Extratropical and Polar Cloud Systems

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Extratropical and Polar Cloud Systems

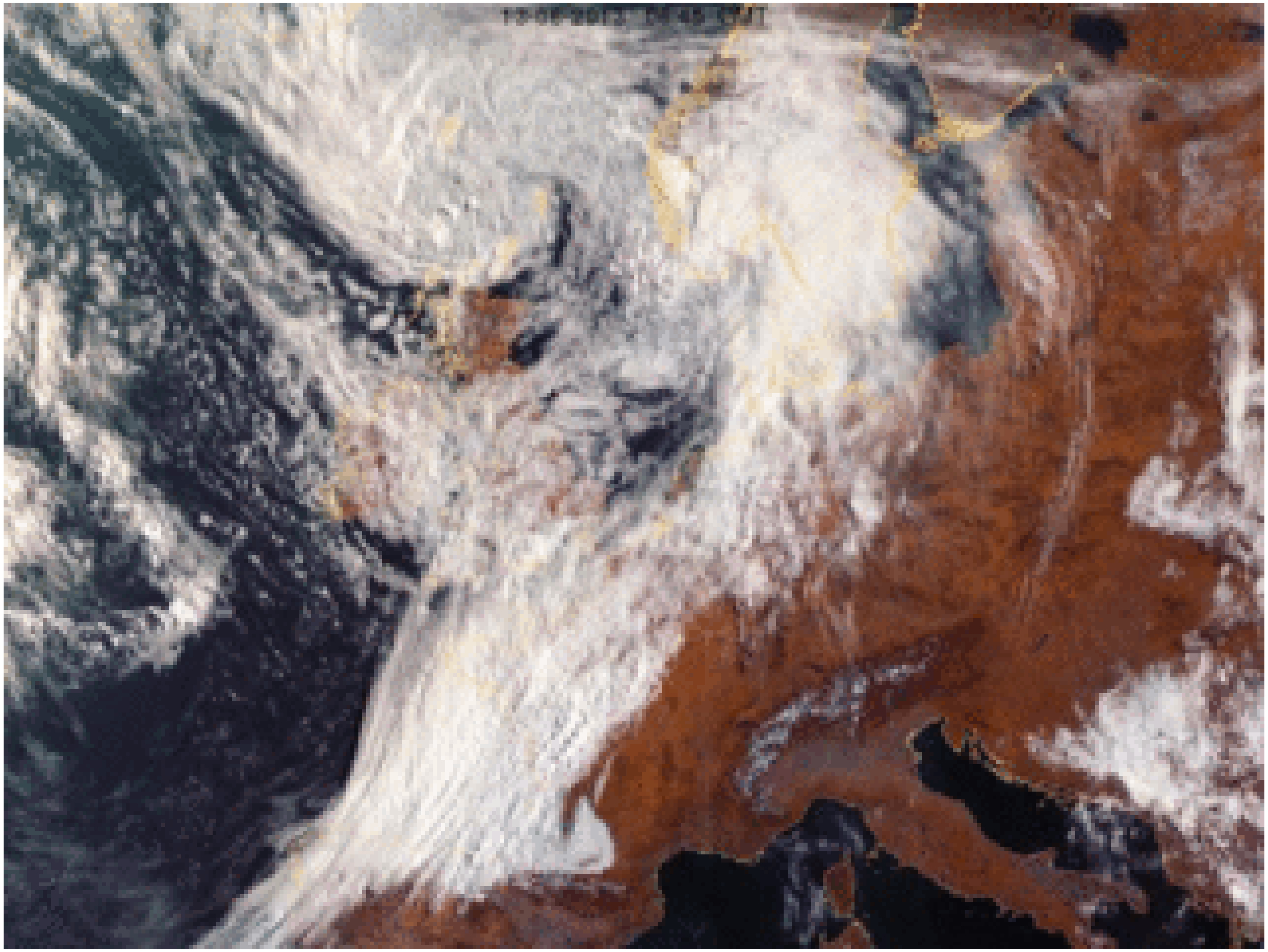
Stockholm University

Lecture 1
Extratropical cyclones

Lecture 2
Polar clouds

Lecture 3
Are these clouds well represented in CMIP5 models? How are they projected to change? Challenges in modeling these clouds?

From EUCLIPSE web site:



Extratropical and Polar Cloud Systems

NASA – Apollo 17

Extratropical and Polar Cloud Systems

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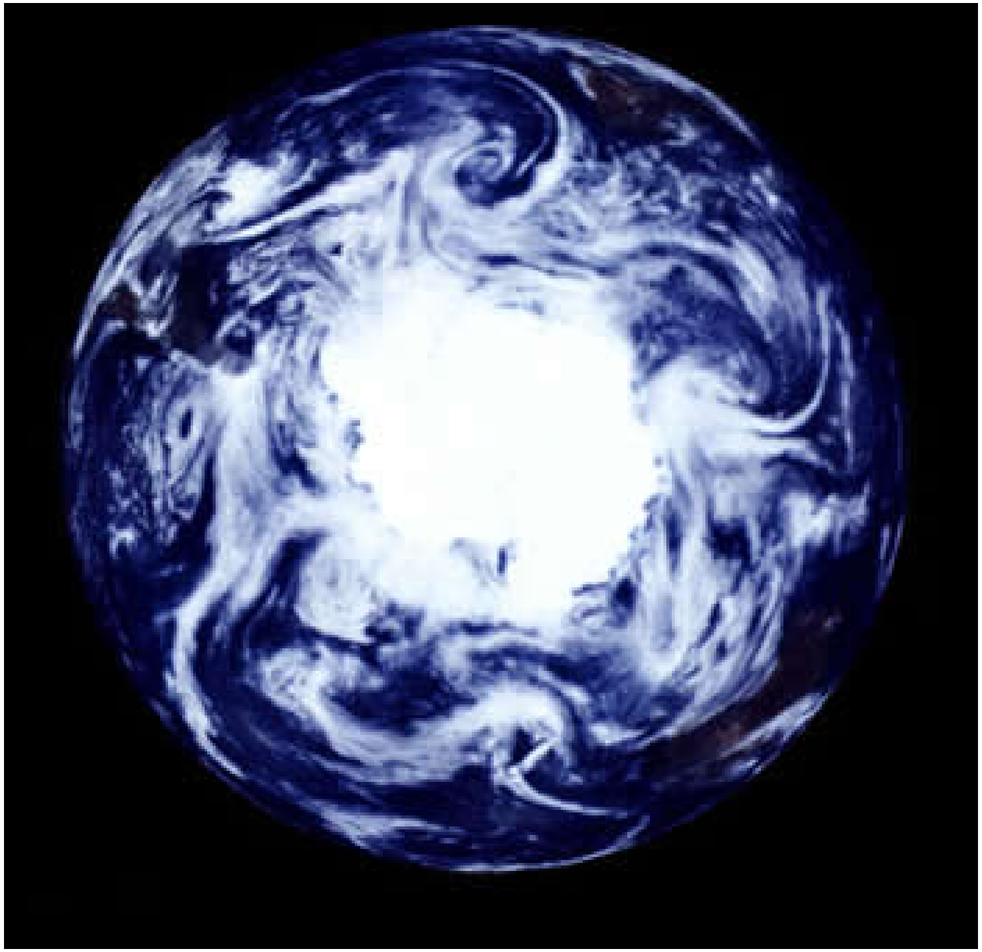
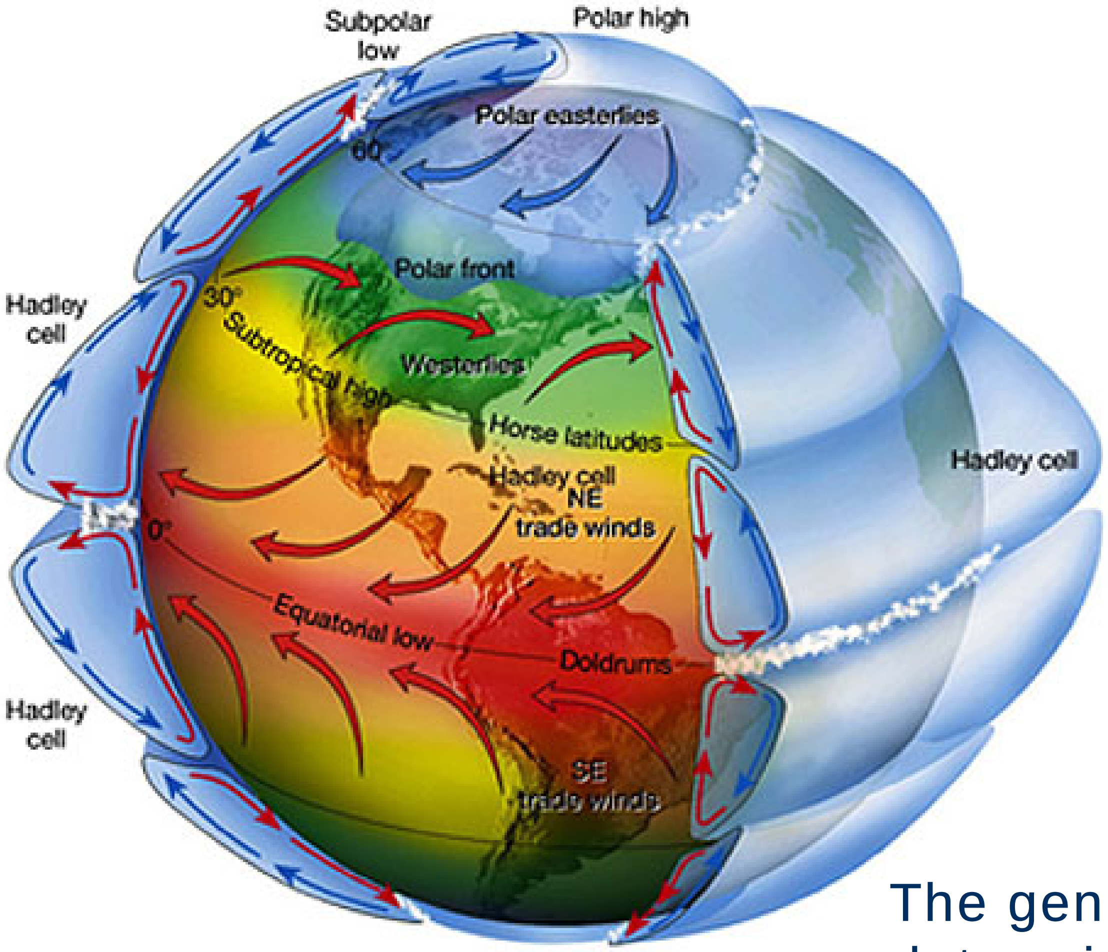


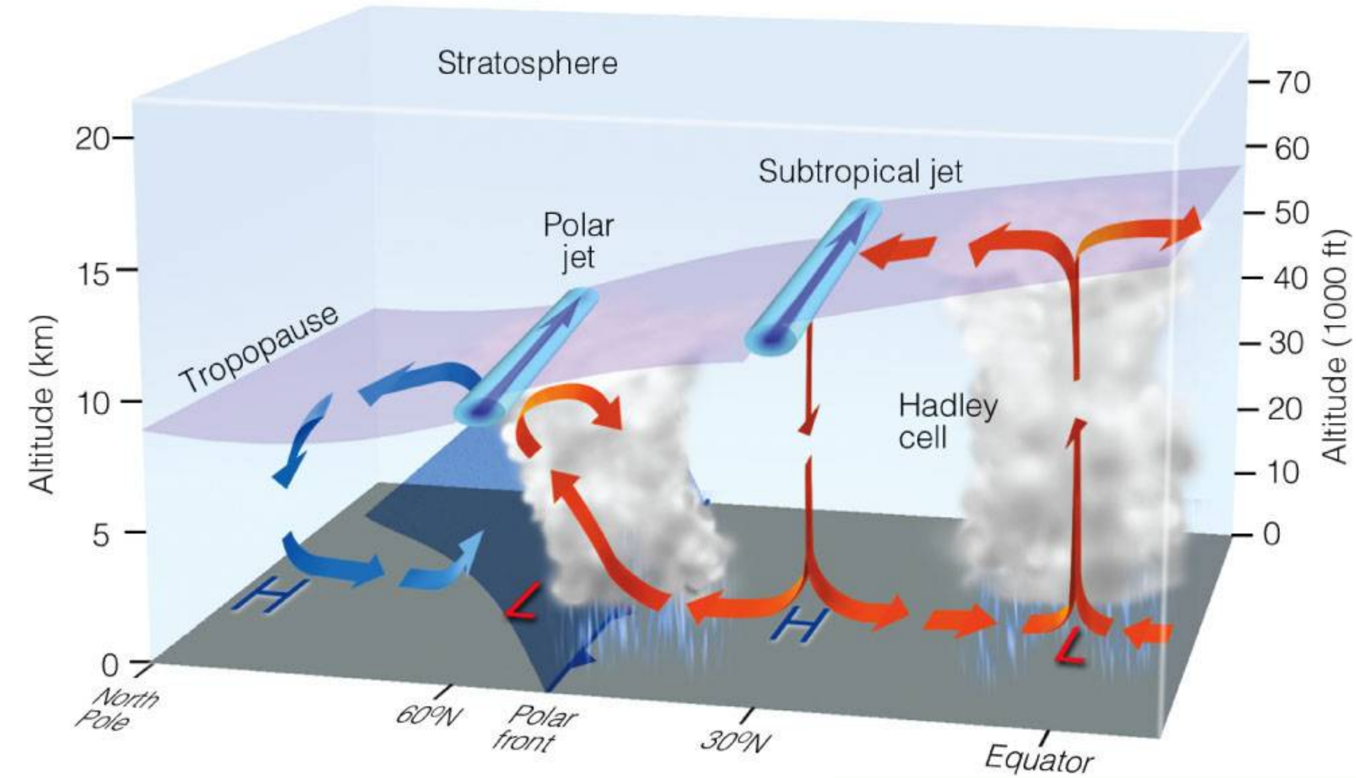
Satellite view of the atmospheric circulation at the South Pole (**Source:** NASA)

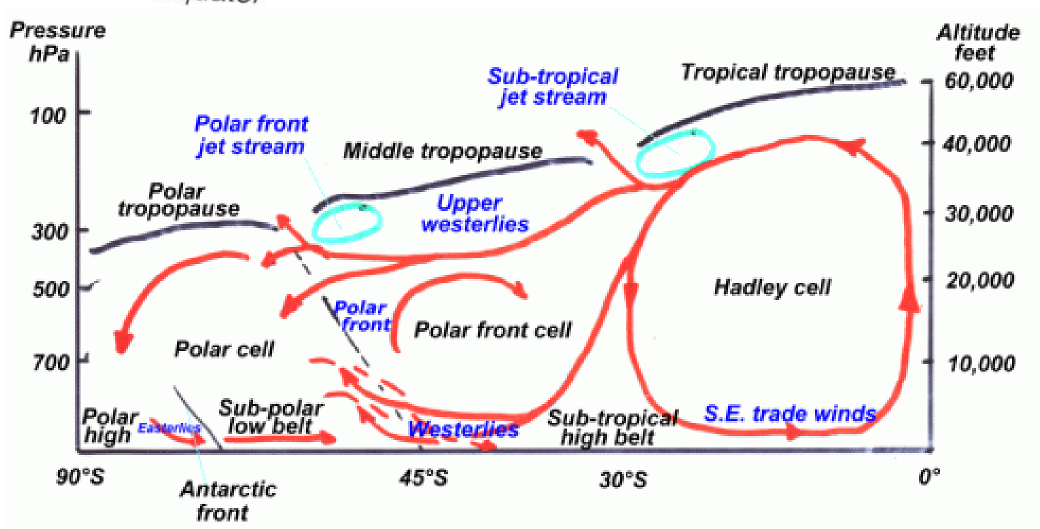
Atmospheric general circulation



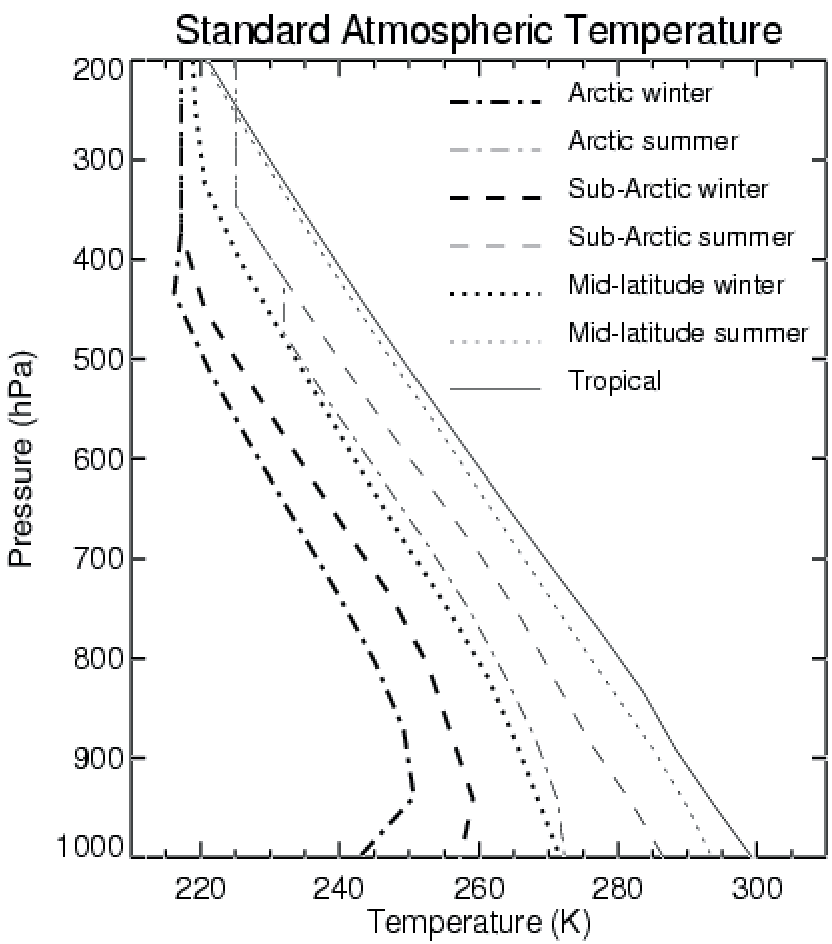
The general circulation determines where the extratropics are located

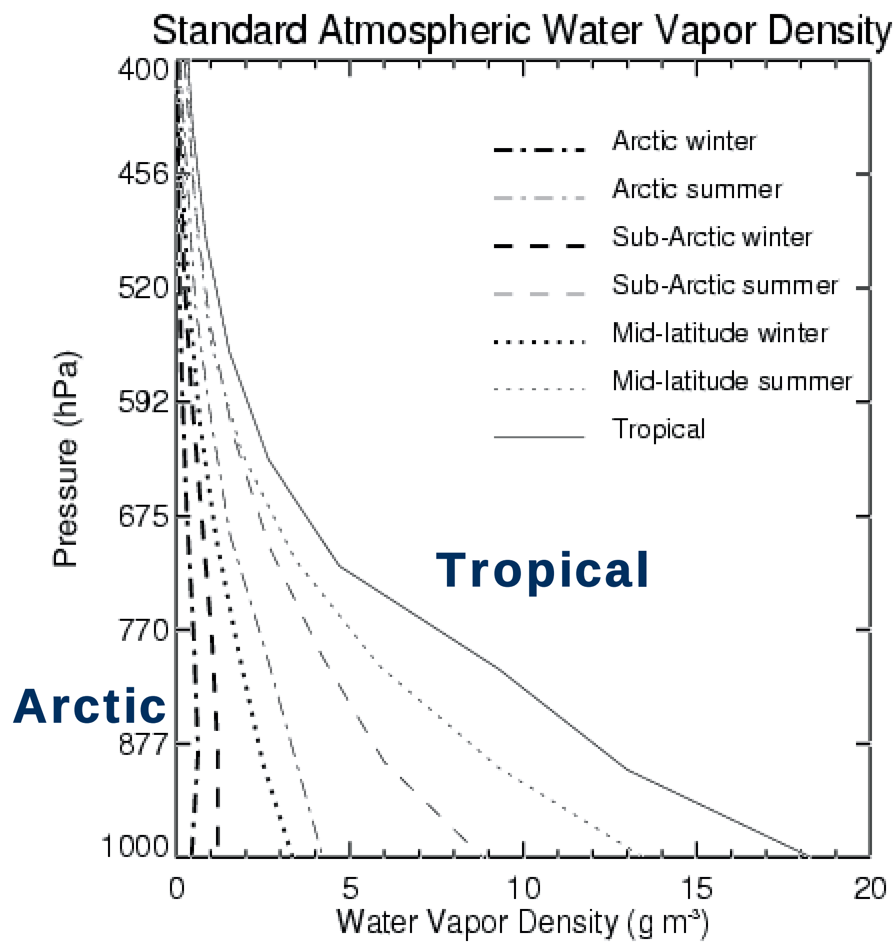
Hadley cell and polar front





Temperature and humidity





Tropics vs Arctic
Temperature tendencies, ECMWF IFS

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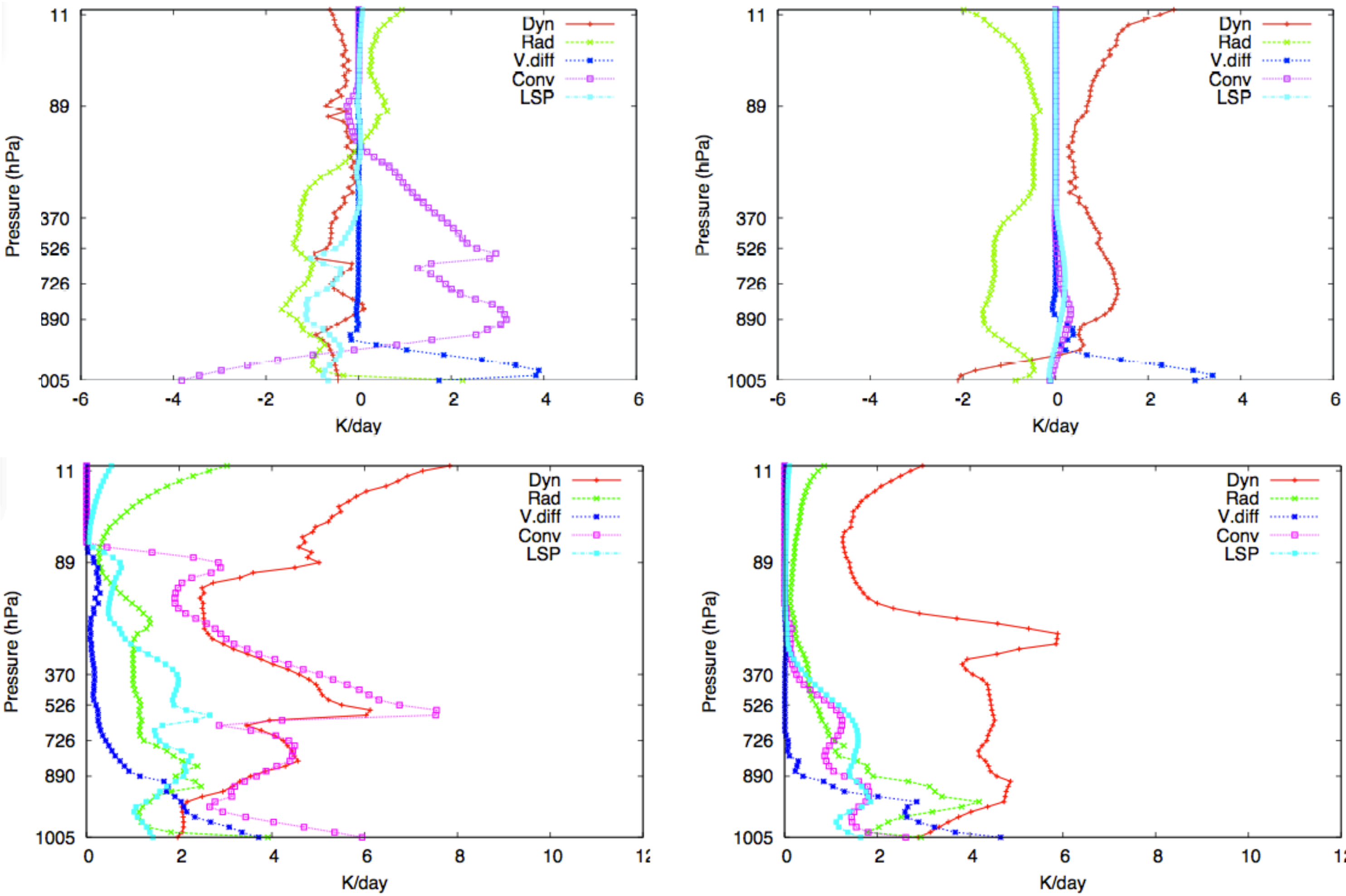
Tropical Ocean **Arctic Ocean**



