# Quantifying "convective influence" on Asian Monsoon UTLS composition using Lagrangian trajectories and Aura MLS observations

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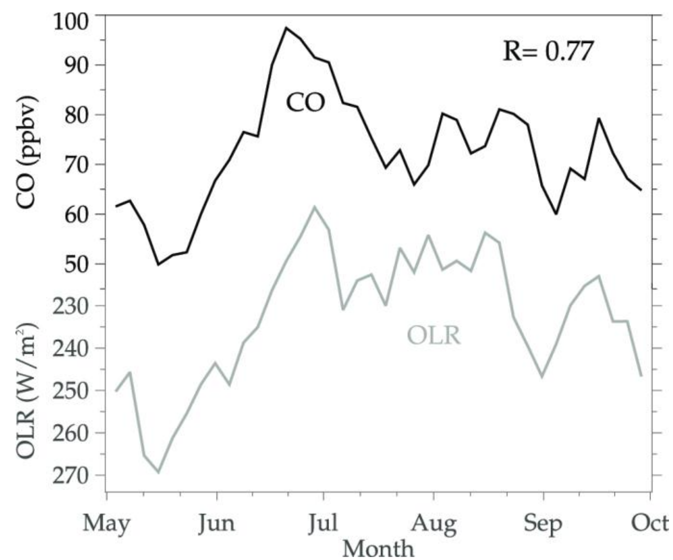
# Background – importance of convection

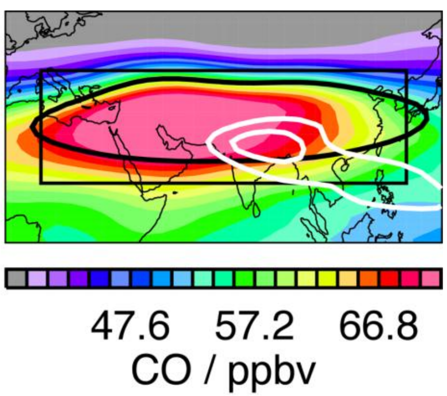


Rapid transport by deep convection is clearly one of the dominant processes affecting the composition of the UTLS in the Asian monsoon region

MLS 100 hPa CO compared to OLR over the Asian Monsoon region in 2005. [*Park et al.*, 2007]




The relationship between convection and composition is clearly complex and has been subject to extensive study




July average (2005–2014) MLS 390 K CO (colors) compared to MLS hPa Ice Water Content (IWC). [*Santee et al.*, in prep.]

Given:

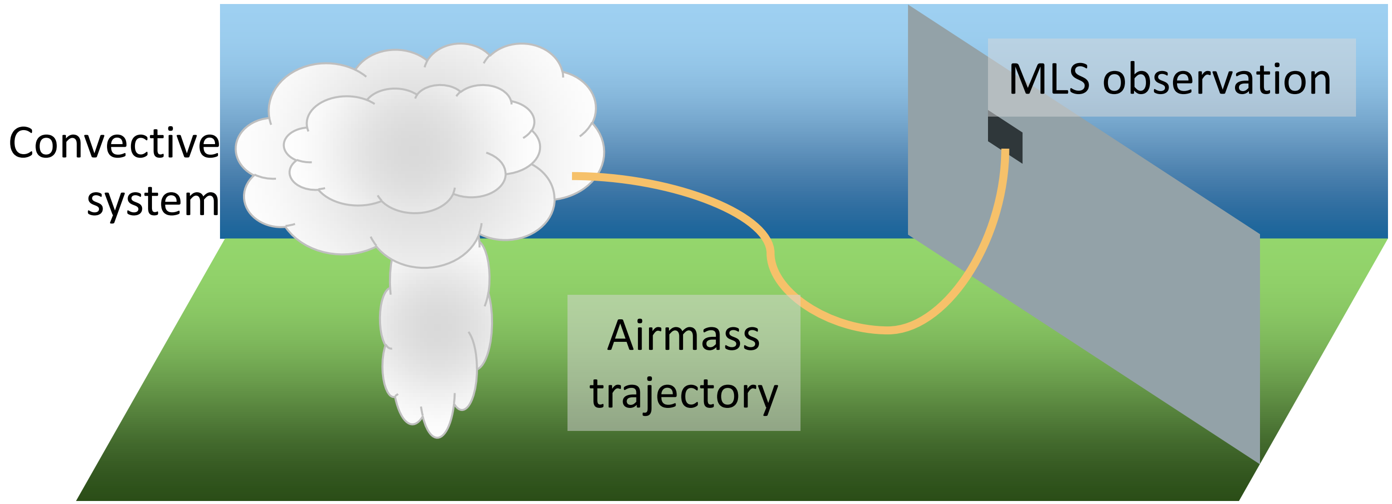
1. Anticipated rapid changes in Asian surface emissions, and
2. The evolution of convection and the monsoon in a changing climate

understanding of these processes is clearly needed for accurate prediction of UTLS composition and thence future climate forcing and air quality

# A “measurement-based” study approach



- Many studies have successfully used models of various forms to understand the impact of convection on composition
- Here, we describe preliminary efforts to develop and employ a more measurement-focused approach to study of convection/composition relationships, particularly in the Asian Monsoon region, but also beyond
- To this end, we have constructed an MLS “Convective Influence Diagnostic” (CID)
- This involves:
  - Launching a set of Lagrangian trajectories from MLS observation locations
  - Advecting these parcels backwards in time and identifying where and when the observed airmasses most recently encountered deep convection



# Outline of talk

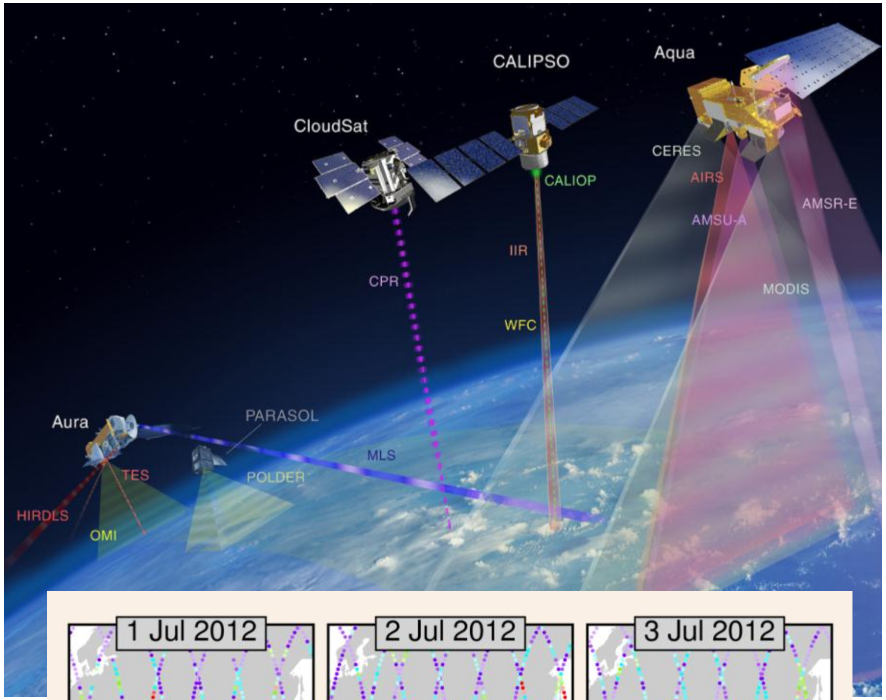


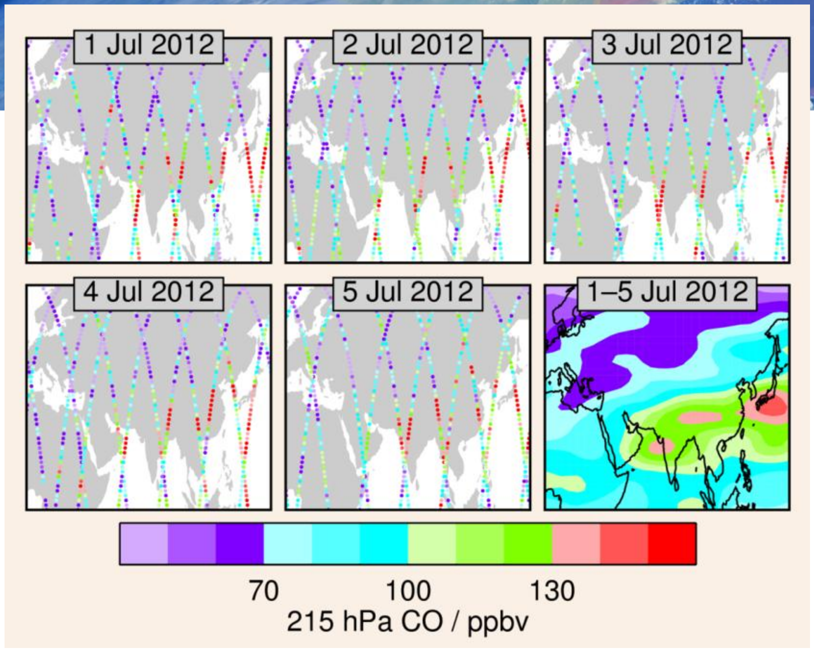
- Brief reminder of key aspects of the MLS observations
- Previous convective influence approaches
- The MLS Convective Influence Diagnostics:
  - Lagrangian Trajectory Diagnostics
  - Quantifying convective cloud top altitude / potential temperature
  - Accounting for the finite MLS resolution
- A global summary of convective influence
- Regional relationships between convective influence and composition
- Source regions within the Asian Monsoon
- Interpretations of the Convective Influence Diagnostic
- Summary and future work

