~al., 2004). Organized
synoptic convective events are most common at the start and the end of the
wet season. These events are caused in large part by a~monsoon circulation
that shifts the ITCZ southward over Manaus and by squall lines that originate
near the coast and propagate to the central region of the basin.
A~consequence of these dual synoptic perturbations is that the number of
organized synoptic convective events per month is high in Manaus, around six
during March and three during October (Machado et~al., 2004).

The cloud cover and rainfall around Manaus is lowest in July and August
during the central period of the dry season and highest in February and
March in the midst of the wet season. Although seasonal variation in
convective available potential energy (CAPE) is small, as is typical for
rain forest close to the equator, rainfall in the wet season is more
continuous but less intense compared to the dry season. The transition
period between dry and wet seasons and the onset of the wet season are the
time periods of maximum intensity for convection. Little seasonal variation
in CAPE yet large variation in cloud cover and rainfall taken together imply
that small perturbations in large-scale circulation in this region can
possibly drive dramatic changes in rainfall.

\subsection{Air pollution sources in Metropolitan Manaus}

Major sources of air pollution from Manaus include the vehicle fleet, power
plants, and industrial activities, all of which are increasing annually. The
population of Manaus grew from 1.5 million in 2004 to 2.0 million in 2014. By
percentage Manaus was the fastest growing major Brazilian city during this
time period (IBGE, 2015). Manaus accounts for 80\,{\%} of the economic
activity of the state of Amazonas.

In regard to the vehicle fleet, in December~2014 there were 622\,675 vehicles
registered in Manaus (DENATRAN, 2015). Outside of Manaus, there were
an additional 133\,088 vehicles in the state of Amazonas. For comparison, ten
years earlier (December~2004), there were 242\,893 registered vehicles in
Manaus, meaning a~250\,{\%} increase in the fleet from 2004 to 2014. In 2014,

255\,758 registered vehicles used alcohol or gasoline, 281\,811 consumed
gasoline only, 54\,158 were powered by diesel, and 30\,948 employed
another
fuel or were unclassified. There were 326\,806 passenger vehicles,
150\,127
motorcycles, 91\,099 pick-ups, 28\,285 trucks, 10\,688 buses, and 15\,690
vehicles of other types.

Electricity in Manaus is largely produced by the combustion of fossil
fuels.
In 2013, the power plants consumed $2.5 \times 10 ^{8}$ kg of fuel oil
(providing 14\,{\%} of electricity produced), $1.3 \times 10
^{9}$\,\unit{m^{3}} of natural gas (55\,{\%}), and $6.1 \times 10 ^{8}$ L
of
diesel (31\,{\%}) (A.~Medeiros, personal communication, 2015). The
nominal
installed capacity was 1.5\,\unit{GW} for fossil fuel power plants
(Eletrobras, 2013). The locations of the plants in the urban
Region are shown in Fig. S4. The consumption of fossil fuels was
complemented by a~hydroelectric
power plant (250\,\unit{MW}), which has operated in Balbina to the north
of
the city since 1989. Following the inauguration in November~2009 of a~gas
pipeline (661\,\unit{km}) from Urucu to Manaus and passing through
Manacapuru, the fuel matrix for electricity production has been shifting
from
a~historical reliance on sulfur-laden fuel oil and diesel to one having
an increasing
fraction of natural gas.

In addition to Manaus, important
but less consequential sources of air pollution include multiple small
municipalities along the Amazon River extending hundreds of kilometers to
the
east all the way to the South Atlantic. Between Manaus and T3, there are
dozens of small brick factories (Fig.~S5). These factories nearly
exclusively
use wood to fire the kilns (B.~Portela, personal communication, 2015).
Site
T2 was impacted by these factories when well-known daily patterns of
local
river breezes transported air masses from the west (direction opposite to
Manaus) (G.~Cirino, personal communication, 2015) (Silva Dias et~al.,
2004;
Trebs et~al., 2012; dos Santos et~al., 2014). With respect to T3,
although
the simulated wind trajectories at times passed near and through the
locations of these factories, elevated concentrations of biomass burning
tracers such as acetonitrile or levoglucosan were rare for the data sets
of
IOP1, suggesting that brick factory emissions did not have a~significant
influence most of the time on measurements at T3 (S.~de S\'{a}, personal
communication, 2015). With respect to background air entering the Manaus

region, the pollution from the small municipalities along the Amazon River as
well as eastern coastal cities can become important in the dry season because
of prevailing easterly winds during that season. Biomass burning also takes
place throughout the basin, especially along the eastern and southern edges
of the forest during the dry season, and can be an important source of
regional pollution.

In 2001, the pollution plume from Manaus was characterized in transect
flights by Kuhn et~al.~(2010). At that time, the plume
consisted of high concentrations of oxides of sulfur, oxides of nitrogen,
submicron aerosol particles, and soot, among other pollutants. Ozone was
produced by photochemical reactions in the plume (Trebs et~al.,
2012). The width of the urban plume was 20 to 25\,\unit{km}, resembling the
dimension of the city itself.

