Using Observations of SF_6 to Examine Inter-annual Variations in Inter-hemispheric Exchange

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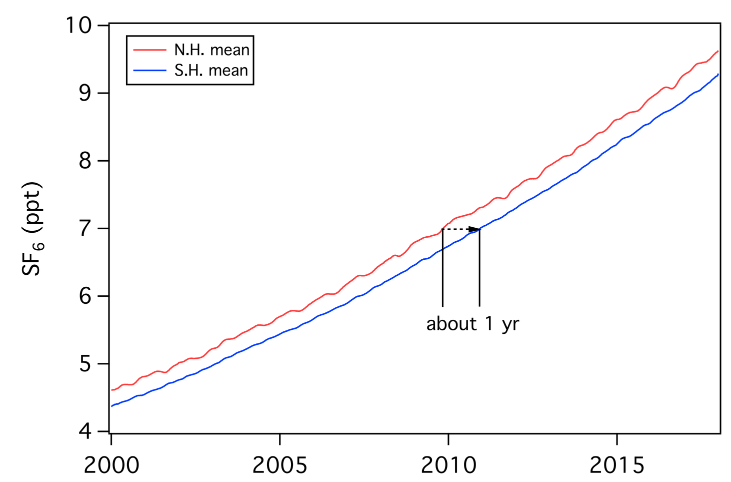
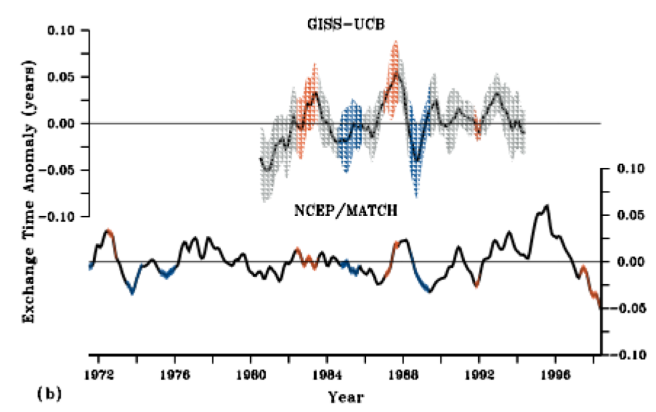
INTRODUCTION

SF_6 is a long-lived greenhouse gas emitted primarily from high-voltage switch gear (electricity distribution). It's atmospheric abundance is steadily increasing. Since it is emitted mostly in the northern hemisphere, and has no tropospheric or stratospheric sinks, it can be used to infer time scales of mixing. There is net transport of SF_6 and other trace gases with predominate N.H. sources from the N.H. to the S.H. The mean mixing time between hemispheres is about 1 yr. Transport mechanisms that contribute to inter-hemispheric air exchange include convective divergence in the upper troposphere, seasonality in the Hadley circulation, and propagation of Rossby waves through western tropical ducts. The mean exchange time might be influenced by climate drivers, such as ENSO (figure to right).

Here we use SF_6 data measured at the surface to examine the inter-hemispheric transport. We show that there is inter-annual variability, and it appears to be related to ENSO, but not all anomalies are correlated with ENSO.

