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Extending TOA radiation back to 1978 using wide field-of-view data

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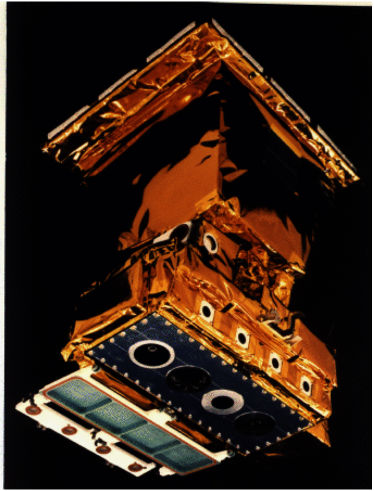
Aim of this work

Fill the gap!

Long time series of the total radiation emitted by the Earth, whose coverage extends as far as possible spatially and temporally, for the purpose of climate studies

- Total radiation (SW+LW) emitted by the Earth, W m^{-2}
- Averaged per month
- Extent in time and space:
  - Coverage from +81° to -81° latitude
  - Coverage from -180° to +180° longitude
  - Coverage from November 1978 to September 1999 (nearly 21 years)

The wide field-of-view radiometer

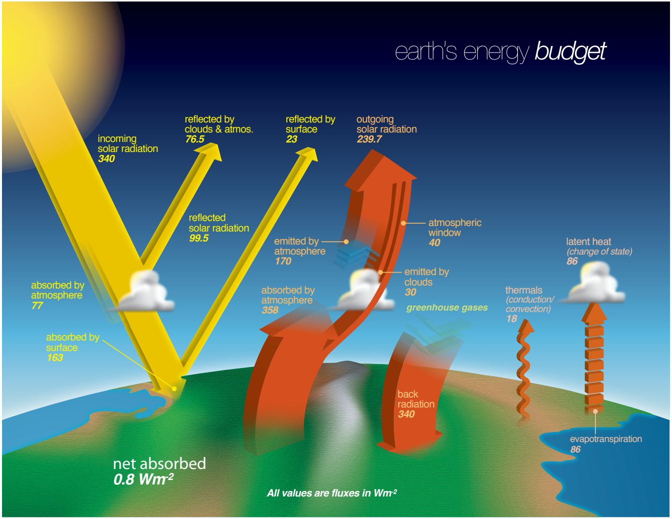


Source: http://mynasadata.larc.nasa.gov/images/erbenonscanner.gif

Nonscanner on board ERBS

- 2 wide field-of-view radiometers:
  - one radiometer for SW: 0.2 to 5 μm
  - one radiometer for TW: all wavelengths
- 2 medium field-of-view radiometers

Earth radiation budget



Source: http://mynasadata.larc.nasa.gov/docs/earth_radiation_budget_17.pdf

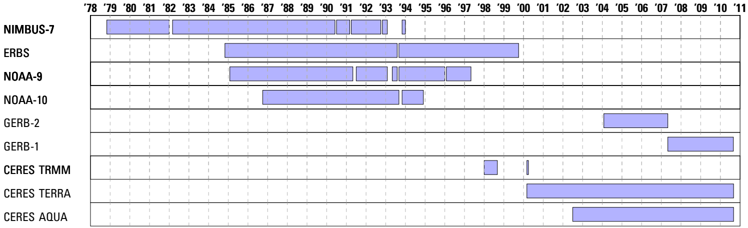
Justification

- Why WFOV?
  - Long, uninterrupted time series (scanner usually broke down after a few years)
- Why total radiation and not SW & LW?
  - SW filter suffers from ageing
  - Little degradation of the total radiation measurements over time
- Disadvantages
  - Cloud forcing cannot be studied
  - Low spatial resolution
- Compared to former work?
  - Improve accuracy of monthly averages by using state-of-the-art models and processing techniques

Data sources

Experiments

- ERB experiment on board NIMBUS-7 spacecraft
  - Solar and Earth Flux Data Tape (SEFDT) dataset
  - 1978/11 – 1993/01
- ERBE experiment on board ERBS, NOAA-9 and NOAA-10 spacecraft
  - Monthly Medium-Wide Data Tape (MWDT) dataset
  - 1984/11 – 1999/9



