Long-term trend in Cloud Fraction using PATMOS-x v6.0 since 1980.

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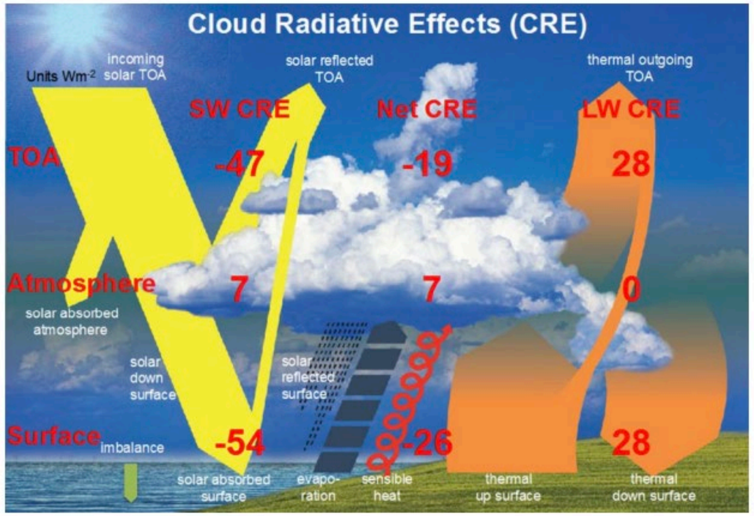
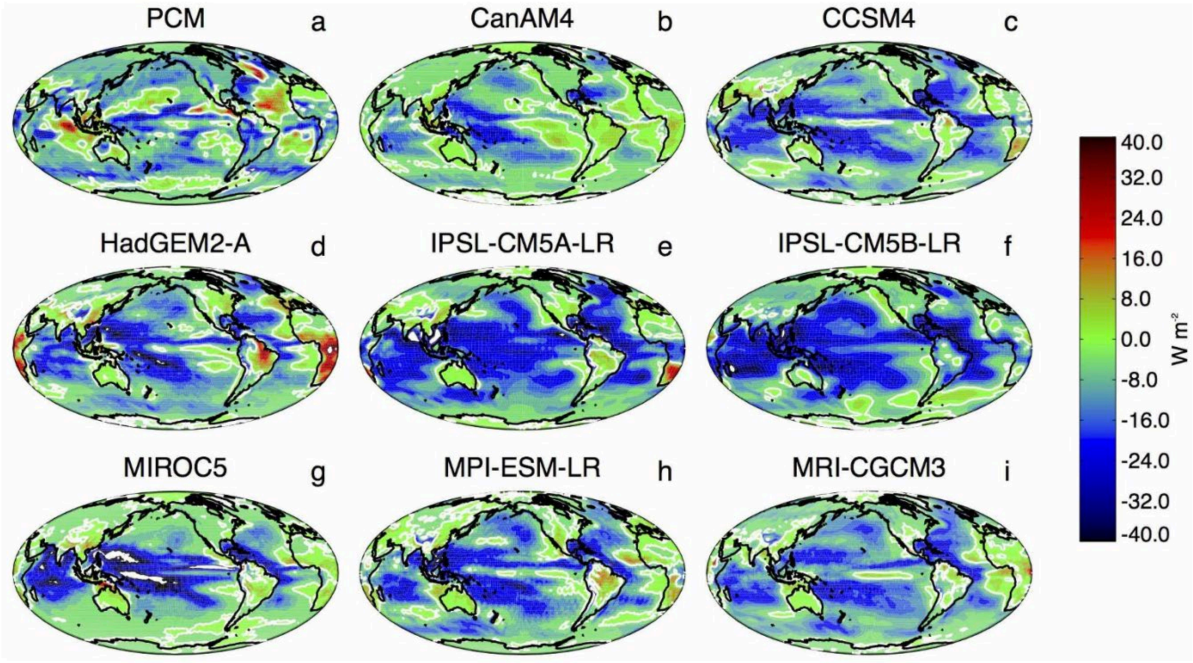
Scientific Background

- Clouds play an essential role in the regional weather as well as global climate change through direct and indirect radiative forcing at shortwave as well as longwave radiation.
- Climate models have uncertainties due to their multifaceted radiative and dynamical effects linked with high cloud feedback sensitivity.
- Global satellite-based cloud climate data records (CDRs) are sufficient to observe some variations in cloud amounts and processes on climate time scale (1980 – present).

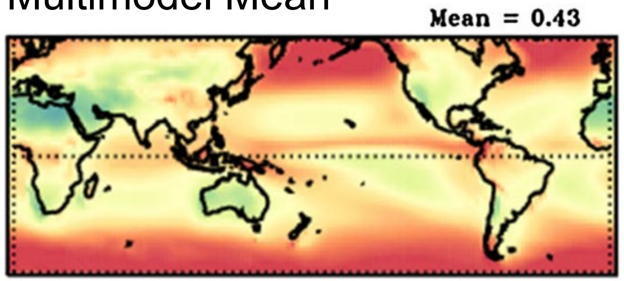


M. Wild et al. 2018

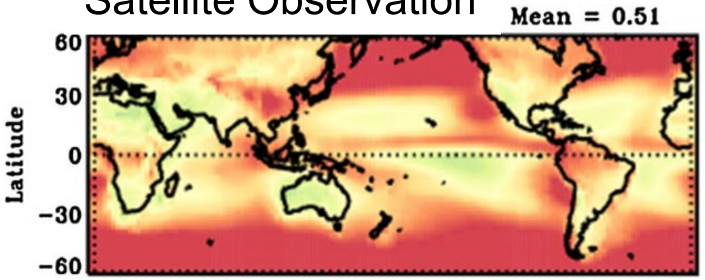


Sherwood et al. 2014

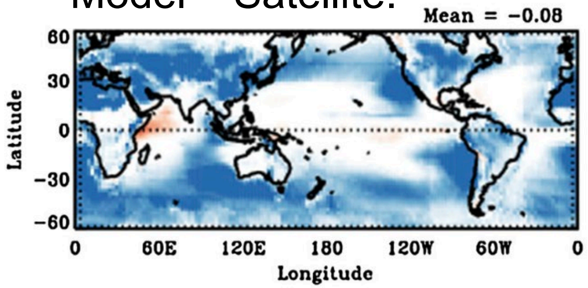
Multimodel Mean



Satellite Observation



Model – Satellite.



