Technical report; TR-161
Technisch rapport; TR-161

Ministerie van Verkeer en Waterstaat

The ASGASEX experiment

W.A. Oost

De Bilt, 1994

the
ASGASEX
experiment

THE ASGASEX EXPERIMENT[1]

W.A.Oost
Royal Netherlands Meteorological Institute (KNMI), de Bilt, the Netherlands

Background

The exchange of the most important greenhouse gas, CO_2, between sea and atmosphere is of prime importance for climate change, due to the large area of the globe covered with oceans.

A problem in this field of research is the large discrepancy between the results of the more traditional methods used to measure this flux and those from a newcomer in the field, the eddy-correlation method. The discrepancy cannot be dismissed as just a pity for the eddy-correlation (e-c) method, because in the e-c technique fluxes are directly measured, whereas all other methods start from the measurement of concentrations, from which the transport is calculated using transport coefficients determined for other gases, by other means or under different circumstances. On the other hand: if the e-c results for the CO_2 flux at the water surface obtained so far would be true on a global scale, it would lead to conflicts with well established parts of the carbon budget.

The solution of the problem requires a thorough study of the circumstances and parameters affecting the CO_2 transport between air and sea. One of the very few places in the world (perhaps the only one) where the experimental part of such a study can be performed, is Meetpost Noordwijk, the research platform of Rijkswaterstaat off the Dutch coast (fig.1). This unique position is caused by the combination of its steadiness, its well-known flow distortion characteristics (a prerequisite for the e-c method), that it has sufficient space for the simultaneous measurement of a large number of parameters and that it is sufficiently far (9 km) from land.

History

CO_2 fluxes were first measured at Meetpost Noordwijk in 1990, during the VIERS-1 experiment, which was also supported by NOP. Attempts to measure these fluxes were made at that time by a Canadian group from BIO (the Bedford Institute of Oceanography) and a Dutch one, from KNMI. The KNMI sensor failed, due to a technical problem that became clear only after the experiment. The BIO group, however, indeed got values for the CO_2 flux (the first ever obtained with the e-c method in open sea), but a comparison with other results was not possible, because the CO_2 content of the sea water turned out to show unexpectedly large fluctuations. Comparison with flux measurements was now impossible, because the sea water samples were not taken simultaneously with the flux runs.

---

[1]Report as required by the conditions for financial support of the Netherlands National Research Program on Global Air Pollution and Climate Change (NOP)

Fig. 1. Research station "Meetpost Noordwijk"

The BIO results and the importance of the problem for climate change caused us to arrange another experiment for the measurement, with as many methods as possible of the CO_2 flux and the parameters that could affect it. This became the Air Sea GAS EXchange experiment, ASGASEX.

Course of events.

In the initial plans ten research groups were involved in ASGASEX. Two of these finally did not participate. The remaining eight groups, the way they will be indicated and their full name as well as the names of their ASGASEX participants, are given in annex 1 and their activities in annex 2.
The experiment proper was planned for September 6 until October 1. The week before this period was used for the larger part of the preparatory work. Beside the very large amount of instrumentation for the individual groups a 21m long outrigger had to be installed, at the end of which all instruments for the e-c method were mounted (along with e.g. a gas inlet and wave measuring equipment, fig.2) and a submerged pump that provided 50 l of sea water per minute for continuous analysis during the experiment. Examples of the time series of the CO_2 content of the water, measured in this way, are given in figs. 3a and 3b. Fig.4 is a schematic picture of the measurements made during the experiment.
There were quite a few problems during the experiment.
The biggest disappointment was the absence of the Canadian CO_2 sensor, which should have been the most sensitive one of the experiment. Only in the course of the experiment it became clear that the technician who was responsible for its construction had seriously underestimated the problems he was to meet. The KNMI CO_2 sensor furthermore broke down and had to be replaced by another less sensitive one.

Another problem was the weather situation. During large parts of the experiment the wind was easterly, which put the outrigger with its instruments in the wake of the platform, where no measurements can be made with the e-c method due to flow distortion. On other occasions the wind was westerly, but no measurements could be made due to rain, that disturbed the optics of the CO_2 sensors.

Results

The experiment nevertheless turned out to be a success.

The large redundancy in CO_2 flux sensors saved the experiment as far as the flux measurements were concerned. Most of the data gathered are from one of the instruments operated by FEL-TNO, which provided a large amount of high quality results that were registered by several groups.

Toward the very end of the experiment, with still only a limited amount of flux data in hand, the wind turned sufficiently to the West to allow making measurements and it stayed that way, without rain, for a fairly long period, enabling a sizable extension of the amount of CO_2 flux measurements. Participants not involved in the e-c measurements had no problems with wind directions and measured continuously.

