Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC^{4}RS): draft plan for U.S. Mission in Aug. -Sept 2013

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SEAC^{4}RS was originally planned as the Southeast Asia Composition, Clouds and Climate Coupling Regional Study to take place in Southeast Asia in 2012. Unfortunately, it was not possible to find a suitable location to base the mission in Southeast Asia from which the science objectives could be met. Therefore, the mission was renamed and reoriented to become a U.S. field program in 2013. This document describes the goals of this mission, provides summary descriptions for the various focused studies that are planned, outlines the reasons for the choice of basing location, defines the instrument payloads that were selected, outlines other field programs that we may interact with, discusses balloons and ground sites, outlines the numbers of flights that might address each focused study, and provides a draft calendar.

A. Goals of SEAC^{4}RS

The goals of SEAR4RS remain as in the original plan, but modified to a U.S. setting:

1. To determine how pollutant emissions are redistributed via deep convection throughout the troposphere.

2. To determine the evolution of gases and aerosols in deep convective outflow and the implications for UT/LS chemistry.

3. To identify the influences and feedbacks of aerosol particles from anthropogenic pollution and biomass burning on meteorology and climate through changes in the atmospheric heat budget (i.e., semi-direct effect) or through microphysical changes in clouds (i.e., indirect effects).

4. To serve as a calibration/validation test bed for future satellite instruments and missions.

B. Focused studies to address SEAC^{4}RS goals

To achieve the goals listed above, we will conduct a series of 4 focused studies. Some science issues overlap with several focused studies and will be included within the focused studies. However, these overlapping issues are discussed separately here.

1. Studies of the North American Monsoon (and clouds). (This focused study is described in detail in Appendix A.) This phenomenon is similar to the Indian Monsoon, but not as intense. Flow from the Gulf of California, Eastern Pacific and Gulf of Mexico penetrates into the dry Southwestern U.S. and Mexico. This results in convective rainfall

from July until September, though it is variable from year-to-year. The most intense convection occurs over Mexico or Central America, but Arizona, and New Mexico are also affected. A significant amount of Southwest American rainfall can come from the monsoon. Satellite data on water vapor and water isotopes show transport occurs into the stratosphere. Both Indian and North American monsoons have clear signatures for enhanced water. The North American Monsoon also shows a clear isotope signature in stratospheric water, probably indicating direct convective transport is more important over North America.
The science questions include: 1) What else is pumped into the UTLS besides water? 2) What are the mechanisms in this region that push the material into the stratosphere, and how do they differ from those in the Asian monsoon? 3) How does the monsoon impact cirrus clouds?

3. Investigations of Forest Fires (and clouds) (This focused study is described in detail in Appendix B.)
Presently much of the central and western U.S. is in extreme drought conditions, with 54% of the contiguous U.S. in drought in February. 2012 was the most severe drought in agricultural areas in 25 years, and as shown in the forecast in Fig. 1 drought conditions are expected to continue into the early summer of 2013. 2012 had extreme drought conditions and there were widespread forest fires. The ten-year average for acres burned is about 6.5 million, while 2012 had 9.2 million (the 3rd most in the past 13 years.), as shown in Fig. 2. (*NOAA National Climatic Data Center, State of the Climate: Wildfires for Annual 2012, published online December 2012, retrieved on January 16, 2013 from http://www.ncdc.noaa.gov/sotc/fire/.)*

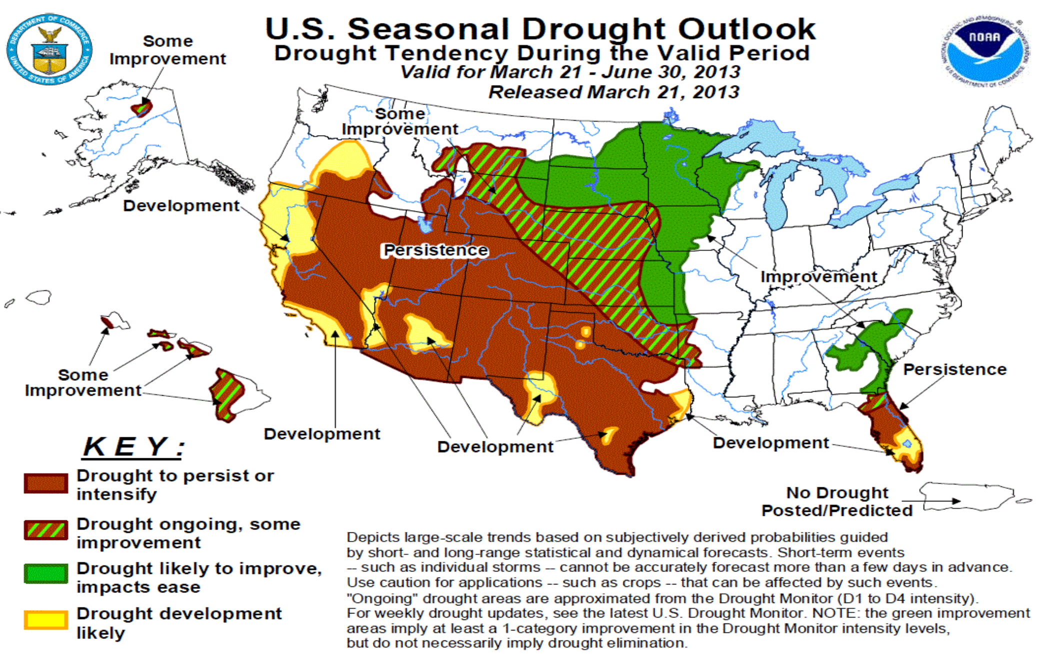


Fig 1. US predicted drought occurrence

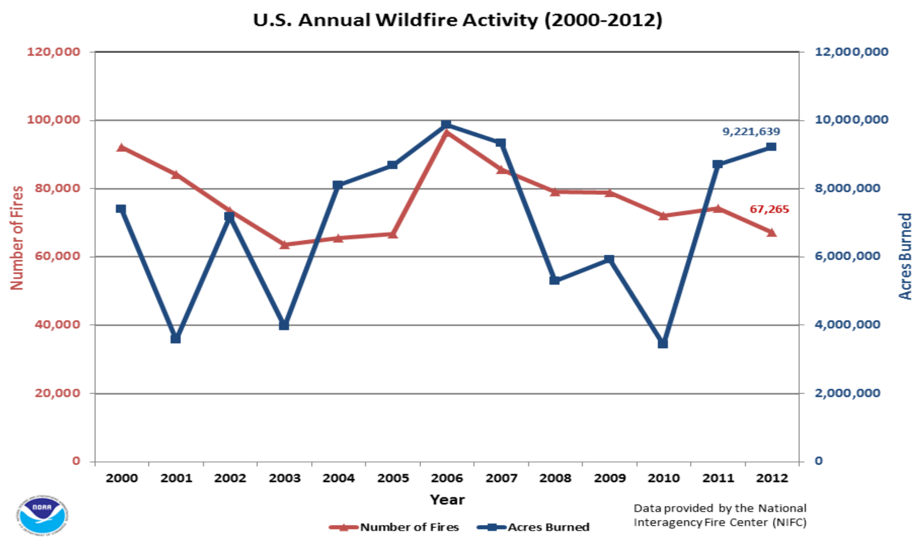


Fig. 2. The yearly history of burned area indicates large variability. 2012 had a relatively small number of large fires.

The science questions include:1) What is emitted from large forest fires, how do the materials interact, and how well do satellites detect it. 2) How much of this material, and which constituents, make it into the stratosphere? 3) What are the impacts on deep convection of large amounts of smoke?

3 Air chemistry over the Southeastern U.S. (and clouds, Discover A-Q, AERONET)
(This focused study is described in detail in Appendix C and Appendix D)

The Southeastern U.S. is a rich environment for atmospheric chemistry in which extensive biogenic emissions mix with air pollution from large urban areas, smoke from agricultural fires, emissions from oil and gas exploration, and clean air from the Gulf of Mexico. All of these chemicals are subject to processing and transport by deep convection. Observations in the Southeast US indicate a strong seasonal change between August and September in a number of constituents including aerosol optical depth, and biogenic gases as well as convection. There is also a satellite record of temporal changes over the last decade in NOx emissions, which is important in regional air chemistry.
The science questions include: *1)* How do anthropogenic and biogenic emissions, and their interactions, affect atmospheric composition in the Southeast US? 2) What is the role of shallow convection in modifying aerosol chemical, thermodynamic and optical properties? 3) What aerosol and chemical processing takes place during deep convection in the Southeast US, and what are the implications for the composition and evolution of the outflow in the UT/LS? 4) What influences and feedbacks do aerosol particles from anthropogenic and natural sources exert on meteorology and climate through changes in the atmospheric heat budget (i.e., semi-direct effect) or though microphysical changes in clouds (i.e., indirect effects)?

Discover-AQ is a NASA field program based in Houston Texas during September 2013. Discover-AQ uses the NASA P-3B with many of the same instruments that will be on the DC-8 in SEAC^{4}RS. The primary objective is to develop remote sensing

techniques that will allow satellites to measure air pollution. There is an extensive network of ground-based instruments in Houston for Discover-AQ. Discover-AQ has a strong overlap with the Southeastern US air chemistry focused studies.
The science questions include: 1) Will DIAL ozone observations over Houston help with Discover-AQ goals? 2) Can the Discover-AQ ground sites help in remotes sensing validation for the SEAC^{4}RS ER-2 observations? This would be especially useful if dust or smoke is present over Houston. 3) Can the P3-B compliment SEAC4RS observations in the Southeastern U.S.?

4) Hurricanes and collaboration with HS3 (and clouds) (This focused study is described in detail in Appendix E)

HS3 is a NASA mission using 2 Global Hawk aircraft to measure the properties of tropical cyclones. The two Global Hawks will carry an extensive suite of instruments for defining the thermodynamic, microphysical and dynamic properties of the tropical cyclones. There are few observations of the vertical transport of tracers in tropical cyclones, and little work has been done to consider the amount of air they may be pumping into the lower stratosphere.
The science questions include: 1) What gases and aerosols actually make it into the UTLS as a result of a tropical cyclone, and in what quantities? 2) What are aerosol and ice particle characteristics in the cloud shields and eyewall areas of the TC? 3) Do TCs hydrate or dehydrate the stratosphere? 4) What is the gravity wave spectrum generated by TCs that propagates into the stratosphere? 5) What are the aerosol characteristics in both the inflow and outflow regions of a tropical cyclone?

5) Overlapping issues
There are several issues that overlap those discussed in the focused studies. We plan to pay attention to these issues as part of multiple focused studies.

i. Penetrating convection (This overlapping area is described in detail in Appendix F)

One of the major goals of SEAC4RS is to understand how deep convection transports material aloft and modifies it during transport. Convection is associated with the North American Monsoon, large fires, Southeastern air pollution and tropical cyclones. Therefore there are opportunities to observe convection in each of these focused field studies. While deep convection is of interest in many of these issues, shallow convection can also be important.
The science questions include: 1) Can we quantify and characterize the convective transport of fresh emissions and water to the upper troposphere within the first few hours of active convection via measurements in the inflow and outflow, investigating storm dynamics and physics (primarily via NWS radar observations), lightning (primarily via lightning network observations) and its production of nitrogen oxides, efficiency of convective transport as a function of species solubility and chemistry in the immediate anvil. 2) Can we quantify the changes in chemistry and composition in the upper troposphere after active convection, focusing on 12-48 hours after convection and the seasonal transition of UT chemical composition.

ii Cirrus nucleation mechanisms and microphysical properties (This overlapping area is described in detail in Appendix G)

Cirrus clouds are an important element of the climate system. Since they are widespread we are likely to be able to sample then en route to areas of focused studies. The DC-8 is well equipped to both measure the microphysical properties of the clouds, and to determine the chemical composition and other properties of aerosols on which they may nucleate. It is unfortunate that the DC-8 sampling cannot be done with a cvi, which would allow the actual nuclei in the ice crystals to be sampled.
The science questions include: 1) What are the size distributions and ice crystal habits in midlatitude/subtropical synoptic and anvil cirrus? 2) Are cirrus microphysical properties related to aerosol composition? 3) Generate a database of cirrus properties to be used for evaluating of climate models and for refinement of remote-sensing retrievals.

iii AERONET retrievals of aerosol single scattering albedo (This overlapping area is described in detail in Appendix H)

There are numerous AERONET observing systems scattered across the US, and a special network in the Houston area for Discover-AQ. AERONET is one of the principal sources of data on aerosol single scattering albedo, an important parameter for calculations of the direct effect of aerosols on climate. The ER-2 and DC-8 instrument provide an opportunity to check the AERONET observations. It should be possible to perform these comparisons in high optical depth regions. About 30% of the time proper conditions for an AERONET retrieval are achieved in the Southeastern U.S.
The science questions include: 1) How well do measurements and retrievals of aerosol absorption from diverse techniques compare? 2) How representative are AERONET L2.0 retrievals (requiring AOD_{440nm}>0.4) of spectral aerosol absorption and single scattering albedo for aerosol conditions at lower aerosol loadings?

iv Profile TTCON sites (This overlapping area is described in detail in Appendix I)

Appendix I provides a The Total Column Carbon Observing Network employs FTIR instruments at a variety of sites to measure the amount of CO2 and other constituents using solar observations in the near infrared. Sites are located in the US at JPL; Lamont, Oklahoma; and Park Falls Wisconsin. The Lamont DOE ARM site would be a useful location for DC-8 vertical profiles in relatively clean conditions and in dusty or smoky conditions to determine the accuracy of the TTCON and other retrievals.

v. Interactions with satellites for aerosols (This overlapping area is described in detail in Appendix J)

1) **A major goal of SEAC4RS is to work the NASA satellites. Such studies are discussed in a number of appendices and in Appendix J for aerosols in particular. There are a number of issues related to aerosols of interest:** 1) Develop a consistent data set of aerosol physical, chemical and optical properties, including those related to aerosol extinction, scattering,

absorption, phase function/lidar ratio, and hygroscopicity as function of chemistry.

2) Is there a substantial change in aerosol optical properties as air masses are advected across the SE biogenic source?
3) Does chemical processing in the convective boundary layer result in substantial differences in optical properties for haze layers or biomass burning smoke in the lower boundary layer, the convective boundary layer, and plumes aloft?
4) Understand the variability in aerosol hygroscopicity, mass extinction /absorption efficiencies and single scattering albedo in aging smoke plumes
5) Is there a maximum sea salt AOT can be found in high wind regions and how does that relate to boundary layer dynamics?
6) Can we constrain dust size parameters thought observation of the "roll off point" in the near IR when dust ceases to be spectrally flat?
7) Can gradients in aerosol concentration relative to cloud scans provide much needed information on aerosol indirect and semi-direct effects, including cloud adjacency effects?

Engineering Goals.

1) Provide polarimeter sensors and lidars a variety of aerosol environments (Haze, smoke, dust, sea salt) to develop their algorithms.
2) Provide data in mosaic land surface scenes such that the influence of lower boundary condition can be separated from aerosol microphysics.
3) Evaluate lidar behavior in partially cloudy boundary layer scenes.

C. Basing location

Optimal basing is different for the various objectives. Unfortunately the best location is not known in advance for time variable events such as large fires. The various Appendices indicate the best locations for the focused studies that are planned.

One could conduct a mission during which the aircraft were based for several weeks at Palmdale to investigate the North American Monsoon, and Western US fires. The aircraft could then transition to Warner Robins Air Force Base near Macon Georgia for studies of hurricanes and Southeastern air chemistry. However, Southeastern air chemistry is time variable and it seems preferable to make a sequence of flights over time to capture the variability. Likewise fires and hurricanes are time variable, so it maximizes our opportunities to be in a central location where many things are within reach. Salina Kansas allows us to perform each of the proposed focused studies, but Atlantic Hurricanes are at the edge of the range. Houston is slightly better for Atlantic hurricanes, but worse for Northwestern fires. Range rings for Salina, Palmdale, Houston and Warner Robins are shown in Figs. 3-6.

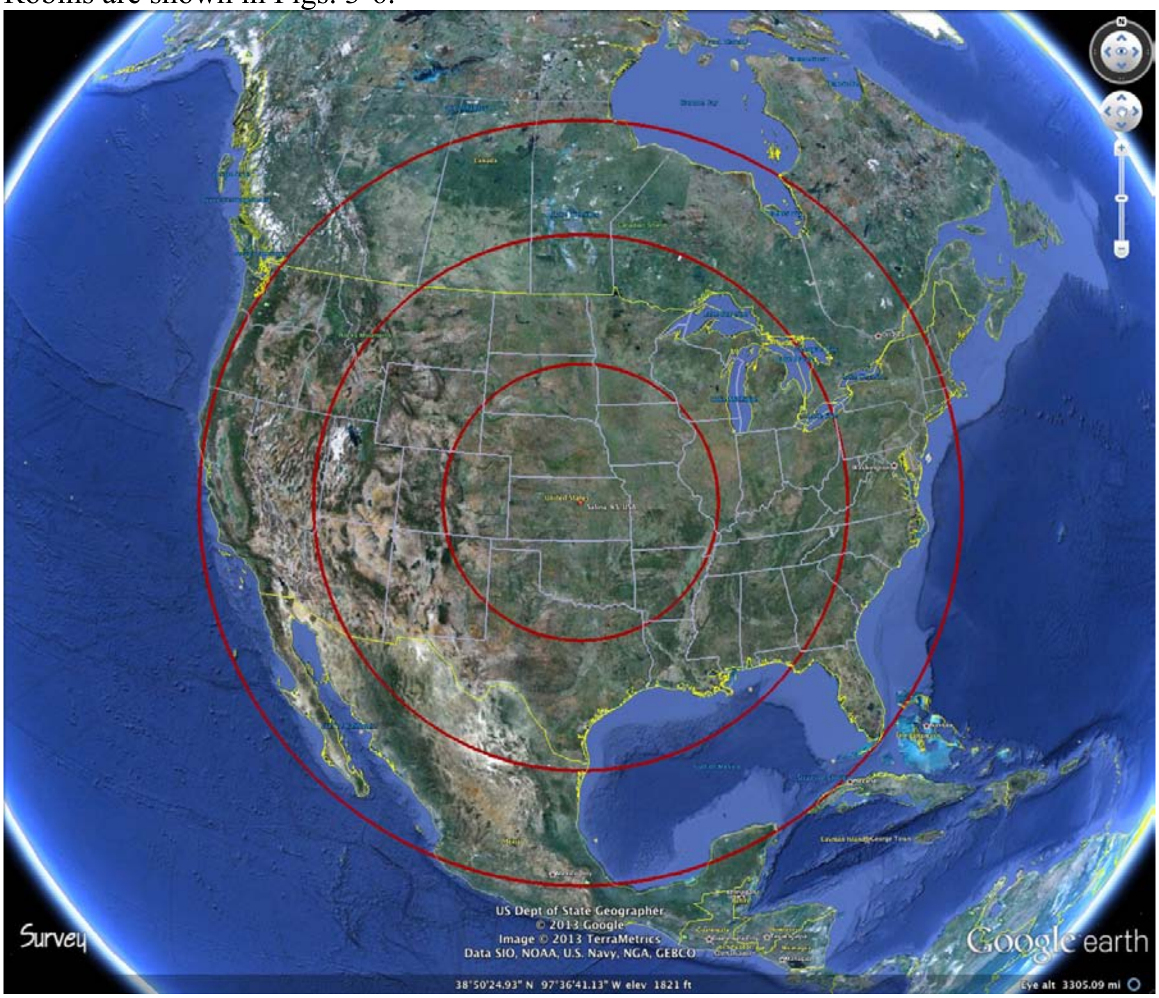


Fig. 3 400, 800, 1200 nm range rings from Salina, Kansas. These correspond to approximately 1, 2 and 3 hour one-way transit times.

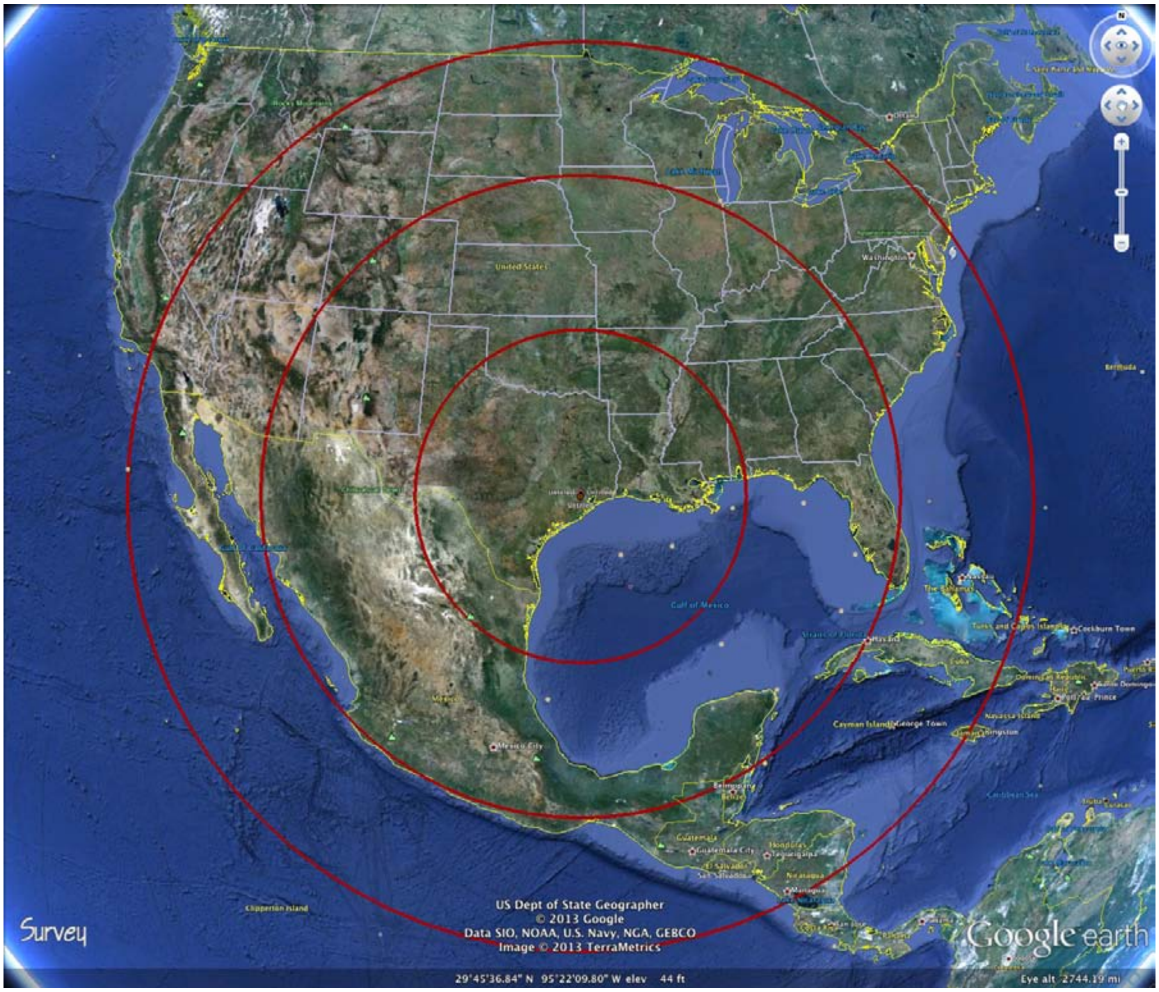


Fig. 4 400, 800, 1200 nm range rings from Houston,Texas. These correspond to approximately 1, 2 and 3 hour one-way transit times.

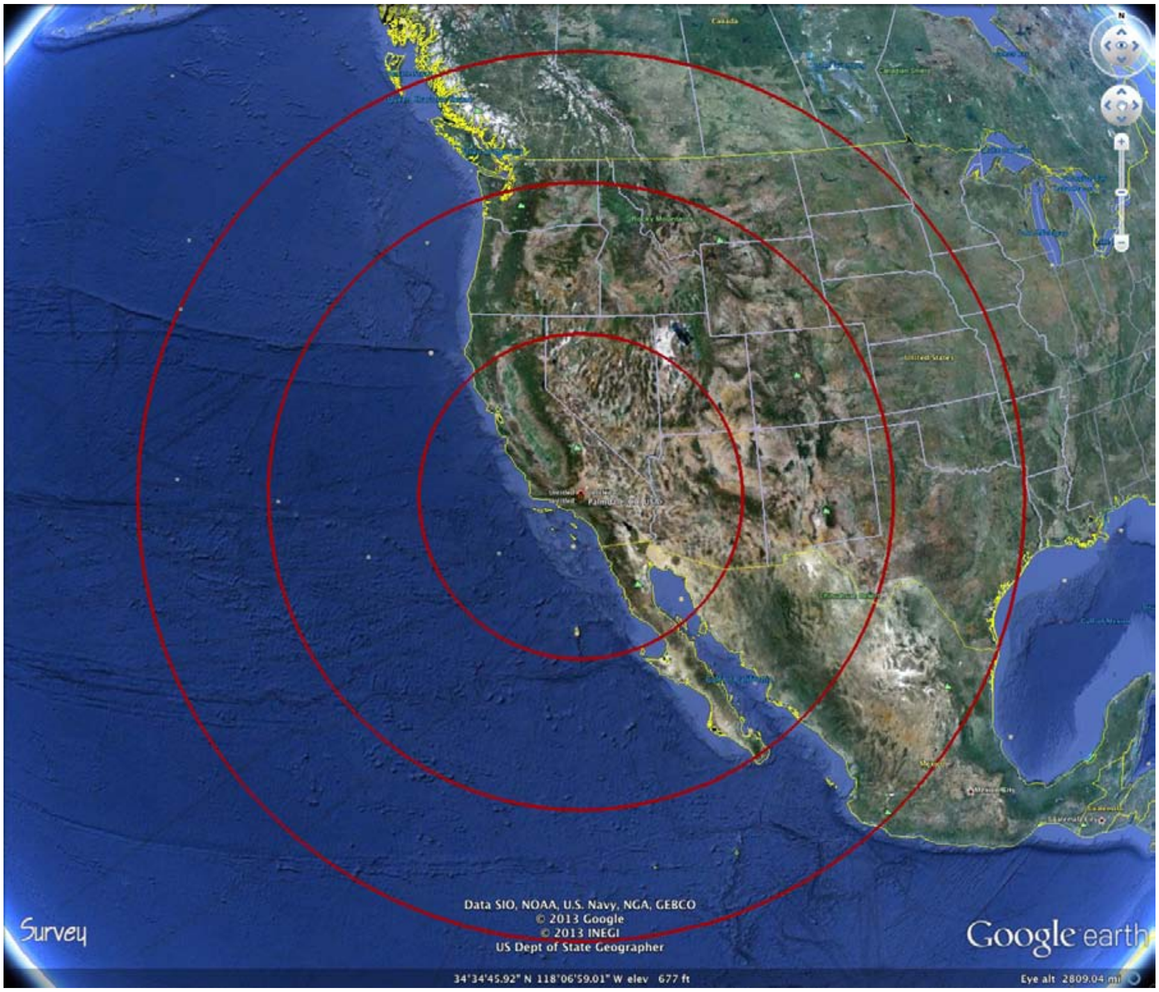


Fig. 5 400, 800, 1200 nm range rings from Palmdale, CA. These correspond to approximately 1, 2 and 3 hour one-way transit times.

