Implications of Recent Experience Modeling Mixed-phase Clouds to measurement and theoretical needs

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Outline

- Brief overview of RAMS microphysics
- Examples of recent simulations of mixed-phase clouds
- Observational and theoretical needs
- Recommendations

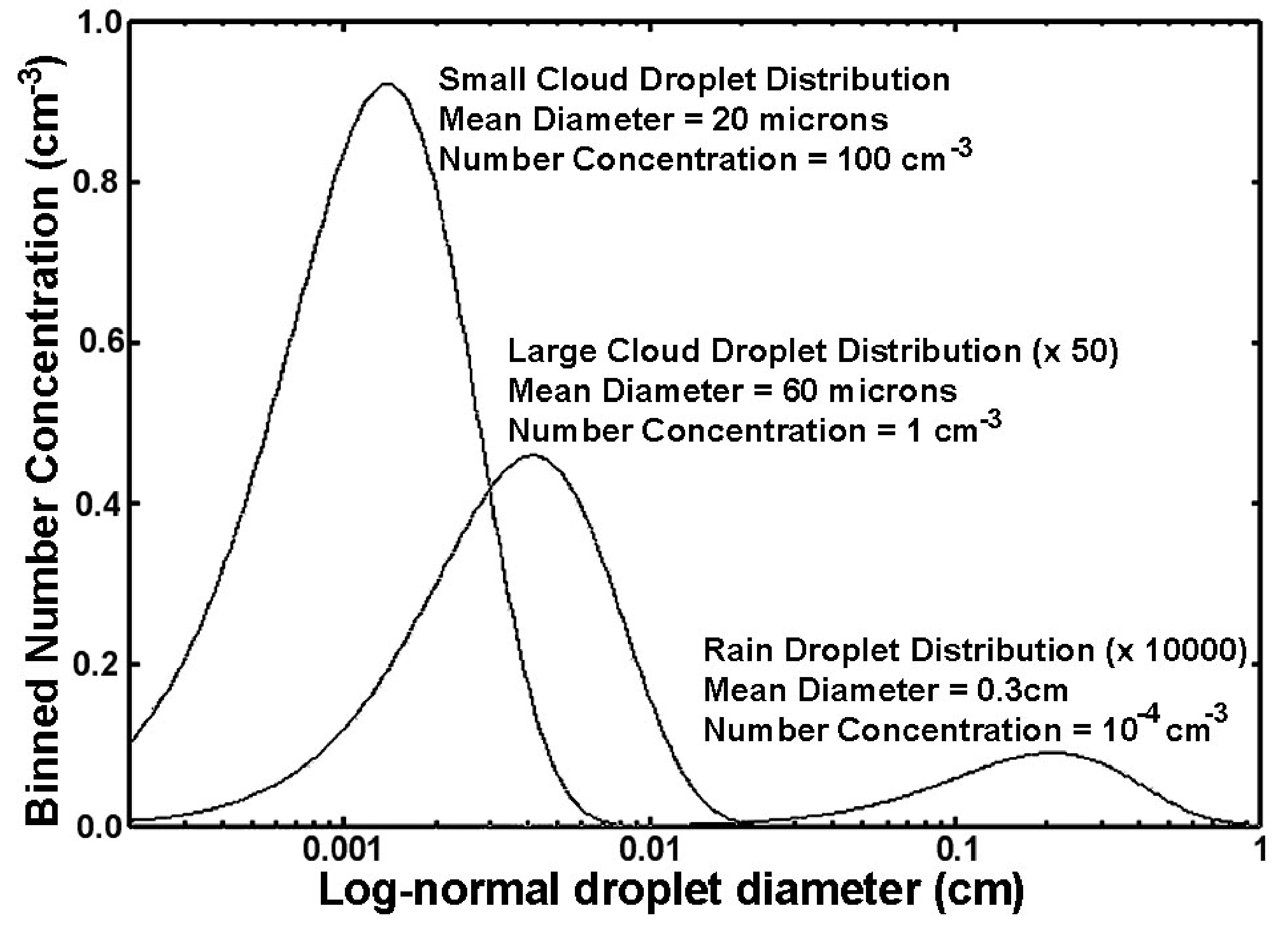
Microphysical Processes Represented in RAMS

- Cloud droplet nucleation in one or two modes
- Ice nucleation
- Vapor deposition growth
- Evaporation/sublimation
- Heat diffusion
- Freezing/melting
- Shedding
- Sedimentation
- Collisions between hydrometeors
- Secondary ice production

Hydrometeor Types

Cloud droplets	C
Rain	R
Pristine ice (crystals)	P
Snow	S
Aggregates	A
Graupel	G
Hail	H

RAMS Liquid Hydrometeor Distributions



Unique Features of RAMS Microphysics:

- Uses generalized gamma distribution basis functions :

$$n(D)=\frac{N_t}{\Gamma(\nu)}\left(\frac{D}{D_n}\right)^{\nu-1}\frac{1}{D_n}\exp\left(-\frac{D}{D_n}\right)$$

  where n(D) is the number of particles of diameter D, N_t is the total number of particles, ν is the shape parameter, and D_n is some characteristic diameter of the distribution. The Marshall-Palmer (exponential) and Khrgian-Mazin distribution functions are special cases of this generalized function.