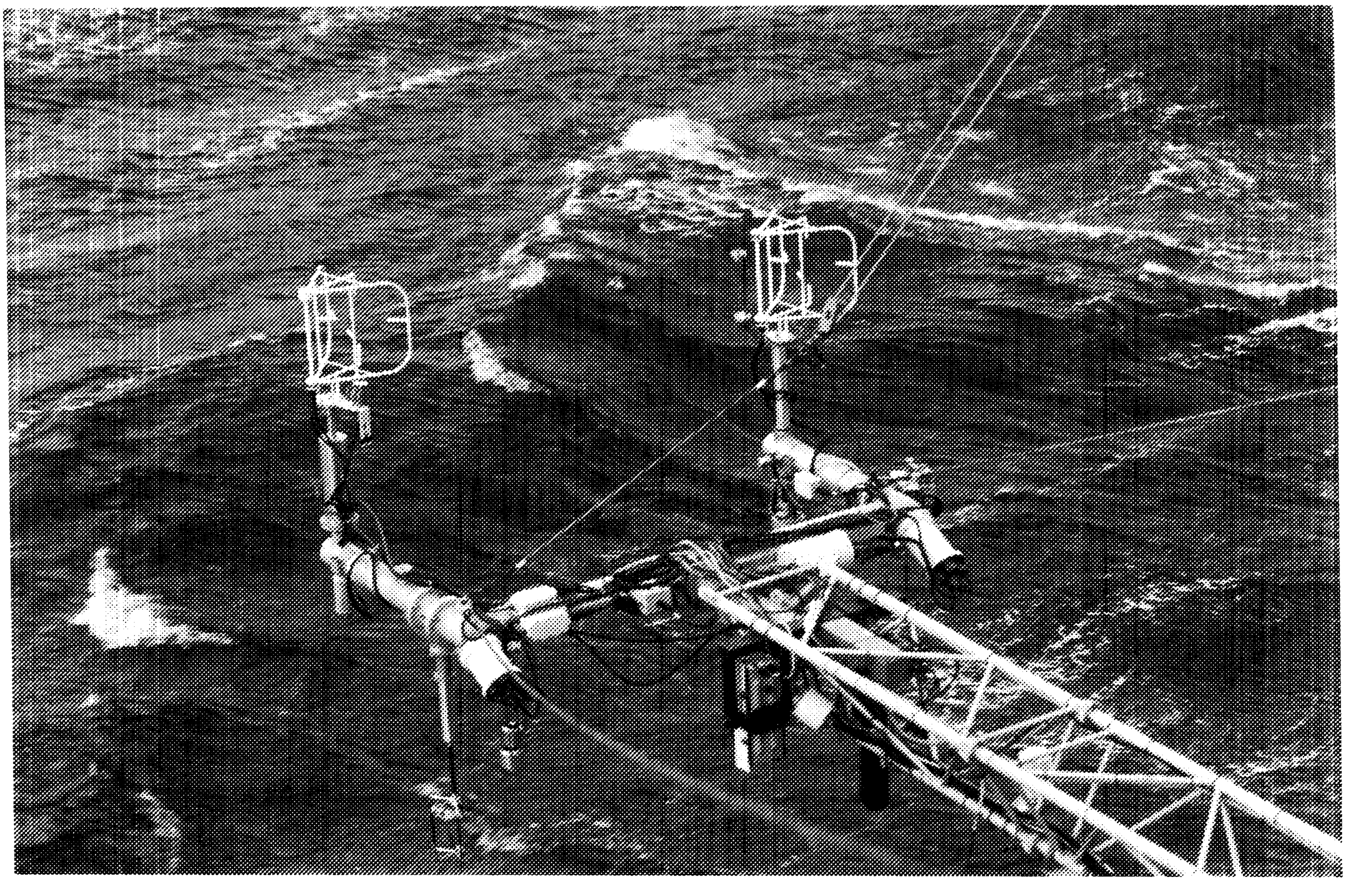


Fig.2 The end of the instrument boom during ASGASEX

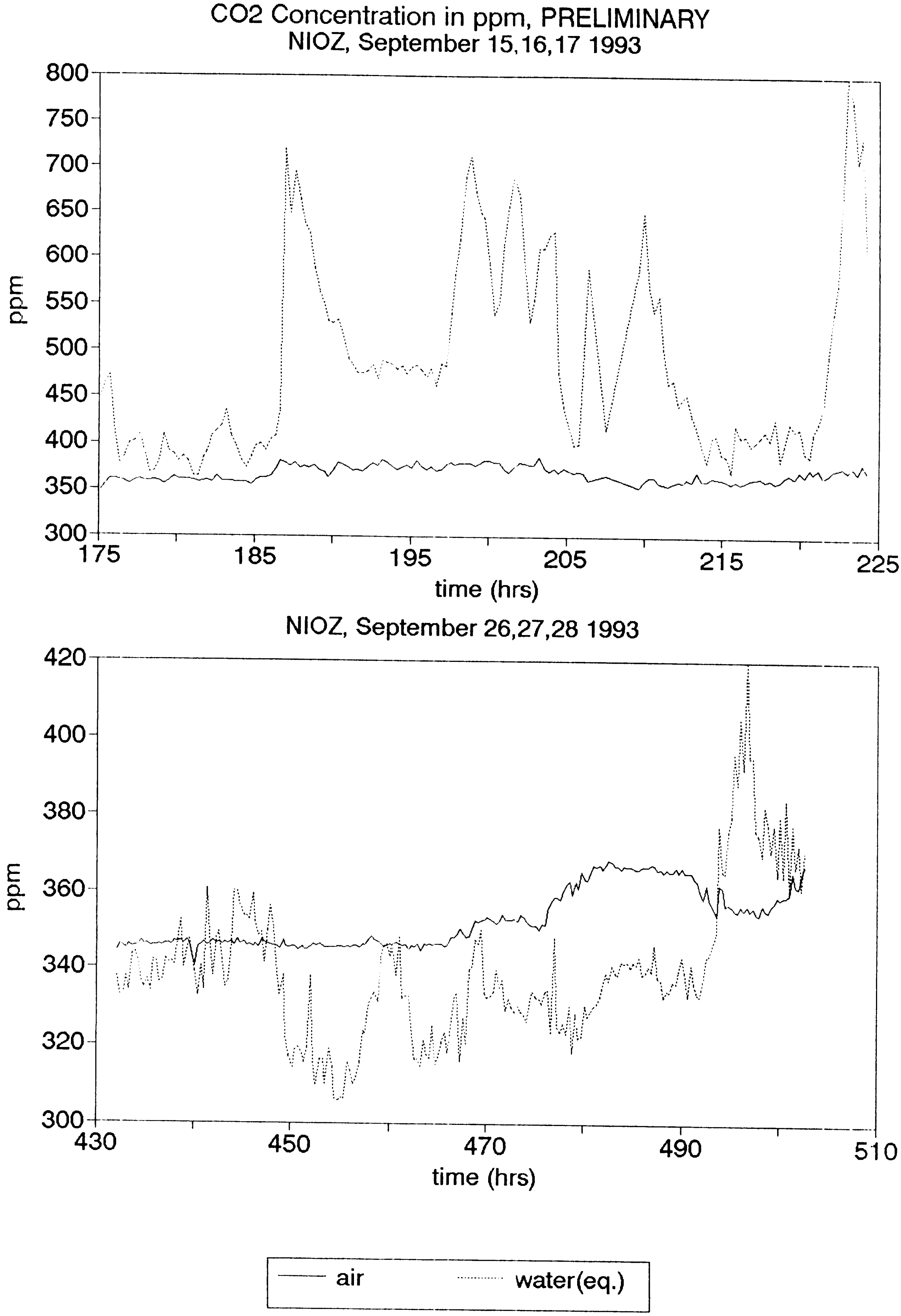


Fig.3 Examples of time series of the CO_2 content of sea water.

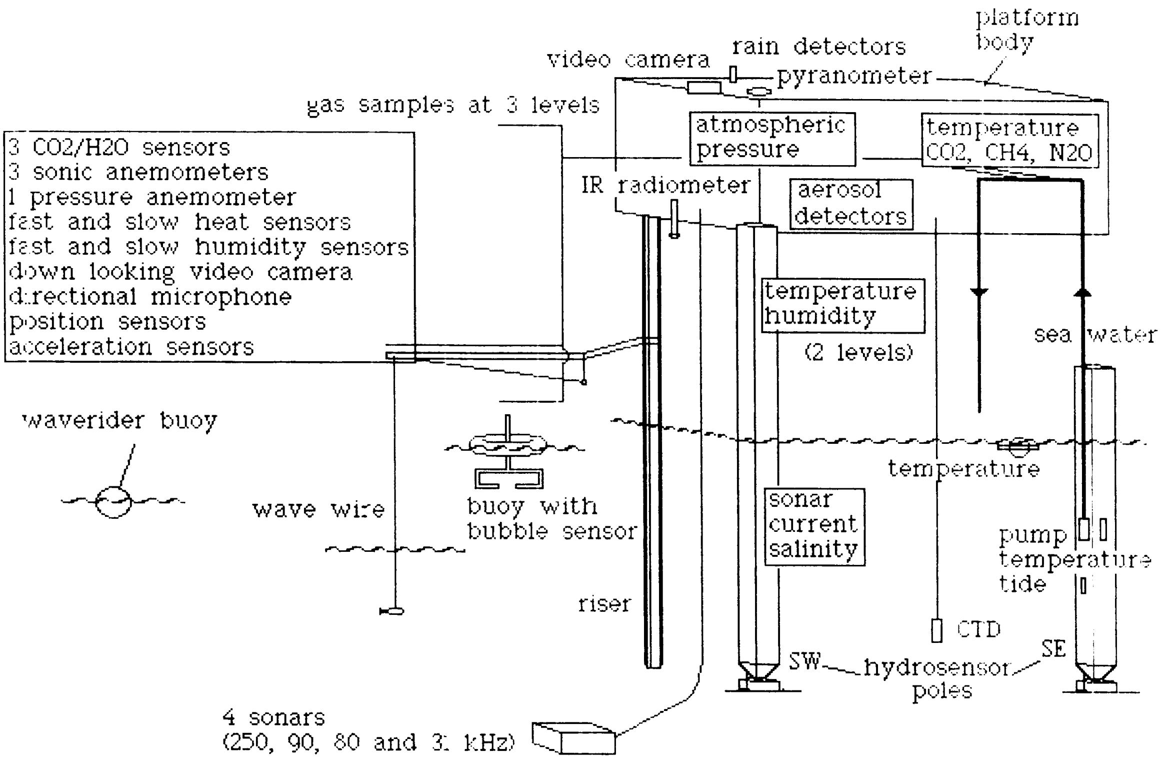


Fig.4 Measurements made during ASGASEX.

The institutes operating sonar equipment (SUDO, UCG and IOSDL) knew already during the experiment that they had obtained important results. For them the experiment on Meetpost Noordwijk was a unique opportunity to prove the almost ubiquitous presence of Langmuir cells, which they detected in large numbers. Langmuir cells provide an important mechanism for the transport of gases through the water.
For most of the other institutes the judgement about the ultimate value of the experiment still has to come, after the data have been analysed. An exeption to this rule is the group of BIO, who made preliminary analyses of their data after each run. They plotted these semi on-line calculations of the CO_2 flux Φ against the Dalhousie $dpCO_2$ values (the difference in CO_2 "pressure" across the water surface), and found a rather convincing picture of a flux that in almost all cases had the same sign as the concentration difference. A regression line showed a clear slope, indicating that they had found something real and not noise. The regression produced a dimensionless transfer coefficient $(\Phi/(U.dpCO_2)$, with U the wind speed) of the order of 10^{-4}. The transfer velocity k $(= \Phi/dpCO_2)$ from their data shows an interesting behavior: it starts at very high values (about 10 m/h) at low wind speeds and then goes down to a few tens of cm/h at a wind speed of 10 m/s. These latter values correspond interestingly enough quite well to those obtained from the Liss-Merlivat coefficients, which are a kind of synthesis of the results of measurements with conventional methods. There is a striking difference at low wind speeds between the k-values of the runs with a positive $dpCO_2$ (upward fluxes) and those with a negative one (downward): all k-values higher than 3 m/h are from runs with negative $dpCO_2$'s.

