ENSO RELATIONSHIP WITH INDIAN RAINFALL IN DIFFERENT MONTHS
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Received 23 March 1999
Revised 1 October 1999
Accepted 4 October 1999

ABSTRACT
The rainfall anomalies in All India (AI) and its six subdivisions, North west (NW), North central (NC), west peninsular (WP), North east (NE), east peninsular (EP), and south peninsular (SP), were examined during years of different categories representing ENSO effects, in the period of 1901–1990. Unambiguous ENSO-U had the best association with droughts in NW, NC, WP, in the monsoon months June, July, August and September, but with large month-to-month variability in some events, indicating the effects of Madden–Julian Oscillations (MJO). In subdivisions NE, EP, SP, effects were mixed, with droughts in monsoon months preceded and/or followed by, or interspersed with, excess rainfall in some months. In La Niñas (C events), effects were generally opposing those of ENSO-U.

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KEY WORDS: sea surface temperature; rainfall; drought; flood; India; El Niño; La Niña; Southern Oscillation; ENSO

1. INTRODUCTION
El Niño (EN) refers to the invasion of anomalously warm surface waters along the southern Ecuadorian and Peruvian coastal regions, which are usually under the influence of cooler waters from coastal upwelling and the northward flowing Peru current. Quinn et al. (1987, Table 1, pp. 14450–14451) have made a determination of occurrence and intensity of EN events by considering several factors at the Peru and Ecuador coastal regions, such as:

1. Disruptions of the anchoveta fishery and marine bird life.
2. Reports of events affecting the coastal regions.
3. Hydrological data.
4. Coastal sea surface temperature (SST).
5. Coastal rainfall.
6. Characteristics of the Southern Oscillation Index (SOI).
7. Data from only one core of the Southern Oscillation (SO).
8. SST over the equatorial Pacific.
9. Rainfall at central and western equatorial Pacific islands.

ENs (warmer waters in the Peru–Ecuador coast) are generally associated with low values of the SOI, represented by Tahiti minus Darwin pressure difference. However, as mentioned in Deser and Wallace (1987), EN can occur both in advance of, and subsequent to, major SOI negative swings. In addition, the two may even occur separately. Differences in the effects of ENs may depend on the longitude distribution of the Pacific SST anomalies (Fu et al., 1986; Ward et al., 1994). Trenberth (1993) refers to different ‘flavours’ of EN. Most of those working in this field obtain composites lumping together all warm events,
e.g. all EN (Rasmusson and Carpenter, 1983), or all SOI minima (Kiladis and Diaz, 1989), or all warm water events in the Pacific (Mooley and Paolino, 1989). Recently, Kane (1997a,b, 1998a,b,c, 1999) attempted a finer classification in which Unambiguous ENSOW type events were found to be overwhelmingly associated with droughts in India, southeastern Australia and some other regions. These were EN years (Quinn et al., 1987, list cited above), during which the SOI (represented by Tahiti minus Darwin atmospheric pressure difference, T − D) had a minimum (SO) and the equatorial eastern Pacific sea surface temperatures SST had a maximum (W) in the middle of the calendar year. In the present communication, the behaviour of rainfall in All India (AI) and its six subdivisions in different months is examined for the various categories of years (ENSW etc.).

2. DATA

Sontakke and Singh (1996) divided India into an optimum six zones: North west (NW), North central (NC), west peninsular (WP), North east (NE), east peninsular (EP), and south peninsular (SP) (Figure 1), and presented a summer monsoon (June–September) rainfall series for periods extending back to the early part of the 19th century, while Singh and Sontakke (1996) presented similar series for other seasons also (JF = January, February; MAM = March, April, May; JJAS = June, July, August, September; OND = October, November, December, and Annual). Following Singh and Sontakke (1996), the rainfall values for JF, MAM, JJAS, OND (in mm) are used in the present analysis, but only from 1901 onwards, as these are expected to be more reliable. Table I illustrates the characteristics of these series.

