Annexes

Annexe A Bandes des produits MODIS Aqua et Terra de niveau 3

TABLE 8 – Bandes spectrales des produits MODIS Aqua et Terra de niveau 3 (GEE, s. d.).

Nom de la bande	Longueur d'onde	Description	Unités
Rrs_412	412 nm	Réflectance de télédétection de la bande 412 nm	sr^{-1}
Rrs_443	443 nm	Réflectance de télédétection de la bande 443 nm	sr^{-1}
Rrs_469	469 nm	Réflectance de télédétection de la bande 469 nm	sr^{-1}
Rrs_488	488 nm	Réflectance de télédétection de la bande 488 nm	sr^{-1}
Rrs_531	531 nm	Réflectance de télédétection de la bande 531 nm	sr^{-1}
Rrs_547	547 nm	Réflectance de télédétection de la bande 547 nm	sr^{-1}
Rrs_555	555 nm	Réflectance de télédétection de la bande 555 nm	sr^{-1}
Rrs_645	645 nm	Réflectance de télédétection de la bande 645 nm	sr^{-1}
Rrs_667	667 nm	Réflectance de télédétection de la bande 667 nm	sr^{-1}
Rrs_678	678 nm	Réflectance de télédétection de la bande 678 nm	sr^{-1}
chlor_a		Concentration de chlorophylle-A	mg/m^3
nflh		Hauteur de ligne de fluorescence normalisée	$mW/cm^2.\mu m.sr$
poc		Carbone organique particulaire	mg/m^3
sst		Température de surface de l'eau	°C

Annexe B Coordonnées délimitant les sites d'étude

B.1 Mpulungu et Kigoma

```
//Zone de 16 km² d'échantillonnage sur la côte de Kigoma
var Kig4km =
    /* color: #98ff00 */
    ee.Geometry.Polygon(
        [[[29.57, -4.83],
          [29.57, -4.87],
          [29.61, -4.87],
          [29.61, -4.83]]]),
//Zone de 16 km² d'échantillonnage sur la côte de Mpulungu
    Mpu4km =
    /* color: #35fffa */
    ee.Geometry.Polygon(
        [[[31.06, -8.71],
          [31.06, -8.75],
          [31.02, -8.75],
          [31.02, -8.71]]]);
```

B.2 Lac Tanganyika

```
//Polygone de la forme du lac Tanganyika
var PolyTang =
    /* color: #d63000 */
    ee.Geometry.Polygon(
        [[[29.14059679115539, -3.478869366791215],
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206             [29.128690187911037, -3.4621419343536037]]]);
```

