Coupling Geo-informatics and Simulation Models for Studying Climate Risk Assessment of Rice Ecosystems and Adaptation Trends in South Asia

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Abstract
Rice has been the harbinger of food and nutritional security in South Asia. Increase in temperature, higher CO_2 *concentrations and abnormal patterns of precipitations coupled with higher frequency and intensity of drought and floods are likely to enhance considerably the climate risk to the rice agro-ecosystems. It is in this context that the study on climate risk assessment to rice based agro-ecosystems, has been conducted. A proof of the concept study was taken up using ORYZA series of soil-vegetation-atmosphere transfer (SVAT) models. These models have been extensively validated in rice agro-ecosystems of different parts of the world as well as in India to simulate the growth and yield of rice. The effects of elevated temperature and* CO_2 *concentrations on the yield of rice grown in three agro-ecologically different environments of South and Eastern parts of India have been analyzed. While higher* CO_2 *concentrations have usually been associated with increasing rice yield and higher temperatures have yield reducing impact, this trend however has been found to be inconsistent in case of the different rice varieties grown in the study areas. Those having higher sensitivity and larger variance in the relationship between rise in temperature and reduction in crop yield have found riskier in climate change scenarios. For those climatic sensitive regions, the adaptation need is therefore to develop rice crop varieties having higher tolerance to increase in temperature and more responsive to higher* CO_2 *concentrations. The adaptation trends with regards to rice to the changing climate have been captured and analyzed along with cross-cutting institutional issues leading to the integration of climate change adaptation and disaster risk reduction in climate sensitive South Asia.*

1. Introduction

While the aggregate effect of climate change on agricultural production at global level could be small to moderate, the regional and sub-regional impacts are likely to be significant on food security scenario especially in the vulnerable agrarian economies. Food security, in varying crop yields and instable levels of productivity, is extremely dynamic as well as complex. The climate change impacts at regional/sub-regional levels as well as ecosystem levels are likely to be uneven and unpredictable. South Asia is one such vulnerable region wherein impacts on food security would be considerable. With the changes taking place in the climate systems vis-à-vis the consequent impact on agricultural ecosystems, food security assumes the prime concern in South Asian region. The layers of vulnerability lie not only to the responses of agricultural ecosystems to the changing climate but embedded into the socioeconomic characteristics of the region. Low-income populations dependent on marginal agriculture are barely food-sufficient and even the slightest decline in yields would turn them food insecure. In the region, the most negative effects are foreseen in dryland areas, and in arid and semi-arid areas, especially for those reliant on rainfed, non-irrigated agriculture (Climate Change and Disasters: SAARC Report 2008). It is likely that marginal agriculture may be most vulnerable both to short term variations of weather and longer term changes of climate. This may be compounded when farming is practiced at or near the edge of its appropriate climatic region (FAO, 2007). In the rural areas of the region, agriculture continues to be the main source of livelihood for the poor and marginalized section of the population. Monsoon variability, alterations in the intensity and seasonal patterns of the precipitation, coupled with an increased risk of critical temperatures during the reproductive phases of crop growth cycle, have added considerable uncertainty to the food production. Agricultural ecosystems, which support the livelihood security to the majority of rural population in South Asia, are progressively being exposed to threats from increased climatic variability and, in the longer run, to climate change. Increasing carbon dioxide and temperature, further compounded by uncertain and abnormal frequency and intensity of drought and flood events, have long-term implications for the sustainability of these ecosystems. As climatic patterns change, so also do the spatial distribution of agro-ecological zones, which can have significant impacts on food security in the future (FAO, 2007). Further, the projected increase of global mean temperature between 1.4 and 5.8^{0}C by 2100 (IPCC, 2007) is expected to have considerable impacts on the hydrological system, sea level, agricultural ecosystems and thus on crop production leading to food insecurity of the poor and marginalized population especially in the rural areas (Chaudhary and Aggarwal, 2009). Understanding climate change impacts on rice based agro-ecosystems at regional/sub-regional levels is not clear because of (i) uncertainties in down-scaling the regional climate change predictions/projections at local levels; (ii) limited insights into certain agricultural processes, such as 'fertilization' response of different crops to increased levels of atmospheric CO_2 in conjunction with elevated temperature; and (iii) uncertainty regarding the potential for adaptation of agricultural practices. In this regard, the paper presents an analysis on the outcomes of well-calibrated rice simulation model with regards to the potential rise in temperature as well as CO_2 in the different rice based agricultural ecosystems as well as adaptation trends and possibilities as well as the challenges in South Asian region towards food security in changing climate regime.

2. Rice, Food Security and Impact of Climate Change in South Asia

Worldwide, rice has been the main source of food and nutritional security to the large cross-section of the people. For example, rice provides more than 500 calories per person per day for over 3 billion people (FAOSTAT, 2008), while rice cultivation has been the principal activity and source of income for more than 100 million households in developing countries in Asia, Africa and Latin America. The advances in research and extension, especially in 70s and 80s, have increased global rice production to be able to meet the demand of the growing population, created marketable surplus to the farming community, and also enhanced nutritional security of the poor populations across the world. The gains made during the Green Revolution, however, are now in the process of diminishing returns in recent years. Since 2000, world rice production has been less than rice consumption and the deficit has been addressed by drawing on rice from buffer stocks. Alarmingly, more than 852 million people continue to suffer from hunger and malnutrition (FAO, 2004). The world population continues to grow steadily, while land and water resources are declining. Furuya and Koyama (2005) have reported that high temperatures would cause a marked decrease in world rice production. In fact, rice in South Asia is the staple food for a large majority of population, and constitutes more than 40% of the total food production. It is grown on more than 50 Mha under a diverse set of agro-environments varying in seasons, temperatures, rainfall, soil types, hydrology, varieties and input management. To meet the increasing demand of ever growing population, for example in India, it is estimated that rice yields must increase by at least 45% by 2020 to meet the future demand (Kumar, 1998 and Mall and Aggarwal, 2002). On the contrary, several intensively cultivated areas such as in north India have started showing signs of rice yield stagnation and deterioration of soil health (Sinha et al., 1998, Kumar and Parikh, 1998 and ICAR, 2007). It is therefore important to understand the potential impact of climate change on rice based production systems for developing appropriate strategies to adapt to the likely outcomes on long-term food security, which will continue to be driven by the interaction between rice production and climate change (Nguyen, 2004). Further, in South Asia, the food security depends on the ability of the agricultural ecosystems to produce rice under the limiting conditions of water, nutrients and lands. In Bangladesh, India, Nepal and Sri Lanka rice provides more than 800 kcal per person per day to more than 50% of the population, and thus holds considerable significance for food and nutritional security. The recent studies suggest that the temperature increases, rising seas and changes in rainfall patterns and distribution expected as a result of global climate change could lead to substantial modifications in land and water resources for rice production as well as in the productivity of rice crops grown in South Asian region (FAO, 2007). The vulnerability of rice-based agro-ecosystems is reflected in terms of varying yields due to increase in the levels of CO_2 and temperature. There are several studies in South Asian conditions, which have brought in impact on climate change/variability on rice crop. In order to investigate the role of climate change on rice cultivation, three rice models namely MACROS (Penning de Vries et al., 1989), RICESYS and CERES rice (Alocilija and Ritchie, 1988) were used to simulate rice growth from the expected climate scenario. Major emphasis was laid on the effect of CO_2 on growth and yield of rice.

