For A Lecture on Scientific Meteorology within Statistical ("Pure") Physics Concepts

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Abstract

Various aspects of modern statistical physics and meteorology can be tied together. Critical comments have to be made. However, the historical importance of the University of Wroclaw in the field of meteorology should be first pointed out. Next, some basic difference about time and space scales between meteorology and climatology can be outlined. The nature and role of clouds both from a geometric and thermal point of view are recalled. Recent studies of scaling laws for atmospheric variables are mentioned, like studies on cirrus ice content, brightness temperature, liquid water path fluctuations, cloud base height fluctuations, .... Technical time series analysis approaches based on modern statistical physics considerations are outlined.

I. INTRODUCTION AND FOREWORD

This contribution to the 18th Max Born Symposium Proceedings, cannot be seen as an extensive review of the connection between meteorology and

*SUPRATECS = Services Universitaires Pour la Recherche et les Applications Technologiques de matériaux Electrocéramiques, Composites et Supraconducteurs
various aspects of modern statistical physics. Space and time (and weather) limit its content. Much of what is found here can rather be considered to result from a biased viewpoint or attitude and limited understanding of the author frustrated because the developments of what he thought was a science (meteorology) turns out to be unsatisfactory to him and sometimes misleading. It seems that other approaches might be thought of. New implementations carried forward. Some are surely made and understood by meteorologists but are not easily available in usual physics literature. Thus the lines below may be rather addressed to physicists. The paper will be satisfactory if it attracts work toward a huge field of interest with many many publications still with many unanswered questions. As an immediate warning it is emphasized that deep corrections to standard models or actual findings can NOT be found here nor are even suggested. Only to be found is a set of basic considerations and reflections expecting to give lines of various investigations, and hope for some scientific aspects of meteorology in the spirit of modern statistical physics ideas.

A historical point is in order. The author came into this subject starting from previous work in econophysics, when he observed that some "weather derivatives" were in use, and some sort of game initiated by the Frankfurt Deutsche Börse\(^1\) in order to attract customers which could predict the temperature in various cities within a certain lapse of time, and win some prize thereafter\(^1\). This subject therefore was obviously similar to predicting the

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\(^1\)A common measure of temperature has arisen from the market: the degree-day. The Heating Degree Day is a (loose) measure of how much heating is needed. For a given day, HDD is equal to the larger of Max \([0, 18^\circ C - \text{daily average temperature}]\). The Cooling Degree Day (CDD) is a (loose) measure of how much cooling is needed: CDD = Max\([0, \text{daily average temperature} - 18^\circ C]\).
S&P500 or other financial index values at a certain future time. Whence various techniques which were used in econophysics, like the detrended fluctuation analysis, the multifractals, the moving average crossing techniques, etc. could be attempted from scratch.

Beside the weather (temperature) derivatives other effects are of interest. Climate is said to be fast changing nowadays. Much is said and written about e.g. the ozone layer and the Kyoto "agreement". The El Niño system is a great challenge to scientists. Since there is some data available under the form of time series, like the Southern Oscillation Index, it is of interest to look for trends, coherent structures, periods, correlations in noise, etc. in order to bring some knowledge, if possible basic parameters, to this meteorological field and expect to import some modern statistical physics ideas into such climatological phenomena.

It appeared that other data are available like those obtained under various experiments, put into force by various agencies, like the Atlantic Stratocumulus Transition Experiment (ASTEX) for ocean surfaces or those of the Atmospheric Radiation Measurement Program (ARM) of the US Department of Energy, among others. Much data is about cloud structure, e.g the cloud base height evolution, on liquid water paths, brightness temperature, ...; they can often freely downloaded from the web. Therefore many time series can be analyzed.

However it appeared that the data is sometimes of rather limited value because of the lack of precision, or are biased because the raw data is already transformed through models, and arbitrarily averaged ("filtered") whence

This notion seems to be a measure that the energy suppliers could use to hedge their supply in adverse temperature conditions.
even sometimes lacking the meaning it should contain. Therefore a great challenge comes through in order to sort out the wheat from the chaff in order to develop meaningful studies.