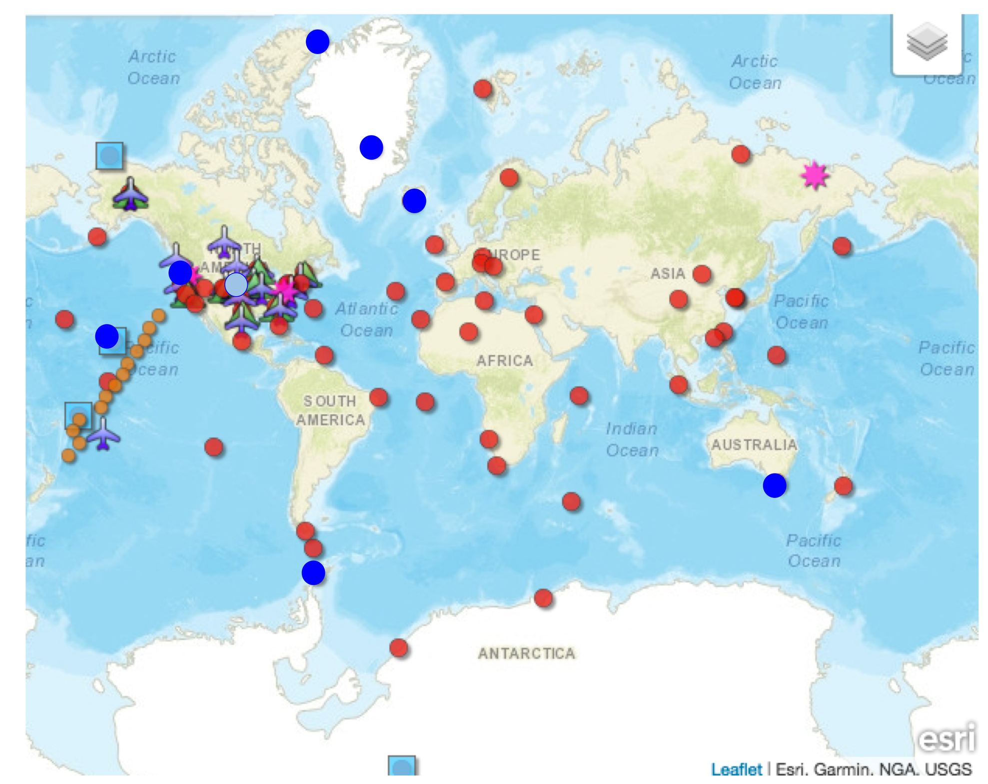
We also examine spatial gradients and seasonal cycles of SF_6, since these might provide clues as to changes in emission patterns, and could provide constraints for modeling atmospheric transport.





from Lintner et al (2004)

GMD Sampling Networks

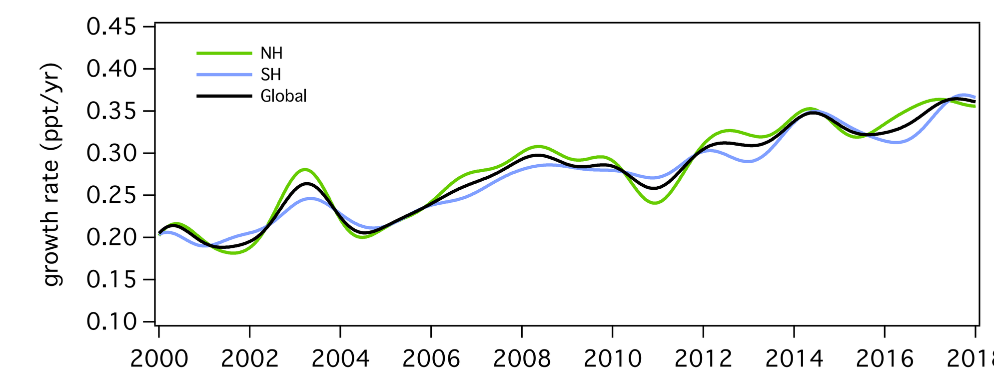


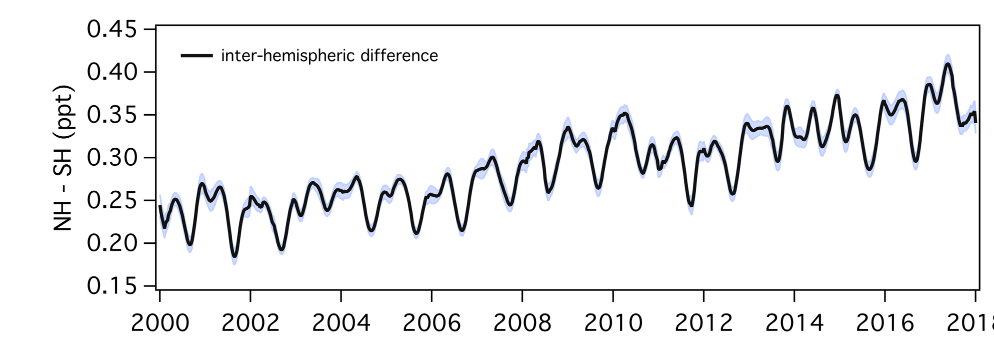
- 12 sites (flask + in situ) (3 high alt.)
- 26 sites + 13 ship (flask) (all MBL)

$$\text{Exchange time (yr.)} = \frac{\left(\frac{E_N}{E_S}+1\right)(X_N - X_S)}{\frac{E_N}{E_S}\frac{dX_S}{dt} - \frac{dX_N}{dt}}$$