# Brief reminder of the key aspects of MLS



- MLS is one of four instruments launched on Aura in 2004
- MLS makes ~3500 vertical scans (from ~0 – 90 km) of the atmosphere each day
- The long (~1 mm) wavelength MLS observations are unaffected by aerosols and all but the thickest clouds (e.g., those found in deep convective cores)
- Although the limb path through the atmosphere is long (100s of km), the MLS data analysis ("Level 2") algorithms apply a "tomographic" approach, enabling along-track resolution as good as 200 km
    - The across track resolution is set by the MLS beam width (typically 5 – 10 km)
- Averaging of some of the "noisier" MLS observations (e.g., UTLS CO, $O_3$) improves the signal to noise



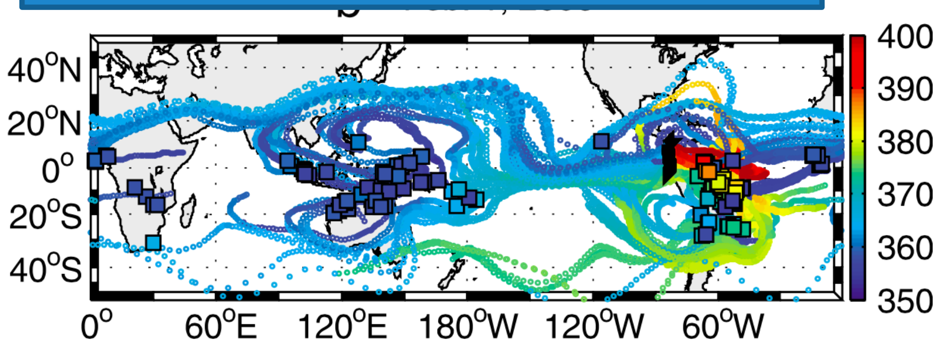



# Previous convective influence approaches

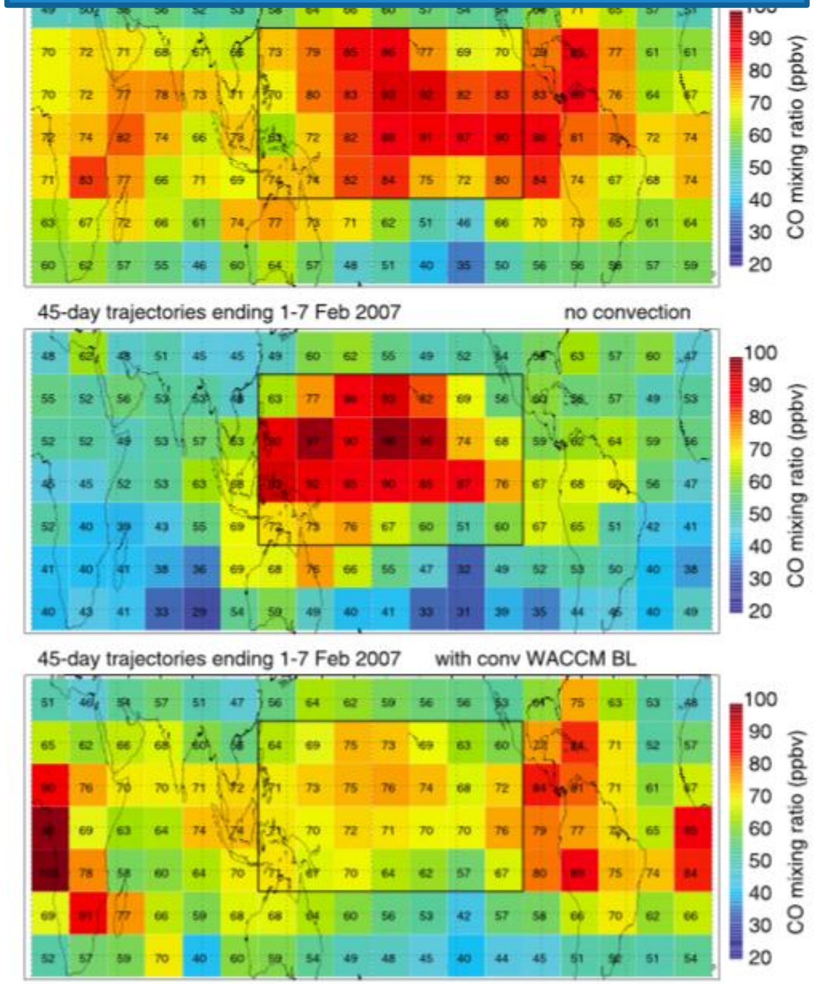


- The convective influence approach was initially developed and applied to aircraft observations by Lenny Pfister
- Examples of its use include studies of the convective impact on the TTL using WB-57 observations of $H_2O$ and δD (below)
- It also has been used as part of Lagrangian models of UTLS composition, in conjunction with surface abundance estimates (right)

Back trajectories (colored lines) from the WB-57 observation locations (shown in black). Convective encounters are shown by black squares. [*Sayers et al.*, 2010]



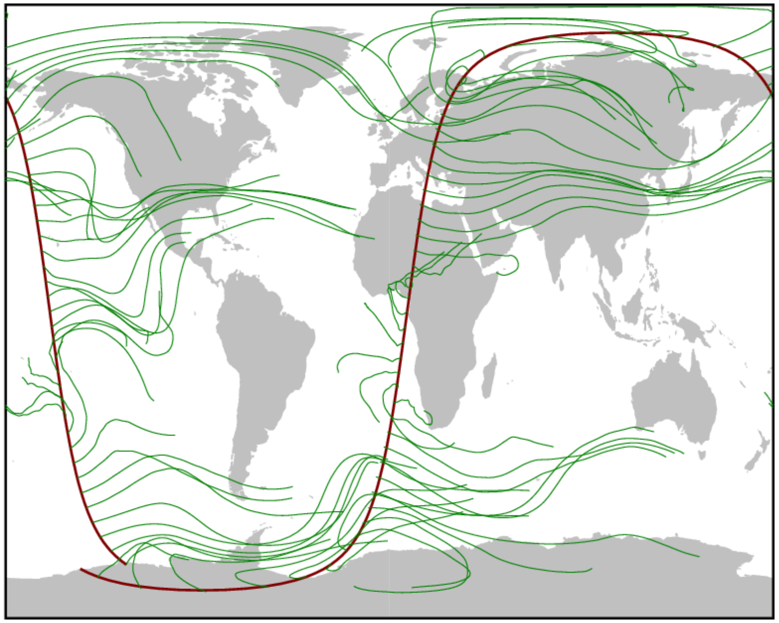

100 hPa CO measured by MLS (top) and modeled assuming slow ascent only (middle) and assuming both ascent and convective lofting. [*Jensen et al.*, 2015]



# The MLS Lagrangian Trajectory Diagnostics



- The MLS "Lagrangian Trajectory Diagnostics" (LTDs) are a relatively new support product for MLS observations
- These are a set of trajectory calculations run forward and backwards 15 days from the location of each MLS observation in the record
  - Currently available for 2004 – 2013 observations using GEOS-5.2 meteorology
  - These are diabatic trajectories using the GEOS-5.2 heating rates, with parcel locations saved every two hours
  - New version, using MERRA-2, will be released shortly, covering entire mission
- In related work, the LTDs have been used in "Match" studies (cases where an airmass is observed by MLS on multiple occasions) to quantify polar ozone loss
  - Livesey et al., ACP, 2015
- For this study, we use a customized set of (MERRA-2-based) LTDs:
  - Reverse trajectories only, parcel locations noted every 30 minutes
  - Use radiative rather than full heating rates



# Obtaining convective cloud-top height information



- To identify where these parcels are influenced by convection, we need a near-continuous global record of convective cloud top potential temperature
  - Analysis fields lack needed accuracy
  - Geostationary imagery reports a lot of anvil cloud in addition to the deep convective cores
  - CloudSat/Calipso/AIRS/MODIS lack needed near-continuous global coverage
- Our approach involves the following steps:
  - Focus on convective cores by considering only regions where TRMM-based 3-hourly precipitation exceed a specified threshold
  - Search for the minimum infrared brightness temperature within a specified radius of these precipitating regions
  - Compute cloud top altitude / potential temperature using analyses (ERA-Interim), including a "mixing" scheme to reflect localized convective cooling
  - Increase altitudes by 1 km, based on earlier validation studies of similar infrared cloud-top-height products
- Comparisons to CloudSat/CALIPSO show good agreement on cloud top altitude (global average well within 1 km in the tropical UTLS)

# Complication – the finite resolution of MLS



- Aircraft in situ instruments make what can, in most studies, be regarded as "point measurements"
- MLS, by contrast, measures the weighted average composition over a volume of air
- This volume is quantified by the MLS "Averaging Kernel"

