**Title:** On Generation, Estimation, Utilization, Availability and Compatibility Aspects of Geodetic and Meteorological Data

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**Supplementary Notes:**


**Generation**

- Estimation
- Utilization
- Geodetic
- Meteorological

Following an introduction, the paper discusses in section 2 the collection or generation of final geodetic data from conventional surveys, satellite observations, satellite altimetry, the Global Positioning System, and moving base gravity gradiometers. Section 3 covers data utilization and accuracy aspects including gravity programmed inertial positioning and subterranean mass detection. Section 4 addresses the usefulness and limitation of the collocation method of physical geodesy. Section 5 is concerned with the computation of classical climatological data. In section 6, meteorological data assimilation is considered. Section 7
deals with correlated aspects of initial data generation with emphasis on initial wind field determination, parameterized and classical hydrostatic prediction models, non-hydrostatic prediction, computational networks and computer capacity. The paper concludes that geodetic and meteorological data are expected to become increasingly more diversified and voluminous both regionally and globally, that its general availability will be more or less restricted for some time to come, that its quality and quantity are subject to change and that meteorological generation, accuracy and density have to be considered in conjunction with advanced as well as cost-effective numerical weather prediction models and associated computational efforts.
In this paper, the collection and utilization of geodetic data from various sources are discussed. Section 1 focuses on introduction and background. Section 2 covers the collection of geodetic data from conventional surveys, satellite altimetry, and the Global Positioning System (GPS), along with their availability and continuity. Section 3 discusses data utilization and accuracy, including gravity programmed inertial positioning and subterranean surveys. Section 4 addresses the usefulness and limitation of the traditional methods of physical geodesy. Section 5 is concerned with the utilization of digital climatological data. In section 6, meteorological and oceanographic data is considered. Section 7 deals with correlated aspects of global data generation with emphasis on initial wind field determination, atmospheric and oceanic hydrostatic prediction models, non-hydrostatic numerical models, and computer capacity. The paper concludes with a summary of some of the issues that are expected to become increasingly more important both regionally and globally, such as the general increase in demand for data, the increased need for quality control, and the need for improved accuracy. The paper also discusses the importance of considering the potential future uses of the data in conjunction with other types of data.

1. Introduction

Fundamental aspects of geodetic data management were addressed at the workshop on management of geodetic data, Copenhagen, August, 1981, and a number of pertinent articles are included in Bulletin Geodésique, Volume 20. While measurement of geodetic data is not restricted to gravity measurements and their associated identifications, they are playing a fundamental role because of the relatively simplicity of their determination, accuracy, frequency density, and geodetic applications, sometimes in combination with satellite and satellite altimetry data. In contrast to essentially static geodetic data and the absence of a critical time constraint to applications, meteorological data for operational numerical weather prediction has to be rapidly acquired and processed for use in dynamic prediction models with
Database accuracy dissemination. The data base has to be preferably world-
wide and the scope extends to several variables and a number of discrete
sections. For this reason, all organizations concerned with operational
forecasting procedures have developed extensive data management systems.

Geodetic and meteorological data management have in common the predominant
requirements of governments or public organizations. There is, however, a much
greater international data exchange in meteorology, dictated by necessity,
with a number of military considerations impose certain restrictions at
the moment. In some cases, proprietary rights are also claimed by private
organizations. To explain from the document, this paper is not concerned with
such limitations, no data technical issues, including consideration of
the extent of data base, and management. It emphasizes the influence of
newer techniques on the data management and identifies some geodetic and
meteorological data management issues and data management systems. In the field
of geodynamics, it emphasizes the identification of gravity gradiometers and its
essential impact on present work development. In meteorology, it emphasizes
the use of high and medium satellite observations and a denser network of
satellite data collection, and centers on the problem of data
management protocols and data measurement with improved dynamic models.

Geodetic data management that are open limitations of necessity not
apply to the overwhelming geodetic and meteorological data
inaccuracies.


Geodetic data for geodetic purposes consist, under deletion of

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the differences of geodetic networks and the conventional
determination of geodetic positions, essentially of:
(1) Satellite Doppler and Related Measurements
(2) Satellite Altimetry Measurements, GEOS 3 and SEASAT
(3) Global Positioning System (GPS) Measurements (New)
(4) Point Gravity Measurements
(5) Elevation Measurements (Topographic Maps)
(6) Geoid Gravity Deflections
(7) Solar Motion Measurements
(8) Height Anomaly or Geoid Representations (Including Combined Solutions)
(9) Satellite Altimetry Representations
(10) Geopotential - Inertially Determined Gravity Vector Components
(11) Geopotential - Geodetically Derived Gravity Vector Components

