Methods to find improvements in Weather forecast in India (specific to Ahmedabad region)

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Abstract— This thesis is a contribution to the subjects of midlatitude atmospheric dynamics and targeting observations for the improvement of weather forecasts. For the first time the fullspectrum ofsingular vectors of the Eady model are considered. The importance and implications of the un-shielding and modal unmasking mechanisms to the computed singular vectors are discussed. The computed singular vectors are used to analyse the vertical structure of the singular vector targeting function commonly used in observation targeting, in a vertical cross-section. Through comparison of this vertical cross-section to the dynamics of singular vectors, inferences about the scale and qualitative behaviour of the perturbations to which particular regions are ’sensitive’ are made. In the final section of the thesis, a new targeting method is introduced. This new targeting method utilises a set of evolved singular vectors to approximate the background errors within the region identified by a set of targeted singular vectors as dynamically connected to the verification region. The two sets of singular vectors can then be used as a computationally inexpensive means of predicting the reduction of forecast error variance that will be obtained from a given deployment of observations. This method differs from previous targeting methods as it makes no use of stationary norms or Kalman filter theory. It allows for both a dynamically determined estimate of the initial condition errors and allows for the operational data assimilation to be taken into account. Another major difference between the new targeting method and existing methods, is that it explicitly predicts the reduction in forecast error variance as the difference between the forecast error variance with and without the targeted observations. This additional feature introduces the potential for the prediction of instances where adding observations is likely to lead to an *increase* in the forecast error variance in the verification region.

Index Terms—Inter anuual Variability,Sea Surface Temperature, Rapid Warming,Gulf of Kutch, Gulf of Khambhat.

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1 INTRODUCTION

Meteorology is the study of atmospheric phenomena, particularly as a means of forecasting future weather events. Weather forecasts are produced by evolving the estimated current atmospheric state forward in time using large non-linear numerical models of the physical and dynamical processes in the atmosphere. The ability to create accurate numerical forecasts is reliant on both the accuracy of these models and the accuracy of the initial conditions. The initial conditions used in weather forecasting are statistically based ’compromises’ between observational data and a previous forecast, which are generated by a process known as data assimilation. Since Lorenz (1963) brought chaos theory to the attention of meteorologists, it has been understood that the non-linear nature of evolutionary process in the atmosphere causes errors (no matter how small) in initial conditions supplied to the forecast models to eventually grow into large errors in the forecast. This chaotic behaviour is referred to as sensitivity to initial conditions and is often summed up with the flippancy “if a butterfly flaps its wings in Brazil a tornado is set off in Texas”. As a direct result of the work of Lorenz (1963), meteorologists began to speculate about the existence of a theoretical upper limits to the times-scales over which an accurate forecast can be made. Since the publication of Lorenz (1963), improvements in numerical models and observation density have lead to large improvements in forecast accuracy. With the continued development of numerical forecasting methods and new observation platforms, it is hoped that there is still room for improvement before any theoretical limit of predictability is reached.

Since the mid 1990s, there has been a move to make forecast generation methods more specific to the atmospheric flow on a particular day and the requirements of the end user. One part of this move has been the development of methods by which the observation distribution resulting in the most accurate forecast may be *objectively* determined. With the development of new ’movable’ observation platforms, the possibility of day to day variations in the observation network based on the specific requirements of the forecast may present itself; Emanuel et al. (1995). Observations obtained in this manner have come to be known as ’targeted’ or ’adaptive’ observations; Lorenz nd Emanuel (1998).

Several questions surround the use of an adaptive observation strategy. Most of these questions are summed up in the words of Thompson (1957):

“What return in increased predictability can be expected from increasing the overall density of reporting stations, and how does this compare with the corresponding outlay offunds? Where is the point of rapidly diminishing return per outlay? How should the new stations be located in efecting the increase of overall station density?”

