SOS Ocean-Atmosphere Literacy Partnership

BEST PRACTICES REPORT

August 2011

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Introduction

In 2008, the American Museum of Natural History (AMNH), the Science Museum of Minnesota (SMM), and the Maryland Science Center (MSC) began a partnership to produce new content for NOAA's Science on a Sphere that promotes scientific literacy about the connections between the ocean and the atmosphere. This "SOS Ocean-Atmosphere Literacy Partnership" was funded by a two-year, $299,607 NOAA Environmental Literacy Grant. The effort had four main goals:

	Goals	Producer	Available at
1	Produce *Forecast: Tropical Cyclone*, a 6-minute autorun program about tropical cyclones	AMNH	http://sos.noaa.gov/datasets/extras/forecast_amnh.html
2	Produce *The Flow: Currents and Climate*, a 6-minute autorun program about ocean-atmosphere thermodynamics	SMM	http://sos.noaa.gov/datasets/extras/flow_smm.html
3	Develop associated live programs using media modified from the autorun pieces	MSC	*Forecast: Tropical Cyclones*: http://sos.noaa.gov/docs/msc_scripts/forecast.html *Tracking a Tropical Cyclone*: http://sos.noaa.gov/docs/msc_scripts/tracking.html *The Ocean-Climate Connection*: http://sos.noaa.gov/docs/msc_scripts/ocean_climate.html
4	Evaluation of content throughout	SMM, ILI	Formative evaluation (*Forecast: Tropical Cyclone*) Summative

			evaluation: http://www.oesd.noaa.gov/network/SOS_evals/Ocean_Atm_Lit_Summ_Report.pdf

Through these activities, we aimed to advance methods and production values for creating both autorun and live content for SOS presentation and other spherical display formats. The following pages summarize our process and recommendations, which we intend to be useful for developers and presenters of data visualization content both in spherical and flat-screen environments to enhance scientific literacy for audiences at informal science institutions. If you are an exhibition developer, media producer, scientist, writer, evaluator, educator, presenter or another member of a museum or science center team that aims to tell a scientific story through visualization, animation and/or video, this document will familiarize you with our production processes, outcomes, and tips to help you:

- Assemble a production team
- Connect and collaborate with scientists
- Define your project management strategy
- Make effective choices in the editorial, design, and audio production realms

Overall Project Management

Management of each goal on pp. 3–4 was conducted largely by the responsible institution, with periodic collaboration—conference calls and video conferencing, in-person meetings, emailing scripts, etc—to ensure that efforts were complementary and reflected input from the partners.

Scientific partners were established at the outset of the partnership to provide data and expertise during the development of autorun and live programming. Scientists from the NOAA Geophysical Fluid Dynamics Laboratory and the NOAA Climate Program Office fulfilled major advisory roles. The interaction consisted of multiple in-depth meetings both in person and on the phone to help guide scientific messaging, data provision, and the accuracy of content. During development, producers also consulted a number of other experts for data and advisement on relevant parts of the content.

Authentic and invested scientific advisement cannot be underestimated as an essential part of a successful science media program. For more on collaborating with scientists, see p. 9.

Autorun Content

I. PROJECT MANAGEMENT

a. Production Process

AMNH and SMM conducted a similar development process for their respective autorun pieces. At the same time, differences in team makeup, resources, and work processes at each institution resulted in unique choices and outcomes for each piece. Roughly, the autorun development process was as follows:

1. Develop scientific literacy goals and main messages for the piece in consultation with scientific advisors.
2. Refine goals.
3. Research content and collect reference materials to develop narrative and visual flow.
4. Prepare outline of narrative; test animation ideas. Review with scientific advisors.
5. Write draft script.
6. Sketch storyboard and/or prepare animatic (animated storyboard) using reference imagery. Review script and storyboard with scientific advisors.
7. Test storyboard and script with visitors.
8. Acquire data for data visualizations and imagery and stock footage; conduct live action shoots.
9. Iterate storyboard/animatic and script drafts with scientific advisers.
10. Develop draft of piece using scratch narration to record periodic script revisions; conduct playback testing and staff reviews. Iterative reviews with scientific advisors.
11. Formative evaluation of draft piece.
12. Revise script and visuals based on evaluation and advisement.
13. Record final narration
14. Summative evaluation of final piece.

b. Time Frame:

The partnership began in May 2008. In 2010, the partnership obtained a 1-year no-cost extension from NOAA. The final summative evaluation report was delivered in November 2010.

The autorun development process above took about 18 months for each team—a process that was longer and involved more staff time than was anticipated in the project proposal. An autorun piece of similar scope could take less or more time depending on staff capacity and experience, production values, and time available. See the next section for more details on budgeting staff time to a similar project.

c. Production Team Assembly

Producers of SOS autorun pieces will face decisions regarding what's possible and desirable to handle using existing staff versus contracting the necessary expertise. The different choices made by AMNH and SMM lend some insight.

The two institutions' production teams included the following:

- **AMNH:** Primary (budgeted) staff: 1 writer/producer, 2 animators, 1 executive producers, 1 editorial director. Additional support (nonbudgeted) from IT specialists, sound engineers, scientific advisors, and a second executive producer. Contracted: Narrator.
- **SMM:** Staff: 1 project leader, 1 exhibit developer/writer. Contracted: 2 media producers, multiple actors, final narrator, audio engineer. Additional support from scientific advisors.

AMNH's Choice: In-House

The AMNH team had not developed an animated spherical visualization before producing *Forecast*, but had extensive experience with flat-screen animated visualization for museum audiences as part of AMNH's Science Bulletins program, a multimedia group that develops HD documentary video, visualization, and animation on current science research. Before proposing the SOS Ocean-Atmosphere Partnership to NOAA for funding, Science Bulletins visualization staff had done some preliminary testing of SOS data visualization. Thus, adapting workflow from flat-screen development to a spherical environment was a relatively seamless transition for the AMNH team. (For some challenges, see Playback Testing, p. 20).

As most members of AMNH's primary production team were on staff at the museum, they were able to more or less flexibly contribute time and effort to the project. This allowed more exploration of ideas and extensive revisions to consummate the project. At some point, however, the piece became a labor of love. For the 5 primary production staff, a total of 24 weeks of full-time work were initially budgeted. In the end, easily twice or three times as much staff time was spent.

SMM's Choice: Contractors

SMM staff had previously developed an SOS film (*Blue Planet*) using the museum's in-house video editor. For *The Flow*, the SMM exhibition team wished to push the boundaries as far as visual appeal, human actors, and story development. The team quickly realized they needed external help to move beyond their internal capacity and therefore sought the creative energy of an outside group of local media experts.

However, an SOS producer can't flip to the "spherical video editors" section of the phone book and pick the best ad. It took some effort to find local producers whom SMM felt confident could adapt to the unique visual medium of the SOS. Through connections with a local journalism school, SMM contracted a pair of media experts who had experience working with a public television station and large-scale, multi-screen trade show displays. Using local talent allowed for physical access to SMM's sphere, a key requirement for a production team who had not developed spherical media before.

The fixed price for SMM's contract was $35,000 for an 8–9 minute film. The contract included production and licensing of all video and audio elements, including payments to actors and voice-over talent, but did not include the cost of writing, which was done in-house by SMM, or scientific review.

In the end, SMM's contract budget proved too limited. The producers recommend at least $40,000 for projects of similar scope. (Consider, however, that the cost of video production around the country varies, so budgeting will depend on location.) Adapting to spherical video was a significant and time-consuming learning process for SMM's external video team. Furthermore, due to the temporal and fiscal constraints of a fixed contract, the SMM team did not have the option of extensive iterations and revisions to their piece. This choice prevented SMM from revisiting certain sections that may have needed more work. It did, however, constrain the amount of staff time spent on the project in a way that AMNH's choice did not.

d. Collaborating With Scientists

The authenticity of the scientific stories in this project was made possible by an enthusiastic group of scientists who were invested as advisors from the planning phases of the grant to the final review of the finished pieces.

The PIs of the grant, themselves PhD scientists, established the framework for scientific advisement at the outset of the project. First, they explored possible collaborations by reaching out to experts in the field—both NOAA and university/other government scientists—to share the project plan, discuss the state of the science in consideration, and elicit ideas for the scientific concepts to be presented. During conversations like these, the “chemistry” of a potential collaboration was gauged so that the most suitable partnership could be identified.

Speaking generally, an effective partnership for scientific advisement on a visualization project benefits all parties: the production team gains access to expert advisement, while the experts see their datasets, findings, and/or expertise utilized for outreach and education, their contributions and institutions credited and, in some instances, their time paid for. Each project will have different conditions and different potential advantages for all parties.

NOAA’s Geophysical Fluid Dynamics Laboratory was selected as the key advising body on this project and was included as a partner on the grant application. In setting up the arrangment, the PIs connected not only with GFDL’s scientists but also their communications officer. Using a media relations liaison while establishing a partnership can, in many cases, be quite helpful to establish the expectations of the partnership, gain buy-in with the scientists, and assist with logistics.

After the grant was awarded for this partnership, a kickoff meeting was organized where the GFDL communications officer and several of the scientists came to AMNH to meet their production team and learn more about the project. This meeting was essential to put names to faces and to establish expectations for the workflow over the coming years.

The advising scientists were more involved in the earlier phases of the project than the later phases, when the production teams were conceptualizing the pieces, acquiring data, drafting early scripts, and developing animatics. Several meetings were set up—some by phone and Skype, some in person at the partners' institutions and at convenient locations like ASTC meetings where multiple partners were convening—between the scientists and the production teams to discuss scientific concepts thoroughly, review draft ideas for technical animations, review scripts, etc. This early involvement helped the production teams feel confident they were getting the science accurate from the outset, rather than doing their research solo and having the scientists review and correct after the fact. Once development was in full swing, advisers were contacted when necessary. A final meeting with the advisers and partners was set up to vet the near-final visualization pieces in person on the Sphere, as well as hearing the live-presented versions, to ensure that each piece was scientifically accurate.

In addition to GFDL, the production teams also connected with other scientists along the way for their expertise or datasets. For example, to build the historical storm account map for the AMNH piece (which initially aimed to include audio clips of actors reading from actual historical storm encounters on British, Spanish, and Chinese vessels), the producers sourced ship log accounts from meteorological and maritime scholars in the UK and USA.

All scientific contributors to the project were acknowledged in the autorun pieces' end credits, and GFDL was listed as a scientific collaborator wherever the final pieces were disseminated.

II. EDITORIAL

a. Narrative and Storytelling

A piece that tells a story will better connect with an audience. In *Storytelling as Best Practice*, communications consultant Andy Goodman notes four main considerations:

> *1. People are hardwired to respond to stories.*
> *2. Individual stories are more convincing than sets of data.*
> *3. Stories bring the invisible and abstract to life.*
> *4. The viral marketing of ideas depends first and foremost on stories.*[i]

AMNH and SMM deliberately employed storytelling techniques in their autorun pieces, such as:

- Giving the narrative a distinct beginning, middle, and end.
- Using chapters.
- Telling a historical story.
- Using characters to bring the science alive.
- Alternating between scenes and exposition.
- Using conflicts to add tension, such as a problem for science to overcome.
- Using humor.

Fig. 1: In *The Flow*, SMM used live action characters such as Ben Franklin to relate the discovery of a key connection between climate and the ocean.

Viewers seemed to respond to the storytelling techniques. For example, the summative evaluation found that SMM's Ben Franklin character "seemed to grab people's attention and effectively illustrate the key concepts intended by the program designers."[ii] When asked what concepts in the AMNH autorun piece were new to the evaluated visitors, twenty-six percent of them said the learned of the long history of understanding tropical cyclones.[iii] That a sizeable proportion of visitors noted this among all the other new content introduced suggests that the historical storytelling made a mark.

b. Editorial Process

Visitor evaluation at SMM has shown that the optimal length for a SOS autorun film is about 8-9 minutes maximum. Much of the editorial process for these pieces, then, is largely about boiling down and focusing on main messages—a few clear, simple, important ones. This approach should not be considered a sacrifice, as it will result in a more broadly effective piece. The summative evaluation found that a significant majority of viewers considered the pieces engaging and were able to report main messages that matched the producers' intent.[iv]

This editorial process takes time and expertise. Both production teams revised their scripts about 25 times using input from staff review, evaluation, and scientific advisement. Some editorial tips:

- In multimedia pieces (both narrated and captioned) short, powerful sentences do much more than long, complex ones.
- Reading scripts aloud helps refine passages that seem appropriate in print, but sound poorly in narration.
- Remember that pauses and pacing are as critical to comprehension as the words conveyed, especially when an important content point is being expressed. Give your audience time to interpret what they're hearing and seeing.
- The narration should match the visual. While producers can get creative about what types of visuals support a passage in the script, it's important that what the audience is hearing is aligned with what they see, and vice versa.

III. VISUALS

a. Visual approaches

AMNH's and SMM's autorun pieces used a variety of visual techniques to relate the scientific stories at hand. The look and feel of the two pieces are quite different, and both were effective.

Forecast: Tropical Cyclone (AMNH) employed mostly 2D animation and data visualization, 3D objects and cutaway diagrams, with only limited photography and no video footage. To support the historical narrative and to make the visualized datasets feel more accessible, the piece began with a "folksy" illustrated look and transitioned over time (assisted by chapter headings) to a more "digital" modern look. The AMNH piece also attempted to capitalize frequently on the spherical nature of the display.

Fig. 2: Illustrated scene from *Forecast: Tropical Cyclone* (AMNH)

The Flow: Currents and Climate (SMM) employed custom-shot footage with human actors, 3D animation of characters and scenes, stock video footage and photography, and minimal data visualization. It employed fast-paced editing, “slick” visuals, and liberal use of imagery in the PIP, or Picture in Picture, style (insets).

Fig. 3: Live-action scene from *The Flow: Currents and Climate* (SMM)

The visuals used in both pieces performed favorably with visitors in the summative evaluation (Out of a scale of 1 to 6, AMNH: median=5; SMM: median=6.) The utility of specific visual images in conveying key concepts of the final pieces was evaluated. Eighty-nine percent of viewers were able to correctly relate Ben Franklin’s role in describing and contributing to the scientific concepts presented in the piece. [v] When asked to name the most useful images that relate the main scientific messages of both pieces, visitors pointed to mapped visualizations and diagrams.[vi]

b. Working With a Spherical Format

Some suggestions:

- **Label Positioning:** To avoid warping and for optimal viewing, keep annotations, text, and other explanatory elements between Tropic of Cancer and the Tropic of Capricorn.