In Sect.2, I will comment on the history of meteorology, observe that the evolution of such an old science is slow and limited by various \textit{a priori} factors. Some basic recall on clouds and their role on climate and weather will be made (Sect.3). This should remind us that the first modern ideas of statistical physics were implemented on cloud studies through fractal \textit{geometry}. Indeed, modern and pioneering work on clouds is due to Lovejoy who looked at the perimeter-area relationship of rain and cloud areas\textsuperscript{2}, fractal dimension of their shape or ground projection. He discovered the statistical self-similarity of cloud boundaries through area-perimeter analyses of the geometry from satellite pictures. He found the fractal dimension $D_p \simeq 4/3$ over a spectrum of 4 orders of magnitude in size, for small fair weather cumuli ($\sim 1021$ km) up to huge stratus fields ($\sim 103$ km). Occasional scale breaks have been reported\textsuperscript{3,4} due to variations in cloudiness. Cloud size distributions have also been studied from a scaling point of view. It is hard to say whether there is perfect scaling\textsuperscript{5–7}; why should there be scaling?

I will point out, as others do, the basic well known pioneering work of modern essence, like the Lorenz model. It was conceived in order to induce predictability, but it turned out rather to be the basic nonlinear dynamical system describing chaotic behavior. However this allows for bringing up to its level the notion of fractal ideas for meteorology work, thus scaling laws, and modern data analysis techniques. I will recall most of the work to which I have contributed, being aware that I am failing to acknowledge many more important reports than those, - for what I deeply apologize.

There is a quite positive view of mine however. Even though the techniques have not yet brought up many codes implemented in weather and cli-
mate evolution prediction, it was recently stressed in a sarcastic way ("Chaos: useful at last?") that some applications of nonlinear dynamics ideas are finding their way onto weather prediction, even though it has to be said that there is much earlier work on the subject.

There are (also) very interesting lecture notes on the web for basic modules on meteorological training courses, e.g. one available through ECMWF website. But I consider that beyond the scientifically sound and highly sophisticated computer models, there is still space for simple technical and useful approaches, based on standard statistical physics techniques and ideas, in particular based on the scaling hypothesis for phase transitions and percolation theory features. These constraints allow me to shorten the reference list! A few examples will be found in Sect. 4.

At the end of this introduction, I would crown the paper with references to two outstanding scientists. First let me recall Friedmann who said that "if you can't be a good mathematician, you try to become a good physicist, and those who can't become meteorologists". Another, Heisenberg was surely aware about errors and prediction difficulties resulting from models. Both men should be guiding us to new endeavors with modesty anyway.

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2 A. Friedmann (1888-1925) had a bad experience with his ideas, e.g. rejected by Einstein. "Thus" in July 1925 Friedmann made a record-breaking ascent in a balloon to 7400 meters to make meteorological and medical observations. Near the end of August 1925 Friedmann began to feel unwell. He was diagnosed as having typhoid and taken to hospital where he died two weeks later. He never became a sociologist.

3 W. Heisenberg (1901-1976) had much difficulty to get his Ph.D. at TU Munchen because he was not a good experimentalist!
II. HISTORICAL INTRODUCTION

From the beginning of times, the earth, sky, weather have been of great concern. As soon as agriculture, commerce, travelling on land and sea prevailed, men have wished to predict the weather. Later on airborne machines need atmosphere knowledge and weather predictions for best flying. Nowadays there is much money spent on weather predictions for sport activities. It is known how the knowledge of weather (temperature, wind, humidity, ..) is relevant, (even fundamental!), e.g. in sailing races or in Formula 1 and car rally races. Let it be recalled the importance of knowing and predicting the wind (strength and directions), pressure and temperature at high altitude for the (recent) no-stop balloon round the world trip.

A long time ago, druids and other priests were the up-to-date meteorologists. It is known that many proverbs on weather derive from farmer observations, - one of the most precise ones reads (in french) "Après la pluie, le beau temps", which is (still) correct, in spite of the Heisenberg principle, and modern scientific advances.