The principal data sources pertaining to satellites is the National Space Science Data Center, Greenbelt, Maryland (World Data Center - A for Rockets and Artificial Satellites) and also includes near-ground studies. Gravimetric information, supplied by the National Geodetic Service Data Center in Seattle, Washington (World Data Center - A for Solid Earth Geophysics). It is derived primarily from the International Gravimetric Bureau, Paris, France, as can be seen from the International Gravity Commission whose data management has been described by Isaac [1982]. Height anomaly or geoid representation may be obtained from Goddard Space Flight Center, Greenbelt, Maryland and from the Department of Geodetic Sciences and Surveying, The Ohio State University, Columbus, Ohio.
While geodetic data generation, except for point measurements, has been
principally facilitated by satellite technology combined with new instrumenta-
tion, dense, uniform, and highly accurate regional gravity vector determina-
tions is expected to be performed in the United States after 1987. The
contemporary accuracy of 0.2 arcsec rms and 1 mgal rms in the context of
constant elevation networks of considerable size and a grid length of about 5
in will revolutionize physical geodesy in many respects and will ultimately,
together with interpolation techniques, simplify many aspects of geodetic data
manipulation. Technical details of the Bell gravity gradiometer have been
introduced by Weisberg and Jusaitis [1981], Heller [1981], and Jordan [1982].
For measurement, theoretical and exteropeodetic-gradiometric gravity vector
measurement and a combination thereof, reference is made to Bausch von
Hammel [1982].

The geophysical measurements generated for both conventional weather
analysis and for nonoptical predictions are performed by balloon soundings,
points, trajectory soundings, and surface pressure measurements in fixed
locations alone. The measurements are supplemented by data from aircraft and
satellites.

Geophysical satellites provide:
- sounding, geopotential, and surface temperatures, snow and ice mapping,
- wind mapping.

Geostationary satellites generate information concerning:
- geographical openings, cloud region (wind in about 2 layers), sea surface
- temperatures, precipitation estimates.

A polar orbiting satellite equipped with a scatterometer may also provide
measurements of ocean surface winds according to Pierson [1983].
Some environmental satellites are depicted in Figure 1 below.
The Solar Environmental Satellite Products List is shown in the

<table>
<thead>
<tr>
<th>Products</th>
<th>Category Code</th>
<th>Spatial Resolution/Geographical Coverage</th>
<th>Schedule</th>
<th>NESR (Original Model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 km near the sub-satellite track, including with some oceanic/continental.</td>
<td>April 1988</td>
<td>NESR (DSM)</td>
<td>ERS (SST)</td>
<td></td>
</tr>
</tbody>
</table>

TABLE

Partial Solar Environmental Satellite Products List, Sounding Products

The National Climate Division of the National Climate Center, Asheville, North Carolina, and the operations and data center of NOAA's National Environmental Satellite Service, Silver Spring, Maryland is the United States governmental environmental satellite data.
The geodetic data generated by different means enumerated in section 2a and section 2b, sometimes in combination, the establishment and utilization of geodetic networks with associated accuracies:

1) Improved Geopotential, Non-uniform Accuracy, Equal to or Better than Spherical Harmonics Representation of Degree and Order 360.

- Height Anomaly RMS Error of the Order 1 m.
- Improved Space Vehicle Trajectories and Orbits

2) Determination of the First Derivatives of the Geopotential in Tidal Causes (Articulated Geopotential and Cross-Component RMS Error of Less than 1 m).
- Geopotential Height Determination.
- Coordinate Transformation from Local to Global System (Mean Equatorial System),

3) Improved Space Vehicle Trajectories.
- Accuracy in Geopotential System with Reduction of Mean and Variance of Position Error and Position Error Due to Acceleration Scale Factors and Gyro Bias Errors, Accuracy of the Order 5.10⁻⁸ for 60 km Traverse with Initial and Terminal Geoid Considered.
- Improved Geodetic Network Adjustment.
(3) Rapid GPS Positioning, RMS Error Dependent on Acquisition Time, Reducible to 1 m or Better.

(4) Subterraneous Mass Detection and Geophysical Prospecting (Oil, Water, Cavities)

The greatest impact on geodetic data management, heretofore strongly constrained with gravity data, has the regional, uniform and accurate determination of gravity vector components by astrogeodetic–gradiometric means in the foreseeable future and the application of suitable interpolation methods addressed in section 4.


The correlation method of physical geodesy is indispensable for many geodetic applications, its weaknesses and limitations characterized by the following:

(1) Interpolation of high accuracy gravity vector components determined by astrogeodetic–gradiometric means in level surface about 500 m above ground and analytical downward continuation to the earth's surface and correct incorporation of point gravity anomalies in semi-flat terrain as an integral part of grid development favored by the uniform distribution of vector components over several regions.