- **Image Wrapping:** When wrapping video footage or imagery around the entire sphere, the edges must be merged to eliminate the seam where they meet. SOS producers should consider these needs when purchasing stock footage and imagery.

- **Full-sphere or Not?:** A spherical display gives the unique opportunity to show spherical objects as they really look, and affords unique perspectives on spiral, cylindrical, and other relevant shapes. It follows that an SOS production team should take advantage of these opportunities when developing a piece.

  However, there are occasions when a full-sphere image is not desirable, even when representing a spherical object. For example, AMNH's *Forecast* largely used full-sphere imagery and maps. In draft review, producers felt like this approach kept the visual at a similar perspective throughout, and needed more variety. Wrapping imagery around the sphere also makes it challenging to represent the 3D atmospheric space around the spherical object, and prevents all viewers from seeing the same perspective on an image in cases where uniform viewing is desirable. For these reasons, the AMNH team decided to represent a scene showing satellite motions around a globe as a repeated inset image instead of a full-sphere wrap (Fig. 4.)

Fig. 4: Scene using repeated spherical images from *Forecast: Tropical Cyclone* (AMNH)

- **Image Repetition:** For elements that are to be repeated around the sphere, such as inset imagery or legends/labels, we advise experimenting to determine the optimal number of repeats. Different elements will require different tactics. Most times, the partnership's pieces used four repeats of inset imagery, especially when the image was relatively simple such as the ship in Fig. 5.

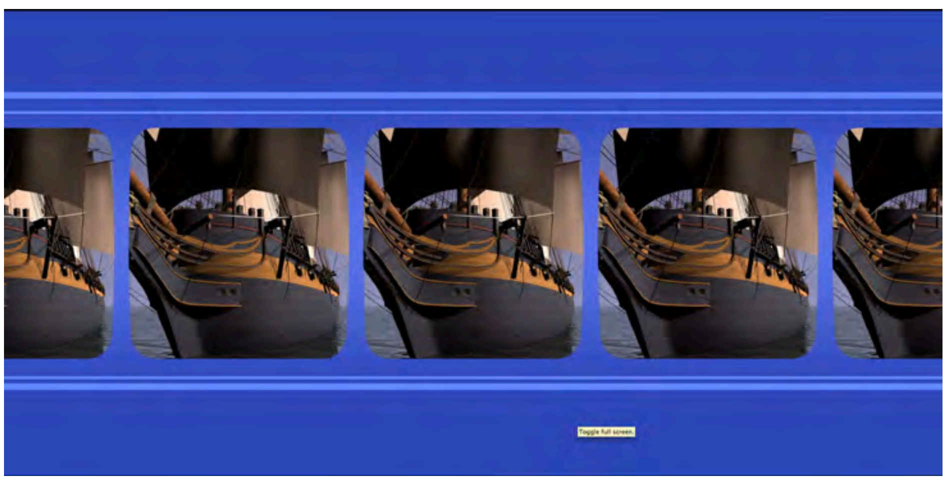

Fig. 5: Scene using four repeated inset images from *The Flow: Currents and Climate* (SMM)

But four repeats didn't work well in cases like the 3-D hurricane diagram in Fig. 6, which is a complex, wide image that is designed to teach a concept. Thus producers felt the diagram required a large, clear display. The fact that the diagram was more or less bilaterally symmetrical factored into this choice of three repeats: Even if a viewer is not positioned around the sphere at the center of one of the three repeats, she is still able to understand what she is seeing because the right and left sides are similar.

Fig. 6: Scene using three repeated inset images from *Forecast: Tropical Cyclone* (AMNH)

- **Rotation:** While the rotation of the final piece can be indicated the SOS playlist file, AMNH chose to spin different sections of their piece at different speeds and sometimes not at all. The "Offset" effect in Adobe AfterEffects was a good way to control the rotation. (For more software suggestions, see Production Tools and Resources, pp. 20–21.)

c. Data Visualization

Viewers assign emotional and scientific values to certain colors, which affects their perception and interpretation of data visualizations regardless of the producer's intention. Red signals hot. Blue cold. Green equals vegetation. Therefore, both AMNH's and SMM's animations and visualizations tended to employ colors that were relevant to perception biases.[vii]

For example, when AMNH compared satellite observations with a model output to illustrate how *alike* they were, initial color attempts (in which both observations and data were similar colors; see Fig. 7) failed to be comprehended by some viewers at the formative evaluation.

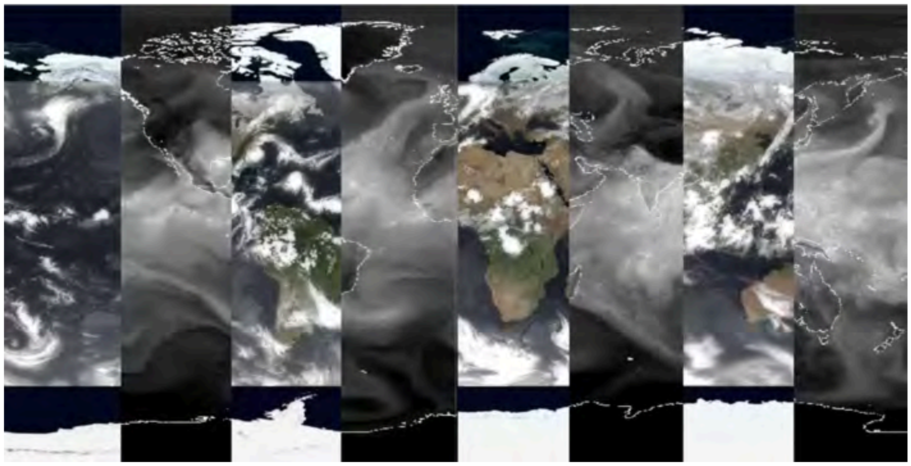

Fig. 7: BEFORE: Draft color comparison of observations vs model for *Forecast* (AMNH)

Subsequent development drew on the use of culturally relevant colors (electric green inspired by early CRT computer monitors) to indicate the “fake” or modeled data versus “real” or natural-toned satellite data. (Figs. 8 and 9.)

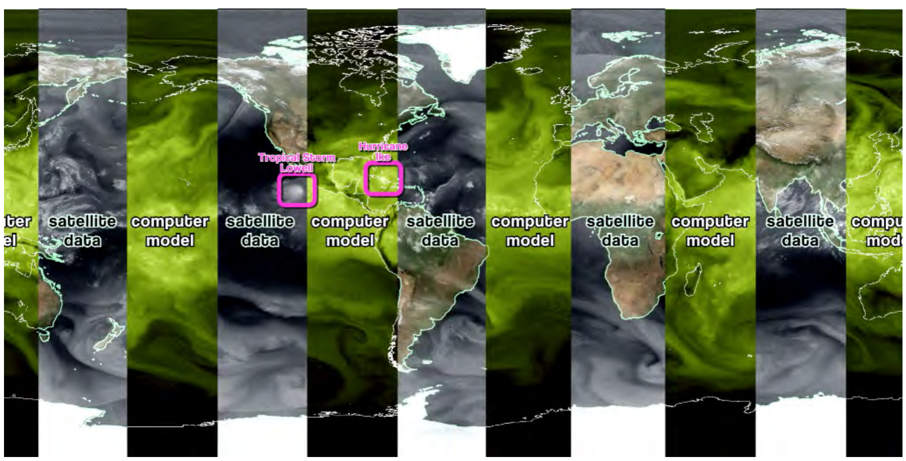

Fig. 8: AFTER: Final color comparison of observations vs model for *Forecast* (AMNH)

This scene is also a good example of the use of two datasets simultaneously on the sphere. Fig. 9 shows the look of the scene wrapped on the sphere. Note that in the draft comparison in Fig. 7, besides the lack of color distinction, AMNH used 8 “slices” of model and satellite data across the sphere. In the final comparison (Figs. 8 and 9), 10 bands were used to increase the opportunities for sphere-viewers to compare the two datasets.

This carefully arranged and colored image proved to be an effective visual image in AMNH’s piece; visitors reported high understanding of the fact that climate models are compared with satellite data to make predictions about future change.[viii]

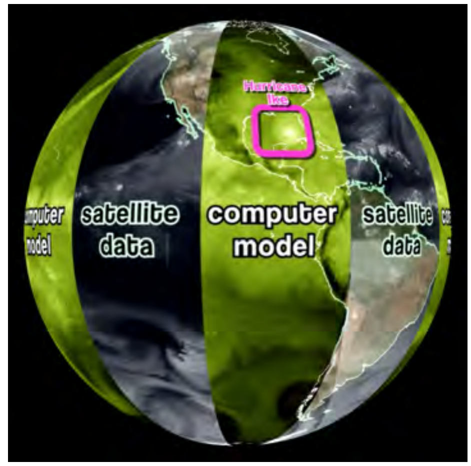

Fig. 9: Sphere view of final color comparison of observations vs model on the sphere for *Forecast* (AMNH) sphere, AKA "orange slices"

Another frequent color choice when visualizing data was the use of monochromatic or duotone color gradients to depict values of a single variable such as temperature or storm intensity (Fig. 10.) Using a common hue that varies in chroma and value suggests an ordered relationship.[ix]

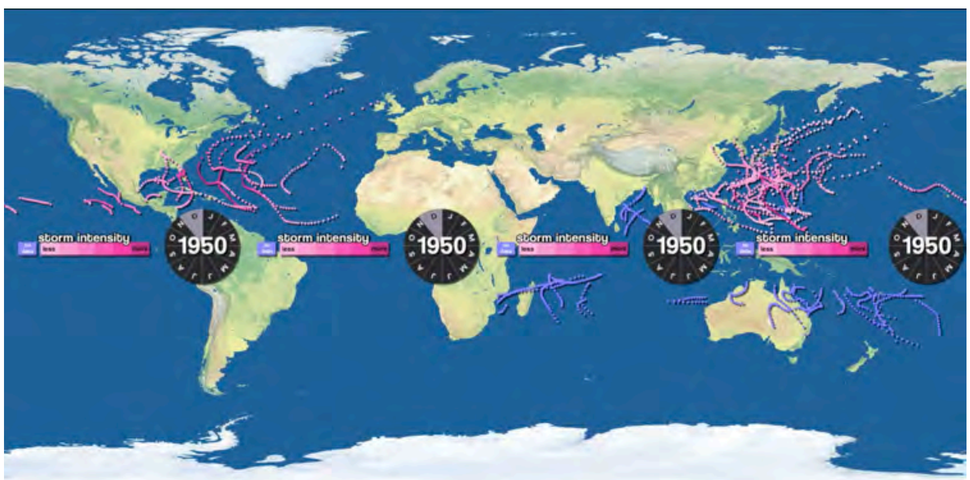

Fig. 10: Scene using monochromatic values and contrast color from *Forecast: Tropical Cyclone* (AMNH)

In *Forecast*, AMNH used a simple blue-to-red color scale to represent satellite observations of sea-surface temperature. (Fig. 11).

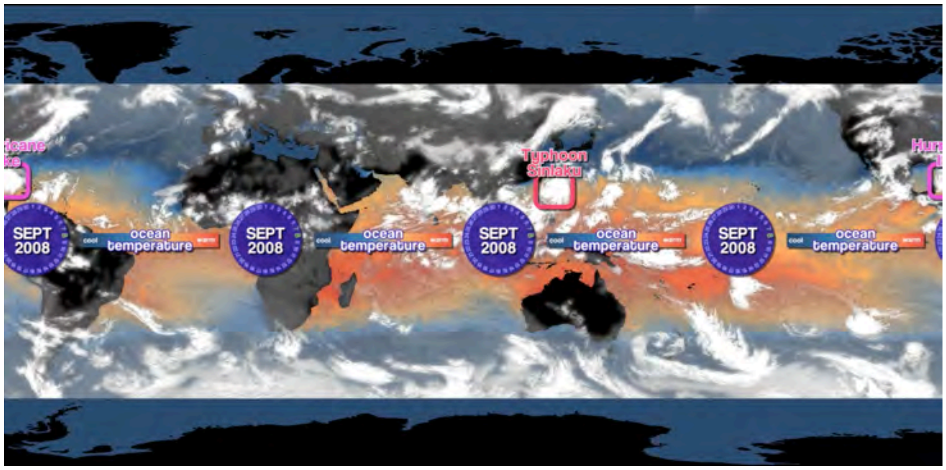

Fig. 11: Scene using duotone color scale from *Forecast: Tropical Cyclone* (AMNH)

Fig. 12, from SMM's *The Flow*, employed an even simpler color palette to indicate the relationship of current temperature to depth. In the summative evaluation of SMM's piece, Fig. 12 was named the most useful to communicate how the oceans and atmosphere interact.[x]

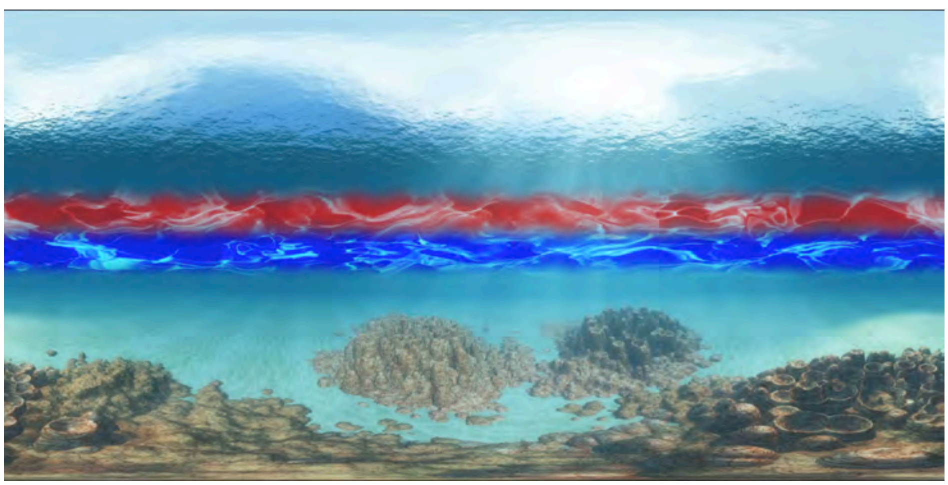

Fig. 12: Scene using simple coloration from *The Flow: Currents and Climate* (SMM)

However, simple color gradients were not considered appropriate for all situations. In *The Flow*, SMM applied a broad-spectrum rainbow color scale to their sea-surface-temperature image, which is a computer model output (Fig. 13).

