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Ice Supersaturation and Cirrus Clouds in HIPPO Global Campaign #1-5

Minghui Diao, *Princeton University*
Mark A. Zondlo, *Princeton University*

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Minghui Diao, Mark Zondlo

Civil and Environmental Engineering

Princeton University

2DC, 260X 2DC ice probes, Dave Rogers, Al Cooper

RAF Technical and Ground Crews

HIPPO Global Campaign Science Team

Photo by Minghui Diao

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Outline

- **Motivation**
  - cirrus clouds climate effects in NH vs SH
  - Ice supersaturation in cirrus cloud formation
- **Instrument and dataset**
  - HIPPO 1-5
  - Water vapor; Temperature; Ice crystal number density
  - Uncertainties
- **Ice supersaturation (ISS) in HIPPO Global campaigns**
  - ISS probability distribution function (PDF) in NH vs SH
  - Pole-to-Pole latitudinal and vertical distribution of ISS
- **ISS and cirrus clouds formation**
  - Separate difference phases of cirrus clouds in HIPPO
  - Cirrus cloud formation mechanism in NH vs. SH
- **Conclusion**

Photo by Minghui Diao

Motivation

- **Cirrus clouds (235-185K, up to 40% coverage)**
  - Climate effect
    - Large & uncertain effect (IPCC, AR4, 2007)

      Warming or cooling (Chen et al. 2000)

      Difference NH vs. SH, anthropogenic activities, inhibit or invoke?

      Microphysical properties (ice crystal number and size distribution)
- **Ice supersaturation (ISS)**
  - **Birthplaces of cirrus clouds: relative humidity with respect to ice (RHi) > 100%**
  - **Anthropogenic aerosols** indirect effect (CCN, IN, lower ISS; organic aerosol, higher ISS)
- **Challenges in observations**
  - **Remote sensing** >> microphysical scale
  - **Small scale observations** limited by spatial temporal coverage

    NH vs. SH, lack of sampling

    INCA Campaign Prestwick 55N and Punta Arenas 55S (Ovarlez *et al.*, 2000)
- **Unsolved questions:**
  - **What is the global distribution of ISS by *in situ* observations in HIPPO?**
  - **Is there any difference in cirrus cloud formation mechanism between NH and SH?**

Photo by Minghui Diao

Instrumentations and dataset

- **Instruments**
  - ***Water vapor***: the VCSEL hygrometer (accuracy 6%)
  - ***Temperature***: Rosemount temperature probe (± 0.5 K)
  - ***Ice crystal number density***: 2DC and 260X 2DC probes (25 µm, 10 µm)
- **HIPPO 1 to 5** deployments
  - HIPPO1 did not have ice measurements
- **Uncertainties**

Relative humidity with respect to ice (T ≤ -40 C)

$$RHi = e/es$$

- **e**: water vapor partial pressure
- $\mathbf{e_s}$: saturated ice vapor pressure