The more final analyses of not only the BIO data, but also those of FEL-TNO, KNMI and NIOZ are presently being made; the intercomparison will be of great interest, in view of these preliminary results.

Future activities

Although in a balance of success and failure ASGASEX '93 can to all probability (the final results are not yet available!) be considered as a success, there is still a number of questions that are only partially answered, there is room for improvement on a number of points and there are other climate-related problems for which an ASGASEX type of experiment could be of great value, but which were no items in the present one.

We are therefore trying to arrange another ASGASEX experiment in 1996. During a EUROTRAC Air Sea Exchange workshop in October of this year in Arcachon, France as well as on other occasions we found a considerable interest for such an activity with scientists from several disciplines, countries and institutes.

KNMI will also take the initiative to organize an ASGASEX workshop in the Netherlands in 1994, either at KNMI or at NIOZ. During that workshop the results of the present experiment will be presented and the plans for the new experiment will be discussed. Financial support is being sought after.

LIST OF ANNEXES

PARTICIPATING INSTITUTES and PARTICIPANTS

BIO
Dr.S.D.Smith
Mr.R.J.Anderson
Bedford Institute of Oceanography
Ocean Circulation Division
P.O. Box 1006
DARTMOUTH, N.S.
Canada B2Y 4A2

DAL
Prof. O Hertzman
Ms. M Poliquin
Ms. M.-C. Bourque
Dalhousie University
Oceanography Department
Halifax N.S.
Canada B3H 4J1

FEL-TNO
Dr.G.de Leeuw
Ir.G.J.Kunz
Ing.L.H.Cohen
Physics and Electronics
Laboratory TNO (FEL-TNO)
P.O. Box 96864
2509 JG Den Haag
The Netherlands

KNMI
Mr.R.Cornet, Dr.W. Kohsiek,
Drs.C. Kraan, Mr.C. van Oort,
Dr.W.A. Oost, Mr.J.W.Schaap,
Mr.H. Wallbrink, Mr.E.H.W. Worrell
Royal Netherlands Meteorological
Institute (KNMI)
P.O.Box 201
3730 AE DE BILT
the Netherlands

NIOZ
Ms.Ir.D.C.E. Bakker
Drs.A.A.J. Majoor
Ir.H.de Wilde
Netherlands Institute
for Sea Research (NIOZ)
Postbus 59
1790 AB Den Burg
Texel

SUDO
Dr.D.Woolf
Southampton University
Department of Oceanography
Highfield
SOUTHAMPTON SO95NH,
United Kingdom

UCG
Dr.M.Cure
Dr.T.Furey
University College Galway
Department of Oceanography
Galway
Ireland

IOSDL
mr. A.Hall
Institute of
Oceanographic Sciences
Deacon Laboratory
Brook Road
Wormley, Godalming
Surrey GU8 5UB
UK

MEASUREMENTS MADE BY THE VARIOUS PARTICIPATING INSTITUTES.
For the meaning of the institute indications, see Annex 1.

PARAMETER/QUANTITY	INSTITUTE
aerosol	FEL
air temperature	BIO, KNMI, RWS
alkalinity	NIOZ
bubbles	SOTON/UCG/IOSDL, FEL
CO2 flux (eddy correlation)	BIO, FEL, KNMI
CO2 flux (gradient method)	NIOZ
current (strength and direction)	RWS
humidity	KNMI, BIO, RWS
humidity flux	BIO, FEL, KNMI
incoming short wave radiation	FEL
Langmuir circulations	SOTON/UCG/IOSDL
momentum flux	BIO, FEL, KNMI
N2O, CH4 in water	NIOZ
N2O, CH4 in air	NIOZ
pCO2 in water Dalhousie,	NIOZ
pCO2 in air Dalhousie,	NIOZ
rain	FEL, KNMI
sea water temperature	KNMI, NIOZ, RWS
sensible heat flux	BIO, KNMI
total CO2 in water	NIOZ
wave height	KNMI, RWS
whitecaps	KNMI
wind speed	BIO, FEL, KNMI, RWS

NETHERLANDS INSTITUTE FOR SEA RESEARCH (NIOZ)
by Dorothee Bakker, Bram Majoor and Hein de Wilde.

Introduction

The partial pressure differences of the greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) between the air and the sea water were studied by means of gaschromatographic analyses. The air-sea fluxes of these gases can be estimated by multiplying the air-sea partial pressure differences with an exchange coefficient. The value of the exchange coefficient strongly depends on wind speed (influenced processes). Although discussion about this dependence has not yet been ended we will use the well known Liss-Merlivat relationship to calculate preliminary fluxes. The partial pressure differences of CO_2 between the air and the water will be compared with the results of Dalhousie University based on Li-Cor (infrared) analysis. Furthermore all fluxes estimated by taking the partial pressure difference and exchange coefficients will be compared with those established by the eddy-correlation technique. Correlations in the concentrations in the water of methane (CH_4),nitrous oxide (N_2O) carbon dioxide (CO_2) and oxygen (O_2) will be looked for.

The partial pressures of nitrous oxide (N_2O) and methane (CH_4) were measured at 3 heights above the sea level in order to detect gradients in their atmospheric concentrations. Combination of a gradient in the atmospheric concentration with wind speed is a third way of measuring air-sea fluxes.

Total inorganic carbon (TCO_2) of sea water and the partial pressure of CO_2 (pCO_2) were monitored continuously to get an understanding of the carbon dioxide system of the water. Tidal changes of the water may be reflected in the carbon dioxide system. Effects of nearby industrial and urban areas on the carbon dioxide system will be carefully searched for.

Methods

- Determination of the partial pressures of carbon dioxide (pCO_2), nitrous oxide (pN_2O) and methane (pCH_4) in sea water at 5 meter depth and in the overlying air at the boom were monitored continuously by two gaschromatographs. (pCO_2 ±0.5%; CH_4 ±0.4%, N_2O ±0.7%). The partial pressures in the water were determined indirectly by measuring air that had been equilibrated with the pumped up seawater. Equilibrating was done by spraying seawater continously through a fixed volume of air.
- Gas tight air bags were filled with air from three different levels during 45 minute runs of pumping. Subsequently the contents of the air bags were analyzed 50 to 100 times for differences in CH_4 and N_2O concentration, in order to establish whether gradients are detectable.
- Total inorganic carbon content (TCO_2) of sea water at 5 meter depth was analysed continuously during day time by a coulome-

ter (±2μmol/kg).
- Water temperature at 5 meter depth was monitored by a Pt100 sensor (±0.01°C),
- Temperature of the sea water supply in the lab was studied in the NIOZ CO_2-equilibrator by a Pt100-sensor belonging to the same setup as the previous one, so the difference between the two was known accurately. (Temperature difference ±0.02°C).
- The surface skin temperature of the sea water was detected continuously by a passive infrared pyrometer (±1°C).
- Sea water salinity was monitored by on line sensors of Rijkswaterstaat. Calibration samples were taken twice daily.
- Atmospheric pressure was determined. (± 1 mbar).

Preliminary Results

The temperature difference between the sea water at 5 meter depth and the water supply in the lab as registered in the NIOZ equilibrator was typically between 0.1 and 0.3 °C. First results indicate that a gradient of methane (CH_4) in the air, was detectable although samples from the lowest air inlet (0.5 - 1 m above the water surface) appeared to be disturbed for some reason.

The water was supersaturated with CO_2 compared to the atmosphere, with very high and variable CO_2 levels at the start of the experiment. During a storm wind period (Beaufort force 8) the partial pressures of CO_2 in the air and the water matched completely. So far, no clear correlation the partial pressure of CO_2 of the water and the tides has been found.

