Agrekon, Vol 43, No 4 (December 2004)

WEATHER DERIVATIVES: CONCEPT AND APPLICATION FOR THEIR USE IN SOUTH AFRICA

JM Geyser[1]

Abstract

Recent innovations in energy markets suggest the possibility of addressing agricultural risk factors by issuing derivatives on weather elements. Such instruments appear particularly attractive, as asymmetric information and loss adjustment issues do not affect them. This article first describes the concept, functioning and application of weather derivatives. It then examines the feasibility of rainfall derivatives to manage agricultural production risk in South Africa by evaluating the merits of rainfall options, and suggesting an option strategy, as a yield risk management tool. The use of rainfall derivatives in South Africa is likely to increase in future as capital markets, financial institutions, insurance companies, crop insurance companies and hedge funds collectively organize themselves to share and distribute weather risks.

1. INTRODUCTION

Weather risk markets are amongst the newest and most dynamic markets for financial risk transfers and include participants from a broad range of economic sectors such as energy, insurance, banking, agriculture, leisure and entertainment. Although the weather risk market is till very much based in the United States (US), new participants from Europe, Asia and Latin America are entering this market.

Although weather risk markets are well advanced in the energy sector, their applications to agriculture are still limited. For one, this type of market is very new and secondly they have to compete with highly subsidized crop insurance schemes in developed countries (Varangis, 2002). For developing countries, weather derivatives create new opportunities for dealing with two fundamental issues. The first is ways to deal with catastrophic or disaster risks and the second is to promote new private-based insurance products for sectors that are highly dependent on weather, such as agriculture.

The traditional market-based instruments for managing weather risks, e.g., insurance, are largely underdeveloped and unavailable in most parts of the

---

[1] *Department of Agricultural Economics, Extension and Rural Development, University of Pretoria.*

world. Given the growing interest in weather insurance markets, there are opportunities for innovation that have not been exploited. A number of studies are recognizing that markets may more easily provide weather insurance than traditional crop insurance in many developing countries (Gautam *et al,* 1994; Sakurai & Reardon, 1997; Skees *et al,* 1999 and Skees, 2000).

This paper examines the feasibility of weather derivatives in the South African agricultural context, and suggests an appropriate strategy for using rainfall options as a yield risk management tool. The next section describes weather derivatives and defines key terms. Section 3 presents a history and utilization of weather derivatives, while the remainder of the paper analyses rainfall options in South Africa, the applicability of weather derivatives for South Africa and the paper ends with a possible option strategy that farmers can use to protect themselves against yield risk.

2. THE CONCEPT OF WEATHER DERIVATIVES

A weather derivative is a contract between two parties that stipulates how payment will be exchanged between the parties, depending on certain meteorological conditions during the contract period. It is important to understand the difference between weather insurance and weather derivatives. Insurance covers a once-off risk and any payout may or may not be proportional to the risk. Weather derivatives are designed to compensate proportionally when the weather circumstances meet those defined in the contract. Buying a weather derivative involves embarking on a financial "balancing act" where some of the higher revenues in good times are bargained away in return for compensation in bad (low income) times (Dischel & Barrieu, 2002).

Insurance companies have been involved in the weather risk market — directly or indirectly — for a very long time. Insurers of domestic or commercial property portfolios are inevitably exposed to severe weather events (underwriting losses can be suffered as a result of windstorms, flooding and freezes). These exposures arise because of insurers' normal undertakings and are not considered a particular focus or speciality. Weather derivatives do not replace insurance contracts since there are a number of significant differences:

- Insurance contracts cover high risk, low probability events, whereas weather derivatives cover low risk, high probability scenarios.
- With weather derivatives, the payout is designed to be in proportion to the magnitude of the phenomena. Weather insurance pays a once-off lump sum that may or may not be proportional and as such lacks flexibility.

- Insurance normally pays out if there has been proof of damage or loss. Weather derivatives require only that a predetermined index value be passed.
- It is possible to monitor the performance of the hedge during the life of the contract. Additional shorter-term forecasting towards the end of the contract might mean that the farmer wishes to release him/herself from the derivative. Because it is a traded security, there will always be a price at which one can sell or buy back the contract.
- Traditional weather insurance can be relatively expensive and requires a demonstration of loss. Weather derivatives are less costly in comparison to insurance, require no demonstration of loss and provide protection from the uncertainty of variable weather conditions.

Weather derivatives differ from traditional derivatives in one major respect, namely that there is no underlying traded instrument on which weather derivatives are based. Whereas equity, bonds or foreign exchange derivatives, for example, have their counterparts in the spot markets, weather is not traded as an underlying instrument in a spot market. This means that unlike other derivatives, weather derivatives are not used to hedge the price of the underlying instrument, as the weather itself cannot be priced. They are used, rather, as a proxy to hedge against other risks affected by weather conditions, such as agricultural yield risk. The concept behind a weather hedge is simple: it is a way to protect businesses from excessive costs or reduced supply due to unfavourable weather conditions. In this sense, weather derivatives are an extension of traditional risk management tools. Although they are a new product to be used to help solve a historical problem, they are based on the same principles and mechanisms as options, futures, swaps and combinations such as straddles, strangles and collars (Zeng & Perry, 2002).

A generic weather derivative contract can be formulated by specifying the following seven parameters (Zeng, 2000):

- Contract type
- Contract period
- An official weather station from which the meteorological data is obtained
- Definition of the weather index (W) underlying the contract
- Pre-negotiated threshold, or strike (S) level for W
- Tick (k) or constant payment (P_o) for a linear or binary payment scheme
- Premium

There are four main types of product used in the weather risk-management market - calls, puts, swaps and collars. A call contract involves a buyer and a seller who first agree on a contract period and a weather index (*W*) that serves as the basis of the contract. At the beginning of the contract, the seller receives a lump-sum premium from the buyer. In return, during the contract or at the end of the contract, if W is greater than the pre-negotiated threshold (*S*), the seller pays the buyer an amount equal to

$$P = k(W - S) \qquad (1)$$

where:

k (tick) is a pre-agreed upon constant factor that determines the amount of payment per unit of weather index. The payment can sometimes be structured or binary. A fixed amount P_0 is paid if *W* is greater than *S*, or no payment is made otherwise. The contract cannot specify a limit to this pay-off since the pay-off is determined by the difference between *W* and *S*.