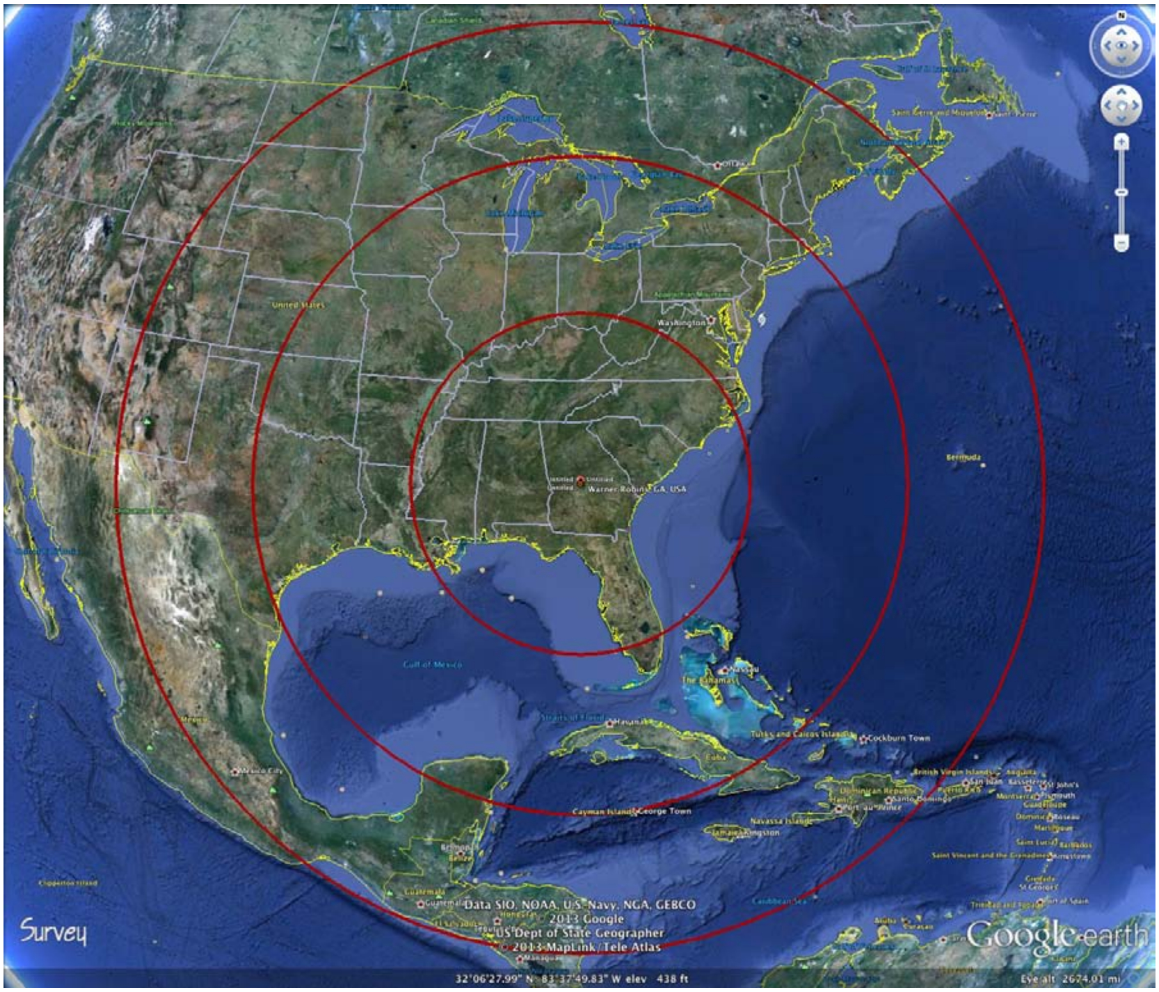


Fig. 6. 400, 800, 1200 nm range rings from Warner Robins, Georgia. These correspond to approximately 1, 2 and 3 hour one-way transit times.

An analysis of weather related issues in operating the ER-2 from Salina is presented in Appendix K. We are working on an analysis for Houston.

D. Instruments

The SEAC^{4}RS instruments were chosen by NASA based on submitted proposals. They are given below in Tables 1 and 2.

Table 1: SEAC^{4}RS DC-8 Payload

Investigator	Acronym	Measurement
Anderson	LARGE	Aerosol measurements - includes Martin Polar Nephelometer
Beyersdorf	AVOCET	CO2
Blake	WAS	Hydro and halo carbons
Brock	AOP	Aerosol extinction and absorption
Bucholtz	BBR	Broadband solar and IR
Bui	MMS	micro met
Cohen	TD-LIF	NO, NO2, Nitrates
Dibb	SAGA	HNO3, bulk aerosols
Diskin	DLH	Water vapor
Diskin	DACOM	CO, CH4, N2O
Fried	DFGAS	CH2O
Gao	HD-SP2	Black carbon aerosol
Hair	DIAL HSRL	O3 and aerosol (backscatter, extinction, depol.) profiles
Hall	CAFS	Actinic flux
Hanisco	ISAF	CH2O
Huey	GT-CIMS	PAN, SO2
Jimenez	AMS	Aerosol mass spectra
Lawson	SPEC	Aerosol parameters
Murphy	PALMS	Single particle composition
Russell	AATS-14	Aerosol optical depth
Ryerson	CSD CL	NO, NO2, NOy, O3
Schmidt	SSFR	Solar and near IR irradiance
Tanelli	APR-2	Precipitation, clouds
Wennberg	CIT-CIMS	Peroxides, HNO3, HCN, organic acids
Wisthaler	PTR-MS	Fast OVOC and NMHC

Table 1: SEAC^{4}RS ER-2 Payload

	Investigator	Acronym	Measurement
Remote Sensing	Bucholtz	IR	broadband IR
	Cairns	RSP	polarimetry
	Diner	Air-MSPI	polarimetry
	McGill	CPL	aerosol & cloud height
	Platnick	eMAS	multi-spectral imagery
	Schmidt	SSFR	hyperspectral flux radiometry
in-situ	Anderson	H20v	H2Ov
	Atlas	WAS	trace gases
	Bui	MMS	state variables and turbulence
	Christensen	Alias	CO
	Gao	O3	O3
	Herman	Herman	H2Ov
	Mahoney	MTP	temperature and pressure
	Wofsy	Wofsy	CO2, CO

E. Interactions with other field programs

There are several opportunities for collaborations. These are detailed in the Appendices. They include flights in hurricanes with the NASA HS3 mission flying the Global Hawk, flights in the Houston area with the NASA Discover-AQ mission flying the P-3, and Bbop flights in forest fire plumes with the DOE G1 aircraft.

F. Potential distribution of flights

Flights will depend on the relevant opportunity being available. Table 3 is meant to be an indication of the possible numbers of flights dedicated to the various focused studies. Several of the focused studies depend on the availability of special conditions, such as hurricanes or forest fires. Others seek to understand phenomena that are expected to vary in time, such as biogenic emissions in the Southeast. A number of science issues are expected to be combined with the focused studies. For example, cirrus properties can be investigated en route to a focused study area.

Table 3 potential distribution of flights (out of 18)

Focused study	Possible collaborator	Flights
NA Monsoon		4
Emissions from fires	DOE-G1	5
Southeast air chemistry	DiscoverAQ-P3	7
Hurricanes	HS3-Ghawk	0-2
Targets en route		
Deep convection		
Aerosol absorption/AERONET	AERONET	
Cirrus nucleation		
Profile TTCON sites	DOE ARM site	

G. Balloons and ground sites

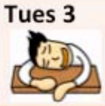
Appendix L provides a proposed balloon campaign aimed at the North American Monsoon goals. A number of other ground sites are under discussion. These include augmented AERONET sites (Appendix M), collaboration with TTCON and possibly the DOE ARM site in Lamont, Oklahoma, as well as extension of the ground sites in use for SOAS (a field mission occurring prior to SEAC4RS in the Southeastern U.S.).

H. Flight calendar (Draft- Start date is uncertain. It would be be preferable to start a week earlier if possible.

August 2013
150 flt hrs-DC-8, ER-2

Sunday	Monday	Tuesday	Wed	Thur 1	Fri 2	Sat 3
4	5	6	7	8	9	10
11	12	13 	14	15 1st Science 	16	17 
18	19 	20 	21	22 	23	24 
25	26 	27 	28	29 	30	31 

September/October 2013

Sun 1	Mon 2 	Tues 3 	Wed 4	Thur 5 	Fri 6	Sat 7 
8	9 	10 	11	12 	13	14 
15	16 	17 	18	19 	20	21 
22	23 	24 	25	26	27	28
29	30 reserve	1 	2	3 reserve	4	5 

Appendix A

Transport by North American Monsoon

1. **North American Monsoon (NAM) system**

The North American monsoonal circulation is characterized by distinct rainfall maxima over western Mexico and the Southwestern United States and by an accompanying upper-level anticyclone over the higher terrain of northwestern Mexico. Heating over the mountains of Mexico and the western United States plays a major role in the development and evolution of the monsoon, in a manner similar to what is observed over the Tibetan Plateau and the Bolivian Altiplano. (NOAA, North American Monsoon: Reports to the Nation, 2004). Figure 1 shows the schematic of the flow pattern. Figure 2 shows the vertical circulation pattern. (NOAA, 2004).

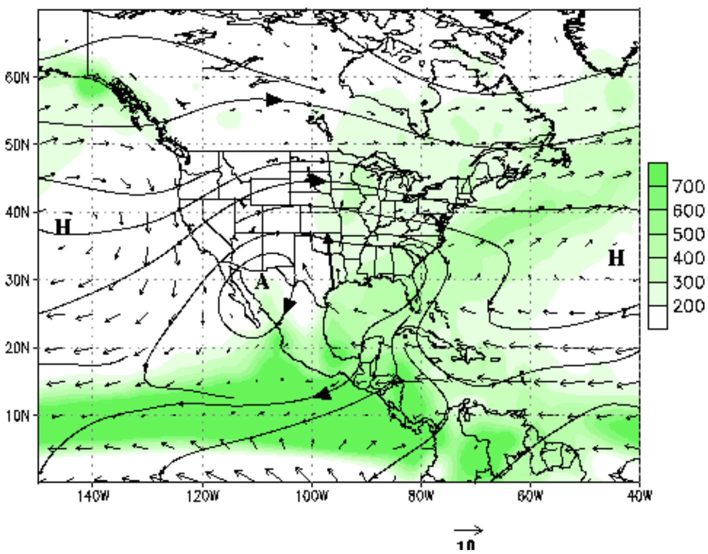


Figure 1. The schematic shows mean (July-September 1979-1995) precipitation (shading) in millimeters, lower-tropospheric (925-hPa) vector wind (m s^{-1}) and upper-tropospheric (200 hPa) circulation pattern (contours). The position of the upper-tropospheric monsoon anticyclone is indicated by "A". The mean direction of the circulation is indicated by the large arrows on the contours. The lower-tropospheric Bermuda and North Pacific subtropical high pressure centers are indicated by "H". The approximate location of the Great Plains low-level jet is indicated by the heavy solid arrow.

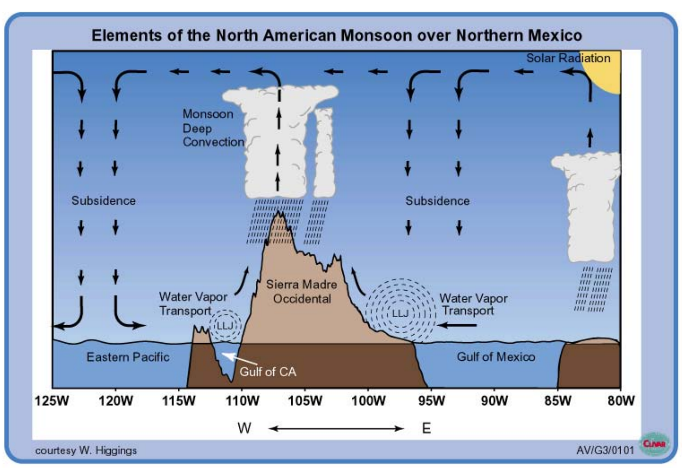


Figure 2. Schematic vertical (longitude-pressure) cross section through the North American Monsoon System at 27.5°N. Topography data was used to establish the horizontal scale and observed wind fields were used to establish the vertical circulations.

Figure 3 shows that the ending time of the NAM over the southwestern US is well into the September time frame. The SEAC4RS deployment time period fits well for investigating the transport by NAM. The convection can be very vigorous and deep, perturbing the tropopause level. An example is shown in Figure 4. (Fig. 5, Rowe et al., 2012). Figure 5 shows a typical example of the NAM flow pattern from 20 August 2006 as revealed by the GOES water vapor channel. With an upper-level anticyclone centered over the Gulf Coast, southerly flow brought deep moisture into the Colorado Plateau. The moisture plume had a sharp western edge with very dry air over California while a broad area of upper-level moisture and cirrus with embedded convection extended eastward into Texas.

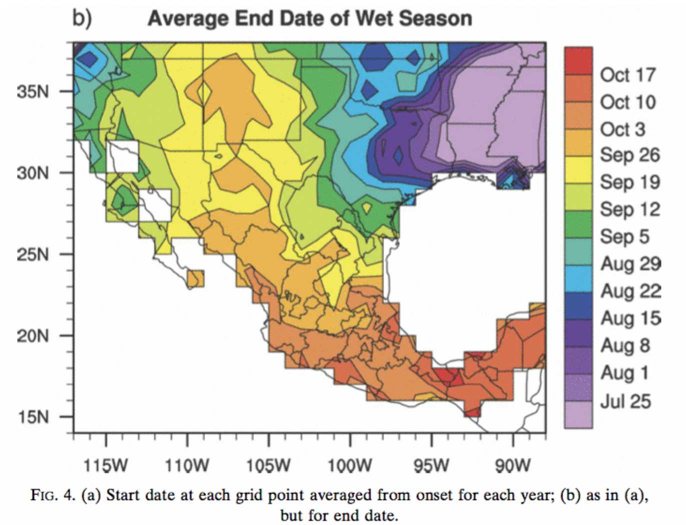


Figure 3. The average end date of wet season from a precipitation climatology for the period 1966-2000. (Fig 4b of Liebman et al., 2008.)

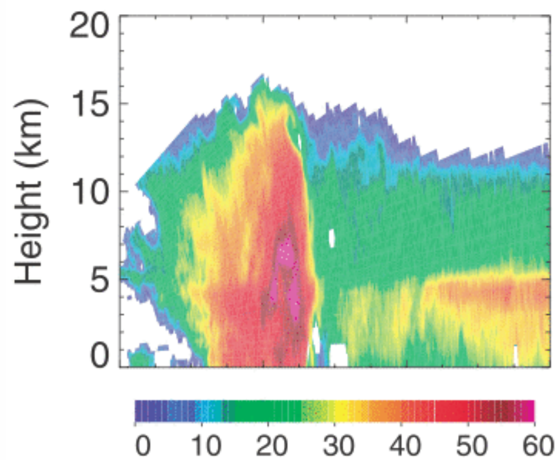


Figure 4. RHI plot of S-Pol radar reflectivity (dBZ) of a cell near Mazatlan, Mexico (~ 23° N) on 5 August 2004. (Rowe et al, 2012). Echo tops extended to 16 km with a large area of 60 dBZ reflectivity in the storm's core.

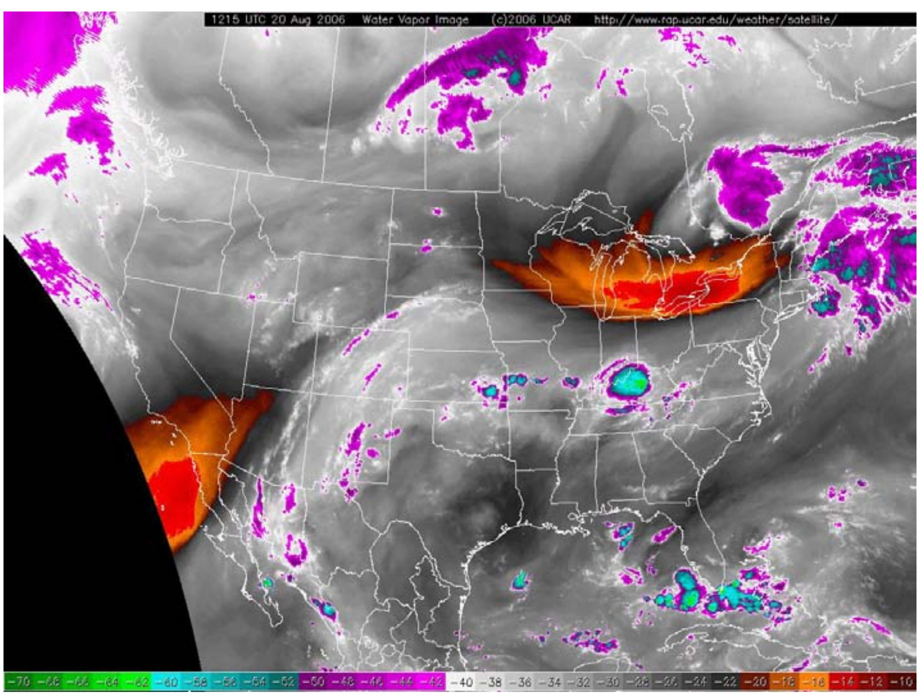


Figure 5. GOES WV image for 1215 UTC , 20 August 2006. This image shows a very representative NAM flow pattern. Note the sharp western edge of the moisture plume over Arizona and Utah with very dry air over California and the broad area of moisture and cirrus across New Mexico and Colorado.

2. Science Questions

The NAM circulation involves convective pumping over Mexico and SW US and outflow at the UTLS level over the S. US. The system is relevant for convective transport of water vapor into the UTLS, cirrus cloud distribution and radiation, biomass burning and pollution transport from N. Mexico to SW US.

Water vapor transport

Understanding the role of the NAM in water vapor transport, comparing and contrasting with the Asian Summer Monsoon (ASM) is a topic of active ongoing research. The NAM system is found to have significant impact on the UTLS water vapor distribution. An interesting analysis shows that the NAM system has a stronger water vapor isotope (HDO/H_2O) ratio signature than the ASM system at the UTLS level (Figure 6) (Randel et al., 2012), indicating a stronger role of convective detrainment in the dry stratosphere over the NAM. Ongoing studies further show that the relative water vapor enhancement at the UTLS shifts from a stronger signature over the ASM at the 150 hPa level to a stronger signature over the NAM at the 100 to 83 hPa levels (Figure 7, courtesy Wang and Randel). These interesting behaviors are not well understood. A trajectory forward domain filling study, using the GPS temperature, further indicates that the northward tilt in the vertical structure of water vapor enhancement over NAM is not well reproduced in the model (not shown). These should be investigated during seac4rs. How high does the signature of deep convective injection extend into the stratosphere? What are the signatures from other tracers, such as CO and CO2? How might the relative sparse sampling of satellite data have blurred the structure? These are some of the question that can be investigated during the seac4rs flights. The vertical and horizontal gradient of water vapor and other tracers at the ER-2 level will provide useful insight to the understanding. The UTLS enhancement signature over the S. US persists into September (Figure 8) and fits into the SEAC4RS deployment domain and time frame.

Impact of NAM on cirrus cloud distribution (See Eric Jensen's writeup)

Biomass burning and pollution transport Following the anticyclonic flow, N. Mexico pollutant and biomass burning would be uplifted and transported into SW US.

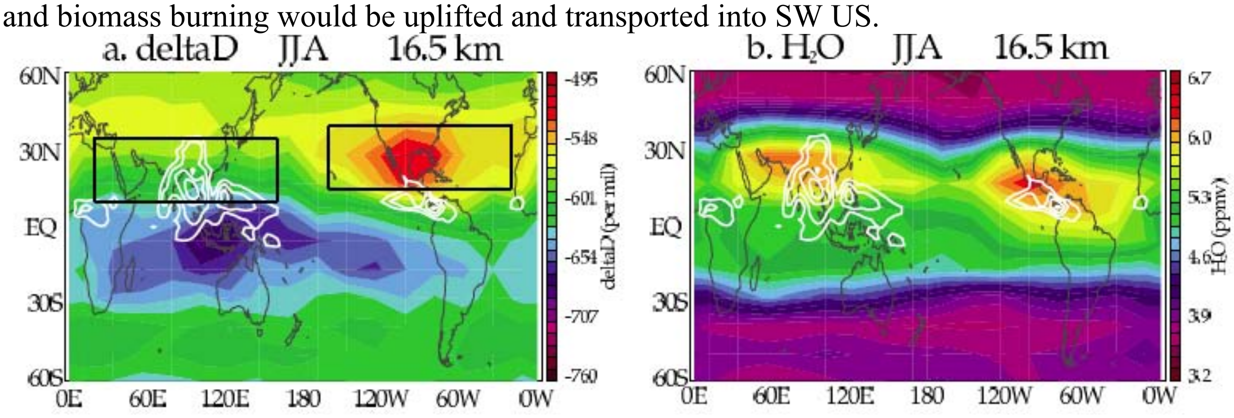


Figure 6. (Fig. 12 of Randel et al., 2012) Maps of (a) **Delta**D and (b) H_2O at 16.5 km during JJA. White contours denote strongest climatological tropical convection, and the black boxes are related to other figures in the paper. Note the isotopic enrichment correlated with high water vapor over the NAM but the lack of a similar signal over the ASM region.

