Total water vapor retrieval in polar regions using AMSU-B

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TWV retrieval from AMSU-B

Basics: RTE

- Starting point: Brightness temperature measured by satellite for not too opaque atmosphere

$$T_b(\theta) = m_p T_s - (T_0 - T_C)(1 - \varepsilon)\mathrm{e}^{-2\tau_0 \sec\theta}$$

θ – incident angle (off-nadir),
m_p ($= 1 + \ldots$) – contains effect of deviation from isothermal atmosphere and difference between surface and air temperature,
T_0 – atmosphere temperature at ground level,
T_C – cosmic background,
τ_0 – nadir opacity of atmosphere

- Assume linear relation between opacity and total water vapor (TWV, a.k.a. column water vapor, total precipitable water), W:

$$\tau_0 = \kappa_v W$$

where κ – mass absorption coefficient of water vapor.

Algorithm

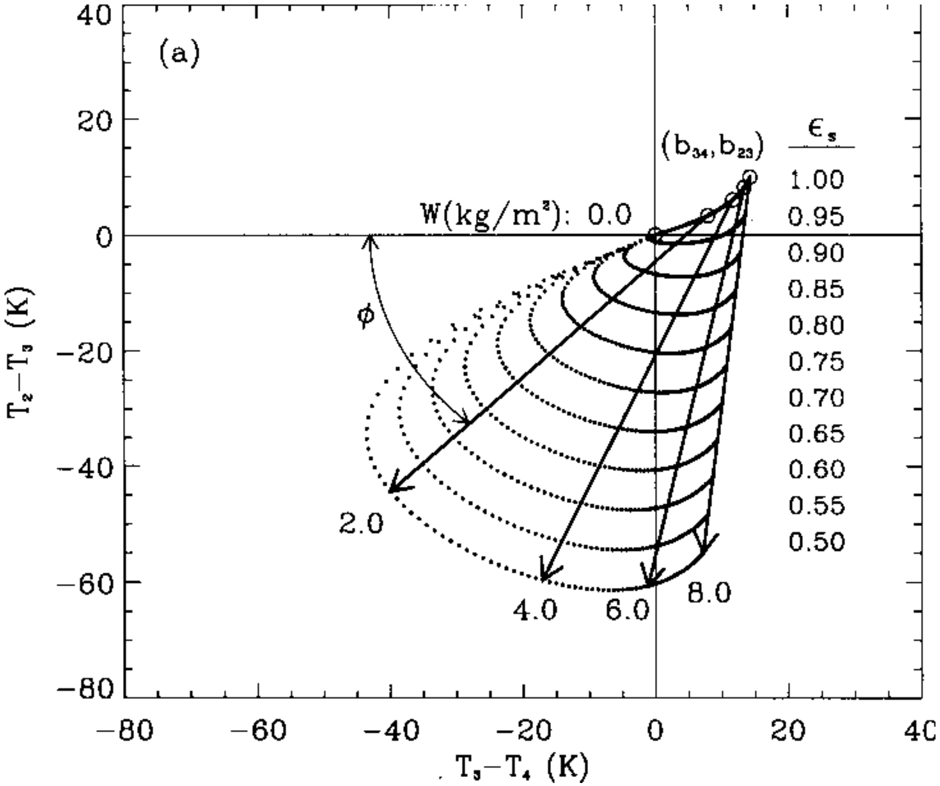
- Measure T_b at 3 different frequencies i, j, k at which ground emissivity ε is similar but water vapor absorption different; $\kappa_i < \kappa_j < \kappa_k$
- Then the following relation can be derived

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

where the “bias” (b_{jk}, b_{ij})

