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A Global Assessment of Precipitation Chemistry and Deposition

*A project of the World Meteorological Organization's Global Atmosphere
Watch Scientific Advisory Group for Precipitation Chemistry*

**Robert Vet
Environment Canada
and
20 Co-Authors**



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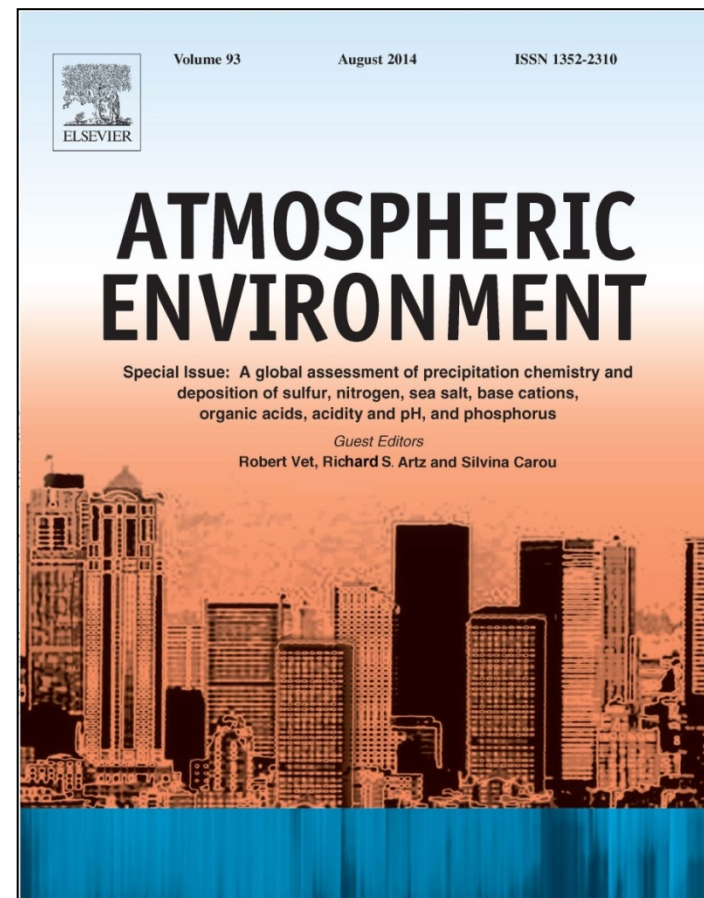
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**A Global Assessment
of
Precipitation Chemistry and Deposition
of Sulfur, Nitrogen, Sea Salt, Base
Cations, Organic Acids, Acidity and pH,
and Phosphorus**

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Precipitation Chemistry and Deposition

-- a Global Concern

- ***The World Meteorological Organization (WMO) Global Atmospheric Watch (GAW) Programme:*** monitoring atmospheric composition and properties on global and regional scales in order to assess the contribution to climate change and other environmental issues.
- ***WMO / GAW Scientific Advisory Group for Precipitation Chemistry:*** a group of international experts committed to standardizing, investigating and encouraging measurements of the chemical composition of precipitation and wet, dry and total deposition
- ***Global issues linked to precipitation chemistry and deposition:*** atmospheric science, acid deposition, eutrophication, biogeochemical cycling, aquatic and terrestrial effects, critical loads, biodiversity, human health, nutrient cycling, chemical transport modelling, deposition of trace metals and POPs, climate change



Global Assessment of Precipitation Chemistry and Deposition - Background

Key Science Questions on Global and Regional Scales:

- What are the spatial patterns of major ions in precipitation and wet, dry and wet+dry deposition on global and regional scales?
- What changes occurred in wet deposition from 2000 to 2007 (and, where data are available, since 1990)?
- What are the major gaps, uncertainties and recommendations in global deposition monitoring?



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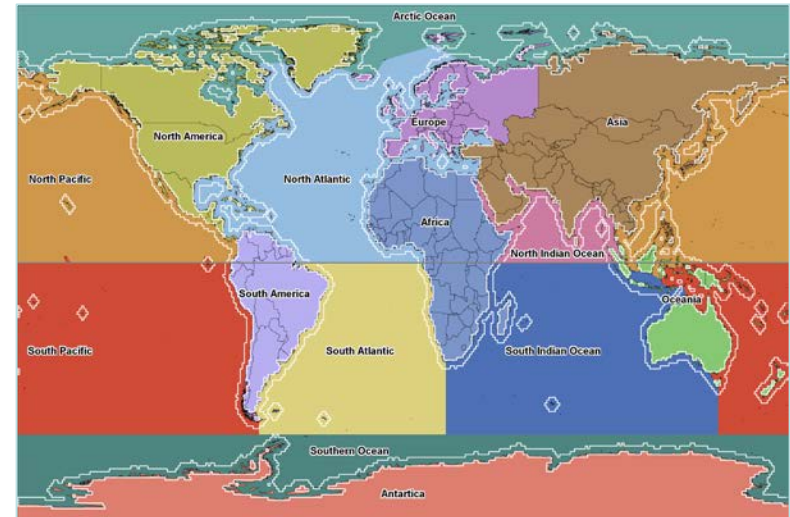
Global Assessment of Precipitation Chemistry and Deposition - Approach

Temporal Period

- 2000 to 2007
- Two 3-year averaging periods: **2000-2002** and **2005-2007**

Spatial Scales

- Global
- Regional: *Africa, Asia, Oceania, Europe, North America, South America, Oceans*



Method:

- Combination of measurement and modelling results

Data:

- Regionally-representative non-urban sites



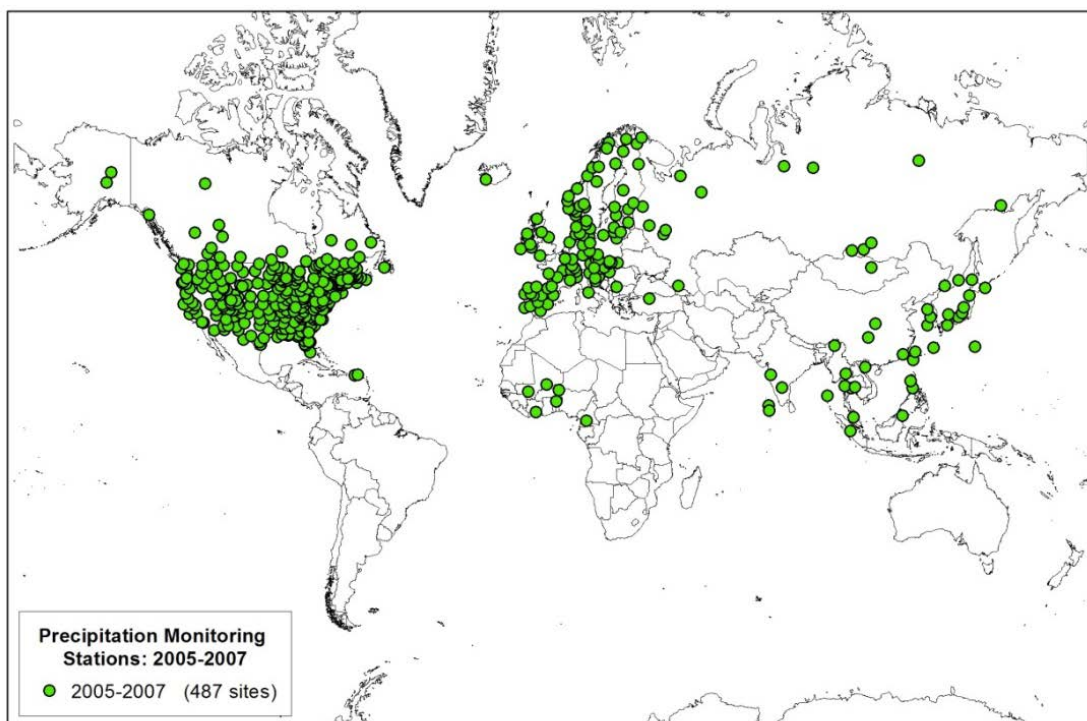
Measurements

Gathered, assessed and integrated data from major regional and national wet deposition monitoring networks

Over 470 sites for the 3-year average wet deposition maps: 2000-2002 and 2005-2007

- **Africa and South America:** Deposition of Biogeochemically Trace Species (IGAC/DEBITS)
- **Canada:** Canadian Air and Precipitation Monitoring Network (CAPMoN) and provincial networks
- **East Asia:** East Asia Network (EANET)
- **Europe:** European Monitoring and Evaluation Program (EMEP)
- **Global:** World Meteorological Organization's Global Atmosphere Watch Programme (WMO/GAW)
- **United States:** National Atmospheric Deposition Program (NADP)
- **Other national networks:** India, Russia

