

John L. Schattel Jr.*, Arthur A. Taylor, and Paul R. Hershberg
 Meteorological Development Laboratory
 Office of Science and Technology
 National Weather Service, NOAA
 Silver Spring, Maryland 20910

Robert Bunge
 Director, Internet Services
 Office of Chief Information Officer
 National Weather Service, NOAA
 Silver Spring, Maryland 20910

1. INTRODUCTION

The National Weather Service (NWS) Strategic Plan (NWS 2005) envisions a future where the United States economy is increasingly able to use weather information to improve its productivity. To meet the needs of a weather hungry society, the NWS will evolve its products and services in new directions. One such frontier involves supplying digital data to NWS customers. The dissemination of weather data in electronic form continues the migration from the last century's legacy text products to the 21st century where the digital database is the preeminent product. The ability to re-purpose digital data, along with its improved temporal and spatial resolution, empowers economic actors to exploit the value of weather information. To make this vision of the future reality, the NWS has continued to improve the ease with which users acquire digital data. Access to weather databases has been made simpler, available on demand, and delivered in a form suitable for reprocessing by the user. To continue to build on these characteristics, the NWS has deployed an experimental web service based on open standards. The web service, which is accessible via the Internet on a continuous basis, uses Open Geospatial Consortium (OGC) Web Feature Service (WFS) standards to disseminate National Digital Forecast Database (NDFD) data encoded in another OGC standard called Geography Markup Language (GML).

To provide a full understanding of the new WFS (ndfdWFS), we begin by describing its source of data—the NDFD. We look at what the NDFD is, what it contains, and for what it is used. We next introduce the OGC and two of its specifications—the WFS and GML. As you read these sections, you develop an appreciation for the WFS's client and server architecture and the requests/responses that allow it to communicate. We conclude the paper by telling you about the NWS's GML dialect, Digital Weather GML (dwGML), and the ndfdWFS it developed to disseminate NDFD data. The discussion of the NWS WFS tells you how

* Corresponding author address: John L. Schattel, W/OST24, 1325 East-West Highway, Silver Spring, MD, 20910; e-mail: John.Schattel@noaa.gov.

the service is accessed and the three data structures used to encode the returned NDFD data.

2. NDFD

The NDFD (Glahn and Ruth 2003) represents the official NWS 7-day forecast of sensible weather elements like maximum temperature, sky cover, and probabilistic tropical cyclone wind speed. The forecasts are prepared at NWS Weather Forecast Offices (WFO) and Centers across the United States and its territories. The forecasts are transmitted to a central server where the digital data are merged into a single database (Fig. 1). The transmitted forecasts are encoded in General Regularly-distributed Information in Binary Version 2 (GRIB2; WMO 2001). The forecast for a given weather element is stored as a grid of values with each value corresponding to a point on the Earth's surface. There are grids for separate geographical areas (i.e. Continental United States, Alaska, Hawaii, Puerto Rico, and Guam). Values in a grid are valid for a particular time or span of time during the forecast period.

Once all the grids are aggregated, the NWS uses NDFD data for a number of products and services. The products include data visualized in images (Fig. 2) and

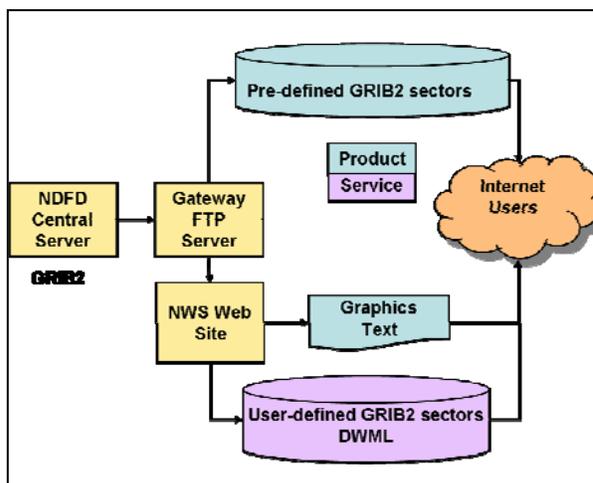


Figure 1: NDFD products and services.

