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Relationship between low stratiform cloud amount and estimated inversion strength in the lower troposphere over the global ocean in terms of cloud types

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Introduction

Seasonal variation in the low stratiform cloud (LSC) amount is associated with inferred inversion strength in the lower troposphere

Klein and Hartmann (1993; KH93)

defined 10 LSC regions:

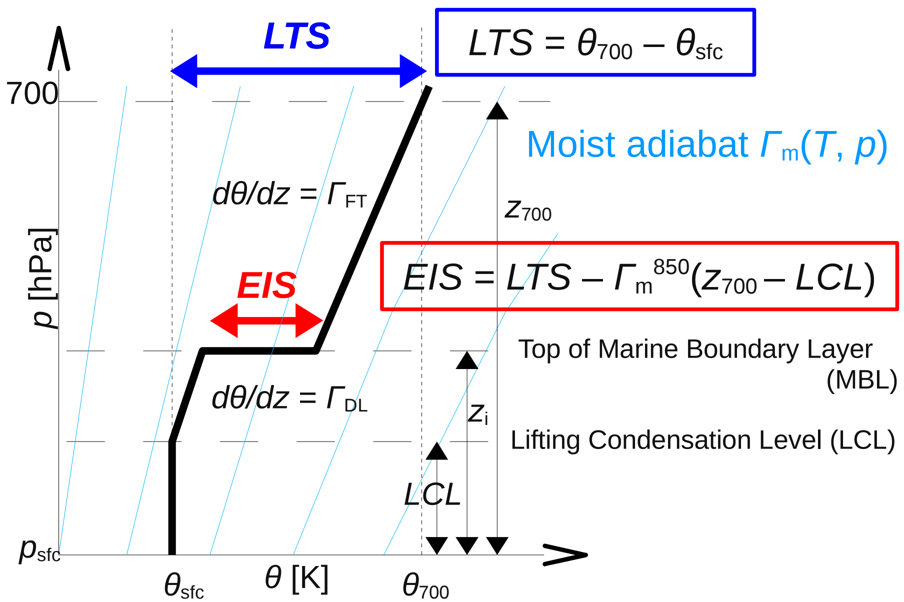
A linear relationship with **LTS**
in the subtropical oceans

Wood and Bretherton (2006; WB06)

new formulation: **EIS**

A single linear relationship with EIS
not only in the subtropical oceans
but also in the mid-latitudes

Idealized profile of lower-tropospheric structure



$EIS = LTS - \Gamma_{FT}(z_{700} - z_i) - \Gamma_{DL}(z_i - LCL)$,
assuming $\Gamma_{FT} = \Gamma_{DL} = \Gamma_m^{850} \equiv \Gamma_m([(T_{sfc}+T_{700})/2], 850\text{hPa})$.

Introduction

However,

1) LSC consists of three different types:
   stratocumulus **(Sc)**, stratus **(St)**, and sky-obscuring fog **(FOG)**

2) it is implied that the existance of temperature inversions at hights consistent with the definition of each LSC type (e.g., field campaigns, Norris 1998)
   → a new measure is required

3) a number of studies have focused on advection over SST gradient to identified processes responsible for the different LSC types

In this study, we demonstrate:

Relationships between the amount of each LSC type (Sc, St, and FOG) and EIS over the global ocean

The correspondence of the inferred inversion strength for three vertical layers within the lower troposphere that we introduce and temperature advection implied by air-sea temperature difference with the relationships

Data

Cloud amount ... LSC(=Sc+St+FOG), Sc, St, and FOG

Calculated from
Extended Edited Cloud Report Archive (EECRA; Hahn and Warren 1998), ship data only

- 5ºx5º Seasonal Climatology (between 60ºN and 60ºS)
- Period: Sep1957–Aug2002
- Only daytime observations were used (surface observers sometimes have difficulty identifying low cloud type on nights)
- Grid boxes with less than 100 observations contributing to the average are omitted to reduce the sampling error below 3% (Warren et al., 1988)

EIS

Calculated from ERA-40 monthly daily means, following the formula given by WB06 (temperature at 700hPa, temperature at 2m, and sea level pressure)

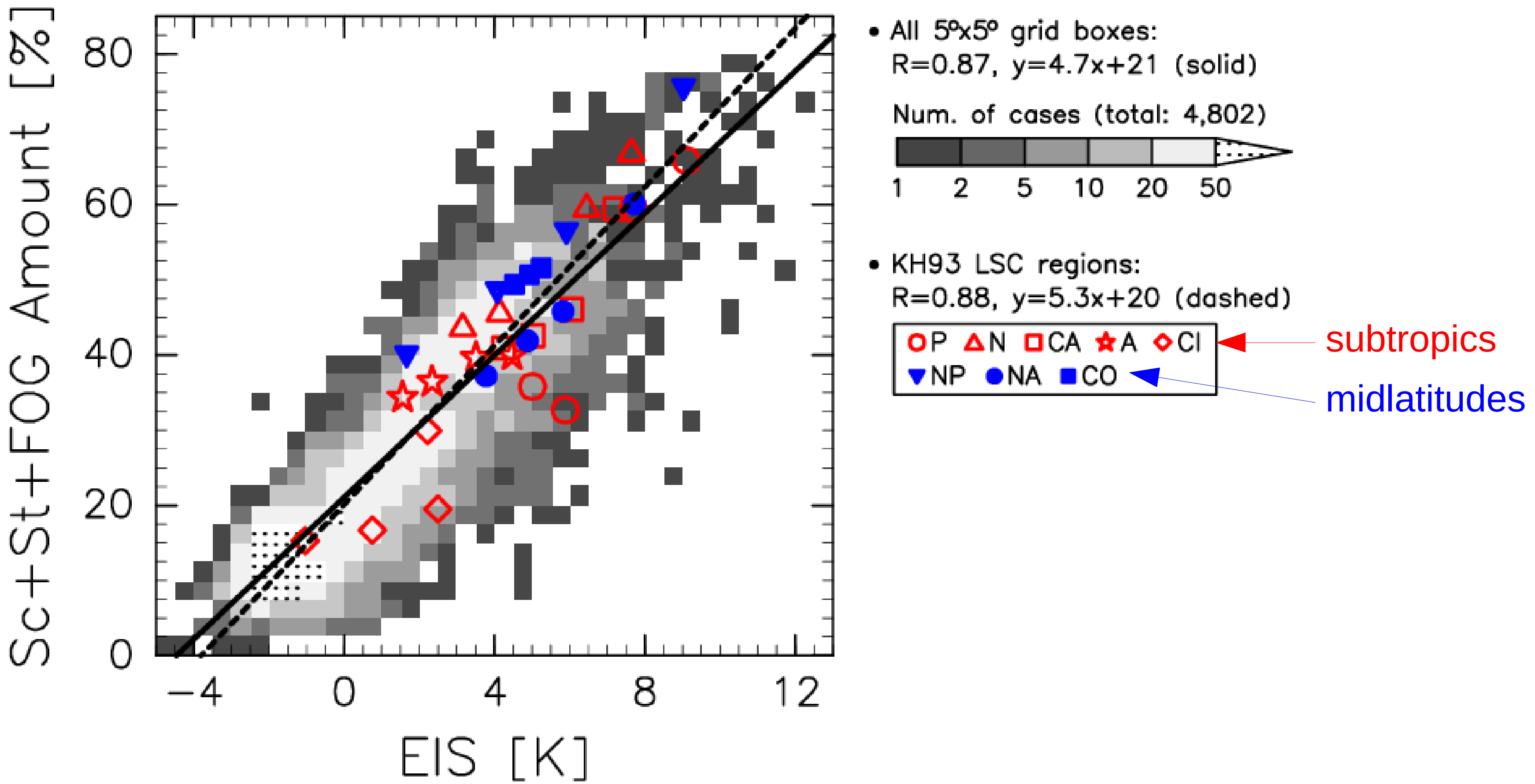
- 5ºx5º Seasonal Climatology (original: 2.5ºx2.5º monthly data)
- Period: Sep1957–Aug2002

SST

Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST)

- 5ºx5º Seasonal Climatology (original: 1ºx1º monthly data)
- Period: Sep1957–Aug2002

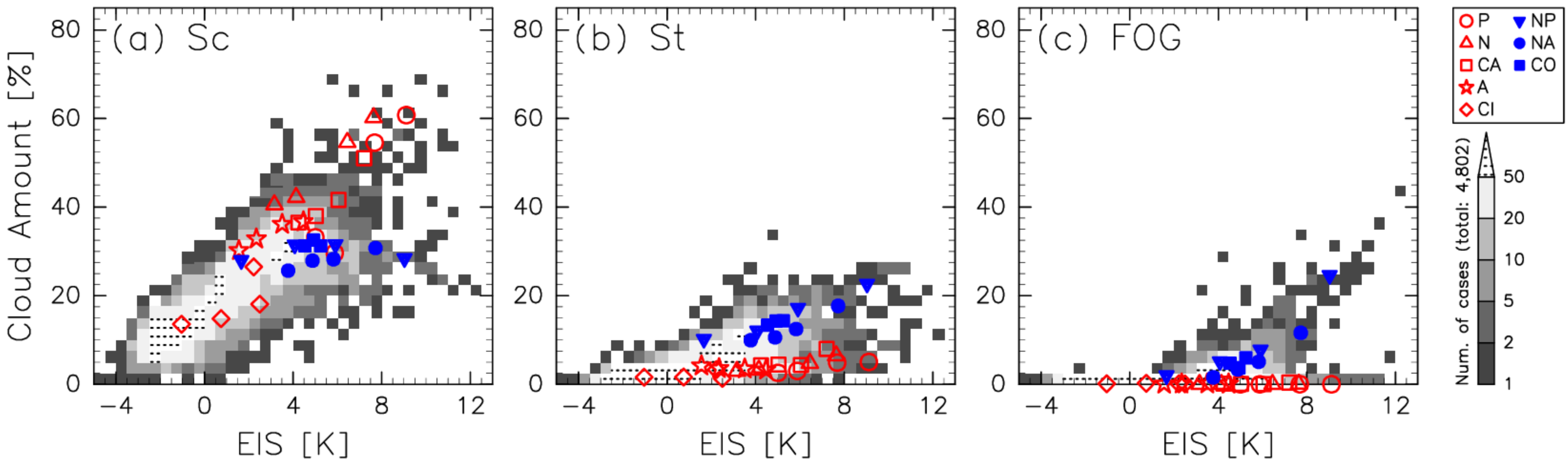
Relationship between the LSC amount and EIS