A put is the same as a call except that the seller pays the buyer when *W* is less than *S*. The maximum amount payable is limited to the premium size. The premium size is determined by market forces such as time to maturity, volatility and supply and demand. A call and a put are essentially equivalent to an insurance policy: the buyer pays a premium, and in return, receives a commitment of compensation when a predefined condition is met. Swaps are contracts in which two parties agree to exchange their risk. The attraction of this arrangement is that neither party pays a premium. Payments are made one way or the other in the amount of $P = k(W - S)$. A swap is a combination of a call sold to B by A and a put sold to A by B. The strike, *S*, is selected in such a way that the call and put command the same premium. Collars are modified versions of swaps: the parties agree to make payments to one another only when *W* moves outside an agreed upper and lower level. A collar is a combination of a call sold to B by A, and a put sold to A by B, but with different strikes.

3. HISTORY AND UTILIZATION OF WEATHER DERIVATIVES

Weather derivatives are very new in the capital markets arena. In the US the weather derivative market has grown out of the energy market. The first weather-based derivative contracts were offered in September 1997 between Enron and Koch (now Entergy-Koch) (Smith, 2000:6). The need for energy, power and heating oil producers to hedge against volume risk caused by temperature fluctuations has meant that the most actively traded of these "products" until now has been temperature.

The majority of weather derivative deals in the US, the United Kingdom (UK) and Japan involve energy companies. Between 70% and 80% of all weather derivative deals have an energy company on at least one side of the contract (Gautam & Foster, 2000). The role has however, now shifted to reinsurance and investment banking firms. A 2002 joint survey between PricewaterhouseCoopers and the Weather Risk Management Association (WRMA) showed that the number of weather transactions grew 43% from April 2001 to March 2002. During this period 3,937 contracts were traded, the total notional value of the transactions was $4.3 billion.

A repeat of the survey in 2003 found a near tripling in the number of weather risk management contract transacted from April 2002 through March 2003, compared to the previous 12 months. During this period 11,756 weather risk management contracts were traded. The notional value was $4.2 billion. The increase in the number of contracts with the notional value staying more or less constant indicates a surge in smaller contracts and a broader spectrum of users (Cooper, 2003). The European weather risk management market grew with more than 90% from the 2002 to the 2003 survey, and the Asian market showed an increase of nearly 85%.

It is obvious that not only energy companies face weather risk. An increasing number of other business sectors and companies are realizing that weather conditions affect their businesses, and that their businesses can benefit from using weather derivatives. Suppliers add value to their products by channelling weather risk away from the consumer. If marketed correctly, the product becomes more attractive to consumers and the supplier can then either raise the sales price for the same level of demand, or allow demand to rise while keeping the sales price the same. The supplier then experiences an overall increase in earnings from the product since the increased risk the supplier faces is "backed out" using a weather derivative, and the cost of the weather derivative is recouped through the increase in sales (Gautam & Foster, 2000).

A second benefit that suppliers may observe is a flattening of sales profiles over a given year, especially with regard to seasonal products where sales are closely linked to weather phenomena. A flattened sales profile brings a number of benefits, including more consistent production over the year, and it improves inventory-holding levels. One company that adopted this strategy was Bombardier, a Canadian snowmobile manufacturer (Ladbury, 2000b). In the winter of 1998, the company offered buyers in the US Midwest a $1,000 rebate on its snowmobiles if a pre-set amount of snow did not fall that season.

The company was able to make such a guarantee by buying a weather derivative based on a snowfall index. A strike point was agreed upon, based on the total millimetres of snow during the winter season. A standard amount of snow was agreed upon, and for every millimetre under this amount, Bombardier would receive recompense. When the season ended, the level of snowfall had been such that no payment was received on the weather derivative. However, Bombardier did not have to pay any rebates to its customers either. The 38% increase in sales generated by the offer easily compensated for the cost of the derivative.

There are many sectors that could benefit from participating in weather risk hedging in South Africa (Ladbury, 2000a):

- **Theme parks and sporting events**. The busiest periods for theme parks and sporting events are the summer months. Unfortunately, these are the same months during which most of the country receives its rain. Attendance figures are closely correlated with weather conditions and drizzle can cause people to avoid outdoor activities.
- **Construction**. In this industry, heavy financial penalties can be imposed for work that runs past its completion schedule. At the same time, delays can also cause projects to run over budget. Construction sites that are under water are subjected to lengthy delays (concrete cannot set and the operation of machinery in rainy conditions is very difficult).
- **Clothing**. Although fashion determines the clothing lines retailers that stock in their stores, weather conditions strongly influence what customers buy. If there is a very mild winter, jacket and sweater manufacturers' products may experience slow sales.
- **Agriculture**. Weather is a major source of risk in agriculture. Sunshine hours, temperature, rainfall and wind can all affect the quality and quantity of a crop. The relationship between weather and crop yield is complex. For example, drought badly affects water-dependent crops, but excessive rain can flood the soil, leading to a restricted oxygen supply to the roots and a higher incidence of disease. The timing of rainfall is also a crucial factor.

4. RAINFALL INSURANCE OPTIONS IN SOUTH AFRICA

Agricultural forward and futures contracts provide farmers with relative straightforward tools to hedge price risk. What is not so straightforward to manage, however, is the volume of produce that will be sold. The quantity produced and sold is in part dependent on weather conditions. Dryland maize farmers, for example, are heavily dependent on the amount and timing of rain received.

The strike quantity, S, of a rainfall option would be based on historical rainfall-data for a particular area, as collected by that area's weather station. Some form of rainfall index, *W* usually measures this historical data. The strike point of the option would then be based on the index, which is the amount of rain, in millimetres, for a particular period. For instance, if the average rainfall for January and February in a particular area were 100mm, a two-month call option for that period would have a strike of approximately 100mm. Actual rainfall over the same period would be the "actual quantity" and that determines the payout of the option. A predefined Rand value per millimetre in excess or less than the strike would determine the payout of the option. Other present properties of the rainfall option would be the all-familiar volatility (σ) of the rainfall and time (T) to expiration of the specific option contract.

