THE STALKER METHOD FOR INCREASED PREDICTABILITY OF FLUIDS BY MOVING BEYOND STATE VARIABLE MEASUREMENTS TO ENABLING UNDERLYING PHYSICAL PROCESSES

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ABSTRACT

Physical processes are not usually measured nor are adequately simulated using the current Numerical Weather Prediction (NWP) models due to the inadequate spatial and temporal resolution such models employ. The state variables, such as wind speed and temperature, are often measured only at relatively fewer number of locations compared to a larger number of measurement locations theoretically required for more accurate fluid depiction and predictability. Because of such fewer measurement locations, the available measurements of the state variables are usually inter(extra)polated to many of these unmeasured locations, without accounting for the underlying physical processes that shape the state variables to start with. These background physical processes may occur at any given fluid location, with collective influences emanating in all of the spatial scales around that location or in the context of the NWP models they occur in both grid-resolvable and subgrid scales. Since sparse information of the state variables is heavily relied upon for depicting the fluid behavior and predictability today, both grid-resolvable and subgrid physical processes are usually unaccounted for in the current fluid simulation efforts. Also, the subgrid physical processes and many other physical process parameterization schemes and methods (e.g., data assimilation) are usually defined in terms of the grid-resolvable state variables. The absence of a detailed treatment of the physical processes in the current NWP methods (or approaches) points to rather large data gaps many fluid sciences deal with and thus is the limitation within such sciences. A scientifically valid method, the Stalker method, to overcome that limitation by filling such data gaps is the crux of this note. The importance of the noted physical process influences is even more critical for the weather modification efforts, as even deeper data gaps exist when resolutions finer than 1 km are required for fluid depiction and predictability.

1.0 PROBLEM STATEMENT

1.1 Preamble to the Problem Statement

A series of questions posed to the current weather/ climate science by the author will form the basis for the preamble of the problem statement as outlined below. The author has formulated these questions based on his weather simulation experience in applying NWP models (e.g., for severe local storms (Stalker and Knupp 2003) and for wind farm assessment (Stalker 2005) and forecasting (Stalker 2008)) for over two decades.

1. I have measured a wind speed value of 10 m s^{-1}, now can you tell me where the measurement was made? The current science knows it can not answer that question.

2. The measurement was made at so and so latitude and longitude, now can you tell me at what height the measurement was made?

The current science knows it can not answer that question.

3. The measurement was made at the 50-m height above ground level, now can you tell me what time of the day it was measured for? Current science knows it can not answer that question.

4. The measurement was made at 10 AM (local time), now can you tell me what day of the year? Current science knows it can not answer that question.

5. It was measured on July 4th, now can you tell me what year it was measured in? Current science knows it can not answer that question.

6. The measurement was made in 2018, now can you tell me what physical processes (e.g., microphysics, radiative transfer) were responsible for that wind speed? Current science either does not know it can not answer this question or it conveniently ignores to answer it and instead resorts to invalid methods in employing NWP simulations.

- One can live with that state variable measurement (wind speed, in this example), along with the first five answers, so long as one uses it for that location/height/time/day/year.

- It is when one tries to use that measured state variable to estimate it at another location/height/time/day/year, where one has not measured it, one will have to know, not just the generalities of such conditions as sunny/cloudy/wet there, but the actual underlying physical processes at the location and in many encompassing scales around that location. These general conditions are mere reflections of those numerous, highly interactive physical processes. In other words, mere state variable measurements do not tell us anything about the underlying physical processes that cause the state variables to change constantly (i.e., the weather/climate science has to answer question #6 in a scientifically valid manner to increase predictability). Put it in a different way, there is no one unique set of physical processes that leads to that 10 m s^{-1} wind speed.

- The Stalker method is all about enabling these underlying physical processes at every location/height/time/day/year of interest than merely interpolating or extrapolating the state variables from the spotty measurement locations and sparse time periods. The latter is essentially what the other NWP modeling approaches are about.

- Current NWP models (or methods) - a huge part of the current scientific endeavors - attempt to do just that, that is interpolate or extrapolate state variables, develop physical parameterization schemes tied to the various state variables that as stated above do not have the ability to give us information on the underlying physical processes that cause those variables to reach those states in the first place.

- The Stalker method that the author has developed is computationally demanding, but it is the only way to simulate weather/climate conditions in a scientifically valid manner.

1.2 Problem Description

All fluids, including the atmosphere and oceans, are depicted for human understanding in terms of certain state variables (e.g., temperature). These state variables can be measured using sensors at the desired locations within a fluid of interest so the state of the fluid in question is known to be understood. However, the state of the fluid in question is only understood at those locations and for the time periods the measurements are made. The finest spatial resolution (dX) and temporal frequency (dT) required of the state variable measurements to ensure adequacy of such understanding depend on the fluid itself. In practice, the actual spatial resolution (DX) and temporal frequency (DT) achievable are much coarser than the finest resolution required via measurement efforts alone. What often makes it even more difficult to achieve the required finest resolution and frequency is the need for knowing fluid states of the past or future periods, for which measurement sensors can not obviously be deployed.