Klein et al. 2013

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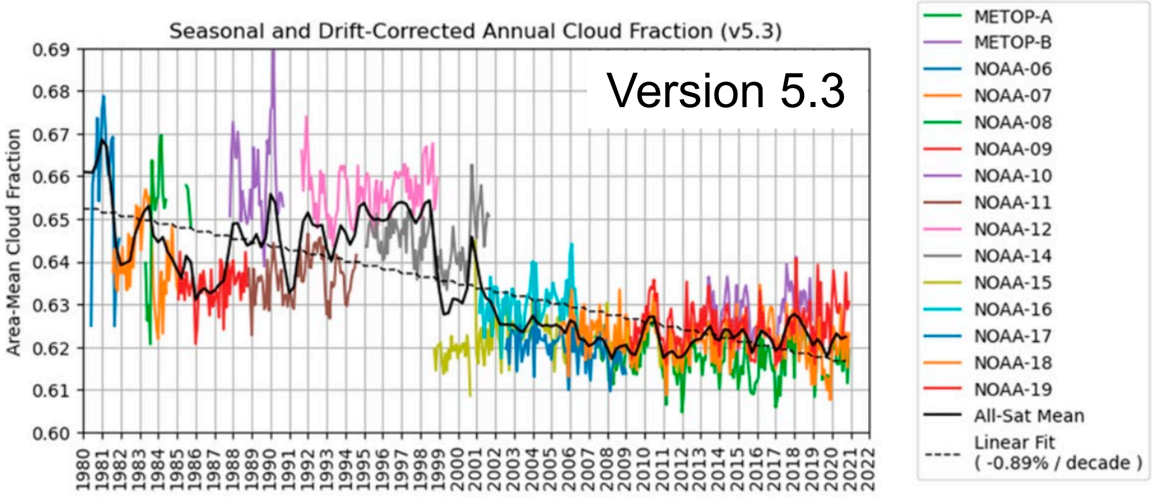
Scientific Background

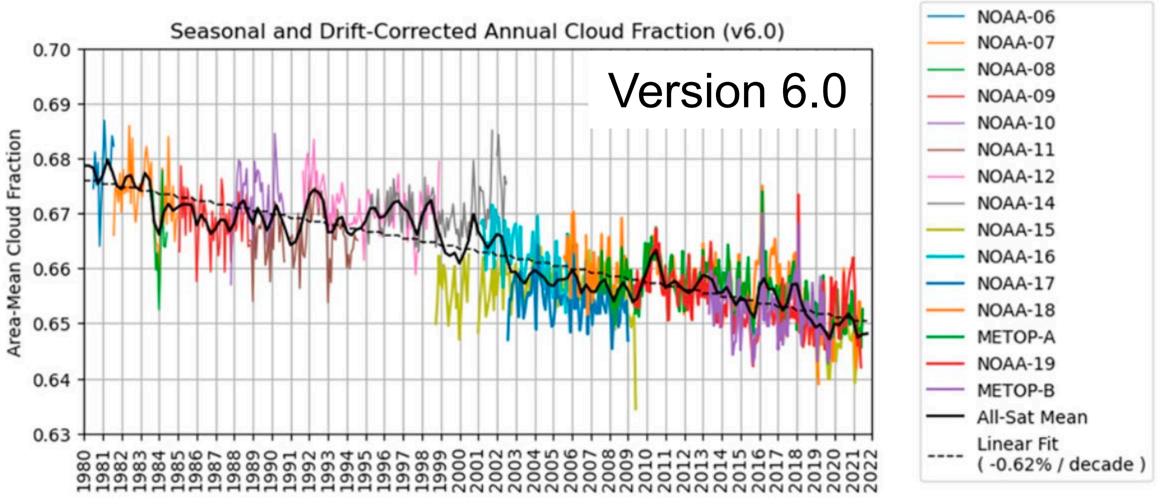
- The Pathfinder Atmospheres–Extended **(PATMOS-x)** dataset developed by National Oceanic and Atmospheric Administration (**NOAA**) in collaboration with the University of Wisconsin-Madison Cooperative Institute for Meteorological Satellite Studies (**CIMSS**) is a long-term cloud record spanning 1979 to present.

- PATMOS-x cloud products are derived from the Advanced Very High Resolution Radiometer (**AVHRR**) sensors flown on the NOAA polar orbiting satellite series and European Organization for the Exploitation of Meteorological Satellites (**EUMETSAT**) Meteorological Operational (**MetOp**) satellites.

- Primary goal PATMOS-x project is to develop satellite-based climate data records (CDRs) of atmospheric cloud properties.

- PATMOS-x v6.0 (New version) is more stable and has more consistent polar cloud detection, phase distribution, and cloud top height distribution with less inter-satellite variability by using ***'imager (AVHRR) plus sounder (HIRS)'*** fusion method than PATMOS-x v5.3.





Foster et al. 2022

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Data and Method

■ **PATMOS-x v6.0 L2b Dataset**

- Temporal Resolution = 2 observations per a day (Ascending and Descending)
- Spatial Resolution = 0.1° × 0.1°