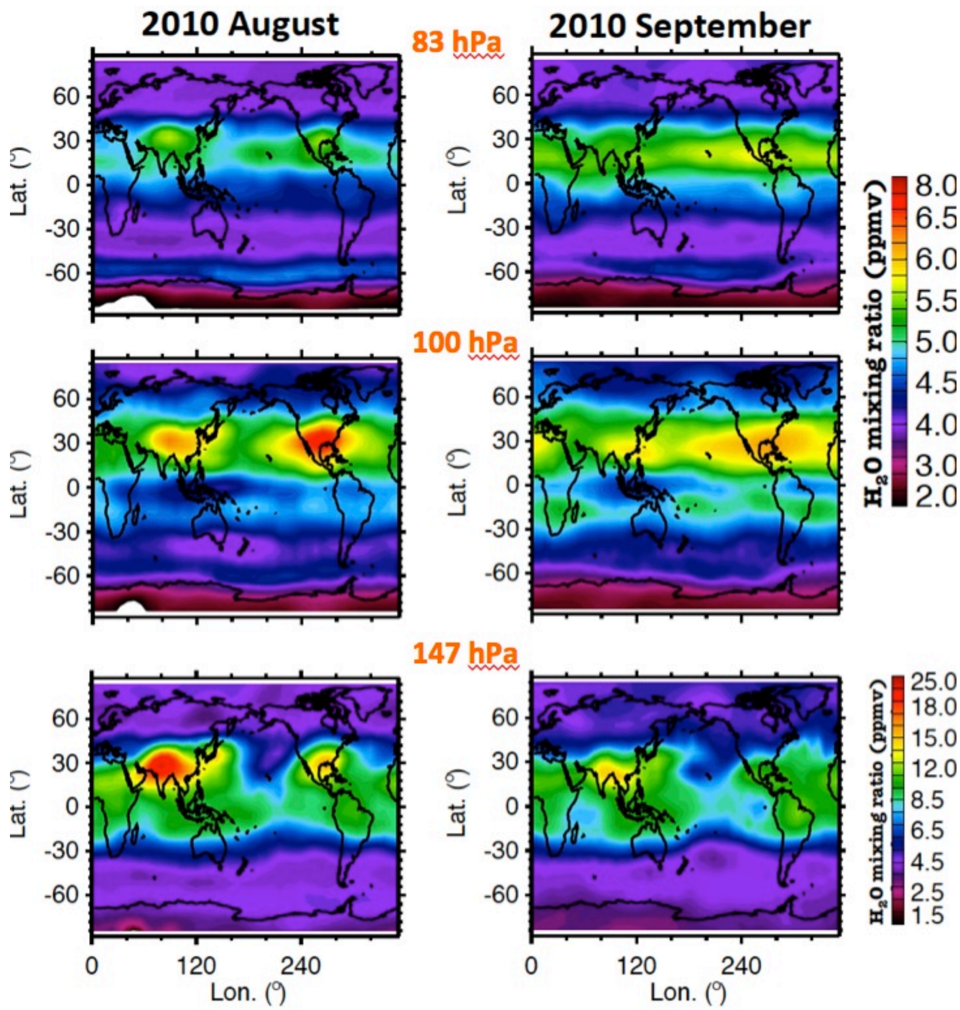


Figure 7. MLS water vapor for August (left) and September (right) at three pressure levels. Note the H2O enhancement at 147 hPa is stronger over the ASM, but at higher levels (100 and 83 hPa), especially in September, the enhancement over the NAM region becomes larger.
(Figure courtesy Tao Wang)

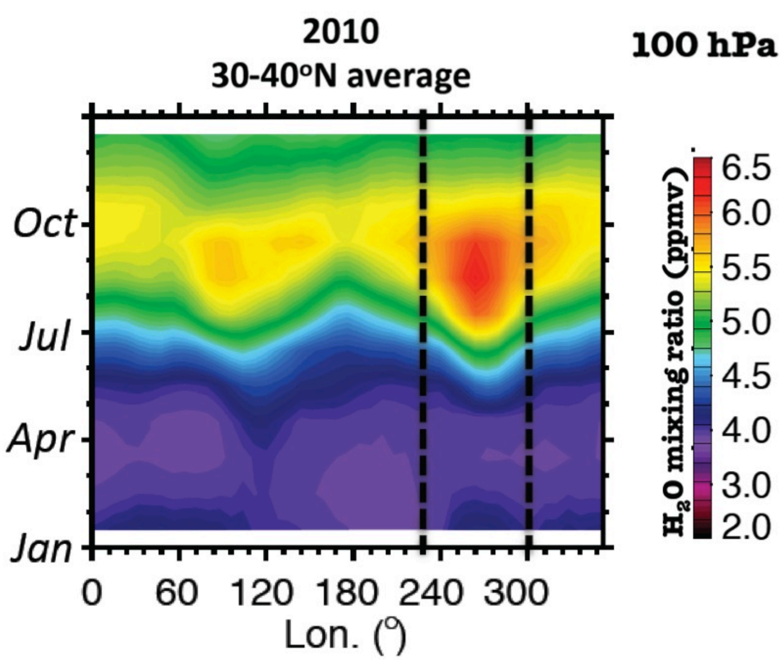


Figure 8. Hovmoller diagram for MLS 100 hPa water vapor, over 30-40°N. The pattern shows that the enhancement over S. US is well into September. The dashed lines mark the approximate longitudes of the US coasts. (Figure courtesy Tao Wang)

3. Flight Considerations

To characterize the transport by the monsoon circulation, the DC-8 and ER-2 should combine their altitude range to map out the horizontal and vertical chemical gradients, including water vapor, across the monsoonal flow. A conceptual flight pattern is proposed below (Figure 9).

The satellite water vapor map for 20 August 2006 shows a representative NAM flow pattern. The deep trough west of the anticyclonic flow is also representative. Cutting across the structure is desirable to contrast the monsoon air mass from the trough coming from the NW. It is not clear from this map how tall/deep the structure is for both the humidity and chemical composition. Vertical profiling inside the monsoonal flow, from the boundary layer (DC-8) to above the tropopause (ER-2) is desirable.

The drawing shows that both Palmdale and Salina are workable bases. Salina is preferable if we consider the likely southward shift of the pattern later in the season.

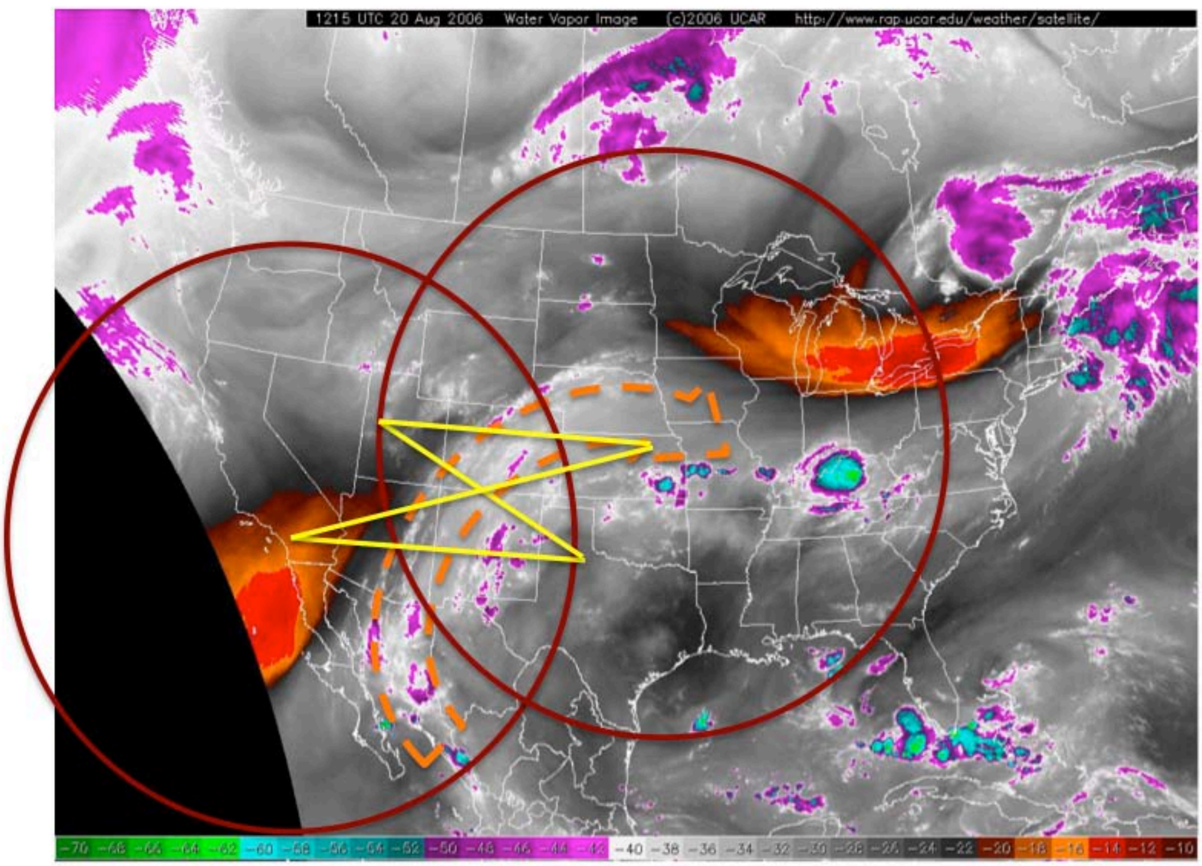


Figure 9. GOES WV image for 1215 UTC, 20 August 2006 (as Figure 7). The orange arrow marks the anticyclonic flow. Yellow lines show the flight region for mapping the gradients. Red rings are estimates of the 2-hour range from Palmdale and Salina.

Figure 10 shows the tropopause height distribution for the deployment time period and within a 3-hour range from each candidate base location, based on 30 year ERA-interim data. The figure indicates that ER-2 will have good opportunity to sample the chemical gradient across the tropopause on all four locations. DC-8 will have more chance to sample the tropopause region in Palmdale and Salina.

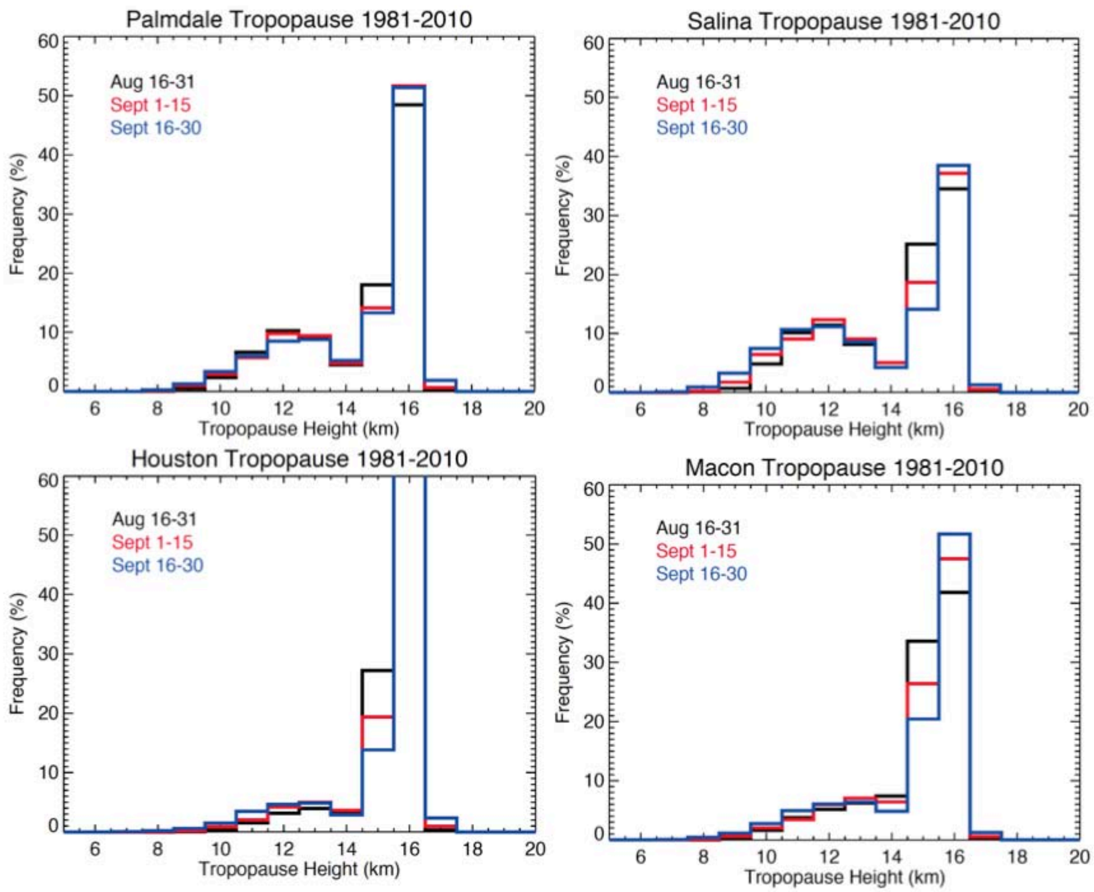


Figure 10. Climatology of the tropopause height distribution for August 15-September 30, in 15-day increments, based on 30 year ERA-interim data (1980-2010). The four panels show the distribution within a 3-hour range from Palmdale, Salina, Houston, and Macon.

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Appendix B. Fire emissions: Science questions and sampling opportunities.

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Main Objective: Fire emissions and their interaction with convection, clouds, and urban pollution.

Base(s) of operation: 1) Palmdale (Salinas second choice, best if possible are Boise, SLC, RMA), and 2) Houston/Macon (2-3 weeks each).

Suitability of payload: Excellent in general; HO_X on the DC-8 would be beneficial**.**

Concerns: eMAS suitability for deployment (may need replacement for IR information).

Season: Wildfires that produce long plumes in the free troposphere, especially in afternoon, peak in the NW US in August (Fig. A1). Prescribed burning that produces regional haze, starts in September in Mississippi Valley and SE US (Fig. A2). Possible collaboration with DISCOVER-AQ & BBOP.

Background. Fires are an important source of trace gases and particles both globally and in the US. There is a large range in the estimates of real-time and annual fire emissions in the various remote-sensing based products. There are few data sets linking the complex, multi-phase organic chemistry of smoke with its aerosol microphysics and climate impacts. Post-emission formation of O_3 and secondary organic aerosol (SOA) are poorly understood; in part because the variable gas/particle partition of semi-volatile species is a critical yet largely ignored component affecting O_3, particles, and radiation. Smoke evolution depends strongly on the initial emissions, the state of the atmosphere (e.g. RH, T, hυ), the extent of mixing with biogenic or urban emissions, and cloud-processing in shallow and deep convection. All these issues fit within the $SEAC^4RS$ theme of emissions and their convective processing. The DC-8 payload is well-suited for in-situ measurements of gas-aerosol-cloud interactions. The ER-2 is well suited for remote sensing of smoke and smoke evolution and validating space-based measurements of plumes and FRP. The ER-2 can also validate fire detection algorithms to characterize the impending transition from MODIS- to VIIRS-based fire products.

Large Aug-Sept NW US wildfires loft smoke into the boundary layer and the free troposphere with the partitioning often influenced by windspeed, vertical mixing, fire growth rates and the flaming/smoldering ratio; all of which often follow a diurnal cycle that also impacts the initial emissions. Different smoke evolution can occur day vs. night and in long isolated plumes in the free troposphere vs. mountain/valley migration of near surface smoke. Shallow and deep convection are important for both aqueous chemistry and as a vertical transport mechanism (Tabazadeh et al., 2004). Deep convection interactions with smoke on the synoptic scale are infrequent in summer, while isolated convection interacting with smoke is more common, but hard to predict > 1-2 days in advance. Prescribed fires that produce small boundary layer plumes and regional haze with embedded fair weather cumulus are frequent in the SE and the west. Co-advection and mixing with other species is also a critical, understudied component of biomass burning emissions. Western wildfire emissions mix with urban emissions (Denver, LA, etc.),

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fracking emissions (Fig A1), and the 4-corners power plant plume. Prescribed fires in the SE US and Mississippi Valley (MV) interact with isoprene emissions and emissions from cities such as Houston, Dallas, St Louis, New Orleans, Atlanta, etc.

Science questions. Tropospheric chemistry objectives include better characterization of fire emissions; how the suite of VOC/NO_X precursors interacts with RH, temperature, and clouds to influence secondary formation of O_3 and OA; and impacts on urban/rural air quality and the UT. Fires produce substantial quantities of GHGs (CH_4, CO_2) and other climate-relevant emissions such as organic/black carbon (OC/BC). Key question include: 1) how fast is BB-BC coated by OC, which increases the mass-absorption, solubility, and cloud impacts, but reduces the lifetime (Akagi et al., 2012)? 2) Does faster formation of O_3 (Singh et al., 2012) or OA (Fig 1.) occur when BB and urban emissions mix? The comprehensive DC-8 payload can measure nearly all of the parameters needed (e. g. H_2O, T, VOC/OVOC, NO_x/NO_y, O_3, key intermediates, speciated aerosol size, mixing state, and composition, and multiple tracers). Addition of a HO_x instrument on the DC-8 would enhance chemistry studies but is not an absolute necessity since HO_x can be estimated from VOC decays. Full mass scans on the PTR-MS would enhance the probe of total organic matter in conjunction with the AMS. The suite of instruments on the ER-2 (eMAS in particular) can probe the relation between FRP and plume height, which impacts transport, on large NW US fires, and validate MODIS and VIIRS detection of well-characterized small fires in the SE US, which mimic tropical burning in their size distribution.

Smoke optical properties objectives include understanding how the evolution of particle chemistry (e.g. vapor/particle partition) relates to particle spectral mass extinction efficiencies, flux efficiencies, absorption, and hygroscopicity as well as CCN efficiency. The DC-8 HSRL and the ER-2 CPL and payload of polarimeters can measure how the optical and physical characteristics of large scale plumes evolve. The recent Polarimeter Definition Experiment (PODEX) did not capture high aerosol loading cases such as optically thick smoke (which induces non-linearity's) that are required to fully test aerosol retrieval algorithms: this could be addressed during SEAC4RS to provide critical test information for NASA's next generation of polarimeters. Measurements from in situ sensors on the DC-8 and DOE G-1 would also help evaluate polarimetric aerosol retrievals.

Flight planning overview. Wildfires and convection are sporadic, but multi-day smoke episodes commonly occur somewhere in the NW US during Aug-Sept and they are mapped several times daily by FLAMBE, Lance, firedetect.noaa.gov, RSAC, inciweb, etc. Access to western wildfires can be had from **Palmdale or Houston** with long range aircraft (DC-8 and ER-2). **Houston and Macon** offer access to prescribed burning in the MV and SE US. Wildfires can also be accessed in the NW US and Canada via suitcase flights on a target of opportunity basis. Within 10-20 miles of the source science aircraft are assigned a frequency and limited to altitudes above 2-5 Kft, but most sampling will be downwind. Complementary activities include the DOE G-1 BBOP program based in Pasco, WA in Aug and early Sept and then Arkansas in late Sept-Oct.

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BBOP has an excellent instrument package for characterizing the optical and morphological evolution of smoke particles – including an SP-AMS to measure the composition of BC coatings. DISCOVER-AQ program may also be interested in sampling fire emissions that impact the Houston area. It may be difficult to coordinate with $SEAC^4RS$ balloons, but a wealth of IMPROVE, EPA, health department, and AERONET ground-based sites are complementary. Mount Bachelor Observatory in Oregon samples smoke routinely. LIDARs and sun photometers at MT State Univ. (Bozeman) measure smoke optical properties (Repasky et al., 2011). The TCCON solar FTIR site near the 4-corners power plant is set up for GOSAT CO_2 validation and is impacted by summer smoke and fracking (Fig. A1).

Fig 1. Possible mixing-induced SOA. The DC-8 could sample the length of the plume and measure urban/fire tracers, O_3, and OA in the scenario shown. Enhanced O_3 formation in mixed BB/urban plumes has been noted by Singh et al. (2012) and others.

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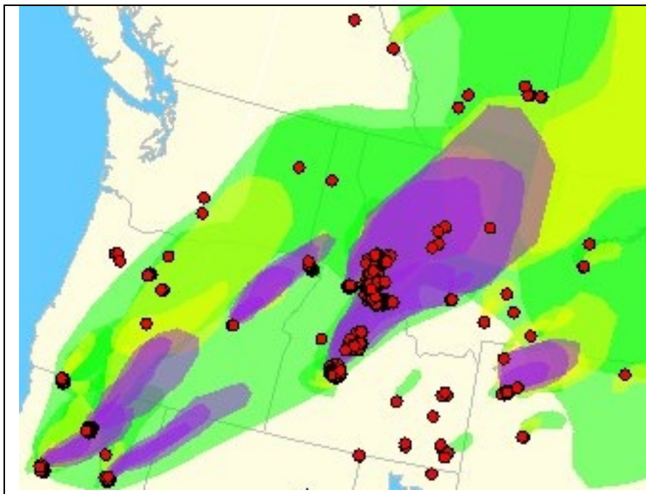
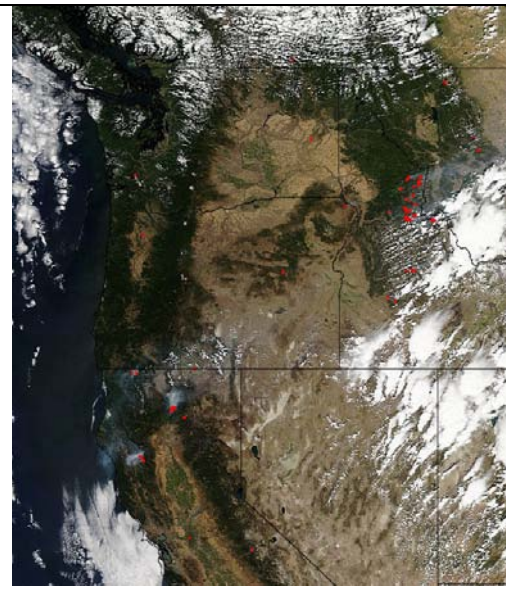
Appendix: Wild and prescribed burning has high interannual variability. Typical summer smoke images make it easy to envision a very large number of useful flight plans.

A1. Multi-day 2012 smoke episode in western US: (upper row) 8-29 (both images) and (lower row) 9-01 (NOAA composite) and 8-31 (MODIS). Left coulmn. NOAA analyst-colored interpretation of GOES smoke plumes. (R) MODIS Aqua RGB w/ active fire hotspots. In Terra the ~10 AM smoke is isolated in the valleys, in Aqua the ~1 PM smoke is a widespread plume. The MODIS RGBs show smoke interacting with small convection. Black circles indicate some fracking areas.





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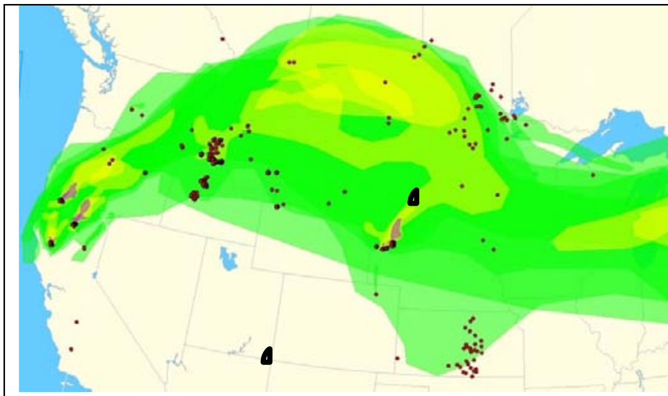

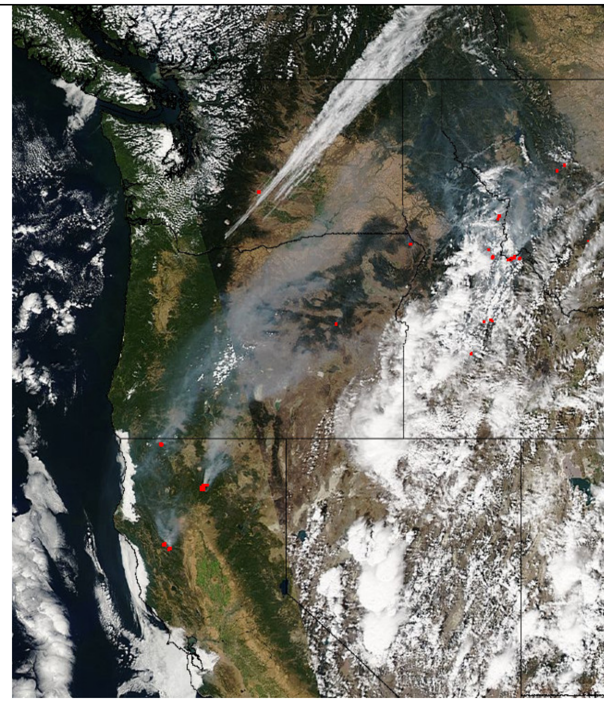

A2. September 26, 2012 smoke from widespread agricultural burning in Midwest and SE US. This type of prescribed burning produces small individual plumes that are difficult to track more than 5-20 miles with an aircraft, which is similar to tropical burning. Also similar to the tropics; many small fires create a regional haze of mixed age smoke. (below) A screen-shot of the South Carolina Forestry Commission website on a fall morning showing planned prescribed fires. The readily available details on size and time make these fires excellent for testing remote-sensing fire detection efficiency. Clicking on icon yields size info as shown in zoom.

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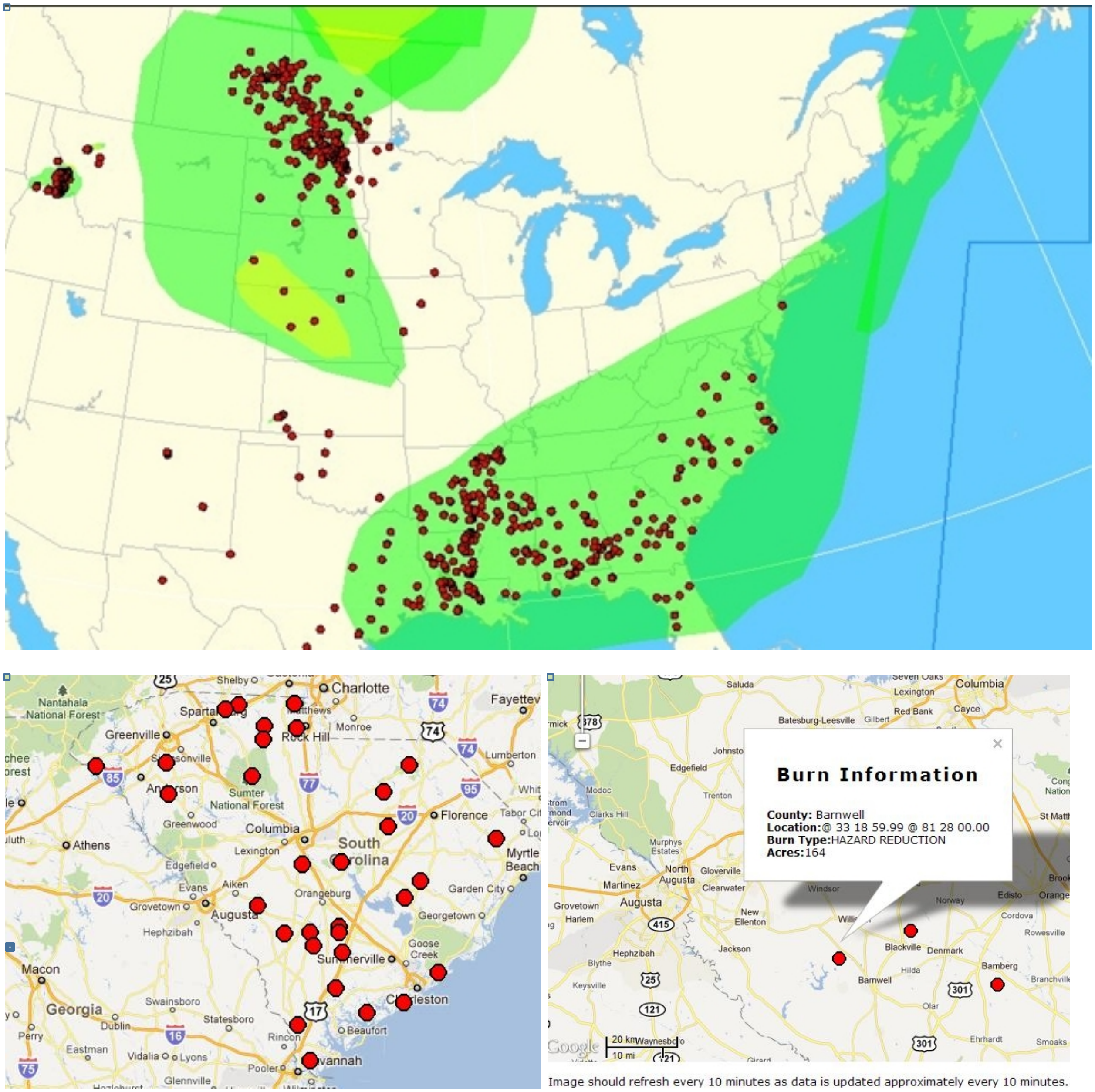

A3. August 7, 2010: an example of commonly occurring long-range transport of smoke from Canada to US.