Data assessed using WMO guidelines



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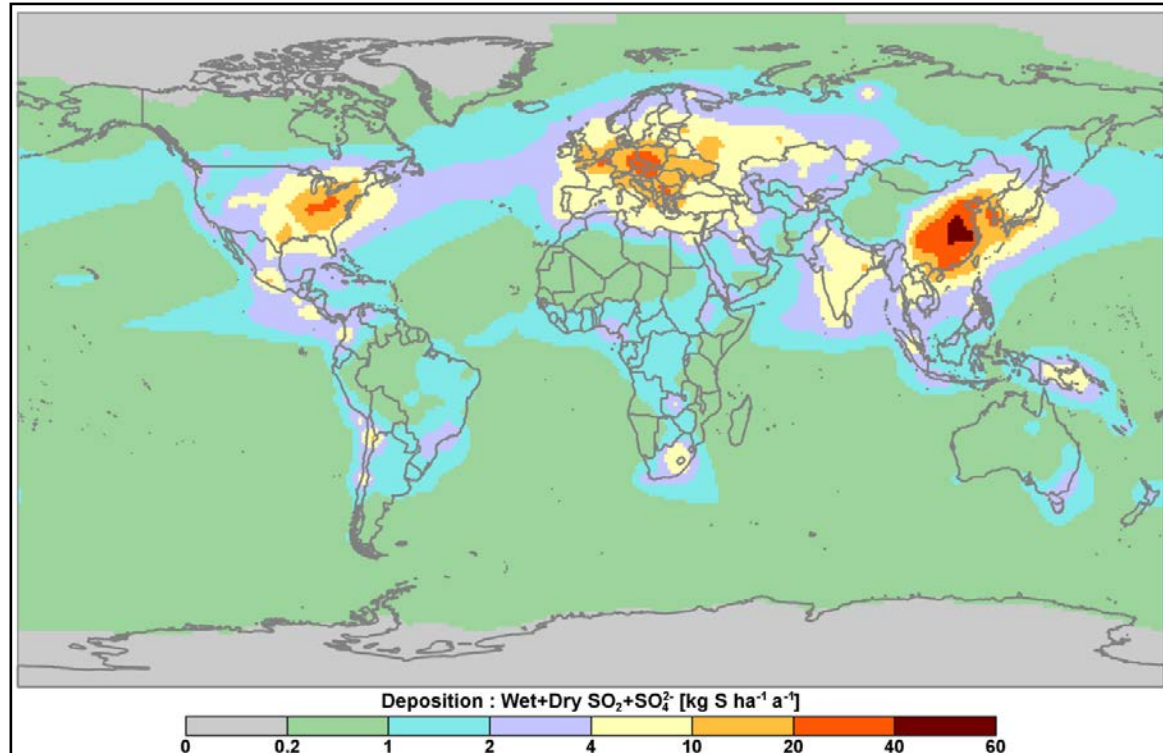
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Models

*The HTAP 2001 Model Intercomparison**

- **28 global models**
- **ensemble mean** model results mapped globally and regionally:
 - Sulphur: 19
 - Oxidized Nitrogen: 16
 - Reduced Nitrogen: 7
 - Precipitation Depth: 16
 - Sea-Salt: 8



* *Coordinated Model Studies Activities of the Task Force on Hemispheric Transport of Air Pollution (TF HTAP) under UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP)*



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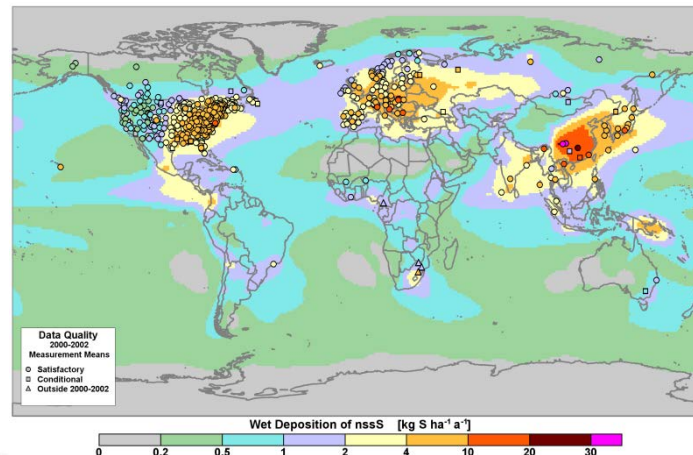
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Products

- **Data Sets:** quality-assured global data set of measurements from regionally-representative sites around the world
 - *downloadable from the World Data Centre for Precipitation Chemistry (<http://wdcpc.org/>)*
 - *accessed/used by several scientific communities*
- **Global maps:**
 - *Measurement-based, model-based, combined measurement-model*
 - *Available in the manuscript and the Addendum (Supplementary Material)*



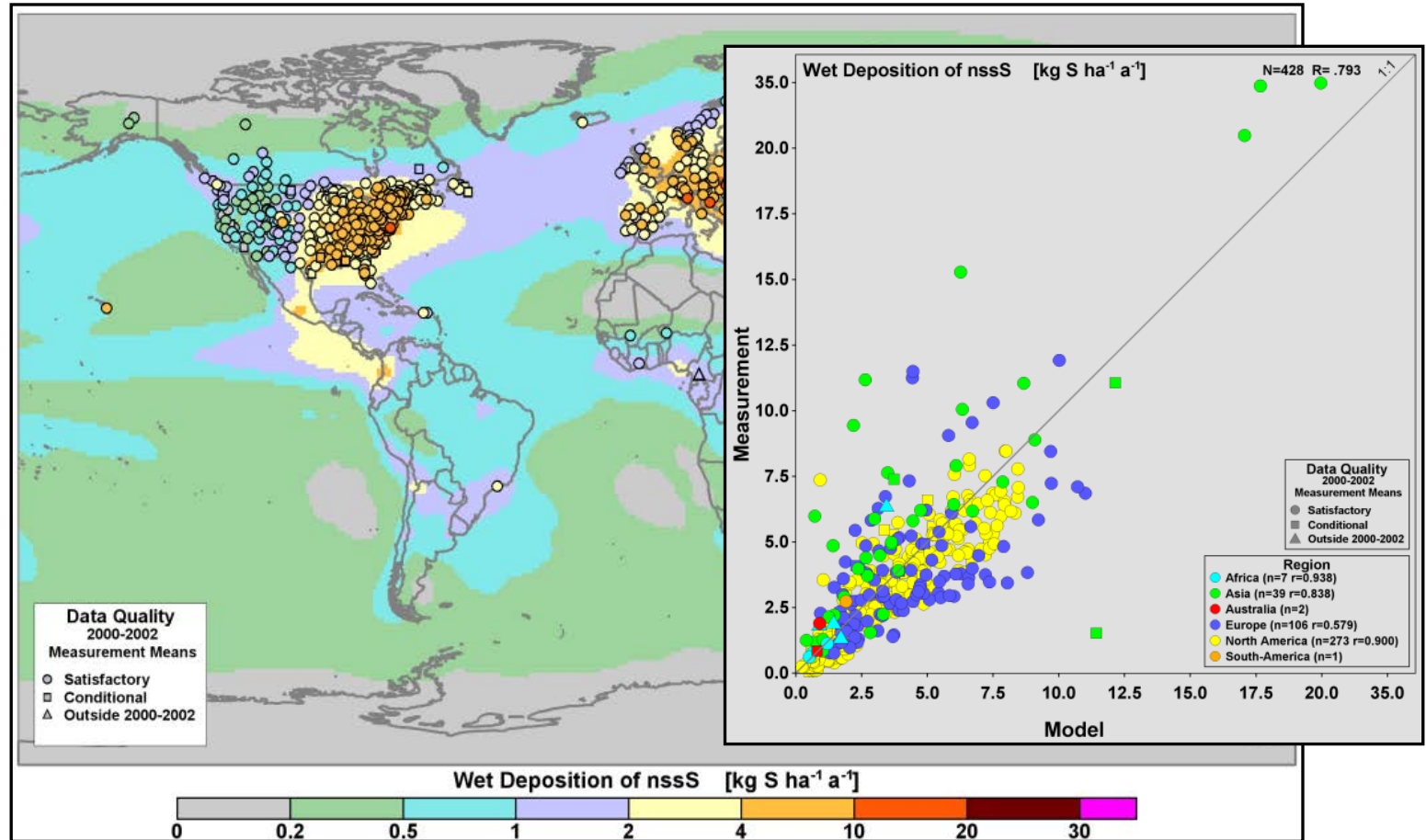
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Global Results

Sulfur: Wet deposition of non sea salt sulfate ($\text{kg S ha}^{-1} \text{a}^{-1}$)