Data sources

Spacecraft

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- NIMBUS-7
  - Sun-synchronous satellite with an inclination ≈ 99°
  - Local time equator passing, ascending node ≈ 11:00 (initially)
- ERBS
  - Precessing satellite with an inclination ≈ 57°
- NOAA-9
  - Sun-synchronous satellite with an inclination ≈ 99°
  - Local time equator passing, ascending node ≈ 14:30 (initially)
- NOAA-10
  - Sun-synchronous satellite with an inclination ≈ 99°
  - Local time equator passing, descending node ≈ 7:30 (initially)

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Assumptions & limitations

- We assume the spectral response of the total wave (TW) measurement is sufficiently flat
- No intercalibration of different satellites (except common reference altitude)
- For the moment: albedo independent of solar zenith angle

Obtaining the monthly average flux

Starting from instantaneous measurements from the WFOV radiometer:

- Conversion of datafiles from native format to NETCDF
- Processing the raw measurements
- Binning in 5°× 5° bins
- Regression of the diurnal model on the data
- Numerical integration of the monthly average diurnal model from 0 to 24 hours
- Checks on the quality of the regression and final output

Conversion of datafiles from native format

- These data were originally stored and processed on mainframes with tape drives
- Decode according to tape specifications
  - ERBE: User's Guide on http://eosweb.larc.nasa.gov/GUIDE/dataset_documents/erbe_s7.html
  - ERB on NIMBUS-7: NASA Contractor Report 170616 (Ray, Tighe & Scherrer, 1984)
- Add useful orbit & instrument information: inclination, orbit type (direct or retrograde), field-of-view aperture

Processing the raw measurements

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- Add required quantities when not available in the datafiles
  - Solar zenith angle
  - Local time at nadir
- Direct sunlight elimination (geometric)
- Quality flags
  - Negative or otherwise unphysical data
  - Instrument looking off-nadir
  - Spacecraft status flags
  - Detector blinded by direct sunlight

Processing the raw measurements

Elimination of direct sunlight

- Not using solar zenith angle: seems to throw away good measurements without taking into account solar eclipse by Earth disc
- But using geometric technique
  - Takes into account angle between spacecraft, Earth and sun
  - Takes into account solar eclipse by Earth (ellipsoid shape with GRS80 parameters)

Regression of the diurnal model

Model equation

- The diurnal model can be specified:
  - In terms of local time
  - In terms of (cosine of) solar zenith angle
    - Assume sloped line (daytime) intercepts flat line (night-time) at solar zenith angle of zero
- We've chosen to regress the model specified in terms of cosine of solar zenith angle
- Two-parameter diurnal model:

$$F(t) = \begin{cases} p_0 + p_1 \cos z(t) & \text{if } \cos z > 0 \\ p_0 & \text{otherwise} \end{cases} \quad (1)$$

- Modified diurnal model during polar winter:

$$F(t) = p_0 \quad (2)$$

Regression of the diurnal model

Why a diurnal model in terms of solar zenith angle?

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- Solar zenith angle at noon varies considerably, depending on season and latitude
- Corollary: even measurements at fixed local time lead to a range of zenith angles, which is better for the regression
- Regression of a linear two-parameter model is the obvious approach when only heliosynchronous data with two measurements per day are available
- Can estimate baseline (night-time) flux without night-time measurements

Disadvantage:

- Limited range of the independent variable at high latitudes

Regression of the diurnal model
Example (Sahara region)