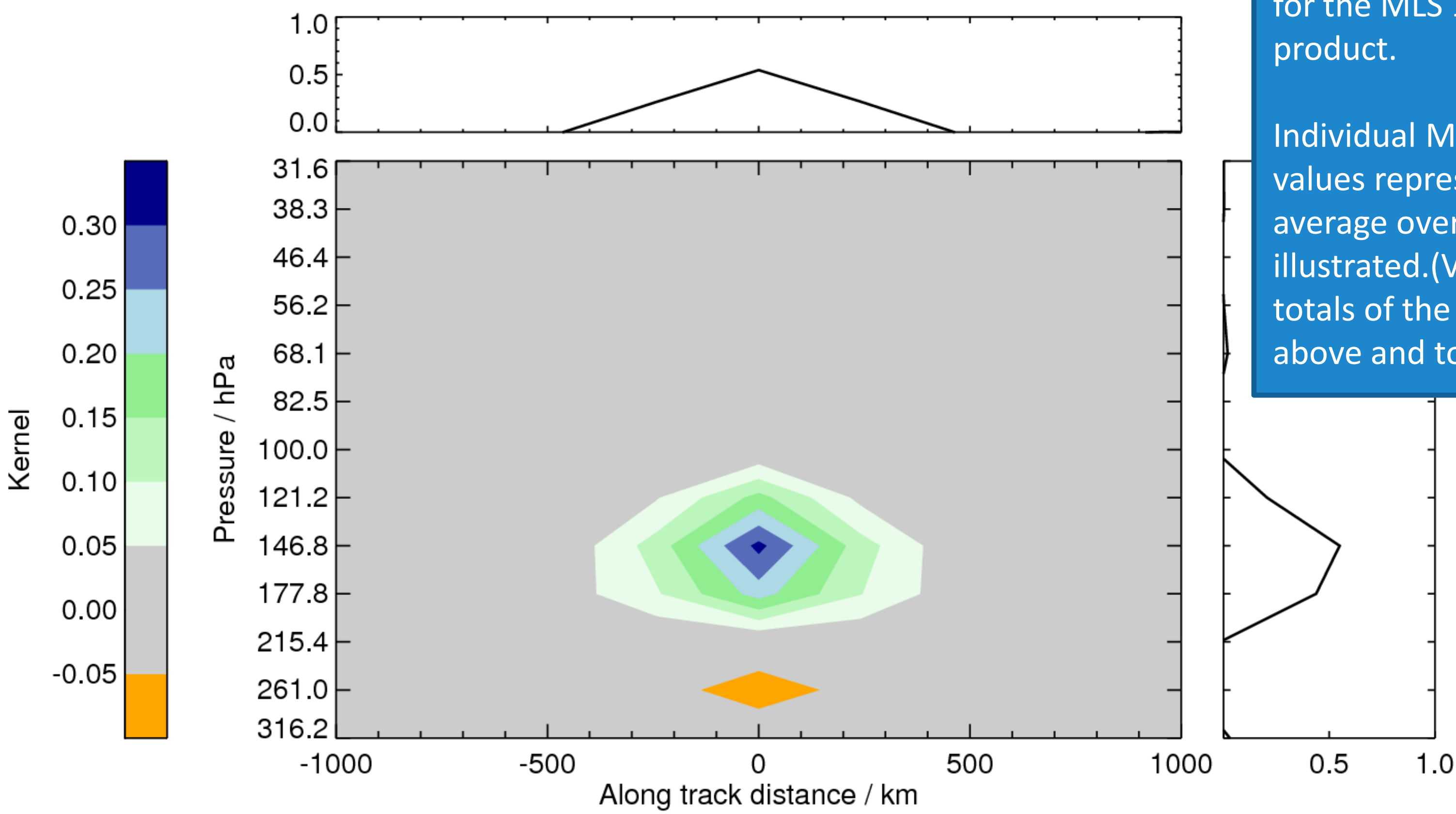



Illustration of the averaging kernel for the MLS 146 hPa ozone product.

Individual MLS 146 hPa ozone values represent a weighted average over the volume illustrated.(Vertical and horizontal totals of the kernel are shown above and to the right

# MLS convective influence approach

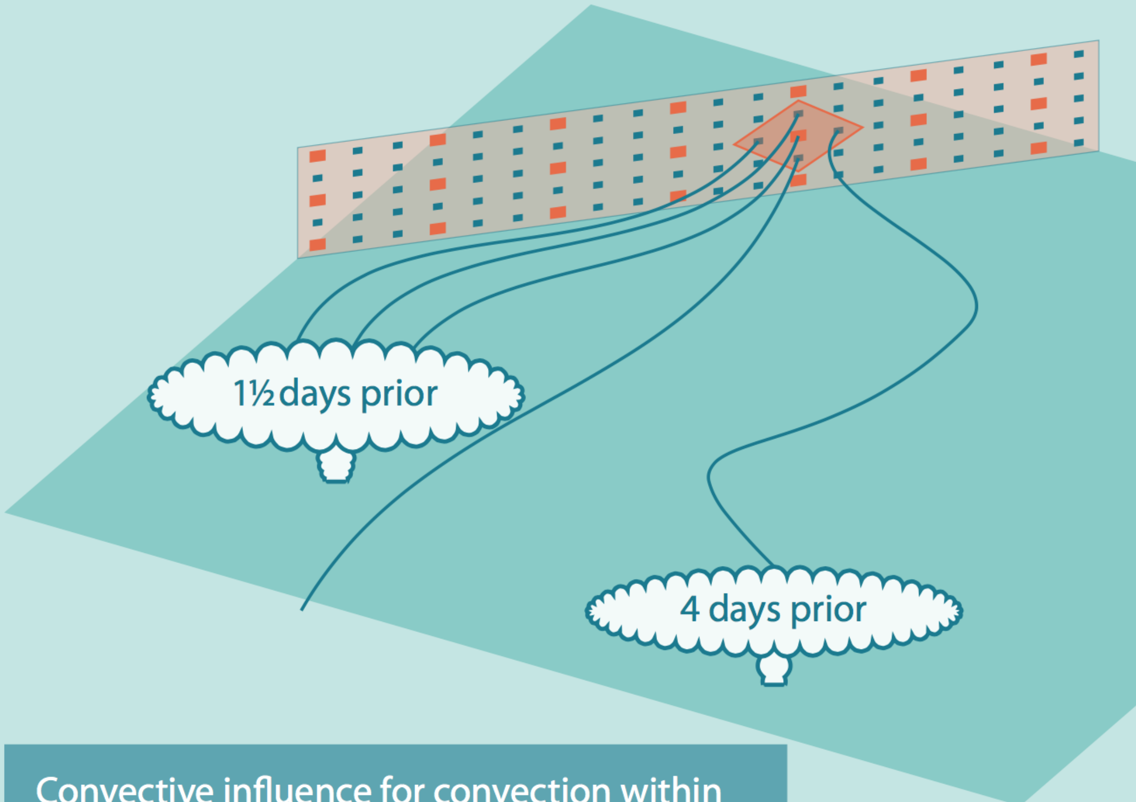


- To account for the finite resolution, we launch a dense curtain of parcels along the MLS measurement path
  - Launches every ~50 km along the track (MLS measurement spacing is ~150 km)
  - Vertical grid of 24 levels per decade change in pressure (MLS species output at 12 or 6)
  - Also have two "flanking" sets of trajectories 5 km either side of the track
- We trace all of these parcels back to convection (up to 15 days prior)
- We record the time, location and cloud top potential temperature of the most recent encounter for each parcel, along with the parcel's potential temperature at the time
- We model the averaging kernel as 2-D "pyramid functions" and use these to collect (weighted) lists of all the relevant convective encounters for each MLS measurement
- To reduce complexity here, we use the same 3 km high, 300 km along-track function for all our analysis (ultimately will tune by species/product, but has little impact on results shown)

| Pressure | Water vapor | Ozone | Carbon monoxide |
|---|---|---|---|
| 100 hPa | 3 x 200 km | 3 x 300 km | 5 x 450 km |
| 215 hPa | 1.5 x 200 km | 3.5 x 350 km | 5 x 700 km |

# MLS convective influence approach, illustration






- Orange points are MLS measurement locations
- Trajectories are launched from these and from the intervening blue points
- The large diamond shows an example averaging kernel (narrow, for simplicity)
- This kernel reports a weight of 0.4 for the center orange point and 0.15 for each of the four surrounding blue points