It was found that 2×CO_2 situations increase the yield under laboratory conditions. Penning de Vries (1993) showed that the potential yield of rice with CO_2 at 50 ppm and 1^0C increase in temperature would result in a slight increase in the potential yield of rice. The increase in the warmest regions is the smallest. Lack of accurate predictions of climate change hampered the certainty of these conclusions. However the effect of climate change on precipitation and its consequences on the yield of rice is not quantified in these studies (Bouman, 1993a, 1993b). Rosenzweig and Parry (1994) have estimated significant adverse impact on the agriculture of many developing countries. In a more detailed study of India, Kumar and Parikh (1997 and 1998) examined the impact on agricultural yields, output, income and prices. They estimated that: (a) yield losses (without considering the carbon fertilization effect) for rice vary between 15 to 42 percent for temperature increases of 2.5°C to 4.9°C; (b) even with carbon fertilization effects, losses would be in the same direction but somewhat smaller; (c) with adaptation by farmers of cropping patterns and inputs losses would remain significant; with a temperature change of +2°C and an accompanying precipitation change of +7 percent, farm level total net-revenue would fall by 9 percent, whereas with a temperature increase of +3.5°C and precipitation change of +15 percent, the fall in farm level total net-revenue would be nearly 25 percent. From South Asia point of view, a 2°C increase would clearly make larger impact to the rice production and would thus have negative impacts on food security.

3. Climate Risk Assessment: Concept, Methods and Study Areas

The climate risk assessment to the agricultural ecosystems holds the key to understand future food security situations as well as to target those ecosystems/region which are extremely vulnerable in the changing climate scenarios. The existing practices of climate risk assessment are quite broad. Crop specific assessment makes it 'actionable' for developing adaptation strategies at local levels. Recent developments in simulation modeling for rice have proven the usefulness of combining hydrologic and crop growth models and their applicability in water use applications (Penning de Vries, 1989, Selvarajan et al., 1991, Palanisamy and Flinn, 1988, Meena Rani et al., 1996, 1999 and 2001, Srivastava et al., 2000 and Aggarwal and Mall, 2002). This methodology has been validated for several rice growing environments in several rice growing regions including India. It is primarily because of this reason that this methodology has been adopted for rice crop risk assessment at different locations of rice ecosystems. The present study thus deals with climate risk assessment with regards to rice based agro-ecosystems based on the universally accepted rice specific crop simulation model study.

3.1 Experimental Study for Crop Risk Assessment

Crop Simulation Models (CSMs) such as ORYZA1 have immense potential in quantifying the potential production of rice in diverse agro-ecological regions. This model has been calibrated and validated in India's agro-ecosystems. Using this model, the present study has been conducted in three different environments/locations representing three different agro-climatic conditions. The three study areas include Orissa, Kerala and Tamil Nadu. In India, rice is hydrologically characterized based on the rainfall of different regions. Kerala, Southern part of India, represents regions with rainy season for six months or more, Orissa, Eastern part of India, represents regions with rainy season for three months or more and Tamil Nadu (part of South India) represents regions with rainy season for two months or more. Agro-ecologically, Orissa is described as sub-humid tropics, Kerala as warm humid and per-humid tropics and Tamil Nadu as warm sub-humid and semi-arid tropics. The present study was carried out in collaboration with the Central Rice Research Institute (CRRI) located at Cuttack in Orissa; Kerala Agricultural University (KAU) at Tavanur in Kerala; and Tamil Nadu Rice Research Institute (TNRRI) in Tamil Nadu. The details with regards to study areas and methodology are explained in Appendix I. Taking into account the typical crop and weather variabilities of the study areas, the experiment was designed to capture these and establish its sensitivity in model simulations.

3.2 Results and Discussion

ORYZA1 predicts potential production for the entire growing season. The main structure and basic routines are from the Wageningen models for potential production (MACROS module L1D – Penning de Vries et al., 1989 and INTERCOM – Kropff and van Laar, 1993). An important advantage of this model is that it can be used to simulate realistic yields and to assess the impact of planting date, weather and latitude at measured leaf nitrogen contents. The experimental results are analyzed hereunder:

3.2.1 Spectral interfaces to ORYZA

Based on statistical modeling involving correlation and regression analysis between leaf area index (LAI) and spectral NDVI (Normalized Difference

Vegetation Index), polynomial functions were fitted between these two variables. The polynomial function was chosen as it represents a more realistic relation between the two variables. The polynomial function was then inverted to calculate LAI within the model. The calculated LAI thus becomes the forcing function (Figure 1) to simulate yield, biomass and various other crop parameters. The results of the different levels of simulation are also graphically depicted in Figures 2a and 2b for Biribati and Kandarpur test sites (near, Cuttuck, Orrisa, India) respectively. From Figures 2a and 2b, it is interesting to note that when the crop model ORYZA is combined with remote sensing data, it certainly performs better by simulating yield closer (simulation levels 3 and 4, i.e. FSSAY – Field Spectroradiometer based Simulated Actual Yield and RSSAY – Remote Sensing based Simulated Actual Yield respectively), to the observed/actual field measurements rather than when the crop model is used on a stand alone basis (ORMSY - ORyza Model Simulated Yield). FLSAY is the Field LAI based Simulated Actual Yield. Spectral interfaces to ORYZA have brought the model output closer to reality. On one hand, the results validate the ORYZA model in agro-ecological conditions of Orissa and on the other hand, the strategy improves the models' performance to a significant extent. The forcing function strategy has been found to be the most effective in interfacing spectral inputs to CSMs.

