Estimation of Wet and Dry Deposition of Gaseous and Particulate Ammonia and Nitric Acid using Buoy in Mikawa Bay, Japan and Evaluation of its Effects on Eutrophication by Fluid Dynamic-Ecological Model

Toshihiro KITADA¹,²)、Naoki SATO²)、Wataru IIDA²)、Takuya HORIO³)、Satoshi OKUDA³)
1) Gifu National College of Technology, Japan
2) Toyohashi University of Technology, Japan
3) Aichi Prefectural Environmental Research Center, Japan
Mikawa Bay (its eastern two-thirds; Atsumi Bay)

- Longitudinal Line for Model Calculation; Segments are defined along the line.

Model Segmentation: x-z structure
Red-tide Events, Blue-tide Events, and Total Red-tide-days in Ise and Mikawa Bay Area, Japan from 1973 to 2007
For one month and a half in Aug ~ Oct, 2009, dry and wet depositions of NH3(NH4+) and HNO3(NO3-) were directly observed over Mikawa Bay by using a buoy (see Fig) as platform, and the deposition was compared with those at two land sites, Toyohashi and Atsumi (see Fig), in the coastal area.

Based on the information obtained, during April to October, 2009, effects of dry and wet depositions of NH3 (NH4+) and HNO3(NO3-) on chlorophyll-a concentration in Mikawa Bay was investigated using a fluid dynamic-ecological model.
Mikawa Bay (its eastern two-thirds; Atsumi Bay)

- Longitudinal Line for Model Calculation; Segments are defined along the line.

![Model Segmentation: x-z structure](image_url)
Observation of Wet/Dry Deposition of N-(NH\textsubscript{3}, H\textsubscript{2}NO\textsubscript{3})

Fig. 2. N-Wet Dep (2009.08.20-10.06): 1 (Aug 20-Sep 14), 2 (Sep 14-24), 3 (Sep 24-Oct 06)

- Buoy-1: NO\textsubscript{3}+NH\textsubscript{4} Total Wet Dep (mg-N/m\textsuperscript{2}/days)
- Toyohashi: NO\textsubscript{3}+NH\textsubscript{4} Total Wet Dep (mg-N/m\textsuperscript{2}/days)
- Atsumi: NO\textsubscript{3}+NH\textsubscript{4} Total Wet Dep (mg-N/m\textsuperscript{2}/days)

Fig. 3. Estimated N-Dry Dep (2009.08.20-10.06; \( V_d = 0.5 \text{ cm/s} \))

- Buoy-1: NO\textsubscript{3}+NH\textsubscript{4} Total Dry Dep (mg-N/m\textsuperscript{2}/days; \( V_d = 0.5 \text{ cm/s} \))
- Toyohashi: NO\textsubscript{3}+NH\textsubscript{4} Total Dry Dep (mg-N/m\textsuperscript{2}/days; \( V_d = 0.5 \text{ cm/s} \))
- Atsumi: NO\textsubscript{3}+NH\textsubscript{4} Total Dry Dep (mg-N/m\textsuperscript{2}/days; \( V_d = 0.5 \text{ cm/s} \))
Fig 4. Estimated Wet & Dry Deposition of Total N (NH$_3$, NH$_4^+$, HNO$_3$, NO$_3^-$) over Atsumi Bay (243 km$^2$) April~October, 2009. Solid line for Rain Fall.
Fig. 5 Monthly Variation of Estimated N Loading to Atsumi Bay in 2009
Comparison of N-Wet Deposition: Bay (Buoy 1 in Atsumi Bay) vs Land Area (Toyohashi and Atsumi-cho)

- **Wet Deposition (mg-N/m²/48days)** for August 20 ~ October 6, 2009
- **Buoy 1**: 86.1
  (Ratio, NO$_3$-N: NH$_4$-N = 0.7:0.3)
- **Toyohashi**: 70.4
  (Ratio, NO$_3$-N: NH$_4$-N = 0.47:0.53)
- **Atsumi-cho**: 65.1
  (Ratio, NO$_3$-N: NH$_4$-N = 0.7:0.3)
Table 1. Molar Ratio of Observed N-compounds in the atmosphere at Buoy 1 (Bay) and Toyohashi (Land)

<table>
<thead>
<tr>
<th></th>
<th>NH$_3$</th>
<th>HNO$_3$</th>
<th>NH$_4^+$</th>
<th>NO$_3^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BUOY 1</strong></td>
<td>53 %</td>
<td>10 %</td>
<td>18 %</td>
<td>19%</td>
</tr>
<tr>
<td><strong>TOYOH ASHI</strong></td>
<td>72 %</td>
<td>7 %</td>
<td>13 %</td>
<td>8 %</td>
</tr>
</tbody>
</table>