■ **Cloud Detecting and Typing**

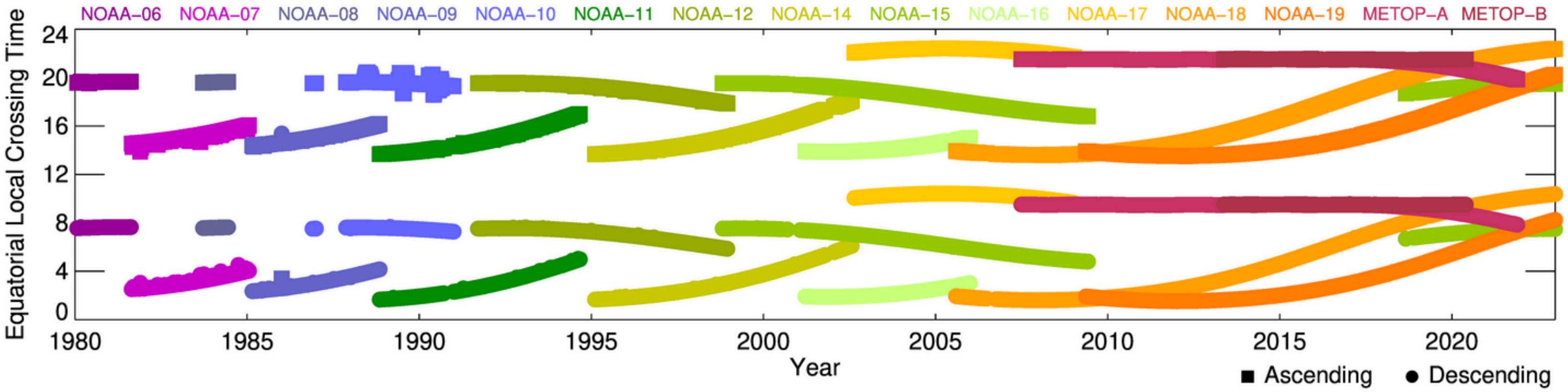
- NESDIS Enterprise Cloud Mask (ECM) represents an evolution of naïve Bayesian cloud detection algorithm (Heidinger et al. 2012)
- Cloud Types are classified with a minimum set of types evident in the spectral signatures. (Pavolonis et al. 2005)
- [Fog, Water, Supercooled Water, Mixed = **Water**, + Opaque Ice, Overlapping, Overshooting, Cirrus = **Ice**] = **All Cloud Type**

■ **Make Monthly Mean Cloud Fraction**

- All the observations corresponding to a specific month have been collected.
- Merging one hundred of 0.1° × 0.1° pixels to one of 1.0° × 1.0°
- Filtering
  1) Bad Pixel Mask, 2) Glint Mask, 3) Sensor Zenith Angle < 50°, 4) Minimum number of observation days per month > 10
- Surface Type = Ocean, Latitude = 60° S – 60° N

Data and Method

■ Apply Diurnal Correction (Correction for different local crossing time and orbit drifting)



- Do backfitting a Generalized Additive Model (GAM) for each 1.0° × 1.0° grid box. (Foster er al. 2022)

- Give weighting to observations to make daily mean; $y_{\overline{daily}} = \sum_{i=1}^{24} y_{obs} \left[\frac{F(x_i)}{F(x_{obs})}\right] \left\{\frac{24^2-(x_{obs}-x_i)^2}{24[\sum 24^2-(x_{obs}-x_i)^2]}\right\}$ (Foster et al. 2013)

■ **Statistical Significance of Trend** (Weatherhead et al. 1998)

- Detection of long-term, linear trends is affected by number of factors, including time span of data and the magnitude of variability, and autocorrelation of the noise in the data.

(1) $Y_t = \mu + \omega X_t + N_t$

(2) $N_t = \phi N_{t-1} - \varepsilon_t$

(3) $\sigma_N^2 = Var(N_t) = \frac{\sigma_\varepsilon^2}{(1-\phi^2)}$

(4) $\sigma_{\widehat{\omega}} \approx \frac{\sigma_\varepsilon}{(1-\phi)} \frac{1}{n^{\frac{3}{2}}} = \frac{\sigma_N}{n^{\frac{3}{2}}} \sqrt{\frac{(1+\phi)}{(1-\phi)}}$ [$\sigma_{\widehat{\omega}}$; Standard Deviation of generalized least squares estimator of the trend ω]

- $|\boldsymbol{\omega}| > \mathbf{1.96} \times \boldsymbol{\sigma_{\widehat{\omega}}}$ → Statistically Significant at the 95% confidence level

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Cloud Fraction [All Cloud Type]