Convective influence for convection within

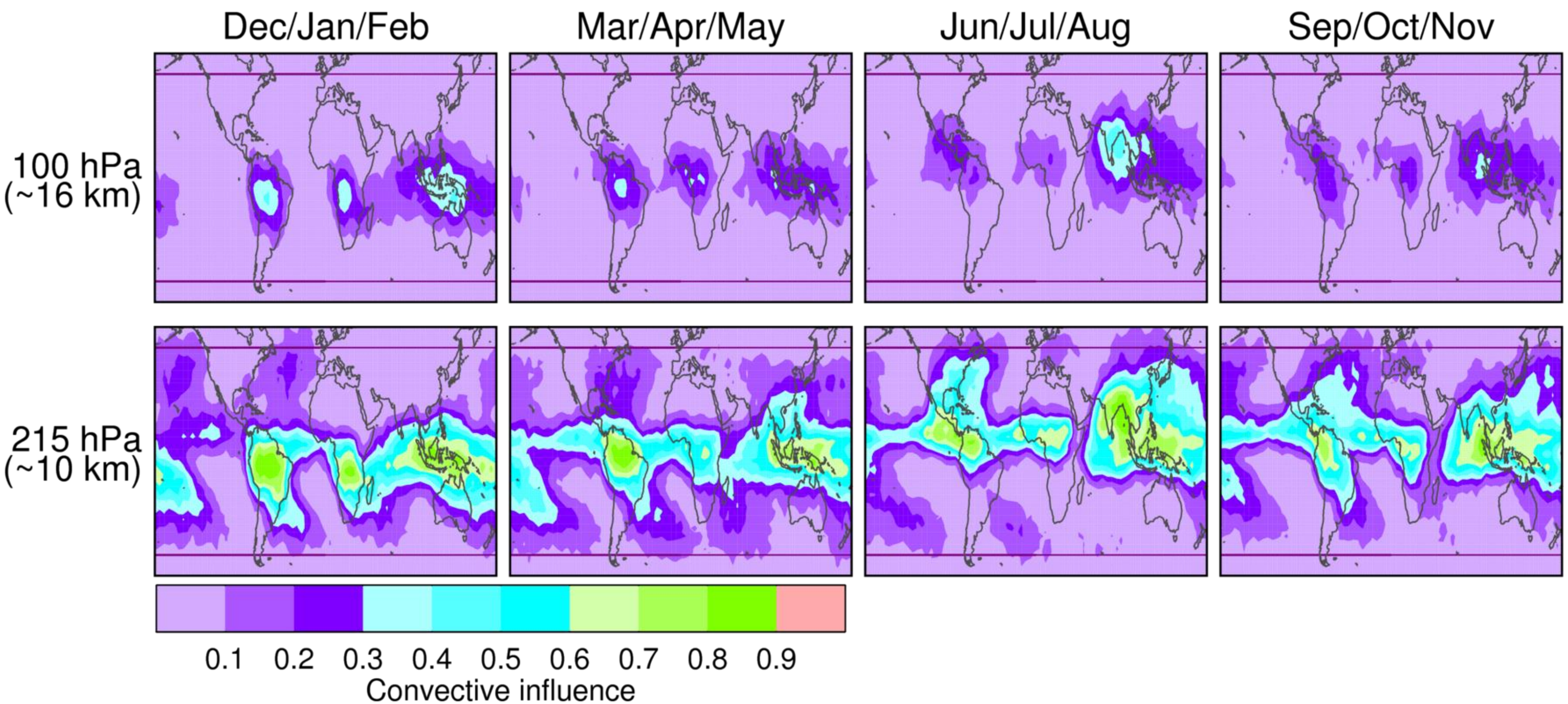
Two days: 0.7 $(= 0.4 + 2 \times 0.15)$

Five days: 0.85 $(= 0.4 + 3 \times 0.15)$

# MLS convective influence climatology (24 hours)



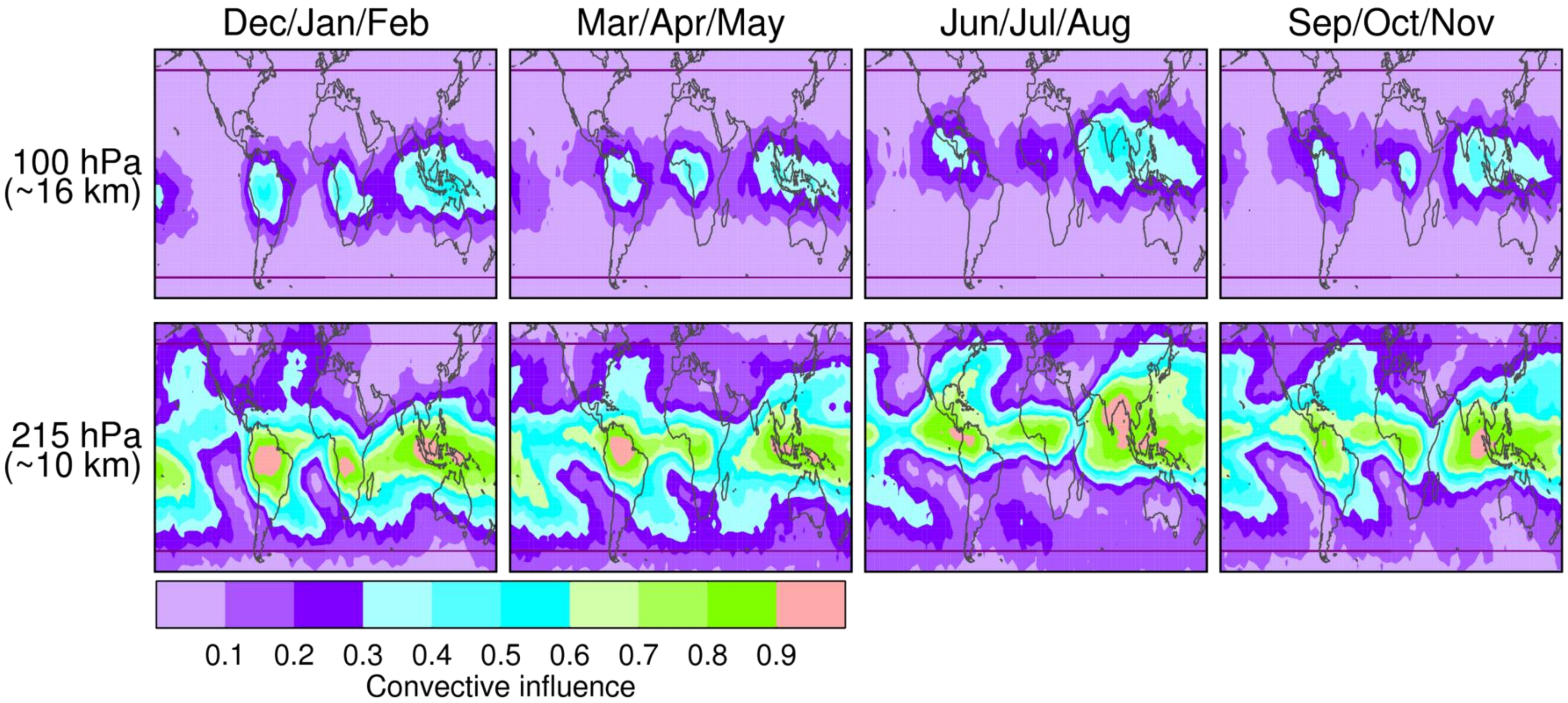
- The maps that follow show seasonal climatology (2007–2012) of convective influence
  - using a 1.5 km-high, 300 km-wide kernel (results for broader kernels are similar)
- This set are for convective influence within <u>24 hours prior</u> to the observation



# MLS convective influence climatology (48 hours)



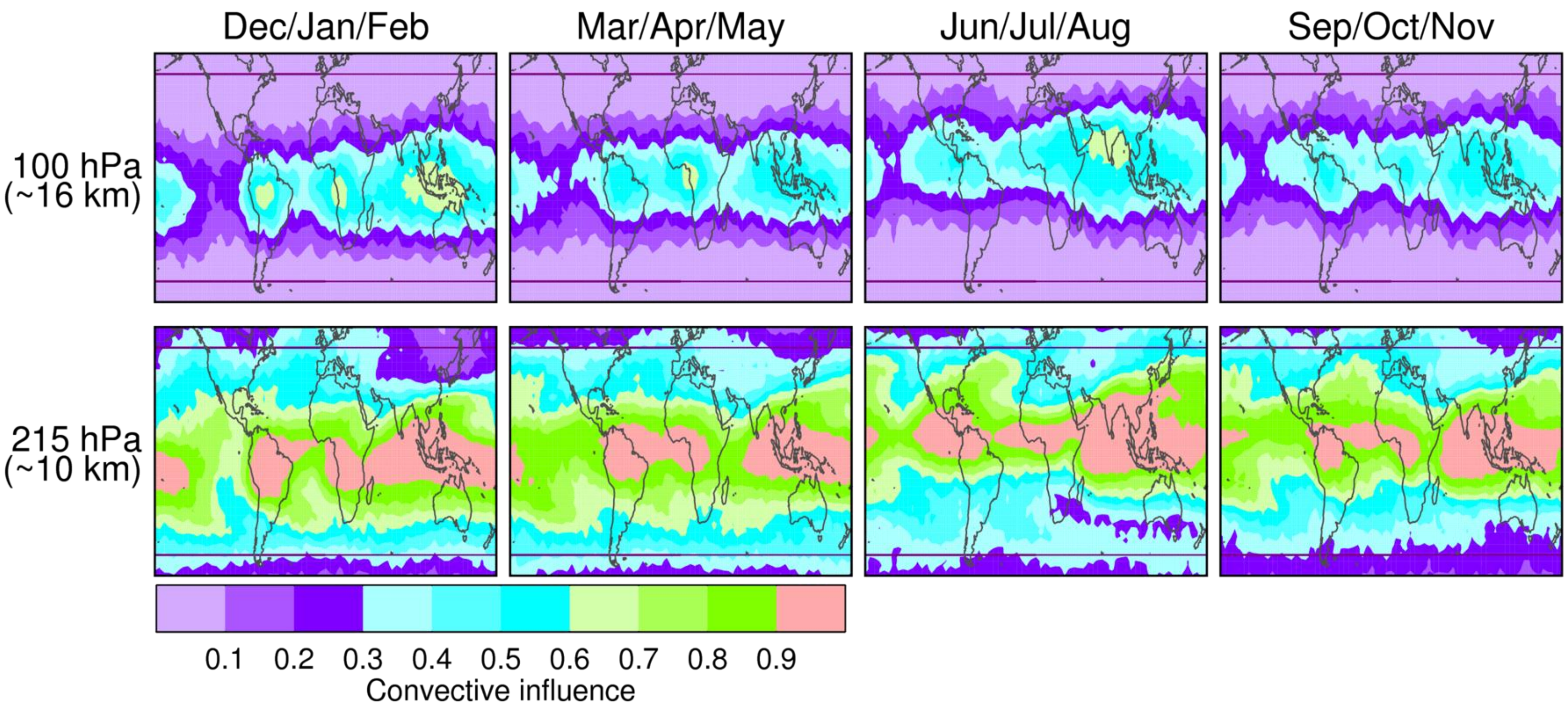
- The maps that follow show seasonal climatology (2007–2012) of convective influence
  - using a 1.5 km-high, 300 km-wide kernel (results for broader kernels are similar)
- This set are for convective influence within <u>48 hours prior</u> to the observation