Mean

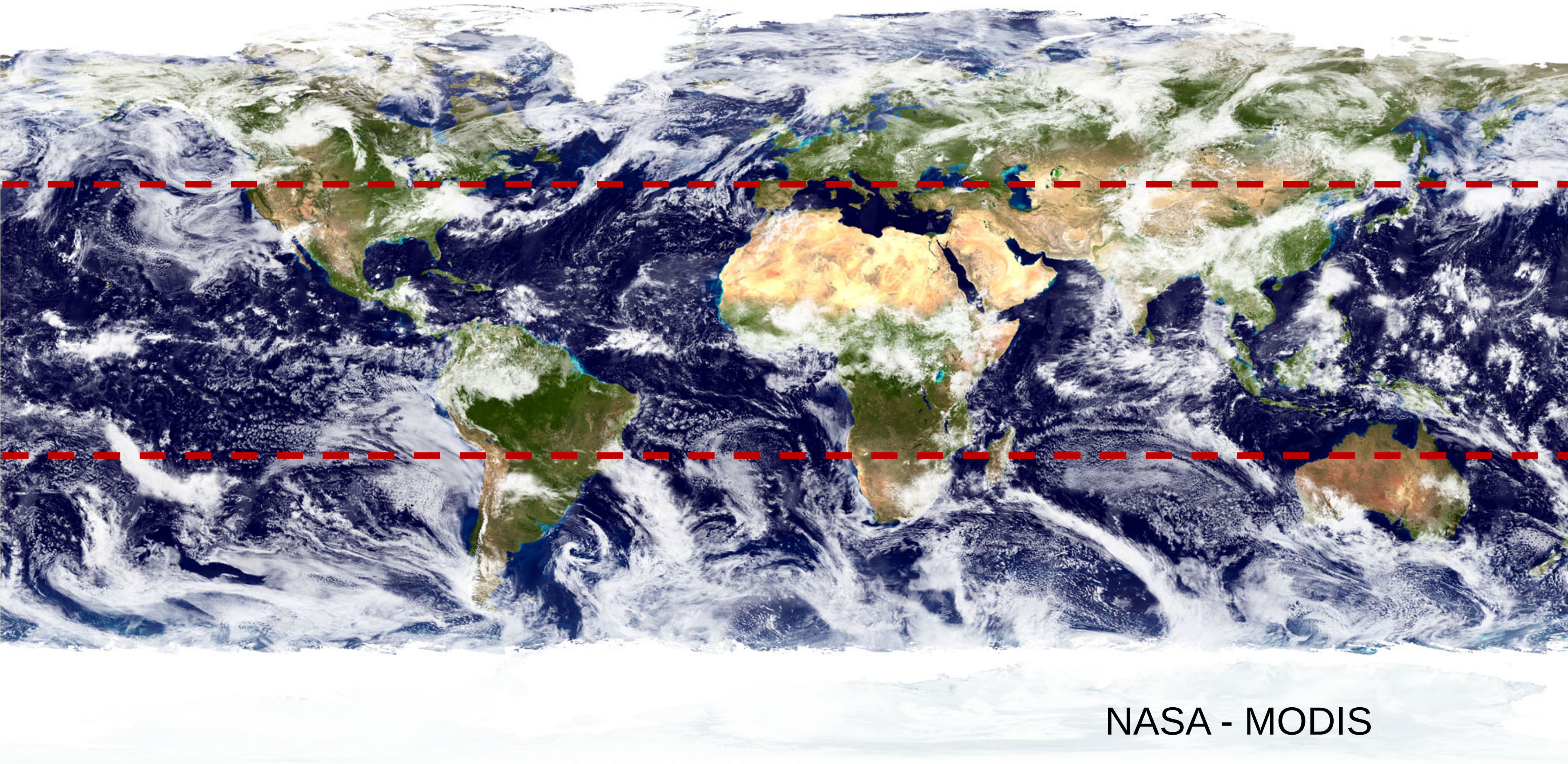
6-hourly initial tendencies

120 forecasts (DJF 1989-2010)

Standard deviation

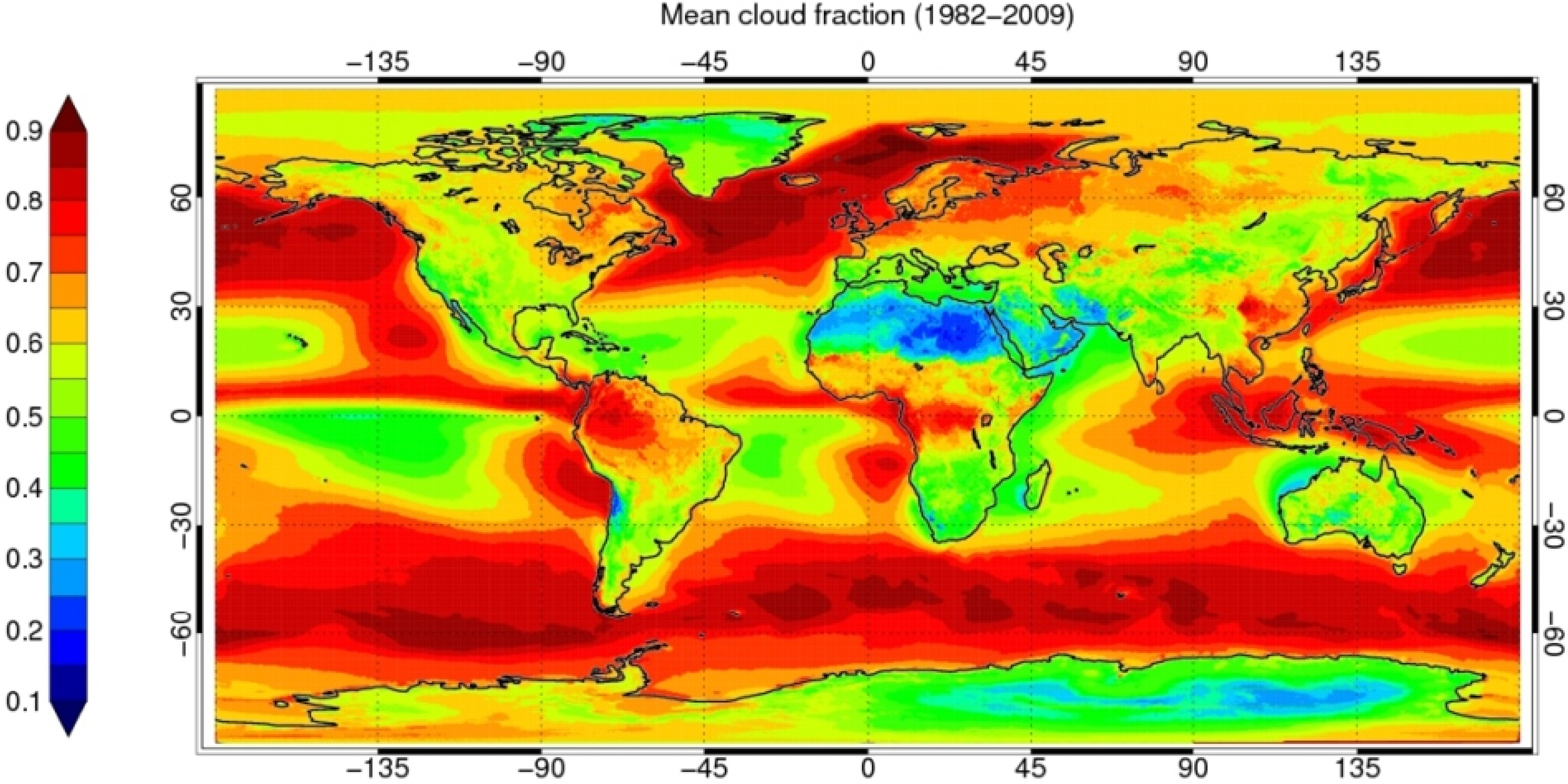
Courtesy of S. Serrar

Extratropical and Polar Cloud Systems



NASA - MODIS

Annual mean total cloud cover



Clouds, surface albedo and radiation from 28 years of NOAA AVHRR data, *CLARA-A1*

Net radiation at TOA for September 2012

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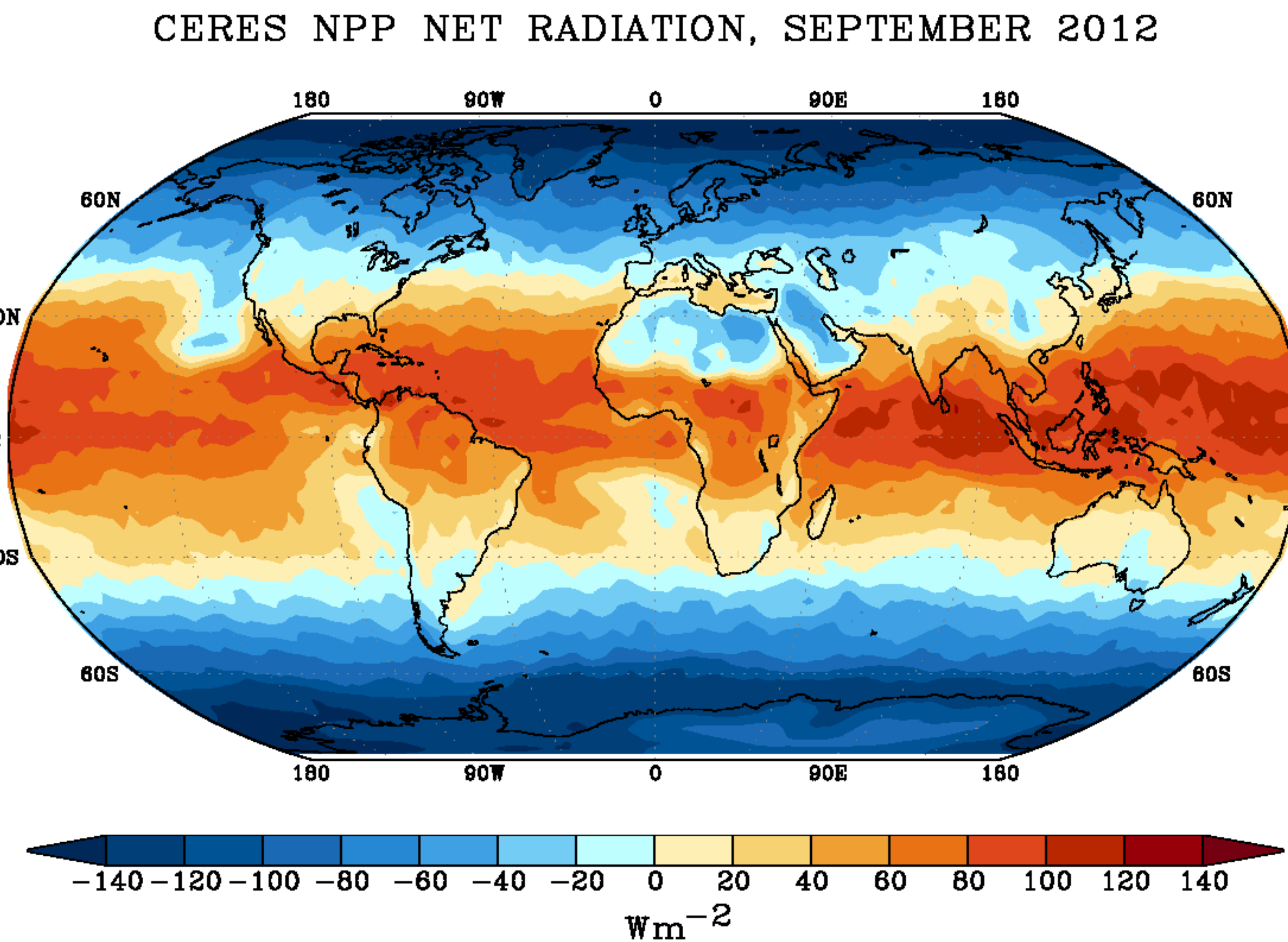
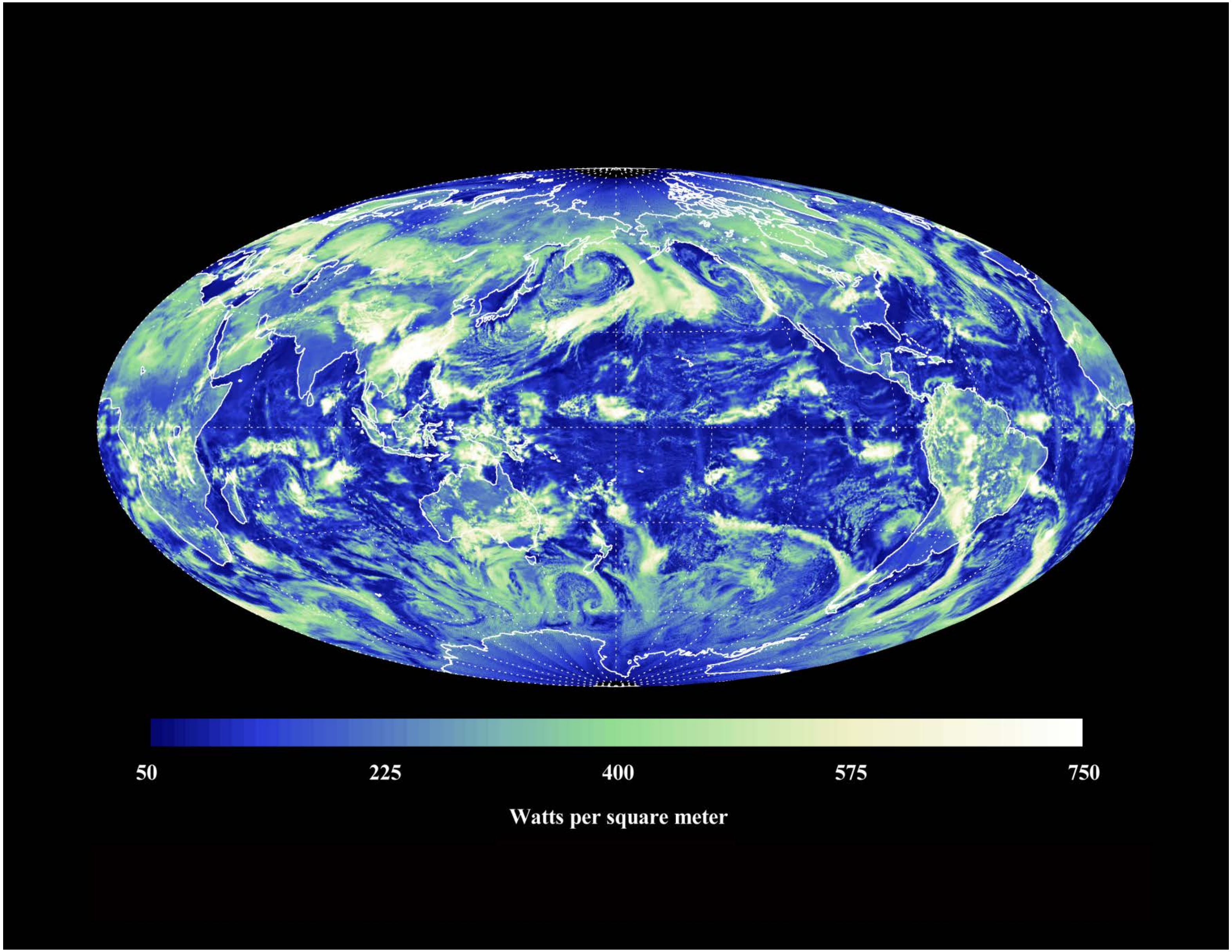


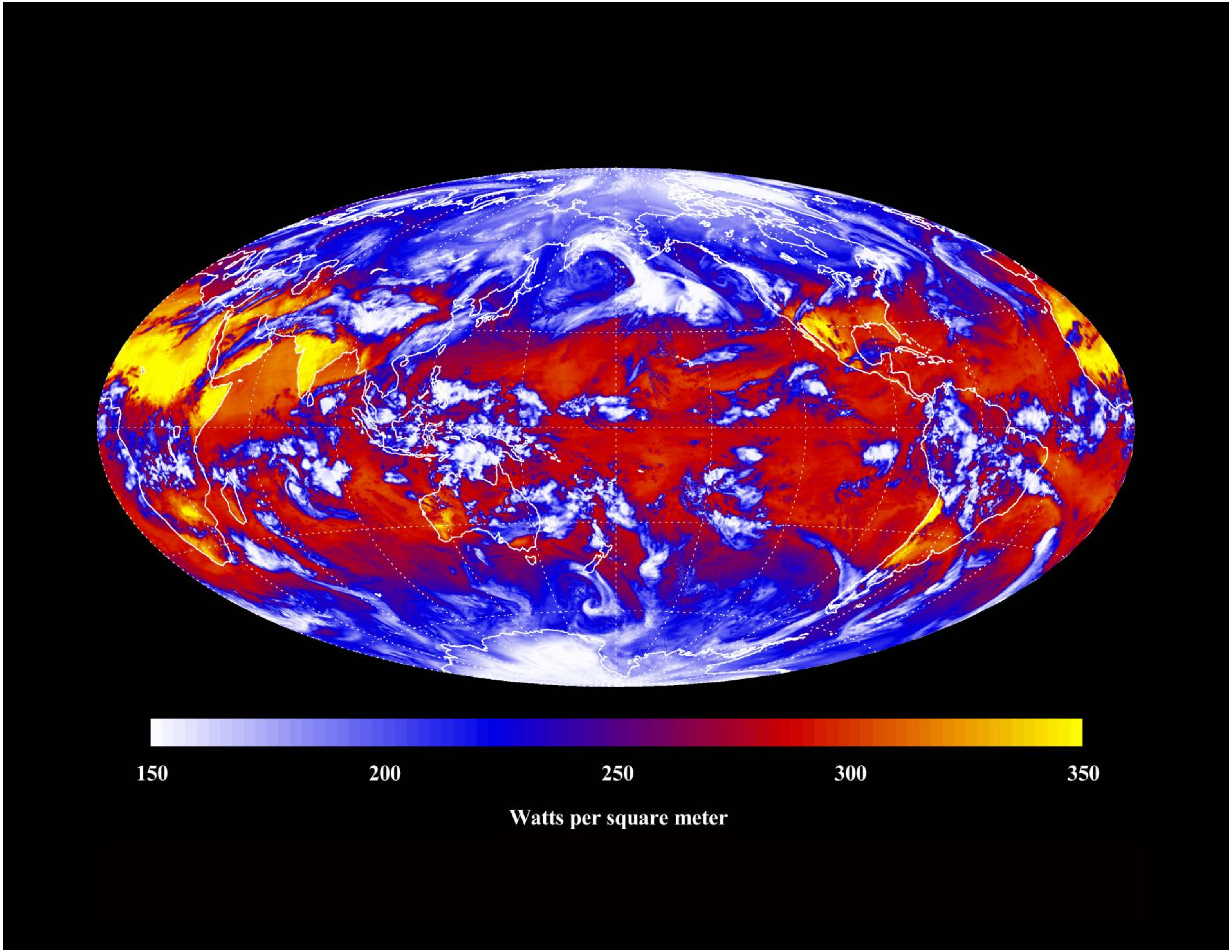
Outgoing shortwave radiation at TOA
March 18, 2011

