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CMOD4 MODEL DESCRIPTION

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Chapter 1 Introduction

This short document is aimed at presenting the backscatter model CMOD4 as implemented in the LRDPF version 4.0.

This version has been activated in all station 24 February 1993 starting with the first orbit processed at Kiruna station.

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Change Record

Issue	Date	Pages	Description of change
0.0	2/1/93	all	Draft issue
1.0	2/10/93	all	First issue
1.1	2/16/93	5	Typo in formula
1.2	3/12/93	1 2 2 and 4 2 5 7 7 8 - 12	Installation date corrected. 10logy substituted by $\log_{10}(y)$ sign in the following formula; $\varepsilon = \tanh(2.5(P1 + 0.35)) - (0.61(P1 + 0.35))$ Typo if $V + \beta > 5$ subsituted by elseif $V + \beta > 5$ THETA = THDEG/DTOR THETP = (THETA - THETM) / THETHR Correction of wind direction definition in the table (the wind direction is the direction where the wind is blowing from).

Chapter 2 Analytical form of CMOD4

This model CMOD6-E1, originating from ECMWF, has been renamed CMOD4.

Its form is :

$$\sigma^{\circ} = b0\,(1 + b1\cos\varphi + b3\tanh(b2)\cos(2\varphi))^{1.6}$$

where :,

$$b0 = \delta \times 10^{\alpha + \gamma \cdot \mathcal{F}^1 (V+\beta)}$$

and:,

$$\mathcal{F}^1(y) = \begin{cases} 0 & if(y \le 0) \\ \log_{10}(y) & if(0 < y \le 5) \\ \dfrac{\sqrt{y}}{3.2} & if(y > 5) \end{cases}$$

δ is a 1 degree resolution bias table defined between 17 and 58 degrees of incidence angle. This bias correction is described in table 1, and α, β,γ and $b1$,$b2$,$b3$ are expanded as combinations of Legendre polynomials as follows :

$$\alpha = c1 + c2 \times P1 + c3 \times P2$$

$$\gamma = c4 + c5 \times P1 + c6 \times P2$$

$$\beta = c7 + c8 \times P1 + c9 \times P2$$

$$b1 = (c10 + c11 \times V) + \varepsilon\,(c12 + c13 \times V)$$

where :

$$\varepsilon = \tanh(2.5\,(P1 + 0.35)) - (0.61\,(P1 + 0.35))$$

$$b2 = c14 + c15 \times (1 + P1) \times V$$

$$b3 = 0.42 \times (1 + c16\,(c17 + P1)\,(c18 + V))$$

The Legendre Polynomials of order 1 and 2 are :

$$P1 = \frac{\theta - 40.}{25.}$$

$$P2 = \frac{(3P1^2 - 1)}{2}$$

In these equations,

V	Is the wind speed in m/s,
φ	the relative radar look -wind in degree,i.e. that this angle is zero when the wind is blowing towards the radar,
θ	the incidence angle in degree.

Incidence Angle	Bias	Incidence Angle	Bias
17.0	1.075	38.0	0.978
18.0	1.075	39.0	0.988
19.0	1.072	40.0	0.998
20.0	1.069	41.0	1.009
21.0	1.066	42.0	1.021
22.0	1.056	43.0	1.033
23.0	1.030	44.0	1.042
24.0	1.004	45.0	1.050
25.0	0.979	46.0	1.054
26.0	0.967	47.0	1.053
27.0	0.958	48.0	1.052
28.0	0.949	49.0	1.047
29.0	0.941	50.0	1.038
30.0	0.934	51.0	1.028
31.0	0.927	52.0	1.016
32.0	0.923	53.0	1.002
33.0	0.930	54.0	0.989
34.0	0.937	55.0	0.965
35.0	0.944	56.0	0.941
36.0	0.955	57.0	0.929
37.0	0.967	58.0	0.929

Table 1: Bias correction

The above coefficient are :

$c1 = -2.301523$ $c2 = -1.632686$ $c3 = 0.761210$
$c4 = 1.156619$ $c5 = 0.595955$ $c6 = -0.293819$
$c7 = -1.015244$ $c8 = 0.342175$ $c9 = -0.500786$
$c10 = 0.014430$ $c11 = 0.002484$
$c12 = 0.074450$ $c13 = 0.004023$
$c14 = 0.148810$ $c15 = 0.089286$
$c16 = -0.006667$ $c17 = 3.000000$ $c18 = -10.000000$

