



Composition, Chemistry MAX-PLANCK-INSTITUT and Transport in the UT/LS during the Asian Monsoon: Results from the IAGOS-CARIBIC Observatory

Angela K. Baker & the CARIBIC team

Monsoon Workshop 08 March 2016



The IAGOS-CARIBIC Project

- In-service Aircraft for a Global Observing System Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container
- Operational May 2005 – Present
- 2-6 flights per month





Where We Fly





satellite image: NASA Earth Observatory

Flights to India 2008



- 1-2 monthly round-trip flights April-December
- Monthly "snapshots" monsoon anticyclone
- 10-12 km altitude



Longitude





Monsoon Period

Latitudinal Transects



Monsoon Period

Source Regions





• South

- More short-lived species
- Marine/SH air

Center

- Still recent, no evidence of marine/SH air
- Most polluted

North

- Longer transport times
- More secondary species
- Less short-lived species

Latitudinal Transects

Frankfurt to Chennai August 13, 2008

Elevated primary and short-lived species in the south (CO, H₂O, aerosols)

Elevated O_3 and NO_y in the north

Transition related to change in wind speed = position in anticylone



Sources & Emissions: CH₄





Sources & Emissions: NMHCs



1000 Investigate using slope = 11.2 ± 4.7 slope = 2.4 ± 0.93 Propane [pptv] Ethane [pptv] 120 $r^2 = 0.70$ $r^2 = 0.67$ 800 **Enhancement ratios** 80 600 to CO: 40 400 200 July and August only 200 50 $slope = 4.8 \pm 1.0$ $slope = 1.2 \pm 0.40$ Acetylene [pptv] $r^2 = 0.78$ Benzene [pptv] = 0.80 40 Low level contact 150 30 100 Age 3-5 days 20 50 10 Biomass Burning 80 100 120 60 80 100 60 120 Biofuel Burning CO [ppbv] CO [ppbv] Urban (Fossil Fuel) ۲۲ ppt NMHC/ppb CO Strong BF signature in 2008 (CARIBIC) 10 combustion products 8 6 • Mix of BF and FF for 4 alkanes 2 0 [Baker et al., 2011 (ACP)] Ethane/CO Propane/CO Acetylene/CO Benzene/CO

Mixing vs. Chemistry



- CARIBIC observations:
 - Propane/Ethane and n-Butane/Ethane
 - Initial ratios of 0.29 and 0.15
 - July and August only
- Kinetic slopes of 2.4 to 3.0
- Biggest deviations in southern samples (marine influence) **Evidence of isolation!** Not much mixing



In(Propane/Ethane)





• Estimate using:

 $\Delta t = \frac{1}{(k_A - k_B) \langle [OH] \rangle} \ln \left(\frac{[A]_t / [B]_t}{[A]_0 / [B]_0} \right)$ - 2.48×10⁶ OH cm⁻³ (S) - 1.44×10⁶ OH cm⁻³ (N)

- Estimate ages of
 - 3-5 days in south
 - 9-14 days in north



- Good agreement between "clocks"
- Good agreement with available back trajectories

O₃ Formation Tendencies



Relationship can be used as a gauge of photochemical efficiency:

- + slope = ozone forming
- slope = ozone depleting (trop) or stratospheric influence

Monsoon outflow transport

- Transport of outflow to Arabian Peninsula and the Mediterranean (Lelieveld et al., 2002; Scheeren et al., 2003 Lawrence et al., 2003; Lawrence and Lelieveld, 2010)
- Transport across the tropopause (Chen et al., 1995; Traub and Lelieveld, 2003; Fu et al., 2006; Randel et al., 2010)
- Our own observations over N. America in 2007



Receptor Regions

	• •	•	
	• •	• •	•
• 0	00	• •	•
• 0 O			•
• • • •	• 0 (• •
• 0 ●		0	0.
• 0	• •	• •	•
	0 🌒	• 0	•
		•	





[Rauthe-Schöch, et al., 2015 (ACPD)]

Monsoon Findings



- CARIBIC flights to India in 2008 provide monthly snapshots of monsoon anticyclone composition
 - Trace gas and aerosol profiles show strong influence of convection and subsequent transport in the anticyclone
 - Used to understand regional emissions and sources
- NMHC ratios support chemical isolation and estimate age
- Tendency towards ozone formation in recently convected air (3-6 days).
- Maximum transport to stratosphere in June and July
- Maximum transport to N. America/across the Pacific in August and September

Unexplored topics/data

- Most of the in situ data, particularly aerosols
 - Can higher resolution data for shorter-lived species give insight into monsoon processes?
- "Secret" monsoon data: Flights to the Maldives during the first phase of CARIBIC (1997-2002)
 World Data Center for Climate, Hamburg
 - Limited dataset compared to IAGOS-CARIBIC
 - Does have WAS with CH4, CO2, NMHCs, halocarbons
 - 03, CO, CN
 - Available in World Data Center for Climate database



Acknowledgements



CARIBIC would not be possible without the support of Lufthansa, Fraport, Munich Airport, the Max Planck Society, Karlsruhe Institute of Technology, the DFG and the hard work of the CARIBIC team.



www.caribic.de angela.baker@mpic.de

Publications

Ojha, N., et al.: Ozone and Carbon Monoxide over India during the Summer Monsoon: Regional Emissions and Transport, *ACPD*, *15*, 21133-21176, **2015.** (accepted for publication in ACP)

Rauthe-Schöch A., et al.: Trapping, chemistry and export of trace gases in the South Asian summer monsoon observed during CARIBIC flights in 2008, *ACPD*, 15, 6967-7018, **2015**. (accepted for publication in ACP)

Leedham Elvidge E. C., et al:, Increasing concentrations of dichloromethane, CH₂Cl₂, inferred from CARIBIC air samples collected 1998-2012, **ACP**, 15, 1939-1958, **2015**.

Umezawa T., et al.: Methyl chloride in the upper troposphere observed by the CARIBIC passenger aircraft observatory: Large-scale distributions and Asian summer monsoon outflow, *JGR-Atmos.*, **2014.**

Schuck T.J., et al: Distribution of methane in the tropical upper troposphere measured by CARIBIC and CONTRAIL aircraft, *JGR*, 117, D19304, **2012**.

Baker A.K., et al.: Estimating the contribution of monsoon-related biogenic production to methane emissions from South Asia using CARIBIC observations, *GRL*, 39, L10813, **2012**.

Patra P., et al.: Carbon balance of South Asia constrained by passenger aircraft CO₂measurements. *ACP*, 11, 4163–4175, **2011**.

Baker A. K., et al.: Characterization of non-methane hydrocarbons in Asian summer monsoon outflow observed by the CARIBIC aircraft, *ACP*, 11, 503-518, **2011.**

Schuck T. J., et al.: Greenhouse gas relationships in the Indian summer monsoon plume measured by the CARIBIC passenger aircraft, *ACP*, 10, 2031-2087, 2010.

This list includes only papers where IAGOS-Monsoon Data played a prominent role.

A complete list of publications (and corresponding pdfs) can be found at <u>www.caribic.de</u> under "publications"