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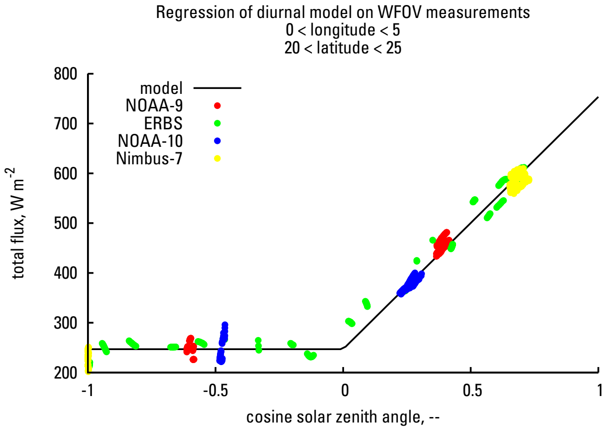
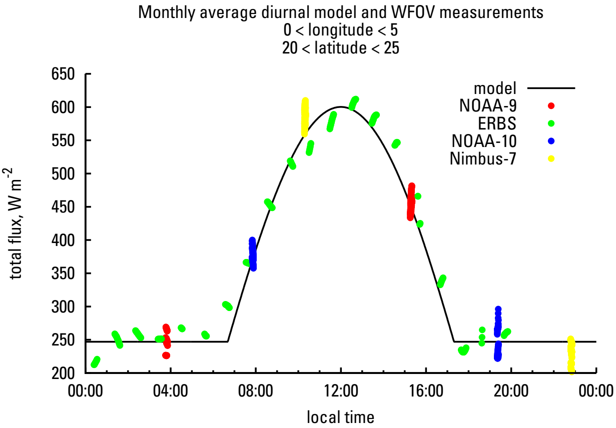


Numerical integration of the diurnal model

Example (Sahara region)



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Checks on the quality of the regression

Values can be rejected for several reasons

1. An error occured during fitting (e.g., too many iterations in Levenberg-Marquardt)
2. Regression as a whole is not significant
3. Regression is useless according to the Box criterion (explains less than the error)
4. Null hypothesis cannot be rejected for at least one of the parameters
5. At least one parameter is nonphysical (e.g., negative night-time flux)
6. Numerical integration cannot be performed for numerical reasons
7. Resulting average flux is nonphysical (i.e., negative)

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Radiation maps

- Fluxes as measured by the instrument at satellite altitude, but reduced to common altitude by inverse-square law
- … And then mapped at nadir in boxes of 5°×5°
- First a set of maps of 1979, obtained using only NIMBUS-7 data (heliosynchronous, two measurements per day)
- Then a set of maps of 1987, obtained using all satellites (NIMBUS-7, ERBS, NOAA-9, and NOAA-10)

Total radiation, W m^{-2}

March 1979

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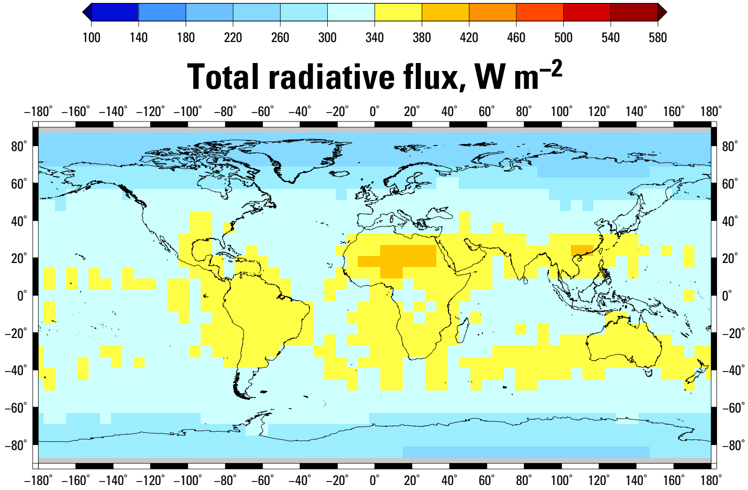
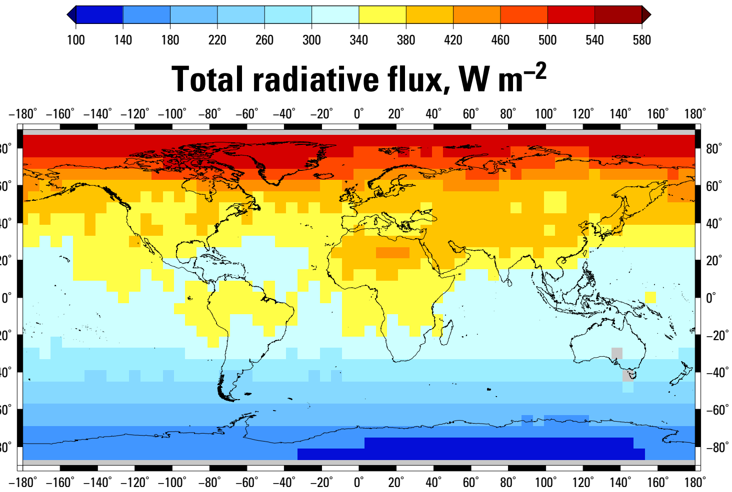