Example of RHi uncertainty

Water vapor mixing ratio: 6%
Temperature: 0.5 K

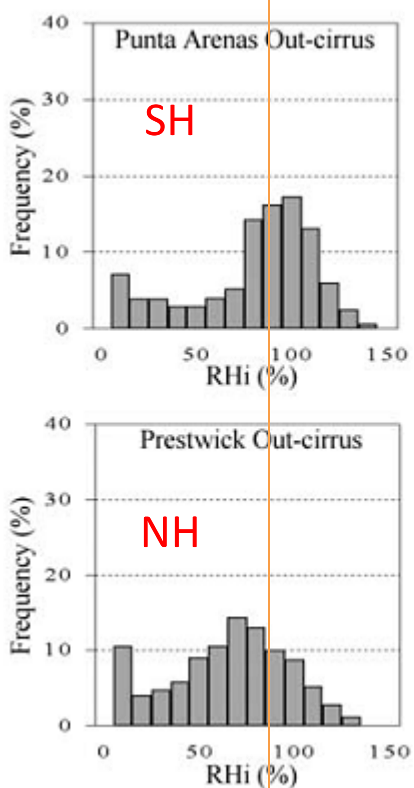
→

RHi 8-10%
@ 233-205K

Clear sky
RHi distribution in NH and SH

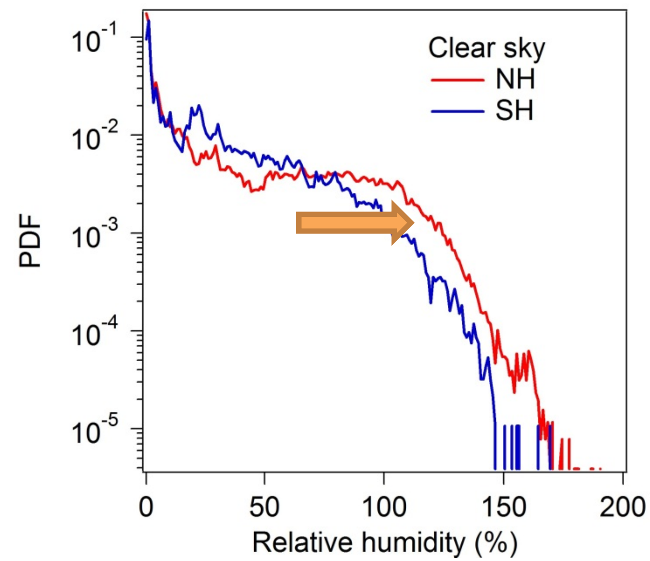
Ovarlez *et al*., 2000

1 Hz



SH higher frequency of ISS

Probability density function of RHi

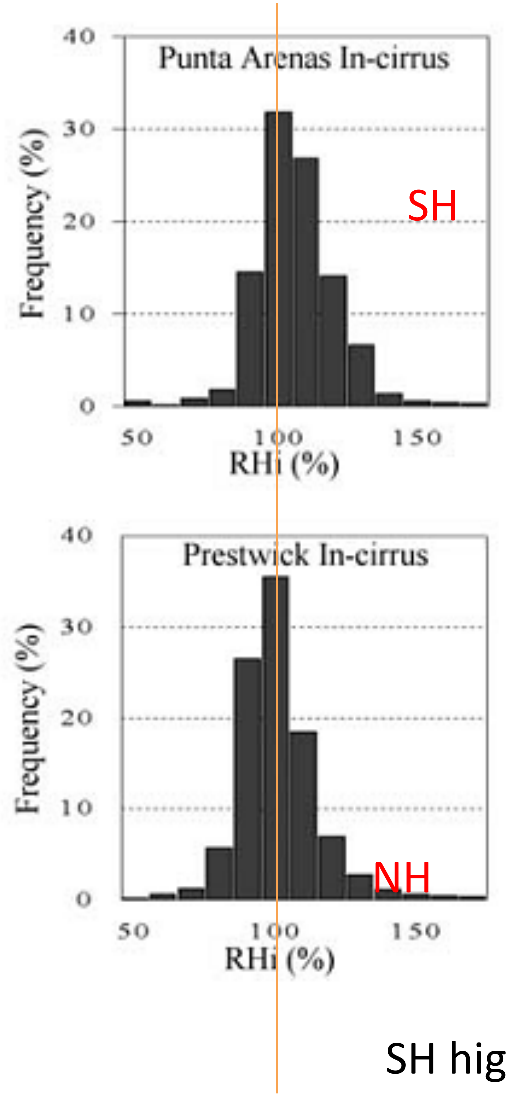


NH RHi distribution shifts to higher ISS

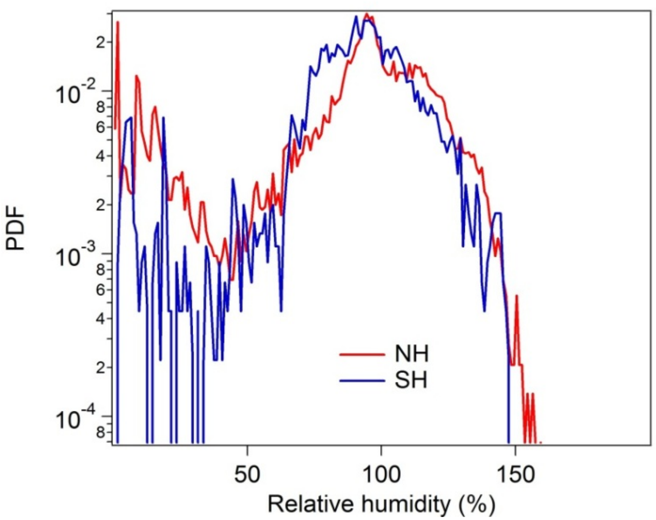
NH: 71 hrs, SH: 26 hrs

Cloudy sky
RHi distribution in NH and SH

Ovarlez *et al.*, 2000



Peaks at ~95% (NH) and ~94% (SH)