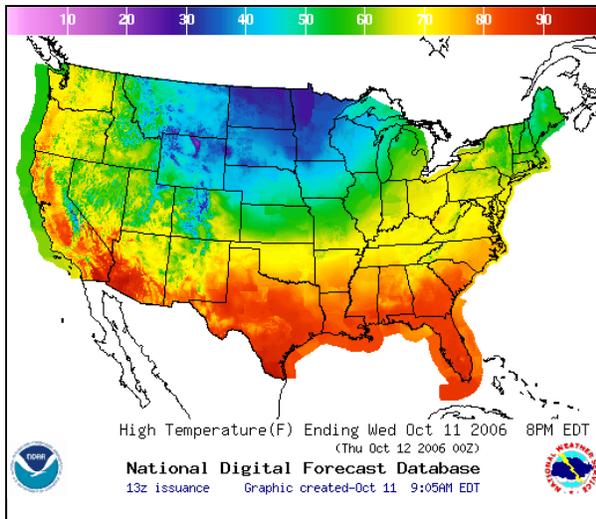


Figure 2: NDFD graphical forecast for maximum temperature.

GRIB2 data made available in files customers can download from the NWS File Transfer Protocol (FTP) site (NWS 2006a). The GRIB2 data comes packaged for 21 sectors and sub-sectors of the database. Using downloaded GRIB2 files, a user employs a decoder to extract the data. The NWS provides users such an application, called degrib (NWS 2006b), which in addition to decoding GRIB2 can convert the data into ASCII text, shapefile, NetCDF, float, and Digital Weather Markup Language (DWML) formats.

NDFD web services consist of a custom GRIB2 sector service and a Simple Object Access Protocol (SOAP; W3C 2003) service. The custom sector service (NWS 2006c) allows users to download only the data they require. The user provides the NDFD element and the location of the rectangle for which they want data. The service returns a file containing the data encoded in GRIB2. This has the benefit of reducing the volume of data being transmitted and ensuring that the retrieved data completely covers the user's geographical area of interest.

The SOAP service (NWS 2006d) allows user written web applications to automatically retrieve portions of the NDFD via the Internet. The data exchange is accomplished using a client and server architecture. The client requests a particular weather element at a specific point on the NDFD grid for a user defined time period. The server returns the requested data encoded in DWML (NWS 2006e). The client application then parses the DWML to extract the NDFD data. Once parsed, the data are available to be used for further processing by the web application. The SOAP service has proven very popular receiving over 50 million requests per month.

3. OPEN GEOSPATIAL CONSORTIUM

The organization that has developed standards useful in disseminating the NDFD data (Section 2) to the Geographic Information Systems (GIS) community is the OGC. The OGC was established in September 1994 to develop open interface specifications for GIS. The OGC is made up of over 300 GIS users and developers as well as corporations, government agencies, and universities interested in supporting the GIS community with technology and data. Members can be found in North and South America, Europe, and Asia. They work together to develop consensus standards that allow geo-processing technologies to interoperate. To date, the OGC has approved 18 specifications. These standards include Web Feature Service (WFS), Web Map Service, Web Coverage Service, and GML.

4. GEOGRAPHY MARKUP LANGUAGE

GML (OGC 2004) is an OGC standard and XML dialect used to create XML languages for exchanging geospatial data. These new dialects are defined by what is called an application schema. A given application schema tailors GML for use within a particular subject matter area. The customization is accomplished by defining relevant feature and feature property names. The user's application schema also determines how the features and feature properties are grouped. When a user creates an application schema, they follow the rules established by the GML schema. By doing so, the user ensures that a GIS that can decode GML will be able to decode their custom dialect. This interoperability is the primary benefit of using GML.

Like all XML languages, GML uses tags to represent features and their properties. The GML in Fig. 3 and application schema in Fig. 4 illustrate how a developer can tailor GML. The tag `<app:Forecast_GmlsfPoint>` in Fig. 3 is a GML feature. Although the name is more descriptive than `<gml:Feature>`, a GML processor decodes `<app: Forecast_GmlsfPoint>` as it would `<gml:Feature>`. In addition to simply renaming GML tags, a user can extend and restrict the content of a GML element. The complex type *NDFD_ForecastType* shown in Fig. 4 demonstrates how a user adds elements to the GML content model. Based on this

```
<app:Forecast_GmlsfPoint>
  <gml:position>
    <gml:Point srsName="NDFD_CRS.xml">
      <gml:pos>38.99 -77.99</gml:pos>
    </gml:Point>
  </gml:position>
  <app:validTime>2006-10-11T00:00:00
  </app:validTime>
  <app:maximumTemperature uom="F">88.0
  </app:maximumTemperature>
</app:Forecast_GmlsfPoint>
```

Figure 3: DwGML feature conforming to the Simple Feature Profile.

```

<element name="NDFD_Forecast"
  type="app:NDFD_ForecastType"
  substitutionGroup="gml:_Feature" />
<complexType name="NDFD_ForecastType">
  <complexContent>
    <extension base="gml:AbstractFeatureType">
      <sequence>
        <xsd:element ref="gml:position" />
        <xsd:element ref="app:validTime" />
        <xsd:element ref="app:maxTemperature" />
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>

```

Figure 4: Sample application schema fragment.

application schema, the <NDFD_Forecast> tag will contain a <gml:position>, <app:validTime>, and <app:maximumTemperature> tag plus all the elements and attributes it inherits from the *AbstractFeatureType*. By renaming GML elements and extending others, a user is able to customize GML to better represent the specific data being encoded.

GML offers a large and robust set of elements to use and perhaps tailor. At the simple end of the spectrum, the GML schema defines elements for types like *stringOrNull*, which is the union of a string and the GML *NullType*, or an *integerList*, which represents a comma separated list of integers. At the other end of the spectrum are the more sophisticated structures like the rectified grid coverage and observation. Fig. 5 shows a GML *Observation* instance tailored to hold a forecast maximum temperature. In addition to the value being forecast, the observation contains a valid time and the location of the forecast. In between the simple and complex types, GML offers a full range of structures for encoding 0 – 3 dimensions of geometry, grids, coordinate reference systems, geographic datum, units, time, and more.

One of the challenges facing developers of GML-conforming processors is that the schema has a large and changing list of elements. This makes it time consuming and resource intensive to implement an application that can decode the entire specification. To ensure that interoperability would not suffer, the OGC created a subset of the GML schema known as the Simple

```

<app:Forecast_GmlObs>
  <gml:validTime>
    <gml:TimeInstant>
      <gml:timePosition>2006-10-11T00:00:00
    </gml:timePosition>
    </gml:TimeInstant>
  </gml:validTime>
  <gml:target>
    <gml:Point srsName="NDFD_CRS.xml">
      <gml:pos>38.99 -77.99</gml:pos>
    </gml:Point>
  </gml:target>
  <gml:resultOf>
    <app:ForecastValue>
      <app:maximumTemperature uom="F">88.0
    </app:maximumTemperature>
    </app:ForecastValue>
  </gml:resultOf>
</app:Forecast_GmlObs>

```

Figure 5: DwGML feature based on the GML Observation element.

Feature Profile (OGC 2006). The Simple Feature Profile provides a restricted subset of GML geometric properties and establishes additional guidelines that keep the compliant GML simple to process.

5. OGC WFS

To share GML encoded data, the OGC developed the WFS (OGC 2005) specification which uses a client and server architecture (Fig. 6) to exchange geospatial feature data. The requests and responses occur over Hypertext Transfer Protocol (HTTP) and are encoded in GML. The WFS specification allows either the keyword-value pair messaging format of the HTTP-GET method or the XML messaging of the HTTP-POST method or both.

An HTTP-GET formatted message appends the request to the Uniform Resource Locator (URL) using a "?" which in turn is followed by an ampersand delimited list of keyword=value pairs. A sample HTTP-GET request follows (line breaks have been added to improve readability in this and subsequent examples):

```

http://host/wfs.cgi?
SERVICE=WFS&
REQUEST=GetCapabilities&

```

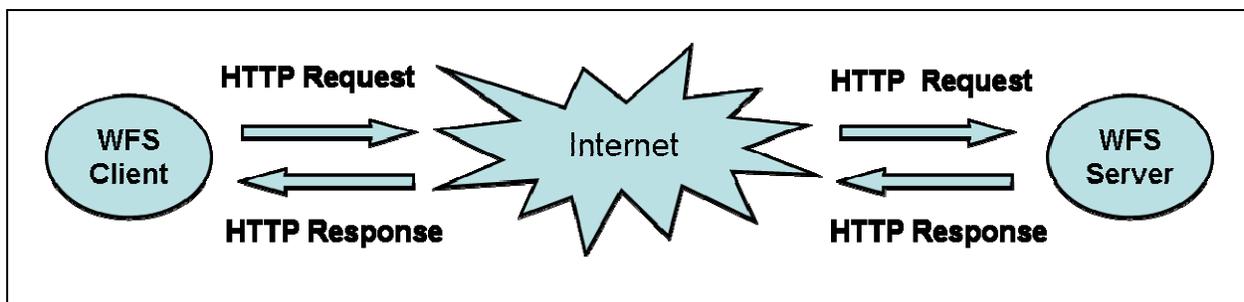


Figure 6: WFS client server architecture.

An HTTP-POST formatted message places the request in the POST document. The POST document contains a GML instance; a sample of which follows:

```
<?xml version="1.0" ?>
<GetCapabilities service="WFS" />
```

Using either the POST or GET method, the client and server accomplish the exchange of data using the GetCapabilities, DescribeFeatureType, and GetFeature requests/responses.

5.1 GetCapabilities

The GetCapabilities request/response allows the WFS client to determine what feature data are available, what operations are permitted on the features, and how to access the feature data. The GetCapabilities response contains this information broken into the seven sections described in Table 1.

5.2 DescribeFeatureType

The DescribeFeatureType request enables the WFS client to learn the structure of features supported by a particular WFS server. The response is a valid GML schema.

5.3 GetFeature

The GetFeature request enables the WFS client to retrieve desired feature types and to constrain the returned set of features both spatially and by weather element and time.

6. DwGML

Using GML (Section 4), the NWS developed dwGML to encode NDFD data. The NWS chose to use GML because of its commitment to standards-based data exchange. That commitment is expressed in the following portion of the NWS Strategic Plan:

"... expand the use of new technologies in data management and information systems, such as new internet-based standards and Geographic Information Systems ..."

With its GML foundation, dwGML helps the NWS to better serve the GIS user community and its role in protecting life and property and enhancing commerce.

Table 1. GetCapabilities section content.

Section	Content
Service Identification	Service type, version, and any fees or access constrains
Service Provider	Name and contact information for the service provider
Operations Metadata	Describes information about the service's GetCapabilities, DescribeFeatureType, and GetFeature operations such as access method and URL
Feature Type List	Name, location, and Spatial Reference System for each supported feature type
Serves GML Objects	List of objects that the service can retrieve by gml:id

Anticipating the diverse data encoding needs of the GIS community, the NWS developed dwGML to provide the three data models described in Sections 6.1 to 6.3. These encoding formats posses varying degrees of complexity and encoding efficiency.

6.1 Forecast_GmlsfPoint Data Model

As the simplest data model, the NWS developed the *Forecast_GmlsfPoint* element (Fig. 3) to reach the largest segment of the GIS community. Based on the OGC Simple Feature Profile, the *Forecast_GmlsfPoint* element encodes one or more NDFD forecast elements valid at a single grid point and time. Multiple *Forecast_GmlsfPoint* can be included in a single instance document by embedding them in a feature collection element (Fig. 7).

6.2 Forecast_GmlObs Data Model

The NWS implemented the *Forecast_GmlObs* element (Fig. 5) to leverage the good support for the GML Observation data type among GML processors. The GML Observation also had the desirable characteristic that it could represent the data as a GML Coverage which offers the chance for efficient data encoding. The *Forecast_GmlObs* element encodes the NDFD using the GML *validTime* element to define the data's valid time, the GML *target* element to specify where the data are valid, and the *resultOf* element to hold the weather element data.

6.3 NdfdTimeSeriesCoverage Data Model

The NWS developed the *NdfdTimeSeriesCoverage* element (Fig. 8) to be the most efficient at encoding large amounts of NDFD forecast data. However, it is also the most complicated and therefore most likely to be beyond the decoding capability of some GML processors. The *NdfdTimeSeriesCoverage* uses a GML Coverage to specify the data grid characteristics and then provide the data in a list. This approach eliminates the need to provide the location and valid time for each data item. For data transmissions involving large numbers of grid points, this can be a more efficient method for data encoding.

6.4 DwGML Spatial Reference System

As with all geospatial data sets, it is paramount that users understand the spatial reference system

```

<?xml version='1.0' ?>
<app:NdfdPointForecast>
  <gml:boundedBy>
    <gml:Envelope srsName="NDFD_Sphere">
      <gml:pos>-77.83 38.98</gml:pos>
      <gml:pos>-77.07 39.31</gml:pos>
    </gml:Envelope>
  </gml:boundedBy>
  <app:featureMember>
    <app:NDFD_Forecast>
      <gml:position>
        <gml:Point srsName="NDFD_Sphere">
          <gml:pos>-77.07 38.98</gml:pos>
        </gml:Point>
      </gml:position>
      <app:validTime>2005-08-23T20:00:00-04:00
      </app:validTime>
      <app:maximumTemperature uom="F">88.0
      </app:maximumTemperature>
      <app:minimumTemperature uom="F">48.0
      </app:minimumTemperature>
    </app:NDFD_Forecast>
  </app:featureMember>
  <app:featureMember>
    <app:NDFD_Forecast>
      <gml:position>
        <gml:Point srsName="NDFD_Sphere">
          <gml:pos>-77.83 39.31</gml:pos>
        </gml:Point>
      </gml:position>
      <app:validTime>2005-08-23T20:00:00-04:00
      </app:validTime>
      <app:maximumTemperature uom="F">85.0
      </app:maximumTemperature>
      <app:minimumTemperature uom="F">45.0
      </app:minimumTemperature>
    </app:NDFD_Forecast>
  </app:featureMember>
</app:NdfdPointForecast>

```

Figure 7: NdfdPointForecast Feature Collection.

applicable to dwGML encoded data. For dwGML and the NDFD data it encodes, the data are geo-located using latitude and longitude on a Lambert Conformal projection (Table 2). The projection is from a nonstandard geographic coordinate system (Table 3) based on a sphere. Together this information can be used to properly geo-locate the data.

7. NdfdWFS

The final component of the system allowing NWS customers to retrieve NDFD data is the ndfdWFS. The ndfdWFS servers NDFD data by providing user interfaces to 1) discover what data the service offers, 2) learn how the data are structured, and 3) retrieve selected portions of the database.

7.1 Learning About the ndfdWFS

The retrieval process begins with an initial GetCapabilities request. The GetCapabilities response allows the user to determine which dwGML types are available and what URL to use to access the service. The following GetCapabilities request can be used with any WFS client or web browser:

```

http://www.weather.gov/forecasts/xml/OGC_services/
ndfdOWSserver.php?
SERVICE=WFS&
REQUEST=GetCapabilities&
VERSION=1.1.0&

```

The ndfdWFS GetCapabilities response tells the user that it supports the HTTP-GET method and serves the Forecast_GmlsfPoint, Forecast_GmlfObs, and Ndfd-TimeSeriesCoverage features.