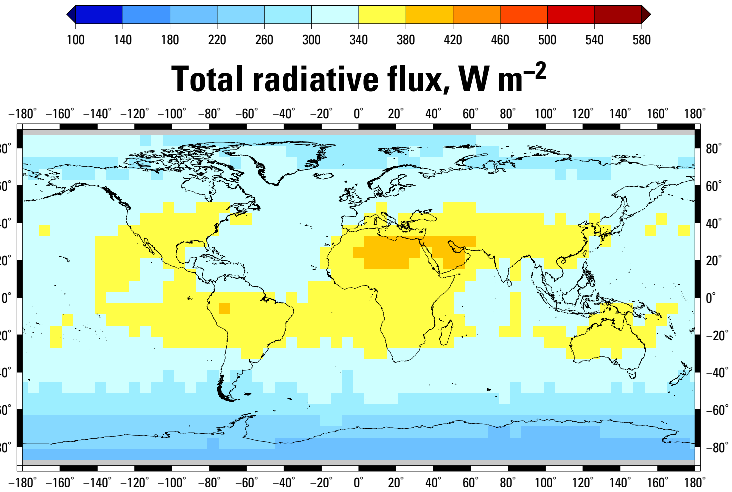
Total radiation, W m^{-2}

June 1979



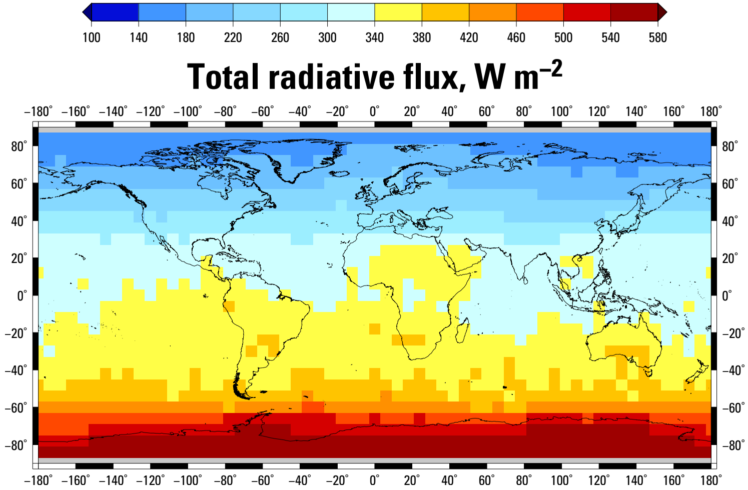
Total radiation, W m^{-2}

September 1979



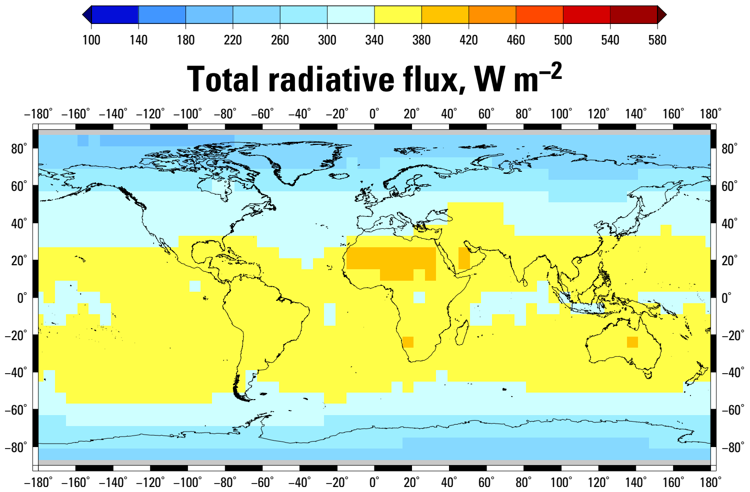
Total radiation, W m^{-2}

December 1979



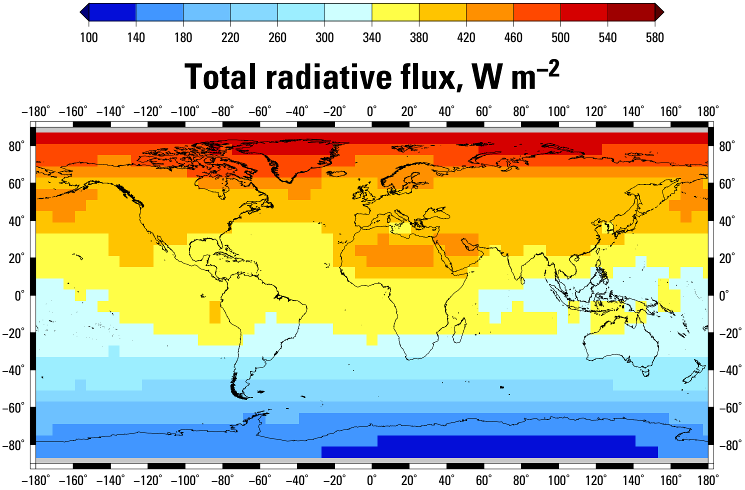
Total radiation, W m^{-2}

March 1987



Total radiation, W m^{-2}

June 1987



Total radiation, W m^{-2}

September 1987

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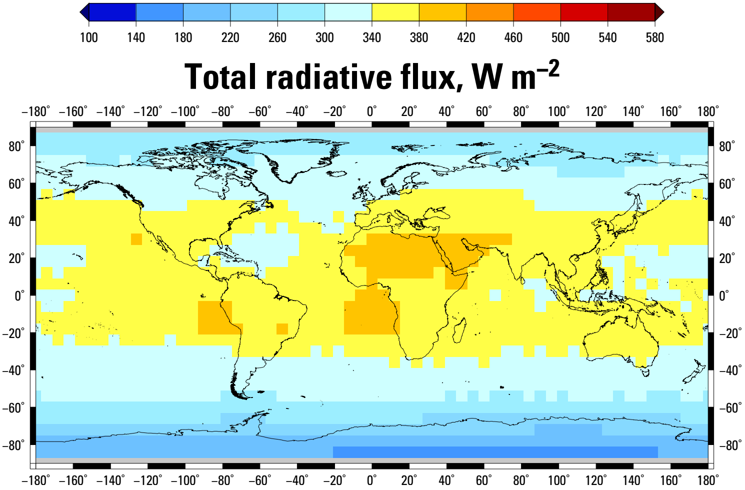