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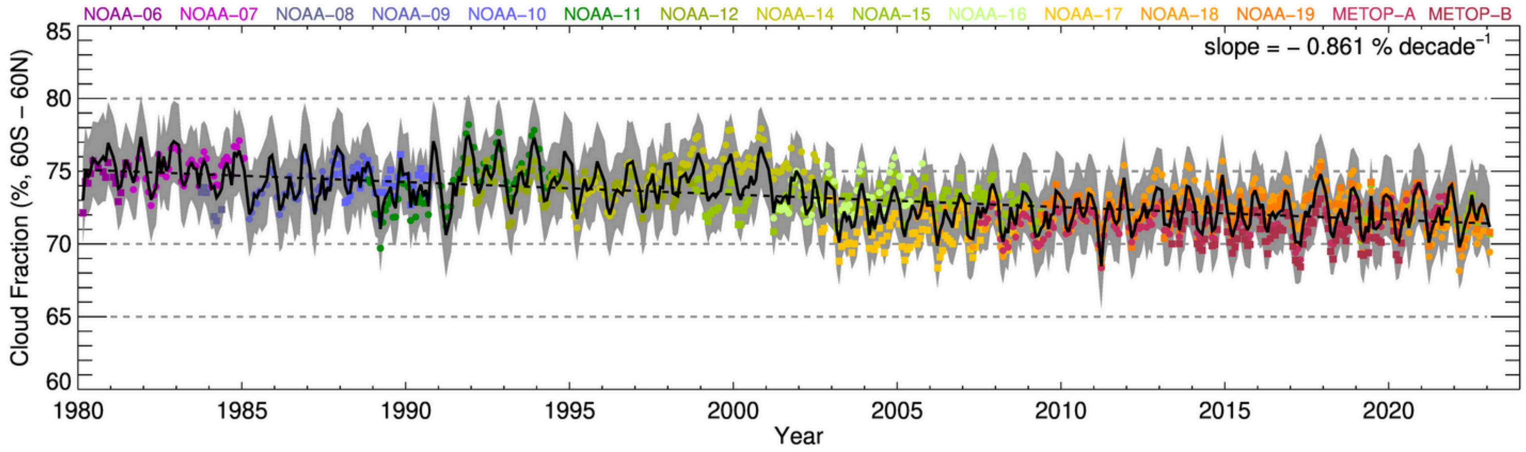
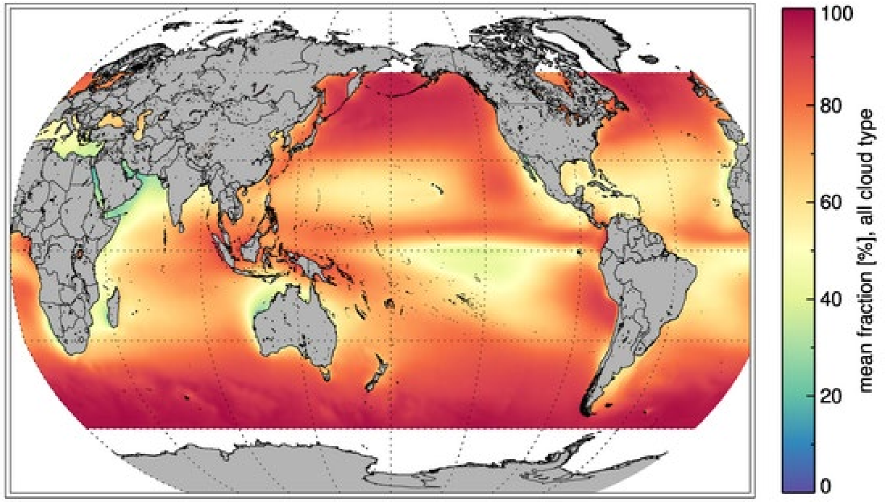
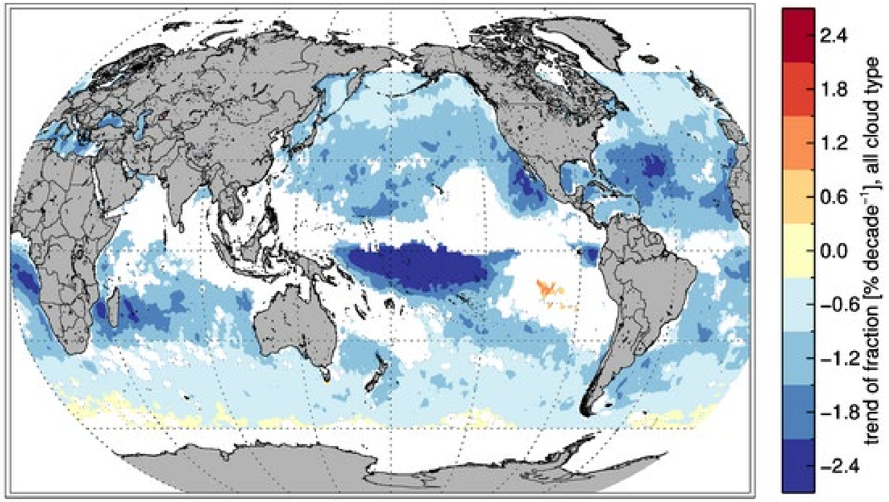




■ **TimeSeries of Mean Cloud Fraction over Ocean**
- Mean Cloud Fraction between 60°S and 60°N is decreasing by 0.86 % per decade.

- Min. Statistical Significance trend at the 95% confidence level = 0.20 % per decade.

→ Decreasing trend of global cloud fraction is statistically significance.



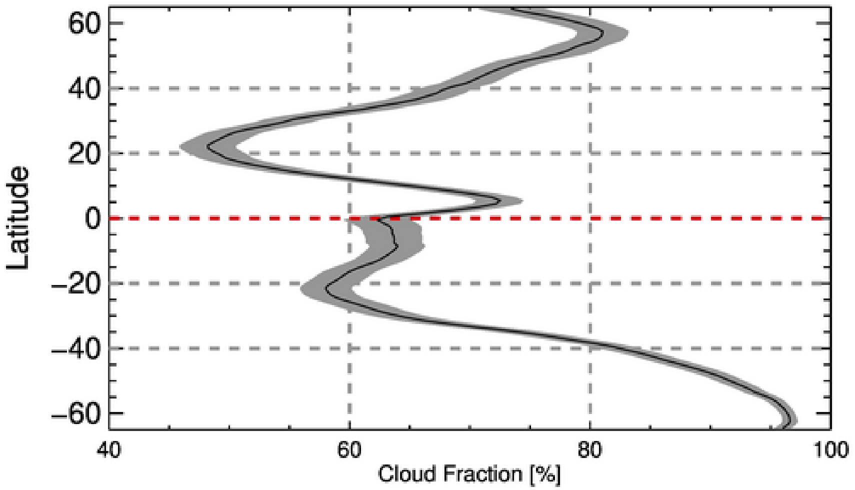
■ **Global Map of Mean and Trend of Cloud Fraction**
- Significant decreases are being observed in the central Pacific Ocean and mid-Latitude.

- In South America's west coast and Indonesia, there is a trend of increasing.

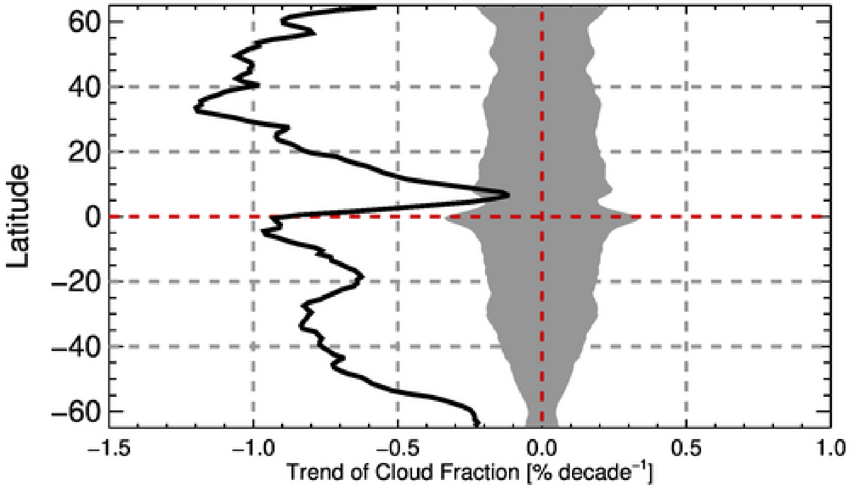
- Many regions continue to show a decreasing trend in cloudiness even after the statistical significance test.