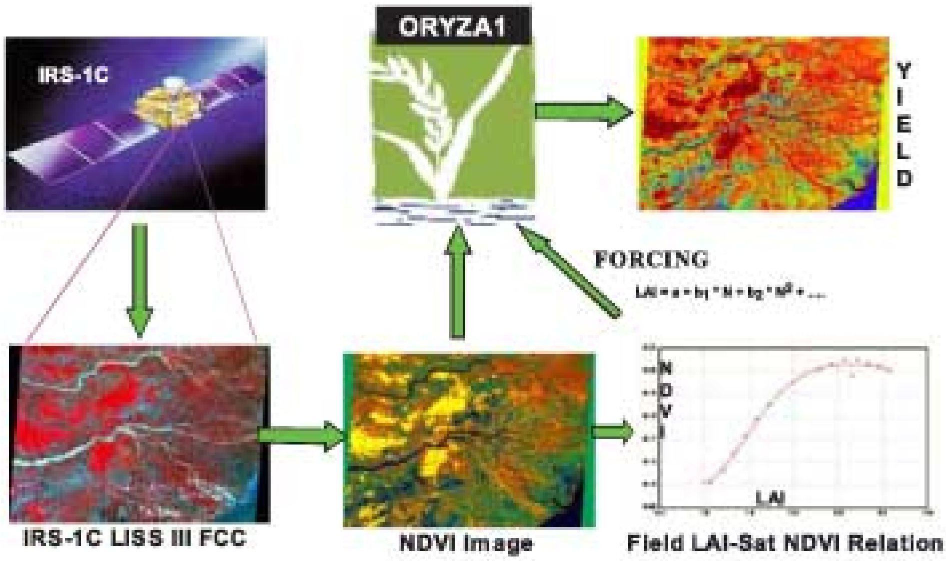

Figure 1: Spectral interfaces to ORYZA: Forcing function strategy

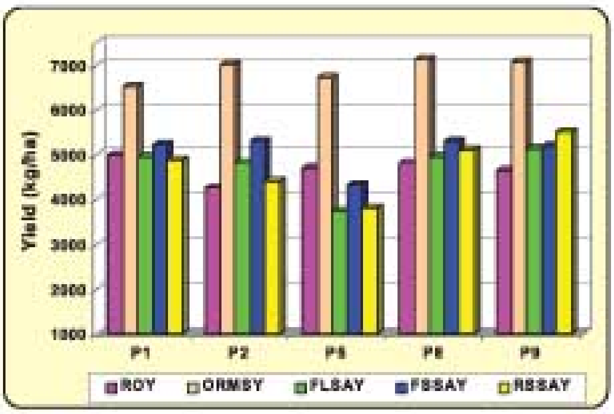

Figure 2a: Validation of yield with reported observed yield (ROY) at Biribati (1996)

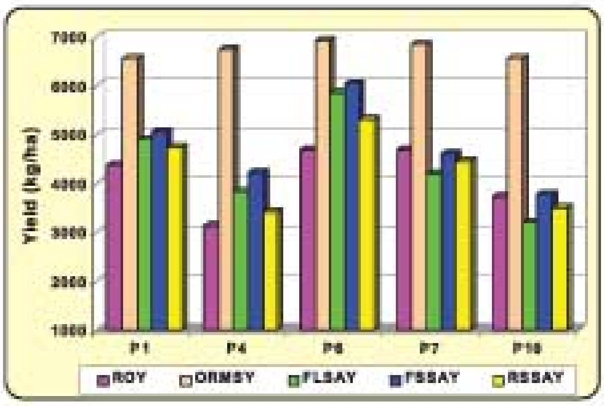

Figure 2b: Validation of yield with reported observed yield (ROY) at Kandarpur (1996)

3.2.2 Effects of increasing CO_2 concentrations on the yield of rice

Estimates were made to quantify the effect of temperature and CO_2 rise on the yield of rice grown in the different study areas. Twelve different climate change scenarios (Matthews et al., 1995) resulting from changes in temperature and atmospheric CO_2 concentration was evaluated with the model for their impacts on rice production. On an average, the study areas exhibited a gradual increase in yield with higher CO_2 concentrations (Figure 3a). The crop growth duration remains constant.

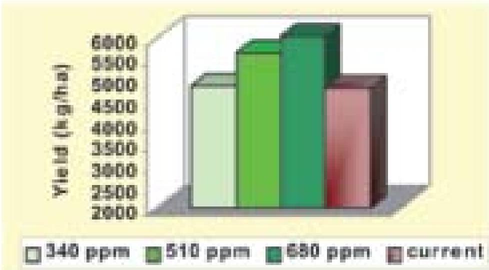

Figure 3a: Yield at 1⁰C rise in temperature and different CO2 concentrations

The cumulative photosynthetically active radiation (PAR) available for photosynthesis remains more or less constant with very slight variation and so is the development stage (DVS). LAI is found to change very slightly but biomass increased considerably. Hence, it may be concluded that the higher yield obtained with increasing CO_2 concentrations is due to an increased photosynthetic activity, where CO_2 availability for photosynthesis is not a constraint. A correlation between CO_2 concentration and rate of photosynthesis was reported in quantitative studies of Kreusler (1887), Brown and Escombe (1902), and Pantanelli (1903). The trends obtained in the present study are in agreement with those obtained by Achanta (1993), using the CERES rice model (Godwin et al., 1993) for weather conditions of Pantnagar in Uttar Pradesh. However, the quantitative expressions of productivity changes differed much as the simulation was done only for the potential production situation. Although increasing atmospheric CO_2 stimulates plant growth, the beneficial effects on rice growth have been observed for levels only up to 500 ppm. Furthermore, the benefits of increased CO_2 would be lost if temperatures also rise as can be seen from the discussion below.

3.2.3 Effects of elevated temperature on the yield of rice

The results of the effects of increasing temperature on rice yield are presented in Figure 3b. On an average, there is a gradual decrease in yield at higher temperatures.