B.3 Zones nord, centrale et sud du lac

```
//Polygone de la forme de la partie nord du lac Tanganyika
var PolyTangN =
    /* color: #ff0000 */
    ee.Geometry.Polygon(
        [[[29.14059679115539, -3.478869366791215],
          [29.136476918108514, -3.492576870748159],
          [29.148149891741326, -3.513137751163352],
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//Polygone de la forme de la partie centrale du lac Tanganyika
    PolyTangC =
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94      ee.Geometry.Polygon(
95          [[[29.383404024994707, -5.6404501442759685],
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97            [29.347698458588457, -5.714244092527642],
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104           [29.35036197970552, -6.308299274919571],
105           [29.36958805392427, -6.315124109004704],
106           [29.36684147189302, -6.341057657223528],
107           [29.395680583221147, -6.397015073323184],
108           [29.406666911346147, -6.448872575045049],
109           [29.425892985564897, -6.497995842041624],
110           [29.46297184298677, -6.52664886831035],
111           [29.47395817111177, -6.504818139461339],
112           [29.49043766329927, -6.508911473460458],
113           [29.48219791720552, -6.537563876086695],
114           [29.49318424533052, -6.564850352168269],
115           [29.48219791720552, -6.603048905044989],
116           [29.49043766329927, -6.657613148732388],
117           [29.49043766329927, -6.709443563654633],
118           [29.530263102752397, -6.723082231593667],
119           [29.53438297579927, -6.766723393523013],
120           [29.63600651095552, -6.821269297074787],
121           [29.673085368377397, -6.911256436318027],
122           [29.72939030001802, -6.963059457813885],
123           [29.74312321017427, -7.002589496827825],
124           [29.77838915101333, -7.042391173319846],
125           [29.81958788148208, -7.069648981563475],
126           [29.94112413636489, -7.093498244816499],
127           [29.983009512341454, -7.112576766204171],
128           [29.99811571351333, -7.140511741799355],
129           [30.08394640198989, -7.201145198827422],
130           [30.58673612457427, -7.502475221427068],
131           [30.61694852691802, -7.352680806897333],
132           [30.52905790191802, -7.200110925641154],
133           [30.56201688629302, -6.962981266704541],
134           [30.43842069488677, -6.810282395394247],
135           [30.39996854644927, -6.815736770013274],
136           [30.40271512848052, -6.755735246655468],
137           [30.33130399566802, -6.627525316398734],
138           [30.139512147218117, -6.4467019463559945],
139           [29.958237733155617, -6.490367496374009],
```

```
            [29.903306092530617, -6.435784970295012],
            [29.727524842530617, -6.228318289835332]]]),
//Polygone de la forme de la partie sud du lac Tanganyika
    PolyTangS =
    /* color: #30bf09 */
    ee.Geometry.Polygon(
        [[[30.08394640198989, -7.201145198827422],
          [30.118278677380516, -7.239292436817196],
          [30.145057852185204, -7.327155022004781],
          [30.18283565134133, -7.367300426182506],
          [30.21579463571633, -7.5259394407985445],
          [30.19382197946633, -7.631099494638977],
          [30.204464984837422, -7.638585636450605],
          [30.236394000950703, -7.723646184356799],
          [30.260941175575073, -7.739711064129299],
          [30.269180921668823, -7.832233941111789],
          [30.288406995887573, -7.849919805856216],
          [30.302826551551636, -7.870325637538948],
          [30.291528278975683, -7.901947850505632],
          [30.300454670577246, -7.903988222456364],
          [30.313500935225683, -7.8910656965059855],
          [30.353326374678808, -7.898547208177899],
          [30.377358967452246, -7.939353064611252],
          [30.42542415299912, -7.957714379058819],
          [30.40619807878037, -7.969954798526454],
          [30.476235920577246, -8.025032147692691],
          [30.584039265303808, -8.140602255142612],
          [30.591592365889746, -8.155555960279553],
          [30.57099300065537, -8.225559033696316],
          [30.58472591081162, -8.233034361298744],
          [30.556895043731668, -8.28553660449284],
          [30.570627953887918, -8.302523198490334],
          [30.559641625762918, -8.310676502671534],
          [30.547282006622293, -8.31271480224241],
          [30.467631127716043, -8.364348183913735],
          [30.446345116973855, -8.48117735665424],
          [30.460764672637918, -8.48117735665424],
          [30.476557519317605, -8.492722505412841],
          [30.470377709747293, -8.508341859573436],
          [30.49166372048948, -8.527355865672218],
          [30.53560903298948, -8.518528051798931],
          [30.539728906036355, -8.507662770455477],
          [30.57680776345823, -8.513774529161749],
          [30.569254662872293, -8.549084999798058],
          [30.545908715606668, -8.561307093578794],
          [30.523936059356668, -8.58914484117636],
          [30.539042260528543, -8.606118075395651],
```

```
187             [30.56856801736448, -8.585750103146765],
188             [30.592600610137918, -8.579639498173789],
189             [30.618693139434793, -8.561307093578794],
190             [30.629679467559793, -8.540936719499676],
191             [30.640665795684793, -8.540257688283548],
192             [30.668818261505105, -8.513095449679177],
193             [30.642039086700418, -8.509020947487288],
194             [30.664011742950418, -8.485252154675283],
195             [30.688730981231668, -8.49136427063811],
196             [30.677058007598855, -8.509020947487288],
197             [30.674311425567605, -8.52871397278801],
198             [30.687357690216043, -8.540257688283548],
199             [30.725809838653543, -8.534825395057025],
200             [30.729243066192605, -8.56945493808653],
201             [30.784861352325418, -8.56606002408425],
202             [30.812447144147963, -8.592460112666487],
203             [31.043160034772963, -8.812371895518716],
204             [31.120064331647963, -8.758084726532601],
205             [31.142036987897963, -8.7173641461285],
206             [31.183235718366713, -8.755370159645235],
207             [31.199715210554213, -8.733652911971541],
208             [31.185982300397963, -8.649486659885723],
209             [31.131050659772963, -8.49196393153581],
210             [31.158516480085463, -8.383289807117826],
211             [31.092598511335463, -8.3724207171939],
212             [30.999214722272963, -8.258277024388189],
213             [30.910294457421063, -8.023412123153664],
214             [30.844376488671063, -7.963574416708003],
215             [30.844376488671063, -7.917330197102975],
216             [30.785324974999188, -7.822105196309102],
217             [30.719407006249188, -7.669700069761832],
218             [30.58673612457427, -7.502475221427068]]]);
```

