On the seasonal variation of stable isotopic composition of precipitation over Asian monsoon region

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δ¹⁸O<sub>p</sub> Background

- Equilibrium Fractionation: rain enriched relative to vapor
- Rayleigh distillation: depletion away from source
- Dansgaard relationship: 7 permil /K
- Amount effect: tropical islands δ¹⁸O decreases with increasing temperature.
GNIP: $\delta^{18}O_p$ increases inland to the northwest in summer.
Our tools (I):
Isotope-enabled LMDZ Climate Model: Risi et al., 2010

- Nudged with ECMWF wind – reasonable simulation of precipitation; Water tracers; 2.5° × 3.75°

Summer minus Winter $\delta^{18}O_p$

[Map showing GNIP Obs and LMDZ model results]
Our tools (II): Satellite Obs of HDO in vapor

**Thermal Emission Spectrometer (TES):**
Averaging kernel peak ~ 600 hPa

**SCIAMACHY:** no vertical variations in averaging kernel. Column HDO dominated by lower tropospheric
Winter: Off-shore winds

δ¹⁸O (permil)

Distance from Hong Kong

Coast
Warm

Inland
Cold

Hong Kong
Guiyang
Guilin
Xian
Yinchuan
Lanzhou
Liangye

Solid: Obs
Dashed: LMDZ

4 permil / 13K
Enriched vapor source: continental ET

7 permil/K
Distillation: Rayleigh
Summer: $\delta^{18}O_p$ increases from coast towards NW

![Graph showing the change in $\delta^{18}O$ from coast to inland in Southeast Asia and Central Asia. The graph indicates that the oxygen isotope ratio increases from the coast towards the northwest.]
Summer: SE Asia

- Precip very depleted ~ −8 permil
- Onshore winds

- Source vapor very depleted ~ −20 permil
**Summer: SE Asia**

- Onshore winds
- Source vapor: depleted

$\delta^{18}O_p$ decreases as the airmass moves from the Indian Ocean to the upstream regions of Southeast Asia

Convergence of low $\delta^{18}O_v$ decreases $\delta^{18}O_p$ over Southeast Asia
Summer: SE Asia, HDO vapor

$\delta D = 8 \delta^{18}O + 10$

Filled symbols: observations
Open symbols: model results

Wet season $\delta D$

Vapor

Upstream rainout

SCIAMACHY

GNIP

$\Delta = 78$ permil

ET enriches near-surface vapor

SE

Rain
Summer Central Asia: lower trop $\delta D_v$

- Vapor more depleted over Central Asia than SE Asia
- Central Asia
  - Air mass from west: little upstream rainout ✗
  - Dry soils: ET small role ✗
Evap of raindrop during descent depletes $\delta^{18}O_v$ and enriches $\delta^{18}O_p$

$20^\circ C$

$\delta_{vapi} : -9.7 \, ^\circ/o$

Initial $-10\, ^\circ/o$

Eqm with vapor

$100\, \%$

RH

70\% RH
• Evaporation of raindrops during descent:
  ○ Depletes vapor, enriches raindrops
Summary: Case Study

SE Asia:
- Winter: continental ET $\rightarrow$ enriched vapor
- Summer: strong convergence of depleted vapor from ocean $\rightarrow$ $\delta^{18}O_p$ more depleted than in winter

Central Asia:
- Winter: Rayleigh distillation
- Summer: Higher rain reevaporation increases $\delta^{18}O_p$
Precipitation is the excess water the atm cannot hold
$\delta^{18}O_p$ records the life history of water:
- ET source of vapor
- variations of $\delta^{18}O_v$ during transport
- $T$ and $\delta^{18}O_v$ at condensation
- post-condensation exchange with vapor
Models relatively mature to aid interpretation of paleoclimate proxies

Supported by NSF, NASA
Reasonable simulation of precipitation

Model JJA (mm/day)

TRMM JJA (mm/day)

Model DJF (mm/day)

TRMM DJF (mm/day)
Tagging experiment

More contribution from continental evapotranspiration over Central Asia, but...
Low isotope values are probably related with strong convergence due to the existence of Tibet.
Winter

But, the temperature effect is small if precipitation is in liquid form.

Over Eurasia

- snow < 10%: $r^2 = 0.13$
- snow > 50%: $r^2 = 0.8$
Summer: Central Asia

% of precip from continental recycling

- Air mass from west
- High regional recycling of water over Central Asia

If continental recycling enriches surface vapor isotopically, $\delta^{18}O$ of near-surface vapor should be high.
Summer Southeast Asia

Minimum $\delta^{18}O$ is located over the downstream of the highest precipitation area.

$\delta^{18}O_p$ decreases as the airmass moves from the Indian Ocean to the upstream regions of Southeast Asia.
Wind vector and Isotachs at 500 hPa