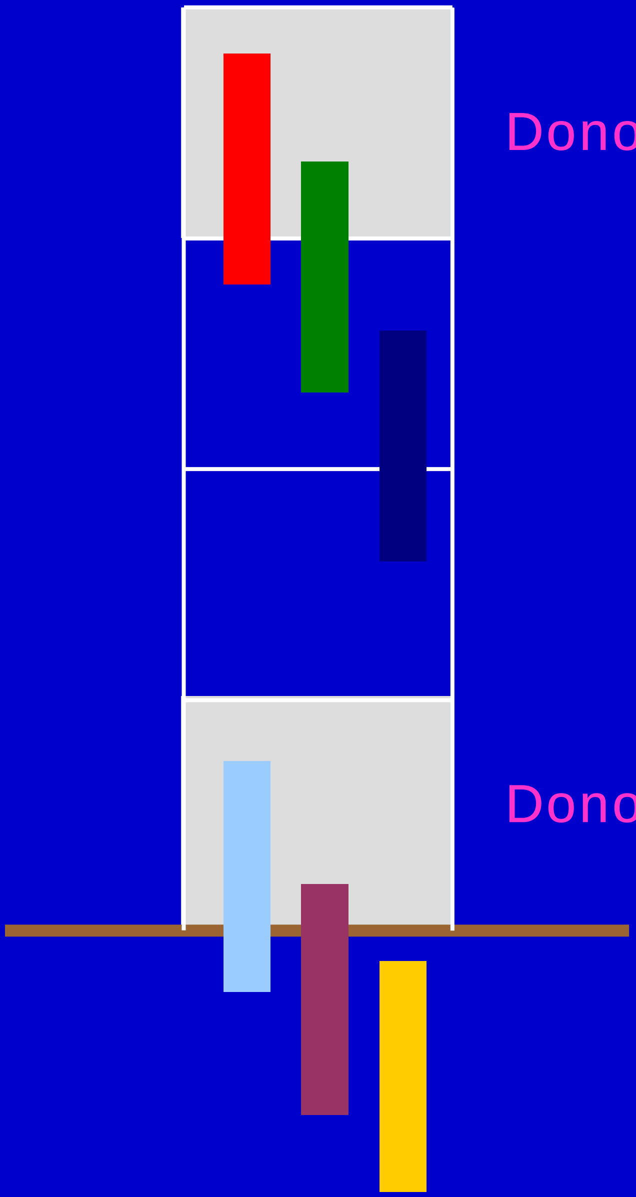
- Simulations can be done with one or two moments. When two-moments of a hydrometeor class is predicted, all that is needed to completely specify the distribution function given by (1) is the specification of ν.

- Collection is simulated using stochastic collection solutions rather than continuous accretion approximations. Owing to the use of look-up tables, it became apparent that it is no longer necessary to constrain the system to constant or average collection efficiencies. Thus the formerly ad hoc auto-conversion formulations in RAMS was replaced with full stochastic collection solutions for self-collection among cloud droplets and for rain (drizzle) drop collection of cloud droplets. This approach is being extended to all hydrometeor interactions.

- The philosophy of bin representation of collection was also extended to calculations of drop sedimentation. Previously, bulk microphysics schemes have treated sedimentation of hydrometeors by integrating over the entire particle size-spectra and obtaining a mass-weighted fall speed. Bin sedimentation is simulated by dividing the gamma distribution into discrete bins and then building look-up tables to calculate how much mass and number in a given grid cell fall into each cell beneath a given level in a given time step.

Sedimentation

Bin Computations



Donor cell

Donor cell

Cloud Droplet Nucleation

Number nucleated obtained from lookup table as a function of

- CCN number concentration
- Vertical velocity
- Temperature

Lookup table generated previously (offline) from detailed parcel-bin model

$N_{c1} = N_{ccn} \quad S_w^b$

$N_{c2} = N_{gccn} \; ; \; S_w > 0.0$

Ice Habits

Pristine ice and snow are allowed to have any of five different habits (shapes): columns, needles, dendrites, hexagonal plates, and rosettes. The dependence of mass and of fall velocity on diameter are different for each habit.

Ice Crystal Nucleation

1. Deposition nucleation

Condensation freezing

$$N_i = N_{IFN} \exp\left[12.96\,(S - S_o)\right]$$

$$S_o = 0.4$$

vapor $\longrightarrow$ IFN

$T < -5^{o}C$

$r_v > r_{si}$ (supersaturation with respect to ice)

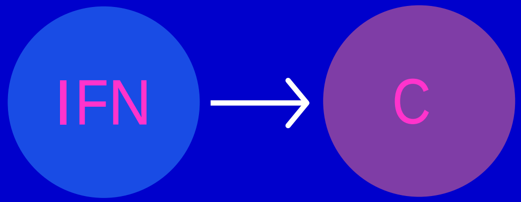
vapor $\longrightarrow$ $\frac{\text{CCN}}{\text{IFN}}$

$T < -2^{o}C$

$r_v > r_{sl}$ (supersaturation with respect to liquid)