Stockholms universitet



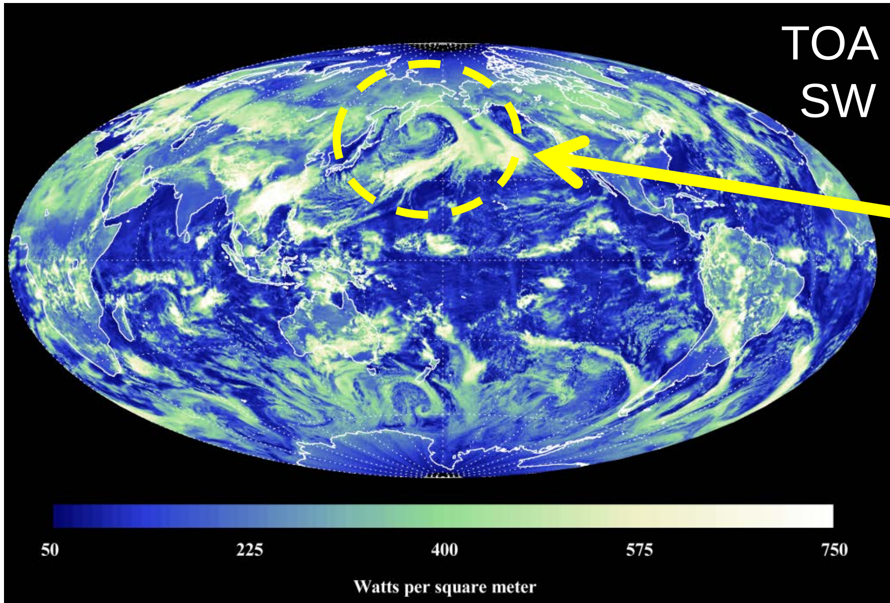
Outgoing longwave radiation at TOA
March 18, 2011

Stockholms universitet

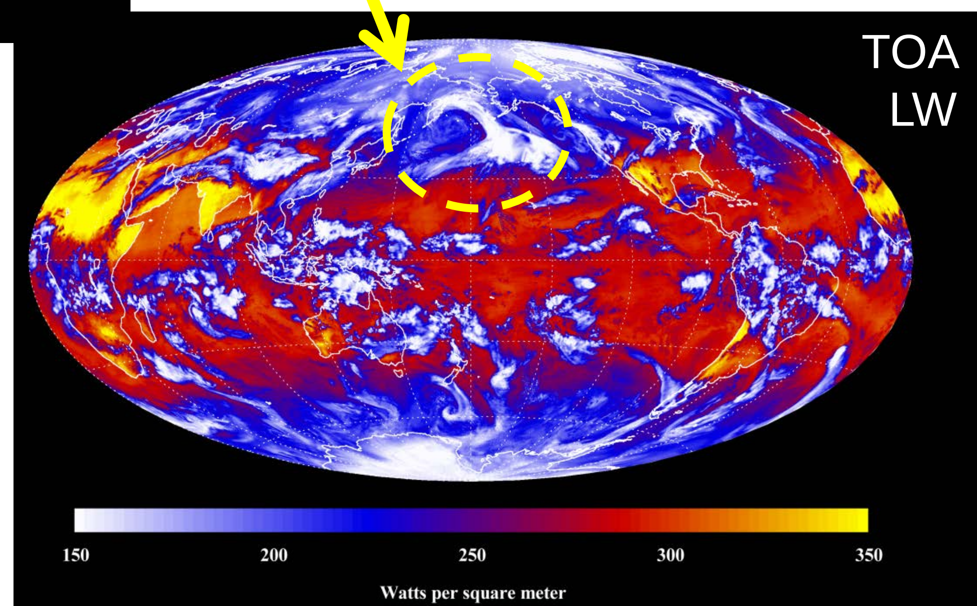


Outgoing shortwave and longwave radiation at TOA
March 18, 2011

Stockholms universitet



Individual baroclinic storms/synoptic systems are clearly seen in the radiation



Conceptual models of extratropical cyclones – the Norwegian cyclone model

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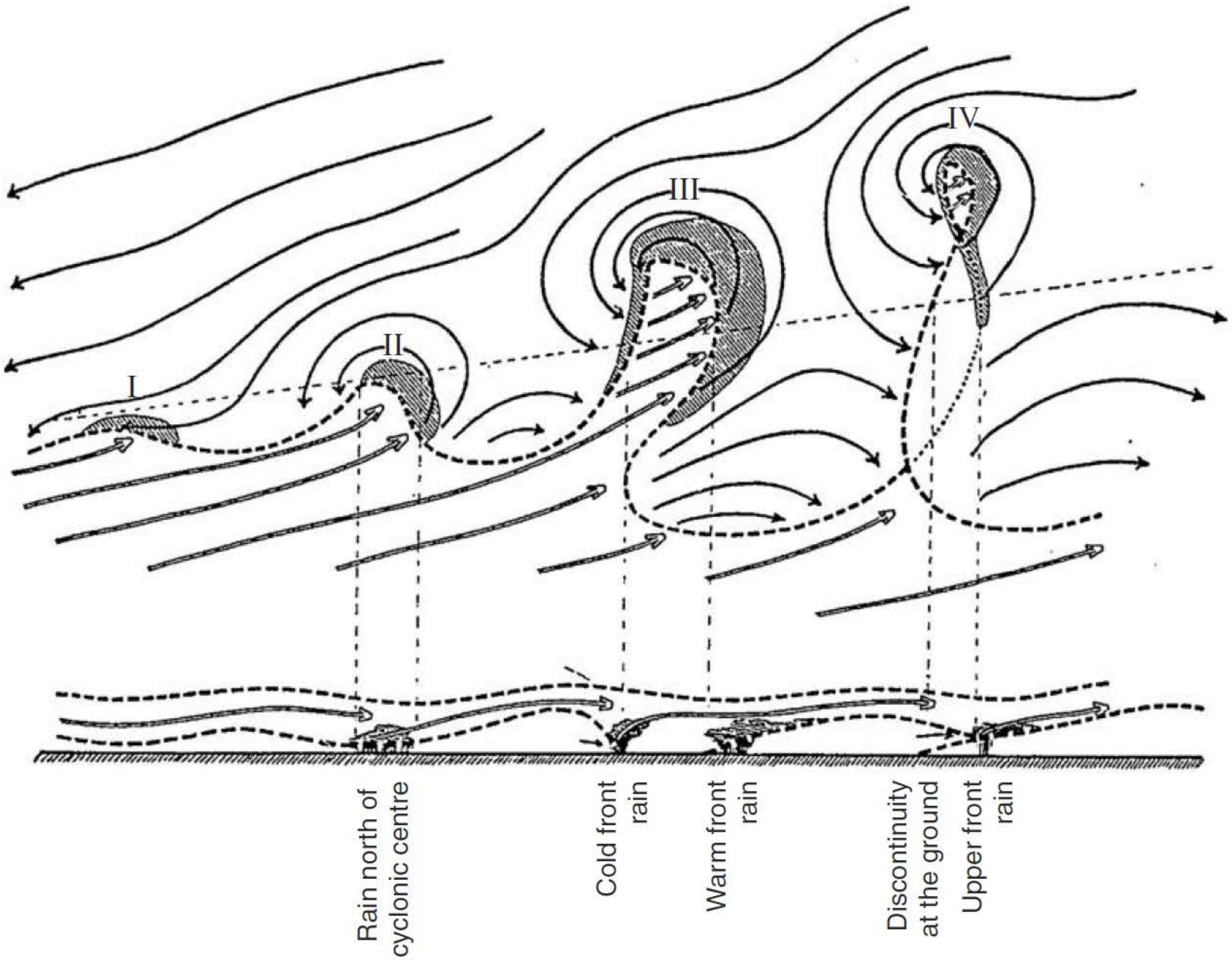


FIGURE 10.4 The Norwegian frontal cyclone model. *(From Bjerknes and Solberg (1922); After Shapiro and Keyser (1990))*

Conceptual models of extratropical cyclones – the Norwegian cyclone model

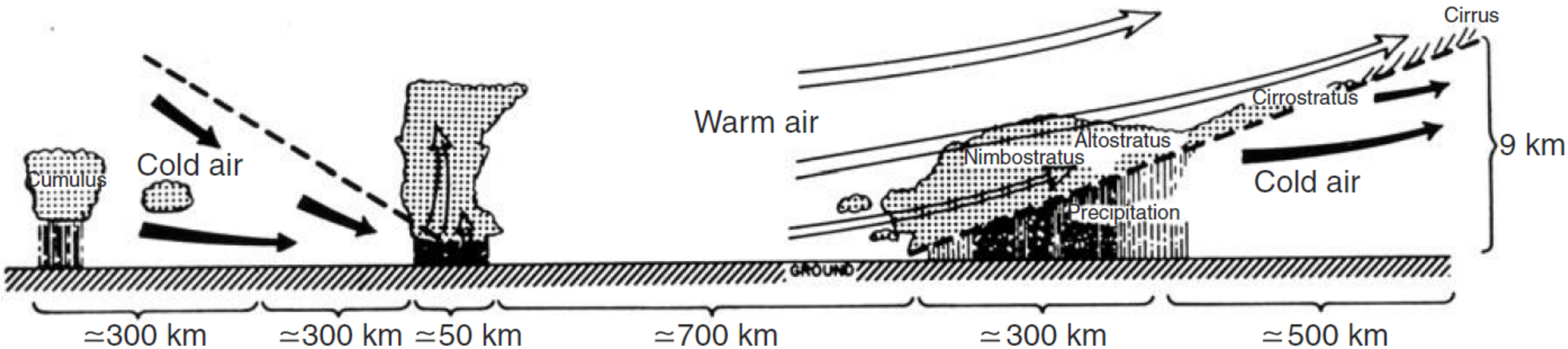
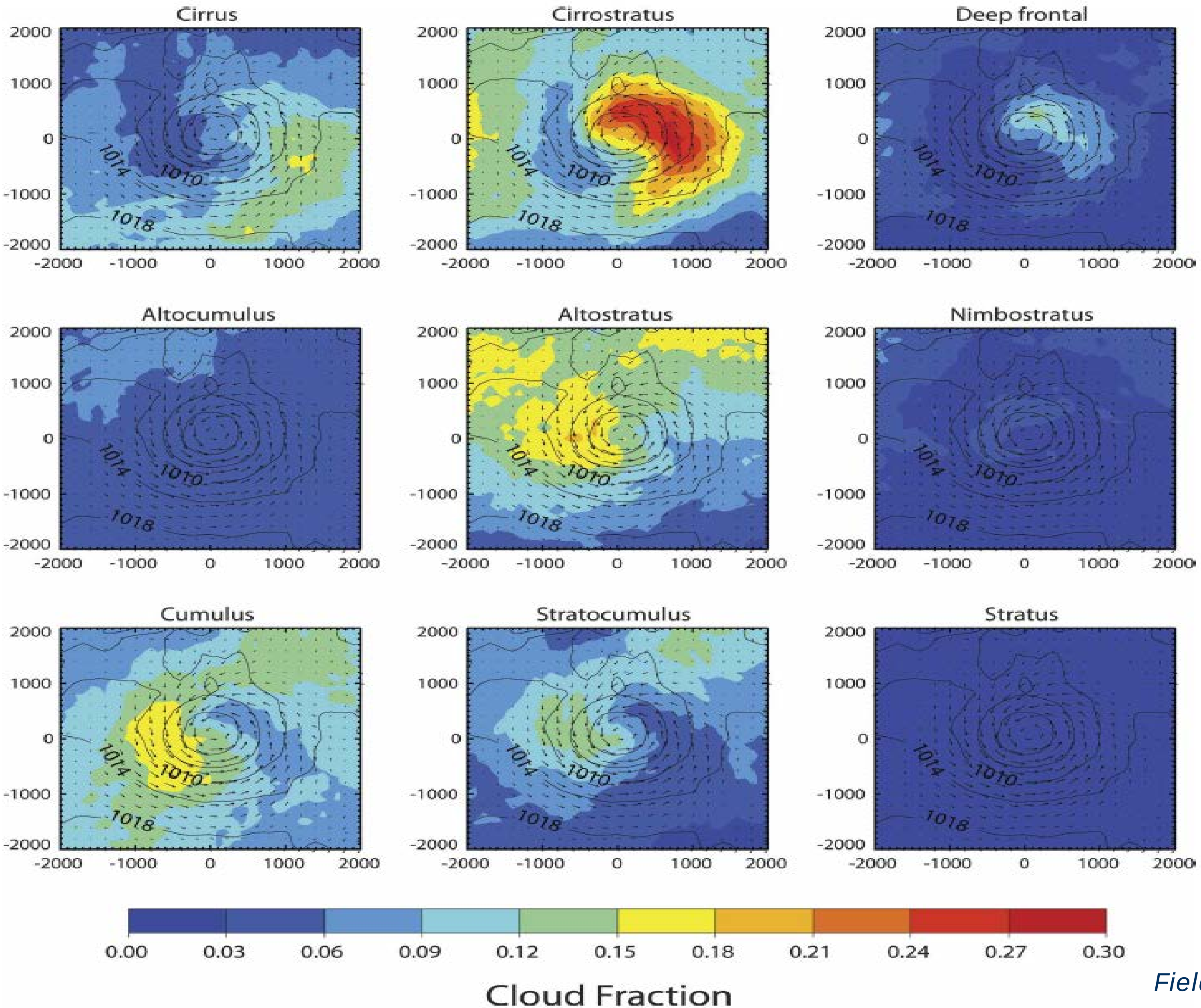


FIGURE 10.5 Idealized vertical cross section through a mid-latitude cyclone, according to the Norwegian Cyclone model. (Vertical scale is stretched by a factor of about 30 compared to horizontal scale.). *(From Houze and Hobbs (1982))*

Storm and Cloud Dynamics, Cotton et al., 2011

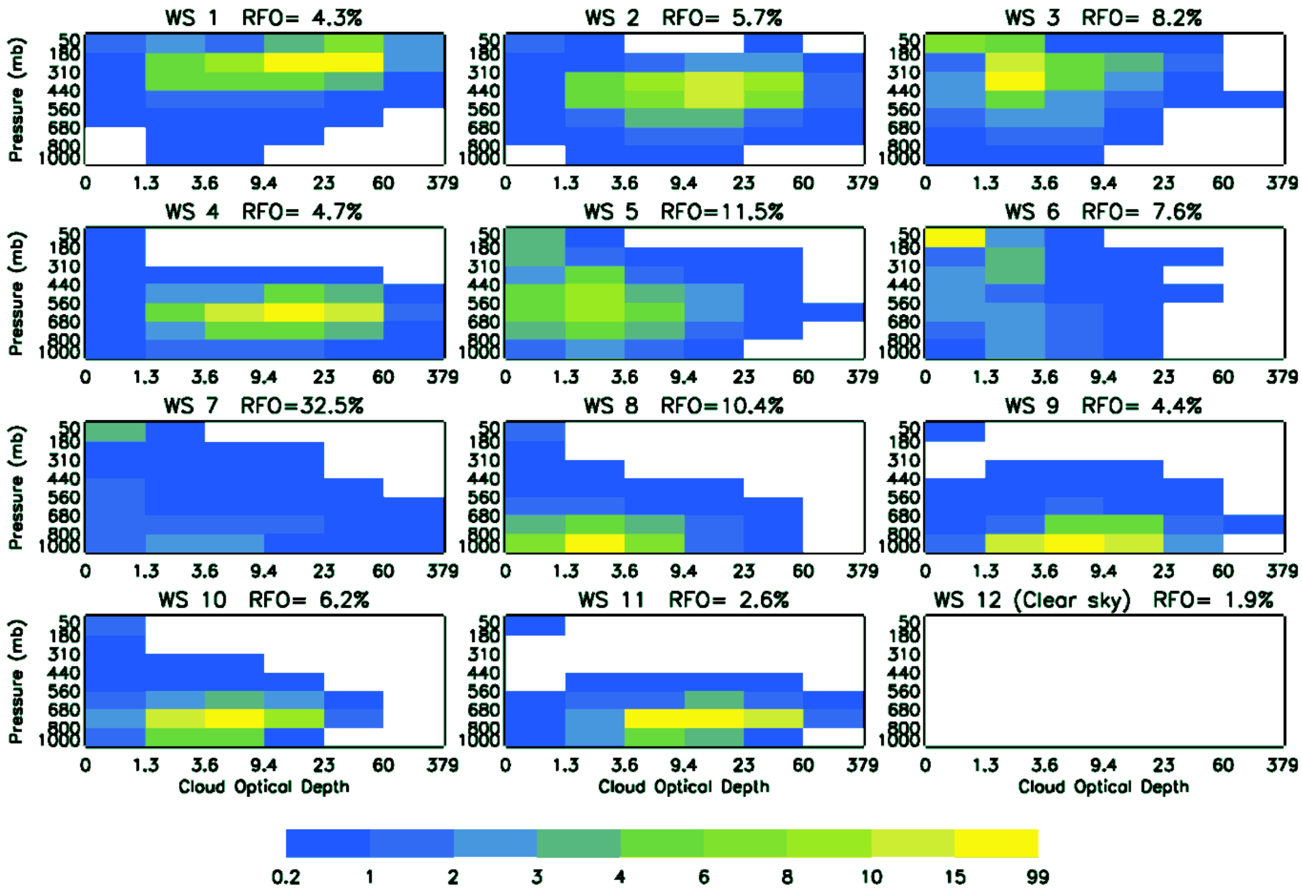
Storm clouds from satellite observations



Composite of many synoptic systems

Field and Wood, 2006

Global Weather States



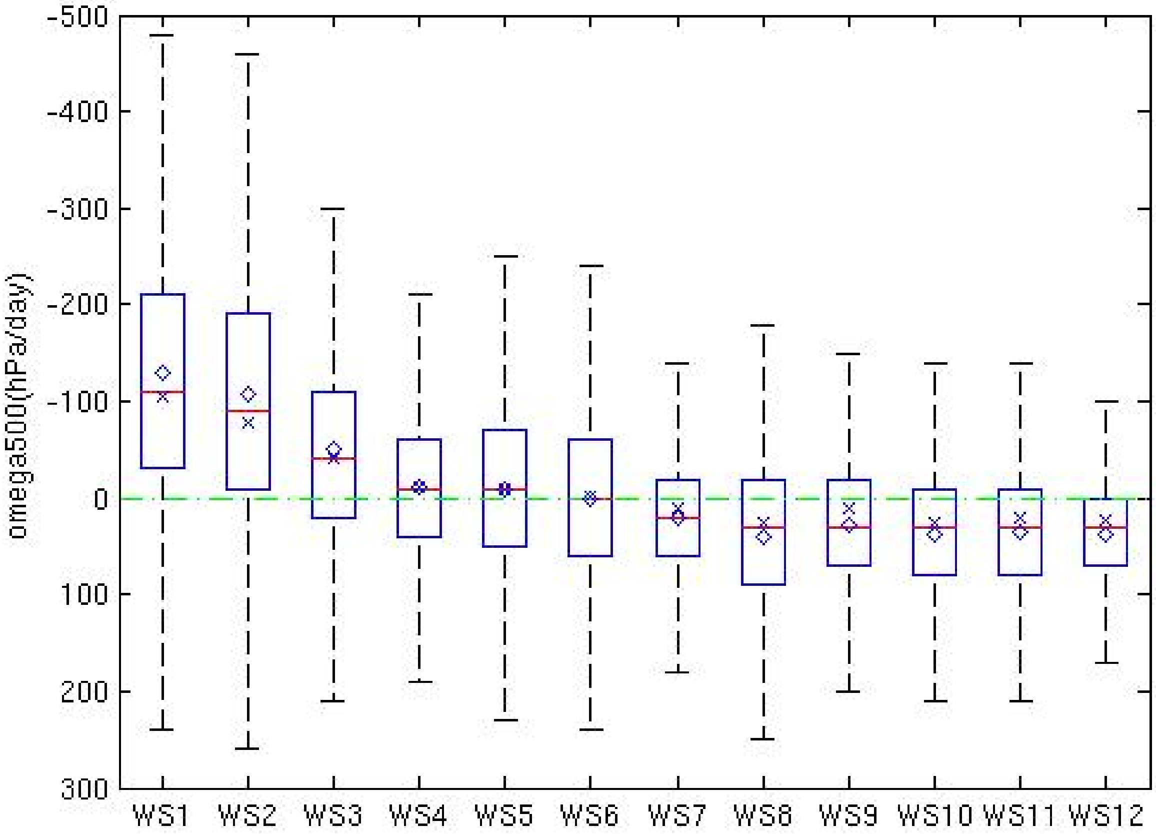
Cluster analysis of ISCCP TAU-PC histograms:

12 Weather states going from deep convective to stratocumulus clouds

(26 years)

Tselioudis et al, 2013

Global Weather States



The relation between the weather states and the large-scale circulation in terms of mean vertical velocity