Annexe C Script GEE utilisé pour extraire les données

C.1 Cartes mensuelles

```
//Fonction utilisée pour découper les limites du lac Tanganyika
var lac = function(image){
  return image.clip(PolyTang)};

//Définition des années de départ et de fin de la période d'étude et création d'une liste des années considérées
var startYr = 2000;
var endYr = 2021;
var yearList = ee.List.sequence({
  start:startYr,
  end:endYr,
  step:1});

//Création des dates de début et de fin de la période d'étude
var startDate = ee.Date.fromYMD(startYr,03,01); // Première date = 1 mars 2000, mars 2000 est le premier mois de données disponibles
var endDate = ee.Date.fromYMD(endYr+1,01,01); // Dernière date = 31 décembre 2021
 print('Start and end date', startDate, endDate);

//Collectes des images MODIS Aqua sur le lac
var modisA = ee.ImageCollection('NASA/OCEANDATA/MODIS-Aqua/L3SMI').map(lac);
//Collectes des images MODIS Terra sur le lac
var modisT = ee.ImageCollection('NASA/OCEANDATA/MODIS-Terra/L3SMI').map(lac);
// Fusion des collections d'images MODIS Aqua et Terra
var modisAT = modisA.merge(modisT);

// Choix du mois observé, trie en fonction des jours de l'année (DOY = day of the year)
// Changer de ligne selon le mois d'intérêt (exemple ici pour le mois de janvier)
 var DOYofinterest = ee.Filter.dayOfYear(1,31); //Janvier
// var DOYofinterest = ee.Filter.dayOfYear(32,59); // Février (Hypothèse de travail : années bisextiles négligeables, tous les mois de février comptent 28 jours)
// var DOYofinterest = ee.Filter.dayOfYear(60,90); // Mars
// var DOYofinterest = ee.Filter.dayOfYear(91,120); // Avril
// var DOYofinterest = ee.Filter.dayOfYear(121,160); // Mai
// var DOYofinterest = ee.Filter.dayOfYear(161,181); // Juin
// var DOYofinterest = ee.Filter.dayOfYear(182,212); // Juillet
// var DOYofinterest = ee.Filter.dayOfYear(213,243); // Août
// var DOYofinterest = ee.Filter.dayOfYear(244,273); // Septembre
```

```
// var DOYofinterest = ee.Filter.dayOfYear(274,304); // Octobre
// var DOYofinterest = ee.Filter.dayOfYear(305,334); // Novembre
// var DOYofinterest = ee.Filter.dayOfYear(335,365); // Décembre

//Filtration des données MODIS Aqua et Terra avec les dates de début et de fin, en gardant uniquement les images du mois choisi. Seule la bande de chlorophylle-A présente dans les produits MODIS est séléctionnée.
var data = modisAT.filterDate(startDate, endDate)
                  .filter(DOYofinterest)
                  .select('chlor_a');
print(data, 'Données MODIS AQUA et TERRA pour le mois considéré entre 2000 et 2021');
// Fonction permettant de trier les données en fonction du nombre de pixels couvrant le lac Tanganyika
// Retrait des données comptant moins de 100 pixels sur l'entièreté du lac
function pixels (image){
  var pixelscount = image.reduceRegion({
    reducer: ee.Reducer.count(),
    geometry: PolyTang,
    scale: 5000,
    maxPixels: 1e9
  }).get('chlor_a');
  var pixcount = ee.Number(pixelscount);
  return image.set('pixcount', pixcount)}

//Application du fitre sur les données
var data_filtered = data
    .map(pixels)
    .filterMetadata('pixcount', 'greater_than', 100);
print(data_filtered);

//Utilisation d'une palette de couleur crée par Gennadii Donchyts en 2018 pour observer les données sur cartes
//Copyright (c) 2018 Gennadii Donchyts. All rights reserved.
var palettes = require('users/gena/packages:palettes')

// Réalisation d'une carte composite montrant une donnée de concentration en chlorophylle-A médiane pour chaque pixel
var compositemedianCHL = data_filtered.median();
Map.setCenter(29.327, -5.275, 7);
Map.addLayer(compositemedianCHL, {min:0, max:5, palette: palettes.cmocean.Algae[7]}, 'MODISATmedianGlobal');
// Export des données dans un dossier sur Google Drive
Export.image.toDrive({
  image: compositemedianCHL,
  description: 'MODISATmedianGlobal1',
  region: PolyTang,
```

```
76    folder: 'Tanganyika',
77    scale: 5000});
78
79  // Réalisation d'une carte composite montrant l'intervalle interquartile des
        concentrations en chlorophylle-A pour chaque pixel
80  //L'intervalle interquartile est calculé avec percentil 75- percentil 25
81  var p25 = data_filtered.reduce(ee.Reducer.percentile([25]));
82  print(p25, 'p25');
83  Map.addLayer(p25, {min:0, max:5, palette:  palettes.cmocean.Algae[7]}, 'p25');
84  var p75 = data_filtered.reduce(ee.Reducer.percentile([75]));
85  print(p75, 'p75');
86  Map.addLayer(p75, {min:0, max:10, palette: palettes.cmocean.Algae[7]},'p75');
87  var IQR = p75.subtract(p25);
88  print(IQR, 'IQR');
89  Map.setCenter(29.327, -5.275, 7);
90  Map.addLayer(IQR, {min:0, max:10, palette: palettes.cmocean.Algae[7]}, '
        MODISATIQRGlobal');
91  // Export des données dans un dossier sur Google Drive
92  Export.image.toDrive({
93    image: IQR,
94    description: 'MODISATIQRGlobal1',
95    region: PolyTang,
96    folder: 'Tanganyika',
97    scale: 5000});
98
99  // Réalisation d'une carte composite montrant le nombre de données collectées
        par pixel
100 var nbpixel = data_filtered.map(lac).reduce(ee.Reducer.count());
101 Map.setCenter(29.327, -5.275, 7);
102 Map.addLayer(nbpixel, {min:0, max:900, palette: palettes.colorbrewer.Blues
        [9]}, 'MODISATpixGlobal');
103 // Export des données dans un dossier sur Google Drive
104 Export.image.toDrive({
105   image: nbpixel,
106   description: 'MODISATpixGlobal1',
107   region: PolyTang,
108   folder: 'Tanganyika',
109   scale: 5000});
```

C.2 Evolution temporelle de la chlorophylle-A par zone

Ce script est également utilisé pour extraire les concentrations médianes en chlorophylle-A sur les zones de Kigoma et Mpulungu.