Ice Crystal Nucleation -- continued

2. Contact nucleation



$T < 0^{\circ}C$

3. Homogeneous freezing of cloud droplets $T < -30^{\circ}C$

4. Homogeneous freezing of haze

Rate depends on T, r_v, amount of haze present

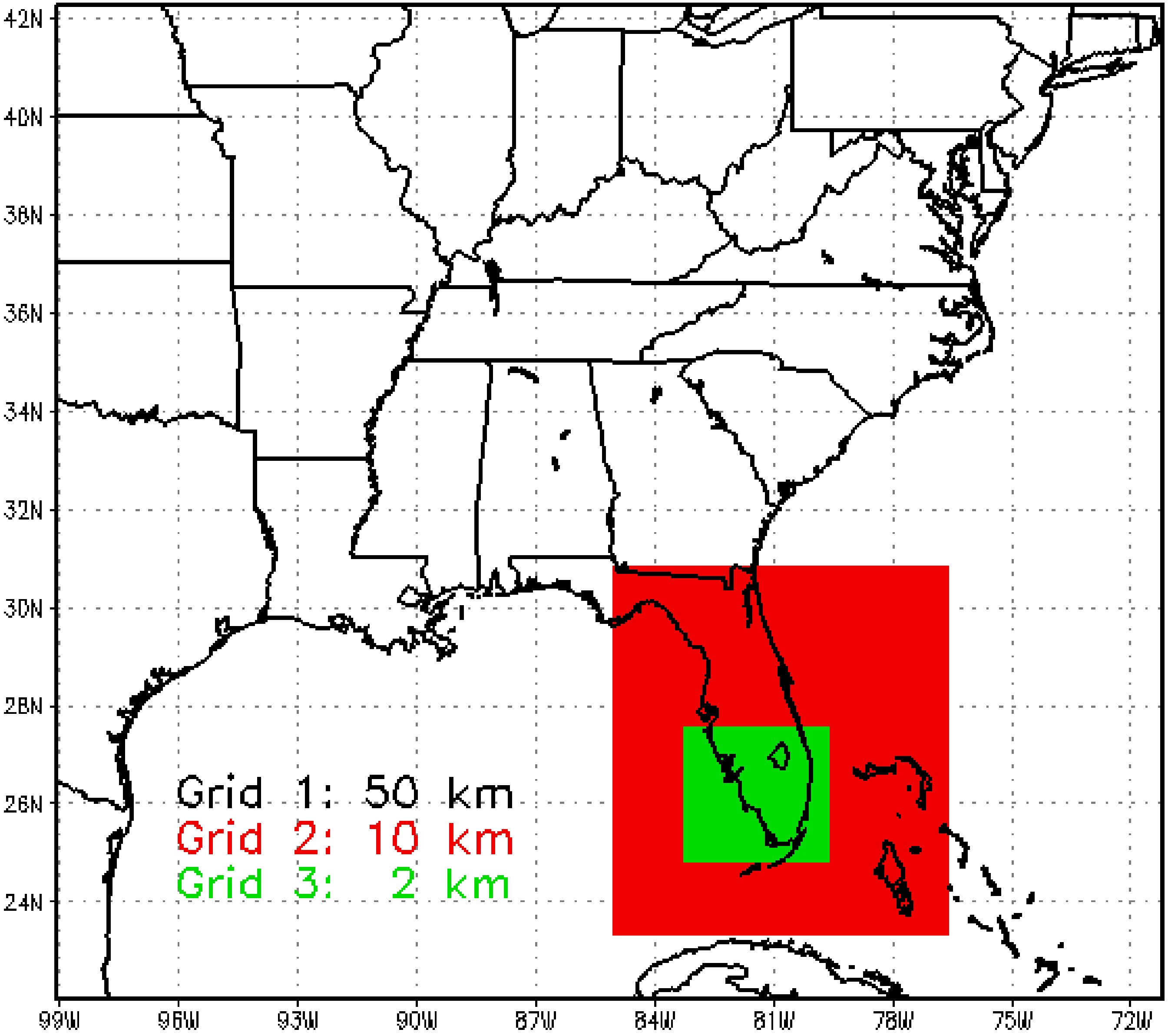
Some Examples of simulations and their implications

Simulations of Florida Thunderstorms during a Saharan Dust Event over S Florida

Model Details

- Regional Atmospheric Modeling System (RAMS@CSU)
- 4 grids
- Horizontal grid spacing:
  - Grid 1: $\Delta x = \Delta y = 50$ km
  - Grid 2: $\Delta x = \Delta y = 10$ km
  - Grid 3: $\Delta x = \Delta y = 2$ km
  - Grid 4: $\Delta x = \Delta y = 500$ m
- Vertical grid spacing:
  - 36 stretched levels
  - 8 levels within first 1 km AGL
- Initialized at 12Z with 40 km Eta data
- Simulation run for 12 hours
- Two-moment microphysics
- Microphysical species: cloud water, rain, pristine ice, snow, aggregates, graupel, hail

