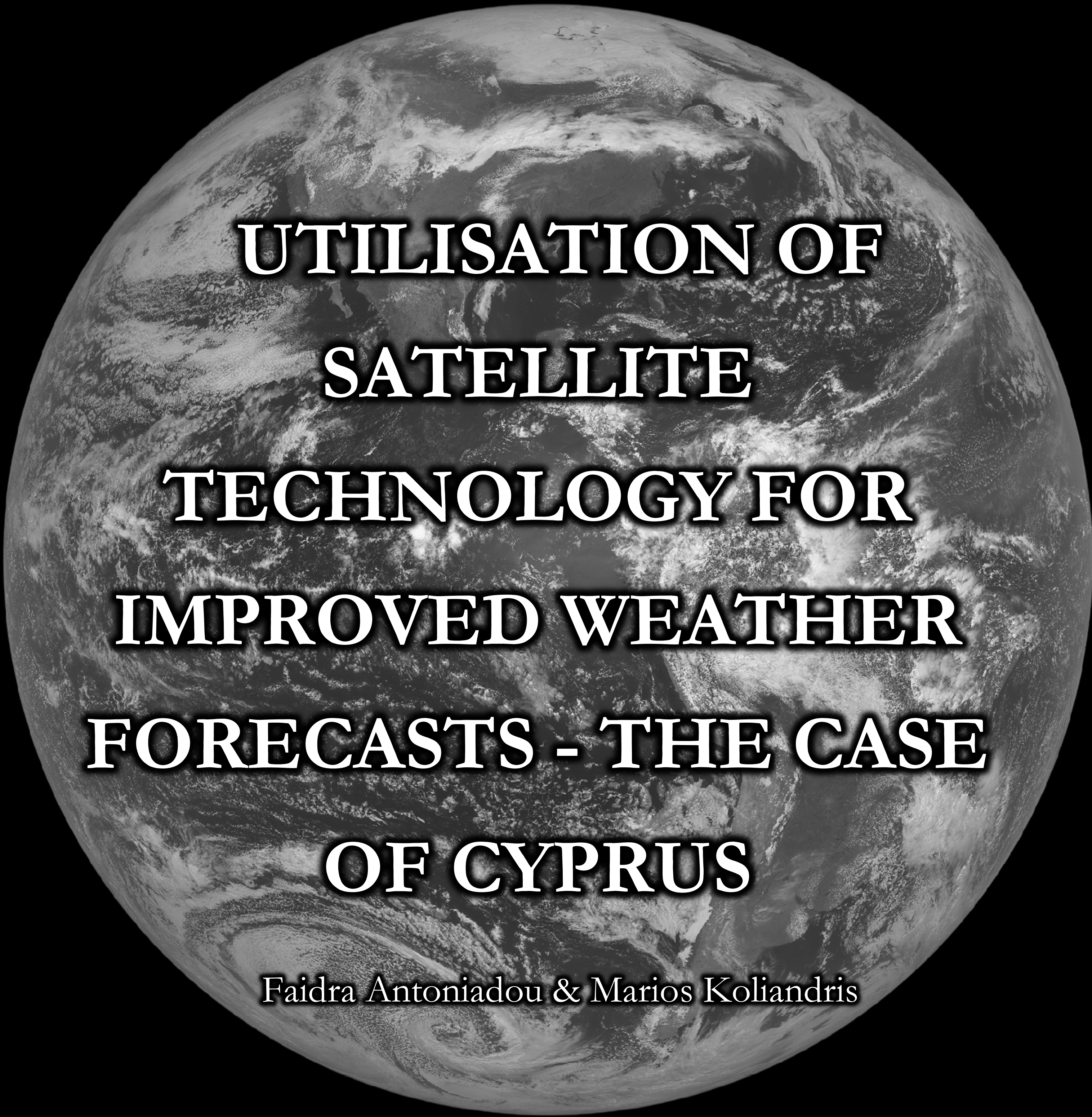

UTILISATION OF SATELLITE TECHNOLOGY FOR IMPROVED WEATHER FORECASTS - THE CASE OF CYPRUS

Faidra Antoniadou & Marios Koliandris

INTRODUCTION

One of the most critical issues humanity is facing today is climate change. With widespread changes and extreme weather events, such as large storms and heat waves, becoming more abundant and more intense, no nation can claim to be unaffected (United States Environmental Protection Agency [EPA], 2015).

In essence, climate variation leads to various global issues (Figure 1). For example, it affects global food security, a complex sustainable development issue linked to the supply of food, and individuals' access to it, economic risks, severe production shocks, food shortages, price spikes and market volatility because of its major effects on agriculture and Globalization (Micu, 2015). This devastates farmers and decision makers in agriculture, since they are responsible to come up with strategies to balance production and efficiency (Jones et al., 2000).

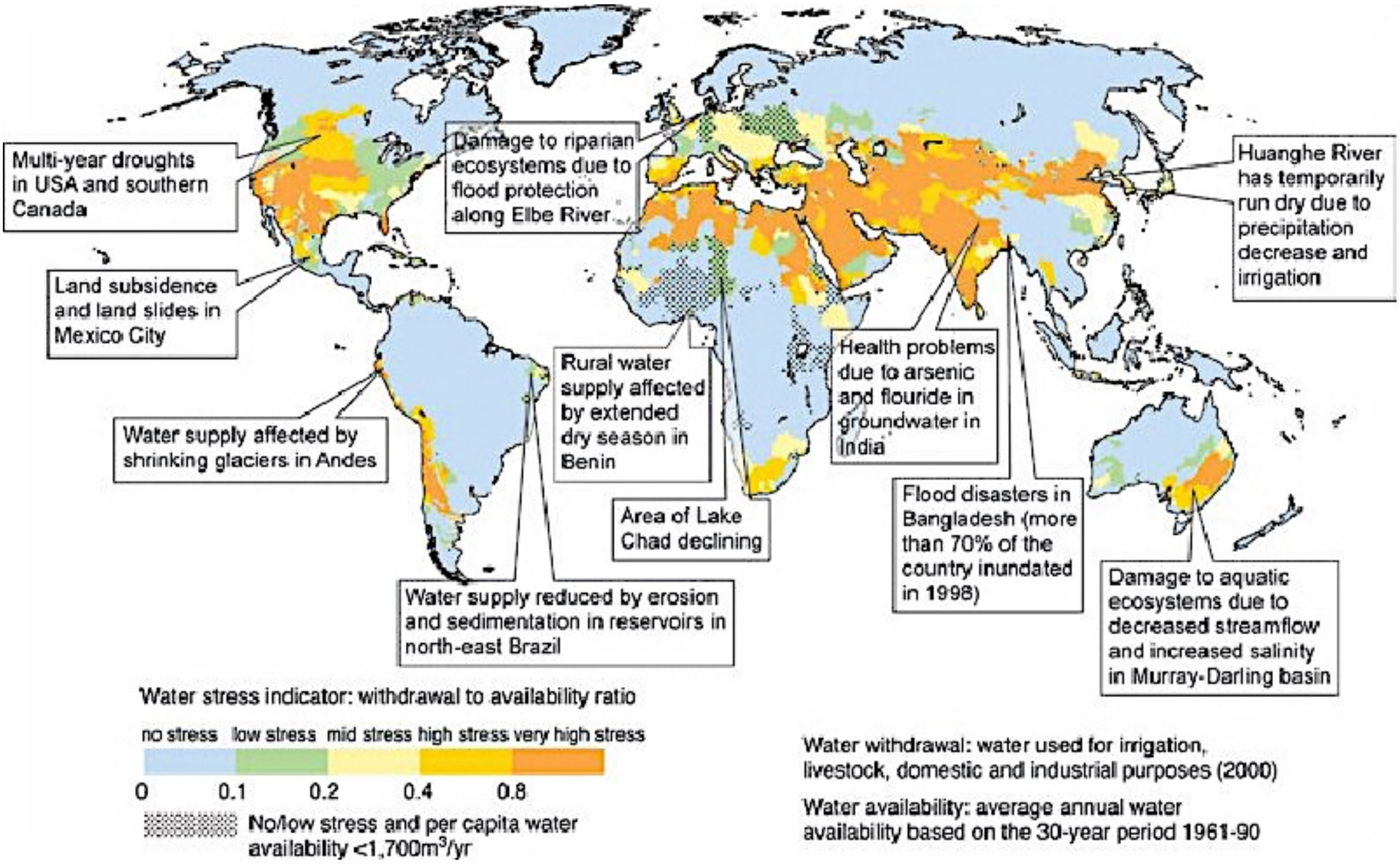

FIGURE 1: GLOBAL MAP INDICATING PROBLEMS ASSOCIATED WITH CLIMATE CHANGE
SOURCE: ALCAMO ET AL., 2012

However, satellite technologies provide precise weather forecasts, which indispensably contribute to the formation of strategies that aim to maintain balance within such industries, while expanding our knowledge on the changing climate. Actually, had it not been for Earth-observing satellites, it would not have been possible for humanity even to understand the weather scientifically, let alone manage to predict natural disasters and provide advance warnings (Hertzfeld, Williamson and Sen, 2003). Advancement in various fields of satellite technology has entirely reformed our perception of the Earth, ever since we were able to look down on the atmosphere, bringing about great socio-economic perquisites (American

Meteorological Society, 2012). It is often claimed that these outdo the drawbacks, i.e. high cost of satellite construction and weather forecast production and ozone damage (Minard, 2009).