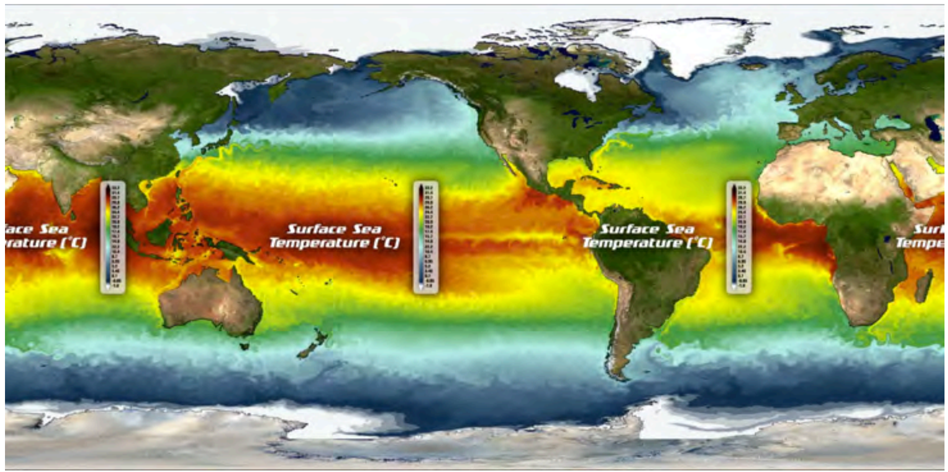

Fig. 13: Scene using full-spectrum color scale from *The Flow: Currents and Climate* (SMM)

The educational message of this section of SMM's piece was to highlight the increasing complexity of climate models. The rainbow appearance offers the greatest visual contrast among values and highlights detail. Since the goal was to convey this complexity and not the nature of sea surface temperature, the classic rainbow seemed a more appropriate color scale than a duotone.

In the summative evaluation of SMM's piece, the rainbow sea-surface temperature model output the second-most-cited image (after the red-hot/blue-cold current image sequence) as the most useful to communicate how the oceans and atmosphere interact.[xi]

d. Labels and Legends

Labels and legends used in the two pieces were not formally evaluated, but it's worth noting some choices.

The production teams employed many different strategies for labels, scale bars, and legends. Placing multiple scale bars horizontally or vertically on the equator (or at the least, between the Tropic of Cancer and the Tropic of Capricorn) seemed the most appropriate locale for optimal viewing by all viewers. (It also reduced warping in the transition from flat to round.)

AMNH also chose to represent time bars as circles (Figs. 10 and 11), especially when real estate was limited given multiple labels.

Geographic labeling was generally used only when relevant, such as in Fig. 13. (Note as well the use of the color red for “warm” cities and blue for “cold” cities at the same latitude).

Fig. 13: Scene using limited relevant labeling from *The Flow: Currents and Climate* (SMM)

A lot of geographic labels can easily clutter a global scene. For example, AMNH labeled the continents and ocean basins in Fig. 14 because this scene came early in the piece, and therefore served as a geographic marker that relieved later scenes from having to do the same. Note as well the use of analogous colors in labels and their respective spatial areas.

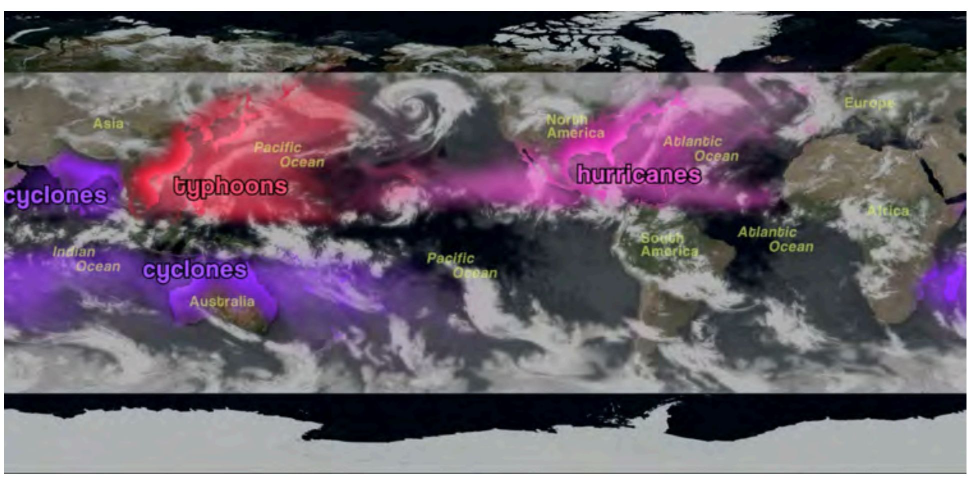

Fig. 14: Scene with lots of labels from *Forecast: Tropical Cyclone* (AMNH)

e. Animation and Video

An 8-minute SOS production is an opportunity to be dynamic. Careful pacing of animation and video is important, however, so that viewers are not overwhelmed with motion, especially when an important content point is being expressed. During less technical moments of the narration, a looser composition or complex mosaic of photos and video can take the limelight.

How much animation and video to use versus other visual choices depends on many factors. As mentioned, SMM's piece made extensive use of video footage, whereas AMNH's piece was entirely animation and some animated still images. In the summative evaluation, some visitors expressed wanting to see more animation and video instead of stills in AMNH's piece.[xii]

f. Sound and Narration

A rich soundtrack (with both music and sound effects) and a professional narration add depth, vitality, and credibility to a sphere production. We recommend recording the final narration at a recording studio and testing the mix at the SOS site before finalizing—it will sound very different through the SOS speakers than at the computer.

IV. TECHNICAL ASPECTS

a. Playback testing:

SMM has a sphere on-site; AMNH does not. Although one draft version and the final version of AMNH's piece were tested on MSC's sphere, AMNH used a 16" diameter Magic Planet spherical display with an internal projector to test intermediate versions "in the round." This choice proved challenging. The Magic Planet software that was used (Magic Planet Storyteller version 2.2.4.0; OnStage version 2.8.3.8) was buggy, calibration/positioning was difficult to get right, and there were serious color differences between the Magic Planet projector and that of the sphere. All of these issues slowed AMNH's process of reviewing flat-screen design work on a spherical surface.

b. Production Tools and Resources

Production software included:

- Adobe Photoshop for image prep and batch coloring and processing
- Adobe Illustrator with Map Publisher plugin for GIS needs, such as interpreting shapefiles and adding lat/long point locations on maps (e.g. storm tracks)
- Maya for 3D modeling and animation
- Adobe AfterEffects for 2D compositing
- Apple Soundtrack Pro for audio master mix
- Apple Quicktime Pro for draft composites, movie previewing
- Apple Compressor for final encoding (At the time of production, Compressor was a more most reliable encoding tool than those offered in AfterEffects or Quicktime software, as far the SOS format is concerned.)
- Magic Planet Storyteller and OnStage for previewing on a spherical surface

Other consulted resources for production:

- Stock imagery and video footage: iStock video and others
- Music and sound effects: APM
- Voice over talent agencies: Abrams Artists, Creative Media Design, and others
- See Appendix 2 for a list of datasets used in *Forecast: Tropical Cyclone* and their sources, and Appendix 3 for content resources about tropical cyclones.

c. Data and image formats

Data was provided by scientific advisors or gathered by the production team in the following formats:

- Satellite data/model output: Rasterized image sequences or single images
- Point source or geographic outline data: .SHP files (GIS shapefiles)
- Reference imagery that was reinterpreted by animators

Production teams made their own 3D models and also purchased 3D objects online that were incorporated into scenes. Actors were filmed against green screens and then incorporated into scenes using video editing software.

d. Output

Early drafts were previewed in Apple Quicktime on a flat screen. Drafts for testing were made at 1024x512. Final versions were output as a self-contained 2048x1024 Quicktime movie. See the SOS Content Creation documentation for more details about output formats.

Live Program Content

I. PROCESS

MSC undertook the effort to develop three scripts for live-presented versions of the two autorun programs. The approach for these facilitated programs was arrived at via several discussions among partners. It was recognized that the live programs needn't follow the storylines of the autorun pieces exactly, and thus they varied in their content and flow. As the autorun pieces were being finalized, AMNH and SMM gave MSC individual scenes and video clips that MSC staff then built into a narrative. These images and clips were complemented by other datasets and images gathered by MSC and assembled in an SOS playlist file. Live demonstrations were also conducted during the facilitated program. Draft live programs were evaluated with audiences at MSC and adjusted. The final programs were then evaluated along with the autorun pieces in the summative evaluation.

All three live programs rated favorably with visitors in the summative evaluation (Out of a scale of 1 to 6, live programs for AMNH piece: medians=5 and 6; live program for SMM piece: median=5.)[xiii]

II. PROGRAM PRESENTATION

Here are MSC's recommendations on presenting live programs for SOS:

- Always begin by telling visitors what the show will entail, i.e. that you will be doing a short, informal presentation. Also, mention the approximate length of the show.
- Invite visitors to ask questions during the show and encourage them to answer questions that you pose during the show.
- Introduce NOAA, its acronym, what it studies, and its role in developing SOS.
- Briefly explain Science On a Sphere and the technology behind it, i.e. that it is not a hologram but suspended from the ceiling with four projectors projecting a piece of the image onto the sphere to create one solid image, that the image is rotating, not the sphere itself, etc.
- Introduce the type of dataset (satellite, model, etc.) when an image first comes on screen. Address color scales and/or how to read an image (e.g. an infrared satellite image indicates temperature and that white indicates higher cloud tops and that dull gray indicates lower level clouds; or the color scale on sea-surface temperature visuallization where red is hot and blue is cold).

- Always speak to the audience and not to the Sphere. Using a lavaliere microphone may be helpful for large crowds. Only turn towards the Sphere to emphasize an important point or highlight a point of interest with a laser pointer.

Evaluation

Formative evaluation for both autorun pieces was conducted at SMM by their evaluation team. Formative evaluation for the live-presented programs was conducted at MSC by their evaluation team. Summative evaluation for the entire program was conducted at MSC by the Institute for Learning Innovation and assisted by MSC staff. All teams had to develop additional informal methods to test ideas along the way.

I. INFORMAL EVALUATION

Since AMNH has no sphere, the production team relied on the use of the Magic Planet for informal early reviews with staff colleagues. Flat-screen drafts were reviewed periodically by scientific advisers and executive producers who were not involved in the day-to-day production.

Since the visual production process for SMM's piece was done by an external contractor, producing even rough media for the sphere was quite expensive and time-consuming. To get around this limitation SMM targeted evaluation efforts on specific questions and individual visualizations. They showed visitors rough slide shows of images to test overall story direction and concepts (See Appendix 1.) It was quite easy to mock up rough sketches of the scenes of the film in Microsoft PowerPoint and then test this with visitors using a laptop or even paper printouts. This process allowed SMM to test out questions such as:

- "Do you like the introduction of the Ben Franklin character here?"
- "What do you think the main message of this film is?"
- "Would you be interested in watching this full film?"

By keeping these slideshows as rough and simple as possible, SMM found that visitors were more likely to give useful feedback on the content and story of the film. When visitors see something that looks even slightly like it might be near the finished product, they can get distracted by wanting to comment on elements of the film that might be in active development such as stand-in animations and images, low-res pictures, or bad editing cuts. This sort of feedback is often not useful since they are about issues already on the to-do list and often distracts from more useful feedback about content.

Near the completion of the final drafts of the pieces, a meeting was arranged at MSC with participants across the partnership, including scientific advisers, for a near-final review of both autorun programs and one of the live-presented programs.

II. FORMAL EVALUATION

Complete details on the formative and summative evaluation processes for these programs can be found in the reports listed in the Introduction to this document.

Footnotes

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[i] Goodman, Andy. *Storytelling as Best Practice*, fourth edition. 2008 pp. 2-3

[ii] Science on a Sphere Ocean-Atmosphere Literacy Partnership Summative Evaluation, p. 32.

[iii] ibid, p. 21.

[iv] Ibid, pp. 22 and 32.

[v] Ibid, p. 27.

[vi] Ibid, pp. 23 and 27.

[vii] Phipps, M. and S. Rowe. Seeing satellite data. *Public Understanding of Science*, April 17, 2009.

[viii] Science on a Sphere Ocean-Atmosphere Literacy Partnership Summative Evaluation, pp. 21 and 23.

[ix] Stone, Maureen. "Choosing Colors for Data Visualization," (Perceptual Edge) p. 8.

[x] Science on a Sphere Ocean-Atmosphere Literacy Partnership Summative Evaluation, pp. 26 and 32.

[xi] Science on a Sphere Ocean-Atmosphere Literacy Partnership Summative Evaluation, pp. 26 and 32.

[xii] Ibid., p. 12

[xiii] Ibid., pp. 11 and 16.