KH93's LSC regions: a single linear relationship for both the subtropics and midlatitudes

The relationship is almost universal over the gobal ocean areas

Relationships between the LSC type amounts and EIS



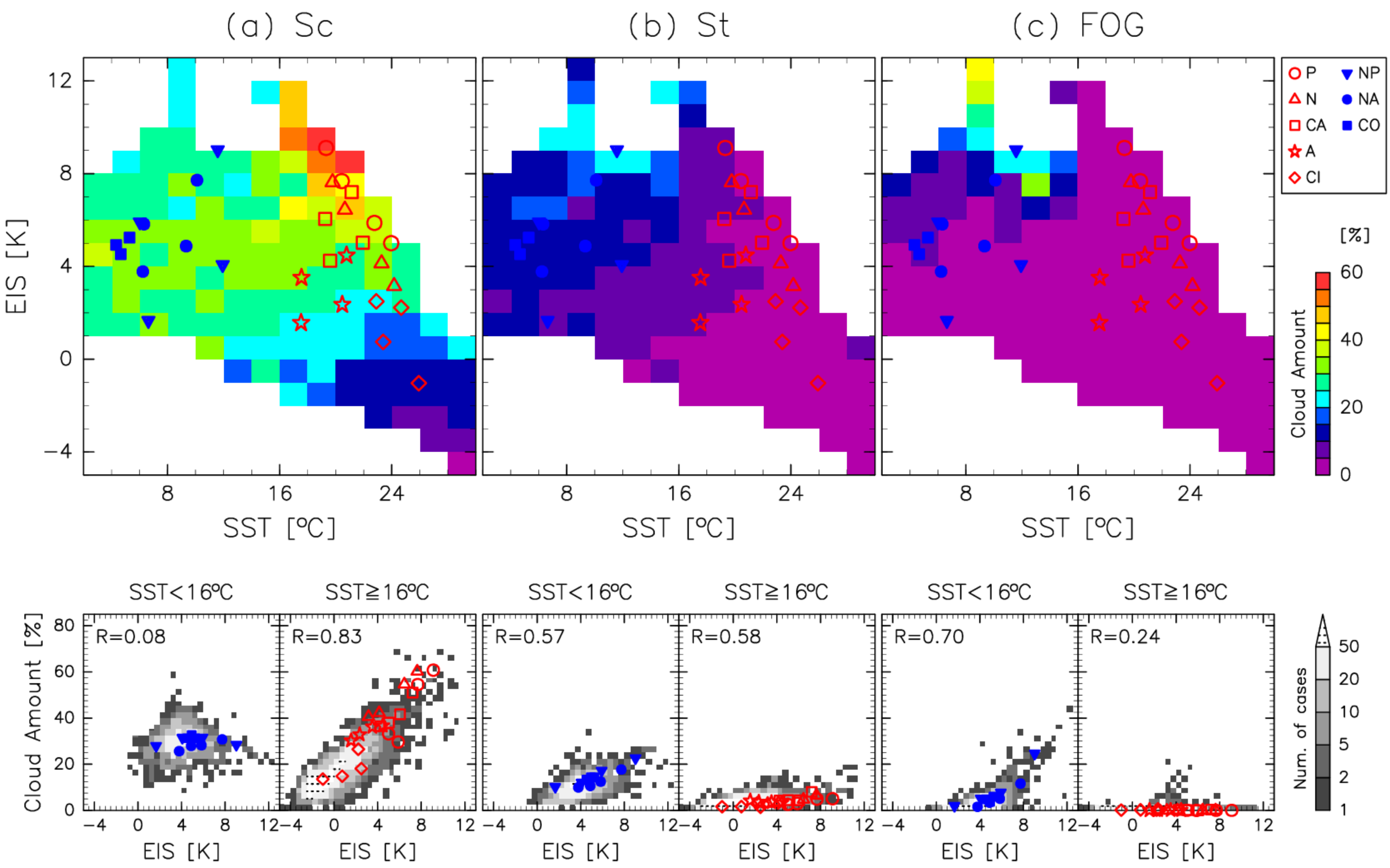
KH93's LSC regions: the relathionships are different between subtropics and midlatitudes

subtropics	increases with EIS	increases with EIS, but less than ~10%	rarely occurs
midlatitudes	around 30%, regardless of EIS	increases with EIS, up to ~25%	increases with EIS

Two relationships with different sensitivities over the gobal ocean areas

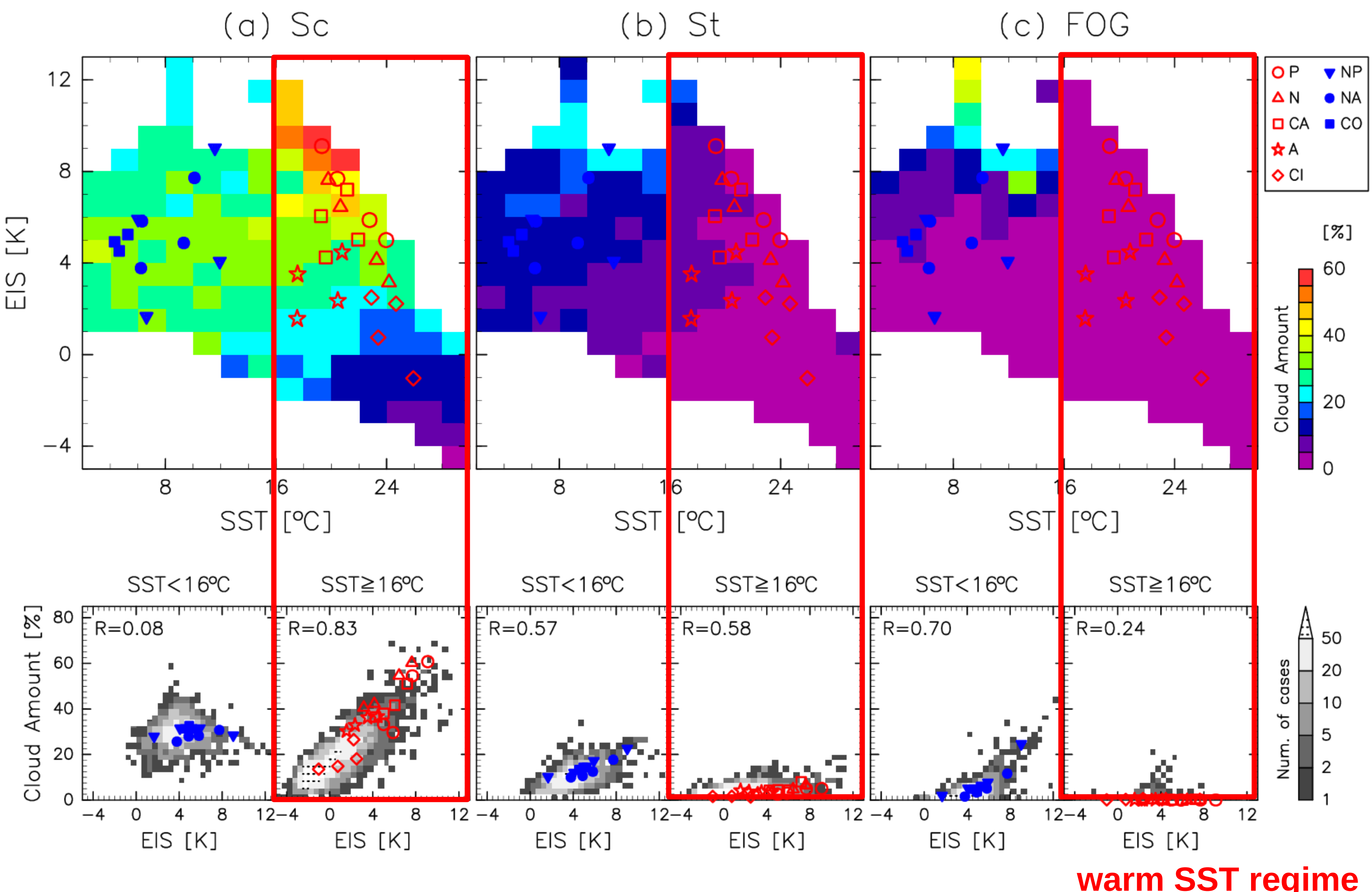
The latitudinal difference → SST?

Variations in the LSC type amounts over the SST–EIS field



The boundary lies at an SST of about 16°C

Variations in the LSC type amounts over the SST–EIS field



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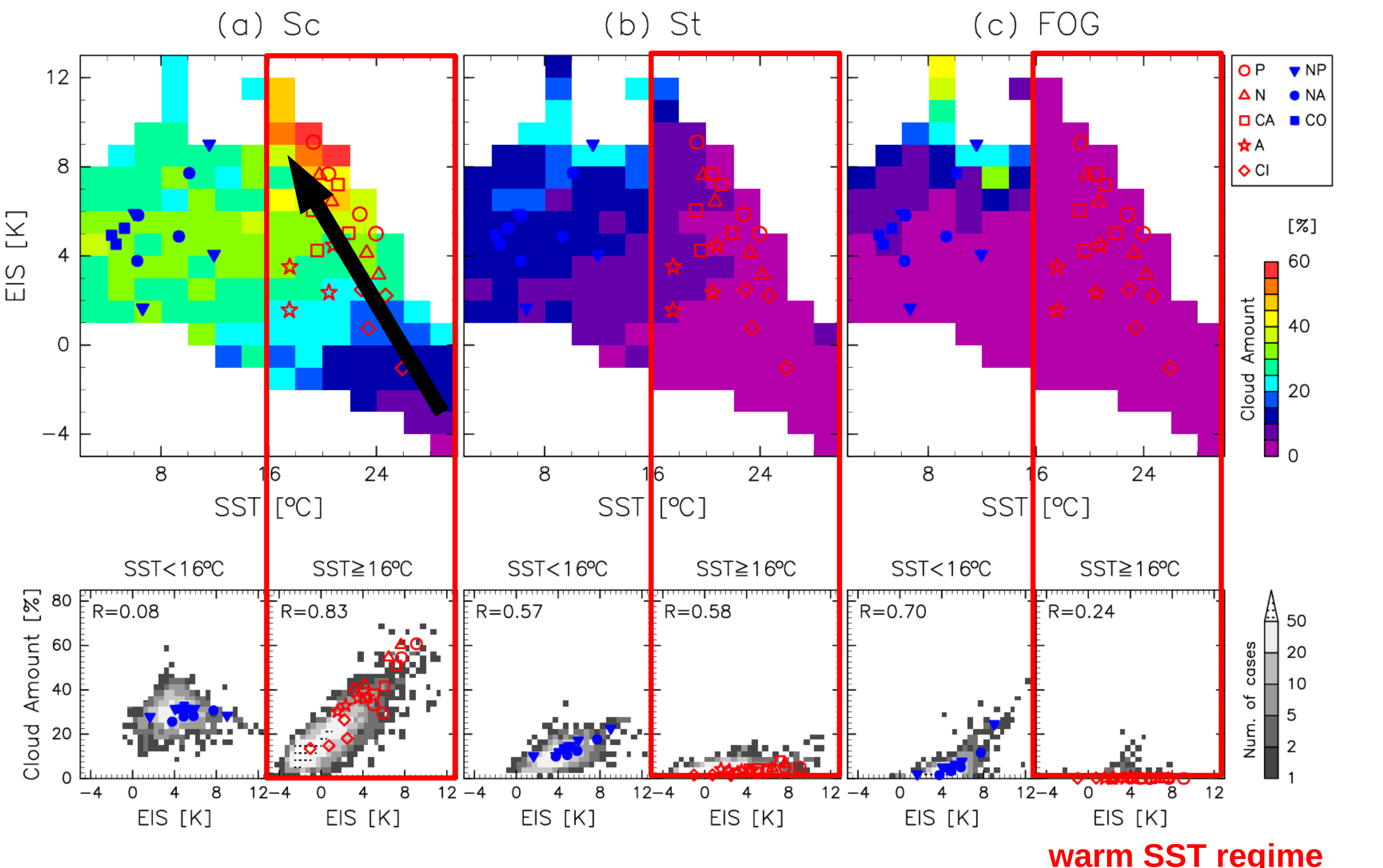

