Diagnosis of the present hydrological cycle using isotope GCM

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Outline
1. New water isotopes dataset in Asia
2. Findings of new dataset
3. Factors controlling the isotopic variation using isotope GCM
4. How to use the isotope tracer to diagnosis of the hydrological cycle
1. Collect rain samples
   - Rain gauge

2. Measure the amount of precipitation

3. Send to WMO through the telecommunication network system
   - WMO (WWW)
   - World Meteorological Organization

3. Replace rain water to glass bottle (6ml)
   - 6ml Bottle

4. Measure the isotopic content of precipitation
   - Ship to Lab.
New Measuring Technique

Laser Absorption Spectroscopy

Tunable laser 1-12 μm

Gas cell

Detector

In-situ observation

Airplane

NASA WB-57

Balloon

TETHEO campaign

Satellite

AURA/TES

Diode laser frequency (cm⁻¹)

H₂¹⁶O

H₂¹⁷O

H₂¹⁸O

HDO
New Measuring Technique

Laboratory → Reduce the measuring time

- CF-IRMS
- Laser mass spec.

Monitoring datasets

- Monthly archive
- Event sampling

Salehard (Lat: 66.5N, Lon: 66.5E, 16m asl)  
(Kurita et al., 2004)

Kolpasevo (Lat: 58.3N, Lon: 82.9E, 75m asl)  
(Kurita et al., 2009 in preparation)

12 hours interval
What can we get from these high frequency monitoring datasets?
Time series of $\delta^{18}$O in precipitation in Siberia

Zhigansk (Lat: 66.8N, Lon: 123.4E, 92m asl)

Kolpasevo (Lat: 58.3N, Lon: 82.9E, 75m asl)

Heavy

Light

Eastern Siberia

Western Siberia
Intra-seasonal variability of $\delta^{18}O_{pre}$ in Siberia

10-30 day band passed filtered anomaly

Kolpasevo (Lat: 58.3N, Lon: 82.9E, 75m asl)

$\Delta \delta^{18}O$ (%)

R=0.71
Seasonal cycle of $\delta^{18}O_{pre}$ in Siberia

The $\delta^{18}O$ value reaches maximum in April.

Kolpasevo

The $\delta^{18}O$ value still keeps low value.

Kolpasevo

The $\delta^{18}O$ value reaches maximum in April.

Kolpasevo

The $\delta^{18}O$ value still keeps low value.
Time series of $\delta^{18}O$ in precipitation in Tropics

Intra-seasonal $\delta^{18}O$ variation >> Seasonal $\delta^{18}O$ variation

Palau (Lat: 7.00N, Lon: 134.27E, 2m asl)

Manado (Lat: 1.53N, Lon: 124.92E, 80m asl)

Makasar (Lat: 5.07S, Lon: 119.55E, 14m asl)
On a monthly timescale, the correlation of $\delta^{18}O$ value with regionally averaged precipitation amount was much higher than that with station based precipitation.

The variability of $\delta^{18}O$ values observed at a station is related with the regional scale hydrological circulation.

(Kurita et al., 2009)
Isotope scheme is incorporated into the physics scheme of GCM

MIROC ver3.2(IPCC AR4)

Isotope physics
Isotope changes only occurs at condensation and surface flux scheme

- Convective rain
- Stratiformed rain
- Evaporation
- Transpiration
- snow
- ocean
- land

Definition of Isotope value

$$
\delta^{18}O = \left( \frac{Q(H_2^{18}O)}{Q(H_2O)} - 1 \right) \times 1000
$$

$Q(TH2O)$: Total moisture (vapor+cloud liquid)
Model performance (H$_2^{18}$O)

MIROC3.2 Precipitation $\delta^{18}$O [DJF]

MIROC3.2 Precipitation $\delta^{18}$O [JJA]

Latitude [N]
Comparison between GISS-E and MIROC

MIROC

GISS-E

gissE-s1b P, AVE
1980-1999 Average

Prec.

δ¹⁸O
Sensitivity Test (Source effect)

Control Exp.

MIROC3.2 Precipitation $\delta^{18}O$ [JJA]

$\delta^{18}O_{evp}$ constant

MIROC3.2 Precipitation $\delta^{18}O$ [JJA]

MIROC3.2 Precipitation $\delta^{18}O$ [DJF]
Rain-out effect

\[
dq_{Dp} = \alpha \left( \frac{q_{Dv}}{q_v} \right) dq_v
\]

Fractionation (\(\alpha\))

heavy isotopes tend to enriched in condensation phase

\[\delta D \text{ (liquid)} > \alpha \delta D \text{ (vapor)} \quad \alpha > 1\]

Water content (\(q_{H2O}\)) become decreasing toward the inland

More steeper due to fractionation (HDO)

Isotope value decreases depending on the rain-out of air mass.
**What is the ROI?**

The concentration is set to zero at the time of evaporation from the ocean, and then is forced to increase the amount of precipitation at each time step.

**Basic Equation for water vapor**

\[
\frac{\partial q^t}{\partial t} = -v \nabla q^t - \frac{1}{\rho} \frac{\partial}{\partial z} (F^D + F^C - F^P)
\]

**The Equation for tracing water vapor**

\[
\frac{\partial}{\partial t} (xq^t) = -v \nabla (xq^t) - \frac{1}{\rho} \frac{\partial}{\partial z} (F^D + F^C - F^P) + q^t_P
\]

**ROI**

\[
ROI = \frac{P^t_{xq}}{P^t_q}
\]

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**For Example**

- P1/P2 = 5/10 → ROI = 0.5

<table>
<thead>
<tr>
<th>t=0</th>
<th>t=1</th>
<th>t=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5mm</td>
<td>5mm</td>
<td>10mm</td>
</tr>
</tbody>
</table>
Rain-out effect

\[ \delta^{18}O_{\text{prec}} \text{ const } \delta_{\text{Evp}} \]

JJA

DJF

precipitation05/precipitation03
T42L20iso

DJF

precipitation01/precipitation
T42L20iso
Global isotopic pattern seems to be controlled by the rain-out history from the source region.
Factors controlling isotopic value

Surface Isotopic distribution

Isotopic variabilty due to rain-out

Isotopic field of precipitation

\[ \delta(\text{prec}) = \delta(\text{source}) + \varepsilon \times \text{ROI} \]  
(\(\varepsilon\): fractionation factor)
Isotopic variability of precipitation is related with moisture transportation pattern associated with low pressure system.

Moisture source contribution

Isotopic variability of precipitation has negative correlation with rainfall amount.

Regional rain-out contribution

Correlation between $\delta^{18}O$ and rainfall
Isotopic variability in the atmospheric water is closely related with integrated history during transportation from source region. Thus, good reproducitiveness of water isotope field results in the model can successfully simulate the hydrological cycle in the atmosphere.
Thank you for your attention!