Total radiation, W m^{-2}

December 1987

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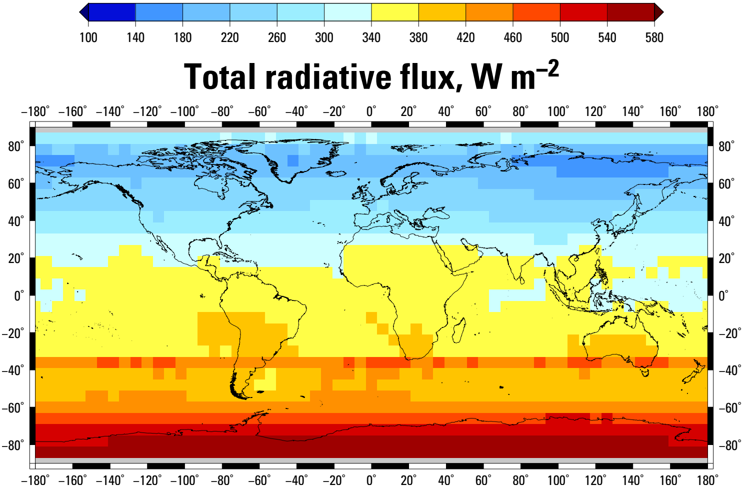
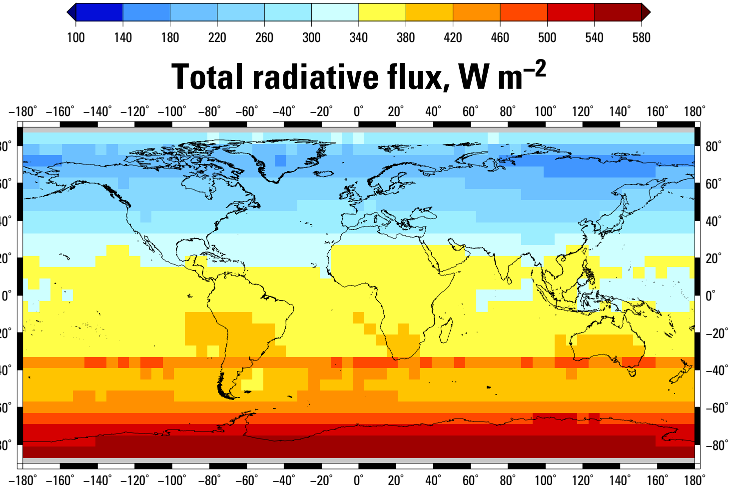


Quality of the regression

- Statistics for the regression
- R^2: multiple correlation coefficient, test for linear correlation
- F: null hypothesis for all parameters simultaneously, test for significance of regression

Total radiation, W m^{-2}

December 1987



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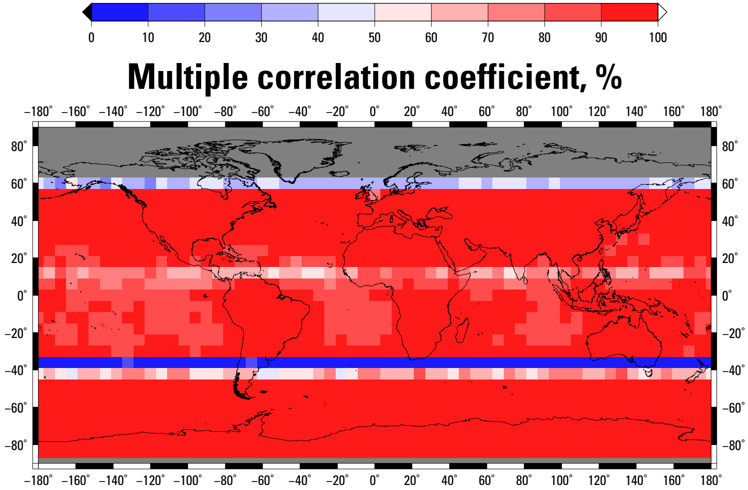

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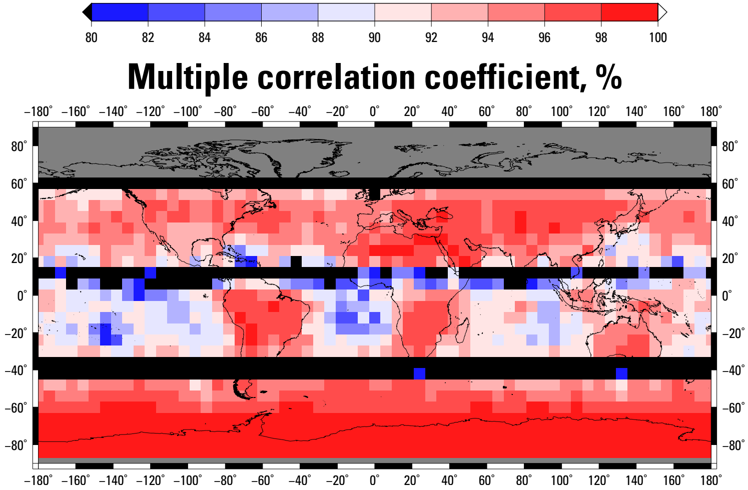
December 1987