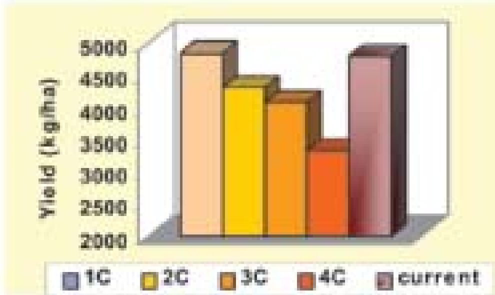

Figure 3b: Yield at 340ppm CO2 concentration and rise in temperature

Analysis of plots of LAI vs time shows a reduction in crop growth duration at higher temperatures and at a given CO_2 concentration. This is essentially seen to happen around the reproductive (grain filling) period of the rice crop, thus causing the decline in yield at higher temperatures. These results also corroborate the findings of Matthews et al. (1995) in the case of potential yield simulation.

3.2.4 Combined effects of elevated temperature and CO_2 concentration on the yield of rice

The combined effects of temperature and CO_2 increase on rice yield are shown in Figure 3c. The fraction of current yield (FCY) depicts that the yield is reduced/increased by a factor x times the current yield. It is a dimensionless variable ranging from 0 to 2 for the different varieties grown in the study areas.

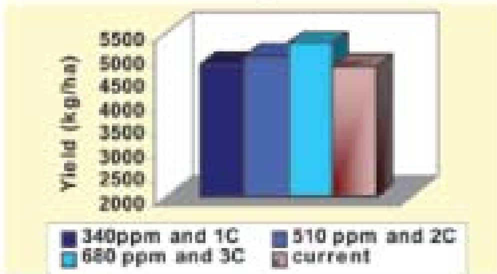

Figure 3c: Combined effects of temperature and CO2 rise

Variations in the trends of FCY are depicted in Figures 4a to 4d for typical rice varieties grown in the different study areas. The FCY curves show different trends in the case of high yielding varieties (HYVs) and traditional varieties grown in Orissa. In the case of CR1018 and CR1077 (Figure 4a), there is a continual decrease in the yield upto +3°C and at all CO_2 levels. Beyond +3°C at all CO_2 levels, the yield is found to increase.

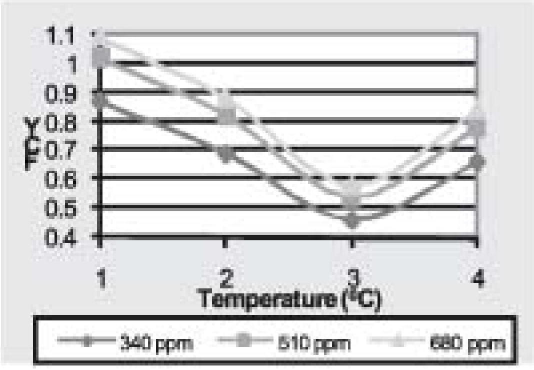

Figure 4a: Variation of yield under different climate change scenarios – CR1077, Plot 3, Kandarpur in Orissa, 1996

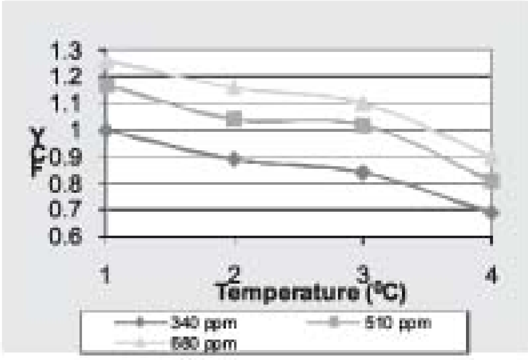

Figure 4b: Variation of yield under different climate change scenarios - Jagannath, Plot 8, Biribati in Orissa, 1996

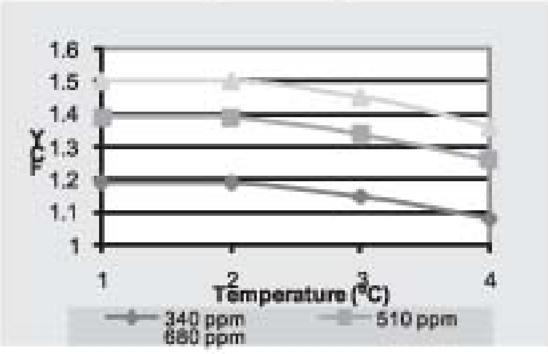

Figure 4c: Variation of yield under different climate change scenarios – Red triveni, Pattambi in Kerala, 1996

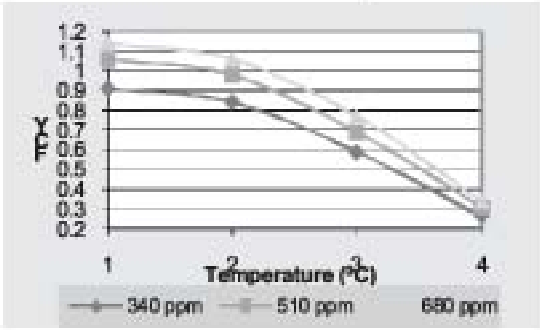

Figure 4d: Variation of yield under different climate change scenarios – ADT36, Kelamaruthuvakudi in Tamil Nadu, 1997

The characteristic trend seen in the HYVs grown in Orissa may be attributed to the efficiency of these genotypes in accommodating itself to the changed climate scenarios. These varieties, being genetically engineered are able to sustain the adverse effects of higher temperature. Though the normal perception is that traditional varieties are more resistant to environmental changes, the present case, particularly in the context of rice does not agree with this. In the case of the traditional variety, Jagannath grown in Orissa, the trend in the response of yield to changes in CO_2 and temperature is quite different (Figure 4b). It is seen that the yield does not stabilize even at +4°C and shows a continual decrease at all CO_2 levels. This response of the traditional varieties may be attributed to the fact that these varieties do not have the capacity to withstand the effects of higher temperatures. This may be causing adverse effects on physiological processes such as enzyme activity, photosynthesis, transpiration, etc. In the case of rice varieties - Red triveni and Kanchana grown in Kerala, the yield is found to be constant upto +2°C (Figure 4c) at all CO_2 levels after which the yield starts decreasing. While in the case of rice varieties grown in Tamil Nadu, the response of yield to climate change shows a very steep reduction in yield especially beyond +2°C and at all CO_2 levels (Figure 4d). Although HYVs are cultivated in Kerala and Tamil Nadu, these are not tolerant to temperature rise as observed in the present study. Such trends may be attributed to the differences in climatic and edaphic factors characteristic of these agro-ecosystems. In general, for all study sites, the yield is found to be stable with a slight decrease upto +2°C and at all CO_2 levels.