For commencement and evolution of the EN, the SST at Puerto Chicama (Peru coast, 8°S, 80°W) are used. These are available from 1925. Since 1950, CPC (Climate Prediction Center of National Oceanic and Atmospheric Administration's National Centers for Environmental Prediction) have submitted their monthly Climate Diagnostic Bulletins, average monthly temperatures in four geographical regions, Niño 1 + 2 near the Peru–Ecuador coast (0°–10°S, 90°W–80°W), Niño 3 at (5°N–5°S, 150°W–90°W) and Niño 4 at (5°N–5°S, 160°E–150°W). Among these, Niño 1 + 2 region temperature variations match those of Puerto Chicama SST very well, except that the Puerto Chicama SST anomalies are larger by an
Table I. The mean rainfalls (mm) and their standard deviations for the Indian zones NW, NC, NE, WP, EP, SP and AI, for the months JF, MAM, JJAS, OND and Annual

<table>
<thead>
<tr>
<th>Region</th>
<th>Period</th>
<th>JF</th>
<th>MAM</th>
<th>JJAS</th>
<th>OND</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW</td>
<td>1844–1994</td>
<td>26 ± 14</td>
<td>26 ± 16</td>
<td>698 ± 1189</td>
<td>35 ± 29</td>
<td>784 ± 138</td>
</tr>
<tr>
<td>NC</td>
<td>1842–1994</td>
<td>37 ± 23</td>
<td>66 ± 30</td>
<td>1037 ± 132</td>
<td>79 ± 51</td>
<td>1218 ± 152</td>
</tr>
<tr>
<td>NE</td>
<td>1829–1994</td>
<td>41 ± 21</td>
<td>431 ± 82</td>
<td>1507 ± 126</td>
<td>170 ± 70</td>
<td>2150 ± 172</td>
</tr>
<tr>
<td>WP</td>
<td>1841–1994</td>
<td>9 ± 10</td>
<td>55 ± 31</td>
<td>925 ± 166</td>
<td>107 ± 53</td>
<td>1095 ± 188</td>
</tr>
<tr>
<td>EP</td>
<td>1848–1994</td>
<td>21 ± 19</td>
<td>81 ± 41</td>
<td>842 ± 108</td>
<td>204 ± 81</td>
<td>1147 ± 152</td>
</tr>
<tr>
<td>SP</td>
<td>1813–1994</td>
<td>24 ± 20</td>
<td>204 ± 66</td>
<td>918 ± 138</td>
<td>395 ± 106</td>
<td>1541 ± 174</td>
</tr>
<tr>
<td>AI</td>
<td>1813–1994</td>
<td>27 ± 13</td>
<td>99 ± 20</td>
<td>903 ± 90</td>
<td>125 ± 35</td>
<td>1153 ± 107</td>
</tr>
</tbody>
</table>

approximate factor of 2. Central Pacific SST index values were obtained from Angell (1981) and Wright (1984) and refer roughly to Niño 3 region. SOI was obtained from Wright (1977, 1984) and Parker (1983).

3. FINER CLASSIFICATION OF ENSO EVENTS

In the literature, the term ENSO is used for the general phenomenon of El Niño/Southern Oscillation. Here, it will be used in the same sense, only in general terms; however, for specific designation of years, their literary meaning is used.

Thus,

1. EN = Presence of El Niño (warmer waters) at Puerto Chicama (Peru–Ecuador coast) (List of Quinn et al., 1987, and later, visual inspection of the plots).
2. SO = Presence of minimum in the SOI, Wright Index or Tahiti minus Darwin atmospheric pressure difference (T – D), i.e. maxima in (D – T).
3. W = Presence of maximum (positive anomalies) in the SST in the eastern equatorial Pacific (Niño 3 region). Anomaly exceeding 1.0°C.
4. C = Presence of minimum (negative anomalies) in the SST in the eastern equatorial Pacific region (Niño 1 + 2 and Niño 3 region). All La Niñas (C events) mentioned by various researchers are included here.