\section{Mesoscale and synoptic meteorology during the Intensive\hack{\break} Operating
Periods}

\subsection{IOP1}

The mesoscale and synoptic meteorology is based on soundings as well as
satellite observations. The trade winds carried equatorial air of the South
Atlantic into the Amazon basin. Fourteen-day back trajectories, originating
100\,\unit{m} above Manaus, are grouped together and shown in Fig.~3a. Manaus
($-$3.1{\degree}) was typically under air masses coming from the Northern Hemisphere
during IOP1 because of the southern positioning of the ITCZ during this time
period.

Time series of altitude profiles of winds and relative humidity based on
soundings launched at the T3 site, as well as a~time series of regional
rainfall based on retrievals from a~radar at T3p, are presented in Fig.~4.
Northeasterly winds prevailed in the atmospheric boundary layer of the
Manaus region (Fig.~4a1 and a2). Regular and strong precipitation events are
apparent in the time series of daily rainfall amounts (Fig.~4a3). Deep
tropospheric moistening because of regular large rain events is apparent
(Fig.~4a4).

The precipitation climatology for 2000--2014 and the associated weather
anomalies are shown in Fig.~5a across a~broad region of the Amazon basin in

the wet season. A band of high precipitation from the South Atlantic to the
central region of the basin accompanied squall lines that originated at the
coast and propagated into the basin (Fig.~5a1). The maximum runs along the
ITCZ. The precipitation anomalies, meaning the precipitation during the IOP
compared to that of the fifteen-year climatology during that same period,
were positive along the general trajectory of winds from the ocean coast to
Manaus (Fig.~5a2). Positive anomalies were consistent with the discharges of
the Madeira River, the main southern tributary to the Amazon River, which
were 74\,{\%} higher than normal. The maximum level (June) of the Black River
at Manaus in 2014 corresponded to the fifth highest during
113\,\unit{years}
of record (Espinoza et~al., 2014). Figure~5a2 also suggests that regions of
strong positive anomalies in rainfall were associated with nearby regions of
negative anomalies, suggesting an importance of mesoscale circulations of
various types (e.g., forest-pasture, river breeze, and topography). On the
synoptic scale, there was an intense warm anomaly in sea surface temperature
(SST) in the southern South Atlantic and a~weaker cold anomaly in the
northern and equatorial South Atlantic (Fig.~S6a). This anomaly in the SST
gradient drove moisture transport from the South Atlantic toward the
southwestern region of the Amazon basin. As a~result, there was increased
precipitation in the western part of the basin.

\subsection{IOP2} During the dry season, the ITCZ shifted northward, and
the Manaus region
was under air masses coming from the Southern Hemisphere (Fig.~3b). The trade winds
carried air and moisture from the South Atlantic to the middle of Amazon
basin. Importantly (cf. Sect.~4), at times there was a~recirculating pattern from
the southern part into the middle section of South America. In the central
region of the Amazon basin, strong easterlies prevailed in the surface
boundary layer (Fig.~4b1 and b2). Compared to the wet season, rainfall was
lower and the free troposphere was drier (Fig.~4b3 and b4). Notable
moistening and higher levels of rain occurred in the final ten days. Unlike
IOP1, temperature anomalies over the South Atlantic during IOP2 were no
longer significant (Fig.~S6b). A~strong warm anomaly was, however, present
over the equatorial Pacific Ocean, corresponding to an El Ni\~{n}o

development. The climatology of precipitation in the basin differs
between
the wet and dry seasons in both magnitude and geographical distribution
(Fig.~5a1 compared to Fig.~5b1). There is in general little rainfall in
the
eastern part of the basin in the dry season, and in particular for 2014
the
precipitation anomaly was overall negative (Fig.~5b2), especially in
September (not shown).

\conclusions[Regional and long-range transport of emissions during the
Intensive Operating Periods]

The wet season is viewed as a~clean time period for background air,
except
for the episodic intrusions from Africa
(Martin et~al., 2010a). The dry
season is sometimes alternatively referred to as the biomass burning
season.
During times of continental recirculation (cf. Sect.~3), biomass burning
emissions from the southern edge of the forest transported south and
southeast across the Atlantic coast of Brazil could in part return to the
central Amazon. The backtrajectories in the dry season also passed
reliably
along the Amazon River, carrying the pollution of riparian communities
and
at times of large cities in the coastal northeast of Brazil into the
Manaus
region.

Fire locations in the near-field of the Manaus region as well as in the
far
field of South America are in the upper and lower rows of Fig. 6,
respectively, for each IOP. Breakdown by week is shown in Figs. S7 and
S8. Near-field fires represent upwind locations
requiring on the order of one day for transport to the Manaus region.
Pollution from these fires can be expected to have physical and chemical
signatures of fresh emissions. Far-field fires represent upwind locations
requiring several days or more for transport to the Manaus region. The
emission signatures by arrival into the Manaus region become
significantly
aged. Figure 6 generally showsa~low incidence of fires during the wet
season (IOP1) compared to a~high incidence during the dry season (IOP2).