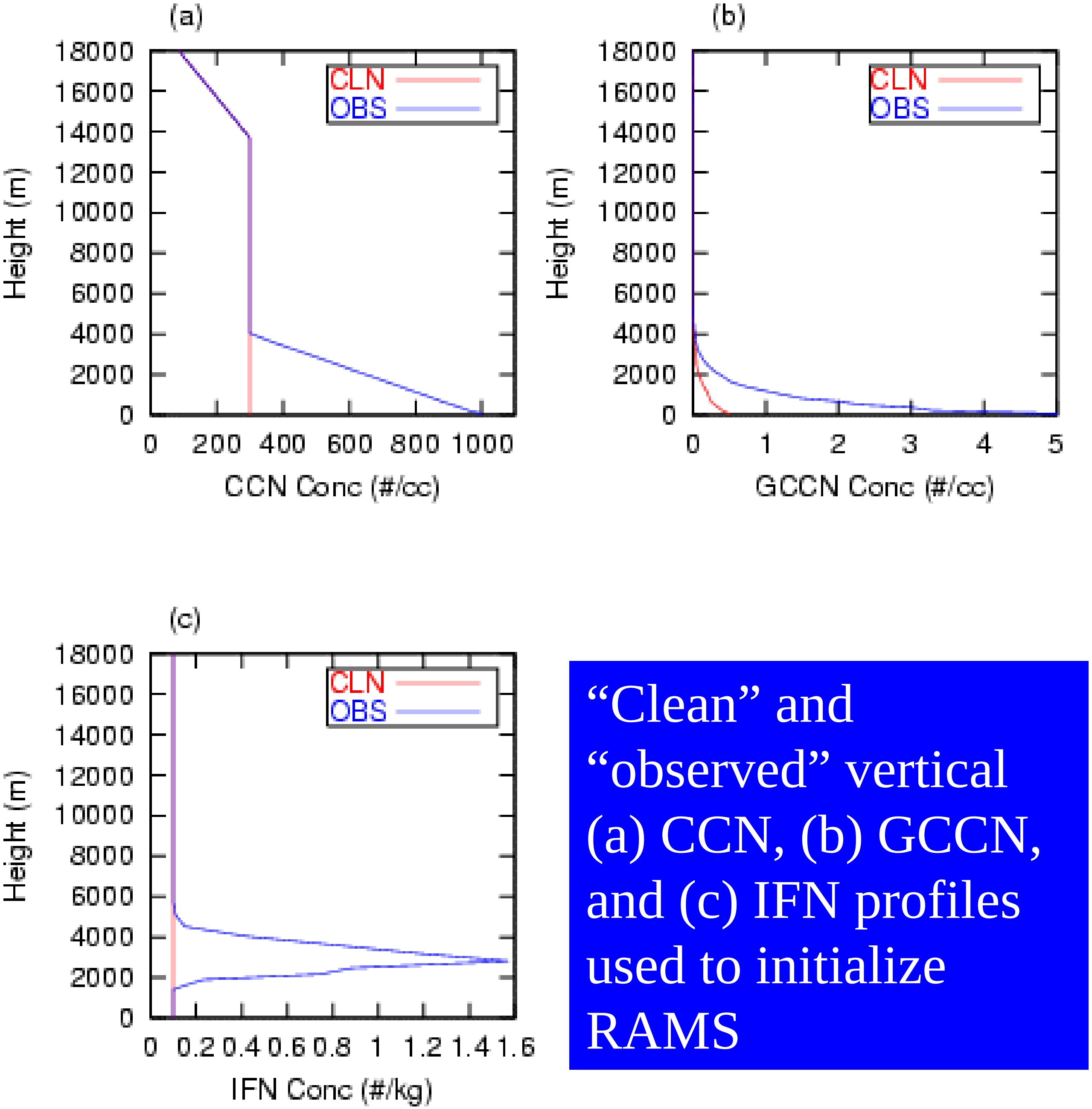
Location of Grids 1, 2 and 3



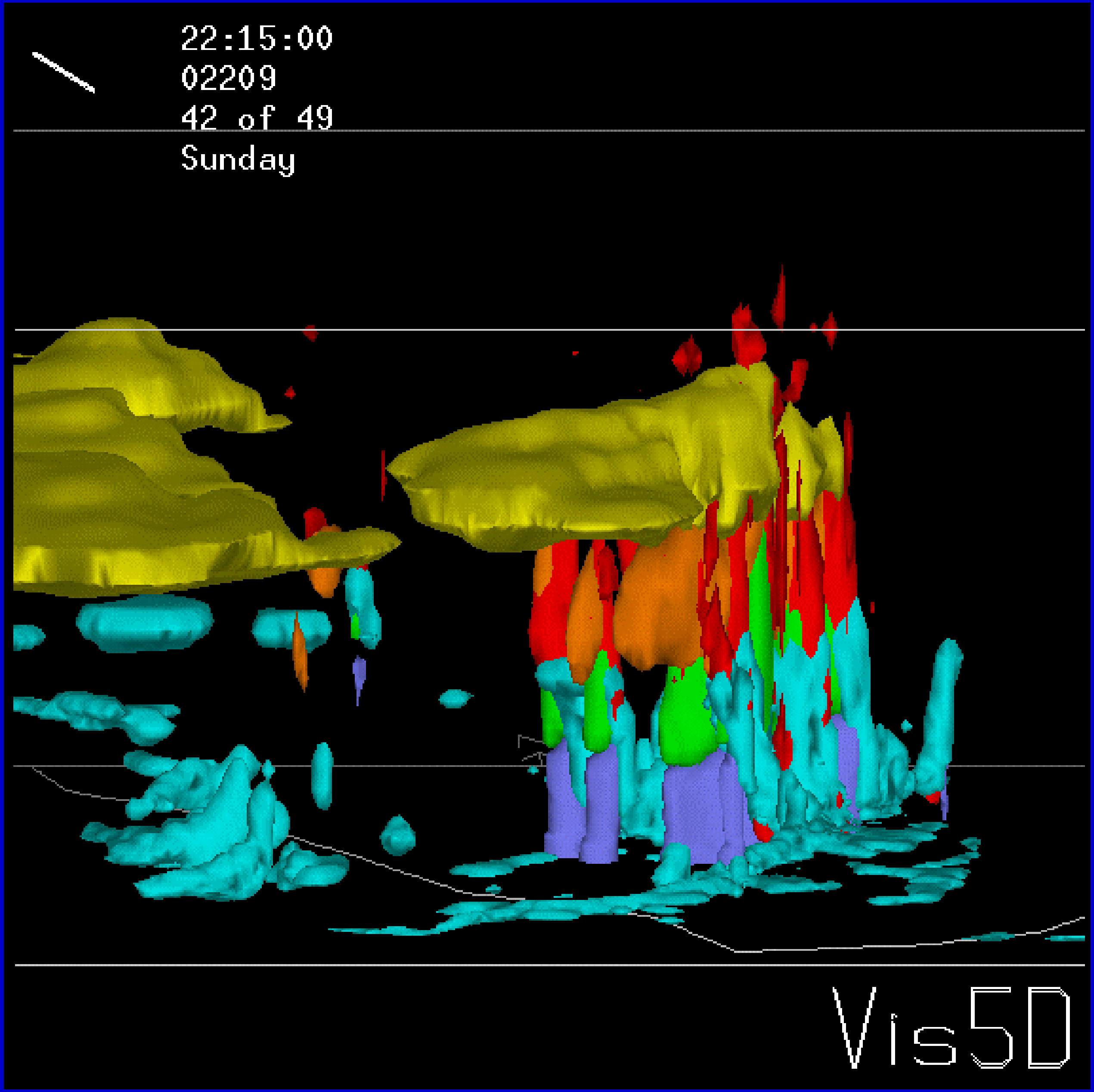
Experiment Design

- Generalized vertical profiles of CCN, GCCN and IFN concentrations were obtained for 28 July 2002 (a high dust day) and for “clean” days using measurements obtained during the CRYSTAL-FACE field project (from Paul DeMott of CSU)
- A series of sensitivity tests were conducted in which:
  1. clean
  2. 25% of the observed
  3. 50% of the observed
  4. observed