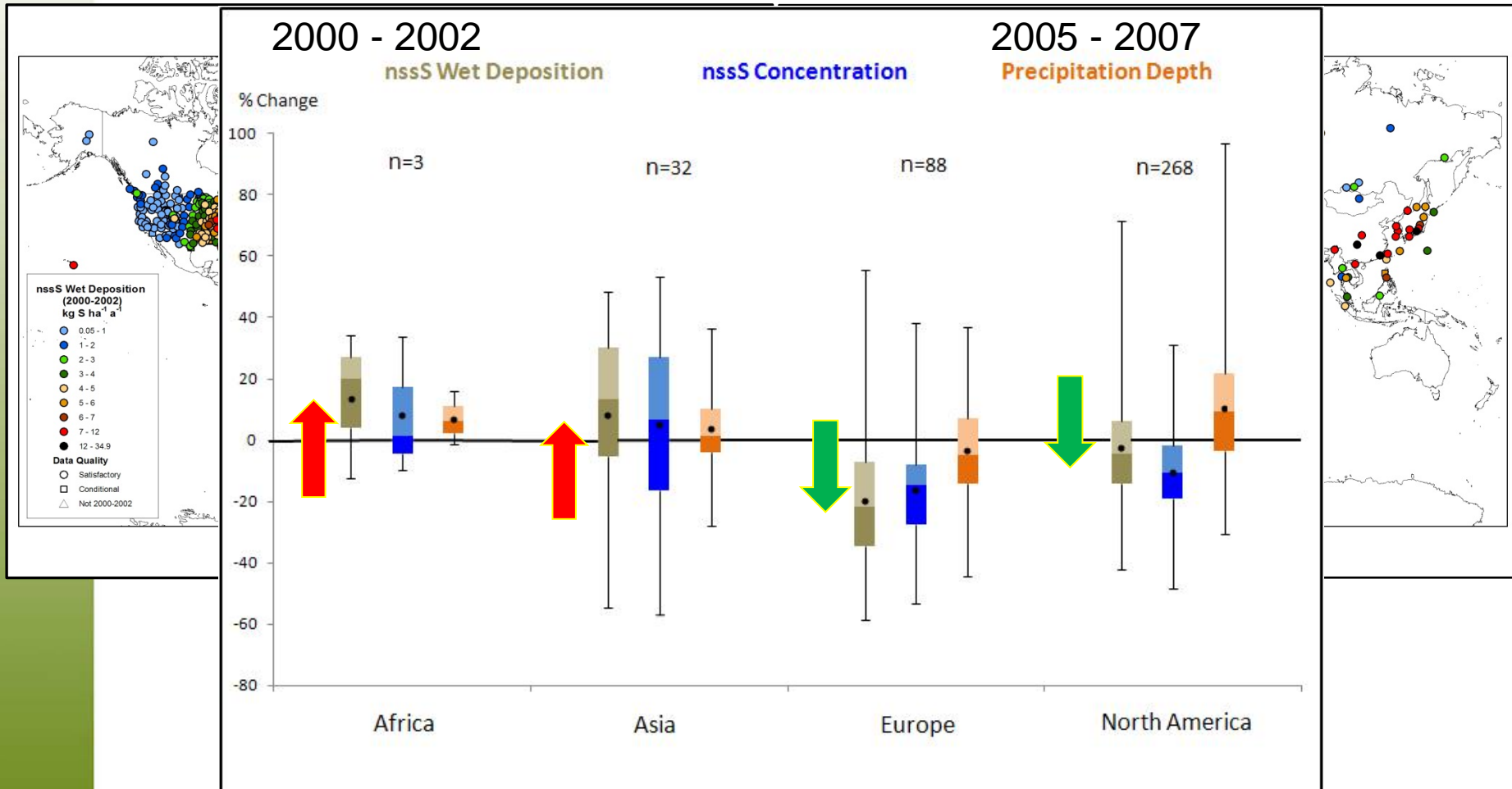


- *High deposition in eastern North America, Europe and Asia*
- *Reasonable model-measurement comparability*



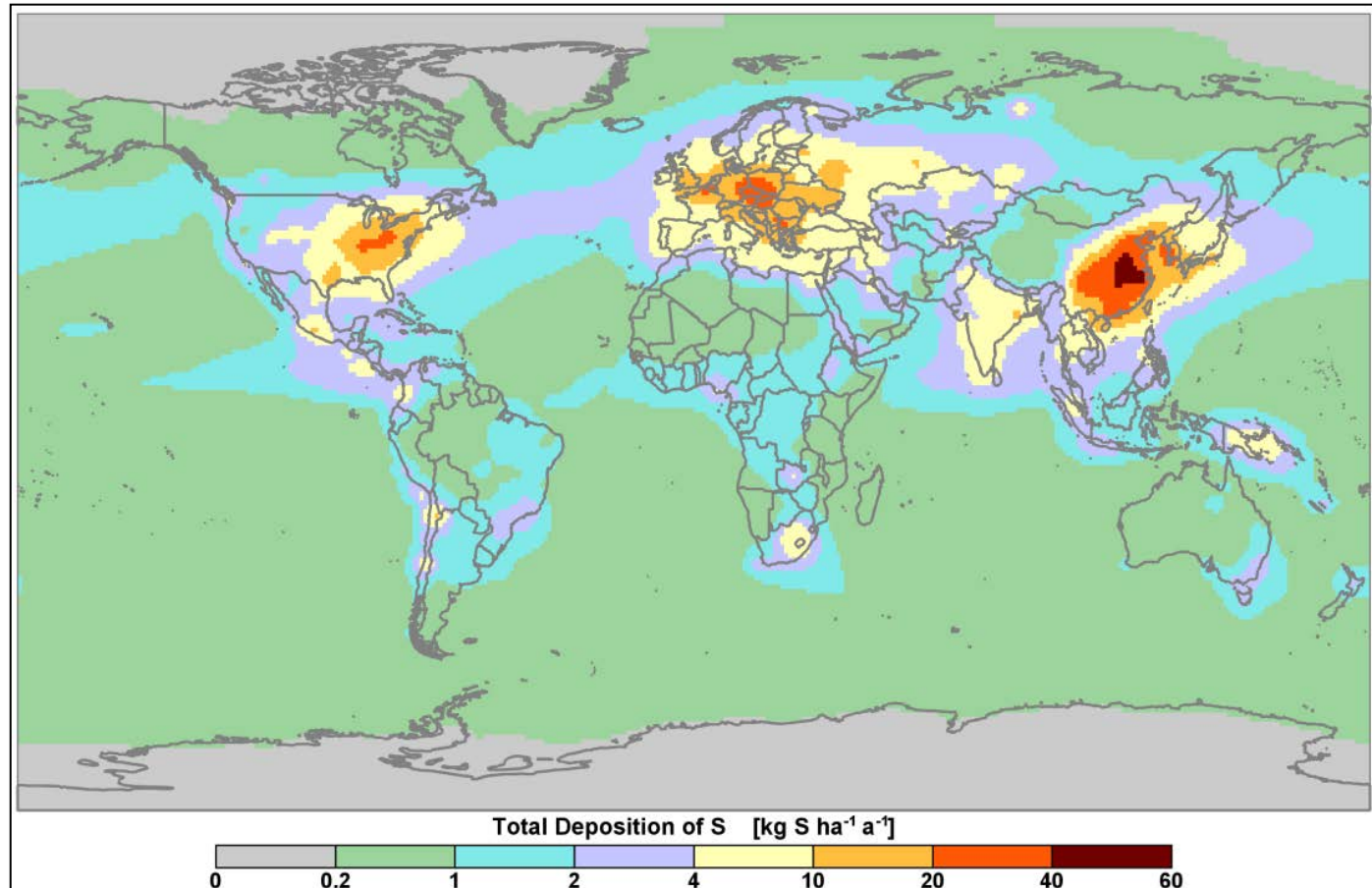
Sulfur: Wet deposition of non sea salt sulfate (kg S ha⁻¹ a⁻¹)

Wet Deposition Changes from 2000-02 to 2005-07



Sulfur:

Wet + Dry deposition ($\text{kg S ha}^{-1} \text{ a}^{-1}$)



- High wet+dry deposition in eastern North America, Europe and Asia
- Ranges from 0.1 to $60 \text{ kg ha}^{-1} \text{ a}^{-1}$

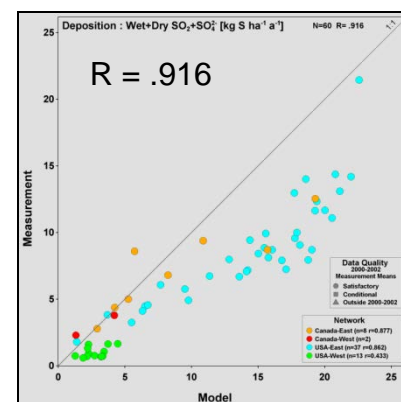
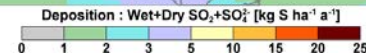
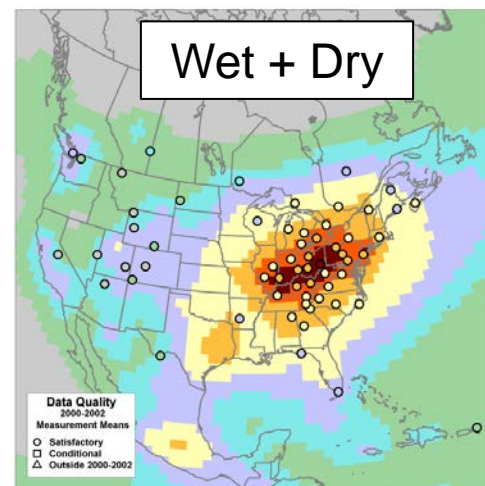
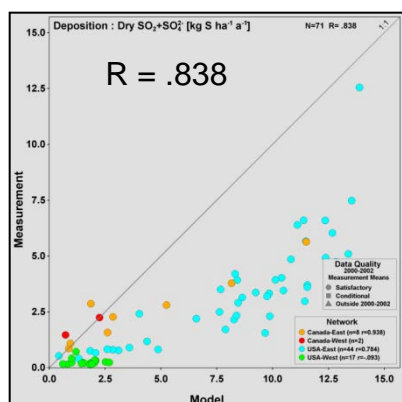
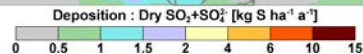
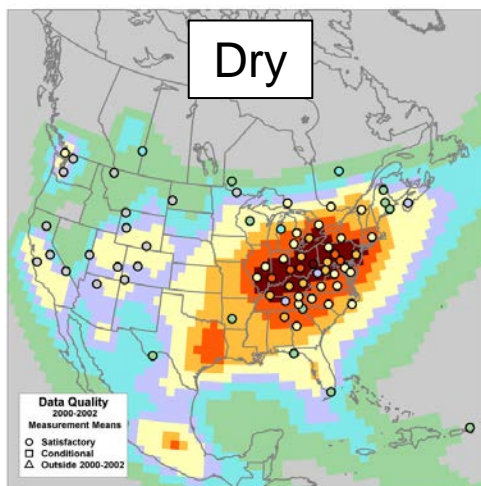
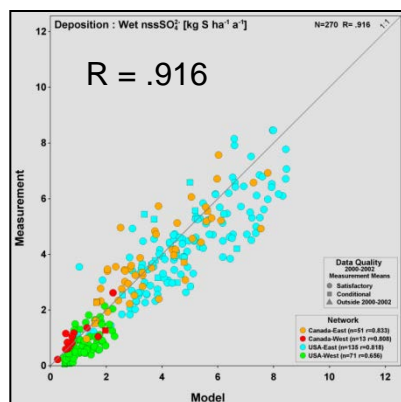
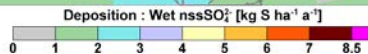
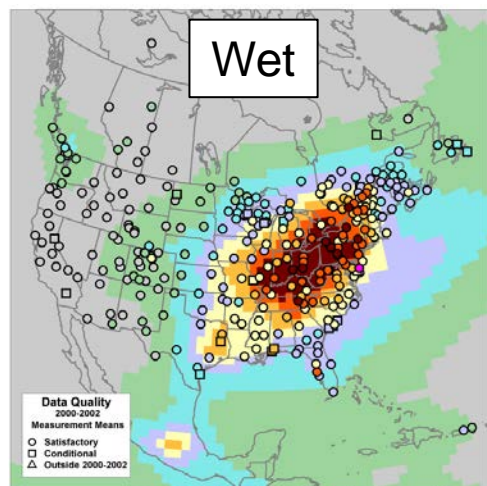