Concentrations and emissions of aerosol particles on a~hemispheric scale
can be visualized by satellite by maps of aerosol optical depth (AOD).
Weekly maps are shown in Fig. S9 for the two IOPs. Dust and biomass
burning emissions from equatorial Africa were transported
episodically into the central Amazon, as explained by the southern
positioning of the ITCZ during this time period. By comparison, during
IOP2 these emissions passed northward to the Caribbean, as
explained by the northward shift of the ITCZ during this time period.
During
IOP2, there were two regions of intense biomass burning. The first

was the central region of South America, representing the burning edge of the
Amazon rain forest and called the ``arc of deforestation''. Recirculation
patterns for the dry season can transport a~portion of these emissions to
the central part of the Amazon basin where Manaus is located. The second
region of biomass burning was the central part of Africa. Emissions from both
of these regions arrived into the central region of the Amazon basin during
IOP2, as can be inferred by an overlay of the backtrajectories apparent in
Fig.~3 and the emissions and transport implied by the aerosol optical
depth in Fig.~S9. Although mass concentrations were greatly reduced during
transport, the subtlety is that the
central Amazon represents quite clean baseline conditions so that even
relatively small amounts of imported emissions (compared to the source
regions) can have a~regionally dominant effect compared to the otherwise
clean receptor region.

In summary, the GoAmazon2014/5 Experiment focused on the complex interactions
among vegetation, atmospheric chemistry, and aerosol production and their
connections to aerosols, clouds, and precipitation. It sought to understand
how aerosol and cloud life cycles were influenced by pollutant outflow from
a~large city in the tropical rain forest, particularly the susceptibility of
the biosphere and atmosphere to human activities, for a~wide range of
synoptic and environmental conditions. It was driven by the need to develop
a~knowledge base of data, processes, and mechanisms for inclusion in models
of different types and scales. The intended future legacy of
\mbox{GoAmazon2014/5} is that more accurate predictions (embedded in models)
should be developed of how the present-day functioning of energy, carbon, and
chemical flows in the Amazon basin might change, both due to external forcing
on the basin from global climate change and internal forcing from past and
projected economic development in the basin. There can be future changes in
direct, semi-direct, and indirect radiative forcing, energy distributions,
regional climate, ecosystem functioning, and feedbacks to global climate.

In conjunction with the Introduction presented herein, research results and
findings of GoAmazon2014/5 appear in the articles of this Special Issue. The

Special Issue is open for new submissions for three years. A~series of three
Overview articles is planned for summarizing and synthesizing the findings
of the papers of the Special Issue. These planned Overviews encompass the
several objectives of GoAmazon2014/5.