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

contains the influence of the atmospheric temperature and water vapor profiles



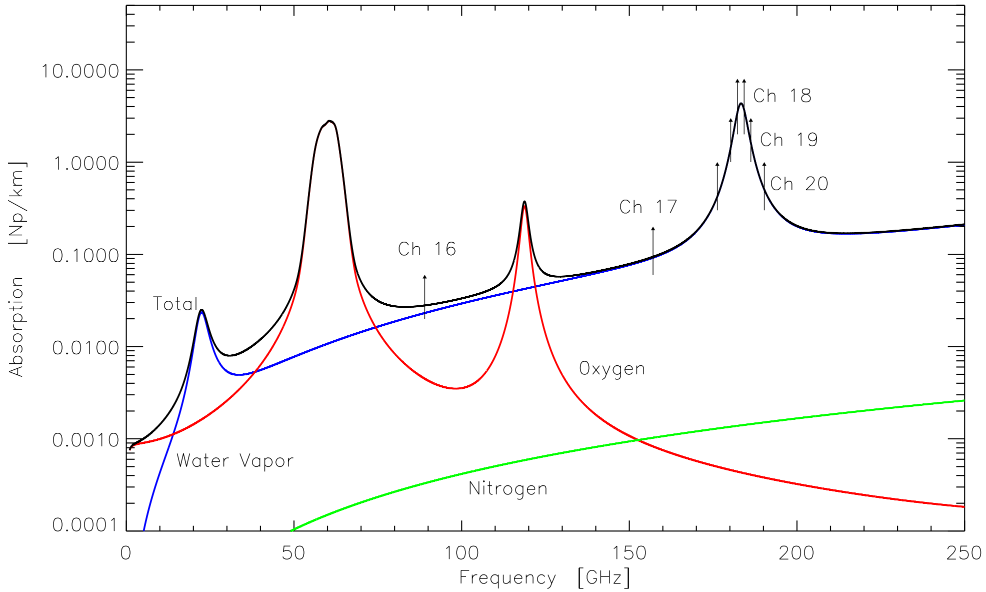
$$\tan\varphi = \eta_c = \frac{T_{b,i} - T_{b,j} - b_{ij}}{T_{b,j} - T_{b,k} - b_{jk}}$$

$$\ln(\tan\varphi) = c_0 + c_1 W \sec\theta$$

Note: (b_{jk}, b_{ij}) slightly dependent on T and W profile

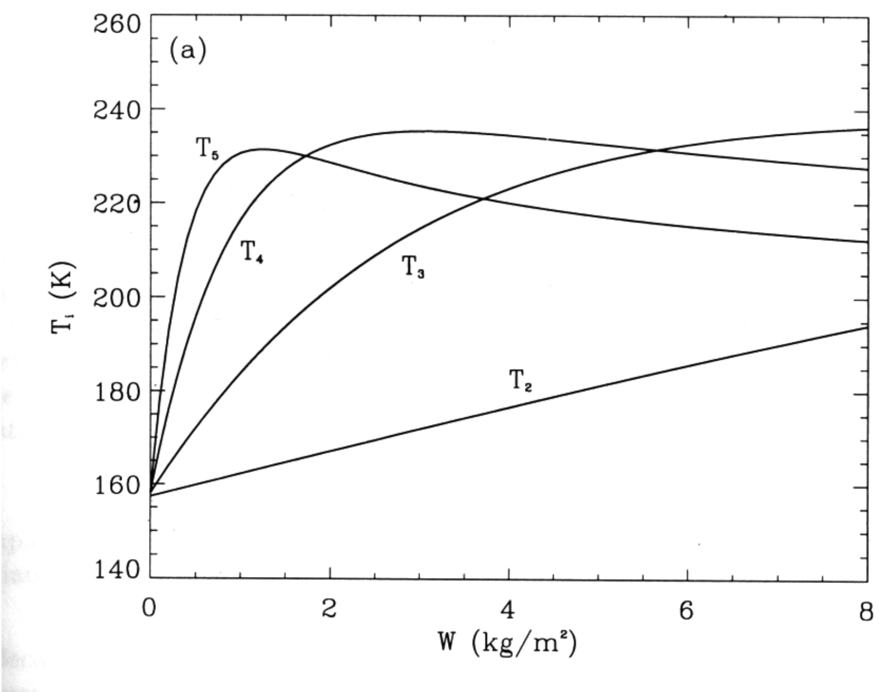
$\Rightarrow$ find some kind of average $(\overline{b_{jk}}, \overline{b_{ij}})$ (focal point, see below)

AMSU-B



AMSU-B channels (sorted such that such that $\kappa_2 < \kappa_3 < \kappa_4 < \kappa_5$)

our no.	1	2	3	4	5
Freq. [GHz]	89.0	150.0	182.31$\pm$7	182.31$\pm$3	182.31$\pm$1
AMSU channel	16	17	20	19	18