The main reason behind the establishment of weather organisations in the first place, was to provide warnings of upcoming storms to ships, so that they considered remaining in port in accordance to the severity of the event. However, it soon became clear that more industries could benefit from weather warnings – for instance, agriculture and international export/import industries. Farmers could protect their produce, while shippers could limit damage to products while en route. Moreover, sailors take advantage of the currents and in general the weather, to plan the fastest, least dangerous and hence least expensive route to sail (weather routing). Today, many ships use fax as their tool to receive weather information, but technology is still improving and new tools are being launched continuously. Therefore, with the improvement of weather satellites, captains and navigators are able to choose their path more accurately and successfully.

Weather impacts on agriculture seem to be even more obvious. Intolerably hot temperatures or freezing icy weather leads to crops dying. Thus, weather forecasts are highly important in agriculture. First, forecasting helps agronomists to plan the amount of crops to be planted, according to the weather. Second, the prediction of rain patterns helps to undertake or withhold the seeding operation: seeds are more easily planted in muddy soils rather than dry ones, which farmers have to work on to make suitable for planting. Moreover, it helps to plan the irrigation of the crops, when to apply fertilizers, or when to start the harvesting process. Importantly, it helps to take precautions to fight frost, so that the crops do not freeze (My Agriculture Information Bank, 2015). The pricing of the crops is also directly or indirectly affected by the weather, which has a direct consequence on stock-market prices; if weather conditions are not suitable for growing, and the whole production of a specific crop is decimated, prices for it will rise. Weather forecasting can therefore make the change of prices smoother, as it enables consumers to expect any rises in prices and save money (Craft, n.d).

In addition to these two industries, and beyond taking precautions for severe weather strikes, weather forecasts are now used for more specialized activities, such as military operations, routing aircraft, planning professional sports teams' strategies, planning construction projects, and estimating demand for goods sensitive to weather changes (Craft, n.d).

On the other hand, satellites have a significant cost to be designed, constructed, launched and monitored. For example, it costs $290 million to build a satellite that can track and monitor hurricanes alone, with an additional $100 million price tag for a satellite that carries a missile-warning device.

Furthermore, geostationary satellites are located at a height of almost 36,000 km from the surface of Earth and positioned directly over the equator. Thus, the sun lines up with satellites and receiving earth stations twice a year, once in spring and once in autumn, in an event called sun outage. As the Sun emits electromagnetic radiation at the frequencies used by satellites as well, when it aligns perfectly with a satellite and the receiving antenna on the ground (as observed by the earth station), its interference is so strong that it can rise above the satellite's carrier signal, drowning it out and causing a temporary loss of reception (Instelsat, n.d).

In this project, a brief history of the methods used to derive weather forecasts from satellite data is described. Then, we focus on the case of Cyprus, specifically describing the forecasting methodology implemented by the Cyprus Department of Meteorology and analyzing empirical data provided by the service itself in order to determine its accuracy. It is hypothesized that satellites contribute positively to the production of accurate forecasts, with the benefits outweighing the drawbacks.

WEATHER FORECASTING HISTORY

Weather forecasting dates back to 650 BC. Predictions made by primeval civilizations at this time relied on recurring meteorological and astronomical phenomena, the latter helping to monitor seasonal weather changes. Specifically, in 650 BC, the Babylonians started predicting weather changes by solely relying on cloud appearance and optical phenomena (Figure 2). About 350 years later (300BC), a calendar created by Chinese astronomers divided the year into 24 different kinds of weather, called festivals.

FIGURE 2: THE BABYLONIANS STARTED PREDICTING WEATHER CHANGES
SOURCE: MANUNICAST, N.D.

Moreover, the Greek philosopher, Aristotle, released *Meteorologica* – a philosophical paper which included theories about the formation of rain, clouds, hail, wind, thunder, lightning, hurricanes and topics such as astronomy, geography and chemistry – around 340 BC (Figure 3). The philosopher made critical meteorological observations, but his work also consists of major discrepancies. However, the majority considered his treatise to be the authority on weather theory up until the 17th century AD.

As centuries went by, attempts at producing weather forecasts essentially based on personal observations, still continued (The Natural Navigator, 2010) and some even became lore. Some of these sayings were true; for instance, 'When clouds look like black smoke, a wise man will put on his cloak' . Some were false, for example, 'Rain before seven, clear by eleven'.

As the Renaissance was reaching its end, humanity seemed to be coming to the realization that philosophers' claims were incomplete. Hence, the atmosphere had to be better understood, which necessitated the acquisition of more data on atmospheric properties (e.g., moisture, temperature and pressure), thereby reaching a point where actual scientific instruments were necessary. In 1400, Leonardo da Vinci designed the first basic hygrometer (Figure 4), used to measure the humidity of air; different types of hygrometers, such as practical hygrometers and more advanced versions, continued developing (Siemers, 2013). Subsequently, the Italian scientist, Galileo Galilei invented the precursor of the thermometer, i.e., a thermoscope, in 1569, while the Danish astronomer, Ole Christensen Rømer transformed the thermoscope into a thermometer by adding a temperature scale in 1701. Italian physicist and mathematician, Evangelista Torricelli, invented the barometer used to measure atmospheric pressure in 1643 (Graham et al. 2002).

FIGURE 3: *METEOROLOGICA* BY ARISTOTLE.
SOURCE: OLIVEIRA, 2009

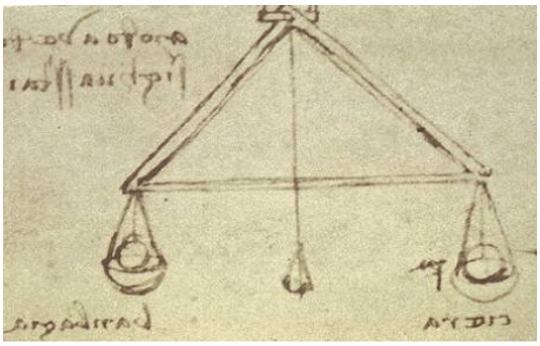

FIGURE 4: LEONARDO DA VINCI'S SKETCH OF THE HYGROMETER
SOURCE: HEAT-TECH, N.D

Improvements were made to these instruments during the 17th to 19th centuries and other relative theoretical, observational and technological advancements played their role to humanity's improving comprehension of the atmosphere. As a result, individuals at dispersed locations started conducting and recording atmospheric measurements. With the invention of the telegraph (Figure 5) in 1840 by Samuel Morse, and the spreading of telegraph networks, the systematic conveyance of weather observations to and from accumulators was made possible, since telegraph companies were supplied with weather instruments. The use of such data enabled the creation of weather maps and the analysis of surface wind patterns and storm systems.

At this time, weather forecasting was not considered a science and struggled for respectability (Figure 6). However, this conception was eventually abolished. By 1860, meteorological stations were built throughout the globe, enabling concise weather forecasting, through compiling and analyzing observations collected concurrently over a broad area (Robbins, 2015).

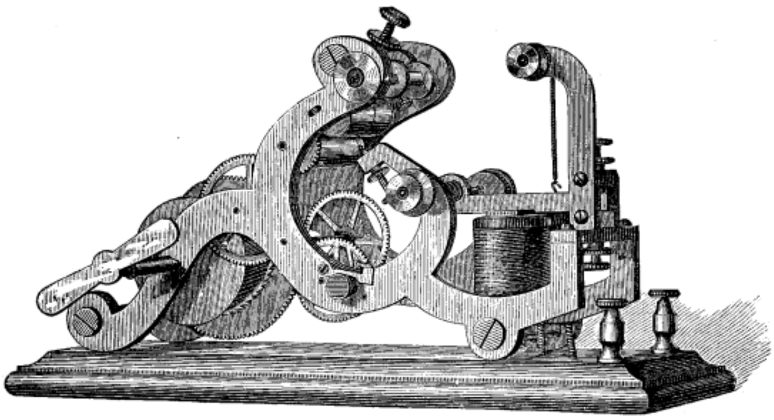

FIGURE 5: THE FIRST TELEGRAPH
SOURCE: KEITH, 1997

"Whatever may be the progress of sciences, never will observers who are trust-worthy, and careful of their reputation, venture to foretell the state of the weather."

-French scientist and Director of the Royal Observatory, François Arago

FIGURE 6: WEATHER FORECASTING STRUGGLED FOR RESPECTABILITY
SOURCE: SCHULTZ, LOMAS AND MULQUEEN, N.D

During the 19th and 20th centuries, access was granted to a wider range of data for observation-based weather forecasting. The invention of the radiosonde (Figure 7) in the 1920s was yet another milestone in weather forecasting, as it had the capacity to monitor the weather at high altitudes. In essence, the radiosonde comprises of a small, expendable package equipped with a radio transmitter and specific weather instruments, which is suspended on a 2-meter-wide balloon filled with hydrogen or helium. As it is carried aloft, during the ascent, sensors on the radiosonde measure profiles of pressure, relative humidity and temperature (Lawson, 2015), which is then transmitted to a ground station where it is processed.