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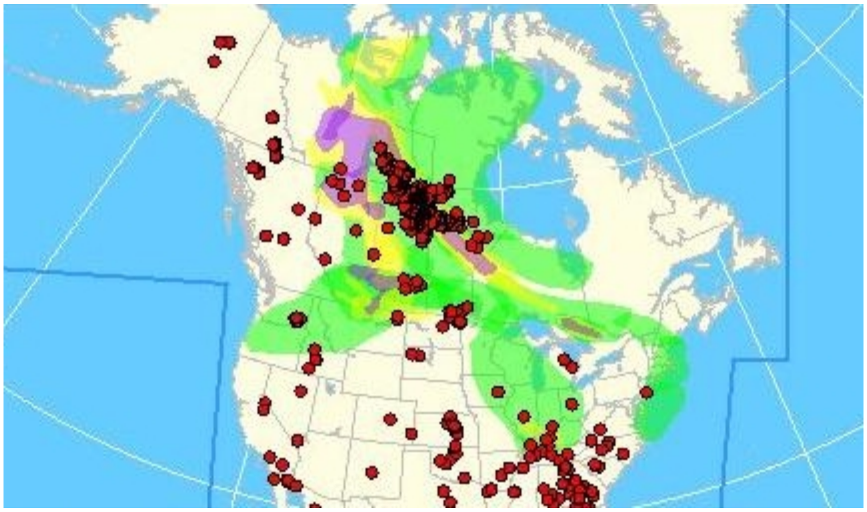


Appendix C
Southeast US Composition, Cloud, Climate Coupling Regional Study (SEAC⁴RS)

Daniel Jacob, Jeff Reid, Hanwant Singh, David Starr, Paul Wennberg

April 1, 2013

1. **General Motivation.** The Southeast US (defined here as extending from Texas to Florida, and north to Tennessee) experiences very strong deep convection in August, lessening into September but with occasional hurricanes. This deep convection injects a complex mix of boundary layer air masses into the upper troposphere and occasionally the lower stratosphere. At the same time, small and intermediate size convection serves as an aqueous reactor for aerosol chemistry, and pumps significant amounts of boundary layer air into the lower free troposphere. The Southeast US is a large anthropogenic pollution source, with major population and industrial centers distributed across the region as well as increasing sources from oil/gas exploration. At the same time, biogenic emissions from vegetation in summer are among the strongest in the world. Prescribed fires and small wildfires are frequent. Clean tropical air over the Gulf of Mexico and subtropical air over the Atlantic provides a sharp contrast. The Southeast US may be highly sensitive to climate change through perturbation of the Bermuda High. For all of these reasons, the Southeast US is a region of considerable interest for both regional air quality and global atmospheric composition, with deep convection providing a major link between the two in the spirit of the SEAC^{4}RS mission goals.

   The Southeast US is a particularly active region for deep convection, with a sharp transition between August and September. Ozonesonde observations in August show a strong UT maximum over the Southeast US (Figure 1, from Cooper et al. JGR 2008) because of deep convective injection of boundary layer air rich in NO_x and VOCs, combined with lightning NO_x, and followed by UT aging in the Southeast US anticyclone. In September that anticyclone disappears as convection loses vigor (Figure 2). This August/September transition in deep convective pumping is also visible in the MLS CO data at 215 hPa (Figure 3, with wind vectors).

   Conducting SEAC^{4}RS over the Southeast US in the August-September time frame will enable better understanding of the role of biogenic VOC emissions for atmospheric chemistry and aerosol formation. Figure 4 shows mean OMI formaldehyde (HCHO) columns over the US in August-September. HCHO columns are a proxy for isoprene emissions. Note the spectacular decrease from August to September, associated with senescence of vegetation and cooler temperatures. Figure 5 shows extremely high mean HCHO concentrations simulated by the GEOS-Chem model in the upper troposphere in August, in contrast to low concentrations in September. The reduction in biogenic emissions from August to September is collinear with a significant drop in aerosol optical thickness (AOT, Figure 6). AERONET data suggest a 30-40% drop in fine mode AOT in this period. Climatologically, there is a drying in overall precipitation (Figure 7) from August to September. This transition is not abrupt; examination of AERONET data suggests that haze events do exist every September. But a clear meteorological regime change begins every year around September 1st.

A SEAC^{4}RS campaign over the Southeast US would also provide the opportunity to better understand and quantify a range of anthropogenic sources, and to document changes that have taken place since the INTEX-A campaign in summer 2004. OMI NO_2 observations indicate a 32% nationwide drop in US NO_x emissions from 2005 to 2011 (Figure 8, from Russell et al. [2012]). Such a decrease would have important implications for the photochemical regime, including the interaction with biogenic VOCs. Here again the August-September transition is of particular interest, as the photochemical regime for ozone production and OH concentrations is expected to switch from NO_x-limited to NO_x-saturated in September due to declining UV radiation.

Finally, ER-2 observations from past NASA missions have shown that thunderstorms over the Southeast US occasionally puncture the tropopause, delivering high water vapor well into the lower stratosphere (Figure 9, from Anderson et al. [Science 2012]) and potentially resulting in chlorine activation (Figure 10). Subsequent aging of the convective outflow in the UT/LS anticyclone provides a unique opportunity to examine the implications of this halogen radical chemistry for lower stratospheric ozone. Radical measurements aboard the ER-2 would be a powerful addition to the currently planned payload.

2. Major science questions

2.1 How do anthropogenic and biogenic emissions, and their interactions, affect atmospheric composition in the Southeast US? This is a critical question for PM and ozone air quality but also has global implications through the connection by deep convection. Major issues relate to the coupling between biogenic and anthropogenic influences in driving organic aerosol formation and affecting ozone; the role of prescribed fires; rising oil/gas exploitation in the south-central US; and the effect of inflow from the Gulf of Mexico. Here SEAC^{4}RS will interface with DISCOVER-AQ in Houston in August-September and will build on the SENEX 2013 field campaign to be conducted in Alabama in July. The August-September transition to be investigated by SEAC^{4}RS will provide unique insights into biogenic-anthropogenic interactions affecting atmospheric chemistry and aerosol formation. Revisiting the Southeast US nine years after INTEX-A will offer an opportunity to examine the effect of the large anthropogenic NOx emission decreases over the past decade.

2.2 What is the role of shallow convection in modifying aerosol chemical, thermodynamic and optical properties? Similar to Southeast Asia, we expect boundary layer clouds to significantly contribute (if not dominate) aerosol evolution chemistry and subsequent impacts on hygroscopicity and optical properties. Cloud processing can also result in pumping of boundary layer air into the lower free troposphere, where evolutionary processes are likely markedly different.

2.3 What aerosol and chemical processing takes place during deep convection in the Southeast US, and what are the implications for the composition and evolution of the outflow in the UT/LS? This will very much follow the original SEAC^{4}RS plan. Limited observations in INTEX-A showed that deep convection over the Southeast US delivered high concentrations of chemicals of boundary layer origin to the upper troposphere, and these together with surprisingly high levels of NO_x from lightning resulted in very active photochemistry. Cooper et al. [JGR 2008] inferred that this was responsible for the observed UT maximum of ozone over the southern US (Figure 1). We need a more deliberate investigation, examining also aerosol outflow and evolution in the UT. We should also have the opportunity to sample convective overshoot from thunderstorms into the lower stratosphere and determine the implications for water vapor injection into the LS [Anderson et al., Science 2012]. Addition of chlorine radicals to the ER-2 payload would enable a direct test of the hypothesis that such convective overshoots may cause large ozone depletion at mid-latitudes.

2.4 **What influences and feedbacks do aerosol particles from anthropogenic and natural sources exert on meteorology and climate through changes in the atmospheric heat budget (i.e., semi-direct effect) or though microphysical changes in clouds (i.e., indirect effects)?** This is largely lifted from the $SEAC^4RS$ planning document. It seems that the Southeast US would provide similar opportunities in that regard as Southeast Asia, with lesser biomass burning influence but larger anthropogenic and biogenic influence.

3. **Location and platforms.** There is frequent deep convection throughout the Southeast US in August, declining in September but with the opportunity to sample hurricanes. The Convective Pumping Topic document by David Starr suggests central Oklahoma and Alabama/Georgia as possible areas of operation. More generally, the document states that "Given our time window, a focus on air mass thunderstorms over the SE USA may be optimal". Central Oklahoma would also offer the opportunity to sample emissions from oil/gas exploration. Alabama/Georgia would be optimal for biogenic emissions as shown in Figure 1. A base of operations in either Houston or Macon would allow reaching either area. Operating out of Salina would be doable but less desirable as Salina lies outside the region of interest. Operating out of Houston would have the advantage of interfacing with DISCOVER-AQ.

   The DC-8 payload is well suited for general sampling of convective inflow and outflow. Deep convective outflow associated with the strongest thunderstorms over the Southeast US may often extend above the DC-8 ceiling. This is what we observed in INTEX-A. These strongest thunderstorms are of particular interest for lightning formation and for delivering water to the lower stratosphere. In situ sampling of the high-altitude outflow with the ER-2 would be of considerable value. Addition of NO_x and chlorine radicals to the ER-2 payload should be considered. Chlorine radicals in particular would allow a test of the Anderson et al. [Science 2012] hypothesis of chlorine activiation in the mid-latitudes LS. It would also be of interest to add UV/Vis remote sensing capabilities aboard the ER-2 for NO_2, HCHO, and glyoxal.

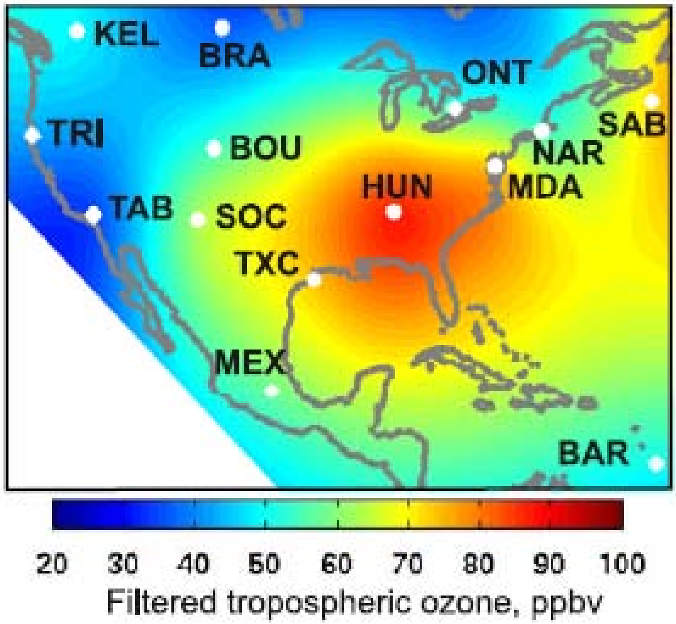


Figure 1. Locations of the 14 sites from which daily ozonesondes were launched during the August 2006 IONS experiment. The full site names are listed in Table 1. Shading indicates the median filtered tropospheric ozone (FTO3) mixing ratios during August 2006 at all 14 measurement sites between 10 and 11 km. FTO3 is the measured ozone within the troposphere with the model calculated stratospheric ozone contribution removed. Details on the methodology are given by *Cooper et al.* [2007]. Figure adapted from *Cooper et al.* [2007].

From Cooper et al. [2008]

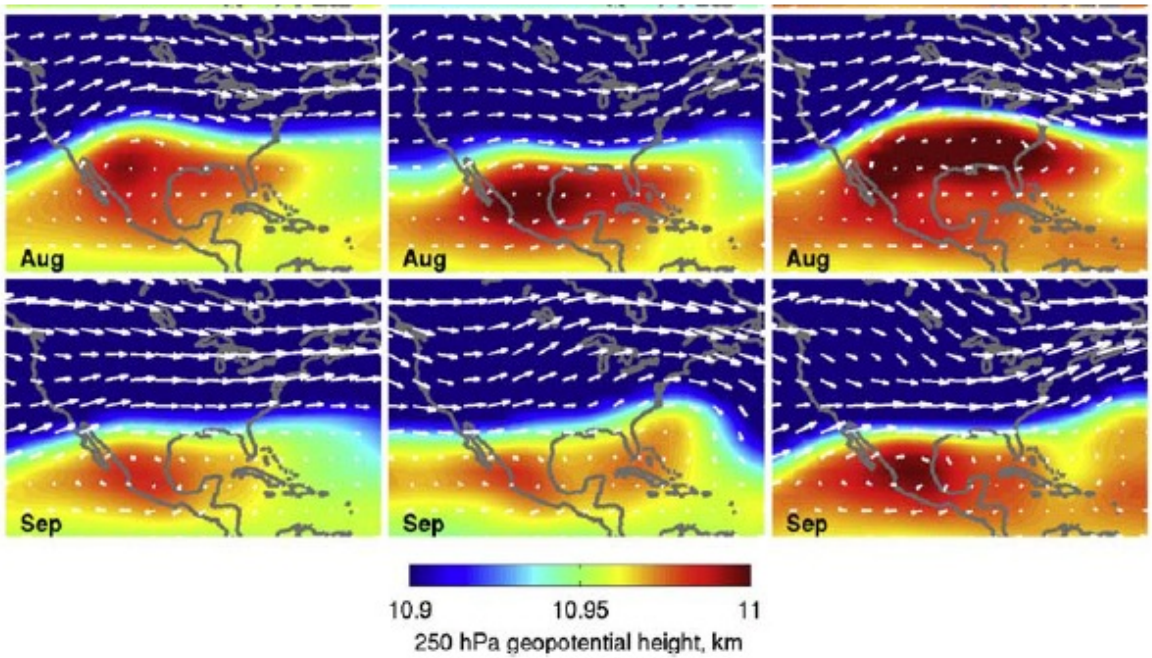


Figure 2. Monthly average 250-hPa geopotential height and wind vectors for May through September for (a) the 20-year (1987–2006) climatology, (b) 2004, and (c) 2006.

From Cooper et al. [2008]

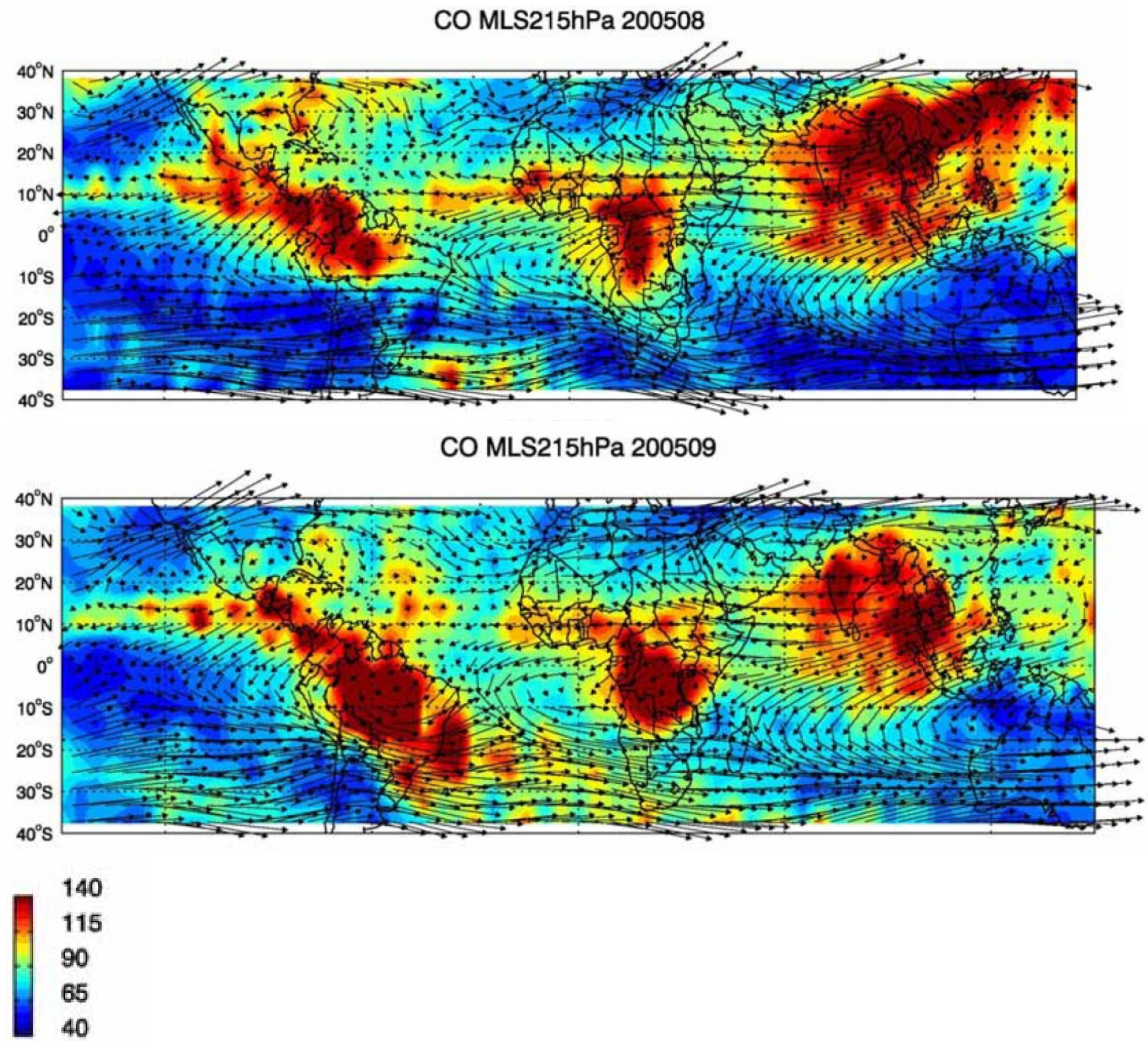


Figure 3. MLS CO (ppb) at 215 hPa in August and September 2005, with wind vectors. From Junhua Liu (Harvard)

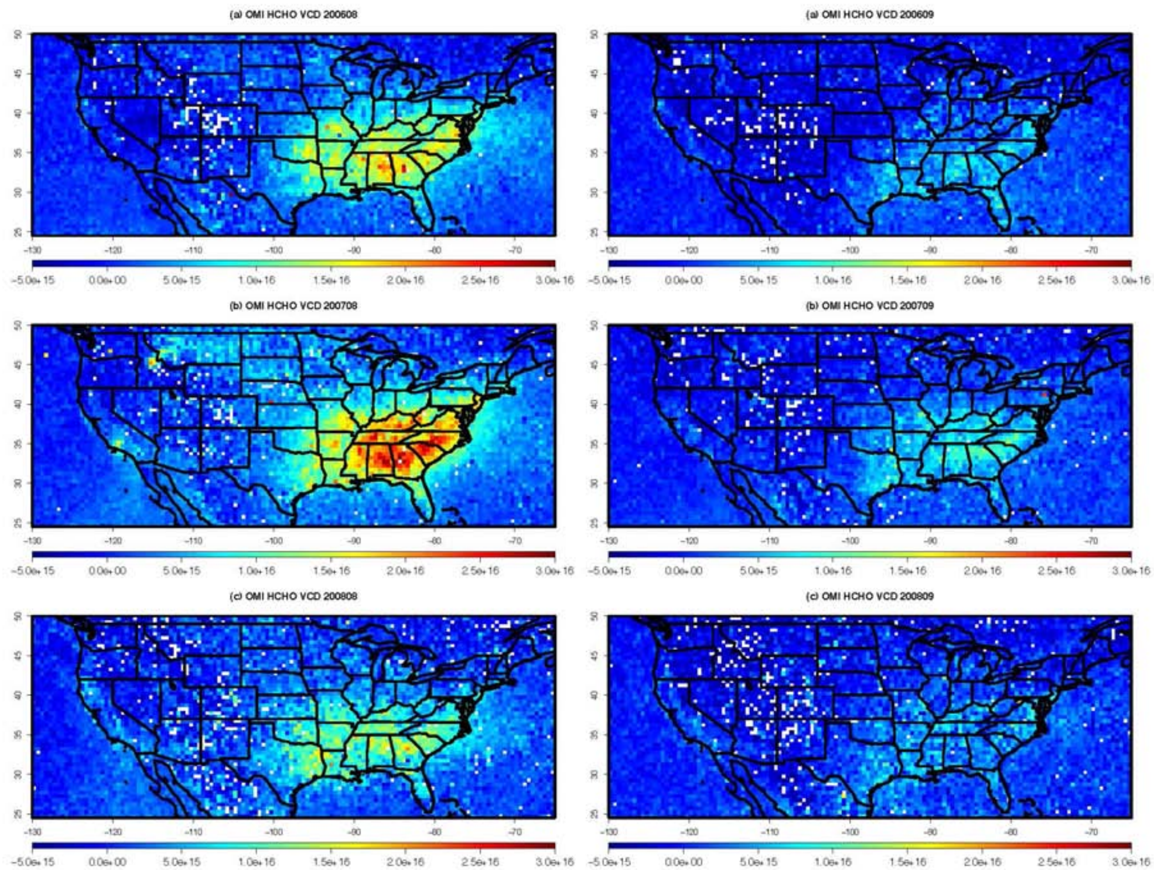


Figure 4. OMI formaldehyde columns in August 2006-2008 (left panels) and September 2006-2008 (right panels). Note the large contrast between August and September reflecting the decline of isoprene emissions. (Lei Zhu, Harvard)

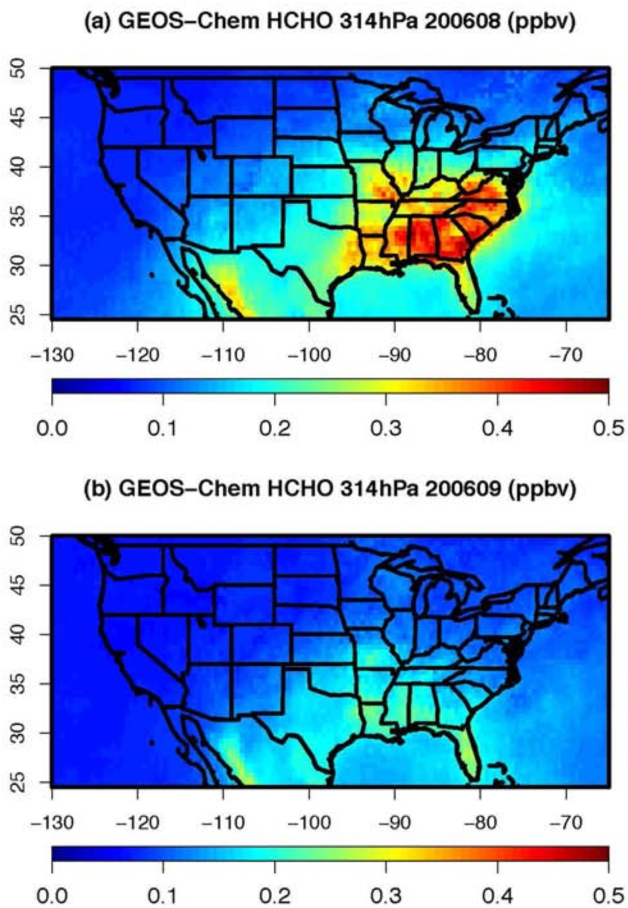


Figure 5. Mean simulated GEOS-Chem concentrations of formaldehyde at 314 hPa in August and September 2006. Note very high concentrations in August and sharp decline in September. (Lei Zhu, Harvard).

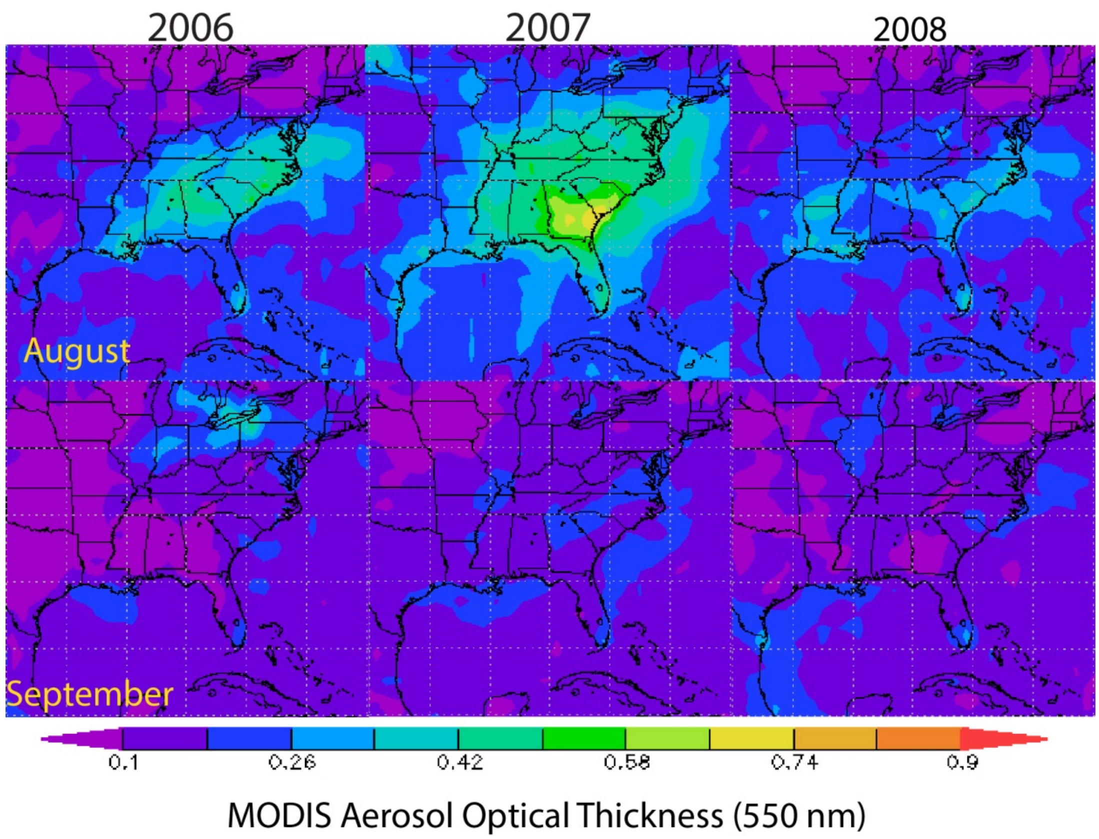


Figure 6. August versus September MODIS aerosol optical thickness for 2006-2008.