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United States (NADP and CASTNET) and Canada (CAPMoN): Sulfur - Wet, Dry and Wet+Dry Deposition of nssS



- High deposition measured and modelled in eastern North America
- Poor dry deposition modelling in eastern USA



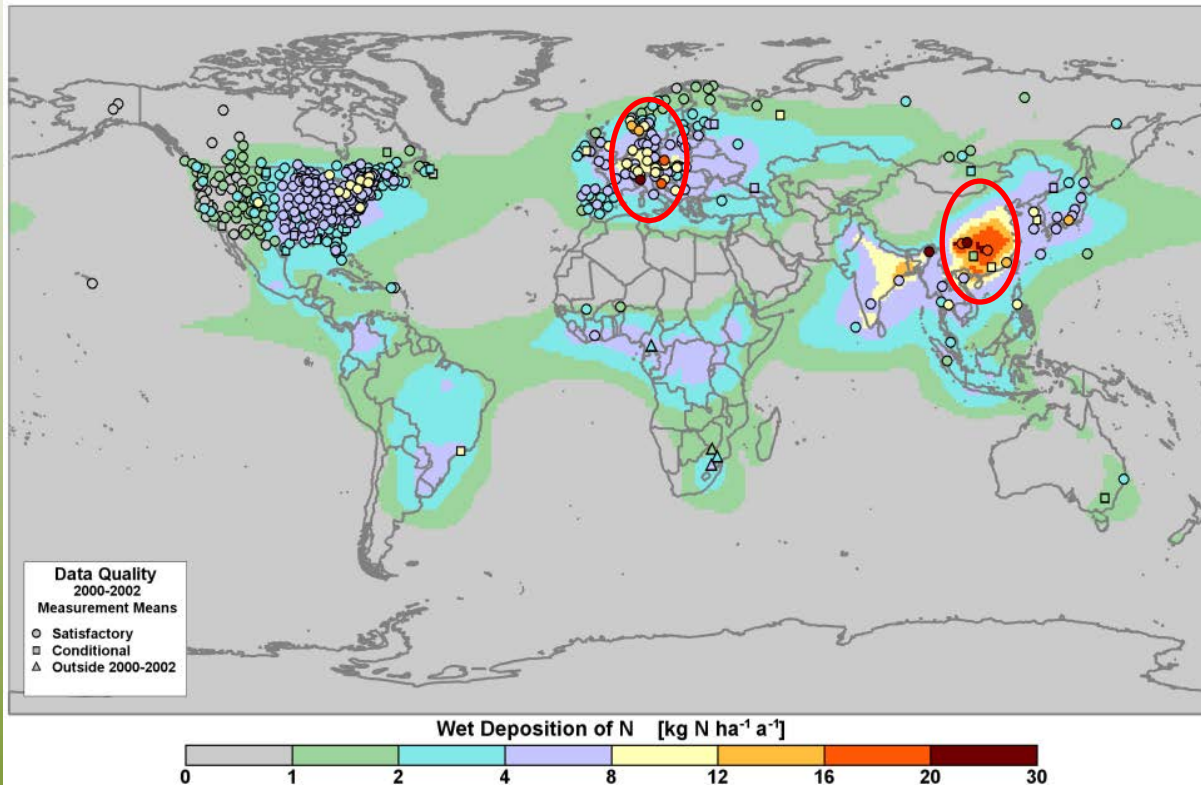
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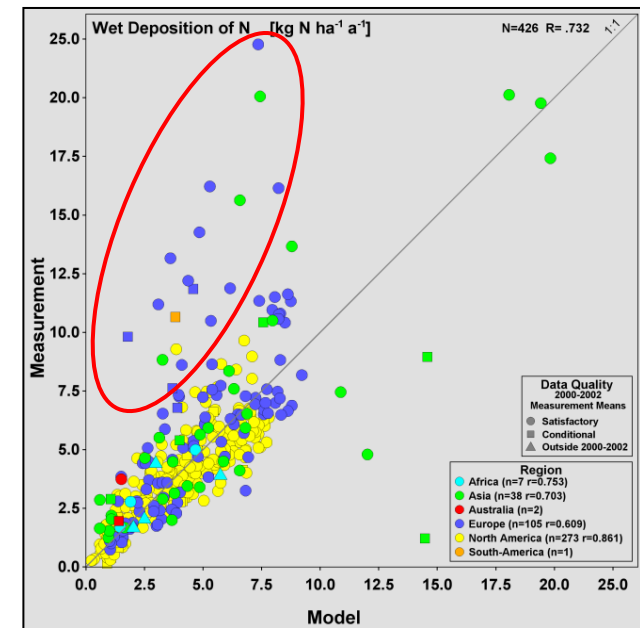
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Nitrogen

Wet deposition of Oxidized + Reduced Nitrogen



Model versus Measurement Results



- High deposition in eastern North America, Europe and Asia
- Reasonable model-measurement comparability except in Europe and parts of Asia



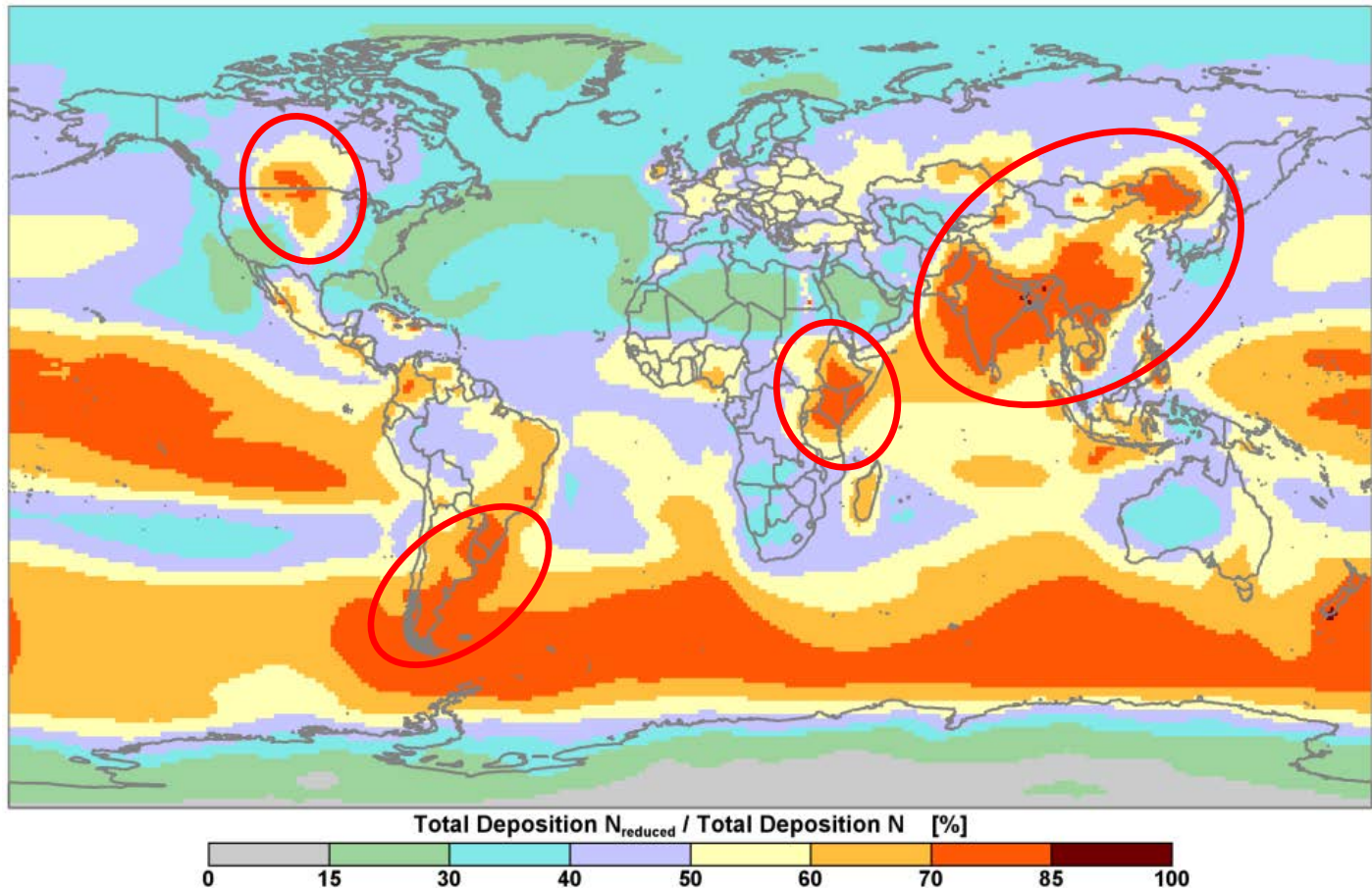
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Nitrogen wet and dry deposition:

Which is more important – oxidized or reduced nitrogen?