In 1922, British mathematician Lewis Fry Richardson published *Weather Prediction by Numerical Process*, where he reported a scheme of predicting the weather before it actually happens through the use of mathematical equations (among other chapters). In order to have the prediction of tomorrow's weather, this involved a room containing approximately 64,000 human calculators. In addition, each human calculator had to compute a different part of the equations and a system had to be invented for the transmitting the results, as necessary, across the room. Even with that number of people working to solve the equations, the solution would often be worked out too late before the weather to be predicted actually arrived (Connor and Robertson, 2003). Nevertheless, Richardson succeeded in developing the concept of numerical forecasting.

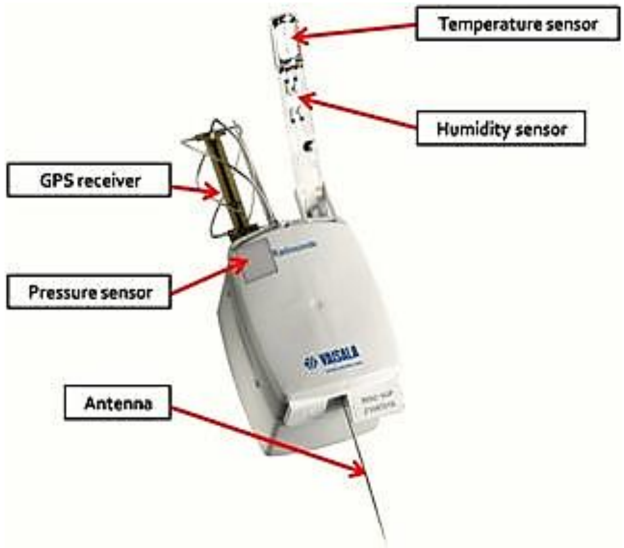

FIGURE 7: RADIOSONDE INSTRUMENTATION
SOURCE: PLYMOUTH STATE UNIVERSITY, N.D

In the late 1940s, the first modern computer was invented. Numerical weather forecasts became more practical by a team of meteorologists and mathematicians at the Institute for Advanced Study (IAS) in Princeton, New Jersey, using the Electronic Numerical Integrator And Computer (ENIAC) (Figure 8). Its construction was directed by a team of scientists, so as to apply it specifically to weather forecasting. The new computers were used along with a revised set of equations, while sound and gravity waves were eliminated from equations, so as to simplify calculations and to focus solely on phenomena needed to predict the evolution of continent-scale weather systems. The group of mathematician John von Neumann (1903-1957) and a team of scientists led by Jule Charney (1917-1981), constructed a successful mathematical model of the atmosphere and demonstrated the feasibility of numerical weather prediction.

The evolution of numerical weather prediction throughout the latter part of the 20th century proceeded at a similar pace at many operational, numerical weather prediction centers worldwide. The first numerical weather prediction models used in the United States ran on grids that covered the Northern Hemisphere. This restriction was based primarily on the amount of computer power as well as the amount of data available to initialize the model. However, a progression of increasingly more powerful computers procured by the US National Weather Service (NWS) throughout the 1960s and 1970s, as well as increasing sources of data – particularly from weather satellites – allowed the expansion of both the domains and the number of models running (National Oceanic and Atmospheric Administration [NOAA] Celebrates 200 Years of Science, Service and Stewardship, 2007).

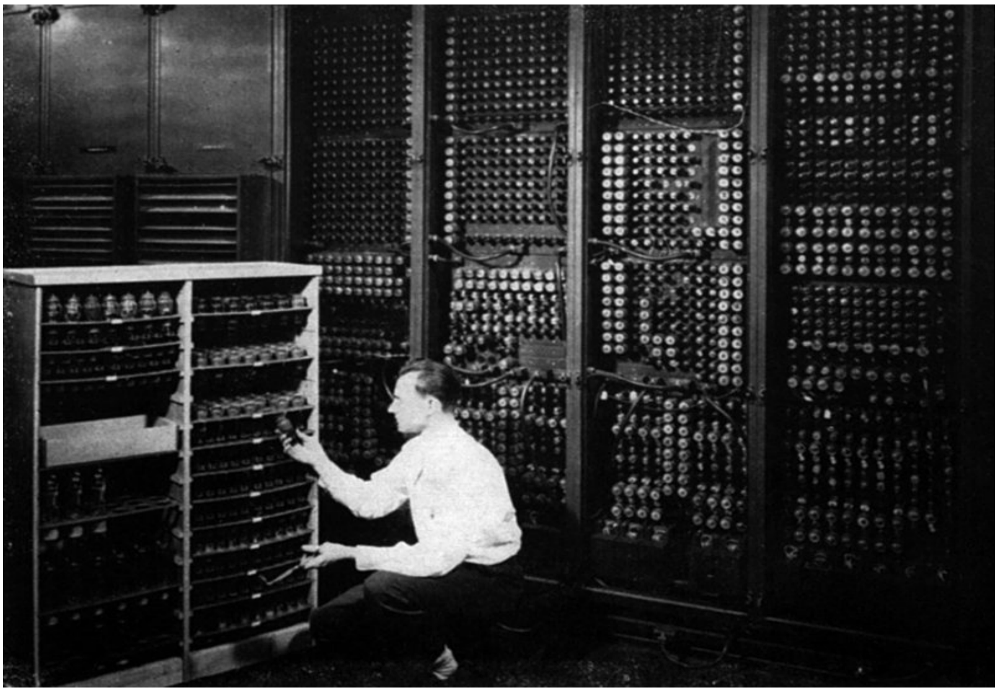

FIGURE 8: ENIAC BEING SET UP
SOURCE: COMPUTER HISTORY MUSEUM, N.D

Improvements were also made to the quantity of vertical levels and the horizontal resolution of the models. A three-layer hemispheric model was introduced in 1962 and a six-layer primitive equation model (Figure 9) appeared in 1966. Additional atmospheric layers allowed more accurate forecasts of winds and temperature, resulting in better prediction of storm motion (National Oceanic and Atmospheric Administration [NOAA], 2007).

"Primitive" Weather Forecasting Equations

$p = \rho R T$ *Ideal Gas Law* (Equation of State)

$$\bar{a}_h = \sum \left(\bar{F}_h / m \right)$$ *Newton's Second Law of Motion*

$$\Delta p = -\rho g \Delta z$$

$$(PGA)_v = g$$

$$\bar{a}_v = \sum \left(\bar{F}_v / m \right) = (\vec{P}\vec{G}\vec{A})_v - \bar{g}$$

Hydrostatic Law (Obtained from the Equation of Vertical Motion)

$$\Delta T = \Delta q / c_p + (1/\rho)\Delta p$$ *First Law of Thermodynamics*

$$(1/\rho)\Delta\rho/\Delta t = -DIV$$

Conservation of Mass Applied to the Atmosphere (Equation of Continuity)

Zonal wind:

$$\frac{\partial u}{\partial t} = \eta v - \frac{\partial \Phi}{\partial x} - c_p \theta \frac{\partial \pi}{\partial x} - z \frac{\partial u}{\partial \sigma} - \frac{\partial \left(\frac{u^2+v^2}{2}\right)}{\partial x}$$

Meridional wind:

$$\frac{\partial v}{\partial t} = -\eta \frac{u}{v} - \frac{\partial \Phi}{\partial y} - c_p \theta \frac{\partial \pi}{\partial y} - z \frac{\partial v}{\partial \sigma} - \frac{\partial \left(\frac{u^2+v^2}{2}\right)}{\partial y}$$

Temperature:

$$\frac{\delta T}{\partial t} = \frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z}$$

Precipitable water:

$$\frac{\delta W}{\partial t} = u \frac{\partial W}{\partial x} + v \frac{\partial W}{\partial y} + w \frac{\partial W}{\partial z}$$

Pressure thickness:

$$\frac{\partial}{\partial t} \frac{\partial p}{\partial \sigma} = u \frac{\partial}{\partial x} x \frac{\partial p}{\partial \sigma} + v \frac{\partial}{\partial y} y \frac{\partial p}{\partial \sigma} + w \frac{\partial}{\partial z} z \frac{\partial p}{\partial \sigma}$$

$$\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + \omega \left(\frac{\partial T}{\partial p} + \frac{RT}{p c_p} \right) = \frac{J}{c_p} \qquad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0 \qquad 0 = -\frac{\partial \phi}{\partial p} - \frac{RT}{p}$$

FIGURE 9: PRIMITIVE WEATHER FORECASTING EQUATIONS INCLUDED IN FORECASTING MODELS
SOURCE: ROBBINS, 2015

WEATHER SATELLITE TECHNOLOGY

With the emergence of satellite technology, observing our planet gradually turned to a worldwide routine application. Apart from accurate weather forecasts, mineral exploration, pollution detection, crop and rangeland monitoring are also conducted by satellite sensors. Remote sensing and its uses have been rapidly developing over the past few decades and continue to do so, since new, improved satellite sensors are placed into orbit.

With the invention of space-borne remote sensing, all abovementioned technologies have achieved the establishment of the perception of the Earth as a system. Ultimately, the most essential outcome of the development of space-borne remote sensing, is the capacity for understanding the processes that control the Earth-atmosphere systems, as well as the human imposed changes, such as the thinning of the ozone layer (Figure 10).

