Investigation of Moisture Recycling over Amazon Basin: A Modelling Approach using HadCM3

Presented by

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Main objectives of this study are

- How land cover changes change hydrological cycle, primarily net precipitation change and spatial distribution of $\delta^{18}O$ change over Amazon Basin

- Quantify the contribution due to recycling changes

- How this is reflected in $\delta^{18}O$ (precipitation)
• Amazon river discharges approximately 17% of all freshwater to the oceans (Callede et al. 2010)

• The Amazon forests have indeed been reduced in size substantially by deforestation

• Changes in vegetation cover effects the amount of water recirculating to the atmosphere, also the hydrological cycle of the basin (Nobre et al. 1991).
Stable water isotope can be used as a good proxy for precipitation.

It is a better tool to study convective processes and the hydrological cycle.

Stable isotopes of water in hydrology are helpful to:
- Identify the moisture source for precipitation.
- Study spatio-temporal variation for moisture in the atmosphere.
- Understand the post-precipitation evaporation.
- Investigate ground water discharge.
- Investigate the effects of evaporation on the ground water systems.
Amazon hydrological cycle isotopes, International Atomic Energy Agency

Cedrela odorata temporal patterns in precipitation

We thus propose to provide a new powerful constraint on the problem by reconstructing large centennial scale trends and ‘regime shifts’. δ^18O changes in the hydrological cycle but require careful analysis, as well as increased data coverage both in space and time. The opposing trends at longer time scales thus may hold clues for recent and future trends of the Amazon hydrological cycle.

During wet years, we would expect a negative relation between the amount of rainfall in the basin and transport across the Basin. During dry years less rainfall in the basin and more depleted in the western part of the Amazon basin due to preferential removal of the heavier water (δ^18O) from the air parcel.

One conclusion is that tree rings are accurate recorders of water isotope signatures in precipitation. During very wet years, δ^18O in precipitation is positively correlated with the increase in Amazon runoff, but instead we find that the trend of the Bolivian tree ring record over the last 150 years is negative (Fig. 2). As the long term trend of δ^18O in precipitation is positive (Fig. 2), this negative relation between the amount of rainfall in the basin and transport across the Basin is possibly shed some light on what to expect in the future.

Specifically, at interannual to decadal scales there is a strong correlation between Amazon. Specifically, at interannual to decadal scales there is a strong correlation between rainfall in the basin and Amazon river discharge at Obidos, which is consistent with reduced evaporation over Amazon. Specifically Lake Titicaca sediment records indicate that the Amazon was drier than today during the last glacial maximum which have been attributed to an intensification of the tropical Atlantic trade winds. During very wet years, δ^18O in precipitation is positively correlated with the increase in Amazon runoff, but instead we find that the trend of the Bolivian tree ring record over the last 150 years is negative (Fig. 2). As the long term trend of δ^18O in precipitation is positive (Fig. 2), this negative relation between the amount of rainfall in the basin and transport across the Basin is possibly shed some light on what to expect in the future.
Changes of precipitation and $\delta^{18}$O over Amazon basin

• Strong correlation between $\delta^{18}$O recorded in eight trees at a Bolivian Amazon site and Amazon river discharge at Obidos

• One conclusion is that tree rings in this species are accurate recorders of $\delta^{18}$O in precipitation.

Brienen et al. PNAS 2012
Simulations

This is a modeling analysis which attempts to give us a better understanding the relation between isotope signatures and changes of the hydrological cycle.

<table>
<thead>
<tr>
<th>Simulations</th>
<th>Greenhouse Gas</th>
<th>Land Use and Land Cover</th>
<th>Simulation Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fixed land Simulation</td>
<td>Fixed at Pre-industrial (280 ppm)</td>
<td>Land cover fixed at 1870</td>
<td>1870 - 1900</td>
</tr>
<tr>
<td>2. Deforestation Simulation</td>
<td>Fixed at Pre-industrial (280 ppm)</td>
<td>Broad leaf trees replaced with bare land</td>
<td>1870 - 1900</td>
</tr>
</tbody>
</table>
Land cover fractions prescribed in three simulations

- Fraction of Broadleaf trees
- Fraction of C4 type Grass
- Fraction of Bare Land

Fixed Land Simulation
Deforestation Simulation
Observed Land Simulation
Results

Deforestation – Fixed land Simulation (1870 – 1900)

Precipitation difference (mm/day)

Land fraction of precipitation

$\delta^{18}O$ in precipitation (per mil)

Recycling from land

Water Isotope ($d^{18}O$)

mm/day

per mil
Observed land – Fixed land Simulation (1870 – 2015)

Precipitation difference (mm/day)

- Dry Season (JJA)
- Wet Season (DJF)
- Annual

Land fraction of precipitation

Recycling from land

$\delta^{18}O$ in precipitation (per mil)

Water Isotope (d18o)
Oceanic fraction of precipitation
In the deforestation simulation, the precipitation reduced and low level circulation got weaken over Amazon.