# MLS convective influence climatology (5 days)



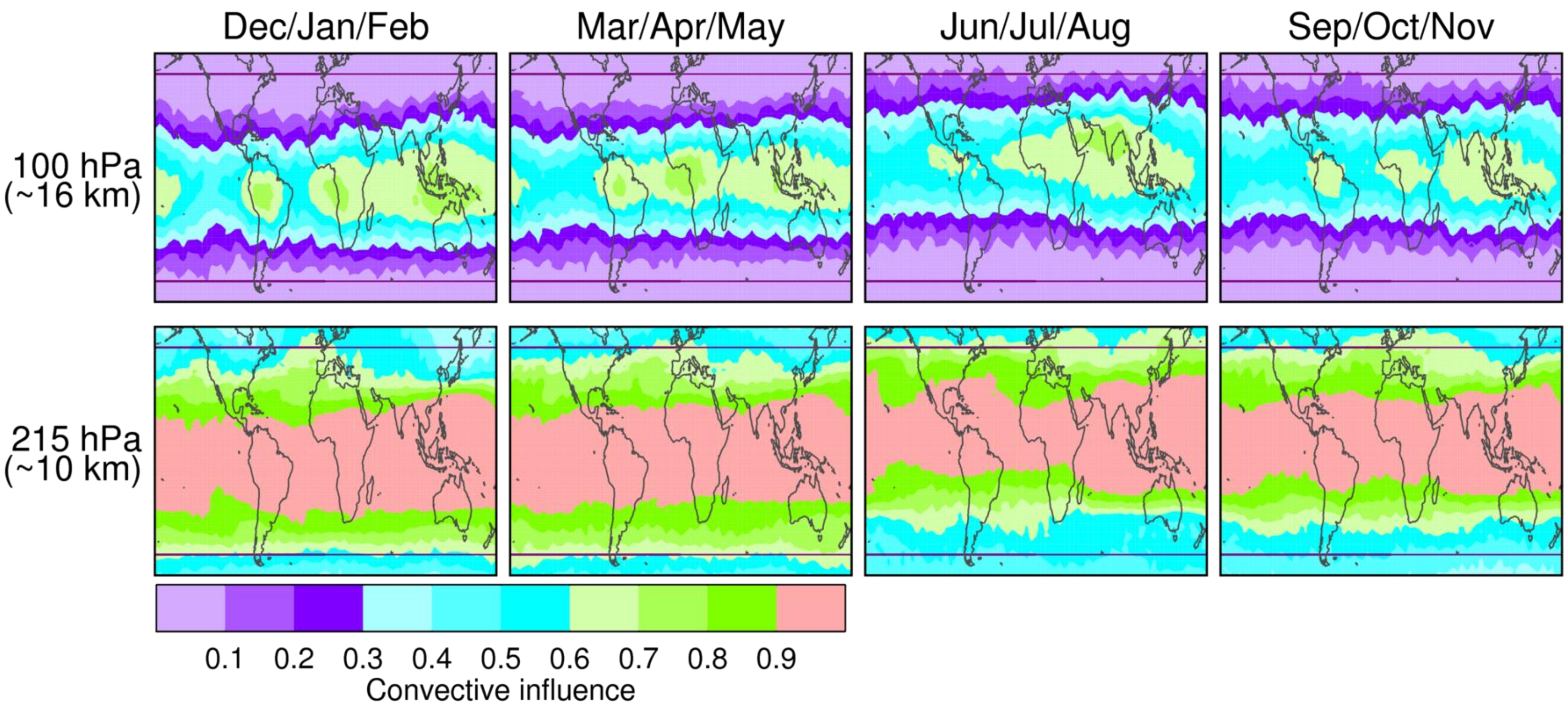
- The maps that follow show seasonal climatology (2007–2012) of convective influence
  - using a 1.5 km-high, 300 km-wide kernel (results for broader kernels are similar)
- This set are for convective influence within <u>5 days prior</u> to the observation



# MLS convective influence climatology (10 days)



- The maps that follow show seasonal climatology (2007–2012) of convective influence
  - using a 1.5 km-high, 300 km-wide kernel (results for broader kernels are similar)
- This set are for convective influence within <u>10 days prior</u> to the observation



# Regional influence / composition relationships



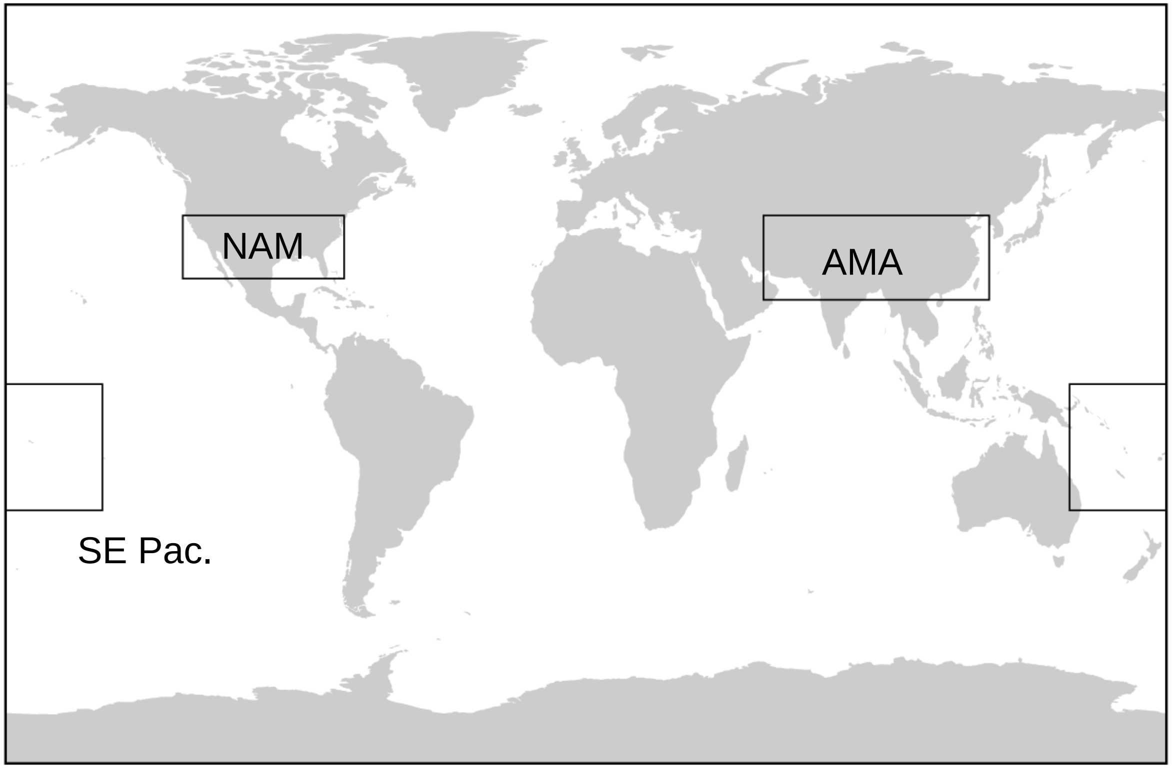
- The next set of figures examine the relationship between MLS composition measurements and the corresponding convective influence
- We focus on MLS observations over three regions, and consider timeseries for three regimes:

  **"Negligible influence"**: 5-day convective influence < 0.1 (grey)

  **"Strong influence"**: 2-day convective influence > 0.75 (orange)

  **"Remainder"**: All other cases (teal)

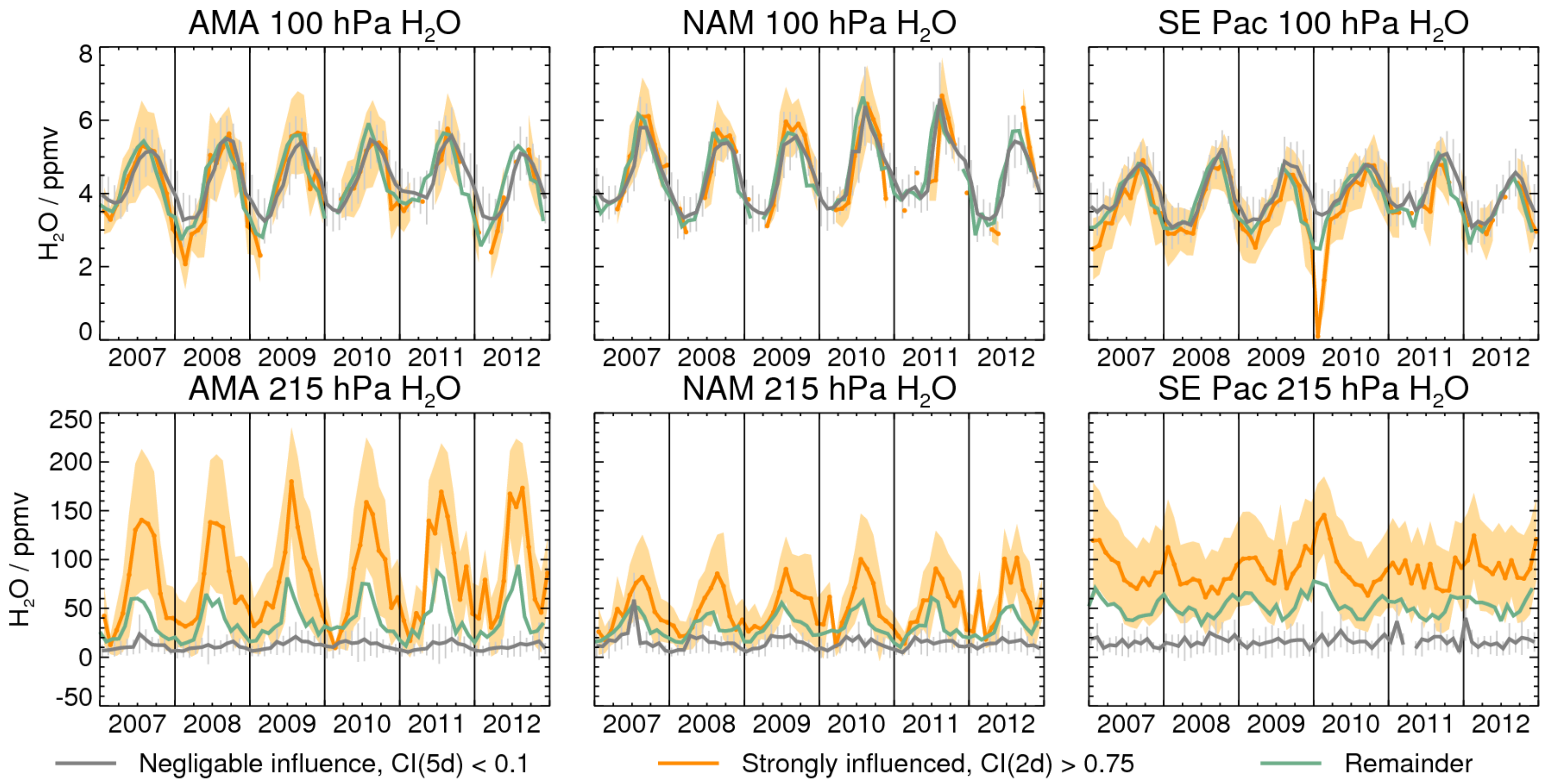
- We include error bars/shading on the "negligible" and "strong"
- These show the 1σ standard deviation
- Note that these are *not* divided by sqrt(n)



# Convective influence and water vapor



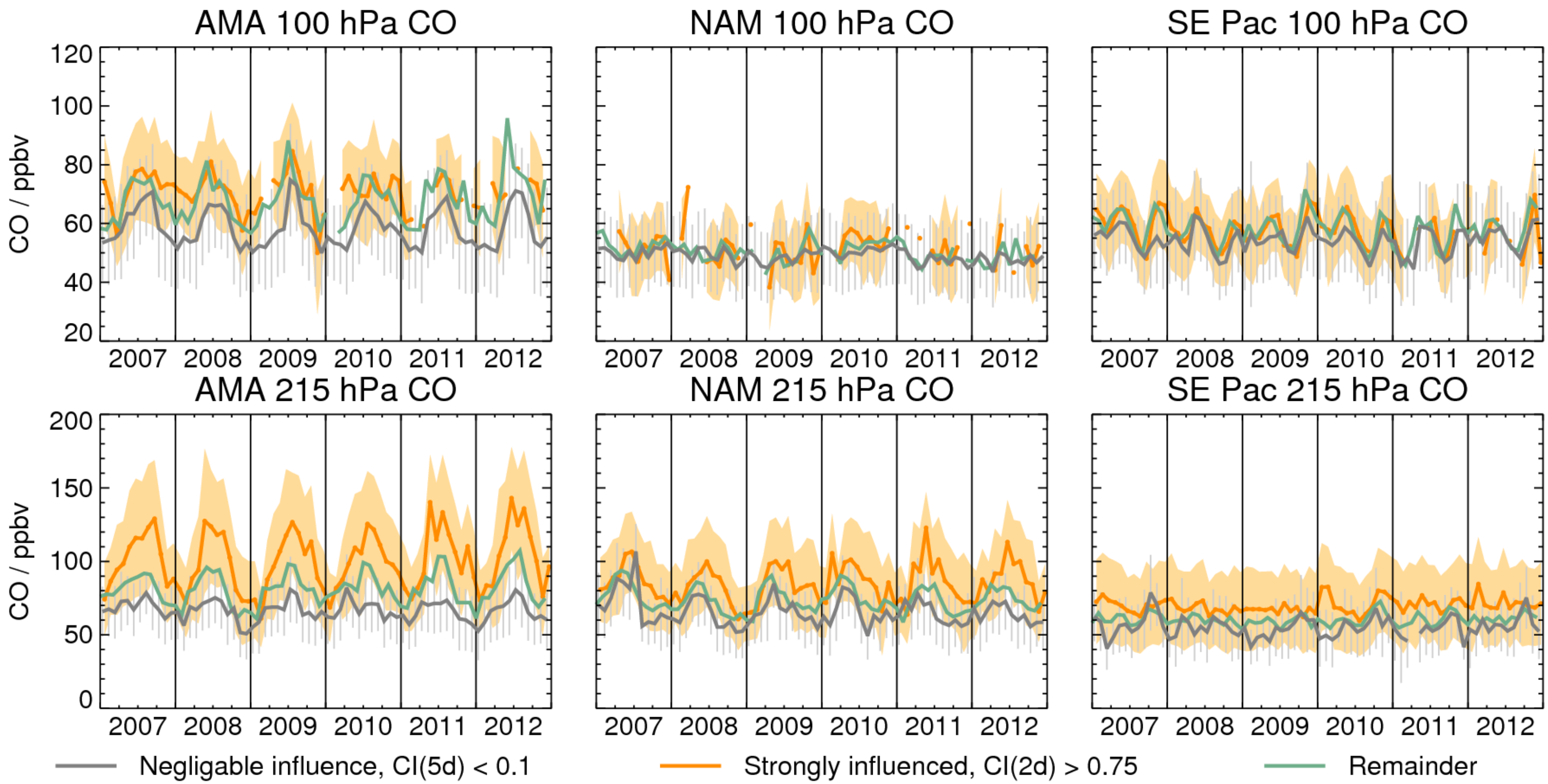
- At 215 hPa, the seasonal cycle in water vapor is strongly affected by convective influence, most notably over the AMA region, with non-influenced air masses showing little to no seasonal cycle
- At 100 hPa, by comparison, convective influence has no clear correlation with water vapor (the hints of slight enhancement over NAM in summer are likely not statistically significant)