No obvious difference

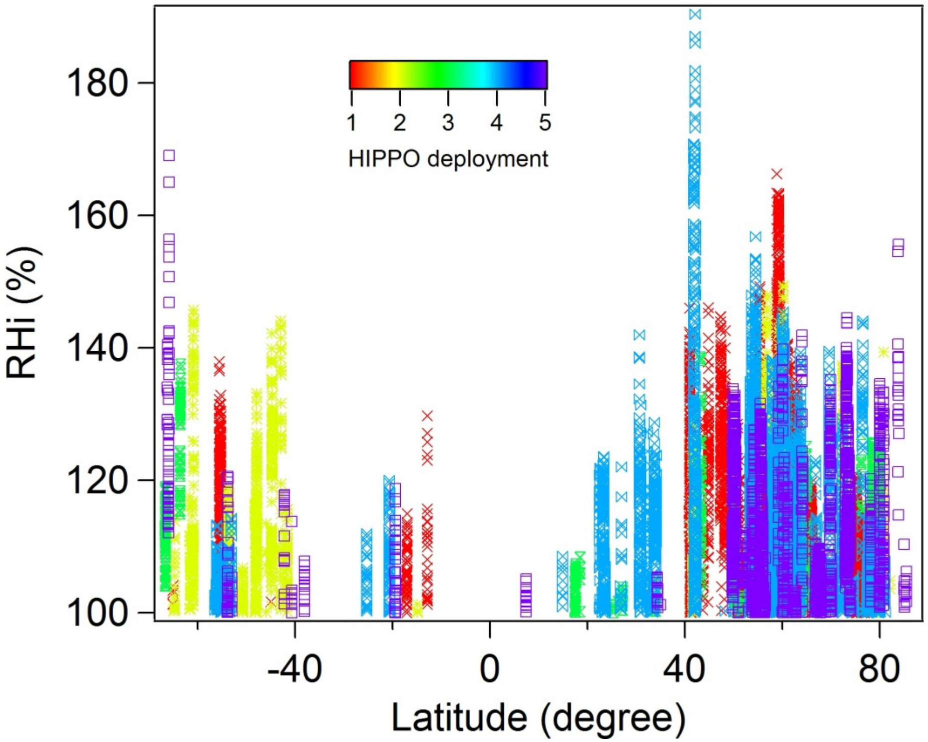
NH: 4 hrs, SH: 1hrs

SH higher frequency of ISS

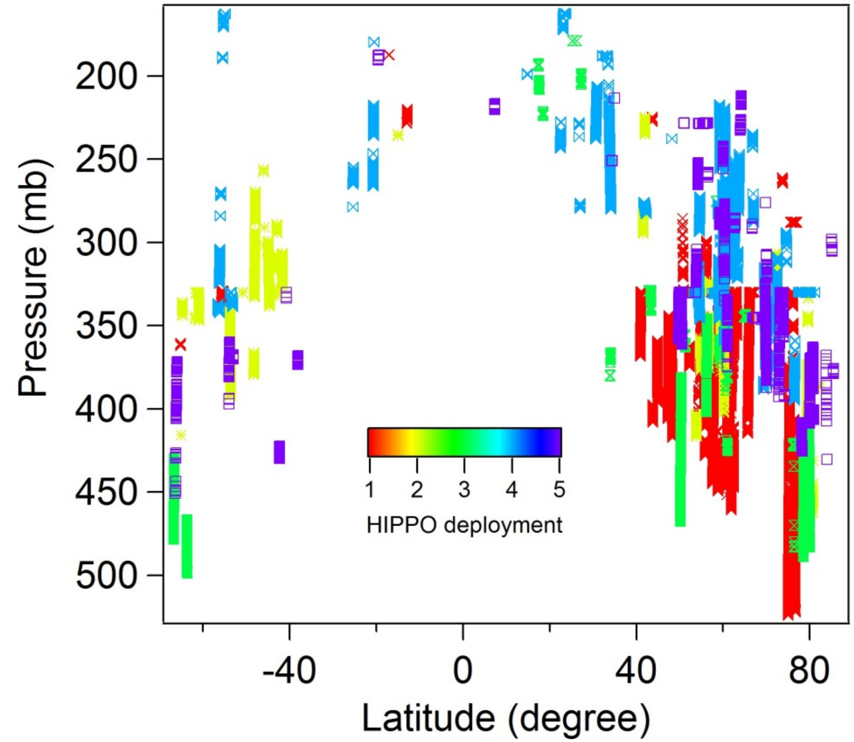
Clear sky

Ice supersaturation (ISS) distribution in NH and SH

ISS magnitude



ISS vertical distribution



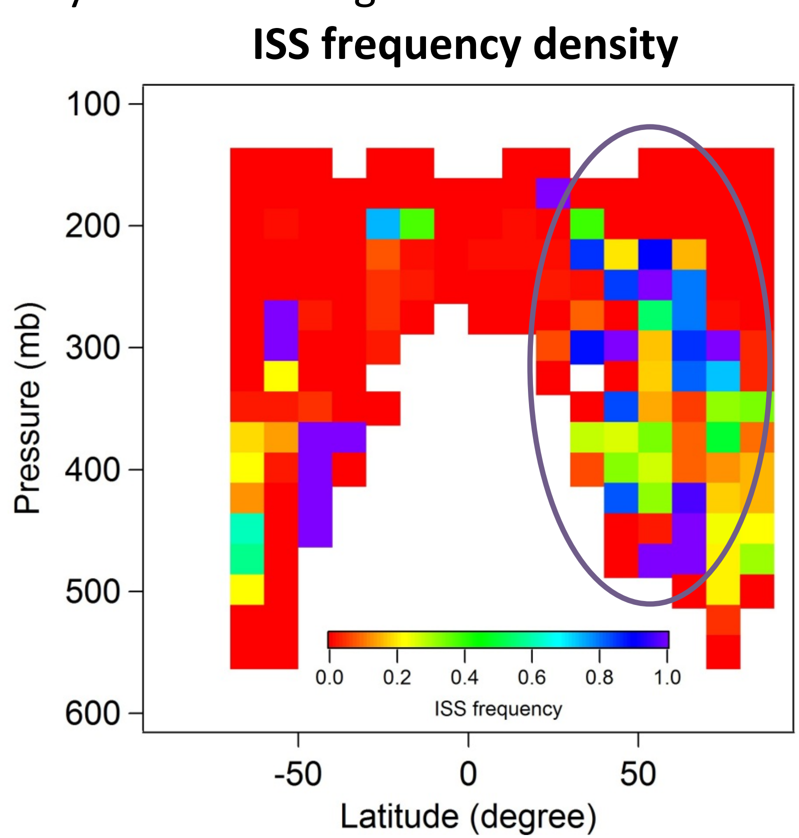
ISS magnitude between two hemispheres
NH has higher ISS

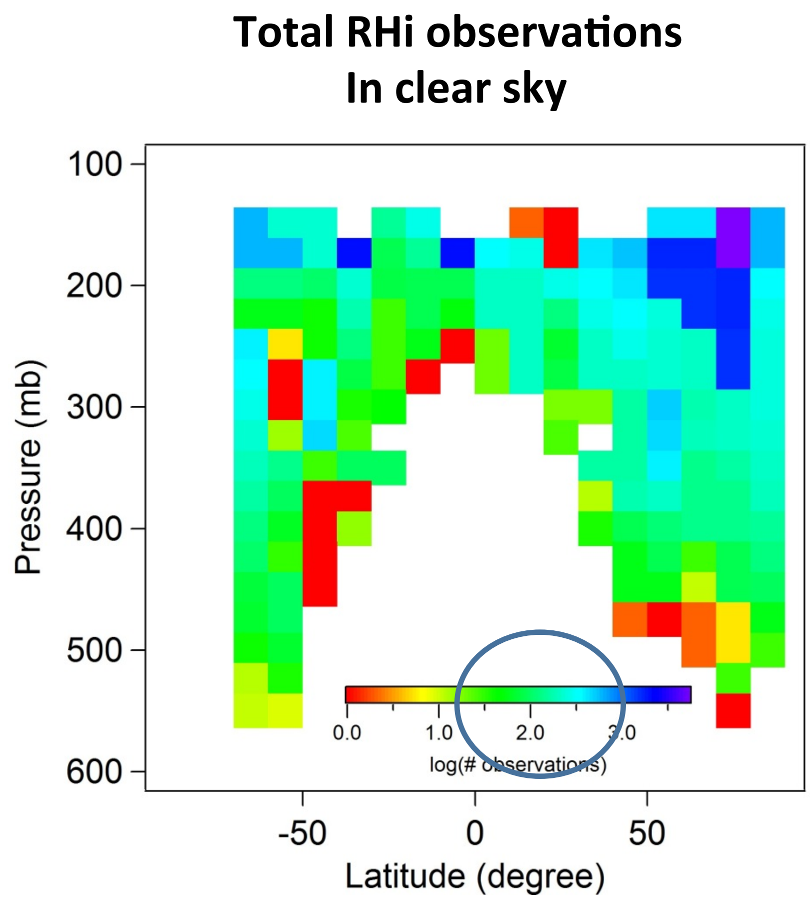
# of ISS between two hemispheres
NH has more # ISS in observations