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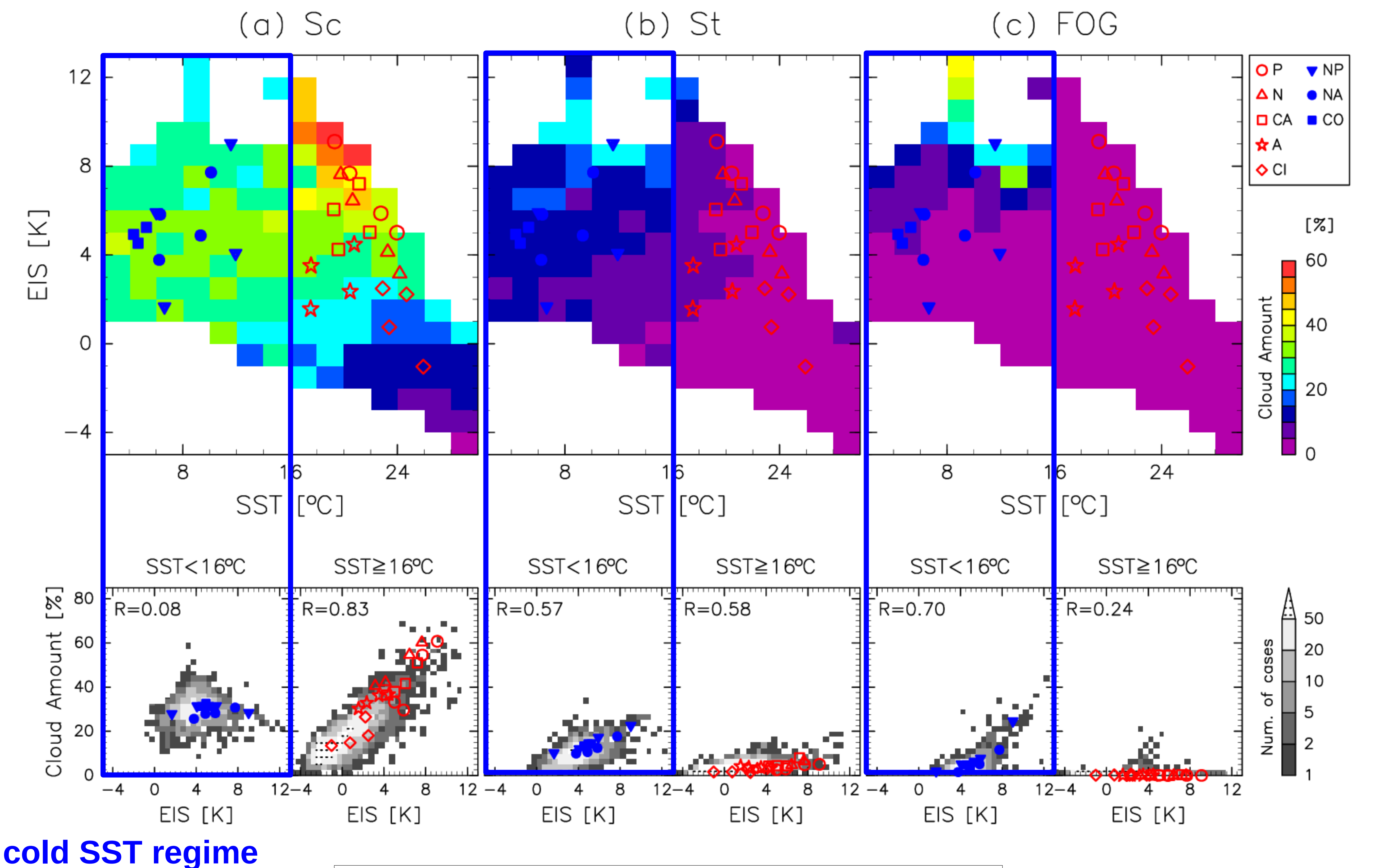

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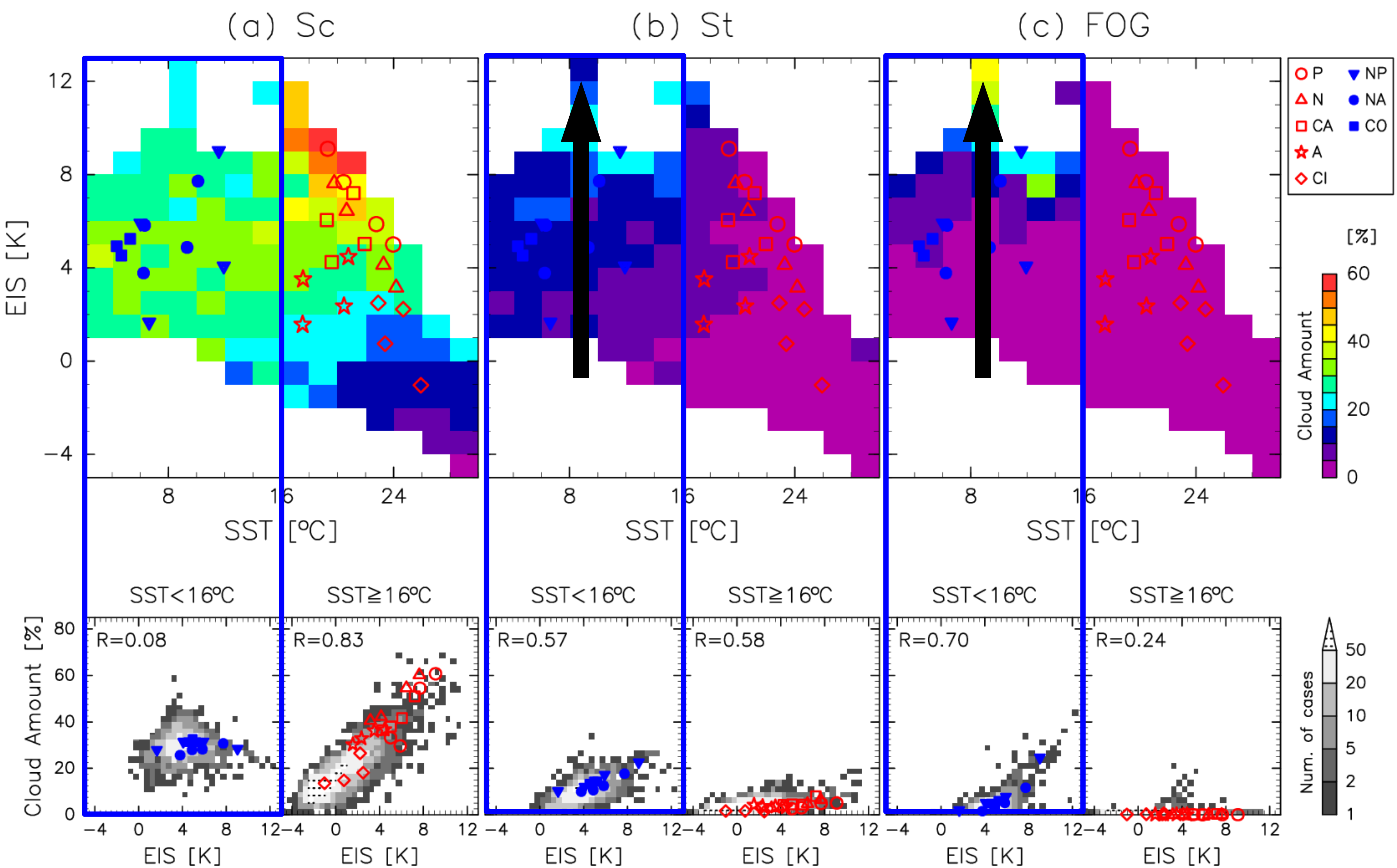


cold SST regime

The boundary lies at an SST of about 16°C

The EISs for divided layers

An increases in EIS is associated with that in different LSC type amount between the warm and cold SST regimes.