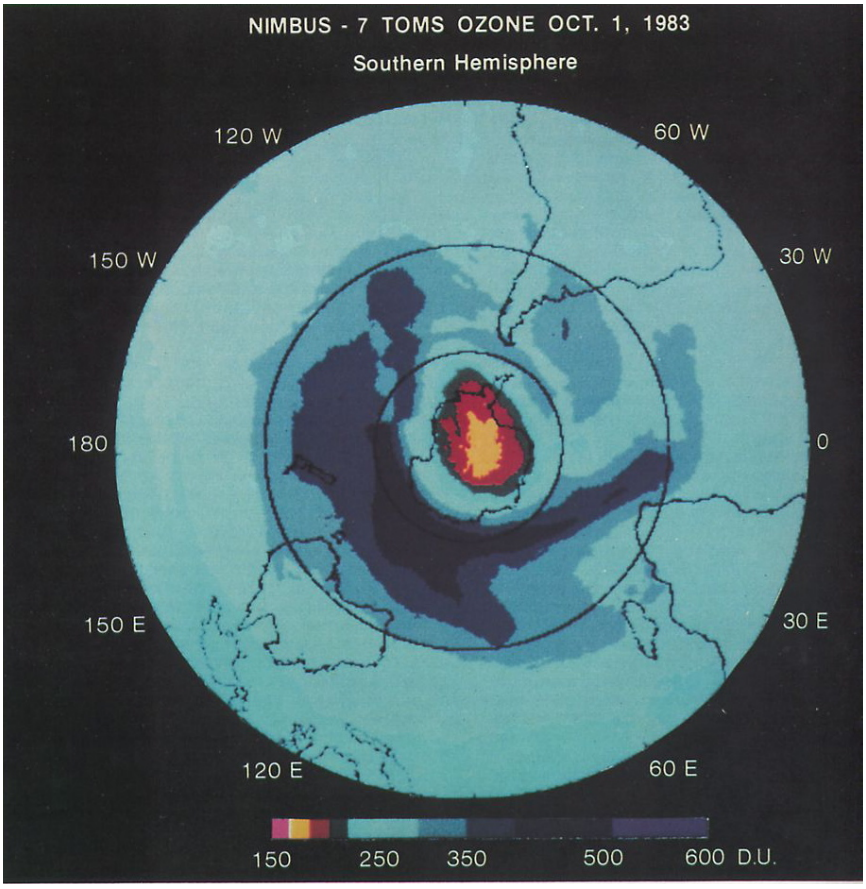

FIGURE 10: SATELLITE-BASED IMAGE THAT REVEALED THE SIZE AND MAGNITUDE OF THE OZONE HOLE. SOURCE: KATHRYN HANSEN NASA'S EARTH SCIENCE NEWS TEAM, 2012

In the early 1950s, various groups (e.g., U.S. Army Evans Signal Laboratory, University of Wisconsin) came up with the idea of constructing weather satellites, after receiving photographs of Earth from rockets being launched into suborbital flights. The actual era of meteorological satellites began after the successful launch of the first artificial satellite, Sputnik 1, by the Soviet Union on 4 October, 1957. Following this, the launch of the first meteorological satellite took place: Television and Infrared Observation Satellite, TIROS-1 (Figure 11), was launched on 1 April, 1960 by the National Aeronautics and Space Administration (NASA). Even after its first few pictures, it changed the way that humans view the future, as it has made it possible to predict potential disasters before they arrive, often enabling us to prepare accordingly. The first picture from TIROS-1 was an image of thick bands and clusters of clouds over the United States. After a few days, it showed a typhoon 1000 miles away from Australia (Choi, 2010). Those images pale in comparison to the much more detailed, high-resolution pictures we receive today from more advanced weather satellites.

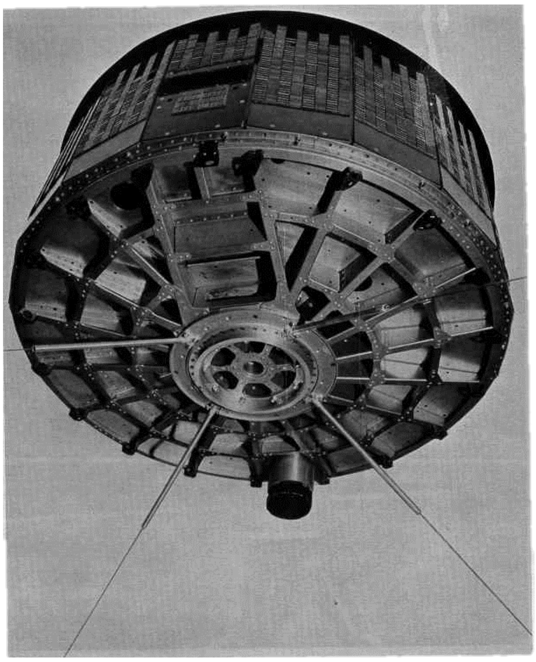

Figure 11: The TIROS-1 satellite
Source: Colorado State University, n.d

Five decades and 38 generations of spacecraft later, the present-day 'Advanced TIROS' satellites of the USA are operated by the NOAA. In collaboration with their military counterparts from the Defense Meteorological Satellite Program (DMSP), they form the backbone of the US weather forecasting system. Their observations are coordinated with those of their powerful European equivalent, MetOp, which constitutes a series of three polar-orbiting meteorological satellites developed by the European Space Agency (ESA) and operated by the European Organisation for the Exploitation of Meteorological Satellites (ESA, n.d). With the commission of such satellite series, various innovative instruments – summarized in Table 1 – were added, improving and establishing new technologies and capabilities. Several satellites that constitute milestones in weather forecasting and meteorological observations are displayed in Table 2.

Furthermore, the technology of Man Computer Interactive Data Access System (McIDAS) became a fundamental tool of data analysis, when primarily used in 1973. It enabled scientists to derive quantitative measurements of atmospheric dynamics, playing a major role in the establishment of earth-imaging programs using instruments on several of the first geostationary communications satellites launched by NASA (Lazzara et al. 1998).

Scientists succeeded in integrating satellite data into global and regional weather forecast models. Instead of converting satellite observations into quantities that are compatible to the ones used by the model, newer models can now assimilate what the satellite actually measures. For instance, one of the components used in the software of NOAA, the Community Radiative Transfer Model, directly uses measurements of radiances, a physical quantity that a satellite instrument measures at a point in space, from a specific direction and at a specific instant in time. Radiance observations from cloudy and rainy areas can be assimilated into the Weather Research and Forecast model. In Figure 12, for example, the new technique produced a temperature field in Hurricane Katrina that was more detailed than its precursors and that better resolved the warm core of the hurricane. The Joint Center for Satellite Data Assimilation, in which National Environmental Satellite, Data, and Information Service (NESDIS) and the NWS participate, uses these satellite observations to improve forecasts of extreme weather events (NOAA Star Center for Satellite Applications and Research, 2013).

TABLE 1: INNOVATIVE INSTRUMENTS

INSTRUMENT	SERIES	MANUFACTURER	CAPACITY	DATE LAUNCHED
Infrared interferometer spectrometer (IRIS)	Nimbus	NASA	Measured atmospheric temperature, water vapor and ozone	1964
Satellite infrared spectrometer (SIRS)	Nimbus	NASA	Similar temperature readings as IRIS for comparison purposes	1964
Spin scan cloud camera (SSCC)	Applications Technology Satellite (ATS-1)	NASA	First time rapid imaging of almost the entire hemisphere	1966
Backscatter Ultraviolet (BUV)	Nimbus	NASA	Determined both total ozone and ozone distribution	April, 1970
Nimbus Experiment Microwave Spectrometer (NEMS)	Nimbus	NASA	First microwave sounding device; first to provide multispectral measurements that separated humidity and cloud water contributions	December, 1972

TABLE 2: FIRST VITAL SATELLITES LAUNCHED

SATELLITE	MANUFACTURER	OPERATOR	OPERATION	DATE LAUNCHED
Geostationary Operational Environmental Satellite (GOES-1)	NASA	NOAA	First weather prediction models, gathered data for the Global Atmospheric Research Programme	16 October, 1975
Meteosat-1	COSMOS	EUMETSAT	Initiation of continuous, reliable meteorological observations delivered from space to a large user community.	23 November, 1977
Geostationary Meteorological Satellite (GMS)	Boeing Satellite Systems (former Hughes Space and Communications Company & Nippon Electric Company Corporation of Tokyo)	Japan Meteorological Agency (JMA)	Japan's first national satellite program for weather and environmental observations from GEO (Geostationary Earth Orbit).	14 July, 1977