Appendix 1: SMM *The Flow* storyboard for visitor testing

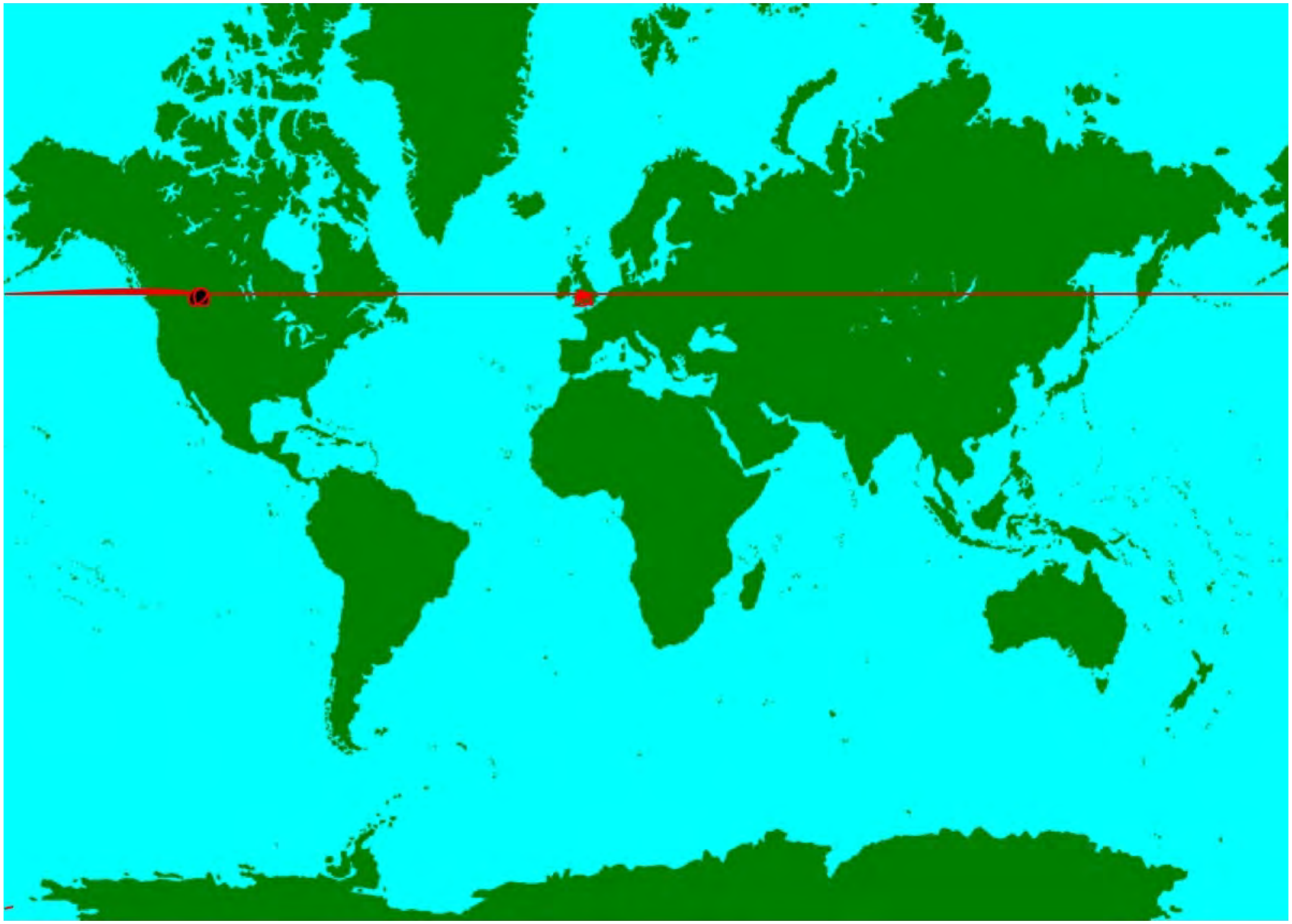
Ocean Atmosphere Thermodynamics!

- Why are winters in London…

- “Allo, Guvna!”

- Far Milder than winters in Calgary, Alberta

- “It’s cold, eh.”



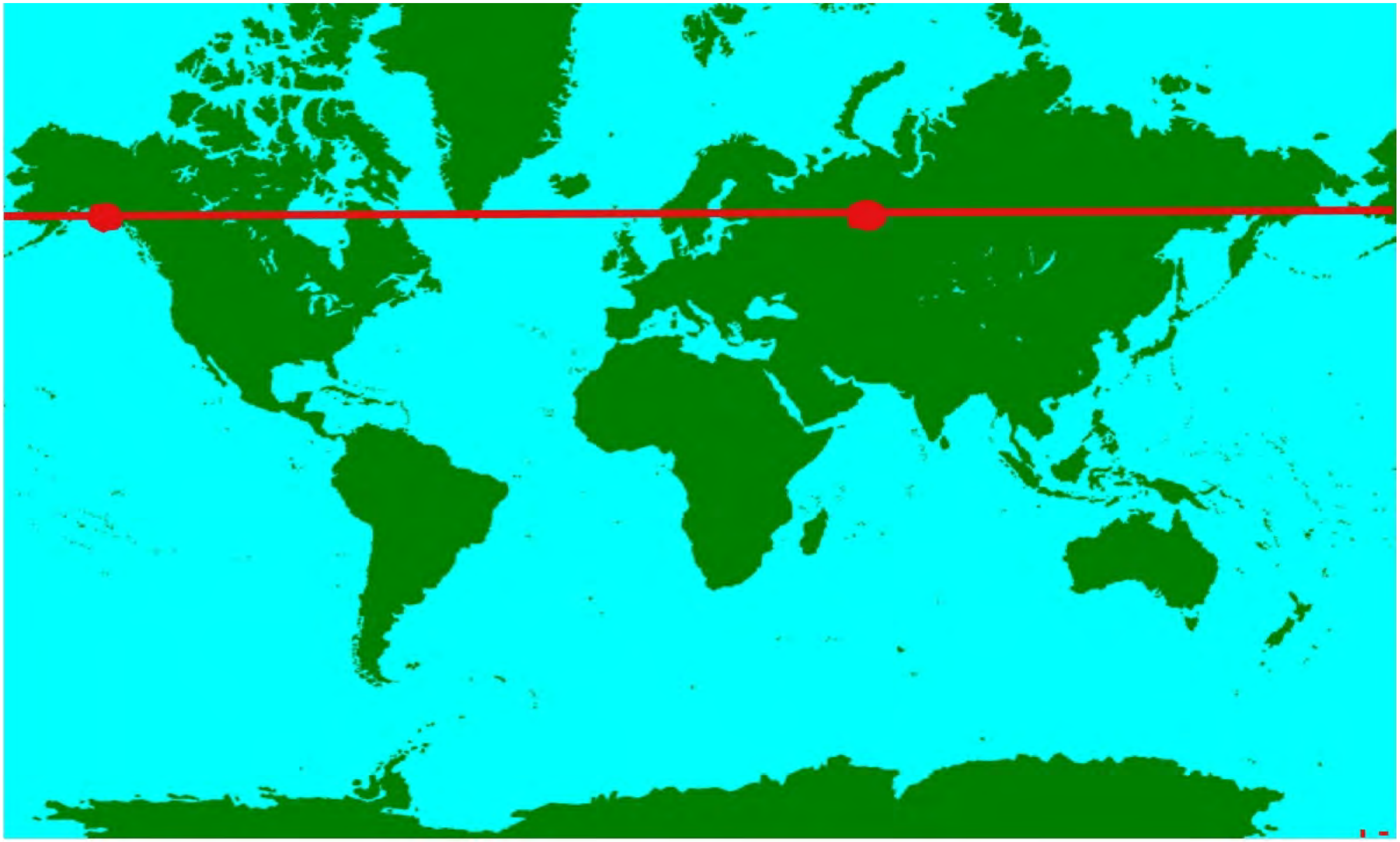
…when both cities are the same distance north of the equator?

- And what makes January in Perm, Russia…

“Privyet!”

…so much more frigid than midwinter in Juneau, Alaska,

“Nice day!”



…when Juneau is X thousand miles due east?

Baking under the tropical sun, the hottest parts of our planet could be much hotter, but some of that heat spreads towards the poles.

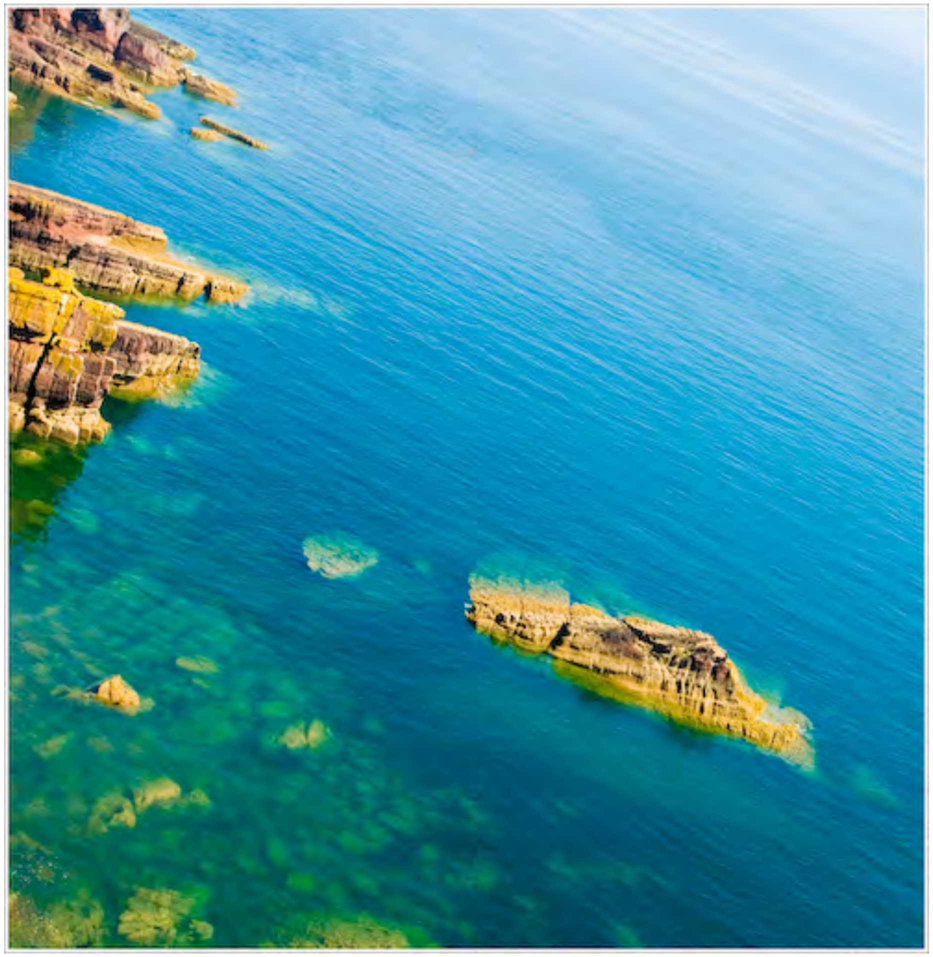
So why does it warm some places so much…

"How pleasant!"

While leaving others in the cold?

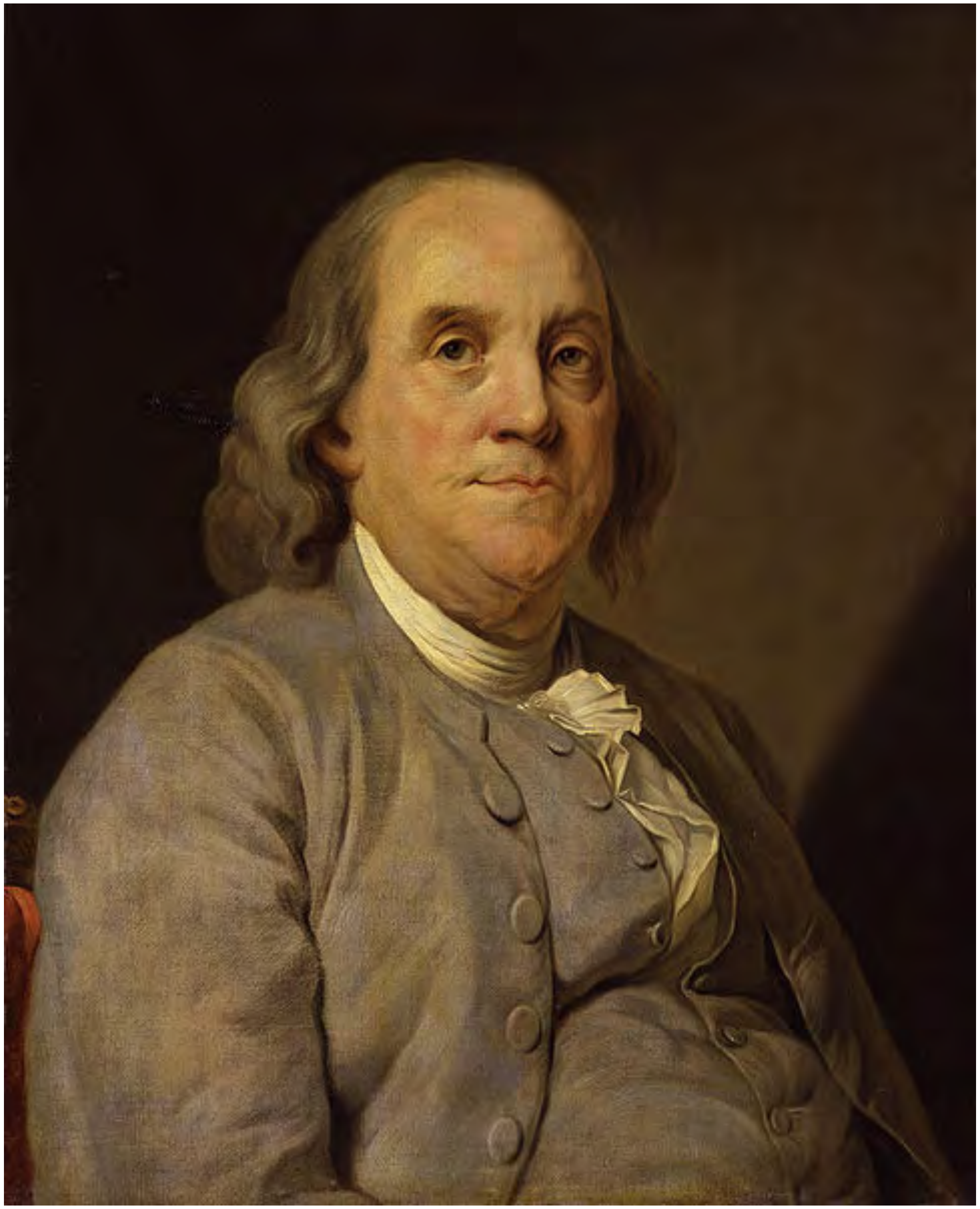
“We’re Canadian, we don’t mind!”

Anyone who has experienced a blistering summer heat wave has felt the atmosphere's ability to move heat and moisture across the planet. But the atmosphere is only part of the story…



There’s also the ocean.