- Reduced nitrogen deposition is more important in agricultural areas, dry areas, and the oceans of the southern hemisphere

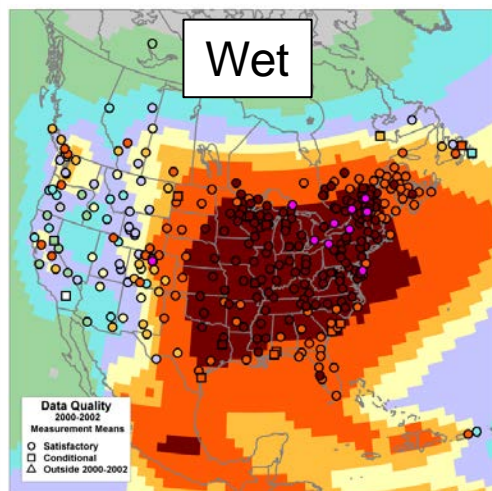


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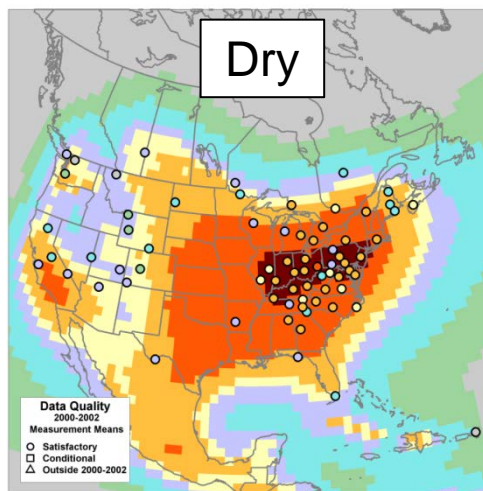
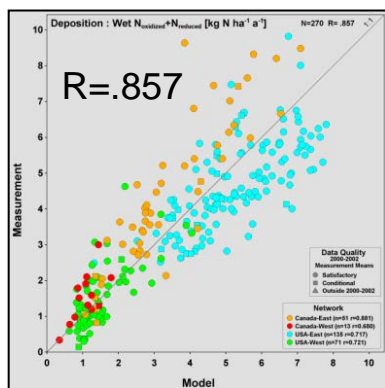
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U.S and Canada: Wet, Dry and Wet+Dry Deposition of N (NO₂ and NH₃ not included in measured dry and total deposition)



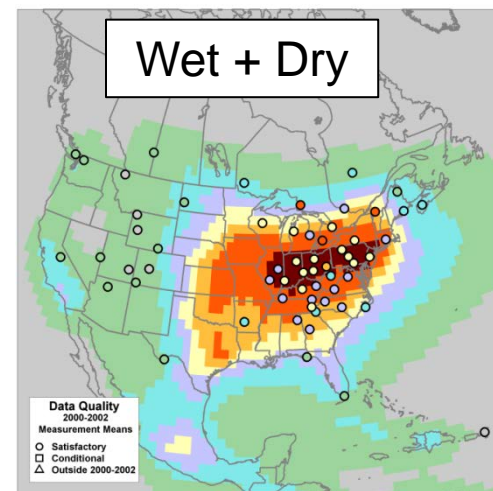
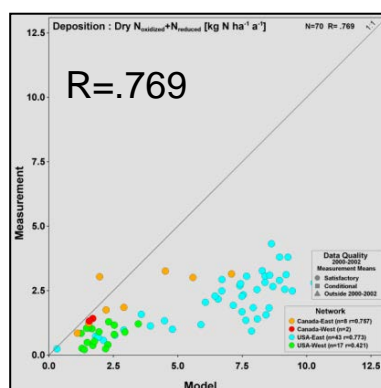
Deposition : Wet N_{oxidized}+N_{reduced} [kg N ha⁻¹ a⁻¹]

0.15 0.3 0.6 0.9 1.2 1.5 2 4 8



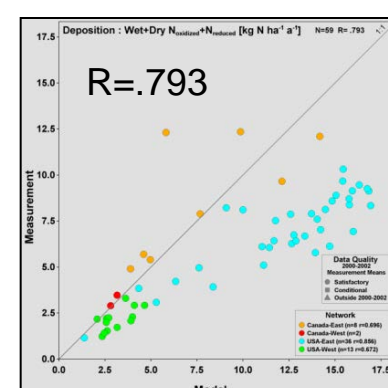
Deposition : Dry N_{oxidized}+N_{reduced} [kg N ha⁻¹ a⁻¹]

0 0.25 0.5 1 1.5 2 4 8 12



Deposition : Wet+Dry N_{oxidized}+N_{reduced} [kg N ha⁻¹ a⁻¹]

0 2 4 6 8 10 12 15 20



- High deposition measured and modelled in eastern North America
- Poor dry deposition modelling in eastern USA



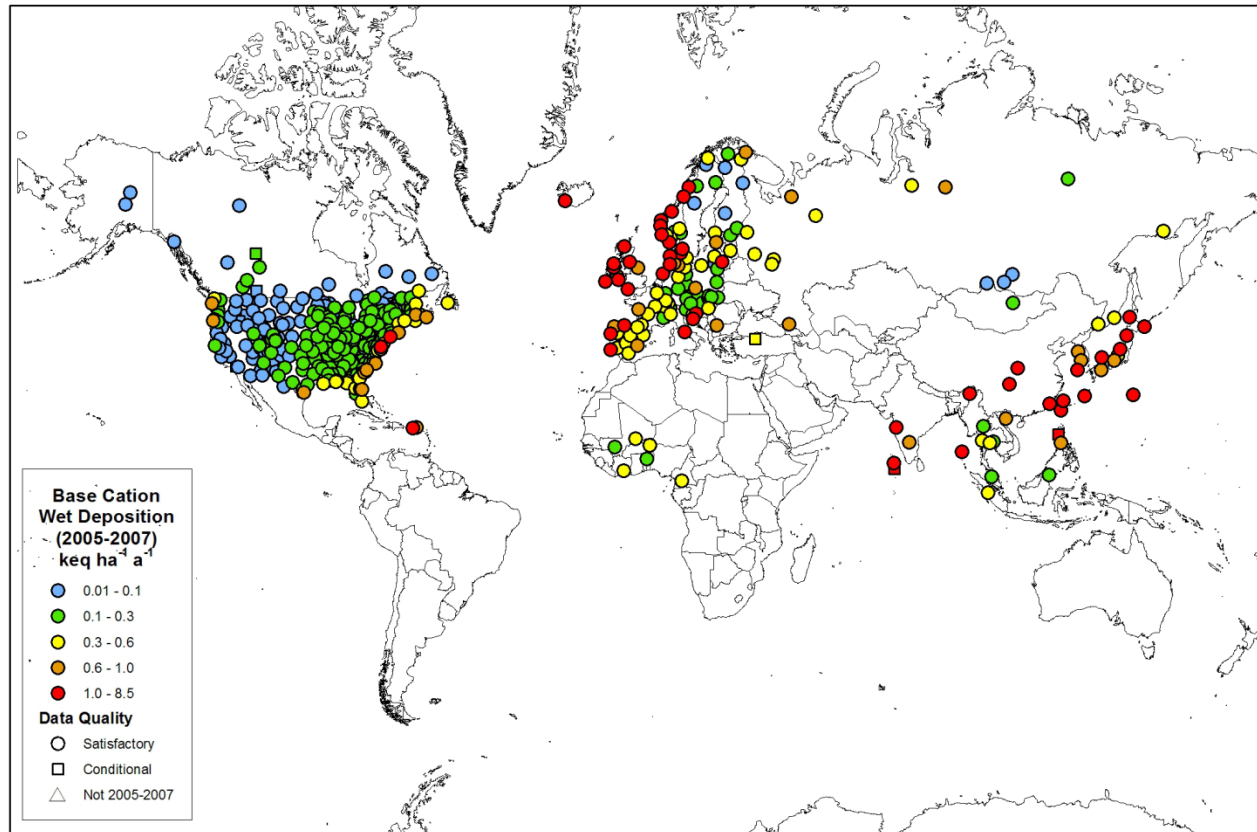
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Base Cations

$\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^{+} + \text{K}^{+}$ wet deposition