Clear sky

ISS frequency density in NH and SH

Bin by 25 mb*10 degrees



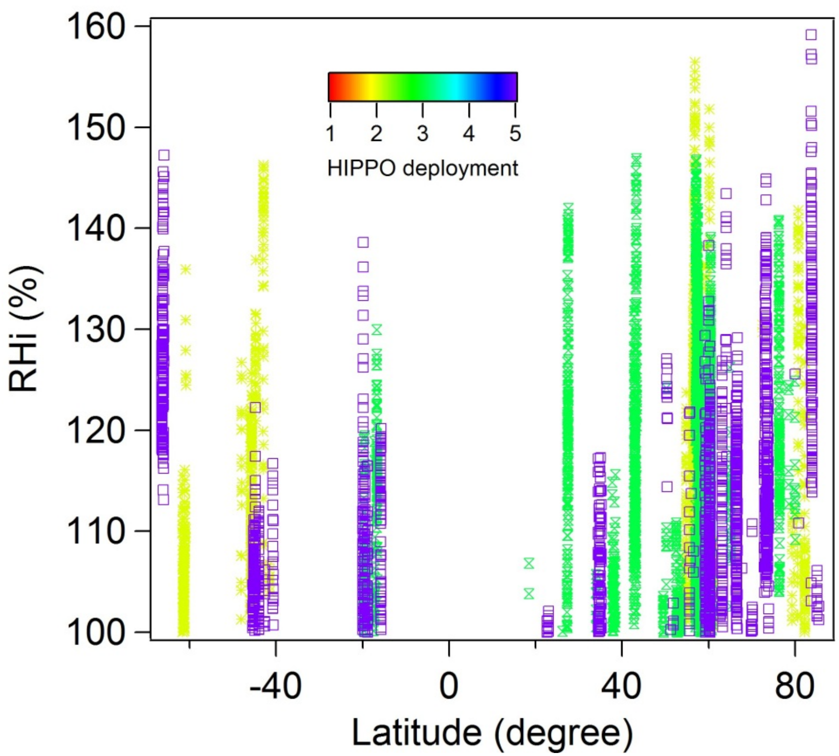


ISS frequency density between two hemispheres

NH has higher frequency of ISS for clear sky

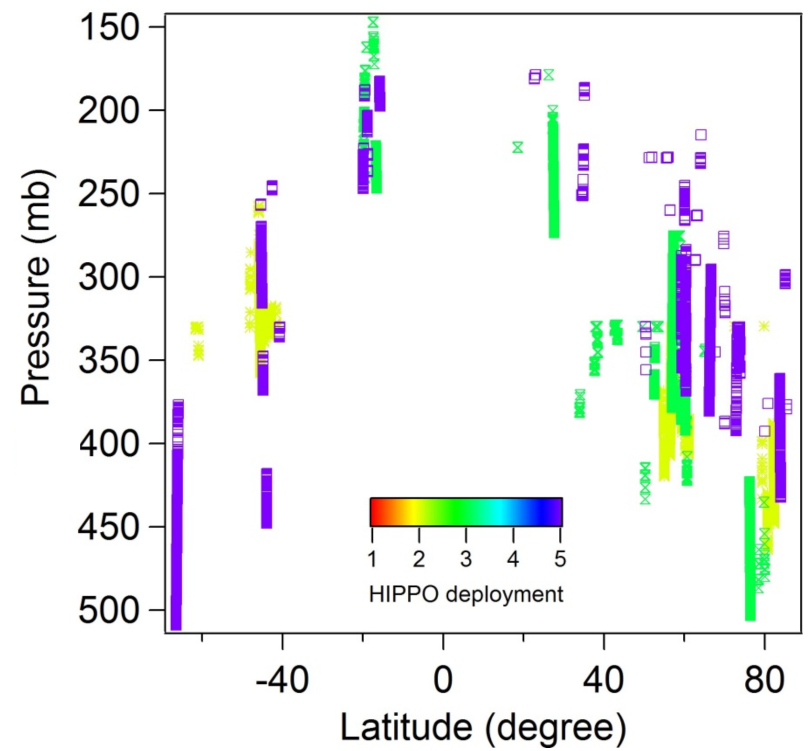
Cloudy sky
ISS distribution in NH and SH

ISS magnitude



HIPPO1 has no ice probe

ISS vertical distribution



ISS magnitude between two hemispheres
NH has higher ISS

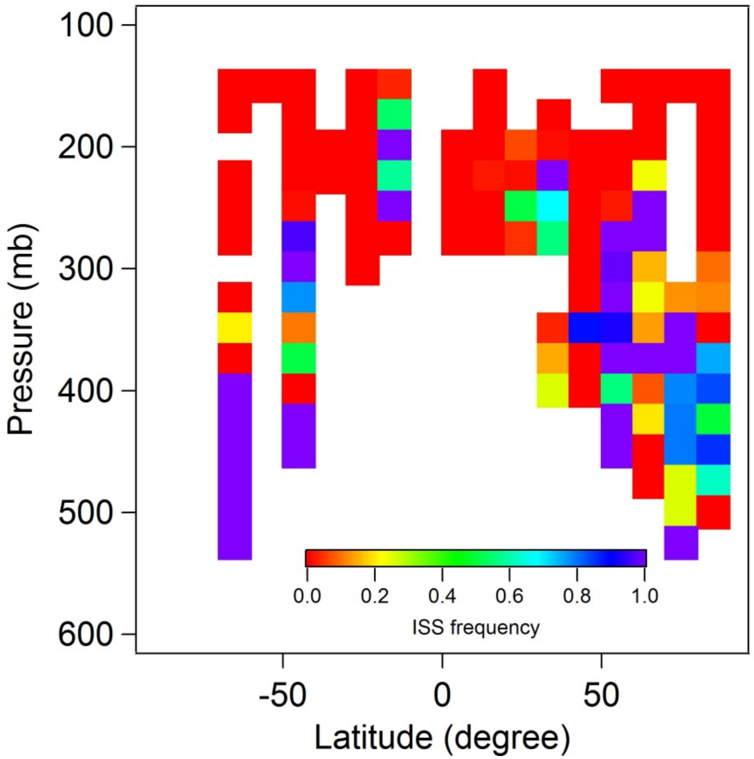
# of ISS between two hemispheres
NH has more # ISS in observations