Nitrous oxide (N_2O) and methane (CH_4) concentrations were rather stable. Surface water was generally slightly supersaturated with N_2O, and highly supersaturated with CH_4. Both N_2O and CH_4 concentrations in water showed a correlation with tide, having highest concentrations about 4 hours after high tide.

Properties of the watermasses await further study.

General Conclusion

The NIOZ group is well pleased with the measuring conditions and the results obtained. The equipment performed satisfactorily during most of the experiment. Comparison of our data with those of others will yield better insight in the methods to determine CO_2 fluxes.

Personal note:

The three of us had a very pleasant stay at the "Meetpost". The crew of the Platform did its utmost to provide us with an ideal working climate. Cooperation with other scientists provided good working conditions and support with difficult repairs or at the busiest times. The social atmosphere allowed for a relaxed kind of recreation between and after work. We still regret the loss though of one of Mr de Leeuw's unique slippers.

SOUTHAMPTON UNIVERSITY DEPARTMENT OF OCEANOGRAPHY (SUDO)
UNIVERSITY COLLEGE GALWAY (UCG)
INSTITUTE OF OCEANOGRAPHIC SCIENCES, DEACON LABORATORY (IOSDL)
by Marcel Cure, Alan Hall and Dave Woolf.

IOSDL contribution
by Alan Hall,
working under subcontract to Dr.D.Woolf (SUDO) and with Prof. S.A.Thorpe F.R.S. (SUDO) as a co-collaborator.

A weighted quadrupod was deployed on the sea bed approximately 40m. S.W. of the S.W. hydrosensor pole in 17m of water. An umbilical cable, made up of 3*12 core cables, a Kevlar strain bearing cable, plus sections of lead line (for weight) were laid along the sea bed to the platform and fixed to the 11.6m deck. The quadrupod is equipped with a narrow beam upward pointing sonar, operating at 250 kHz, which profiles the bubble clouds as they advect through the beam with the tidal flow. Two side scan sonars are mounted at right angles to each other and inclined upwards at an angle of 15° from the horizontal and operated at 90 and 80 kHz. These sonars produce a side scan image of the horizontal distribution of the bubble clouds as they advect through the beams. It was anticipated and has proved the case that the dominant process in organizing the bubble clouds is Langmuir circulation. Some evidence of another mechanism, Bottom Generated Turbulence may have also been detected.

A third side scan transducer, operating at 31 kHz was operating as a trial. For this work it is important that the quadrupod was oriented so that one side scan transducer was parallel to the tidal flow and the other at right angles to the current direction; this was accomplished (with some difficulty). Also mounted on the quadrupod was a pressure case containing a compass and two inclinometers, to enable the direction and attitude of the rig to be determined.

Four channels of sonar data are recorded on video tape in digital code, utilizing PCM/VCR and this data on selected portions will be analysed later at SUDO. In addition two channels of data are displayed and recorded on a Waverley Line Scan recorder; this allows real time interpretations and diagnosis. Later it will be the basis for selecting VCR tapes for detailed analysis.

As of 24 September all sensors have performed faultlessly and there have been no equipment failures. The closeness of the quadrupod to the MPN platform has meant that only tides from the SW could be used, virtually every opportunity presented has been recorded, ranging from flat calm to force 8 gale.

SUDO Deliverables
by Dave Woolf.

1. The upward pointing sonar will be useful in combination with UCG's side scan sonar and FEL-TNO's bubble measuring system to describe bubble injection i.e.

SUDO - upward pointing sonar, provides bubble cloud penetration depth and relative concentration,
UCG - side scan sonar mounted in the SW hydro sensor pole, provides density and intensity of breaking wave crests,
TNO - bubble measuring system provides near surface bubble concentration and size distribution.

From these data statistics will be produced of relative scattering strength (~bubble concentration) and penetration depth as a function of time and environmental parameters (U_{10}, u_*, H_s, ...).

2. The side scan sonars have yielded an unprecedented amount of data on the large scale (10-100m) distribution of bubbles and coherent motions (e.g. Langmuir circulations) on these scales. The processing and analysing task is enormous!

3. An attempt shall be made to calculate gas transfer velocities (and supersaturations) from the dissolved oxygen data - using a basically "classical" budget method. This will require detailed attention to currents etc. to exclude advective effects. The chlorophyll measurements should help to gauge the biological influence on dissolved oxygen concentrations. (I should have liked to do the same for nitrogen, but the prototype TGM needs a lot of work!)

4. Observations of coastal fronts (along with a Galway ST profile) might be combined with an ERS-1 SAR image (if available) to look into the effects of this front.

The UCG contribution to ASGASEX 1993
contributed by Marcel Cure 28/10/93

Background and aims.

There is a growing awareness that to successfully model turbulent transport (of gas, momentum or heat) at or near the ocean surface, dynamical processes need to be specifically included. Such processes include wave breaking, but other processes are known to organise bubble plumes; Langmuir circulation (Thorpe, Cure, Graham, J.Phys.Oceanogr., submitted), shear instability (Thorpe and Hall, 1987), and forced convective plumes (Cure and White, 1991). The upper ocean boundary layer does not appear to resemble a constant stress layer (Osborn et al, 1992). Unfortunately our knowledge of the fully turbulent structures in this unique boundary layer could be described as sketchy; we need to be able to parameterize their effects since we cannot yet solve the relevant equations to all scales.

In this study we are primarily concerned with the development of the bubble plumes immediately behind the crest of breaking waves, and with the field of Langmuir cells which seem to be omnipresent whenever the windspeed exceeds about 3 ms^{-1} (Thorpe, Cure, Graham, submitted to J. Phys. Oceanogr.). Experimental studies have shown that breaking waves are responsible for the injection of CO_2 (Wallace and Wirick, 1992;

SUDO/UCG/IOSDL INSTRUMENTS AND MEASUREMENTS

Location	Instrument	Property	Methodology	Period of Operation (weeks)	Frequency of Record
Quadrupod, 35m off SW sensor pole	a)upward-pointing sonar	vertical bubble distribution	upward-pointing 250kHz pencil beam	1-2,3-4	very high frequency during most periods of slack tide or approaching current
	b)side-scan sonars	horizontal bubble distribution	80kHz, parallel to current	1-2,3-4	
			90kHz, cross-current	1-2,3-4	
			31kHz, cross-current	3-4	
SW sensor pole, at about 5m depth	YSI 6001 Environmental Monitoring System	Temperature	Metallic oxyde thermistor	0-4	15 mins.
		Conductivity	Ni electrodes	0-4	15 mins.
		Dissolved Oxygen	Ag/Au pulsed electrodes	0-4	15 mins.
		pH	Potentiometric	0-4	15 mins.
Seawater supply a) Flow through system	Endeco 1125 pulsed oxygen controller	dissolved oxygen	Ag/Au pulsed electrodes	1-2,3-4	5 mins.
	+ 2 probes	temperature (*2)	single bead thermistors	1-2,3-4	5 mins.
	Prototype total gas meter	Total partial pressure of dissolved gases	differential pressure, gas permeable tubing	3-4	rare!
	Turner designs fluorometer	chlorophyll	fluorescence	1-2,3-4	5 mins.
b) discrete samples	sample bottles and titration	dissolved oxygen	modified Winkler method	1-2,3-4	at least 3 triplicates/day
	manual filters	chlorophyll	freeze-stored, filtered samples	1-2,3	daily

Farmer et al, 1992), and idealised Langmuir cells have been used to model the transport of tiny bubbles, their dissolution leading sometimes to a supersaturation of gases (Thorpe, 1982; Woolf and Thorpe, 1991). The high void fraction region behind the breaking wave crests may be influential in the flux of CO_2 (D. Woolf, personal communication).

Fortunately bubbles are an excellent target for high frequency sonar and the ocean is relatively transparent to sound compared to electromagnetic waves. In this experiment we used upwardly directed sidescan sonars. One has a frequency of 312 kHz which gives a good spatial resolution and is useful for imaging breaking wave crests. The other sonar (frequency 104 kHz) was able to excite tiny bubbles with a radius of about 50 microns in monopole resonance, causing a large sonar backscatter cross-section. These bubbles rise very slowly (a few cm/s) and are long lived (a few minutes) and are trapped beneath surface convergences of water such as between Langmuir cells, which the 104 kHz sonar was ideally suited to image.