Chapter 3 PDL Code Description

3.1 Code in PDL

PDL code description in order to generate the table given in chapter 4.2

Initiate Cmod 4 model data array C(18)

Initiate Swath bias correction array $\delta(\theta)$

Loop for all beam incidence angles θ

Define θ dependent variables

$$P_0 = 1$$
$$P_1 = \frac{\theta - 40}{25}$$
$$P_2 = \frac{3P_1^2 - 1}{2}$$

Define velocity dependant intermediate variable for b_0

$$\alpha = c_1 \cdot P_0 + c_2 \cdot P_1 + c_3 \cdot P_2$$
$$\gamma = c_4 \cdot P_0 + c_5 \cdot P_1 + c_6 \cdot P_2$$
$$\beta = c_7 \cdot P_0 + c_8 \cdot P_1 + c_9 \cdot P_2$$

Define velocity independent intermediate variable for b_1

$$\varepsilon = \tanh(2.5 \cdot (P_1 + 0.35)) - 0.61 \cdot (P_1 + 0.35) \;;$$

Loop over all wind directions φ

Loop over all wind speeds V

Define major variables

$$\text{if } V + \beta \le 0 \text{ then } b_0 = \delta_\theta \times 10^{\alpha}$$

elseif $V+\beta>5$ then $b_0 = \delta_\theta \times 10^{\alpha+\gamma\cdot\frac{\sqrt{V+\beta}}{3.2}}$

else $b_0 = \delta_\theta \times 10^{\alpha} \times (V+\beta)^{\gamma}$

$$b_1 = (c_{10} + c_{11}\cdot V) + \varepsilon\cdot(c_{12} + c_{13}\cdot V)$$

$$b_2 = c_{14}P_0 + c_{15}\cdot(1+P_1)\cdot V$$

$$b = 0.42\cdot(1 + c_{16}\cdot(c_{17}+P_1)\cdot(c_{18}+V))$$

Calculate $\sigma^0(\theta, \varphi, V)$

$$\sigma^0 = b_0(1 + b_1\cdot\cos(\varphi) + b_3\cdot\tanh(b_2)\cdot\cos(2\varphi))^{1.6}$$

Close V loop

Close φ loop

Close θ loop

Write out σ^0 array.