One major factor that complicates the hedging process for derivative end-users is basis risk (Dischel, 2000:25). Basis risk originates when the price of the derivatives does not exhibit the same movement as that of the underlying instrument. In weather derivative terminology, this happens due to the difference in weather conditions at the different weather sites across the country. The apprehension is that the weather at a measurement site that is distant from a weather exposure region may not be representative of the exposure. Farmers would obviously prefer contracts written that relate to the levels of rain expected to fall on their fields. This is not as simple because the market needs long-term accurate measurement records to assess the value of a weather derivative, and independent parties at these locations do not generally compile measurement records. The end-users of a derivative must accept a basis risk concession or forgo the potential benefit of weather derivative hedging. If this basis risk were quantified, they (end-users) might comfortably compromise and accept measurements from a site some distance from their exposure site.

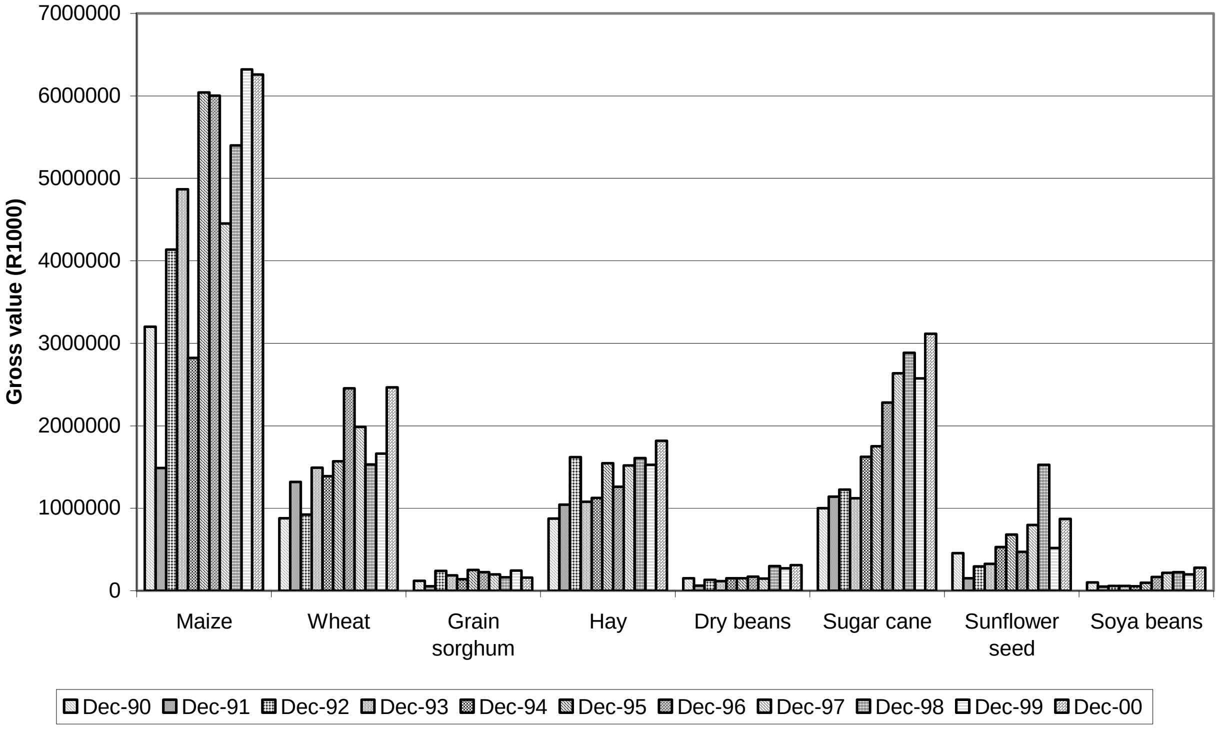
One of the problems facing the weather derivatives markets is how these derivatives should be priced. In the absence of a tradeable contract in weather and equilibrium price cannot be established using conventional means (Dischel, 1998). At one end of the pricing spectrum, Cao and Wei (1999) developed a pricing model based on expected utility maximization with an equilibrium developed from Lucas's (1978) model. Davis (2001) also concludes that a Black-Scholes type framework is not appropriate for pricing weather derivatives as a matter of course, but under the assumptions of

Brownian motion, expected utility maximization, a drift rate that includes the natural growth rate of the degree day measure, the natural growth rate in the spot price of a commodity (e.g. fuel price) and the natural growth rate in firm profits, then degree day options can be priced by a Black-Scholes analogue. Turvey (2001) presents a number of flexible rainfall and heat related option contracts based upon historical probabilities.

There must be a positive correlation between yields and rainfall in order to create the demand for trading in rainfall options in South Africa. Sections 5 and 6 discuss the methodology used to investigate this correlation in South Africa over the period 1990/91 to 1998/99.

5. ASSESSMENT OF THE APPLICATION OF RAINFALL OPTIONS IN SOUTH AFRICA

In order to see if weather derivatives in South Africa could have a role to play, the following steps were followed: Firstly, an appropriate type of grain was identified based on gross annual crop value. Given that maize is the biggest grain crop produced in South Africa (RSA, 1996; 2000) - as shown in Figure 1 — it was used to assess the viability of weather derivatives.

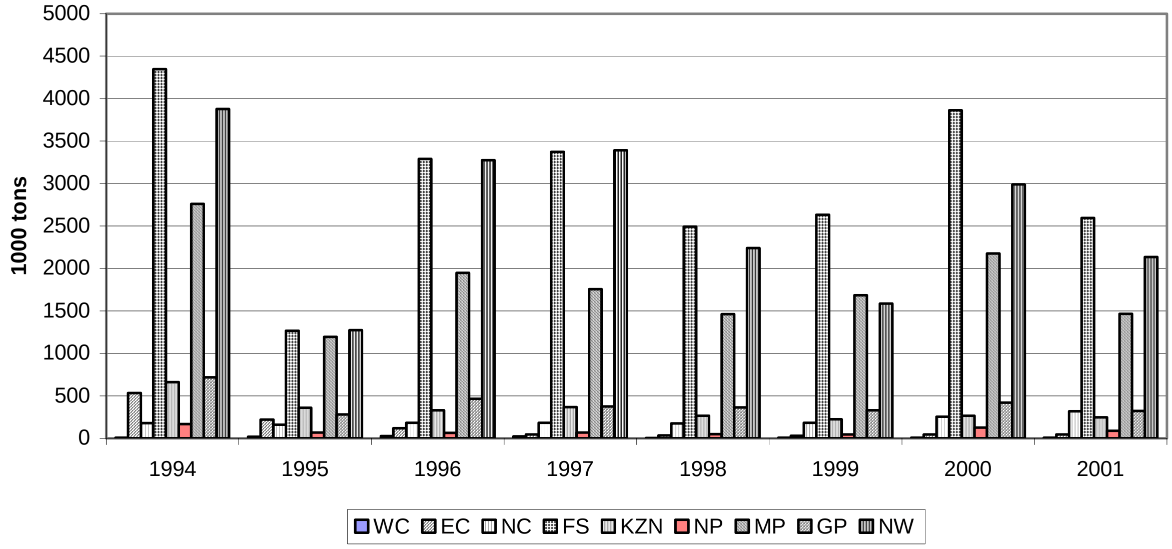


Source: RSA (1996; 2000)