Various combinations of these were seen. Of major interest are events of type ENSOW, where EN existed (Quinn et al., 1987, list), SOI minima (SO) also existed and, eastern equatorial Pacific SST was warmer (W). The SOI and SST plots of monthly values are often erratic. However, their 12-monthly running means are smooth and show distinct maxima and minima, as seen in the various plots in Kane (1997a,b). These were used to check whether the SOI minima and/or SST maxima occurred in the middle of the calendar year (May–August). If so, the events were termed as ENSOW-U, i.e. Unambiguous ENSOW. If the extremes were in the earlier or later part of the year (not in the middle), the events were termed as ENSOW-A, i.e. Ambiguous ENSOW. As shown in Kane (1997a,b, 1998a,b,c, 1999), the ENSOW-U were overwhelmingly associated with droughts in India, southeastern Australia, and some other regions. Other combinations were ENSO, ENW, in which EN existed at Puerto Chicama, but either SOI minima or W existed, not both (dephasing mentioned by Deser and Wallace, 1987), and ENC (EN followed by C in the same year). Other combinations not involving ENs were

1. SOW which means SOI minima (SO) existed, equatorial eastern Pacific temperature was warmer (W), but there was no EN mentioned in the Quinn et al. (1987) list.
2. SO, only SOI minima existed.
3. W, only central Pacific was warmer.
4. SOC (SO followed by C in the same year).
5. C (the cold) events.
6. Years having neither an EN, nor SO, nor W, nor C, termed as non-events.
All the years are classified in six major categories, namely: (a) ENSOW-U; (b) ENSOW-A; (c) Other ENs; (d) SOW etc.; (e) Non-events; (f) C events, where (a, b, c) refer to ENs only. The classification is available from 1871 onwards.

4. EN EFFECTS IN DIFFERENT MONTHS

4.1. Effects on AI rainfall

In AI, major rainfall (78%) occurs in the summer months JJAS (more in July and August). A similar pattern is seen in NW, NC and WP, which together form 69% of total Indian area. The pattern in NE (8% area) is broader, with substantial rainfall in spring also. In EP (11% area) and SP (12% area), there are substantial rainfalls in autumn and winter also.

Figure 2 is a plot of AI rainfall anomalies (deviations from the long-term average, in mm) in different months (JF, MAM, JJAS, OND), for sequences of 4 successive years, in which the second year is either an ENSOW-U or an ENSOW-A. Rainfalls above normal (positive anomalies, excess rainfall, and floods) are shaded black, while rainfalls below-normal (negative anomalies, deficit rainfall, and droughts) are shown hatched. Table II gives the average rainfall anomalies (composites) for the various months for various categories of years (ENSO etc.). The following may be noted:

1. The anomalies in the months JF, MAM and OND are very small (a few mm) and insignificant. Thus, for AI rainfall, EN effects in non-monsoon months are not important.
2. In the monsoon months (JJAS), the ENSOW-U has a significant association with rainfall deficits in all 4 months. Figure 3 shows the frequency distribution of the AI rainfall anomalies for this group of 12 ENSOW-U years. Most of the anomalies are negative (droughts).
3. In the ENSOW-A events and other types of ENs, the average anomalies are smaller and mixed, positive as well as negative.
4. In events not involving EN, but involving SO and/or W, results are mixed, deficits in June, August, and September and excess rainfall in July.
5. In non-events, anomalies are small and insignificant, as expected. However, some standard errors are large (exceeding 10 mm), indicating large anomalies in some non-event years.
6. In C events, the anomalies in June are small; but anomalies in July, August and September are large, positive and significant. Thus, the effects of cold events are opposite to those of the ENs of the ENSOW-U type, as expected.

Are these effects seen for every individual event in each category? An examination of Figure 2 reveals the following:

1. In the ENSOW-U of 1905, 1918, 1951, 1965, 1972 and 1987, at least 3 months among JJAS had negative anomalies (droughts) and 1 month was negative, or near normal. In the ENSOW-U of 1902, 1911, 1930, 1957, only 2 months had negative anomalies. In ENSOW-U of 1982, June, July, September had strong negative anomalies; but August had a strong positive anomaly.
2. In the ENSOW-A of 1914, 1919 (II), 1923, 1925 (I), 1926 (II), 1931 (II), 1940 (I), 1948, 1953, 1958 (II), 1963, 1969, 1976, 1983 (II), at least 2 months had positive anomalies, while the other 2 months were normal or had negative anomalies. Several of these are II-year events (I and II represent first or second year of consecutive events, 1925 (I), 1926 (II) etc.). Thus, none of the several ENSOW-A is associated with droughts as such; some are associated with floods.
3. In the other ENs, the ENSO of 1912 and EN of 1932 gave mixed effects (2 months with positive deviations, 2 with negative deviations), while the EN of 1929 and 1939 gave at least three negative deviations (droughts), as expected. In the other events, ENC of 1907 gave three negative deviations, indicating that the EN part was effective; but ENC of 1917, 1927, 1973 gave more positives than negatives, indicating the effect of C. In these events, the duration of EN seemed to be important. For example, in the double event of 1972–1973, the 1973 part of EN was effective only for 2 months, JJ. For later months, including the Indian summer months, only C was operative and excess rainfall was expected and observed.
4. Among events not involving ENs but only SO and/or W, the SOW of 1904 and 1913 had droughts as expected, but SOW of 1977 and SO of 1959 had floods, while SO of 1974 had mixed results. The W of 1920, 1968, and 1986 had droughts, also expected.

Figure 2. AI rainfall anomalies (mm) during intervals of 4 successive years, in which the second year is either an ENSOW-U or an ENSOW-A; positive anomalies are painted black and negative anomalies are shown hatched

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Table II. Average AI rainfall anomalies (mm) in different months, for years of different categories (ENSOW etc.)

<table>
<thead>
<tr>
<th>Category</th>
<th>JF</th>
<th>MAM</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>OND</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENSOW-U</td>
<td>-3 ± 3</td>
<td>1 ± 5</td>
<td>-28 ± 9</td>
<td>-50 ± 15</td>
<td>-23 ± 10</td>
<td>-21 ± 10</td>
<td>-7 ± 9</td>
</tr>
<tr>
<td>ENSOW-A</td>
<td>-5 ± 4</td>
<td>1 ± 6</td>
<td>-20 ± 10</td>
<td>25 ± 10</td>
<td>24 ± 12</td>
<td>-11 ± 9</td>
<td>-3 ± 7</td>
</tr>
<tr>
<td>Other EN</td>
<td>5 ± 4</td>
<td>2 ± 6</td>
<td>-10 ± 11</td>
<td>4 ± 11</td>
<td>4 ± 12</td>
<td>-5 ± 19</td>
<td>14 ± 12</td>
</tr>
<tr>
<td>SOW etc.</td>
<td>2 ± 4</td>
<td>3 ± 6</td>
<td>-11 ± 9</td>
<td>15 ± 9</td>
<td>-21 ± 10</td>
<td>-24 ± 11</td>
<td>7 ± 10</td>
</tr>
<tr>
<td>Non-events</td>
<td>5 ± 5</td>
<td>-5 ± 5</td>
<td>9 ± 10</td>
<td>4 ± 10</td>
<td>-2 ± 10</td>
<td>-1 ± 14</td>
<td>-10 ± 8</td>
</tr>
<tr>
<td>C events</td>
<td>0 ± 3</td>
<td>1 ± 8</td>
<td>1 ± 8</td>
<td>13 ± 8</td>
<td>23 ± 7</td>
<td>25 ± 6</td>
<td>4 ± 9</td>
</tr>
</tbody>
</table>

5. Among the non-events, 1901, 1915 and 1952 had droughts, 1947, 1978, 1981 and 1984 had floods and 1989 was normal. The average effect was normal, but individual non-event years could have unexpected droughts or floods.

6. Among the C events, a majority (1903, 1910, 1916, 1922, 1924, 1942, 1950, 1954, 1955, 1956, 1964, 1975 and 1988) had floods, 1906 was normal, 1962, 1970 and 1971 were mixed, and 1928 had droughts. Thus, the majority effect for C was of floods, as expected, but some events were unexpected.

4.2. Effects on rainfall in subdivisions

For studying the effects in the six subdivisions, the ENSOW-U of 1905, 1918, 1951, 1965, 1972 and 1987 (moderate or strong EN) were chosen as, in these years, at least 3 summer months had shown association with droughts in AI rainfall. The following was noted:

1. The drought effects were clearly seen in all events for subdivision NW of India. In subdivisions NC and WP, similar drought effects were seen; but in some months, there were significant positive anomalies (excess rainfall), probably as a result of causes unrelated to the EN.