Chapter 4 Implementation in Fortran

4.1 Code as a Fortran function

```
C
C
      FUNCTION cmod_Zad( V,D,THDEG,AZM,KBEAM,PCOEF)
      DIMENSION PCOEF(18)
C
C ALF LONG ESTEC
C AD STOFFELEN ECMWF 03/05/91
C
C THE FUNCTIONAL FORM OF THE MODEL RELATING WIND DATA TO RADAR
C RESPONSES. ASSUMES THE PARAMETER STRUCTURE DEFINED BELOW.
C V WIND SPEED                                      (M/S)
C D ANGLE WIND WRT NORTH                            (DEGREES)
C AZM BEAM POINTING  WRT NORTH                      (DEGREES)
C THDEG BEAM INCIDENCE ANGLE                        (DEGREES)
C P(NPAR) MODEL PARAMETERS VECTOR
C SIGMOD RADAR RESPONSE                             (LINEAR)
C PCOEF(18) TRANSFER MODEL COEFFICIENTS
C-----------------------------------------------------------------
      PARAMETER ( DTOR = 57.29577951,
     & THETM = 40/DTOR,
     & THETHR = 25/DTOR )
      REAL V , FI ,  , D , AZM ,
     & P0,P1,P2,P3, GAM, ALPH,
     & THSQ , THETP ,
     & CSFI , CS2FI,
     & B0,B1,B2
      dimension rbias(17:58)
      data rbias /
c17 :
     +  1.075, 1.075, 1.072, 1.069
     +  ,1.066, 1.056, 1.030, 1.004, 0.979
c26 :
     +  ,0.967 ,0.958, 0.949, 0.941, 0.934
     +  ,0.927 ,0.923, 0.930, 0.937, 0.944
c36 :
     +  ,0.955 ,0.967, 0.978, 0.988, 0.998
     +  ,1.009 ,1.021, 1.033, 1.042, 1.050
c46 :
     +  ,1.054 ,1.053, 1.052, 1.047, 1.038
     +  ,1.028 ,1.016, 1.002, 0.989, 0.965
```

```
c56 :
     +   ,0.941 ,0.929 ,0.929 /
C
C 1. ANGLES WRT ERS1 BEAM AND IN RADIANS
C
         FI=D - AZM
         FI=FI/DTOR
C
C 2. CALCULATE LEGENDRE TERMS P0 TO P3 AT ARGUMENT THETP(NORMALISED)
C
         THETA = THDEG/DTOR
         THETP = (THETA - THETM) / THETHR
         THSQ = THETP*THETP
         P0 = 1.0
         P1 = THETP
         P2 = (3.0*THSQ-1.0)/2.0
         CSFI = COS(FI)
         CS2FI= 2.00 * CSFI * CSFI - 1.00
C
C 3. CALCULATE TERMS IN  AND IN THE END
C
         ALPH = PCOEF( 1) + PCOEF( 2)*P1 + PCOEF( 3)*P2
         GAM = PCOEF( 4) + PCOEF( 5)*P1 + PCOEF( 6)*P2
         zp1str = P1 + 0.35
         ztnhb1 = exp( -5.*zp1str )
         ztnhb1 = (1. - ztnhb1 )/(1. + ztnhb1) - 0.61*zp1str
         B1 = PCOEF(10) + PCOEF(11)*V
     +   + (PCOEF(12) + PCOEF(13)*V)*ztnhb1
         zspm = V
         zspm = zspm +
     +   PCOEF( 7) + PCOEF( 8)*P1 + PCOEF( 9)*P2
         if( zspm.le.0.0 )then
                 B0 = .000001
         elseif( zspm.gt. 5. )then
                 B0 = 10.**( GAM*sqrt(zspm)/3.20 + ALPH )
         else
                 B0 = zspm**GAM * 10.0**ALPH
         endif
C
C Interpolate bias in physical space ( log(1+x) = x assumption, but dx < 2 % )
C ( max. error < 0.02 % )
C
         ith1 = int( THDEG )
         ith1 = min( max( ith1, 17 ) , 57 )
         zw2 = THDEG - real( ith1 )
         zw1 = 1. - zw2
         zbias = zw1*rbias(ith1) + zw2*rbias(ith1+1)
         B0 = B0*zbias
         B2 = PCOEF(14)
```

```
     +  + (PCOEF(15) + PCOEF(15)*P1)*V
        zexpmn = exp(-2*B2)
        ztnhb2 = ( 1. - zexpmn )/( 1. + zexpmn )
        B2 = 0.420 * ztnhb2
     +  * ( PCOEF(16)*(PCOEF(17) + THETP)*(PCOEF(18) + V) + 1. )
        ztanh = 1.60
        zharm = abs(1.0 + B1*CSFI + B2*CS2FI)
        cmod_Zad = B0*zharm**ztanh
C
C
        RETURN
        END
C
```

4.2 Results of Fortran Function

This table gives some samples of sigma naught computed with CMOD_4. In this table, the wind direction is measured up wind. 0 degree correspond to a wind blowing along the beam, toward the antenna.

Speed (m/s)	Direction (degrees)	Incidence Angle (degrees)	Sigma 0 (linear scale)
1.0	0.0	17.0	0.0000012
7.0	0.0	17.0	1.3618497
13.0	0.0	17.0	1.8543721
19.0	0.0	17.0	2.3379886
25.0	0.0	17.0	2.8307469
31.0	0.0	17.0	3.3360467
37.0	0.0	17.0	3.8530095
43.0	0.0	17.0	4.3788843
49.0	0.0	17.0	4.9099154
55.0	0.0	17.0	5.4417453
1.0	60.0	17.0	0.0000010
7.0	60.0	17.0	1.1301798
13.0	60.0	17.0	1.5029413
19.0	60.0	17.0	1.8645495
25.0	60.0	17.0	2.2376523

Speed (m/s)	Direction (degrees)	Incidence Angle (degrees)	Sigma 0 (linear scale)
31.0	60.0	17.0	2.6324744
37.0	60.0	17.0	3.0559995
43.0	60.0	17.0	3.5140944
49.0	60.0	17.0	4.0122399
55.0	60.0	17.0	4.5558405
1.0	120.0	17.0	0.0000010
7.0	120.0	17.0	1.1762400
13.0	120.0	17.0	1.5597858
19.0	120.0	17.0	1.9294542
25.0	120.0	17.0	2.3086598
31.0	120.0	17.0	2.7077839
37.0	120.0	17.0	3.1337779
43.0	120.0	17.0	3.5923848
49.0	120.0	17.0	4.0889039
55.0	120.0	17.0	4.6285114
1.0	180.0	17.0	0.0000012
7.0	180.0	17.0	1.4612162
13.0	180.0	17.0	1.9780250
19.0	180.0	17.0	2.4799590
25.0	180.0	17.0	2.9865086
31.0	180.0	17.0	3.5012846
37.0	180.0	17.0	4.0232716
43.0	180.0	17.0	4.5494533
49.0	180.0	17.0	5.0757499
55.0	180.0	17.0	5.5974641
1.0	0.0	37.0	0.0005172
7.0	0.0	37.0	0.0468635
13.0	0.0	37.0	0.1249496