Total: 100% 100%
Brief Description of the Model

CE-Qual-W2
Laterally integrated 2-Dimensional Hydrodynamic and Water Quality Model

Hydrodynamic:
• Temperature
• Tide
• Velocity
• Salinity

Water qualities:
13 state variables
(chlorophyll-a, DO, NH4, NO3, PO4, LDOM, LPOM, RDOM, RPOM, Silica, Sediment)
Calculation Scenario looking at Effect of N-loading by Wet and Dry Deposition on Chlorophyll-a Concentration in Atsumi Bay

- **Case 1 (Base)**: No loading by wet (rain) and dry deposition
- **Case 2**: Loading by rain
- **Case 3**: Loading by rain and dry deposition (Vd=0.2 cm/s)
- **Case 4**: Loading by rain and dry deposition (Vd=0.5 cm/s)
Effects of N-loading by Wet and Dry Deposition on Eco-system in Atsumi Bay: Comparison of Various Cases (April 1 ~ October 31, 2009)
TN Concentration (Surface Layer: April 1 ~ October 31, 2009): (a) Inner-most Bay (Seg_2)、(b) Central Bay (Seg_16)

図8. 表層TN濃度の時間変化; (a) 湾奥Seg 2, 観測点A13(図7), (b) 湾中央Seg16, 観測点A7（図7）. Case 1〜4（表2）、○観測値. JDAYはジュリアン日を表し、1月1日を1日目として数えた通しの日数.
Chl-a Concentration (Surface Layer: April 1 ~ October 31, 2009): (a) Inner-most Bay (Seg_2)、(b) Central Bay (Seg_16)

図9. 表層Chl-a濃度の時間変化: (a) 湾奥Seg 2、観測点A13、(b) 湾中央Seg 16、観測点A7。Case 1～4 (表2参照)、○観測値。
Increase of Chl-a Concentration VS N-loading during past 5 days’ rain; $\Delta$Chl-a= Chl-a (Case 2) - Chl-a (Case 1)

(a) June, Seg 16.
(b) July, Seg 16.

図10. 過去5日間の降水による積算N負荷量（湿性沈着量）によるChl-a濃度の増分$\Delta$= Case 2 – Case 1. 表2にケースの説明. (a) 2009年6月、(b) 2009年7月.
Increase of Chl-a concentration VS N-loading during past 5 days’ dry deposition; \( \Delta \text{Chl-a} = \text{Chl-a (Case 4)} - \text{Chl-a (Case 2)} \)
Conclusions

• (1) Wet deposition of N-component at Atsumi Bay (Buoy 1) was similar to that at Toyohashi. However, its composition was different between Buoy 1 and Toyohashi; At Toyohashi site, NH4-N was 53 % (NO3-N was 47%) while at Atsumi Bay (Buoy 1), NO3-N was 70% and NH4-N was 30%.

• (2) On dry deposition of N-component, total N-concentration (molar basis) at Atsumi Bay was about 70% of that at Toyohashi City. Contribution of NH3 was larger; 72% of total N-concentration at Toyohashi, and similarly 53% at Atsumi Bay (Buoy 1).

  Ratio of gas (NH3 +HNO3) to particulate (NO3-N+ NH4-N) was 3.7 at Toyohashi and 1.7 at Atsumi Bay (Buoy 1).
(continued)

3) Relative strength of various N-loading sources to Atsumi Bay (for 6 months, April to Sept, 2009) was estimated as: River 1, Waste water Treatment Plant 0.2, Wet Deposition 0.06, Dry deposition 0.06 (for assumed average-dry-deposition-velocity Vd=0.2 cm/s) ~ 0.15 (for assumed Vd=0.5 cm/s).

4) Effect of N-loading by wet and dry deposition on TN and Chlorophyll-a was investigated using CE-Qual-W2 (a fluid dynamic-ecological model in 2-D space).

Its effect is larger in central bay area.

TN concentration at surface level was increased by 0.11 mg/L at its largest which can be about 30% of TN at central bay, while chlorophyll-a was increased by 2.5 mg/m3 also at its largest which was about 25% at central bay.
• (5) It was inferred that N-loading rate (intensity) needs to exceed some value so that the wet deposition shows visible influence on chlorophyll-a concentration. For example, in July N-loading accumulated for the past 5 days was always less than 20 mg/m2/5days, and no significant effect on chlorophyll-a concentration was observed. On the other hand, in June when N-loading rate exceeded 40 mg/m2/5days in some occasion, increase in chlorophyll-a concentration was predicted at central bay.

• (6) N-loading by dry deposition did not show visible change in chlorophyll-a concentration. Total N-loading by dry deposition, for example its value per month, is quite large. However, the loading rate (intensity) does not exceed 30 mg/m2/5days, and the dry deposition seems not to affect chl-a concentration.