3.3 Key Findings

The study arrives at the following conclusions:

a) The operational framework for coupling spectral inputs to the Soil Vegetation Atmosphere Transfer (SVAT) Model, ORYZA for rice-based agro-ecosystems has been established. Spectral interfaces to the SVAT model have enabled the simulation of yield, LAI and other variables very close to the actual field estimates. c) The results obtained from the different levels of simulation have been interpreted for all the study areas comprising different agro-ecological zones viz., Cuttack (Orissa-Eastern India), Thanjavur (Tamil Nadu-Southern India) and Malappuram/Palakkad

(Kerala-Southern India). About 100% increase in rice cultivation in coastal Orissa between 1950 and 1990 has contributed to the extent of more than 300% increase in water flux through crop transpiration.

d) Unlike Coastal Orissa, there has neither been a dramatic increase in rice cultivation nor the phenomenal migration of moisture flux from rice based agro-ecological regions comprising Kerala and Tamil Nadu. However, the increase in cropping intensity has contributed to a substantial amount of moisture outflux in these ecosystems as well.

e) Studies on the impact of elevated temperature and CO_2 concentrations reveal that high CO_2 concentrations favor production while high temperatures are associated with yield reduction. Aggregating together the impacts of increased temperature and CO_2 concentration, it was observed that the negative impacts on yield because of temperature rise are likely to be compensated by increasing CO_2 concentrations.

f) High Yield Varieties (HYVs) grown in Cuttack (CR1018 and CR1077) respond differently to temperature rise by showing decrease in yield upto +3°C and increase in yield beyond +3°C. The traditional varieties (Jagannath) were not found to withstand the effects of higher temperatures and this is the reason probably, that the yield continues to decrease with increasing temperature. The HYVs grown in Kerala and Tamil Nadu show continual decrease in yield at higher temperatures. Varieties grown in Tamil Nadu show greater yield reduction than those grown in Kerala. The trends observed in the Southern regions have been attributed to the inherent agro-ecological conditions. In general, for all study sites, the yield is found to be less sensitive upto +2°C and at all CO_2 levels.

g) From climate risk assessment point of views, the study reveals clearly that rice-based agro-ecosystems in Tamil Nadu have shown much greater sensitivity and variance to the crop yield with respect to the rise in temperature, and thus having higher degree of risk and vulnerability followed by Kerala and Orissa.

h) The impact of climate change on water use of the rice crop is found to be quite significant in the study sites located in Orissa and those in Kerala and Tamil Nadu. With rise in temperature and CO_2 concentration, the water use is expected to go up and consequently, the withdrawal of water from the local hydrological cycle to meet crop water requirement will increase significantly in the future. This phenomenon may result in altering the hydrological regimes in many rice-growing areas of the country.

4. Climate Change Adaptation for Food Security: Emerging Trends

Adaptation involves adjustments to decrease the vulnerability of rice production to climate changes (Burton 2004). There are a range of technological options which could potentially be developed in the near future for enhancing the rice production systems' ability to adapt to and mitigate the effects of climate changes. The engineering/technological adaptation options are more visible (Box I) than autonomous adaptation at community level, which is more pronounced among small and marginal farmers of South Asia. Reilly and Schimmelpfenng (1999) have shown the relative speed of adoption of various adaptation measures (Table 1). While the time taken for relatively soft adaptation measures such as variety adoption and fertilizer adoption could be in the range of 3 to 10 years, the hard options like development of irrigation equipment and irrigation systems take much longer time. In a significant work, Jodha (1989) estimated response time of 5-15 years for items such as productive life of farm assets, crop rotation cycles, and recovery from major disasters. Broad categories of responses include: improved training and general education of populations dependent on agriculture; identification of the present vulnerabilities of agricultural systems; agricultural research to develop new crop varieties; food programmes and other social security programmes to provide insurance against supply changes; transportation, distribution, and market integration to provide the infrastructure to supply food during crop shortfalls; removal of subsidies, which can, by limiting changes in prices, mask the climate change signal in the marketplace.

Table 1: Adaptation options (Source: Reilly and Schimmelpfenng, 1999)

Adaptation Measures	**Adjustment Time (years)**
Variety adoption	3-4
Dams and irrigation	50-100
Variety development	8-15
Tillage systems	10-12
Opening new lands	3-10
Irrigation equipment	20-25
Fertilizer adoption	10

These adjustment times indicate that soft options could be more cost effective and hence should be explored first. Often the soft options may provide dual advantage of gearing up for the future climate change as well as providing benefits under the present-day conditions (Ravi, 2009). Adaptation leading to adjustment between rice ecosystems and climate conditions is therefore necessary in order to counterbalance any negative impacts of a changing climate. Farmers must have the ability to adjust to changes by adapting farming practices. Adaptation, such as changes in crops and crop varieties, improved water management and irrigation systems, and changes in planting schedules and tillage practices will be important in limiting the negative effects and taking advantage of the beneficial effects of changes in climate. More efficient use of mineral fertilizers and other adjustments in agricultural practices could also act to counteract the effects of climate change (Darwin et al., 2005 and Ravi, 2009). Various types and levels of technological and socioeconomic adaptations to climate change are possible. The extent of adaptation depends on the affordability of such measures, particularly in developing countries. Recent national studies show that the increased costs of agricultural production under climate change scenarios would be a serious economic burden for South Asian countries. Other important factors will be access to know-how and technology, the rate of climate change, and biophysical constraints such as water availability, soil characteristics and crop genetics (Nguyen, 2005). The biggest problem arises with the uncertainty surrounding the effects of climate change and the unknown time frames. For vast majority of developing countries climate change is a distant and invisible threat whereas they are presently exposed to a range of stresses (including climate related shocks such as cyclones, droughts and floods). If climate change response strategies were to be embraced by these countries it is imperative that such response strategies are aligned with development agenda. Also, the local population should feel that the adaptation is relevant and in their own interest. It is unrealistic to expect special policy initiatives to deal with climate change adaptation by itself, especially when so many of the suggested adaptation measures (such as drought planning, coastal zone management, early warning etc.) are currently being addressed in other policies and programmes.