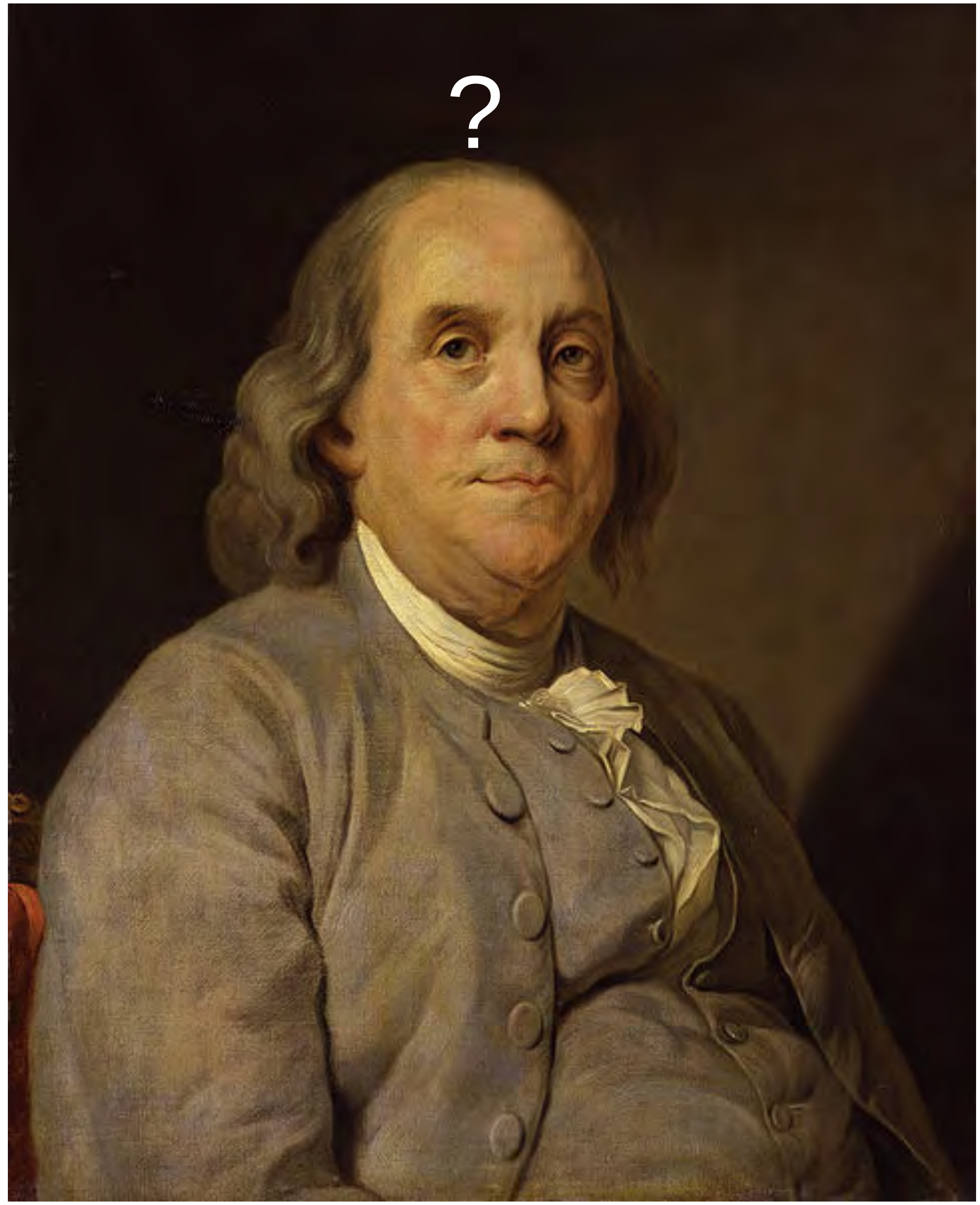
In 1769, an assistant postmaster general named Benjamin Franklin came to an important realization:



For some reason, ships carrying mail from America to England

Arrived much sooner than the ships carrying mail from England to America.

It was too great a mystery for Franklin to ignore.



On his next few trips across the Atlantic, Franklin began to chart the borders of large currents, and he took temperature readings of the water all across the ocean.

When he was finished, Franklin had created a map of what he called “the Gulf Stream” current. The Gulf Stream, he realized, was like a river running across the surface of the ocean, and it wasn’t just carrying mail ships—

it was also bringing warm water from the tropics to the north Atlantic.

Years later, other sailors would begin to discover *how* these currents worked.

To help understand how water temperature related to weather patterns, sailors captured samples from the sea surface.

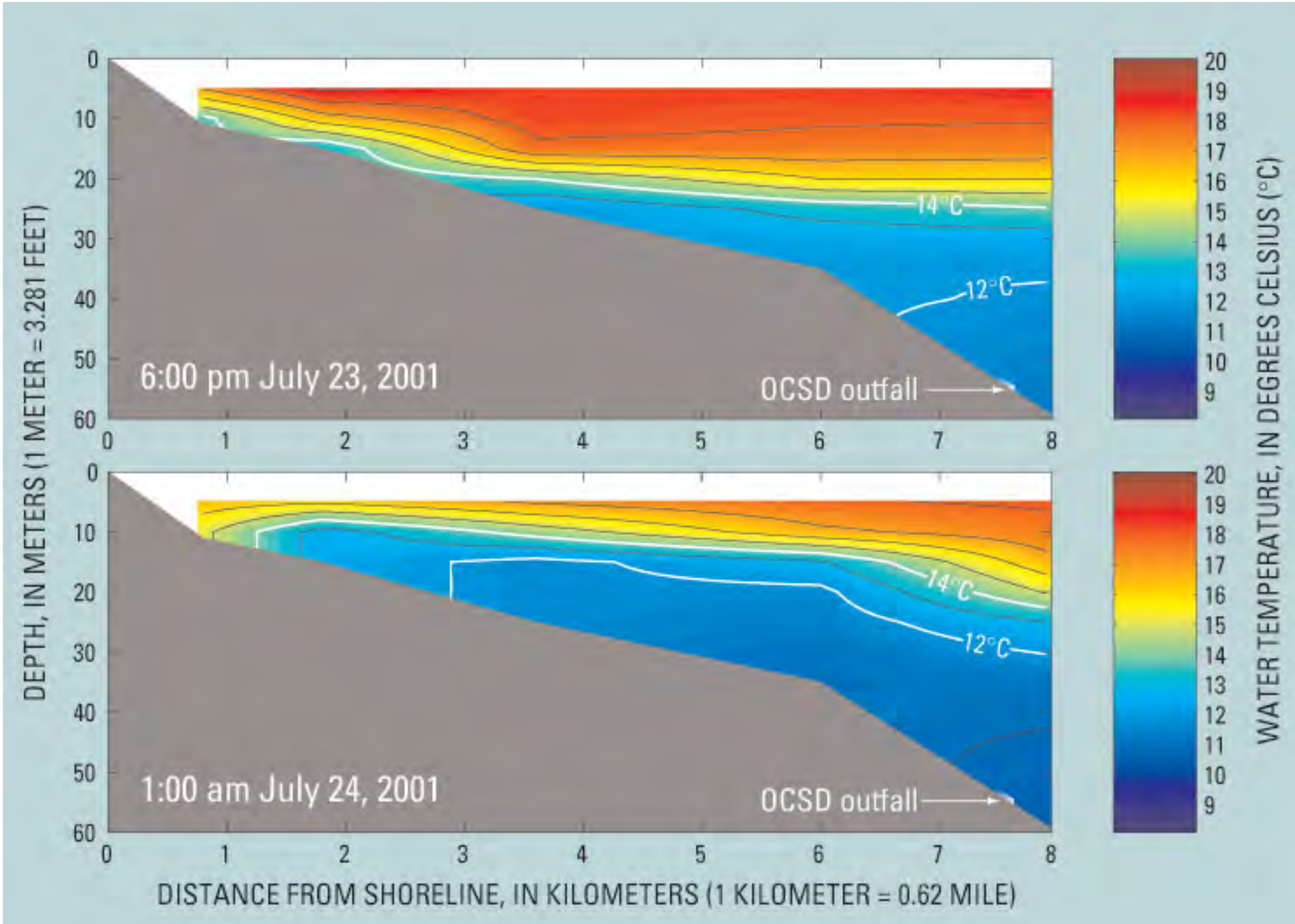
It was very often warm.

“Feels like a storm”

But when they sampled the water just beneath the warm surface currents, they discovered…

It was cold, even in the bright, sunny tropics.

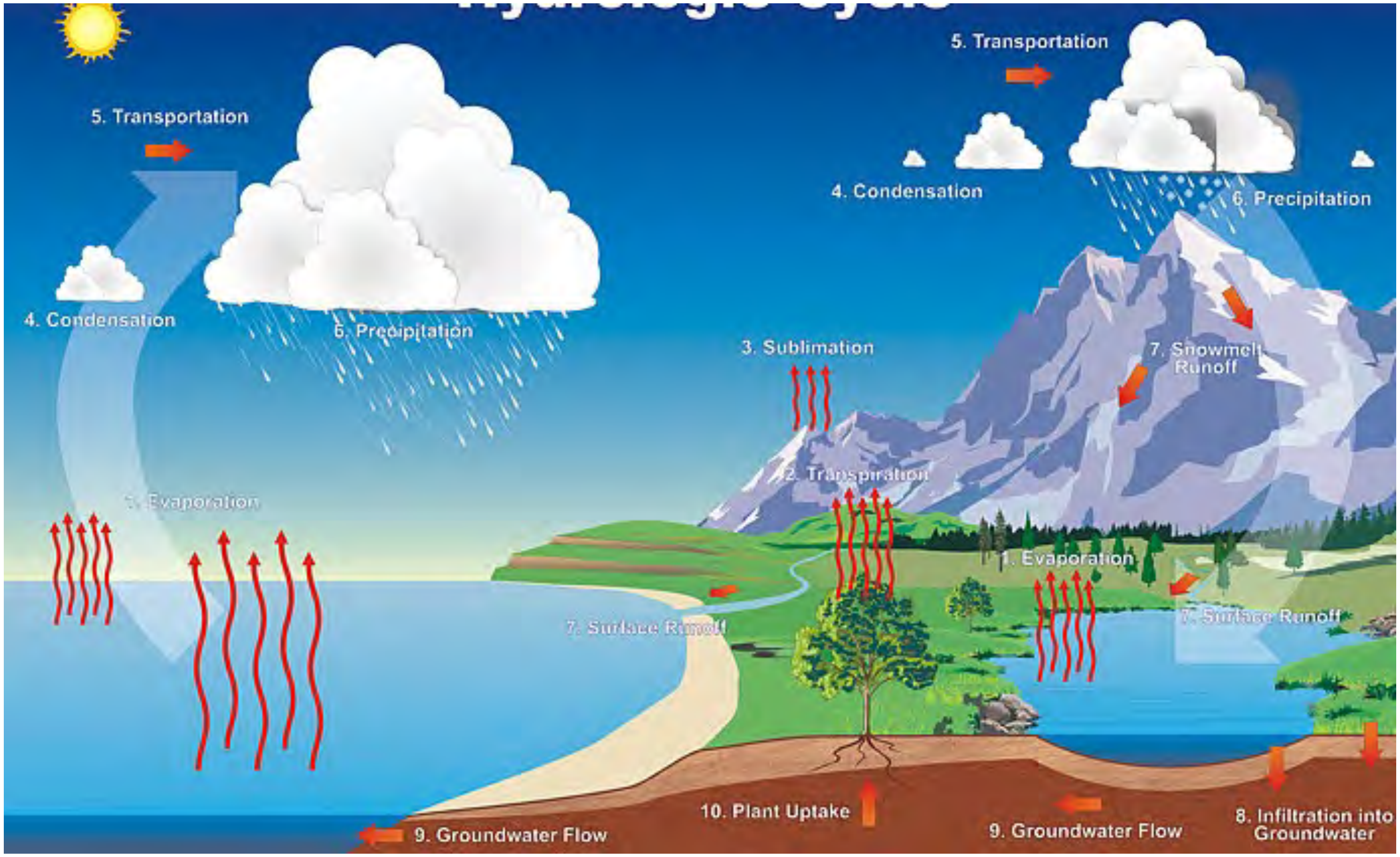
“*Aahh! So cold!*”



This is because warm water is less dense than cold water,

And, heated by the tropical sun, it floats over the layers of cool water below.

Regular wind patterns and the rotation of the Earth drive the warm surface water into Franklin's river-like currents.

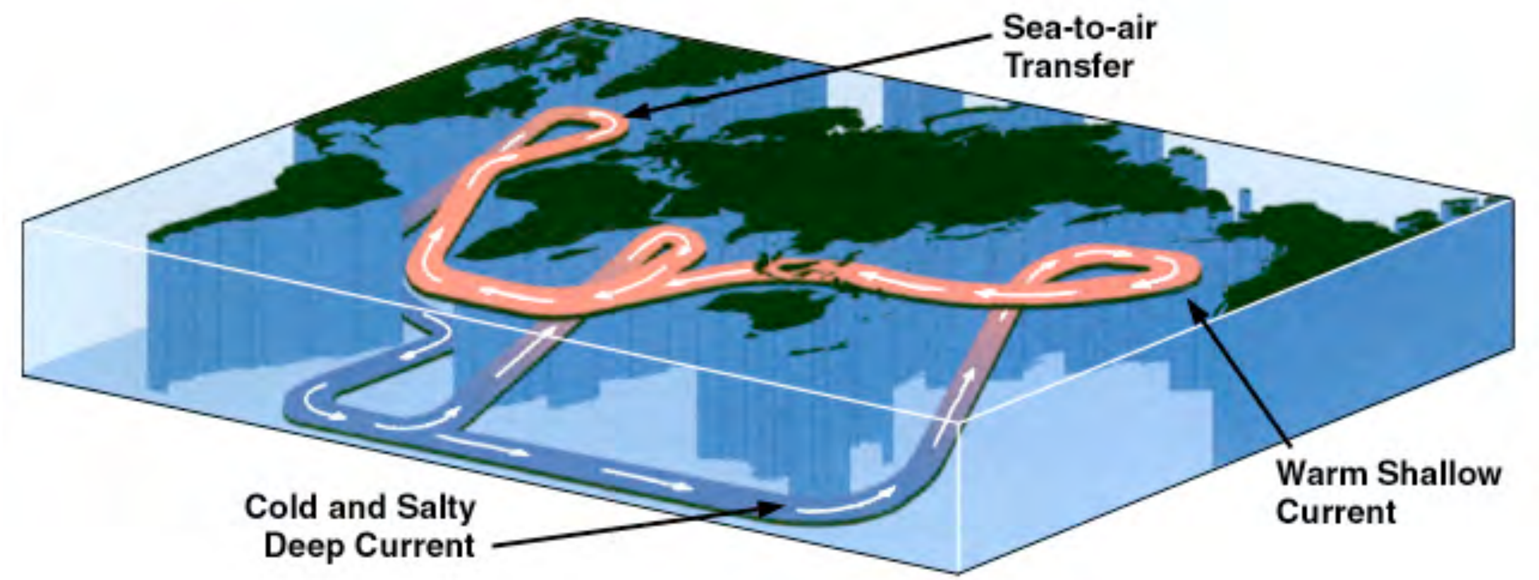


As these warm currents flow to colder regions, they release heat and moisture to the air.
All that warm, wet air moderates climate nearby.
So a city like London is saved from the cold and snow…

“Hurrah!”