To consider the vertical levels in which temperature inverison contributing to EIS exists within the framework of WB06, **the EISs for three divided layers** are introduced:

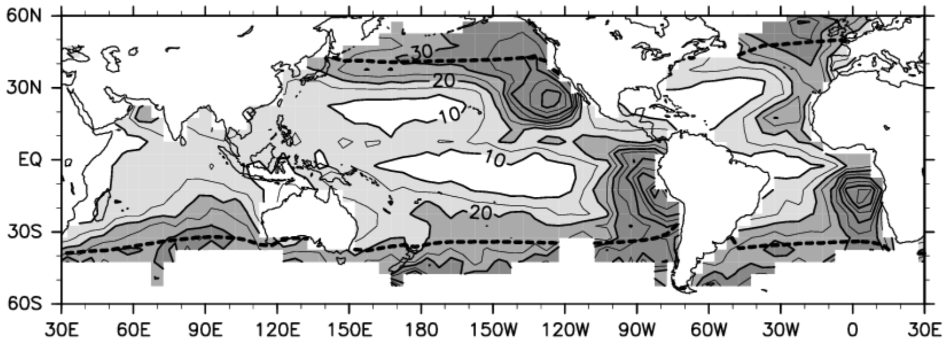
$$EIS = (\theta_{700} - \theta_{sfc}) - \Gamma_m^{850}(z_{700} - LCL)$$

$$= (\theta_{700} - \theta_{850}) - \Gamma_m^{850}(z_{700} - z_{850}) \quad + \quad (\theta_{850} - \theta_{925}) - \Gamma_m^{850}(z_{850} - z_{925}) \quad + \quad (\theta_{925} - \theta_{sfc}) - \Gamma_m^{850}(z_{925} - LCL)$$

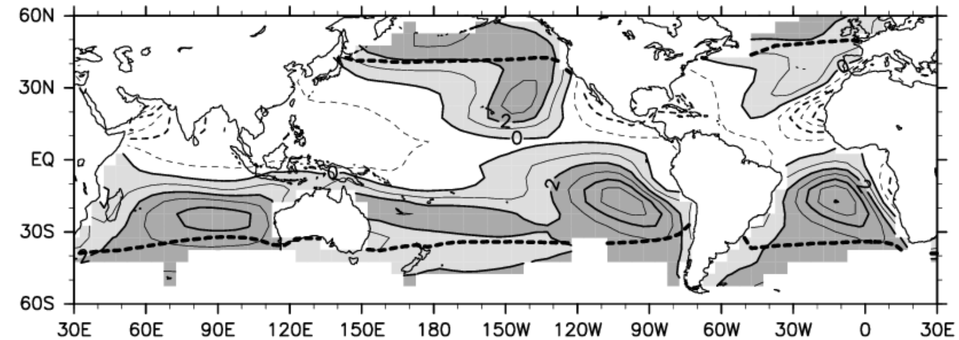
$$\equiv EIS^{700}_{850} \; + \; EIS^{850}_{925} \; + \; EIS^{925}_{sfc}$$

The LSC type amounts and the EISs for divided layers (JJA)

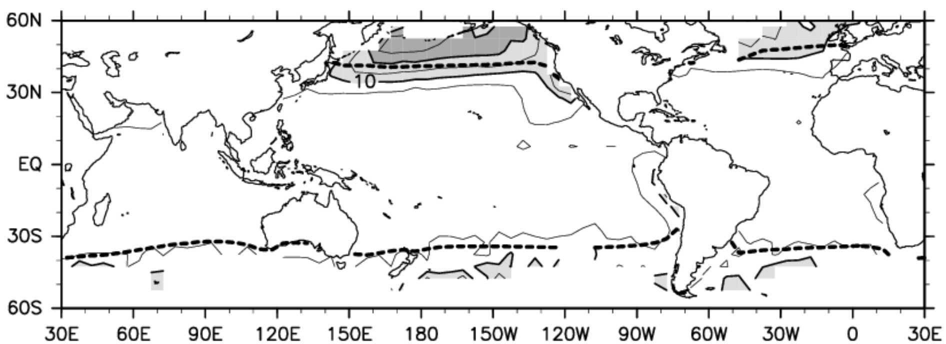
Sc amount [%]



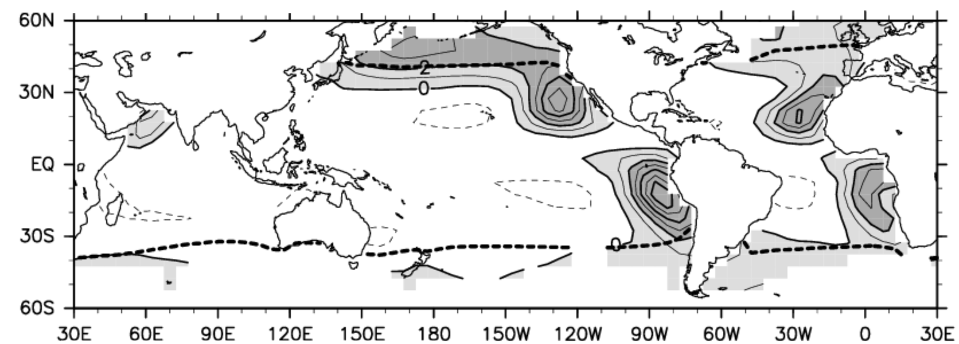
EIS^{700}_{850} [K]



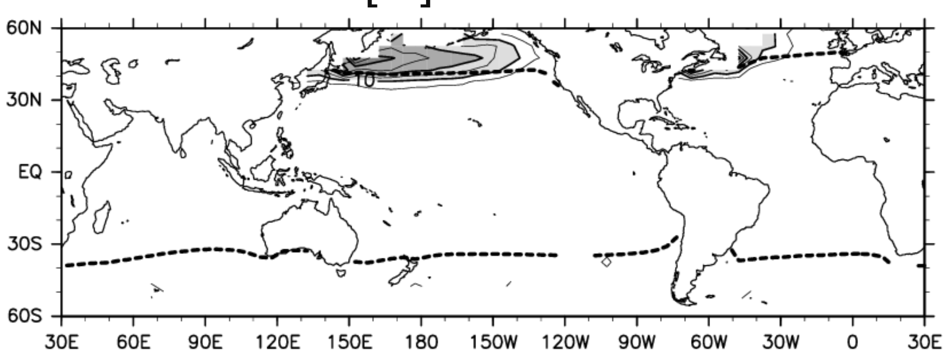
St amount [%]



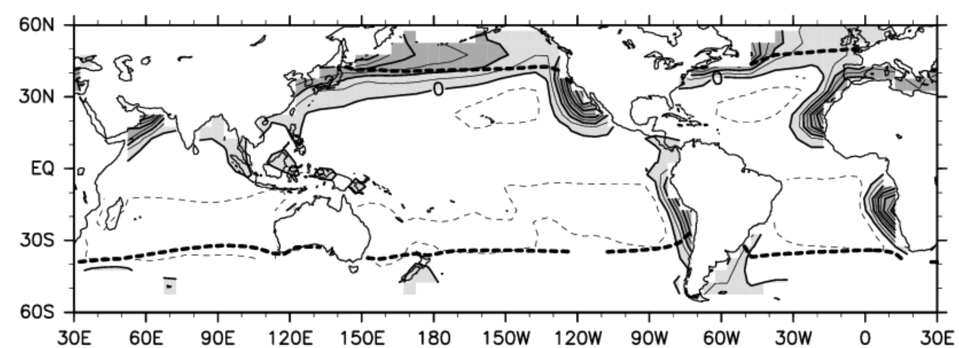
EIS^{850}_{925} [K]



FOG amount [%]

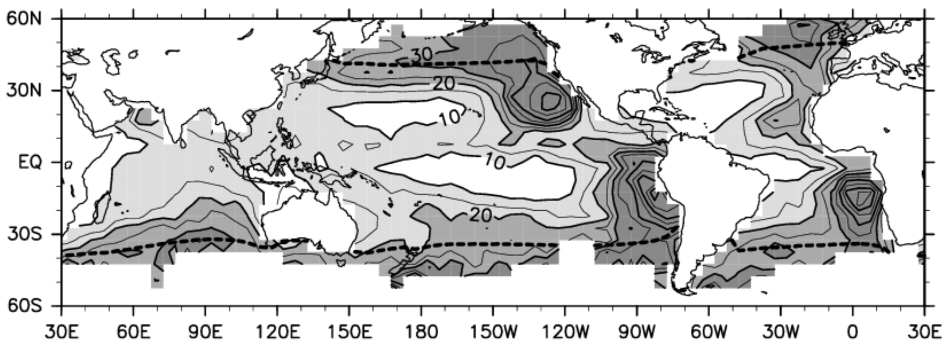


$\mathrm{EIS}^{925}_{\mathrm{sfc}}$ [K]

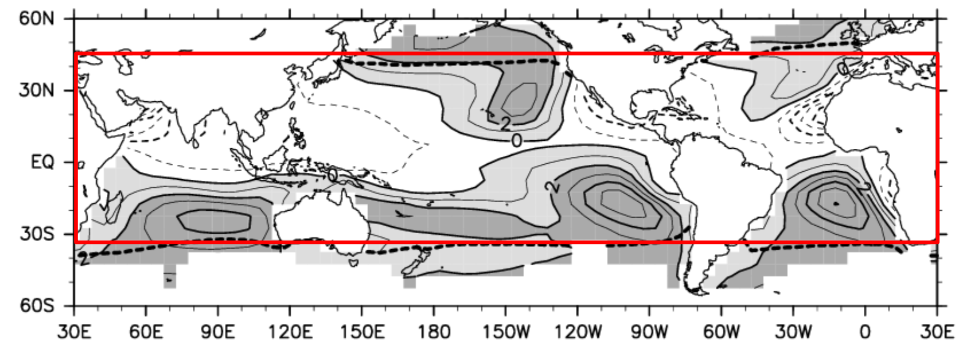


The LSC type amounts and the EISs for divided layers (JJA)

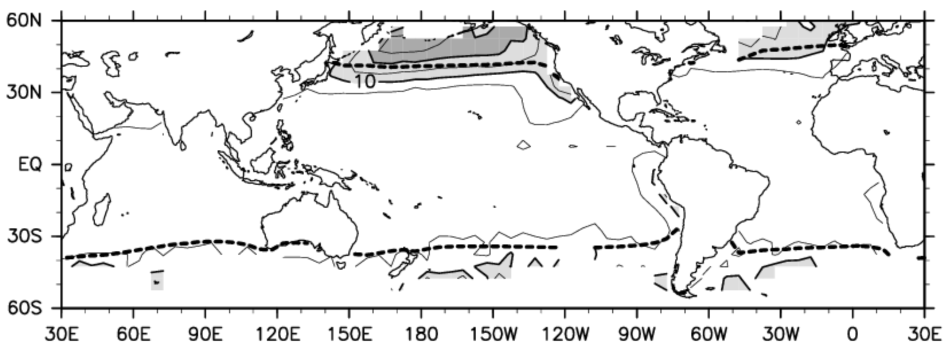
Sc amount [%]