Figure 1: Annual gross value of grains in South Africa, 1990[1] - 2000

[1] 1990 = 1990/91

Secondly, the major maize-producing area in South Africa was identified. Maize is produced in all nine provinces of the country, with the Free State province producing the biggest quantity of maize (an average of 34,6% as shown in Figure 2). The Free State was thus selected as the area to test the viability of using weather derivatives in South Africa.



Source: RSA (1996; 2000)

Figure 2: Annual maize production per province in South Africa, 1994 - 2000

The final step was identifying three districts within the Free State province that were suitable for testing the viability of weather derivatives. The selection criteria were that the three districts should be from different regions and that the three districts must have weather data available from 1990. The three randomly chosen districts were: Bloemfontein (the Glen Weather Station), Bethlehem (The Loch Lamond Weather Station) and Bothaville (the NAMPO Weather Station).

Rainfall over southern Africa is highly seasonal (Tyson, 1986). Except for the southwestern Cape, the southern coastal regions and adjacent interior, more than 80% of the annual rainfall occurs between October and March. Figure 3 indicates the variable rainfall at the three selected weather stations for the period January 1990 to December 2003. The next section analyses the extent to which rainfall and maize yields in the three districts are correlated.

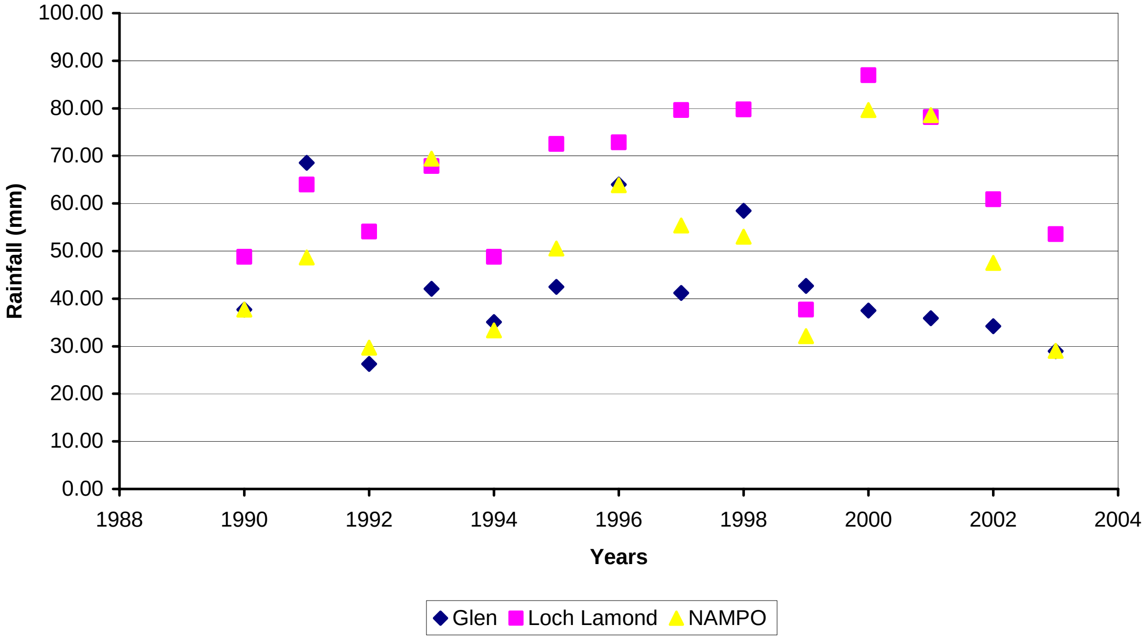


Figure 3: Average annual rainfall (mm) at the three selected Free State weather stations, 1990 - 2003

6. CORRELATION BETWEEN RAINFALL AND MAIZE YIELD

The rainfall at the three Free State weather stations varies every year. Table 1 indicates the monthly rainfall for the period 1990/91 to 2002/03.

Average rainfall and the occurrence of rain both vary between the months. Table 2 indicates the variation of rainfall for the months of October to March, January to February (the kernel forming stage) for the period 1990 to 2003 at the three rainfall stations.

The data clearly show that Free State farmers experience highly variable levels of rainfall during the critical kernel-forming stage of maize development. Before the application of weather derivatives in South Africa can be tested, the relationship between rainfall and maize yield must be determined. Note that not only rainfall but also climate as a whole has an impact on maize yield. Temperature, for instance, can have an adverse effect on yield. This paper, however, only attempts to determine the relationship between maize yield and rainfall during the critical kernel-forming stages of January and February. Table 3 indicates the yields achieved in the districts of the three selected weather stations.

Table 1: Monthly rainfall for the three selected weather stations in the Free State, 1990 – 2003