Speed (m/s)	Direction (degrees)	Incidence Angle (degrees)	Sigma 0 (linear scale)
19.0	0.0	37.0	0.2528330
25.0	0.0	37.0	0.4460009
31.0	0.0	37.0	0.7261118
37.0	0.0	37.0	1.1209614
43.0	0.0	37.0	1.6647769
49.0	0.0	37.0	2.3989720
55.0	0.0	37.0	3.3731883
1.0	60.0	37.0	0.0003891
7.0	60.0	37.0	0.0248808
13.0	60.0	37.0	0.0584895
19.0	60.0	37.0	0.1186747
25.0	60.0	37.0	0.2217945
31.0	60.0	37.0	0.3901611
37.0	60.0	37.0	0.6546178
43.0	60.0	37.0	1.0576098
49.0	60.0	37.0	1.6569070
55.0	60.0	37.0	2.5302336
1.0	120.0	37.0	0.0003595
7.0	120.0	37.0	0.0218332
13.0	120.0	37.0	0.0487911
19.0	120.0	37.0	0.0945820
25.0	120.0	37.0	0.1696611
31.0	120.0	37.0	0.2874062
37.0	120.0	37.0	0.4655034
43.0	120.0	37.0	0.7274413
49.0	120.0	37.0	1.1041948
55.0	120.0	37.0	1.6362375
1.0	180.0	37.0	0.0004521

Speed (m/s)	Direction (degrees)	Incidence Angle (degrees)	Sigma 0 (linear scale)
7.0	180.0	37.0	0.0392010
13.0	180.0	37.0	0.0993822
19.0	180.0	37.0	0.1895260
25.0	180.0	37.0	0.3125326
31.0	180.0	37.0	0.4721096
37.0	180.0	37.0	0.6712149
43.0	180.0	37.0	0.9106337
49.0	180.0	37.0	1.1877812
55.0	180.0	37.0	1.4955605
1.0	0.0	57.0	0.0000278
7.0	0.0	57.0	0.0132653
13.0	0.0	57.0	0.0406131
19.0	0.0	57.0	0.0911603
25.0	0.0	57.0	0.1776706
31.0	0.0	57.0	0.3176034
37.0	0.0	57.0	0.5340723
43.0	0.0	57.0	0.8571554
49.0	0.0	57.0	1.3253309
55.0	0.0	57.0	1.9870034
1.0	60.0	57.0	0.0000192
7.0	60.0	57.0	0.0056413
13.0	60.0	57.0	0.0171430
19.0	60.0	57.0	0.0425301
25.0	60.0	57.0	0.0929727
31.0	60.0	57.0	0.1864668
37.0	60.0	57.0	0.3512844
43.0	60.0	57.0	0.6307268
49.0	60.0	57.0	1.0897410

Speed (m/s)	Direction (degrees)	Incidence Angle (degrees)	Sigma 0 (linear scale)
55.0	60.0	57.0	1.8240196
1.0	120.0	57.0	0.0000178
7.0	120.0	57.0	0.0049260
13.0	120.0	57.0	0.0142849
19.0	120.0	57.0	0.0340632
25.0	120.0	57.0	0.0718298
31.0	120.0	57.0	0.1393236
37.0	120.0	57.0	0.2543943
43.0	120.0	57.0	0.4435747
49.0	120.0	57.0	0.7455838
55.0	120.0	57.0	1.2160501
1.0	180.0	57.0	0.0000245
7.0	180.0	57.0	0.0113027
13.0	180.0	57.0	0.0327594
19.0	180.0	57.0	0.0688518
25.0	180.0	57.0	0.1246476
31.0	180.0	57.0	0.2052645
37.0	180.0	57.0	0.3149305
43.0	180.0	57.0	0.4558799
49.0	180.0	57.0	0.6268488
55.0	180.0	57.0	0.8211775