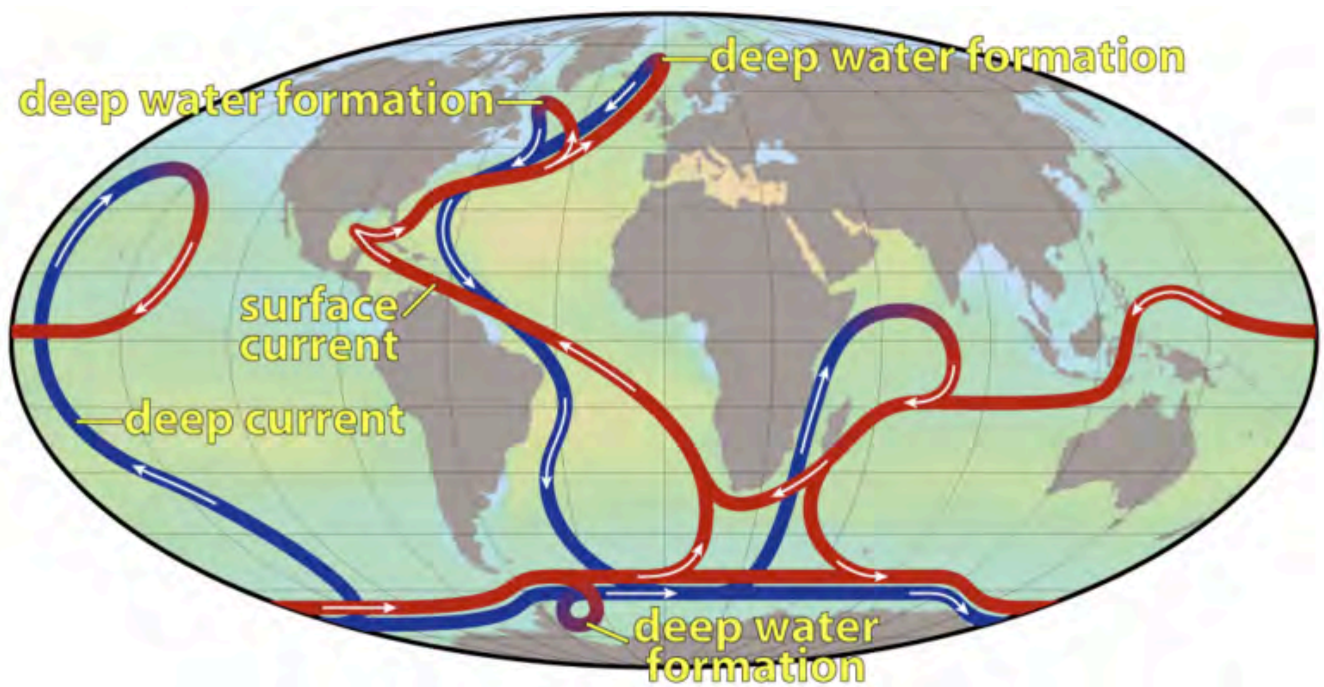
Instead it is mild and damp.

“Crikey!”



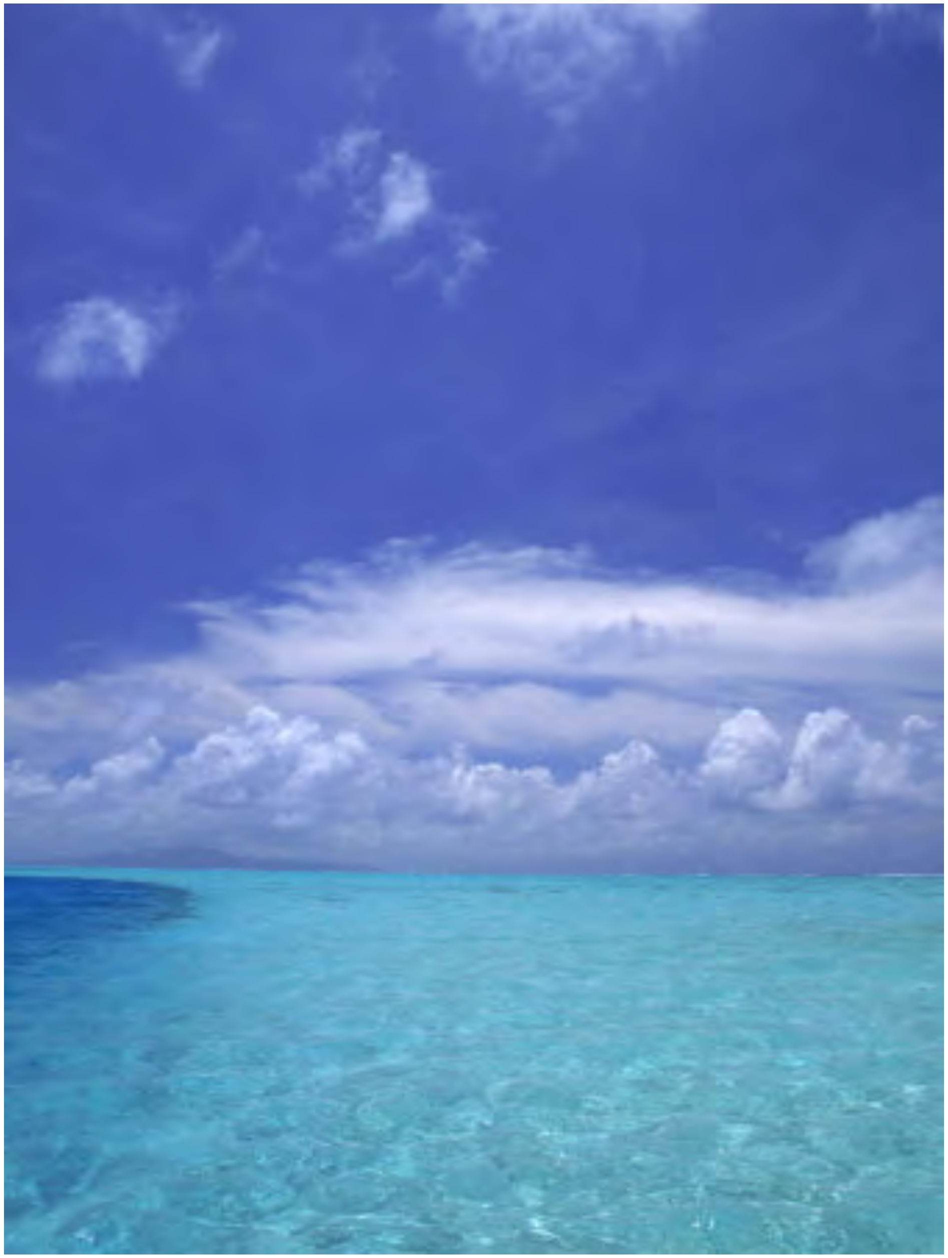
After losing enough heat, surface water becomes cool, and it sinks.

With more cooling water flowing down all the time, the cold water at the bottom of the oceans forms huge, icy *underwater* rivers…



These deep currents can travel for thousands of miles and hundreds of years…

Before returning to the surface to be heated again by the sun.



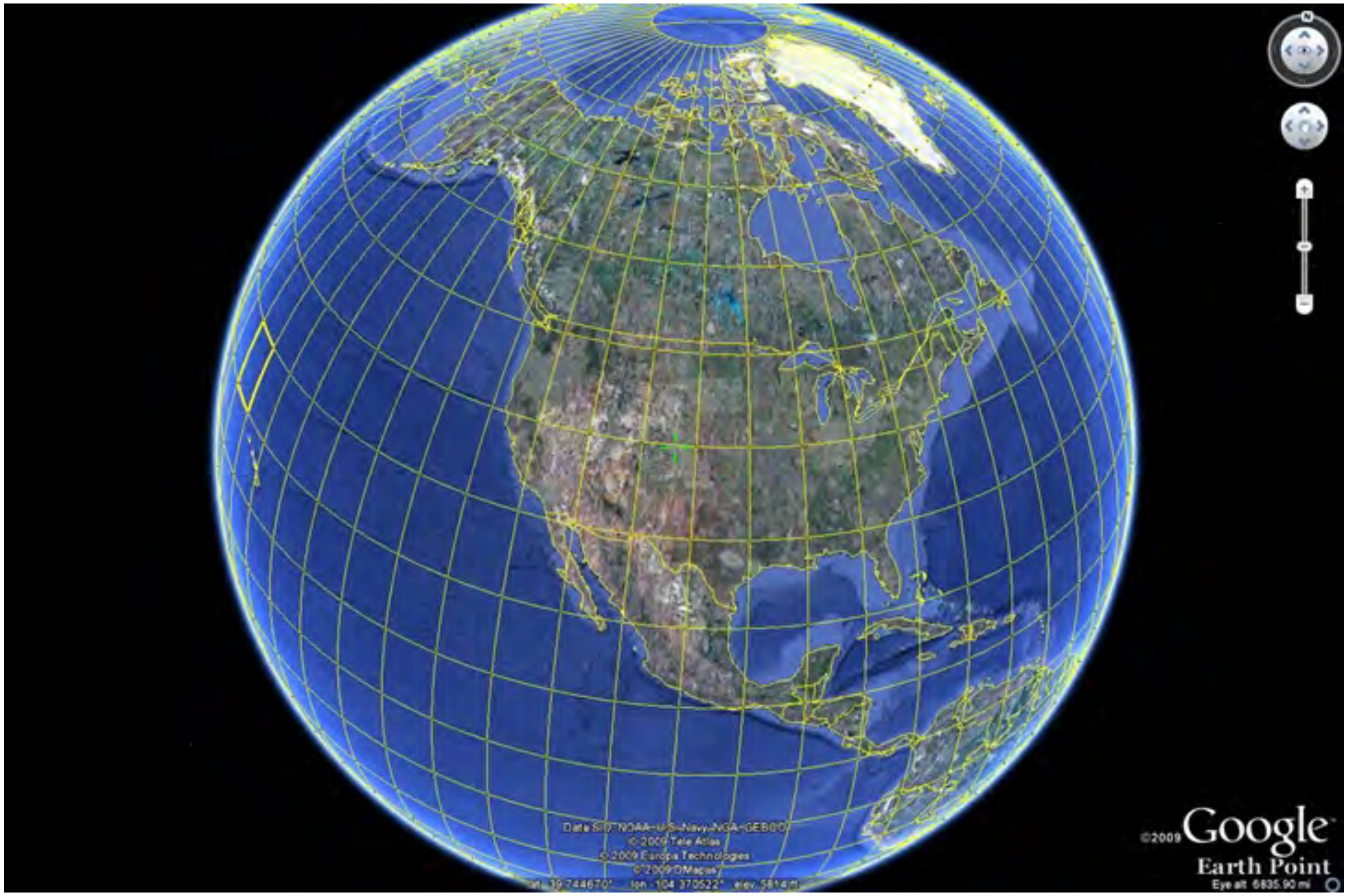
It’s that energy from the sun that powers global climate.

The oceans act like a gas tank for the energy, storing it as heat, and moving it across the planet. The oceans store so much energy, in fact, that just the top three meters of seawater can hold as much heat as the entire global atmosphere.

The exchange of heat and moisture between the oceans and atmosphere maintains global climate as we've known it for thousands of years. But human activity is now warming the atmosphere. The system is being thrown out of balance, and we can no longer rely on what we know from the past to understand what will happen in the future.

So we make a new Earth to test our ideas on.

Or… at least a computer simulation of the Earth.



Computer climate simulations, or *models*, are made by first splitting up the planet's land, oceans, and atmosphere into tiny, 3-dimensional boxes…

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{dy} + w\frac{\partial u}{\partial z}\right) =$$

$$\rho g_x - \frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left[2\mu\frac{\partial u}{\partial x} + \lambda\nabla\cdot\mathbf{V}\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right]$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{dy} + w\frac{\partial v}{\partial z}\right) =$$

$$\rho g_y - \frac{\partial p}{\partial y} + \frac{\partial}{\partial y}\left[2\mu\frac{\partial v}{\partial y} + \lambda\nabla\cdot\mathbf{V}\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right] + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right]$$

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{dy} + w\frac{\partial w}{\partial z}\right) =$$

$$\rho g_z - \frac{\partial p}{\partial z} + \frac{\partial}{\partial z}\left[2\mu\frac{\partial w}{\partial z} + \lambda\nabla\cdot\mathbf{V}\right] + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right]$$

…And then programming all that we know about the behavior of these regions into each box, in the form of mathematical equations.

When we start the models running in 1900, climate on the computer-Earth looks pretty much like it does in the world outside our windows.

But when we bring planet-warming greenhouse gases up to the levels we'll be achieving in just a few years… things get a little strange.

Changes in ocean temperatures could possibly intensify warm water-fueled phenomena, like hurricanes or El Niño.

A warming atmosphere might also release a flood of icy glacial melt water into the oceans, slowing the warm currents that keep the weather in places like Juneau and London mild despite their high latitudes.

?

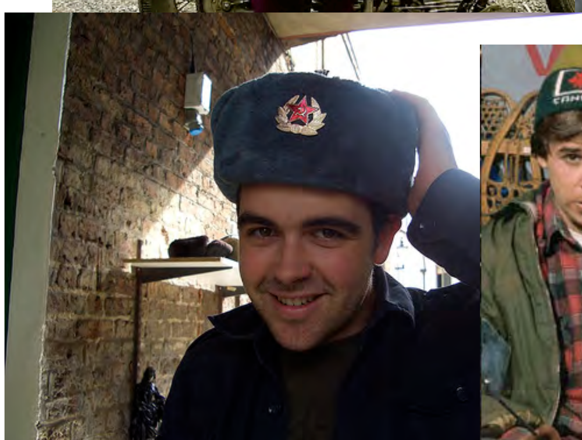
The further they're run into the future, our models' ability to forecast what will happen to global climate gets a little foggy.

So scientists around the world continue to study ocean and atmosphere interactions. From the NOAA research station in [LIST PLACES HERE?] to [???], we're gathering data to build more sophisticated models, and to create a better scientific understanding of the changes the planet is undergoing.