Box I: Technical options for adaptation of rice crop to support food security

Selection of appropriate planting date: Germination and emergence of rice seedlings are more likely to be governed by maximum and minimum temperature. The selection of the appropriate date for planting the rice crop holds the key. As temperature varies from month to month, it is possible to select the right date for crop establishment in such a way that the reproductive and grain filling phases of rice fall into those months with a relatively favorable temperature. This would minimize the negative effect of temperature increase on rice yield. Efforts to collect and disseminate the information on month-to-month variation in temperature regimes in major rice-growing areas, therefore, are essential for helping rice production to adapt to climate changes.

Selection and development of appropriate rice varieties: Rice varieties have different abilities to tolerate high temperature, salinity, drought and floods. Rice varieties with a high level of salinity tolerance have been utilized to expedite the recovery of rice production in areas damaged by the *tsunami*. The selection of appropriate rice varieties is, therefore, another technical option for adaptation to global climate changes. Also, the development of rice varieties that have not only high-yielding potential, but also a good degree of tolerance to high temperature, salinity, drought and flood, would be very helpful under the environment of global warming.

Optimization of high CO2 concentration for higher yield: The high CO2 concentration present in the atmosphere under global warming could be harnessed to increase the productivity of the rice crop. The grain yield of IR8, for example, was significantly increased with carbon dioxide enrichment before and after heading. C4 plants, such as maize and sorghum, are more productive than C3 rice and wheat, because C4 plants are 30 to 35 percent more efficient in photosynthesis, especially when the level of CO2 concentration in the atmosphere is high. Cloned genes from maize may be required to regulate the production of enzymes responsible for C4 synthesis to alter the photosynthesis of rice from C3 to C4 pathway.

(Source: Nguyen, V.N. 2004 and Peng et al., 2004)

5. Cross Cutting Issues: Integration of Disaster Risk Reduction in Climate Change Adaptation

In the broader sense, climate change adaptation envisages climate proofing to the development programmes. At community level, there is autonomous adaptation which depends on the inherent adaptive capacity. Capacity could be enhanced further by more investment and absorption of technologies. It's a basically a planned adaptation and most of the interventions at policy and investment levels are made to realize this. Further, there are externalities, like Bali Action Plan, which bring priorities on strengthening both planned as well as autonomous adaptation (Burton I 2004. Fussel HM 2007; Ivey JL et al 2004; Moench M, Dixit A 2004). Disaster risk reduction is similar to climate change adaptation in several ways but not the exact. There is autonomous resilience which brings in coping at the community level. Preparedness for risk reduction calls for applications of technologies and also investments. There are externalities like Hyogo Framework of Action (2004) which place focus on disaster risk reduction by strengthening autonomous resilience as well as preparedness. What is therefore required is the integration of disaster risk reduction to climate change adaptation and vice versa (Pearce L 2003; Pittock AB, Jones RN 2000). Integration of Disaster Risk Reduction (DRR) into Climate Change Adaptation (CCA) is one of the challenges of crop risk management especially in case of rice in South Asia. There are several cross-cutting issues and the task can be addressed by identifying those areas which create divergence between DRR and CCA processes, as also those which create convergence between the two. The forces that create divergence are the following:

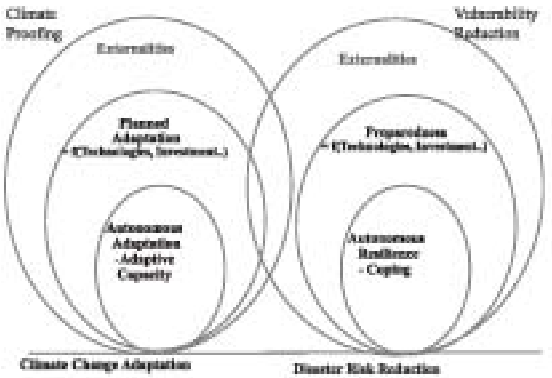

Figure 5: Twin processes of Climate Change Adaptation and Disaster Risk Reduction

Diverse Institutional Structure: The institutional arrangements that exist in South Asian countries are such that DRR and CCA experts and functionaries are usually different, respond to different needs and to the different constituencies and do not have authority to implement policy decisions in the areas other than their specific responsibilities. In fact, such structural barriers also exist at international and regional levels.

Disconnected Policies, Planning and Programmes: DRR and CAA policies, planning and programmes often take place in isolation without sharing the respective goals, methodologies and objectives.

Lack of Relevant Information: Information concerned with DRR and CCA are inherently complex which cannot be packaged easily for integration into respective concerns. DRR related info, for example, often does not describe environmental and socio-economic information of underlying risk factors which are required in support of pursuing CCA.

Ad-hoc Short-term Approaches: For most of DRR projects, risks to investments are not considered for the full life-time of the project and thus ignores climate change risks, impact and adaptation factors. The convergence between DRR and CCA processes has been observed in certain types of projects which need to be recognized for scaling-up and replications in the region, especially through regional cooperation. These are:

a) Integrated Coastal Zone Management
b) Participatory Watershed Development Programme
c) Land Use Planning in areas sensitive to climate and disaster risks
d) River-basin Floodplain Management
e) Integrated Drought Mitigation

The tools and techniques used for DRR such as early warning systems, hazard, risk and vulnerability analysis, risk assessment and monitoring, risk mitigation as well as response strategies need to be integrated with CCA strategies in the critical sectors like human health, food, water and environmental security, agriculture, forestry, tourism, etc. There are success stories and good practices demonstrating such integration, which should be replicated and further scaled up (Farrington, 1997, Govt of India, 2006 and Kerr et al., 2002). There are enabling mechanisms for integrating DRR and CCA through integration of appropriate technologies like Information and Communication Technologies (ICTs), Automatic Weather Stations (AWS), Doppler Weather Radars (DWR) etc. Similarly, networking of DRR and CCA institutions at national, regional and global levels coupled with multi-stakeholder communication and dialogues as well as exchange of information and expertise may catalyze such integration. From the 'conceptual framework' as outlines above to 'actionable strategies' (Figure 6), the following steps are suggested:

Step I: Targeting Climate Related Disaster Risks: Most of the Hazard, Vulnerability and Risk (HVR) Assessment efforts are based on the frequency of occurrence of disasters in spatial and temporal domains. Climate risks are not captured well and also the simulated climate change scenarios are not factorized to target the climate related disaster risks especially in the 'hotspots' of South Asian region. While the strategy calls for recasting HVR mapping efforts, such efforts enable closer integration of DRR and CCA in the operational domain of end-to-end project implementation. It is here in this context crop risk assessment assumes significance.