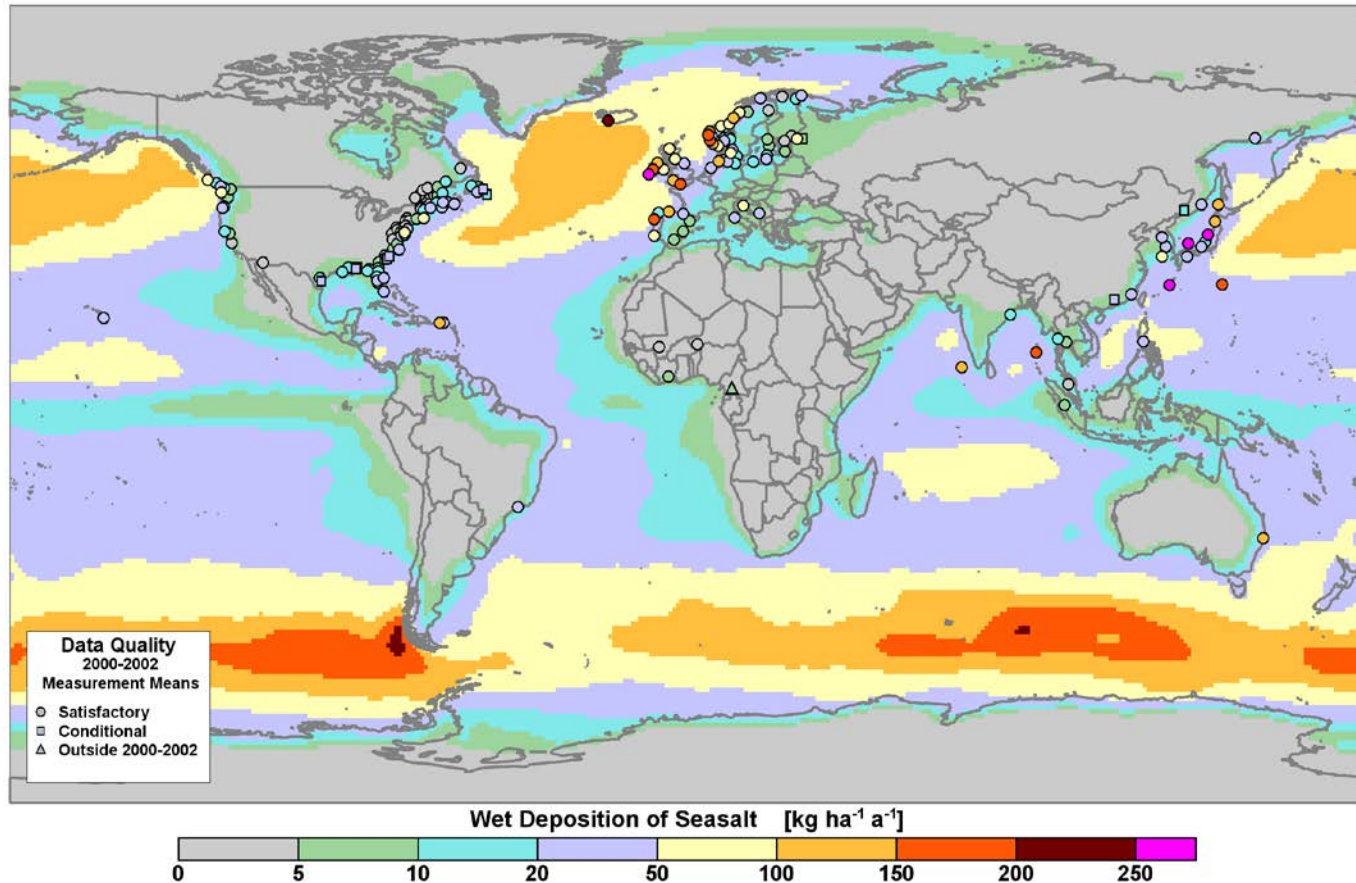


- *High deposition along coastlines and in dusty areas*
- *Range from 0.1 to 8.5 $\text{keq ha}^{-1} \text{a}^{-1}$*



Sea Salt

Modeled and measured wet deposition ($\text{kg ha}^{-1} \text{ a}^{-1}$)



- Areas of deep continental penetration (up to 500 km) and areas of little penetration for wet, dry and wet+dry deposition



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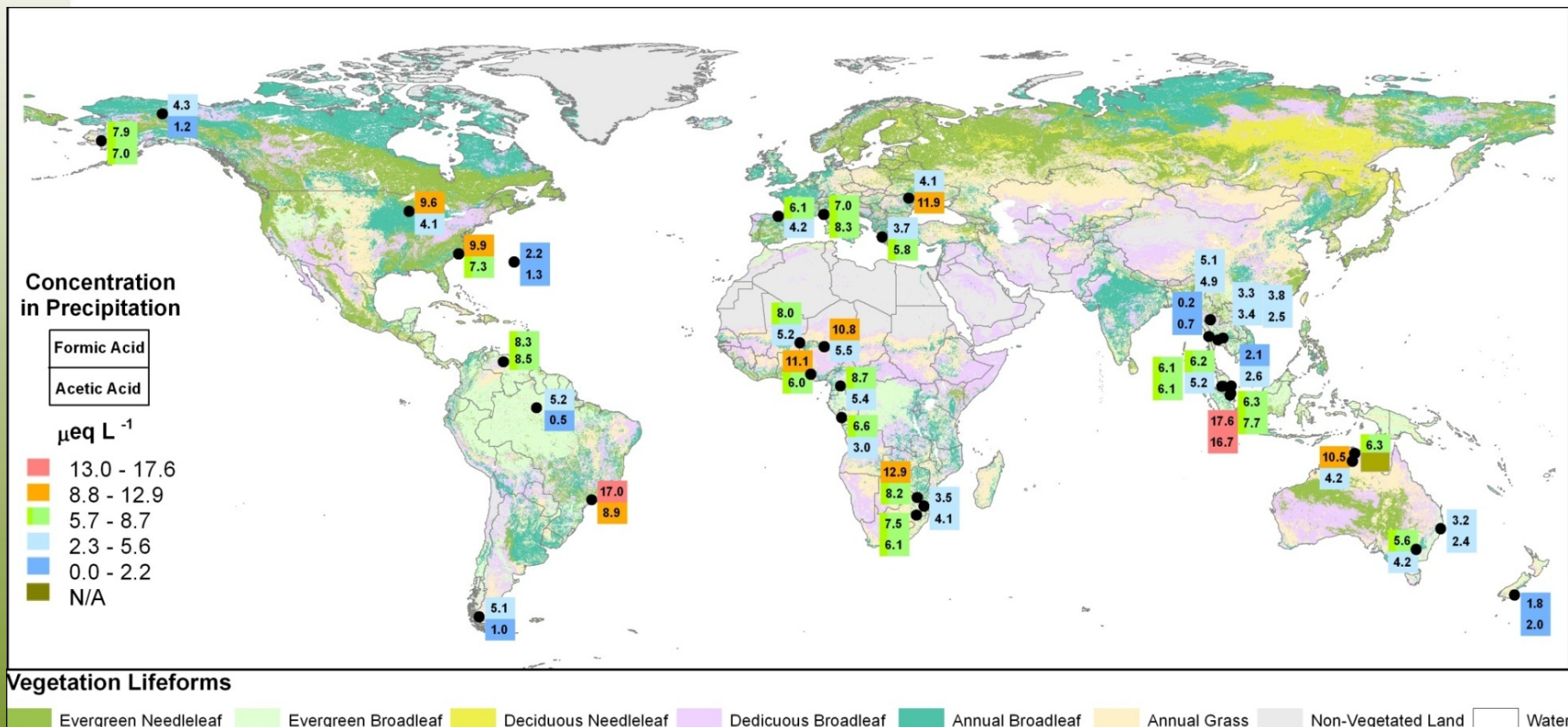
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Organic Acids

Formic (top) and Acetic (bottom)

Concentration ($\mu\text{eq L}^{-1}$)



- In general, formic acid > acetic acid*
- No routine measurements anywhere but Africa*



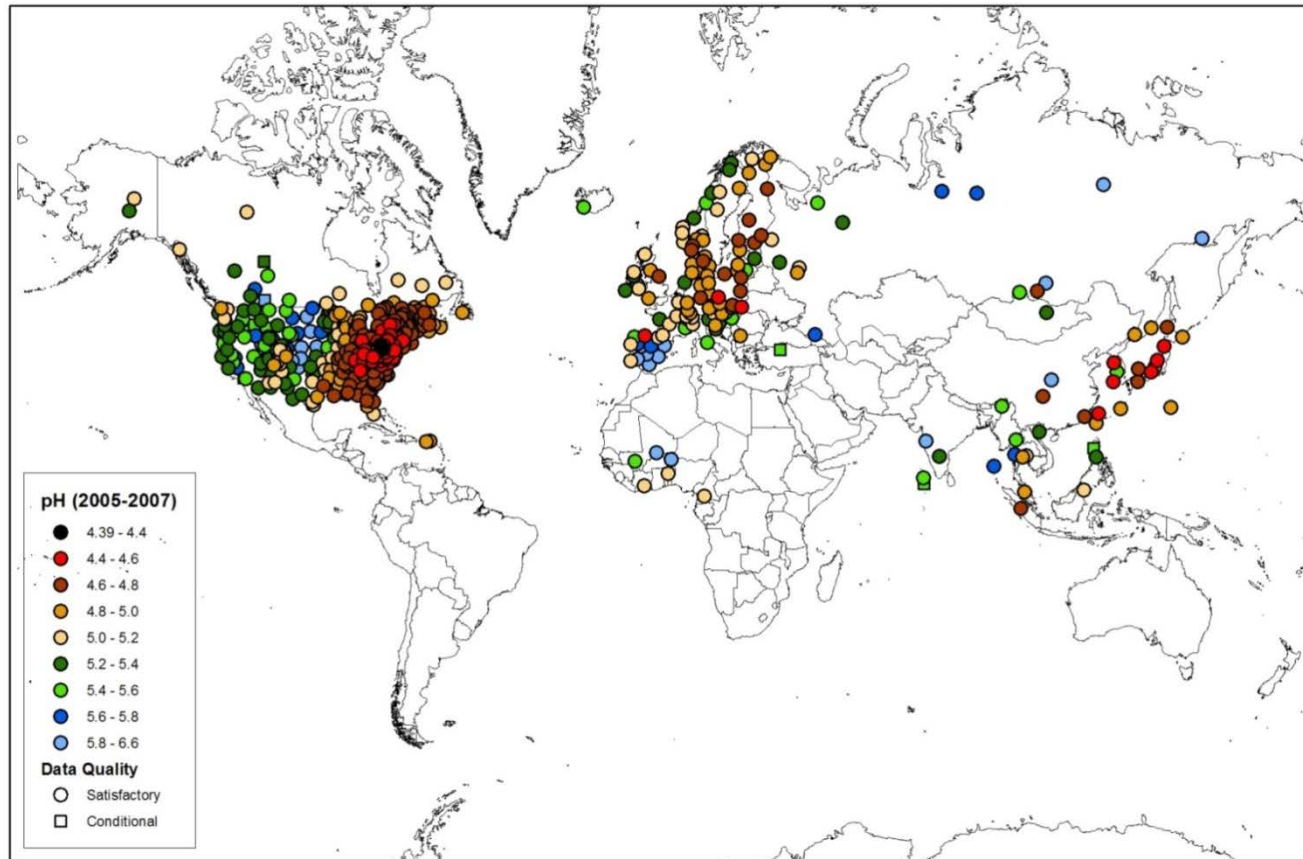
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pH

(2005-2007)