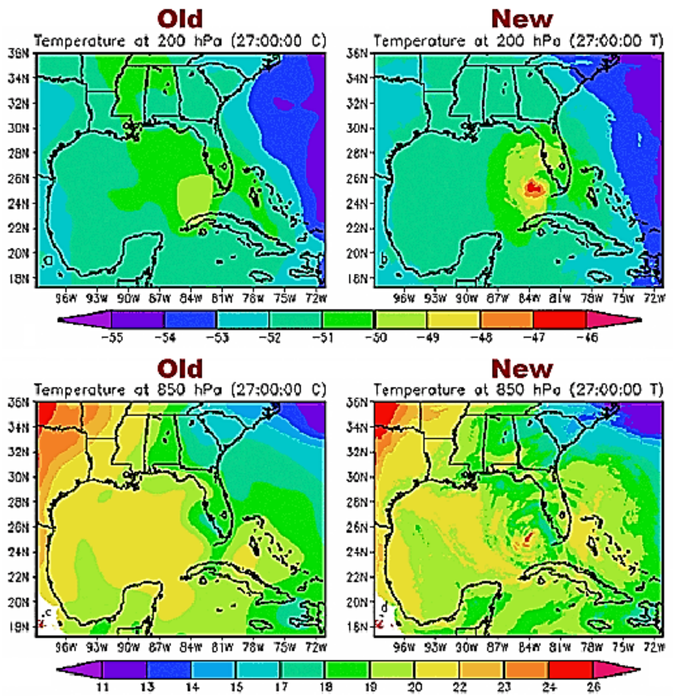

FIGURE 12: TEMPERATURE FIELD IN HURRICANE KATRINA COMPARISON BETWEEN WEATHER MODELS SOURCE: NOAA STAR CENTER FOR SATELLITE APPLICATIONS AND RESEARCH, 2013

METEOROLOGY IN CYPRUS

In the case of Cyprus, the German non-hydrostatic Lokal-Modell for Europe (LME) is mainly run, along with the Unified Model developed by the United Kingdom Met Office (UKMET), and the Global Forecast System (GFS). Thus, principally data from the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) are employed. Observations are executed on the main synoptic hours (0000, 0600, 1200, and 1800 UTC [Coordinated Universal Time]) and three-hourly intermediate observations are taken from all weather stations in Limassol, Larnaca, Paphos, Polis, Prodromos, Nicosia and Paralimni. The data reported from each weather station are analyzed to create surface charts, the isobars of which depict the features of the horizontal pressure field at mean sea level, enabling them to be used for forecasting. (P. Michael, personal communication, 16 December 2015 [see Appendix 1]).

From the past decades, Dr. Michael claims that the precision of the Cyprus Department of Meteorology has improved by 20% (now being approximately 85%), since computer technologies were either prior to, or at the very start of emerging. Figures 12 and 13 show two older types of maps, one of which is drawn by hand and the other is printed by the mufax machine. Even for these, measurements were taken using satellite technology.

Therefore, we decided to conduct an experiment in order to verify this claim, thereby providing answers to the following research questions:

> Is the accuracy of weather forecasts derived from weather models significantly improved through satellites? If so, what is the level and importance both on day-to-day forecasts as well as in predicting extreme weather phenomena? In other words, is the use of satellites worth the investment (both monetary and environmental)?

Obviously, since the data available to us is through the Cyprus Department of Meteorology, we will investigate these research questions for the case of Cyprus. However, they do enable us to test the initial hypothesis (that satellites are valuable to production of precise forecasts that minimize impacts and losses on a social and economic level) through real empirical evidence. Academic research on this subject has not been done before in Cyprus, so, despite being at a low scale and non-professional level, this work is innovative in that it brings to the forefront local meteorology for the first time.

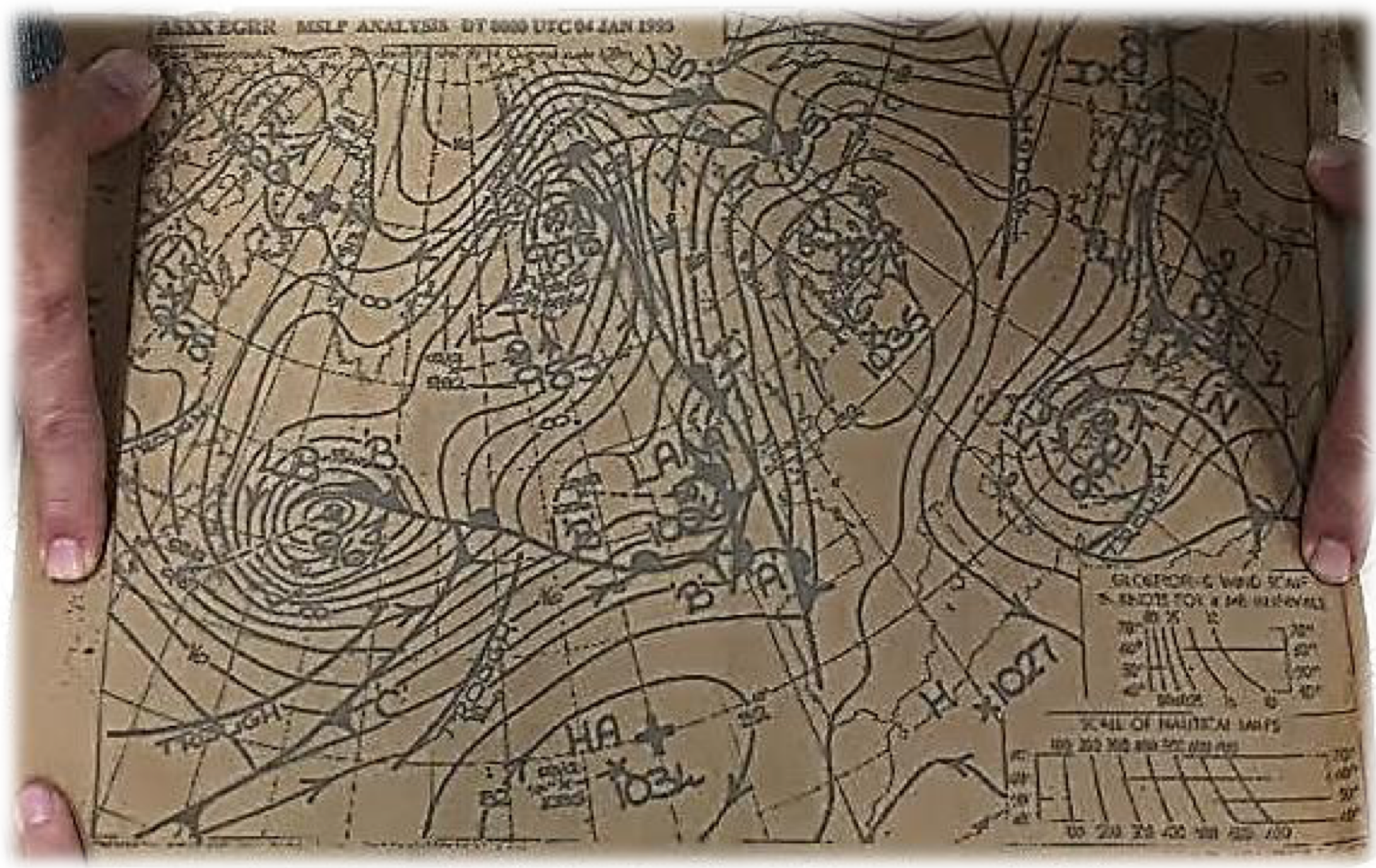

FIGURE 13: A SURFACE CHART PRODUCED BY THE MUFAX MACHINE

EXPERIMENTAL METHODOLOGY

In order to investigate the feasibility of the project for the case of Cyprus, we came into contact with Dr. Panayiotis Michael – Officer at the Cyprus Department of Meteorology – and conducted a semi-open interview with him in his office at the Ministry of Agriculture, Natural Resources and the Environment. A script was prepared, but the semi-formal and semi-open nature of the discussion led to additional questions being brought up. Appendix A displays all the questions asked during the interview.

Dr. Michael expanded our background knowledge and explained the approach adopted by the service when producing weather prognoses. He also estimated that the precision of the Meteorological Service's weather prognoses is on average 85%, noting that it has considerably increased since the 1980s, when precision was only 60-70%.