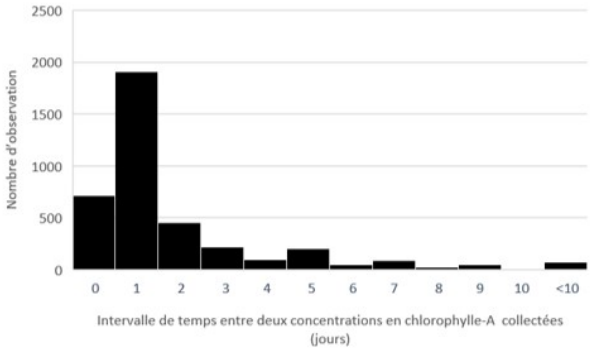
```
//Collecte des données de MODIS Aqua

// Import des concentrations en chlorophylle-A de la bande "chlor_a" de MODIS Aqua et Terra et filtration des dates
// La période de mars 2000 à décembre 2021 doit être découpée en différents intervalles de temps, étant donné le grand nombre de données, afin de pouvoir collecter l'ensemble des données
var modisA = ee.ImageCollection('NASA/OCEANDATA/MODIS-Aqua/L3SMI')
  .filterDate('2000-03-01', '2002-07-04') // Date de fin non compris
  //.filterDate('2002-07-04', '2007-01-01')
  //.filterDate('2007-01-01', '2012-01-01')
  //.filterDate('2012-01-01', '2017-01-01')
  //.filterDate('2017-01-01', '2022-01-01')
  //.filterDate('2002-03-01', '2006-08-01') // dates utilisées pour les observations réalisées à Mpulunfu et Kigoma lors de la comparaison avec des données in-situ
  .select('chlor_a'); // sélection de la bande de chlorophylle-A
print(modisA, 'MODIS AQUA data')

//Conversion de l'identifiant des données par des dates
var MODA = modisA.map(
function adddateA (image){
var dA = image.select('chlor_a');
        var dateA = ee.Date(image.get('system:time_start'));
        var monthA = dateA.get('month');
        var yearA = dateA.get('year');
  return dA.set('month', monthA)
    .set('year',yearA).set('system:time_start', dateA);
});

// Observation sous forme graphique des données provenant de MODIS Aqua uniquement.
var graphmodisA = ui.Chart.image.series({
  imageCollection: MODA,
  region: PolyTang, //PolyTangN, //PolyTangS, //PolyTangC, //Kig4km, //Mpu4km,
  reducer: ee.Reducer.median(),
  scale: 5000,
  xProperty: 'system:time_start'})
 .setOptions({
  titlePostion: 'none',
  legend: {position: 'none'},
  hAxis: {title: 'Time'},
```

```
37    vAxis: {title: 'MODIS Aqua ChloA median [mg/m ]'},
38    series: {0: {color: '23cba7'}}});
39  print(graphmodisA, 'graphmodisA');
40  //-------------------------------------------------------------------------
41  // Collecte des données de MODIS Terra
42
43  // Import des concentrations en chlorophylle-A de la bande "chlor_a" de MODIS
        Terra et Terra et filtration des dates
44  var modisT = ee.ImageCollection('NASA/OCEANDATA/MODIS-Terra/L3SMI')
45    .filterDate('2000-03-01', '2002-07-04')
46    //.filterDate('2002-07-04', '2007-01-01')
47    //.filterDate('2007-01-01', '2012-01-01')
48    //.filterDate('2012-01-01', '2017-01-01')
49    //.filterDate('2017-01-01', '2022-01-01')
50    //.filterDate('2002-03-01', '2006-08-01') // pour Mpulungu et Kigoma
51    .select('chlor_a');
52  print(modisT, 'MODIS TERRA data')
53
54  //Conversion de l'identifiant des données par des dates
55  var MODT = modisT.map(
56  function adddateT (image){
57  var dT = image.select('chlor_a');
58          var dateT = ee.Date(image.get('system:time_start'));
59          var monthT = dateT.get('month');
60          var yearT = dateT.get('year');
61    return dT.set('month', monthT)
62       .set('year',yearT).set('system:time_start', dateT);
63  });
64
65  // Observation sous forme graphique des données provenant de MODIS Terra
        uniquement.
66  var graphmodisT = ui.Chart.image.series({
67    imageCollection: MODT,
68    region: PolyTang, //PolyTangN, //PolyTangS, //PolyTangC, //Kig4km, //Mpu4km,
69    reducer: ee.Reducer.median(),
70    scale: 5000,
71    xProperty: 'system:time_start'})
72   .setOptions({
73    titlePostion: 'none',
74    legend: {position: 'none'},
75    hAxis: {title: 'Time'},
76    vAxis: {title: 'MODIS Terra ChloA median [mg/m ]'},
77    series: {0: {color: '23cba7'}}});
78  print(graphmodisT, 'graphmodisT');
79  //-------------------------------------------------------------------------
80  //Fusion des 2 collections d'images, fitration des données et création de
        graphiques
```