Tselioudis et al, 2013

Clouds in the global domain

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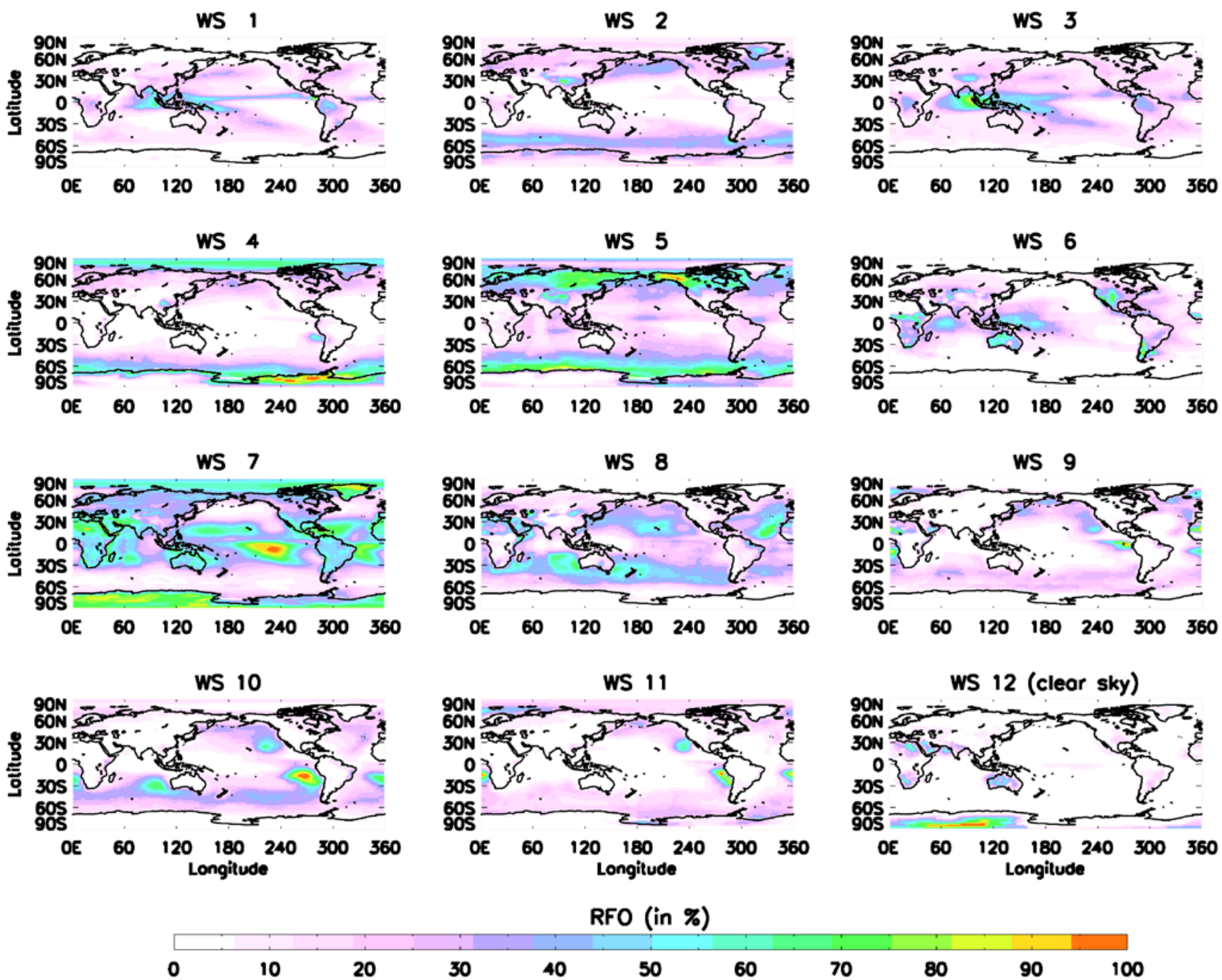
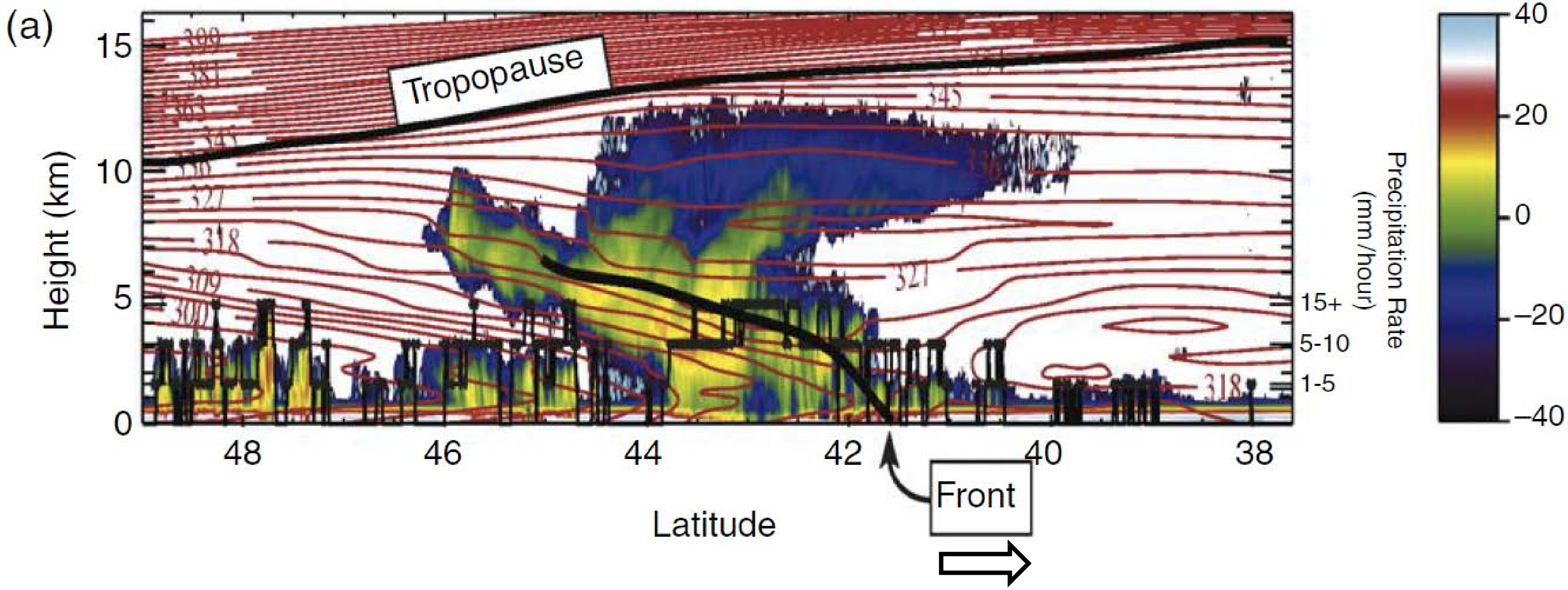


Cluster analysis separates tropical convective (WS1) and midlatitude storm (WS2) clouds

Midlatitude storm clouds tend to have lower tops and be somewhat optically thinner than tropical convective clouds

Tselioudis et al, 2013

Storm clouds from satellite observations
Cold front



CloudSat observed radar reflectivity overlaid with ECMWF-analyzed equivalent potential temperature. Precipitation rate estimates are also shown.

Storm and Cloud Dynamics, Cotton et al., 2011

Storm clouds from satellite observations
Warm front

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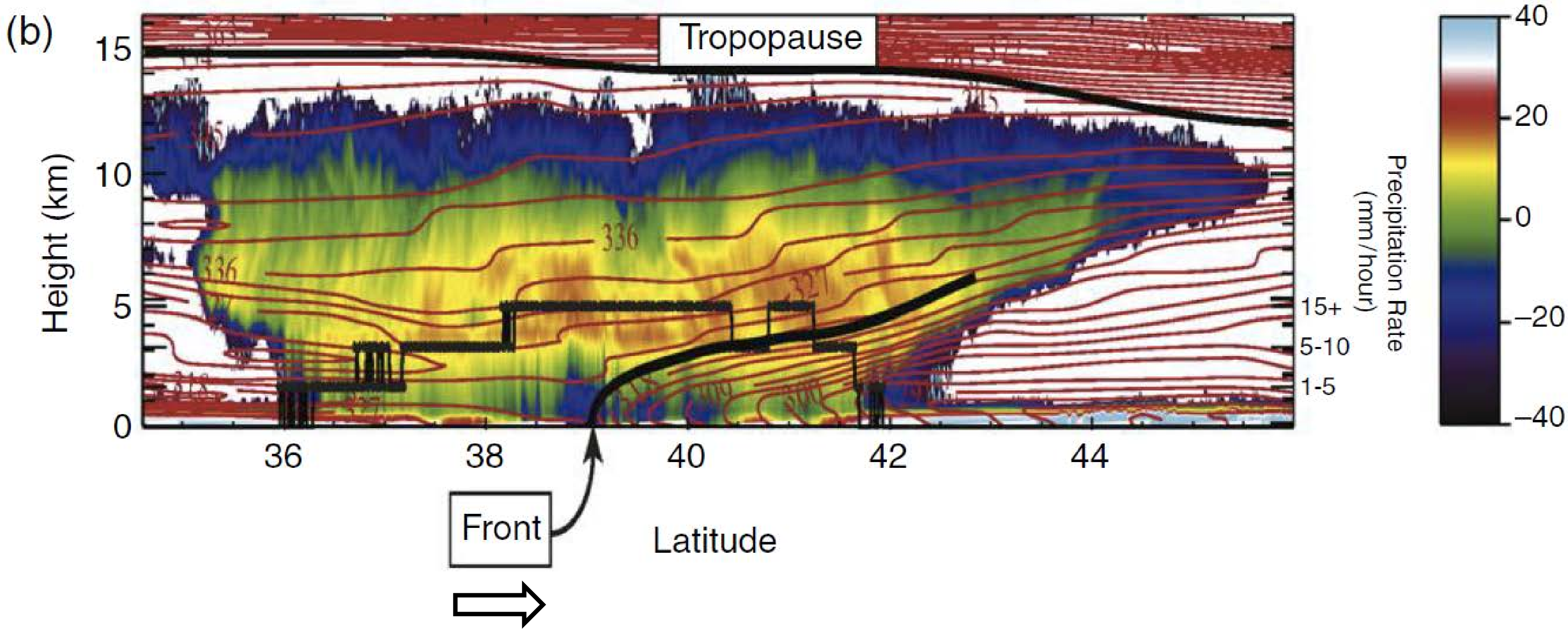
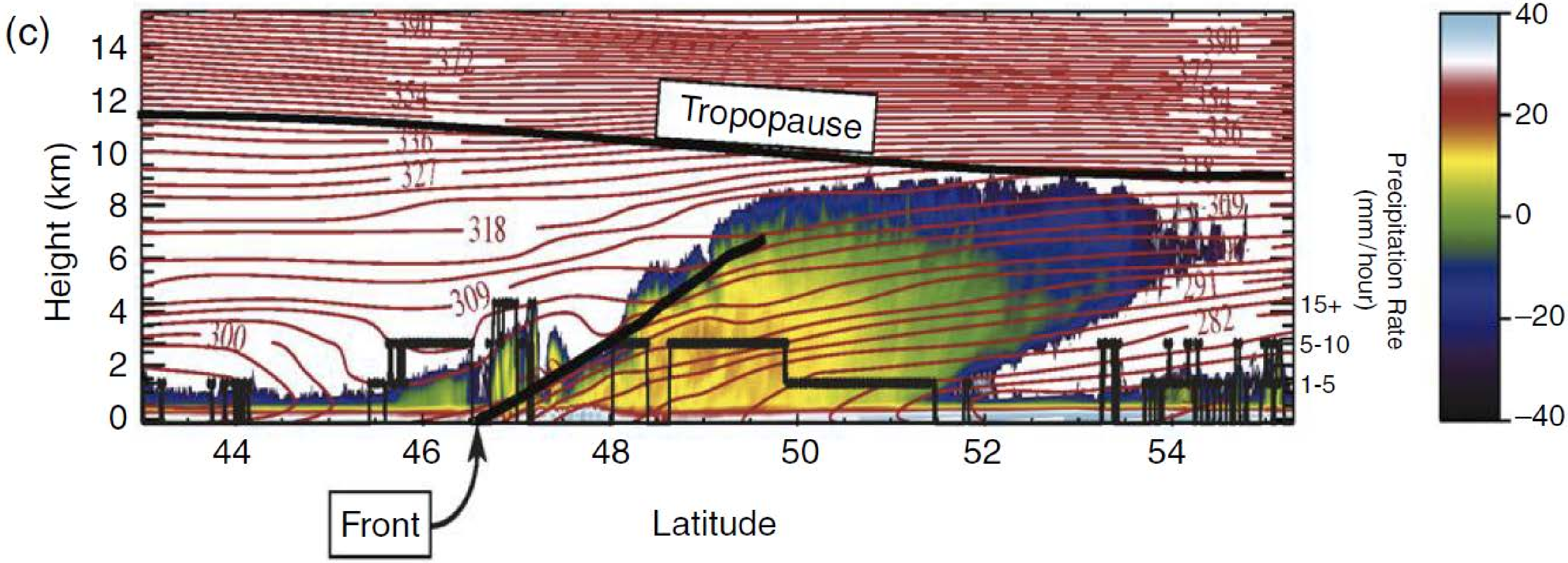


CloudSat observed radar reflectivity overlaid with ECMWF-analyzed equivalent potential temperature. Precipitation rate estimates are also shown.

Storm and Cloud Dynamics, Cotton et al., 2011

Storm clouds from satellite observations
Occluded front



CloudSat observed radar reflectivity overlaid with ECMWF-analyzed equivalent potential temperature. Precipitation rate estimates are also shown.

Storm and Cloud Dynamics, Cotton et al., 2011

Conceptual models of extratropical cyclones - Conveyor band view

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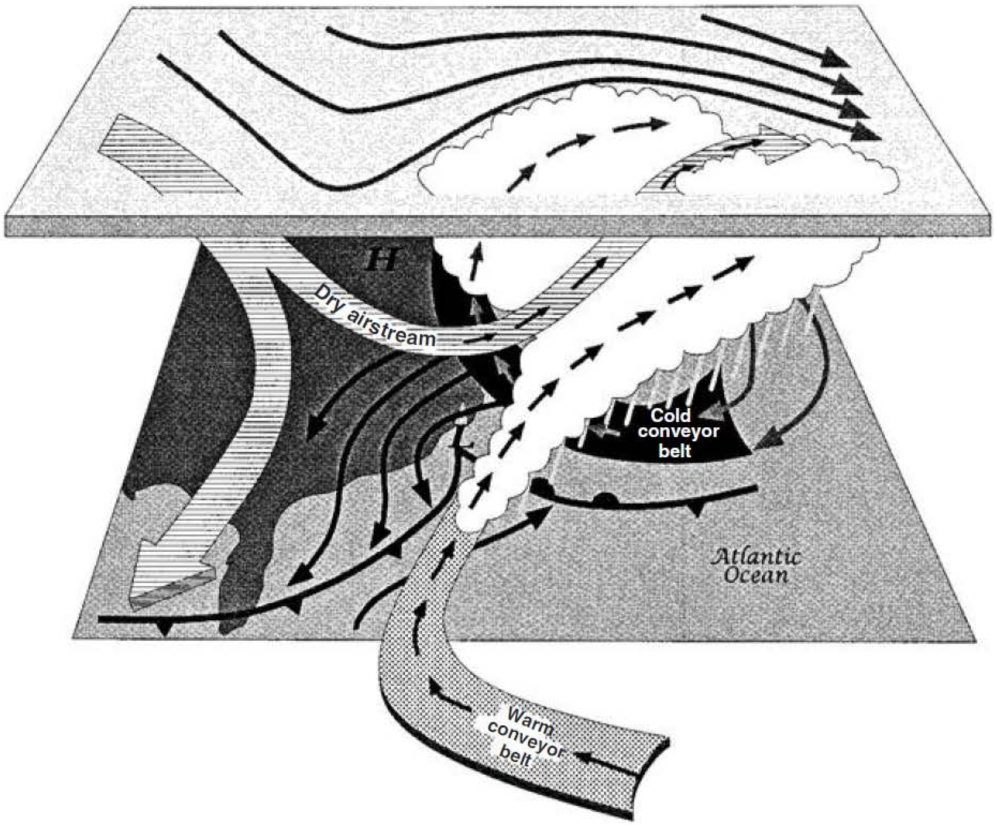


FIGURE 10.8 **The conveyor-belt model of airflow through a northeast US snowstorm.** *(Adapted from Kocin and Uccellini 1990, Fig. 26, based on the Carlson (1980, Figs 9 and 10) conceptual model [after Schultz (2001)])*

Storm and Cloud Dynamics, Cotton et al., 2011

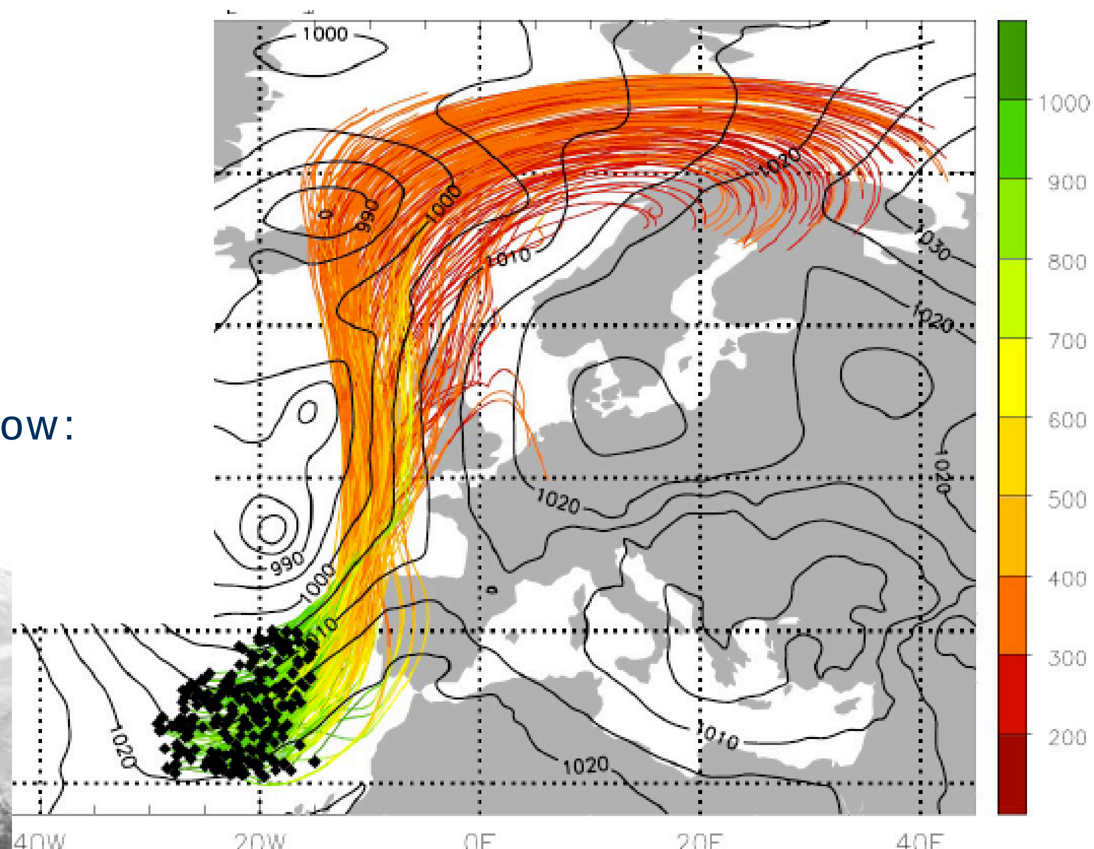
Key cloud system in cyclones:
warm conveyor belt in the limited area model COSMO

Within 2 days:

- ascent > 600 hPa
- poleward transport > 3500 km
- latent heating > 20 K
- low PV in the outflow

flow structure in extratropical cyclones with strongest latent heat release & precipitation

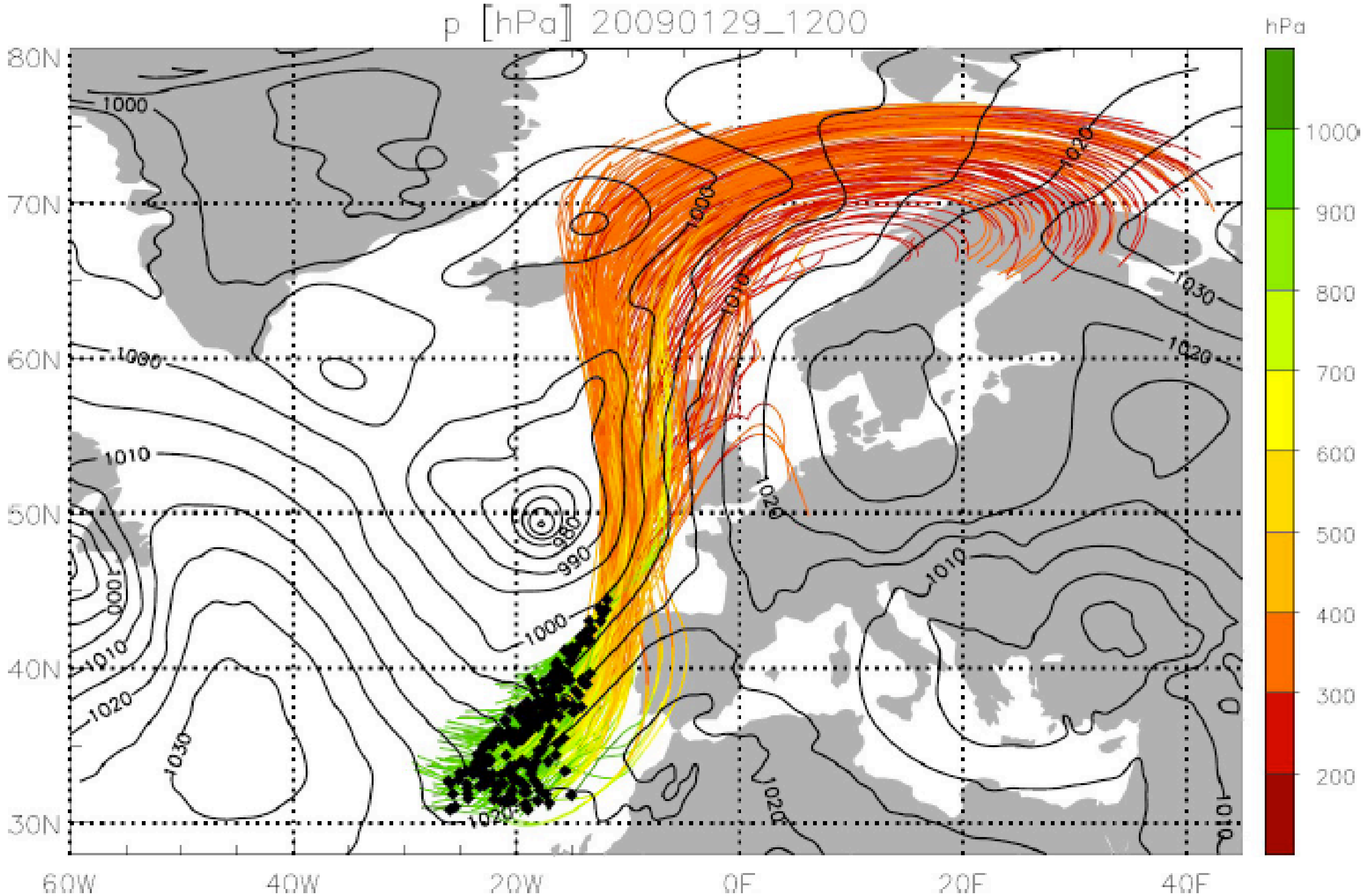
cloud characteristics change along flow:
warm → mixed-phase → ice