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Glen														
Jan	84.6	212.4	18.8	33.5	140.7	81.2	109.2	114	139.3	68.7	73.6	31.1	114.9	63.3
Feb	72.4	80.1	8.3	77.1	155.2	28	137.5	26	146	30.7	31.1	54.3	34.6	80.4
March	92.9	132.4	23.6	63.3	45.9	109.8	12	102	116.1	26.5	70.4	2.3	15.2	99
Apr	92.1	1.8	22.9	27.5	10.6	23.9	75.5	43.4	9	32.5	54.1	36.8	29.6	5.8
May	5	0.4	0	11.3	0	0	9.6	34.3	3	65.1	17.6	19.8	52.2	12.4
Jun	25	18.5	0	2.6	0	0.6	0	5.2	0	5	2.3	18.5	7	0.4
Jul	6.5	7	0	0	1	0	34.6	21.5	3.5	2	1.7	2.1	0.2	0
Aug	16.5	0	22.3	27	0.2	6	6	6	1.9	1.5	0.6	19.3	65.2	6.3
Sept	0	64.5	0	3	0	11.2	17	17.3	19	0	50.1	27.1	13	30.4
Oct	2.5	213.3	30.1	181.3	2	59.5	72.2	50.6	71	81.9	49.4	96.3	32.6	9.7
Nov	4	32.6	161	40.5	34.8	45	203	35.5	102.8	56.5	50.1	27.1	13	30.4
Dec	50.6	59.4	28.1	38	30.9	144.5	91.3	38.6	89.9	141.8	49.4	96.3	32.6	9.7
Ave	**37.68**	**68.53**	**26.26**	**42.09**	**35.11**	**42.48**	**63.99**	**41.20**	**58.46**	**42.68**	**37.53**	**35.92**	**34.18**	**28.98**
STDEV	**38.17**	**78.24**	**44.05**	**49.91**	**55.17**	**47.64**	**63.18**	**34.25**	**58.27**	**42.46**	**26.25**	**31.51**	**31.59**	**33.65**
Variation	**6.18**	**8.85**	**6.64**	**7.06**	**7.43**	**6.90**	**7.95**	**5.85**	**7.63**	**6.52**	**5.12**	**5.61**	**5.62**	**5.80**
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Loch Lamond														
Jan	45.2	247.6	35.8	102.2	158.7	48.9	157.1	74.9	180.4	76.5	251	72.2	141.3	128.8
Feb	85.2	140.2	73.7	90.9	118.4	58.5	119.2	32.8	176.9	118.2	137.8	80.9	69.9	142.2
March	108.6	87.6	43.1	51.9	52.4	127	55.2	112.9	125.4	78.8	161.5	98.6	61.9	80.6
Apr	138.3	1	8.9	41	48.2	64	62.6	92.9	4.9	30.8	89.9	85.5	45.2	1.5
May	16.9	8.4	0	14	0	28.8	40.9	98.3	1.2	36.3	60.6	18.5	40.4	5.5
Jun	1.7	24	0	2.2	0	1.7	0	21.9	0	8.5	9.5	0	27.6	13.3
Jul	8.4	0	0	0	0	0	42.1	29.1	0	1.6	0.3	12.2	0	0
Aug	16.1	0	85.1	17.9	3.3	22	11.5	19	0	5.7	0	44	84.1	14.7
Sept	4.8	47.2	1.5	6.1	11	1	26.2	86.7	31.8	0	73.7	83.4	30.1	6.9
Oct	52.7	68.8	86.6	250.4	69.8	114.7	193	69.1	51.5	66.6	85.4	234.2	50.2	30.1
Nov	30.9	39.1	235.1	82.2	25.5	233.7	72.4	177.9	245.9	27.8	96	77.8	13.2	219
Dec	77	103.6	79.6	155.8	97.8	169.8	93.7	140.4	138.9	1.5	78	130.6	166.8	0
Ave	**48.82**	**63.96**	**54.12**	**67.88**	**48.76**	**72.51**	**72.83**	**79.66**	**79.74**	**37.69**	**86.98**	**78.16**	**60.89**	**53.55**
STDEV	**44.65**	**73.50**	**67.32**	**75.12**	**53.06**	**74.39**	**58.58**	**49.47**	**88.78**	**38.81**	**72.09**	**62.40**	**49.66**	**72.76**
Variation	**6.68**	**8.57**	**8.21**	**8.67**	**7.28**	**8.62**	**7.65**	**7.03**	**9.42**	**6.23**	**8.49**	**7.90**	**7.05**	**8.53**
NAMPO														
Jan	73	175	54	108	109	95.9	33.4	123.5	141	68.5	295	54	44.5	68.5
Feb	60.6	42.5	8	160	112	17.5	129.5	37	56	20	99.5	106.5	63	72
March	54.5	172.3	11	17.5	35	74.5	99	126.5	96.5	14	91.9	79	44.5	66.5
Apr	135.5	0	16.5	37.5	29	32	168.5	104	15.6	7	33.5	52.5	20	2
May	4.5	0	0	0	0	63	43	85.2	0	44.3	43	34	37.5	0
Jun	0	17	0	0	0	0	0.5	0.4	0	0	2.5	15	5	2.5
Jul	2.2	0	0	0	0	0	38	10	0	0	0	0	0	0
Aug	0	0	21.3	10	0	13	6	5.5	0	0	0	0	34	5
Sept	17	35.6	3	8	0	19	2	19	13.7	3	20	0	42.8	0
Oct	24	35	49.5	185.4	17	64.5	76	36.5	60.5	0	100	148.5	44.5	34
Nov	29	49	120.5	44.5	41.9	113	115	45.5	120.5	50.4	88	212.5	57.5	97
Dec	51.9	57.3	73	262.5	56	114	54.9	71.8	132.5	178.5	182	240.5	176.5	0.5
Ave	**37.68**	**48.64**	**29.73**	**69.45**	**33.33**	**50.53**	**63.82**	**55.41**	**53.03**	**32.14**	**79.62**	**78.54**	**47.48**	**29.00**
STDEV	**40.13**	**61.93**	**37.57**	**88.69**	**40.84**	**42.49**	**54.40**	**45.63**	**56.21**	**51.62**	**87.15**	**82.93**	**44.85**	**36.69**
Variation	**6.33**	**7.87**	**6.13**	**9.42**	**6.39**	**6.52**	**7.38**	**6.76**	**7.50**	**7.18**	**9.34**	**9.11**	**6.70**	**6.06**

Table 2: Rainfall (millimetres) at the three selected Free State weather stations for selected months, 1990/91 to 2002/03