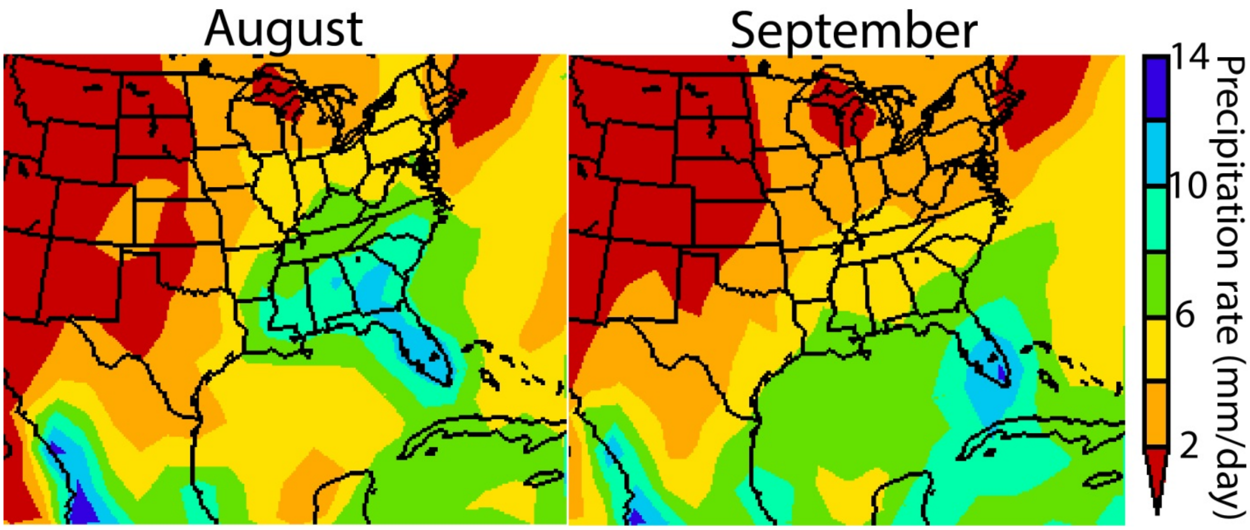


Figure 7. NCAR Reanalysis of precipitation rate (1990-2010)

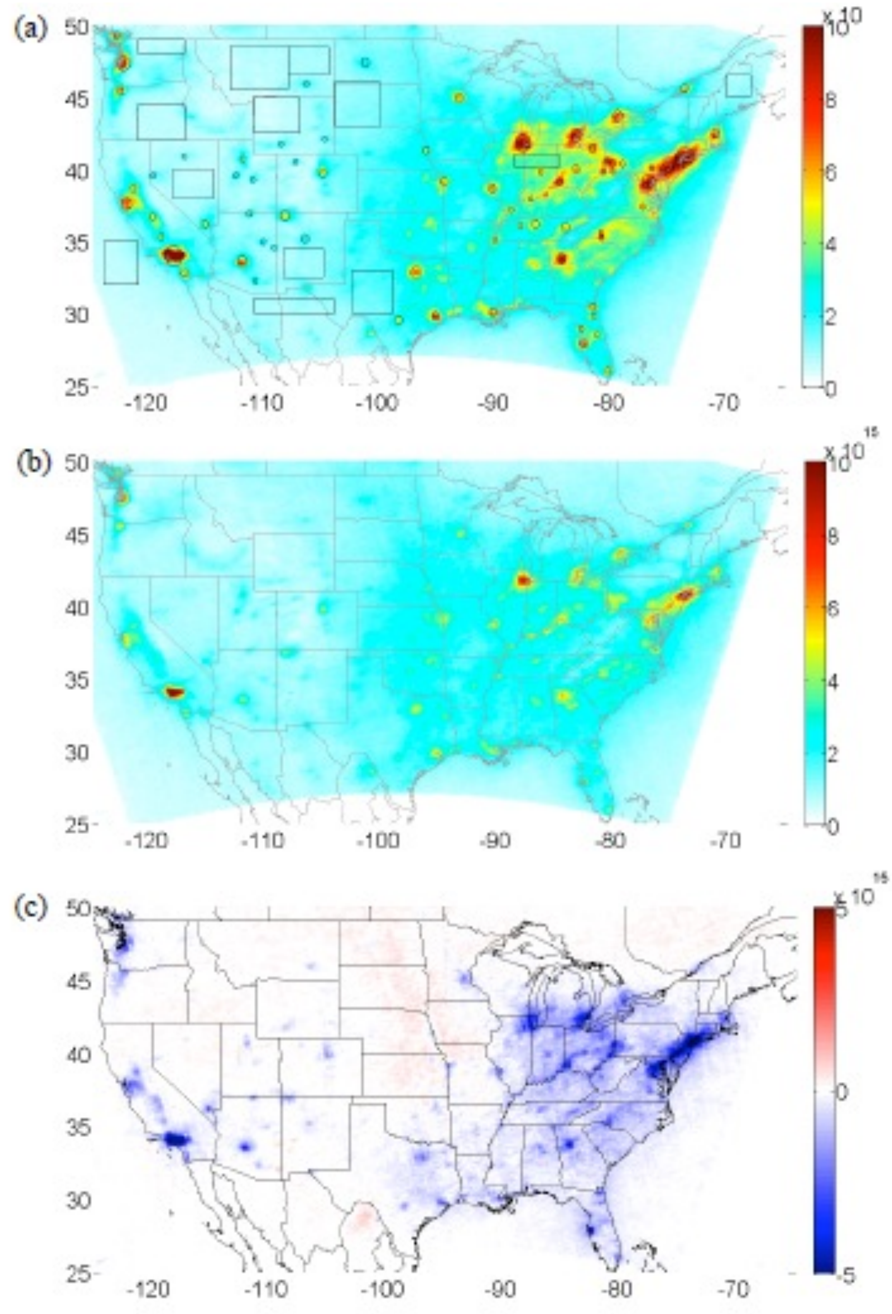


Fig. 1. Average summertime (April–September) OMI BEHR NO_2 column densities (molecules cm^{-2}) for **(a)** 2005, **(b)** 2011, and **(c)** the difference, 2011–2005.

Figure 8, from Russell et al. [ACP 2012]

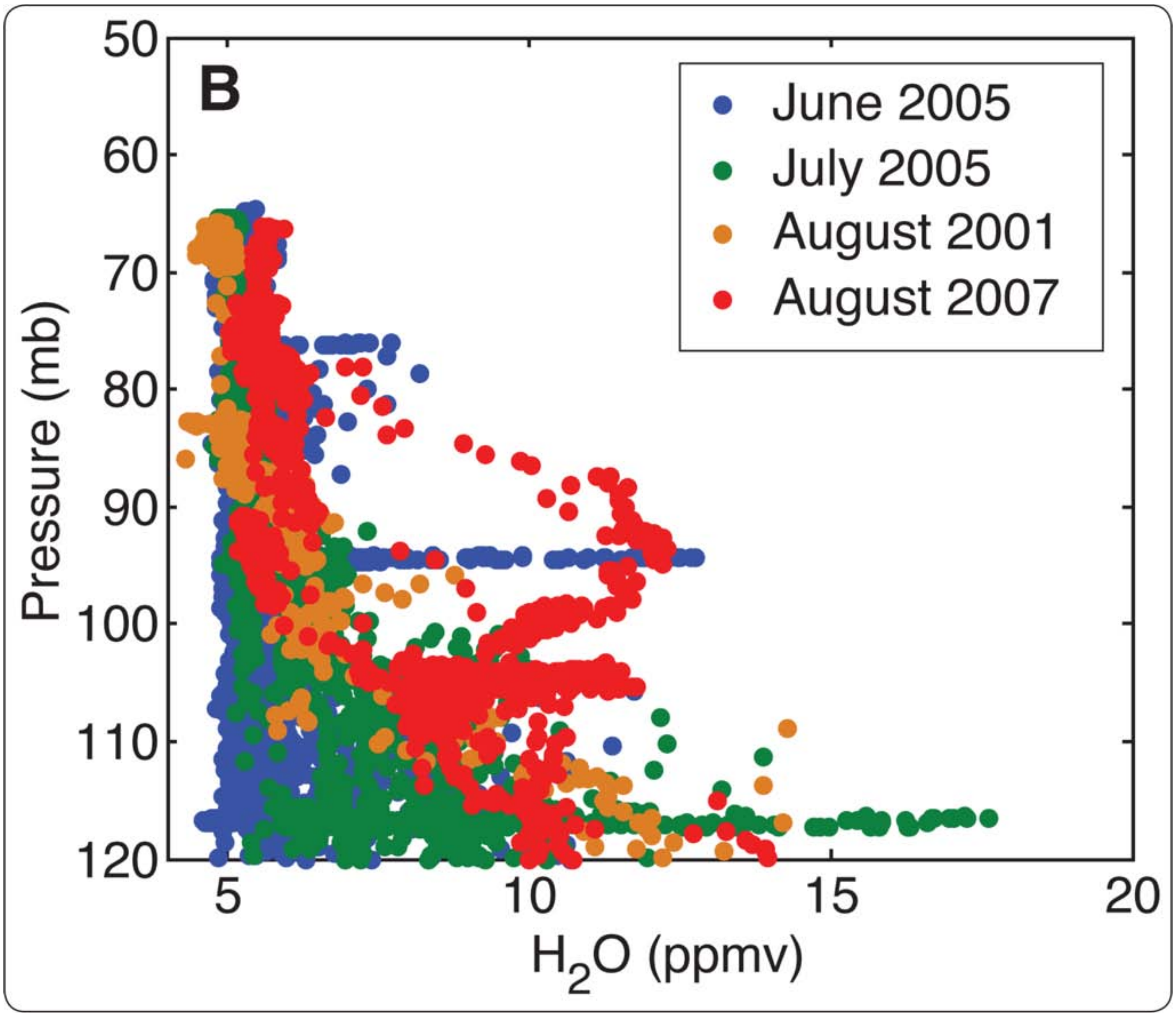


Figure 9. Water vapor vertical profiles sampled by the ER-2 over the US in summer, from Anderson et al. [Science 2012].

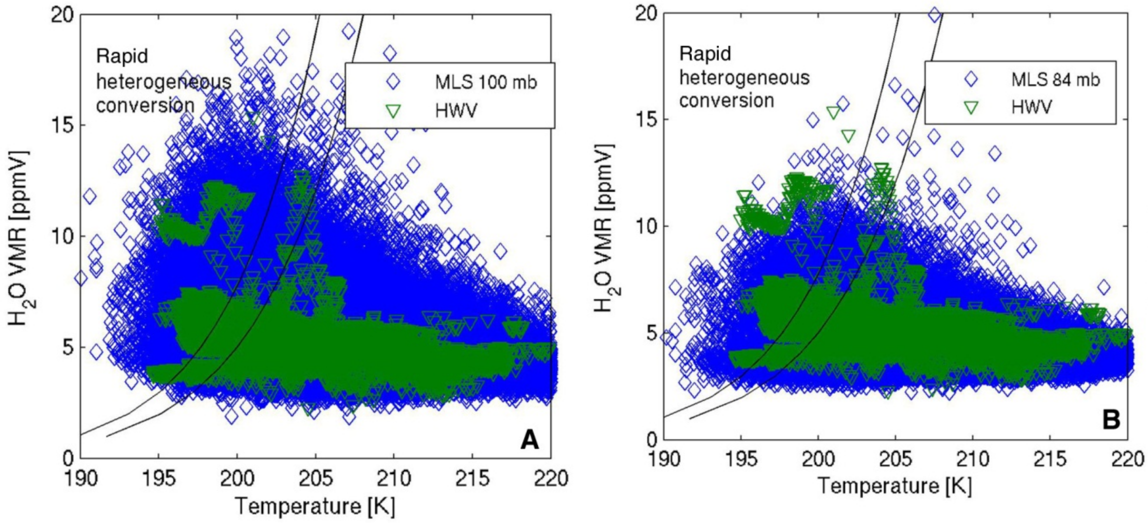


Figure 10. MLS and in situ H_2O concentrations and temperatures at 100 hPa over the US in summer. Conditions to the left of the curves correspond to rapid heterogeneous conversion of chlorine reservoirs to radicals in sulfuric acid aerosols. The Figure shows that these conditions occur frequently. From Jim Anderson, Harvard.

Appendix D
Synergies between SEAC^{4}RS and DISCOVER-AQ

Jim Crawford, Hanwant Singh, and Rich Ferrare

1. **General Motivation.** The rescheduling and relocation of SEAC^{4}RS to a domestic setting has generated both difficulties and opportunities. The difficulties are primarily related to scheduling and resource conflicts for those investigators involved in the DISCOVER-AQ campaign which fully overlaps with SEAC^{4}RS. DISCOVER-AQ integration for the P-3B and King Air will take place in August followed by a 30-day deployment to Houston, Texas in September. The opportunities include several collaborative possibilities to perform joint science between the aircraft and ground assets involved in both campaigns.

2. **Logistical Considerations.** Given the large number of investigators that are impacted, logistical considerations are discussed first. While it has been suggested that the ER-2 cannot operate from Houston, the precise reasons are unclear and should be ascertained before completely eliminating Houston as a consideration for basing the DC-8 and ER-2.

   The DISCOVER-AQ and SEAC4RS campaigns will divide the attention of several research groups. While this cannot be avoided, it can be mitigated in terms of the risks and stresses put on the investigators. In some cases, new instruments are being built to accomplish the work and often, the cache of spare parts and repair equipment are a shared resource that may be needed by either or both instruments depending on circumstances. While basing the aircraft together does not relieve the need for operators on two aircraft, it could allow some groups to require fewer personnel on the ground and enable rotation of personnel to reduce time spent in the field. The following table lists the affected researchers and groups.

Investigator	Measurement/Role	New Instrument?
Diskin	DACOM and DLH	Yes for DACOM
Anderson	LARGE (aerosols)	No spares
Cohen	TD-LIF (NO_2 and reactive nitrogen)	Upgrades to an older instrument
Fried	DFGAS (CH_2O)	Modifications to an existing instrument
Wisthaler	PTR-MS	
Beyersdorf/Yang	AVOCET (CO_2)	
Ferrare	HSRL (DAQ) / ER-2 lead (SEAC^{4}RS)	

3. **Science Benefits.** The compatibility in the science payloads for DISCOVER-AQ and SEAC4RS is evident based on the overlap in investigators. The primary impediment to full collaboration is the very limited domain of the DISCOVER-AQ flights, which will be focused on the Houston metropolitan area and the augmented ground network of air quality observations. Nevertheless, there are a number of potential synergies that could be exploited.

3.1 DIAL ozone observations over Houston: The observing strategy for DISCOVER-AQ includes in situ vertical profiling for trace gases and aerosols as well as aerosol lidar to provide details on the spatial and temporal distribution of pollutants. Obtaining a few curtains of ozone over the area in the late afternoon or early evening would significantly improve the characterization of vertical and horizontal ozone variability on the scales needed to evaluate satellite retrievals for future satellites such as TEMPO. This would require the investment of 30-45 minutes at the end of a DC-8 science flight if the DC-8 was based in Houston or sometime during the flight if the DC-8 was located at another site.

3.2 Remote sensing validation/ACE observing strategies: During DISCOVER-AQ California, joint flights were conducted with the ER-2 in support of PODEX. For SEAC^{4}RS, the remote sensing payload for the ER-2 is very similar as shown in the list below. Under the right circumstances, (e.g. long range transport of dust or smoke) the ER-2 might find benefit in overflying the DISCOVER-AQ aircraft and the ground network which is again planning at least fifteen AERONET sunphotometers distributed across the Houston flight domain. A similar network of AERONET instruments was very valuable for assessing polarimeter aerosol retreivals for data acquired during the PODEX mission. However, PODEX did not obtain coincident polarimeter and AERONET aerosol measurements in cases of high aerosol loading or for cases of absorbing aerosols. Also possible, but subject to DISCOVER-AQ priorities, flights over the Gulf could be requested as was the case in California.

PODEX		SEAC^{4}RS
RSP	←same→	RSP
AirMSPI	←same→	AirMSPI
SSFR	←same→	SSFR
CPL	←same→	CPL
AMS	←related→	eMAS
PACS	←removed	
	added→	BBIR

3.3 Direct support of SEAC^{4}RS with P-3B: DISCOVER-AQ intends to fly 10 science flights over the Houston area. It is not unreasonable to expect that 13-14 total flights could be executed. In Maryland, 4 extra DISCOVER-AQ flights were flown. In California, 2 extra flights were flown in support of PODEX. It is possible that the P-3B could be used to directly support SEAC^{4}RS on a few occasions. This would of course be subject to DISCOVER-AQ priorities. The King Air is not included in this option since it will be conducting additional flights in support of the GEO-CAPE ship cruise in the Gulf. The P-3B would be useful for helping the DC-8 with any number of goals including but not limited to characterization of source emissions and sampling long range transport from fires. Such coordination would also introduce the need for an intercomparison flight to ensure that the two payloads agree for common measurements.

Appendix E
Hurricanes (Tropical Cyclones)

Leonhard Pfister, Paul Newman, Laura Pan, Eric Ray, Karen Rosenlof, David Starr, Sean Freeman

Background:

Tropical cyclones (TCs) are rotating convective systems characterized by: strong regional scale organization, long life, and deep convective penetration. There is long-standing qualitative evidence for troposphere-stratosphere mass transfer (Pfister et al, 1993; Kelly et al, 1993). Rosenlof and Tuck (1999, unpublished) used ER-2 tracer measurements downstream of a TC to estimate that TCs could account for as much as 33% of upward transfer to 70mb in the 20-30 degree latitude band. TCs' long lifetime also implies significant impacts on upper tropospheric tracer distributions, particularly significant moistening of the upper troposphere (Ray and Rosenlof, 2007). Their organization means that low-level air from large regions can be funneled into a persistent convective pipe into the upper troposphere, and possibly, the lower stratosphere. To the extent that the TCs' extensive precipitation could wash out chemicals and aerosols, TCs might be viewed as a regional scale atmospheric cleaner.

Past aircraft investigations of tropical cyclones have, for obvious reasons, focused on a better understanding of the dynamics, specifically forecasting intensity and tracks. These include the NASA CAMEX series of missions, TCSP, NAMMA, GRIP, and, most recently HS3. Very few aircraft experiments have attempted to examine tropical cyclones with a tracer payload. Perhaps the first was STEP 1987, where the ER-2 made a number of penetrations into the anvils of tropical cyclones measuring meteorological variables, water vapor, particles, NOy, ozone, and CO. PEM West A had a DC-8 flight into the outflow of a typhoon on September 27, 1991. Another TC flight was in summer 2005, when the WB-57 penetrated Hurricane Cindy measuring water, water isotopes, methane, and CO2. However, there has yet to be a systematic investigation of both inflow and outflow of tropical cyclones with a chemical payload involving multiple aircraft.

Part of posing suitable science questions is knowing some of the possible mechanisms whereby TCs can move trace constituents to the UTLS. Like many large convective systems, we expect a tropical cyclone to bend the theta surfaces upward, effectively inhibiting troposphere-to-stratosphere exchange. We also expect convective injection and mixing, so that boundary layer and tropospheric air reach potential temperatures substantially higher than the highest equivalent potential temperatures at the surface. Of particular specific interest at the latitudes where SEAC4RS is operating is interaction with the subtropical jet, where air lifted by the TC can enter the stratosphere quasi-isentropically through the sloping tropopause.

The current DC-8 payload gives us the opportunity to address chemistry and chemistry transport issues associated with TCs. The presence of the ER-2, with a rudimentary tracer payload, gives us the ability to sample all the relevant altitudes associated with a TC (this assumes that the ER-2 is willing to make dives to 13 km well outside the eye and eye-wall regions of a TC, and away from the rain band mesoscale convective systems). In addition, the DC-8 has extensive instrumentation to sample cloud particles, aerosols, and radiation. The ER-2 has remote polarization instruments, which are useful for remote sampling of aerosols and cloud particles. In addition, the collaboration with HS3, occurring at the same time, has real possibilities. HS3 will be using 2 Global Hawk aircraft with a Doppler radar (winds, & cloud structure) and microwave sensors (T, RH, rainfall, and surface winds) on AV-1, and dropsondes (winds, T, and RH), and IR radiomenter (T, RH) and a cloud lidar (cloud structure and aerosols) on AV-6. Combined with satellite observations, the HS3 payloads can be used to define outflow structure and altitude for the DC-8 and ER-2. Furthermore, the Global Hawk payloads can be used to initialize transport models for the tracer payloads of the ER-2 and DC-8. Coordination of the platforms can be easily achieved by regular conference calls and Web-ex discussions between the SEAC4RS and HS3 teams. An obvious point to be emphasized is that joint flights of three aircraft (only one Global Hawk will operate at a time) require careful coordination, if for no other reason than the fact that the GH will be launching numerous dropsondes. Nevertheless, successful interaction with HS3, which will provide excellent definition of the dynamical and thermal structure of a surveyed TC, gives us a very powerful tool to investigate the compositional and microphysical aspects of TCs

TCs are highly individual phenomena, especially at midlatitudes where each interacts with midlatitude jets and fronts in a different way. In general, Gulf Hurricanes, with air sources from the Atlantic Ocean, are likely to transport clean air upward and have deeper convection (warmer SST), while Atlantic Hurricanes that approach the coast can loft significant amounts of pollution into the UTLS.

Science Questions

(1) What gases and aerosols actually make it into the UTLS as a result of a tropical cyclone, and in what quantities? More generally, in what way do TCs modify the chemical and aerosol environment of the UTLS? To answer these questions, we will need a DC-8 survey of air entering the TC in the boundary layer and other low levels (up to 700mb), along with measurements in the main outflow region. The ER-2 would need to dip into the Upper Troposphere (at least to the DC-8 ceiling) to (at least) verify that the DC-8 can actually capture the characteristics of the main outflow. The required measurements include basic fast-response tracers available on both the ER-2 and DC-8 (water vapor, CO, methane, ozone, and CO2), and, more importantly, WAS tracers (such as hydrocarbons for an indicator of continental pollution and methyl iodide/nitrate for oceanic air). We note that WAS exists on both the ER-2 and the DC-8. Some related science questions:

> **(a)** How does the composition of TC outflow evolve downstream? TCs (see attached figures) will often have strong, organized outflows that can be tracked with large scale models. This would involve looking at the evolution of tracers to evaluate mixing, and ozone and the nitrogen oxides to examine chemical changes.
>
> **(b)** What are the transport characteristics as the TCs interact with fronts, the subtropical jet, and Rossby Wave Breaking events? As pointed out above, SEAC4RS occurs at latitudes where midlatitude phenomena suggest additional mechanisms whereby air can get into the stratosphere (through the Subtropical Jet). Required measurements would be the same as above,

(2) What are aerosol and ice particle characteristics in the cloud shields and eyewall areas of the TC? How do these characteristics evolve as the cloud evolves? Measurements required would be the in-situ aerosol and ice crystal data, as well as remote measurements from HS3 and the ER-2 (polarimetery, HS3 radars, and CPL). Sampling strategy would be to have both aircraft fly (as much as possible) along a streamline following the cirrus outflow.

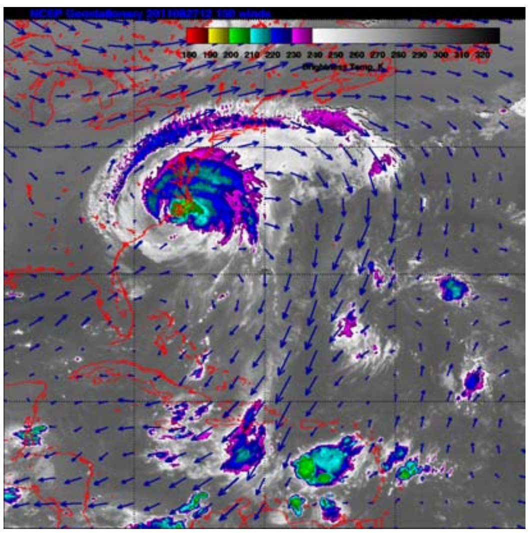
(3) Do TCs hydrate or dehydrate the stratosphere? This relates to the nature of the mechanism of exchange, since convective injection is likely to hydrate, whereas slow ascent through upwardly bent theta surfaces (which will be cold) will put dry air into the stratosphere. Required measurements are water vapor and eMAS. The sampling strategy for hydration is to use eMAS visible imagery to spot convective overshoots and water vapor from the ER-2 during dives in the high level (100mb) outflow stream. Establishing dehydration would require water vapor plus tracers measured in the outflow stream during dives, and comparing these measurements to tracer-water relationships in the "undisturbed" environment.