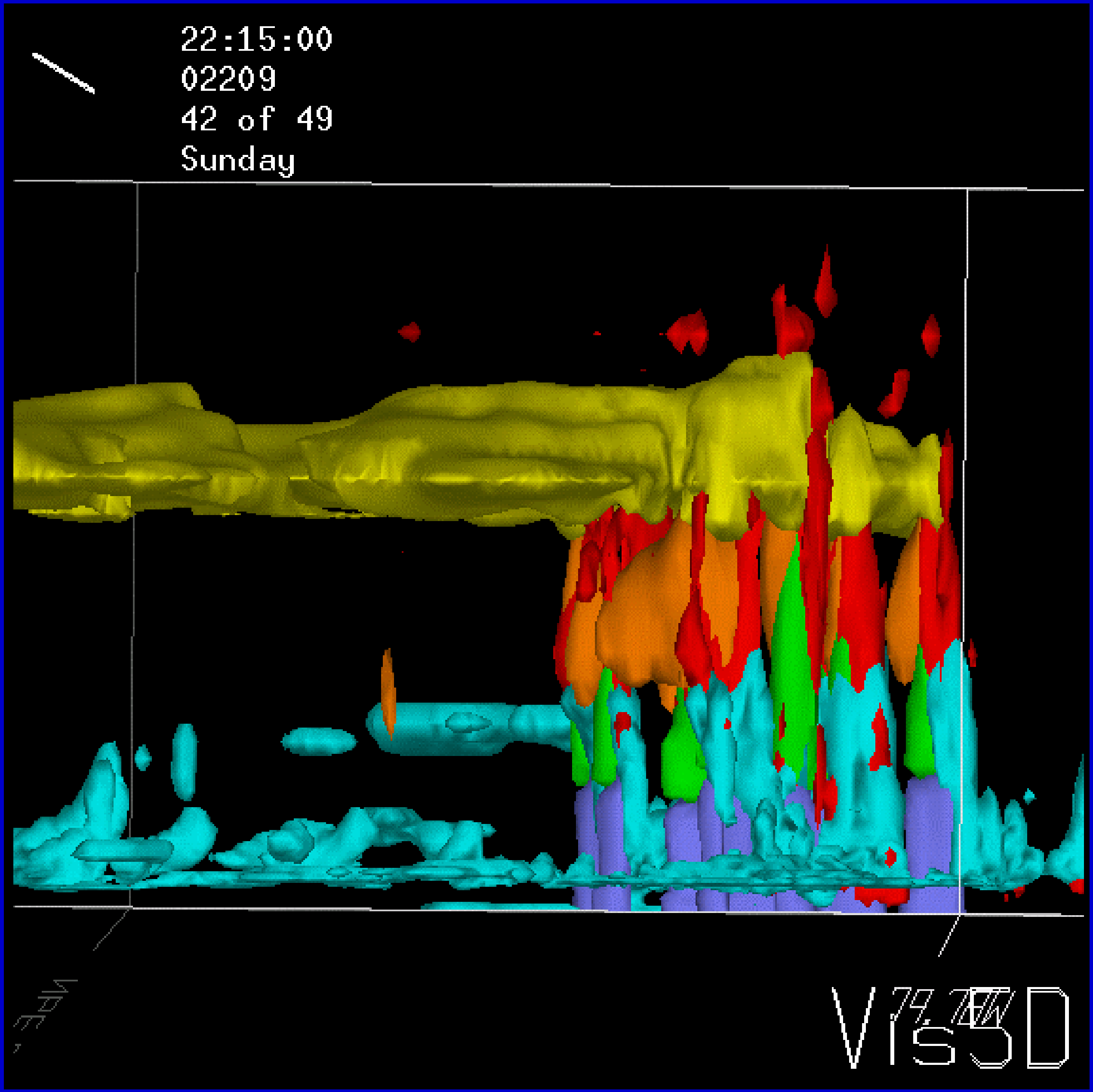
  CCN, GCCN and IFN concentrations were used to initialize RAMS (all 3 aerosol concentrations are considered as *prognostic* variables in RAMS)
- A factor separation analysis (Stein and Alpert, 1993) was performed on the “clean” and observed simulations to determine which aerosol type has the greatest effect on the ice mixing ratio fields



“Clean” and “observed” vertical (a) CCN, (b) GCCN, and (c) IFN profiles used to initialize RAMS



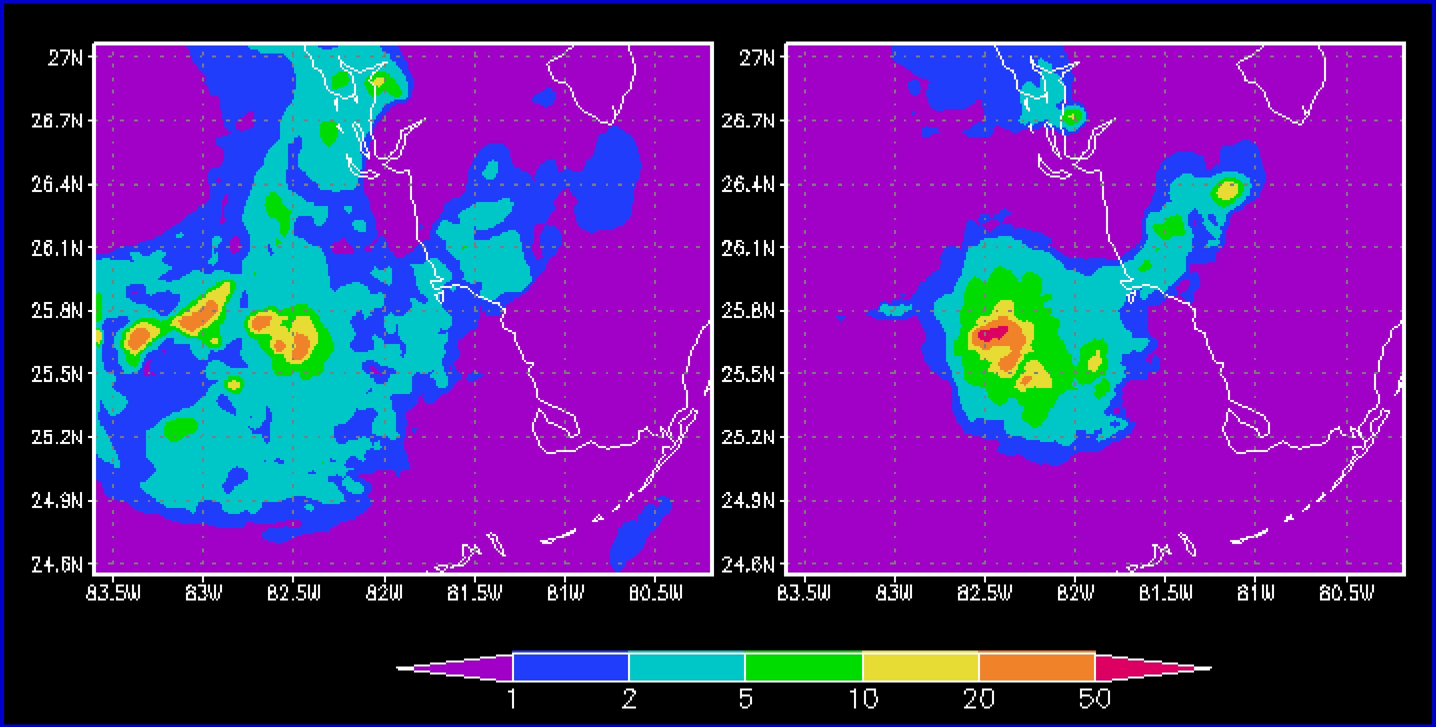
Vertical velocity (red, 1m/s), pristine ice (yellow, 0.3 g/kg), hail (green, 1g/kg), rain (mauve, 1g/kg), graupel (orange, 1g/kg) and cloud water (blue, 0.3 g/kg)