	Glen	**Loch Lamond**	**NAMPO**
Rainfall from October to March			
1990/91	80.33	106	82.45
1991/92	59.33	60.68	35.72
1992/93	65.52	107.72	88.08
1993/94	100.27	136.32	124.73
1994/95	47.78	71.25	50.47
1995/96	84.62	141.62	92.23
1996/97	101.42	96.62	88.82
1997/98	87.68	145.02	74.55
1998/99	64.93	118.3	69.33
1999/2000	75.88	107.7	119.22
2000/2001	43.48	85.18	101.58
2001/2002	80.87	119.28	125.58
2002/2003	62.18	96.97	80.92
Average	**73.41**	**107.13**	**87.21**
Std Dev	**18.16**	**25.65**	**26.90**
Rainfall from January to February			
1990/91	146.25	193.9	129.93
1991/92	13.55	54.75	24.33
1992/93	55.3	96.55	95.17
1993/94	147.95	138.55	85.33
1994/95	54.6	53.7	62.63
1995/96	123.35	138.15	87.3
1996/97	70	53.85	95.67
1997/98	142.65	178.65	97.83
1998/99	49.7	97.35	34.17
1999/2000	52.35	194.4	197.25
2000/2001	42.7	76.55	80.25
2001/2002	74.75	105.6	53.75
2002/2003	71.85	135.5	70.25
Average	**80.38**	**116.73**	**85.68**
Std Dev	**44.49**	**51.15**	**43.76**
Rainfall from December to February			
1990/91	114.37	154.93	89.80
1991/92	28.83	71.03	39.77
1992/93	46.23	90.90	113.67
1993/94	123.06	144.30	161.17
1994/95	46.70	68.40	56.47
1995/96	130.40	148.70	92.30
1996/97	77.10	67.13	71.80
1997/98	107.97	165.90	89.60
1998/99	63.10	111.20	73.67
1999/2000	82.17	130.10	191.00
2000/2001	53.07	77.03	114.17
2001/2002	81.83	113.93	116.00
2002/2003	74.27	145.93	105.67
Average	**79.16**	**114.58**	**101.16**
Std Dev	**31.98**	**36.28**	**40.79**

Table 3: Average maize yield for the districts of the selected weather stations in the Free State, 1991/92 – 2002/03

	Bethlehem	**Bloemfontein**	**Bothaville**
	t/ha		
1991/92	0.73	0.46	0.92
1992/93	3.33	1.48	2.66
1993/94	3.40	2.49	3.46
1994/95	1.40	0.78	1.60
1995/96	2.18	1.42	3.24
1996/97	2.68	2.34	2.87
1997/98	2.31	3.78	2.08
1998/99	3.29	1.97	2.39
1999/2000	2.90	2.98	3.04
2000/2001	3.11	1.92	3.26
2001/2002	2.12	2.23	2.91
2002/2003	2.25	2.42	3.12
Average	**2.47**	**2.02**	**2.63**
STDEV	**0.82**	**0.91**	**0.76**
Variation	**0.90**	**0.96**	**0.87**

The degree to which maize yields and rainfall are related can be measured by a correlation coefficient. A correlation coefficient of –1 means that if rainfall turns out to be lower than expected, yield will always be greater than expected. Conversely, a correlation coefficient of zero means that there is no relationship between maize yield and rainfall.

A strongly positive, statistically significant correlation coefficient up to a maximum of 1 represents movements in the same direction. In other words, the higher the rainfall, the higher the yield and *vice versa*. Table 4 indicates the estimated correlation coefficients between the average maize yield and average rainfall from 1991/92 to 2002/03.

Table 4: Estimated correlation coefficients between average maize yield and average rainfall for the three selected Free State districts, 1991/92 to 2002/03

	Rainfall-yield correlation		
Weather station	**Oct - March**	**Jan - Feb**	**Dec - Feb**
Bethlehem	0.51	0.33	0.28
Bloemfontein	0.53	0.56	0.57
Bothaville	0.86	0.45	0.71

The planting season for Bethlehem starts much earlier than Bothaville. This is also confirmed by the relative weaker correlation between yield and rainfall from January to February. There is a strong relationship between average rainfall over the full production period and the average maize yield. There are also direct relationships between average rainfall and average maize yield for the periods January to February and December to February. This positive correlation indicates the importance of weather yield derivatives for maize farmers in South Africa. If farmers can protect themselves against adverse rainfall patterns during the critical kernel-forming stages of maize, yield risk will decrease substantially.

The longer farmers can protect themselves against low rainfall, the more expensive the weather derivative would be. A farmer needs to determine which period is most critical for the crop yield and to purchase a weather derivative for this crucial period only.

In the next section, a possible rainfall option strategy is examined.

7. A POSSIBLE RAINFALL OPTION STRATEGY

In agriculture farmers face three main sources of risk: price risk, event risk and yield risk (Parihar, 2003).

Price risk can be defined as the probability of an adverse movement in the price of an agricultural commodity. Traditionally, price risk management was not the responsibility of South African farmers, but after the deregulation of the market and the abolishment of the various grain boards, it became their responsibility. Since 1996 farmers could choose between forward and futures contracts to hedge their price risk. These contracts help to hedge against price risk, but do not provide protection against volume risk – for example, variations in total return on a hectare of farmland.

Event risk can be defined as the probability of the occurrence of an exceptional event (catastrophe) that would have a negative effect on agricultural yields. Event risk by definition implies high risk with associated low probability of occurrence. Examples of event risk would include floods or hail damage. Traditionally South African farmers could hedge against this risk category by means of agricultural insurance purchased from companies such as Sentraoes.

Note, however, that below- or above-normal rainfall that does not fall into the drought or flood categories does not qualify as being event risk. This discourages the provision of insurance products to the agricultural sector, since even slight deviations from normal, average rainfall patterns (even one standard deviation from the mean rainfall value) can affect agricultural yields negatively. Insurance products do not cover such risk and only pay out on the occurrence of an exceptional event that leads to extreme loss (Roberts, 2002).

Yield risk refers to the possibility of obtaining a less than normal yield (output) on inputs. Yield risk, in contrast to event risk, implies low risk with associated high probability of occurrence. As was illustrated in section 6 above, one of the main contributors to yield risk is the amount (and timing) of rainfall as an input to the agricultural process.

Figure 4 illustrates the yield risk profile of a typical maize farmer. Given the strong correlation between the amount of rainfall and maize yield shown in section 6, it is important to note that farmers depend on an expected (normal) amount of rainfall per year. In the diagram, this amount is illustrated, for example, as between 200mm and 800mm of rainfall per annum. Yields diminish where the actual rainfall falls below or above this average rainfall band. Figure 4 shows that the farmer runs a risk that losses will be incurred where the average rainfall between 200mm and 800mm per annum does not materialize.