For many fluids of interest, the most likely scenario is to make the best use of the available state variable measurements of coarse resolution, DX, (DX >> dX) and inadequate temporal frequency, DT, (DT >> dT), for the past periods and the current conditions. Because of the severe inadequacy of the state variable measurements, available at a few known locations, such information is used to estimate state variable information at other locations where no such measurements are available. The main intent is to improve the accuracy of the understanding of the fluid state, i.e., by pushing the spatial resolution and the temporal frequency toward dX and dT, respectively. In other words, coarser-resolution information is utilized to achieve finer-resolution information based on the available sparse state variable measurements. Computational Fluid Dynamics (CFD) models are usually used for increasing the spatial resolution and the temporal frequency.

It is understandable why such an effort to increase accuracy through improved data resolution is desirable, but the approaches used in such efforts are often scientifically invalid. One of the fundamental reasons why such approaches are invalid is because of the fact that these state variables are shaped by the underlying physical processes constantly and such process influences are unaccounted for when inter(extra)polations are employed. Observations of the state variables point to the fact that different combinations of the physical processes can lead to the same magnitudes of any state variables in consideration. In other words, there is no one unique relation between the state variables and the underlying physical processes that shape these state variables.

Because such unique relations between the state variables and any specific combinations of the physical processes do not exist, estimation of the state variables based on the state variables alone may lead to significant errors in those estimated values.

If the spatial resolution and temporal frequency of measurements were to reach dX and dT, respectively, the type of physical process information noted in this paper would not obviously be required. In the meantime, the available spatial resolution and temporal frequency are rather coarse and the available state variable measurements constitute a small percent of the required data (see Section 2 for details) and practical increases in those measurements will not move the data needle toward reaching those finest-resolution goals.

While this problem is not unique to the NWP application for the atmosphere, the remainder of this paper discusses the problem within the context of the atmosphere only.

Section 2 provides a discussion on the context for the problem as it relates to weather and climate. In Section 3, the distinction between the process variables and the state variables is made. In Section 4, some conclusions are provided.

2.0 DISCUSSION ON THE WEATHER AND CLIMATE PROBLEM CONTEXT

The weather and climate information is collected using various measurement platforms, such as radars, satellites, surface weather stations, radiosondes (balloons), etc. This type of information is also augmented with the simulated output using the current NWP models, statistical methods, etc. for use in the hindcasting, nowcasting, and forecasting efforts. Depending on the temporal scales considered, e.g., days vs. decades, such forecasting efforts may be addressing the short-term weather or the long-term climate behavior, respectively.

Irrespective of the above-mentioned temporal scales of the application, there are inherent spatial-resolution and temporal-frequency related limitations in the approaches currently used to produce the weather and climate data. These limitations tend to reduce the overall achievable accuracy or may not yield the desired increases in the accuracy, with the desirable consistency, within the weather and climate data, relied upon for the purposes of hindcasting, nowcasting, and forecasting today.

Within the weather and climate science efforts, measurements of the state variables have been steadily increasing. There is no doubt such increases have been significant over the past few decades with the technological advancements. However, a proper context to ascertain whether the available data volume is small or large, in terms of the spatial resolution and temporal frequency, relative to dX and dT, respectively, must be defined. In such context, the available measured data and the other coarse-resolution simulation based data (if any) constitute a small percent of the required data indeed.

If the highest desired accuracy is assumed to be achievable at the 100-m spatial resolution (dX), from the state variable measurements alone, the need to account for the physical process influences can be ignored. On the other hand, if the spatial resolution of the state variables is on the order of 5 km or coarser, and such data are used to achieve, for example, 1-km spatial resolution via the state variables alone, the achievable accuracy would suffer due to the fact that the influences of the underlying physical processes are ignored (see Section 3 for details). As the resolution decreases or as DX increases, the influences of such physical processes become relatively even more dominant, in the efforts to improve spatial resolution toward 1 km, due to the substantial data gaps that exist in the coarser-resolution data. Table 1 shows the type of data gaps that can exist in coarser-resolution information.

From the standpoint of the horizontal spatial resolution, the existing data gaps may be 90+%, as shown in Table 1. From the standpoints of vertical and temporal resolution, these data gaps are pronounced even further (not shown). The data gaps from the point of view of the information (or lack thereof) on the underlying physical processes are even more restrictive as discussed in Section 3. If the desired resolution is finer than 1 km, such as 100 m within weather modification research and operations, the data gaps shown in Table 1 would be much more severe. In other words, capture of the physical process influences will become that much more imperative.

Table 1. Data Gaps in Coarse-Resolution Information

Available Data Resolution (km)	Desired Data Resolution (km)	Data Gaps (%)
3	1	89
5	1	96
12	1	99.3
32	1	99.9
55	1	99.97
110	1	99.99

*The data gap is defined as (1-1/{value(column1)*value(column1)})*100.

