Report for IOMASA Deliverable 1.1:

Baseline data and algorithms for atmospheric sounding

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1 Baseline Data

The two-year offline study period, agreed upon at the Kick-off meeting: **2001-2002**.
Data available at IUP:

Sensor	**Type/Format**	**Source**	**Time period**
AMSU-A (NOAA-15,16)	lvl 1B	NOAA SAA	2000-2003
AMSU-B (NOAA-15,16)	lvl 1B	NOAA SAA	1999-2003
Radiosonde (stations)	TEMP	DMI	1996-2002 (Nov.)
Radiosonde (RV Polarstern)	ASCII	AWI	(research cruises since 1998)

As the data volume is very high (hundreds of GB), it is not meaningful to copy all data to media like CDs or DVDs and distribute them to all partners. They will be provided to partners upon request, on CD, DVD or via ftp.

AMSU-A and B level 1B data for the years 1998-2003 (from satellites NOAA-15 and 16) are stored at IUP on local hard disk. Total data volume is about 200GB. Processing software (AAPP) to convert to level 1C is available at IUP.

Radiosonde station data are stored at IUP on local hard disk and CD, and are also available at DMI. They are in TEMP format (World Meteorological Organization).

Radiosonde data from RV Polarstern of Alfred Wegener Institute, Bremerhaven, Germany, are routinely acquired during research cruises.

- Table of past Polarstern cruises (since 1998):
  http://www.awi-bremerhaven.de/php/ResearchPlatform/Display.php?year=∗&type=ship&name=polarstern
- Graphical Interface for Data from Polarstern:
  http://www.awi-bremerhaven.de/MET/Polarstern/GraphInter.html
- The instrument used is *Vaisala RS80* , and the data can be retrieved from the graphical interface at AWI in two types: mean pressure levels (100 profiles can be retrieved at a time) or full height resolution (5 profiles can be retrieved at a time)

Retrieved data are as ASCII tables, with some HTML-formatted description and a link to a quicklook of each profile. All retrieved profiles are in one file.
Moreover, there are data from Koldewey-Station, Svalbard, also available via web interface on AWI web site (http://www.awi-bremerhaven.de/MET/index.html) Some data also available within IUP, so they do not have to be downloaded from AWI.

2 Baseline Algorithms

2.1 Total Water Vapour

The total water vapour algorithm relies on a satellite radiometer (SSM/T2, AMSU-B) measurement of the brightness temperature at three different frequencies i, j, k at which the ground emissivity ε_s is similar but the water vapour absorption is different, $\kappa_i < \kappa_j < \kappa_k$.
Then the following relation can be derived [*Miao*, 1998; *Miao et al.*, 2001]

$$\log \eta_c = \ln \left(\frac{T_{b,i} - T_{b,j} - b_{ij}}{T_{b,j} - T_{b,k} - b_{jk}} \right) = c_0 + c_1 W \sec\theta \tag{1}$$

where the "bias" terms (b_{jk}, b_{ij})

$$b_{ij} \approx \int_0^H \left[\mathrm{e}^{\tau_i(z,H)\sec\theta} - \mathrm{e}^{\tau_j(z,H)\sec\theta} \right] \frac{\mathrm{d}T(z)}{\mathrm{d}z} \,\mathrm{d}z \tag{2}$$

contain the influence of the atmospheric temperature and water vapour profiles.
Equation (1) can be inverted to yield, in linear approximation:

$$W \sec\theta = C_0 + C_1 \log \eta_c \tag{3}$$

Miao [1998] has shown that this linear approximation is accurate enough to retrieve the TWV of the polar atmosphere. The constants C_0 and C_1 and the mean of the bias terms (b_{jk}, b_{ij}) have been determined by a regression using radiosonde profiles from Antarctica and simulated SSM/T2 brightness temperatures based on the radiosonde profiles [*Miao*, 1998].
The the humidity sounder SSM/T2 sensor has five channels, three of which are centered around the strong water vapour absorption line at 183.3 GHz; the other two are window channels at lower frequencies:

SSM/T2 channel	1	2	3	4	5
Frequency [GHz]	91.655	150.0	183.31±7	183.31±3	183.31±1

For low TWV values, SSM/T2 channels 3, 4 and 5 are used for TWV retrieval. For TWV values above about 1.5 kg/m^2, channel 5 becomes saturated (see Figure 1) i.e., $T_{b,5} - T_{b,4} > 0$ and thus η_c becomes negative and $\log \eta_c$ would be undefined. In that case, the algorithm switches over to using channels 2, 3 and 4.
The two different sets of constants (C_0, C_1) needed are determined by using only subsets of radiosonde profiles – one with TWV$<$ 1.5 kg/m^2, one with TWV$>$ 1.5 kg/m^2.
For the code of the algorithm, see appendix A on p. 4.

2.2 Cloud Liquid Water

The cloud liquid water (CLW) algorithm relies on satellite radiometer radiometer (SSM/I) measurement of the brightness temperature at two different frequencies, f_1, f_2, and both H and V polarisations. Then the so-called R-factor, $R(f_1, f_2)$, can be defined as

$$R(f_1, f_2) = \ln \frac{T_\mathrm{V}(f_1) - T_\mathrm{H}(f_1)}{T_\mathrm{V}(f_2) - T_\mathrm{H}(f_2)} \tag{4}$$

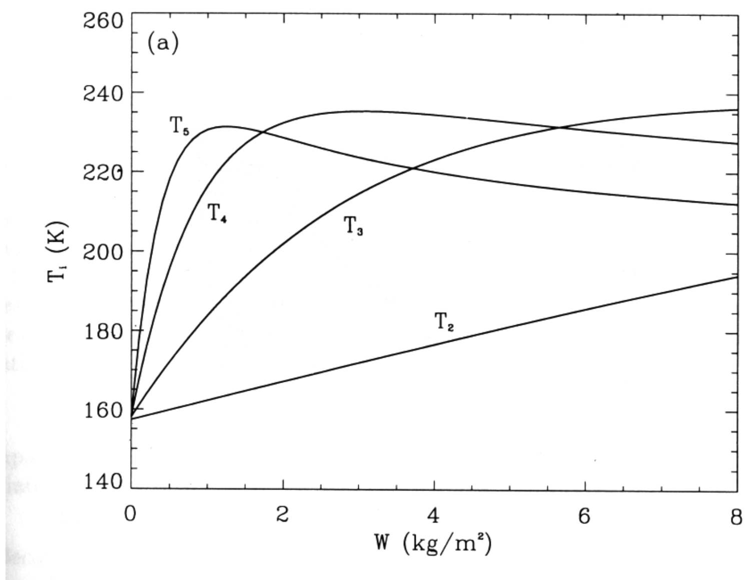

Figure 1: Dependence of brightness temperatures measured by satellite on total water vapour

It can be shown that [*Miao et al.*, 2000]

$$R(f_1, f_2) = \underbrace{R_{\text{sfc}}(f_1, f_2)}_{\text{surface}} + \underbrace{R_{\text{d-a}}(f_1, f_2)}_{\text{dry air}} + \underbrace{\beta(f_1, f_2)}_{\sim\Delta\kappa_L} \cdot [L + \underbrace{\alpha_{\text{WL}}(f_1, f_2)}_{\Delta\kappa_W/\Delta\kappa_L} \cdot W] \qquad (5)$$

where L is the liquid water path, W it the total water vapour, κ_W and κ_L the mass absorption coefficients of water vapour and liquid water, respectively, and $\Delta\kappa_W$ denotes the V-H difference of κ_W, i.e., $\kappa_{W,V} - \kappa_{W,H}$.
It is possible to select such frequencies that

- α is small so that the contribution of CLW to the R-factor is large
- β is large and R_{sfc} small so that the contribution of the surface to the R-factor is small.