- Channels 3,4,5 for low TWV ($<$ 1.5 kg/m^2, otherwise channel 5 saturates, i.e., does not see the whole column)
- Channels 2,3,4 for higher TWV ($<$ 6 to 7 kg/m^2, otherwise channel 4 saturates)

Algorithm Development for AMSU-B

Algorithm development algorithm

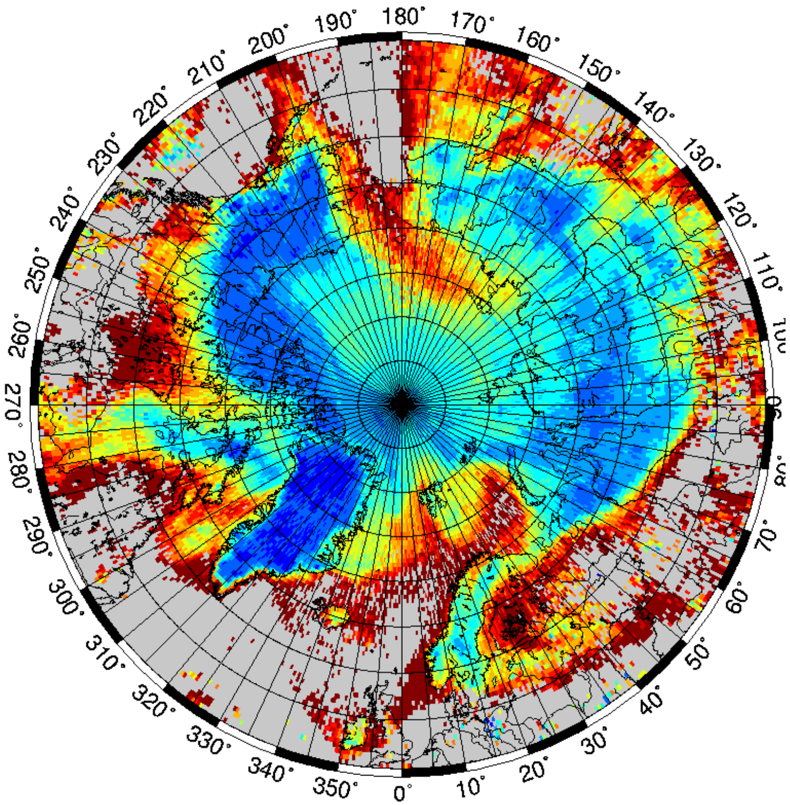
1. - Use radiosonde (RS) profiles, integrate TWV from them
   - Simulate AMSU-B brightness temperatures T_1, T_2, T_3, T_4, T_5 for a range of ground emissivities ε for each RS profile, (using ARTS)
2. Linear fit of ΔT_{ij} vs. ΔT_{jk} for each RS profile (many different emissivities)
3. Find focal point $(\overline{b_{jk}}, \overline{b_{ij}})$ as point of least square distance from all fitted lines
4. Linear fit of $TWV \sec\theta$ vs. $\ln \eta_c = \ln \left(\frac{\Delta T_{ij} - \overline{b_{ij}}}{\Delta T_{jk} - \overline{b_{jk}}} \right)$ yields:

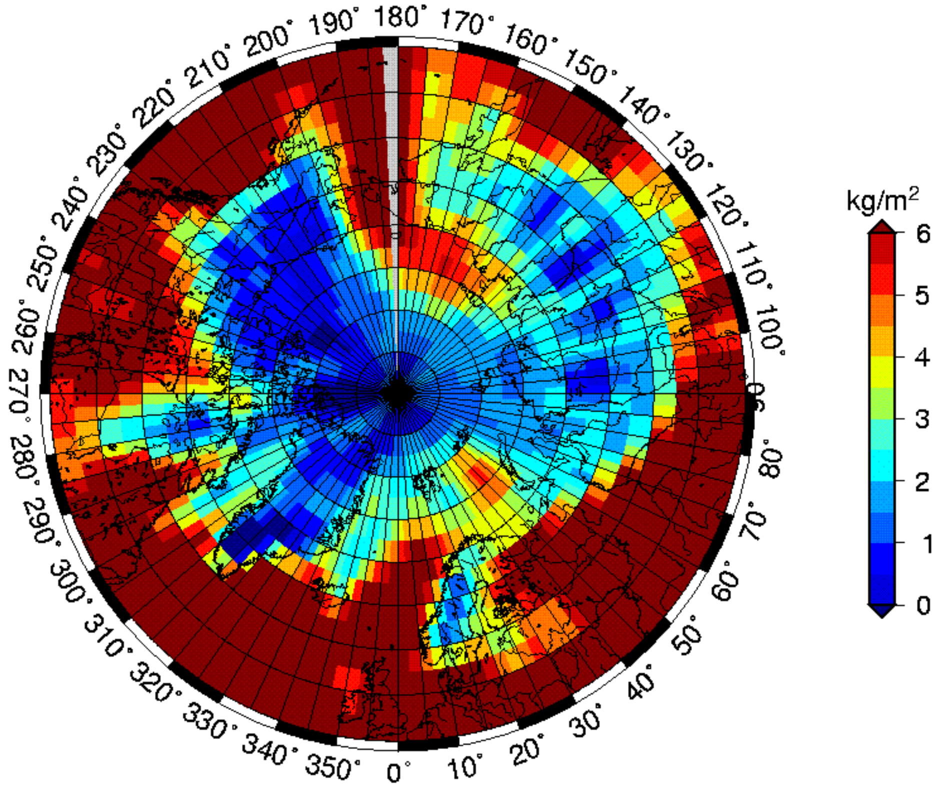
$$TWV \sec\theta = C_0 + C_1 \ln \eta_c$$

Note:

- Use only RS profiles with $TWV < 1.5$ (kg/m^2) for algorithm with $(i, j, k) = (3, 4, 5)$
- Use only RS profiles with $1.5 < TWV < 6$ for algorithm with $(i, j, k) = (2, 3, 4)$

