Growing emissions and Asian monsoon as dominant factors for atmospheric greenhouse gas variations over Asia

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Signs observed earlier—Aircraft over Japan—









- The monthly air sampling program started in 1979 with CO₂ measurements
- CH₄ measurements started in 1988, CO in 1990, N₂O in 1991, SF₆ in 2001
- While CH₄ at lower heights showed seasonal minima in summer, maxima is observed at the upper troposphere – why? Where did the air masses come from?

Signs observed earlier—Aircraft over Pacific— **CON** Region 6 (a) 32° N (b) 26° N NRT 40° N JAPAN AIRLINES Reaion 5 HNL 1850 1850 CH⁴ (bbp) 20° N CH₄ (ppb) obs Latitude 1800 model 1750 1750 20° S SYD or BNE 40° S 20 ppb South Asia 60°E 80°E 100°E 120°E 140°E 160°E 180 160°W140°W Lonaitude East Asia Baseline (No tagged (a) -46.6 South Asia East Asia -46.8δ¹³C (‰)

2006

(b`

Umezawa et al. 2012 ACP

560

550

Reciprocal of the CH_4 mixing ratio (ppb⁻¹)

570

580x10

540

530

-47.0

-47.2

-47.4

δD (‰)

-80

-90

-100

520

2007

2008

2009

2010

- Air samples collected in the upper troposphere over the northwestern Pacific showed high CH₄ in summer
- Tag tracer model experiments indicated that summertime high CH₄ is of South Asia/East Asia origins

2006

2007

2008

2009

2010

Air masses of South Asia/East Asia origins showed lower isotope ratios, inferring substantial contributions from biogenic CH₄ (e.g., rice paddies, livestock)



Produced from Umezawa et al. (2018, ACP)

What's occurring at the surface— CO_2

China

India

herlands —

elaium ----

Iran 💳 Saudi Arabia 📟

Turkey -

Iraq

frica -

Egypt

Czech

United Arab Emirates

I his sankey diagram represents 602 emissions in Mit602 from five major sources (left column) and their distibution over region (middle column) and country (right column, 50 highest). China, the US, Europe and India continue to be the world's top emitters in 2014, amounting to 59% of global emissions.

In this view, the emissions of each country are cumulative across sources. To see the breakdown, click the 'Histograms' button above.



See http://lsce-datavisgroup.github.io/CO2emissions/





Patra et al. 2013 Biogeosciences

What's occuring at the surface? — CH₄

(a) Ftot, total budget



Asian summer monsoon: transport pathways

Backward





Honomichl & Pan 2020 JGR

Upstream measurements







CO₂ & CH₄ propagate upward (July to September)



Figures produced based on ongoing work by Chandra, Patra et al. in preparation

Downstream measurements (ongoing)



- Since 2017, CONTRAIL air samplings have been continued along flight tracks from/to Asian cities such as Bangkok, Singapore and Shaghai
- A set of 12 flasks in total is filled during cruising and vertical portions of flights
- Greenhouse gases and selected VOCs are analyzed
- After the COVID-19 outbreak, flight area was limited around Japan

Downstream measurements (ongoing)



 Analysis of air samples show clear seasonal patterns every year over East Asia with minimum in CO₂ and maximum in CH₄ in summer (consistent with earlier measurements)

JAPAN AIRLINES

 Both CO₂ and CH₄ continue to rise over the last years



Summary

- Earlier measurements have helped us understand large-scale distributions of CO₂ and CH₄ over Asia in association with the Asian summer monsoon
- Given that Asia now plays a central role in greenhouse gas emissions, it is important to monitor changes in atmospheric greenhouse gases in Asia so that regional to country level emissions are effectively constrained
- Ongoing programs in Japan keep measurements in the downstream of the Asian monsoon region
- Denser regular data in Asian countries (upstream regions) will greatly improve our understanding of greenhouse gas budgets regionally and globally