2-Box Model

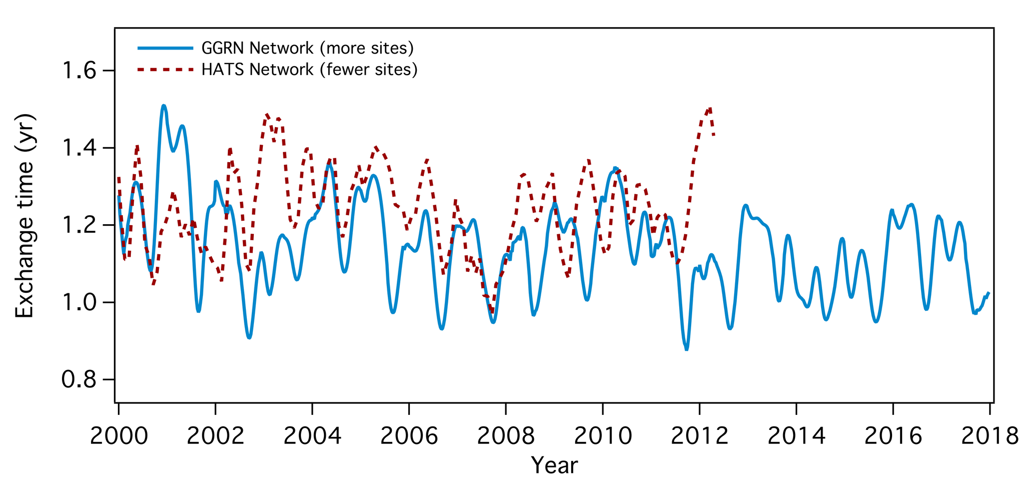
Where X_N and X_S are mean mixing ratios in each hemisphere, and E_N and E_S are emissions in each hemisphere. We calculate dX_N/dt and dX_S/dt (growth rates) from hemispheric mean mixing ratios (below). We do not consider the loss term (global lifetime ~850 yr.), or exchange between the troposphere and stratosphere. We assume that 97% of emissions are from the N.H., and that emissions do not vary seasonally.