Joos and Wernli 2012

Warm conveyor belts

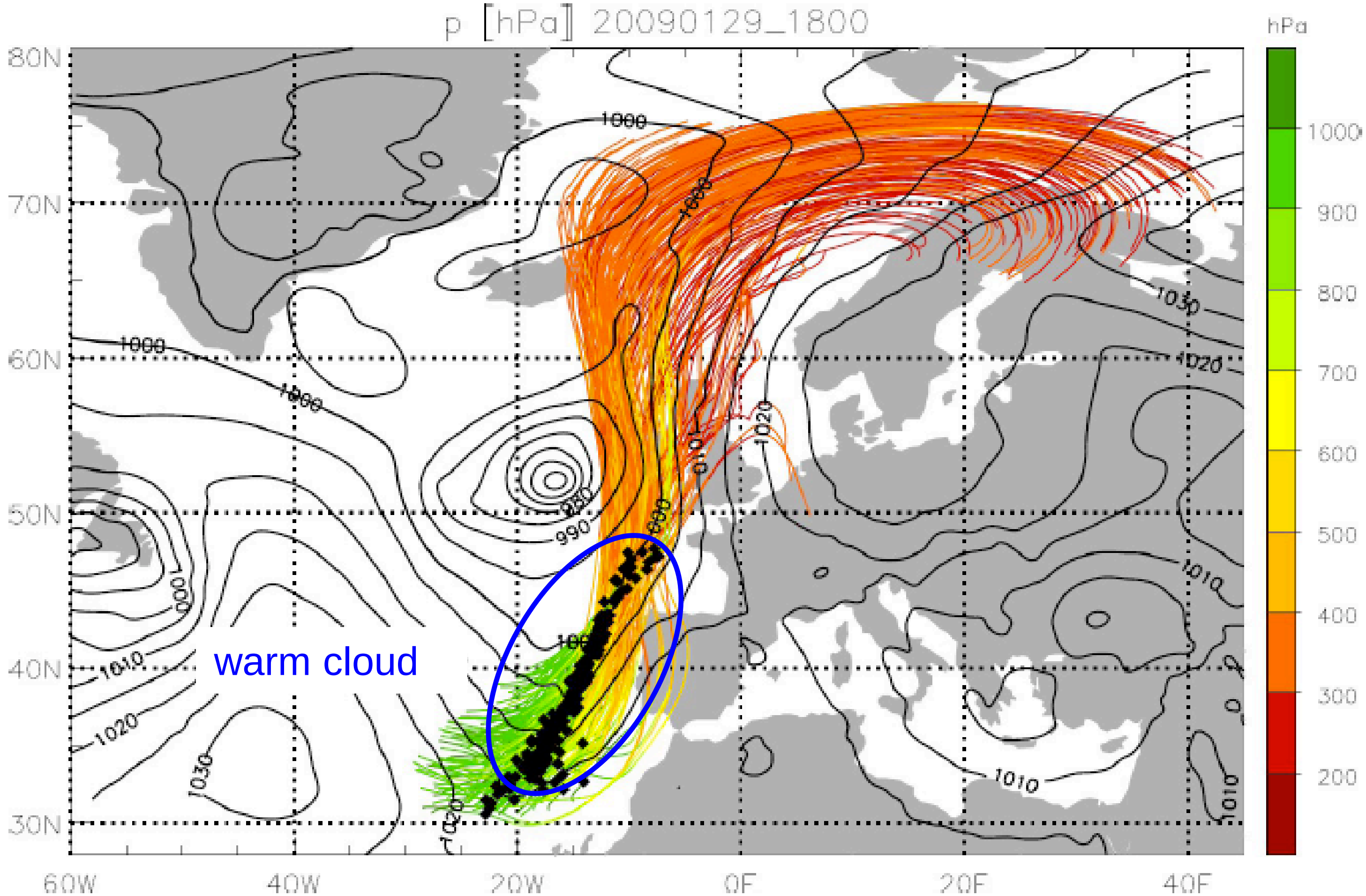
SLP and position of WCB air parcels



Joos and Wernli 2012

Warm conveyor belts

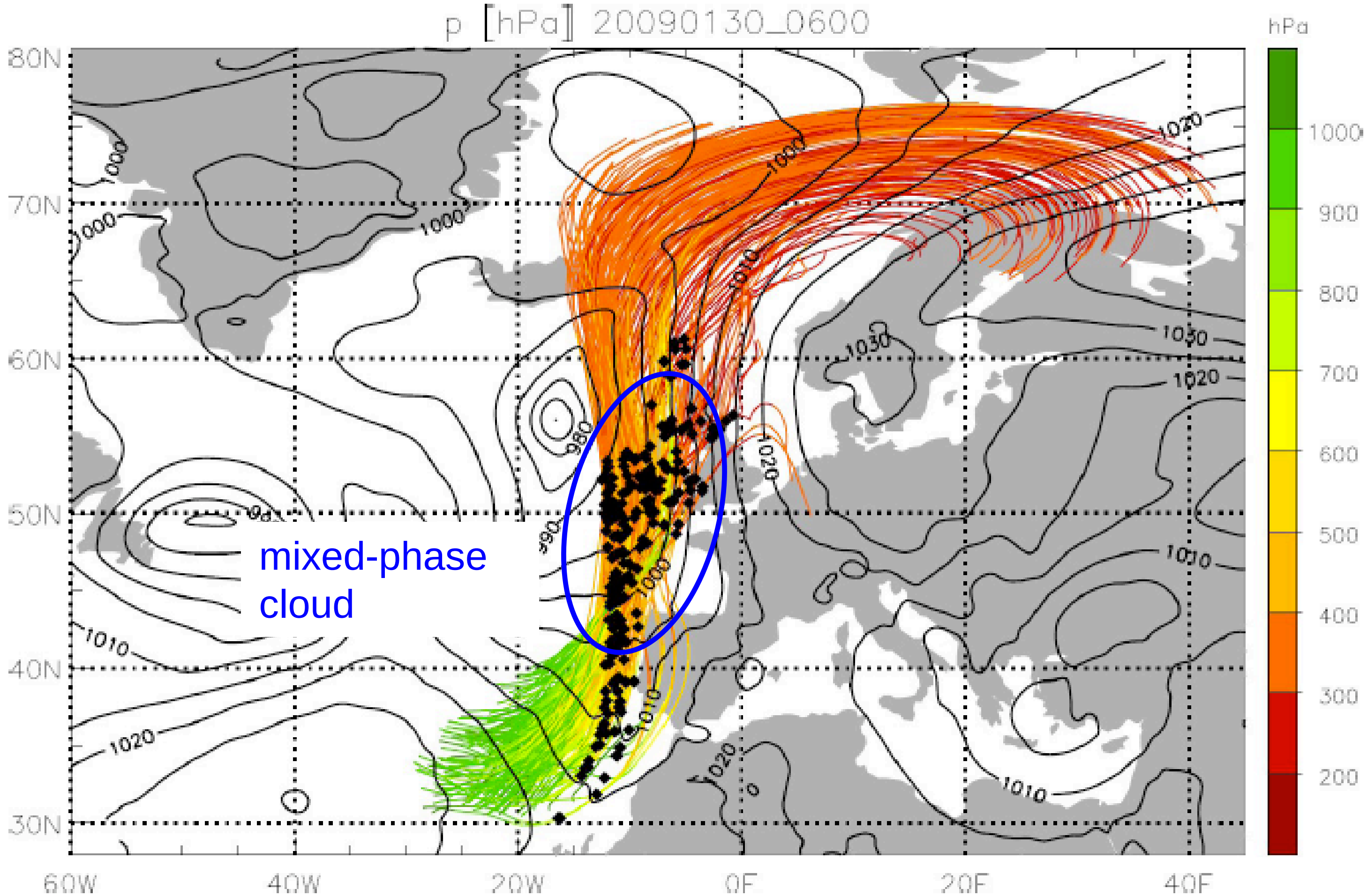
SLP and position of WCB air parcels



Joos and Wernli 2012

Warm conveyor belts

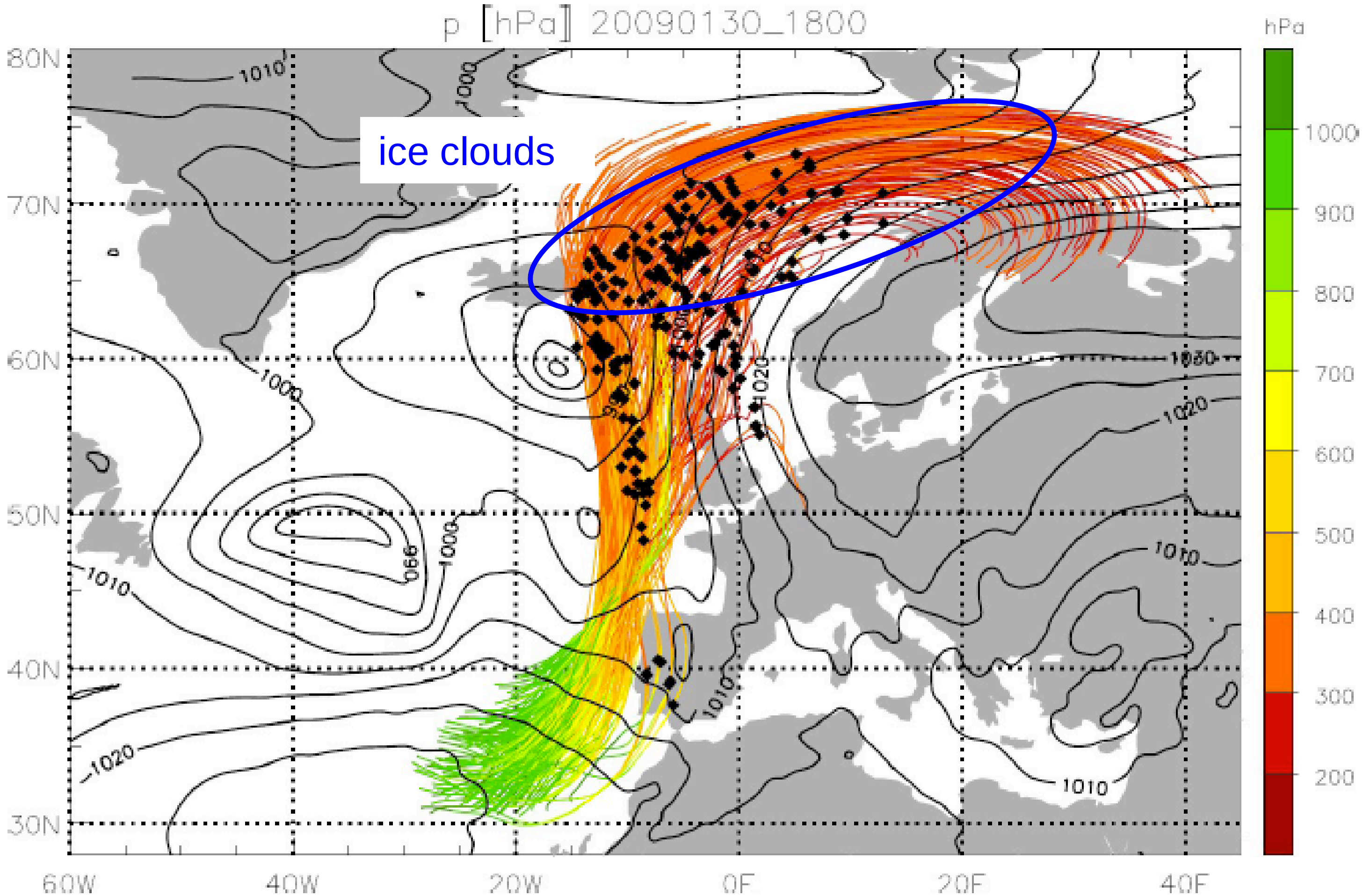
SLP and position of WCB air parcels



Joos and Wernli 2012

Warm conveyor belts

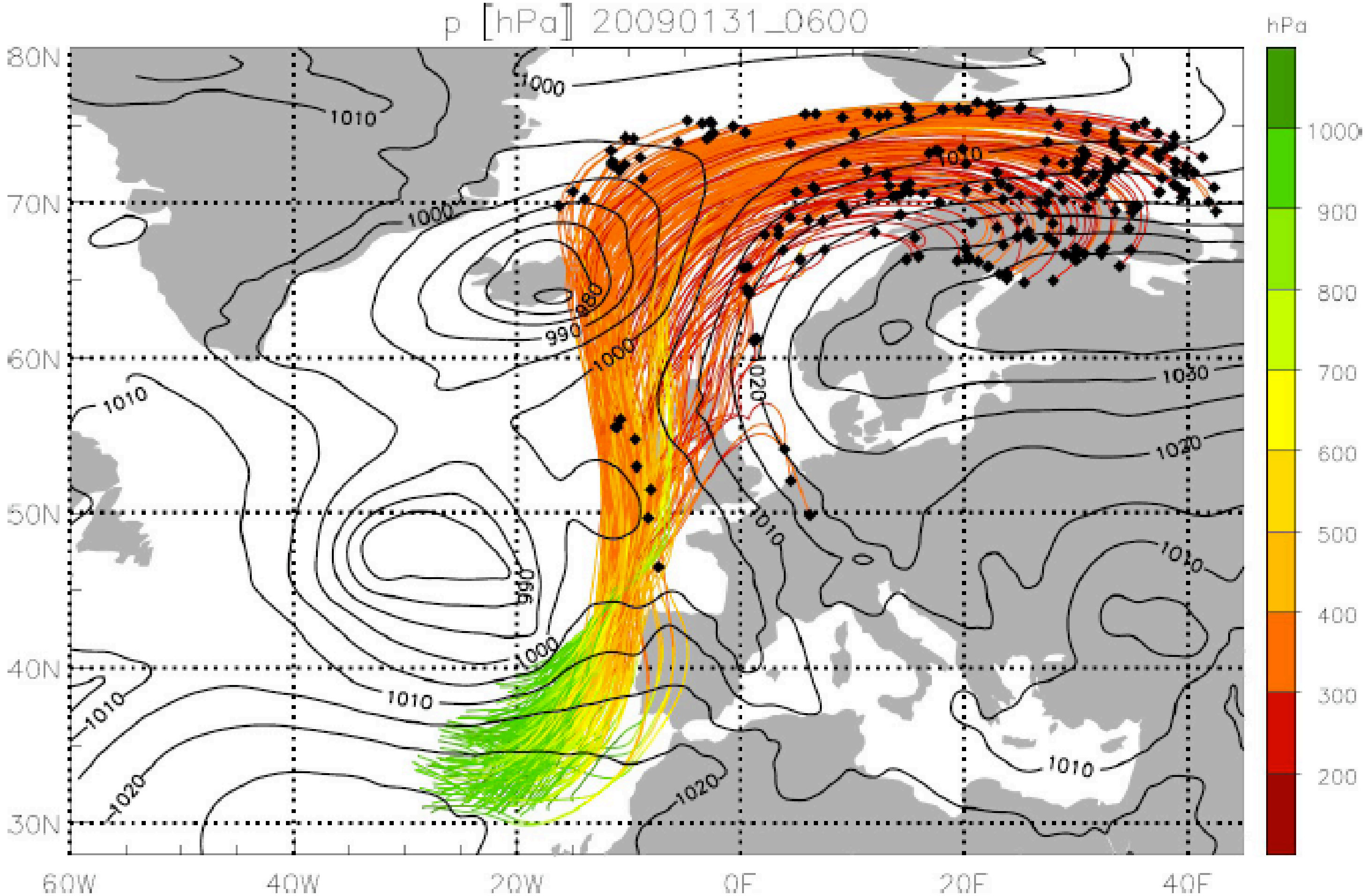
SLP and position of WCB air parcels



Joos and Wernli 2012

Warm conveyor belts

SLP and position of WCB air parcels



Joos and Wernli 2012

Climatology of WCBs (DJF 1989-2009)

WCB (ascent > 600 hPa in 2 days) starting points (t=0)

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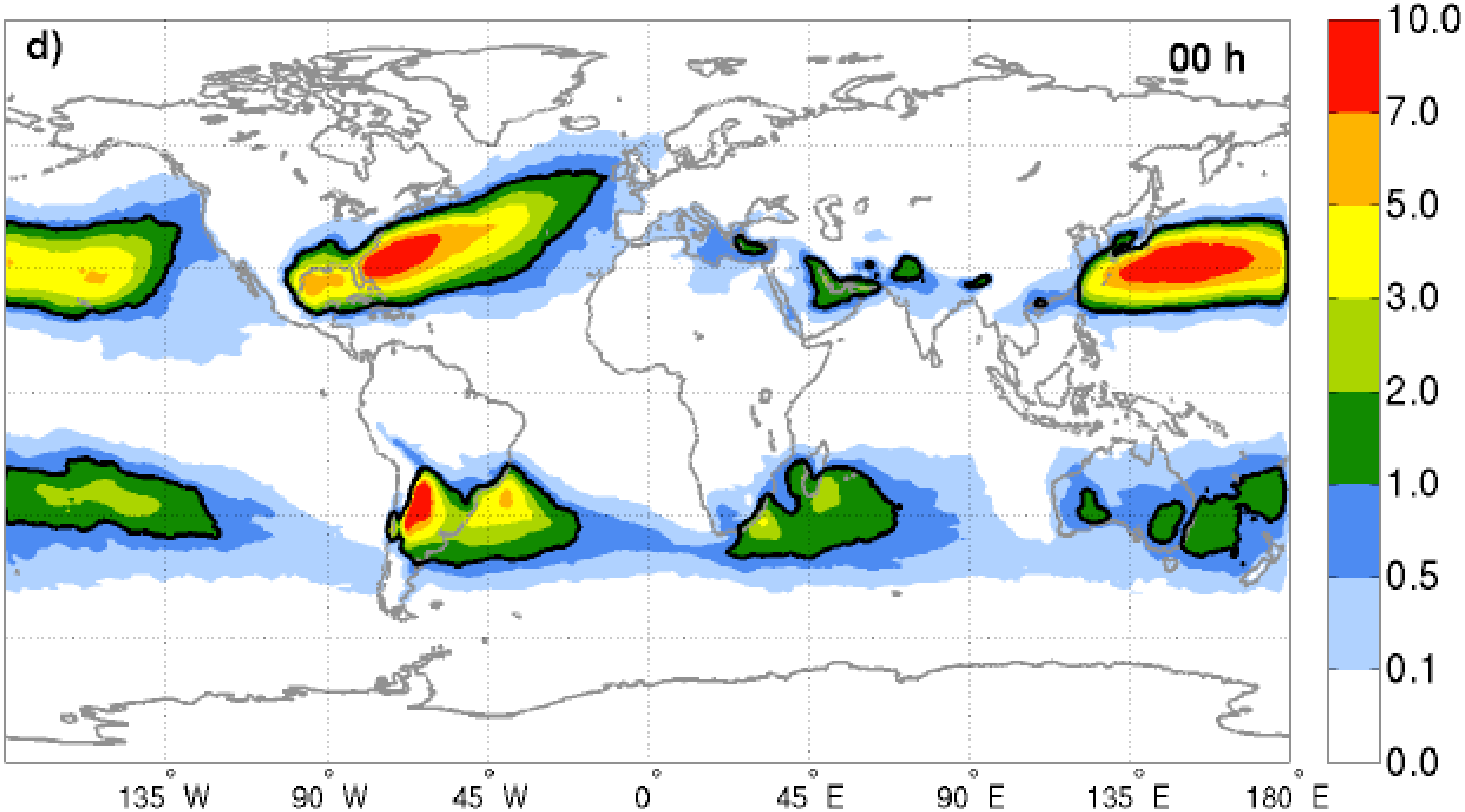
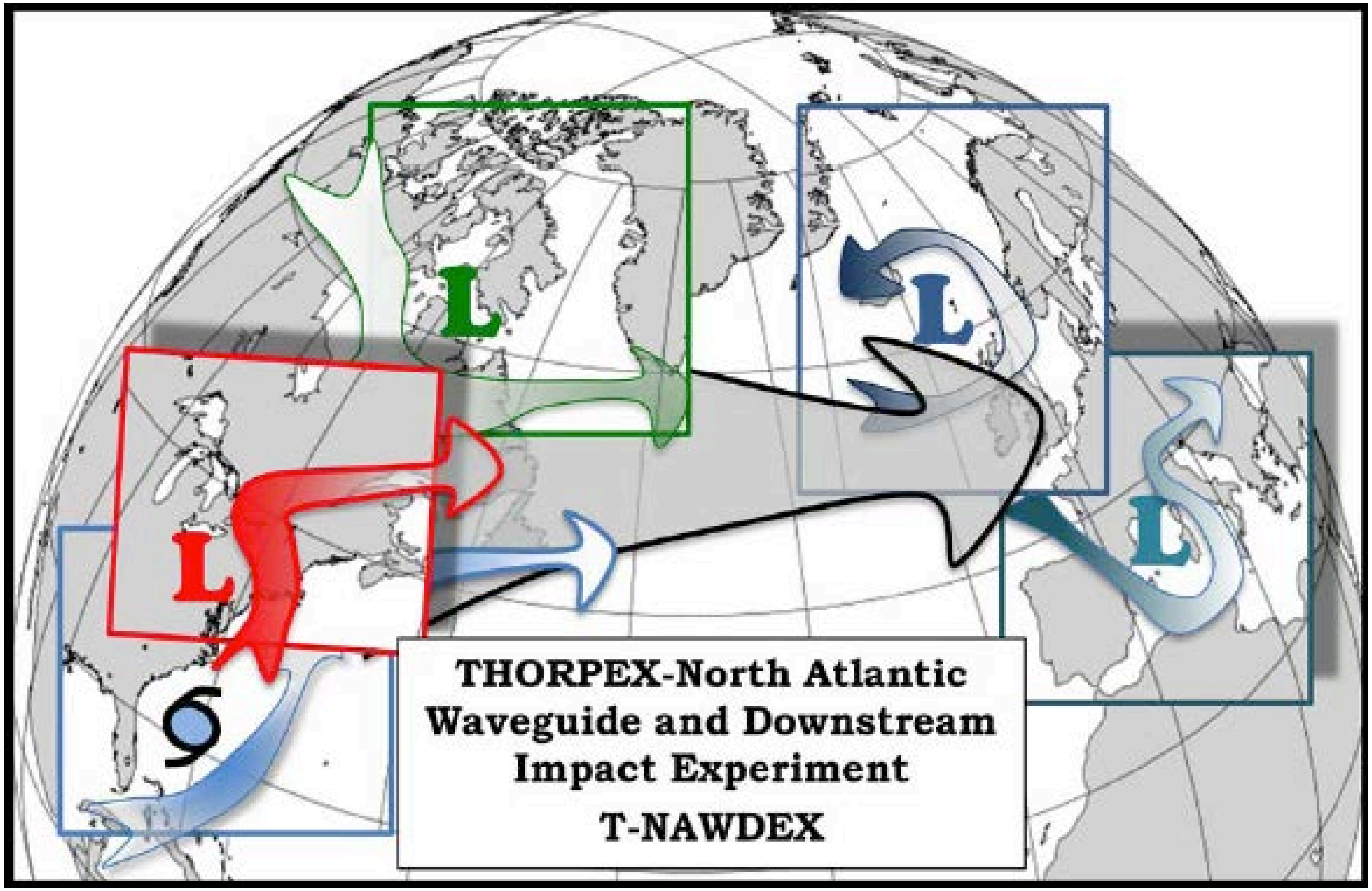


