Characterize land-ocean convective differences using lightning/radar
Attempt to explain differences
Detangle thermodynamic/aerosol effects
Comparison with my thesis results

Lightning strong function of vertical motions
Stronger/broader updrafts over land
Why?
Also prefers terrain

TRMM PR 40 dBZ echoes > 7 km
TRMM PR ‘warm rain’ pixels
(> 18 dBZ below freezing level)
Thermodynamic effect

- Sun warms land more than oceans
- More unstable buoyant forcing -> stronger updrafts
- Use lightning as proxy for updrafts
- Supply mixed phase region with more liquid water
- Effects take place below/above cloud base
- Use lightning over islands to test thermal/aerosol hypothesis

W = 5 m/s; h = 500 m; r = 1 km; τ = 1 hr
MINIMUM ISLAND AREA ≈ 110 km²

Aerosol effect

- Continental regions have more pollutants
- Higher CCN concentrations
- Modify drop size distribution
- Inhibit/delay warm rain processes
- Effects only in-cloud
\[ 2 R/h > 100 \]

A Huge area difference

\[ \pi \left( \frac{100A}{2} \right)^2 = 20,000 \text{ km}^2. \]

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THERMAL EFFECTS

AEROSOL EFFECTS

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United Nations Environmental Program/ WMO

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Land</th>
<th>Ocean</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCS Concentration (per cm²)</td>
<td>&gt;1000</td>
<td>100–200</td>
</tr>
<tr>
<td>Surface relative dryness (%)</td>
<td>20–40</td>
<td>80</td>
</tr>
<tr>
<td>Cloud base height (m)</td>
<td>1000–4000</td>
<td>500</td>
</tr>
<tr>
<td>( T_\text{s} - T_\text{a} ) (°C)</td>
<td>1–10</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Median cloud base uplift speed (m/s)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>CAPE (J kg(^{-1}))</td>
<td>0–1000</td>
<td>0–3000</td>
</tr>
<tr>
<td>Bowen ratio ( emissible/latent)</td>
<td>0.2–1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\[ W_{\text{RBC}} = \sqrt{2 \text{ CAPE}}. \]

\[ \frac{W_{\text{Land}}}{W_{\text{Ocean}}} = \sqrt{\frac{\text{CAPE}_{\text{Land}}}{\text{CAPE}_{\text{Ocean}}}}. \]
Higher cloud bases → broader updrafts (thermal or dynamic)

Also thicker boundary layers → more continental surface air in updrafts??
STRONGER UPDRAFT AT CLOUD BASE (Aerosols not to blame)

Summary

- Argue for thermal hypothesis
  - Dry boundary layer
- Island size
- Aerosols only take effect in-cloud
- Parcel theory not enough, need to take account of other thermodynamic variables/effects

Lightning, thermodynamic and hydrological comparison of the two tropical continental chimneys
E.R. Williams, G. Satori
Parsons Laboratory, Massachusetts Institute of Technology, USA
Geodetic and Geophysical Research Institute, Hungarian Academy of Sciences, Sopron, Hungary

ATS 780: ATMOSPHERIC ELECTRICITY;
PROF. DR. STEVEN RUTLEDGE
Introduction

- The two major tropical continental zones of active convection—Africa and South America—are compared from the standpoint of lightning activity, rainfall, thermodynamics, hydrology and aerosol-influenced cloud microphysics.
- Comparisons of temperature, diurnal temperature range, insolation, Bowen ratio, response to semiannual forcing, inundation fraction, boundary layer relative humidity and associated cloud base height are done.
- All self-consistent in showing a more continental surface for Africa than South America.

Global lightning and Schumann resonance intensity

- In every month of the year, the flash rate density in the Congo exceeds that in the Amazon, by a substantial margin.
- The African dominance is attributable both to the greater number of thunderstorms and to a higher mean flash rate per storm (Williams et al., 2000).
- The African chimney dominates the signal in Hungary and the South American chimney dominates in the U.S. (Satori et al., 1999).

Fig. 1: Monthly mean values flashes/km$^2$/yr for the two basins are shown.

- Fig. 2 shows the annual mean of daily-validated Schumann resonance intensity, $E_z$, for Hungary and $H_{NS}$ at the Rhode Island station in the U.S., both before and after the removal of distortions.
- Two independent stations with different field components and correction factors for Africa and the US.
- Both show Africa as the dominant chimney region, peaking in the time frames 14–17 UT as in the classical analysis of the global circuit (Whipple, 1929).
- The Schumann resonance results are therefore consistent with the space-based lightning observations.
Rainfall in tropical chimneys

- The easterly flow toward Africa is diverted by off-equatorial land mass upstream, most notably by India in producing the Indian monsoon in Northern Hemisphere summer.
- No such diversion of easterly flow occurs in the southern hemisphere in the case of Africa.
- A second influence — elevated terrain on the eastern margins of continental chimneys.
- The Ethiopian highlands and the East African Plateau in Africa induce rising motion that removes condensate from easterly flow and deprives the regions downstream of rainfall.

Hydrology and water balance

- The mean annual Congo basin rainfall (1570 mm) is < the Amazon (2150 mm).
- A key distinction — the mean elevation, with the Congo more elevated than the Amazon by 300–400 m.
- The combination of greater rainfall and lower, flatter topography in the Amazon blurs the distinction there between land and water.