Cloud Fraction [All Cloud Type]

Mean



Trend



■ **Monthly Cloud Fraction**

- Range of Mean Cloud Fraction is from 65% on August to 74% on December.
- Min. Statistical Significance trends at the 95% confidence level < 0.10 % per decade.
- Clouds show a decreasing trend in all months (July = –0.63%, April = –0.84%)

■ **Latitudinal Cloud Fraction**

- Range of Mean Cloud Fraction is from 50% at 20°N and 90% at 60°S.
- Cloudiness is decreasing at all latitudes, and most of trends are statistically significant except near the equator.
- The highest decreasing trend is observed at 30°N (–1.2% per decade)

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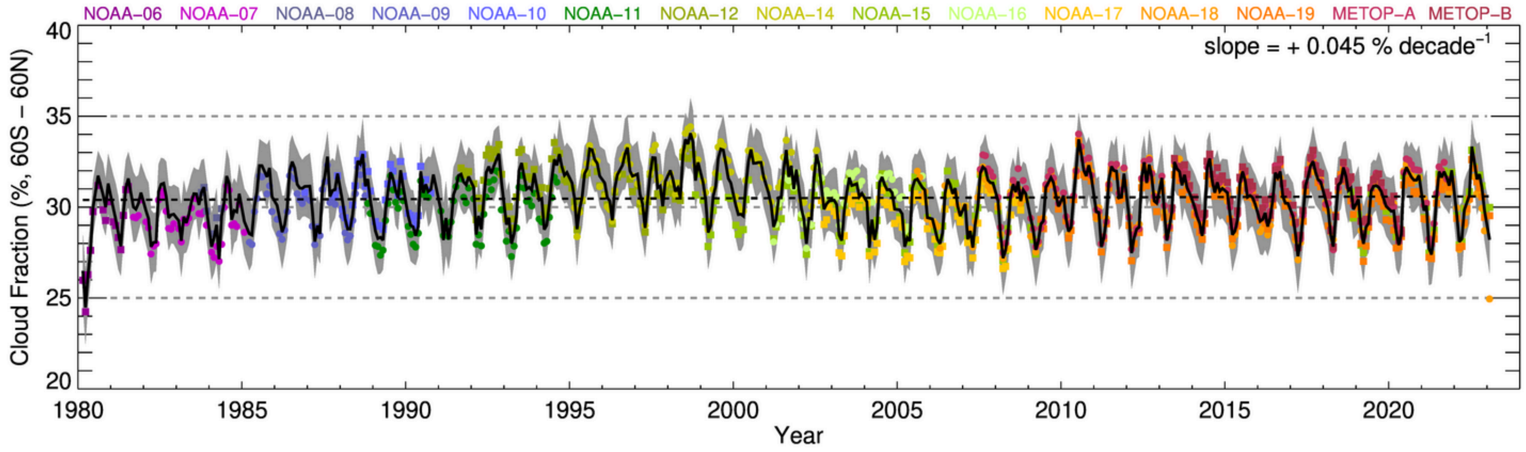
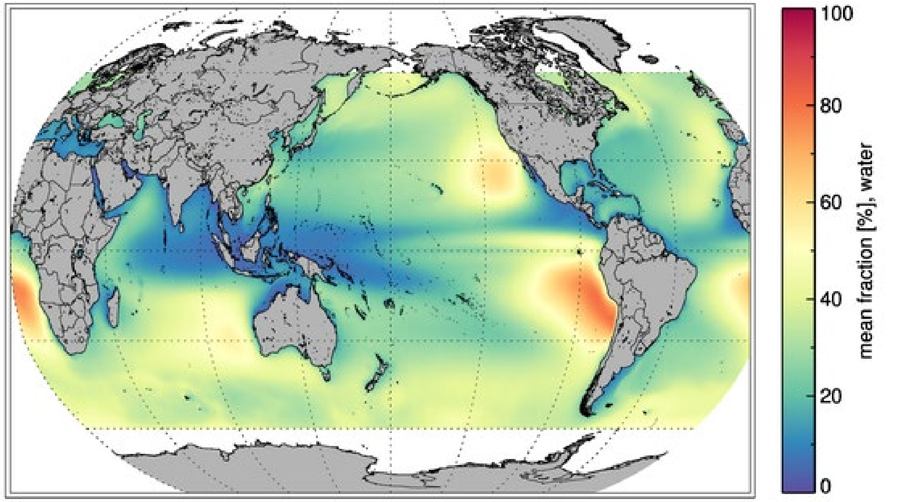
Cloud Fraction [Water Cloud Type]



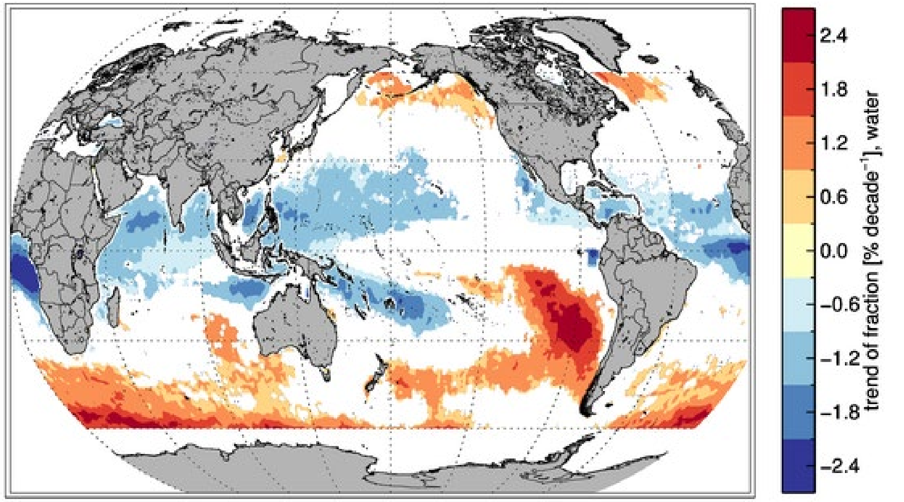


■ TimeSeries of Mean Cloud Fraction over Ocean

- Mean Cloud Fraction between 60°S and 60°N is increasing by 0.045 % per decade.

- Min. Statistical Significance trend at the 95% confidence level = 0.26 % per decade.

→ Trend of global water cloud fraction is not statistically significance.