Madonna et al., submitted

T-NAWDEX
International experiment in 2016



Research focuses on the predictability of High Impact Weather systems (HIW)

- Upper-level Rossby wave trains: generation, propagation and wave-breaking
- Moist processes and diabatic Rossby waves
- Ensembles and adaptivity

Annual mean front frequency
(1989-2009, averaged over ERAI, NCEP, JRA and MERRA)

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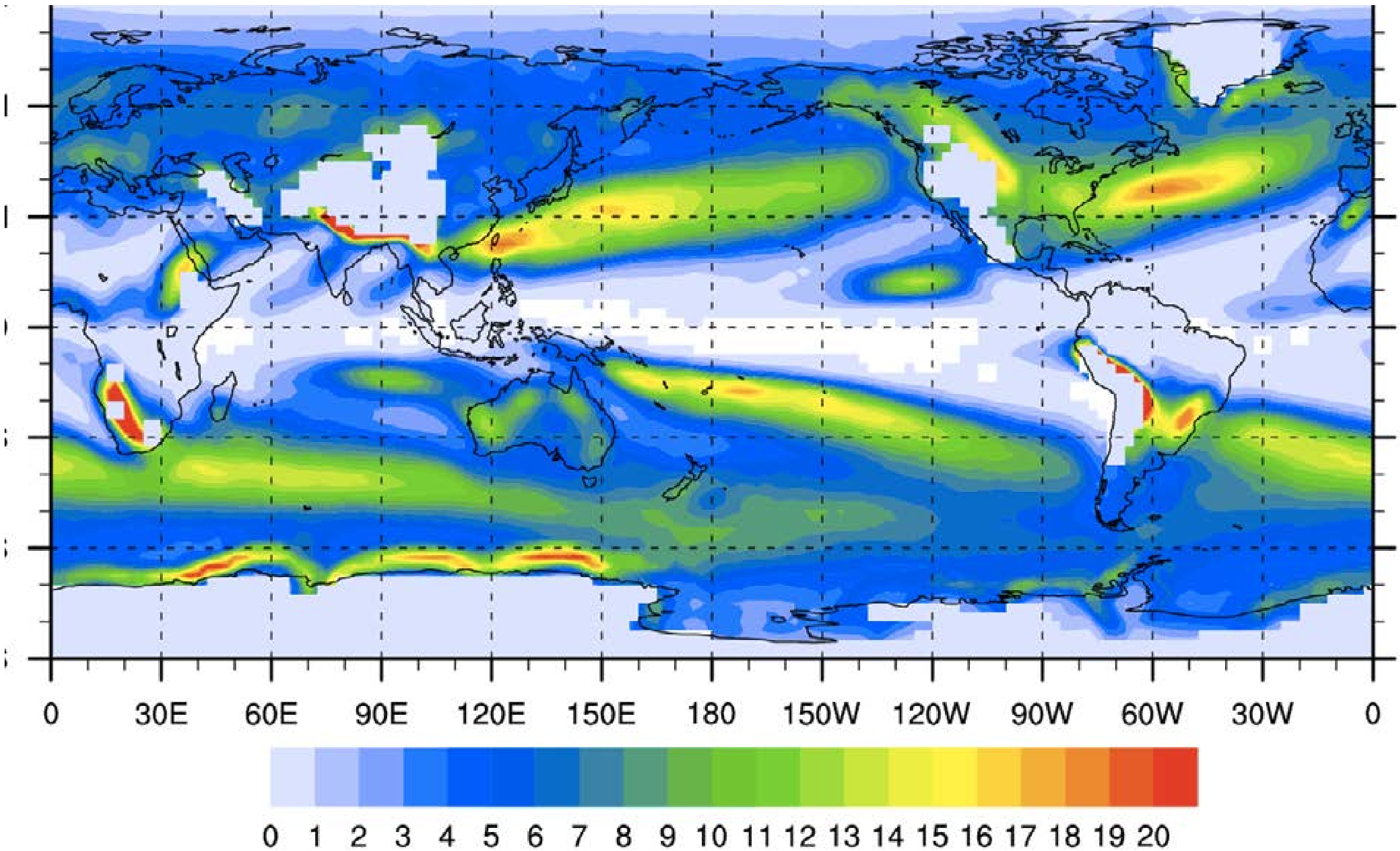
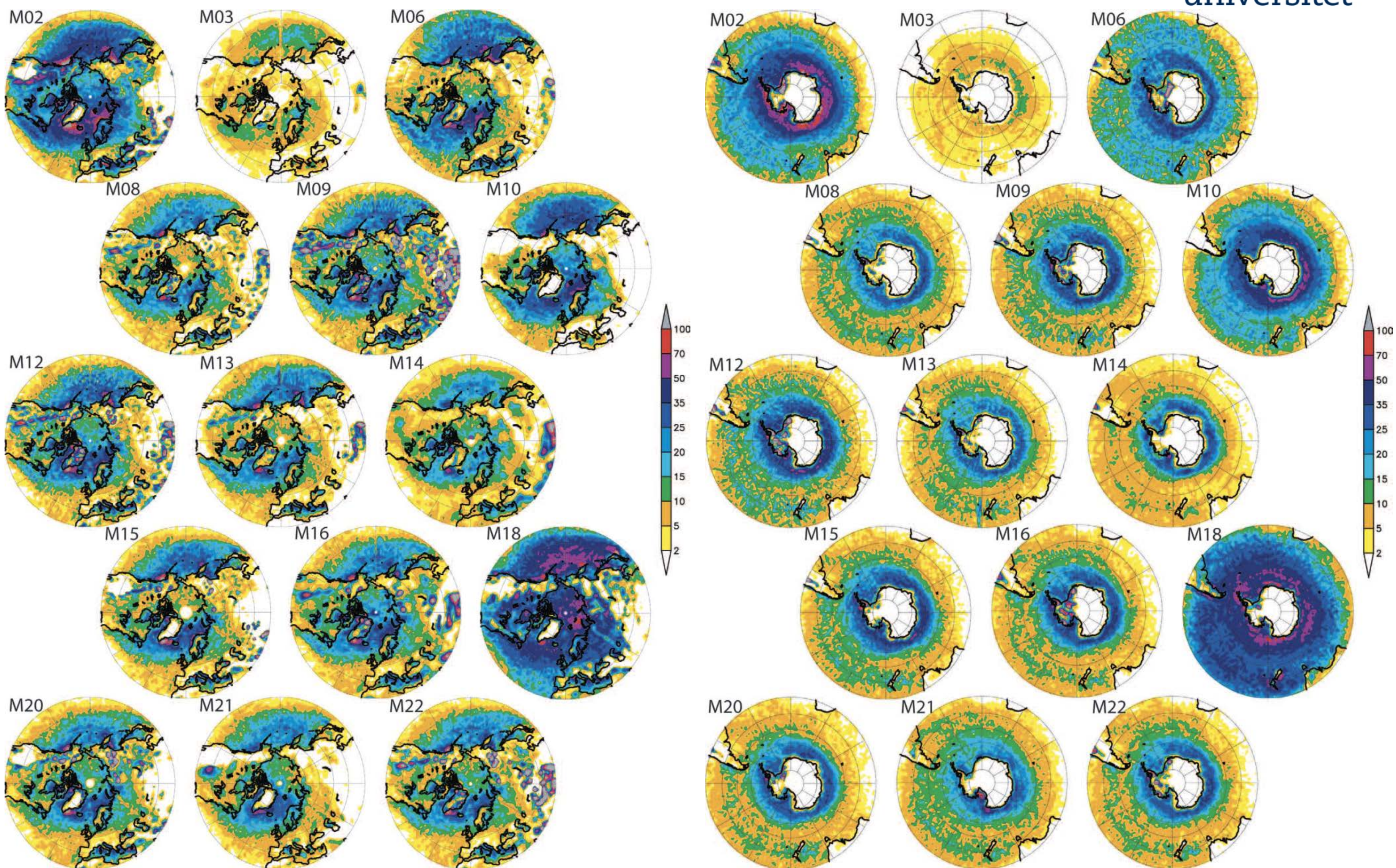


Berry et al., 2011

Total cyclone center density
Tracking intercomparison MILAST, Cyclones lasting (≥ 24 h)
ERA-Interim (1989-2009)

Stockholms universitet



Neu et al., 2013

Interannual variability

Tracking intercomparison MILAST, Cyclones counts (1989-2009)

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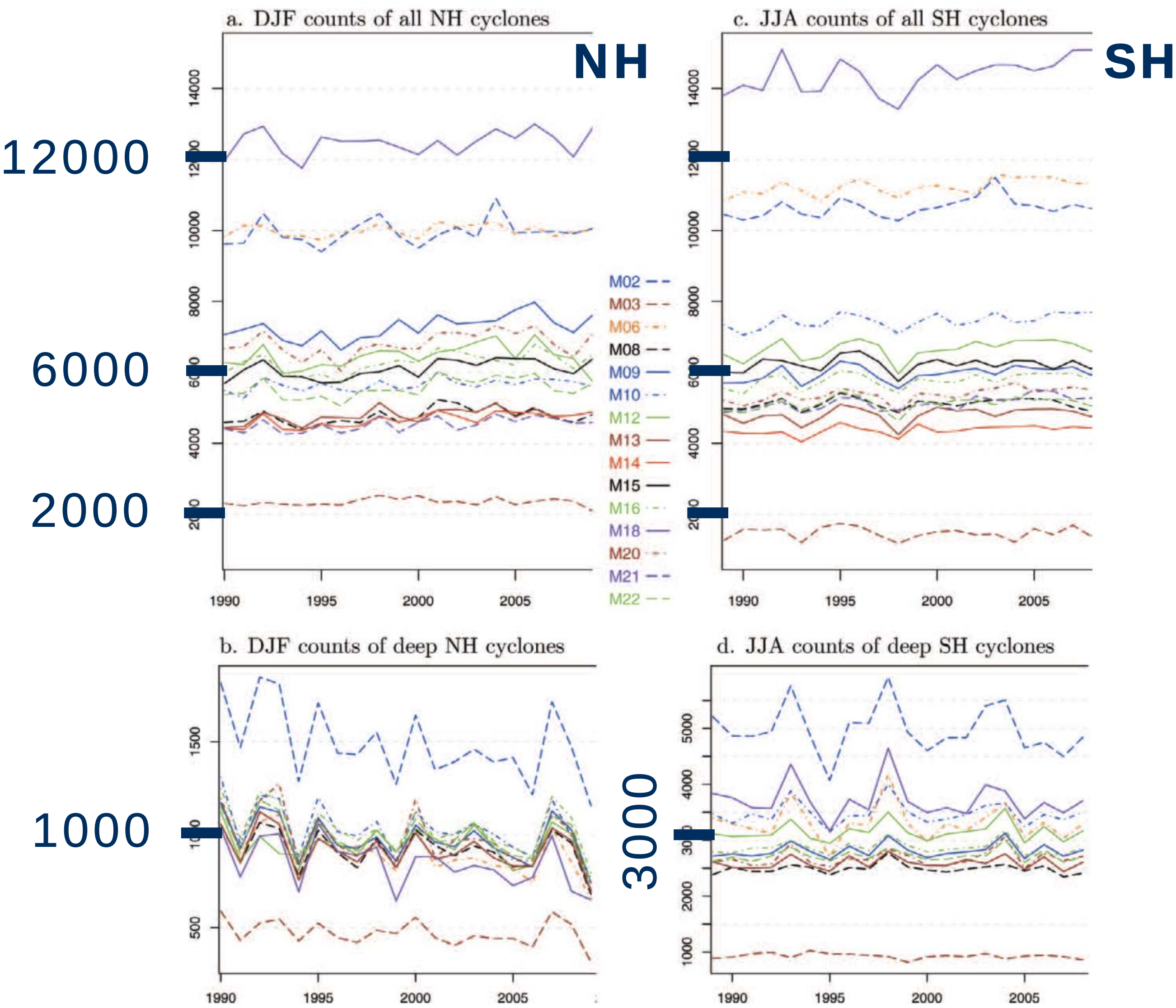


All cyclones

Deep cyclones ≤980 hPa

Neu et al., 2013

IMILAST – definitions related to extratropical cyclones and tracking

Cyclone: There is no accepted universal definition of what a cyclone is or where its exact position is. In this study, “cyclone” refers to a point (the cyclone “center”) identified on the Earth’s surface at a certain time through different approaches, often by searching for a minimum of MSLP or a maximum of lower-tropospheric cyclonic vorticity.

Track: A cyclone track consists of a series of cyclones identified in sequential time steps at adjacent locations, which are deemed to represent the same physical feature in reality.

Number of cyclones: Count of cyclone tracks over a certain region (globe, hemisphere, etc.).

Neu et al., 2013

Frontal precipitation

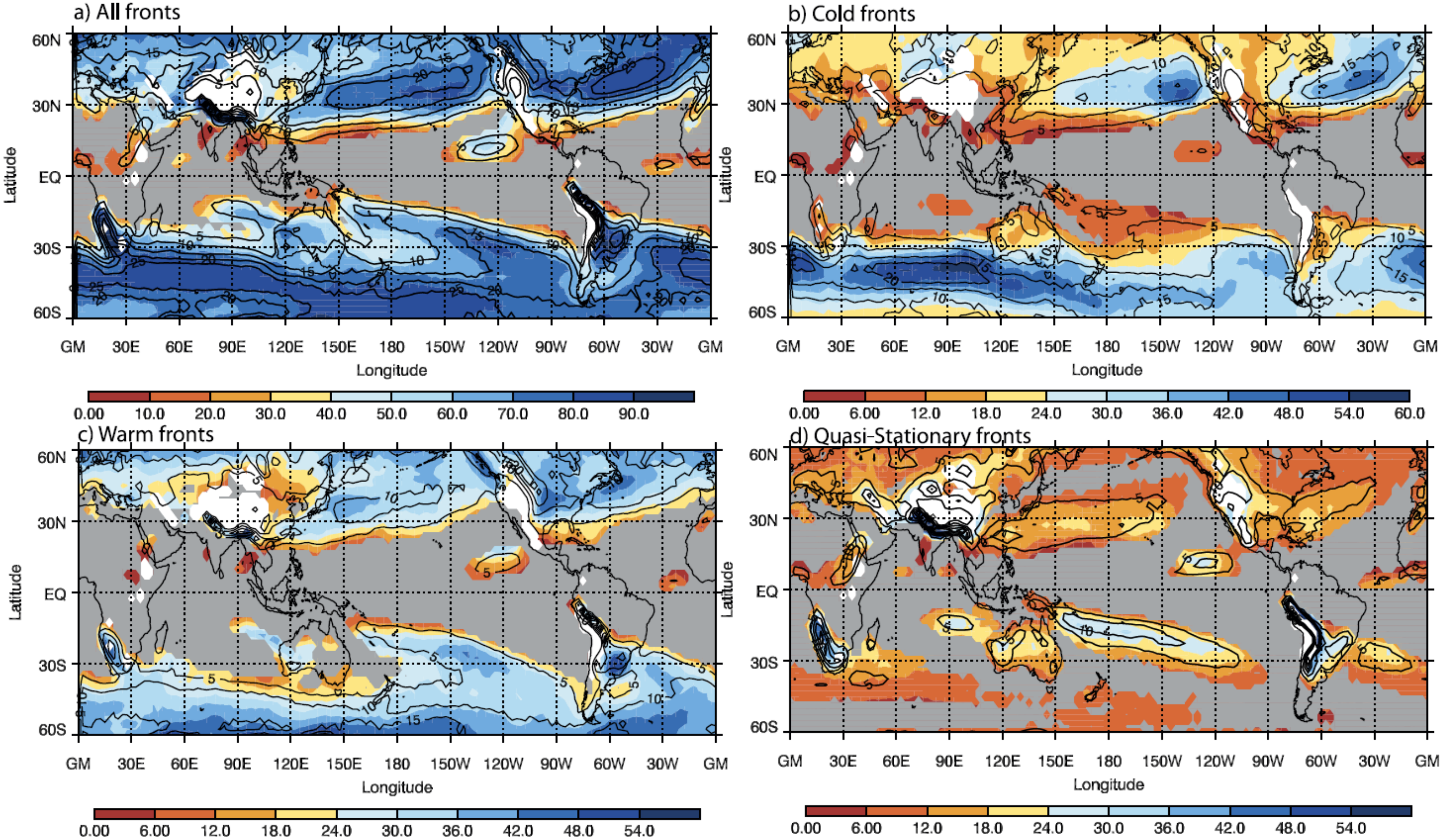
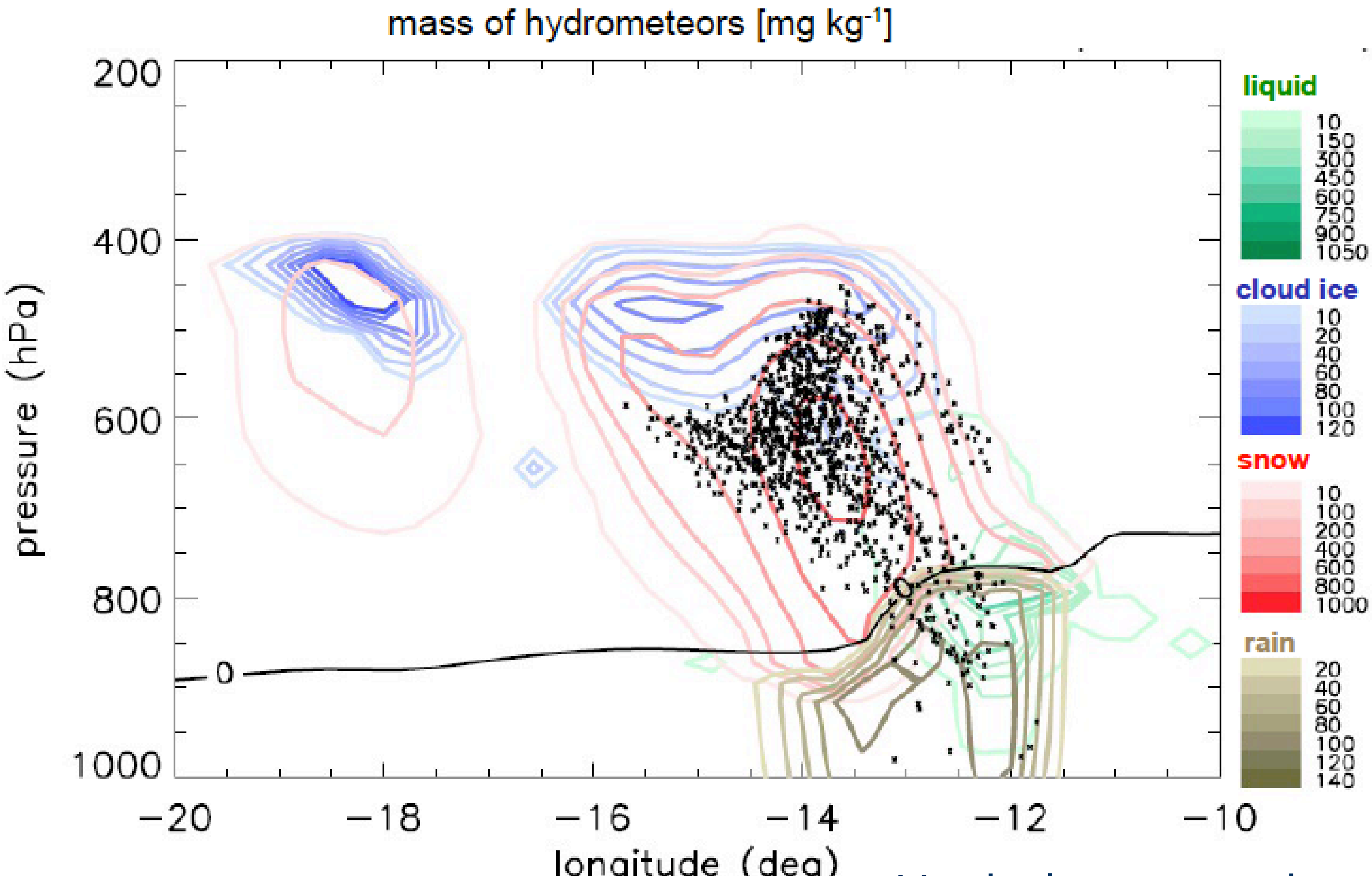


Figure 1. Colors show annual proportion of precipitation that occurs with (a) any front, (b) cold front, (c) warm front, (d) quasi-stationary front within a 5° box. The black contours show the front frequency as a percentage time that a front was located within each grid box. Polewards of ±60° has been cut off due to problems with the convergence of the meridians. Regions where the surface topography is higher than 1.5 km (850 hPa in a standard atmosphere) have been blanked out, and areas where the front frequency is less than 3% have been shaded grey.