Cloudy sky

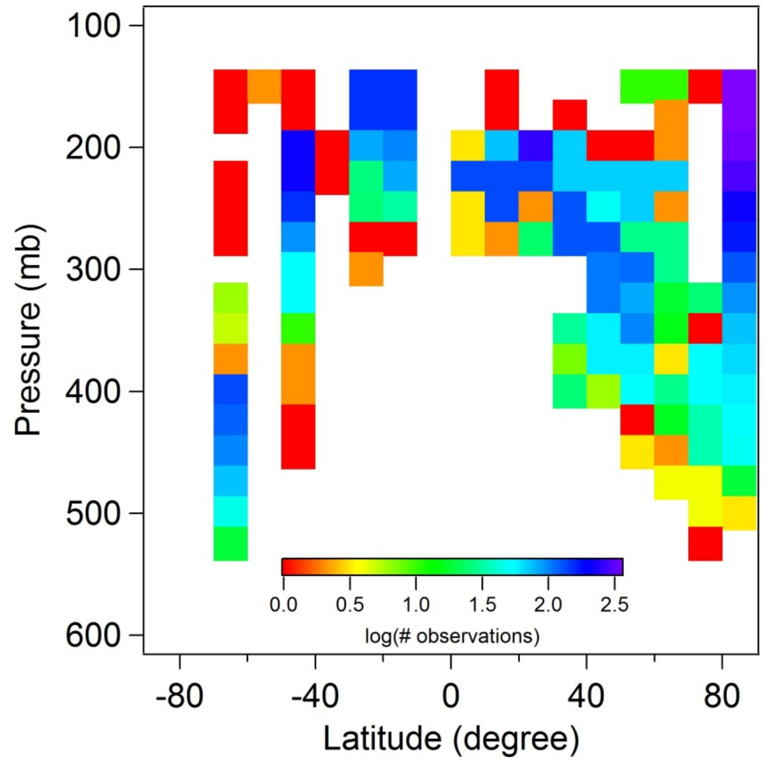
ISS frequency density in NH and SH

Bin by 25mb*10degrees

ISS frequency density



Total RHi observations
In cloud



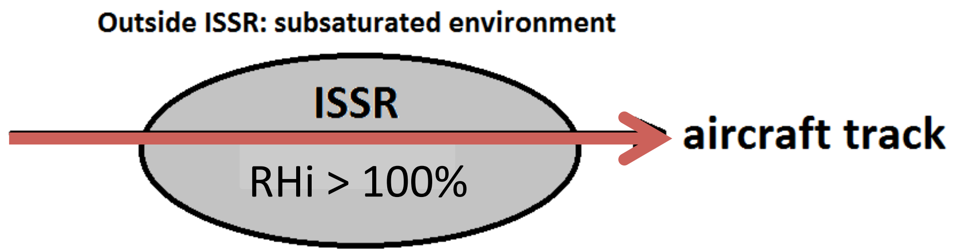
No obvious difference for in-cloud ISS frequency

Limited cloud data in SH

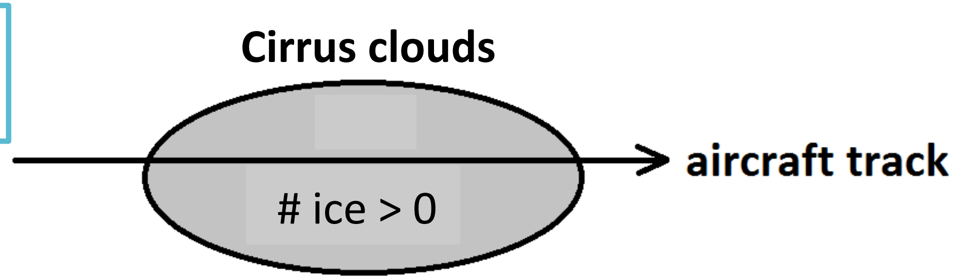
Ice supersaturated regions (ISSRs) and ice clouds

ISSRs: spatially continuous region where RHi > 100%, with or without ice crystals

Pathlength, RHi, ice crystal number



Cirrus: 2DC or 260X 2DC ice number density > 0



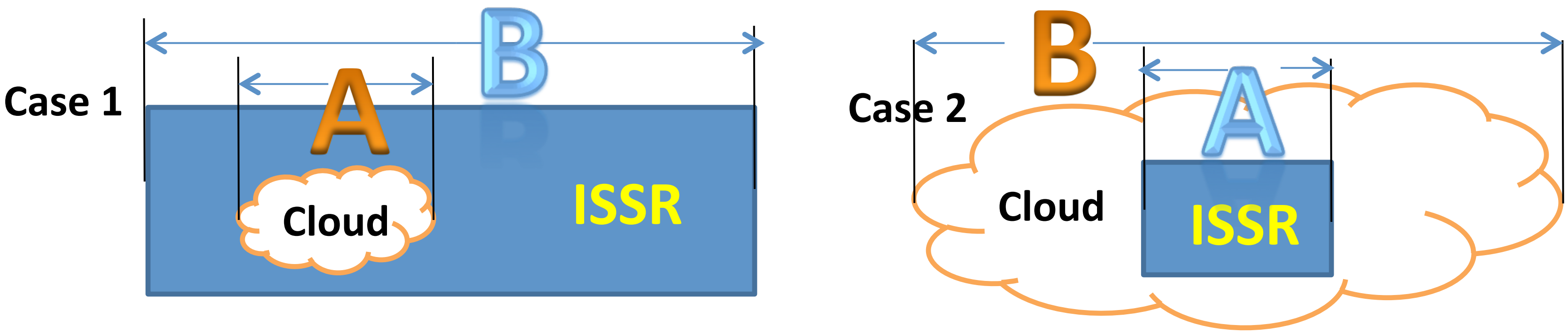
ISS magnitude is highly related to the formation and evolution of cirrus clouds

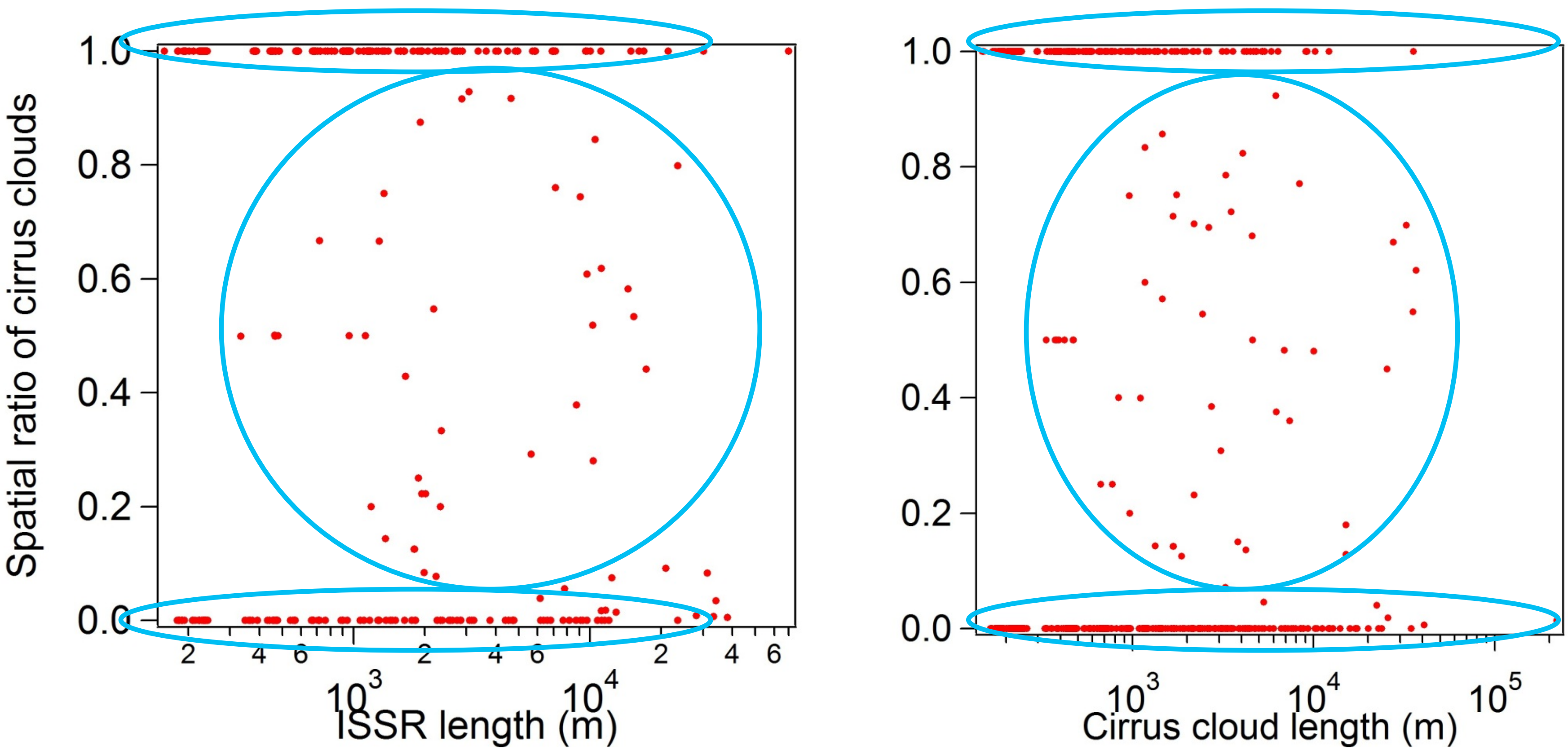
During which phase of cirrus cloud evolution does NH has higher ISS than SH? – Nucleation? Removal?