Equipment configuration

The sonars were situated at 4m depth on the liftable Hydrosensor pole on the SW corner of MPN. They were elevated at an angle of 14° from the horizontal and could be rotated about a vertical axis. The configuation is shown in fig. 1. The sonars could be directed to point at the upward looking sonars operated by SUDO and IOS, as well as at the end of the boom on the west face of MPN. Sonar signals were simply recorded on tape for later replay and analysis.

In addition to the sonars, The Galway group have collected a certain number of temperature and salinity profiles. Temperature resolution was only 0.1°C and salinity 0.1 ppt.

Future analysis of data

It is difficult to state at this stage exactly how we shall proceed with our analysis. Some interesting features were, however, apparent during the experiment.

1. When the sonars were directed upwind into the approaching wave crests we collected some data with very good time and spatial resolution from which we may get the duration of breaking events and the speed of the approaching turbulent bubble front for a variety of wind conditions.
2 Sonars directed across the wind direction, might yield the spatial intermittency of breaking along individual crests for a variety of wind/wave conditions.
3. Sonars directed at the upward sonars of SUDO/IOS can indicate exactly when a wave has broken above the SUDO/IOS rig. At times of slack water, the vertical evolution of the resulting buble cloud can be estimated.
4. Sonars directed at the SUDO/IOS rig and uptide show the vertical appearance of very old and deep bubble clouds that have been advected over the bottom rig. These bubble clouds have been significantly affected by turbulence.
5. At slack water sometimes, the sonars were continuously

ASGASEX '93 GALWAY SONAR CONFIGURATION

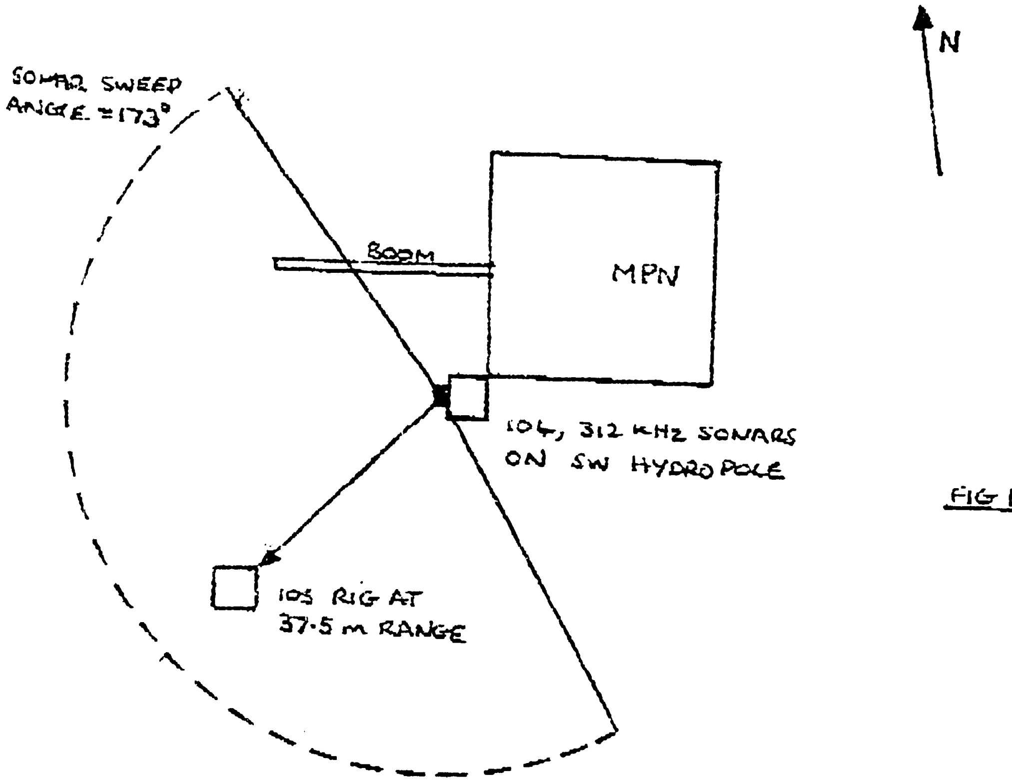


FIG 1a PLAN VIEW

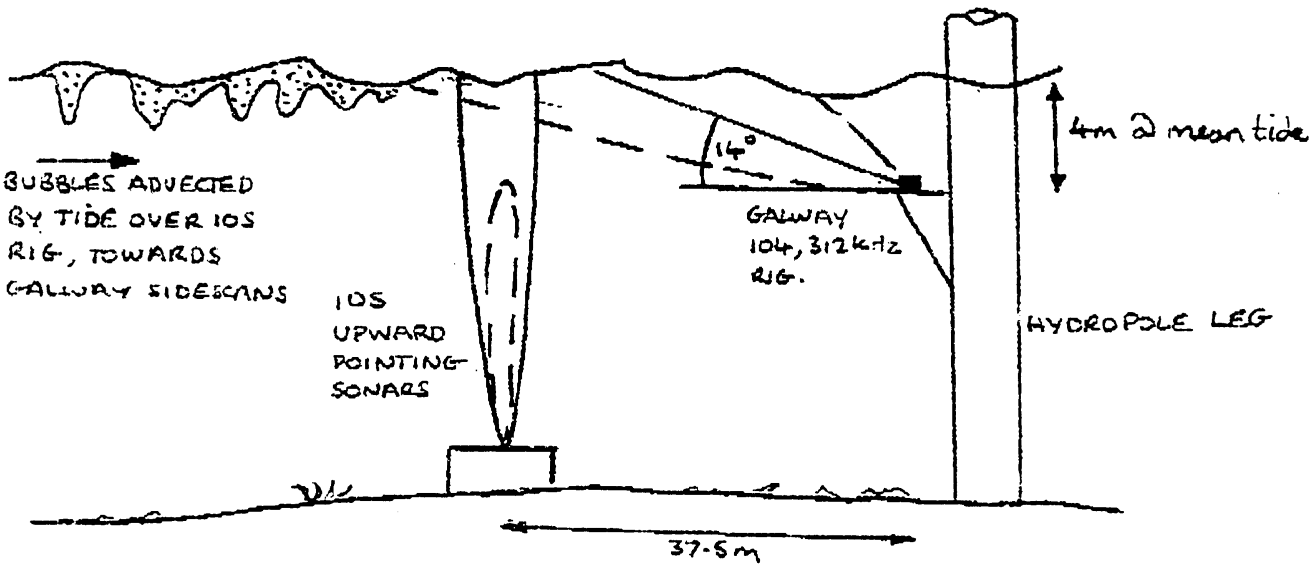


FIG 1b ELEVATION

rotated in order that later with some digital processing, a radar-like image could be synthesised, showing the spatial evolution of the Langmuir cells.

6. KNMI were kind enough to supply us with data from their downward pointing directive microphone situated on the boom end. We would like to correlate the noise generated by wave breaking with the strength of sonar backscatter from these waves. We have a very limited data set for this comparison.

We look forward to a fruitful continuation of our collaboration with the other scientists in ASGASEX. In particular we would like to put measurements of gas flux into the context of the physical processes which we have observed.

References

Cure, M.S., 1988. Some observations of near surface convection in calm and windy conditions in the Iceland-Faeroes region, MSc dissertation, University of Southampton, UK.

Farmer, D.M, McNeil, C.L., Johnson, B.D., 1993. Evidence for the importance of bubbles in increasing air-sea gas flux. Nature, **361**, 620-623.

Osborn, T., Farmer, D.M., Vagle, S., Thorpe, S.A., Cure, M.S., 1993. Measurements of turbulence and bubble plumes from a submarine. Atmosphere-Ocean, **30**, 419-440.

Thorpe, S.A. 1982. On the clouds of bubbles formed by breaking wind waves in deep water and their rôle in air-sea gas transfer. Phil. Trans. R. Soc. **A304**, 155-210.

Thorpe, S.A., Cure, M.S., Graham, A., 1993. Sonar observations of Langmuir circulations and estimation of dispersion of floating particles. Submitted to J. Phys. Oceanogr.

Thorpe, S.A., Cure, M.S., White, M., 1991. The skewness of temperature derivatives in oceanic boundary layers. J. Phys. Oceanogr., **21**, 428-433.

Thorpe, S.A. and Hall, A.,J., 1987. Bubble clouds and temperature anomalies in the upper ocean. Nature **328**, 48-51.