After land travel and commerce, the control of the seas was of great importance for economic, whence political reasons. Therefore there is no surprise in the fact that at the time of a British Empire, and the Dutch-Spanish-Portuguese rivalry the first to draw sea wind maps was Halley\textsuperscript{14}. That followed the "classical" isobaths and isoheights (these are geometrical measures !!!) for sailors needing to go through channels. Halley, having also invented the isogons (lines of equal magnetic fields) drew in ca. 1701, the first trade wind and monsoon maps\textsuperscript{14}, over the seas\textsuperscript{4}. It may be pointed out that he did

\textsuperscript{4}Halley is also known for the discovery of a comet bearing his name and for using Breslau mortality tables, - the basis of useful statistical work in actuary science.
not know Coriolis forces yet.

A second major step for meteorology seems to be due to Karl Theodor who between 1781 and 1792 was responsible for the Palatinate Meteorological Society. He invited (39) friends around the world\textsuperscript{14}, from Massachusetts to Ural, to make three measurements per day, and report them to him, in order to later publish ”Ephemerides”, in Manheim.

I am very pleased to point out that Heinrich Wilhelm Brandes(1777-1834), Professor of Mathematics and Physics at the University of Breslau was the first\textsuperscript{14} who had the idea of displaying weather data (temperature, air pressure, a.s.o.) on geographical maps\textsuperscript{5}.

Later von Humboldt (1769-1859) had the idea to connect points in order to draw isotherms\textsuperscript{14}. No need to say that this was a bold step, - the first truly predictive step implying quantitative thermodynamics data. Most likely a quite incorrect result. It is well known nowadays that various algorithms will give various isotherms, starting from the same temperature data and coordinate table. In the same line of lack of precision, there is no proof at all that the highest temperature during the 2003 summer was 42.6°C at the point of measurement at Cordoba Airport on Aug. 12, 2003. There is no proof that the highest temperature was 24.9°C in Poland, in Warsaw-Okęcie, on that day in 2003. There is no proof that we will ever know the lowest temperature in Poland in 2003 either. In fact the maximum or minimum temperature as defined in meteorology\textsuperscript{15,16} are far from the ones acceptable in physics laboratories. Therefore what isotherms are drawn from such data? They connect data points which values are obtained at different times! What

\textsuperscript{5}It seems that H.W. Brandes left Breslau to get his Ph.D. thesis in Heidelberg in 1826. Alas it seems that the original drawings are not available at this time. Where are they?
is their physical meaning? One might accept to consider that isotherms result from some truly averaged temperature during one day (!) at some location (?). What is an average temperature? In meteorology, it is NOT the ratio of the integral of the temperature distribution function over a time interval to that time interval\(^{15,16}\). Nor is it a spatial mean. In fact, what is a ”mean temperature” ... for a city, a country, ... for the world? One might propose that one has to measure the temperature everywhere and continuously in time, then make an average. Questions are not only how many thermometers does one need, but also what precision is needed. Does one need to distribute the thermometers homogeneously? What about local peculiarities? like nuclear plants? Should we need a fractal distribution in space of thermometers? Might one use a Monte Carlo approach to locate them such that statistical theories give some idea on error bars. What error bars? There is no error bar ever given on weather maps, in newspapers or TV, on radio and rarely in scientific publications. Errors are bad! and forgotten. There is rarely a certitude (or risk) coefficient which is mentioned. It might not be necessary for the public, but yet we know, and it will be recalled later, that for computer work and predictions the initial values should be well defined. Therefore it seems essential to concentrate on predicting the uncertainty in forecast models of weather and climate as emphasized elsewhere\(^{17,18}\).

**III. CLIMATE AND WEATHER. THE ROLE OF CLOUDS**

Up to von Humboldt there was no correlation discussed, no model of weather, except for qualitative considerations, only through the influence of the earth rotation, moon phases, Saturn, or Venus or Jupiter or constellation locations, etc. However the variables of interest were becoming to be known, but predictive meteorology and more generally climate (description and) fore-
casting had still a need for better observational techniques, data collecting, subsequent analysis, and model outputs.