Step II: Designing Risk Reduction Strategies: Designing Risk Reduction Strategies for hydro-meteorological risks must essentially be based on using the knowledge of climate risks. For instance, if it is to develop an effective and people's centred EWS to provide 'actionable' information about a climate hazard to a vulnerable population, the assessment of climate risk should form the key inputs. Further, the strategies must be dynamic and in tune with the changing practices and conditions such as depletion of the ecological foundation of the natural resources such as coral reefs and mangrove forests may aggravate risks; further effective insurance and micro-finance initiatives to transfer risks and provide additional resources may reduce risks.

Step III: Integrating Climate, Weather & EWS Information in Decision Making; Besides implanting DRR in CCA projects, it is important to utilize advanced climate forecast information in managing risks from the existing climate variability and also utilize results from climate change models especially where known climate change impacts lead to a certain direction.

DRR - CCA Integration

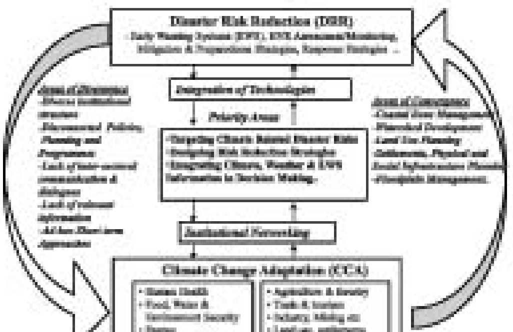

Figure 6: Converging and diverging factors of Climate Change Adaptation and Disaster Risk Reduction

As climate hazards are growing in number, more and more people in the region are turning vulnerable because of poverty, powerlessness, population growth, and the movement of people to marginal areas. Climate change has the potential to derail the poverty alleviation efforts in the region, punishing first and most, the very people least responsible for greenhouse-gas emissions – and increasing their vulnerability to the natural disasters further. Concerted national efforts are necessary in support of climate change adaptation and disaster risk reduction. Uniquely, with the inherited traditional knowledge reflected in several autonomous adaptation practices to reduce the crop vulnerability in face of weather variability, South Asia has got the civilizational heritage in terms of indigenous coping and community resilience. These heritages need further empowerment in terms of technology and knowledge to withstand the potential climatic shocks and their extremes. Further, with the growing climate risk, the adaptive capacity in South Asia is to be enhanced by providing the necessary financial resources, access to technology and knowledge, and by enhancing the institutional capacity. For example, the capital-intensive agricultural systems are less sensitive to climate, perhaps because they can control so many more inputs. Agriculture, water management, land use practices etc in South Asia are therefore to harmonize with changing climate regimes.

5.1 Thematic Areas for Enhancing Adaptation

The following focused thematic areas are recommended to pursue in addressing cross-cutting issues and promoting integration of DRR into CCA.

I. Adaptation to Climate Change

- Adaptation to climate change impacts and risks in vulnerable communities, locations and ecosystems,
- Adaptation in sectors (e.g. water, agriculture, fisheries, health and biodiversity)
- Adaptation to extreme climate events (e.g. flood, cyclone, glacial lake outburst, droughts and heat and cold waves)
- Adaptation to climate change impact (e.g. sea level rise, salinity intrusion, glacial melt and coastal and soil erosion,)
- Adaptation suited to urban settlements, coastal structures and mountain terrain

II. Management of impacts and risks due to climate Change

- Climate risk modeling and capacity building in the region on impact assessment of climate change.

- Sharing of information and capacity building in the management of climate change impacts and risks through cooperation in early forecasting, warning and adaptation measures,
- Cooperation in exchange of information on climate and climate change impacts (e.g. sea level rise, glacial melts, droughts, floods, etc.).
- Cooperation and sharing of good practices in disaster management

6. Conclusions

Rice holds immense importance for food security in South Asia. At the same time, rice is extremely sensitive to the climate change. The climate risk assessment of rice is therefore an important aspect for adaptation options. The present study demonstrates crop simulation modeling based approach for climate risk assessment to the rice crop grown in different agro-ecological zones of India. The results show that climate change as such could have major impacts on rice production even at the farm level in three major rice based agro-ecosystems. While the decline in expected yields due to temperature rise is likely to be compensated by the increase in yields due to high atmospheric CO_2 concentrations, it is not universal in all the cases. Rice agro-ecosystems in Tamil Nadu State of India have shown much greater variance with respect to rise in temperature vis-à-vis yield, and thus have higher degree of climate risk than the rice ecosystems of Kerala and Orissa. It is necessary to develop the crop variety by which rice plants may perform better from increases in atmospheric CO_2 while minimizing the adverse effects of warmer temperatures. Since it is likely that the negative outcome for rice would be compensated by the development of new varieties, it is important to develop further insights into this problem. On the other hand, the positive effects are likely to be limited by physiological acclimatization and unpredictable occurrences of extreme weather conditions. The adaptation of rice-based agro-ecosystems to climate change depends on such improvements in crop varieties. The soft adaptation options like agricultural extension services, land use modifications etc are more important than hard options of building dams and reservoirs, which take longer time to adapt to the climate change. The cross-cutting institutional issues are equally important while integrating disaster risk reduction into climate change adaptation. Watershed management, coastal zone management, flood-prone river-basin and land use planning have shown the possibilities of integrating disaster risk related tools, techniques and information into multi-sectoral climate change adaptation strategies. Particularly, the integration of disaster risk reduction into agriculture sector especially those related to rice provides yet another opportunity for food security in changing climate regime.

Appendix I

Study Areas

The study has been conducted in three different agro-ecological zones of India. The three study areas are located in Kerala, Orissa and Tamil Nadu. In India, rice is hydrologically characterized based on the rainfall of different regions. Kerala is representative of regions with rainy season for six months or more yielding two to three crops of rice, Orissa is representative of regions with rainy season for three months or more yielding one crop of rice while Tamil Nadu represents regions with rainy season for two months or more yielding just one crop of rice and that too with supplemental irrigation.