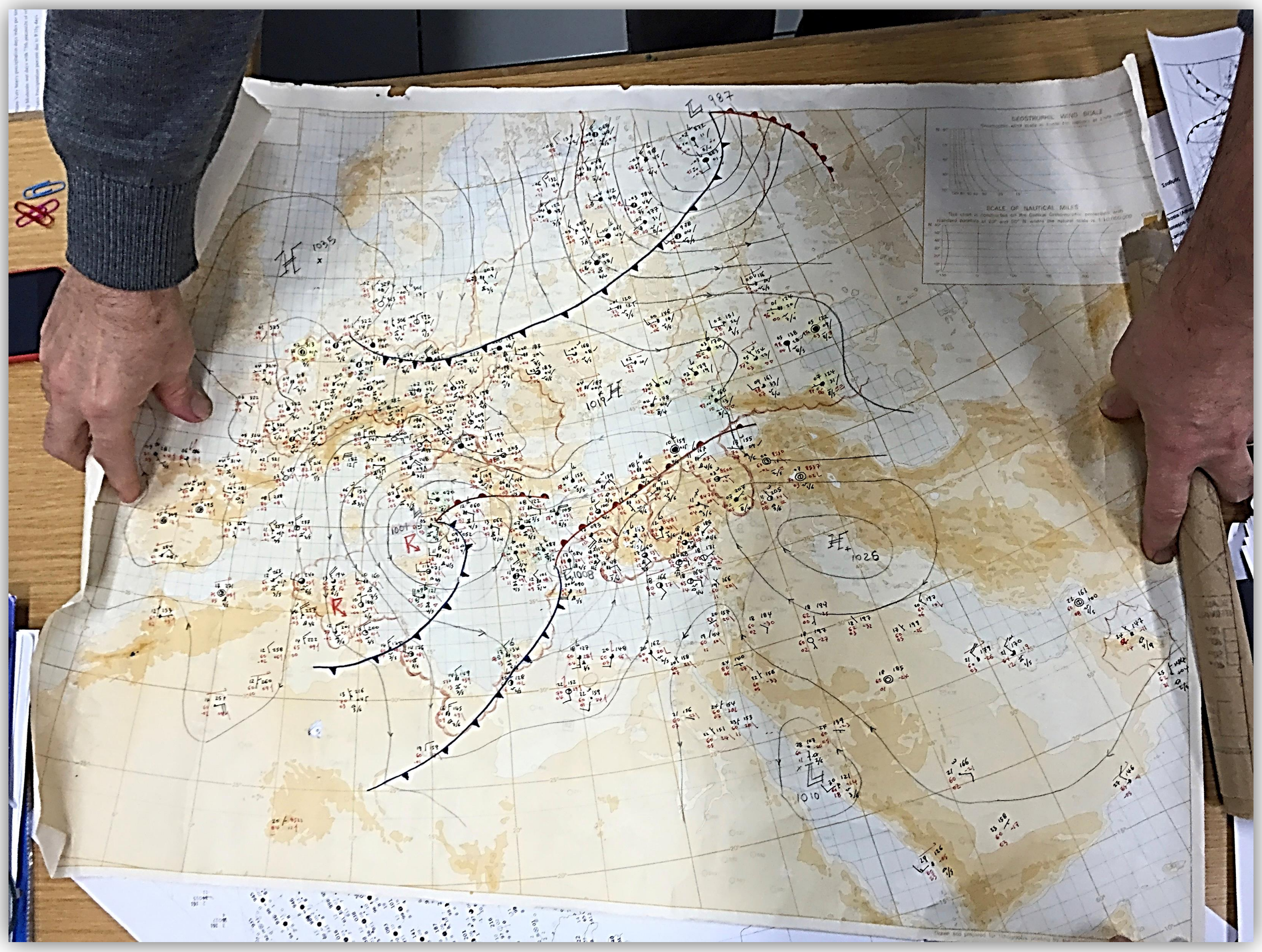

FIGURE 14: A SURFACE CHART DRAWN BY HAND BY DR. MICHAEL

We therefore set out to test the claim for such a high precision of their forecast model. Day-to-day forecasts (referred to as Bulletin C) are uploaded in the official website of the service daily, around 1600 UTC (http://www.moa.gov.cy/moa/ms/ms.nsf/DMLindex_en/DMLindex_en?OpenDocument). Bulletin C displays predicted outcomes of the wind, maximum and minimum temperature and weather conditions (including: Mainly Fine, Partly Cloudy, Showers, Rain, Thunderstorms, Snow Showers or Snowfall), for each region on the island. We were given access to these empirical data by Dr. Michael (personal communication, 16 December 2015), and specifically the predicted values of these forecast elements, which we could use to compare with the actual values over 21 December 2015 to 7 January 2016.

The observed and predicted data was used to check the forecasting accuracy of the Department of Meteorology as follows. The precision in predicting each element of the weather forecast was examined separately. Specifically, we looked at maximum and minimum temperatures (in °C) in various regions, maximum wind (Bf) and atmospheric conditions (including: Mainly Fine, Partly Cloudy, Showers, Rain, Thunderstorms, Snow Showers or Snowfall). Data for the last two elements were kindly provided by Dr. Michael.

For each element of the forecast, we prepared a spreadsheet algorithm that compared its predictions in various regions with its actual measurement(s) made in one or more cities or locales in that region.

Thus, the predictions for the North Coast were compared with measurements in Polis, those for the East Coast to Paralimni, the West Coast to Paphos, the South Coast to the average of the measurements between Limassol and Larnaca, the Inland prediction to Nicosia and the Mountain Region to Prodromos.

The predictions for max and min temperatures and max wind were deemed successful when the observed quantities matched the prediction within the internationally accepted deviations. For the temperatures, the prediction and observation are said to be a match when they are ±2 ºC of each other. For the wind, the accepted offset is ±1 Bf.

As there are no international standards for general weather conditions, we decided to use the severity of the condition to evaluate the precision. For example, a prediction of Partly Cloudy versus Mainly Fine skies hinges on the number of hours in which cloud coverage is observed; for the latter, the cloud coverage must be less than 6 hours. Given that the precise duration of cloud coverage is trivial in planning day-to-day events, we took either observation as a match to the prediction if the prediction was for either one or the other. On the other hand, in cases where a prediction was made either for showers or rain, and the other event was actually observed, the prediction was taken as unsuccessful. Despite the subtle difference, our reasoning was that rain is a prolonged, persistent and widespread event while showers are sporadic and localized.

Using these comparisons, our algorithms calculate the precision of the forecast of each element for each region, by dividing the number of successful predictions into the total number of predictions. For the quantitative data (temperatures, wind speed), we also plotted line graphs of the predicted and observed quantities against the date per region. For the qualitative data (weather conditions), we plot bar charts per region to illustrate the precision of the predictions. Finally, the total average precision is also calculated for the whole of Cyprus.

As our spreadsheets are completely automated, Dr. Michael has requested (and was granted) our permission to use them beyond the present project, internally in the Cyprus Department of Meteorology to continue checking the precision of their predictions.

Subsequently, quantitative data (including maximum, minimum temperature and wind) were plotted on line graphs, against the matching date, in order to representing the patterns of all conditions' predictions and outcomes in each city. In the end, bar charts were plotted, illustrating the precision of qualitative data (weather condition predictions) and the average percentages of precision. Finally, the total average precision of weather forecasts in Cyprus, was calculated.

EVALUATIONS & CONCLUSIONS

Figure 15 shows the average precisions of predicting the maximum, minimum and average temperatures over the entire island in the time during which we conducted our experiment. As indicated, the precision of the mean temperature in all regions varied, but never fell below 50%. The greatest variation was effected by the unstable temperature changes taking place within our experimental timeframe, as a cold wave affected all regions near the end of December. According to Dr. Michael, the precision of forecasts at such times is lower, since due to the island's Mediterranean climate, weather and temperature changes occur abruptly and rapidly. Our analysis was able to confirm this phenomenon. Nevertheless, it is notable that the average precision of the predictions is at or greater than 80%.

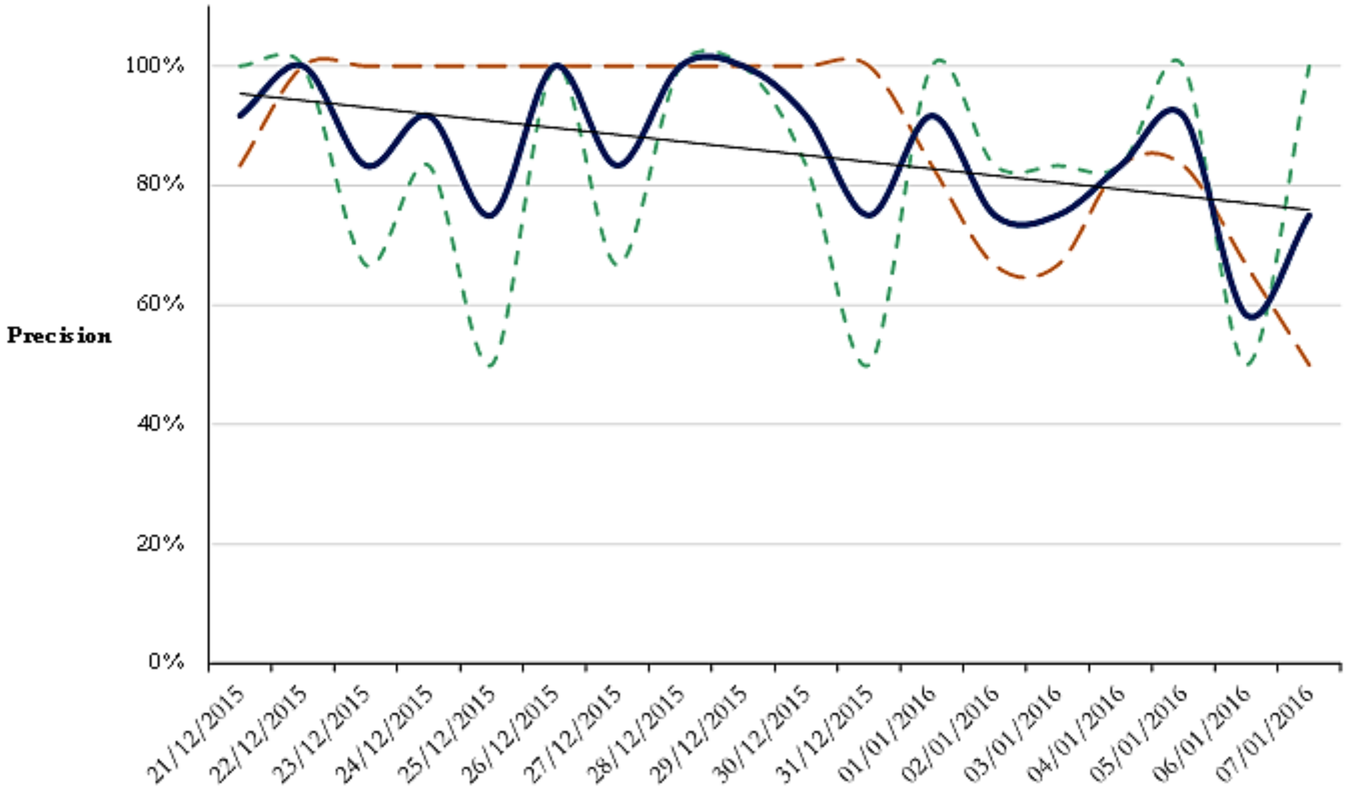

FIGURE 15: THE PRECISION OF THE PREDICTIONS OF MAXIMUM TEMPERATURE (GREEN, SHORT-DASHED LINE), MINIMUM TEMPERATURE (ORANGE, LONG-DASHED LINE) AND AVERAGE TEMPERATURE (SOLID LINE) FOR THE ALL REGIONS OF CYPRUS COMBINED OVER THE PERIOD 21/12/2015 TO 07/01/2016.