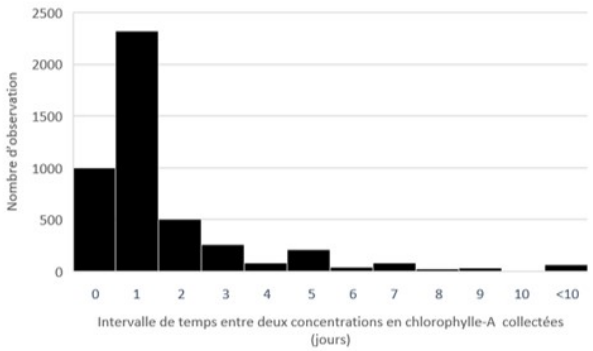
```
81
82 // Fusion des 2 collections d'images (Aqua + Terra)
83 var MODAT = MODA.merge(MODT);
84 print(MODAT, 'MODIS AQUA and TERRA data')
85
86 // Fonction permettant de trier les données en fonction du nombre de pixels
       couvrant le lac Tanganyika
87 // Retrait des données comptant moins de 100 pixels sur la totalité du lac
88 function pixels (image){
89   var pixelscount = image.reduceRegion({
90     reducer: ee.Reducer.count(),
91     geometry: PolyTang, // uniquement lorsqu'on observe la totalité du lac!
92     scale: 5000,
93     maxPixels: 1e9
94   }).get('chlor_a');
95   var pixcount = ee.Number(pixelscount);
96   return image.set('pixcount', pixcount);
97 }
98
99 //Application de la fonction sur les données
100 var MODAT_filtered = MODAT
101     .map(pixels)
102     .filterMetadata('pixcount', 'greater_than', 100);
103 print(MODAT_filtered, 'Données MODIS AQUA et TERRA contenant plus de 100
       pixels');
104
105 //Graphique contenant les données médianes de concentration en chlorophylle-A
       provenant de MODIS Aqua et Terra. La médiane est réalisée sur la zone
       considérée.
106 var graphmodisATmedian = ui.Chart.image.series({
107   imageCollection: MODAT_filtered,
108   region: PolyTang, //PolyTangN, //PolyTangS, //PolyTangC, //Kig4km, //Mpu4km,
109   reducer: ee.Reducer.median(),
110   scale: 5000,
111   xProperty: 'system:time_start'})
112  .setOptions({
113   titlePostion: 'none',
114   legend: {position: 'none'},
115   hAxis: {title: 'Time'},
116   vAxis: {title: 'ChloA median [mg/m ]'},
117   series: {0: {color: '23cba7'}}});
118 print(graphmodisATmedian, 'Concentrations en chlo-A médiane provenant de MODIS
       AQUA et TERRA');
119
120 // Graphique contenant les données de MODIS Aqua et Terra montrant le nombre
       de pixels collectés par image.
121 var graphpixelcount = ui.Chart.image.series({
```

```
122     imageCollection: MODAT_filtered,
123     region: PolyTang, //PolyTangN, //PolyTangS, //PolyTangC, //Kig4km, //Mpu4km,
124     reducer: ee.Reducer.count(),
125     scale: 5000,
126     xProperty: 'system:time_start'})
127   .setOptions({
128     titlePostion: 'none',
129     legend: {position: 'none'},
130     hAxis: {title: 'Time'},
131     vAxis: {title: 'Nombre de pixel'},
132     series: {0: {color: '23cba7'}}});
133   print(graphpixelcount, 'Nombre de pixels collectés par image provenant de
        MODIS AQUA et TERRA');
```