RMI CM SAF Climate Monitoring

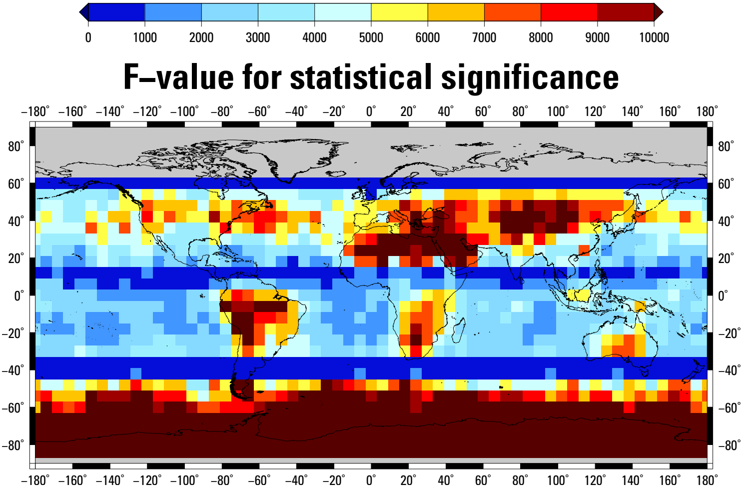
Quality of the regression

R^2-value

- No R^2 at high latitude in northern hemisphere: polar winter, one-parameter model
- Band of low-quality regression at 40 degrees latitude south
  - Seems to be caused by NIMBUS-7 (and sometimes NOAA-10) measurements
  - Related to refracted light?
  - Related to viewing geometry?
- R^2 seems to be higher over land than over ocean
  - More pronounced diurnal cycle over land
  - Related to cloud cover?

