Cloud Type and Cloud Phase Products of Fengyun Satellites

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2023.11, AOMSUC-13

Contents

Research purpose

- Diagnosis of atmospheric radiation budget: due to the different scattering properties of light for ice and water particles, their effects on solar incidence and ground radiation are also different. Therefore, the accurate judgment of cloud phase is very helpful to the study of atmospheric radiation budget

- Weather monitoring and mechanism research: the thermodynamic process associated with cloud phase changes is directly related to the formation and evolution of various scale weather and climate systems:
  - to estimate the freezing time of cumulus cloud top, so as to help determine the intensity of storm and make a near forecast for severe convective weather
  - to track the size and shape of tropical cyclones, thus to estimate the intensity of tropical cyclones
  - can also avoid the risk of ice accretion on aircraft
  - Cloud phase is an important input for the calculation of cloud optical thickness and effective particle radius
  - Identify the operation area from the mixed phase cloud during weather modification
  - Early input of convective Initiation recognition: water cloud and hybrid cloud are regarded as the areas that may generate convection in the future

Inversion Algorithm Overlook

- The process of cloud phase classification is to extract features according to the optical properties of the cloud, obtain spectral and texture features that describe various types of cloud tops, and classify them accordingly. The main methods are as follows:

- Band crossing method: The cloud phase is determined by solving the radiative transfer equation. Derrien et al. (2007) used AVHRR and Goes infrared and visible cloud images to classify the clouds. There always large bias occurs in the classification of low and medium clouds.

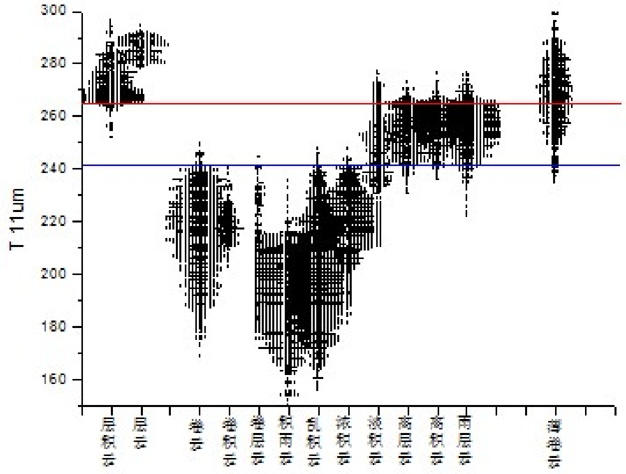
- Threshold method: the bright temperature difference between 11, 12 and 6.7 μm channels of GMS-5 as the threshold is used to judge the cloud (Yang et al. 2002), which was better in the judgment of whether there was cloud or not and the judgment of high and low clouds.

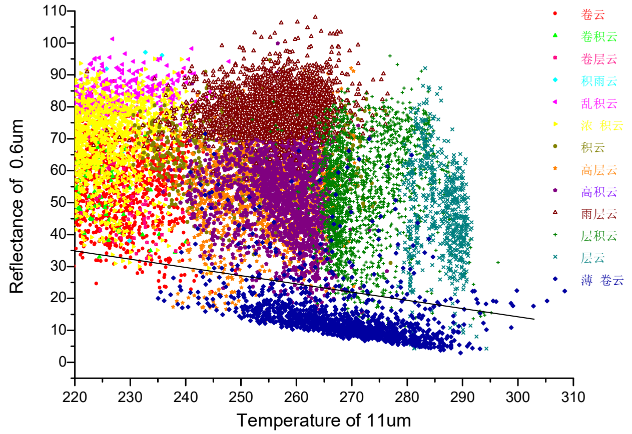
- Statistical method: according to a certain statistical variable, the cloud images are classified. The commonly used statistical methods include threshold method, histogram method and cluster analysis. For example, K-clustering technology is used to realize the identification of eight kinds of cloud of FY-2. The effect depends on the characteristics of the observation object in the satellite observation, which makes it difficult to get a more consistent criterion for cloud classification.