\Supplementary{pdf}

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\begin{table}
\caption{Names and locations of research sites and platforms
deployed in GoAmazon2014/5. Other common names, as well as the relative
distances and angles from T1 (INPA), are also listed.}
\scalebox{0.6}[0.6]{
\begin{tabular}{p{30mm}p{25mm}lllllp{42mm}p{35mm}}
\tophline &&\multicolumn{2}{c}{Location} &\multicolumn{2}{c}{Position
Relative
  to T1} & & \\
GoAmazon2014/5\par
Reference&Other\par
Reference&Latitude&Longitude&Distance (km)&Heading
(0{\degree\,N)}&{Reference} &{Reference} \\
\middlehline
T0a&ATTO&$-$2.1466{\degree} &$-$59.0050{\degree} &151.4&45.8{\degree}
&{Forested site upwind of Manaus for 325\,\unit{m} tall tower
(inaugurated Aug~2015) }&{Andreae et~al.~(2015)} \\
T0e&EMBRAPA&$-$2.8942{\degree} &$-$59.9718{\degree} &22.5&4.3{\degree}
&{Pasture site north of\par Manaus} &{Barbosa et al.~(2014)} \\

```latex
T0k&K34, ZF2&$-$2.6091{\degree} &$-$60.2093{\degree} &59.4&335.5{\degree}
&{Closed canopy, forested\par site north of Manaus} &{Ara\'{u}jo
et~al.~(2002)} \\
T0t&TT34, ZF2&$-$2.5946{\degree} &$-$60.2093{\degree}
&60.9&336.1{\degree} &{Broken canopy, forested\par site north of Manaus}
&{Martin et~al.~(2010b)} \\
T1&INPA&$-$3.0972{\degree} &$-$59.9867{\degree} &n/a&n/a&{On INPA campus
in\par Manaus} & \\
T1p&Ponta Pelada&$-$3.1461{\degree} &$-$59.9864{\degree}
&5.4&179.6{\degree} &{Ponta Pelada Airport (PLL)} &{} \\
T2&Tiwa Hotel&$-$3.1392{\degree} &$-$60.1315{\degree}
&16.8&253.9{\degree} &{Adjacent to river, just downwind of Manaus;  river
width of 7.5 to 11.7\,\unit{km} depending on direction of prevailing
winds} &{} \\
T3&MAOS,\par AMF-1, Fazenda Agropecu\'{a}ria Exata&$-$3.2133{\degree} &$-$
60.5987{\degree} &69.4&259.2{\degree} &{Pasture site downwind of Manaus}
&{}Mather et al. (2014)  \\
T3u&UEA&$-$3.2953{\degree} &$-$60.6282{\degree} &74.6&252.9{\degree} &{On
UEA campus in\par Manacapuru} &{} \\
G-1&AAF,\par G-159\par Gulfstream I&n/a&n/a&n/a&n/a&{} &{Schmid
et~al.~(2014)} \\
HALO&Gulfstream G550&n/a&n/a&n/a&n/a&{} &{Wendisch et~al.~(2015)} \\
\bottomhline
\end{tabular}}
\end{table}




\begin{figure}
%\includegraphics[width=120mm]{f01.pdf}
\caption{Locations of GoAmazon2014/5 research sites in the
environs of the city of Manaus ($-$3.1{\degree}, $-$60.0{\degree}) in
the state of Amazonas in the country of Brazil. Table~1 provides further
information on the labeled sites. Manaus is located at the confluence of
the
Black River (``Rio Negro'') with the Solim\~{o}es River, which together
form
the Amazon River. The map rectangle is drawn from ($-$3.66{\degree}, $-$
$60.92{\degree})
in the southwest to ($-$1.91{\degree}, $-$58.58{\degree}) in the
northeast. The left inset shows the location of the experimental domain
within South America. For prevailing winds, Manaus is on the order of
1200 (IOP1) to
 1600\,\unit{km} (IOP2) from the South Atlantic. The right inset shows
nighttime illumination in the environs of the city of Manaus for the year
2010. Figure S1 provides an expanded view of the regional nighttime
illumination.}
\label{}
\end{figure}

\begin{figure}
%\includegraphics[width=70mm]{f02.pdf}
```

\caption{Flight tracks of the G-1 aircraft during \textbf{(a)} IOP1 and
\textbf{(b)}
IOP2 for all altitudes. The flight periods were from 22 February to 23
March~2014 in IOP1 and 6 September to 4 October~2014 in IOP2. The flight
tracks
segregated by altitude appear in Figs.~S2 and S3.}
\label{acpd-2015-0780-f01}
\end{figure}

\begin{figure}
%\includegraphics[width=70mm]{f03.pdf}
\caption{Fourteen-day back trajectories initialized at 100\,\unit{m}
above T3
during \textbf{(a)} IOP1 and \textbf{(b)}~IOP2. Meteorological fields
were
from the $1{\degree} \times 1{\degree}$ Global Data Assimilation System
(GDAS). Source: \url{http://www.arl.noaa.gov/HYSPLIT_info.php}, last
access:
15 August~2015. } \label{acpd-2015-0780-f05 }
\end{figure}

\begin{figure}
%\includegraphics[width=70mm]{f04.pdf}
\caption{Time series of meteorological quantities during \textbf{(a)}
IOP1
and \textbf{(b)} IOP2. (1) Altitude profile over T3 of wind velocities
from the east
(negative values; ``U'' winds). (2) Same as panel (1) but for wind
velocities from the north (negative values; ``V'' winds). (3) Area-
averaged
rain rate in the Manaus region. Red circles indicate when the G-1
research
aircraft flew a~mission. (4) Altitude profile of relative humidity over
T3.
Scale bar of panels (1) and (2) is at the top of the figure. Scale bar
for
panel (4) is at the bottom of the figure. Data for wind and relative
humidity were collected by four daily radiosondes launched at T3, and
rows 1, 2, and 4 were prepared by interpolation of these data sets.
Precipitation rates were based on measurements by an S-band radar
operated
by the Amazon Protection System (SIPAM) at T1p for returns at a height
of 2.5\,\unit{km}
and within a~range of 110\,\unit{km}. Other data sources:
\url{https://www.arm.gov/campaigns/amf2014goamazon}, last access: 12
September~2015.}
\label{acpd-2015-0780-f06}
\end{figure}

\begin{figure}
%\includegraphics[width=120mm]{f05.pdf}
\caption{\textbf{(left column)} Mean accumulated precipitation from 2000
to 2014

throughout the Amazon basin based on the Tropical Rainfall Measuring
Mission
(TRMM) satellite and the Multi-Satellite Precipitation Analysis (TMPA)
product (version 7 of the ``3B42'' algorithm). \textbf{(right column)}
Anomaly of 2014
compared to the mean of 2000 to 2014. Results are shown for time periods
of
(top row) IOP1 and (bottom row)~IOP2. Source:
\url{ftp://meso-a.gsfc.nasa.gov/pub/trmmdocs/3B42_3B43_doc.pdf}, last
access:
12 September~2015. } \label{acpd-2015-0780-f07}
\end{figure}