Earth’s climate is clearly determined by complex interactions between sun, oceans, atmosphere, land and biosphere. The composition of the atmosphere is particularly important because certain gases, including water vapor, carbon dioxide, etc., absorb heat radiated from Earth’s surface. As the atmosphere warms up, it in turn radiates heat back to the surface that increases the earth’s "mean surface temperature", by some 30 K above the value that would occur in the absence of a radiation-trapping atmosphere. Note that perturbations in the concentration of the radiation active gases do alter the intensity of this effect on the earth’s climate.

Understanding the processes and properties that affect atmospheric radiation and, in particular, the influence of clouds and the role of cloud radiative feedback are issues of great scientific interest. This leads to efforts to improve not only models of the earth’s climate but also predictions of climate change, as understood over long time intervals, in contrast to shorter time scales for weather forecast. In fact, with respect to climatology the situation is very complicated because one does not even know what the evolution equations are. Since controlled experiments cannot be performed on the climate system, one relies on using ad hoc models to identify cause-and-effect relationships. Nowadays there are several climate models belonging to many different centers. Their web sites not only carry sometimes the model output used to make images but also provide the source code. It seems relevant to point out here that the stochastic resonance idea was proposed to describe climatology evolution.

Phenomena of interest occurring on short (!) time and small (!) space scales, whence the weather, are represented through atmospheric models with a set of nonlinear differential equations based on Navier-Stokes equations.
for describing fluid motion, in terms of mass, pressure, temperature, humidity, velocity, energy exchange, including solar radiation ... whence for predicting the weather. It should be remembered that solutions of such equations forcefully depend on the initial conditions, and steps of integrations. Therefore a great precision on the temperature, wind velocity, etc. cannot be expected and the solution(s) are only looking like a mess after a few numerical steps.

The Monte Carlo technique suggests to introduce successively a set of initial conditions, perform the integration of the differential equations and make an average thereafter. If some weather map is needed, a grid is used with constraints on the nodes, but obviously the precision (!) is not remarkable, - but who needs it ?

It is hereby time to mention Lorenz’s famous pioneering work who simplified Navier-Stokes equations. However, predicting the result of a complex nonlinear interactions taking place in an open system is a difficult task.

Much attention has been paid recently to the importance of the main components of the atmosphere, in particular clouds, (see Appendix A) in the water three forms — vapor, liquid and solid, for buffering the global temperature against reduced or increased solar heating. Owing to its special properties, it is believed, that water establishes lower and upper boundaries on how far the temperature can drift from today’s. However, the role of clouds and water vapor in climate change is not well understood. In fact, there may

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6. It is fair to mention Sorel work about general motion of the atmosphere in order to explain strong winds on the Mediterranean sea. The quoted reference has some interesting introduction about previous work

7. Beautiful and thought provoking illustrations can be found on various websites, demonstrating Poincaré cross sections, strange attractors, cycles, bifurcations, and the like.
be positive feedback between water vapor and other greenhouse gases. Studies suggest that the heliosphere influences the Earth climate via mechanisms that affecting the cloud cover. Surprisingly the influence of solar variability is found to be strong on low clouds (3 km), whence pointing to a microphysical mechanism involving aerosol formation enhanced by ionization due to cosmic rays.

At time scales of less than one day, significant fluxes of heat, water vapor and momentum are exchanged due to entrainment, radiative transfer, and/or turbulence. The turbulent character of the motion in the atmospheric boundary layer (ABL) is one of its most important features. Turbulence can be caused by a variety of processes, like thermal convection, or mechanically generated by wind shear, or following interactions influenced by the rotation of the Earth. This complexity of physical processes and interactions between them create a variety of atmospheric formations. In particular, in a cloudy ABL the radiative fluxes produce local sources of heating or cooling within the mixed-layer and therefore can greatly influence its turbulent structure and dynamics, especially in the cloud base.