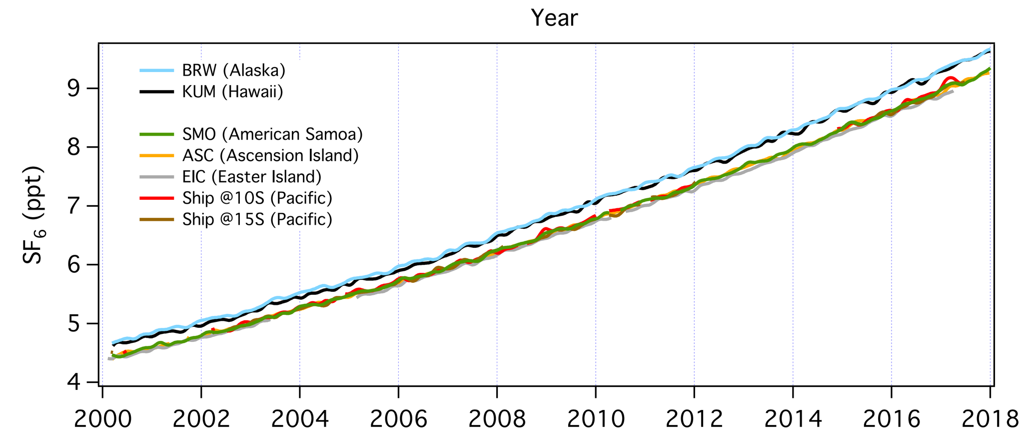




Using these data

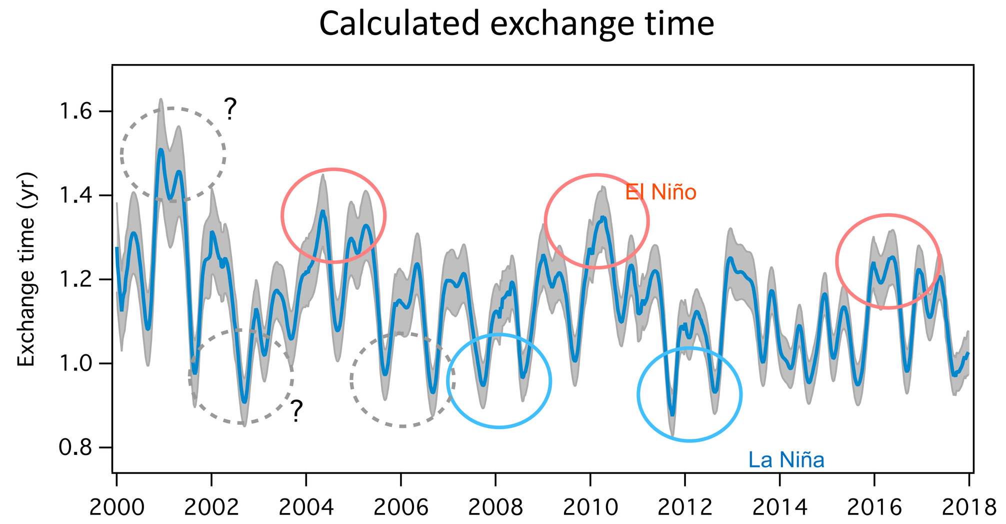
Calculated exchange time

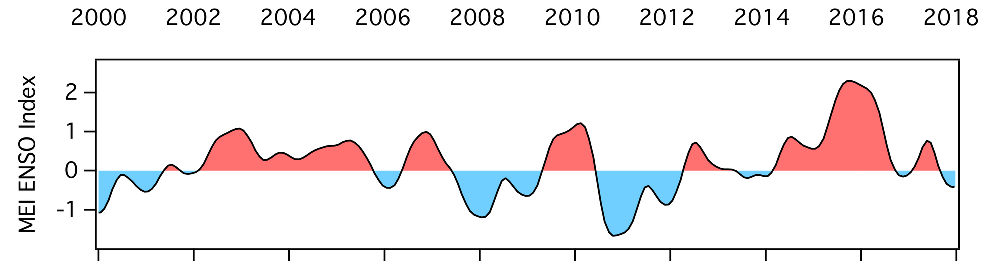




Exchange times calculated from SF_6 data show a seasonal cycle (minimum in Aug.-Sept.). The seasonality is similar between different sampling networks, but inter-annual variability shows some large differences, particularly in 2003 and 2012. This could be due to sampling density, especially in the S.H. The HATS network is limited to only one site in the 0-30S region.