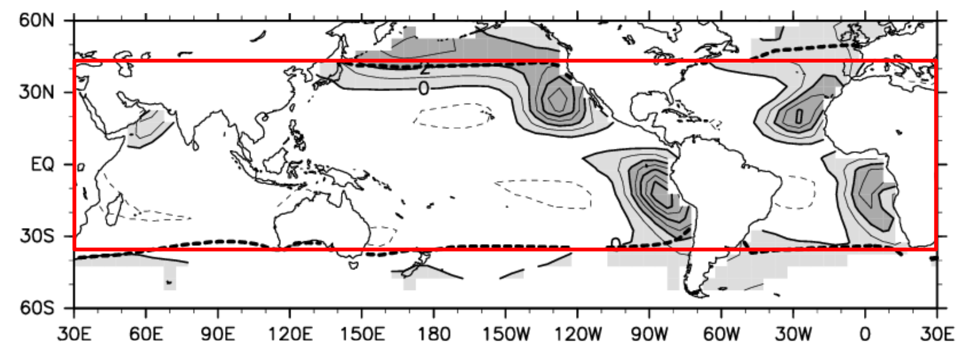
EIS_{850}^{700} [K]



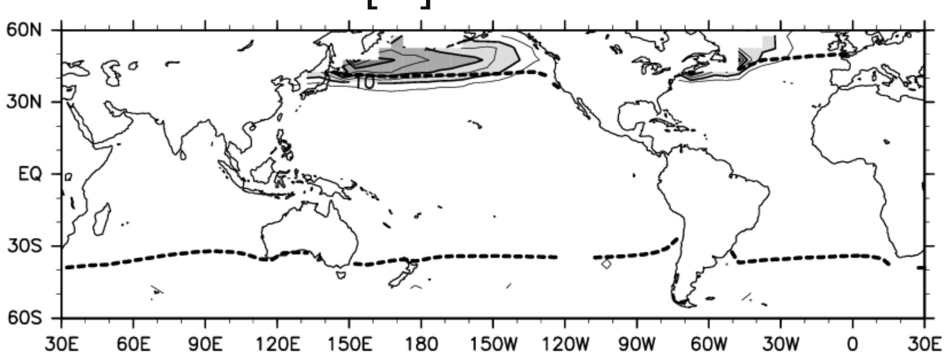
St amount [%]



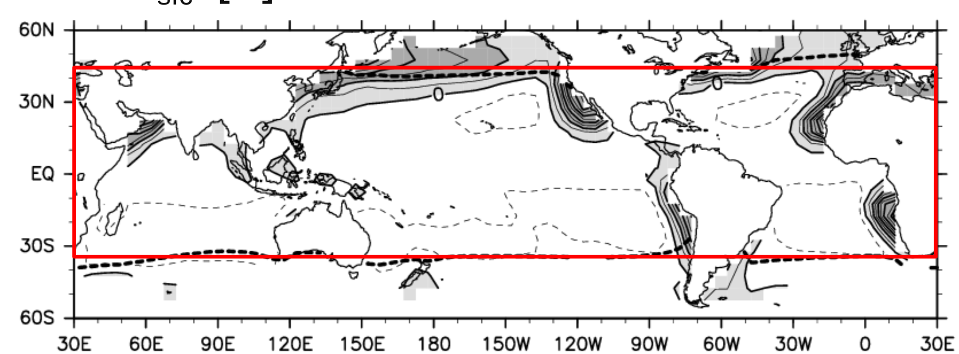
EIS_{925}^{850} [K]



FOG amount [%]

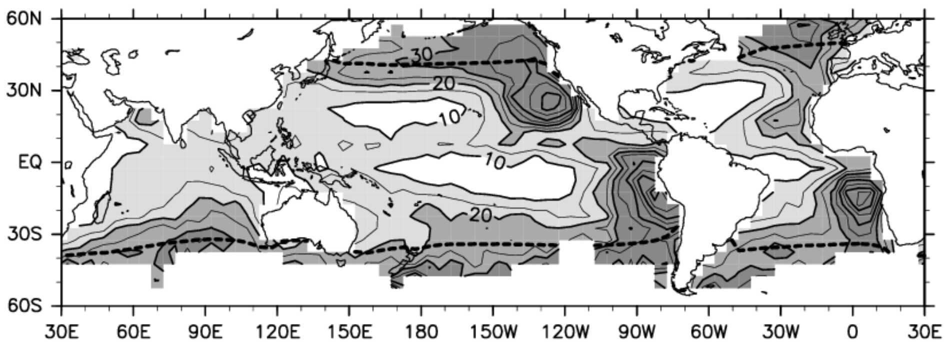


EIS_{sfc}^{925} [K]

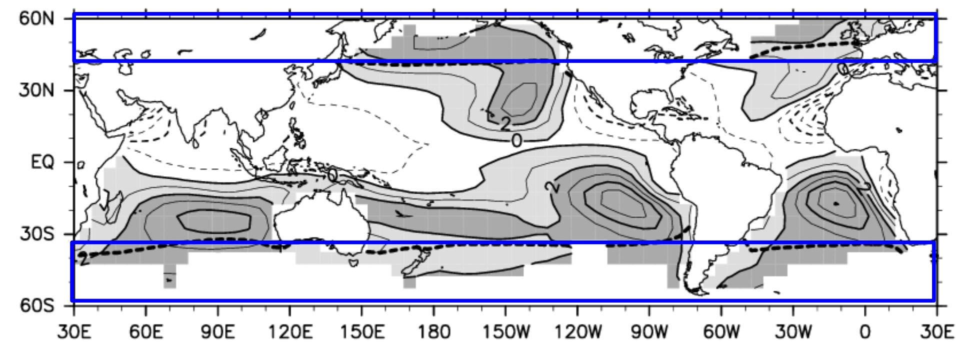


The LSC type amounts and the EISs for divided layers (JJA)

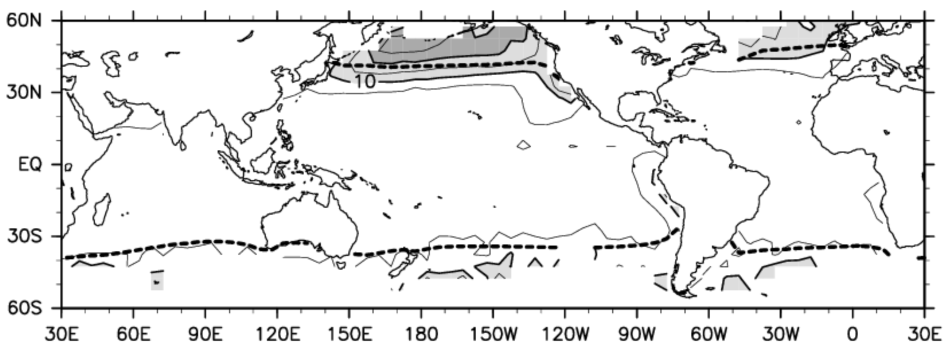
Sc amount [%]



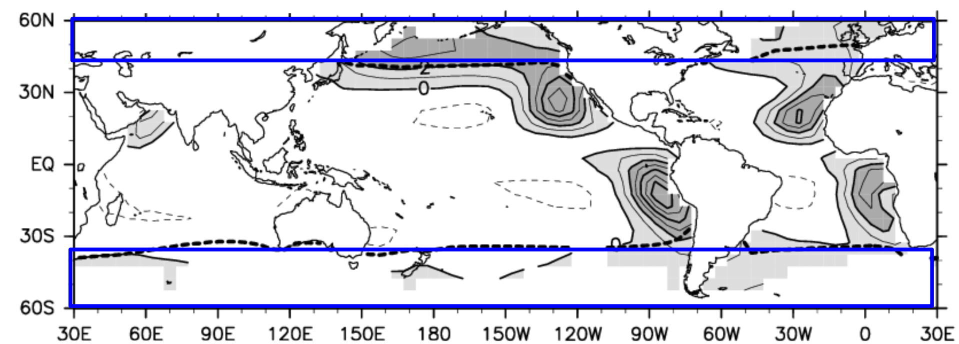
EIS^{700}_{850} [K]



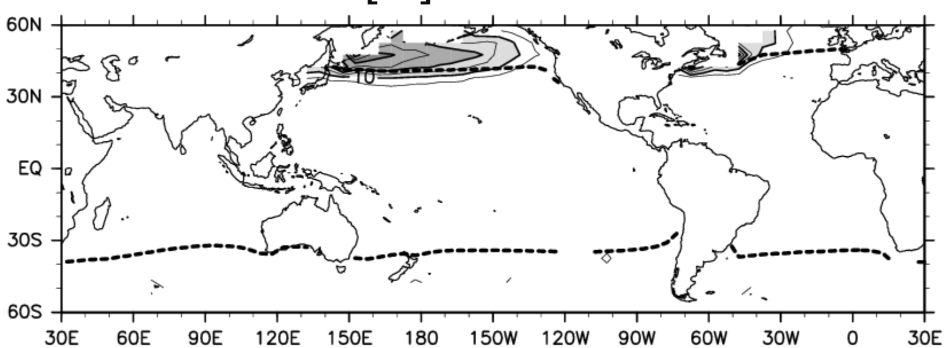
St amount [%]



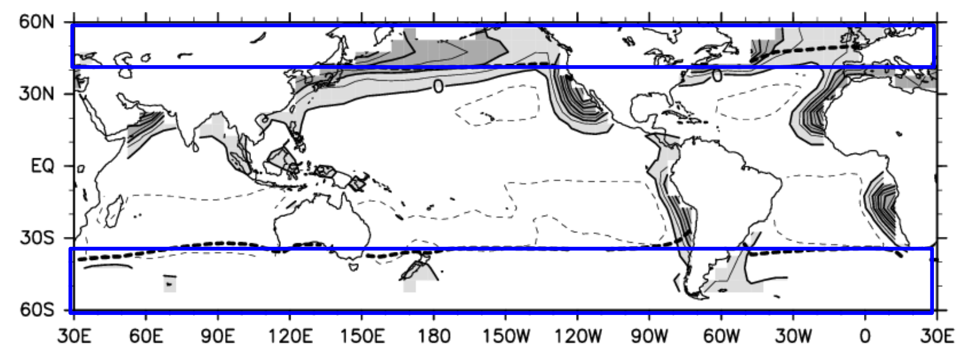
EIS^{850}_{925} [K]



FOG amount [%]



EIS^{925}_{sfc} [K]



The LSC type amounts and the EISs for divided layers (JJA)