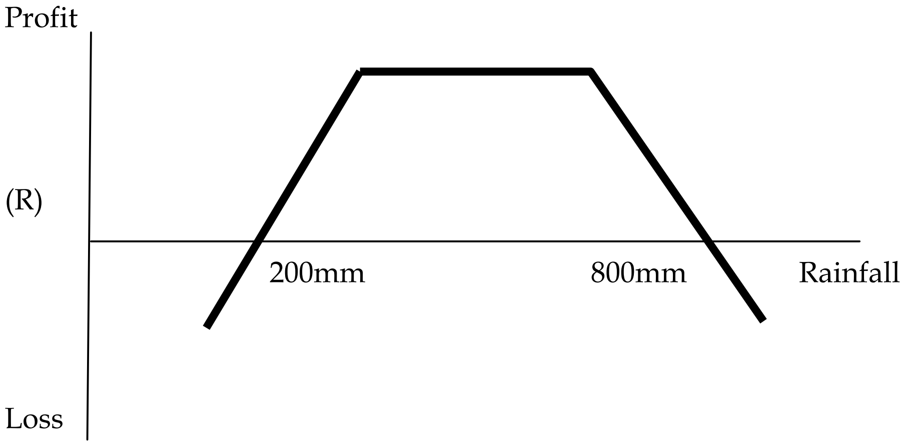


Figure 4: Yield risk profile for a typical maize farmer

Since either too much or too little rainfall leads to yield variability, it is suggested that an options strategy of using a combination of a long call and a long put be used. This combination, known as a "long strangle", will provide the farmer with a hedge traditionally associated in the financial markets with high volatility of the underlying risk exposure. As shown in Figure 5, the farmer needs to buy a put (lower strike) and to buy a call (higher strike) with the same maturity and the same amount. The expected payoff from such a strategy ensures that the farmer benefits from any rainfall outside of the "normal" rainfall pattern.

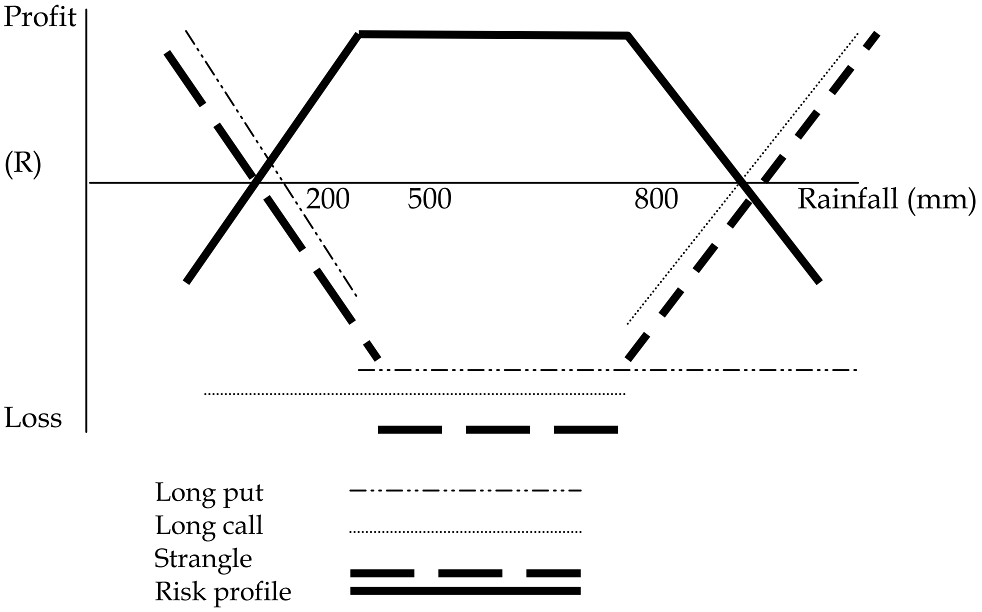


Figure 5: Long strangle option payoff for a typical maize farmer

The net profile of the above exposure can be algebraically deduced as follows:

Risk profile: 1; 0; -1
+ Buy long call: 0; 0; 1
+ Buy long put: -1; 0; 0
= Net profile: 0; 0; 0

The long strangle is constructed by purchasing single season, equally far out-of-the money call and put contracts. Since the underlying instrument is the amount of rainfall per annum, the at-the-money call and put amount will be set at either the average amount of rainfall expected for the year or the historical amount of rainfall for the year (as determined by a rainfall index, *W*). The farmer should then determine from which two points crop yields should diminish due to deviations from the expected mean rainfall for the year. Since both of the option contracts that make up the strangle are out-of-the-money, this strategy requires relatively low premiums and is much more affordable than, for example, a straddle option strategy.

An additional application that was highlighted in section 6 above is the variation in the rainfall pattern *during* a season. Even though the total rainfall in one season could be sufficient, the *timing* of the rainfall is also crucial. For example, rainfall during spring and summer is critical, but rainfall delays time-critical operations when crops are ready for harvest. If this is the case a farmer could also employ a strangle contract for the specific month in which rainfall is crucial to the crop yield, that is, December or January.

One may utilize historical rainfall statistics from a climate database to calculate the "fair value" price of the aforementioned option strategy. However, if the seasonal forecasts display skill, the "fair value" price of the option should vary, depending upon the seasonal forecast. To illustrate, if a dry season is forecast, and it is known that that forecast has a better than random chance of success, then the aforementioned option should have a higher price.

But, how is the price of the aforementioned strategy determined? The pricing of a given weather derivative by calculating the expected value of its appropriately discounted payoff is inherently related to weather forecasting and simulation (Brody *et al*, 2002; Zeng, 2000 and Cao & Wei, 2000). Weather derivatives have important differences with respect to traditional commodity price derivatives. The fundamental difference is that the underlying of a weather derivative is not a traded good. Without trades on the underlying asset there is clearly no possibility of developing weather futures contracts. Although the strategy is based on options, the Black and Scholes formula is not applicable. Dischel (1998) argues that weather options accumulate value over a strike period. This accumulation is similar to the averaging feature in Asian-style options, under which the payout is based on the average value of the underlying over the option's life. Stochastic option models can be formulated (as for interest rate models) for an underlying variable that need not be a security (Martin *et al,* 2001). Pricing of weather derivatives is therefore usually based on actuarial calculations. The absence of a universal pricing method generates lack of market transparency and increases transaction costs.