Calculated exchange time

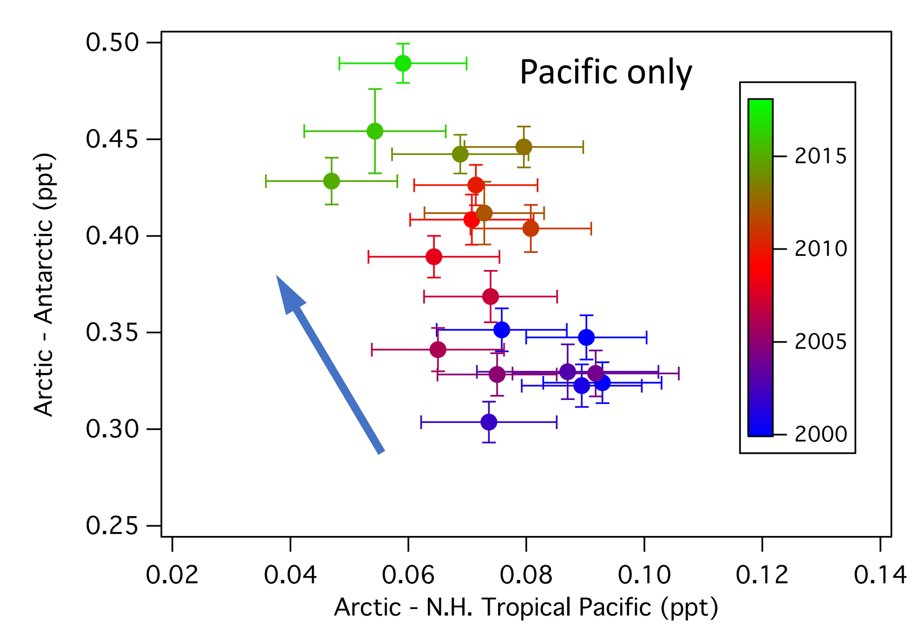


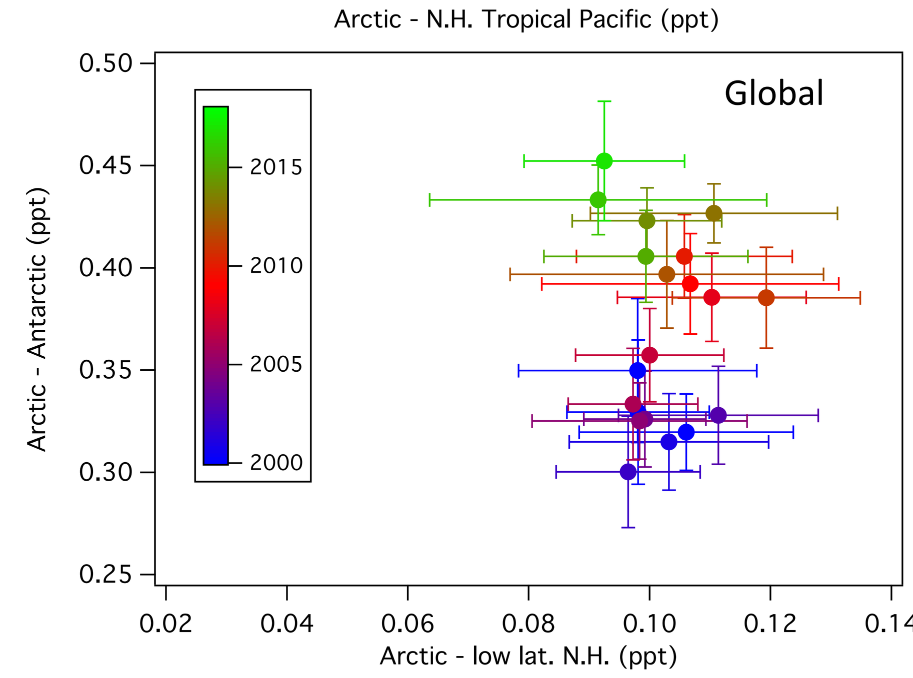


Using only at data from the GGRN network, we observe that inter-annual variability appears to be correlated with ENSO, with longer (slower) exchange times during El Niño, and shorter (faster) exchange times during La Niña periods. Some of the more prominent excursions do not appear to be correlated with ENSO (e.g. 2001, 2003).

What else might we learn from global SF_6 observations?

Changes in N.H. gradient related to changing source distribution.