■ **Global Map of Mean and Trend of Cloud Fraction**

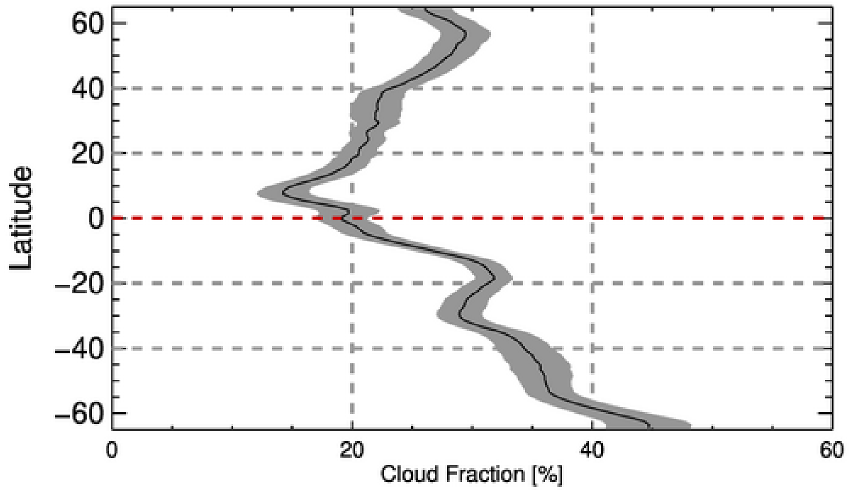
- Significant decreasing are being observed near the equator and west coast of Africa.

- In South America's west coast and mid-latitudes, there is a trend of increasing.

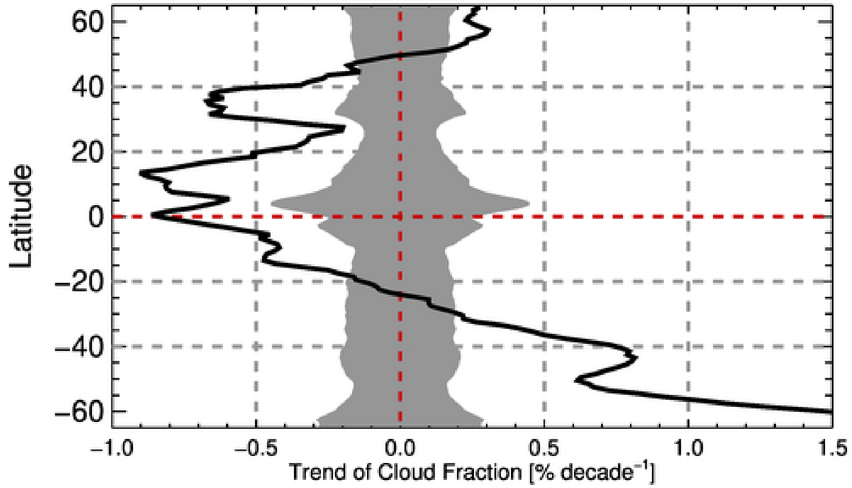
- Many regions continue to show a decreasing and increasing trend in cloudiness even after the statistical significance test.

Cloud Fraction [Water Cloud Type]

Mean



Trend



- **Monthly Cloud Fraction**
  - Range of Mean Cloud Fraction is from 25% on April to 29% on October.
  - Min. Statistical Significance trends at the 95% confidence level < 0.06 % per decade.
  - Clouds show a decreasing trend in most months except for August (+0.03%).
  - There are eight months with a statistically significant decreasing trend.

- **Latitudinal Cloud Fraction**
  - Range of Mean Cloud Fraction is from 15% at 10°N and 45% at 60°S.
  - Cloudiness is decreasing between 20°S and 40°N
  - The highest decreasing trend is observed at 15°N. (−0.9% per decade)
  - Cloud Fraction is increasing above 50°N and 30°S.
  - The highest increasing trend of water cloud is observed at 60°S. (+1.5% per decade)