# Convective influence and carbon monoxide



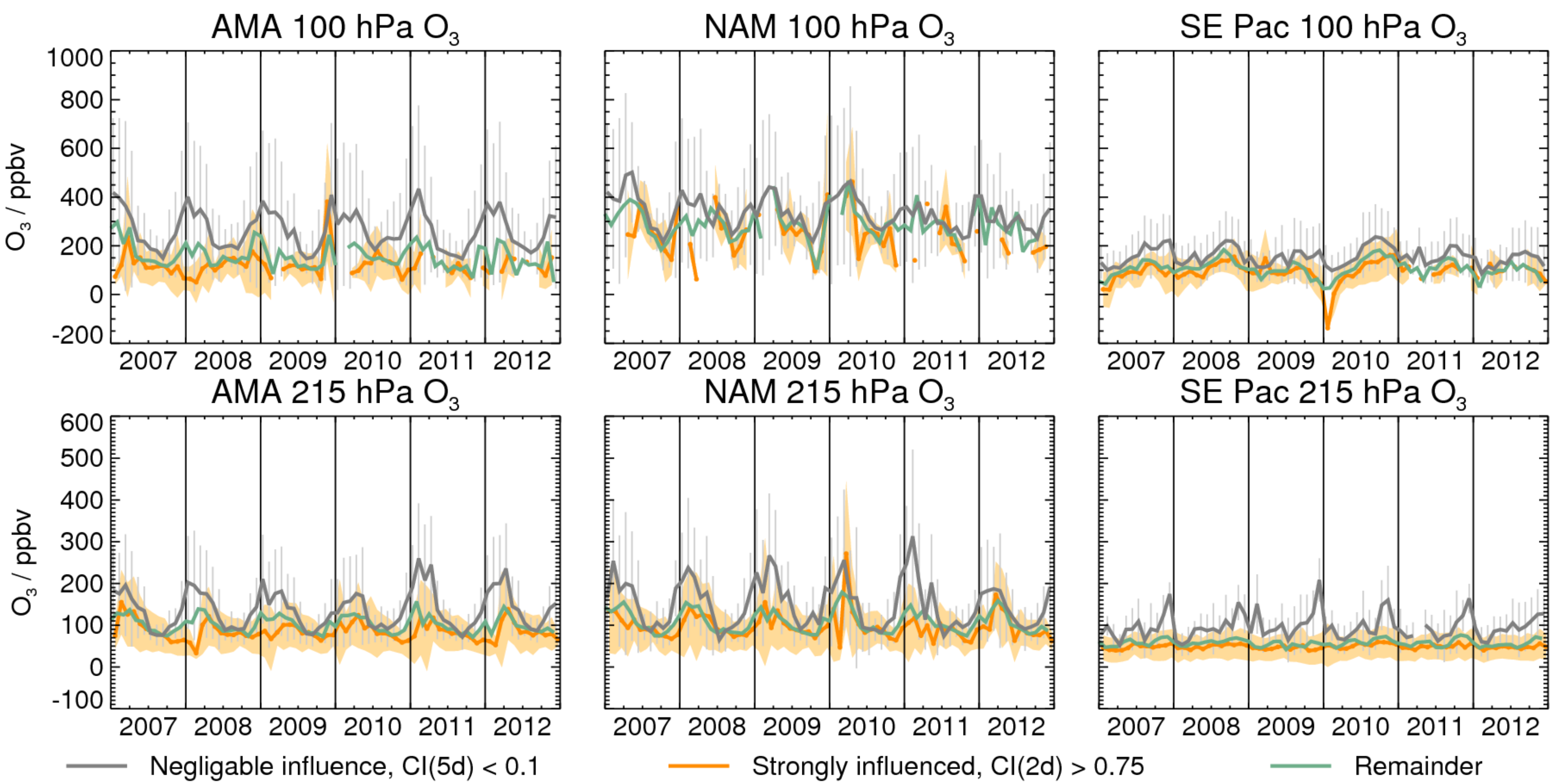
- Convectively influenced 215 hPa observations are nearly universally associated with greater CO abundances than those with little convective influence (over AMA and NAM influenced observations have a larger seasonal cycle also)
- At 100 hPa only AMA shows significant impact of convective influence



# Convective influence and ozone



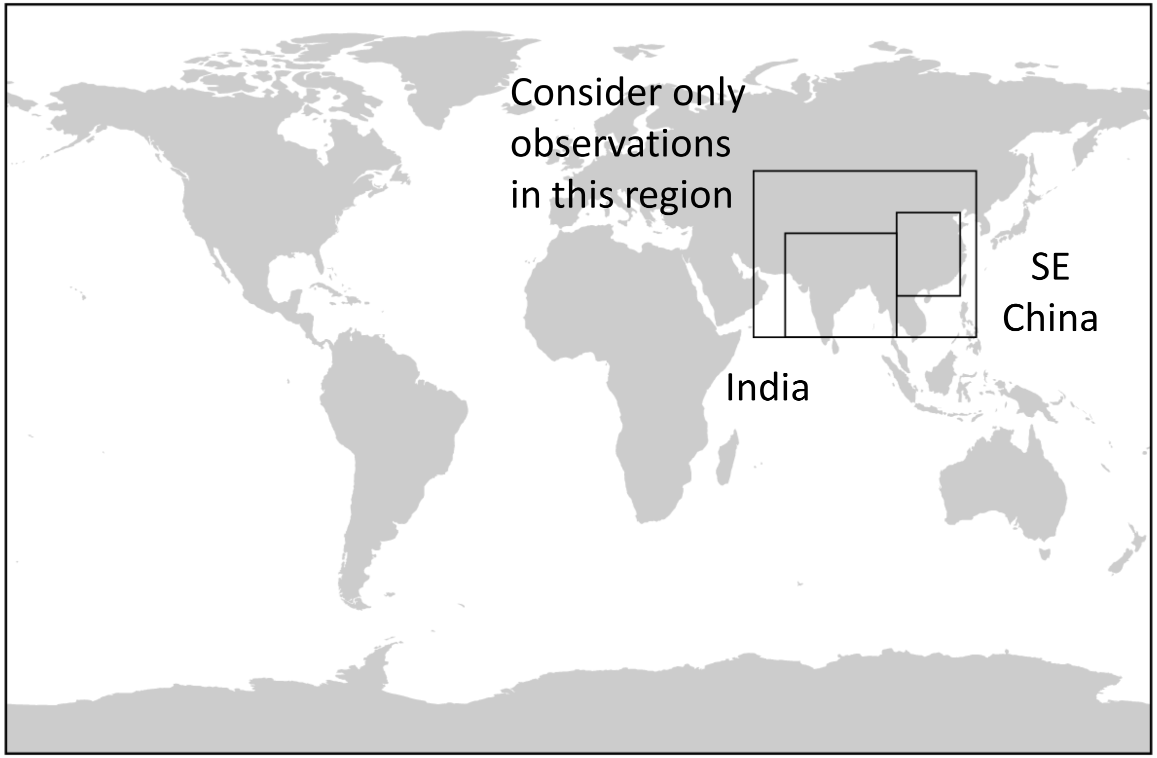
- For ozone, conversely, convective influence mutes the seasonal cycles and reduces mean values
- This is consistent with expectations, given  ozone is a “stratospheric tracer”



# Convective regions within the Asian Monsoon



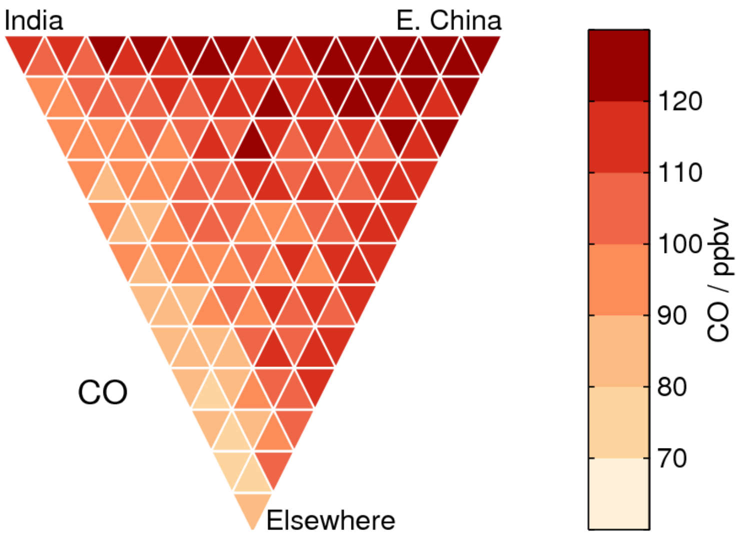
- In the analysis that follows, we consider only MLS observations within the large AMA region shown below
- For each observation in that region, we compute the convective influence and the contributions thereto from the each of the two smaller regions and from everywhere else
- We then quantify how MLS-observed composition varies depending on the relative contributions to convective influence from each region