\begin{figure}
%\includegraphics[width=50mm]{f06.pdf}
\caption{Satellite-based detection of fires on (top) regional scale and
(bottom)
on the scale of South America. Left and right columns represent periods
of IOP1
and IOP2, respectively. On regional scale, each fire icon indicates the
detection
of one fire event during the two-month observation period of each IOP.
The yellow
markers indicate the locations of GoAmazon2014/5 research sites (cf. Fig.
1).
On the scale of South America, the color scaling in red runs from 0 to
100 fire
events detected in a $1{\degree} \times 1{\degree}$ grid box during the
two-month observation period of each IOP. Some grid boxes have more than
100 events. The green point represents the location of Manaus. Source:
\url{http://www.dpi.inpe.br/proarco/bdqueimadas/}, accessed 7 August
2015. }
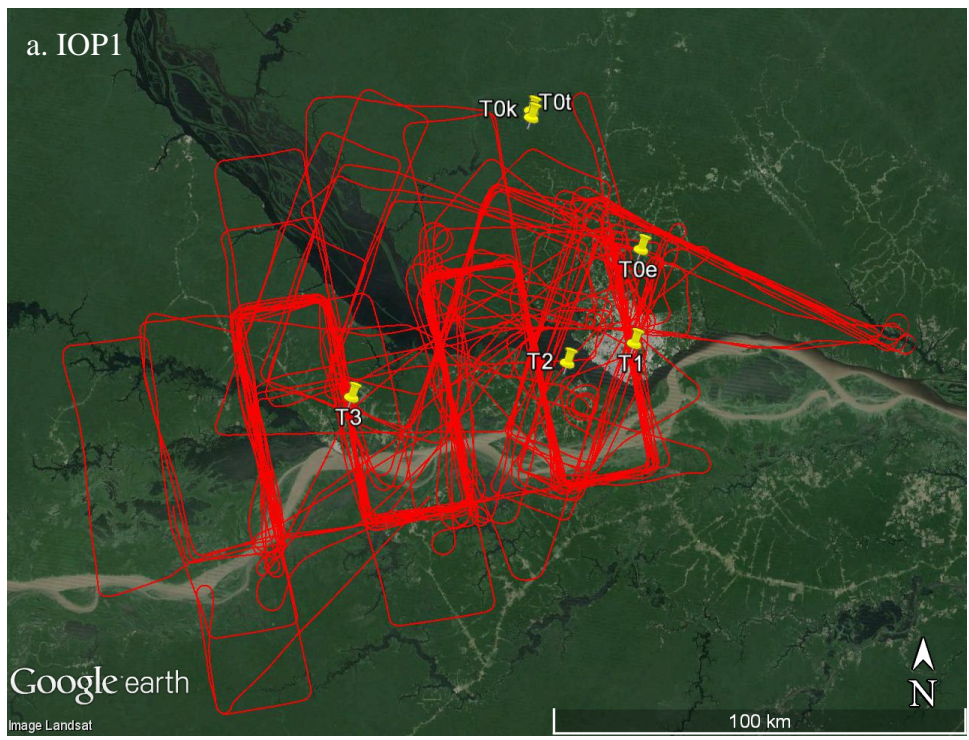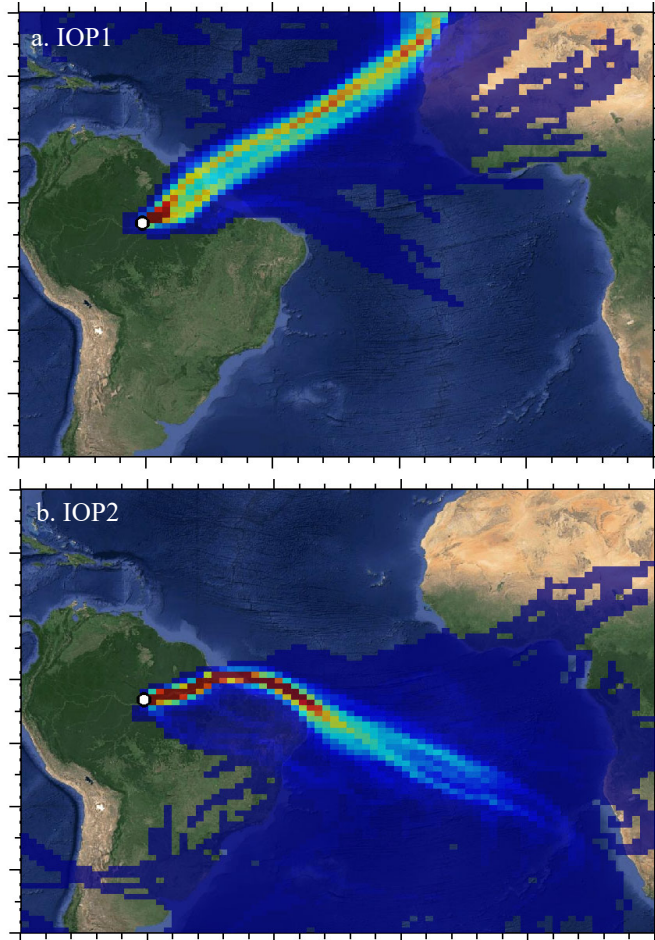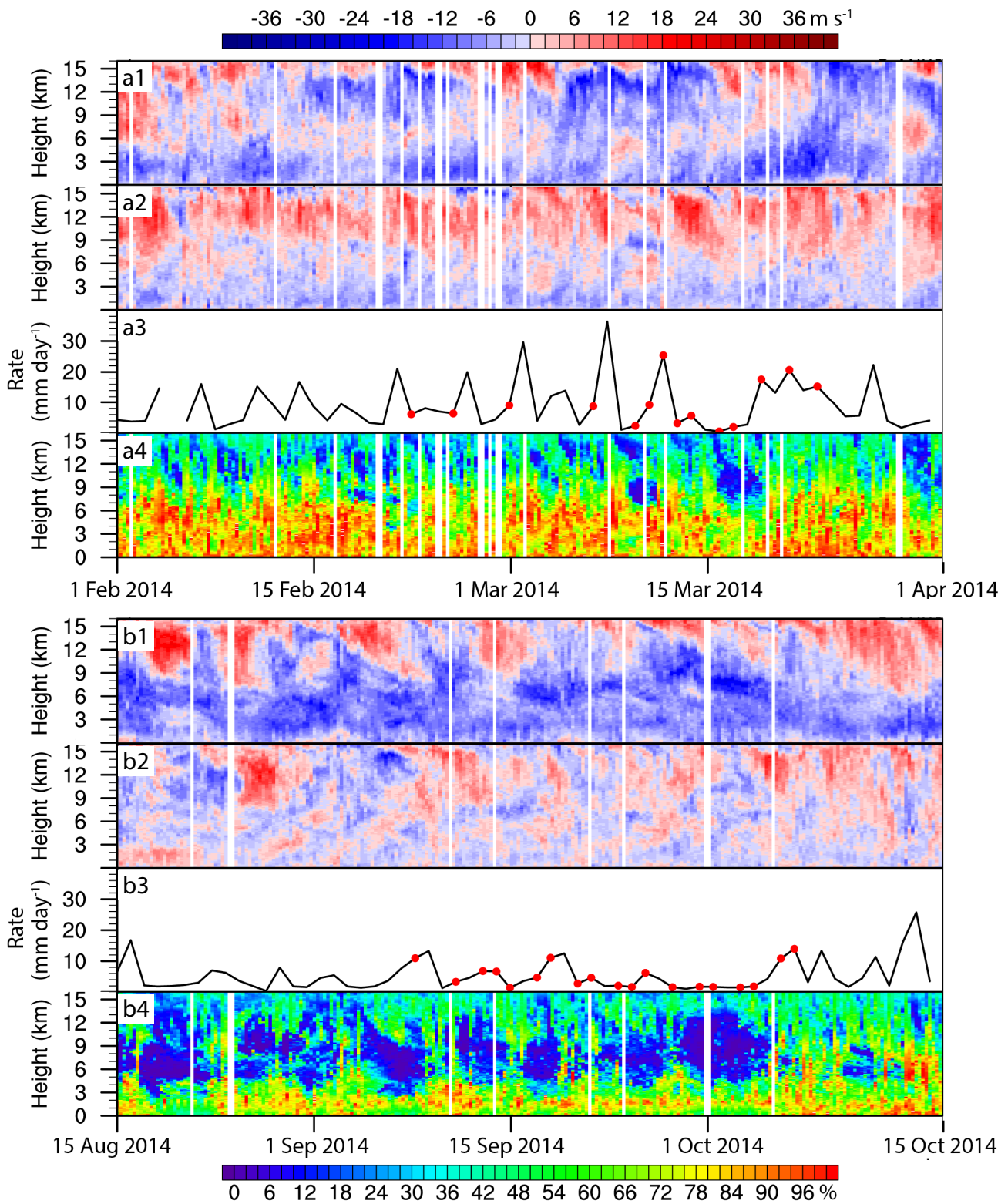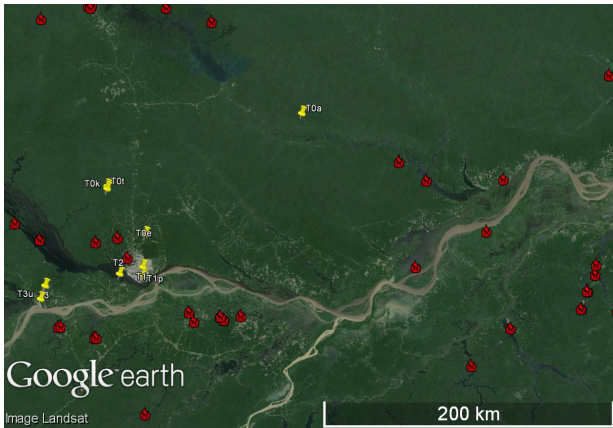\label{acpd-2015-0780-f10}
\end{figure}