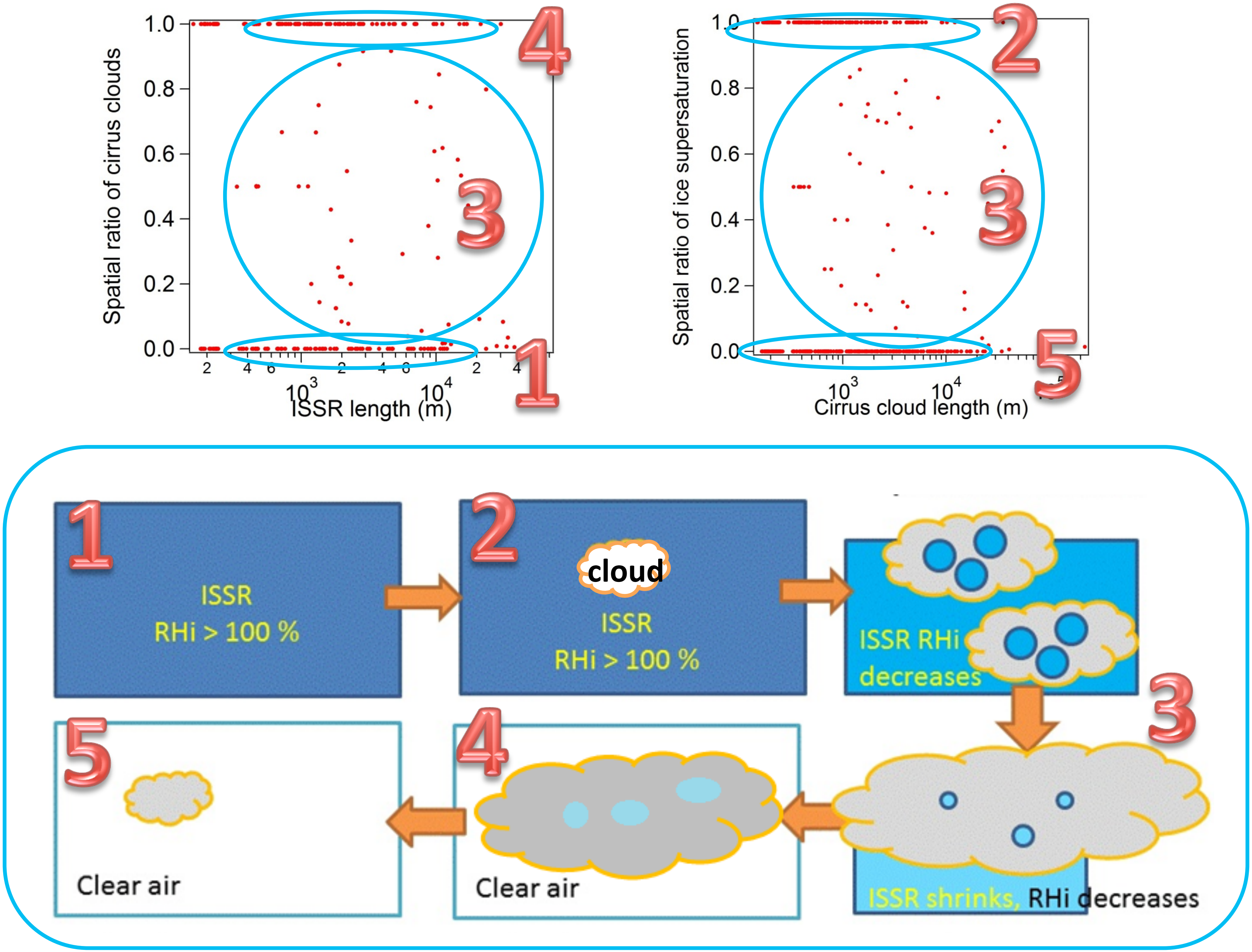
How can we separate out different evolution phases of cirrus clouds?

