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

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Background

- Equilibrium Fractionation: rain enriched relative to vapor
- Rayleigh distillation: precipitation depletion away from source
- Dansgaard relationship: $7$ permil /K
- Amount effect: tropical islands, $\delta^{18}O_p$ decreases with increasing precip

Long-term monthly and annual mean $\delta^{18}O$ values for tropical island stations of the IAEA/WMO global network ($20^\circ$S to $20^\circ$N), plotted as a function of monthly and annual precipitation. (from Rozanski, 1993)
GNIP: $\delta^{18}O_p$ increases inland to the northwest in summer.
Isotope-enabled LMDZ Climate Model: Risi et al., 2010

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

Our tools (I):

Summer minus Winter $\delta^{18}O_p$
Our tools (II): Satellite Obs of HDO in vapor

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

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

Solid: Obs
Dashed: LMDZ

$\delta^{18}O$ (permil)

4 permil / 13K
Enriched vapor source: continental ET

7 permil/K

Rayleigh Distillation:

Distance from Hong Kong

Coast
Warm

Inland
Cold
Summer: $\delta^{18}O_p$ increases from coast towards NW

Southeast Asia

Central Asia

Coast Wet

Inland Dry

Distance from Hong Kong
Summer: SE Asia

- Precip very depleted ~ −8 permil
- Onshore winds

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

- Onshore winds
- Source vapor: depleted

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

Convergence of low δ^{18}O_v decreases δ^{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

Upstream rainout

SE Asia

ET enriches near-surface vapor
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°C
$\delta_{vapi} = -9.7\%$

Initial -10‰

1 km PBL

Evap of raindrop during descent depletes $\delta^{18}O_v$ and enriches $\delta^{18}O_p$.

Eqm with vapor

70% RH

100% RH

Lee and Fung, HP, 2008
• 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:
  o ET source of vapor
  o variations of $\delta^{18}O_v$ during transport
  o $T$ and $\delta^{18}O_v$ at condensation
  o post-condensation exchange with vapor
• Models relatively mature to aid interpretation of paleoclimate proxies

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Reasonable simulation of precipitation
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%: $r^2=0.83$
% 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.
Minimum $\delta^{18}O$ is located over the downstream of the highest precipitation area in Southeast Asia.

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