Thompson (1957), however, was writing about the development of a larger network of *fixed* ob-servations, and so for ’targeted’ observations a further question exists: What methods can be used to identify the best observation locations on a day to day basis? Attempting to answer these questions several targeting methods have already been proposed and tested ’in the field’. This thesis is a further contribution to the answers to two of these questions, namely,

1. Where should the additional observations be located?

We shall give a more detailed explanation of the subject of adaptive observations. To put the subject of adaptive observations in context, the following section discusses the properties of a ’generic’ weather forecasting system.

2. What method should be applied to identifying these locations?

The production of accurate weather forecasts requires the ability to perform two tasks: Firstly to propagate an estimate of the current atmospheric state forward in time; Secondly to make accurate estimates of the current atmospheric state. The first of these tasks is performed using large numerical weather prediction (NWP) models. The second is performed by combining observations of the current state of the atmosphere with an estimate of the atmospheric state from a previous forecast.

Hence the additional feature introduces the potential for prediction of instances where adding observations is likely to lead to an increase in the forecast error variation in the verification region.

2 MATERIALS AND METHODS

2.1 Area of Study

In and around Ahmedabad, located in the western zone of India , Gujarat.

Ahmedabad is the largest city and former capital of the Indian state of Gujarat.

The city is the administrative headquarters of Ahmedabad district and is the judicial capital of Gujarat as the Gujarat High Court is located here. With a population of more than 5.8 million and an extended population of 6.3 million, it is the fifth largest city and seventh largest metropolitan area of India. It is also ranked third in Forbes' list of fastest growing cities of the decade. Ahmedabad is located on the banks of the River Sabarmati, 32 km (20 mi) from the state capital Gandhinagar.

Though incorporated into the Bombay Presidency during British rule, Ahmedabad remained one of the most important cities in the Gujarat region. The city established itself as the home of a developing textile industry, which earned it the nickname "Manchester of the East". The city was at the forefront of the Indian independence movement in the first half of the 20th century and the centre of many campaigns of civil disobedience to promote farmers' and workers' rights, and civil rights apart from political independence.

The city has large populations of Hindus, Muslims and Jains, and these cultures are preeminent in the city, with their religious festivals and cuisine dominating the city's culture. Cricket is a popular sport in Ahmedabad, and the Sardar Patel Stadium is situated within the city. In 2012, The Times of India chose Ahmedabad as the best city to live in India.

Map of Gujarat: Coordinates: 23.03°N 72.58°E

Geography

Ahmedabad is located at 23.03°N 72.58°E in western India at an elevation of 53 metres (174 ft) from sea level on the banks of the Sabarmati river, in north-central Gujarat. It covers an area of 464 km^2 (179 sq mi).

The Sabarmati frequently dries up in the summm only a small stream of water, and the city is lo sandy and dry area. The steady expansion of th Kutch threatens to increase desertification aroun area and much of the state. Except for the s of Thaltej-Jodhpur Tekra, the city is almost flat. are within the city's limits—Kankaria Lake and Lake. Kankaria lake, in the neighbourhood ofMa an artificial lake developed by the Sultan of Delhi, Qutb-ud-din Aybak, in 1451. According to the Bureau of Indian Standards, the town falls under seismic zone-III, in a scale of I to V (in order of increasing vulnerability to earthquakes) Ahmedabad is divided by the Sabarmati into two physically distinct eastern and western regions. The eastern bank of the river houses the old city, which includes the central town of Bhadra. This part of Ahmedabad is characterised by packed bazaars, the *pol* system of close clustered buildings, and numerous places of worship. It houses the main railway station, the General Post Office, and few buildings of the Muzaffarid and British eras. The colonial period saw the expansion of the city to the western side of Sabarmati, facilitated by the construction of Ellis Bridge in 1875 and later the relatively modern Nehru Bridge. The western part of the city houses educational institutions, modern buildings, residential areas, shopping malls, multiplexes and new business districts centred around roads such as Ashram Road, C. G. Road & Sarkhej-Gandhinagar Highway.