Temperature

- The role of air temperature in influencing lightning activity is interesting.
- A direct comparison of surface air temperature is problematic due to the contrast in surface elevation and the systematic decline of temperature with altitude.
- The use of potential temperature corrects for this.
- Reduced humidity over Africa in comparison with South America is responsible for lower wet-bulb values over Africa (imp for instability and lightning activity).
Insolation

- Sunlight reaching the Earth’s surface is crucial for surface air temperature, controlling surface evapotranspiration, and in destabilizing the atmosphere to produce local rainfall and lightning activity.
- More sunlight reaches the surface during the wet season in Africa than in South America.
- The mean values for the Congo are 34% greater than the Amazon.
- During the driest months, the mean surface insolation in the Congo is less than the Amazon. This result may be attributable to the effect of smoke from fires in the dry season in Africa.

Response to diurnal forcing

- The diurnal temperature range (DTR), quantified as the difference between mean max and min daily surface air temperature, is an important measure of surface properties and their response to sunlight.
- The DTR is small (1◦C) over oceans (Bottomley et al., 1990) where evaporation dominates over sensible heat flux.
- DTR is quite large over deserts (∼20◦C) where sensible heat flux dominates.
- In both wet and dry situations, the mean DTR in Africa is greater than in South America, approximately 2◦C.

Response to semiannual forcing

- A substantial contrast in response to the semiannual forcing between the Congo and the Amazon basins is apparent in temperature, rainfall and lightning activity.
- SR records at both NC and RI, and at both 16-17 UT and 19-20 UT, exhibit maxima in the Northern hemisphere summer (June-July) due to the increased lightning activity.
- The semiannual SR variations are in accordance with the OTD/LIS satellite lightning observations (Christian et al., 2003).
- Both kinds of lightning observations indicate different seasonal (semiannual) characteristics in the tropical latitudes of Africa and South America.
Relative humidity and cloud base height

- Updraft width and velocity should scale with cloud base height.
- Broader updrafts are less likely to be diluted by mixing and more likely to achieve speeds predicted by parcel theory.
- Explanation for contrast in lightning between land and sea (Williams and Stanfill, 2002).
- The cloud base height is established when surface air is lifted and cooled to the point of water saturation.
- Cloud base height is determined by relative humidity, with only minor temperature dependence in this relationship.

Fire and smoke

- Tropospheric aerosols affecting precipitation (Rosenfeld, 1999; McCollum et al., 2000) and the electrification of clouds.
- The months with greatest number of fires are August for the Amazon basin and June/July for the Congo basin.
- More year-to-year variance in the Amazon than the Congo.
- These months also show minimum values for relative humidity of surface air in the two basins.
- Satellite measurements of aerosol optical depth (Chu et al., 2002) also show a more polluted Africa on a continental scale.

Discussion

- Thermal hypothesis: less rainfall in Africa (on account of synoptic-scale low), less surface evaporation, larger Bowen ratio, a deeper, drier boundary layer, larger convective bubbles entering the moist phase, more efficient conversion of CAPE to updraft kinetic energy, larger, broader cumulonimbus updrafts, more intense phase microphysics, and greater lightning activity.
- Congo basin is more continental than the Amazon.
- Insolation fraction, max daily potential temperature, diurnal temperature, response to solar forcing on semiannual time scale.
- Thermodynamically favorable to stronger updrafts and greater lightning activity over Congo.
- More continental surface in the Congo basin is characterized by a larger Bowen ratio.
- Bowen ratio = ratio of sensible heat flux to latent heat flux.
- Annual water balance results and the surface insolation.
Mean evaporation is comparable in the two basins, but the insolation evidence (Fig. 6) indicates that greater sunlight is required at the surface for the Congo to achieve the same evaporation.

- The runoff coefficient (R.C.) is another measure of continentality.
- R.C. = Runoff/Rainfall = 1 – (Evaporation/Rainfall)
- Smaller R.C. for the Congo.
- Enhanced dry bulb temperature is favored over an enhanced dew point temperature in influencing instability necessary for lightning activity (Williams et al., 2003).
- Enhanced dry bulb temperature is favored over an enhanced dew point temperature in influencing instability necessary for lightning activity (Williams et al., 2003).
- The systematic differences in measured relative humidity (and inferred cloud base height) between Amazon and Congo basins (Fig. 9) are consistent with the systematic contrast in lightning activity (Fig. 1).

Role of the aerosol

- Aerosol hypothesis: More prevalent fires in Africa -> larger aerosol production -> smaller cloud droplets -> reduced precipitation efficiency -> reduced rainfall -> drier surface conditions -> drier and more flammable vegetation -> enhancement in liquid water content attaining the mixed phase region of moist convection.
- Drier conditions favor the aerosol hypothesis, and great lightning activity.
- Fire is dominant within the Amazon basin on an annual basis (Fig. 10), yet the Congo clearly dominates in the lightning activity (Fig. 1).
- The aerosol chain of reasoning neglects the synoptic-scale delivery of moisture to continental chimneys that may be fundamental to the lightning contrast between the Amazon and Congo.

The Global circuit issue

- 37% more rainfall in the Amazon basin than the Congo basin.
- Observations of lightning from space (Fig. 1) show greater flash rate density over the Congo than the Amazon by a mean annual factor of 2.8.
- Williams and Stanfill (2002) show evidence for more numerous shower clouds of the “warm” cloud variety in the Amazon than the Congo.
- May be the basis for South America’s predominance in the “dc” global circuit and the maximum of the “Carnegie Curve” near 19 UT.
- The apparent contradiction in the behavior of the global electrical circuit presented by Africa’s clear lightning dominance is resolved by the presence of larger numbers of electrified rain showers in South America than in Africa.
- This asymmetry may also have origins in both thermodynamics and aerosol physics.