The SSM/I has four channels, at 19, 22, 37, and 85 GHz; the 22 GHz has only V polarisation, the others have both H and V. Previous investigations have shown that the best frequency combination over sea ice is f_1 =85 GHz and f_2 =37 GHz [*Miao et al.*, 2000].
For the code of the R-factor algorithm, see appendix B on p. 7.

A TWV algorithm (FORTRAN 77)

```
C      This subroutine is used to calculate the Total Water Vapor of
C      the atmosphere in the polar
C      regions. It is adapted from the IDL program written by Jungang
C      Miao in April 1998.
C      This FORTRAN version HAS NOT BEEN TESTED by now.
```

```
C        --- Jungang Miao
C        --- April 4, 2003, Bremen, Germany.
C
C      The channel numbers of SSM/T2 used here are:
C        Channel 1:   92 GHz
C        Channel 2:  150 GHz
C        Channel 3:  183.31+/-7 GHz
C        Channel 4:  183.31+/-3 GHz
C        Channel 5:  183.31+/-1 GHz
C
C      input parameters:
C        n_scan:  total scan number of SSM/T2, i.e. the size of
C                 the second dimension of 2-D
C                 arrays of ch12, ch23, ch34, ch45, and twv.
C        ch12: a 2-D array with dimensions (28, n_scan), denoting
C              the Tb difference of channels 1 and 2.
C        ch23: a 2-D array with dimensions (28, n_scan), denoting
C              the Tb difference of channels 2 and 3.
C        ch34: a 2-D array with dimensions (28, n_scan), denoting
C              the Tb difference of channels 3 and 4.
C        ch45: a 2-D array with dimensions (28, n_scan), denoting
C              the Tb difference of channels 4 and 5.
C      output parameter:
C        twv:  a 2-D array with dimensions (28, n_scan), denoting
C              the Total Water Vapor.


      SUBROUTINE vapor_ssmt2_200304 (n_scan, ch12, ch23, ch34, ch45, twv)

      INTEGER*2 n_scan
      REAL*4 dt23, dt34, dt45, fact_twv
      REAL*4 ch12(1:28,1:n_scan), ch23(1:28,1:n_scan), ch34(1:28,1:n_scan),
     *       ch45(1:28,1:n_scan), twv(1:28,1:n_scan)
      REAL*4 scan_angle(1:28)
      DATA scan_angle/47.26, 43.50, 39.83, 36.22, 32.66, 29.13, 25.64,
     *               22.18, 18.73, 15.31, 11.89,  8.49,  5.09,  1.70,
     *                1.70,  5.09,  8.49, 11.89, 15.31, 18.73, 22.18,
     *                25.64, 29.13, 32.66, 36.22, 39.83, 43.40, 47.26/


      do 10 i=1, 28
         scan_angle(i)=cos(scan_angle/180.0*3.1415926)
 10      continue

         do 30 i=1, 28
            do 20 j=1, n_scan
```

```
              dt23=ch23(i,j)
              dt34=ch34(i,j)
              dt45=ch45(i,j)
              call newalgo(dt23, dt34, dt45, fact_twv)
              twv(i,j)=fact_twv*scan_angle(i)
 20           continue
 30           continue

              return
              end

C     -------- subroutine newalgo --------

      subroutine newalgo(dt23, dt34, dt45, fact_twv)

      if ((dt45.gt.0).or.(dt34.gt.0)) then
        if ((dt34.gt.0).or.(dt23.gt.0)) then
           fact_twv=9999.9
           goto 40
        else
           call algo_234(dt23, dt34, fact_twv)
           goto 40
        endif

      else
        call algo_345(dt34, dt45, fact_twv)

        if(fact_twv.gt.1.5) then
          call algo_234(dt23, dt34, fact_twv)
          goto 40
        endif

      endif

 40   return
      end

C     -------- subroutine algo_234 --------


      subroutine algo_234(dt23, dt34, fact_twv)

      INTEGER*2 nr
      REAL*4 px(1:4), py(1:4), c0(1:4), c1(1:4)
      DATA px/4.066, 1.451, 5.591, 3.525/
      DATA py/2.458, 0.744, 4.754, 0.384/
      DATA c0/2.041, 1.887, 2.010, 2.414/
```

```
      DATA c1/2.275, 1.789, 2.316, 2.110/

      nr=1
      fact_twv=c0(nr)+c1(nr)*alog((dt_23-py(nr))/(dt34-px(nr)))

      return
      end


C     -------- subroutine algo_345 --------


      subroutine algo_345(dt34, dt45, fact_twv)

      INTEGER*2 nr
      REAL*4 px(1:4), py(1:4), c0(1:4), c1(1:4)
      DATA px/2.556, 1.831, 1.378, 3.380/
      DATA py/1.370, 0.901, 0.343, 3.027/
      DATA c0/0.689, 0.685, 0.671, 0.693/
      DATA c1/0.723, 0.690, 0.565, 0.753/

      nr=1
      fact_twv=c0(nr)+c1(nr)*alog((dt_34-py(nr))/(dt45-px(nr)))

      return
      end
```