Contents

Current Status of FY-3D Operational Products

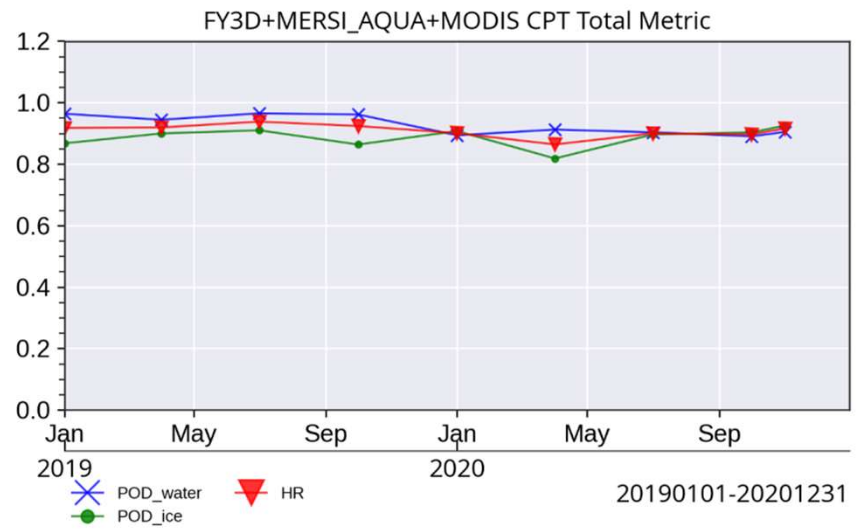
- Multispectral Method, Channels: 0.65, 1.65, 3.75, 10.8, and 12.0 µm, can only be performed during the day time.
- Output type: The cloud type is divided into high, medium, and low clouds, and the cloud phase is composed of water phase, ice phase, and mixed phase
- Resolution: 1 km and 5min for orbit products, while 0.05 ° for global daily synthesis
- Under the premise of reasonable L1 and cloud mask product, the cloud phase recognition results are relatively ideal, and the product accuracy after August 2018 is higher than 88%.





Cloud top brightness temperature and reflectance for different cloud types

Performance estimates



Physical Basis

The atmospheric radiation transfer equation under cloud conditions can be written as:

Above cloud to TOA upwelling atmospheric radiance

Plank Fuction

$$R_{obs}(\lambda) = \varepsilon(\lambda) R_{ac}(\lambda) + t_{ac}(\lambda)\varepsilon(\lambda) B(\lambda, T_{eff}) + R_{clr}(\lambda)(1-\varepsilon(\lambda))$$

The observed top of atmosphere radiance

Above cloud to TOA upwelling atmospheric transmittance

TOA clear sky radiance

Effctive cloud emisstivity

Effctive cloud emisstivity:

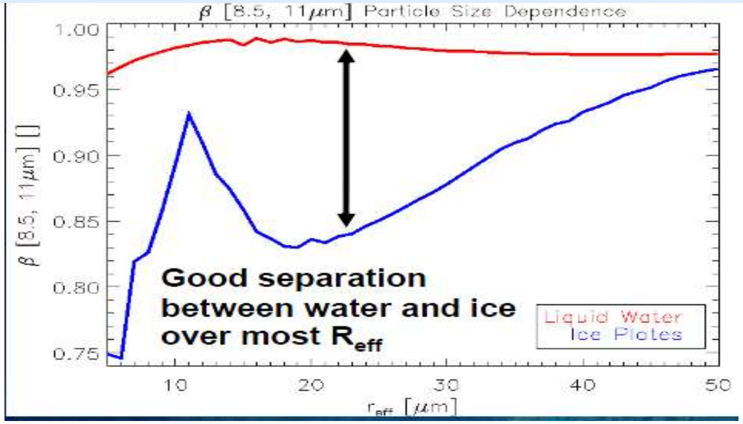
$$\varepsilon(\lambda) = (R_{obs}(\lambda) - R_{clr}(\lambda)) / ([B(\lambda, T_{eff}) tac(\lambda) + R_{ac}(\lambda)] - R_{clr}(\lambda))$$

The cloud's microphysical information cannot be obtained solely by relying on the effective emissivity of a single channel or wavelength. It is necessary to utilize the spectral variation of the cloud's effective emissivity, which is the effective absorption optical thickness ratio （β Ratio）:

$$\beta_{obs} = \ln[1-\varepsilon(\lambda_1)] / \ln[1-\varepsilon(\lambda_2)] = \tau_{abs}(\lambda_1) / \tau_{abs}(\lambda_2)$$