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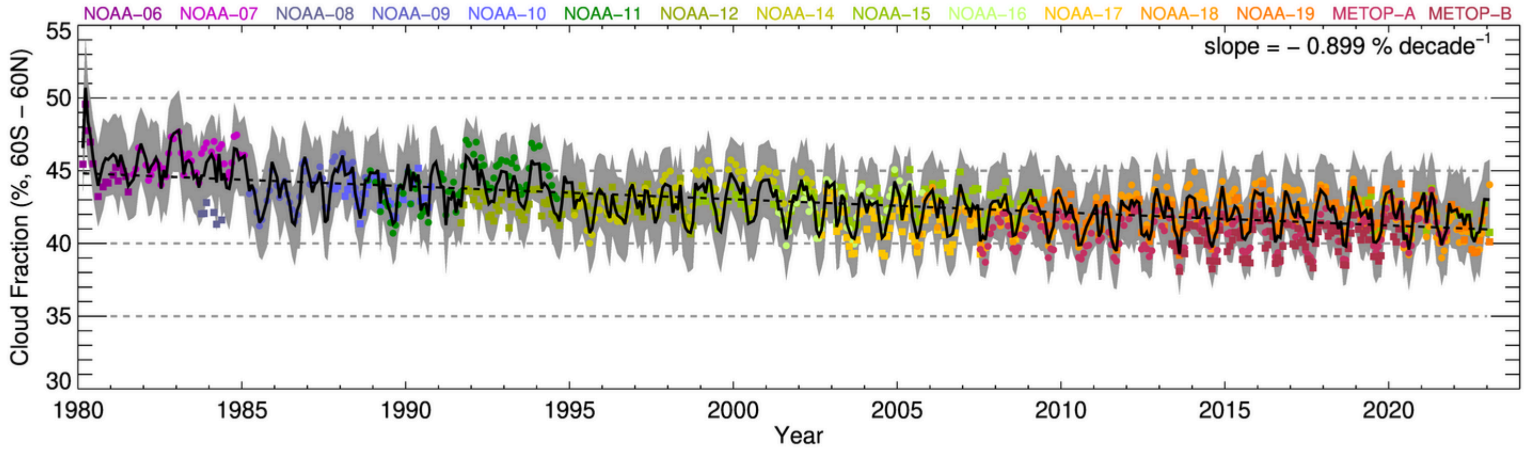
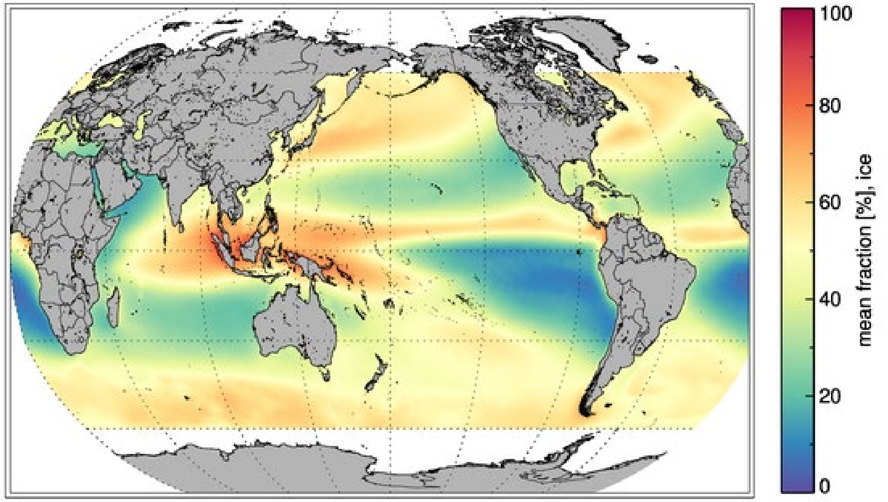
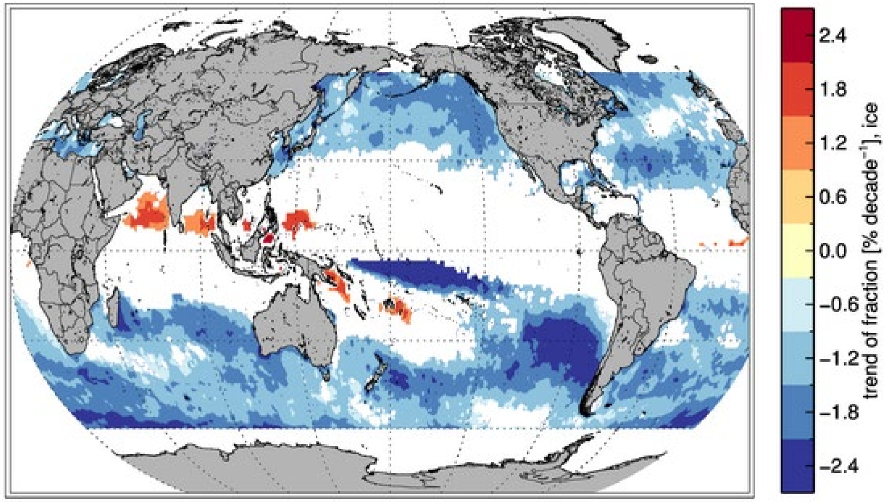
Cloud Fraction [Ice Cloud Type]





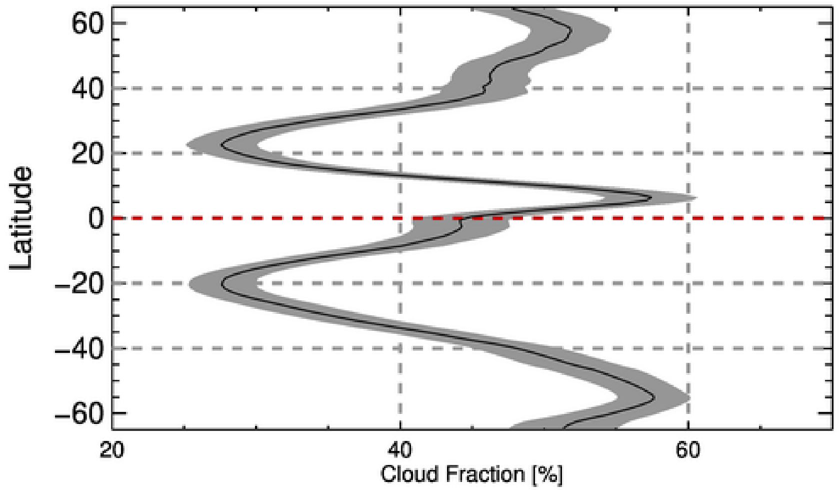
- ■ TimeSeries of Mean Cloud Fraction over Ocean
  - Mean Cloud Fraction between 60°S and 60°N is decreasing by 0.899 % per decade.
  - Min. Statistical Significance trend at the 95% confidence level = 0.20 % per decade.
  - → Decreasing trend of global ice cloud fraction is statistically significance.



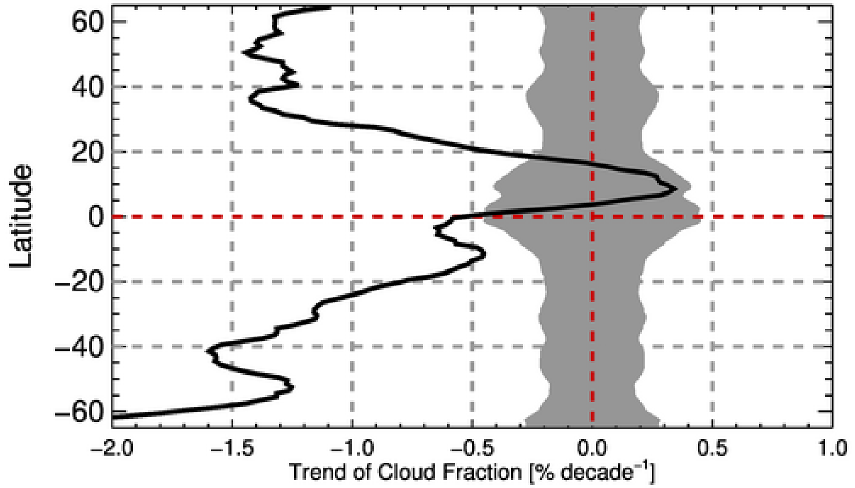
- ■ **Global Map of Mean and Trend of Cloud Fraction**
  - Decreasing trends are dominant except for Indonesia and Arabian Sea.
  - Mid-latitude regions continue to show a decreasing trend in cloudiness even after the statistical significance test.