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Figure 3. Frequency distribution of the AI rainfall anomaly magnitudes (mm) for the 12 ENSOW-U events for the months JJAS; the mean values (with standard deviations) for these months are indicated

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2. The anomalies in subdivision NE were almost opposite to those of NW, NC, WP in some events (1905 and 1918) but similar in some other events (1972). Thus, NE could have droughts or floods during EN years.

3. In subdivisions EP and SP, drought effects were seen but there were generally positive anomalies also, before or after the monsoon months (JJAS), or occasionally even during JJAS. Thus, EN effects in these subdivisions were mixed and not unique.

4. An interesting feature was the large month-to-month variability seen in some events, including change of sign (positive anomalies followed by negative anomalies, or vice versa). It is well known that over a major part of India, rain occurs in spells under the influence of favourable circulation conditions, with quasi periods of 3–6 days and 10–20 days. In monthly values, only the 30–60 day variation would be seen. Such an oscillation, called Madden–Julian oscillation (MJO, Madden and Julian, 1971) is associated with the globally eastward-moving wave, number 1 and 2, in the tropics. Over monsoon regions like India, there is a poleward movement of weather anomalies, including rainfall (Singh et al., 1992 and references therein). Using data for 80 years (1901–1980), Singh et al. (1992) studied the MJOs in the Indian monsoon rainfall and concluded that their intensity and period had considerable interannual variability, but it was not related to the overall performance of the monsoon, or the ENSO. Vernekar et al. (1993) examined the MJOs in several global meteorological fields for two contrasting monsoon seasons, 1987 (deficient monsoon) and 1988 (excess rainfall), and found that the global spatial distribution of MJOs was greater in 1987 than in 1988, and many other characteristics were different in 1987, as compared with those in 1988. Because both MJOs and ENSO are global scale dynamical features of the tropics, and both involve slow eastward shift of the large scale convective anomalies, it is expected that the two phenomena should have some interrelation, for example, that envisaged in the hypothesis of Lau and Chan (1986, 1988). However, the month-to-month variability was very large in some events, but very small in some others, indicating that MJOs are not equally effective in all EN events (not even in all ENSOW-U type events) and MJOs and ENSO may or may not be related.

5. Recently, there was a very strong EN (1997–1998, stronger than even the 1982–1983 event, which was the strongest till then), but the SST anomaly maxima and SOI minima occurred in the end part of 1997, not in the middle, and hence, 1997–1998 is a double event in which both 1997 and 1998 are ENSOW-A (like 1925–1926 or 1991–1992). As such, only normal rainfalls were expected in AI in 1997 and 1998. This expectation came true. From consideration of other parameters, the India Meteorological Department (IMD) had also predicted near normal rainfall in both 1997 and 1998, and their prediction came true. However, press reports indicate that the rainfalls in various parts of India varied considerably from month-to-month. MJOs were very active in both these years. Trenberth (1998) mentions the presence of intraseasonal oscillations (40–50 day MJO), which were very prominent in the westerly wind anomalies in the far western Pacific, with westerly bursts in December 1996, February, May, August, October and November 1997, each one traceable as a down-welling Kelvin wave propagating rapidly eastwards across the Pacific in about 3 months. Thus, within the overall envelope of the eastward developing subsurface temperature anomalies in the Pacific during the first half of 1997, there was a structure, as a result of the MJOs. The first surface warming in March 1997 coincided with the arrival of the down-welling Kelvin wave generated in December 1996. Thus, the role of MJOs in the development of at least some EN events, such as the 1997 event, seems to have been important (Li and Liao, 1998).