Figure 16 illustrates the precision with which the Department of Meteorology was able to predict the maximum wind speed. The image shows the average for all the regions of the island. Note that wind observations only falling below the acceptable range (80%-100%) twice, with the average value exceeding 80% for the duration of the experiment.

As Figure 17 illustrates, the average precision to which each weather element was predicted remained relatively high, which given the instability of conditions (and forecast precision) was considered a success of the models. The same holds for the precision with which the weather conditions were predicted in all regions (Figure 18). Figure 19 shows the average predictions for all weather elements individually for each region. Note that the lowest success rate is 79% (inland) and the highest approaches 93% (mountain region). As an indicator of the potential of the weather models used by the Department of Meteorology, we calculated the overall average of all these precisions: 88%.

The fact that the accuracy of forecasts arising from weather models, which are initialized on satellite data, is so high, leads to the realization that the utilization of satellites has not only been a milestone in humanity's effort to predict future weather events accurately. It has also enabled the efficient broadcasting of alerts leading to decisions that enable us to prosper for a sustainable future, decreasing losses due to unpredicted weather (extreme or otherwise).

Specifically, the total benefits from Meteosat alone (a satellite series which contributes to the creation of the weather models used in Cyprus) have been estimated to equate to about €125 million annually in cost savings for all industries and €137 million in saving lives and reduction of environmental damage. Agriculture alone saves €30 million and civil aviation €11 million each year. Moreover, the capacity of weather satellites to gather long-term measurements from space in support of climate-change studies is of growing importance (Wilson, 2005).

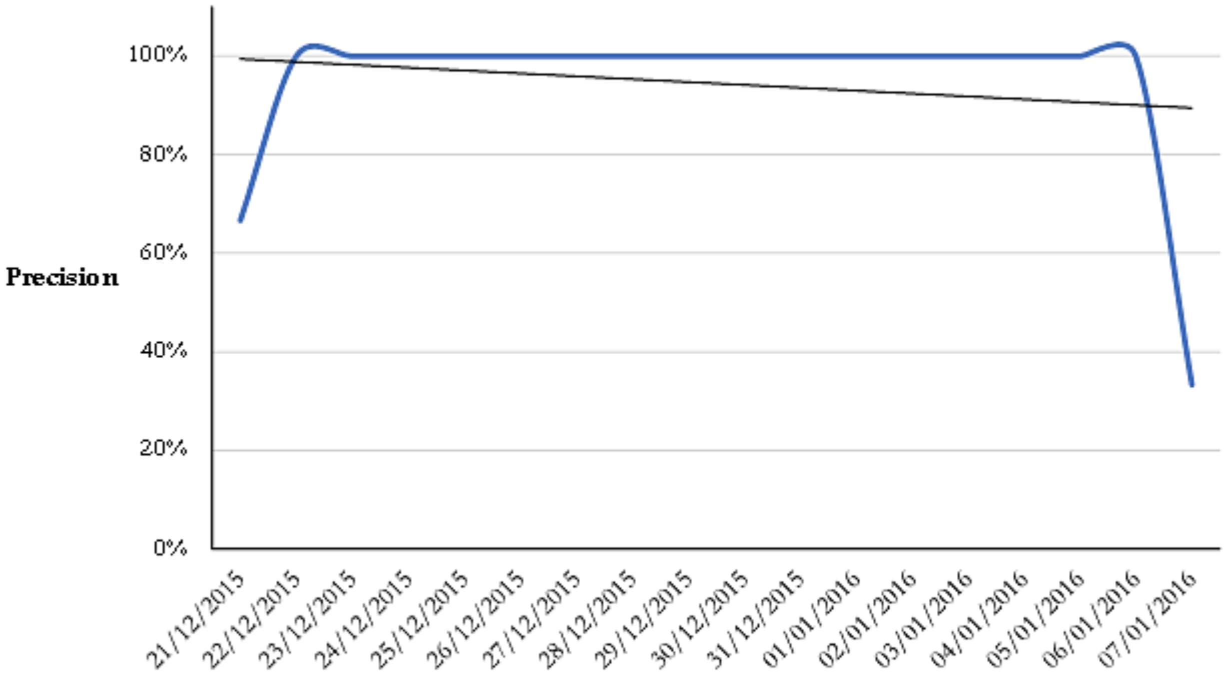

FIGURE 16: WIND AVERAGE PRECISION OF ALL REGIONS COMBINED, OVER THE EXPERIMENTAL PERIOD.

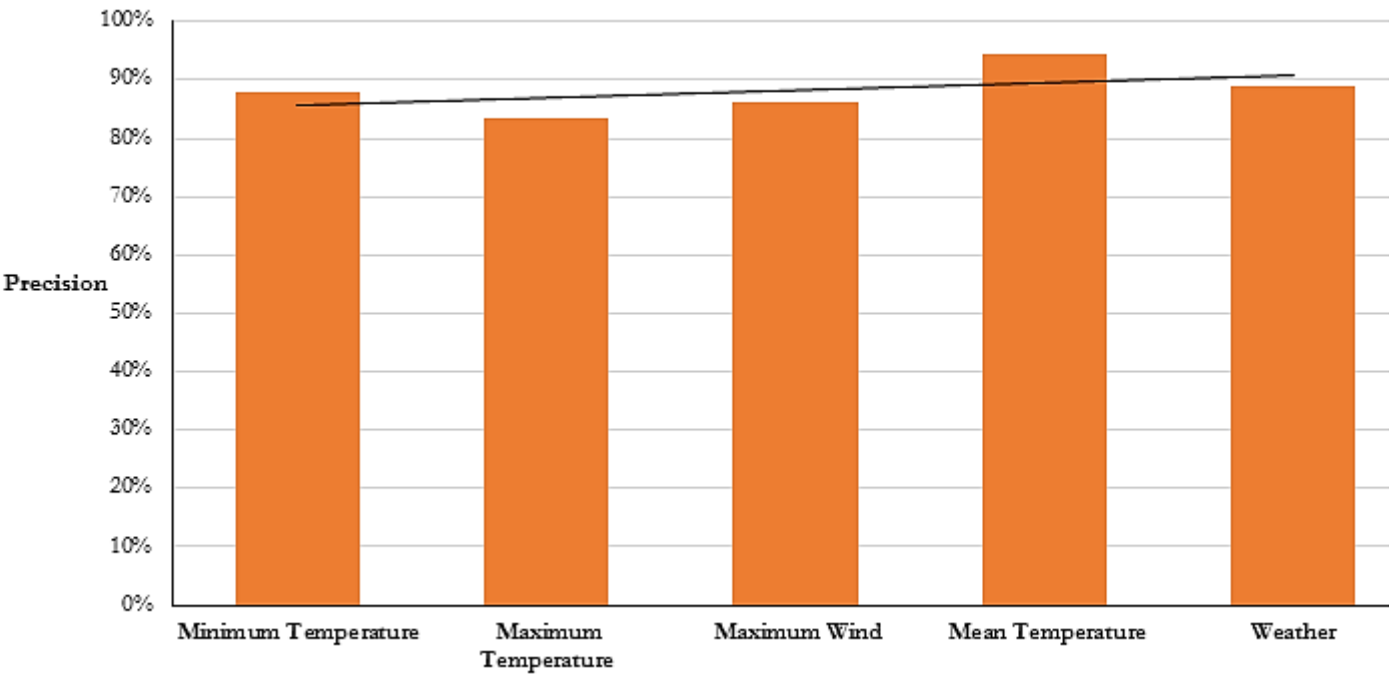

FIGURE 17: BAR CHART OF AVERAGE PRECISION OF ALL REGIONS COMBINED FOR ALL THE EXAMINED WEATHER ELEMENTS.