B CLW algorithm (IDL)

```
pro rfactor, iv19, iv37, ih37, iv85, ih85, imgr
;+
;NAME:
;     RFACTOR
;PURPOSE:
;     Procedure that calculates the R-factor from the 37 GHz and 85 GHz
;     channels of SSM/I data
;USAGE:
;     rfactor,  iv19, iv37, ih37, iv85, ih85, imgr
;      iv19: 2D array (float) containing 19 GHz, vertical polarisation
;             SSM/I radiances
;      iv37: 2D array (float) containing 37 GHz, vertical polarisation
;             SSM/I radiances
;      ih37: 2D array (float) containing 37 GHz, horizontal polarisation SSM
;             SSM/I radiances
```

```
;       iv85: 2D array (float) containing 85 GHz, vertical polarisation SSM/I
;              SSM/I radiances
;       ih85: 2D array (float) containing 85 GHz, horizontal polarisation SSM
;              SSM/I radiances
;       imgr: name of the 2D array to which the R-factor will be
;              written (float)
;-

        ; Index NaN (bad values) are taken from 19GHz channel
        indnan=where(finite(iv19) ne 1,countnan1)

        ; R-Factor ------------------------------------------
        imgr=alog((iv37-ih37)/(iv85-ih85))
        indnan2=where(finite(imgr) ne 1,countnan2); Bad Values

        ; Cut off 0.0-2.5
        indhr=where(imgr lt 0.0,counthr)
        indlr=where(imgr gt 2.5,countlr)
        imgr=imgr*100.0
        if countlr ne 0 then imgr(indlr)=0
        if counthr ne 0 then imgr(indhr)=250
        if countnan1 ne 0 then imgr(indnan)=255
        if countnan2 ne 0 then imgr(indnan2)=255
        ; ---------------------------------------------------
end
```

References

Guissard, A., P. Sobieski, A simplified radiative transfer equation for application in ocean microwave remote sensing, *Radio Science*, vol. 29, no. 4, p. 881–894, 1994.

Miao, J., K. Kunzi, G. Heygster, T. A. Lachlan-Cope, J. Turner, Atmospheric water vapor over Antarctica derived from SSM/T2 data, *J. Geophys. Res.*, vol. 106, no. D10, p. 10187–10203, 2001.

Miao, J., *Retrieval of Atmospheric Water Vapor Content in Polar Regions Using Spaceborne Microwave Radiometry*, Dissertation Univ. Bremen, Fachbereich 1 (Physik und Elektrotechnik) and: Reports on Polar Research 289/1998, 109 pp., Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, 1998.

Miao, J., K.-P. Johnsen, S. Kern, G. Heygster, K. Kunzi, Signature of clouds over antarctic sea ice detected by the Special Sensor Microwave/Imager, *IEEE Trans. Geosci. Remote Sens.*, vol. 38, no. 5, p. 2333–2344, Sep 2000.