Catto et al., 2012

Microphysics in warm conveyor belts

Hydrometeors in COSMO model simulation

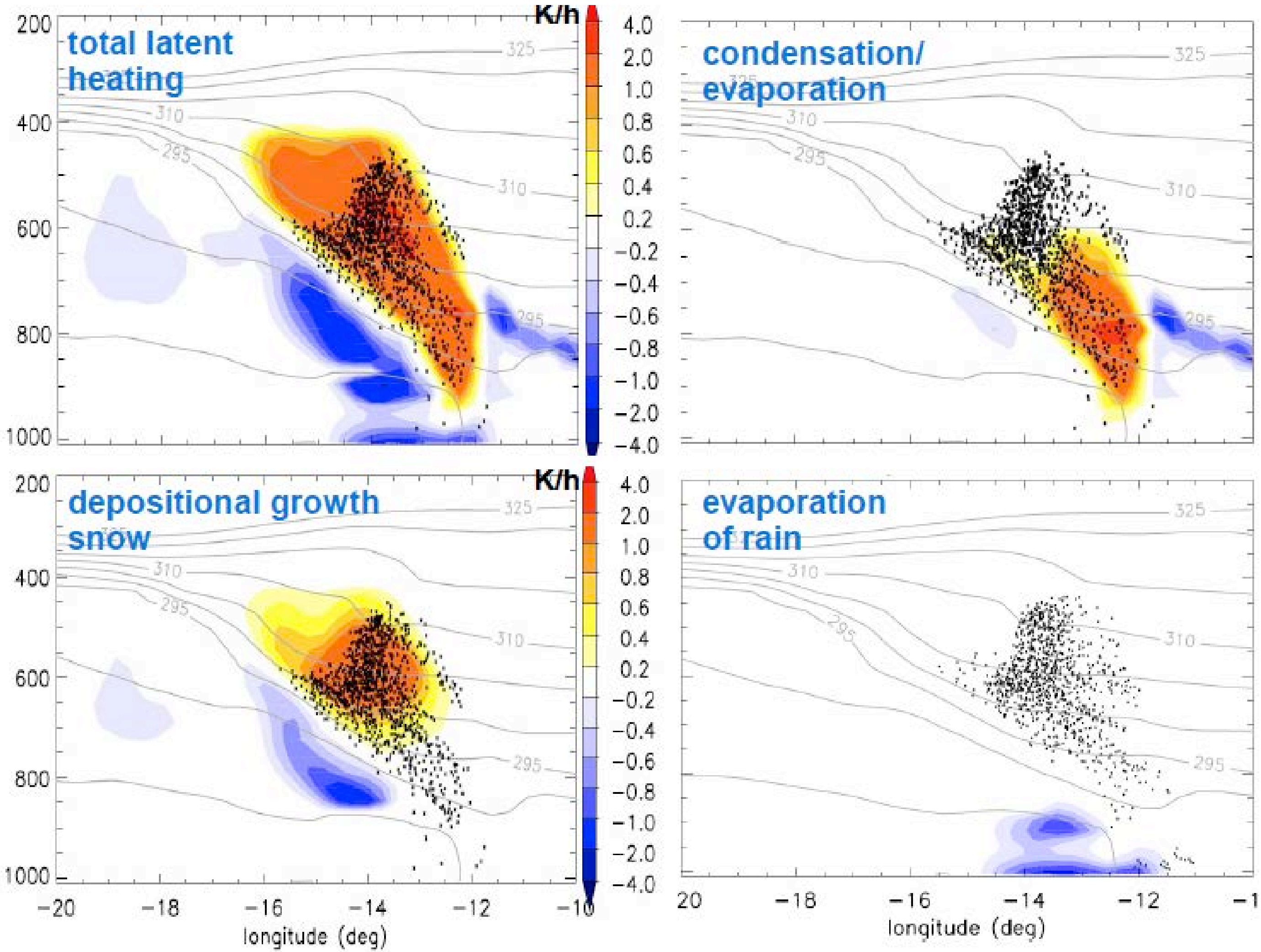


Vertical cross-section through a warm conveyor belt along a latitude

Joos and Wernli 2012

Microphysics in warm conveyor belts
Hydrometeors in COSMO model simulation

Stockholms universitet



Joos and Wernli 2012

Microphysics in warm conveyor belts
Hydrometeors in COSMO versus ECMWF IFS

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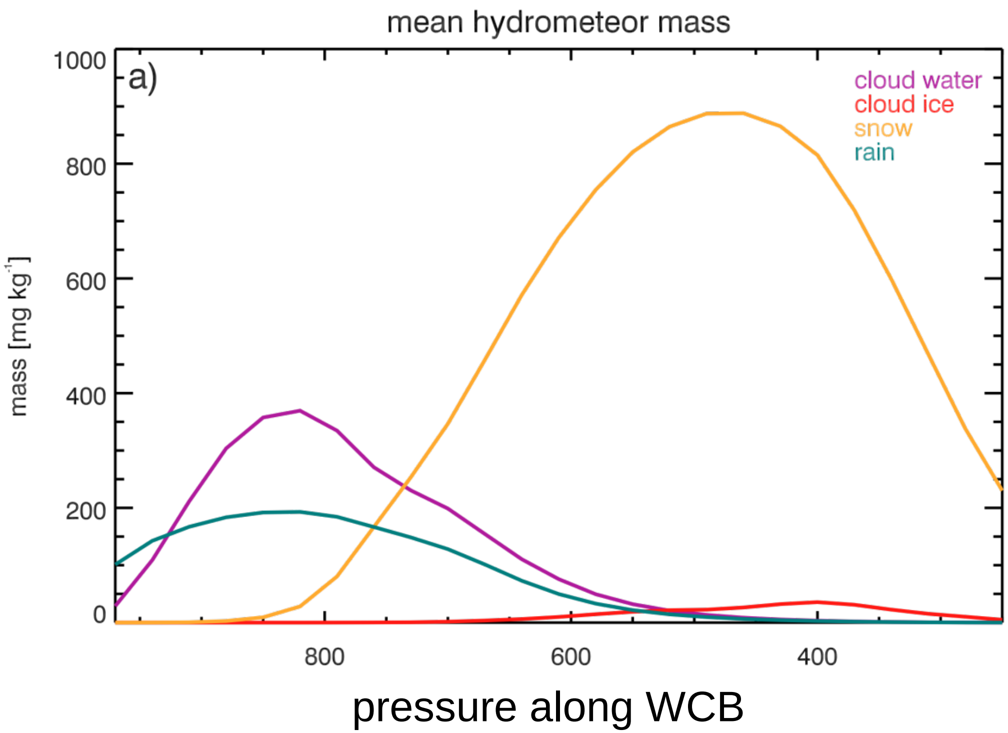
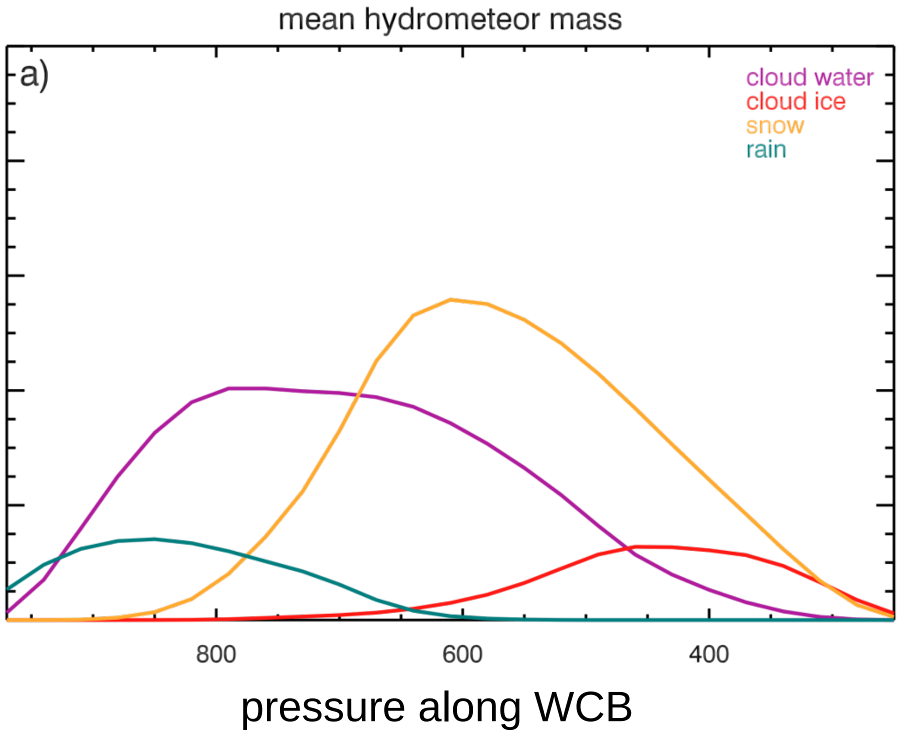
COSMO



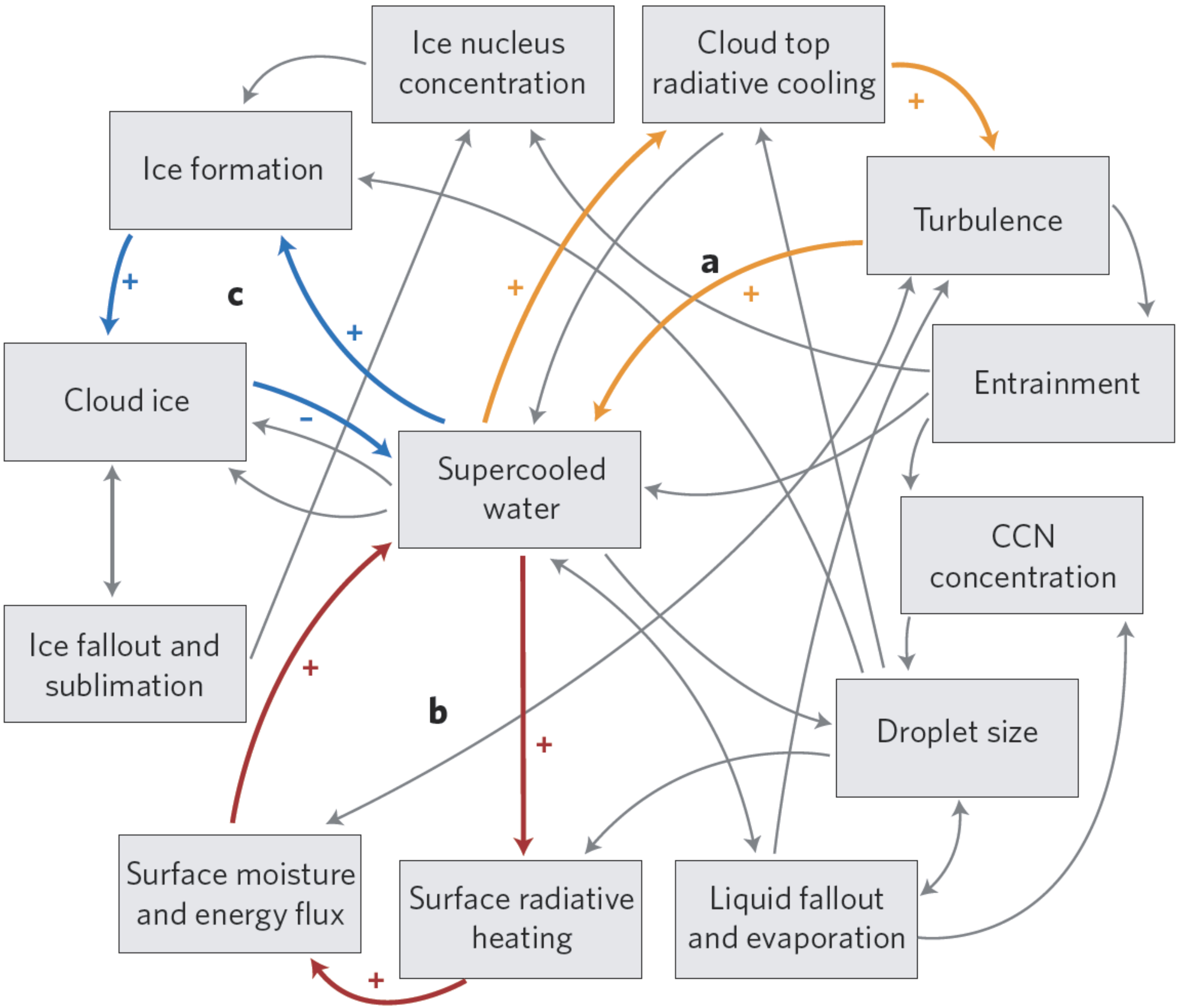
IFS



The mid-latitude flow is strongly influenced by diabatic processes that are dependent on the microphysics

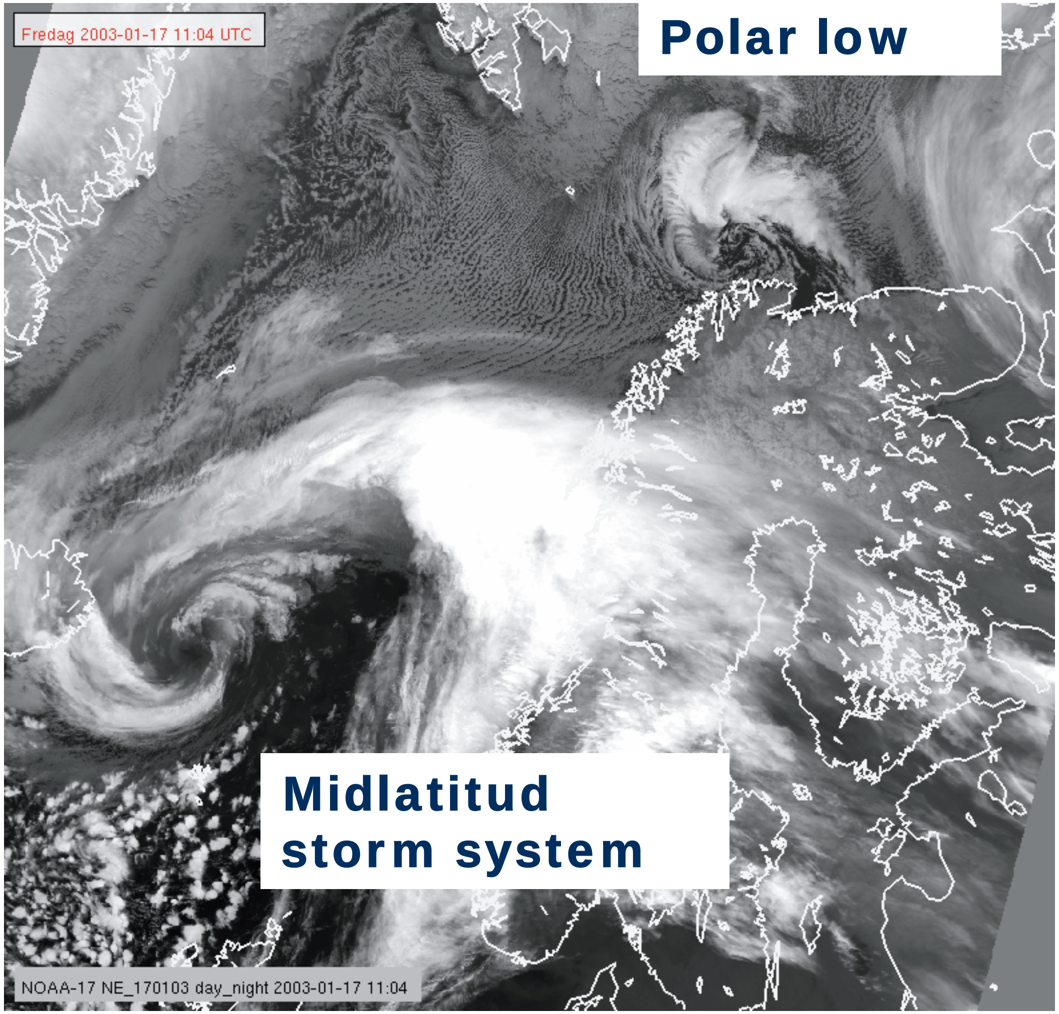
From Hanna Joos

Interactions in clouds



Morrison et al., 2012

Polar low



A small-scale, rapidly developing and fairly intense cyclone over ice-free ocean

October - May (NH)