The term 'effective' is due to the fact that the emissivity of clouds depends on the effective cloud temperature. Due to the fact that the emissivity of clouds usually originates from a certain level within the cloud, the level of cloud emissivity depends on the transmission profile of the cloud

Cloud phase relationship derived from single scatter properties

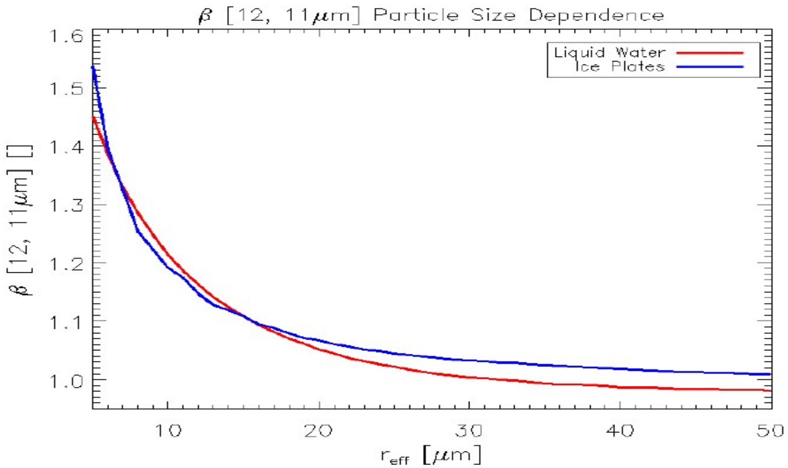


As in Pavolonis (2010), effective absorption optical depth ratios (β Ratio) are used to infer cloud microphysical information

On 8-15 μ In the m-band range, the multiple scattering effect is very small, and the spectral ratio of the extinction coefficient can reflect the essence of cloud radiation transmission:

$$\beta_{observed} = \frac{\ln(1.0 - \varepsilon_{\lambda 1})}{\ln(1.0 - \varepsilon_{\lambda 2})} \quad \beta_{theoretical} = \frac{(1.0 - \omega_{\lambda 1} g_{\lambda 1})\sigma_{ext\lambda 1}}{(1.0 - \omega_{\lambda 2} g_{\lambda 2})\sigma_{ext\lambda 2}}$$

$$\beta_{theoretical} \approx \beta_{observed}$$



β (12/11) μ m) Although sensitive to particle size, it is difficult to provide effective information to distinguish cloud phase states. β (12/11) μ m) Sensitivity to cloud particle size can be used to distinguish opaque clouds.

Algorithm Outputs (cloud type & phase)

The process of cloud type classification is to extract features based on the optical properties of clouds, obtain a series of spectral and texture features that describe various cloud top types, and classify them accordingly. Then merge ice clouds to generate cloud phase products.

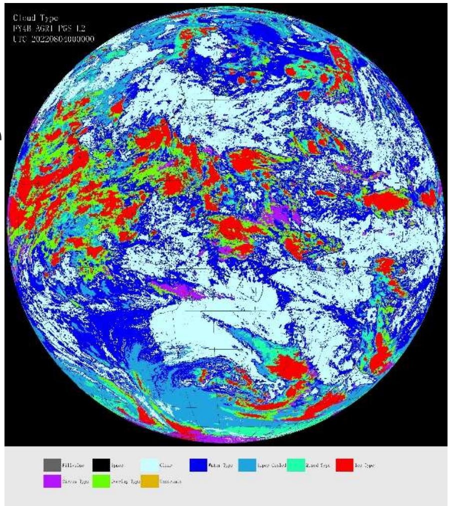
Category	Description	Value
Clear	Clear cloud mask output	0
Liquid water	Liquid water cloud with an 11 μm brightness temperature > 273 K	2
Supercooled water	Liquid water cloud with an 11 μm brightness temperature < 273 K	3
Mixed phase	High probability of containing both ice and liquid water near cloud top	4
Opticallly thick ice	Ice toopped cloud that is opaque or near opaque in the infrared (infrared optical depth greater than about 1.0)	5
Optically thin ice	Ice toopped cloud that is opaque or near opaque in the infrared (infrared optical depth of about 1.0 or less)	6
Multilayered ice	Semi-transparent ice cloud overlapping a lower, opaque cloud layer	7