Spatial ratio between ISSRs and cirrus clouds

Spatial ratio = A / B

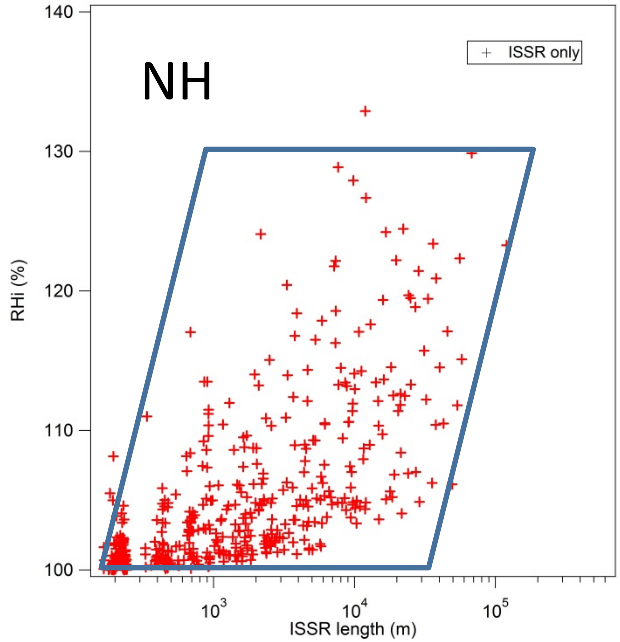


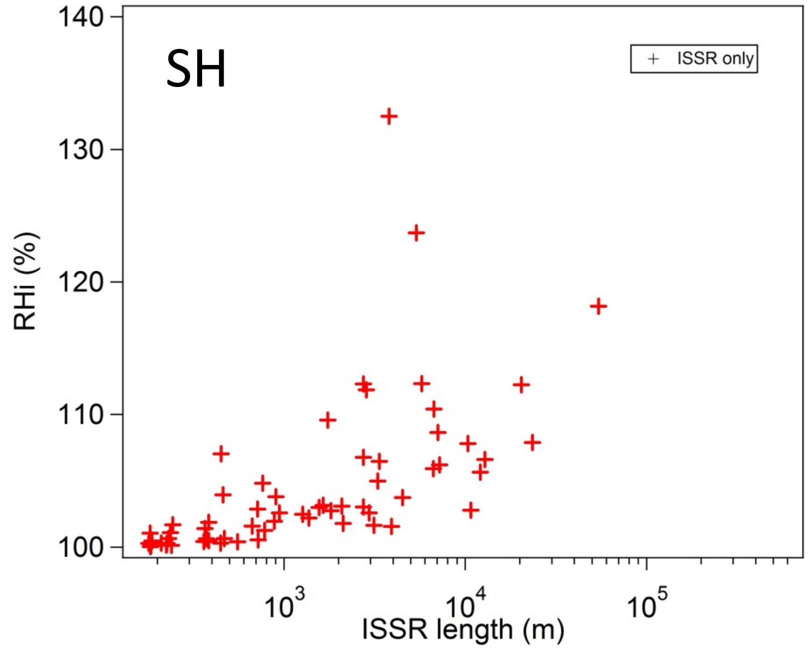




Spatial ratio of cirrus clouds
ISSR length (m)
Spatial ratio of ice supersaturation
Cirrus cloud length (m)
1
ISSR
RHi > 100 %
2
cloud
ISSR
RHi > 100 %
ISSR RHi
decreases
3
ISSR shrinks, RHi decreases
4
Clear air
5
Clear air