Unfortunately, it is conventionally believed by the global weather and climate community that the available weather and climate data are quite adequate as "they are," but that is not so when the context is properly defined as in this note. The global weather and climate community is also of the opinion that as long as we keep measuring the state variables at the current locations and perhaps keep adding new locations, the weather and climate science will achieve its objective of reaching the highest accuracy. It should be realized that these data gaps in the sparse observations are going to persist, no matter how many observations, of the state variables, will be added in the foreseeable future. In other words, observations of the state variables will essentially be facing a data ceiling, as the answer to this persistent problem lies elsewhere within the constantly changing physical processes.

While effective approaches to account for the physical processes are required, the global weather and climate community resorts to using these limited measurements of the state variables, interpolation/extrapolation schemes, statistical and empirical methods, and severely inadequate climate and mesoscale NWP models, for estimating past, current, and future weather conditions and for projecting climate scenarios. Because of the huge (90+%) data gaps that exist in the current approaches (as shown in Table 1), these methods should be appropriately referred to as the 10-percent methods/approaches. In other words, more measurements of the state variables will still face the 10-percent data ceiling described in this note. Thermal stability (temperature at two heights) and wind shear (wind speed at two heights) are offered as useful variables in a significant way but such variables are still the state variables and, thus, will not overcome the 10-percent data ceiling or help overcome the limitations of the 10-percent approaches in any significant way.

3.0 STATE VARIABLES VS. PHYSICAL PROCESS VARIABLES

As mentioned in the previous sections, a clear distinction has to be made between the state and physical process variables (or process variables, hereafter) in order to understand the limitations that restrict the ability to improve accuracy of the fluid depiction and predictability. The state variables are those that are usually measured by the various measurement platforms available, such as wind speed, direction, temperature, etc. The process variables, on the other hand, are those variables related to the underlying physical processes that constantly shape these state variables. For example, wind, a state variable, gets shaped by the many physical processes, including radiative processes, surface exchange processes, transport and mixing processes, microphysical processes, etc. Because of the fact that numerous processes may be responsible for shaping any single state variable, at a location, at any instance, measurements of the state variables do not explicitly contain the process information or the information about the right combination of the processes responsible for the observed wind speed (as an example herein). The influence of the underlying processes in shaping state variables is not unique to wind speed alone. All the other state variables, such as temperature, pressure, humidity, do constantly get shaped by the numerous underlying processes.

Understandably, there is no way to determine the multiple processes and/or their exact combinations that have shaped a state variable, from the measurement of that one state variable itself. One state variable doesn't lend itself or can not be used to determine five or more process variables. What also makes the process variables difficult to measure is the expensive instrumentation necessary. The process variables can also be affected by the many spatial and temporal scales relevant within a fluid under consideration. A closer inspection at the process variables shows that each such process variable may comprise various scale-dependent components at a location and for any specific time. For example, based on the spatial scales involved, a process, p1 (e.g., p1A), may be further divided into scale-dependent components such as p1A1, p1A2, p1A3,...p1An, where p1A1 may represent a scale of 100 km on p1, while p1An may represent a scale of 10 m on p1. The individual component contribution to a process variable at that location does constantly change with time. Also, at any given location, p1A1 may be dominant at one time and at another time, it may be less dominant or even be nonexistent altogether. What makes this problem of capturing processes so complex is that, in addition to the scale dependency, multiple physical processes (e.g., p1, p2,...pn) are at play simultaneously in shaping various state variables. Only a robust physics-based modeling strategy will allow the weather and climate community to capture all the relevant process components.

As mentioned before, when using the limited state variable information to estimate the state variable information at the other locations and for the other time periods, the accuracy of the estimated state variables suffers because of the lack of the process information at and around that location. Needless to state that the current NWP methods that use the state variables (e.g., wind speed) to estimate the same state variables (e.g., wind speed), without accounting for these underlying physical processes, are severely inadequate and unscientific.

4.0 CONCLUDING REMARKS

- Measurements of the state variables are limited in many fluids. Measurements of the process variables (which are many) are almost non-existent. Because of the absence of the process variables that continuously shape state variables, the inadequacy of the state variable measurements is further pronounced in depicting and predicting the fluid state accurately.
- It is also due to the absence of the process variables, interpolation/extrapolation schemes to estimate the state variables at the other locations and for the other times, based on the state variables alone, are scientifically invalid. This is due to the fact that the state variables do not uniquely contain the process variable information. Even though such processes are responsible for shaping the state variables constantly, such processes are more often ignored or mistreated in the current NWP models.
- It is also because of the limitations of the state variables, noted in this note, data assimilation methods, other physical parameterization schemes, including the subgrid models, using only the state variable information, are ineffective and scientifically invalid.
- The Stalker method has been implemented within a meso-microscale model with the capabilities of simulating robust physics to enable the underlying physical processes. With the Stalker method implemented, this model can be used to achieve finer resolution and increased accuracy of depiction and predictability simultaneously. An extended paper on the Stalker method has been submitted to the Journal of Weather Modification for publication.
- The Stalker method will be crucially important for the design, operation, and evaluation/feedback phases of all the weather modification efforts globally and so publication of this note and the full article publication subsequently will be of interest to the readers of the Journal of Weather Modification. The author presented a talk on the Stalker method at the 100th Anniversary of the American Meteorological Society in January 2020 (Stalker 2020).

5.0 REFERENCES

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