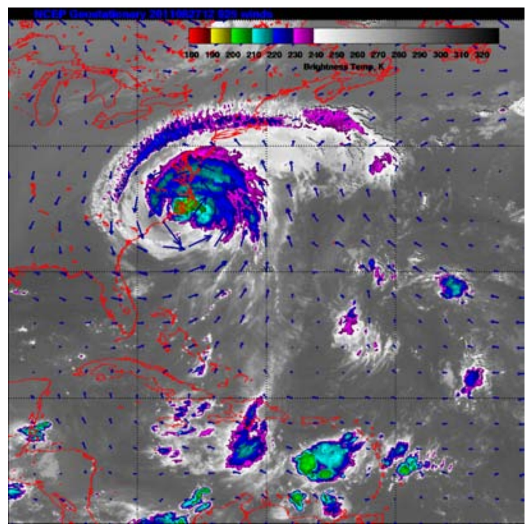
(4) What is the gravity wave spectrum generated by TCs that propagates into the stratosphere? Required measurements aboard the ER-2 are eMAS, CPL, MMS, and MTP. The remote measurements would yield information about the character of the forcing, while the MMS and MTP would characterize the gravity waves that are presumably generated by the storm. Sampling strategies include standard "cross" patterns across the cyclone or flights following a streamline

(5) What are the aerosol characteristics in both the inflow and outflow regions of a tropical cyclone? This bears on the extent to which aerosols are removed by convection. Convection in tropical cyclones probably acts in a similar way to convection in other meteorological contexts. However, the broad inflow and outflow patterns in TCs may make this an easier sampling problem than in the complex pattern of multiple convective plumes in less well-organized systems. There are a variety of types of aerosols that will be affected differently (sea salt, dust, organics, etc). In the Atlantic/Caribbean region, the Saharan Air Layer is thought to have significant impact on TCs. Can we indentify SAL air being entrained into a TC and the resulting detrained air the UTLS? It should be noted that the SAL objective would have to be addressed in August, since the SAL is much reduced in September.

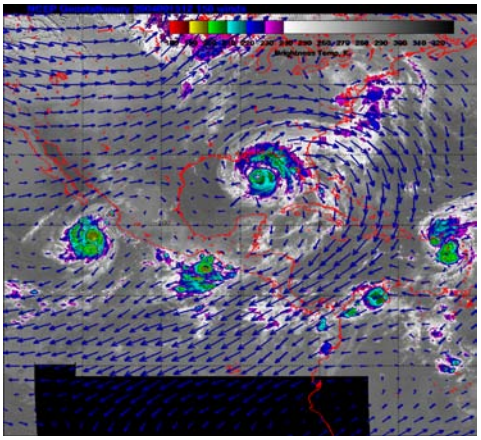
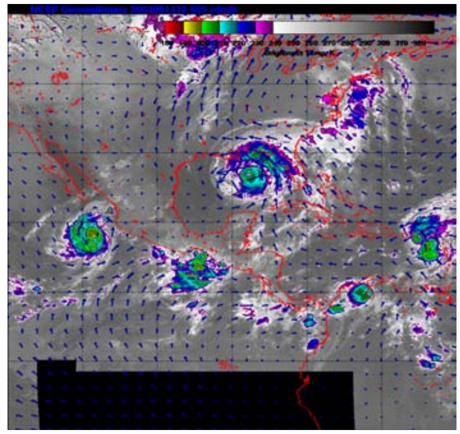
General Sampling Strategy – some examples

The figures below (right with 925 mb flow, left with 150 mb flow) shows hurricane Irene (a major hurricane) passing over Cape Hatteras in August, 2011. Maximum radar tops were near 17 km. Clearly, significant low level flow from the continent (presumably polluted from the Ohio valley) is entering the TC at 925 mb, which would be the major advantage of sampling this storm. A notable disadvantage would be that HS3 would be grounded in this situation (!). Most of the outflow heads to the NNE, but (consistent with vorticity generation by divergence), curves anticyclonically into the tropics. The DC-8 could sample the inflow by doing vertical profiles along an arc from about (70W, 30N) west northwestward to about (80W, 40N). After flying above the storm and across it for science questions 2, 3, and 4, the ER-2 could sample the outflow safely between (70W, 30N) and (60W, 42N) for questions 1 and 5

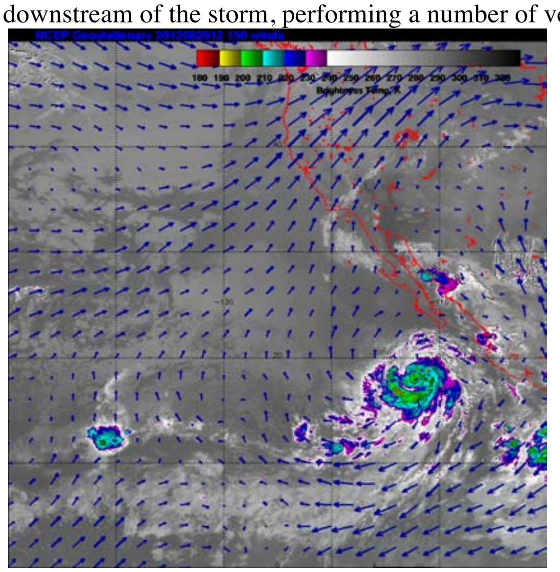




The next example is a Gulf Hurricane, Ivan (2005) is shown below (left, 150mb, right 925mb). In this case, most of the inflow is from the Atlantic. Outflow is again towards the north initially, curving into the tropics. In fact, outflow from this TC dominates the central American tropics for several days. For questions 1 and 5, the DC-8 could do low level inflow sampling on an arc from Central Florida southward and westward around the storm to north of the Yucatan Peninsula. The ER-2 might take off later, cross the center of the storm with the GH while the DC-8 underflew, thus obtaining simultaneous in situ and remote measurements of cloud properties in the active portion of the TC. This track would also obtain gravity wave measurements. The DC-8 could then jointly sample outflow in an arc north and east of the storm. If the ER-2 had time left, it could do a Langrangian run following rain band or outflow band of cirrus. under the DC-8 and the GH while the ER-2 sampled outflow on an arc north and east of the storm.

The last example shows the 150mb meteorology with Hurricane Ileana , an east Pacific TC. These storms will tend to be further away from Palmdale than Gulf and “near field” Atlantic hurricanes. Pacific hurricanes are shifted slightly earlier in the season. If sampled in August, the mean upper level flow is westward and northward around the anticyclone, so UTLS air influenced by the hurricane will be heading mostly towards our base. For these storms, we would try to answer question 1 from the point of view of what TCs do to the UTLS environment without necessarily actually going into the storm itself. The DC-8 has sufficient range to sample the inflow, and then follow the outflow as it rounds the NAM anticyclone heading to California. The ER-2 may be able to cross the storm once, but would mostly sample downstream of the storm, performing a number of vertical profiles.



Recommended Bases/other considerations

Palmdale would be fine for sampling Pacific hurricanes in August. For the Gulf and Atlantic hurricanes, Warner-Robins would be best. Basing in Salina or Houston would mean we would have to confine our attention to Gulf Hurricanes. As indicated above, interaction with HS3 would be very profitable for SEAC4RS. SEAC4RS would gain a great deal of information about the wind and thermal structure of the storm from the dropsondes, radar, and microwave instruments that we would not otherwise have. The HS3 radars would enhance our remote instruments (polarimeters and CPL), as well as our DC-8 in situ instruments in measuring particles.

D.Starr
March 20, 2013

Appendix F
Convective Pumping Topic

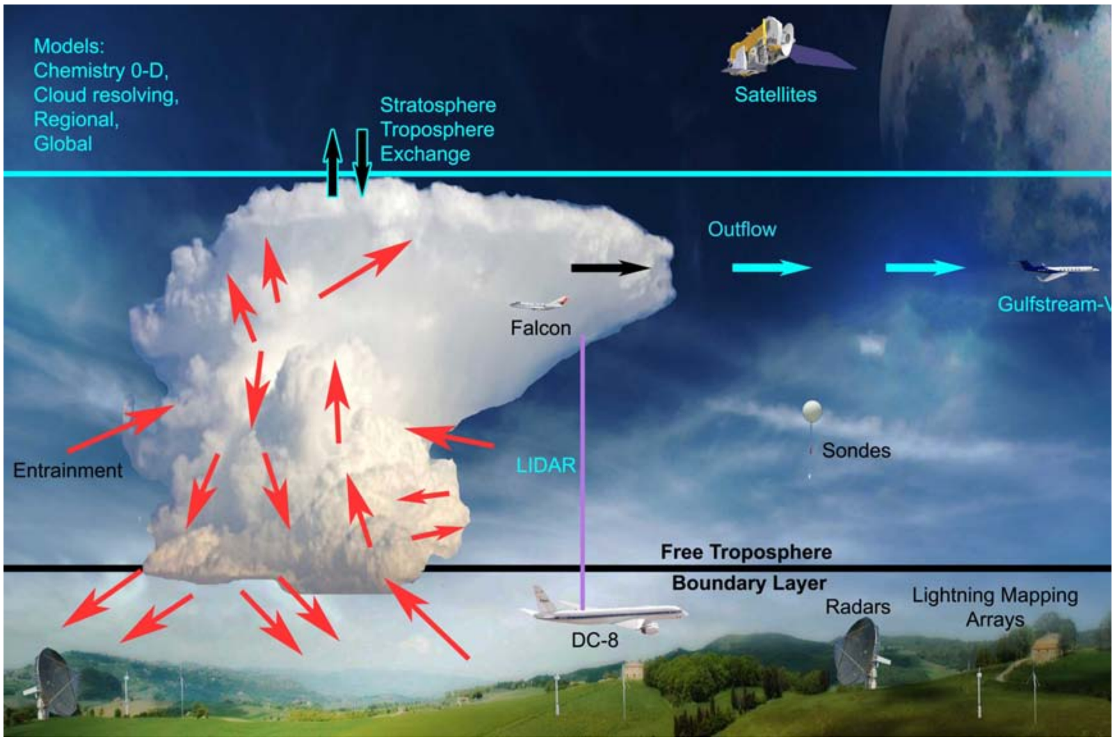
This activity investigates the impact of deep, midlatitude continental convective clouds, including their dynamical, physical, and lightning processes, on upper tropospheric (UT) composition and chemistry. It mimics DC3 (2012), absent the NSF/NCAR Gulfstream-V (GV) aircraft to study the high altitude outflow and downwind chemical evolution of the convective plume of the thunderstorms. This is mitigated, imperfectly, by tasking the DC-8 with the dual purpose of characterizing the convective storm inflow (low altitude boundary layer sampling, and column characterization) and in-situ sampling of the upper tropospheric outflow, a capability that was demonstrated successfully during the DC3 campaign. Contribution of the ER-2 is to characterize the physical, mostly radiative, properties of the clouds, mostly for the outflow given the lack of cloud radars on the ER-2 payload. In-situ sampling of the anvil region by the ER-2 seems highly unlikely from safety considerations. In-situ sampling of air injected into the stratosphere, after it advects away from the convective turrets, is possible, assuming that such injection commonly occurs on scales large enough to be located. Data from the NWS operational network of WSR-88D radars would be used to depict the physical and kinematic characteristics of the storm (appropriately skilled investigators must be added to accomplish this). Data from available lightning networks would be used as needed. If DC-8 sampling of PBL is unobstructed by overlying clouds, ER-2 could profitably focus on aerosol remote sensing objectives (cloud-free scenes) during this portion of a flight.

NWS radar network and available satellite observations, primarily GOES, would be used to for flight planning and to direct aircraft in real-time, and help guide sampling strategies.

The optimal region for these flights would be the southeast USA (Alabama-Georgia) where sampling during DC3 was the least successful in terms of storm opportunities and number of visits (only 2 visits to Alabama contrasted with 8 storms sampled in Colorado and 5 sampled in Oklahoma-Texas). Flights over central Oklahoma could also benefit from useful synergy with DoE ASR observations. The types of sampled storms could include air mass, multicell, and supercell convection. The latter require significant risk mitigation strategies for hazard avoidance where we would draw upon the lessons learned and experience of DC3 for this. Given our time window, a focus on air mass thunderstorms over the SE USA may be optimal. Convective pumping could also be an aspect of a hurricane-sampling mission in concert with HS3, though the scales and strategies may be different.

Goals: 1) Quantify and characterize the convective transport of fresh emissions and water to the upper troposphere within the first few hours of active convection via measurements in the inflow and outflow, investigating storm dynamics and physics (primarily via NWS radar observations), lightning (primarily via lightning network observations) and its production of nitrogen oxides, efficiency of convective transport as a function of species solubility and chemistry in the immediate anvil. 2) Quantify the changes in chemistry and composition in the upper troposphere after active convection, focusing on 12-48 hours after convection and the seasonal transition of UT chemical composition. These observations will improve current knowledge of convection and chemistry by providing a comprehensive suite of chemical measurements within the context of excellent kinematic, microphysical and electrical ground-based measurements. These measurements will provide the necessary information to estimate ozone sources and sinks in the upper troposphere where ozone is radiatively active as a greenhouse gas.

Deep Convective Clouds and Chemistry Experiment (DC3) – Schematic Overview



DC3 Sampling of an Air Mass Thunderstorm

Although the schematic shows three aircraft sampling inflow, near-field outflow, and downwind outflow, the NASA DC-8 aircraft engaged in all three roles during DC3. The DC-3 was employed in this diverse manner owing to its more complete in situ payload and remote sensing capability to aid in flight planning and column characterization. Ground-based radar networks were used to depict the physical and kinematic characteristics of the storm and provided input to the aircraft operations. The impact of lightning on outflow composition was constrained through detailed measurements from lightning mapping arrays. The forecasting and analysis was improved through other observations such as radiosondes (only routine NWS sondes for SEAC4RS).

Appendix G
Cirrus microphysics
Eric Jensen

Background

Measurements of cirrus microphysical properties are critical for quantifying cirrus impact on climate, improving and evaluating cirrus parameterizations in global models, and providing a priori information about crystal size distribution for remote-sensing retrievals. Until recently, measurements of ice cloud microphysical properties have been plagued by artifacts from ice crystal shattering on inlets and protruding instrument surfaces. As a result, the historical database of cirrus microphysical properties is highly suspect, particularly for quantifying total ice concentration and the contribution of small crystals to cirrus optical properties. Probes such as 2D-S, that are designed to prevent shattering artifacts, along with post-processing techniques to identify and remove the artifacts, have provided reliable measurements in recent years. The 2D-S probe was used to sample tropical and midlatitude cirrus in TC4 and MACPEX. However, the sampling of cirrus with reliable instruments to date is limited. Recent measurements of ice crystal residuals suggests that heterogeneous nucleation dominates the production of ice crystals in the upper troposphere, raising the possibility that anthropogenic influences on aerosol composition and loading may affect cirrus occurrence and/or radiative properties. Although, the SEAC4RS payload does not include a CVI that would permit analysis of residual composition, the payload does include numerous measurements of aerosol properties, which could be related to measured cirrus microphysical properties.

Science questions and measurement objectives

1. What are the size distributions and ice crystal habits in midlatitude/subtropical synoptic and anvil cirrus?
2. Are cirrus microphysical properties related to aerosol composition?
3. Generate a database of cirrus properties to be used for evaluating of climate models and for refinement of remote-sensing retrievals.

Sampling considerations

SEAC4RS offers the opportunity to sample midlatitude and subtropical cirrus microphysical properties with the SPEC instrument package. A key SEAC4RS objective involves measuring the composition of air detrained from deep convection; this objective meshes well with the goal of measuring the microphysical properties of anvil cirrus produced by deep convection. Synoptic cirrus systems could be sampled during transits to other targets or as segments of the DC-8 flights. Ample cirrus associated with the monsoon flow should be present in late August and early September.

A sampling pattern designed to measure outflow from deep convection should work well for anvil cirrus sampling. 15-20 min flight legs along the wind downstream of the convective source are desirable, but cross-wind legs would also provide valuable data. Ideally, the entire depth of the anvil would be sampled in a stair step pattern or a deep spiral. Multiple cases are desirable, preferably in different stages of cloud evolution. Flights into the Gulf (or as far south as possible) to sample tropical cirrus would also be desirable.

Appendix H
Aerosol absorption measurement intercomparisons anchored by AERONET observations in SEAC^{4}RS

Jens Redemann, Rich Ferrare, Jeff Reid

Motivation. SEAC^{4}RS is partly designed to benefit future missions recommended by the National Research Council (NRC) decadal study panel (NRC, 2007) by providing an important opportunity for defining the instruments, evaluating the measurement techniques, and developing and testing the retrieval algorithms under consideration for these future satellite missions. The set of polarimeters to be flown on the ER-2 in SEAC^{4}RS can provide important data sets for the evaluation and optimization of polarimeter instrument configurations for the ACE (Aerosol, Cloud, Ecosystems) mission in terms of channel selection, achievable measurement accuracy, and angular resolution and coverage of viewing geometries. Polarimetry holds a significant promise for the retrieval of spectral aerosol absorption (e.g., Cairns et al., 2009; Knobelspiesse et al., 2011), which is crucial for determining the direct and semi-direct aerosol radiative forcing of climate. Currently, climate and chemical transport models rely heavily on AERONET retrievals of aerosol absorption for the constraint of aerosol black and brown carbon concentrations, and their ensuing radiative effects (Bond et al., 2013). Analogously, satellite retrievals of aerosol absorption and single scattering albedo rely heavily on the same set of AERONET retrievals (e.g., Jethva and Torres, 2011) for testing. The AERONET retrievals, however, require a set of observational conditions, most notably a minimum aerosol optical depth (at 440nm) of 0.4 to obtain their highest quality (L2.0) data product. These observational requirements may conceivably restrict the available aerosol absorption retrievals to conditions that are not representative of global conditions.

The SEAC4RS payloads on the ER-2 and DC-8 could provide important aerosol, chemical, and radiation measurements to test the representativeness of the AERONET absorption retrievals and to compare the different techniques for measuring and retrieving aerosol absorption. Specifically, the following aerosol absorption measurements/retrievals could be intercompared:

A. ER-2 polarimeter retrievals (aided by CPL lidar profile measurements),
B. AERONET ground based sky radiance retrievals,
C. DC-8 in situ measurements,
D. DC-8 remote sensing methods (inference of aerosol absorption from combined irradiance and AOD measurements, 4STAR retrievals).

Hence, a conceivable set of science questions includes:

1) Polarimeters: How well do measurements and retrievals of aerosol absorption from diverse techniques compare? Does the agreement/disagreement depend on viewing geometry and surface albedo for remote sensors (polarimeters, AERONET, 4STAR, SSFR), and aerosol type or other factors (all techniques)?
2) AERONET: How representative are AERONET L2.0 retrievals (requiring AOD_{440nm}>0.4) of spectral aerosol absorption and single scattering albedo for aerosol conditions at lower aerosol loadings? Is there a significant difference between the agreement of AERONET L2.0 retrievals and L1.5 retrievals with the other methods of determining aerosol absorption? Is there a different dependence of aerosol single scattering albedo on total aerosol loading for

different aerosol types? Is the spatial variability of certain aerosol types after transport to specific AERONET sites more conducive to the sky radiance retrievals?

Measurement logistics: Timing and location. To address the question of where to deploy the SEAC^{4}RS platforms in the August-September 2013 time period, we carried out an analysis of all available historical data for AERONET level 2 (L2) retrievals. Figures 1 and 2 show the probability density functions (PDF) for AERONET-derived aerosol absorption optical depth (AAOD) at 441nm for the month of August and September, respectively. Note the difference in the y-scales. The text inside each pdf plot indicates the number of successful L2 aerosol absorption retrieval (N-Absp), the number of successful L2 retrievals without absorption retrievals (N-Ext, essentially L2 retrievals that did not meet the AOD>0.4 requirement for a successful AAOD retrieval), the number of months on record from distinct stations (N-station-months), the number of distinct stations (N-stations), and the average number of successful absorption retrievals per month and station in that grid box (#Abs). For the month of August, the quadrant containing Washington, DC shows the highest number of successful L2 absorption retrievals (8.7), followed by the quadrants containing Florida (7.4) and New York (6.3). For the month of September, there are historically about 60% fewer successful L2 retrievals in the study region (partly due to intensive field deployments, e.g., DRAGON-DC in August 2011). The largest number of successful L2 September retrievals per station and month (see Figure 2) is still in the DC area, with three quadrants showing about equal success rates of ~2.5 retrievals per month and station: Florida, New York , and the quadrant containing the US Mid-West. From this analysis, the best chance for overflying an AERONET site with successful L2 absorption retrievals is in the DC area, and the US SouthEast, with the timing favoring an earlier deployment in the August-September time frame. If the focus of a deployment would be lower single scattering albedos (see Figures 3 and 4), the quadrant centered on Texas appears to provide the retrievals with ssa between 0.9 and 0.95 most frequently. Finally, an important site for testing the AERONET L1.5 retrievals would be La Parguera (Puerto Rico), where there are a lot of successful sky radiance measurements in August and September, but their low AOD prevents their designation as L2.

Measurement logistics: Observational strategies. There are different observational strategies required for the science questions regarding the polarimeter absorption retrievals from those required for the AERONET intercomparisons. The easiest in terms of flight clearance are the ER-2 over-flights of AERONET stations. These will have to be timed in such a way that the AERONET almucantar scans cover the widest possible range of scattering angles, hence early-morning or late-afternoon over-flights will be desired. The DC-8 flight patterns will depend heavily on air traffic control restrictions. Air traffic control aside, the in situ measurements will require straight and level legs inside the heart of the aerosol layers, while the remote sensing instruments would prefer to be situated inside or below, and above the main aerosol layers. If some of the AERONET station locations can still be chosen, we would like to target a range of surface albedos, including dark vegetation, crop fields, and bright surfaces, such as vegetation. To help constrain the impact of surface albedo, flights over the dark ocean for targets of opportunity (i.e., significant dust transport from the Sahara, significant pollution transport off the US East Coast) would also be desired, in which the 4STAR instrument will serve as a mobile AERONET station.

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Figures.

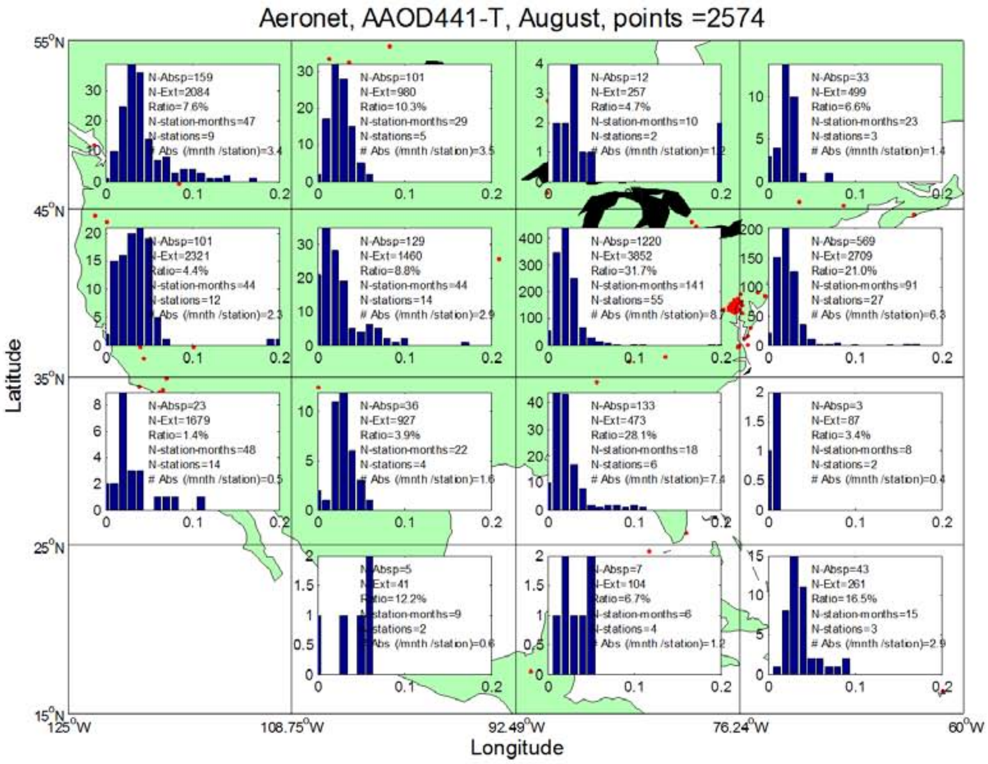


Figure 1. PDFs of AERONET L2 aerosol absorption retrievals for the month of August from all years and stations available.