The atmospheric boundary layer is defined by its inner (surface) layer. In an unstably stratified ABL the dominating convective motions are generated by strong surface heating from the Sun or by cloud-topped radiative cooling processes. In contrast, a stably stratified ABL occurs mostly at night in response to the surface cooling due to long-wave length radiation emitted into the space.

In presence of clouds (shallow cumulus, stratocumulus or stratus) the structure of the ABL is modified because of the radiative fluxes. Thermo-dynamical phase changes become important. During cloudy conditions one can distinguish mainly: (i) the case in which the cloud and the sub-cloud layers are fully coupled; (ii) two or more cloud layers beneath the inversion,
with the lower layer well-mixed with an upper elevated layer, decoupled from
the surface mixed layer or (iii) a radiation driven elevated mixed cloud layer,
decoupled from the surface.

Two practical cases can be considered: the marine ABL and the continental ABL. The former is characterized by a high concentration of moisture. It is wet, mobile and has a well expressed lower boundary. The competition between the processes of radiative cooling, entrainment of warm and dry air from above the cloud and turbulent buoyancy fluxes determine the state of equilibrium of the cloud-topped marine boundary layer\textsuperscript{21}. The continental ABL is usually dryer, less mobile, better defined lower and upper boundaries. Both cases have been investigated for their scaling properties\textsuperscript{43–45}

\section*{IV. MODERN STATISTICAL PHYSICS APPROACHES}

The modern paradigm in statistical physics is that systems obey "universal" laws due to the underlying nonlinear dynamics independently of microscopic details. Therefore it can be searched in meteorology whether one can obtain characteristic quantities using the modern statistical physics methods as done in other laboratory or computer investigations. To distinguish cases and patterns due to "external field" influences or mere self-organized situations in geophysics phenomena\textsuperscript{46} is not obvious indeed. What sort of feedback can be found? or neglected? Is the equivalent of chicken-egg priority problem in geophysics easily solved? The coupling between human activities and deterministic physics is hard to model on simple terms\textsuperscript{47}, or can even be rejected\textsuperscript{48}.

Due to the nonlinear physics laws governing the phenomena in the atmosphere, the time series of the atmospheric quantities are usually non-stationary\textsuperscript{48,49} as revealed by Fourier spectral analysis, - which is usually the
first technique to use. Recently, new techniques have been developed that can systematically eliminate trends and cycles in the data and thus reveal intrinsic dynamical properties such as correlations that are very often masked by nonstationarities, 50, 51. Whence many studies reveal long-range power-law correlations in geophysics time series 46, 49, 52 in particular in meteorology 53–60. Multi-affine properties 45, 61–69 can also be identified, using singular spectrum or/and wavelets.

There are different levels of essential interest for sorting out correlations from data, in order to increase the confidence in predictability 70. There are investigations based on long-, medium-, and short-range horizons. The \( i^\) diagram variability (\( iVD \)) method allows to sort out some short range correlations. The technique has been used on a liquid water cloud content data set taken from the Atlantic Stratocumulus Transition Experiment (ASTEX) 92 field program 71. It has also been shown that the random matrix approach can be applied to the empirical correlation matrices obtained from the analysis of the basic atmospheric parameters that characterize the state of atmosphere 72. The principal component analysis technique is a standard technique 73 in meteorology and climate studies. The Fokker-Planck equation for describing the liquid water path 74 is also of interest. See also some tentative search for power law correlations in the Southern Oscillation Index fluctuations characterizing El Niño 75. But there are many other works of interest 76.

A. Ice in cirrus clouds

In clouds, ice appears in a variety of forms, shapes, depending on the formation mechanism and the atmospheric conditions 3, 4, 41, 61, 77, 78. The cloud inner structure, content, temperature, lifetime, .. can be studied. In cirrus clouds, at temperatures colder than about \(-40^\circ C\) ice crystals form. Because
of the vertical extent, ca. from about 4 to 14 km and higher, and the layered structure of such clouds one way of obtaining some information about their properties is mainly by using ground-based remote sensing instruments (see Appendix B), and searching for the statistical properties (and correlations) of the radio wave signal backscattered from the ice crystals. This backscattered signal received at the radar receiver antenna is known to depend on the ice mass content and the particle size distribution. Because of the vertical structure of the cirrus cloud it is of interest to examine the time correlations in the scattered signal on the horizontal boundaries, i.e., the top and bottom, and at several levels within the cloud.