Comparison With NCEP Reanalysis Data

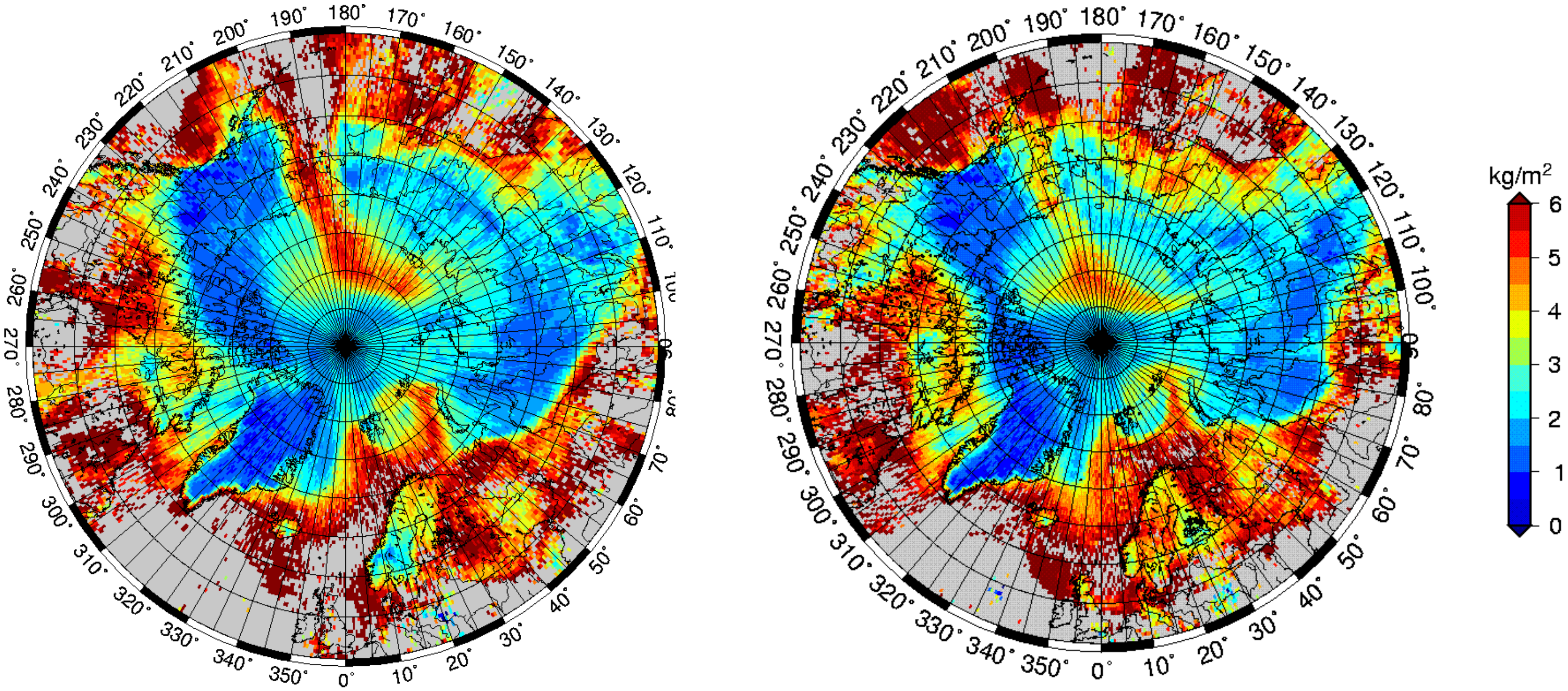




AMSU-B derived TWV map of Arctic, 18 March, 2001, 0.5°grid (Grey = failure of algorithm because of too high TWV).

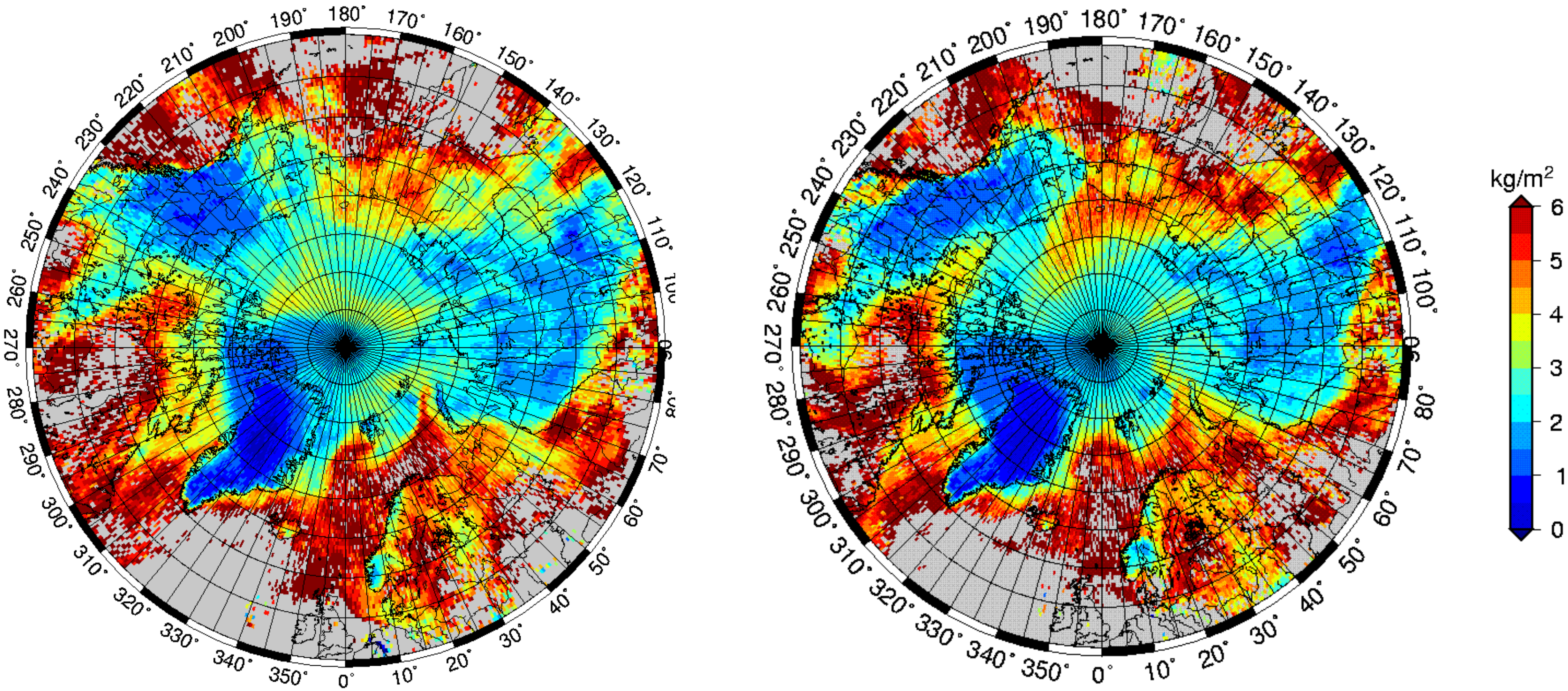
NCEP (National Centers for Environmental Prediction) reanalysis TWV map, same day, 2.5°grid.