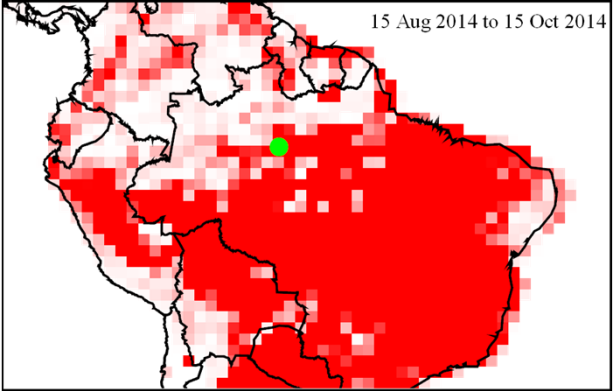
\end{document}

Figure 1

Figure 2

a. IOP1
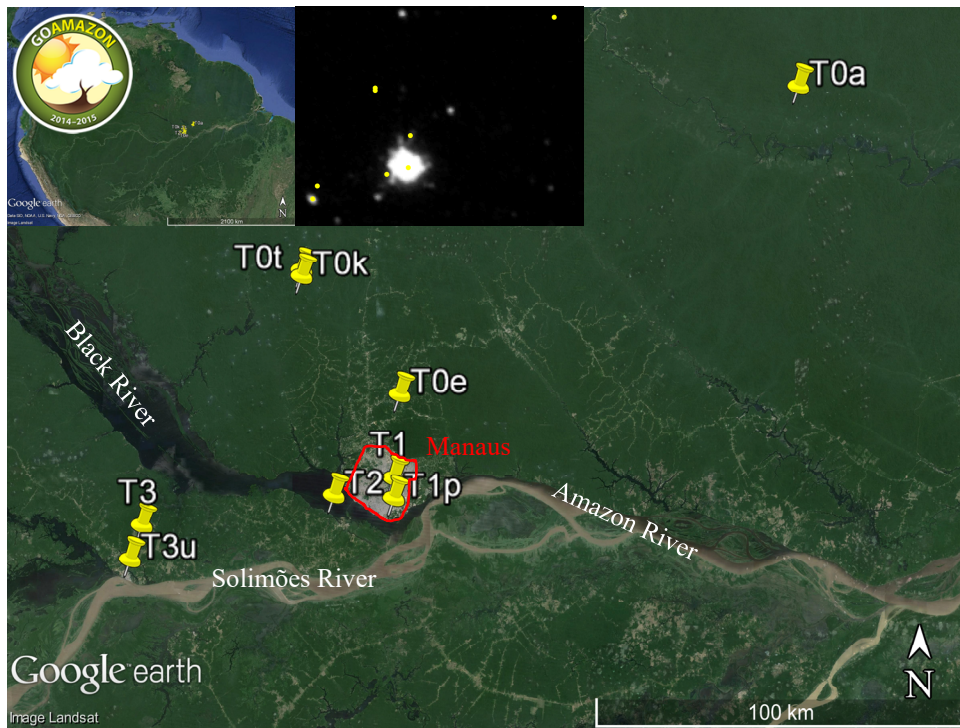