Rapidly changing weather

Gale or storm force winds

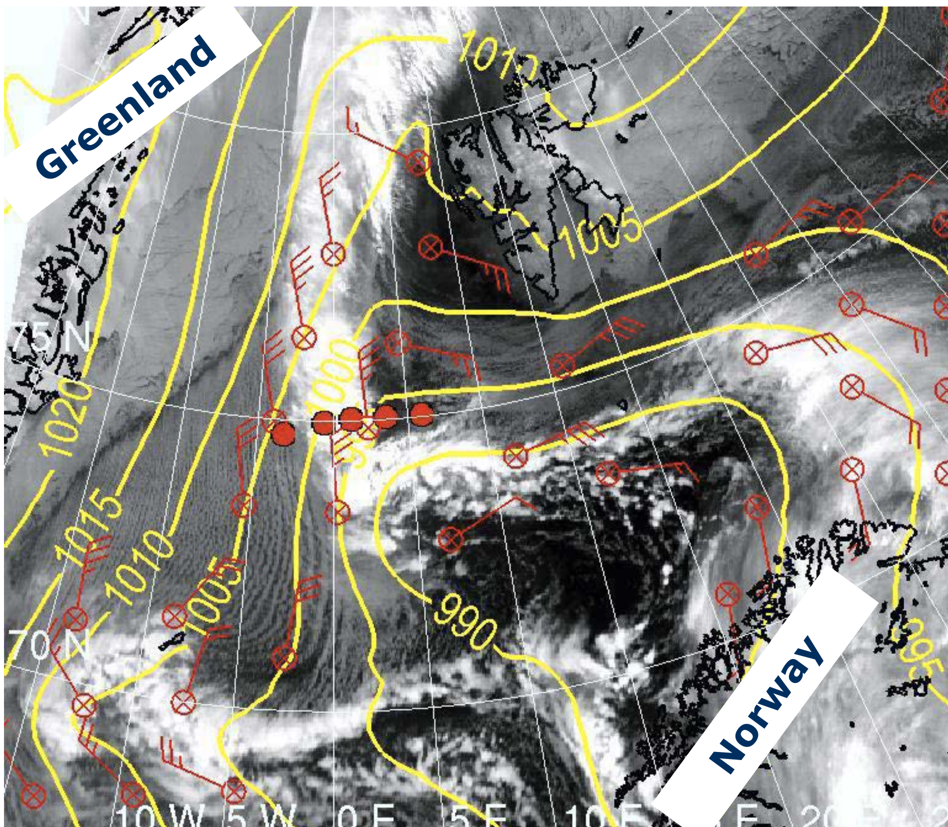
Severe snow intensity

Polar Low
Initial baroclinic phase

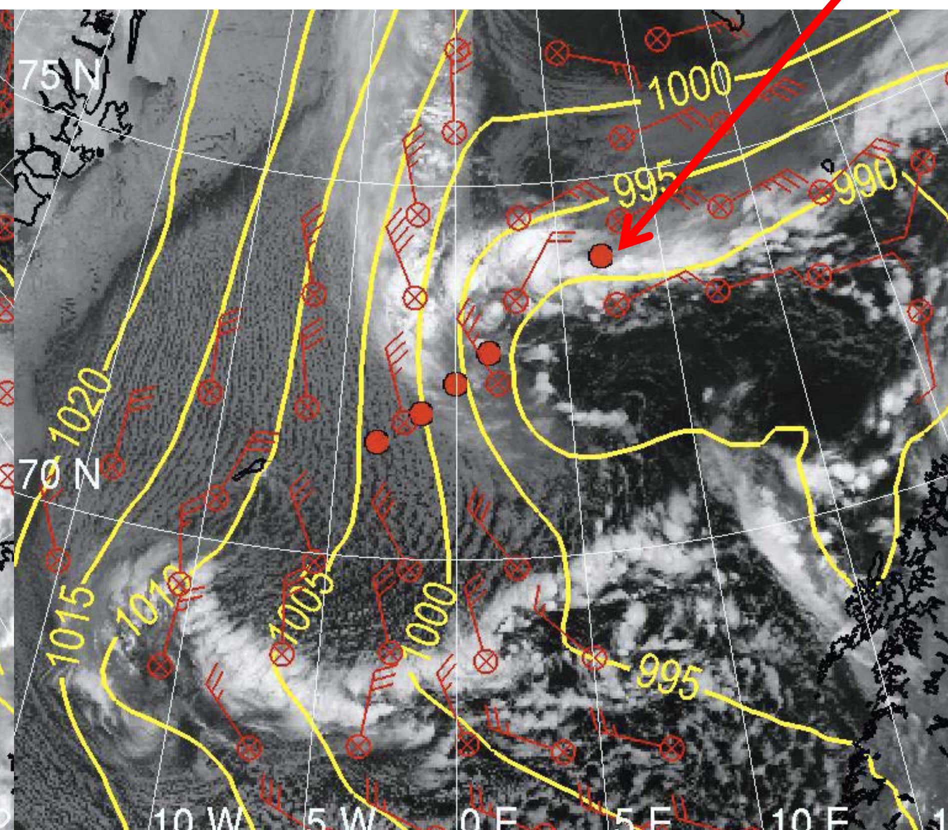
Stockholm University

Flight track with drop sondes

12:21 UTC on 3 March



16:01 UTC on 3 March

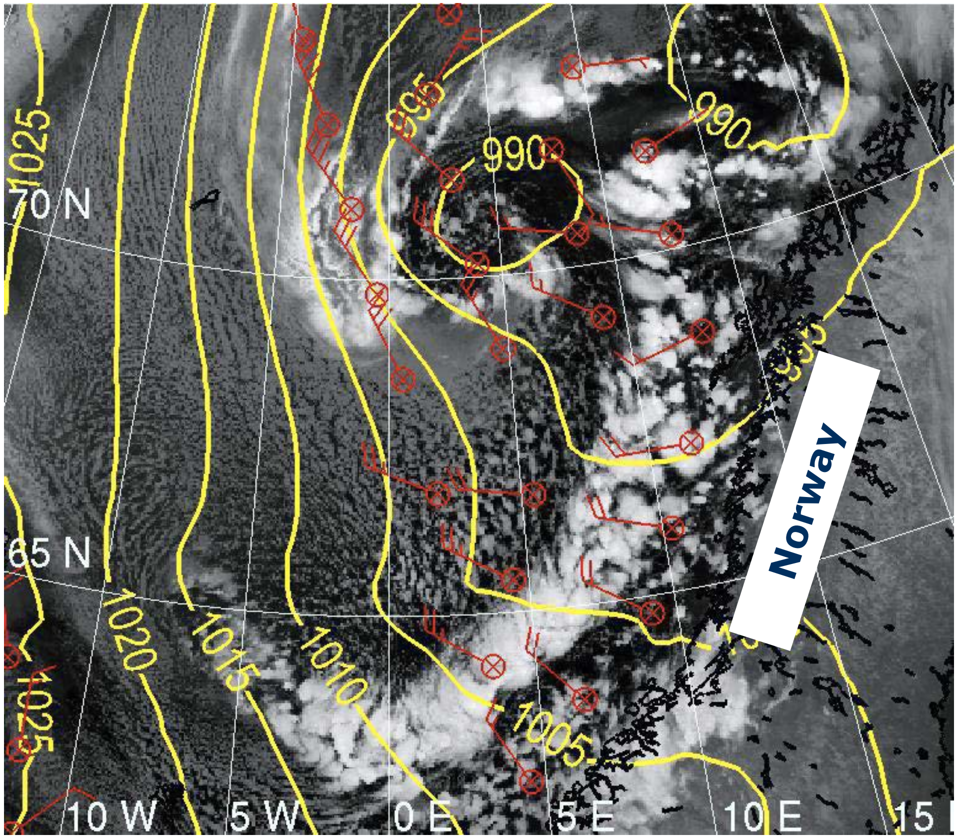


Kristjánsson et al. 2011

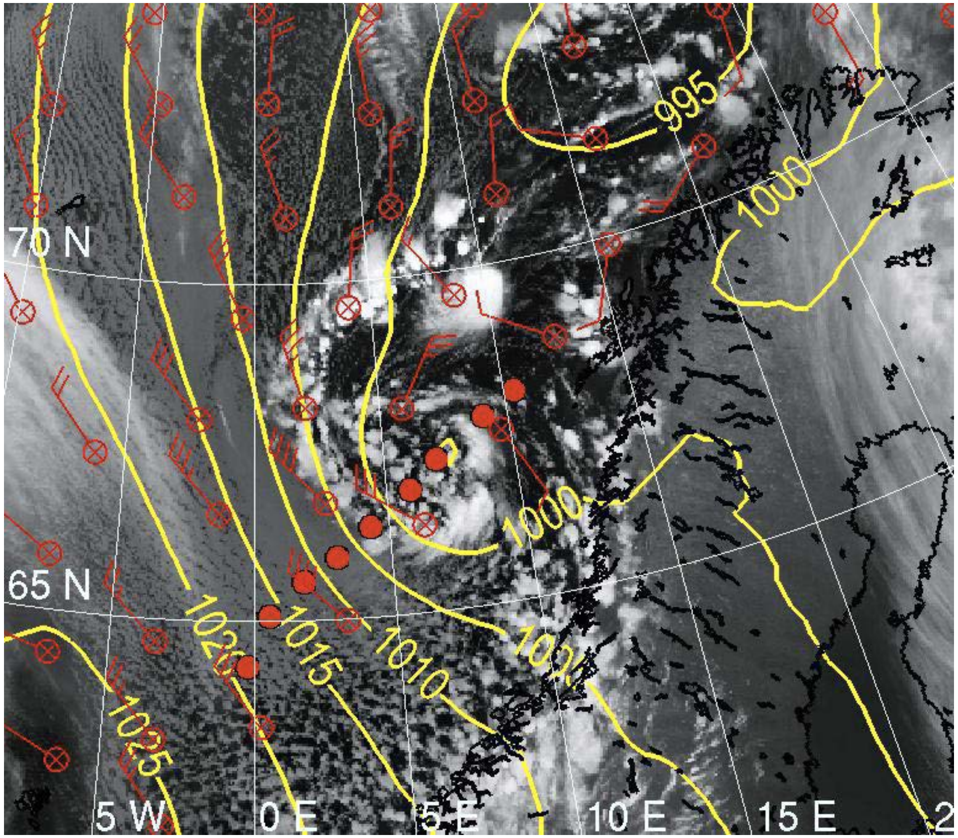
Polar Low
Mature Convective Phase

Stockholm University

03:07 UTC on 4 March



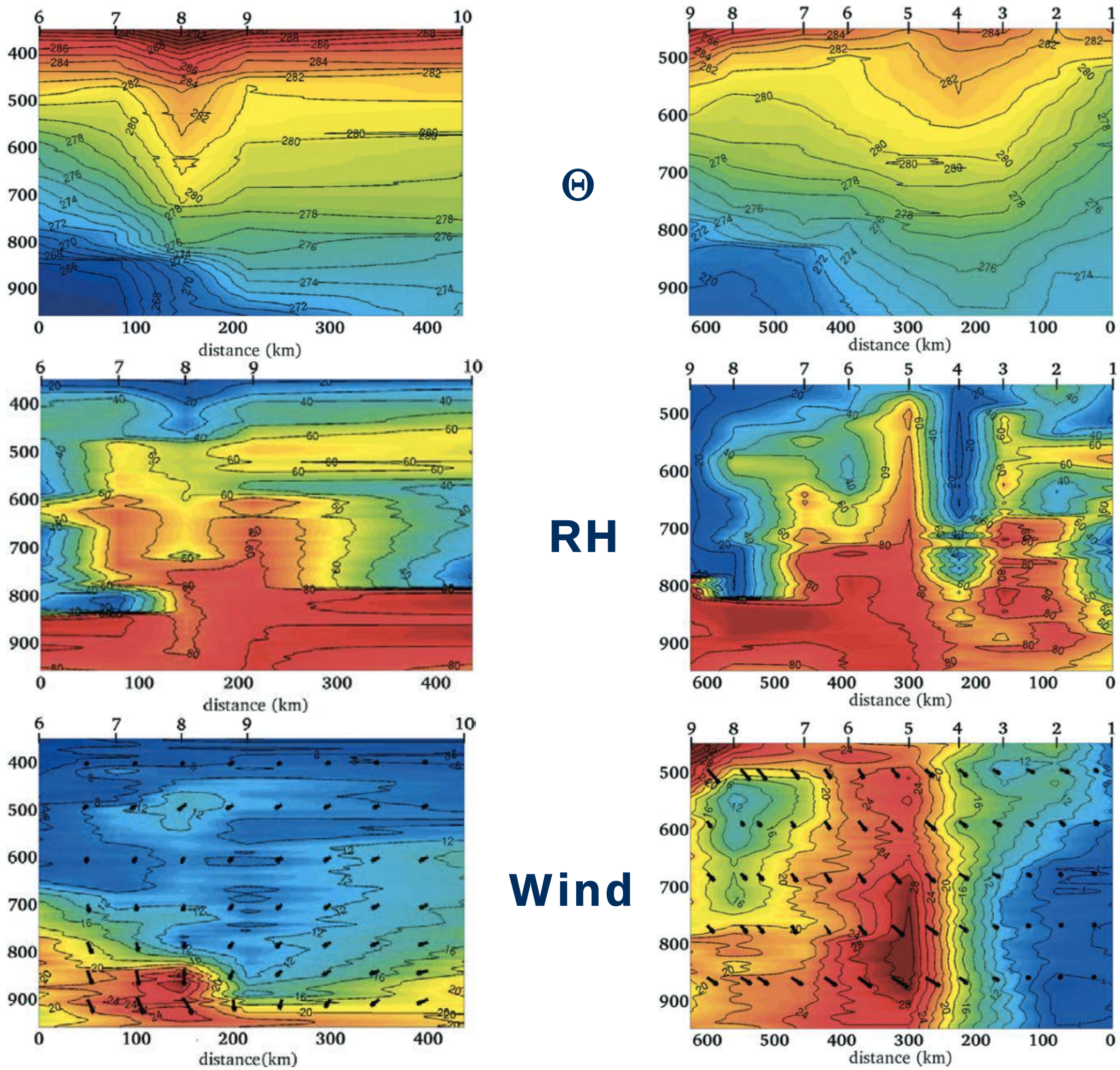
11:28 UTC on 4 March



Kristjánsson et al. 2011

Polar Low
Vertical structure

16:01 UTC on 3 March **11:28 UTC on 4 March**



Initial state:
Cold air outbreaks combined with low level baroclinicity and/or upper level PV anomalies

Mature state:
Windy marine PBL with large surface fluxes of heat

Deep convective clouds

Føre et al, 2011

Summary of extratropical storms

The large-scale flow and location of baroclinicity determines where the systems will occur

Most types of clouds are found in the vicinity of extratropical storms

Responsible for the northward heat transport from the midlatitudes and poleward – warm conveyor belt important

The latent heat released when the clouds are formed are important energy source for the storms

Dynamics and microphysics interact and is challenging to get right in models

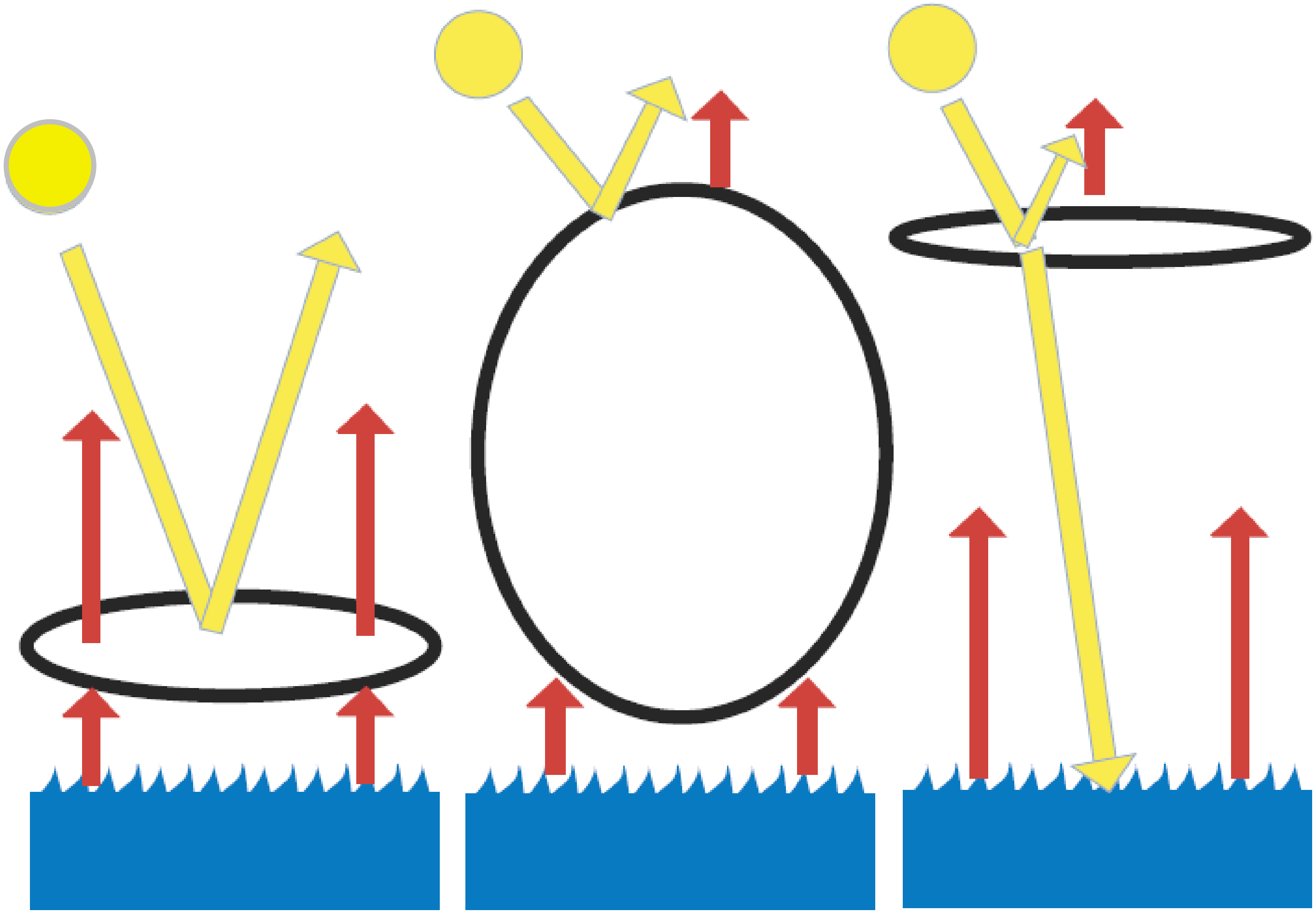
Cloud Radiative Effect at TOA

Stockholms universitet

Large negative CRE

No net effect

Small positive CRE



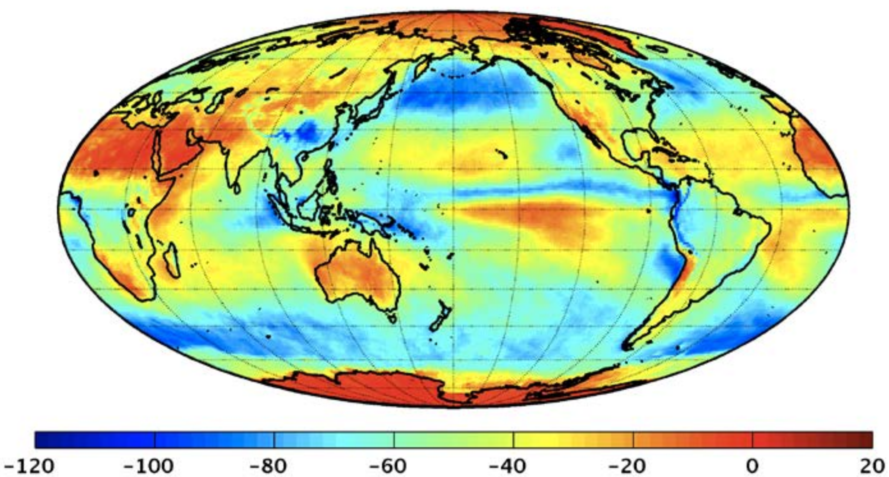
$$CRE_{TOA} = LW\uparrow_{cs} - LW\uparrow + SW\uparrow_{cs} - SW\uparrow$$

Karlsson, 2009

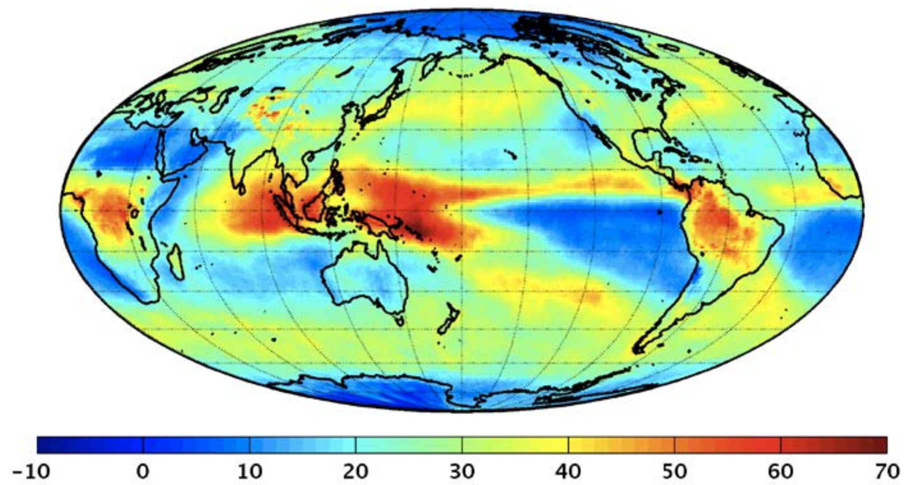
Cloud Radiative Effect at TOA
CERES, Annual mean

Stockholms universitet

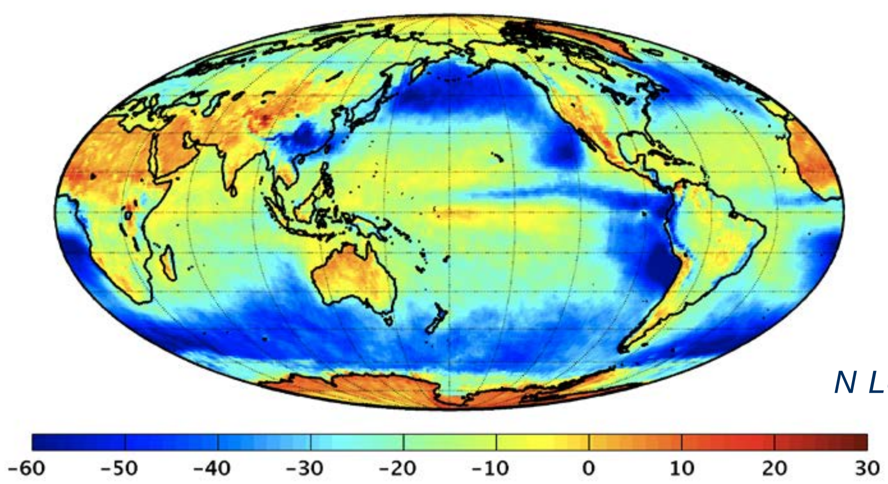
Annual mean TOA SW CRE =−47.1W m^{-2}



Annual mean TOA LW CRE =26.5W m^{-2}



Annual mean TOA Net CRE =−20.6W m^{-2}



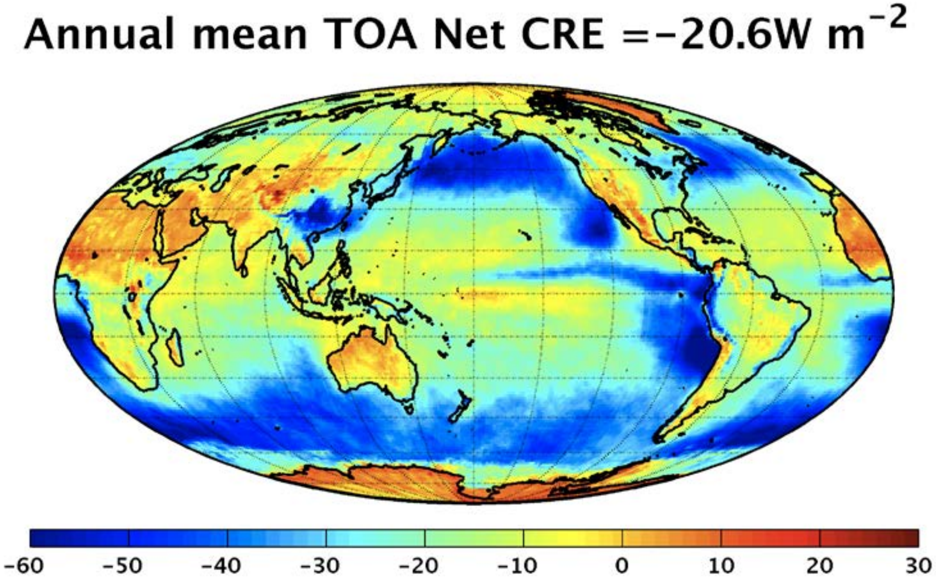
N Loeb

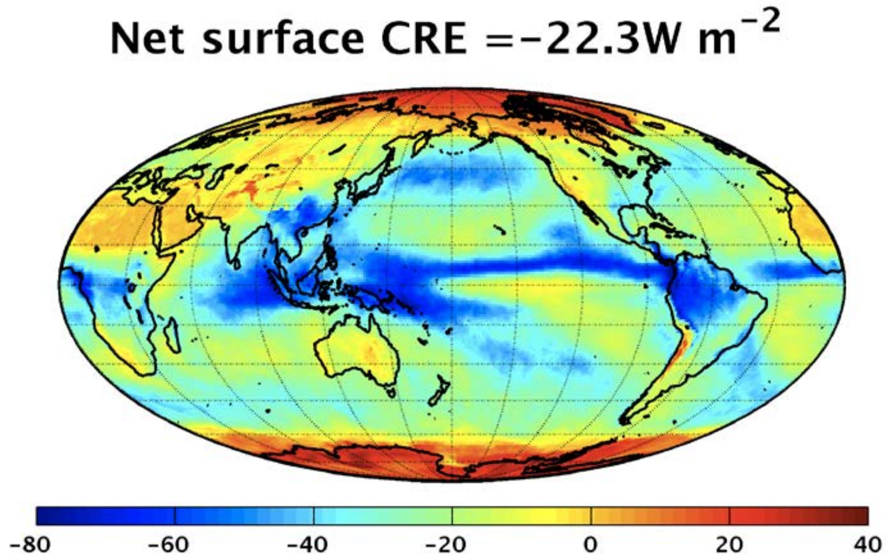
Midlatitude storm clouds, along with tropical convection, produce the strongest SW radiative cooling at TOA

Cooling effect is stronger in the summer due to stronger insolation despite weaker storm track

Cloud Radiative Effect at TOA and surface
CERES, Annual mean

Stockholm University



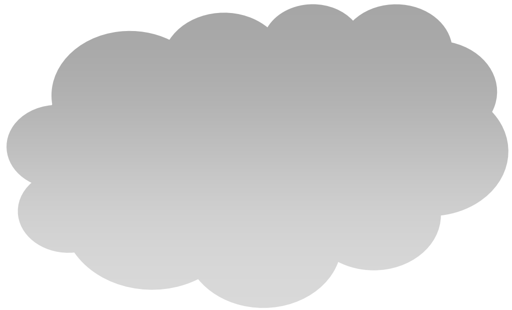


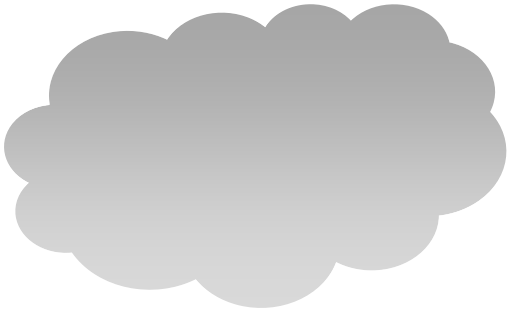
N. Loeb

Cloud Radiative Effect at Surface

The cloud radiative effect at the surface:

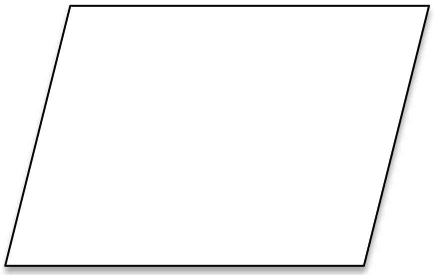
$$CRE = (SW\downarrow_{all} - SW\downarrow_{cs}) \cdot (1-\alpha_s) + LW\downarrow_{all} - LW\downarrow_{cs}$$





Smaller α_s $\longrightarrow$ Shortwave cloud albedo effect dominates

Larger α_s $\longrightarrow$ Longwave cloud greenhouse effect dominates



Questions?