(2) Post-mission adjustment of gradiometric data or optimal gravity vector computation under consideration of initial and terminal vector components.
5. Climatological Data, Univariate and Multivariate Analysis.

Of immediate interest to climate data management are the Guidelines on Climate Data Organization and Formats, published by the World Meteorological Organization in 1982 (WPC-31). It addresses climate data types, data management principles, management of data bases, and advanced techniques. Associated with the generation of climate data is the establishment of a multivariate statistical interpolation scheme. Such schemes have been discussed by Lorenc [1980] and Gustavsson [1981]. Although climatological means are subtracted from measured or model-generated random variables to be used in the regression estimation, the assumption of homogeneity and isotropy is often made for simplification. Significant in this respect is that the statistical estimation corresponds to the generation of meteorological variables by a simpler model. For the same reason, means, variances and covariances are subject to variations, i.e., do not behave in accordance with an ergodic generation process. In the context of the use of climatological data for estimation purposes the following should be noted:

1) Stationary statistics involving first and second order moments compatible with an ergodic generation process is applied for the estimation using variables generated by a non-stationary process.

2) Winds utilized for interpolation and extrapolation of geopotentials are associated with a geostrophic estimation structure and tend to cause imbalances in multivariate analysis, ascertained by Williamson, Daley and Schlatter [1981].

3) Univariate geopotential estimation does not appear to introduce significant errors if the data points are not widely separated.
(4) For improved univariate estimation, winds require a decomposition in non-divergent and divergent components.

(5) The utilization of measured winds for the estimation of geopotentials should preferably be accomplished in the context of 4-dimensional data assimilation, by univariate analysis, and employment of an improved balance equation addressed in section 7. The ultimate estimation of the geopotential would then be a weighted univariate solution.

(6) The existence of measurement errors and correlated noise can be considered in univariate and multivariate estimation.


An overview of meteorological data assimilation has been presented by Morel [1981] under inclusion of grid point analysis by multivariate techniques, dynamics of adjustment, normal mode initialization, and 4-dimensional data assimilation. He emphasizes the development of filtering techniques and the consideration of artificial damping pertaining to the generation of meteorological noise during dynamic prediction because of the generation of divergent winds and stated that the mathematical basis for understanding the continuous or discontinuous adjustment process involved in 4-dimensional data assimilation is not well established as yet.
Eamitsu, Kallberg, and Uppala (1982) discuss the 4-dimensional data assimilation at ECMWF. The respective scheme is evident from figure 2 below.

![Diagram](image)

**FIGURE 2**

The different stages in 4-dimensional data-assimilation at ECMWF (*archived through the whole FGGE year, **archived during the Synopses*).

In this scheme, the scalar field variables at a specific time are estimated from their values generated from fields established 6 hours prior to time $t_0$. This approach presupposes the existence of errors pertaining to the generated and observed fields and their covariances and requires a considerable empirical effort. Nonlinear model initialization was applied for the

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2**FGGE**: First GARP Global Experiment (GARP: Global Atmospheric Research Project).

3**ECMWF**: European Center for Medium Range Forecasts (Reading, United Kingdom)
computation of quasi-balanced wind and mass fields. The significance is that
this approach does not only lead to reduced scalar field errors at time $t_0$ but
also to a partial influence of the respective observed fields. For this
reason, accurate initialization is important.

The global data assimilation system at the National Meteorological Center
has been described by Ward, Kistler, Tracton and Gordon [1981].

7. Initialization, Dynamic Model Improvement, Predictability and
Compatibility.

Initialization for determination of the wind field from the mass field
under no or limited consideration of diabatic processes and dynamic model
improvement and correlated computer capacity impose data management
considerations. Although they enteris paribus increase predictability,
progress must be to be compatible with the generation of denser and more
accurate data primarily by satellites and a greater number of surface pressure
sensors, particularly in oceanic areas. A marginal utility analysis would
further have to assign weights to short and long range forecasts under
consideration of the spectrum of applications. There are already implications
that relatively accurate and correspondingly expensive long range predictions
for non-military purposes should be centralized in the future. Of specific
interest here are the following topics.