Time Evolution of TWV



AMSU-B-derived TWV maps of the Arctic for 4 consecutive days: March 19 (left) and March 20 (right) . . .

Time Evolution of TWV (ctd.)



. . . March 21 . . . and March 22, 2001.

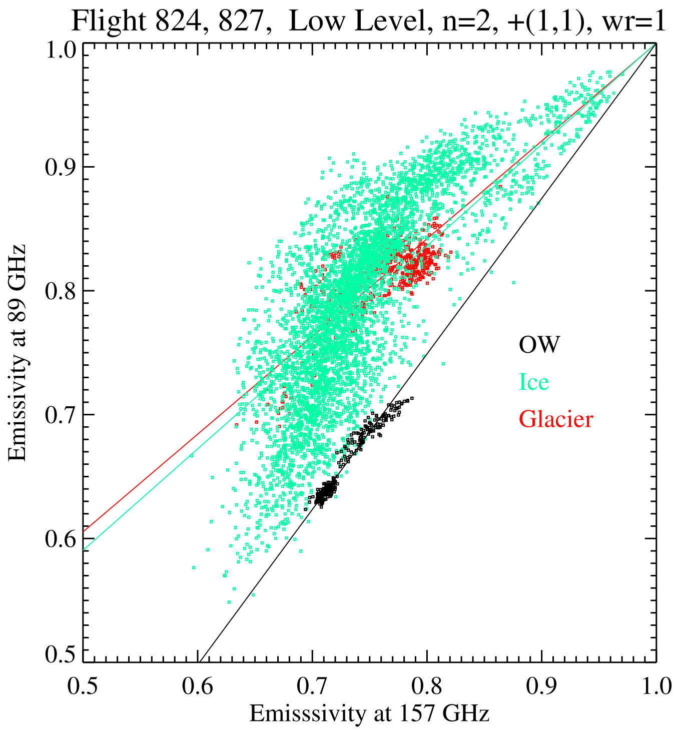
Extension to Higher TWV Using Emissivity Information

- TWV $>$ 6 to 7 kg/m^2 $\Rightarrow$channel 4 saturated as well:
  No TWV retrieval with the algorithm as is (upper 4 channels)
- Use channels 1 (89 GHz), 2 (150 GHz), 3 (183 ± 7 GHz), but: channel 1 emissivity $\neq$ other emissivities