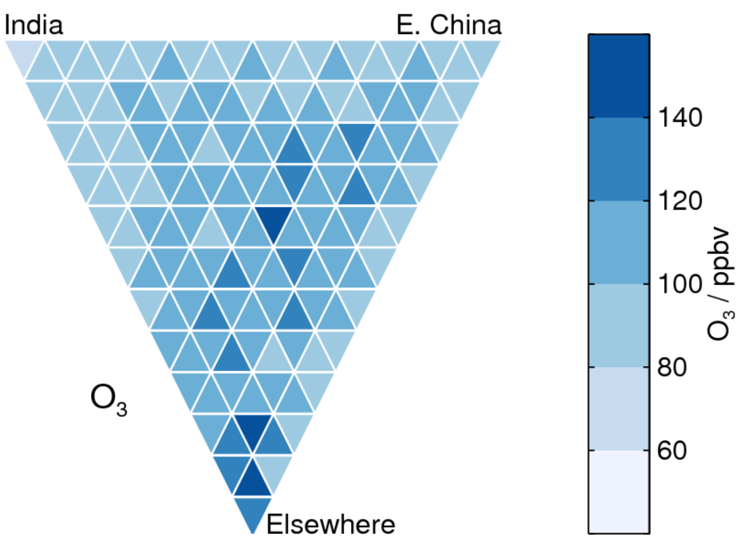


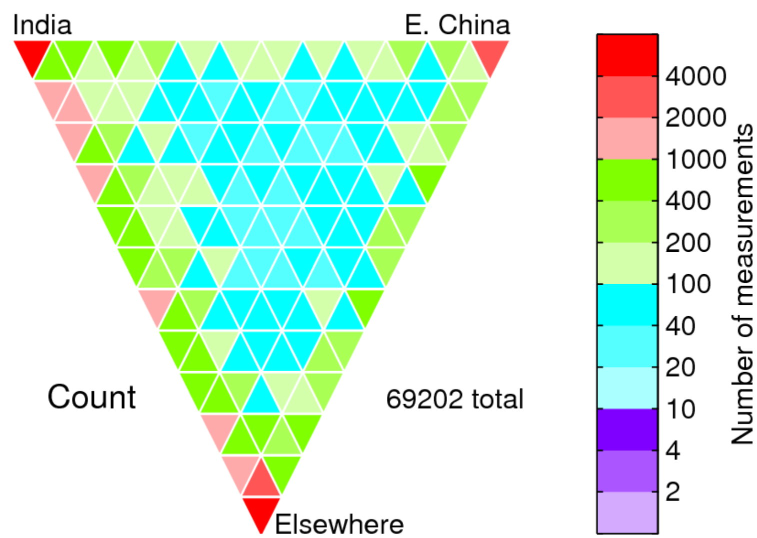
# Regional influences at 215 hPa



- Plots show all the 215 hPa MLS JJA 2006–2012 observations within the ASM region with >0.75 convective influence over the last 5 days (sooner is similar)
- Convection over Eastern China is associated with larger CO abundances than India (and much more than “elsewhere”)
- Hints that ozone abundances are greater for E. China convection also

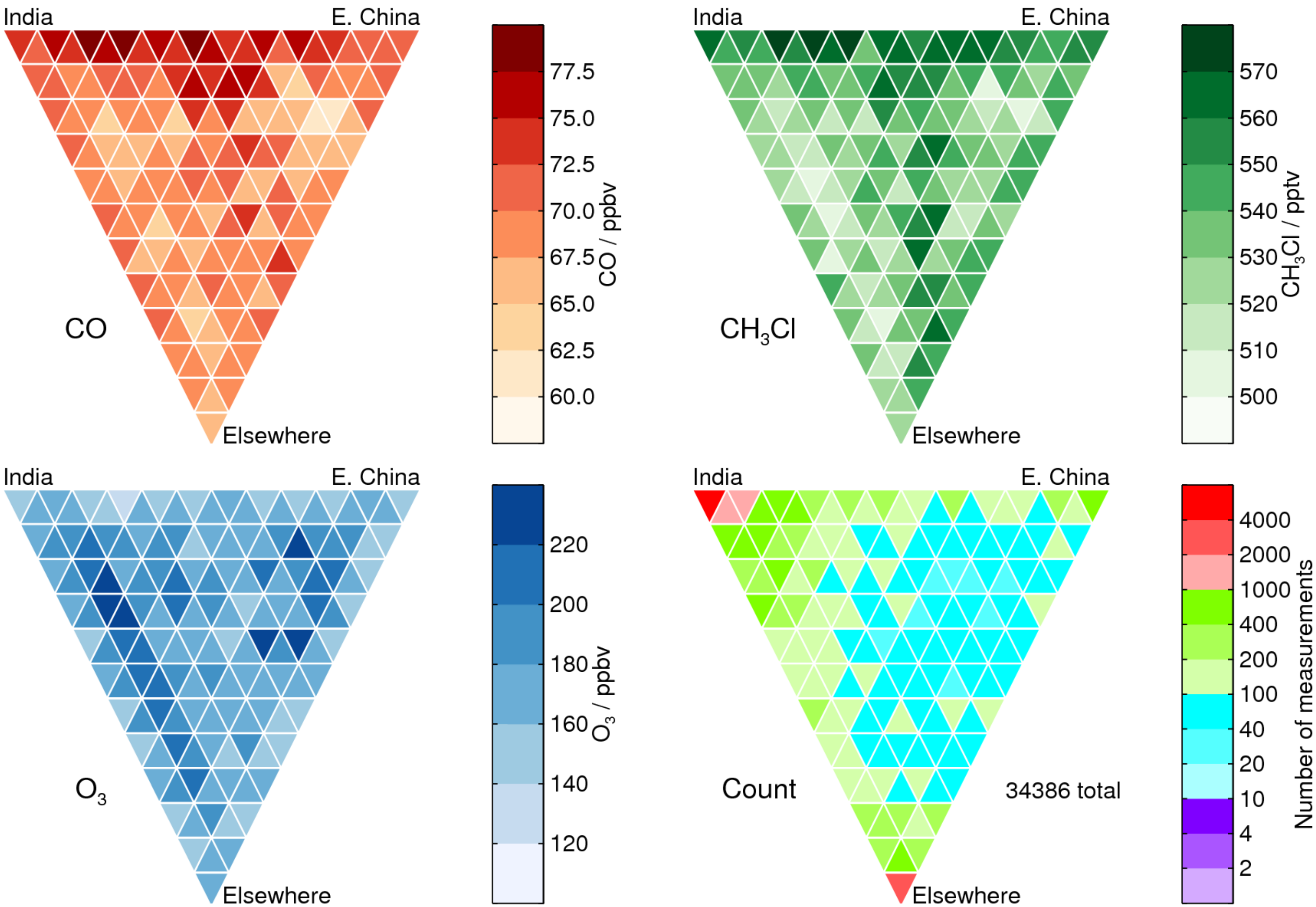


# Regional influences at 100 hPa (24h influence > 0.75)

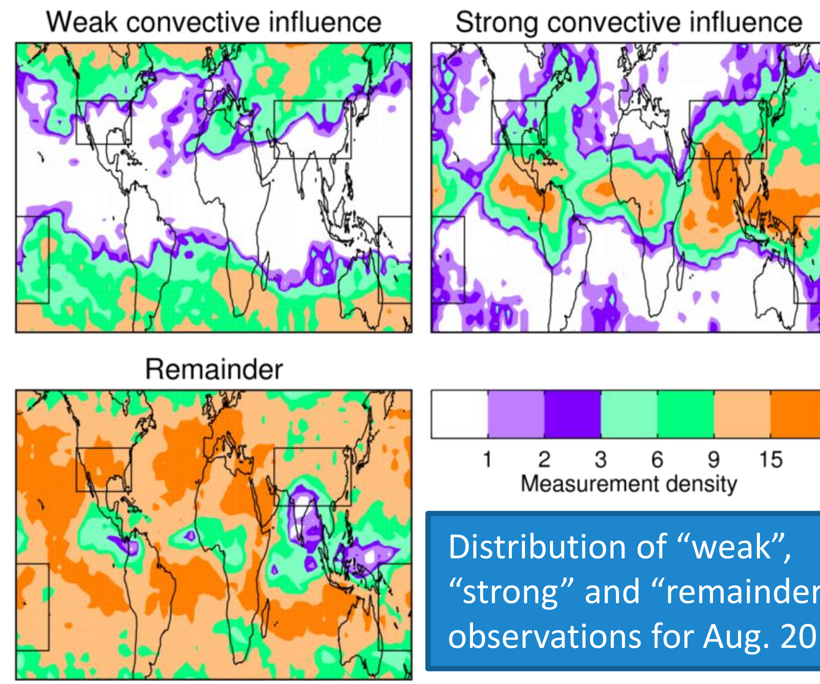




# Interpretation of the results – sampling biases



- The new diagnostic enables us to discriminate between strongly and weakly convectively influenced MLS observations
- When initially working with this diagnostic, I was thinking of it as being weakly analogous to looking at model-simulated composition fields with and without convective parameterizations enabled
- Of course, the reality is more complex
- Some of the differences between observations with weak and strong convective influence may simply reflect geographical variability
- For example, if convection is biased towards the equatorward side of a region, our differences may simply reflect latitudinal gradients
- On the other hand, in many cases it is the convection itself that is driving these geographical (and also temporal) variations
- Thus, convective influence, might be better though of as a “coordinate system” rather than a “diagnostic”




Distribution of “weak”, “strong” and “remainder” observations for Aug. 2011

# Summary and further work



- A new MLS convective influence diagnostic has been developed
  - The trajectories upon which it is based are publicly available
  - The diagnostic dataset, while not particularly voluminous, is made somewhat unwieldy by the large dimensionality (akin to that found with adjoint models)
  - Many aspects of the diagnostic/composition relationship remain to be explored (e.g., relationship between composition and time since convection)
- Relationships between convective influence and observed composition are in line with expectations. Within the Asian monsoon region we find:
  - At 215 hPa, convective influence is associated with large abundances and seasonal cycles of water vapor and carbon monoxide, and lower ozone abundances
  - At 100 hPa, convective influence is associated with larger CO abundances, but there is little impact on water vapor
- Relationships between MLS-observed composition and the locations of convection give insights into surface distribution of pollutants
- For future work, we plan to consider this diagnostic on a more global scale
- We also plan to explore sensitivity to tuning of the cloud top calculation, and to use product/height-specific averaging kernels