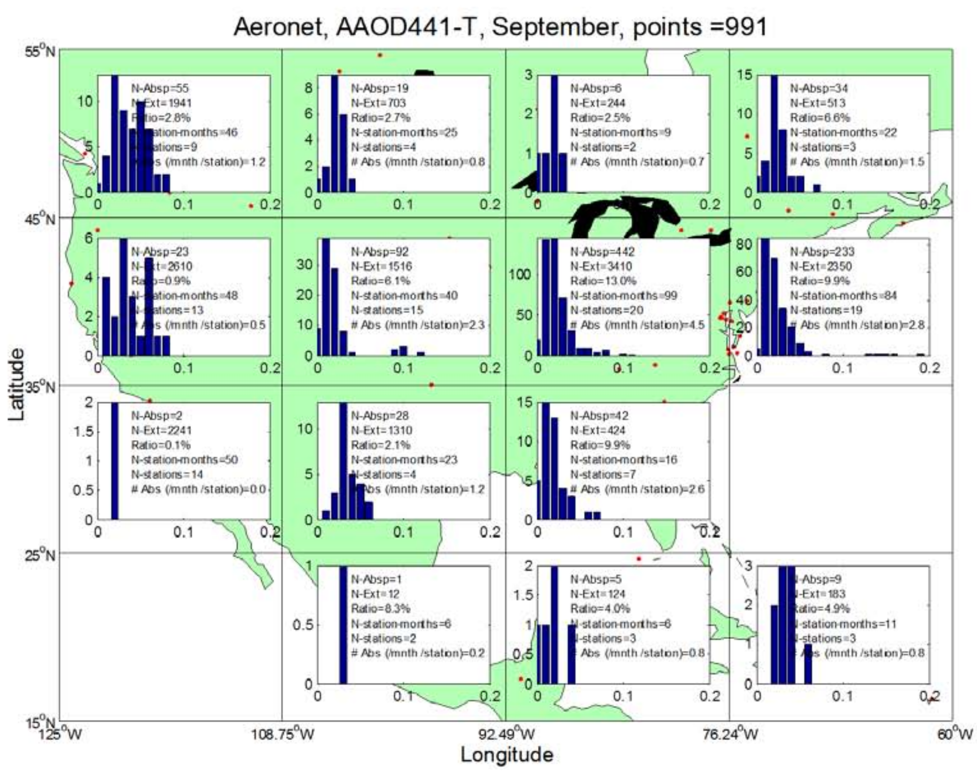


Figure 2. Same as Figure 1, but for the month of September.

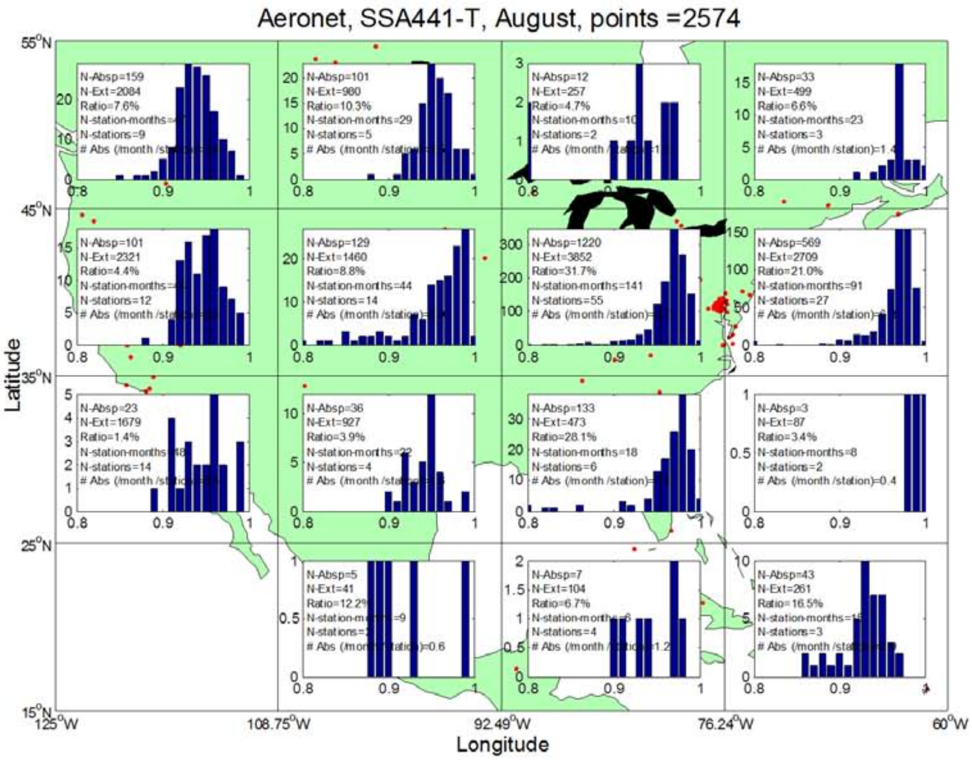


Figure 3. Same as Figure 1, but for the aerosol single scattering albedo at 441nm.

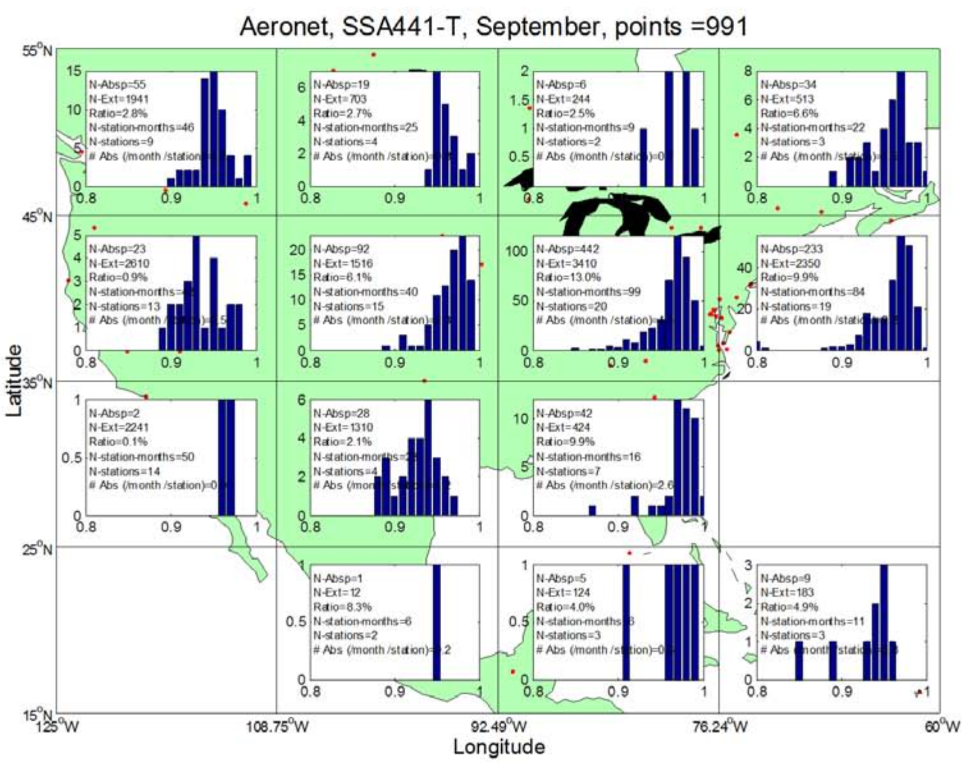


Figure 4. Same as Figure 2, but for the aerosol single scattering albedo at 441nm.

This is a request to measure several profiles of CO_2, CH_4, N_2O, CO, and H_2O over the 5 US Total Carbon Column Observing Network (TCCON) stations during the SEAC^{4}RS campaign. These stations are located in Park Falls, WI, the Southern Great Plains (SGP) facility near Ponca City, OK, Four Corners, NM, Pasadena (Los Angeles), CA, and Dryden, CA (see Figure 1 and Table 1).

1 Rationale

Each TCCON facility contains a solar-viewing Fourier transform spectrometer that measures spectra of the direct sun. We retrieve total column abundances of greenhouse and other trace gases in the atmosphere from their absorption signatures in the solar signal. Our main focus is on CO_2, CH_4, N_2O, CO, and H_2O. We rely on spectroscopic databases that describe the absorption signatures to produce total column abundances of the trace gases from our spectra. Due to uncertainties in the spectroscopy, we need to calibrate our data against WMO-standard instrumentation. Aircraft profiles over the TCCON stations have been essential in performing this calibration.

There are (at least) two spurious features in the column abundances retrieved from TCCON spectra that are caused by spectroscopic uncertainties: one is an overall bias, and the second is a solar zenith angle-dependent bias. While we believe we have a reasonable handle on the overall bias from our previous aircraft profile comparisons, the solar zenith angle-dependent bias is still under investigation. It would be very helpful to have a series of profiles over each TCCON station at a variety of solar zenith angles to determine the solar zenith angle-dependent bias of each site. We therefore request several profiles over each TCCON station, including one at local noon, and one about an hour before sunset. The ideal experiment for us would be to have profiles of all the target gases every few hours over a single site on a day with clear skies, from about an hour after sunrise to about an hour before sunset.

2 Requirements

In the past, the aircraft have either performed spirals over the site of interest, or missed approaches at nearby municipal airports (e.g., the Ponca City municipal airport). We do not have a preference, but since we measure the total column abundances, profiles of as much of the atmosphere as possible (by mass) are critical. That is, from as close to the ground as possible, to as high as possible – preferably reaching above the tropopause altitude. From our perspective, this can be done at as fast as you wish.

We would like to calibrate CO_2, CH_4, N_2O, and CO, and to compute dry-air column abundances for all these gases, measurements of the H_2O profile are also necessary. Also, as our instruments are solar-viewing, we can only record spectra when it is sunny: high cirrus cloud is not a problem, but we cannot measure under cloudy conditions, nor at night.

To summarize, the critical requirements are:

- Measured species: CO_2, CH_4, N_2O, CO, H_2O
- Meteorological measurements: temperature, pressure and altitude
- Altitude range: from below 1000 ft to 40,000 ft (or as high as possible - preferably above the tropopause) for each profile
- Measurement frequency: variable times of day including one profile near local noon, and one an hour or two before sunset
- Weather: daytime clear skies (some light high cloud is okay)

3 References

For further information about TCCON, please feel free to visit our wiki: `https://tccon-wiki.caltech.edu`. Other information can be found in the following paper, and references therein:

Wunch, D., G. C. Toon, J.-F. L. Blavier, R. A. Washenfelder, J. Notholt, B. J. Connor, D. W. T. Griffith, V. Sherlock, and P. O. Wennberg (2011), The total carbon column observing network, Philosophical Transactions of the Royal Society - Series A: Mathematical, Physical and Engineering Sciences, 369(1943), 2087-2112, doi:10.1098/rsta.2010.0240. Available from: `http://rsta.royalsocietypublishing.org/content/369/1943/2087.abstract`.

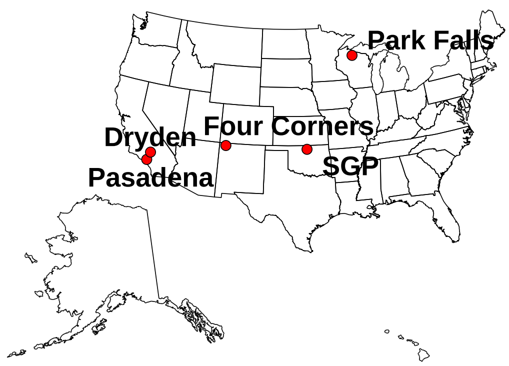


Figure 1: Locations of the TCCON stations in the US.

Site Name	Latitude (°N)	Longitude (°W)
Park Falls, WI	45.945	90.273
SGP, OK	36.604	97.486
Pasadena, CA	34.13623	118.126897
Dryden, CA	34.95	117.83
Four Corners, NM	36.728	108.218

Table 1: The site locations for the 5 TCCON stations in the US.

Potential for measurement of varying aerosol optical properties in support of remote sensing based aerosol research in a Southeast CONUS campaign.

A consideration for the deployment of the DC-8 and ER-2 within CONUS in August-September 2013 is their ability to advance remote sensing technology and science. A SEAC^{4}RS-like mission should support the pre-ACE polarimeters such as AirMSPI and RSP. This would also provide an opportunity for Soumi-NPP (particularly VIIRS) verification, allow the Collection 6 MODIS 3 km aerosol product to be well exercised, and test MISR Local Mode acquisitions to support 4.4 km aerosol retrievals as was done during PODEX and DISCOVER-AQ. The HSRL on the DC-8 and the CPL on the ER-2 will also provide excellent value in situ, as well as when combined with ER-2 polarimeter data.

The typical remote sensing components of aerosol microphysics, land surface/lower boundary conditions, and cloud masking are also considerations in evaluating remote sensing systems. Preferably, one chooses regions or events that provide natural partial derivatives of each of these components against the others, along with a network of in situ monitoring stations for measurement validation. In this respect, deployment of the research aircraft to Warner Robins, Georgia, may prove to be a good compromise location for providing remote sensors an opportunity to perform important science while providing much needed data to develop the next generation of algorithms. The late summer/fall transition period selected for this campaign should provide valuable natural variability in vegetation and atmospheric properties.

From an aerosol microphysics point of view, the Southeastern CONUS (hence SECONUS) has a moderate regional Aerosol Optical Thickness (AOT) ranging from ~0.3-0.4 to 0.15-0.25 from August into September. As discussed in the associated whitepaper on SECONUS atmospheric chemistry (Jacobs et al.), this is likely due to high biogenic emissions such as isoprene accelerating secondary particle production. We might expect aerosol chemistry to also vary north to south, with Houston, TX being well in range from Warner Robins (this is the same distance to Salina, KS). As biogenic emissions fall off in September, so does AOT. At the same time, the region is drying, resulting in less aerosol hygroscopicity and likely a higher real index of refraction, the sensitivity to which is an important scientific test for polarimetric retrieval algorithms. Also, as the region dries, agricultural waste burning of rice, cotton, sugarcane and other crops begins to pick up, providing smoke as a second species for study. Burning can be quite significant in the Mississippi river valley, creating a haze that often transports across the SECONUS. The ability of multiangle, polarimetric, and UV-based techniques for determining the heights of these transported plumes can then tested with comparisons against coincident CPL and HSRL observations. If transported early enough, this haze will also react with biogenic emissions, perhaps resulting in further secondary particle production. In Louisiana, Alabama and Georgia, prescribed burning is more isolated, leading to well defined Gaussian plumes with near constant burning conditions and gradients of AOTs from thin to semi-infinite, providing yet another good target type from remote sensing science. Great Smoky Mountain National Park, on the border of North Carolina and Tennessee, is 290 km from Warner Robins, and has been an

IMPROVE monitoring site since 1988, providing an opportunity for follow up to the Southeastern Aerosol and Visibility Study (SEAVS) conducted in 1995 and now the 2013 Southeast Photo-Oxidant Study (SOAS). To our knowledge neither SEAVS nor SOAS had a remote sensing component. As shown in the supplemental figures, the Southeastern US provides a good network of in situ particulate matter measurement stations, providing opportunities test methodologies for estimating ground-based PM from total column retrievals of AOT.

The mosaic land surface over the SECONUS also provides an opportunity to collect much needed data to improve retrievals. Often, agricultural land is intermixed with forest, resulting in a patchwork of different land surface types. Fallow field, varying agriculture, forest, urban and even small lakes and irrigation ponds provide a changing surface, yet the atmospheric optics remain the same, providing a second natural partial derivative of aerosol particles versus land surface in retrievals. We expect to take advantage of this for both pollution/haze and for smoky conditions. And, as there is regional drying in SECONUS from August into September, there is also a decrease in precipitation and the start into fall foliage in the far north, but still within range of the aircraft. This may provide additional opportunities to disentangle atmospheric and land surface properties in remote sensing data.

Regional drying during the seasonal transition may also result in a decrease in cloudiness. Periods of very clear air as well as scattered cumulus along clear air mass boundaries are common. Much science discourse is devoted to the properties and radiative effects of aerosol particles in the vicinity of clouds. With the expected DC8 and ER-2 payload, we will be able to explore cloud adjacency effects both radiatively and microphysically. We will also be in a position to evaluate clear sky biases between clear and partially cloudy conditions.

The basing of aircraft out of SECONUS could also make the research aircraft available for measurement well out into the subtropical Atlantic. There, dust is not uncommon, with dust AOTs typically in the 0.15-0.2 range in August, with peaks up to 0.3. With the base location providing the possibility of flights to explore tropical cyclones and their outflow, the ER2 may be able to scan in very high wind conditions or significant wave height or moderately high coarse mode sea salt load (AOT>0.1) conditions. On the outside of hurricanes, the DC-8 may be able to infer sea salt AOT using the onboard HSRL lidar – a particularly pressing problem for remote sensing systems.

While a SECONUS deployment could provide a much needed dataset to advance remote sensors' technology, these sensors will provide much needed information on aerosol processes, particularly in regard to boundary layer processing. The DC-8 package will be perhaps the world's most complete for studying the optical and physical properties of nearly all aerosol species that exist in CONUS in a consistent fashion (anthropogenic sulfate/organics, smoke, dust, sea salt). But, while the DC-8 in situ complement will certainly be the basis of answering many science questions, extrapolation to regional or climate scales can only be done with the help of remote sensing technology. Combined lidar/polarimeter data, along with surface network data, can be used in joint retrievals to examine variability in aerosol features vertically as well as horizontally. Convective boundary layer chemical processing, likely leading to differences in aerosol optical and microphysical properties above, within, and below the fair weather cumulus region, can also be measured. Understanding the importance of these layers in a climate context will require convolving 2-D passive remote sensing through the aid of the third dimension provided by lidar measurements, which are sparse or non-existent from ground-based sensors in this region. Gradients in aerosol concentration relative to clouds can provide much needed information on aerosol indirect and semi-direct effects.

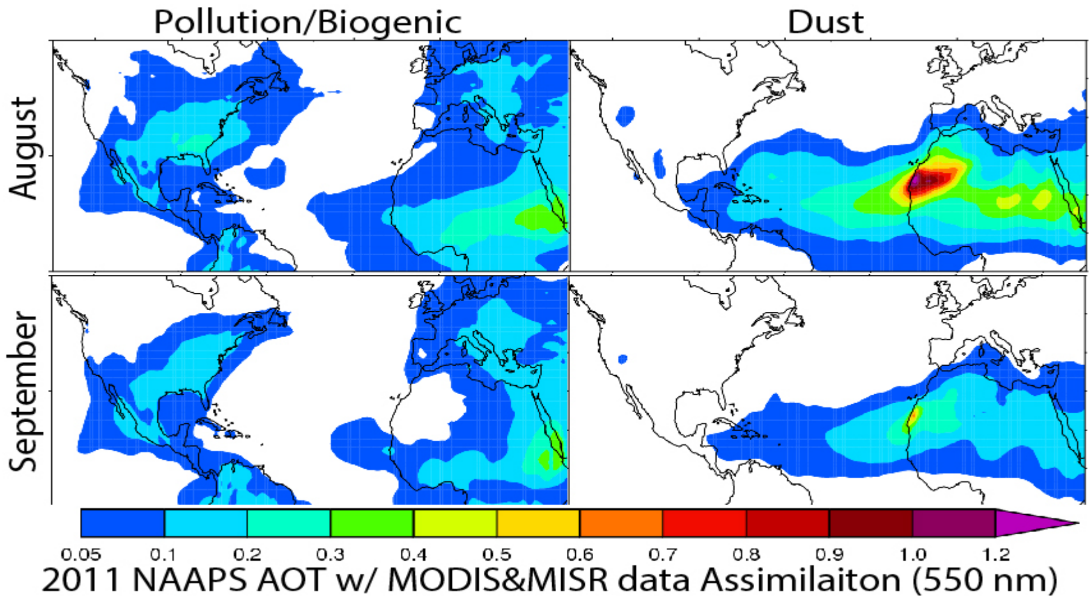
Science Goals

1) Develop a consistent data set of aerosol physical, chemical and optical properties, including those related to aerosol extinction, scattering, absorption, phase function/lidar ratio, and hygroscopicity as function of chemistry.
2) Is there a substantial change in aerosol optical properties as air masses are advected across the SE biogenic source?
3) Does chemical processing in the convective boundary layer result in substantial differences in optical properties for haze layers or biomass burning smoke in the lower boundary layer, the convective boundary layer, and plumes aloft?
4) Understand the variability in aerosol hygroscopicity, mass extinction/absorption efficiencies and single scattering albedo in aging smoke plumes.
5) Is there a maximum sea salt AOT that can be found in high wind regions and how does that relate to boundary layer dynamics?
6) Can we constrain dust size parameters thought observation of the “roll off point” in the near IR extinction when dust ceases to be spectrally flat?
7) Can we constrain aerosol refractive indices of dusty aerosol mixtures from polarimetric measurements?
8) What are air-quality impacts of varying aerosol properties in anthropogenically-influenced environments?
9) Can gradients in aerosol concentration relative to cloud scans provide much needed information on aerosol indirect and semi-direct effects, including cloud adjacency effects?

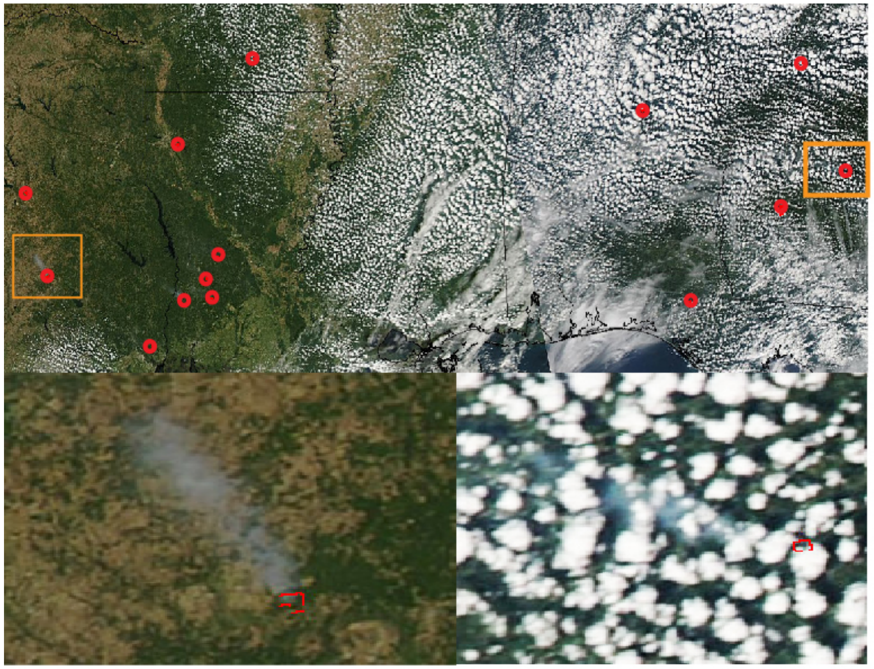
Engineering Goals.

1) Provide polarimeter sensors and lidars a variety of aerosol environments (haze, smoke, dust, sea salt) to develop their algorithms.
2) Provide data in mosaic land surface scenes such that the influence of lower boundary condition can be separated from aerosol microphysics.

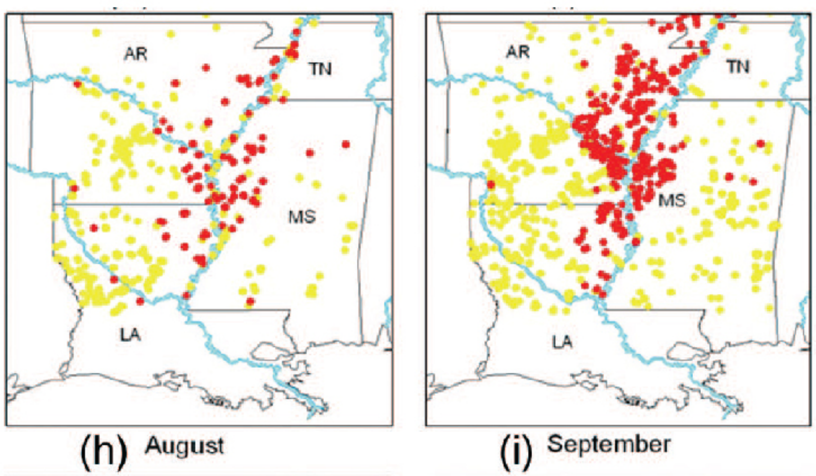
3) Evaluate lidar behavior in partially cloudy boundary layer scenes.



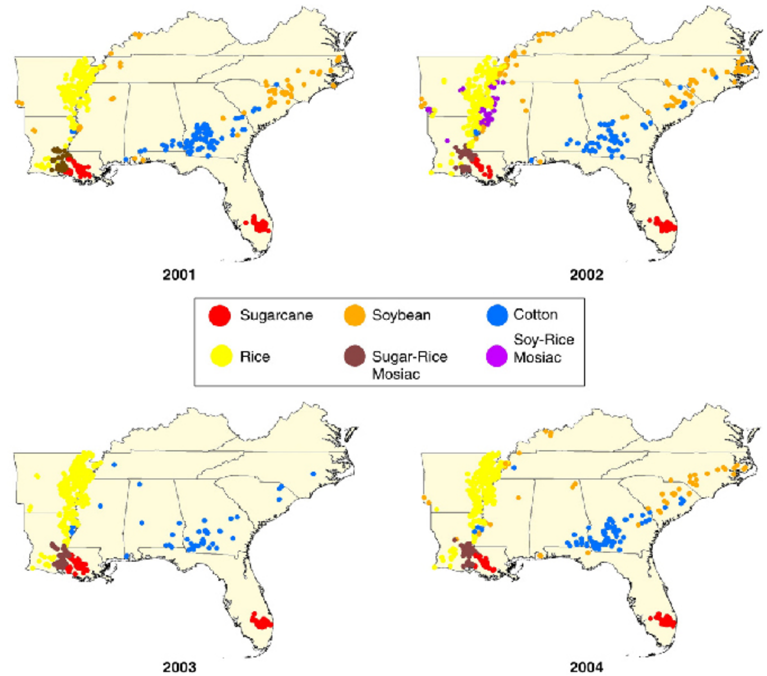
NAAPS Average AOT fields for the Pollution/Biogenic and dust components for the months of August and September. Simulations include data assimilation from the MODIS and MISR instruments.