Basic information of FY-4 products

The cloud types and cloud phase products of FY-4/AGRI are divided into full disk, daily, ten-day, and monthly products. The daily/ten-day/monthly products record the frequency of cloud occurrences of different types (phase) in the current day/ten-day/month (newly added in FY-4B)

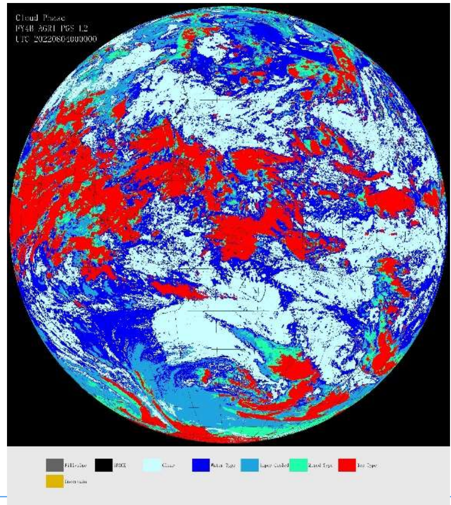
Time coverage: since March 2018 (FY -4A), August 2022 (FY-4B)

FY-4B Cloud type



Basic information of Cloud type and Cloud phase data

	Name	Refresh rate	Level	resolution
1	Disk	15 min (FY-4B)	L2	4 km
2	REGC	5 min (FY-4A)	L3	4 km
3	Month	monthly	L3	4 km



FY-4B Cloud phase

Contents

Performance Estimates

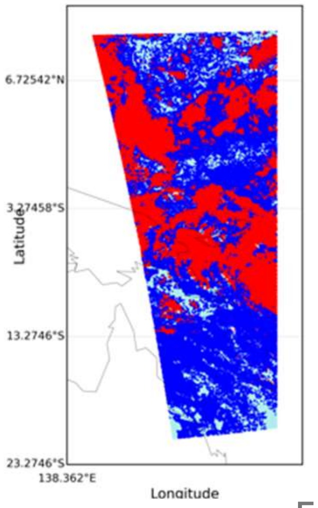
Verification source data: MODIS cloud product dataset MYD06

Spatiotemporal matching threshold：5 min，1 km

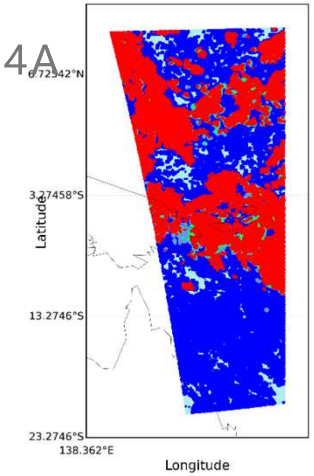
statistical indicators	Meanings	methods
POD	Probability of detection	a/(a+b)
FAR	False alarm rate	c/(a+c)
HR	Hit rate	(a+d)/(a+b+c+d)
KSS	Kss score	(ad-cb)/[(a+b)*(c+d)]