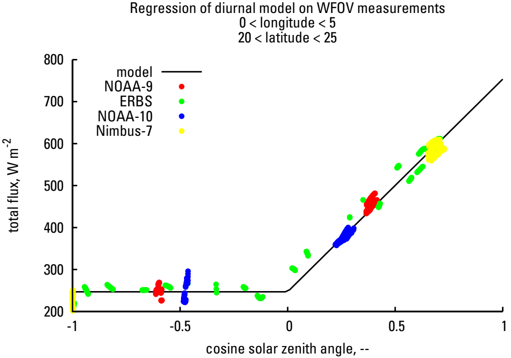
Quality of the regression

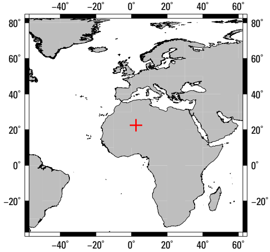
December 1987



An example of a good regression

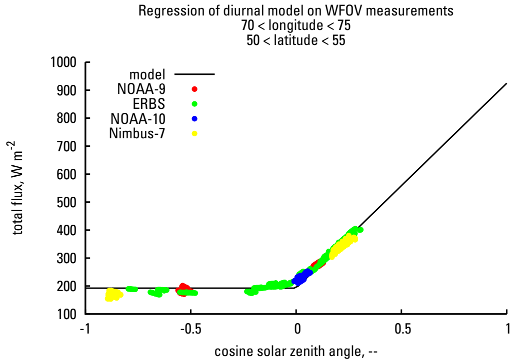
$R^2 = 0.98$

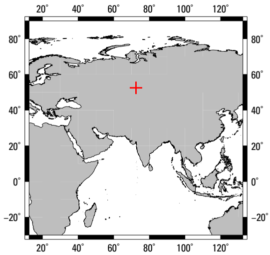




Partially sunlit at sunrise/sunset transition

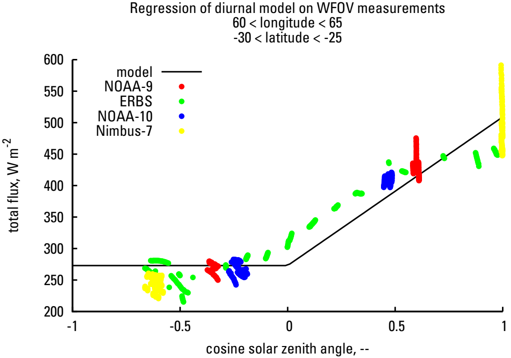
$R^2 = 0.96$

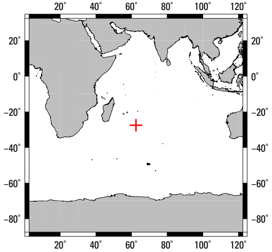




Zenith angle dependence over ocean surface

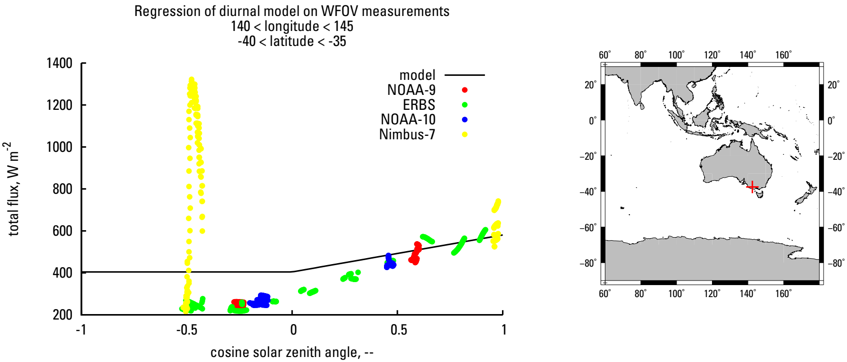
$R^2 = 0.91$





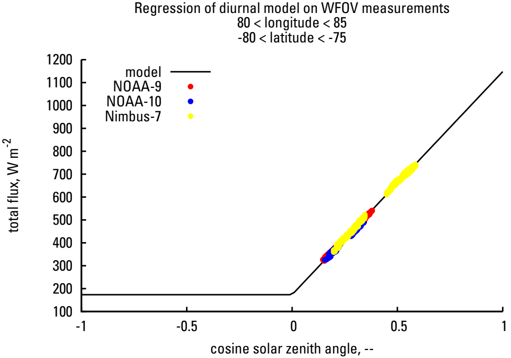
A very poor regression

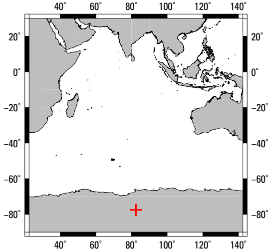
$R^2 = 0.05$ with NIMBUS-7 data, $R^2 = 0.96$ without



Estimate intercept with daytime measurements only

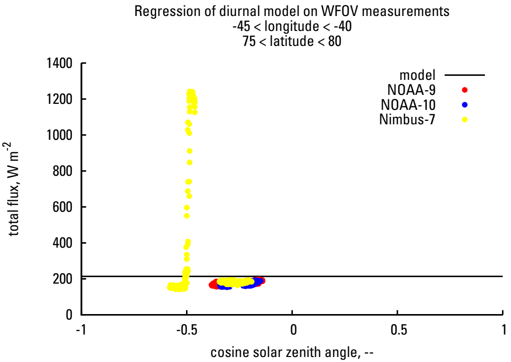
$R^2 = 0.99$

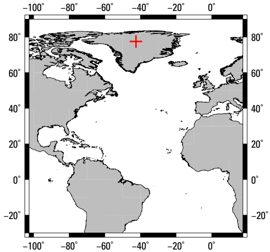




Modified diurnal model during polar winter

$s^2 = 37705$ with NIMBUS-7 data, $s^2 = 91$ without





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Conclusions

- Revived the old NIMBUS-7 and less older ERBE data
- WFOV measurements do contain usable spatial information
- Made TOA radiation maps over nearly 21 years (November 1978 – September 1999) and nearly the entire globe, sometimes with scarce data
- Problems remain: stray light? diurnal models inappropriate?

Future work

- Incorporate more recent measurements (GERB, CERES)
- Better filtering of the data
- Improve diurnal models
- Applications: e.g. volcanic eruptions (El Chichón 1982, Pinatubo 1991)

Acknowledgements

- Dr. George L. Smith
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- RMIB