- *lowest pH where sulfate and nitrate are highest*
- *ranges from 4.4 to 6.6*



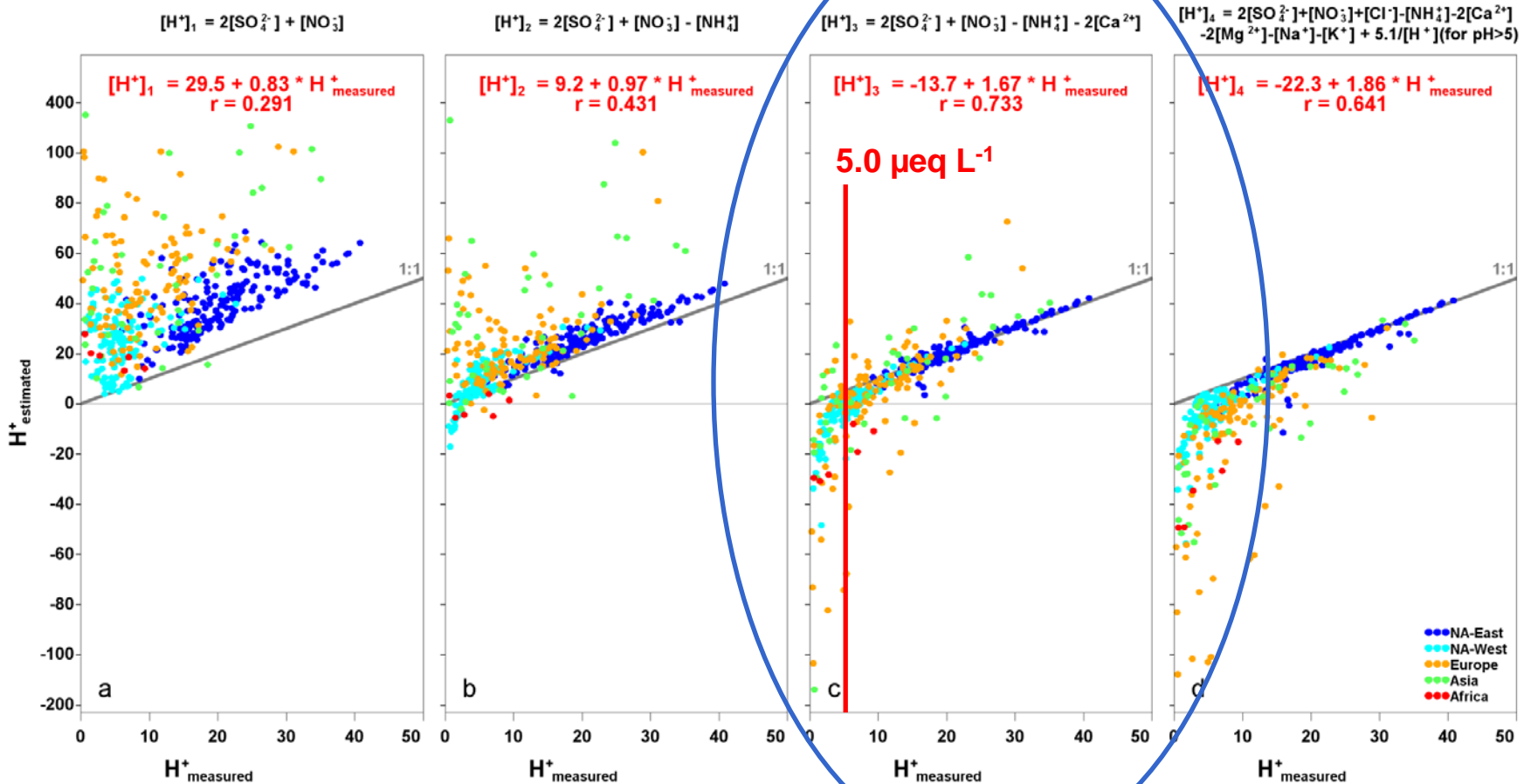
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H⁺ Concentration (μeq L⁻¹)

Estimated [H⁺] compared to measured [H⁺]



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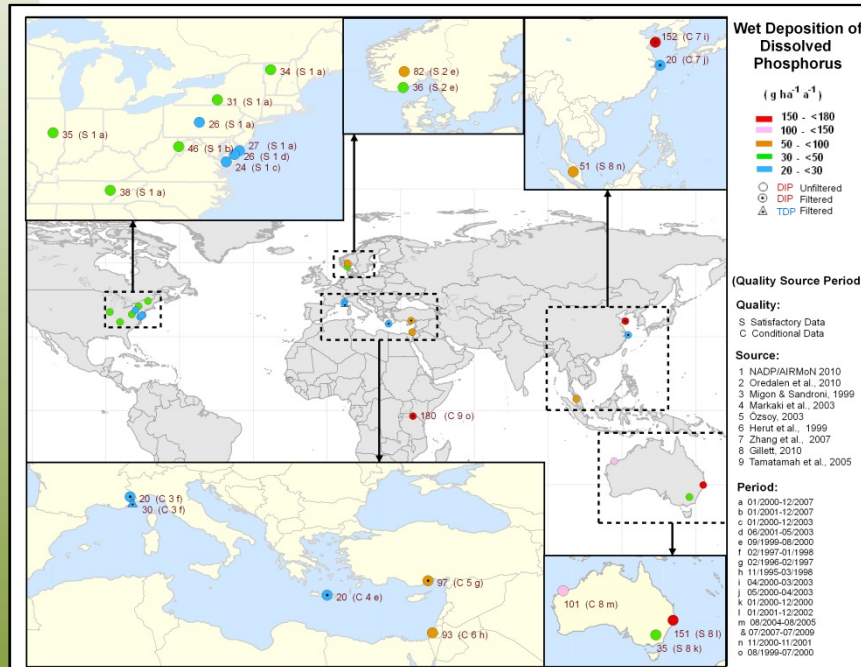
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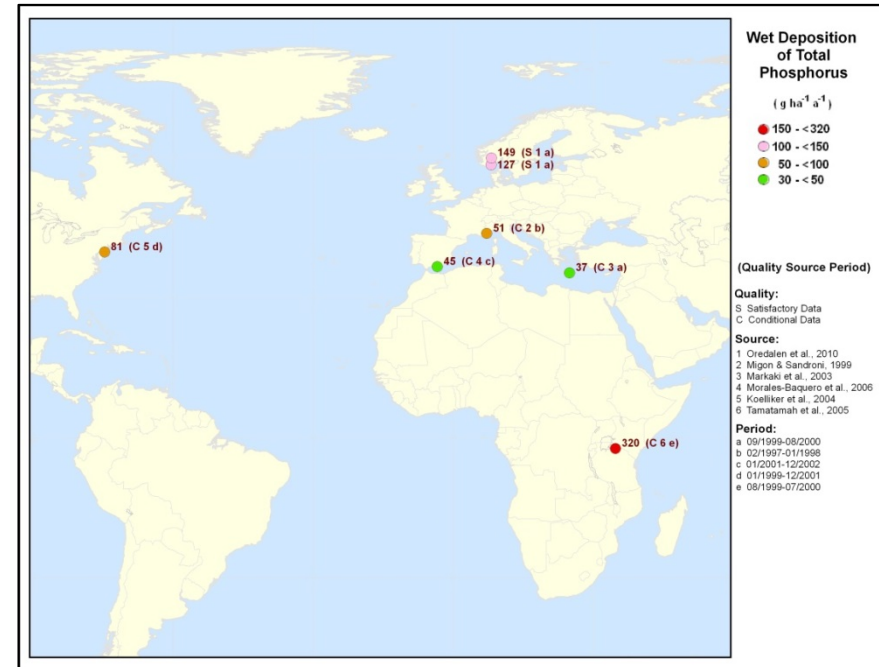
Phosphorus