	MERSI_water	MERSI_ice
MODIS_water	a	b
MODIS_ice	c	d

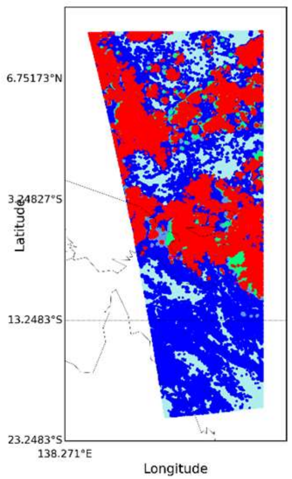
MODIS



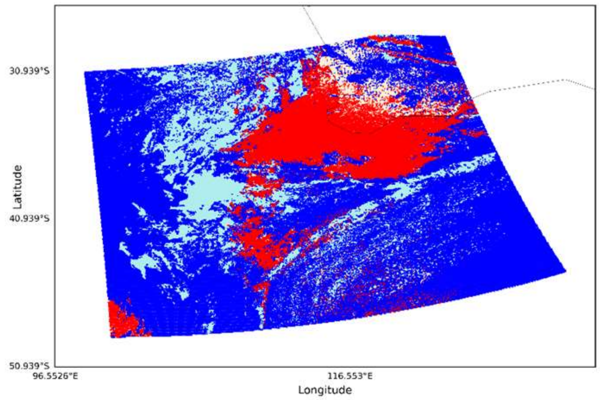
FY-4A



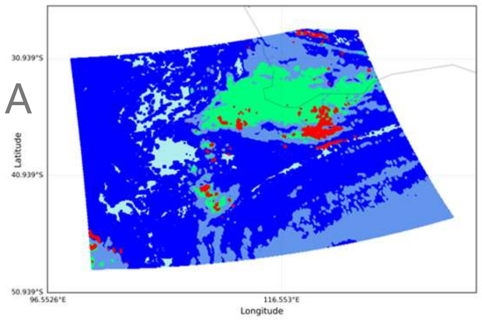
FY-4B



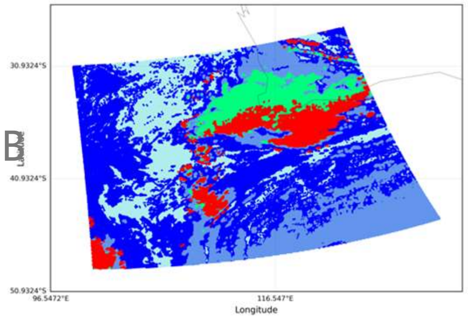
MODIS



FY-4A



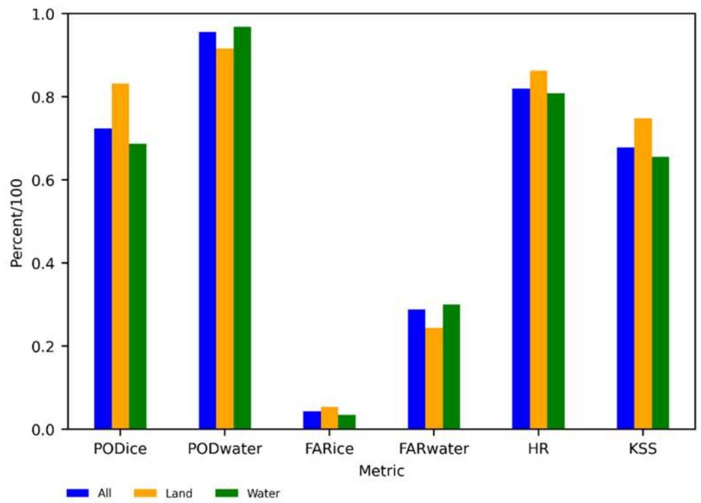
FY-4B

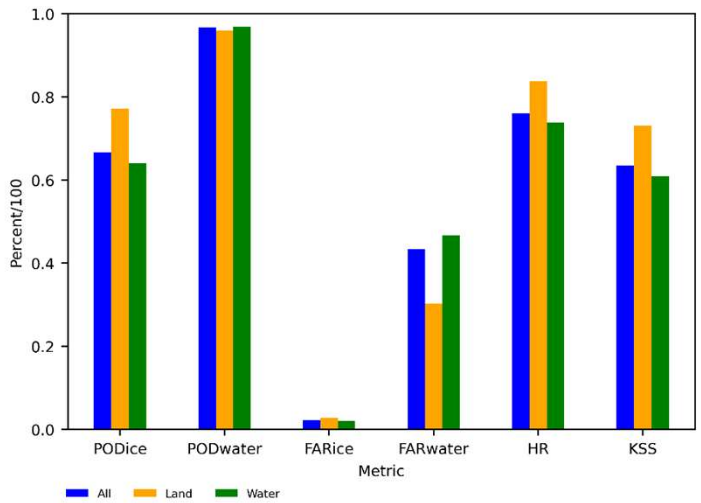


Clear ice warm mix
uncertain

- FY-4A

FY-4B





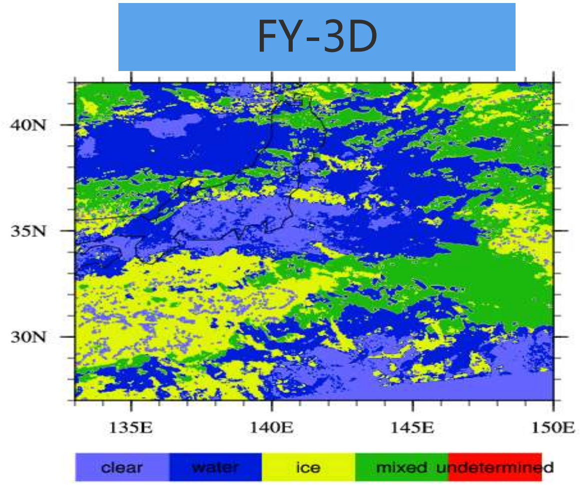
	N	POD_ice	POD_water	FAR_ice	FAR_weater	HR	KSS
land	1488642	0.772	0.959	0.028	0.302	0.838	0.731
Water	12296991	0.64	0.969	0.02	0.466	0.738	0.609
all	15834000	0.667	0.967	0.022	0.433	0.77	0.634

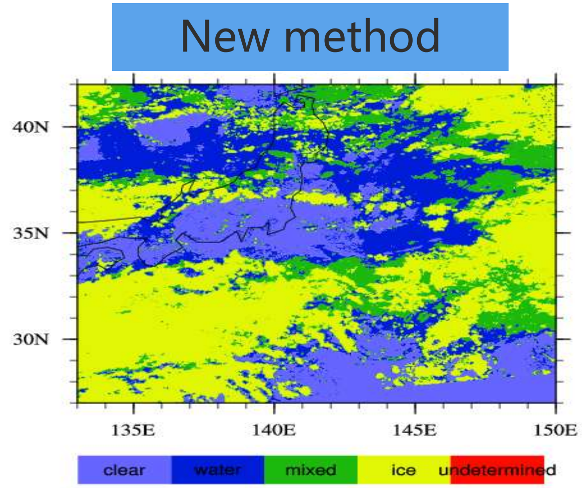
Contents

Future plan

- This method will be applied to the new morning star of the FY-3 series, FY-3F
- In the algorithm development stage, all inputs for L1 and cloud detection product are from FY-3D. Therefore, in order to eliminate the inconsistency of cloud detection results and the impact of L1 inconsistency, FY-3D's daytime cloud phase product is used for validation.

Middle and low latitudes in East Asia (Japan Island+Northwest Pacific) Northwest Pacific





Good consistency except for mixed clouds

Comparison with FY-3D products (July and October 2019)

		POD_water	POD_ice	FAR_water	FAR_ice	HR	KSS
Land	new	0.932	0.911	0.08	0.075	0.922	0.843
	FY-3D	0.979	0.801	0.179	0.024	0.887	0.78
Water	new	0.922	0.969	0.023	0.101	0.942	0.892
	FY-3D	0.962	0.94	0.055	0.042	0.951	0.902
Total	new	0.924	0.956	0.034	0.095	0.938	0.881
	FY-3D	0.965	0.91	0.082	0.038	0.938	0.875

		POD_water	POD_ice	FAR_water	FAR_ice	HR	KSS