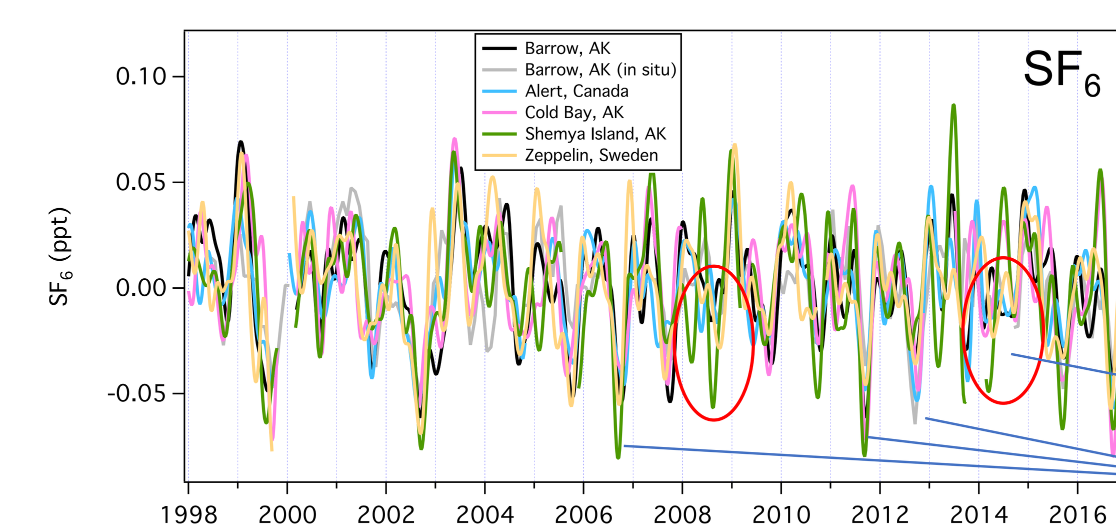




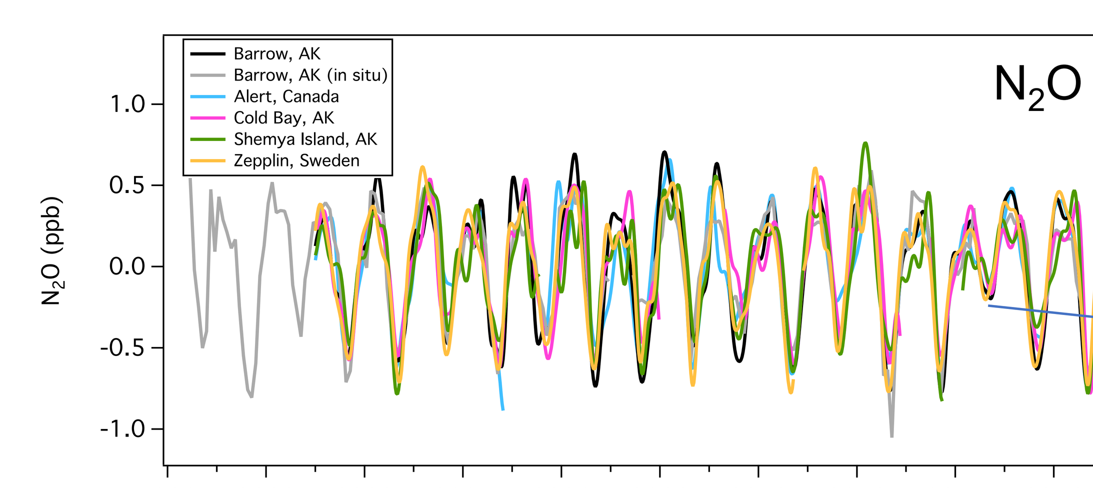
These figures show changes in surface gradients of SF_6 over time. As emissions increase, we expect the N-S gradient to increase. If the geographic distribution of emissions does not change, we would expect the gradient in the NH to stay roughly the same over time.

The upper panel shows the pole-to-pole (N-S) gradient vs the gradient in the N.H. Pacific basin. The pole-to-pole gradient was derived from sites in Alaska (BRW, CBA, SHM) and Antarctica (SPO, PSA). Tropical Pacific sites are represented by KUM (Hawaii) and GUI (Guam). There is a trend towards a smaller gradient in the N.H. Pacific, which could indicate a southward shift in SF_6 emissions. However, this trend is less apparent when the N.H. gradient is derived from sites spread across longitudes (lower panel). The lower panel shows a similar pair of gradients derived from zonal mean mixing ratios (60-90N, 0-30N, 60-90S) incorporating data from many more sites. This suggests a change in the distribution of emissions (increasing emissions at lower latitudes) in the Asia-Pacific region, but not across the globe as a whole.

Seasonal cycle at Arctic marine boundary layer sites



In the Arctic, we typically observe a minimum in the seasonal cycle of SF_6 in late summer (~September). The minima is often consistent across several sites. But in some years, such as 2008 and 2014, this seasonal minima is attenuated and/or not apparent at all sites.



Summary

- Inter-hemispheric exchange time, derived from global surface observations of SF_6, shows inter-annual variability that corresponds with ENSO (slower exchange during El Niño, faster during La Niña).
- Our surface observations also suggest a change in the latitudinal distribution of SF_6 emissions, towards More southern latitudes in the N.H., with indications that this trend is more pronounces in the Pacific (Asia).
- The seasonal cycle of SF_6 in the Arctic shows an anomalous attenuation in 2014, which is also shown in N_2O data.