We have reported along the DFA correlations in the fluctuations of radar signals obtained at isodepths of winter and fall cirrus clouds. In particular we have focussed attention on three quantities: (i) the backscattering cross-section, (ii) the Doppler velocity and (iii) the Doppler spectral width. They correspond to the physical coefficients used in Navier Stokes equations to describe flows, i.e. bulk modulus, viscosity, and thermal conductivity. It was found that power-law time correlations exist with a crossover between regimes at about 3 to 5 min, but also $1/f$ behavior, characterizing the top and the bottom layers and the bulk of the clouds. The underlying mechanisms for such correlations likely originate in ice nucleation and crystal growth processes.

**B. Stratus clouds**

In another case, i.e. for stratus clouds, long-range power-law correlations and multi-affine properties have reported for the liquid water fluctuations, beside the spectral density. Interestingly, stratus
cloud data retrieved from the radiance, recorded as brightness temperature,\(^8\) at the Southern Great Plains central facility and operated in the vertically pointing mode\(^8\) (see Appendix B for a brief technical note on instrumentation) indicated for the Fourier spectrum \(S(f) \sim f^{-\beta}\), a \(\beta\) exponent equal to \(1.56 \pm 0.03\) pointing to a nonstationary time series. The DFA statistical method applied on the stratus cloud brightness microwave recording\(^5,8\) indicates the existence of long-range power-law correlations over a two hour time.

Contrasts in behaviors, depending on seasons can be pointed out. The DFA analysis of liquid water path data measured in April 1998 gives a scaling exponent \(\alpha = 0.34 \pm 0.01\) holding from 3 to 60 minutes. This scaling range is shorter than the 150 min scaling range\(^5\) for a stratus cloud in January 1998 at the same site. For longer correlation times a crossover to \(\alpha = 0.50 \pm 0.01\) is seen up to about 2 h, after which the statistics of the DFA function is not reliable.

However a change in regime from Gaussian to non-Gaussian fluctuation regimes has been clearly defined for the cloud structure changes using a finite size (time) interval window. It has been shown that the DFA exponent turns from a low value (about 0.3) to 0.5 before the cloud breaks. This indicates that the stability of the cloud, represented by antipersistent fluctuations is (for some unknown reason at this level) turning into a system for which the fluctuations are similar to a pure random walk. The same type of finding was observed for the so called Liquid Water Path\(^9\) of the cloud.

\(^8\)http://www.phys.unm.edu/ duric/phy423/l1/node3.html

\(^9\)The liquid water path (LWP) is the amount of liquid water in a vertical column of the atmosphere; it is measured in cm\(^{-3}\); sometimes in cm !!!
The value of \( \alpha \approx 0.3 \) can be interpreted as the \( H_1 \) parameter of the multifractal analysis of liquid water content\(^\text{[44,45,62]} \) and of liquid water path\(^\text{[67]} \). Whence, the appearance of broken clouds and clear sky following a period of thick stratus can be interpreted as a non equilibrium transition or a sort of fracture process in more conventional physics. The existence of a crossover suggests two types of correlated events as in classical fracture processes: nucleation and growth of diluted droplets. Such a marked change in persistence implies that specific fluctuation correlation dynamics should be usefully inserted as ingredients in \textit{ad hoc} models.

The non equilibrium nature of the cloud structure and content\(^\text{[82]} \) should receive some further thought henceforth. It would have been interesting to have other data on the cloud in order to understand the cause of the change in behavior.