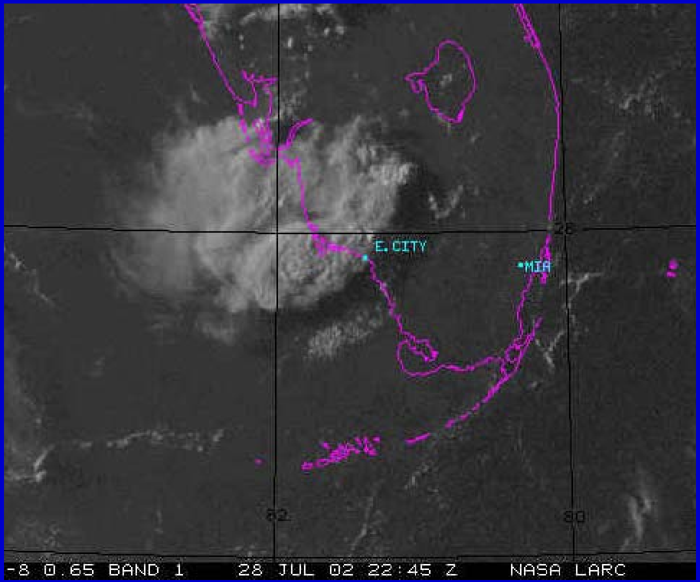


Vertical velocity (red, 1m/s), pristine ice (yellow, 0.3 g/kg), hail (green, 1g/kg), rain (mauve, 1g/kg), graupel (orange, 1g/kg) and cloud water (blue, 0.3 g/kg)

CLEAN

OBSERVED





Vertically-integrated condensate (mm, color) for the clean and observed cases and the corresponding visible satellite imagery (NASA LARC) at 22:45 UTC

RANK	RUN	Volumetric Precipitation (acre-feet)
1	GCCN	925
2	OBS	923
3	GCCN+IFN	908
4	CCN	878
5	CLN	877
6	IFN	876
7	CCN+IFN	871
8	CCN+GCCN	848

Conclusions

- Increasing aerosol concentrations increases:
  - the maximum updraft speeds
  - the depth of the anvil
  - the pristine ice + snow mixing ratios
  - the aggregate mixing ratios initially, but this trend reverses toward the end of the simulation due to sedimentation

Conclusions (cont)

- The factor analysis shows that the pristine ice + snow mixing ratio is most strongly influenced by increases in CCN. The sensitivity to increases in IFN and GCCN are similar in magnitude. Contributions due to the interactions between CCN, IFN and GCCN are greater than those made solely due to IFN and GCCN increases.
- The factor analysis shows that the aggregate mixing ratios are most strongly affected by the interactions between the CCN, GCCN and IFN.
- Increases in GCCN have the greatest effect on volumetric precipitation. Increasing CCN increases volumetric precipitation slightly. Increasing IFN tends to decrease the volumetric precipitation. Increasing both CCN and GCCN simultaneously also decreases volumetric precipitation.

EFFECTS OF AEROSOL ENTRAINMENT ON SEA-ICE FREEZING AND MELTING RATES

OBJECTIVES:

Assess the impact of the aerosol entrainment from the above the inversion on the structure of Arctic boundary layer clouds and on sea-ice thickness.

SIMULATIONS

Three-month CRM simulations for the melting season (1 May-31 July 1998), using 4 May observed aerosol profiles as benchmarks.

MELTING SEASON MULTIMONTH SIMULATIONS

- Domain: 5X4 Km, $\Delta x = 50$m, $\Delta z = 30$m, $\Delta t = 2$sec.
- Simulation time: 92 days from 1 May 1998
- Cyclic boundary conditions and nudging using 2-3 daily SHEBA soundings.
- Two-moment microphysics.
- Sub-grid thickness distribution: six categories with a linear remapping scheme (Lipscomb, 2001).
- Initial mean thickness of the distribution: 2.41m. (Average of seven closest gauges for 1 May)

Experiment design

- All experiments were initialized with “clean” CCN and IFN concentrations.
- Clean and polluted profiles are nudged below and above the varying altitude of the inversion.

Concentrations nudged above the inversion

Exp	IFN [l^{-1}]	CCN [cm^{-3}]
EC-C	3 (clean)	100 (clean)
E.50-C	40	100(clean)
E1-C	80	100 (clean)
E1-1	80	250

SUMMARY

- Results indicate that increasing the IFN concentrations within the upper layer:
  - increases total condensate path,
  - decreases the liquid water fraction,
  - decreases the relative importance of ice sedimentation by reducing their free fall speed,
  - increases net radiative forcing,
  - enhances sea-ice melting rates when mixed phase clouds are present.
- Results suggest that CCN entrainment has an opposite although less important effect.