Cloud Fraction [Ice Cloud Type]

Mean



Trend



- **Monthly Cloud Fraction**
  - Range of Mean Cloud Fraction is from 38% on September to 48% on December.
  - Min. Statistical Significance trends at the 95% confidence level < 0.10 % per decade
  - Clouds show a decreasing trend in all months and statistically significant. (Oct; −1.1%, July; −0.76% per decade)

- **Latitudinal Cloud Fraction**
  - Range of Mean Cloud Fraction is from 30% at 20°N/S and 60% at 5°N and 60°S.
  - Cloudiness is decreasing except for between 0°N and 20°N
  - The highest decreasing trend is observed at 60°S. (−2.0% per decade)
  - Cloud Fraction is increasing between 0°N and 20°N.
  - An Increasing trend of ice clouds is observed at 10°N. (+0.35% per decade), but it is not statistically significant.

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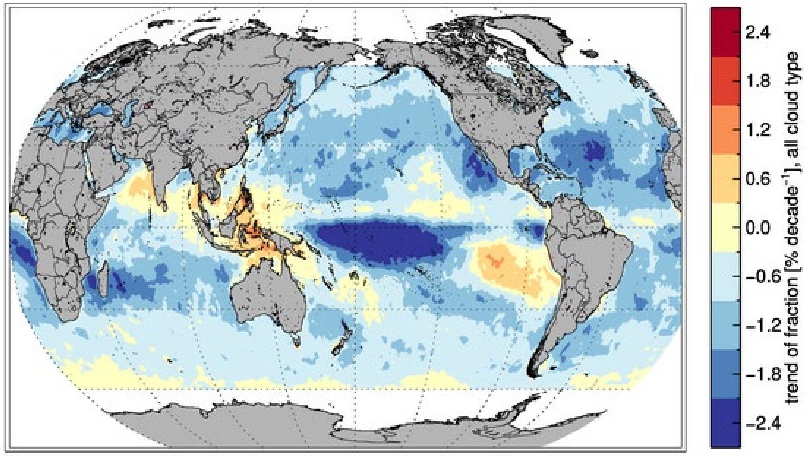
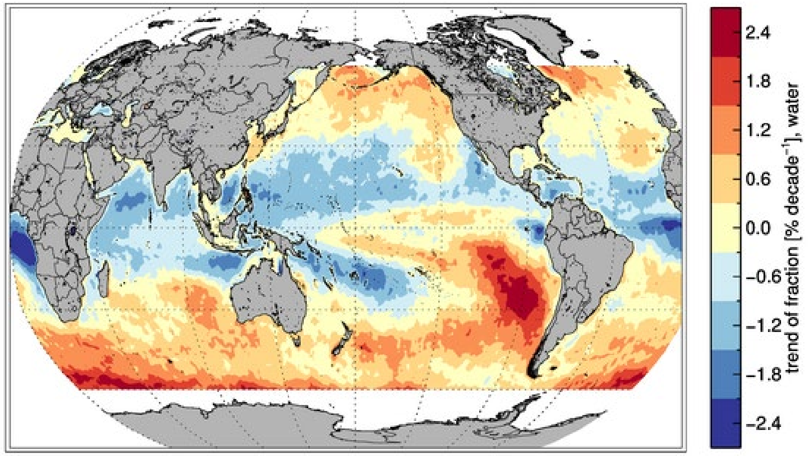
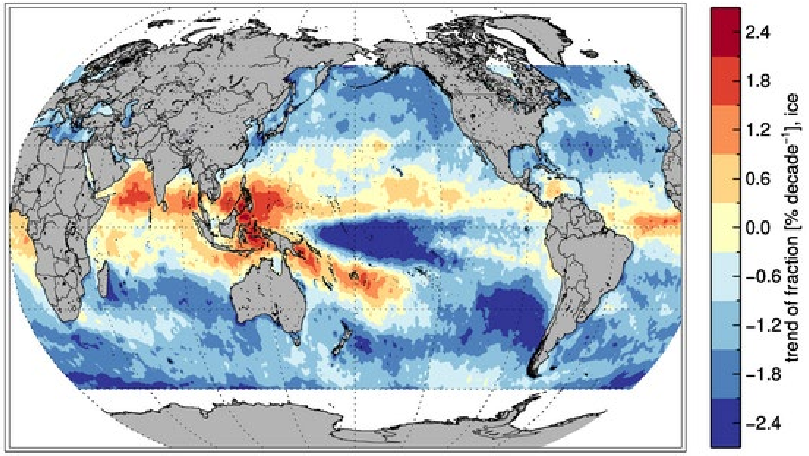
Summary and Future Plan



All Cloud Type



Water Cloud Type



Ice Cloud Type

■ **All Cloud Type**
- Cloudiness is decreasing in most regions, and these are statistically significant.
- Decreasing trends are being observed at every latitude and month.

■ **Water Cloud Type**
- Decreasing trends are observed near the equator and increasing trends are observed at the west coast of South America and mid-latitude regions.
- Decreasing trends are dominant in monthly mean water cloudiness.

■ **Ice Cloud Type**
- Ice cloudiness is decreasing in most regions, and most of the decreasing trends are statistically significant.
- Decreasing trends are being observed at every latitude and month.
- Ice cloudiness is increasing near the equator, but it is not statistically significant.

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Summary and Future Plan

■ **Comparison with other observations and models.**
- Other dataset from satellites using AVHRR, MODIS, and CALIPSO, Climate models…

■ **Studying trends in other cloud products**
- Cloud Radiative Effect, Cloud Top Height, Cloud Top Pressure, and Cloud Top Temperature.

■ **Investigating relationship between trends in cloudiness and atmospheric drivers**
- ENSO, inversion strength, surface temperature, vertical velocity at 500 mb, …

■ **Developing ECM2 Cloud Masking**
- Investigating classifiers and training dataset to improve accuracy of cloud detection.

■ **Investigating Consistency between AVHRR satellites and VIIRS satellites**
- Comparing between AVHRR (NOAA-18 and 19, and MetOp-A and B) and VIIRS satellites (NOAA-20 and Suomi-NPP)

Thank You ☺