(1) Normal Mode Initialization (NMI): Nonlinear NMI along the lines
of Williams and Temperton [1980] is the presently preferred and practiced
method to derive mutually balanced mass and wind fields. As shown by Phillips
[1982], multivariate optimum interpolation analysis is consistent with NMI if
the model-generated first guess data contain only slow modes with correspond-
and of which observations are used. As indicated in
univariate and of the data analysis and the univariate
methods, the models used for computed and sufficiently
the conditions which can result in higher modes and the
terms in the truncated balance equation. The truncated balance
application (5) of the geopotential \( \Phi \) has been
recognized (5) in the study of elliptic regions in balanced
and divergence in which to emphasize the need for a
an appropriate approximation. For instance, the inadequacy of BE
and
canonically balanced regions has further been established by
by means of the geopotential equation and the range equation
between the geopotential equation and the range equation
of assimilation of the geopotential equation. As a result, there is no
numerical
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The equations (1) and (2) the symbol \( \alpha \) indicating a filtered variable has been included since smooth \( \theta \)-data are employed for initialization. Equation (2) approximates the phenomenon to the thermodynamic equation with 3 ellipticity coefficients forming a new condition criterion. The new diagnostic equations are typically employed in the chemical balance equation, particularly under turbulent-averaging assumption. They were derived by Emanuel von Luetzow [19] and are based on a broader concept including non-hydrostatic effects.

(2) Thermodynamic Integral Formulation: The vorticity equation, the momentum equation, the continuity equation, the diagnostic equation (1), and the thermodynamic integral formulation represent a hydrostatic signal generation model with the assumptions of ellipticity, compatibility, and which parameter associated to different influences initially considered to the extent that the pressure terms in the momentum equation are only related to small subgrid scale phenomena. In most generation processes has a definite prognostic capability with the temperature, the dominated sources of spectral dynamic effects, the additional source of diagnostic terms, and shortcomings of the spectral dynamic approach.

(3) Traditional Hydrostatic Prediction (Principle Equations): The
subjected to conditions requiring adjustment schemes, and thus cannot not fully
address the continuity equation for water vapor. Prognostically, this
subjectivity has an increasingly degrading effect, also with respect to the
simulation of radiation which has not been well accomplished yet at the
National Meteorological Center as reported by Fauzy, Gerrity and Sela [1981].

(8) Nonhydrostatic Prediction: The use of the prognostic equation
for the vertical velocity component is generally prohibited because of
incompatibility in the initial fields, the lack of time-varying boundary
conditions at the bottom and the top of the atmosphere, and the computational
effort required. For a limited area, for the purpose of research, and with
some modifications, Saso and Watts [1976] have considered a non-hydrostatic
atmospheric model. leaving the structure of the continuity equation in the
GFDL-athmospheric model, Lucas von Luepke [1971] derived a higher order
difference equation for the vertical velocity component, modified in 1980. The
permanent system, free of internal sound waves, is compatible with a
computational grid length down to about 10 km and allows for an essentially full
approximation of the continuity equation for water vapor. The system simul-
taneously allows for many vertical levels. As a consequence of computational
amount classification, it requires an enlarged computer capacity. In
agreement with findings by Gordon and Stern [1982], the spectral method is
expected to be more suitable in this system, tantamount to the requirement of
higher order difference schemes.

(9) Predictability and Compatibility Aspects: Sophisticated models
are the necessary prerequisite for long range weather prediction under full
utilization of the geopotential, humidity and cloud observations, and
understand self-derived equatorial winds. However, these models cannot
reasonable for the lack of dense and accurate data. From the standpoint of
numerical weather, a grid length of 100 km appears to be fully adequate. At the
present time, this length must be relaxed. In view of the availability of effective
numerical weather models, in particular equation 1 and the associated omega
equations, the initial data problem is the most crucial, calling for more and
improved meteorological satellites, considerably more surface pressure sensors
in remote areas, and an improvement in wind measurements in equatorial
regions. Equally, the density and accuracy of available data are not
compatible with sophisticated models and also not with initialization
methods. This is in agreement with results summarized by Reuter [1982] at the
International Seminar on Weather Prediction, Vienna, Austria, June 1982. Thereafter, meteorological data management has to reconcile scientific-
technical specifications with cost-benefit analyses.

2. Conclusion

Because of the availability of new and powerful technology in the near
future, diagnostic and meteorological data are expected to become increasingly
more distinctive and valuable both regionally and globally, and its quality
and quantity are subject to change. Primarily in the field of geodesy, its
availability will be questioned because of military considerations. Gravity
measurement surveys are expected to have a profound effect on geodetic data
assimilation. Meteorological data generation, accuracy and density have to be
enhanced to conjunction with advanced as well as cost-effective numerical
weather prediction models and associated computational efforts. For the
initialization of wind fields, diagnostic equations superior to the classical
meteorological equations are available. Long range numerical weather
The results presented here suggest the feasibility of extending the model to a broader range of atmospheric conditions and to incorporate a more comprehensive set of observations. The model has been successfully applied to a variety of real-world scenarios, providing valuable insights into atmospheric processes.

References:


