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Improved Capacity Utilization by Integrating Real-time Sea Bottom Temperature Data

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PSIG Pipeline Simulation Interest Group

ABSTRACT

The temperature of the medium surrounding a pipeline significantly affects the pipeline's hydraulic capacity. However, often the ambient temperatures are approximated by statistical averages of historical data, hard-coded in a model file. Such data may at times deviate from the true temperatures by a few degrees Celsius. Especially for on-line systems the lack of up-to-date ambient temperature data may limit maximum utilization of the existing pipeline capacity.

Integration of up-to-date ambient temperatures enable Gassco, and other pipeline operators, to improve the usage of the available network capacity and will allow for better planning of the day-to-day capacity that can be offered for sale. This paper presents how up-to-date sea bottom temperatures were integrated in Gassco's Pipeline Modeling System. The increased modeling accuracy enabled Gassco to commit an additional 7 million Sm3/d gas for any particular cold day.

THE IMPORTANCE OF UP-TO-DATE AMBIENT TEMPERATURE DATA

Gassco supplies Norwegian gas to the European market through more than 4,850 miles (7,800 km) of large diameter high-pressure sub-sea pipelines. Contractual deliveries in 2005 amounted to nearly 84 billion Sm3. During winter, the request for gas exceeds the current estimated transport capacity of the pipelines. Consequently, Gassco constantly evaluates the accuracy of the margins applied when calculating the hydraulic capacity of the pipelines. Such studies concern in-situ capacity tests of the pipelines, evaluation of the theoretical aspects of flow models (such as the friction factor used in the pipeline models, see Langelandsvik et al., 2005) and improvement of data sources that are used as input in the pipeline models.

Currently, capacity estimates are typically based on traditional on-line data from the transport network (pipeline inlet/outlet pressure, flow rates, gas temperature and composition) in combination with conservative estimates of the historical ambient temperatures. A preliminary study showed that when actual day-to-day ambient temperatures were integrated into the Pipeline Modeling System (PMS), Gassco would be able to more accurately predict and use the available transport capacity in its gas pipeline system.

For example, Figure 1 shows the hydraulic capacity that is offered for sale (green line) for a particular pipeline. This capacity is an estimate based on a conservative scenario, i.e., high ambient temperatures based on statistical historical data (red line) combined with an additional margin. However, in case up-to-date daily temperature data show that the ambient temperature in fact is lower, the extra margin in the pipeline capacity can be utilized. In this example, nearly 3% extra gas can be transported and sold on a cold day.
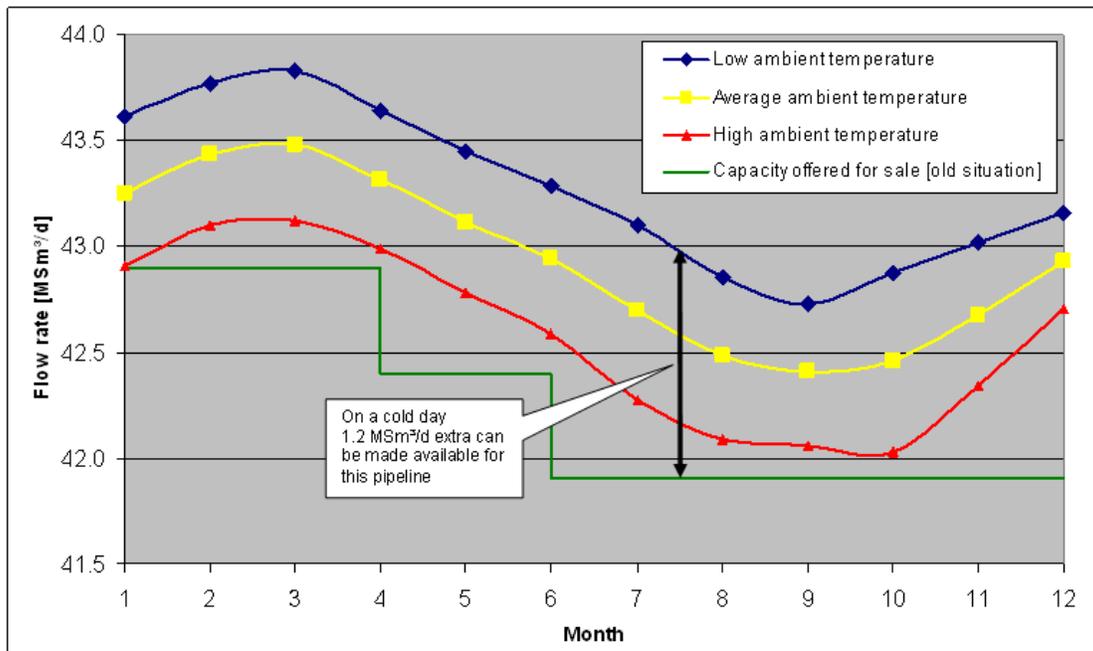
Figure 1 – Example hydraulic capacities for a pipeline.

Improved accuracy in the ambient temperature data thus makes it possible to increase pipeline capacity and to better meet the increased demand for gas during the winter season. For instance, for each particular cold winter day, the increased modeling accuracy makes it possible for Gassco to commit an additional 7 million Sm3 gas per day. Since Gassco's PMS did not allow for integration of external sources for ambient temperature data it was necessary to modify the existing PMS to incorporate this functionality.

The real-time ambient data are based on a standard format for temperature reporting and can therefore be used for any pipeline model, seabed or land, and independent of geographical location, as long as climatological forecasts are available. The up-to-date ambient temperature data allows the ambient temperature to be specified over most, if not all, of the pipeline. Exceptions are generally at or close to an offshore platform or riser and tunnel sections. For the Gassco network, with predominantly sub-sea pipelines, the focus has been on sea floor ambient temperatures and therefore exception is currently also taken for the short landfall sections. For these sections the ambient temperature is derived from monthly average tables. In all cases, the change of ambient temperature with respect to time can be determined.

The ambient temperature profile along the pipeline varies considerably with the season and the location on the pipe, see Figure 2. Notice that at greater water depths (low KP) there is less seasonal variation than at shallow locations. The daily changes, particularly at the shallower depths, correspond to the prevailing weather conditions and are reflected in the up-to-date ambient temperature data sets.   It should also be noted that the changes for the different pipeline locations are not in phase with one another; see Figure 3.
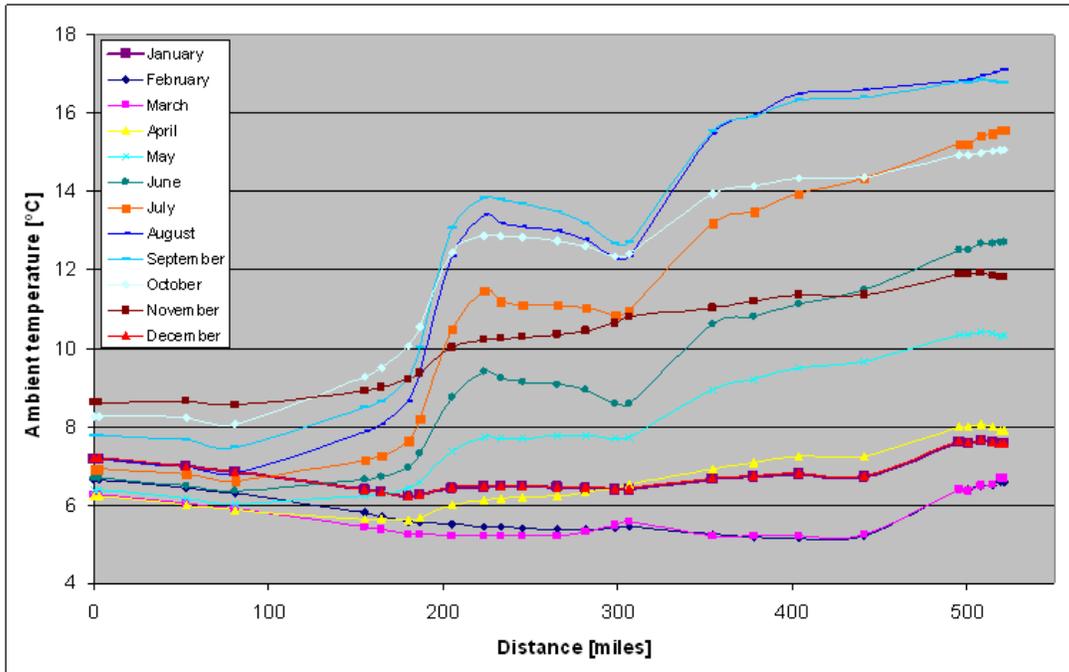
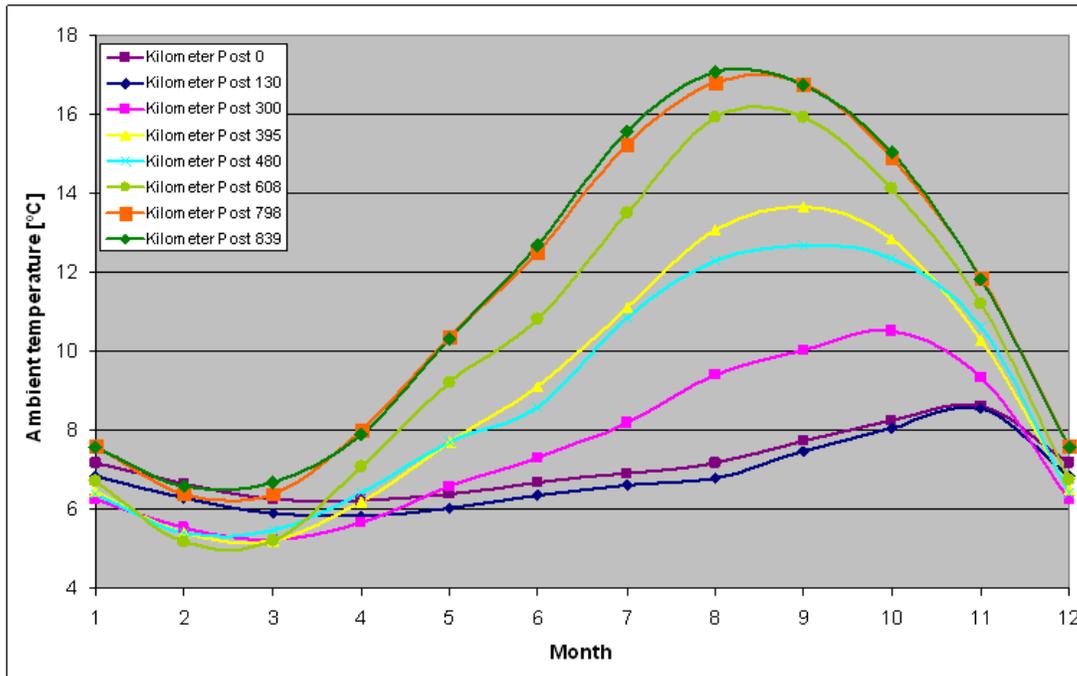Figure 2 – Monthly Average Profiles.

Figure 3 – Seasonal Changes.

USE OF SEA TEMPERATURE DATA

<u>Numerical ocean models</u>

Near real time seawater temperatures along pipelines may be obtained from the use of numerical ocean models. A total of more than 50 ocean circulation models are presented on the Internet. Some of these models are freely available, some are freely available for research purposes only and some are not available at all (or available at a cost). Some model operators (notably meteorological institutes) make data from their model runs commercially available. Typically the data are provided as now-casts and up to five-day forecasts.

Most numerical ocean models are only approximations to the basic equations describing the dynamics and thermodynamics of the oceans. Also, the initial and boundary conditions used when running these models are only partly known. Consequently, the results from these models are only approximations. One way to improve the results from the models is to use a technique called data assimilation whereby results from measurements of the ocean are assimilated or blended with the model results. In this way the results of the computations are forced towards the observations.

Generally the quality of the results from a numerical model depends on the quality of the input data and the quality of the numerical model. Our interest is primarily on sea bottom temperature. It seems especially important that the model is initialized using proper sea temperature and salinity data. The uncertainties associated with using climatologically averaged data, therefore, need to be examined and quantified.

Probably the most important factor regarding the quality of the sea bottom temperatures depends on whether the numerical model uses assimilated data or not. Most likely, the data obtained from numerical models that do not support data assimilation will be of only marginally better quality than the climatologically averaged data.

Of the operational numerical models that cover the North Sea only the UK Met Office Shelf-seas model was considered to provide sufficiently accurate sea bottom temperature data for Gassco's needs. The Shelf-seas model has not implemented a data assimilation scheme, but both the boundary conditions and the forcing fluxes (from atmospheric models) use assimilated data. Other available models do not make use of assimilated data.

<u>Validation of Shelf-seas model</u>

The quality of the Shelf-seas model is explored by comparing results from measurements during the period 2002 – 2003 with Shelf-seas model data and climatological averaged data. Comparisons for various data groups are made according to the following procedure:

1. Select data group based on area or depth criteria
2. Compute differences ($T_{model} - T_{measured}$) between model and measured data and difference ($T_{climatological} - T_{measured}$) between climatological and measured data

3. Determine minimum (Min) and maximum (Max) differences
4. Compute mean (Bias) and standard deviation (Std) from differences

The results obtained are presented in Table 1.

Description	Number of data points	$T_{model} - T_{measured}$			$T_{climatological} - T_{measured}$		
		Min/Max	Bias	Std	Min/max	Bias	Std
Southern North Sea	572	-5.9 / 4.5	0.17	1.33	-5.9 /5.7	-1.21	1.72
Northern North Sea	1704	-4.0 / 2.6	-0.37	0.92	-4.8 / 2.6	-0.62	0.72
Area 56° – 62° N, 0° – 4° E	849	-3.4 / 2.5	-0.40	0.92	-2.3 / 2.6	-0.61	0.66
Depth < 50 m	97	-3.4 / 2.2	-0.01	0.78	-2.9 / 2.6	-0.58	0.83
Depth < 100 m	861	-4.0 /2.5	-0.23	0.80	-4.7 / 2.6	-0.61	0.84
Depth > 200 m	527	-3.8 / 2.5	-0.63	0.84	-4.8 /2.6	-0.67	0.64
Norwegian Trench, depth > 200 m	378	-2.8 / 1.2	-0.61	0.63	-2.3 / 1.7	-0.62	0.56

Table 1 – Summary of comparison of measured data versus model data and climatologically averaged data. All data values are given in °C.

The total error of the Shelf-seas and climatological data relative to the measured data is defined as:

$$Total\ error = \sqrt{(Bias)^2 + (Std)^2}$$

The total error, computed from the bias and standard deviation in Table 1, are given in Table 2.

Description	Shelf-seas model Total error	Climatological data Total error	Model – Climate Error difference
Southern North Sea	1.34	2.10	-0.76
Northern North Sea	0.99	0.95	0.04
Area 56° – 62° N, 0° – 4° E	1.00	0.90	0.10
Depth < 50 m	0.78	1.01	-0.23
Depth < 100 m	0.83	1.04	-0.21
Depth > 200 m	1.05	0.93	0.12
Norwegian Trench, depth > 200 m	0.88	0.84	0.04

Table 2 – Computed total error of Shelf–seas and climatological data versus measured data. All data values are given in °C.

The total error is a measure of the accuracy of Shelf-seas model and the climatological data. It follows from Table 2 that in the southern North Sea the overall accuracy of the Shelf-seas model data is about 0.8 °C better than that of the climatological data. This is the area where the temperature fluctuations are the largest. At depths less than 100 m in the northern North Sea the model performs slightly better than the climatological data, but is about similar to the climatological data at greater depths.

Comparison of measured and model data is shown in Figure 4 and 5. About 90 - 95 % of the Shelf-seas model data are found to be within ±2 °C of the measured sea bottom temperature values. In the southern North Sea, where the temperature fluctuations are the largest, about 8 % of the model data are outside the ±2 °C range. Of the climatological data (in the southern North Sea) about 30 % are found to be outside this range.
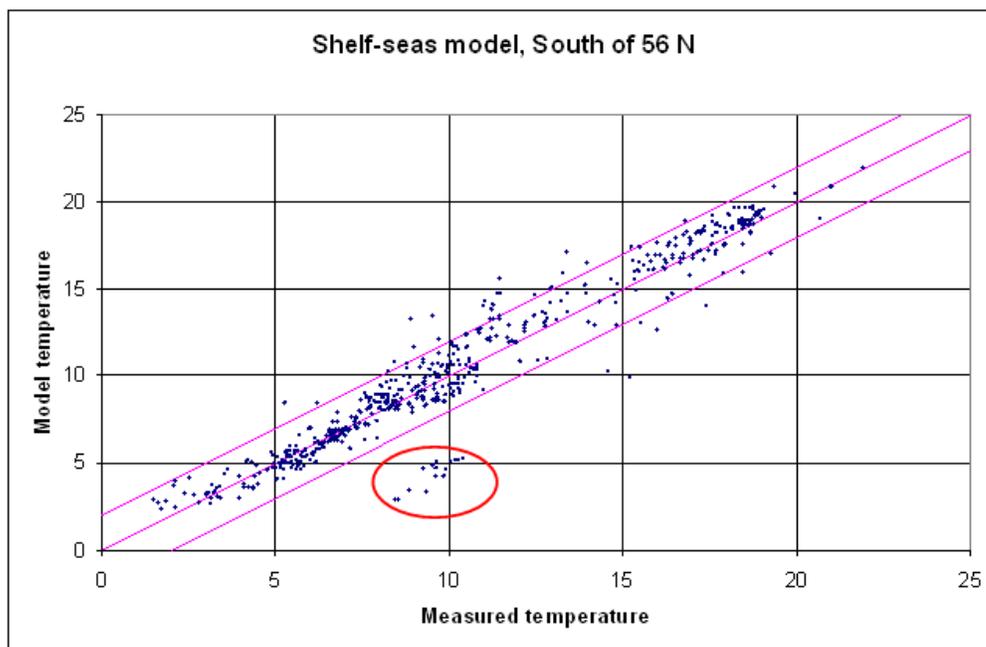

Figure 4 – Comparison of Shelf-seas model and measured sea bottom temperature data in the southern North Sea. The pink lines represent a temperature difference of ±2 °C. The data within the oval are from the German Bight during 6 – 8 January 2003.
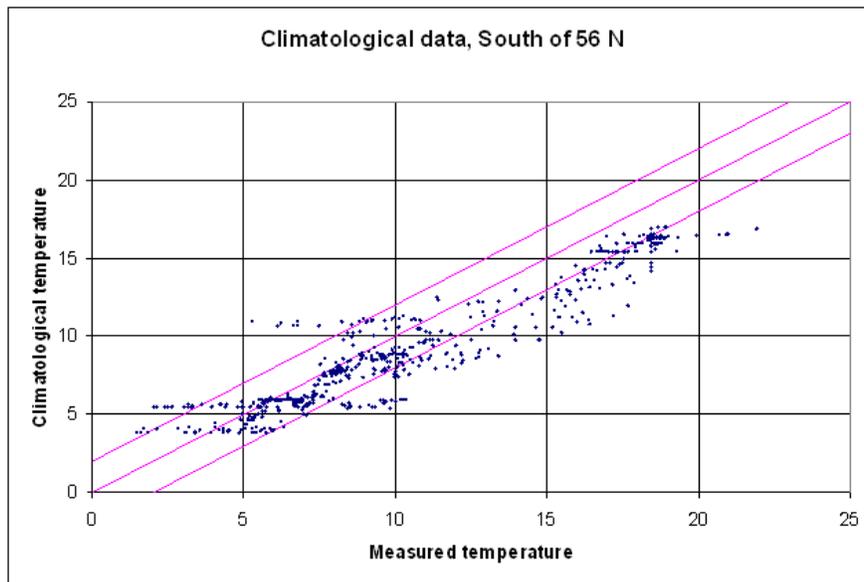
Figure 5 – Comparison of climatological and measured sea bottom temperature data in the southern North Sea. The pink lines represent a temperature difference of ±2 °C.

The main conclusion reached from the data comparisons made may be summarized as follows:

- The average total error (difference) between model and measured data is slightly above 1.0 °C.
- The Shelf-seas model performs best in the southern North Sea where the water depths are less than 50 m and the temperature fluctuations are the largest.
- The accuracy of the Shelf-seas model data in the southern North Sea (south of 56° N) is about 0.8 °C better than the climatological data.
- At depths less than 100 m in the northern North Sea the shelf-seas model performed slightly (about 0.2 °C) better than the climatological data.
- At greater depths the accuracy of the model data is similar to the climatological data.

Based on these conclusions it was decided that integrating ambient temperature data predicted by the shelf-seas model into the PMS would be a major improvement.

SHELF SEAS MODEL

Model description

The model used to generate the ambient temperature data is the Met Office Shelf-seas model, and in particular the Atlantic Margin Model (AMM) operational implementation of ~7.5 miles resolution (12 km) Proudman Oceanographic Laboratory Coastal Ocean Modeling System (POLCOMS; Holt et al., 2003).

A detailed description of the model can be found in Holt and James (2001), In brief, it is a 3D baroclinic finite difference model which uses an Arakawa-B grid in the horizontal and includes a sophisticated advection scheme, the "Piecewise Parabolic Method" (PPM) (James, 1996), making it well suited to the modeling of

horizontal density variations. The model has 34 hybrid sigma levels in the vertical, whereby in depths less than 150 m the vertical spacing is equal through the water column but in greater depths the vertical levels become increasingly focused in the surface waters. Pressure gradient calculations are made by interpolation onto horizontal planes and the equation of state for sea water includes a term for the variation of compressibility with temperature and salinity. The equations of motion are solved using the Buossinesq and hydrostatic approximations and there is mode splitting between the barotropic and baroclinic parts. Turbulence is modeled using the Mellor-Yamada-Galperin level 2.5 closure scheme with an algebraic mixing length (Mellor and Yamada, 1974; Galperin et al., 1988). A Craig and Banner, 1994 scheme is used to implicitly model the affects of breaking waves on the turbulence. Horizontal diffusion is explicitly modeled.

POLCOMS has been shown to successfully simulate the region of interest at a variety of scales; numerous descriptions of the POLCOMS modeling system as applied within the North-East Atlantic region can be found in the literature (e.g. Proctor and James, 1996; Holt et al., 2001; Siddorn et al., 2003).

The AMM is one-way nested within the Met Office operational Forecasting Ocean Assimilation Model (FOAM) 1/3 degree resolution deep ocean model (Bell et al., 2003). Temperature, salinity, barotropic velocity and sea-surface height (6-hourly fields in the case of FOAM, daily temperature and salinity fields and hourly velocity and elevation fields in the case of AMM) are used in the nesting process. Surface forcing is provided from the Met Office's Global Numerical Weather Prediction (NWP) model (at approximately 22.3 miles resolution) via 6-hourly average fields of penetrating and non-penetrating heat fluxes (corrected for intra-model SST differences by a flux correction term, after Haney, 1971), moisture fluxes, and hourly instantaneous fields of wind speed and surface pressure.

The FOAM and NWP models include operational data assimilation systems that allow the full model hierarchy to benefit from the best set of near-real time observations possible.

Area covered, update frequency
The model domain used in this version of the Shelf-seas model extends from 40oN 20oW to 65oN 13oE (Figure 6).
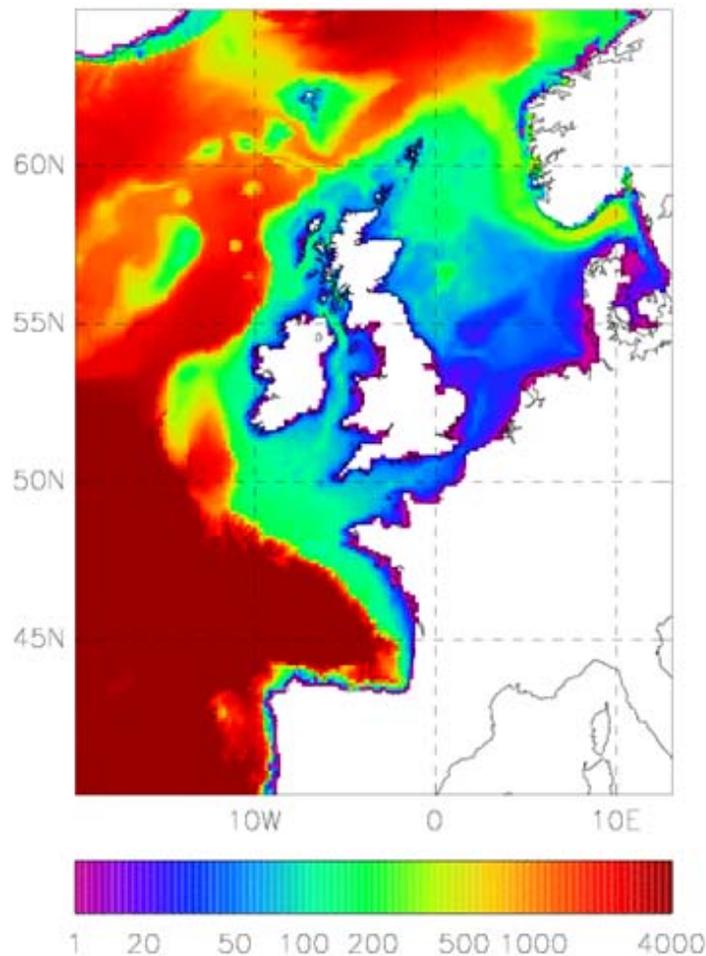
Figure 6 – The Met Office's Atlantic Margin Model domain. Shown is the model bathymetry (depth in meters).

The models are run daily with a five day forecast to a fixed schedule with operator supervision in the suite of forecast models at the Met Office Output. Products are available by a specified time each day. The safeguards built into this system ensure that the data is produced in a fully robust and timely manner. Hourly and daily mean fields are available for temperature, currents and salinity (daily mean only) on a daily basis.

Strengths and weaknesses

A series of upgrades to this modeling system are presently being implemented to improve certain aspects of its skill. Detailed validation work has shown that the temperature in deep waters off the shelf break is too low in the model version detailed here. This has been ascribed to a combination of over active deep convection in part due to the convective scheme used in the model and in part due to problems in obtaining a well prescribed shelf slope current. Both these deficiencies have been overcome and will be introduced as part of a model upgrade planned for later this year, validation of which is showing significantly improved skill in the deep water areas.

Clearly also with models of this nature horizontal resolution becomes an issue as you move on to the shelf. The Atlantic Margin model at ~7.5 miles is not eddy resolving (or indeed permitting) so much of the mesoscale behavior in the North Sea is not possible within this system. Higher resolution models are being run at the Met Office based on the same POLCOMS model, with the Medium-Resolution Continental Shelf model (Siddorn et al., in press) of the North-West European continental shelf at ~4.3 miles and the Irish Sea model at ~1.1 miles also being run within this domain.

DATA FORMATS AND PROCESSING

To achieve a robust system that allows for ambient temperature validation and fall back functionality the PMS implementation was developed to take advantage of two separate grid formats:

1. A format containing up-to-day daily ambient temperature forecasts, referred to as "daily grid files". This format is used for Online modeling and for re-running particular events offline. The data in this format originate from the Shelf-seas model operated by the Met Office and is refreshed every day.

2. A format containing historical data, referred to as "monthly grid files". Two files of this format are in use: one file for average ambient temperatures and one file for standard deviations in the ambient temperatures. The data in these two files are currently based on the data compiled in the World Ocean Atlas 2001. These files have a higher data resolution than the daily grid files. Because they contains statistical averages and have a higher data resolution, these files are used for the following purposes:

   - Medium- and short-term booking simulations
   - Reference ambient temperatures for data validation each time a daily grid file is received.
   - Provide fall back ambient-temperatures for on-line simulations in case the daily forecasts are not available for whatever reason.

An additional advantage of these monthly grid files is that the data has a higher spatial resolution than the climatological data that was previously used and that the data is more recent, thus including durable changes in sea water temperature. All ambient temperatures in the grid files are given for the seabed/ground level. In addition to the two grid-based formats it is possible to assign ambient temperatures and their standard deviations in a tabular form for example for risers, tunnels or areas not covered by the grid files.

Format of daily grid files

The daily grid files are the principal source of ambient temperature data for the on-line models. Every day, these files are retrieved from the Met Office server via automated file transfer (ftp). The grid range reaches from lat 48.83°N to 65.00 °N and long 348.00°E to 14.18°E, with resolution of 1/9° latitude and 1/6° longitude; (~7.5 miles).

The data files received from the Met Office are in GRIB (GRIdded Binary) format; a standardized format used to store binary meteorological data. A simple computer program, TrfCnt (Transfer Control), is used to decode

the files received, perform initial data control, create data files for use in Gassco's Pipeline Modeling System and to create files for displaying temperature contour maps.

The initial data control checks if the data are read correctly from file and if the change in temperature from one day to the next is within limits; currently set to 3.0 ºC. On output from the TrfCnt program the daily grid files cover the area from lat 50.04ºN to 64.89ºN and long 357.01ºE to 9.93ºE. After pre-processing each daily grid file starts with a number of header lines, identifying date and time of placement on the Met Office server and of conversion by Gassco. Moreover, the upper and lower bounds for the data point locations are given together with the number of data points in each direction.

The daily file currently consists of five records, containing yesterday's ambient temperatures, ambient temperature forecast for today and the forecast for the next three days, respectively. Each record starts with four text lines (sub-header). After this subheader the ambient temperatures are listed in a grid format, with the corner points and sizes as defined in the file header. Data points for which the model does not provide temperatures are assigned the dummy value -99.99. Gassco's PMS has provisions in place that allow extending the daily grid files with additional records containing additional forecast temperatures.

Format of monthly grid files

The data contained in the monthly grid files is based on the historical averages from the World Ocean Atlas 2001 for the middle of each month. As an example for April, this will be midnight between April 15 and April 16. For other simulation dates and times, the ambient temperatures and standard deviations are interpolated accordingly.

The World Ocean Atlas 2001 data base contains monthly global sea temperature statistics given by 1º × 1º squares at 24 depths. Data files for use in Gassco's PMS are obtained from spatial interpolation of these data. The data files used in the PMS cover the area latitude 50º to 66ºN and longitude 357ºE to 10ºE with a resolution of 0.083º × 0.083º.

Two monthly files are in use, containing the historical average ambient temperatures and standard deviation in the averages, respectively. Each file consists of 12 records, one record for each month of the year. Again, data points for which the model does not provide temperatures are assigned the dummy value -99.99. As previously noted, the temperature variations depend on water depth. Such variations are reflected in the standard deviation tables – small standard deviations are usually observed at the larger depths while larger deviations accompany shallower depths.

IMPLEMENTATION IN PMS

Implementation in PMS

Gassco's PMS was adapted to process the incoming data and assign near real-time sea bottom temperatures to the appropriate nodes in the pipeline models. Processing can be broken into the following steps:

- Geographical coordinates link the model to the grid file and extract ambient temperatures from a grid data matrix as a function of location, date and time of day. The temperatures in the grid files are arranged according to latitude and longitude coordinates.
- Grid data are interpolated based on geographical coordinates assigned to pipeline nodes in the model files.
- Ambient temperatures at the model's calculation points between nodes are determined by linear interpolation based on the pipeline length between nodes.
- Data validation
- On-line temperature tuning
- On-line and off-line temperature tuning using standard deviations
- Fall back mechanisms: fallback routines are in place for those cases in which no valid updated daily grid data are available. The fall back should occur according to the following hierarchy: Daily grid, Monthly grid, Monthly average pipe segment tables, and User-assigned time invariant temperature.

Data extraction and interpolation

As the temperature grid data are defined at geographical locations by latitude and longitude, the pipeline model requires that such data are used to define locations within the model. For ease the pipeline model nodes are defined by latitude and longitude. These are used to identify the grid cell containing the model node. Grid data are then obtained for the current model time by simple linear interpolation. Monthly grid data are assumed to apply at mid-month.

Where a fully validated cell is present, the ambient temperature for the model node is determined by linear interpolation within the cell. For cells where one or more of the cell vertices contains an invalid temperature (-99.99) special routines are in place. Should a cell contain no valid ambient temperatures, the fall-back routine is invoked.

Given the ambient temperature at the model's nodes, the values at the calculation points are determined by linear interpolation along the pipeline segment length. Errors resulting from long pipe segments could be mitigated by providing the latitude and longitude of the model's calculation points or by dividing long pipe segments into smaller sections such that the number of nodes is increased – the geographical location of each node must be provided. However, the grid resolution (~7.5 miles) must be noted.

Data Validation

Before any new ambient temperature grid data are used by the model, they must pass a series of validation tests. These tests can result in the rejection of the data received. The tests applied are:

- Consistency across the days in the Daily grid file or across the months in the Monthly grid file.
- Validity of data within a cell.

- Data timestamps are consistent within the Daily grid file.
- Data timestamps are consistent with data generation times.
- Differences between Daily and Monthly average temperatures are checked against standard deviations.
- Predicted temperature changes between yesterday and today, and today and tomorrow are checked against standard deviations.

In general, consistency failures result in the rejection of the data, standard deviation checks are reported to allow manual verification of the data. Validation is only performed on the grid area containing the pipeline models that use the data.

Temperature Tuning in the On-line Model

The ambient temperature files provide only predictions of the expected sea bottom temperatures. The operating pipeline provides measurements of actual gas temperature, but in general only at the pipeline entry and exit. A tuning algorithm is needed to combine the measurements with the predicted changes and provide a more accurate model. The tuning algorithm is outlined in the following steps:

- Calculate the error in the measured gas temperature at the instrument location(s) and apply the required filtering.
- Using the standard deviation profile for the ambient temperatures, calculate the ambient temperature increment due to the error in the measured fluid temperature at each node/calculation point. The incremental profile is applied as a ratio of the standard deviation at the calculation location to that at the instrument location. Thus, a ratio of 1 is applied at the instrument location with all others being in proportion.
- A user-specified weighting shall then be applied to give the tuning increment due to measurement error, $\Delta T_{(tuning)}$.
- From the supplied temperature grid, calculate the increment in the ambient temperature at each calculation point for the current time-step, $\Delta T_{(grid)}$.

The actual increment in ambient temperature, $\Delta T_{(amb)}$, to be applied to the pipeline at each calculation point is then given by:

$$\Delta T_{(amb)} = \Delta T_{(tuning)} + \Delta T_{(grid)}$$

The "tuning" and "grid" increments may be of opposite sign and the applied increment may change sign along the pipeline, depending on the relative magnitudes of the local values. Thus, seasonal and daily changes are followed.

Temperature Adjustments in the Offline Model

Clearly in the offline, there are no direct temperature measurements to balance the model against. The offline model may use either daily grid data (current daily data or a previously archived file) or monthly average grid

data, or a combination of the two. The selected data provide the base ambient temperature profile for the date and time of the modeling. The user may then apply variations to the profile using the standard deviation tables. Tuning is accomplished by the application of a factor to the standard deviation profile. The resulting profile of ambient temperature increments is then applied to the base profile.

RESULTS

Although the main business driver for integrating real-time ambient temperature data into the PMS was the need for increased day-to-day capacity utilization, this project has generated a range of significant additional benefits.

The areas of use and benefits of this project are summarized below:

- It was shown that the shelf-seas data matches the actual ambient temperatures better than averages based on climatological data. Having this more accurate data available on a day-to-day basis allows Gassco to better utilize the day-to-day capacity of its transport network. Short-term booking can potentially be increased by approximately 7 MSm3/d for the Gassco operated pipeline network.

- Better ambient temperature modeling leads to a better modeling of the gas velocities in the pipeline. Consequently, the uncertainties in the prediction of the estimated time of arrival (ETA) for quality fronts and scrapers/pigs have been reduced. This allows for better predictions and planning of mixing requirements to reduce "off-spec" gas. Ultimately, this reduces penalties due to "off-spec" gas.

- Before integrating the external real-time data source, the ambient temperature was assigned to a pipeline leg at one particular point, typically halfway, and the same ambient temperature was used for the entire length of that particular pipeline leg. Moreover, at the junction of two pipeline legs, small discontinuities in ambient temperature would exist. In the new approach, the ambient temperature is retrieved from the grid file for each begin and end node of a pipeline leg, and intermediate temperatures are calculated from linear interpolation between the two nodes. This leads to a smoother and more realistic modeling. Moreover, this removes temperature discontinuities at junctions. Future work can extend this functionality and ambient temperatures can be extracted and assigned to the pipeline model with the spacing as used in the temperature grids, (~ 7.5 miles). As some of the pipeline models used by Gassco currently have legs exceeding 60 miles in length it is expected that this will lead to further improvements in the capacity estimations and ETA predictions.