We know how the current temperature affects all of us …

"Not a bad day!"

"Rain again?"



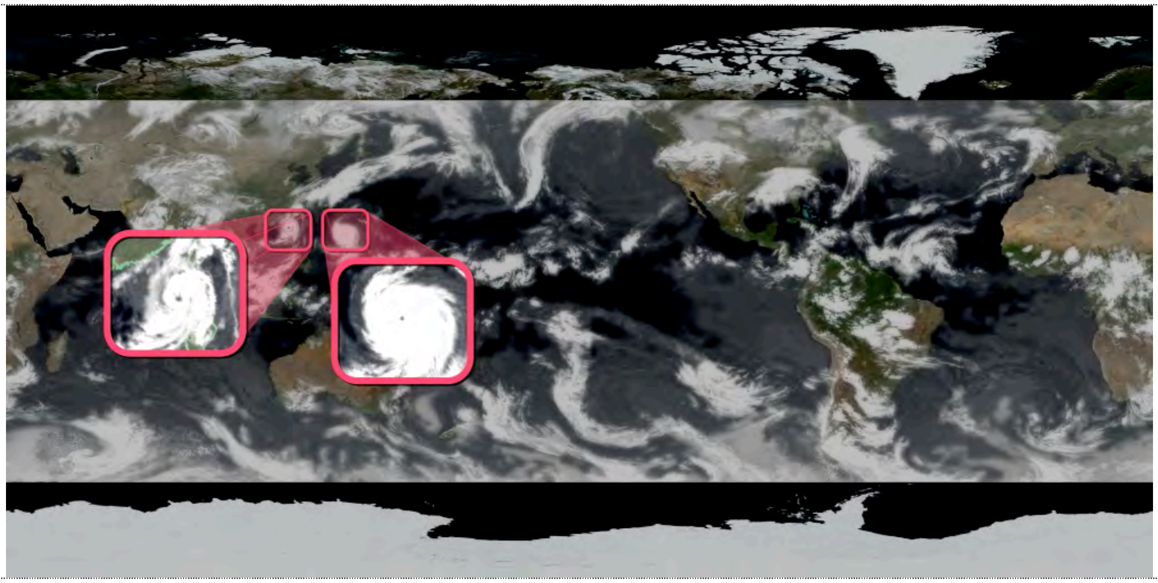
"Snow again?"

"More snow? Well, that's all right."

But how temperature currents could change our world is the kind of scientific mystery we can’t ignore.

THE END

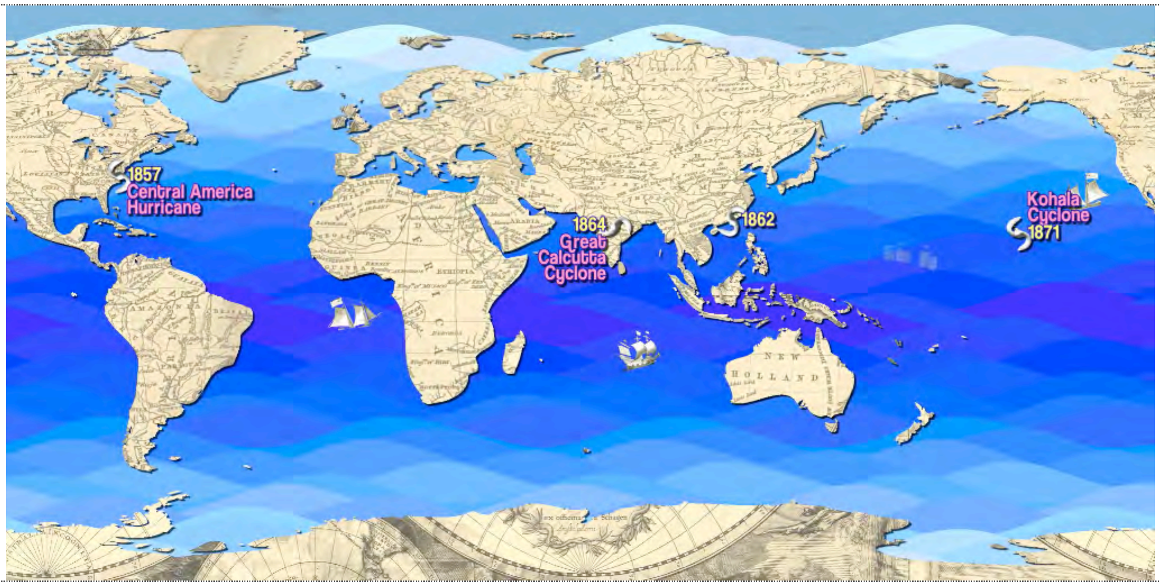
Appendix 2: Datasets used in FORECAST: TROPICAL CYCLONE



↑GLOBAL CLOUD COVER—IR MOSAIC
From: GOES-East, GOES-West, Meteosat-9, Meteosat-7, and MT-SAT satellites
Data source: NOAA Climate Prediction Center, http://www.cpc.noaa.gov/

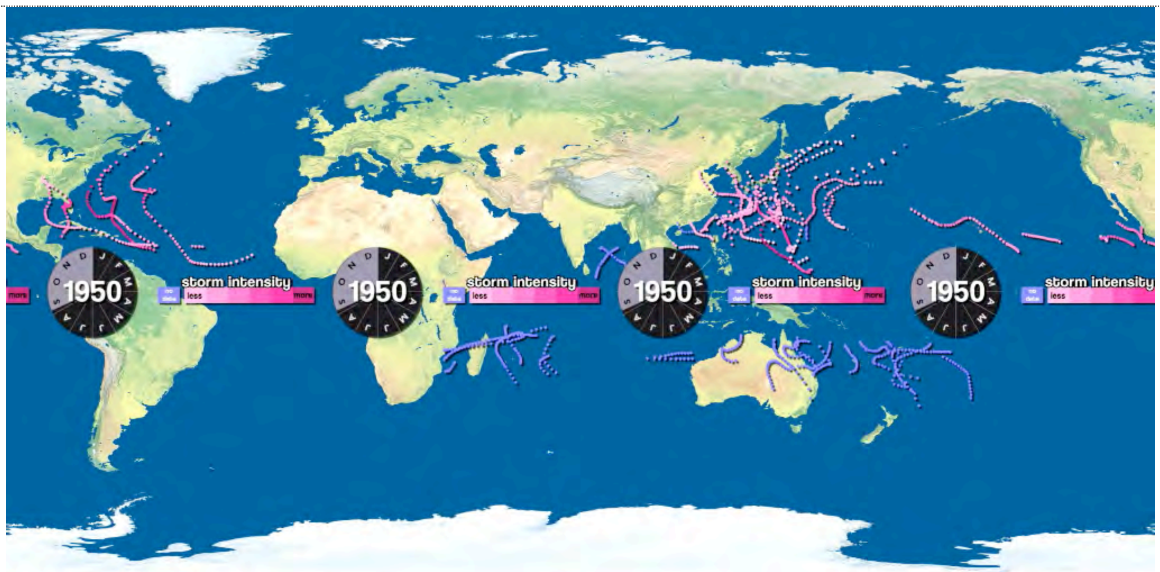
Description: This dataset merges the observations of five geostationary satellites into a seamless mosaic that covers parts of the globe where climatologists require continual measurements. The satellites' sensors measure thermal infrared radiation — essentially, heat — emitted by clouds in the atmosphere as well as land and ocean surfaces. The warmer these surfaces are, the more infrared radiation they emit. Radiation intensity is represented by grayscale values, where the warmest surfaces (land) are black and the coldest surfaces (clouds) are white. Since temperature generally decreases as altitude increases, the tops of high-altitude clouds show the whitest traces. Often this indicates large, robust storms like hurricanes or intense thunderstorms.

The dataset, which the satellites capture every half hour, day and night, is processed by programmers and scientists from NOAA's Climate Prediction Center. It is one of the few datasets that give scientists a whole-Earth, near-real-time view of how storm systems evolve. It is used for weather forecasting, climate monitoring, and to diagnose problems with climate models.



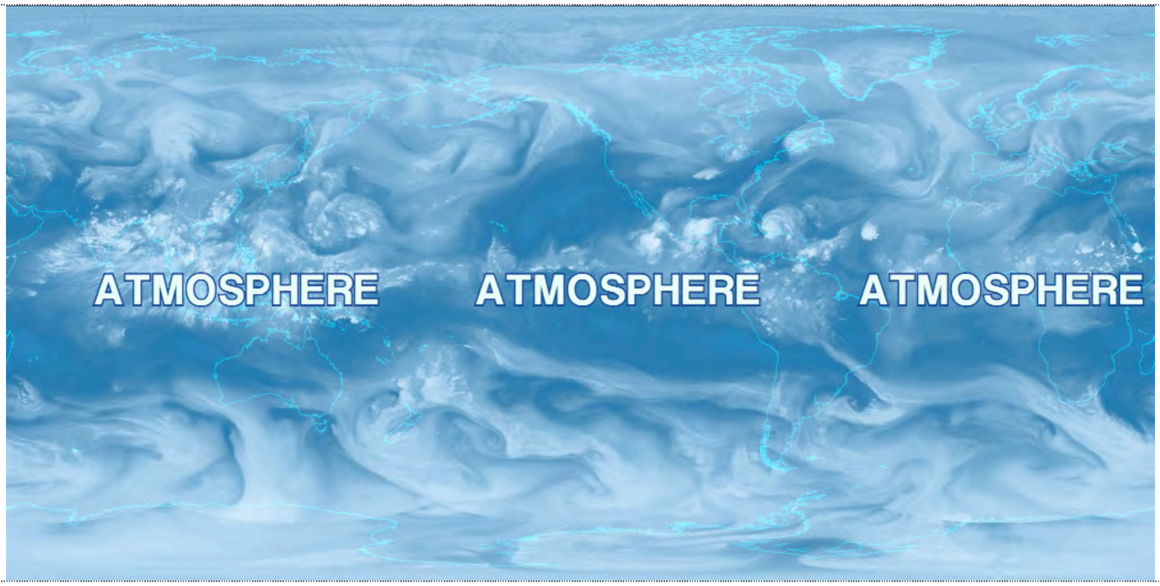
↑NOTABLE HISTORICAL TROPICAL CYCLONES
Source: Various

We mapped landfall and ocean records of selected tropical cyclones from the period 1279 to 1938. Sources include NOAA and other online resources as well as books and historical documents. See AMNH_Forecast_useful_resources.doc.

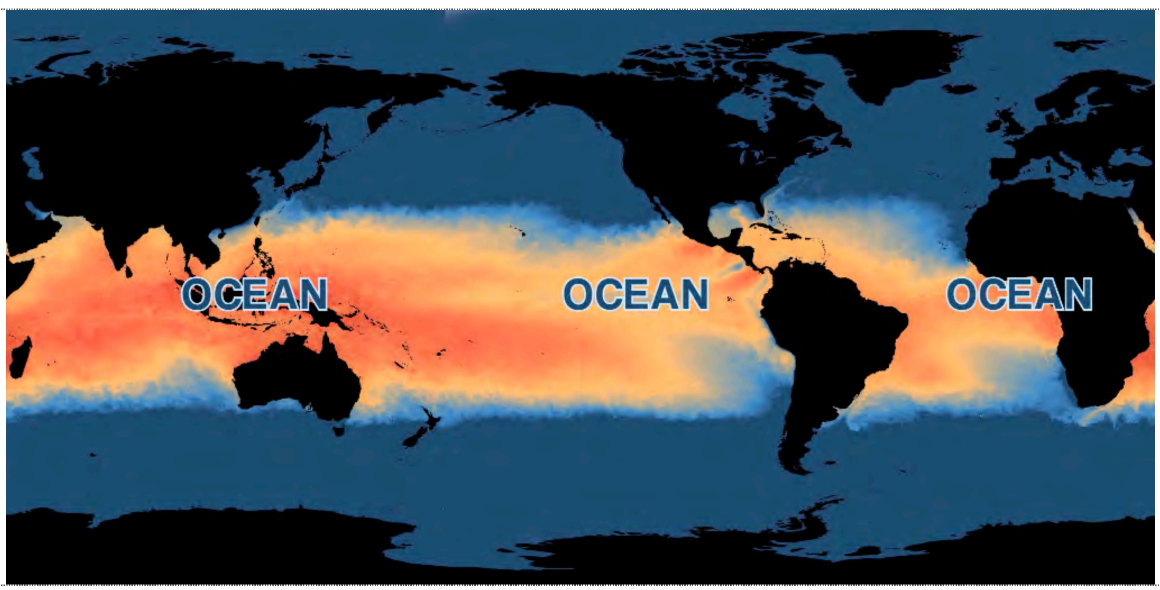


↑1950 TROPICAL CYCLONE TRACKS
Data source: International Best Track Archive for Climate Stewardship (IBTrACS), NOAA National Climatic Data Center
http://www.ncdc.noaa.gov/oa/ibtracs/
Description: IBTrACS is a global dataset of tropical cyclone tracks. It merges track data that exist separately at 12 meteorological centers around the world.

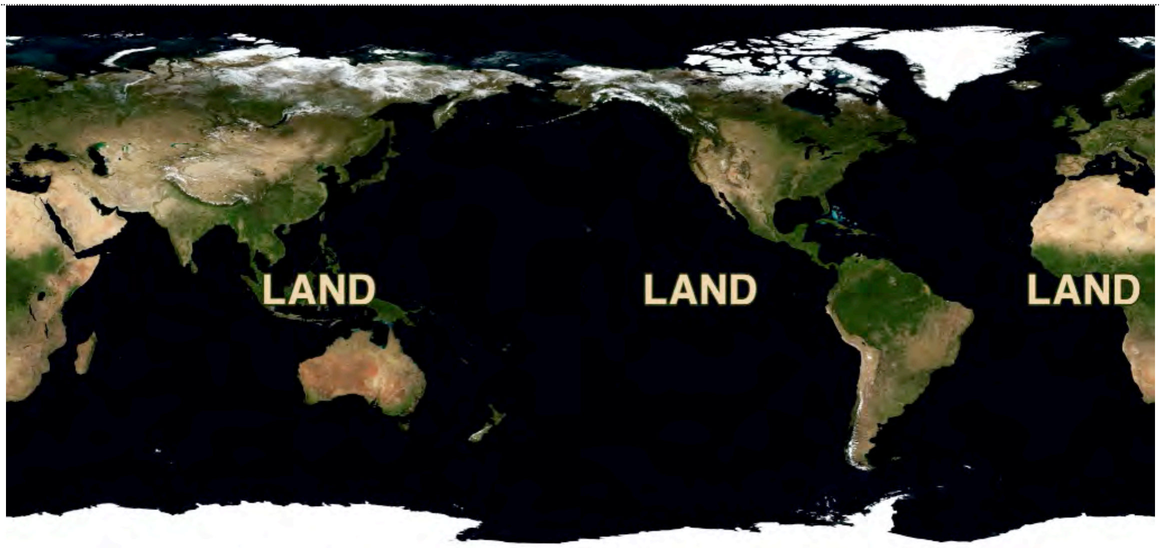
Each track contains separate storm observations plotted in time and space.