8. CONCLUSION AND RECOMMENDATIONS

When a weather event is a source of economic risk for agriculture, a weather derivative can become a hedging tool for farmers and for risk underwriters. The introduction of weather derivatives to manage yield risks in agricultural markets in South Africa could be of great benefit to farmers. Combining, for example, a rainfall option strategy with existing insurance contracts and agricultural futures contracts could allow farmers to focus more of their attention on the actual farming process since the major risk categories — yield, event and price risks — would have all been hedged.

In order to develop weather derivatives for agriculture, just as for any other weather derivative, the weather variable must be measurable, historical records must be adequate and available and all parties involved in the transaction must consider such measures objective and reliable. In addition, more so than with other weather derivatives, the existence of a complex relationship between the product and the weather factor must be carefully explored. For many weather derivatives traded in the energy sector, for example, derivatives on heating degree days (HDD), the relationship between temperature and demand for heating is simple and direct: the lower the HDD the higher the demand for energy. For agricultural production the relationship is not always as straightforward since differences in products, crop growth phases and soil textures have different responses to the same weather factor. Also, the more skilled and advanced the cultivating techniques, the greater the entrepreneurial influence on yields, the smaller the portion of variability generated by the specific weather elements.

This type of insurance is relatively easy to market. It could be sold through banks, farm cooperatives, input suppliers and micro-finance institutions, and perhaps even sold directly to farmers. Weather derivatives is not only for farmers and rural people. Banks and rural finance institutions could also purchase weather derivatives to protect their portfolios against defaults caused by severe weather events. Once financial institutions can offset the risk with this type of contracts, they may be in better positions to expand credit at perhaps improved terms. This is a critical issue as credit availability to agriculture is constrained, partly because of weather risks. Finding solutions to protect borrowers against adverse weather events could contribute to improving credit markets in developing countries.

Generally speaking, the development of weather derivatives in agriculture does not seem to be limited by availability of adequate weather statistics. What may prove problematic is access to the data, both in terms of bureaucratic procedures and cost of purchase. Gensec Bank has taken the initiative in South Africa and has developed a yield risk insurance product in the form of rainfall options. Just as with the introduction of agricultural futures contracts to South Africa, weather derivatives will only be successful if a substantial education process accompanies their introduction. Not only do producers of agricultural products have to be made aware of the use and benefits of these derivatives, but also other potential end-users such as theme parks and event organizers, who can act as counter-parties to such contracts.

REFERENCES

BRODY DC, SYROKA J & ZERVOS M (2002). Dynamical pricing of weather derivatives. *Quantitative Finance* 2:189–198.

CAO M & WEI J (1999). *Pricing weather derivatives: An equilibrium approach.* Working Paper, The Rotman Graduate School of Management, University of Toronto, October.

CAO M & WEI J (2000). Pricing the weather. *Risk Magazine* 13(5):67–70. May.

COOPER V (2003). *WRMA 2003 annual survey finds use of weather contracts triples.* WRMA press release, June 5th.
http://64.125.144.31/librarydocs/bc51_wrma/public/file552.doc.

DAVIS M (2001). Pricing Weather derivatives by marginal value. *Quantitative Finance* 1:305-308.

DISCHEL B (1998). Options pricing — Black-Scholes won't do. *Weather Risk*. October.
http://www.financewise.com/public/edit/energy/weatherrisk/wthr-options.htm.

DISCHEL B (2000). Is precipitation basis risk overstated? *Weather Risk*. August.
http://www.financewise.com/public/edit/energy/weather00/wthr00-rainfall.htm.

DISCHEL RS & BARRIEU P (2002). *Financial weather contracts and their application in risk management.* In: Dischel RS, Climate risk and the weather market. Risk Waters Group Ltd, London.

GAUTAM MP, HAZELL P & ALDERMAN H (1994). *Rural demand for drought insurance*. Policy Research Working Paper No 1383.

GAUTAM J & FOSTER D (2000). Come rain, come shine. *Weather Risk.* August.
http://www.financewise.com/public/edit/energy/weather00/wthr00-beyondenergy.htm.

LADBURY A (2000a). A false new dawn? *Risk Professional* 2(6):48-50. July/August.

LADBURY A (2000b). Watering the roots. *Risk Professional* 2(6):23. July/August.

LUCAS RE (1978). Asset prices in an exchange economy. *Econometrica* 46:1429-1445.

MARTIN SW, BARNETT BJ & COBLE KH (2001). Developing and pricing precipitation insurance. *Journal of Agricultural and Resource Economics* 79(1):206-215.

NATIONAL CROP ESTIMATING COMMITTEE (2000). *Final production estimate of summer crops: 1998/99.* Government Printer: Pretoria.

ROBERTS J (2002). *Weather risk management in the alternative risk transfer market.* In: Dischel RS, Climate risk and the weather market. Risk Waters Group Ltd, London.

RSA (1996). *Abstract of Agricultural Statistics.* Pretoria: Department of Agriculture.

RSA (2000). *Abstract of Agricultural Statistics.* Pretoria: Department of Agriculture.

PARIHAR J (2003). *Risk and uncertainty in agricultural markets.* In: Scott N (Ed), Agribusiness and commodity risk: Strategies and management. Incisive Risk Ltd, London.

SAKURAI T & REARDON T (1997). Potential demand for drought insurance in Burkina Faso and its determinants. *American Journal of Agricultural Economics* (79):1193–1207.

SKEES JR (2000). A role for capital markets in natural disasters: A piece of the food security puzzle. *Food Policy* 25:365–378.

SKEES JR, HAZELL P & MIRANDA M (1999). *New approaches to crop insurance in developing countries.* EPTD Discussion Paper No 55. International Food Policy Research Institute, Washington, November.

SMITH C (2000). An enormous potential: Weather derivatives. *The Financial Times* 28 June: 6.

TURVEY CG (2001). Weather insurance and specific event risks in agriculture. *Review of Agricultural Economics* 23(2):333-351. Fall/Winter.

TYSON PD (1986). *Climate change and variability in Southern Africa.* Oxford University Press: Cape Town.

VARANGIS P (2002). Innovative approaches to cope with weather risk in developing countries. *The Climate Report* (2)4:14-21. Fall.

ZENG L (2000). Weather derivatives and weather insurance: Concept, application and analysis. *Bulletin of the American Metrological Society* 81:2075–982.

ZENG L & PERRY KD (2002). *Managing a portfolio of weather derivatives*. In: Dischel RS, Climate risk and the weather market. Risk Waters Group Ltd, London.