Climate:

Ahmedabad has a hot semi-arid climate (Köppen climate classification: BSh), with marginally less rain than required for a tropical savanna climate. There are three main seasons: summer, monsoon and winter. Aside from the monsoon season, the climate is extremely dry. The weather is hot through the months of March to June; the average summer maximum is 41 °C (106 °F), and the average minimum is 27 °C (81 °F). From November to February, the average maximum temperature is 30 °C (86 °F), the average minimum is 15 °C (59 °F), and the climate is extremely dry. Cold northerly winds are responsible for a mild chill in January. The southwest monsoon brings a humid climate from mid-June to mid-September. The average annual rainfall is about 800 millimetres (31 in), but infrequent heavy torrential rains cause local rivers to flood and it is not uncommon for droughts to occur when the monsoon does not extend as far west as usual. The highest temperature recorded is 48.5 °C (119.3 °F).

Climate data for Ahmedabad (1971–

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Average high °C (°F)	28.3 (82.9)	30.4 (86.7)	35.6 (96.1)	39.8 (103.6)	41.5 (106.7)	38.4 (101.1)	33.4 (92.1)	31.8 (89.2
Daily mean °C (°F)	20.1	22.2	27.3	31.7	33.9	32.8	29.5	28.2

	(68.2)	(72)	(81.1)	(89.1)	(93)	(91)	(85.1)	(82.8)	(84.4)	(83.3)	(76.5)	(70.3)	(81.4)
age low °C (°F)	11.8 (53.2)	13.9 (57)	18.9 (66)	23.7 (74.7)	26.2 (79.2)	27.2 (81)	25.6 (78.1						
fall mm (inches)	2 (0.08)	1 (0.04)	0 (0)	3 (0.12)	20 (0.79)	103 (4.06)	247 (9.72						
rainy days (≥ 0.1 mm)	0.3	0.3	0.1	0.3	0.9	4.8	13.6						
n monthly sunshine hours	288.3	274.4	279	297	328.6	237	130.2						

e: HKO[33]

Effects of climate change :

Following a heat wave in May 2010, reaching 46.8 °C (116.2 °F), which claimed hundreds of lives, the Ahmedabad Municipal Corporation (AMC) in partnership with an international coalition of health and academic groups and with support from the Climate & Development Knowledge Network, has developed the Ahmedabad Heat Action Plan. Aimed at increasing awareness, sharing information and coordinating responses in order to reduce the health effects of heat on vulnerable populations, the action plan is the first comprehensive plan of its kind in India.

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3 SECTIONS

The **climate of India** resolves into six major climatic subtypes; their influences give rise to desert in the west, alpine tundra and glaciers in the north, humid tropical regions supporting rain forests in the southwest, and Indian Ocean island territories that flank the Indian subcontinent. Regions have starkly different—yet tightly clustered—microclimates. The nation is largely subject to four seasons: winter (January and February), summer (March to May), a monsoon (rainy) season (June to September), and a post-monsoon period (October to December).

India's geography and geology are climatically pivotal: the Thar Desert in the northwest and the Himalayas in the north work in tandem to effect a culturally and economically break-all monsoonal regime. As Earth's highest and most massive mountain range, the Himalayan system bars the influx of frigid katabatic winds from the icy Tibetan Plateau and northerly Central Asia. Most of North India is thus kept warm or is only mildly chilly or cold during winter; the same thermal dam keeps most regions in India hot in summer.

Though the Tropic of Cancer—the boundary between the tropics and subtropics—passes through the middle of India, the bulk of the country can be regarded as climatically tropical. As in much of the tropics, monsoonal and other weather patterns in India can be wildly unstable: epochal droughts, floods, cyclones, and other natural disasters are sporadic, but have displaced or ended millions of human lives. There is widespread scientific consensus that South Asia is likely to see such climatic events, along with their aleatory unpredictability, to change in frequency and are likely to increase in severity. Ongoing and future vegetative changes and current sea level rises and the attendant inundation of India's low-lying coastal areas are other impacts, current or predicted, that are attributable to global warming.