\textbf{C. Cloud base height}

The variations in the local \( \alpha \)-exponent ("multi-affinity") suggest that the nature of the correlations change with time, so called intermittency phenomena. The evolution of the time series can be decomposed into successive persistent and anti-persistent sequences. It should be noted that the intermittency of a signal is related to existence of extreme events, thus a distribution of events away from a Gaussian distribution, in the evolution of the process that has generated the data. If the tails of the distribution function follow a power law, then the scaling exponent defines the critical order value after which the statistical moments of the signal diverge. Therefore it is of interest to probe the distribution of the fluctuations of a time dependent signal \( y(t) \) prior investigating its intermittency. Much work has been devoted to the cloud base height\(^\text{[64–66]} \), under various ABL conditions, and the LWP\(^\text{[67,74]} \). Neither the
distribution of the fluctuations of liquid water path signals nor those of the cloud base height appear to be Gaussian. The tails of the distribution follow a power law pointing to "large events" also occurring in the meteorological (space and time) framework. This may suggest routes for other models.

D. Sea Surface Temperature

Time series analysis methods searching for power law exponents allow to look from specific view points, like atmospheric or sea surface temperature fluctuations. These are of importance for weighing their impacts on regional climate, whence finally to greatly increase predictability of precipitation during all seasons.

Currently, scientists rely on climate patterns derived from global sea surface temperatures (SST) to forecast precipitation e.g. the U.S. winter. For example, rising warm moist air creates tropical storms during El Niño years, a period of above average temperatures in the waters in the central and eastern tropical Pacific. While the tropical Pacific largely dictates fall and winter precipitation levels, the strength of the SST signal falls off by spring through the summer. For that reason, summer climate predictions are very difficult to make.

Recently we have attempted to observe whether the fluctuations in the Southern Oscillation index (SOI) characterizing El Niño were also prone to a power law analysis. For the SOI monthly averaged data time interval 1866-2000, the tails of the cumulative distribution of the fluctuations of SOI signal it is found that large fluctuations are more likely to occur than the Gaussian distribution would predict. An antipersistent type of correlations exist for a time interval ranging from about 4 months to about 6 years. This leads to favor specific physical models for El Niño description.
V. CONCLUSIONS

Modern statistical physics techniques for analyzing atmospheric time series signals indicate scaling laws (exponents and ranges) for correlations. A few examples have been given briefly here above, mainly from contributed papers in which the author has been involved. Work by many other authors have not been included for lack of space. This brief set of comments is only intended for indicating how meteorology and climate problems can be tied to scaling laws and inherent time series data analysis techniques. Those ideas/theories have allowed me to reduce the list of quoted references, though even like this I might have been unfair. One example can be recalled in this conclusion to make the point: the stratus clouds break when the molecule density fluctuations become Gaussian, i.e. when the molecular motion becomes Brownian-like. This should lead to better predictability on the cloud evolution. Many other examples can be imagined. In fact, it would be of interest for predictability models to examine whether the long range fluctuations belong to a Levy-like or Tsallis or ... rather than to a Gaussian distribution as in many self organized criticality models. This answer, if positive, would enormously extend the predictability range in weather forecast.

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Appendix A. CLOUDS

It may be of interest for such a type of proceedings to define clouds, or at least to review briefly cloud classifications. Clouds can be classified by their
1. **High clouds:** High clouds are those having a cloud base above 6000 m, where there is little moisture in the air. Typically they contain ice crystals, often appear thin and wispy, and sometimes appear to create a halo around the sun or the moon. High clouds are Cirrus (Ci), Cirrostratus (Cs), Cirrocumulus (Cc) and Cumulonimbus (Cb).

2. **Middle clouds:** Middle clouds have a cloud base between 2000 m and 6000 m. These clouds are usually composed of water droplets, but sometimes contain ice crystals, if the air is cold enough. Middle clouds are Altostratus (As) and Altocumulus (Ac).

3. **Low clouds:** Low clouds have a cloud base at less than 2000 m and appear mostly above the sea surface. Usually composed of water droplets except in winter at high latitudes when surface air temperature is below freezing. Low clouds are Stratus (St), Stratocumulus (Sc) and Cumulus (Cu).

or by their shape:

1. **Cirrus:** The cirrus are thin, hair-like clouds found at high altitudes.