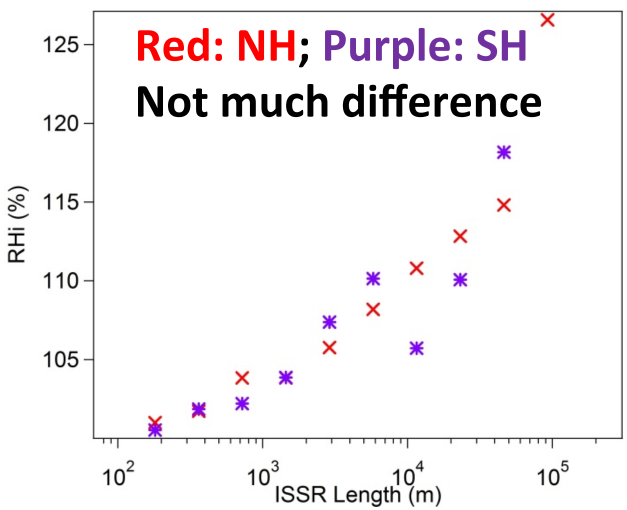
Phase 1 Clear sky ISSRs





Total ISSR + Cirrus clouds
NH 3966; SH 4147

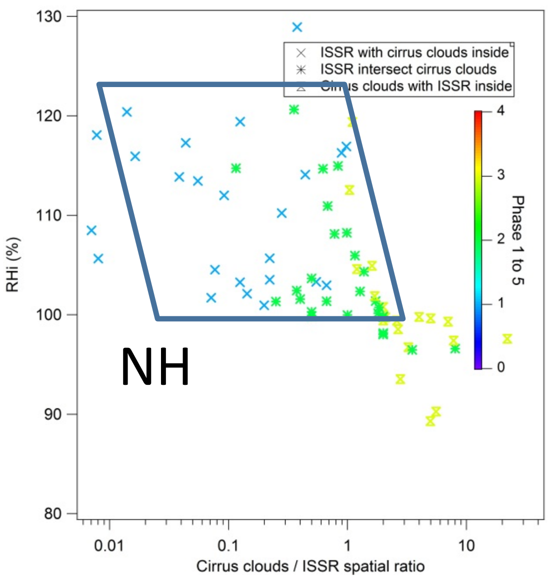
Mean RHi value of each bin

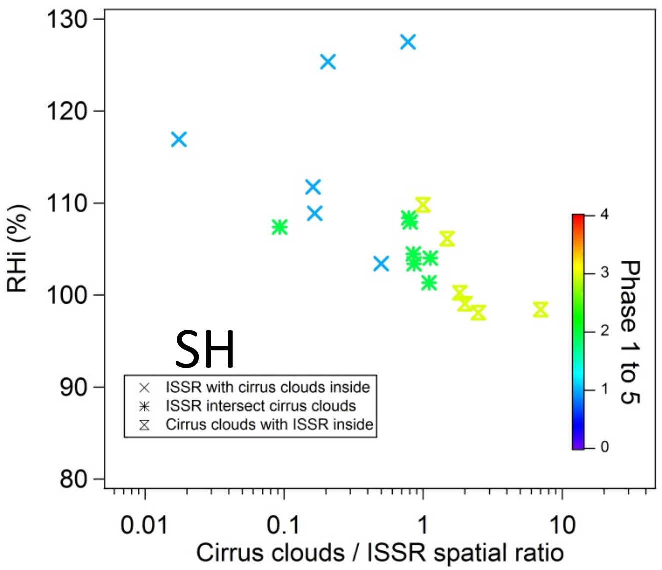


NH has broader scope of RHi inside totally clear sky ISSRs

-> PDF of RHi in clear sky

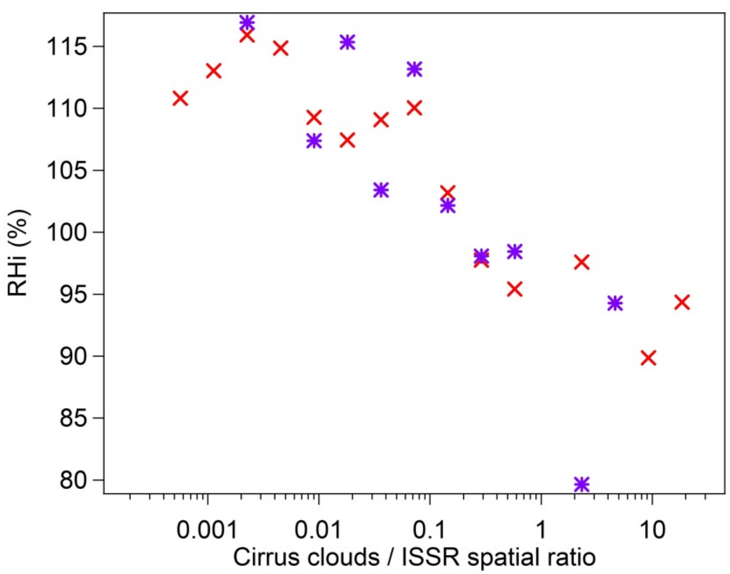
Phase 2+3+4 Cirrus cloud growth





Color Phase 1,2,3

Mean RHi value of each bin

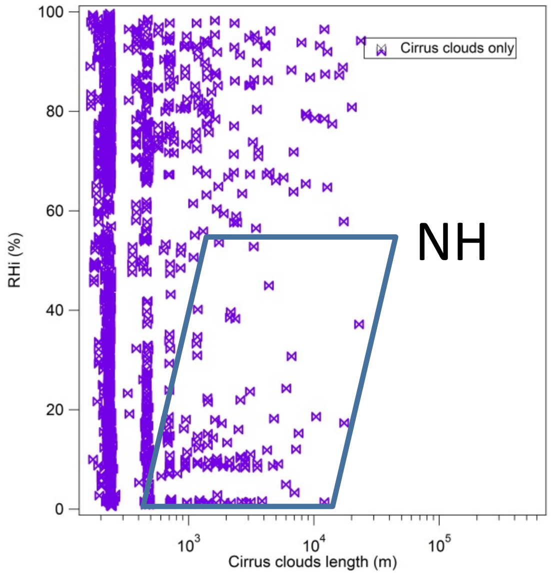


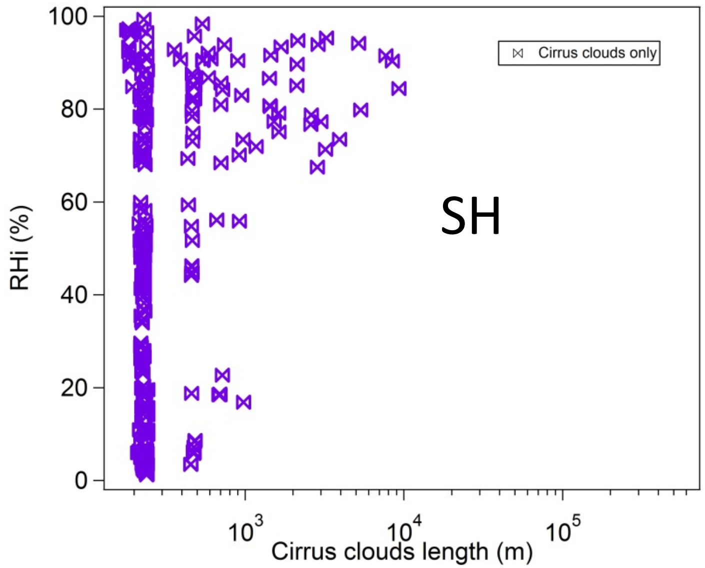
Red: NH; Purple: SH

Not much difference

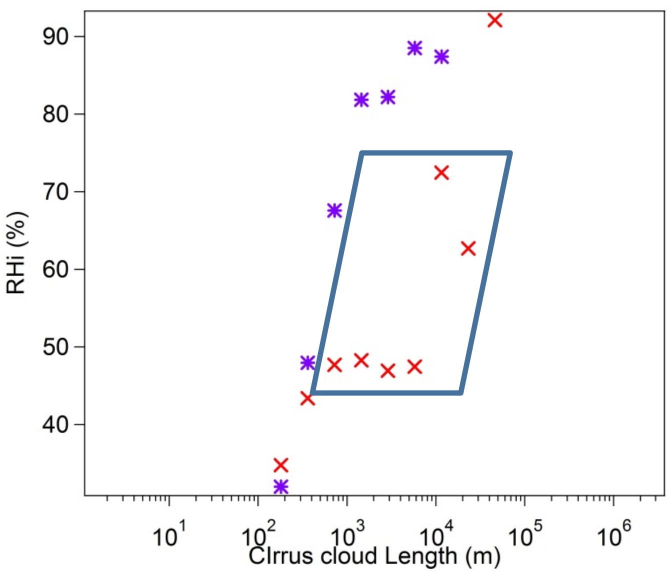
NH has boarder RHi scope during cirrus cloud growth.

Phase 5 Cloud sedimentation and evaporation





Mean RHi value of each bin



Red: NH; Purple: SH

NH has many low RHi in-cloud.

Conclusions

- 1. Ice supersaturation in NH and SH with global *in situ* HIPPO data
  - PDF of RHi NH shifts to higher ISS than SH for both in-cloud and clear sky
  - ISS frequency density
    - Clear sky NH > SH
    - In-cloud no difference
- 2. Evolutions from ISSR to cirrus clouds
  - Proposed a scheme to separate evolution of cirrus clouds by *in situ*, quasi-Eulerian sampling
  - Link large scale RHi difference to cloud microphysics
- 3. Mechanism of cirrus cloud formation in NH and SH
  - Separate out new-born clouds from aged clouds
  - NH vs. SH have similar mean RHi value at each cloud evolution phase
  - NH has broader range of RHi at each phase

Future work:

Meteorology, local sampling bias, instrument uncertainties (START08 SID_Num_2H).

Large scale dynamics? Aerosol background? Pollution?

Photo by Minghui Diao

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RAF Technical and Ground Crews
HIPPO Science Team

Fellowship and award	
2008-2012	Princeton Francis Upton Fellowship
2009-2012	NASA Earth and Space Science Fellowship
2011	Princeton Environment and Climate Scholars Travel Grant
2010	Outstanding student paper award for AGU Fall Meeting, San Francisco
2009	Outstanding student paper award for AGU Spring Assembly, Toronto
2009	Travel Award to attend Water Vapor and the Climate System (WAVACS) summer school, France

Thanks!

Questions?