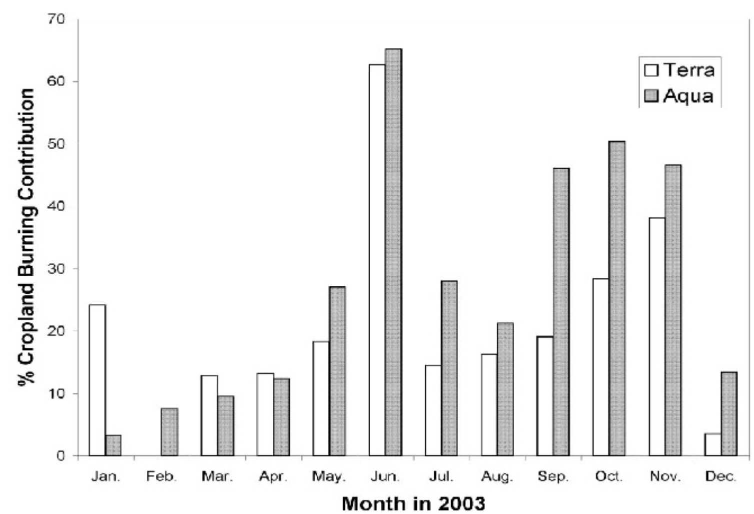
RGB image of MODIS plus fire detects on Sept 11, 2012 from east Texas through Georgia which shows a cloud/aimass change. and mosaic nature of land surface Fires in clear and cloud y areas are highlighted. This is a low fire day.



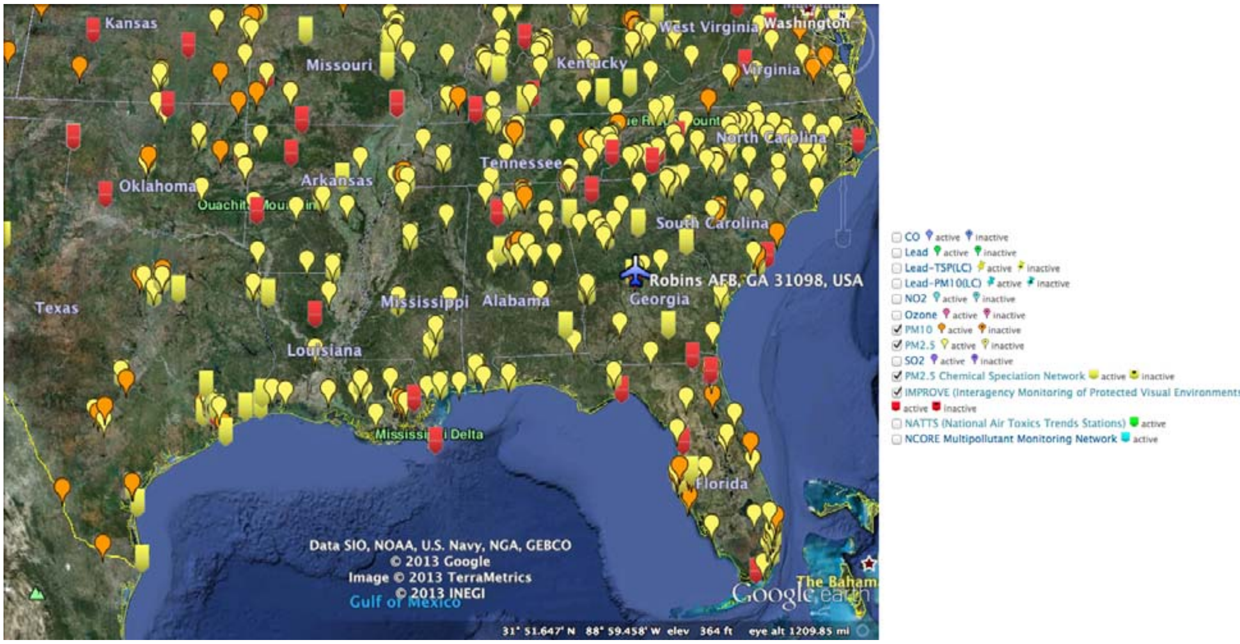
Korontzi et al., 2008, Figure 2. Spatial distribution of cropland and non-cropland fires detected by MODIS Terra and Aqua in the study region in 2003. (a–l) Monthly spatial distribution.
Red: Crop fires; Yellow Other fires.



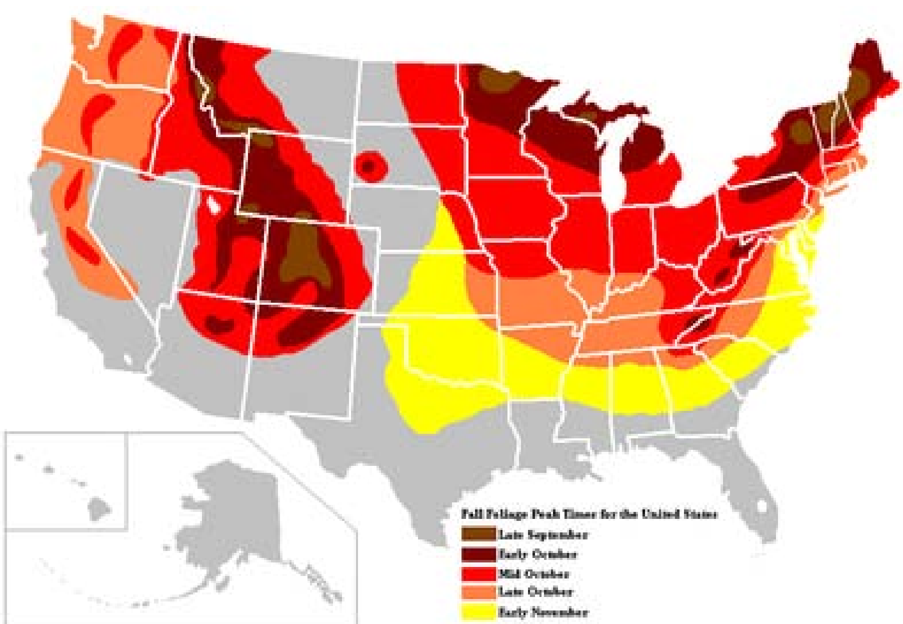
McCarty 2006 Figure 2. Spatial distribution of cropland and non-cropland fires detected by MODIS Terra and Aqua in the study region in 2003. (a–l) Monthly spatial distribution.



Mccarty Korontzi e tal., 2008 annual fire activity in the study region in 2003.



Location of active particulate matter (PM10, PM2.5) monitoring sites, IMPROVE site, and EPA speciation networks sites. Robins AFB is marked with the aircraft symbol.



Peak times for fall foliage in US. Peak time for Georgia is not until mid- to late-October in the northern part of the state.

Appendix K
Salina weather hazards – potential weather scrubs for the ER-2

An analysis of potential flight scrub days for the ER-2 based on *hourly* surface observations at Salina Kansas from August 10-October 7 (inclusive – 2003-2012) was performed. Salina has a main runway of 12kft pointing north-south. It also has an 8500 foot cross runway pointing 132-312.

"Constant" assumptions:

- Max crosswind of 15 knots (use gust reports to define wind)
- Max total wind of 30 knots (use gust reports to define wind)
- Minimum ceiling of 500 feet
- Minimum visibility of .5 miles
- No thunderstorms allowed

Variable assumptions:

- Availability or non-availability of the cross runway for the ER-2.
- Sensitivity to precipitation in the absence of T-storms. We consider a scrubbable event to be a rain observation during a 6 hour period of > .1 inches of rainfall. An alternate assumption is no sensitivity to precip in the absence of T-storms.
- On a flyable day, weather must be good 7-10 AM (TO) and 3-6 PM (LNDNG). That is, we have 6 observations (3 hourly in the morning and 3 hourly in the afternoon). ONE "bad" one will scrub the day. An alternate assumption is that we have some option for waiting and that only *one* of the three hours in the morning *and one* of the three hours in the afternoon/evening need to have good weather. Thus, two out of six "good" observations, properly placed, will make the day flyable.

Results are tabulated below. "Basic" applies to the most restrictive assumption concerning flyability (3rd variable assumption above). "Liberal" applies to the situation where we have some option for waiting. There are 59 total days during the examined period.

Description	Mean scrub days	Standard Deviation
Basic, cross	10.0	3.7
Basic, no cross	11.9	3.7
Basic, cross, no precip	9.0	3.9
Basic, no cross, no precip	10.9	3.7
Liberal, cross	1.6	2.0
Liberal, no cross	2.2	1.8
Liberal, cross, no precip	.8	1.0
Liberal, no cross, no precip	1.4	1.1

The difference between the basic and liberal operational assumptions illustrates the difficulty of translating weather statistics into actual operational experience. I would argue that the basic assumption is definitely too restrictive (requiring 3 hours continuous good weather at both landing and takeoff). Actual experience should be closer to (but not at) the "liberal" assumption. Not shown is the relative importance of the different hazards. Wind is the most important (even with the cross runway in operation), followed by precip and thunderstorms. (So, NOT using the gusts in the hourly reports will lower the number of scrubs also). I admit, sadly, that this approach alone is not giving us the definitive answer we want for Salina ER-2 flyability using the "bankers hours" we would like to operate under. If necessary, I can examine the diurnal variation, but an alternative is suggested below.

These sorts of statistics might be viewed as a quantity that requires some absolute calibration. That is, we run the statistics for a period when we *know* the ER-2 operated successfully (or did not operate successfully) and compare. That period was April 9 through May 15, 1996 (SUCCESS – by definition(!) we had successful ER-2 operations). The results for this period are listed below.

Description	scrub days
Basic, cross	12.0
Basic, no cross	16.0
Basic, cross, no precip	12.0
Basic, no cross, no precip	16.0
Liberal, cross	2.0
Liberal, no cross	6.0
Liberal, cross, no precip	2.0
Liberal, no cross, no precip	6.0

Winds are the more dominant factor during the April-May period, which is consistent with the overall climatology of a higher incidence of high wind days in

Spring as opposed to Fall. Also, the number of scrub days is higher for all the statistics than during the fall. Thus, the simple conclusion is that, if we operated successfully in Spring 1996, we should be able to operate successfully this fall.

Appendix L
Water vapor profiling for SEAC4RS-North America, Aug-Sep 2013

Rennie Selkirk, Anne Thompson, and Mark Schoeberl
3 April 2013

Project title: Balloon sonde profiling of water vapor and ozone for SEAC4RS

Water vapor and the North American monsoon: Associated with the North American monsoon circulation is a pool of relatively moist air in the TTL centered over the American subtropics (see Figure 1 below). While located in the same latitude band as a similar feature associated with the Asian monsoon, this pool of moist air (indicated by the arrow in the figure) is actually more pronounced in the North American monsoon and extends over a broader range of latitudes. It is also centered to the north of the primary zone of convective activity during this season (see Fig. 1 in Laura Pan's writeup). However, moist low-level flow from both the Gulf of Mexico and from the subtropical Pacific can fire off deep convection over land throughout the monsoon region. (See the schematic in Fig. 2 of Laura Pan's writeup.) This deep convection may play a role in the TTL water budget as suggested in *Randel, et al.* [2012].

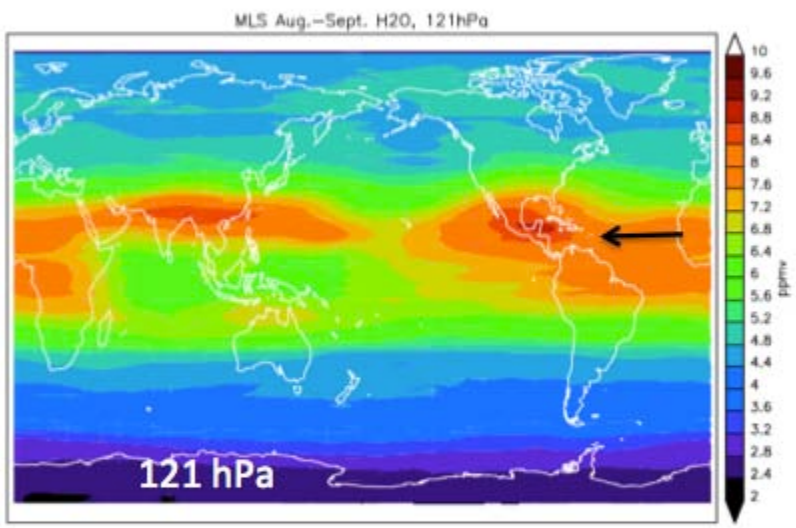


Fig. 1: 5-year average of water vapor from MLS at 121 hPa for the months of August and September (courtesy Mark Schoeberl.)

This short proposal for SEAC4RS-North America (SEAC4RS-NA) is addressed at understanding the causes for the moistening of the TTL during the North American monsoon. *Schoeberl et al.* [submitted to ACP, 2013] have shown that the large-scale vertical circulation associated with regions of tropical deep convection can account for much of the zonal and seasonal variations of UT/LS water vapor in the tropics. However, it remains an open question where within these regions rising air is dehydrated to the levels observed entering the stratosphere. One possibility is wave-driven dehydration over deep convection. *Selkirk et al.* [JGR, 2010], for example, have shown that there is very regular variability in the winds and temperature at 10°N in Costa Rica which lies within the ITCZ, the convective southern flank of the North American monsoon. From there air flows into the anti-cyclonic large-scale monsoonal circulation, and it would appear from the MLS fields, this air is moistened. Along the northern flank of the circulation - over northern Mexico and the southern United States – the water vapor content of the air will have been modified by processes within the monsoon as a whole, and these will change the character of the UT/LS water vapor in this area as compared to Costa Rica.

High-resolution balloon sonde profiles of water and ozone, properly situated relative to the North American monsoon, could be used to assess the roles of the two process above: (a) wave-driven dehydration of air flowing into the monsoon circulation and (b) the moistening processes within the monsoonal UT/LS proper. High-resolution data would also be used to characterize the vertical structure obscured by the satellite measurements and more accurately assess its temporal variability.

Figure 2 from *Schoeberl et al.* [submitted to ACP, 2013] suggests the monsoonal anticyclone can entrain quite different types of air, dusty air from Africa and air from China. Costa Rica can sample air moving into the south side of the High, while sondes from Houston or Dryden can sample the north side.

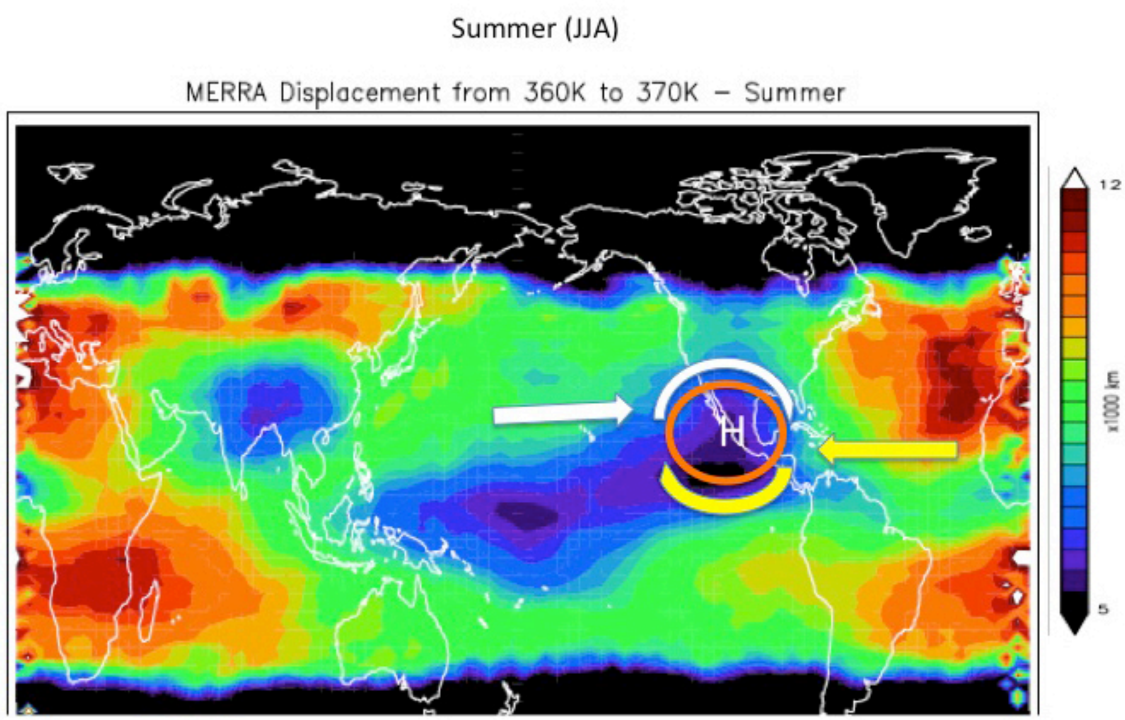


Fig. 2: The upper level high over the American monsoon is shown with the trajectory displacement field form *Schoeberl et al*. [2013, ACP].

A **proposal for water vapor measurements in SEAC4RS-NA:**

Originally we had proposed to characterize the coupled vertical structure and temporal variability of water vapor and ozone in the convectively active Southeast Asian environment late in the summer monsoon. Twenty CFH/ECC payloads were to be launched at the primary SEAC4RS site in partnership with Anne Thompson's SEACIONS project, and last spring we purchased those sondes and associated equipment before the missions was cancelled.

For SEAC4RS-NA we propose a program of 20 CFH/ECC soundings over the SEAC4RS mission period in August and September at each of two locations sampling the southern and northern flanks of the North American monsoon. For the former there is the Ticosonde site at the University of Costa Rica in San José, Costa Rica [10°N, 84°W], and for the latter two of of the SEACIONS-NA sites recently proposed by Anne Thompson would be appropriate: Table Mountain and Houston. At Houston there is the great advantage of integrating the water vapor sondes into the continuation of a daily ozone sonde program for DISCOVER-AQ that Anne Thompson and Gary Morris are supporting. The advantage of Table Mountain is that it would potentially provide inter-comparison opportunities with the ER-2. However, it may be too far upstream and too far north to provide a good sampling of the North American monsoonal outflow.

Ground sites for a NASA airborne mission in August-September 2013

The proposed flight operations for the SEAC4RS could take the DC-8 and ER-2 aircraft anywhere in the continental US, and out into the Caribbean. Single flights can cover >5000 km. With such an operations area, wide spatial range, near real time data are required to plan missions and direct flights when underway. At the same time, the representativeness of data collected by the aircraft is a concern. The primary ground system for monitoring Aerosol Optical thickness (AOT) is the NASA Aerosol Robotic Network (AERONET), a network of Cimel sun photometers. Spectral AOTs are usually available within an hour of collection at most sites. Inversions of size, phase function, index of refraction and single scattering albedo are also generated hourly, with suggested use for AOT(440 nm)>0.4. A map of current operational AERONET stations is presented in Figure 1.

The largest cluster of sites is in the Southwest United States, split into a southern California/southern Nevada region, as well as a line following the Rocky Mountains down into New Mexico. A second cluster of sites is in the Pacific Northwest and southwestern Canada. Both of these groups of sites are well suited to capture smoke from western biomass burning, and thereby support that component of the mission. Isolated AERONET sites dot the Great Plains, increasing in prevalence into the industrial Northeast United States. A number of sites also stretch well into the Atlantic and Caribbean. The largest gap in conus AERONET coverage is in the Southeast Unites States. AERONET has only three sites in the Gulf coast states, with large empty spaces up to three sites at the boundary of the Northeast United States. Historically, this has always been the case with the AERONET network. Occasional temporary sites have operated in this region, but not in long term or organized regional networks.

In support of SEAC4RS, an additional 10 AERONET sites will be deployed across the Southeast United States to give the first coherent regional ground network of sun photometer data. There is the potential for an additional five sites, depending on maintenance schedules and availability. A first draft of suggested sites is presented in Figure 2. Final site selection will be based on a combination of science quality and site sustainability. Included on the figure are currently supported NASA lidar sites, as well as proposed bases of operations. The current AERONET deployment plan should fill the much needed holes between these lidars. Mission investigators are also currently exploring locations to aid in AERONET retrieval verification. Projections as to proper locations for such work are currently underway.

If possible, AERONET instruments will be deployed to sites with additional aerosol or air chemistry data. Currently the ground team is taking an inventory of air quality resources in the region with a particular emphasis on potential supersites. For example, the SOAS program expects to deploy 13 flux towers to the region. These may prove to be good sites for AERONET deployment as well.

There are numerous collateral sites which can be of use to the mission. The EPA Air Now (http://airnow.gov/); and Air Now Tech (http://www.airnowtech.org/) can provide near real time data at hundreds of regional air quality sites across CONUS, including PM2.5, PM10, and ozone. PM10/PM2.5 data collocated with near real time satellite AOT can also be found in association with the IDEA project (http://www.star.nesdis.noaa.gov/smcd/spb/aq/index.php). After the mission, IMPROVE network aerosol composition data (Figure 3 for locations) can be incorporated into the mission dataset (http://vista.cira.colostate.edu/improve/). Other state and local datasets can be found on the same website

Figure 1. Map of 2012 AERONET sun photometers expected to carry over through 2013.

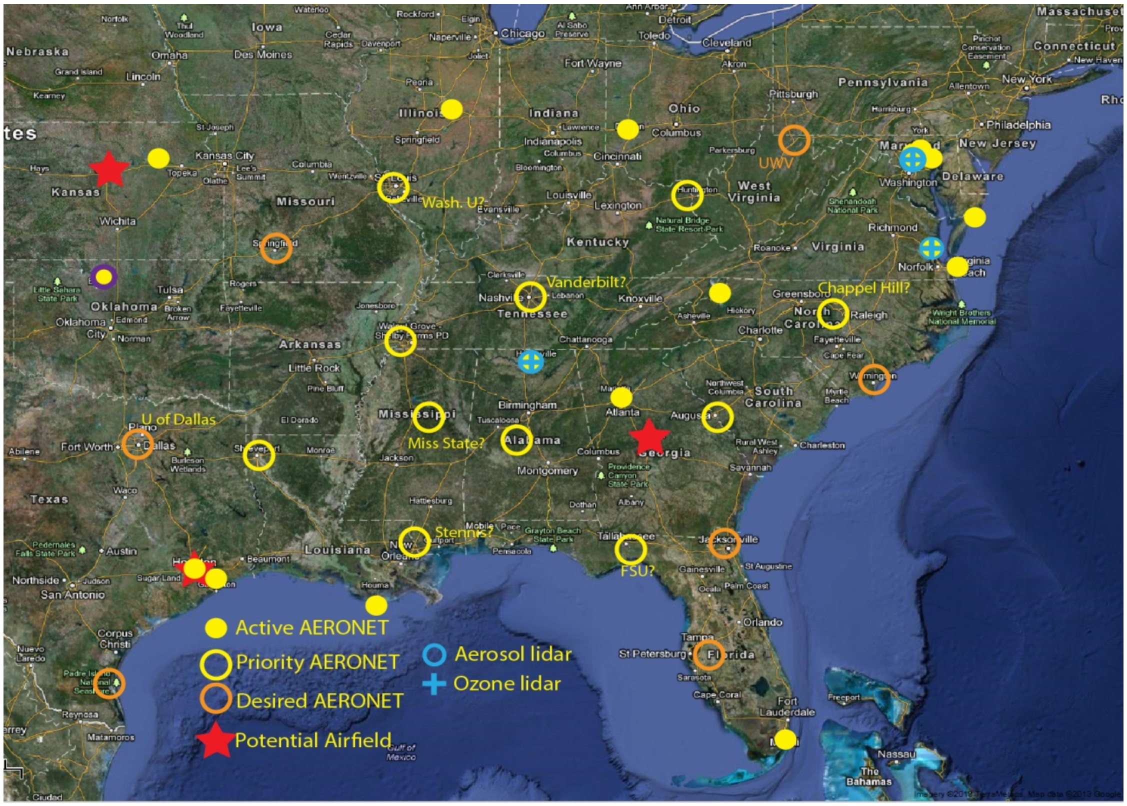


Figure 2. Proposed AERONET expansion for summer 2013 to support the mission formally known as SEAC4RS. Included on this map are existing NASA supported lidar sites as well as potential airbases for flight operations.

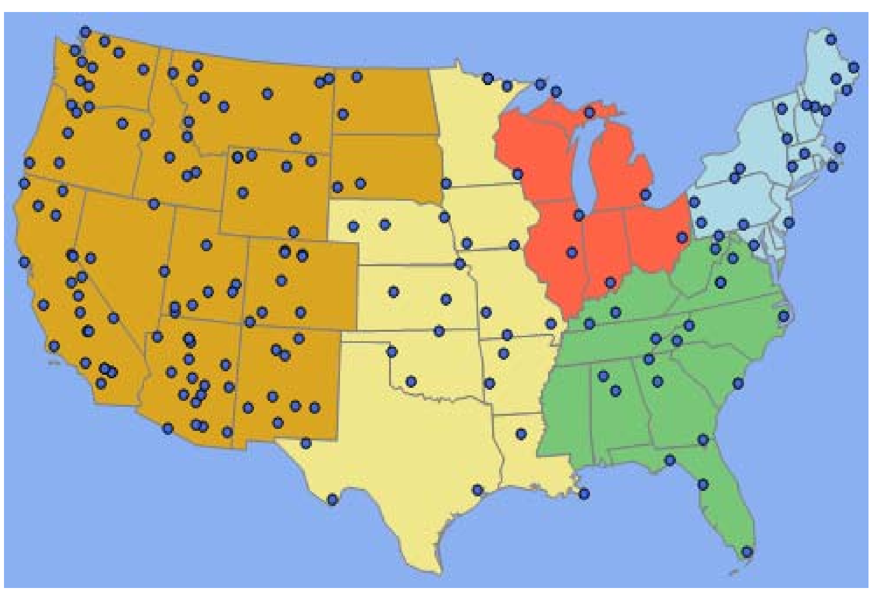


Figure 3. IMROVE aerosol chemistry network sites for post mission analysis.