5. PREDICTIONS BASED ON ENSO AND OTHER PARAMETERS

In the various plots, there are indications that ENSO may not be the only parameter affecting Indian rainfall. When plots were made for AI rainfall anomalies for 10 non-events, it was noticed that some non-events were associated with substantial positive and/or negative anomalies, obviously as a result of parameters unrelated to ENs. The month-to-month variations were large, indicating MJO effects even in...
non-events. Generally, for Indian rainfall, Himalayan and Eurasian snow cover are reported to have an inverse relationship. A recent study by Kripalani et al. (1996), however, suggests that the Indian monsoon is better related to snow depth over Russia than to Eurasian snow cover. Relationships with SST and wind speed over the central Arabian Sea, with stratospheric wind Quasi-biennial Oscillations (QBO) and with the latitudinal location of the axis of the 500 hPa ridge along 75°E are also reported. Presently, attempts are being made to apply statistical models using three types of predictors, namely: (i) upper air flow over India; (ii) heat low development over southern Asia and meridional pressure gradient and cross-equatorial flow over the Indian Ocean; and (iii) the SO (Gowarikar et al., 1989, 1991; Thapliyal and Kulshrestha, 1992). Long range seasonal forecasts for the southwest monsoon rainfall for the Indian summer (JJAS) are issued by the IMD sometime in May. For the last few years, this scheme is giving very good predictions for the JJAS Indian summer monsoon rainfall. For the 1997 summer monsoon, their prediction was of near normal rainfall, which actually happened, in spite of the strong EN. However, for the 1998 summer monsoon, IMD predicted normal rainfall, for the 11th year in succession. Actually, the rainfall turned out to be excessive in many parts of India. It is interesting to note that in the finer classification of Kane (1997a,b), the 1997–1998 EN would be an ENSOW-A in both the years and was not expected to yield droughts. It is also interesting to note that Kripalani and Kulkarni (1997a,b) reported epochal behaviors for All India Summer Monsoon (AISM) series, i.e. for long epochs, the rainfall was either above normal (1880–1895 and 1930–1963), or below-normal (1895–1930 and 1963–1990), further reporting that the El Niños were more effective in causing droughts when the epoch was below-normal. This may be a definite conclusion about the ENSO relationship with Indian rainfall because, since 1990, AISM is in the above normal epoch and hence, EN effects would be less severe, as appears to have happened in 1997–1998. Incidentally, Harrison et al. (1997, p. 29) used the UKMO unified model (integrated) to predict AISM and concluded the following: ‘The present skill of the model does not allow a quantitative forecast of the monsoon rainfall over India. However, the spatial pattern of anomalies does indicate below-average rainfall over India during July–September, 1997’. This prediction did not come true.

6. CONCLUSIONS

The relationships between the month-to-month rainfall anomalies in the AI rainfall and rainfall in 6 subdivisions NW, NC, NE, WP, EP, and a finer classification of EN, C event and other types of years were examined for 1901–1990. The following was noted:

1. Not all EN years were associated with droughts in India. The ENSOW-U type years had the best association with droughts in subdivisions NW, NC and WP. In some events, large month-to-month variations were observed, indicating the effect of MJOs. In subdivisions NE, EP and SP, effects were mixed, with negative anomalies followed or preceded by, or interspersed with, positive anomalies.
2. In other types of EN years, or events of types SOW, SO, W, effects were mixed or insignificant.
3. In C types of events, excess rainfall occurred in NW, NC, WP, with large month-to-month variability in some events. In NE, EP, SP, effects were mixed.
4. In some non-events, extreme rainfalls (large positive or negative anomalies) were observed, indicating that these could be caused by parameters unrelated to the ENSO phenomenon.

The role of ENSO and other parameters in affecting Indian rainfall is already being taken into account in the prediction schemes by the IMD. For the last 11 years, their predictions have been of more or less normal monsoons, which have been realized (rainfalls within ±9% or ±σ of normal), in spite of the presence of ENs in 1991–1992 and 1997–1998. The role of MJOs seems to be very important in causing month-to-month variability. The MJO effects may differ from subdivision to subdivision and may cause altogether different rainfall patterns in the different subdivisions. MJOs are prominent in some EN events but not in all. MJOs are prominent in some non-events also, indicating that MJO and ENSO phenomena may not be interrelated, or may operate at least partly independently. Furthermore, ENs are better associated with droughts in India during below-normal rainfall epochs.
Thanks are extended to Dr Todd Mitchell and Dr Don Garrett for supplying Puerto Chicama SST data and to Dr Don Garrett for EN and other data through the Web site of Climate Prediction Center, NOAA, NCEP, Washington. Thanks are also extended to Dr Angell and Dr Wright for supplying updated SST data. This work was partly supported by FNDCT, Brazil, under contract FINEP-537/CT.

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