Variations in precipitation and cloud optical properties due to changes in aerosol concentrations

- Summer storms over Florida:
  - 25% variation in the total volumetric precipitation received at the surface
  - 52% variation in optical thickness
- Winter storms:
  - CO: 15-30% snow
  - NE USA: 10-30% rain; 30-50% snow

How can we obtain initial concentrations of

CCN

GCCN

IFN??

An Aerosol Source model

- Direct emission sources include desert dust, sea salt, natural and anthropogenic sources of SO2 and sulfates, certain strains of bacteria, forest fires and biomass burning.
- Dust emissions are based on surface topographic features, near-surface winds, erodible area, and soil moisture.
- Sea salt emissions are based on near-surface winds.

Model Development

- After implementing the aerosol source functions the model will be tested using satellite and ground-based measurements for comparisons.
- After testing, parameterizations will be implemented converting the aerosol distributions to CCN, GCCN and IFN distributions for input in the microphysics package.

CCN

- Parameterizations for conversion of SO_2 and sulfate concentrations to CCN are being constructed. This includes oceanic DMS production and conversion to CCN, and smoke conversions to CCN.
- At this time chemistry will be parameterized by a conversion factor from SO_2/DMS to sulfate rather than assuming background oxidant concentrations and explicitly modeling chemistry.

GCCN

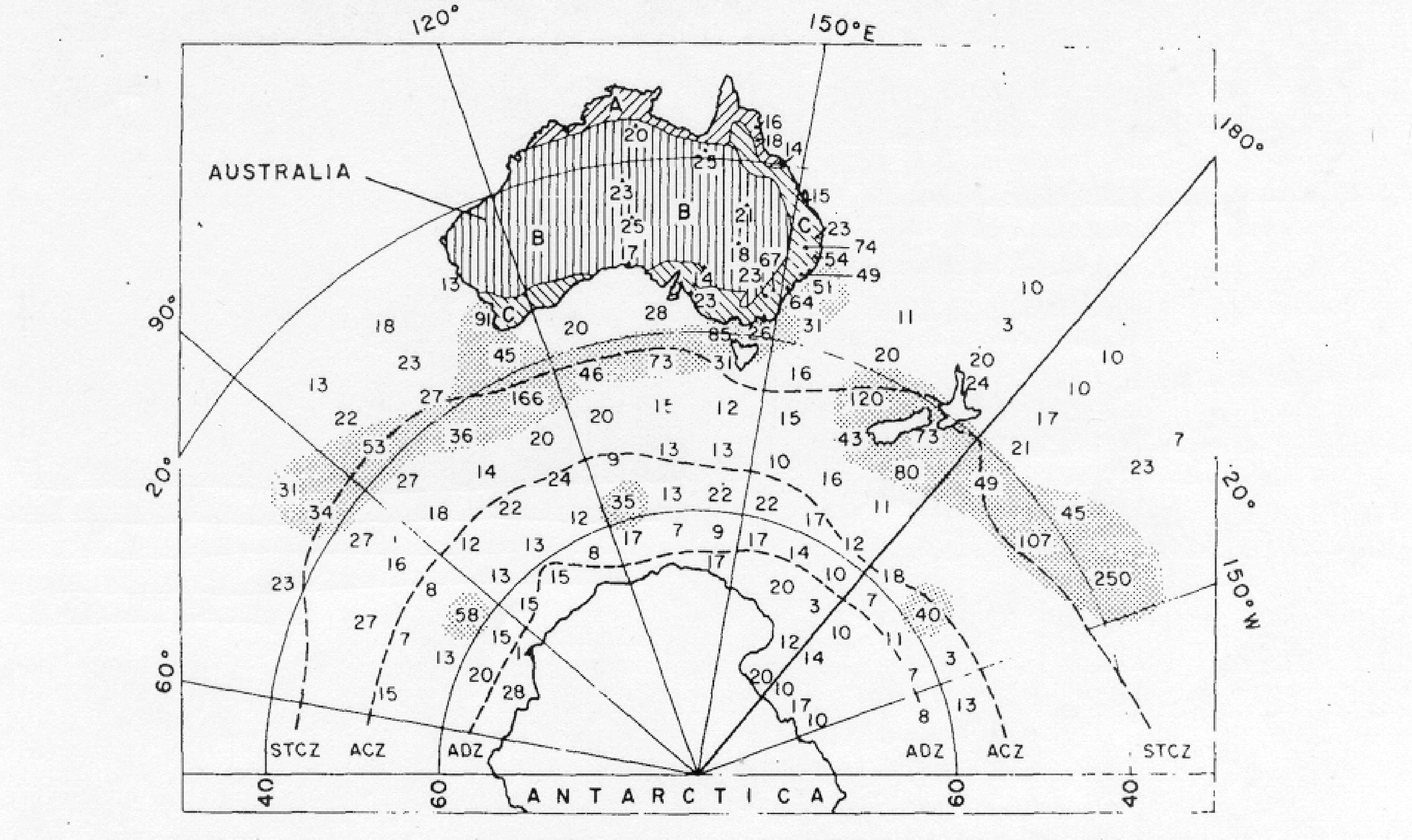
- The primary sources of GCCN are dust, sea salt, industrial (like paper pulp mills), diesel engines, and perhaps biogenic material.
- Parameterizations of conversion from these sources are being constructed.

IFN

- Primarily sources of IFN are inorganic soil particles like clays (correlated with dust), biogenic materials, and industrial sources like heavy metal industries.
- Conversion rates from dust to IFN has to be derived.
- Biogenic sources include decay of plant litter over land and blooms of phytoplankton over the oceans.