Wet Deposition of Dissolved Inorganic P and Total P

Wet Deposition of Dissolved Inorganic P



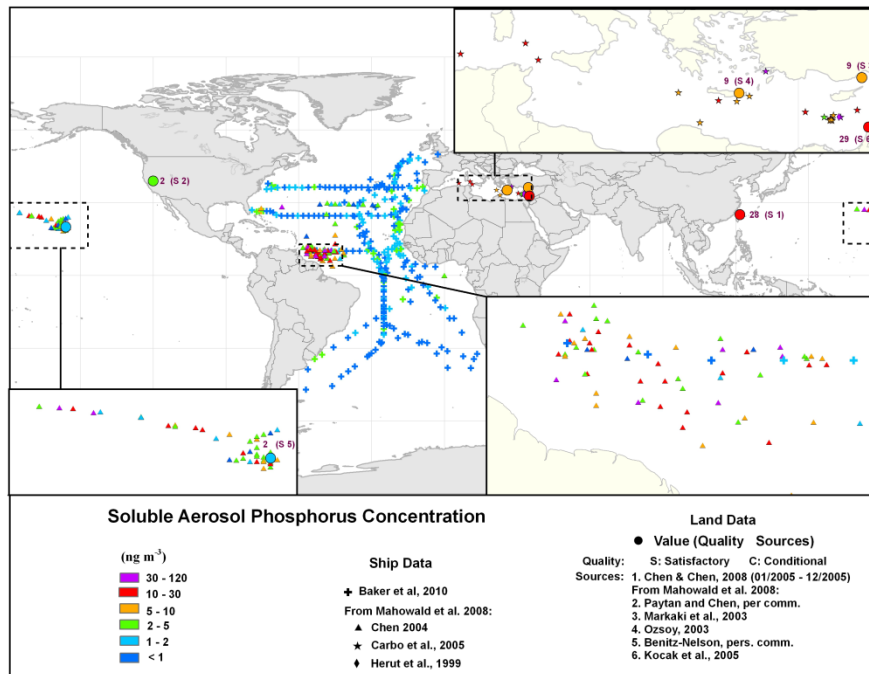
Wet Deposition of Total P



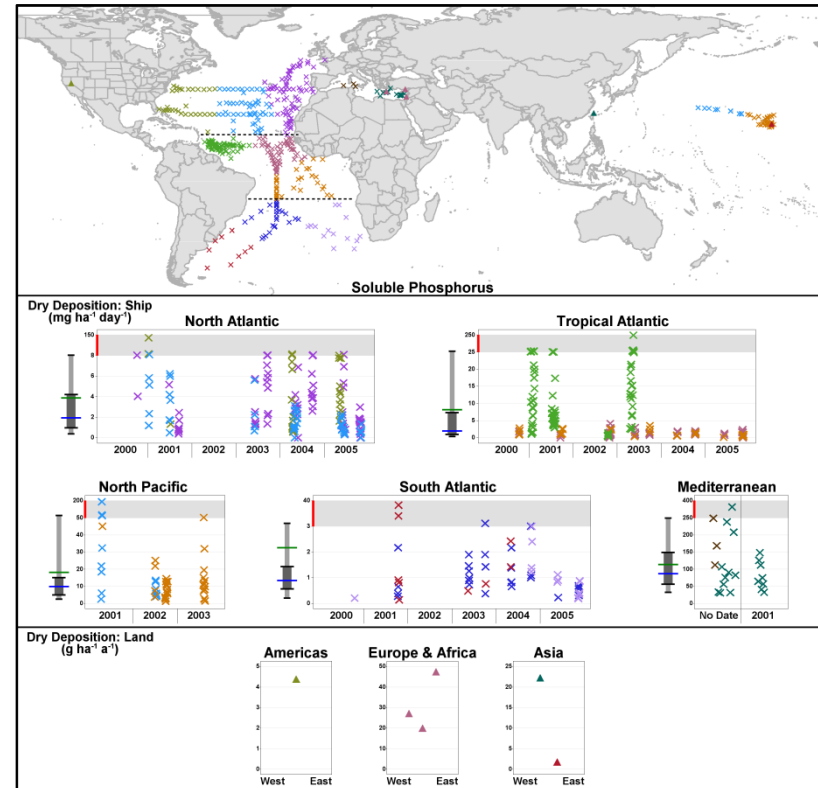
Phosphorus

Air concentrations and dry deposition estimates of soluble aerosol phosphorus

Air Concentrations of Soluble Aerosol P ($\mu\text{g m}^{-3}$)



Dry Deposition of Soluble Aerosol P



Dry deposition = Measured concentration x modeled dry deposition velocity



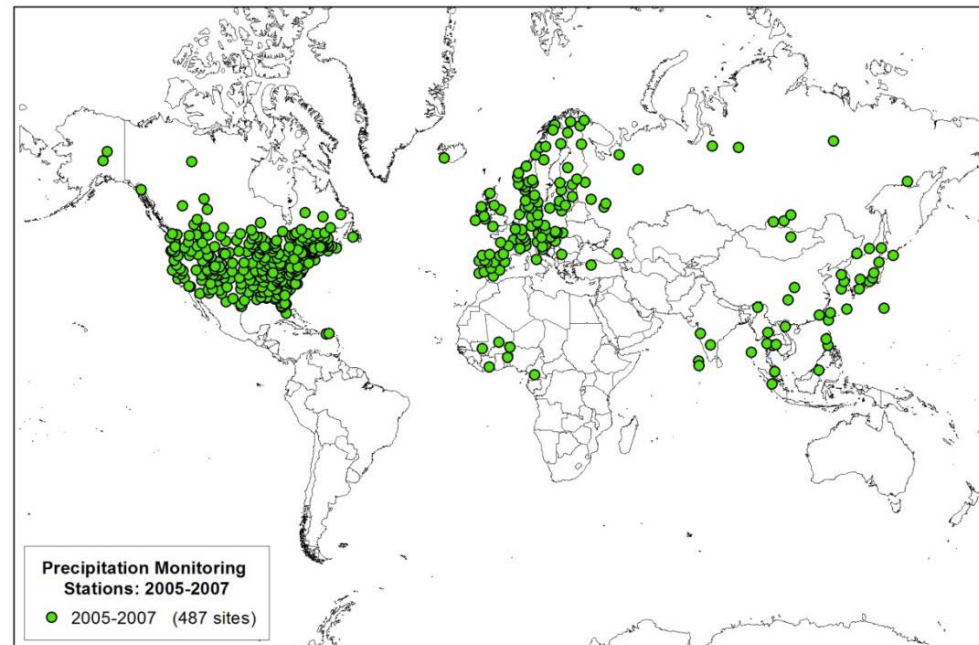
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Gaps and Recommendations

- There are large areas of the world, including areas where emissions are increasing, that remain under-monitored or not monitored, e.g. South America, Africa, northern Canada, Asia, Oceania
- Increased spatial coverage is needed for long term wet and dry deposition measurements of acidifying species, base cations, sea salt, organic acids and phosphorus.



Gaps and Recommendations

- Dry deposition is poorly monitored and inconsistently estimated worldwide. Canada and the USA need routine measurements of NO_2 and NH_3 to close the nitrogen deposition budget. The two countries also need to reconcile their inferential dry deposition models
- Inferential dry deposition models need to be applied in other areas of the world where regionally-representative air concentration data are available, most notably Europe and Asia
- In eastern Canada, there is a need to investigate the increasing influence of organic acids while the influence of strong acids decrease (sulfuric and nitric)
- Bicarbonate, formate and acetate should be measured in areas of the world where $[\text{H}^+] > 5 \mu\text{eq L}^{-1}$ (including North America)



Gaps and Recommendations

- Wet and dry deposition of phosphorus is poorly understood and measured worldwide; scientific direction is needed
- Deposition and long-range transport of hazardous air pollutants (POPs, metals) were not addressed in this assessment but are of global and regional concern
- Measurements are needed to evaluate and improve chemical transport models (e.g., AQMEII)
- Measurements, models and remote sensing results need to be combined (measurement/model fusion) to establish best spatial distributions of pollutants and deposition.



NADP in the global context

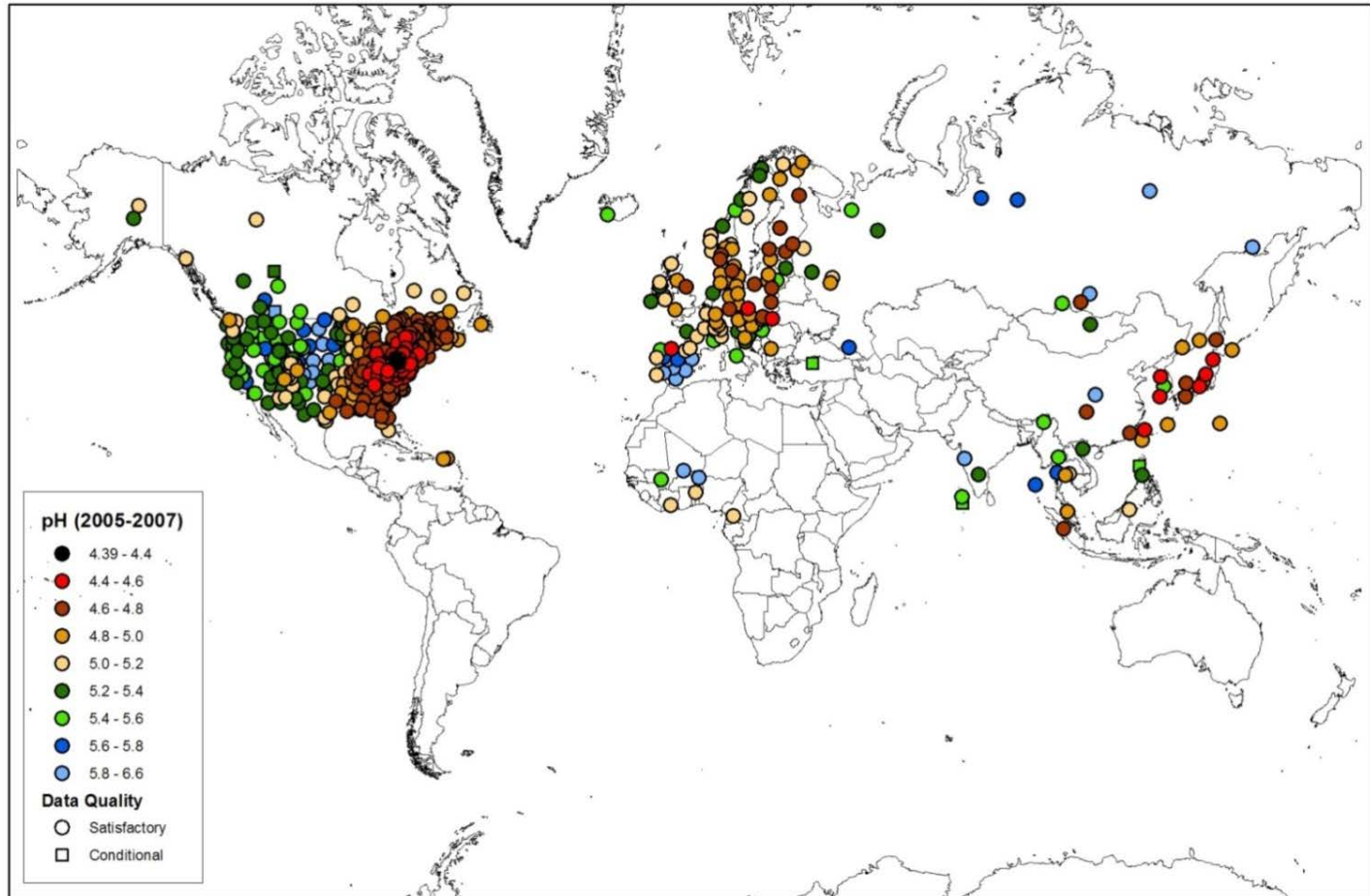
“Outstanding”

- *Every NADP site is important regionally and globally*
- *NADP’s emphasis on high quality measurements has paid off*
- *Dry deposition and total deposition are still high priority issues and the combination of NAPD and CASTNET is extremely important*



End

Global Distribution of pH (2005-2007)



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