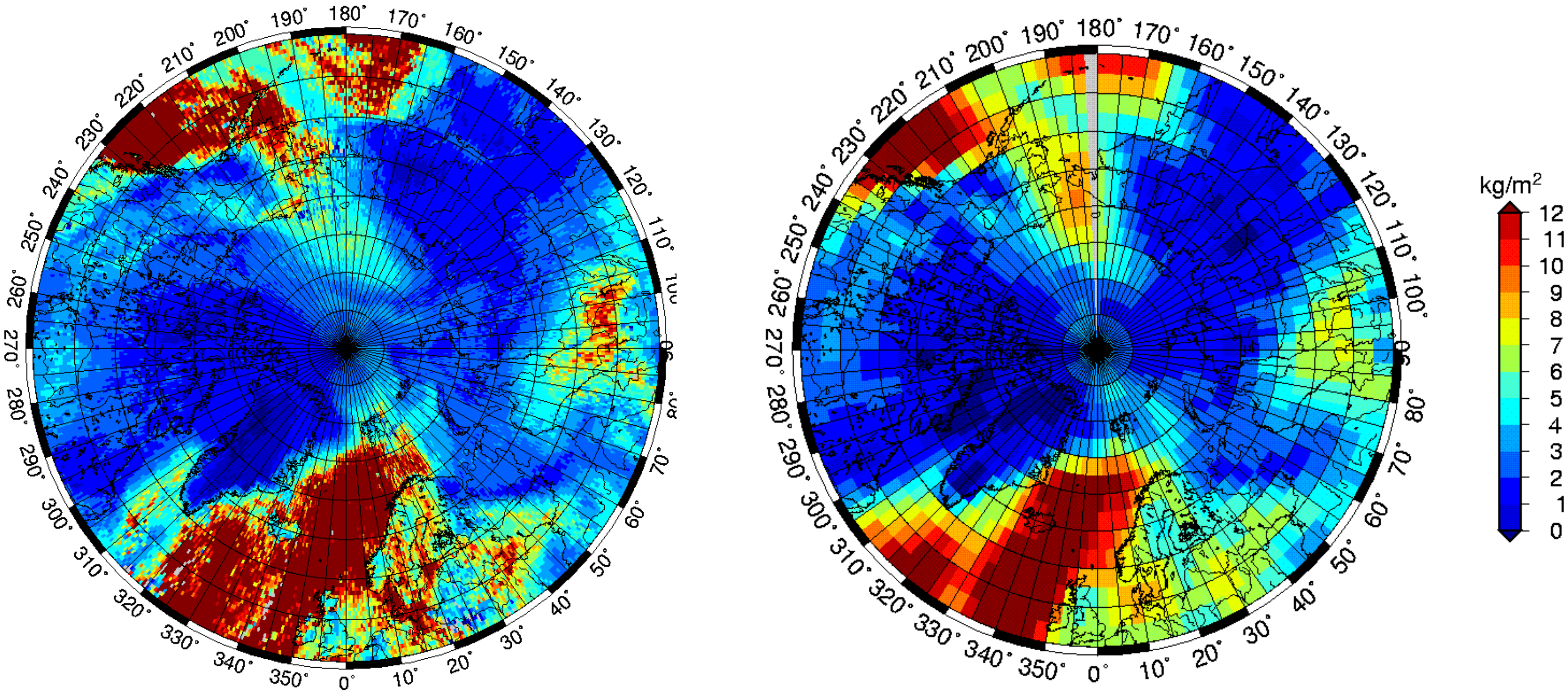
$\Rightarrow$ Algorithm not independent of emissivity any more: $W \sec\theta = C_0 + C_1 \log \tilde{\eta}_c$
where $\tilde{\eta}_c = \frac{r_2}{r_1}\left[\frac{T_{b,1}-T_{b,2}-b_{12}}{T_{b,2}-T_{b,3}-b_{23}} + 1\right] - 1$ and $r_i = 1 - \varepsilon_i$ (reflectivity)

Extension to Higher TWV Using Emissivity Information (ctd.)

- From SEPOR/POLEX campaign [Selbach, 2003], emission of various surface types (ice, water) in winter was determined for frequencies needed here (89 GHz, 157 GHz)
- Linear regression of SEPOR/POLEX data yields $\varepsilon(89)$ as a function of $\varepsilon(157)$: $\varepsilon(89) = 0.1809 + 0.8192\varepsilon(157)$.
- For the brightness temperature simulations (for deriving calibration parameters C_0, C_1,b_{12}, b_{23}), $\varepsilon(89)$ as a function of $\varepsilon(157)$ needed
- For the retrieval, only the reflectivity ratio $r_2/r_1 = (1 - \varepsilon(150))/(1 - \varepsilon(89))$ needed



TWV Map from Extended Algorithm



AMSU-B-derived TWV,18 Feb, 2001, (only valid over ice-covered arctic ocean)

NCEP reanalysis data.

Humid air intrusion into the Arctic north of the Bering strait.

Summary etc.

- Total water vapour (TWV) retrieval from microwave radiometer data (AMSU-B, SSM/T2) independent of surface emissivity for TWV < 6 kg/m^2.
- TWV retrieval from microwave radiometer data with additional information on surface emissivity can be extended up to TWV of about 10 kg/m^2 over ice.
- Spatial resolution considerably higher than, e.g., reanalysis data.

... etc.

- Assimilation of AMSU-B-derived TWV into numerical weather prediction models is being explored at present within EU project IOMASA (Integrated Observing and Modelling of the Arctic Sea Ice and Atmosphere, EVK-CT-2002-00067).
- TWV data might also be used together with regional models for water cycle investigations.
- Data from Antarctic (2000, 2001) and Arctic (2001, 2002) available, more planned (`http://www.uni-bremen.de/~pharos/iomasa-member`)
- current data (among other atmospheric and surface data) at `http://www.seaice.dk/iomasa/icebrowser/`