2. **Stratus:** The stratus clouds are layered clouds with distinguished top and bottom. Found at all altitudes, they generally thinner when high: (i) High: The high stratus are called Cirrostratus; (ii) Middle: The middle stratus are called Altostratus; (iii) Low: The low ones are stratus and nimbostratus

3. **Cumulus:** The cumulus clouds are fluffy heaps or puffs. They are found at all altitudes; generally they are lighter and smaller when become high: (i) High: The high cumulus are called Cirrocumulus; (ii) Middle: The middle cumulus are called Altocumulus; (iii) Low: The low ones are Stratocumulus and Cumulus.

4. **Cumulonimbus:** The cumulonimbus clouds are thunder clouds. Some large cumulus clouds are height enough to reach across low, middle and even high altitude.
Note that due to their relatively small sizes and life time cumulus clouds produce short time series for remote sensing measurements (see App. B). Therefore such clouds and data series are not often suitable for many techniques mentioned in this report. It is fair to point out on such clouds the study pertaining to a phenomenon of Abelian nature, rain fall. Much work has been devoted to rain of course, see e.g. Andrade et al. or Lovejoy et al.

APPENDIX B. Experimental techniques and data acquisition

Quantitative observations of the atmosphere are made in many different ways. Experimental/observational techniques to study the atmosphere rely on physical principles. One important type of observational techniques is that of remote sounding, which depends on the detection of electromagnetic radiation emitted, scattered or transmitted by the atmosphere. The instruments can be placed at aircrafts, on balloons or on the ground. Remote-sounding techniques can be divided into passive and active types. In passive remote sounding, the radiation measured is of natural origin, for example the thermal radiation emitted by the atmosphere, or solar radiation transmitted or scattered by the atmosphere. Most space-born remote sounding methods are passive. In active remote sounding, a transmitter, e.g. a radar, is used to direct pulses of radiation into the atmosphere, where they are scattered by atmospheric molecules, aerosols or inhomogeneities in the atmospheric structure. Some of the scattered radiation is then detected by some receiver. Each of these techniques has its advantages and disadvantages. Remote sounding from satellites can give near-global coverage, but can provide only averaged values of the measured quantity over large regions, of order of hundreds of kilometers in horizontal extent and several kilometers in the vertical direction. Ground-based radars can provide data with very high vertical resolution (by measuring small differences in the time delays of the return pulses), but only
above the radar site.

For a presentation of remote sensing techniques the reader can consult many authors\textsuperscript{21,80,92–95}, or the ARM site\textsuperscript{96–98}. For example, microwave radiometers work at frequencies of 23.8 and 31.4 GHz. At the DOE ARM program SGP central facility, in the vertically pointing mode, the radiometer makes sequential 1 s radiances measurements in each of the two channels while pointing vertically upward into the atmosphere. After collecting these radiances the radiometer mirror is rotated to view a blackbody reference target. For each of the two channels the radiometer records the radiances from the reference immediately followed by a measurement of a combined radiances from the reference and a calibrated noise diode. This measurement cycle is repeated once every 20 s. Note that clouds at 2 km of altitude moving at 10 m s\textsuperscript{−1} take 15 s to advect through a radiometer field-of-view of approximately 5°. The 1 s sky radiances integration time ensures that the retrieved quantities correspond to a specific column of cloud above the instrument.

The Belfort Laser Ceilometer (BLC)\textsuperscript{92,98} detects clouds by transmitting pulses of infrared light (\(\lambda=910\) nm) vertically into the atmosphere (with a pulse repetition frequency \(fr=976.6\) Hz) and analyzing the backscattered signals from the atmosphere. The ceilometer actively collects backscattered photons for about 5 seconds within every 30-second measurement period. The BLC is able to measure the base height of the lowest cloud from 15 up to 7350 m directly above mean ground level. The ceilometer works with a 15 m spatial resolution and reaches the maximum measurable height of 4 km. The time resolution of CBH records is 30 seconds.
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