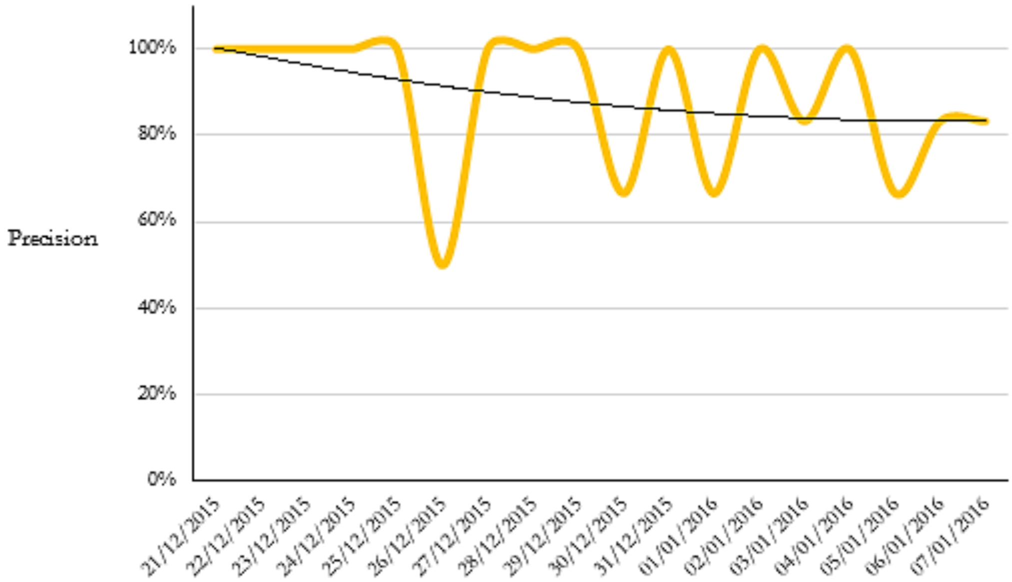

FIGURE 18: AVERAGE PRECISION FOR THE FORECAST OF THE WEATHER CONDITIONS IN ALL REGIONS OF CYPRUS COMBINED OVER THE PERIOD 21/12/2015 TO 07/01/2016.

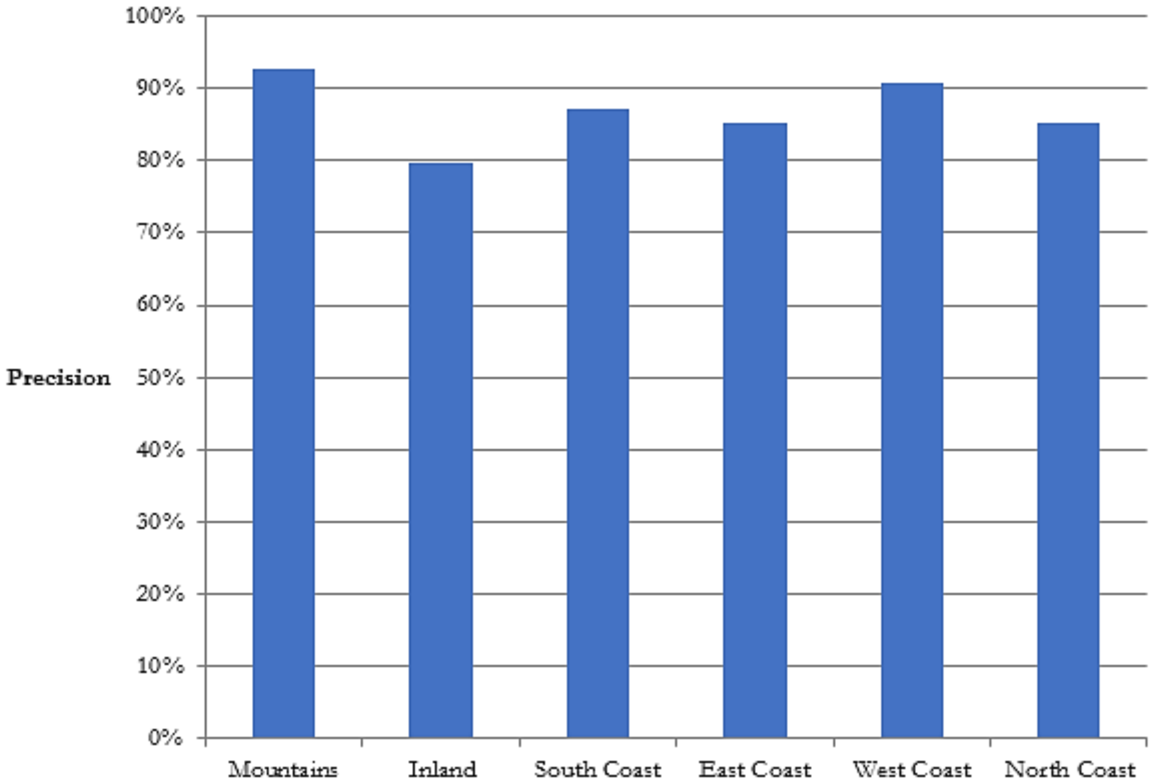

FIGURE 19: AVERAGE PRECISION OF ALL CONDITIONS COMBINED, FOR EACH REGION.

As our spreadsheets are completely automated, Dr. Michael has requested (and was granted) our permission to use them beyond the present project, internally in the Cyprus Department of Meteorology to continue checking the precision of their predictions. In essence, our objective was to raise awareness with regards to the actual crux of satellite technology applications and development. We consider that we have shown that one of their capacities supports society, in making forecasts comply with constantly changing weather patterns and climate, at least in the case of Cyprus.

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We also thank all the sources where we took images for the clip we prepared to raise awareness regarding the contributions of weather satellites: https://www.youtube.com/watch?v=jwZfdDJIf_k

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APPENDIX A

Interview 16 December 2015

The interview was semi-open and semi-formal, as a questionnaire was prepared in advance, though some questions were added during the conversation (Table 3).

Interviewee: Panagiotis Michael, Officer of the Cyprus Department of Meteorology

Interview Setting: Interview conducted in the Meteorological department in the facilities of the Ministry of Agriculture, Natural Resources and Environment

TABLE 3: FULL LIST OF QUESTIONS ASKED

Question
1. What methods and data do you use exactly to make weather observations?
2. What has been different ever since you were given access not only to infrared and visual but also to pictures with various wavelengths?
3. What are the steps followed in the production of weather forecasts?
4. Are hot and cold weather fronts shown in weather forecasts broadcasted on TV in Europe? If so, why are they not shown in Cyprus TV weather broadcasts?
5. Could you estimate a percentage indicative of the accuracy of the weather model you use?
6. Could you name the satellites used in the formation of this particular model?
7. Hypothetically, had meteorologists not been granted access to satellite data, how would forecasts differ?
8. Do you ever compare your weather predictions with the actual outcome? If so, what is your mean accuracy?
9. Have you ever failed to predict an extreme weather phenomenon? If so, what is your mean accuracy?
10. Did you receive any complaints regarding the dust storm?

The interview lasted approximately 2 hours and the background, as well as the advice given by Dr. Michael helped us decide on taking the first initiatives towards designing our experiment.

APPENDIX B

CONDITIONS' AVERAGE PRECISION OF ALL REGIONS COMBINED OVER THE PERIOD 21/12/2015 TO 07/01/2016.

Date	Minimum Temperature Precision	Maximum Temperature Precision	Mean Temperature Precision	Weather Average Precision	Wind Average Precision	Total Average Precision
21/12/2015	83%	100%	92%	100%	67%	88%
22/12/2015	100%	100%	100%	100%	100%	100%
23/12/2015	100%	67%	83%	100%	100%	90%
24/12/2015	100%	83%	92%	100%	100%	95%
25/12/2015	100%	50%	75%	100%	100%	85%
26/12/2015	100%	100%	100%	50%	100%	90%
27/12/2015	100%	67%	83%	100%	100%	90%
28/12/2015	100%	100%	100%	100%	100%	100%
29/12/2015	100%	100%	100%	100%	100%	100%
30/12/2015	100%	83%	92%	67%	100%	88%
31/12/2015	100%	50%	75%	100%	100%	85%
01/01/2016	83%	100%	92%	67%	100%	88%
02/01/2016	67%	83%	75%	100%	100%	85%
03/01/2016	67%	83%	75%	83%	100%	82%
04/01/2016	83%	83%	83%	100%	100%	90%
05/01/2016	83%	100%	92%	67%	100%	88%
06/01/2016	67%	50%	58%	83%	100%	72%
07/01/2016	50%	100%	75%	83%	33%	68%
Average	**88%**	**83%**	**86%**	**89%**	**94%**	**88%**

AVERAGE PRECISION OF FORECASTS FOR EACH CITY/ REGION AND CONDITION.

Condition	Area/City	Average Precision
Minimum Temperature	Inland/ Nicosia	72%
	South Coast/ Larnaca &Limassol	89%
	West Coast / Paphos	94%
	East Coast/ Paralimni	83%
	Mountains/ Prodromos	94%
	North Coast/ Polis	94%
	Average	**88%**
Maximum Temperature	Inland/ Nicosia	89%
	South Coast/ Larnaca &Limassol	83%
	West Coast / Paphos	78%
	East Coast/ Paralimni	83%
	Mountains/ Prodromos	94%
	North Coast/ Polis	72%
	Average	**83%**
Mean Temperature	Inland/ Nicosia	81%
	South Coast/ Larnaca &Limassol	89%
	West Coast / Paphos	86%
	East Coast/ Paralimni	83%
	Mountains/ Prodromos	94%
	North Coast/ Polis	83%
	Average	**86%**
Maximum Wind	Inland/ Nicosia	100%
	South Coast/ Larnaca &Limassol	89%
	West Coast / Paphos	94%
	Average	**94%**
Weather	Inland/ Nicosia	78%
	South Coast/ Larnaca &Limassol	89%
	West Coast / Paphos	100%
	East Coast/ Paralimni	89%
	Mountains/ Prodromos	89%
	North Coast/ Polis	89%
	Average	**89%**
	Total Average	**88%**