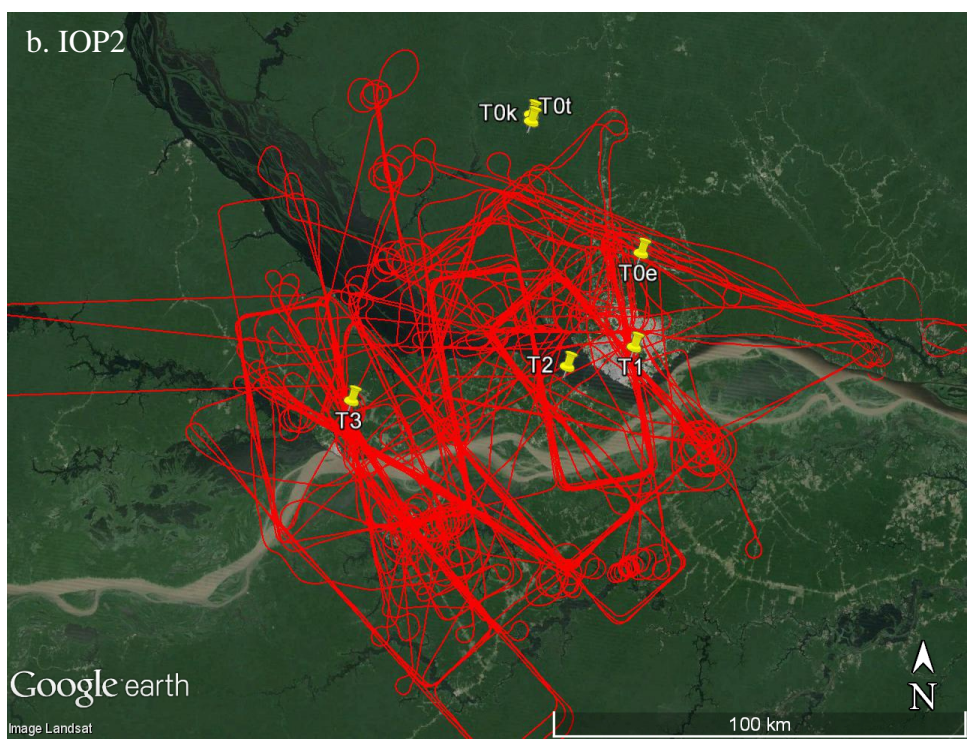
b. IOP2
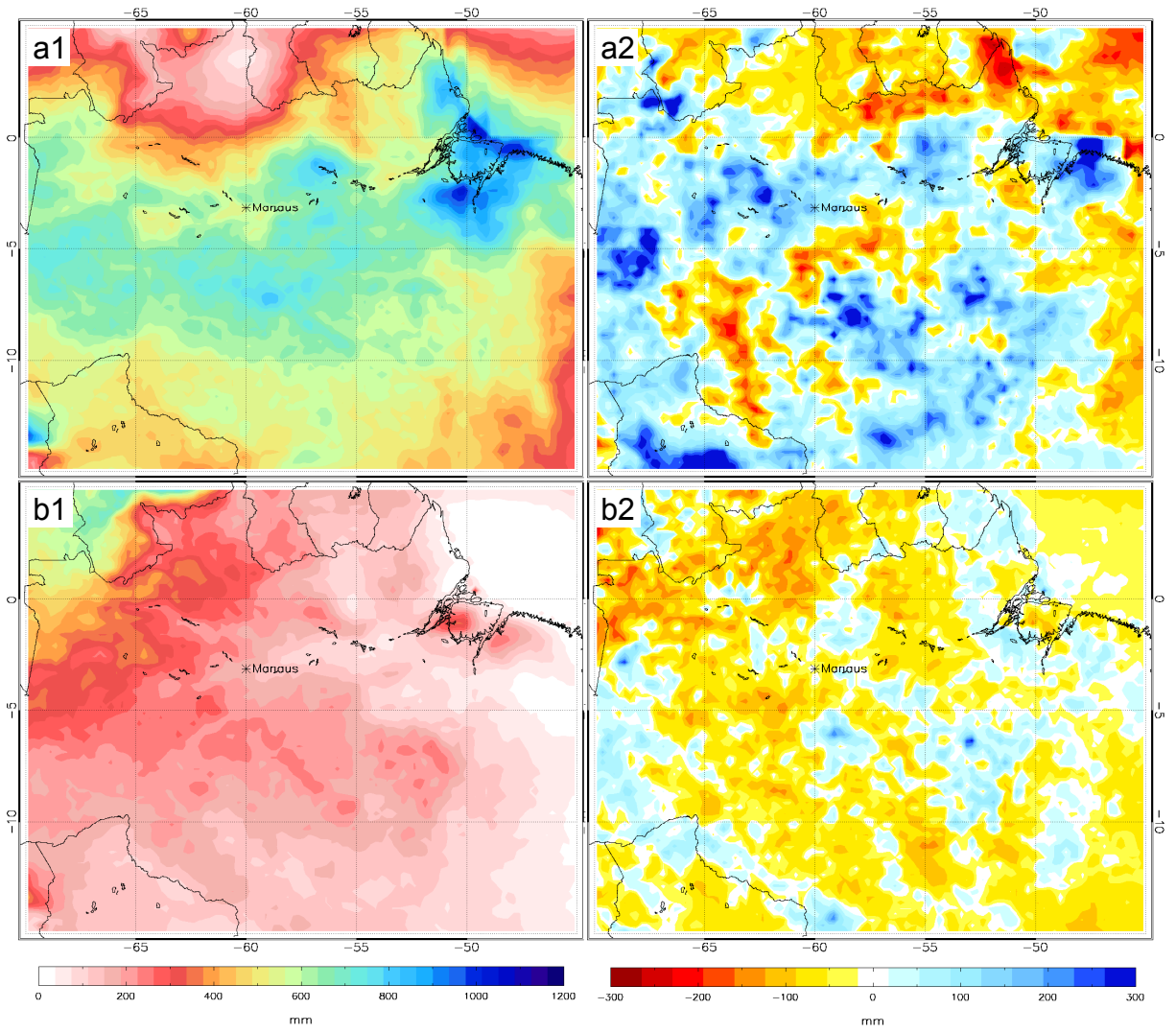
Figure 3

Figure 4

Figure 5

IOP1

IOP2

Figure 6