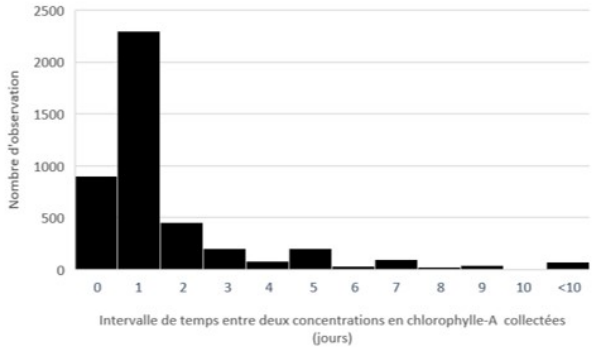
Annexe D Chlorophylle-A



(a) Zone nord

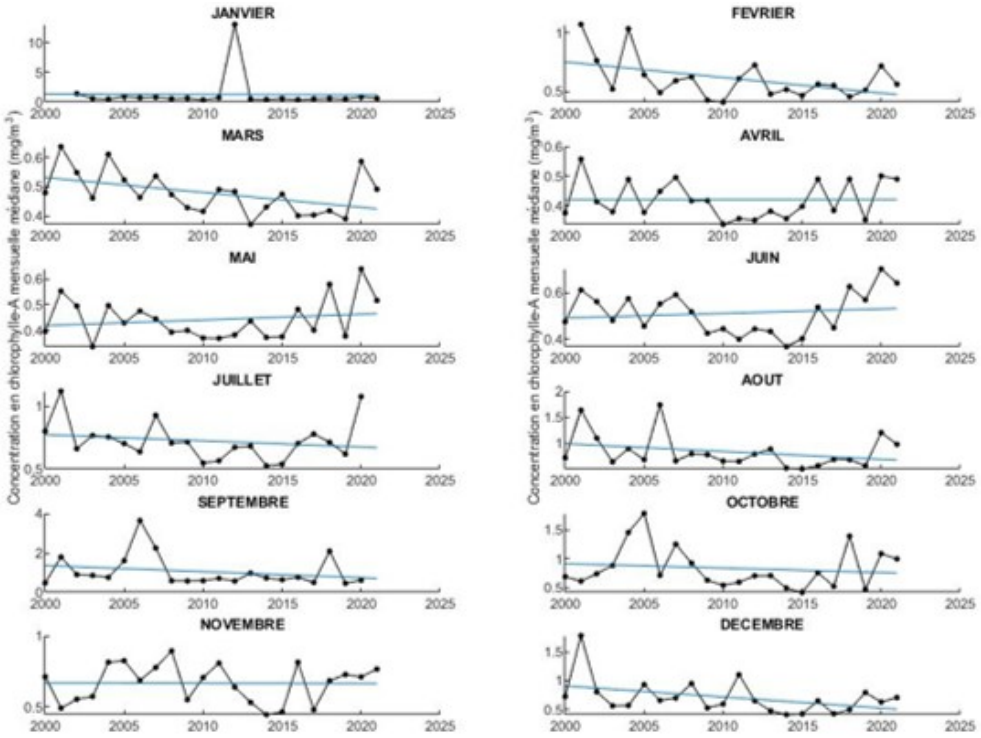


(b) Zone centrale

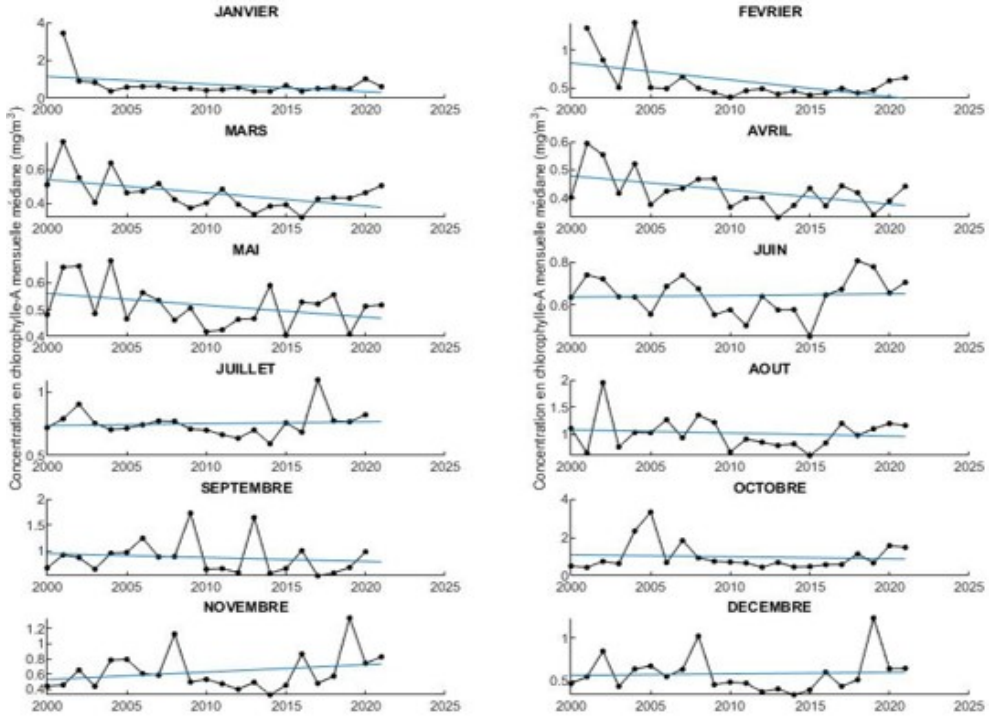


(c) Zone sud

FIGURE 28 – Intervalle de temps observé entre deux données collectées. Grâce à la combinaison des données de MODIS Aqua et Terra jusqu'à deux données par jour peuvent être observées, correspondant alors à un intervalle de zéro jour.