Tectonic movement by the Indian Plate caused it to pass over a geologic hotspot—the Réunion hotspot—now occupied by the volcanic island of Réunion. This resulted in a massive flood basalt event that laid down the Deccan Traps some 60–68 Ma, at the end of the Cretaceous period. This may have contributed to the global Cretaceous–Paleogene extinction event, which caused India to experience significantly reduced insolation. Elevated atmospheric levels of sulphur gases formed aerosols such as sulphur dioxide and sulphuric acid, similar to those found in the atmosphere of Venus; these precipitated as acid rain. Elevated carbon dioxide emissions also contributed to the greenhouse effect, causing warmer weather that lasted

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long after the atmospheric shroud of dust and aerosols had cleared. Further climatic changes 20 million years ago, long after India had crashed into the Laurasian landmass, were severe enough to cause the extinction of many endemic Indian forms. The formation of the Himalayas resulted in blockage of frigid Central Asian air, preventing it from reaching India; this made its climate significantly warmer and more tropical in character than it would otherwise have been.

The India Meteorological Department (IMD) designates four climatological seasons:

- **Winter**, occurring from December to March. The year's coldest months are December and January, when temperatures average around 10–15 °C (50–59 °F) in the northwest; temperatures rise as one proceeds towards the equator, peaking around 20–25 °C (68–77 °F) in mainland India's southeast.
- **Summer** or **pre-monsoon** season, lasting from April to June (April to July in northwestern India). In western and southern regions, the hottest month is April; for northern regions, May is the hottest month. Temperatures average around 32–40 °C (90–104 °F) in most of the interior.
- **Monsoon** or **rainy** season, lasting from July to September. The season is dominated by the humid southwest summer monsoon, which slowly sweeps across the cou try beginning in late May or early June. Monsoon rains begin to r cede from North India at the beginning of October. South India typ cally receives more rainfall.
- **Post-monsoon** or **autumn** season, lasting from October through November. In northwestern India, O tober and November are usually cloudless. Tamil Nadu receives mc of its annual precipitation in the northeast monsoon season.

The Himalayan states, being more temperate, experience a additional season, *spring*, which coincides with the fir weeks of summer in southern India. Traditionally, Indiar note six seasons or *Ritu*, each about two months lon, These are the spring season (*Sanskrit:* vasanta), summ (*grīṣma*), monsoon season (*varṣā*), autumn (*śarada*), wint (*hemanta*), and prevernal season[24](*śiśira*). These are base on the astronomical division of the twelve months into si parts. The ancient Hindu calendar also reflects these sea sons in its arrangement of month.

Statistics :

Shown below are temperature and precipitation data for selected Indian cities; these represent the full variety of ma jor Indian climate types. Figures have been grouped by the four-season classification scheme used by the IMD;[N 1] year-round averages and totals are also displayed.

4 CITATIONS

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5 EQUATIONS

The production of accurate weather forecasts requires the ability to perform two tasks: Firstly to propagate an estimate of the current atmospheric state forward in time; Secondly to make accurate estimates of the current atmospheric state. The first of these tasks is performed using large numerical weather prediction (NWP) models. The second is performed by combining observations of the current state of the atmosphere with an estimate of the atmospheric state from a previous forecast.

The second task required for the successful production of a forecast needs slightly more explanation. Ideally the model would be initialized using a set of homogeneously distributed accurate observations, at least equal in number to the number of variables in the model state vector χ. Unfortunately, due to the high dimension of the model state and the inaccessibility of many required observation locations, the observations are neither large enough in number nor homo-geneous enough in their distribution to specify entirely the model state. In order to solve this problem the observational data are combined with a previous forecast to produce the estimated current atmospheric state, χa, based on the estimated statistics of the error in both the forecast and observations. This process is known as data assimilation. The forecast used in the data as-similation process is known as the background. The estimated state obtained through the data assimilation process is known as the analysis.

$$\chi f(T) = M\,[\chi a(0), T\,]$$

where χ is a vector containing the model state variables (pressure, temperature, velocity at different grid points for example) and *M* is a non-linear operator containing the model equations.