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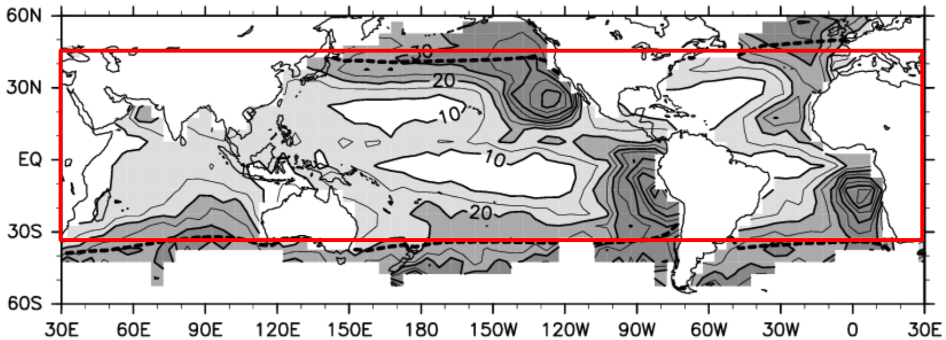
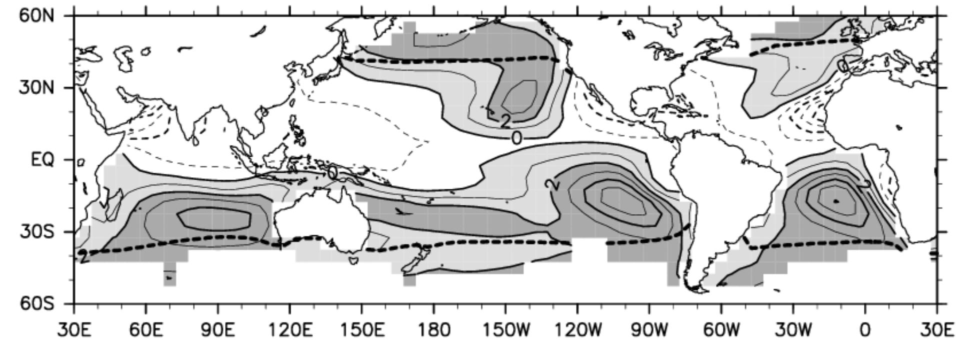
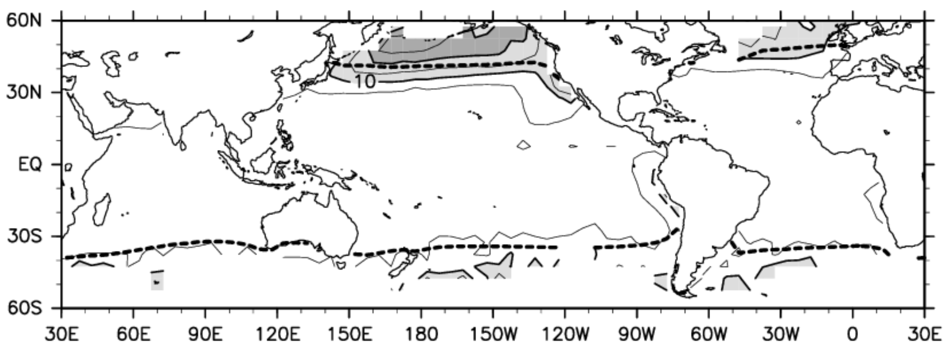


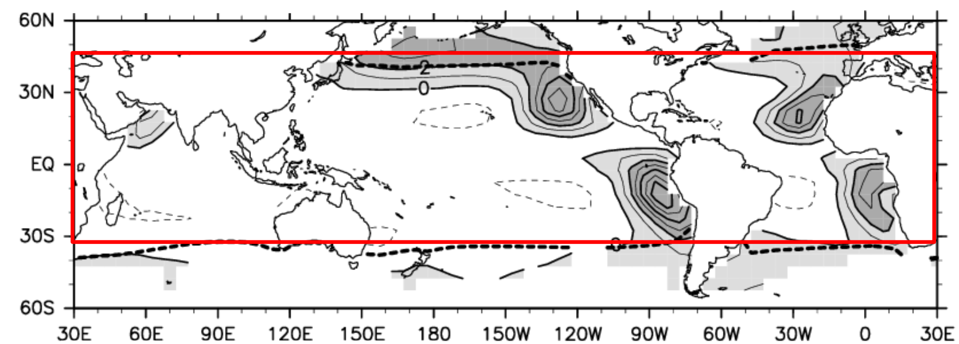
EIS_{850}^{700} [K]



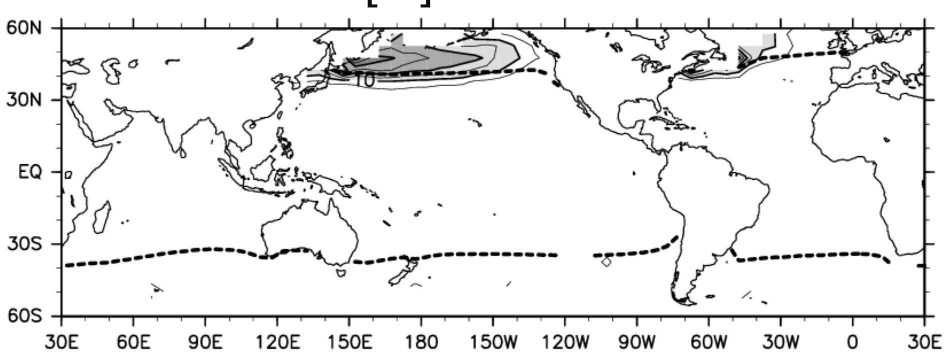
St amount [%]



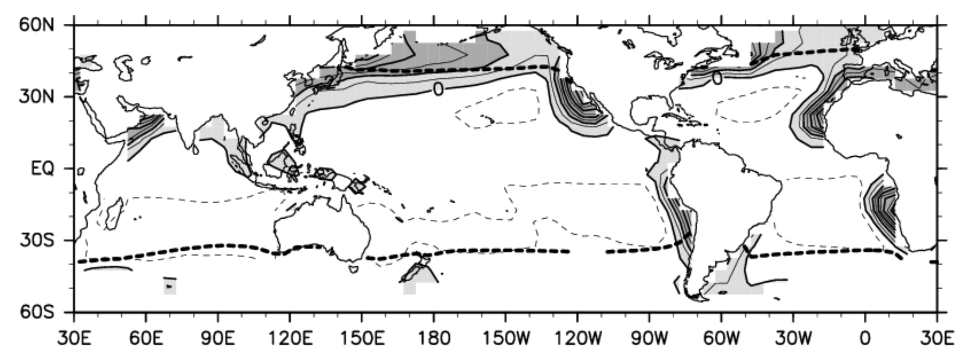
EIS_{925}^{850} [K]



FOG amount [%]

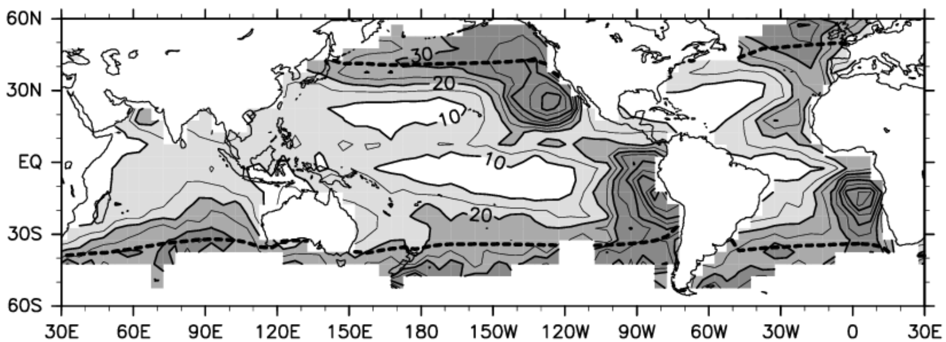


EIS_{sfc}^{925} [K]

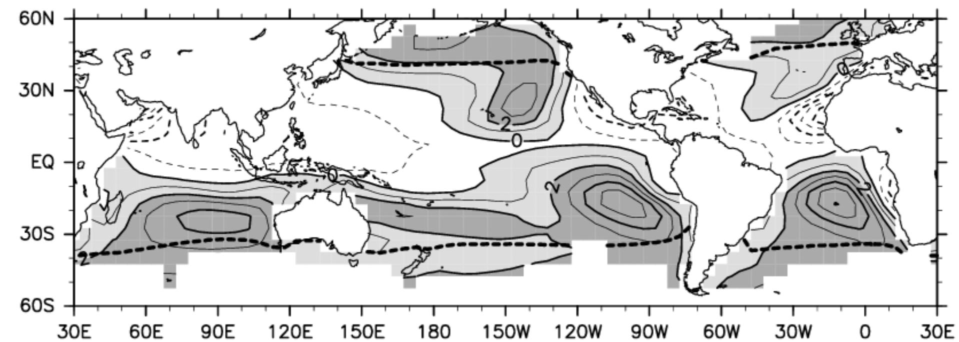


The LSC type amounts and the EISs for divided layers (JJA)

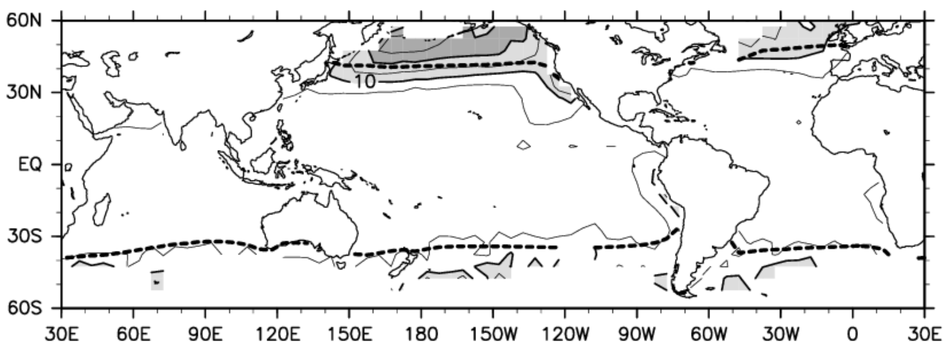
Sc amount [%]