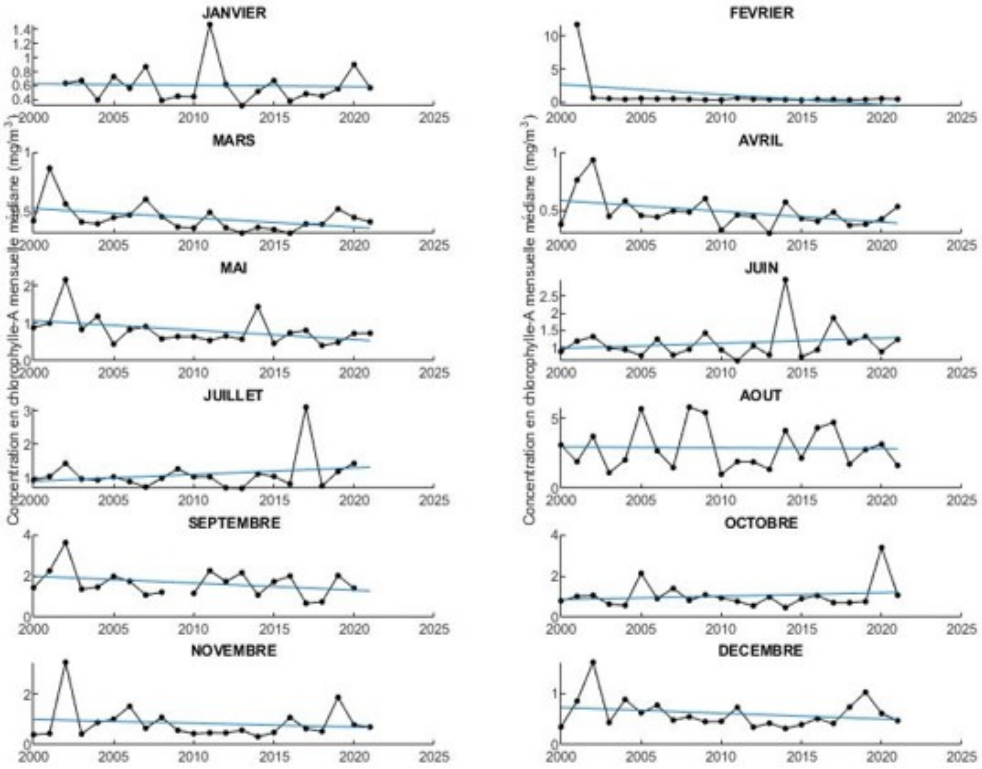


(a) Zone nord



(b) Zone centrale

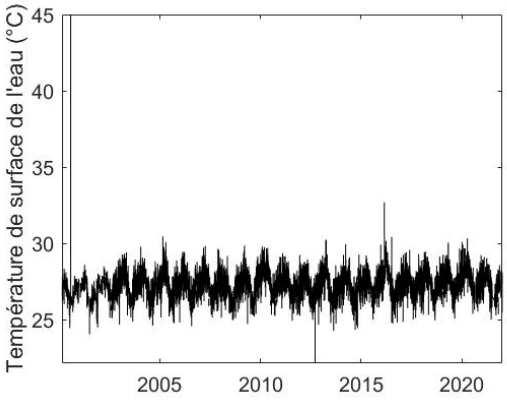
FIGURE 29 – Évolution des concentrations mensuelles médianes en chlorophylle-A entre 2000 et 2021.



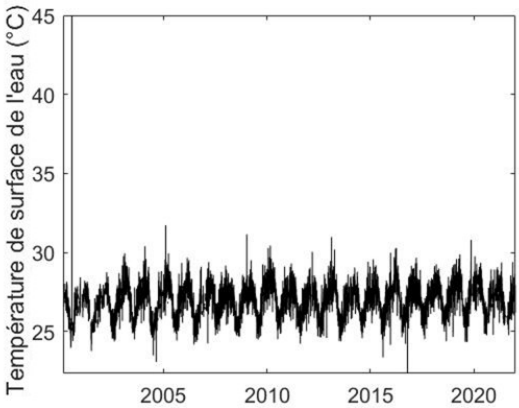
(c) Zone sud

FIGURE 29 – Évolution des concentrations mensuelles médianes en chlorophylle-A entre 2000 et 2021 (suite).

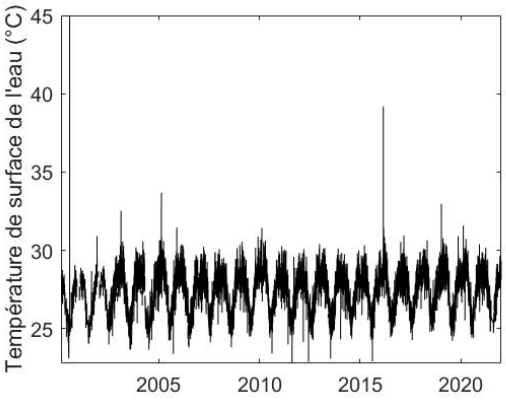
Annexe E Température de surface de l'eau par zone



(a) Zone nord du lac

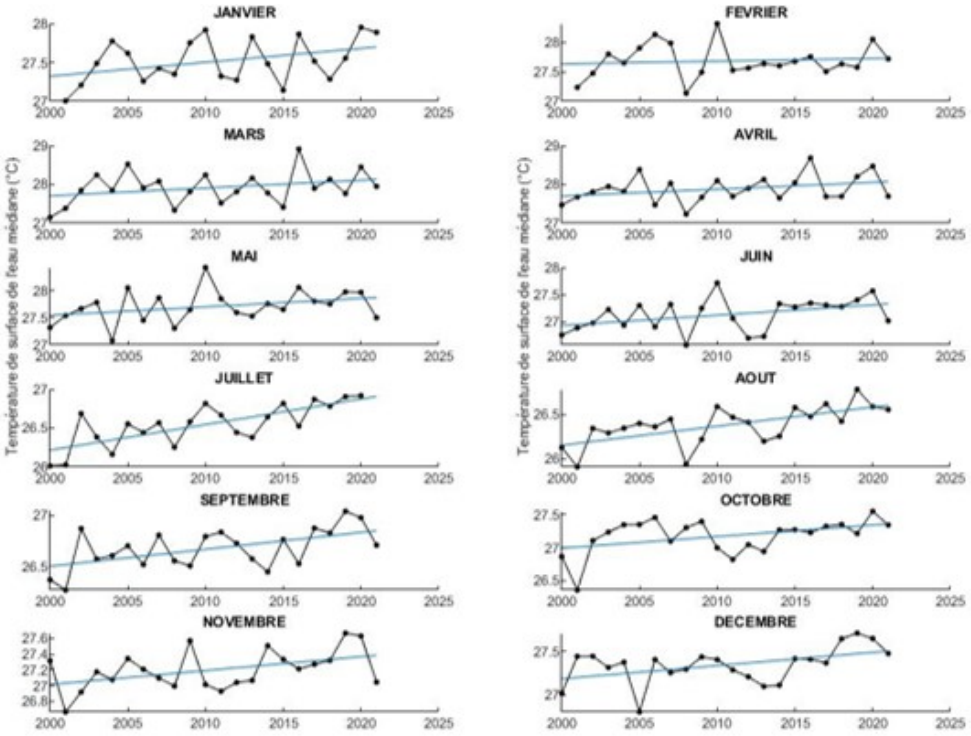


(b) Zone centrale du lac

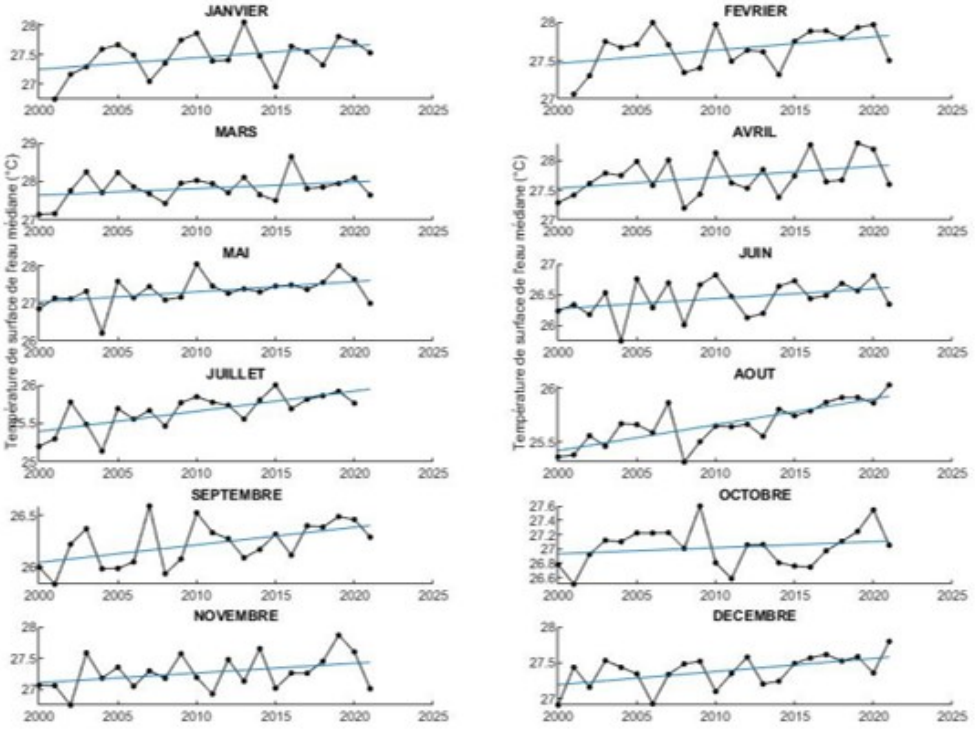


(c) Zone sud du lac

FIGURE 30 – Évolution des températures de surface de l'eau médianes par zone entre 2000 et 2021.

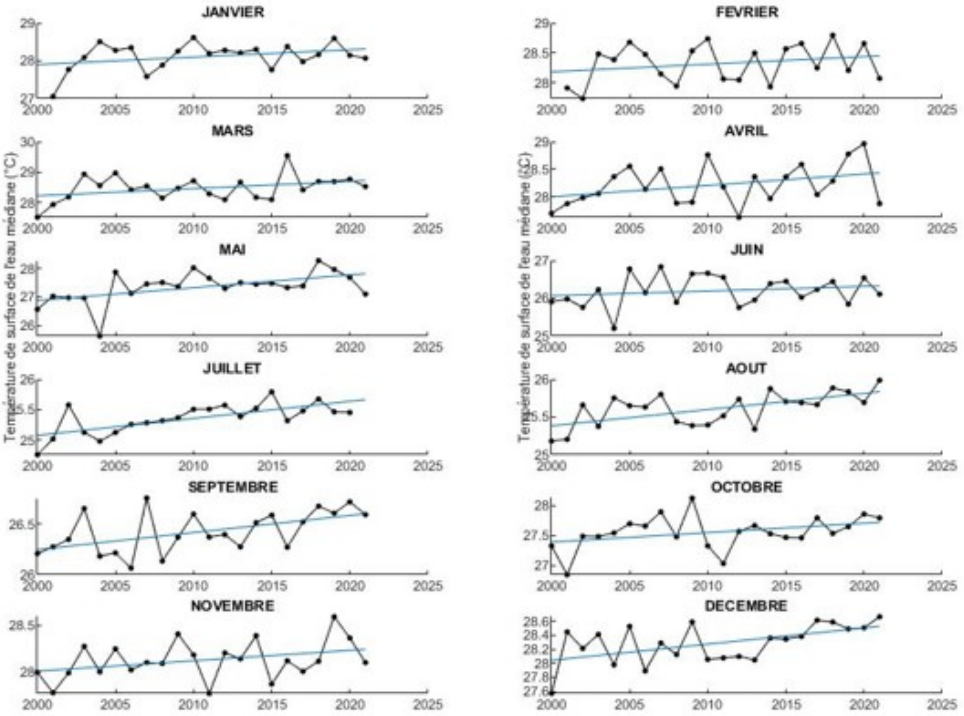


(a) Zone nord



(b) Zone centrale

FIGURE 31 – Évolution des températures de surface de l'eau mensuelles médianes par zone entre 2000 et 2021.



(c) Zone sud

FIGURE 31 – Évolution des températures de surface de l'eau mensuelles médianes par zone entre 2000 et 2021 (suite).