7.2 Accessing Feature Content Models

The second step in learning about the data offered by the ndfdWFS involves sending a

```

<app:NdfdTimeSeriesCoverage>
  <gml:rectifiedGridDomain>
    <gml:RectifiedGrid dimension="1"
    srsName="NDFD_CRS_Dictionary.xml">
      <gml:limits>
        <gml:GridEnvelope>
          <gml:low>322412</gml:low>
          <gml:high>322556</gml:high>
        </gml:GridEnvelope>
      </gml:limits>
      <gml:axisName>t</gml:axisName>
      <gml:origin>
        <gml:Point gml:id="timePoint1">
          <gml:pos>322412</gml:pos>
        </gml:Point>
      </gml:origin>
      <gml:offsetVector>24
      </gml:offsetVector>
    </gml:RectifiedGrid>
  </gml:rectifiedGridDomain>
  <gml:rangeSet>
    <gml:DataBlock>
      <gml:rangeParameters>
        <gml:CompositeValue>
          <gml:valueComponent>
            <app:MaximumTemperature uom="F">
              template
            </app:MaximumTemperature>
          </gml:valueComponent>
        </gml:CompositeValue>
      </gml:rangeParameters>
      <gml:tupleList>57 48 57 56 63 64 67
      </gml:tupleList>
    </gml:DataBlock>
  </gml:rangeSet>
</app:NdfdTimeSeriesCoverage>

```

Figure 8: DwGML feature based on the GML Coverage.

Table 2. DwGML Lambert Conformal Projection.

Parameter	Value
Central Meridian	-95.0
Standard Parallel	25.0
Latitude of Origin	25.00
False Easting	2,800.0 km
False Northing	270.0 km
Scale Factor	1.0

Table 3. DwGML Spatial Reference System.

Parameter	Value
Prime Meridian	Greenwich
Angular Unit	Degree
Shape of Earth	Sphere
Radius of Earth	6371.2 km

DescribeFeatureType request. Like the GetCapabilities request, the DescribeFeatureType request will likely be submitted once. The following DescribeFeatureType request will return the schema for the Forecast_GmlsfPoint feature:

```
http://www.weather.gov/forecasts/xml/OGC_services/
ndfdOWSserver.php?
SERVICE=WFS&
REQUEST=DescribeFeatureType&
VERSION=1.1.0&
TYPENAME=Forecast_GmlsfPointType&
```

7.3 Retrieving Feature Data

The final step and one that may be repeated multiple times involves sending a GetFeature request to the ndfdWFS. The ndfdWFS requires users to provide the input variables listed in Table 4 in their GetFeature request. A sample GetFeature request follows:

```
http://www.weather.gov/forecasts/xml/OGC_services/
ndfdOWSserver.php?
SERVICE=WFS&
REQUEST=GetFeature&
VERSION=1.1.0&
LATLONLIST=38.99^77.99&
TIME=2006-10-12T00:00:00&
ELEMENTS=maxt&
TYPENAME=Forecast_GmlsfPointType
```

Table 4. NdfdWFS input requirements.

Variable	Description	Example
latlonlist	A comma delimited list of latitude^longitude pairs corresponding to the desired NDFD grid points (see capabilities document for grid locations)	38.98^77.07,19.69^155.08
time	The Coordinated Universal Time time for which data are desired	2006-10-12T00:00:00
elements	A comma delimited list of desired NDFD weather elements	maxt,mint,wx

8. SUMMARY

The NWS has deployed an experimental OGC-compliant WFS to enhance its ability to share NDFD data with the GIS community. The WFS server can disseminate NDFD data using three GML data models. Each model offers varying degrees of complexity and encoding efficiency. During the service's experimental phase, the NWS will assess which data model is most popular with customers and partners. The NWS NDFD WFS represents another step down the road to a future where digital services play a key role in meeting customer needs. These digital services, including the NDFD WFS, are helpful in meeting society's increasing need for weather, water, and climate information.

9. ACKNOWLEDGEMENTS

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