- Both the shelf-seas model and the pipeline models themselves are only approximations of the actual transport network. Deviations between measured and model data therefore are to be expected, and tuning algorithms are in place to provide more accurate on-line modeling. Previously, in the case where the model predicts a too high pipeline outlet temperature, the ambient temperature was adjusted downwards along the entire profile by a constant. However, Figure 8 shows that when a constant factor is used, the ambient temperature variations in deep water (in the beginning of the

pipeline) are overestimated while variations at shallow water depths (the end of the pipeline) are underestimated. This would result in an incorrect model of the gas velocity profile in the pipeline.
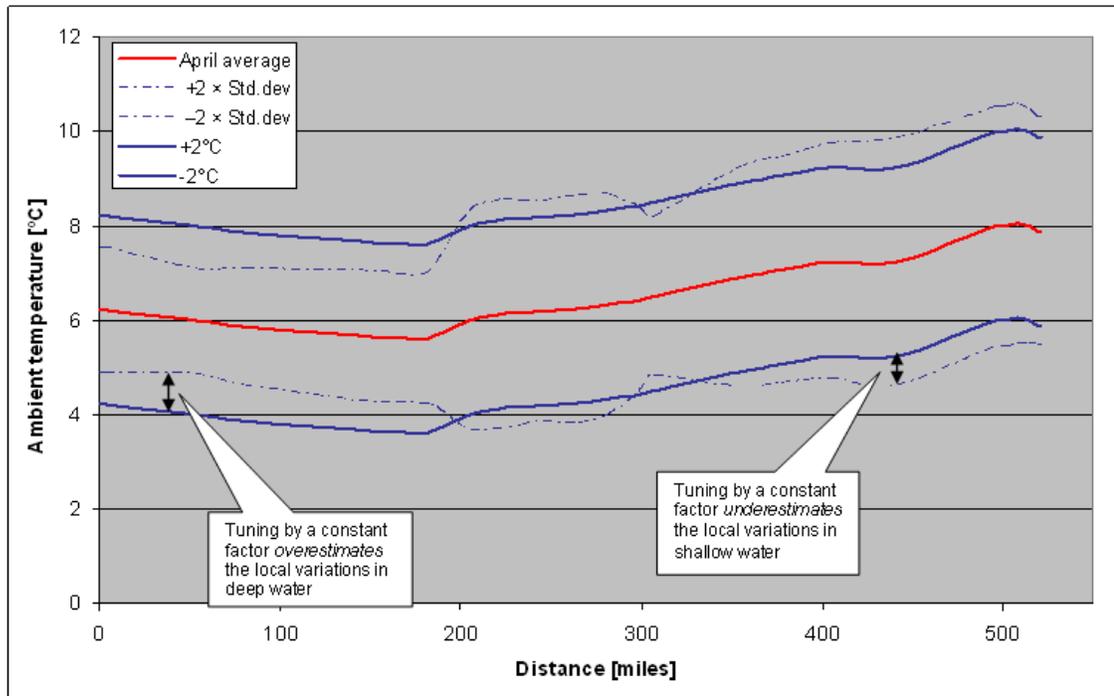

Figure 8 – Tuning mechanisms on a pipeline profile.

- Simultaneous with the implementation of reading ambient temperature grid files, the possibility for reading grid files with standard deviation has been implemented. By using the local standard deviations from the grid file a more accurate ambient temperature profile is achieved, again leading to a more accurate model.

- The full integration of ambient temperature grids and their standard deviations not only allows Gassco to accurately calculate arrival temperatures but also the probability of certain arrival temperatures. This feature is extremely convenient during design studies of new downstream processing plants. In such studies it may be necessary to assess the range of pipeline outlet temperatures, often with a certain probability. For example, cooling or heating duty at a processing plant may need to be specified with a given regularity.

- Furthermore, the full integration of ambient temperature grids facilitates design studies of new pipelines. As the external ambient temperature data sources are fully integrated in the pipeline modeling system, the user only needs to define the (approximate) lat/long coordinates for a new pipeline, and the appropriate ambient temperatures are automatically extracted from the temperature grids. Moreover, these temperature data will be consistent with all other pipeline models.

- The ambient temperature data contained in the monthly grids has a higher resolution and is more recent than used previously. Moreover, the monthly grid files provide a consistent, uniform and traceable data source for all pipeline models operated by Gassco. Based on this higher quality data, Gassco has been able to provide more accurate medium- and long-term assessment of the pipelines.

- Currently approximately four years worth of files with daily ambient temperature data are available. The newly developed modeling system also offers the opportunity to re-read these previous daily grid files for off-line simulations in order to re-simulate particular events in the transportation network. Based on these data it is possible to further tune the models with respect to, for instance, ETA of quality fronts and scrapers.

- Data from previous capacity tests were analyzed again using the more accurate daily temperatures instead of the historical average temperatures. As a result, the base capacities for medium and long-term for three of the pipelines were adjusted upwards by a combined 0.82 MSm3/d. It should be noted that this is a structural adjustment of the day-to-day capacity estimate and that additional transport opportunities for cold days are not even included in this.

AUTHORS

Patrick Hendriks holds an engineering degree and a PhD. in Applied Physics. He started his professional career in Medusa Explorations where he worked on the development of well-logging tools and multiphase meters. After working three years as a senior engineer employed by Polytec R&D Foundation at Gassco's Transport Division he is now fully employed by Gassco AS.

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