↑GLOBAL CLOUD COVER (WATER VAPOR MOSAIC)
From: GOES-East, GOES-West, MTSAT, Meteosat-7, MSG-9, and NASA Terra and Aqua satellites
Data source: Space Science and Engineering Center, University of Wisconsin, http://www.ssec.wisc.edu/data/
Description (from SOS site): Because water vapor emits radiation, satellites can be set to detect water vapor in the atmosphere. All clouds contain water vapor, so when the satellite detects an area with a high concentration of water vapor, it is detecting a cloud. The clouds in hurricanes are easy to detect because they are well formed and contain an excess of water vapor.

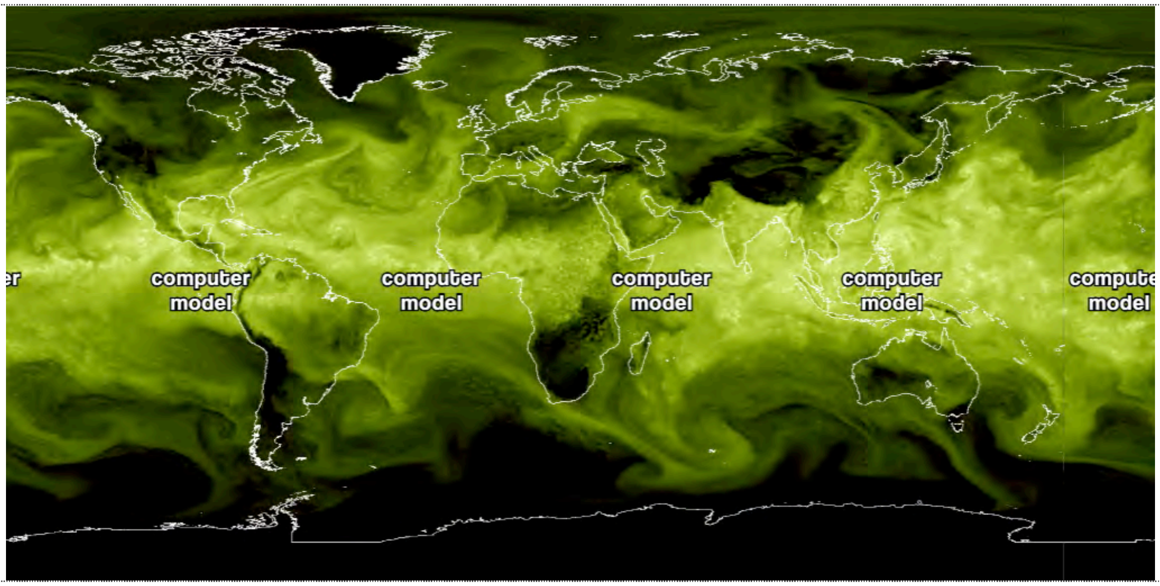


↑SEA SURFACE TEMPERATURE
From: NASA Aqua satellite, AMSR-E sensor
Data source: http://neo.sci.gsfc.nasa.gov/Search.html?group=30
Description (from NASA NEO): Most satellite sensors measures sea surface temperatures by observing infrared energy emitted by Earth's oceans, but infrared energy cannot pass through clouds. Because large areas of the Earth are cloud-covered each day, daily global maps of sea surface temperature from infrared-sensing satellite sensors are patchy. The Advanced Scanning Microwave Radiometer for EOS (AMSR-E) on NASA's Aqua satellite measures sea surface temperature by observing energy coming from Earth in the microwave frequency. Some frequencies of microwave radiation pass through any clouds, allowing AMSR-E to map global sea surface temperatures every day. AMSR-E is a collaboration between the Japanese space agency, JAXA, and NASA.

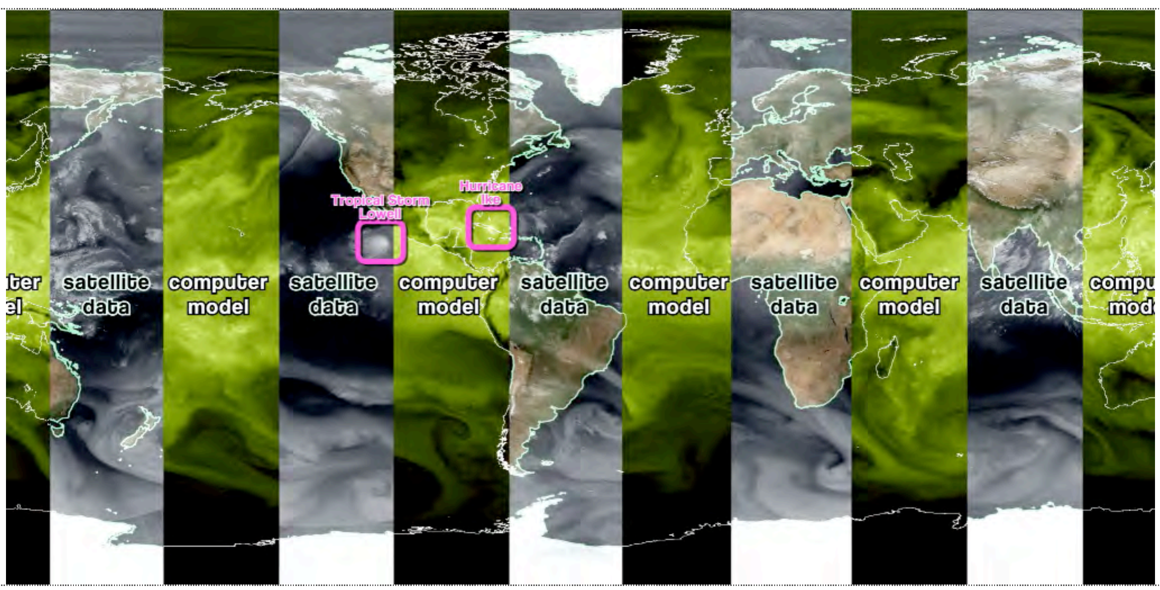


↑BLUE MARBLE NEXT GENERATION
From: NASA Terra satellite, MODIS sensor
Data source: http://neo.sci.gsfc.nasa.gov/Search.html?group=15
Description (from NASA NEO): The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite sees Earth's entire surface almost every day. Over time, scientists can combine MODIS' daily views of the globe into single images of the whole Earth, called "global composites." The images you see here (named "Blue Marble: Next Generation") show the Earth's land surface in true color. Twelve Blue Marble images are available in NEO -- one composite image for each month of the year 2004. These datasets allow visitors to explore changes on the land surface of our home planet over time. Notice how the patterns of green (plants), browns (exposed land surface), and white (snow) change through the course of the seasons. Clouds were removed to allow a maximum view of the surface. The BMNG series of global images was made by Reto Stockli, of NASA's Earth Observatory, using data courtesy the MODIS Land

Science Team.



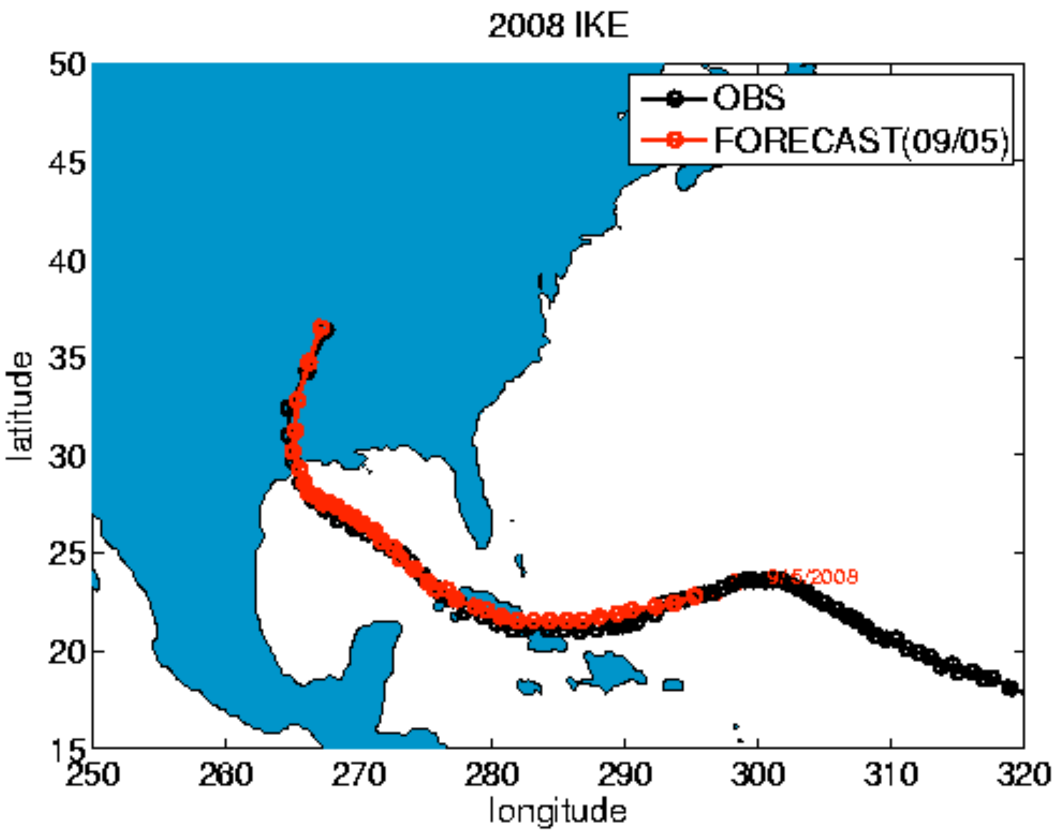
↑WATER VAPOR MODEL SIMULATION
Source: Shian-Jiann Lin, NOAA Geophysical Fluid Dynamics Laboratory, http://www.gfdl.noaa.gov/
Description: This is an output of a high-resolution global computer model that simulates the circulation of water vapor in Earth's atmosphere (see Water Vapor Mosaic dataset above) for the period September 6 – 14, 2008. The simulation highlights several major tropical cyclones, including Hurricanes Hanna and Ike.



↑WATER VAPOR MODEL VS OBSERVED
Description: We compared the satellite-derived water vapor dataset with the water vapor model output for the period September 6 – 14, 2008. While the

computer model cannot precisely duplicate observed water vapor patterns, the two sequences are very similar, especially at the outset of the model sequence. This is because the model's forecast begins on September 6 from a set of initial conditions. Small differences between actual conditions and simulated conditions in the initial state become larger differences as time continues: the hallmark of a chaotic system.

Below is a comparison of the observed track of Hurricane Ike with the model's predicted 10-day track. As you can see, the GFDL model's forecast for this particular storm is quite accurate.



Appendix 3: Resources to learn more about the content in *Forecast: Tropical Cyclone*

GENERAL TROPICAL CYCLONE INFO

Emanuel, Kerry. *Divine Wind*. New York: Oxford University Press, 2005.

Marchok, Timothy (NOAA Geophysical Fluid Dynamics Laboratory, adviser for *Forecast: Tropical Cyclone*) PDF of Powerpoint slides for Princeton University Summer Science Workshop on hurricane science and forecasting.

NOAA AOML Hurricane FAQ
http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqHED.html

NOAA National Hurricane Center
http://www.nhc.noaa.gov/

NOAA National Weather Service Photo Library
http://www.photolib.noaa.gov/nws/index.html

Norcross, Brian. *Hurricane Almanac.* New York: St. Martin's Press, 2007.
http://www.hurricanealmanac.com/

NASA Earth Observatory: Hurricanes—The Greatest Storms on Earth
http://earthobservatory.nasa.gov/Features/Hurricanes/hurricanes_1.php

Physicalgeography.net: Tropical Weather and Hurricanes
http://www.physicalgeography.net/fundamentals/7u.html

ABC News: Flying into the Eye of a Hurricane
http://abcnews.go.com/Travel/story?id=5752159&page=1

New York Times: Hurricanes and Tropical Storms
http://topics.nytimes.com/top/reference/timestopics/subjects/h/hurricanes_and_tropical_storms/index.html

TROPICAL CYCLONE PREPAREDNESS

National Hurricane Center Hurricane Preparedness Week
http://www.nhc.noaa.gov/HAW2/english/intro.shtml

National Weather Service Hurricane Awareness
http://www.nws.noaa.gov/om/hurricane/index.shtml

CDC Hurricane Preparedness
http://www.bt.cdc.gov/disasters/hurricanes/

HISTORICAL TROPICAL CYCLONES

NOAA Coastal Services Center: Historical Hurricane Tracks
http://csc-s-maps-q.csc.noaa.gov/hurricanes/index.jsp

NOAA Hurricane FAQ Hurricane Timeline
http://www.aoml.noaa.gov/hrd/tcfaq/J6.html

NHC Hurricane Preparedness Week: Hurricane History
http://www.nhc.noaa.gov/HAW2/english/history.shtml#galveston

Central Pacific Historical Hurricanes
http://www.prh.noaa.gov/cphc/summaries/

Science magazine: Logbooks Record Weather's History
http://www.sciencemag.org/cgi/content/full/322/5908/1629

Oldweather.org
http://www.oldweather.org/

Larson, Erik. *Isaac's Storm*. New York: Vintage Books, 2000.

Longshore, David. *Encyclopedia of Hurricanes, Typhoons, and Cyclones.* Checkmark Books, 2000.

COMPUTER MODELING

NOAA Geophysical Fluid Dynamics Laboratory
http://www.gfdl.noaa.gov/

UCAR: What Is a Climate Model?
http://www.windows.ucar.edu/tour/link=/earth/climate/cli_models2.html

EdGCM: Educational Global Climate Modeling
http://edgcm.columbia.edu/

USA Today Weather: Forecasters rely on computer models
http://www.usatoday.com/weather/wmodels.htm