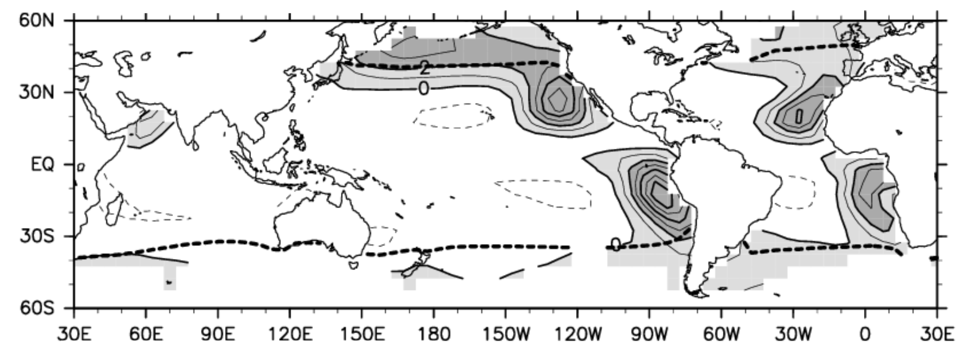
EIS_{850}^{700} [K]



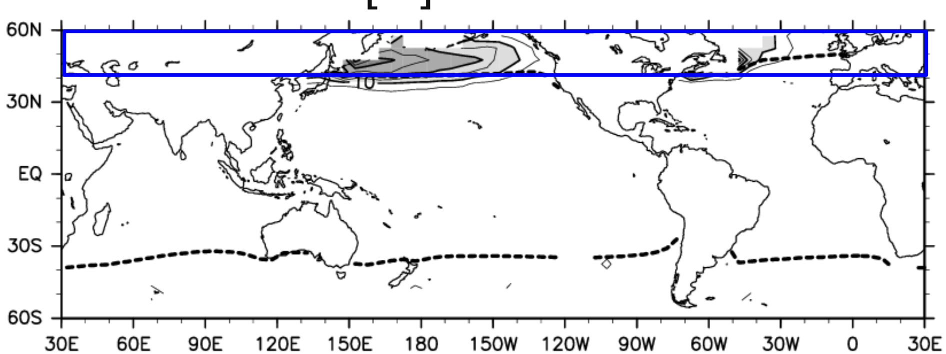
St amount [%]



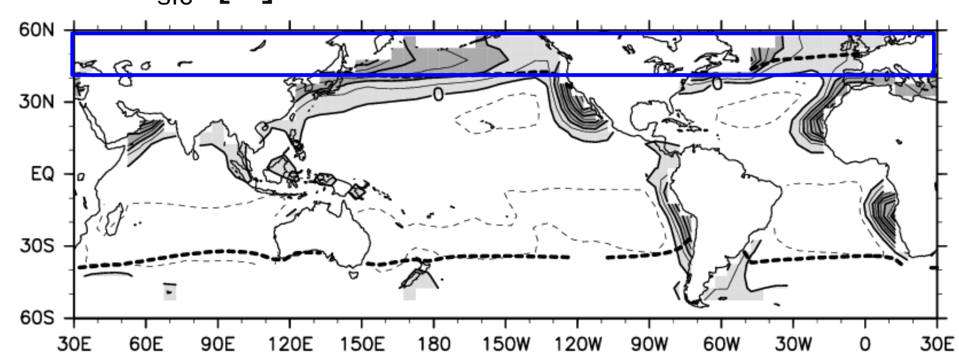
EIS_{925}^{850} [K]



FOG amount [%]



EIS_{sfc}^{925} [K]



Relationships between the LSC type amounts and the EISs for divided layers

$$EIS = (\theta_{700} - \theta_{sfc}) - \Gamma_m^{850}(z_{700} - LCL)$$

$$= (\theta_{700} - \theta_{850}) - \Gamma_m^{850}(z_{700} - z_{850}) \quad + \quad (\theta_{850} - \theta_{925}) - \Gamma_m^{850}(z_{850} - z_{925}) \quad + \quad (\theta_{925} - \theta_{sfc}) - \Gamma_m^{850}(z_{925} - LCL)$$

$$\equiv EIS_{850}^{700} \ + \ EIS_{925}^{850} \ + \ EIS_{sfc}^{925}$$

Correlation coefficients of the LSC type amounts with the EISs for divided layers and EIS (60°N-60°S)

	SST $\geq$ 16°C				SST $<$ 16°C			
LSC type	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS
Sc	0.51	0.80	(0.04)	0.83	0.42	0.17	−0.31	0.08
St	0.25	0.48	0.26	0.58	0.34	0.56	0.32	0.57
FOG	(0.03)	0.13	0.27	0.24	0.16	0.63	0.66	0.70

Relationships between the LSC type amounts and the EISs for divided layers

$$EIS = (\theta_{700} - \theta_{sfc}) - \Gamma_m^{850}(z_{700} - LCL)$$

$$= (\theta_{700} - \theta_{850}) - \Gamma_m^{850}(z_{700} - z_{850}) \quad + \quad (\theta_{850} - \theta_{925}) - \Gamma_m^{850}(z_{850} - z_{925}) \quad + \quad (\theta_{925} - \theta_{sfc}) - \Gamma_m^{850}(z_{925} - LCL)$$

$$\equiv EIS_{850}^{700} \ + \ EIS_{925}^{850} \ + \ EIS_{sfc}^{925}$$

Correlation coefficients of the LSC type amounts with the EISs for divided layers and EIS (60°N-60°S)

	SST $\geq$ 16°C				SST $<$ 16°C			
LSC type	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS
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Relationships between the LSC type amounts and the EISs for divided layers

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$$= (\theta_{700} - \theta_{850}) - \Gamma_m^{850}(z_{700} - z_{850}) \quad + \quad (\theta_{850} - \theta_{925}) - \Gamma_m^{850}(z_{850} - z_{925}) \quad + \quad (\theta_{925} - \theta_{sfc}) - \Gamma_m^{850}(z_{925} - LCL)$$

$$\equiv EIS_{850}^{700} \;+\; EIS_{925}^{850} \;+\; EIS_{sfc}^{925}$$

Correlation coefficients of the LSC type amounts with the EISs for divided layers and EIS (60°N-60°S)

	SST $\geq$ 16°C				SST $<$ 16°C			
LSC type	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS
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Relationships between the LSC type amounts and the EISs for divided layers

$$
\begin{aligned}
EIS &= (\theta_{700} - \theta_{sfc}) - \Gamma_m^{850}(z_{700} - LCL) \\
&= (\theta_{700} - \theta_{850}) - \Gamma_m^{850}(z_{700} - z_{850}) \;+\; (\theta_{850} - \theta_{925}) - \Gamma_m^{850}(z_{850} - z_{925}) \;+\; (\theta_{925} - \theta_{sfc}) - \Gamma_m^{850}(z_{925} - LCL) \\
&\equiv EIS_{850}^{700} + EIS_{925}^{850} + EIS_{sfc}^{925}
\end{aligned}
$$

Correlation coefficients of the LSC type amounts with the EISs for divided layers and EIS (60°N-60°S)

	SST ≥ 16°C				SST < 16°C			
LSC type	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS
Sc	0.51	0.80	(0.04)	0.83	0.42	0.17	−0.31	0.08
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Relationships between the LSC type amounts and the EISs for divided layers

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$$= (\theta_{700} - \theta_{850}) - \Gamma_m^{850}(z_{700} - z_{850}) \quad + \quad (\theta_{850} - \theta_{925}) - \Gamma_m^{850}(z_{850} - z_{925}) \quad + \quad (\theta_{925} - \theta_{sfc}) - \Gamma_m^{850}(z_{925} - LCL)$$
$$\equiv EIS_{850}^{700} + EIS_{925}^{850} + EIS_{sfc}^{925}$$

Correlation coefficients of the LSC type amounts with the EISs for divided layers and EIS (60°N-60°S)

	SST $\geq$ 16°C				SST $<$ 16°C			
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Relationships between the LSC type amounts and the EISs for divided layers

$$
\begin{aligned}
EIS &= (\theta_{700} - \theta_{sfc}) - \Gamma_m^{850}(z_{700} - LCL) \\
&= (\theta_{700} - \theta_{850}) - \Gamma_m^{850}(z_{700} - z_{850}) \;+\; (\theta_{850} - \theta_{925}) - \Gamma_m^{850}(z_{850} - z_{925}) \;+\; (\theta_{925} - \theta_{sfc}) - \Gamma_m^{850}(z_{925} - LCL) \\
&\equiv EIS_{850}^{700} + EIS_{925}^{850} + EIS_{sfc}^{925}
\end{aligned}
$$

Correlation coefficients of the LSC type amounts with the EISs for divided layers and EIS (60°N-60°S)

	SST $\geq$ 16°C				SST $<$ 16°C			
LSC type	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS	EIS_{850}^{700}	EIS_{925}^{850}	EIS_{sfc}^{925}	EIS
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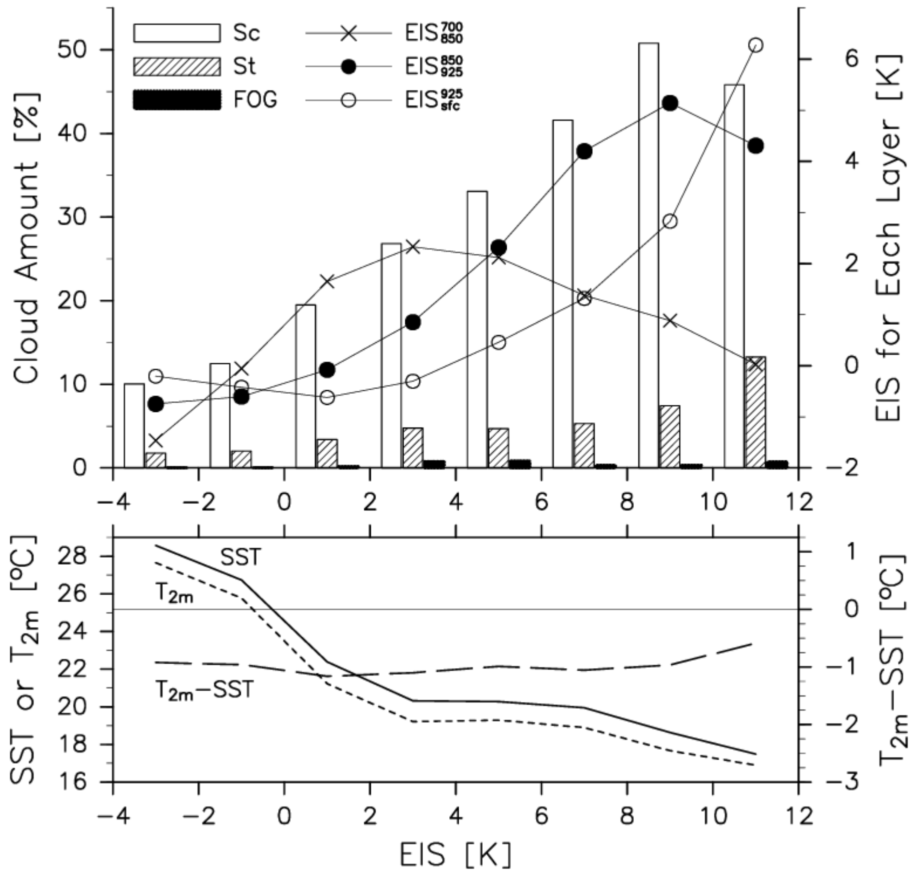
St	0.25	0.48	0.26	0.58	0.34	0.56	0.32	0.57
FOG	(0.03)	0.13	0.27	0.24	0.16	0.63	0.66	0.70