The various data assimilation methods in use in weather forecasting centres derive from the minimisation of the quadratic cost function:

$$J\,(\chi) = ½\,(\chi - \chi^{b})^{T}\,B^{-1}(\chi - \chi^{b}) + 1/2\,(y-H[\chi])^{T}\,R^{-1}(\,y- H[\chi])$$

where the vector χ is the control vector1, χb is a vector containing the background, y is a vector containing the observations, H is the forward model (or observation operator) which transforms the model variables to the observed variables R is matrix containing an estimate of the covariance between observational errors, and B is a matrix containing an estimate of the covariance between the errors in the background. From this cost function the analysis χa can be defined as the vector χ for which J(χ) is minimised. In order to formulate the cost function, certain assumptions have to be made about the background and observation errors. These assumptions are, that the observation and background errors are statistically independent, and that individually the assumed error statistics must lead to non-singular covariance matrices. The assumption of non-singular covariance matrices essentially implies that all possible states must have a reasonable probability of existing, even if in the current atmospheric flow they are so unlikely that their probability of existing is very close to zero. A useful property of the cost function is that if the approximation to the background and observation errors is 'good' and the forward model can be approximated by the linear operator H, the analysis error covariance matrix A is equal to the inverse of the Hessian (second derivative with respect to χ) of the cost function; i.e(1).

$$A= [\delta 2J/\,\delta\, x^{2}]^{-1}=[B^{-1} +H^{T}\,R^{-1}H]^{-1}$$

Ideally the covariance matrices in the cost function would depend on the time of observation and the observations would be used to correct the model state corresponding to the time of observation. To make the background error covariance time specific one could in theory evolve the analysis error covariance matrix. In reality however the dimension of the model state vector is typically greater than 106 so that the background error covariance cannot be stored by current computers, let alone evolved or explicitly inverted. Due to the limitations in computational power and concerns that evolving covariance matrices may become singular, many methods of solving approximate cost functions have been developed.

6 HELPFUL HINTS

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The first of the two targeting methods that were used in the At REC field experiment is the singular vector method. In simplistic terms the essential components of the singular vector method can be summarised thus: A small set of perturbations (the singular vectors) that maximise the amplification of small perturbations to the initial conditions over the finite forecast integration period are calculated; the observations are then targeted to regions in which this set of perturbations weighted by their amplification over the forecast period have large amplitude. The finer details of this method are somewhat more complex than this simplistic explanation so we shall break it down into three sections. Firstly we shall describe the mathematical properties and computation of the singular vectors. Secondly we shall describe the implementation of the targeting method using the singular vectors. Finally we shall identify some assumptions that may be used to link the method to the generic description of ’A-optimal’ targeting methods.

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Table 7.1: Results showing the mean, RMS, and STD of 0015m SEVIRI, inC, for the area 45 N to 25 N and 300 E to 330 E during ^{1st7th} January 2006. The numbers in parenthesis compare only those results calculated at locations and days simulated in each case.

7 END SECTIONS

7.1 Appendices

Appendixes, if needed, appear before the acknowledgment. In the event multiple appendices are required, they will be labeled “Appendix A,” “Appendix B, “ etc. If an article does not meet submission length requirements, authors are strongly encouraged to make their appendices supplemental material.

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7.2 Acknowledgments

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7.3 References

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4 CONCLUSION

For the first time the full spectrum of sir gular vectors of theEady model are consid ered. The importance and implications c the unshielding and modal unmaskin mechanisms, to the computed singular vec tors are discussed. The computed singula vectors are used to analyse the singula vector targeting function commonly used i observation targeting, in a vertical cross section.

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