IFN sources and Climate Zones

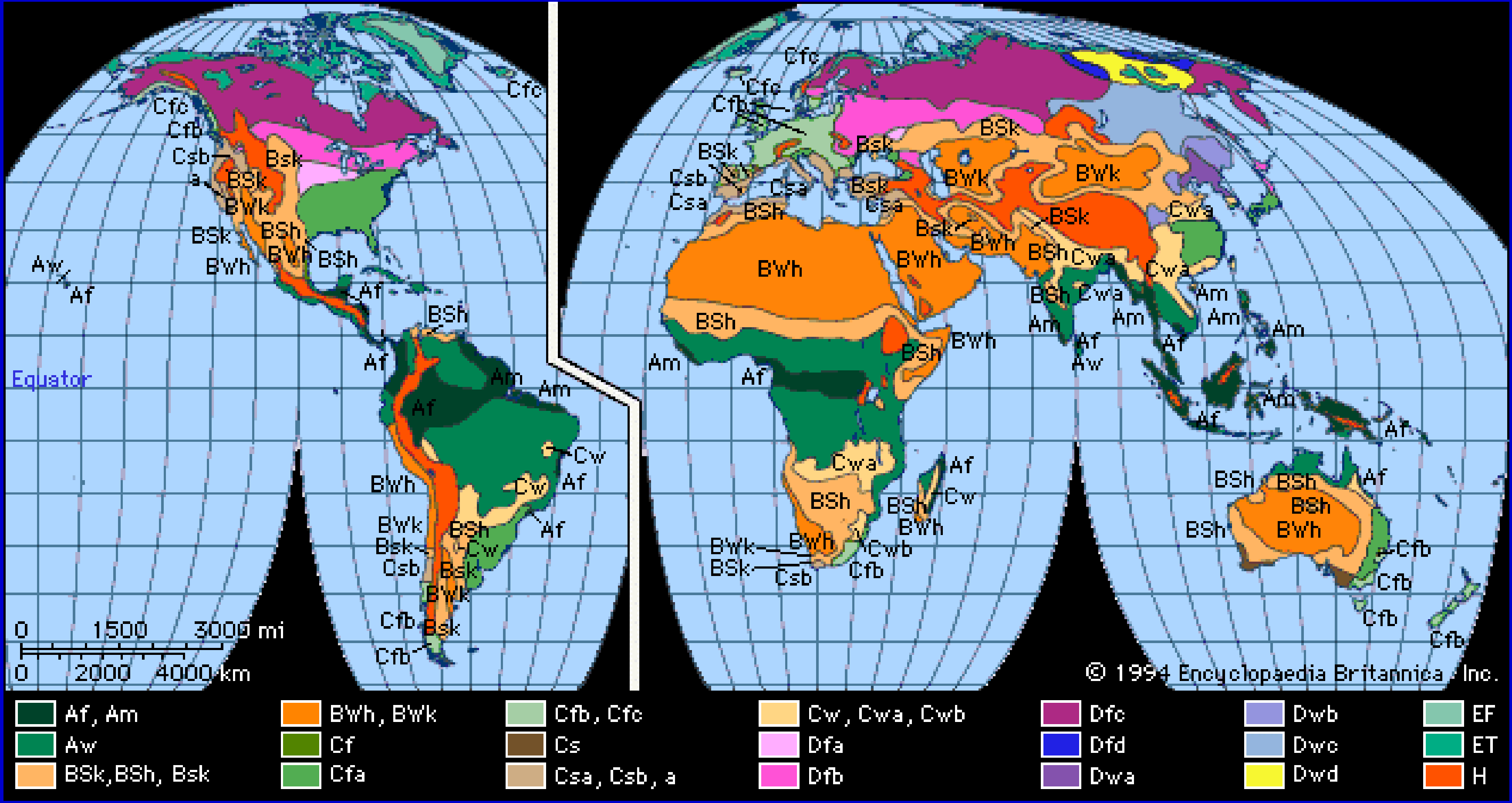
- A-zone: tropical (extensive vegetation)
- B-zone: dry
- C-zone: humid mesothermal (extensive vegetation)
- D-zone: microthermal (extensive vegetation)
- E-zone: polar
- H-zone: undifferentiated highlands
- M-zone: marine



From Schnell and Vali, 1976.

Leaf-derived nuclei

- Koppen Climate Zones:
  - Extensive vegetation: A-tropical; C-mild mid-lat ; D-cold mid-lat



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IFN and climate zones

- A-type: low
- B-type: somewhat larger than A
- C-type: highest
- M-type: variable depending on T and upwelling/mixing—high values near Australian and Antarctic coasts are regions of upwelling and continental shelf where plankton are highest in the world.

CCN/GCCN/IFN Retrieval Scheme

Objective:

Examine the feasibility of retrieving cloud-nucleating aerosol concentrations using the cloud resolving version of RAMS in an ensemble Kalman filter assimilation system.

Brief Algorithm Description

1) Identify locations where the CCN, IFN and GCCN concentrations wish to be estimated.

1) Do backward trajectory analyses using RAMS (or another mesoscale model), in regions where boundary layer clouds are prevalent.

2) Produce ensembles of CRM forward integrations along those trajectories in which we apply ensemble Kalman-filter assimilation procedures.

3) Cloud-nucleating aerosol concentrations are retrieved at the end of the forward integrations.

Brief Algorithm Description (continued)

- Forward integrations are performed with a CRM version of RAMS that uses the explicit cloud nucleating microphysical module.

- The trajectories generated by the mesoscale model define time-evolving boundary conditions for the CRM.

- Even when the CRM domain is 2-D, only horizontal averages are involved in the system state vector.

- Satellite radiances will be periodically assimilated into the CRM, minimizing the cost function between simulated and observed cloud radiances.

Other Model Microphysics Uncertaities

- Riming collection efficiencies
- Aggregation collection kernals
- Unknown secondary ice multiplication mechanisms as implied by Hobbs and Rangno observations of rapid generation of high ice crystal concentrations—one possibility is secondary particle production during ice crystal and graupel evaporation:Hallett bits!

Recommendations

- We need baseline CCN, GCCN, IFN concentration measurements to develop and calibrate cloud nucleating aerosol source models and retrieval estimates
- We need field campaigns in cumulus clouds to examine further and document conditions for Hobbs and Rangno type observations of rapid ice crystal formation

Recommendations(cont)

- We need to combine advanced measurement systems like cloud radars, lidars, radiometers, and insitu ground and airborne measurements with inverse modeling techniques using advanced microphysics and dynamics models for microphysics parameter estimation(eg. PDFs of aggregate collection kernals).