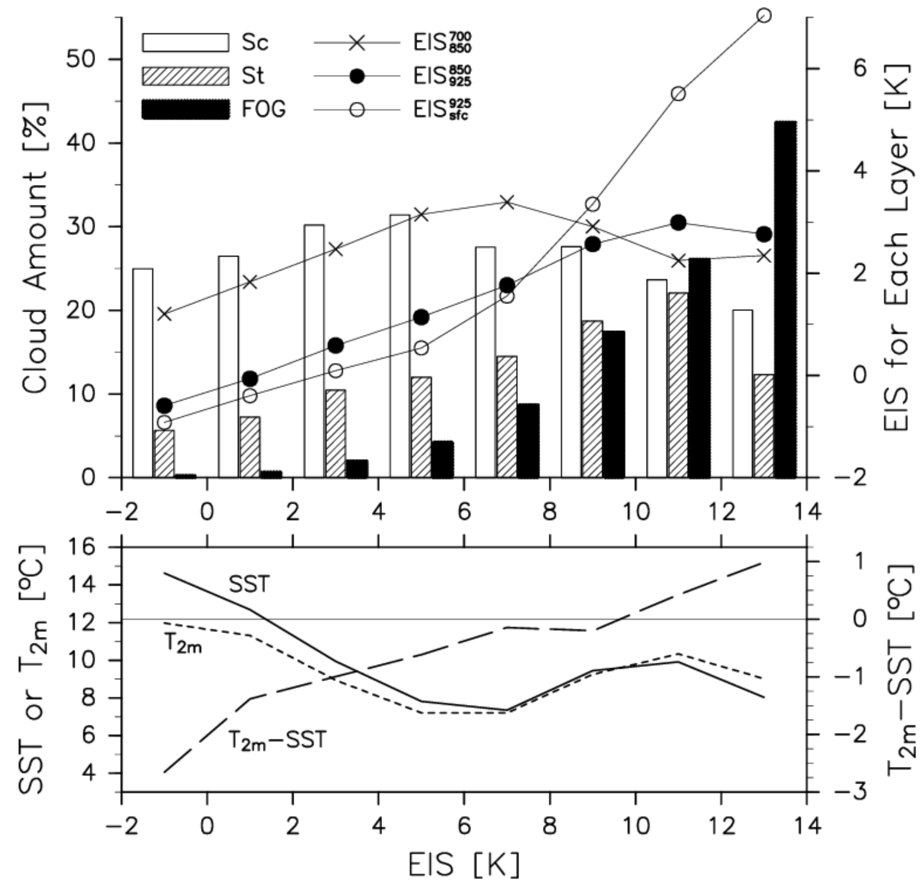
The EISs for divided layers appear to capture well the corresponding LSC type amounts in the two regimes

Responses of the LSC type amounts and the EISs for divided layers to EIS and their relation to temperature advection

warm SST regime SST≧16℃



cold SST regime SST<16℃



Sc ↔ ● EIS^{850}_{925}

increase in (Sc,EIS^{850}_{925}) ↔ decrease in SST ↔ general occurrence of cold advection

Sc ↔ x EIS^{700}_{850} St ↔ ● EIS^{850}_{925} FOG ↔ ○ EIS^{925}_{sfc}

transition from (Sc,EIS^{700}_{850}) to (FOG,EIS^{925}_{sfc}) ↔ cold-warm transition of advection

Coclusions

Although it is known that a single liear relationship applies to the variations in the LSC amount and EIS, two relationships with different sensitivities are found between each LSC type amount and EIS.

The boundary lies at an SST of about 16°C.

In the warm SST regime,
the Sc amount is strongly correlated with EIS, corresponding to the increase in the inferred inversion strength between 850 and 925 hPa.

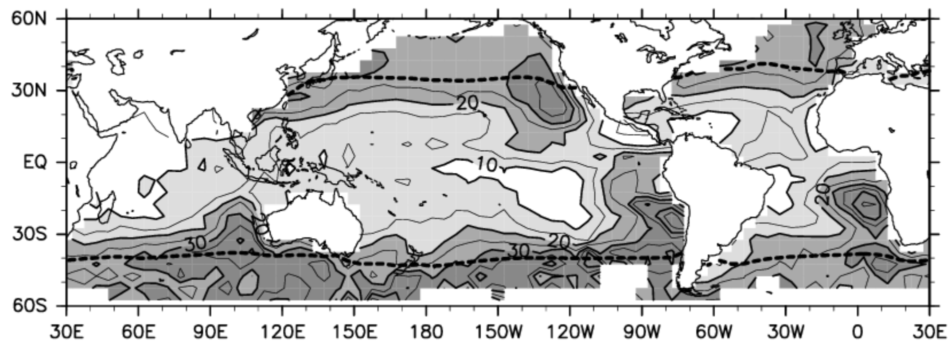
In the cold SST regime,
as EIS increases, relatively high values of inferred inversion strength between 700 and 850 hPa change to a rapid increase in that between 925 hPa and the surface, which coincides with the transition from Sc to FOG.

Temperature advection implied by air-sea temperature difference provides favorable conditions to the different variations in the two regimes:
the general occurrence of cold advection in the warm SST regime and
the cold-warm transition of advection in the cold SST regime.

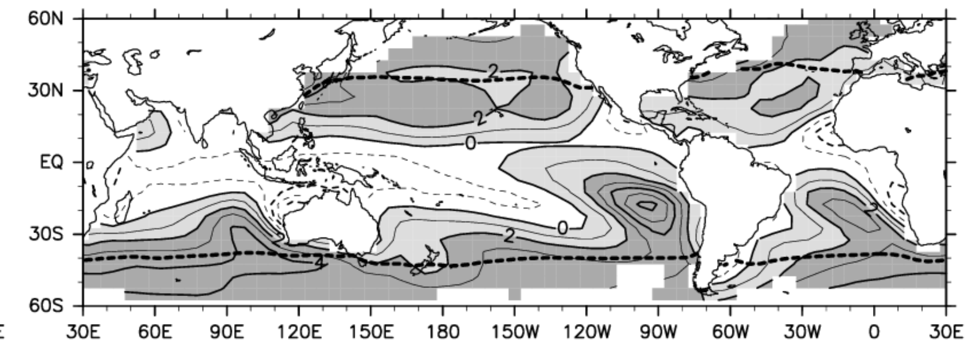
Backup slides

The LSC type amounts and the EISs for divided layers (DJF)

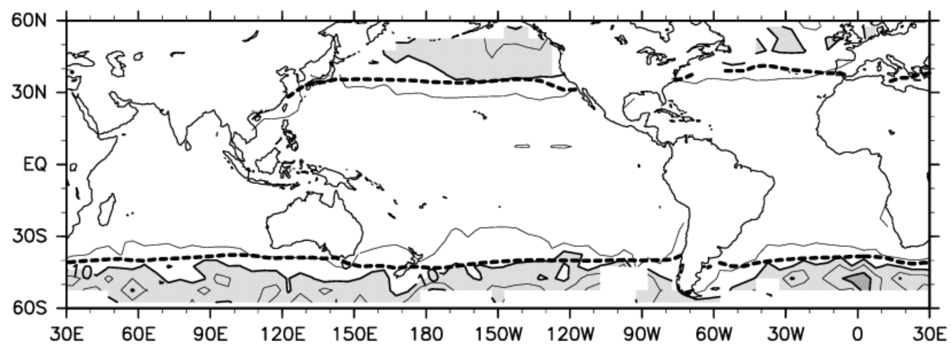
Sc amount [%]



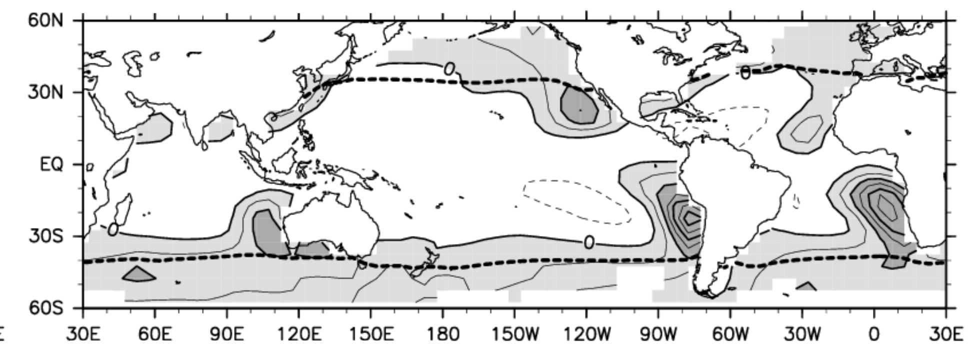
EIS_{850}^{700} [K]



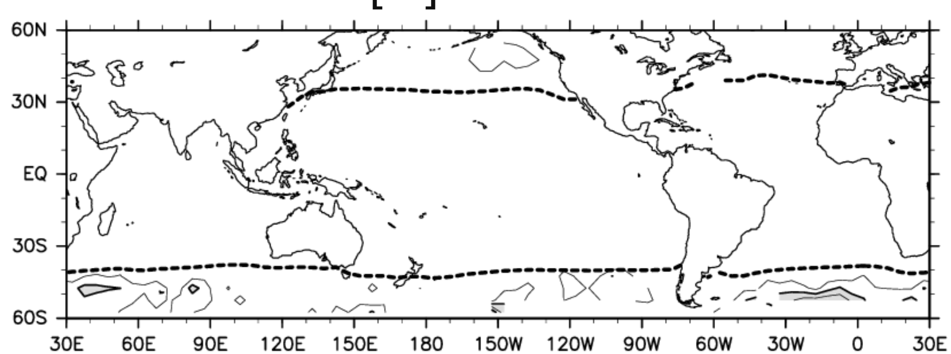
St amount [%]



EIS_{925}^{850} [K]



FOG amount [%]



EIS_{sfc}^{925} [K]