Effects of changes of land surface on hydrological cycle

The general patterns of fields in Deforestation – Fixed and Observed – Fixed are similar but magnitude much larger.

The effect of deforestation is higher in the dry season than in the wet season. The moisture recycling from the land has reduced by about 20%.

Moisture recycling tracer proofs helpful to understand the patterns in isotopes
Thank You
• The $\delta^{18}$O simulated from observed land cover simulation have been validated against GNIP data. ... you may need to explain a tiny bit

• Global Network of Isotopes in Precipitation (GNIP) observational database
Observed Land Simulation vs CRU Precipitation (1975 – 2012)

a. HadCM3 (JJA)
b. CRU (JJA)
c. HadCM3 - CRU (JJA)
d. HadCM3 (DJF)
e. CRU (DJF)
f. HadCM3 - CRU (DJF)
g. HadCM3 (Annual)
h. CRU (Annual)
i. HadCM3 - CRU (Annual)
Ecuador series
\[ r_{\text{mean}} = 0.45 \]
\[ \text{EPS} = 0.93 \]

Bolivia series
\[ r_{\text{mean}} = 0.69 \]
\[ \text{EPS} = 0.99 \]
Trend for the period 1870-2015

Precipitation Trend (JJA)

Precipitation Trend (DJF)

Precipitation Trend (Annual)

d18o Trend (JJA)

d18o Trend (DJF)

d18o Trend (Annual)

Recl rat T1 Trend (JJA)

Recl rat T1 Trend (DJF)

Recl rat T1 Trend (Annual)
Stable water isotope can be used as a good proxy for precipitation.

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Stable isotopes of water in hydrology are helpful to:

- Identify the moisture source for precipitation
- Study spatio-temporal variation for moisture in the atmosphere
- Understand the post-precipitation evaporation
- Investigate ground water discharge
- The effects of evaporation on the ground water systems
Wind@850 difference w.r.t. Fixed land simulation

Bare–Fixed Sim(JJA)

Observe–Fixed Sim(JJA)

Bare–Fixed Sim(DJF)

Observe–Fixed Sim(DJF)

Bare–Fixed Sim(ANN)

Observe–Fixed Sim(Annual)
Mean Wind@850 hPa from All Three Simulations

- Bareland Sim(JJA)
- Bareland Sim(DJF)
- Bareland Sim(ANN)
- Observeland Sim(JJA)
- Observeland Sim(DJF)
- Observeland Sim(Annual)
- Fixedland Sim(JJA)
- Fixedland Sim(DJF)
- Fixedland Sim(Annual)
MSLP difference w.r.t. Fixed land simulation
Divergence from All three Simulations

Bareland Sim(JJA) 1870 – 1899

Bareland Sim(DJF)

Bareland Sim(Annual)

Observeland Sim(JJA) 1985 – 2014

Observeland Sim(DJF)

Observeland Sim(Annual)

Fixedland Sim(JJA) 1870 – 1899

Fixedland Sim(DJF)

Fixedland Sim(Annual)
Conclusions

- The
seasonality (DJF-JJA)
annual average temp

deg C

-10  -5.  0.0  5.0  10.  15.  20.  25.  30.  35.  40.
standard deviation - annual temp

degC

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 4.0
standard deviation - annual precip

mm/month

0.0  1.0  2.0  4.0  8.0  16.  32.  64.  128  256  512  102
Oxygen isotopes in the Amazon hydrological cycle

-16‰  →  -15‰  →  -14‰  →  -13‰

-7‰  →  -6‰  →  -5‰  →  -4‰

"Continental effect"

Dry years

Tropical North Atlantic

Wet years
Amazon river discharge at Obidos

Amazon basin precipitation

Tropical Atlantic SST (17S to 20N)

Gloor et al. GRL 2013
Oxygen isotopes in the Amazon hydrological cycle

Dry years

Wet years

“Continental effect”
Rayleigh Distillation

Isotopic ratio of water isotopes \((R)\)

\[
\frac{R(t)}{R(0)} = f^{\alpha - 1}
\]

\(f\) - Fraction of water remaining

\[
f = \frac{N(t)}{N(0)}
\]

From conservation of momentum,

we can conclude that \(\frac{N(t)}{N(0)}\) may change

But cannot say that \(N(0)\) changed
Maybe show records of Roel / possibly Jessica

There seem to be long-term patterns

[maybe also one slide with main winds / circulation of the lower troposphere over Amazon – 1991 paper of Nobre ..]

Explain possible mechanisms - mention Raleigh distillation

...

Show a map with deforestation in Amazon
1991 paper of Nobre .. [two stable states ???]

This is a modelling analysis which attempts to give us a better understanding the relation between isotope signatures and changes of the hydrological cycle

Simulations and diagnostics

- Use your table
- Need to explain what the recirculation ratio is – Van der Ent paper
  say how implemented – add an additional water vapor tracer – water vapor which is evaporated from the land ...
What can water oxygen isotopes tell us about changes in the Amazon Hydrological Cycle?

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