Wallace, D.W.R. and Wirick, C.D., 1992. Large air sea gas fluxes associated with breaking waves. Nature, 356, 694-696.

Woolf, D.K. and Thorpe, S.A., 1991. Bubbles and the air sea exchange of gases in near saturation conditions. J. Mar. Res., **49**, 435-466.

BEDFORD INSTITUTE OF OCEANOGRAPHY (BIO)
DALHOUSIE UNIVERSITY (DAL)
by Stu Smith, Bob Anderson and Owen Hertzman.

BIO-Dalhousie eddy flux system
by Stu Smith, Bob Anderson and Owen Hertzman.

Sensors (on the left prong of the boom):

Kaijo Denki DAT-300 sonic anemometer-thermometer on rotor with azimuth and tilt readout;
Micro-thermistor probe and Fastip thermistor probe for high frequency temperature measurements;
Bare ERC Lyman-a for fast response humidity measurements (only in fine weather).

Air-sea data logging and analysis system.

Based on a 486 (or 386) PC, this system takes up to 16 channels of analog input. Information for data logging and analysis is by a configuration (.CFG) file, which is edited between runs if changes are made to the system. It samples at 256Hz, but normally we log the raw data (.RAW file) at 16Hz by block averaging in groups of 16 samples. Each run is assigned a unique name, consisting of a 5 character prefix (e.g. ASGAS) that normally remains the same and a 3 digit number that is automatically incremented.

At the completion of each run the data are analysed. First the voltages are converted to physical units. A number of optional corrections can be specified in the .CFG file: Sonic winds are converted from probe (A,B,W) to orthogonal (U,V,W) coordinates and rotated to align the coordinates with the indicated wind tilt and azimuth. Sonic temperatures are corrected for horizontal wind (U^2), vertical wind (dW/dT) and humidity (using a designated humidity channel). The "Webb" correction for temperature and humidity is applied to the time series of CO_2 data. Means and trends are removed and the analysed time series can be saved as a .TIM file. The mean, rms, linear, trend, maximum and minimum values are calculated for each channel. Data for any channel can be advanced in time by an integer number of samples to compensate for time delay in the sensor, e.g. for aspirated sensors.

Covariances and correlation coefficients are calculated for all pairs of channels. The distribution of values for each channel can be printed in the form of a histogram.

Spectra and cospectra are computed for specified channels and pairs and saved in the .SPC file. They can be plotted in various formats by a separate program ASPLOT. For specified wind and temperature channels dissipation analysis fits an $f^{-5/3}$ line to the inertial subrange, calculates u_* and t_* and then U_{10N}, C_{10N}, C_{TN} etc. If the current is specified in the .CFG file, the "absolute" wind is calculated relative to the water surface and a Doppler shift is applied to the spectrum fit.

Eddy flux analysis calculates U_{10N}, C_{10N}, C_{TN}, C_{EN}, C_{CN} etc.

The .CFG information and the analysis results are stored in a header (.HDR) file. Files may be automatically backed up on a diskette in compressed form using PKZIP.

Data logging can be set to run in an automatic mode at preset intervals and run lengths, e.g. 30 min. of every 120 min. The AUTOEXEC.BAT file can be made to restart the program in the event of a power interruption.

Data analysis can be rerun using an existing .RAW file and a re-edited .CFG file. For example, data on currents may become available at a later date. Usually the prefix is changed (e.g. ASGrr) so that the run number can be kept the same.

Scientific results of ASGASEX from BIO/Dalhousie (preliminary).
by Stuart Smith

1. Our CO_2 eddy flux measuring programme has been a success in combination with the signals from the TNO/RisØ Advanet sensor. Our own Kartech (M.Moschos) sensor unfortunately was not ready in time for deployment in this experiment (it promises 0.1 ppm resolution, as opposed to 1 ppm for Advanet). CO_2 fluxes together with wind stress, heat flux and water vapour fluxes were recorded during all episodes of suitable (westerly, >4m/s) winds.

Preliminary on-line analysis from the new BIO data software shows CO_2 flux to be correlated with $U.dp(CO_2)$. A dimensionless exchange coefficient $C_c = 0.06 * 10^{-3}$ is estimated, in general agreement with Smith et al (BLM, 1991). This is 5% of the HEXOS value of C_E in similar conditions, suggesting that 95% of the resistance to CO_2 flux is in the water microlayer. This is the FIRST direct measurement of C_c at an offshore site.

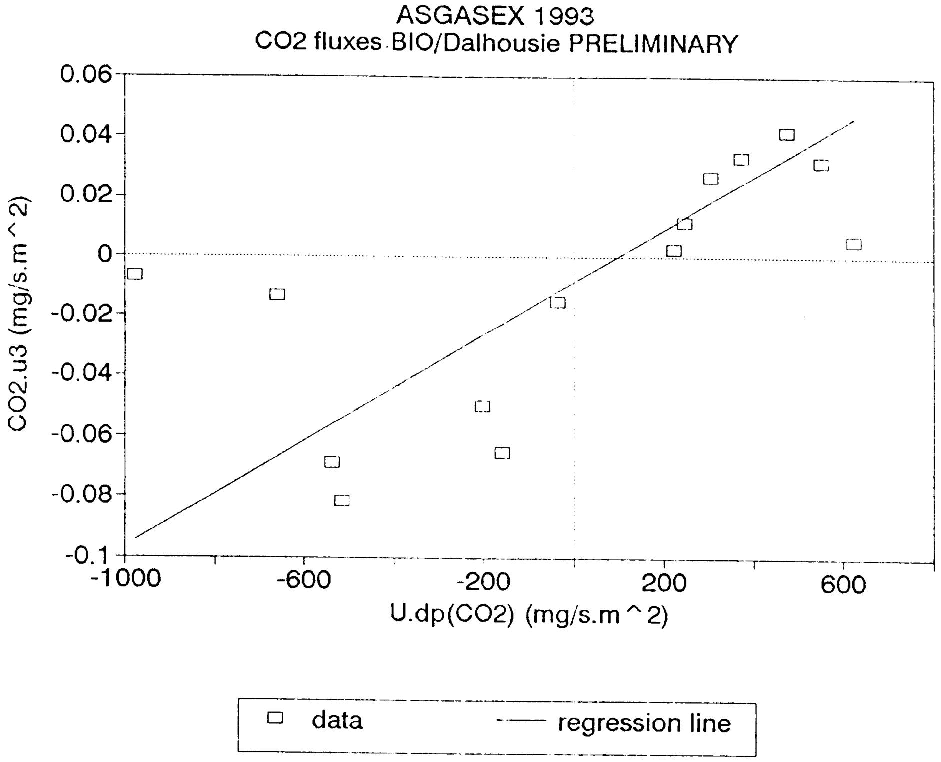
A new Dalhousie University Li-Cor based system for measuring $dp(CO_2)$ gave plausible results that will be compared with those of NIOZ. Rapid variation of CO_2 in seawater indicates that at MPN such measurements must be made at rapid (e.g. 10 min) intervals. Further engineering development is needed to make the operation less labour-intensive.

In Fig.1 some preliminary results are presented of the CO_2 flux Φ plotted against the product of the wind speed U and the Dalhousie $dpCO_2$ values and of the transfer velocity k (= $\Phi/dpCO_2$) against U.

2. We have high-quality water vapour fluxes using IR sensors and Ly-α, with excellent agreement among redundant systems. Together with the VIERS-1 ('90) data set we can write a note confirming HEXOS results.

3. A secondary goal of BIO was to test automated dissipation wind stress analysis. We intend to further develop this system for routine use on our ships, with an R.M.Young wind monitor (fast response propellor) on a bow mast.

4. As usual, the unique MPN site and the professionalism of the KNMI technical staff were the keys to a successful experiment.