Land	new	0.921	0.906	0.097	0.076	0.914	0.827
	FY-3D	0.985	0.76	0.241	0.015	0.858	0.745
Water	new	0.87	0.943	0.023	0.276	0.889	0.813
	FY-3D	0.957	0.913	0.043	0.087	0.942	0.87
Total	new	0.878	0.931	0.035	0.22	0.895	0.808
	FY-3D	0.961	0.864	0.081	0.067	0.924	0.825

- Water phase: The POD of the FY-3D is higher. Ice phase: The POD of the new algorithm is higher
- Land: New algorithm with higher HR. water: FY-3D with higher HR
- In July, the accuracy level of the two methods was equivalent, while in October, the accuracy of the new algorithm was only 0.029 lower than that of the business algorithm

- The multi-spectral inversion of cloud phase products used in FY-3D business has a significantly higher accuracy above water underlying surface than above land, and a significantly higher inversion accuracy for liquid clouds than for ice clouds
- Due to the complex shape of ice crystal particles, it' s usually more difficult to invert ice phase than water phase. Meanwhile, due to the heterogeneity of the underlying surface of land, the composition and texture structure of clouds above land are often more complex, making phase inversion relatively difficult.
- The cloud phase product based on the effective absorption optical thickness ratio method significantly improves the inversion ability of cloud phase under complex conditions such as ice phase clouds above land, and the available time of the product is extended from day to day
- We will make further improvements to the recognition of thin cirrus clouds in the polar regions


THANKS
NSMC
NCSW