Cuttack, Orissa

In Cuttack, Orissa the study has been carried out in collaboration with the Central Rice Research Institute (CRRI) located at Cuttack in Orissa. Figure 1 shows the location of the study sites in Cuttack. Cuttack is situated at 20° 48'N latitude and 85°E longitude in the coastal tract of Orissa comprising the river basins - Baitarani, Brahmani, Mahanadi and Rishikulya. This region is the most fertile area of the state and is composed of alluvial deposits with varying textures. Birbati and Kandarpur villages of Cuttack are the actual study sites and are situated at an altitude of 83.21 m MSL. Biribati village is located 5 km from CRRI and Kandarpur village is situated 11 km from CRRI. The annual rainfall at Cuttack is about 1225 - 1575 mm and is mostly received during June to October from the southwest monsoon (Annual Report 1996 - '97). Ten representative farmer's field well distributed over the entire area was selected in Biribati and Kandarpur villages of Cuttack during Kharif 1996 and 1997 for observation and distinctive sampling of plants. The study area has the unique environment for rice cultivation especially with respect to rainfall, temperature, sunshine hours, soils and other climatic factors.

Tavanur and Malappuram, Kerala

Kerala is situated between 8° 18' to 12° 48'N latitudes and 74° 52' to 77° 22'E longitudes. It has a coast line of 590 km (Figure 2). The major crops grown in this region are rice, tapioca, banana and other plantains, coconut, arecanut, pepper, rubber, ginger, cardamom, tea, coffee, cashew and cocoa.

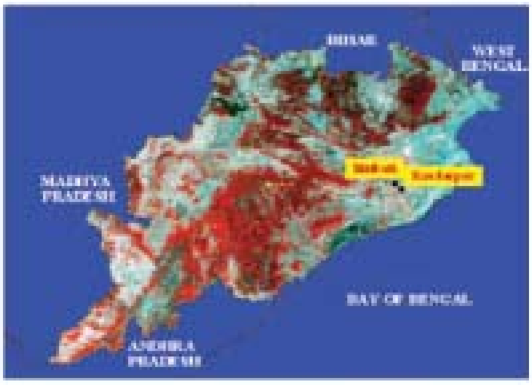

Figure 1: Study sites located in Orissa

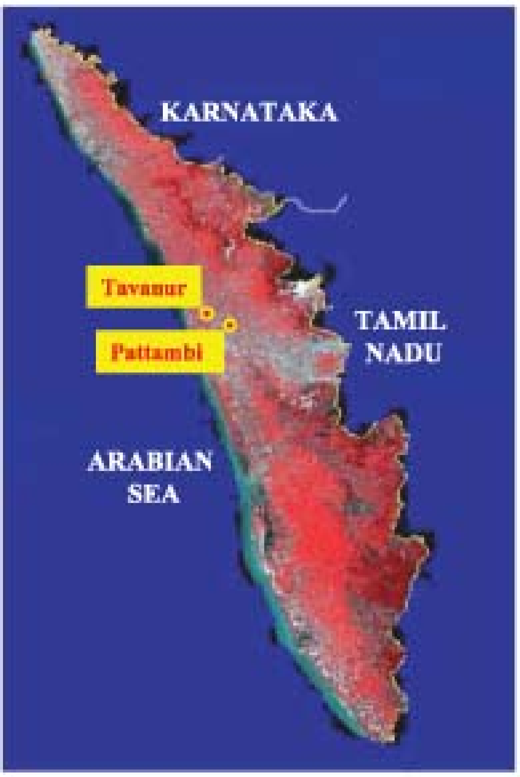

Figure 2: Study sites located in Kerala

The average annual rainfall in Kerala State is 3125 mm. Kerala has 541.33 thousand ha under rice cultivation. Rice is mainly grown under flooded conditions. Rice is transplanted or direct seeded during three seasons depending on the availability of water and other local conditions. For summer rice under limited resources of water, supplemental irrigation is practiced to the advantage of saving substantial quantity of irrigation water without any significant reduction in yield. The rice varieties grown in Tavanur study site include Aryan and Jaya and those grown in Pattambi include Red Triveni and Kanchana. Data for ISRO-GBP SVAT rice modeling collaboration project were obtained from Kerala Agricultural University (KAU), Tavanur. The two study sites are located at Tavanur Campus in Malappuram district and at RARS, Pattambi, in Palakkad district. Tavanur is situated at 10° 53′ 30″N latitude and 76°E longitude at an altitude of 10 m above MSL. Pattambi is situated at 10° 48′N latitude and 76° 12′E longitude at an altitude of 25 m above MSL.

Figure 3: Study sites located in Tamil Nadu

Thanjavur, Tamil Nadu

Tamil Nadu, generally experiences a sub tropical climate throughout the state and there is no sharp variation in climate. The annual rainfall in Tamil Nadu varies from a minimum of 400 mm to a maximum of 4300 mm and the average annual rainfall is 925 mm. Thanjavur is located in the eastern part of Tamil Nadu and is situated between latitudes 10° 20′ to 11° 25′N and longitudes 78° 49′ to 79° 30′E. It has a geographical area of 1691.28 sq km. The study sites lie in the southern portion of Thanjavur district in Tamil Nadu (Figure 3). The study sites include Kelamaruthuvakudi, Suriyanarkoil, Ammachathiram, Eragram and Kadalangudi. The average rainfall of this region is 987 mm. Irrigated lowland typically represents the rice belts of Tamil Nadu.

Methodology

Field data pertaining to LAI and total dry matter of rice were collected throughout the growing season. These data were used to simulate yield using ORYZA1 and ORYZA_W per se. The two models have been coupled with remotely sensed inputs of NDVI derived via field spectroradiometer measurements as well as from NOAA-AVHRR satellite data. The spectrally interfaced model outputs including yield have been validated with field measurements for the different test sites included in the study and has demonstrated the simulation of yield very close to the actual observed field estimates. Using the spectrally interfaced and validated versions of the two models, viz. ORYZA1 and ORYZA_W, simulations were carried out to quantify the effect of temperature and CO_2 changes on the yield of rice grown in the three agro-ecological zones. Twelve different scenarios (Matthews et al., 1995) that result from changes in temperature and atmospheric CO_2 concentration were evaluated with the model for their impacts on rice cultivation. The 12 different scenarios chosen for the analysis are given in Table.

Table Changed temperature and CO_2 concentration scenarios

Change in CO_2 concentration	**Change in current temperature**
340 ppm CO_2 concentration	Current temperature
	+1°C, +2°C, +3°C, +4°C rise in current temperature
510 ppm CO_2 concentration	Current temperature
	+1°C, +2°C, +3°C, +4°C rise in current temperature
680 ppm CO_2 concentration	Current temperature
	+1°C, +2°C, +3°C, +4°C rise in current temperature

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