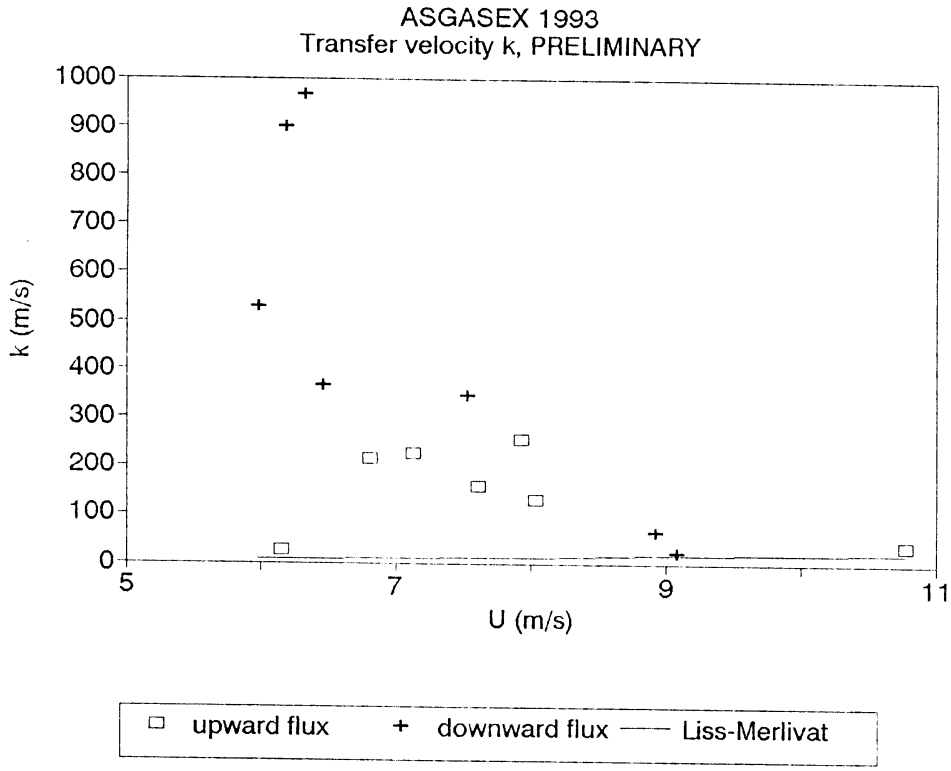


Fig.1 Preliminary on-line analysis results of the CO_2 flux as a function of U.dp(CO_2) and of the transfer velocity k against U.

ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE (KNMI)

by Wiebe Oost

Instrumentation.

Instruments at the boom head.

KNMI operated two eddy flux systems, one based on a sonic anemometer (Kaijo Denki DAT-300), the other on a pressure anemometer (PA), an instrument developed at KNMI for wind vector measurements low over the water surface. Both wind meters provided independent measurements of the momentum flux and both could be combined with a set of fast heat (cold wire) and humidity (Ly-α) sensors in a protective housing to calculate the heat and moisture fluxes. The latter sensors were combined with slow and stable ones for on-line calibration. Fixed to the sonic anemometer sensor head was a CO_2/H_2O sensor based on infrared absorption (4.2 μm). The instrument was developed at NCAR and KNMI; its sensitivity for CO_2 was estimated as 0.3ppm. The combination of the vertical wind measured by the sonic and the CO2 signal provided the CO_2 flux. The combination of the CO_2 signal with that of the PA was not very well suited to calculate this flux due to the rather large vertical distance (~2m) between the two instruments.

Waves were measured by KNMI with a free hanging wave wire with a load at the free end; the angle of the wire with the vertical was measured by a potentiometer. Two types of data were registered from this instrument, viz. the complete signal and a high-pass filtered one (frequencies >1Hz). The latter signal was amplified and separately registered to prevent the high frequency data to be drowned in the much larger low frequency signal.

Also mounted at the boom head were a vertically down looking video camera and a directional microphone. These were used to detect breaking waves (whitecaps) in the neighbourhood of the boom head. Other sensors at the boom head were two inclinometers to register the orientation of the boom head and a three component accelerometer to detect its movements and those of the instruments mounted on it. All atmospheric and oceanographic sensors were mounted on the northerly prong of the boom.

KNMI instruments at other places on the platform.

On the helideck another, steerable video camera was mounted to provide areal information on whitecaps. Other sensors used by KNMI were a floating temperature sensor to measure the sea water surface temperature and a rain sensor that gave a (fixed) signal when it became wet.

Preliminary results of KNMI

The KNMI CO_2 sensor needed a large part of the available time before it functioned in a dependable way. After a few initial runs, during which the sensor appeared to function well for short periods, the noise level increased dramatically and it turned out that the cryogenic infrared detector had failed. The detector had to be replaced by a non-cryogenic one with a somewhat lower sensitivity (~1ppm). After this replacement and the accompanying software changes the instrument functioned well, but from that time on the weather was not very cooperative: there was either an easterly wind (which meant that the flow was severely distorted by the platform) or rain, that spoiled the optical properties of the sensor. Finally, on the final measurement day, a number of runs was obtained with dry weather and a SSW wind.

All other KNMI instruments functioned well during the full period. A few times a wave wire broke and had to be replaced. On one occasion a PA failed and was likewise replaced by another specimen. In these cases the loss was restricted to the wave or PA data of a single run.

Analysis

Despite the problems with their CO_2 sensor the KNMI group expects to be able to calculate CO_2 fluxes for a decent number of runs by

a. analyzing full runs where both the sonic anemometer and the CO_2 sensor worked properly;
b. selecting and analyzing sections of runs in which both instruments worked properly;
c. combining KNMI wind data from either PA or sonic with data from the FEL-TNO/Risø Advanet sensor.

From our own ASGASEX data we will further extract momentum, heat and moisture fluxes, high and low frequency wave fields, average values of wind, temperature (air and sea) and humidity, breaking wave concentrations etc. These data are needed for the study of the relations between the CO_2 fluxes and other environmental parameters, but they are also of direct interest for other fields of air-sea interaction, such as the relation between momentum flux and wave age.

After these analyses the results will be compared with other ASGASEX data, especially the $dpCO_2$ values of NIOZ. Furthermore relations will be sought with the bubble clouds measured by the SUDO/IOSDL/UCG group. Comparisons will be made with the flux results of BIO and FEL-TNO.

PHYSICS AND ELECTRONICS LABORATORY - TNO (FEL-TNO)
by Gerrit de Leeuw

The contributions of the TNO Physics and Electronics Laboratory (FEL-TNO) to ASGASEX are:
1. Micrometeorological measurements of the air-sea exchange of CO_2, water vapour, heat and momentum, using eddy correlation and dissipation methods (a collaborative effort with Risø, Denmark (Dr.Søren Larsen)).
2. Measurements of bubble size distributions and particle concentrations in the sea at depths between 0.5 and 2 m.
3. Measurements of aerosol particle size distributions and their profiles in the surface layer.
4. In addition, some meteorological parameters are recorded.

Flux system.

The TNO/Risø flux system consists of:
- Gill Ultrasonic anemometer to measure the three turbulent flow components and the fluctuations in the air temperature (from speed of sound), sample rate 25 Hz;
- Two Advanet Infrared CO_2 and H_2O fluctuation meters, model E009A, CO_2 sensitivity 50 ppm FS (10 V), noise level 1 ppm, H_2O sensitivity 5 g/kg FS, noise level 0.04 g/kg), sample rate 30 Hz.

The purpose of having two IR CO_2 and H_2O fluctuation meters is to correlate the signals to reduce noise and thus obtain higher sensitivity for CO_2. The two instruments are mounted close together on a flat plate fitted to a T-shaped flange on the left prong of the boom, pointing downward. The centers of the sample volumes are approximately 0.4 m below the boom. The sonic has been mounted on the same flange, with the center of the sensor volume at 0.9 m below the boom. The horizontal separation between the sonic and both Advanets is 0.26 m, the vertical separation is 0.5 m. The position of the TNO/Risø instrumentation has been chosen to minimize flow distortion due to other sensors on the boom.
The eight signals (u, v, w, speed of sound, 2 CO_2 and 2 H_2O signals) and two control signals are fed into an A/D converter and logged with frequency of 20 Hz on an HP Vectra 386 computer with the Risø data aquisition (DAQ) system. The DAQ program has been set up to measure continuously during three days. Data are recorded during pre-set time intervals (during ASGASEX usually 45 minutes). The analog values can be monitored and every five minutes the means are displayed. After each measurement the data are de-multiplexed, sonic temperatures are calculated as well as the covariance between the various signals. The covariance matrix and the compressed data file, including run information, are stored in a data directory. Every day a new directory is made with the name of the Julian day. The data filename is composed of the date and time, e.g., <254> 110922.zip contains data recorded on 11 September at 09:22 MET.
Software for off-line processing is available, which calcula-

tes the covariance matrix, and covariance and quadrature spectra. At this moment, spectra are only calculated for the two CO_2 and H_2O signals. Time series and spectra can be graphically displayed.
Since the Advanet is a fluctuation meter, the signals are manually offset to obtain a maximum sensitivity on full scale (± 5 V). Hence the output fluctuates around 0 V and the offsets are logged for determination of the absolute values of the CO_2 and H_2O concentrations. Because of drift, the Advanet requires calibration at regular intervals. To this end, a calibration cell is fitted over the measurement head and filled with Nitrogen containing 250 or 450 ppm CO_2 and the offsets are logged after allowing for stabilization. A calibration curve is calculated assuming a linear relation between the signals and the concentrations (as verified from the factory calibration curve). For H_2O no calibration gases are available and absolute humidities will be obtained by using other instrumentation at the boom (Lyman alpha's, Rotronic air temperature and relative humidity).
Expected achievements of the CO_2 flux measurements during ASGASEX are:

- the development of a technique based on two CO_2 sensors to increase sensitivity,
- to apply and further develop the dissipation technique for CO_2 flux measurements, for application from a ship during the OMEX cruises in the Celtic Sea (1994-1995),
- to compare the results from the above techniques with those from application of eddy correlation techniques as applied by both other participants and ourselves,
- to compare the results from micro-meteorological measurements with those obtained by other ASGASEX participants using conventional techniques to measure CO_2 exchange based on partial pressure differences in water and air,
- to contribute to the general goals of ASGASEX to improve techniques and increase the knowledge on air-sea gas exchange.

Bubble measurements

At FEL-TNO a system has been developed to measure the size of single bubbles in sea water, in the diameter range from 30 μm to 1000 μm, to obtain bubble spectra and relate the results to environmental parameters (wind speed, air and sea temperature, atmospheric thermal stability). This information is expected to contribute to a better understanding of the air-sea exchange of gases and aerosols. The TNO system is based on an optical method employing a diode laser, a telescope, a ccd camera and image processing. The optics and electronics have been assembled in an instrument that is employed from a small bouy at depths that can be varied from about 0.5 m to 2 m. Because of the experimental nature of the system, it is used with a long power supply/data cable and signals are recorded on S-VHS video tapes and processed afterward. A hardware solution for on-line image processing is being developed and we hope to finally obtain a self-contained system which telemeters the processed bubble spectra to a receiving station ashore.

The processing assumes a spherical bubble shape and the aspect ratio is used as a selection criterium. Non-sperical particles will be interpreted as particles and will be counted to obtain the number concentration of particles in the sea water. An accelerometer has been added to the system for infornation on the wave motion, which could be valuable to obtain bubble fluxes from the processing of successive images. This option has not yet been implemented.

The bubble measuring system is employed from the NW corner of the platform to have optimum exposure in the prevailing wind directions. To get away from the spume generated by waves breaking on the platform and drifting in the tidal current, the system is usually mounted on the mast extending north (10 m).

Expected achievements of the bubble measurements during ASGASEX are:

- to test the bubble measuring system in open sea,
- to obtain bubble spectra for use in conjunction with larger scale bubble measurements from the sonar techniques employed by SUDO and UCG, as well as gas exchange data, to gain better insight into the effect of bubbles on air-sea gas exchange,
- to derive a source function for sea-spray aerosol, from the bubble spectra, as a function of environmental parameters, and get better insight into the relative contribution of the various sources of sea-spray aerosol (in particular bubble-generated jet drops and spume drops that are generated at high wind speeds by spin drift), - to prepare for future studies on the influence of bubbles on gas exchange off the Irish coast in cooperation with UCG and SUDO (1994-1995).

Aerosol measurements

During ASGASEX two systems are used to measure aerosol particle size distributions and profiles.

Aerosol particle size distributions in the 0.2-20 μm diameter range are measured with a Particle Measuring Systems (PMS) optical particle counter CSASP-200. Particles are aspirated and pass through a laser beam. The intensity of light scattered in the near-forward direction (4°-22°) is a measure for the size of the particle. Single particles are sized and counted in 32 size bins. Particle size distributions are continously monitored on the screen of a PC. The data are recorded in a data file as 1-minute averages. The optical particle counter is mounted at the SW corner of the platform fixed to the rail.

Particle size distribution profiles (0.2-11 m above the sea surface) are measured with Rotorod rotating impactors consisting of polished stainless steel rods mounted in protective housing, and a small motor. The rods tip up when the motor starts rotating. The linear speed of the rods is 10 m/s and particles are impacted on the silicon-coated surface of the rods. Microscope images of the rods are digitized and preprocessed using a framegrabber. The actual sizing and counting are perfromed afterward, to obtain particle size distributions in the 10-200 μm diameter range. The Rotorods are used on a buoy system to obtain data in the lower 2 m above the instantaneous sea surface (wave following). The profile is extended to higher levels by fixing the Rotorods to a tube that slides along a guide line.

Expected achievements from the aerosol measurements during ASGASEX are:

- to collect data for determining the aerosol source function and the relative contributions of jet and spume droplets, in connection with bubble spectra,
- to obtain a 'long-term' data set, in combination with data from the MAPTIP experiments in October 1993, for the evaluation of (empirical) aerosol models and the (further) development of models describing the aerosol dynamics; as a consistency check, the latter can be used to retrieve the bubble spectra by backward calculation.

Environmental parameters

In addition to the MPN local presentation, some meteorological parameters are continuously logged. These include air temperature and relative humidity from Rotronic Hygromers mounted on the hydrosensor pole (5.2 and 6.6 m above NAP), on the railing at the SW corner (z=13 m) and in the meteomast (z= 27 m), while for comparison and Advanet calibration purposes a Rotronic has been mounted on the boom. A calibrated rain gauge at the 11 m deck (SW corner) is used to log the rain rate. A pyranometer has been mounted on the heli deck to log solar irradation. Two nephelometers have been mounted on the decks at 13 m and 15.6 m to monitor aerosol scattering and visibility.

Instrumentation FEL-TNO during ASGASEX

Parameter	Instrument	Height [m]	position on MPN
Fluxes:			
turb. CO_2/H_2O conc.	Advanet model E009A (TNO)	var.	boom
turb. CO_2/H_2O conc.	Advanet model E009A (Riso)	var.	boom
turb. air flow	Gill ultrasonic anemometer	var.	boom
turb. air temp.	Gill ultrasonic anemometer	var.	boom
bubble size distr. & part. conc.	TNO Bubble Measuring System		-0.5..-2 buoy, from mast NW corner
Aerosols:			
part. size distr. 0.2-20 μm	PMS CSASP 200 (optical particle counter)	13	SW corner
part. size distr. >13 μm	Rotorod (rotating impaction samplers)	0.2-11	from mast NW corner
part. scatt. & visibility	Nephelometer 1	13	SW corner
part. scatt. & visibility	Nephelometer 2	15.7	boom deck
Environmental parameters:			
air temp. & RH	Rotronic Hygromer	var.	boom
air temp. & RH	Rotronic Hygromer	5.2	SW hydrosensor pole
air temp. & RH	Rotronic Hygromer	6.6	SW hydrosensor pole
air temp. & RH	Rotronic Hygromer	13	SW corner
air temp. & RH	Rotronic Hygromer	27	meteo mast
solar irradiation	Pyranometer	18.6	helo deck
rain rate	TNO rain gauge	11.6	SW corner

Heights relative to mean water level (NAP)

RIJKSWATERSTAAT (RWS)
by Wiebe Oost

The North Sea Directorate of the Netherlands Department of Harbours and Public Works (Rijkswaterstaat) made the Meetpost Noordwijk platform available, as well as the services of the platform manager. RWS/Noordzee furthermore operated a waverider buoy at a short distance from the platform and an acoustic current meter fixed to the platform on the SW hydro sensor pole.

It should be stressed that without the continuing support of Rijkswaterstaat and its personnel the experiment would not have been possible. The ASGASEX participants therefore would like to express at this point their big gratitude to their "silent partner". The unique facility of Meetpost Noordwijk is a "sine qua non" for experiments of this type.